Thermonuclear bursts on neutron stars: News at high accretion rates

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Astro-NS, St. Petersburg, July 2011

Headlines

Circinus X-1:

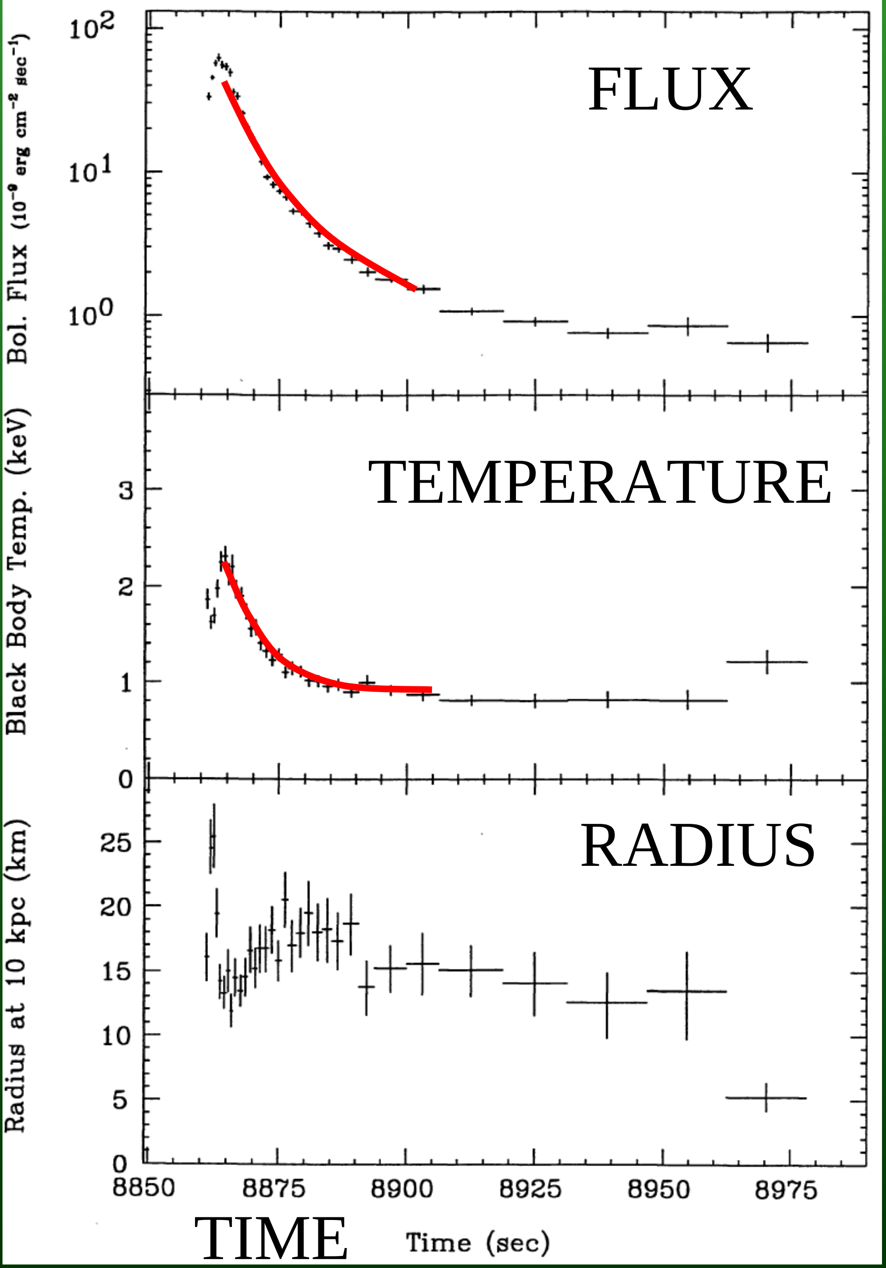
- The return of the bursts

Terzan 5:

- Thermonuclear bursts without cooling tail
- Additional heating in the neutron star envelope

NASA

Thermonuclear bursts on neutron stars



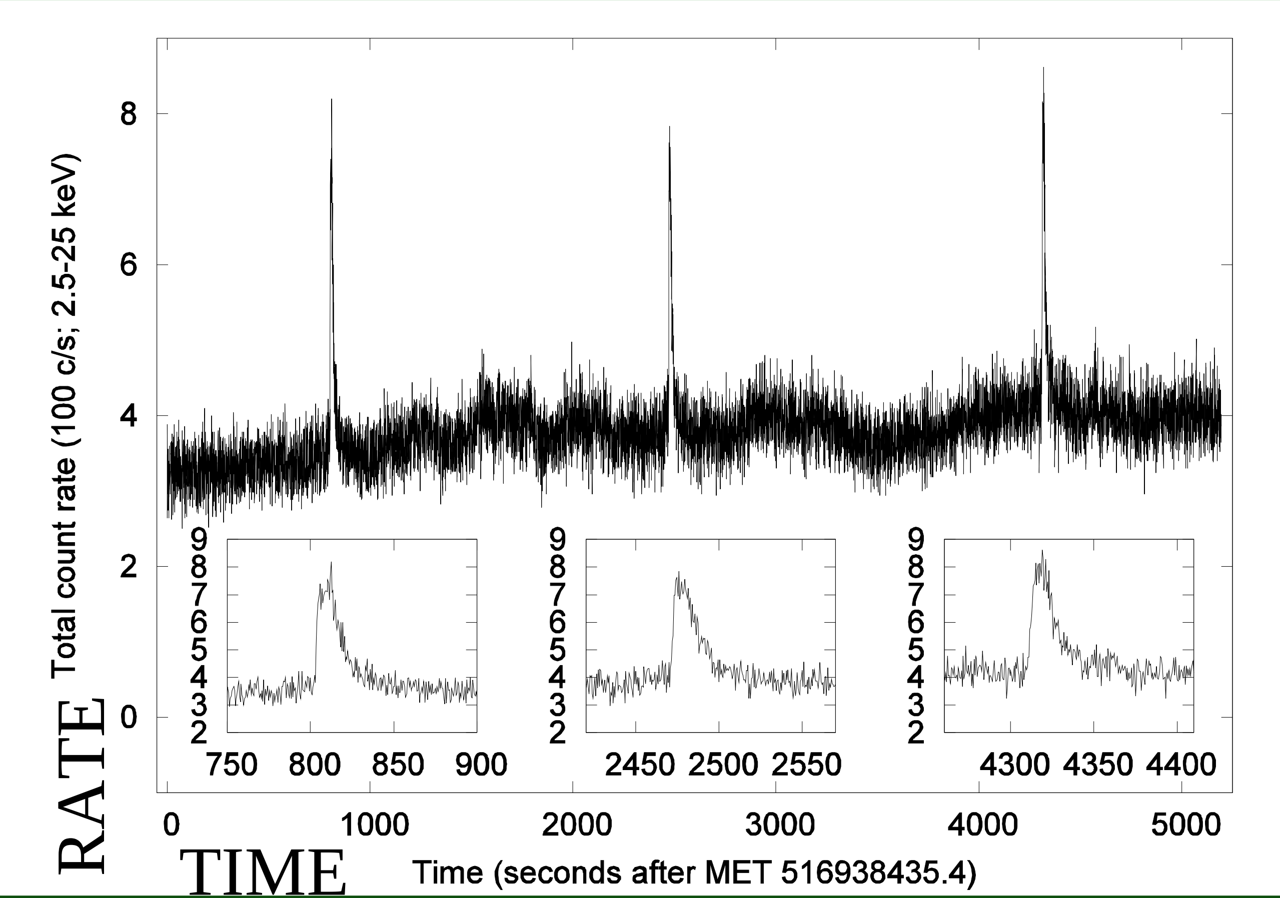
Type I X-ray burst ↔ thermonuclear burst

Defining property:
thermal (~0.5-3 keV) spectrum
+ cooling along the decay: “cooling tail”

Cooling of the neutron star photosphere after the fast injection of heat during thermonuclear runaway

From Oosterbroek in Lewin et al (1993); Hoffman et al (1978)

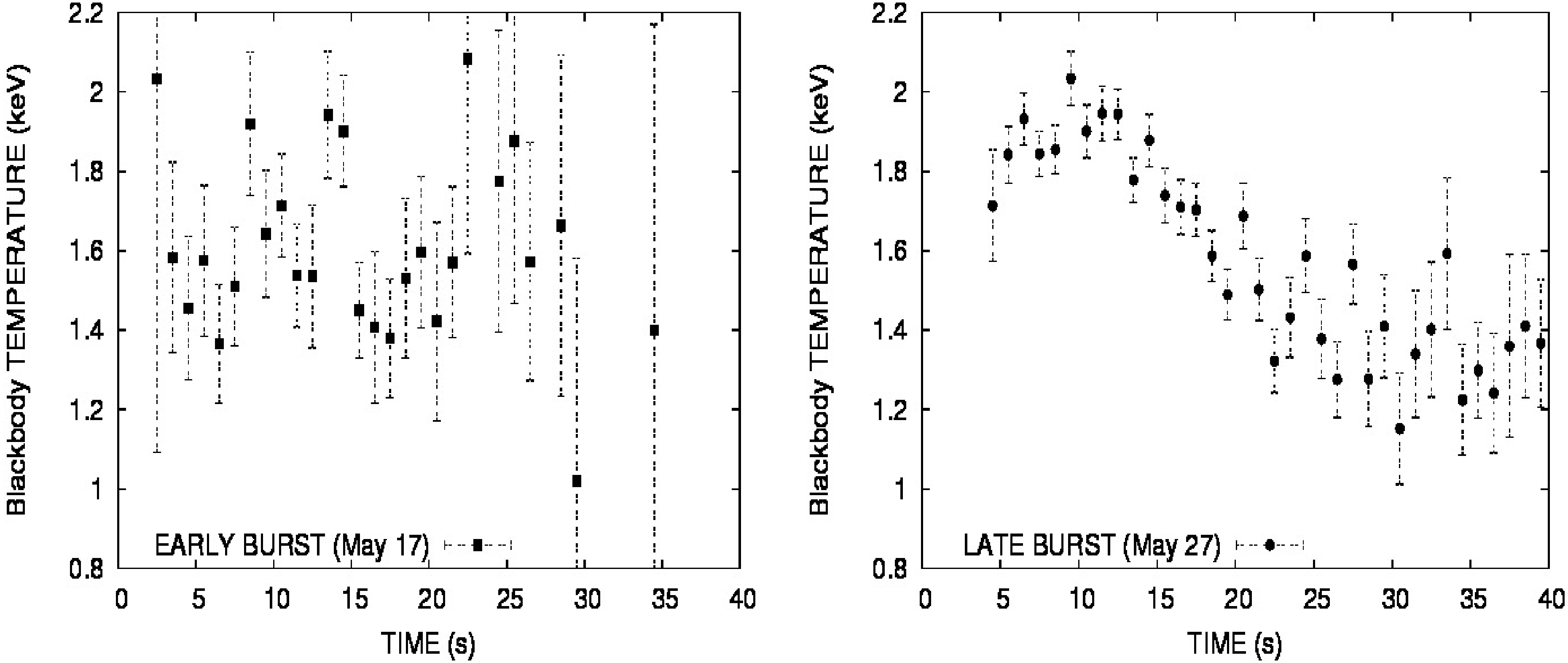
Circinus X-1: The return of the bursts



Linares et al (2010), ApJ-L, 719, 84

Thermonuclear bursts from Cir X-1 (May 2010 with Swift & RXTE)
25 years after the first and only previous detection (Tennant et al. 1986)
→Confirmed as NS; Crust cooled down? Cooling/non-cooling bursts…

Circinus X-1: The return of the bursts



"Late bursts": cooling, canonical type I X-ray bursts.

"Early bursts": no cooling detected ('non-cooling') ?...

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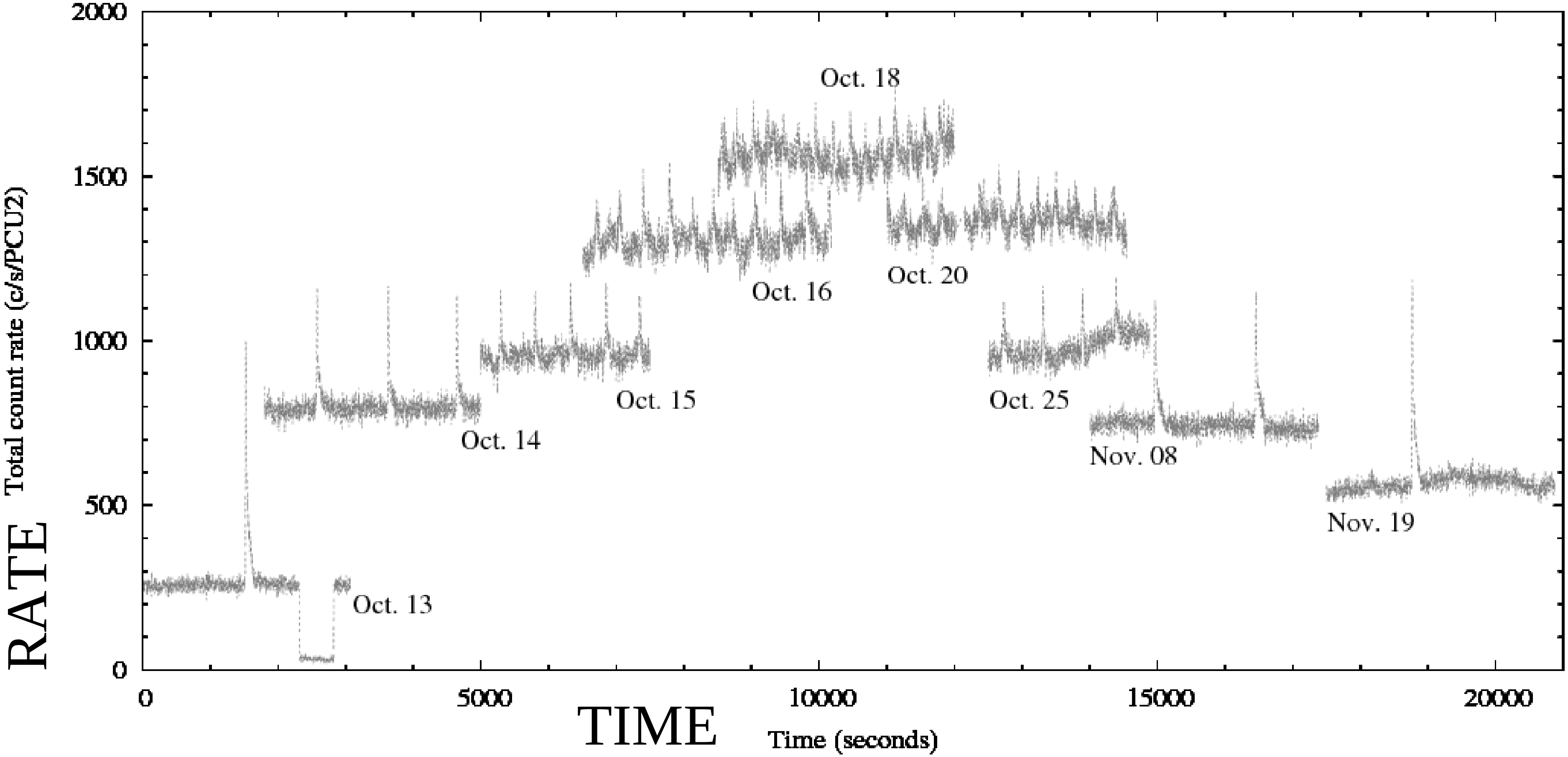
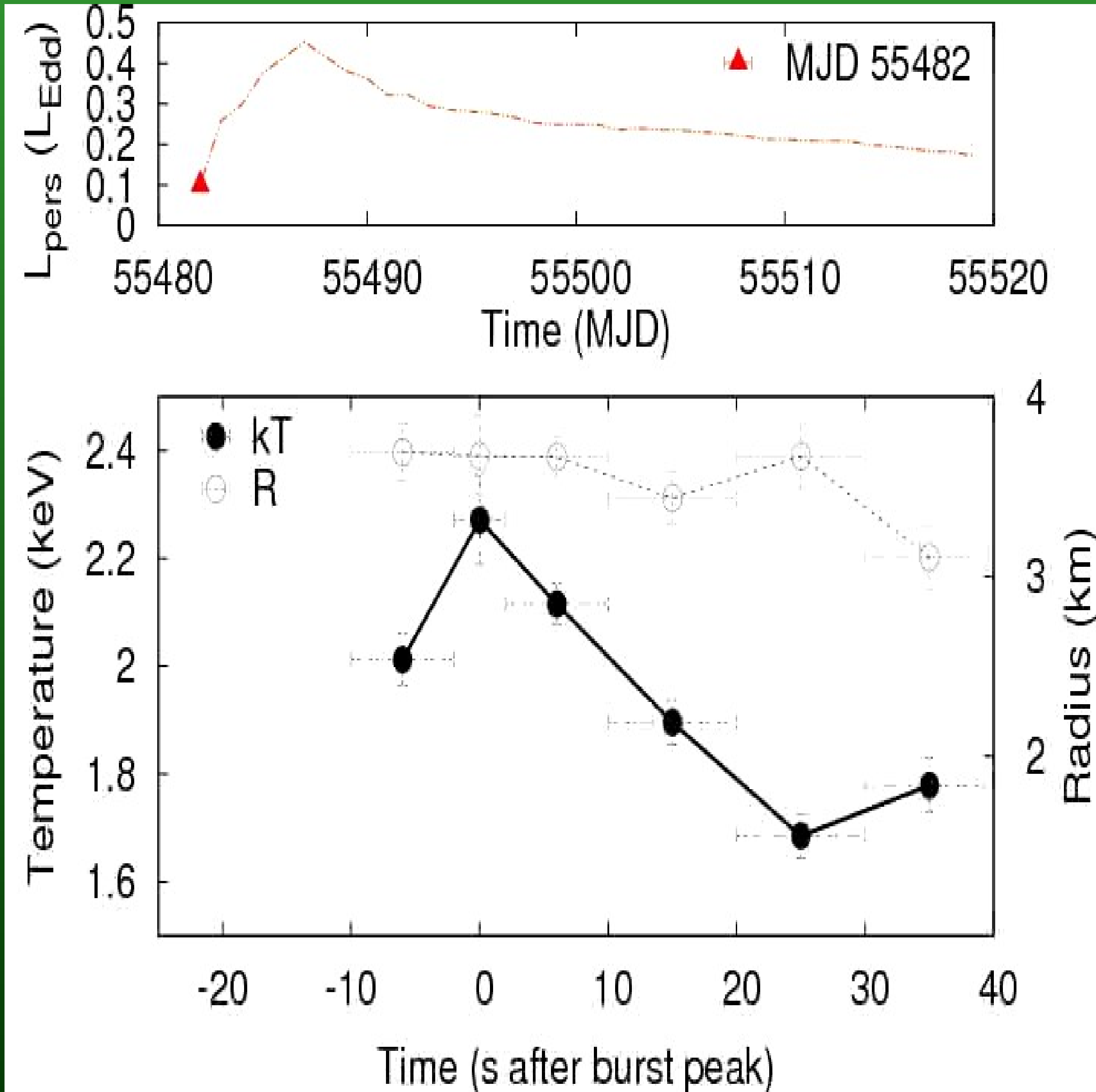
Terzan 5: smooth burst evolution



11 Hz pulsar in a ~21hr orbit (Strohmayer et al. 2010; Papitto et al. 2011) showing MANY X-ray bursts (~400 between Oct. 13 – Nov. 19, 2010)

Interesting burst properties, mHz QPOs (Linares et al. 2010) …

Terzan 5: smooth burst evolution



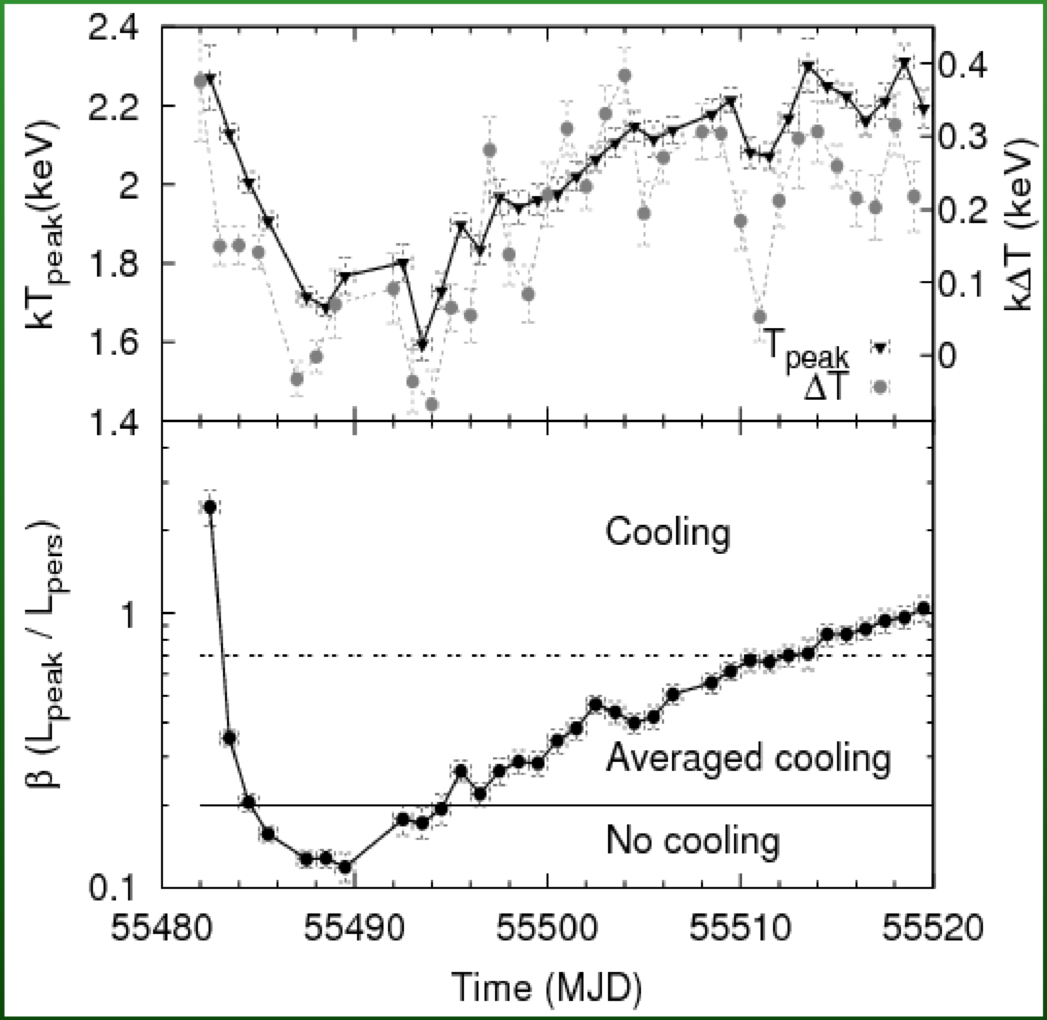
Energetics: thermonuclear

($\alpha \equiv E_{accretion}/E_{burst} \sim 100$)

Smooth evolution from type I to 'non-cooling' X-ray bursts, and vice versa.

→ First X-ray bursts without cooling tail identified as thermonuclear!

Terzan 5: smooth burst evolution



Quantifying cooling as a function of:

$$\beta \equiv \frac{\text{Peak burst luminosity}}{\text{Persistent luminosity}}$$

β ≡ Peak burst luminosity / Persistent luminosity

- β>0.7: type I X-ray bursts.
- 0.2<β<0.7: single bursts DON'T but daily averages DO show cooling.
- β<0.2: no cooling.

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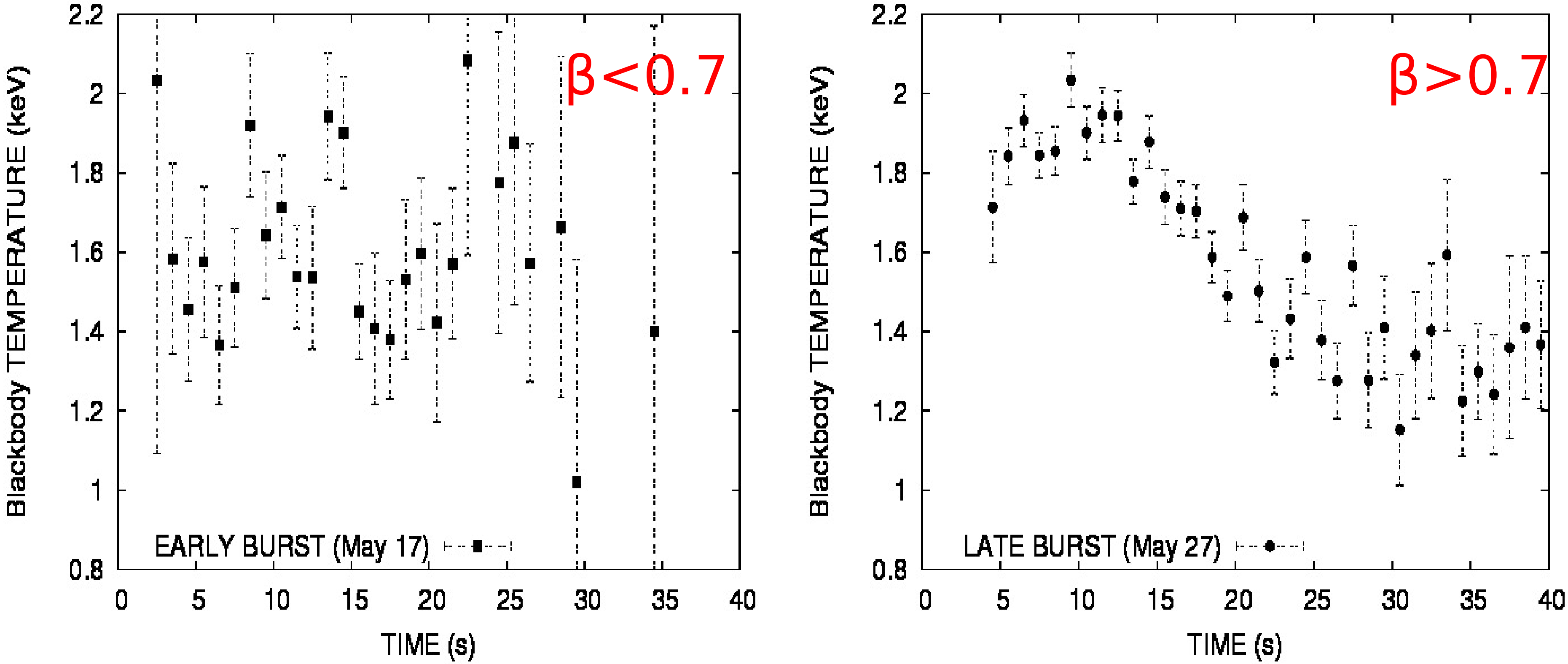
Terzan 5 vs. Circinus X-1



Same β=0.7 threshold explains Cir X-1 “early vs. late” bursts!!

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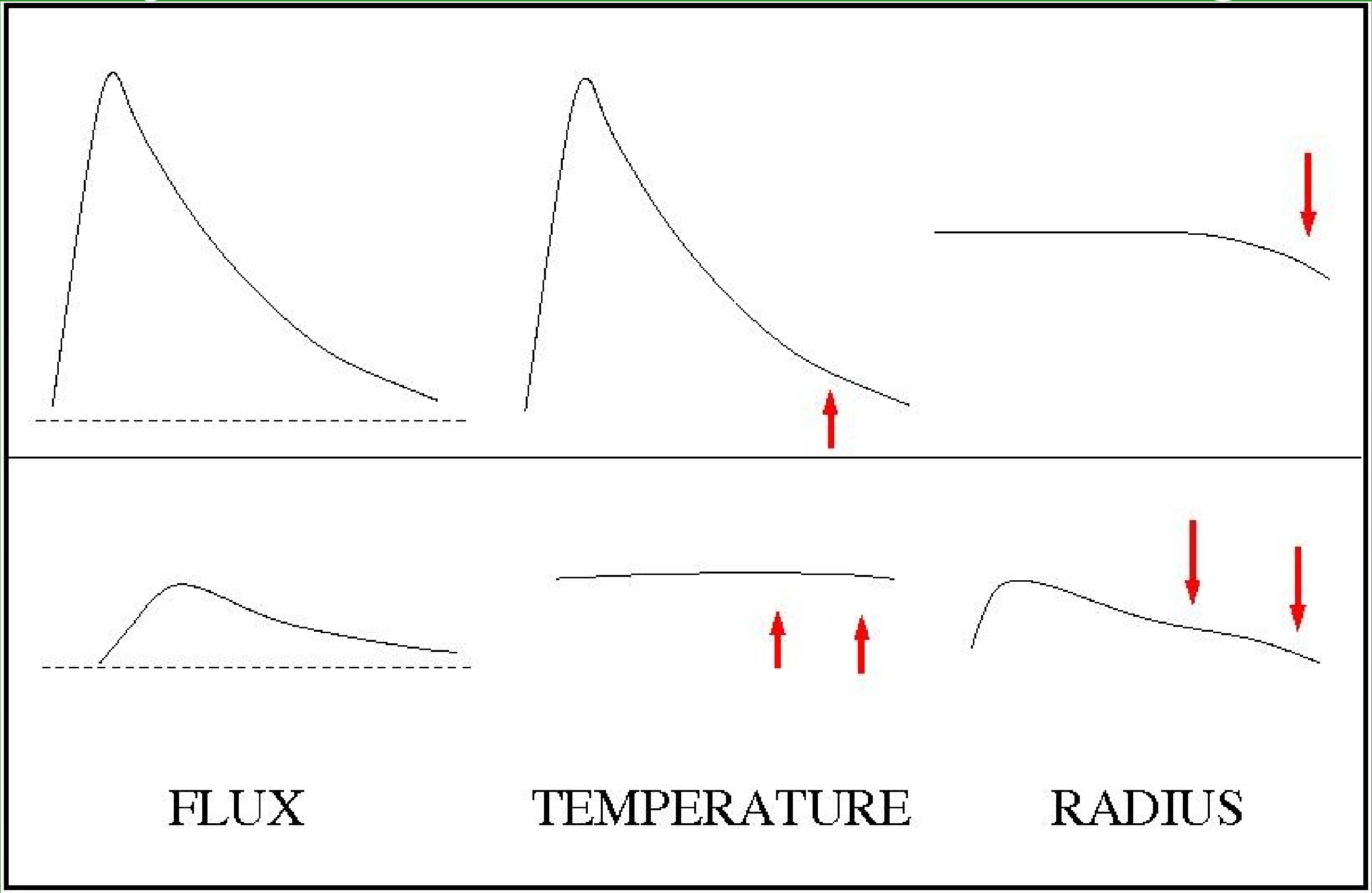
Systematics hides cooling

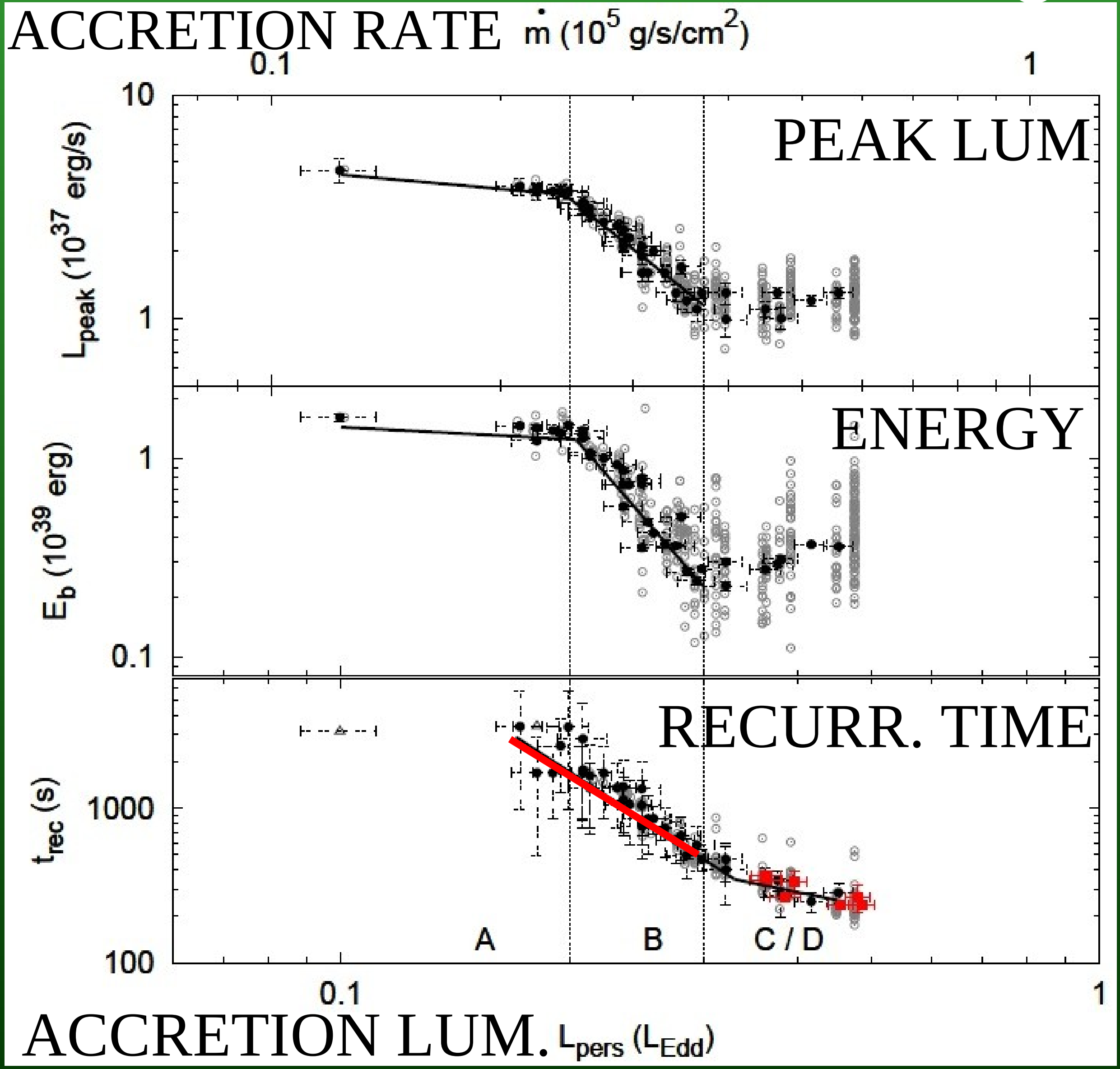


-If persistent NS surface emission dominates, "standard spectroscopy" over[under]estimates T[R] (van Paradijs & Lewin 1986)

→ A hot NS *between* bursts can hide cooling *during* faint bursts.

(Supported by spectral simulations; M. Zamfir priv. comm.)

Terzan 5: bursting regimes



The highest burst rate, in a regime (persistent luminosity > 0.2 L_{Edd}) where bursts were extremely rare!

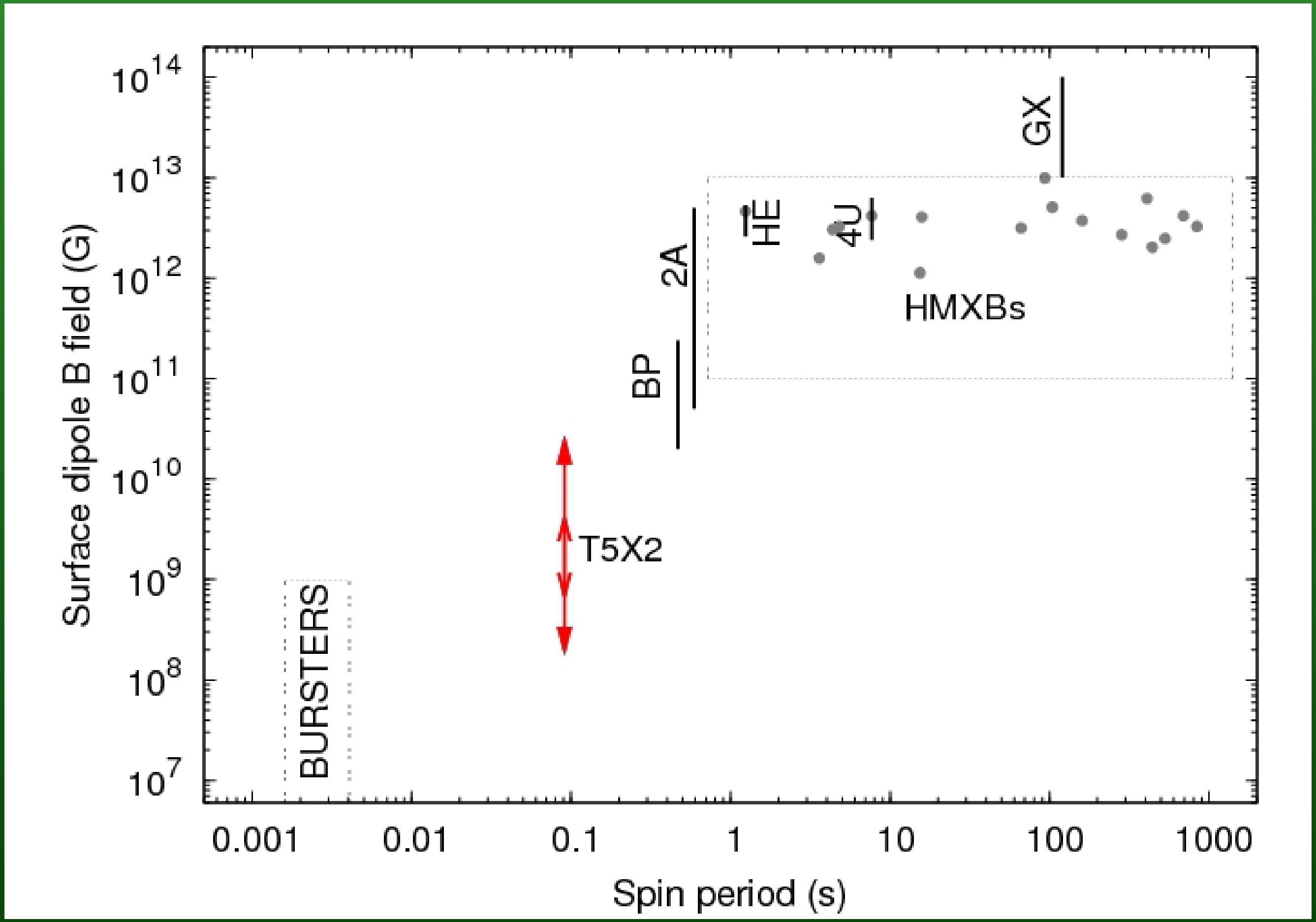
$t_{rec} \sim L_{pers}$ **$^{-3.2+/-0.5}$**

In this regime 'hot CNO' should give constant heating rate: (Cumming & Bildsten 2000)

Need extra heating, from triple alpha? or previous bursts?

Terzan 5: bridging the gap

B and spin between typical LMXB and HMXB values:



Bildsten et al. (1997); Caballero & Wilms (2011); Papitto et al. (2011); Miller et al. (2011)

B needed to stabilize burning (below 0.5 L_{Edd}) is at least ~10^{10} G.

Does (slow) spin influence burning regimes?

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Summary

Circinus X-1:

The return of the bursts after 25 yr.

Terzan 5:

X-ray bursts smoothly evolve from type I to “non-cooling”.

Cooling vs. thermonuclear X-ray bursts: Sufficient but not necessary!

Linares, Chakrabarty & van der Klis (2011), ApJ-L, 733, 17

Systematics of standard burst spectroscopy can hide cooling

(threshold: β=Lpeak/Lpersistent=0.2)

Extremely high burst rate, t_{rec} ~ Lpers **-3**

Extra heating by He burning or ‘hot ashes’?

Circinus X-1: The return of the bursts

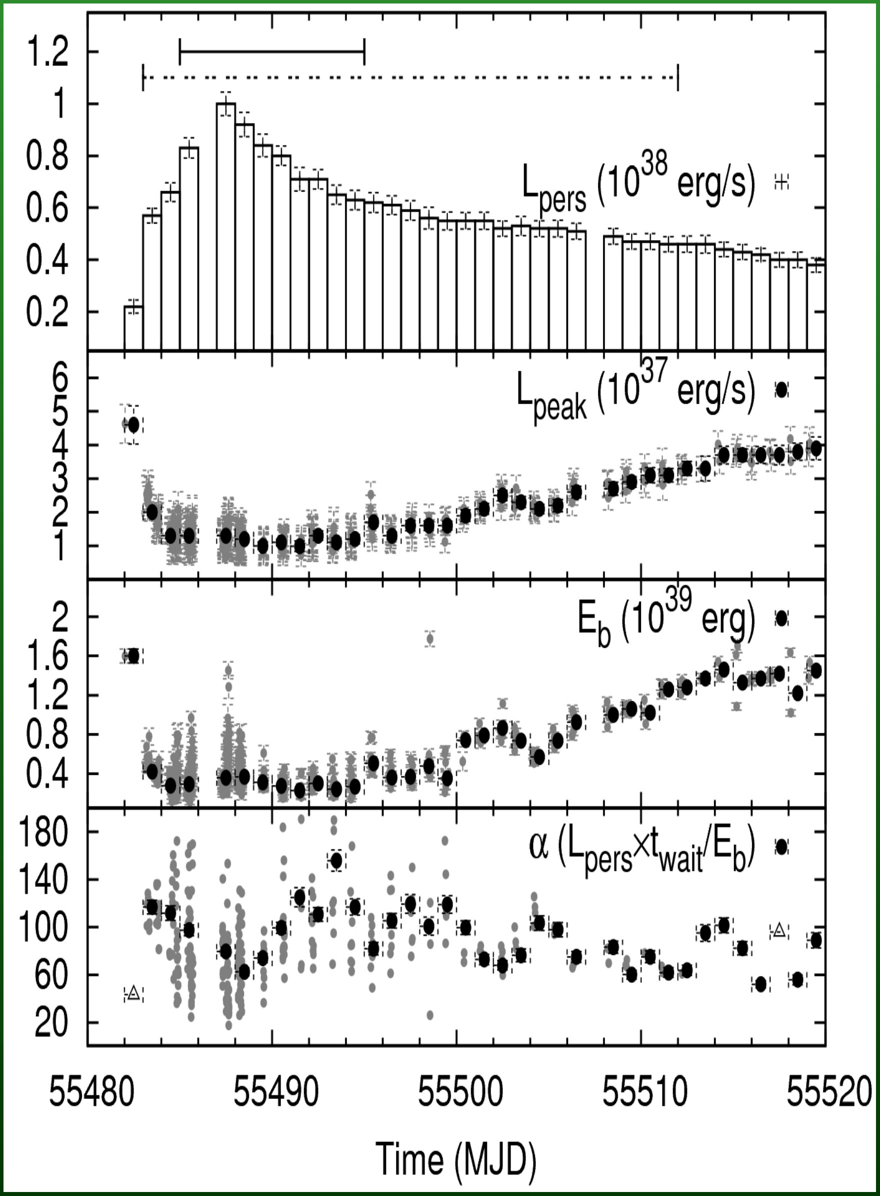
March 11 – Mikhail Gorbachev becomes General Secretary of the Soviet Communist Party and de facto leader of the Soviet Union.

April 23 – Coca-Cola changes its formula and releases New Coke. (The response is overwhelmingly negative, and the original formula is back on the market in less than 3 months.)

July 3 – Back to the Future opens in American theatres and ends up being the highest grossing film of **** in the United States and the first film in the successful franchise.

July-August:
Tennant et al. discover type I X-ray bursts from Circinus X-1

Terzan 5: smooth burst evolution



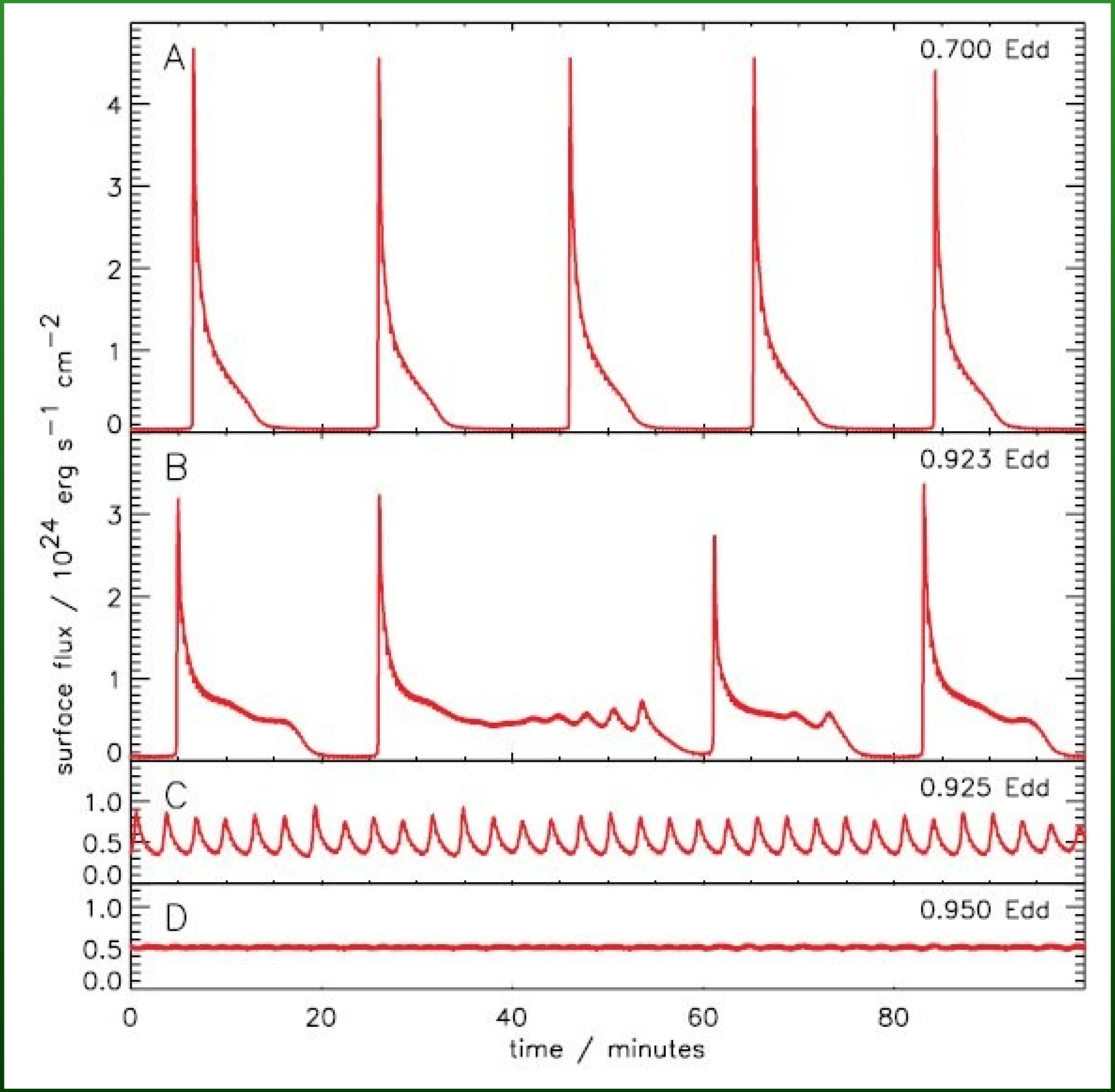
Series of faint and frequent bursts form the observed mHz QPO (burst rate = mHz QPO frequency).

BURSTS EVOLVE INTO A mHz QPO!

Different than 4U 1608, 4U 1636, where bursts and mHz QPOs are clearly distinguishable (Revnivtsev; Altamirano). Lower frequency in Terzan 5 (2-4 mHz vs. 7-9 mHz).

Also, different persistent luminosity when mHz QPOs are present: in Terzan 5 Lpers~80% Eddington, consistent with stable burning boundary for accretion onto full NS surface.

Terzan 5: smooth burst evolution

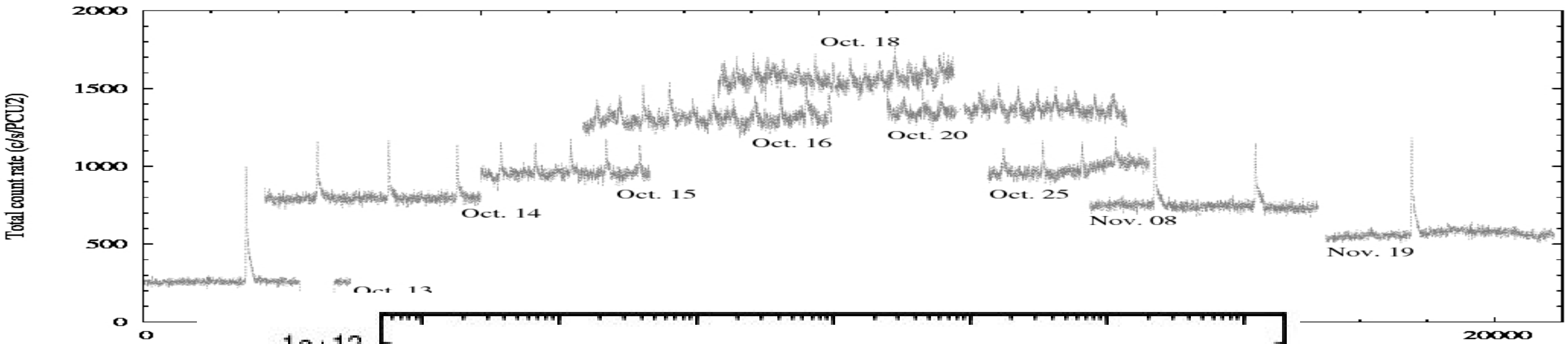


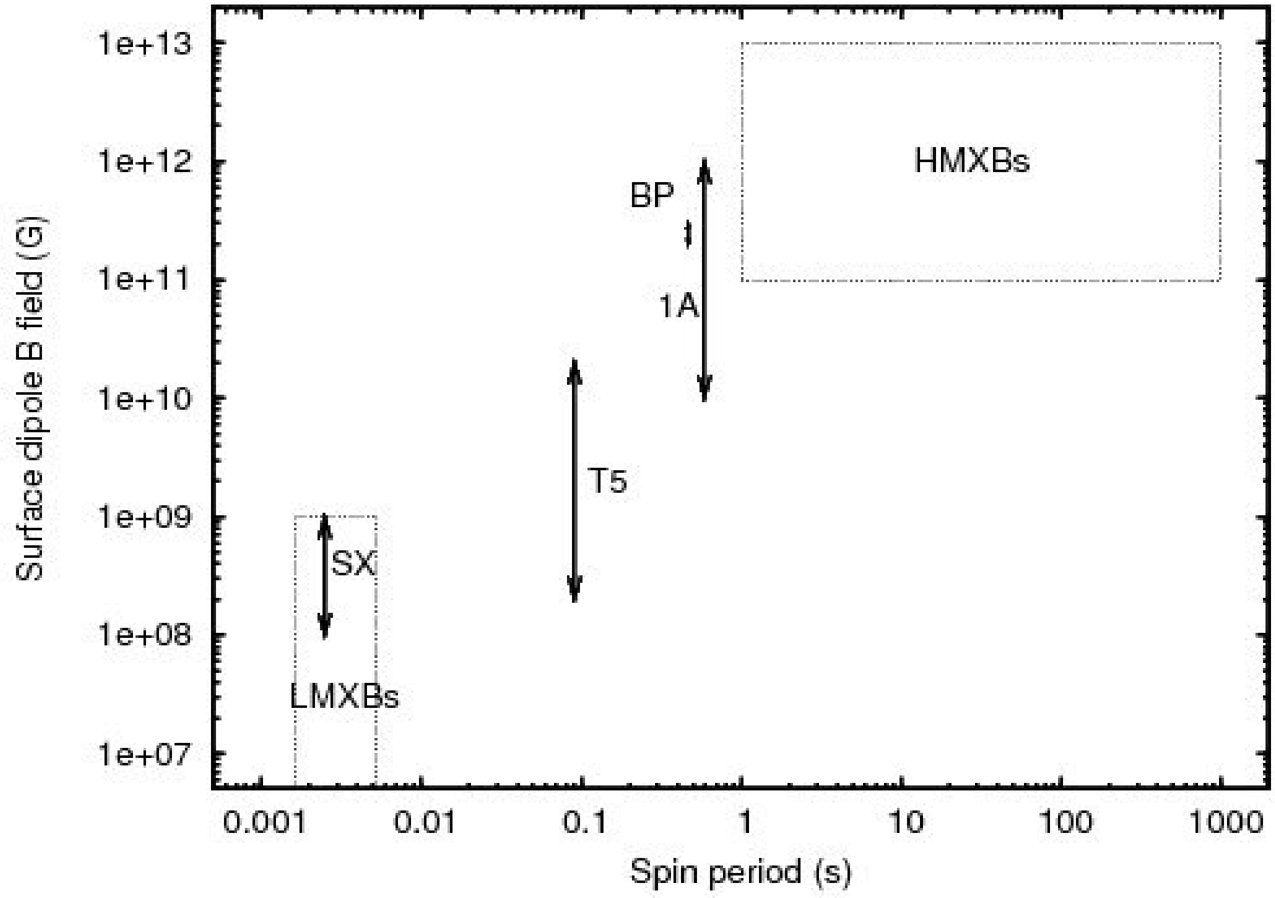
Heger et al (2007)

Why is Terzan 5 the exception and not the rule?

Intermediate spin and B field?

Terzan 5: smooth burst evolution





...es. Astro-NS 2011

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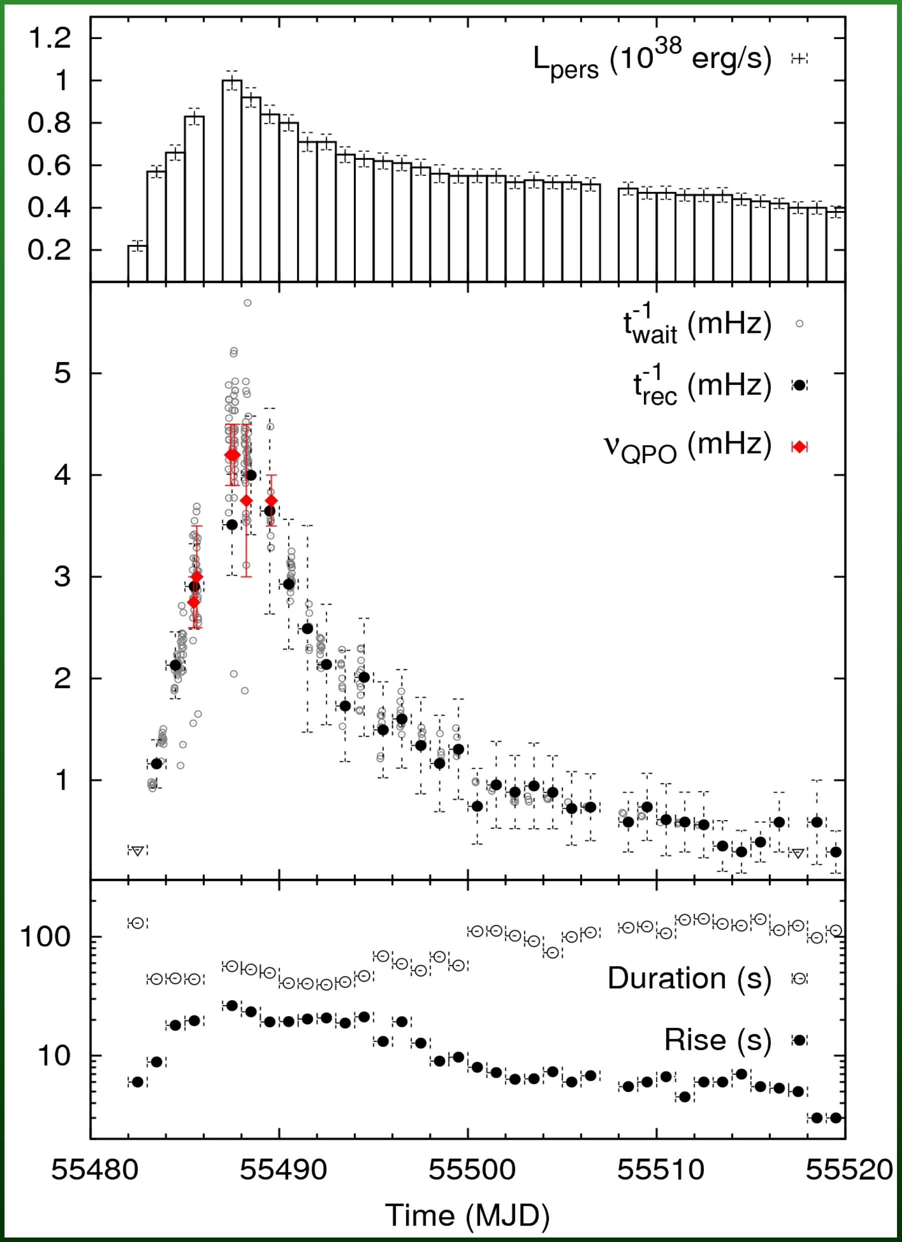

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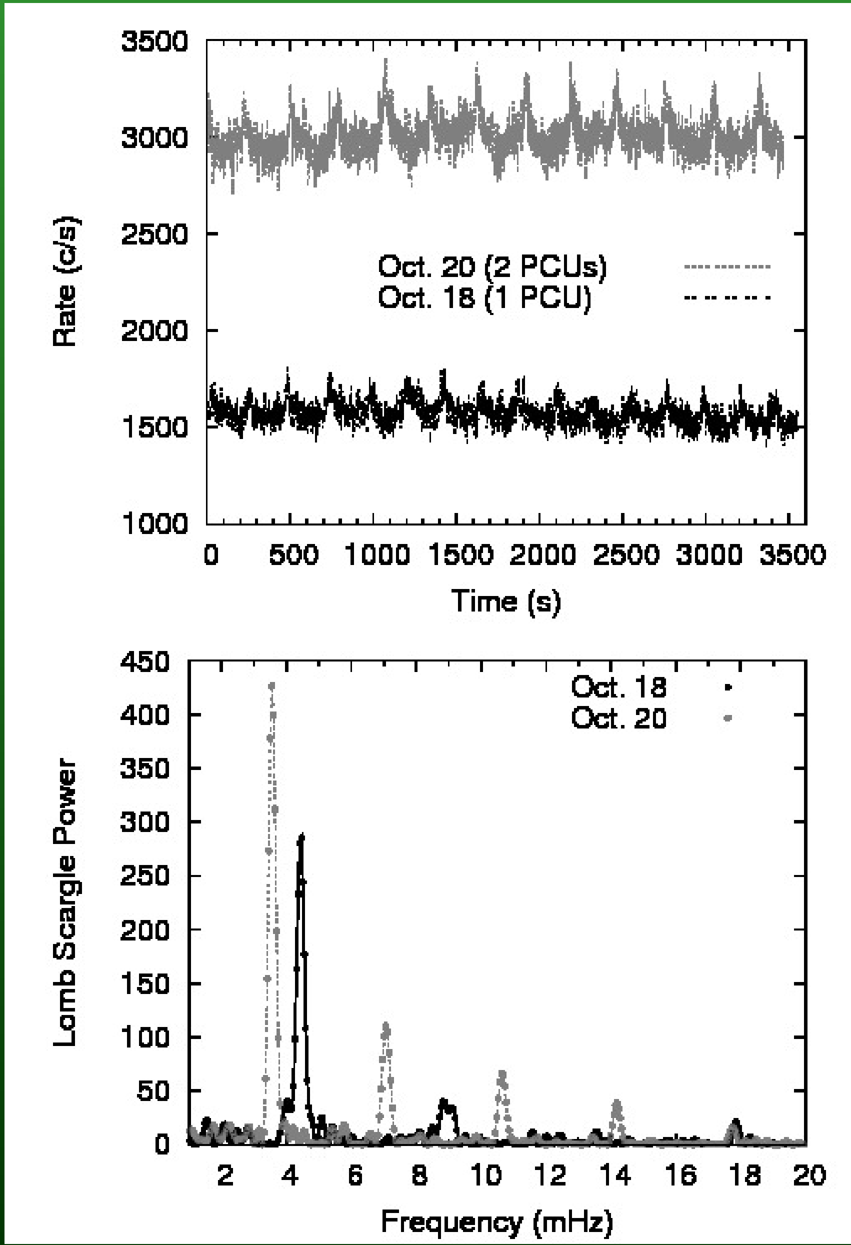

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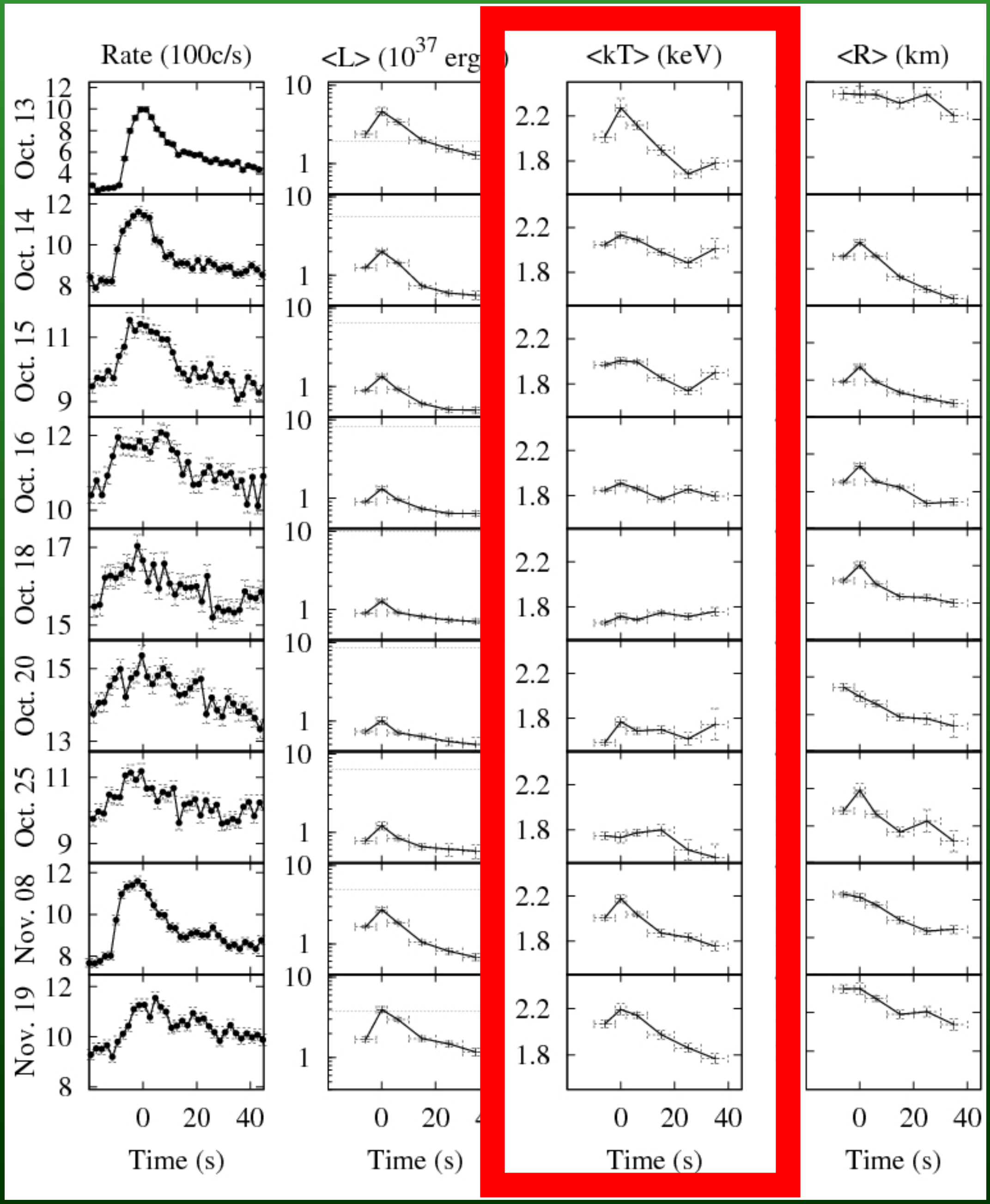

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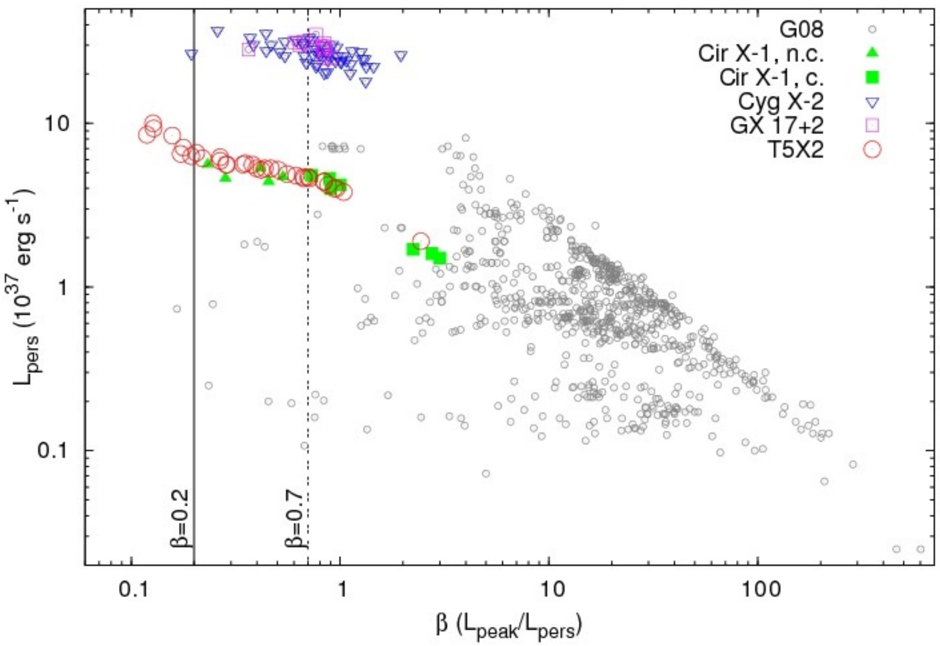

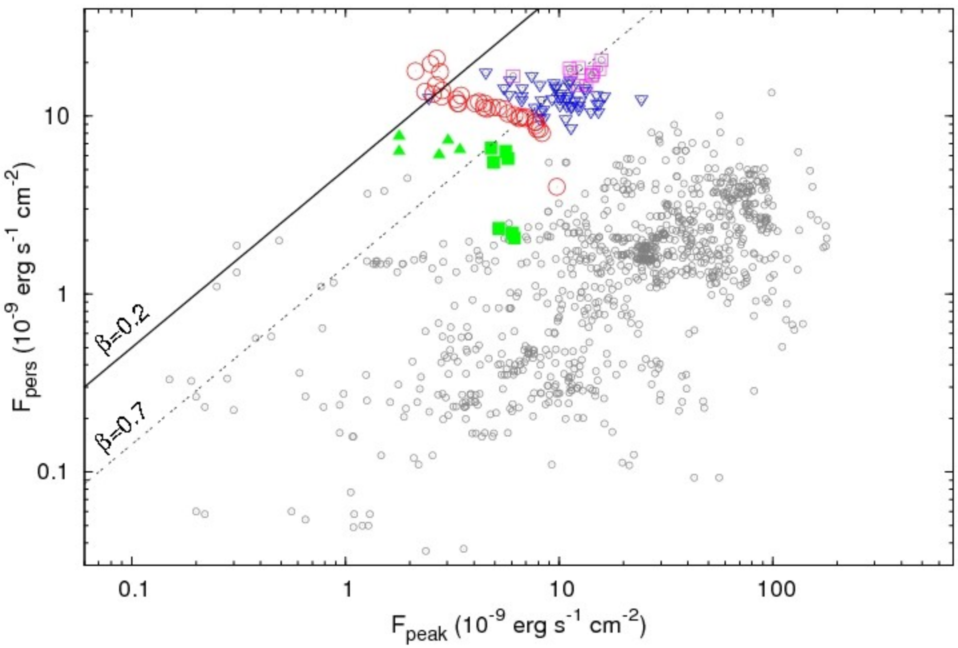

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Cooling vs. thermonuclear: sufficient but not necessary!

Type I X-ray burst (cooling) → thermonuclear burst
but the opposite is not always true.

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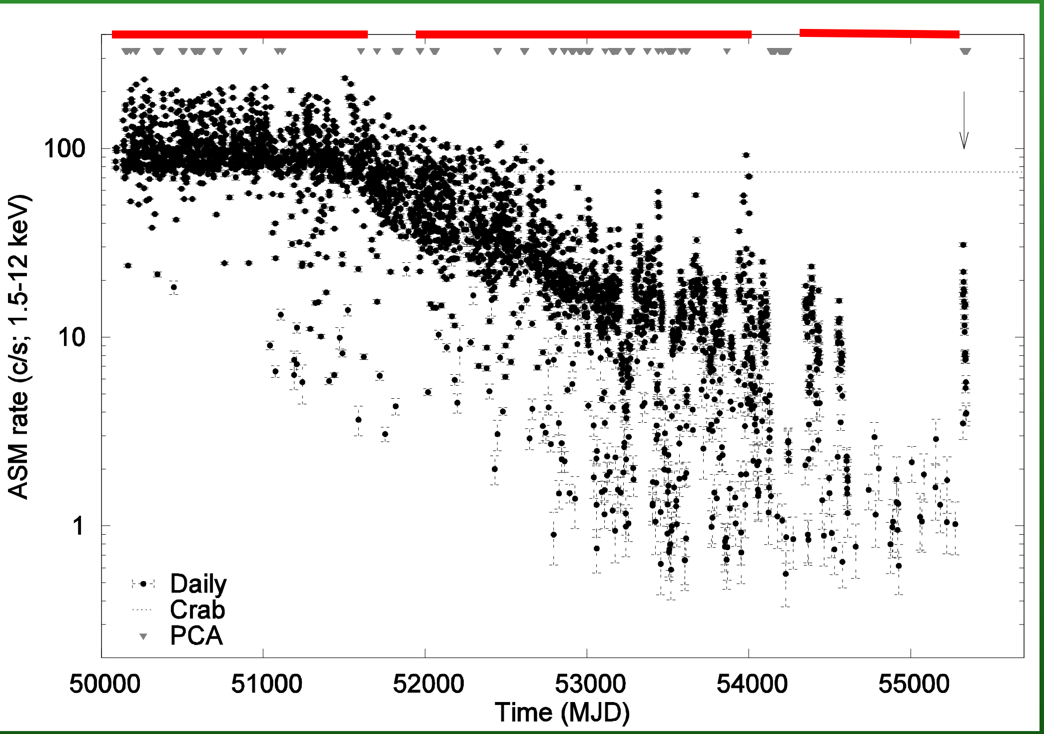
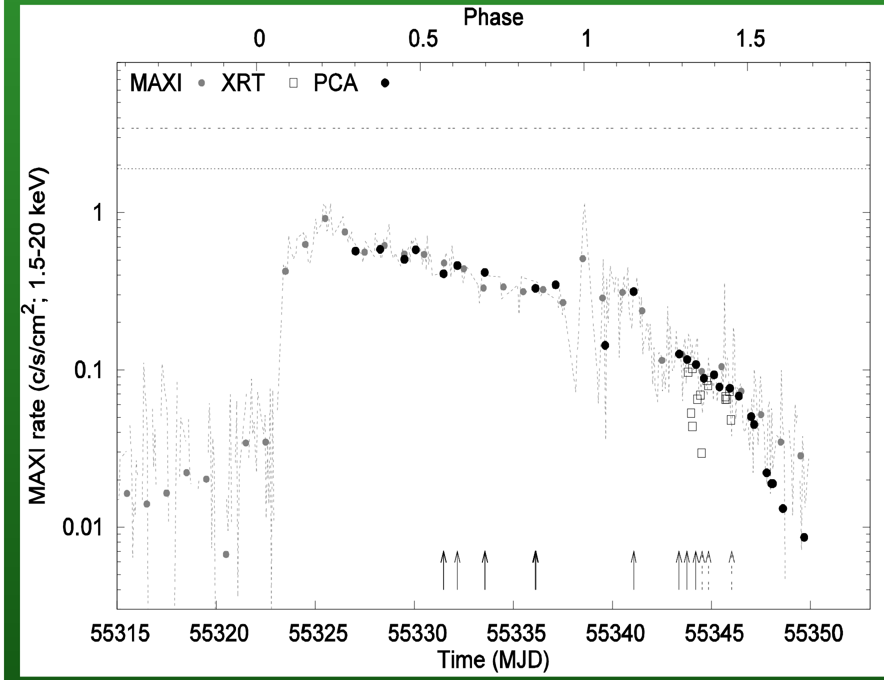
Circinus X-1: The return of the bursts





- 15 X-ray bursts from RXTE and Swift observations, 25 yr after the first and only previous detection (Tennant et al. 1986)
- NS crust may have cooled down during the ~2yr period of very low accretion (2008-2010).
- Lower heat from inner crust could allow for unstable burning, when the mass accretion rate is in the “right” range (10-20% Eddington in May 2010).

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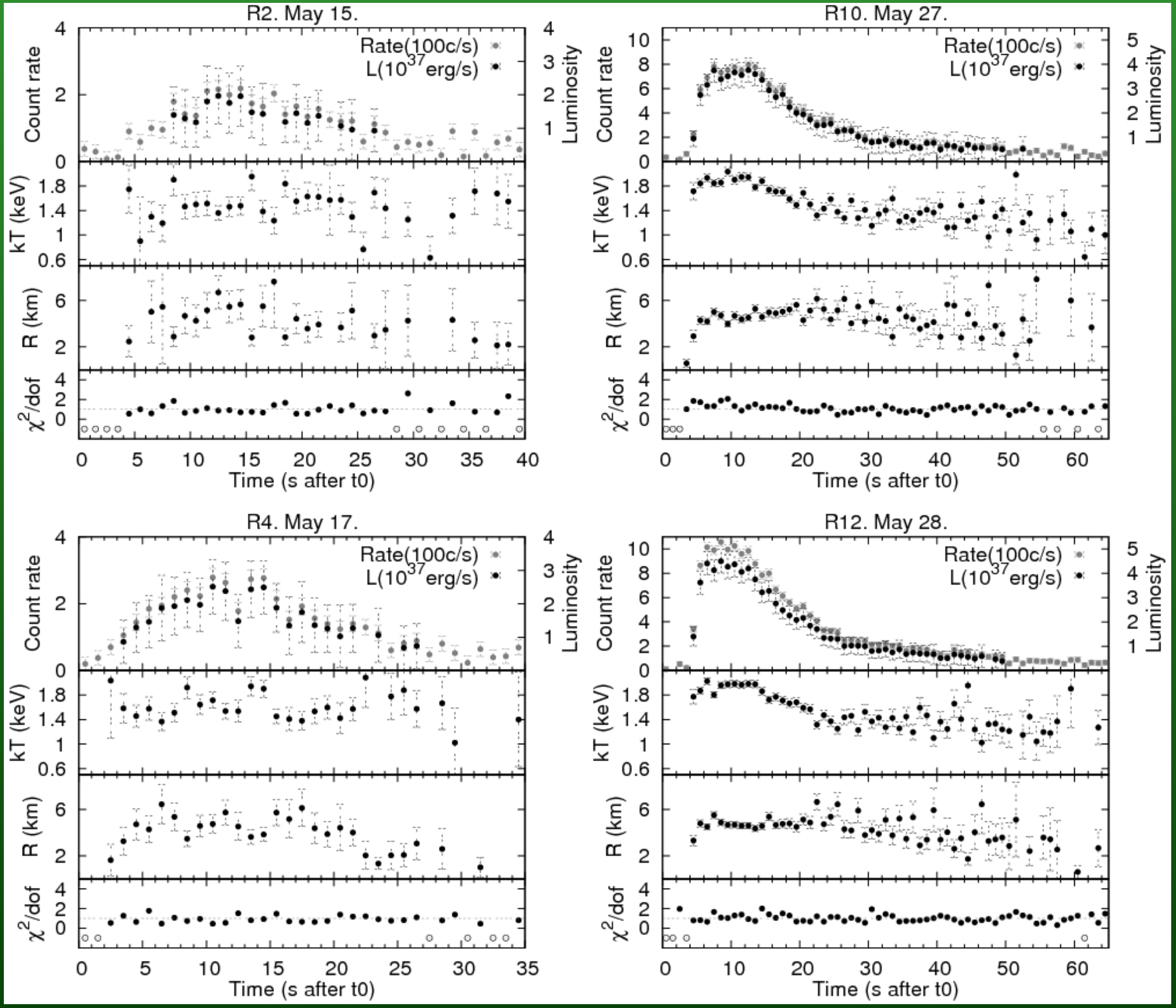

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"Late bursts": cooling, canonical type I X-ray bursts.

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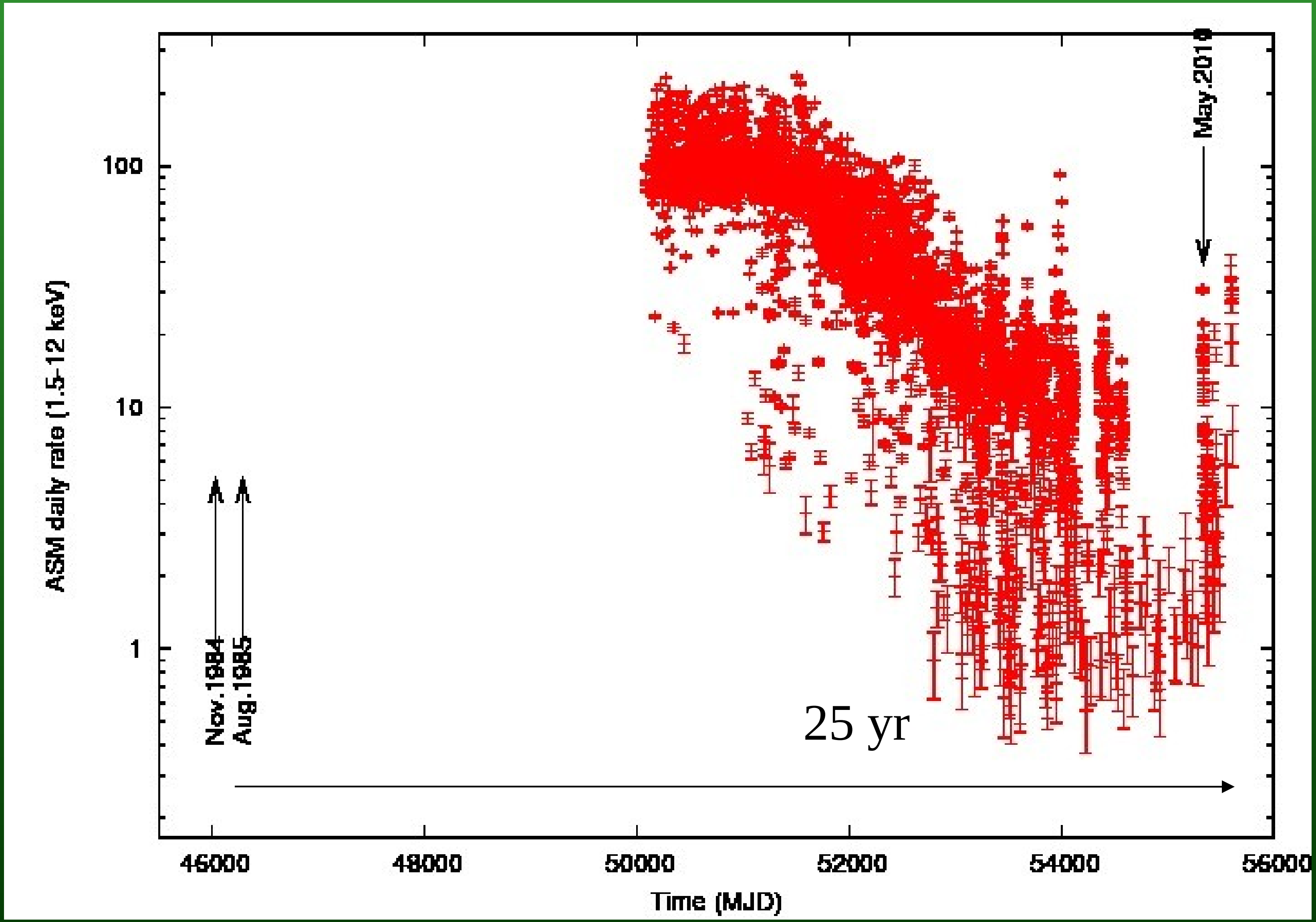

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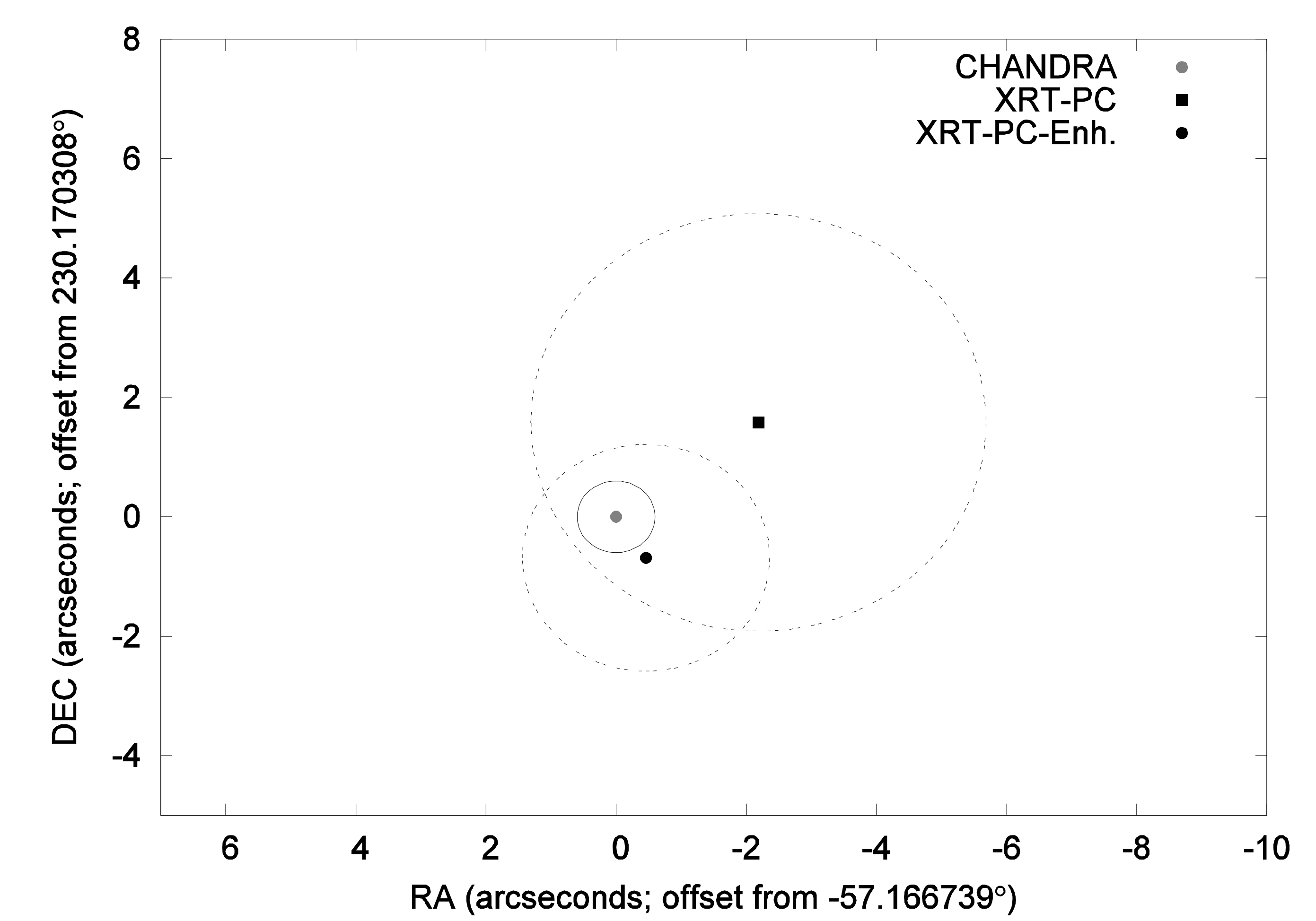

Confirm Cir X-1 is a low magnetic field accreting neutron star.

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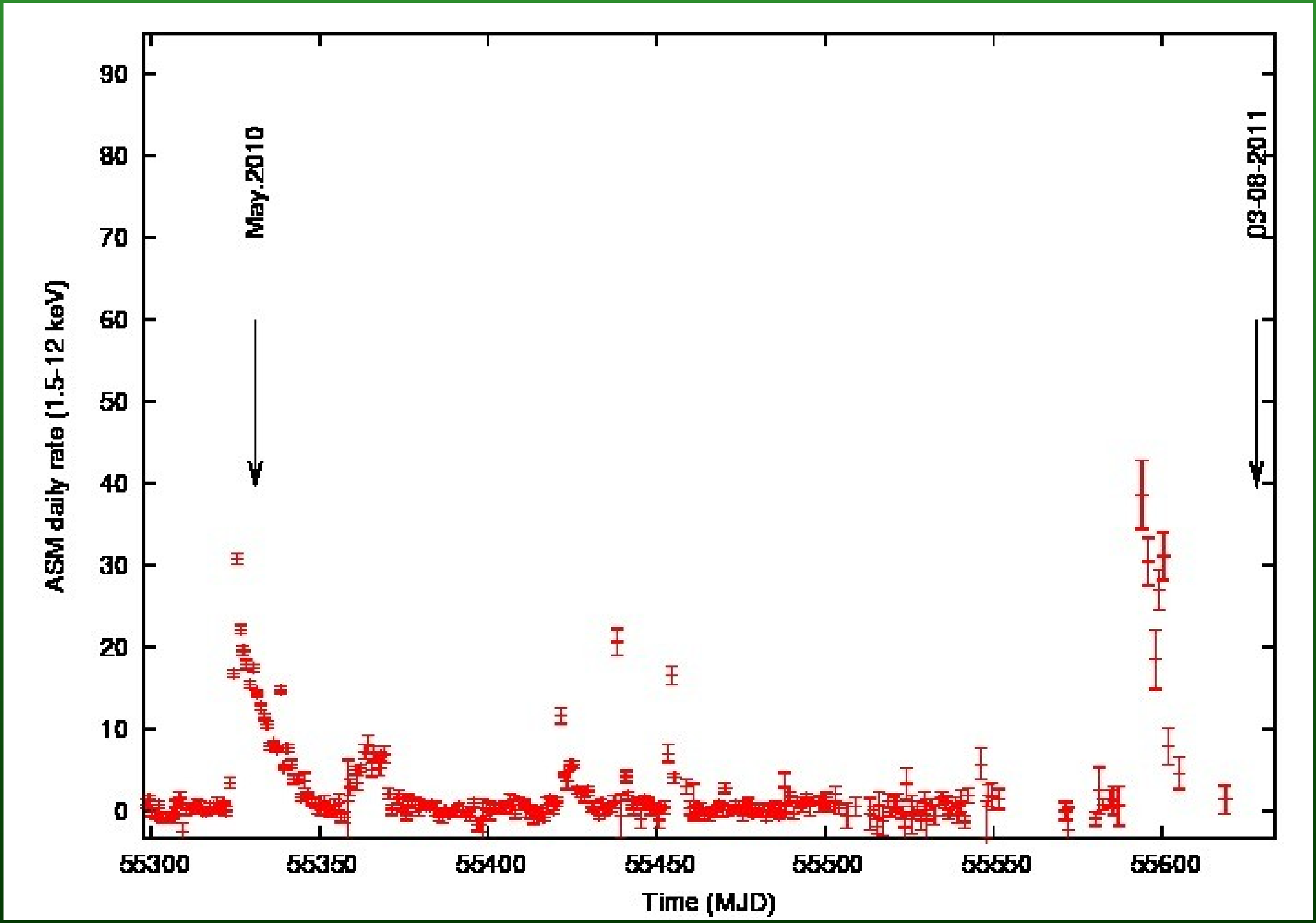

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