Thermonuclear (type-I) X-ray bursts

Duncan Galloway
Monash University
In the last 72 hr a large bushfire affected the national park surrounding the observatory (site of the 4-m Anglo-Australian Telescope, 1.2-m UK Schmidt Telescope, and the 1.35-m Skymapper telescope), 350 km north-west of Sydney.

Fire has destroyed nearby homes and some telescope buildings, but nobody hurt, and telescopes appear unscathed apart from external smoke damage.

For more information, see

- [http://www.anu.edu.au](http://www.anu.edu.au)
- Amanda Bauer’s blog [http://astropixie.blogspot.com](http://astropixie.blogspot.com)
Thermonuclear X-ray bursts

- Occur in neutron stars accreting from low-mass binary companions; ~90 bursters known, ~$10^4$ bursts observed since early 1970s

- Understood since the `80s as resulting from unstable ignition of accreted H/He on the NS surface (e.g. Fujimoto et al. 1981, ApJ 247, 267)
Observational milestones

• Photospheric radius-expansion bursts reach the (local) Eddington limit; utility as standard candle Basinska et al. 1984; Kuulkers et al. 2003

• Burst oscillations measure the neutron star spin; exhibit 1–2 Hz drifts Strohmayer et al. 1996; Chakrabarty et al. 2003

• “Superbursts” with durations of hours likely arising from carbon burning Cornelisse et al. 2000

• “Intermediate duration” bursts arising in low-accretion rate systems, burning of large pure-He fuel reservoirs in ‘t Zand et al. 2005

• Burst spectra exploited to measure neutron star $M, R$ Özel et al. 2006

... see also in ‘t Zand, arXiv:1102.3345, Strohmayer & Bildsten 2003

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Diverse burst behaviour

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Research priorities

Now and into the future

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1. Burst oscillations

- RXTE end-of-mission (Jan 2012) means no more high-time resolution X-ray capability
- A key diagnostic for neutron stars, so perhaps still a research priority
- Future missions include ASTROSAT and LOFT (ESA M3 candidate, launch >2020)

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Also seen in AMSPs

Note rapid drifts – thought to occur only in AMSPs (influence of stronger B-field?)

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Mechanism unknown

- Anisotropy during rise natural consequence of spreading, but oscillations also observed in tails e.g. Galloway et al. 2008

- Detected preferentially in high/soft spectral state Muno et al. 2004

- Correlation between spin frequency (including pulsars) and orbital period -> evolutionary link?

- Bursters/pulsars K-S stat = 0.583, P=0.019

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Link btw bursts and pulsations?

- Early in the outburst of HETE J1900.1-2455 occurrence of bursts seemed to “trigger” persistent pulsations Galloway et al. 2007

- Related phenomenon in one other quasi-persistent pulsar (SAX J1748.9-2021; Gavriil et al. 2007, Altamirano et al. 2008) but not the other (Aql X-1; Casella et al. 2008)
2. Probes of thermonuclear burning

- Increasing dialogue between observers and theorists to provide more comprehensive comparisons of observations and numerical model predictions

- Emerging (soon-to-be-public?) resources:
  - Large burst samples (e.g. MINBAR)
  - Large samples of simulation results (predicted lightcurves) from KEPLER &c
  - Grids of atmosphere model predictions (Suleimanov &c)

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Crust and core

- Long bursts (both intermediate duration and “super” bursts) are sensitive to thermal conditions in the crust
- These rare (~80 known since ~1970s) events are priorities for observations
- Also He-rich bursts
New phenomenology: Terzan 5 X2

- A new transient outburst of a previously unknown globular cluster LMXB Atel #2919
- 11 Hz pulsations (<< typical freq); 21-hr orbit Atel #2919
- Bursts occurred more frequently as the luminosity approached Eddington \( \rightarrow \) quasi-stable burning
- First time this transition has been observed, although details differ from models e.g. Chakraborty et al. 2012, MNRAS 422, 2351; Motta et al., 2011, MNRAS 414, 1508; Linares et al., 2012, ApJ 748, 82L; Cavecchi et al., 2011, ApJ 740, 8; etc. etc.
3. NS parameters from burst spectra

- The spectrum is thought to be distorted slightly; a correction factor is generally applied (e.g., Madej et al. 2004, ApJ 602, 904).

- Net burst spectrum (subtracting the pre-burst, persistent emission as background) is usually fitted with a blackbody.

- Such spectra are characterised by the temperature and the apparent radius of the emitting object.

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The Özel method

- Use 3 measurables to solve for the mass and radius, under a number of assumptions
Özel 2006, Nature, 441, 1115

- Presented results so far on EXO 0748-676 and 5 additional sources: 4U 1608-52, EXO 1745-248, 3A 1820-30, KS 1731-26 and GRS 1748.9-2021

- Criticism has been raised regarding the assumptions and the statistical treatment


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**Figure 5.** Plot of 1σ and 2σ contours for the mass and radius of the neutron star in EXO 1745–248, for a hydrogen mass fraction of $X = 0$, based on the spectroscopic data during thermonuclear bursts combined with a distance measurement to the globular cluster. Neutron star radii larger than $\sim 13$ km are inconsistent with the data. The descriptions of the various equations of state and the corresponding labels can be found in Lattimer & Prakash (2001).
Issues for inferring $R$

- Apparent radius (blackbody normalisation) depends on the distance, redshift ($M$ & $R$), spectral correction factor $f_c$:

$$R = R_{bb}df_c^2\xi^{1/2}(1 + z)^{-1}$$

where $d$ is the distance, and $\xi$ parametrises the anisotropy of the burst emission.

- Distance must be determined independently (i.e. not from PRE bursts, since the peak PRE burst flux is one of the other required measurables).

- Anisotropy always appears in combination with distance; analytic estimates only, based on inclination (usually unknown).

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Revised

How does $f_c$ vary – if at all?

- Constant $R_{bb}$ in some bursts suggest constant $f_c$ with flux, but this is counter to models
- Attempts to verify model predictions have met with only partial success
- Observational evidence for a different type of $f_c$ variation

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Figure 4. Comparison of averaged blackbody normalization profiles for bursts from GS 1826–24 measured in 1997–1998 (nos. 1–5 of G08) and 2000–2007 (nos. 9, 10, 11, 12, 13, 16, 17, 19, 20). The vertical dashed lines indicate the time of maximum flux for each set of bursts. Note the agreement in the normalization throughout the burst rise and maximum, and the increasing discrepancy from 10 s after the burst start. The inset shows the corresponding variation of the averaged burst flux.
Non-Planckian spectra during bursts

- A study of a very large (>60,000) sample of burst spectra indicate that they are not (en masse) consistent with blackbodies
- Efforts are under way to better understand the burst spectrum
- Continuum distortions that are not predicted by the atmosphere models

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~2000 bursts observed with RXTE
(One of) many systematic issues

- Burst spectra are not always blackbodies
- Joint RXTE-Chandra observations of a bright burst from SAX J1808.4-3658 suggest that the accretion rate is not constant during the burst
- Effect of to Poynting-Robertson drag on the disk material?

In ‘t Zand et al. 2013, arXiv:1301.2232

- See also Worpel et al.

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The future

- **Burst oscillations**
  - Update of early observational reviews (Muno &c)
  - Further theoretical work on spreading, detectability of oscillations, correlation with source spectral state
  - ISSI team (from 2012 Dec)

- **Thermonuclear burning**
  - Detailed observation/model comparisons can provide constraints on fuel composition, individual reaction rates, NS properties(?)

- **Mass/radius measurements**
  - Substantial shortfall in our understanding of spectral formation during bursts, which needs to be addressed
  - Influence of accretion disk; spectral state etc.