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ABSTRACT BOOK

Oral Communications and Posters

Edited by

Felix Fürst

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Chapter 1

Invited Speakers

A lustrum of discoveries in X-ray binaries: from the most luminous transients to ultra-compact systems.

Montserrat Armas Padilla[1,2]
[1] *Instituto de Astrofísica de Canarias*
[2] *Universidad de La Laguna*

X-ray binaries are excellent laboratories to study accretion processes from Eddington luminosities to the dim quiescent states, as well as the ejection of relativistic outflows and particle acceleration to ultra-high energies. We are continuously witnessing exciting breakthroughs in this field, obtained with the most advanced astronomical facilities in (mainly) the X-ray, optical, and radio domains.

I will take you in a tour throughout the X-ray luminosity range by presenting new results on key and newly discovered X-ray binaries. I will discuss some of the most exciting X-ray binary outbursts observed in recent times, in addition to the global properties of other growing populations that are fundamental to understand accretion onto compact objects.

Last Decade of Science with Galaxy Cluster Surveys in the X-ray band

Esra Bulbul[1]
[1] *MPE*

Clusters of galaxies trace the highest peaks in the cosmic density field and offer an independent and powerful probe of the growth of structure and cosmology. Therefore, locating clusters through well-planned multi-wavelength surveys is of importance for testing gravitational theory and cosmology. In this talk, I will review the X-ray cluster surveys successfully executed in the past decade. Recenelty launched eROSITA, the German-built telescope array operating in 0.2-8 keV band on board the Russian-German Spectrum-RG (SRG) mission, just delivered more than 10,000 confirmed clusters of galaxies and galaxy groups in its first all-sky survey. Additionally, I will present science highlights from this first cluster survey of eROSITA. I will also provide an outlook for deeper future surveys.

Dark matter properties in massive galaxy clusters

Dominique Eckert[1]
[1] *University of Geneva*

In spite of its numerous successes, the LambdaCDM model of cosmology is fundamentally incomplete, as 95% of the postulated matter-energy content is in an unknown form. Specifically, the LambdaCDM model postulates the existence of an unknown dark matter component, which outweighs all the normal matter by a factor of 5-6. In this respect, deep X-ray observations of nearby galaxy clusters play a key role in our understanding of the gravitational field of collapsed halos. Indeed, the pressure exerted by the hot intracluster medium (ICM) equilibrates the gravitational force, such that the total enclosed mass can be derived point-by-point from the thermodynamic properties of the ICM. I will review our current knowledge of the gravitational field of galaxy clusters and what can be learned from it on the properties of the postulated dark matter, with an emphasis on several recent studies focusing on the thermodynamic properties of 12 massive, nearby systems. I will show how such observations can be used to constrain the self-interaction cross section of dark matter and how the measured gravitational field sets constraints on modified gravity theories. Finally, I will discuss how the current framework can be extended to additional observables, in particular from gravitational lensing.

Studying nuclear physics with X-ray observations of neutron stars

Sebastien Guillot[1]
[1] *IRAP, Toulouse, France*

More than 50 years after the discovery of neutrons stars, their interior composition and structure remains unknown. Because the extreme densities in neutron star interiors is completely out of reach for Earth laboratories, nuclear physics relies on assumptions for the interior composition, and on extrapolations from our knowledge of low-density matter. As a consequence, the so-called "Dense matter equation of state" is unknown, with important implication for astrophysics and fundamental physics. Thankfully, measurements of neutron stars masses and radii are direct probes of the interior of these compact objects. In the past two decades, X-ray observatories have provided some measurements of neutron star radii and therefore some constraints on the dense matter equation of state. Recently, the results from the NICER Observatory have proved the most promising. I will review some of the key results of this important topic of neutron star astrophysics and provide an overview of expected constraints from future observatories.

X-ray variability & reverberation

Adam Ingram[1]
[1] *Newcastle University, Newcastle Upon Tyne, UK*

The rapid variability observed in the X-ray signal from accreting black holes provides a powerful diagnostic to indirectly map the ultra compact region in the vicinity of the black hole horizon. I will review some of the X-ray variability properties of accreting black holes, with an emphasis on comparing X-ray binaries with active galactic nuclei. I will review the current status of the field of X-ray reverberation mapping, and how this can be used to measure black hole mass.

AGN STORM 2: The Multi-Wavelength Reverberation Mapping Campaign of Mrk 817

Erin Kara[1]
[1] *MIT*

In this talk, I will present on behalf of the AGN STORM 2 Collaboration, the results of the largest yet multi-wavelength reverberation mapping campaign on a single AGN. The target is Mrk 817, a nearby Seyfert 1 AGN, which we observed at roughly daily cadence for over a year with HST, Swift, NICER and several ground based Optical/IR ground-based observatories. Moreover, XMM-Newton and NuSTAR performed 4 deep observations every few months during the campaign. While Mrk 817 was originally selected in part because it had never shown X-ray or UV obscuration, in fact, during our campaign, we observed broad UV absorption troughs and significant X-ray obscuration. In this talk, I will present our results on the nature of this multi-phase obscuring outflow, and its implications on reverberation lag measurements of the accretion disk, broad line region and torus.

X-ray Quasi-Periodic Eruptions (QPEs)

Giovanni Miniutti[1], Margherita Giustini[1], Riccardo Arcodia[2], Richard D. Saxton[3]
[1] *Centro de Astrobiología (CAB), CSIC-INTA, Villanueva de la Cañada, Spain*
[2] *MIT Kavli Institute for Astrophysics and Space Research, Cambridge (MA), USA*
[3] *Telespazio-Vega UK for ESA, European Space Astronomy Centre (ESAC), Villanueva de la Cañada, Spain*

X-ray Quasi-Periodic Eruptions (QPEs) are a new type of extreme X-ray variability phenomenon associated with supermassive black holes. QPEs are short-lived, high-amplitude, thermal-like soft X-ray bursts typically recurring every few hours and often being superimposed to super-soft quiescent X-ray emission with typical temperature of 50-60 eV. QPEs were first observed in the (repeating) TDE candidate GSN 069 by XMM-Newton (2019), and they have been securely detected in the nuclei of several (up to 7) other low-mass galaxies since then. In my presentation, I will review the properties of X-ray QPEs as well as their diverse phenomenology in the QPE-sources detected so far. I will also discuss some of the physical scenarios that can be invoked to explain this new, and not that rare anymore, extreme-variability phenomenon and the emerging possible connection between QPE sources and TDE candidates.

Hot news on hot stars

Yaël Nazé[1]
[1] *FNRS/ULiege*

In the stellar populations, hot massive stars play a leading role, notably regarding feedback. The X-ray production in these stars is in fact intimately linked to their physical properties, in particular their mass-loss which shapes the circumstellar environment. In this contribution, I'll review the most recent results in this field and highlight how the various circumstellar structures (magnetically confined winds, colliding winds, co-rotating wind regions, decretion disks,...) are probed by X-ray observations.

X-rays observations of stars with planets.

Ignazio Pillitteri[1]
[1]*INAF-Osservatorio Astronomico di Palermo*

The X-ray emission from the coronae of stars can influence the evolution of the planets orbiting around them. In particular, the effects of high energy radiation can alter the chemical composition of the primordial planetary atmospheres, and induce inflation and evaporation. I will present the results obtained by XMM-Newton observations of stars with planets and put them in the wider context of characterization of the planetary systems in synergy with other observatories like HST, JWST and the forthcoming Ariel mission.

High-resolution X-ray spectroscopy of AGN

Delphine Porquet[1]
[1]*CNRS, Laboratoire d'Astrophysique de Marseille, France*

The environment of supermassive black holes (SMBH) in AGN is very rich and complex with various components in accretion and/or in ejection on a large spatial scale, from a few gravitational radii to several kpc. I will show how today's high-resolution X-ray spectroscopy provides us with very powerful tools to probe their physical and dynamical properties. I will also present the new generation of X-ray microcalorimeters which will allow us a huge leap forward in our understanding of the growth of SMBHs over cosmic time and of the possible feedback process with their host galaxies.

Magnetized neutron stars and the transient multi-band sky

Nanda Rea[1]
[1] *Institute of Space Sciences (ICE-CSIC, IEEC)*

I will review the state of the art of the X-ray emission from magnetars and its connection with the transient multi-band sky, from Gamma-ray Bursts to Fast Radio Bursts. I will also present a new class of pulsars with very long spin periods, challenging our paradigm of pulsar spin period evolution, X-ray cooling models and coherent radio emission.

Changing-look Active Galactic Nuclei

Claudio Ricci[1,2]
[1] *Universidad Diego Portales, Chile*
[2] *KIAA, China*

AGN are known to show flux variability over all observable timescales and across the entire electromagnetic spectrum. Over the past decade, a growing number of sources have been observed to show dramatic flux and spectral changes, both in the X-rays and in the optical/UV. Such events, commonly described as "changing-look AGN", can be divided into two well-defined classes. Changing-obscuration objects show strong variability of the line-of-sight column density, mostly associated with clouds or outflows eclipsing the central engine of the AGN. Changing-state AGN are instead objects in which the optical/UV continuum emission and broad emission lines appear or disappear, and are typically triggered by strong changes in the accretion rate of the supermassive black hole. In my talk I will review our current understanding of these objects, and then focus on a few recent X-ray monitoring campaigns of Changing-state AGN.

An updated X-ray view of cool stars

Beate Stelzer[1]
[1] *Universität Tübingen, Tübingen, Germany*

I will depict the development in our knowledge and understanding of the X-ray emission of objects in the cool half of the Hertzsprung Russell diagram, which includes stars from the pre-main sequence to the giant stage. The focus of this talk will be on the lower main-sequence and the substellar regime. Recent observations will be considered in synergy with multi-wavelength approaches that are essential to shed light onto the physics of the hot outer atmospheres in which the high-energy "coronal" radiation of photospherically cool stars is generated.

Completing the X-ray view of SN 1987A

Lei Sun[1,2], Jacco Vink[2,3], Yang Chen[1,4], Emanuele Greco[2], Ping Zhou[1,4], Dmitry Prokhorov[2], Gerd Puhlhofer[5], Denys Malyshev[5], Salvatore Orlando[6], Marco Miceli[6,7]
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[2] *Anton Pannekoek Institute, GRAPPA, University of Amsterdam, Amsterdam, The Netherlands*
[3] *SRON, Netherlands Institute for Space Research, Utrecht, The Netherlands*
[4] *Key Laboratory of Modern Astronomy and Astrophysics, Nanjing University, Nanjing, China*
[5] *Institut fur Astronomie und Astrophysik, Eberhard Karls Universitat Tubingen, Tubingen, Germany*
[6] *INAF-Osservatorio Astronomico di Palermo, Palermo, Italy*
[7] *Dipartimento di Fisica e Chimica, Universita degli Studi di Palermo, Palermo, Italy*

SN 1987A provides us a unique opportunity to study in detail the birth and the early evolution of the supernova remnant. The 14-year XMM-Newton monitoring of SN 1987A reveals a steady increase in the 3-8 keV flux, but a recent decrease in the 0.5-2 keV flux. Along with the decreasing emission measure of the low-temperature plasma, this indicates the blast wave has now left the main equatorial ring, and is still propagating into the high-latitude gas. The Fe K lines are clearly detected in SN 1987A. The high centroid energy ($\geq$ 6.65 keV) corresponds to a high plasma temperature 3 keV, and a recent decrease in the centroid energy could be related to the newly shocked Fe-rich ejecta clumps. The high energy resolution of RGS and the wide energy coverage of EPIC-pn allow us to investigate the continuous temperature distribution of the X-ray gas in SN 1987A, which shows great consistency with the MHD simulation results. The NuSTAR observations reveal an excess of the 10-20 keV flux with respect to the pure-thermal spectral model, which is best reproduced by a heavily absorbed power law. This provides evidences for a pulsar wind nebula embedded in the heart of SN 1987A.

X-raying our Solar System

Affelia Wibisono[1,2]
[1] *Royal Observatory Greenwich, London, UK*
[2] *Mullard Space Science Laboratory, UCL, Surrey, UK*

There is no shortage of X-ray emitters in our Solar System. The Sun, planets, moons, comets, and even Pluto have all been observed to emit at this waveband through a variety of mechanisms. These include charge exchange, electron bremsstrahlung, fluorescence, and scattering. Studying X-rays from Solar System objects and understanding how the X-rays are produced can reveal unique insights about that object. For example, scattered solar X-rays from planetary atmospheres, planetary rings and the surfaces of rocky bodies can reveal their elemental composition. Furthermore, cometary X-rays due to charge exchange can reveal conditions in the solar wind and the interactions between the solar wind and a planet's magnetosphere can be probed by studying the auroral X-ray emissions of that planet. Simultaneous in-situ and remote sensing measurements of relatively local objects, such as Jupiter which currently hosts the Juno orbiter, have proved to be very powerful and could help shed light on the conditions needed for more exotic objects from further afield to emit X-rays. In this talk I will give an update on the ongoing research of Solar System X-rays and look ahead to how future Solar System missions could advance our understanding of our local neighbourhood and beyond.

Chapter 2

Solicited Speakers

The XMM-SERVS Survey of the LSST Deep-Drilling Fields

Niel Brandt[1], XMM-SERVS Team[2]
[1]*The Pennsylvania State University, University Park, USA*
[2]*Multiple Institutions*

Cosmic X-ray surveys over the past two decades have played a critical role in transforming our understanding of growing supermassive black holes (SMBHs) in the distant universe. I will describe one key survey, recently completed, advancing this effort: the 13.1 deg^2 XMM-SERVS survey. XMM-SERVS has successfully mapped three LSST Deep-Drilling Fields (DDFs) at 50 ks XMM-Newton depth, focusing on the SERVS areas of W-CDF-S, XMM-LSS, and ELAIS-S1. These fields have first-rate multiwavelength coverage already and are LSST/DES DDFs, MOONS/PFS massive spectroscopy fields, prime TolTEC/ALMA fields, and SDSS-V/4MOST multi-object reverberation-mapping fields. About 12,000 X-ray sources have been detected and characterized, the majority of which (86%) are active galactic nuclei (AGNs), and these are presently being studied. I will summarize ongoing XMM-SERVS science investigations including multiwavelength fitting of infrared-to-X-ray spectral energy distributions, identification of the most highly X-ray obscured AGNs, dwarf AGN studies, and combined radio/X-ray AGN investigations. I will also briefly highlight how the proposed STAR-X MIDEX mission could obtain much more sensitive X-ray coverage of the LSST DDFs as it conducts its 12 deg^2 Deep and 300 deg^2 Medium-Deep time-domain surveys.

NICER: Astrophysics from the International Space Station

Keith Gendreau[1], Zaven Arzoumanian[1]
[1]*NASA/GSFC, Greebelt, MD, USA*

The Neutron Star Interior Composition Explorer (NICER) is a NASA Astrophysics Mission of Opportunity on the International Space Station (ISS). Since 2017, NICER has been observing neutron stars, black holes, and other celestial objects. The ISS provides for rapid response capability and massive data downloads and enables an effective target of opportunity (TOO) program. We will describe the instrument and operations on the ISS as well as new TOO capabilities and recent results.

NewAthena: the Large-Class X-ray observatory of ESA

Matteo Guainazzi[1], NewAthena Science Redefinition Team[2]
[1] *ESA/ESTEC*
[2] *ESA*

"NewAthena" is the provisional name of the latest incarnation of the Large-Class X-ray observatory of the European Space Agency (ESA), to be launched in the second half of the 2030s. After the premature demise of Athena - deemed to be too expensive for the current level of resources of the ESA Science Program - NewAthena constitutes an innovative mission design concept with a science instrument module open to space. The Science Reformulation Team (SRDT) - appointed by ESA to revise the science case of the mission - is convincingly demonstrating that the majority of the original Athena science objectives in the "Hot Universe", "Energetic Universe" and "Observatory Science" themes will be addressed by New Athena. Most of this talk will describe the latest science simulations carried out by the SRDT and the Athena community Topical Panels. The NewAthena industrial Phase A is scheduled to start at the beginning of 2024 - pending endorsement by the Science Program Committee -, leading to the commencement of the 9-year implementation about 3 years afterwards.

Results from the Imaging X-ray Polarimetry Explorer

Giorgio Matt[1]
[1] *Roma Tre University*

The Imaging X-ray Polarimetry Explorer (IXPE), launched on December 2021, is providing a wealth of interesting - and often unexpected - results on many sources belonging to different classes. In this talk I will present some of these results, with the aim to show the importance for the understanding of cosmic X-ray sources of adding the polarimetric information.

Revolutionising our view of the hot phase of the Milky Way with XMM and eROSITA

Gabriele Ponti[1,2]
[1] *INAF Osservatorio Astronomico di Brera*
[2] *Max Planck Institut fuer Extraterrestrische Physik*

Standard theory of galaxy evolution dictates that hot, X-ray emitting plasma should fill the halo of galaxies and be linked to the activity in the center and disc of galaxies. Indeed, outflows and feedback mechanisms are clearly observed in AGN and starburst galaxies, while the situation is still unclear for quiescent galaxies as our own Milky Way. I will review the growing evidence for the presence of the Galactic outflow, starting from the XMM survey of the central molecular zone, the discovery of the Chimneys feeding into the FERMI bubbles and the recently discovered eROSITA bubbles. I will also discuss how the connection between XMM and eROSITA data might provide us with the prospect of better understanding the hot phase of the Milky Way.

CHEX-MATE: The Cluster HEritage project with XMM-Newton: Mass Assembly and Thermodynamics at the Endpoint of structure formation

Gabriel Pratt[1], Stefano Ettori[2,3], CHEX-MATE Collaboration[4]
[1] *Université Paris-Saclay, Université Paris Cité, CEA, CNRS, AIM, 91191, Gif-sur-Yvette, France*
[2] *INAF, Osservatorio di Astrofisica e Scienza dello Spazio, Via Pietro Gobetti 93/3, 40129 Bologna, Italy*
[3] *INFN, Sezione di Bologna, Viale Berti Pichat 6/2, 40127 Bologna, Italy*

We will present a status update on the CHEX-MATE project, an XMM Multi-Year Heritage programme to obtain X-ray observations of a minimally-biased, signal-to-noise-limited sample of 118 galaxy clusters detected by Planck through the SZ effect. The programme studies the ultimate products of structure formation in time and mass. It is composed of a census of the most recent objects to have formed (Tier-1: $0.05 < z < 0.2$; 2×10^{14} $M_\odot$ $< M_{500} < 9 \times 10^{14}$ $M_\odot$), together with a sample of the highest mass objects in the Universe (Tier-2: $z < 0.6$; $M_{500} > 7.25 \times 10^{14}$ $M_\odot$). The programme aims to obtain the statistical properties of the population, measure how the gas properties are shaped by collapse into the dark matter halo, uncover the source of non-gravitational heating, and resolve the major uncertainties in mass determination that limit the use of clusters for cosmological parameter estimation. We have acquired X-ray exposures of uniform depth, yielding individual mass measurements accurate to 15–20% under the hydrostatic assumption. We will present the project motivations, describe the programme definition, and detail the ongoing multi-wavelength observational (lensing, SZ, radio) and theoretical effort that is being deployed in support of the project.

eROSITA insights on the hot and energetic Universe.

Mara Salvato[1]
[1]*MPE, Garching*

eROSITA was successfully launched on board the Russian-German "Spectrum-Roentgen-Gamma" (SRG) satellite on July 13th 2019. With this instrument we wanted to: 1) detect the hot intergalactic medium of more than 100,000 galaxy clusters and groups and the hot gas in filaments between clusters to map out the large-scale structure of the Universe for the study of cosmic structure evolution; 2) detect systematically all obscured accreting Black Holes in nearby galaxies and many (up to 3 Million) mostly new distant active galactic nuclei, and 3) study in detail the physics of galactic X-ray source populations, like pre-main sequence stars, supernova remnants, and X-ray binaries. In total, eROSITA will map the entire sky 8 times, and while 4 passes have been already completed, we are preparing for the release of all data related to the first pass (eRASS:1, about 8 times deeper than the predecessor ROSAT). In my talk, I will highlight how eROSITA is already changing what we know about the hot and energetic Universe.

Status of X-Ray Imaging and Spectroscopy Mission (XRISM)

Makoto Tashiro[1,2]
[1]*Saitmaa University, Saitama, Japan*
[2]*ISAS/JAXA, Tsukuba, Japan*

The X-Ray Imaging and Spectroscopy Mission (XRISM) is a JAXA/NASA X-ray observatory with collaboration from ESA and several institutes and academic institutions worldwide. It has been developed to pioneer the new high-resolution X-ray spectroscopy with imaging once realized but unexpectedly terminated by a mishap of ASTRO-H/Hitomi. XRISM carries two sets of X-ray Mirror Assemblies with an X-ray micro-calorimeter array and an aligned X-ray CCD camera on the focal plane. With the combination of high-resolution spectroscopy imaging and the broader field of view, XIRSM explores the new horizon of the universe in X-ray astrophysics. After the mission and system definition in 2017, the production and tests of the onboard instruments were successfully finished. We carried out the proto-flight tests of the integrated spacecraft from May 2022 to March 2023 to launch the spacecraft. This paper reports the development and test results, current status, the observation plan in the performance verification phase, and the plan for the following guest observations.

XMM2ATHENA, the H2020 project to improve XMM-Newton analysis software and prepare for Athena

Natalie Webb[1], Francisco Carrera[2]
[1] *IRAP, Université de Toulouse, CNRS, CNES, Toulouse, France*
[2] *Instituto de Física de Cantabria (CSIC-UC), Santander, Spain*

X-rays allow us to detect a wide range of energetic objects in the sky. XMM-Newton, the large European Space Agency X-ray observatory, has been observing the X-ray, ultra-violet and optical sky for over 23 years. During this time, astronomy has evolved to study populations rather than single sources, using multi-wavelength, multi-messenger and time domain data to understand the X-ray sources.

Here we present the H2020 project, XMM2ATHENA, carried out by key members of the XMM-Newton Science ground segment, the Athena Science ground segment, and members of the X-ray community. XMM2ATHENA develops and tests new methods and software to follow the X-ray transient sky, identify multi-wavelength/messenger counterparts, determine source distances, provide spectral fits for all X-ray detections, and determine the X-ray and optical/UV source nature using machine learning. Innovative stacking algorithms will allow the faintest sources to be revealed and a revised sensitivity estimator is provided. Much of the software and many products are already available and they will all be used to produce an enhanced version of the XMM-Newton catalogue, 5XMM, expected in 2025. These methods will then be adapted for the Athena software and the newly detected/identified sources will help us prepare for Athena.

The Einstein Probe mission

Weimin Yuan[1]
[1] *National Astronomical Observatories, Chinese Academy of Sciences, China*

The Einstein Probe (EP) is a space mission dedicated to X-ray time-domain astrophysics, with a broad range of scientific goals. It will carry two instruments, one wide-field X-ray telescope (WXT) to monitor the soft X-ray sky in 0.5-4keV with a 3600 square-degree field-of-view, and one narrow-field X-ray telescope (FXT) for deep follow-up observations in 0.3-10keV and precise source locating. The WXT is an imaging telescope making use of novel X-ray focusing technology of lobster-eye micro-pore optics, which enables the detection of fainter X-ray sources than those by conventional non-focusing techniques. Transient alerts will be issued quickly to trigger follow-up observations at multi-wavelengths. The Einstein Probe is a mission of the Chinese Academy of Sciences in collaboration with ESA, MPE and CNES. This talk will introduce the mission and its current status. Initial results from the EP-WXT pathfinder LEIA will also be briefly discussed.

A new regime for the X-ray nuclear properties of the first quasars

Luca Zappacosta[1]
[1] *INAF-Osservatorio Astronomico di Roma, Monte Porzio Catone, Italy*

The existence of luminous quasars (QSOs) powered by well grown $> 10^9$ $M_\odot$ supermassive black holes (SMBH) at the Reionization Epoch (EoR; i.e. $z > 6$), when the Universe was only < 1 Gyr old, seriously challenges models of SMBH formation. In order to probe their nature we selected the HYPerluminous quasars at the Epoch of ReionitION (HYPERION) sample which includes 17 QSOs at $z = 6 - 7.5$, whose SMBH have had the most rapid mass growth at EoR. HYPERION builds on a 2.4 Ms Multi-Year Heritage XMM-Newton Programme designed to accurately characterize the X-ray nuclear properties of these QSOs by carrying out the first systematic and sensitive X-ray spectroscopic exploration of QSOs at EoR. In this talk I will mainly present the results of the 1st year of the Heritage programme reporting, for the first time for QSOs at EoR, an average photon index significantly steeper than what measured at lower redshift for samples of similar QSOs. This is interpreted as redshift evolution and provides tantalizing indications for a different accretion disc/corona regime for the luminous QSO population at early cosmic epochs.

Chapter 3

Solar System

SRG/eROSITA and the first ever clear view of the soft diffuse X-ray sky

Konrad Dennerl[1], Gabriele Ponti[1,2], Xueying Zheng[1], Michael Freyberg[1], Susanne Friedrich[1], Thomas Müller[1]
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The ROSAT discovery of X–ray emission from comets has revealed the importance of a process for the generation of soft X–rays that had been underestimated in its efficiency before: charge exchange. As this process is characterized by high cross sections, even very tenuous gas can become a source of soft diffuse X–ray emission. Such gas is not only present in the Earth's exosphere but also in the whole solar system because interstellar gas is streaming through it. Thus, emission originating in the solar system may be present in any X–ray observation, affecting all studies of the local hot bubble, the galactic corona, the circum-galactic medium, and the cosmic X–ray background. With its privileged location outside the Earth's exosphere, SRG/eROSITA is the first satellite to see an X–ray sky that is free from geocoronal emission, and by scanning over the full sky repeatedly, it provides a unique opportunity to identify and isolate the time variable heliospheric component. We show how we utilize this unprecedented situation to obtain, for the first time ever, a clear view of the soft diffuse X-ray sky.

Modeling of solar wind charge exchange emission from the Earth's magnetosphere and exosphere

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We report on modeling of geocoronal solar wind charge exchange (SWCX) events detected with Suzaku. Highly charged solar wind ions undergo charge exchange with Earth's exospheric neutrals and emit soft X-ray photons. This emission is an immediate foreground for all the soft X-ray observations from Earth-orbiting satellites (e.g., Cravens et al. 2001). However, it remains difficult to predict some observational properties such as time series and overall flux levels for arbitrary spacecraft look directions. We analyzed five Suzaku detections of bright geocoronal SWCX events. The strongest OVII and OVIII emission lines were extracted in the same way as Ezoe et al. (2011). We then built an empirical model to predict OVII and OVIII line intensities using a simplified formula of the Hodges exosphere model, WIND and ACE solar wind data, charge exchange cross section values of the Bodewits model, and Earth's magnetic field models. The modeled intensities of OVII emission lines were consistent with the observed ones within a factor of three, except for an intense geomagnetic storm event, while those of OVIII emission lines were underestimated by a factor of three or more. After scaling, our model reproduced OVII and OVIII light curves including short-term variations from cusp regions.

Chapter 4

Exoplanets and their host stars

High-latitude flares on rapidly rotating M dwarfs - a special corona?

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How low mass stars and their planets co-evolve eludes us, in part because we lack observing methods that spatially resolve the strong small scale stellar fields. For instance, as launch sites of particle eruptions, the latitudes of energetic flares relative to a planet's orbit can determine whether the planet will be hit or missed by the energetic particles. Can we measure these latitudes? We find that, under certain conditions, we can:

We present precisely localized flares on the surfaces of four rapidly rotating mid-to-late M dwarfs. The light curves of these flares lasted longer than one full rotation period. They appeared modulated as the flaring region moved in and out of view, revealing their latitudes. All flares were found closer to the pole than to the equator.

One of the stars, an M7 dwarf rotating at about 5h, shows a flare almost pole-on, at 81 deg latitude. We followed this exciting object with XMM-Newton for two full rotation periods to place its coronal properties in the broader context of active M dwarfs. We discuss under what conditions such high latitude flares can occur, and what this implies for the space weather of planets orbiting these stars.

X-ray variability of Proxima Centauri

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Proxima Centauri has long been known as a flare star and, due to its proximity, is a very bright X-ray source. With the discovery of a planet in its habitable zone in 2016, Proxima Centauri has become a key target for studies of stellar activity and its impact on planets. In this talk I will present a comprehensive study of the X-ray variability of this M5 dwarf with XMM-Newton data from 2001 to 2017 together with eROSITA data from the four all-sky surveys, counting two years of observations. The large data base allowed us to identify the quiescent X-ray emission level of this hyper-active star, and to perform a separate spectral analysis of quiescence and a multitude of flares of different amplitude. We thus recover the temporal evolution of the plasma temperature and emission measures, as well as changes in abundances. We determined the energy emitted by the individual X-ray flare leading to the first X-ray flare energy frequency distribution (FEFD) for M dwarfs, to be compared with the ubiquitous FEFD in the optical waveband derived from planet transit search missions like Kepler and TESS.

Variability and mass loss estimation of exoplanets around triple star system LTT 1445

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The high-energy environment of the host stars could be deleterious for their planets. It is crucial to characterize this contextual information of the terrestrial exoplanet atmospheres. We aim to better understand a unique triple system, LTT1445, with three known rocky exoplanets around LTT1445A. The X-ray irradiation and flaring of this system is studied with a new 50 ks observation divided into 10 ks, 10 ks, and 30 ks, conducted two days apart, and two months apart respectively. This is complemented by an archival Chandra observation approximately one year earlier, and repeated observations with eROSITA, enabling the X-ray flux behavior across multiple time scales. The obtained flux from these observations will be used to estimate the photoevaporation mass loss of the individual exoplanets, from the host stars.

Simultaneous Multiwavelength Observations of the Highly Active M Dwarf CN Leo

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M dwarf stars are cool low-mass stars that are the most common stellar type in our galaxy and are known to frequently host small planets. Most M dwarfs exhibit high levels of activity in the form of flares and coronal mass ejections due to magnetic reconnection processes. This energetic activity may subject potential planets, orbiting around them, to significantly more radiation than we receive from the Sun. It remains unclear just how much this radiation affects a planet's atmosphere and potential habitability. I will present preliminary results on our multiwavelength analysis of the highly active M6V dwarf, CN Leo, also known as Wolf 359, located at 2.41 pc. We used simultaneous ultraviolet, X-ray, and optical observations from the Neil Gehrels Swift Observatory, XMM-Newton, and the Transiting Exoplanet Survey Satellite (TESS) taken during December 2021. We analyzed the energy partition of the flares and compared the flare frequency distribution (FFDs) of events, observed by the different observatories, to estimate the overall energy output, allowing us to investigate the relationship of stellar activity at different wavelengths.

Chapter 5

Stars & White Dwarfs

The EWOCS view of the unique population of Wolf-Rayet stars in Westerlund 1

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Wolf-Rayet (WR) stars are the latest stage in the evolution of very massive stars, before they finally explode as supernovae (SN) or possibly gamma-ray bursts. They exhibit dense and powerful stellar winds, that along with their ultimate death as core-collapse SN, dominate the feedback to the local interstellar medium in star-forming galaxies. Studying in more detail the properties of the short-lived WR phase, will advance our understanding on star-formation processes and will test stellar evolutionary predictions. The best laboratory to study the WR phase, is the massive star cluster Westerlund 1. It is the closest massive star cluster to the Sun, and it contains an impressive large sample of coeval massive stars including one of the largest population (24) of WR stars. With a very deep Chandra survey (1Ms; as part of the Extended Westerlund One Chandra Survey; EWOCS) we are able to unravel the X-ray properties of the entire WR population, extract spectral information for more 2/3 of them, and retrieve insights on their X-ray production mechanism. We discuss these results in the context of different spectral subtypes of WR stars, as well as binarity, since several of them show signs of colliding-wind X-ray binaries.

Spatial and dynamical structure of the NGC2264 star-forming region

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Star formation and the early stages of stellar evolution are active research topics. We present new results on NGC 2264, a benchmark star-forming region. We revisited its structure, dynamics, and star-forming history using original XMM-Newton X-ray data, GAIA eDR3, and other public and published catalogs. We assemble a catalog of >2200 candidate members, a ∼100% increase over previous determinations. Since the region was suspected to extend beyond the better studied areas, a wide 2.5×2.5 degrees FOV was considered.

GAIA parallaxes yielded a new average distance of 722±2 pc and suggest that the Spokes subregion is embedded ∼20 pc within the molecular cloud. Proper motions and radial velocities indicate both global expansion and rotation. At the same time, we observe two substructures collapsing and coalescing where active star formation is taking place. The inhomogeneous accretion disk fraction suggests that star formation has occurred for millions of years. The low disk fraction around the O VII star S Mon may imply external disk photoevaporation or an older age of the region.

To conclude, the present configuration of NGC 2264 is likely the result of multiple dynamical processes which occurred for million of years, and we identify the process that is likely responsible for the ongoing formation activity.

The EWOCS project: stars, planets, compact objects and stellar exotica in young starburst clusters

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Star formation in our Galaxy typically occurs in environments counting a few 10^2, 10^3 stars. However, a few more extreme star forming environments exist, where hundreds of thousands to millions of stars form in dense regions, often in single events of star formation. Often called "starburst regions", they are rare in our Galaxy today, while they are common in galaxies experiencing epochs of intense star formation and in the early Universe. With a distance of 3.87 kpc from the Sun, and an estimated initial mass of 52000 Msol, Westerlund1 is the closest starburst cluster to the Sun. It offers the unique possibility to study star and planet formation, early stellar evolution and compact objects in a starburst environment. In this talk I will present the EWOCS project (Extended Westerlund One Chandra, and JWST, Survey) which is based on a 1Msec Chandra/ACIS-I Large Project, oncoming JWST observations of Westerlund 1, and other optical/infrared data at high spatial resolution (GEMS/GSAOI, HST, etc..). I will discuss the objectives of the project, present the status of the art of data analysis and some preliminary results. I will also discuss the (poor) future perspective of studies of starburst clusters with next X-ray telescopes

Delayed Soft X-ray Glow at the Magnetic Loop Footpoints in Two Superflares from the Sun-like Star, κ^1 Ceti

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Solar and stellar flares are the most energetic events driven by magnetic activity on low-mass stars. The rising phase holds crucial information on the flare geometry and heating mechanism, but earlier studies did not have enough statistics to study their rapid spectral evolution. The NICER X-ray observatory observed two superflares from the nearby young sun-like star, κ^1 Ceti, in 2019. Two-temperature thermal plasma components at $kT \sim$0.3−1 keV and $\sim$2−4 keV can reproduce the time-resolved spectra: both components vary similarly, but the cool component's emission measure (EM) lags by $\sim$200 sec with 4−6 times smaller emission measure than the hot component. These profiles match with the behavior of the cool X-ray plasma near the magnetic loop footpoints in 1D HYDRAD hydrodynamic flare loop simulations, which suggests that plasma cools via thermal conduction. The second flare had a longer rise time delay, a smaller cool EM peak ratio over the hot EM, and a longer flare decay than the first, consistent with a more extended magnetic loop event. The cool component's time lag and EM ratio probably provide essential constraints on the flare loop geometry. We also propose an X-ray spectral model useful for fitting solar and stellar flare X-ray spectra.

Effects of non-equilibrium collisional plasma on the X-ray emission from the RS Ophiuchi during its recent eruption

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RS Ophiuchi is a recurrent nova consisting of a massive white dwarf and a red giant (RG) donor star in a binary orbit of 453.6 days. It underwent its most recent eruption on 8 August 2021 and was monitored extensively by NICER. The rapidly evolving NICER spectrum consisted of both line and continuum emission which we modelled using non-equilibrium ionization collisional plasma models. The evolution of the X-ray spectrum is consistent with the nova ejecta driving a forward shock in the dense stellar wind of the RG star.

Simultaneous X-ray and optical variability of M dwarfs observed with eROSITA and TESS

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M dwarfs are cool, highly active main sequence stars. In order to study their magnetic activity, the activity phenomena need to be observed at different wavelengths, which correspond to different but related phenomena occurring at different layers of the stellar atmosphere.

We used data from the extended Roentgen Survey with an Imaging Telescope Array (eROSITA), which has scanned the entire sky four times since December 2019 in the soft X-ray band (0.2-10 KeV) and the Transiting Exoplanet Survey Satellite (TESS), which has monitored nearly the whole sky since July 2018.

An optimized sky area for variability studies with eROSITA and TESS are the ecliptic poles, where both surveys provide the longest exposure times. Here, we focus on the southern ecliptic pole, where we identified 874 M dwarfs. 25 of the X-ray brightest stars in this sample had simultaneous observations and were analyzed.

This data set is remarkable, as there are limited flare observations in both wavebands available in the literature. We present the frequencies of flare occurrence, their energies and examine the relation between the X-ray and optical events, and how their properties depend on the rotation rate that we determined from the TESS light curves.

Understanding the physical state of hot plasma formed through stellar wind collision in WR140 using high-resolution X-ray spectroscopy

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We present results of our analysis on the long-period colliding-wind binary WR140 observed with the RGS onboard XMM-Newton from May 2008 to June 2016. X-rays emitted from the colliding shock of the stellar winds from the two stars are detected when the O star is in front of the WR star. The X-ray spectra are dominated by emission lines from Ne, O, and Fe in the band 0.5-1.0 keV. We calculated the shape of the contact surface of the shock cone with ram-pressure balance between the winds from the two stars. Averaged distances of the Ne line-emission sites from the shock stagnation point are successfully obtained by comparing the ratio of observed line-of-sight velocity and its dispersion to that calculated. We measured the electron number density of the Ne line-emission site to be $\sim 10^{12}$ cm^{-3} at orbital phases well before the periastron passage using the intensity ratios of the He-like triplet of Ne. We confirmed that the photo-excitation effect to the Ne He-like triplet by extreme ultraviolet lights from the O star is only 1-10 per cent of that of the collisional excitation at those phases.

e-ROSITA view of Be stars

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The Be category gathers early-type stars that show or have shown Balmer emission lines, attributed to the presence of a circumstellar decretion disk. In the X-ray domain, they display various properties: besides HMXBs, they can be associated to supersoft emissions, typical of massive star emissions, or hard and bright thermal emissions of gamma-Cas type. The statistics on the incidence of these various conditions remain difficult to establish as up to now no distance-limited sample had been studied. Using e-ROSITA surveys, we now provide such an analysis, unveiling the actual X-ray properties of Be stars.

Collisions in evolved massive binaries

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XMM has monitored WR21 and WR31, two binary systems containing an evolved Wolf-Rayet star and an O-type star. Changes are detected in the X-ray observations and appear phase-locked with the binary orbit. They can be interpreted as linked to colliding winds, with varying wind absorption along the line-of-sight playing the leading role. This result is backed up by spectropolarimetric information, which helps constrain the system's parameters. These two short-period systems are then compared to a comparable and well-known case, V444 Cygni, to get a more general overview.

An unconventional approach to use high-resolution spectra to distinguish between variability in emission and absorption

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RS Oph is a recurrent nova (powered by explosive nuclear burning on the surface of a white dwarf) exploding every 10-20 years. Since the system parameters don't change, each nova outburst should behave the same. Nevertheless, Swift found much fainter Super-Soft-Source (SSS) emission in 2021 compared to 2006. I present an unconventional approach with which 2006 and 2021 high-resolution X-ray RGS spectra can unambiguously answer the question whether this was due to less emission (e.g. lower effective temperature) or more absorption. Spectral modeling to the Swift/XRT CCD spectra, assuming blackbody or atmospheric source emission, left it ambiguous.

The problem leading to the ambiguity is the high degree of complexity of the source emission. Bypassing the challenge of finding a spectral emission model by simply multiplying a 2006 RGS spectrum by an absorption model yields a scaled spectrum impressively agreeing with the 2021 RGS spectrum.

This allows the important conclusion that the central nuclear burning engine was identical during both outbursts and that there exists no unknown process that could influence the nuclear burning rate under the same conditions. Further, the absorbing material above the white dwarf must be highly inhomogeneous leading to different absorption behaviour at different times.

X-ray Flaring in the Contact Binary KIC 9832227

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Contact binaries are pairs of non-degenerate stars orbiting so closely that they share a common envelope and exhibit rapid stellar rotation. This results in high levels of chromospheric and coronal activity, making these stars strong sources of X-ray radiation. We present an analysis of X-ray and UV data obtained with XMM-Newton of the contact binary star KIC 9832227. Our analysis finds that the binary is a soft X-ray source whose emission originates from a multi-temperature plasma with temperatures up to 1 keV. We identify two distinct components in the X-ray spectrum. The hotter component is eclipsed during part of the orbital cycle and appears to originate from a compact flare near the contact region between the two stars. The cooler component is not eclipsed and could originate from the polar region on the primary star or an extended corona. The UV emission exhibits a sinusoidal modulation similar to that observed at longer wavelengths. We model the UV light curve using stellar atmosphere models and deduce the presence of a starspot near the polar region of the primary.

X-ray and optical monitoring of HD108

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Optical and X-ray spectroscopy has been gathered for the magnetic massive star HD 108, known for its extreme rotation period (54yrs). Radial velocity variations were detected, unveiling a companion in a 8.5yrs orbit. Comparing the X-ray behaviour since the minimum emission state that occurred in 2007-2008, we found a slight increase of the flux and a spectral hardening of the emission. A dedicated MHD simulation yields an overall X-ray spectral energy distribution in excellent agreement with the observations. This suggests a faster wind for HD 108 than expected up to now. In addition, the varying emission lines in the optical provides for the first time constraints on the inclination angle of the rotation axis and the obliquity of the magnetic axis.

Chapter 6

Isolated Neutron Stars

An X-ray phase shift in the variable gamma-ray pulsar PSR J2021+4026

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PSR J2021+4026 is an energetic radio-quiet pulsar located within the shell of the G 78.2+2.1 supernova remnant. Pulsations were first detected in the gamma rays by Fermi-LAT, then in the X rays by XMM-Newton. In October 2011 Fermi-LAT simultaneously observed an abrupt decrease in its gamma-ray flux by 20% and a 6% increase in its spin-down rate. There was no change in the pulse profile, but the gamma-ray cut-off energy decreased. The pulsar persisted in this state until December 2014, when flux and spin-down rate returned to their original values. Later, two similar mode changes occurred, suggesting a quasi-periodic variability over a time scale of a few years. Here we report the results of a multiwavelength timing analysis combining Fermi-LAT data with two XMM-Newton observations, taken in April 2012 and August 2015. Our study revealed that the position of the X-ray peak relative to the gamma-ray profile shifted in phase across the 2014 mode change. We interpret the results in terms of a multipolar magnetic field, and we discuss the implications on the geometry of the magnetosphere. Since the gamma-ray mode changes of PSR J2021+4026 are still unique, a multiwavelength monitoring activity is crucial for studying variability in high-energy pulsars.

The first outburst of the young radio-loud magnetar Swift J1818.0–1607

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Swift J1818.0–1607 is a rapidly rotating magnetar (P $\sim$ 1.36 s) that was discovered in March 2020 during an outburst. Follow-up radio observations confirmed its nature and identified it as the sixth radio-loud magnetar known to date. Swift J1818.0–1607 is also one of the most rapidly spinning magnetars and one of the youngest neutron stars in the galaxy. In this talk, I will present the results of X-ray observations of Swift J1818.0–1607 using the XMM–Newton, NuSTAR, and Swift telescopes. These observations allowed us to study its spectral and temporal properties in great detail during the first 7 months of its outburst. Additionally, we conducted a long-term study of the flux and the spectral evolution over the first 19 months of the outburst. This study revealed a decrease in luminosity by a factor of about 90 over 1.5 years since the outburst onset. We also observed Swift J1818.0–1607 with the VLA, which allowed us to detect the radio counterpart of the magnetar and a half-ring-like structure of bright diffuse radio emission. We suggest that this radio structure may be associated with a supernova remnant.

Three-dimensional numerical simulations of ambipolar diffusion in NS cores.

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We numerically model evolution of magnetic fields inside a neutron star under the influence of ambipolar diffusion. Our simulations are 3D and performed in spherical coordinates. Our model covers the neutron star core and includes crust where the magnetic field decay is due to Ohmic decay. We discover an instability of poloidal magnetic field under the influence of ambipolar diffusion. This instability develops in the neutron star core and grows on a time-scale of 0.2 dimensionless times, reaching saturation by 2 dimensionless times. The instability leads to formation of azimuthal magnetic field with azimuthal wavenumber m = 14 (at the moment of saturation) which keeps merging and reaches m = 4 by 16 dimensionless times. Over the course of our simulations (16 dimensionless times) the surface dipolar magnetic field decays, reaching 20 per cent of its original value and keeps decaying. The decay time-scale for the total magnetic energy is six dimensionless times. The ambipolar diffusion induces electric currents in the crust. Strong electric currents in the crust lead to heating, which could correspond to luminosities of 1e29 erg/s during hundreds of Myrs for an initial magnetic field of 1e14 G.

Toward Self-Consistent Constraints on Pulsar Mass, Radius, and Magnetic Field Structure Through Nicer and Fermi

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Modeling of the NICER X-ray waveform of the pulsar PSR J0030+0451, aimed to constrain the neutron star mass and radius, has inferred surface hot spots, i.e., the magnetic polar caps, that imply significantly non-dipolar magnetic fields. To this end, we investigate magnetic field configurations that comprise offset dipole plus quadrupole components using static vacuum field and force-free global magnetosphere models. We compute geodesics from the observer plane to the polar caps to compute the resulting X-ray light curve and we explore, through Markov chain Monte Carlo and machine learning techniques, the detailed magnetic field configurations that can reproduce the observed X-ray light curve and have discovered degeneracies. Having obtained the force-free field structures, we then compute the corresponding synchronous gamma-ray light curves and we compare these to those obtained by Fermi-LAT, to provide models consistent with both the X-ray and the gamma-ray data, thereby restricting further the multipole field parameters. An essential aspect of this approach is the proper computation of the relative phase between the synchronous X- and gamma-ray light curves. The next steps and the broader implications of this study will be discussed.

Expanding the X-ray dim isolated neutron star population with the SRG/eROSITA All-Sky Survey

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X-ray dim isolated neutron stars (XDINS), famous for their predominantly thermal X-ray emission, could make up a significant part of the Galactic isolated neutron star (INS) population. Studies of their population properties, evolution and links to other INS families are limited by the small known sample of seven nearby objects. The SRG/eROSITA All-Sky Survey is ought to detect the elusive XDINS beyond the immediate solar vicinity. In this talk, we want to present the search strategy, report the discovery of the first two promising candidates and give an outlook on our still ongoing identification campaign that aims to lay the basis for a complete flux-limited sample down to 10^{-13} erg/s/cm^2 (0.2-2.0 keV).

Multi-wavelength Observations of Nearby Fast Radio Bursts

Walid Majid[1]
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Fast radio bursts (FRBs) are bright, milli-second duration radio pulses of unknown origin. Since their discovery in 2007, FRBs have been shown to have extragalactic origins and enormous energy outputs in the radio band alone. Hunting for FRBs and understanding their physical origin(s) have become a leading scientific goal in astrophysics. As neither the progenitors nor their emission mechanisms are known, simultaneous multi-wavelength studies of repeating FRBs would enable new tests of emission models. In this presentation, we will describe a multi-wavelength campaign to observe nearby FRBs, including observations spanning the radio, visible, and X-ray wavelengths. The presentation will include a description of a new novel radio/optical hybrid instrument under development at the NASA Deep Space Complex in Goldstone, CA, that is enabling simultaneous observations at the two widely separated wavelengths. Combined with excellent sensitivity with the NICER X-ray instrument, this campaign will provide a unique opportunity to search for multi-wavelength counterpart of FRBs, a key observable for discriminating between the various proposed progenitors and emission mechanisms for FRBs.

Serendipitous isolated neutron star candidates from the 4XMM-DR9 and 4XMM-DR12 catalogues

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We report the results of XMM-Newton fulfil programs 088419, 090126, and 092282 to observe new thermally emitting isolated neutron star (INS) candidates from 4XMM-DR9 and 4XMM-DR12. With the goals to assess long-term variability and improve spectral determination and source localisation for follow-up studies, our program explores a more remote and better characterised INS population than that detectable in the full sensitivity of the eROSITA All-Sky Survey. The identification of these rare X-ray emitters relies heavily on probabilistic catalogue cross-matching and screening of suitable candidates; as such, it is a direct scientific validation of the catalogues, tools, and data products being delivered within the scope of the EU Horizon 2020 XMM2ATHENA project.

The 2021 Activity of the Galactic Magnetar SGR 1935+2154 as Observed by Fermi-GBM

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The galactic, fast-radio-burst-emitting magnetar SGR 1935+2154 has been the most active in recent years. It entered an active x-ray burst episode in 2021 September, nearly a year after the activity that included a Fast Radio Burst (FRB) with an x-ray counterpart. We report on the temporal and spectral properties of Fermi Gamma-ray Burst Monitor observations of the activity and compare it to previous episodes. The bursts show mean log-Gaussian duration $T_{100} \sim$ 77.34 ms, cutoff power-law peak energy $E_{peak} \sim 26.62$ keV and photon index $\Gamma_{CPL} \sim 0.49$, and blackbody soft and hard temperatures $kT_{BBs} \sim 5.23$ keV and $kT_{BBh} \sim 9.24$ keV. The burst fluence spans 3 orders of magnitude ($10^{-8} - 10^{-5}$ erg cm^{-2}) and follows $dN/dS \propto S^{-0.93}$. The anti-correlation between the blackbody temperature and the emission area is weaker in the hard component at $R^2_{BBh} \propto kT^{-4.56}_{BBh}$ but is improved in the soft component at $R^2_{BBs} \propto kT^{-1.63}_{BBs}$, compared to previous activities, with an overall $R^2_{BB} \propto kT^{-3.82}_{BB}$ correlation. Comparing the 2021 activity to the previous six episodes during 2014-–2020, the 2021 bursts have the highest average ($\sim 16.46\times10^{-4}$ erg cm^{-2}) and integrated fluence (1.28×10^{-4} erg cm^{-2}) and are relatively shorter than the 2019–2020 activities. During 2014–2021, the bursts' mean peak energy (E_{peak}) shows a slight softening and is generally softer than other magnetars.

25-year trends for the persistent emission of magnetar SGR 1806-20

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The prototypical magnetar, SGR 1806-20, has the strongest magnetic field ($\sim 10^{15}$ G) and the shortest characteristic age among this class of objects. Since the localization by ASCA, it has been observed for more than 30 years, meanwhile it exhibited large activity variations of the persistent emission in addition to the giant burst at the end of 2004. In this study, we analyzed all the available data of SGR 1806-20 taken by ASCA, Suzaku, XMM-Newton, and NuSTAR, to investigate the temporal and spectral evolution of its persistent emission over 25 years from 1993 to 2018. The flux increased by about a factor of 3 at the 2004 burst and decayed exponentially with a time constant of $\sim$ 1.8 years which agrees with Younes et al. (2017). By 2018, the flux reached a bottom level which is lower by 25
Throughout this activity change, the unabsorbed spectra are generally represented by a power law with a photon index of $\sim$ 1.3, plus a blackbody with kT $\sim$ 0.7 keV which contributes about 10
The relative contribution of the blackbody increased after the giant burst.

The puzzling X-ray pulsations of the middle-aged pulsar B1055-52

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We present a detailed timing and phase-resolved spectral analysis of X-ray emission based on recent XMM-Newton observations. In the first step, we explored the consistency of the phase-integrated spectrum with previous X-ray observations. We also investigated the applicability of existing neutron star atmosphere models to these sensitive data and concluded the spectrum is best fitted with a three-component (two blackbodies + power law) model. The X-ray timing solution shows a discrepancy with respect to the long-term radio timing solution. We discuss possible instrumental and non-instrumental origins, as well as constraints from partly simultaneous radio observation. Our analysis of the phase-resolved X-ray spectra reveals changes in thermal emission parameters with the pulsar's rotation phases phase, presumably associated with a nonuniform temperature distribution over the neutron star surface. We compare our results with similar thermally emitting isolated neutron stars, emphasizing pulse fractions, phase-energy maps, and pulse-phase variations of fitted parameters. We speculate about possible implications such as the temperature and magnetic field distributions.

New Timing Results of the MSPs

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Millisecond pulsars (MSPs) are known for their long-term stability. Using six years of observations from the Neutron Star Interior Composition Explorer (NICER), we have analyzed the X-ray timing results of several MSPs, including PSR B1937+21, PSR B1821-24, PSR J0437-4715, PSR J0030+0451, PSR J0218+4232, and PSR J2124-3358. We have calculated the σ_z, which represents the timing stability of pulsars, and achieved timing stabilities on the order of 10^{-14} for PSR B1821-24 and PSR J0437-4715, and 10^{-13} for PSR B1821-24, PSR J0218+4232, PSR J0030+0431, and PSR J2124-3358, respectively.

Chapter 7

White Dwarf, Neutron Star and Black Hole Binaries

Absorption variability of Vela X-1: long-term monitoring study in the 2–10 keV energy band

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Vela X-1 is important for the understanding of the accretion processes in high-mass X-ray binaries on account of its natural variability and inhomogeneous wind, being easily observable due to the close distance and high inclination of the system. In this project, we conduct a systematic long-term X-ray monitoring study of the source in the 2 to 10 keV band with the Monitor of All-sky X-ray Image mission, which offers a unique avenue to explore the significant fluctuations of absorption over the orbit. To do this, we use the hardness ratios as an indicator of variability in absorption and look at individual binary orbits in contrast to the average trends of the more than thirteen years of observations. Our output is consistent with previous works that explain this variability with a model of an inhomogeneous environment, where the overdensities arise from the line-driven instability triggered in the stellar wind near the photosphere. Furthermore, we look at individual orbits of the time intervals of spin-up and spin-down episodes aiming to find recurring evolutions. These results provide us insights into the accretion and wind physical properties of Vela X-1 in particular, but they also shed light on the properties of other similar sources.

Testing white dwarf X-ray masses in intermediate polars with dynamical studies

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In intermediate polars, the temperature of the plasma in the region where the accreted material hits the white dwarf surface is thought to depend only on the white dwarf mass. The main cooling mechanism is assumed to be the emission of X-rays. Hence, many authors have derived estimates of the white dwarf masses in these systems from X-ray spectral modelling. However, this technique is known to suffer from significant model- and instrument-dependent systematic effects. To overcome these shortcomings, we are performing dynamical studies of intermediate polars using optical and near-infrared data obtained with the 10.4-m Gran Telescopio Canarias and other telescopes. In this talk we present the dynamical white dwarf masses of GK Per and XY Ari, and compare our results with several estimates from X-ray spectral modelling. We find that a major revision of the cooling models currently assumed for the accretion in intermediate polars is needed.

Probing the quiescent behaviour of Galactic X-ray Binaries with eROSITA

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The eROSITA survey has revealed a myriad new X-ray sources in its completed four scans, with several new X-ray Binaries popping up. Here, we report on analysis of eROSITA data of nearly 200 known galactic XRBs, in addition to follow-up efforts of newly discovered ones by eROSITA. The behaviour of highly magnetised neutron star binaries at low luminosities is currently at the crux of neutron star science in the X-ray regime. To investigate the quiescent properties of known galactic XRBs, especially those hosting neutron stars, we probe into their transition into low luminosity stable accretion by studying their spectral behaviour and variability in the eRASS. This is conducted with the ultimate goal of modelling the X-ray luminosity function of the magnetised NS XRBs in the soft band. We also report on the follow-up of eROSITA detected XRB candidates conducted using NuSTAR and XMM-Newton, which resulted in two robust X-ray binary discoveries, each proposed to be high mass X-ray binaries hosting neutron stars: SRGA J124404.1−632232, and ERASSU J084850−420035, further enriching the sample of candidates for stably accreting low luminosity neutron star binaries, and contributing to an overall improved understanding of NS XRBs in quiescence.

A fresh look on the Galactic XRB population

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X-ray binaries (XRBs) are the end-points of stellar evolution and some of the most extreme objects in the Galaxy. We present updated catalogs of the Galactic High and Low mass X-ray binaries and discuss constraints on their spatial distributions, X-ray luminosity functions and accretion physics which can be obtained using this sample. Finally, we discuss methods of identification of new candidates in the eROSITA survey to expand the census of known XRBs. We also discuss the impact of expansion of the sample of known XRBs on the obtained results.

The NuSTAR view of the 2021 giant X-ray outburst of EXO 2030+375

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In 2021, the BeXRB EXO 2030+375 underwent a giant X-ray outburst, the first since 2006, which reached a peak flux of ~600 mCrab. NuSTAR and NICER observed this outburst near the peak and once during the decline phase after a characteristic evolution of the pulse profile had been observed through extensive NICER monitoring. After this transition, the relative strength of two peaks is reversed in the pulse profile and hardness ratio. Our observations confirm the behavior seen in previous outbursts. Here, we present a joint NuSTAR and NICER analysis of the spectral transition associated with this pulse profile change. We also investigate the spectral variability with pulse phase of the two NuSTAR observations and compare the spectral evolution to geometrical models of the accretion column emission obtained from relativistic ray-tracing simulations. We further discuss putative CRSF detections reported in the literature, especially the possible 10-keV absorption feature in the context of the complex soft X-ray continuum.

Density and abundance diagnostics of photo-ionized plasmas
New results for GRO J1655-40

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Astrophysical photo-ionized plasmas are often characterized by a broad range of ionization stages. The column density as a function of ionization parameter (ξ) in such plasmas is called the Absorption Measure Distribution (AMD). In black hole outflows, the broad AMD makes for a line-rich spectrum full of diagnostics, many of which will be boosted later this year with new data from the XRISM observatory. The talk will demonstrate how to use these lines to derive physical properties of the outflows, such as their density profiles and elemental abundances. Particularly interesting new results will be presented for the outflow of GRO J1655-40, during its famous 2005 outburst.

Explaining the Z-track of GX 340+0 using wideband observations with *AstroSat*

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Z-track sources are a few of the brightest low mass X-ray binaries which accrete close to Eddington rate. They are characterised by their peculiar tracing of the 'Z' shape on the Hardness intensity diagram. Historically, they have been modelled with either a thermal blackbody and a comptonised emission or a multi-colour blackbody to model the accretion disk and a non-thermal component to account for either comptonisation or the boundary layer emission. In this talk, I will discuss our analysis of deep observation of a well-studied Z-source GX 340+0 with *AstroSat* in 0.5–25 keV. We investigate the evolution of the source by characterising the spectral and temporal properties as a function of the Z-track. With the observed variations of the fluxes of various components, we can reproduce the motion of the source along the Z-track. I will discuss the picture of the Z-track evolution revealed by the spectral and temporal properties of the source.

Temporal and spectral analysis of the BHC 4U 1543-47 during the major outburst of 2021

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4U 1543-47 is the brightest X-ray novae detected by MAXI, in last 11 years. 4U 1543-47 exhibited an outburst almost every 10 years from discovery upto the year 2002. The source showed outbursts in 1971 (Matilsky et al. 1972, Li et al. 1976), in 1983 (Kitamoto et al. 1984), in 1992 (Harmon et al.1992), and in 2002 (Park et al. 2004, Kalemci et al. 2005). However no outburst was observed around the year 2012. After 17 years of quiescence the source started a new outburst on June 11, 2021 (MJD 59376) and reached the peak flux on June 15, 2021 (MJD 59380). The peak flux is very high (8.6 Crab) during the 2021 outburst. The source flux decreased below the one-day detection limit of about 15 mCrab around December 16, 2021 (MJD 59564). Thus the outburst continued for almost 188 days. In this work we provide a detailed spectral and temporal analysis of the source during the 2021 outburst using archive data from multiple satellites namely AstroSat, Nicer and NuSTAR. We have found a QPO of centroid frequency 0.5+/-0.01 Hz on July 10, 2021 (MJD 59405) in the declining phase of the outburst using the AstroSat data.

A global view of ultra-compact X-ray binaries

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Ultra-compact X-ray binaries (UCXBs) are a group of low-mass X-ray binaries (LMXBs), where a compact object, either a neutron star or a black hole, accretes matter from a degenerate (hydrogen poor) donor star in a tight orbit with orbital periods shorter than 80 minutes. The UCXB population is scarce (about 20 confirmed systems) but is of great interest for testing binary evolution theories and probing the physics of mass accretion in the absence of hydrogen. Moreover, these objects are expected to be powerful sources of gravitational waves and have been selected as preferential targets for future dedicated missions (e.g., LISA).

Although several studies were conducted for each of these sources, a systematic and homogeneous analysis of the spectral properties of UCXBs is still missing, making it difficult to build an overall picture of the characteristics of these systems as a whole. We have created the UltraCompCAT catalog, which provides a thorough and complete overview of ultra-compact and short orbital period X-ray binaries, having great legacy value for both observers and theoretical astrophysicists. In this talk, I will review the general properties of this intriguing class of LMXBs and will focus on a systematic X-ray spectral study of the confirmed UCXBs.

Matter ejections behind the highs and lows of a transitional millisecond pulsar

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I will describe the results of the most extensive multiwavelength observational campaign ever carried out on the prototype of the class of transitional millisecond pulsars, PSR J1023+0038. The campaign aimed to find an explanation once and for all for the peculiar variability pattern shown by the source during its current sub-luminous X-ray accretion disk state. The results of the data analysis indicate that this phenomenology is due to the evolution of the innermost region of the accretion disk. This evolution causes the emission of discrete mass ejecta on top of that of a compact jet when the source switches from high-intensity mode to low-intensity mode. A subsequent re-enshrouding of the pulsar accounts for the switch in the opposite direction.

Global Understanding of the Outbursting Nature of Transient Black Hole Sources

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Stellar Massive Black Hole X-ray Binaries (BHXRBs) are very interesting as they show rapid variation in their spectral and timing properties. BHXRBs are generally two types: persistent and transient. Transient BHXRBs stay most of their life time in a low luminosity quiescent phase. They become occasionally active and show single or multi-peaked outbursts. The nature of these outbursts in terms of the duration, the number of peaks, maximum peak intensity, and so on varies. Recently, we have studied three well-known recurring transient BHXRBs: H 1743-322, GX 339-4, 4U 1630-472 using archival data of RXTE/ASM and MAXI/GSC for around two and half decades. Studying these sources, we have made an effort to understand the triggering mechanism of outbursts, their relation with the quiescent phases, etc. We also tried to find a physical reason behind the complete (when four defined spectral states, such as hard, hard-intermediate, soft-intermediate and soft are observed) or failed outbursts. In a failed outburst, we generally do not see the presence of the soft state, sometimes even intermediate states are also found to be missing. So, our study of three recurring transient BHXRBs sheds light on long-term accretion dynamics in outbursting sources.

A study of the Cyclotron line in XTE J1946+274 through the 2018 and 2021 outbursts using NuSTAR, Astrosat and HXMT

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XTE J1946+274 is a transient Be/X-ray binary showing several outbursts in the last three decades. It houses an X-ray pulsar with a 15.7 s spin period with an eccentric $\sim$ 170 day orbital period. It underwent major outbursts in 1998, 2010, 2018 and most recently in 2021. It is also among the subset of sources that exhibit a Cyclotron Resonant Scattering Feature in it's hard X-ray spectrum. We have investigated the pulse-phase dependence of the cyclotron line at 38 keV using data from NuSTAR, Astrosat and HXMT, instruments which had observed it during the 2018 outburst. The NuSTAR observation was made during the declining phase of the 2018 outburst, while Insight-HXMT and Astrosat observations were during the peak. We further investigate the cyclotron line feature using data from Astrosat observation of the 2021 outburst. We present a comparative study exploring the evolution of the spectral and temporal features of the 2018 and 2021 outbursts and the dependence of the cyclotron line parameters on pulse-phase and luminosity in this work.

The X-ray spectrum of MAXI J1820+070: addressing black hole spin through Bayesian modelling

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We report the latest results of a project to model X-ray spectra of black hole LMXBs using Bayesian methods on XMM-Newton and NuSTAR data. The spectra should contain important information about the geometry of the inner accretion flow and spacetime near the black hole but inferences about its spin and the inner flow geometry remain controversial. Spectral models involve many parameters that can be hard to constrain given only X-ray data; there are often degeneracies or multiple solutions to the fitting problem. We use the best available information on system properties (e.g mass, distance, inclination) as informative priors for modelling, together with RGS data to model ISM absorption. Rather than "fit for" spin, we examine two extreme models: zero and maximal spin. We use Bayesian methods for model comparison and compare the plausibility of parameters in each case. Our test case is MAXI J1820+070 data over the 0.8 — 70 keV range using 3 XMM-Newton and 2 NuSTAR observations. We find a preference for low spin. We are applying the same approach to XMM-Newton data from a further 4 confirmed and 8 candidate black hole XRBs in an attempt to break the deadlock over XRB geometry.

From stellar winds in neutron star high-mass X-ray binaries to constraining the equation of state of dense matter

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By constraining the equation of state of dense matter inside Neutron Stars (NS), we probe their nature which is still unknown. One possible method is to constrain the NS mass from radial velocity curves derived by Doppler shifts in spectral lines in the NS vicinity. In High-Mass X-ray Binaries (HMXBs), the stellar wind strongly impacts the lines' shape and we cannot disentangle the shifts due to the NS orbital motion from the intrinsic wind variability with current X-ray instruments. In order to make predictions for future missions such as *Athena* and *XRISM* and devise the best observational strategy to constrain the equation of state inside NS HMXBs, we need a better understanding of the wind structure. The archetypical Vela X-1 is a key HMXB for such studies since it has a complex disturbed stellar wind and prominent emission lines. We observed Vela X-1 with *XMM-Newton* at orbital phase $\sim$0.37 to $\sim$0.51 and followed the evolution of spectral parameters down to the pulse period time-scale. We observed high-absorption variability caused by clumps and large-scale structures, the accretion- and photoionisation wakes, along the NS orbit. For the first time, we traced the onset of the wakes with high-time resolution.

X-ray polarization properties of the thermal state of black hole X-ray binary measured for the first time

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We report the first highly significant detection of polarization of X-rays from a BH accretion disk. We observed the transient XRB, 4U1630-47, during its outburst and we found it in the thermal emission state. The classical theory of geometrically thin and optically thick accretion disks, pioneered by Shakura and Sunyaev in 1973, is believed to give an excellent description of the properties of such systems. The IXPE observations revealed unexpectedly high polarization degree in the 2-8keV band, seen to increase linearly with the energy while the polarization angle remained constant. This result shows that this BH cannot rotate at extreme spins. The polarization arises due to the scattering of the thermal photons in the highly ionized surface layer of the disc that is viewed at high inclination. Moreover, the temporal variability of the polarization degree and absorption line properties implies a relationship between the innermost regions of the accretion disk and the wind outflow, which provides important clues about the physical mechanisms behind the launch of the winds from the accretion disk.

Studying the accretion physics of asynchronous polars using broadband X-ray data

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Asynchronous polars (APs) (asynchronosity ∼1-15% between spin and orbital period) are a rare and unique type of magnetic cataclysmic variables (mCVs) that neither conforms to polars (asynchronicity ∼0%) nor intermediate polars (IPs) (asynchronicity $> \sim 90\%$). We discuss broadband (0.3-40 keV) X-ray study using simultaneous XMM-Newton and NuSTAR observation for two such unique systems – CD Ind and Paloma. Our work highlights the essential X-ray properties of these systems, like the multitemperature nature of plasma in post-shock region, presence of intrinsic absorber, and periodic variation of the observed flux. We find both systems show significant spectral variability during their rotation cycle, arising due to presence of powerful and complicated intrinsic absorber. Regarding the shock height, our study revealed a weak neutral Fe K-alpha line and weak Compton reflection in the hard X-rays, implying a tall shock scenario for both sources. We also note one distinguishing feature of Paloma, showing strong orbital peak and weak spin peak in the power spectrum. Our study aims to compare the properties with other asynchronous polars and how that fits in the broader picture of mCVs.

Pulse profile diagnostics in high-mass-X-ray-binary neutron stars

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I will present the first outcomes of a project to characterized the energy-dependent emission of magnetized X-ray binaries folded at their spin frequency, the so-called pulse profiles. We collected all the observations performed on this class of sources with the NuSTAR observatory, apply a consistent reduction pipeline and investigate recurrent features. At first, we focuse on the pulsed fraction and find that there are local reduction of this quantity in correspondence of line-like features in the energy spectrum, namely iron fluorescence and cyclotron resonance scattering features. We also find a general increasing trend of the pulsed fraction with energy and a change of slope around 10–20 keV. We discuss the implication of our results in relation to the spectral models and radiation beam patterns. In particular, we show how timing signatures can be used as a complementary diagnostic tools.

A Detailed Spectral Study of Intermittent–AMXPs; Aql X–1 & SAX J1748.9–2021 during ***Pulse-on*** and ***Pulse-off*** Stages

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Spin periods of neutron stars (NS) associated with Low Mass X-ray Binaries (LMXBs) are mostly unknown due to the lack of pulsations. We present a detailed spectral analysis during the *pulse-on* and *pulse-off* stages of intermittent-accreting millisecond X-ray pulsars (AMXPs); Aql X–1 & SAX J1748.9–2021 which are unique labs to study absence of pulse phenomena in LMXB systems. We first performed temporal analysis to define durations of intermittent pulses. We then followed three main routes to study the spectral properties by using Rossi X-ray timing Explorer data; We obtained the spectral parameters for each 128s time segments independently for the ObsIds including pulse with the previous and latter ObsIds for each source (*i*; Route 1). We model pulse-on regions by using the results from pulse-off segments as an input background model to obtain pulse effect (*ii*; Route 2). For a deeper investigation, we applied phase-resolved spectroscopy to the pulse-on regions by splitting into the phase intervals between 0.25-0.75 (*pulse-low*) to 0.75-0.25 (*pulse-high*; *iii*; Route 3). We show there is a clear discrepancy of the spectral parameters between pulse-low and pulse-high stages upto 13.0 keV which corresponds to the evolution pulse power over energy.

The role of steady nuclear burning for type-I bursts and superbursts

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Frequent X-ray bursts are observed from accreting neutron stars, arising from unstable ignition of accreted H/He on the neutron star surface. In many systems exhibiting these "type-I" bursts, we also observe infrequent "super"-bursts, thought to arise from ignition of carbon. Uncertainty remains as to how sufficient carbon can be produced to power these bursts, as it is produced only inefficiently in the usual unstable H/He burning. An interval of steady burning (without bursts) prior to each superburst may provide sufficient fuel. However, there is also evidence that at high accretion rates steady burning can coexist with unsteady, leading to the low burst efficiency which is sometimes observed. We examine the properties of bursts at high accretion rates and estimate the amount of carbon that might be produced. In parallel, we review the prior accretion and burst history of the known superburst events and test for the presence of such steady burning. The absence of burst-free intervals may be evidence that high-state steady burning contributes to the carbon fuel production for superbursts.

Mass-loss and composition of wind ejecta in type I X-ray bursts

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X-Ray bursts (XRB) are powerful thermonuclear events on the surface of accreting neutron stars (NS), which can synthesize intermediate-mass elements. Their luminosities sometimes exceed Eddington value, and some of the material may be ejected by radiation-driven winds. We aim at determining the mass-loss and chemical composition of this ejecta and its significance for Galactic abundances. We also report on the evolution of observational quantities during the wind phase, which can help constrain the mass-radius relation in NS. A modern non-relativistic radiative wind model was linked through a new technique to a series of XRB hydrodynamic simulations, that include over 300 isotopes. This allows us to construct a quasi-stationary evolution of the XRB+wind. Results show 0.1% of the envelope mass ejected per burst, at an average rate of 2.6% the accretion rate, and 90% of the ejecta composed by ^{60}Ni, ^{64}Zn, ^{68}Ge and ^{58}Ni. The ejecta also contained traces of some light p-nuclei, but not enough to account for their Galactic abundances. The photospheric magnitudes showed remarkable correlations that could be used to link observable quantities to the physics of the envelope's interface with the NS crust. This is a promising result regarding the issue of NS radii determination.

The accreting millisecond pulsar SAX J1808.4-3658 during its 2022 outburst: hints of an orbital shrinking

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Accreting millisecond pulsars (AMSPs) are rapidly rotating neutron stars hosted in a tight binary system with a low-mass companion. Their millisecond periods result from a Gyr-long phase in which old radio pulsars are spun up by accreting matter from a donor via a Roche lobe overflow. SAX J1808.4-3658 was the first AMSP discovered in 1998. Since then, the source has undergone ten ∼1-month-long outbursts with ∼2-3 years recurrence, making it the most thoroughly investigated of its type. When the onset of a new outburst was detected in August 2022, we performed a multi-wavelength campaign with three X-ray telescopes - XMM-Newton, NuSTAR, and NICER -, the fast optical photometer TNG/SiFAP2, and the HST. I will present a coherent timing analysis of X-ray pulsations during this latest outburst, confirming the long-term spin-down rate compatible with the expected energy losses from a rotating magnetic dipole of 10^8 G. This may indicate that a radio pulsar is active in the system during quiescence. For the first time in the last twenty years, we found hints of an orbital decay. I will discuss this evolution in terms of a gravitational coupling between the orbit and variations in the mass quadrupole of the companion star.

Superorbital modulations in supergiant High Mass X-ray binaries

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A puzzling variety of superorbital modulations have been discovered in several supergiant High-Mass X-ray binaries. To investigate the mechanisms driving these superorbital modulations, we have analyzed Swift/BAT lightcurves of these sources and constructed their dynamic power spectra and superorbital intensity profiles. These Swift BAT observations are complemented by pointed Swift XRT, NICER and NuSTAR observations performed at the predicted maximum and minimum phase of a single superorbital cycle for each of these sources. The results from this analysis indicate the possible presence of structures in the stellar winds of the supergiant stars in the form of multiple co-rotating interaction regions (CIRs) or from tidal oscillations.

The population of high-mass X-ray binaries in the LMC detected during the first eROSITA all-sky survey

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The Magellanic Clouds are our closest star-forming galaxies with low Galactic foreground absorption. This makes them a unique laboratory to study the population of high-energy sources. The SMC hosts a large population of Be/X-ray binaries associated with high star formation activity 25-40 Myr ago. The HMXB population in the LMC is associated with a star formation period at an earlier epoch and a lower HMXB formation efficiency. Due to the large angular extent and resulting insufficient coverage of the LMC, this information is far from complete.

An essential asset for studying the HMXB population in the entire LMC was the launch of eROSITA. eROSITA scans the sky in great circles which cross at the ecliptic poles. Due to the vicinity of the south-ecliptic pole, sources in the LMC are monitored for up to several weeks during each all-sky survey, leading to a deep total exposure and the possibility of studying long-term temporal behaviour. This allowed us the discovery of several new HMXBs and the verification of candidate HMXBs. During my presentation, I will first focus on the HMXB population properties in the LMC. Then I will talk about several individual objects for which follow-up observations showed us their peculiar nature.

Element abundance measurement and absorption measure distribution for the stellar black hole GRO J1655-40

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X-ray binaries (XRBs) have been studied for many years, but there remain open questions regarding different stages in their evolution, and the role of accretion and outflow states. Since XRBs show dramatic changes over short time periods, there are only a handful of high-resolution outflow observations, especially in the X-ray band. One exceptional outflow was observed in the transient stellar black hole GRO J1655-40 during its 2005 outburst. Its launch mechanism remains in dispute. The spectrum features deep absorption lines from many elements, including rare ones. We find that the relative element abundances, and the Absorption Measure Distribution (AMD) are closely entangled. By using the equivalent width measurement and theoretical curve of growth we infer an ionic column density from each resolved line. Some H-like ions include Lyman series lines of α, β, γ, and δ, which tightly constrains the ionic column densities. From these, we construct an AMD, and the density profile of the wind, which provides insights into the physical wind launching mechanism. The elemental abundances are also surprising, and hint to the precursor of the black hole in this XRB.

The vertical disk wind structure of Hercules X-1 in the Main High and Short High states

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Hercules X-1 is an X-ray binary with a warped, precessing accretion disk, manifesting through a 35-day cycle of alternating High and Low flux states. This disk precession introduces a changing sightline towards the X-ray source, through an ionized accretion disk wind, allowing us to uniquely sample the wind at different heights above the disk and measure the vertical distribution of its properties. We analyzed all XMM-Newton and Chandra observations of the Main High state of Her X-1, including a large XMM campaign totaling 400 ks, and produced the first 2D map of a disk wind. To follow-up on this opportunity, we searched the archive of Her X-1 Short High state observations. I will present the detection of ionized absorption in a Chandra HETG observation taken during Short High. We find that we are observing the same wind structure that has been detected during Main High. Interestingly, the best-fitting wind properties indicate that we are likely seeing the outflow at lower heights above the disk than at comparable precession phases of the Main High. Combining the results from Main and Short High states, we can thus measure the Her X-1 wind structure over a great range of heights above the disk.

Spectro-polarimetric results of Cyg X-1 in the hard state

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Cygnus X- is one of the most studied X-ray binaries with a black hole. We will discuss new results obtained with the Imaging X-ray Polarimetry Explorer. The electric field position angle aligns with the outflowing jet, indicating that the jet is launched from the inner x-ray emitting region. The polarization degree was measured to be 4% increasing with the energy in the 2-8 keV band. This value is higher than expected, implying that the accretion disk is viewed closer to edge-on than the binary orbit. The observations revealed that hot X-ray emitting plasma is spatially extended in a plane perpendicular to the jet axis, not parallel to the jet.

Cygnus X-1's fast X-ray variability behaviour in the 70s revisited: never throw away old data!

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Apollo 15 (and 16) did not only bring people to the Moon, but also experiments to study our neighbour and its environment, such as the X-ray fluorescence spectrometer. When traveling back to Earth, the experiment was also used for X-ray astronomy. One of the sources observed was the famous black-hole X-ray binary Cygnus X-1. X-ray states in X-ray binaries are mainly defined by their spectra and timing behaviour; these states correspond to different accretion regimes of the compact object. With the advent of high-throughput, high-time resolution experiments (such as onboard ASTROSAT, EXOSAT, Ginga, NICER, RXTE) emphasis has been shifting to study X-ray variability at high time resolution (typically less than milliseconds). For most of the earlier X-ray experiments in the 1960's and 1970's information is only available down to about milliseconds. We show that for Cygnus X-1, X-ray data taken with second to subsecond time resolution can uniquely help in defining its X-ray states. This is done by using digitized light curves and power density spectra as presented in the literature, from Uhuru (the 1st X-ray satellite), SAS-3 and HEAO-1, and various rocket experiments, in the 1970's, as well as newly analysed data from the X-ray experiment onboard Apollo 15.

Low-Frequency QPOs, Self-Oscillations, and the Corona

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Low-frequency quasi-periodic oscillations (LFQPOs) are frequently present in the X-ray flux of black hole binaries. They appear in the power spectrum as coherent peaks. Their centroid frequencies are in the range of 0.01-10 Hz. Even though they have been identified in various sources and are readily measurable, the exact nature of their origin still eludes us. Thus far, no models have provided a comprehensive or satisfactory explanation. In this work, we propose that the origin of these low-frequency QPOs is related to the corona. Specifically, the LFQPOs are a result of self-oscillations. Self-oscillations can generate and maintain a periodic motion by a power source that lacks periodicity. As a result, unlike in the scenario of a resonant case, there is no need to find a periodic driver. These self-oscillations associated with the corona can create the X-ray modulation detected as a QPO. Another instrumental consequence of this model is that it can shed light on the elusive physical properties of the corona itself.

High-density reflection spectroscopy of black hole X-ray binaries in the hard state

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X-ray reflection spectroscopy is a powerful tool to probe the accretion geometry of black holes. Previous reflection model often assume a disk electron density of 10^{15} cm^{-3}, which may be appropriate for massive AGNs but is too low for black hole XRBs. In this work, a reflection model with the disk density as a free parameter is applied to a sample of black hole XRBs in the hard state. The measurements of the disk density are compared to the theoretical predictions. The impact of the assumption of the disk density on other spectral parameters (e.g. the inner disk radius, the iron abundance and the disk ionization parameter) is also discussed.

Testing the Kerr metric using X-ray reflection spectroscopy and continuum fitting method

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Black holes are extremely compact objects predicted by general relativity. The strong gravity in the vicinity of black holes makes them ideal laboratory to test gravity theories. To measure black hole parameters, techniques such as X-ray reflection spectroscopy and continuum fitting method have been developed in the last decades. In the past years, we have developed the non-Kerr version of the ionized blurred reflection model relxill and the disk thermal emission model kerrbb. We have applied these non-Kerr models to X-ray spectra of some well studied black systems trying to constrain possible deviation from Kerr spacetime. We have found no evidence of deviation and we summarized some important sources of uncertainties for this kind of test during the study. For instance, the disk geometry, the disk temperature and the modeling of emissivity profile can all affect the constraint of non-Kerr parameters.

Rapidly alternating flux states of GX 339–4 during its 2021 outburst captured by Insight–HXMT

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The low-mass X-ray binary GX 339–4 was found to rapidly alternated between low flux and high flux states on a time-scale of hours during its 2021 outburst. Two high flux states lasted only for a period comparable to the orbital period of the observatory. Time-resolved spectral analysis shows that the sudden changes of flux are confined in the hard X-ray band (>4 keV). The variable non-thermal emission, including the power-law continuum from the corona and the reflected emission from the inner accretion disc, is responsible for the observed variability. There is no evidence for changes of the disk thermal emission, the inner disk radius or the corona height. Mechanisms that cause sudden changes in the coronal power can explain this kind of variability.

The temporal properties of black holes with Insight-HXMT

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We report the X-ray timing results of the black hole binaries(BHBs) observed by Hard X-ray Modulation Telescope (Insight-HXMT) observations,such as MAXI J1820+070, MAXI J1535-571, MAXI J1348-630, etc. Low frequency quasi-periodic oscillations (QPOs) are found in the low hard state and hard intermediate state of BHBs. With the large effective area of Insight-HXMT at high energies, we are able to present the energy dependece of the QPO parameters and phase lag up to 200 keV, which has rarely been explored by previous satellites.In the black hole MAXI J1820-070, We find that the centroid frequency and the full width at half maximum (FWHM) of the QPO do not change significantly with energy. However, as the spectra softening, the QPO phase lags at high energies changes from decreasing with energy to increasing with energy. Our results suggest that the high-energy radiation of the QPOs come from the samll-scale relativistic jet.

Supersoft X-ray sources as progenitors of Type Ia supernovae in the Large Magellanic Cloud

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Type Ia supernovae are instrumental to our understanding of the Universe due to their use as cosmic distance indicators, and their importance in enriching the interstellar medium with heavy elements. They are understood to be the thermonuclear explosions of white dwarfs, but their formation paths are still debated, especially their progenitors. There are two classes of progenitor models. In "single-degenerate" models, the progenitors are accreting white dwarfs (WDs). In "double-degenerate" models, the explosion is initiated through mass transfer between and/or the merger of two WDs. Here we present two supersoft X-ray sources in the direction of the LMC which are promising candidates as progenitors of SN 1a. In one case we find a supersoft source as a candidate for a double degenerate polar. In the other case we find the first evidence of a supersoft source with an accretion disk whose optical spectrum is completely dominated by helium, suggesting that the donor star is hydrogen-free. The properties of the system provide evidence for extended pathways towards Chandrasekhar-mass explosions, and allow to recover the population of the sub-energetic so-called Type Iax supernovae.

Impact of ionization and electron density gradients in X-ray reflection spectroscopy measurements

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Models currently used for the analysis of reflection spectra of black holes usually assume disc with constant ionization and electron density. However, there is some debate on the impact of these assumptions on the estimate of the properties of the sources, in particular when the fits suggest very steep emissivity profiles in the inner part of the accretion disc. In this work, we re-analyse a selected set of high-quality NuSTAR and Suzaku data of Galactic black holes and we fit the reflection component with three different models: relxill_nk, in which the ionization parameter and the electron density are constant, relxillion_nk, where the electron density is still constant but the ionization profile is described by a power law, and relxilldgrad_nk, where the electron density profile is described by a power law and the ionization profile is calculated self-consistently from the electron density and the emissivity. While relxillion_nk can fit the data better, we do not find any substantial difference in the estimate of the properties of the sources among the three models. Our conclusion is that models with constant electron density and ionization parameter are probably sufficient, in most cases, to fit the currently available X-ray data of accreting black holes.

A Comprehensive Study of the X-ray Source Populations in the Galactic Center

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The Galactic Center (GC) is home to a vast array of exotic X-ray sources, including a large concentration of accreting compact objects (low-mass X-ray binaries and cataclysmic variables). The study of those sources has significant implications for a wide range of topics, like galaxy evolution, dark matter, and gravitational wave events. Previous studies of X-ray sources in the GC were hampered by the high density and faintness of X-ray point sources in that region, as well as high levels of extinction towards the GC. Here we present a new study that utilizes narrow-band and continuum near-infrared (NIR) data to identify the X-ray populations inhabiting the GC and explore how they vary over different regions. We utilize the data from new X-ray surveys conducted with the XMM-Newton and Chandra observatories, in conjunction with the GALACTICNUCLEUS survey and supplementary NIR data from the Gemini, VLT, and HST observatories. This study will revolutionize our understanding of the thousands of X-ray point sources that have been found in the GC region, providing unprecedented observational insights into the origin and migration of stellar remnants in the vicinity of Sgr A*, and allowing us to evaluate the accuracy of theories and simulations of GC dynamics.

The accreting environment around the sg-HMXB IGR J18027-2016 through X-ray wind tomography.

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Supergiant High Mass X-ray Binaries (sg-HMXB) are usually comprised of a neutron star accreting from the wind of an OB supergiant companion. As the neutron star moves through the dense stellar wind, it accretes material from its donor star and therefore emits X-rays. The wind will be highly unstable revealing a rich phenomenology. The presence of a neutron star, deeply embedded within the winds from its massive companion, strongly influences the wind flow, allowing the study of stellar wind properties in situ. For X-ray wind tomography, precise knowledge of the orbital phase is essential. We utilize archival data for IGR $J18027-2016$ using XMM-Newton, NuStar, and swift satellites. Spectral analysis reveals a strong variability along the orbit, indicative of an accretion wake trailing the neutron star (nH$\sim 10^{24}$ cm^{-2}). We employ state-of-the-art hydrodynamical simulations to reproduce the observed variability. Comparison between the simulation outcome and the observations allows estimates on the geometrical, dynamical, and wind parameters of this system. Recent accretion models in massive binaries, ranging from detailed descriptions of the wind acceleration to modeling of the structure of the flow of matter on a global (binary-wide) scale and on a very close to neutron star are also discussed.

New avenues for multi-messenger discoveries in high energy astrophysics

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The upcoming start of LIGO's O4 observation run is driving a new era of data-driven discovery, in which finding and characterizing associated high energy electromagnetic counterparts to gravitational wave events is crucial. Fast X-ray transients (FXTs) occur when the merger of neutron stars results in a rapidly spinning magnetar, and can be detected over a broader range of viewing angles with respect to gamma-ray bursts, and at larger distances with respect to kilonova emission. Yet, Chandra or XMM-Newton are not equipped to automatically detect such transients. We propose a framework for the automatic discovery of FXTs and a broad range of high energy anomalies in archival and newly acquired X-ray observations. Novel representations of the event files are input to an auto-encoding neural network that has been pre-trained to isolate relevant features such as transient-like variability and spectrally extreme objects. We demonstrate this approach by applying it to a large number of X-ray sources detected by Chandra. We demonstrate that FTXs and other variability relevant variability patterns tend to occupy particular regions in the embedded representation created by the neural network. The framework could be easily incorporated into the data processing flow of new Chandra or XMM-Newton observations.

A new insight into density and location diagnostics of photo-ionized outflows

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The line resolved spectrum of XRBs outflows provides us with diagnostics of the physical processes in them.A powerful diagnostic is to measure the electron density, by estimating the population of a metastable level through X-ray absorption or emission lines from this level. In hot plasmas, high electron density affects these line intensities by depleting the metastable levels. Photo-excitation can have a similar effect, and is usually neglected.In photo-ionized plasmas the photo-excitation flux and the electron density are related through the ionization parameter. We show analytically that the two effects of density and UV flux must always come together, at the right distance from the source central. We demonstrate this effect on the 2005 outflow of GRO J1655-40. Considering collisional excitation, radiative recombination, and photo-excitation, we present a collisional radiative model of FeXXII with 63 energy levels, which calculates the n2/n1 population ratio, and gives rise to the 11.77A absorption line from the metastable level 2. We show that the observed ratio yields an electron density, and hence distance from the source, which indicates that photo-excitation is also important. We conclude that both density and photo-excitation processes must always be considered, in order to obtain a better understanding of these outflows.

New X-ray detections of magnetic period-bounce cataclysmic variables from XMM-Newton and SRG/eROSITA

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Period-bounce cataclysmic variables (CVs) are systems where a white dwarf (WD) accretes from a brown dwarf donor, reaching a point where the degeneracy of the donor reverses orbital period evolution. A large portion of the CV population (40-70%) is predicted to be period-bouncers, however, due to their intrinsic faintness, only few of these systems have been observed and confidently identified so far. We emphasize the importance of X-ray data in order to identify period-bounce CVs, as it provides proof of accretion from the substellar companion onto the WD because in this type of system the coronal emission of the donor is below the sensitivity of current instruments. We have observed the period-bouncer candidate SDSS J151415.65+074446.4 with XMM-Newton and we report here detection of X-ray orbital modulation. We determine the orbital period through the analysis of the X-ray light curve and we derive a mass accretion rate from the X-ray luminosity. Our analysis establishes SDSS J151415.65+074446.4 as a sibling of SDSS J121209.31+013627.7, the only other WD and L dwarf system confirmed as a period-bouncer through its X-ray properties. We provide an outlook of the eROSITA all-sky survey capabilities for the X-ray detection of period-bouncers and first eROSITA results on such systems.

The IXPE observation of Cyg X-3

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Cyg X-3 is a remarkable microquasar: it is one of the few black hole binaries with a Wolf-Rayet companion and one of the few to be observed in gamma-rays. IXPE, the first observatory with the sensitivity to detect polarization from tens of sources belonging to different classes, pointed at this source during its first year in orbit. In this contribution, we will report on the results: a large polarization degree, higher than 20%, is observed, with a peculiar variation with energy and orbital phase. The scenario that can be derived from these new results is changing our understanding of the source.

The spin down evolution of the transitional millisecond pulsar PSR J1023+0038 across the 2013 state transition.

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Transitional millisecond pulsars (tMSPs) are Rosetta Stone objects that switch between an accretion powered X-ray pulsar state and a rotation powered radio pulsar state. They present an opportunity to test the recycling model, whereby neutron stars are spun up over time to millisecond rotation periods by accretion from a companion star, resulting in an old, isolated radio MSP. PSR J1023+0038 was the first tMSP to be discovered and is still the only transitional millisecond pulsar for which we have pulsation data in both the accretion and rotation powered states. I will present detailed modelling of the radio pulsations before the 2013 transition to the X-ray state, and the X-ray pulsations after the transition. Surprisingly, we find that the spin-down rate increases during the accreting state, rather than reversing to spin-up as predicted by recycling. Previous studies revealed this spin-down enhancement, but they were limited in confidence due to the presence of stochastic fluctuations in the binary orbital period; now accounted for through our piecewise modelling. I will present the new spin-down enhancement measurement and the results of Gaussian process modelling of the orbital period variations, which could help determine the elusive physical trigger of the state transition.

XMM-Newton observations of Nova V407 Lup and the symbiotic stars SMC 3 and Lin 358

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In the framework of a program to monitor novae that were well studied in outburst as they return to quiescence, we obtained new observations of Nova V407 Lup 3.5 years after the eruption. V407 Lup is an intermediate polar (IP) candidate with a rotation period of $\approx$9.42 minutes. The modulation of the X- ray flux is still retrieved at quiescence, confirming it is indeed an IP. We discuss how magnetic field and outburst properties seem to be connected. The X-ray spectrum is complex and appears to have multiple components. Like in other novae-IP, there is still significant very soft flux. We also observed the Small Magellanic Cloud symbiotic stars SMC 3 and Lin 358 29 years after they were discovered to be luminous supersoft X-ray sources. SMC 3 appears to be still undergoing the obscurations during the orbital period of 4.5 years that were previously inferred by Sturm et al. (2011). Lin 358 was observed at constant temperature, but at higher luminosity, which may be an indication that it also undergoes obscurations of the X-ray flux over the orbital period. We discuss the possible implications for the evolution of the systems.

Synergic X-rays and optical eyes tackle the challenge of millisecond pulsars

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Millisecond pulsars in binary systems play a substantial role for the astrophysics of neutron stars. According to the standard paradigm, either the rotation of the pulsar magnetic field or the in-fall of the mass captured from the companion star powers their emission. In transitional millisecond pulsars, variations of the mass accretion rate produce observable swings between a rotation-powered radio pulsar regime and an accretion-powered X-ray pulsar state. These systems showcase the different possible outcomes of the interaction between a quickly spinning magnetized NS and the accretion disk matter. These include an enigmatic, X-ray sub-luminous intermediate state that unfolds when the accretion and spin-down power are comparable. Bright optical and UV pulsations recently discovered from a transitional (and later from an accreting) millisecond pulsar added a piece to the puzzle. Hardly fitting the standard paradigm of pulsars, these findings demand unconventional solutions. Observations performed by XMM-Newton and NICER simultaneously to fast optical photometry strongly suggest that X-ray and optical pulsations are powered by the synergy of accretion and rotation-power. I will discuss the main results of multi-wavelength observing campaigns and show how optical and X-ray pulsations might originate at the shock boundary between the relativistic pulsar wind and the disk plasma.

The current state of disk wind observations in BHLMXBs through X-ray absorption lines in the iron band

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The first detection of X-ray wind signatures (mainly FeXXV/XXVI absorption lines between 6 and 8 keV) in Black Hole Low Mass X-ray Binaries (BHLMXBs) took place more than 20 years ago. In the last decade, it has become apparent that these winds are only detected in strongly inclined objects, hinting at them originating from the disk, although there is still no unequivocal evidence for a magnetic or thermal origin. On the other hand, most detections occur during the soft spectral state, for reasons yet to be understood. We present an update of the current state of wind detections in BHLMXBs, through the analysis of all available XMM-EPIC and Chandra-HETG data of all LMXBs currently classified as BH or BH candidates, from the BlackCAT and WATCHDOG catalogs. We will discuss the number of sources with statistically significant detections in the 6-8 keV band, the associated EWs, blueshifts and line ratios, and their correlation with inclination and spectral state. Following this, we will present preliminary comparisons with synthetic spectra of MHD accretion-ejection models.

The first X-ray polarimetric observation of LMC X-1

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The NASA/ASI mission Imaging X-ray Polarimetry Explorer (IXPE) was launched in December 2021 and until now has brought a handful of observations of stellar-mass accreting black holes in the 2–8 keV band, namely Cyg X-1, 4U1630-47, Cyg X-3 and LMC X-1. In this talk, we will focus on our recent broadband X-ray spectro-polarimetric observational campaign of the high-mass X-ray binary system LMC X-1. The X-ray spectra of this system have been studied in detail in the past and thus all its basic parameters, such as mass, inclination and distance, are well constrained. Further, this system is well known for being persistently in the high/soft state without strong flux variations in X-rays. The source was observed for 600 ks in October 2022 with the IXPE polarimetric mission together with parallel spectral observations with NICER, NuSTAR and ART-XC. This enabled us to decompose the observed spectrum into thermal and comptonized components as well as characterize the absorption. This is important for the interpretation of the IXPE polarization results in 2–8 keV. We will briefly discuss the new data in the context of previous LMC X-1 studies and in the context of IXPE observations of other accreting black holes.

The first giant outburst of LS V +44 17 since discovery observed by XMM-Newton

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The Be/X-ray transient LS V +44 17 was discovered during the ROSAT galactic plane survey. This system showed two normal outbursts in 2010 and 2011 that were monitored by several X-ray facilities like Swift, RXTE and INTEGRAL. Afterwards, LS V+44 17 did not show any X-ray activity till December 2022. What seemed to be a normal outburst became the precursor of the first giant outburst of LS V +44 17 ever observed. Since then, we have monitored the outburst behaviour of the source with Swift/XRT, and obtained a unique XMM-Newton observation at its peak. In this poster we present the first results of our X-ray monitoring and XMM-Newton observation of LS V +44 17 during its giant outburst. We also compare our new dataset to the 2011 XMM-Newton observation that was obtained during a low X-ray luminosity state of the source. We strive to obtain a better understanding of how accretion works at different luminosity states and, most importantly, to unveil the conditions that were in play to make this the first giant outburst of LS V +44 17.

Broad Energy Band Spectral Analysis And Reflection Effects In Intermediate Polars IGR J17195-4100 And IGR J15094-6649 Using NuSTAR And XMM-Newton

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In magnetic cataclysmic variables, the X-ray emission is generated from optically thin shock-heated plasma at the poles of the white dwarf. The X-ray emitting plasma shows a continuous temperature distribution and can be reflected and/or reprocessed by the surface of the white dwarf. The X-ray spectral result of this reflection is the Compton scattering hump seen in the 10-30 keV range and the Fe Kα fluorescent line at 6.4 keV. In this study, we present a detailed analysis of NuSTAR and XMM-Newton mission data in the 0.3-78.0 keV range of Intermediate Polar sources, IGR J17195−4100 and IGR J15094−6649 using a reflection model ($reflect$), photionized and/or neutral absorption models ($zxipcf$, $pcfabs$) and multi-temperature plasma emission models ($cevmkl$, $mkcflow$) within XSPEC. For IGR J15094−6649, we find a reflection component with a reflection amplitude "a" in a range $\sim$ 2 - 3 and for IGR J17195-4100 the reflection amplitude is ≤ 1. The X-ray plasma temperatures of the IGR J17195-4100 and IGR J15094-6649 are $\sim$ 30 keV and $\sim$ 35 keV, respectively. We find warm absorber effects and several absorption features in the spectra with very low interstellar neutral hydrogen absorption.Our reliability tests for the presence of reflection effect yield more than 3σ.

A Systematic Pulse Scan for Intermittent–AMXPs via Z^2 and Maximum Likelihood Techniques

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We present a detailed systematic pulse search for three Intermittent-Accreting Millisecond X-ray Pulsars; (Intermittent-AMXPs), HETE J1900.1−2455, SAX J1748.9−2021, Aql X−1, via Z^2 and maximum likelihood techniques by using 20 years of RXTE data. We first performed pulse scan by using Z^2 technique for every 25s time interval by shifting 1s in millisecond sensitivities to cover all observation data set around the detected frequency given in the literature. We tracked the Z^2 power over time and flagged the time intervals exceeding defined threshold as pulse candidates. We built the pulse profiles for the candidate segments and checked the amplitude of the pulses to better define pulsed regions. The pulse list throughout our scan has new discoveries while covering the pulsed regions presented in the literature for these three sources. For a deeper search, using the pulses obtained from Z^2 method as probability density function as input parameter, we rescanned the duration covering $\pm$ 100 days around the obtained pulse by using maximum likelihood technique. We checked a systematic phase shift pattern over search duration. In conclusion, we discuss the advantages and disadvantages of the timing methods in millisecond rages as well as identifying new pulsed regions in intermittent-AMXPs.

Broad-band mHz QPOs and spectral study of LMC X-4 with AstroSat

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LMC X-4 is a highly luminous and eclipsing high-mass X-ray binary pulsar which is known to exhibit variations in X-ray flux over a wide range of time scales. The Large Area X-ray Proportional Counter (LAXPC) and Soft X-ray Telescope (SXT) instruments onboard the AstroSat observed the source in August 2016. The source was found to emit an X-ray luminosity of $\sim 2 \times 10^{38}$ erg/s in the energy range of 0.5–25 keV. The power density spectrum showed the presence of coherent pulsations at 13.5 s along with a $\sim$ 26 mHz quasi-periodic oscillation feature. From the joint analysis of the SXT and LAXPC spectral data, the 0.5–25 keV spectra were found to be comprised of an absorbed high-energy cut-off power law with a photon index of $\sim$ 0.8 and cut-off at $\sim$ 16 keV, a soft thermal component with $kT_{BB} \sim 0.14$ keV, and emission lines due to Fe Kα, Ne IX, and Ne X. We will discuss the implications of these results.

Intriguing nature of CV candidate CXOU J204734.8+300105

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CXOU J204734.8+300105 is a proposed eclipsing polar-type candidate that was discovered during the Chandra ACIS Timing Survey Project. Polars are cataclysmic variable (CV) systems in which the white dwarf primary possesses a magnetic field strong enough to prevent the formation of an accretion disc. The observation of an eclipse in this source at an orbital period of $\sim$ 6097 seconds by Chandra suggests that it is a polar-type system. However, subsequent XMM-Newton observations showed very different characteristics of the source. One of the XMM-Newton observations of the Cygnus Loop, where the source is at the edge of EPIC-pn CCD, did not show any variability while the newer XMM-Newton observation suggested periodicity at $\sim$ 2049 seconds, most likely due to the spinning of the compact object. These observations raise questions about the nature of the source. Spectral analysis of the X-ray emission from CXOU J204734.8+300105 revealed a power-law spectrum with a photon index of $\Gamma \sim 1$, a soft thermal component with a blackbody temperature of $kT_{BB} \sim 0.12$ keV, and an emission line due to Fe. These spectral characteristics are consistent with those observed in other CV systems. We will present detailed results and their implications.

Type I X-ray bursts as probes of the neutron star accretion environment

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Neutron star accretion in low-mass X-ray binaries can lead to unstable nuclear burning on the neutron star surface, causing a Type I X-ray burst. The burst irradiates the accretion environment, consisting of an accretion disk and a corona. Theoretical models predict that the burst radiation will change accretion flow properties. The burst photons exert Poynting Robertson drag on the disk, which enhances the mass accretion rate in simulations, and which could be the cause of an increased persistent emission and an observed soft excess <3 keV during the burst. The enhanced accretion rate furthermore drains the inner disk region, causing its inner edge to recede outwards. Calculations also predict a highly ionized disk during the burst. The predicted reflection spectra feature emission lines and a soft excess varying in strength as the flux on the disk changes. Additionally, the burst will cool the corona, causing a drop in observed hard X-ray flux >30 keV related to the corona geometry. In this presentation, I will review the theoretical predictions of the burst interaction with the accretion flow and how they translate into observational properties. Overall, X-ray bursts provide a unique opportunity to probe accretion disk physics with a repeatable experiment.

From hard to soft: Following the evolution of QPOs

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In 2021, the Neutron star Interior Composition Explorer (NICER) onboard the International Space Station closely monitored an outburst of GX 339-4, the prime example of a low-mass black hole X-ray binary. The dense coverage of this outburst and the increased sensitivity of NICER compared to previous missions allowed us to study in detail the evolution of quasi-periodic oscillations (QPOs) and noise components in the intermediate states as the source transitions from the hard to the soft state. The evolution between these states is a somewhat erratic process with multiple transitions. In our study, we were able to follow the emergence and disappearance of the different types of QPOs in more detail and gain further insight into their evolution. In addition to the power-density spectra, we also investigated the evolution of spectral parameters, but found only a strong correlation between the hardness ratio and the type of QPO observed. We present the results of our study and discuss implications of our findings for the occurrence and coherence of type-B QPOs and their relation to changes in the accretion geometry of the system. We will also consider them in light of Comptonisation models for type-C and type-B QPOs.

Unveiling the characteristics of the GX 301-2 pre-periastron flare as seen by MAXI

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The XMM-Newton satellite took two observations of the high mass X-ray binary GX 301-2 during its pre-periastron flare. The study of spectra obtained from both observations shown stable fluorescent emission lines such as Ar Kα, Fe Kα, Fe Kβ, Ni Kα and an extended Compton Shoulder, and a radius of the emitting region consistent with a hot spot on the neutron star surface. Orbital phase spectroscopy around the pre-periastron passage using data from the Gas Slit Camera onboard MAXI is presented in this work. Variations in the spectral features are observed suggesting long-term evolution of the accretion rate material. An apparent modulation of the iron fluorescent emission line is present being detected in the flare and starting the post-flare but no in the pre-flare. The highest value of the luminosity in the flare is consistent with previous results and indicate the possibility of an accretion due to both a disc and the stellar wind during the pre-periastron flare.

The SMC BeXRB Zoo: patterns of optical variability as seen by OGLE

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BeXRBs are a subgroup of high-mass X-ray binaries (HMXBs) that contain the majority of X-ray pulsars and are associated with recent star formation. Their donor star is a rapidly-rotating Be star surrounded by a disk of its own ejected ionized gas, i.e. the so-called “decretion” disk. The rapid disk variability regulates the mass transfer to the compact object and the compact object can truncate or entirely deplete the disk. To better understand this complex interaction and the resulting X-ray behavior in these systems, we analyze the optical light curves of SMC BeXRBs observed by OGLE. For systems with available data, we directly compare the X-ray and optical variability. Furthermore, to help predict and monitor future X-ray outbursts, we formulate an updated list and analysis of orbital periods. However, the optical light curve variability is often more significant and complex on super-orbital timescales. We present and quantify a taxonomy for this behavior. We find that our categorization connects to optical color properties and aids in the search for physical explanations of the multi-wavelength patterns of variability.

New Chandra insights into the neutron star population of M28

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We present a detailed spectral and temporal study of the neutron star population in the globular cluster M28, after analyzing the full ACIS dataset from the Chandra X-ray Observatory. We discover an orbital modulation in the X-ray flux of the redback and transitional millisecond pulsar PSR J1824-2452I during the pulsar state. Its orbital X-ray light curve shows a double-peaked maximum centered on the inferior conjunction of the pulsar, which suggests that the intrabinary shock is wrapped around the pulsar. We present improved mass and radius constraints from spectral fits of the quiescent LMXB in M28, using both hydrogen and helium neutron star atmosphere models. We also discover six new variable X-ray sources in the cluster.

Evolution of QPOs in GX 339-4 and EXO 1846-031 with Insight-HXMT and NICER

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We present the results from the latest Insight-HXMT and NICER observation of GX 339−4 and EXO 1846−031. With the high-cadence monitoring programme of Insight-HXMT and NICER, we conduct a detailed temporal and spectral analysis. We confirm that the Type-C QPOs appear in the end of low-hard state and/or hard-intermediate state. The period is characterized by increasing of the QPO frequency $f_{\rm QPO}$ and decreasing of inner disk radius $R_{\rm in}$. The results reveal that the QPO frequency is closely related to the inner disk radius and mass accretion rate in two sources. Existing models cannot well describe the correlation we get in GX 339–4 and EXO 1846–031, except the dynamic frequency model. It can accurately predict the observed results and give a measurements of black hole spin, which is consistent with that from other methods. The dynamic frequency model is first tested in GRS 1915+105 by Misra et al.(2020) and Liu et al.(2021). We note that GRS 1915+105 is a persistent source with particular properties. We extend the application of the model from GRS 1915+105, a persistent source, to these two more general transient sources, GX 339–4 and EXO 1846–031, which makes the model advantageous in explaining QPOs.

Chapter 8

Ultra Luminous X-ray Sources

Should Hyperluminous and Ultraluminous X-ray sources fall under the same category?

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Ultraluminous X-ray sources (ULXs) are typically defined as extra-Galactic, off-nuclear, point-like X-ray sources with luminosities higher than $\sim 10^{39}$ erg/s. Among them, sources with X-ray luminosities equal to or greater than 10^{41} erg/s are often referred to as Hyperluminous X-ray sources (HLXs). It is not clear whether HLXs are just more extreme ULXs, whether they may host the longed-for intermediate mass black holes, or whether they are a mix of the two types. A way to tackle this problem is to compare the properties of HLX and ULX populations. To do so, we investigated archival X-ray data of more than one hundred HLXs. For those with good-quality spectra, we performed spectral fits with an absorbed power law and derived the unabsorbed fluxes and luminosities to populate the HLX hardness-intensity diagram. For the sources with multiple observations, we also attempted a study of their spectral evolution. Here we present the results of this investigation and highlight the differences in the populations of ULXs and HLXs.

The High Energy X-ray Probe (HEX-P): Broadband studies of ultraluminous X-ray sources

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HEX-P is a probe-class mission concept that will combine high spatial resolution X-ray imaging (¡10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR), to enable revolutionary new insights into a variety of important astrophysical problems. We will present simulations of HEX-P observations of ultraluminous X-ray sources (ULX) in nearby galaxies, showing how HEX-P will (1) study in detail populations of ULXs in a fraction of the time required by NuSTAR, pushing by a factor 25 the high-energy sensitivity. (2) characterize their hard-energy spectrum, with much higher sensitivity than NuSTAR, looking for high-energy cyclotron resonance features; and (3) perform detailed timing studies of these sources thanks to the very low background and the enhanced response in the energy ranges where pulsations are stronger. More information on HEX-P, including the full team list, is available at https://hexp.org.

Measuring the magnetic field in the extreme ultra-luminous X-ray pulsar NGC 5907 ULX-1

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NGC 5907 ULX-1 is the brightest known ultra-luminous X-ray pulsar (ULXP), with luminosities exceeding 1e41 erg/s during the high state. However, it shows large variability, and was in an off state between 2017-2020. Based on precise measurements with XMM-Newton of the pulse period just before and immediately after the off state, we show that the pulsar slowed down in this period. This is the first time a strong spin-down is seen during a low flux state in a ULXP. We interpret this as a spin-down due to the propeller effect, where accretion is magnetically inhibited, and the large magnetosphere slows the pulsar down. Based on this interpretation, the dipole magnetic field of the neutron star is larger than 1e13G. On the other hand, based on the strong spin-up before and after the off-state we find magnetic field strengths of the order of 1e12-1e13G. These data therefore provide the best estimate of the magnetic field in this ULXP and how that the neutron star is very strongly magnetized.

Nebular Emission from “Simple X-ray Populations”: the Impact of Ultra-luminous X-ray Sources on IR-to-optical Emission Line Diagnostics

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We present a framework for modeling the contribution from ultra-luminous X-ray sources (ULXs) to the nebular emission from starburst regions. We develop a physical model for the intrinsic ULX spectral energy distribution (SED) assuming supercritical accretion onto a stellar mass compact object, as well as a methodology to normalize the ULX SED as a function of different burst ages and metallicities using results from binary population synthesis. These models, which we refer to as ”simple X-ray populations”, are then self-consistently coupled with simple stellar populations and used as input to the photoionization code Cloudy to produce grids of nebular line and continuum emission as a function of burst age, metallicity, and ionization parameter. The results of this modeling have applications to: (1) distinguishing between different sources of hard ionizing radiation (e.g., accreting stellar versus intermediate mass black holes) via custom emission line diagnostics; (2) understanding the sources that power high ionization emission lines in high redshift galaxies and their nearby analogs, and; (3) constraining the intrinsic SED of accreting black holes across a range of black holes masses.

Synchrotron radiation from pulsars as the origin of spectral cutoff in ULXs

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Ultraluminous X-ray sources (ULXs) are the best candidates for super-Eddington accretion onto stellar-mass compact objects. Recent discoveries of neutron star ULXs confirm that the Eddington ratio can be a few hundred. Interestingly, most ULXs exhibit unique spectral curvature around $\sim$ 10 keV firmly established by broadband observations. We discuss a theoretical model based on the first principle of synchrotron radiation, which explains the origin of such spectral cutoff. The emission angle of the radiation, the velocity distribution of particles, and the magnetic field are the key factors that determine the cutoff energy in the spectra. For known pulsar ULXs like NGC 5907 ULX1 and NGC 7793 P13, the relevant magnetic field is consistent with neutron star typical field strength (i.e., $\sim 10^{12}$ G). Emissions from ultra-relativistic plasma close to the plane of the orbit of the particles and semi-relativistic plasma at higher latitudes would give rise to a similar spectral cutoff. Using the stationary phase approximation, we also discuss how the cutoff appears mathematically from the properties of Bessel functions. If this model represents the physical scenario for ULXs, we propose that most ULXs that show such spectral cutoff host neutron stars at their core.

The case of pulsating ULX M51 X-7: a QPO to find them all?

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Pulsating ultraluminous X-ray sources (PULXs) are accreting neutron stars whose luminosities exceed 500 times their Eddington limit. The discovery of PULXs offers for the first time a way to test our theories about super-Eddington accretion regime. M51ULX-7 (ULX-7 hereafter) is a recently discovered PULX, with a spin period of P $\sim$ 2.8s. During a 400ks-long XMM Large Program campaign of ULX-7 in 2021-2022, we found a quasi-periodic modulation in the X-ray flux with a timescale of $\sim$ 3ks. ULX-7 was observed at a flux level and in a spectral state similar to those during which pulses at $\sim$ 2.8s were discovered. However, the search for these pulsations has given negative results, suggesting the presence of a process, observed in this PULX for the first time, able to hide them. This phenomenon might represent another limiting factor in detecting new PULXs. I analyzed the Large Program observations and older archival data to infer the main spectral and timing properties of the QPOs and their occurrence in past observations. QPOs have been observed in at least another PULX (M82X-2) and in many other non-pulsating ULXs: the study and comparison of the QPOs properties could represent an additional tool to identify new PULXs.

Unraveling the Accretion Flow Structure of Ultra-Luminous X-ray Pulsar NGC 300 ULX-1 with the C3PO Method

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Despite the intensive studies over decades, the spectral nature of Ultra-Luminous X-ray sources is still poorly understood due to the continuum-dominated X-ray spectrum. To perform a new phase-resolving analysis, we revisited the data of Ultra-Luminous X-ray Pulsar (ULXP) NGC 300 ULX-1 taken with XMM-Newton and NuSTAR on 2016 December 16th. In addition to the classical phase-restricting analysis, we newly employed a method developed in active galactic nuclei studies. It has revealed that the rotating flow consists of at least two representative emission regions. Furthermore, we successfully decomposed the spectrum into an independent pair in each interval. One is an unchanging-component spectrum that can be reproduced by a standard disk model with a 720^{+220}_{-120} km inner radius and a 0.25 ± 0.03 keV peak temperature. The other is the spectrum of the component that coincides with the pulsation. This was explained with a Comptonization of a $0.2^{+0.2}_{-0.1}$ keV black body and exhibited a harder photon index in the brighter phase interval of two. The results are consistent with a picture that the pulsating emission originates from a funnel-like flow formed within the magnetosphere, and the inner flow exhibiting a harder continuum is observed exclusively when the opening cone points to the observer.

Accreting highly magnetized neutron stars above the Eddington limit: ULXs playing hide and seek

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ULXs have been traditionally thought as hosts of Intermediate mass black holes. The paradigm changed with the discovery of pulsating ULXs indicating that many must host highly magnetized Neutron Stars (NS). What is the cause of such high luminosities? For once the Eddington limit is not strictly violated as we have presence of strong magnetic fields. Moreover, the accretion disk can form strong outflows that can form an optically thick funnel. In addition, since reprocessing is happening on the funnel we would also expect signatures of reprocessing and scattering. Thus, a decade later and we still do not have a clear picture about many of the characteristics of ULXPs. Perhaps the major question is, if there is a smoking gun – other than pulsations – that can help us identify ULXs hosting NSs. To search for answers we will look at nearby accretors that can momentarily transition to ULXs, i.e. BeXRB major outbursts. Such systems can help us understand transitions to super-Eddington regime and pinpoint spectral signature in the continuum of ULXPs. Another question we would like to address is whether we can see reflection and reprocessing features in these super-Eddington accretors, and under which conditions these features might form.

Constraining Binary Evolution Models with X-ray scaling relations and ULXs

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Constraining binary stellar evolution models is critical for our understanding of supernovae, compact objects, X-ray binaries (XRBs), ultraluminous X-ray sources (ULXs), gamma-ray bursts, gravitational-wave sources, as well as the effect of energetic sources in the evolution of galaxies and the heating of the early Universe.

With almost 25 years of high-quality X-ray data from XMM-Newton and contemporary observatories, observations of normal galaxies in the low and intermediate redshifts offer a detailed view on the populations of accreting compact objects in different galactic environments, an excellent means for constraining binary evolution models.

Using binary population synthesis models with different physical assumptions, and realistic metallicity-dependent star-formation histories (SFHs) of galaxies from the Illustris-TNG cosmological simulation, we construct a library of synthetic XRB populations. We compare these models against local-Universe X-ray luminosity functions and ULX demographics, as well as low and high-redshift X-ray scaling relations. In addition, having the SFHs for individual galaxies allows us to study, for the first time, different types of galaxies, as well as the constraining power of the scatter of scaling relations. Finally, we discuss the potential of future deep observations in resolving model degeneracies through the redshift evolution of scaling relations.

Mining new ULX catalogues for HLXs and PULXs

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We have now catalogued close to 2000 candidate ULXs from archival X-ray observations, with hundreds more on the cusp of being revealed in the eROSITA all-sky survey. These large samples can provide key insights into ULX physics and demographics by expanding our samples of rare and interesting objects such as pulsating ULXs (PULXs) or hyperluminous X-ray sources (HLXs). Here we present new studies of objects drawn from the Walton et al. (2022) multi-mission ULX catalogue, and eRASS1. A total of 71 HLX candidates were catalogued in the Walton sample. After removing suspected contaminants and correcting fluxes we are left with a sample of 20 good HLX candidates, whose properties and behaviour we study. Interestingly, several show similarities to ESO 243-49 HLX1, with others similar in appearance to the PULX, NGC 5907 ULX. We also present studies of new sources selected as potential PULX candidates, on the basis of high luminosity and flux. Three such objects come from Walton et al., with one appearing a very promising candidate PULX on the basis of its spectral hardness. The final object is the first eRASS1 source selected as a PULX candidate, for which we report the results of a pilot study.

A new intermediate mass black hole candidate in the high/soft state

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We search for X-ray-detected intermediate mass black holes (IMBHs) in two distinct environments: i) the halo of early-type galaxies; ii) the nucleus of late-type spirals. Old-halo IMBHs are expected as remnants of accreted satellites, which contribute most of the stellar population in those environments. Nuclear IMBHs are expected in disk galaxies with very small stellar bulges. First, we illustrate the X-ray and optical properties of a recently discovered, transient IMBH candidate in an elliptical galaxy at a distance of 130 Mpc. The purely thermal (disk-blackbody) spectrum with a peak temperature of about 0.2 keV and a peak 0.3–10 keV luminosity of 5×10^{42} erg/s in *XMM-Newton* observations suggest an $\approx 10^4 M_\odot$ IMBH in a high/soft state, perhaps similar to the well-known IMBH candidate HLX-1 (also a likely satellite remnant). Its $g \approx 24.5$ mag optical counterpart may represent a remnant stellar cluster around the IMBH. Second, we summarize preliminary results and future developments of our search for nuclear IMBHs in suitable late-type galaxies, selected on the basis of recently revised scaling relations between galaxy properties and nuclear black hole mass, for different Hubble types.

From X-ray binaries to intermediate-mass black holes: what's behind ultraluminous and hyperluminous X-ray sources?

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Ultra-/hyperluminous X-ray sources (ULX/HLX, sources brighter than 10^{39} and 10^{41} erg s^{-1} located outside the nucleus of their galaxy) constitute interesting laboratories to further improve our understanding of the supermassive black hole growth through super-Eddington accretion episodes and successive mergers of lighter holes. ULXs are generally thought as X-ray binaries (XRBs) accreting above Eddington, while HLXs may hide accreting intermediate mass black holes (IMBHs). One of them, HLX-1, shows enormous variability suggesting partial tidal disruption events around a $10^4 M_\odot$ black hole. However, a significant portion of samples of ULXs/HLXs derived from catalog searches are actually background AGN, so gathering a large sample first requires a reliable identification of archival X-ray detections, still unexplored to a large extent. To this end, I present a general-purpose, probabilistic approach to classify X-ray sources found in catalogs, based on their spatial, spectral and variability properties and their multi-wavelength counterparts. I show how this optimized Naive Bayes classifier has been applied to clean up samples of ULXs and HLXs, hiding in the Swift, XMM and Chandra catalogs. I will compare, among other properties, the luminosity function of XRBs, ULXs and HLXs, and explore how these populations connect to their environment, investigating their origin and nature.

From BeXRBs to ULXPs: connecting the "dots"

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Spin-evolution in accreting objects is dictated by well known principles and can provide indirect estimates of the magnetic field of the NS. Moreover, the observed flux from a system is a good proxy of the mass accretion rate onto the compact object. However, in ULXPs things become complicated. The accretion disk is no longer Keplerian and the flux can show variations on super-orbital scales that are related to disk precession and can result in beaming effects. Thus to study the spin-up of NS above the Eddington limit we need to take into account these extra effects. In my talk I will introduce evidence from observational campaigns of ULXPs that help us understand the flux-mass accretion coupling in ULXPs that provide input to torque modeling in super-Eddington accretion. An ideal case study are very bright BeXRBs – like SMC X-3, RX J0209.6-7427 and Swift J0243.6+6124 – that can exceed the Eddington limit and can help us explore the complicated parameter space of torque modeling.

The Unusual Broadband Spectral Variability of the ULX Holmberg IX X-1

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Holmberg IX X-1 is one of the brightest and best studied ultraluminous X-ray sources, reaching truly extreme luminosities of Lx 4e40 erg/s and lying at a distance of only 3.5 Mpc, and is likely a key touchstone for our understanding of super-Eddington accretion. Throughout late 2020 we undertook a new, broadband observing campaign on Holmberg IX X-1 with XMM-Newton and NuSTAR, performing 5 new coordinated observations with the intention of building a multi-epoch broadband dataset for this remarkable source, and further understanding the unusual spectral variability seen in previous broadband observations. I will present results from this new coordinated campaign, which reveal the detection of a new broadband X-ray spectral state from this source in which the hard X-ray flux is significantly suppressed, and discuss how this strange new spectral evolution may fit in with our current understanding of the super-Eddington accretion-ejection paradigm.

Chapter 9

Supernovae, GRBs, GW Events

XMM-Newton/EPIC detects the prompt emission of the bright GRB221009A

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On 2022, October 9, around 13:20 UTC, a Gamma-ray Burst (GRB) of unprecedented intensity lit up in the sky in the direction of the constellation Sagitta. XMM-Newton was hit by the burst of high energy radiation while performing an observation, pointing about 38 degrees away from the coordinates of the GRB. A dramatic variation in the background rate of the EPIC cameras is seen, simultaneous with the GRB, with a temporal pattern closely following the prompt GRB light curve shape. The signal has peculiar properties and is most likely produced by electrons, Compton scattered within the EPIC detectors by hard X-ray photons from the GRB. Analysis of such an unusual observation yields very interesting insights both on the EPIC instrument behaviour and on the phenomenology of this exceptional GRB.

General Coordinates Network (GCN): NASA's Next Generation Alert System for Multimessenger Astronomy

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Gamma-ray Coordinates Network (GCN) is a collaborative platform operated by NASA to facilitate the sharing of alerts and quick communications regarding high-energy, transient, and multimessenger phenomena among the astronomy research community. Over the last 30 years, GCN has enabled significant advances by disseminating observations, predictions, requests for follow-up observations, and observing plans. GCN distributes alerts between space and ground-based observatories, physics experiments, and thousands of astronomers worldwide. As new transient instruments spanning the electromagnetic spectrum and multimessenger facilities become available, coordinating efforts have become more vital and complex than ever. Introducing the General Coordinates Network (GCN), an updated version of GCN designed with modern, open-source, reliable, and secure alert distribution technologies, and deployed in the cloud. The new GCN is built on Apache Kafka, the same alert streaming technology that the Vera C. Rubin observatory uses. We will present the current status and design of the new GCN, the streaming of notices and circular alerts with Kafka, and a vision of its growth as a community resource in the future.

The X-ray rings of the brightest gamma-ray burst: tomography of the Galaxy and reconstruction of its soft X-ray emission

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GRB 221009A is the brightest gamma-ray burst (GRB) ever observed and occurred behind the Galactic Plane. As a result, bright expanding rings were produced by the scattering of the prompt GRB X-ray photons with the dust contained in all the Galactic clouds along the line of sight. Two XMM-Newton observations performed a few days after the GRB allowed us to accurately measure the distance of 20 dust clouds at distances ranging from 0.3 to 18.6 kpc and to probe the properties of their dust grains. Moreover, we could constrain the fluence and spectral shape of GRB 221009A in the 0.7-4 keV band, which could not be directly observed.

Chapter 10

Supernova Remnants

SRG/eROSITA and XMM-Newton observations of Vela Jr

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With the launch of the eROSITA X-ray telescope, it became possible to observe the one degree wide Vela Jr SNR in its full entirety only for the second time after the ROSAT all-sky survey. The eROSITA data allowed us to characterize the emission of Vela Jr and distinguish it from the underlying emission of Vela SNR, providing new images and spectra also from the inner remnant region. Archival XMM-Newton pointed observations on the North-West rim were employed additionally to the eROSITA data to determine the cutoff electron energy. These spectra provided an estimate for the magnetic field in the shock front and the distance of the remnant, confirming the region as very likely particle acceleration site. From the spatial resolved spectral analysis, we find the remnant spectrum is uniformly featureless in most regions, except for two inner regions where an extra thermal component improves the statistics. Moreover, eROSITA allowed us to determine the geometrical remnant center with higher accuracy than possible before. The geometrical remnant center and the position of the CCO are found to be in agreement with each other, suggesting a very small proper motion and reinforcing the association between the CCO and a proposed faint optical/IR counterpart.

Typing SNR G352.7−0.1 using X-ray observations

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Supernova remnants (SNRs) drive shocks into the interstellar medium and enrich it with heavy elements. These elements keep crucial information and allow us to establish a connection between SNRs and their progenitors. G352.7−0.1. is an asymmetric SNR that is considered to have a Type Ia origin, but it shows some properties typical for core-collapse SNRs. We revisit the X-ray data of SNR G352.7−0.1 and present a detailed analysis of the elemental abundances. We also show the spatial distribution of metal abundances across the SNR and examine its relation with the ambient medium. Our X-ray analysis provides information about this remnant's SN type and the origin of its thermal-composite morphology.

Detection of a fast ejecta fragment in the atomic cloud interacting with the southwestern limb of SN 1006

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Supernova remnants interacting with molecular/atomic clouds are interesting X-ray sources to study nonthermal emission. X-ray emission in these systems can be produced by different processes, e.g. low energy cosmic rays interacting with the cloud and fast ejecta fragments moving in the cloud. SN1006 is a Type Ia supernova remnant that presents an X-ray nonthermal bilateral emission, in its northeastern and southwestern limbs. Despite evolving in a fairly uniform environment, SN1006 shows two regions of interaction with atomic clouds, (northwest and southwest).We performed a combined image-spectral analysis of the X-ray emission in the interaction region between the southwestern limb of SN1006 and the cloud with NuSTAR, Chandra and XMM-Newton. We discovered an extended X-ray source approximately 2 pc upstream of the shock front. The source is characterized by a hard continuum and by Ne, Si and Fe emission lines. The observed flux suggests that the origin of the X-ray emission is not associated with low energy cosmic rays interacting with the cloud. On the other hand, the spectral properties of the source, together with the detection of an IR counterpart visible with Spitzer-MIPS at 24 μm are in agreement with expectations for a fast ejecta fragment moving within the atomic cloud.

Study of Tycho SNR's asymmetries with three-dimensional velocity vector field

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For the 450th anniversary of the Tycho's Supernova Remnant (SNR), we propose a new analysis of the three-dimensional ejecta dynamics with Chandra's X-ray data. This ejecta dynamic is a key to understand the progenitor explosion. New methods are used to study the velocity in the plane of the sky and along the line of sight to reconstruct 3D vector field and study the asymmetries of the expansion. In the plane of the sky, we developed a new tool to measure the shift of small, two-dimensional features by matching their morphology between epochs using a Poisson likelihood. This new method allows to generate more than a thousand velocity measurements instead of the usual tens. For the line-of-sight velocity, a blind source component analysis (GMCA) is used. This method separates the cube into various components, each with an image and associated spectrum. For Tycho, blue and redshifted components are obtained. This allows us to reconstruct a map of dynamics based on the Doppler line shift which reveals a large-scale North/South. To understand its origin, a detailed mapping of the parameters (temperature, ionization rate...) with full coverage of the SNR has been carried out and the first results will be presented.

Large nearby supernova remnants in eROSITA

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Large nearby supernova remnants (SNRs) are unique objects for studying the physics and evolution of hot, X-ray emitting environments in unparalleled detail. With the recent extended ROentgen Survey with an Imaging Telescope Array (eROSITA) mission we finally have the opportunity to fully study those objects at CCD resolution for the first time. We studied the two largest nearby SNRs on the sky with eROSITA: the Monogem Ring and Antlia SNRs. Previous studies suggest they could both be old, evolved SNRs that are interacting with the surrounding ISM. Both objects have a very large extent of 30° and a low surface-brightness. We studied the X-ray background in the vicinity of those objects across a large area of the sky - essential for studying low surface-brightness objects - and developed a detailed Galactic background model. With this, we performed detailed spectral analyses of both objects with high spatial resolution and were able to determine the plasma conditions down to small scales. This allowed us to put new constrains on the evolutionary parameters like the age and explosion energy, while multi-wavelength data allowed us to further study the evolution of the SNRs and their surrounding ISM, and to constrain their distance.

Characterizing thermal and nonthermal X-ray emission in the Vela supernova remnant with SRG/eROSITA

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The Vela supernova remnant (SNR) is one of the most nearby and extended objects in the X-ray sky. It exhibits bright thermal X-ray emission from shock-heated plasma, and synchrotron emission originating from the plerion (Vela X) of its central pulsar. During its first four all-sky surveys, the SRG/eROSITA instrument has accumulated an X-ray dataset of Vela which exhibits a much higher sensitivity and spectral resolving power than the data gathered by its predecessor ROSAT.

In this contribution, we will introduce the results of a detailed spectro-imaging analysis of the Vela SNR that we have carried out with this eROSITA dataset, which allows disentangling thermal and nonthermal contributions to the emission. We will present the complex, energy-dependent morphology of Vela observed in multi-band imaging of the SNR, and discuss how it is related to foreground absorption, plasma temperature, and the presence and composition of ejecta across the remnant. Intriguingly, our analysis reveals extremely extended X-ray synchrotron emission from Vela X, reaching up to three degrees (or 14 pc) from the pulsar. We will discuss how this extended nonthermal X-ray structure fits into the multiwavelength picture of Vela X.

Detection of X-rays and study of the Spaghetti nebula with SRG/eROSITA

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We report the detection of the complete X-ray counterpart of the Spaghetti nebula or Simeis 147, a large extended supernova remnant, using data from the first four eROSITA all-sky surveys. Results are augmented with data from two XMM-Newton observations that cover small parts of the remnant with deeper exposures than what is available to us from our eROSITA observations. 14.5 years of Fermi-LAT data were exploited to confirm the detection of the remnant's GeV counterpart, and provide updated imaging and spectral analysis results. We present a complete multiwavelength picture and discuss implications for the interpretation of the object.

XMM observations of the TeV-discovered supernova remnant HESS J1534-571

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We report the results obtained from XMM-Newton observations of the TeV-detected supernova remnant (SNR) HESS J1534-571. In this work, we use XMM-Newton observational data to search for X-ray emissions from the source. A broadband spectral analysis, using data ranging from the radio to the TeV domain is employed to investigate cosmic ray production scenarios. No signatures of X-ray synchrotron emission were detected from the SNR and an upper limit for the flux is derived in the energy band 2-10 keV, which places constraints on the relativistic leptonic particle content in the SNR. However, a leptonic scenario for the gamma-ray emission cannot be ruled out, leaving a potential relativistic hadronic particle content unconstrained by the gamma-ray data. Furthermore, evidence of a line-like emission is detected at 6.4 keV from localized regions. The result is consistent with earlier results obtained with Suzaku from other regions of the object. The emission can be interpreted as the result of interactions between lower energy ($\sim$ MeV) cosmic ray protons with high gas density regions in and around HESS J1534-571, potentially from particles accelerated in the SNR.

An X-Ray View of SNR 1987A: Shock Evolution Beyond the Inner Ring

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We present the latest results from our regular semi-annual monitoring of SNR 1987A with Chandra. Our Chandra monitoring data show recent developments in the soft X-ray light curve and the overall SNR expansion rate. The soft X-ray flux has been moderately declining in the last several years. While the overall expansion of the bright inner ring shows a constant rate of 1500 km/s until 2022, the faint outermost boundary appears to expanding at a higher rate of 4000 km/s for the last several years. These results support that the blast wave is now interacting with the low-density gas beyond the dense inner ring, probably propagating into the progenitor's stellar winds produced in its red supergiant stage before the explosion.

Completing the X-ray view of SN 1987A

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SN 1987A provides us a unique opportunity to study in detail the birth and the early evolution of the supernova remnant. The 14-year XMM-Newton monitoring of SN 1987A reveals a steady increase in the 3-8 keV flux, but a recent decrease in the 0.5-2 keV flux. Along with the decreasing emission measure of the low-temperature plasma, this indicates the blast wave has now left the main equatorial ring, and is still propagating into the high-latitude gas. The Fe K lines are clearly detected in SN 1987A. The high centroid energy ($\geq$ 6.65 keV) corresponds to a high plasma temperature 3 keV, and a recent decrease in the centroid energy could be related to the newly shocked Fe-rich ejecta clumps. The high energy resolution of RGS and the wide energy coverage of EPIC-pn allow us to investigate the continuous temperature distribution of the X-ray gas in SN 1987A, which shows great consistency with the MHD simulation results. The NuSTAR observations reveal an excess of the 10-20 keV flux with respect to the pure-thermal spectral model, which is best reproduced by a heavily absorbed power law. This provides evidences for a pulsar wind nebula embedded in the heart of SN 1987A.

Likely Ca-rich Transient Origin of Galactic SNR G306.3-0.9 Revealed by X-ray Spectroscopy

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G306.3-0.9 is a Galactic supernova remnant (SNR), whose progenitor has been thought to be a Type Ia supernova (SN), but its high Ca abundance appears inconsistent with the Type Ia origin. To uncover the origin of this SNR, we performed a spatially resolved X-ray spectroscopic analysis of XMM-Newton and Chandra observation data using two-temperature models. Neither Type Ia nor core-collapse SN models can account for the abnormally high abundance ratios of Ar/Si, Ca/Si, or the shape of the abundance curve. A comparison with the Ca-rich transient models suggests that G306.3-0.9 is likely to be the first identified Galactic Ca-rich transient remnant, although the theoretical production of element S is slightly lower. Between groups of Ca-rich transient explosion models, we prefer the He shell detonation for an accreting white dwarf (WD), rather than the merger of a WD and a neutron star, considering metal masses, explosion energy and merger rates. The hybrid WD-CO WD merger scenario is also disfavoured because of its high Ar abundance.

Statistical study of SNRs in the Large Magellanic Cloud with eROSITA Survey

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The supernova remnants (SNRs) are the residual of these stellar explosions. Their emission is visible in different wavelength from radio to X-ray. The SNRs can be studied to infer information about the explosion it self and on the property of the surrounding ISM. The best laboratory for the study the SNRs population in a galaxy is the Large Magellanic Cloud (LMC). The LMC is the nearest star-forming galaxy with low absorption along the line of sight. The eRosita telescopes are the best instrument available to make such a survey thanks to the large field of view and the high sensitivity in the softer part of the X-ray emission. We present the initial results from eRosita data collected to inspect the SNR population in the LMC in the X-ray band. We made a spectral analysis of the brightest SNR in the sample and compared the spectral result with the previous results from XMM-Newton observation. The eRosita data also allowed us to investigate the very recent SNR candidate detected in the radio band using ASKAP interferometry, among the other SNR candidates proposed in radio and optical. Furthermore we present the detection of new SNR candidates never observed by other X-ray telescope before.

Chapter 11

Diffuse Emission and Galactic Halos

Study of the excess Fe XXV line emission in the central degrees of the Galactic centre using XMM-Newton data

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The diffuse 6.7 keV line emission observed in the Galactic ridge is widely accepted to be produced by a superposition of a large number of unresolved X-ray point sources. However, in the very central degrees of our Galaxy, the existence of an extremely hot diffuse plasma is still under debate. In this session I will present the results we obtained by analysing all (370; 6.5 Ms) available XMM-Newton observations of the Galactic centre and inner disc, along with recent stellar mass distribution models. We find that within the central degree of our Galaxy the 6.7 keV emission is 1.3-1.5 times in excess of what is expected from unresolved point sources, that cannot be attributed entirely to very hot plasma. However, we find that almost the entire excess we observe can be explained by assuming GC stellar populations with iron abundances 1.9 times higher than those in the Galactic bar/bulge, a value that can be reproduced by fitting diffuse X-ray spectra from the corresponding regions. Even in this case, a leftover X-ray excess is concentrated within the central half degree of the Galaxy, which can be reproduced by the estimated supernova explosion rate in the GC.

Interstellar Dust seen at high X-ray resolution in the star-forming region hosting Cyg X-1

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Over the last few years, we made tremendous progress in our understanding of interstellar dust in the X-rays. In particular, X-ray spectroscopy is able to fill the gaps in our knowledge left by longer wavelength studies. The results from these studies challenge our understanding of dust formation and structure (e.g. Zeegers, Costantini et al. 2017, 2019; Rogantini, Costantini et al. 2019, 2020; Psaradaki, Costantini et al. 2020, 2022). In this talk, we will illustrate these recent findings using the extraordinary case of the Cygnus X-1 line of sight. This source is only 2 kpc away, allowing us the most detailed analysis possible of dust in the Cygnus area complex region. This is the most powerful nearby star forming region, with OB stars and still-mysterious dust structures. Observations of Cygnus X-1 by XMM-Newton and Chandra (Costantini et al. in prep) show dust properties (e.g. dust size, chemistry and crystallinity) that are unlike any other sight line. Only thanks to our detailed dust models, based on our large experimental measuring campaign, these high-quality, high-resolution data set could be meaningfully studied.

From macro to micro: constraining turbulence in the hot circumgalactic medium of the Milky Way using X-ray absorption

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The hot ($> 10^6$ K) circumgalactic medium (CGM) of the Milky Way is often modeled with an underlying assumption of isotropic density distribution. However, the large (>order-of-magnitude) scatter in the dispersion measure (DM) of the hot CGM, $\int n\_edl$, contradicts that assumption. DM is calculated from $z = 0$ absorption lines of OVII Kα, Kβ, and OVIII toward extragalactic ($b > 20°$) QSO sightlines using X-ray grating spectroscopy and an assumed uniform metallicity, O/H, across the sky. We calculate the structure-function, $S(\theta) \propto \langle \delta n\_e^2 \rangle$ from DM as a measure of the density fluctuation, δn_e. We find that $S(\theta)$ grows with θ, the angular separation between sightlines, at a power-law slope of 5.8 ± 1.9, deviating from the Kolmogorov-like slope of 5/3 by $> 2\sigma$. The driving scale of turbulence, beyond which $S(\theta)$ saturates, is $30°$, indicating large-scale turbulence in the hot CGM of the Milky Way. We also estimate the non-thermal line-broadening from the absorption of OVII Kα, Kβ, and OVIII, and find it to be significantly non-zero, indicating the presence of micro-turbulence in the hot CGM of the Milky Way.

Holistic View of the Milky Way Diffuse X-ray Emission: The Enigmatic eROSITA Bubbles and the Extended Halo

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The newly discovered eROSITA bubbles show enhanced X-ray emission from the shells around bubbles. Previous works assumed that X-ray emitting gas in the shells has a single temperature component and that they trace the shock-heated lower-temperature Galactic halo gas. However, using Suzaku/XMM-Newton observations we find that the thermal structure of the eROSITA bubble shells is more complex.

The X-ray emission from the shells is best described by a two-temperature thermal model, one near Galaxy's virial temperature at kT $\approx$ 0.2 keV and the other at super-virial temperatures ranging between kT = 0.4 − 1.1 keV. Furthermore, we show that temperatures of the virial and super-virial components are similar in the shells and in the ambient medium, although the emission measures are significantly higher in the shells. This leads us to conclude that the eROSITA bubble shells are X-ray bright because they trace denser gas, not because they are hotter. We rule out that the bubble shells trace adiabatic shocks, in contrast to what was assumed in previous studies. We also observe non-solar Ne/O and Mg/O ratios in the shells. Our observations favor the stellar feedback models for the formation of the Galactic bubbles, settling a long-standing debate on their origin.

Searching for degree-wide X-ray halos around middle-aged pulsars with eROSITA

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Recently, extended gamma-ray TeV emission (TeV halos) around middle-aged pulsars has been detected. A proposed model to explain these TeV halos is that electrons from a degree-wide Pulsar Wind Nebula (PWN) get up-scattered by cosmic microwave background photons through inverse Compton processes (Li et al. 2021). However, no X-ray degree-wide faint diffuse PWNe have been found around these middle-aged pulsars. We performed a search for this emission using eROSITA data. To do so, we selected a list of suitable candidate pulsars in the eROSITA-DE part of the sky. These include J0633+1746 (Geminga), B0656+14, J0633+0632, B0540+23 and J0631+1036. However, Geminga and PSR B0656+14 are located in the Monogem Ring, a nearby 20-degree wide supernova remnant, which hampers the search for faint diffuse emission around these pulsars. B0540+23 is located near the bright Crab pulsar, which shines out the full eROSITA PSF and partly overlaps the position of PSR B0540+23. Therefore, we detected no degree-wide diffuse emission around these pulsars. Nevertheless, the upper limits of it provide useful information on magnetic field strength and its spatial distribution around pulsars and give important input into the proposed theory for the formation of TeV halos around middle-aged pulsars.

X-rays from Superbubble Candidates in M31

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A superbubble is hot, dilute, and X-ray-emitting gas cavity produced by stellar winds or supernova explosions, or both. We perform an XMM-Newton study of the four superbubble candidates SBC1 − 4 in the northern disc of galaxy M31 from the X-ray catalogue by Huang et al. (in prep). The four candidates exhibit extended, and relatively soft emission features (< 5 keV). We analyze the X-ray spectrum of each candidate and represent it with a collisional equilibrium plasma component apec. The radiation temperature of the four candidates is < 0.5 keV, and the X-ray luminosity in $0.2 - 10.0$ keV band is about $10^{37}\,\mathrm{erg\,s^{-1}}$. We estimate the physical properties of the four candidates assuming a superbubble scenario. We also discuss the probability of the four candidates as hypernova remnants. By comparison, we argue that, for SBC1, SBC2, and SBC4, the superbubble scenario is more consistent with observations, while SBC3 favors the hypernova remnant scenario. We find shell-like structures from Hα images that spatially coincide with SBC1 and SBC2. These two superbubbles are likely blown by central supernova explosions and stellar winds. They sweep up and compress the ambient gas to create a dense shell, and consequently trigger the star formation in this region.

The Milky Way hot circumgalactic medium as seen by eROSITA

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The first all-sky maps of high ionization Oxygen and Neon lines observed in X-rays by eROSITA provide an excellent probe for the study of the hot phase ($T \sim 10^6$ K) of the Milky Way circumgalactic medium (CGM). These full-sky maps are a first ever of their kind, long awaited since the detection of soft-X background features in the ROSAT broad energy range maps. Thanks the images and spectra from the first eROSITA data release, the different components making the soft X-ray background can be finally separated and constrained. We find that an oblate geometry component, embracing the Galactic stellar disk, best describes most of the intensity commonly attributed to the CGM. Most of its emission is likely produced within a few kpc from us. We also find a minor contribution to the soft X-ray intensity by a more extended ($\sim 10 - 100$ kpc) isotropic component (i.e. the halo). The emission from this halo becomes increasingly important with Galactic (absolute) latitude, roughly matching the oblate component intensity at the Galactic poles. Our results finally provide crucial insight into the long-standing debate on the shape, nature and extension of the hot phase of the Milky Way CGM.

The Circumgalactic Medium: triumphs and challenges

Smita Mathur[1]
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The circumgalactic medium (CGM) plays a critical role in galaxy formation and evolution. The X-ray missions Chandra, XMM-Newton, and Suzaku opened a new window on CGM studies, allowing us to probe the warm-hot gas where most of the galactic baryons reside. In over two decades since the launch of Chandra and XMM-Newton, we have made great strides in understanding the CGM, but significant challenges remain. I'll review our progress so for, highlight new discoveries, outline the open questions, and discuss paths for future progress.

Detection of the Galaxy's Missing Baryons in the CGM of three L* Galaxies

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The amount of baryons hosted in the disks of galaxies is lower than expected based on the mass of their dark-matter halos and the fraction of baryon-to-total matter in the universe, giving rise to the so called galaxy missing-baryon problem. It has been suggested, that the galaxy missing baryons may hide in a hot gaseous phase of the circum-galactic medium, possibly near the halo virial temperature. Here we report the first direct high-statistical-significance (5.3-6.8 sigma) detection of Ovii and Nvi absorption in the stacked XMM-Newton and Chandra spectra of three quasars. We show that these absorbers trace hot medium in the X-ray halo of these systems, at logT(in k) 5.88-6.1 K. We estimate a mass of the X-ray halo M(hot-CGM) (1.4-1.6)x1e11 Msun, corresponding, for these systems, to a galaxy missing baryon fraction xi = M(hot-CGM)/M(missing) 0.99-1.13 and thus closing the galaxy baryon census in typical L* galaxies. Our measurements contribute significantly to the solution of the long-standing galaxy missing baryon problem and to the understanding of the continuous cycle of baryons in-and-out of galaxies throughout the life of the universe.

Interstellar dust mineralogy in the X-ray regime

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Interstellar dust is an important ingredient of the interstellar medium (ISM) of galaxies. High-resolution X-ray spectroscopy is a powerful tool for studying interstellar dust mineralogy. X-ray absorption fine structures (XAFS) are oscillatory modulations observed near the X-ray photoelectric absorption edges, and their shape is the ultimate footprint of the dust chemical composition, size and lattice structure. In this presentation I will demonstrate the newest laboratory measurements of XAFS from astrophysical dust templates in the O K and Fe L photoabsorption edges (Psaradaki et al. 2020,2021), and their application to high-resolution X-ray spectra of a sample of bright Galactic X-ray sources. I will present recent results (Psaradaki et al. 2022) on dust mineralogy in the diffuse regions in our Galaxy using XMM-Newton/RGS and Chandra/HETGS observations. This study gave the most comprehensive view of the silicate mineralogy in the diffuse regions of ISM, through the X-ray energy band. We found that the Mg-rich amorphous pyroxene dust composition (Mg0.75Fe0.25SiO3), and metallic iron represents the bulk of the dust chemistry in the diffuse ISM. Finally, I will discuss the prospects of studying the dust grain chemistry in denser regions of the ISM through the XRISM performance verification phase (PV) target, GX 13+1.

X-ray predictions from Hydrodynamic Cosmological Simulations

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Hydrodynamic Cosmological Simulations offer a unique perspective in studying various aspects of structure formation in the universe. In particular, they hold great value in quantifying statistical properties such as the composition and enrichment of the baryonic matter distribution in the knots and filaments of the cosmic web. While it is observationally challenging to extract information from faint, low-density gas found in filaments and outskirts of galaxies, the projected capabilities of future X-ray missions, such as Athena, provide new pathways towards a deeper understanding of these environments. We present a collection of X-ray studies performed on the hydrodynamical simulation suite *Magneticum*. We make use of the matter properties traced by the simulation to produce exemplary mock observations of filaments connecting galaxy clusters as well as the CGM and ISM in poster-child disk and elliptical galaxies from the simulation, connecting X-ray and physical properties. We produce all-sky predictions of the foreground and background emission of simulated milky-way analogues while also taking into account contamination from stellar sources such as X-ray binaries. With these studies we aim to further our understanding of physical processes driving X-ray observables as well as to put constraints and limiting factors towards observational targets.

The diffuse soft X-ray foreground revealed by giant molecular clouds

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Nearby giant molecular clouds (GMCs) provide the ideal sight lines to probe the soft diffuse X-ray foreground as they efficiently absorb the background. Using the sight lines of three GMCs that dwell on the surface of the Local Hot Bubble (LHB), we attempt to decompose the often degenerate solar wind charge exchange (SWCX) emissions and the thermal emission from the LHB. For this purpose, we leverage data from the eROSITA All-Sky Survey, which provide a wide field of view necessary for GMC observations. More importantly, it allows multiple visits in a 6-month cadence, which is key to estimating the contribution from the time-variable SWCX. Combined with the spectral information and stable instrumental background, we can isolate the LHB emissions from the heliospheric SWCX emissions. From the three distinct lines of sight and precise distances to these GMCs, our result indicates the LHB is consistent with constant density and confirms previous observations of a temperature dipole pointing towards the Galactic centre. A clear correlation between the heliospheric SWCX with the solar cycle is observed. Additionally, we found the heliospheric SWCX to decrease toward the ecliptic poles, consistent with the expected solar wind ion density trend.

Population study of hot gas around z¡0.1 galaxies with eROSITA

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Studying the distribution and properties of hot gas around galaxies is helpful to understand the evolution of central galaxies, but its observation is challenging. The eROSITA all-sky survey allows us to study hot gas with a large sample of galaxies and provide relatively unbiased results. Using the DESI Legacy Imaging Surveys DR9, we build a sample of approximately 200k galaxies at $z < 0.1$ with $10^{10}M_\odot < M_* < 5 \times 10^{11}M_\odot$. We split the sample into red/blue populations and different stellar mass bins and stack them to obtain the X-ray surface brightness profile of each galaxy population. Our analysis detects extended X-ray emission around blue galaxies up to about 100 kpc. For red galaxies, the X-ray profile is so extended that proper modelling of the projection effect is needed to interpret the stacking result. We get the observed relationship between X-ray luminosity and the stellar mass of a galaxy. Additionally, we investigate whether the feedback and inflow of hot gas affect the geometry of hot gas by rotating and stacking edge-on star-forming galaxies selected from DR9. Although no anisotropy of X-ray emission was observed from the approximately 3k galaxies stacked with current eRASS:4 data, the observation can be used to constrain theoretical models of feedback.

SRG/eROSITA maps of the soft X-ray emission lines

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Mapping the X-ray emission lines from hot plasma such as the CircumGalactic Medium (CGM) and Galactic halo has long been a challenging task, due to their diffuse and faint nature. With its large effective area, the extended ROentgen Survey with an Imaging Telescope Array (eROSITA) proves to be an optimal instrument for this goal. In this talk, we present the line emission (C V, O VII, O VIII and Ne IX) and soft band (0.2-5.0 keV) maps belonging to the eROSITA_DE collaboration, as seen during the first eROSITA all sky survey. We use line ratios as temperature diagnostic and we present a novel perspective on the radiation processes underlying the different components of the soft X-ray diffuse emission. After masking the galaxy clusters, our analysis reveals that the line ratio in the high latitude region exhibits significant fluctuation. We will discuss the possible origins of such variations.

Chapter 12

Galaxies & Galactic Surveys

A Very Large Program with Chandra: investigating the metallicity effect on the formation and evolution of young X-ray binaries

Vallia Antoniou[1,2], Andreas Zezas[3,4,2], Konstantinos Droudakis[1], Jeremy Drake[2], Frank Haberl[5], Jaesub Hong[2], Paul Plucinsky[2], Grigoris Maravelias[6], Manami Sasaki[7], Jeff Andrews[8], Ben Williams[9], on behalf of the LMC VLP team

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Our nearest star-forming galaxy, the Large Magellanic Cloud (LMC), has been largely neglected in X-ray binary (XRB) populations studies targeting quiescent luminosities. In Chandra Cycle 24, we were awarded a Very Large Program (1 Msec) to perform a comprehensive survey of sources brighter than 2×10^{32} erg s^{-1} in 10 LMC fields dominated by young (10–100 Myr) stellar populations of different ages, matching those sampled in the similar survey of the Small Magellanic Cloud (SMC). This luminosity limit probes all active XRBs and reaches into the regime of quiescent binaries and X-ray emitting normal stars. This program will provide the deepest X-ray luminosity functions (XLFs) for XRBs ever recorded, and in combination with the SMC survey will allow us to directly measure their formation efficiency as a function of age and metallicity and address the XLF evolution in the 10–100 Myr range. Here we present the first promising results from the analysis of the first observations of three different LMC fields.

NGC 2403: A hard X-ray look of a nearby low metallicity bulgeless spiral galaxy

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We present a NuSTAR investigation of the hard X-ray source population of the spiral galaxy NGC 2403, the most isolated of the three nearby ($\leq$ 3 Mpc) morphologically analogous galaxies. NGC 2403 extends the sample of galaxies used to derive the first scaling relations in the hard X-rays to very vigorously star-forming galaxies with specific star-formation rates (sSFR) of log(sSFR)= -10.4 yr^{-1}. The supporting XMM-Newton observations provided the point source lists for the localization and determination of the source properties in the NuSTAR observations. We present a detailed spectroscopic analysis of NGC 2403 X-1, a well-known ULX with a black-hole mass of 10–15 $M_{\odot}$. Reaching down to $L_{X,limit} \sim 10^{38}$ erg s^{-1} (4–25 keV), we also studied a transient accreting X-ray pulsar discovered in 2007 with a spin period of 18 s, and two additional NuSTAR sources. We also discuss the luminosity distribution of the remaining X-ray binaries detected in the XMM-Newton and NuSTAR observations of NGC 2403 and constraints on their nature based on the NuSTAR X-ray colors.

Far and Near UV sources in the UVIT deep field around IC4329a and their Multi-wavelength Counterparts

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We have detected 1000 sources in FUV and 3133 sources in NUV band above 3 SNR level by analysing a deep field (total exposure time of 84ks in FUV and 82 ks in NUV) around Seyfert Galaxy IC4329a observed during February-June, 2017 by UVIT onboard AstroSat. We performed astrometry and photometry on all the detected sources and produced a catalogue containing their sky position, Far and Near UV flux, magnitudes and UV colours. By cross-matching our catalogue with Gaia DR3 catalogue we could find optical counter-parts for 90 out of 1000 sources in FUV and 631 out of 3133 sources where as in SIMBAD catalogue we could found only 26 matches in our field. We have used simultaneous imaging and variability study in Far and Near UV band to determine the nature of the UV emission of our detected sources. We are also analysing available archival data from XMM-Newton to find the counterpart of our detected sources, which will further help to categorise our sources using multi-wavelength data. The low number of matches found in Gaia and SIMBAD catalogue shows how our study can add a lot of new sources, some of them might be really interesting to study further.

eROSITA and the Magellanic System

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The soft X-ray instrument eROSITA on board the Spektrum-Roentgen-Gamma (SRG) mission began scanning the sky in great circles in December 2019. Four full sky surveys were completed, whereas a fifth was stopped in February 2022. The survey strategy with scans along great circles (six per day), which intersect at the ecliptic north and south poles leads to a higher number of scans across sources near the poles. In particular, the Large Magellanic Cloud (LMC) is located sufficiently close to the south-ecliptic pole to have large regions scanned for up to three weeks. eROSITA provides the first complete surveys of the Magellanic Cloud System (MCS) with a sensitive imaging telescope in the 0.2-8 keV band. The higher exposure and longer monitoring makes the MCS ideal for X-ray source population studies. Previous partial surveys with e.g. XMM-Newton increased our knowledge about high-mass X-ray binaries, supersoft X-ray sources and supernova remnants in the Magellanic Clouds. I'll report on new discoveries with eROSITA in the full MCS. We performed follow-up X-ray and optical observations to characterise the sources.

The first unbiased survey of star-forming galaxies with eROSITA: Scaling relations and a population of X-ray luminous starbursts

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eROSITA, the first 0.2-8.0 keV all-sky X-ray survey, provides the first unbiased census of X-ray galaxies in the local Universe. We combine the first scan of eROSITA (eRASS1) with the HECATE catalog of nearby galaxies ($D \leq 200Mpc$) resulting in a sample of $\sim$ 20000 highly-secure star-forming galaxies. This allows us to investigate the L_x-SFR-M_*-Metallicity relation with less biased and a larger sample than any other previous study. Our analysis reveals a population of star-forming galaxies with ($L_x \geq 10^{40}$ erg/s) and significant deviations from the standard scaling relations. By stacking the X-ray emission of the galaxies in (SFR,M_*,D) bins we find that: i) the average scaling relations resulting from this unbiased sample are still significantly higher than those currently used, ii) there is a strong anti-correlation between metallicity, age and X-ray luminosity. Based on these results we provide new calibration of the scaling relations, we quantify the scatter, and we investigate the nature of the most X-ray luminous galaxies which tend to be young low-metallicity starburst galaxies serving as analogs for high-z galaxies.

X-ray Binary Population Luminosity Functions in Galaxies and their Dependence on Star-Formation History and Metallicity

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The formation of X-ray binary (XRB) populations in galaxies has long been understood to be sensitive to both galaxy star-formation history (SFH) and metallicity; however, the details of this relationship has not yet been clearly quantified. In this talk, we will present a new empirical framework modeling the SFH and metallicity dependence of XRB population luminosity functions (XLFs) that self-consistently describes XRB XLFs over the full range of galaxy types. We develop our model framework using 2000 X-ray point-sources within 44 galaxies at D ¡ 30 Mpc that span a broad range of metallicity and SFH (spanning early-to-late type morphologies). Our models provide unifying quantitative context for scaling relations that have been well studied in the literature, including, e.g., the high-mass XRB (HMXB) luminosity versus SFR relation (LX(HMXB)/SFR), the LX(HMXB)-SFR-metallicity plane, the ultraluminous X-ray source frequency as a function of metallicity and age, the low-mass XRB (LMXB) luminosity scaling with stellar mass (LX(LMXB)/M*), and the observed evolution of LX(HMXB)/SFR and LX(LMXB)/M* relations with cosmic time. We will discuss how these relationships serve important roles in a variety of Astrophysical studies beyond XRB populations (e.g., AGN, gravitational-wave sources, cosmological studies of the early Universe, ISM ionization, and population synthesis models).

Elemental Abundances of the Hot Atmosphere of Luminous Infrared Galaxy NGC 3690

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Hot atmospheres of massive galaxies are enriched with metals. Elemental abundances measured in the X-ray band have been used to study the chemical enrichment of supernova remnants, elliptical galaxies, groups, and clusters of galaxies. Here we measure the elemental abundances of the hot atmosphere of luminous infrared galaxy NGC 3690 observed with XMM-Newton. To measure the abundances in the hot atmosphere, we use a multi-temperature thermal plasma model, which provides a better fit to the Reflection Grating Spectrometer data. The observed Fe/O abundance ratio is subsolar, while those of Ne/O and Mg/O are slightly above solar. Core-collapse supernovae (SNcc) are the dominant metal factory of elements like O, Ne, and Mg. We find some deviations between the observed abundance patterns and theoretical ones from a simple chemical enrichment model. One possible explanation is that massive stars with $M* \sim 23 - 27$ Msun might not explode as SNcc and enrich the hot atmosphere. This is in accordance with the missing massive SNcc progenitors problem, where very massive progenitors $M* \sim 18$ Msun of SNcc have not been clearly detected. It is also possible that theoretical SNcc nucleosynthesis yields of Mg/O yields are underestimated.

Modelling the X-ray emission of Milky Way analogs embedded in large-scale structures

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The mechanisms responsible for quenching star-forming galaxies is a crucial question in galaxy formation. The circumgalactic medium (CGM) hosts the star-forming fuel and modulates quenching mechanisms, affecting the efficiency of feedback processes in galaxies. Therefore, studying the CGM hot phase ($T > 10^6$ K) is a step forward in solving the puzzle of galaxy quenching. Recent studies detect the CGM hot gas by stacking milky-way sized (M_*) galaxies, thanks to the high sensitivity of eRosita soft band (< 2.0 keV) data. Interpretation of the measurements remains challenging owing to the complexity of contributing factors. I will present a new model describing the overall X-ray emission from galaxies, accounting for contributions from projection effects (i.e. light-cones), AGN and XRB contamination and the emission from the hot CGM. We apply our model to the state-of-the-art data from the eRosita all-sky survey (eRASS), providing insights on the efficiency of feedback mechanisms in M_*-galaxies. In addition, we compare the results from large-scale hydrodynamical simulations like IllustrisTNG and Magneticum. This comparison is also essential for improving next-generation hydrodynamic simulation feedback models.

Iron Kα echoes from the Circumnuclear Disk orbiting Sgr A*

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Molecular clouds in the Galactic Center reprocess radiation from past outbursts, generating a strong Fe-Kα fluorescent line (6.4 keV). The closest molecular clouds lie just 1.5 pc from Sgr A* in the Circumnuclear Disk (CND) torus-like structure. By analyzing the last 20 years of XMM-Newton observations, we discovered an increase of the Fe-Kα flux in a region consistent with the CND starting from 2019 and persisting in 2021 and 2022. The scenario is consistent with being an echo radiation of the outburst of the magnetar SGR J1745-2900, which happened in the Galactic Center in April 2013. The magnetar is thought to orbit Sgr A*, and the illuminating wavefront scans the distribution of the clouds at different times. Starting from the total energy emitted by the source and the fluorescent line's measured intensity, we derived the hydrogen column density of the distribution of the clouds. The results are consistent with the estimates derived from radio observations. Moreover, we show that the fluorescence can be partially related to two other transients in 2016. In this case, the time delay between the echo radiation and the transients allowed us to constrain the position of the illuminating source with respect to the CND.

Two faces of M 31: AstroSat/UVIT counterparts of XMM-Newton sources

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M 31 is a large spiral galaxy that is located in close proximity to our own Galaxy. The well known distance to it and the moderate foreground absorption in its direction makes it an ideal target for source population studies. Its X-ray source population has been intensively studied by XMM-Newton. Based on a recently published catalogue of UV sources detected with AstroSat, we identified UV counterparts of X-ray sources in the field of M 31 observed with XMM-Newton. We investigated the UV colours and fitted UV spectra with simple phenomenological models. In addition, we used the X-ray spectral fits of the XMM2Athena project to study the X-ray spectra and see how they evolve with time. We discuss our results in terms of the different source populations that can be identified in the field of M 31.

X-ray emission of extremely star-forming dwarf galaxies

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Most galaxies in the early Universe were compact dwarf galaxies with intense star formating activity. The ionising radiation from these starburst galaxies is considered to be the main mechanism for the reionisation of the Universe. The best local analogues of these high-z compact star-forming galaxies are Green Pea and Blueberry galaxies. The first X-ray observations with XMM-Newton for this type of galaxies, including 4 Green Peas and 6 Blueberries, shows large scatter in their X-ray luminosity with some showing an excess and some a deficit. We will discuss the origin of this scatter and possible indications for presence of AGN in 3 X-ray bright sources.

Discovery of the lensed quasar 1eRASS-J050129.5-073309 with *SRG*/eROSITA, *Gaia*, and NTT/EFOSC2

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We report the discovery and NTT/EFOSC2 spectroscopic identification of a new bright doubly lensed quasar 1eRASS-J050129.5-073309 at redshift $z = 2.47 \pm 0.03$. The source was selected from the first all-sky survey of the *Spectrum Roentgen Gamma (SRG)* eROSITA telescope and the *Gaia* EDR3 catalog. We systematically search for extragalactic sources with eROSITA X-ray positions having multiple *Gaia* counterparts. 1eRASS-J050129.5-073309 is the optically brightest object in our sample and possesses remarkable properties. The two images are separated by 2.7", and their average *Gaia* magnitudes are gmag=16.95 and gmag=17.33. Legacy Survey DR10 imaging and image modeling reveal both the lensing galaxy and tentatively the lensed image of the quasar host galaxy. Archival optical light curves show evidence of a variability time delay where the fainter component lags the brighter by about 60 to 100 days. The fainter image has also decreased its brightness by about 1 magnitude since 2019. This dimming was still noticeable at the spectroscopic observations and is likely caused by microlensing. The discovery of this new lensed quasar and the time delay found in the optical light curve make 1eRASS-J050129.5-073309 a suitable source for cosmological studies.

Chapter 13

Active Galactic Nuclei: inner disk and UFOs

Black Hole Spins in AGNs: A Systematic Perspective

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Black holes have remained enigmatic laboratories that study the most severe settings in the Universe despite the simplicity attributed to being fully characterized by their mass and angular momentum. Although a lot of research has been made in the last ten years, we still don't fully comprehend how spin is distributed in black holes. In this work, utilizing the "relativistic reflection" method derived from those data, we present a systematic examination of a few known black holes in Active galactic nuclei (AGNs) that have been previously seen by NuSTAR but have not yet undergone a spin measurement. We discuss the significance of this research for our comprehension of the "relativistic reflection" spin measurement approach, as well as potential systemic sources of uncertainty that could affect the results of our measurements.

The Wind-Driven X-ray Variability of 2MASS 0918+2117

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According to the Unified Model, AGN of different classification are discriminated based on the viewing angle. "Changing Look" AGN (CL-AGN), a subclass that shows drastic spectral variations on relatively short timescales, threaten such static prescription and require the inclusion of more complex dynamical processes. 2MASS0918+2117 (2M0918) is a CL-AGN, as witnessed by 2 XMM-Newton observations (dating 2003 and 2005, Pounds&Wilkes 2007), which revealed an increase in its X-ray flux by a factor 10, possibly due to a decrease in obscuration. In this work we re-analyse the XMM-Newton spectra and investigate the X-ray variability by extending the light curve through dedicated 2020 XMM-Newton+NuSTAR follow-up observations and eROSITA data. The 2005 spectrum showed tentative evidence of absorption features above 7.8 keV rest-frame, which can be interpreted as highly ionized and fast winds launched from the accretion disk, known as UFOs. The UFO is confirmed in the 2020 spectra with v=0.15c. The X-ray spectral properties of 2M0918 suggest a scenario in which winds play a crucial role in the displacement of obscuring material in and out of the l.o.s. In addition, the detection of galaxy-scale outflows in the 2005 optical SDSS spectrum allows to constrain the wind propagation scenario as momentum-driven.

About the X-ray coronae of high-luminosity AGN: the case of APM 08279+5255

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Optical/UV disk photons are Compton upscattered by the relativistic electrons of the "hot corona", giving rise to the primary X-ray emission of AGN. Such interaction generates positron-electron pairs when the total energy exceeds the rest mass energy of two electrons. Pair production increases the electron density, thus the temperature, of the hot corona, yet it is predicted to act as a thermostat when the system exceeds a certain threshold in the temperature-compactness plane. Such a prediction was verified widely in the local Universe, but only few high-z sources allowed us to probe hot coronae in the high-luminosity range ($\log L_{\rm X} > 45.3$). I will present our efforts in measuring the coronal properties of high-z AGN through dedicated NuSTAR+XMM-Newton joint programs. I will focus on the highest-redshift AGN of our sample, APM 08279+5255. This source manifested a prominent reflection component for the first time during our campaign, which we demonstrated to be a long-lasting feature of APM 08279+5255 based on the re-analysis of previous observations. Through the observational version of the compactness-temperature diagram, that is the X-ray luminosity vs. high-energy cutoff plane, I will show that high-z, high-luminosity AGN comply to the same model predictions as low-z, low-luminosity AGN.

Still alive and kicking: a significant outburst in changing-look AGN Mrk 1018

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Mrk 1018 is a unique twice-changed changing-look AGN. Almost a decade ago it returned from a Seyfert type 1 to a type 1.9. We have been monitoring Mrk 1018 in the u'-band since this last major transition. In 2020, our long-term monitoring detected the most significant outburst in the last few years. With a flux increase of a factor $\sim$13, the outburst alone would have flagged Mrk 1018 as a CL-AGN in photometric searches. It is asymmetric in the u'-band with a rise of $\sim$100 days and decrease of $\sim$200 days. It was followed up in X-ray, UV, optical and infrared (including XMM-Newton data) to compare the AGN components before and after outburst. Optical spectra showed no change several months after, X-ray primary flux returned to its previous state but the 6.4 keV line increased in strength and UV emission was increased. The IR light curve also responded extremely quickly. The optical light decay is best described by a linear decline, indicating that the outburst was not caused by a tidal disruption event of a star. I will summarise a recently submitted paper on the outburst, including speculation as to why Mrk 1018 changes its energy output repeatedly and drastically.

Exploring the circumnuclear environment of SMBHs using ray-tracing simulations in the X-ray band

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The X-rays generated close to the SMBH are reprocessed by the gas and dust around the AGN, thus providing information about the surrounding material. Using the RefleX platform, a ray-tracing code that generates X-ray spectra (Paltani&Ricci, 2017), we have developed two new X-ray spectra models, featuring more complex and realistic geometries than the models that are currently available. The first one, includes a toroidal dusty component along with a polar medium perpendicular to the plane of rotation of the SMBH. For the second model, we take advantage of the capability of RefleX to handle complex geometries and therefore, we include, besides the torus and the polar medium, the accretion disk and broad-line region. In my presentation, I will introduce the new Table models, and present their configurations in detail. Moreover, some examples of the models applied on real data will be illustrated. Complex models will play a crucial role in the coming years with the advent of high-resolution X-ray instruments, such as the one on XRISM.

The X-ray polarisation of the Seyfert 1 galaxy IC 4329A

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I will present results on the recent Imaging X-ray Polarimetry Explorer (IXPE) observing campaign on the type 1 active galactic nucleus (AGN) IC 4329A. IXPE provides, for the first time, sensitivity to X-ray polarisation in the 2-8 keV band, and IC 4329A is only the third type 1 radio quiet AGN to be observed since IXPE's launch. We obtain a 1 sigma upper limit on the X-ray polarisation degree of 5 %, implying a reasonably low viewing angle as expected from its type 1 Seyfert classification. We jointly model the spectrum observed by XMM, NuSTAR and IXPE and the Stokes Q and U parameters provided by IXPE only. We confirm the presence of a relativistic reflection component, from which we measure a low inclination angle, and a small disk inner radius that is also consistent with moderate truncation outside of the black hole's innermost stable circular orbit. Our fits are consistent with the polarisation being dominated by radiation observed directly from the Comptonising corona from a small inclination angle. Since IC 4329A is an edge-on galaxy, our results are consistent with a large misalignment between the AGN disk and the host galaxy disk.

Uncovering the geometry of the hot X-ray corona in the Seyfert galaxy NGC4151

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We will present a detailed X-ray spectro-polarimetric analysis of the bright Seyfert galaxy NGC4151. The source has been observed with XMM-Newton (50 ks) and NuSTAR (100 ks) simultaneously to the Imaging X-ray Polarimetry Explorer (IXPE; for 700 ks) pointing. We detect a polarization degree (PD) of 4.9% ± 1.1% at an angle (PA) of 86° ± 7° (68% confidence level) in the 2-8 keV band. The large PD excludes a 'spherical' lamp-post geometry for the corona, suggesting instead a slab or wedge-shaped geometry, as determined via Monte Carlo simulations. This is further confirmed by the X-ray polarization angle, which coincides with the direction of the extended radio emission in this source and suggests the X-ray corona to be extended parallel to the accretion flow. NGC4151 is the first AGN with an X-ray polarization measure for the corona, probing the potential of this type of analysis and enhancing the importance of performing a joint XMM-NuSTAR-IXPE observation.

Coordinated X-ray and UV absorption within the accretion disk wind of the active galactic nucleus PG 1126-041

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PG 1126-041 is a low redshift ($z = 0.062$) active galaxy hosting a highly-dynamical nuclear wind originating on inner accretion disk scales, manifesting as variable blueshifted absorption troughs in the UV (broad absorption lines, BALs) and in the X-ray band (ultra-fast outflows, UFOs). We present the physical properties of the accretion disk wind derived from the analysis of eight XMM-Newton observations pointed at PG 1126-041 between 2004 and 2015, of which the last four were taken quasi-simultaneously with the Cosmic Origins Spectrograph (COS) onboard the Hubble Space Telescope. The X-ray spectrum of PG 1126-041 is complex and absorbed by ionised material which is highly variable on multiple time scales, sometimes as short as 11 days. Variations in column density ($N_H \sim 5-20\times10^{22}$ cm^{-2}) of a partially covering absorber drive the observed X-ray spectral variability of PG 1126-041. Thanks to the quasi-simultaneous XMM-Newton and COS observations we were able to unveil coordinated absorption variability between the blueshifted C IV ions and the X-ray partially covering absorber. We discuss our results in the context of theoretical scenarios for accretion disk winds in active galactic nuclei.

X-Ray Bolometric Corrections from a Large Multi-Wavelength Study of Nearby Unobscured AGN

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Active galactic nuclei (AGN) are powered by mass accretion and emit electromagnetic radiation mainly at optical, ultraviolet, and X-ray wavelengths. Hence, a detailed analysis of the multi-wavelength spectral energy distributions (SEDs) of AGN can provide fundamental insights into their accretion properties. A complete and consistent study of AGN SEDs can be used to estimate what fraction of the total accretion luminosity of AGN is emitted in the X-rays (bolometric corrections), additionally shedding light on the X-ray coronal emission and how it couples with the optical/UV disk emission.

In my work, I used an almost unbiased sample of hard-X-ray-selected AGN in the local universe. All these sources have multi-wavelength coverage thanks to the BAT AGN Spectroscopic Survey (BASS). I compiled and processed high-quality, simultaneous, optical, UV, and X-ray data for my sample of 300 unobscured AGN to construct and fit their optical to X-ray SEDs. In this talk, I will present the main results from my Ph.D. research, including X-ray bolometric corrections over a wide range of black hole masses, luminosities, and Eddington ratios, and also discuss the key parameters regulating them.

The Densities of Black Hole Accretion Discs and Their Implications in X-ray Data

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Conventionally, the standard thin disc model by Shakura and Sunyaev is utilised to explain the optical and UV observations of AGN, where the thermal emission from the accretion disc in AGN dominates. But observations suggest dramatic energy exchanges between the disc and the corona: most of the accretion power, e.g. up to 90%, must be dissipated in the hot corona to explain the multi-wavelength data of AGN. One of the consequences of having a high coronal illumination is an even higher density in a high-accretion rate, radiation-dominated disc compared to the predictions of the standard thin disc model.

I will present the X-ray spectral modelling of AGN by considering a variable density parameter for the surface of the innermost accretion discs, and their effects on the resulting reflected emission. This key attribute has been long overlooked by previous work where a low, fixed density was assumed but promises to reveal key insights into the detailed disc structures, disc energy exchanges and the connection between supermassive and stellar-mass BHs. I will summarise the latest progress in high-density disc reflection spectroscopy and demonstrate our plan for the development of relevant spectral models.

The Awakening Beast in the Seyfert 1 Galaxy KUG 1141+371

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KUG 1141+371 is a Seyfert 1 galaxy that shows a significant simultaneous flux increase followed by a rapid decay from the optical to the X-ray bands in the past 13 years. For instance, Swift observations show that the UVW2 and X-ray flux of the AGN in KUG 1141+371 steadily increased by a factor of 10 from 2009 to 2020 and has followed a rapid decay ever since 2020. The significant multi-wavelength luminosity change is likely due to a boost in mass accretion rate. The timescale of such mass accretion changes is much shorter than the viscosity timescale of the disc assuming the measured black hole mass of 100 million solar masses for KUG 1141+371.

I will present a detailed multi-epoch X-ray spectral analysis focusing on the variability of the X-ray continuum emission and the puzzling soft excess emission. In addition, our SED models also suggest a simultaneous increase in disc temperature and a decreasing inner disc radius along with the increasing accretion rate. Simultaneous ground-based optical observations also show significant changes in the permitted line profiles and optical continuum. Finally, I will discuss the possible connection between KUG 1141+371, stellarmass-black hole transients in outburst and changing-look AGN.

The first X-ray look at the most luminous quasar in the last 9 Gyr

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Most of our detailed knowledge of AGN, and in particular of their X-ray properties, is based on the study of nearby, low-mass, low-accretion rate sources. Understanding high-mass and high-accretion rate AGN requires deep observations sources at $z > 2$. SMSS J114447.77−430859.3 (J1144; $z = 0.83$) has been identified as the most luminous quasar ($L_{bol} = 6E + 47\,erg/s$) in the last $\sim 9\,Gyr$, making this source a unique proxy of luminous QSOs usually found at cosmic noon. In this talk, I will present the first X-ray observations of this source. I will report on the eROSITA/Spectrum-Roentgen-Gamma (SRG) observations of J1144 from the eROSITA All Sky Survey, along with the results from recent monitoring performed using Swift, XMM-Newton, and NuSTAR. Surprisingly, J1144 is highly variable in X-rays by a factor of $\sim 10(3)$ on a timescale of a year (week). The broadband SED is successfully modelled by assuming either a standard accretion disc illuminated by a central X-ray source, or a thin disc with a slim disc emissivity profile. We measured the coronal properties (temperature and optical depth) and updated the black hole mass and accretion rate measures of the source. We have also found strong hints of the presence of outflow driven by radiation pressure.

Measuring the coronal temperature of AGN

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The hard X-ray emission universally found in AGN is believed to be produced in the so-called corona, of which the physical nature remains unclear. A fundamental parameter is the coronal temperature (Tc), which could be measured by fitting the high-energy cutoff in the hard X-ray spectra. Utilizing the NuSTAR data, we measure Tc in a large sample of both radio-loud and radio-quiet AGN. We compare Tc in the two subsamples, and investigate the correlations between Tc and other parameters (photon index Γ and Eddington ratio). We find significantly larger mean Tc in the radio-quiet sources than in the radio-loud ones. A strong positive correlation between Tc and Γ is detected, while none between Tc and Eddington ratio. Meanwhile, we observe an interesting variation pattern of Tc in individual sources. Tc is found to increase with Γ at $\Gamma < 2.05$, but reversely decrease at $\Gamma > 2.05$, indicating multiple mechanisms are involved. In addition, we report a cross-calibration issue between the NuSTAR and XMM-PN observations, which could severely bias the measurement of Tc when performing a joint fitting.

Far UV spectroscopy of AGN using AstroSat/UVIT

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We study accretion disk emission from eight Seyfert 1 - 1.5 active galactic nuclei (AGN) in the far UV band ($1300 - 1800$Å) using AstroSat/UVIT observation. We correct for the Galactic and intrinsic extinction, contamination from host galaxy, narrow and broad-line regions, and derive the intrinsic continua. We use *HST* COS/FOS spectra to account for the emission/absorption lines in the low-resolution UVIT spectra. We find generally redder power-law ($f_\nu \propto \nu^\alpha$) slopes ($\alpha \sim -1.1 - 0.3$) in the far UV band than predicted by the standard accretion disk model ($\alpha \sim 1/3$). We fit accretion disk models such as the multi-temperature blackbody (`DISKBB`) and relativistic disk (`ZKERRBB`, `OPTXAGNF`) models. We measure the inner disk temperatures ranging from $\sim 3.6 - 5.8$ eV. The inner disks in two AGN, NGC 7469 and Mrk 352, appear to be truncated at $\sim 35 - 125 r_g$ and $50 - 135 r_g$, respectively. While our results show that the intrinsic FUV emission from the AGN are consistent with the standard disks, the UV continua may be affected by the presence of soft X-ray excess emission and other emission components. Joint spectral modeling of simultaneously acquired UV/X-ray data may be necessary to further investigate the nature of accretion disks in AGN.

The powerful, multi-phase Ultra Fast Outflow in IRAS F11119+3257

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IRASF11119+3257 (z=0.189) is a ULIRG/merger hosting a type-1 QSO. It shows a strong UFO feature (v_out$\sim$ 0.25c) in archival Suzaku and Nustar spectra and it is the first system in which the energetics of the UFO was connected to that of the Mid-IR galaxy-scale outflow suggesting an energy-conserving scenario. We obtained in 2021 the first XMM long-look (117ks), with simultaneous Nustar coverage (53ks) for this source. The unprecedented high-quality spectrum allows to detect at $> 4\sigma$ c.l. two absorption features (9.1 and 11.0 keV rest-frame), associated with dense (N_H$\sim 10^{24}$ cm^{-2}) highly ionized (log(xi)$\sim$5) gas outflowing at v_out=0.28+-0.01c. Furthermore, an emission and absorption feature at 1.1-1.3 keV reveals for the first time a broad and blueshifted P-Cygni profile in the soft band, associated with Ne/Fe low ionization transitions. We interpret this as emission/absorption from distant clouds outflowing at the same speed of the highly ionized UFO, a recently-discovered phase also called Entrained-UFO. The mass outflow rate, momentum flux and kinetic energy are among the highest reported in local Quasars.

Probing high-λ_Edd accretion with X-HESS: a new XMM-Newton sample of serendipitous highly accreting AGN

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The Eddington ratio λ_{Edd} is the key parameter that describes the accretion mode of active galactic nuclei (AGN). Among the different modes, high-λ_{Edd} accretion is particularly fascinating because of its implications in the context of accretion physics, as well as AGN feedback. However, due to their relative paucity in the local Universe (z<0.1), only few dedicated observations of AGN accreting in the high-λ_{Edd} regime are currently available. To tackle this issue we exploit the vast database of XMM-Newton serendipitous observations to create a new, large sample of highly accreting AGN named as XMM-Newton High-Eddington Serendipitous AGN Sample (X-HESS). X-HESS includes 143 observations of 61 AGN, $\sim$40% of which disposing of multi-epoch observations, disclosing the unprecedented possibility to study not only the spectral but also variability features of high-λ_{Edd} AGN in much broader intervals of redshift, black hole mass, bolometric luminosity and λ_{Edd} with respect to the bulk of pre-existing AGN samples. Approximately two-thirds of the X-HESS observations are complemented with simultaneous OM measurements. Thanks to the high-quality XMM-Newton observations we probe a large variety of correlations between the X-ray spectral, variability, optical/UV and physical properties of high-λ_{Edd} AGN, extending the dynamical range of previously reported relations towards poorly explored intervals.

Hot coronae in AGN explored via X-ray polarimetry

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The Imaging X-ray Polarimetry Explorer (IXPE) mission has opened a new observing window on astrophysical sources, and it is the Rosetta Stone for the geometry of the innermost regions of AGN. In particular, bright Seyfert galaxies are perfect laboratories for studying the geometry of the hot corona responsible for the X-ray nuclear continuum. I will present the recent observations of MCG-05-23-16, IC 4329A and NGC 4151 and discuss the implications of such polarization measurements. Thanks to the synergy with simultaneous XMM-Newton and NuSTAR pointings, clear insights on the geometry and on the main physical parameters of the hot coronae in these sources have been obtained.

The origin of the soft-excess in AGN: still an unanswered question?

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The X-rays from Active Galactic Nuclei (AGNs) are tightly connected with the optical-UV emission of these sources. Observations support this evidence and current models assuming that the optical-UV seed photons are inverse-Comptonised up to X-ray energies nicely fit the data. However, the presence of an excess of emission in the soft band, the so-called soft X-ray excess, is not yet fully understood and its origin is still hotly debated. X-ray observations alone cannot provide a conclusive answer and simultaneous ultraviolet exposures are mandatory to discriminate between the possible models and to better constrain this spectral component. In fact, models for the soft-excess provide similar estimates for the X-ray flux but diverge in the UV energy range. XMM-Newton, thanks to the unprecedented effective area of the EPIC camera and the capability of performing simultaneous optical-UV observations, gives us the unique opportunity to test the origin of the soft-excess in high signal to noise and broadband datasets. In this talk, I will present the most updated results on the soft-excess based on simulations and observations by XMM-Newton of different sub-classed of AGN.

Narrow Fe-Kα reverberation mapping reveals the presence of a deactivated broad-line region in a changing-state AGN

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Some AGNs change their types between types 1 and 2 with drastic luminosity variation on timescales of years, which is presumably due to the state transition of an accretion flow (e.g., Noda & Done 2018, MNRAS, 480, 3898). Although they are attracting attention as "changing-state AGNs", it is still unclear how materials in their broad-line regions (BLRs) change through the type transition: Do they appear/disappear or remain at the same position while the line production is simply activated/deactivated? We performed X-ray–optical monitoring on a changing-state AGN, NGC 3516, during the type-2 (faint) phase, by *Suzaku* and ground telescopes, and detected significant flux variation of the narrow Fe-Kα emission line on a timescale of tens of days. We conducted "narrow Fe-Kα reverberation mapping" comparing the Fe-Kα flux variation with those of the X-ray continuum and B-band continuum, and obtained an Fe-Kα time lag of $10^{+5.8}_{-5.6}$ days (1σ errors) behind the continuum, which is consistent with the position of the BLR determined in optical spectroscopic reverberation mapping during the type-1 (bright) phase. This result shows that the BLR materials remained at the same position without emitting optical broad lines during the type-2 phase (Noda et al. 2023, ApJ, 943, 63)

Reproducing the UV/optical variability of AGN

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AGN continuum reverberation mapping is based on the broadly accepted idea that the X-ray corona irradiates the accretion disk, causing a delayed UV/optical response. However, in recent years, the results of several multi-wavelength studies pointed at a discrepancy between observations and the underlying theory, detecting low X-ray/UV correlations and larger than expected interband time lags. In order to further examine the assumption of disk X-ray reprocessing, we developed a physical model to reproduce the UV/optical power spectra of AGN assuming the thermal reprocessing of the X-rays in the disk. We apply our model to a sample of sources and we found that the observed power spectra and time lags can be well explained. Expanding on this result, we show that the low X-ray/UV correlation is, in fact, expected if the corona is dynamic. This is simply due to the underlying assumptions in the definition of the cross correlation function statistic. Our results suggest that X-ray disk reprocessing accounts for the full variability properties of the observed AGN disk emission, reconciling observations with theoretical predictions; while our model offers a novel way to probe the inner region of AGN.

Time-resolved, broad band SED modelling of NGC 5548

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Thermal reverberation in AGN accretion discs due to X-ray illumination is thought to be the reason of the continuum UV/optical time lags seen in AGN. Recently, we developed KYNSED, a physical model for the broadband SED of X-ray illuminated accretion discs that takes into account the mutual interaction of the accretion disc and the X-ray corona, including all the relativistic effects induced by the strong gravity of the central black hole on light propagation and on the transformation of photon energies. We use KYNSED to fit time-resolved broadband SEDs of NGC 5548, using data from the multiwavelength campaign of the osurce in 2014, which is one of the most intense campaigns that has even been carried out for an AGN so far. We constructed 15 broad-band SEDs, from opitcal/UV to X-rays, during bright and faint X-ray source states, and we show that X-ray illumation of the accretion disc can successfully explain the variable, broad band SED of the source. We discuss the constraints on the inner disc/X-ray corona geometry, and on the physical origin of the X-ray and UV/optical variations in this source. We also provide a physical explanation for the apparent weak X-ray/UV/optical cross-correlation strength in this object.

X-ray Vision on Local Obscured AGN

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Most of the Cosmic X-ray Background (CXB) radiation from 1-100 keV is the result of AGN emission. Unlike unobscured AGN, the detection of obscured AGN, which are responsible for a significant fraction (40% at peak) of the CXB, is found to be challenging. By observation, the obscured Compton-Thick (column density> $10^{24} cm^{-2}$) AGN fraction in the local universe is 10-50% lower than expected from CXB population synthesis models. Therefore, an almost complete census of obscured AGN is needed at different wavelengths to fill the gap between observations and model predictions. On that path, I will present a comprehensive and systematic analysis of a sample of seven local obscured AGN candidates (z<0.05) through X-ray spectral analysis with Chandra and XMM-Newton at E<10 keV, coupled with NuSTAR data at E>10 keV, to characterize the torus obscuration. The purpose is to update the census of CT-AGN by studying the different properties of the torus over the energy range 0.6-50 keV using physically motivated torus models like- MyTorus, borus02 and UxClumpy. Adding our analysis to the previous results, we find the total population of local CT-AGN almost reduces to half when using NuSTAR observation. We also find around 78% population shows clumpy nature of torus.

X-ray polarization simulations to infer the geometry of hot coronae in AGN

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The geometry of the hot corona, responsible for the primary X-ray emission of AGN, is still largely unknown. The coronal emission, however, being due to Comptonization, is polarized, with a degree and angle depending on the symmetry of the system. Here we present simulations of the polarization of the hot corona with the Monte Carlo radiative transfer code MONK, that takes into account general relativistic effects. We explore different coronal geometries, corresponding to different physical scenarios, and the impact of physical parameters such as temperature and optical depth. We discuss a comparison with results from IXPE/XMM-Newton/NuSTAR coordinated observations of two Seyfert galaxies, MCG-05-23-16 and IC4329A, which allow us to derive constraints on the hot corona geometry.

On behalf of the IXPE team.

X-raying the Torus: A multi-epoch study of obscuration in nearby AGN

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Active galactic nuclei (AGN) are powered by accreting supermassive black holes, surrounded by a torus of obscuring material. Its exact geometry has been a subject of debate, with models advancing from the initial homogeneous torus to a variety of possibilities, ranging from cloud distributions, to warped disks, to outflows. It is clear, however, that this distribution is clumpy: X-ray determinations of line-of-sight (l.o.s.) obscuration show variability in timescales from <1 day to years. X-ray observations are the only way to probe the l.o.s. obscuring column density at any given time, and thus the optimal tool to place constraints on the exact distribution of this material.

In here, we present a multiepoch X-ray analysis of 12 local obscured AGN, totaling 85 observations, spanning more than 20 yrs of observing time. Our analysis shows l.o.s. column density variability for 7/12 sources. Surprisingly, we observe large differences between l.o.s. column densities and average torus column densities for most sources. This suggests that the material responsible for obscuration and reflection is not the same, pointing toward added complexities in the torus structure. We also conclude that variable sources tend to have higher obscuration in average (i.e. denser tori), and broader cloud distributions.

X-ray variability properties of the BASS unobscured AGN from XMM-Newton observations.

Alessia Tortosa[1]
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I will present the analysis of the X-ray variability properties of the Seyfert 1 Galaxies belonging to the BAT AGN Spectroscopic Survey (BASS) using XMM-Newton observations. This sample includes more than 500 observations of 151 local AGN. The aim of this work is to constrain the relation between the common estimators of the variability amplitude (i.e., the normalised excess variance), with the physical and accretion properties of AGN such as the black hole mass of the central supermassive black hole (estimated from either broad Balmer lines or reverberation mapping) and Eddington ratios (estimated combining the M_{BH} measurements with the estimates of the bolometric luminosity derived from the BAT luminosity). We find a strong anti-correlation between the excess variance and the M_{BH}. We do not find correlation between the excess variance and the Eddington ratio but we find a strong anti-correlation with the 2-10 keV luminosity, which disappears removing the dependence of the excess variance on the M_{BH}. I will also show the comparison of the variability property of the unobscured AGN of the BASS sample with the X-ray variability properties of a sample of 5 Super and Hyper-Eddington sources ($1 < \lambda_{Edd} < 426$) belonging to the Super-Eddington Accreting Massive Black Holes sample.

Deep investigation of X-ray winds in super-Eddington sources

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Super-Eddington accretion periods are expected to be extremely important to explain the fast growth of the first supermassive black holes. I present the analysis of simultaneous XMM-Newton and NuSTAR observations of Hyper and Super-Eddington accreting AGN with $1 < \lambda_{Edd} < 426$. These sources are part of a dedicated campaign of the first systematic broad-band X-ray study of Super-Eddington Accreting Massive Black Holes, that I recently published. They show the presence of multi-phase outflowing components in the soft X-ray band (0.3-2 keV) with the typical features of the warm-absorbing (WA) and nuclear ultra-fast (UFO) outflowing components. In particular, the most extreme source of our sample, namely IRAS04416+1215 ($\lambda_{Edd} \sim 426$) shows multiple X-ray absorption components, composed of three phases. The estimate of the minimum and maximum distances of these X-ra winds suggests two different interpretations, one consistent with the three X-ray winds being co-spatial, and possibly driven by magnetohydrodynamical processes, the other consistent with the multi-phase winds being also multi-scale. This work is paving the way to shed light on X-ray outflows in extreme super-Eddington AGN which is also crucial to constrain the role of these sources at high-z.

X-ray polarimetry of the torus in the Circinus Galaxy

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We present the Imaging X-ray Polarimetry Explorer (IXPE) observation of the Circinus Galaxy, the closest and X-ray brightest Compton-thick AGN. We find the source to be significantly polarized in the 2-6 keV band. The X-ray spectrum is known to be dominated by reflection components, both neutral (torus) and ionized (outflow cone). From the spectropolarimetric analysis of IXPE and Chandra data, we find a polarization degree of 20-30% for the neutral reflector, and a polarization angle roughly perpendicular to the radio jet. A comparison with Monte Carlo simulations shows that the neutral reflector is consistent with being an equatorial torus with a half-opening angle of 45-55 deg. This has been the first X-ray polarization detection in a Seyfert galaxy, confirming the basic predictions of the Unification Model.

Dissecting the active galactic nucleus in Circinus in X-rays

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The Monte Carlo radiative transfer code SKIRT has recently been extended into the X-ray range, to study the gas and dust surrounding AGN based on their reprocessed X-ray emission (Vander Meulen et al. 2023). This code can now cover the X-ray to mm wavelength range self-consistently, with all features of the established SKIRT framework available.

We used the SKIRT code to model the circumnuclear medium of Circinus in X-rays, adopting a distribution of gas and dust consistent with recent mid-IR VLTI observations. Our X-ray model incorporates the clumpy structure of the polar wind component, X-ray interactions with dust grains and the effect of gas and dust kinematics, improving upon previous X-ray modelling efforts. We produced synthetic model spectra, which we compared with XMM-Newton, Chandra, NuSTAR and Swift observations. In addition, by simulating both the X-ray band and the IR-to-UV range, we could link X-ray reprocessing to dust modelling in Circinus.

We compared how these empirical models relate to hydrodynamical simulations of the circumnuclear gas and dust in Circinus. Finally, we demonstrate how detailed SKIRT models can be used to leverage the high energy resolution of XRISM to constrain the complex distribution of gas and dust in AGN.

Are binary black-holes playing peek-a-boo with us?

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Since the early detections of gravitational wave signals from compact object mergers, sometimes coupled with their post-merger electromagnetic counterparts, theoreticians and observers alike have been looking for the smoking gun signal that could help identify pre-merger systems. Indeed, such signals would help us identify binary black holes at different stages of the pre-merger, hence gathering data on plasma in strong gravity. While previous works have shown the periodic modulation from the lump orbiting the circumbinary edge to be a promising timing feature to detect binary black-holes, we recently proposed this structure to be caused by the Rossby-Wave-Instability. In turn this raises the question of how to distinguish the RWI naturally occuring at the inner edge of the disk around a single-black-hole from the RWI developing at the edge of a circumbinary disk. Using GR simulations of the RWI in both systems we compute the associated observables to explore if they could be distinguished. We see that a lot of the features from a circumbinary disk can be reproduced by a SBH system with different masses, distances or inner disk as those are not easily distinguishable in observables, hence asking the question if BBH could have already been observed but misclassified.

Sculpting the outer disk of an AGN with a secondary disruptor

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Super massive binary black-hole systems are expected to occur with some regularity as galaxies merge. While gravitational wave observatories are expected to detect close-to-merger systems, not so much is known about the earliest stages of the pre-merger, in particular when the shrinking of the orbit is not yet dominated by the GW emission. In those early stages one can expect the primary's outer disk to be shaved off by the gravitational impact of an approaching secondary disruptor.

After the observation of a possible outer edge at $\sim 1700 r\_g$ for NGC 4395 it seems interesting to explore if this could be caused by a secondary disruptor and see what other set of observables exists that could help discriminate the causes for that outer edge. Using our Numerical Observatory of Violent Accretion systems (NOVAs) we studied how the presence of a distant secondary disruptor impacts the outer region of an AGN disk. We focused in particular on how that would sculpt and reshape the primary disk and the associated observational consequences.

Ultra-fast outflows response in highly-accreting narrow line Seyfert 1 galaxies

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The interplay between accretion and ejection in active galactic nuclei (AGN) is crucial for understanding the evolution of the central supermassive black hole and the host galaxy. However, the physical mechanisms underlying these phenomena are not yet fully understood. Ultra-fast outflows (UFO) launched from the inner accretion disk can help probe this connection. In this study, we systematically investigate the UFO response to source variations in seven highly accreting narrow-line Seyfert 1 AGN through time- and flux-resolved spectroscopy of archival XMM-Newton observations, expanding the sample size from three to ten. Our results reveal that the UFO is faster during brighter states in four out of the seven sources, indicating radiatively-driven outflows. However, we do not observe any significant UFO response in the remaining three sources, likely due to their relatively stable nature or rapid variability, which constrains the density of UFOs. A comparison of the outflow response to the continuum in these sources with those found in the literature provides insight into the nature of ultra-fast outflows in high-accretion systems.

The Low Temperature Corona in ESO 511–G030 Revealed by NuSTAR and XMM-Newton

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We present the results from a coordinated XMM-Newton + NuSTAR observation of the Seyfert 1 Galaxy ESO 511–G030. With this joint monitoring programme, we conduct a detailed variability study and spectral analysis. The source remained in a low flux and very stable state throughout the observation period. The broadband (0.3-–78 keV) spectrum shows the presence of a power-law continuum with a soft excess below 2 keV, a relatively narrow iron Kα emission ($\sim$6.4 keV), and an obvious cutoff at high energies. We describe the application of phenomenological and physically motivated spectral models to characterize the X-ray emission, and the result present a strikingly low coronal temperature (kTe $\sim$ 13 keV). While low temperature coronae have now been observed in several AGNs, the significantly sub-Eddington rate ($\lambda_{\rm Edd} \sim 0.002$) of accretion in this source makes it unique, as the majority of reported sources have fairly high Eddington rates. We investigate the uncertainty from the background spectrum by the inclusion of background modeling analysis, which is not commonly observed in the literature. In addition, we give an extensive discussion of possible scenarios for low coronal in the sub-Eddington regime and the possibility of future X-ray missions distinguishing the possible physical scenarios.

Chapter 14

Active Galactic Nuclei: outflows and feedback

Radio-mode AGN feedback in the first eROSITA all-sky survey

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Radio-mode Active Galactic Nuclei (AGN) feedback is one of the most promising candidates to explain the lack of the coldest gas in the center of cool-core galaxy clusters, also known as the "riddle of cooling flows". Using the most comprehensive X-ray cluster catalog to date, the first eROSITA all-sky survey eRASS:1, and a combination of fifteen radio surveys yielding good spectral coverage, we investigate this feedback mode in a high purity sample of 6500 galaxy clusters. We discuss morphological differences between cool-core and non-cool-core clusters and find relations between the 1.4 GHz radio luminosity and other cluster parameters, like classical mass deposition rate and X-ray luminosity. We test for selection effects with a variety of statistical tests. We conclude that radio-mode feedback by AGN is an important feedback process with an effect on the overall cluster environment that can account for a majority of the cooling losses.

What will next-generation X-ray observatories do for the large scale jets of quasars?

Markos Georganopoulos[1]
[1]*UMBC*

Our understanding of the physics of powerful quasar jets has been severely constrained by the fact that Chandra imaging of the X-ray knots is barely able to resolve the knots and/or displacements between their radio and X-ray images, and this only for some of the brightest X-ray jets. As a result of that, all the modeling and theoretical arguments in the literature are based on one zone considerations even in the few cases where displacements are clearly seen between the X-ray and the radio knots. AXIS will make a substantial difference, because, although the angular resolution of Chandra and AXIS will be similar, the sensitivity of AXIS will be a factor of 10 higher, This will allow us to produce high quality X-ray maps for sources that currently have only a few X-ray counts, and can only be studied via statistical tools like LIRA.

X-ray analysis of type 1 Seyfert galaxies with polar-polarization

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The Unified Model proposes an orientation scheme to describe the different types of Active Galactic Nuclei (AGN). In this context, the study of polarized light by Smith et al. (2004) proposes to interpret the observational properties of Seyfert galaxies with the presence of two scattering regions, equatorial and polar, supposedly present in all Seyferts. We selected 12 Seyfert 1 sources with polar-polarization observed by Chandra and XMM-Newton and we analyzed their spectra in order to seek a connection between X-ray absorption and the orientation scheme proposed: a polar-polarized type 1 is observed through the outer layers of the obscuring torus, where mild ionization of the line-of-sight gas can be expected. Our X-ray study consists in testing the presence of absorption and if this absorption is produced by neutral or ionized material. Our results show that of the 12 sources, only two have cold absorption and the remaining 10 have warm absorption, in all cases with low equivalent Hydrogen columns of the order of $10^{21} - 10^{22} cm^{-2}$. This result is in agreement with the orientation scheme proposed for the polarization observations.

A Highly Accreting Low-Mass Black Hole Hidden in the Dust

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Studying the circumnuclear environment is the first step in probing obscured accretion and understanding the formation and growth history of supermassive black holes. An interesting discovery by large X-ray surveys is that radiative feedback on dusty gas is regulating the circumnuclear environment.

I will present a peculiar NLS1 AGN, Mrk 1239. Unlike typical type-1 AGN, its soft X-ray emission is so obscured that the X-ray emission from the star-forming region dominates. Meanwhile, Mrk 1239 also remains a high accretion rate as most other NLS1s. Therefore, radiation-driven dusty winds might be forming near the edge of its torus along our line of sight. In the NIR band, Mrk 1239 shows strong blackbody emission of 1200 K. Such a high temperature is rare as it is close to the sublimation limit. This strong thermal emission is believed to be from the dust on the inner side of the torus heated by the radiation from the central engine.

In the end, I will discuss how the study of Mrk 1239 provides a pilot study for future large surveys of obscured AGN at higher redshifts e.g., from Athena, JWST and 8m class ground-based telescopes.

A panchromatic view of the broad line region of a narrow-line Seyfert 1

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The broad line region of active galactic nuclei, tightly connected to the activity of the central engine, is still not well understood. In this talk, we present an analysis of X-ray, UV and optical spectroscopic observations of the broad emission lines applied for the first time to a narrow-line Seyfert 1 (Juranova et al., to be subm.). For the panchromatic modelling of the broad-line emission, we adopt the 'locally optimally emitting cloud' approach and investigate the possible scenarios resulting in the observed complexity of the data. We compare the results with the broad line regions observed in normal Seyfert 1s and demonstrate the power of this method in placing constraints on the properties of the active galactic nucleus environment. Finally, we show that models with wind-like geometry based on this approach are promising candidates for more insightful description of the broad line region structure.

SUBWAYS, first results: Ultra-fast outflows in QSOs beyond the local Universe

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We present the X-ray spectroscopic study of 22 luminous (Lbol=10^{45-46} erg/s) AGN at $0.1<z<0.5$, as part of the SUBWAYS sample. 17 targets were observed with XMM in 2019-2020 and the remaining 5 are from previous observations. The aim of this LP (1.45Ms) is to characterise the various manifestations of X-ray winds driven by supermassive black holes. Here we focus on the search and characterization of UFOs, detected through blueshifted absorption troughs in the Fe K band. We confirm with Monte Carlo simulations the detection of absorption lines corresponding to highly ionised iron (Fe XXV/XXVI) in 7/22 sources at the $>95\%$ confidence level. We find a UFO detection fraction of $\sim30\%$ on the total sample, in agreement with previous findings. The SUBWAYS campaign extends at higher luminosity and redshifts than previous local studies on Seyferts. This work independently provides further support for the existence of highly-ionised matter propagating at mildly relativistic speed ($>0.1c$) in a considerable fraction of AGN over a broad range of luminosities. This is expected to play a key role in the self-regulated AGN feeding-feedback cycle.

TEPID: Time Evolving Photoionisation with Current and Future X-ray Telescopes

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Thanks to the high resolution and high-throughput of XMM-Newton (and Chandra), photoionised gas around powerful X-ray sources has been extensively studied since early 2000s. This led to the discovery of the ubiquitous presence of outflows in accreting systems and, in turn, revealed a wealth of information on the ionising sources. However, current photoionisation codes usually assume time-equilibrium and, thus, cannot self-consistently model the gas response to a time-variable (or transient) ionising source, as in most of the astrophysical systems, and leads to incorrect results when fitting their X-ray spectra. Moreover, gas density and distance are degenerate at equilibrium and, thus, the outflows energy and mass rates can be determined only with order-of-magnitude uncertainties.

To maximise the scientific return of current X-ray telescopes, and get ready for the incoming XRISM mission, we developed one of the first Time Evolving Photo-Ionisation Device (TEPID), which follows the gas ionisation in response to a (time-varying) luminosity source. The code is highly flexible and can model any astrophysical scenario, from variable AGNs to GRBs and diffuse nebulae. We are now analysing archival XMM-Newton observations of time-variable AGN absorbers, with a particular focus on those that will be observed in the Performance Verification phase of XRISM.

Multi-wavelength observations of the obscuring wind in the radio-quiet quasar MR 2251-178

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Obscuring winds driven away from active supermassive black holes are rarely seen due to their transient nature. An X-ray obscuration event in MR 2251-178 was caught in late 2020, which triggered multi-wavelength (NIR to X-ray) observations targeting this radio-quiet quasar. In the X-ray band, the obscurer leads to a flux drop in the soft X-ray band from late 2020 to early 2021. X-ray obscuration events might have a quasi-period of two decades considering earlier events in 1980 and 1996. In the UV band, a forest of weak blueshifted absorption features emerged in the blue wing of Lyalpha in late 2020. Our XMM-Newton, NuSTAR, and HST/COS observations are obtained simultaneously, hence, the transient X-ray obscuration event is expected to account for the UV outflow, although they are not necessarily caused by the same part of the wind. Both blueshifted and redshifted absorption features were found for He I 1.08 micron, but no previous NIR spectra are available for comparison. The X-ray observational features of MR 2251-178 shared similarities with some other type 1 AGNs with obscuring wind. However, observational features in the UV to NIR bands are distinctly different from those seen in other AGN with obscuring winds.

The realm of the most luminous quasars in the Universe

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Quasars at the brightest end of the active galactic nuclei luminosity function (i.e., log(L_bol/L_sun)> 14) shining at Cosmic Noon (i.e., z ∼2-4) offer a unique opportunity for improving our understanding of both the physical processes occurring close to the most massive SMBHs and the SMBH-galaxy coevolution in case of extremely large radiation output. After a short introduction on the multiple flavors of luminous quasars, I will review the main results obtained by: (i) the recent XMM-Newton/ Chandra campaign to complete the X-ray coverage of the 85 broad-line WISE/SDSS selected hyper-luminous (WISSH) quasars. Specifically, I will focus on the large dispersion in X-ray luminosity, and the large population of intriguing "X-ray weak" quasars found in WISSH. Thanks to the very extensive multi-band data coverage of the WISSH sample, I will also discuss a wealth of relations between X-ray and spectral/luminosity properties at other frequencies. (ii) deep X-ray observations of Hot Dust-Obscured Galaxies (aka Hot DOGs), which results to host the most obscured hyper-luminous quasars. They likely represent a unique and short-lived stage of massive galaxy evolution in which both heating and ejection of dusty ISM through outflows driven by the central quasars are caught in the act.

Untangling the Positive and Negative Impacts of AGN-driven Outflows in Galaxies and Clusters

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Outflows driven by AGN are an important channel for accreting SMBHs to interact with their hosts. Properties of the outflows are however poorly constrained due to the lack of kinematically resolved data of the hot plasma. In order to untangle the impacts of AGN feedback, we use simulations to study the evolution of AGN-driven outflows. (1) By modeling M87 and Perseus, we demonstrate that the outflow-to-accretion mass-loading factor can be constrained between 200-500. Our results indicate an efficient coupling of the outflows with the surrounding medium on length scales below 1 kpc. (2) We demonstrate that cold gas can continuously fragment out of the radiatively cooling outflow, forming elongated structures extending tens of kiloparsecs. For a range of physically relevant temperature and velocity configurations, a ring of cold gas perpendicular to the direction of motion forms in the outflow. This naturally explains the formation of the blue loop of star-forming region in the Perseus cluster. Our simulation studies strongly suggest that AGNs tightly control both the thermal balance of the hot ICM and the scattered star formation in giant elliptical galaxies, and shed light on the complex interactions between SMBHs and their hosts mediated by the multiphase AGN-driven outflows.

Wind of Change: Unveiling the power of outflows in Mrk 335 through time-dependent photoionization modeling

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Outflows in active galactic nuclei (AGN) are considered promising candidates for driving AGN feedback on large scales. It is, however, notoriously challenging to access their kinetic power because of our limited knowledge of their density and spatial location. The key to obtaining this crucial information is to measure how the outflow responds to changes in the AGN continuum luminosity. Recently, I developed a new time-dependent photoionization (TPHO, Rogantini+2022) which allows precise mapping of the different outflows phases providing tight constraints on the kinetic energy and the mass transferred to the surrounding medium. I will present the results of the spectral-timing TPHO analysis of the new large XMM-Newton campaign of the variable AGN Mrk 355 taken in 2021. The source has not fully recovered yet the high flux shown before the obscuration event occurred in 2019 and its rich RGS spectra show the presence of multiple and variable fast ionized absorbers. I will describe the physics, structure, and energetics of these X-ray outflows focusing on their influence on the surrounding environment. Finally, I will present the power of the synergy between the TPHO model and the upcoming XRISM observations to determine the role of X-ray winds in AGN feedback.

Disc winds and soft excesses in eROSITA AGN

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The hard X-ray emission from Active Galactic Nuclei (AGN) is typically dominated by the hot corona, but additional emission and absorption components are often observed in the soft band, and their origin remains hotly debated. The excellent soft X-ray response and spectral resolution of eROSITA has yielded new insight into the nature of these features. We apply physical models to hard X-ray selected samples of AGN, including soft X-ray emission from a warm corona, partial covering, and ionised (warm) absorption. Using Bayesian X-ray Analysis (BXA), we show that eROSITA can distinguish between soft emission and absorption troughs that can mimic a soft excess. Investigating the Eddington ratio dependence of these features, we observe that low Eddington ratios sources preferentially host host warm absorbers, while high Eddington ratios more commonly feature a warm corona. We demonstrate that warm absorbers are consistent with line-driven disc winds launched close to the central region. Similarly, warm coronae found in sources with higher Eddington ratios may arise from over-ionised winds which remain bound to the system. We highlight the new parameter spaces opened by eROSITA in the investigation into AGN outflows, potential wind ionisation instability regions, and the nature of emission from the central region.

Revisiting the Circumnuclear X-Ray Emission of Seyfert Galaxy NGC 2992

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The innermost region of the Seyfert galaxy NGC 2992 has long been suspected to be the location of intense AGN-host galaxy interaction, but photon pile up in previous high-resolution observations hampered the study of the soft X-ray excess and the interaction near its nucleus. We present an X-ray imaging and spectroscopic analysis of the circumnuclear (1”-3”) region of NGC 2992 using the zeroth-order image of a 135 ks grating observation obtained with Chandra, which captured the nucleus in a historically low flux state. Extended soft X-ray emission is detected in the circumnuclear region with an observed luminosity of L X 7 × 1039 erg s-1. The majority of the previous, puzzling detection of soft excess could be associated with the outflow, indicated by the morphological correspondences between the soft X-ray emission and radio bubbles.

Chapter 15

Active Galactic Nuclei: Jets and BL-Lac Objects

A comparison of the X-ray- and radio-detected AGN population with eROSITA and LOFAR

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The eROSITA eFEDS survey reaches an unprecedented combination of X-ray sensitivity and sky coverage, additionally being enhanced by numerous multiwavelength surveys. This project investigates how radio- and X-ray-selected SMBHs populate galaxies. We use the complete/spectroscopic GAMA09 survey to measure the fraction of galaxies hosting AGN, defined using LOFAR and eROSITA data. We find that the incidence of radio AGN with compact morphologies as a function of 'radio luminosity/stellar mass' results in more massive galaxies being more likely to host radio AGN. Yet, when reformulating this as a function of 'jet power/Eddington luminosity' (ie. specific BH kinetic power), low and high mass show consistent trends, indicating a possible mass-invariant jet powering mechanism, much like the universal triggering/fueling mechanisms found here and in past X-ray work. Furthermore, the fraction of quiescent vs. star forming galaxies hosting radio AGN is comparable, defying the view that only red and dead galaxies host radio AGN. The impact of environment on jet powering is also probed by including 'complex' radio AGN (e.g.FRIIs). Finally, using both X-ray- and radio-detected sources, we investigate how the balance of power is distributed between coronal and jet emission. This work provides useful information on the AGN duty cycle for feedback simulations.

The High Energy X-ray Probe (HEX-P): the most powerful jets through the lens of a superb X-ray eye

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HEX-P is a probe-class mission concept that will combine high spatial resolution X-ray imaging (<10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR), to enable revolutionary new insights into a variety of important astrophysical problems.

The unprecedented observational capability of HEX-P will enable us to study the most extreme jets in the Universe powered by supermassive black holes. The instrument's superior angular resolution will enable us to image jet structures, and its excellent sensitivity will uncover the bulk of their population in the early universe. Acceleration and radiative processes responsible for the majority of their X-ray emission will be pinned down by HEX-P excellent timing capabilities. For the first time, truly simultaneous soft- to hard X-ray coverage will enable us to study in detail the particle population responsible for these jets high-energy radiation. All in all, HEX-P is the ideal mission to unravel the science behind the most powerful jets in the universe, and the simulations presented here demonstrate so.

More information on HEX-P, including the full team list, is available at https://hexp.org.

X-raying the Southern Radio Sky in the SKA era

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We recently built the G4Jy-3CRE, a catalog of extragalactic radio sources, based on the GLEAM 4-Jy (G4Jy) sample, with the aim of increasing the number of powerful radio galaxies and quasars with similar properties as the Third Cambridge catalog (3CR). The G4Jy-3CRE consists of a total of 264 radio sources mainly visible from the Southern Hemisphere that can be observed with state-of-the-art and future cutting-edge astronomical facilities. Here, we present an initial X-ray analysis of 89 radio sources listed therein having archival X-ray observations collected with the Neil Gehrels Swift Observatory. Then we also present preliminary results achieved thanks to XMM-Newton and Chandra archival datasets for 48 radio sources in comparison with radio and optical observations. X-ray observations revealed to be a unique tool to complete the search for counterparts of radio nuclei and to discover extended X-ray emission around radio galaxies, due to intracluster medium or being counterparts of their diffuse radio structures. Finally, we will outline improvements that can be achieved collecting X-ray observations of radio sources visible from the Southern Hemisphere while entering in the SKA era in comparison with what we learned from the X-ray campaign of the 3CR catalog carried out in the last decades.

X-raying blazars in the gamma-ray sky

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BL Lac objects are one of the most extreme class of active galactic nuclei (AGNs) belonging to the largest population of gamma-ray sources: blazars. Two strong connections, linking radio and mid-infrared emission of blazars to that in the gamma-ray band are well established and have been recenlty strenghten thanks to Fermi observations. They constitute the basis to associate gamma-ray sources with their low energy counterparts. Here we show the results of the analysis of SWIFT X-ray observations of gamma-ray blazars and their comparison with the Fermi data for a selected sample of nearly 350 sources aiming at establishing a X-ray vs gamma-ray connection. Finally, we will show on the possible use of X-ray observations to search for new blazars within a selected sample of more than 300 unidentified/unassociated gamma-ray sources (UGSs). We will prove that selection of X-ray BL Lac candidates is a sucessfull method to find new counterparts of Fermi UGSs.

AGN Jets are X-ray Variable on kpc-scales

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The advent of Chandra, the only X-ray observatory capable of sub-arcsecond-scale imaging, has lead to the surprising discovery of strong X-ray emission from jets on kpc scales. The origin of this X-ray emission, which appears as a second spectral component from that of the radio emission, has been debated for over two decades. The most commonly assumed mechanism is inverse Compton upscattering of the CMB by very low-energy electrons in a still highly relativistic jet (IC/CMB). Under this mechanism no variability in the X-ray emission is expected. We report the detection of X-ray variability in the large-scale jet population, using a novel population-based approach and statistical analysis of 53 jets with multiple Chandra observations. We find that typical variability is on the 10-30% scale and occurs in at least 30% (and possibly as high as 100%) of the jet population. Assuming a synchrotron origin, the X-rays must be emitted by very energetic multi-TeV energy electrons. Combined with a very small emitting volume (on the order of light-months), it is possible to produce the observed variability. Such small volumes, however, are in conflict with the typical assumption of particle acceleration which is distributed throughout the jet cross-section.

Chandra study of the Proper Motion of HST-1 in the Jet of M87

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The radio galaxy M87 is well known for its jet, which features a series of bright knots visible from radio to X-ray. We analyze the X-ray image and flux variability of the knot HST-1. Our analysis includes all 112 available Chandra ACIS-S observations from 2000-2021, with a total exposure time of ~887 ks. We use deconvolved images to study the brightness profile of the X-ray jet and measure the relative separation between the core and HST-1. From 2003-2005 (which coincides with a bright flare from HST-1), we find a correlation between the flux of HST-1 and its offset from the core. In subsequent data, we find a steady increase in this offset. We discuss possible origins for these results, including superluminal motion and changes in the knot structure.

Chapter 16

Active Galactic Nuclei: Evolution & high-z

Constraining the High Redshift X-ray Luminosity Function of AGN

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Although AGN play an important role in galaxies, little is known about the formation and evolution of these powerful objects within the early Universe. The X-ray Luminosity Function (XLF), a measure of the comoving space density of AGN as a function of redshift and luminosity, traces AGN population growth. However, at high-redshifts, there is insufficient data to fit models of the XLF due to limitations in survey depth and sky area with current telescopes, until now. With only a few observed sources we are able to place some of the first constraints on the $z > 5$ XLF.

I will present work using the COSMOS2020 galaxy survey with Chandra data, and the new Extragalactic Serendipitous Swift Survey (ExSeSS) catalogue of X-ray selected AGN, to place constraints on the high redshift XLF. Even with just the one $z > 6$ AGN identified in ExSeSS, and an upper limit on the number of more luminous AGN, we are able to place constraints to the bright-end of the XLF at $z = 5.7 - 6.4$. Using deep Chandra data, extracting X-ray flux of COSMOS2020 galaxies, we are able to extend our observational constraints to fainter AGN. Probing towards the faint-end of the high-redshift XLF, and the majority of early AGN growth.

Can we measure the host galaxy mass of Seyfert 1?

Johannes Buchner[1]
[1] *MPE*

Light from Active Galactic Nuclei contaminates the Spectral Energy Distribution (SED) of galaxies, making the measurement of stellar masses and star-formation rates notoriously unreliable. Overly high masses when the AGN model is incomplete are typical. This prevents evolutionary tests comparing black hole and host galaxy properties and is difficult to solve, because we lack independent access to a ground truth stellar mass. We present a novel benchmark data set where host galaxy masses and AGN properties are known. This is a data driven approach blending the light of pure galaxies with that of quasars without assuming a true model of the AGN. We test a variety of SED fitting codes and critically evaluate their ability to infer stellar mass. Finally, we present an unbiased SED fitting method, GRAHSP, Grasping Reliably the AGN Host Stellar Population.

The black hole mass accretion history with eROSITA, Chandra and NuSTAR

Johannes Buchner[1]
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Based on 2-10keV X-ray surveys from eROSITA and Chandra, combined with NuSTAR spectra, a new AGN population synthesis model is constructed. A wide variety of obscurer models are tested and distinguished using the Compton-thick number counts from NuSTAR and BAT surveys and the Cosmic X-ray background. The large-area surveys of eROSITA provides novel constraints on the number of unobscured and obscured luminous AGN since redshift 5. We demonstrate that the black hole mass accretion history diverges from the cosmic star formation history at high redshifts. Combining the population model with the luminosity-dependent merger fraction relation, mergers are an important but minority contribution to the total black hole mass density.

Exploring the X-ray Properties of Low Metallicity Galaxies

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One of the primary outstanding questions in extragalactic astronomy is the formation and early evolution of the supermassive black holes that are seen in nearly every massive galaxy. Low metallicity dwarf galaxies may offer the most representative local analogs to pristine early galaxies, making them a vital tool in probing black hole seed models through the study of the intermediate mass black holes (IMBHs) possibly hosted therein. These dwarf galaxies, and the IMBHs they may host, however, are typically not as well-studied in this context as their higher metallicity and higher mass counterparts. In this presentation, I will discuss the X-ray properties of a sample of 38 low metallicity dwarf galaxies using archival XMM observations and compare the properties and multi-wavelength scaling relations of this population against a representative sample of higher metallicity counterparts. In addition, I will highlight the detection of ten sources with 0.3-10 keV luminosities in excess of 10^{40} erg/s, and their potential to be IMBH candidates based on multi-wavelength selection criteria.

New constraints on the hard X-ray number counts with the Extragalactic Serendipitous Swift Survey

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Presenting the Extragalactic Serendipitous Swift Survey (ExSeSS), providing a new well-defined sample constructed from the observations performed using the Swift X-ray Telescope consisting of 79,342 sources across three energy bands. Using the new ExSeSS sample we present measurements of the differential number counts of X-ray sources as a function of 2-10 keV flux that trace the population of Active Galactic Nuclei (AGN) in a previously unexplored regime. We find that taking the line-of-sight absorption column density into account has an effect on the differential number count measurements and is vital to obtain agreement with previous results. In the hard band, we obtain a good agreement between the ExSeSS measurements and previous, higher energy data from NuSTAR and Swift/BAT when taking into account the varying column density of the ExSeSS sample as well as the X-ray spectral parameters of each of the samples we are comparing to. We find discrepancies between the ExSeSS measurements and AGN population synthesis models, indicating a change in the properties of the AGN population over this flux range that is not fully described by current models at these energies. We also use multiwavelength counterparts to classify the sources, estimate redshifts, and explore the different populations.

Constraining the X-ray reflection in low accretion rate AGN using XMM-Newton, NuSTAR and Swift

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An interesting feature in AGN accreting at low rate is the weakness of the reflection features in their X-ray spectra, which can result from the gradual disappearance of the torus with decreasing accretion rates. It has been suggested that low luminosity AGN (LLAGN) would have a different reflector configuration compared with high luminosity AGN. Our purpose is to constrain the geometry and column density of the reflector in a sample of LLAGN covering a broad X-ray range of energy combining data from XMM-Newton+ NuSTAR+Swift. We use XMM-Newton+ NuSTAR + Swift observations of a hard X-ray-flux limited sample of 17 LLAGN from BASS/DR2 with accretion rates $\lambda_{Edd} < 10^{-3}$. We fit all spectra using the reflection model for torus and accretion disk reflectors. We found a tentative correlation between the torus column density and the accretion rate, LLAGN shows a lower column density compared with the high-luminosity objects. We also confirm the relation between Γ and λEdd, with a smaller scatter than previously reported, thanks to the inclusion of high-energy data and the reflection models. Our results are consistent with a break at $\lambda_{Edd} \sim 10^{-3}$, suggestive of a different accretion mechanism compared with higher accretion AGN.

Exploring black hole scaling relations via the ensemble variability of active galactic nuclei

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One of the most influential relations in extragalactic astrophysics is the one that links the stellar-mass component of galaxies (Mstar) to the masses of the supermassive black holes (MBH) at their centres. Observational constraints on the shape, normalisation and redshift evolution of the Mstar-MBH relation provide important clues on the co-evolution of galaxies and their supermassive black-holes. Unfortunately, measuring the Mstar-MBH relation, particularly at higher redshifts, is challenging and prone to systemics. In this contribution I will present a new method that provides a handle on the Mstar-MBH relation by modelling the ensemble variability of X-ray selected AGN samples. A key ingredient of the method is the modelling strategy that links, for the first time, the demographics of AGN to the physics of the stochastic flux variations of accretion flows and allows the interpretation of the variability properties of AGN populations. I will demonstrate the predictive power of the model by comparing in a forward manner with observational measurements of the ensemble excess variance of X-ray AGN in the Chandra Deep Field South. I will also discuss future prospects for joint constraints on both models of AGN variability and the Mstar-MBH relation as a function of redshift.

Self-consistent population synthesis of AGN from observational constraints in the X-rays

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The cosmic X-ray background (CXB) is produced by the emission of unresolved active galactic nuclei (AGN), thus providing key information about the properties of the primary and reprocessed emission components of the AGN population. Equally important, studies of individual sources provide more constraints on the properties of AGN, such as their luminosity and obscuration. Until now, these constraints have not been self-consistently addressed fully, i.e. linking absorption and reflection. Here we perform numerical simulations with our ray-tracing code, RefleX, which allows the self-consistent modelling of the X-ray emission of AGN with flexible circumnuclear geometries. Using the RefleX-simulated emission of an AGN population, we attempt to simultaneously reproduce the CXB and other constraints obtained in the X-rays, e.g. the Nh distribution and obscured fraction of observed AGN. We use an intrinsic X-ray luminosity function and construct gradually more complex, physically-motivated, geometrical models. We examine how well each model can match all observational constraints, and finally, derive the fraction of Compton-thick ($\log \mathrm{Nh/cm^{-2}} > 24$) sources.

Representative spectral shapes of nearby AGN

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Signatures of reflection by cold material (presumptive torus) are prominent in X-ray AGN spectra. We have studied NuSTAR spectra of nearby AGN, covering the relevant spectral range to constrain the torus properties (using UXCLUMPY, a clumpy torus model) and to have a reference with which to compare higher z objects.

Our sample includes 58 nearby (z<0.06) AGNs (29 Type-I, 15 Compton-thin, & 14 Compton-thick Type-II).

Classical fitting with MCMC sampling found that the model parameters were highly degenerate and not well constrained. Apart from heavily obscured objects preferring more compact tori, a clear tendency of a given object type was not found.

We then performed fitting with parameters fixed to those in the UXCLUMPY table. Parameter combinations (models) are chosen based on how well they fit the sample and how well they fit each object. We found just 26 models fit all sources. Heavily absorbed sources preferred a low to medium torus spread, consistent with the classical fitting. The models were sorted into four groups based on column density. The fraction of different AGN types spanned by each group is consistent with what we expect from their type. We have also obtained the average spectral shape of the groups.

Obscuration-dependency of the AGN accretion rate

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The acccretion rate λ is a key parameter of the growth of supermassive black holes (SMBH). The specific accretion rate $P(\lambda|\lambda,z,M^*)$ represents the probability of a galaxy with a given redshift and stellar mass to host an AGN with a specific $\lambda = Lx/M^*$.

In this work, we analyse 4000 AGN up to redshift 4 observed by XMM-Newton and Chandra to measure the dependancy of $P(\lambda)$ on the obscuration.

To this purpose, our AGN sample's spectral energy distribution (SED) is fitted with a new robust Bayesian algorithm, GRAHSP, returning the stellar mass of the host galaxy. Following Laloux+23, we use the AGN mid-infrared luminosity, calculated from the SED fit, to guide the X-ray spectroscopy. This multi-wavelength approach breaks the degeneracy between intrinsic luminosity and obscuration, yielding better constraints on the physical parameters.

By accurately characterising the X-ray selection function particularly impacted by the obscuration, we calculate in a non-parametric approach the AGN X-ray luminosity function as a function of the redshift and obscuration. Finally, by convolution with the stellar mass function, we retrieve the $P(\lambda)$ for both obscured and unobscured AGN, showing differences between the two regimes.

I will discuss the implications of our results on the history of SMBH growth.

The most powerful jets at the dawn of time

Lea Marcotulli[1]
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High-redshift MeV blazars are some of the most extreme sources in the Universe. With jet power exceeding 10^{47} erg s^{-1}, they are fueled by billion solar masses black holes and are found when the Universe was barely one to two billions years old. These sources are of great astrophysical importance as they can provide us crucial information about the origin and growth of supermassive black-holes in the early Universe. Detection in the hard X-rays is desired to find the most powerful objects of this class and understand their properties. Using the superb capabilities of the Nuclear Spectroscopic Telescope Array (NuSTAR), we have identified six new MeV blazars, all lying beyond redshift 4, at the peak of these sources cosmic evolution. In this talk, I will present the latest results on high redshift blazars with NuSTAR and discuss their implications for the larger population of extreme jets and supermassive black holes.

Evolution of AGN incidence in massive clusters across cosmic time

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An increasing body of evidence suggests an intimate relationship between the formation of stars in galaxies and the growth of supermassive black holes at their centres. A physical description of this interplay requires a better understanding of the conditions that promote accretion events onto supermassive black holes. This presentation addresses the role of a small-scale (<1Mpc) environment in the activation of supermassive black holes at the centre of galaxies. At the core of my analysis is a novel semi-empirical model of AGN and galaxies in the Universe based on the latest observations of X-ray AGN populations. Using a forward-modelling approach, I compare the predictions of the semi-empirical model with observational results on the fraction and radial distribution of X-ray selected AGN in massive clusters of galaxies out to redshift z≈1.25. I will discuss these results in the context of physical mechanisms that operate in dense environments and modulate the triggering of accretion events onto the supermassive black holes of galaxies. Evidence for variations of the incidence of AGN in galaxy clusters as a function of redshift will be presented and discussed.

Investigating the link between AGNs and their host galaxies with X-ray surveys

Qingling Ni[1]
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X-ray surveys have been an effective way to study growing supermassive black holes (SMBHs). Utilizing X-ray survey fields that have extensive multiwavelength data coverage, we can probe how SMBH growth links with the properties of their host galaxies, which will ultimately reveal the physical mechanisms behind the potential coevolution of SMBHs and their hosts. Recent studies show that a "universal" relation between SMBH growth and stellar mass or star formation rate is likely a substantial oversimplification of the coevolution scenario. We found that among star-forming galaxies, long-term average SMBH accretion rate (BHAR) relates to host-galaxy compactness (represented by the central surface-mass density within 1 kpc, $\Sigma1$), and the relation between BHAR and $\Sigma1$ is more fundamental than the relation between BHAR and stellar mass or star formation rate, suggesting a link between SMBH growth and the properties of the central $\sim$kpc regions of host galaxies.

AGN-DB: A Spectro-Photometric and Morphological Database of AGN

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The AGN database (AGN-DB) is the repository of all discovered AGN. It contains every publicly available catalog of AGN, along with their redshift, classification, and spectro-photometric properties from the radio to the X-ray wavebands. Objects from different catalogs are securely cross-matched with LYRA, a robust algorithm that includes Bayesian statistics, photometric priors, and machine learning techniques. AGN-DB already contains more than 7 million AGN from 237 catalogs. Information currently available in the database includes multiwavelength photometry (up to 48 bands), redshift, AGN type, X-ray obscuring column density, and host galaxy morphology.

As soon as a new AGN catalog is published, our pipeline ingests it: all the tables are formatted to CSV files, and all the properties are converted to the standard cgs system. The ultimate goal of AGN-DB is to sample AGN across the Universe and make them publicly available to the scientific community in a single, uniform, and complete database. Data are accessible through an SQL query system, jupyter notebooks, an intuitive user interface, and an imaging retrieval system interfaced with hips2fits. Moreover, CIGALE software is implemented in our user interface, allowing the user to perform SED fitting directly on the AGN-DB website.

Uncovering the dark side of the universe: are we missing a hidden and heavily Compton-thick AGN population?

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We present a study of over 3000 X-ray AGN in the Stripe 82X field, analyzing their intrinsic properties and deriving model-independent obscured and unobscured AGN evolution up to redshift 4. Our findings reveal a discrepancy when tracing the black hole accretion density by comparing our results with current and up-to-date evolutionary models. Specifically, we find evidence for a heavily Compton-thick AGN population that remains undetected even when combining X-ray and infrared data at all redshifts (z>0.5). These results challenge our understanding of AGN evolution and suggest that Compton-thick sources play a larger role in the accretion history of AGN than previously thought.

X-ray luminosity function in the Early Universe: Comparing the AGN growth with the evolution of galaxies

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The black hole accretion density (BHAD) evolves in parallel with the cosmological evolution of galaxies up to z= 2. However, there are significant differences at higher redshifts, where the theoretical BHAD estimates can be up to five times higher than those obtained from X-ray surveys. The latter can be constrained through the X-ray luminosity function (XLF) that explores the evolution and growth of the supermassive black hole (BH) population over cosmic time.

In this work, we aim to derive the XLF in the Early Universe (3¿z¿6) using the largest sample so far (¿600) of high-redshift AGNs selected in the Chandra deep fields, Legacy-COSMOS and XMM-XXL northern fields. We derived the X-ray properties (Lx, NH, etc.) for all sources via spectral fitting, using a consistent technique and model in all fields. For modeling the parametric form of the XLF, we used a Bayesian methodology allowing us to correctly propagate the uncertainties for the observed X-ray properties of our sources into the XLF model parameters.

Thus, we were able to provide the most complete and accurate yet XLF at high redshifts, while we improved the BHAD measurement, hence placing the tightest yet observational constraints to numerical/cosmological simulations.

The impact of AGN selection on measurements of the AGN halo occupation distribution

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The connection between AGN and their host dark matter halos provides powerful insights into how supermassive black holes (SMBHs) grow and coevolve with their host galaxies. Here I show the impact of AGN selection on the AGN halo occupation distribution (HOD) by forward-modeling AGN activity into cosmological N-body simulations. By assuming straightforward relationships between the SMBH mass, galaxy mass, and (sub)halo mass, as well as a uniform distribution of Eddington ratios, I show that luminosity-limited AGN samples result in biased HOD shapes. While Eddington-limited AGN fractions are flat across halo mass by definition, luminosity-limited AGN fractions peak around galaxy-group-sized halo masses and then decrease with halo mass. The decrease is more rapid for higher luminosity limits. These results are consistent with recent HOD constraints from AGN clustering measurements, which constrain a shallower rise of the number of satellite AGN with halo mass than for the overall galaxy population.

Determining the intrinsic relation between X-ray and UV/optical tracers of supermassive black hole growth

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Understanding the relationship between the UV/optical emission from the accretion disc and the X-ray emission associated with the corona is vital to understand differing AGN accretion states and thus the growth phases of black holes. The optical-to-X-ray spectral slope describes the relative strength of the hard X-rays to the accretion disc emission which peaks in the UV. The well-established anti-correlation between α_{ox} and UV luminosity has long suggested that the more luminous the quasar, the weaker the corona and the weaker the hard ionising radiation. However, this observational α_{ox} relation is subject to selection effects and biases. Utilising the optically-selected sample of AGN in the XXL field and Stripe 82 region ($0.5 < z < 4$), alongside their XMM X-ray observations, we have carefully controlled for the X-ray incompleteness, by way of maximum likelihood fitting, to derive the distribution of X-ray and UV luminosities and the intrinsic α_{ox} relation, while accounting for any possible redshift evolution. As a result, we can evaluate our understanding of the connection between the accretion disc and corona.

The near-infrared view of the BLR in X-ray selected local AGN: BASS DR2

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Virial black hole mass (M_{BH}) determination involves directly knowing the broad line region (BLR) clouds velocity distribution, their distance from the central SMBH, and the virial factor f. Understanding whether biases arise in M_{BH} estimation or if an evolutionary difference in the BLR structure of AGN exist as a function of obscuration is possible only by studying a large statistical sample of obscuration unbiased (hard) X-ray selected AGN in the rest-frame near-infrared (NIR, 0.8-2.5μm) since it penetrates deeper into the BLR than the optical. We present a detailed analysis of ~300 high spectral resolution (R~5000) unique NIR spectra of local ($z < 0.1$) Swift/BAT-selected Seyfert galaxies as part of the BASS DR2 (i.e., Ricci et al. 2022,ApJS,261,8R). This represents the largest and least biased NIR AGN database assembled yet, a benchmark for next-generation surveys in X-rays and NIR. These observations have allowed us to test the presence of correlations between BLR dynamics (enclosed in f) and AGN properties for the first time in a complete (both obscured and unobscured) statistical sample of local AGN. Our results show the critical impact obscuration can have on BLR characterisation and the importance of the X-rays and NIR for a less biased view of the BLR.

Detection of a Compton Thick AGN at redshift 5

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In the last decades a growing corpus of evidence strongly suggests that a large population of heavily obscured Active Galactic Nuclei (AGN) exists at high redshifts. Synthesis population models for the Cosmic X-ray Background need a significant population of Compton Thick (CT) AGN. Population studies of IR-selected AGN also find a large fraction of high redshift sources without X-ray counterparts, strongly suggesting that they are heavily absorbed in X-rays. Theoretical considerations and cosmological simulations also predict a large number of accreting galaxies at $z > 3$. However, this population remains largely undetected in X-rays, given the capabilities of the current generation of X-ray observatories. We will present here strong evidence for the first detection in X-rays of a CT AGN at redshift ~ 5. A very hard X-ray source in the XXL field, observed with XMM-Newton and identified as a r-dropout in HSC optical images. Further analysis of its SED and GTC optical spectrum points towards a highly obscured AGN with $z = 5.2$. We will discuss the properties of this AGN and its host galaxy, and possible implications for the detection of this kind of sources in current archival data and for future X-ray missions.

Black Hole and Galaxy Coevolution in X-Ray Selected Type-1 Quasars at $0.2 < z < 0.8$ in Stripe 82 Region

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We investigate AGN and host galaxy properties of X-ray selected SDSS type-1 quasars at $0.2 < z < 0.8$ in the Stripe 82 region, utilizing their multiwavelength photometries from radio to X-ray bands. The spectral energy distributions are fitted with the latest version of X-CIGALE code where an AGN clumpy torus and a dusty polar outflow are included. To most reliably separate the contributions from the stellar and AGN components, we utilize the results by Li et al. (2021) based on the HSC image-deconvolved optical photometries of the host galaxies. We find that the mean ratio between the black hole mass ($M_{\rm BH}$) and total stellar mass is similar to that between M_{BH} and bulge mass ($M_{\rm bulge}$) in the local universe. This suggests that the black holes are overmassive relative to the bulges because our objects are known to show disk-dominant morphologies. The mean ratio between the AGN bolometric luminosity ($L_{\rm bol}$) to star formation rate is larger than that expected from the local $M_{\rm BH} - M_{\rm bulge}$ relation, indicating that our objects are in an BH-growth dominant phase. We confirm that the UV/optical-to-X-ray spectral index correlates with the UV luminosity or Eddington ratio in a similar way to that reported previously.

X-ray properties and obscured fraction of AGN in the J1030 Chandra field

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The characterisation of AGN demographics and their evolution is crucial to understand the history of the accretion onto SMBHs and their relation with their host galaxies. However, the presence of gas and dust poses a significant challenge to AGN detection and characterisation. In this context, X-ray surveys provide one of the most effective ways to detect obscured AGN over a wide range of redshifts and luminosities. I will present the X-ray analysis of the 243 AGNs around the z=6.31 quasar SDSS J1030+0524, detected in the 500ks Chandra ACIS-I survey, and how we used it to derive the fractions of obscured AGN as a function of redshift and intrinsic luminosity. The obscured fractions we measure are significantly higher than what is seen in the local Universe, pointing towards an increase of the average AGN obscuration towards early cosmic epochs, as observed in other X-ray surveys. I will compare our results with recent analytic models that ascribe the larger obscuration observed in AGN at high redshifts to the dense ISM of their hosts. Combined with literature measurements, our results favor a scenario in which the ISM total column density and its individual clouds' characteristic surface density increase towards early cosmic epochs.

A Bayesian Study of Supermassive Black Hole Spins across mass scales

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Understanding the evolution of Supermassive Black Hole (SMBH) growth across cosmic time and mass scales is a long-lasting aim of modern astronomy. According to the no-hair theorem of GR, at a fundamental level, astrophysical Black Holes (BHs) are characterised by their mass (M) and spin. X-ray reflection and reverberation methods have thus importantly provided SMBH spin constraints for dozens of AGNs in the range $\log(M/M\odot) = 6$ - 10 (*Bambi+21*). Currently, the high spins of most of these lower-mass SMBHs suggest they may grow via coherent accretion, whilst the most massive SMBHs, with moderate upper spin bounds, may grow through incoherent accretion and/or SMBH-SMBH mergers. I will present a Bayesian study of SMBH spin in which we infer the parameters describing the underlying spin distribution from the observational estimates (*Bambi+21*). I will then introduce how such a distribution varies for observed AGNs in different mass bins, as well as with the inclusion of the low-mass AGN spin constraints studied by *Mallick+22*. Importantly, our Bayesian model includes the spin dependence of the radiative efficiency. Our findings will be finally discussed in the context of SMBH growth channels across mass scales.

X-ray and UV lightcurves of a strongly variable QSO at cosmic dawn

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We recently discovered that the $z = 6$ QSO J1641+3755 ($L_{\rm bol} \approx 10^{13}\,L_\odot$) is characterized by remarkably high variability, which may be related with the physics of fast accretion in high-redshift QSOs required to form $> 10^8\,M_\odot$ BHs in < 1 Gyr. The X-ray flux of J1641+3755 varied by a factor > 7 from 2018 (Chandra) to 2021 (XMM-Newton), corresponding to 115 rest-frame days. Such a large variation in a short timescale for a luminous object is in conflict with our understanding of the general QSO population. Surprisingly, we found that J1641+3755 shows significant rest-frame UV brightening by Δmag ≈ 0.4 from 2003 to 2021, in qualitative contradiction with the X-ray fading behaviour. Additional three X-ray (Chandra) and rest-frame UV (multiple telescopes) quasi-simultaneous epochs are being collected. I will present new results obtained with this ongoing monitoring campaigns, and discuss possible physical interpretations for the variability properties of J1641, which might provide us with useful insights into the physical processes responsible for the rapid growth of SMBHs in the early universe.

ON THE COSMIC EVOLUTION OF AGN OBSCURATION IN THE STRIPE 82X

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This study analyzes XMM and Chandra observations in the 31.3 deg^2 Stripe82X field (S82X, LaMassa+16), focusing on 2937 candidate AGN with solid redshifts and sufficient counts. We derived the intrinsic, model-independent, fraction of obscured AGN ($22 < \log \mathrm{NH}/cm^{-2} < 24$) up to $z = 4$, finding an increase with redshift and a decline with luminosity. This work constrains the AGN obscuration and spectral shape of the still uncertain high-luminosity and high-redshift regimes ($\log \mathrm{L_X}/erg/s > 45.5$, $z > 3$), where the obscured AGN fraction is $64 \pm 12\%$. The total, obscured, and unobscured XLFs are determined up to $z = 4$, with obscured AGN dominating at $z > 2$ at all luminosities. Intriguingly, the derived black hole accretion density (BHAD) evolution shows that Compton-thick ($\log \mathrm{NH}/cm^{-2} > 24$) AGN contribute to the accretion history of AGN as much as all other AGN populations combined, significantly exceeding previous estimates (e.g., Ueda+14, Aird+15).

Chapter 17

Groups of Galaxies, Clusters of Galaxies and Superclusters

AGN feedback imprints on the thermodynamical gas properties of galaxy groups detected by eROSITA

Emre Bahar[1], Esra Bulbul[1], Vittorio Ghirardini[1], Ang Liu[1], Xiaoyuan Zhang[1], Matthias Kluge[1], Nicolas Clerc[2], Christian Garrel[1], Emmanuel Artis[1], Jeremy Sanders[1], Kirpal Nandra[1]
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Galaxy groups can be considered as the building blocks of the large-scale structure due to their abundance and relatively high mass. Due to their shallower potential wells compared to galaxy clusters, they are prone to non-gravitational mechanisms such as AGN feedback. This makes them good laboratories for understanding and quantifying baryonic feedback mechanisms. Since its launch, eROSITA has detected an unprecedented number of groups thanks to its large effective area and surveying strategy. Uniformly observing the sky allows constructing group samples with well-understood selection functions that is ideal for population studies. In our work, we extract thermodynamical gas properties and constrain AGN feedback using the deepest available eROSITA observations of a large sample of groups detected in eROSITA's first all-sky survey. Moreover, we provide a theoretical framework by comparing our findings with MilleniumTNG simulations and expand our knowledge on the baryons living in the moderately explored low mass halo regime.

Radio-X study of CHEX-MATE radio halo clusters

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In this talk, I will present the first homogeneous X-ray and radio study of galaxy clusters using LOFAR, MeerKAT and CHEX-MATE observations. Past studies have shown the presence of a radio-to-X-ray connections in galaxy clusters and used them to derive constraints on cluster energetics and particle (re-)acceleration. However, many aspects of these processes are yet to be understood. With the advent of new radio facilities at low frequencies, spatially resolved analyses on clusters are becoming available, providing new crucial information about different acceleration models and on the distribution of cosmic ray particles.
As a first step of a wider systematical study, we analyzed a sample of 11 radio halo clusters of the CHEX-MATE sample also observed by the LoTSS and the MeerKAT Galaxy Cluster Legacy Survey. We find strong correlations between X-ray and radio brightness in almost every target, evidencing sub-linear and (close to) linear relations. We also show that a single scaling between the radio and X-ray brightness is not sufficient to explain the observed features. Finally, we present results of a tentative comparison between radio model expectations and observed data, deriving new insights on the non-trivial distribution of cosmic ray electrons in the ICM.

CHEXMATE: constraining the origin of the scatter in galaxy cluster radial X-ray surface brightness profiles

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We present a detailed study of the surface brightness profiles derived from a representative sample of 118 clusters selected via the Sunyaev-Zel'Dovich effect. These profiles represent an ideal tool to investigate the properties of the hot plasma filling the cluster volume. Detailed studies of these profiles have been hampered by selection biases. We overcome these problems leveraging the recently accepted XMM-Heritage program CHEXMATE which observed an unbiased sample of 118 clusters drawn from the Planck catalogue in the redshift z=$[0.1, 0.7]$ and mass $M_{500} = [2 \times 10^{14}, 2 \times 10^{15}] M_{\odot}$ range with an unprecedented homogeneous data quality. We investigate the shape of the surface brightness profiles and we break down the origin of the scatter between them leveraging this exceptional dataset and by comparing them with a matching sample drawn from cosmological simulations.

A new view on galaxy clusters with the FLAMINGO simulations

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We use FLAMINGO, the biggest full hydro cosmological simulation ever, to study the most massive objects in the universe and do a direct comparison with observations. FLAMINGO hosts many thousands of massive clusters, in their full cosmological environment, making it an ideal testing ground to do a statistically relevant comparison with observations. Using a new forward modelling pipeline, including photo-ionization models from CLOUDY, we can accurately model the x-ray emission from clusters and their surroundings in a wide mass-range. We study how x-ray scaling relations are impacted by mass, cool-core fractions and redshift. Tracing mergers through time, we show how merging clusters move on x-ray scaling relations and elucidate whether merging clusters have a discernable offset from relaxed objects. Furthermore, because FLAMINGO has 9 observationally motivated feedback variations, we show the impact of AGN and stellar feedback on cluster profiles. For all FLAMINGO clusters, we also fit their profiles to estimate the hydrostatic bias, which we can now do for thousands of massive clusters, and as a function of cluster properties. With the unprecedented size of the FLAMINGO simulations, we can do all these things for statistically relevant sample sizes, enabling a real comparison with observations at all masses.

Investigating the turbulent hot gas in the X-COP galaxy clusters

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Turbulent motions in the hot intra-cluster medium trace the unrestful dynamical assembly of large galaxy clusters. Turbulence physically links together multiple scales; deeper understanding of its nature reveals physical properties of the dilute plasma, the processes governing cluster build-up and possible non-thermal pressure support affecting halo mass estimates. Simulations predict chaotic motions induce gas density fluctuations, thus enabling observation of this phenomenon in imaging data. We measured X-ray surface brightness variations in XMM-Newton mosaics of 12 nearby clusters forming the X-COP sample. We used forward modelling to grasp the entire error budget and we quantified the amount and spatial distribution of density fluctuations in these systems. Interpreting our measurements as a characterization of stochastic turbulent motions, we find within R_{500} a spectral index consistent with a Kolmogorov cascade. We deduce a non-thermal pressure profile in agreement with simulations beyond $0.5R_{500}$, but inconsistent in inner regions. Interpreting our measurements as gas clumping instead provides results consistent within $0.5R_{500}$ with independent studies, but in tension beyond this radius. We attribute our findings to the presence of central structures, residuals of the dynamical assembly of clusters.

Metal abundance distribution and pattern in the hot medium of early-type galaxies with XMM-Newton RGS spectroscopy

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We report the RGS analysis of 15 early-type galaxies, including the well-known brightest cluster galaxies of Fornax, Virgo, Centaurus, and Perseus. Spatial distribution of the O/Fe, Ne/Fe, and Mg/Fe ratios is flat at the central 60-arcsecond regions, regardless of whether or not a central Fe abundance drop has been reported with CCD studies. Common profiles between noble gas and normal metal suggest that the dust depletion process does not work dominantly in these systems. Therefore, observed abundance drops are possibly attributed to other provenances like systematics in the atomic codes. The mass-loss winds accumulated over the Hubble time are insufficient to congregate the observed gas mass in some large galaxy clusters like Perseus. These massive objects with hot gas (around 2 keV) show the solar N/Fe, O/Fe, Ne/Fe, Mg/Fe, and Ni/Fe ratios. Contrarily, light objects with sub-keV plasma, including isolated or group-centred galaxies, generally exhibit super-solar N/Fe, Ni/Fe, Ne/O, and Mg/O ratios. The latest supernova nucleosynthesis models fail to reproduce such a super-solar abundance pattern. We also discuss possible systematic uncertainties contributing to such high ratios with the important role of future X-ray missions.

The abundance profiles of the DR1 subsample of CHEX-MATE

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The Cluster HEritage project with XMM-Newton– Mass Assembly and Thermodynamics at the Endpoint of structure formation (CHEX-MATE) is a three-mega-second Multi-Year Heritage Programme to obtain X-ray observations of a minimally-biased, signal-to-noise-limited sample of 118 galaxy clusters detected by Planck through the Sunyaev-Zeldovich effect. The programme aims to study the ultimate products of structure formation in time and mass. Here we will report the first results on the abundance profiles on the objects in the first data release sub-sample (DR1) meant to be representative of the parent sample and to test our state of the art analysis methods. We will show the robustness of the abundance profiles with respect the major sources of systematic errors and link the iron abundance to the core properties and to the scatter of the thermodynamical quantities in the external regions.

Sloshing, merging and feedback velocities in the ICM

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The intracluster medium (ICM) velocity structure is important to understand cluster physics for several reasons: it affects the cluster mass estimates, help to constrain AGN feedback models and regulate the transport of metals within the ICM. However, there are few direct measurements of the ICM velocity structure, despite its importance for understanding cluster physics. In this talk I will present the analysis of long exposure XMM-Newton X-ray observations of multiple Galaxy clusters using a novel technique which consist of using background X-ray lines seen in the spectra of the EPIC-pn detector to calibrate the absolute energy scale of the detector. This technique allows us to obtain velocity measurements with unprecedented accuracy down to 100 km/s, providing accurate constrains in the energy budget estimation. We have also measured, by the first time, the velocity structure function (VSF) of the hot ICM using these X-ray astronomical observations. Given the exquisite quality of the observations, we have also carried out a comprehensive analysis of the abundances spatial distribution for individual elements. Finally, I will also discuss on the future prospects to study the detailed ICM velocity structure with future X-ray observatories.

The catalog of galaxy clusters and superclusters from the first eROSITA All-Sky Survey

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eROSITA has finished its first All-Sky Survey (eRASS1) as of June 2020. The source catalogs and science results from eRASS1 will be released in 2023. In the Western Galactic Hemisphere, we detected and optically confirmed ∼10k galaxy clusters. Several hundred superclusters are firmly identified based on this cluster catalog. In this talk, I will briefly overview the eRASS1 catalog of galaxy clusters and superclusters, present the X-ray data analysis we have performed on this largest X-ray cluster/supercluster catalog, and their general properties.

Scaling properties and the effects of feedback for an X-ray selected sample of galaxy groups

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Studies of galaxy groups are important for understanding the gravitational and thermal evolution of the bulk of matter in the Universe. Because of shallow gravitational potential, groups are systems where the roles of complex baryon physics is expected to be significant. We present the X-ray analysis of a flux limited sample of galaxy groups. We constrained slope, normalization, and scatter of the scaling relations with an accuracy similar to what has been achieved with X-ray selected samples of clusters. We will show the correlation (or lack of) between the group properties and the presence of a radio loud AGN in the core.

Revealing deeper secrets: Developing a new higher-resolution technique for XMM imaging analysis

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We develop a new technique to resolve small-scale structures in galaxy groups and clusters using XMM-MOS. This study takes advantage of the steep nature of the on-axis XMM PSF which encloses ∼60% of the incident photon energy within 10 arcsec. Standard pipeline processing of XMM-MOS data yields images with 4 arcsec binning by default; however, images may be created with 1 arcsec bins to better sample the PSF. Our study demonstrates that this sampling can highlight structures such as cavities better than the default processing. We apply this technique to XMM-MOS observations of multiple objects, all of which have confirmed cavity structures detected in Chandra images. By creating unsharp masked images, we demonstrate that this new technique is most effective if the cavities are located beyond the very core (< 10 arcsec) where the PSF blurring remains the main limitation. Cavities beyond this region are clearly revealed. By measuring the decrease in the azimuthally averaged surface brightness at the position of the detected cavities, we estimate a statistical significance of 2-3 sigma for these features. Many of these features remain undetected however if we apply unsharp masking to the 4 arcsec binned images created by the default XMM-MOS processing.

Robust discovery of diffuse inverse-Compton emission in a galaxy group

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At the dawn of the high-energy astrophysics era, the origin of the bright, extended X-ray emission seen towards clusters and groups of galaxies was debated. The advent of dedicated space observatories established that these systems shine in X-rays via thermal bremsstrahlung and line emission from a hot ($\sim 10^7$-10^8 K), magnetised, collisionally ionised medium permeating them. However, radio wavelength detections of diffuse synchrotron radiation from relativistic electrons in some systems implies the existence of a non-thermal component that should also boost cosmic microwave background (CMB) photons up to X-ray energies. So far, such inverse-Compton (IC) emission had not been unambiguously detected on cluster/group scales. In this talk, we report and discuss a robust (4.6 σ) detection of X-ray IC emission in a large-scale gravitationally bound system – the group of galaxies MRC 0116+111. This detection provides a unique unbiased estimate of (1.9 +/- 0.3) μG of the volume-average magnetic field intensity within this group. We will see how this unrivaled accuracy in the magnetic field strength is a pre-requisite for a realistic understanding of processes underlying the magnetic genesis within the largest gravitationally bound structures in our Universe.

Cooling and AGN feedback in Galaxy Groups

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Galaxy groups, as the environment hosting the majority of galaxies in the Universe, are key to our understanding of galaxy evolution, AGN feedback, and the development of the hot intergalactic medium (IGM). Nearby massive, X-ray luminous groups provide an excellent laboratory for studying the cycle of cooling and AGN feedback that governs the thermal equilibrium of the IGM. I will present recent work on AGN feedback in nearby groups, including results from the Complete Local-volume Groups Sample (CLoGS), an optically-selected, statistically complete set of 53 groups within 80 Mpc. XMM, Chandra and GMRT observations trace AGN outbursts in $\sim$40% of the X-ray luminous systems, while CO and Hα+[NII] provide a window on cooling. In most cases, X-ray luminous groups are well described by the "bubbling" feedback model, with regular low-power outbursts preventing excessive cooling, but a few groups host more powerful AGN whose impact may be more long-lasting, and we also find examples of rapid shifts in AGN jet axis which are difficult to explain. Our X-ray observations also reveal examples of group types uncommon in previous archival studies, which may be more common in future surveys.

X-ray study of the merging cluster of galaxies AS0592

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In this talk I will present the results of our study of the AS0592 massive cluster by using 100 ks Chandra observations.

AS0592 is a binary merger, at redshift of 0.22, with a global gas temperature of 9.7 ± 0.3 keV. The two merging components are clearly visible as surface brightness peaks in the X-ray image. The primary system harbours a strong cool core (kT 4 keV), which shows signs of sloshing induced by the merger event. We detected other merging signatures such as the bullet-like morphology of the secondary, the shock front found in the vicinity of secondary and a central region of dense gas with significantly higher temperature compared to the ambient medium.

I will discuss the thermodynamic properties of the AS0592 cluster and how the observed merging characteristics were used to constrain a merging scenario for this system.

Chandra observations of the AS0295 merging cluster

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I will present the results of the X-ray analysis of the AS0295 cluster, a massive cluster caught in the process of merging. Chandra X-ray images show a disturbed morphology, with X-ray emission elongated in the SE-NW direction. While the secondary cluster has a clearly visible X-ray peak and cool gas (6 keV) associated with it, the primary has a flatter surface brightness distribution and a high temperature (9.5 keV), similar to the mean temperature of AS0295.

We detected several merging signatures, such as a cold front close to the secondary's core, a plume of cool gas emerging from primary cluster and two possible shocks: one in the vicinity of primary and the other leading the secondary.

Comparing the X-ray information with literature results of binary merger simulations, I will discuss the dynamical state of AS0295. Moreover, published optical and radio studies of this cluster show the presence of an offset between gas and dark matter in the primary cluster and radio emission associated with this system. Having all this complementary information about AS0295 cluster, I will discuss how this system represents a promising candidate for the understanding of the process of cluster merging and the nature of dark matter.

Enrichment history in poor galaxy clusters: a detailed study of the iron-abundance profile in MKW3s

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The general picture of the enrichment history in galaxy clusters and groups is still far from being thoroughly understood. On the scale of massive galaxy clusters, Ghizzardi et al. (2021) showed that iron-abundance profiles are remarkably flat up to R_{500}, reinforcing the idea of an 'early enrichment' scenario. Less clear is the case of the low-mass cluster regime, where abundance profiles have often been measured to be decreasing with radius, thus challenging our understanding of the physical processes at these scales. In my talk, I will show a detailed measurement of the iron abundance profile for MKW3s, a poor galaxy cluster with $M_{500} = 2.5 \times 10^{14}$ $M_{\odot}$. Although Riva et al. (2022) demonstrated that Fe L-shell measurements in poor clusters are reliable in the high source-to-background regime, serious biases may arise from an incorrect estimate of the background contribution at large radii, where the source-to-background level is low. I will show how a correct and detailed estimate of the particle background of XMM-Newton and of the galactic foregrounds highly impact the measurements for this cluster, allowing to correct a decreasing abundance profile to a flat one.

Galaxy Cluster Mergers at Different Stages As Seen by NuSTAR, Chandra, XMM-Newton and Suzaku

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Galaxy clusters (GC) host hundreds of galaxies embedded in a hot and tenuous intracluster medium (ICM). Mergers of GCs are the last step of the hierarchical formation of astrophysical objects that create shock and cold fronts, and large scale radio structures. While the thermal ICM shines brightly in X-rays, the non-thermal processes are captured in radio and in hard X-rays. Since mergers occur within a $\sim$Gyr timescale, studying multiple systems at various merger stages are crucial to obtain a complete picture of these most energetic events in the universe.

In this talk, I will present three different stages of merging GCs using spectro-imaging analyses of NuSTAR, Chandra, XMM-Newton and Suzaku data complemented by their radio counterparts. Firstly, I will present a pre-merger case of A3391-A3395 system focusing on the cluster outskirt-filament interface. I will then discuss an early stage merger of ZWCL 1856.8 hosting a rare double relic system. Finally, I will share our findings on the late stage merger CL 0217+70, where we discovered multiple weak secondary shocks. I will conclude my talk with brief descriptions of our novel methods aimed at taking full advantage of NuSTAR data.

Investigating the ICM-Radio AGN Interplay in Galaxy Clusters in the ASKAP/EMU Pilot Survey Field

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The AGN feedback by the central radio source of the galaxy cluster controls the cluster's dilute gas, the intracluster medium (ICM). For instance, it is known as a reliable heating source that could prevent the ICM from catastrophic cooling, also distributing the metal-rich from the cluster core outwards. The ICM, on the other hand, shapes the evolution of radio galaxies in clusters. In this project, we study the central AGN-ICM using a galaxy cluster sample of the first eROSITA All-Sky Survey (eRASS1) in the Evolutionary Map of the Universe (EMU) pilot field using the Australian ASKAP radio telescopes. Our sample consists of about 70 clusters that cover a large redshift range ($0.04 < z < 1.14$). We will present the X-ray clusters' morphological properties of this sample, such as centroid shift, surface brightness concentration, Gini coefficient, power ratios, photon asymmetry, and M20. First, we use these parameters to define the dynamical states of the clusters (disturbed/relaxed and Cool Core/Non-Cool Core). Then, we correlate them with some radio properties obtained from the ASKAP/EMU radio data, such as the largest linear size and radio kinetic luminosity of the central galaxy to investigate how the radio sources affect the morphology of the ICM.

Buoyant Bubbles in Galaxy Clusters and their Role in Shaping Cluster Cores

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Buoyant bubbles of relativistic plasma are essential for AGN feedback in galaxy clusters, stirring and heating the intracluster medium (ICM). Observations show that these rising bubbles maintain their integrity and sharp edges much longer than hydrodynamic predictions. In this talk, I will show that such intact bubbles and their "long-term" interactions with the ICM play an important role in shaping cluster multiphase gas cores, e.g., forming H-alpha and CO filaments and generating internal gravity waves. In our simulations, well-developed eddies are observed in the wake of buoyantly rising bubbles, responsible for most of the gas mass uplift from the cluster center. These eddies are gradually elongated and eventually detached from the bubble due to the strong density stratification of the atmosphere. Meanwhile, gravity waves are efficiently generated on the bubble downstream. This picture naturally explains the presence of long straight and horseshoe-shaped Hα filaments in the Perseus cluster, inward and outward motions of the gas, and the X-ray-weighted gas velocity distributions near the northwestern bubble observed by Hitomi, and will help shed light on how we interpret future observations from, e.g., XRISM, Athena.

Outskirts of Galaxy Clusters beyond a Self-similar Picture

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Measurement of the hot intracluster medium (ICM), especially in the cluster outskirts, is one of the major goals of the next-generation X-ray and sub-mm/SZ telescopes. An interesting feature of the ICM is its shock wave structures, driven by energetic feedback, mergers, and smooth accretion. In this talk, I will discuss the formation and evolution of Mpc-scale shock waves in galaxy clusters. I will start from the concept of runaway merger shocks - considered as promising candidates for powering radio relics in the periphery of clusters. I will show that the Coma cluster provides a beautiful example of the runaway shocks based on its multi-wavelength observational data (e.g., Planck, SRG/eROSITA, LOFAR). From the theoretical point of view, the steep gas density profile of the ICM helps maintain the strength of runaway shocks over a large distance, which eventually overtake the accretion shock at the boundary of the ICM and re-shape the gas atmospheres in the cluster outskirts. This picture naturally explains the significant radial offset between the boundaries of the ICM and dark matter halo in galaxy clusters, a famous puzzle long noticed in the cosmological simulations.

Characterizing X-ray emission from cosmic web filaments using the data from the eROSITA All-Sky Survey

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Numerical simulations predict that $\sim 40\%$ of the missing baryon in the local Universe resides in the large-scale filamentary structures and is in the form of the warm-hot intergalactic medium (WHIM). Though the detection of X-ray emission from filaments has been reported, the spatial distribution and physical conditions of the WHIM are less constrained by observations. The eROSITA all-sky survey (eRASS) provides us an unprecedented opportunity of characterizing the properties of the hot phase WHIM. We will present the results of the X-ray emission study of the WHIM in the SDSS optically identified filaments using the first two-year eRASS-DE data.

Tight connection between the nonthermal radio halo emission and thermal ICM properties

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Radio halos are ubiquitous in galaxy clusters, especially in dynamically disturbed systems. The merger-induced turbulent acceleration is thought to be responsible for generating radio halos. Based on the turbulent acceleration scenario, we obtained a quantity $[kT \times Y_{\rm X}]_{r_{\rm RH}}$, which is a proxy of turbulent flux channeled to particle acceleration. Using the radio halo sample in LoTSS-DR2 and archival XMM-Newton data, we found that $[kT \times Y_{\rm X}]_{r_{\rm RH}}$ is highly correlated with radio halo power at 150 MHz with a unity slope, which suggests that the thermal contents in the ICM are closely linked to the nonthermal contents by turbulent acceleration.

Chapter 18

Clusters of Galaxies: X-ray and SZ

Evolution of the Cooling Flow Problem in SPT-Selected Galaxy Clusters

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For years we have grappled with the "cooling flow problem" in galaxy clusters, where massive reserves of hot (10^7 K) gas in the intracluster medium (ICM) are universally observed to form stars with an efficiency of only 1-10%. Feedback from accreting active galactic nuclei (AGN) has been identified as the likely heating source capable of suppressing runaway cooling by up to two orders of magnitude. However, many details about how this balance between cooling and feedback is established, and for how long it's been operating, are still unresolved. Recent SZ-based surveys have been discovering galaxy clusters out to high redshifts at a prodigious rate, allowing us to begin answering questions about how clusters and the multiphase gas, stars, and galaxies within them evolve over cosmic time. We will present new results based on our large ($\sim$100) sample of galaxy clusters discovered by the *South Pole Telescope*, spanning a redshift range ($0.3 < z < 1.7$) corresponding to 10 Gyr in evolution. With multiwavelength follow-up from *Chandra*, *Magellan*, ATCA, and other observatories, this sample is ideal for addressing whether AGN feedback was more or less effective in the past, and whether the ICM conditions that lead to AGN feeding and feedback have evolved with time.

Iron budget in the core of cool-core clusters and metal enrichment history.

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Measurement of the iron budget and stellar mass of galaxies contained in the massive and local clusters of the XCOP sample showed a strong discrepancy between the measured iron-yield value for these systems and the value expected from stellar evolution models and supernova measurements. This result shows how stars residing inside the clusters apparently are unable to produce all the iron we observe, leading to one of the most important puzzles in our understanding of the history of cluster enrichment. A fruitful path to shed light on this problem may come from the study of the center of cool core clusters, where the distribution of metals exhibits a peak and where a BCG, reasonably responsible for the production of this iron, is located. We present results of the measure of the iron-yield derived in the cores of a small sample of massive cool core clusters at redshift $z < 0.3$ showing how the discrepancy with expected values vanishes and we discuss the implications of our findings for the metal enrichment history scenario.

Exploring Dark Energy Survey redMaPPer galaxy clusters with complete X-ray observations

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We present the X-ray analysis of Dark Energy Survey redMaPPer (DESRM) clusters using data products from the XMM Cluster Survey (XCS). In total, 469 DESRM clusters fall within the footprint of four contiguous regions of XMM-Newton observations. Matching to X-ray detections within these regions, this yielded 178 confirmed X-ray detections, with the remaining 291 DESRM clusters undetected. We explore potential reasons for the lack of X-ray emission for these clusters in order to test the validity of the redMaPPer cluster catalog. Of the 178 with X-ray data, we construct various X-ray-to-optical scaling relations, including upper-limit measurements for the undetected clusters. Additionally, using the four contiguous regions, we construct a sample of X-ray selected galaxy clusters in order to compare between optically and X-ray selected clusters and the effect on the derived scaling relations. As a follow-up to this work, we will detail plans to investigate DESRM clusters with the eROSITA All-Sky Survey (eRASS), offering an unprecedented $\sim$4000 deg^2 area of overlap between the DES and eRASS. Finally, we outline how these results can impact our assumptions in preparation for the cluster samples constructed from the Legacy Survey of Space and Time.

Hidden in plain sight: exploring cluster selection bias in the X-ray and optical up to $z \sim 2$

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Selection bias among galaxy clusters is one of the most prevalent issues in observation and with extensive galaxy cluster surveys on the horizon with implications for cosmological models, our understanding of these biases is crucial. We aim to continue to push the understanding of how the properties of galaxy clusters can result in evaded direct detection, specifically in the X-ray, as a function of redshift. Using the Spitzer Adaptation of the Red Sequence Cluster (SpARCS) survey, X-ray cluster surveys from XMM-XXL, X-ray point source catalogs and XMM-Newton and X-ray maps of the XMM-LSS field, W-CDFS, and ELAIS-S1 fields, we examine the galaxy formation efficiency of clusters at different redshifts for X-ray faint and bright clusters. We use the optically-MIR selected SpARCS BCG cluster positions combined with stacking in the X-ray to explore the average properties of clusters that are faint or undetected in the X-ray. Our stacking analysis allows us to incorporate a large range of properties in our cluster sample, specifically to push to lower richnesses and higher redshifts ($z \sim 2$). We explore the potential misclassification of X-ray point sources which have an optical cluster counterpart and use principal component analysis to search for unclassified X-ray bright clusters.

The X-CLASS survey: A catalogue of 1646 X-ray-selected galaxy clusters up to z∼1.5

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The XMM Cluster Archive Super Survey, X-CLASS, is a serendipitous search of X-ray-detected galaxy clusters in 4176 XMM-Newton archival observations. All observations are clipped to exposure times of 10 and 20 ks to obtain uniformity and they span ∼269 sq. deg. across the high-Galactic latitude sky. The new X-CLASS catalogue comprises 1646 well-selected X-ray-detected clusters that span a wide redshift range, from the local Universe up to z∼1.5, with 982 spectroscopically confirmed clusters, and over 70 clusters above z=0.8. Because of its homogeneous selection and thorough verification, the cluster sample can be used for cosmological analyses, but also as a test-bed for the upcoming eRosita observations and other current and future large-area cluster surveys. In this talk we will present the detection algorithm, the visual inspection, the verification process and the redshift validation of the cluster sample, as well as the cluster selection function computed by simulations. We will also describe the various metadata that are released with the catalogue. It is the first time that such a catalogue is made available to the community via an interactive database which gives access to a wealth of supplementary information, images, and data.

Tracing the full length of the A3391/95 intergalactic medium emission filament

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Filaments form connections between galaxy clusters, the nodes of the cosmic web. Studying filaments can improve our understanding of the growth of structure in the universe and might help solve the missing baryon problem. The eROSITA X-ray telescope opened up the possibilities for the detection of new filaments owing to its unique soft response and large field of view (FOV). A search for filaments was conducted in a ∼216 square degree field around the A3391/95 galaxy cluster system using data of the first four eROSITA all-sky scans (eRASS:4), expanding the investigated area by a factor of 14 compared to previous works. Corrected and wavelet filtered RGB images were created and combined with multi-wavelength data, such as Planck SZ map and an optical galaxy density map. We found that for fractions of the FOV, a significant amount of contamination by foreground emission is present. Keeping the constraints by the foreground emission in mind, hints for a possible filament-like structures were found in the East (∼10 Mpc) of the A3391/95 system, as well as towards the North (∼11 Mpc) and South (∼9 Mpc). In the inner region close to the main cluster system, results from previous works could be mostly confirmed.

Cross-calibration of eROSITA, XMM-Newton, and Chandra cluster temperatures

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Galaxy cluster gas temperatures are a crucial part of cluster astrophysics and cosmology. However, it has been shown that cluster temperature measurements can significantly vary between different X-ray telescopes. As those temperatures determine our view on galaxy cluster physics, mass estimates and cosmological parameters, it is of utter importance to cross-calibrate X-ray instruments to avoid systematic biases. In this work, we present for the first time the cross-calibration of eROSITA against XMM-Newton and Chandra. We measured and compared core and core-excised temperatures of 51 common clusters between eROSITA and XMM-Newton and 120 clusters between eROSITA and Chandra. The comparison takes place in the full, soft, and hard X-ray bands, to better understand the origin of any discrepancies. Overall, significant deviations between the temperature measurements are observed across all instruments. For the full X-ray band and average-sided clusters, eROSITA measures 10% and 25% lower temperatures than XMM-Newton and Chandra respectively. The agreement is better for the soft band and/or galaxy groups and worse for the hard band and/or massive clusters. This work will have great implications for future cluster studies when data from different X-ray instruments are combined.

A detailed X-ray view of the filament of gas between the galaxy clusters Abell 2029 and Abell 2033

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The warm-hot intergalactic medium (WHIM) is considered an ideal candidate to search for missing baryons. Observationally, however, it is highly challenging to detect the WHIM due to its low X-ray surface brightness. One approach is to observe large-scale filaments between a close pair of galaxy clusters which are aligned such that our line of sight looks along the length of the filament, which maximizes the volume of gas we are looking through. Here, we present Suzaku, XMM, and Chandra observations of the Abell 2029/2033 system to investigate the nature of a bridge of X-ray emission joining the two. By modeling the contributions from the outskirts of the two clusters, we find a significant excess of X-ray emission between the two at the level of 7.0σ, that cannot be explained by the overlap of the clusters. This excess is consistent with being emission from a filament with 1.0 Mpc wide with an average gas density of $3.7^{+1.0}_{-0.7} \times 10^{-5}$ cm^{-3}, corresponding to 160 times the mean baryon density of the Universe. This excess emission is significantly colder (1.4 ± 0.6 keV) than the outskirts emission from the two clusters, consistent with the temperature expected from the hottest parts of the WHIM.

Powerful yet lonely: is 3C 297 a high-z fossil group?

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The environment of the high redshift (z = 1.408), powerful radio-loud galaxy 3C297 has several distinctive features of a galaxy cluster. Among them, a characteristic halo of hot gas revealed by Chandra X-ray observations. In addition, a radio map obtained with the Very Large Array (VLA) shows a bright hotspot in the north-western direction, created by the interaction of the AGN jet arising from 3C297 with its environment. In the X-ray images, emission cospatial with the northwestern radio lobe is detected, and peaks at the position of the radio hotspot. The extended, complex X-ray emission observed with our new Chandra data, is largely unrelated to its radio structure. Despite having attributes of a galaxy cluster, no companion galaxies have been identified from new spectra of neighbouring targets of 3C297 obtained with the Gemini Multi-Object Spectrograph. None of the 19 galaxies for which a redshift was determined lies at the same distance as 3C297. The optical spectral analysis of the new Gemini spectrum of 3C297 reveals an isolated type-II radio-loud AGN. We postulate that the host galaxy of 3C297 is a fossil group, in which most of the stellar mass has merged into a single object, leaving behind an X-ray halo.

Metal enrichment: the apex accretor perspective

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We present a simple description of the metal enrichment process as viewed from massive halos. We find our model is consistent with a large body of observational evidence: the Fe Abundance vs Entropy anticorrelation; flat and low scatter abundance profiles in cluster outskirts; lack of redshift evolution in cluster outskirt abundance and lack of substantial abundance ratio differences between core and circum-core regions. Finally the model makes predictions on group abundance profiles and offers a solution to the long standing iron yield problem.

Investigating galaxy cluster scaling relations using XMM-Newton data of clusters from the eeHIFLUGCS sample

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High quality X-Ray galaxy cluster measurements are very important for cosmological and galaxy cluster studies. Such measurements have not been widely available for large cluster samples. We use XMM observations of ~230 galaxy clusters from the X-Ray flux limited survey eeHIFLUGCS to determine galaxy cluster properties such as core-included and core-excised X-Ray luminosities, cluster gas masses, half-light-radii, and characteristic radii R_{500}. The use of XMM-Newton data for this analysis is crucial, because it allows for a more precise determination of the aforementioned parameters in comparison to previous studies of those clusters using ROSAT data. We investigate the scaling relations between the core included and core excised properties. Comparisons with previous studies show a reduction in scatter. The results will be used in cosmological applications of the eeHIFLUGCS sample such as studies of the cosmic isotropy.

The Multi-Wavelength Environment of Second Bologna Catalog Sources

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We present the first results of the *Chandra* Cool Targets (CCT) survey of the Second Bologna Catalog (B2CAT) of bright radio sources, with the goal of investigating the nature of the extended X-ray emission surrounding these sources. For the first 28 sources observed in the B2CAT CCT survey, we performed both imaging and spectral X-ray analysis, producing multi-band *Chandra* images, and compared them with LOFAR, GMRT, and VLA observations. We detected X-ray nuclear emission for 22 sources. In addition, we detected 7 regions of increased X-ray flux originating from radio hot-spots or jet knots, and a region of decreased flux, possibly associated with an X-ray cavity. We performed X-ray spectral analysis for six bright nuclei with a power-law model, finding slopes 1.5-1.9, and intrinsic absorption significantly larger than the Galactic values for two of them. We detected significant extended X-ray emission in five sources, finding temperatures 2-4 keV. In the case of the source B2.1 0742+31, the surrounding hot gas is compatible with the ICM of low luminosity clusters of galaxies, while the X-ray diffuse emission surrounding the highly disturbed WAT B2.3 2254+35 features a luminosity more appropriate to galaxy groups, although its temperature is that of a galaxy cluster.

Can spiralling cold fronts in galaxy clusters be sustained against mixing?

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Cold gas in cluster cores is attributed to local thermal instability with the filamentary structure arising from the local magnetic field. We revisit the global linear overstable g-modes and find that warm-cool gas may span across large scales as spirals centered at the cluster center. In Perseus, spiral cold fronts are visible in the X-ray surface brightness as isobaric, low-amplitude density enhancements. While these are often assumed to be formed due to gas sloshing, we argue that global thermal instability may also explain such cold fronts. A major concern regarding the sustenance of such large-scale warm-cool phase is destruction by mixing. We examine the role of magnetic fields in supporting the survival of azimuthally stretched out warm-cool phase in cluster cores. Magnetic field can drive slow waves to overstability leading to growth at smaller azimuthal scales (than a global spiral), forming a volume-filling complex medium with structures at multiple scales. However, it can still support the survival and growth of azimuthally stretched cooler phase against turbulence and/or g-mode oscillations. We discuss this using 3D HD/MHD simulations of galaxy clusters which highlight breakdown of azimuthal coherence and how magnetic field and non-linear perturbations contribute towards preservation of the azimuthal structure.

Exploring AGN Feedback as a Driver of Gas Sloshing in Galaxy Clusters

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X-ray observations of galaxy clusters have revealed the presence of spiraling gas sloshing features, particularly about 95 percent in cool core (CC) clusters. These features are believed to arise from the motion of the intracluster medium induced by mergers or other disturbances. While simulations of merging clusters have reproduced such features, their limitations (e.g., merging is rare in CC clusters) have prompted the investigation of alternative mechanisms. AGN feedback is one such mechanism, and its potential role in driving gas sloshing has been the focus of recent research. We present evidence of gas sloshing motion in a cosmic ray (CR) dominated AGN jet feedback simulation of galaxy clusters. Our simulation, carried out using magnetohydrodynamics, shows spiral-like gas sloshing features with a scale of 20-100 kpc, consistent with some current X-ray observations of CC clusters. We investigated the results in various projections and compared them with real X-ray observations from Chandra and XMM Newton. Our findings suggest that AGN jet feedback can drive gas sloshing in galaxy clusters. These findings have important implications for understanding the formation and evolution of galaxy clusters and the role of AGN feedback in shaping their properties.

Intercluster Filaments, Cluster Outskirts, and the Interface Between Galaxy Clusters and the Cosmic Web

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Several studies have shown that entropy profiles of the intracluster medium (ICM) generally do not match self-similar predictions near the virial radius, with the measured values typically being less than predicted. There are several proposed mechanisms to explain this discrepancy, including weakening accretion shocks, electron-ion non-equilibrium, and unresolved cool gas clumps that bias X-ray measurements. These effects are expected to correlate with the local orientation of cosmic filaments, as they interface with the outskirts of the ICM. I will present results from deep X-ray observation of early-stage, binary cluster mergers, where the merger axis is expected to be aligned with a local large scale filament. We find that the ICM entropy profiles are consistent with self-similar predictions, even in these dynamically active, merging systems, likely due to the relatively low subcluster masses (3-4 keV). We also find tantalizing evidence for diffuse emission with properties that are consistent with the dense end of the warm-hot intergalactic medium (WHIM) only along the merger axes (but not at the same radii away from the merger axes), consistent with the expectation that the merger axes in these systems are aligned with local cosmic filaments.

The temperature profiles of CHEX-MATE galaxy clusters

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CHEX-MATE (“The Cluster Heritage project with XMM-Newton: Mass Assembly and Thermodynamics at the Endpoint of structure formation”) is one of the few multi-year Heritage programs appointed so far. It allows homogeneous observation of a large, complete, and minimally biased sample of 118 galaxy clusters, which represent the ultimate products of structure formation in mass and time. The observations were completed during 2022 and the data analysis is ongoing. I will present the new spectroscopic pipeline, with MCMC fit, and the new physically-motivated background model of the XMM particle background that we developed for this project. I will then focus on the first results on temperature profiles for a representative subset of clusters, showing their distribution, average profile and scatter. I will compare the results with previous sample in the literature and with predictions from numerical simulations.

Offset between X-ray and optical centers in clusters of galaxies: connecting eROSITA data and simulations

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Characterizing the dynamical state of galaxy clusters is key to studying their evolution and selection and using them as a cosmological probe. The offsets between different centers provide an estimate of the cluster disturbance.

I will present a study of the offset between X-ray and optical centers for clusters detected by eROSITA in eFEDS and eRASS1. We connect observations to predictions by hydrodynamical simulations and N-body models. We assess the astrophysical effects affecting the displacements.

We find that eFEDS clusters show a smaller offset than eRASS1 because the latter contains a larger fraction of massive and disturbed structures. We measure an average offset of 76.3+30.1−27.1 kpc when focusing on 87 massive eFEDS clusters at low redshift. Our result agrees with the TNG and Magneticum simulations and the theoretical distribution of the offset parameter Xoff from dark matter-only (DMO) simulations. The tails of the distributions are different due to baryonic effects. We find a correlation between the offset measured on hydrodynamical simulations and Xoff measured on their DMO run. It accurately predicts the Xoff distribution in Magneticum and TNG, introducing the offsets in a cosmological context with a new method to marginalize selection effects related to the dynamical state.

First XMM ‘observations’ of the TNG-Clusters simulations

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TNG-Clusters is a new suite of zoom simulations of high-mass galaxy clusters, and an extension to the Illustris-TNG cosmological simulation project. The aim is to supplement the high-resolution Illustris-TNG 300 Mpc^3 simulation box by improving the sampling and statistics of halos with masses greater than $10^{14.5} M_\odot$. A total of 350 galaxy clusters are drawn from a 1 Gpc^3 dark-matter-only simulation, and then re-simulated at the same resolution as the TNG300-1 box. I present the first results from realistic *XMM* observations of these simulated clusters, including comparisons with X-ray properties of real galaxy clusters. Such comparisons are an excellent diagnostic to assess the veracity of simulated galaxy clusters, and have been used for past Illustris simulation suites. The simulated X-ray observations are analysed in a completely consistent manner to the Local Volume Complete Cluster Survey (LoVoCCS), making use of the X-ray: Generate and Analyse (XGA) module. Global properties of the real and simulated clusters (such as temperature and luminosity) are compared, as well as radial profiles of density and temperature.

First X-ray properties of LoVoCCS galaxy clusters

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The Local Volume Complete Cluster Survey (LoVoCCS) is an optical/near-infrared survey of a local sample of X-ray luminous galaxy clusters, selected from the MCXC catalogue. Observations are being taken using the Dark Energy Camera (DECam; previously used for the Dark Energy Survey) to a depth equivalent to the Legacy Survey of Space and Time year 1-2 survey. LoVoCCS data are being processed using LSST pipelines, and the analysis tools being developed will be compatible with LSST data. One of the key outputs of the optical/near-infrared investigation will be individual weak-lensing shear and mass maps for the galaxy clusters, which will be particularly powerful when combined with other wavelengths which directly probe the intra-cluster medium. As such, complementary X-ray analyses of LoVoCCS clusters are being performed using *XMM* archival data, providing a window into the baryonic content of these clusters. This combination of individual weak-lensing masses and uniform X-ray analyses is uniquely powerful. I will present the first results of this X-ray analysis, introducing the methodology and the open-source analysis module used for the work; X-ray: Generate and Analyse (XGA). The X-ray properties of the clusters will be summarised, and compared to previous work and samples.

Chapter 19

Clusters of Galaxies: Mass-proxies

Models of, and constraints on, the non-thermal pressure in X-ray galaxy clusters

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I will discuss the role of non-thermal pressure support as a major source of the difference between the hydrostatic and the total "true" halo mass in galaxy clusters. I will present new models and methods to constrain this non-thermal pressure, highlighting the role of the next generation of X-ray observatories, like XRISM and Athena, in constructing a consistent picture of the formation and composition in mass and energy of galaxy clusters.

The evolution of the mass - X-ray luminosity relation in the CODEX galaxy cluster sample

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Precise measurements of X-ray scaling relations in galaxy clusters are imperative to probe cosmology and study baryonic processes in the intercluster medium. The correlation between X-ray luminosity and the total mass of clusters is well established in the self-similar model (Kaiser 1986), on which only gravitational processes were considered. The evolution of this relation is expected when non-gravitational processes (e.g. radiative cooling and AGN feedback) are meaningful.

We are using the CODEX catalog, which was thoroughly constructed by adopting an X-ray and optical selection of clusters in a reanalysis of Rosat All Sky Survey data. The mass for our CODEX-CFHT sample of 26 galaxy clusters was obtained by weak gravitational lensing, a method sensitive to the entire matter of the cluster.

For the analysis of the scaling relation, we introduce a Bayesian hierarchical model to account for heteroscedastic measurement errors, intrinsic scatter, optical and X-ray selection functions, and the subsample's construction criteria. Our sample is well fit by a power law with an exponent of 1.3 ± 0.6, with no evidence for redshift evolution. Our results significantly contribute to previous studies due to the use of a larger sample, the high data quality, and the statistical robustness.

A very large sample of galaxy cluster hydrostatic masses measured by XCS

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Galaxy cluster masses are useful for many analyses, but are difficult to measure directly, especially for large samples of clusters (very high-quality data is required). A common approach for large surveys is to construct mass-observable relations (where the observable has a tight correlation to mass, and is easier to measure); as such calibrating the normalisation of mass with observable, and understanding the scatter, is essential. This is particularly true when deriving cosmological parameters from the halo mass function, something that is currently a main focus of several surveys; e.g. the Dark Energy Survey (DES) and the *eROSITA* All-Sky Survey. In order to support DES cosmology efforts, and to explore the scatter of mass with observable (obscured when using stacked weak-lensing masses), I present a sample of over 300 unique hydrostatic cluster masses measured by XCS. The mass methodology is built into an open-source Python module, X-ray: Generate and Analyse (XGA), and as such is available for the community to use. Masses have been measured from *XMM* archival observations, and the clusters have been selected from the DESY3, SDSS, and ACT-DR5 cluster catalogues. Scaling relations with X-ray, optical, and Sunyaev-Zel'dovich observables are presented.

The NuSTAR Perspective on the Chandra/XMM-Newton Temperature Discrepancy in Galaxy Clusters

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Observations of many galaxy clusters with Chandra and XMM-Newton over two decades have consistently shown a roughly 10% discrepancy on average in the measured broadband temperature of the same clusters by the two missions. Despite its worse spatial resolution, the NuSTAR observatory provides a new way to probe this calibration difference, given its superior (and rising) effective area in the hard band, where the temperature is also more easily constrained due to the exponential drop in the continuum. We present a sample of global temperature measurements of clusters from the NuSTAR archive and compare them with those from Chandra, finding 10% lower temperatures with NuSTAR – which are in good agreement with XMM-Newton's measurements for those clusters. While the NuSTAR temperatures are consistent with the broadband temperatures from XMM-Newton, the NuSTAR spectra are inconsistent with both Chandra and XMM-Newton in the overlapping 3-10 keV bandpass. However, recent experimental updates to the XMM-Newton hard-band effective area alleviate this discrepancy with NuSTAR (by construction) and provide more internally consistent broad band single temperature fits to the XMM-Newton spectra alone. We demonstrate the implications of these results for cluster mass estimates and the inferred cosmological parameters from cluster abundance studies.

Chapter 20

Cosmology with Clusters of Galaxies

Probing modified gravity with eROSITA cluster sample

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Cosmological observations gradually challenge the ΛCDM model. One of the well-known tensions is the difference between the Hubble constant measured locally and the one extracted from the cosmic microwave background. Additionally, the large-scale structures usually measure an $S8$ parameter (a combination of the matter density and density fluctuations) smaller than the one inferred from the cosmic microwave background. Since we are entering the era of precision cosmology, it is time to start going beyond the standard model of structure formation. In this work, we focus on the most straightforward generalization of general relativity, namely the $f(R)$ gravity theory, specifically the Hu-Sawicki model. D'Agostino & Nunes, 2020 recently showed that this framework alleviates the $H0$ tension to a certain precision. We use the tremendous statistical power of the first data release of eROSITA's X-ray-detected clusters to probe this extension of general relativity. We investigate whether this could solve the H0 tension and potential departure from Einstein's theory.

The erosita X-ray angular power spectrum

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With the emergence of large-scale surveys, the clustering of galaxy clusters has proven to be an efficient additional probe to study different cosmological scenarios. Given the abundance of clusters and their spatial alignment are both sensitive the underlying cosmology, the use of clustering combined with the cluster abundance constitutes a powerful tool.

The X-ray angular power spectrum, while not requiring clusters selection function nor cluster masses, is sensitive to cluster astrophysics. It is then a promising probe to study cosmological tension, constraining simultaneously the cluster physics and the cosmological parameters.

With its large area and statistical power, the eROSITA survey will be at the forefront of cosmology. We propose to make use of the X-ray angular power spectrum using the first eROSITA All-Sky Survey.

Focusing on the possible systematics that will affect our measurements, such as exposure time inhomogeneities across the sky, we will present an analysis tool for clustering measurements and provide the first preliminary results obtained on the eRASS1 data.

This method will be used to perform a first independent cosmological inference of the cosmological parameters and subsequently allow a joint cluster count + angular power spectrum cosmological analysis.

New cosmological results from the XMM-XXL survey

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[11] *IRAP - Université de Toulouse - CNRS - UPS - CNES, Toulouse, France*
[12] *Argelander Institut für Astronomie - Universität Bonn, Bonn, Germany*

We present the latest results from the XXL survey, the largest XMM cluster programme. The XXL cosmological analysis performed so far, using a sample of 178 XXL clusters with a well-defined selection function, performs a forward modelling based on diagrams of X-ray instrumental observables. The ASpiX method bypasses any direct cluster mass calculation and consistently takes into account the effects of selection and of scaling relations. This allowed us to improve our previous results by a factor of two and provides constraints on σ_8 and Ω_m that rival the Planck-SZ cluster analysis, performed on a sample twice as large (Garrel et 2022).
We shall present the new XXL analysis, this time on the Dark Energy equation of state, by combining ASpiX and the cluster 3D spatial information. A thorough investigation of the remaining systematic errors allows us to pave the way for the future more ambitious X-ray cluster surveys (Garrel et al 2023, in prep).
Twenty-three years after the launch of XMM, XXL (and XCLASS) remain the only XMM serendipitous cluster surveys that provided cosmological constraints thanks to innovative and rigorous concepts at all stages of the data analysis.

Optical confirmation of eROSITA galaxy cluster candidates

Matthias Kluge[1], Johan Comparat[1], Jacob Ider Chitham[1], Esra Bulbul[1], Ang Liu[1], Vittorio Ghirardini[1], Emre Bahar[1], Fabian Balzer[1], Riccardo Seppi[1], Christian Garrel[1], Georg Lamer[1], Sebastian Grandis[2], Jeremy Sanders[1], Xiaoyuan Zhang[1], Emmanuel Artis[1]
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The primary goal of eROSITA is to constrain cosmological models using galaxy cluster number counts. This requires a large and clean sample of galaxy clusters with known redshifts. We run the red-sequence-based cluster finder eROMaPPer on the DESI Legacy Survey DR10 optical and NIR source catalogs. The search locations are fixed to eRASS1 extended sources. This results in 14000 photometric redshifts of the cluster candidates with high quality ($\Delta z/(1+z) \sim 0.005$) for $0 < z < 0.8$. The catalog is to be optically cleaned from contamination by AGNs, supernova remnants, and others using a mixture model, which compares the cluster properties to those of AGNs and random points in the sky. Simulations predict 50% contamination for the conservatively selected sample. For 20% of the clusters, we also measure spectroscopic redshifts and velocity dispersions based on a large collection of galaxy redshifts from the literature. Further optical properties are provided including richnesses, optical centers, and BCGs.

Redefining the isotropy of the local Universe with X-ray galaxy clusters

Konstantinos Migkas[1], Vardan Nazaretyan[2], Florian Pacaud[2], Thomas Reiprich[2]
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[2] *University of Bonn, Bonn, Germany*

The isotropy of the Universe at > 150 Mpc scales is a crucial assumption of LCDM. Any significant, observational deviation from this consensus can strongly challenge the standard cosmological model. X-ray scaling relations of galaxy clusters are an excellent, powerful tool to scrutinize cosmic isotropy. Several scaling relations with different cosmological dependencies can be built by measuring multiple X-ray cluster properties. The apparent angular variation of these relations provides us with numerous independent tests of cosmic isotropy. In Migkas et al. (2021) we detected a 9% anisotropy of the local Hubble constant (i.e. cosmic expansion rate) at a 5.4σ level. This anomaly can be attributed to a 900 km/s cluster bulk flow motion extending up to 500 Mpc. These results are in strong tension with LCDM. In this work, we build several new, more precise scaling relations by using XMM-Newton to measure the core-excised X-ray luminosity, gas mass, isophotal radius, and temperature of > 250 clusters. This new analysis confirms the previous findings, further boosting the statistical significance of the observed local anisotropy at unprecedented levels. Finally, we use the 1st eROSITA cluster catalog and show that, amazingly, eROSITA clusters independently detect the same anisotropy at the $z < 0.3$ Universe.

Chapter 21

Cosmology with AGN & Extragalactic Deep Fields

Searching for the warm-hot intergalactic medium using XMM-Newton RGS spectra

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The problem of missing baryons in the local universe remains an open question. One propose alternative is that at low redshift missing baryons are in the form of the Warm Hot Intergalactic Medium (WHIM). We present a detailed analysis of X-ray high-resolution spectra of six extragalactic sources, Mrk 421, 1ES 1028+511, 1ES 1553+113, H2356-309, PKS 0558-504 and PG 1116+215, obtained with the XMM-Newton RGS to search for signals of WHIM and/or circumgalactic medium (CGM) X-ray absorbing gas. First, we modeled the multiphase ISM including cold, warm and hot components. Then, we included an additional component to model the WHIM. We found no statistical improvement in the fits when including such component in any of the sources, concluding that we can safely reject a successful detection of WHIM absorbers towards these lines of sights. Our simulation shows that the presence of the multiphase ISM absorption features prevents detection of low-redshift WHIM absorption features in the ¿ 17 Åspectral region for moderate exposures using high-resolution spectra.

Comparing the ages of the host galaxies of obscured and uuobscured AGN

Ioannis Georgantopoulos[1], Ektoras Pouliasis[1], George Mountrichas[2], Arjen van der Wel[3], Stefano Marchesi[4], Giorgio Lanzuisi[4]
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We explore the properties of the host galaxies of X-ray-selected AGN in the COSMOS field using the Chandra Legacy sample and the LEGA-C survey VLT optical spectra. Our main goal is to compare the relative ages of the host galaxies of the obscured and unobscured AGN by means of the calcium break D_n(4000) and the H_δ Balmer line. Our sample consists of 50 unobscured or mildly obscured (N_H $< 10^{23}$cm^{-2}) and 23 heavily obscured AGN (N_H $> 10^{23}$cm^{-2}) in the redshift range $z = 0.6 - 1$.The majority of unobscured AGN appear to reside in young galaxies, in contrast to the obscured AGN which are found in galaxies located between the young and old galaxy populations.The host galaxies of the obscured AGN have significantly lower levels of specific star formation. Moreover, the obscured AGN have lower Eddington ratios, indicating a link between star formation and accretion onto the black hole. We compare our findings in COSMOS with those in the local Universe using the BAT AGN sample combined with SDSS spectra.

Number densities of X-ray point sources in the universe

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Limited by small areas of previous X-ray surveys, the number density of extragalactic X-ray point sources (AGN) is always considered uniform and only an averaged number counts distribution is measured. The full-sky survey of eROSITA opens a new window in X-ray astronomy, that is, the nonuniform number density map of point sources. At small scales, overdensities in this map could reveal the large scale structure of the universe. At large scales, this map provides an independent test of the isotropy of the universe, or in other words, the universe's potential dipole structure. We present a method of creating unbiased X-ray point source number density maps, which are corrected for bias caused by nonuniform exposure depth and Galactic absorption. Applying the method to eRASS:4, the 2-year eROSITA full-sky survey, we present the number density map of the eROSITA_DE hemisphere. Based on multi-band counterpart properties, we separate Galactic sources and AGN, and mainly focus on the latter. This map could also be used in AGN clustering analysis and tomography analysis.

Quasars as standard(isable) candles (and the physics behind)

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I will discuss what the perspectives of quasars in the context of observational cosmology are and I will present new measurements of the expansion rate of the Universe based on a Hubble diagram of quasars detected up to the highest redshift ever observed ($z \simeq 7.5$). Our cosmological measurements are based on a recent technique our group has developed, which employs the non-linear relation between the UV and the X-ray emission of quasars to gauge their distances. I will then present our latest results on the analysis of this non-linear X-ray to UV relation in a sample of optically selected quasars from SDSS, cross-matched with the most recent XMM-Newton and Chandra catalogues. I will show that this correlation is very tight, implying that the observed relation is the manifestation of an ubiquitous (but still unknown) physical mechanism, that regulates the energy transfer from the disc to the X-ray corona in quasars. I will finally show that the synergy amongst multi-wavelength facilities (current and future) will provide the needed sample statistics to obtain constraints on the cosmological parameters which will rival and complement those available from the other cosmological probes and study the dispersion of the X-ray-UV relation especially at $z = 4$ and beyond.

Large-scale Clustering of Buried X-ray AGN: Trends in AGN Obscuration and Redshift Evolution

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Large-scale clustering of active galactic nuclei (AGN) connects accreting supermassive black holes with their cosmological environments in order to constrain AGN unification and evolutionary models, as well as the AGN-galaxy co-evolution. Differences in the large-scale environments of unobscured and obscured AGN is still under a debate, and little is known about the Compton-thick AGN regime. We have compiled one of the largest X-ray selected AGN samples from existing 8 deep XMM/Chandra and multi-wavelength surveys in order to measure the clustering in terms of redshift $z < 3$ and AGN obscuration derived from X-ray spectral analysis, targeting for the first time also the highly obscured AGN with hydrogen column densities $> 10^{23.5}\,\mathrm{cm}^{-2}$. We have measured the projected two-point correlation function and the large-scale bias, and interpret it in terms of the typical dark matter halo mass. We find that the typical environments of highly obscured AGN resemble their less obscured counterparts, in agreement with simple AGN unified models. Within errors, the redshift evolution of the AGN bias follows a passive evolution track irrespective of obscuration, implying that for those AGN the clustering is mainly driven by the mass growth rate of the hosting halos and galaxies across cosmic time.

Chapter 22

Current and Future Missions

Athena, the next generation X-ray observatory: synchrotron facilities for the assembly and characterization of Silicon Pore Optics

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Athena is the next generation X-ray observatory from the European Space Agency to be launched in the mid-2030s. It uses a unique modular technology to realize its 2.5 m diameter optics made of several hundreds co-aligned mirror modules. The telescope has a Wolter-Schwarzschild design with a 12-m focal length, aiming to give 1.4 m2 of effective area with a point spread function of 5" half-energy width at 1 keV and an energy range of 0.2 to 12 keV. For this new technological challenge, Silicon Pore Optics (SPO) has been developed using the highest-grade double-side polished 300 mm wafers commercially available. The mirror modules are assembled and characterized using beamlines at synchrotron radiation facilities. In this work, we present an overview of the work carried out at the X-ray Pencil Beam Facilities (XPBF1 & XPBF2) of the PTB at BESSY II (Berlin, Germany) and, in the near future, MINERVA at ALBA (Barcelona, Spain). The new beamline is planned to be operational during 2023.

Cosmology, fundamental physics and and Multi-Messenger Astrophysics with next generation GRB missions

Lorenzo Amati[1]
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The huge luminosity, the redshift distribution extending at least up to z 10 and the association with the explosive death of very massive stars make long GRBs extremely powerful probes for investigating the early Universe (pop-III stars, cosmic re-ionization, SFR and metallicity evolution up to the "cosmic dawn") and measuring cosmological parameters. At the same time, as demonstrated by the GW170817 event, short GRBs are the most prominent electromagnetic counterpart of gravitational-wave sources like NS-NS and NS-BH merging events, and both long and short GRBs are expected to be associated with neutrino emission. Moreover, the combination of extreme distances, huge number of photons emitted over wide photon energy range and the variability down to few ms makes these phenomena a promising tool for performing tests of fundamental physics like Lorentz Invariance Violation (LIV). I will review the status, concept and expected performances of space mission projects like THESEUS aiming at fully exploiting these unique potentialities in great synergy with the large facilities of the future (e.g., LSST, ELT, TMT, SKA, CTA, ATHENA in the electromagnetic domain, Einstetein Telescope in and km3NeT in GW and neutrino domains, respctively).

Analysis of minimum ionising particles and soft protons using XMM-Newton EPIC pn-CCD as a particle detector

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Spacecrafts with imaging telescopes often carry a charge coupled device (CCD) in their focal plane to detect electromagnetic radiation. Charged particles such as electrons, protons, and heavy ions can reach the CCD and deposit their energy in the detector material. To counteract this undesirable effect, algorithms are usually implemented to reject them. CCDs can also be seen as particle detectors. Even though rejection algorithms are often active to immediately discard undesired radiation, data including charged particles of XMM-Newton and Gaia were stored over the whole mission lifetime. We primarily analyse and characterise the charged particles that were detected by XMM-Newton. A comparison to data from Gaia is also presented. To characterise the particle flux in the spacecraft orbits we used all publicly available observations where no rejection algorithm was used in combination with observations where the rejection algorithm was used. The particle flux is analysed over time and space of the XMM-Newton orbit. Our analysis shows that the rate of charged particle events has a modulation of about 11 yr and that particle flux and solar activity are anti-correlated. Moreover, we also show that often more than one charged particle hits the CCD simultaneously. Published in A&A 670, A78 (2023)

X-ray mirror coating performance of newAthena

Desiree Della Monica Ferreira[1]
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We present an overview of the development of the X-ray reflective coatings for the NewAthena mission based on the latest mission concept reported by the Science Re-definition Team (SRDT). Along with optimised expected performance based on single layer, bi-layer, tri-layer and multilayer coating designs, we also report on the latest experimental results on X-ray performance of the coatings deposited onto SPO plates.

The High Energy X-ray Probe (HEX-P)

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[1] *California Institute of Technology, Pasadena, CA, USA*
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HEX-P is a Probe-class mission concept that will combine high spatial resolution X-ray imaging (¡10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR), to enable revolutionary new insights into a variety of important astrophysical problems. With this leap in observational capability, HEX-P will be capable of addressing fundamental questions about the extreme environments around black holes and neutron stars, map the growth of supermassive black holes, and quantify the effect they have on their environments. HEX-P will resolve the hard X-ray emission from dense regions of our Galaxy and nearby galaxies to understand the high-energy source populations, and investigate dark matter candidate particles through their decay channel signatures. We present the baseline mission design and core science pillars. More information on HEX-P, including the full team list, is available at https://hexp.org.

The High Energy X-ray Probe (HEX-P): Probing the Power of Accreting Compact Objects

Javier Garcia[1], Dominic Walton[2], Dan Wilkins[3], John Tomsick[4], Riley Connors[5], Renee Ludlam[6], Katja Pottschmidt[7], Matteo Bachetti[8], Matt Middleton[9], Suvi Gezari[10], Thomas Wevers[11], Lea Marcotulli[12], Marco Ajello[13], Guglielmo Mastroserio[8], The HEX-P Team[14]
[1] *Caltech, USA*
[2] *University of Hertfordshire, UK*
[3] *Stanford University, USA*
[4] *UC Berkeley/SSL, USA*
[5] *Villanova University, USA*
[6] *Wayne State University, USA*
[7] *UMD Baltimore, USA*
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[9] *University of Southampton, UK*
[10] *UMD, USA*
[11] *ESO, Chile*
[12] *Yale University, USA*
[13] *Clemson University, USA*
[14] *NASA/JPL, USA*

HEX-P is a probe-class mission concept that will combine high spatial resolution X-ray imaging (¡10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR), to enable revolutionary new insights into a variety of important astrophysical problems. Given their copious emissions in the X-ray band, accreting compact objects are some of the primary targets of HEX-P. We present a broad range of new exciting science that will be accessed by exploiting the superior capabilities of HEX-P's design. This includes studies of spin distributions for supermassive and stellar-mass black holes (including ultraluminous X-ray sources); accreting neutron stars, their magnetic fields and equations of state; characterization of tidal disruption events in X-rays; broadband spectroscopy of blazars; and spectral-timing analysis in general. More information on HEX-P, including the full team list, is available at https://hexp.org.

The High Energy X-ray Probe (HEX-P): Resolved X-ray Populations in Extragalactic Environments

Bret Lehmer[1], Breanna Binder[2], Francesca Fornasini[3], Kristen Garofali[4], Ann Hornschemeier[4], Margaret Lazzarini[5], Toni Venters[4], Neven Vulic[4], Dan Wik[6], Mihoko Yukita[4], Andreas Zezas[7], Hannah Fritze[6], Kaya Mori[8], Javier Garcia[5], Daniel Stern[9]
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[2] *California Polytechnic State University, San Luis Obispo, CA, USA*
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[9] *NASA JPL/Caltech, Pasadena, CA USA*

HEX-P is a probe-class mission concept that will combine high spatial resolution X-ray imaging (¡10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR) to enable revolutionary new insights into a variety of important astrophysical problems. We will present simulations of HEX-P observations of a variety of extragalactic environments (e.g., normal, starburst, and passive galaxies) to demonstrate the power of the HEX-P observatory. We will show that HEX-P will (1) provide unique information about X-ray binary populations in external galaxies, including accretor demographics (black hole and neutron stars), accretion state distributions, and cadences of state transitions; (2) detect and characterize, for the first time, inverse Compton emission associated with particle accelerations in starburst environments; and (3) put into clear context the contributions from X-ray emitting populations to both ionizing surrounding interstellar mediums in low-metallicity galaxies and heating the intergalactic medium in the z ¿ 8 Universe. More information on HEX-P, including the full team list, is available at hexp.org.

The International Astronomical Consortium for High Energy Calibration (IACHEC)

Kristin Madsen[1], Catherine Grant[3], Matteo Guainazzi[4], Vinay Kashyap[5], Herman Marshall[3], Lorenzo Natalucci[6], Eric Miller[3], Paul Plucinsky[5], Yukikatsu Terada[7], Karl Forster[2]
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[7] *University of Saitama*

The International Astronomical Consortium for High Energy Calibration (IACHEC) was founded in 2006 and has since then been annually hosting a workshop attended by calibration scientists from all high-energy observatories. The IACHEC provides standards for high energy calibration and conducts cross calibration between different missions. Organized into working groups, IACHEC members cooperate to define calibration standards and procedures. The scope of these groups is a practical one: data and results published in refereed journals coming out of a coordinated and standardized analysis of references sources ("high-energy standard candles"). Past, present and future high-energy missions can use these results as a calibration references. In addition, the IACHEC strives to research and promote best practices in data analysis of high energy data.

Advanced X-ray Imaging Satellite (AXIS)

Eileen Meyer[1], on behalf of AXIS Team[2]
[1] *University of Maryland, Baltimore County*
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The Advanced X-ray Imaging Satellite (AXIS) is a probe-class concept that will extend and enhance the science of high angular resolution X-ray imaging and spectroscopy in the next decade with a 1” angular resolution over a wide 24’x24’ field of view and an order of magnitude more collecting area than Chandra in the 0.3-12 keV band, while providing rapid response capabilities for transients and gravitational wave sources. AXIS will open new windows on the hot and dynamic Universe revealing the birth and early growth of supermassive black holes, their impact on galaxies, and the drivers behind the most powerful and diverse explosive events in the Universe, and the aftermath on diversity of compact stellar remnants. With a nominal early 2030s launch, AXIS benefits from natural synergies with the WFIRST, ELTs, LSST, SKA, ALMA, ATHENA, and CTA. AXIS utilizes breakthroughs in the construction of lightweight X-ray optics from mono-crystalline silicon blocks, and developments in the fabrication of large format, low noise, high readout rate detectors allowing a robust and cost-effective design. This poster will give an overview of the AXIS mission and instrumentation and highlight exciting science cases.

Advanced X-ray Imaging Satellite (AXIS)

Eileen Meyer[1], AXIS Team[2]
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XMM-Newton: Scientific Strategy and Prospects

Norbert Schartel[1]
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With about 380 refereed papers published each year, XMM-Newton is one of the most successful scientific missions of ESA ever. The talk discusses aspect of the scientific strategy behind this success of XMM-Newton and scientific observing perspectives for the next years.

Constraining Physics Beyond the Standard Model with Current and Future X-ray Observatories: A case for Axion-Like Particles

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Axion-Like Particles (ALPs) are predicted by string theories and are promising dark matter candidates. In the presence of a magnetised plasma, photons may inter-convert into ALPs of mass m as determined by the photon-ALP coupling strength g. X-rays from bright cluster-hosted AGNs should therefore undergo photon-ALP conversion as they travel through the magnetised ICM, resulting in energy-dependent irregularities or “wiggles” in the spectrum. This can be used to place bounds on g for very-light ALPs, of masses $\log(m/\mathrm{eV}) < -12$, given a model for the ICM magnetic field. I will first present the current most sensitive bounds on g for very-light ALPs from *Chandra* transmission grating observations of the luminous cluster-hosted quasar H1821+643. Using a cell-based cluster field model, our results are most sensitive to assumptions on plasma beta. I will then introduce the exciting projected ALP bounds from *Athena*/X-IFU observations of NGC1275 in the Perseus cluster, given its unprecedented spectral resolution and collecting area compared to current spectroscopic X-ray missions. We have tested the potential impact of detector miscalibration via a novel machine learning technique that disentangles between ALP- and miscalibration-induced “wiggles”. Finally, I will present projected constraints on ALPs from the probe-class *AXIS* mission, also expected to improve from the current best limits.

New features in the XMM-Newton serendipitous source catalogues from overlapping observations

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Since the early 2000s, the XMM-Newton Survey Science Centre publishes catalogues of serendipitous sources detected in all public XMM-Newton observations. For the meanwhile more than 30% multiply covered XMM-Newton sky area, we develop and compile dedicated stacked catalogues on a yearly basis, performing simultaneous source detection in all overlapping observations. They are more sensitive to faint sources than detection runs on individual observations, and they provide information on long-term variability derived directly from the source-detection parameters. With the most recent versions, we have introduced additional measures of flux variability and additional flux measurements from PSF photometry on lower-quality data which are not suited for source detection. Here, we present the 2023 edition of the stacked catalogue: 4XMM-DR13s.

The next frontier in galaxy surveys: monitoring and wide area surveys with STAR-X

Andreas Zezas[1], Ann Hornschemeier[2], Antara Basu-Zych[3], Mihoko Yukita[4], William Zhang[2], Edmund Hodges-Kluck[2], STAR-X Team[5]
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The Survey and Time-domain Astrophysics Research eXplorer (STAR-X) is a MIDEX-class mission selected for a NASA Phase-A study. It features a combination of wide-field, sensitive, high spatial resolution X-ray and UV telescopes, and the ability for cadenced surveys and fast response observations. I will present the capabilities and science goals of STAR-X, focusing on the wide-area surveys and monitoring observations of a representative sample of nearby galaxies. The latter will provide the first systematic constraints on the duty cycles of X-ray binaries in different galactic environments. The wide area surveys will give a sensitive census of the X-ray luminosity of galaxies as a function of their star-formation rate, stellar mass, metallicity, and age, from the local universe up to intermediate redshifts. These surveys will be 10-50 times deeper than the eROSITA survey, reaching the sensitivity of the Chandra Deep Field surveys. I will discuss the scientific leaps in our understanding of compact-object populations and their cosmological evolution enabled by this new era of X-ray and UV surveys, and their implications for compact object mergers and the role of X-ray binaries in the epoch of reionization.

The Growth and Seeding of Supermassive Black Holes in the Early Universe with AXIS

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The Advanced X-ray Imaging Satellite (AXIS) probe, with its unprecedented X-ray imaging sharpness over a large field of view, provides two order of magnitudes improvement in survey grasp with respect to Chandra. With this powerful combination of depth and field of view, AXIS will extend our knowledge of supermassive black hole (SMBH) growth up to $z \sim 10$ and beyond, peering into the epoch of SMBH seeding and growth. By combining AXIS data with spectro-photometric surveys collected by the Roman, Euclid and JWST observatories we will be able to both complete the census of all AGN at $z < 6$ and compare the newfound high-z X-ray luminosity function with AGN seeding models. AXIS will be the state of art "survey machine" of the 2030's and will perfectly complement NASA efforts to study the epoch of the first light.

Chapter 23

Analysis and related software (e.g. SAS, xspec)

Massive spectral fitting of XMM-Newton spectra

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The pipeline processing of all XMM-Newton observations extracts automatically spectra for over a third of the detected sources, amounting to more than 300000 spectra for 4XMM-DR11.

As part of the Horizon 2020 project XMM2ATHENA, we have prepared four deliverables exploiting this huge resource.

Our first deliverable (D6.1) includes fits to all individual detection spectra (after some quality filters) with a simple absorbed powerlaw model.

Taking advantage of the repeated observations in some parts of the sky (parallel to the stacked catalogue 4XMM-DR11s), we have combined all spectra belonging to the same physical source, fitting absorbed powerlaw and absorbed black body models to the combined spectra (D6.2).

In order to get spectral information for all detections, even for those without extracted spectra, we have used the 5 band countrates from the 4XMM-DR11 catalogue as low resolution spectra, finding the best fit of an absorbed powerlaw to then (D6.3).

Finally, taking advantage of the identifications and photometric redshifts provided by other parts of the project, we have also fitted physically-motivated spectral models to the sources with good identifications (D6.4).

We will present the deliverables and highlight some preliminary scientific results.

Preparing the SPEX spectral fitting package for the next generation of high-resolution spectrometers

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SPEX is a spectral fitting package optimized for high-resolution spectroscopy. It has been developed since the 1990's and was based on the popular MEKAL code. In the last decade, we expanded the atomic database, added new models and improved the user experience. A new 3D model for clusters of galaxies and a time-dependent non-equilibrium photo-ionization model are two of the most recent additions. Like most of the SPEX models, the software provides several output options for plasma parameters like, for example, ionization balance, transition rates, and line lists, which enables advanced interpretation of the plasma properties. A Python interface is added, allowing users to control and get data from a SPEX session, which makes scripting much easier. This year, we expect to release SPEX version 4. This version will have a modular setup with documented libraries, enabling the integration of SPEX in other software. With the upcoming launch of XRISM, we will have a very capable spectral fitting tool to interpret the upcoming high-quality spectra from Resolve, but also the existing high-resolution grating spectra of XMM-Newton and Chandra.

Spatially variant point spread function removal in X-ray observations

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During the measurement of photon counts, X-ray observatories leave unwanted effects in the data, which should be removed accurately. Some detector effects can be inverted easily, while others are not trivially invertible such as the point spread function and the shot noise. Using information field theory the posterior mean and uncertainty for the X-ray flux can be inferred using prior knowledge about the involved physics and the information about the instrument thereby removing these detector effects. The spatial variability of point spread functions increasingly degrades the resolution of the data with increasing off-axis angle. Approximating the true point spread function of the instrument by an interpolated and patched convolution makes it possible to retrieve a fast and accurate representation of it as part of a numerical instrument model, which can be used within a Bayesian imaging algorithm. Due to the incorporation of the spatial variability of the point spread function also far off-axis events can reliably be taken into account, increasing the signal to noise ratio. This reconstruction method is demonstrated using a series of observations of the Perseus galaxy cluster taken by Chandra X-ray Observatory.

Keywords: spatially variant point spread functions; X-ray imaging; information field theory; Perseus galaxy cluster;

Towards Automatic Point Source Detection

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For a deep understanding of the X-ray universe, it is crucial to rely on complete and accurate information on its primary constituents. These constituents, such as active galactic nuclei, galaxies, and other compact objects show distinct features in the sky and therefore imprint differently on astronomical data. In this work, we leverage these differences to construct statistical models for their a priori independent distributions in the sky. This not only enhances the overall observation reconstruction, but also allows to segregate the flux of the various components that populate the sky and more accurately study their individual features. Specifically, we introduce a new technique that uses a notion of model stress to automatically separate point-like sources from diffuse, correlated structures. We showcase our results on publicly available X-ray data.

Studying X-ray variability with the EPIC XMM Outburst Detector Ultimate System (EXODUS)

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XMM-Newton has a high sensitivity, and the EPIC instruments possess good temporal resolution that enable the recording of rapid X-ray transients. However, the current pipeline is designed to extract lightcurves and search for variability only for sources with at least 100 EPIC counts. Since almost 2/3 of the sources have EPIC counts below this threshold, their variability is not calculated. Further, very faint sources showing very short variability may be difficult to detect.

To address this, we developed EXODUS, an algorithm that identifies variability in the whole EPIC field of view irrespective of source detection and counts. It accomplishes this by binning the observations into short time windows and comparing pixel counts per window to the median pixel counts to detect variable sources within the observation, making EXODUS computationally inexpensive. By applying EXODUS to all observations composing the 4XMM-DR11 catalogue, we identified a diverse range of variable sources, including new sources, HMXB, LMXB, ULXs, and others. Our study revealed a large number of faint variable sources, and we show that running EXODUS to search for short term variability helps to detect low-mass AGN. We present the algorithm, some of the results, and analysis of some of the variable AGN.

SAS future plans and dreams

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The XMM-Newton Science Analysis Software (SAS) is the application used for processing the data obtained with the scientific instruments on board XMM-Newton, an indispensable tool that has been helping scientists in the publication of nearly all refereed scientific papers published up to date. SAS is a robust software that has allowed users to produce good scientific results since the beginning of the mission. This has been possible given the SAS capability to evolve from a stand-alone to a SaaS (Software as a Service) application and adapt to the needs of the scientific community.

The SaaS version of SAS is called RISA (Remote Interface for Science Analysis). It is offered to the scientific community through the XMM-Newton Science Archive interface. The RISA web service is currently used by approximately 100 external users, submitting around 1200 request per year. During 2021, the RISA system was migrated to Amazon AWS services, probing the potential scalability of the system. RISA-AWS prototype is ready to be deployed in any public or private cloud environment.

The XMM-Newton project is currently working in the adaptation of the SAS application to the new ESA Datalabs infrastructure adding a new suite of SAS-Python functionalities.

Machine-learning classification of X-ray sources in the era of modern X-ray observatories: lessons and challenges.

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The rapidly growing volume of multiwavelength data demands automated classification of numerous sources that are being constantly discovered. Machine Learning (ML) appears to be the only feasible approach to learning about the astrophysical nature of millions of unclassified sources stored in large catalogs such as those produced by current and future X-ray observatories. We present the current state of our automated multiwavelength ML classification pipeline (MUWCLASS) which relies on supervised learning. Over the course of several years, we have compiled two training datasets of X-ray sources (one based on 4XMM-DR12 and the other on CSCv2) with reliably determined astrophysical types. We describe the content of these datasets and ways to access and utilize them. We also describe the workflow of MUWCLASS which uses up to 29 multiwavelength features per X-ray source to perform probabilistic prediction of the X-ray source nature after accounting for the measurement uncertainties of the features used in classification. We also discuss the impact of cross-matching uncertainties onto the accuracy of classifications, which is particularly important for galactic sources detected by XMM-Newton and eROSITA. Finally, we make a pitch for creating the "living" database of reliably classified X-ray sources which can serve as an ultimate training dataset.

A new perspective of the hard X-ray sky

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The origin of the Cosmic X-ray Background (CXB) is mainly related to the integrated emission of active galactic nuclei (AGN). To obtain a precise estimate of the contribution of different AGN classes it is thus crucial to obtain a full characterization of the hard X-ray sky. Here a multi-frequency analysis of all sources listed in the 3rd release of the Palermo Swift-BAT hard X-ray catalogue is presented. A classification scheme, based on radio, infrared and optical datasets, allowed us to distinguish unidentified and unclassified hard X-ray sources, as well as to classify those belonging to both the Galactic and the extragalactic sky. The refined analysis of the 3PBC lists 1176 classified sources, 820 belonging to the extragalactic sky, mainly Seyfert galaxies, while 356 lying in our Galaxy. Then there are 199 unclassified and 218 unidentified sources. Finally, results achieved on SWIFT follow up X-ray analysis of nearly 200 unidentified hard X-ray sources, for a total of more than 1200 observations (i.e., 1.8 Msec) reduced, will be also presented.

How far are you? A new tool for automated redshift estimation from X-ray spectra of AGN

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In extragalactic X-ray surveys, spectroscopic redshift extraction is an expensive process. Our aim is to develop an automated algorithm to extract redshifts from X-ray AGN spectra alone.

Signatures of reflection are ubiquitous in X-ray spectra. And one such important feature is the Fe-Kα line at 6.4 keV rest frame energy. By employing appropriate mathematical tools, proper continuum subtraction/modeling, and correcting for instrument artifacts, we can identify the energy at which the Fe-Kα line is present. With this information, the redshift of the object can be obtained directly.

Realistic simulations are needed to test and develop the algorithm. For this purpose, we have used NuSTAR and a clumpy torus model and identified 26 representative sets of parameter combinations by employing a holistic approach. These representative sets are then used for performing realistic simulations with Athena/WFI matrices. Simulations were carried out with different exposure times for the redshift range z = 1 - 4 and luminosity range $LX_{2-10keV} = 10^{43} - 10^{45}$ ergs/s.

We have developed an automated algorithm employing novel noise-filtering and sophisticated feature detection techniques. We will report on the preliminary results of the performance of our newly developed method on the simulations.

Polarised reflection: Creating polarised XILLVER tables

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The results from recent IXPE observations suggest that the X-rays reflected off accretion discs form an important contribution to the polarisation spectrum seen from accreting systems. This poster will showcase the latest work to expand the X-ray reflection code XILLVER to solve the radiative transfer problem with the addition of polarisation information, to produce tables of the polarised reflection spectra.

Streamlining Multiple X-ray Telescope Analyses with DAXA and XGA

Jessica Pilling[1]
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Soon (May 2023), observations comprising the eROSITA All-Sky Survey (eRASS) will be publicly released. In this poster, we will detail our efforts at incorporating eROSITA Calibration and Performance Validation observations, with the view to shortly include eRASS-1, into DAXA and their subsequent analysis by XGA. Both DAXA (Democratising Archival X-ray Astronomy) and XGA (X-ray: Generate and Analyse, Turner et al., 2022) are open source Python modules shielding the user from the wearisome interactions with various telescope specific software, thereby streamlining X-ray analysis pipelines and making the generation of advanced X-ray data products accessible to astronomers unfamiliar with X-ray analysis. Furthermore, the compatibility of XGA and DAXA with eROSITA and XMM will facilitate the collation of X-ray data from both missions, thus making multi-telescope analysis an uncomplicated and standardised process. The adoption of this software will enable the science of the hot and energetic universe to become available to a plethora of scientists, and encourage the analyses of sources using multiple X-ray telescopes.

STATiX: A source detection pipeline for X-ray transients

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The recent serendipitous discovery of a new population of short duration X-ray transients has motivated efforts to build up statistical samples by mining X-ray telescope archives. Most searches to date however, do not fully exploit recent developments in the signal and imaging processing research domains to optimise searches for short X-ray flashes. We present a new source detection pipeline, STATiX (Space and Time Algorithm for Transients in X-rays), which directly operates on 3-dimensional X-ray data cubes consisting of two spatial and one temporal dimension. The algorithm leverages wavelet transforms and the principles of sparsity to denoise X-ray observations and then detect source candidates on the denoised data cubes. The light curves of the detected sources are then characterised using the Bayesian blocks algorithm to identify flaring periods. We describe the implementation of STATiX in the case of XMM-Newton data, present extensive validation and performance verification tests based on simulations and also apply the pipeline to a small subset of seven XMM-Newton observations, which are known to contain transients sources.

Status report of the Science Analysis System

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We present a summary of the status of the XMM-Newton Science Analysis System (SAS) and the contents of the recent SAS v21 release. SAS has traditionally been released to the community as a set of operating-specific binaries. We discuss the challenges involved with also making the full source code available with each SAS release and look at the details of how builds can be made more robust by removing dependencies on third-party software.

Pushing the limits of XMM-Newton source detection: XMM2ATHENA WP4 "The enhanced stacked catalogue"

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The EU Horizon 2020 program XMM2ATHENA explores new methods, software, and science from XMM-Newton data, aiming at moving on to the next X-ray and multi-messenger facilities. Its work package 4, named "The enhanced stacked catalogue", has implemented a new source-detection scheme on XMM-Newton observations to improve sensitivity towards the faintest X-ray sources. Assuming constant flux over all observations in the first place, a newly created collection of energy conversion factors is used to determine and fit the observed photons and the main spectral parameters of the source. Potential long-term variability is accounted for in separate PSF photometry on all detected sources. The first proto-catalogue from selected overlapping observations shows the potential of the new approach.

The eROSITA Upper Limits

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The X-ray telescope eROSITA on board the Spectrum-Roentgen-Gamma (SRG) observatory has successfully completed four of the eight planned all-sky surveys, detecting more than one million X-ray sources during the first scan. However, many more sources are hidden below the source detection limit. For sources that are detected at wavelengths other than X-rays, X-ray flux upper limits can be crucial to understand their physical and statistical properties. Thus, the eROSITA upper limits can contribute to significant scientific goals such as long-term X-ray variability, the search for transients, and timing analysis. We provide a detailed description of the process of retrieving SRG/eROSITA upper limits for a large set of input positions, as well as of the eROSITA data, the X-ray aperture photometry, the upper limit calculation via a Bayesian approach, and the final data products. We also characterize the architecture of the database and the web tool, which are designed to handle large queries of input positions. This is the first time that the eROSITA upper limits will be presented to the community, as they are part of the official first German eROSITA all-sky survey (eRASS1) data release.

XGA and DAXA: Opening up X-ray astronomy with powerful, easy-to-use, tools

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Analyses of X-ray observations are challenging, but enormously beneficial to the study of many objects. Also, serendipitous science is possible for many sources, by using the large archives of various X-ray telescopes. Unfortunately though, data challenges can be a barrier to entry that limit their use outside expert working groups. I describe my attempt to make X-ray astronomy easier, an open-source, generalised, Python module, X-ray: Generate and Analyse (XGA), which can perform complex analyses on sources observed by *XMM* or *eROSITA* (more telescopes supported soon). XGA uses a 'source based' paradigm, where astrophysical objects have equivalent Python objects, with physical properties such as position, size, and redshift. XGA identifies and processes relevant observations automatically, and provides powerful interfaces with common data products such as images and spectra. I also introduce another Python module; Democratising Archival X-ray Astronomy (DAXA). This module allows the creation of multi-mission archives of X-ray data, either for every observation of an X-ray telescope, or only those of interest to the user. The acquisition and processing of data for different missions is made consistent and given a Python interface, enabling access for novice X-ray astronomers whilst preserving low-level control for experts.

Bayesian Spatio-spectral Imaging of SN1006

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The supernova remnant SN1006 has been extensively studied by various instruments and telescopes, due to its historical record, proximity, and brightness. To accurately study the properties of the remnant itself, it is essential to isolate its emission from that of other sources in the field. Here, we present a spatio-spectral image reconstruction method based on information field theory which allows to effectively separate the signal into two components: diffuse emission and point-sources. Leveraging prior knowledge about the spatial and spectral correlation structure of these components, our method provides a detailed and denoised view of SN1006. To enhance the accuracy and efficiency of the imaging process, we initiate the image reconstruction using only a small spectral range and use this as the starting point for the subsequent full spatio-spectral reconstruction. We apply the method to the latest, merged Chandra data on SN1006, providing a high-quality visualization of its complex features.

Keywords: SN1006, information field theory, X-ray imaging, Bayesian imaging, spatio-spectral reconstruction, component separation

Chapter 24

TDE/QPE

Accretion disc alignment process breaking the UV/X-ray coupling in a tidal disruption event

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A star can be tidally disrupted by a black hole as a tidal disruption event (TDE). As the stellar orbit is likely to be mis-aligned with the plane perpendicular to the black hole spin, a tilted accretion disc can form initially. In this talk, I will discuss the observational evidence of an accretion disc alignment process that follows the tilted disc formation and is theoretically predicted long-time ago. I will highlight how the accretion disc alignment process can de-couple the UV and X-ray lightcurves in a TDE, resulting in X-ray flares at early times. With a growing effort in the community to study the mass and the spin of black holes through TDEs, I will discuss the impact of the disc alignment process on measuring those black hole parameters in TDEs.

The remarkable quasi-periodic eruptions in RX J1301.9+2747

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RX J1301.9+2747 ($z = 0.024$) is the second galaxy where X-ray quasi periodic eruptions (QPEs) have been discovered. Belonging to a small group of galaxies at the edge of the Coma Cluster, RX J1301.9+2747 is a young post-starburst galaxy harboring a nuclear stellar cluster and a supermassive black hole with low mass, $M_{BH} < 5 \times 10^6\, M_\odot$. It is active in X-rays since at least 40 years, and displays QPEs since at least 22 years. The QPEs in RX J1301.9+2747 have a duration comparable to those of the QPE discovery source GSN 069, but their pattern of repetition is much more enigmatic; instead, a bimodality in QPE intensity and a pattern of alternating shorter/longer QPEs are observed. I will discuss the results of the latest observational campaign on RX J1301.9+2747 comprised of three XMM-Newton orbits, each coordinated with 10 hours of VLA radio observations, in the context of the physics of massive black hole accretion, tidal disruption events, and extreme mass ratio inspirals in galactic nuclei.

Discovery of the extremely luminous X-ray ignition eRASSt J234402.94−352640

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eRASSt J234402.9-352640 was discovered as a new, bright object in the second all-sky survey of SRG/eROSITA. The object brightened by a factor of at least 150 in 0.2-2.0 keV flux and reached a 0.2-2 keV peak luminosity of log(Lbol[erg/s])=44.7, making it the most luminous X-ray transient detected in the German half of the eROSITA sky. The transient X-ray emission is associated with a host galaxy at z=0.1, which showed an optical brightening of ∼3 mag around the time of the X-ray discovery. I will present the results of our multiwavelength follow-up campaign, including data from XMM-Newton, Swift, and NICER, as well as optical spectroscopy. The X-ray data reveal a very soft spectrum, with significant flux variability on multiple timescales. The optical spectra show a blue continuum with broad, asymmetric Balmer emission lines as well as narrow emission lines. The event displays characteristics of a TDE as well as of AGN. I will show that the observed properties best match a TDE within a low-luminosity or turned-off AGN.

A repeating partial tidal disruption events discovered by eROSITA

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During its first two years of the All-Sky Survey, SRG/eROSITA uncovered a large sample of X-ray transients associated with the nuclei of quiescent galaxies. In this talk, I will highlight one exceptional repeating nuclear transient eRASSt J045650-203751 discovered by SRG/eROSITA. Extensive monitoring with XMM-Newton, Swift, and NICER revealed four repeating X-ray/UV flares and repeating transient radio emission. This makes J0456-20 a promising repeating partial Tidal Disruption Event (pTDE) candidate. A detailed analysis of the available data shows that the characteristic X-ray variability for each flare can be best explained by the accretion state transitioning between the thermal and the steep power-law states, accompanied by the formation and destruction of the coronae. This indicates that similar accretion processes are at work across a broad range of BH masses and accretion rates and that the corona can be formed and destructed within a few weeks to months. I will also present evidence of a potential evolution of the recurrence time of the flares, hinting at a change in the orbital period of the stellar remnant. This highlights the role of repeating pTDEs as effective probes of the stellar dynamics around supermassive BHs beyond our Galaxy.

From X-rays to physical parameters: a comprehensive analysis of thermal tidal disruption event X-ray spectra

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I will present results of a comprehensive analysis of a population of 19 X-ray bright tidal disruption events (TDEs), fitting their X-ray spectra with a new, physically self-consistent, relativistic accretion disc model. Physically interpretable parameters for a subsample of 11 TDEs are determined. The radial sizes measured from these spectra lie at values consistent with the innermost stable circular orbit of black holes with masses given by the M-sigma relationship, and can be used as an independent measurement of MBH. The bolometric disc luminosity can also be inferred from X-ray data. All of the TDEs have luminosities that are sub-Eddington (Lbol, disc less than Ledd), and larger than the typical hard-state transitional luminosity of X-ray binary discs (Lbol, disc greater than 0.01Ledd). The peak bolometric luminosity is found to be linearly correlated with the M-sigma mass. The TDE X-ray-to-bolometric correction can reach values up to 100, and grows exponentially at late times, resolving the missing energy problem. Finally, we also show that the peak disc luminosities of some TDEs are smaller than their observed optical luminosities, implying that not all of the early time optical emission can be sourced from reprocessed disc emission.

Tidal Disruption Events with eROSITA and XMM-Newton

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Thanks to its unique observing strategy and sensitivity, the eROSITA instrument onboard SRG provides a treasure trove for uncovering many X-ray transients. In my presentation, I will describe our systematic search for transients associated with the centres of otherwise dormant galaxies, particularly candidate Tidal Disruption Events (TDEs), in the German half of the eROSITA sky. I will summarise the sample selection aimed at deriving a luminosity function for X-ray-detected TDEs. In addition, I will present some of the spectacular findings made by eROSITA and enabled mainly by our follow-up observations with XMM-Newton, Swift, and NICER, which emphasise the extreme diversity of observational properties among the nuclear transient population. Highlights include the puzzling double-peaked nature of AT2019avd (Malyali et al. 2021), the first detection of a new class of "slow and faint" TDE (Malyali et al. 2023a) and their link to prompt accretion disk formation, and two repeating partial TDEs with drastically different recurrence time scales (Liu et al. 2023, Malyali et al. 2023b).

Searching for supersoft sources: TDEs hiding in the XMM catalogue

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Tidal disruption events (TDEs) occur when a star is torn apart by the powerful gravitational force of a massive black hole. These events are typically identified through their transient nature at X-ray or optical wavelengths and are characterized by a unique "super-soft" X-ray emission. To search for TDEs, we cross-correlated optical and X-ray catalogues and we looked for near-nuclear extragalactic sources with very steep X-ray spectra (photon index > 3) and high luminosities ($L\_X > 10^{41}$ erg/s). Our search retrieved about 60 sources, with 15 of them being previously known TDEs or supersoft AGN. 36 sources were classified as standard AGN based on their optical properties, while the remaining nine sources showed spectral properties consistent with TDEs or extremely soft-excess dominated AGN. In this talk, I will present these nine peculiar and interesting sources with a particular focus on the four most-convincing candidate TDEs: these represent the first ever spectroscopically discovered TDEs in the X-ray band.

Live to die another day: the rebrightening of AT2018fyk as a repeating partial tidal disruption event

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Stars that interact with supermassive black holes (SMBHs) can either be completely or partially destroyed by tides. In a partial tidal disruption event (TDE) the high-density core of the star remains intact, and the low-density, outer envelope of the star is stripped and feeds a luminous accretion episode. The TDE AT2018fyk experienced an extreme dimming event at X-ray (factor of 6000) and UV (factor $\sim$15) wavelengths $\sim$500–600 days after discovery. Here we report on the re-emergence of these emission components roughly 1200 days after discovery. We find that the source properties are similar to those of the pre-dimming accretion state, suggesting that the accretion flow was rejuvenated to a similar state. I will discuss the scenario of a repeating partial TDE, where the partially disrupted star is on a $\sim$1200 day orbit about the SMBH and is periodically stripped of mass during each pericenter passage, which we propose powers its unique lightcurve. This scenario provides a plausible explanation for AT2018fyk's overall properties, including the rapid dimming event and the rebrightening at late times.

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