Similar global parameters, different interiors - how to distinguish between neutron stars?

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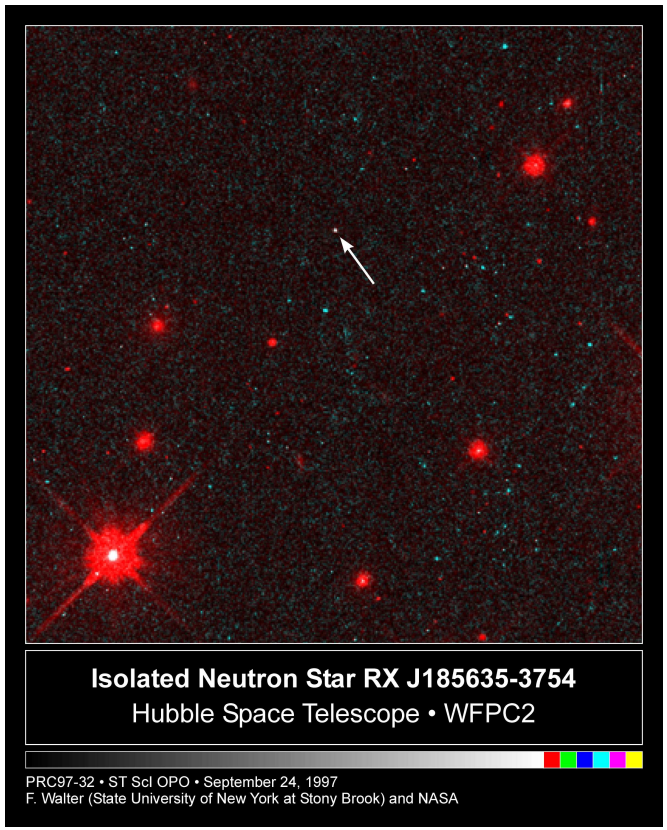
Outline

Observations

First direct look, in visible light, at alone neutron star, seen by NASA's Hubble Space Telescope.



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Potentially measured in the future:

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- Radius (redshifted: $R_{obs} = R(1+z)$)
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Indirectly:

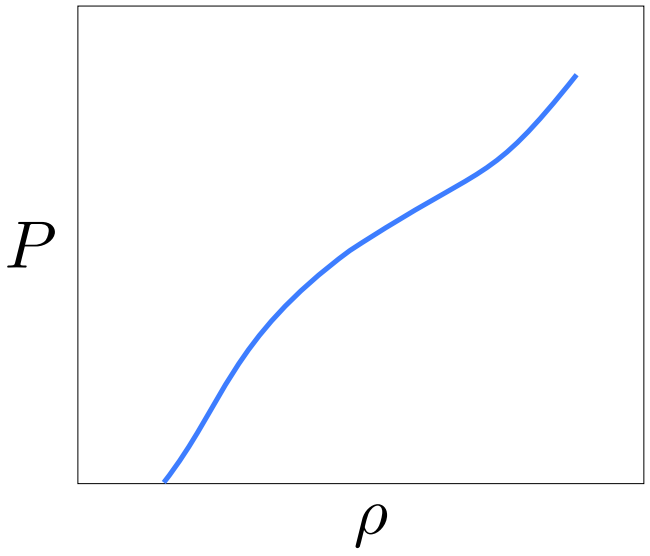
- Magnetic field (from spin and spin-down)

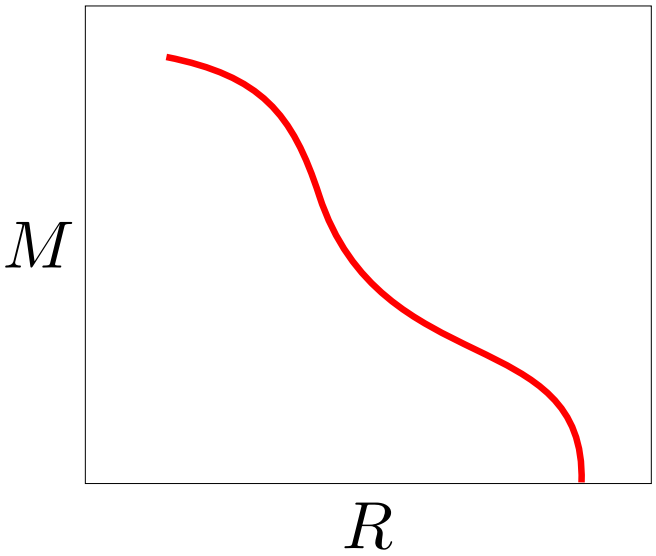
Potentially measured in the future:

- Moment of inertia ($I \propto MR^2$)
- Surface redshift ($z = \frac{1}{\sqrt{(1-\frac{2GM}{Rc^2})}} - 1$

EOS - M(R) relation

Establishing via observations M(R) relation for NSs is crucial to determine the equation of state (EOS) of dense matter.





Theory

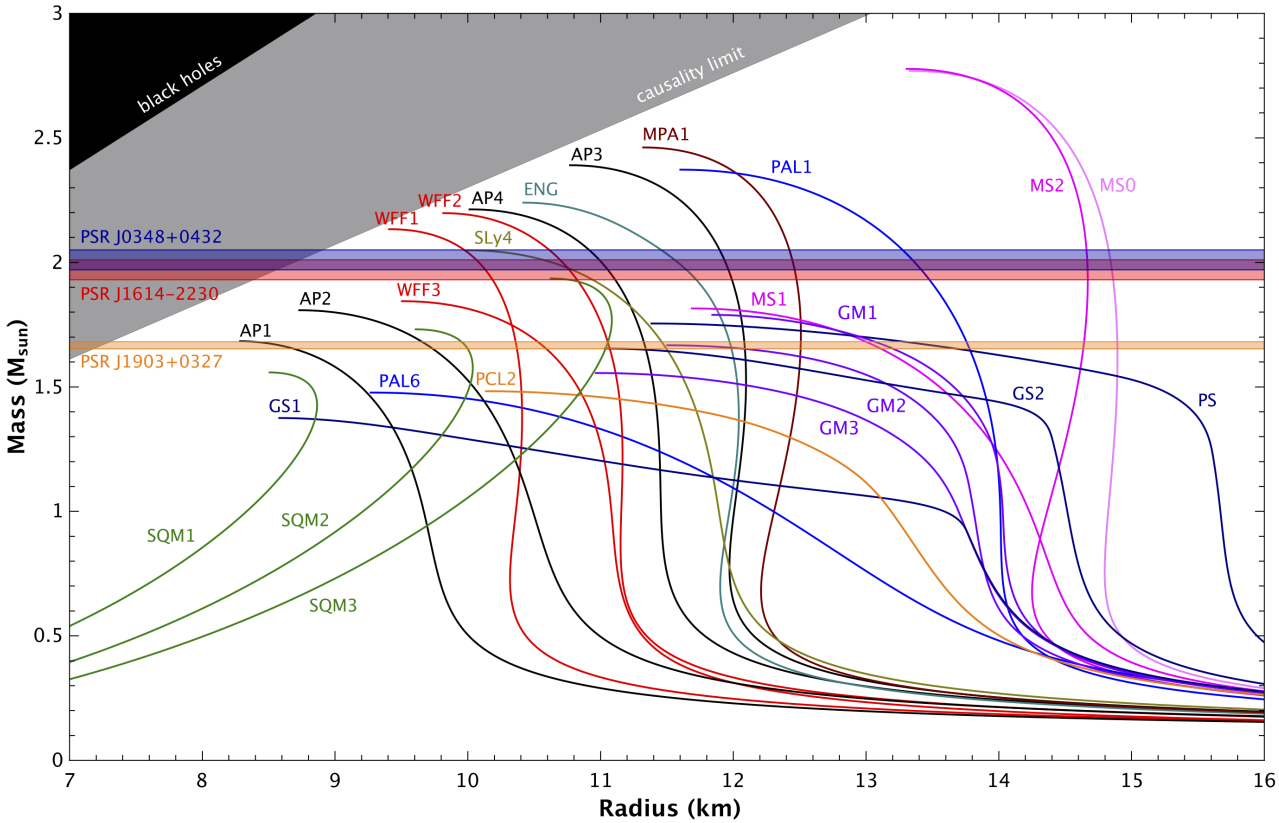


Figure created by Norbert Wex.

How to distinguish between neutron stars with similar $M(R)$ relation, but different interiors using current and future missions (and their observational errors)?

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Rotation(?)

Introduction

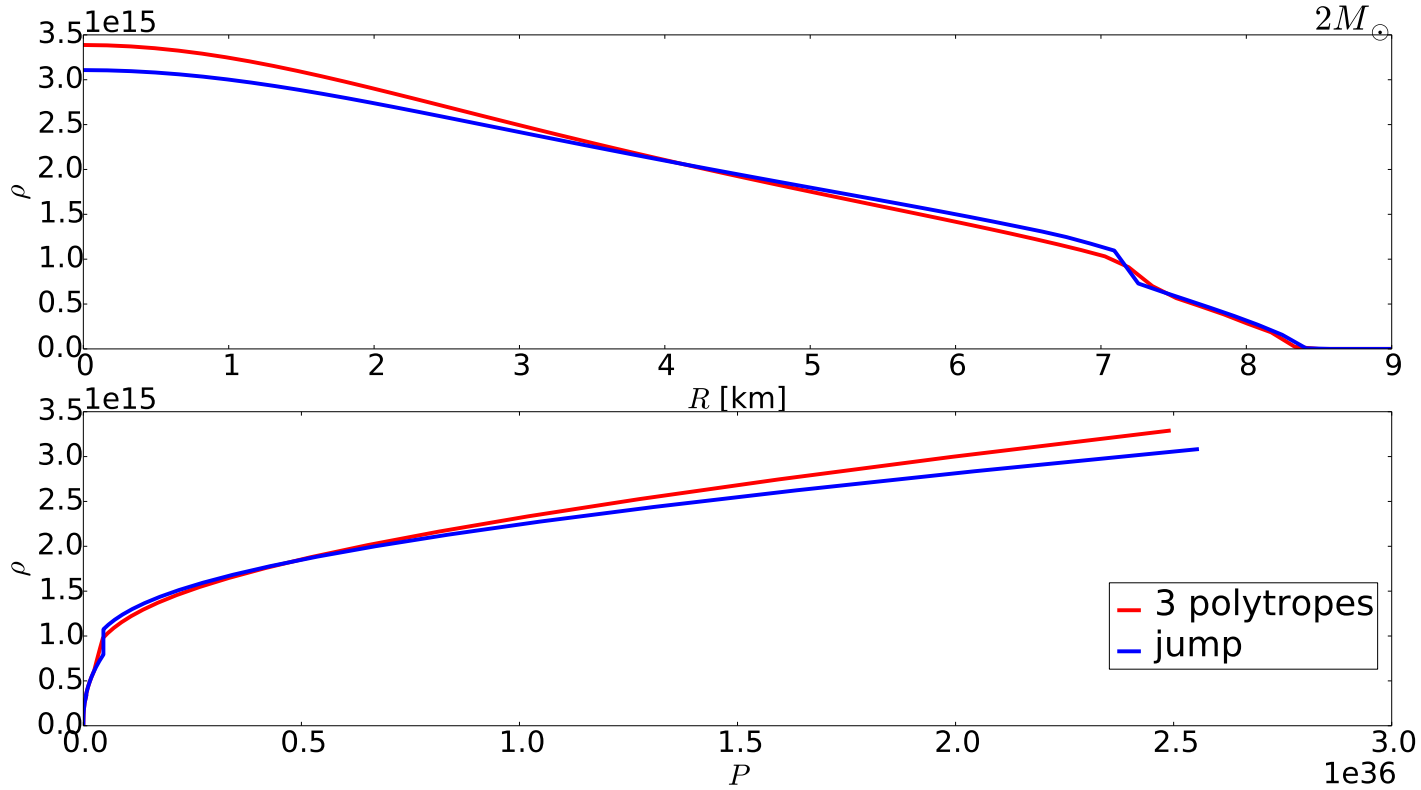
Two different NSs ($2M_\odot$):

- jump: 2 polytropes with density jump between them
- 3polytropes: 3 different polytropes (softened middle one)

+ crust - SLy4 model (Douchin & Haensel (2001))

$$P = \kappa_1 n^\gamma, \quad \rho = \frac{P}{\gamma} + n m_b c^2 \tag{1}$$

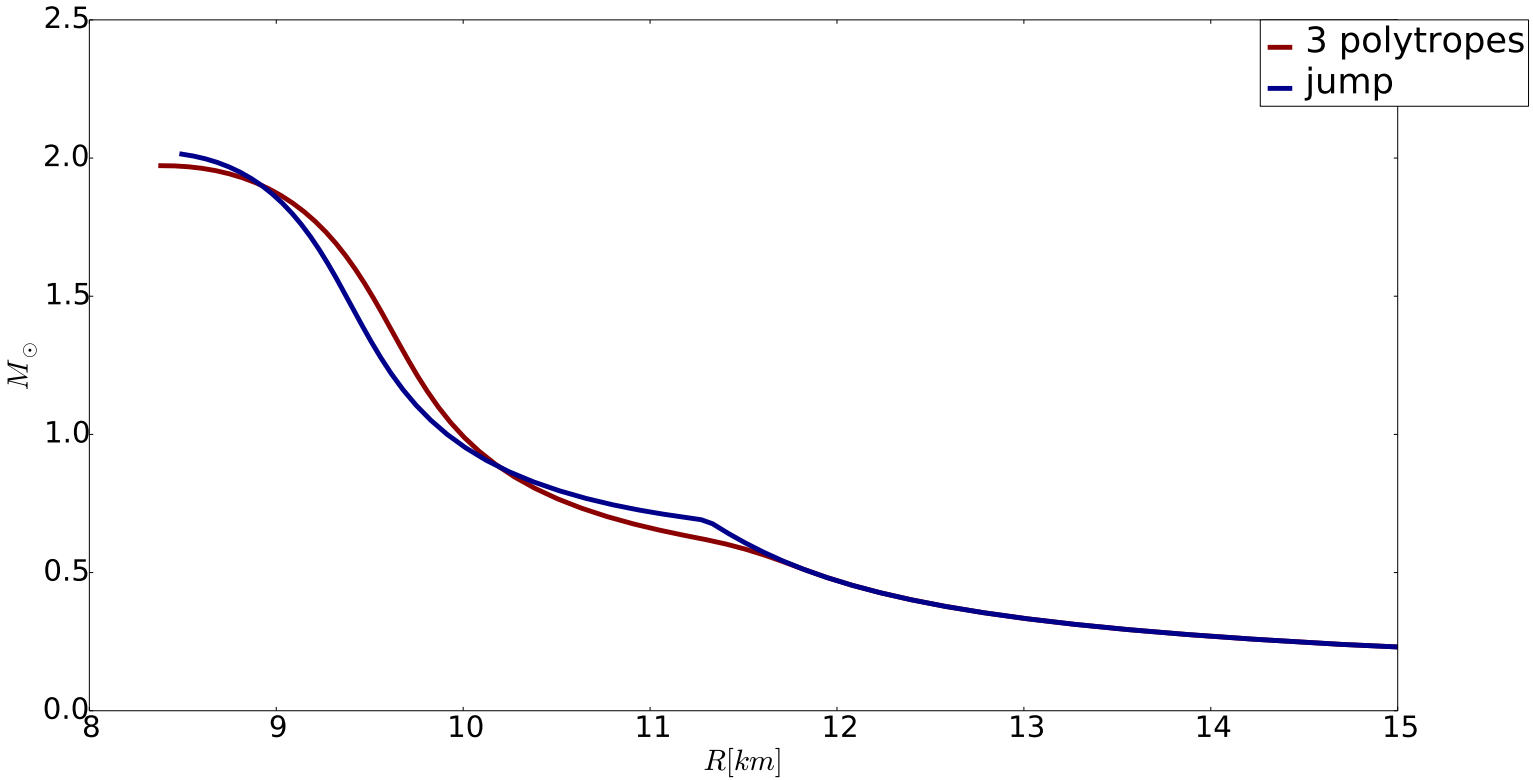
Introduction



$M(R)$ relation

Solving the Tolman-Oppenheimer-Volkoff (TOV) equation of hydrostatic equilibrium for a given equation of state (EOS), produces the family of non-rotating neutron-star models and the same time limits for their masses (M) and radii (R).

$M(R)$ relation



Future missions

ATHENA

The Advanced Telescope for High ENergy Astrophysics (ATHENA):

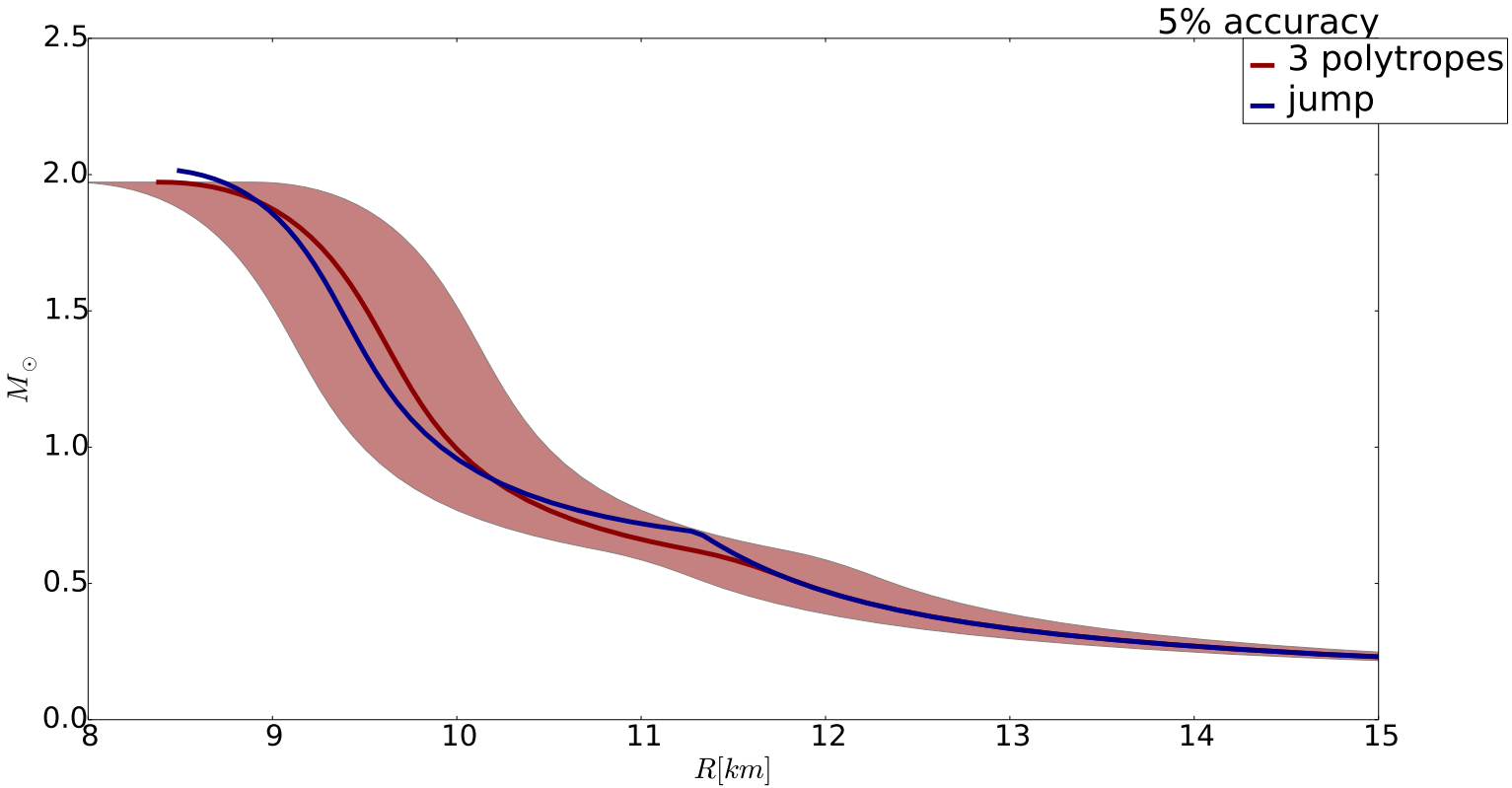
- planned X-ray telescope (launch date: 2028)
- measurements of R and M with an accuracy of a few %

NICER

The Neutron star Interior Composition Explorer (NICER):

- spectroscopy of NSs in soft X-rays (launch date: 2017)
- measurements of R with $<$ 10% precision

TOV solutions; 5% accuracy



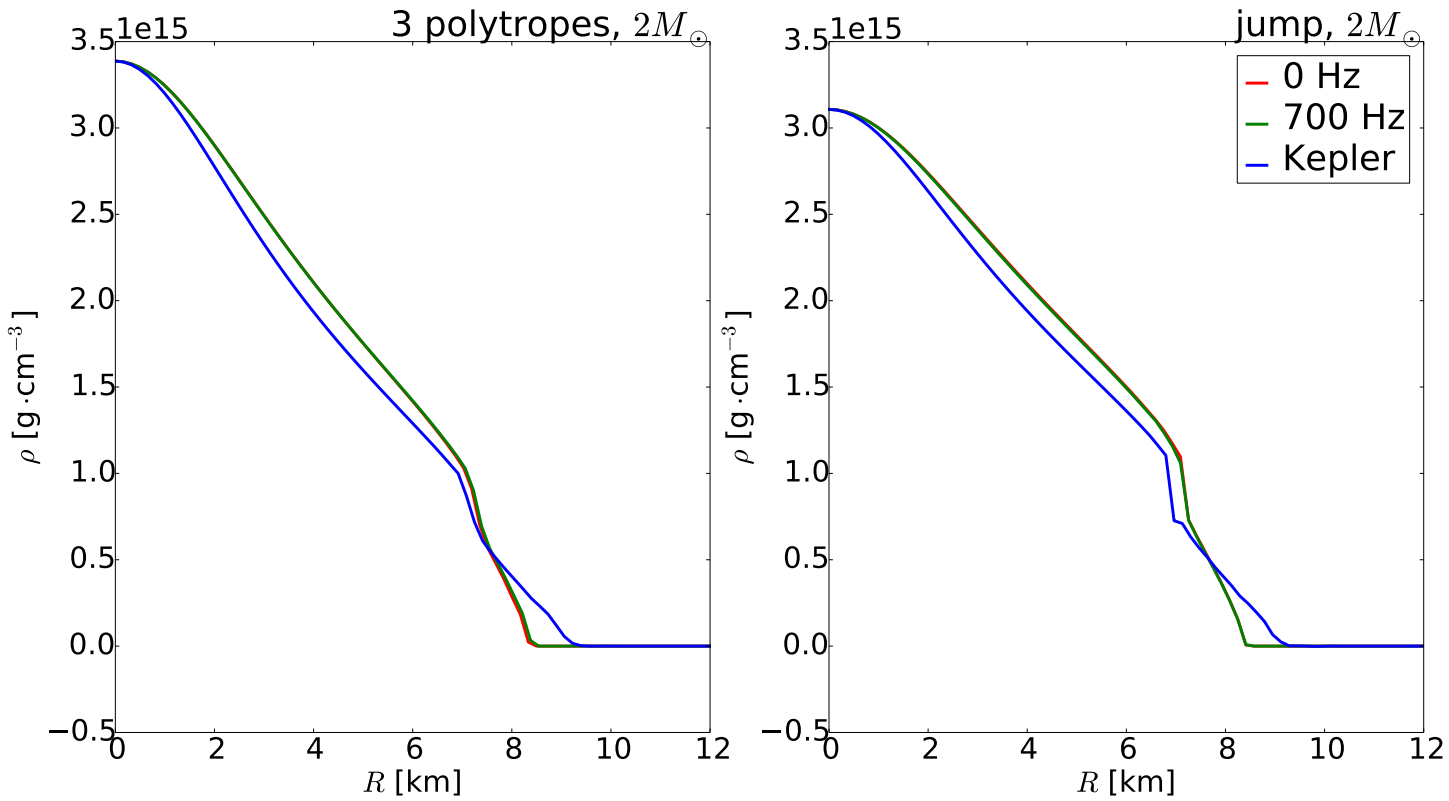
How to rotate stars?

Useful tool:

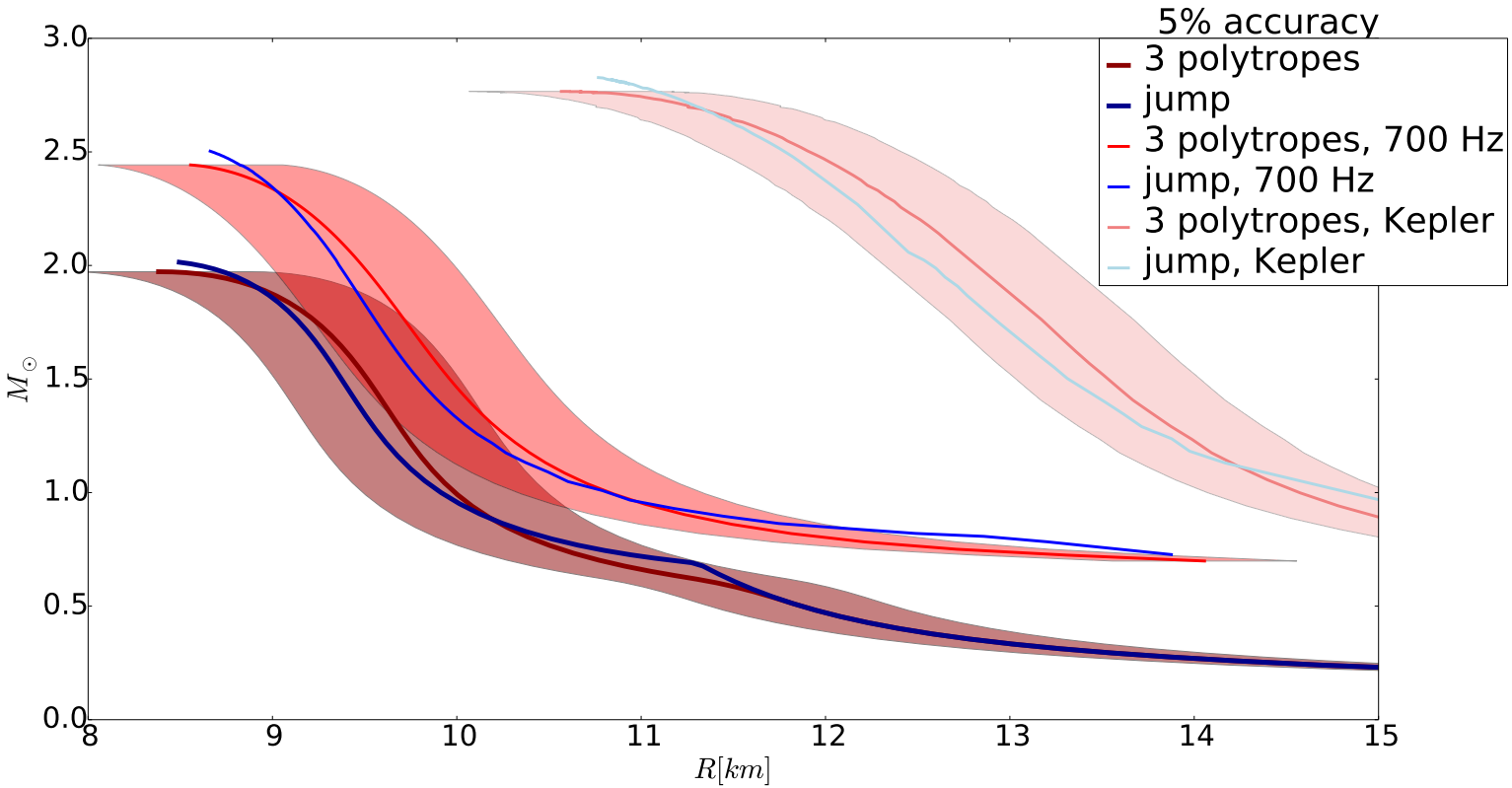
Langage Objet pour la RElativité NumériquE (LORENE) - set of C++ classes to solve problems arising in numerical relativity (solving partial differential equations by means of multi-domain spectral methods).

LORENE/nrotstar code - for rotating compact objects

Rotation


3 polytropes, $2M_\odot$
jump, $2M_\odot$
1e15
ρ [g·cm^{-3}]
R [km]
0 Hz
700 Hz
Kepler

M(R) relation; 5% accuracy



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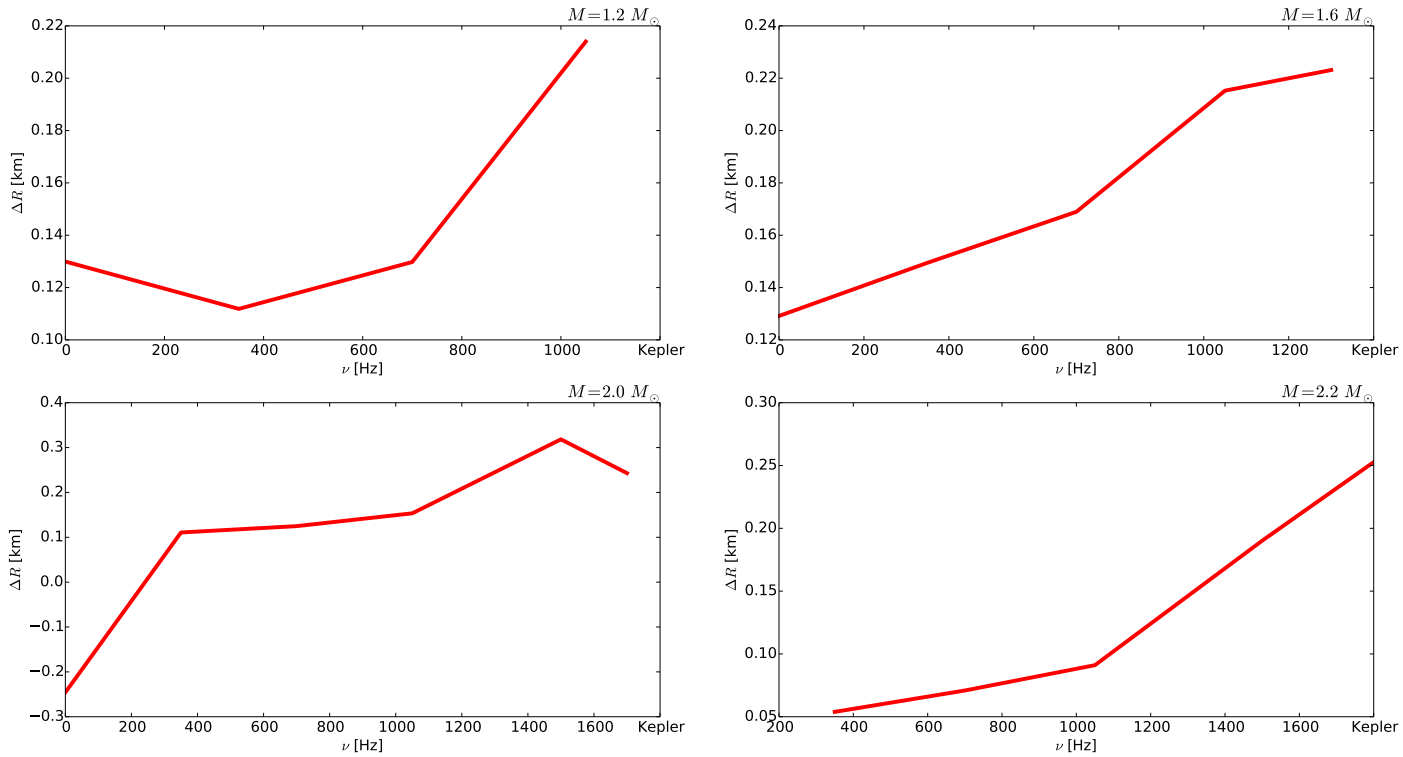
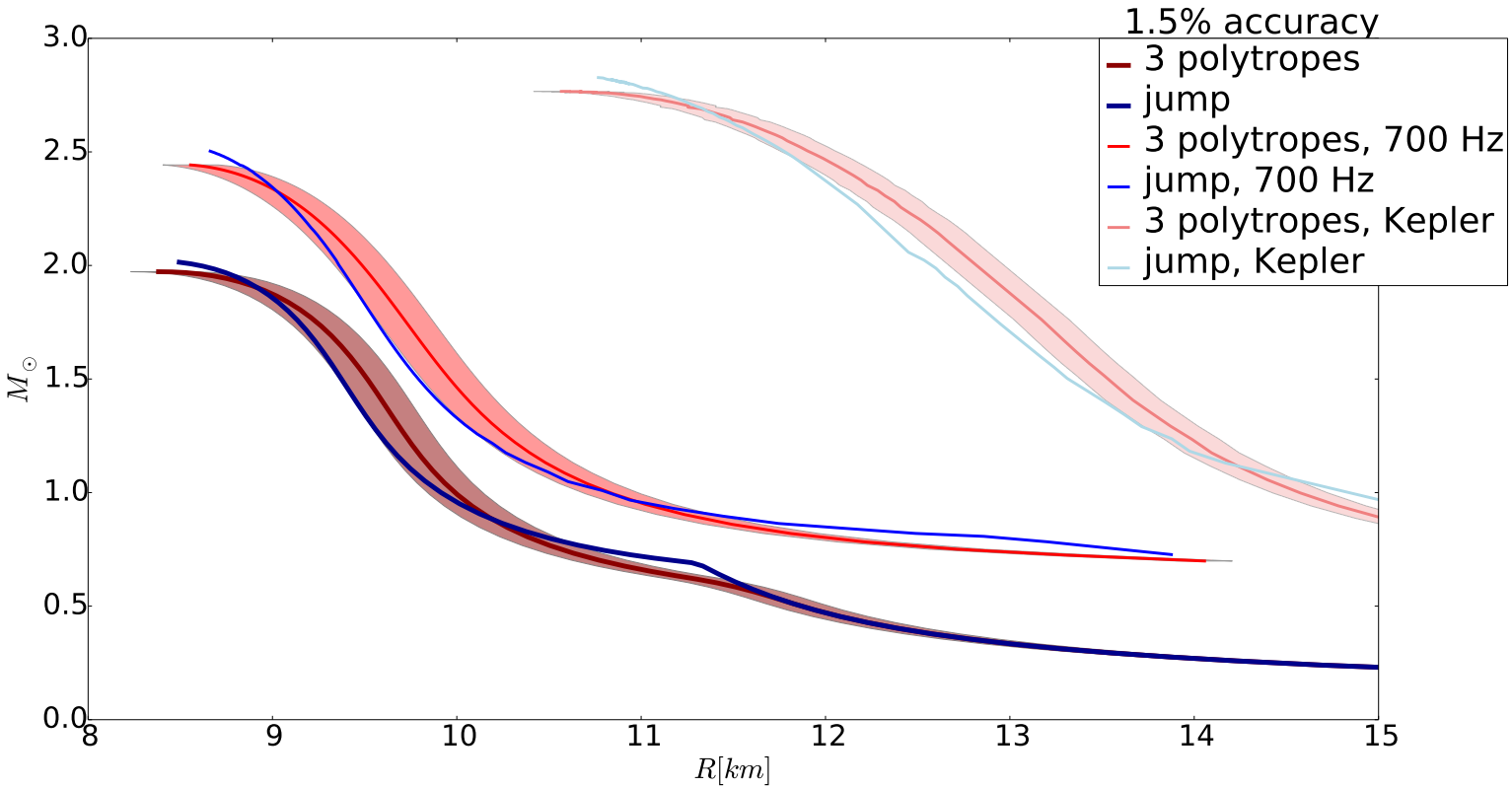


M(R) relation; 1.5% accuracy



Conclusions

- To distinguish between involved models, large frequencies and well observational accuracy are needed.

How to improve our results? - plans

- Pulsations/oscillations
- Observables related to the density (cooling)
- Gravitational waves
- ?

Bibliography

Douchin F. & Haensel P., 2001, A&A, 380, 151

Haensel P., Potekhin, A. Y., Yakovlev, D. G., 'Neutron Stars 1, Equation of State and Structure'

Ross, L.V., 'New Research on Astrophysics, Neutron Stars and Galaxy Clusters'

... and references therein

The End

THANK YOU FOR YOUR ATTENTION