Insights from Swift J0243.6+6124 during its 2017-2018 outburst

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✓ ***Uncovered a new transition at L_{coul}, consistent with B ~ 5×10¹² G and d = 5.2 kpc.***

✓ ***Found elevated timing noise strengths above super-Eddington levels, may originate from emerging quadrupole fields.***

Source

- Discovered in 2017. Outbursts in 2017-2018 & 2023.
- Be X-ray binary with P_{spin} ~ 9.8 sec, P_{orbit} ~ 27.7 d [a][b]
- Studied in detail: 25+ articles so far!
- 2017-18 outburst: X-ray luminosity varying by 5 orders of magnitude!
- First detected ultraluminous X-ray pulsar (ULX) in the Milky Way! L_{peak} ~ 1×10^{39} erg/s at 5.2 kpc [c]
- Highest-energy CRSF ~ 120-146 keV → B ~1.6×10^{13} G, too high! Associated with multipole fields? [c]

⚠ We used the Gaia EDR3 distance: 5.2 ± 0.3 kpc (revised from 6.8 kpc by Gaia EDR2)

Data

- 480 ks *NICER*/XTI observations: MJD 58030-58530
- Public *Fermi*/GBM pulse frequency & *Swift*/BAT daily light curve histories

Pulse Timing

- Strong spin-up at the outburst beginning → phase-coherent timing technique unfavorable. So, we used this approach:

Fermi/GBM freq.s → Polynomial synthetic timing solutions → Freq. residuals = freq. - model → ∫ → Phase model

NICER/XTI data → *NICER* pulse profiles & ToAs → *NICER* frequencies

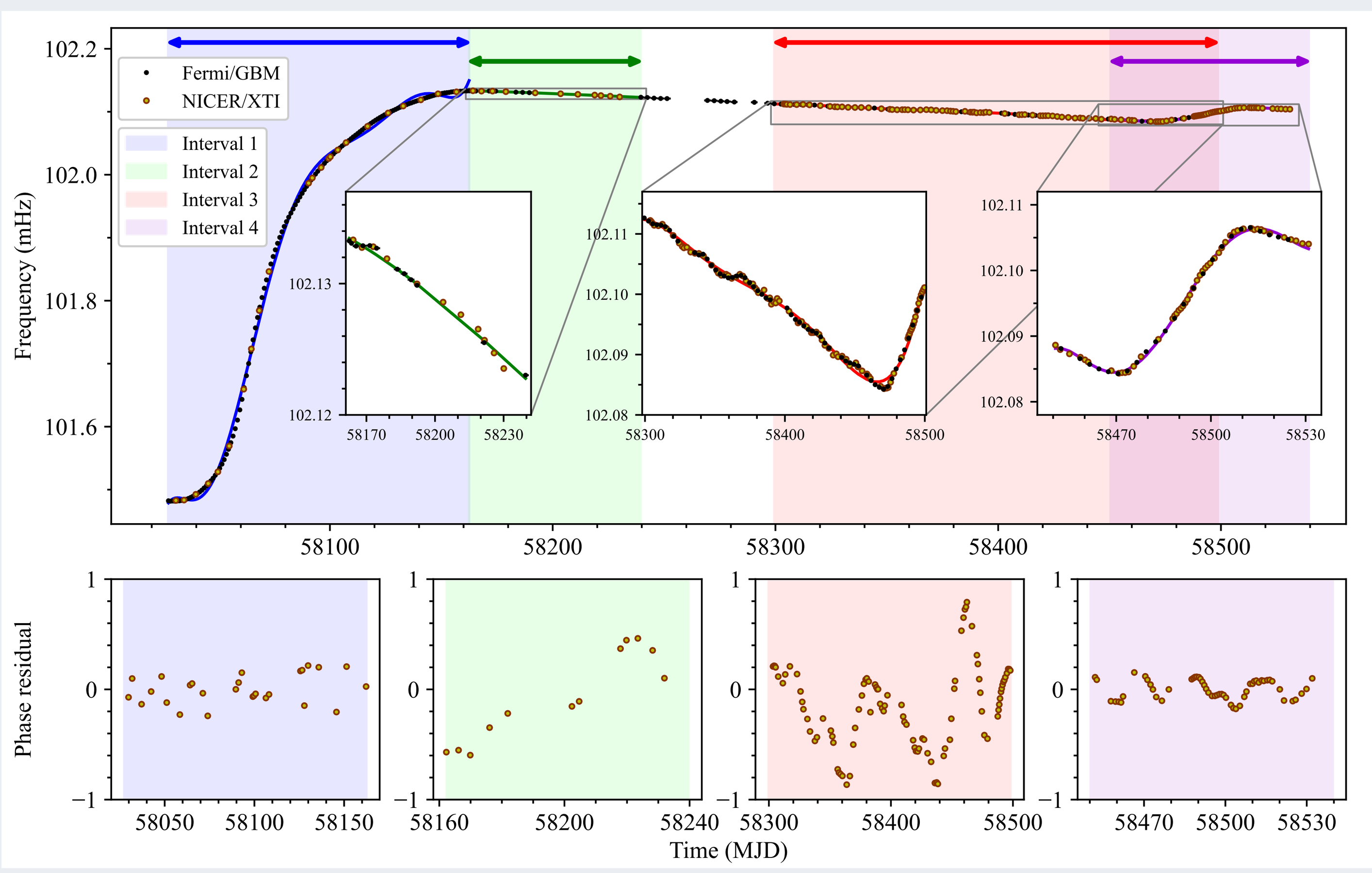

Figure 1: Spin frequencies, timing solutions and corresponding *NICER* phase residuals

- Previously, 2 transitional luminosity levels reported: L_1 & L_2 [c]

Becker's model: [d]			pulses are:
supercritical	radiation braking	fan beam, RPD disk? [c]	double-peaked
L_2			~2.6×10³⁸ erg/s
supercritical	radiation braking	fan beam	single-peaked
L_1			~8.8×10³⁷ erg/s
subcritical	Coulomb braking		double-peaked
L			~7×10³⁶ erg/s
subcritical	gas shock	pencil beam	single-peaked

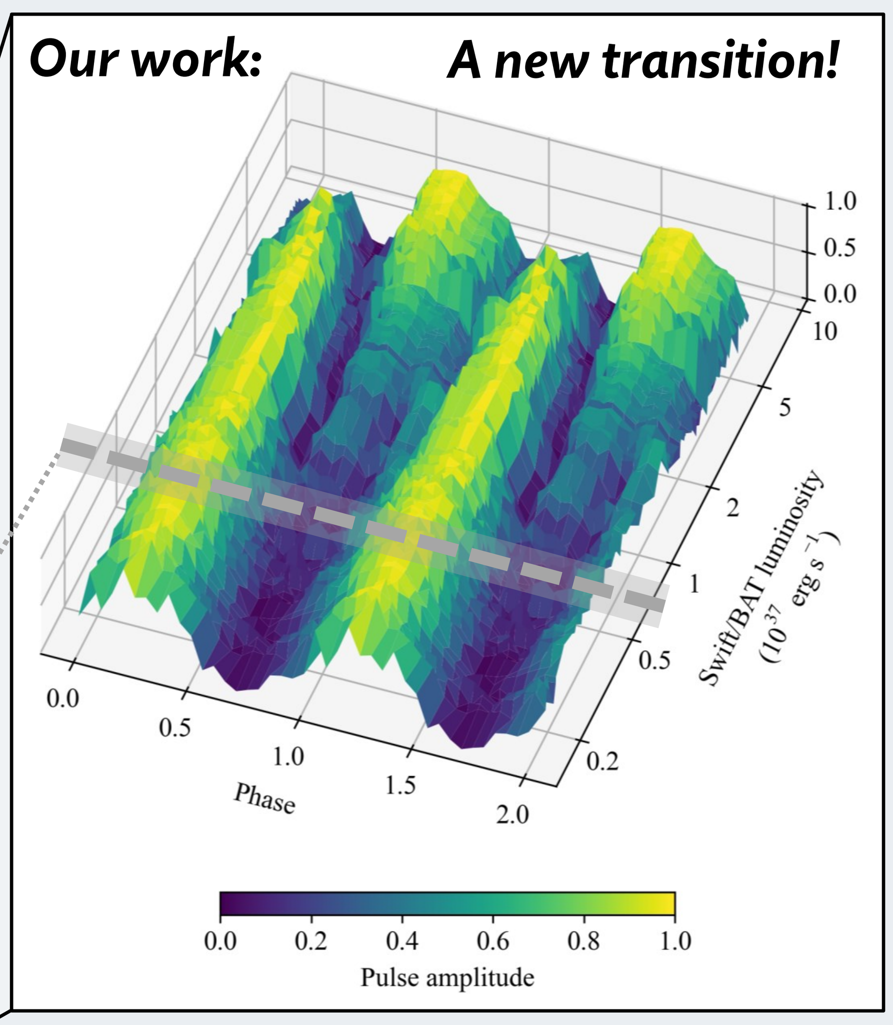

Figure 2: *NICER*/XTI pulse profile evolution: MJD 58300-58500, sorted by luminosity, normalized to [0, 1], two cycles plotted

- **L ~ 7×10³⁶ erg/s → Consistent with L_{coul} of Becker's model [d]: pencil beam to mixed pencil & fan beam**

L → B ~ 4.7×10¹² G
L_1 → B ~ 5.3×10¹² G
all consistent at d = 5.2 kpc!

ℹ Below L_{coul}, Coulomb interactions cannot stop the accretion flow: gas shock only.

Timing Noise

ℹ When torque fluctuations are…
…uncorrelated, wind accretion → white noise (flat, Γ = 0)
…correlated, disk accretion → red noise (Γ = -2)

- Generated two power density spectra (PDS) of frequency derivatives via the rms-value technique [f] (Figure 3)
- Along with the standard method, we applied a torque-luminosity model to spin frequencies and then used the residual frequencies → minimizes the disk accretion contribution to noise levels
- **Standard method: Red noise component has Γ = -3.36 ± 0.64, steeper than similar sources**
- **Modified method: Γ = -0.91 ± 0.38, luminosity-dependent model removed most (*but not all*) the red noise component**

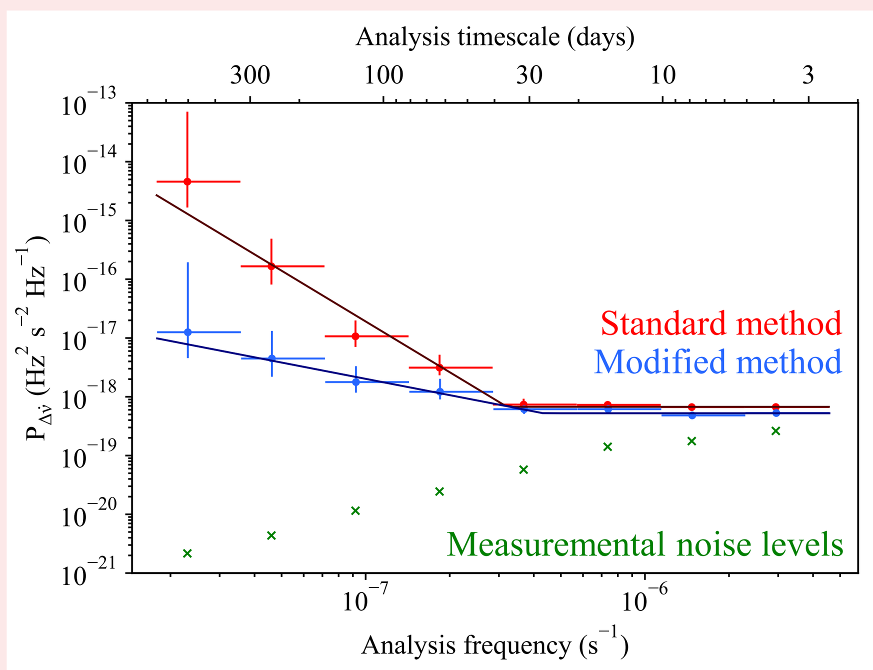

Figure 3: PDS of spin frequency derivatives with broken power law fits

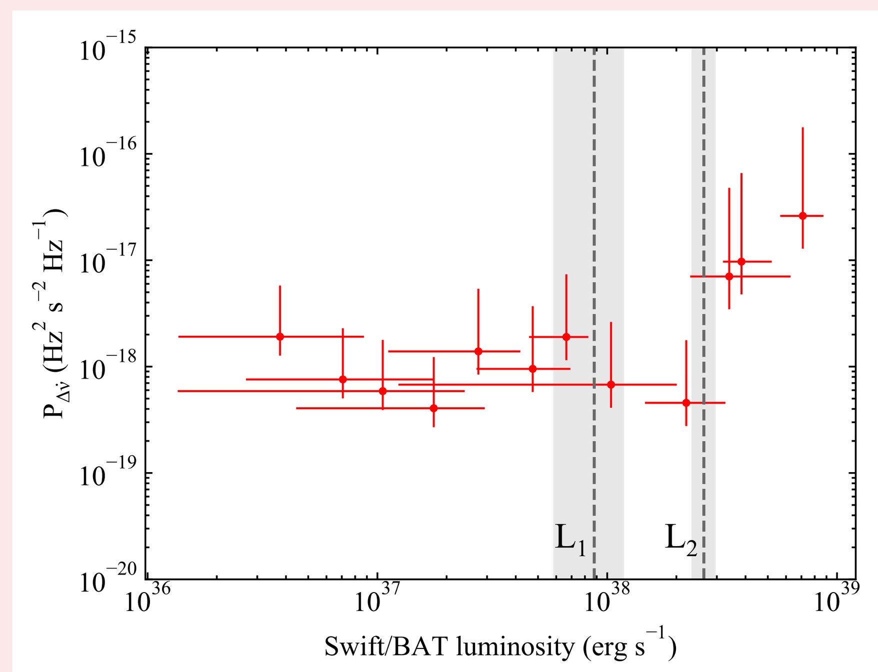

Figure 4: Luminosity dependence of timing noise strengths

- We also checked the luminosity dependence of timing noise strengths using the standard method (Figure 4)
- **At the highest luminosities, torque interactions become less efficient & noisier → supports the previous deductions of interactions with quadrupole components of magnetic field** [c]

ℹ ***Torque-Luminosity Model:*** more accretion → more luminosity → more torque on NS ⇒ more spin-up/down!

- Ghosh-Lamb model [g]: $\dot{\nu} \propto L^{6/7}$ (We used $\dot{\nu}_{model} = \beta L^{\alpha} + \dot{\nu}_0$)

References

[a] Kennea et al. 2017, ATel #10809
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