GRMHD Simulations of Compact Object Binaries

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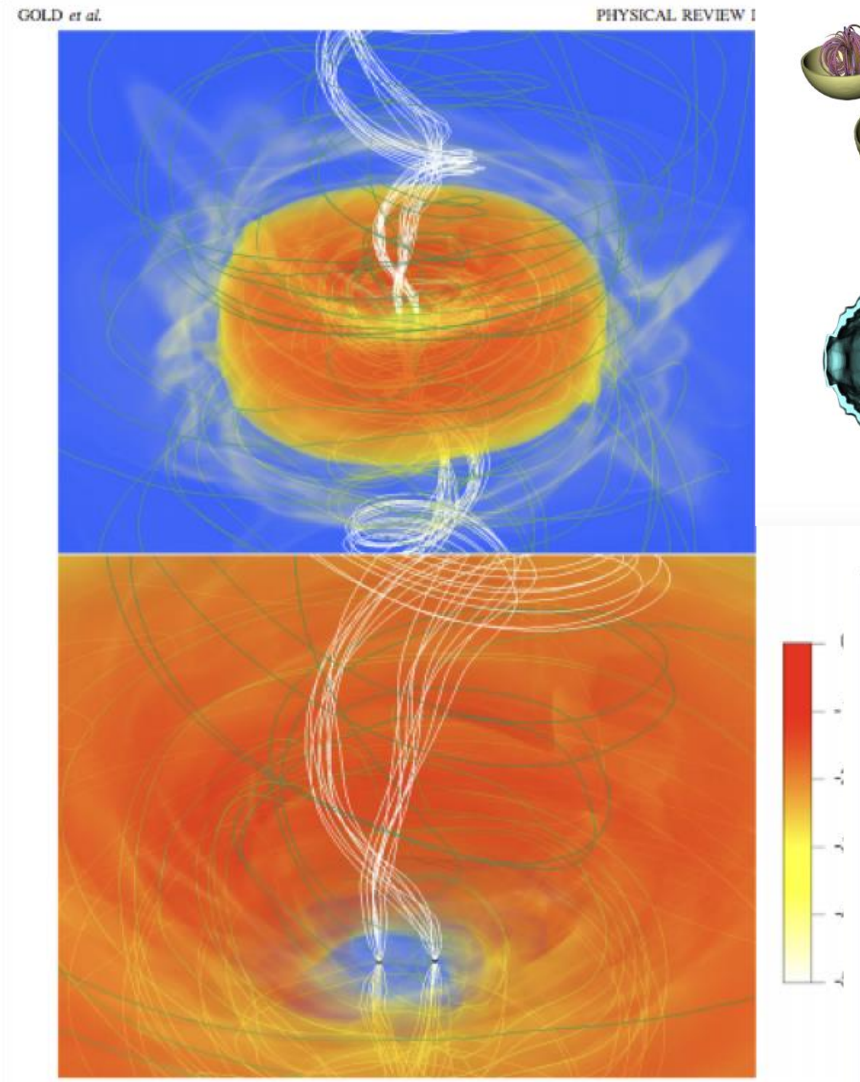
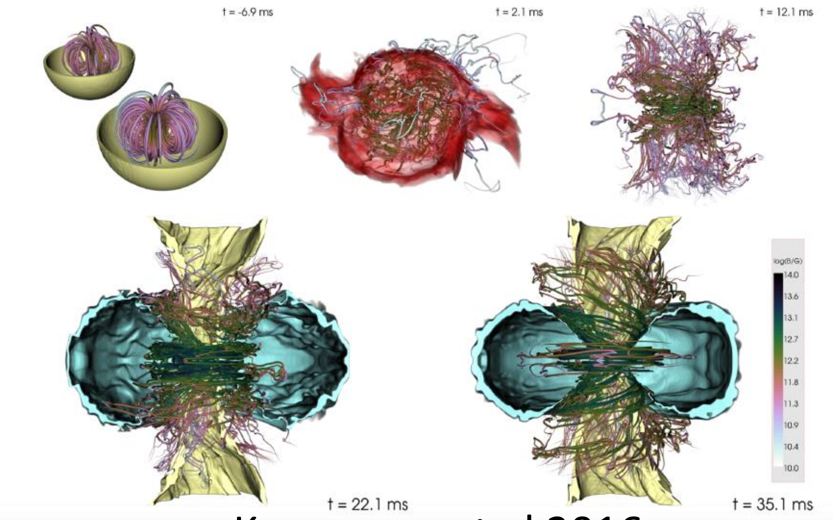
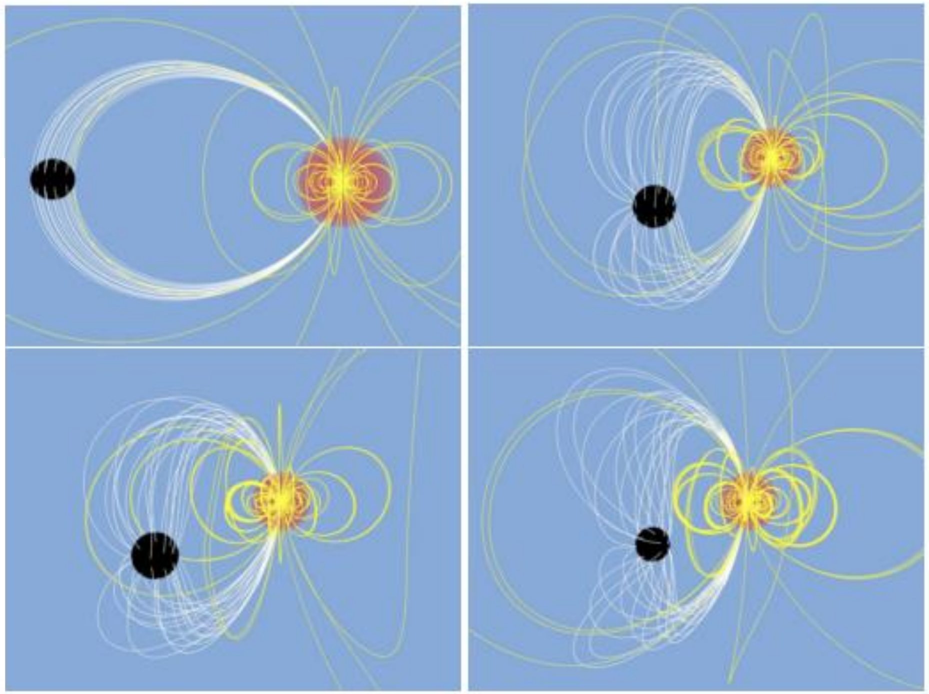
GRMHD APPLICATIONS



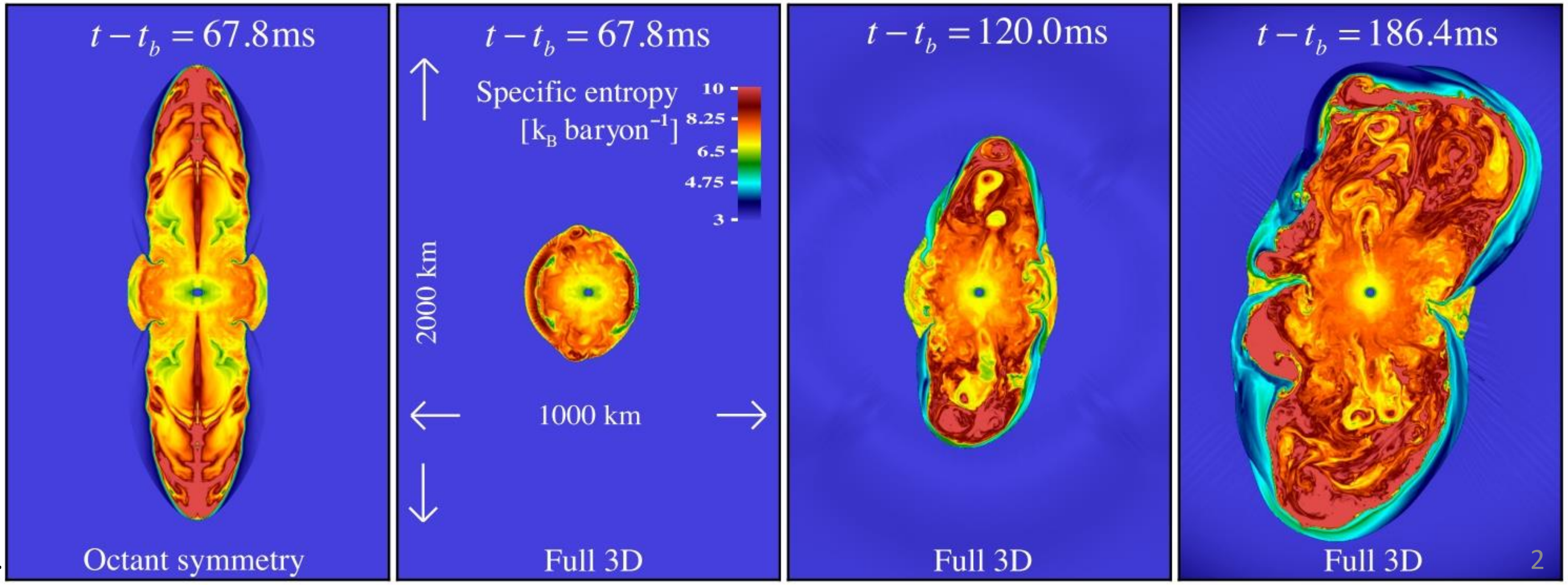
Gold et al 2014



Kawamura et al 2016

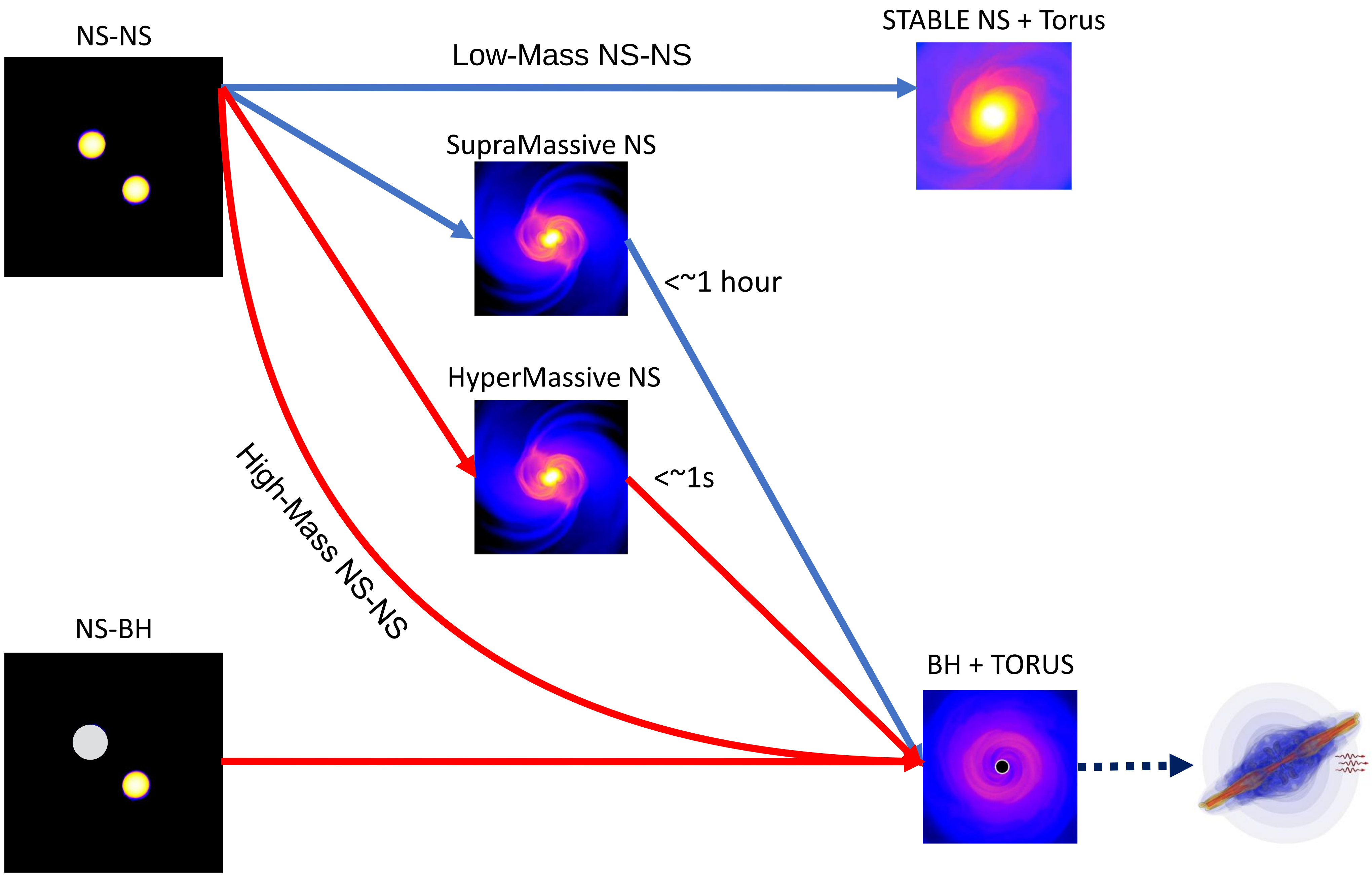


Paschalidis et al 2013

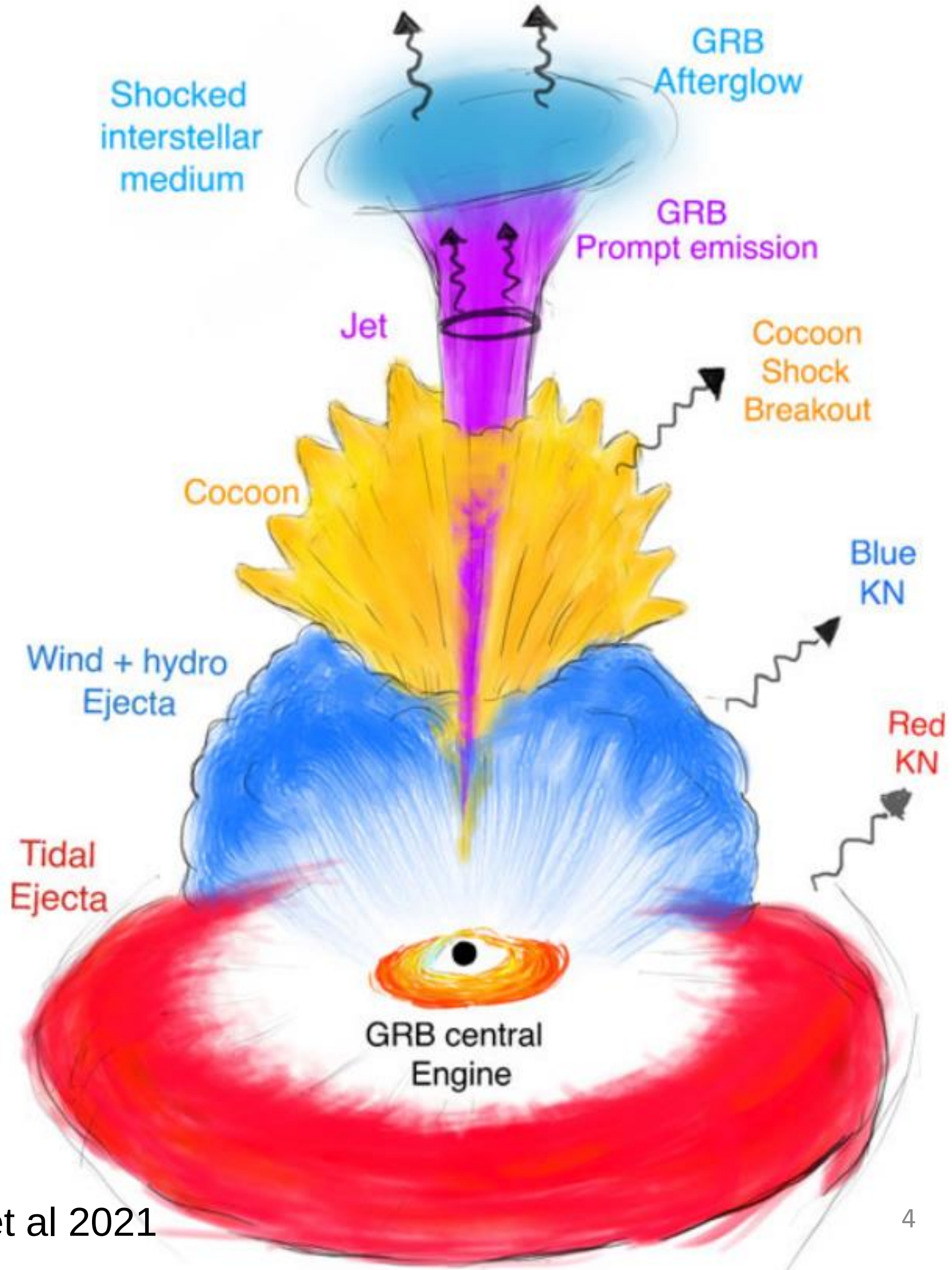


Moesta et al 2014

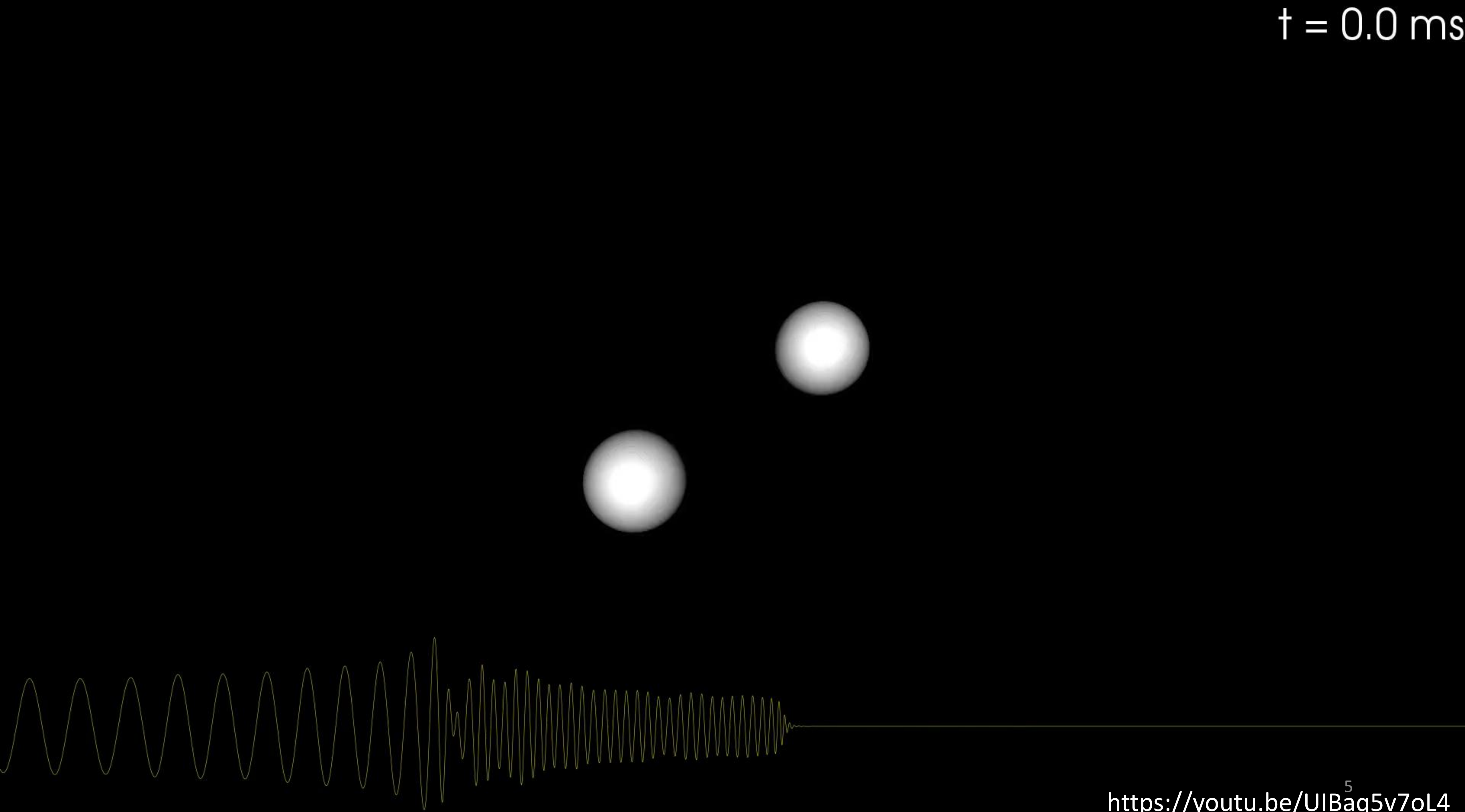
Neutron Star Binary Mergers



EM Emission from NS-NS Mergers

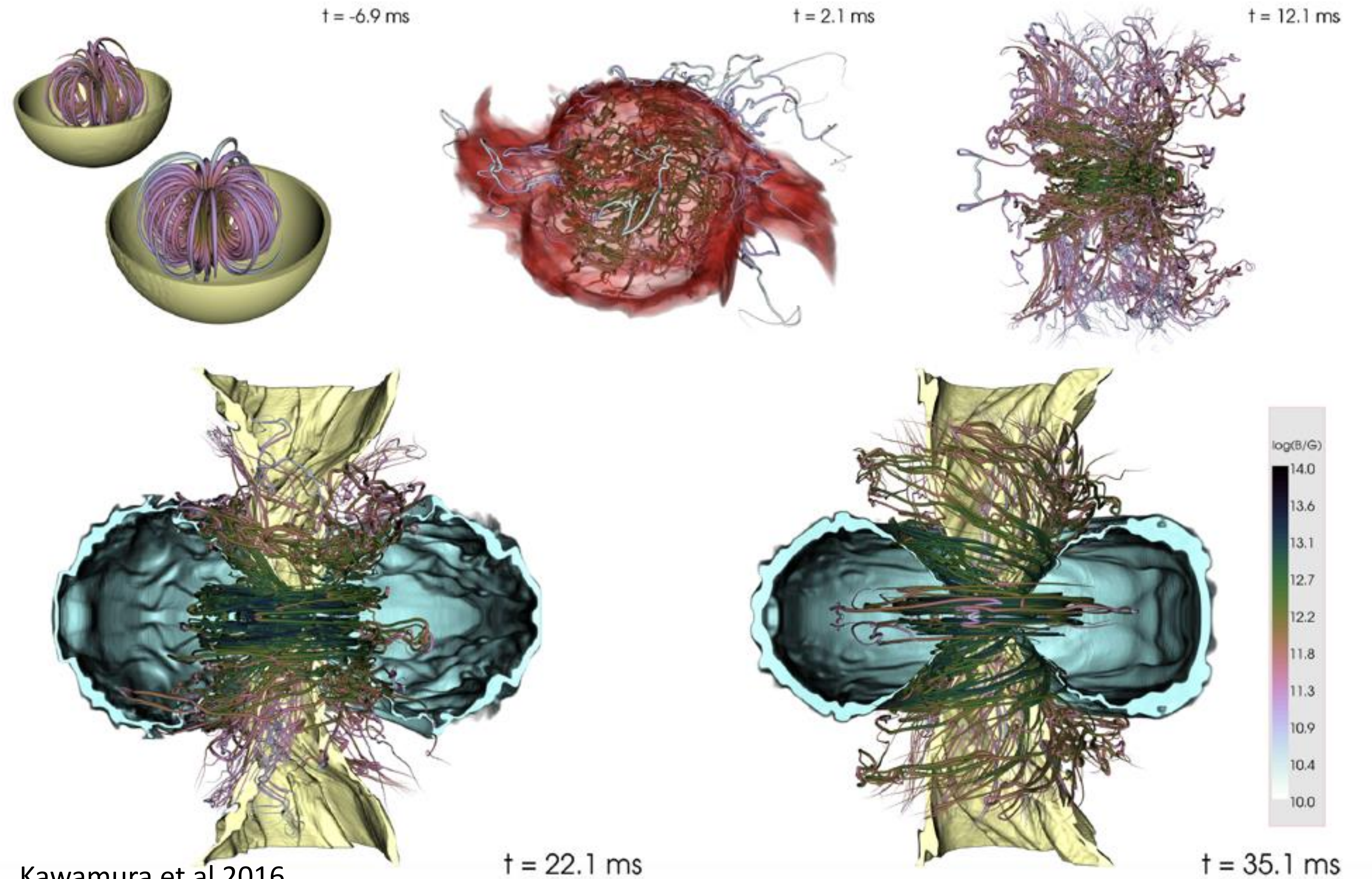


Ascenzi et al 2021



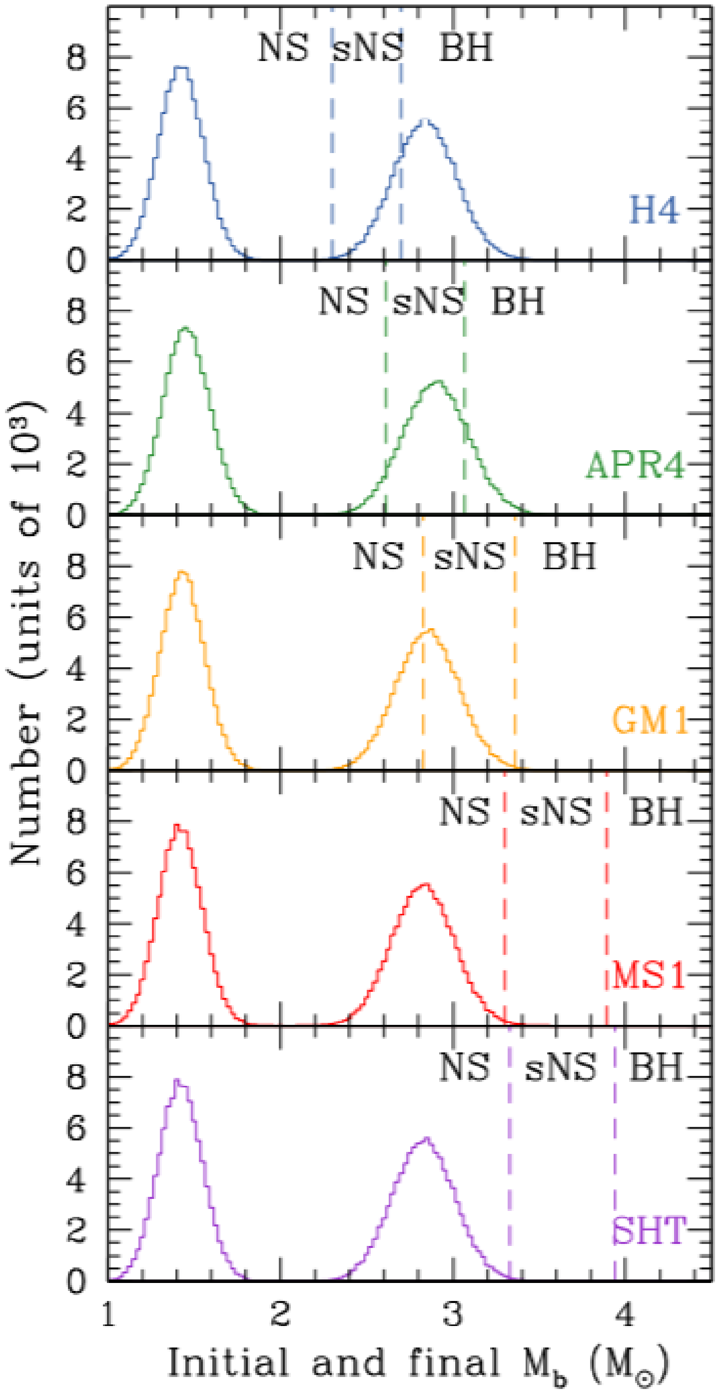
https://youtu.be/UIBaq5v7oL4

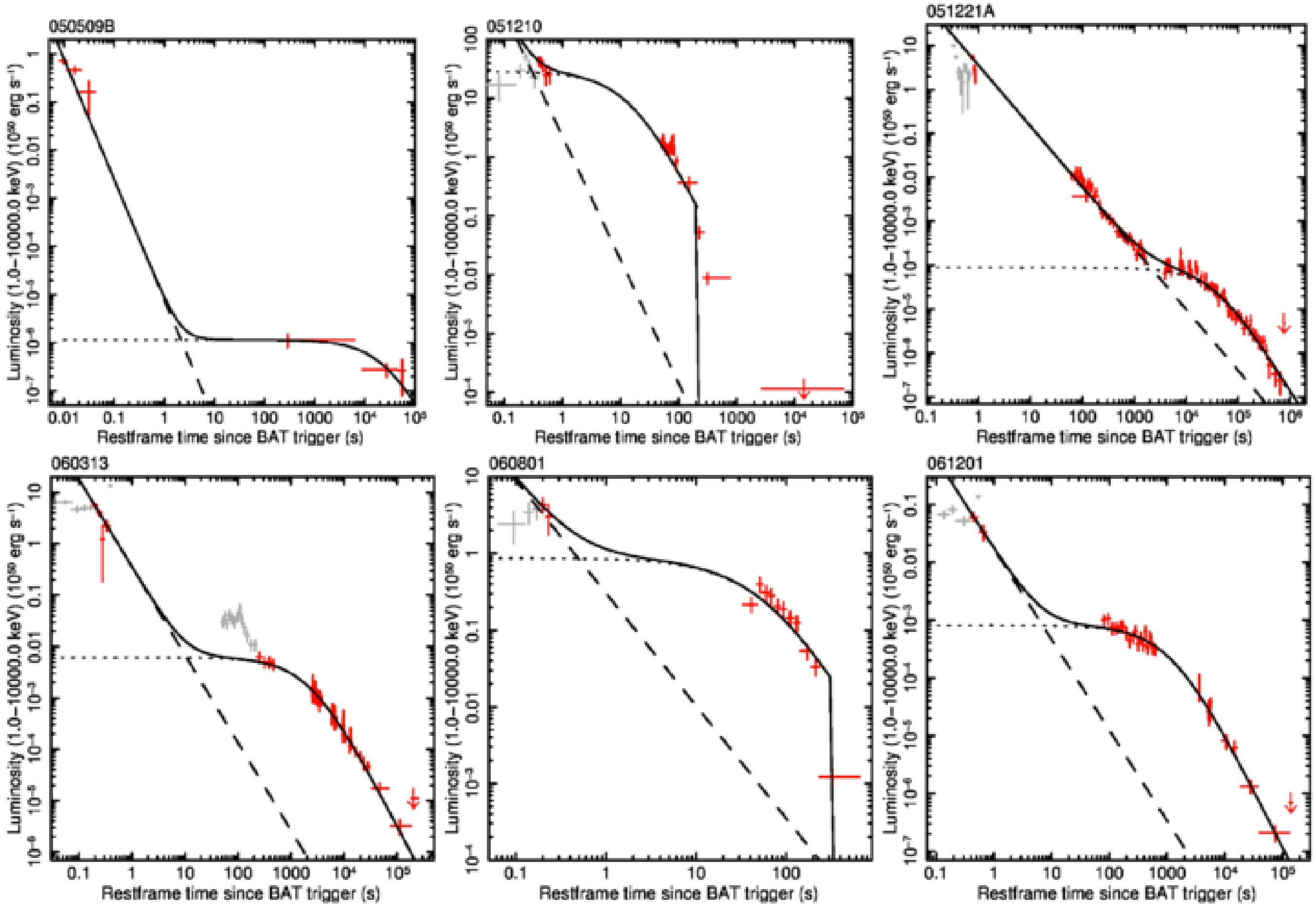
Magnetic Field Structure Evolution



Kawamura et al 2016

Piro, Giacomazzo & Perna 2017



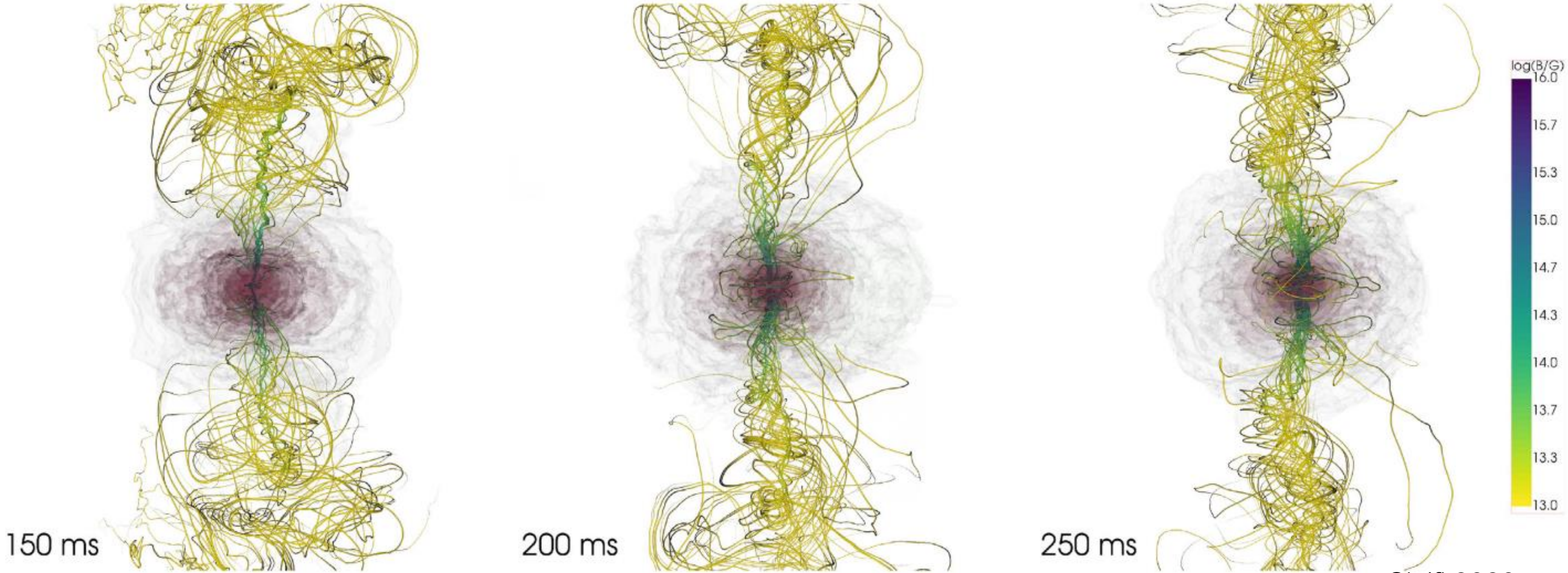


Rowlinson et al 2013

Long-lived NS remnants may also form from BNS mergers.

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

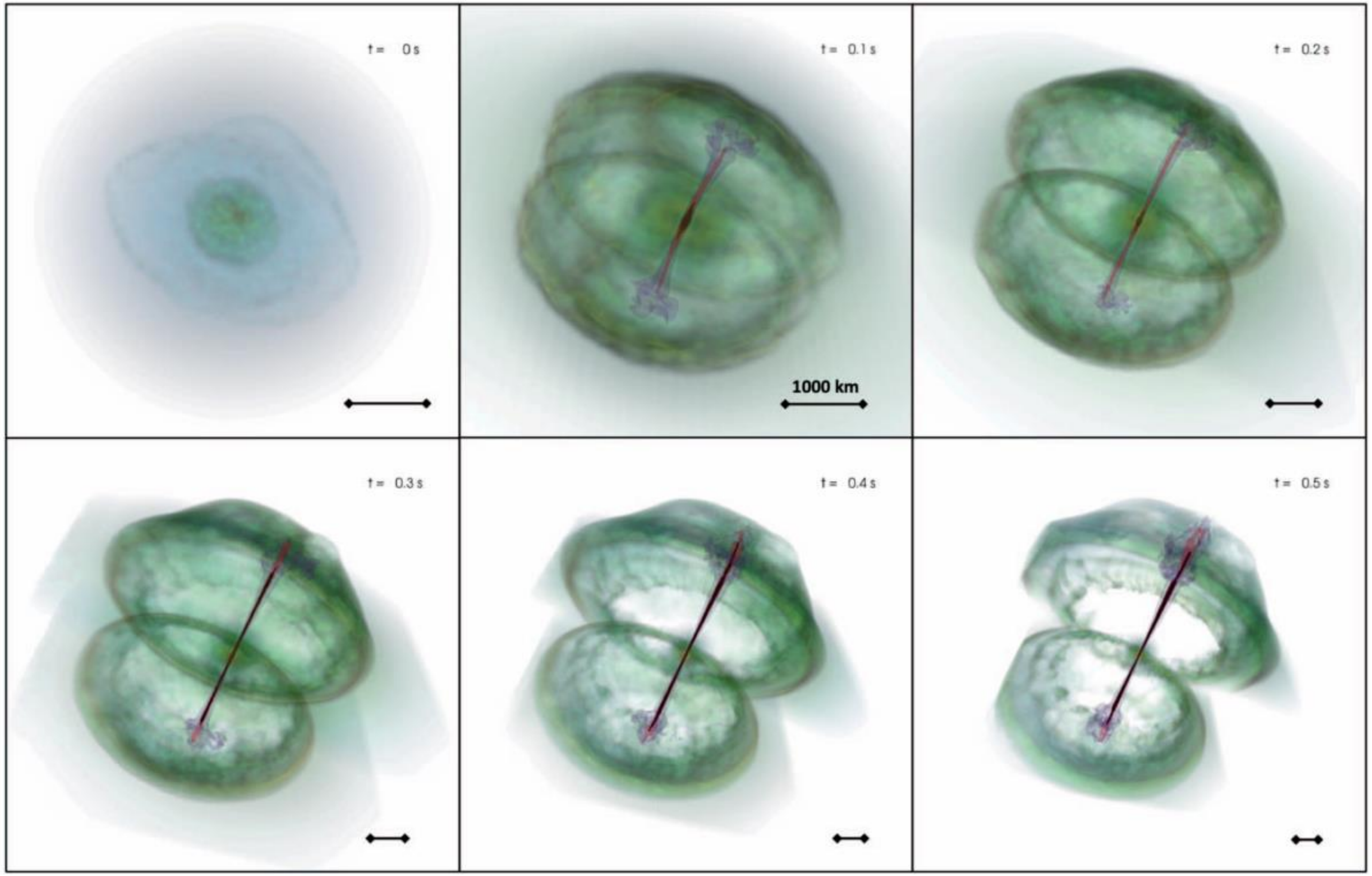
Collimated outflows from long-lived BNS merger remnants



Ciolfi 2020

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)

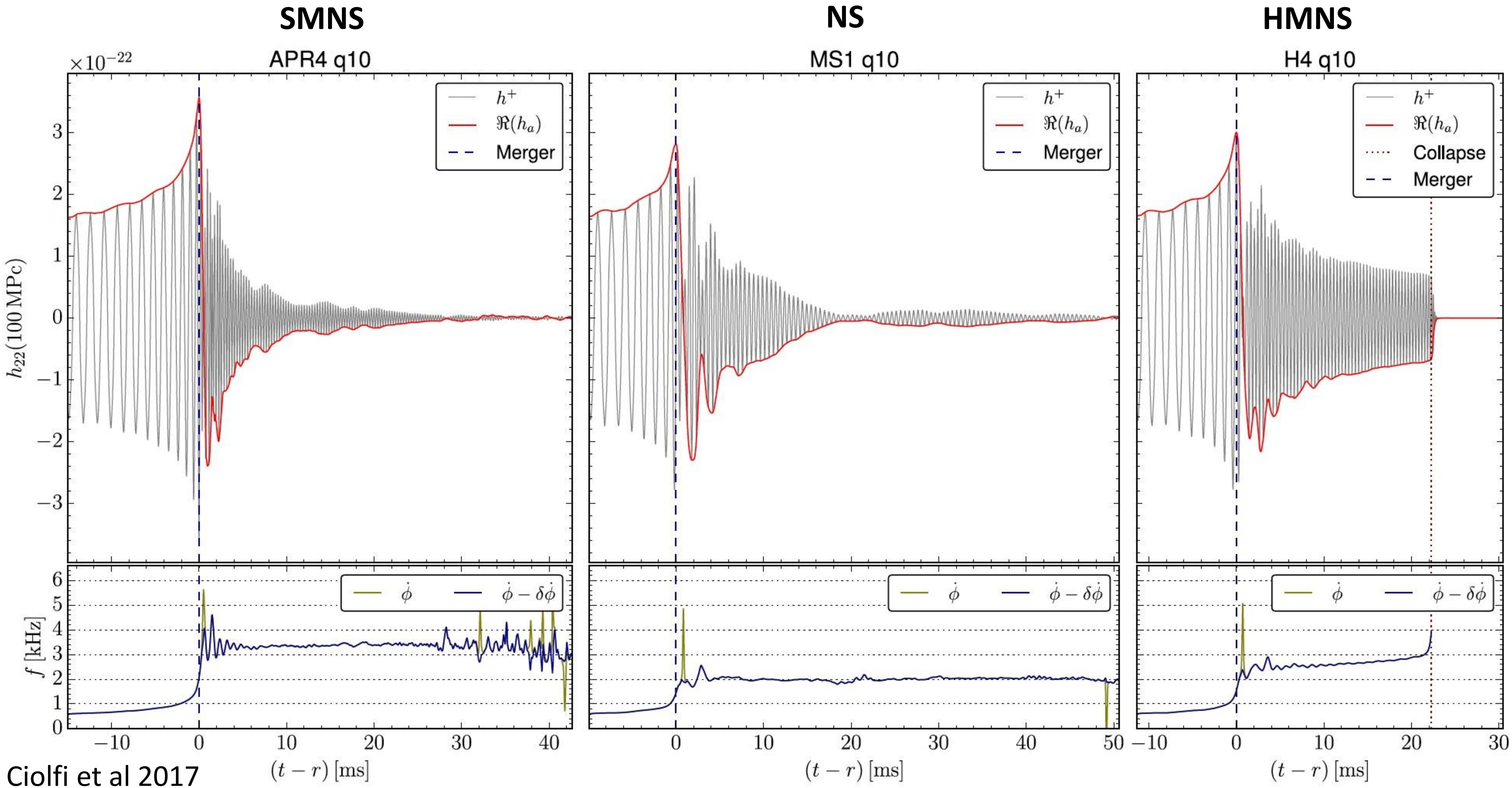


Once a jet is produced, we need to follow its propagation on a long-time scale.

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

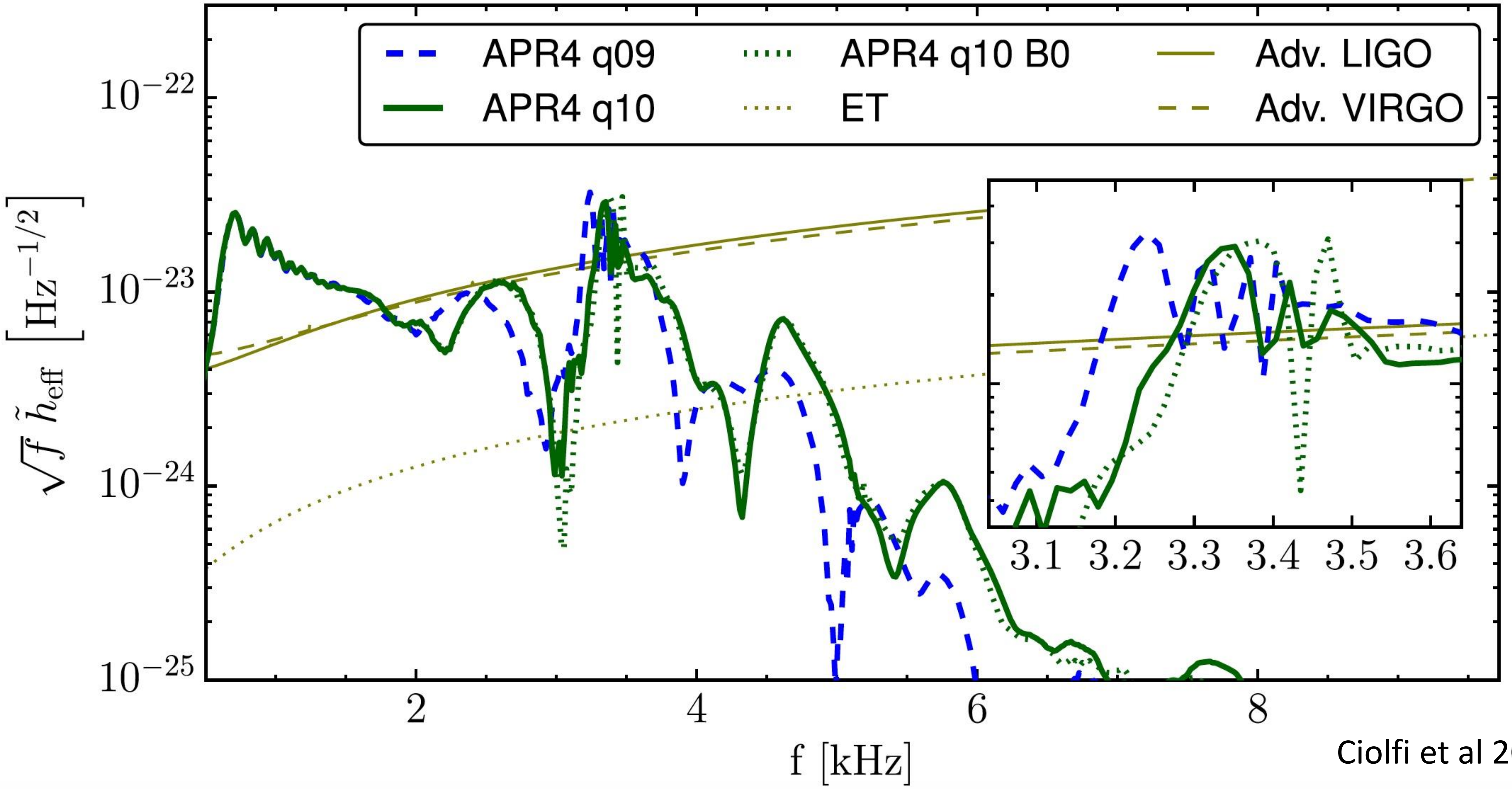
We imported the outcome of a GRMHD simulation into a special relativistic hydrodynamic code. The breakout time is found to be ~0.6 s (see also Pavan et al 2021, Nathanail et al 2021).

MAGNETIC FIELDS EFFECTS ON GWS



Ciolfi et al 2017

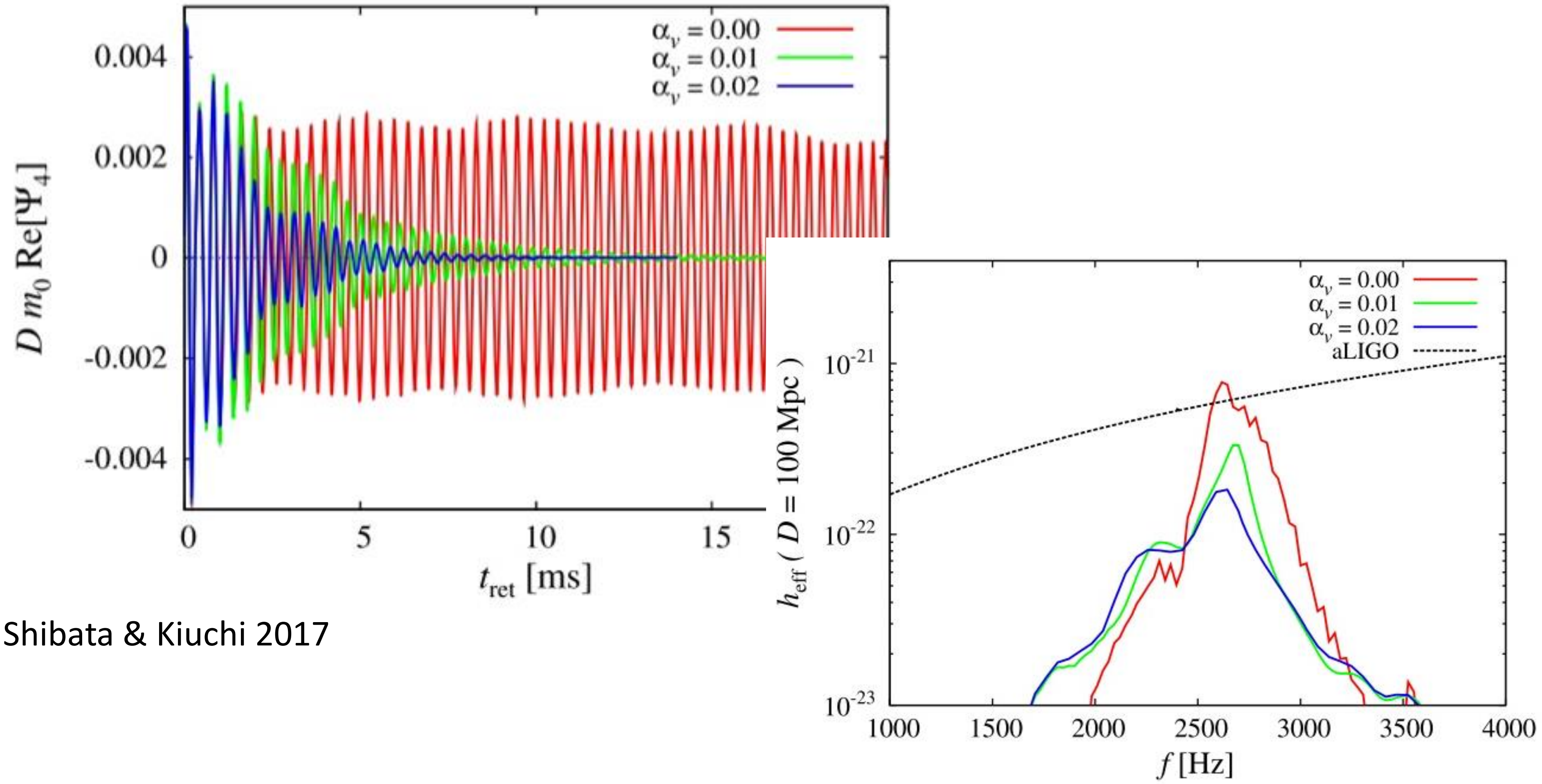
Magnetic Field Effects on Post-Merger GW Emission



Ciolfi et al 2017

Evolved "low-mass" BNS with high magnetic fields (~10^{15} G during inspiral, ~10^{16} G after merger). Negligible differences in the post-merger peak.

Magnetic Field Effects on Post-Merger GW Emission



Shibata & Kiuchi 2017

Shibata & Kiuchi 2017 state instead that strong magnetic fields can damp quickly the GW signal (result obtained using viscosity as a model for magnetic field effects).

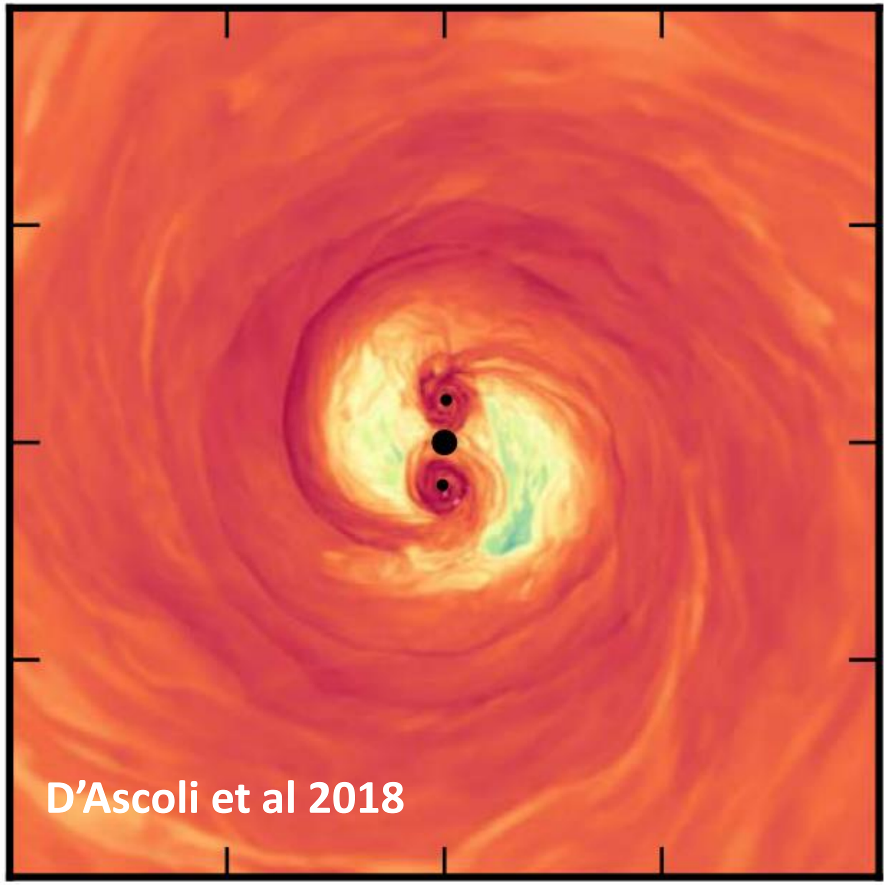
Supermassive Black Hole Binary Mergers

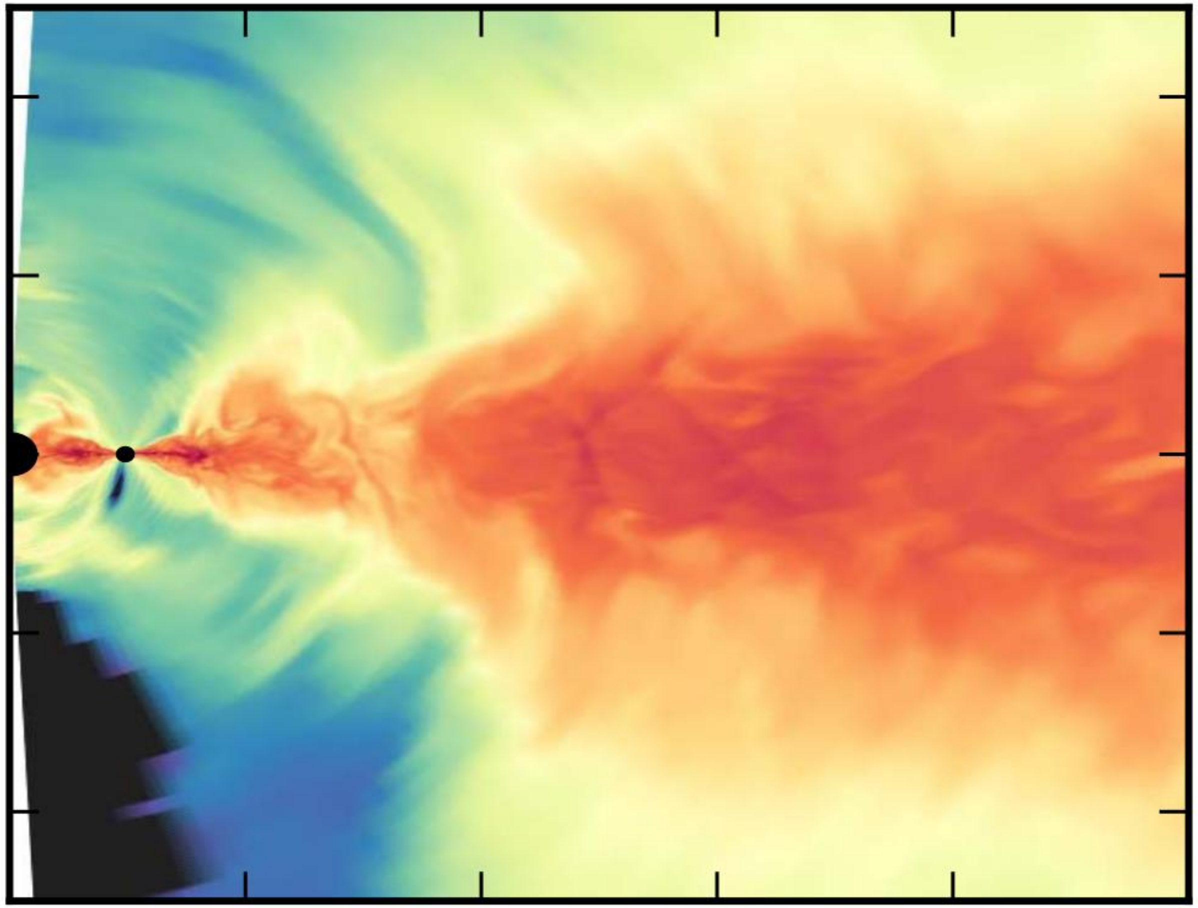
- They can form after galaxy mergers

- They may be surrounded by accreting matter:
  - **Circumbinary Disk Model**
  - **Gas Cloud Model**

- When magnetized, the gas may lead to powerful ejecta and bright EM emission

Circumbinary Disk Model





Equal-mass non-spinning BHs (see Combi et al 2021, Paschalidis et al 2021 for a spinning case).
Electromagnetic emission peaking in UV (thermal) and X-ray (inverse Compton) bands.

Light from Merging Supermassive Black Holes

Visualization by Mark Van Moer of NCSA, simulation by Stephan d'Ascoli, Dr. Dennis Bowen, Dr. Manuela Campanelli, and Dr. Scott Noble (https://www.youtube.com/watch?v=vGvE17uX5r4)

Gas Cloud Model

We extended previous works on the gas cloud model including (for the first time in GRMHD) the effect of BH spins (aligned and misaligned).

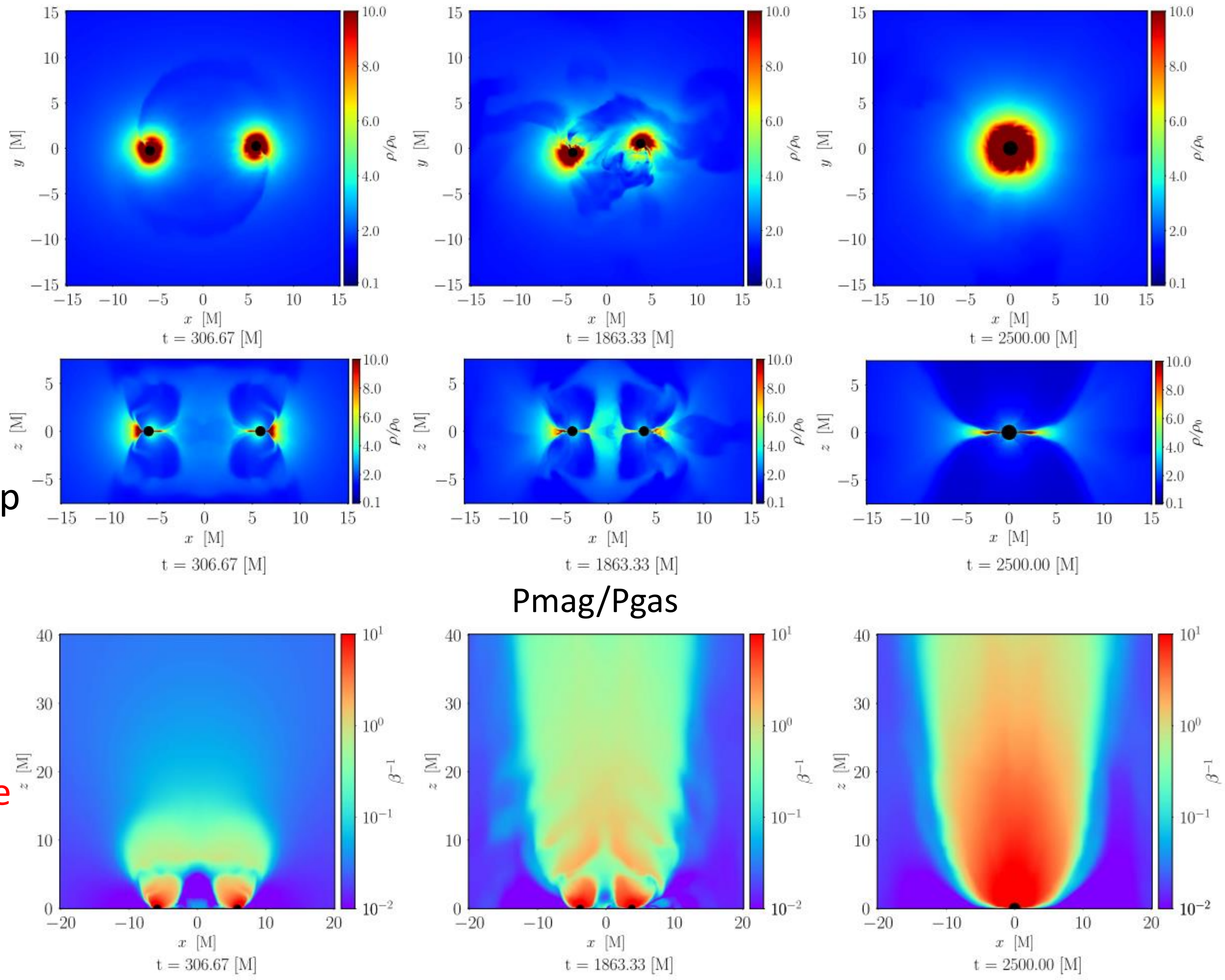
Accretion rates in magnetized models found to be smaller by up to ~3 times.

Aligned spins also reduce accretion by up to ~50%.

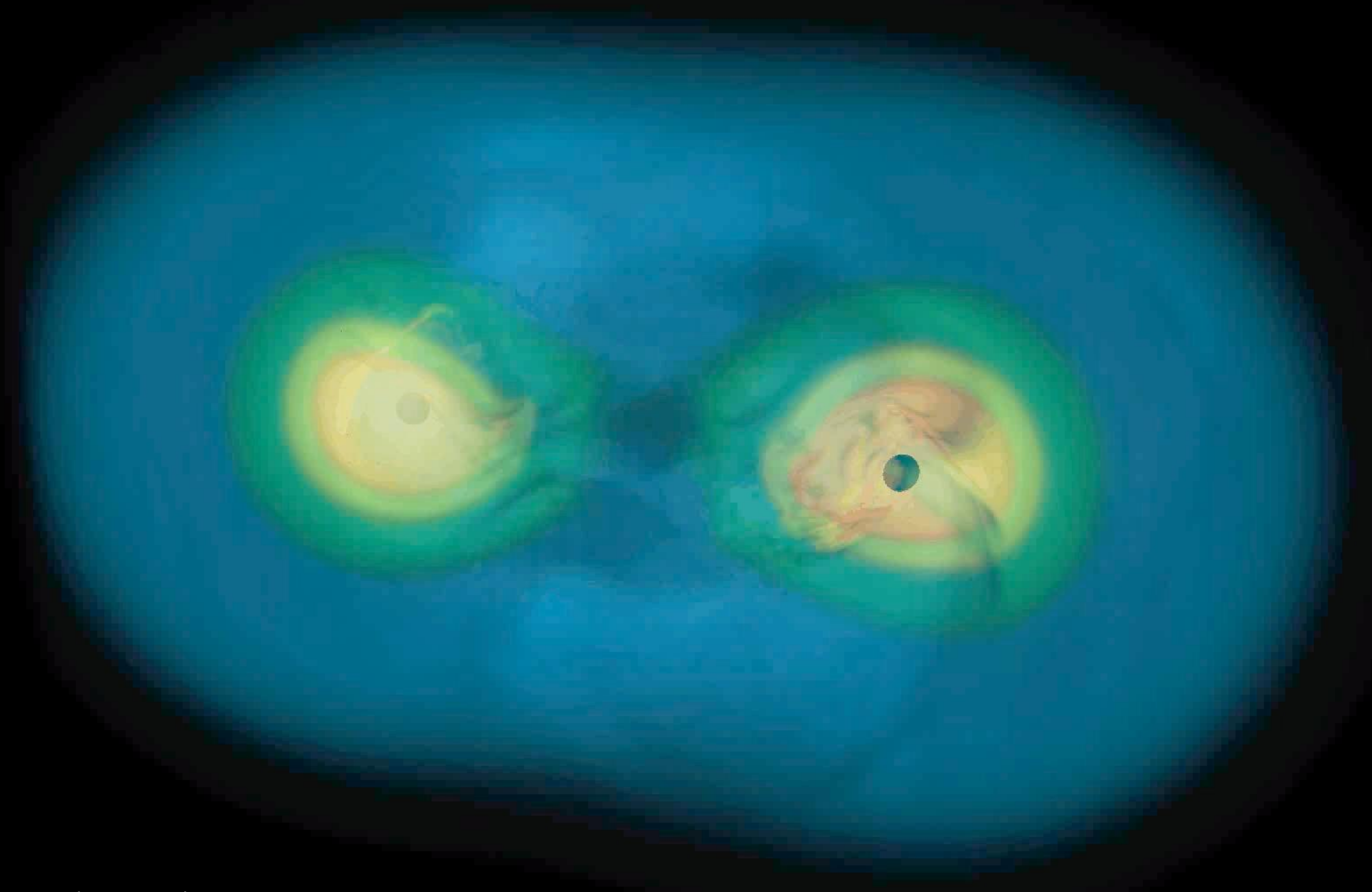
Aligned spins increase Poynting luminosity by a factor ~2.

Both spins and magnetic fields affect the dynamics of these systems.

rest-mass density

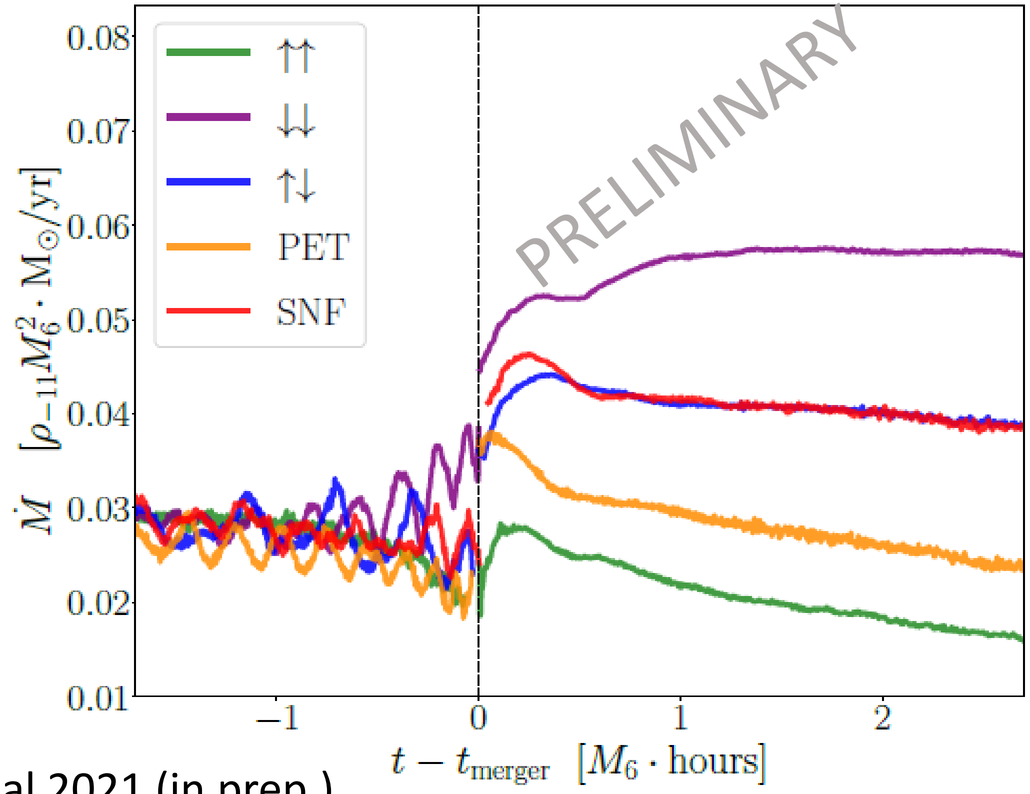


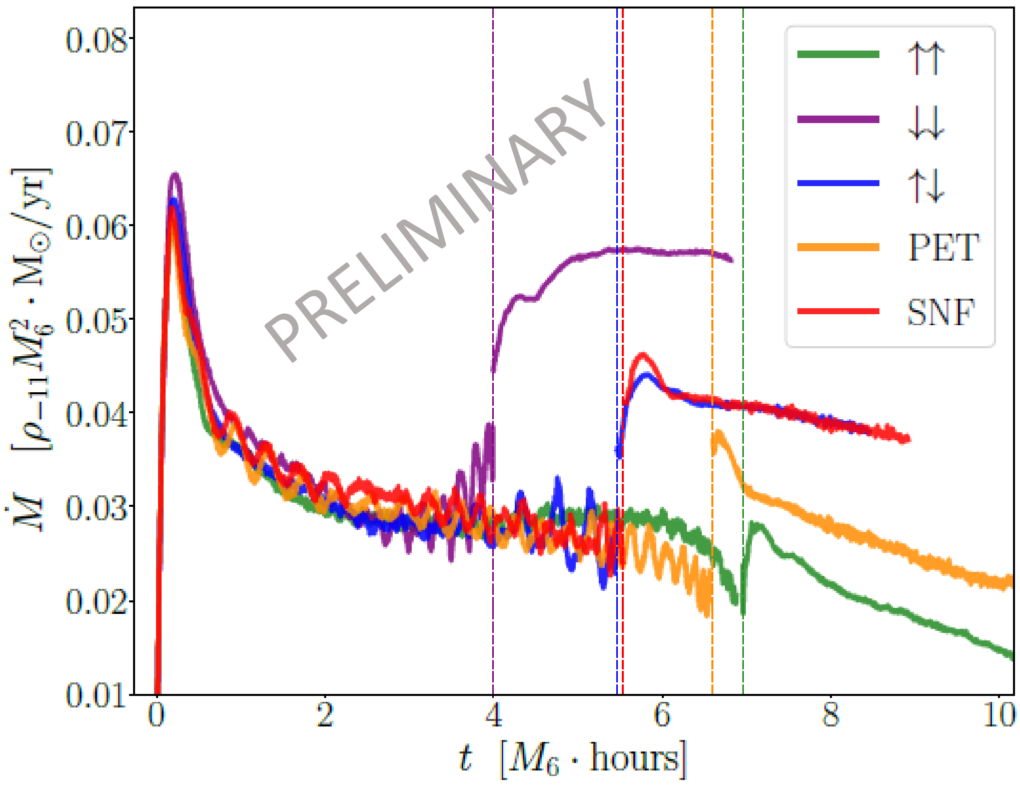
Cattorini et al 2021



Cattorini et al 2021 (in prep.)

Gas Cloud with Misaligned Spins





Cattorini et al 2021 (in prep.)

Periodicity in accretion rates and Poynting luminosity may be used to infer binary properties.

CONCLUSIONS

- Magnetic fields can play an important role in BNS mergers:
  - **Short GRBs** (launch and collimation of relativistic jets)
  - **Ejected matter** (kilonova and heavy element production)
  - **Gravitational Waves** (?)

- For a full description of BNS dynamics it is crucial to account also for temperature effects and neutrino emission

- Magnetic fields are also important in accretion onto supermassive BH mergers

- Accretion models can strongly influence emission (e.g., periodicity)

- Still a lot of work to be done to translate current NR results into observables

Some Advertisement

- My collaborators and I developed the first publicly available code for GRMHD simulations including also finite temperature effects and neutrino emission: **The Spritz Code** (https://zenodo.org/record/4350072)

- Rosalba Perna and I edited a special research topic issue on GWs. It is open access and an ebook version is also available: https://www.frontiersin.org/research-topics/11345/gravitational-waves-a-new-window-to-the-universe

- The Einstein Toolkit: https://einsteintoolkit.org/