Binary Neutron Star Mergers and Nuclear Physics

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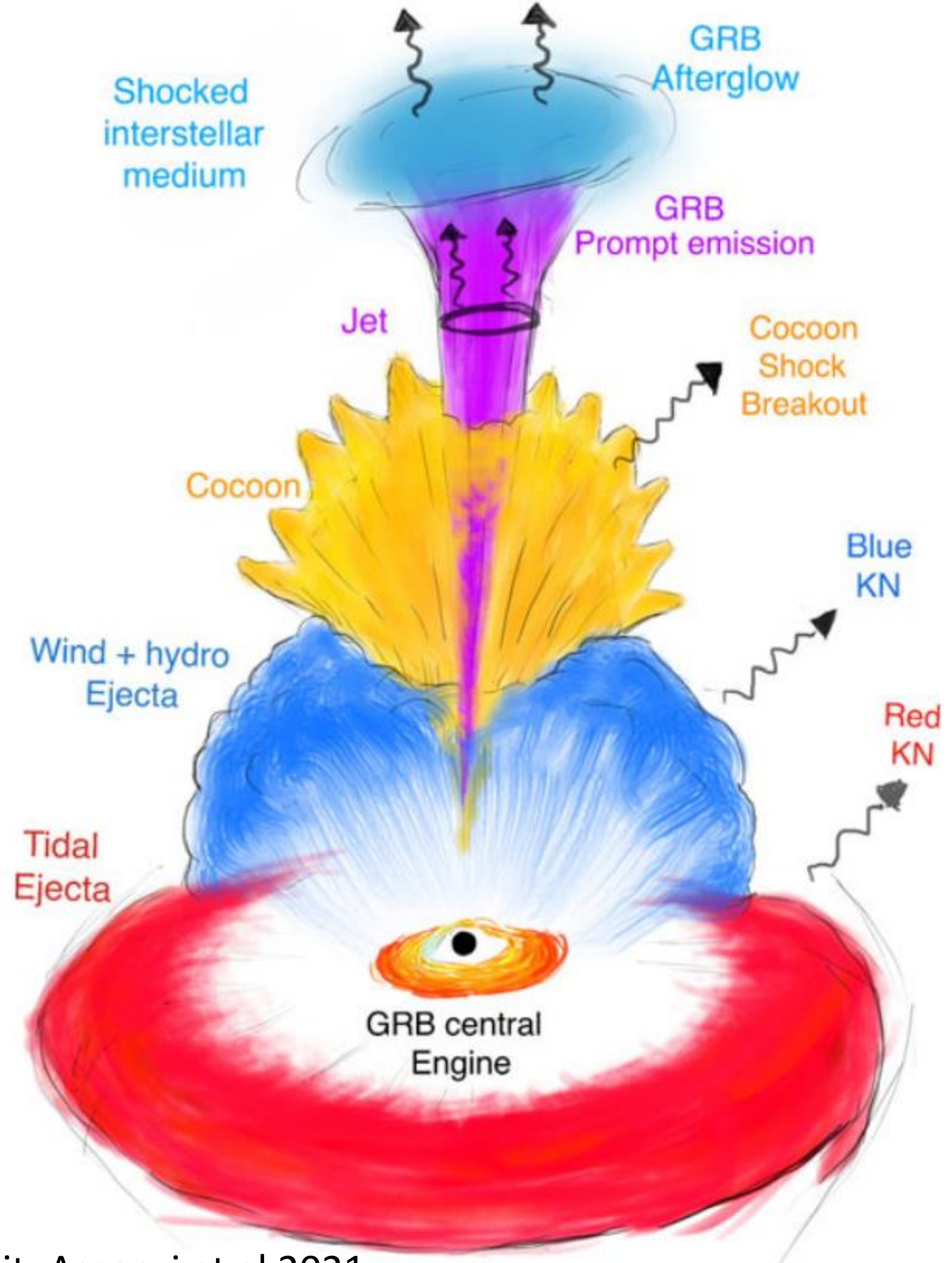
INFN Istituto Nazionale di Fisica Nucleare

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Plan of the Lectures

1. Isolated and Binary Neutron Stars: an Introduction
2. Gravitational Wave Emission from Binary Neutron Star Mergers
3. Electromagnetic Emission from Binary Neutron Star Mergers
4. Observations of Binary Neutron Star Mergers



Credit: Ascenzi et al 2021

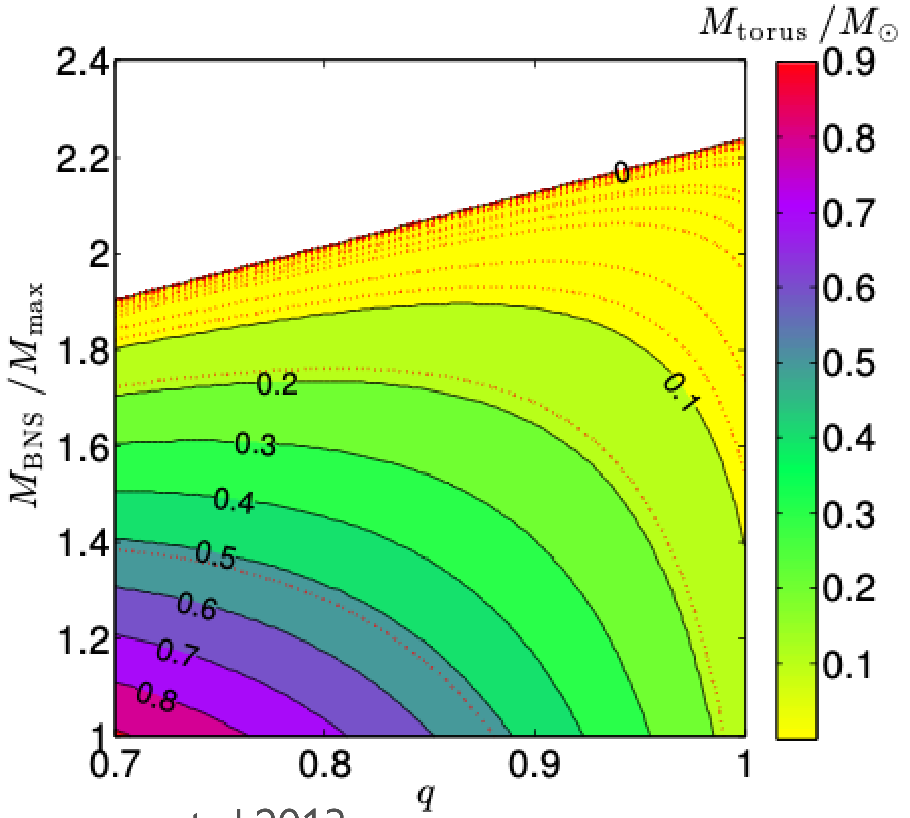
Electromagnetic Emission

(see also the posters by
Alessandro Camilletti on Kilonovae
and by Duncan Neill on precursors)

SGRB

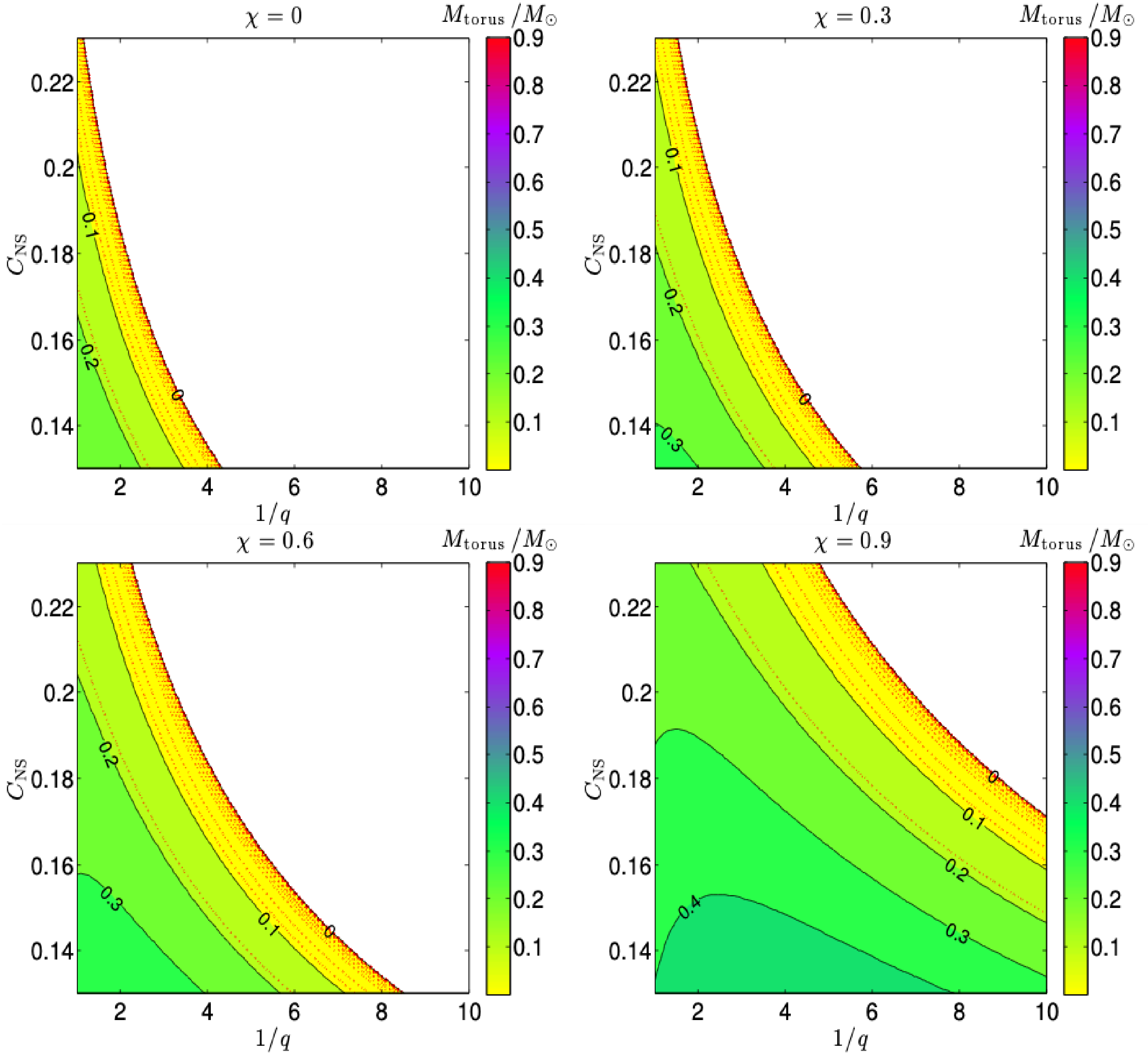
Torus Masses from Mergers

NS-NS

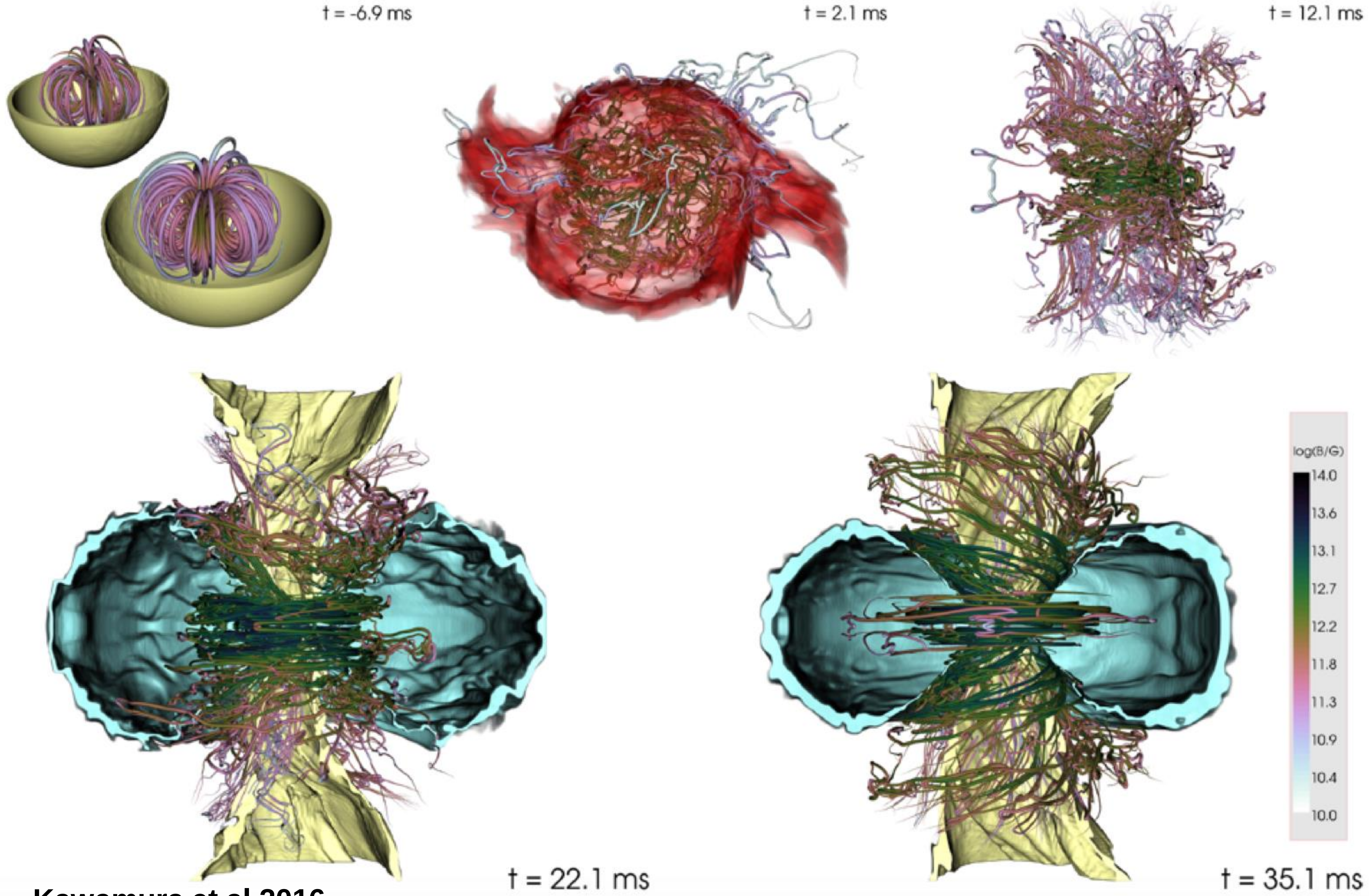


Giacomazzo et al 2013

NS-BH



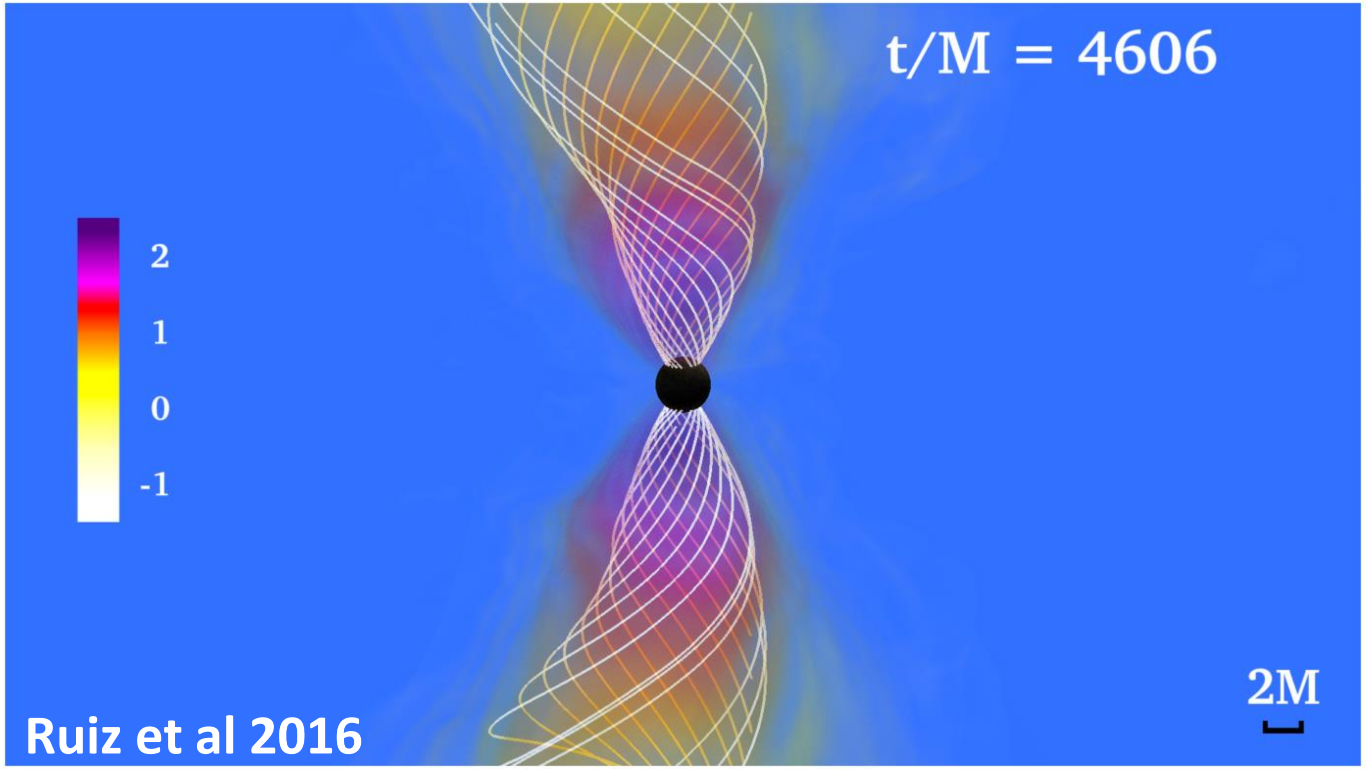
Both NS-NS and NS-BH may produce massive tori.



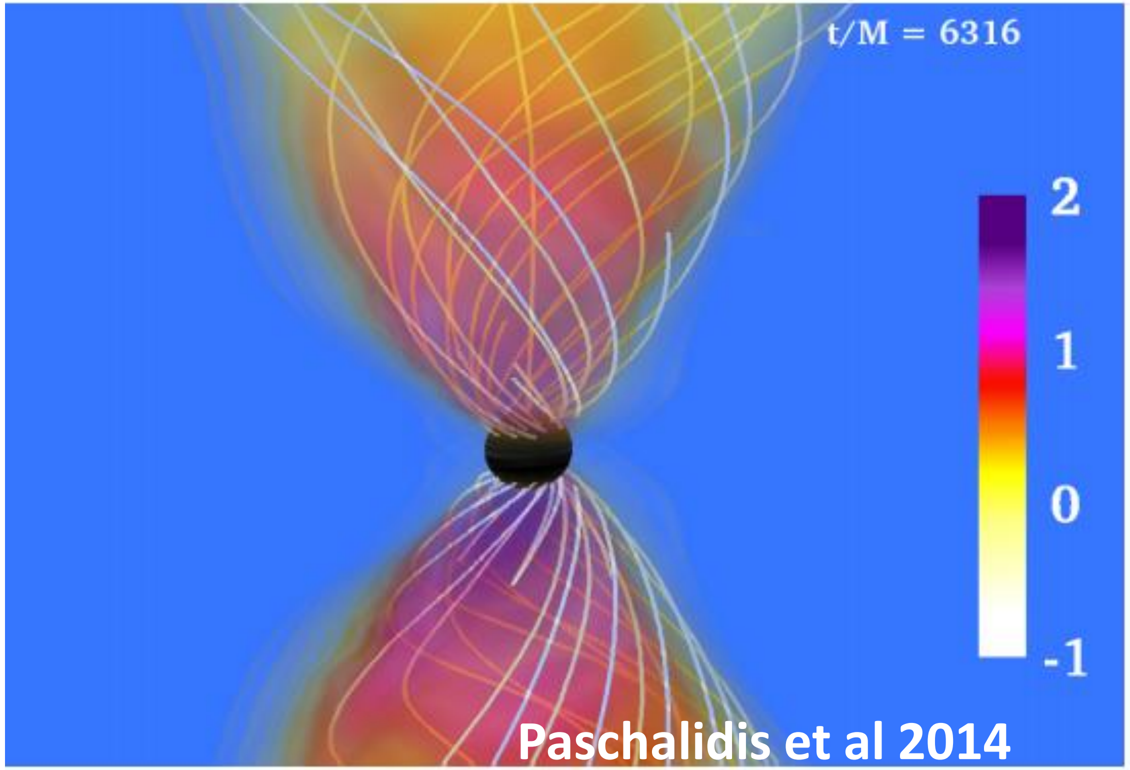
Kawamura et al 2016

JETS FROM NS BINARY MERGERS

NS-NS



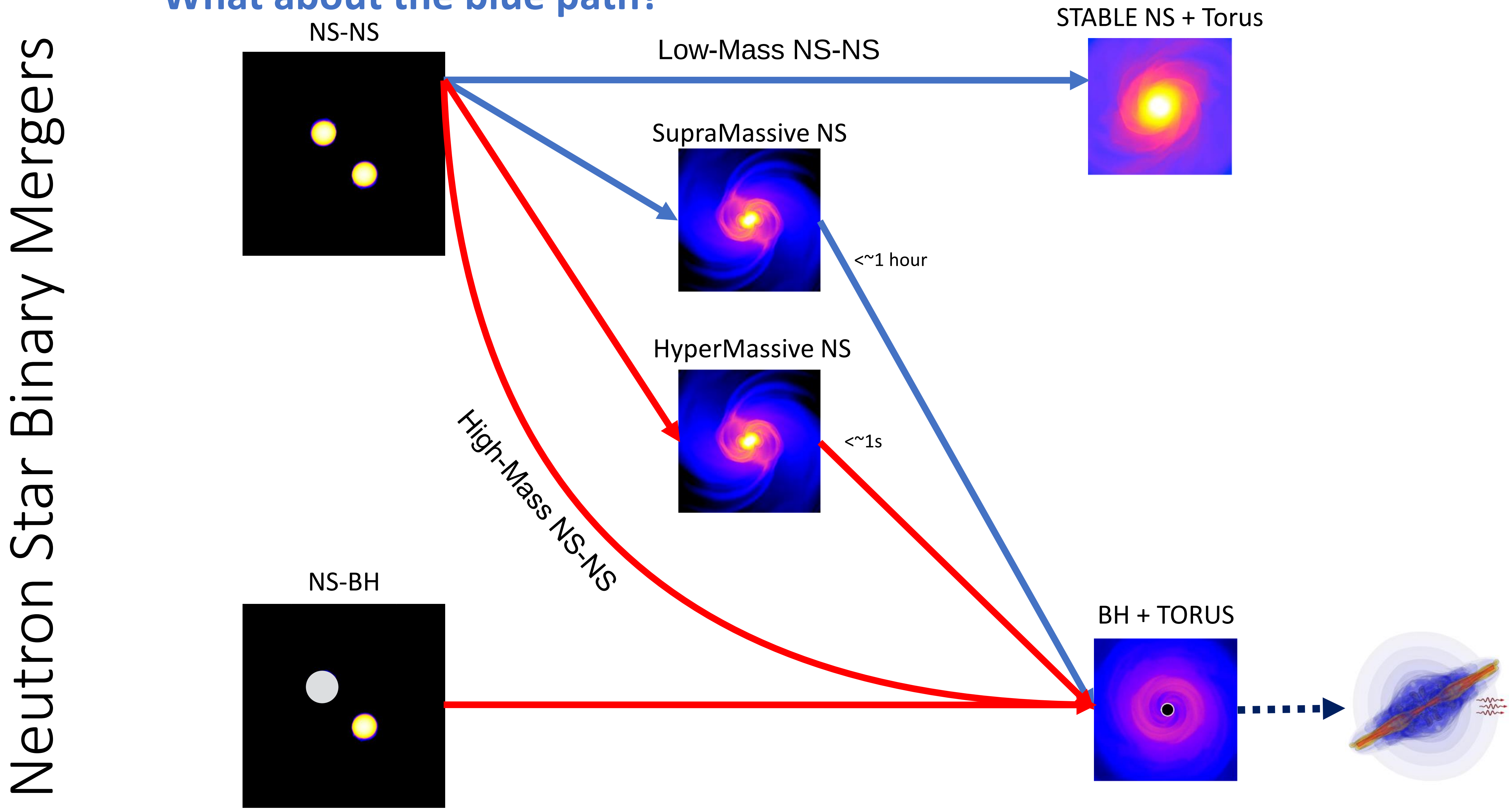
NS-BH



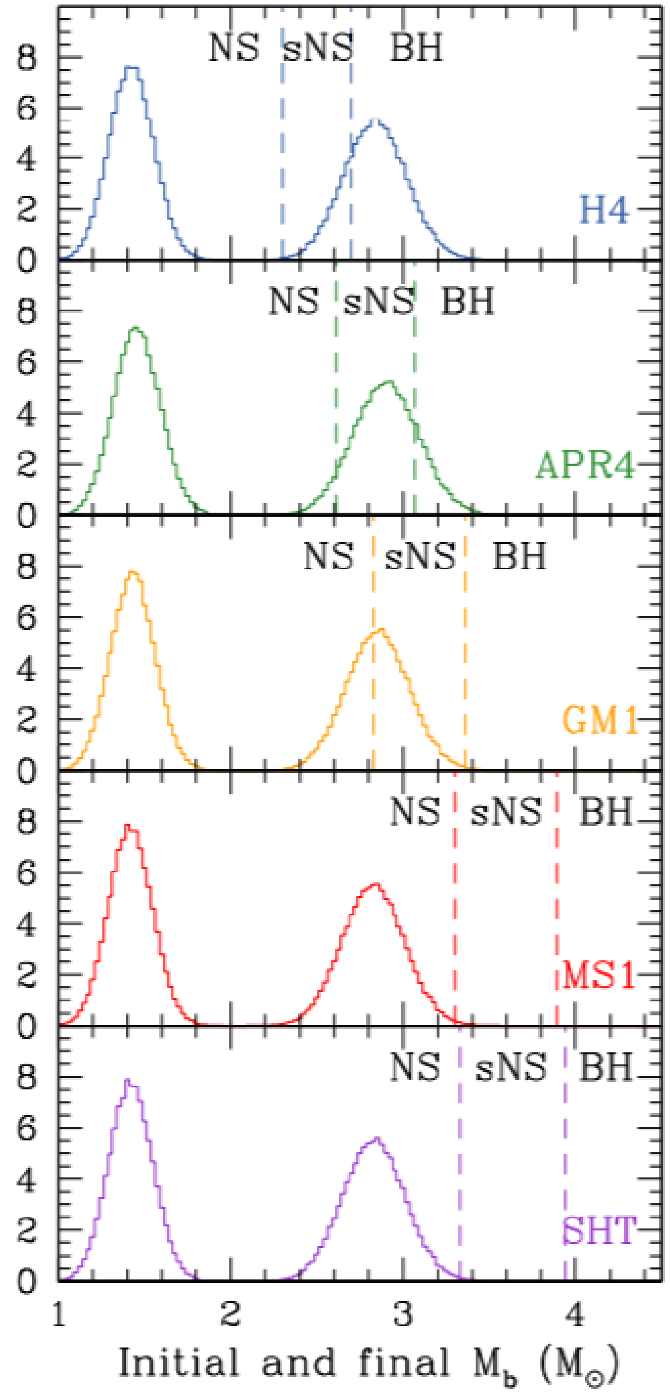
Possible to form jets both in NS-NS and NS-BH binaries

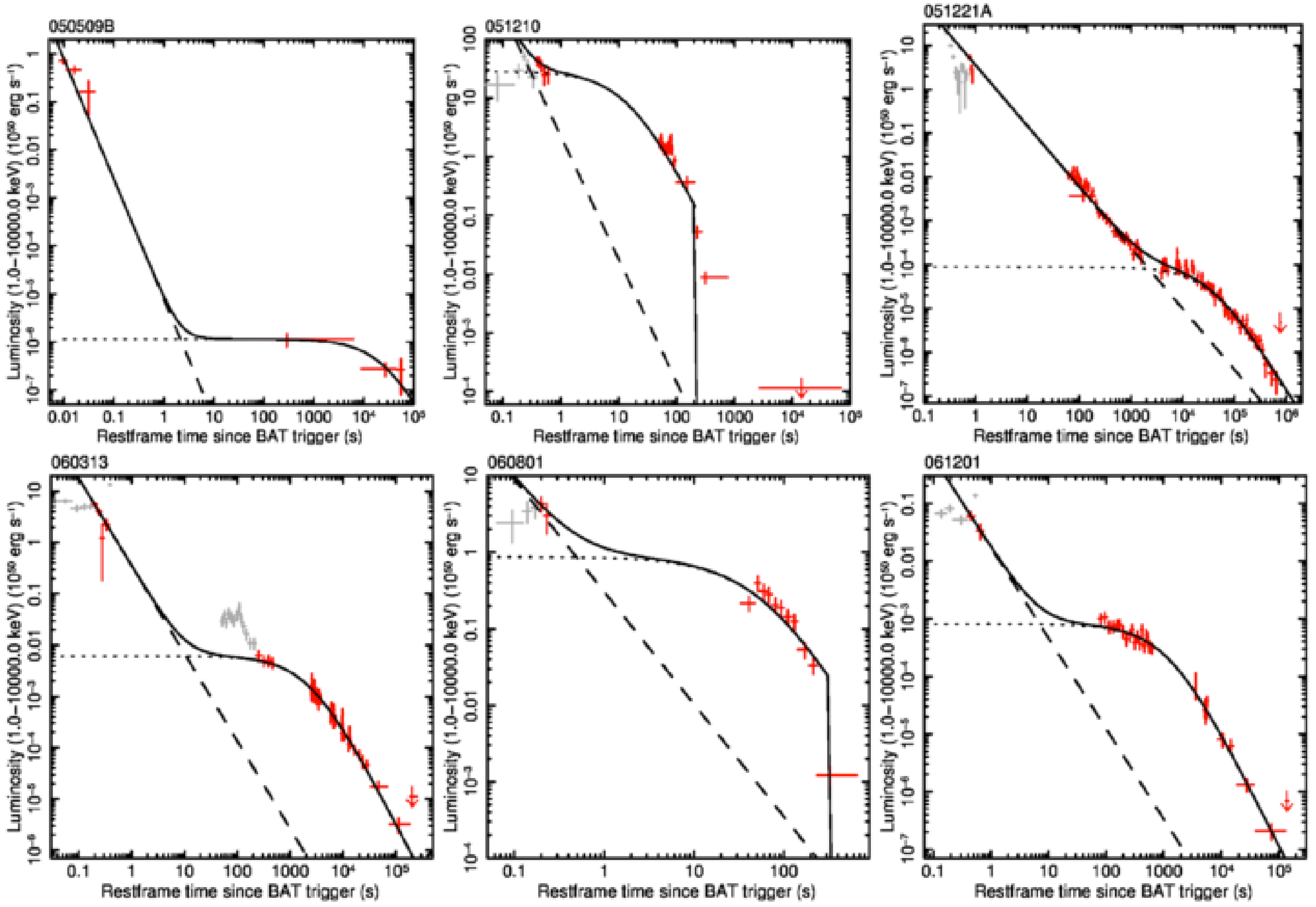
In both cases the emission is due to the Blandford & Znajek (1977) mechanism

What about the blue path?



Piro et al 2017



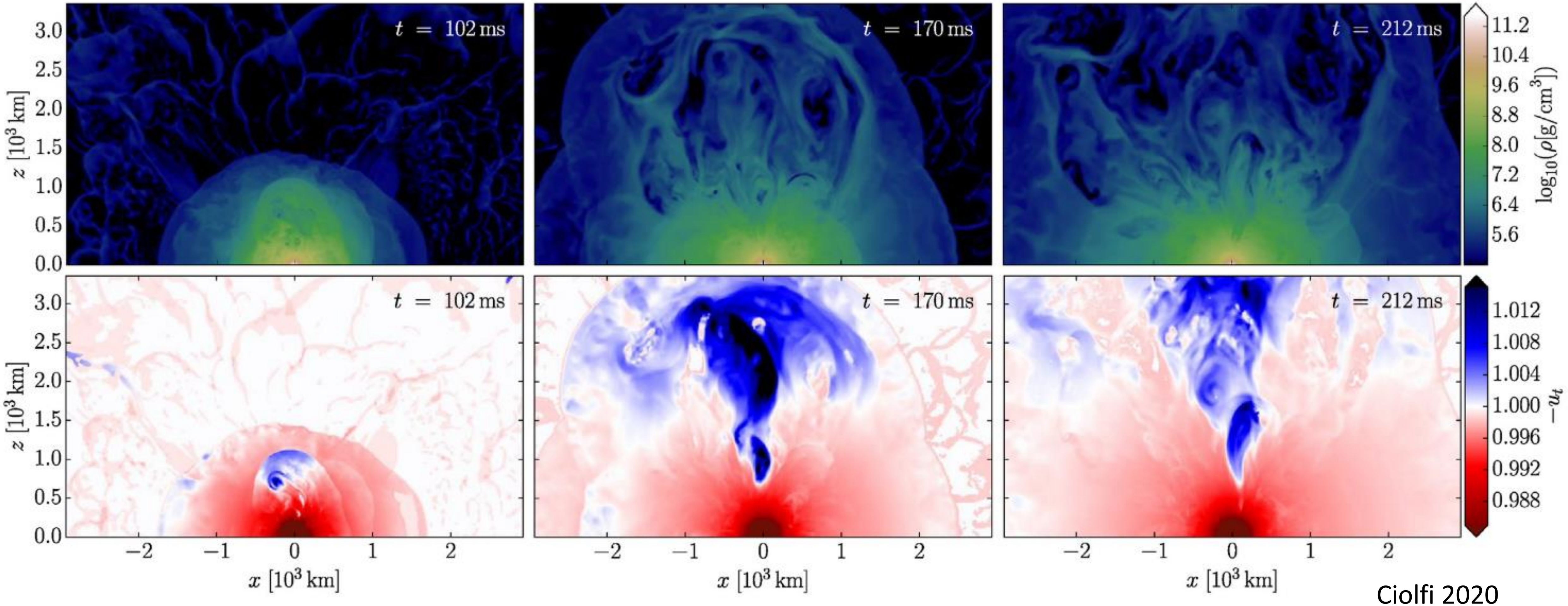


Rowlinson et al 2013

Long-lived NS remnants may form from BNS mergers.

A long-lived magnetar could also explain X-ray plateaus and extended emissions from SGRBs.

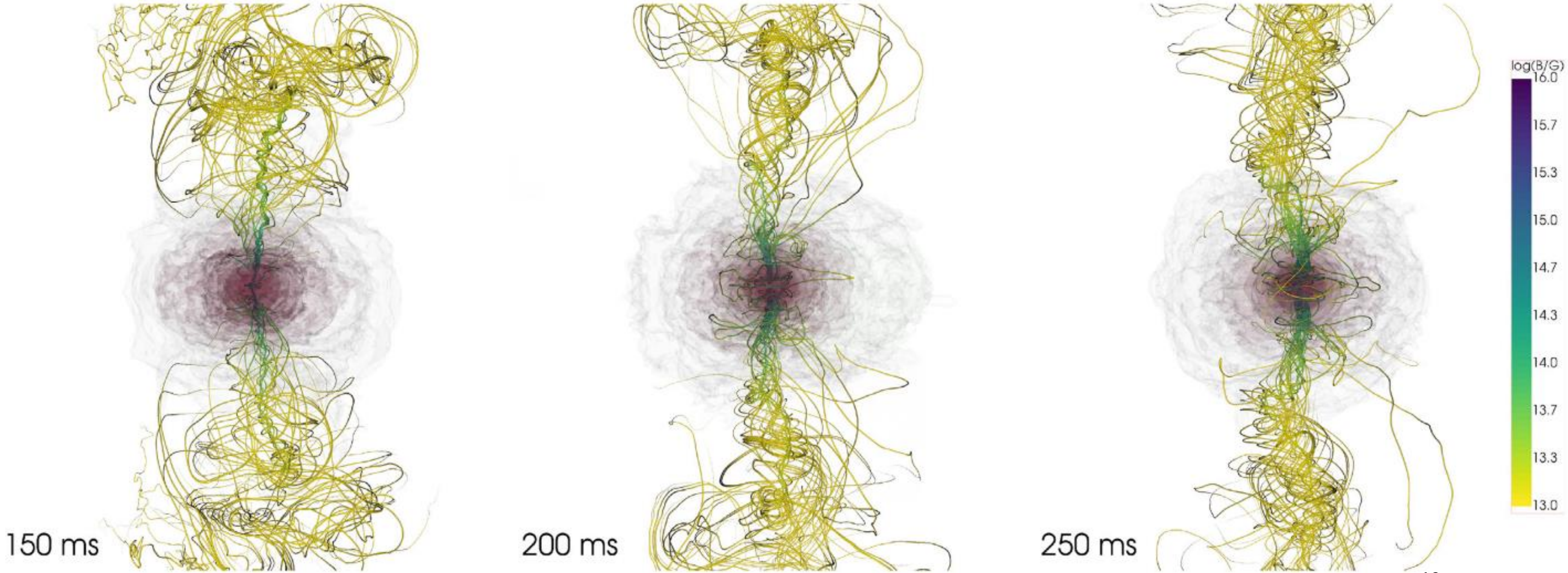
Collimated outflows from long-lived BNS merger remnants



Ciolfi 2020

Very long post-merger simulation (250 ms), APR4 EOS (1.44-1.29$M_{\odot}$), $B \sim 5 \times 10^{15} G$.
An outflow is produced along the BH spin axis.

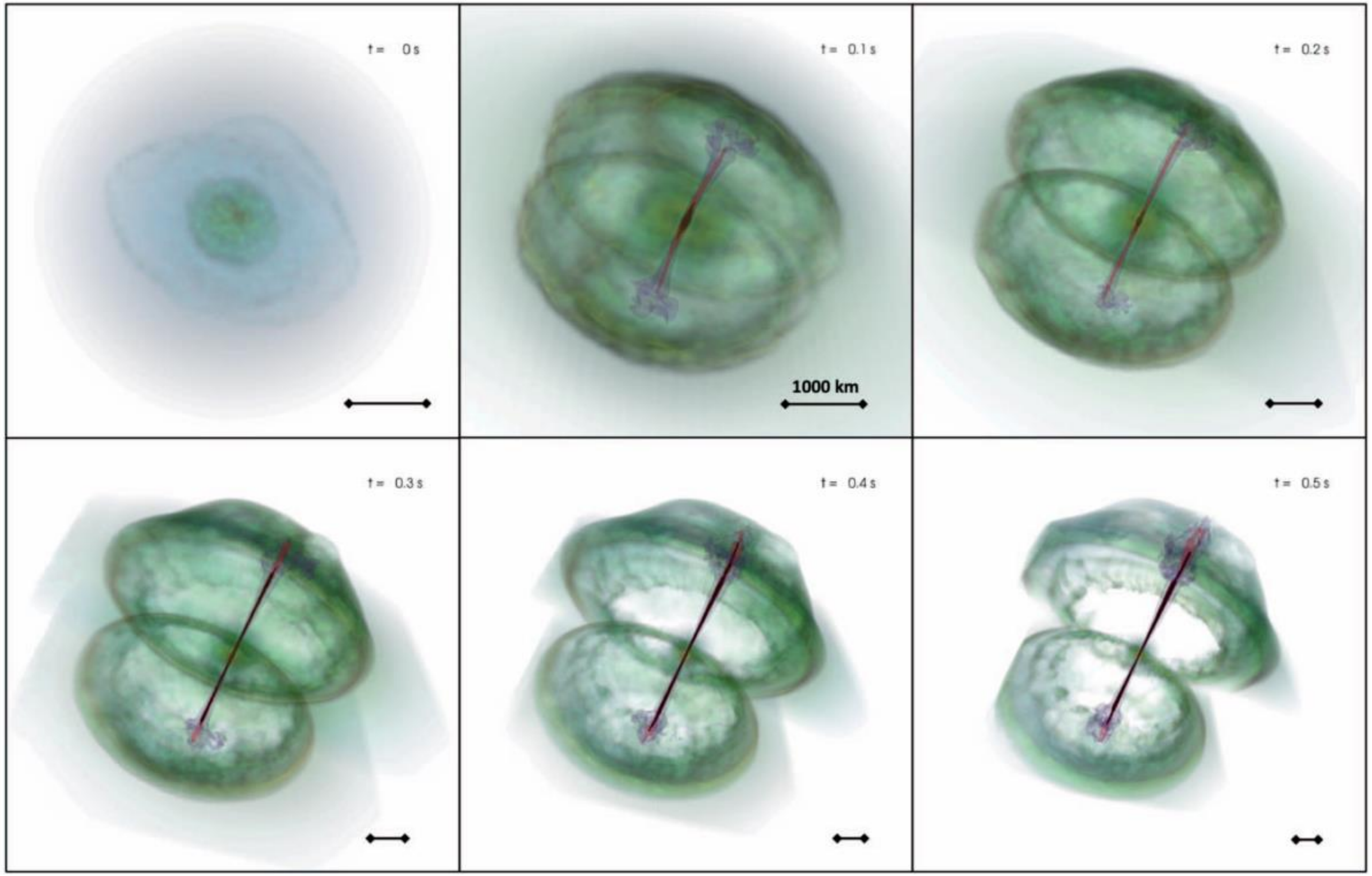
Collimated outflows from long-lived BNS merger remnants



Ciolfi 2020

The magnetic field shows signs of collimation with a half-opening angle of ~15^{o}.
Lorentz factor (<10) and energy (~10^{49} erg) are not enough to power an SGRB.

Jet Propagation in BNS Merger Ejecta (Lazzati et al 2021)

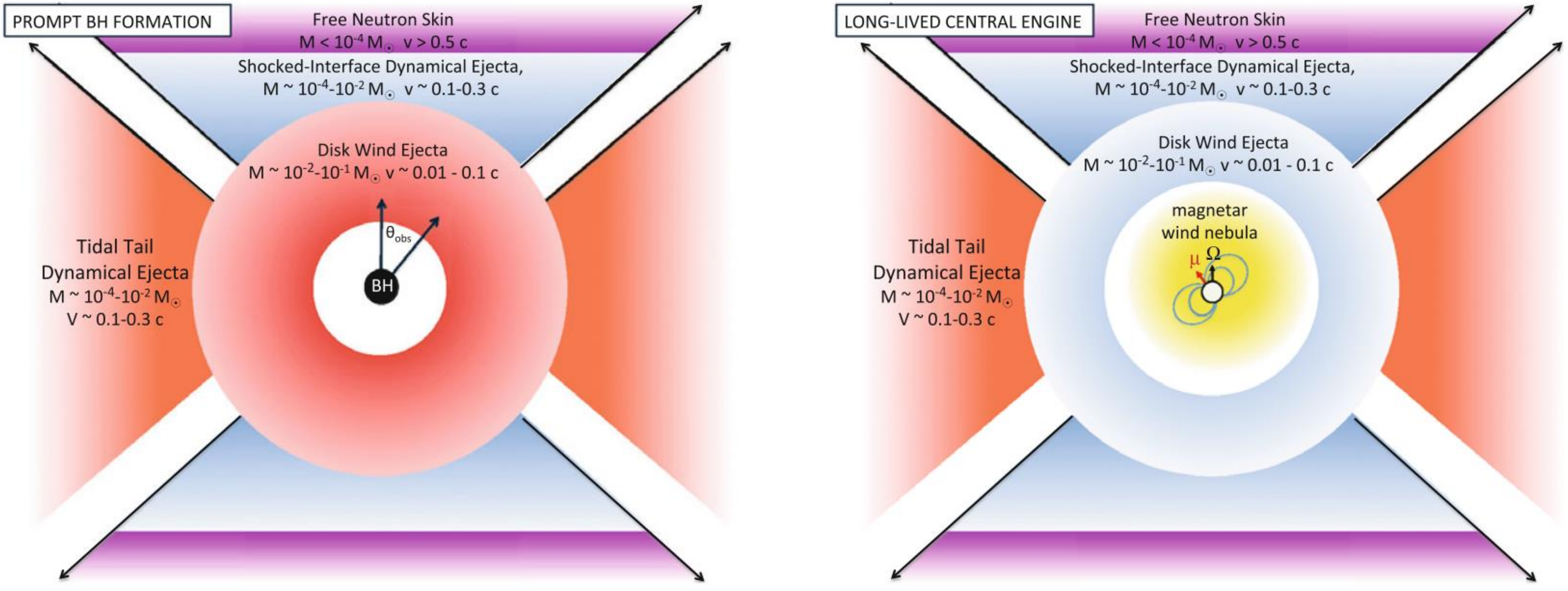


Once a jet is produced, we need to follow its propagation on a long-time scale

This is not feasible in full GR and most works considered analytical setup for the ejecta.

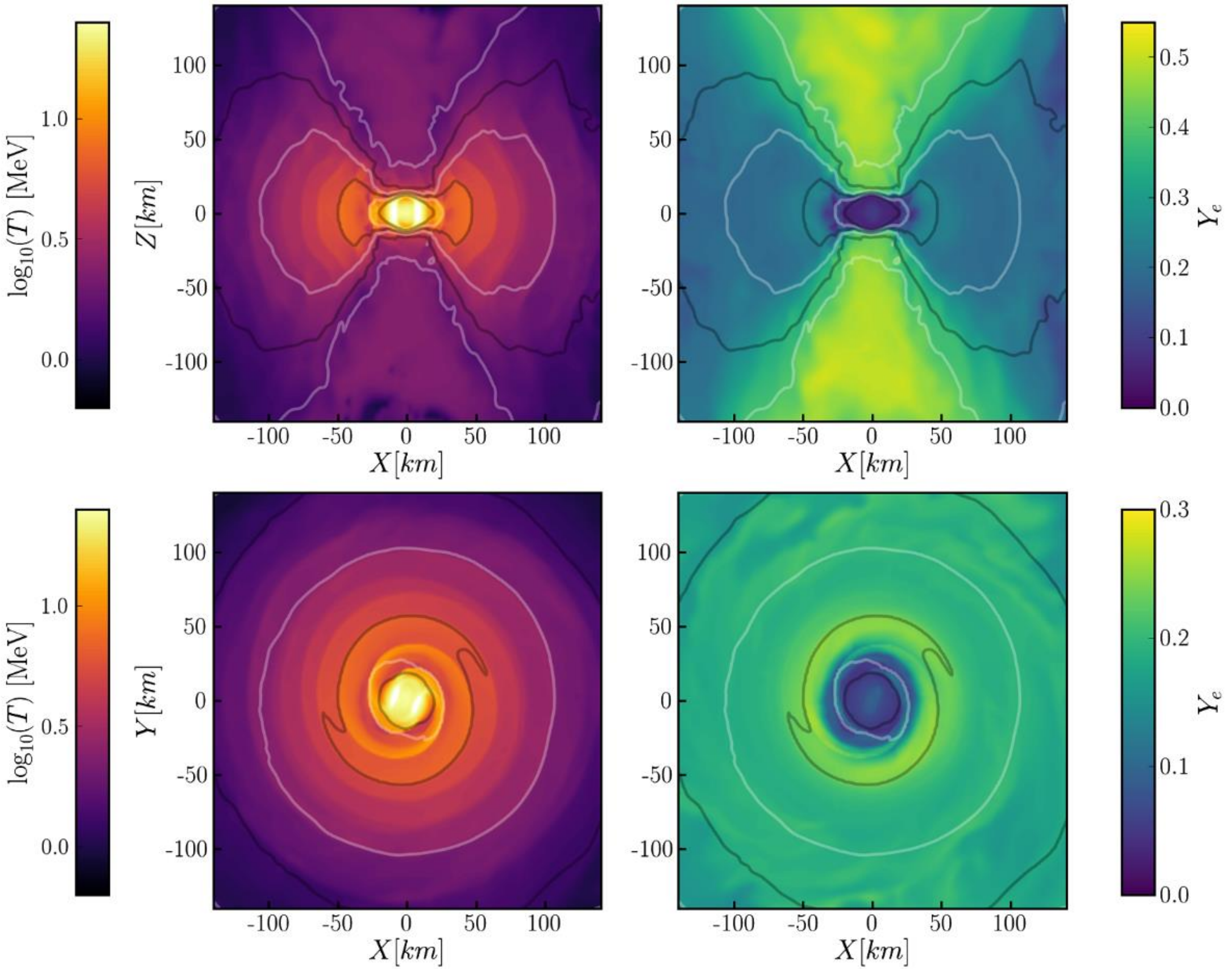
We imported the outcome of a GRMHD simulation into a special relativistic hydrodynamic code. The breakout time is found to be ~0.6 s (see also Pavan et al 2021, Nathanail et al 2021).

Kilonova



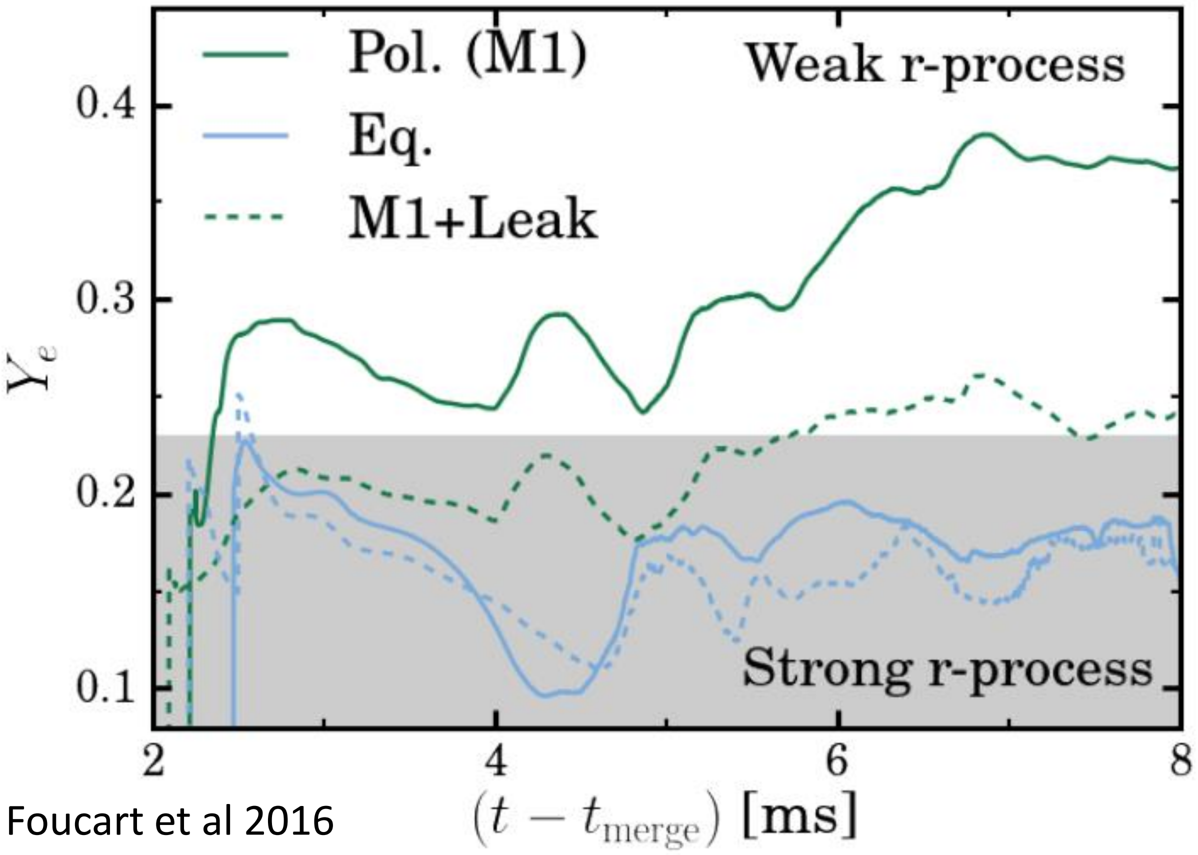
Metzger, B.D. Living Rev Relativ (2017) 20: 3. https://doi.org/10.1007/s41114-017-0006-z

The kilonova has an “early” blue (optical) and a “late” red (infrared) component depending on the mass ejection mechanism and neutrino absorption.



log10(T) [MeV]
Z[km]
X[km]
Y[km]
Ye
1.0
0.5
0.0
100
50
0
-50
-100
0.5
0.4
0.3
0.2
0.1
0.0

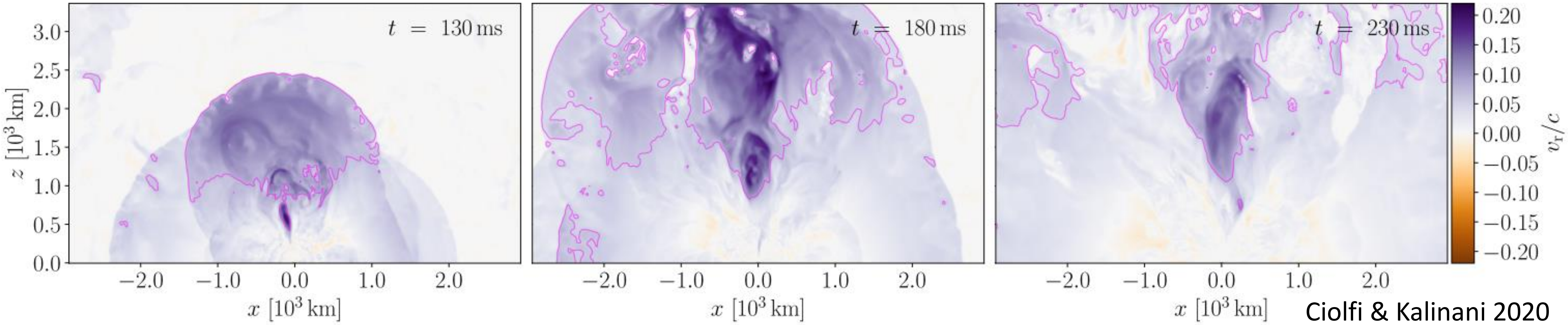
The Importance of Neutrino Modelling



Foucart et al 2016

The numerical scheme used to evolve neutrinos may have a relevant impact on r-process and kilonova emission (especially in the polar region, see also Foucart et al 2018).

The Importance of Magnetic Fields

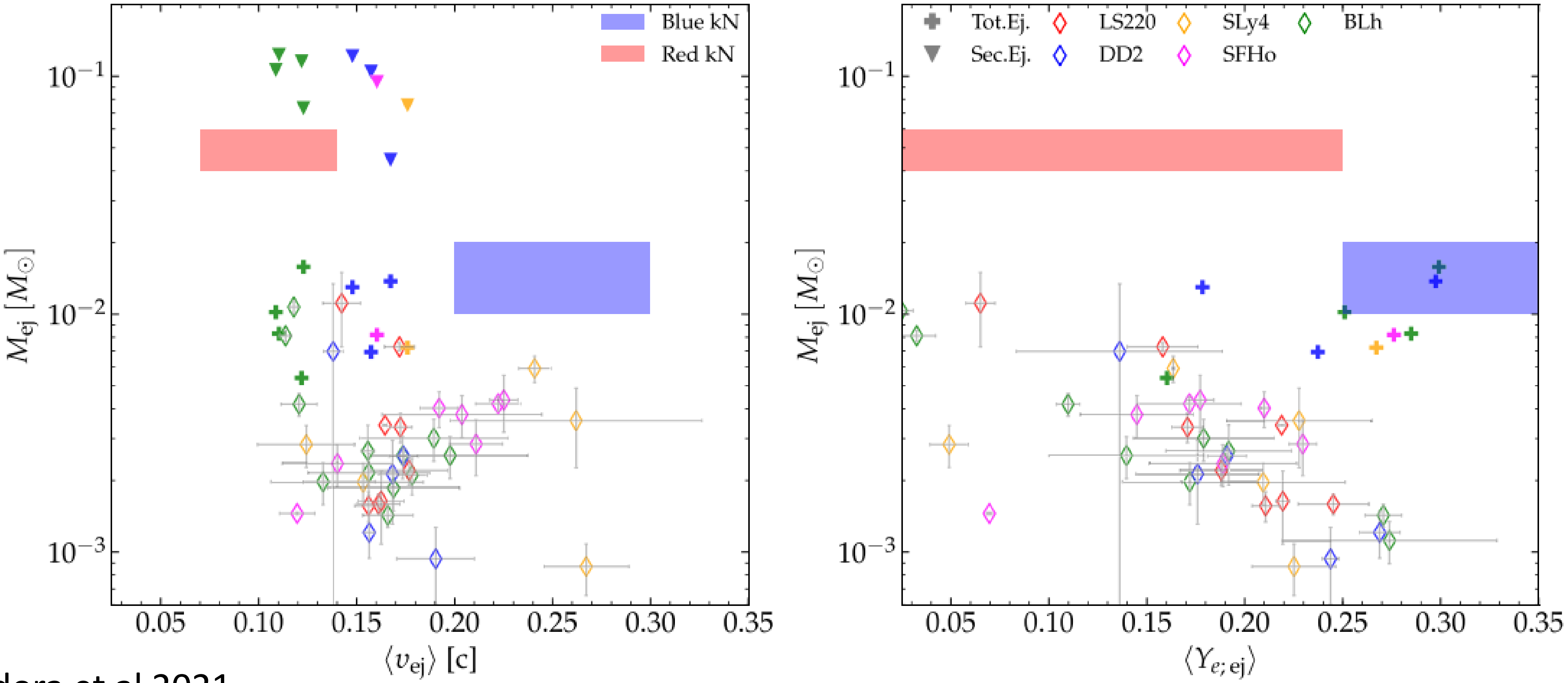


Ciolfi & Kalinani 2020

Strong magnetic fields also contribute to the ejected mass and in particular to the blue kilonova component.

BNS simulation by Ciolfi & Kalinani shows up to $\sim 3 \times 10^{-2} \mathrm{M}_{\odot}$ of ejecta due to magnetic fields. Matter is mainly ejected between ~50 and ~200 ms after merger with a maximum speed of ~0.22 c.

Observations vs Simulations



Nedora et al 2021

ADDITIONAL REFERENCES

- GR Simulations of Compact Binary Mergers as Engines for Short GRBs
  https://doi.org/10.1088/1361-6382/aa61ce

- Gravitational Waves: A New Window to the Universe
  https://www.frontiersin.org/research-topics/11345/gravitational-waves-a-new-window-to-the-universe

- Neutron star mergers and how to study them
  https://link.springer.com/article/10.1007%2Fs41114-020-00028-7

- Kilonovae
  https://link.springer.com/article/10.1007/s41114-019-0024-0

- Binary Neutron Star mergers
  https://link.springer.com/collections/jgeicbdiig