IACHEC

International Astronomical Consortium for High Energy Calibration

Chair: Kristin K. Madsen[1]

Working group chairs: V. Burwitz[7], A. Foster[5], K. Forster[9], C. E. Grant[3], M. Guainazzi[4], V. Kashyap[5], H. L. Marshall[3], L. Natalucci[6], E. D. Miller[3], P. P. Plucinsky[5], Y. Terada[8], and Felix Fuerst[2]

[1] Goddard Space Flight Center, USA; [2]ESA-ESAC, Spain; [3]MIT, USA; [4]ESA-ESTEC, The Netherlands; [5]Center for Astrophysics | Harvard & Smithsonian, USA; [6]IAPS-INAF, Italy; [7] MPE, Garching, Germany; [8]University of Saitama, Japan; [9]Caltech, USA

What is IACHEC?[13]

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.

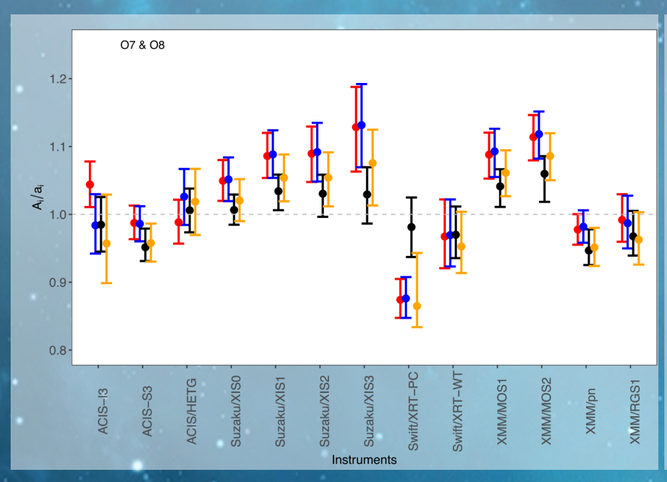
Working Groups and Activities

- **Calibration Statistics**[1]: A forum for the discussion of statistical, methodological, and algorithmic issues that affect the calibration of astronomical instruments, of how calibration data are used in data analysis, and how the analysis results are interpreted.
- **Clusters of Galaxies**[3][7][10]: Aims at a systematic comparison of high energy spectroscopic results of clusters of galaxies obtained with all current major high energy missions in order to evaluate the effective area cross-calibration uncertainties.
- **Contamination**: Aims to understand the chemical composition, time dependence, and spatial variation of molecular contamination on all in-orbit instruments, and how such contamination can be mitigated for current and future missions.
- **Coordinated Observations**[2][8]: The goal of this working group is to facilitate the coordination of calibration observations among operational observatories and the analysis and publication of the corresponding data
- **Detectors and Background**: Provides a forum for cross-mission discussion and comparison of detector-specific modeling and calibration issues, and for measuring and modeling instrument background in the spatial, spectral, and temporal dimensions.
- **Heritage**[5]: Strives to prevent the corpus of knowledge and best practices accumulated by the IACHEC from vanishing in the mists of time, by preserving and documenting it.
- **High Resolution**: Aims at a complete census of emission lines in high resolution observations made by the Chandra LEG/HEG and RGS, starting with the spectrum of Capella.
- **Non-Thermal Supernova Remnants (SNR)**[9][11]: Aims at the cross-calibration of operational payloads above 10 keV using primarily the Crab Nebula and G21.5-0.9.
- **Thermal SNR**[4]: Aims to use the time-invariant, line-rich spectra of the SNRs 1E 0102.2-7219 and N132D to improve the response models of the various instruments (gain, CTI correction, QE, spectral redistribution function, etc) and to compare the absolute effective areas of the instruments at the energies of the bright line complexes.
- **Timing**[12]: Provides a forum for in-orbit and on-ground timing calibrations, focusing on calibration discussions, issues, and lessons learned.
- **White Dwarfs and Isolated Neutron Stars**: Aims to compare atmospheric models in conjunction with analysis of high-resolution data.

Best Practices and New Analysis Methods

IACHEC researches and advocates best practices for high energy data analysis. Examples of topics that have been discussed and researched:

- How to bring disparate flux measurements with different instruments into concordance despite there not being an absolute reference point [1,19]
- Characterizing calibration and atomic data uncertainty and other systematics and incorporating them into spectral analysis [15,16,17,21]
- Cstat as a better alternative to χ^2 in spectral fitting, though there is room for improvement [14,22]
- Machine Learning techniques to pick out the spatial information present in images [20]
- Better characterize polarization via improved statistics and new calibration files.



Suggested corrections to the effective areas of several instruments based on the measurements of O VII and O VIII line fluxes from the SNR 1E 0102.2–7219[1]. Different colors represent different assumptions about the intrinsic calibration uncertainty τ of each instrument, encoded as a prior width. **BLACK**: all instruments assumed to have the same 2.5% uncertainty; **ORANGE**: all with 5% uncertainty; **BLUE**: with separate assessments as set by the respective instrument teams; **RED**: with realistic assessments that also include correlations across photon energies.

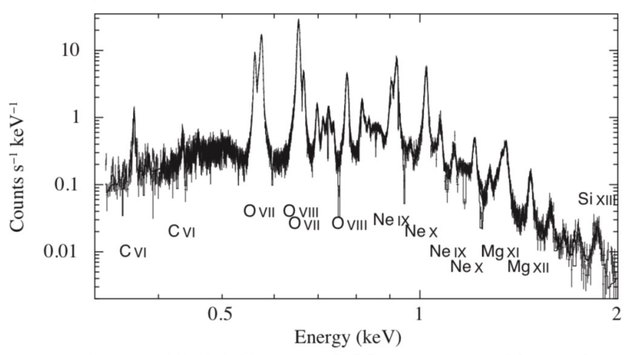
https://iachec.org/calibration-statistics/#library

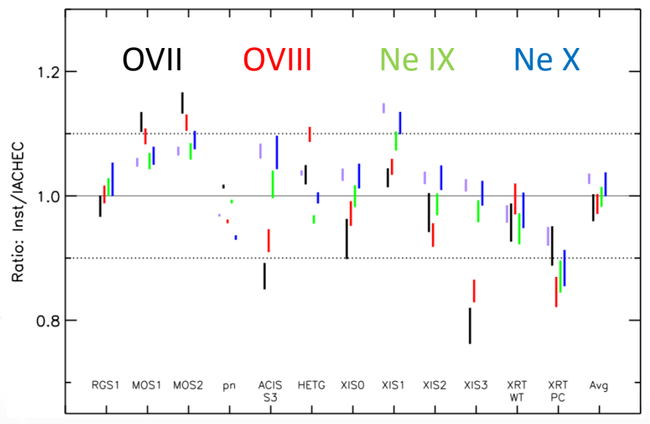
Standard Candles and Cross-calibration Campaigns

The main pillars upon which IACHEC was founded are the selection of **standard candles** to be used for calibration of current and future high energy observatories and the organization of **cross-calibration campaigns** for current high energy observatories. **Standard candles**, in a calibration sense, are sources that have fluxes stable over time. This category, consisting of SNR, isolated neutron stars, and clusters, is unfortunately often dependent on energy band; a source which may be ideal for one observatory may not be for another. Broad-band **cross-calibration** is therefore often supplemented with spectrally simple and tolerably bright sources (such as quasars and blazars). Due to source variability, they require simultaneous observations and planning, which is where the IACHEC has stepped in to identify the best sources and facilitate the organization of these **campaigns**.

1E 0102.2-7219[4]

This thermal SNR is the ideal **standard candle** for soft X-ray instruments. IACHEC members have developed a spectral model for 1E 0102.2-7219 and fit this model to the spectra extracted from the CCD instruments on *Chandra*, *Suzaku*, *Swift*, and *XMM-Newton*. The model is empirical in that it includes Gaussians for the identified lines, an absorption component in the Galaxy, another absorption component in the SMC, and two thermal continuum components with different temperatures.



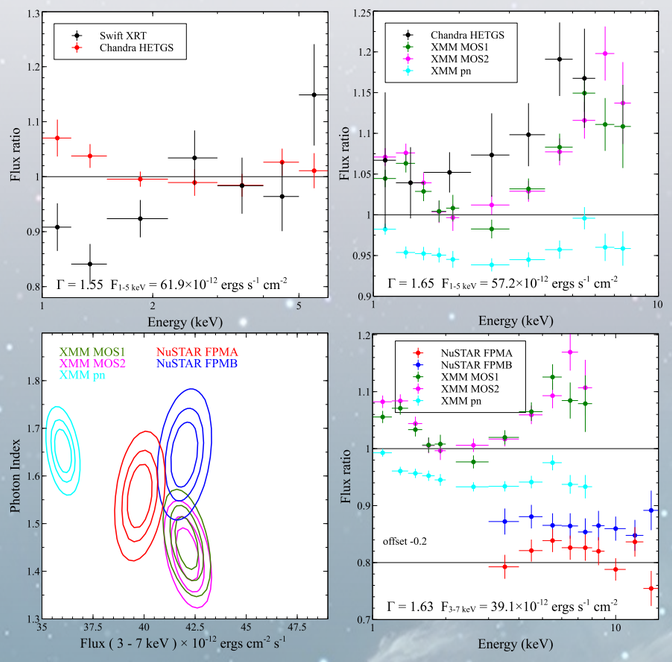


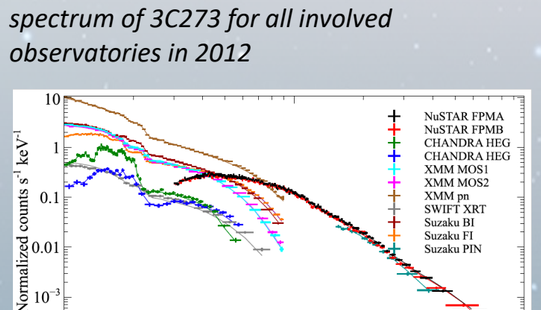
Above: XMM-Newton RGS spectrum. Right: line normalization offsets between instruments.

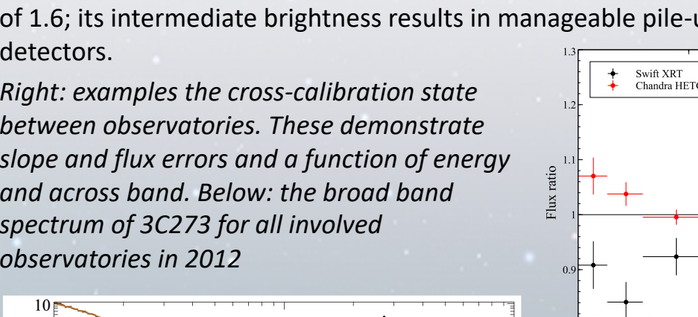
3C 273[2]

This quasar is the **cross-calibration** work-horse of the IACHEC. Since 2012, the IACHEC has conducted an annual campaigns, most recent in 2022 where it was observed by *Chandra*, *NICER*, *NuSTAR*, *Swift*, and *XMM-Newton*. The quasar has a mildly variable, nearly featureless hard spectrum with a photon index of 1.6; its intermediate brightness results in manageable pile-up in modest exposures with CCD detectors.

Right: examples the cross-calibration state between observatories. These demonstrate slope and flux errors and a function of energy and across band. Below: the broad band spectrum of 3C273 for all involved observatories in 2012







Meetings and Participation

The annual workshop is typically held in a secluded location, rotating between North America, Europe, and Asia. Anyone is welcome to participate and contribute. To receive newsletters and announcements, please go to our webpage and sign up. Or join us on Slack.

iachec.org

iachec.slack.com

References

[1] H. Marshall, et al., 2021, The Astronomical Journal, 162, 6
[2] K. Madsen, et al., 2017, AJ, 153, 2
[3] G. Schellenberger, et al., 2015, A&A, 575, 30
[4] P. Plucinsky, et al., 2017, A&A, 597, 31
[5] M. Guainazzi, et al., JATIS. 1(4), 047001
[6] A. Read, et al., 2014, A&A, 564, 75
[7] K. Kettula, et al., 2013, A&A, 552, 47
[8] M. Ishida, et al., 2011, PASJ, 63, 657
[9] M. Tsujimoto, et al., 2011, A&A, 525, 25
[10] J. Nevalainen, et al., 2010, A&A, 523, 22
[11] M. Weisskopf, et al., 2010, ApJ, 713, 912
[12] Y. Terada, et al., 2008, PASJ, 60, 25
[13] S.Sembay, et al., 2010, AIPC, 1248, 593
[14] Kaastra 2017, A&A 605, A51
[15] Drake et al. 2006, Proc. SPIE 6270,62701I
[16] Lee et al. 2011, ApJ 731, 126
[17] Xu et al. 2014, ApJ 794, 97
[18] Kaastra & Bleeker 2016, A&A, 587, A151
[19] Chen, Y, et al., 2019, J. Am. Stat.Assoc, 114, 1018
[20] Sweere, S. F., et al., 2023, arXic:2205.01152
[21] Bonamente, M., et al., 2023, MNRAS, arXiV:202302.04011
[22] Bonamente, M., et al., 2019, J. Appl. Stat., 47, 2044