Thermonuclear bursts on neutron stars: News at high accretion rates

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Circinus X-1:
- The return of the bursts

Terzan 5:
- Thermonuclear bursts without cooling tail
- Additional heating in the neutron star envelope
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

Circinus X-1: The return of the bursts

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’) ?...
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
($\alpha \equiv \frac{E_{\text{accretion}}}{E_{\text{burst}}} \sim 100$)

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:

\[ \beta = \frac{\text{Peak burst luminosity}}{\text{Persistent luminosity}} \]

- \( \beta > 0.7 \): type I X-ray bursts.
- \( 0.2 < \beta < 0.7 \): single bursts DON’T but daily averages DO show cooling.
- \( \beta < 0.2 \): no cooling.
Same $\beta=0.7$ threshold explains Cir X-1 “early vs. late” bursts!!

→ 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 $L_{\text{Edd}}$) where bursts were extremely rare!

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

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

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

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Terzan 5: bridging the gap

B and spin between typical LMXB and HMXB values:

B needed to stabilize burning (below $0.5 \, L_{\text{Edd}}$) is at least $\sim 10^{10}$ G. Does (slow) spin influence burning regimes?
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!

Systematics of standard burst spectroscopy can hide cooling
(threshold: $\beta=L_{\text{peak}}/L_{\text{persistent}}=0.2$)

Extremely high burst rate, $t_{\text{rec}} \sim L_{\text{pers}}^{-3}$
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
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 $L_{\text{pers}} \sim 80\%$ 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
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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.
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).
Circinus X-1: The return of the bursts

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Circinus X-1: The return of the bursts

25 yr
Confirm Cir X-1 is a low magnetic field accreting neutron star.
Circinus X-1: The return of the bursts