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

UNIVERSITY OF ALBERTA

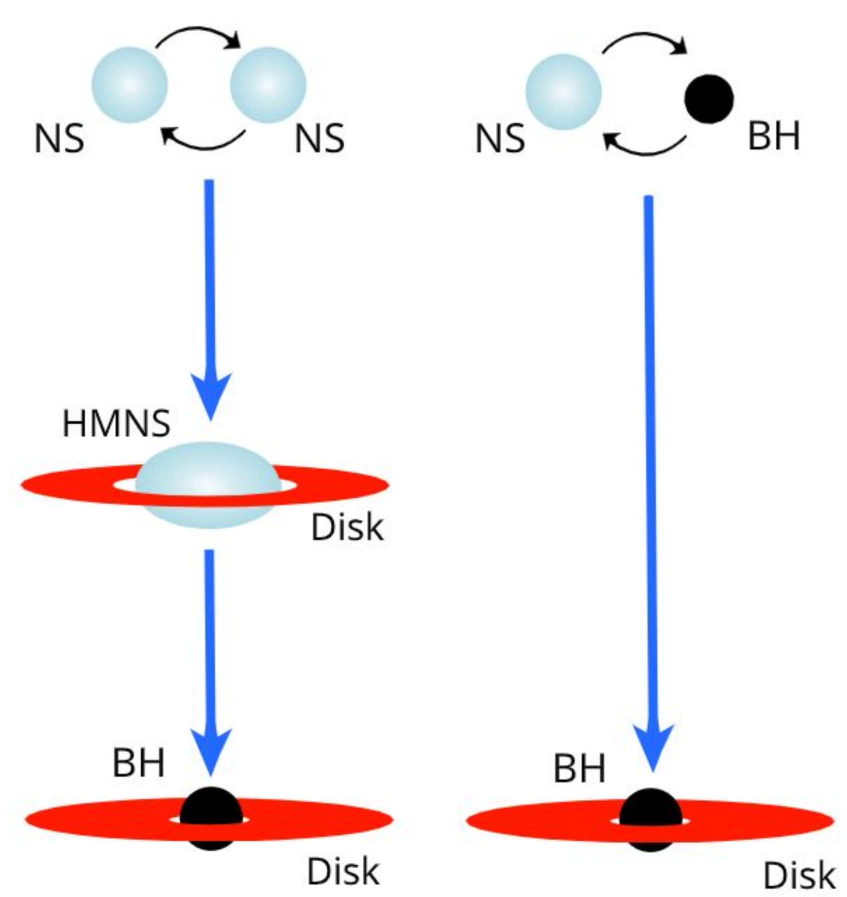
Steven Fahlman and Rodrigo Fernández

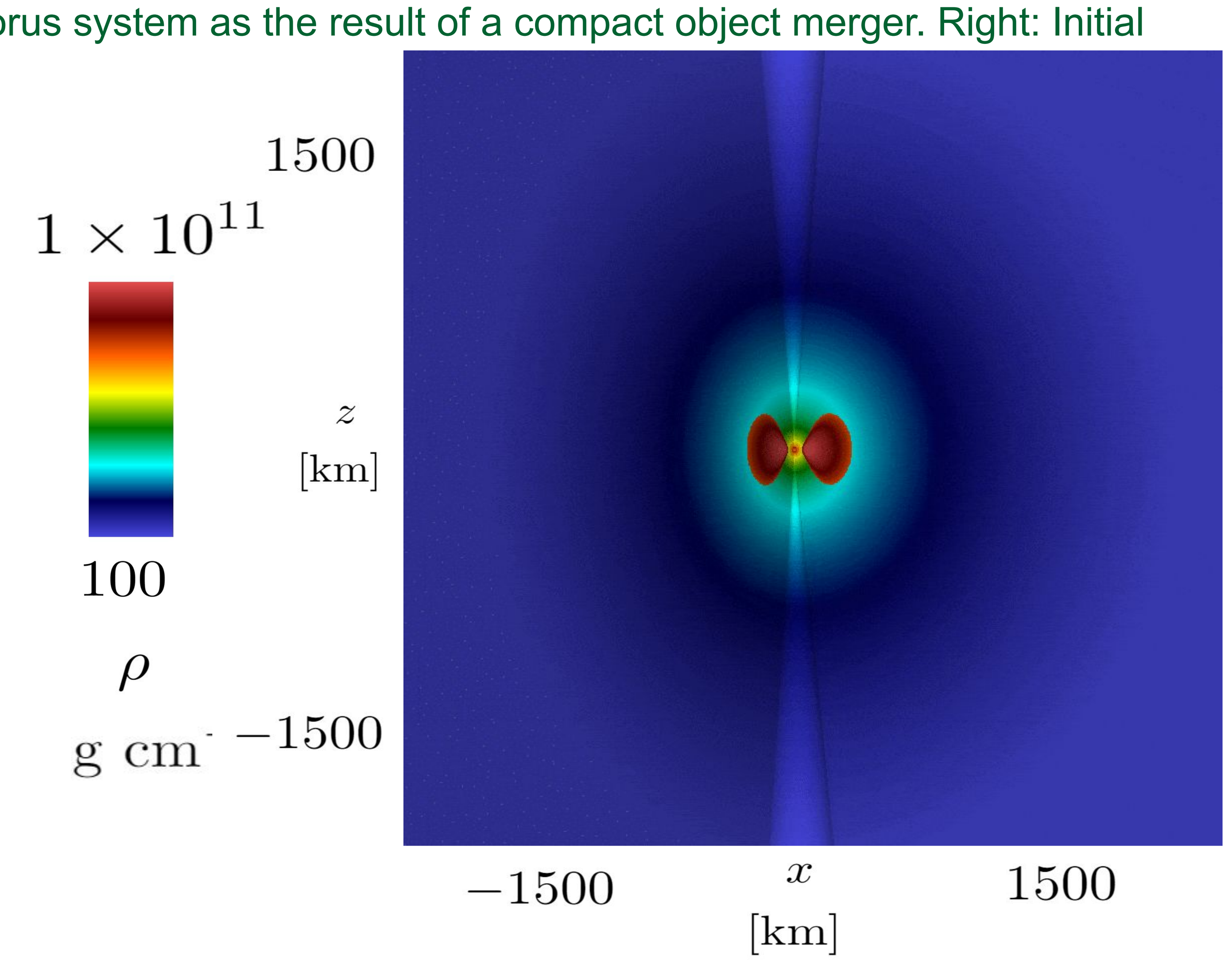
We examine the long-term evolution of accretion tori around the black hole remnants of compact object mergers involving at least one neutron star, to better understand the role of secular outflows in the creation of kilonovae and the synthesis of r-process elements. We modify the FLASH code to evolve magnetohydrodynamics in non-uniform 3D spherical coordinates, enabling efficient evolution of magnetic fields over large simulation domains. Gravity is implemented as a pseudo-Newtonian potential. We include neutrino evolution via an improved lightbulb/leakage scheme and take into account nuclear recombination of α-particles in the equation of state. With this new framework, we evolve post-merger systems of tori around black holes and examine the outflows. We find results broadly consistent with general relativistic simulations. Magnetically driven outflows unbind a significant fraction of torus mass over a few seconds, with velocities ~0.1c and average electron fractions favouring lanthanide-rich ejecta. Ejected torus mass is negatively correlated with system compactness. The fraction of mass with $Y_e > 0.25$ is insufficient to explain the blue kilonova of GW170817 based on current kilonovae models.

INTRODUCTION

Neutron star mergers are thought to be an important site for the synthesis of r-process elements, the heaviest in the universe. The mass outflows from neutron star mergers are thought to power the associated electromagnetic counterpart to gravitational wave observations, known as the kilonova. The long term (over a timescale of seconds) outflows from the formed remnant and torus system after merger can be responsible for the majority of outflows

Left: Two possible formation scenarios of a BH torus system as the result of a compact object merger. Right: Initial setup of our base simulation in density





METHODS

We evolve multiple BH-tori systems in magnetohydrodynamics, taking into account magnetic fields, neutrino heating and cooling via a leakage/absorption scheme, and nuclear recombination.

We start from an idealized initial condition of a BH surrounded by an equilibrium torus threaded with an imposed magnetic field. Our base model matches the parameters of GW170817. We also choose a black hole and torus mass which could be the result of a BHNS merger, and vary the initial magnetic field geometry.

Left: Model parameters. Right: Mass ejecta parameters inferred from GW170817.

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

GW170817 Blue KN requires

$\langle M_{\rm ej} \rangle \sim 10^{-2} {\rm M}_\odot$

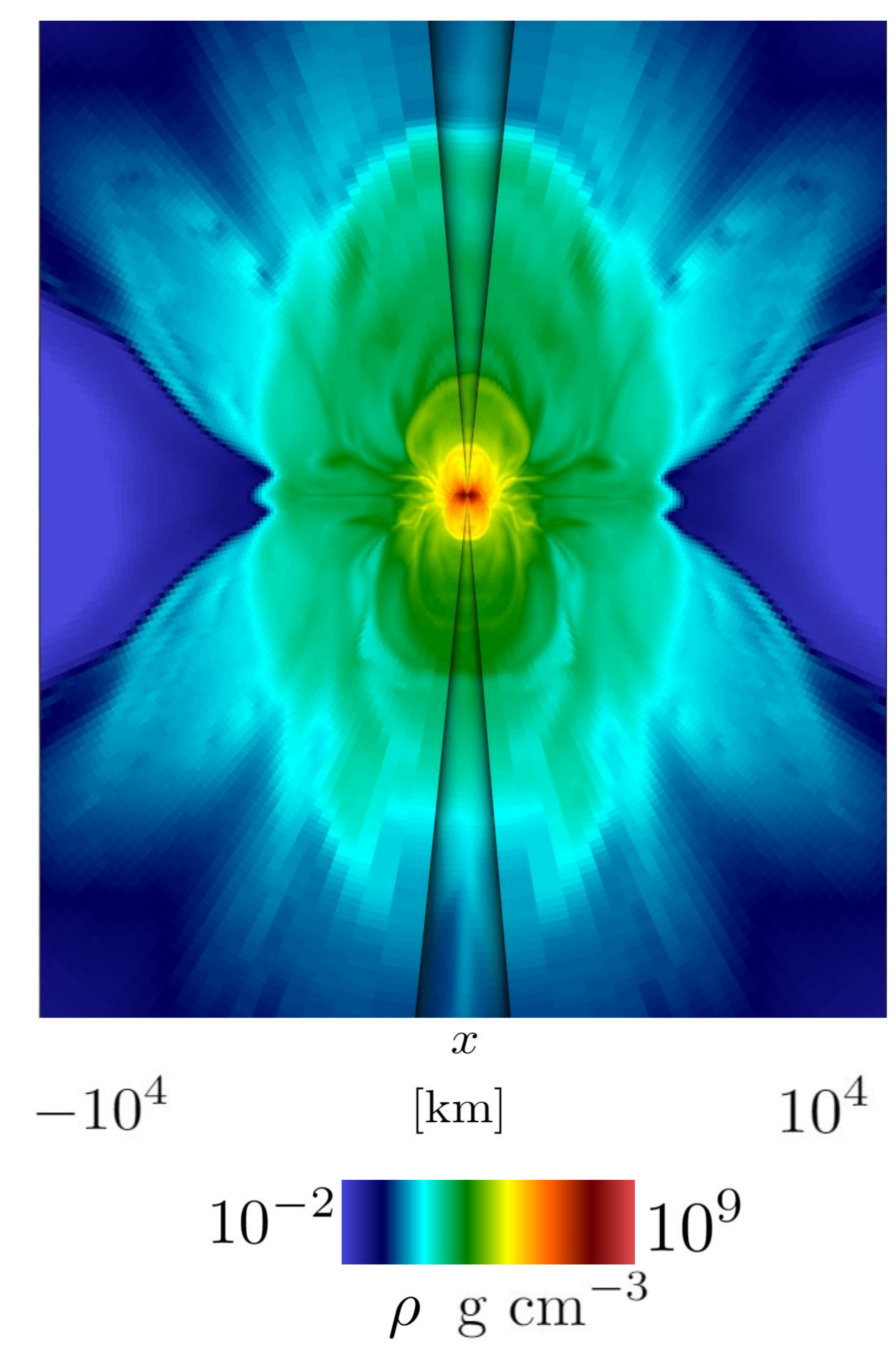
$\langle v_{\rm ej} \rangle \sim 0.25{\rm c}$

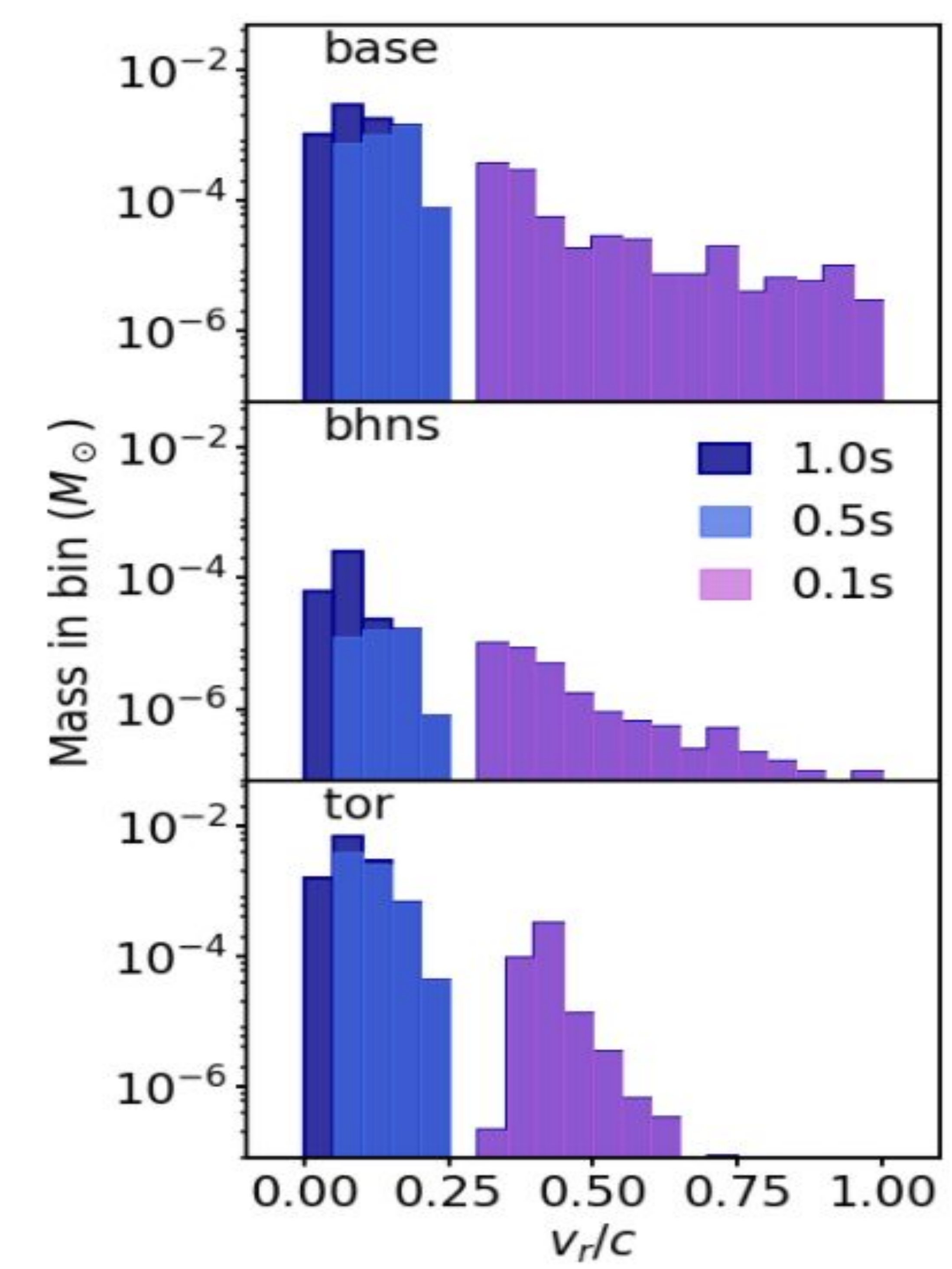
$\langle Y_e \rangle \gtrsim 0.25$

RESULTS

Mass is ejected at relativistic velocities through a combination of MHD stresses, neutrinos, and alpha particle recombination over the first 100 ms. At late times (s), the torus settles into a steady state and mass is ejected via turbulent energy injection.

We report an "hourglass" shaped morphology to the outflow, in contrast to an isotriopic spherical outflow.
The amount of mass ejected with velocities greater than 0.25c is insufficient to explain the blue kilonova of GW170817 based on current kilonova models.
Left: Ejecta morphology at t~0.8s in density. Right: Velocity binned histograms of the ejected mass.





CONCLUSIONS

Our simulations show that the mass ejection mechanisms are robust across our parameter space of post merger BH-tori systems, but more work is required to fully understand the blue kilonova of GW170817.

Contact: sfahlman@ualberta.ca https://sites.ualberta.ca/~sfahlman