A library of super Eddington outbursts in the era of modern observatories

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Motivation & Goals

• *Context of this work:* X-ray pulsars offer a unique laboratory for the study of radiation processes in extreme accretion are X-ray pulsars. These are found typically in high-mass X-ray binaries (HMXBs), while the brightest and most variable ones are those where the donor is a Be star (i.e. BeXRBs). Their environment combines some of the strongest magnetic fields ($> 10^{12}$ G) and effects of strong gravity, while also allowing us to gain insight onto the Neutron Stars (NS) equation of state. Bright outbursts of BeXRBs have also helped us understand the brightest binary systems, the so-called Ultra-luminous X-ray sources.

• *Our work:* We analyzed X-ray data from multiple observatories (e.g. Swift, NICER, NuSTAR, XMM-Newton) from super-Eddington outbursts of BeXRB pulsars in the local Universe (LMC, SMC or Milky Way). We studied their spectral hardness and pulsed fraction evolution with X-ray Luminosity. We identified patterns of variability that hint at changes in the accretion regime and probed super Eddington accretion. Here we present results from this unique library of events.

• *Our goal:* We aim to provide online products for major outbursts of BeXRB major outbursts located in the MCs. This would include spectral files, light-curves, and unbinned event files. Spectra, will analyzed with empirical models via `xspec`, and temporal analysis would be performed to study pulse profiles.

Systems studied

Name	Distance (kpc)	Date$^{(a)}$ (MJD)	L_X (10^{38} erg/s)
BeXRBs - literature values			
LXP 8.04 [6]	50	56675	4
	SX(50+), Nu(2), X(2)		
SMC X-2 [1]	60	57300	7
	S(50+), X(3), Nu(4), N(10+)		
SMC X-3 [3]	60	57630	25
	S(20+), X(1), Nu(2)		
LXP 9.3 [5]	55	58800	20
	SX(20+), N(20+), Nu(1), X(1)		
Swift J0243.6[2]	5.5	58067	10
	SX(200+), N(300+), Nu(9), X(2)		
SXP 4.78	60	58450	1.8
	SX(20+), N(50+), X(1)		

Notes: In the table we list number of observations for observatories: *XMM-Newton*(X), *NuSTAR*(Nu), *NICER*(N), *Swift*/XRT (SX). Most Outbursts were detected by *Swift*/BAT, MAXI and *Fermi*/GBM. SMC X-2 had two major outbursts in last decade one in 2015 and one in 2022. LXP 8.04 had a recent outburst in 2024.

Products:

Spectra: phase averaged spectra, fitted with empirical and physical models (see Poster by M. Kouzis). Light-curves with spectral properties (e.g. slope, nH).

Temporal: Event files and binned light-curves. Energy resolved pulsed profiles and pulsed fractions. Phase resolved event Energy matrix, and phased resolved hardness ratios.

Code: Notebooks for plotting and manipulating products; e.g. re-binning energy matrix.

References

[1] Jaisawal G. K. et al., 2023, MNRAS, 521, 3951
[2] Liu J. et al., 2022, MNRAS, 517, 3354
[3] Townsend L. J. et al., 2017, MNRAS, 471, 3878
[4] Trümper J. E. et al., 2013, ApJ, 764, 49
[5] Vasilopoulos G. et al., 2020, MNRAS, 494, 5350
[6] Yang H. N. et al., 2025, MNRAS, 536, 1357

Contact & Acknowledgments

Questions and feedback are welcome: G.V: gevas@phys.uoa.gr

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Example Plots

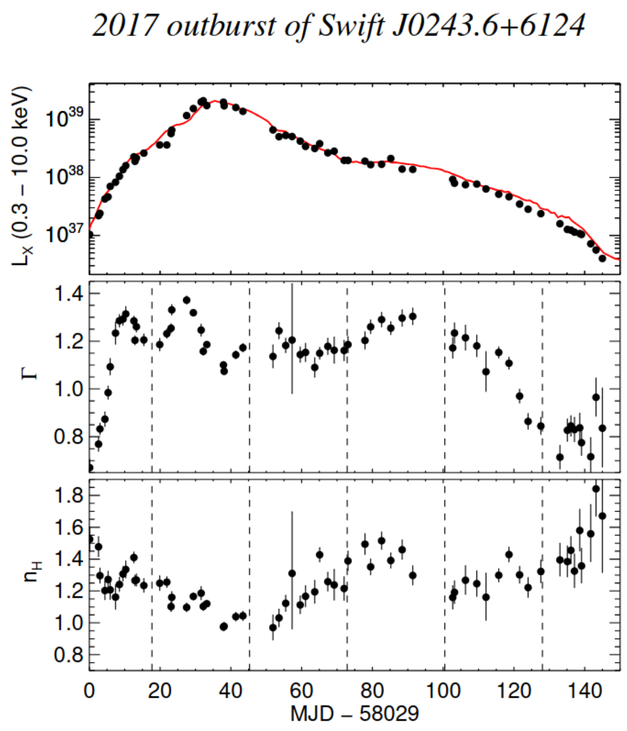

Figure 1: Swift J0243.6, spectral evolution with *Swift*/XRT.

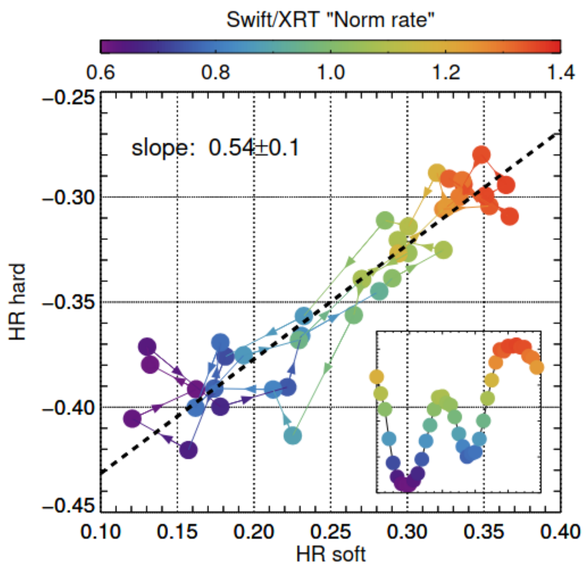

Figure 2: Swift J0243.6 major outburst: phased resolved soft (1.0-2.0 keV / 2.0-4.5 keV) vs hard (2.0-4.5 keV / 4.5-10.0 keV) hardness rasio.

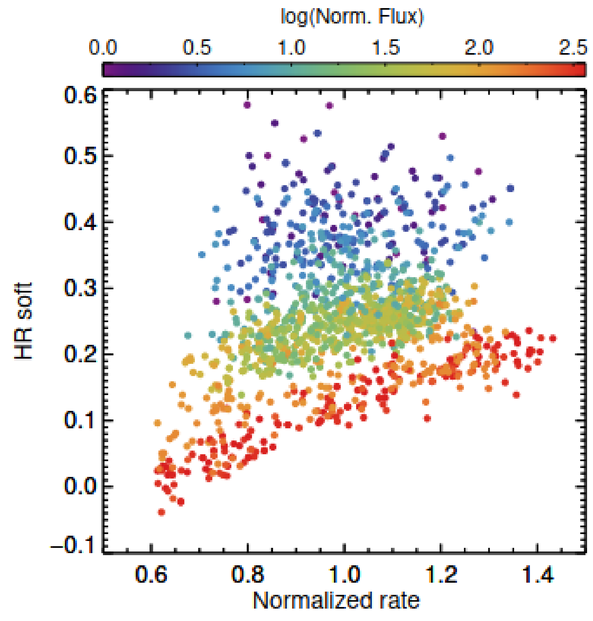

Figure 3: Swift J0243.6 major outburst: Phase resolved soft Hardness Ratio (1.0-2.0 keV vs 2.0-4.5 keV) for all *Swift*/XRT observations. X axis indicate normalized pulsed intensity, and colors the relative intensity between observations (see Fig. 1)

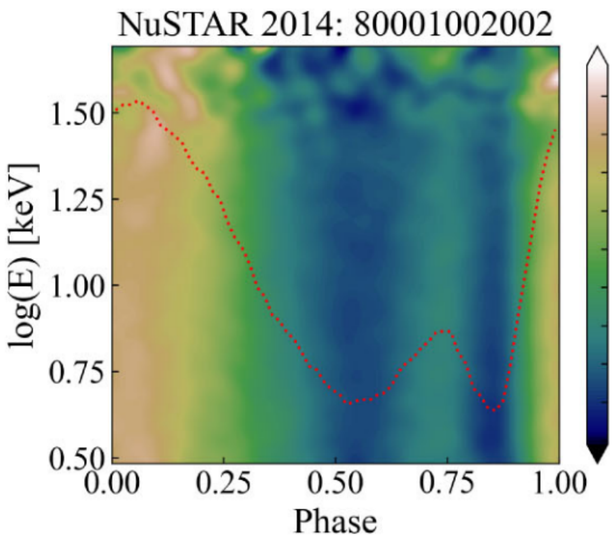

Figure 4: *NuSTAR*phase energy matrix for LXP 8.04 during 2014 outburst (Credit: [6]).

Pulsed Fraction

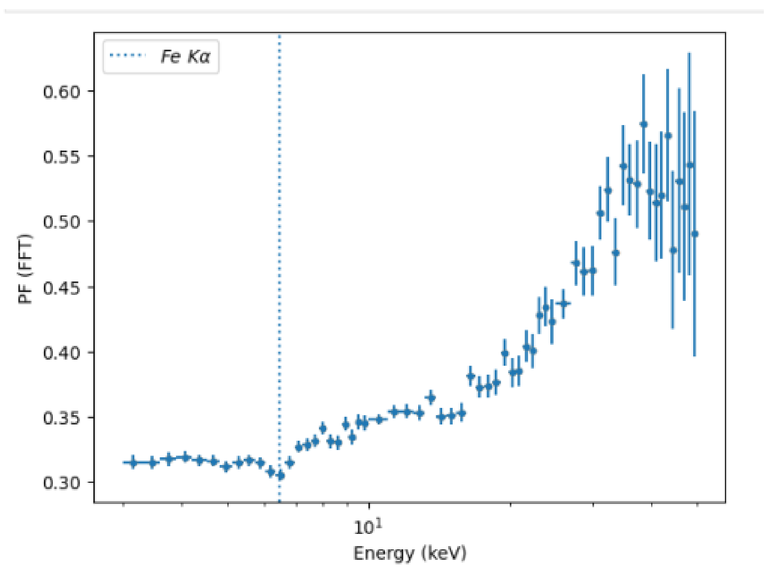

Figure 5: SMC X-3 Pulsed Fraction (PF) computed from *NuSTAR* data from 2016 major outburst.

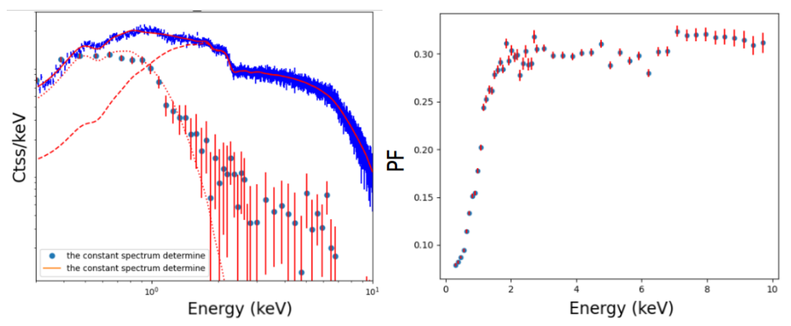

Figure 6: SMC X-2: PF from *XMM-Newton* data from 2015 major outburst compared to spectrum.

Pulse Profile modeling

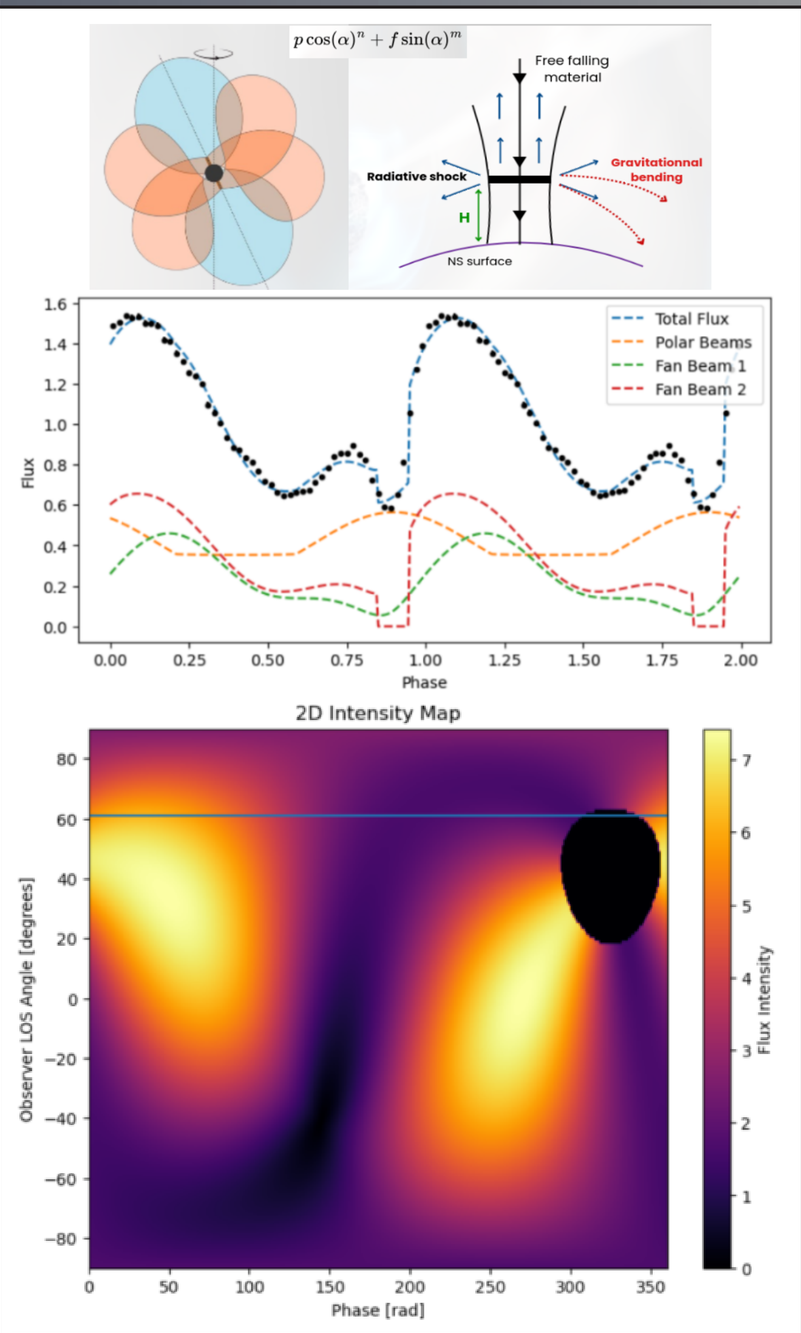

Figure 7: *Top:* Pulse profile code developed based on [4]. The model assumes with a fun plus pencil beam emission with azimuthal variation and gravitational bending. *Mid*: Pulse profile modeling for LXP 8.04. *Bottom*: Reconstructed 3D emission pattern where observer is along the horizontal line.

Conclusions

X-ray observations of major outbursts offer a unique sample of data with potential of discoveries from systematic analysis.

github + database: ETA for public access: September 2025. Interesting before that? contact us!