INAF
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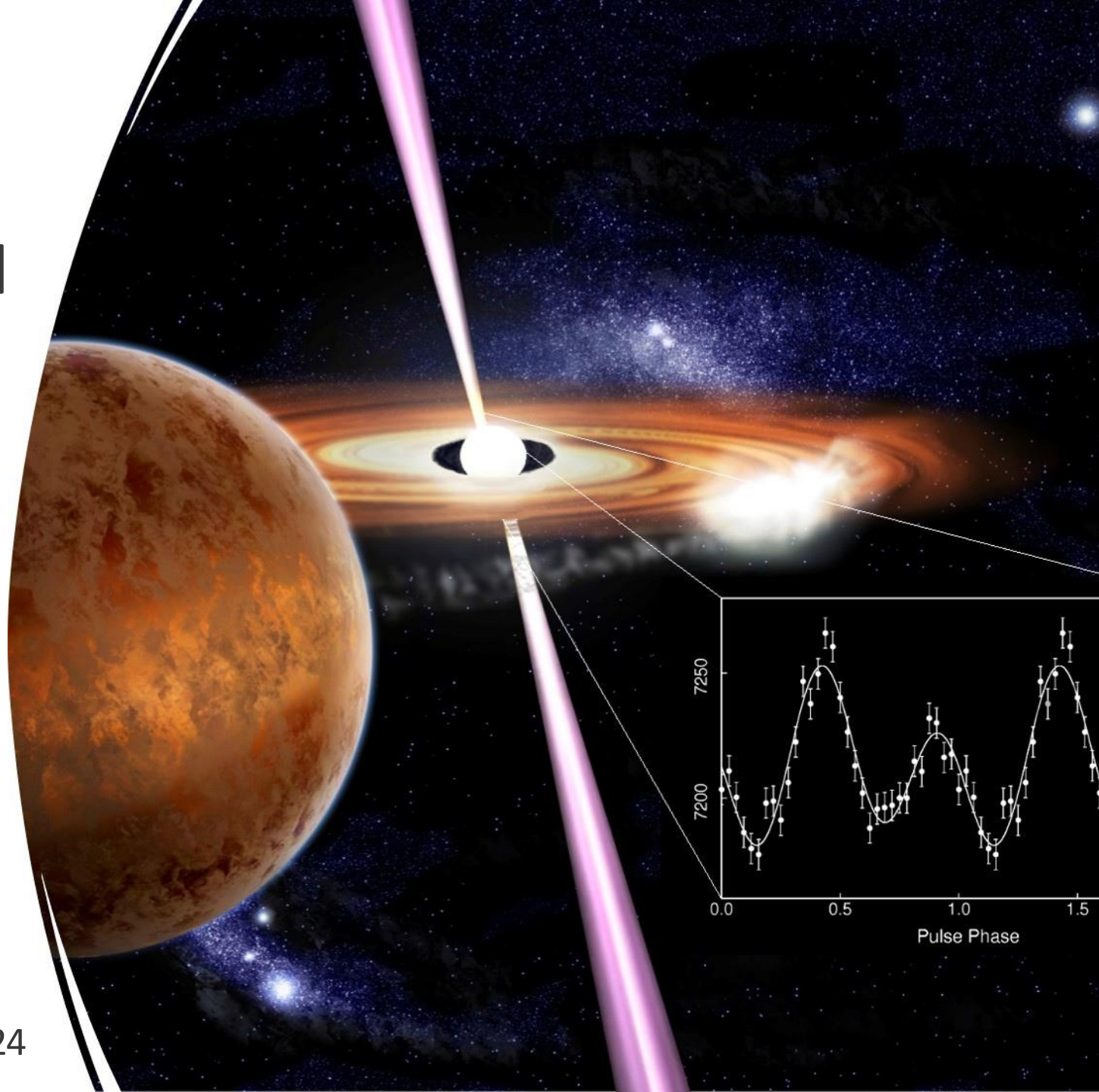
DI ASTROFISICA

Snooping around transitional millisecond pulsars: can accretion- and rotation-powered states co-exist?



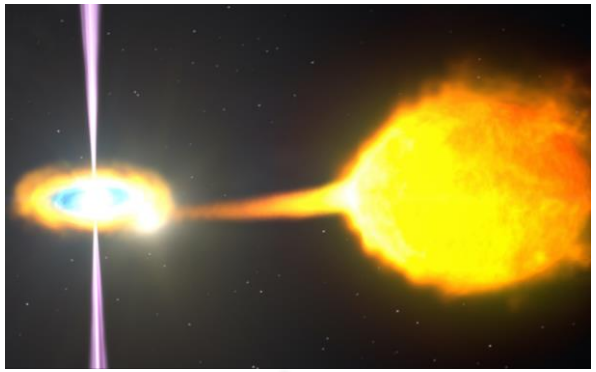
Giulia Illiano

In collaboration with A. Papitto, F. Coti Zelati, A. Miraval Zanon, F. Ambrosino, and many more

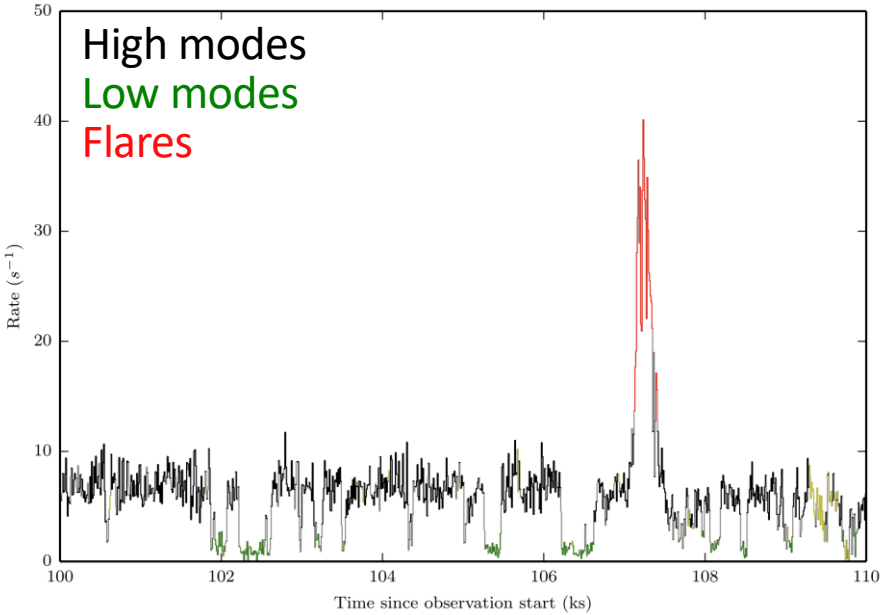
XMM-Newton 2024 Workshop ESAC June 6, 2024

Transitional millisecond pulsars

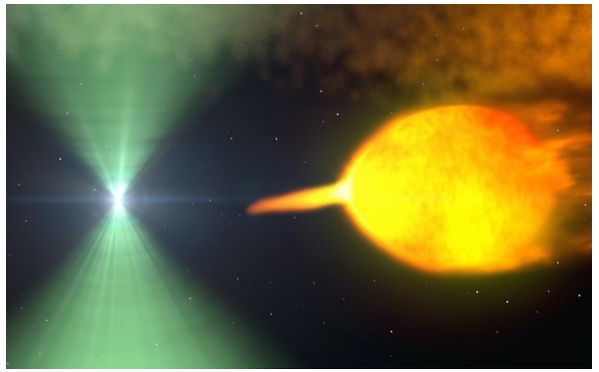
Accretion-powered (X-ray) state



Sub-luminous disk state



[PSR J1023+0038; Archibald+ 2015]

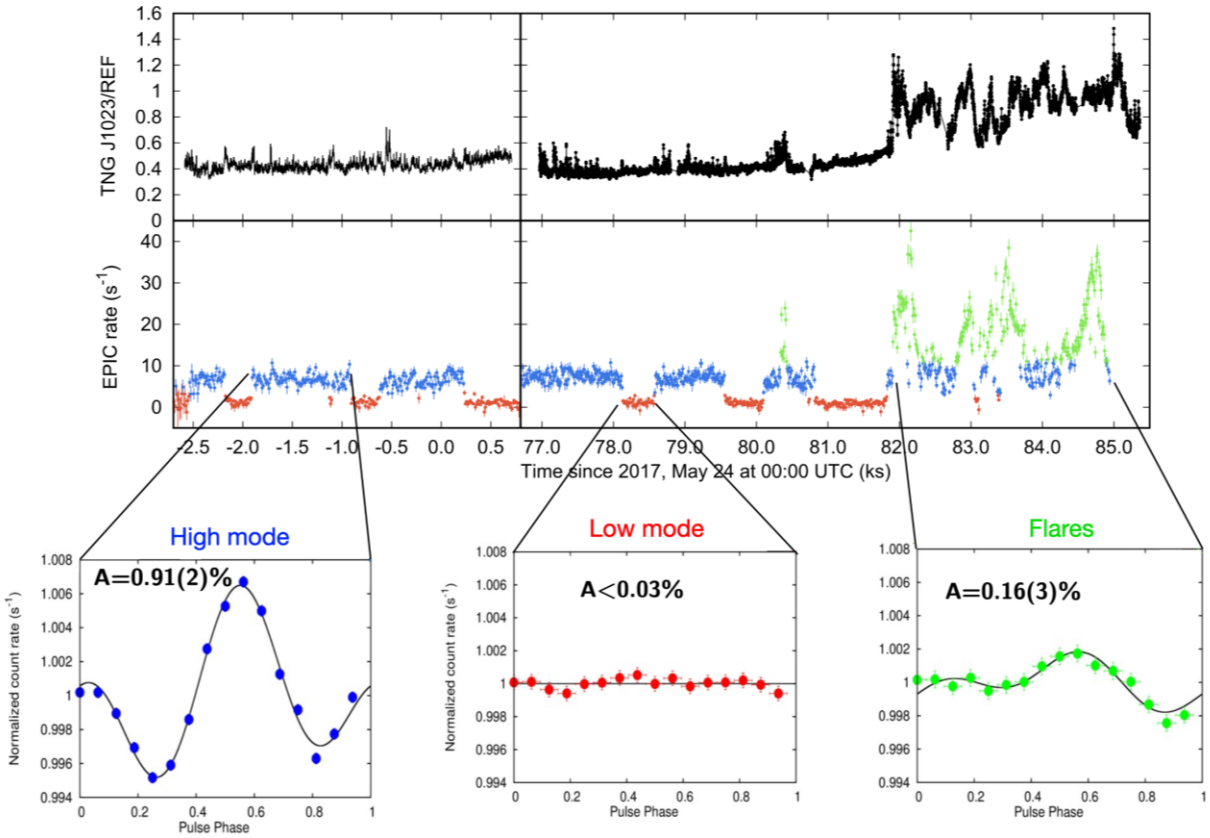


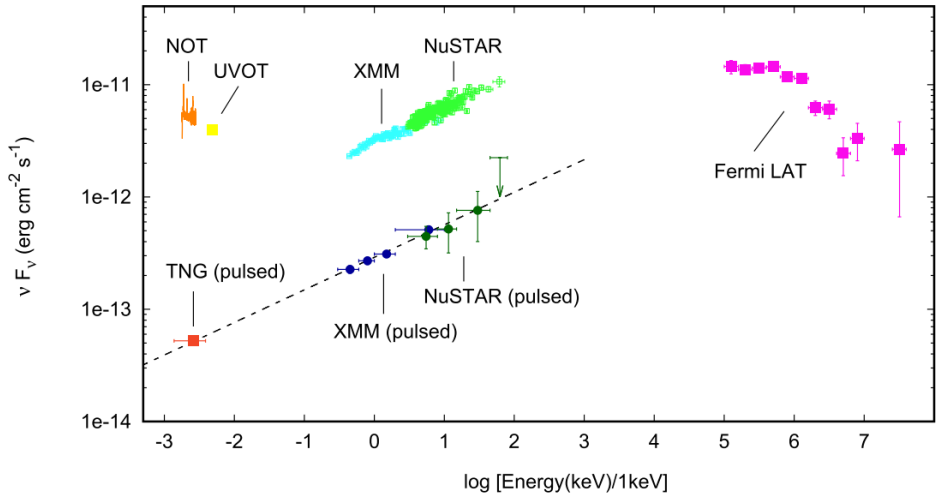
Rotation-powered (radio) state

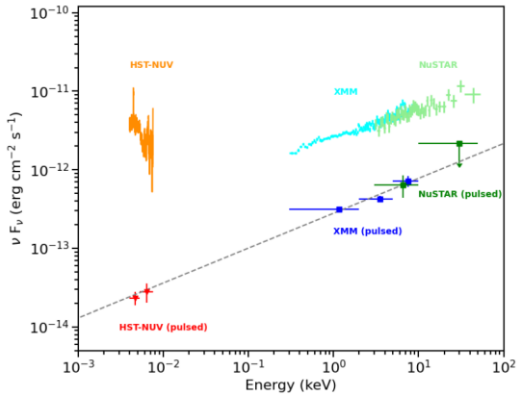
Optical/UV ms pulsations from PSR J1023+0028

- Simultaneously observed during the high modes
- Similar pulse shape
- Pulsed SED compatible with a single power-law

→ Optical, UV and X-ray pulses are produced by the **same process**

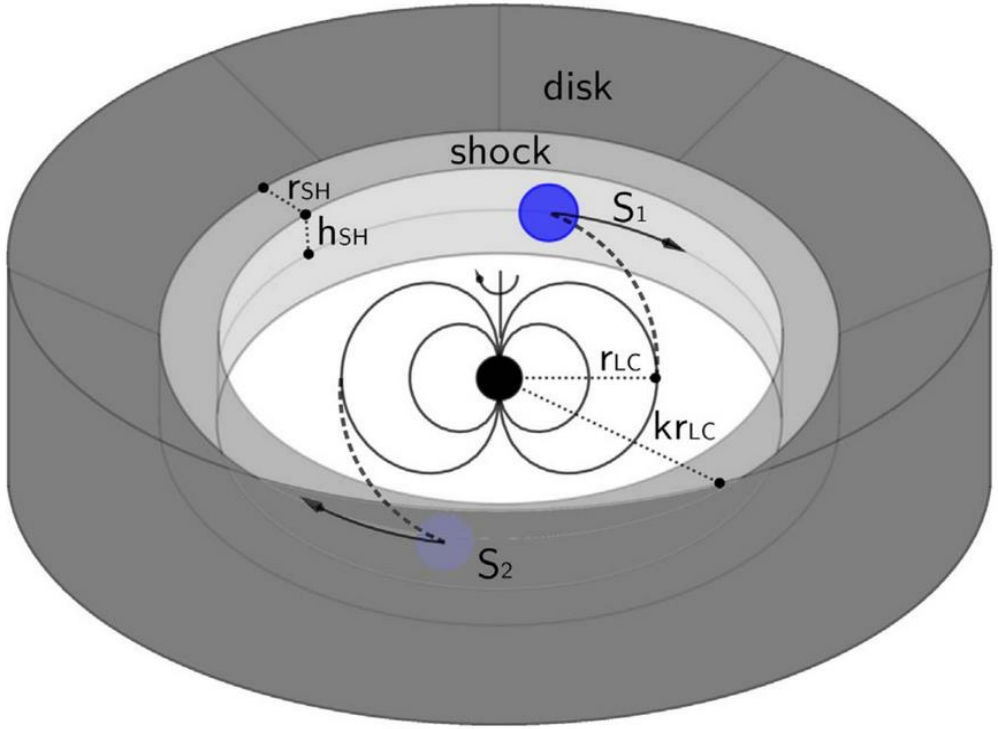






[Ambrosino, Papitto+ 2017 ; Papitto+ 2019; Jaodand+ 2021; Miraval Zanon+ 2022]

Co-existence between accretion- and rotation-powered states?



[Papitto+ 2019]

- Synchrotron radiation from the shock between the striped wind and the accretion disk

  See A. Papitto's talk

- Different synchrotron timescales of optical (~3 μs) and X-ray photons (~220 μs) :

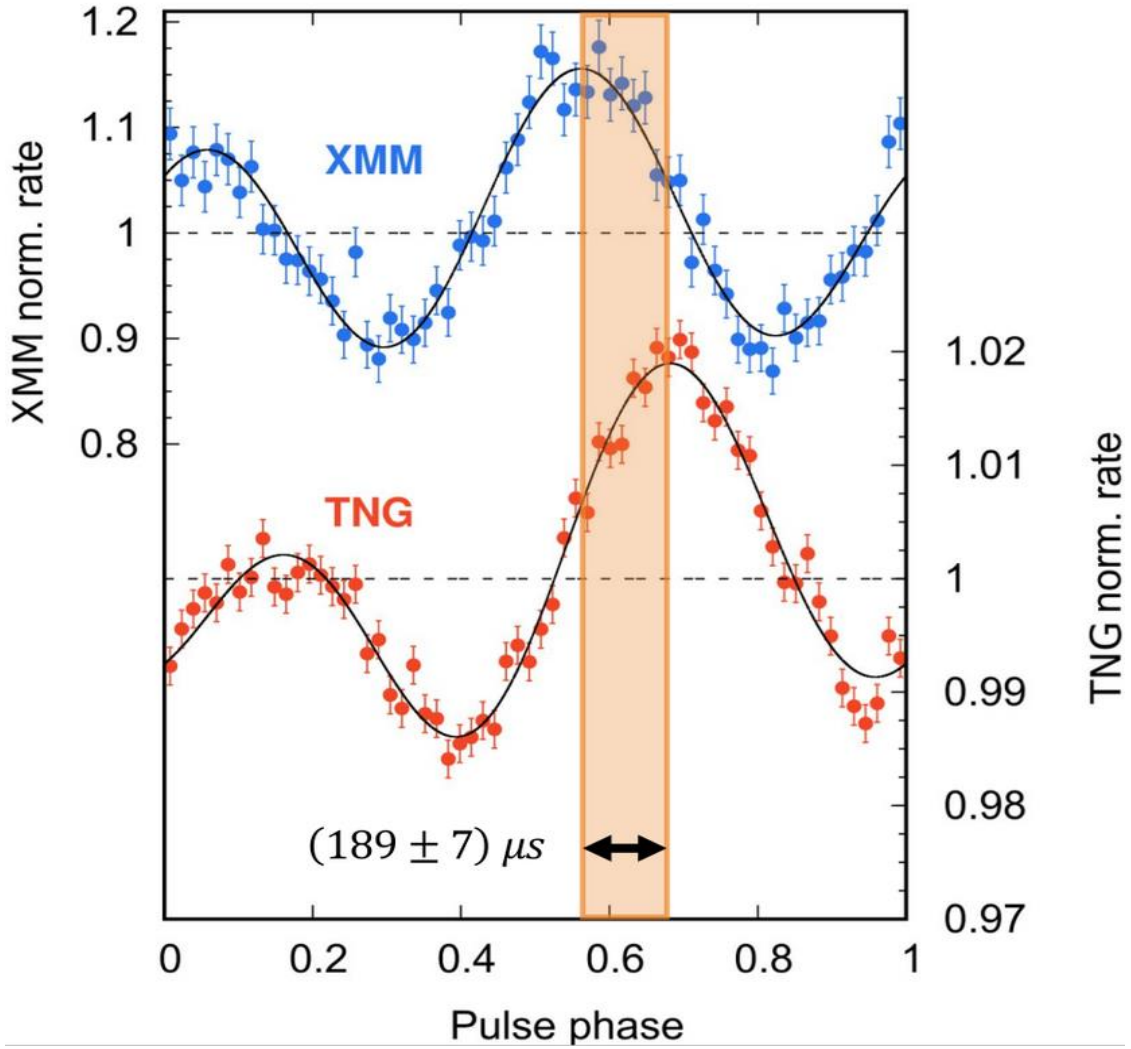
$$t_{\rm sync} \propto \epsilon^{-1/2} B_{\rm s}^{-3/2}$$

Photon energy

Surface magnetic field

[see also Veledina+ 2019]

Time lags between optical and X-ray pulsations



[Papitto+ 2019]

Absolute timing accuracy:

- SiFAP2: ~ 60 μs
- XMM-Newton: ~ 100 μs

↓

New goal: data acquired by instruments with negligible absolute timing uncertainties

Optical/X-ray phase shift over the simultaneous observation of ~11 ks

↓

New goal: verify that the phase shift is maintained over time

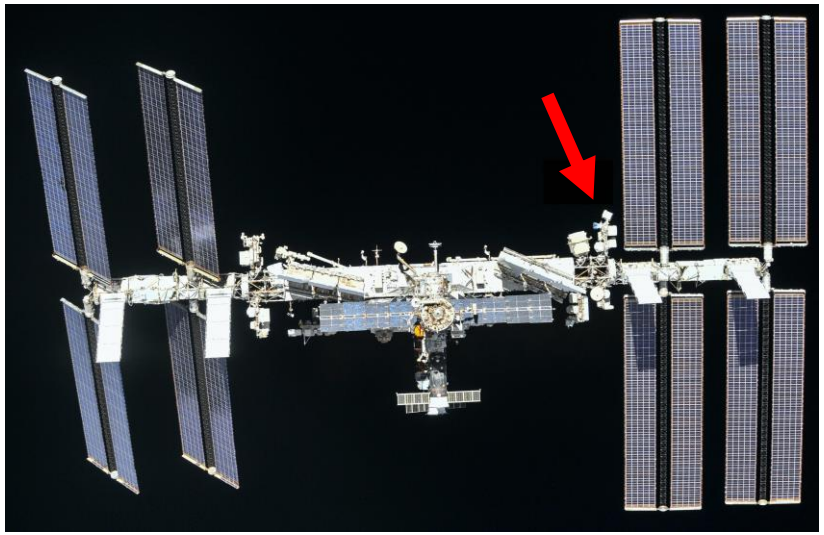
Five years of optical and X-ray observations

TNG/SiFAP2
[Credit to G. Tessicini]

Copernicus/Aqueye+
[Credit to MEDIA INAF]

Telescope/Instrument
2017 May - overlap: 11.0 ks *XMM-Newton*/EPIC TNG/SiFAP2
2018 December - overlap: 10.8 ks *XMM-Newton*/EPIC Copernicus/Aqueye+
2018 December - no overlap; temporal gap: 41 ks *XMM-Newton*/EPIC Copernicus/Aqueye+
2019 January - overlap: 2.3 ks *NICER* TNG/SiFAP2
2019 February - overlap: 1.1 ks *NICER* Copernicus/Aqueye+
2019 June - overlap: 340 s *NICER* TNG/SiFAP2
2020 January - overlap: 4.6 ks *NICER* TNG/SiFAP2
2020 January - overlap: 520 s *NICER* Copernicus/Aqueye+
2022 January - overlap: 1.7 ks *NICER* Copernicus/Aqueye+

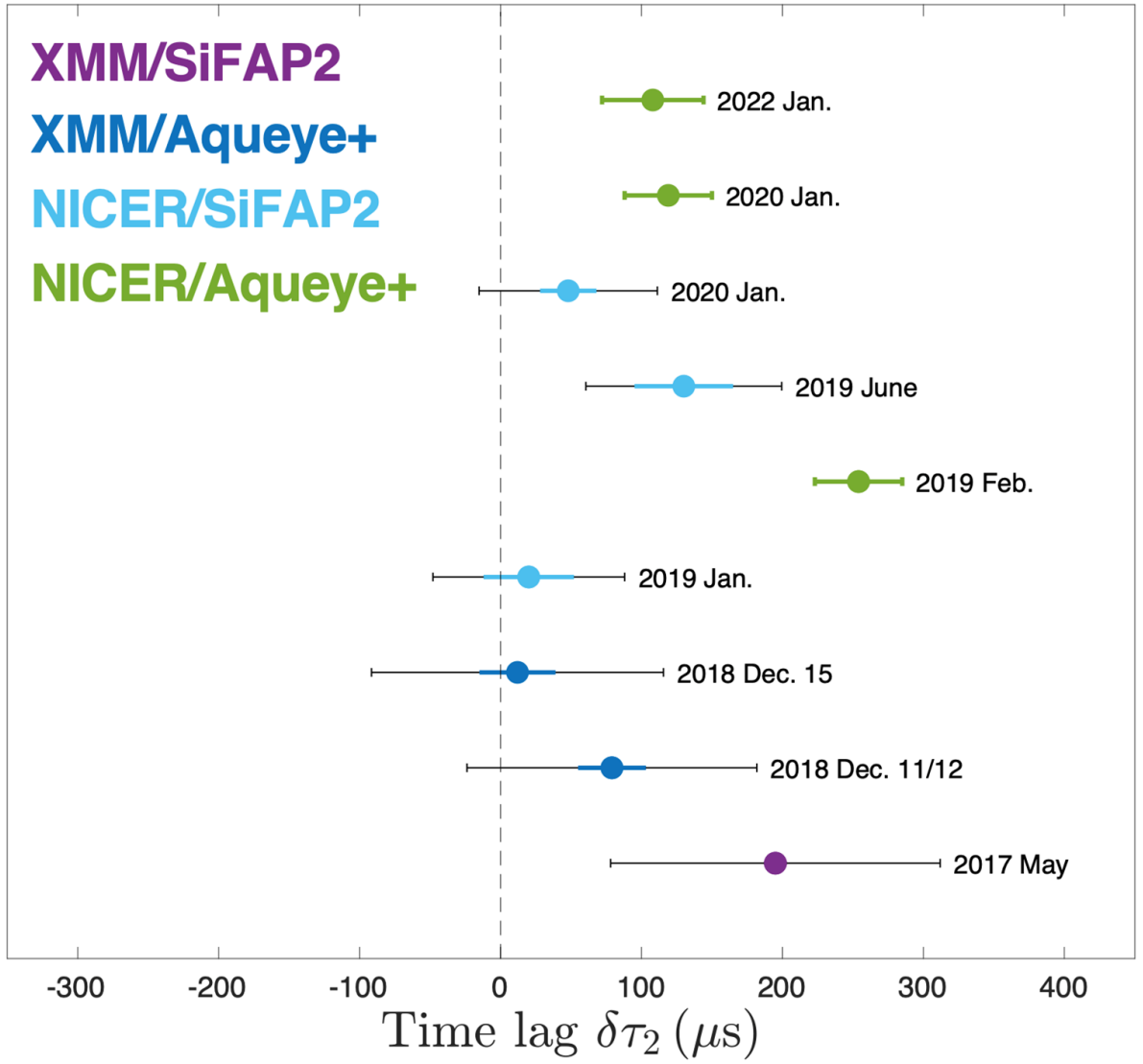
[Illiano+ 2023a]



NICER
[Credit to NASA]

XMM-Newton
[Credit to NASA]

Time lags between optical and X-ray pulsations



[Illiano+ 2023a]

Multi-wavelength campaign on the candidate 3FGL J1544.6-1125

DAY 1

XMM-Newton/EPIC (PI: Miraval Zanon)

HST/STIS (→ *first UV observation of this source ever*!) (PI: Illiano)

XMM-Newton/OM B-band (PI: Miraval Zanon)

TNG/SiFAP2 (PI: Illiano)

REM (PI: Baglio)

VLA (PI: Miraval Zanon)

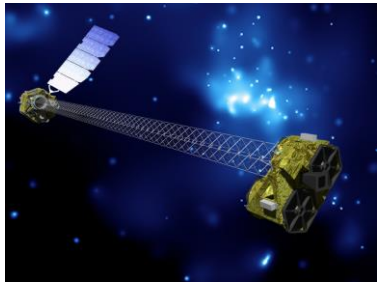
DAY 2-3-4

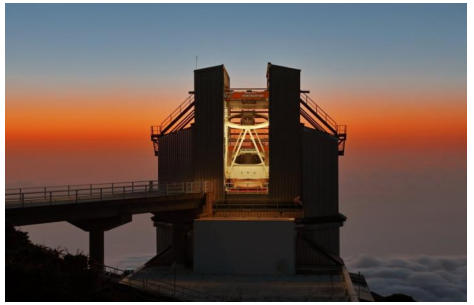
NuSTAR (PI: Miraval Zanon)

NICER (PI: Illiano)

REM (PI: Baglio)

GTC/HiPERCAM (PI: Coti Zelati)





WORK IN PROGRESS!

Multi-wavelength campaign on the candidate 3FGL J1544.6-1125

DAY 1

XMM-Newton/EPIC (PI: Miraval Zanon)

HST/STIS (→ *first UV observation of this source ever*!) (PI: Illiano)

XMM-Newton/OM B-band (PI: Miraval Zanon)

TNG/SiFAP2 (PI: Illiano) → Bad weather

REM (PI: Baglio)

VLA (PI: Miraval Zanon)

Only day 2/3 due to a ToO

DAY 2-3-4

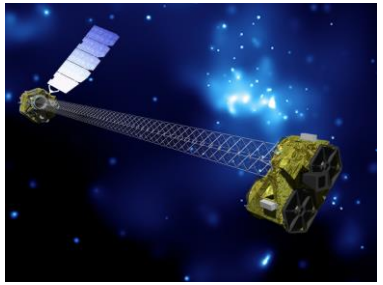
NuSTAR (PI: Miraval Zanon)

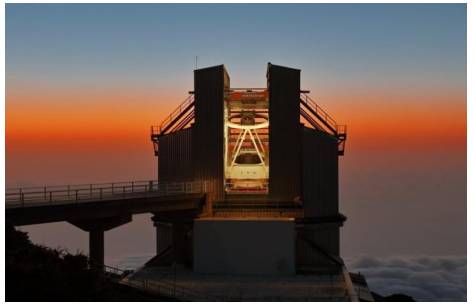
NICER (PI: Illiano) → Visibility issues

REM (PI: Baglio)

GTC/HiPERCAM (PI: Coti Zelati)

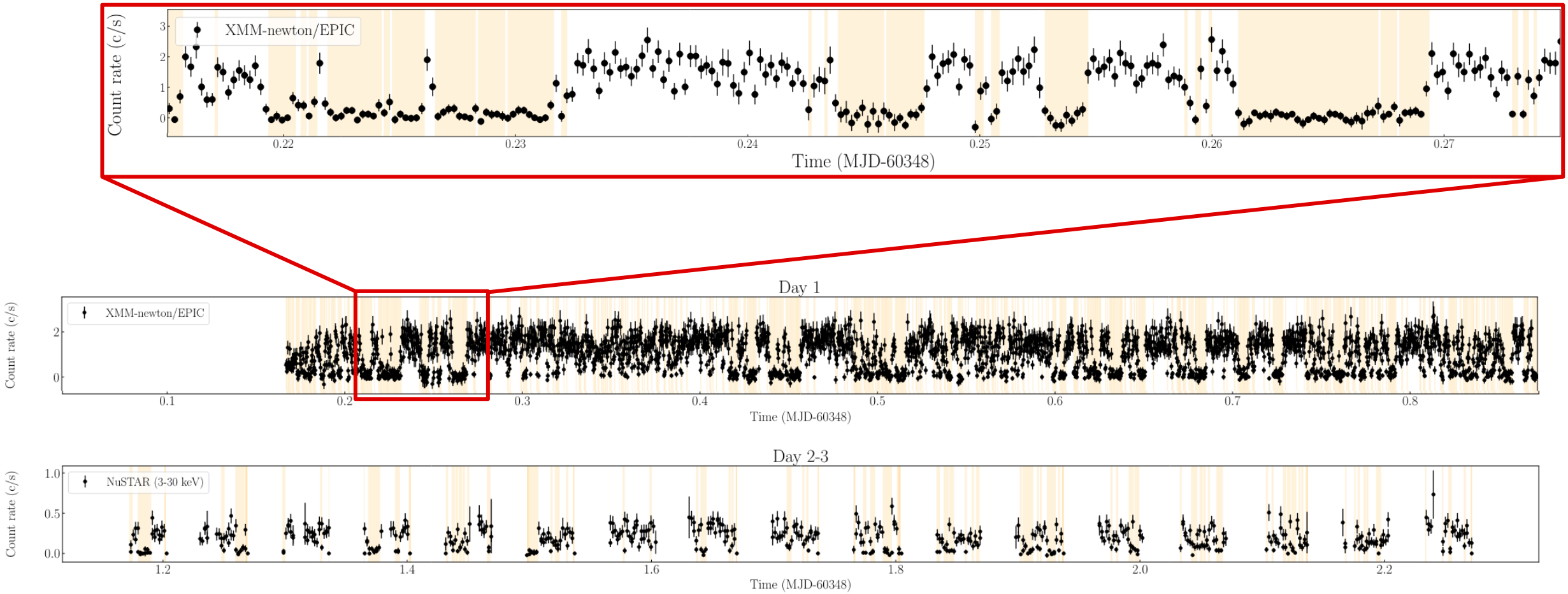
Only day 4 due to bad weather





WORK IN PROGRESS!

A strong candidate transitional pulsar: X-ray high and low modes

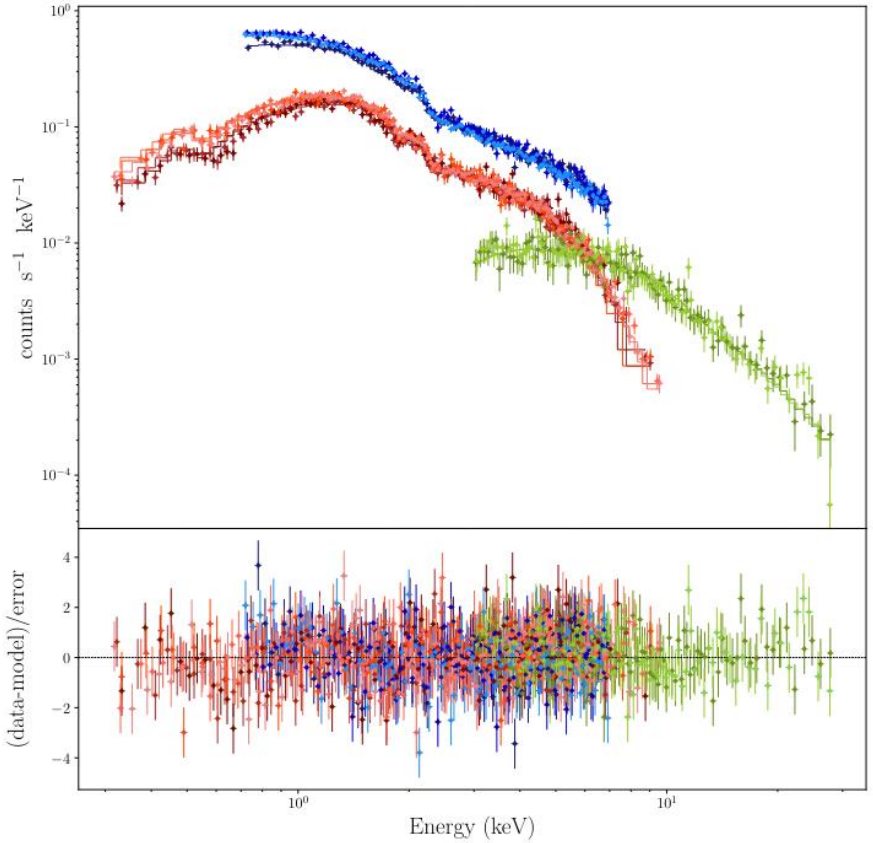


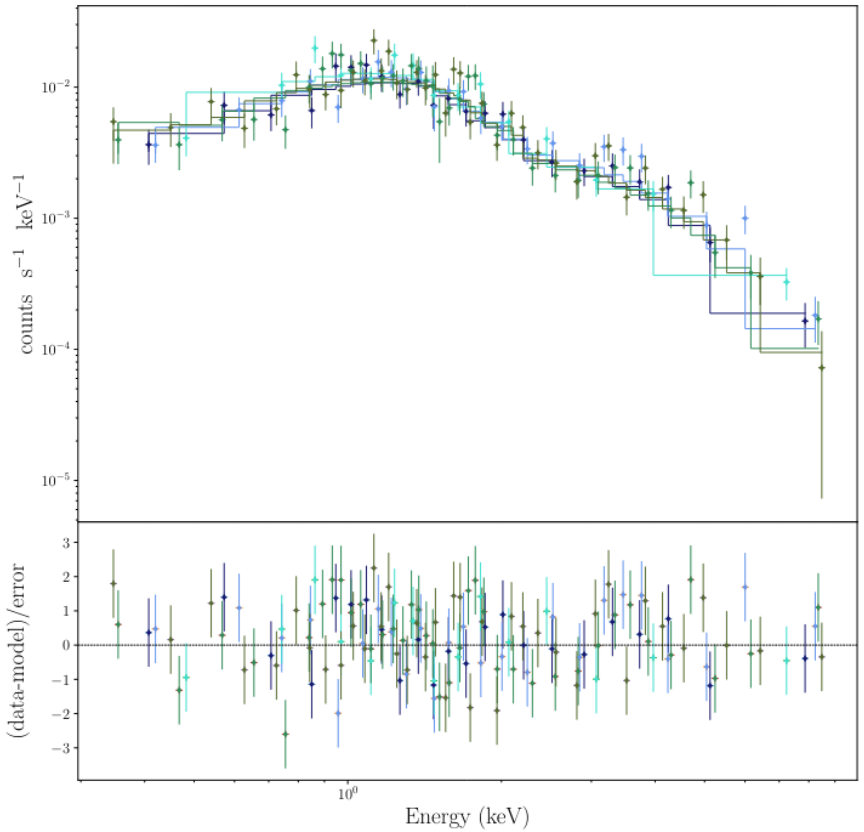
[Illiano, Coti Zelati +, in prep.]

[see also Bogdanov+ 2015, 2016]

X-ray spectra extracted in the high and low modes

Our XMM-Newton and NuSTAR observations + XMM-Newton archival observations



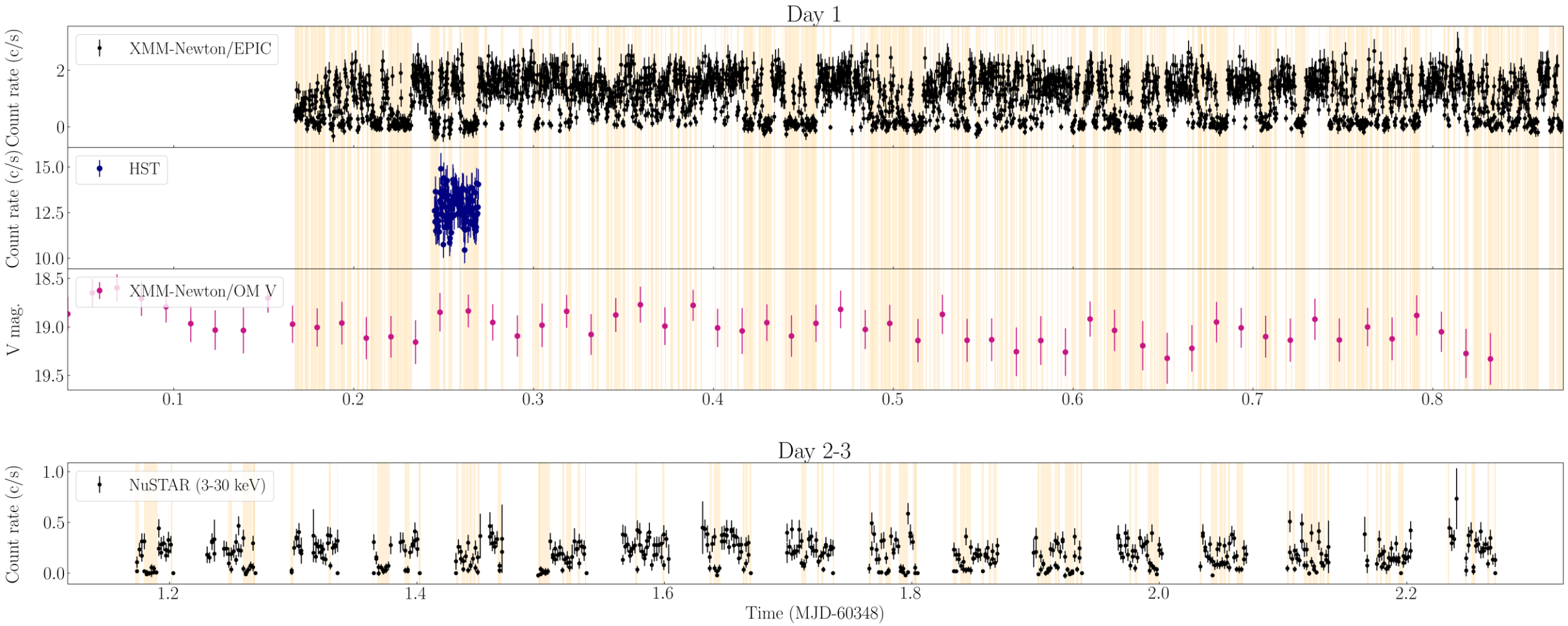


- **High mode**: $\Gamma = 1.627 \pm 0.004$, $F_X(0.3\text{–}10\ \text{keV}) = (5.57\ \pm 0.04) \times 10^{-12}\ \text{erg cm}^{-2}\text{s}^{-1}$
- **Low mode**: $\Gamma = 1.66 \pm 0.06$, $F_X(0.3\text{–}10\ \text{keV}) = (0.38\ \pm 0.02) \times 10^{-12}\ \text{erg cm}^{-2}\text{s}^{-1}$

[Illiano, Coti Zelati +, in prep.]

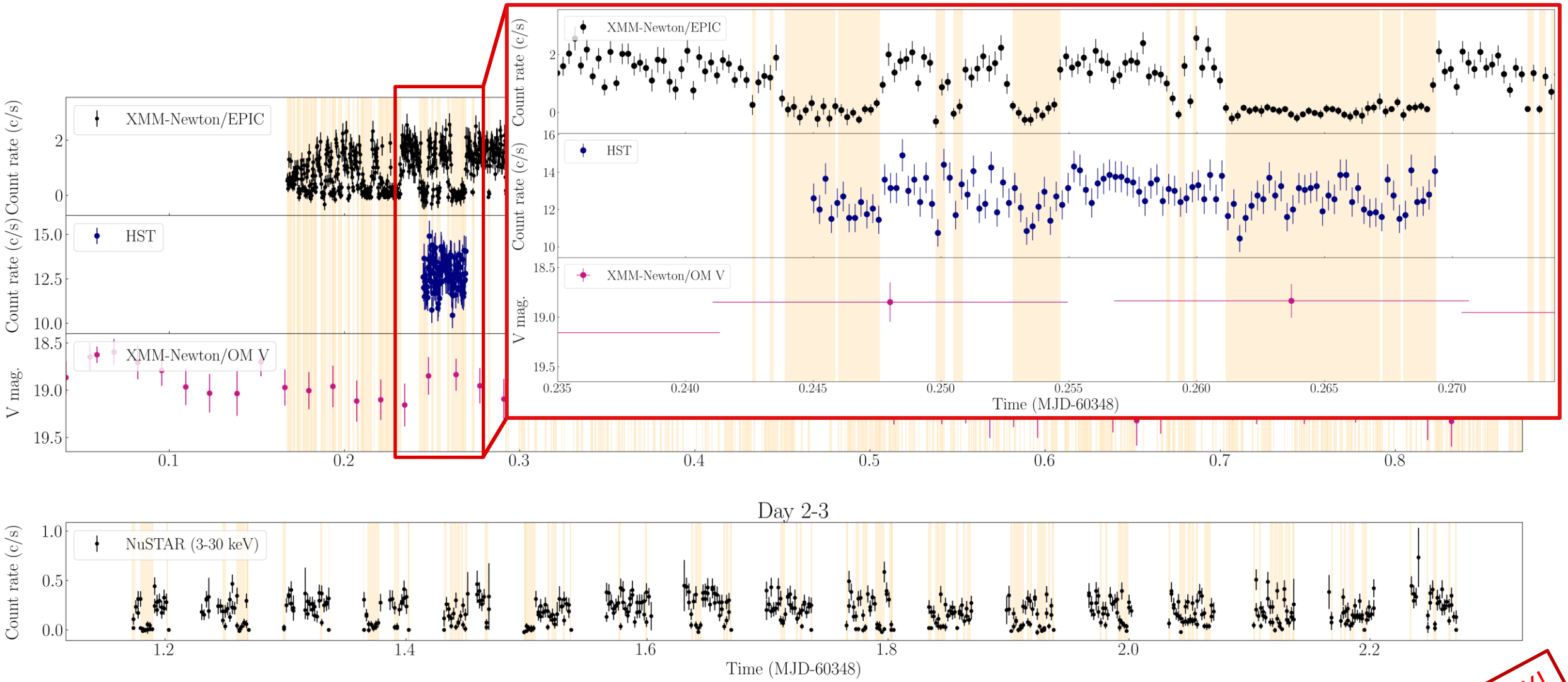
[see also Bogdanov+ 2016]

Multi-wavelength campaign on the candidate J1544



[Illiano, Coti Zelati +, in prep.]

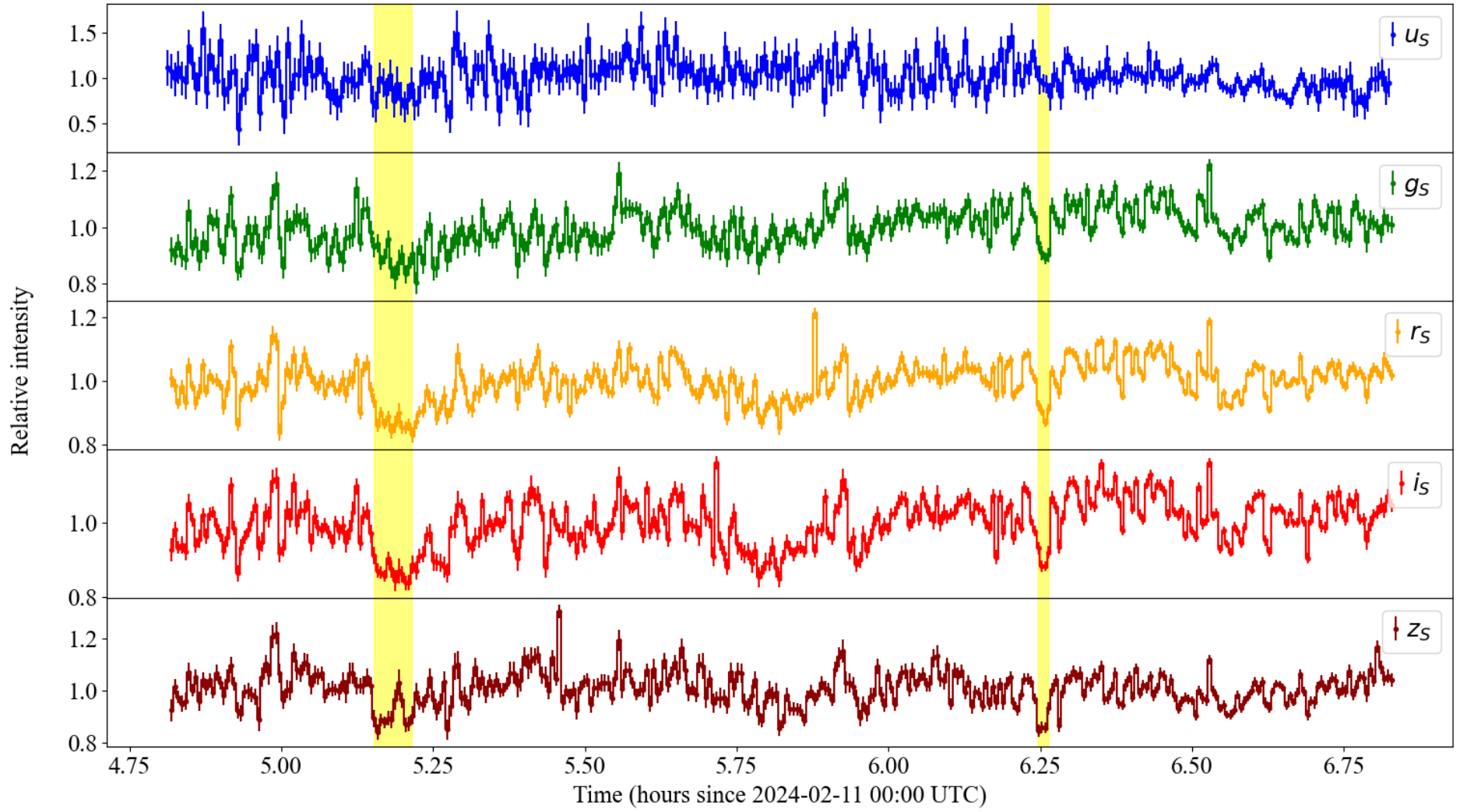
Multi-wavelength campaign on the candidate J1544



[Illiano, Coti Zelati +, in prep.]

PRELIMINARY!

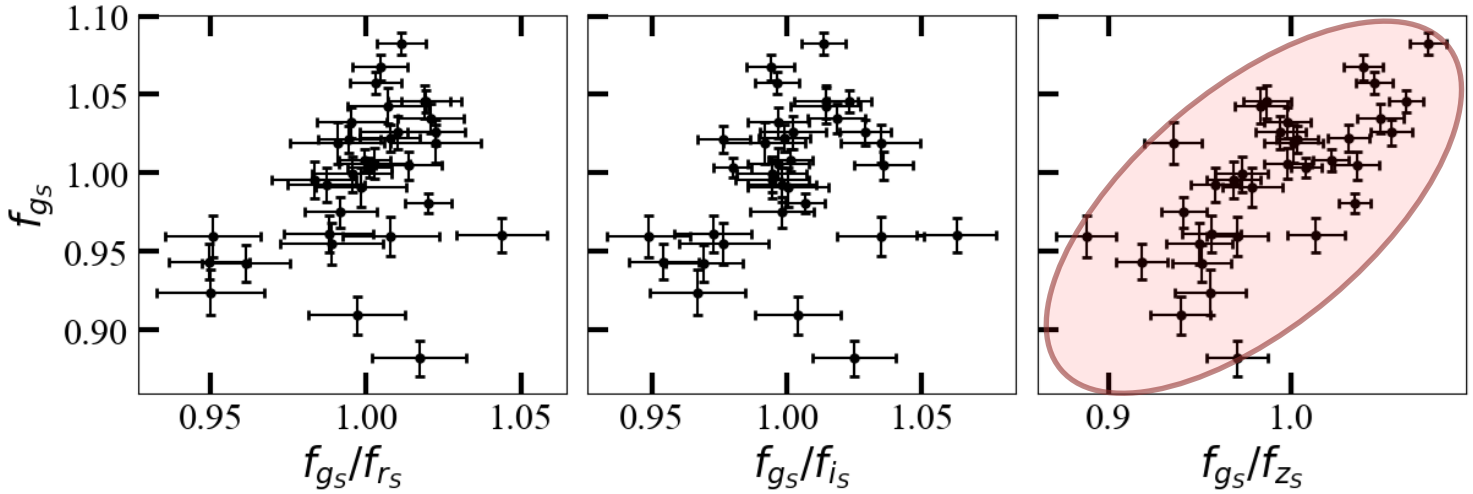
GTC/HiPERCAM observation in five different filters



[Illiano, Coti Zelati +, in prep.]

Optical emission from the inner accretion flow?

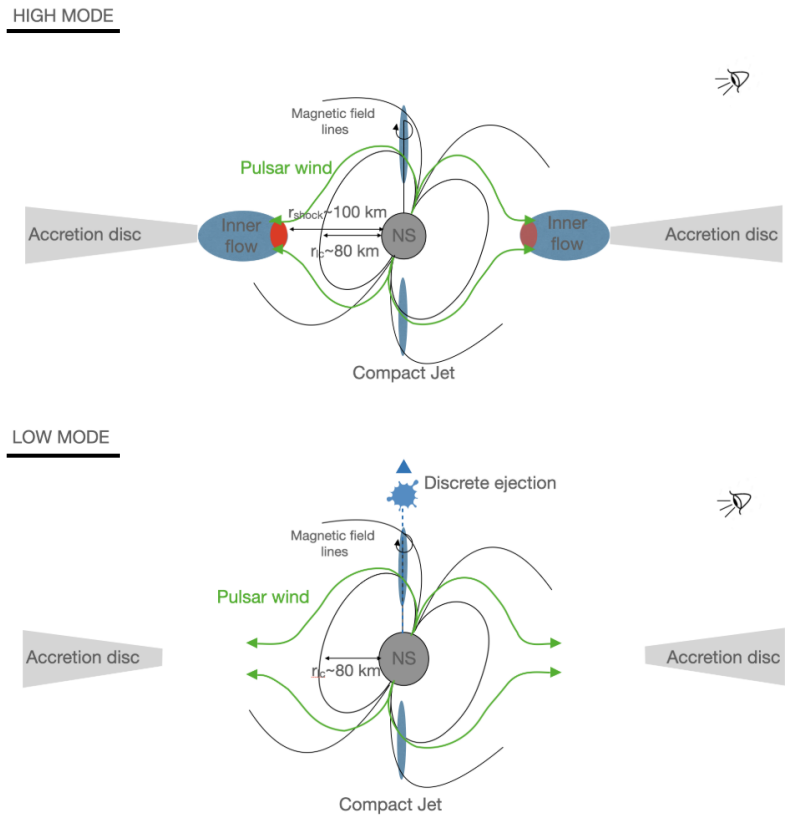
Inner, hotter accretion flow ejected at the high-to-low mode switch
→ **reddening** of the optical emission



[Illiano, Coti Zelati+, in prep.]

Similar reddening observed in NTT/ULTRACAM observations of the candidate transitional pulsar CXOU J110926.4−650224

[Coti Zelati+, submitted]



M.C. Baglio and A. Papitto's talks

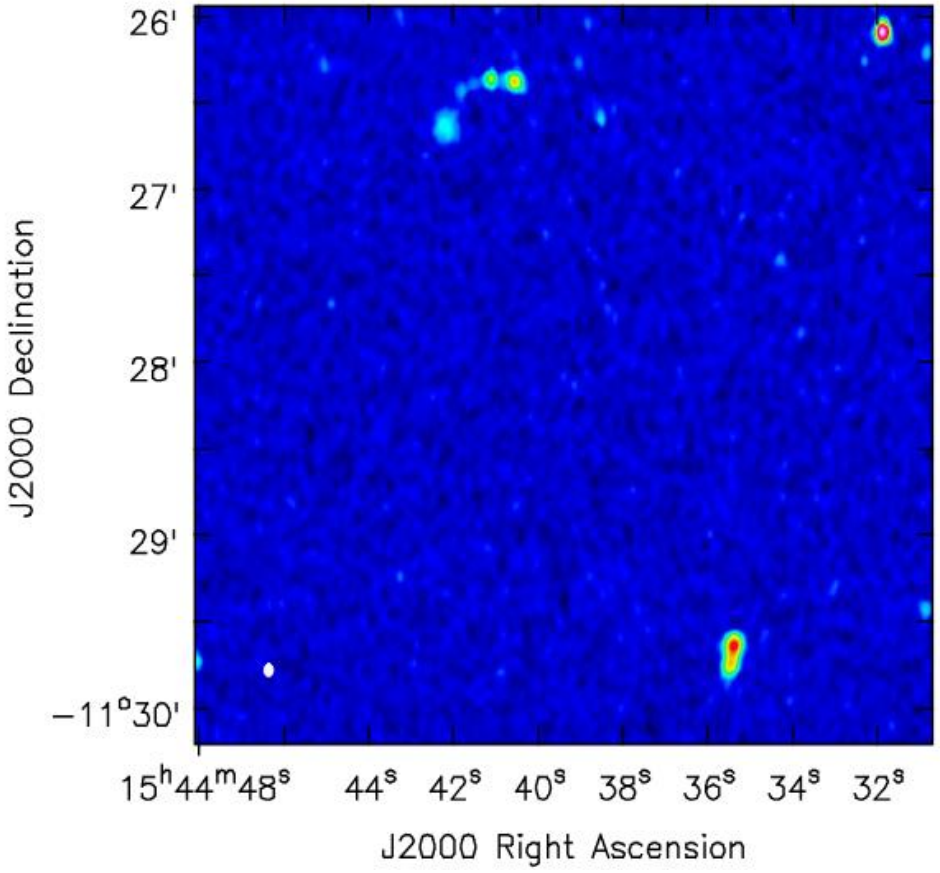
[Baglio, Coti Zelati+ 2023]

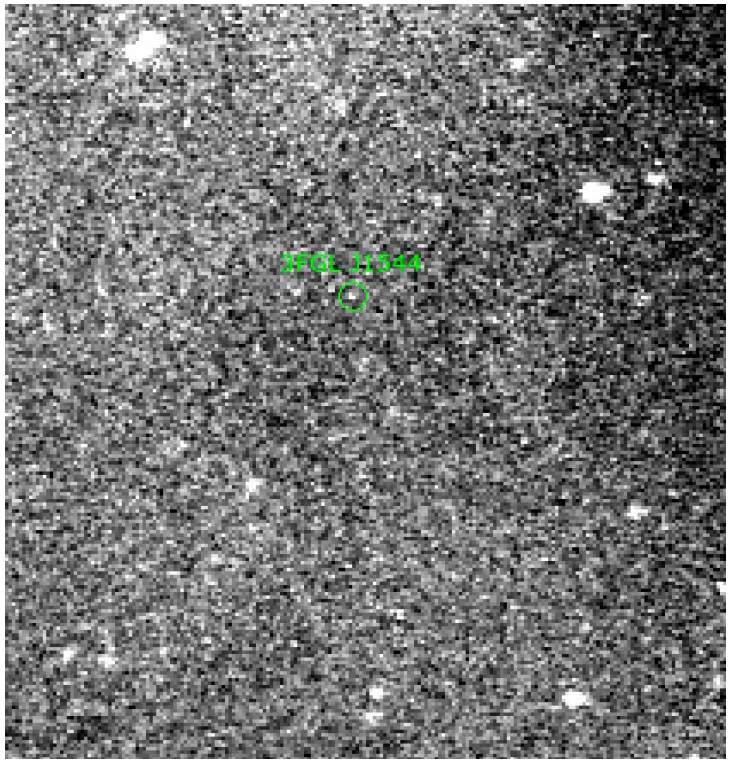
[see also Papitto+ 2019; Campana+ 2019]

PRELIMINARY!

Radio and infrared observations

- 4-hour radio observation with VLA, simultaneous with XMM-Newton → the source is not detected
- ~10-min infrared observation with REM for four days → tentative detection





[Thanks to S. Giarratana, M. Giroletti, M.C. Baglio]

PRELIMINARY!

Radio variability of J1544

- 4-hour radio observation with VLA, simultaneous with XMM-Newton
- Radio images extracted separately in the X-ray high and low modes

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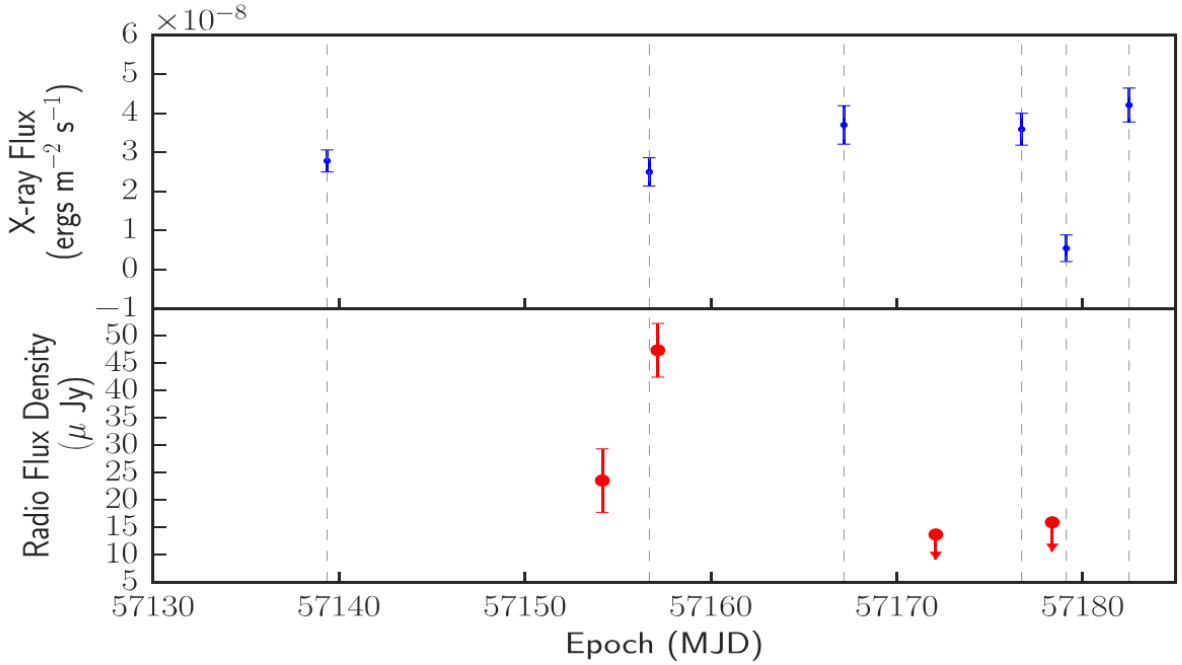
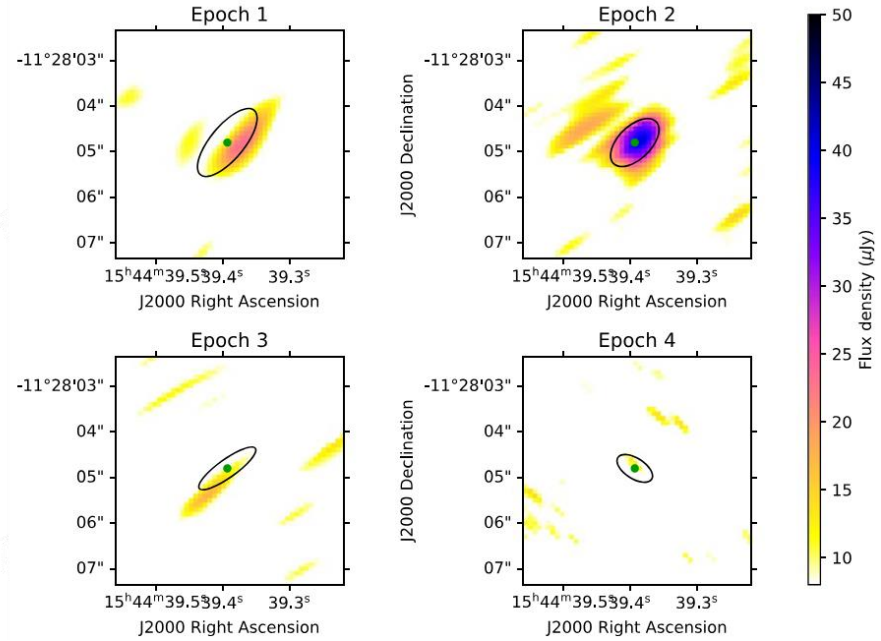
The source is **not detected** in radio despite the standard behavior in X-rays



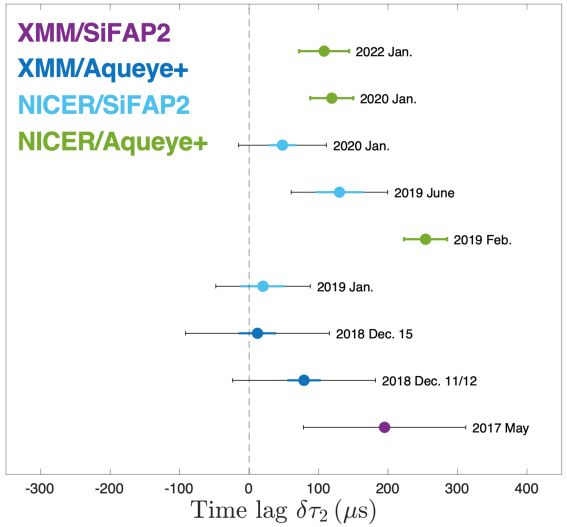


[Jaodand+ 2021]

Co-existence of accretion- and rotation-powered states?

Very fast (∼ms) variability in J1023

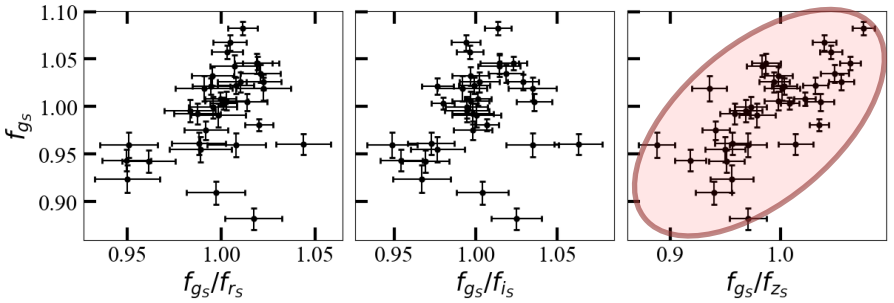
- Optical/UV/X-ray pulses simultaneously only in the high modes
- Pulsed SED compatible with a single power-law
- Optical/X-ray time lags of ∼200 μs



[Illiano+ 2023a]

Fast variability (∼tens of sec) in J1544

- Hints of low modes in GTC/HiPERCAM observations: reddening of the optical emission



[Illiano, Coti Zelati+, in prep.]

↓

Similar to NTT/ULTRACAM observations of J1109
[Coti Zelati+, submitted]

Optical/UV/X-ray emission from synchrotron radiation at the shock front between the pulsar wind and the inner accretion flow