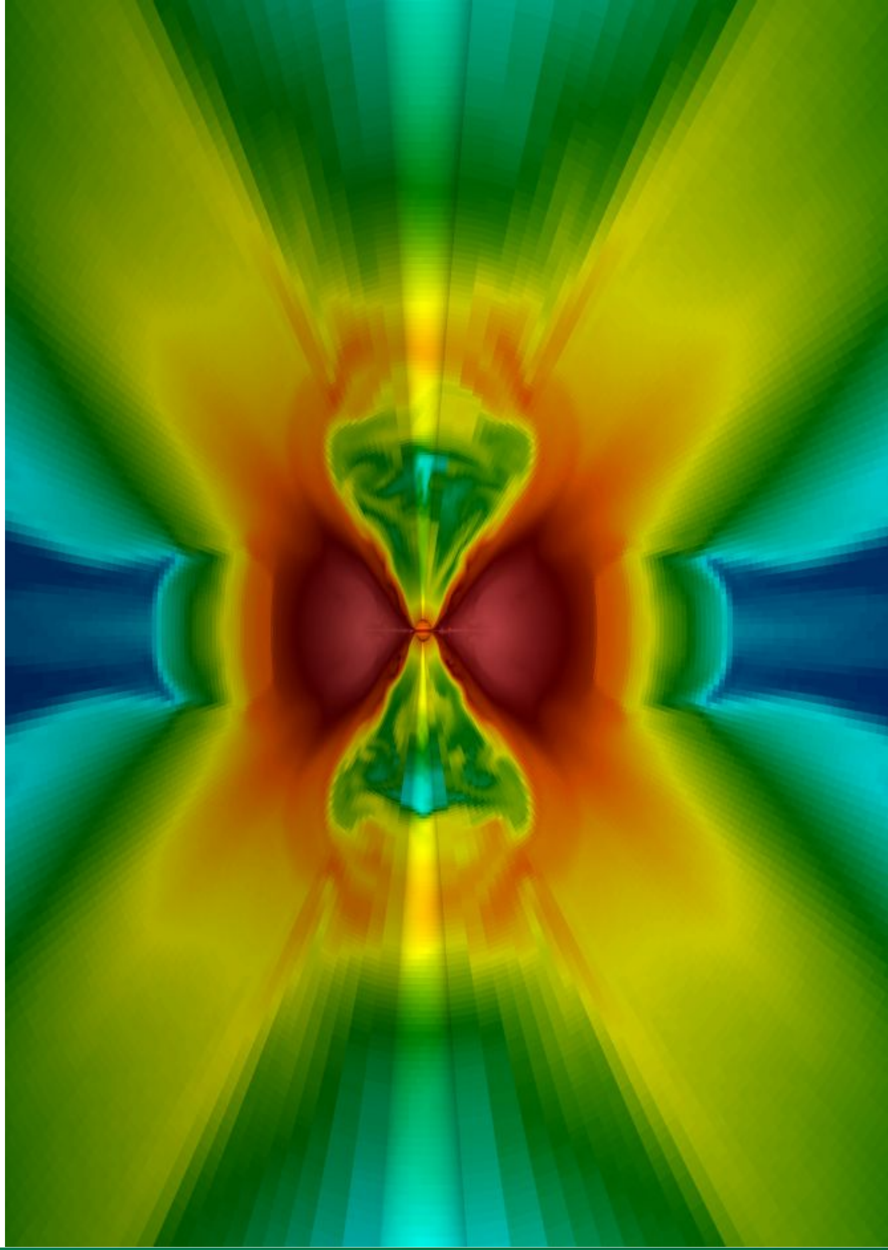
Long Term 3D-MHD Simulations of Neutron Star Merger Accretion Tori with Realistic Microphysics



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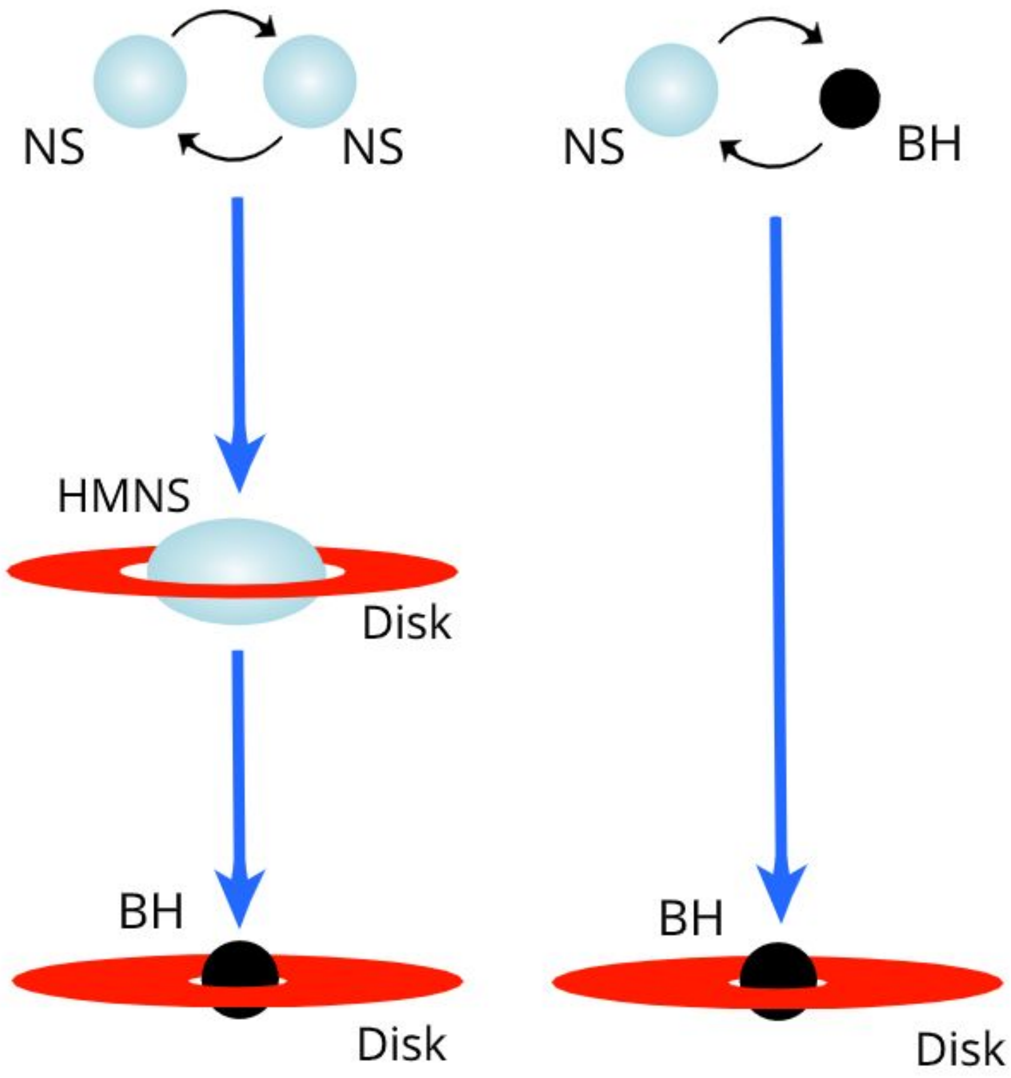
Why are BH-tori systems important?

1. Site for the synthesis of r-process elements
2. Kilonovae counterparts to GW detections



BH-Tori with viscous hydrodynamics

To name a few…

Just et al 2015

Fernández et al 2020

Fujibayshi et al 2020

Nedora et al 2020

Broad agreement in simulations	GW170817 Blue KN requires
$\langle M_{\rm ej}\rangle \sim (10^{-4} - 10^{-2})\mathrm{M}_\odot$	$\langle M_{\rm ej}\rangle \sim 10^{-2}\mathrm{M}_\odot$ ✔
$\langle v_{\rm ej}\rangle \sim (0.01 - 0.1)\mathrm{c}$	$\langle v_{\rm ej}\rangle \sim 0.25\mathrm{c}$ ❌
$\langle Y_e\rangle \sim (0.01 - 0.3)$	$\langle Y_e\rangle \gtrsim 0.25$ ✔

Solution: Magnetohydrodynamics?

MHD stresses can accelerate ejecta to much higher velocites

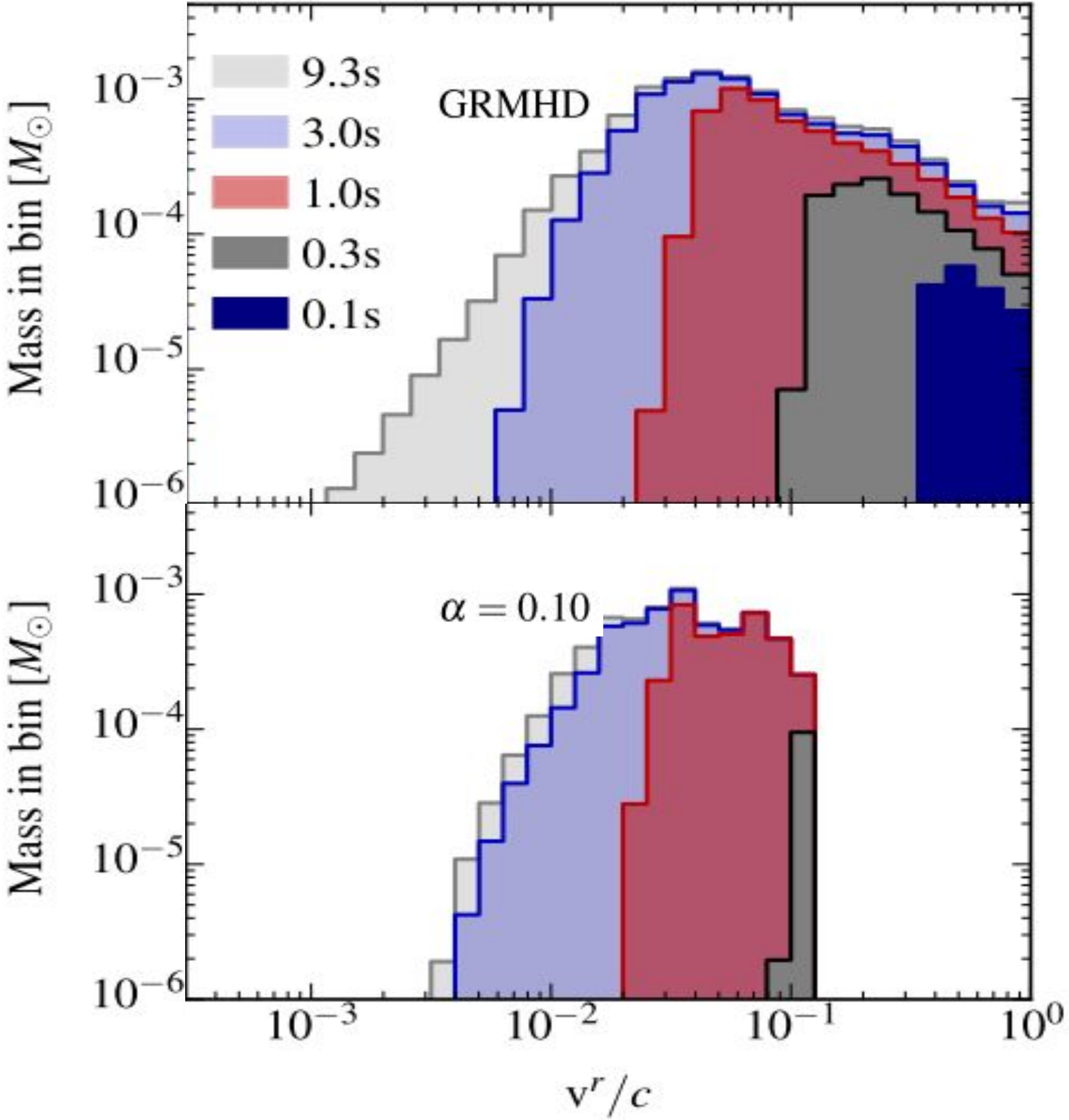


Figure adapted from Fernández et al 2019

BH-Tori with (GR)MHD

Handful of simulations with a small parameter space

Work	BH Mass ($M_\odot$)	Torus Mass ($M_\odot$)	Gravity	Neutrino Scheme	B-Geom
Hossein Nouri et al 2018	7.95	0.14	GR	Leakage	Poloidal
Siegel & Metzger 2018	3.00	0.03	GR	Leakage	Poloidal
Fernandez et al 2019	3.00	0.03	GR	Leakage	Poloidal
Christie et al 2019	3.00	0.03	GR	Leakage	Toroidal
Miller et al 2019	2.68	0.12	GR	Monte Carlo	Poloidal
Just et al 2021	3.00	0.01	Artemova-SR	Leakge/Absorption	Poloidal

BH-Tori with (GR)MHD

No broad agreement, even between similar simulations

Work	Timescale (s)	$\langle M_{\rm ej} \rangle$ ($M_\odot$)	$\langle v_{\rm ej} \rangle$ (c)
Hossein Nouri et al 2018	0.05	10^{-5}	-
Siegel & Metzger 2018	0.38	3×10^{-3}	0.03-0.10
Fernandez et al 2019	9.3	1.3×10^{-2}	0.01
Christie et al 2019	4.0	8.9×10^{-3}	0.05
Miller et al 2019	0.13	4.3×10^{-3}	0.10
Just et al 2021	2.10	1.5×10^{-3}	0.13

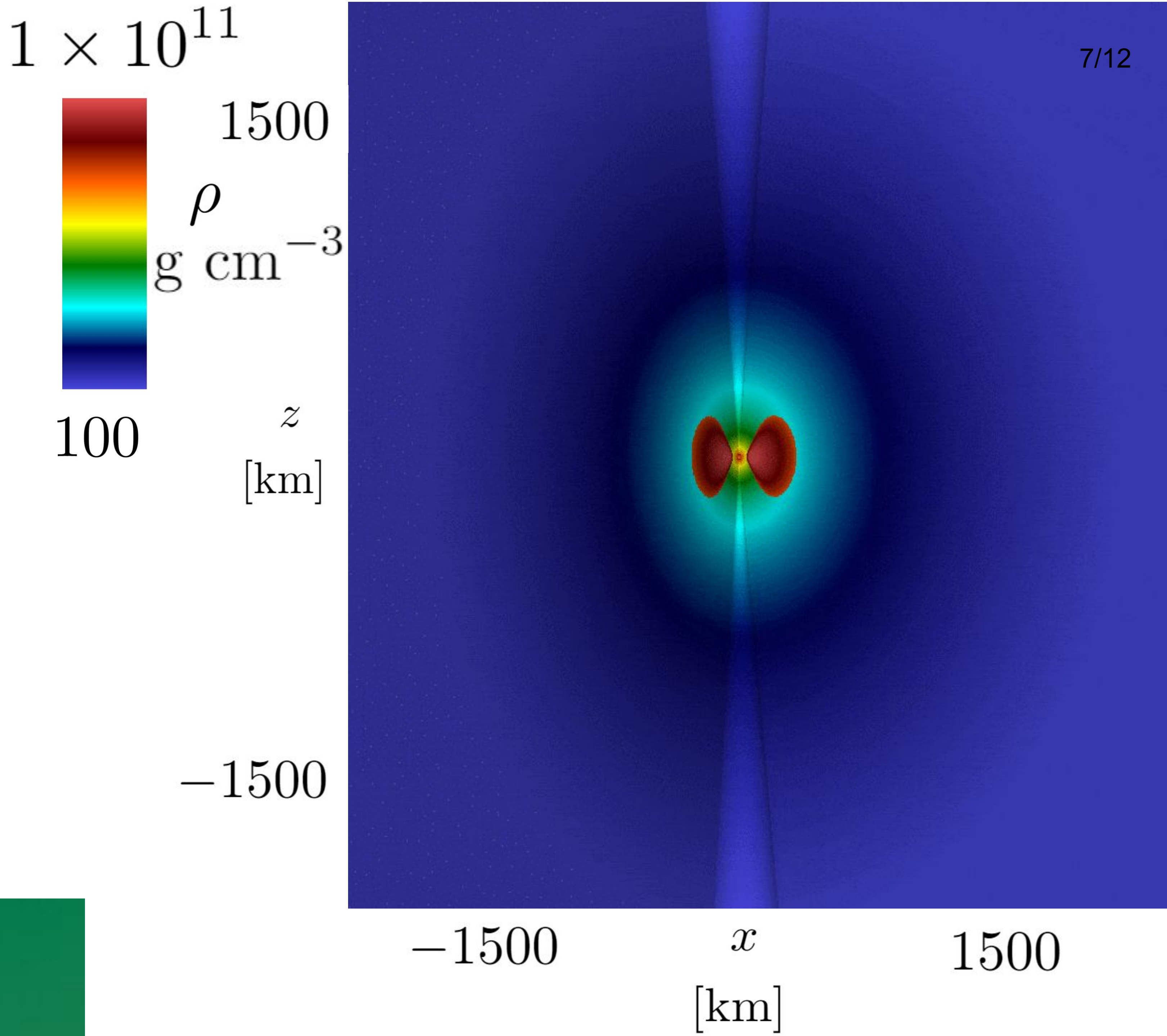
Modify FLASH to in a computationally efficient way to evolve disk over ~s

Pseudo-Newtonian gravity

Helmholtz EOS

Mass ejected via:

- Nuclear Recombination
- MHD effects



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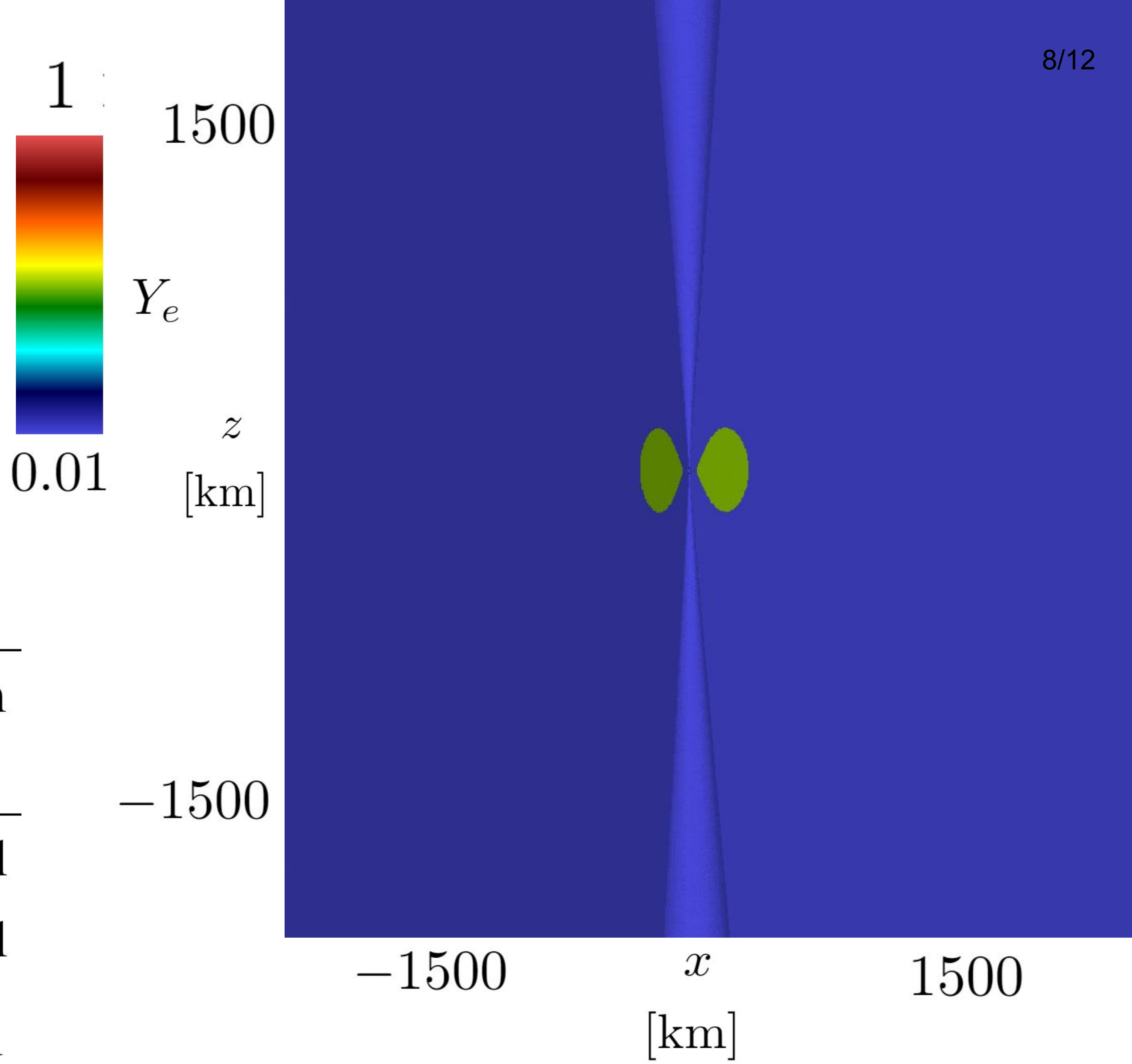
Mass ejected via:

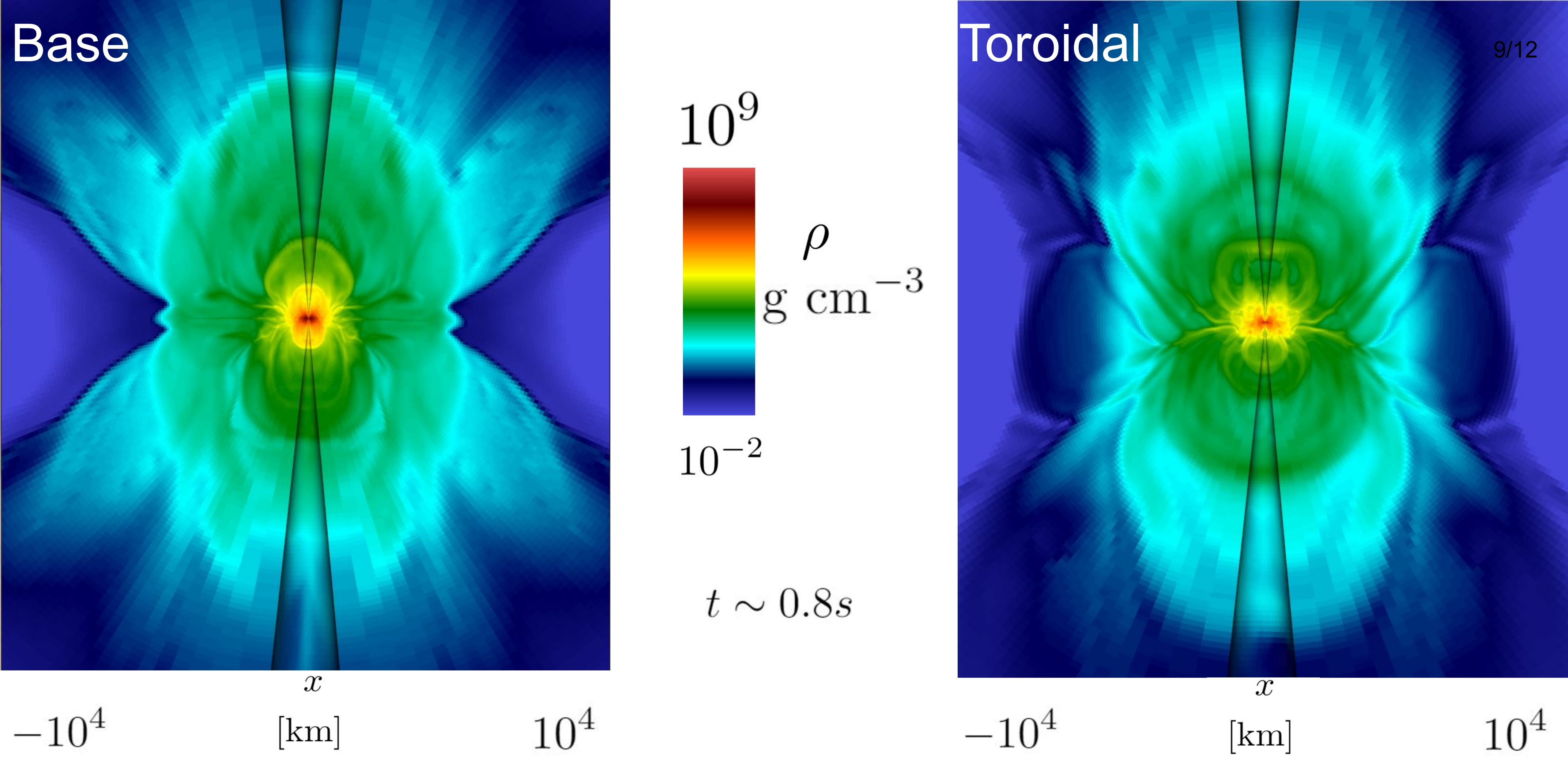
Neutrino heating

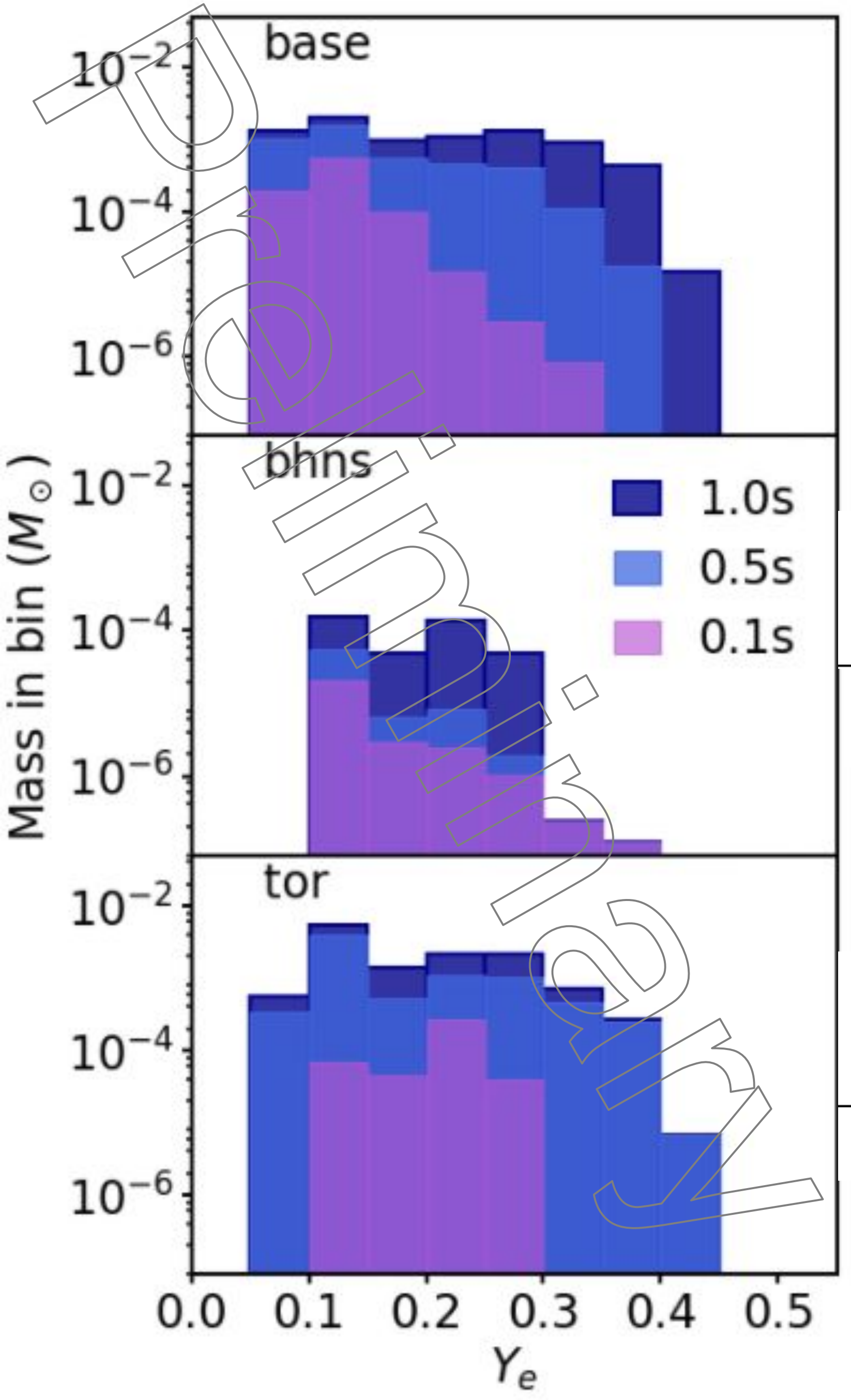
Handled with leakage/absorption scheme

Run a few different models with idealized initial conditions

Model	$M_{\rm bh}$ $(M_\odot)$	$M_{\rm t}$ $(M_\odot)$	**B**-geom
base	2.65	0.10	poloidal
bhns	8.00	0.03	poloidal
tor	2.65	0.10	toroidal




Base
Toroidal
10^9
ρ
g cm^{-3}
10^{-2}
$t \sim 0.8s$
x
-10^4
[km]
10^4
x
-10^4
[km]
10^4



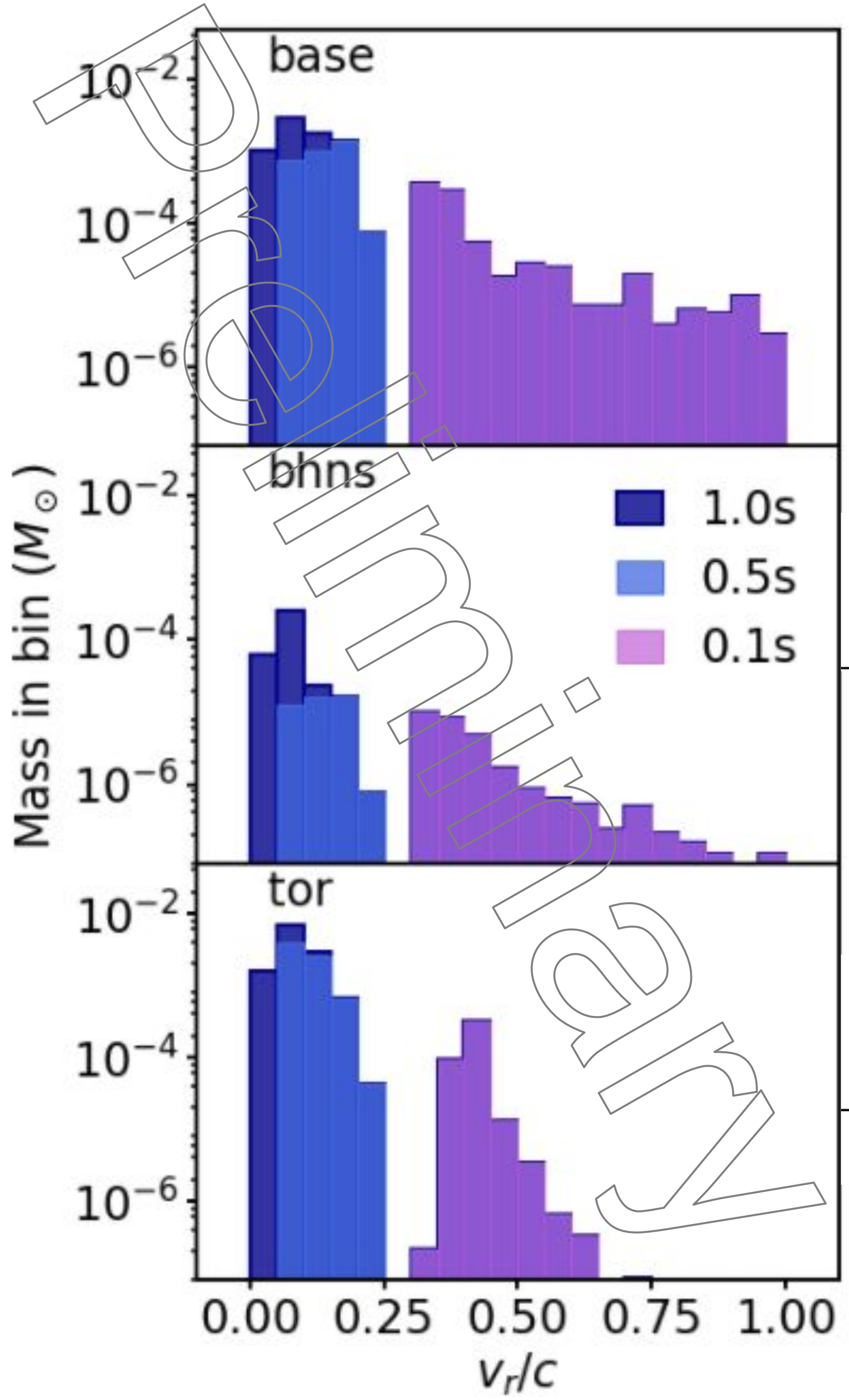
M_{bh} ($M_\odot$)	M_t ($M_\odot$)	**B**-geom
2.65	0.10	poloidal

M_{bh} ($M_\odot$)	M_t ($M_\odot$)	**B**-geom
8.00	0.03	poloidal

M_{bh} ($M_\odot$)	M_t ($M_\odot$)	**B**-geom
2.65	0.10	toroidal

Simulations still running

Distribution in Ye broadens with time



M_{bh} ($M_\odot$)	M_t ($M_\odot$)	**B**-geom
2.65	0.10	poloidal

M_{bh} ($M_\odot$)	M_t ($M_\odot$)	**B**-geom
8.00	0.03	poloidal

M_{bh} ($M_\odot$)	M_t ($M_\odot$)	**B**-geom
2.65	0.10	toroidal

We find mass accelerated to >0.25c

Not enough (currently) to fully explain the GW170817 kilonova

Conclusions

We develop a framework to evolve a parameter space of BH-Tori with MHD, neutrinos, and nuclear dissociation to better understand the ejecta mechanisms responsible for creating kilonovae

Our simulations show that the mass ejection mechanisms are robust across our parameter space, but more work is required to fully understand the blue kilonova of GW18017.