Cooling tail method for X-ray bursting neutron star masses and radii determination

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1 Method

- Observed spectra of X-ray bursting NSs are fitted by blackbody spectra with two parameters: color temperature $T_{\rm BB}$ and normalization $K = R^2_{\rm BB}[{\rm km}]/D^2_{10}$.
- Model spectra of X-ray bursting NSs are close to a diluted blackbody $F_{\rm E} = f_{\rm c}^{-4}\, B_{\rm E}(f_{\rm c} T_{\rm eff})$ with color correction factrors $f_{\rm c}$ in the range 1.4 - 1.8 (Fig.1), therefore K is connected to the real NS radius via $f_{\rm c}$ and gravitational redshift z: $K = (R(1+z))^2/(f_{\rm c}^2 d_{10})^2$.
- At late stages of photospheric radius expantion bursts (when the photosphere radius is equal to the neutron star radius) K depends on $f_{\rm c}$ only.
- We suggest to fit observed dependences $K^{-1/4} - F$ by theoretical dependences $f_{\rm c} - L/L_{\rm Edd}$ (Fig.2), where F is the observed bolometric flux.
- Three parameters can be obtained from the fits: $A = (R(1+z)[{\rm km}]/D_{10})^{-1/2}$, $F_{\rm Edd} = GMc/(0.2(1+X)\,(1+z)\,D^2)$, where X is a hydrogen mass fraction, and $T_{\rm Edd,\infty} = 1.14 \times 10^8\, A\, F^{1/4}_{\rm Edd,-7}$ K, where $F_{\rm Edd,-7} = F_{\rm Edd}/10^{-7}$ erg cm^{-2} s^{-1}.
- A curve on the $M - R$ plane corresponds to each obtained parameter (Fig.3). Crossing points give the possibly solutions for M and R.

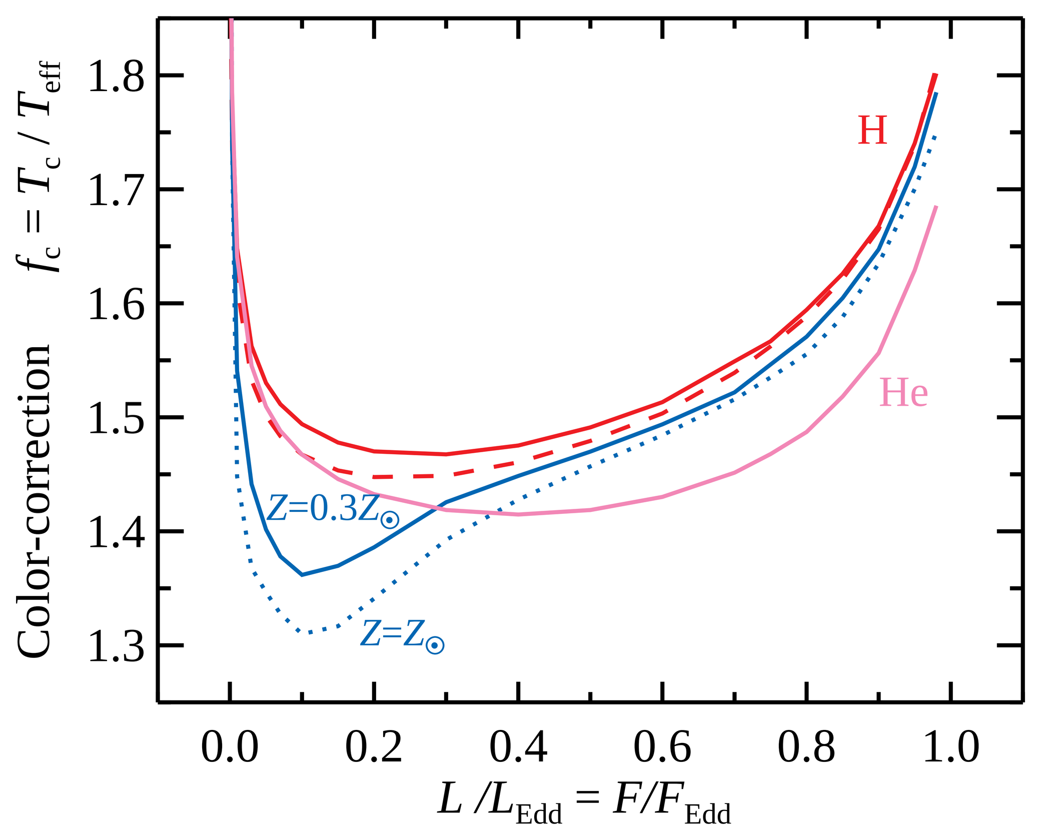

Figure 1: Color-correction factor as a function of the NS luminosity for different chemical compositions (see Suleimanov et al. 2011a). The surface gravity is taken to be $g = 10^{14.0}$ cm s^{-2}. The dashed curve shows the results for a hydrogen atmosphere at larger gravity of $\log g = 14.3$.

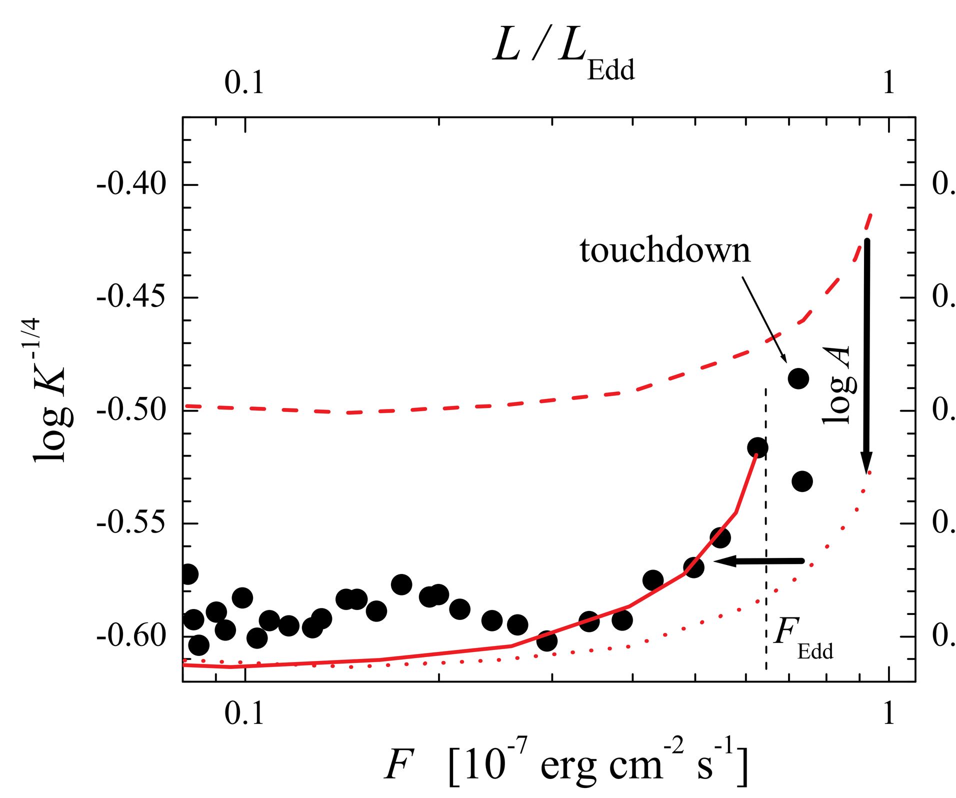

Figure 2: Illustration of the suggested new cooling tail method.

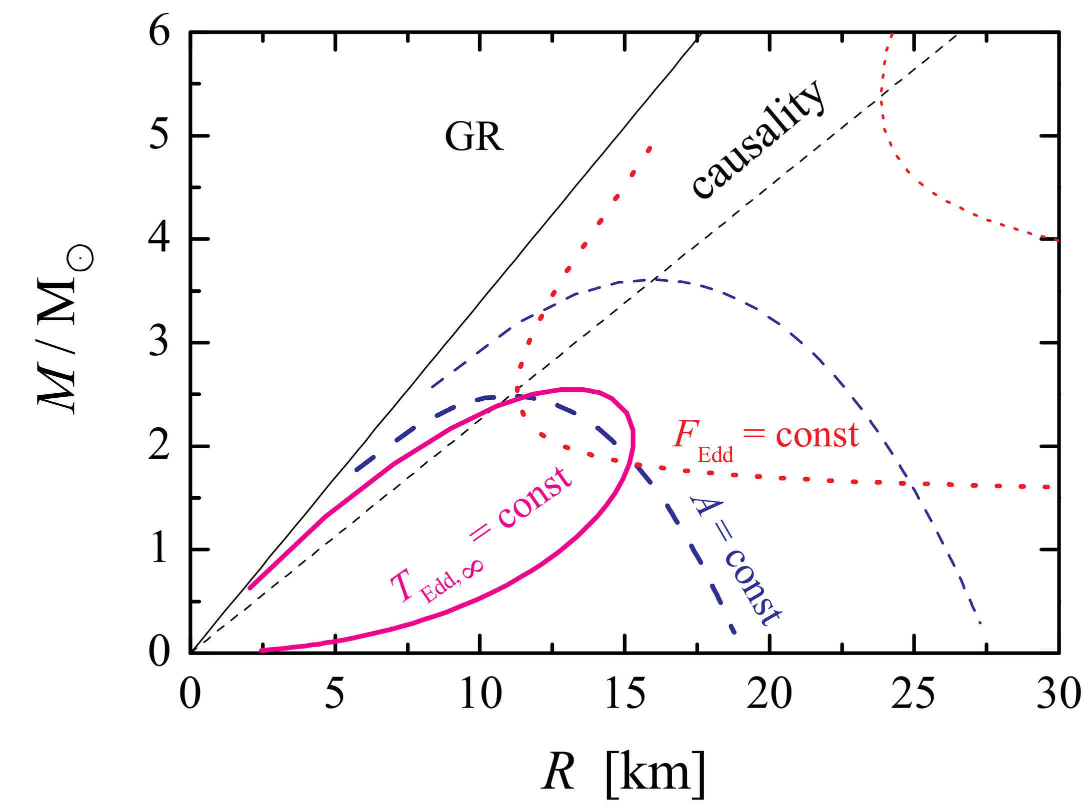

Figure 3: Constraints on M and R from various observed values. If the assumed distance is too large, there are no solutions (the corresponding curves for $F_{\rm Edd}$=const and R_∞=const shown by thin lines do not cross).

2 Application to a long burst of 4U 1724−307, a LMXB in the globular cluster Terzan 2

- *RXTE* has observed three photospheric radius expanshion bursts (Fig.4), one long and two short.
- Differences in the observed properties can be explained by different accretion disk states (Fig.5).
- The dependence $K^{-1/4} - F$ observed in a long burst can be fitted by the theoretical $f_{\rm c} - L/L_{\rm Edd}$ dependences (Fig.6).

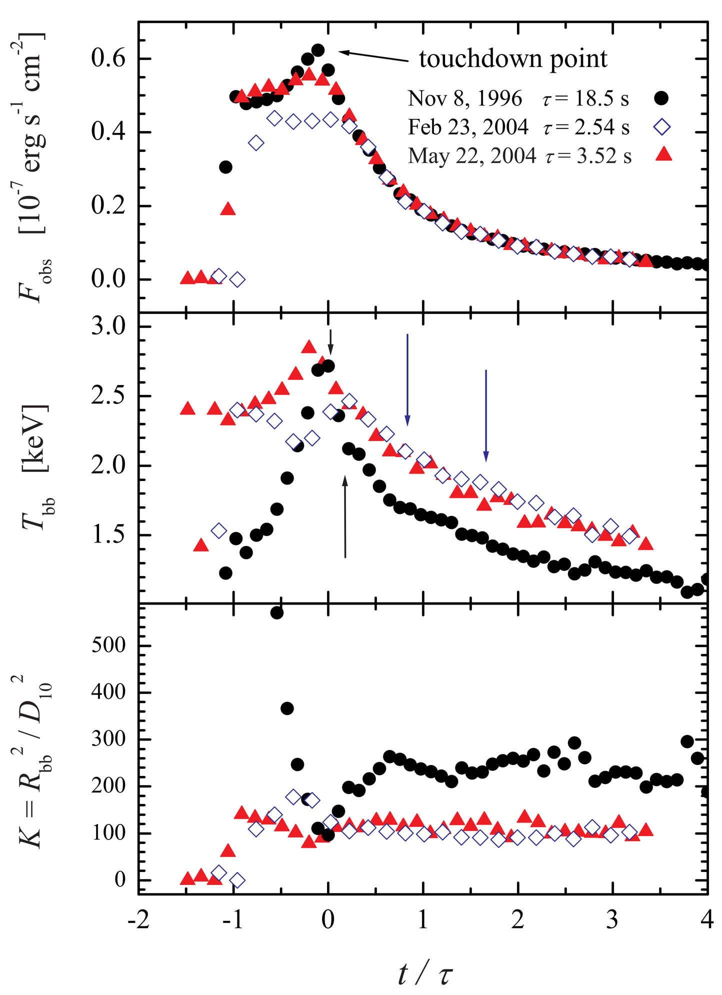

Figure 4: Evolution of the observed blackbody fluxes, color temperatures and normalizations for a long (black circles) and short bursts from 4U 1724−307.

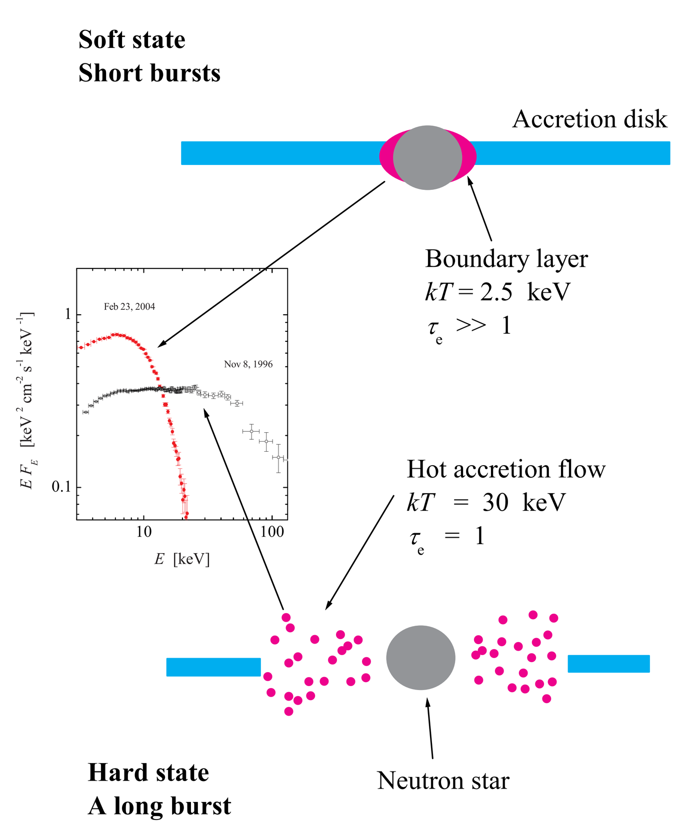

Figure 5: Different spectral states of the 4U 1724−307 accretion disk before a short and a long burst.

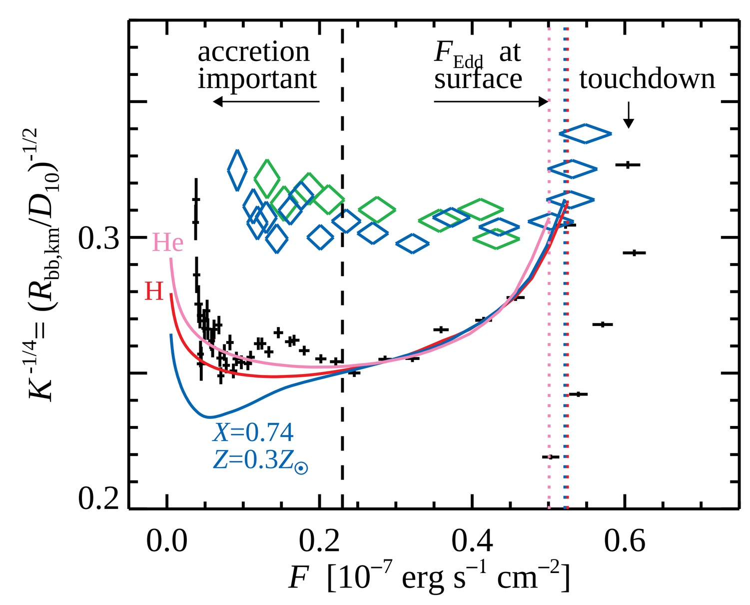

Figure 6: Comparison of the X-ray burst data for 4U 1724−307 to theoretical models of the NS atmosphere. The crosses represent the observed dependence of $K^{-1/4}$ vs. F for the long burst, while diamonds represent the two short bursts.

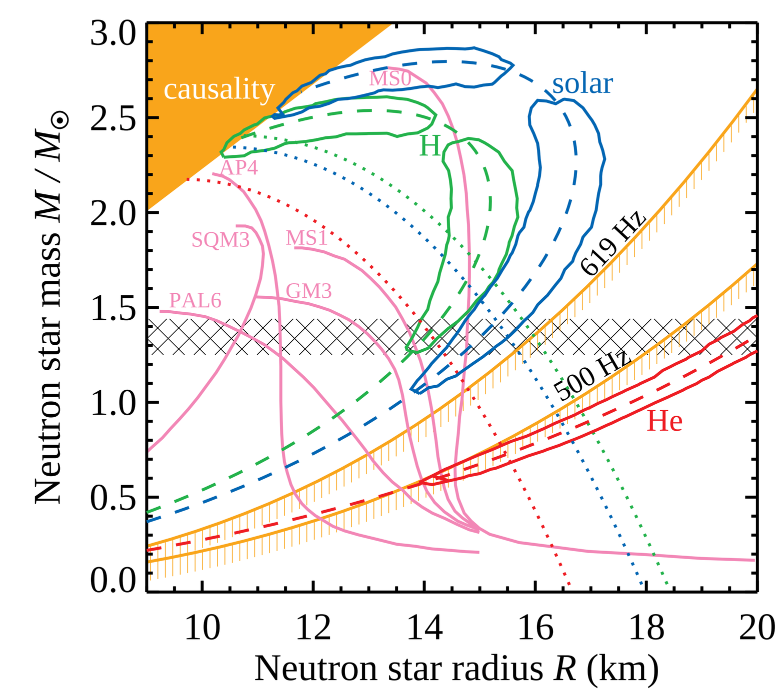

Figure 7: Constraints on the mass and radius of the NS in 4U 1724−307 from the long burst spectra. These correspond to the three chemical compositions: green for pure hydrogen, blue for the solar ratio of H/He and subsolar metal abundance $Z = 0.3Z_\odot$ appropriate for Terzan 2, and red for pure helium.

3 Conclusions

- The neutron star radius in 4U 1724−307 is larger than 14 km for masses below 2.3 solar mass (Fig.7).
- Most probably, the inner core of the neutron star is characterized by a stiff equation of state.

Details see in papers:

V. Suleimanov, J. Poutanen, K. Werner, A&A, 527, A139, 2011a;
V. Suleimanov, J. Poutanen, M. Revnivtsev, K. Werner, ApJ (in press), 2011b (arXiv:1004.4871).

Acknowledgements The work is supported by the DFG grant SFB / Transregio 7 “Gravitational Wave Astronomy” (V.S.), the Academy of Finland (grant 127512, J.P.), and DFG cluster of excellence “Origin and Structure of the Universe” (M.R.).