Understanding the Enigmatic Nature of the Transient X-ray Binary 4U 1630–47

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Outline of the talk:

4U 1630-47 outburst recurrency.

Companion star and system characteristics

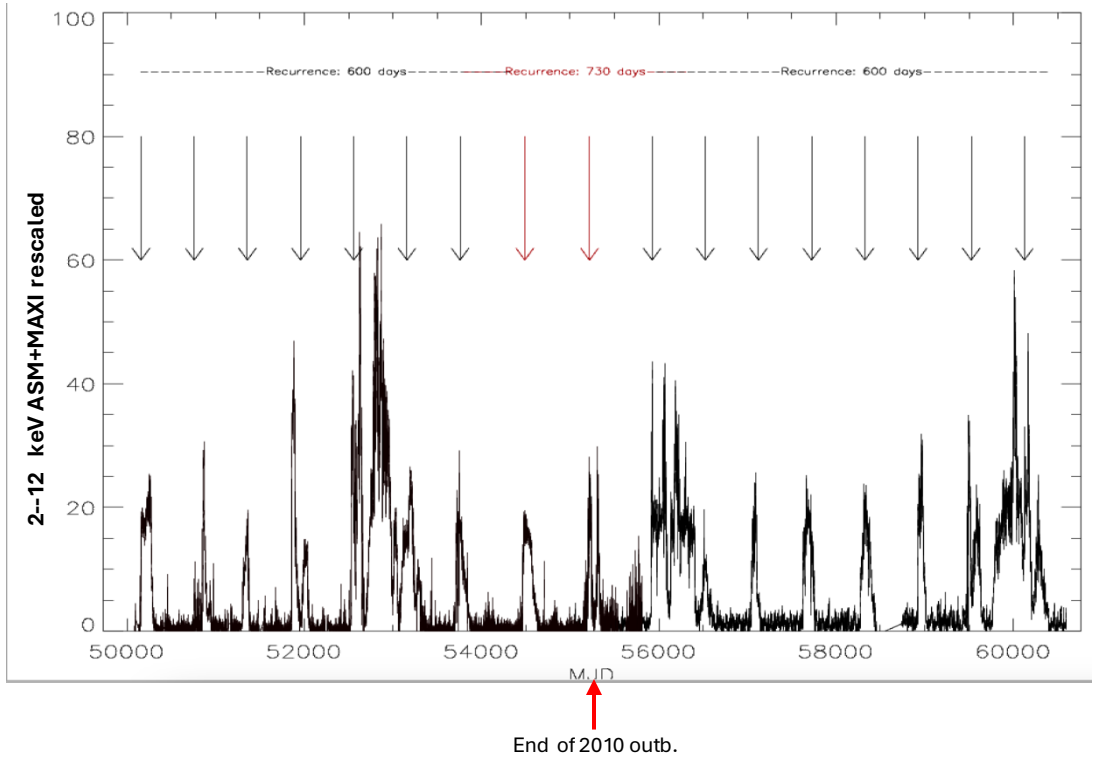
Lack of bright hard states.

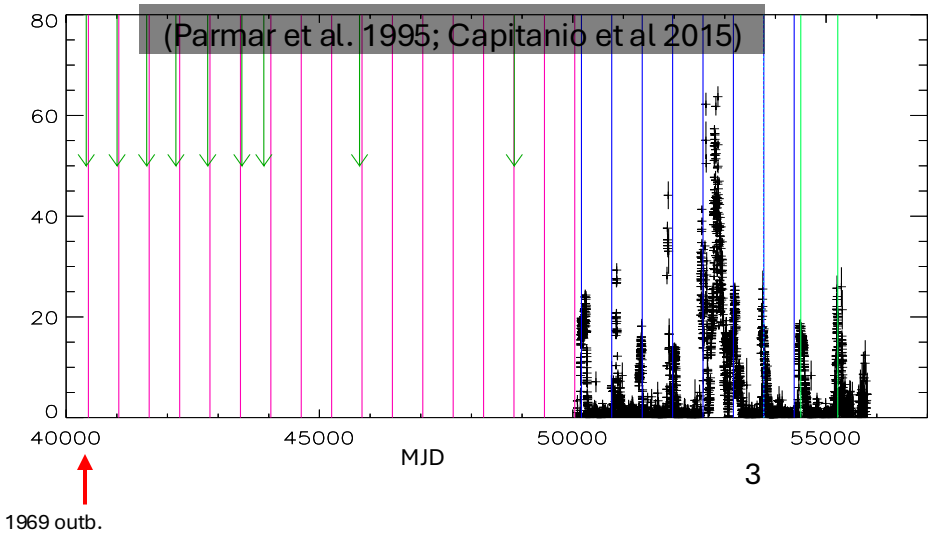
A close look to polarimetry in the soft state of the 2022/2023 outburst (preliminary new results).

Conclusions.

4U 1630-47 the only BH-LMXB with a precise recurrence period of the outbursts

- Classified as BH-LMXB, 4U 1630-47 has shown periodic outbursts since 1969 with about 610-day period
- The periodicity of the outbursts remains constant even after very long and bright outbursts. In fact these prolonged outbursts often show a rebrightening after 610 days from the start of the outburst .
- Two times a 110-day shift in the outburst recurrence time has been detected. However, then the 610-day periodicity is resumed
- To date, 4U1630-47 is the only one BH-LMXB showing this behavior so strictly.

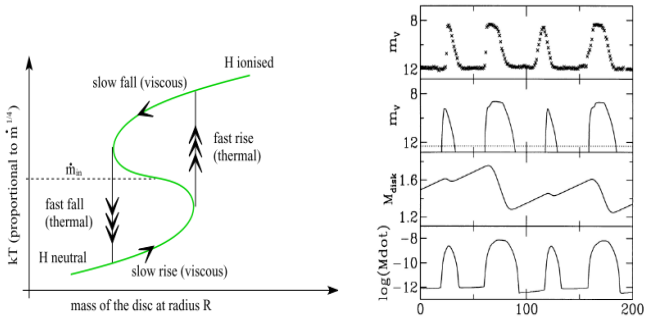




Possible explanation of periodic outbursts

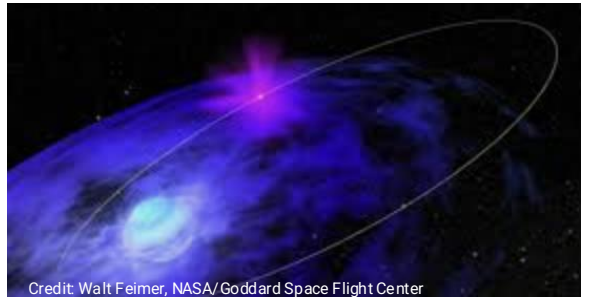
a 3rd body in a hierarchical configuration. The 3rd body near the instability limit could be a good candidate to cause periodic outbursts (see Capitanio et al. 2018). The 3rd body should have a highly eccentricity orbit and should arrive at the periastron a very near to the binary system to alter the disk temperature. However, the sporadic shift of about 100 days in the period is not easy to explain in this case

A limit cycle of the hydrogen ionization instability. This kind of behavior is currently observed in dwarf novae and cataclysmic variables, which exhibit a fast-rise/exponential decay shape of light curves and regular outbursts. Generally, the situation is different for BH and NS X-ray binaries: the outburst recurrence is not regular, and the light curves show more complex shapes compared to the simple profile (FR & ED).

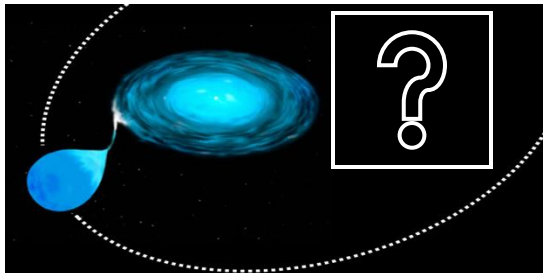


Done, Gierli´nski & Kubota 2007

A Be-X-ray binary with a Black hole. At the moment there is only one known Be X-ray hosting a Black hole as compact object . 4U 1630-47 would be the only accreting BH-Be X-ray binary.



A X-ray binary system with an eccentric orbit. It is difficult to explain on the evolutionary poi of view if we consider 4U 1630-47 a low mass X-ray binary

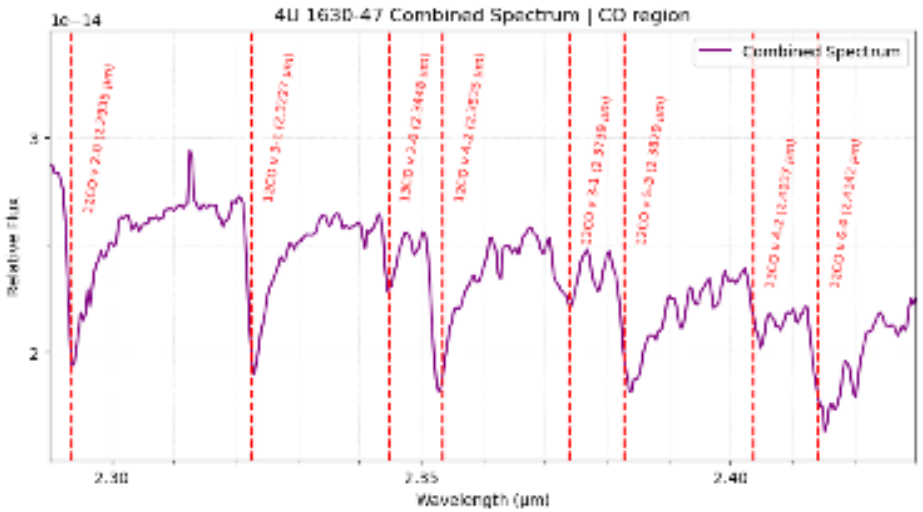


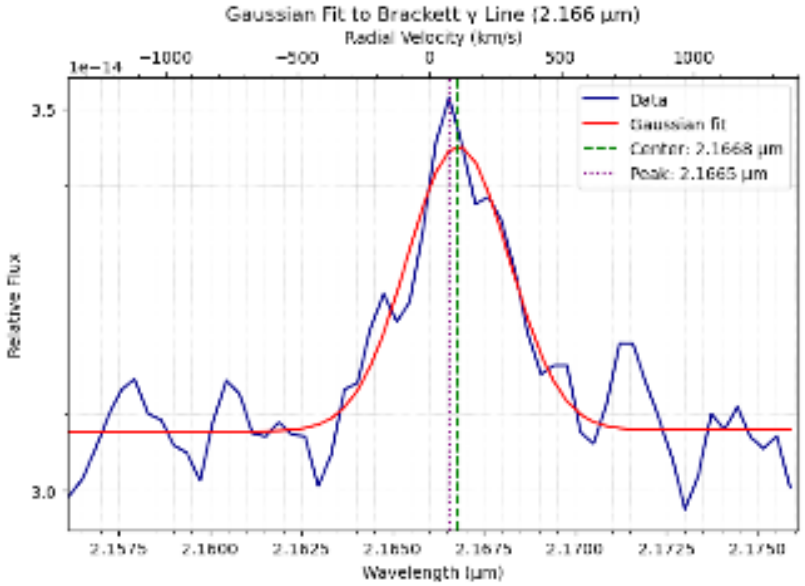
Nature of the Companion star of 4U 1630-47

- Recently GEMINI Flamingos-2 K-band spectroscope observed the source 2 times to investigate the nature of 4U 1630-47 companion star.
  - Nature of the companion star: Not a Be star, but an evolved star.

Based on the spectrum (CO band and relative depths of Al/Mg at ~4200 cm^{-1} and Ca/Sc/Ti at ~4740 cm^{-1}), we get a spectral type of **M0 III Giant**. (using Wallace & Hinkle, 1997).

- The quasi-periodic outbursts are probably the result of an orbital period of ~610 days.
- This may be the first Black Hole Symbiotic X-ray Binary we have observed.
- The Brackett γ emission line originates from the accretion disk around the black hole.



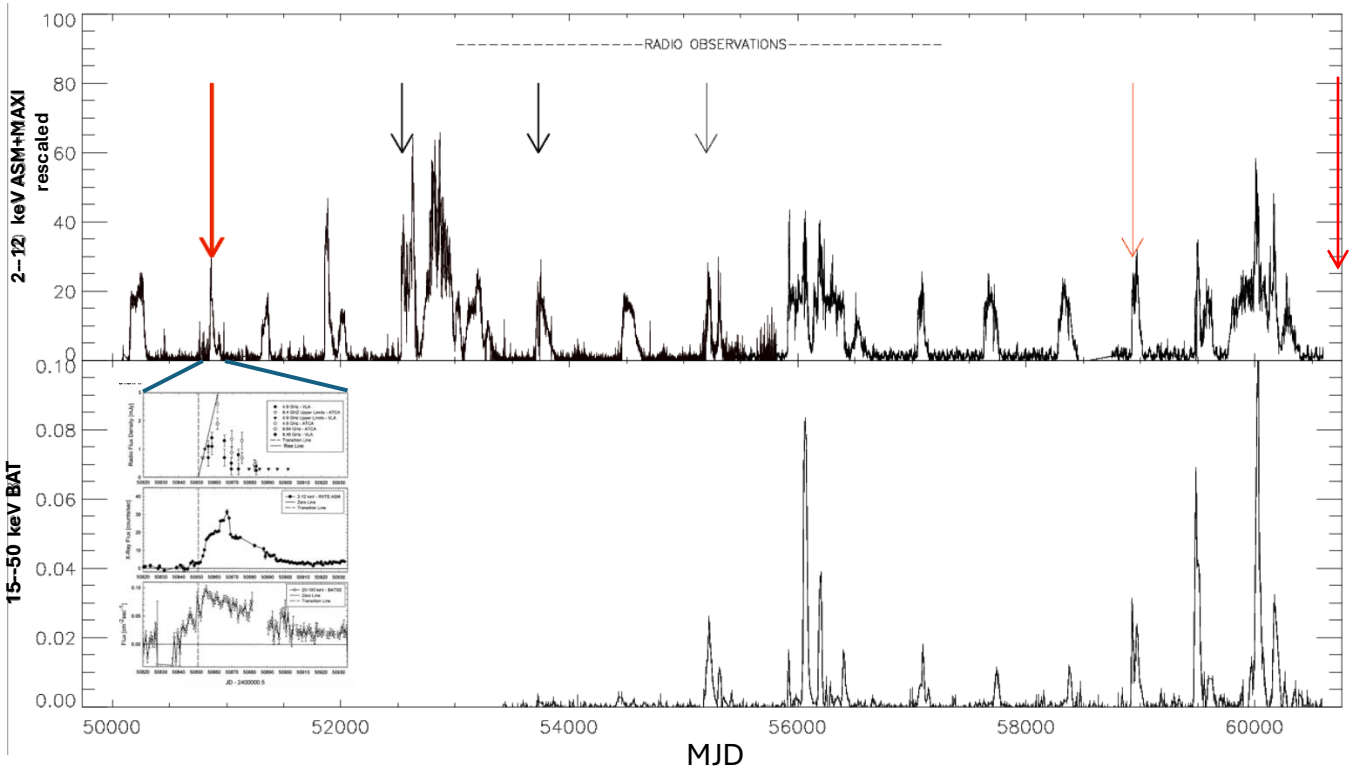


new results

Droudakis, K. et al in preparation

4U 1630-47 a “quasi” radio-quiet transient BH-LMXB

- Several radio campaign were carried on during the source outbursts.
- Most of them obtained only a stringent upper limit.
- No relativistic radio jets have ever been observed in 4U 1630-47
- However, 3 times the observations succeed to catch the source emitting at radio frequencies.
- In 1997 the source was detected in radio band along all the outburst
- In 2020 and 2025 the source was detected in radio band too (compact jets).

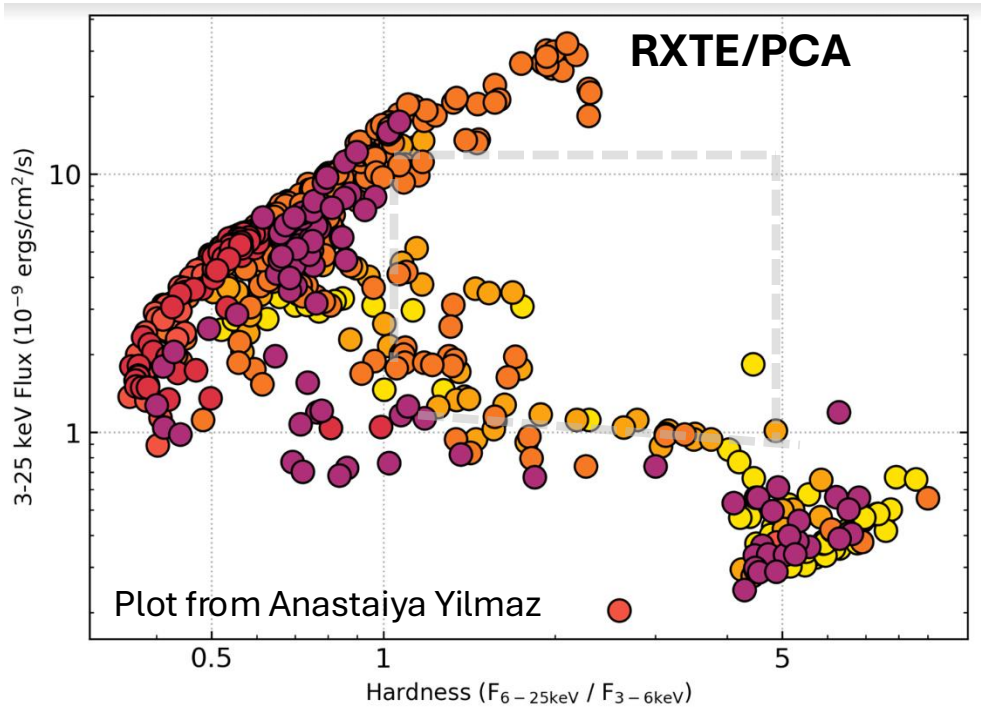


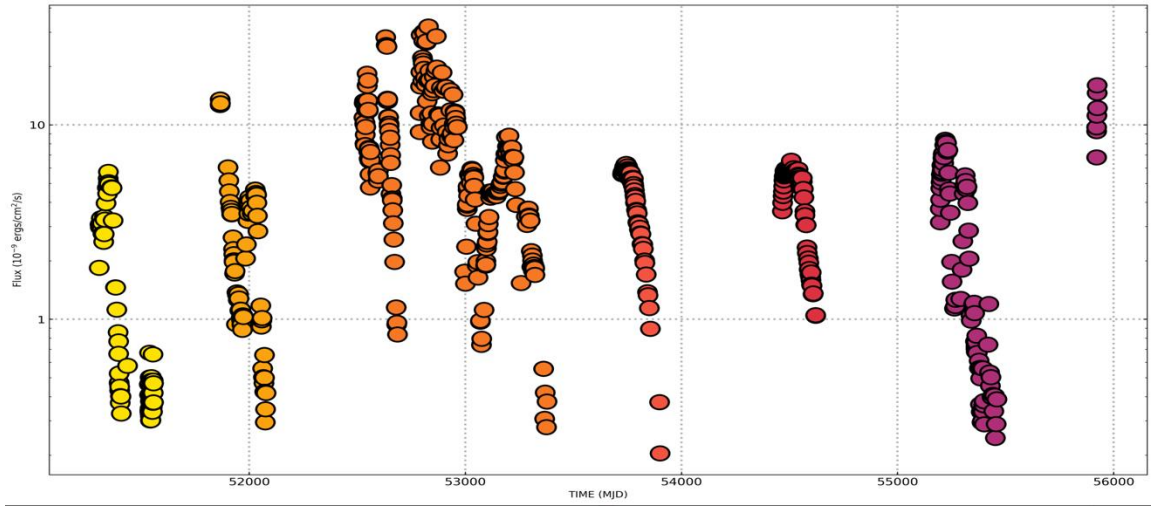
Hjellming et al. 1999;
AteL#: 108;
Atel #: 685;
ATel #2370;
Julien et al. ATel #:13592
Miariani et al. Atel #17164

→ Radio detection
→ No radio detection

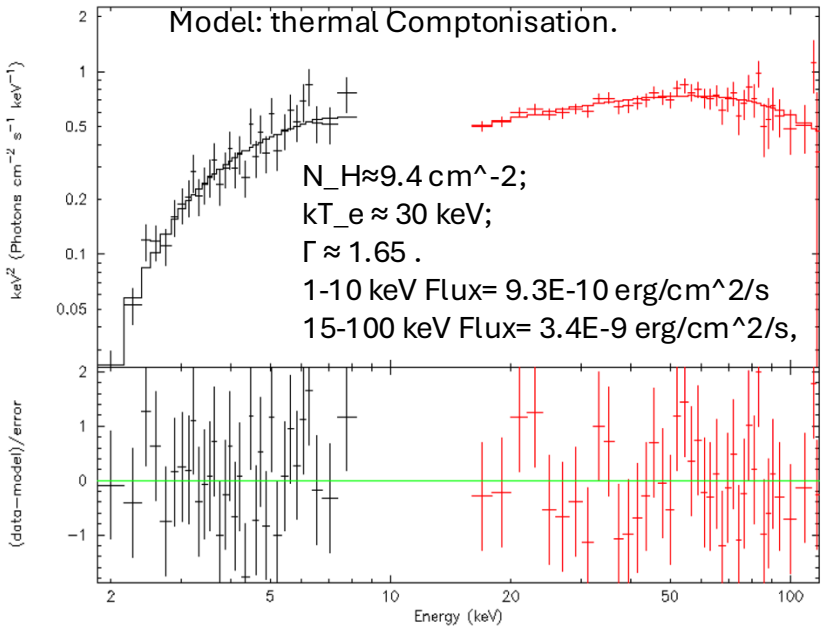
Lack of bright hard states

- As the HID of all the RXTE/PCA data shows, the bright hard state, are not present in 4U 1630-47. The HID has not the classical Q shape as observed in other BH-XRB
- the hard state emission is present but subluminous and comparable with the quiescent state.
- Few times the hard emission was found slightly brighter
- The bright hard (15-50 keV) emission in some outbursts increase simultaneously with soft emission (2-10 keV) and became very bright (steep power low state)

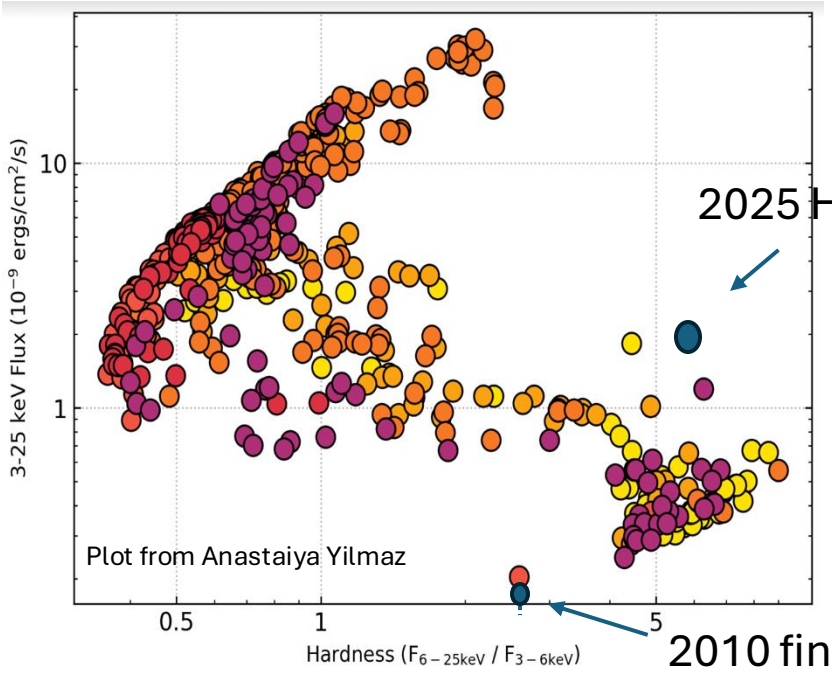




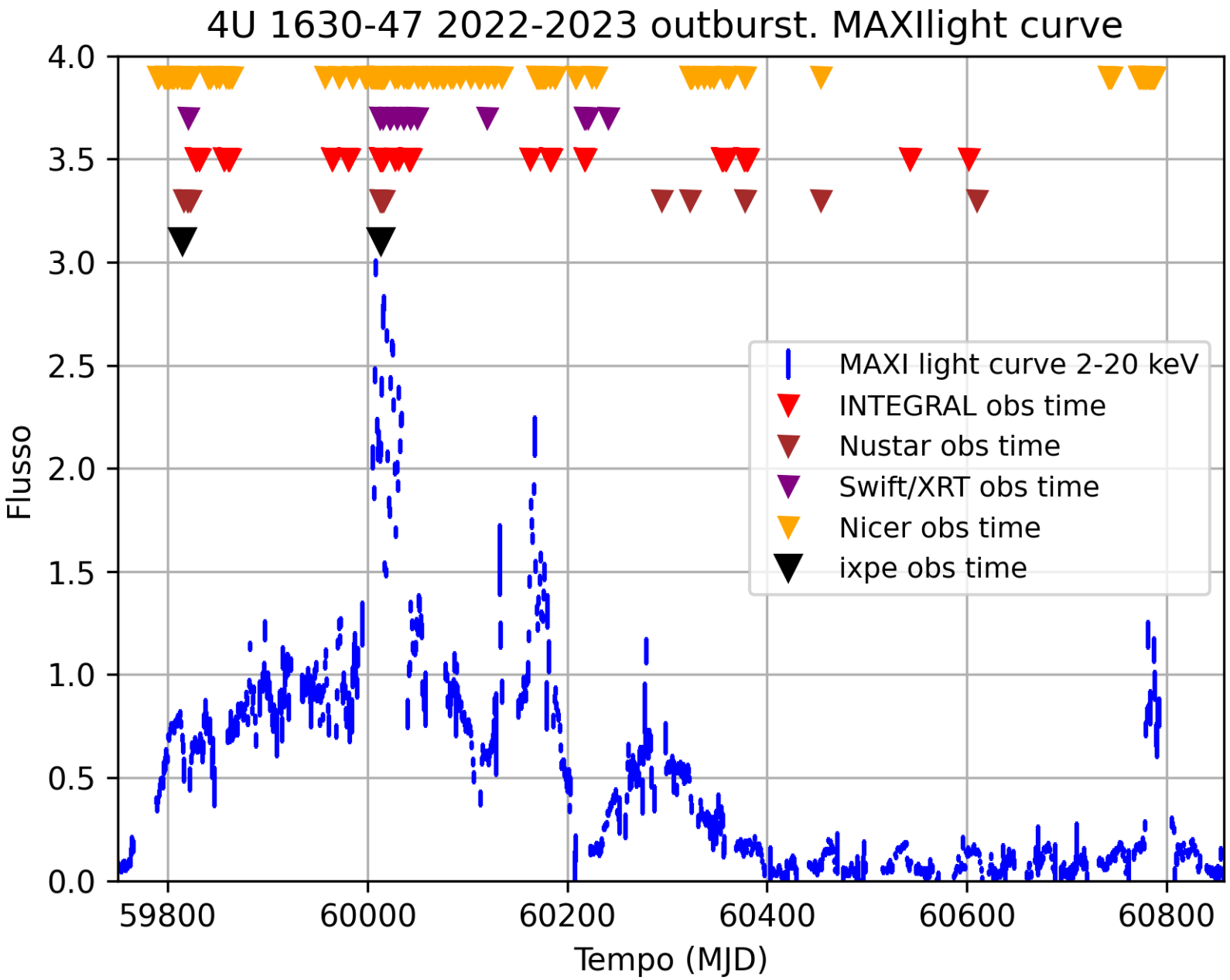
Looking at the detected hard states



- A typical hard state spectrum has been observed at the beginning last outburst (6-7 April 2025; Del Santo et al. 2025 Atel 17139). It appears subluminous consistently with the previous observed "relatively bright" hard states by PCA (yellow , orange and purpure outbursts).
- In the subsequent days the source was also unusually bright in radio band (Mariani et al 2025 Atel 17164)
- Searching in literature, we found that also during the 1997 outburst (yellow points in HID), the source was particularly active in radio band.



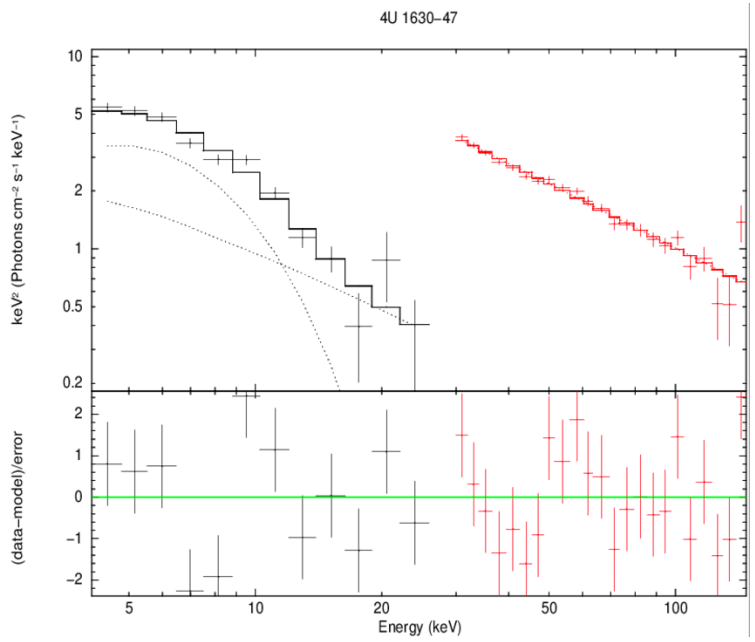
- During the 2010 outburst Tomsick et al. 2015 discovered that the transition back to the final hard state occurred when the source was near the quiescent state at luminosity 0.03% LE.
- Black point in figure. We noticed that this final hard state has the same luminosity level and hardening of the final pointing of a previous outburst (observed by RXTE/PCA, orange points in figure)

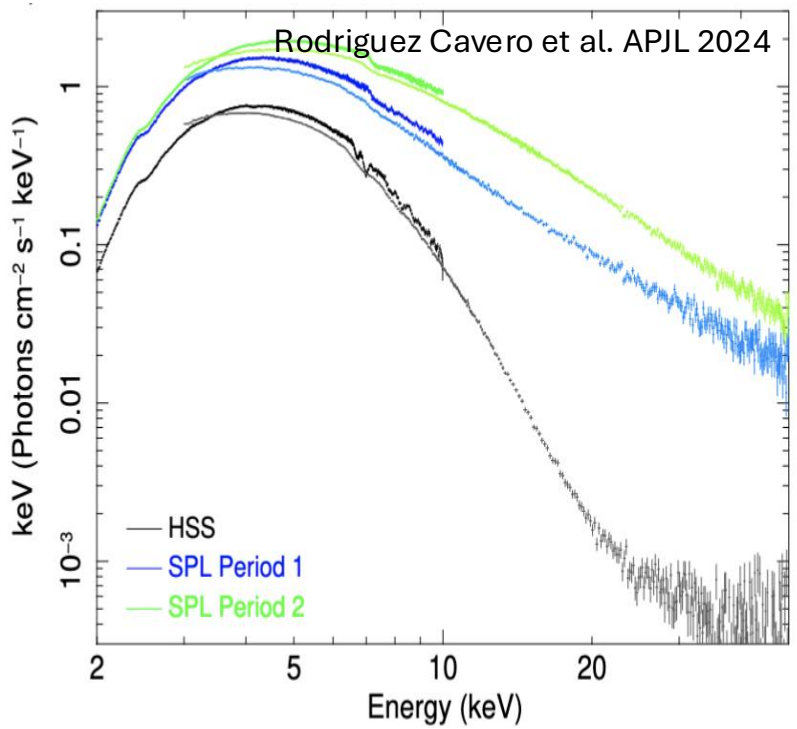


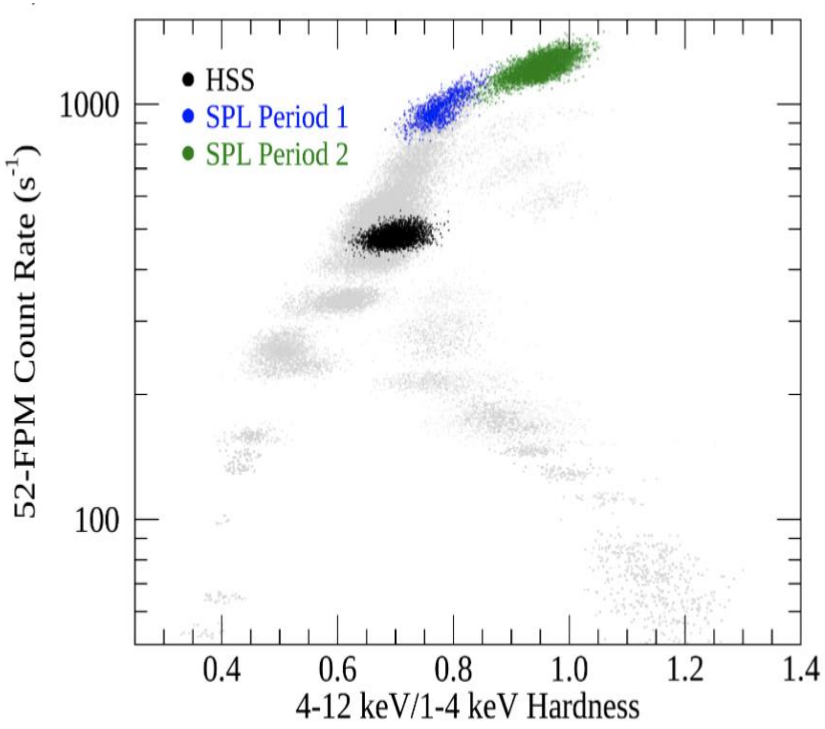
2022-2023 outburst. Multiwavelength campaign

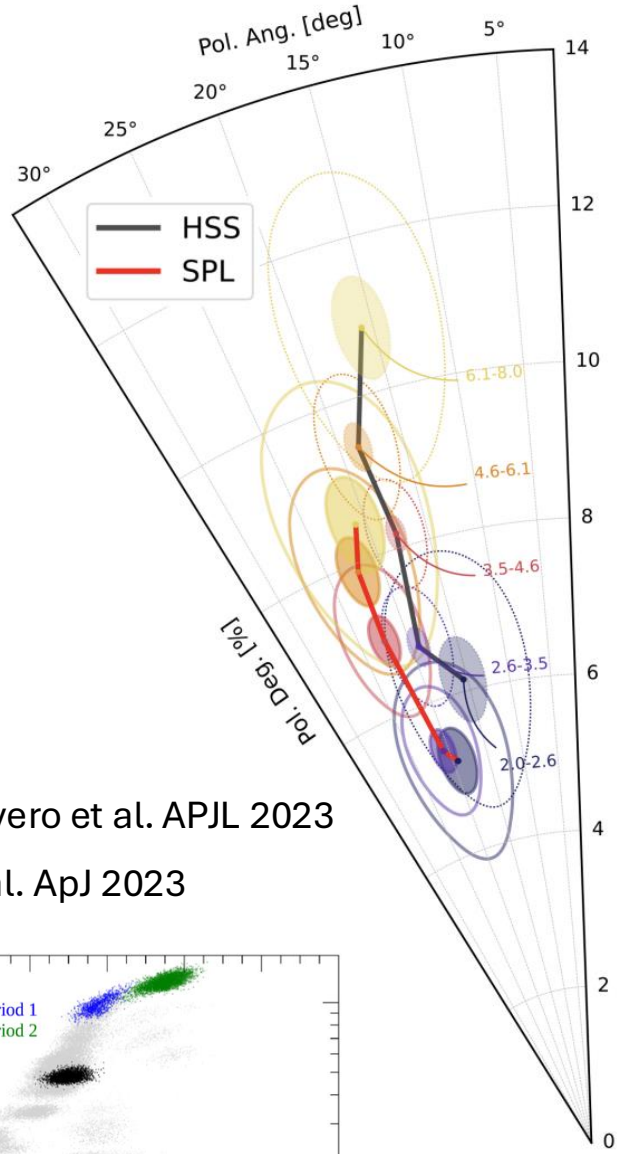
4U 1630-47 2022/2023 outburst IXPE observations

- Despite the dense Nicer observations, it seems that the 2022-23 outburst totally lacked a bright hard state.
- A huge multifrequency campaign has been carried out during this outburst: Nicer, Swift, Nustar, INTEGRAL, IXPE. Unfortunately, not always perfectly coordinated
- It brightened at high energies late during the outburst, directly showing the typical soft-state non-thermal corona, as confirmed by INTEGRAL/IBIS high-energy data.



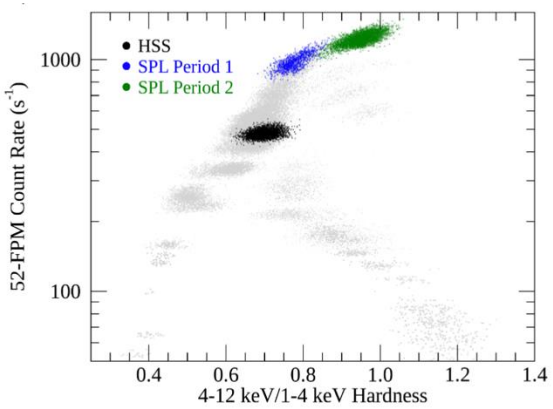






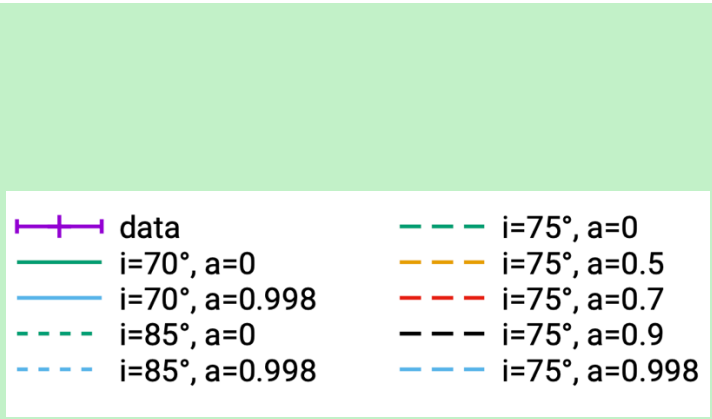
Rodriguez Cavero et al. APJL 2023

Ratheesh et al. ApJ 2023

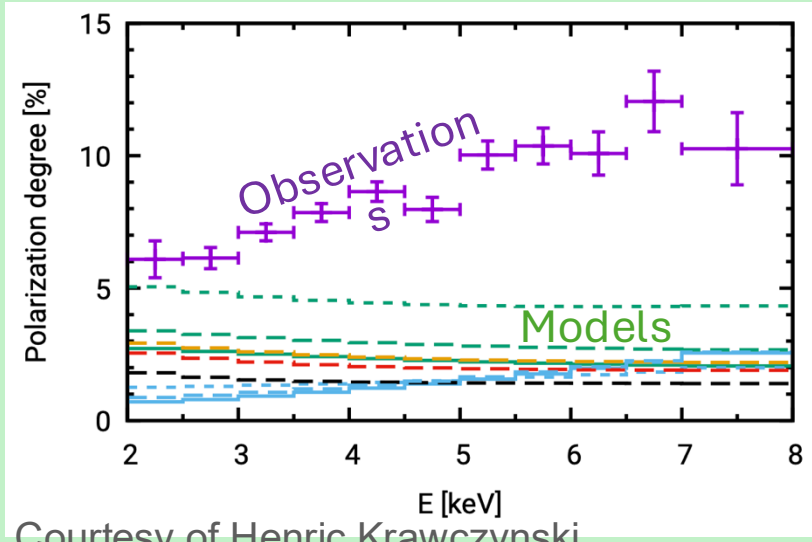


4U 1630-47 shows a higher polarization degree than that observed from other sources."

- Detection of higher level of polarization degree compared to other transient BH-LMXBs
- No substantial variation of polarization with source state. In other BH-LMXB, PD% is very low in HSS (GX339-4; Cyg X-1, Swift J1727.8–1613)
- Presence of wind in HSS, spectra
- in SPLS no winds are detected and the spectrum changes drastically. But no substantial changes in PD and PA
- the polarization results to be independent of spectra, wind, and accretion rate variation.

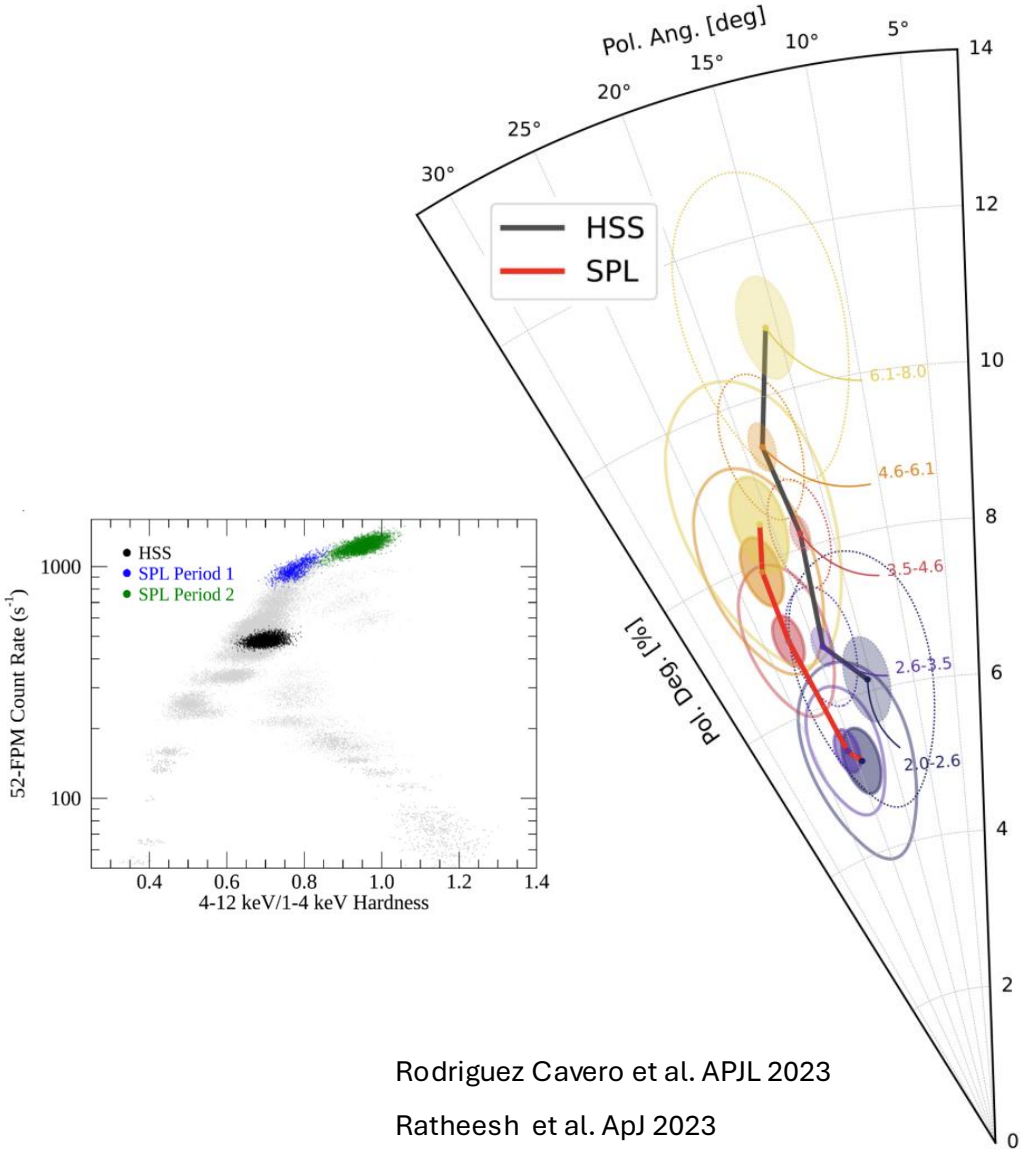


Krawczynski et al ApJ, 977,L10



Courtesy of Henric Krawczynski

Reanalysis of the polarimetric data: First IXPE observation

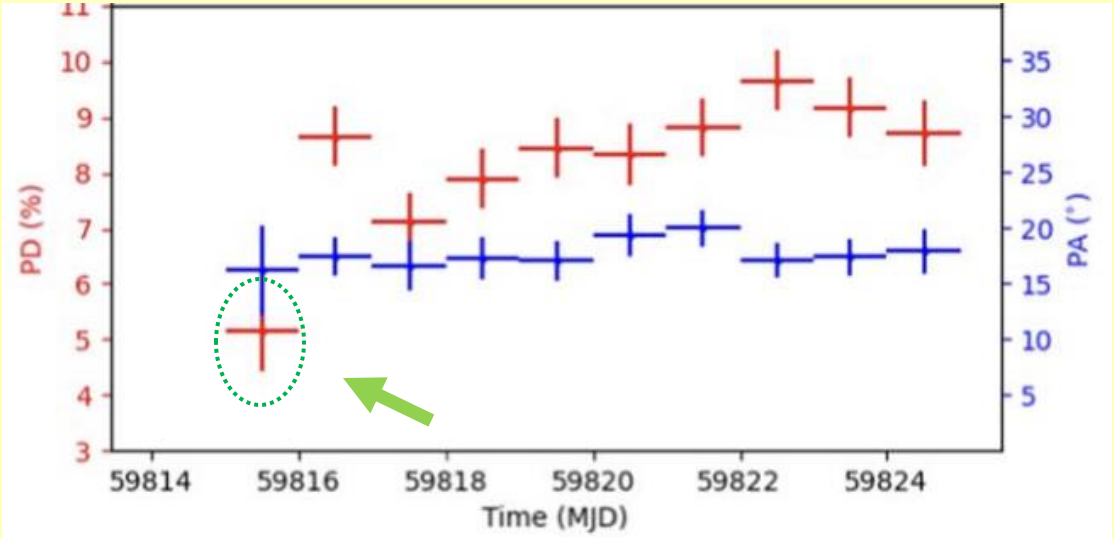


Rodriguez Cavero et al. APJL 2023

Ratheesh et al. ApJ 2023

- However, the PD and PA vs time in HSS state (Figure 4, Ratheesh et al. ApJ 2023) reports a lower value of the PD at the beginning of the curve.
- We re-analised the polarimetric data in details producing a PD and PA vs energy spectrum for each point of the curve shown below

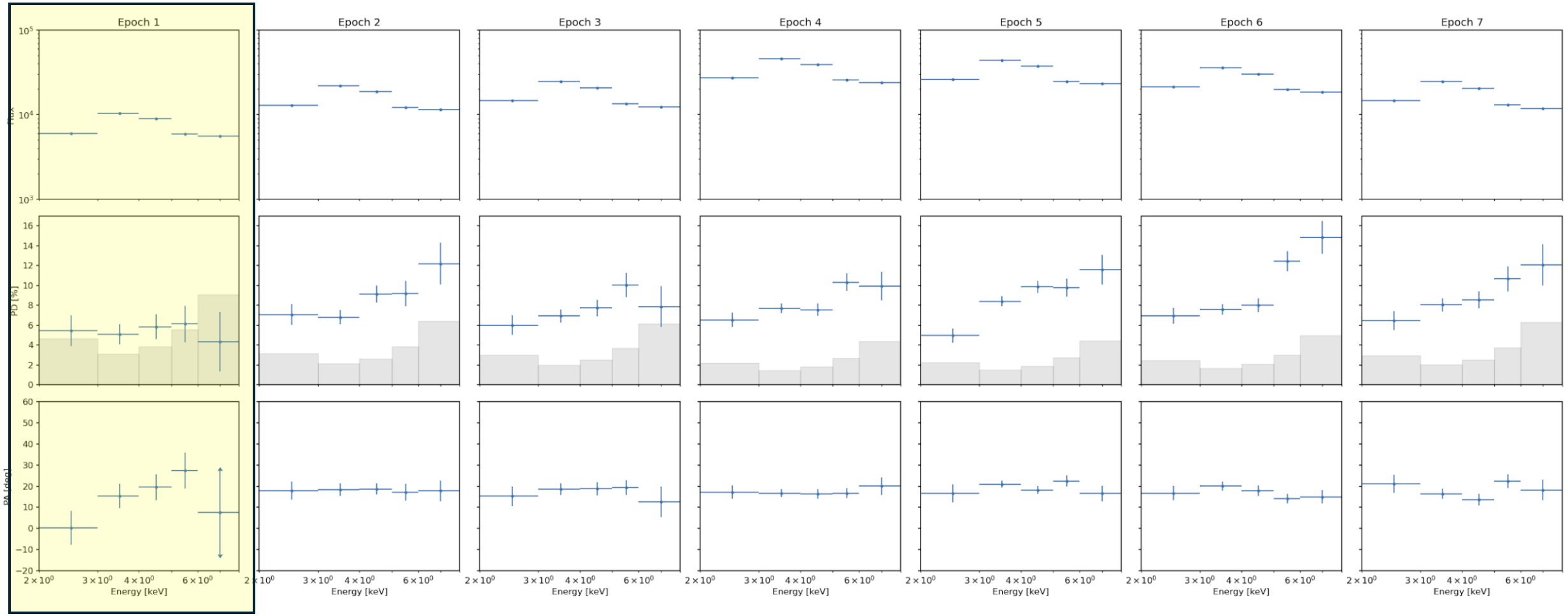
PD (red) and PA (blue) vs Time in HSS. First IXPE observations.



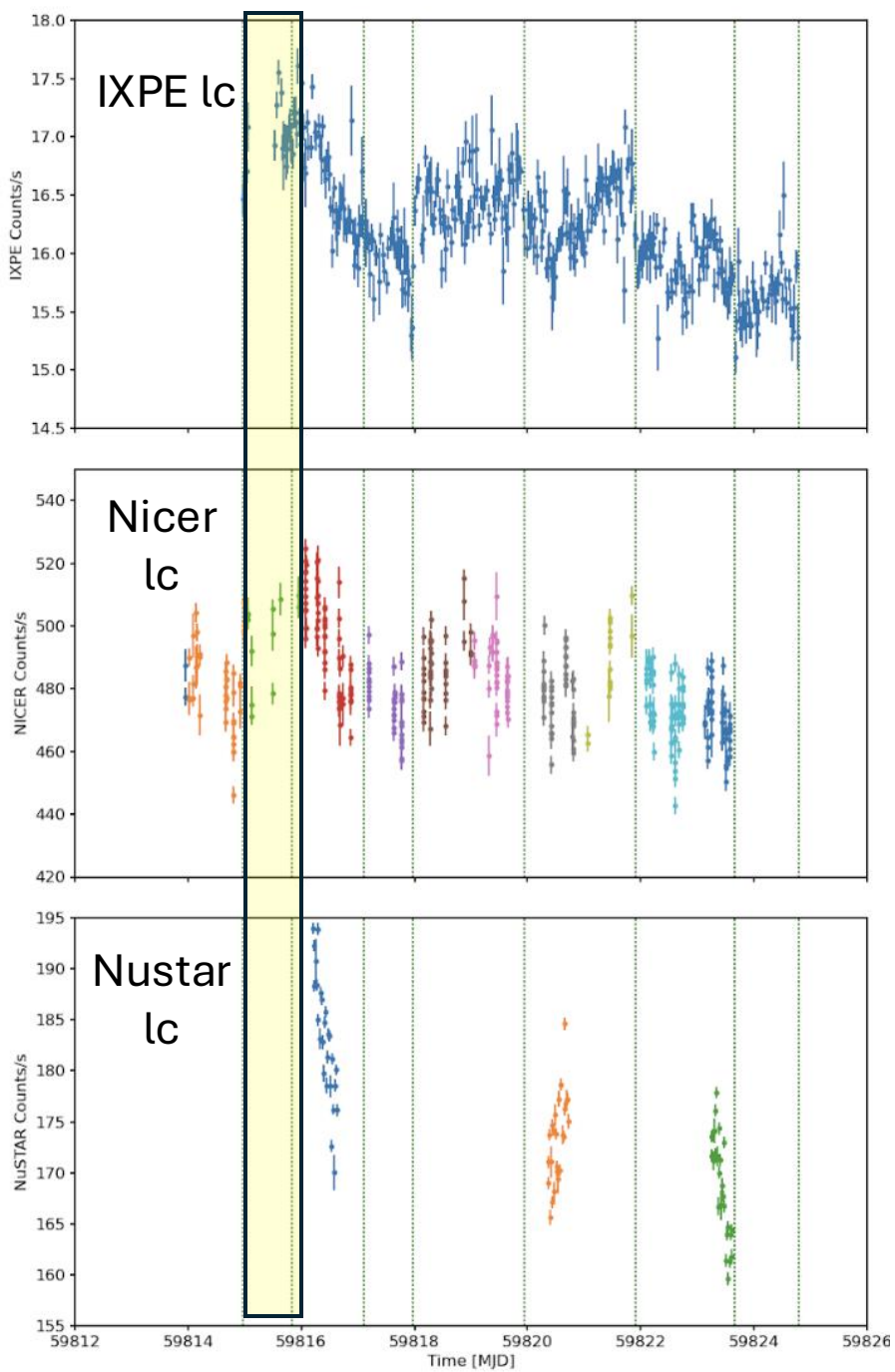
Ratheesh et al. ApJ 2023 Fig 4.

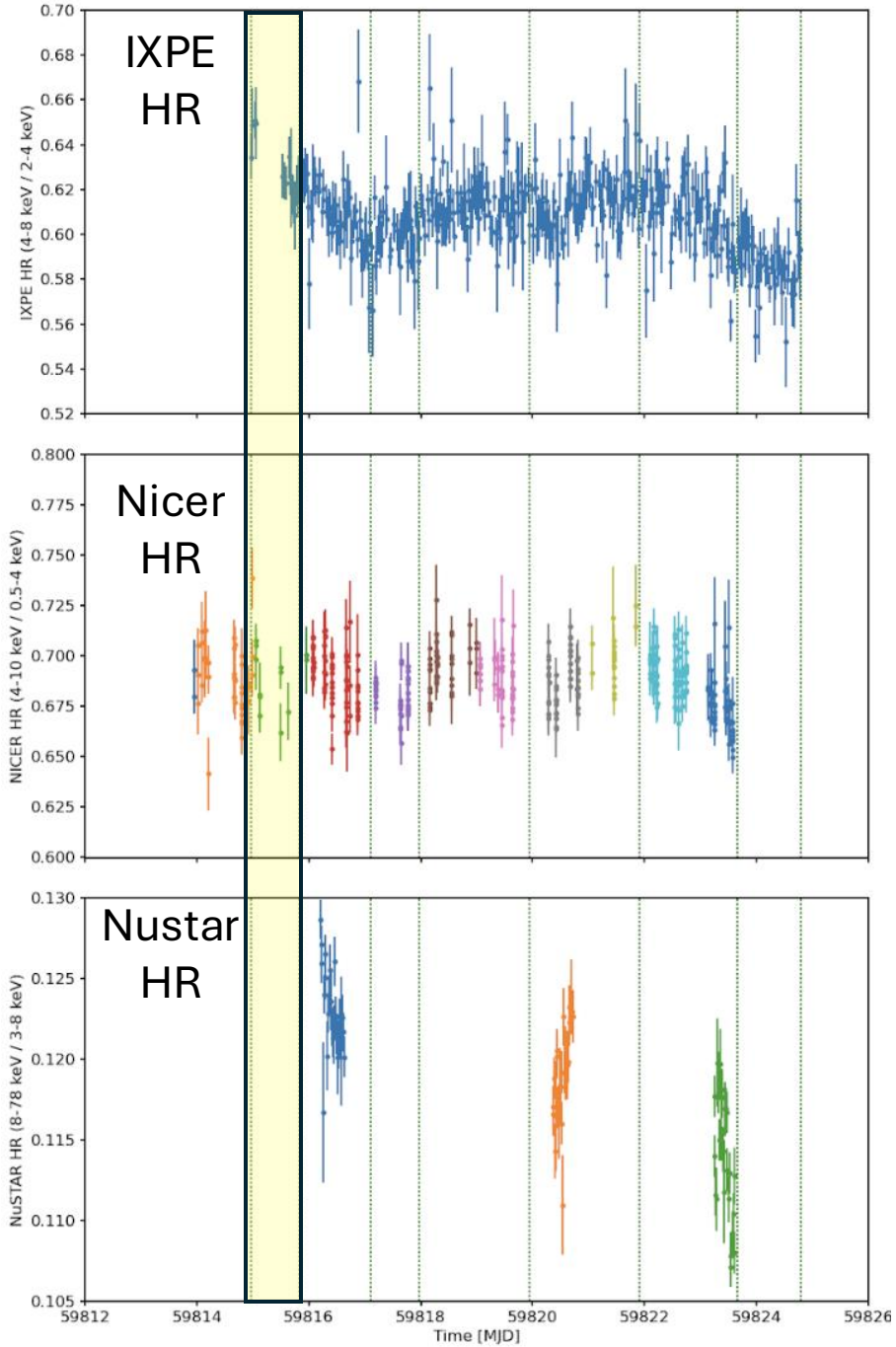
Preliminary results

We divided the observation in 7 Epochs.
Epoch 1 shows different PD% and PA respect to the other Epochs.



Marra et al. in preparation





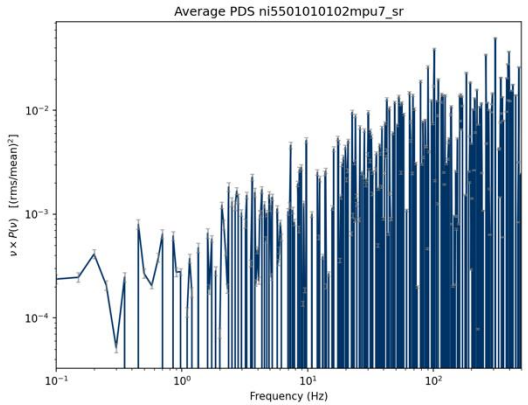
Limited variations of H/R and flux are present in the different Epochs.

we do not have any information about the spectral evolution above 8 keV in Epoch1. The Nustar obs. started later in Epoch2

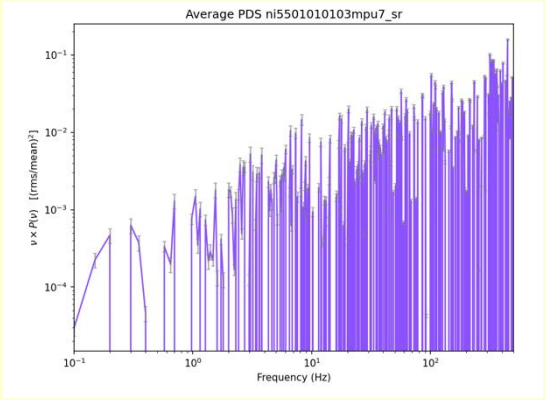
The only simultaneous observation during the Epoch1 is a very short Nicer observation.

The spectra remain constant in Epoch1, and Epoch2 as far as power spectrum and RMS% does not show evident changes

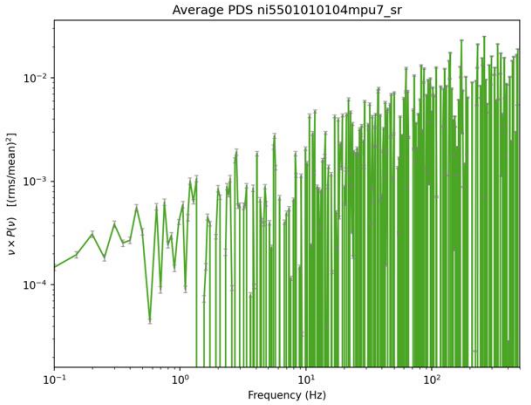
Nicer obs (pre IXPE)
$F_{2\text{-}10\,keV}$: $5.1e^{-09}$ ergs/cm^2/s
Model const*
phabs*claudy*(diskbb)
err at 90%
Chi2=0.79
$Nh=7.46_{-0.04}^{+0.08}$
Tin=1.47+/- 0.01
$Norm=1.64_{-0.07}^{+0.08}$ (10^2)



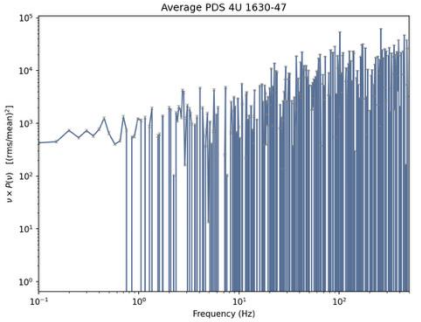
Epoch 1 IXPE obs.
$F_{2\text{-}10\,keV}$: $4.2e^{-09}$ ergs/cm^2/s
Model const* phabs*(diskbb)
err at 90%
Chi2=0.93
Nh=8.44 +/- 0.06
Tin=1.54+/- 0.01
Norm=1.10 +/-0.06 (10^2)
C_DU1=1 fixed
C_DU2=1.024+/-0.006
C_DU3= 1.006+/- 0.006



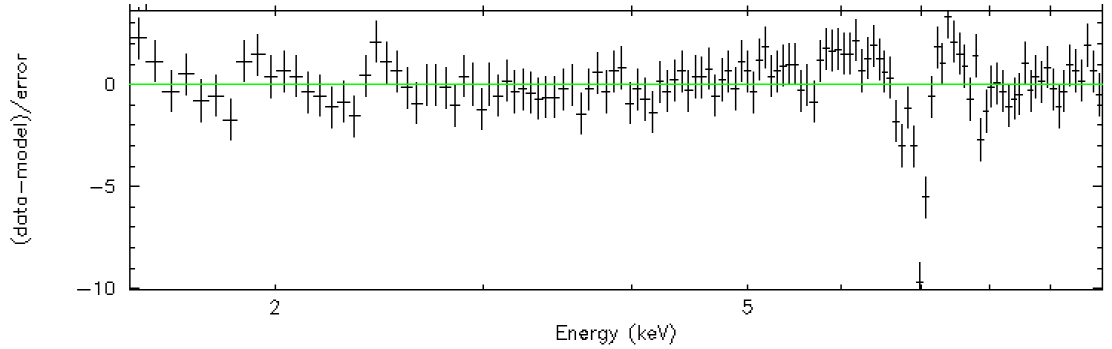
Epoch 2 IXPE obs.
$F_{2\text{-}10\,keV}$: $3.9e^{-09}$ ergs/cm^2/s
Model const* phabs*(diskbb)
err at 90%
Chi2=1.5
Nh=8.24 +/- 0.04
Tin=1.51+/- 0.01
Norm=1.11 +/-0.03 (10^2)
C_DU1=1 fixed
C_DU2=1.026+/-0.003
C_DU3= 1.005+/- 0.003



Averaged powspec

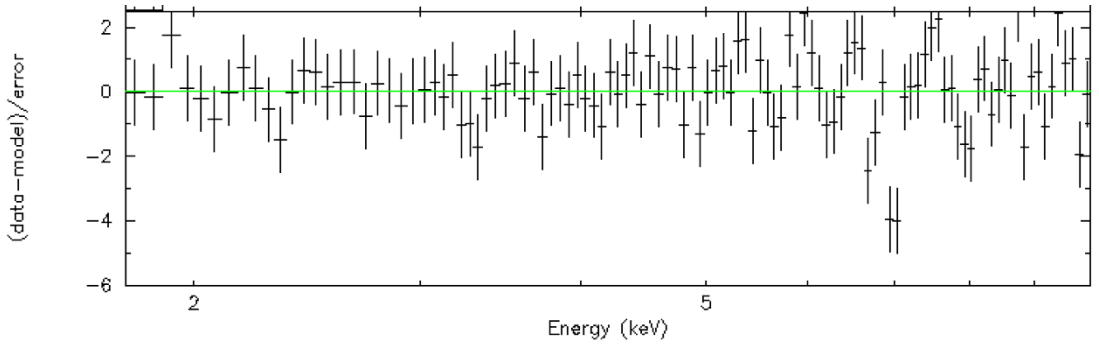


As well as wind features.

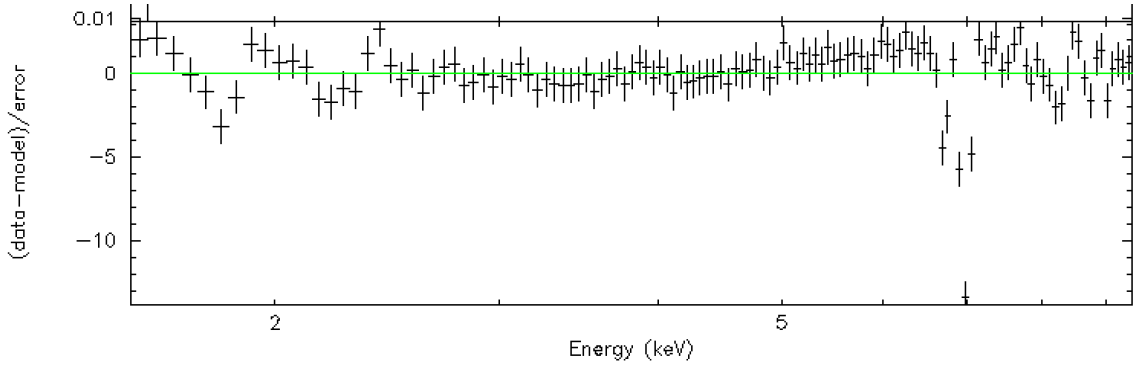


Nicer obs. **pre ixpe obs;**
Exposure time 2ks

Logxi =5.2(-0.5;+0.3)
Lognh=24.1(-0.5;+0.2)



Nicer obs. Simultaneous to **Epoch1** (first IXPE obs)
Exposure time 0.4 ks
Logxi =4.8(-0.5;+0.9)
Lognh=23.5(-0.5;+0.7)



Nicer obs. Simultaneous to **Epoch2** (second IXPE obs.)
Exposure=3.9 ks

Logxi =5.0(-0.1;+0.2)
Lognh=24.0(-0.1;+0.1)

Conclusions

4U 1630-47 is a peculiar BH-XB in many aspects:

- It shows periodic outbursts equally spaced in time
- It has a red giant companion and probably it is a symbiotic binary hosting a BH as compact object
- It lacks bright hard states. But often sub-luminous hard states are detected both at the beginning and at the end of the outbursts and are correlated with more pronounced activity in radio bands.
- It shows a particularly high level of X-ray polarization that is inexplicable with actual models that does not vary with the spectral changes and with the presence of wind features.
- On the contrary, It shows variations in X-ray polarization at shorter timescale that seem not correlated with any other variation of the system properties.

Can the red giant companion explain the peculiarities of the source?

Thank you