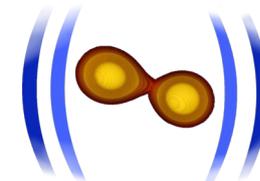




PennState
Eberly College of Science



CoRe collaboration

Compact Binary Mergers

David Radice – October 28, 2025



NP3M



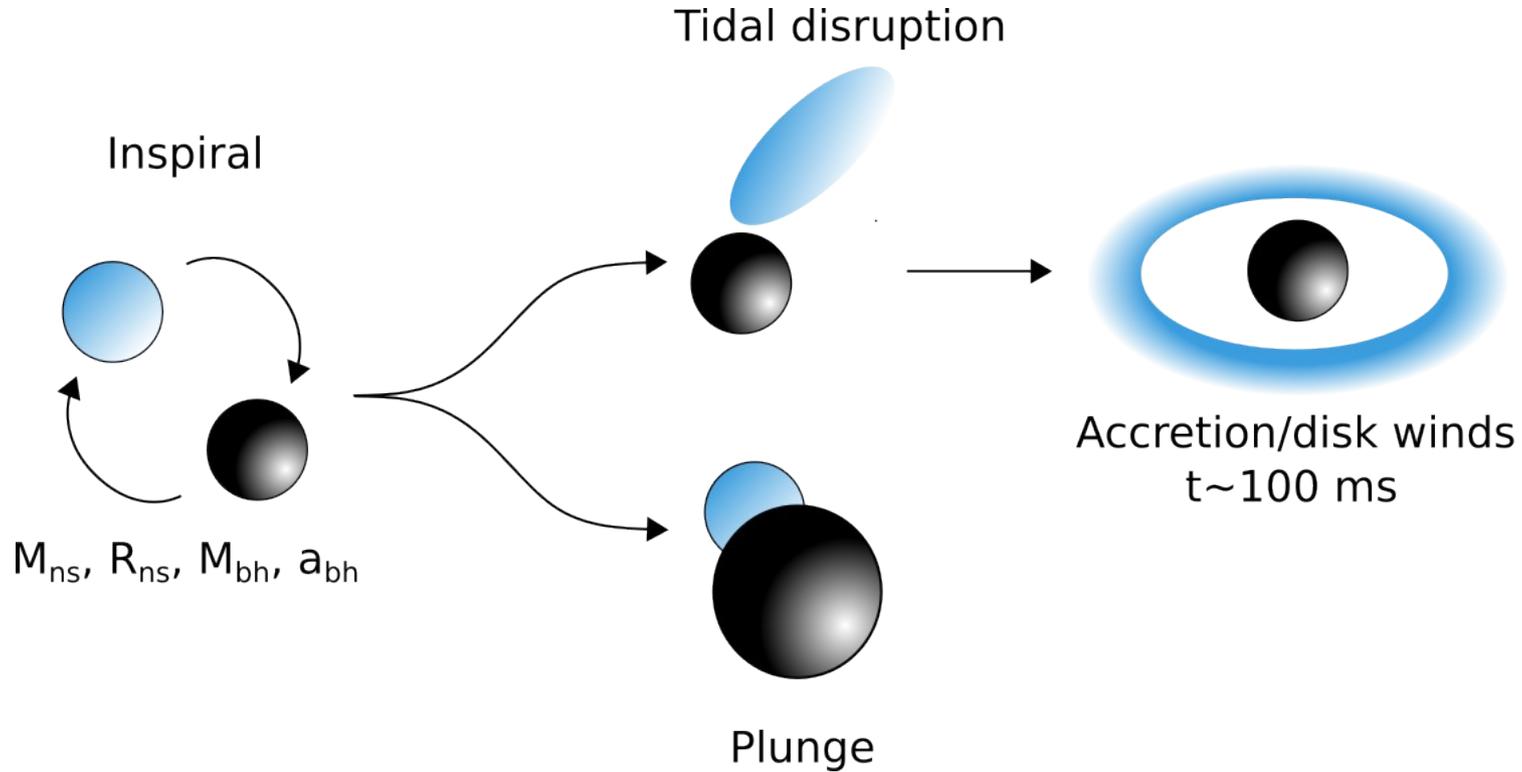
N3AS

Network for Neutrinos,
Nuclear Astrophysics,
and Symmetries

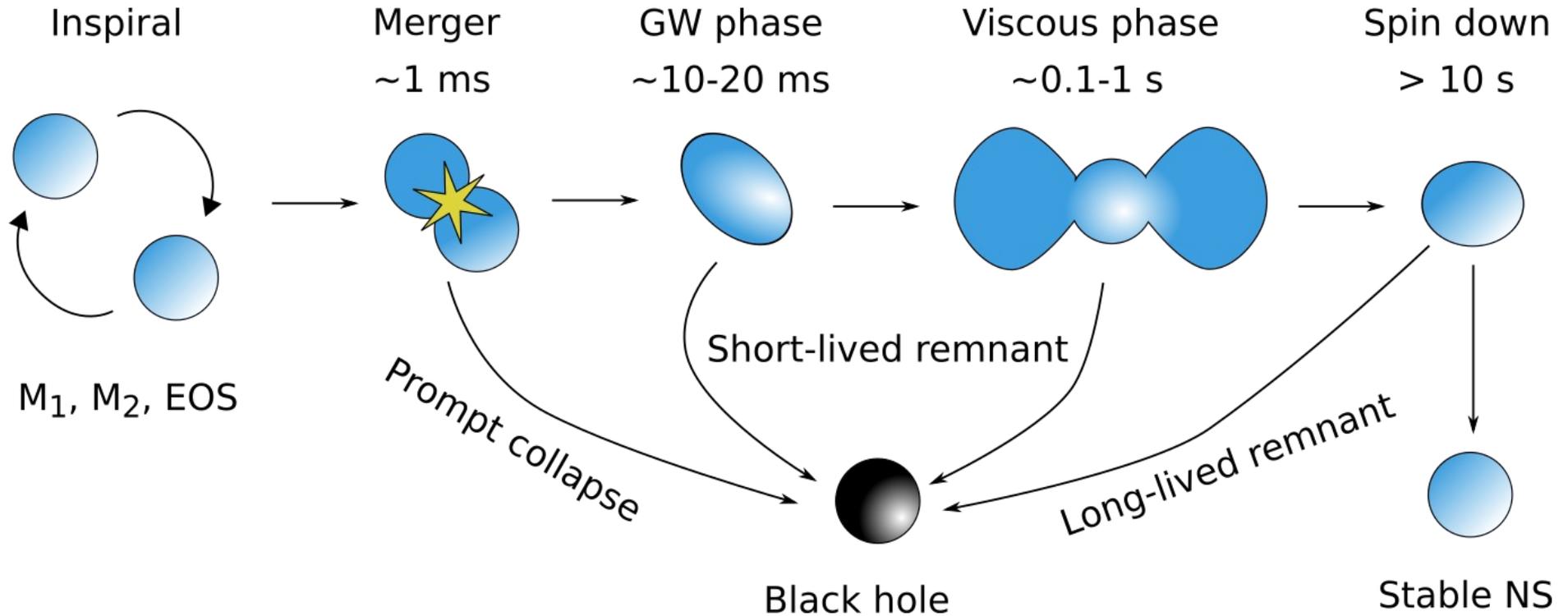
PHYSICS FRONTIER CENTER

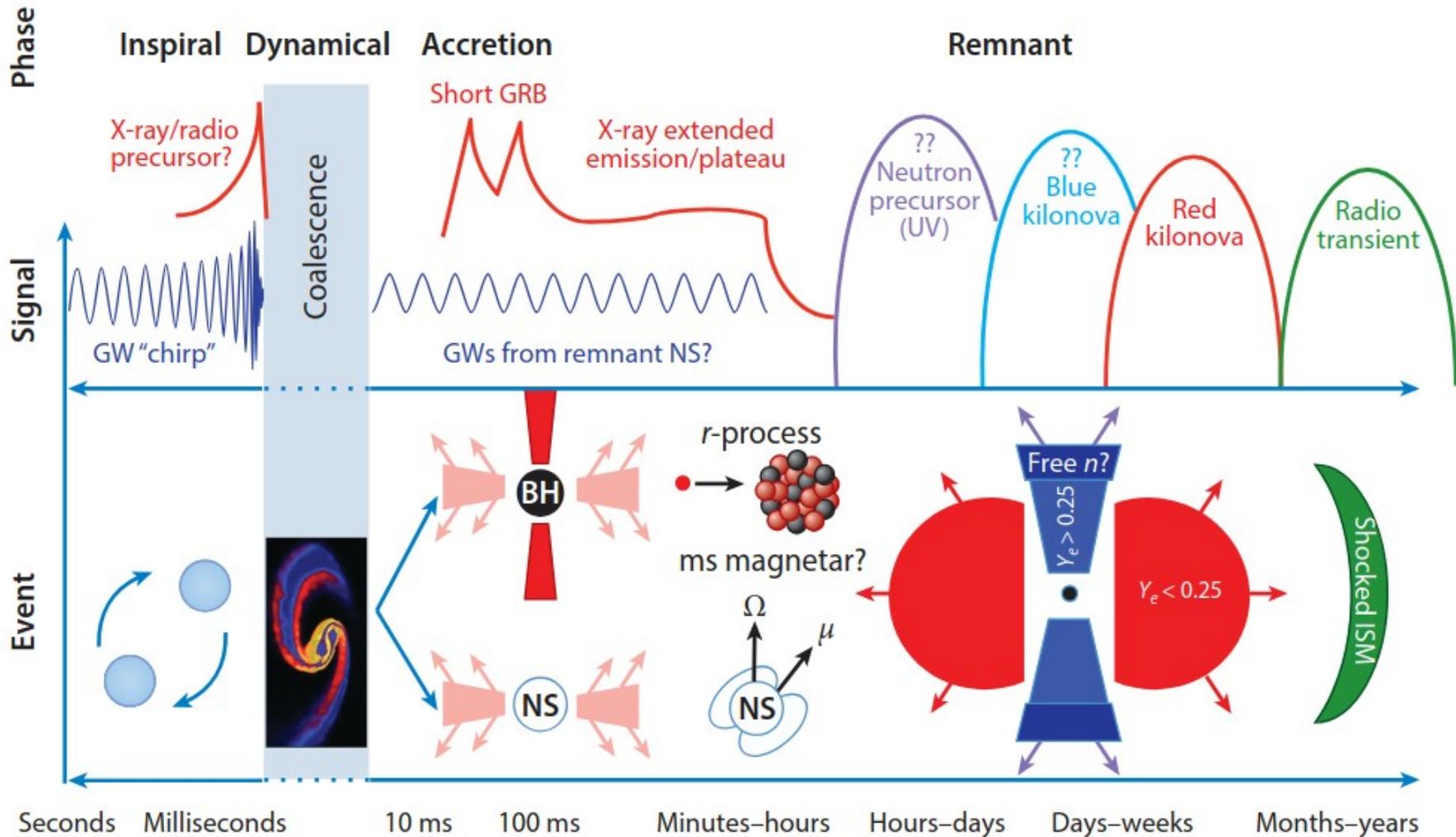


Black-hole neutron-star mergers

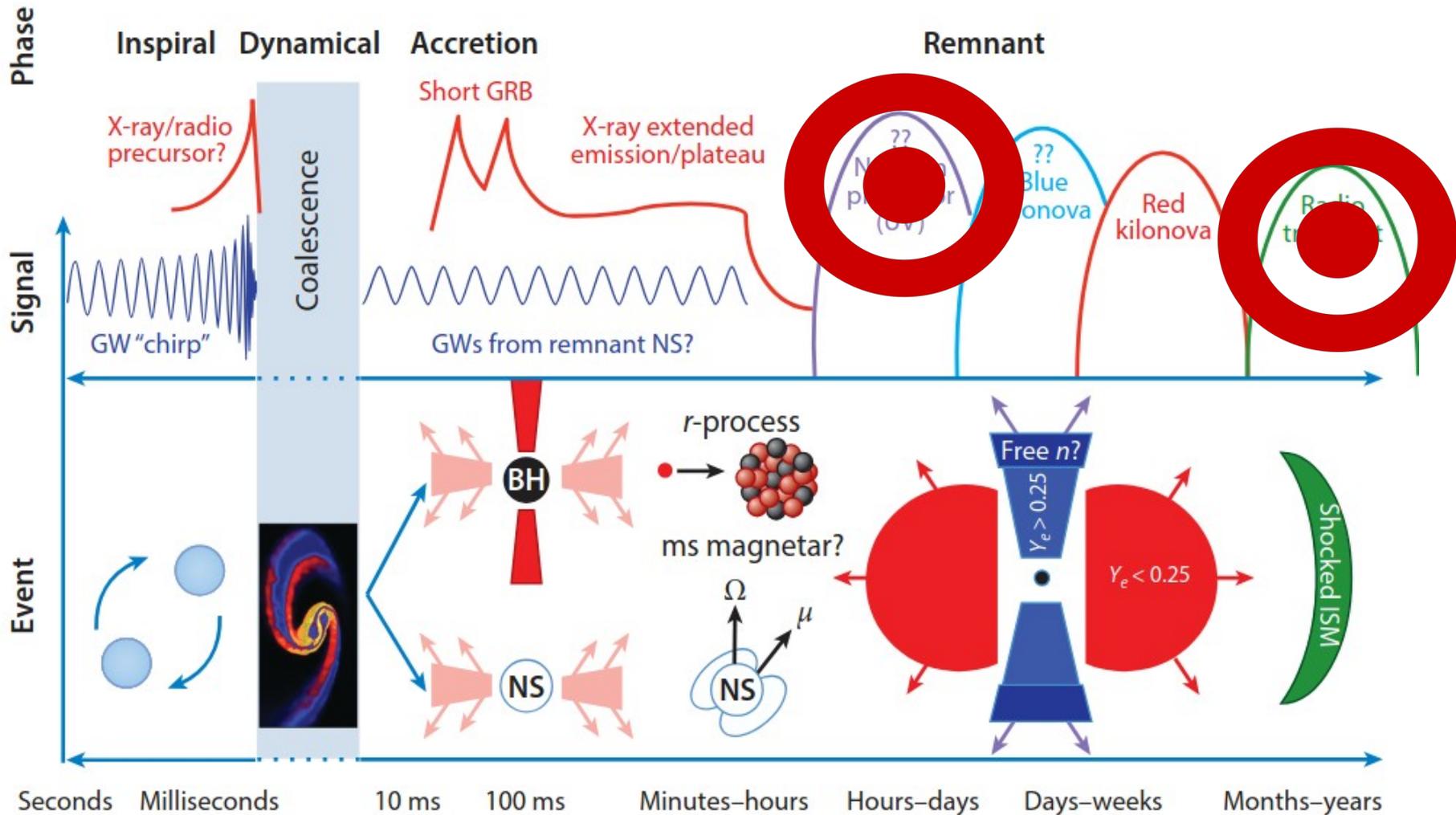


Neutron star merger





From Fernandez & Metzger (2016)

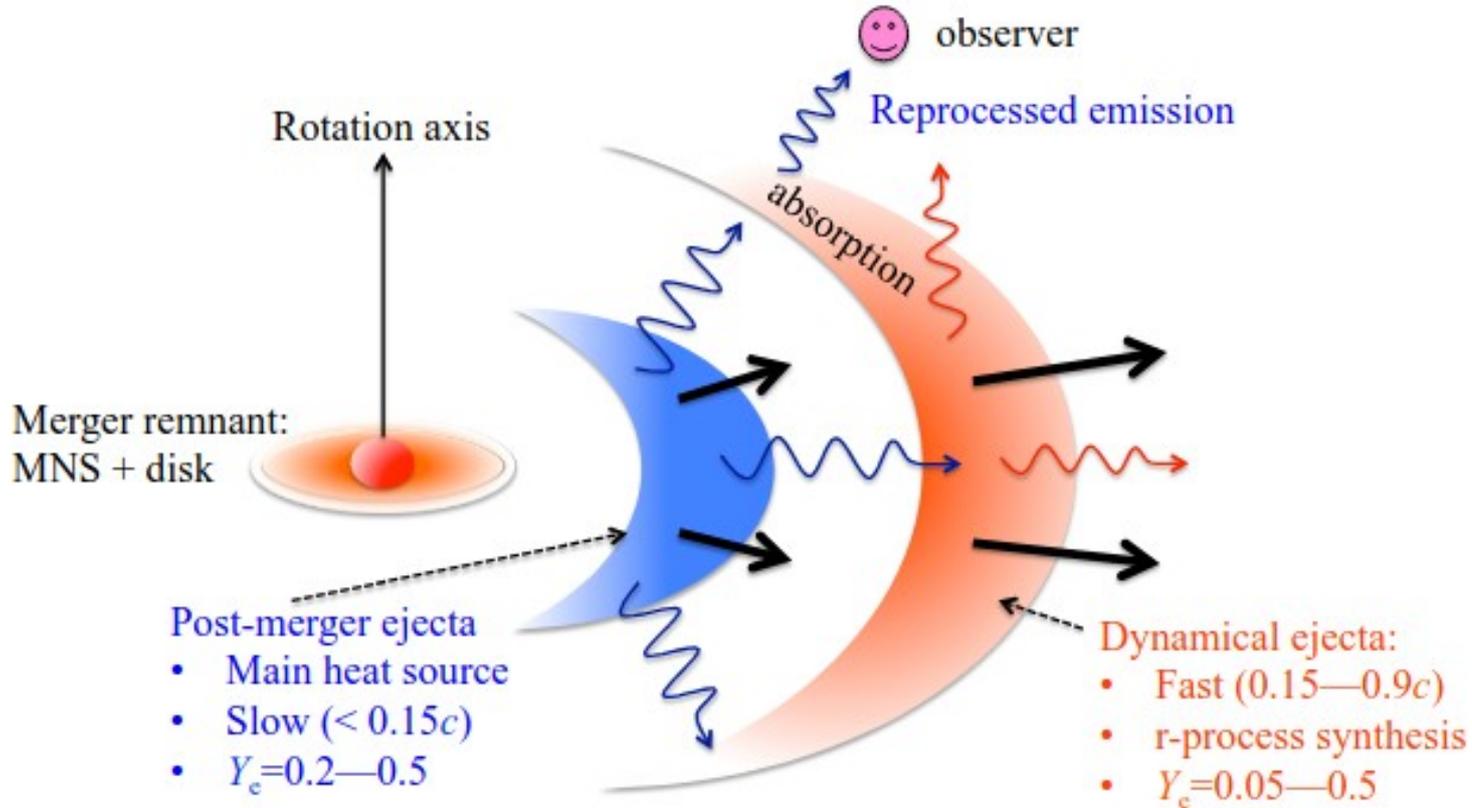


From Fernandez & Metzger (2016)

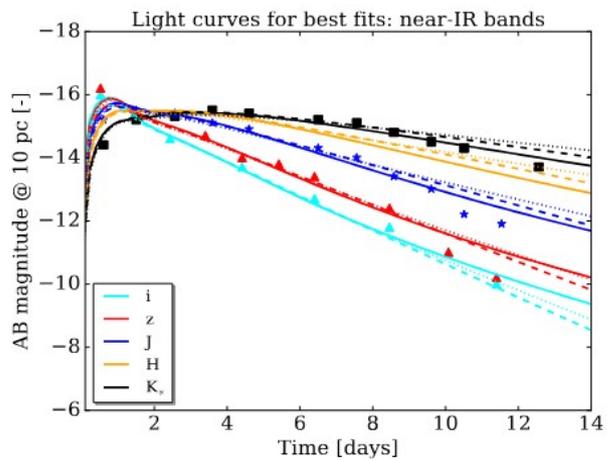
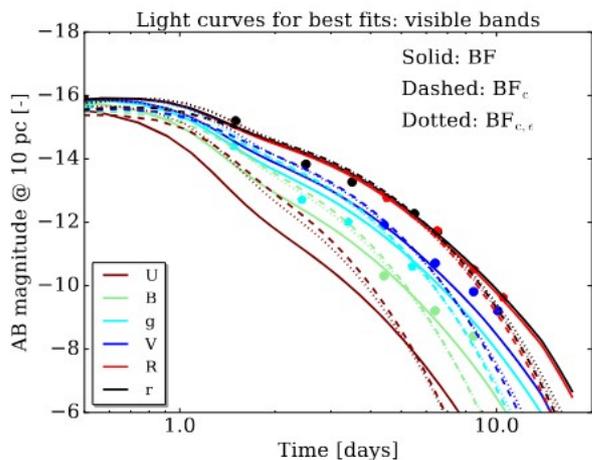
Open questions

- What is the nature of matter inside neutron stars?
- What fraction of the r-process elements do neutron star mergers produce?
- What binaries make GRBs? What type of GRBs?
- Can we use compact binary mergers for cosmology?
- Does general relativity break down in mergers?

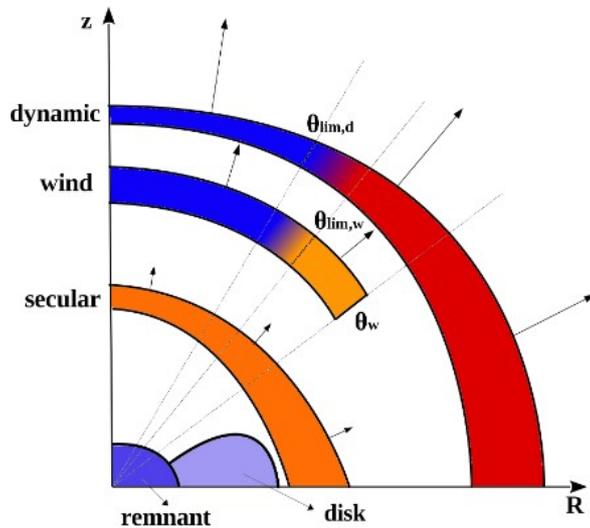
Mass ejection and kilonovae



AT2017gfo

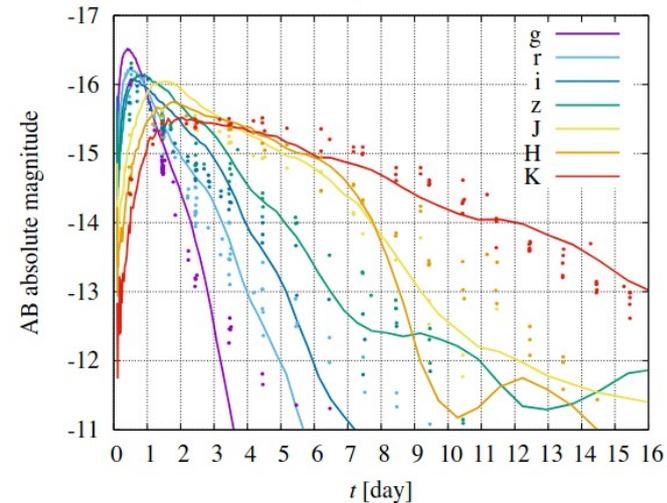
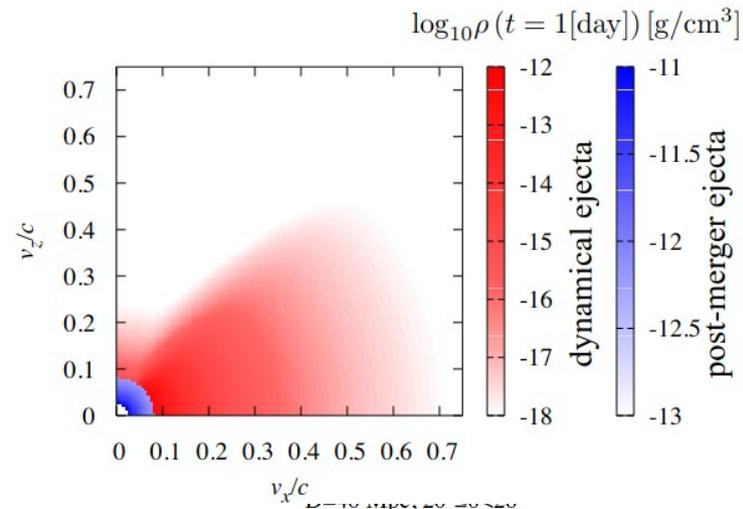


From Perego+ 2017



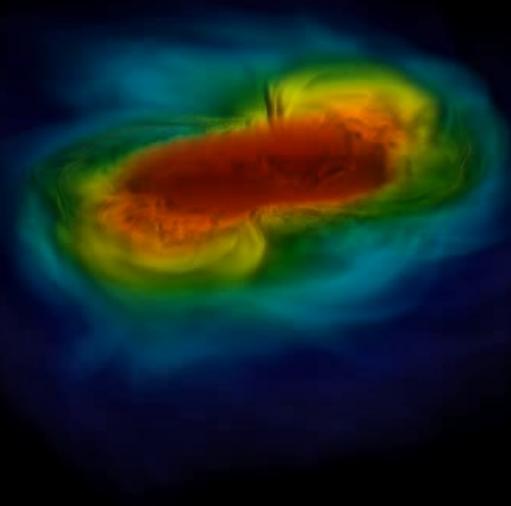
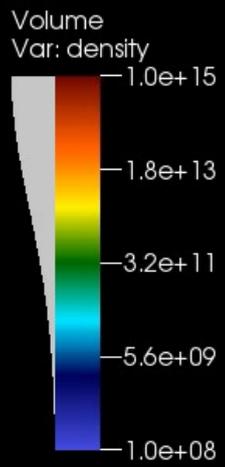
$$M_{\text{dyn}} \simeq 0.01 M_{\odot}$$

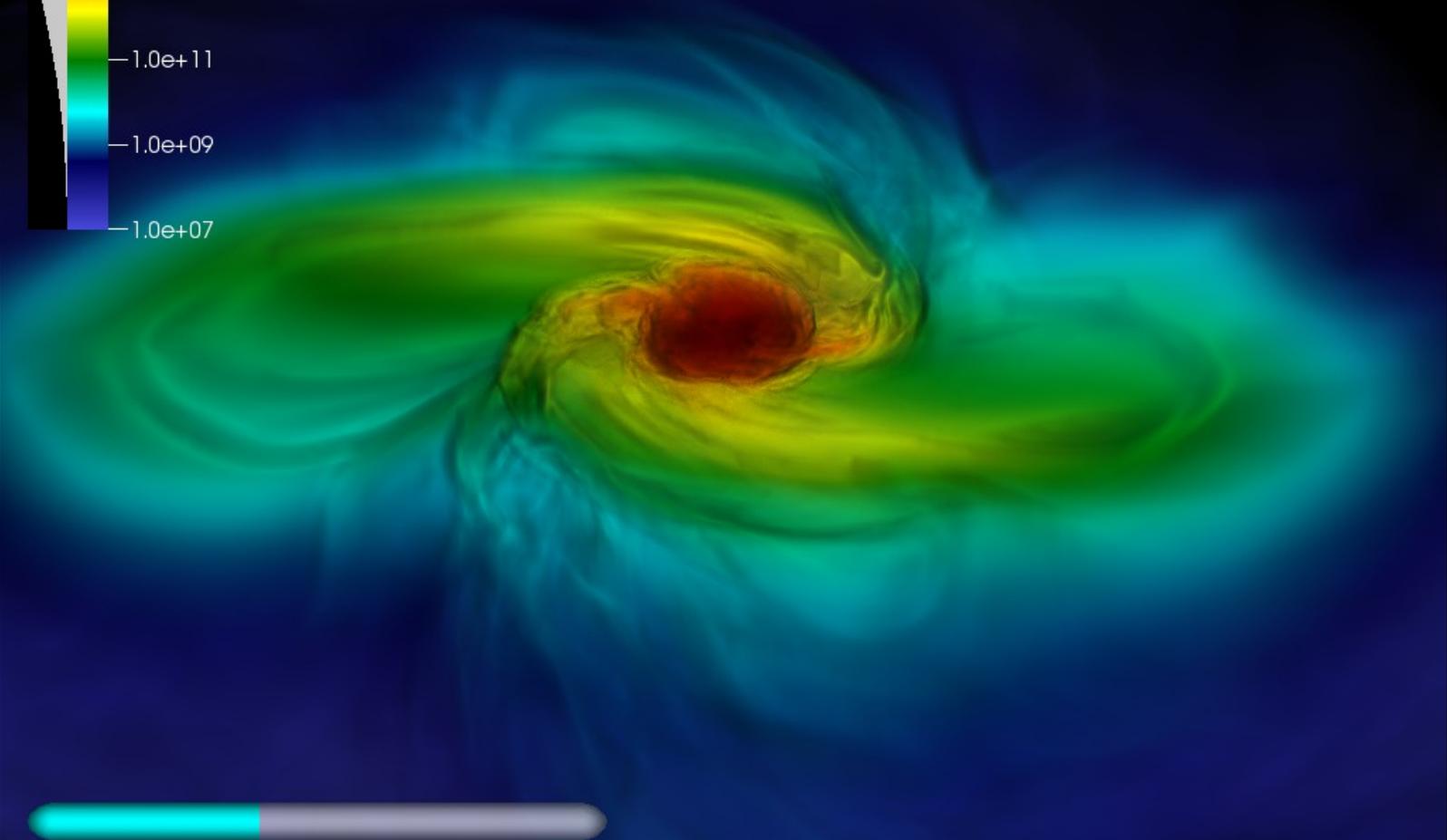
$$M_{\text{pm}} \simeq 0.02 M_{\odot}$$



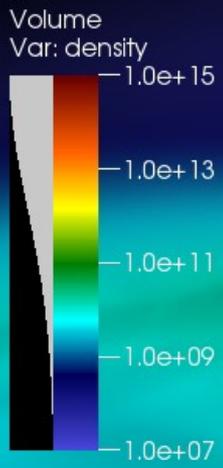
From Kawaguchi+ 2018

See also Kasen+ 2017, Miller+ 2019, ...

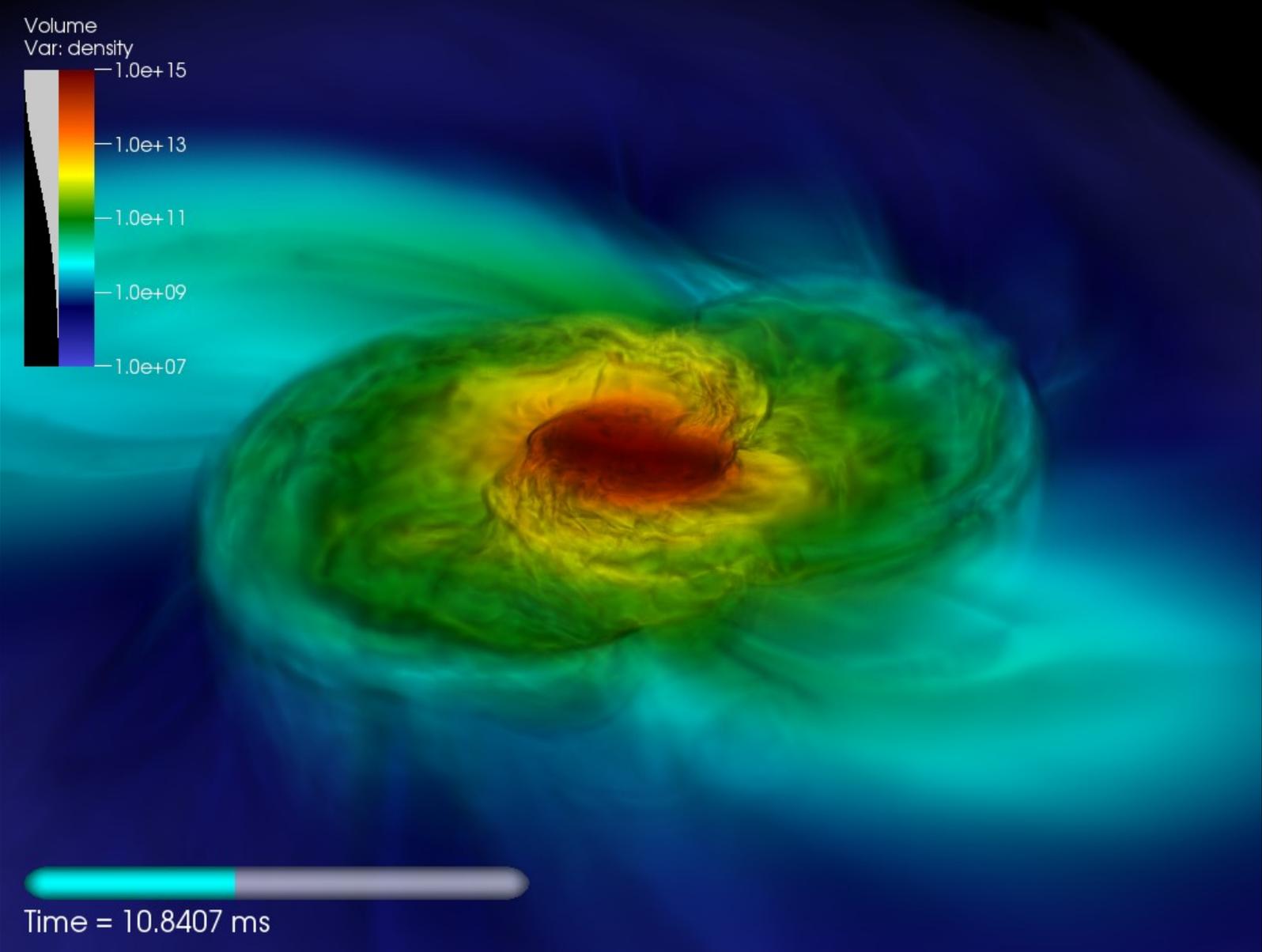


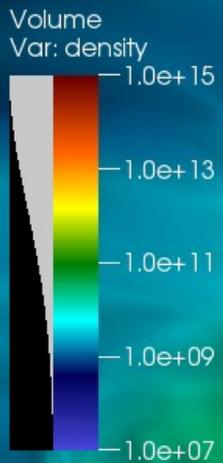


Time = 10.1136 ms



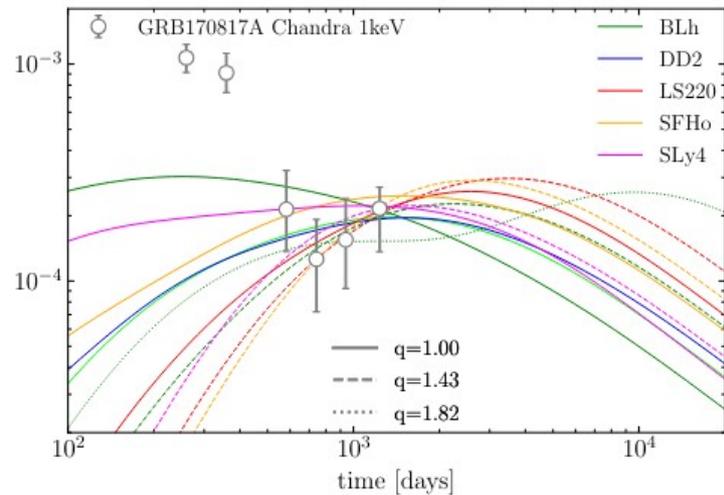
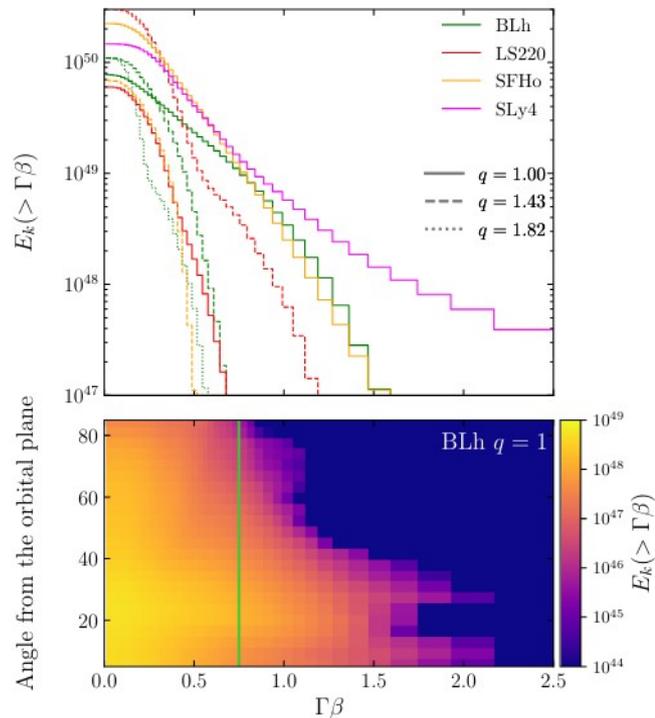
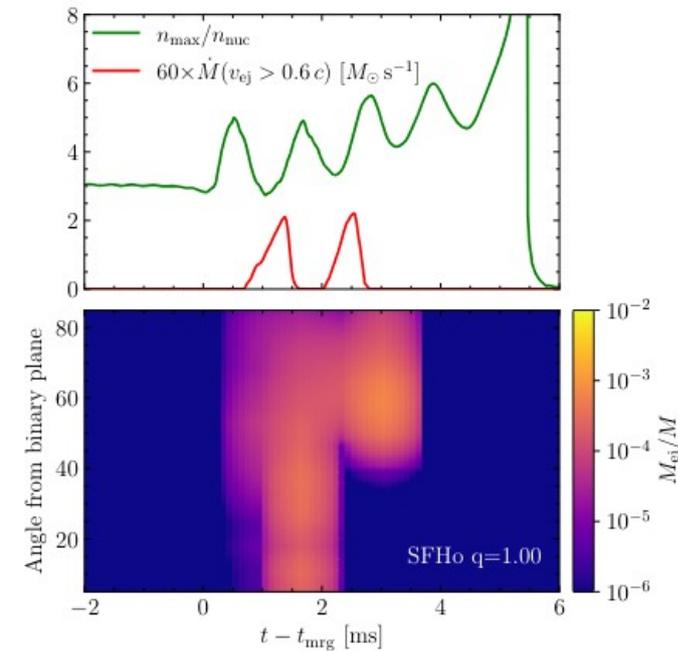
Time = 10.8407 ms





Time = 12.6081 ms

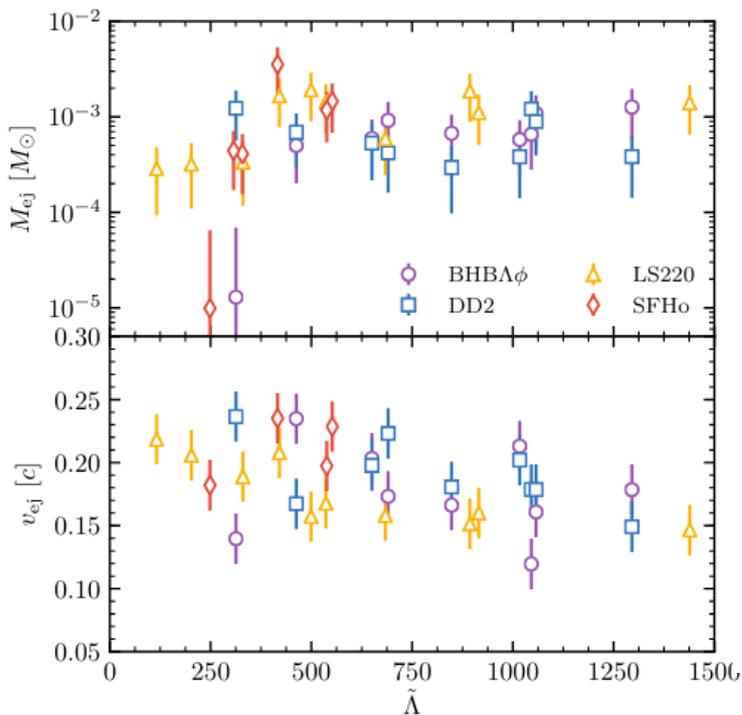
Shocked ejecta



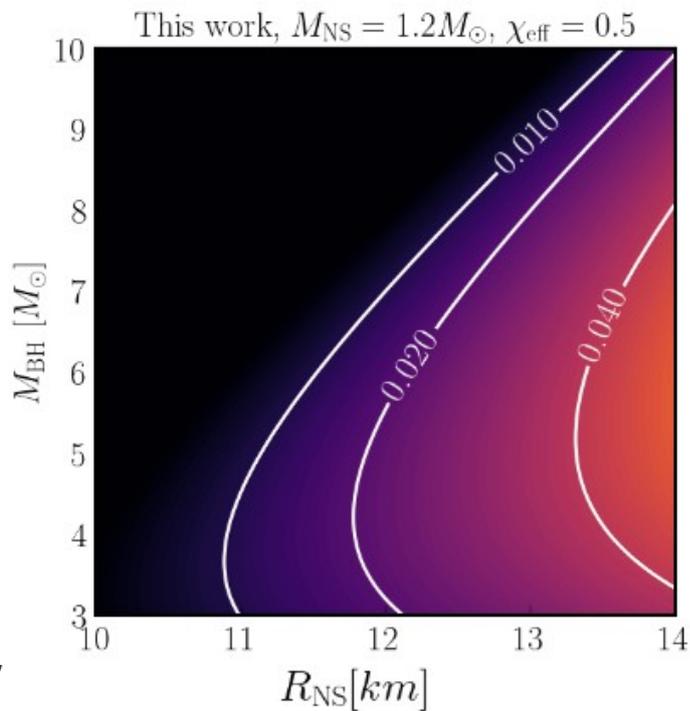
From Nedora, DR+, 2021

See also Nakar & Piran 2011; Hotokezaka+ 2015, 2018; Radice+ 2018; Desai+ 2019; Dean+ 2021; ...

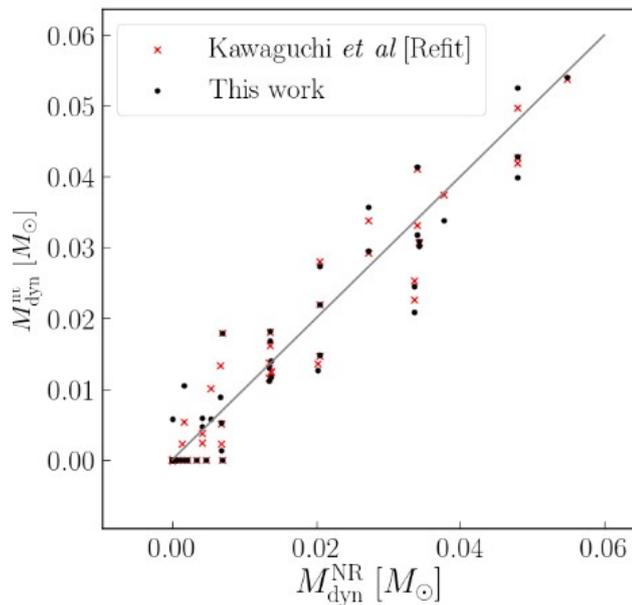
Dynamic ejecta: NS+NS & BH+NS



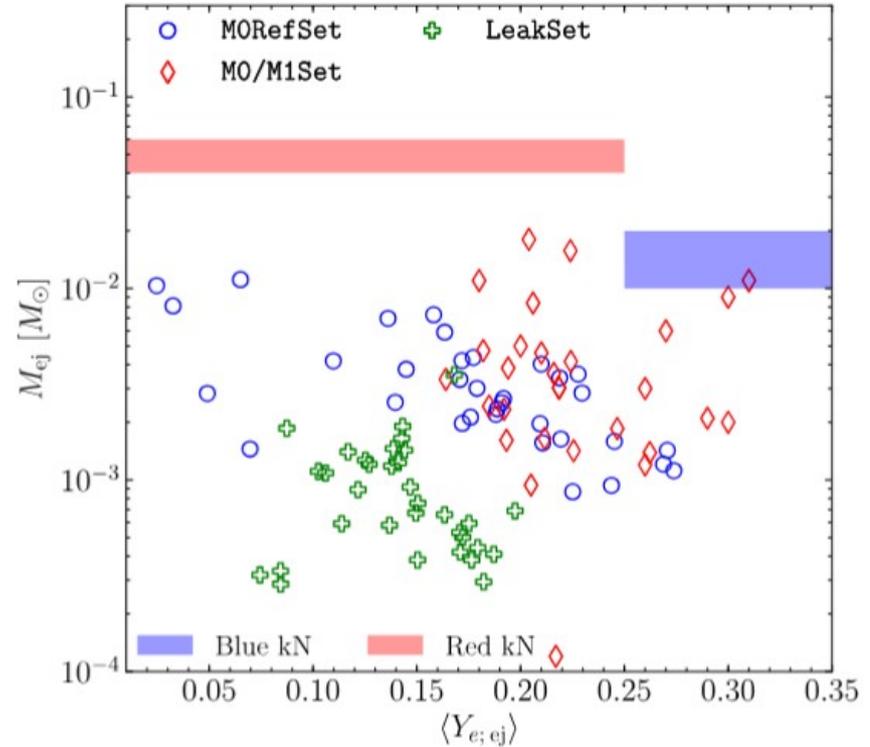
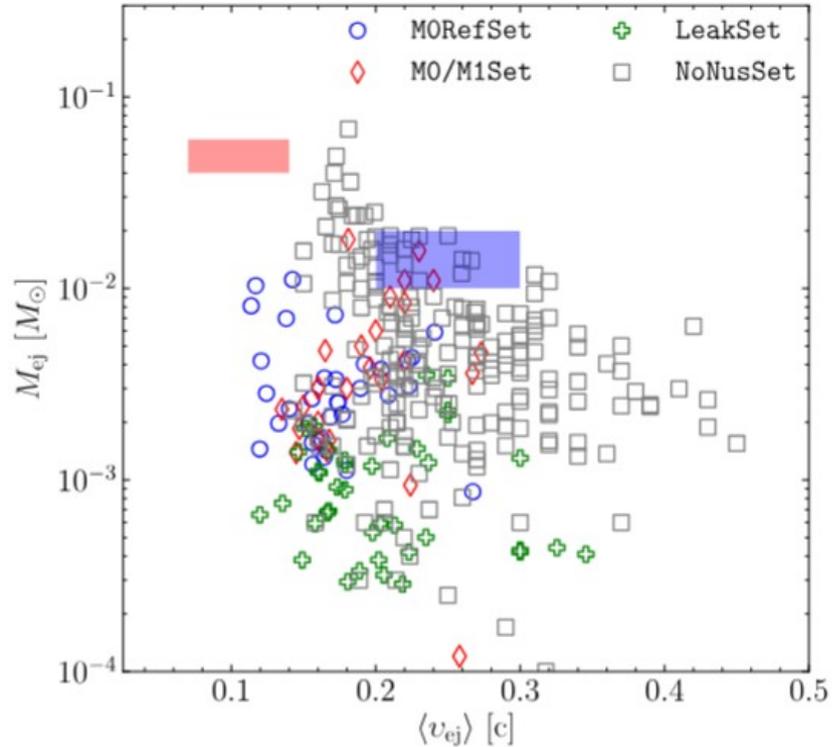
NS+NS mergers dynamical ejecta
from Radice+ 2018



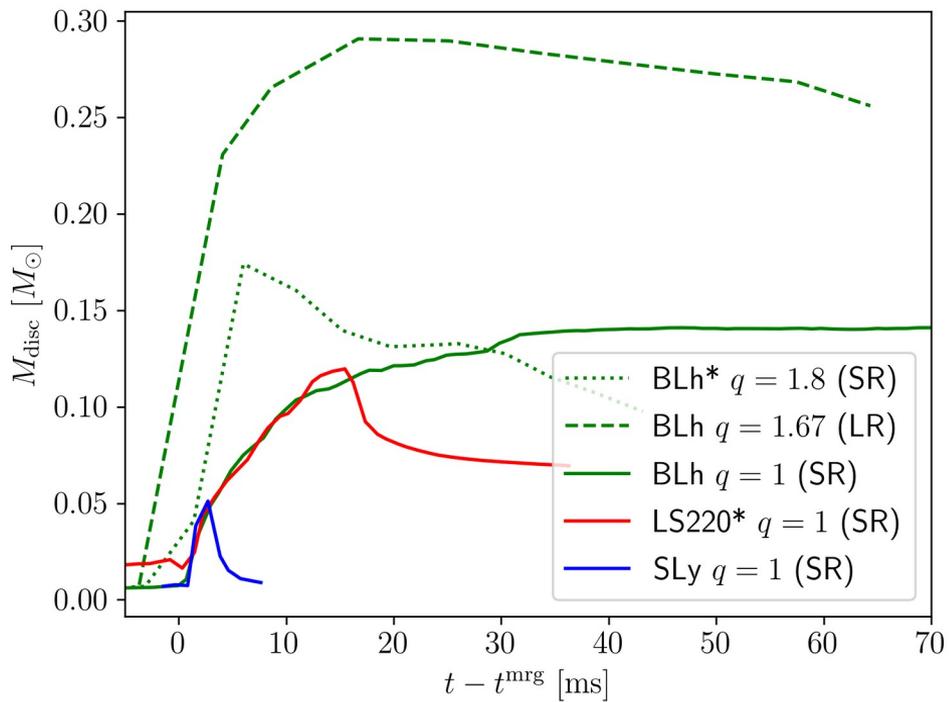
BH+NS mergers dynamical Ejecta
from Krüger & Foucart 2020



NS+NS dynamical ejecta systematics

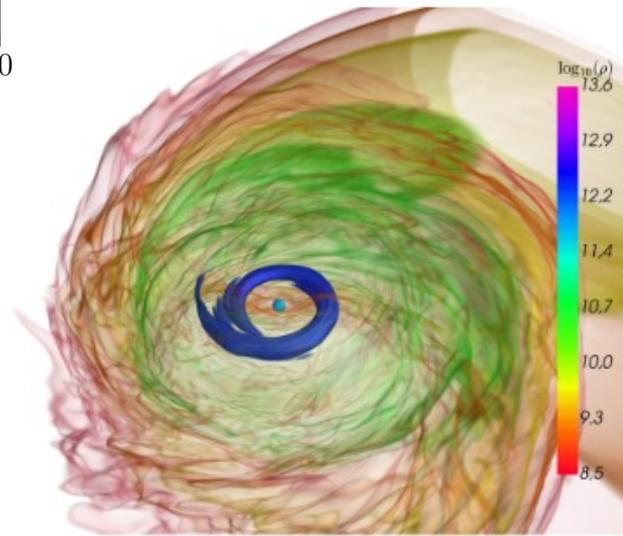
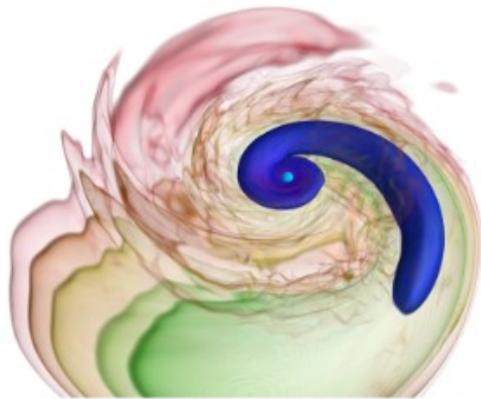


NS+NS dynamical ejecta masses from Nedora+ 2022

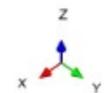


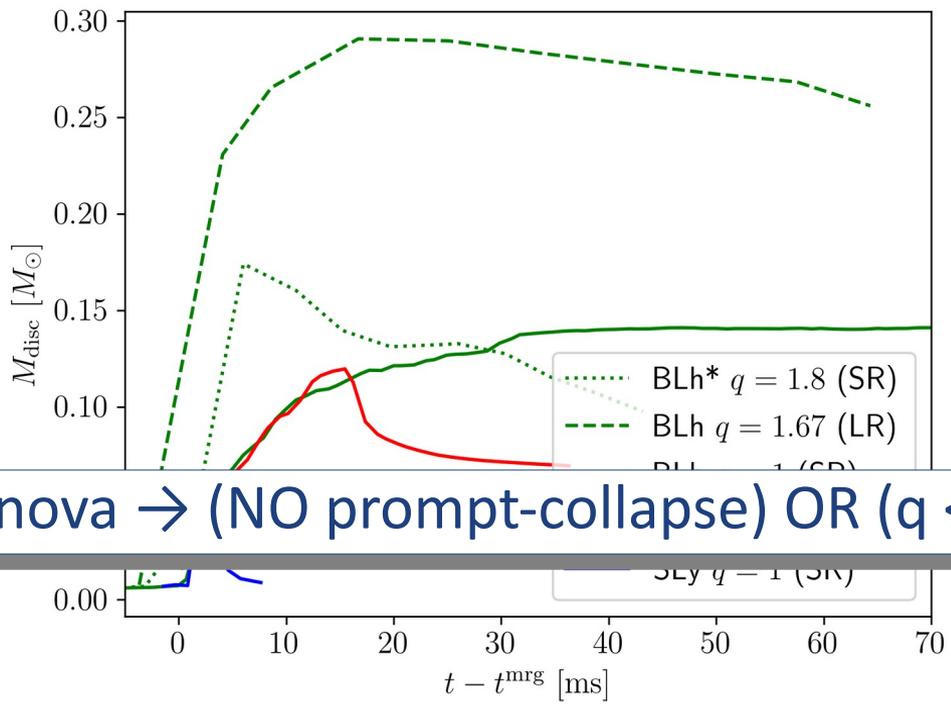
$q = 1.8$

25 km



From Bernuzzi+ 2020

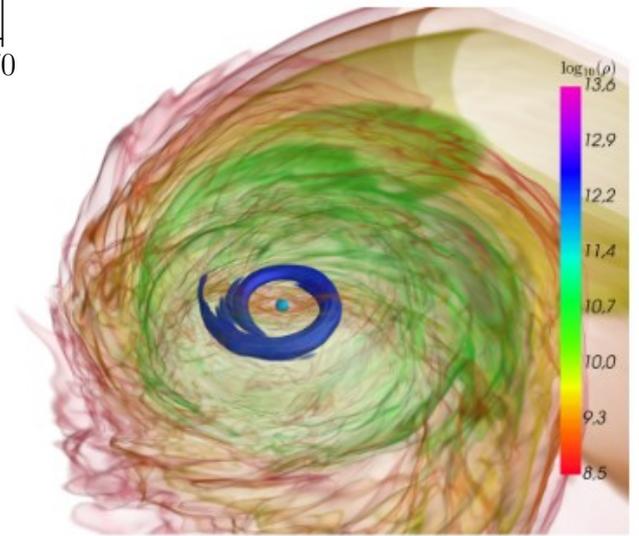
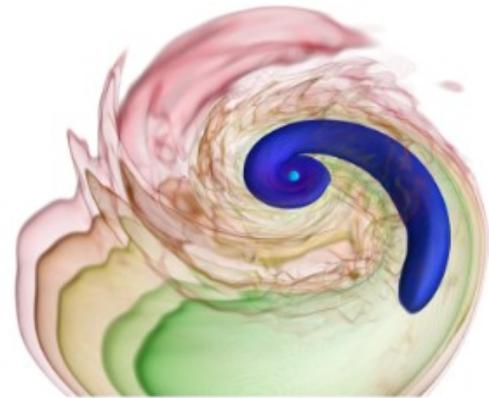




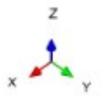
Kilonova → (NO prompt-collapse) OR ($q < 0.75$)

$q = 1.8$

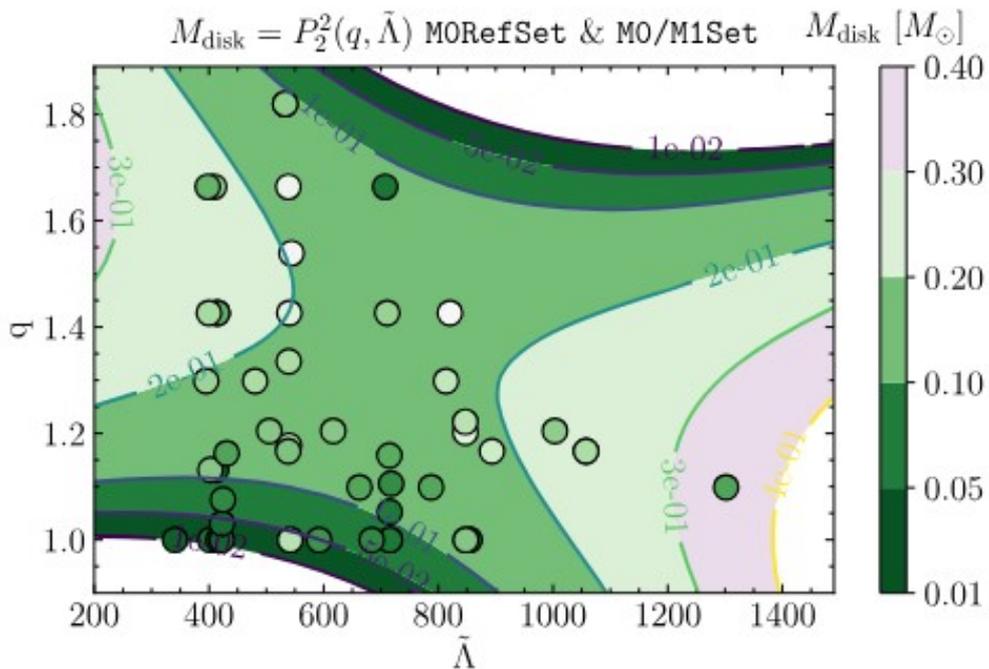
25 km



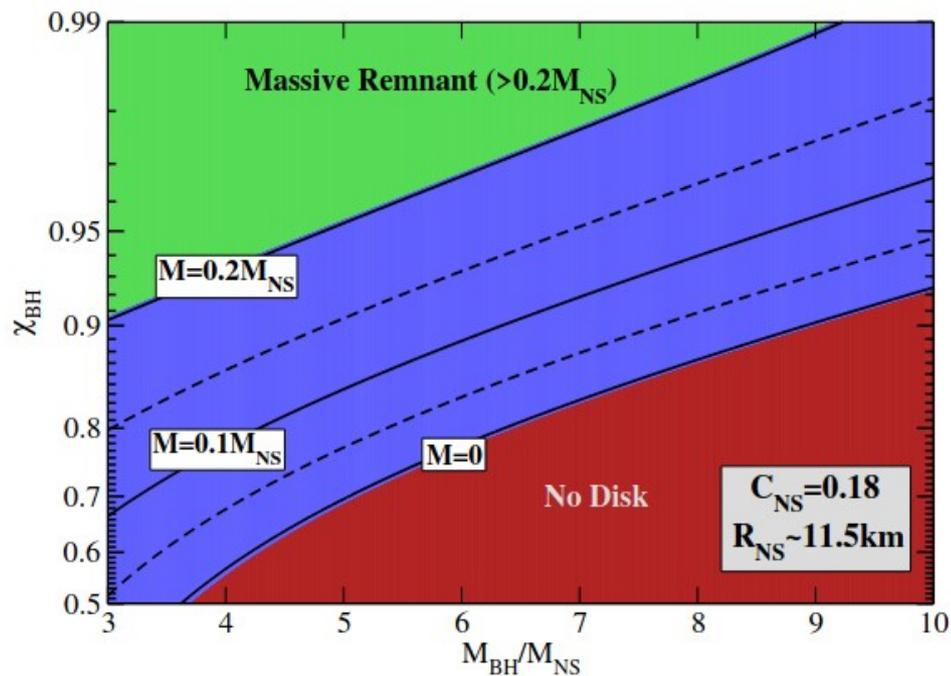
From Bernuzzi+ 2020



Remnant disks

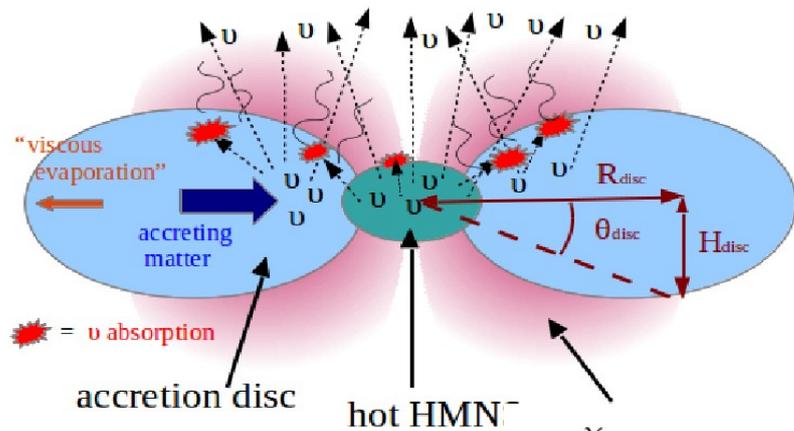


NS+NS disk masses from Nedora+ 2022

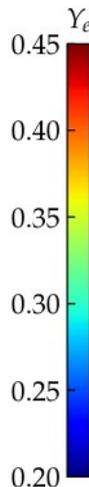


BH+NS disk masses from Foucart 2012

Neutrino driven winds: NS+NS

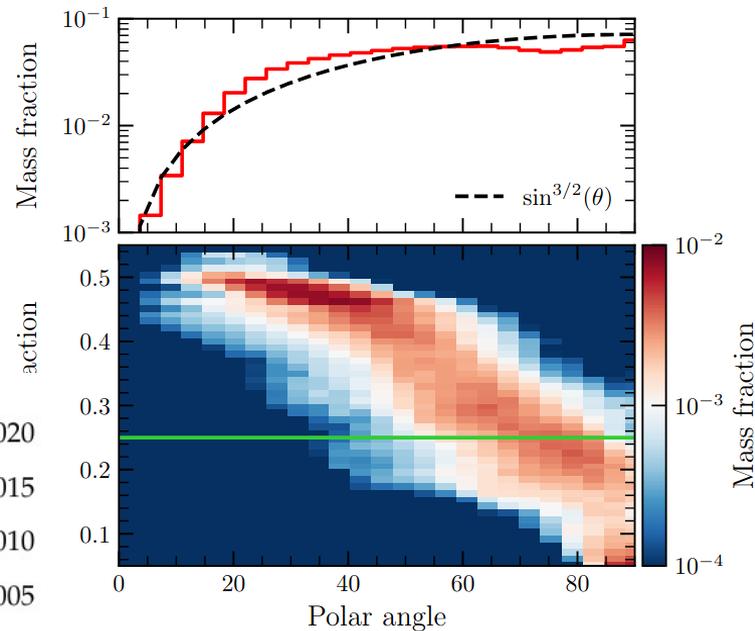
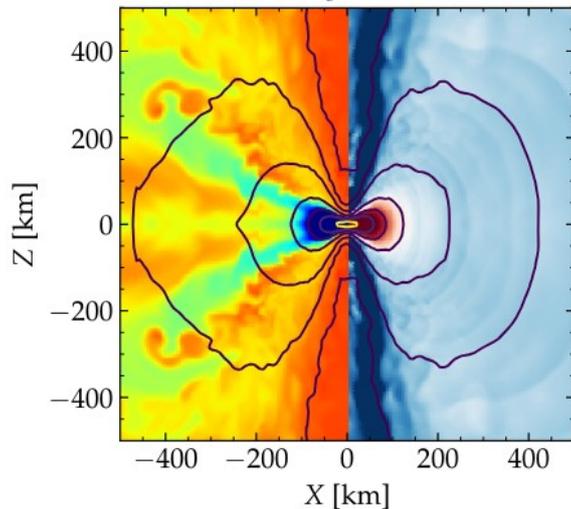


Perego+ 2014

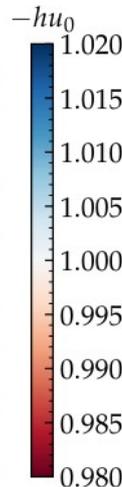


Nedora+ 2021

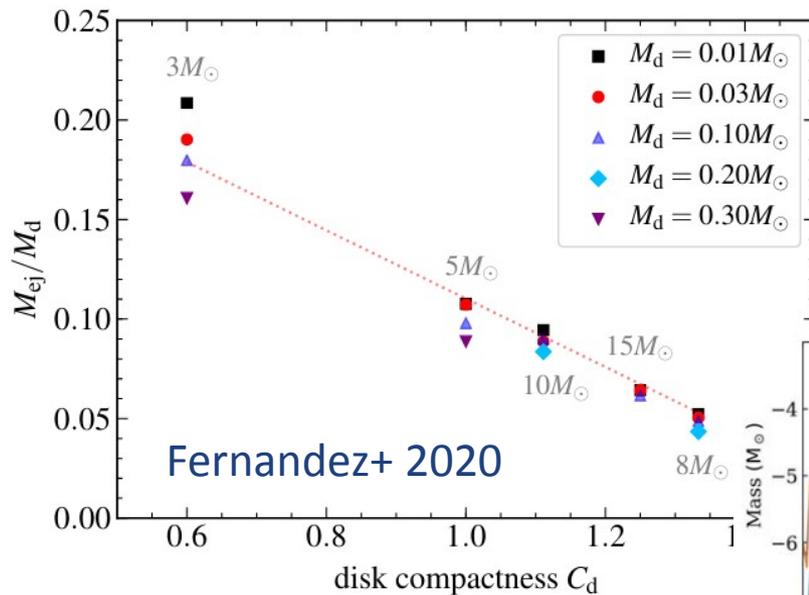
$t - t_{merg} = 88.8$ ms



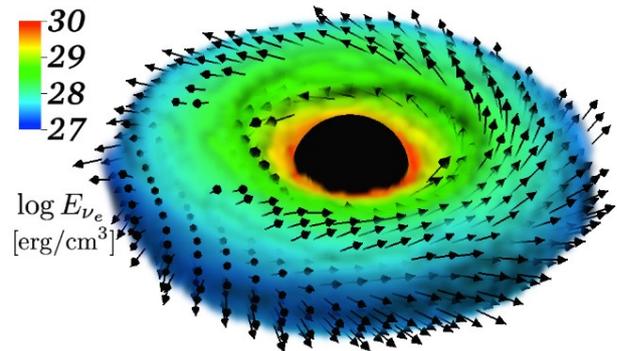
Radice+ 2023



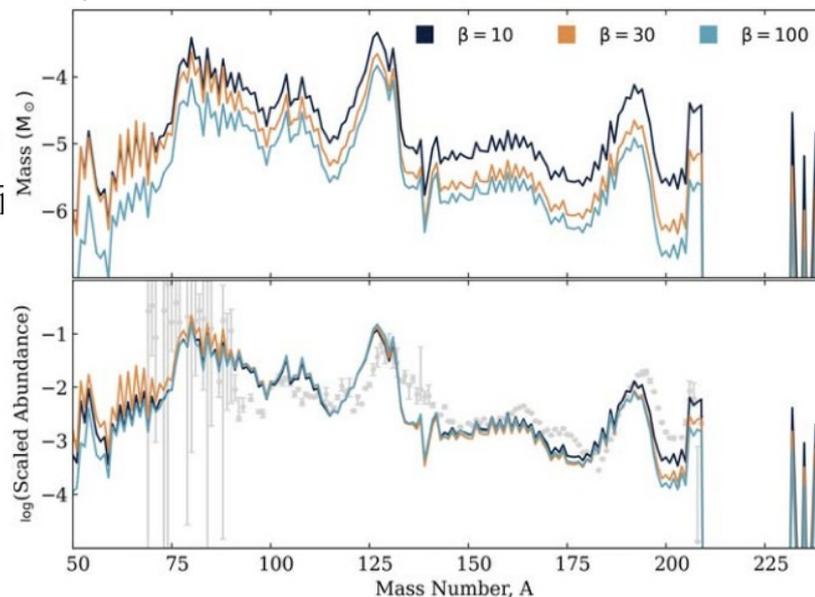
Neutrino driven winds: BH+NS



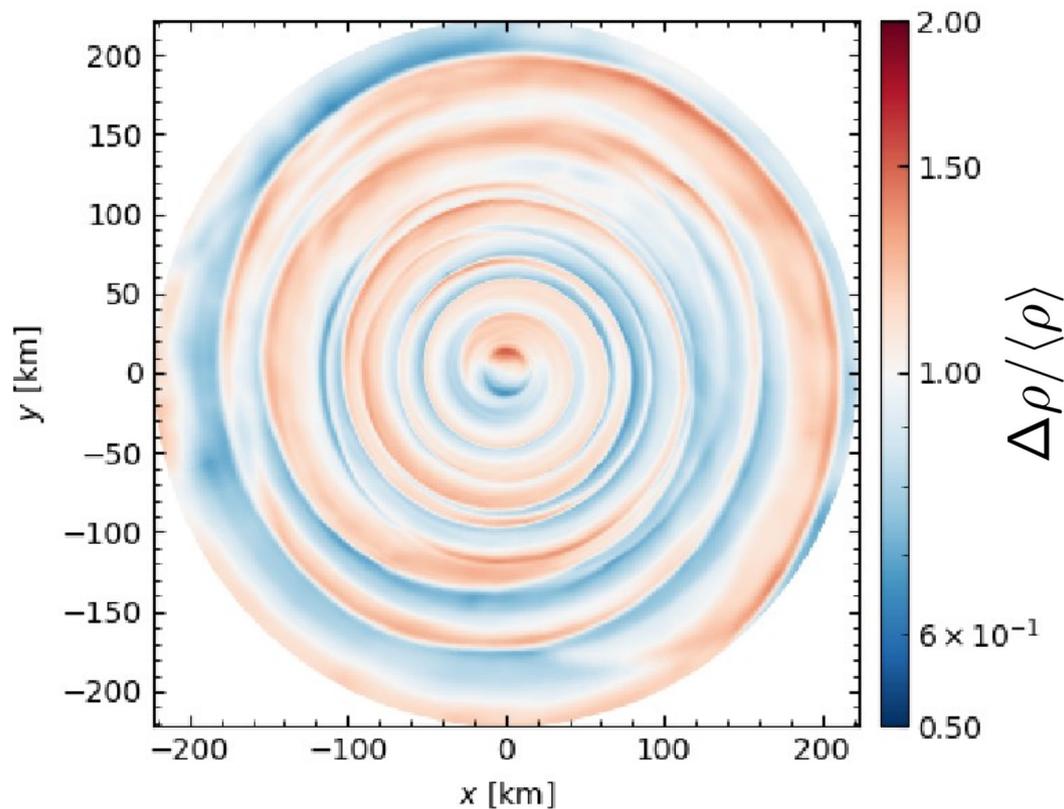
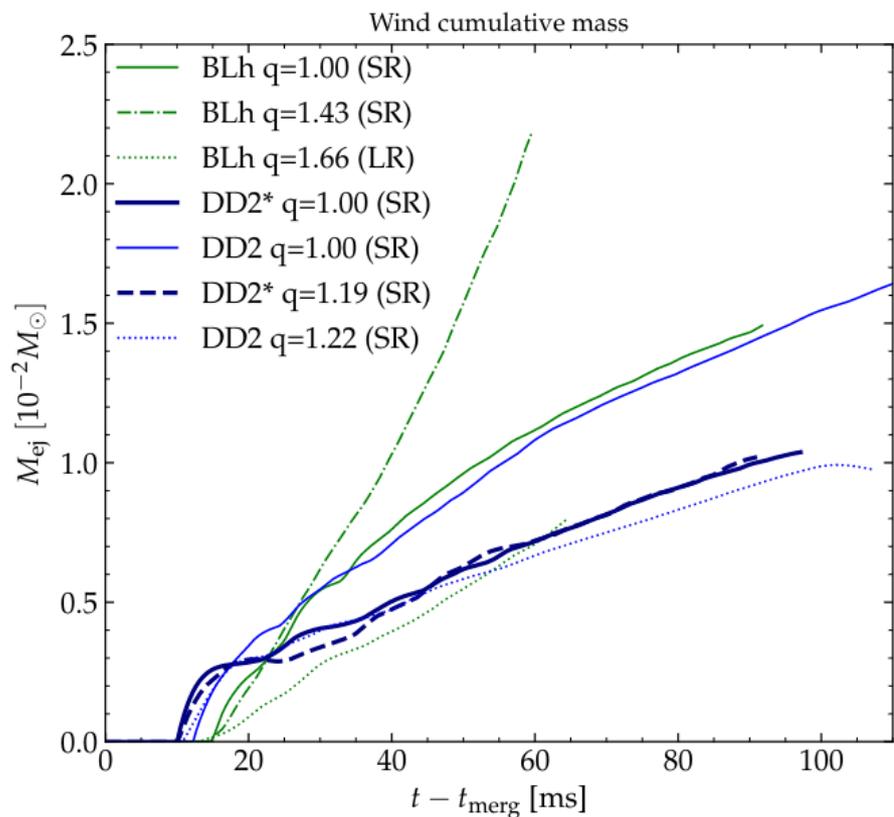
Foucart+ 2015



Lund+ 2024



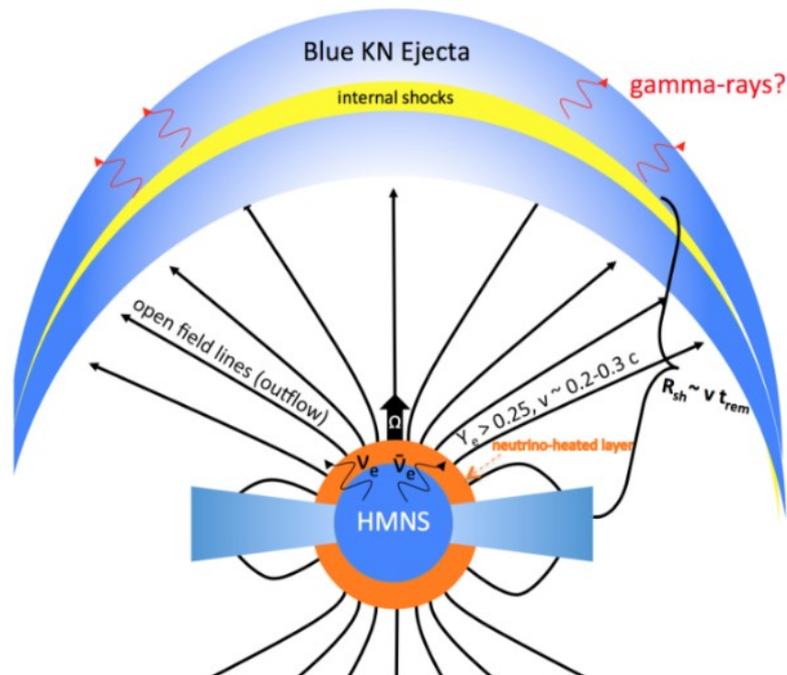
Spiral-wave wind



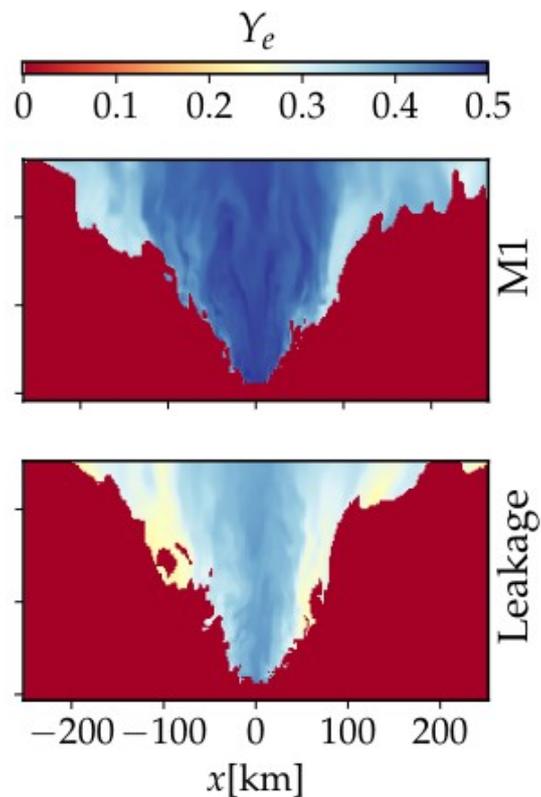
See also Siegel+ 2017; Fujibayashi+ 2018-2023;
Radice+ 2018; Mösta+ 2020; Curtis+ 2023; Combi+ 2023; ...

Nedora+ ApJ 906:98 (2021);
Radice+ ApJ 959:46 (2023)

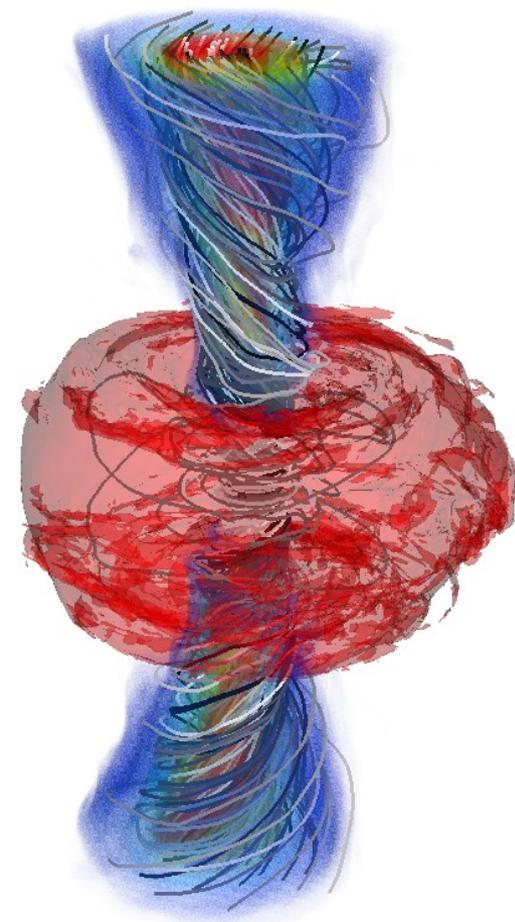
Magnetized winds (I)



Metzger+, ApJ 856:101 (2018)

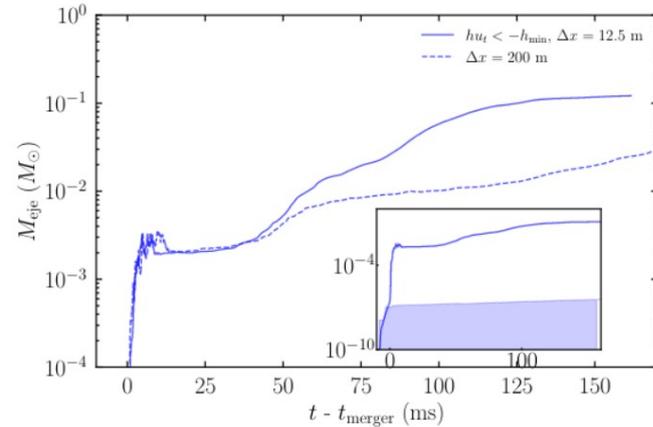
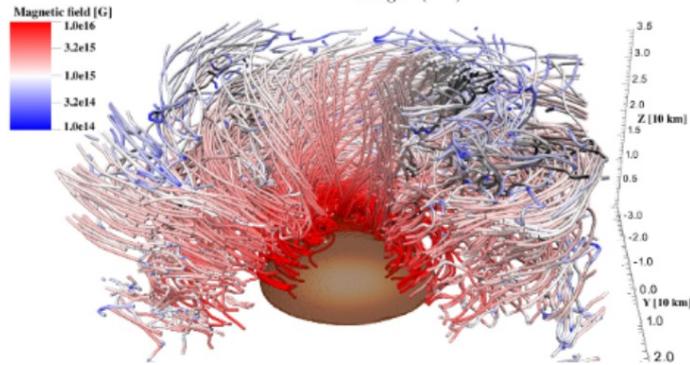
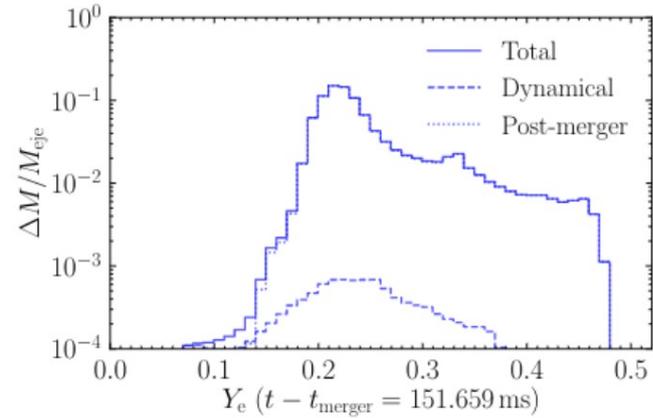
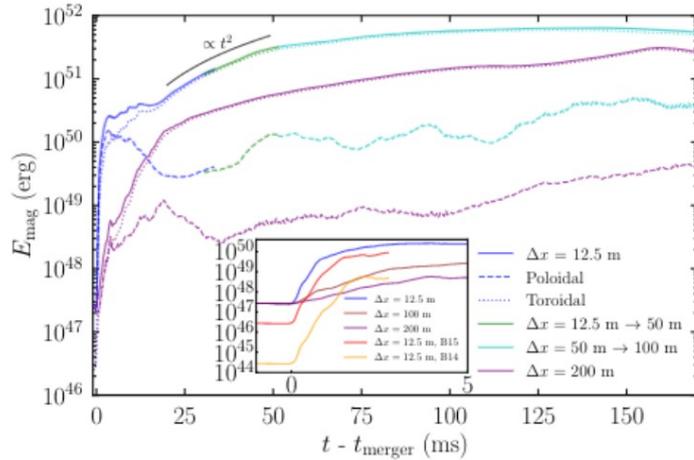


Curtis+, ApJL 961:L26 (2023)

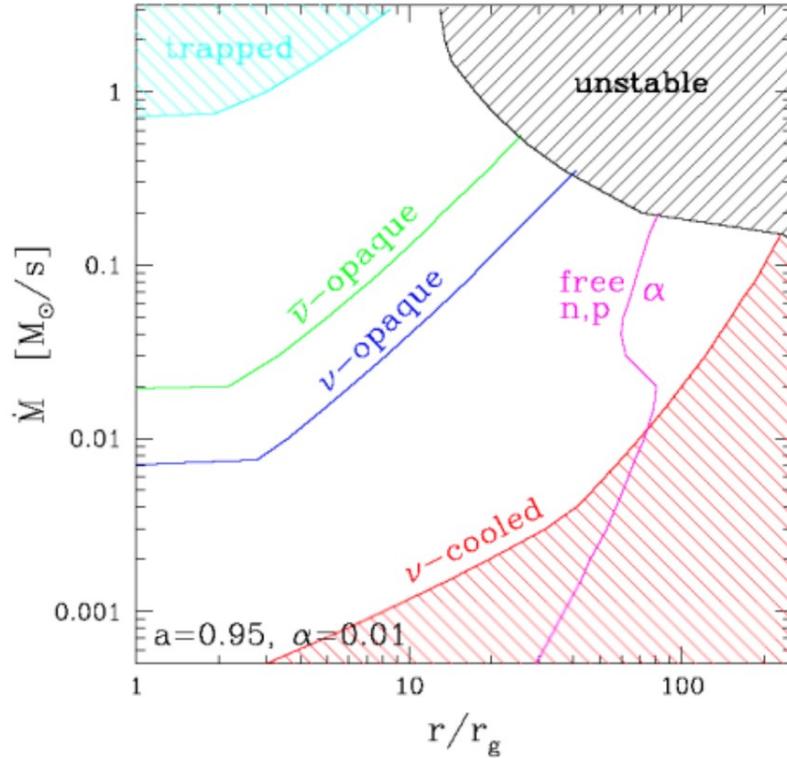


Moesta+, ApJL 901:L37 (2020)

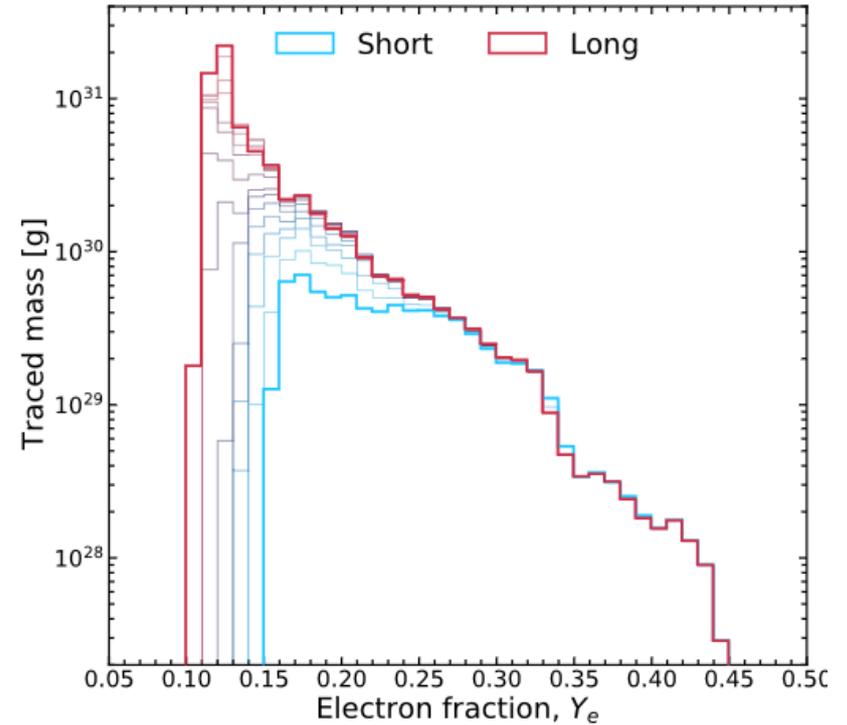
Magnetized winds (II)



Disk recombination



From Beloborodov AIP Conf.Proc. 1054 (2008)

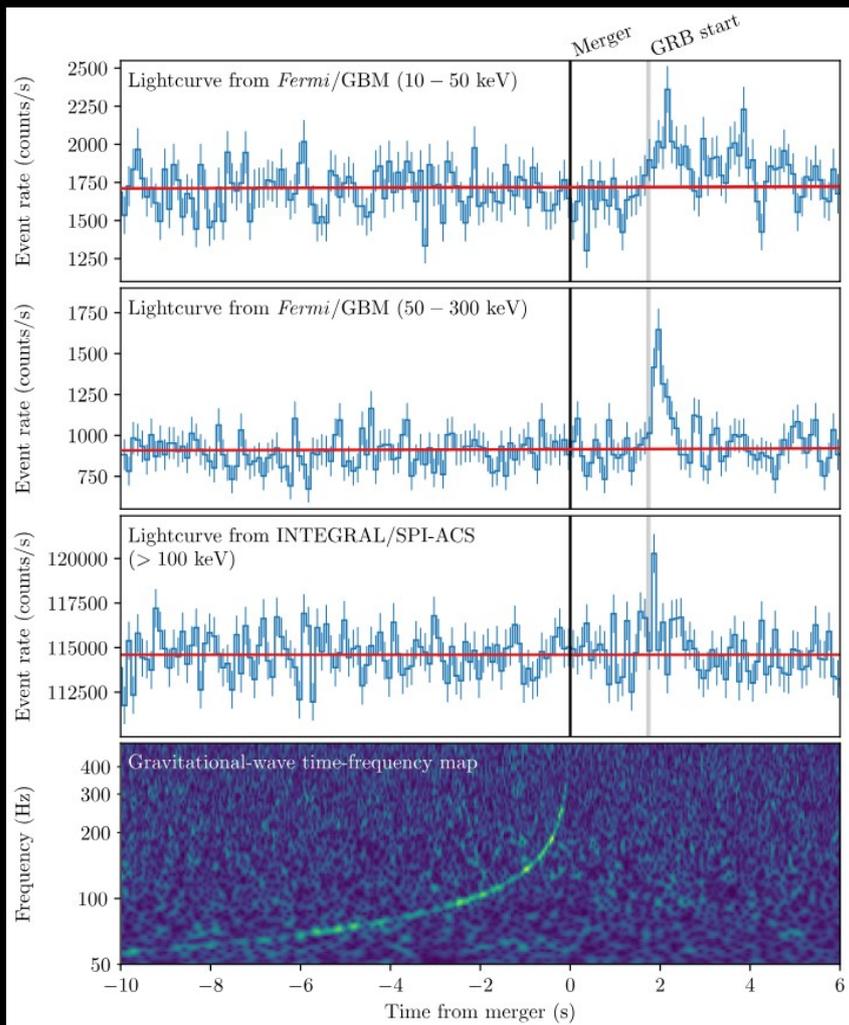


From Sprouse+ ApJ 962:79 (2024)

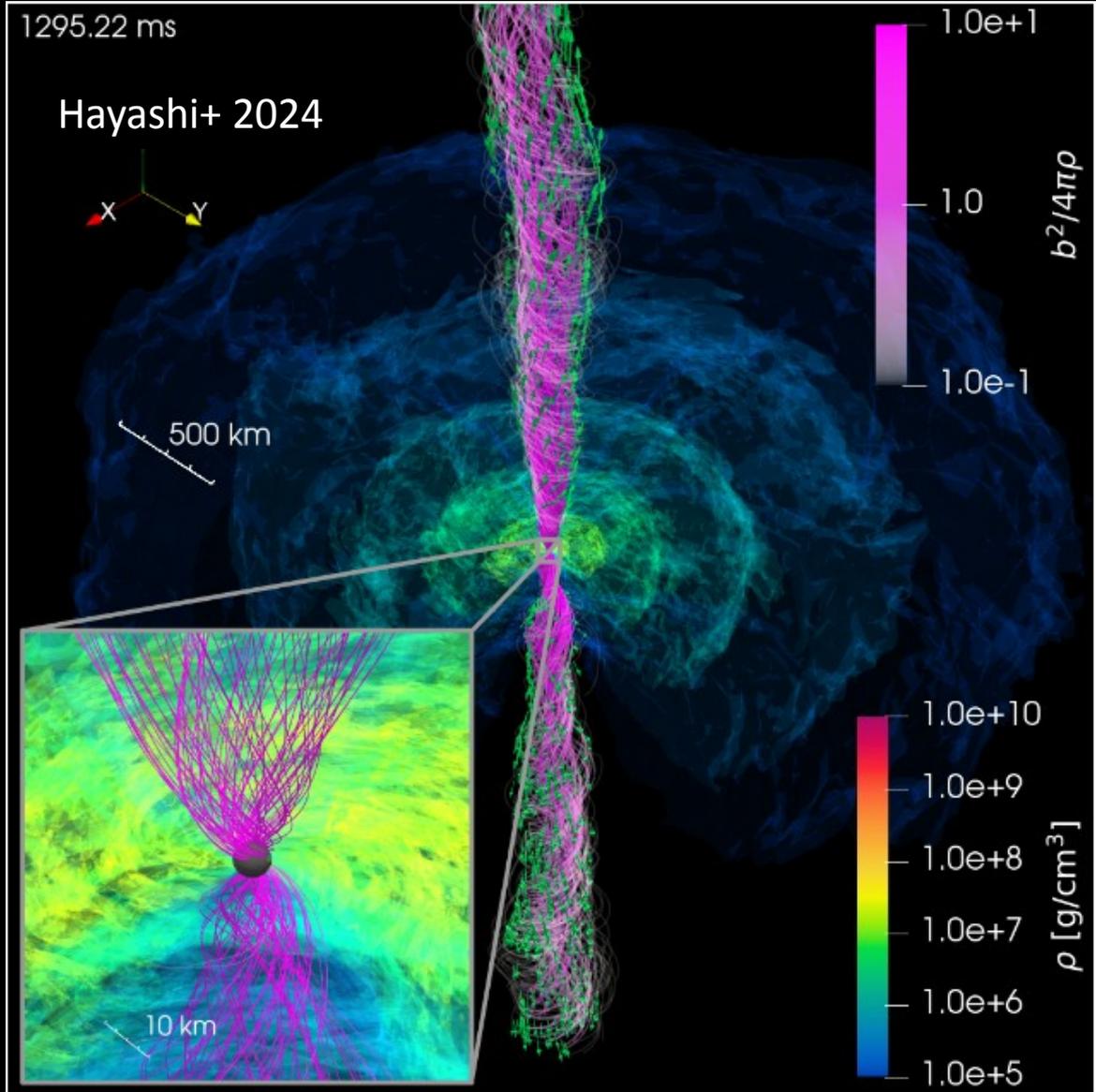
See also Beloborodov (2003); Fernandez+ (2013); Metzger+ (2014); Perego+ (2014); Siegel+ (2017); ...

Open issues

- Can we observe the fast shocked ejecta?
- How do binary properties map to ejecta/disk properties?
- What is the overall nucleosynthesis output of mergers?
- What is the role of neutrino flavor transformation? Missing physics?
- How can we test theory? Color light curves, spectra, r-process abundances in metal poor stars, etc.



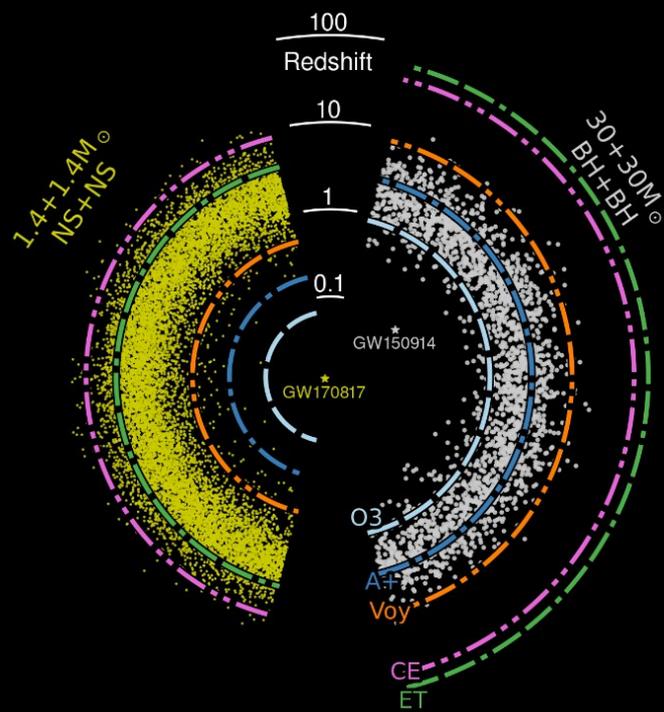
LIGO, Fermi, Integral, 2017



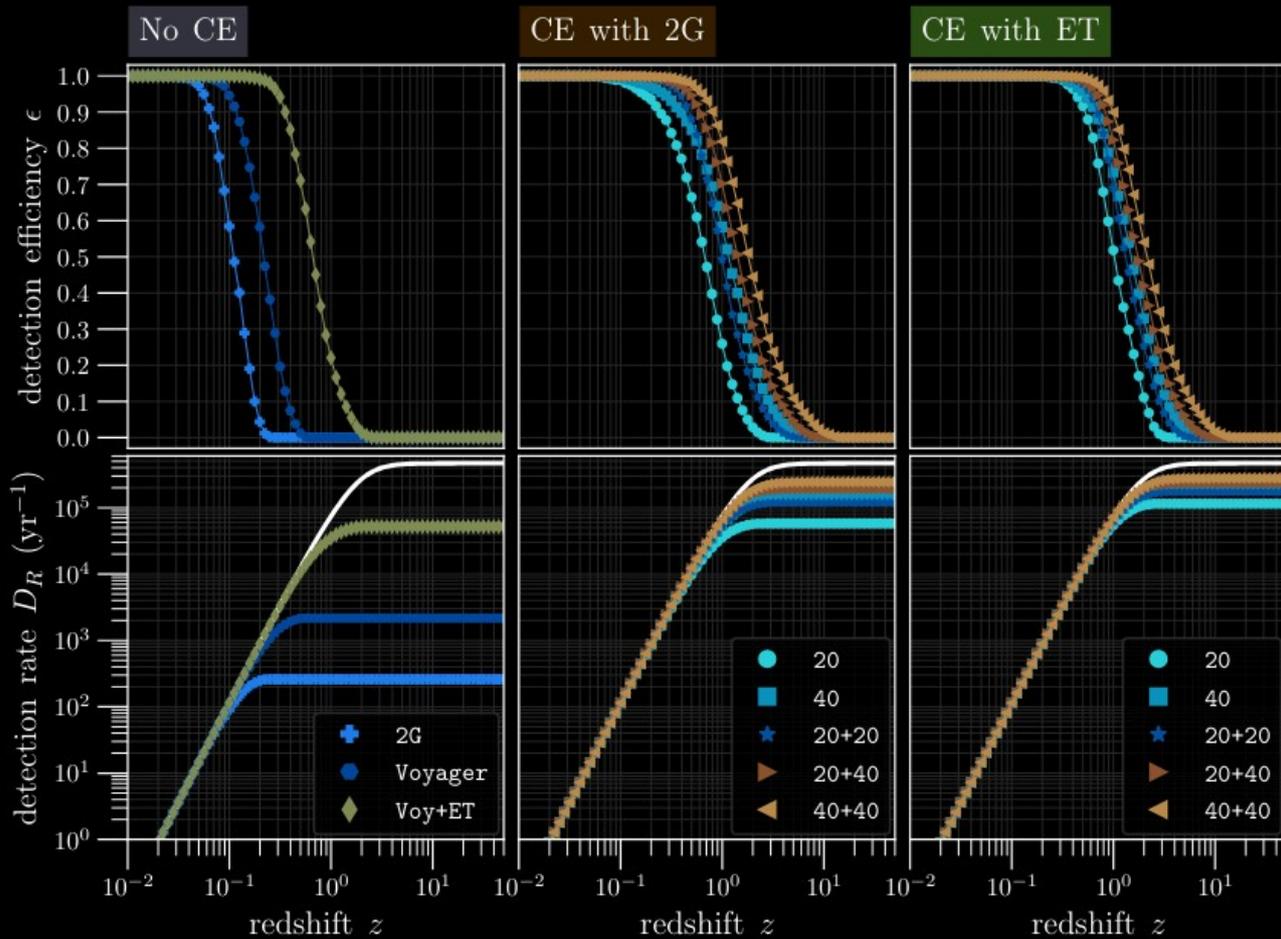
Open questions

- What is the central engine of GRBs?
- Can mergers power both short- and long-GRBs?
- What is the origin of precursors, tails seen in GRBs?
- Joint constraints with GW+GRB data?

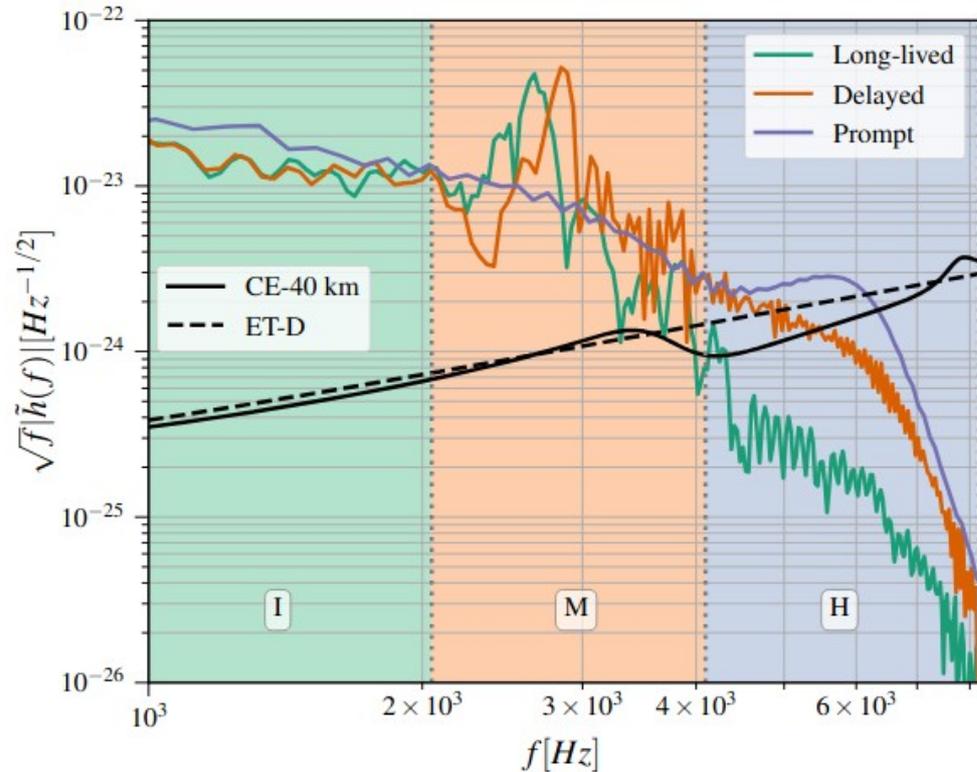
XG GW detectors



From CE Horizon study (2021)



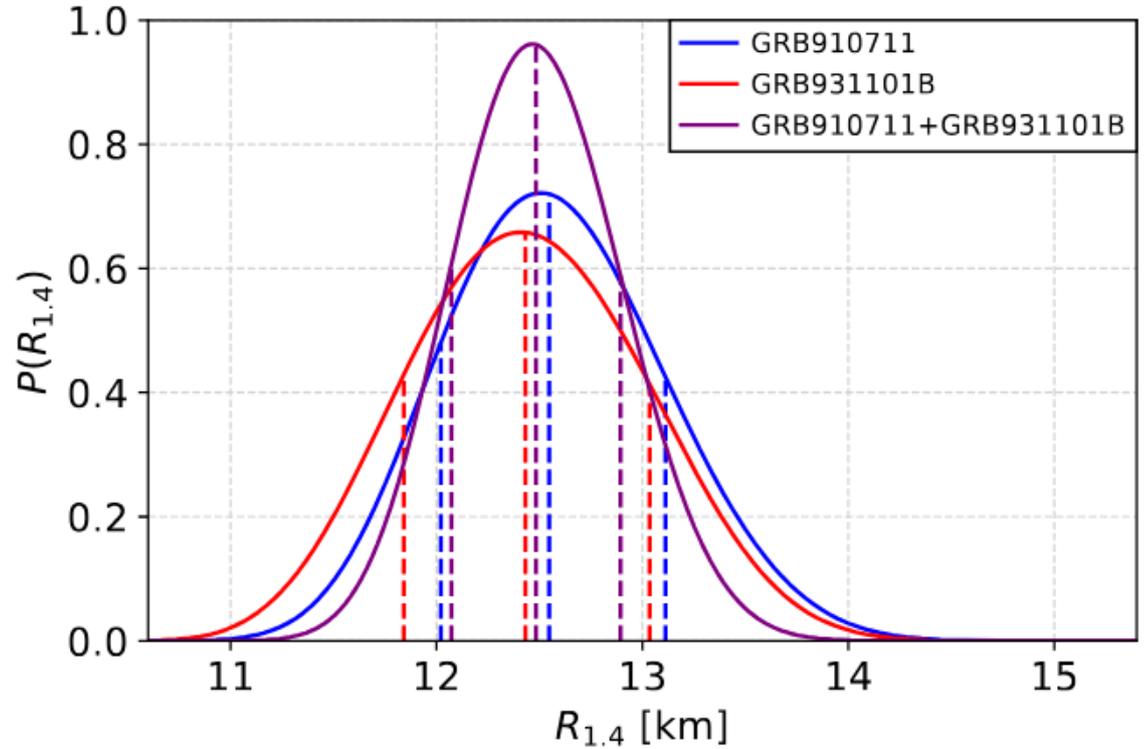
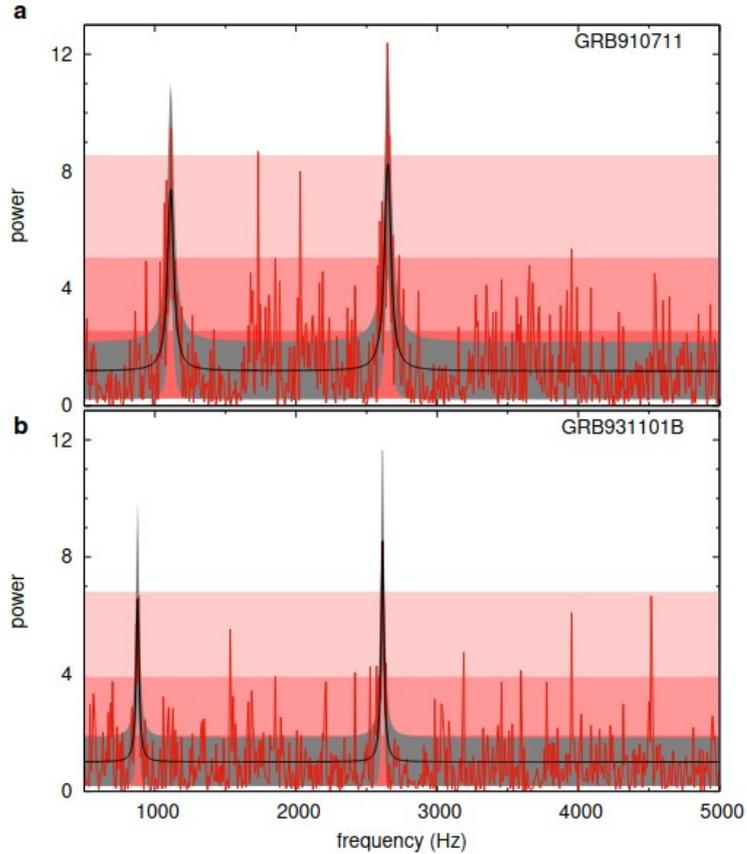
Postmerger GW signal



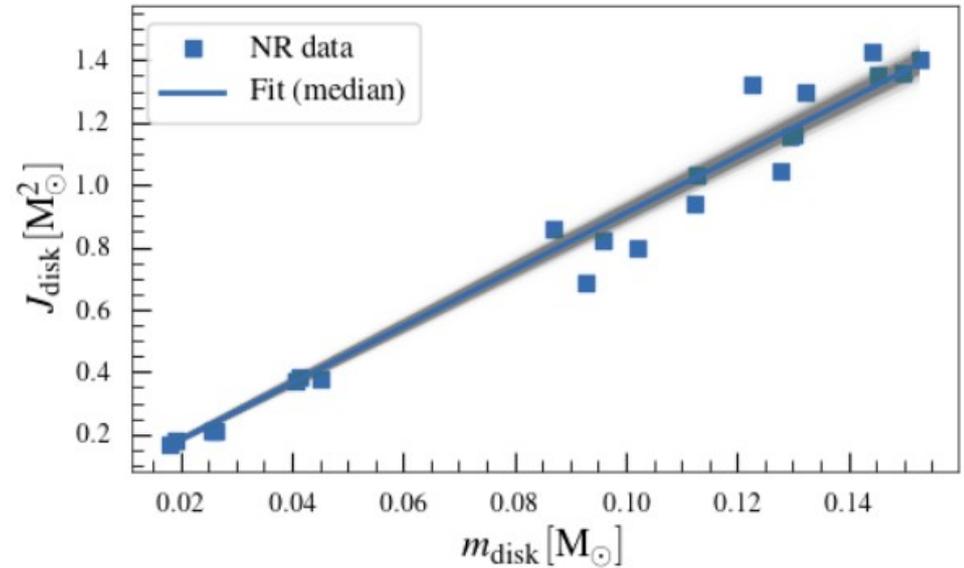
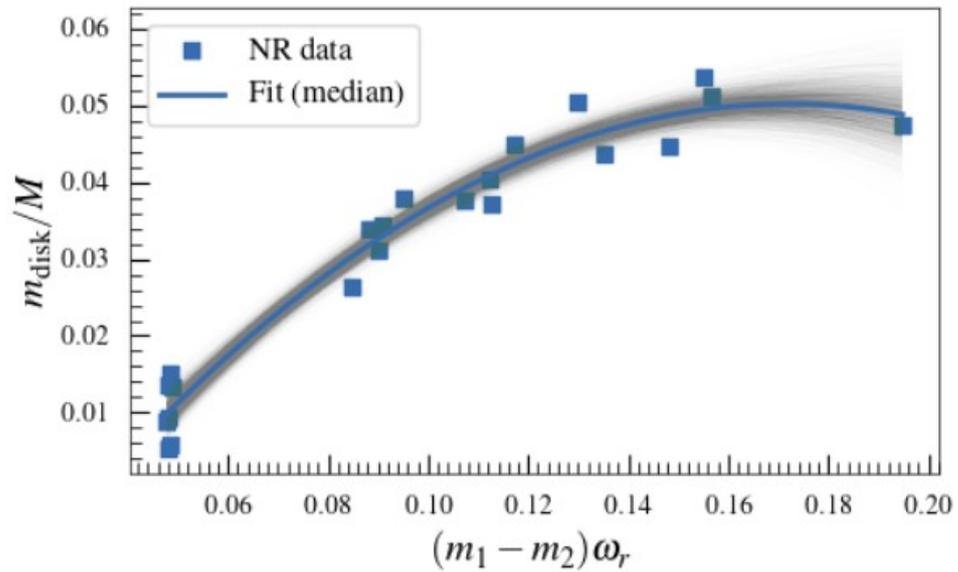
- Merger is at 1-2 kHz
- Massive NS remnant signal 2-4 kHz (rotation rate, not f-mode!)
- Higher frequency signal: BH formation (ring down)
- Large literature on these, but large systematic errors in simulations

See also Bauswein+ 2012, 2015, 2019; Takami+ 2014; Bernuzzi 2015, Rezzolla+ 2016; Dietrich+ 2016; Radice+ 2017; Breschi+ 2019; ...

QPOs from short GRBs?

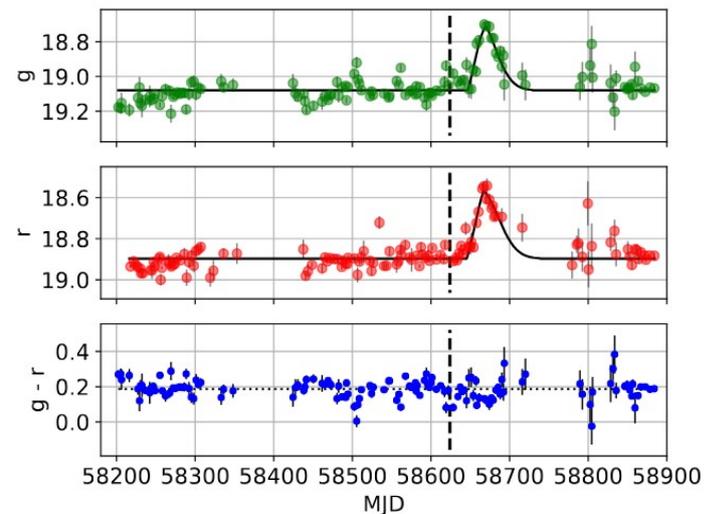


Measuring the disk mass with GWs

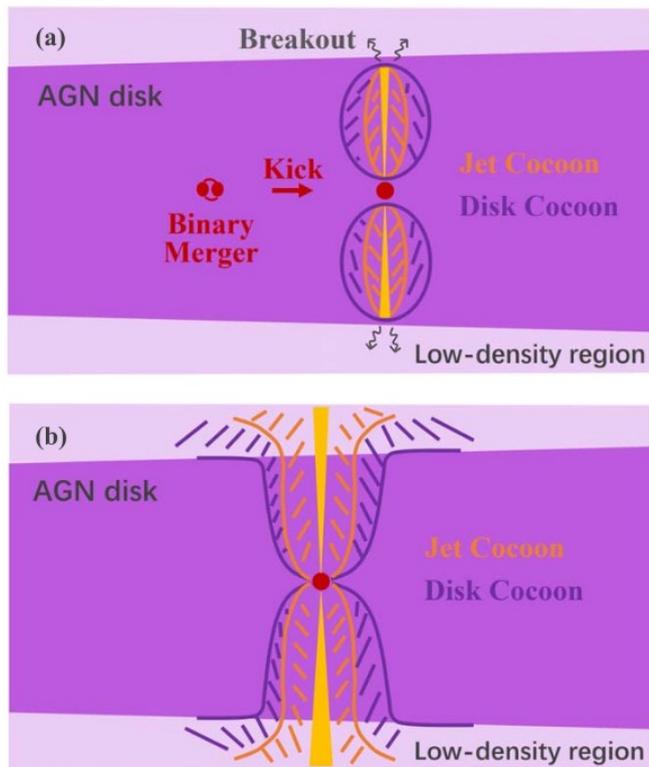


We could measure the disk mass with a precision of $\sim 10\%$ at SNR of 5!

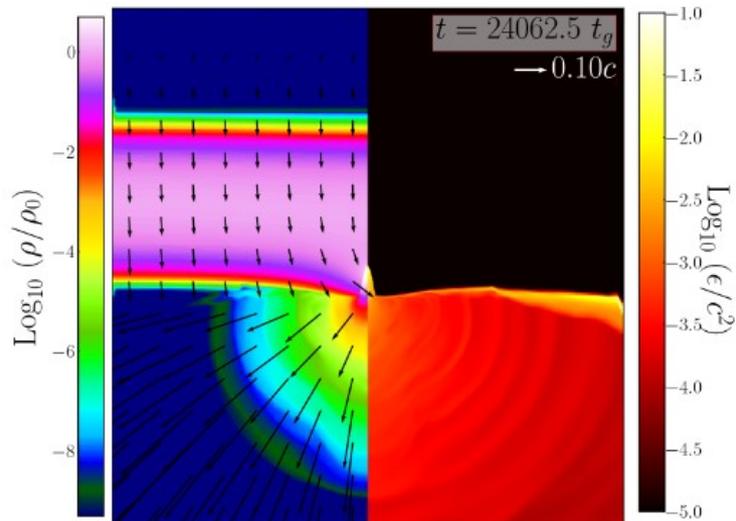
EM emission from binary BH mergers?



Graham+ 2020



Chen & Dai 2023



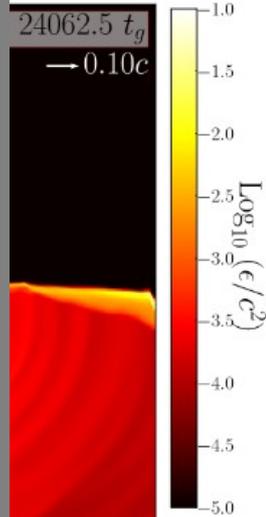
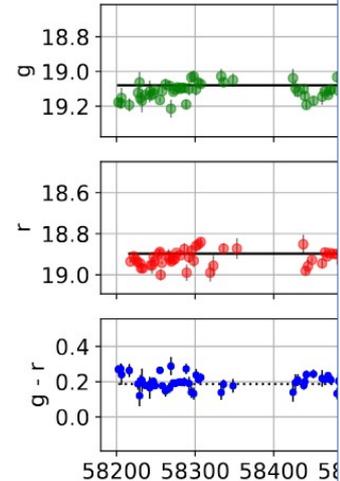
Lam+ 2025

EM emission from binary BH mergers?

(a) Product

- Black hole mergers in AGN disks
- Binary AGN mergers [LISA band]
- Super radiant instability?
- Charged Bhs?!?

Need better theory predictions!



Graham+ 2020

Chen & Dai 2023

Lam+ 2025

Conclusions

- We learned a lot about compact objects from multi-messenger observations, theory, and simulations
- There are many open questions left to be addressed
- Both **theory** and **observations** are needed!

