Disk formation from the collapse of a rotating neutron star

Giovanni Camelio
with Tim Dietrich and Stephan Rosswog
to be published on MNRAS, arXiv:1806.07775

September 13rd, 2018
European Einstein Toolkit Workshop
Lisbon

Motivation

Is it possible to generate a GRB from a neutron star collapse?

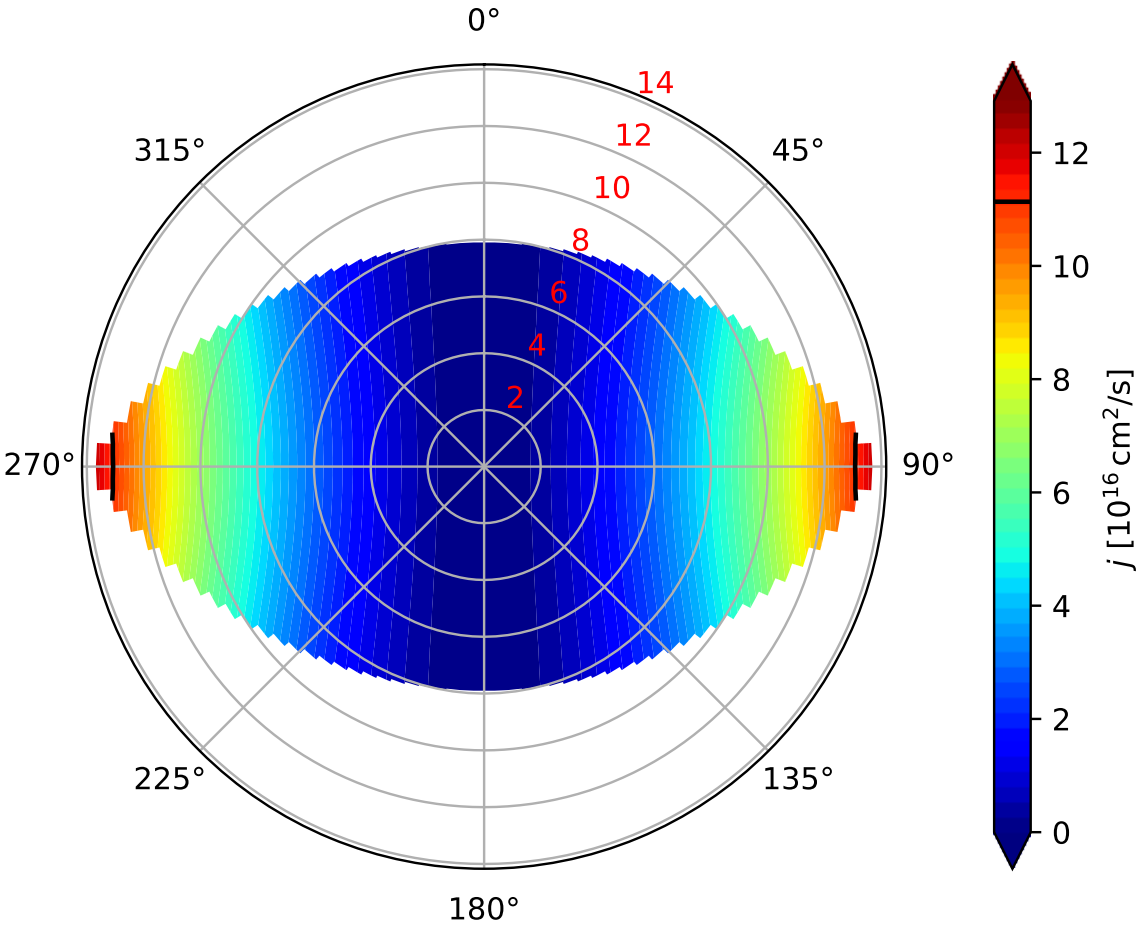
A possible scenario (MacFadyen+ 2005):

1. marginally stable rotating neutron star
2. gravitational collapse
3. black hole + debris disk
4. gamma ray burst
5. GRB interaction with non-compact companion
6. X flare lasting ~ 100 s

Margalit+ (2015) found that only a very soft EOS can produce a debris disk.

We want to extend and validate with dynamical simulations their analysis.

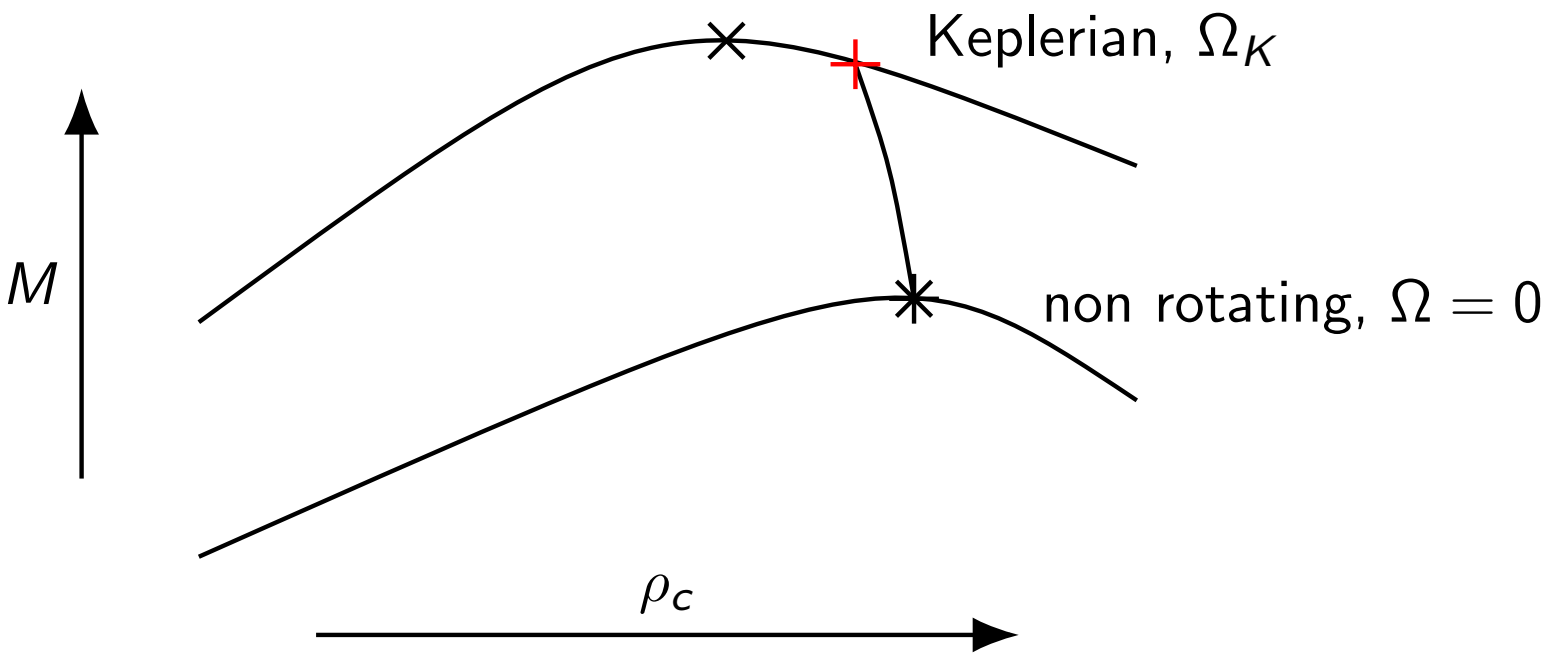
The idea



Some neutron star material can escape the black hole formation (and generate a disk, Shapiro 2004) if

$$\text{j/m (NS equator)} > \text{j/m (BH ISCO)}$$

Initial configuration



- Not all configurations can collapse: $\left.\frac{\partial M}{\partial \rho_c}\right|_J = 0$
- Increasing $\Omega \to$ j/m (NS equator) grows

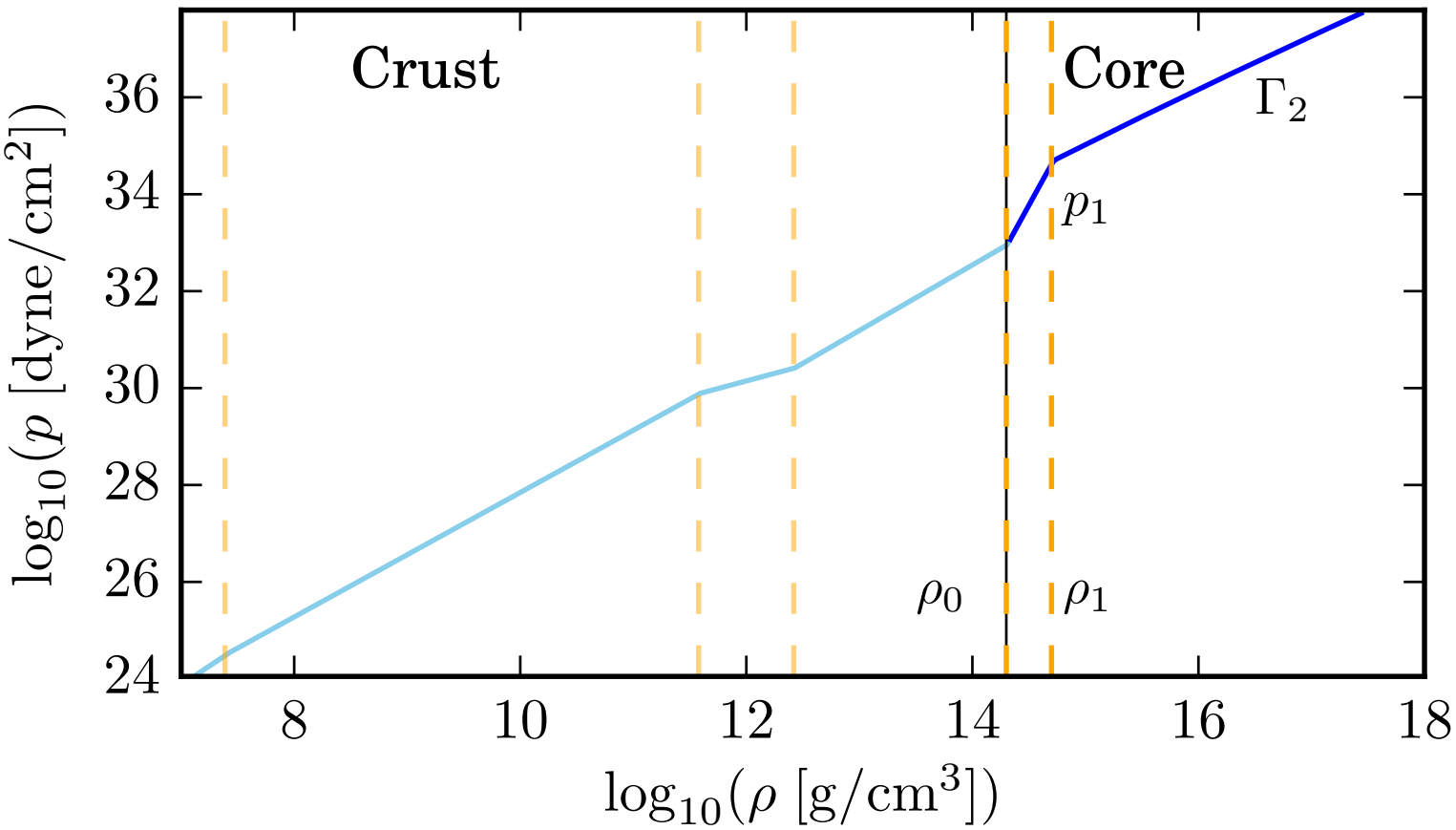
we take the marginally stable Keplerian configuration.

Equation Of State

Polytropic EOS:

$$p = K\rho^{\Gamma}$$

Piecewise polytropic EOS (Read+ 2009):



Assumptions

- equilibrium configuration
- neutron star in rigid rotation
- no angular momentum transport during the collapse (i.e., no viscosity)
- BH with the same mass and angular momentum of the NS

We are NOT considering:

- normal star collapse to a black hole (Shapiro 2004)
- pre-existing disk around the neutron star
- thermal effects (in the equilibrium analysis)
- magnetic fields

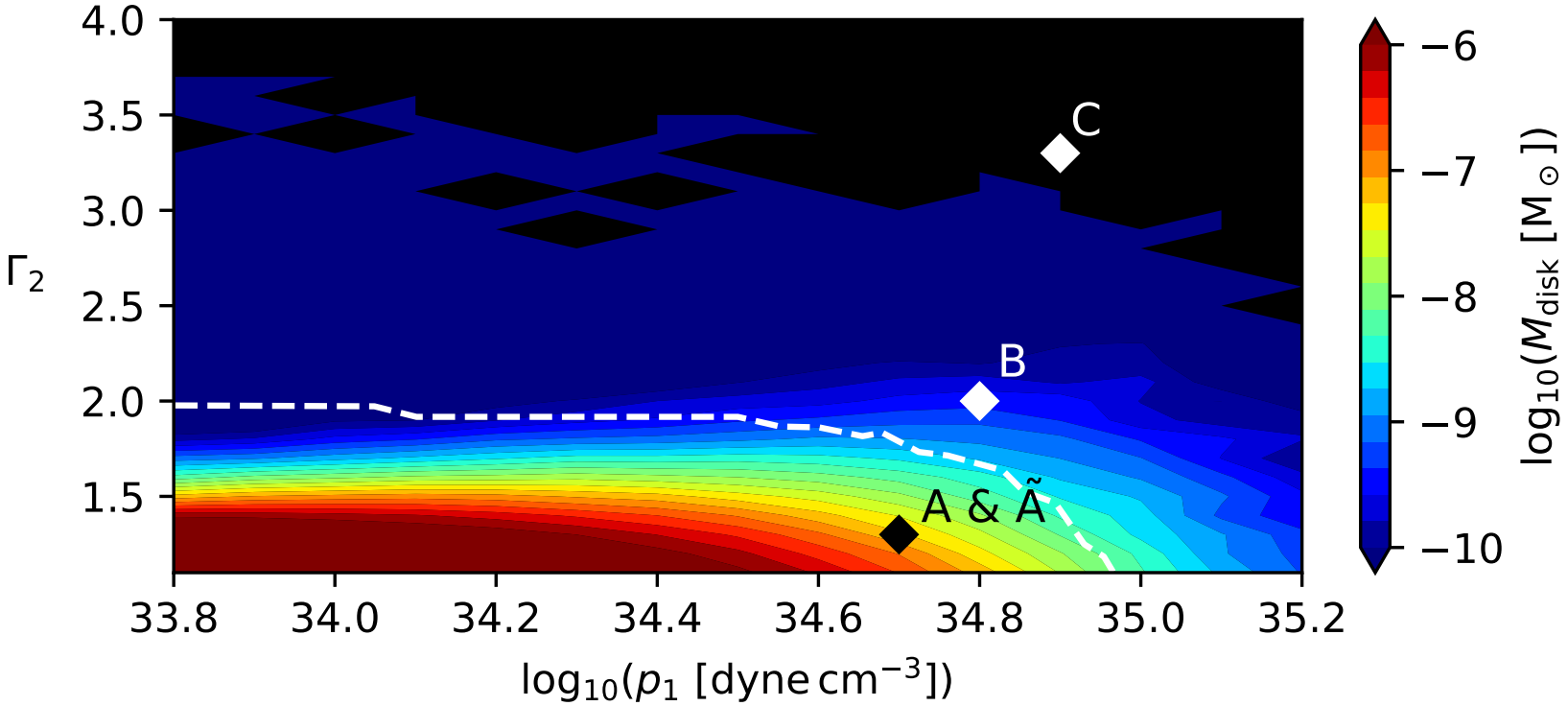
Numerical methods

We modified XNS (Bucciantini & Del Zanna 2011, Pili+ 2014):

- equilibrium configuration of a rotating neutron star
- harmonic decomposition on θ
- finite difference on r
- XCF approximation (Cordero-Carrión+ 2009):
  - eXtended: smart choice of variables $\rightarrow$ uniqueness
  - Conformal Flatness: $\gamma_{ij} = \psi^4 \eta_{ij}$
  - hierarchical decomposition of the equations
- originally written for the GRMHD XECHO code
- main modification: Self Consistent Field Method
  - namely, iteratively solve ∇ (new) $=$ old

We then tested some selected configuration with the GRHD BAM code (Brügmann+ 2008, Thierfelder+ 2011).

Results from the equilibrium model

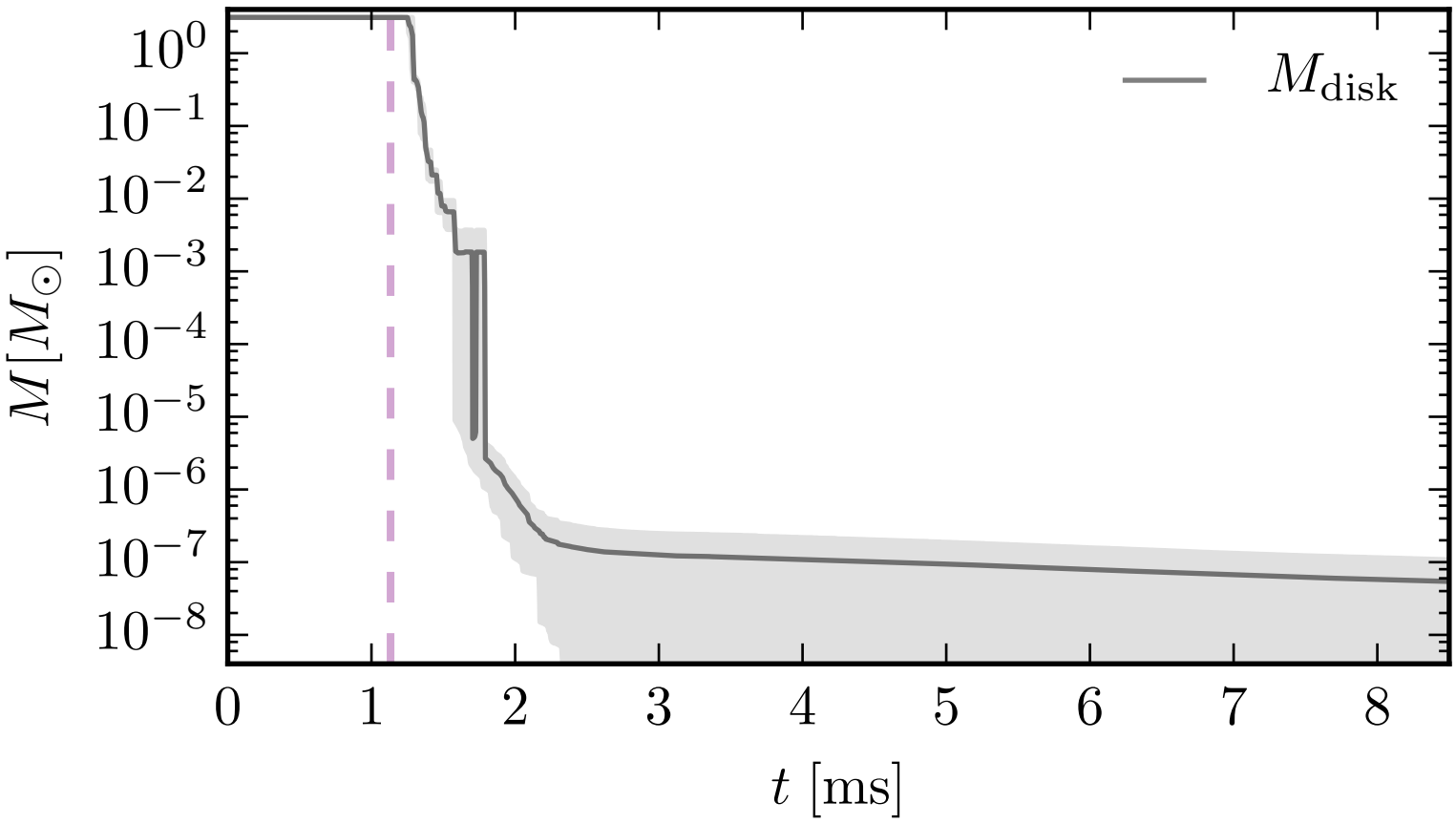


$$\text{model B: } M_{\mathrm{disk}} = 3 \times 10^{-10}\,\mathrm{M_\odot} \rightarrow E_{\mathrm{GRB}} \lesssim 5.4 \times 10^{43}\,\mathrm{ergs}$$

(efficiency = 10%)

Dinamical simulations

(performed by Tim Dietrich with the BAM code)



model B: $M_{\rm disk} \lesssim 10^{-7}\,{\rm M}_\odot \rightarrow E_{\rm GRB} \lesssim 1.8 \times 10^{46}\,{\rm ergs}$

Conclusions

- confirmation of the results of Margalit+ (2015)
- results further checked with dynamical simulations (see also Shibata+ 2000)
- very small disk formation from NS collapse to BH
- not enough energy to trigger a GRB
- similar results for realistic EOSs

Thanks!

contact: giovanni.camelio@astro.su.se

main references:

- Shibata et al., *Stability and collapse of rapidly rotating, supramassive neutron stars: 3D simulations in GR*, PRD **61**:044012 (2000).
- Shapiro, *Collapse of uniformly rotating stars to black holes and the formation of disks*, ApJ **610**:913 (2004).
- MacFadyen et al., *X-ray flares following short γ-ray bursts from shock heating of binary stellar companions*, arXiv:astro-ph/0510192.
- Margalit et al., *Does the collapse of a supramassive neutron star leave a debris disk?*, PRL **115**:171101 (2015).
- Camelio, Dietrich and Rosswog, *Disk formation in the collapse of supramassive neutron stars*, to be published on MNRAS, arXiv:1806.07775.