Investigating Outburst Dynamics of Ultraluminous X-Ray Pulsar Swift J0243.6+ 6124

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Abstract

Ultraluminous X-ray pulsars (ULXPs) are a subset of ultraluminous X-ray sources powered by accreting neutron stars with strong magnetic fields. ULXPs exhibit luminosities exceeding the Eddington limit for a neutron star (typically ~10^{38} erg/s), often reaching values up to ~10^{40} erg/s. Swift J0243.6+6124 is the only known Galactic ULXP that offers a unique opportunity to study emission variability due to its proximity and brightness. In this study, we examine the evolution of the pulse profile, pulse fraction, and phase-resolved deviations using all the existing observations of Swift J0243.6+6124 during its recent outburst in 2023. We present our results from this detailed investigation of this source.

Introduction

- Very few known ULXPs have been observed till date such as **M82 X-2** (*Bachetti et al. 2014*), **NGC 7793 P13**, **NGC 5907 ULX1** (*Israel et al. 2017*), **NGC 300 ULX1** (*Carpano et al. 2018*), **NGC 1313 X-2** (*Sathyaprakash et al. 2019*) with all of them being extragalactic sources. Swift J0234.6+6124 is a Be/X-ray binary that was detected in 2017 during its giant outburst as the first Galactic ULXP.

Source Parameters	
Period	~9.8 sec
Optical Companion	O9.5 Ve
Peak Luminosity (0.1 – 10 keV)	~2 x 10^{39} erg/s

- The accretion on neutron stars at the super-Eddington regime has been explained using simulations that invoke the formation of a shock region in the hollow accretion column. (*Kawashima et al. 2016*) **(refer to Fig 1)**, sustaining accretion at such limits.

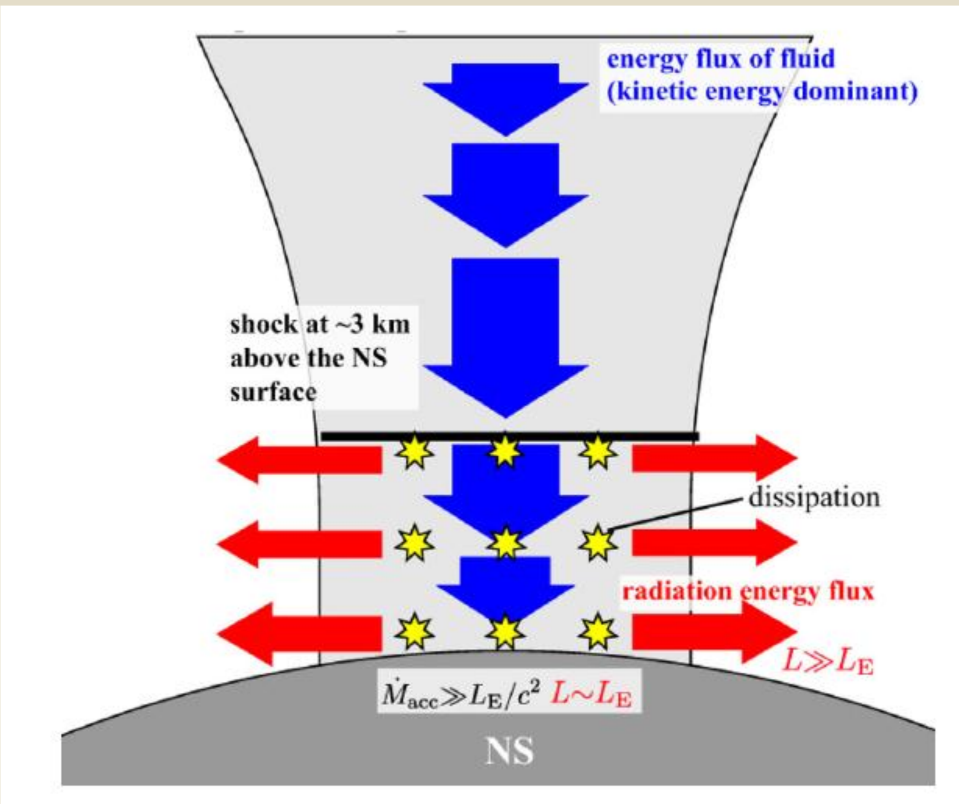

Fig 1: Schematic of supercritical accretion column (Kawashima et al 2016)

- Other studies like *Mushtukov et al 2019* and *Doroshenko et al 2020* have shown the possible existence of a **radiation-pressure dominated inner accretion disk and accretion through envelope with the prediction of wind outflows** for highly magnetized neutron stars (**refer to Fig 2**) following formation of super-Eddington accretion disks

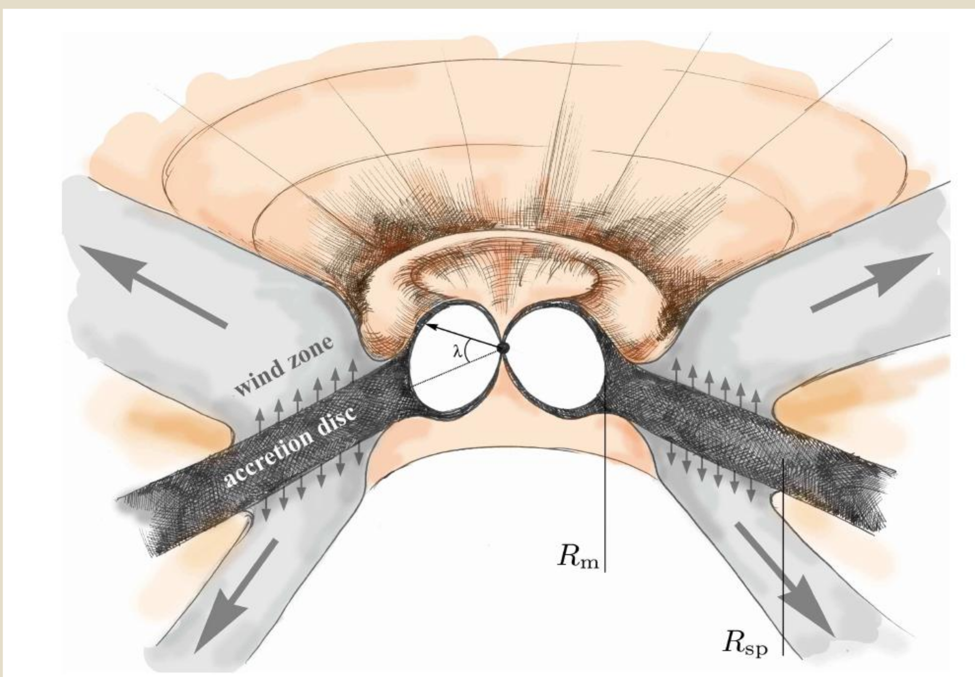

Fig 2: Schematic of accretion disk on neutron star (Mushtukov et al 2019)

- The pulse profile of the source **shows complex morphology that was luminosity-dependent.** The profiles also changed significantly above L=10^{38} erg/s (Wilson-Hodge et al. 2018; Tsygankov et al. 2018; Beri et al. 2020). The profiles also change with energy with variations till 150 keV during outburst phases, as can be seen in **Fig 3.**
- Thus, we aim to investigate the accretion dynamics of this ULXP by probing the **dependence of timing features on luminosity and energy for the 2023 outburst.**

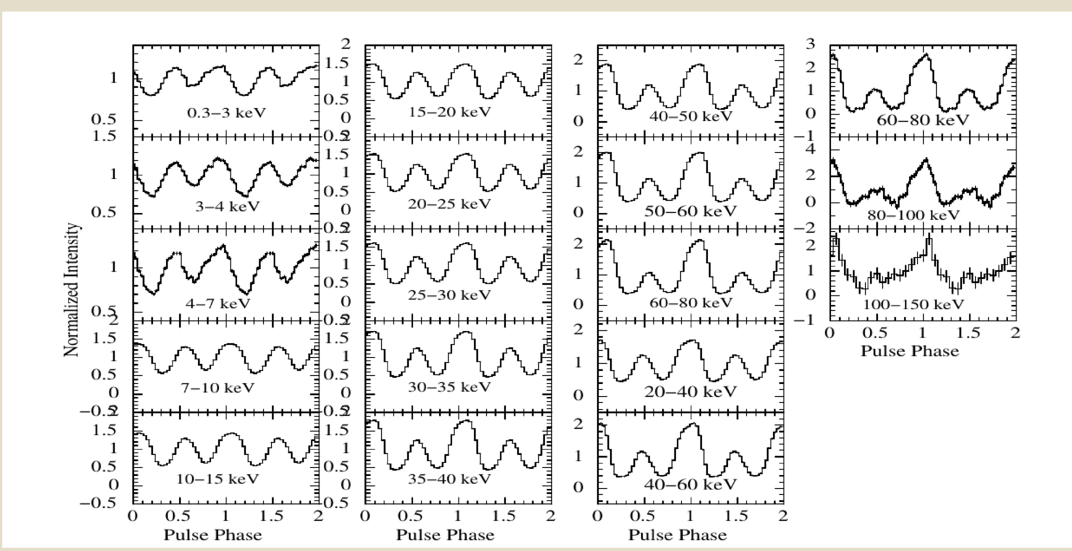

Fig 3: Pulse profile evolution as observed with AstroSat-SXT, LAXPC, CZTI 2017 outburst from (Beri et al 2020)

Observation

- The NICER XTI instrument observed the source during **the 2023 outburst with coverage of the 1-10 keV** range.
- There are **~60 observations** under consideration between June and September 2023, which is the outburst phase.

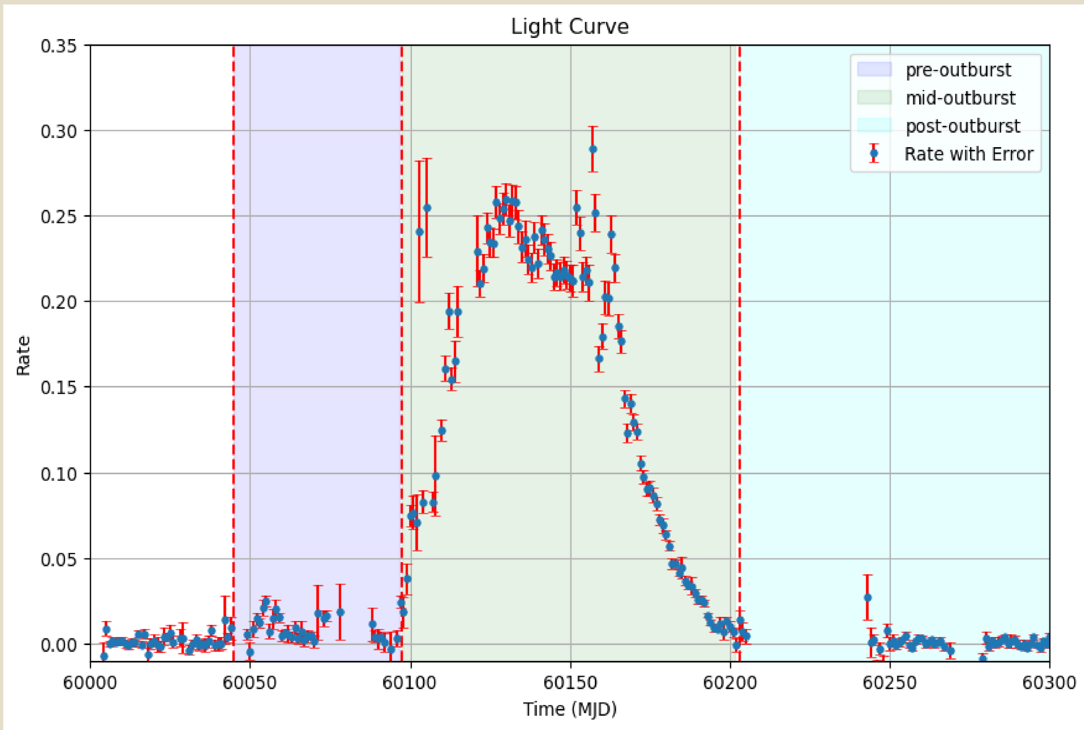

Fig 4: SWIFT BAT Monitor light curve plotting for 2023 in MJD

Pulse Fraction

- Computed using folded pulse profile for all NICER observations.
- We use the luminosity calculated from NICER for energies between 1 and 10 keV.
- Indicates the contribution of pulsation over continuum.

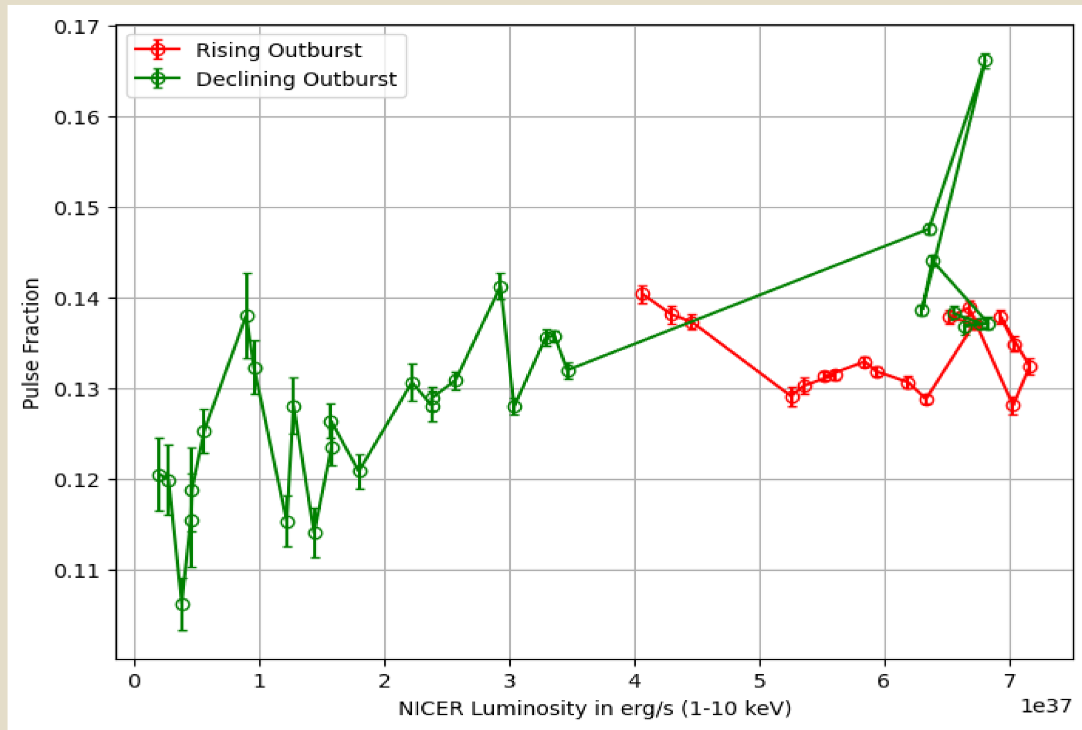

Fig 5: Pulse fraction for all NICER observations during outburst plotted against SWIFT luminosity computed from count rate by constant factor with distance=6.8 kpc (refer Doroshenko et al 2019)

Pulse Profile and RMS Variation

- Average Pulse profile plotted as photon flux variation for 2 phase cycles using NICER data from 1-10 keV for different luminosity through the outburst.
- RMS for each phase bin normalized with the mean flux of the observation was computed to find the stability of the pulsations.

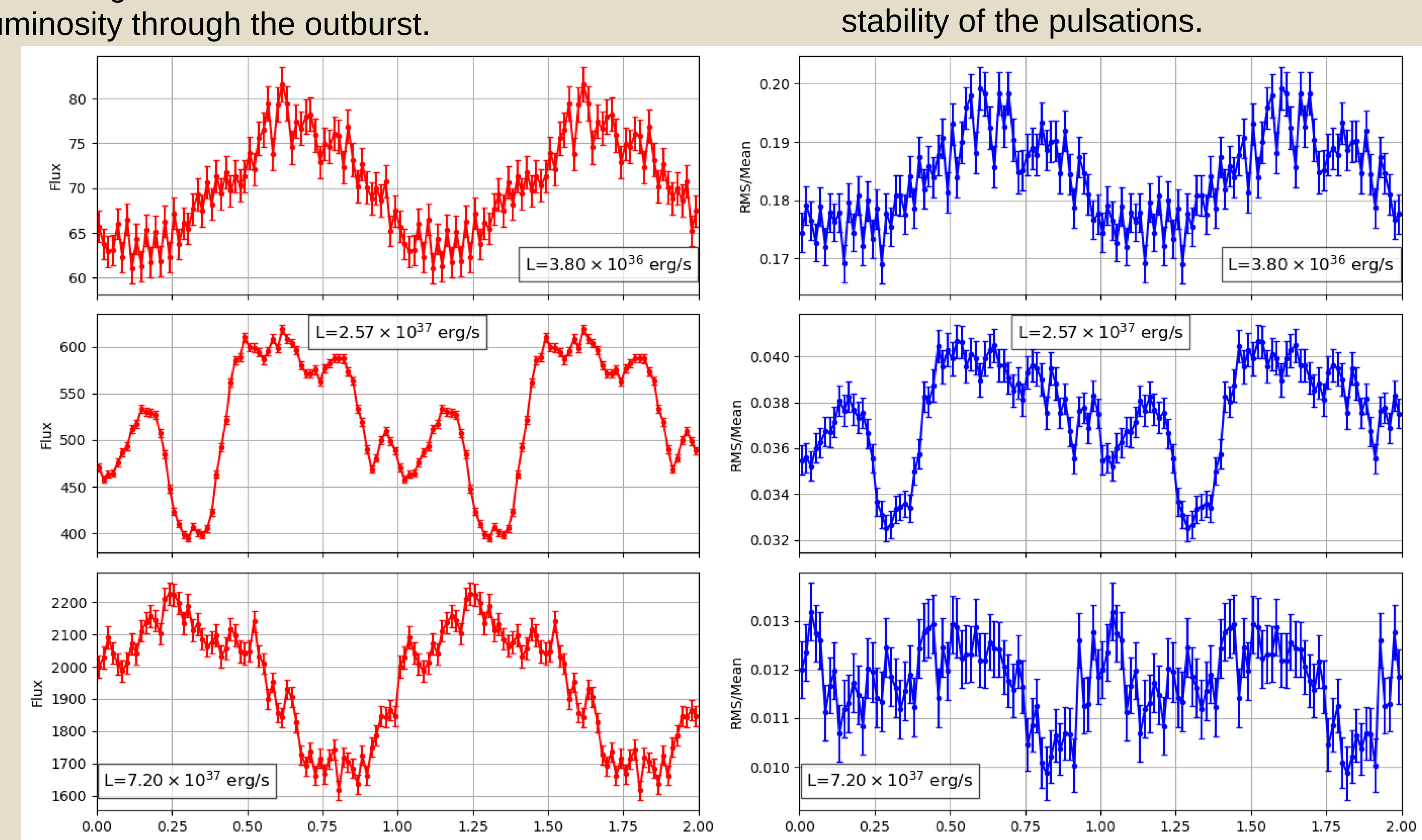

Fig 6: Pulse profile plotted for three NICER observations representing increasing luminosity from top panel to bottom. Left panels are corresponding RMS normalized by mean flux

Summary

- The Average Pulse profile shifts from a single peak symmetric structure to a transitionary structure as luminosity rises with a broad structure at the peak luminosity (L=9.0 x 10^{37} ergs/s) of outburst in NICER energy ranges.
- The pulse fraction at the same time shows a slight increase from 12% to 15% (**Fig 5**) during the rising and declining outburst phase.
- There is a presence of variability in the pulsar emission at timescales smaller than the spin period, as indicated by the RMS profile (**Fig 6**). The RMS variability closely follows the pulse profile for all luminosity.
- We have also found that the RMS profile varies with luminosity during this outburst, hinting towards a possible relation with the accretion flow in this system.

Reference

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Happy to collaborate on X-ray/ Radio Pulsars!!

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