Recent progress (or lack thereof) from neutron star radius determination from X-ray bursts

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Motivation: constraining the EOS

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A possible constraint from burst measurements

NS parameters from burst spectra

- For the vast majority of bursts the X-ray spectra throughout are consistent with a Planck (blackbody) spectrum

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

- Once the burning has spread to the entire NS surface, we can use the blackbody radius $R_{bb}$ to infer the NS radius

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Issues for measuring $R$

- Neutron-star radius depends on the blackbody normalisation $R_{\text{bb}}$ & the distance $d$:

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

assuming that the spectrum is indeed a blackbody, and emission covers the entire surface.

- Several additional factors must be considered:
  - redshift ($M$ & $R$)
  - spectral correction factor $f_c$
  - the anisotropy of the burst emission $\xi$

- Not easy to disentangle all these effects

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A promising approach...

- Özel (2006) used three independent measurements (including $R_{bb}$ & the Eddington flux) to infer M, R in EXO 0748-676 (Özel 2006, Nature, 441, 1115)

- since presented results on four additional sources: 4U 1608-52, EXO 1745-248, 3A 1820-30, and KS 1731-26

- Although see also Steiner et al. 2010, ApJ 722, 33

**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 ~ 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).
... but beware the systematics

- **Substantial known systematic issues for measurements of blackbody radii**
- **BB normalisations tend NOT to be constant throughout the burst tail** (Bhattacharyya et al. 2010, MNRAS 401, 2)
- **Furthermore, radius values from burst to burst can vary** (true also for EXO 1745-248)

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How good a blackbody really?

- Largely unexamined issue
- A study of a very large (>60,000) sample of burst spectra indicate that they are not (en masse) consistent with blackbodies
- One contributing factor likely the variation in the persistent flux (e.g. Worpel et al. 2013, submitted)

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Variation in $f_c$ during bursts

- NS atmosphere expected to slightly modify emitted spectrum
- Usually parametrised as a spectral correction factor $f_c$
- Lack of consensus in the community over what value to use, whether it varies

- We now have good evidence that $f_c$ may not be constant during bursts Galloway & Lampe 2012, ApJ 747, #75

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• Models of Suleimanov &c do predict variation in $f_c$ as a function of burst flux
• BUT the observed variation in $R_{bb}$ does not match these predictions
• More work is required to reconcile the observations with the model predictions
• These should include comprehensive comparisons of the model spectra with data


This is not unexpected
Another avenue for constraints

- Consistent, regular bursts for which the fuel composition and accretion rate can be inferred, may be compared with burning models Heger et al. (2007), ApJ 671, 141L

- An alternative avenue for distance+anisotropy constraints (as well as a nuclear reaction probe)

- For GS 1826-24 gives a redshift range $1+z = 1.25-1.34$ (for $f_c = 1.4-1.5$)


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Summary and future work

• The thermonuclear burst spectroscopy field is extremely dynamic at the moment

• We are making significant progress, with
  – Better understanding the burst behaviour through both data and modelling studies (or ideally, integrating these two)
  – Improving on our ability to extract meaningful information from the burst spectra and behaviour

• We need to acknowledge, and ultimately address, the many serious systematic issues which remain

• There is much yet to be done, and still (relatively) unexplored areas (i.e. tests of GR)... stay tuned!

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