Determination of fundamental parameters for the compact star in X-ray burster MXB 1728-34

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Plan of my talk

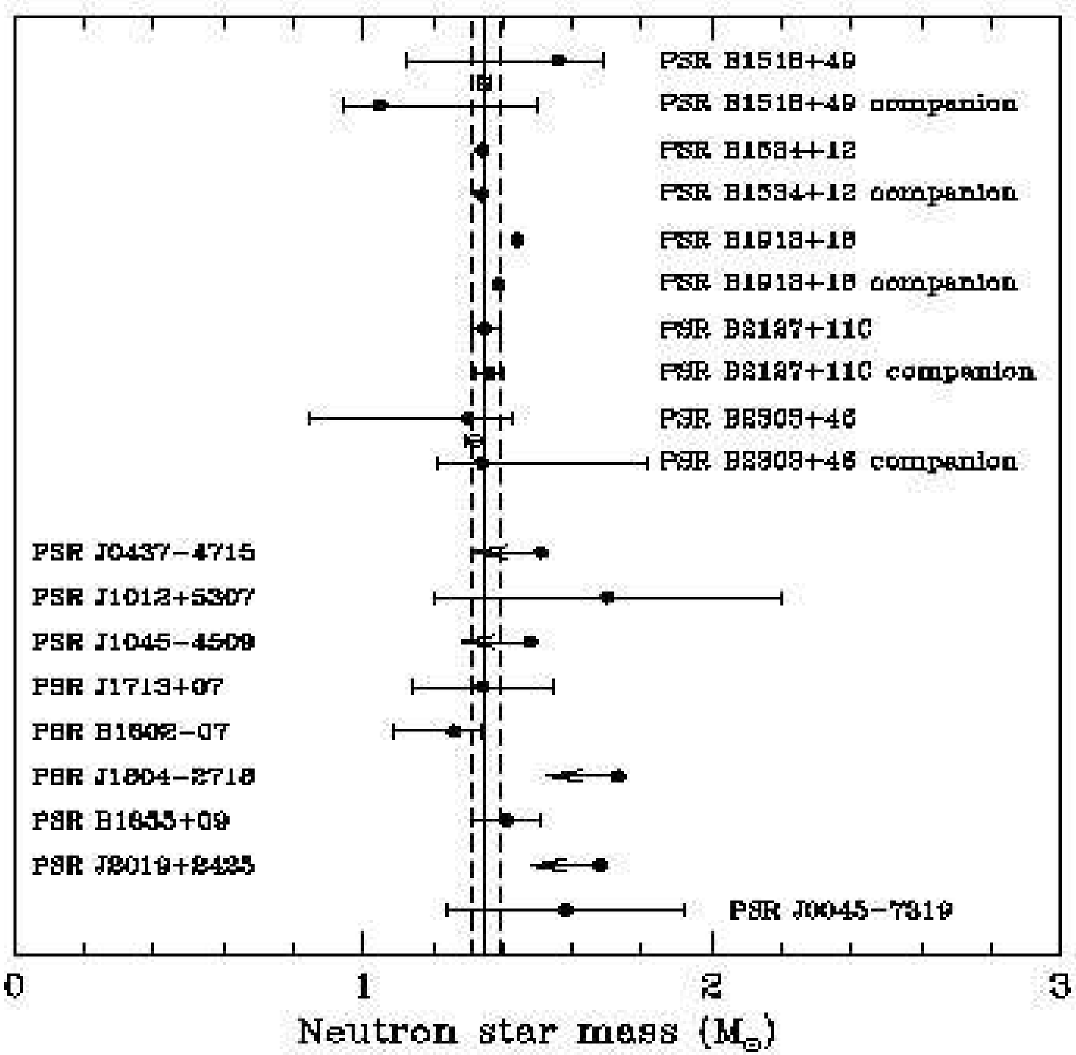
- Why the determination of fundamental parameters of the neutron star in X-ray bursters is important?
- MXB 1728-34 - what is this?
- Our method.
- Results.
- Summary and conclusions.

Why determination of fundamental parameters of neutron stars in X-ray bursters is important?

Determination of the neutron star parameters in X-ray bursters:

- allows one to constrain of the EOS and to understand physics of superdense matter
- provides new informations about the model of a neutron star birth as well as about the model of binary stars evolution

Masses of neutron stars in binary pulsars



Thorsett & Chakrabarty (1999)

Values of NS masses are strongly concentrated around 1.4 M_sol.

Is it true for other classes of compact objects?

Properties of MXB 1728-34

- discovered as X-ray source in 1976 during Uhuru sky monitoring
- identified as X-ray burst source in 1976 (Lewin et al.; Hoffman et al.)
- source type atoll
- time between X-ray bursts is typically in the range 4 - 8 hr
- spin frequency of the neutron star is 364 Hz
- optical counterpart was not observed
- estimated distance is 4.2 – 5.1 kpc
- this source do not show superbursts

Our method for mass and radius determination

- Our method is based on the fitting of theoretical spectra for hot neutron star atmospheres to observed X-ray spectra.
- We use model atmospheres with Compton scattering (ATM21 code) plus models offered by `xspec` package.
- Best models allow us to determine the effective temperature, surface gravity and gravitational redshift simultaneously, therefore, we can determine mass and radius of the neutron star. We assumed chemical composition of the atmosphere.
- This method is independent on the distance!!!!!!
- Our method works also when only part of the NS surface is bright in X- rays.

Basic assumptions of our method

- We fitted spectra of MXB 1728-34 during quiescent phase assuming negligibly small contribution from the disk to the total X-ray flux.
- Only the atmosphere of the NS is the source of X-ray photons.
- We assume that dynamical effects of accretion on the neutron star atmosphere are negligible.
- During a chosen integration time we assign a fixed effective temperature to the neutron star.
- We include here assumptions specific to the model atmosphere computations by ATM21 code.

Basic assumptions of the model atmosphere (ATM21 code)

- plane-parallel geometry
- hydrostatic and radiative equilibriums
- non-rotating neutron star
- magnetic field does not modify opacity coefficients
- we do not include relativistic corrections in model atmosphere equations
- we include free-free, bound-free, bound-bound processes and Compton scattering
- photons are scattered on relativistic electrons with thermal velocity distribution
- we allow for large relative energy and momentum exchange between photon and electron during a single scattering
- we reject well-known Kompaneets approximation!

Method of fitting

- We analyzed 18 spectra of X-ray satellite RXTE obtained by PCA instrument during the period 1996 - 1999.
- We have chosen spectra from banana and island spectral state of the source, and we omitted spectra during the extreme island state.
- We integrated our spectra over 96 sec time period.
- We use xspec package to analyze observed spectra.
- We have chosen emission model: wabs*plabs(ATM21+gaussian)

Method of fitting

- We used three grids of comptonised model atmosphere and spectra (ca. 250 models each), computed for different chemical compositions: H-He of solar proportion plus Fe of various abundance. Effective temperature ranged from 10^7 K to 3×10^7 K, logarithm of surface gravity from the critical gravity to log(g)=15.0.
- The quality of each fit was estimated by the value of chi^2/d.o.f.
- We rejected a given fit if it implied the mass of a neutron star lower than 0.01 M_sol.

Equations for mass and radius

$$(1+z)=\left(1-\frac{2GM}{Rc^2}\right)^{-1/2}$$

$$g=\frac{GM}{R^2}\left(1-\frac{2GM}{Rc^2}\right)^{-1/2}$$

combining above equations we obtain M and R relations

$$R=\frac{zc^2}{2g}\times\frac{(2+z)}{(1+z)}$$

$$M=\frac{z^2c^4}{4gG}\times\frac{(2+z)^2}{(1+z)^4}$$

How we obtain values of the parameters?

- For a given observed spectrum we fit theoretical models for each combination of T_eff, log(g) and the surface redshift z, the latter changing in the range 0.0 – 0.60 in steps 0.01.
- For a given observed spectrum we obtained hundreds of fits with acceptable (low) values of chi^2/d.o.f. Therefore, the unique determination of T_eff, log(g), and z was not possible.
- Mass and radius of the compact object can be determined from log(g) and z. Note, that the effective temperature is no longer useful.

How we obtain values of the parameters?

- We selected all sets of log(g) and z with chi^2/d.o.f. in the range $(\chi^2_{min}, \chi^2_{min} + \Delta)$, delta corresponding to 1-σ confidence range for 8 free parameters.
- For each spectrum we determined fundamental parameters of a compact star.
- Our best value of a given parameter is calculated as arithmetic mean of particular determinations.
- We estimated errors as the error of arithmetic mean.

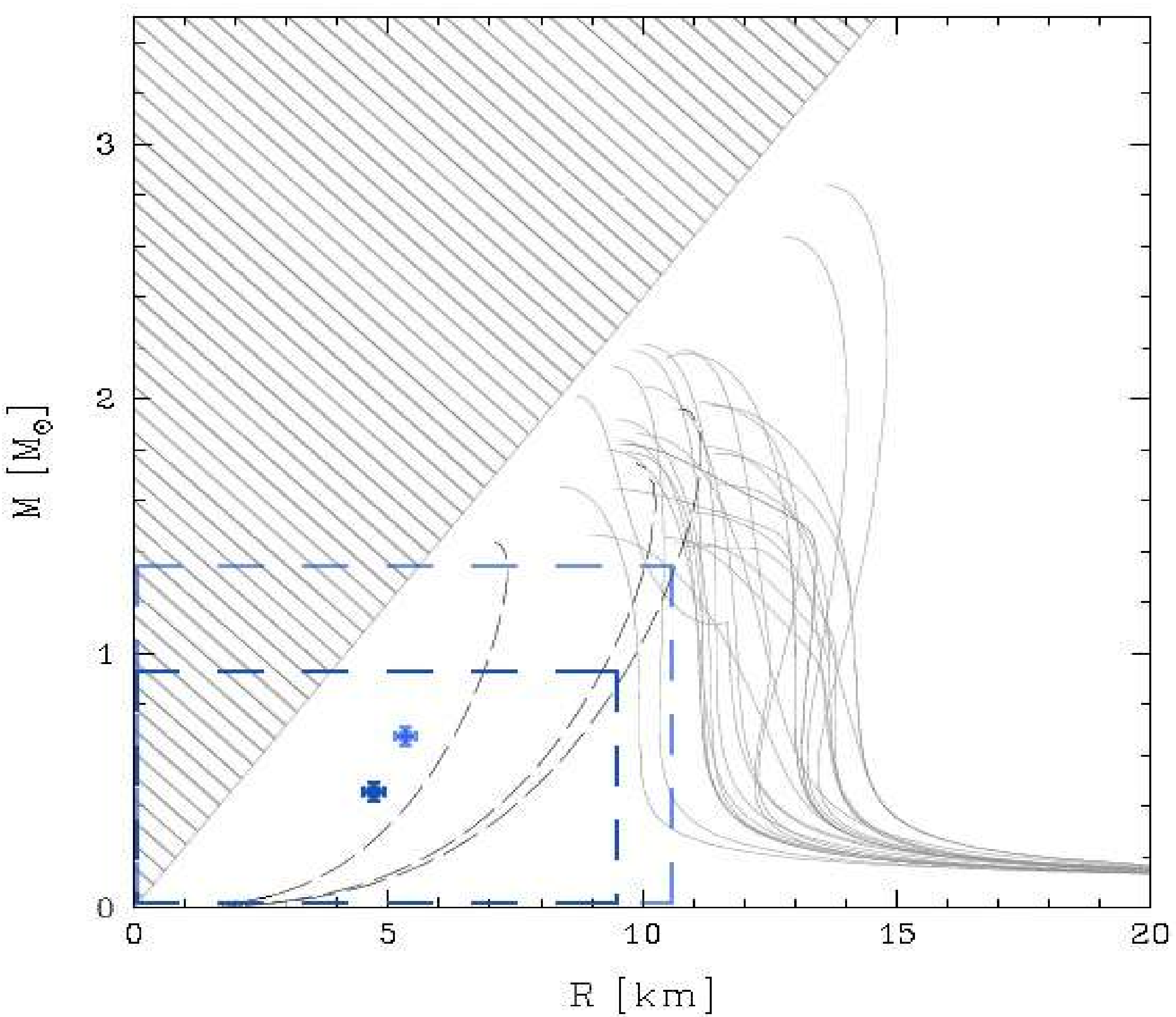
Parameters of the neutron star

H-He model		
	Recommended values	1-sigma level
log(g)	14.6	14.0-15.0
z	0.13	0.01-0.25
M [M_sol]	0.46	0.01-0.93
R [km]	4.75	0.01-9.49

H-He-Fe model		
	Recommended values	1-sigma level
log(g)	14.6	14.0-15.0
z	0.21	0.01-0.42
M [M_sol]	0.67	0.01-1.35
R [km]	5.33	0.01-10.66

Recommended values are consistent with an equation of state of strange quark matter.

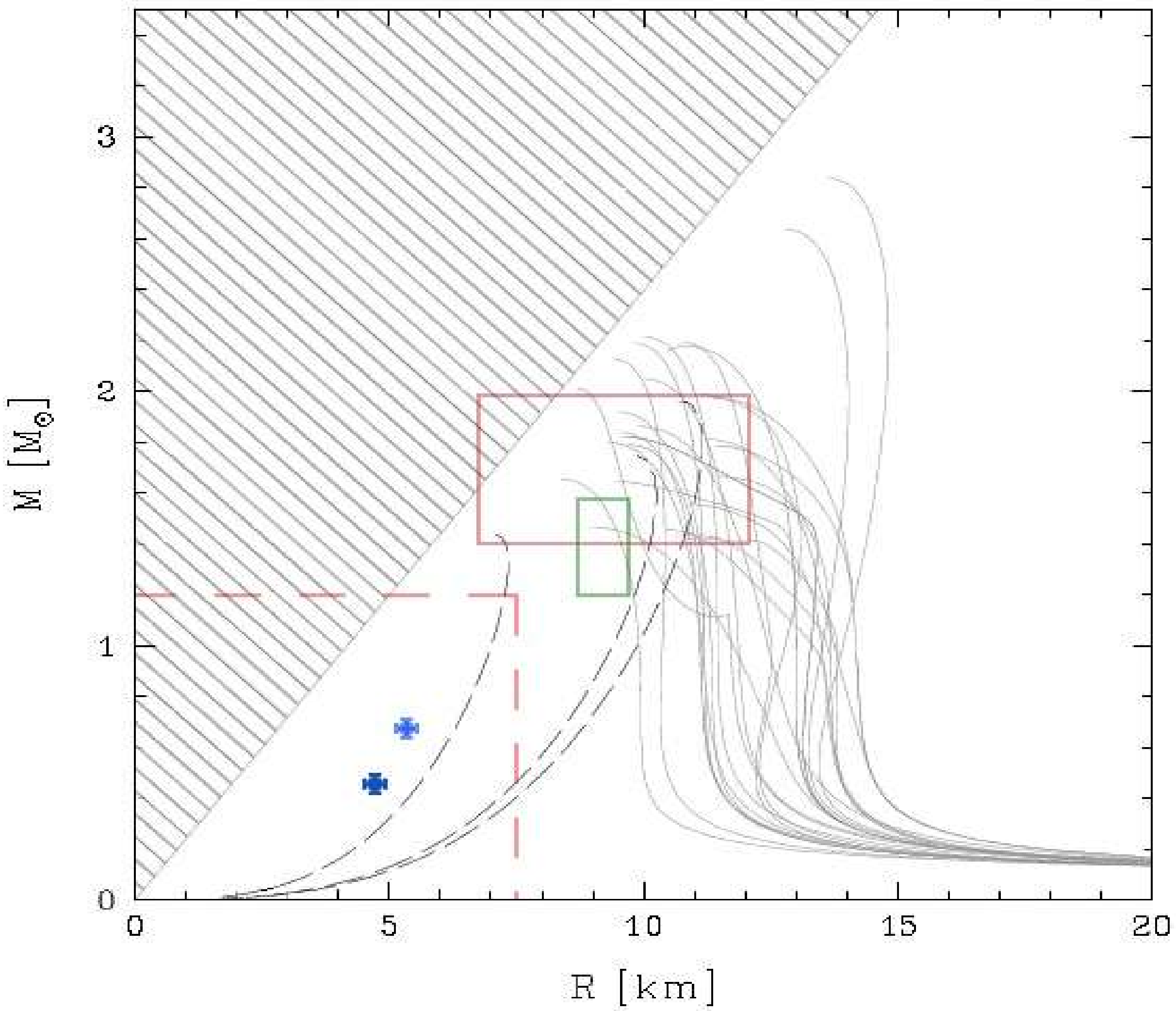
Our determinations of NS parameters



Our determination of compact star parameters and 1-σ confidence ranges.

Light blue - H-He-Fe model
Dark blue - H-He model

Comparison with other determinations



green rectangle - Shaposhnikov et al. (2003)
red one - Kaminker et al. (1989)
dashed rectangle - Fujimoto & Gottwald (1989)

dots with errors - Majczyna & Madej (2005)

Summary and conclusions

- Our method allows us for the determination of a neutron star parameters, which are independent on the distance.
- We determined radius of the neutron star, and not just the radius of emitting area!
- The final values:

  H-He model M=0.46± 0.02 M_sol R=4.75± 0.22 km

  H-He-Fe model M=0.68± 0.02 M_sol R=5.33± 0.22 km

  are in agreement with EOS of strange quark matter
- However, 1-σ confidence range for H-He-Fe model do not exclude EOS for normal matter due to too large number of free parameters.
- In the future we plan reduce number of free parameters to improve our method.
- More mass and radius determinations for other X-ray bursters will be obtained in the forthcoming months.