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Stability of differentially rotating compact objects against a prompt collapse

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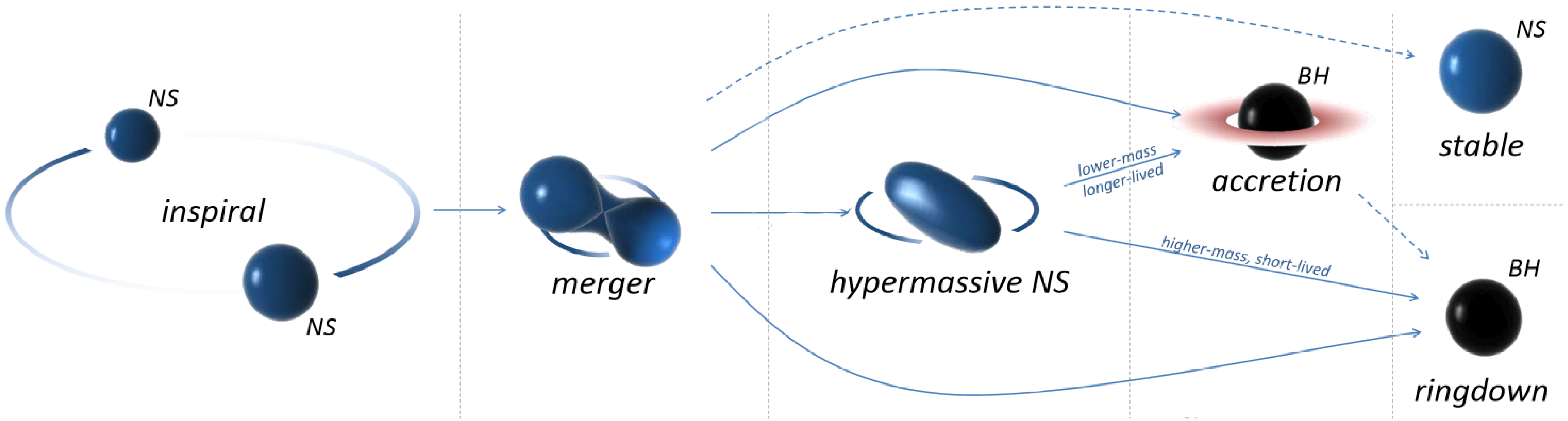
Astrophysical context

Differentially rotating remnants are produced in:

- Massive stellar core collapse
- Binary neutron star mergers



(Bartos, Brady, Marka 2013)

Outline

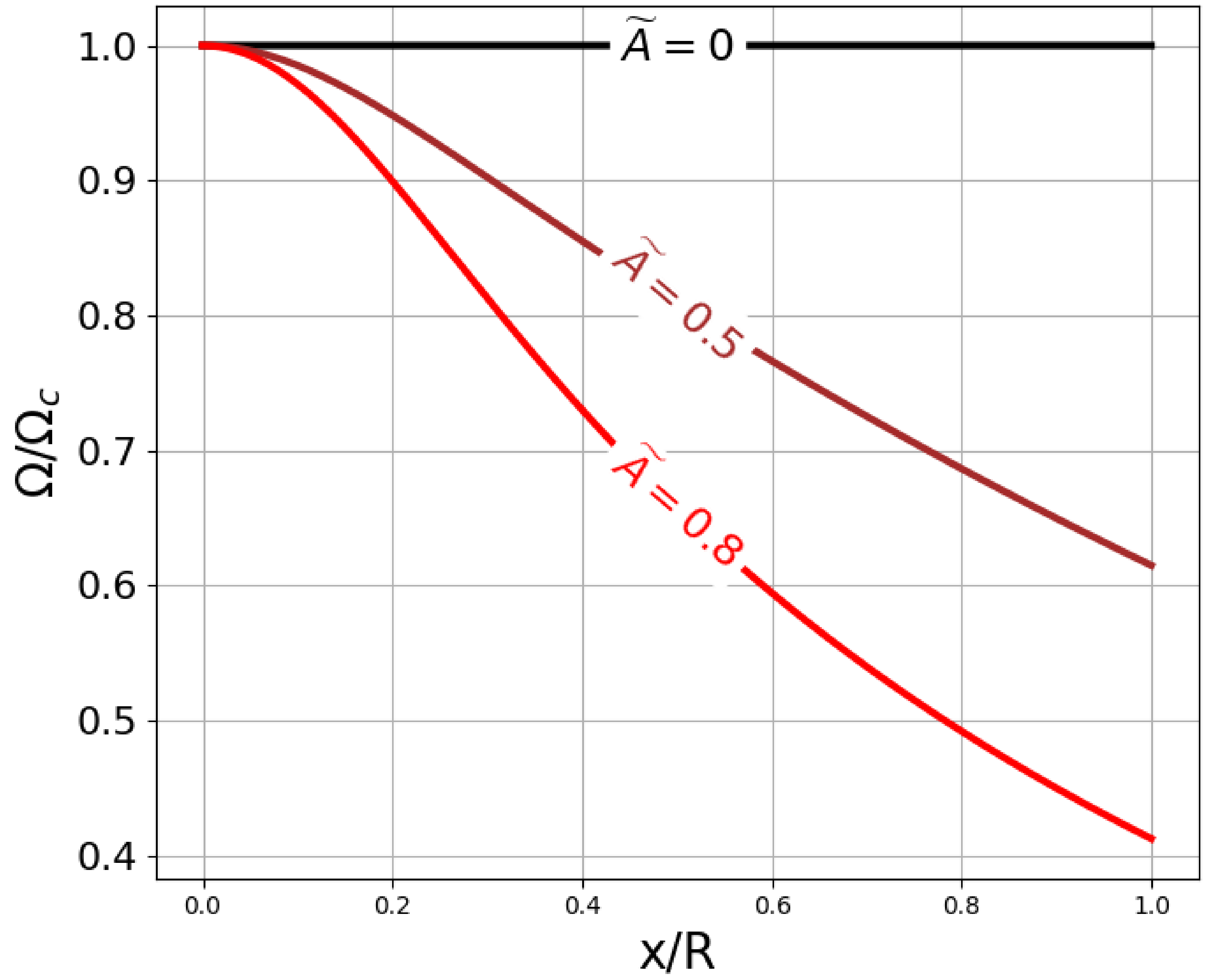
- Relativistic FlatStar code for neutron stars (NS) and strange quark stars (SQS) equilibria
- What is the maximum mass of differentially rotating NS?
- Multiple types of solutions
- Estimations of stability
- Hydrodynamical simulations of evolution

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):

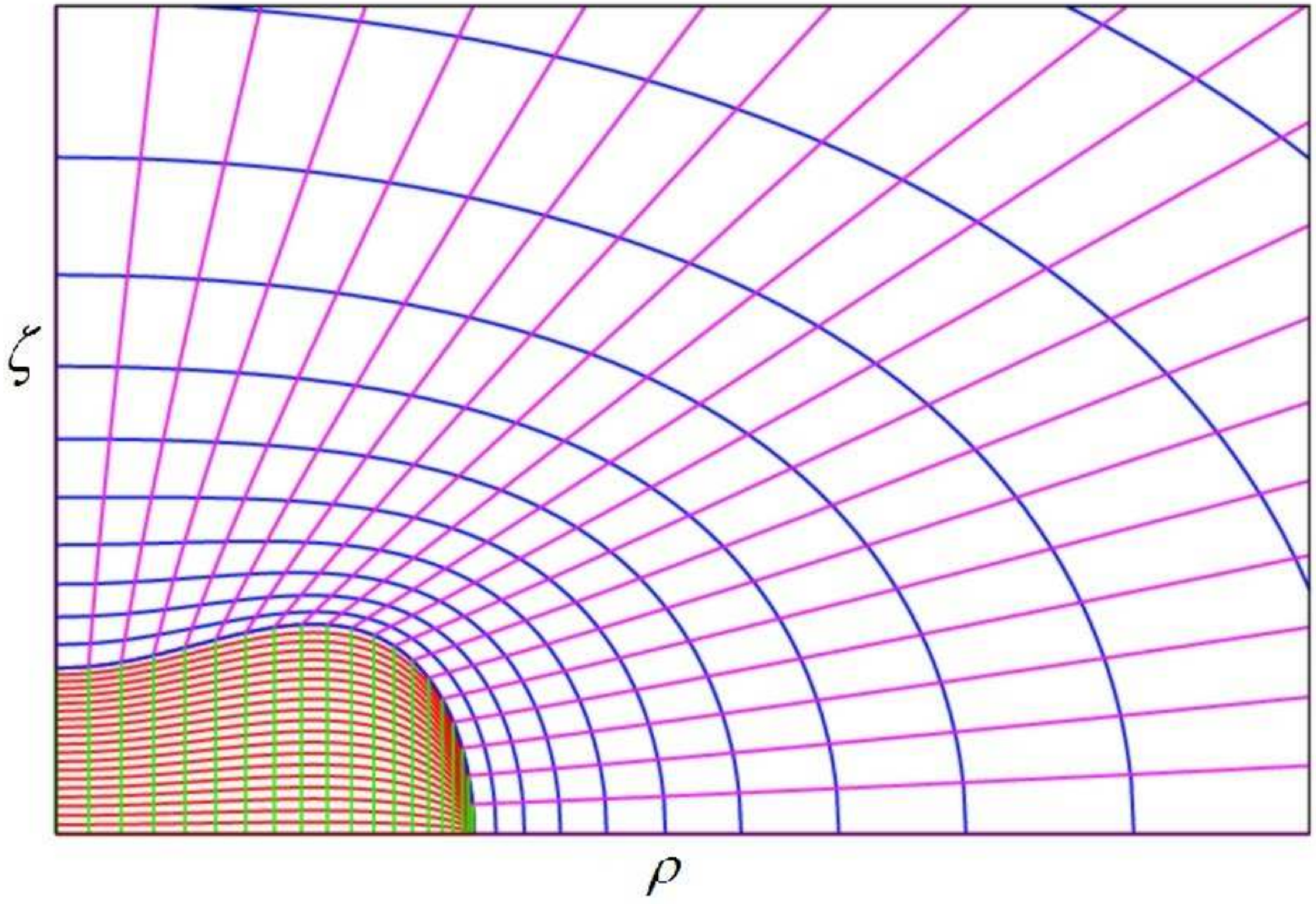
$$u^t u_\phi = F(\Omega) = A^2(\Omega_c - \Omega) \qquad \widetilde{A} = \frac{r_e}{A}$$

- consistent with core-collapse remnant



Rotation profiles in equatorial plane for different values of Ã

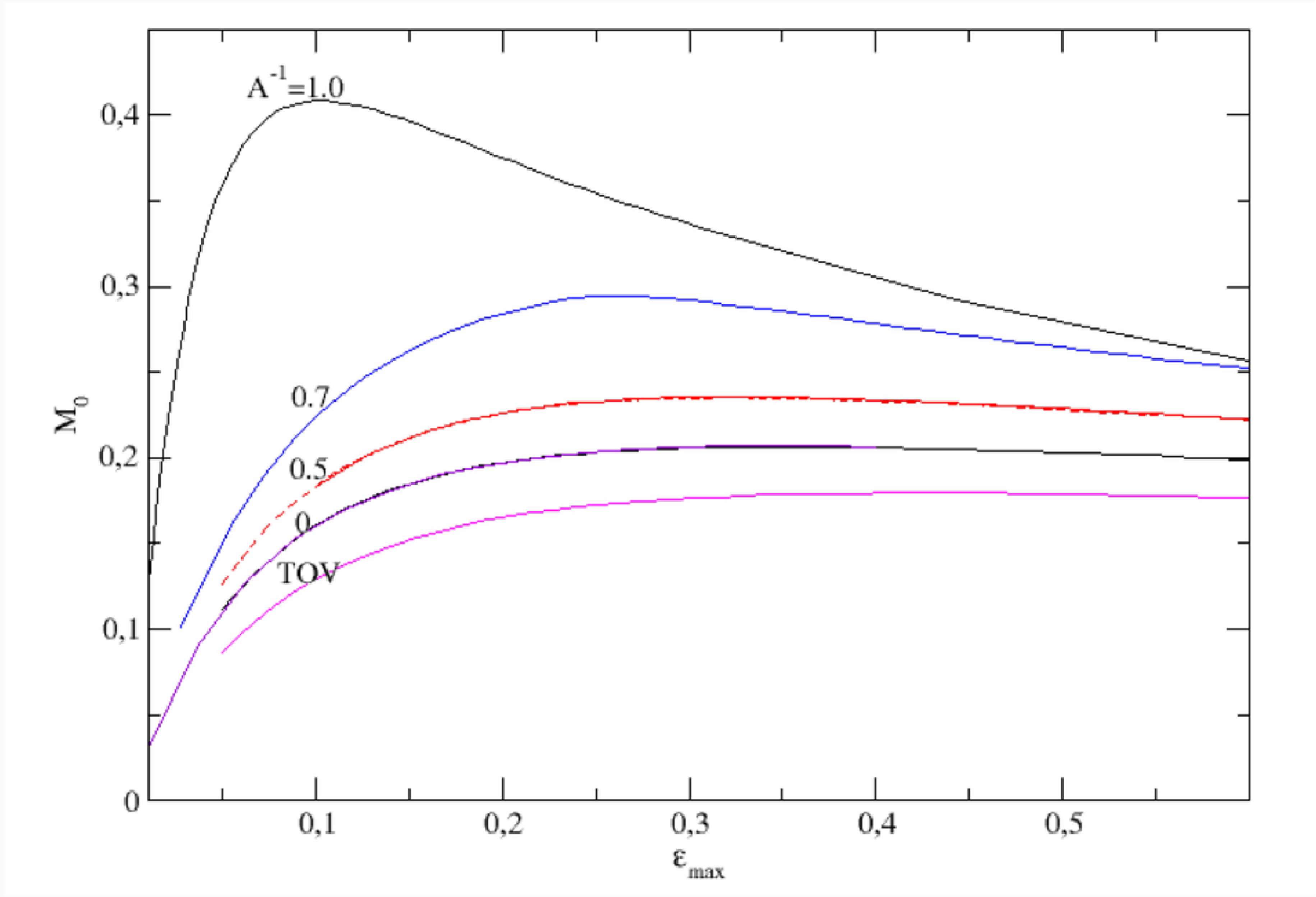
Equilibrium configurations - numerical scheme



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

Effects of rotation on maximum NS mass

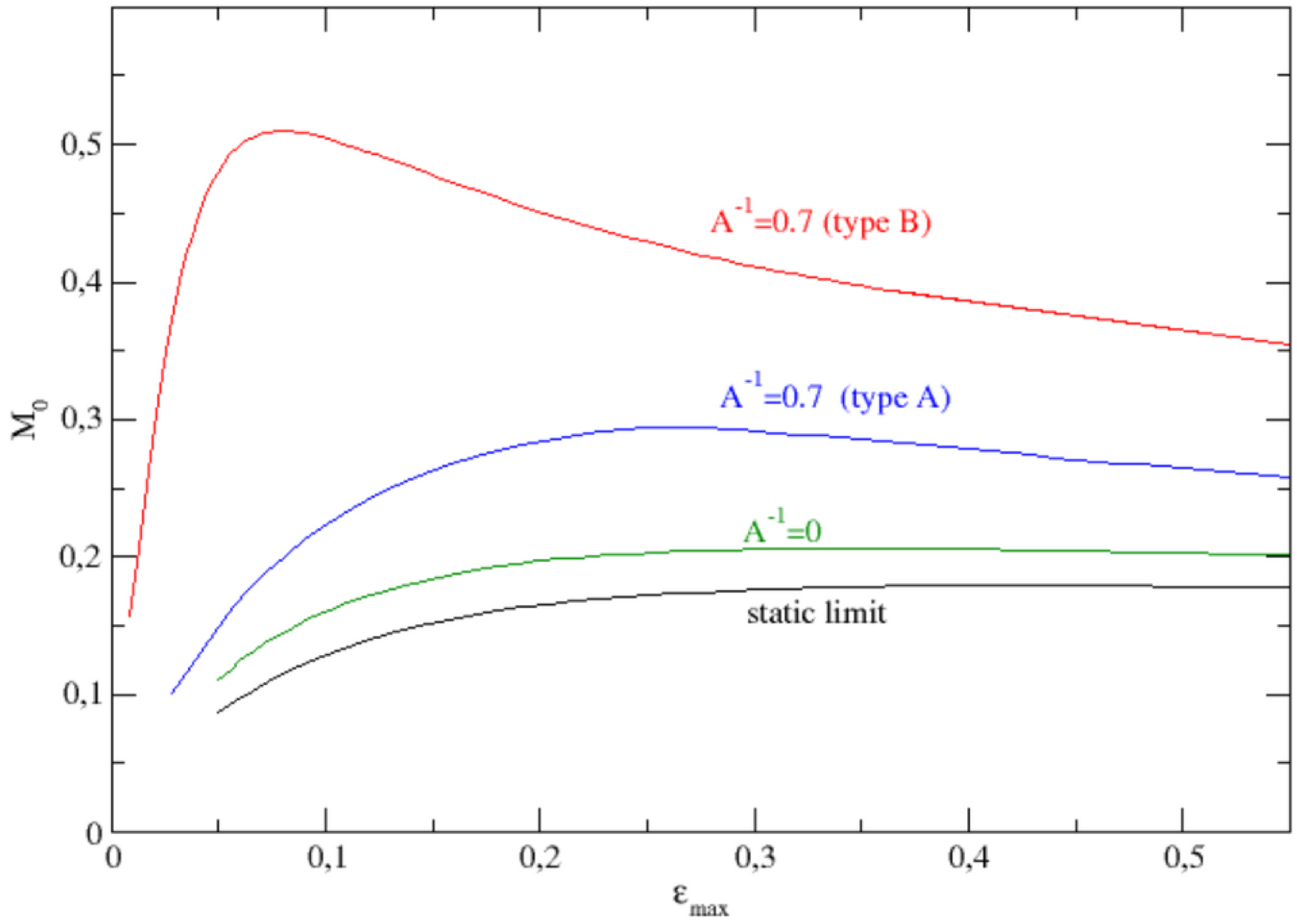
- No rotation: M_TOV
- Rigid rotation: increase of maximum mass by ~20% (e.g. Cook et al. 1994)
- Differential rotation: maximum mass depends on Ã (Baumgarte et al. 2000)



Maximum mass for types A and C, for a range of values of Ã

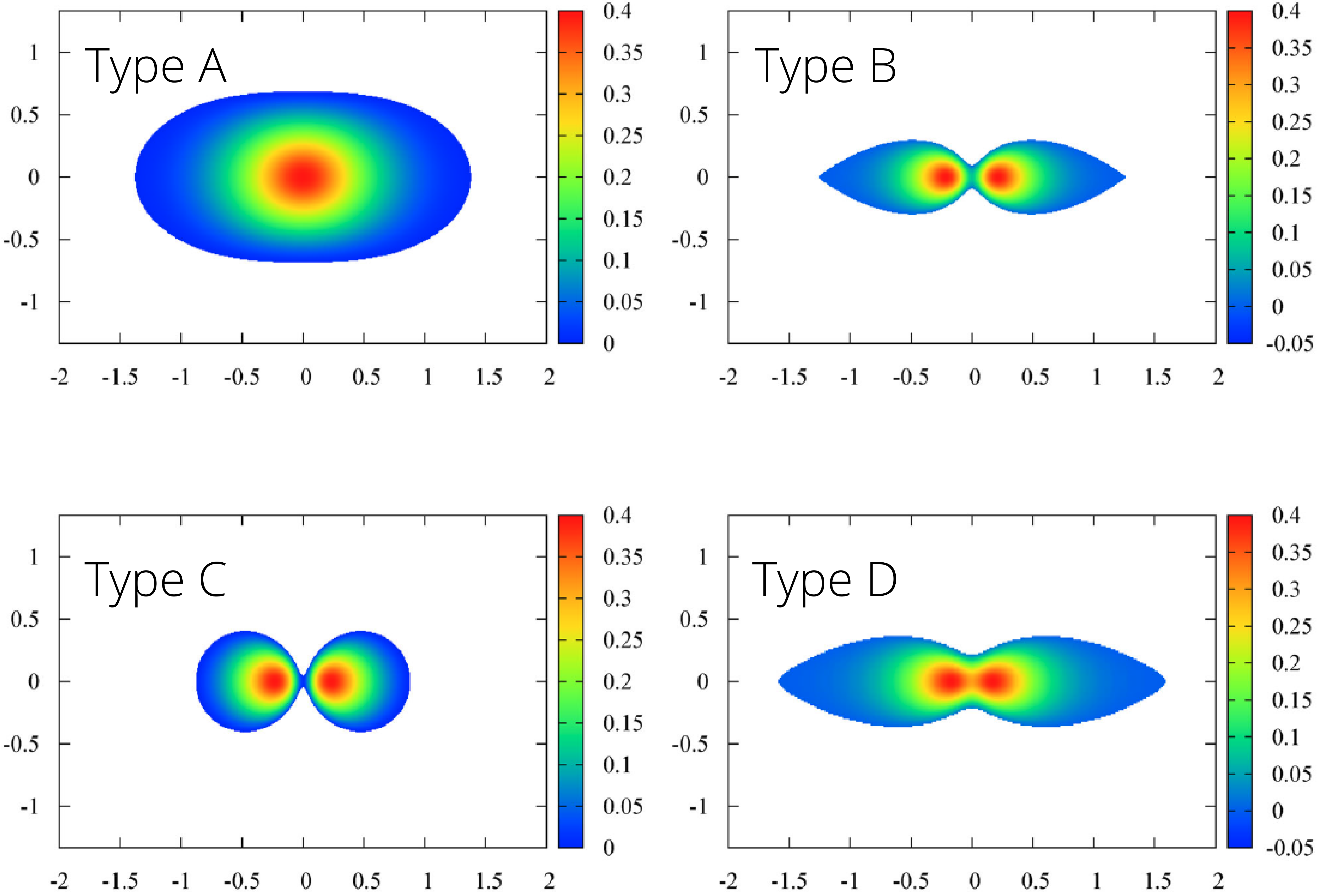
Effects of rotation on maximum NS mass

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

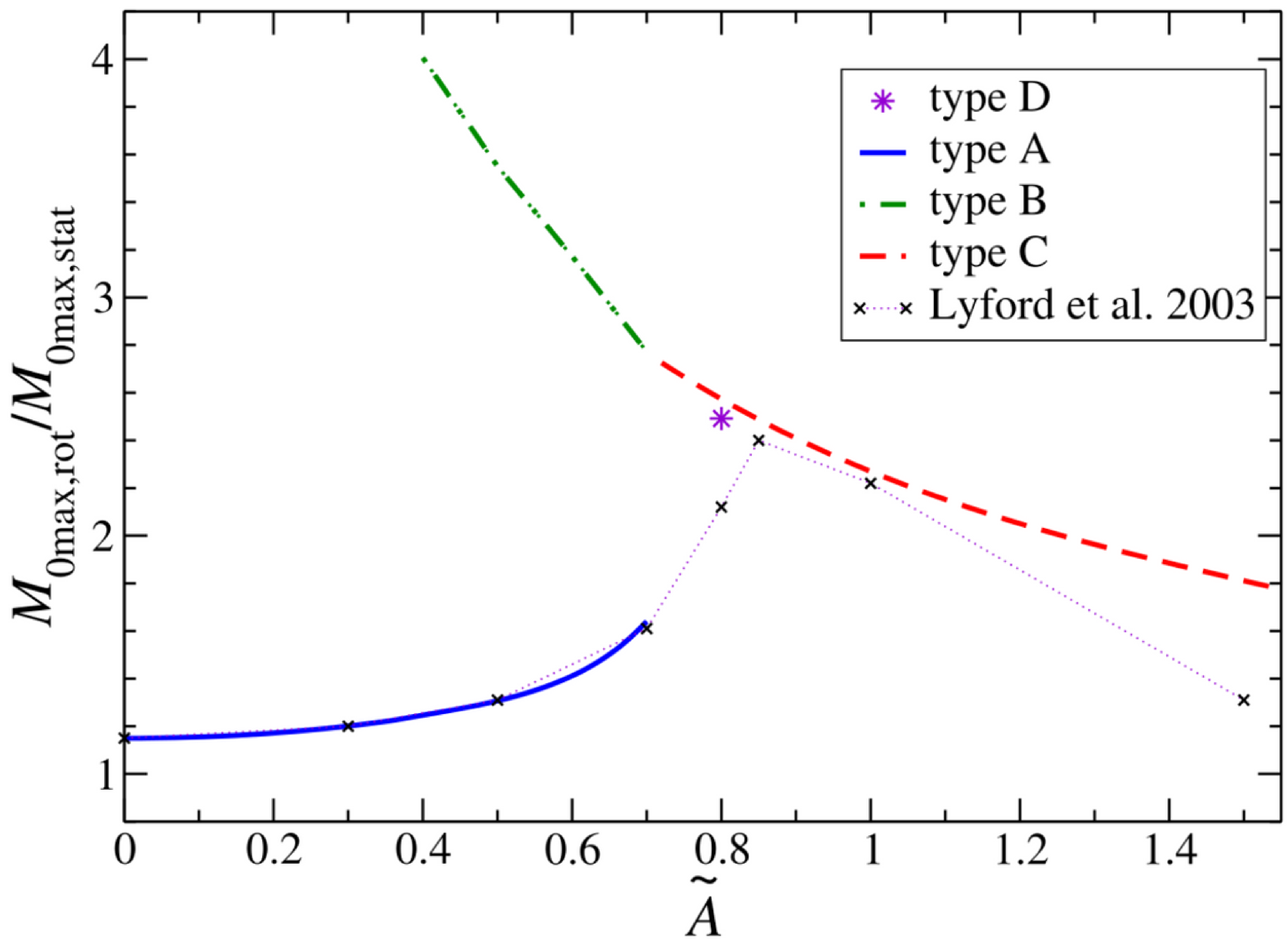


Maximum mass for types A and B, Ã=0.7

Different types of solutions

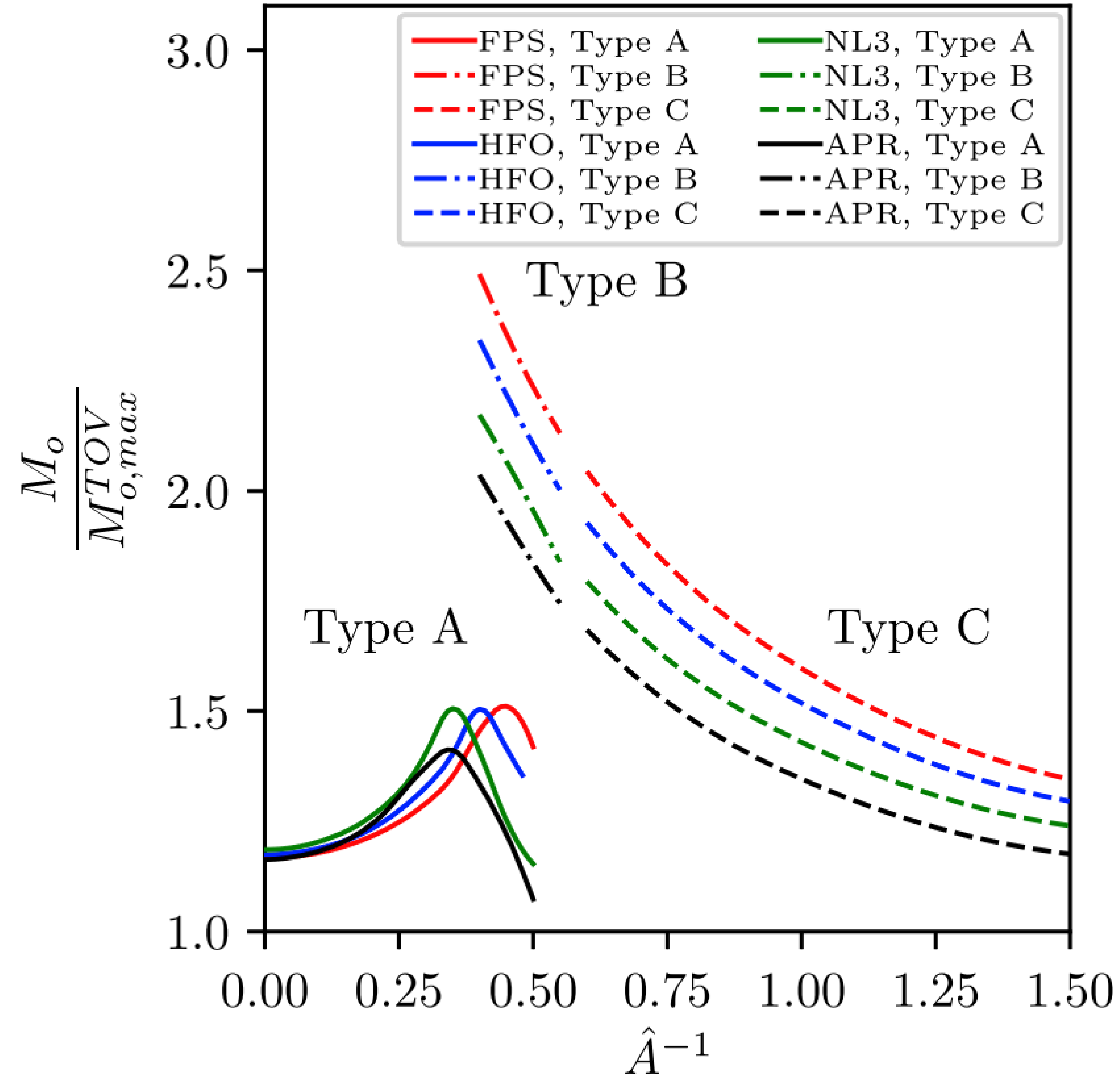


Effects of rotation on maximum NS mass

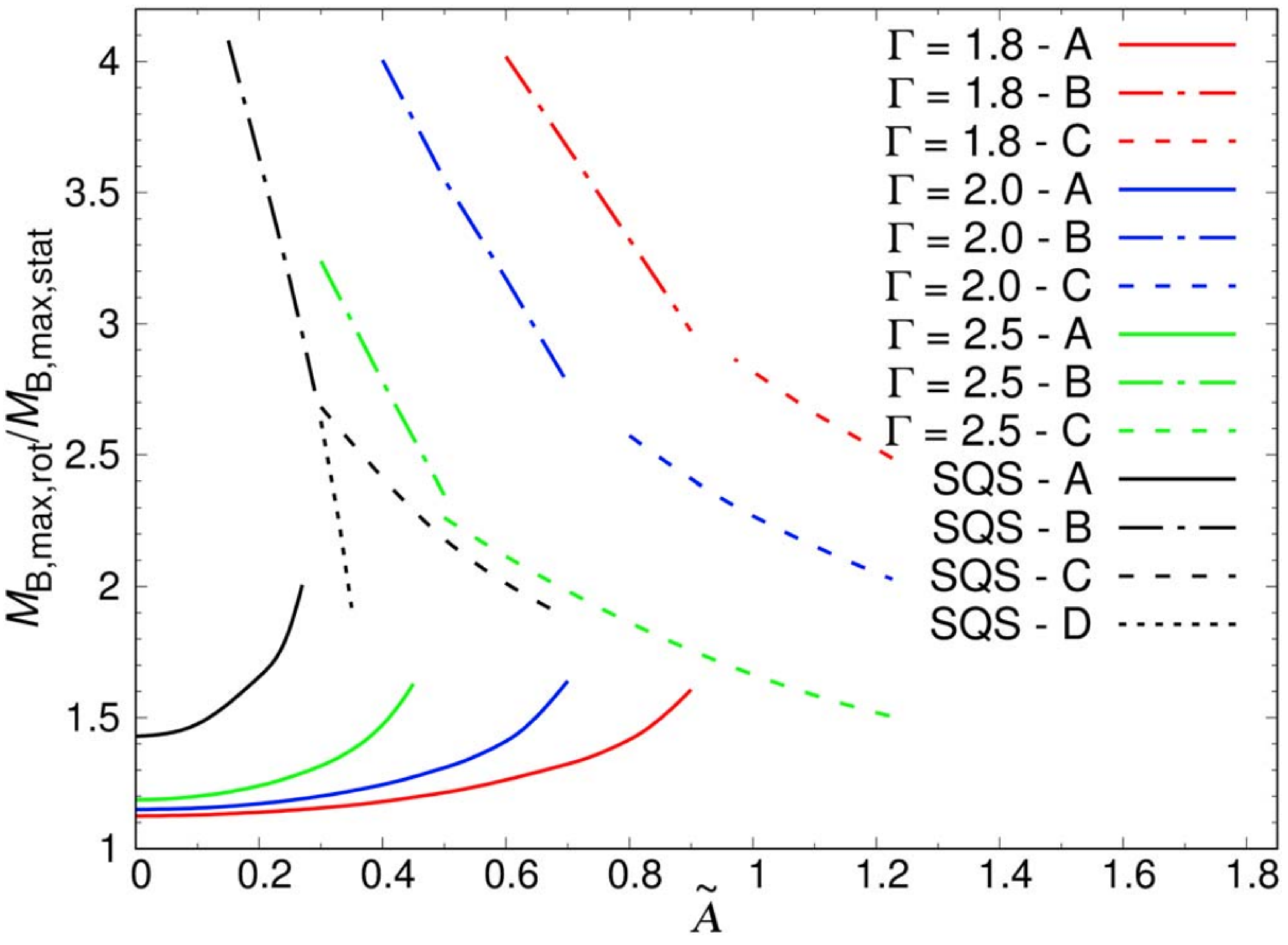


- **Differential rotation** leads to larger possible masses than rigid rotation
- Maximum mass at a **moderate** degree of differential rotation
- Similar properties for different polytropes (Studzińska et al. 2016), strange stars (Szkudlarek et al. 2019) and realistic NS EOS (Espino and Paschalidis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

Effects of rotation on maximum NS mass



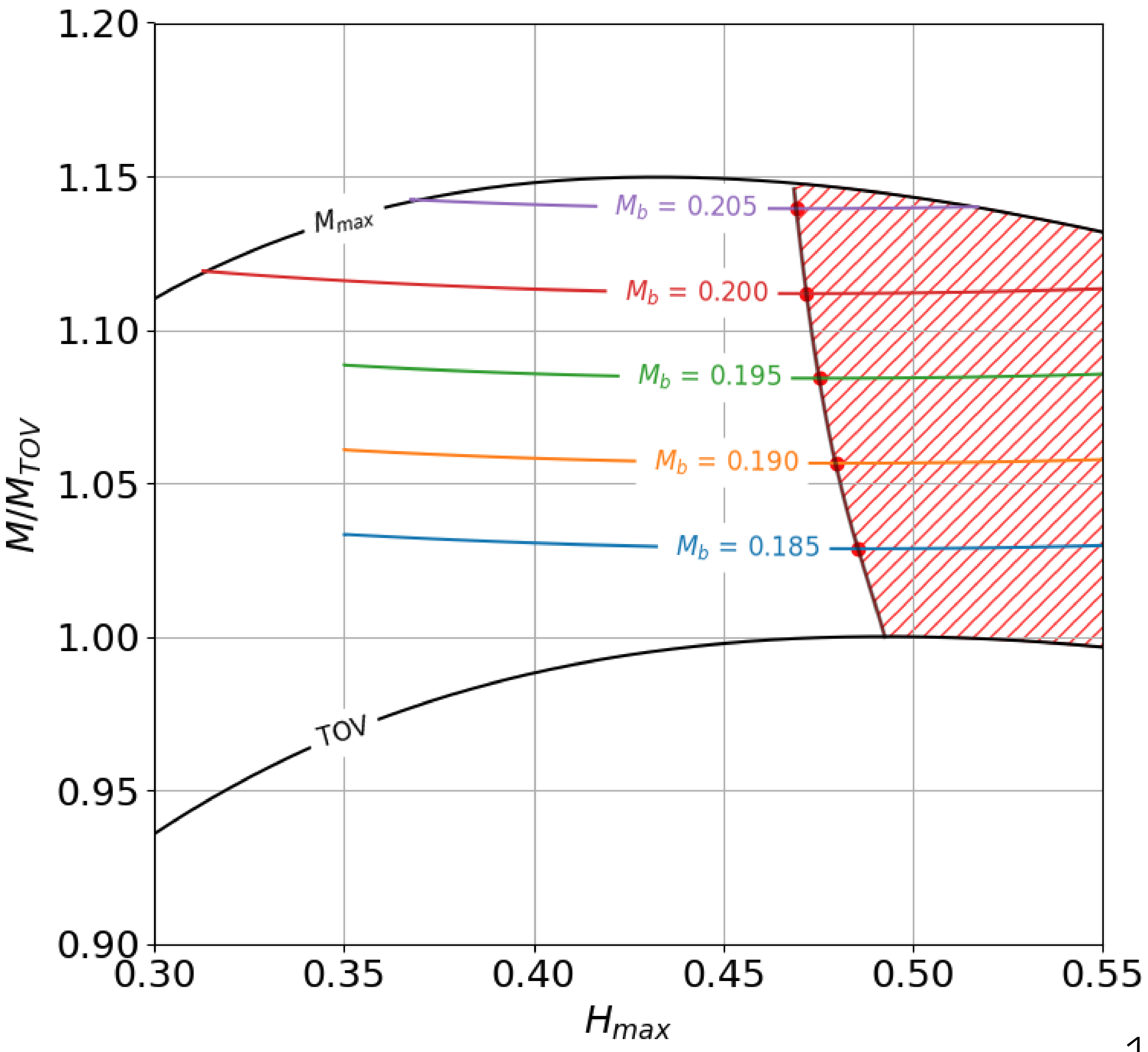
Max. mass for realistic EOS
(Espino & Paschalidis 2019)



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

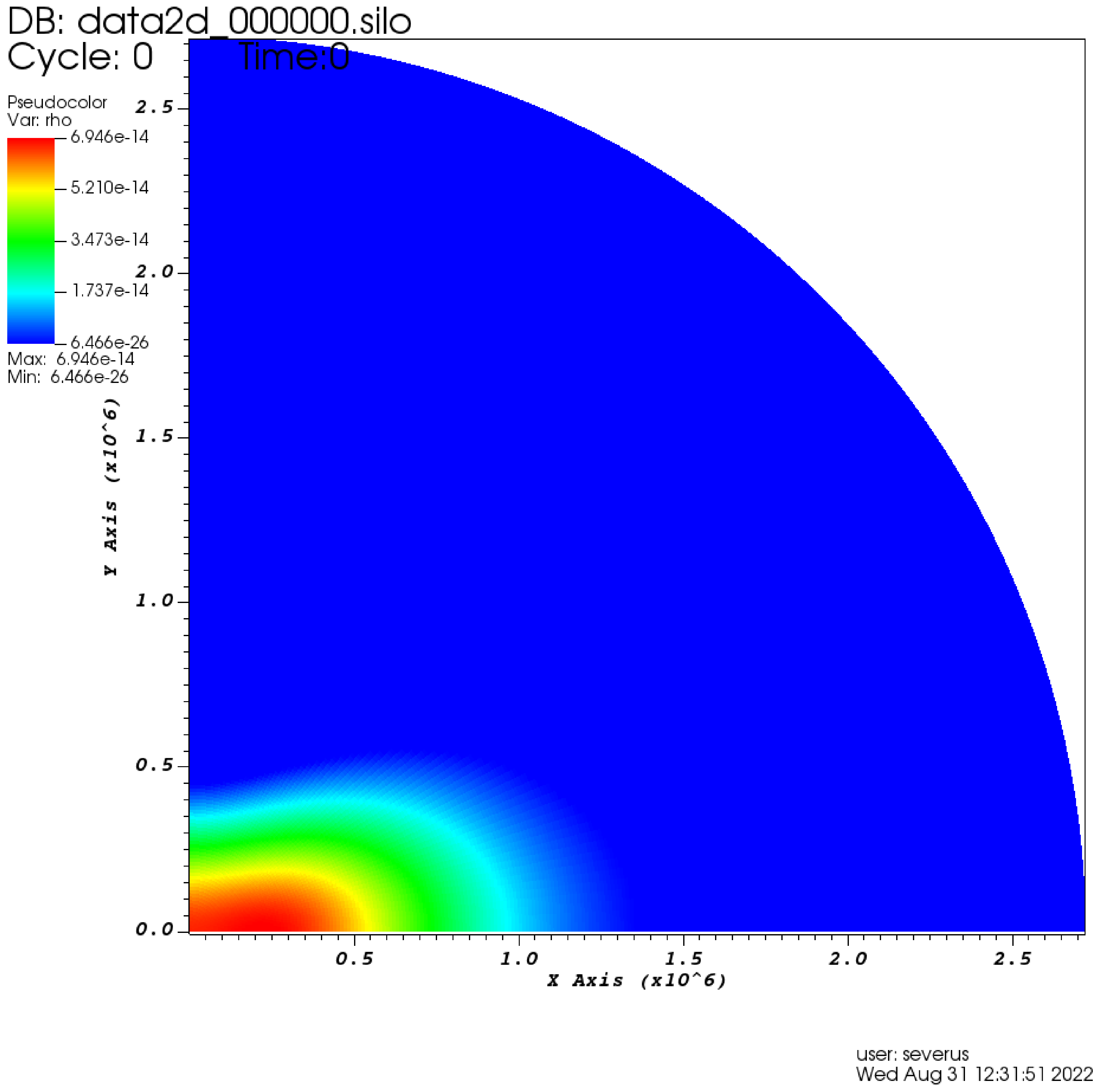
Turning point criterion for rigid rotation

- 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?

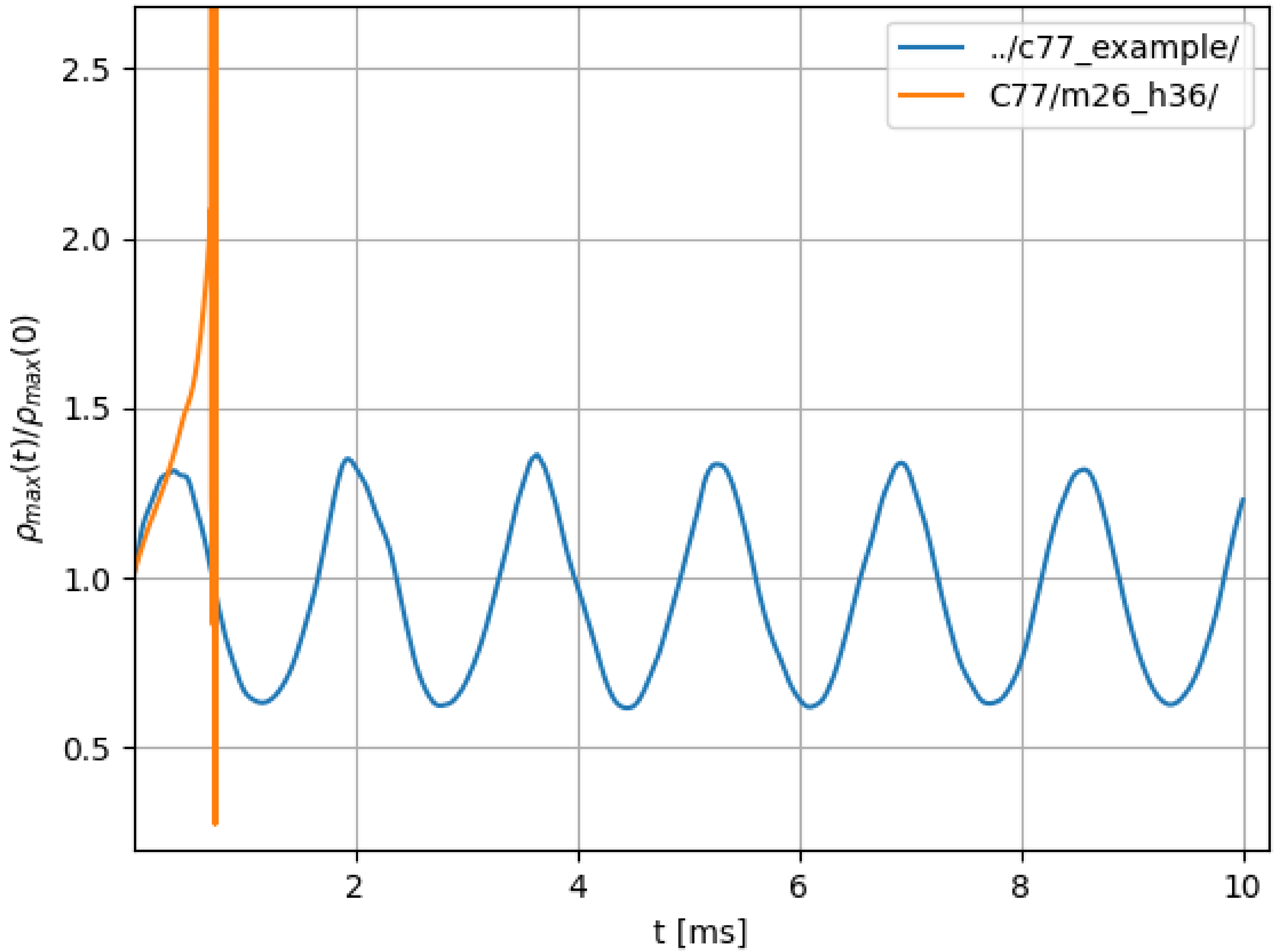


Numerical scheme

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

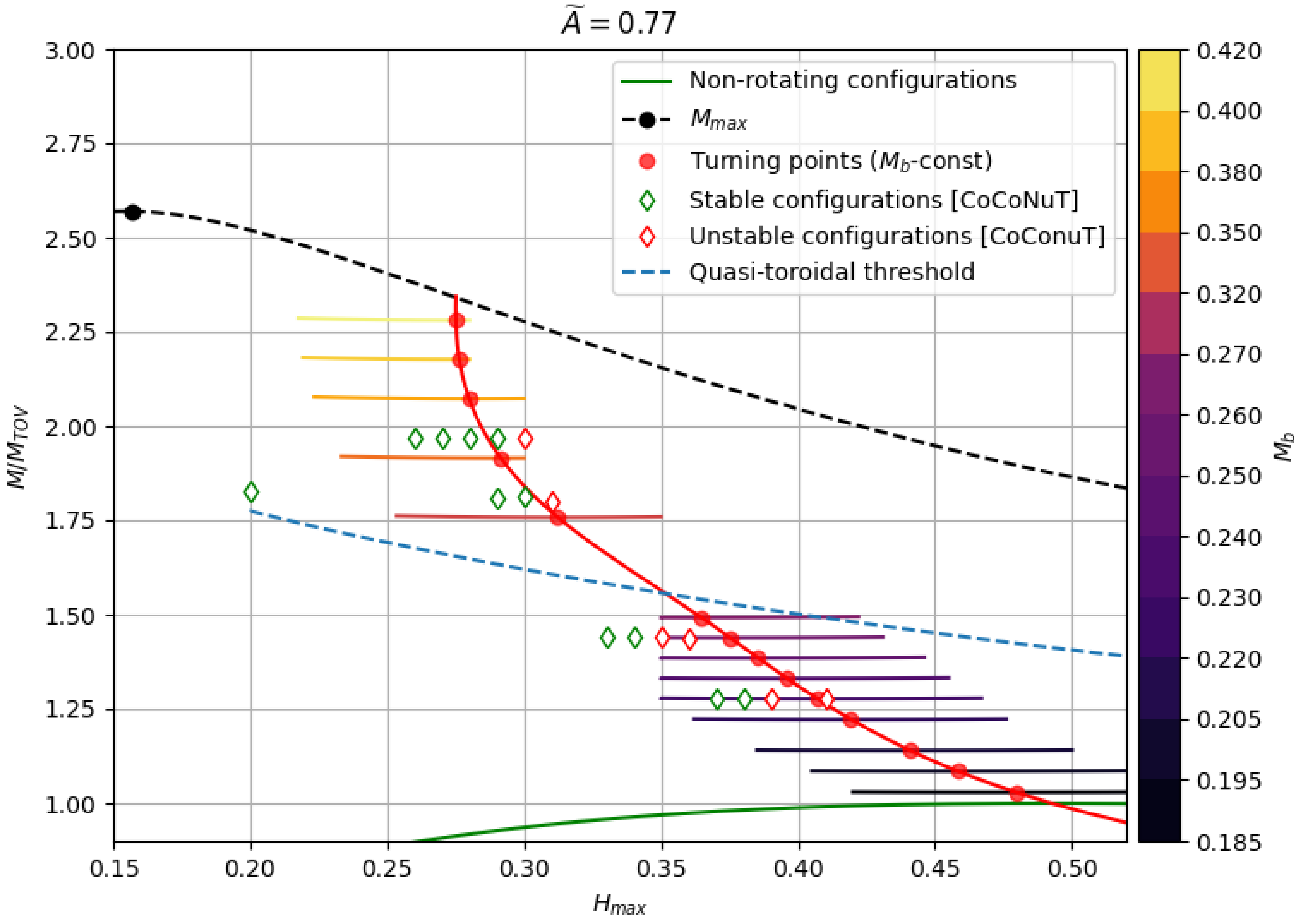


Numerical scheme



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

Summary

- Four types of equilibrium solutions for NS and SQS
- Massive NS can be stabilized by differential rotation
- Maximum mass depends on the degree of differential rotation and type of solution (Gondek-Rosińska 2017), similar for realistic EOSs (Espino 2019) and SQS (Szkudlarek 2019)
- No simple stability criterion
- Potential source of gravitational waves at collapse (Giacomazzo et al 2011)