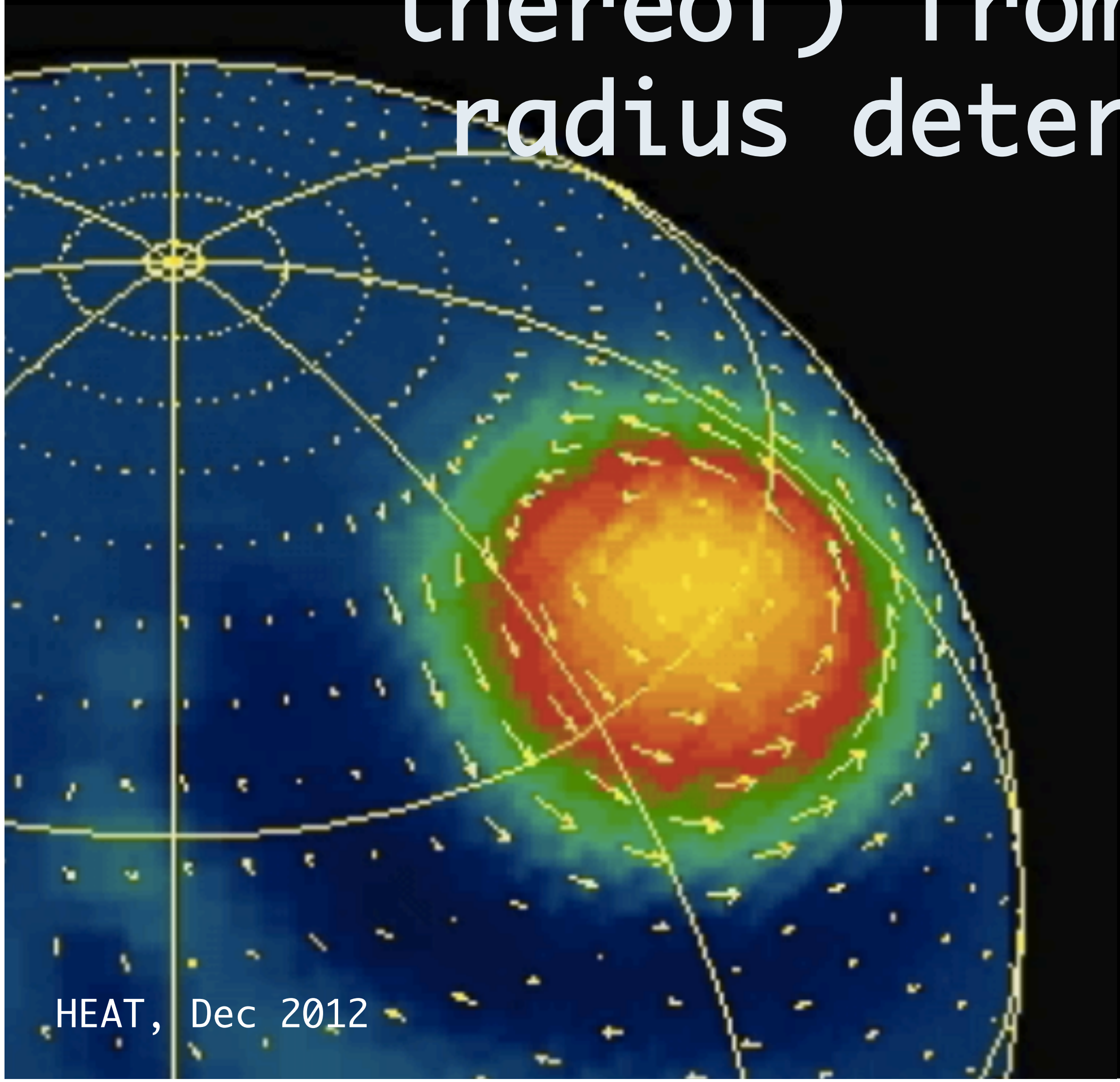
MONASH University

MoCA Monash Centre for Astrophysics

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



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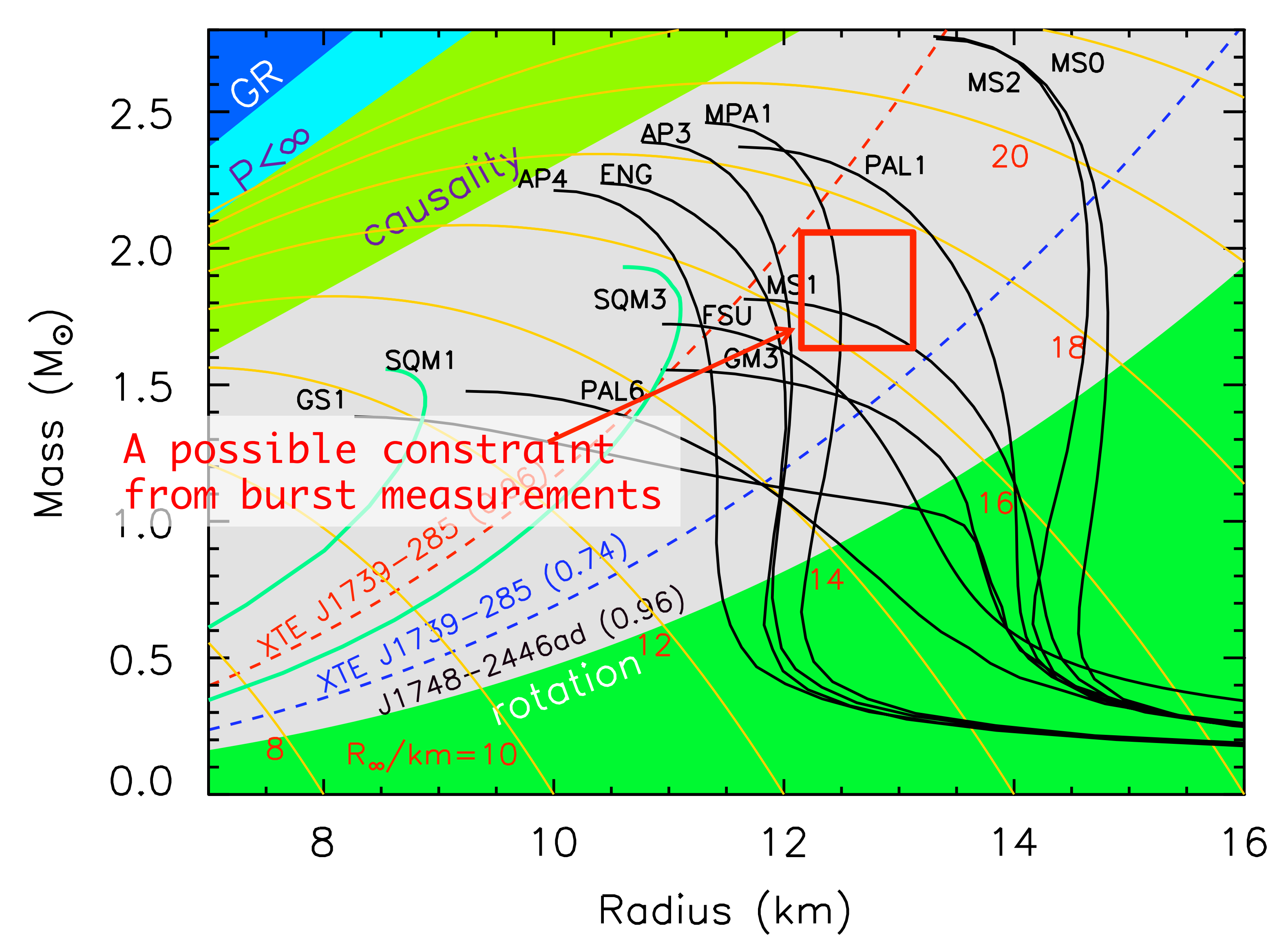
Hauke Worpel
Andrew Cumming &
Michael Zamfir *McGill*

HEAT, Dec 2012

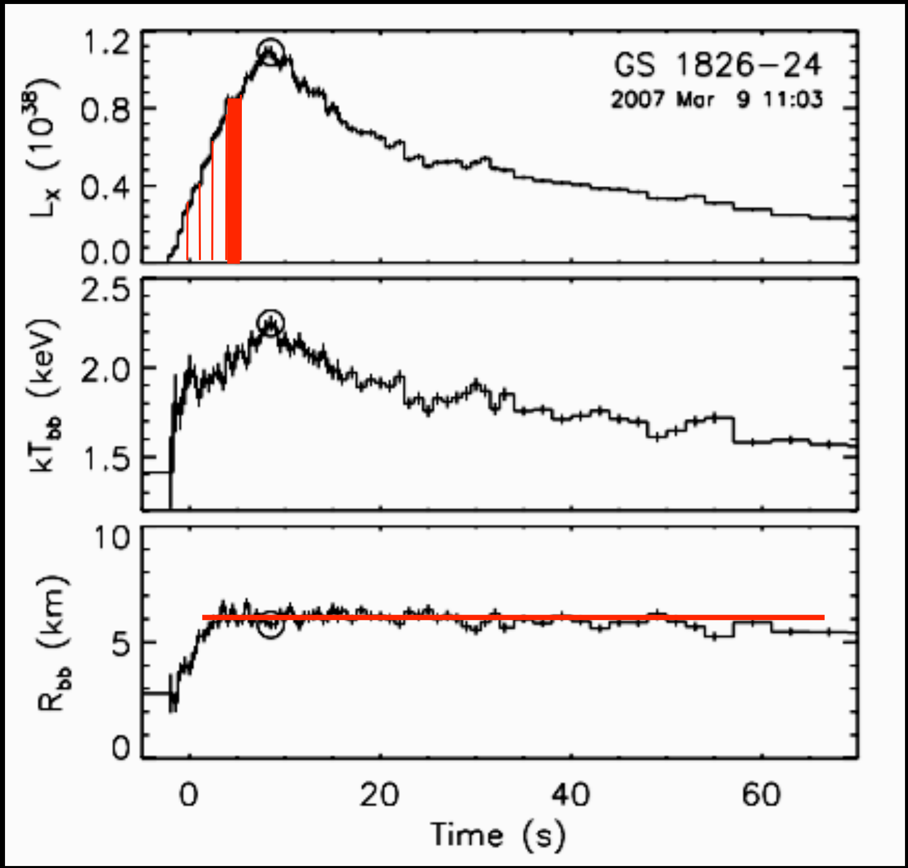
Motivation: constraining the EOS



Lattimer & Prakash 2007, Phys. Rep. 442, 109

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

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

Issues for measuring *R*

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

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

  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 ξ
- Not easy to disentangle all these effects

A promising approach…

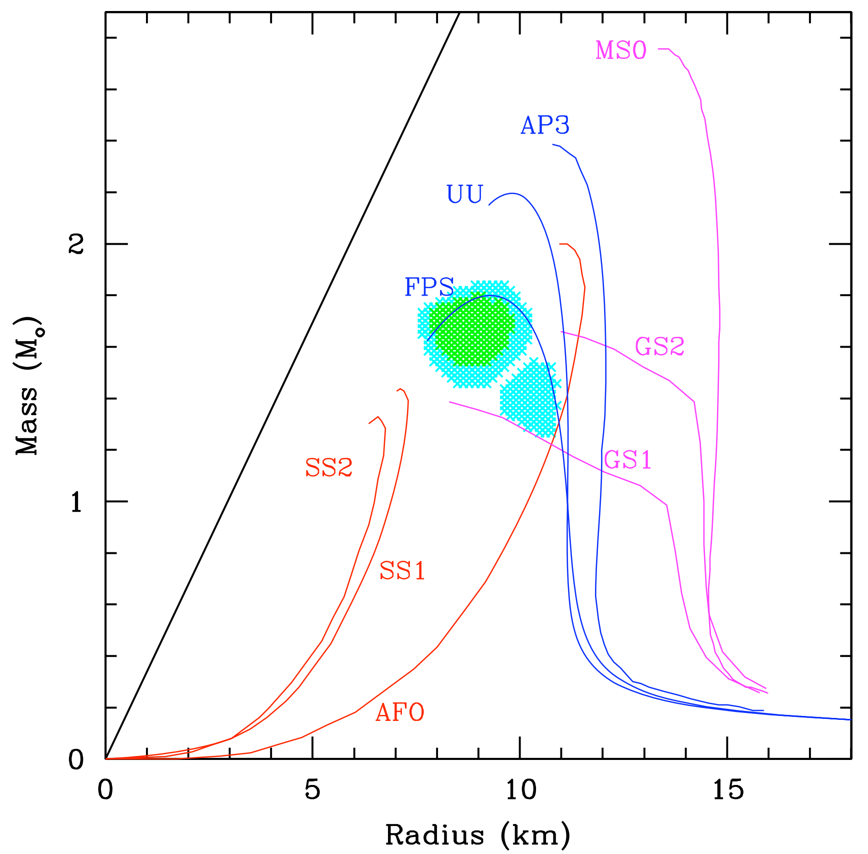
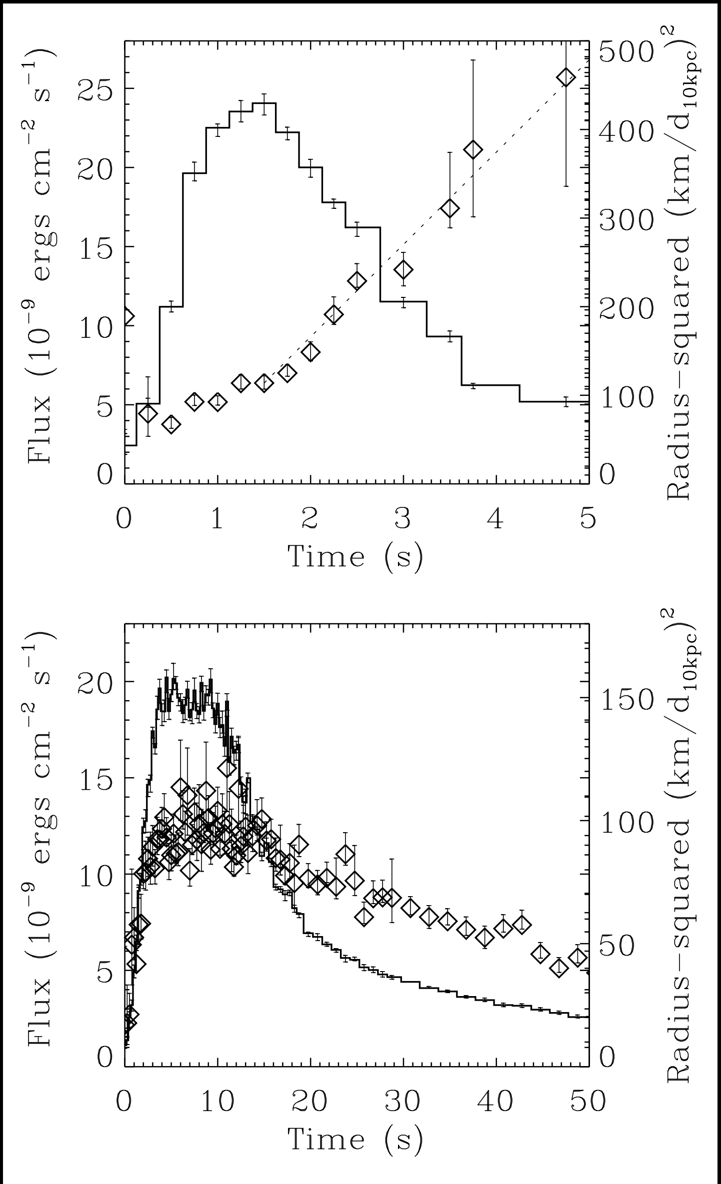


Figure 5. Plot of 1σ and 2σ contours for the mass and radius of the neutron star in EXO 1745−248, for a hydrogen mass fraction of $X = 0$, based on the spectroscopic data during thermonuclear bursts combined with a distance measurement to the globular cluster. Neutron star radii larger than $\sim$ 13 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).

- 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

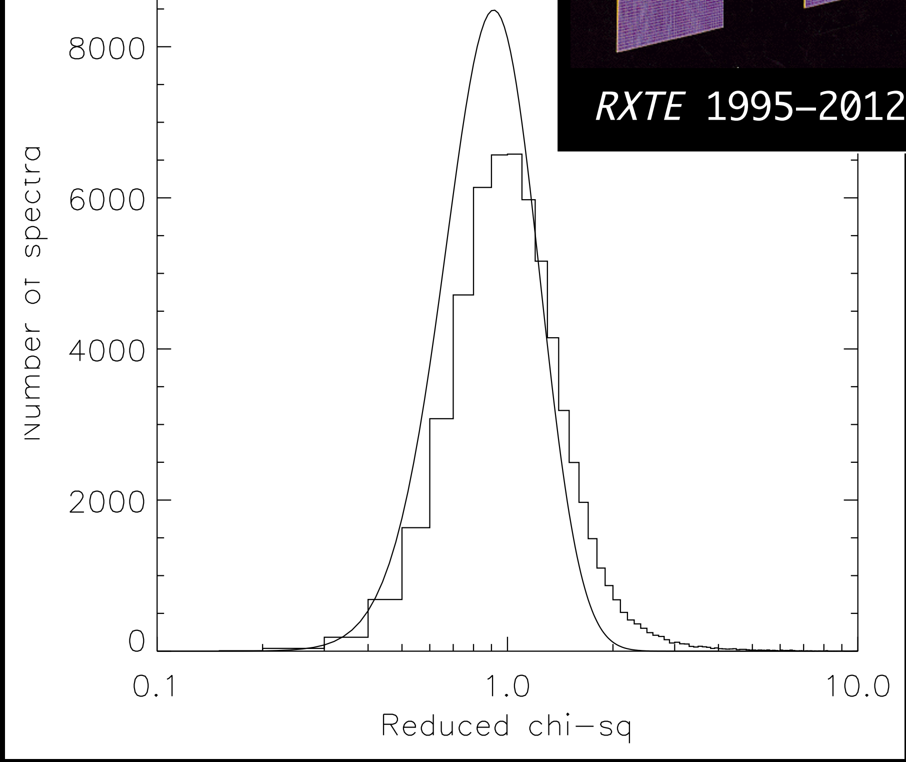
… but beware the systematics

- 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)



How good a blackbody really?

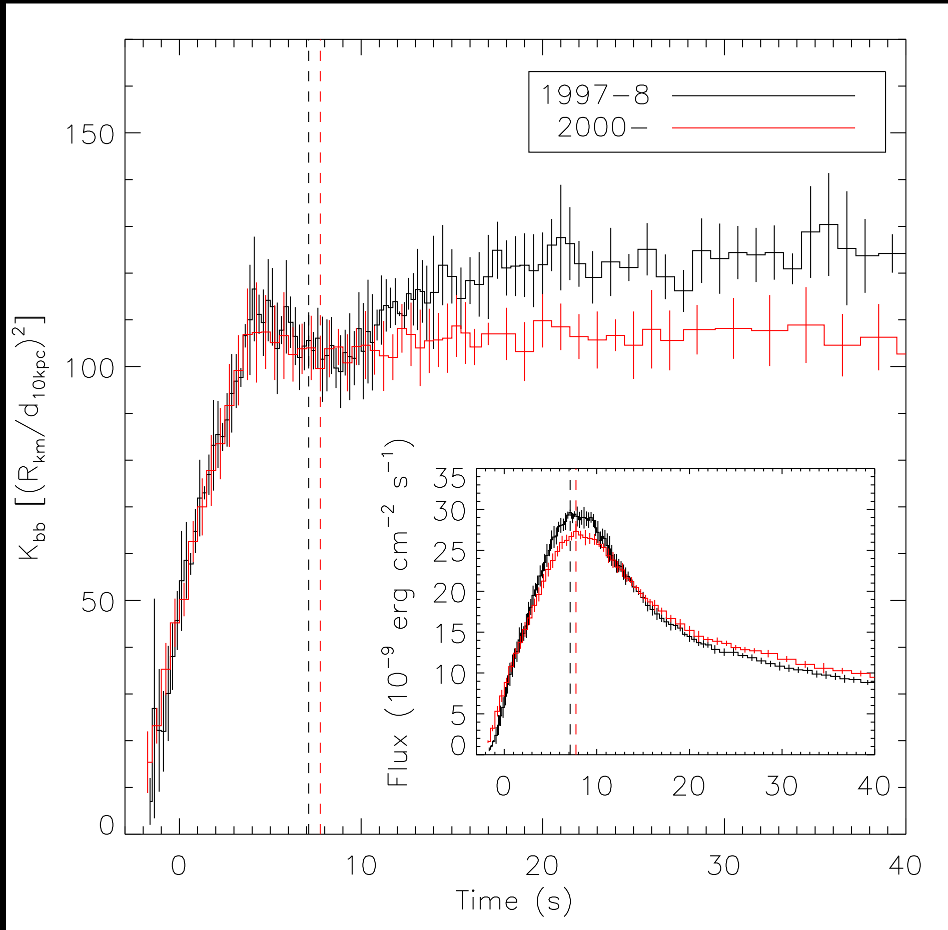
- Largely unexamined issue
- A study of a very large (>60,000) sample of burst spectra indicate that they are not (en masse) consistent with blackbodies
- One contributing factor likely the variation in the persistent flux (e.g. Worpel et al. 2013, submitted)



RXTE 1995–2012

Variation in f_c during bursts

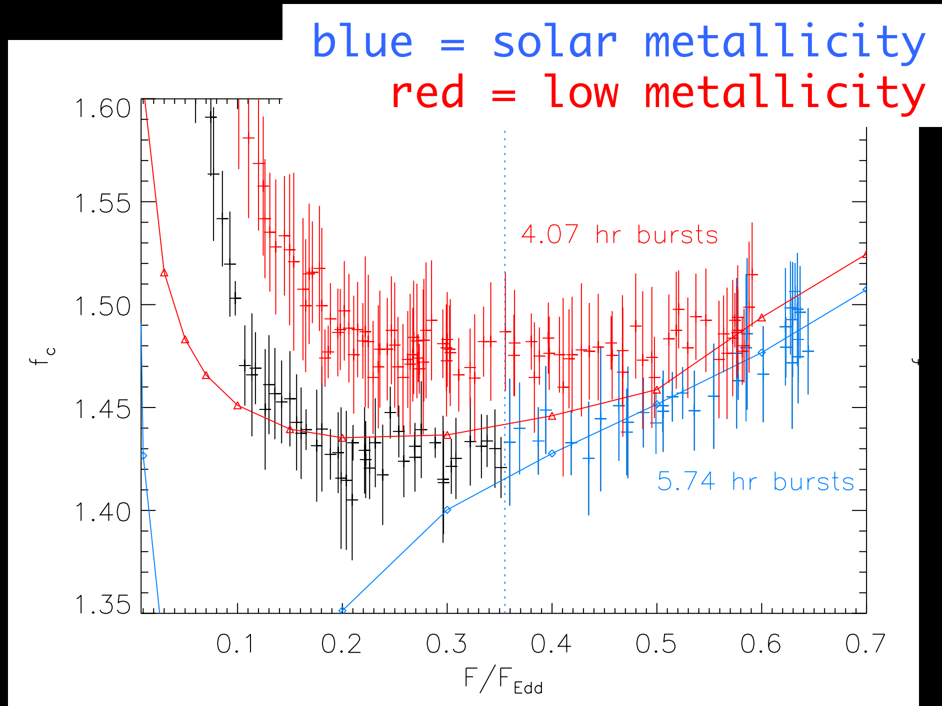
- NS atmosphere expected to slightly modify emitted spectrum
- Usually parametrised as a spectral correction factor f_c
- Lack of consensus in the community over what value to use, whether it varies



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

This is not unexpected

- 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



Zamfir &c 2012, ApJ 749, #69

- More work is required to reconcile the observations with the model predictions
- These should include comprehensive comparisons of the model spectra with data

Another avenue for constraints

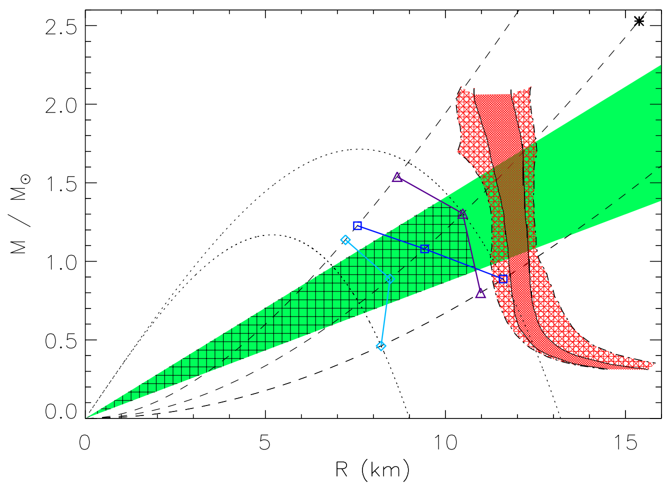


Figure 5. Summary of distance-independent constraints in the neutron star mass–radius plane. The dashed curves are lines of constant surface gravity $\log_{10}(g) = 14.0, 14.3, 14.6$ (bottom to top), values at which the spectral models were evaluated. In green, we show the redshift from Equation (5) for $f_c = 1.4$–1.5 and an assumed 10% uncertainty in F_{obs}/F_{model}. The squares (dark blue), diamonds (light blue), and triangles (purple) represent the upper limits on R_∞ computed from fits to the solar H/He abundance models with 0.01 $Z_\odot$, 0.1 $Z_\odot$, and $Z_\odot$ metallicities, respectively, each at a specific surface gravity. The upper limit on R_∞ for the pure helium atmosphere model (log = 14.3) is also shown as a black asterisk. Two constant R_∞ curves are plotted as dotted lines for the highest and lowest values found within solar H/He abundance models. The region hashed in black represents what is allowed by the combination of the constraints derived from the fit to the burst light curve and spectral fits to solar H/He abundance models. These constraints are independent of the source distance and anisotropy parameters ξ_b, ξ_p. The region in red represents the mass–radius relation derived by Steiner et al. (2010; based on the $r_{ph} \gg R$ assumption), with the 1σ and 2σ regions delimited by solid and dot-dashed lines, respectively.

- 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)

Zamfir &c 2012, ApJ 749, #69

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!