Model atmospheres of X-ray bursting neutron stars

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Abstract. We present an extended set of model atmospheres and emergent spectra of X-ray bursting neutron stars in low mass X-ray binaries. Compton scattering is taken into account. The models were computed in LTE approximation for six different chemical compositions: pure hydrogen and pure helium atmospheres, and atmospheres with a solar mix of hydrogen and helium and various heavy elements abundances; Z = 1, 0.3, 0.1, and 0.01 $Z_{\odot}$, for three values of gravity, $\log g$ =14.0, 14.3, and 14.6 and for 20 values of relative luminosity $l = L/L_{\rm Edd}$ in the range 0.001 - 0.98. The emergent spectra of all models are fitted by diluted blackbody spectra in the observed *RXTE*/PCA band 3 - 20 keV and the corresponding values of color correction factors $f_{\rm c}$ are presented. We also show how to use these dependencies to estimate the neutron star's basic parameters.

Keywords: radiative transfer - stars: neutron - X-rays: bursts - X-rays: individual: 4U 1724−307
PACS: 97.10.Ex,97.10.Nf,97.10.Pg,97.60.Jd,97.80.Jp

The most important and useful sources for the aim of neutron stars (NSs) M and R finding are X-ray bursting NSs with photospheric radius expansion [1]. The relation between observed normalization K (for blackbody fit of spectra) and the real ratio of NS radius R to distance on late outburst phases is:

$$K^{1/2} = \frac{R_{\rm BB}({\rm km})}{D_{10}} = \frac{R({\rm km})}{f_{\rm c}^2\, D_{10}}(1+z), \tag{1}$$

where D_{10} is the distance in units of10 kpc, and $f_{\rm c} = T_{\rm c}/T_{\rm eff}$ is a color correction factor. Therefore, on these phases $K(t)$ dependence reflects $f_{\rm c}(t)$ dependence only. We suggest to fit the observed $K^{-1/4} - F$ relation by a theoretical $f_{\rm c} - l \equiv L/L_{\rm Edd}$ relation, where F is the integral observed flux. From this fit we can obtain two independent values: $R({\rm km}) \times (1+z)/D_{10}$ and $F_{\rm Edd} \sim L_{\rm Edd}/((1+z)D_{10}^2)$. Combining these values, we can obtain an observed M/R relation, which is independent on the distance and physically corresponds to a maximum possible effective temperature on the NS surface. If the distance is known we can find M and R simultaneously. For this method extended theoretical $f_{\rm c}(l)$ calculations are necessary.

We computed model atmospheres of X-ray bursting NSs subject to the constraints of hydrostatic and radiative equilibrium assuming planar geometry in LTE approximation with Compton scattering taken into account (see details of the code in [2, 3]).

We calculated an extended set of NS model atmospheres with 6 chemical compositions (pure H, He, and solar H/He mixture with Z = 1, 0.3, 0.1 and 0.01 $Z_{\odot}$), 3 sur-

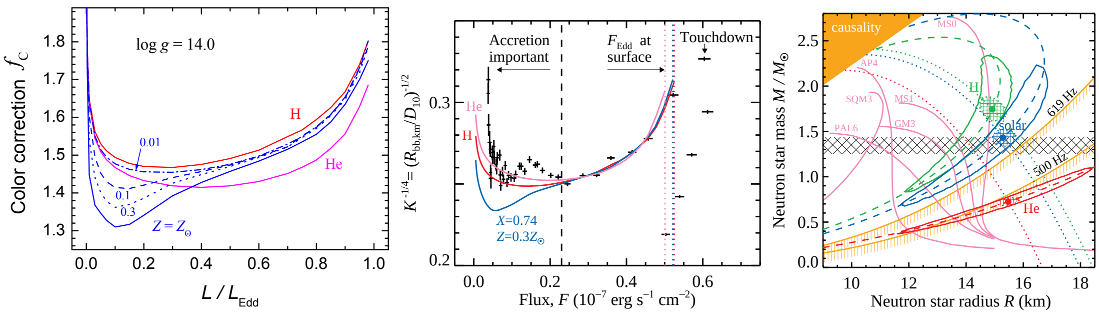

FIGURE 1. *Left:* Dependence of color correction factors on the relative luminosity for low gravity and various chemical compositions in NS atmosphere models. *Middle:* Comparison of the observed dependence of $K^{-1/4} - F$ for 4U 1724−307 (croses) to the best fit theoretical models $f_c - l$. *Right:* Constraints on mass and radius of the neutron star 4U 1724−307.

face gravities: log g = 14.0, 14.3 and 14.6, and 20 luminosities L: 0.001, 0.003, 0.01, 0.03, 0.05, 0.07, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, and 0.98 $L_{\rm Edd}$. Corresponding $T_{\rm eff}$ were calculated from L using $\log g$ and chemical composition. The model emergent redshifted spectra were fitted by diluted blackbody spectra $F_{\rm E} = wB_{\rm E}(f_c T_{\rm eff})$ in the *RXTE*/PCA energy band $3-20$ keV. Here $w \approx f_c^{-4}$ is the dilution factor. The accepted redshifts were calculated from $\log g$ assuming $M = 1.4 M_\odot$. Results are partially presented in Fig. 1, left panel.

We fitted the observed $K^{-1/4} - F$ relation, obtained for the extremely long outburst of 4U 1724−307 in November 8, 1996 (*RXTE*, [4]) by computed $f_c - l$ relations. We obtained limitations on R and M for the adopted distance $D = 5.3 \pm 0.6$ kpc [5] and various chemical compositions, see Fig. 1. The values of M and R obtained for H-rich atmospheres correspond to a stiff Equation of State in the inner NS core. Helium atmospheres are not acceptable. More details can be found in [6].

ACKNOWLEDGMENTS

The work is supported by the DFG grant SFB / Transregio 7 “Gravitational Wave Astronomy” (V.S.), Russian Foundation for Basic Research (grant 09-02-97013-p-povolzhe-a, V.S.), and the Academy of Finland (grant 127512, J.P.).

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