Disk formation from the collapse of a rotating neutron star

Giovanni Camelio
with Tim Dietrich and Stephan Rosswog

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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 $\sim 100$ 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.
Some neutron star material can escape the black hole formation (and generate a disk, Shapiro 2004) if

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

- Not all configurations can collapse: \( \left. \frac{\partial M}{\partial \rho_c} \right|_J = 0 \)
- Increasing \( \Omega \rightarrow j/m \) (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 $\theta$
▶ 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 $\nabla (\text{new}) = \text{old}$

We then tested some selected configuration with the GRHD BAM code (Brügmann+ 2008, Thierfelder+ 2011).
model B: $M_{\text{disk}} = 3 \times 10^{-10} M_\odot \rightarrow E_{\text{GRB}} \lesssim 5.4 \times 10^{43} \text{ ergs}$

(efﬁciency = 10%)
Dynamical simulations

(performed by Tim Dietrich with the BAM code)

model B: $M_{\text{disk}} \lesssim 10^{-7} M_\odot \rightarrow E_{\text{GRB}} \lesssim 1.8 \times 10^{46}$ 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:


