Stability properties of differentially rotating neutron stars

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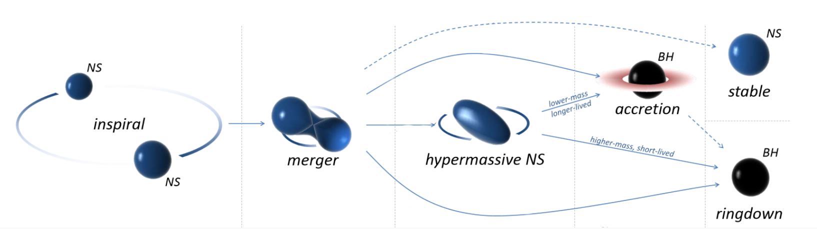
Astrophysical context

Differential rotation may play important role in:

- NS-NS mergers
- Massive stellar core collapse



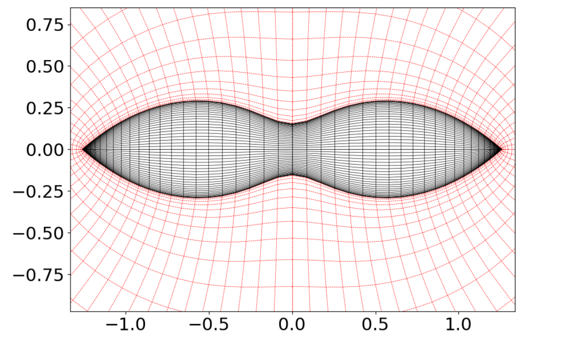
Bartos, Brady, Marka 2013

Outline:

- Relativistic *FlatStar* code for neutron stars (NS) and strange quark stars (SQS) equilibria
- Maximum mass of differentially rotating NS
- Multiple types of solutions
- Stability properties of differentially rotating NS

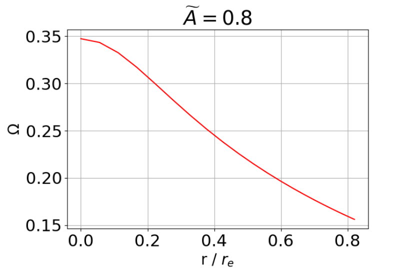
FlatStar code

- Relativistic multidomain spectral code for stationary, axisymetric models of differentially rotating NS and SQS
- Highly accurate and stable
- Can calculate configurations, which are difficult to obtain for other codes



Example numerical grid for highly flattened configuration

Equilibrium model for differentially rotating NS



Example rotation curve in equatorial plane

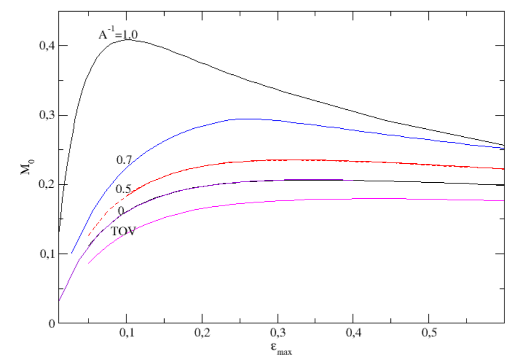
- j-const rotation law (consistent with core-collapse results) $u^t u_\phi = F(\Omega) = A^2(\Omega_c - \Omega)$ (Komatsu et al. 1989)
- A is length describing **degree of differential rotation**, i.e. $\Omega(r = A) = \frac{\Omega_c}{2}$ $\widetilde{A} = \frac{r_e}{A}$
- **polytropic EOS**: $P = K\rho^\Gamma$ (e.g. $\Gamma = 2$)

Effects of rotation on maximum allowed NS mass

- No rotation: $M_{max} = M_{TOV}$
- **Rigid** rotation: increase of M_{max} by 20% (e.g. Cook et al. 1994)

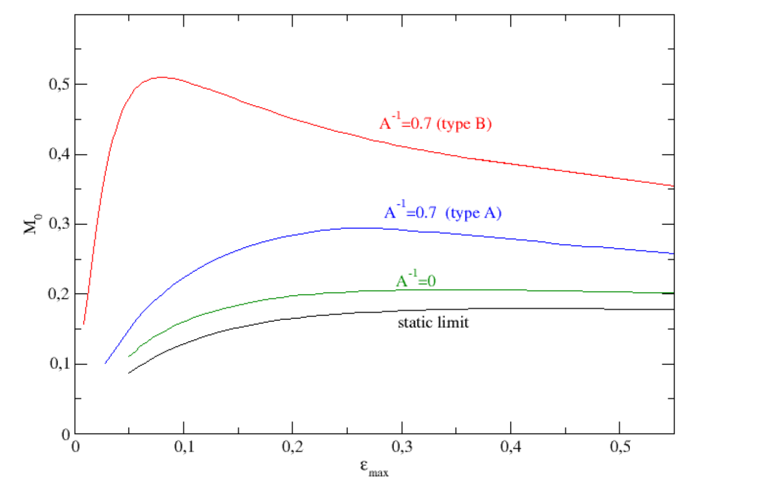
Effects of rotation on maximum allowed NS mass

- No rotation: $M_{max} = M_{TOV}$
- **Rigid** rotation: increase of M_{max} by 20% (e.g. Cook et al. 1994)
- **Differential** rotation: M_{max} depends on $\widetilde{A}$ (Baumgarte et al. 2000)



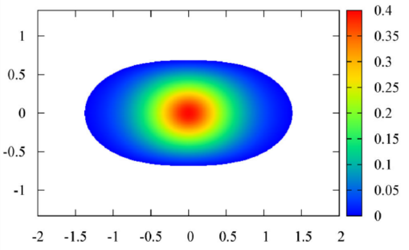
Upper limit on rest mass for different degrees of differential rotation (Gondek-Rosińska et al. 2017)

Maximum mass of differentially rotating NS: existence of type A and B

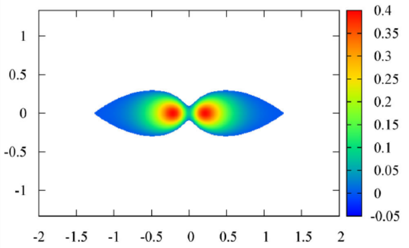


Coexisting types A and B for $\widetilde{A} = 0.7$ (Gondek-Rosińska et al. 2017)

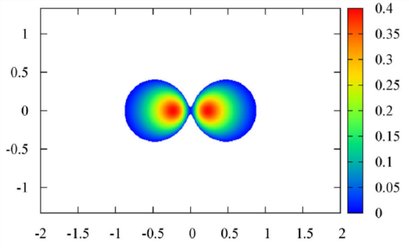
Examples of four types of solutions (Studzińska et al. 2016)



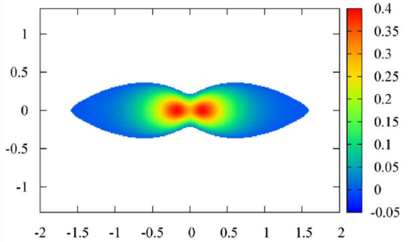
Type A with $\widetilde{A} = 0.7$



Type B with $\widetilde{A} = 0.8$

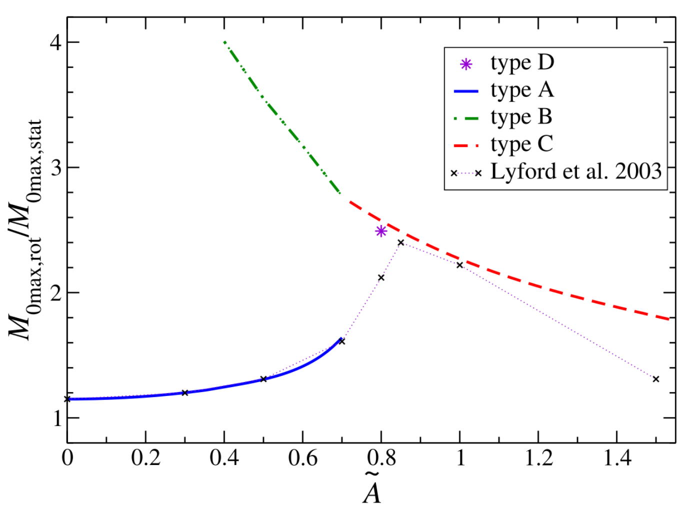


Type C with $\widetilde{A} = 1.1$



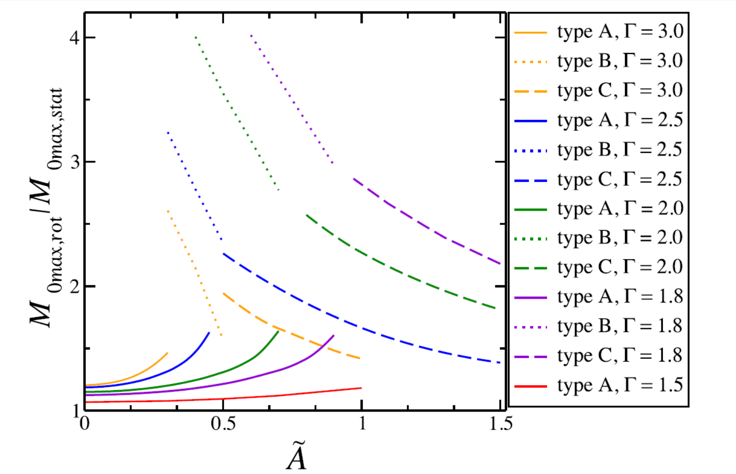
Type D with $\widetilde{A} = 1.1$

Maximum allowed mass for differentially rotating NS



Maximal masses for differentially rotating NS depend on the **degree** of differential rotation and solution **type**, for polytrope with $\Gamma = 2$ (Gondek-Rosinska et al. 2017)

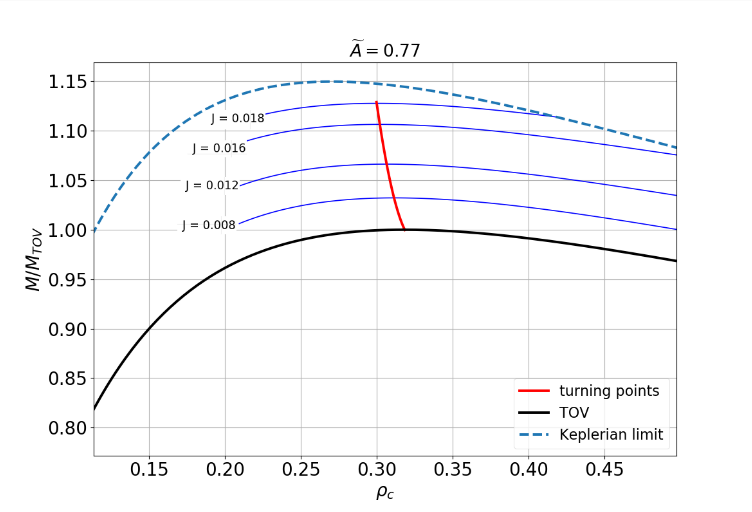
Effect of EOS on M_{max}



Universal feature for different **polytropes** (Studzińska et al. 2016) confirmed also for **realistic EOS** (Espino et al. 2019) and for **SQS** (Szkudlarek et al. 2019)

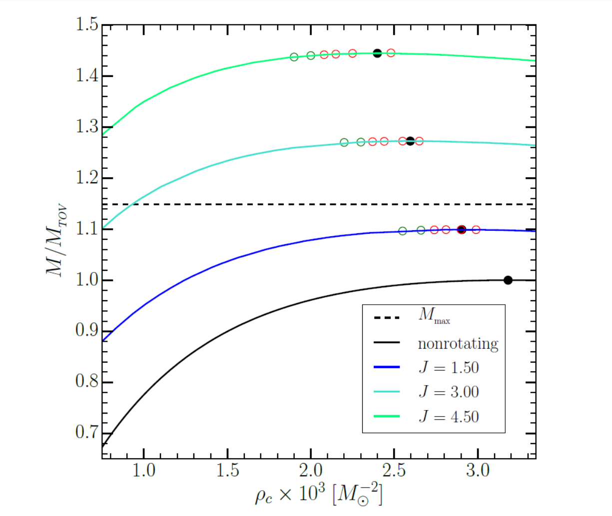
Are massive, differentially rotating neutron stars stable against prompt collapse to BH?

Stability criteria for uniform rotation



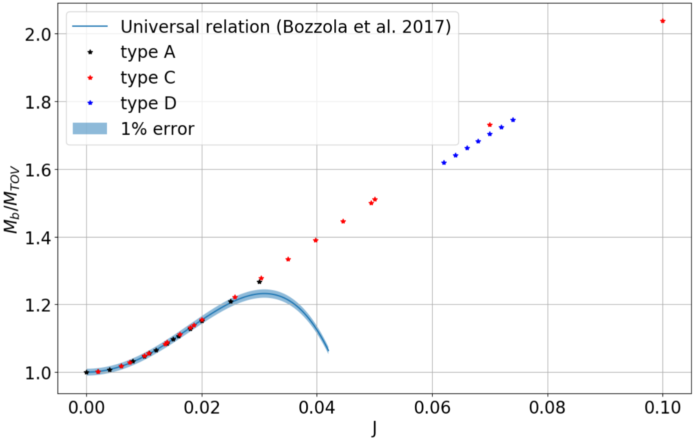
Turning-point criterion (see Friedman, Ipser and Sorkin, 1988)

Is the turning-point criterion valid for differential rotation?



Example const-J sequences for differential rotation with $\widetilde{A} = 0.77$ (Weih, Most and Rezzolla 2017)

Quasi-universal relations for turning points

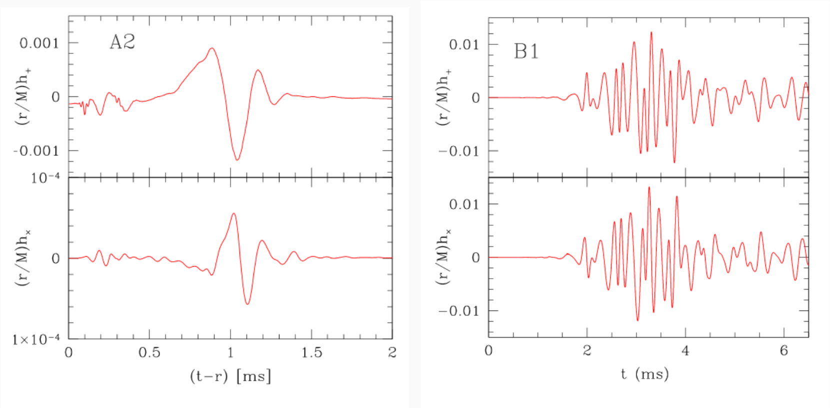


Universal J-M_b relation for low J

Summary

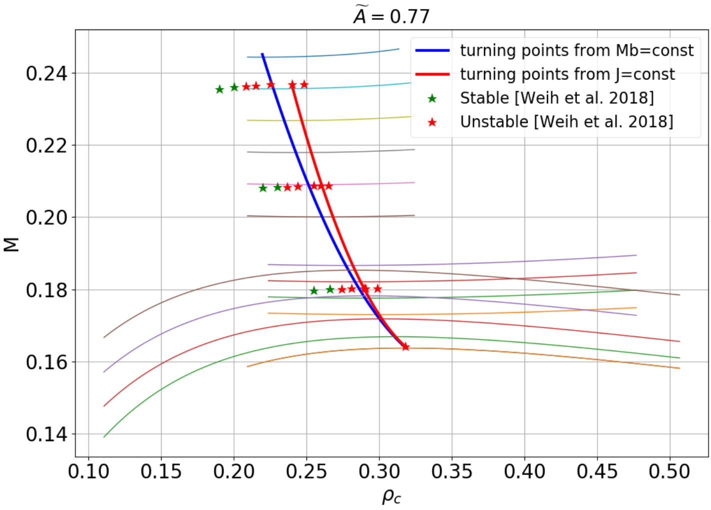
- Four types of equilibrium solutions for NS and SQS (Ansorg et al. 2009)
- Massive NS can be stabilized by differential rotation
- M_{max} depends on degree of differential rotation and type of solution (Gondek-Rosińska et al. 2017), similar for realistic EOSs (Espino et al. 2019) and SQS (Szkudlarek et al. 2019)
- No simple stability criterion
- Quasi-universal relations for turning points
- Potential source of gravitational waves at collapse (Giacomazzo et al 2011)

GW signal during collapse



Gravitational-wave amplitudes h_+ and h_x for two collapses, left: $J/M^2 < 1$, right: $J/M^2 > 1$ (Giacomazzo et al 2011)

Const-M_b turning points



Turning points J=const and M_b=const compared with stability