

Insights from IXPE, Swift, VLT and VLA

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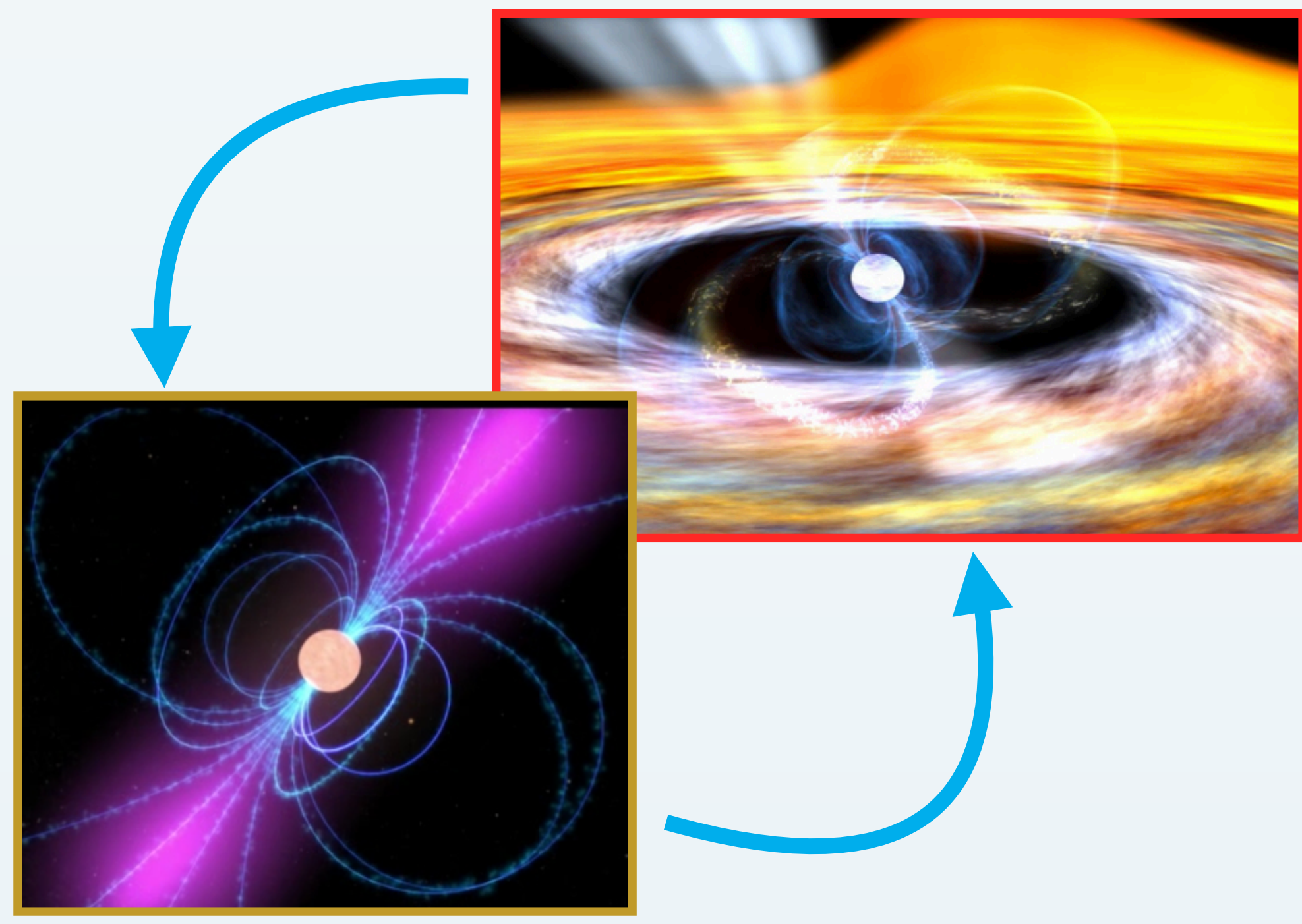
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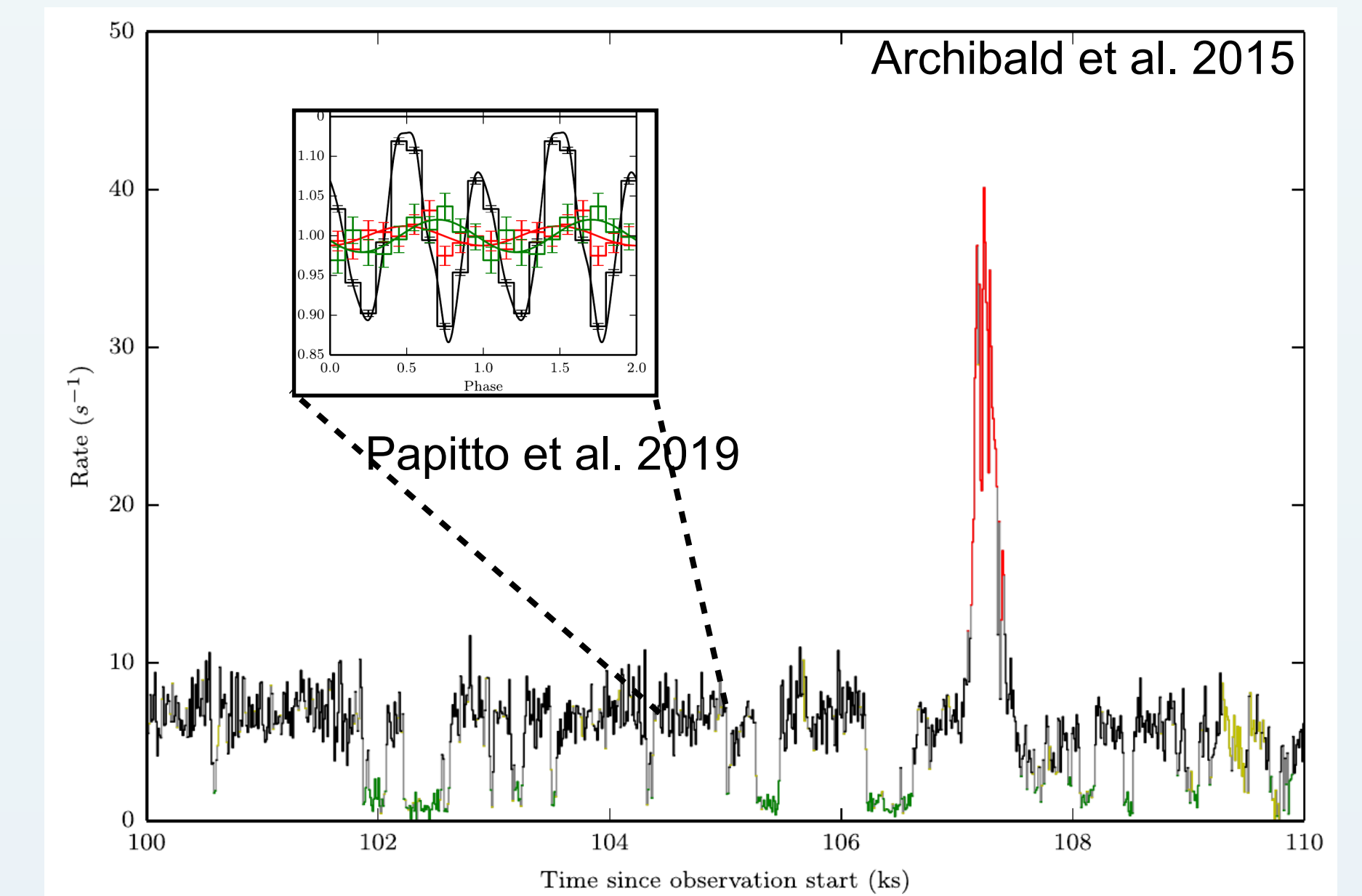
Introduction

Transitional millisecond pulsars (tMSPs) bridge the evolutionary gap between accreting neutron stars in low-mass X-ray binaries and millisecond radio pulsars, offering a unique laboratory to study the interplay between accretion and pulsar activity. These systems exhibit a distinctive **subluminous X-ray state** characterized by alternating **high**, **low** and **flaring** emission modes. **PSR J1023+0038**, the prototype of the class, has been in the sub-luminous state since 2013 and has been extensively studied at all wavebands.

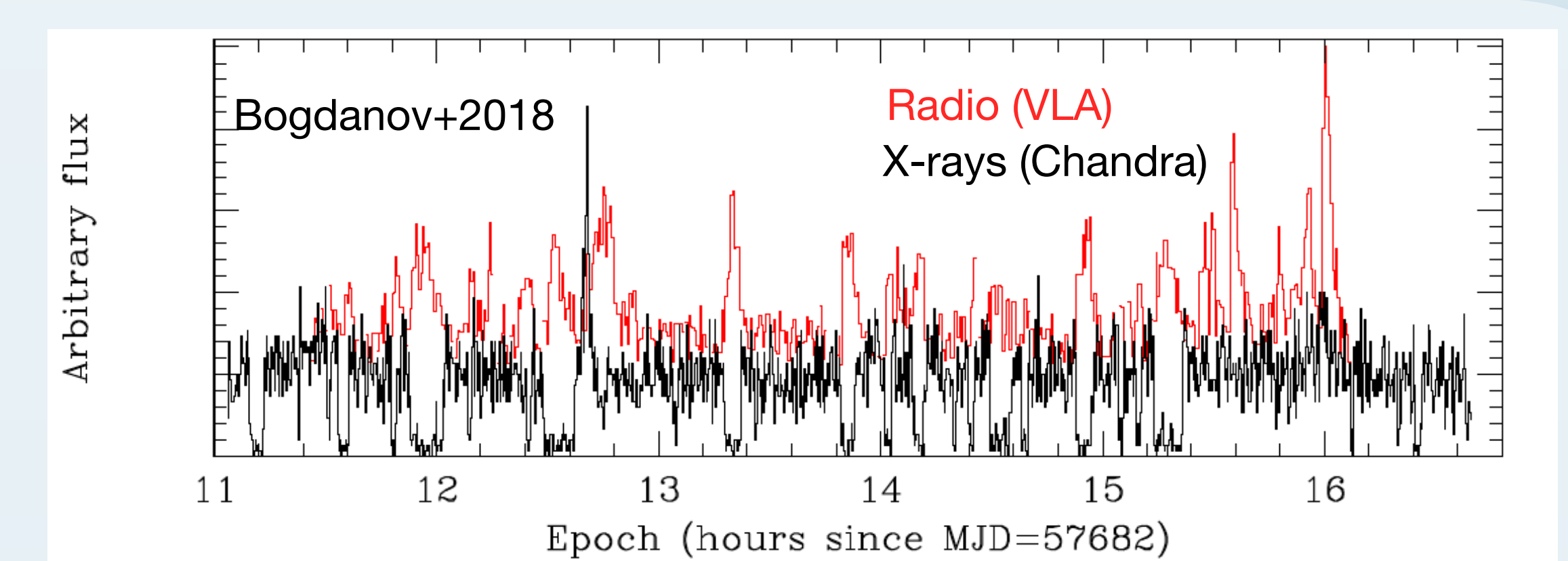


Swift/XRT has always had a key role in identifying mode transitions in PSR J1023+0038.

Only when in high mode, tMSPs show coherent X-ray pulsations at the pulsar's spin period. Ambrosino et al. 2017 discovered millisecond **optical pulsations** as well happening in high mode. Pulsed flux is described by a single power-law from optical to X-rays: it is the same component pulsating at all frequencies (Papitto et al. 2019).



Anticorrelated radio/X-ray emission: possibly related to ejections of **plasmoids** while in low modes. In high modes, the presence of a **compact jet** is indicated by a flat radio spectrum.

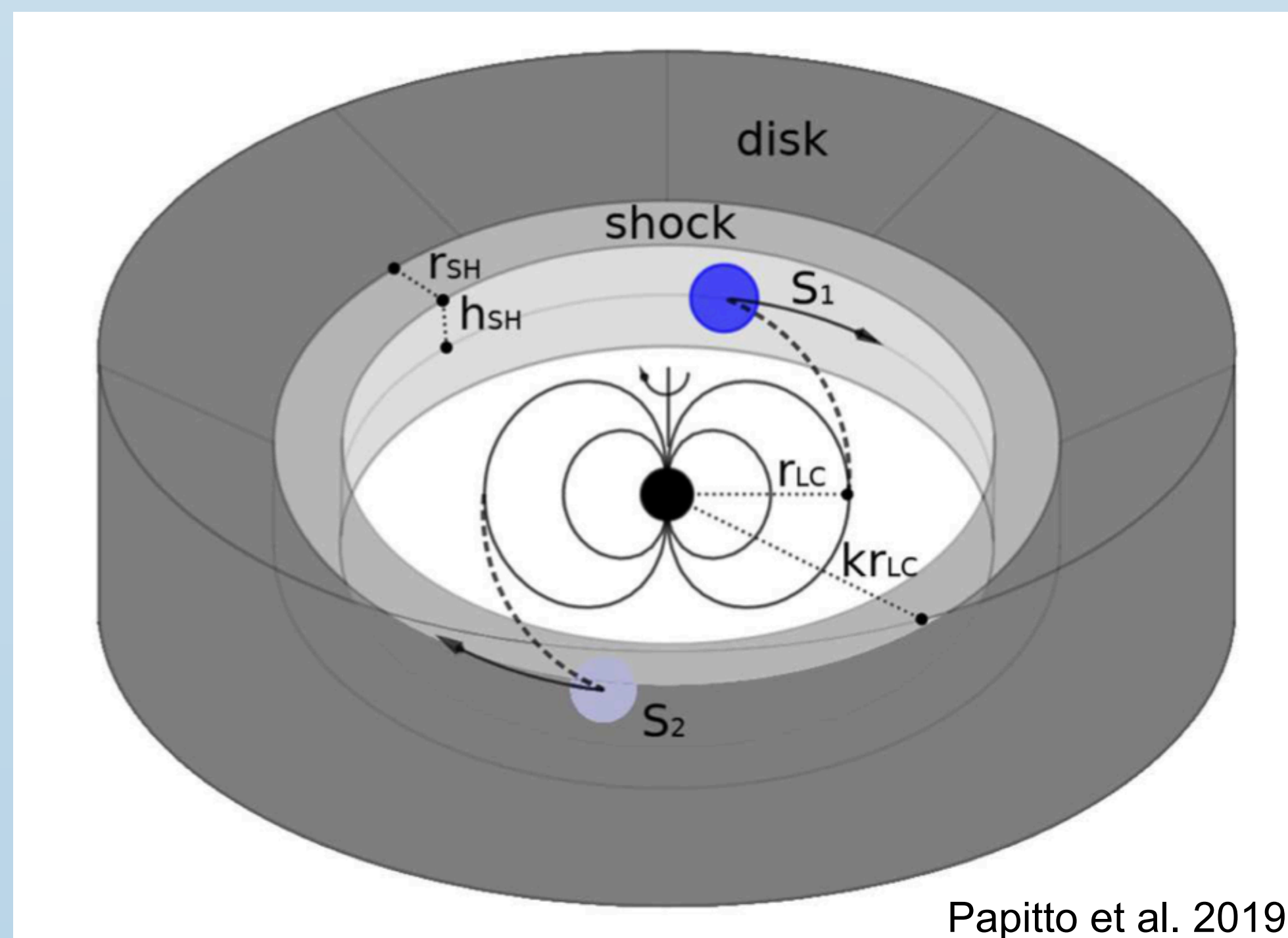


Mini pulsar wind nebula scenario

High mode: the radio pulsar is active; the wind interacts with the innermost accretion flow in a region of **shock**. The dissipation at the shock produces most of the X-ray emission via synchrotron, and is responsible for coherent pulsations from optical up to X-rays.

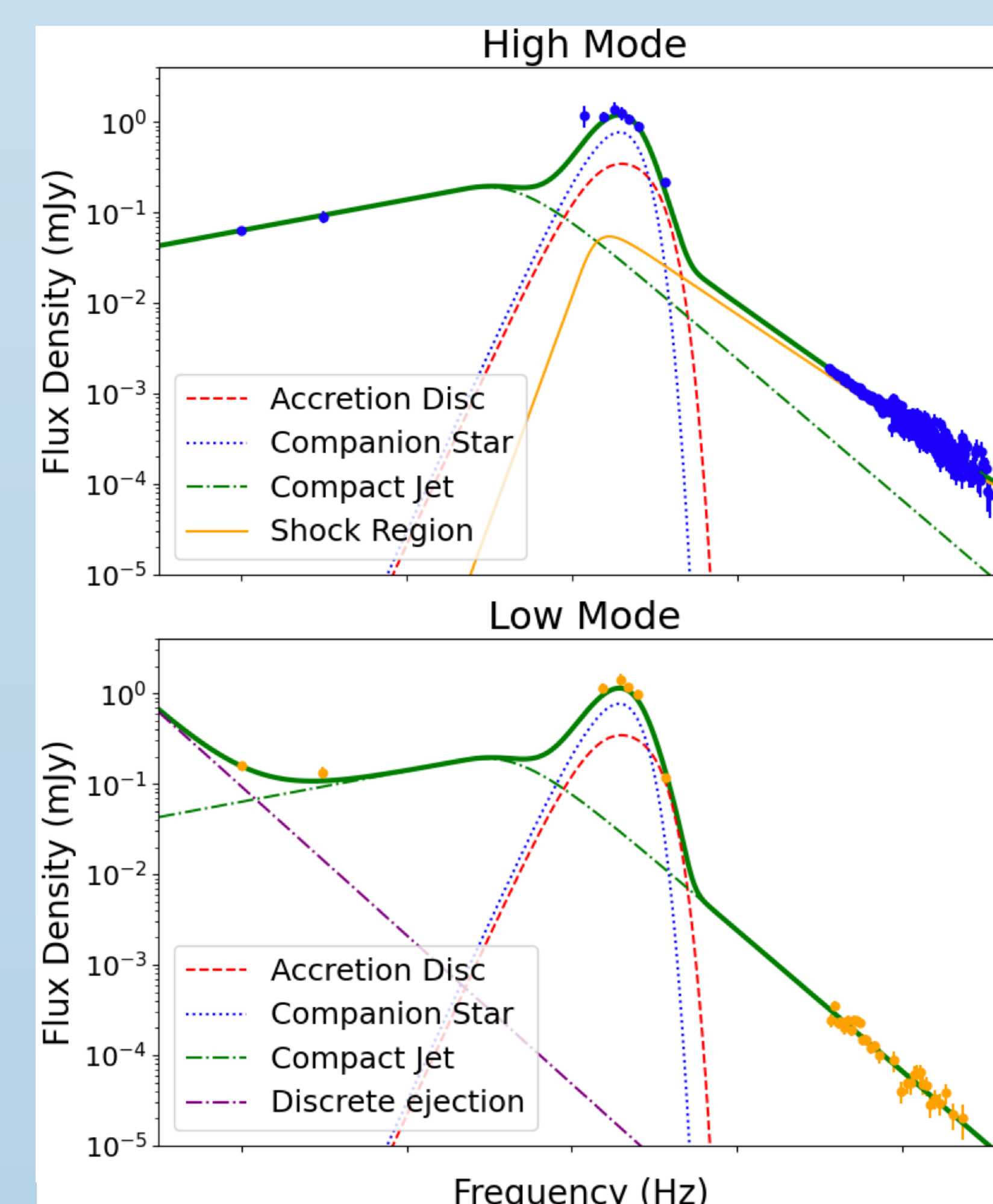
Low mode: the shock moves outwards; X-rays are lower and pulsations are washed out.

Flaring mode: the shock increases its dimension, giving origin to episodes of high X-ray fluxes.



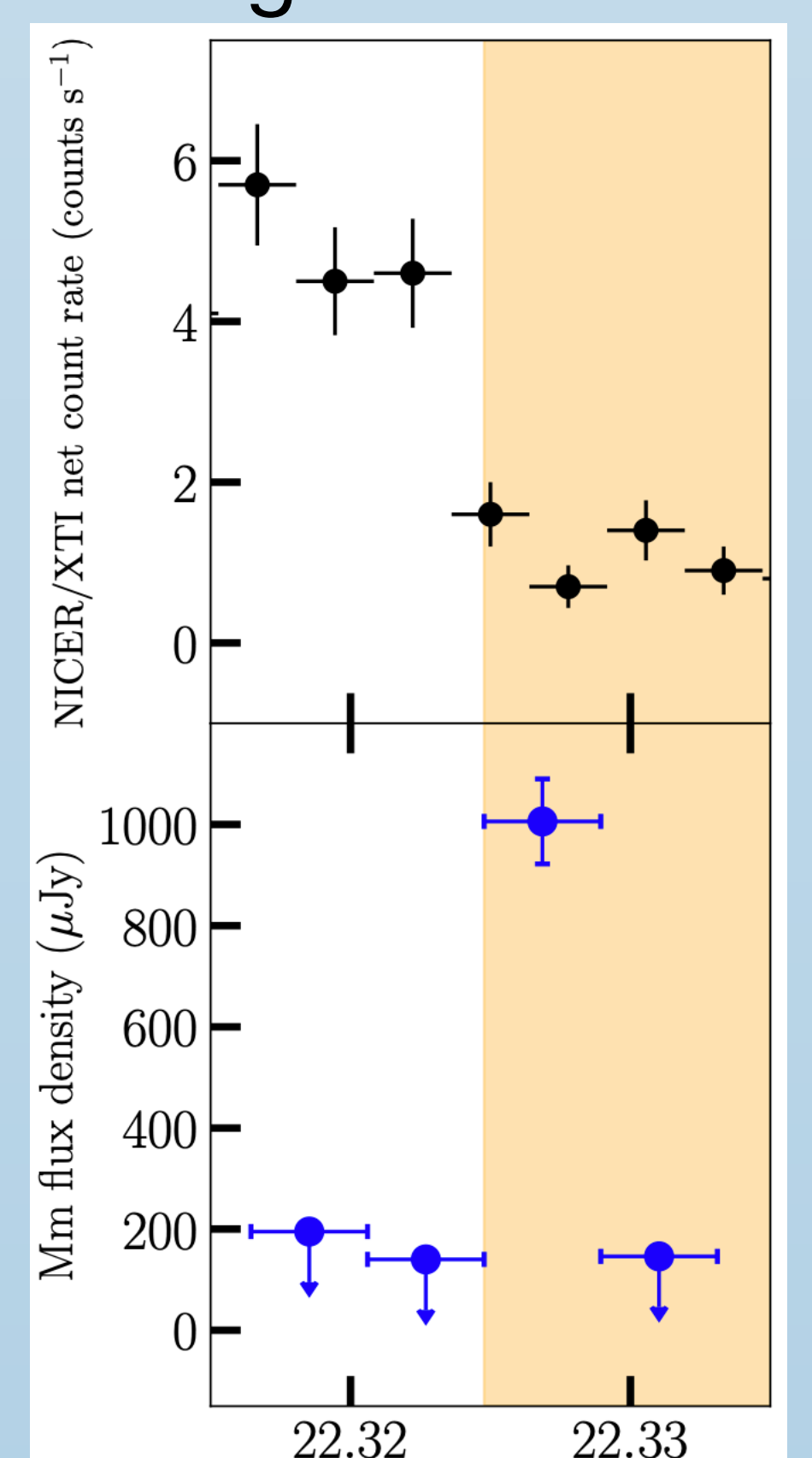
Papitto et al. 2019
See also Veledina et al. 2019

Matter ejections to explain highs and lows



By modeling the broadband spectral energy distributions in both emission modes, we show that the mode switches are caused by changes in the innermost region of the accretion disc.

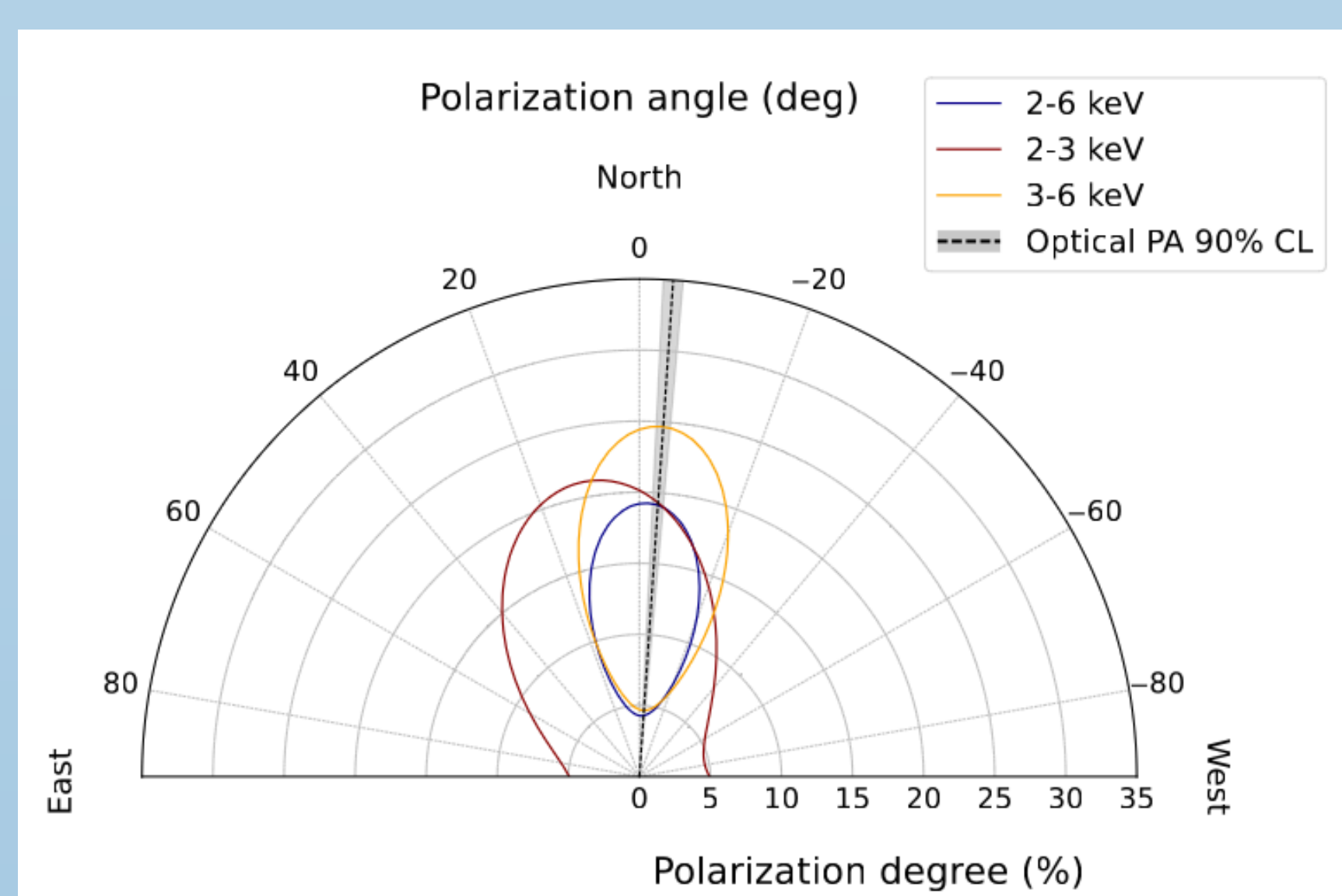
These changes trigger the emission of discrete mass ejections, which occur on top of a compact jet, as testified by the detection of at least one short-duration millimeter flare with ALMA at the high-to-low mode switch.



The pulsar is subsequently re-enshrouded, completing our picture of the mode switches.

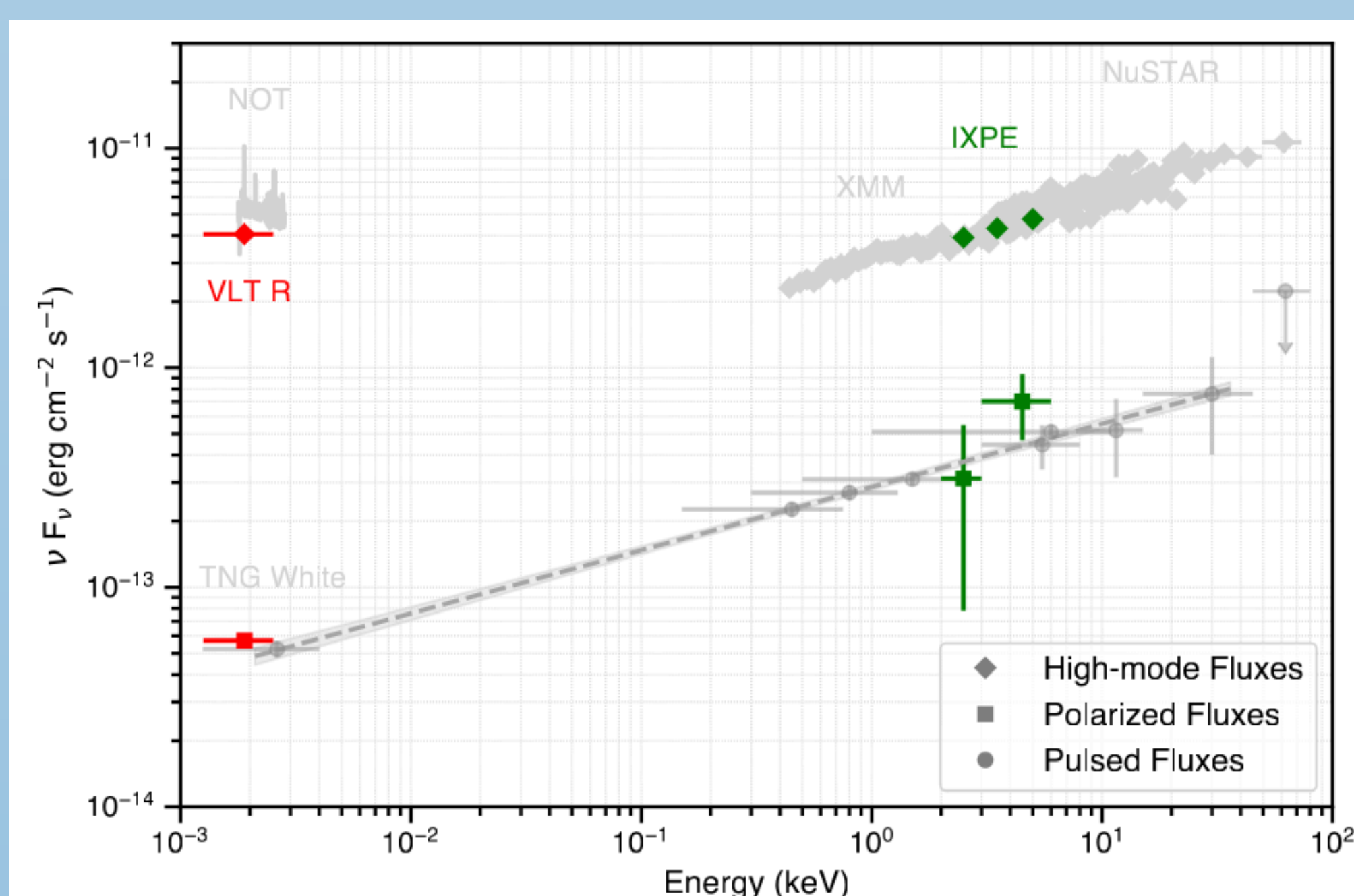
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Insights from polarization

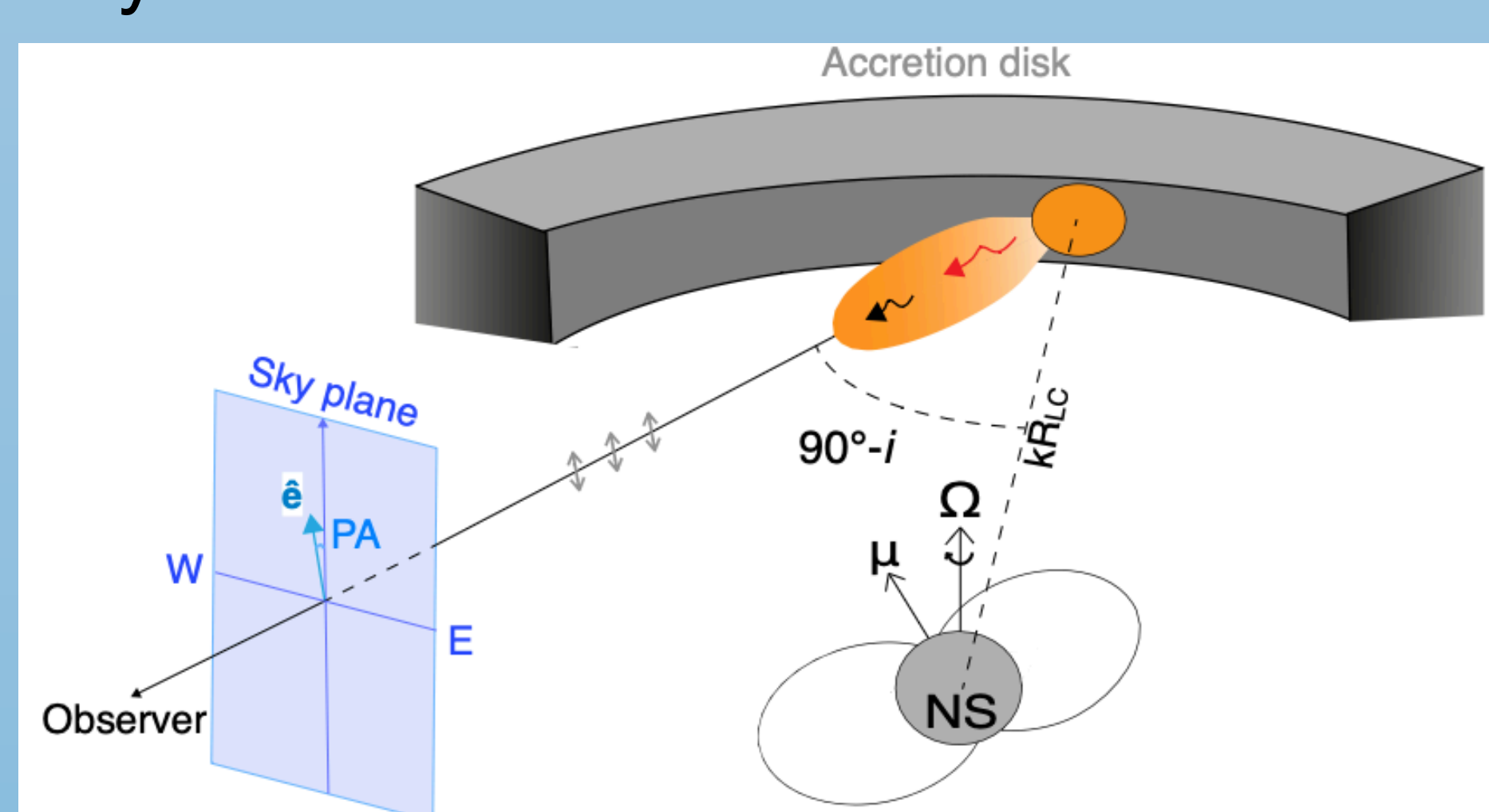


We present multi-wavelength polarimetric observations of PSR J1023+0038 in the subluminous X-ray state.

During the high mode, we detect polarized emission in the 2-6 keV energy range, with a polarization degree of $(12 \pm 3)\%$ and a polarization angle of $-2^\circ \pm 9^\circ$ measured counterclockwise from the North celestial pole towards East.



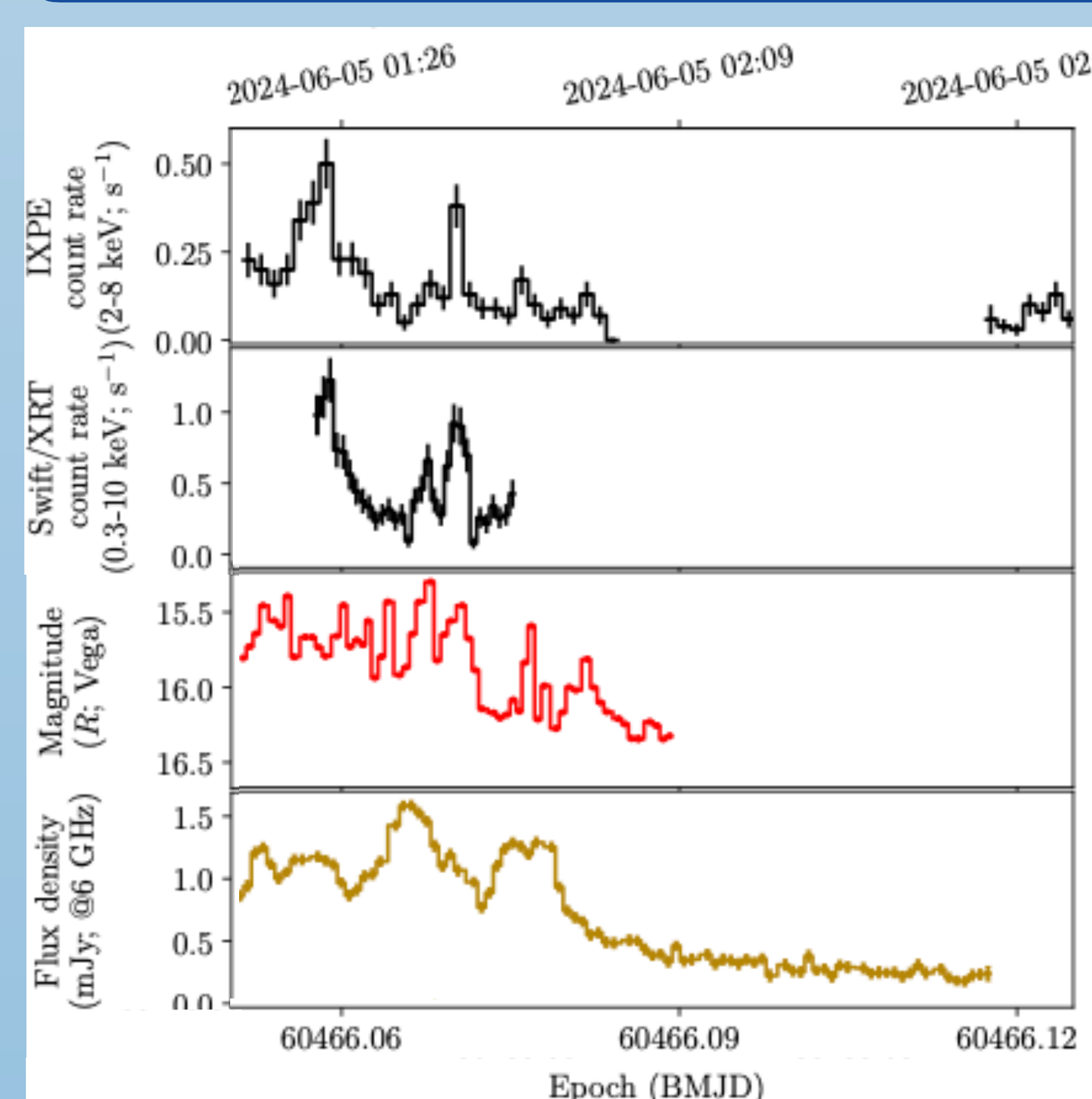
At optical wavelengths, we find a polarization degree of $(1.41 \pm 0.04)\%$ and a polarization angle aligned with that in the soft X-rays, **suggesting a common physical mechanism operating across these bands**. Remarkably, the polarized flux spectrum matches the pulsed emission spectrum from optical to X-rays.



Our results provide direct evidence that the polarized and pulsed emissions both originate from synchrotron radiation at the shock formed where the pulsar wind interacts with the inner regions of the accretion disk.

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The enigmatic flaring mode



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We observed unpolarized optical and radio flares corresponding to the episode of flaring mode detected in X-rays by **Swift/XRT** and IXPE.

We propose that the thickening of the disc, which enlarges the shock region between the pulsar wind and the accretion flow and may drive the X-ray flaring observed in tMSPs, enhances the ionization level of the disc, thereby generating an increased number of free electrons. These electrons could then be channelled by magnetic field lines into the jet. This increased jet mass-loading could drive the associated radio and optical variability.

References

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