The 3rd International Online Conference on Universe — 4–6 March 2026

IOCU 2026 Conference

X-Ray Dips and Polarisation Angle Swings in GX 13+1: constraining the geometry of the outer disk region

MDPI universe

sciforum-161519

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GX 13+1: a peculiar LMXBs

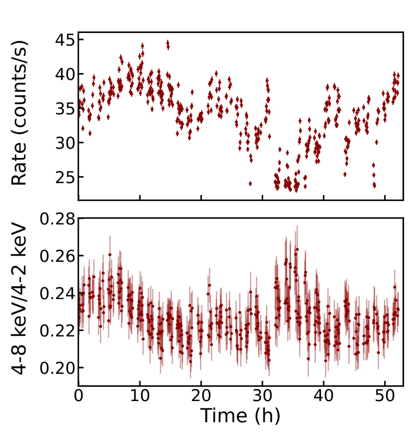
Accreting weakly magnetized neutron stars (WMNs) are typically hosted in low-mass X-ray binaries (LMXBs). WMNSs accrete matter via Roche lobe overflow from a stellar companion with $M<M_{\odot}$. These sources are classified into Z or atoll sources based on either the shape of their tracks in the X-ray hard-color/soft-color diagram (CCD) or their hard-color/intensity diagram (HID). **In LMXBs viewed at high inclination (>60°), sometimes X-ray flux modulations are observed as related to their orbital period;** most commonly, these are absorption-driven intensity dips that recur once or twice per orbit and show variable shape and phase jitter. These dips likely arise from clumpy material in the outer disk near the impact point of the accretion stream from the companion. X-ray eclipses caused by the companion star are rare, and the X-ray emission that still gets through during these eclipses (like in EXO 0748−676), along with small, steady changes in brightness, suggests there is an electron cloud above the disk where scattering occurs. **This extended, optically thin, highly ionized region is known as the extended accretion disk corona (ADC),** and spectroscopy in high-inclination systems supports its existence, even if its nature and geometry are not well understood.

GX 13+1 is a peculiar NS-LMXB with a unique position between Z and Atoll sources: bright as a Z source with persistent radio emission, but also showing a CCD shape closer to an atoll. It shows a 24.5-day periodic dip, as well as short, erratic dips. Previous X-ray spectral studies of GX 13+1 found strong line-of-sight obscuration consistent with a disk wind and inferred an inclination in the 60°–80° range.

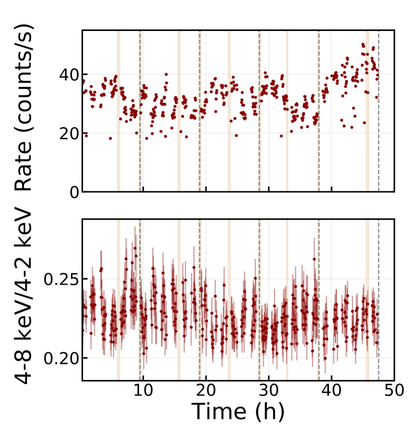
X-ray Polarisation

Spectral and timing properties of NS-LMXBs provide clues to their emission mechanisms, but degeneracies limited our understanding. **X-ray polarimetry has brought a new way to study NS-LMXBs by introducing the polarisation angle (PA) and the polarisation degree (PD) as further parameters.** These provide insight into the accretion physics of NS-LMXBs and the geometry of the accretion regions, allowing **for the study of the presence of the ADC or disk wind**. The Imaging X-ray Polarimetry Explorer (IXPE) is the first mission that allows for measuring X-ray polarisation in the 2-8 keV energy range.

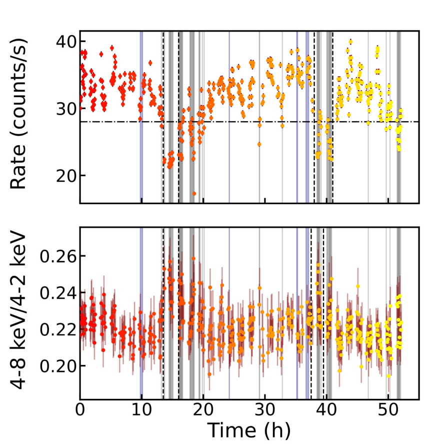
IXPE observations of GX 13+1



First observation (October 2023)



Second observation (February 2024)



Third observation (April 2024)

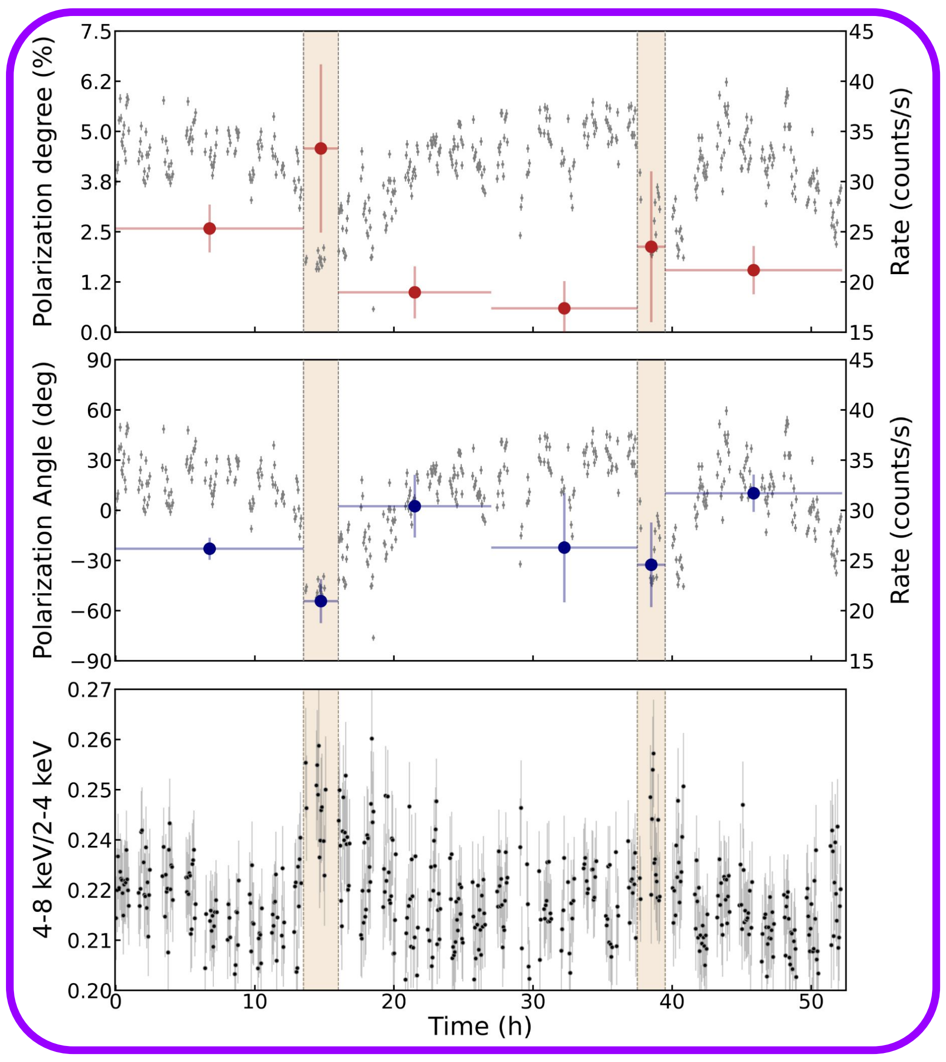
Three IXPE observations:

- one dip in the first observation
- no dips in the second observation
- two dips in the third observation

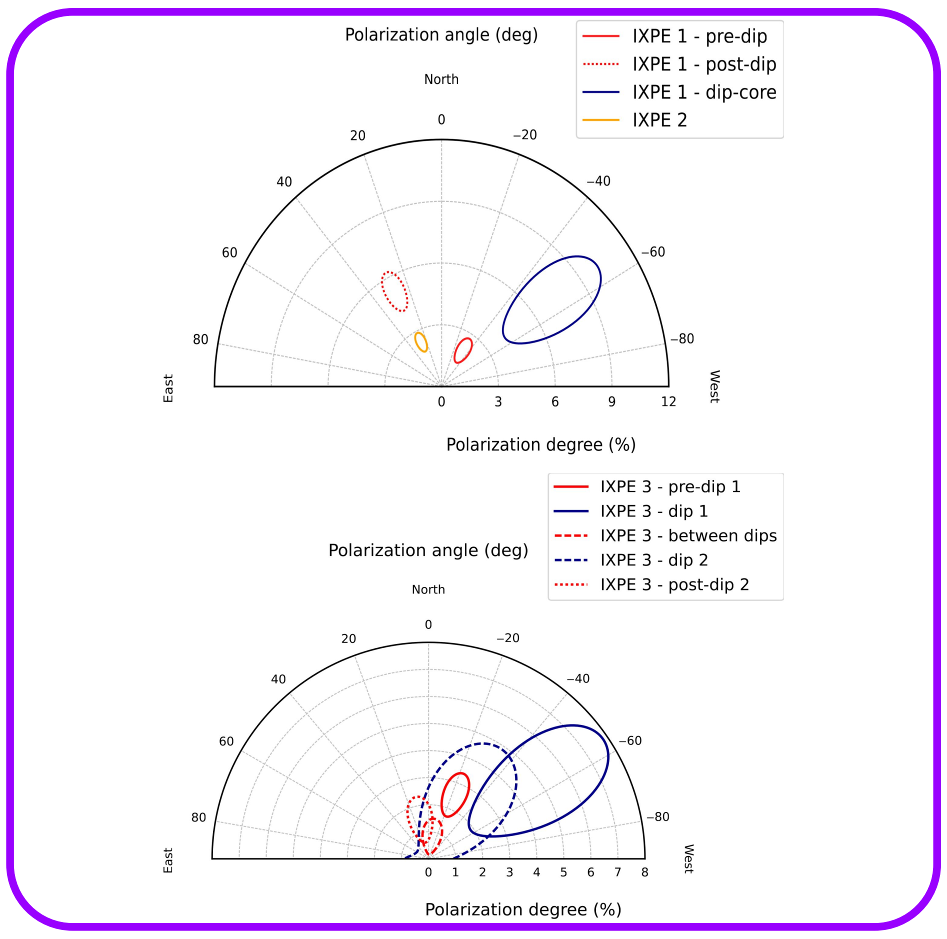
None of the observations covered the periodic dip

X-ray polarisation of the dips

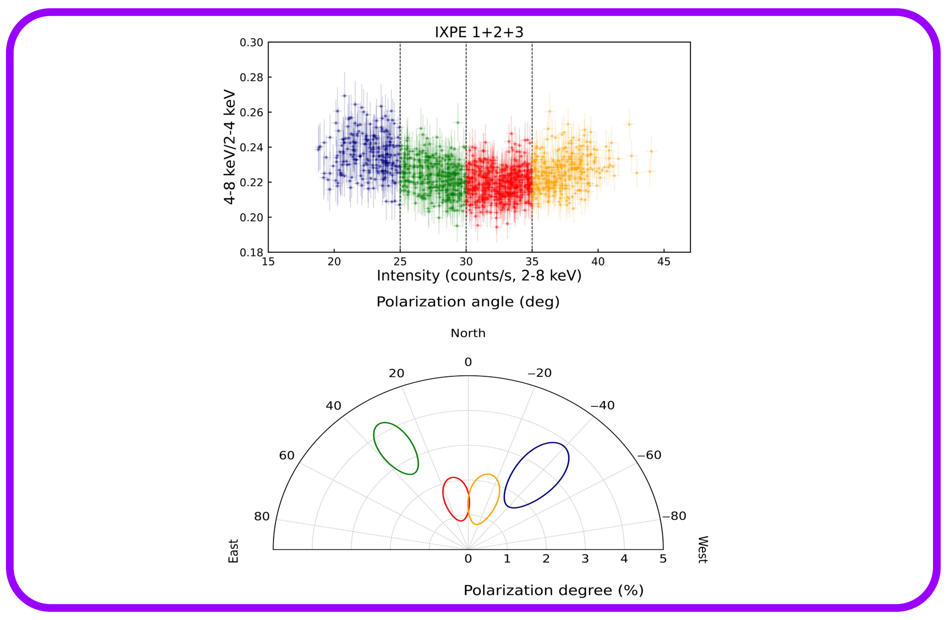
The polarimetric behavior during the third IXPE observation showed that the PA changed from north to west during the dips, linked to an increase in PD up to about **5%**. A similar behavior was observed during the dip in the first IXPE observation.



Comparing the third observation to the previous two, the **PA during the two dips was compatible with the PA in the dip during the first observation**, and after the second dip, the PA attained a value similar to the post-dip PA of the first observation, also matching the PA throughout the entire second observation (which had no dips). Overall, **the polarisation behavior is similar across all three observations.**



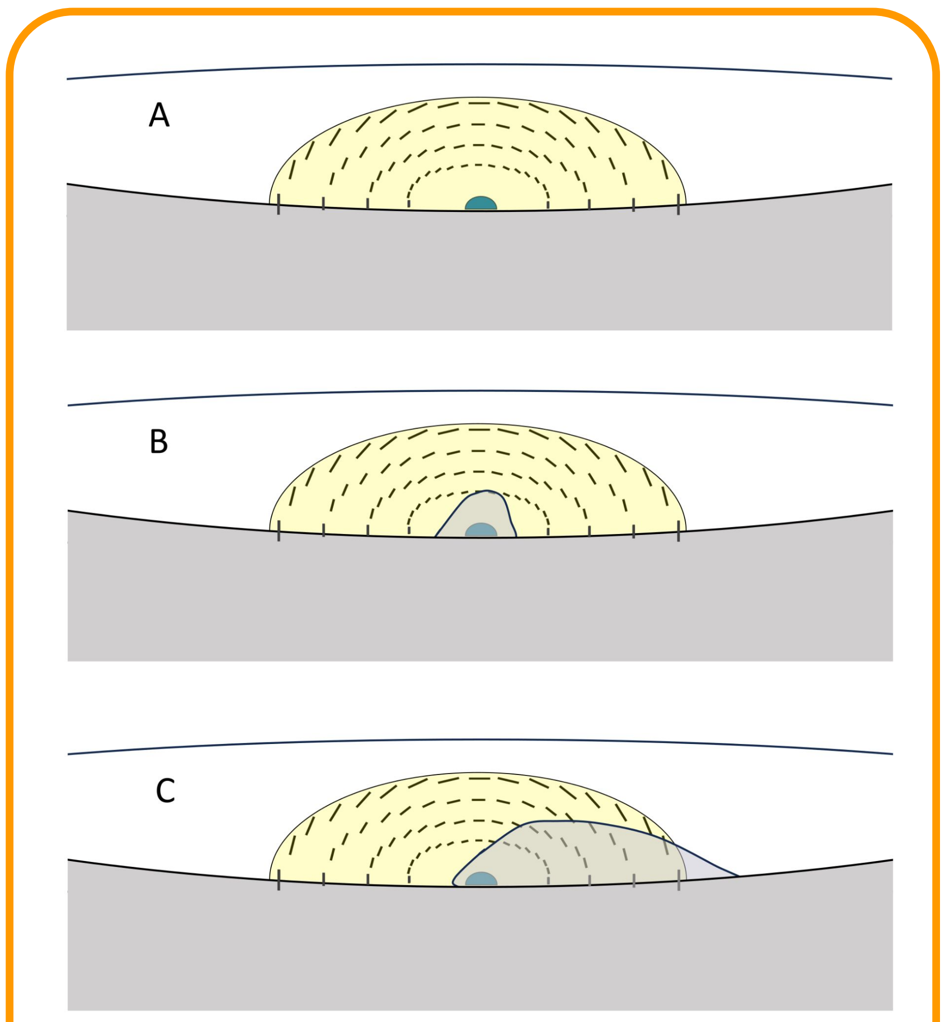
By combining the three IXPE observations into a single data set to study intensity-correlated variability, we found that **low and low-intermediate intensity are associated with a higher PD, whereas higher intensity corresponded to a lower PD, with an overall PA swing of ~70° between the extremes**.



Polarisation from ADC or Disk Wind

The high PD seen during the dip and the changing PA can't be explained by the emission from the disk or the surrounding areas, since we expect PAs to be either parallel or at right angles, with PDs lower than 4% in those cases. **Higher PD values are expected if n additional region of polarized radiation is considered, such as an ADC or disk wind.**

The scattering in an **ADC with modest optical depth (order ~0.1) can boost the observed PD and drive polarization-angle PA rotations during dips**: when a clump blocks the direct (unscattered) central emission but leaves most of the ADC visible, **the changing balance between direct and scattered components "mixes" their polarization vectors and shifts the net PA. Additional PA rotation can occur if a large clump partially covers the ADC, breaking its axial symmetry.**



Proposed geometry of GX 13+1 (not to scale). The gray region represents the outer disk rim, the yellow region the ADC, and the blue circle the central X-ray source. The black segments show the PA of the radiation scattered by the ADC. The PA at the observer (given by the average of the PAs) changes from the off-dip state (A) to the dip state when a small clump obscures the central source and a negligible part of the ADC (B) and a large clump obscures the central source and a fairly large fraction of the ADC (C).

Similar considerations would hold if the scattering region was the disk wind rather than the ADC. A fan-shaped, 30° aperture wind launched from a radius of 10^{10}–10^{11} cm, as inferred in M. Diaz Trigo et al. (2012), is similar in size and height to the ADC discussed above and may give rise to comparably large PDs. The size of this equivalent "wind corona" of GX 13+1 exceeds the size of the clumps, and **PA rotation can be produced in the same way as in the ADC case by the break of the symmetry and the mixing of the components.**

A new IXPE observation campaign of GX 13+1 during its periodic dip is under analysis.

For more information

A. Di Marco, F. La Monaca, A. Bobrikova et al., "X-Ray Dips and Polarization Angle Swings in GX 13+1", ApJL 979:L47, 2025