Probing accretion with thermonuclear bursts

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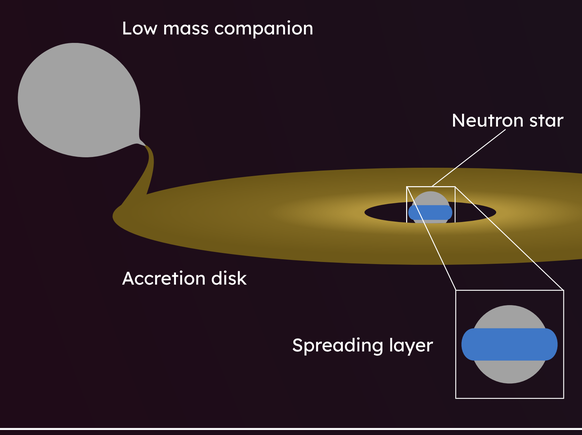
Thermonuclear bursts are experiments of accretion flow dynamics



Neutron Stars (NSs) in X-ray binaries are surrounded by an accretion disk. The accreted material triggers unstable nuclear burning, resulting in thermonuclear bursts that typically last 10-100 seconds and repeat every few hours (Fig. 1). These bursts are observed with various X-ray telescopes that allow for time-resolved spectral analysis.

Thermonuclear bursts are a dynamic probe into accretion physics and extreme matter; NSs contain the most compact visible matter in the universe!
If we understand the different processes contributing to the spectral evolution, thermonuclear bursts provide an opportunity for independent measurements of the masses and radii of NSs, which help us determine what kind of material NSs are made of.

Here, we put together a theoretical model incorporating disk heating and carving-out, resulting in simulated time-dependent emission spectra (Fig. 3).

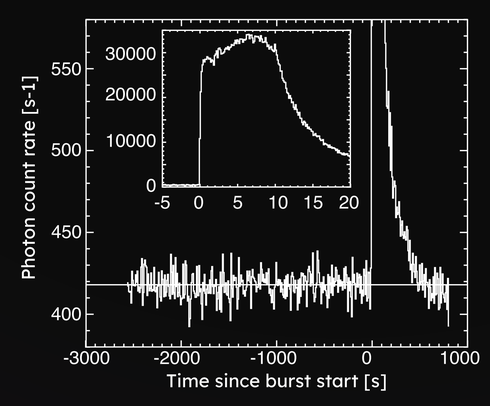
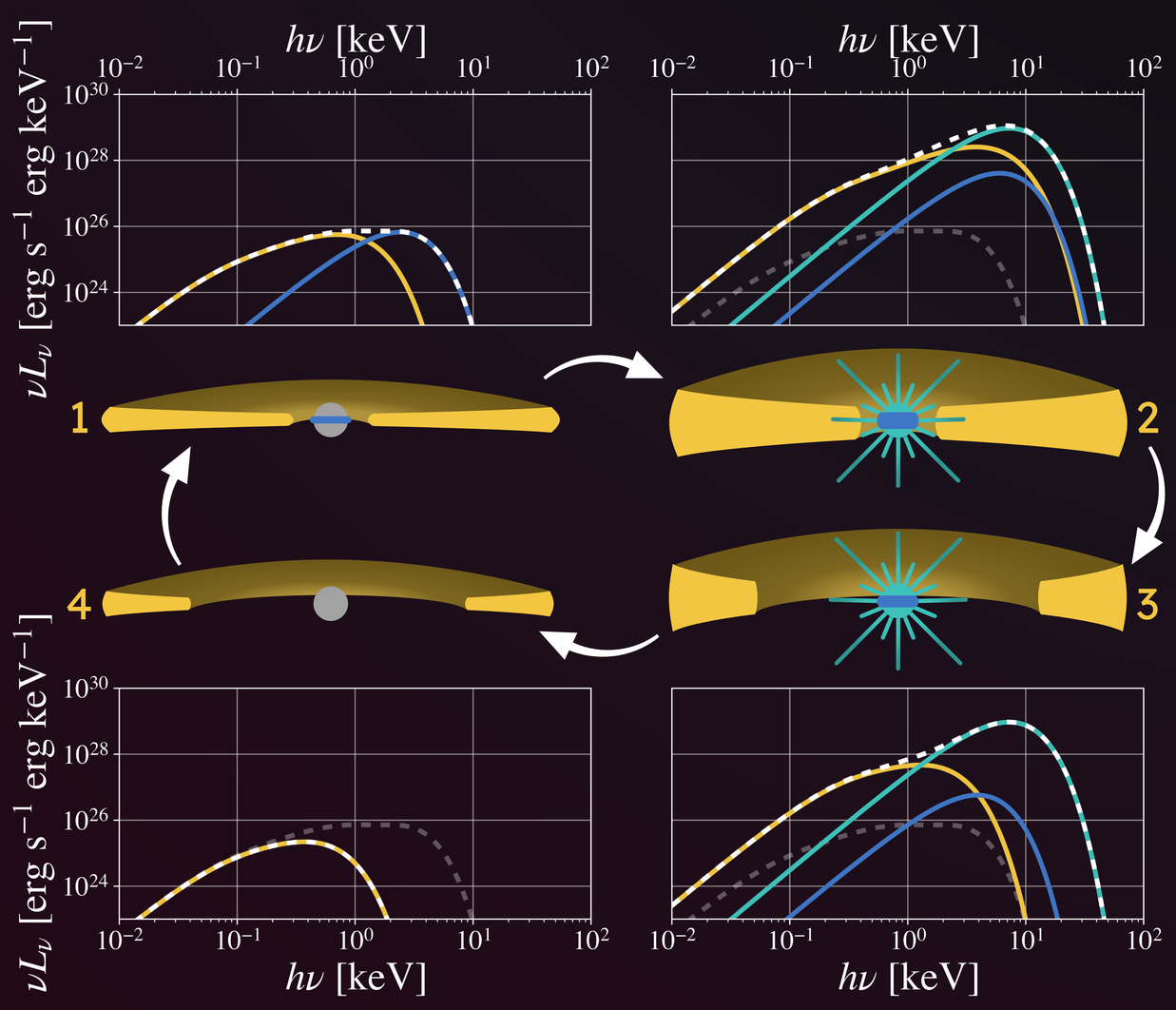


Fig. 1: X-ray light curve of a thermonuclear burst in SAX J1808.4–3658, adopted from [2].

Our new model [1]: bursts heat accretion disks and make them retreat over time

1: Standard thin disk

- Geometrically thin [3]
- Soft state
- 0.03% - 0.1% of the Eddington limited accretion rate ($\dot{M}$ ~ 10^{18} g/s)
- Multi-color black body disk spectrum
- Spreading layer (SL) on the NS surface



2a: Disk heating

- Absorption of burst radiation
- Brighter and hotter disk (higher photon energies)

2b: Enhanced accretion

- Poynting-Robertson (PR) drag [4]
  - Relativistic beaming effect on disk
  - Loss of orbital angular momentum
- More luminous SL

4: Recovering disk:

- Colder disk (pre-burst temperatures)
- Carved out disk is fainter (absence of high energy photons)
- Absence of SL until disk has recovered
- Refilling the carved out gap (Fig. 2)

3: Carved out inner disk:

- Enhanced accretion (Fig. 4)
- Inner disk gap

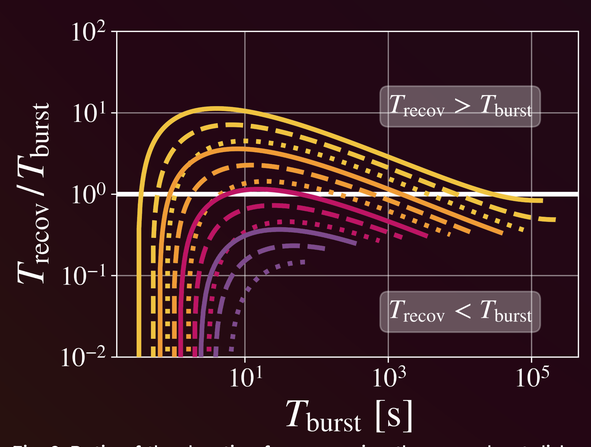


Fig. 2: Ratio of the duration for recovering the carved-out disk and the burst duration as a function of burst duration.

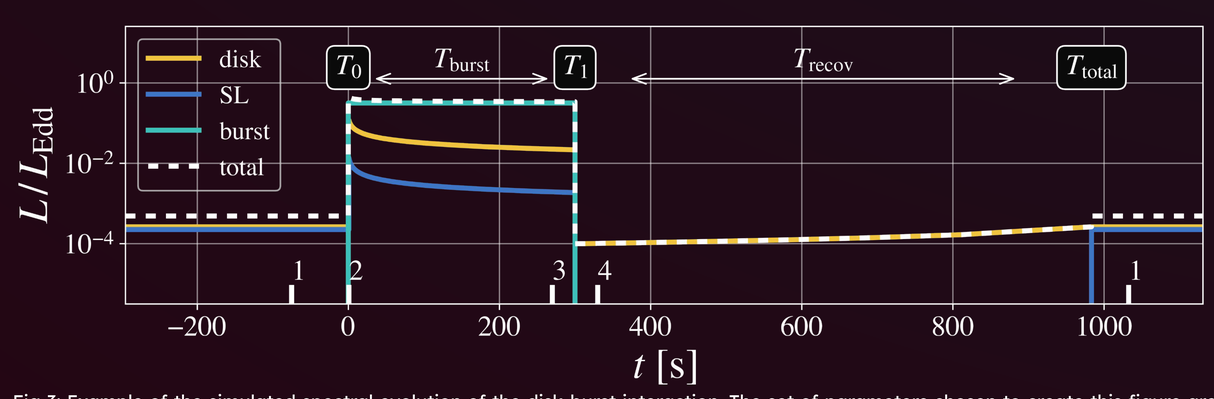


Fig 3: Example of the simulated spectral evolution of the disk-burst interaction. The set of parameters chosen to create this figure are an accretion rate of $\dot{M} = 0.03\%$ Edd, a burst luminosity of $L^{\infty}_{burst} = 0.5 L_{Edd}$, and a burst duration of 300 s.

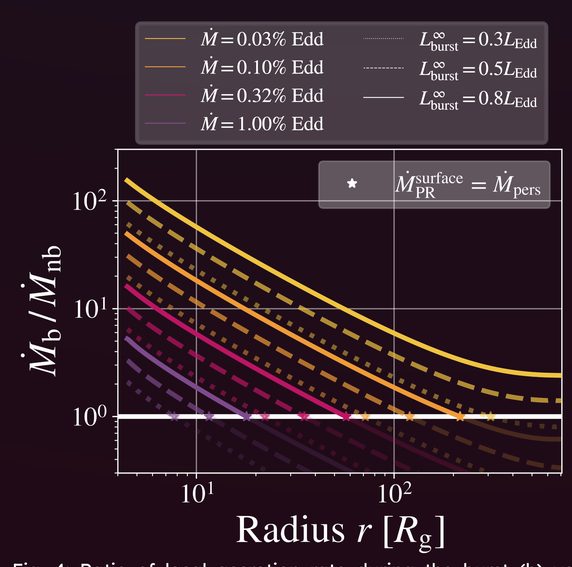


Fig. 4: Ratio of local accretion rate during the burst (b) versus before the burst (nb) for different choices of $\dot{M}$ and L^{∞}_{burst}.

Without modelling disk dynamics, fitting bursts can lead to mis-estimated NS parameters

Predictions:

- Spectral shape of persistent emission varies on multiple time scales due to:
  - disk heating
  - carving-out
- Disk heating rather than enhanced accretion is dominant in persistent emission increase

- Traditional fitting methods overestimate the size of the bursting region
- Heated disk emission accounts for up to 1/3 of the total luminosity during the burst
- Disk recovery duration is comparable to the burst duration (up to a factor 0.1-10)

NEW RESULTS!

Impact

- Towards more accurate NS mass/radius measurements
- Understanding jet brightening in relation to enhanced accretion

References

1. Van de Vosse et al. (2026, in prep.)
2. in 't Zand et al. 2013, A&A, 553, A83
3. Shakura, N. I. & Sunyaev, R. A. 1973, A&A, 337, 24
4. Walker, M. A. & Meszaros, P. 1989, ApJ, 844, vol. 346

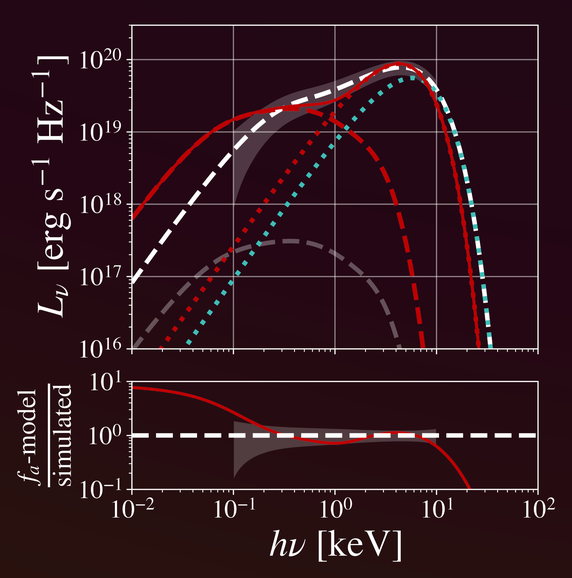


Fig. 5: Example of a simulated spectrum (white dash) and the fitted model (red solid). Notice the difference between the simulated (light blue dotted) and the fitted burst spectrum (red dotted).

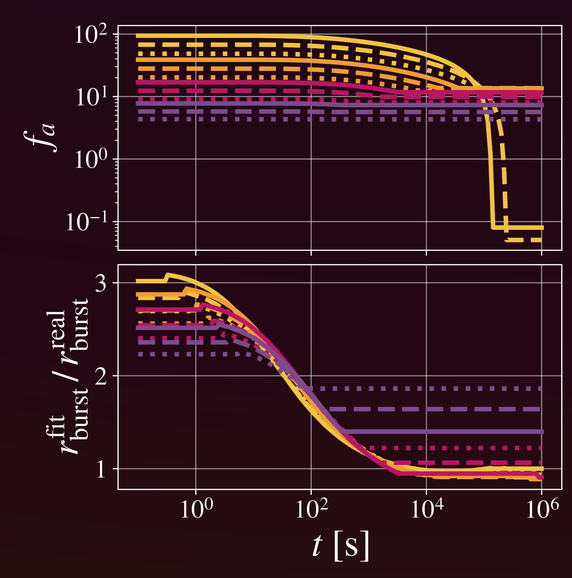


Fig. 6: Time dependent parameters: the fitted multiplication factor for the persistent emission (top) and the fitted burst radius relative to the simulated value (bottom).