An Investigation into the Parameters of Photospheric Radius Expansion X-ray Bursts

M. von Steinkirch, J. M. Lattimer, A. C. Calder

Stony Brook University

Stony Brook University

Abstract

The determination of the equation of state (EoS) of the cold ultradense matter in the core of neutron stars (NS) has been one of the biggest challenges of high-energy astrophysics. This EoS can be constrained if the NS masses and radii are determined from observational methods. For instance, these parameters can be obtained from certain X-ray bursting NS's; some of which can be strong enough to reach the Eddington luminosity and will exhibit photospheric radius expansion (PRE) bursts. These events give us insight into the underlying NS's compactness, which simultaneously leads to estimates of their masses and radii. At present, there is disagreement over the interpretation of these bursts, resulting in relatively small or large radius estimates. An open question to be investigated is whether or not the touchdown is the moment when the photosphere coincides with the neutron star surface. We present preliminary results from studies on the PRE X-ray bursts aiming towards discerning and characterizing differences in the interpretation of these events.

What are X-ray Bursters?

- More than **2000 neutron stars** have been discovered, from pulsating sources in radio to bright persistent sources in X-rays [1].
- There is evidence of neutron star surface emission from **thermonuclear X-ray bursters** (**Type I X-Ray Bursters, XRB**) in **low-mass X-ray binaries (LMXB)**. These sources can put constraints on the **neutron star (cold dense matter) equation of state** [2].
- Observations of neutron stars during thermonuclear bursts have led to the **first constraining measurements of neutron star radii**: 9 km $<$ R $<$ 12 km [3].

The Photospheric Radius Expansion during X-ray Bursts

- Observations of neutron stars come from the outermost layer, the **photosphere**, which is in radioactive equilibrium given by a flux,
$$F = \sigma_S T_{\rm eff}^4,$$
where σ_S is the Stefan's constant and T_{eff} is the **effective temperature** at the surface.
- **Photospheric Radius Expansion bursts** are a **very bright** subset of thermonuclear X-ray bursts. After the radius expansion, the moment when the photosphere returns to the neutron star radius is called **touchdown point**.
- A first attempt to extract the neutron stars masses and radii was by identifying the moment of touchdown to the moment when the atmosphere reaches the **Eddington (luminosity) limit**,
$$L_{\rm Edd} = 4\pi R^2 \sigma_T T_{\rm eff}^4.$$
- This approach is not accurate enough and **further refinement of the results of the ref. [3] for the equation of states of the cold dense matter depends on better atmosphere modeling**.
- Realistically, the **spectra of the neutron star's atmosphere** look likes a **black-body function**, but **shifted to higher temperatures** by a **color correction factor**,
$$f_c = \frac{T_c}{T_{\rm eff}}.$$

References

- [1] T. Strohmayer & L. Bildsten, *New Views of Thermonuclear Bursts*, 2003.
- [2] L. Bildsten, *Theory and Observation of Type I X-Ray Bursts from Neutron Stars*, 2000.
- [3] A. W. Steiner et al, *The Equation of State from Observed Masses and Radii of Neutron Stars*, 2010.
- [4] V. Suleimanov et al, *X-ray Bursting Neutron Star Atmosphere Models*, 2010.
- [5] Models simulated by Zach Medin (work in progress), 2012.

Acknowledgments

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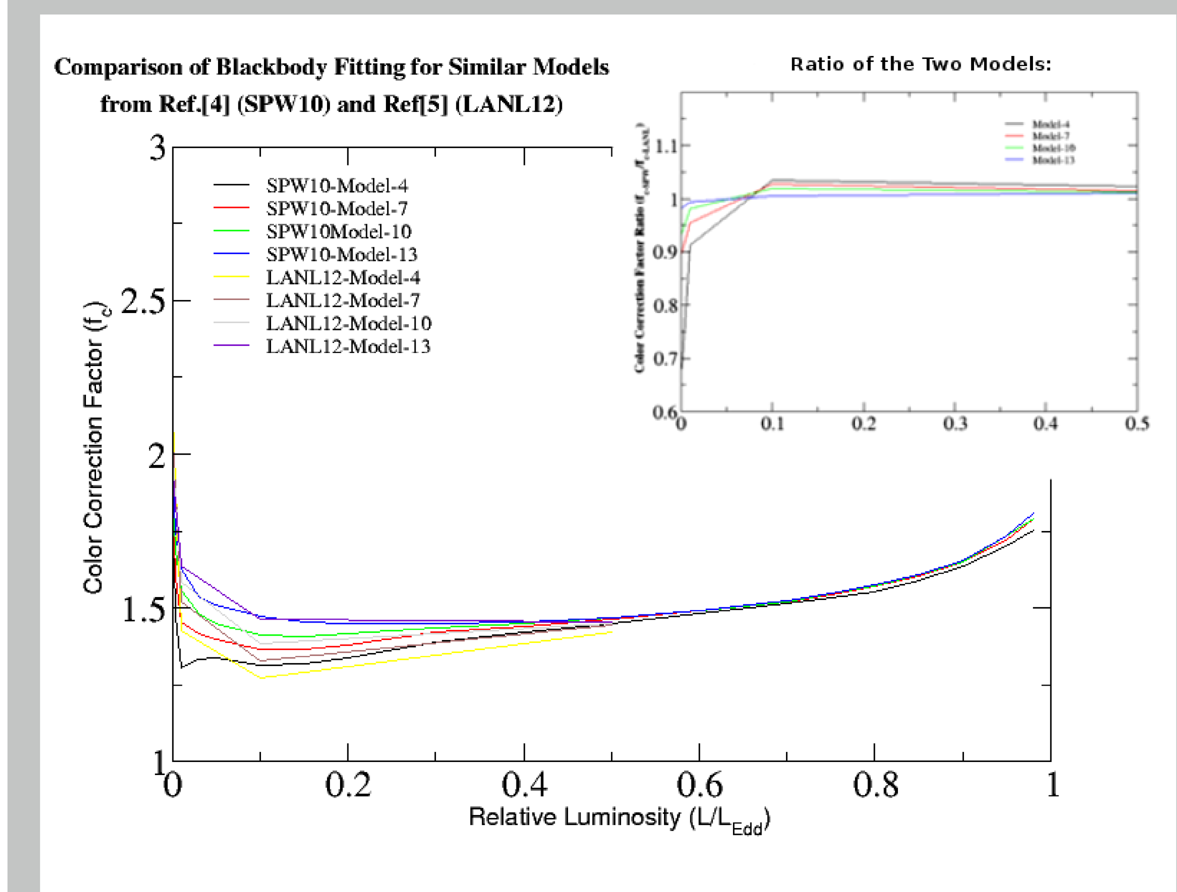
Atmospheric Simulations of Thermonuclear X-ray Bursters

- Simulations of **models for the Neutron Star's atmosphere** provide the **spectrum and pattern of radiation** from their crusts and cores.
- The **basic assumptions** for these simulations are **plane-parallel geometry**, **radioactive equilibrium**, and **hydro-static equilibrium**.
- Many **different physical parameters** are considered in these models: different **chemical compositions** (*e.g.*, the hydrogen fraction, X), **gravitational acceleration at surface** (g), **magnetic field strengths**, and **temperature at the surface** (T_{eff}).

Preliminary Results on Atmospheric Modeling and Spectra Fitting

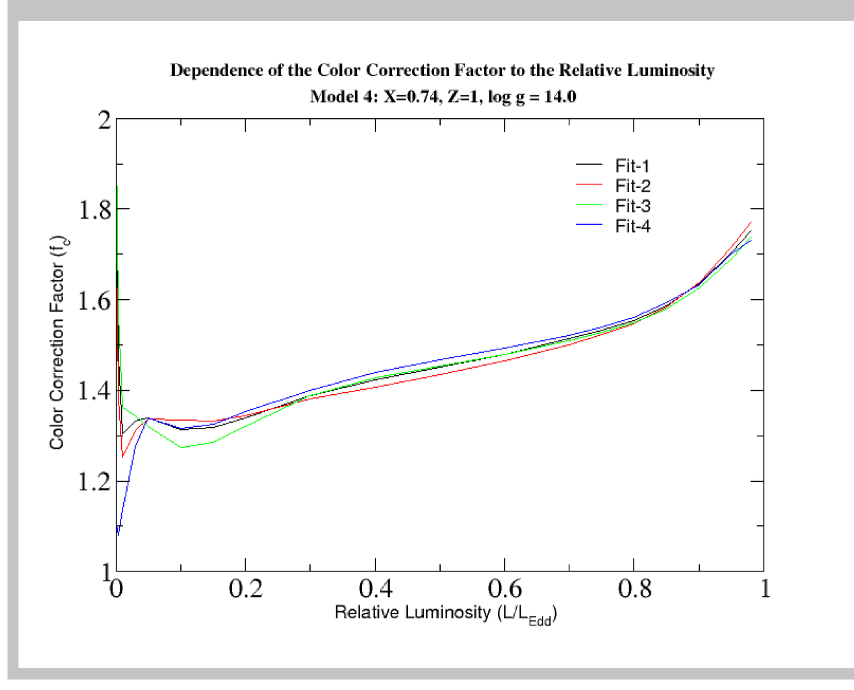
Our study begins by fitting a diluted black-body spectrum to existing models [4] [5] to verify our method. We have fitted these data to a black-body spectrum in five different ways, with f_c as one of the parameters.

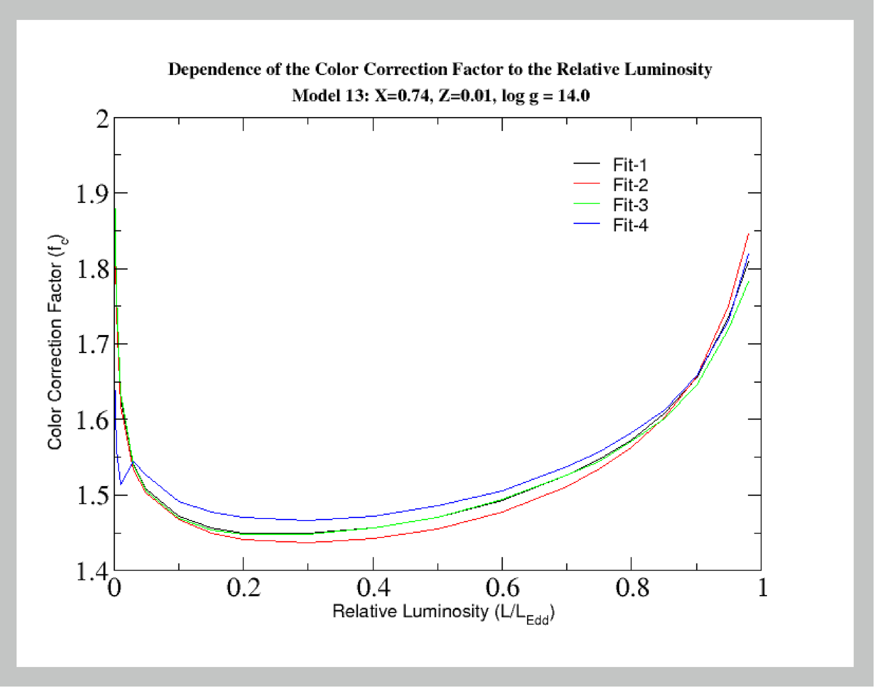


All the displayed models have $\log g = 14.0$ with the following parameters:

- model 4: $X = 0.74$, $Z = Z_\odot$,
- model 7: $X = 0.74$, $Z = 0.30Z_\odot$,
- model 10: $X = 1$, $Z = 0.1Z_\odot$,
- model 13: $X = 1$, $Z = 0.01Z_\odot$.

Comparison of all the four fitting modules for model 4 and module 13:





Discussion Conclusions

- X-ray bursts are an useful tool for inferring **neutron stars masses and radii**. However, systematic and statistical errors currently do not allow us to pin down a **unique equation of state of the cold ultra-dense matter**.
- We have developed and tested a **module for fitting a diluted black-body spectra to simulations of photospheric X-ray bursts**.
- With this verified technique, we will **explore parameters and new models** to determine **masses and radii of neutron stars** from observed **X-ray bursts** and further constrain the **equations of state**.

steinkirch@gmail.com