Determination of fundamental parameters of neutron star in MXB 1728–34 from fitting of burst spectra by the ATM model atmospheres

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Plan of my talk

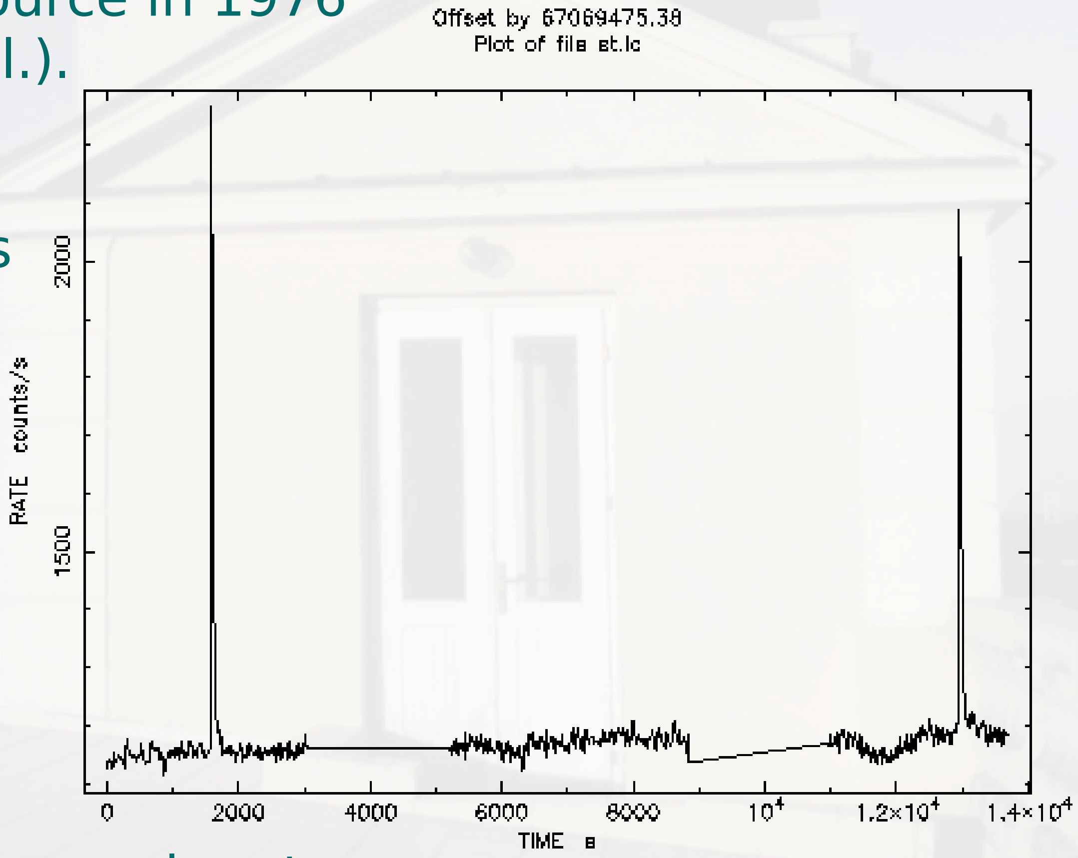
- MXB 1728-34 - what is it?
- Our method.
- Results.
- Summary and conclusions.

Basic features of X-ray bursters

- Discovered 35 years ago by Grindlay et al. (1976) and by Belian et al. (1976).
- These sources are neutron stars in interacting binaries.
- Companion star has low/very low mass.
- Weak magnetic field of the neutron star.
- During decay of the burst spectrum becomes softer – type I of the burst.
- X-ray bursts are recurrent events but not strictly periodic.
- Time intervals between bursts are typically in the range $\sim 10^4 – 10^5$ s.
- Energy released per burst is $\sim 10^{39}$ ergs.
- The source of the X-ray burst is the thermonuclear flash.

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 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.



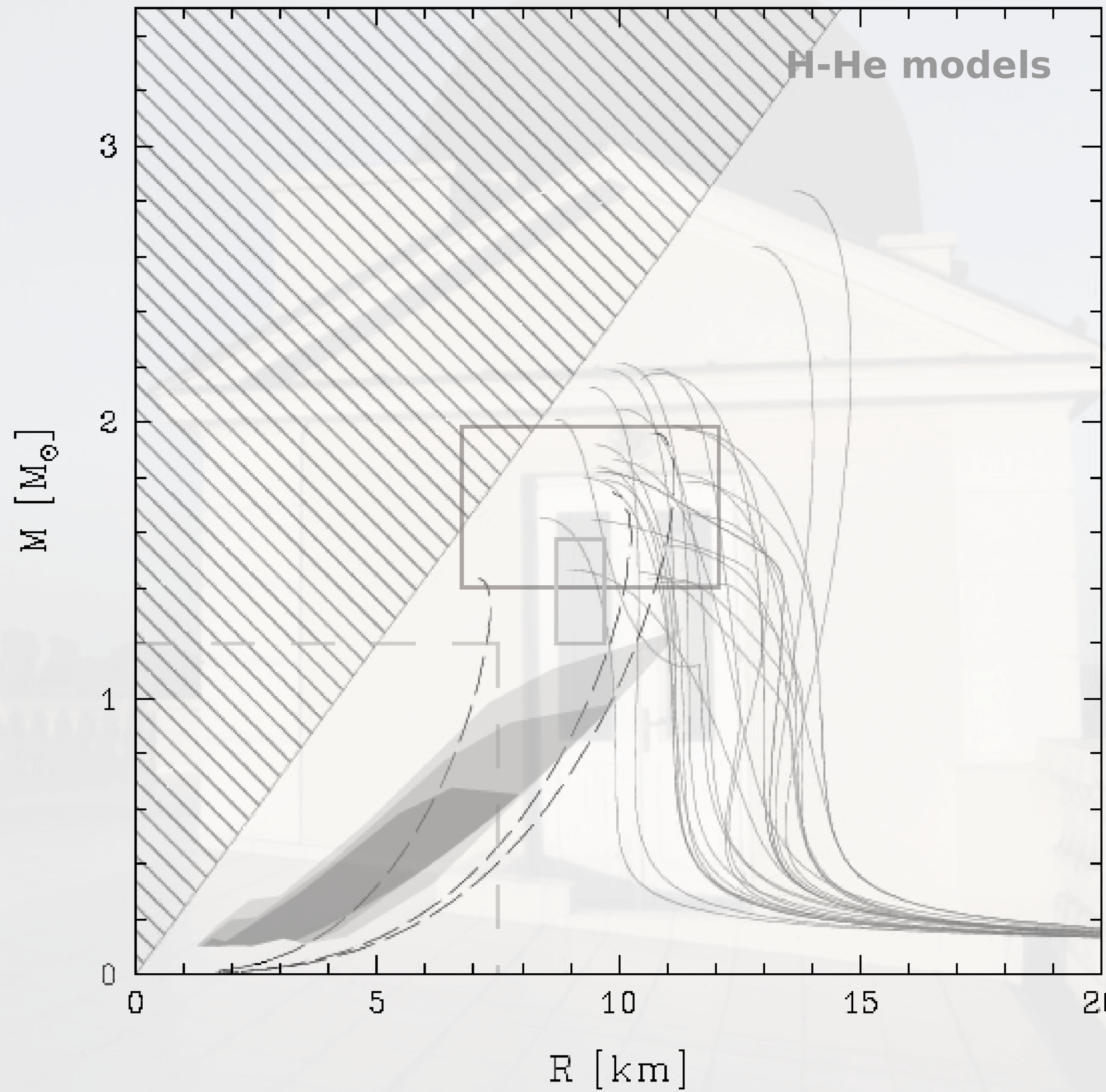
- This source does not show superbursts.

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.
- <u>This method is independent on the distance!!!!!!</u>
- Our method works also when only part of the NS surface is bright in X-rays.

Our previous determinations of NS parameters

1, 2 and 3-σ confidence ranges (gray contours), based on spectra in quiescence phase.

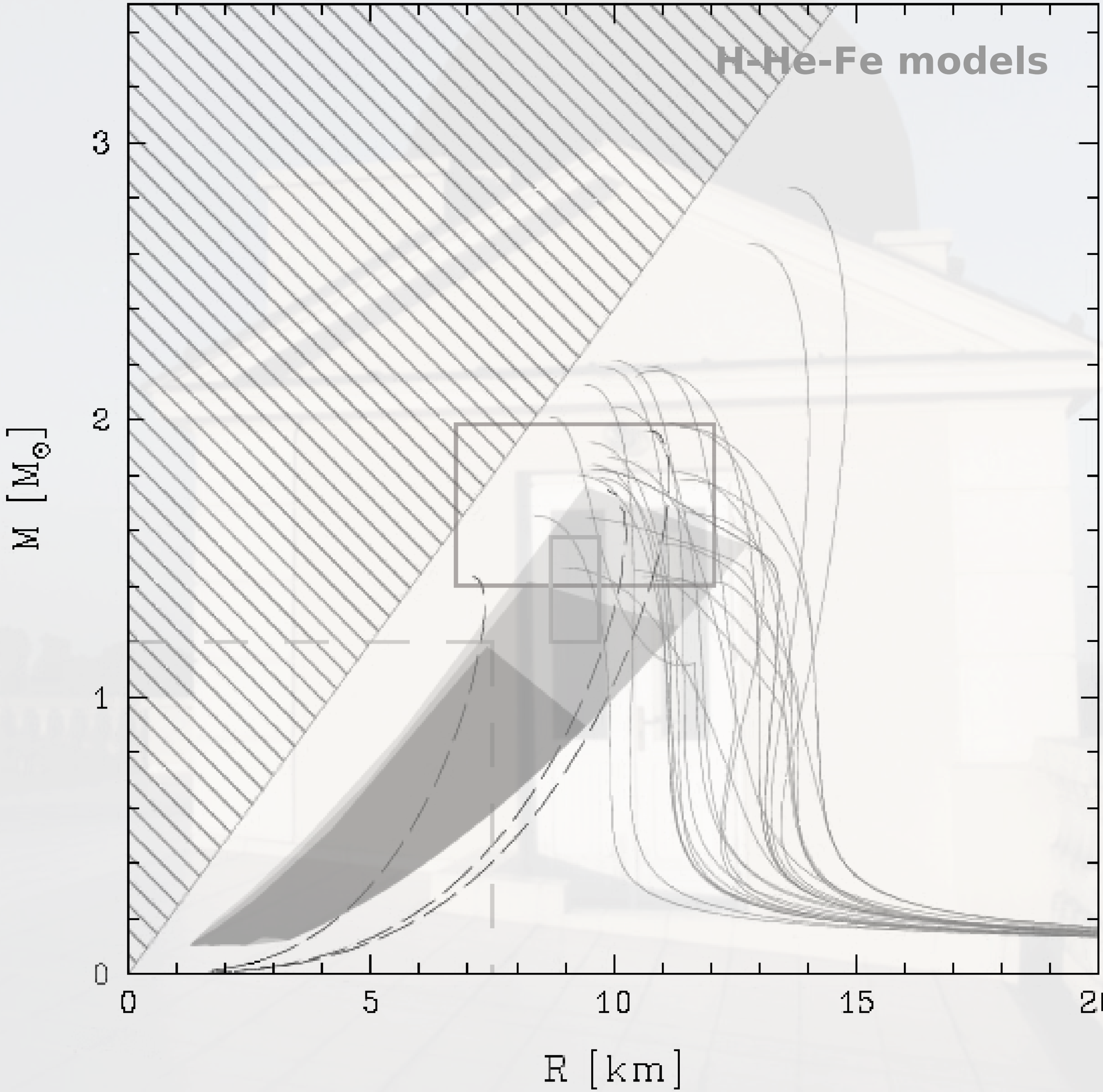


Majczyna & Madej (2005)

Shaded areas – Majczyna & Madej (2005),
light gray rectangle – Shaposhnikov et al. (2003),
dark gray rectangle – Kaminker et al. (1989),
dashed line – Fujimoto & Gottwald (1989).

Our previous determinations of NS parameters

The same for models with iron.

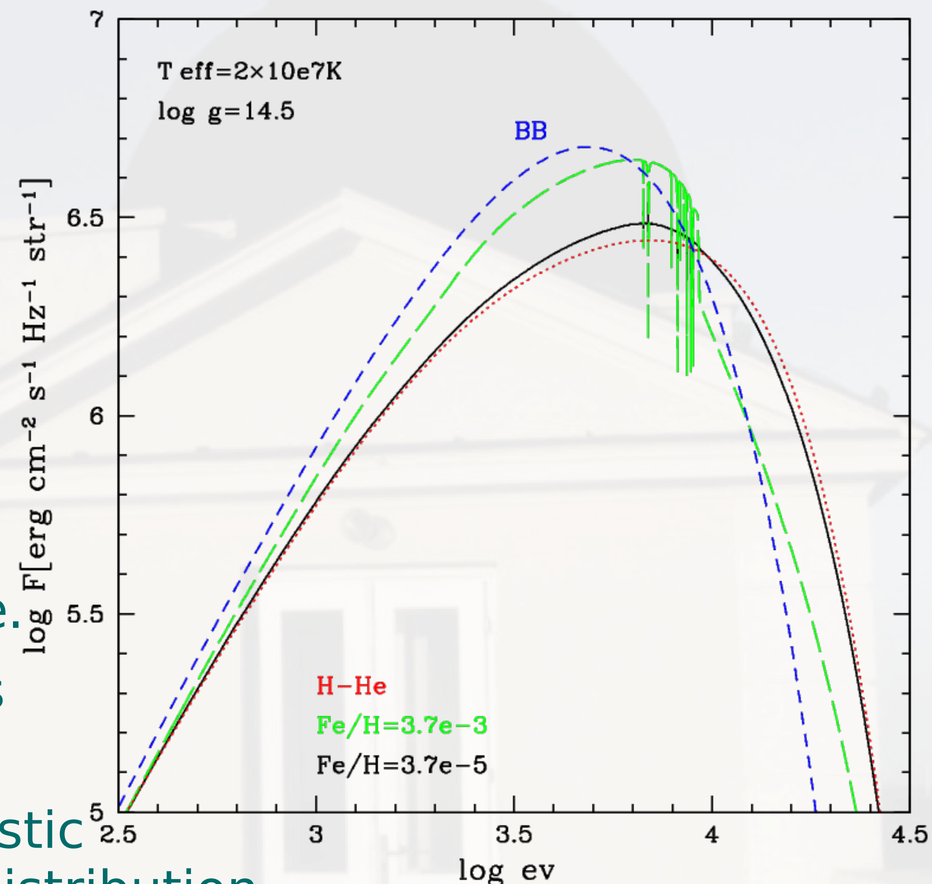


Majczyna & Madej (2005)

Basic assumptions of our method

- We fitted spectra of MXB 1728-34 at the end of bursts when as we believe the atmosphere is already static.
- Only the atmosphere of the NS is the source of X-ray photons.
- 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.

Assumptions of the model atmosphere (ATM 21 code)

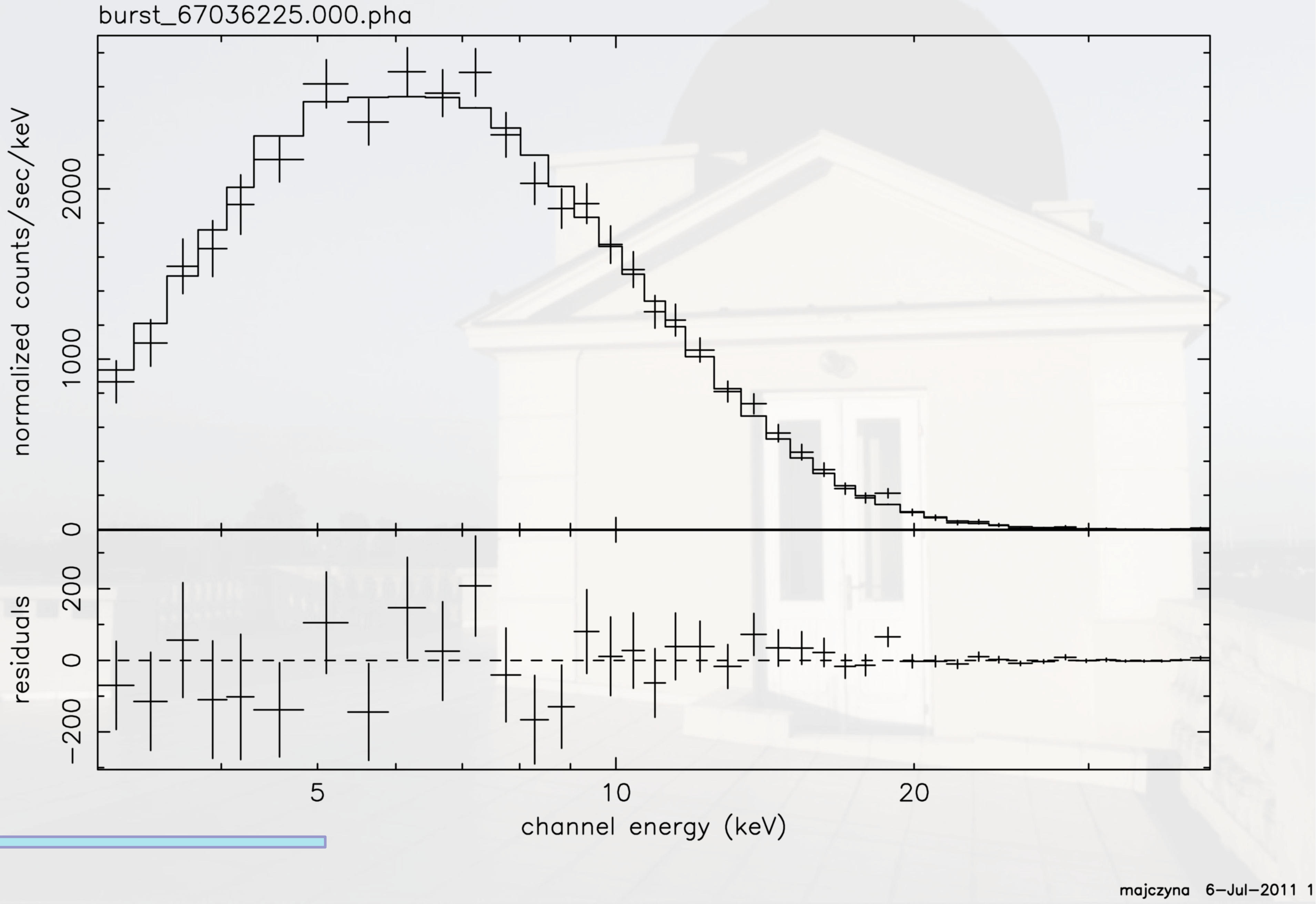


- Plane-parallel geometry.
- Hydrostatic and radiative equilibrium
- Non-rotating neutron star.
- Magnetic field does not modify opacity coefficients.
- We do not include relativistic corrections in model atmosphere.
- We include f-f, b-f, b-b processes and Compton scattering.
- Photons are scattered 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 9 spectra of X-ray satellite RXTE obtained by PCA instrument during the period 1996-2005.
- We have chosen spectra at the very end of the burst.
- Spectra was integrated over 0.25 s time period. We used xspec package to analyze observed spectra.
- We have chosen emission model: wabs(ATM21).
- 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 χ^2/d.o.f.
- We rejected a given fit, if it implied the mass of a neutron star lower than 0.1 $M_\odot$ and greater than 3.0 $M_\odot$.

Example of spectrum at the end of burst



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 large number of fits with acceptable (low) values of χ^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.
- We selected all sets of log(g) and z with χ^2/d.o.f. in the range (χ^2_{min}, $\chi^2_{min} + \Delta$), delta corresponding to 1, 2 and 3-σ confidence ranges for 2 free parameters.

Parameters of the neutron star

- 1-sigma:

  z = 0.05-0.52 logg = 14.0-14.9

  M = 0.103-1.516 $M_\odot$ R = 1.948-9.779 km

- 2-sigma:

  z = 0.05-0.58 logg = 14.0-15.0

  M = 0.103-1.564 $M_\odot$ R = 1.618-10.062 km

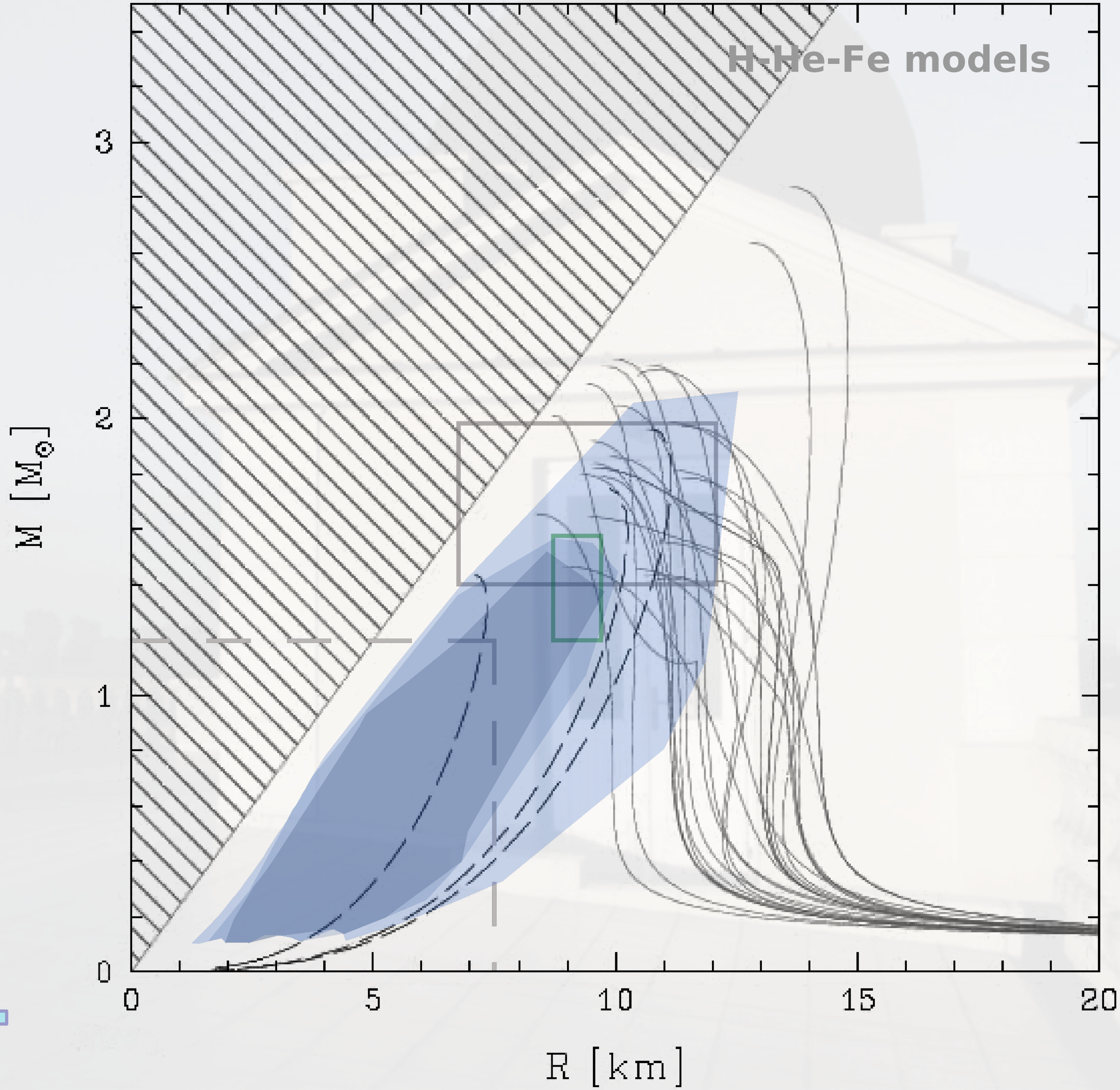
- 3-sigma:

  z = 0.04-0.6 logg = 13.9-15.0

  M = 0.101-2.98 $M_\odot$ R = 1.26-12.537 km

Our determinations of NS parameters

1, 2 and 3-σ confidence ranges (gray contours), based on spectra during the bursts.



Light gray rectangle – Shaposhnikov et al. (2003),
dark gray rectangle – Kaminker et al. (1989),
dashed line – Fujimoto & Gottwald (1989).

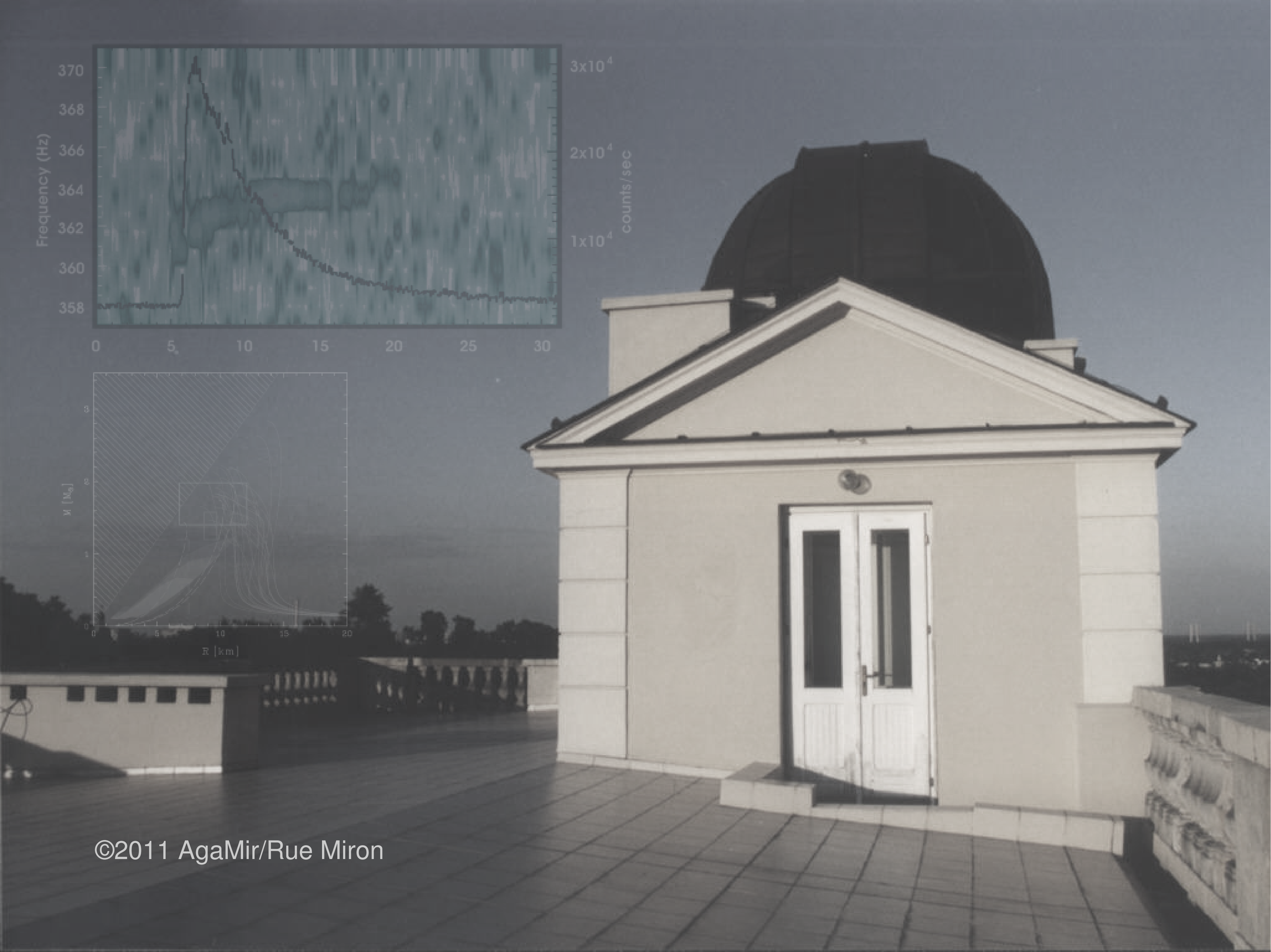
Summary and conclusions

- 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 best fit we obtained for models with He/H=0.11 Fe/H=10^{-3}. For these models 1-σ confidence level gives:

$M = 0.103\text{-}1.516\ M_\odot$ R = 1.948-9.779 km

- ***These parameters are in agreement with EOS of strange quark matter***.
- In the very near future, models with other chemical compositions will be fitted.


The end
Frequency (Hz)
370
368
366
364
362
360
358
3x10^4
2x10^4
1x10^4
counts/sec
0
5
10
15
20
25
30
R [km]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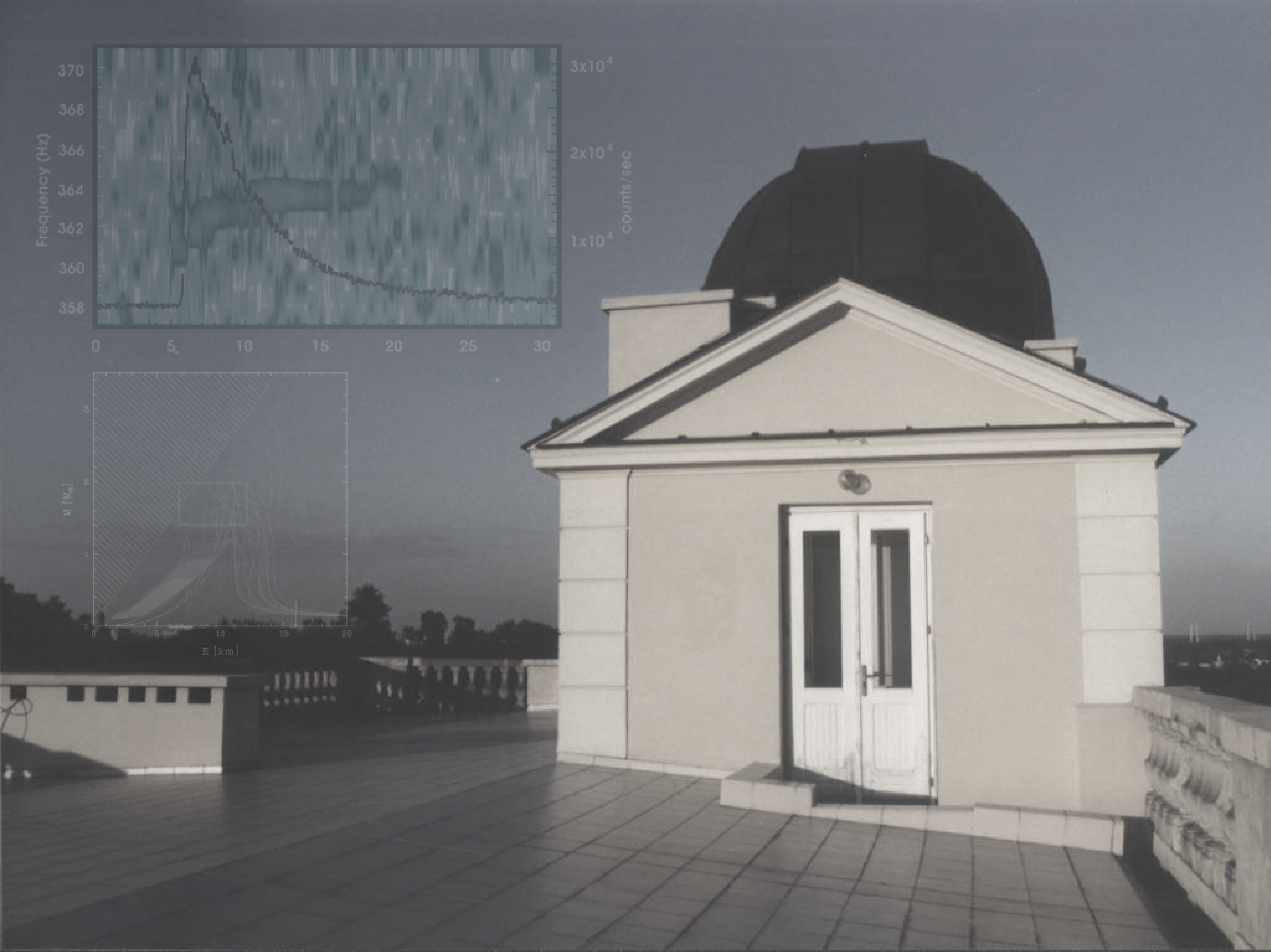
M [M⊙]
R [km]



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R [km]

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:

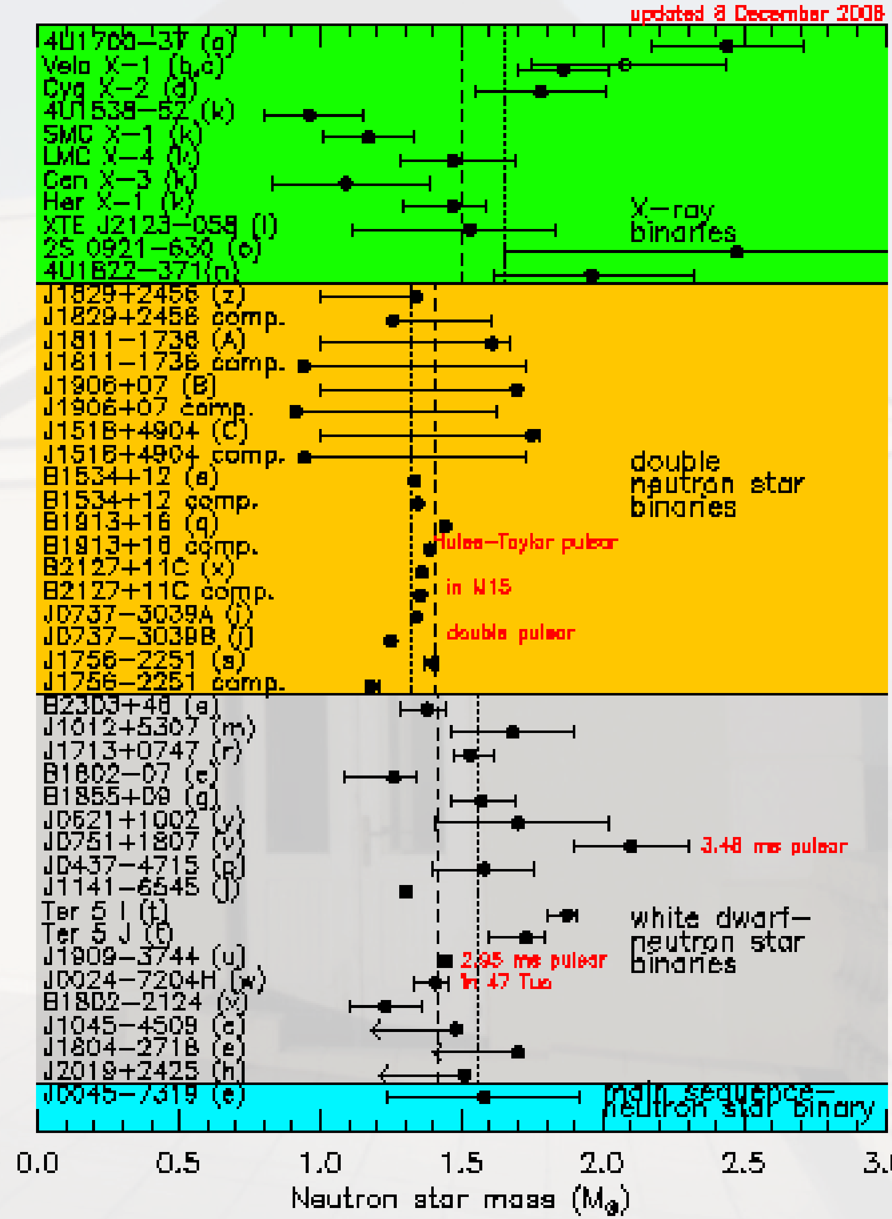
$$M = \frac{z^2 c^4}{4g\,G} \times \frac{(2+z)^2}{(1+z)^4}$$

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

Masses of neutron stars in binary pulsars

Values of NS masses are strongly concentrated around 1.4 $M_\odot$.

Is it true for other classes of compact objects?



Lattimer & Parkash (2006)

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.