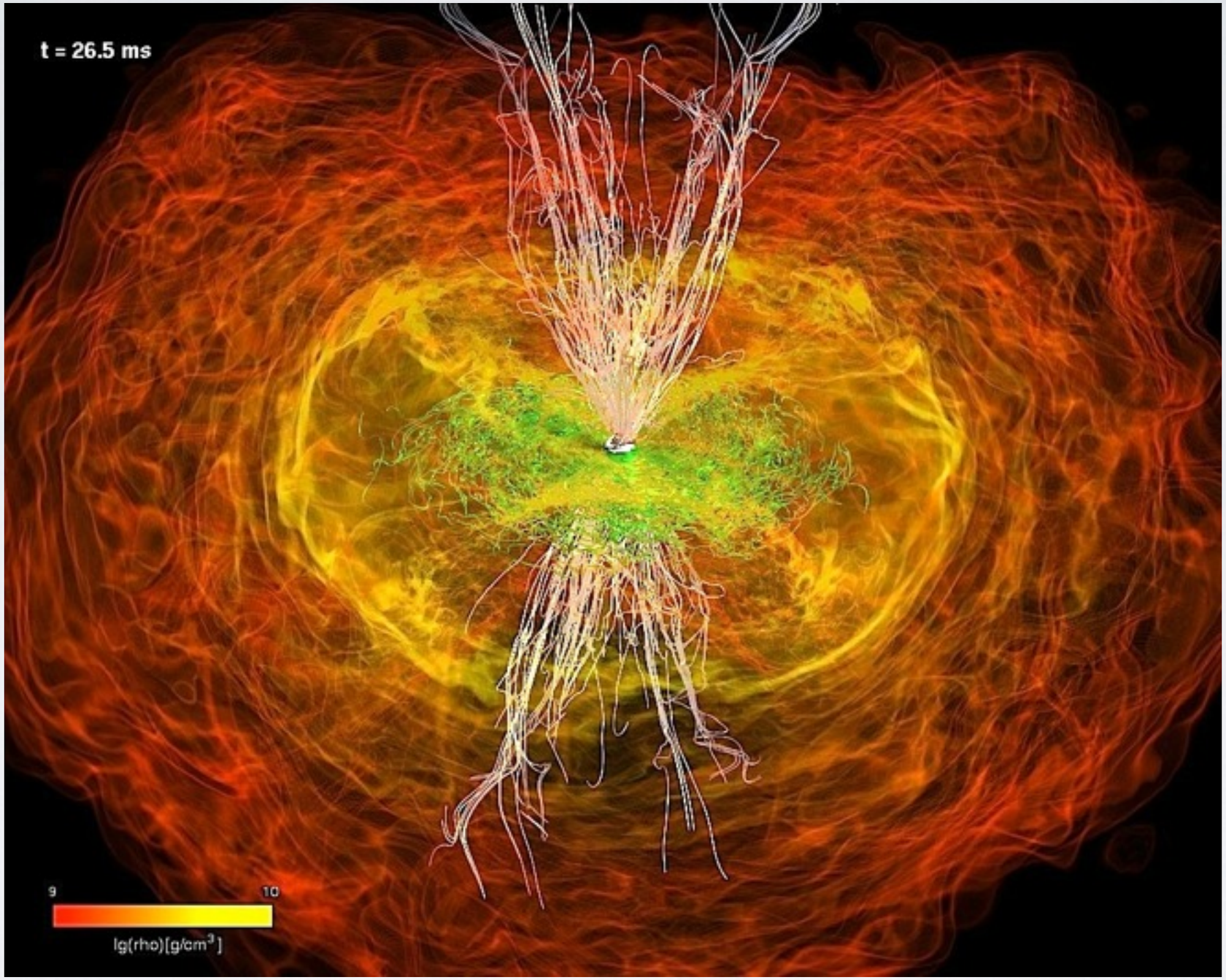
COMPACT BINARY PROGENITORS OF SHORT GAMMA-RAY BURSTS



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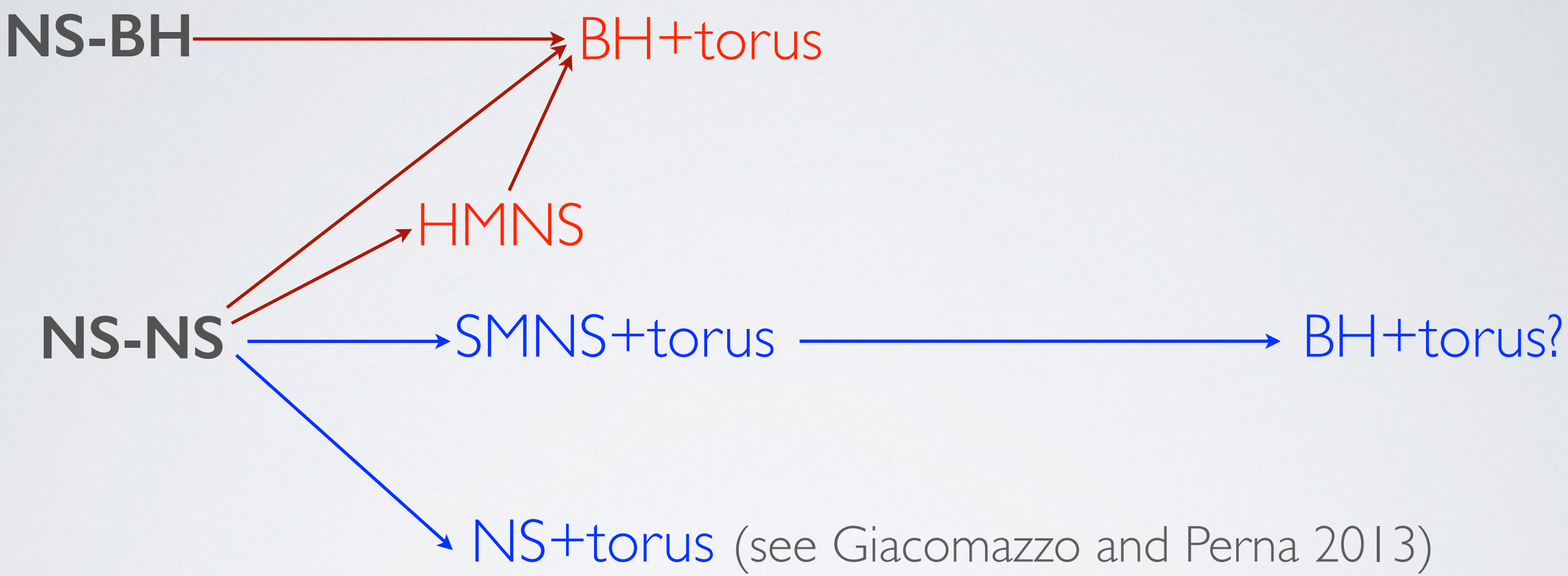
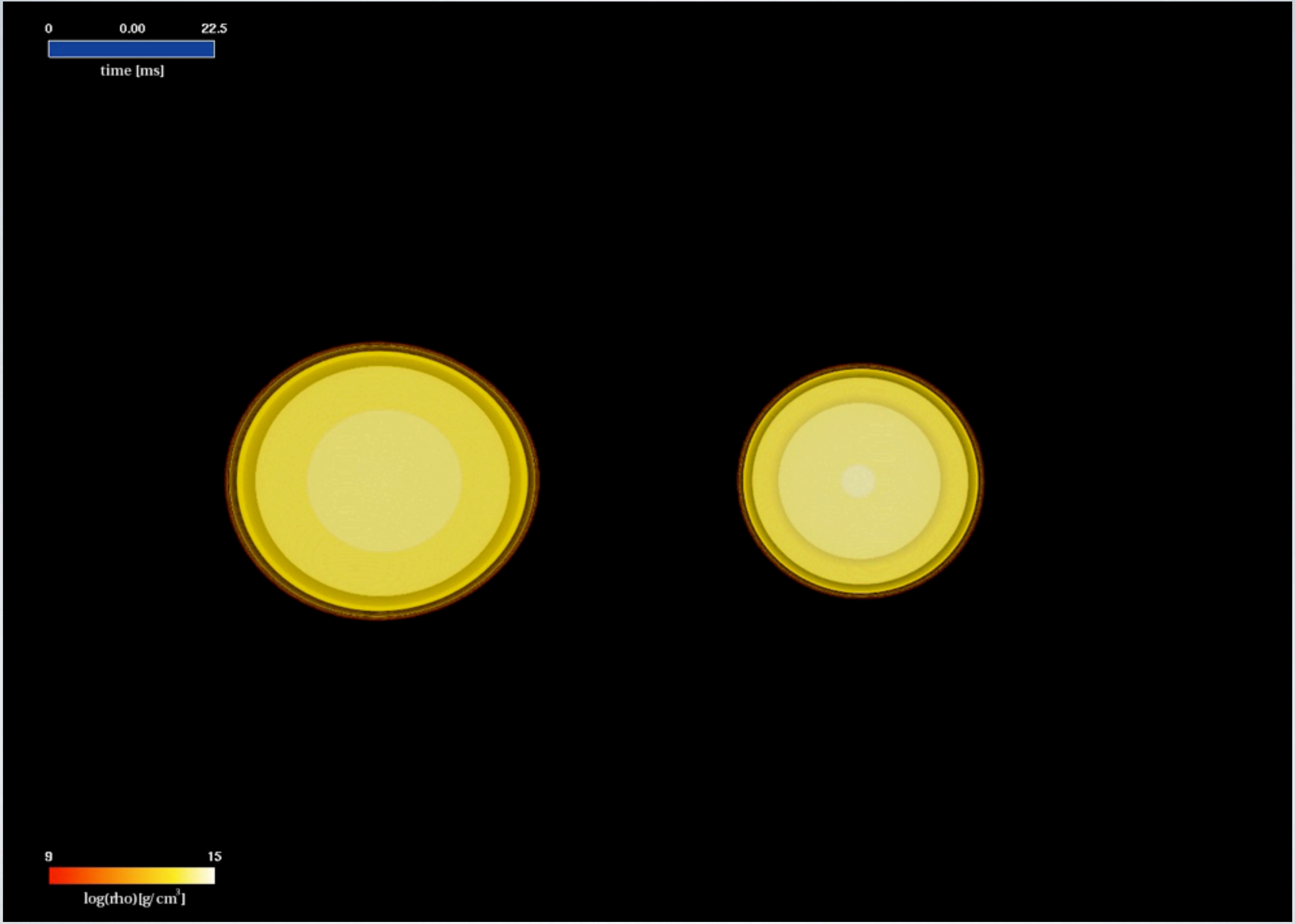
COMPACT BINARY MERGER OUTCOME

Depending on mass and EOS several post-merger scenarios:



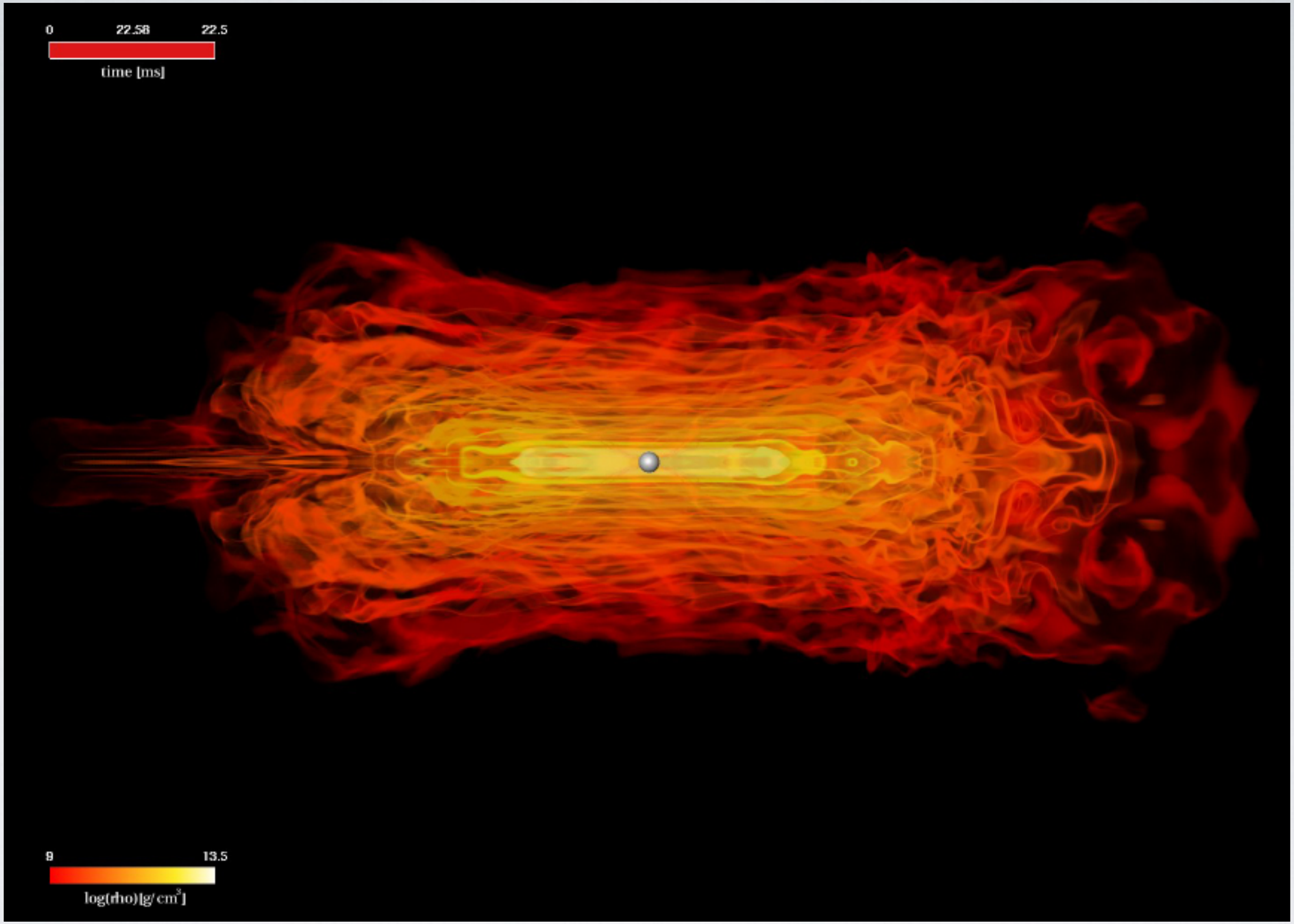
Magnetic fields play fundamental role in post-merger dynamics (jets from BH/NS+torus, NS collapse to BH, ...)

All these scenarios may lead to SGRBs with different properties



Visualization by Giacomazzo, Koppitz, Rezzolla

see NASA GSFC video at https://www.youtube.com/watch?v=vw2sLcyV7Vc

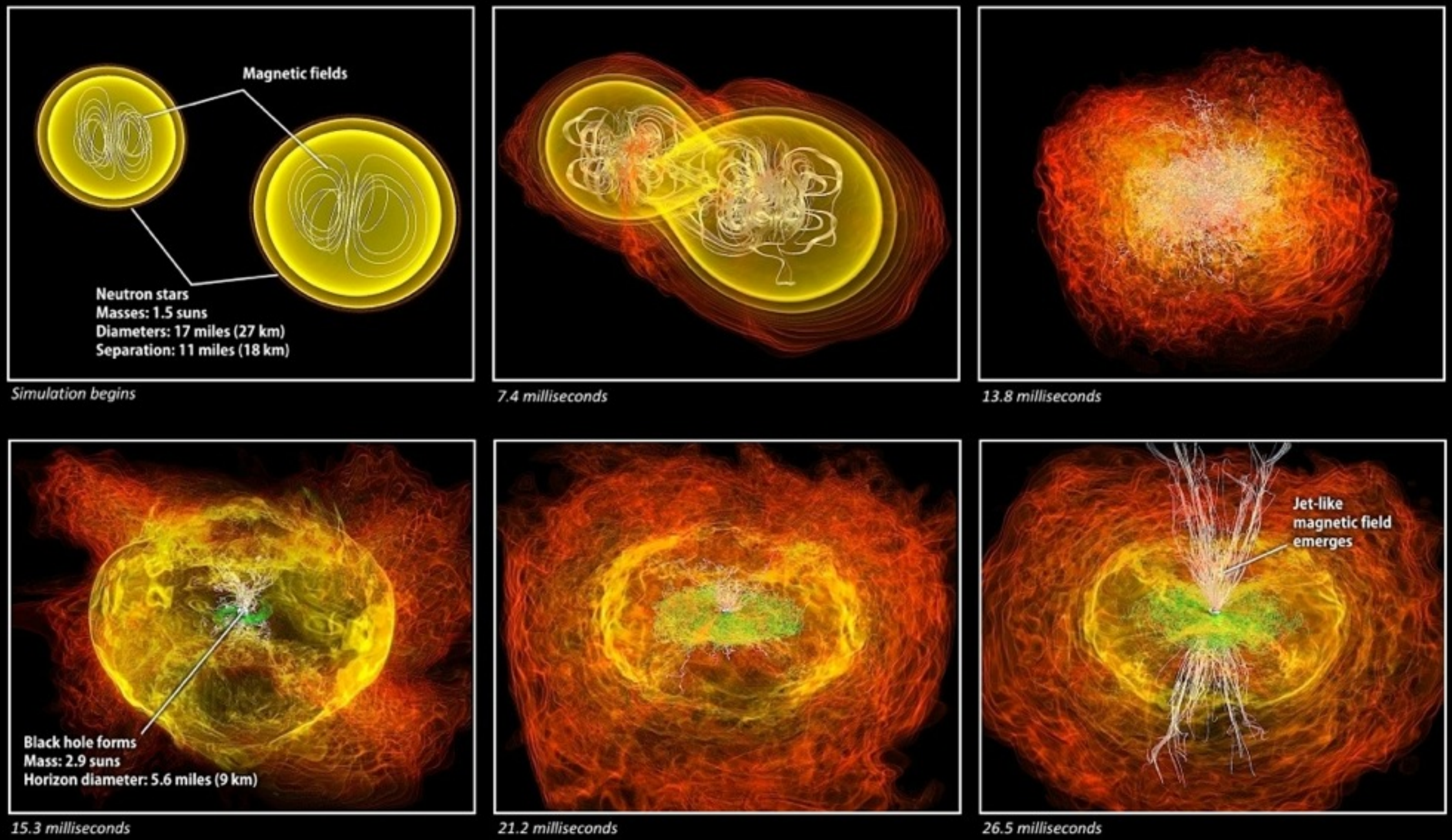


Visualization by Giacomazzo, Koppitz, Rezzolla

NS-NS and NS-BH mergers can produce tori around spinning BHs (e.g., Rezzolla et al 2010, Giacomazzo et al 2011, Foucart 2012)

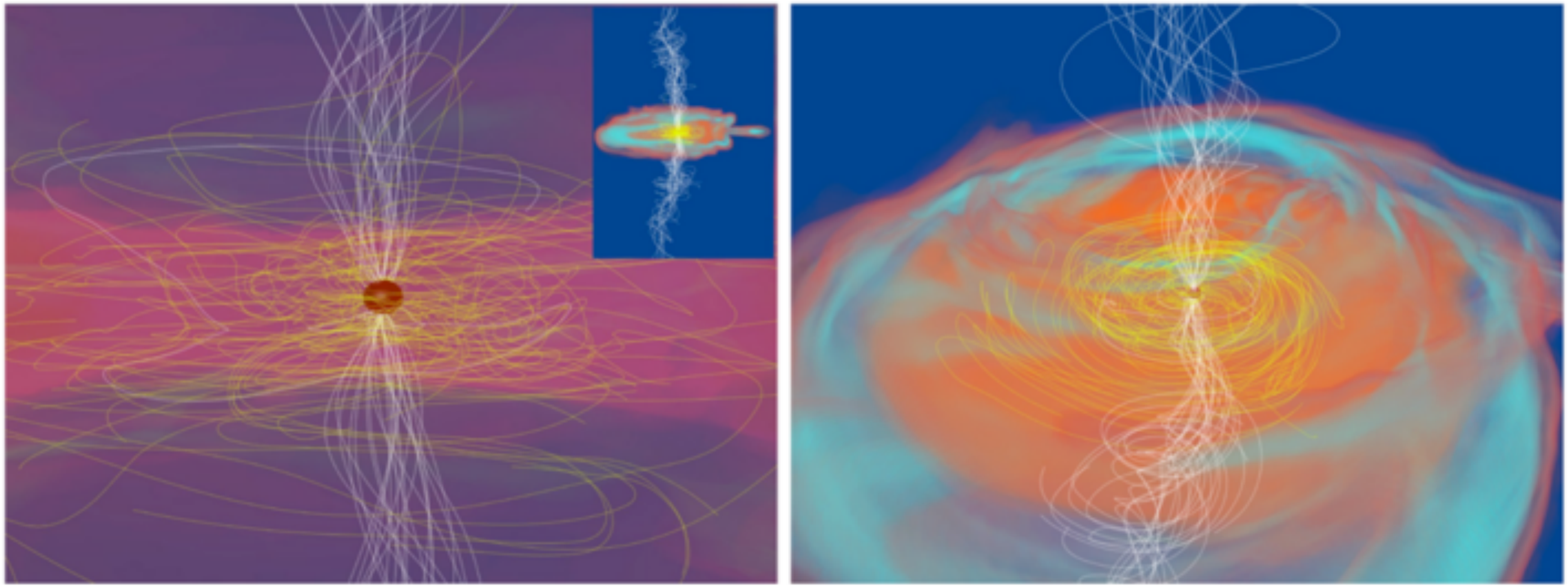
JETS FROM BNS MERGERS?

Rezzolla, **Giacomazzo**, Baiotti, Granot, Kouveliotou, Aloy 2011, ApJL 732, L6



JETS FROM NS-BH MERGERS?

Etienne, Paschalidis, Shapiro 2012, PRD 86, 084026



Similar simulations were performed in NS-BH
Possible jet formation also in this case

COMPACT BINARY PROGENITORS OF SHORT GAMMA-RAY BURSTS

(**Giacomazzo**, Perna, Rezzolla, Troja, and Lazzati 2013, ApJL 762, L18)

BNS and NS-BH can produce tori around spinning BHs.

When NSs are magnetized this can lead to the production of relativistic jets.

Energy extraction from the disk can power short GRBs.

Can we link SGRBs observations with numerical simulations?

We considered the current sample of SGRBs with measured energies

Table 1
SGRB Sample

GRB Name	z	$E_{\gamma,\mathrm{iso}}$ (erg)	ΔE (keV)	M_{torus} ($M_\odot$)
050509B	0.225	9.1×10^{47}	15–150	1.0×10^{-5}
050709(EE)	0.161	3.4×10^{49}	10–10^4	3.8×10^{-4}
050724(EE)	0.257	1.9×10^{50}	15–150	2.1×10^{-3}
051221A	0.546	2.9×10^{51}	10–10^4	3.3×10^{-2}
061006(EE)	0.438	2.1×10^{51}	10–10^4	2.4×10^{-2}
070429B	0.902	2.1×10^{50}	15–150	2.3×10^{-3}
070714B(EE)	0.923	1.6×10^{52}	10–10^4	1.8×10^{-1}
071227(EE)	0.381	1.2×10^{51}	10–10^4	1.4×10^{-2}
080905A	0.122	4.5×10^{49}	10–10^4	5.1×10^{-4}
090510	0.903	4.7×10^{52}	10–10^4	5.2×10^{-1}
100117A	0.920	1.4×10^{51}	10–10^4	1.6×10^{-2}
111117A	1.3	5.3×10^{51}	10–10^4	6.0×10^{-2}
051210	1.3	4.0×10^{50}	15–150	4.5×10^{-3}
060801	1.130	1.9×10^{50}	15–150	2.1×10^{-3}
061210(EE)	0.410	5.6×10^{50}	15–150	6.2×10^{-3}
070724A	0.457	2.3×10^{49}	15–150	2.5×10^{-4}
070729	0.8	1.6×10^{50}	15–150	1.8×10^{-3}
080123(EE)	0.495	5.7×10^{50}	15–150	6.3×10^{-3}
101219A	0.718	7.4×10^{51}	10–10^4	8.2×10^{-2}
060502B	0.287	9.8×10^{48}	15–150	1.1×10^{-4}
061217	0.827	6.8×10^{49}	15–150	7.6×10^{-4}
061201	0.111	9.4×10^{48}	15–150	1.1×10^{-4}
070809	0.473	7.9×10^{49}	15–150	8.8×10^{-4}
090515	0.403	1.0×10^{49}	15–150	1.2×10^{-4}

We made the following assumptions:

- SGRBs are powered via magnetic fields
- SGRBs energy is provided by the disk
- Efficiency is constant

$$E_{\gamma,\mathrm{iso}} = \epsilon M_{\mathrm{torus}} c^2$$

$$\epsilon \equiv \epsilon_{\mathrm{jet}} \epsilon_\gamma$$

$$\epsilon_{\mathrm{jet}} = 10\%$$

$$\epsilon_\gamma = 50\%$$

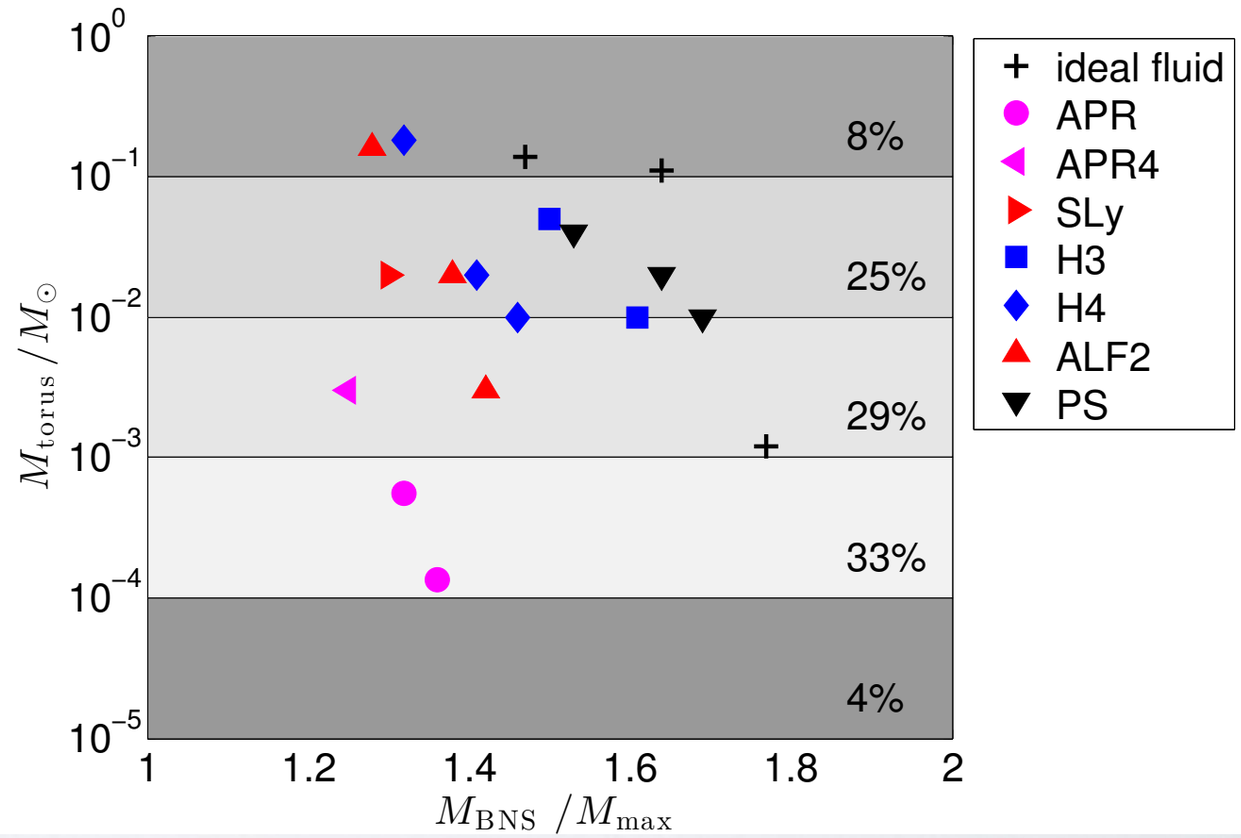
ε_{jet} is inferred from disk simulations (Fragile, McKinney, Tchekhovskoy, ...)

ε_γ is derived from observations (e.g., Zhang et al 2007)

We then considered a sample of 25 accurate GR BNS simulations

Table 2
BNS Simulations and Torus Masses

Model	M_{BNS} ($M_\odot$)	q	M_{torus} ($M_\odot$)	M_{max} ($M_\odot$)	M_{BNS}/M_{max}
1.46-45-IF	3.24	1.00	0.1374	2.20	1.47
1.62-45-IF	3.61	1.00	0.1101	2.20	1.64
M3.6q1.00	3.90	1.00	0.0012	2.20	1.77
M3.7q0.94	4.03	0.94	0.0121	2.20	1.83
M3.4q0.91	3.76	0.92	0.1202	2.20	1.71
M3.4q0.80	3.72	0.81	0.2524	2.20	1.69
M3.5q0.75	3.80	0.77	0.1939	2.20	1.73
M3.4q0.70	3.71	0.72	0.2558	2.20	1.69
APR145145	2.87	1.00	0.000549	2.18	1.32
APR1515	2.97	1.00	0.000134	2.18	1.36
APR1316	2.87	0.81	0.0275	2.18	1.32
APR135165	2.97	0.82	0.00707	2.18	1.36
APR4-28	2.77	1.00	0.003	2.21	1.25
SLy-27	2.67	1.00	0.02	2.05	1.30
H3-27	2.68	1.00	0.05	1.79	1.50
H3-29	2.87	1.00	0.01	1.79	1.61
H4-27	2.68	1.00	0.18	2.03	1.32
H4-29	2.87	1.00	0.02	2.03	1.41
H4-30	2.97	1.00	0.01	2.03	1.46
ALF2-27	2.67	1.00	0.16	2.09	1.28
ALF2-29	2.87	1.00	0.02	2.09	1.38
ALF2-30	2.97	1.00	0.003	2.09	1.42
PS-27	2.68	1.00	0.04	1.76	1.53
PS-29	2.88	1.00	0.02	1.76	1.64
PS-30	2.97	1.00	0.01	1.76	1.69



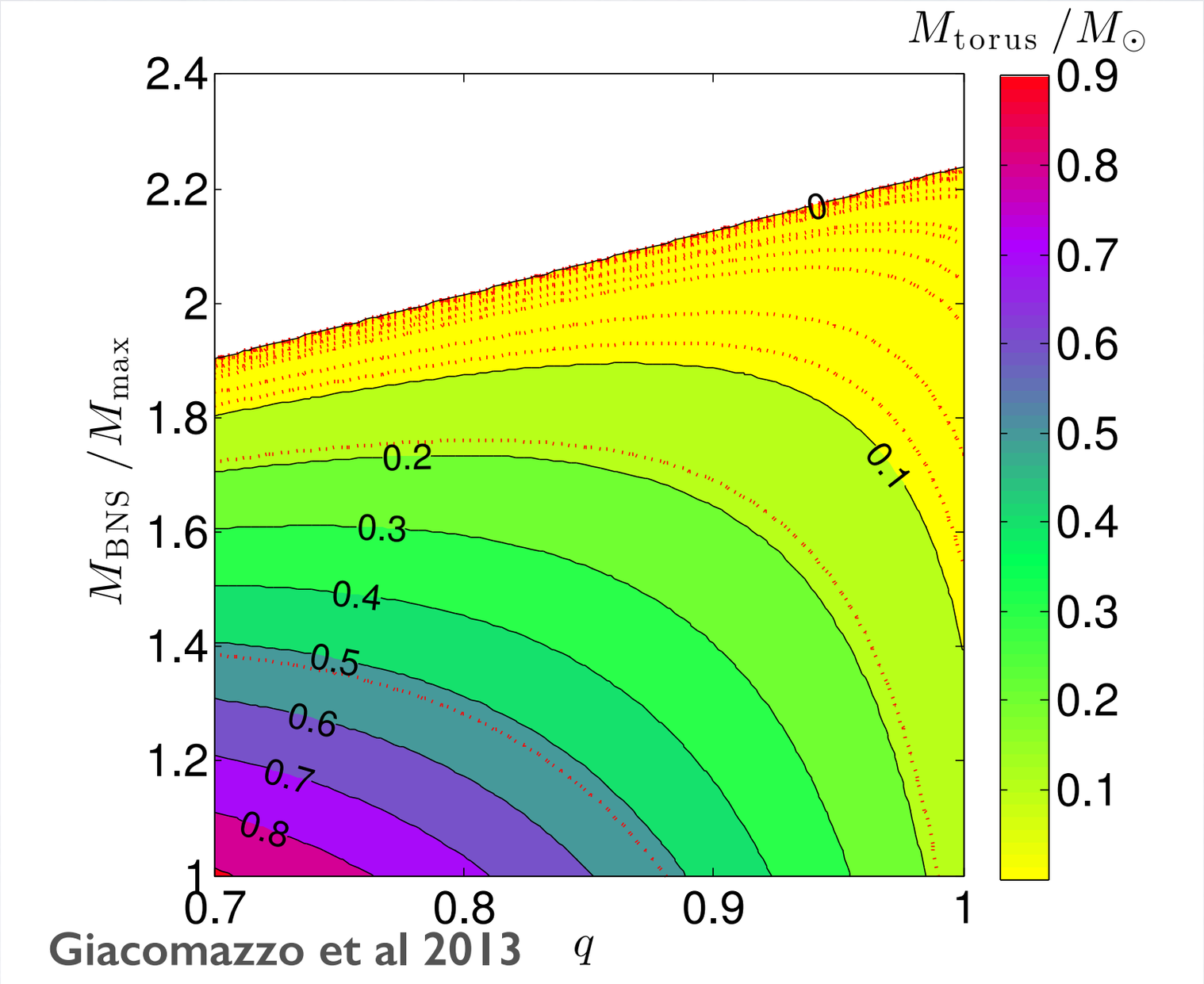
Giacomazzo et al 2013

And we compared their torus masses with the distribution derived from observations

Note that most SGRBs requires tori with masses <~0.1 M⊙

From the BNS simulations we computed a fit to relate the mass of the torus to the NS masses and their mass ratio q:

$$M_{\rm torus} = [c_1(1-q)+c_2][c_3(1+q) - M_{\rm BNS}/M_{\rm max}]$$



Giacomazzo et al 2013

Almost all SGRBs are produced by high-mass BNSs. These BNSs produce an HMNS that survive only few ms before collapse to BH (consistent with Murguia-Berthier et al 2014).

"low-energy" SGRBs
(<~1e51 erg)

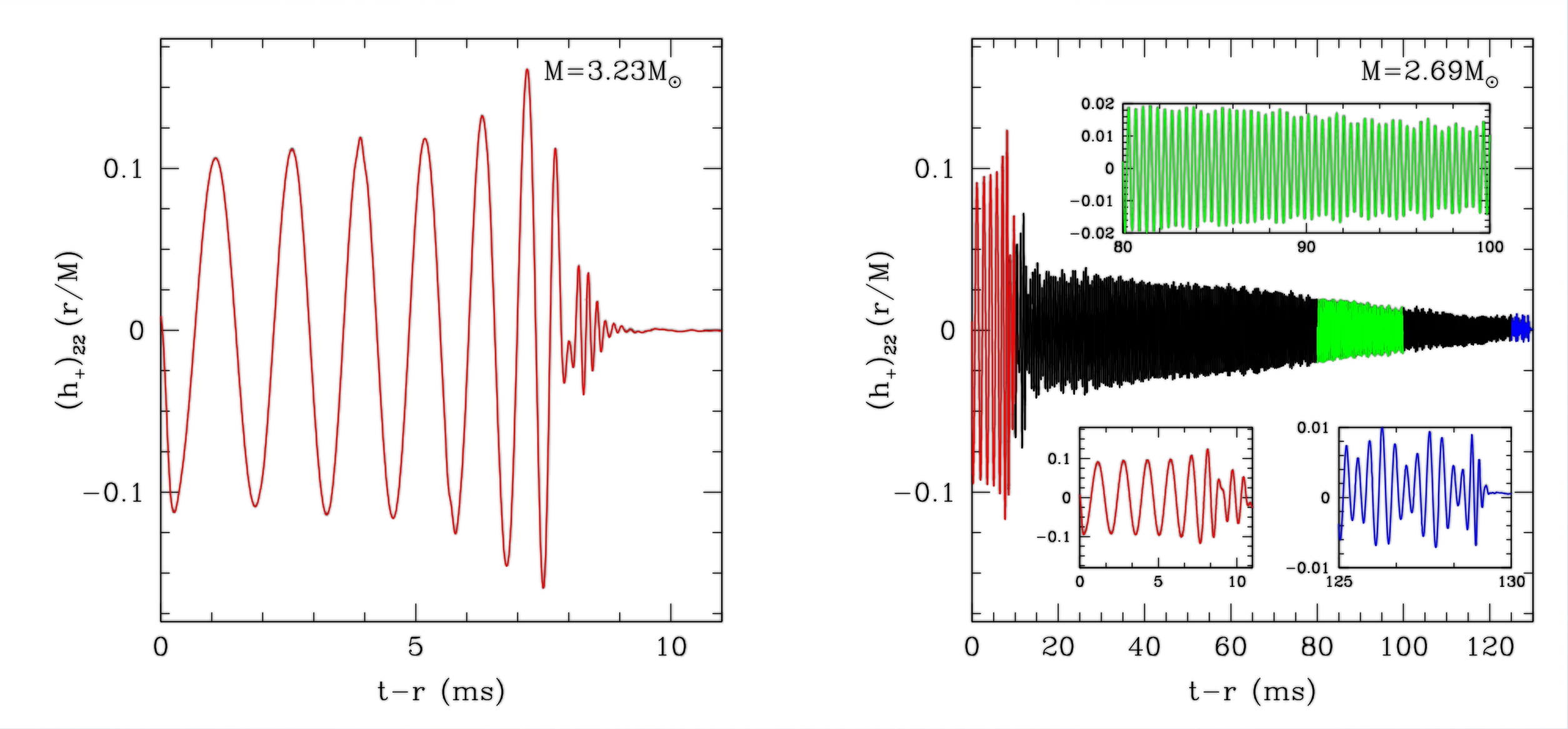
↓

"high-mass" BNSs

"high-energy" SGRBs
(>~1e51 erg)

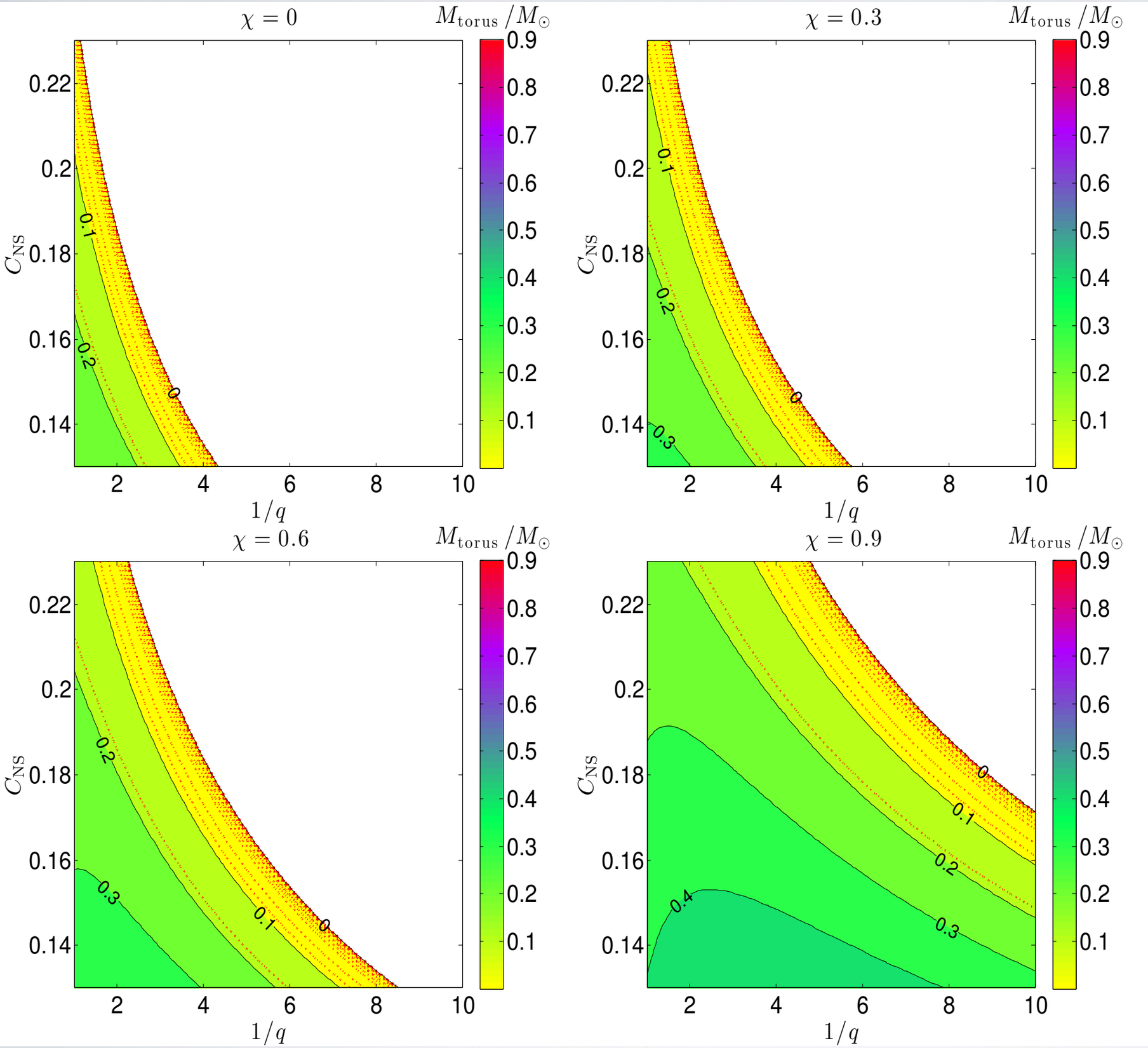
↓

"low-mass" BNSs



Simultaneous GW/EM detection will help validate this model

Foucart 2012 derived a similar fit from NS-BH GR simulations

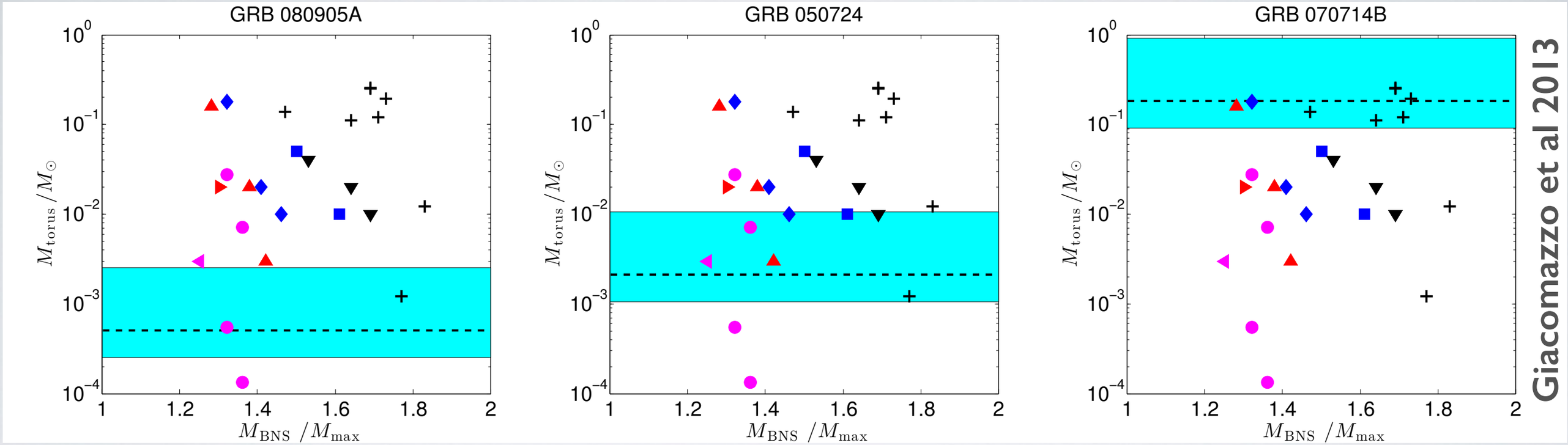


if M_{BH}/M_{NS}>~7 only rapidly spinning BHs (J/M^2>~0.9) may produce SGRBs.

Most energetic bursts cannot be explained with NS-BH mergers.

Giacomazzo et al 2013

What can we learn from a simultaneous GW-SGRB observation?



- From the GW we can get M_{BNS}
- From the GRB we can get M_{torus}

Combining these two informations we may further restrict the BNS parameters (EOS, mass ratio, ...)

The same could be done for NS-BH mergers to infer BH spin and NS compactness.

CONCLUSIONS

- We compared results of GR numerical simulations of NS-NS and NS-BH to observations of SGRBs
- Determined for the first time which systems may be responsible for the observed SGRBs (assuming SGRBs powered by magnetic fields)
- Most SGRBs are generated by high-mass BNSs:
  - less energetic SGRBs are powered by high-mass BNSs
  - more energetic ones by low-mass BNSs
- NS-BH may explain some of the SGRBs if the BH is rapidly spinning
- A simultaneous detection of an SGRB with a GW can be used to validate this model and may help to constrain binary parameters (NS EOS, compactness, BH spin, ...)