UNIVERSITY
OF WARSAW

STABILITY OF HYPERMASSIVE NEUTRON STARS AGAINST A PROMPT COLLAPSE

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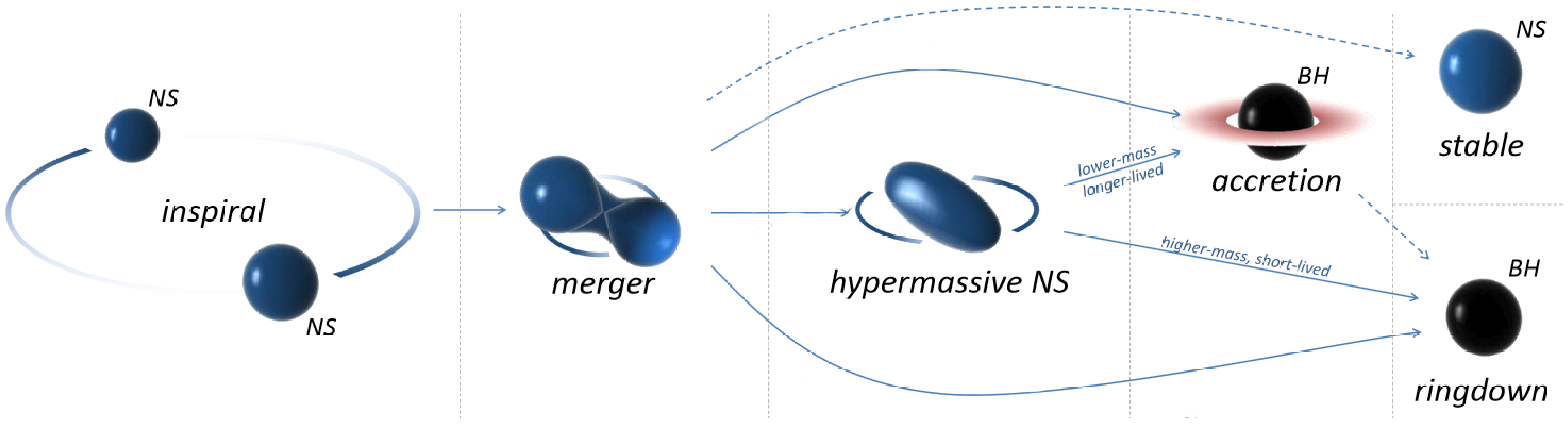
Astrophysical context

Differentially rotating remnants are produced in:

- Massive stellar core collapse
- Binary neutron star mergers



(Bartos, Brady, Marka 2013)

Outline

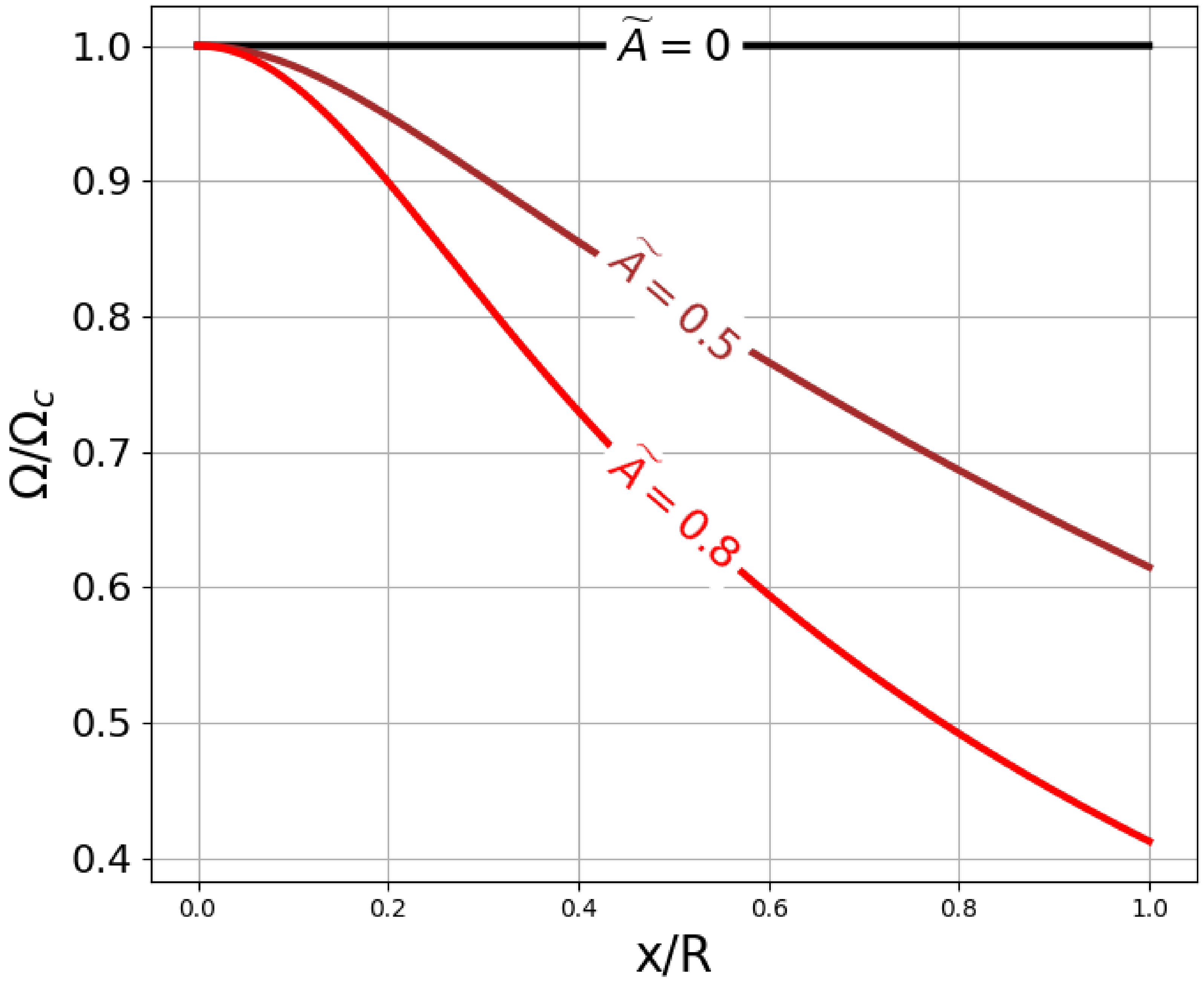
- Astrophysical motivation
- Stationary case
- Estimations of stability
- 2D simulations with CoCoNuT
- Plans for the future

Equilibrium configurations

- Axisymmetric stationary NS models with differential rotation (Ansorg, Gondek-Rosinska, Villain 2009)
- Polytropic EOS ($P = K\rho^2$)
- j-const (KEH) rotation law (Komatsu et al. 1989):

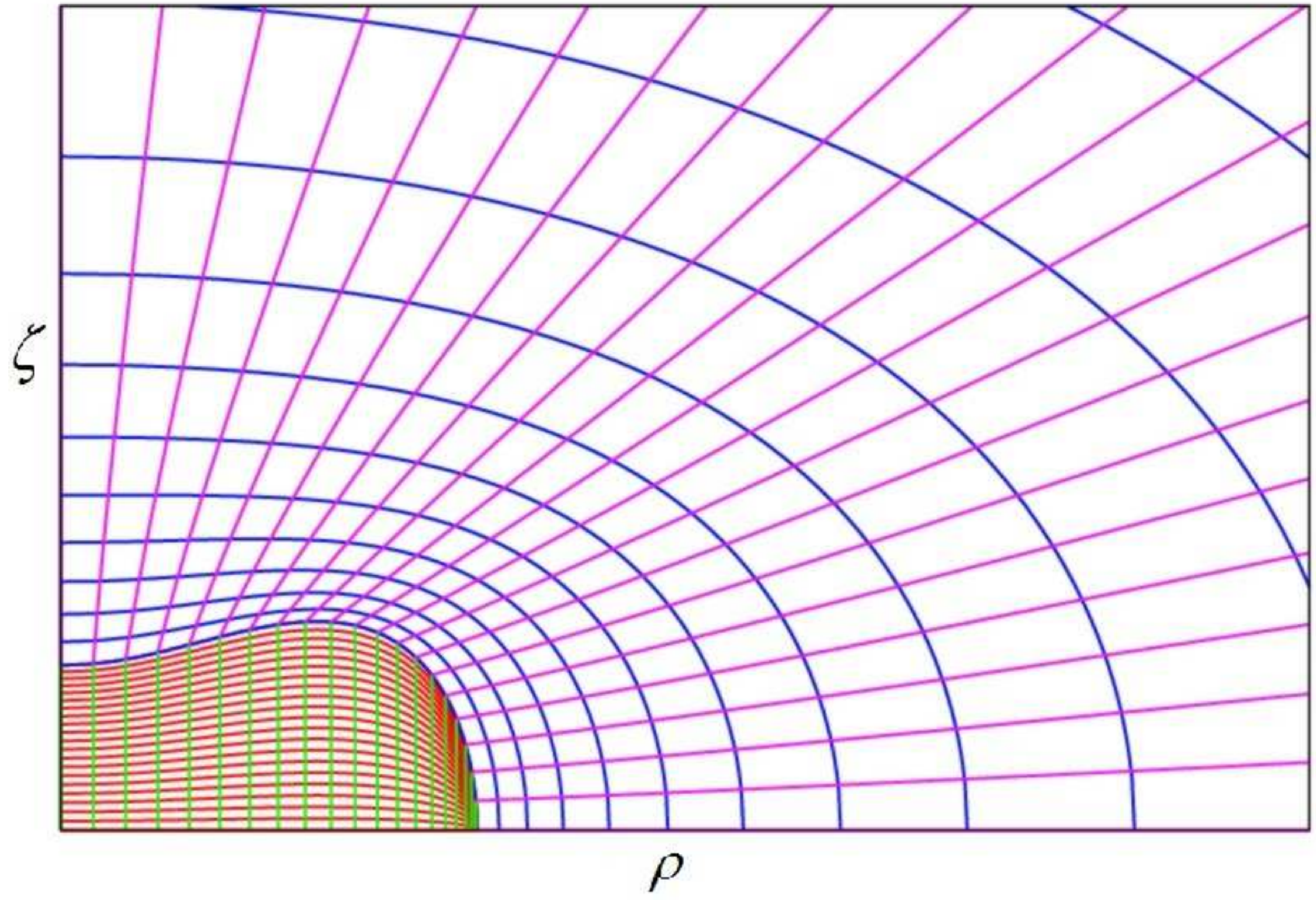
$$u^t u_\phi = F(\Omega) = A^2(\Omega_c - \Omega) \qquad \widetilde{A} = \frac{r_e}{A}$$

- consistent with core-collapse remnant



Rotation profiles in equatorial plane for different values of Ã

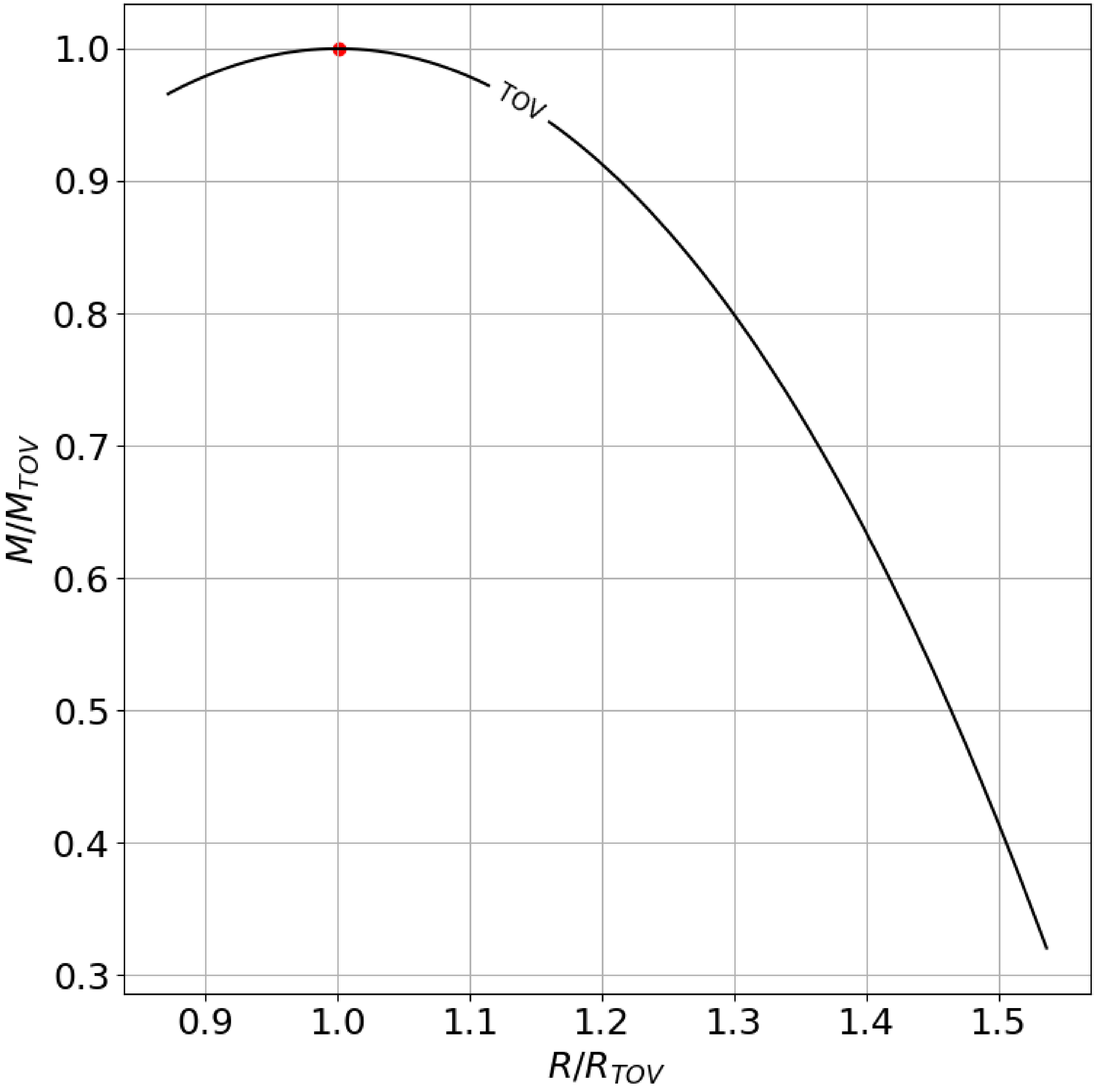
Equilibrium configurations - numerical scheme



- **FlatStar** numerical code
- Spectral, multidomain method
- High accuracy
- Cyllindrical coordinates
- Works for highly flattened configurations

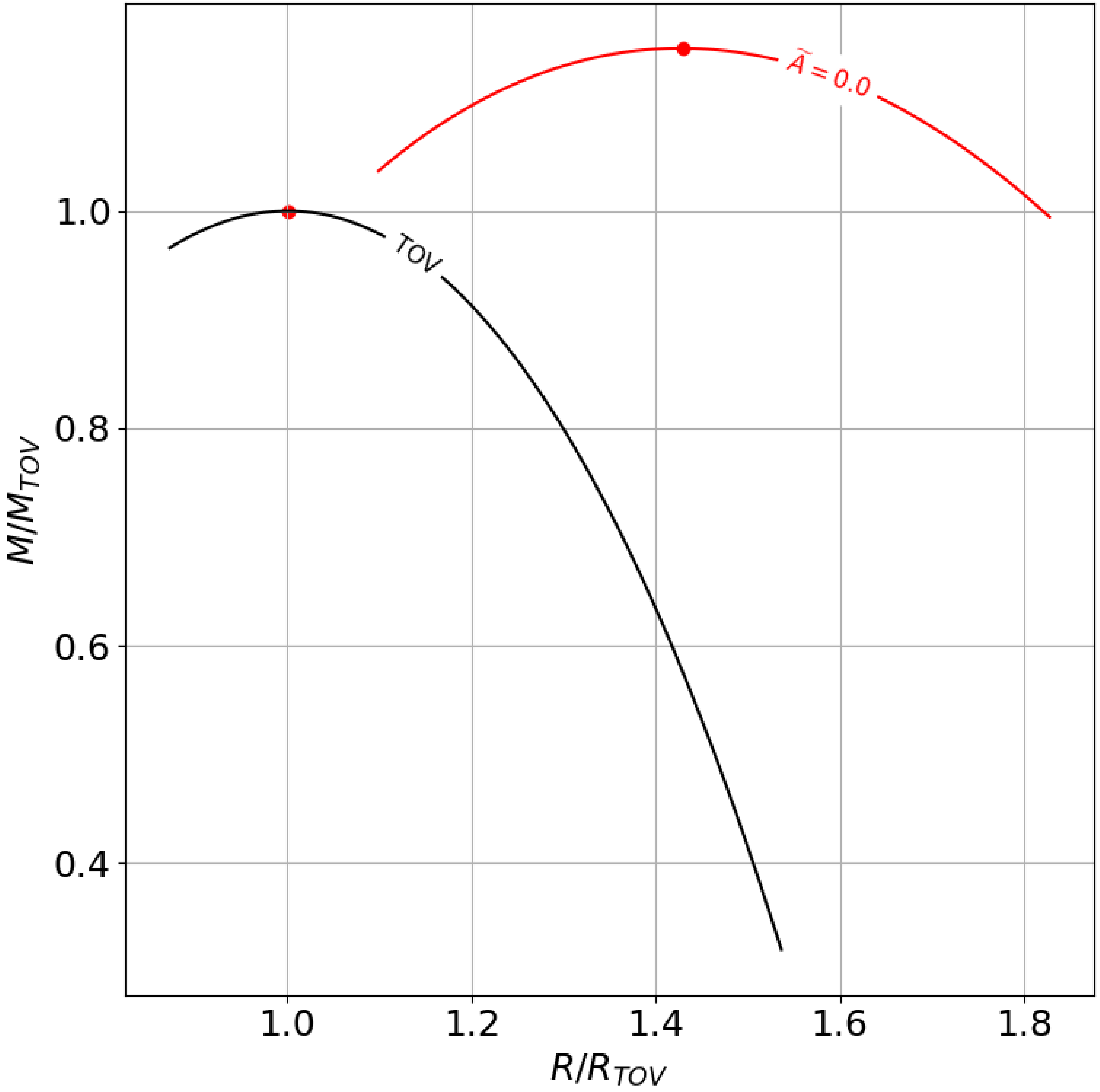
Maximum mass

- Limit of mass exists for non-rotating NS
- 2 - 2.5 solar masses



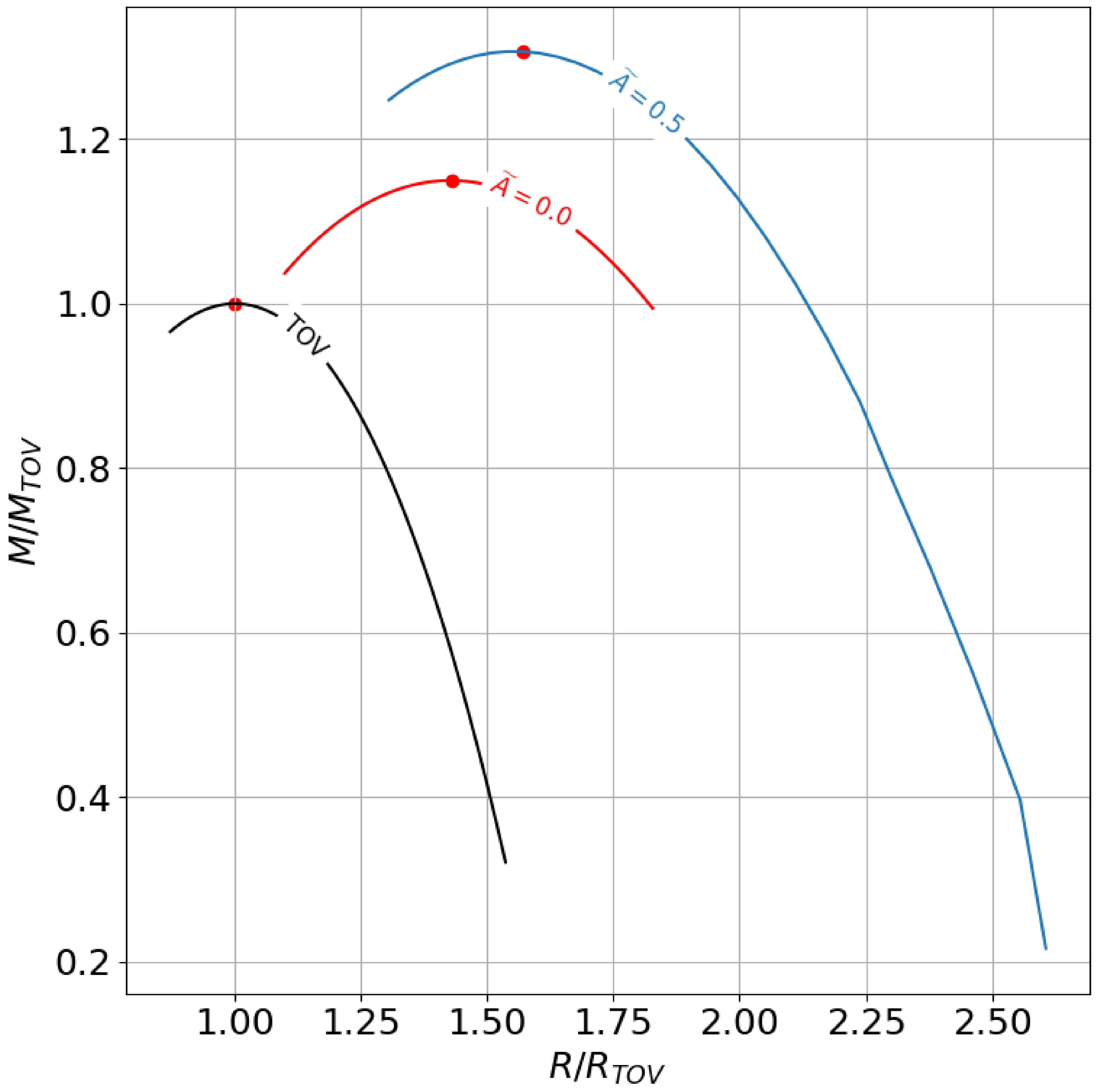
Maximum mass

- Limit of mass exists for non-rotating NS
- **Rigid rotation** can increases the limit by ~20%



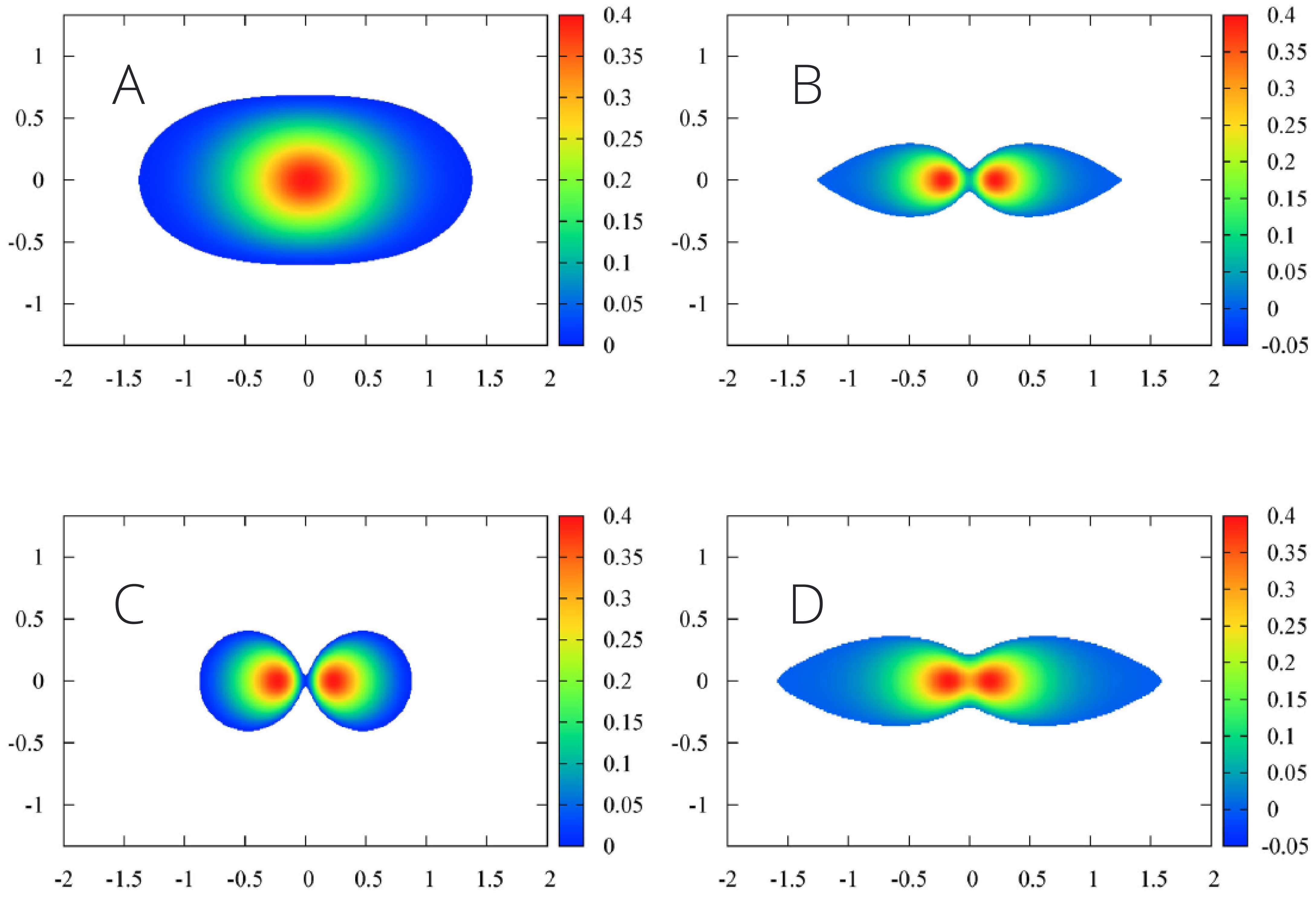
Maximum mass

- Limit of mass exists for non-rotating NS
- **Rigid rotation** can increases the limit by ~20%
- **Differential rotation** increases the limit even further. By how much?



Different types of solutions

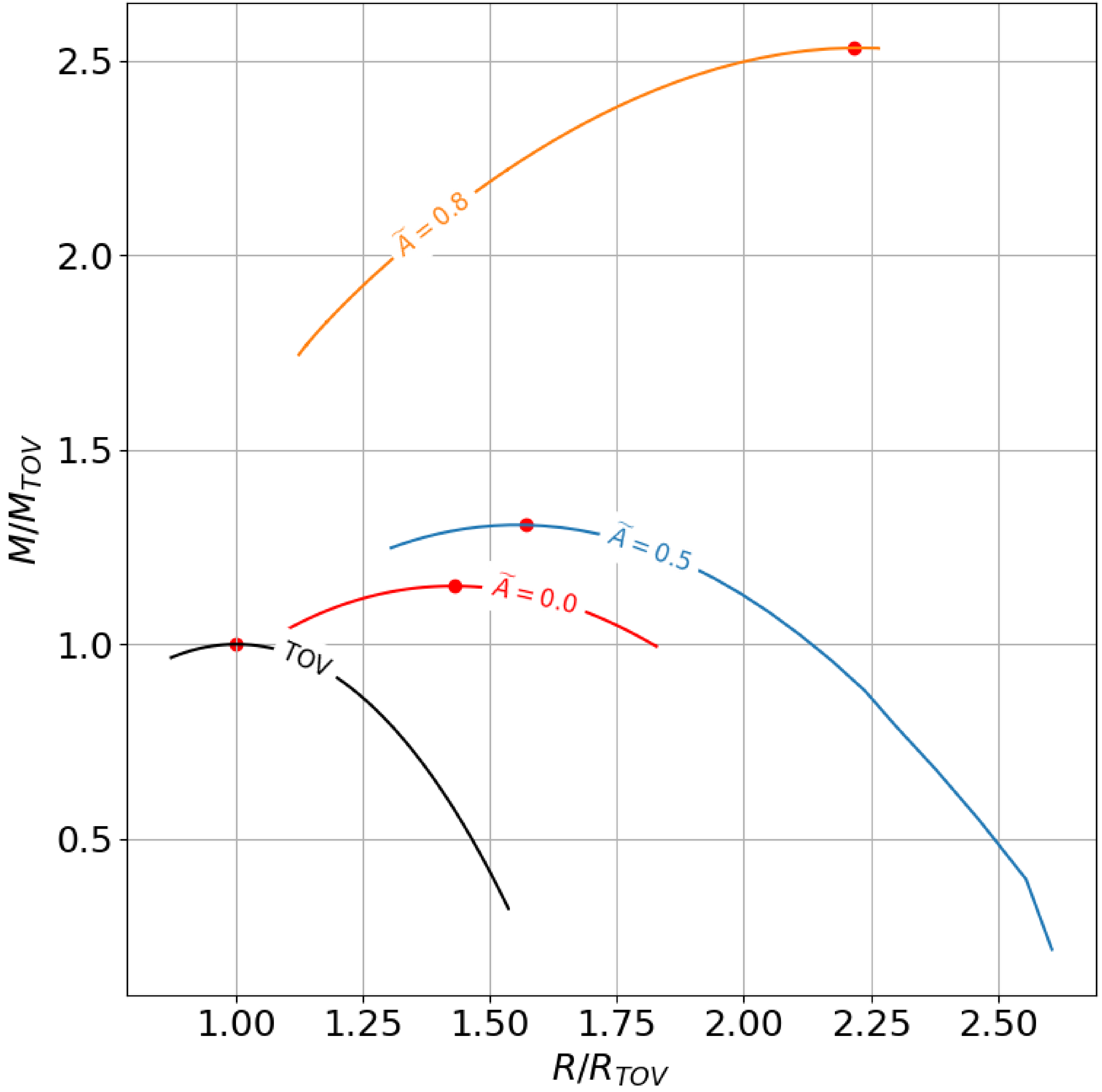
- Four different types of solutions (Ansorg, Gondek-Rosinska, Villain 2009)
- Quasi-toroidal shapes possible in types B, C and D



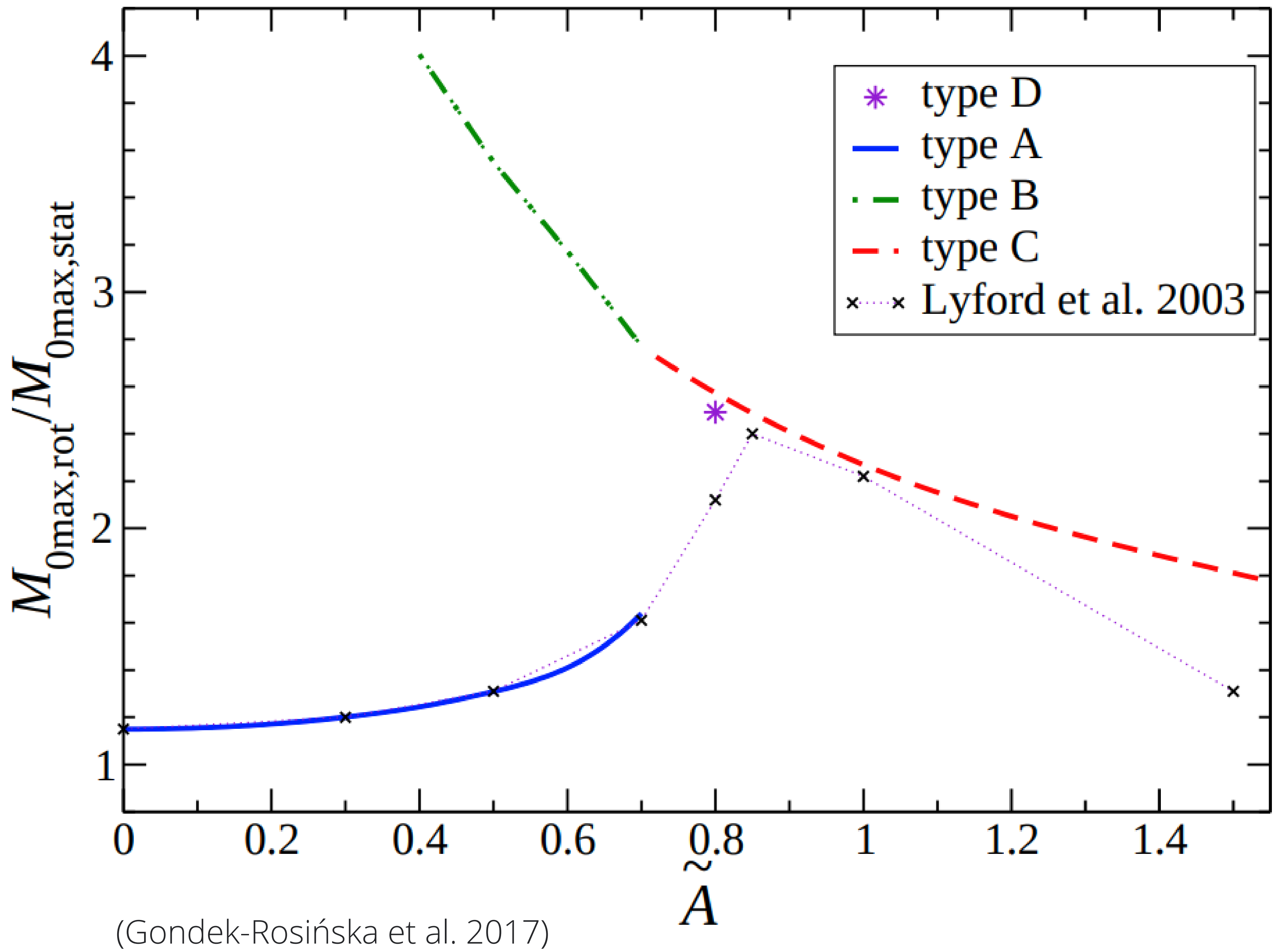
(Studzinska et al. 2016)

Maximum mass

- Limit of mass exists for non-rotating NS
- **Rigid rotation** can increases the limit by ~20%
- **Differential rotation** increases the limit even further
- More than 2 times the TOV limit



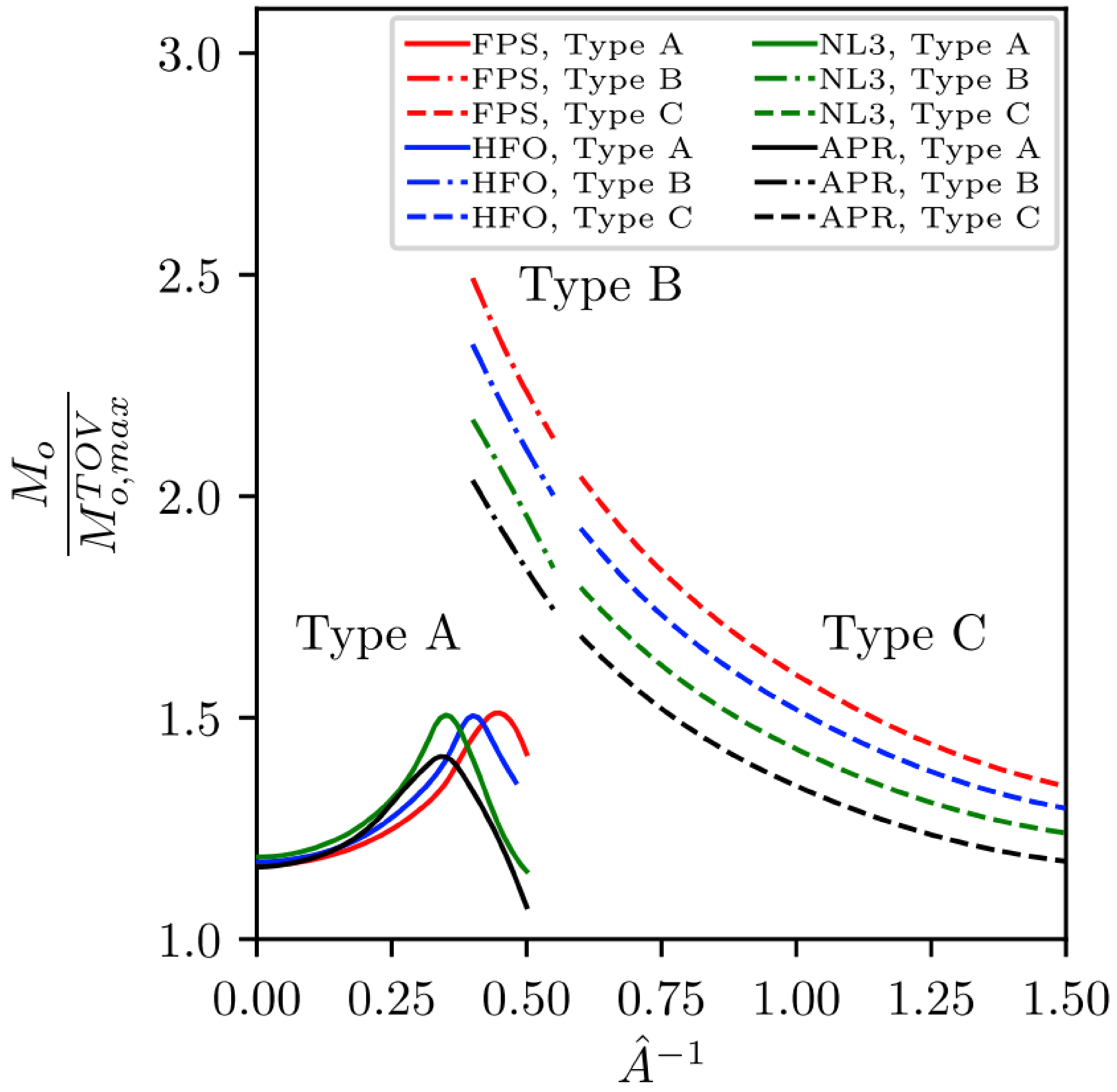
Maximum mass



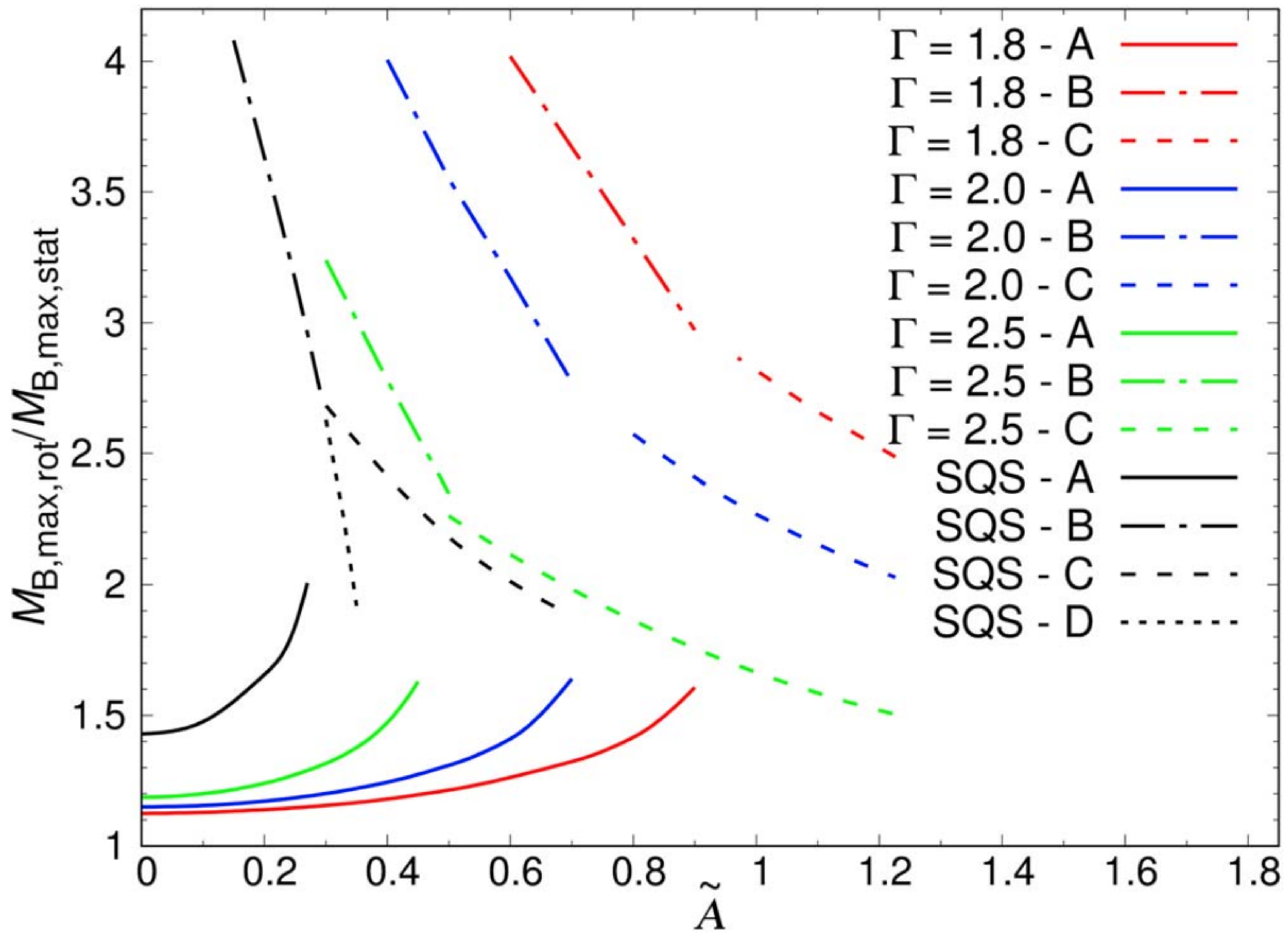
(Gondek-Rosińska et al. 2017)

- **Differential** rotation leads to larger possible masses than rigid rotation
- Maximum mass at a **moderate** degree of differential rotation
- Similar properties for different polytropes (Studzińska et al. 2016), strange stars (Szkudlarek et al. 2019) and realistic NS EOS (Espino and Paschalidis 2019)
- Are massive configurations dynamically **stable**?

Maximum mass



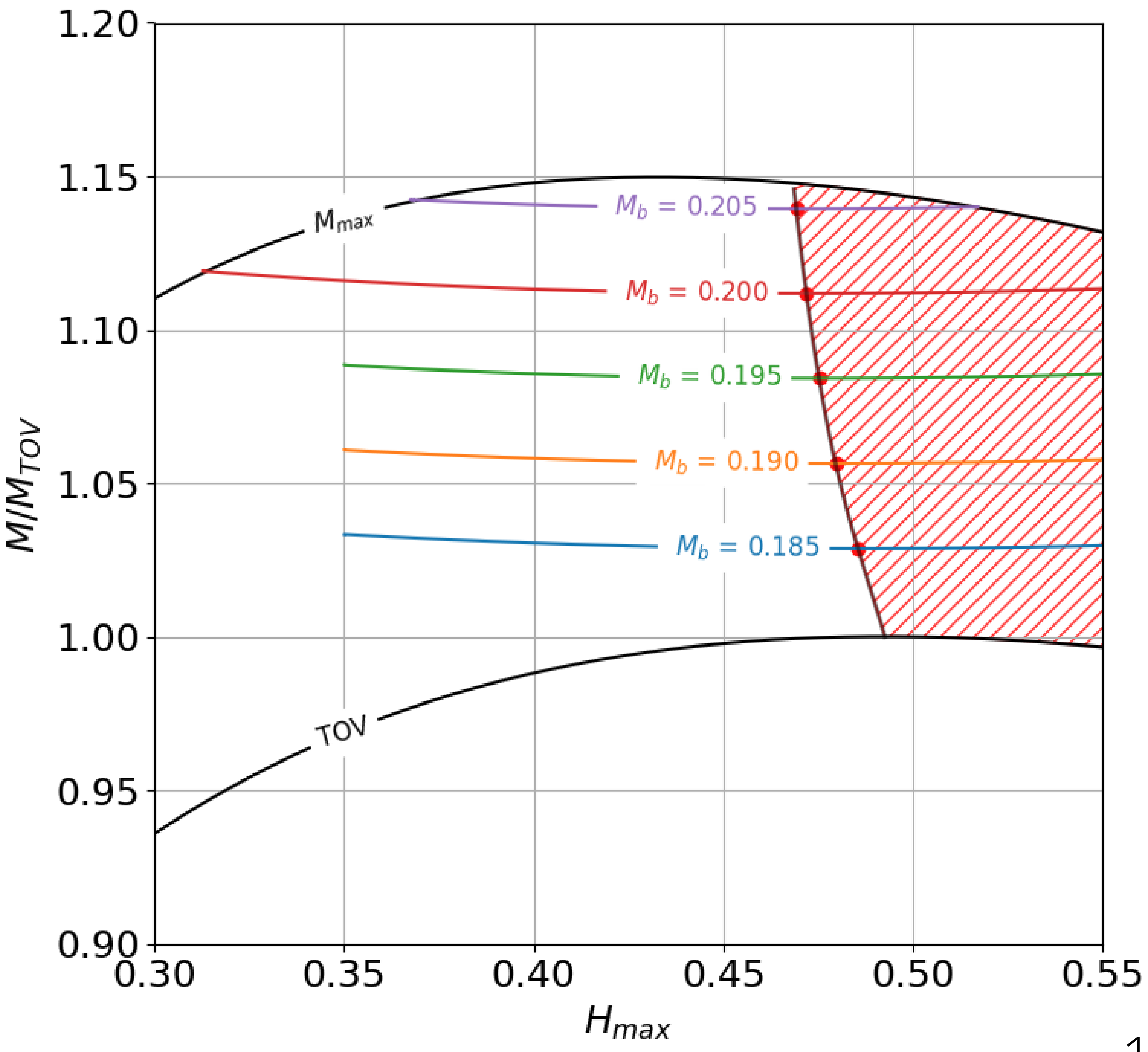
Max. mass for realistic EOS
(Espino & Paschalidis 2019)



Max. mass for polytropes and strange stars
(Szkudlarek et al. 2019)

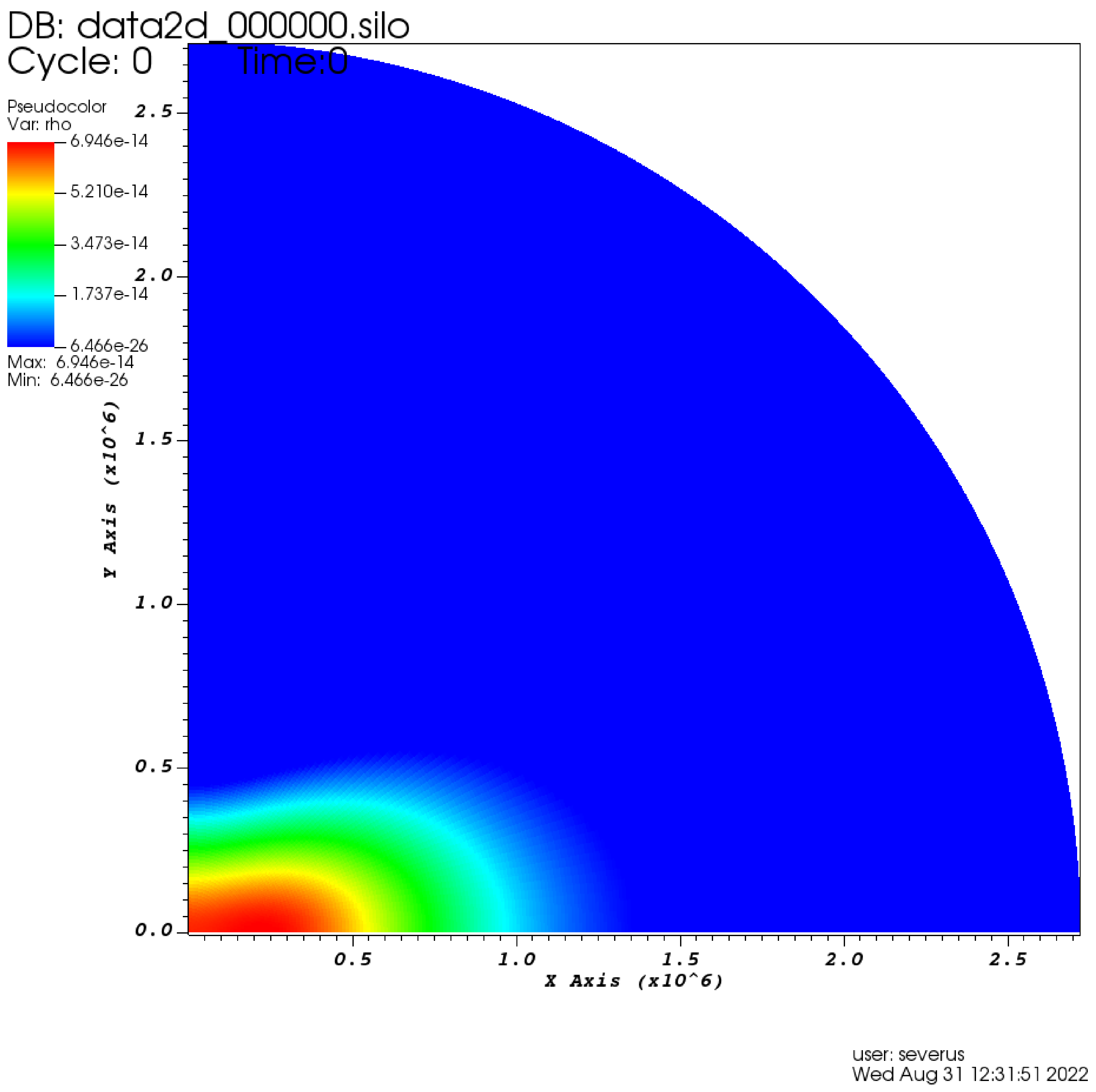
Turning point criterion for rigid rotation

- Stationary points on constant angular momentum or constant rest mass sequences
- Sufficient criterion of dynamical instability for rigid rotation (Friedman, Ipser, Sorkin 1988)
- What about differential rotation?

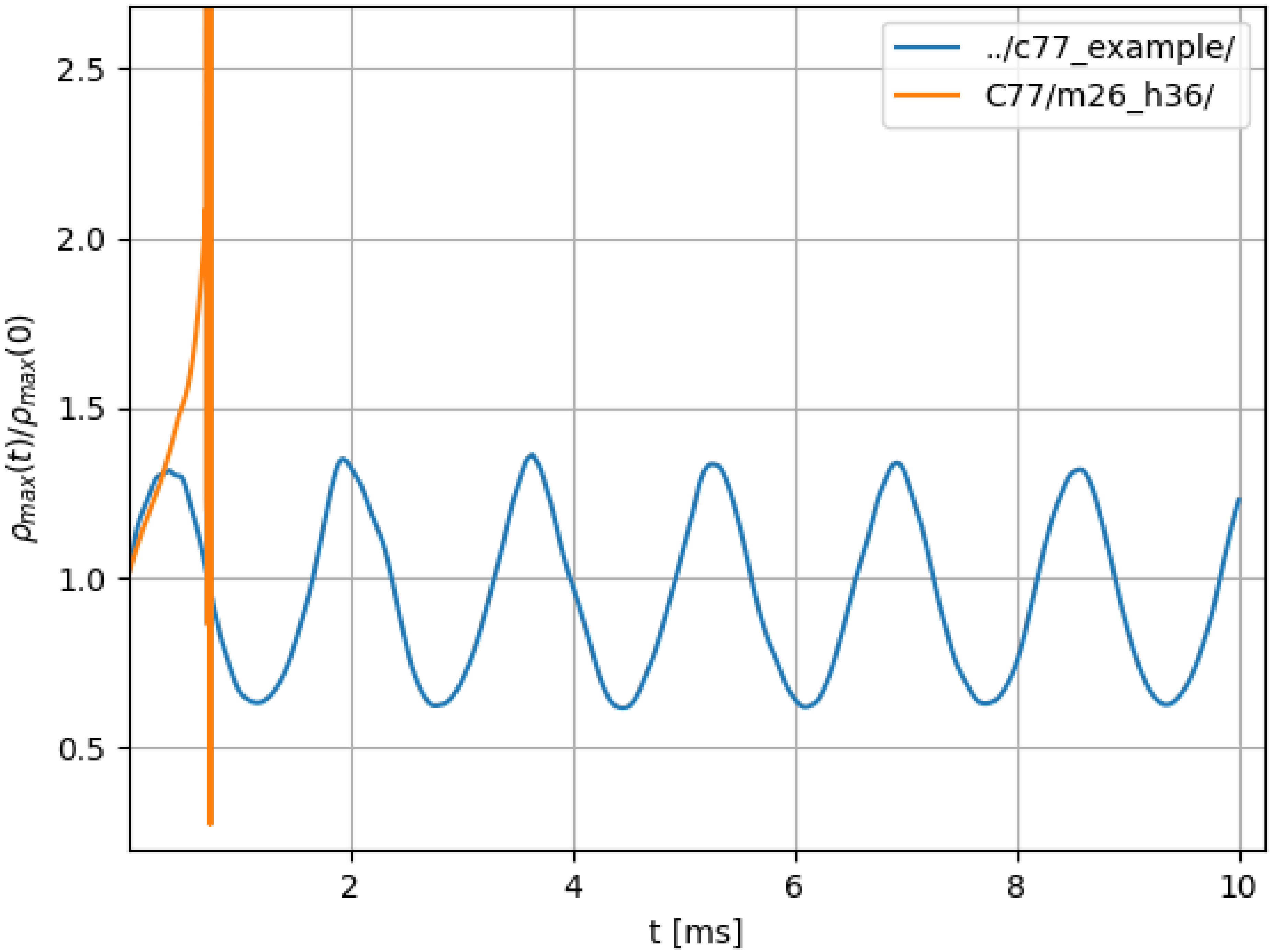


Numerical scheme

- Initial data calculated by FlatStar
- CoCoNuT code (relativistic hydrodynamics, dynamical space-time evolution)
- Axial symmetry
- CFC approximation
- Additional radial perturbations
- 10ms length

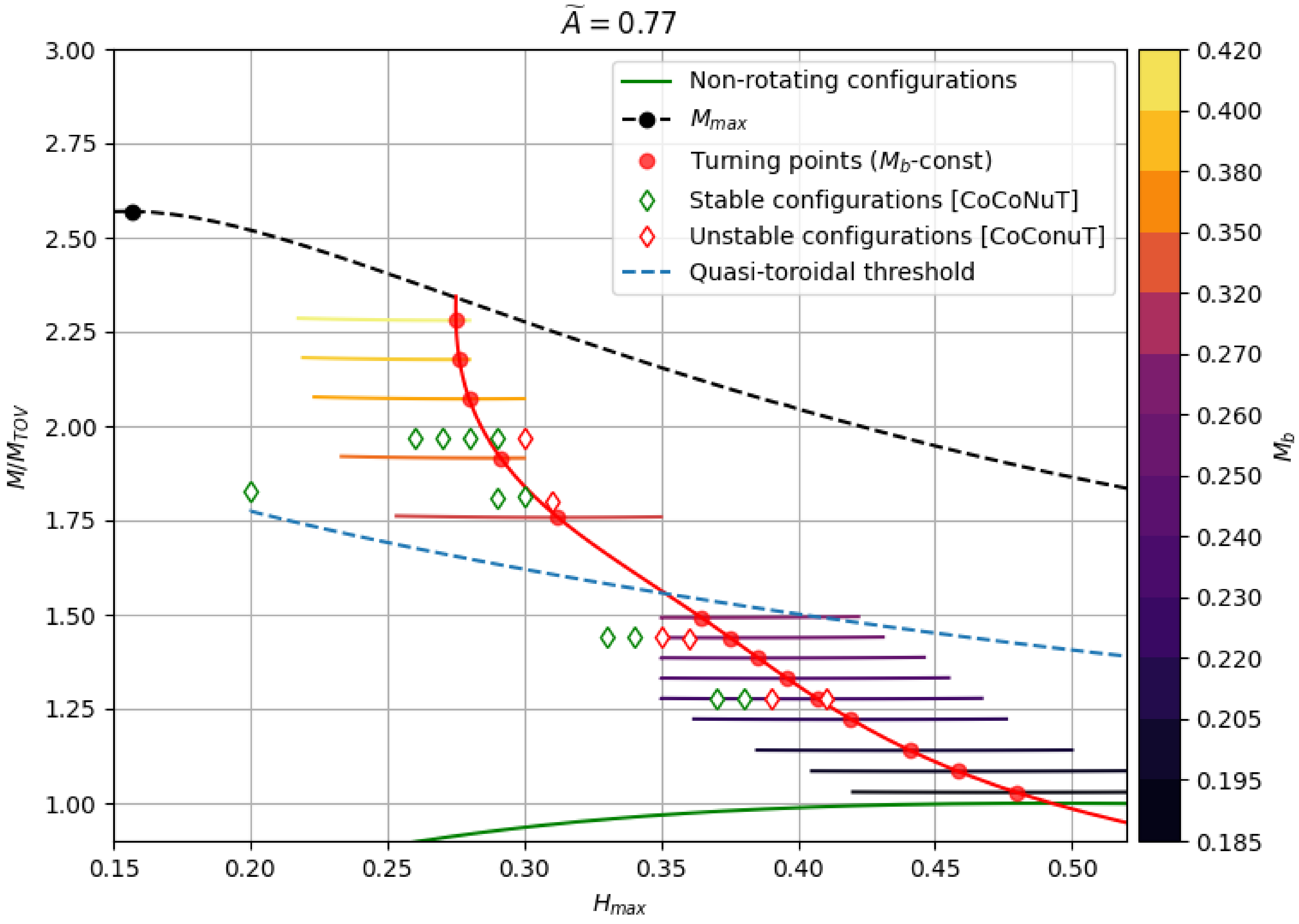


Numerical scheme



Central density evolution for stable and unstable case

Stability limit for differential rotation



- A range of massive stable solutions tested
- Turning points - still a good estimation
- Stable solutions even **twice as massive** as limit for non-rotating NS
- Consistent with Weih et al. (2017)

Summary

- Massive NS can be stabilized by **differential rotation**
- The most massive configurations can be estimated to be dynamically stable by the **turning-point criterion**
- Maximum mass for stationary solution is ~4M_TOV
- We found stable configurations with M=2M_TOV
- Need a check with full-GR simulation (no CFC) and 3D simulation (non-radial modes)
- Potential source of gravitational waves at collapse (Giacomazzo et al 2011)