Thermonuclear (type I) X-ray bursts arise from unstable ignition of accumulated fuel on the surface of accreting neutron stars. Regular bursts powered by mixed H & He offer the best agreement between observations and theoretical models. We present an attempt to use such comparisons to constrain the gravitational redshift, as well as neutron star mass and radius, using time-dependent 1-D model results and data from burst sources GS 1826-24 and KS 1731-26. The burst models are coupled approximately to models describing the spectral formation in the atmosphere, which allow us to constrain the spectral hardening factor $f_c$. We thus measure the redshift in the two sources, up to a factor of $f_c$. The additional Eddington flux measurement in KS 1731-26 via radius-expansion bursts leads to limits on the mass and radius in this system.

### The neutron star radius

The apparent (blackbody) radius measured through the burst decay depends upon the gravitational redshift as well as the distortion of the neutron star atmosphere, here parametrised by the color correction factor $f_c$:

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

where $R$ is the true neutron star radius and $R_{\text{bb}}$ the apparent (blackbody) radius. Unlike some sources, the regular bursts from GS 1826-24 and KS 1731-26 exhibit apparent radii that are consistent from burst to burst, even in events separated by years. Moreover, the burst models with which the lightcurve comparison is made also predict the temperature profile, which can be matched to atmosphere models to give the best possible estimate of $f_c$ (Madej et al. 2004).

### Comparisons of observed and predicted burst lightcurves allow constraint on the source distance (Heger et al. 2007), although the (1-D) model lightcurve must be scaled by the assumed neutron star radius and gravitational redshift.

The explicit distance constraint has the form

$$ d = c_x R (1 + z)^{-\frac{1}{2}} \xi_b^{-1/2} $$

where $d$ is the source distance, $R$ the neutron star radius, $(1+z)$ the gravitational redshift and $\xi_b$ a parameter accounting for the possibility of beaming of the burst X-ray emission. The prefactor $c_x$ is the scale required to match the observed and predicted lightcurves (e.g. Fig. 1).

### References


### Putting it all together

The distance and radius constraints can be combined to eliminate $R$, $d$, and $\xi_b$, so that the redshift is expressed as a function of the observables and $f_c$. The resulting values of 1.34 and 1.421 are compatible with a range of conventional equations of state (Fig. 2). Few other measurements of surface redshift are available; the report of X-ray spectral lines from the neutron star surface in EXO 0748-676 (Cottam et al. 2002) has likely been refuted by the recent discovery of 552 Hz burst oscillations in that source (Galloway et al. 2009). The measurement of the Eddington flux in KS 1731-26 allows an added restriction to the M-R region.

### Figure 1

Comparison of average burst lightcurves observed by RXTE from KS 1731-26 in 2000 August with the model predictions, both the solar H-fraction (dashed line) and the low H-fraction model (thick solid line). The observed lightcurve (filled circles with errorbars) has been scaled to match the predicted luminosity for the low H-fraction lightcurve; the corresponding distance (assuming isotropic emission) is 7.46 kpc.

### Figure 2

Redshift constraints plotted as ±1σ confidence regions for KS 1731-26 (45° hatched) and GS 1826-24 (vertical hatched) for the assumed color correction factor of 1.64. The measurement of the Eddington flux from photospheric radius-expansion bursts in KS 1731-26 defines the red- (1σ) and green- (2σ) hatched regions, for which the additional width compared to the redshift regions alone arises from the most conservative possible range of $f_c$ values. The region permits only rather massive neutron stars (≥1.6M_☉) for KS 1731-26, which cannot yet rule out any of the candidate equations of state (from Lattimer & Prakash 2007).