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Surface gravitational redshift of a neutron star measured with a thermonuclear X-ray burst with photospheric radius expansion from GRS 1747–312

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We analyzed a thermonuclear X-ray burst from GRS 1747–312 observed with Suzaku to constrain the mass-radius relation of neutron stars (NSs). The burst was a long burst with photospheric radius expansion (PRE). It is known that the luminosity of the PRE burst is saturated at the Eddington limit in good accuracy. However, the apparent luminosity by a distant observer actually changes due to the variations of the gravitational red shift. We utilized an apparent variation of the Eddington luminosity, which yielded a gravitational red shift of $1+z = 1.7 \pm 0.2$. We discuss systematic uncertainties of this result, mostly originated from the deviation of the burst spectra from a blackbody.

1. Introduction

- GRS 1747-312 is a type I X-ray burst source located in the globular cluster Terzan 6 (Predehl et al. 1991, Pavlinsky et al. 1994). In the previous studies, three PRE bursts were observed with RXTE/PCA (in't Zand et al. 2003a, 2003b).
- We aim to measure the gravitational red shift of a NS to constrain the mass-radius relation with distance-independent methods.
- We analyze thermonuclear X-ray bursts from a NS with PRE by measuring the apparent variation of the Eddington luminosity ΔL_{Edd} by a distant observer due to the different gravitational redshift at different photospheric radii (van Paradjis et al. 1989).
  - CAVEAT 1 - L_{Edd} is inversely proportional to the electron scattering opacity $\kappa \approx 0.2(1+X)\ cm^2\ g^{-1}$, where X is the fractional hydrogen abundance by mass of the NS atmosphere.
  - CAVEAT 2 - Ambiguity of the color correction factor $f_C = T_{col}/T_{eff}$ (ratio between color and effective temperature)

2. Suzaku archive data

- GRS 1747–312 was observed as a part of Galactic bulge mapping for *45.3 ksec* in September, 2009.
- A long PRE burst, whose e-folding time was *117+-6 sec*, was detected from GRS 1747–312.

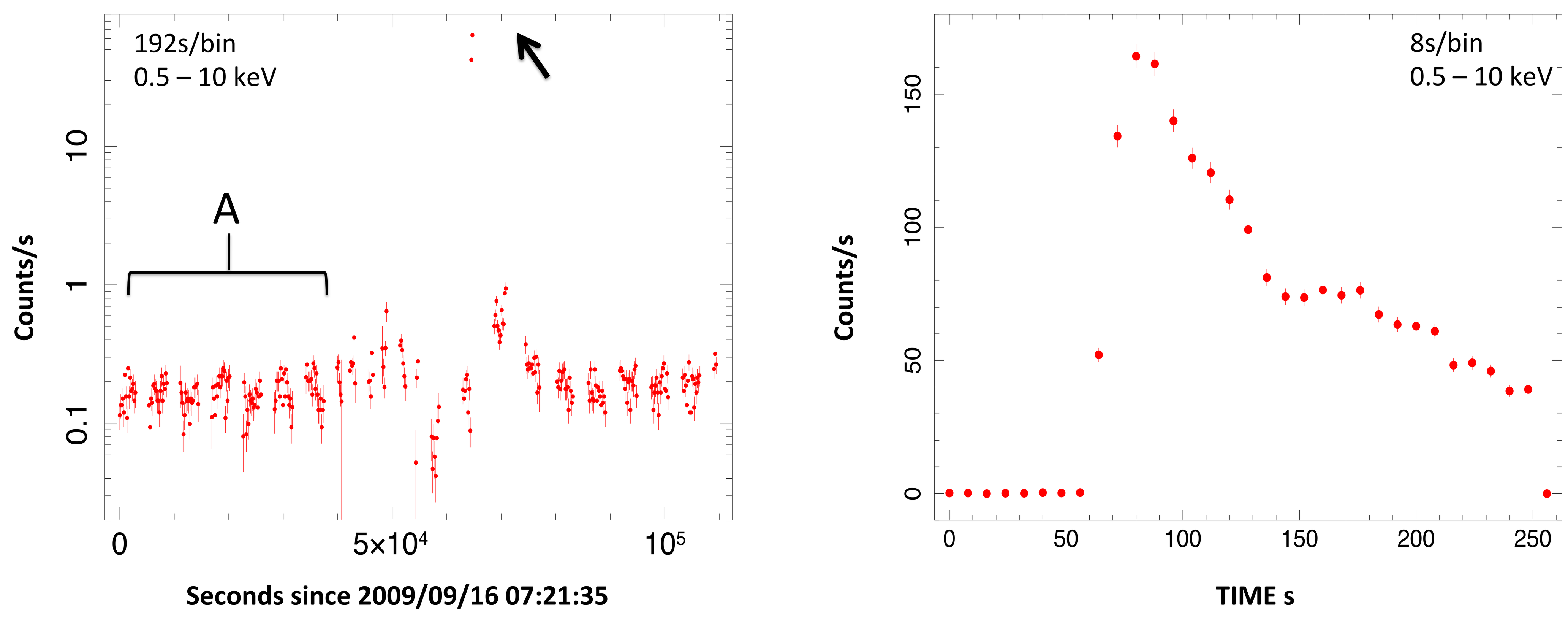

Fig. 1. (Left) XIS0+3 light curve of GRS 1747–312. An X-ray burst is indicated by an arrow. The region A in Fig.1 is used to subtract persistent emission from the burst data. (Right) Close up light curve of the burst. No data were obtained after 250 s due to the SAA.

3. Analysis and Results

– Evolution of the spectral parameters

- Apparent radii, color temperatures, and bolometric luminosities were obtained by fitting an absorbed blackbody model with constant absorption $N_H = 1.4 \times 10^{22}\ cm^{-2}$ (Fig. 2).
- A clear PRE was observed in initial *80 sec* after the burst onset (Fig. 2).

– Composition change?

- Apparent luminosities are expected to correlate with the radii in the PRE phase, which was not observed.
- This may be due to the variations of composition from the cosmic ($X=0.73$) to hydrogen-poor ($X=0$).
- Sugimoto et al. (1984) discussed the similar composition change of the NS atmosphere in the burst from MXB 1636–53.

– Estimation of the gravitational redshift

- According to van Paradjis et al. (1989), the gravitational redshift is derived from $(1+z)^2=(\psi^2-1/\psi\chi)/(1-1/\psi\chi)$ with $\chi=\chi_{bb}t^2$, where ψ, χ_{bb}, and t are a ratio of the Eddington luminosities at PRE and touch-down, those of the apparent radii and the color correction factors, respectively.
- The color correction factor f_C was adopted from Suleimanov et al. (2011), assuming that f_C varies with T_{col} in the same way during the radius contraction as during the cooling phase.
- Assuming the composition of the NS atmosphere changed during PRE phase, the gravitational redshift was estimated to be $1+z = 1.7 \pm 0.2$ from ΔL_{Edd} in Fig. 2. This value corresponds to the NS radius of $R_{NS} = 6.4 \pm 0.9\ km$ for $M_{NS} = 1.4 M_{\odot}$.

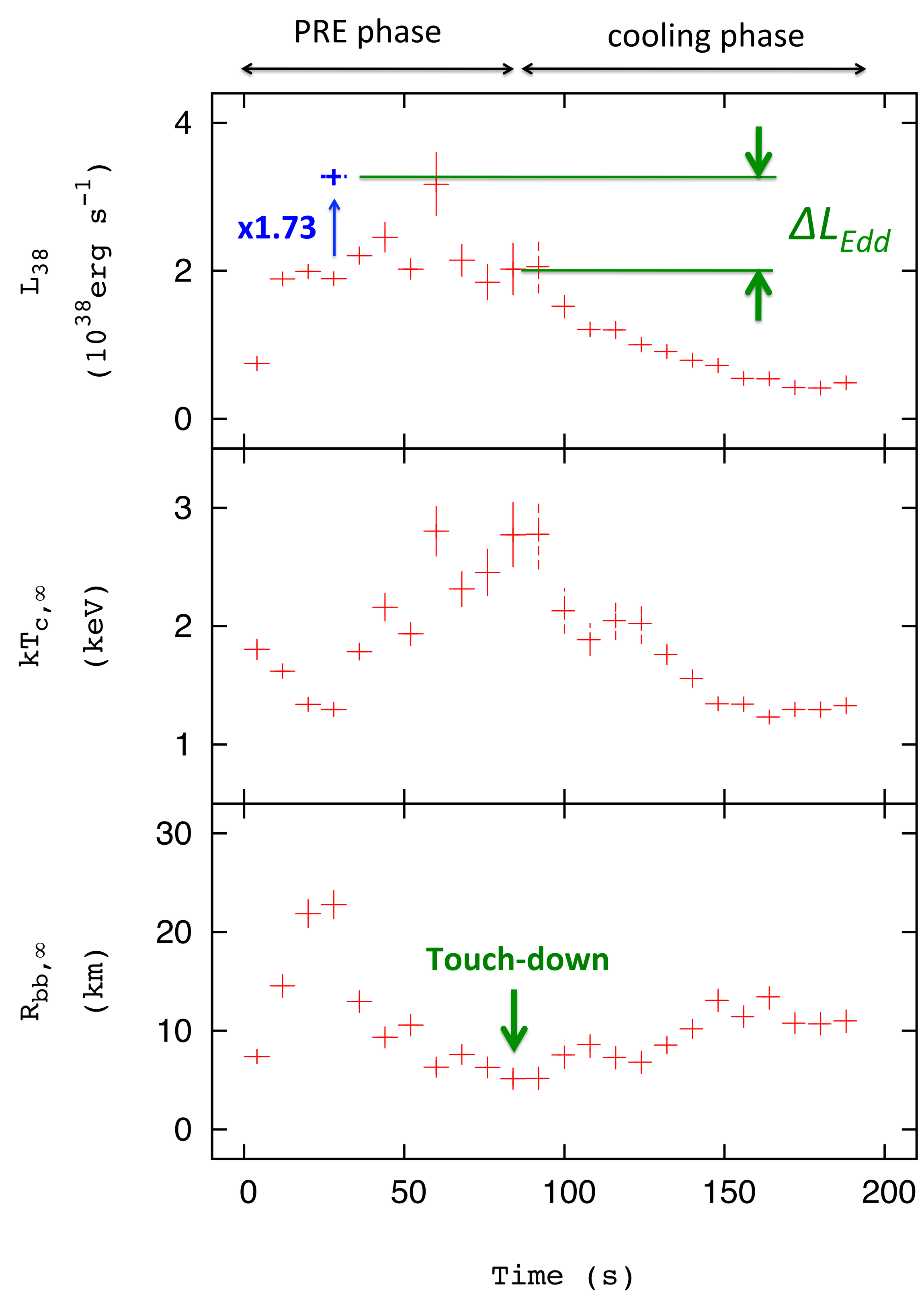

Fig. 2. Evolution of spectral parameters during the burst. The source distance is assumed to be *9.5 kpc* (Kuulkers et al. 2003). The blue cross indicates the hydrogen-poor Eddington luminosity at the peak radius, which is converted from the observed luminosity by assuming the composition change.

5. Discussions

- This method suffers from various systematic uncertainties. Most significant one is the deviation of the energy spectra from a blackbody, which is represented by the color correction factor f_C.
- Other systematics include hydrogen column density during the burst, Eddington luminosity determined by the composition and temperature of the burst atmosphere, isotropy of the burst emission, and so on.
- In spite of these systematic errors, this method is potentially useful as it is applicable to many PRE bursts.

References: Predehl et al. 1991, A&A, 246, L21; Pavlinsky et al. 1994, ApJ, 425, 110; in't Zand et al. 2003a, A&A, 406, 233; in't Zand et al. 2003b, A&A, 409, 653; Van Paradjis et al. 1989, PASJ, 42, 633; Kuulkers et al. 2003, A&A, 399, 66; Sugimoto et al. 1984, PASJ, 36, 839; Sleimanov et al. 2011, A&A, 527, A139