From gamma-ray bursts to fast radio bursts: simulations and thoughts

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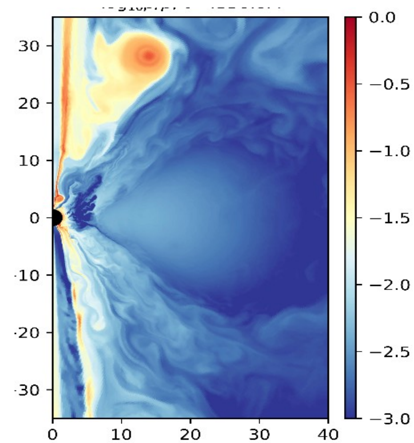
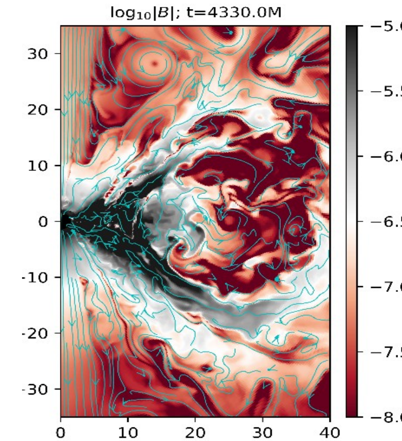
Plasmoids in GRMHD

trace them, track them and light them up

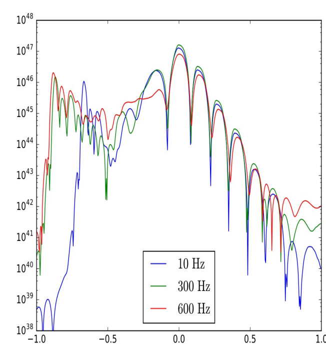
FRBs (timescale and energetics)

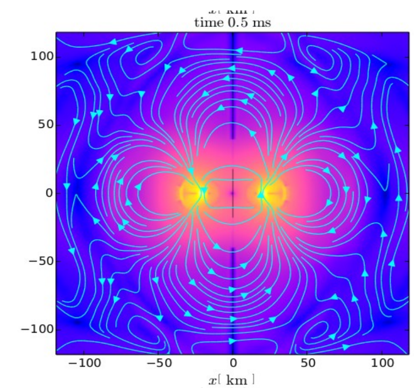
Blitzar model

Supramassive NS collapse

NS head on collision &

BNS prompt collapse

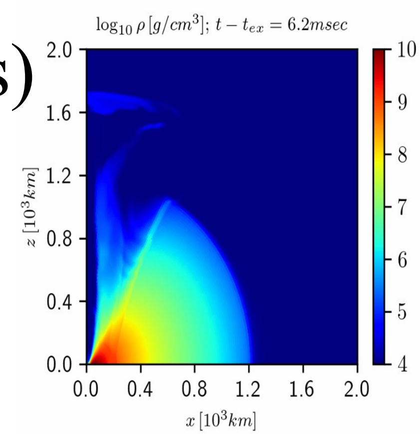


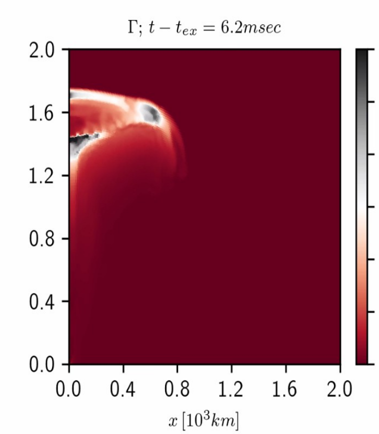


GRBs (short from BNS)

jet or no jet? (where it depends)

Collapse of the SMNS after 1 sec from merger



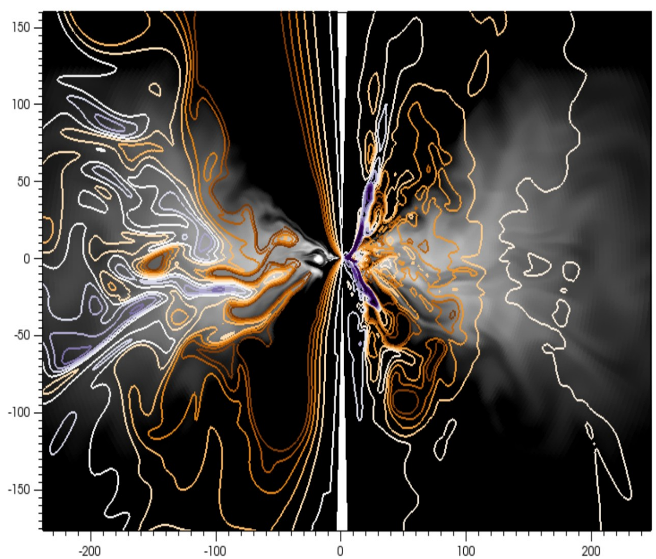


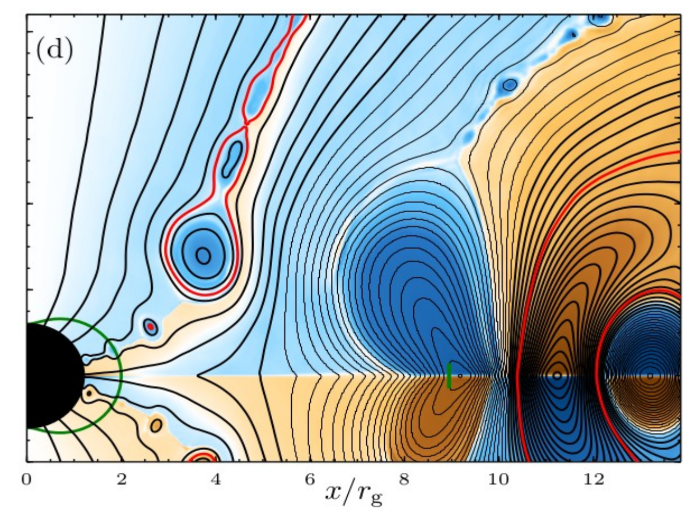
Plasmoids in GRMHD

trace them, track them and
light them up

Motivation

- Sgr a* flares
- relativistic reconnection
- models that naturally develop reconnection layers





Parfrey, Giannios & Beloborodov 2015

for example
Contopoulos, Nathanail, Sadowski, Kazanas & Narayan 2018

Plasmoids in GRMHD

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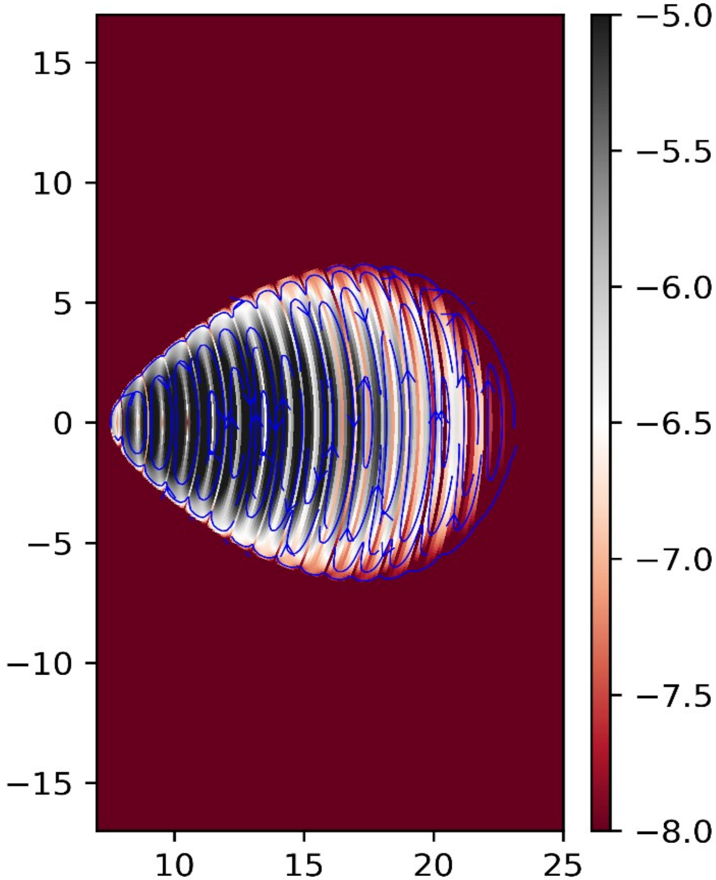
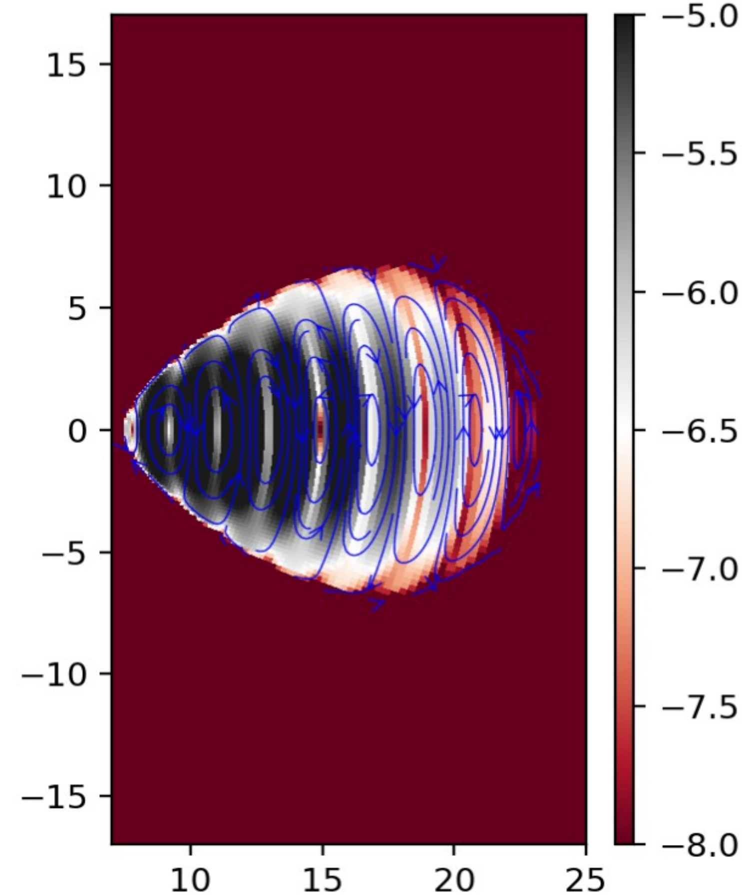
initial magnetic field configuration

Multi-loops, different widths and scalings



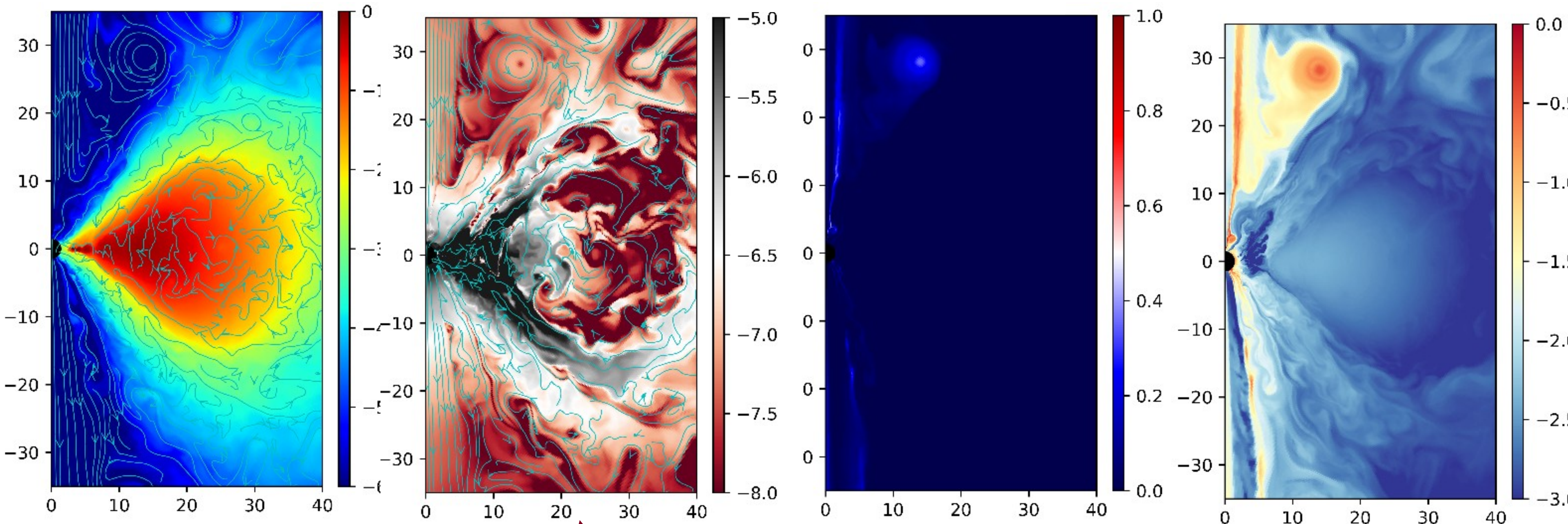
BHAC code:
GR Ideal MHD
Porth et al. 2017



Plasmoids in GRMHD

trace them, track them and light them up

How to find them and isolate them?



density

magnetic field strength

hut unbound matter

temperature

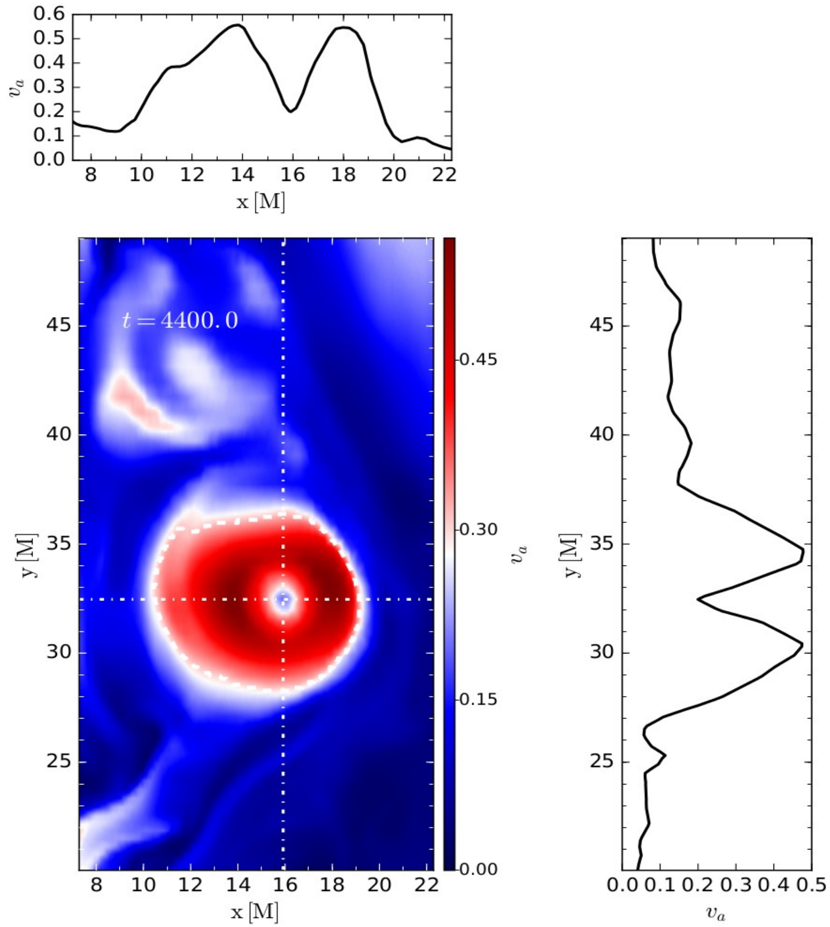
What is their radiation imprint?
Compare with the jet emission...

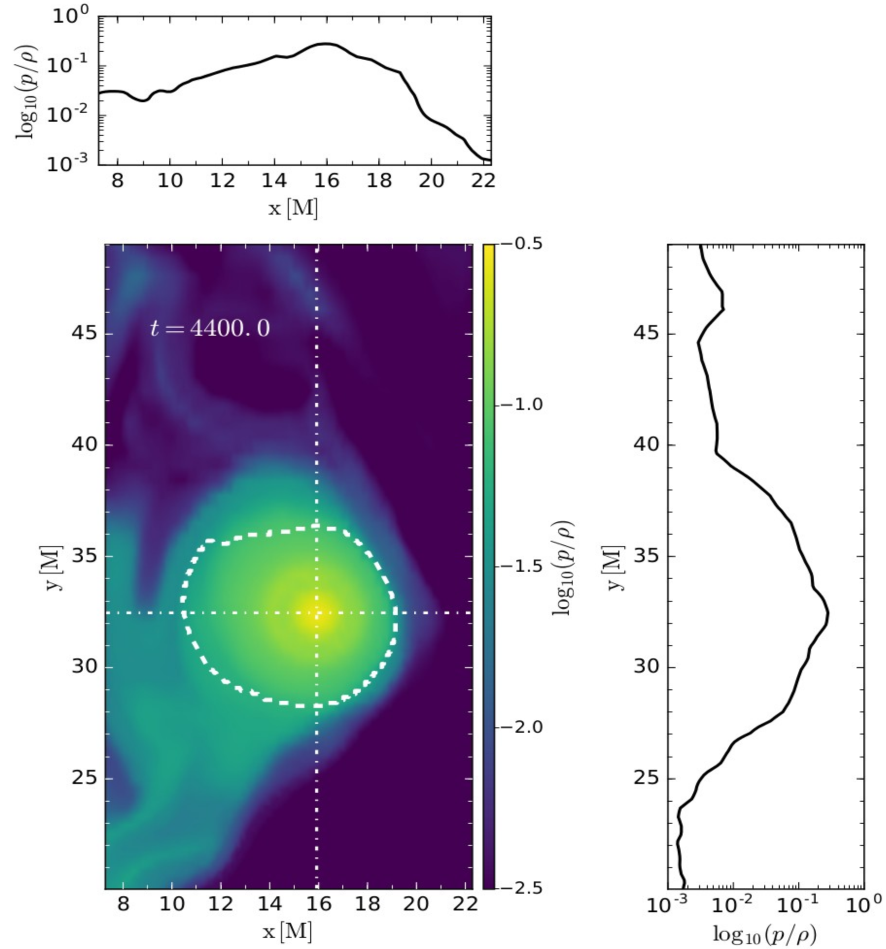
Nathanail et al. 2018 (in prep.)

Plasmoids in GRMHD

trace them, **track them** and
light them up

How to find them and isolate them?





Nathanail et al. 2018 (in prep.)

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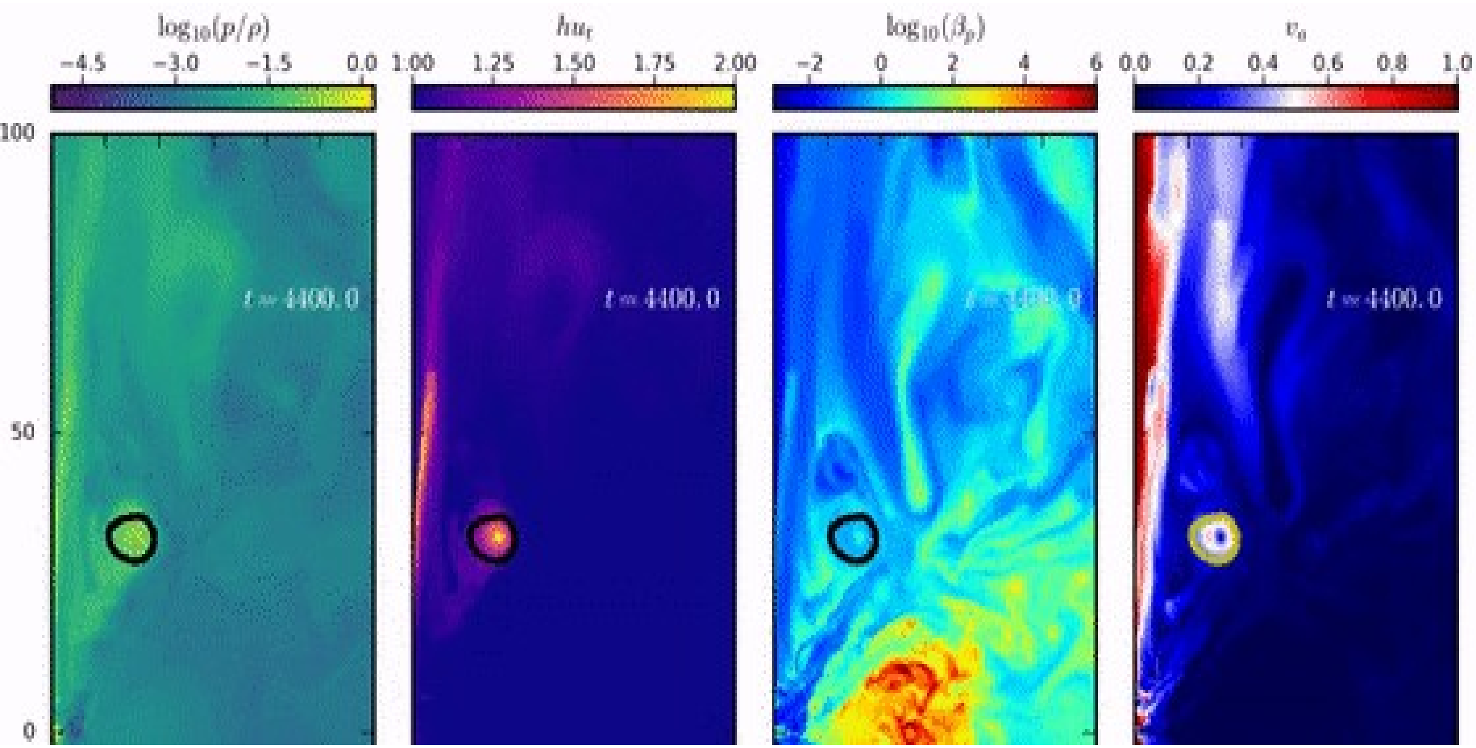
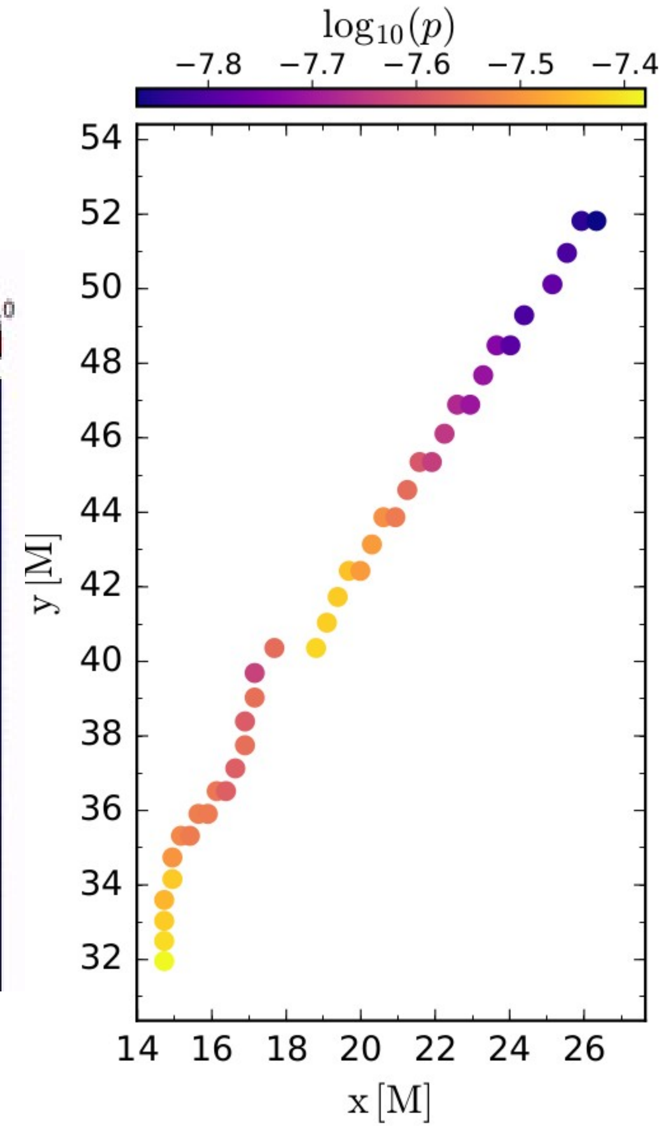




Nathanail et al. 2018 (in prep.)

Plasmoids in GRMHD

trace them, track them and

light them up

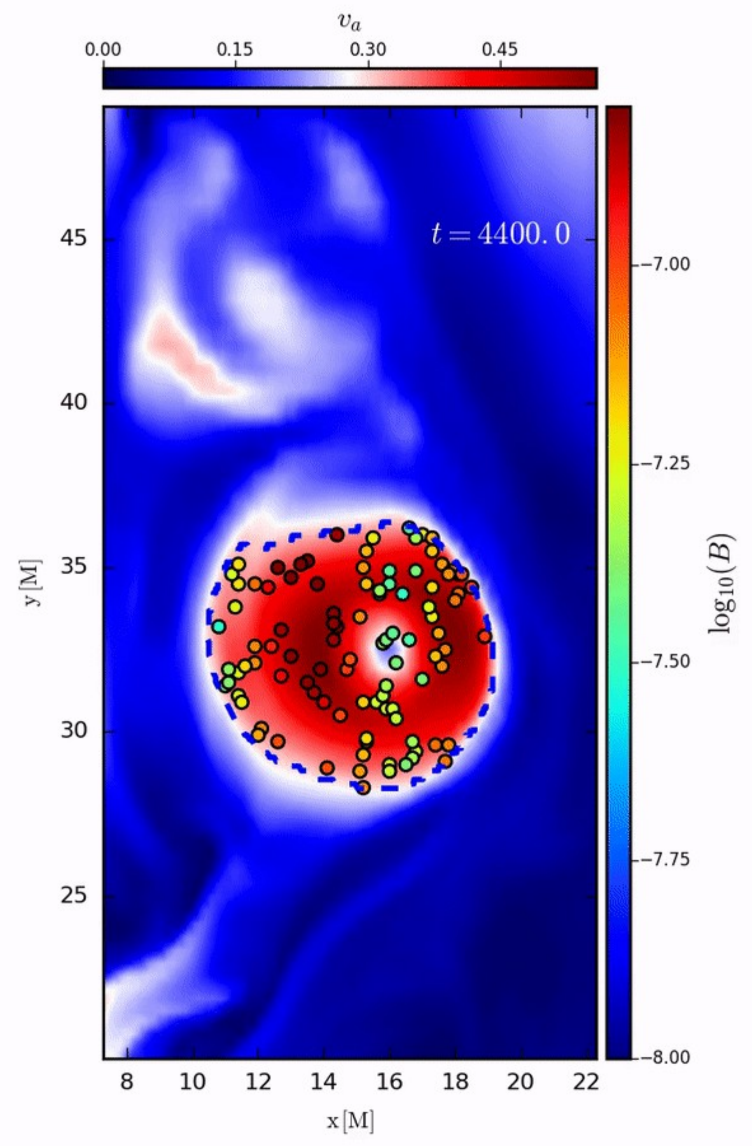
Particle pusher

It expands....
It cools....

How do particles evolve?

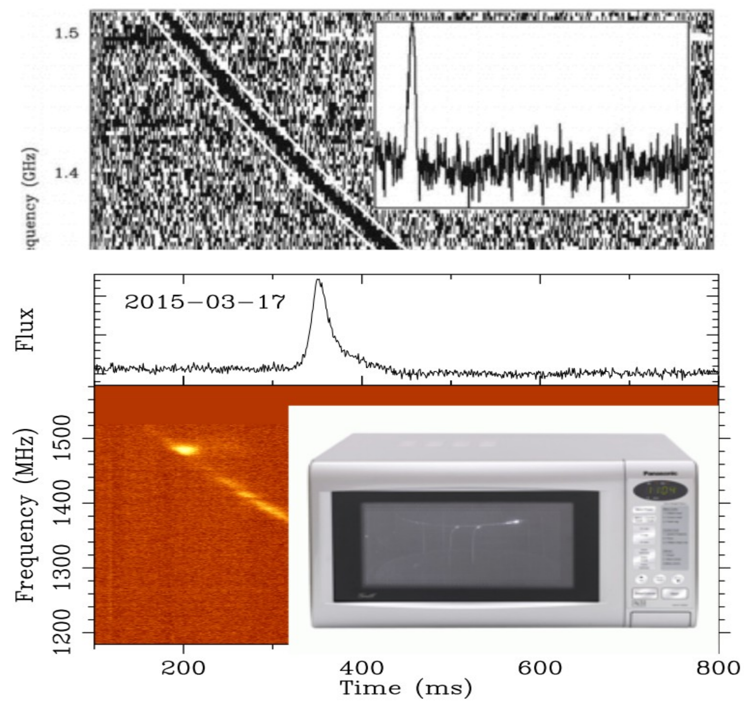
Which particles leave the plasmoid?

Which particles are trapped?



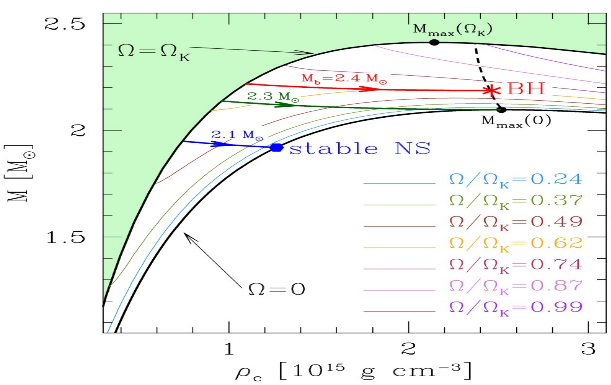
Nathanail et al. 2018 (in prep.)

Fast Radio Bursts...



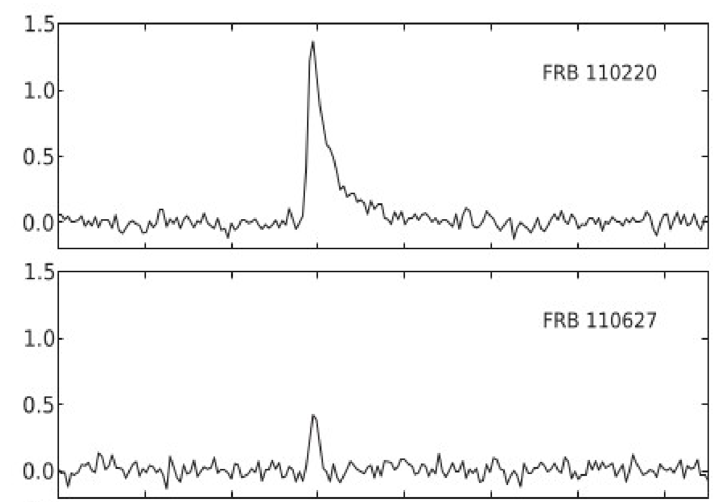
- 2007: First FRB discovered in data from 2001 ("Lorimer Burst")
- 2010: Concern about strange interference ("perytons")
- 2013—2016: 25 more FRBs found in old and new data
  - 4 different telescopes
  - first real-time detection in 2014
  - first interferometric detection in 2016 (Molonglo)

slide:Petroff



10^{40} erg $\sim 10^{33}$ J

millisecond scale

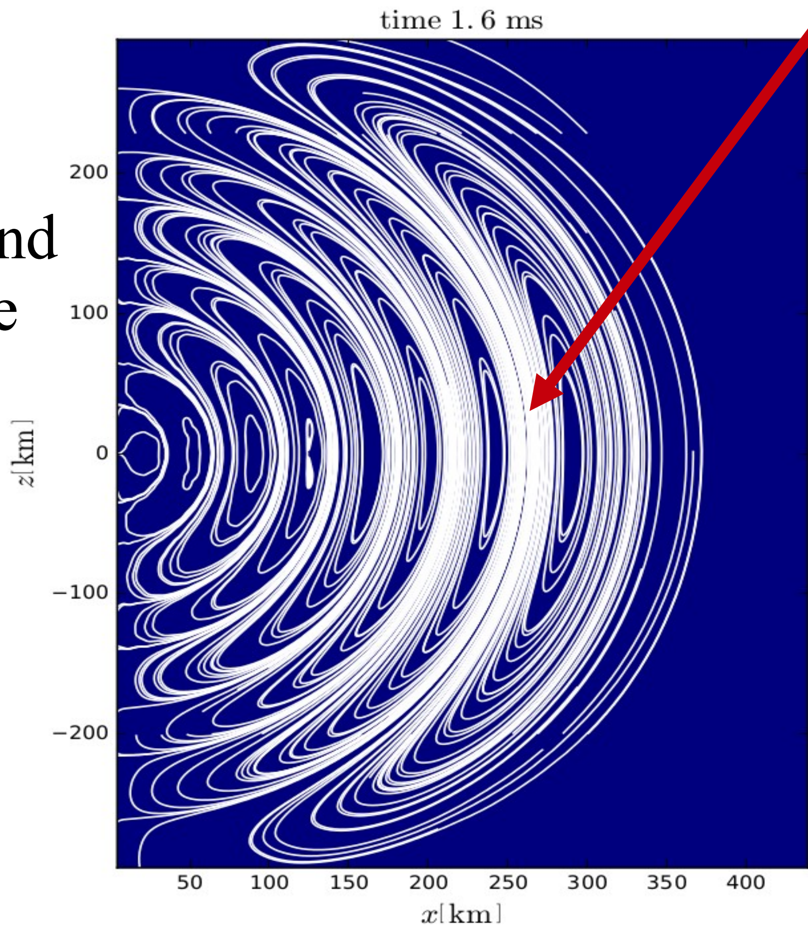


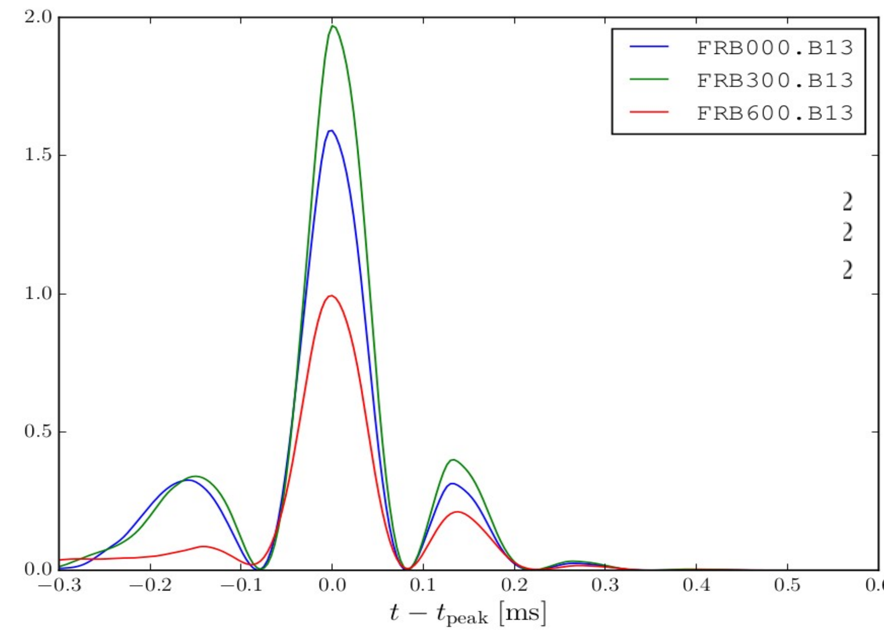
The "Blitzar" model for Fast Radio Bursts

Falcke & Rezzolla 2014

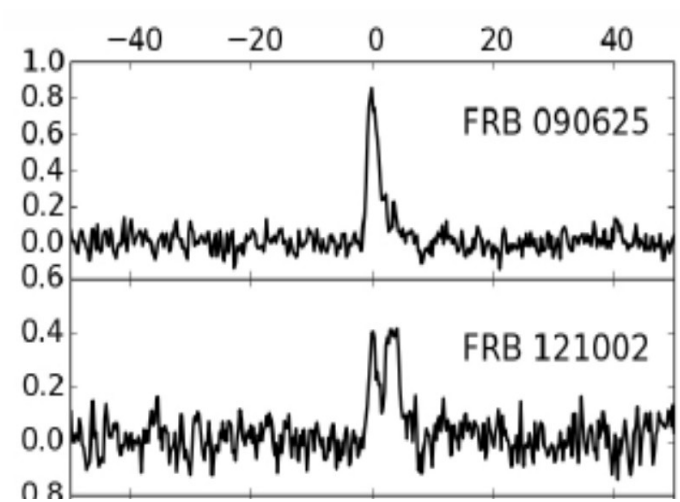
The traveling pulses ...

The big pulse





energy and timescale matches FRBs...



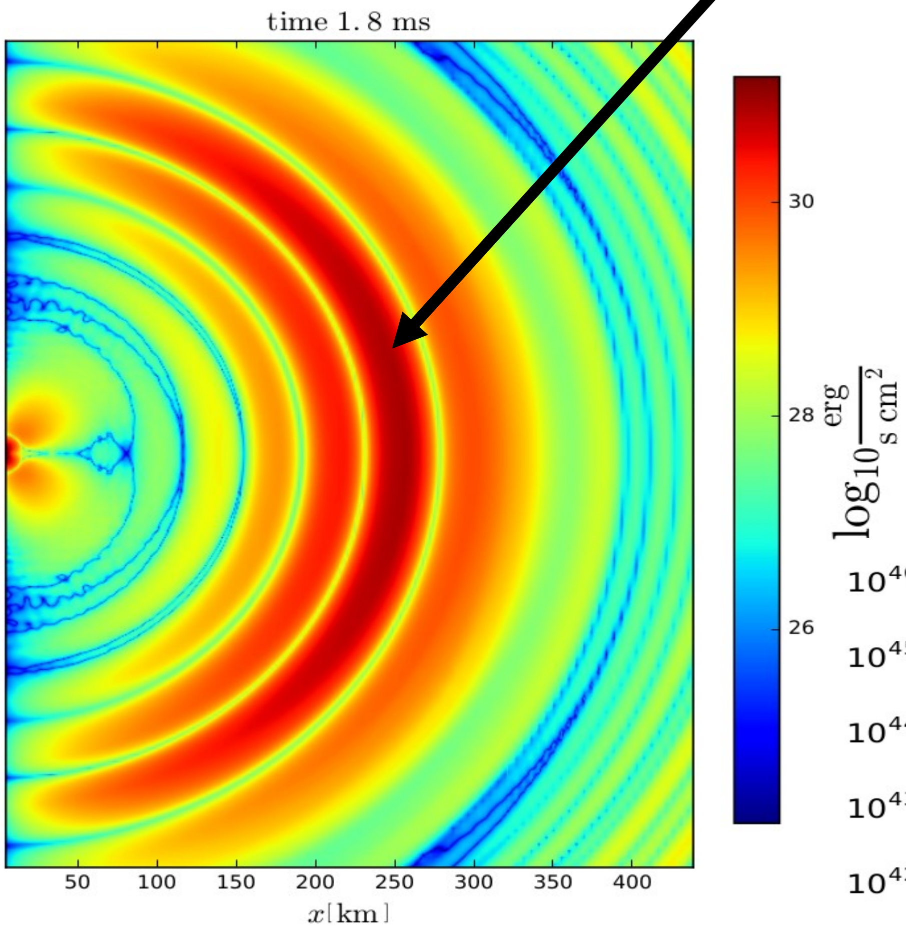
WhiskyRMHD code:
GR resistive MHD (electrovacuum)
Dionysopoulou et al. 2013

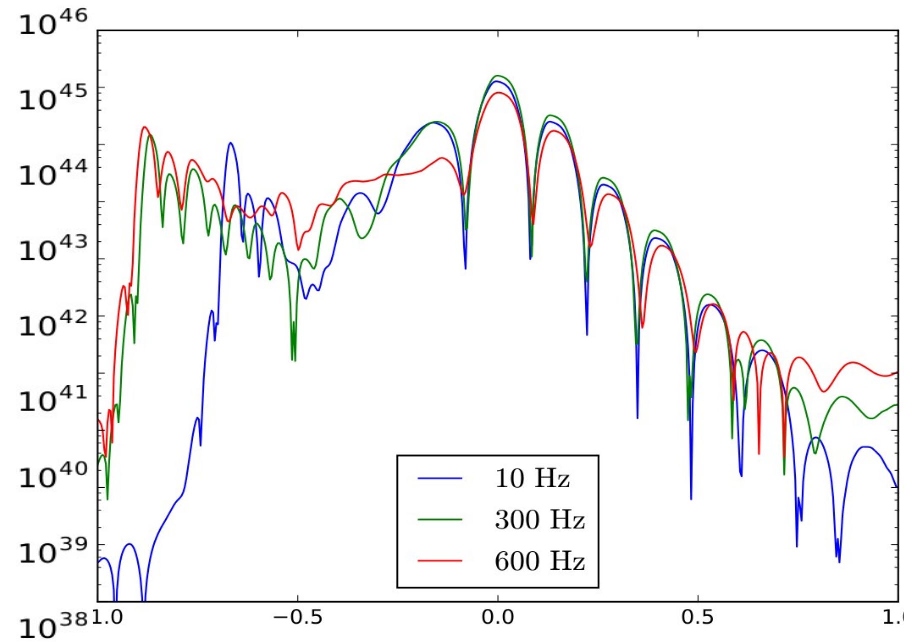
Most, Nathanail & Rezzolla 2018

The traveling pulses ...

The big pulse

energy and
timescale
matches
FRBs...





WhiskyRMHD code:
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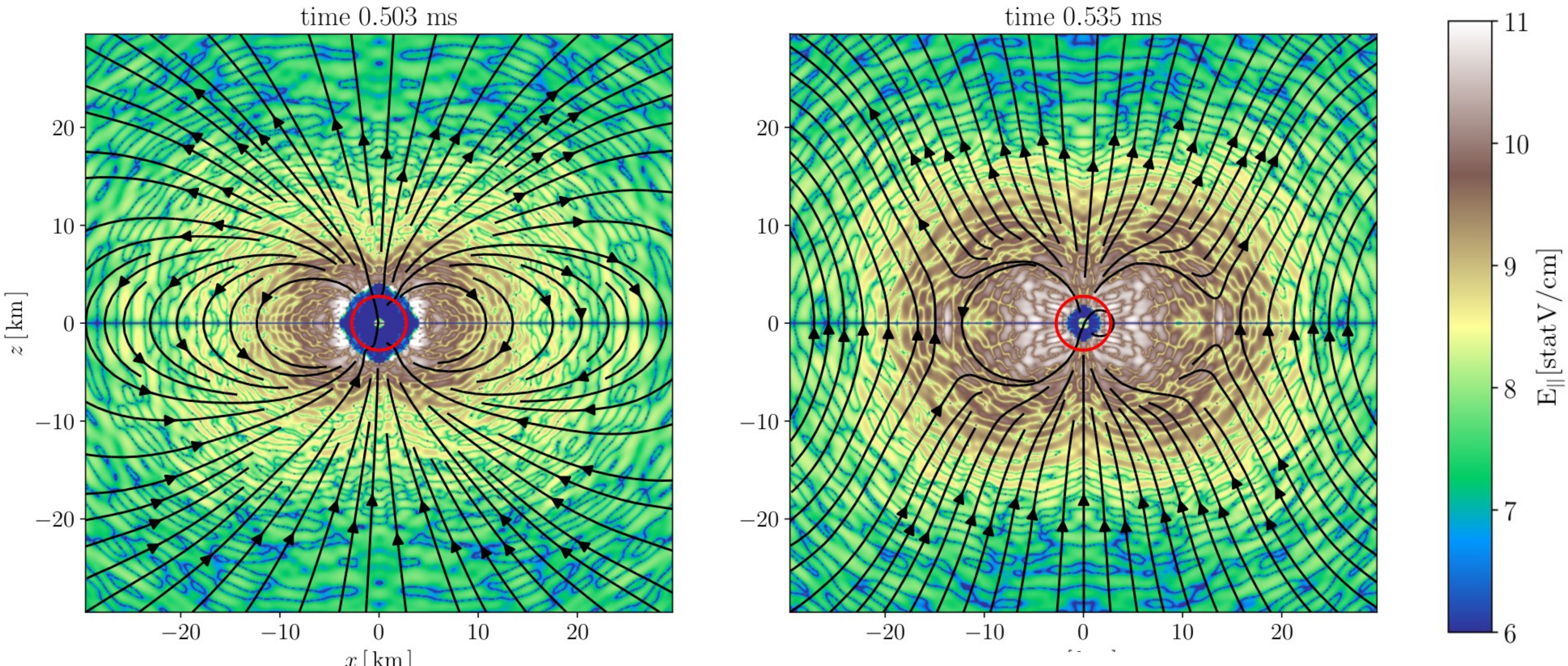
Most, Nathanail & Rezzolla 2018

What about pair creation?



Just before all matter is lost behind the horizon...

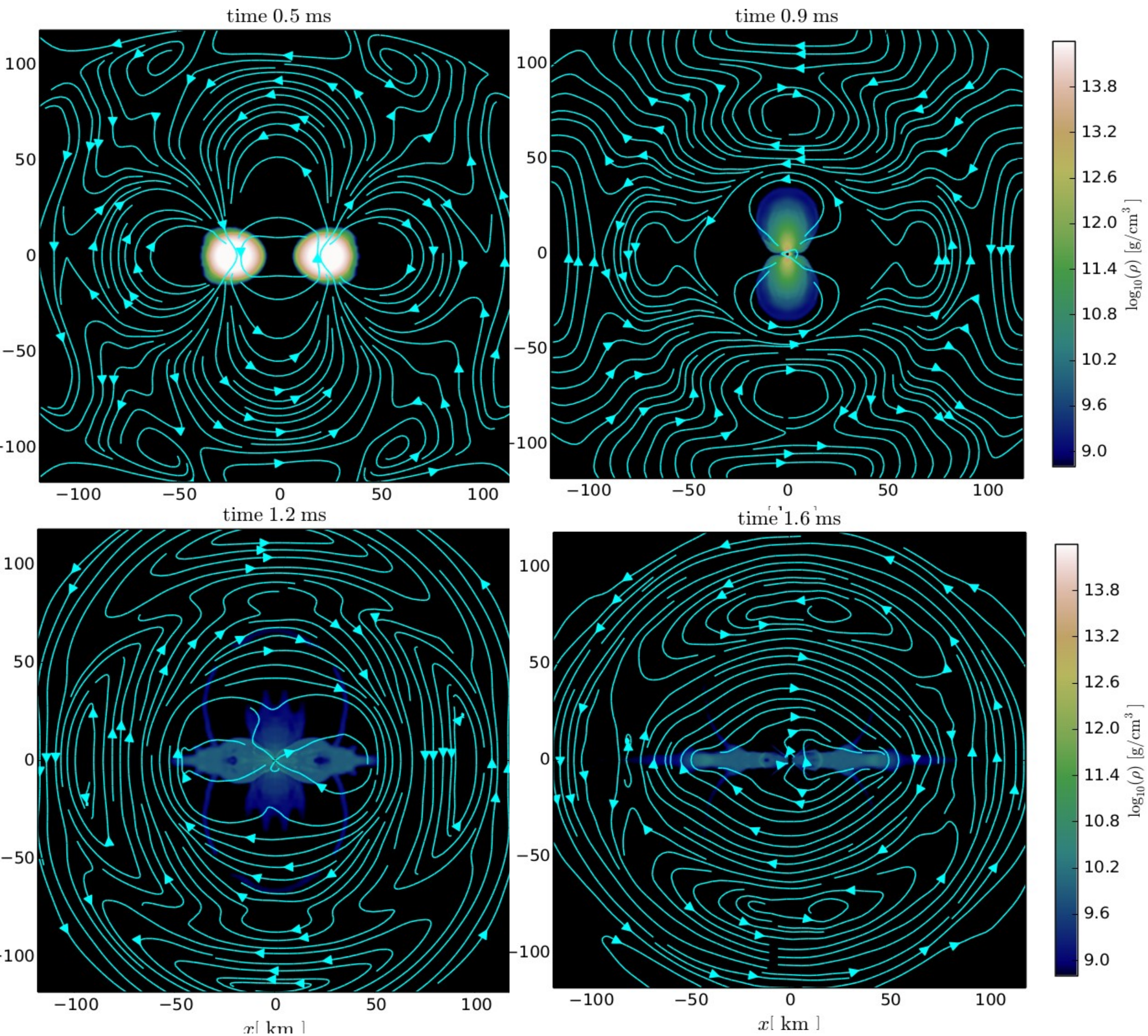
$$\Delta V \lesssim 10^{16}\, volts \left(\frac{r_c}{5km}\right)^{-1} \left(\frac{B_{local}}{10^{10}G}\right) sin(\theta)$$

for an itinial field of and period of 1 sec $B_{\rm pol} = 10^{12}\,{\rm G}$.

for $B_{\rm pol} < 10^{12}\,{\rm G}$ →

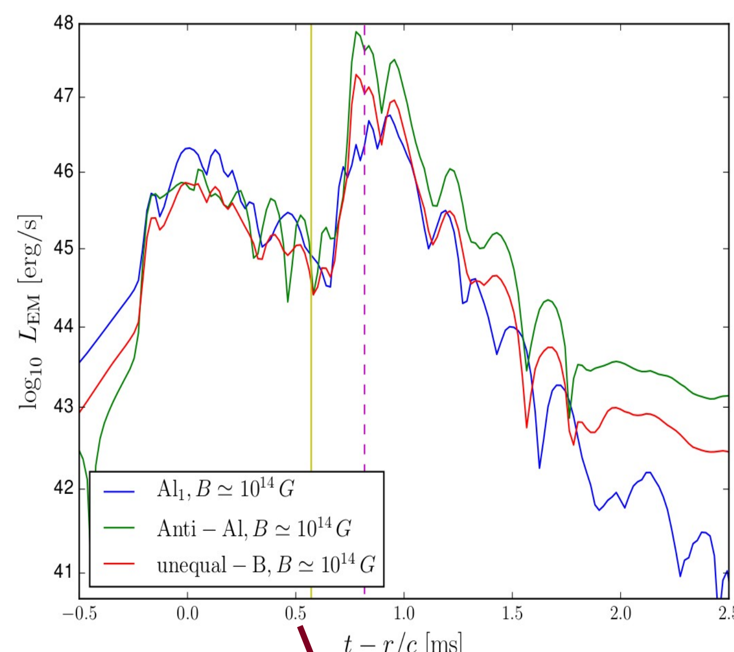
$$E_{\rm EM} = P_{\rm MS}\,\Delta t_{\rm EM} \simeq 8.4 \times 10^{41}\ \eta_{\rm B}\, b_{12}^2\, r_{10}^3\ \ {\rm erg}$$

Fast Radio Bursts... from binary NS?



(head on collision)

negligible amount of mass is left after merger, all matter is gone in some miliseconds, the magnetic field dissipates away...



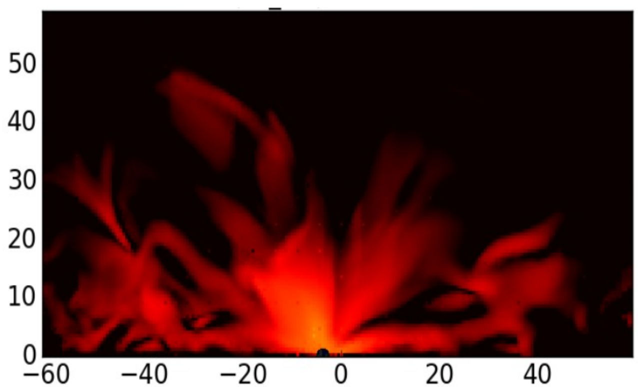
$$E_{EM} = P_{MS}\,\Delta t_{EM} \simeq 16.8 \times 10^{41}\ \eta_B\ b_{12}^2\ \ \text{erg}$$

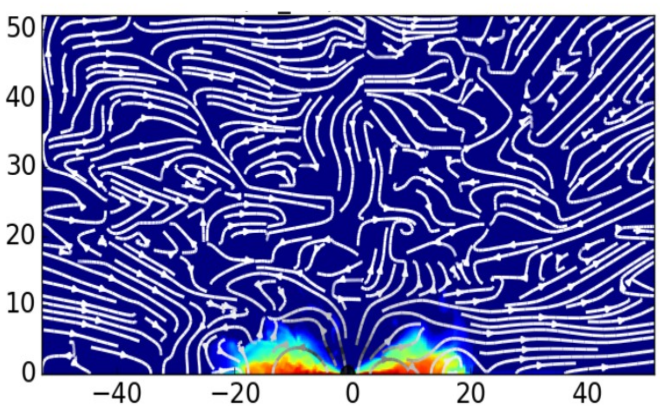
Nathanail, Most & Rezzolla 2018 (to be sub.)

Fast Radio Bursts... from binary NS?

the case of prompt collapse

negligible amount of mass is left after merger, all matter is gone in some miliseconds, the magnetic field dissipates away...





"Following prompt black hole formation, there is no evidence of mass outflow or magnetic field collimation."

Ruiz & Shapiro 2018

EM from binary NS

Prompt collapse (in the first msec)

delayed collapse (after tens of msec)

further delayed collapse (~1sec)

no collapse

Total mass of the binary in $M_\odot$

4 3.2 2.8 2.6

EOS is extremely important...

EM from binary NS

Prompt collapse (in the first msec)

delayed collapse (after tens of msec)

further delayed collapse (~1sec)

no collapse

Total mass of the binary in $M_\odot$

4 3.2 2.8 2.6

FRB?

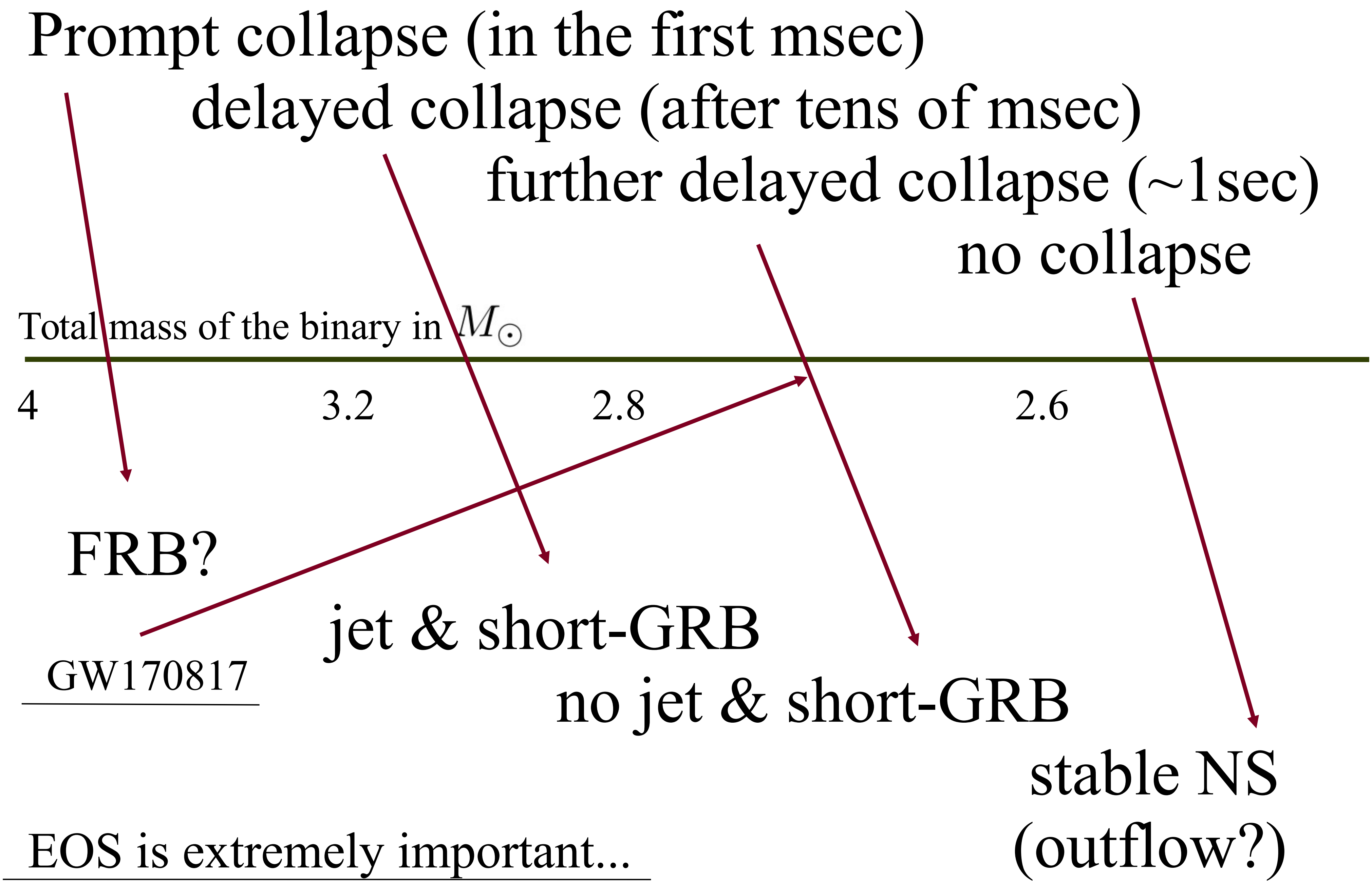
jet & short-GRB

no jet & short-GRB

stable NS (outflow?)

EOS is extremely important...

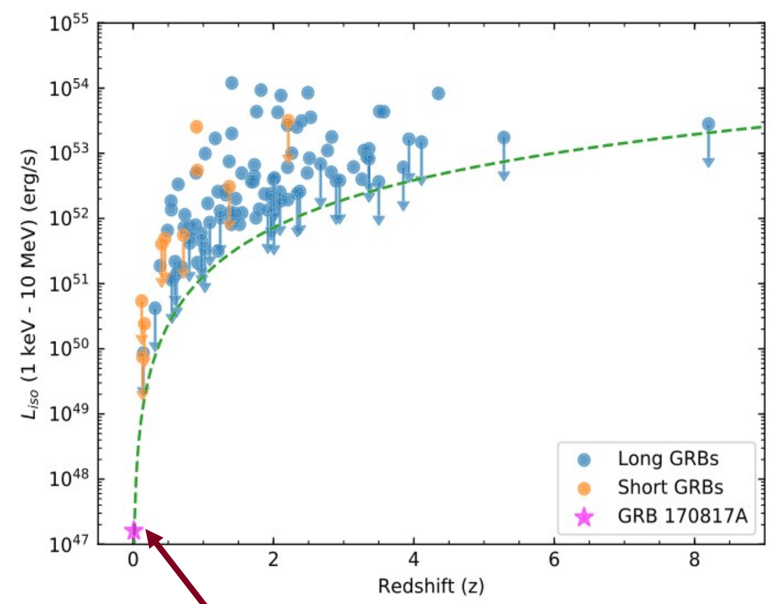
EM from binary NS



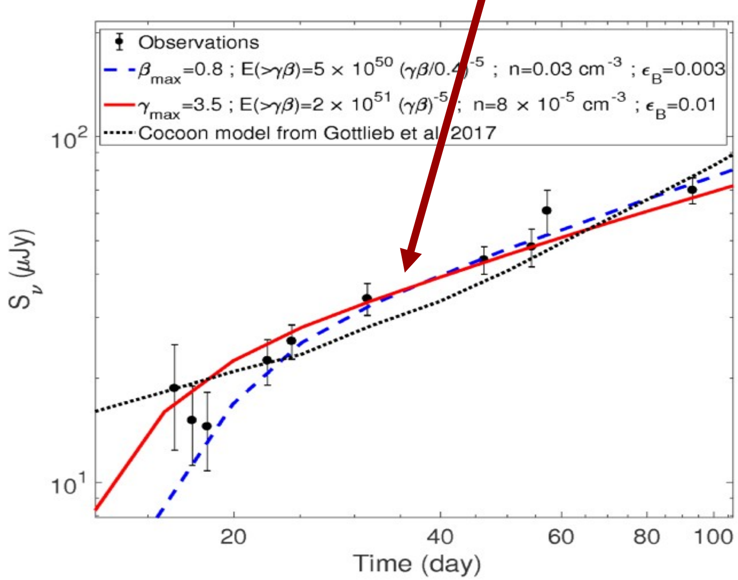
Some things we saw from GW170817 BNS

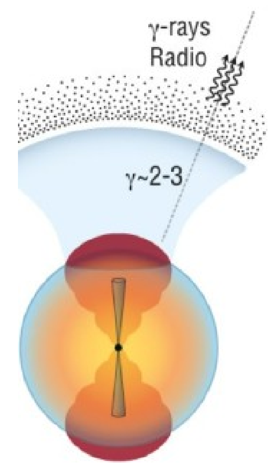
"The radio light curve of GW170817 is inconsistent with numerical models of an offaxis jet afterglow and instead requires a quasispherical, mildly relativistic outflow [...] We find that most, if not all, of the jet energy is transferred to this cocoon and there is no direct evidence that the jet produced a classical SGRB."

Abbott et al.



GW170817

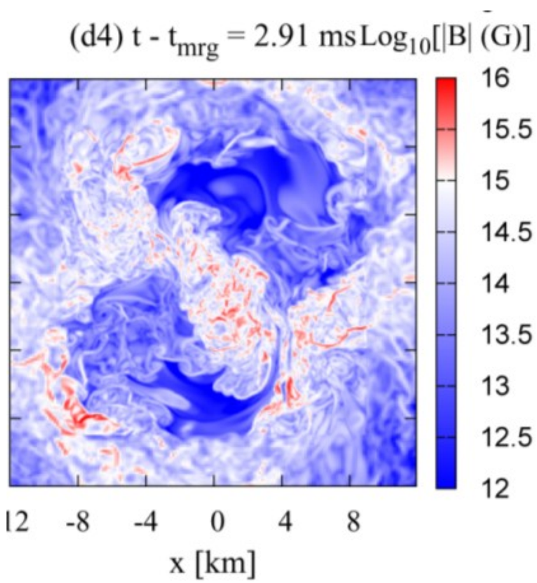




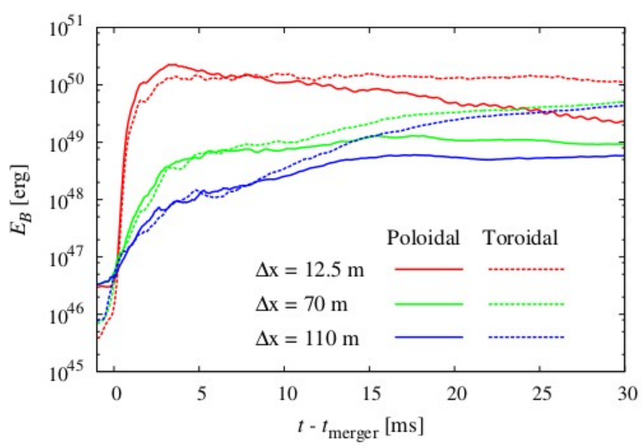
Mooley et. al 2018

Things we know for binary NS...

Magnetic field amplification

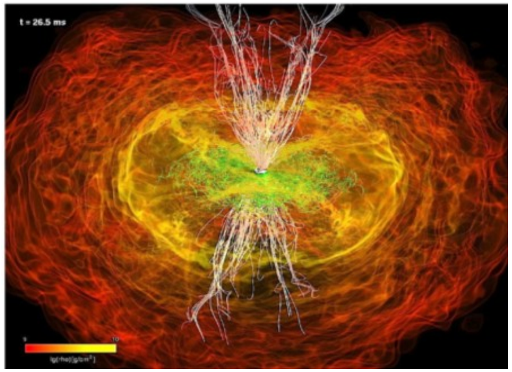


Kiuchi et al. 2015



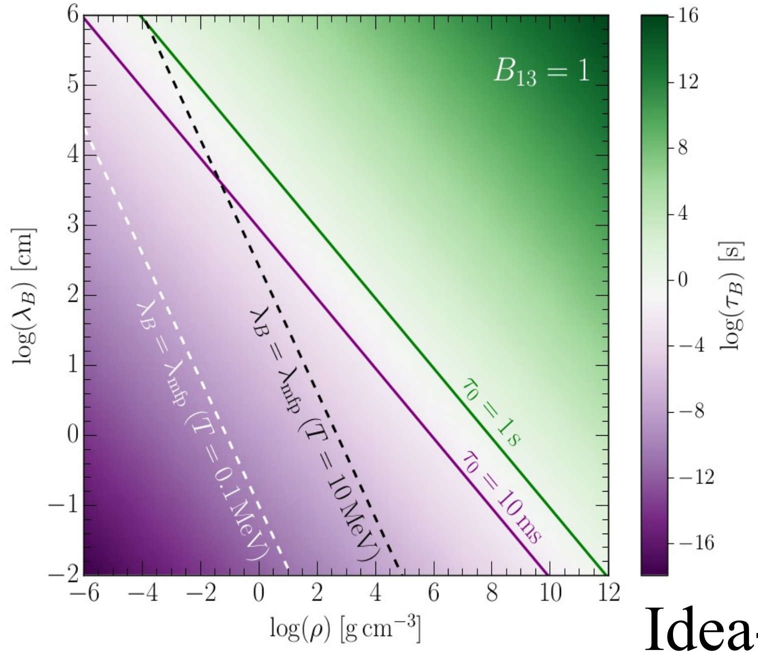
Kiuchi et al. 2017

Magnetic jet structure



Rezzolla et. al 2011

When does Electrical Resistivity becomes important in BNS

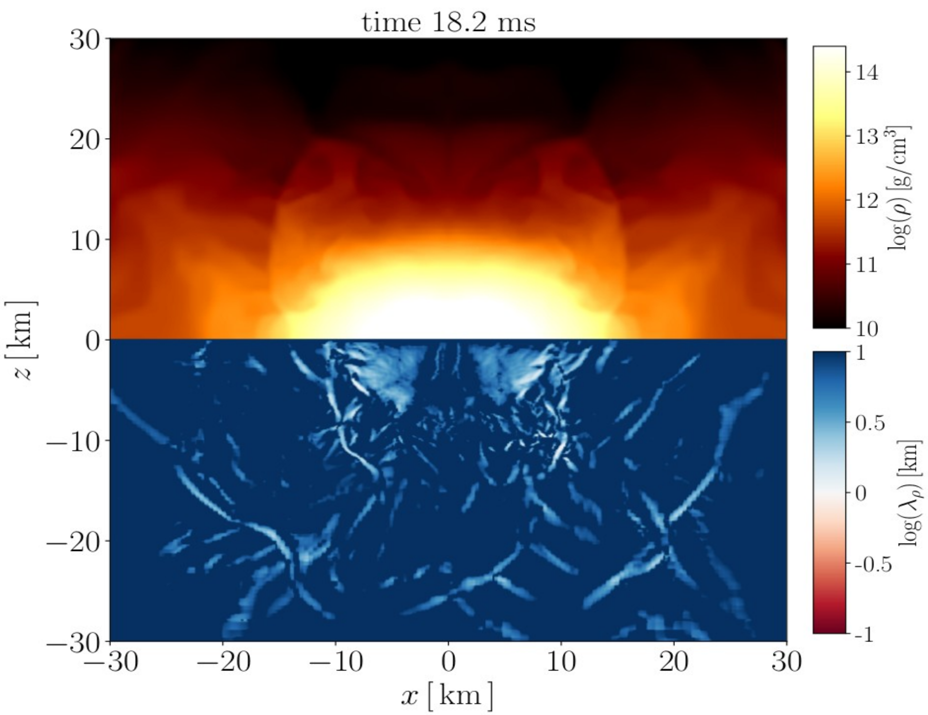


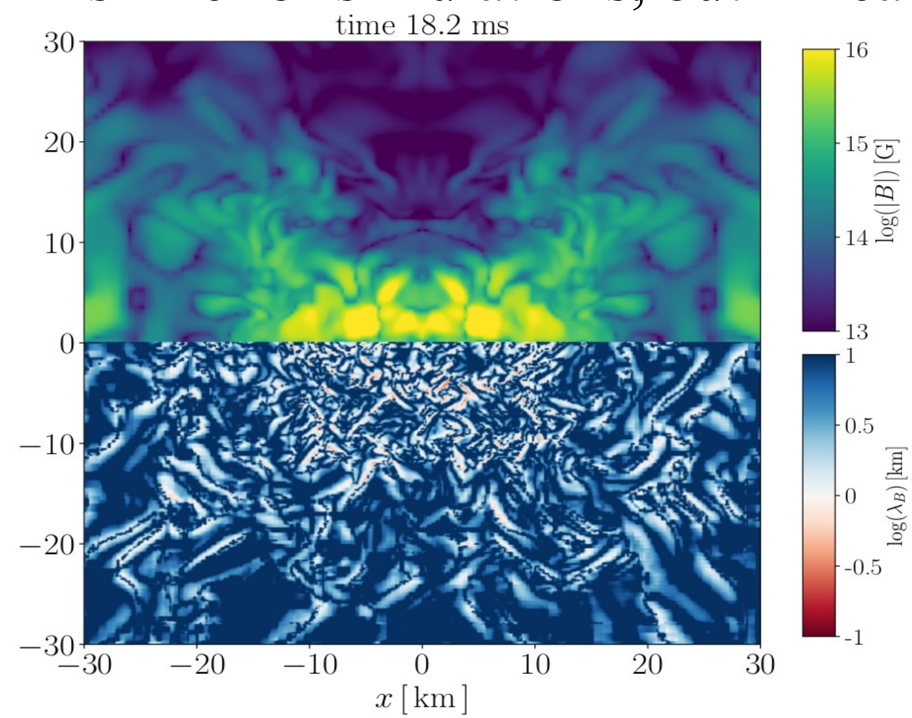
Ohmic dissipation $\tau_d \simeq \dfrac{4\pi\sigma\lambda_B^2}{c^2}$

Hall $$\tau_B := \frac{\tau_d}{\omega_c \tau} = \frac{4\pi n_e e \lambda_B^2}{cB} = \frac{4\pi e \rho \lambda_B^2}{cB}\frac{Z}{Am_n}$$

$$\tau_B \simeq 1.2 \times 10^2 \times B_{13}^{-1} \left(\frac{\rho}{1\,{\rm g\,cm^{-3}}}\right)\left(\frac{\lambda_B}{1\,{\rm km}}\right)^2 \,{\rm s}$$

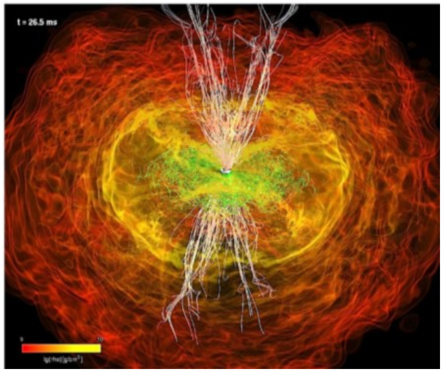
Idea-MHD is fine for simulations, but in reality....





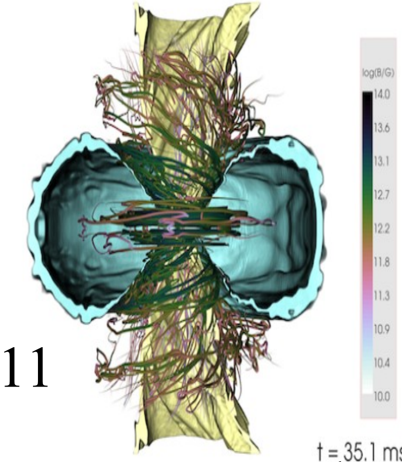
Harutyunyan, Nathanail, Rezzolla & Sedrakian 2018

efforts have to be combined for binary NS...



Rezzolla et. al 2011

$M_{tor} = 0.063 M_\odot \quad t_{accr} \simeq M_{tor}/\dot{M} \simeq 0.3$ s



Kawamura et. al 2016

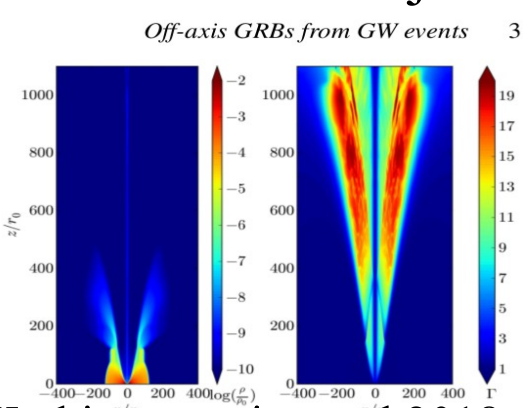
Numerical relativity BNS

short-GRB jet opening angles
θ ~ 3-10
Fong et al. 2015

These are for the case of the delayed collapse

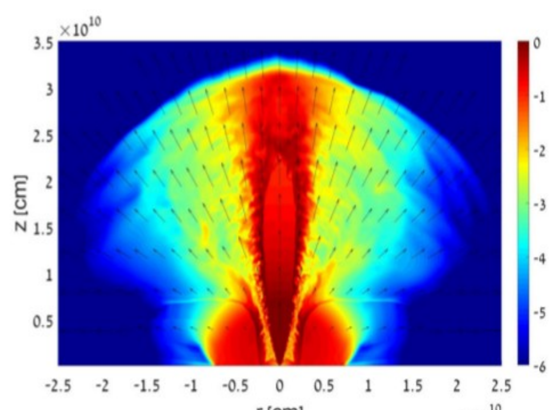
$2.8 - 3.2\, M_\odot$, collapse to BH after tens of msec

Off-axis sGRB jets



Kathirgamaraju et. al 2018

Coccoon



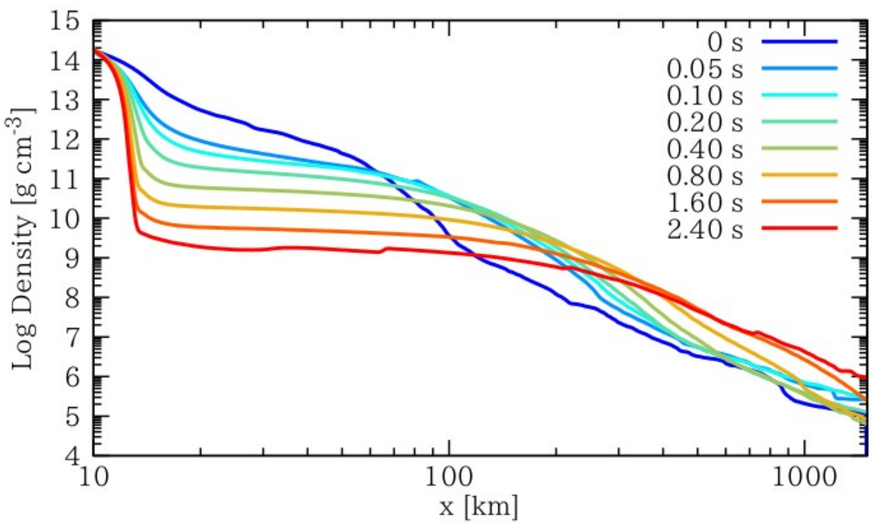
Gottlieb, E. Nakar and T. Piran 2018

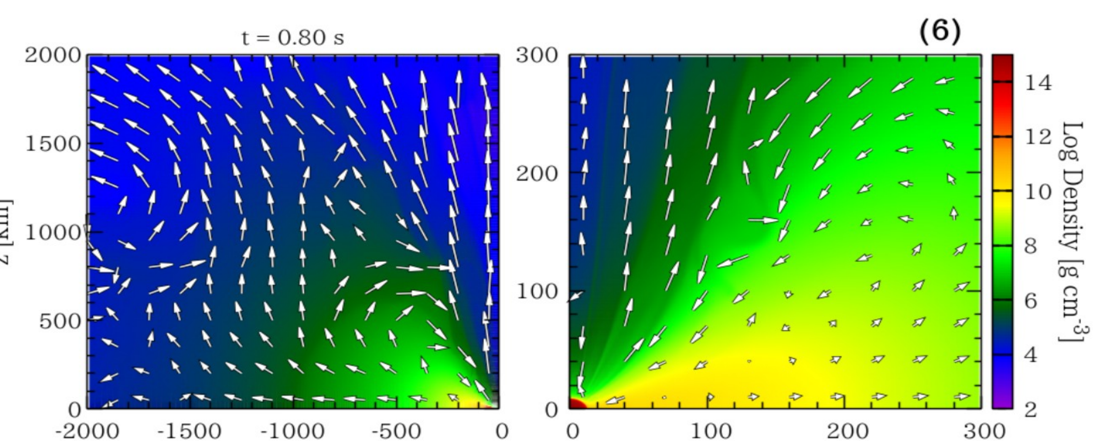
short GRB Jet simulations

collapse after 1sec → no jet & short-GRB

Total mass of the binary in $M_\odot$ — Nathanail 2018

4 — 3.2 — 2.8 — 2.6





Fujibayashi et al. 2017

- neutrino cooling
- loss of thermal pressure
- mass accretion
- torus expansion

$$t_\nu^{diff} \simeq 3\,\tau_\nu \frac{\Delta R}{c} \sim 0.8\,sec \left(\frac{\tau_\nu}{10^3}\right)\left(\frac{\Delta R}{20\,Km}\right),$$

$$t_{accr} \simeq 1\,sec \left(\frac{R_T}{50\,Km}\right)^2 \left(\frac{H_T}{25\,Km}\right)^{-1} \times \left(\frac{\alpha}{0.01}\right)^{-1} \left(\frac{c_s}{0.1c}\right)^{-1}$$

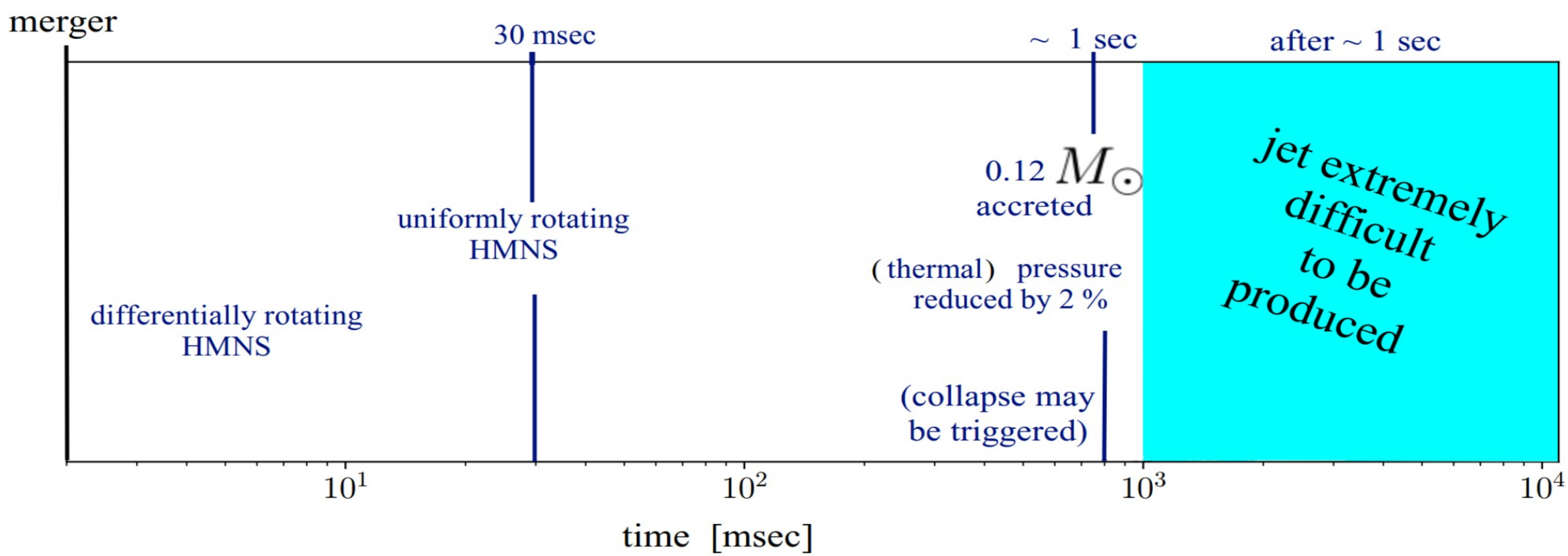
$$\rho_T \simeq \frac{M_T}{2H_T \pi R_T^2} \sim 9.2 \times 10^9 g/cm^3 \left(\frac{M_T}{0.08 M_\odot}\right) \times \left(\frac{R_T}{140\,Km}\right)^{-2} \left(\frac{H_T}{70\,Km}\right)^{-1},$$

$$\dot{M}_{HMNS} \simeq \frac{M_T}{t_{accr}} \sim 0.2\,M_\odot s^{-1} \left(\frac{\alpha}{0.01}\right)\left(\frac{M_T}{0.2 M_\odot}\right) \times \left(\frac{R_T}{50\,Km}\right)^{-2} \left(\frac{H_T}{25\,Km}\right),$$

collapse after 1sec → no jet & short-GRB

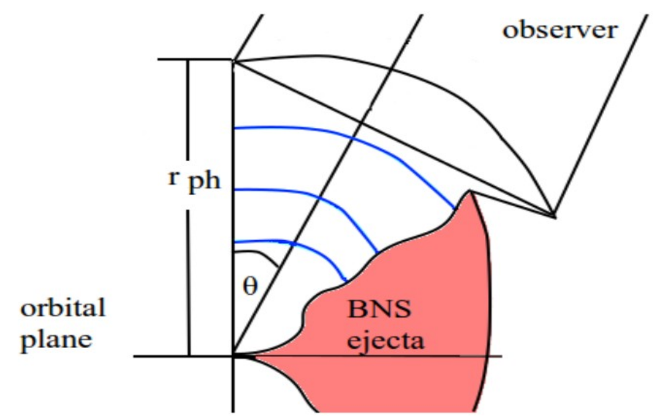
Total mass of the binary in $M_\odot$ — Nathanail 2018

4 — 3.2 — 2.8 — 2.6



$$B^2_{HMNS}/8\pi \gg 2.6 \times 10^{28}\, dyn/cm^2 \sim \dot{M}c/4\pi r^2_{BH}.$$

The collapse of the compact remnant powers an explosion.....



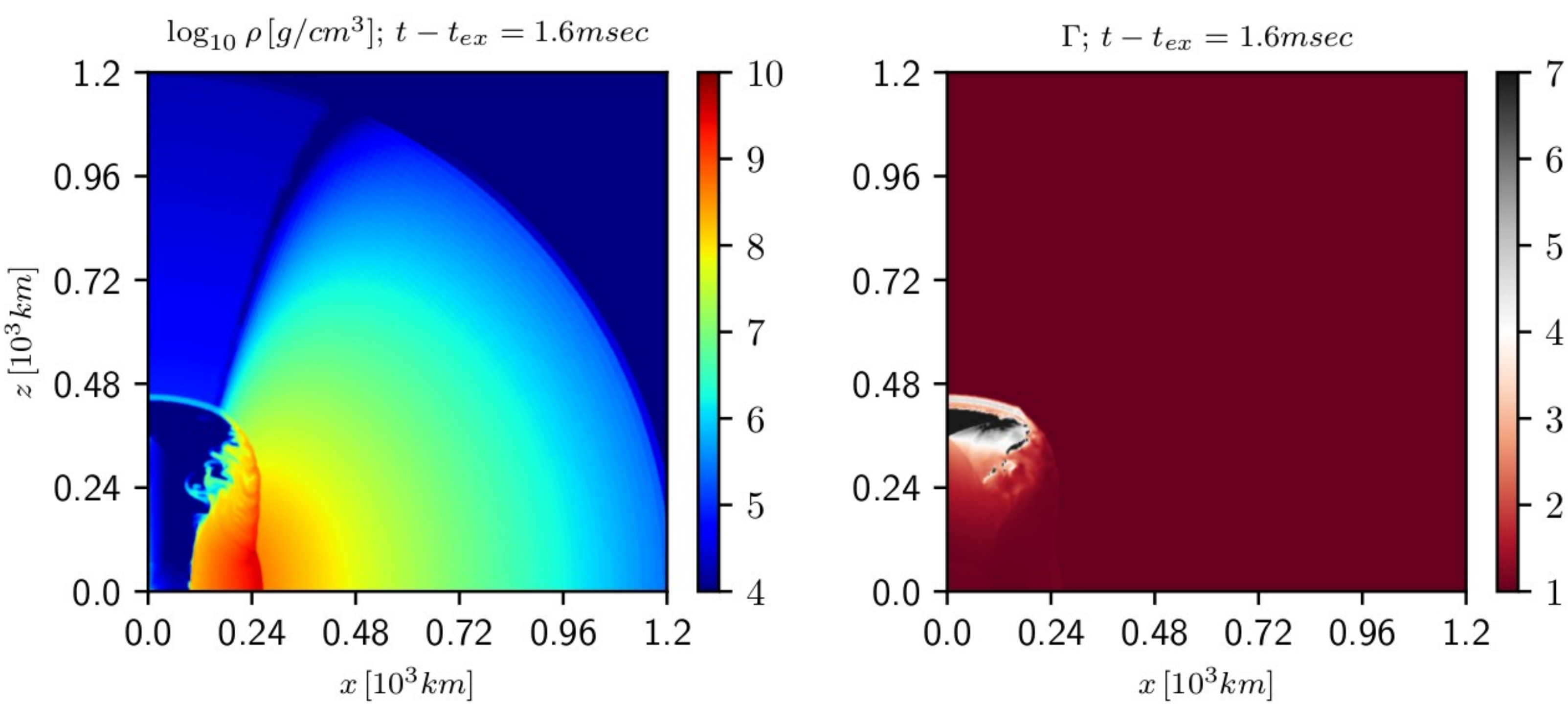
collapse after 1sec → a different outflow

a first simple Hydrodynamic model

Parameters: energy of the explosion
maximum density of the torus

all the energy is released in a shell
in the form of pressure

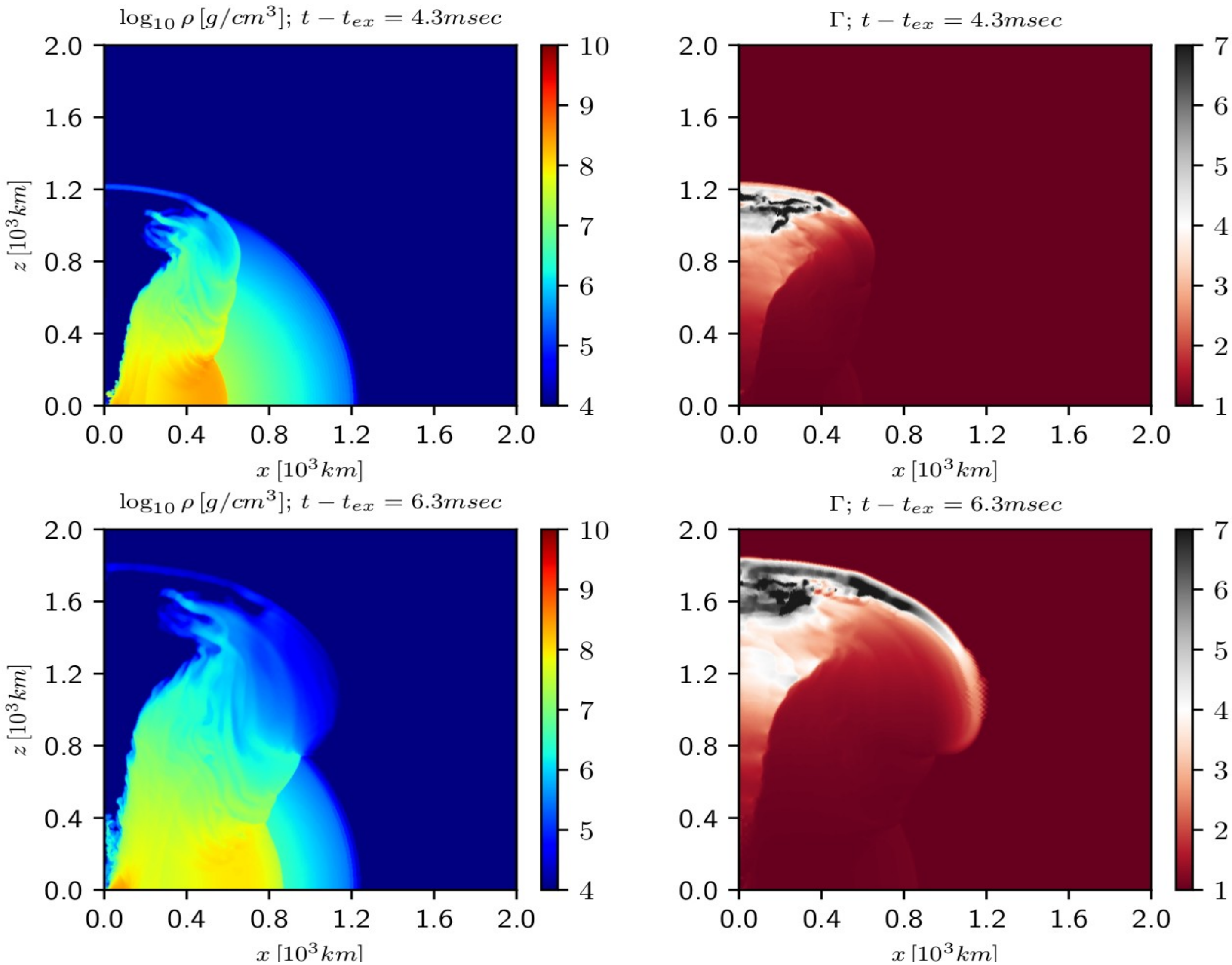
BHAC code:
GR Ideal MHD
Porth et al. 2017



Nathanail, Porth et al. 2018 (to be subm.)

collapse after 1sec → a different outflow

a first simple Hydrodynamic model

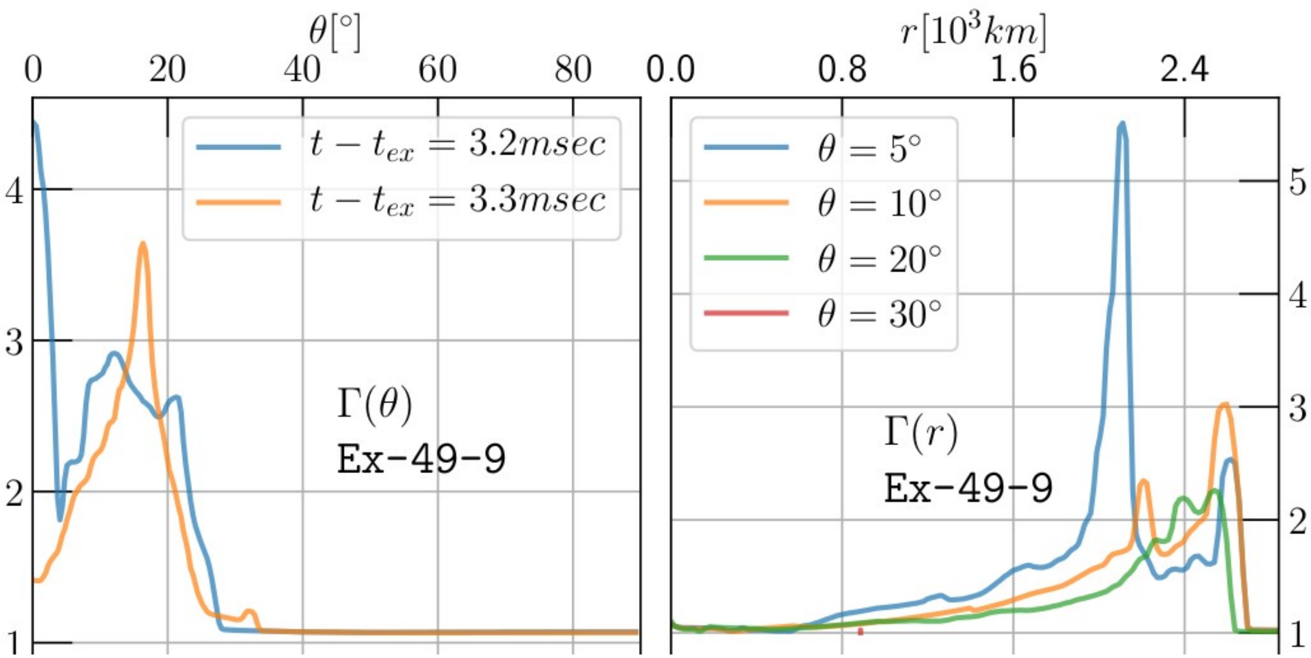


the outflow quickly surpass the BNS ejecta and breaks out

Nathanail, Porth et al. 2018 (to be subm.)

collapse after 1sec → a different outflow

a first simple Hydrodynamic model



the outflow inherits an angular and radial structure

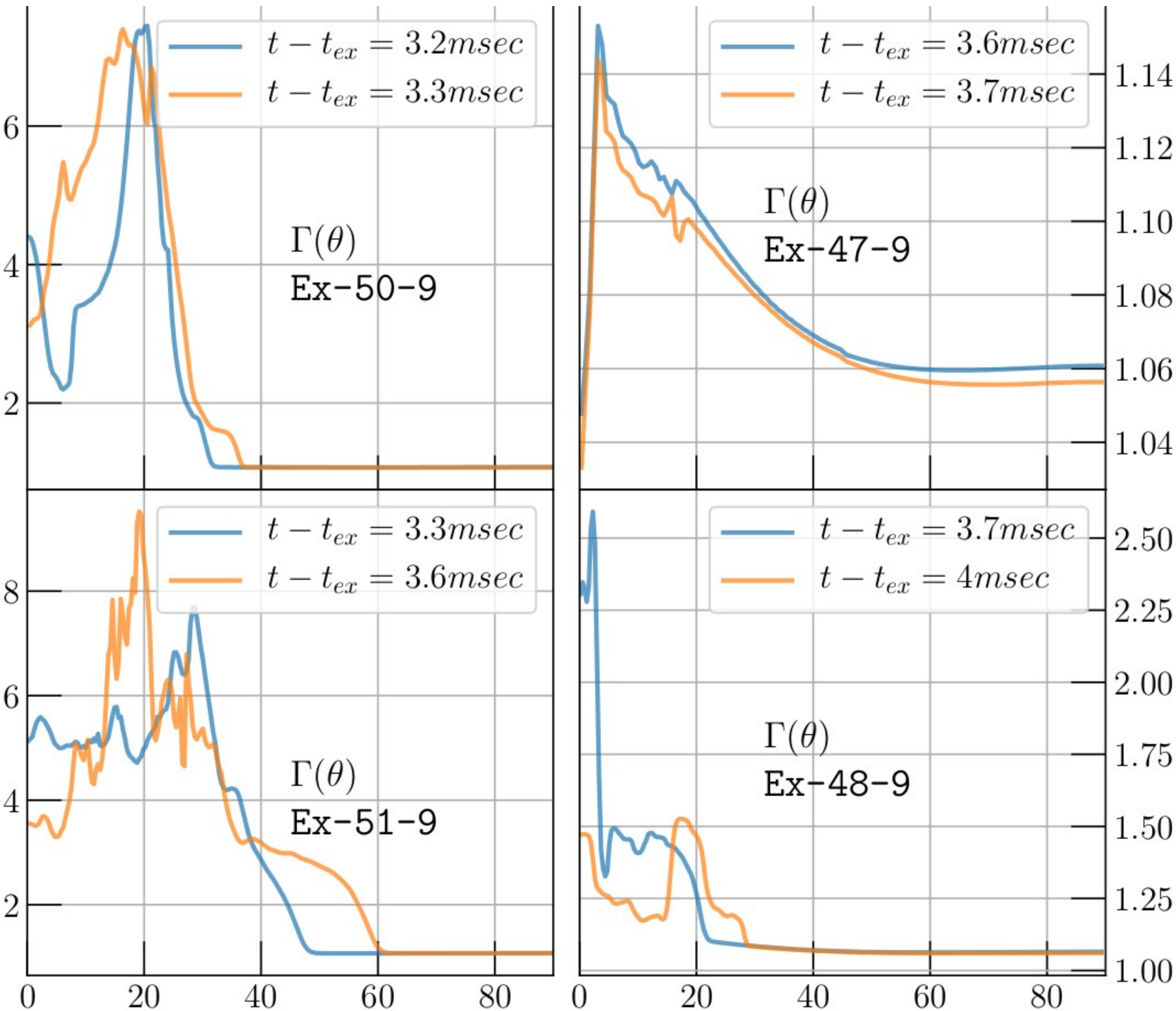
Model

$$E \sim 10^{49}\, erg$$
$$\rho_T \simeq 10^9 gcm^3$$

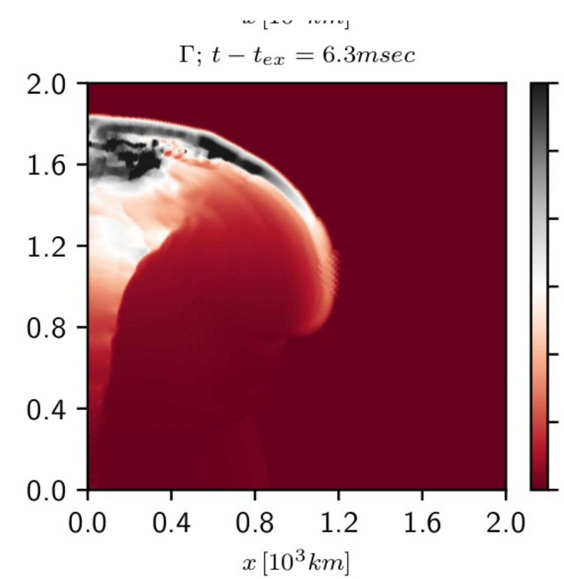
Nathanail, Porth et al. 2018 (to be subm.)

collapse after 1sec → a different outflow

a first simple Hydrodynamic model



most models give a wide angle mildly relativistic outflow

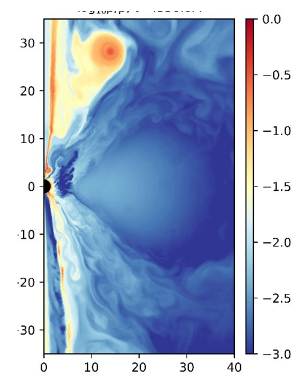
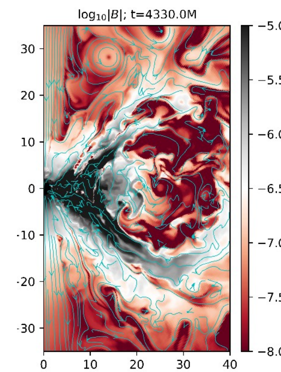


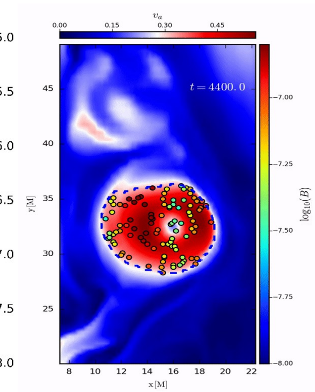
Nathanail, Porth et al. 2018 (to be subm.)

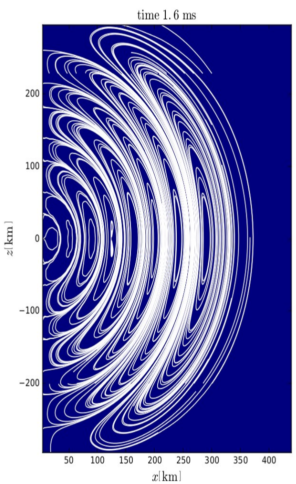
Key points

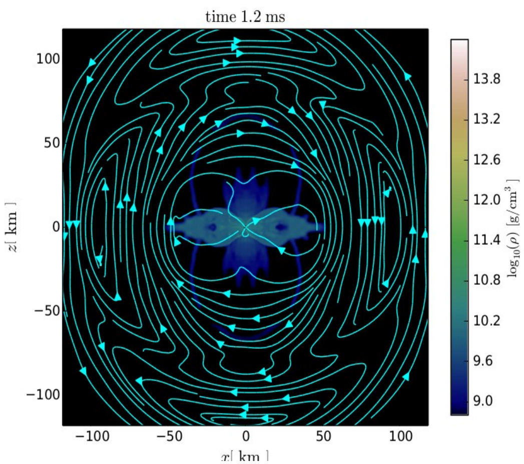
Plasmoids in GRMHD

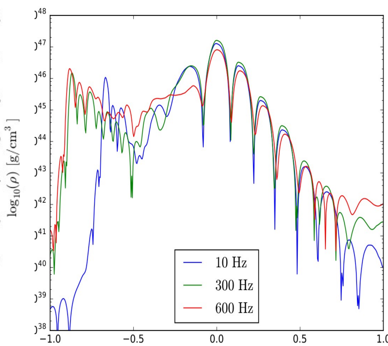
trace them, track them and light them up









FRBs

Supramassive NS collapse
NS head on collision &
BNS prompt collapse

GRBs (short from BNS)

jet or no jet? (where it depends)
Collapse of the SMNS after 1 sec from merger gives a wide angle mildy relativistic outflow