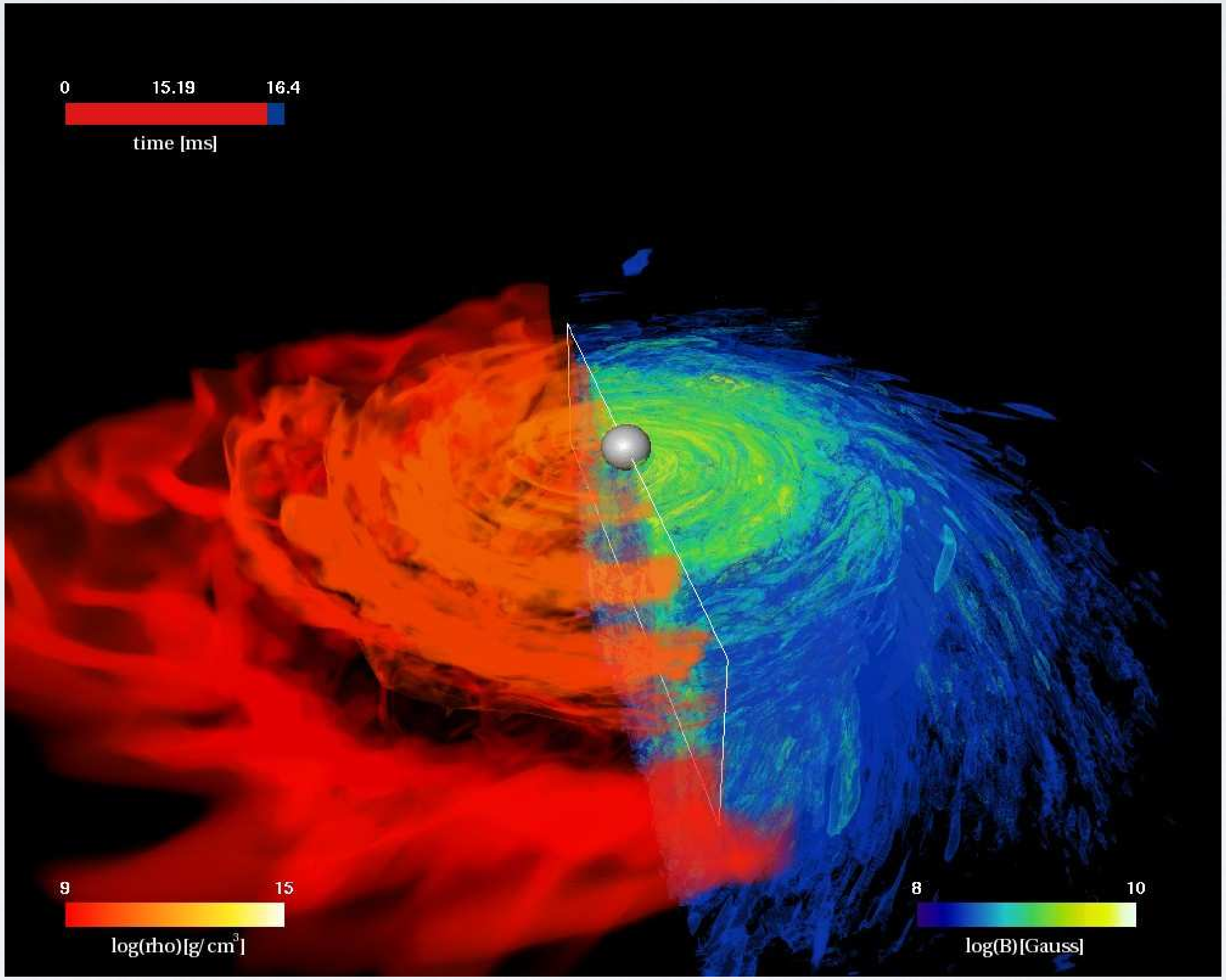
MAGNETAR FORMATION FROM THE MERGER OF BNS



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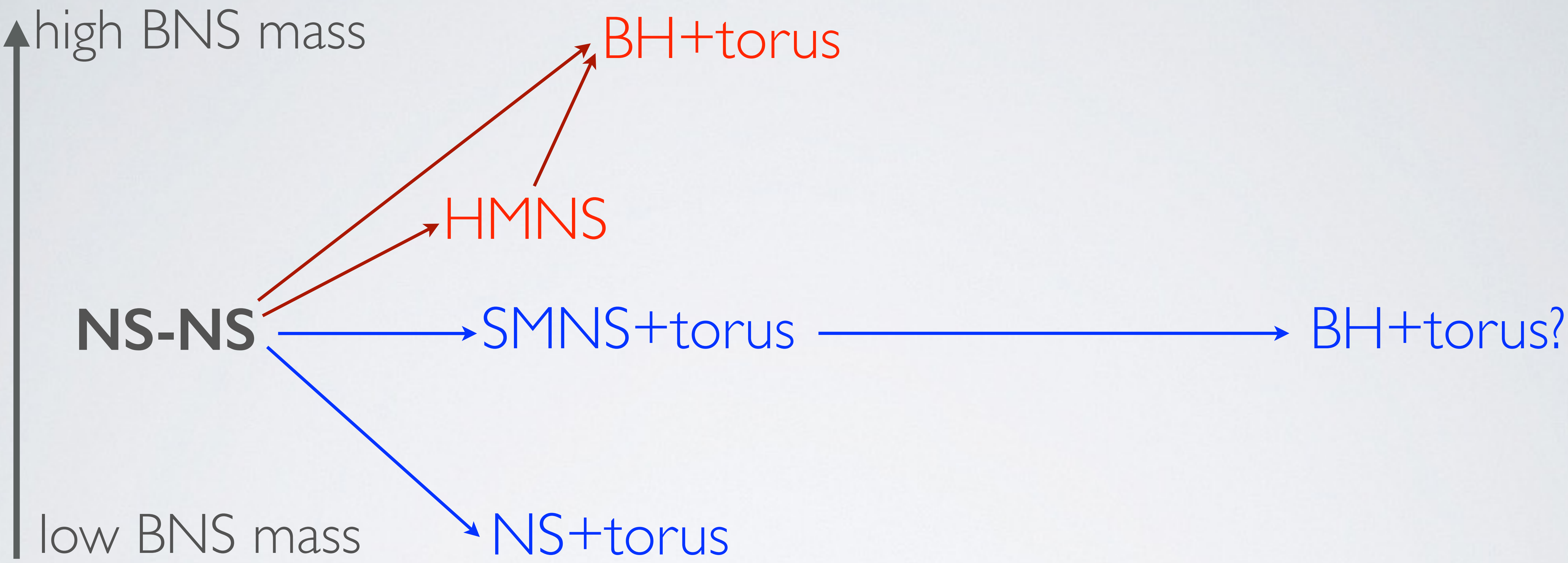
BNS POST-MERGER EVOLUTION

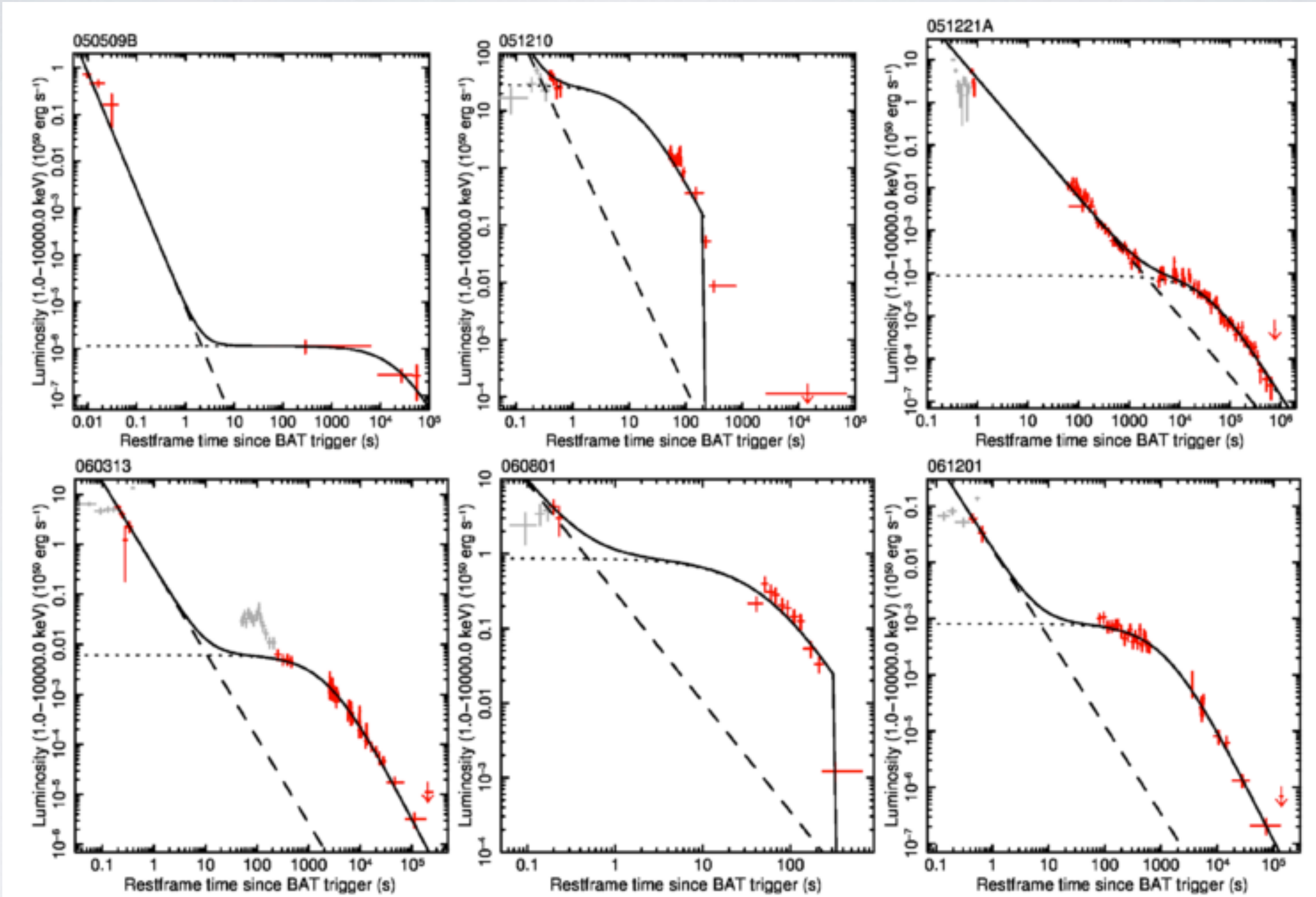
Depending on mass and EOS several post-merger scenarios:



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, ApJ Letters, 798, L36)

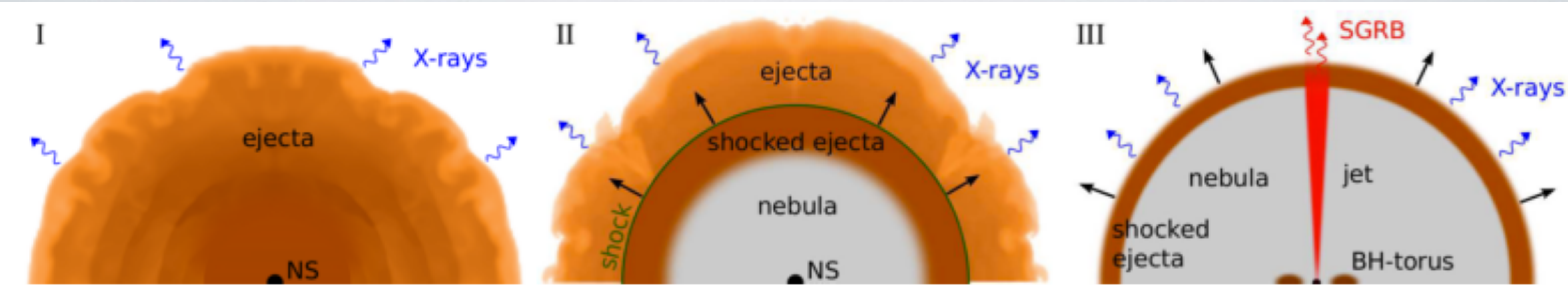
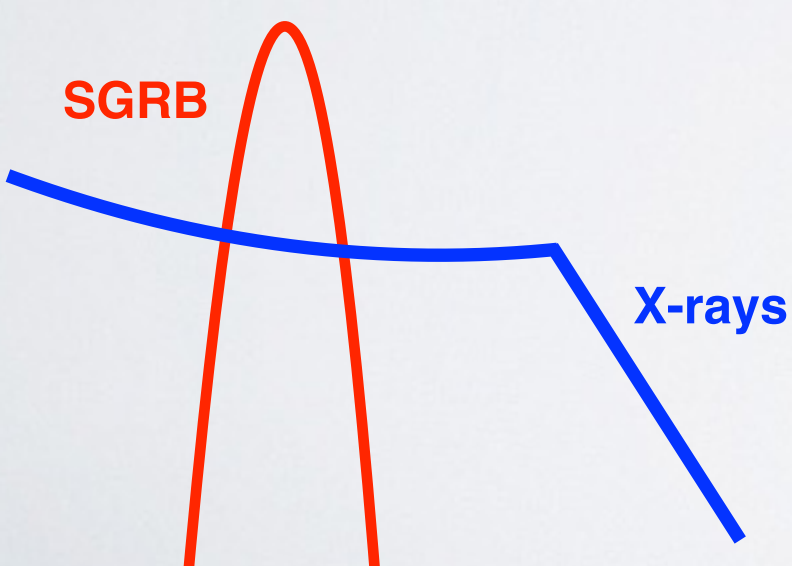


Figure 1. Evolution phases: (I) The differentially rotating supramassive NS ejects a baryon-loaded and highly isotropic wind; (II) The cooled-down and uniformly rotating NS emits spin-down radiation inflating a photon-pair nebula that drives a shock through the ejecta; (III) The NS collapses to a BH, a relativistic jet drills through the nebula and the ejecta shell and produces the prompt SGRB, while spin-down emission diffuses outwards on a much longer timescale.

Ciolfi & Siegel 2014

X-ray afterglow emitted by magnetar

SGRB emitted by BH after magnetar collapse

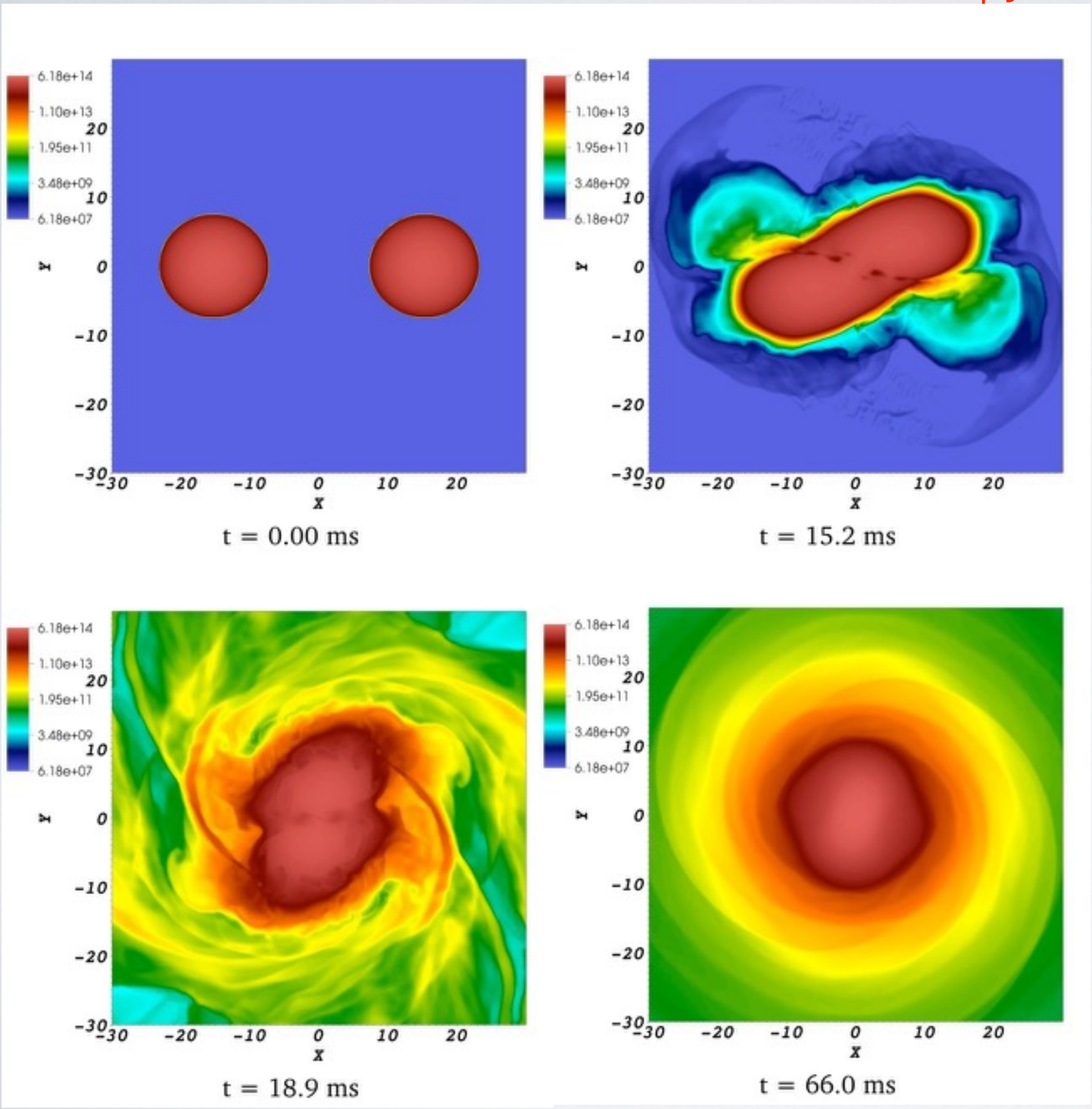


X-ray precursors or GW emission can be used to validate this model

Can we form magnetars from BNS mergers?

MAGNETAR FORMATION

Giacomazzo & Perna 2013, ApJ Letters, 771, L26

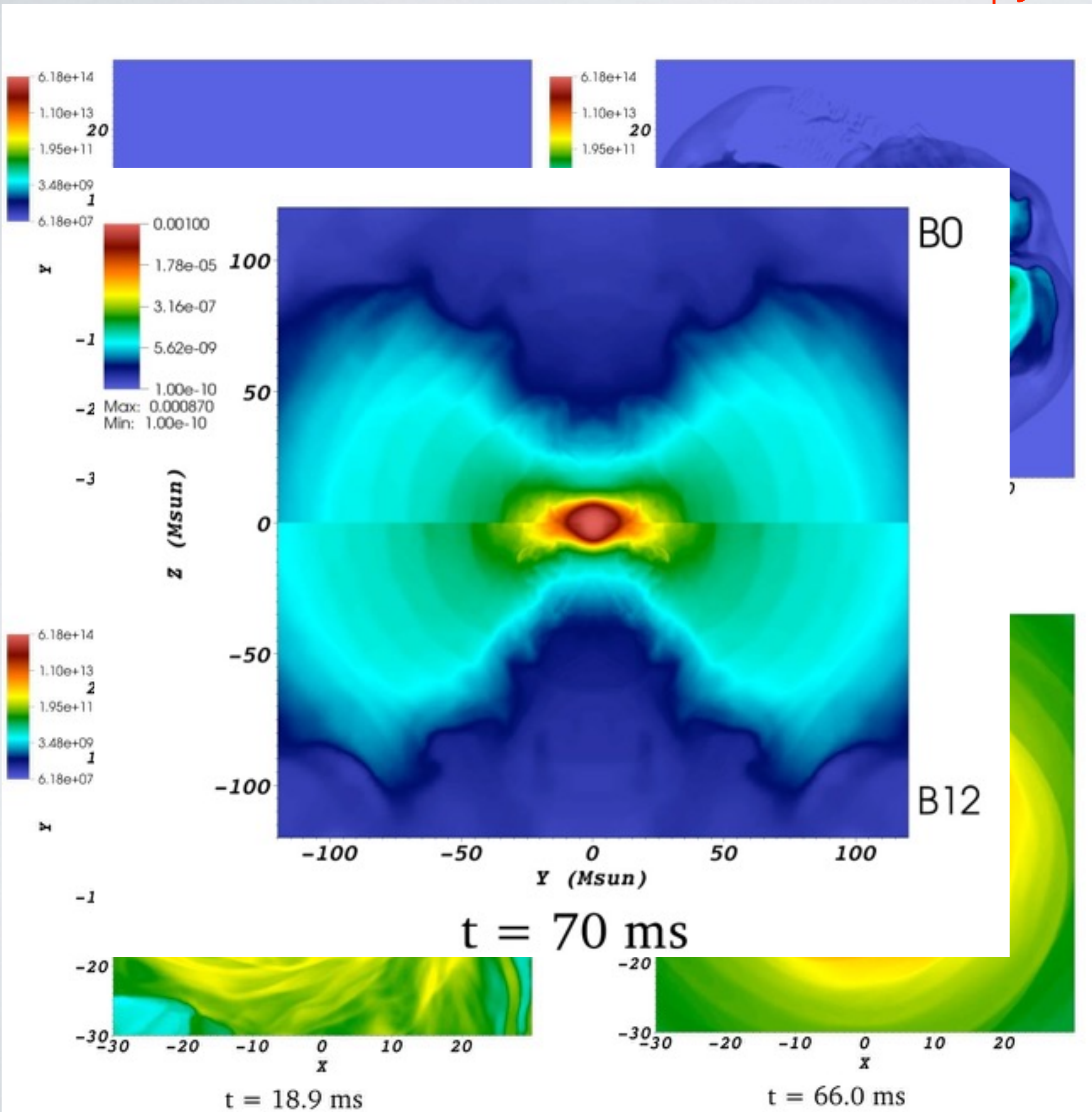


Investigated merger of two 1.2 M⊙ NSs

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

MAGNETAR FORMATION

Giacomazzo & Perna 2013, ApJ Letters, 771, L26



Investigated merger of two 1.2 $M_\odot$ NSs

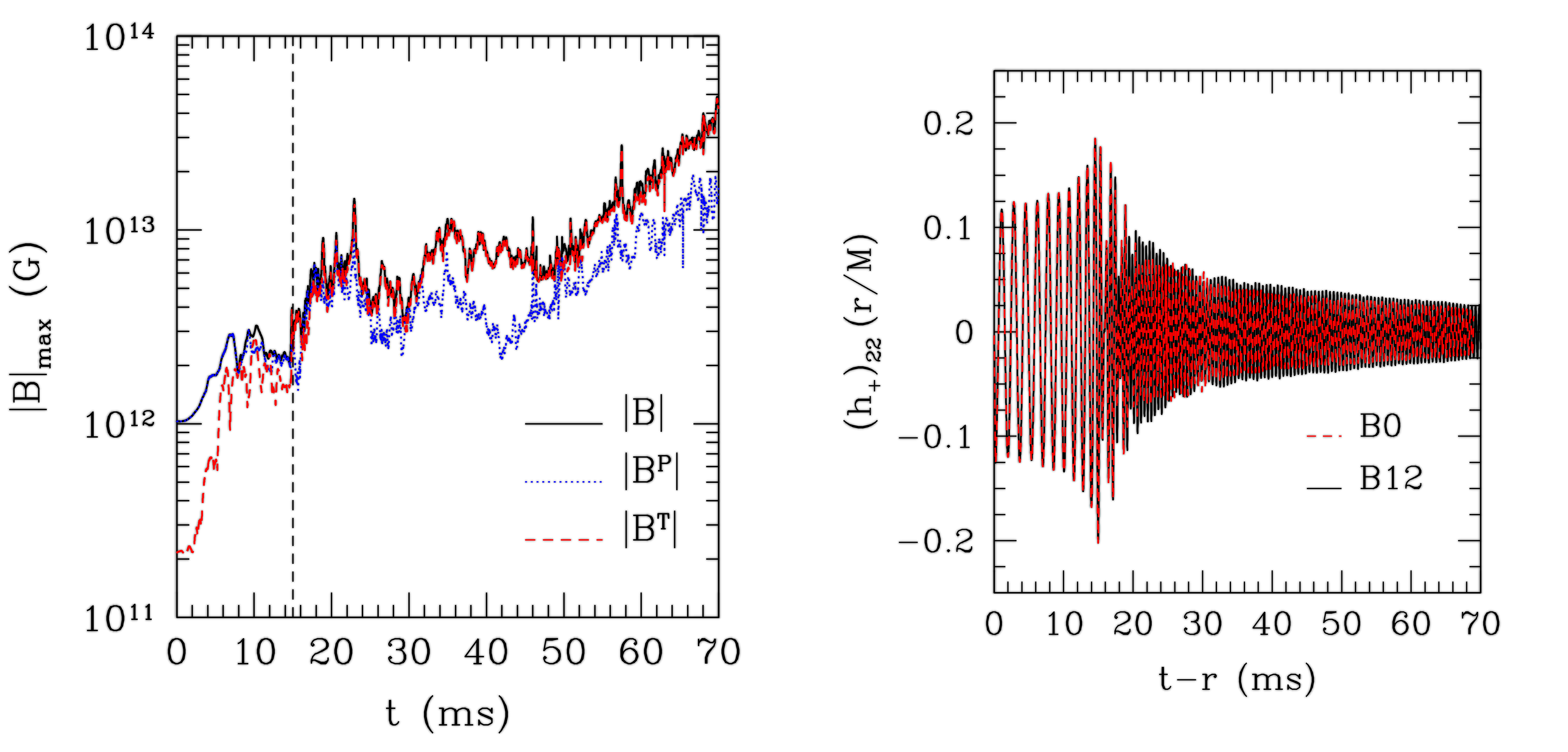
Used Ideal Fluid, Gamma=2.75, k=30000 (Oechslin et al 2007)

Produced a stable "ultraspinning" NS ($J/M^2 \sim 0.9$) surrounded by a magnetized disk of ~0.1 $M_\odot$.

MAGNETAR FORMATION

Giacomazzo & Perna 2013, ApJ Letters, 771, L26

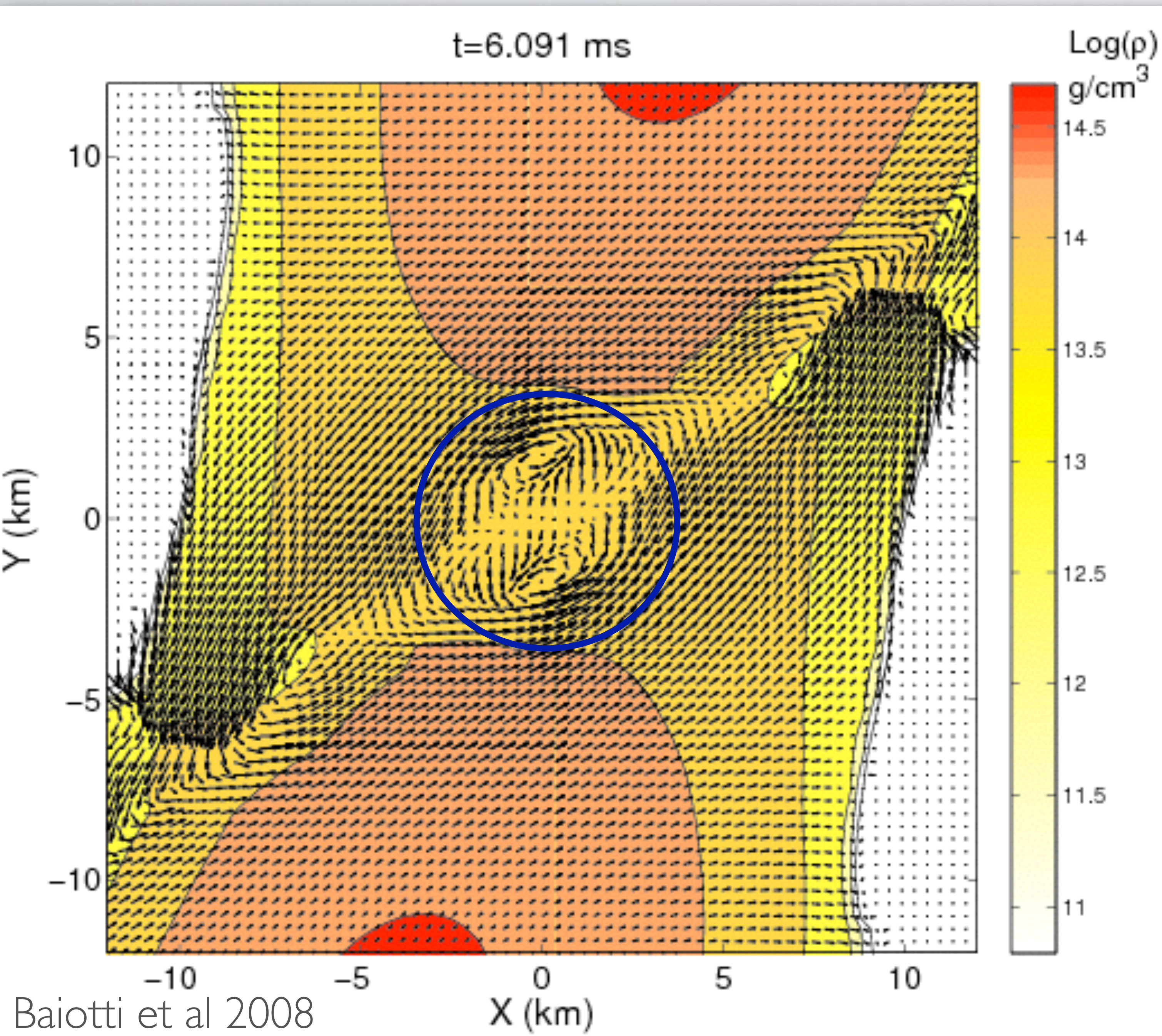
Magnetic field amplified of ~2 orders of magnitude. Difference in the GW signal are small and present only in the post-merger phase.



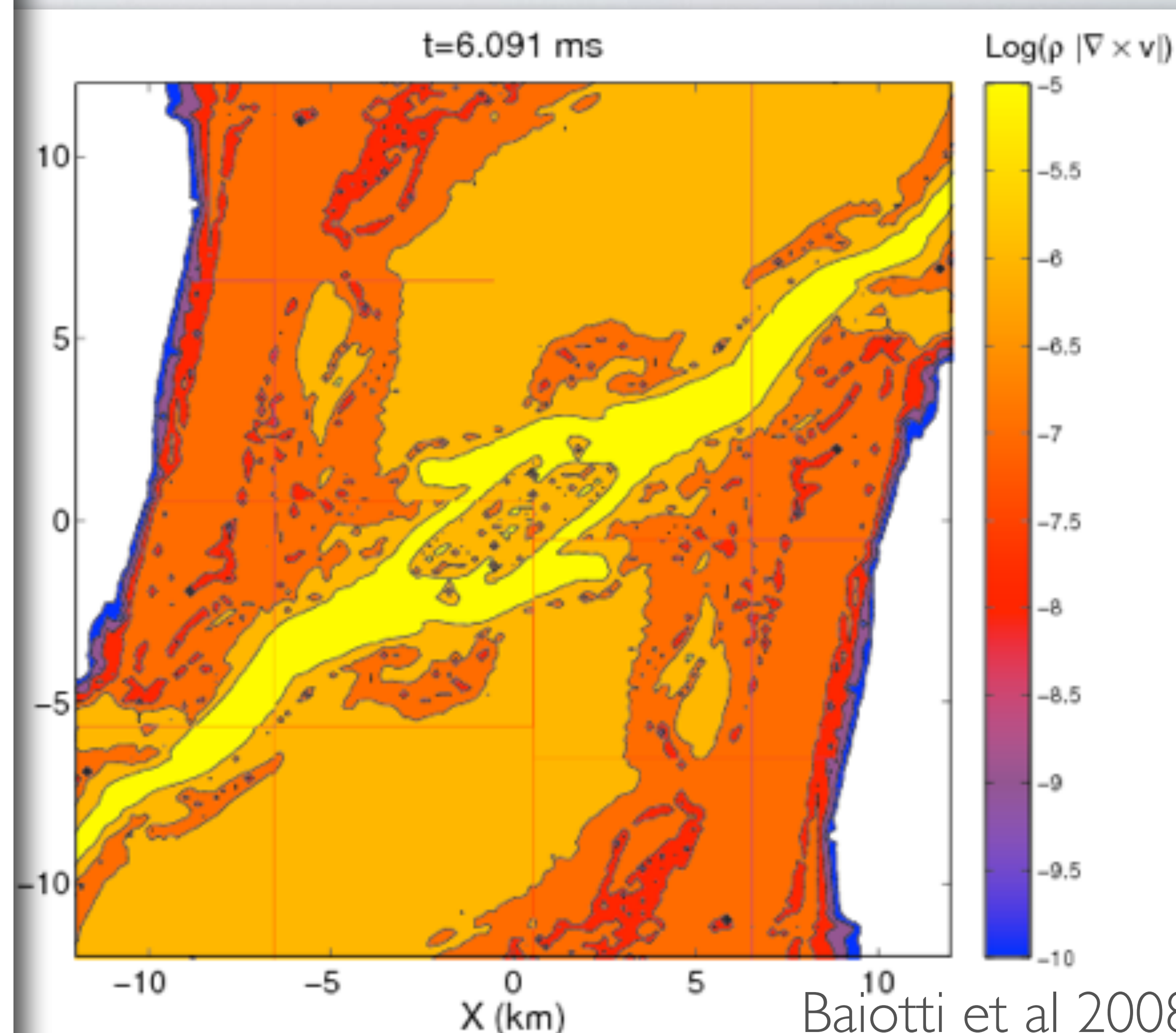
GWs publicly available for download at www.brunogiacomazzo.org/data.html

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.

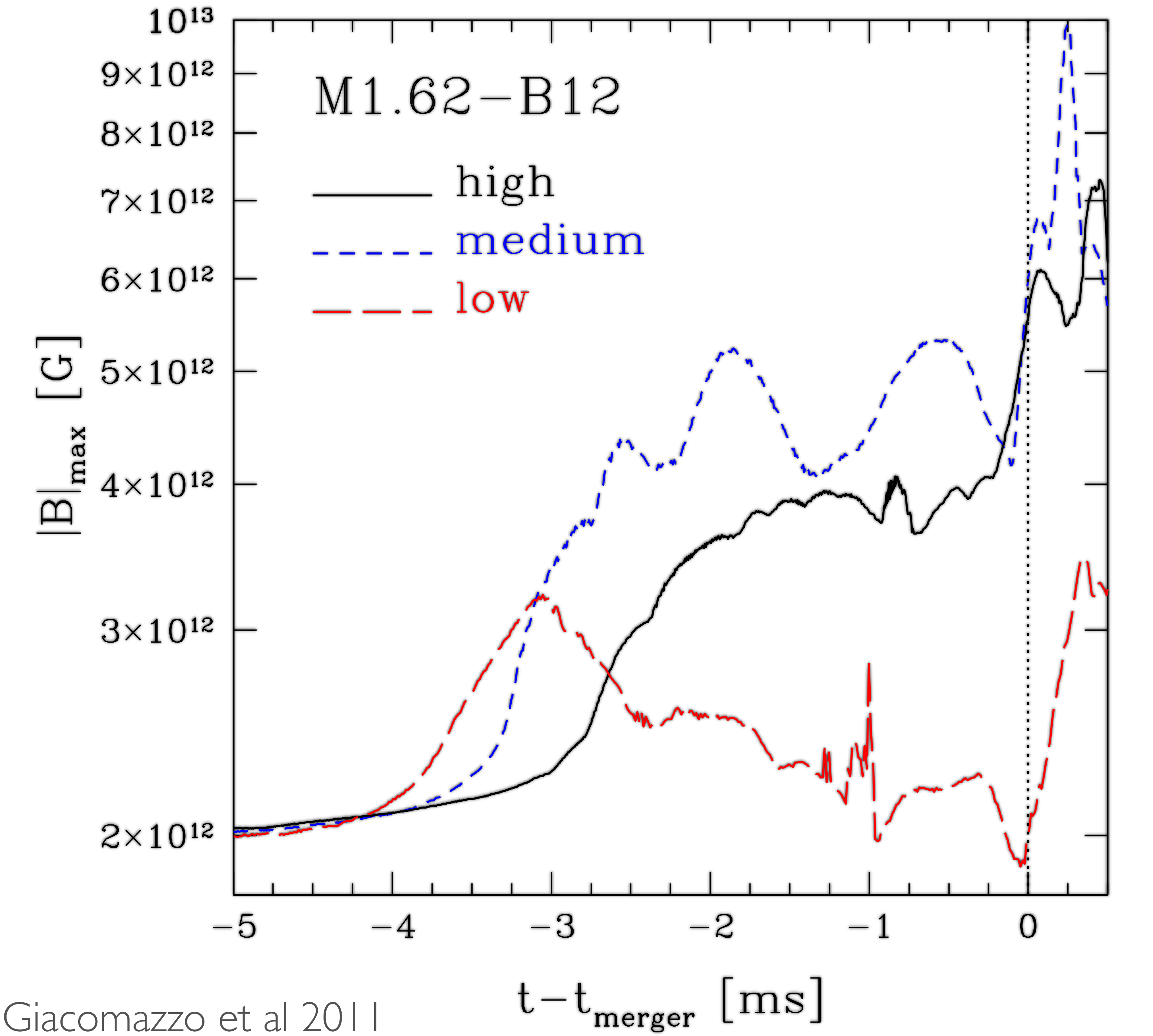


(v^x, v^y) in "corotating" frame



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

MAGNETIC FIELD AMPLIFICATION AT MERGER

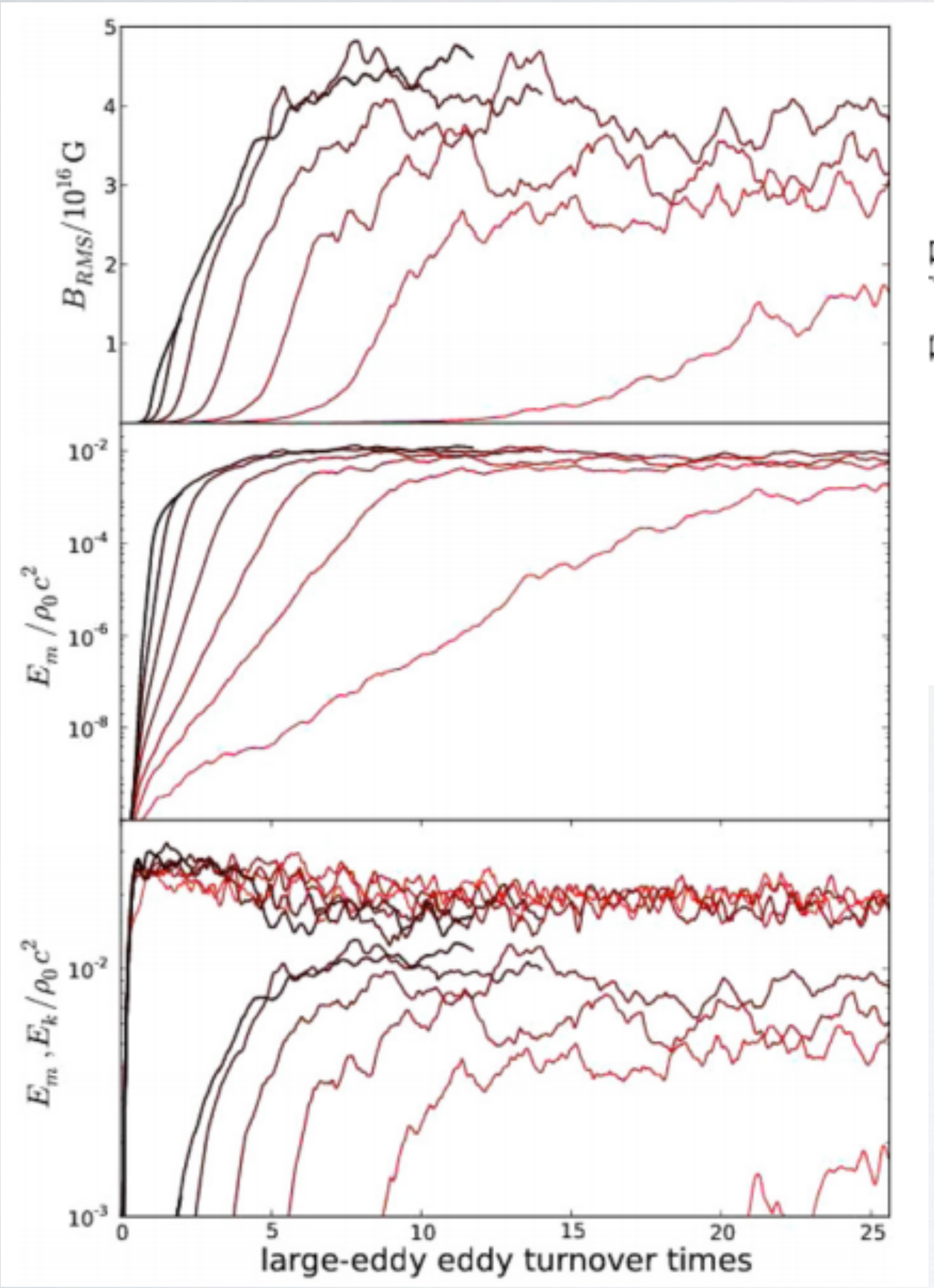


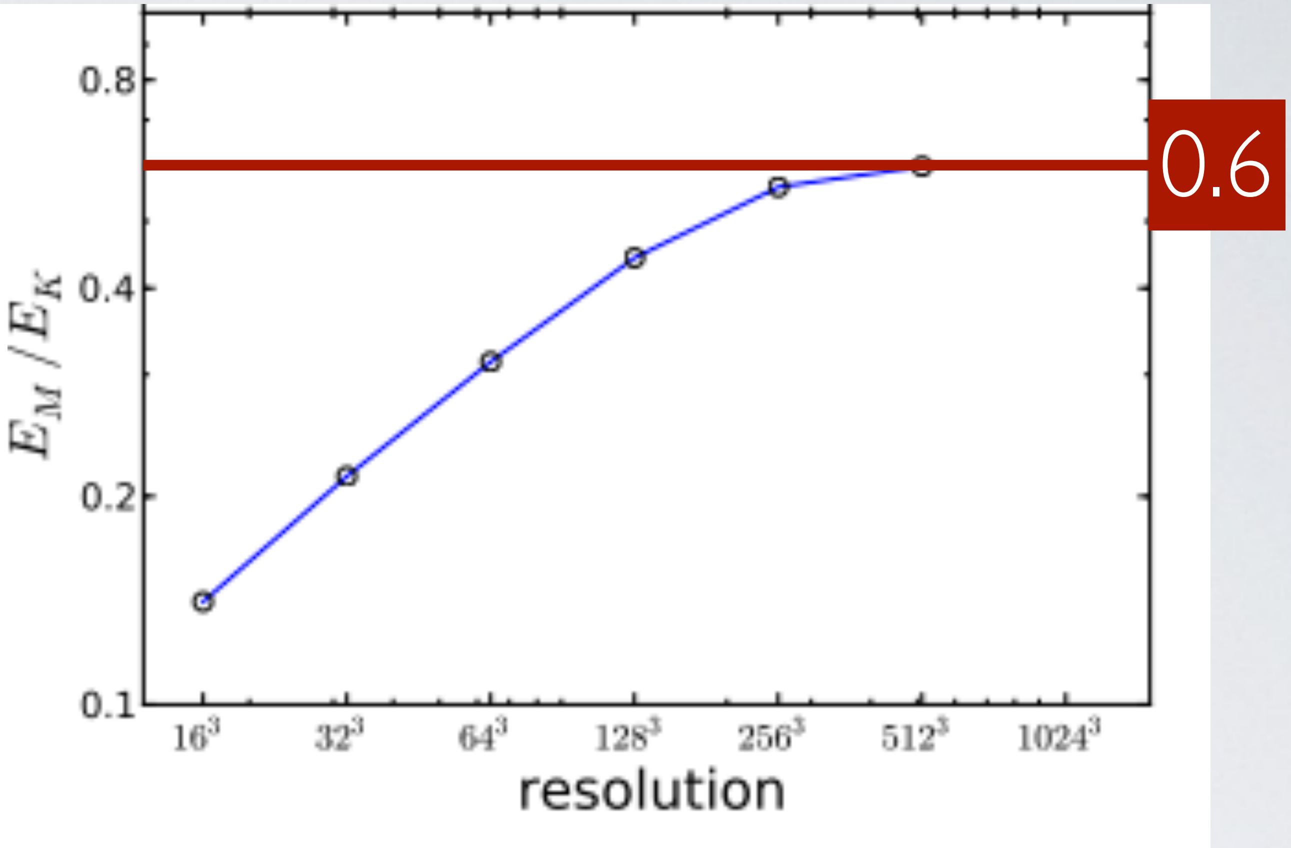
Giacomazzo et al 2011

Even with quite high resolutions (up to ~170m) we do not observe strong magnetic field amplifications in our simulations. It looks difficult to produce magnetar-level fields.

LOCAL SIMULATIONS

(Zrake and MacFadyen 2013)





Performed local very high resolution relativistic MHD simulations of turbulent flows.

Magnetic energy reaches equipartition with kinetic energy

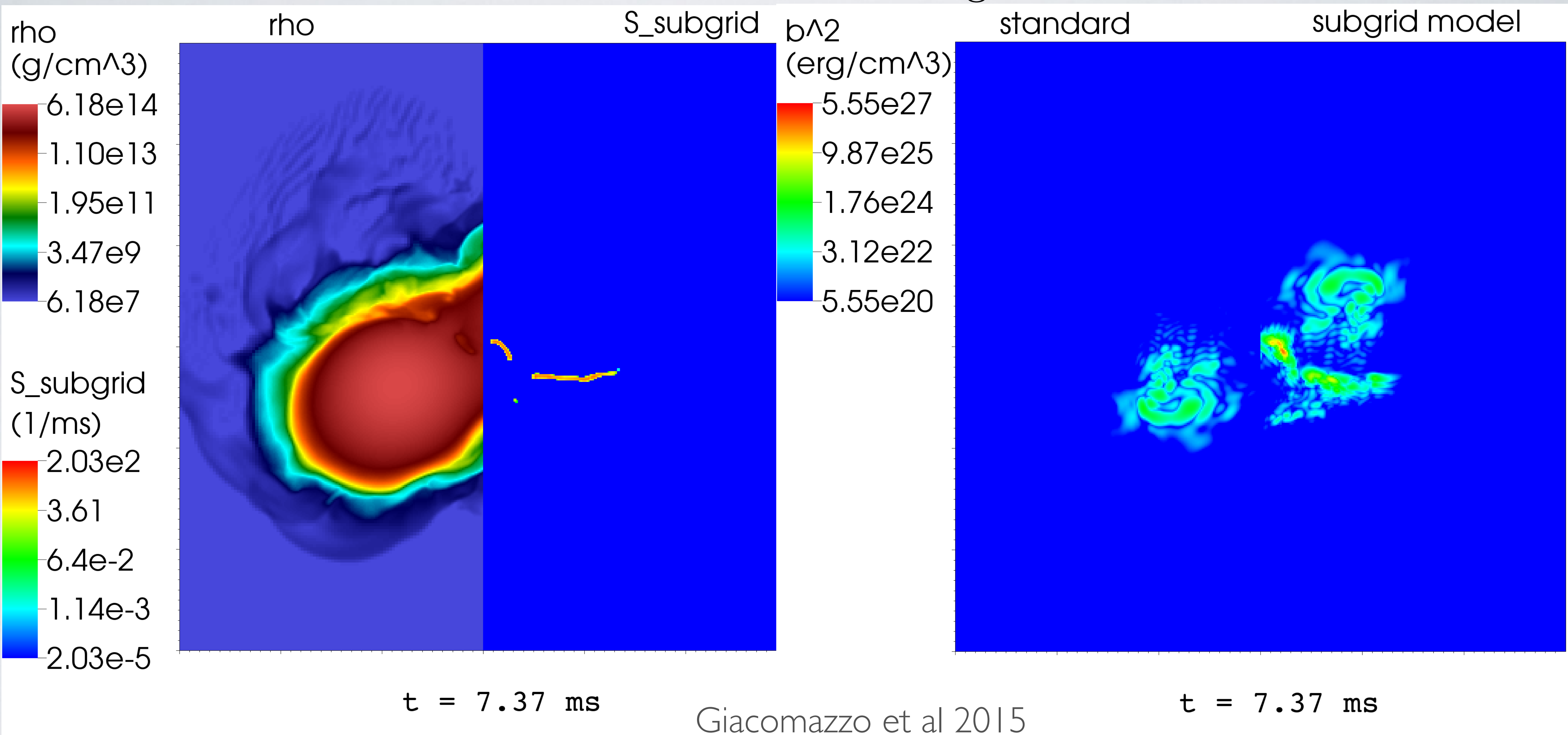
Similar results (in Newtonian MHD) were obtained by Obergaulinger et al 2010

MAGNETIC FIELD AMPLIFICATION AT MERGER

Giacomazzo, Zrake, Duffell, MacFadyen, Perna 2015, ApJ, 809, 39

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

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



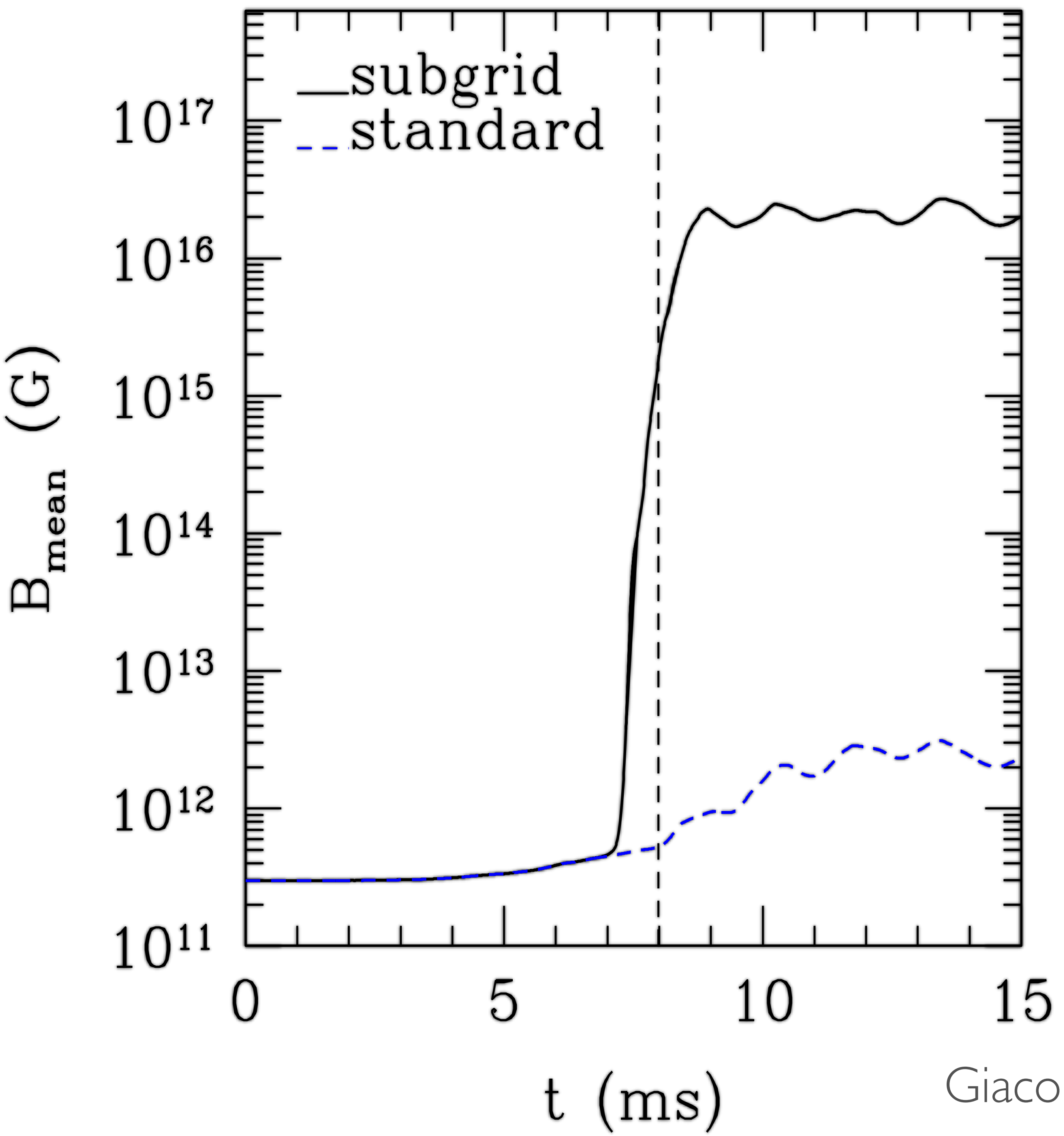
Giacomazzo et al 2015

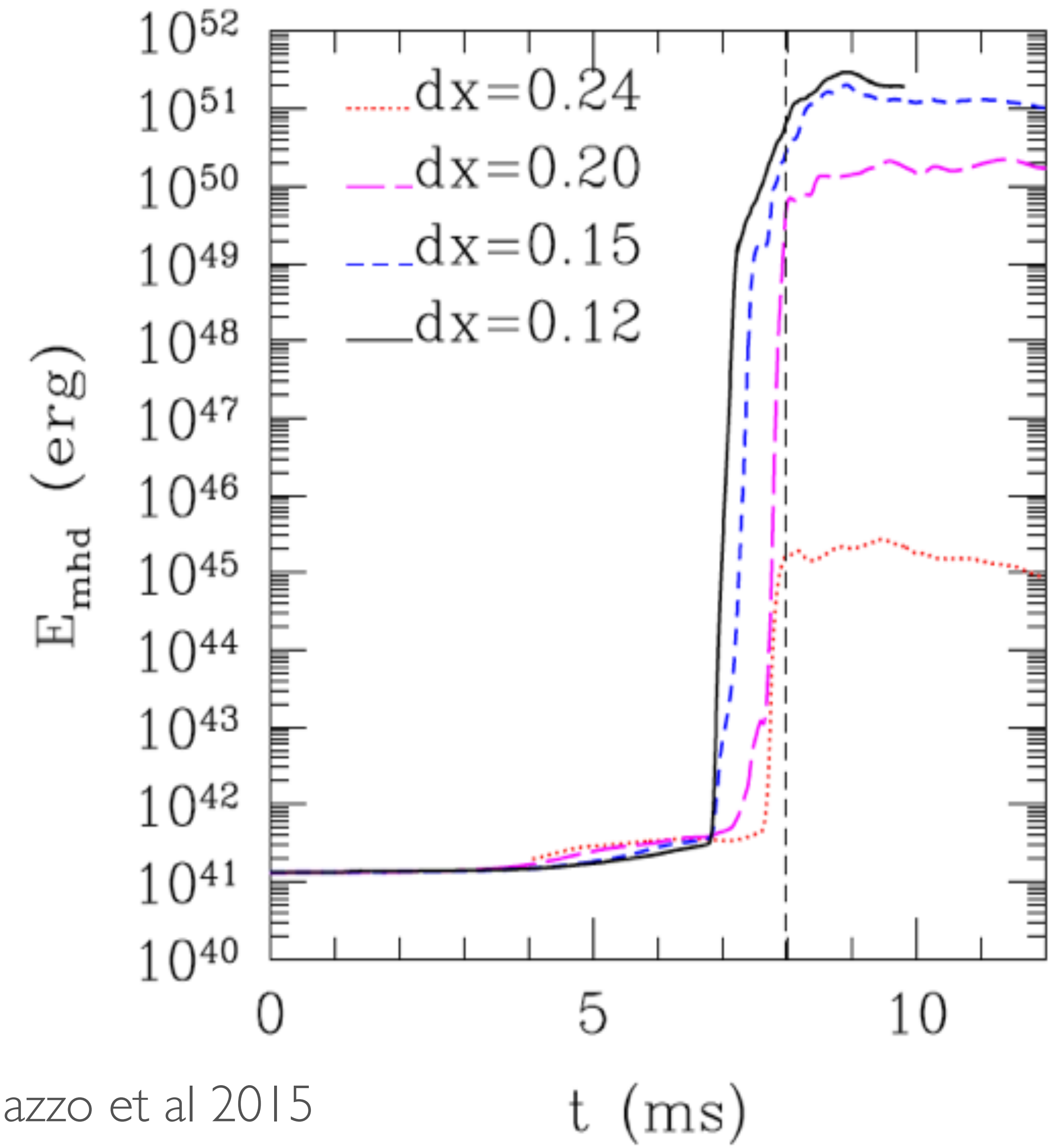
$S_{\rm subgrid}$ is different from zero only in the central turbulent region. Magnetic field amplification is larger in the central vortices.

MAGNETIC FIELD AMPLIFICATION AT MERGER

Giacomazzo, Zrake, Duffell, MacFadyen, Perna 2015, ApJ, 809, 39

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





Giacomazzo et al 2015

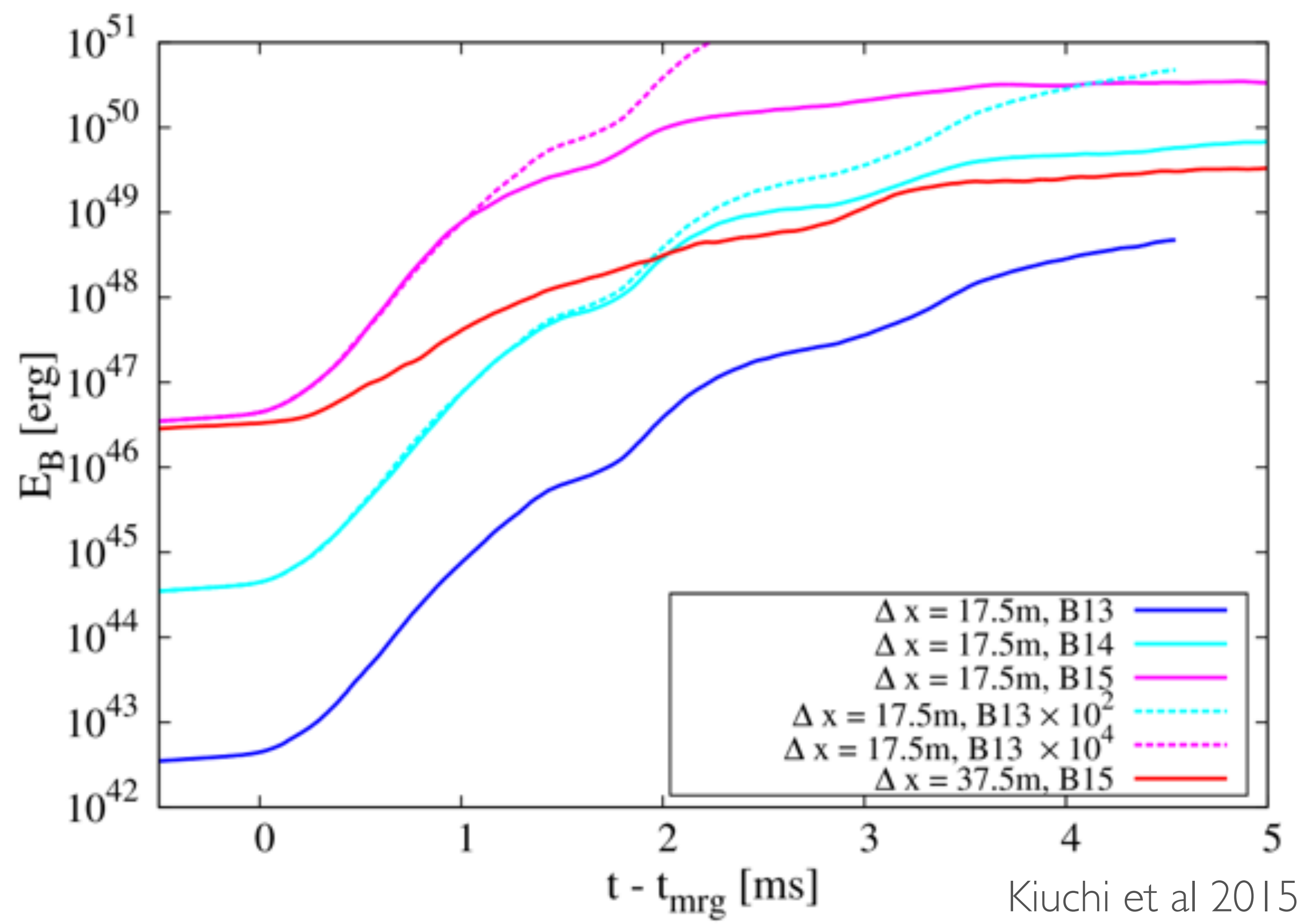
IS IT "REAL"?

(Kiuchi et al 2015, arXiv:1509.09205)

Used resolutions more than 10 times higher than "standard" BNS simulations (17.5 m vs ~200 m).

Magnetic field grows of at least ~3 orders of magnitude

Magnetic energy grows to ~10^{50} erg



Kiuchi et al 2015

Very expensive supercomputer simulation. Subgrid model may help when investigating large parameter space.

CAN WE DETECT MAGNETARS FROM BNS MERGERS?

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

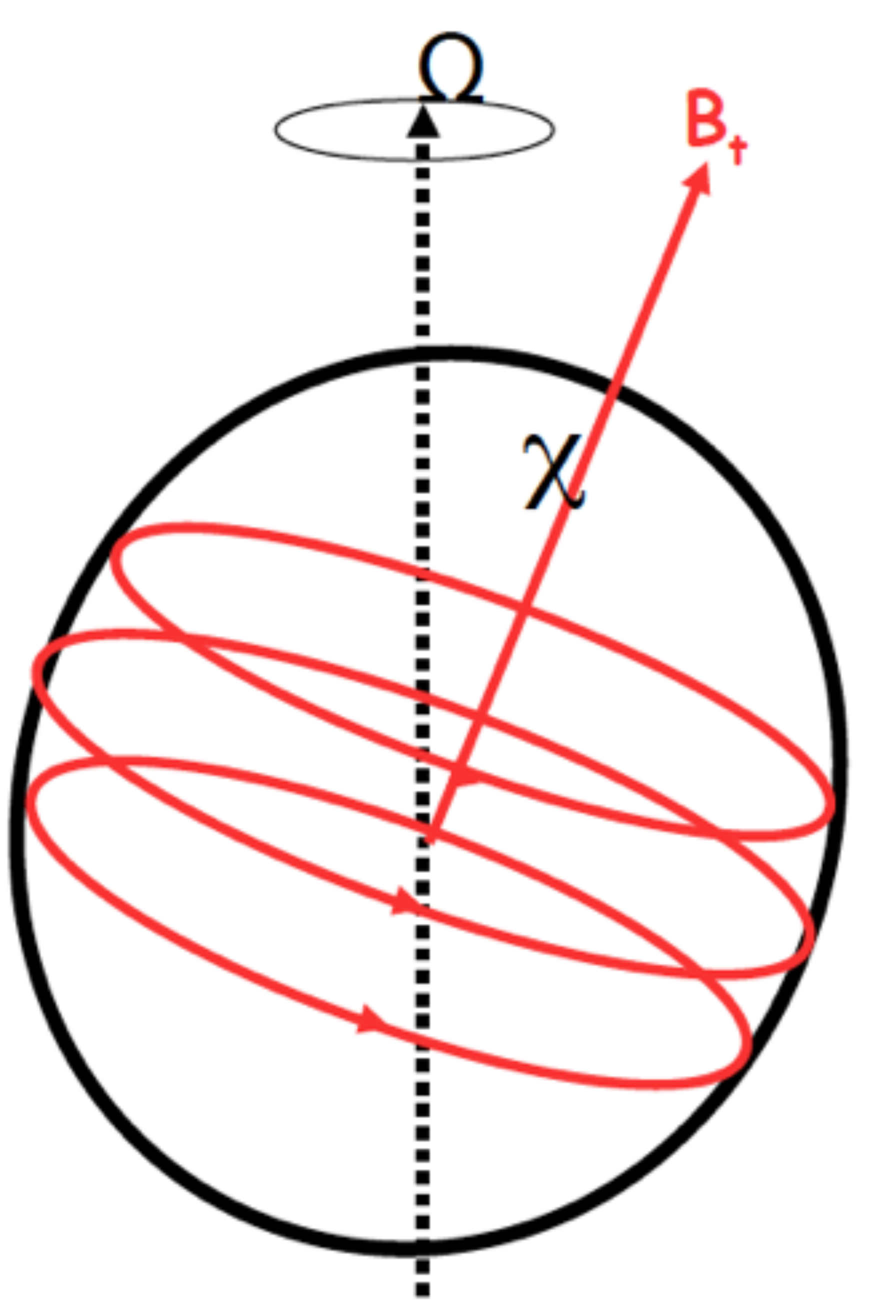
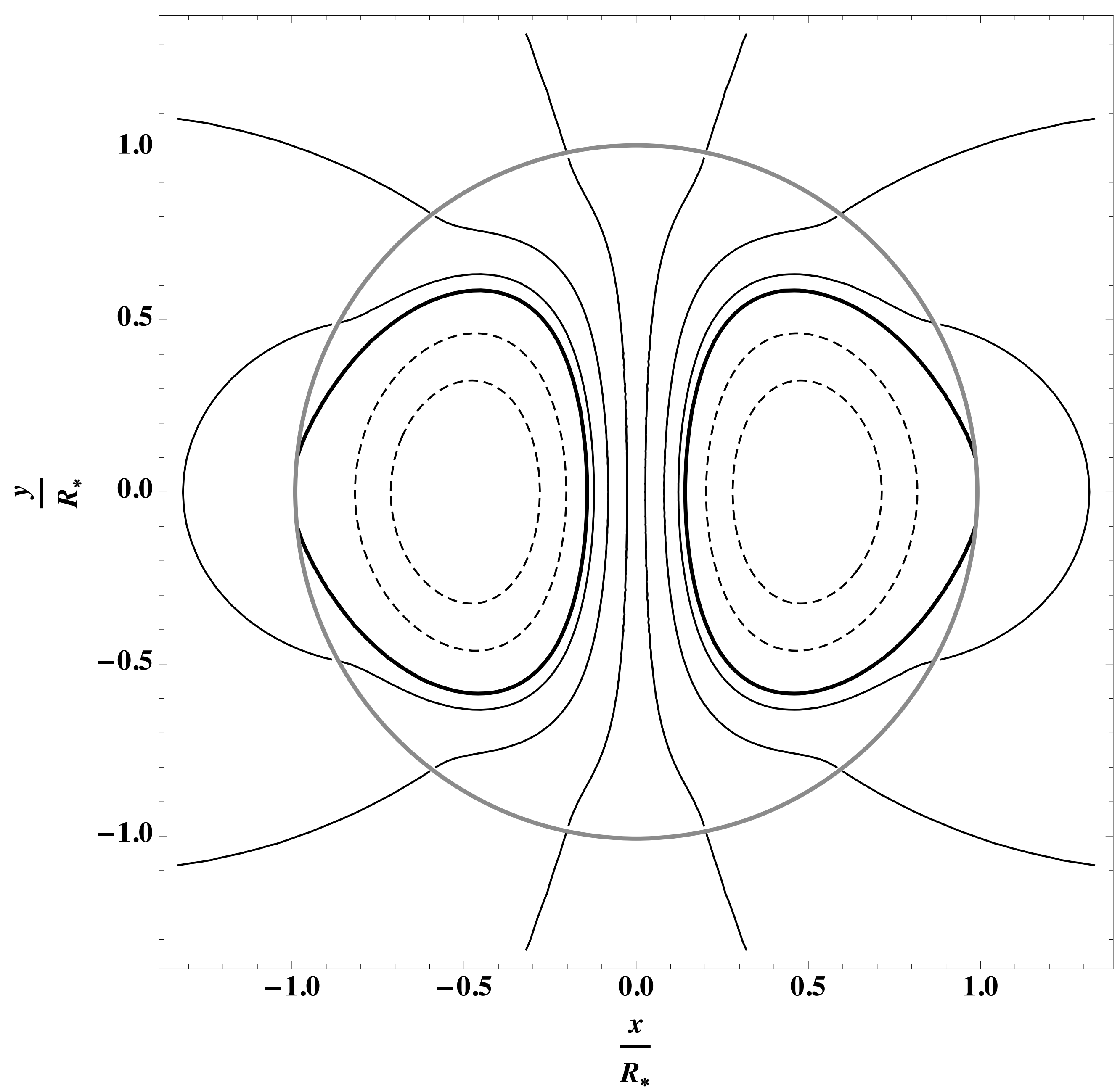


Figure by Dall'Osso



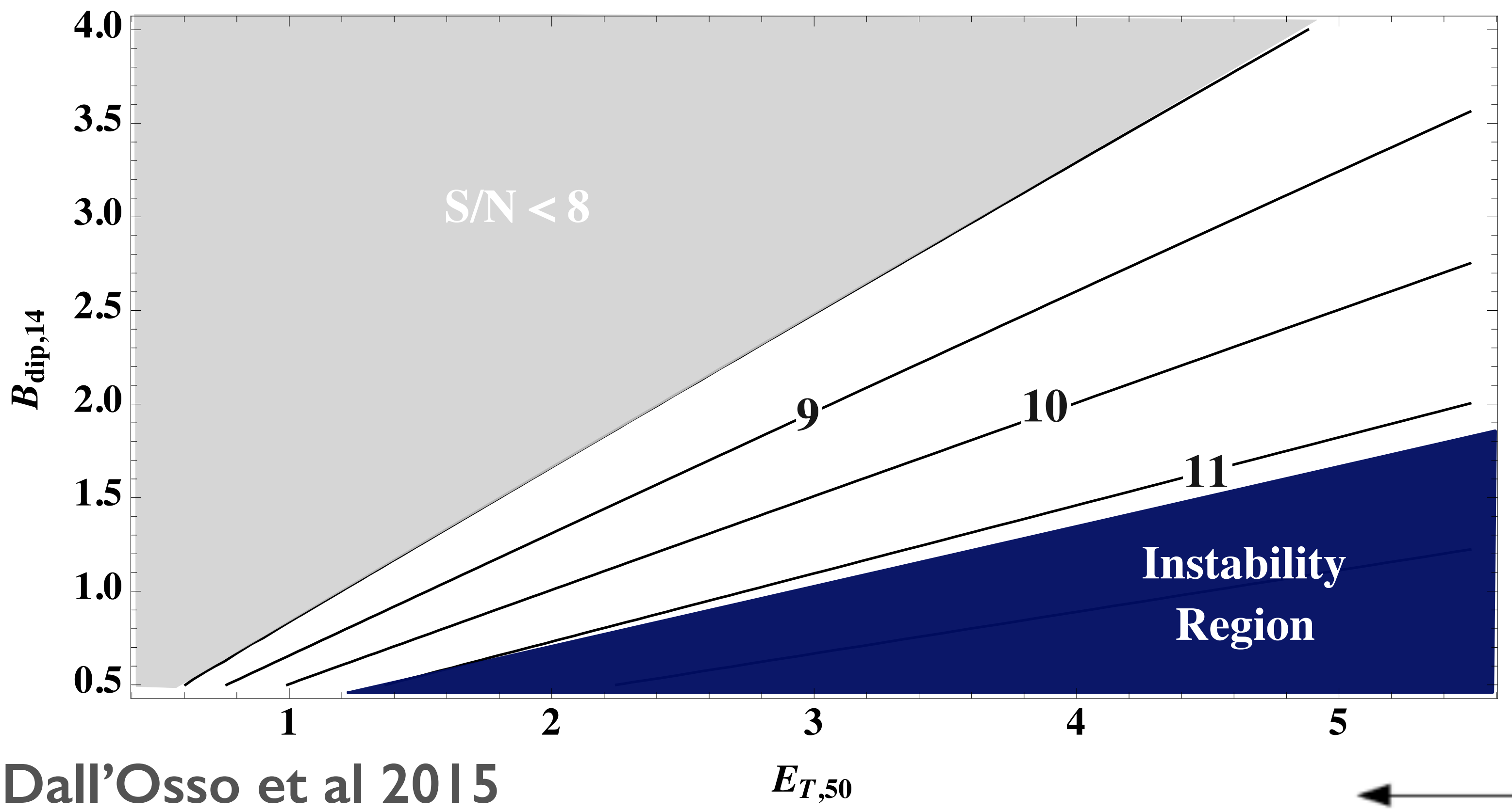
Dall'Osso et al 2015

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 2015

SNR for stable magnetar at D~75 Mpc

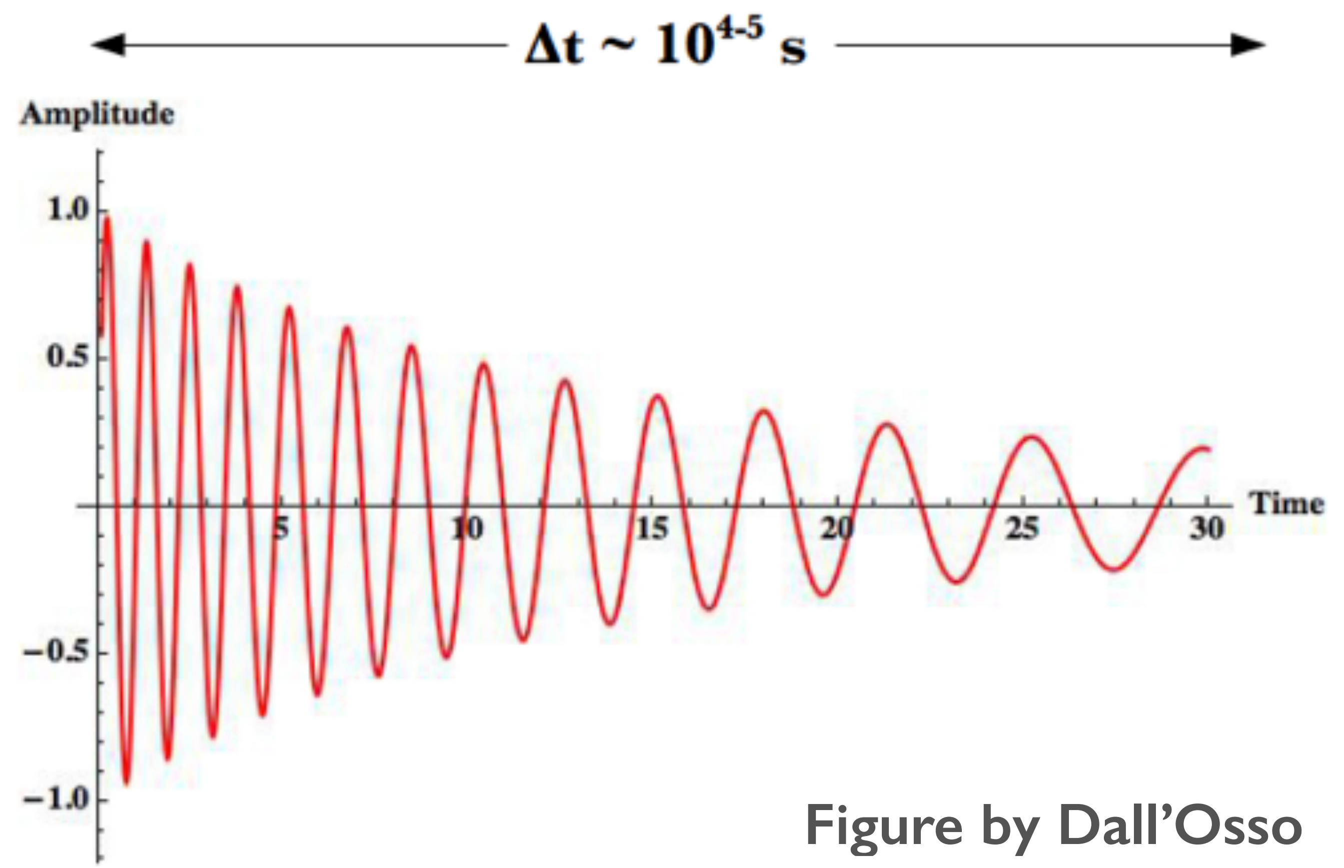


Figure by Dall'Osso

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, ApJ, 809, 39