X線バースター観測による
原子核飽和パラメータの制限

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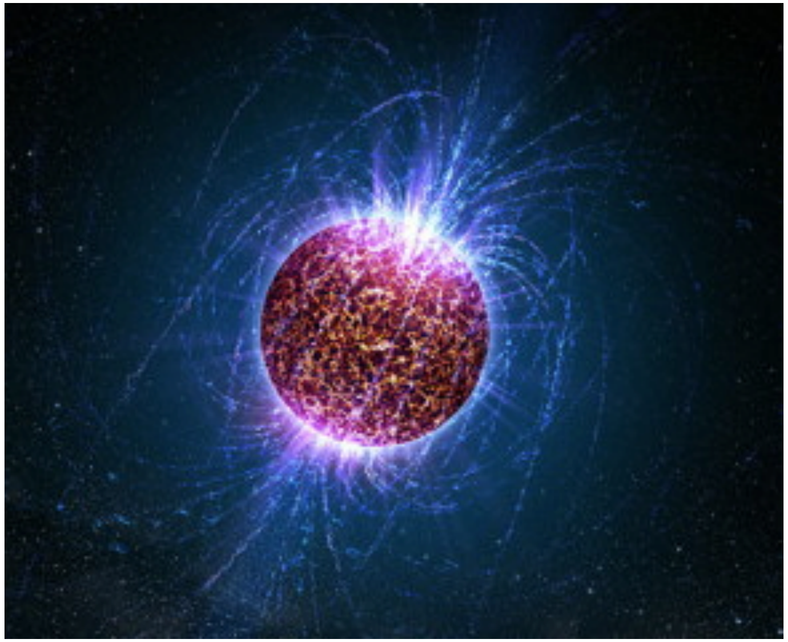
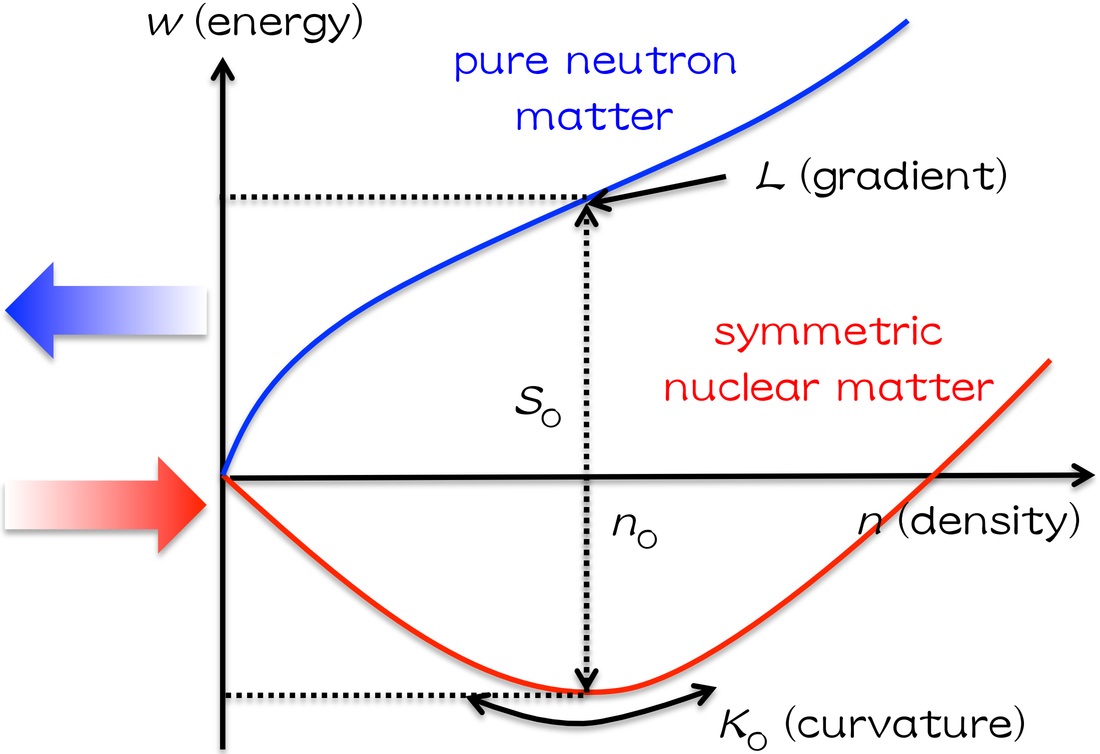
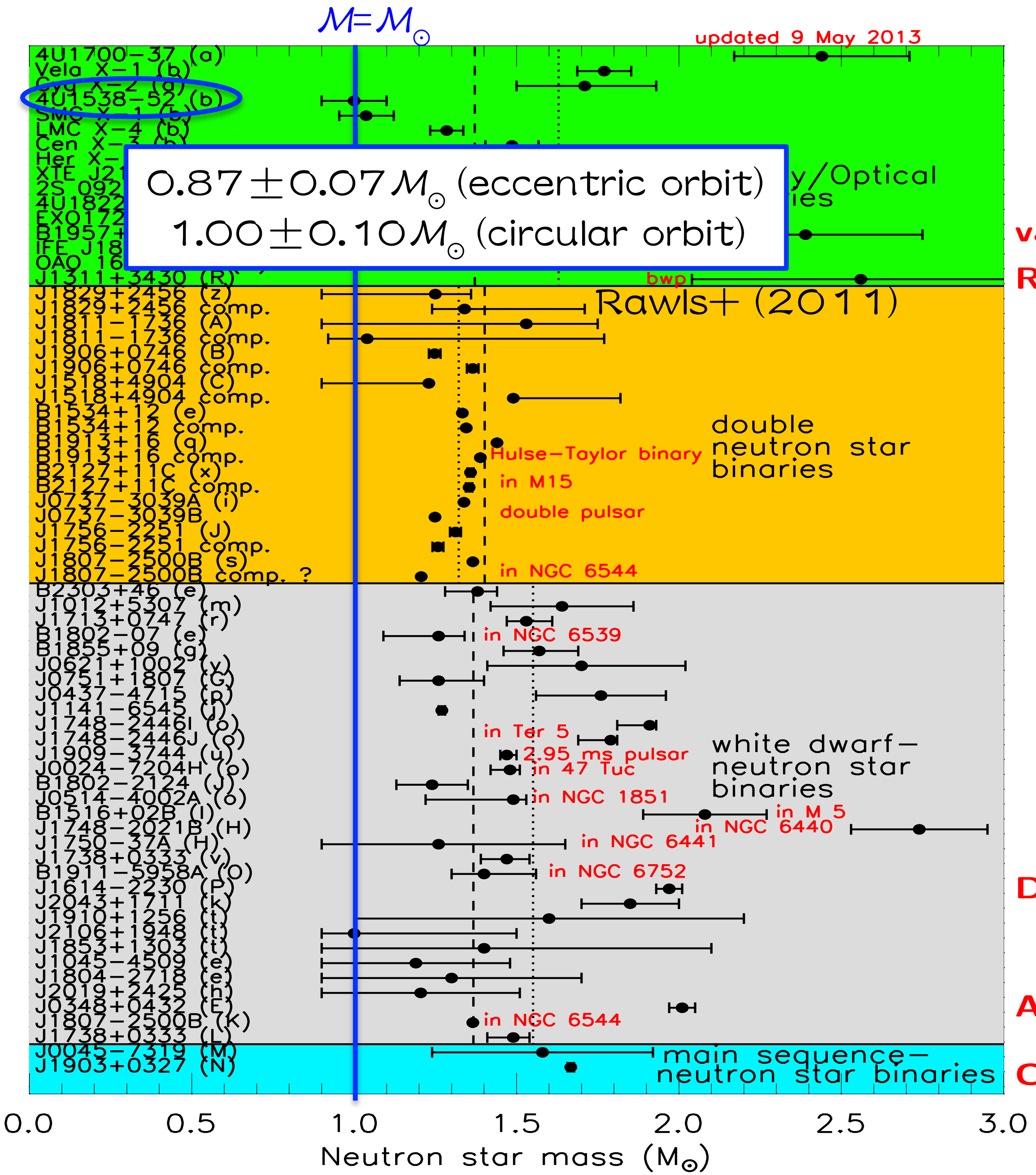
NS - EOS





- physics in NS crust
- low-mass NS



vanKerkwijk 2010

Romani et al. 2012

Demorest et al. 2010

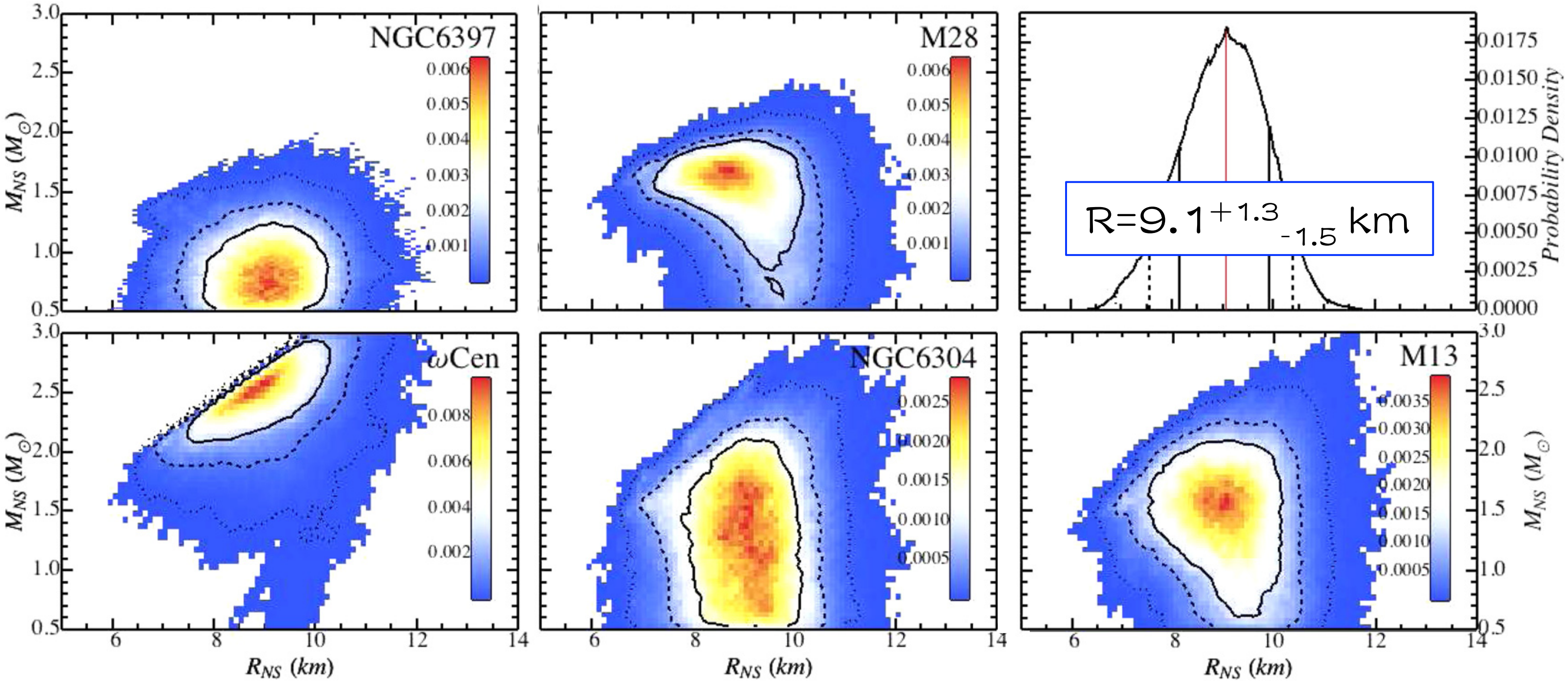
Antoniadis et al. 2013

Champion et al. 2008

Lattimer 2013

observations of NSs

- candidates of <u>low-mass NSs</u> have been also discovered in binary system (Lattimer & Prakash 2011)
- radiation radius of X-ray source (Rutledge+ 2002)
  e.g.) R_∞ = 14.3±2.1km : CXOU 132619.7-472910.8 in omega Cen
- M & R from thermal spectra from quiescent low-mass X-ray binaries (Guillot+ 2013; Lattimer & Steiner 2013)



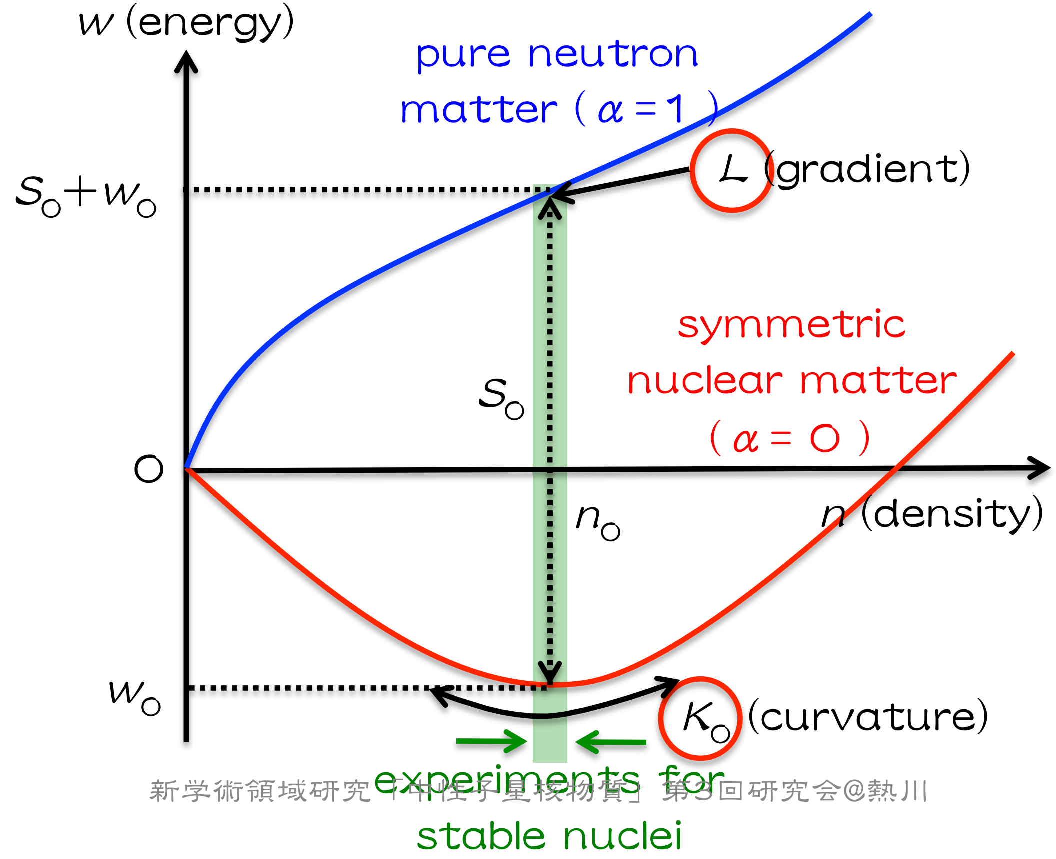
Guillot+ 2013

EOS near the saturation point

- Bulk energy per nucleon near the saturation point of symmetric nuclear matter at zero temperature;

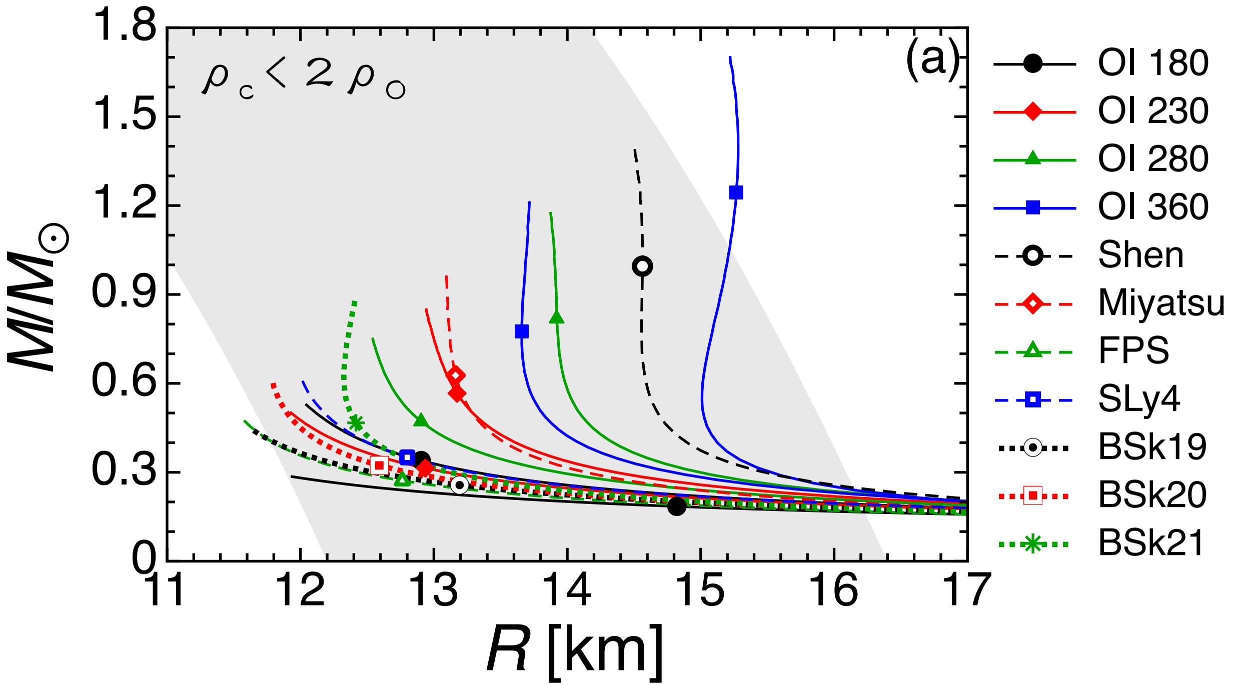
incompressibility / symmetry parameter

$$w = w_0 + \frac{K_0}{18n_0^2}(n-n_0)^2 + \left[S_0 + \frac{L}{3n_0}(n-n_0)\right]\alpha^2$$



MR relations

- NS models are constructed with various sets of K_0 & L

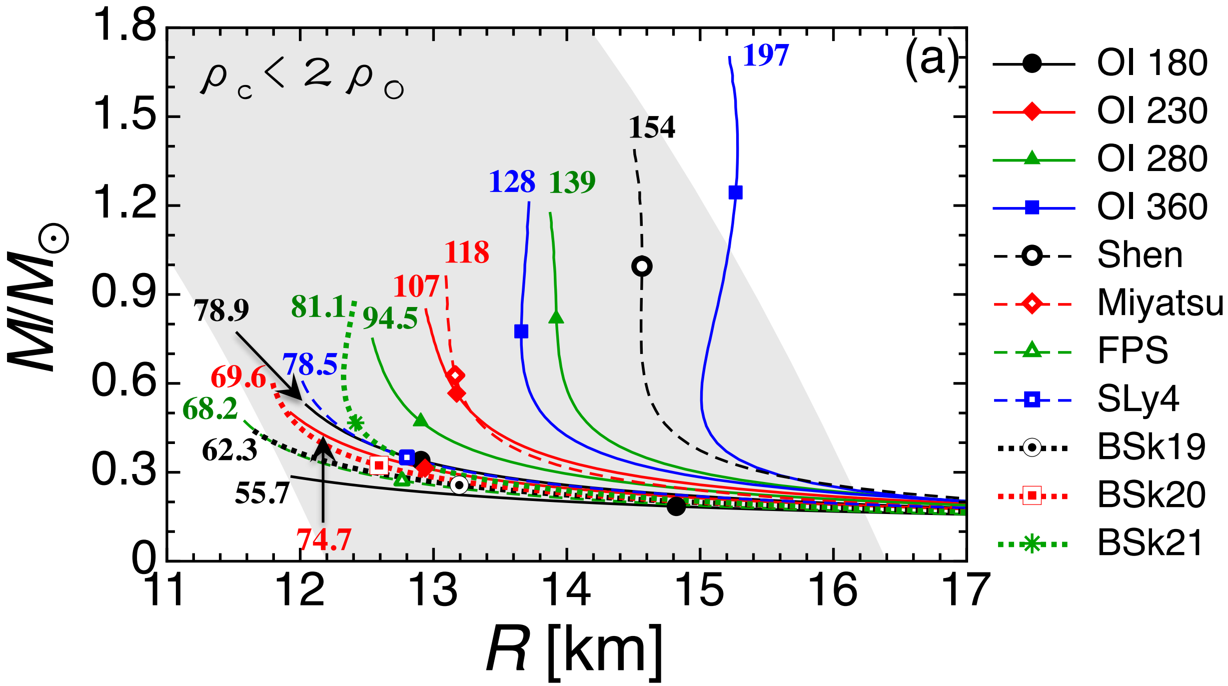


EOS	K_0 (MeV)	L (MeV)
OI-EOS	180	31.0
	180	52.2
	230	42.6
	230	73.4
	280	54.9
	280	97.5
	360	76.4
	360	146.1
Shen	281	114
Miyatsu	274	77.1
FPS	261	34.9
SLy4	230	45.9
BSk19	237	31.9
BSk20	241	37.4
BSk21	246	46.6

MR relations

- NS models are constructed with various sets of K_0 & L
- We can find the specific combination of K_0 & L describing the low-mass NSs,

$$\eta = (K_0 L^2)^{1/3}$$



EOS	K_0 (MeV)	L (MeV)	η (MeV)
OI-EOS	180	31.0	55.7
	180	52.2	78.9
	230	42.6	74.7
	230	73.4	107.4
	280	54.9	94.5
	280	97.5	138.6
	360	76.4	128.1
	360	146.1	197.3
Shen	281	114	154.0
Miyatsu	274	77.1	117.7
FPS	261	34.9	68.2
SLy4	230	45.9	78.5
BSk19	237	31.9	62.3
BSk20	241	37.4	69.6
BSk21	246	46.6	81.1

how to determine R

- Unlike M, R is generally much more difficult to determine
- Thermal emission from NS surface must be one of the good chances to obtain the information associated with R.
  - thermonuclear X-ray bursts at NS surfaces
  - photospheric radius expansion
  - quiescent low-mass X-ray binaries

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how to determine (M, R) 1

- Assuming that Eddington limit reaches at the stellar surface…
- Eddington luminosity

$$L_{\mathrm{Edd}} = \frac{4\pi GMc}{\kappa_e}(1+z) = 4\pi R^2 \sigma_{\mathrm{SB}} T_{\mathrm{Edd}}^4 \qquad 1+z = (1-2GM/Rc^2)^{-1/2}$$

$\kappa_e = 0.2(1+X)\ \mathrm{cm^2\ g^{-1}}$ electron Thomson scattering opacity

X : hydrogen mass function

$$F_{\mathrm{Edd}} = \frac{L_{\mathrm{Edd},\infty}}{4\pi D^2} = \frac{GMc}{\kappa_e D^2}\frac{1}{1+z} \qquad L_\infty = \frac{L}{(1+z)^2}$$

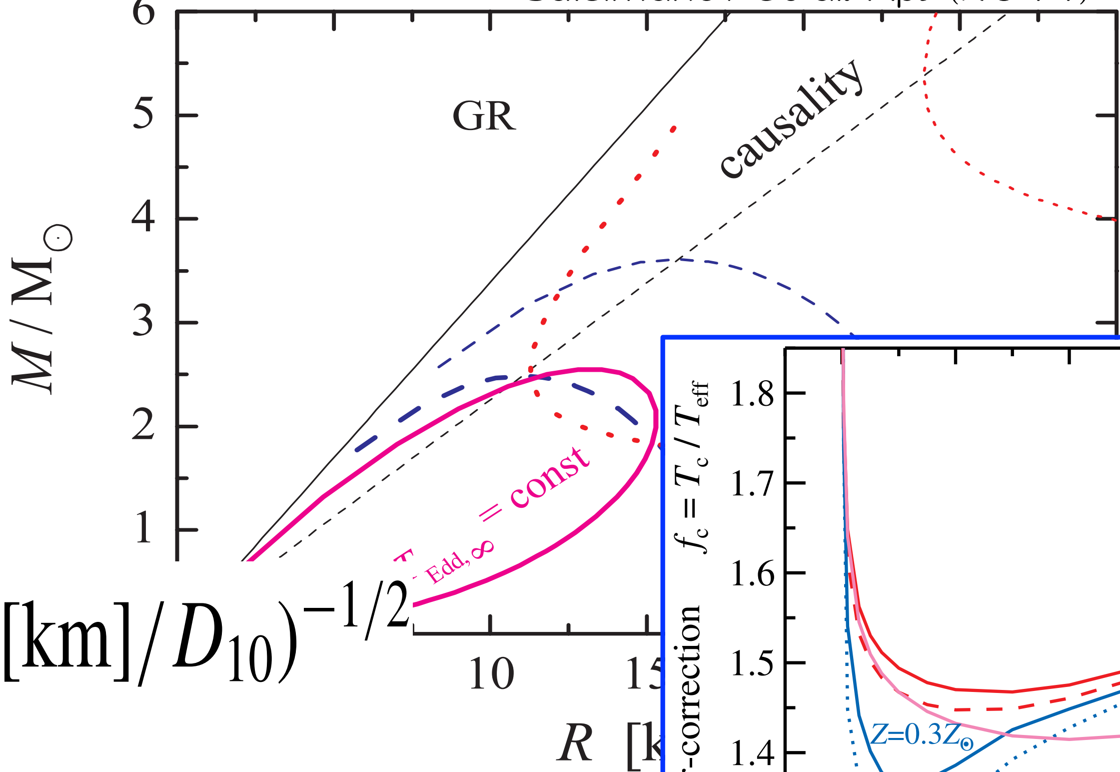
observed Eddington flux

- X depends on an atmosphere model
  - pure hydrogen: X = 1
  - pure helium: X = 0
  - solar H/He + Z=0.3$Z_\odot$: X = 0.74, where $Z_\odot$= 0.0134

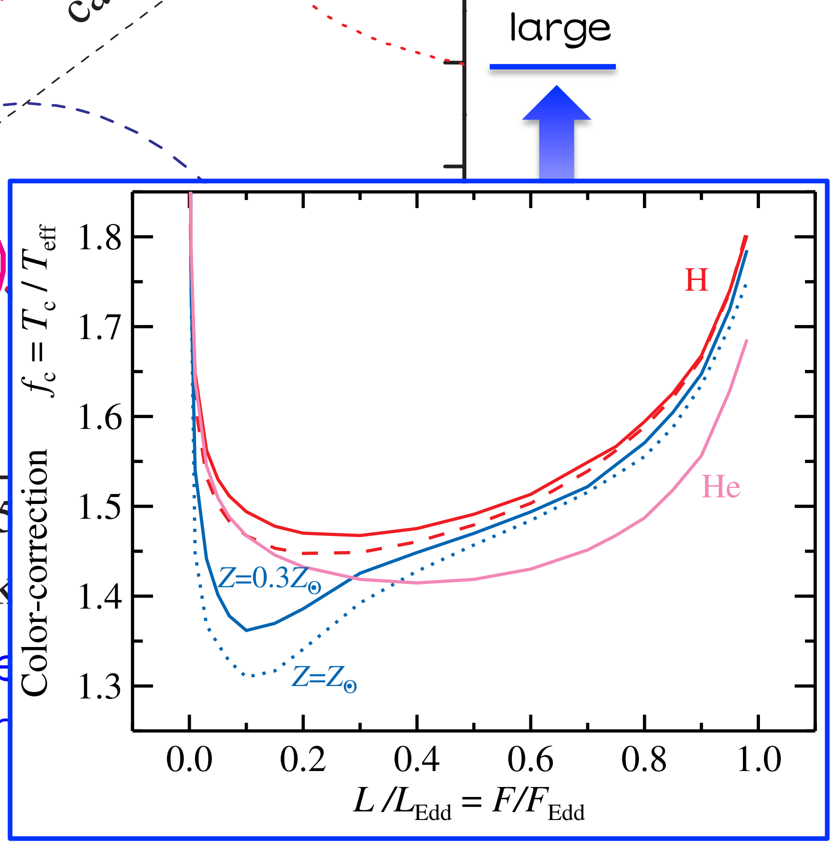
how to determine (M, R) 1

- if D would be known…

Suleimanov et al. ApJ (2011)



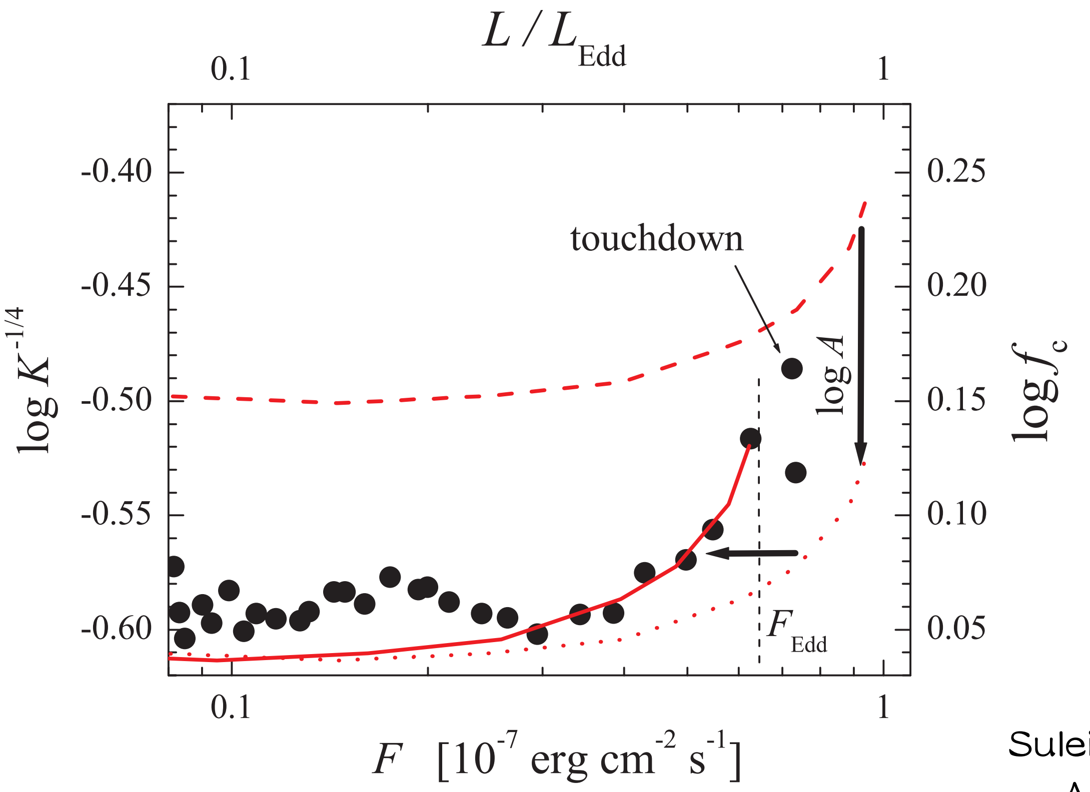
$$A = (R_\infty[\mathrm{km}]/D_{10})^{-1/2}$$



- BUT, the determination of the e
luminosity reaches Eddington lim
quite uncertain…

Suleimanov idea

- in order to minimize the theoretical uncertainties, the whole cooling track is adopt to determine the values of F_{Edd} & A

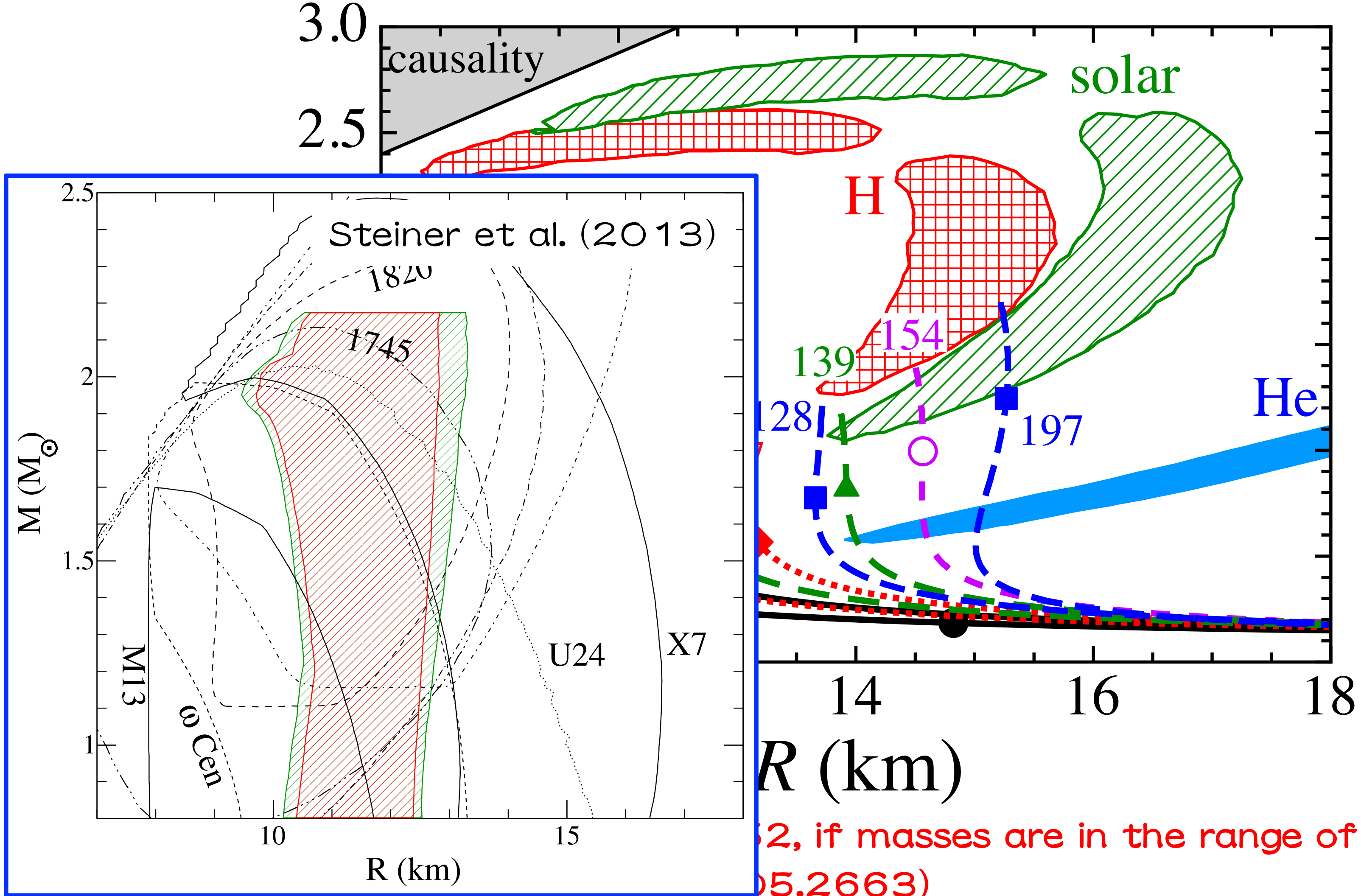


Suleimanov et al. ApJ (2011)

X-ray burster 4U 1724-307

- in the globular cluster Terzan 2
  - solar *H*/*He* + subsolar metal abundance $Z = 0.3Z_\odot$ (Ortolani et al. 97)
- Distance
  - $D = (5.3 - 7.7) \pm 0.6$ kpc (Kuchinski et al. 95, Ortolani et al. 97)
- data observed by Rossi X-ray Timing Explorer (RXTE)

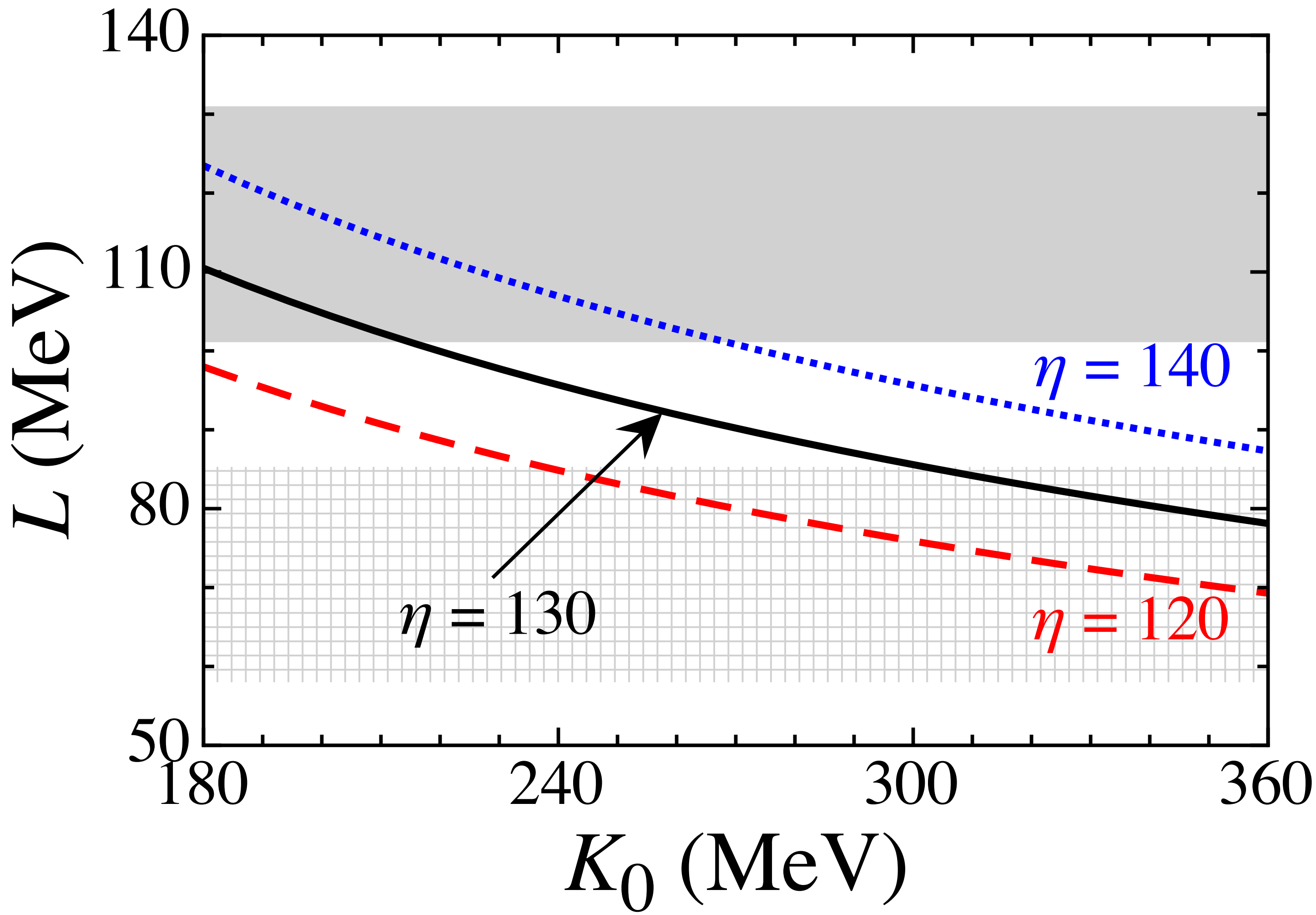
allowed region in MR relation



2, if masses are in the range of 1.2-

5.2663)

constraint on (L, K_0)



summary

- we have found a nice combination of nuclear saturation parameters, $\eta = (K_0 L^2)^{1/3}$, to describe low-mass neutron stars
- using the mass-radius relation obtained from the observations in X-ray burster 4U 1724-307 by Suleimanov et al. (2011),
  we show a possibility to make a constraint on the nuclear saturation parameters
  - consistent with the constraints obtained from the QPO frequencies observed from the giant flares in soft-gamma repeaters