The crucial role of binary interactions for energetic explosions of massive stars

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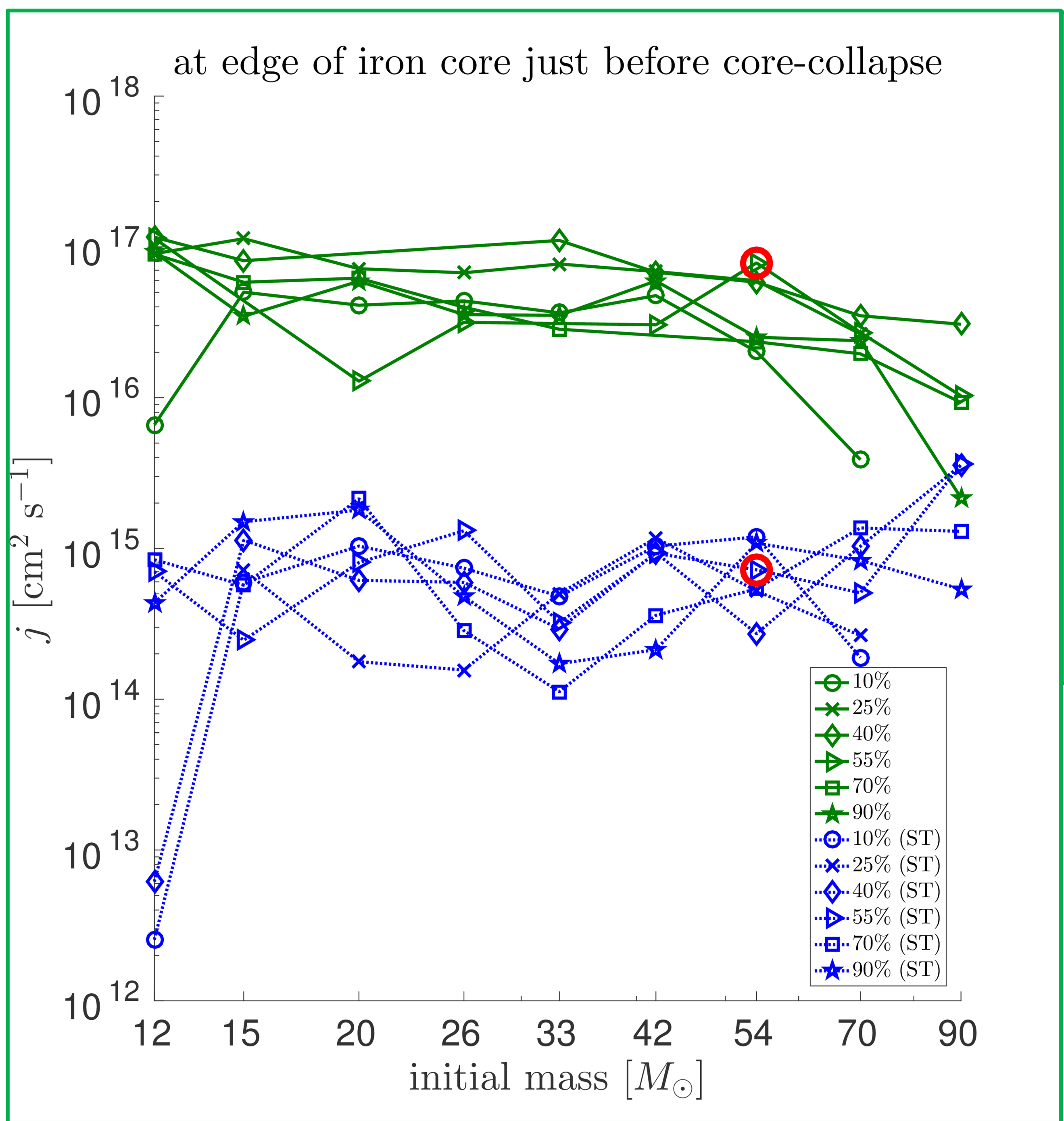
Abstract

I study the core rotation rate in numerous stellar models, and find that it is rather insensitive to the initial rotation rate and initial mass. The decisive factor is the slow-down of the core due to magnetic fields, modeled with the Spruit-Tayler dynamo. Binary interactions are therefore crucial for explosions of energetic supernovae and those with jets and magnetars, where high rotation is called for.

Numerical Method

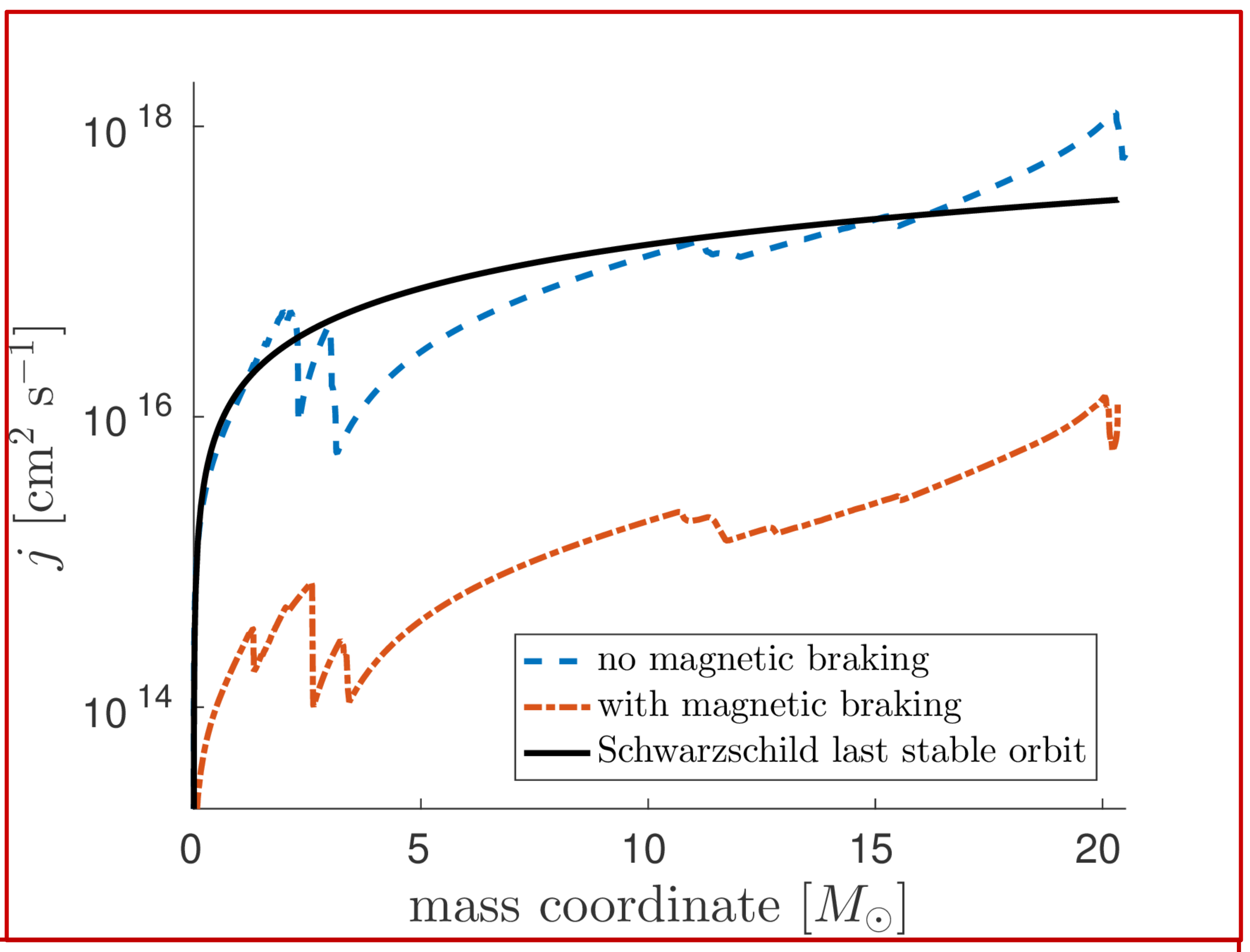
I evolve a set of stellar models up to the point of core-collapse (in-fall velocity reaches 1000 km/s) with the MESA code (Paxton et al. 2011, 2013, 2015). 98 models with initial masses between 12 and 90 solar masses and initial rotation rates between 10% and 90% of breakup are evolved with some including the Spruit dynamo (Spruit 2002) and with some excluding it. Out of these, two models with the same initial rotation rate and mass but differing by the inclusion of the Spruit dynamo are mapped into the hydrodynamic solver FLASH (Fryxell et al. 2000), which includes core deleptonization and approximate neutrino transport (following the methods of Couch & O'Connor 2014). The flow dynamics are followed for several hundreds of milliseconds after core bounce.

What affects core rotation?



Magnetic braking dramatically affects the core rotation rate. For the most part, the initial rotation rate (indicated as percentage of the breakup rotation value) and mass have little importance. The stellar models are clearly divided to those without magnetic braking (green, above) and those with (blue, lower).

How fast is 'fast'?

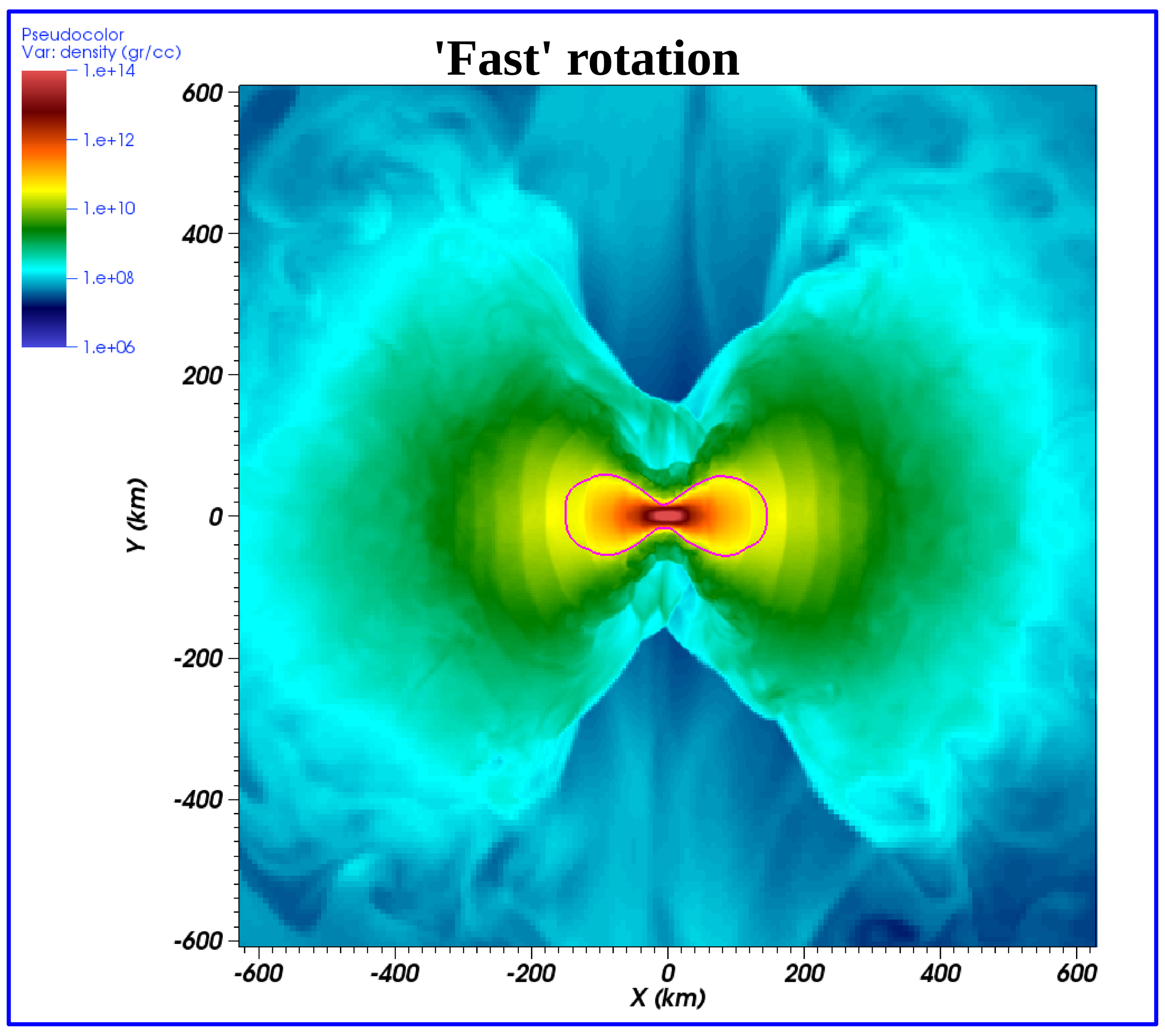


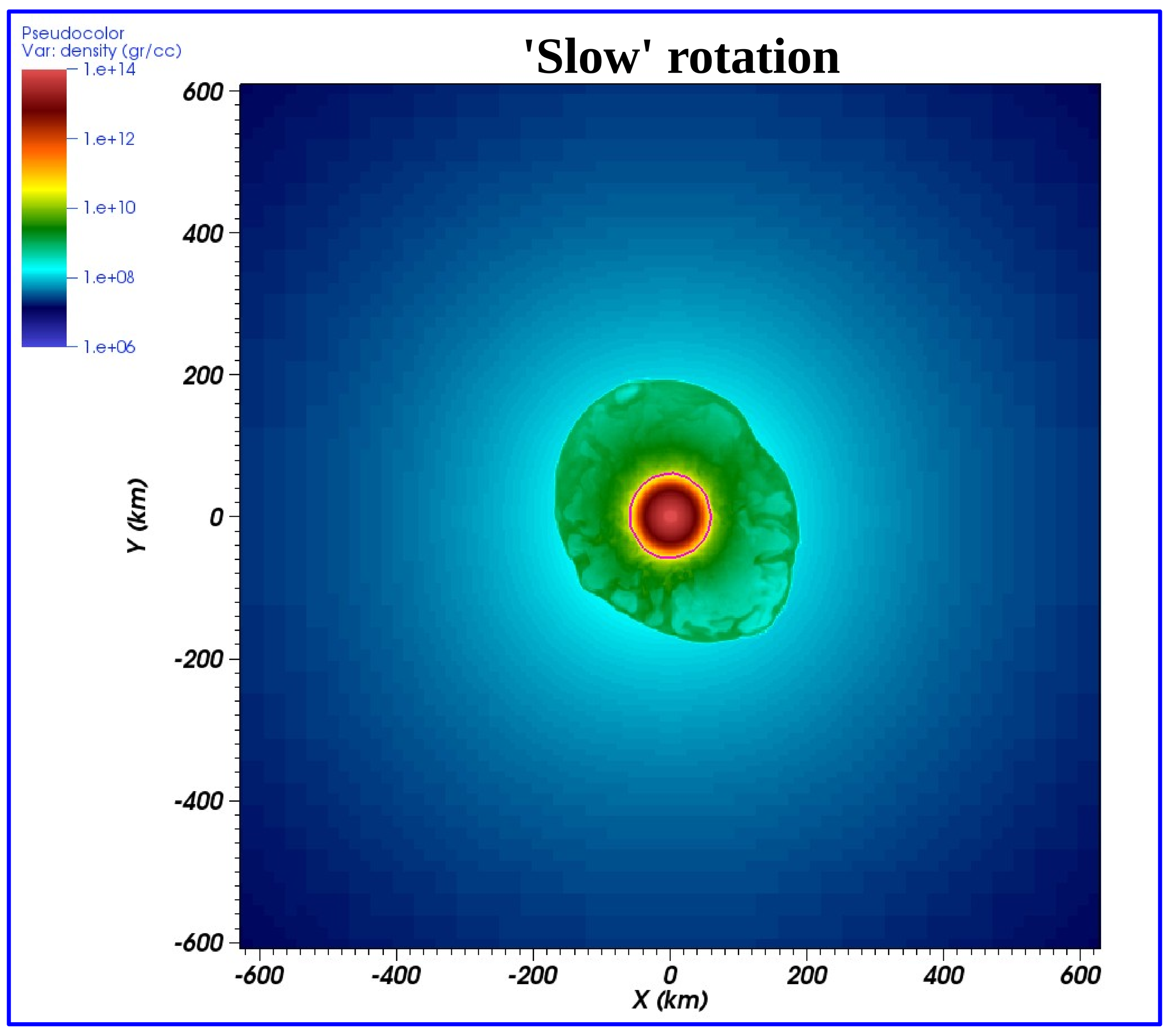
Specific angular momentum as function of mass coordinate at the time of transition from evolution with MESA to simulation with FLASH. When the Spruit dynamo is not taken into account, the specific angular momentum before collapse is comparable to that of the innermost stable circular orbit around a Schwarzschild black hole. These two models are marked with red circles in the figure on the left.

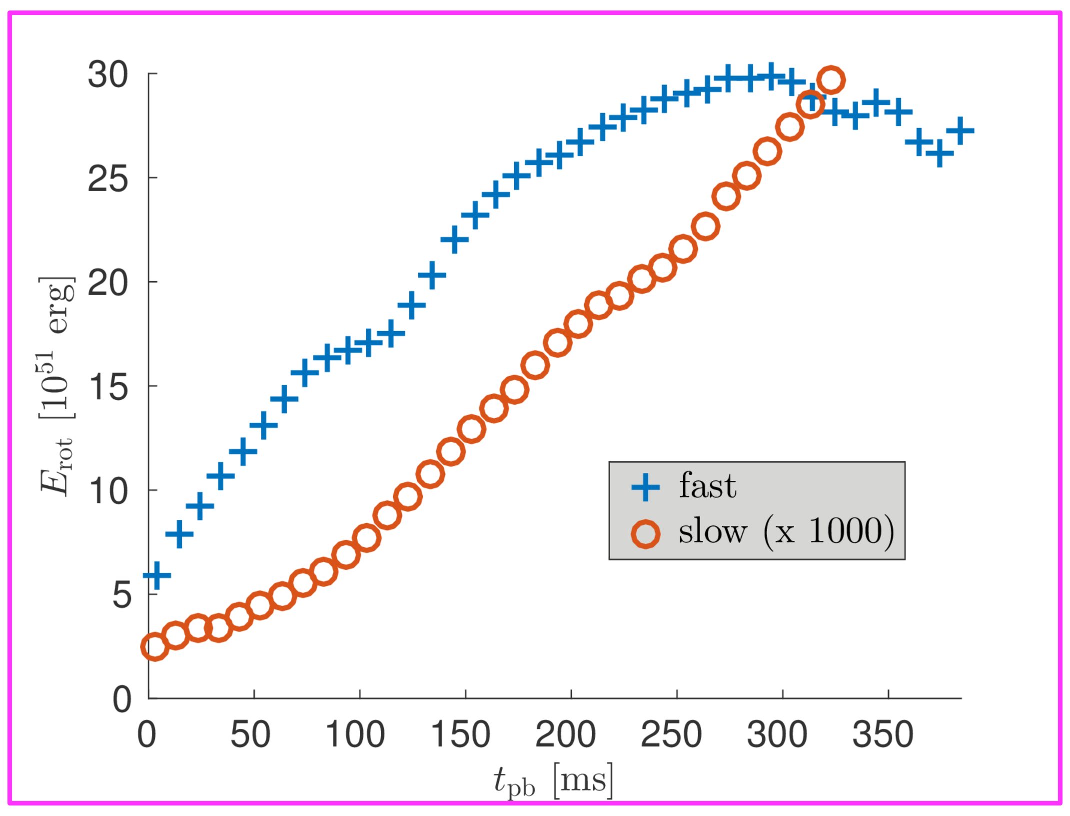
Why is rotation important?

- High pre-collapse rotation produces a post-collapse neutron-rich accretion disk surrounding a rapidly-rotating proto-neutron star (Gilkis 2016).
- Super-luminous or super-energetic supernovae powered by a magnetar and/or collimated jets require high core rotation rates, and amplification of magnetic fields (possible in regions of high shearing).

325 ms post-bounce







Rotational kinetic energy of the proto-neutron star as function of time from core bounce. The fast rotation case has a kinetic energy equivalent to many supernova explosions!