Unveiling the nature of 4U 1630-47 with INTEGRAL and IXPE

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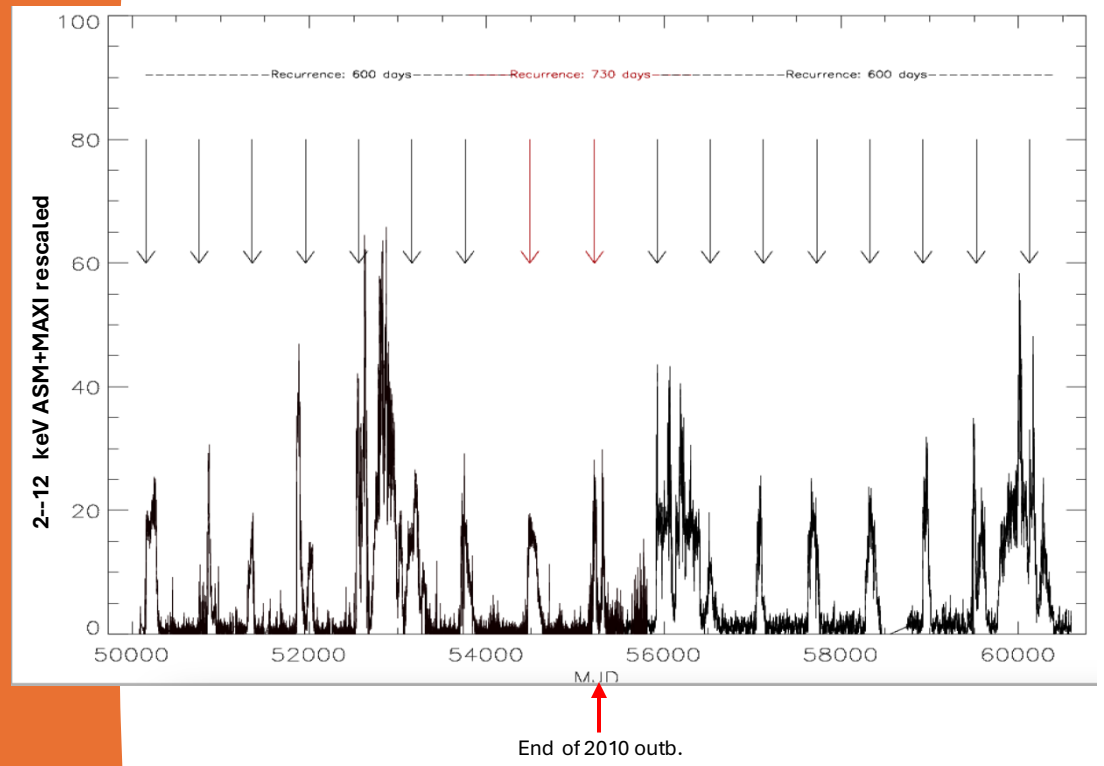
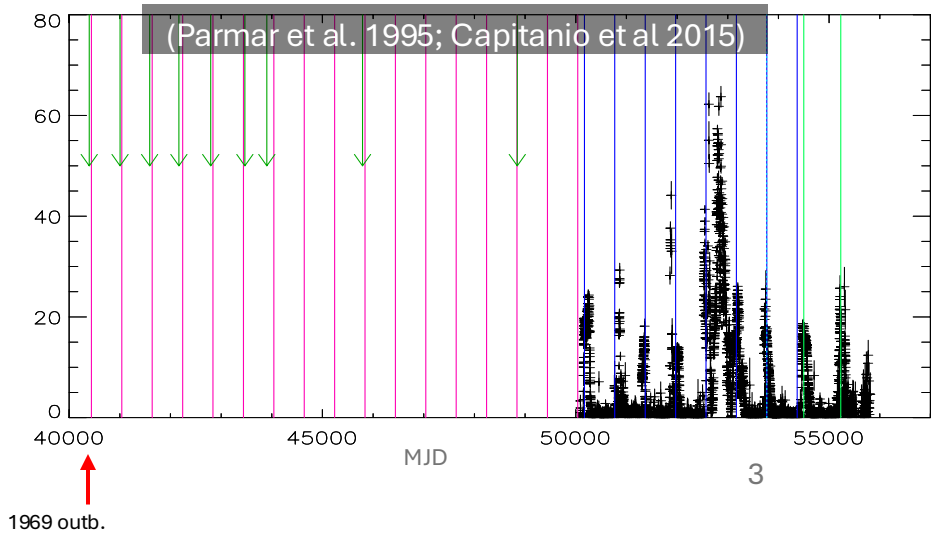
Outline of the talk:

- 4U 1630-47 outburst recurrency.
- Lack of bright hard states.
- Radio emission.
- A close look to the soft state of the 2022/2023 outburst.
- Polarimetry.
- Winds.
- Conclusions.

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

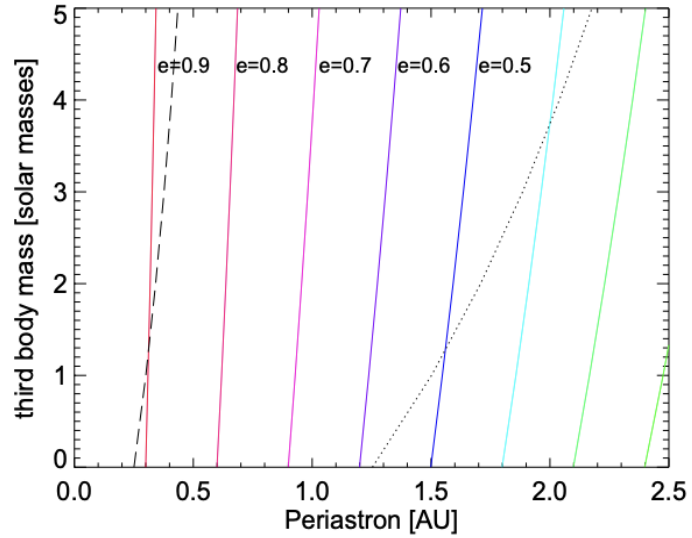
- Classified as BH-LMXB, 4U 1630-47 has shown periodical outbursts since 1969 with a 630-day period
- The periodicity of the outbursts remains constant even after very long and bright events.
- These prolonged outbursts often show rebrightening at the end of each periodic cycle.
- Around MJD 54500 there was a 110-day shift. Then the 630-day periodicity resumed
- To date, 4U1630-47 is the only one BH-LMXB showing this behaviour so strictly.
- Reconstructing the past outburst recorded in literature, the periodicity remains unaltered till 1969. Another ~110-day shift is present at the beginning of 1996.





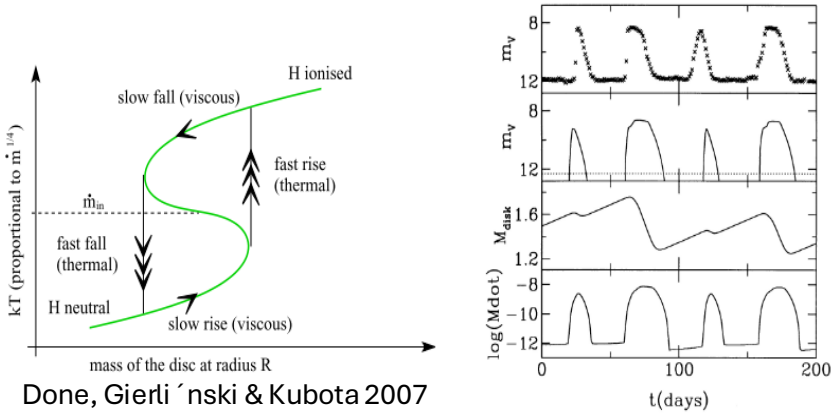
A 3rd body in a hierarchical configuration? Or the limit cycle of the hydrogen ionization instability?

- **a 3rd body in a hierarchical configuration.** The 3rd body near the instability limit could be a good candidate to cause periodical 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



Capitanio et al. 2018

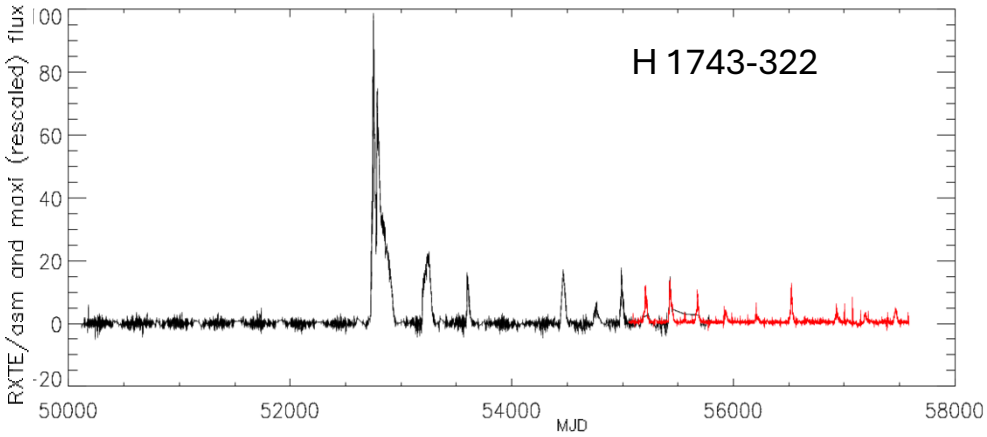
- **A limit cycle of the hydrogen ionization instability.** This kind of behaviour is currently observed in dwarf novae and cataclysmic variables, which exhibit a fast-rise/exponential decay shape of light curves and regular outbursts.
- Generally, the situation is different for BH and NS X-ray binaries: the outburst recurrence is not regular, and the light curves show more complex shapes compared to the simple profile (FR & ED).
- 4U 1630-47 to date is the only BHC showing outbursts equally spaced in time

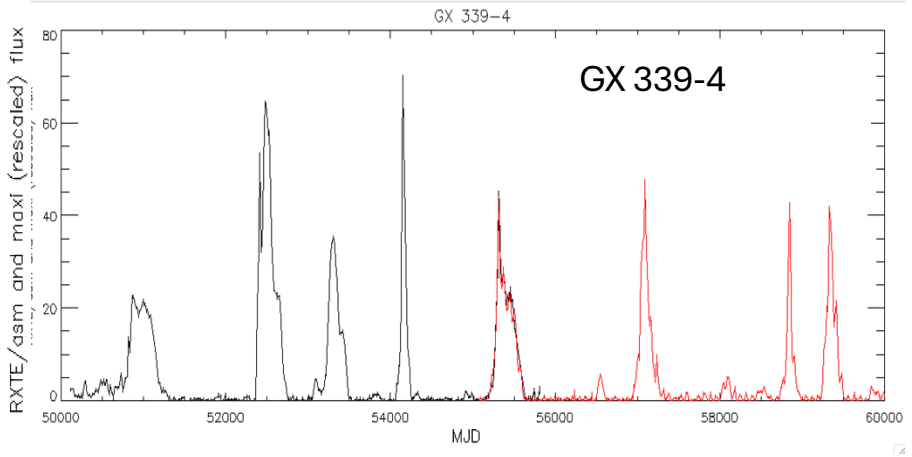


Done, Gierli´nski & Kubota 2007

A 3rd body in a hierarchical configuration? Or the limit cycle of the hydrogen ionization instability?

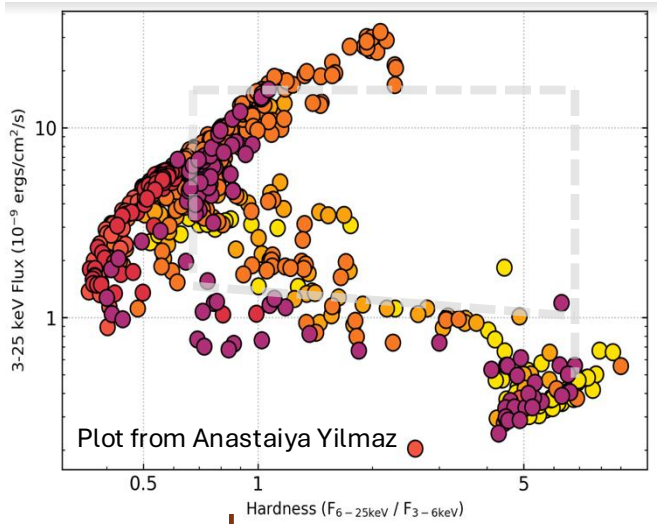
- Even if the outburst ignition in X-ray binaries, as for dwarf novae, is thought to be due to hydrogen ionization instability . The limit cycle of hydrogen ionization should not be the only mechanism of the outburst recurrence.
- There are other processes that modify both the light curve profile and the recurrence period of the outbursts. (i.e. irradiation of the disk)
- For example, GX 339-4 exhibits irregular outbursts repetitions while the outburst shapes are often similar to fast-rise/exponential decay
- H 1743- 47 has shown equally spaced outbursts after the main outburst of 2006. however, after 3 or 4 outbursts the period changed and more recent outbursts the periodicity is totally lost

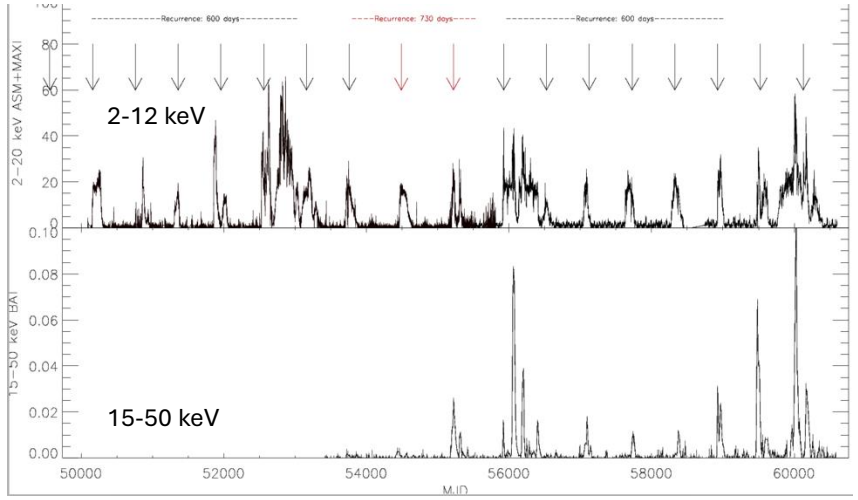




Lack of bright hard states

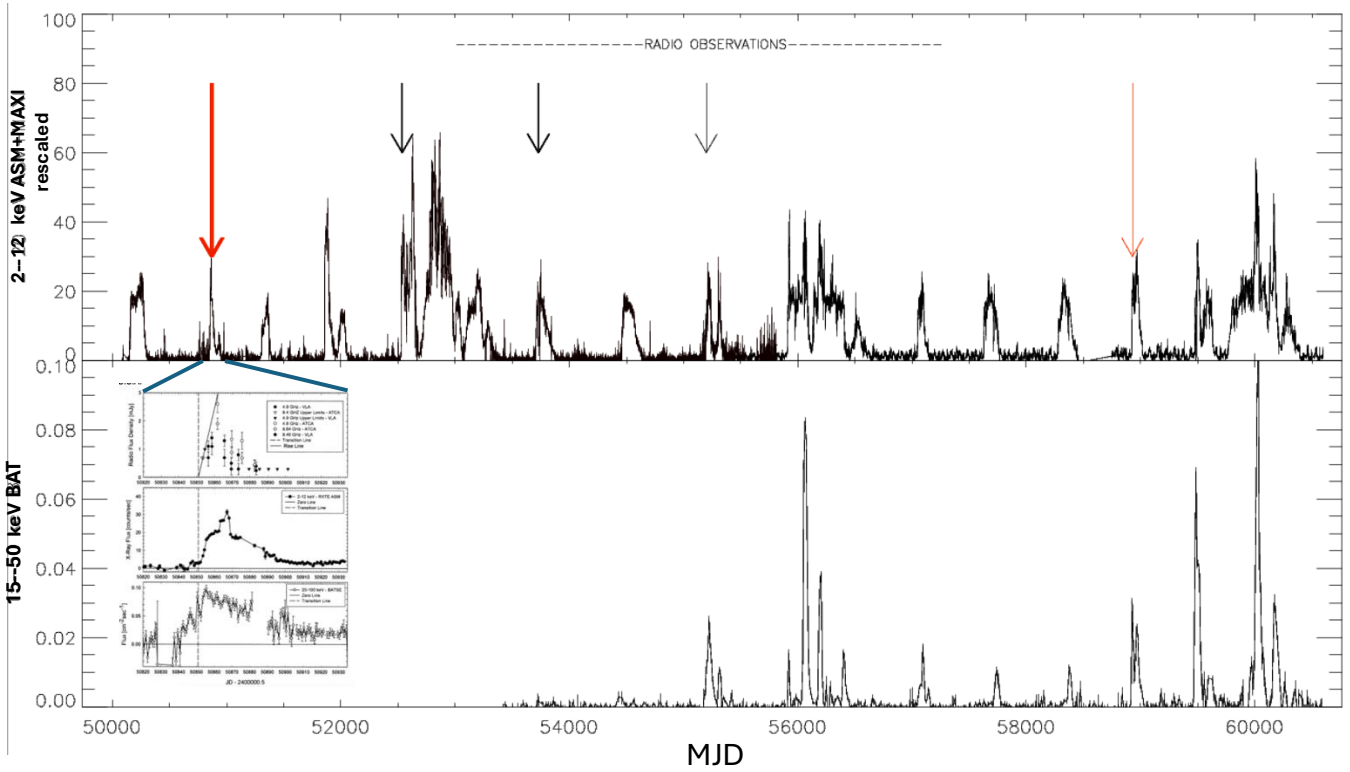
- 4U 1630-47 often lacks the bright hard state at the beginning of the outbursts
- Sometimes the hard state emission seems to not be present at all (MJD 54500).
- Sometimes the hard emission (15-50 keV) increase simultaneously with soft emission (2-10 keV) and became very bright
- As the HID of all the RXTE/PCA data shows, the bright hard state, are not common in 4U 1630-47. The HID has not the classical Q shape as observed in other BH-XRB





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

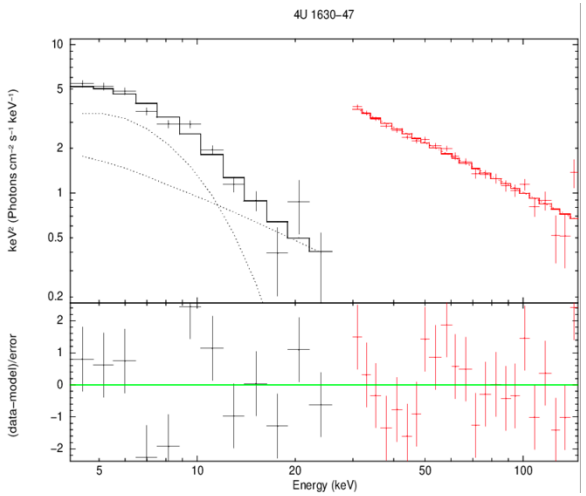
- Several radio campaign were carried on during the source outbursts.
- Most of them obtained only an stringent upper limit.
- No relativistic radio jets have ever been observed from 4U 1630-47
- However, two times the observations succeed to catch the source emitting at radio frequencies.
- In 1997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

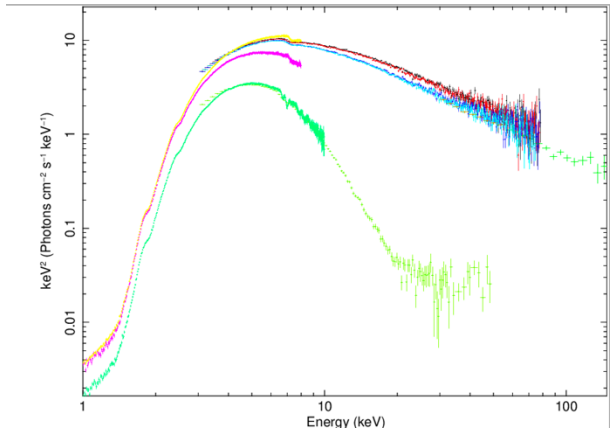


Hjellming et al. 1999;AteL#: 108; Atel #: 685; ATel #2370; ATel #:13592

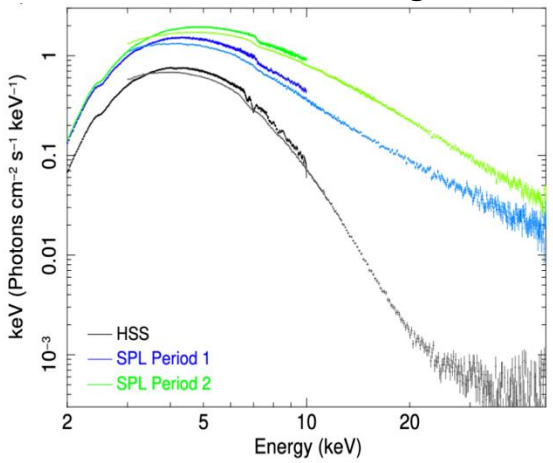
4U 1630-47 2022/2023 outburst

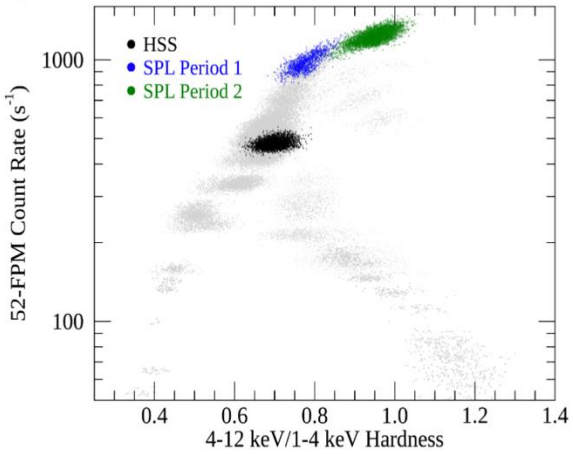
- For example, the most recent outburst totally lacked a bright hard state too .
- A huge multifrequency campaign has been carried out during this outburst: Nicer, Nustar, INTEGRAL, IXPE
- It brightened at high energies late during the outburst, directly showing the typical soft-state non-thermal corona, as confirmed by INTEGRAL/IBIS high-energy data.



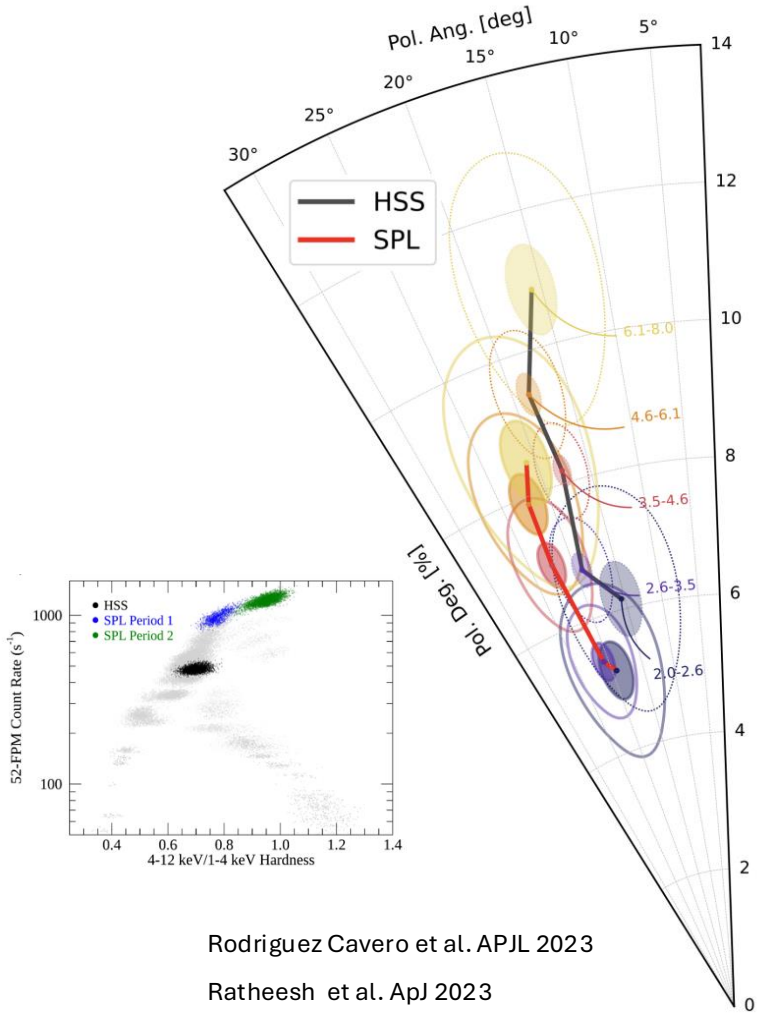


Rodriguez Cavero et al. APJL 2024





Capitanio, Marra et al. in preparation



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 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)
- In HSS, spectra show absorption lines indicating the presence of wind
- in SPLS no winds are detected and the spectrum changes drastically.
- the polarization results to be independent of spectra, wind, and accretion rate variation.

No theoretical expanation exists for such high polarization degree of 4U 1630-47

Evaluation of several explanations of the strong X-ray polarization of the black hole X-ray binary 4U 1630–47

Henric Krawczynski [1], Yajie Yuan [2], Alexander Y. Chen [2], Kun Hu [1], Nicole Rodriguez Cavero [1], Sohee Chun [1], Ephraim Gau [1], James F. Steiner [3] and Michal Dovčiak [4]

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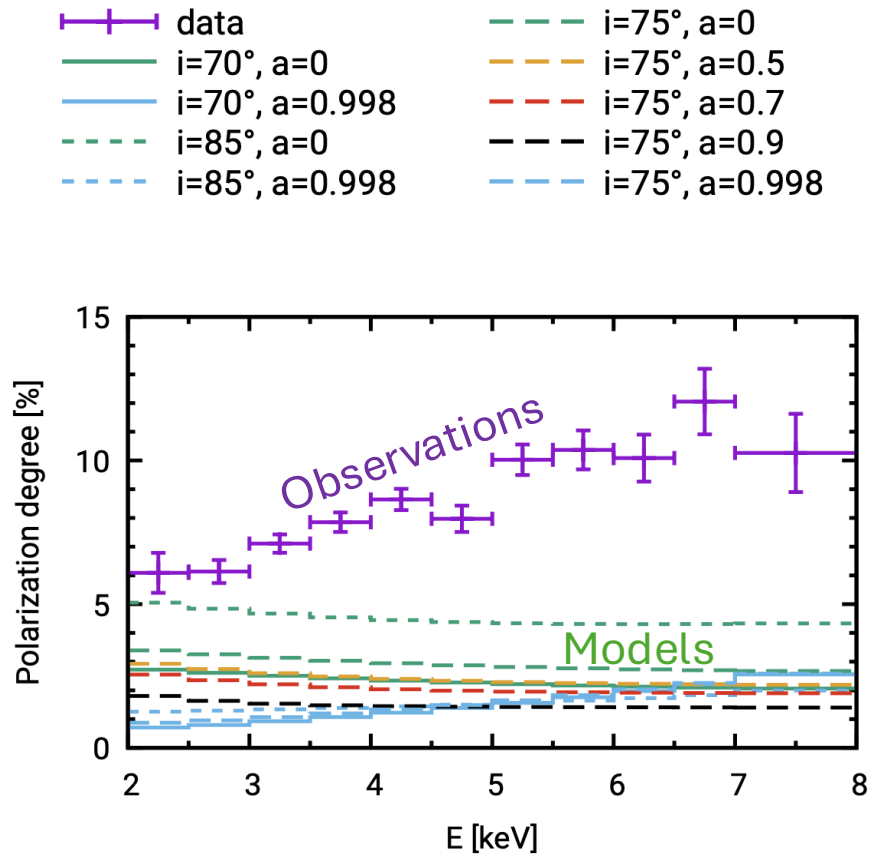
ABSTRACT

The *Imaging X-ray Polarimetry Explorer (IXPE)* observations of the X-ray binary 4U 1630–47 in the high soft state revealed high linear polarization degrees (PDs) rising from 6% at 2 keV to 10% at 8 keV. We discuss in this letter three different mechanisms that impact the polarization of the observed X-rays: the reflection of gravitationally lensed emission by the accretion disk, reprocessing of the emission in outflowing plasma, and electron and ion anisotropies in the accretion disk atmosphere. We conducted detailed raytracing studies to evaluate the impact of the reflection of strongly gravitationally lensed emission on the PDs. Although the reflected emission can produce high PDs in the high-energy tail of the thermal emission component, we do not find models that describe the PDs and are consistent with independent estimates of the source distance. We discuss the energetics of another proposed mechanism: the emission or scattering of the X-rays in mildly relativistically moving plasma outflows. We argue that these models are disfavored as they require large mechanical luminosities on the order of, or even exceeding, the Eddington Luminosity. We investigated the impact of electron and ion anisotropies, but find that their impact on the observed PDs are likely negligible. We conclude with a discussion of all three effects and avenues for future research.

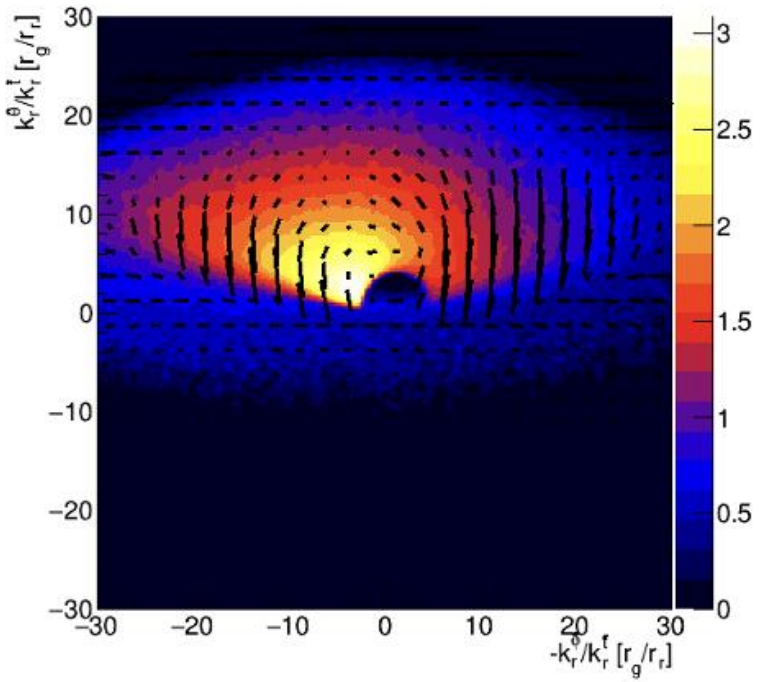
arXiv:2307.13141v2 [astro-ph.HE] 10 Oct 2024



Standard geometrically thin, optically thick accretion disk model fails to explain:
(i) high PDs, and (ii) increase of PD with energy.

Possible solutions for 4U 1630-47's high PDs

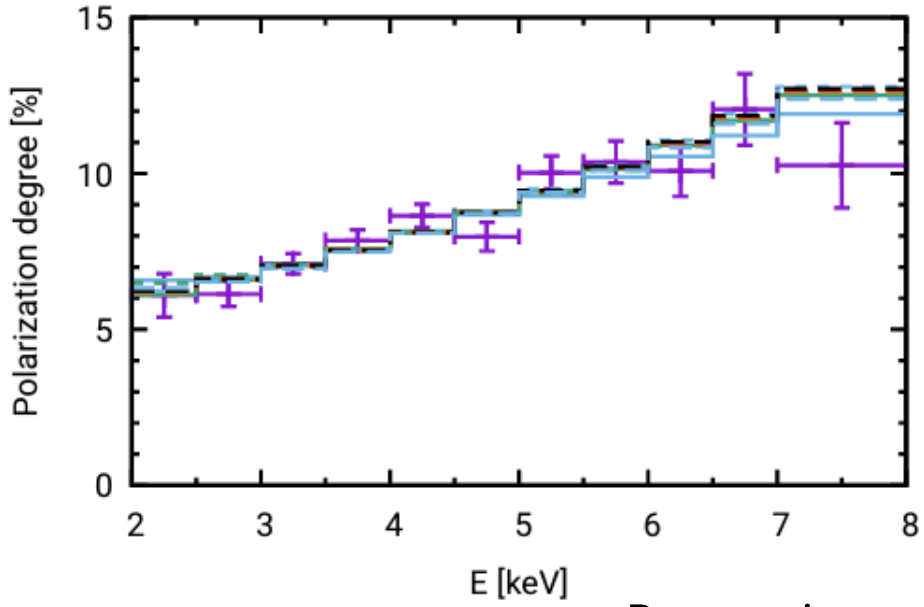
(1)



Geometrically thick accretion disk gives higher PDs.

West & Krawczynski,2023, Ratheesh+2024

(2)



Relativsticlly (0.5 c) outflowing plasma increases polarization (Ratheesh+2024, Poutanen+2023)

But requires near-Eddington or super-Eddington mechanical luminosity. (Krawczynski+ 2024)

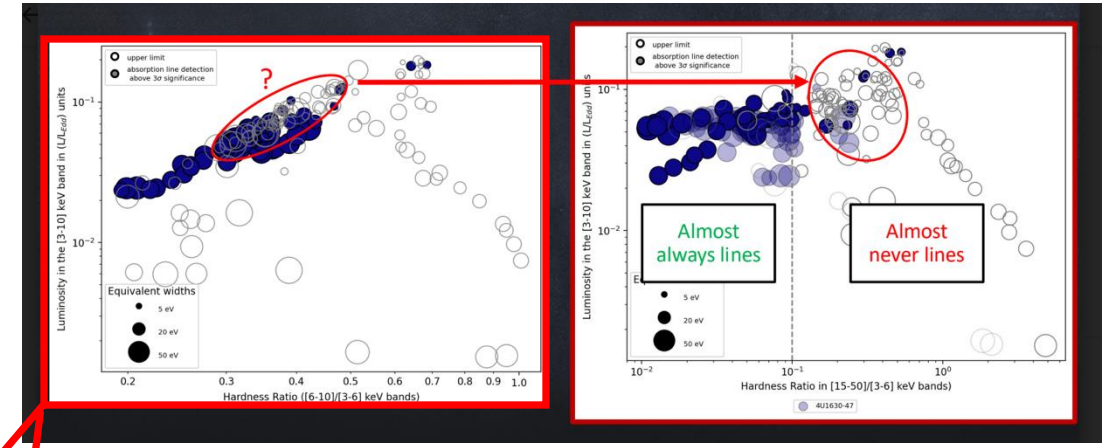
(3) Reflection of gravitationally lensed emission off the disk requires too small distances.

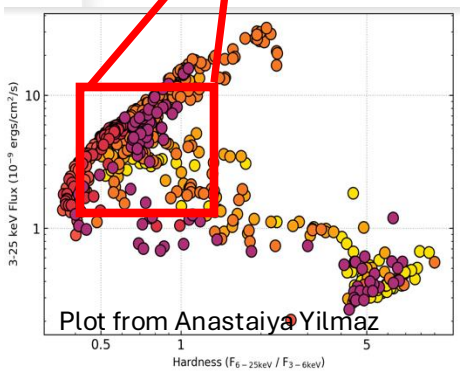
(4) Impact of particle anisotropies is negligible. (Krawczynski+2024)

(4) Reflection by not-yet-identified plasma?

Winds in 4U 1630-47

- 4U 1630-47 shows fast wind outflow that appears and disappears within soft states.
- In fact modifying the HID taking in consideration the higher energies (15-50 keV); using BAT and INTEGRAL data, it is possible to divide the zone of the HID where the wind is present and the zones where the wind is absent
- The presence of wind is influenced by the the hard energy tail (non-thermal corona)





Outburst period	Outburst type	Daily Epochs				
		Chandra	NICER	NuSTAR	Suzaku	XMM
2002-2004	super (triple)	**1**	0	0	0	0
2006	standard	0	0	0	**6**	0
2010	standard (double)	0	0	0	**1**	0
2012-2013	super (triple)	**7**	0	**2**	**2**	**8**
2015	standard	0	0	**2***	**3**	0
2016-2017	standard	**1**	0	0	0	0
2018	standard	0	**33**	0	0	0
2020	standard	**3**	**39**	0	0	0
2021-2022	standard (double)	0	**29**	0	0	0
2022-2024 †	super (double)	0	~100	**7***	0	0
Total		12	172	11	11	8

Each point represent every single XMM/Chandra/NICER/NuSTAR/Suzaku observation since 2004, combined with daily BAT and INTEGRAL fdata within the same day. For a total of 9 different outbursts observed

Parra et al. 2024 in preparation

Conclusions

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

- It shows periodical outbursts equally spaced in time
- It lacks bright hard states.
- It lacks radio jets
- It shows a very bright hard power law during disk-dominated state.
- It has a fast wind outflow that appear and disappear within soft states and depends on the high energy behaviour of the source
- It shows a particularly high level of X-ray polarization that is un-explicable with actual models