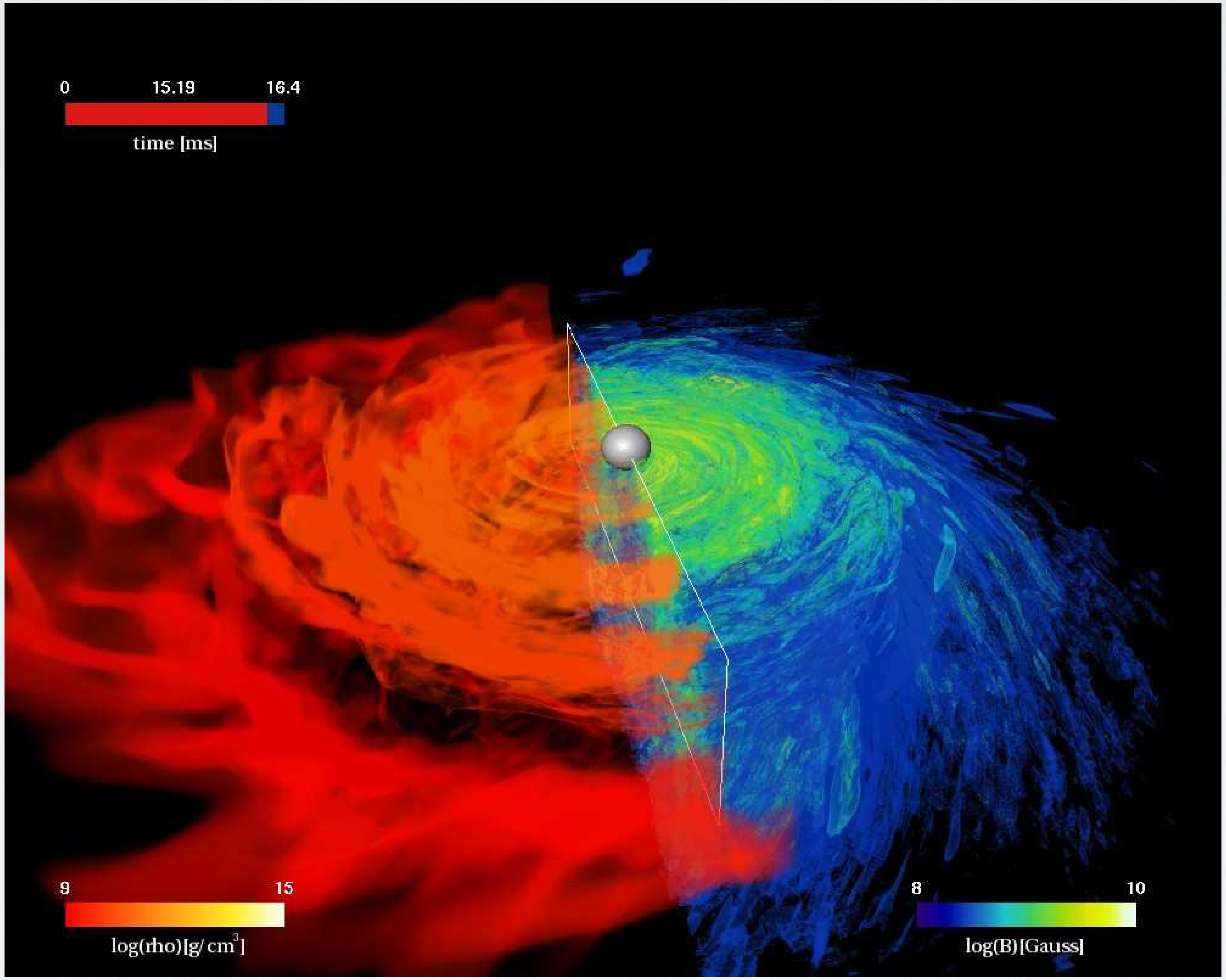
MAGNETAR FORMATION FROM THE MERGER OF BNS



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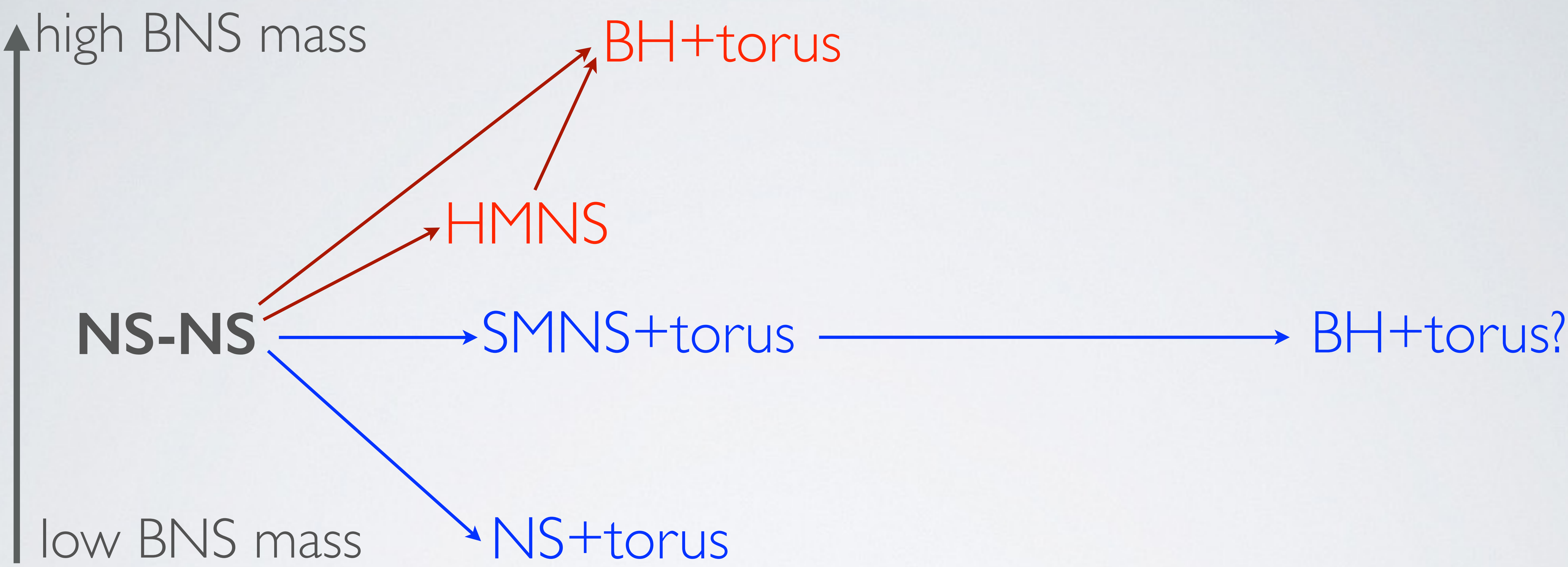
BNS POST-MERGER EVOLUTION

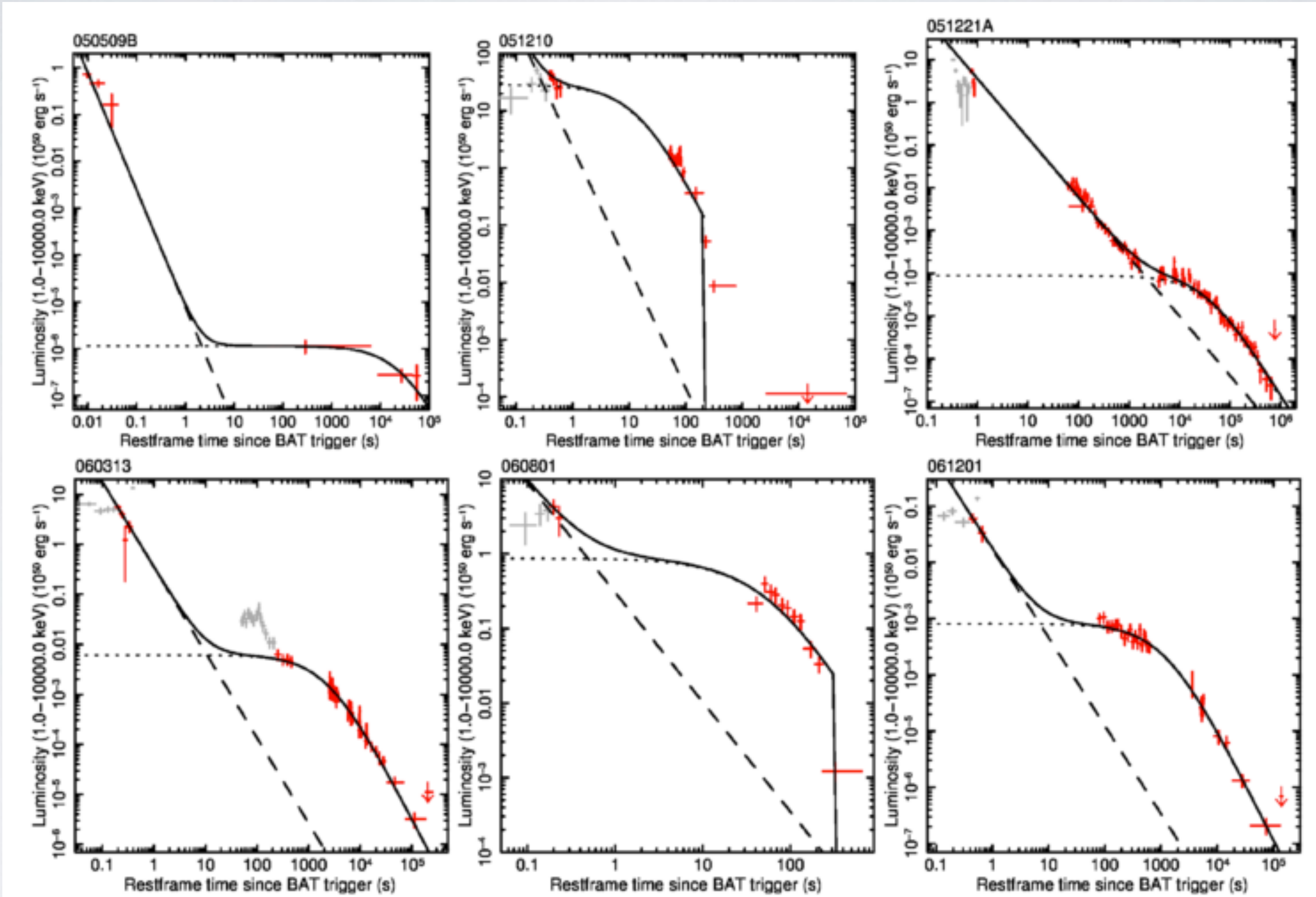
Depending on mass and EOS several post-merger scenarios:



Magnetic fields play fundamental role in post-merger dynamics
(jets from BH/NS+torus, NS collapse to BH, ...)

All these scenarios may lead to SGRBs with different properties

WHY DO WE NEED A MAGNETAR?



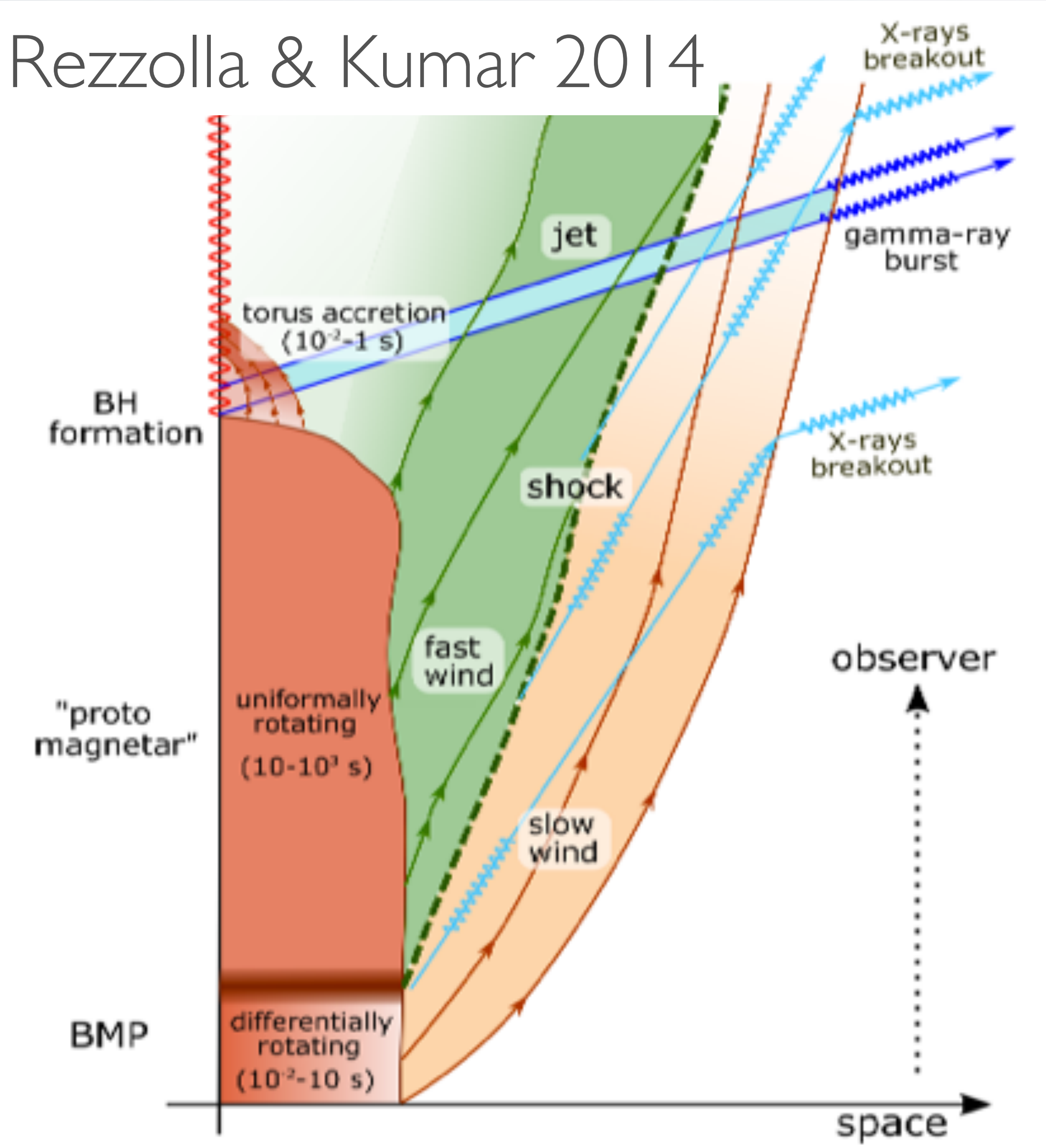
Rowlinson et al 2013

A stable or supramassive magnetar could be used to explain X-ray plateaus and extended emissions from SGRBs (e.g., Rowlinson et al 2013).

TIME-REVERSAL SGRB MODEL

(Ciolfi & Siegel 2014, Rezzolla & Kumar 2014)

Rezzolla & Kumar 2014

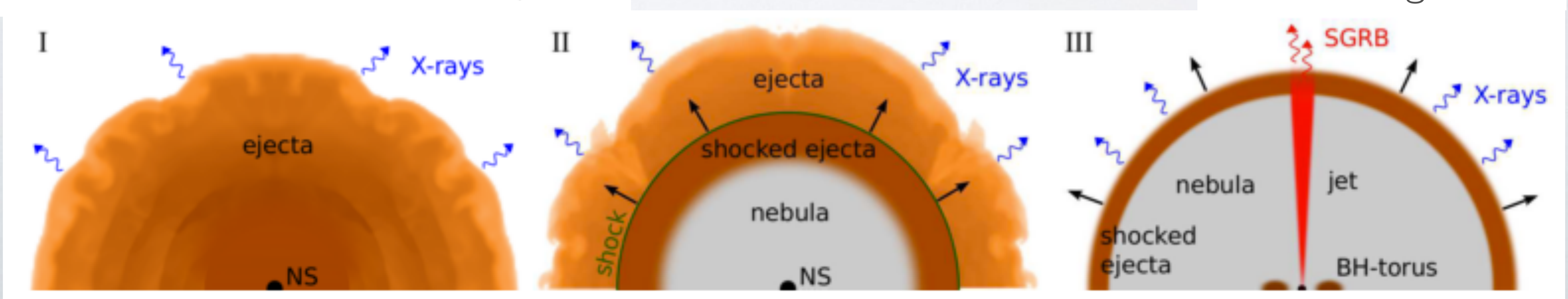


X-ray afterglow by magnetar

SGRB emitted by BH after collapse

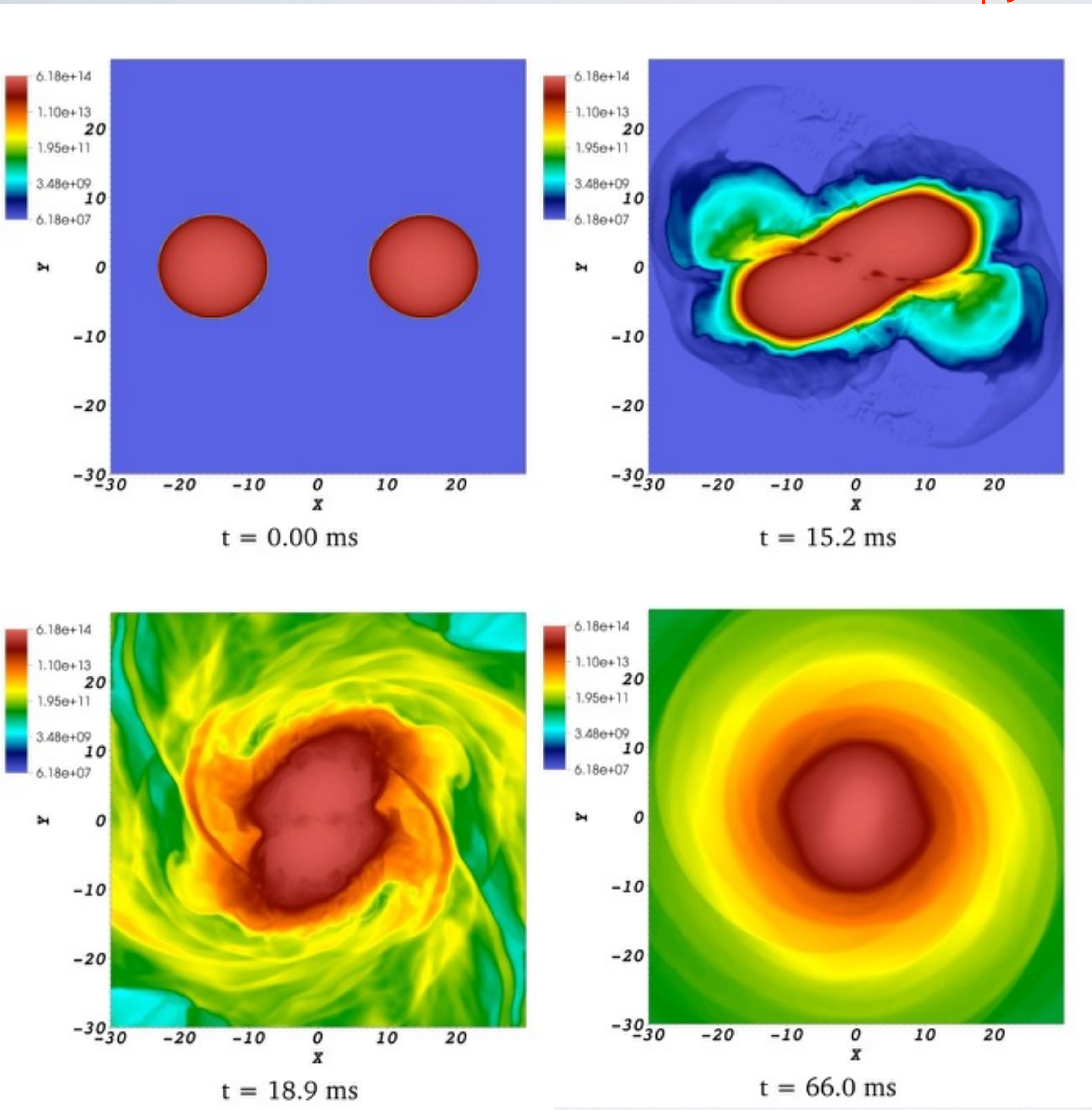
Can we form magnetars from BNS mergers?

Ciolfi & Siegel 2014



MAGNETAR FORMATION

Giacomazzo & Perna 2013, ApJ Letters, 771, L26

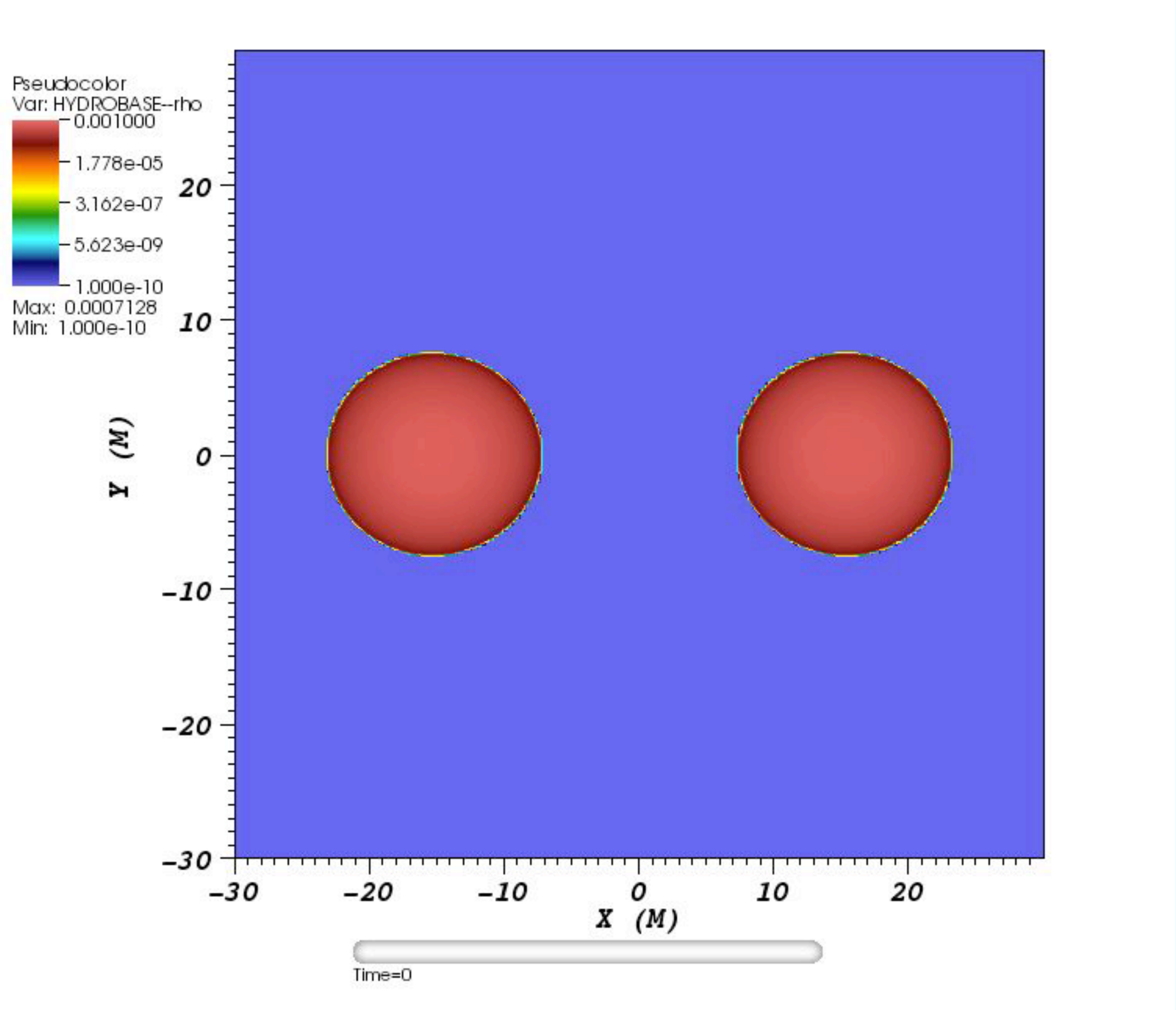


Investigated merger of two 1.2 M⊙ NSs

Used Ideal Fluid, Gamma=2.75, k=30000 (Oechslin et al 2007)

MAGNETAR FORMATION

Giacomazzo & Perna 2013, ApJ Letters, 771, L26



MAGNETAR FORMATION

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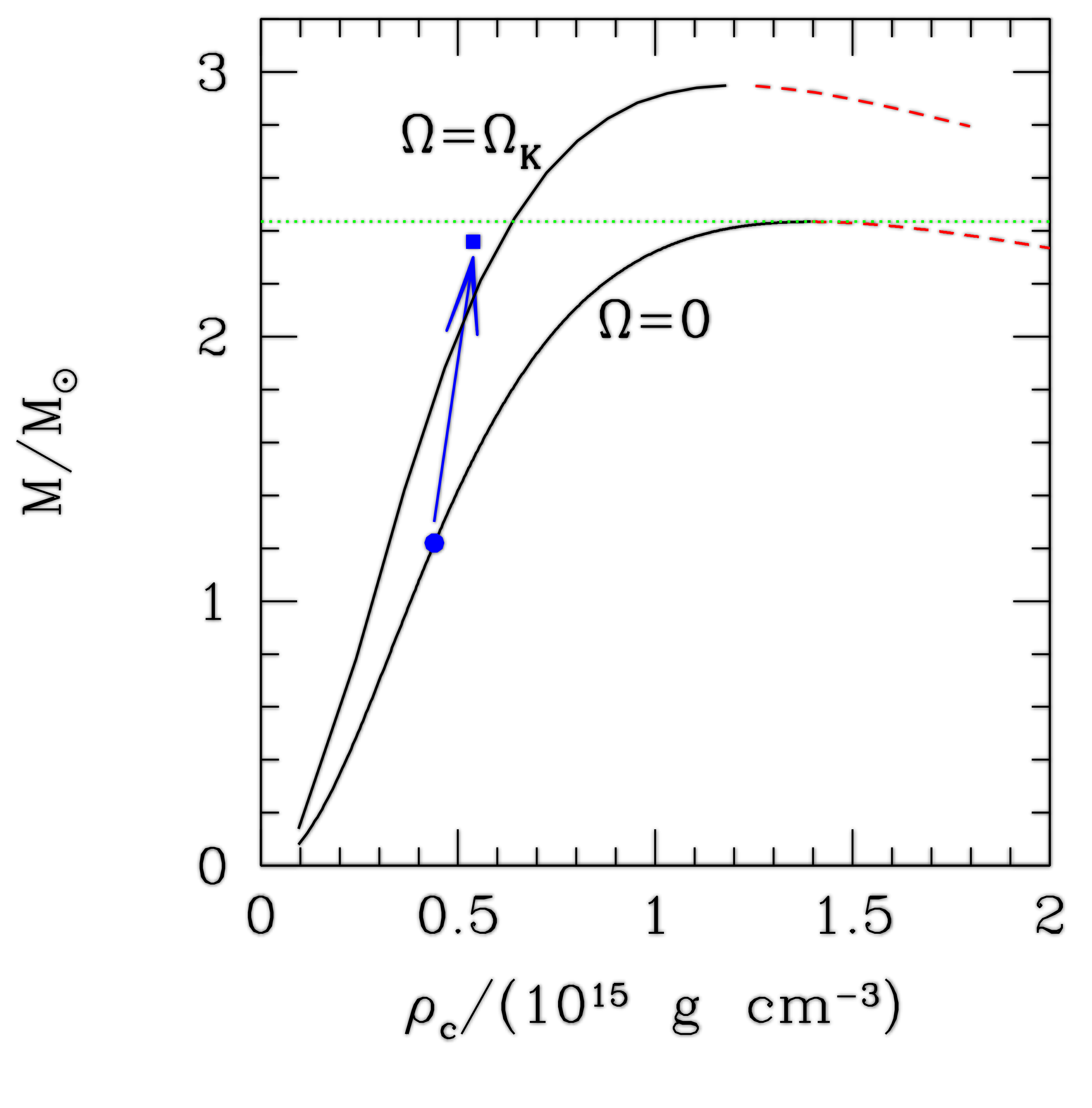
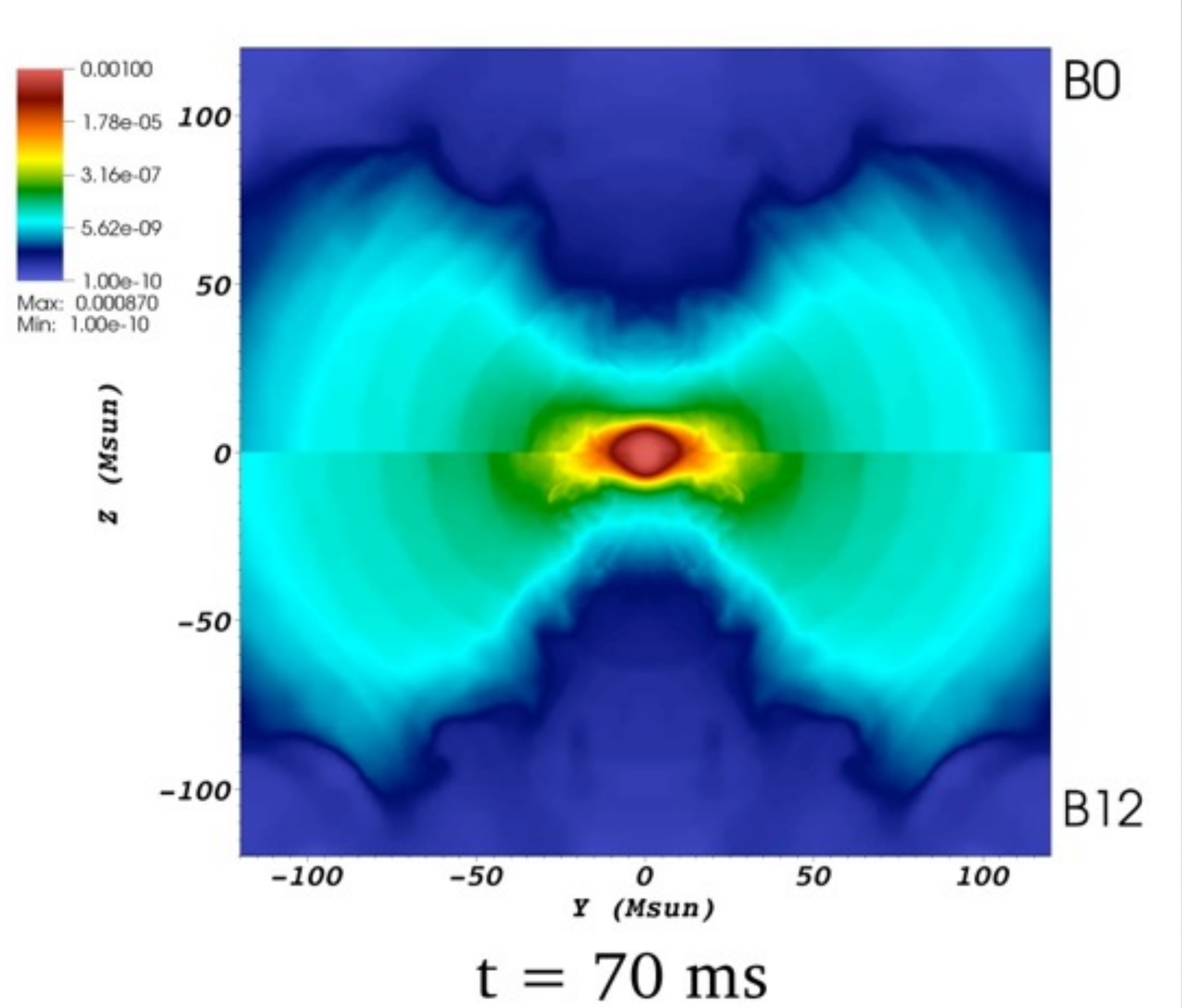


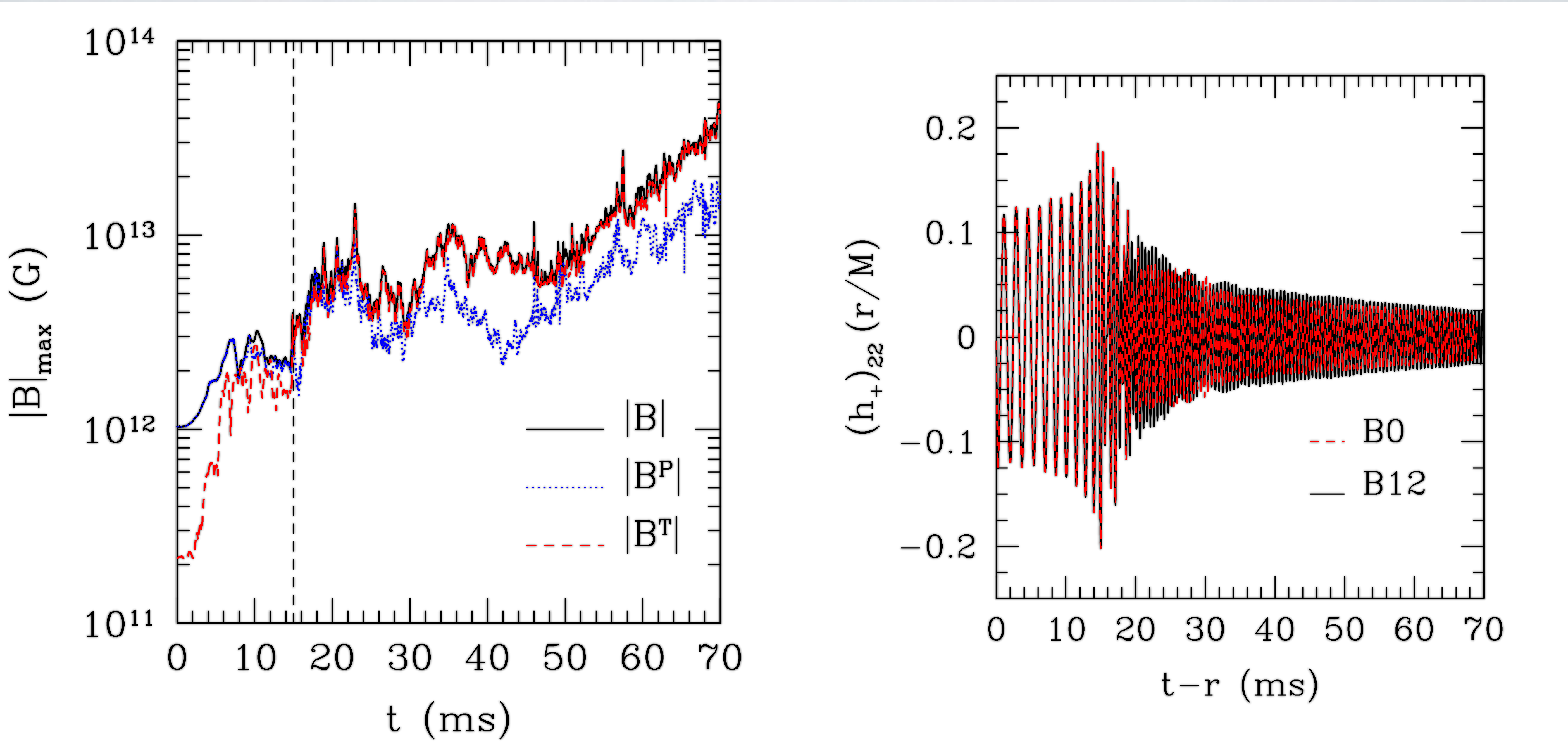


Produced a stable "ultraspinning" NS surrounded by a magnetized disk of ~0.1 M⊙

MAGNETAR FORMATION

Giacomazzo & Perna 2013, ApJ Letters, 771, L26

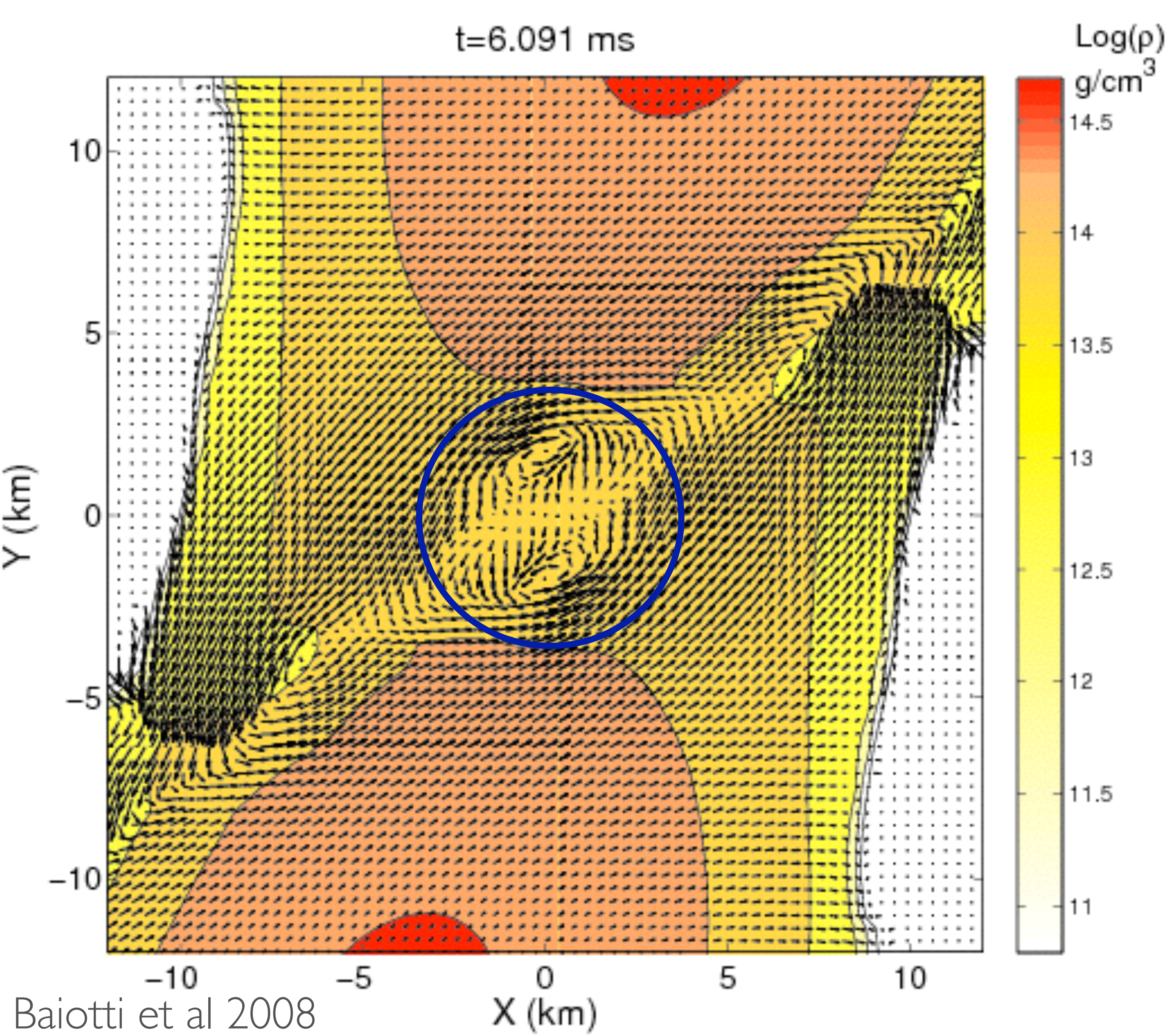
GWs publicly available for download at www.brunogiacomazzo.org/data.html



Magnetic field amplified of ~2 orders of magnitude. Difference in the GW signal are small and present only in the post-merger phase.

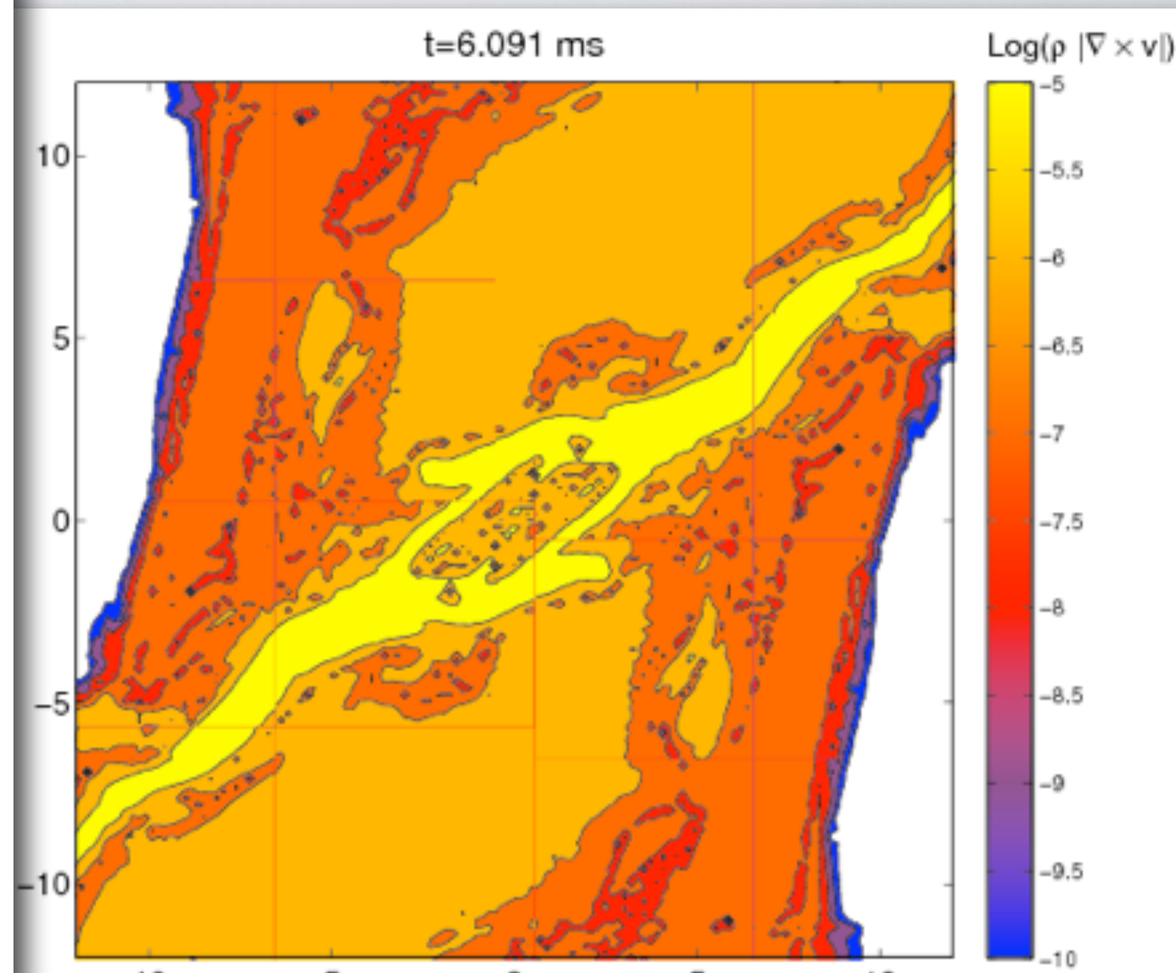
MAGNETIC FIELD AMPLIFICATION AT MERGER

During the merger a shear interface forms and it develops a Kelvin-Helmholtz instability which produces a series of vortices.



Baiotti et al 2008

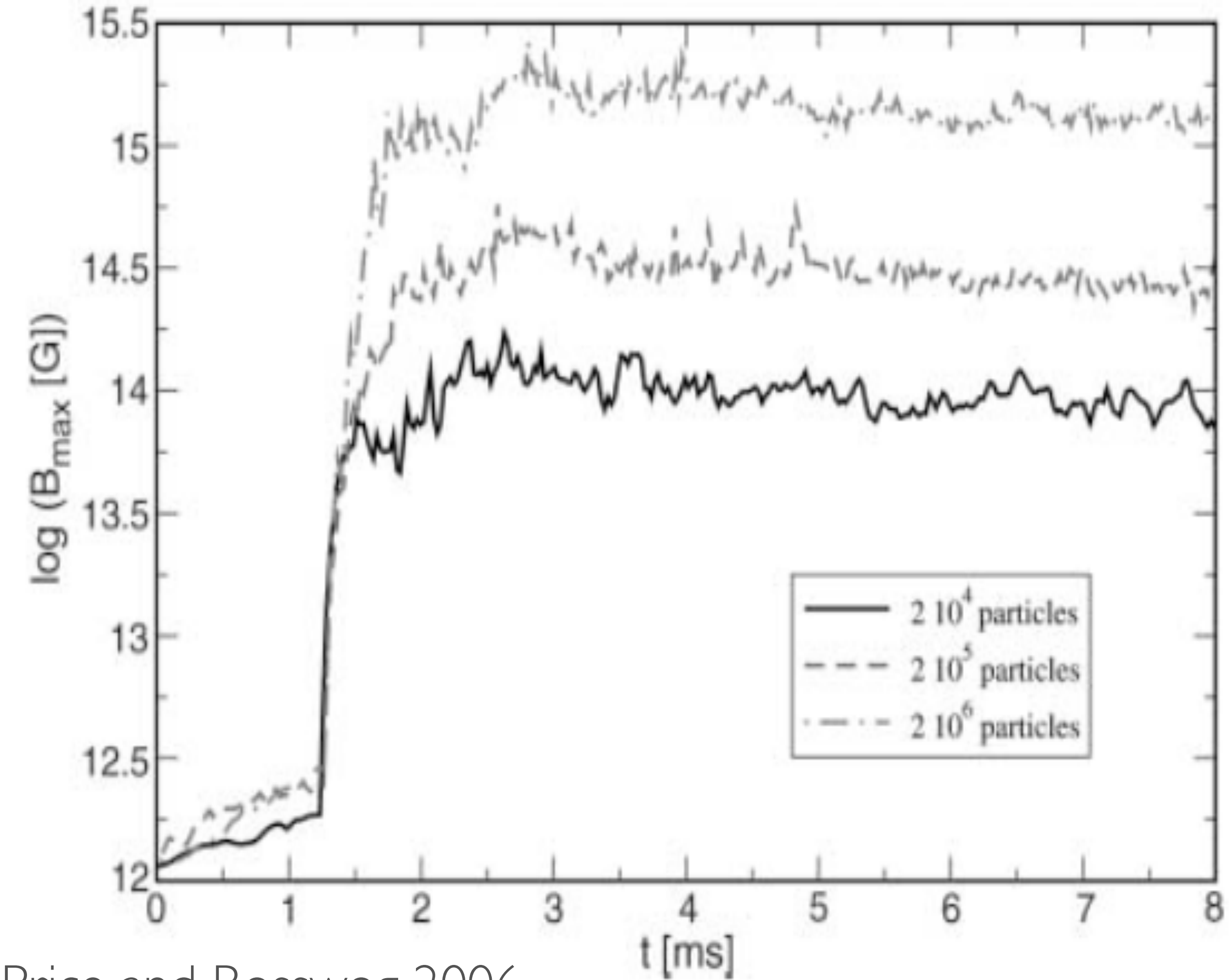
(v^x, v^y) in "corotating" frame



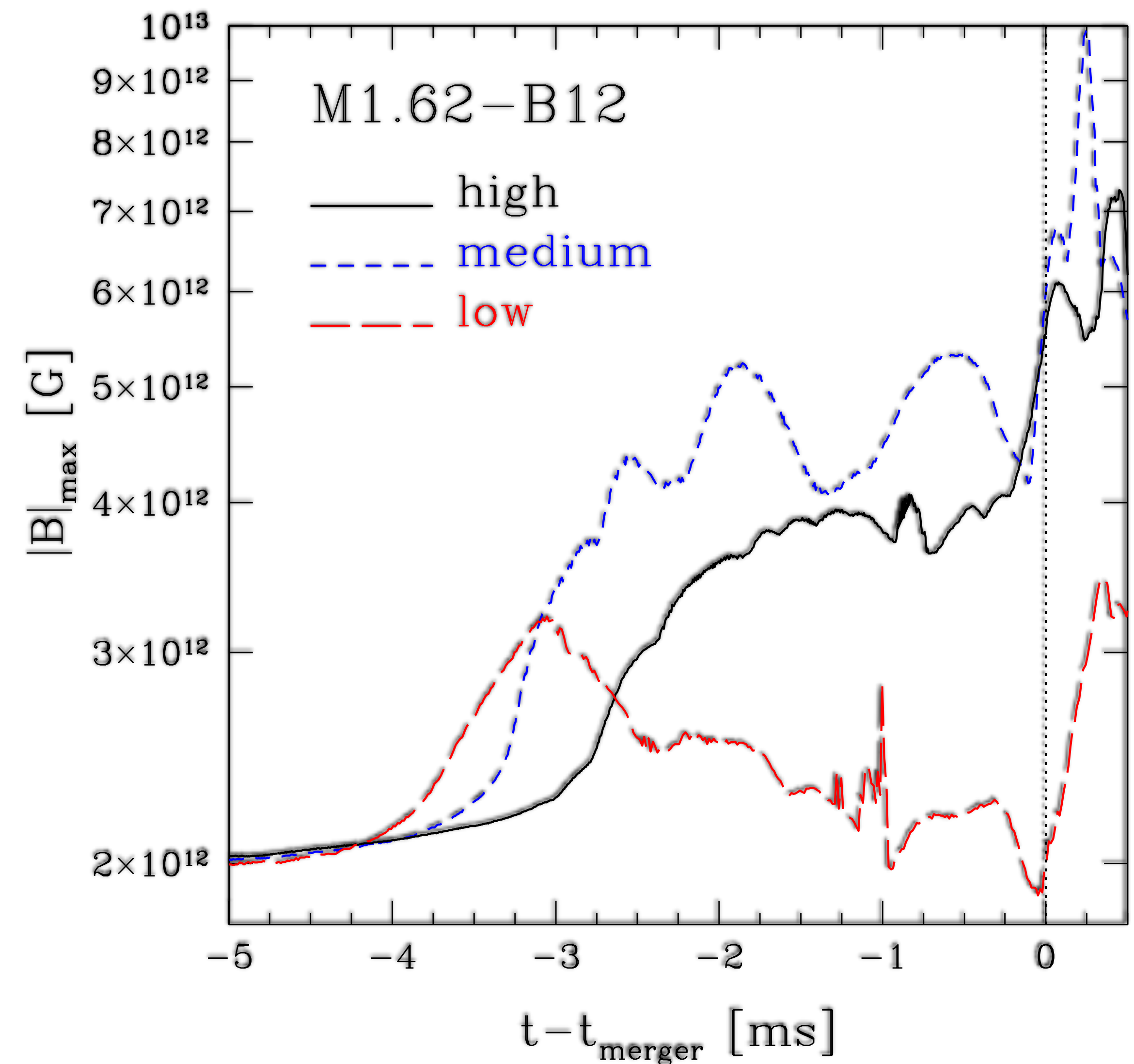
Baiotti et al 2008

$\rho|\nabla \times v|^z$

MAGNETIC FIELD AMPLIFICATION AT MERGER



Price and Rosswog 2006



Giacomazzo et al 2011

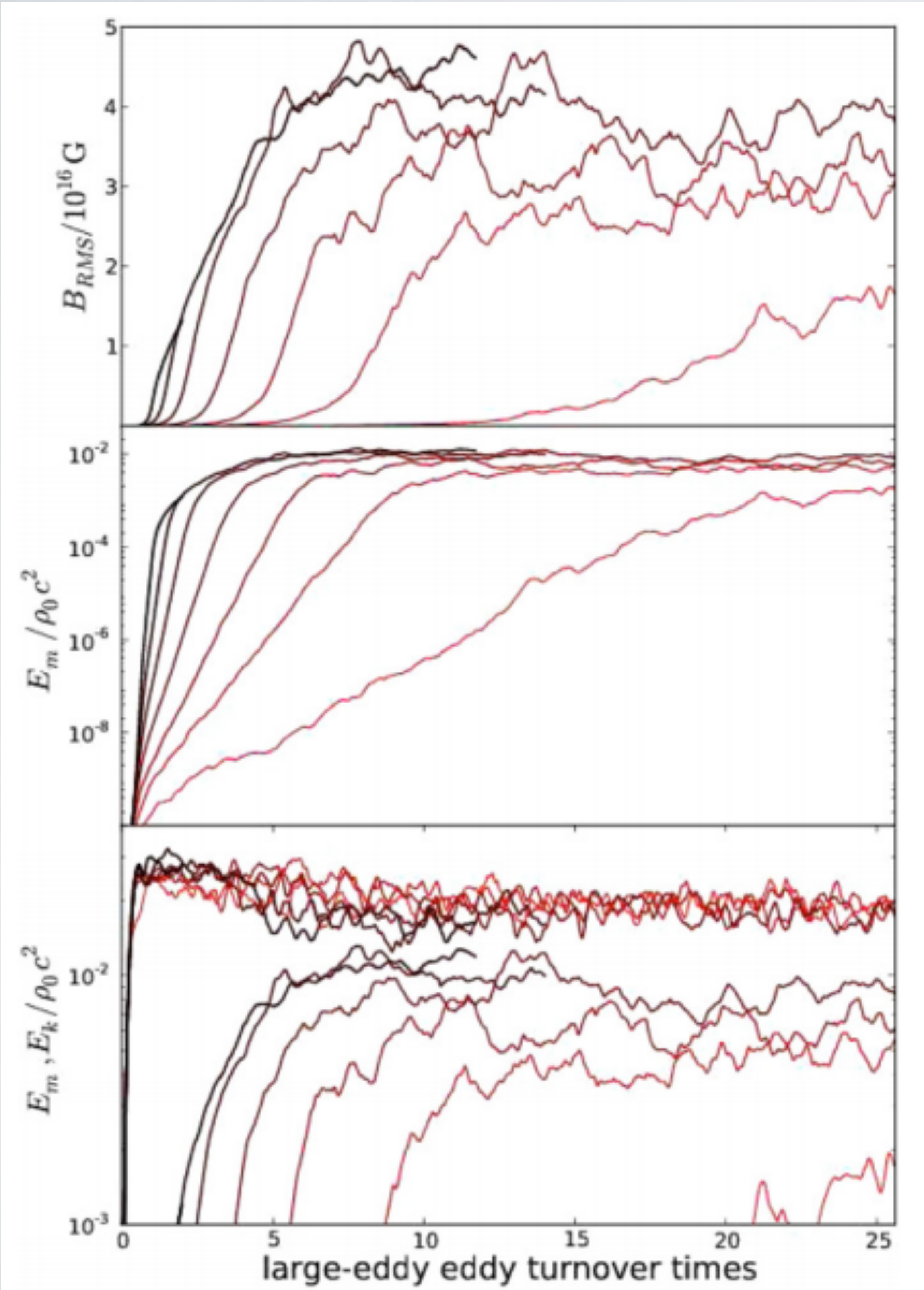
Previous Newtonian simulations by Price and Rosswog showed large magnetic field amplification (but not reproduced by other groups).

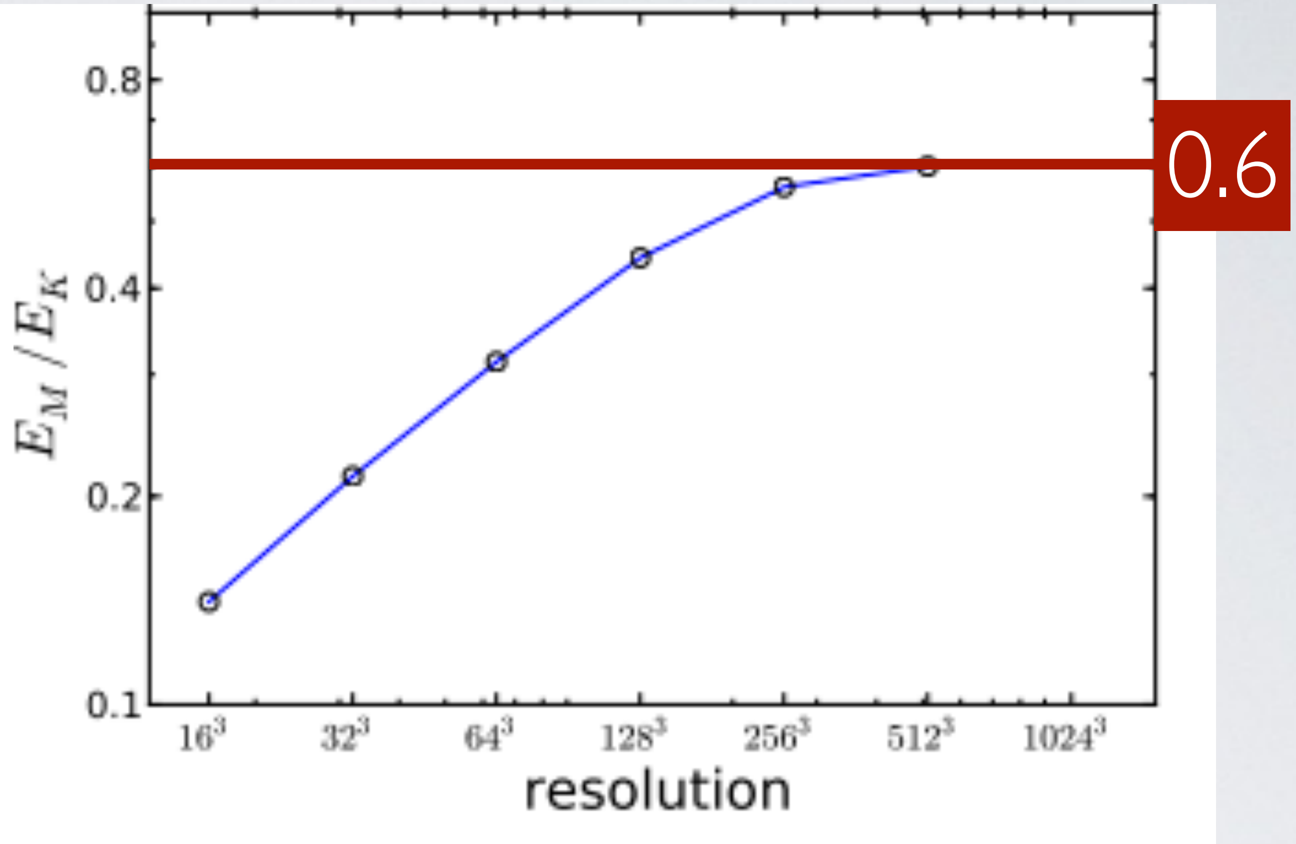
Even with high res we do not observe amplifications of several orders of magnitudes (similar results by other GR groups).

Local very high-res simulations shows that magnetic fields could be strongly amplified (Zrake & MacFadyen 2013), but res unfeasible for global BNS sims!

LOCAL SIMULATIONS

Zrake and MacFadyen 2013





Performed local high-res relativistic MHD simulations of turbulent flows.

Magnetic energy reaches equipartition with kinetic energy

Similar results (in Newtonian MHD) were obtained by Obergaulinger et al 2010

MAGNETIC FIELD AMPLIFICATION AT MERGER

Giacomazzo, Zrake, Duffell, MacFadyen, Perna 2015, arXiv:1410.0013

We developed a sub-grid model to account for small scale effects:

$$\partial_t A_i = -E_i + S_{\rm subgrid}\, A_i$$

$$S_{\rm subgrid} \equiv c_1 \max\left(|\nabla \times v| - c_3, 0\right) \times \max\left(1 - c_4 \frac{\rho_{\rm atmo}}{\rho}, 0\right) \times \max\left(1 - \frac{b^2}{c_2 \Delta w}, 0\right)$$

where $w \equiv \rho + \rho\epsilon$ is the energy density and

$$\Delta w \equiv <\rho>_{Cons} + <\rho\epsilon>_{Cons} - <\rho>_{Vol} - <\rho\epsilon>_{Vol}$$

which is equal to the turbulent kinetic energy (Duffel and MacFadyen 2013).

This model has four parameters: two need to be fine tuned (c_3 and c_4) and two (c_1 and c_2) are based on local simulations (Zrake & MacFadyen 2013).

MAGNETIC FIELD AMPLIFICATION AT MERGER

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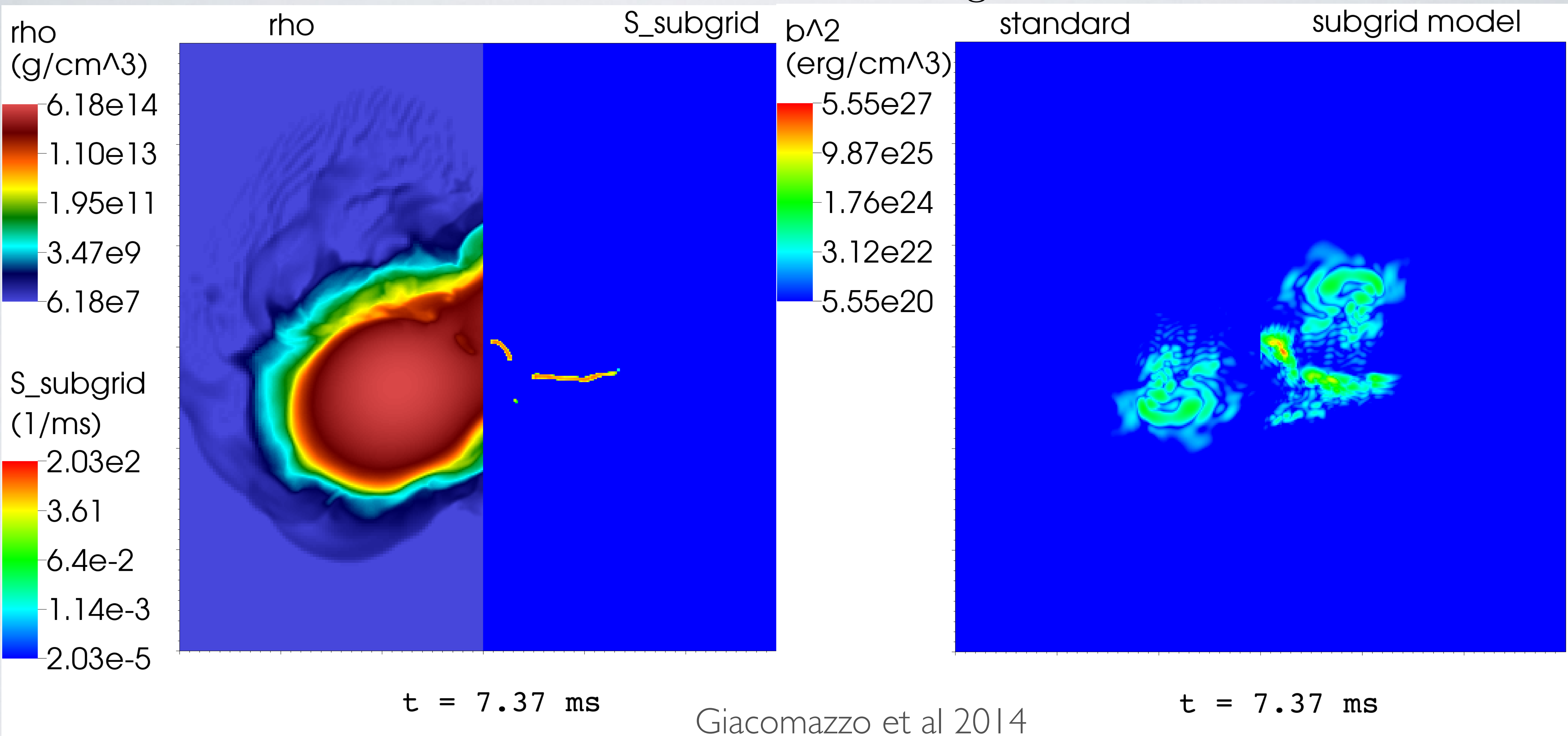


Giacomazzo et al 2014

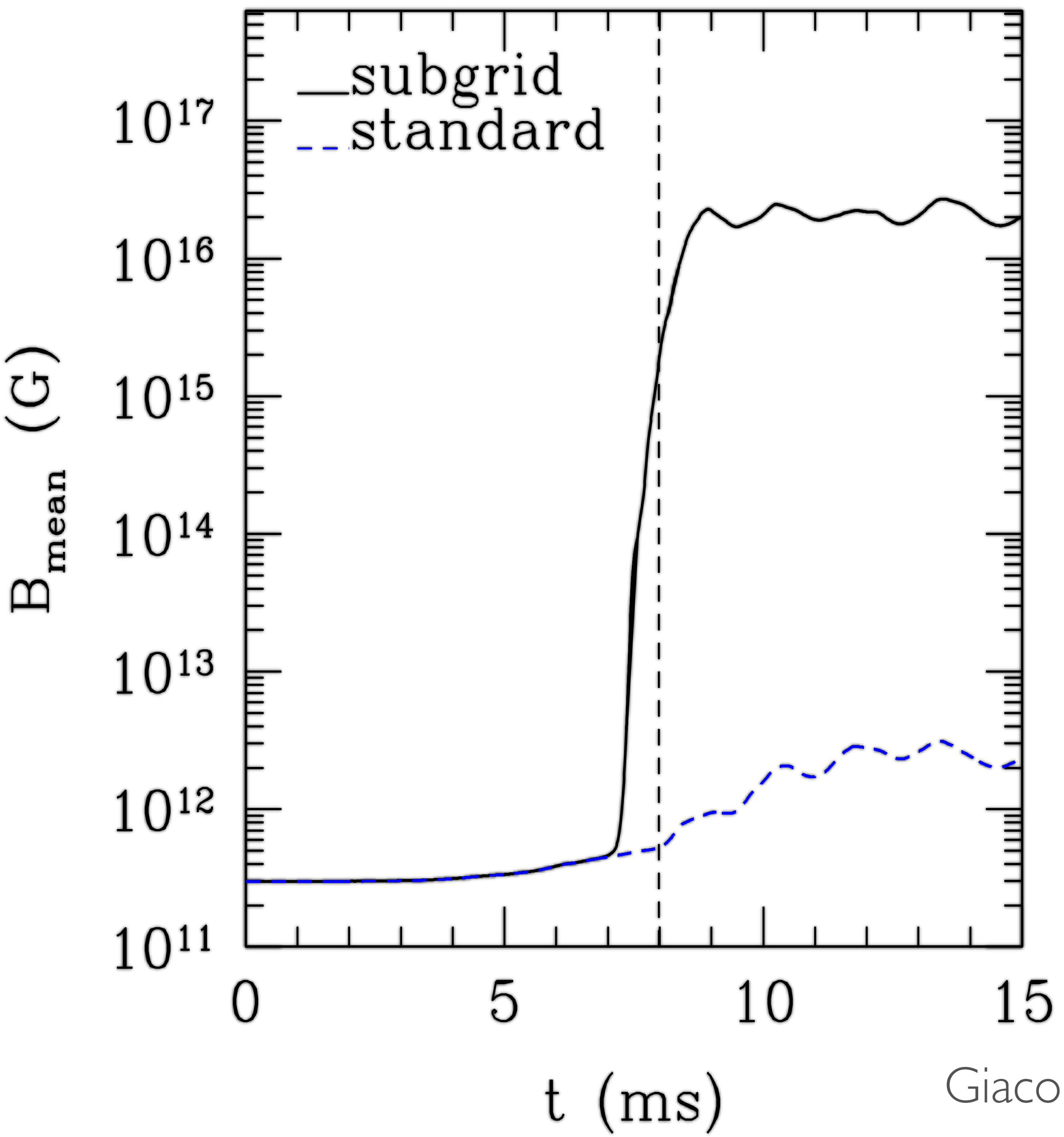
$S_{\rm subgrid}$ is different from zero only in the central turbulent region.

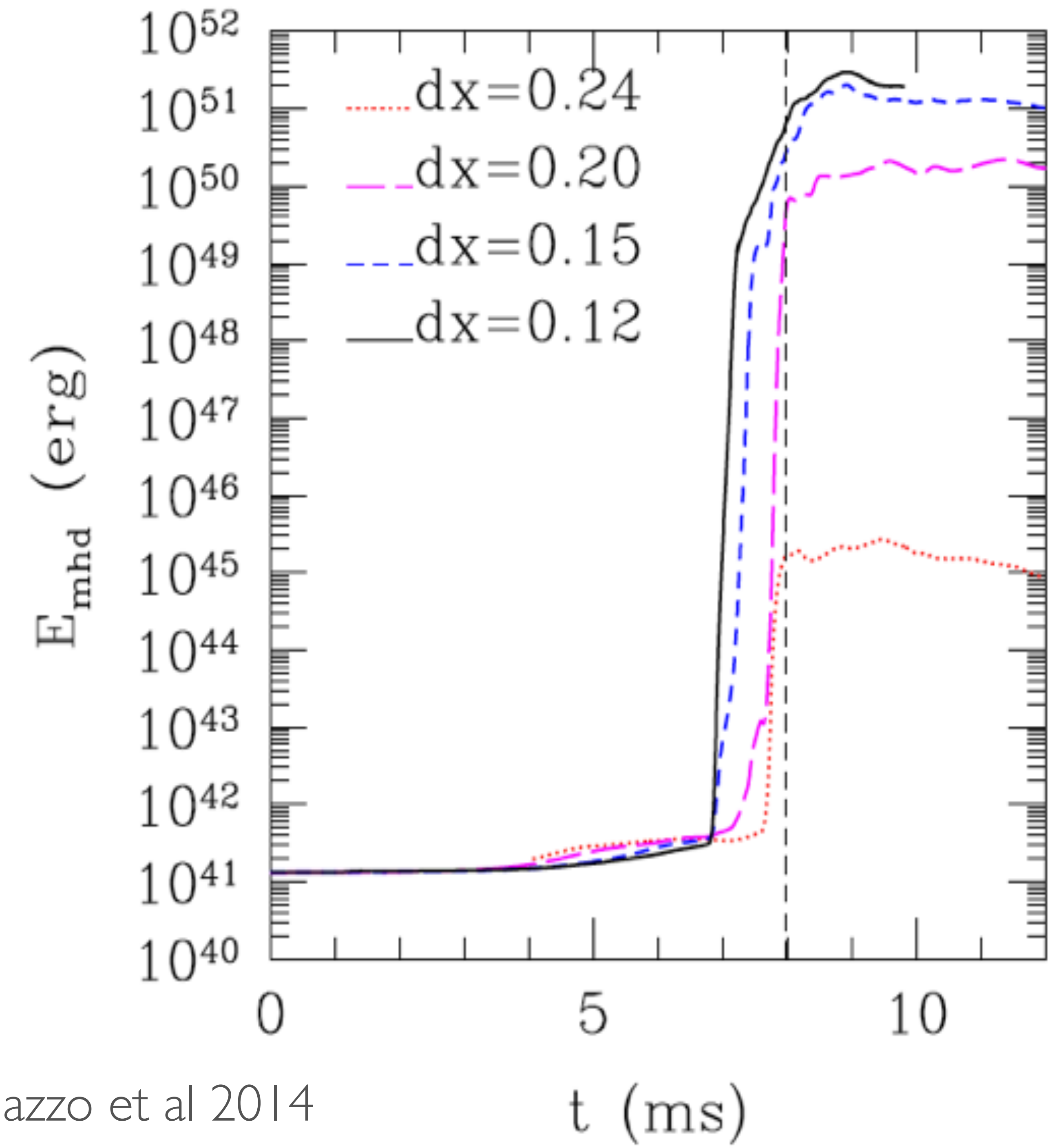
Magnetic field amplification is larger in the central vortices.

MAGNETIC FIELD AMPLIFICATION AT MERGER

Giacomazzo, Zrake, Duffell, MacFadyen, Perna 2015, arXiv:1410.0013

We implemented the sub-grid model in our GRMHD code Whisky and run a set of NS-NS simulations.





Giacomazzo et al 2014

GWS FROM MAGNETARS

Dall'Osso, **Giacomazzo**, Perna, Stella 2015, ApJ 798, 25

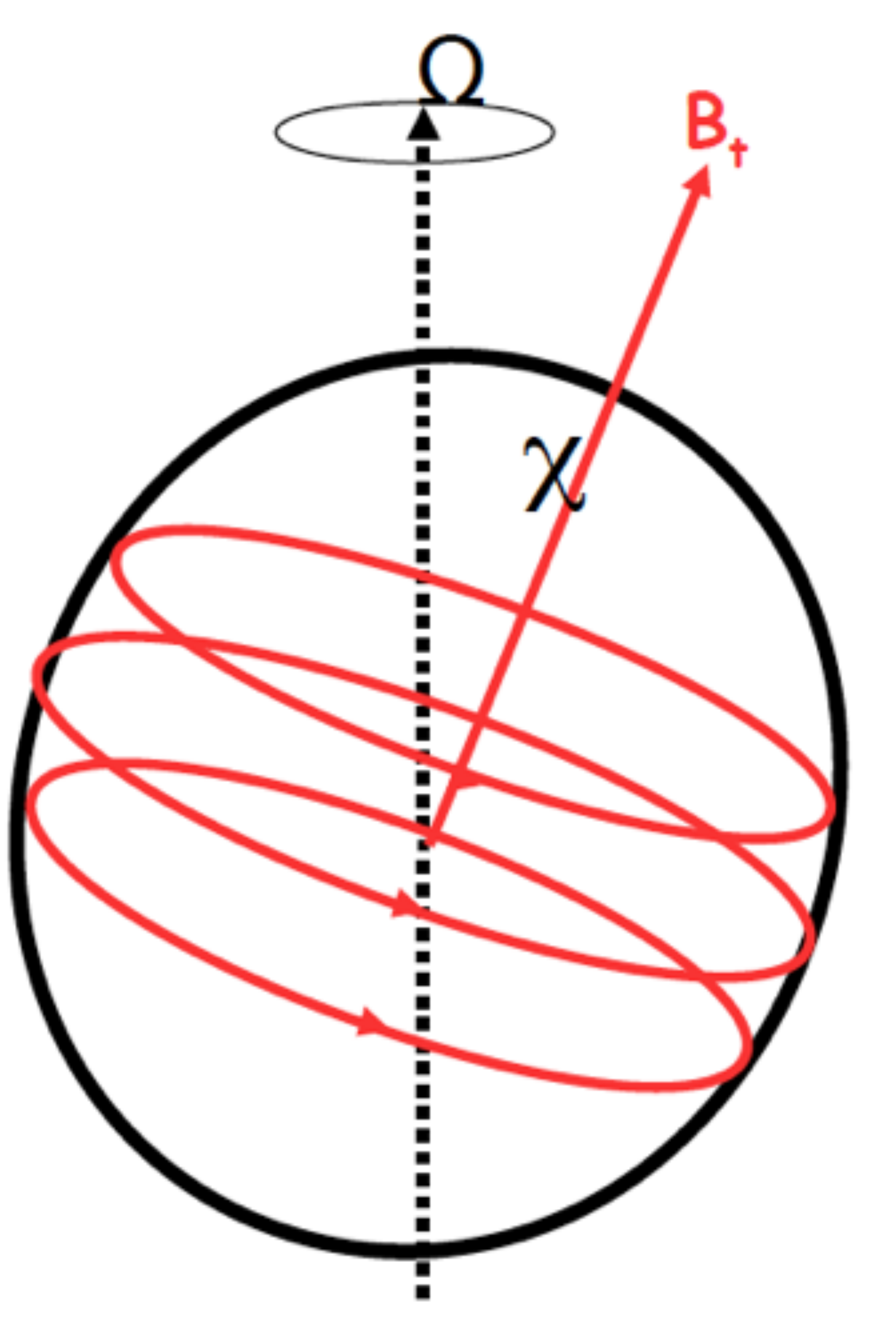
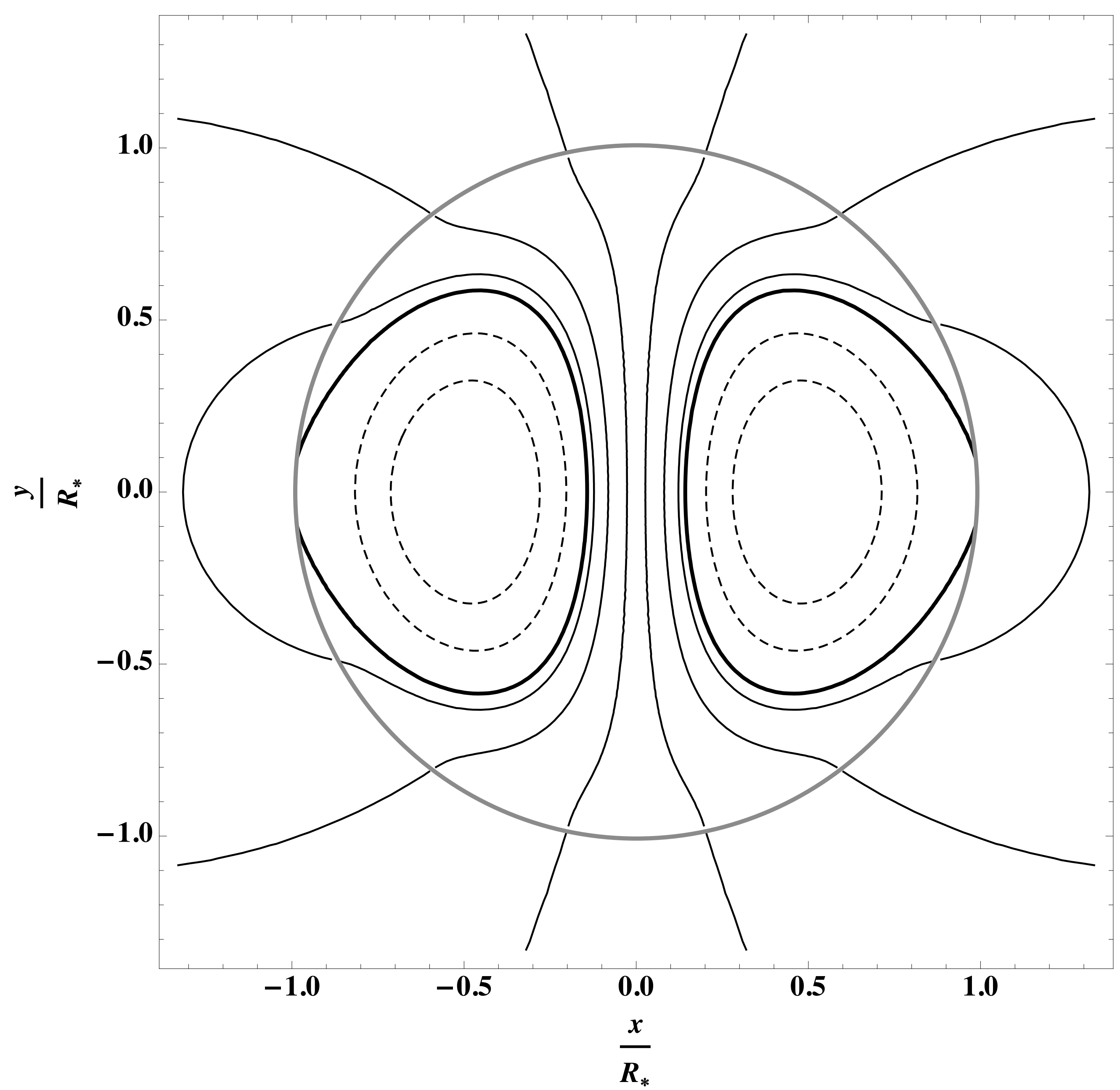


Figure by Dall'Osso



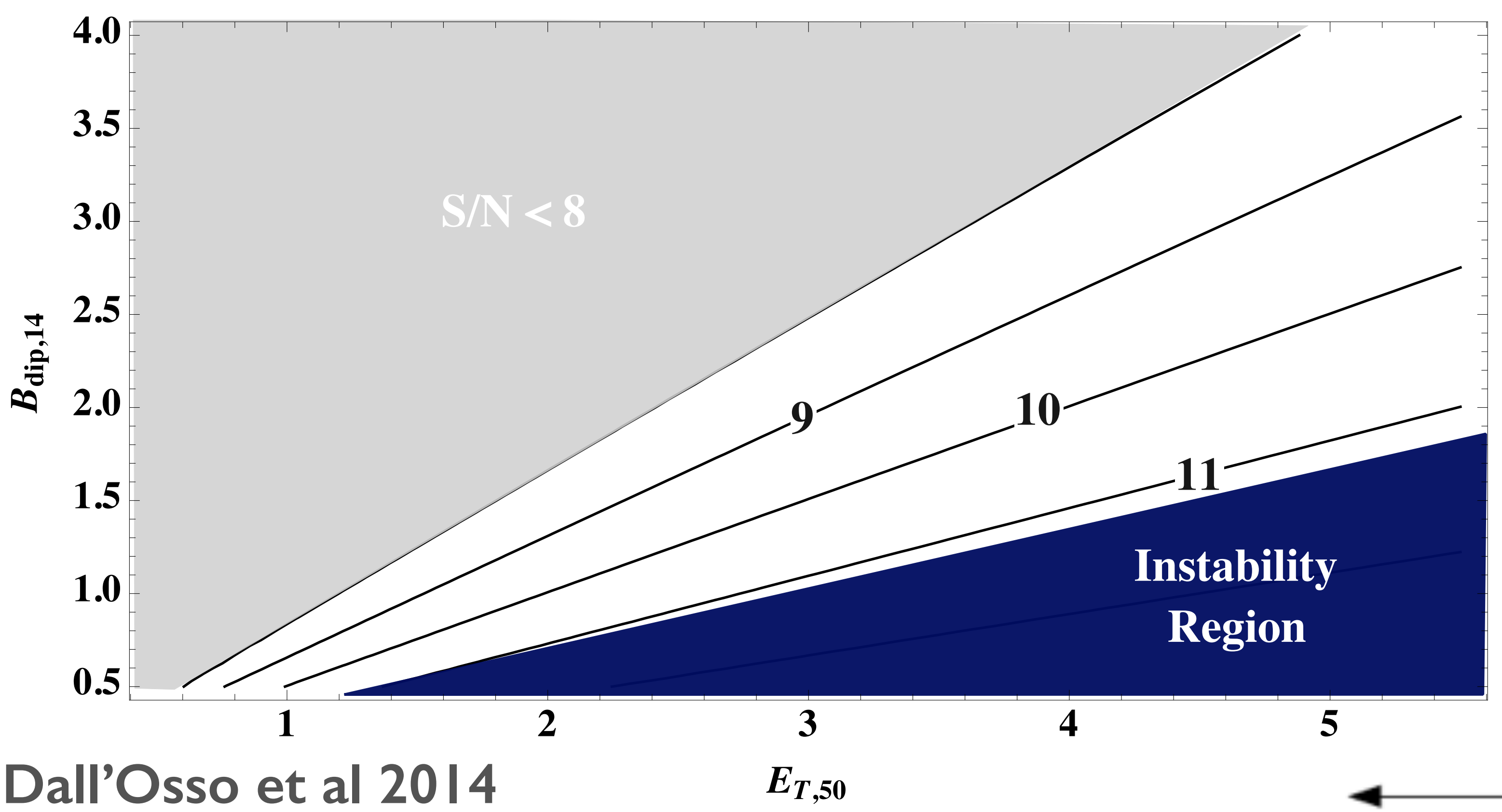
Dall'Osso et al 2014

Strong toroidal field can deform the NS in a prolate shape

We used new twisted torus NS equilibrium configurations

GWS FROM MAGNETARS

Dall'Osso, **Giacomazzo**, Perna, Stella 2015, ApJ 798, 25



Dall'Osso et al 2014

SNR for stable magnetar at D~75 Mpc

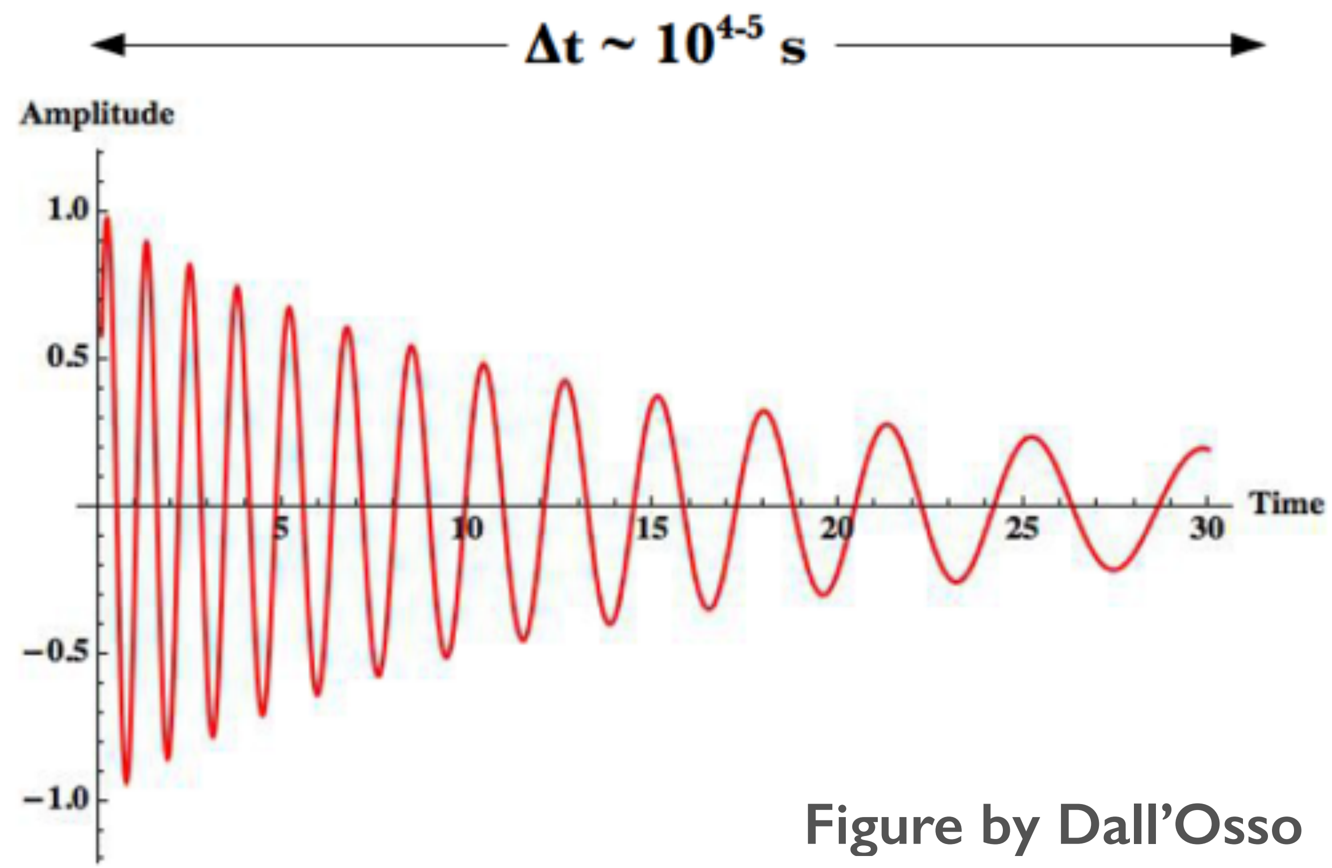


Figure by Dall'Osso

If NS EOS supports 2.4 M☉ then long post-merger signal in ~kHz range.

Signal may be truncated by collapse or EM spindown.

CONCLUSIONS

- Stable and Supramassive NSs may be formed after merger
- Magnetic fields can be strongly amplified via small scale turbulence (but still a lot of work to do to get an actual magnetar)
- GW and EM signals may be affected by magnetar formation
- GW detection from long-lived magnetar could also constrain EOS
- Note: magnetar scenario strongly dependent on max NS mass!

References:

Giacomazzo & Perna 2013, ApJ Letters, 771, L26

Dall'Osso, **Giacomazzo**, Perna, Stella 2015, ApJ 798, 25

Giacomazzo, Zrake, Duffell, MacFadyen, Perna 2015, arXiv:1410.0013