Title: General Relativistic Magnetohydrodynamic Simulations of Circumbinary Disk Accretion onto Unequal Mass Black Hole Binaries

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Collection/Series: Magnetic Fields Around Compact Objects Workshop

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Abstract:

Accreting supermassive binary black holes (SMBBHs), which are the expected outcome of galaxy mergers, are potential powerful multimessenger sources of gravitational waves (GWs) and electromagnetic (EM) radiation. The latter may be periodically modulated by an asymmetric density distribution in the circumbinary disk (CBD), typically referred to as the “lump”. Possible enhancement of this modulation is predicted to occur when considering unequal mass binaries. In that scenario the less massive black hole (often called the "secondary") is expected to consume a majority of the inflowing gas as it gets closer to the inner edge of the CBD possibly dominating the overall EM luminosity.

We perform the first set of full 3D general relativistic magnetohydrodynamic (GRMHD) simulations of astrophysically realistic unequal mass (q=1:2) black hole binaries, both spinning and non spinning, embedded in a CBD, adopting the IllinoisGRMHD code. We use relaxed initial data for the CBD retrieved from a previous long-term simulation, performed with the SphericalNR code, which employs curvilinear coordinates and a post-Newtonian (PN) metric with a cutout excising the central region containing the binary. We study the dependence of multiple diagnostics, including the mass accretion rate, the Poynting flux and the mass enclosed at different radii, on the spins of the black holes and their mass ratio. Additionally, we analyze the dynamics and structure of the minidisks surrounding each black hole and the evolution of the jets ejected by them.

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General Relativistic Magnetohydrodynamic Simulations of Circumbinary Disk Accretion onto Merging Super Massive Black Hole Binaries

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Magnetic Fields Around Compact Objects Workshop 2025

Astrophysical Motivation

- Supermassive black holes (SMBHs) are observed at the center of almost all galaxies
- Supermassive binary black hole (SMBBH) mergers are believed to be the natural outcome of galactic mergers
- Mergers are expected to occur in gas-rich environments leading to **electromagnetic (EM) emissions**

stand-alone identification

counterparts for GW detections (PTA, LISA)

ESA/Hubble & NASA

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"Hand-off" procedure

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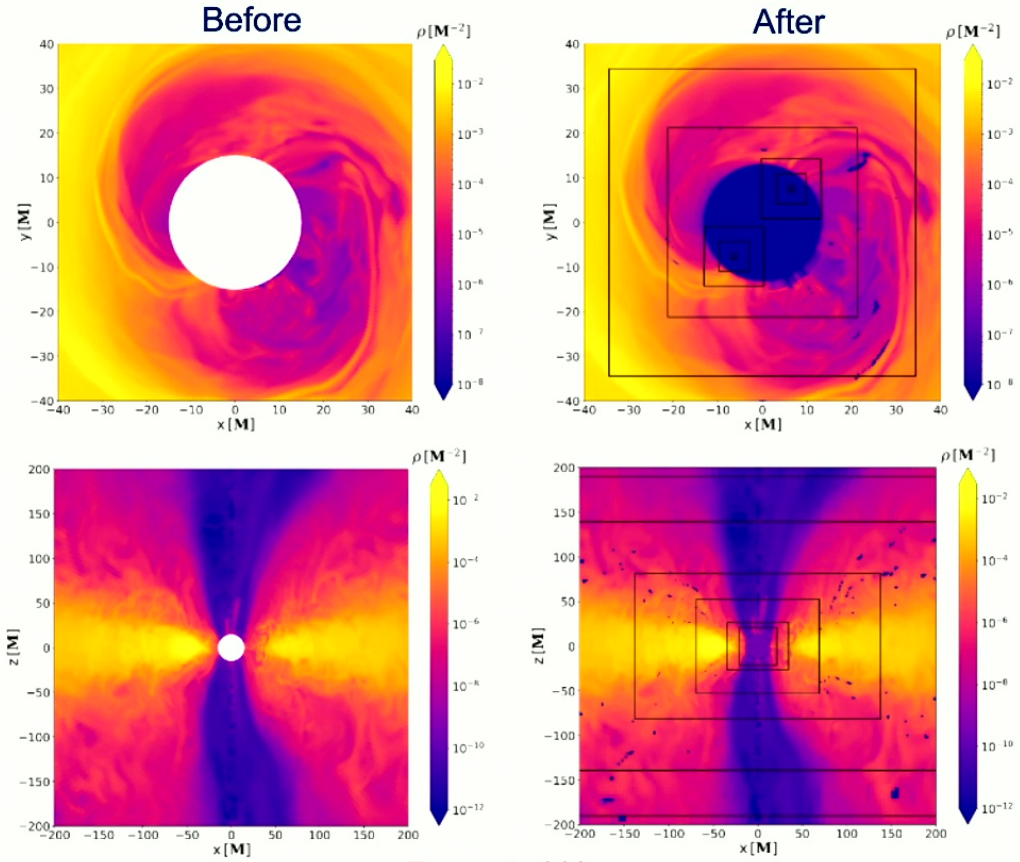


Ennoggi+ 2025

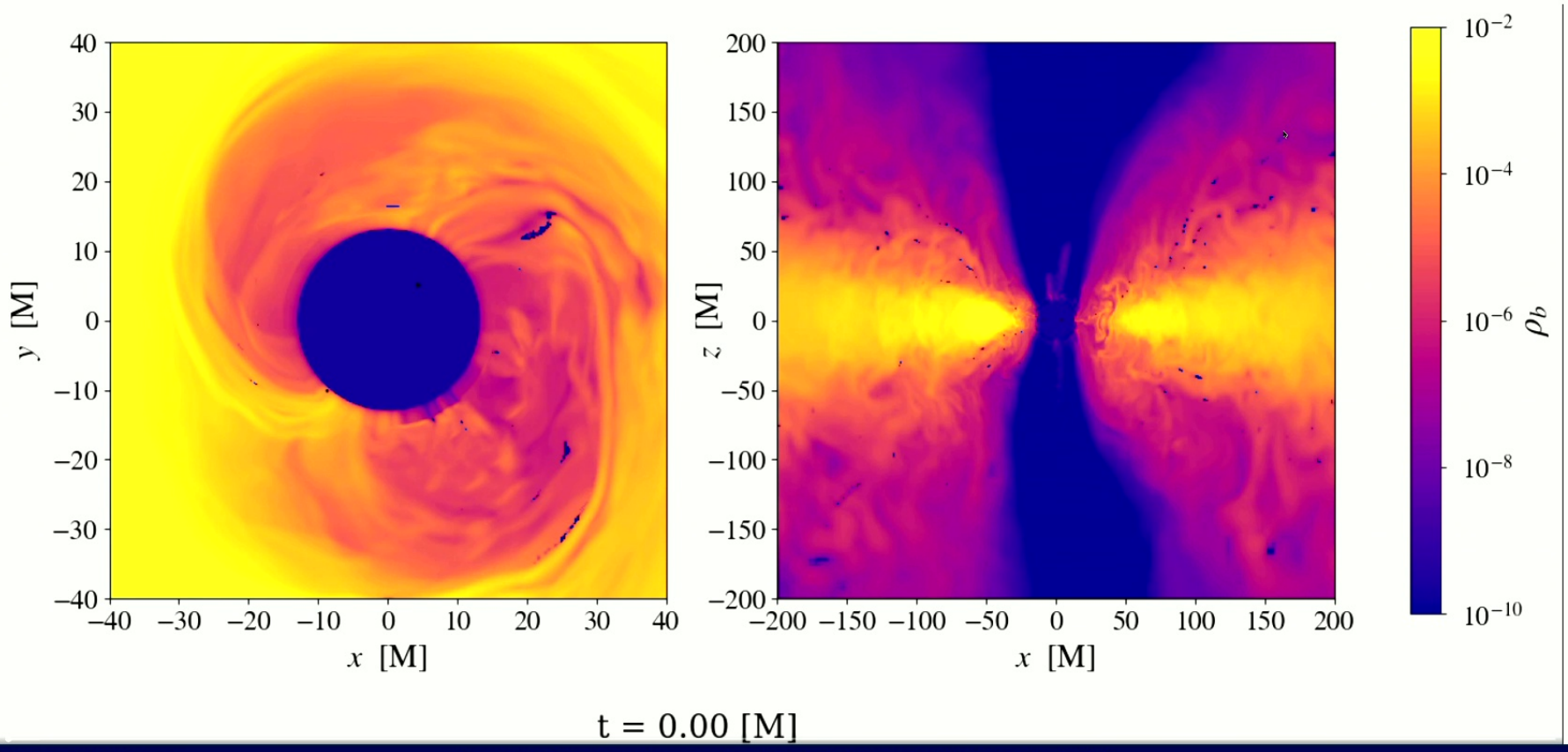
STEP 1 Long term CBD simulation using **SphericalNR** (*Mewes+ 2018, 2020*)

STEP 2 Interpolation of the SphericalNR MHD primitives onto a Cartesian grid

STEP 3 Evolution of the SMBBH in <u>full GR</u> from inspiral up to merger and postmerger using **IllinoisGRMHD**

Unequal mass SMBBHs

$q = 0.5 \;\; a_{spin} = 0.8$



Preliminary results

$$M(t) \equiv \int_V dV \sqrt{-g}\, \rho u^t$$

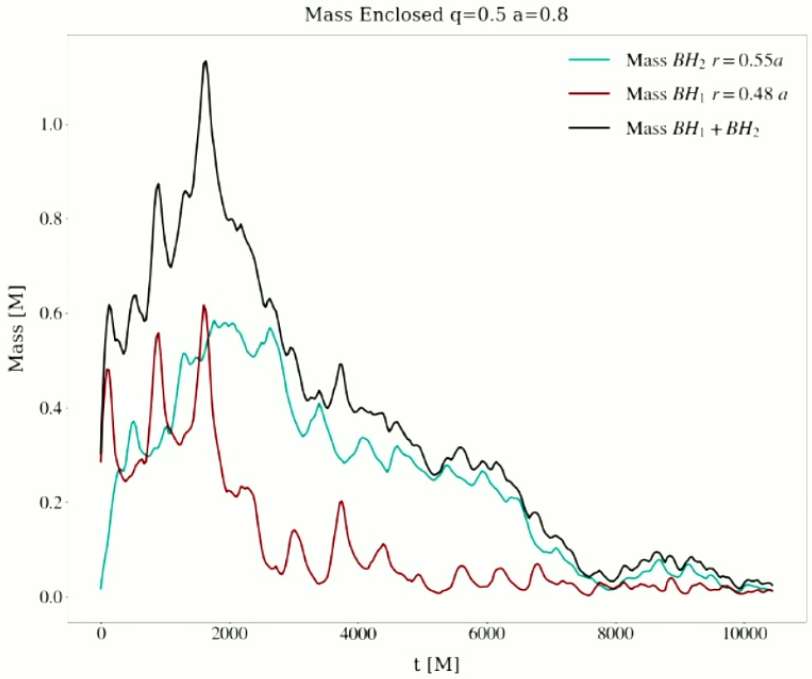
$$q = \frac{M_1}{M_2} < 1 \quad \frac{\dot{M}_1}{\dot{M}_2} > 1$$

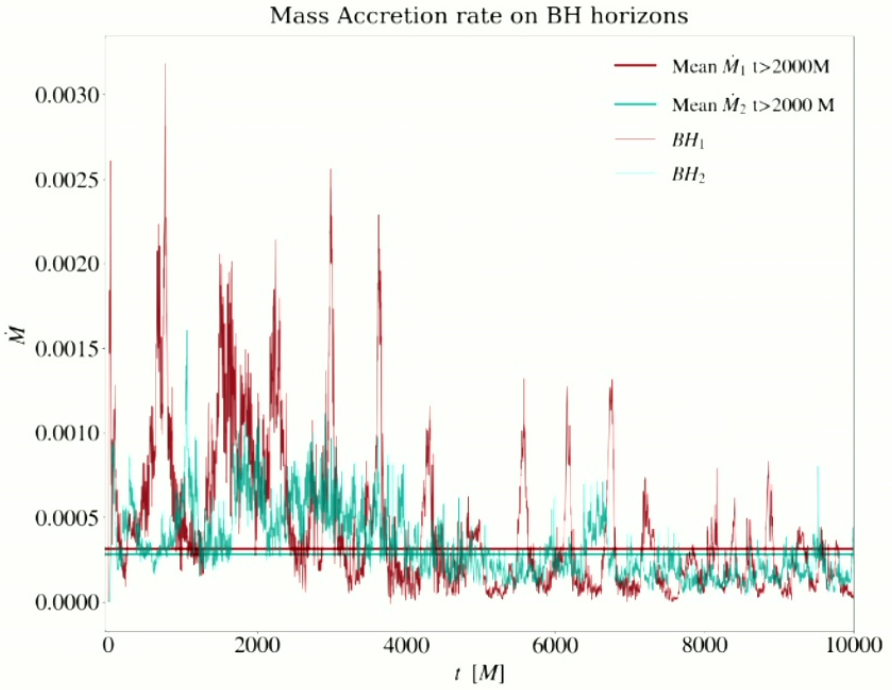
"Stream-like": minimum mass and maximum accretion

"Disk-like": maximum mass and minimum accretion

Preferential accretion rate onto the smaller BH

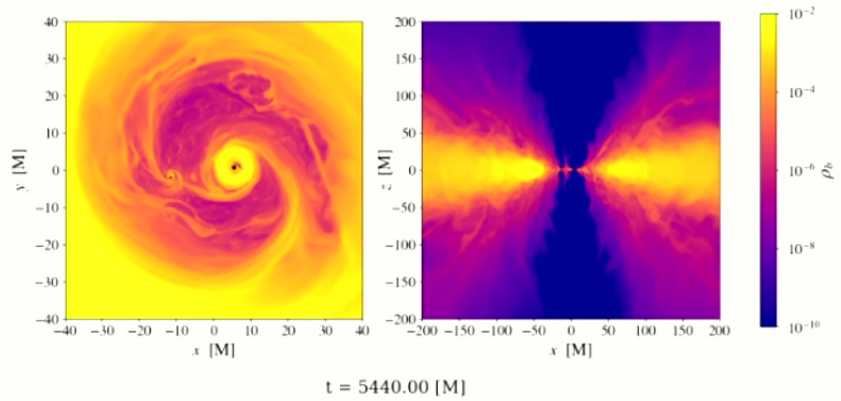
(*Duffel+2020,Munoz+2020*)





Preliminary results

$q = 0.5\ a_{spin} = 0.8$



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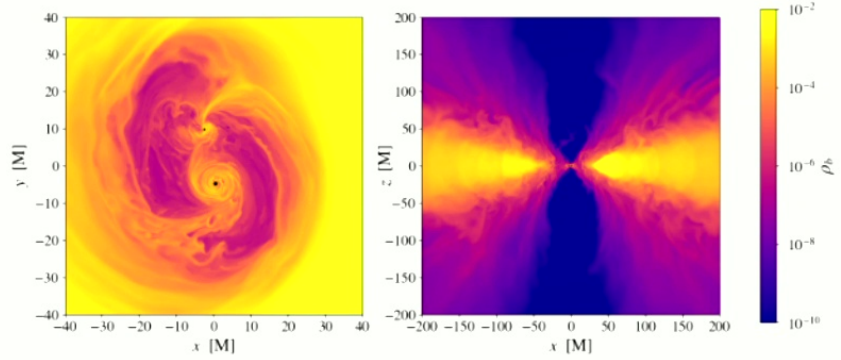

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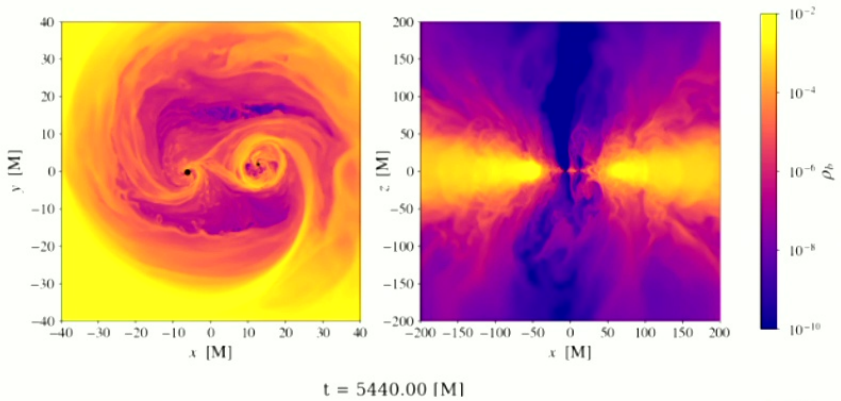

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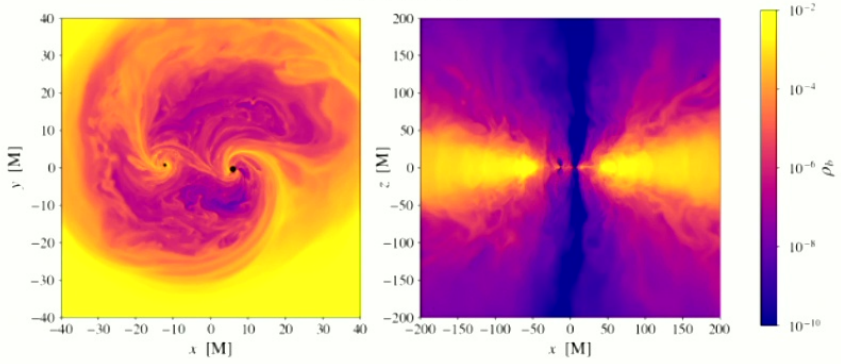

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Preliminary results

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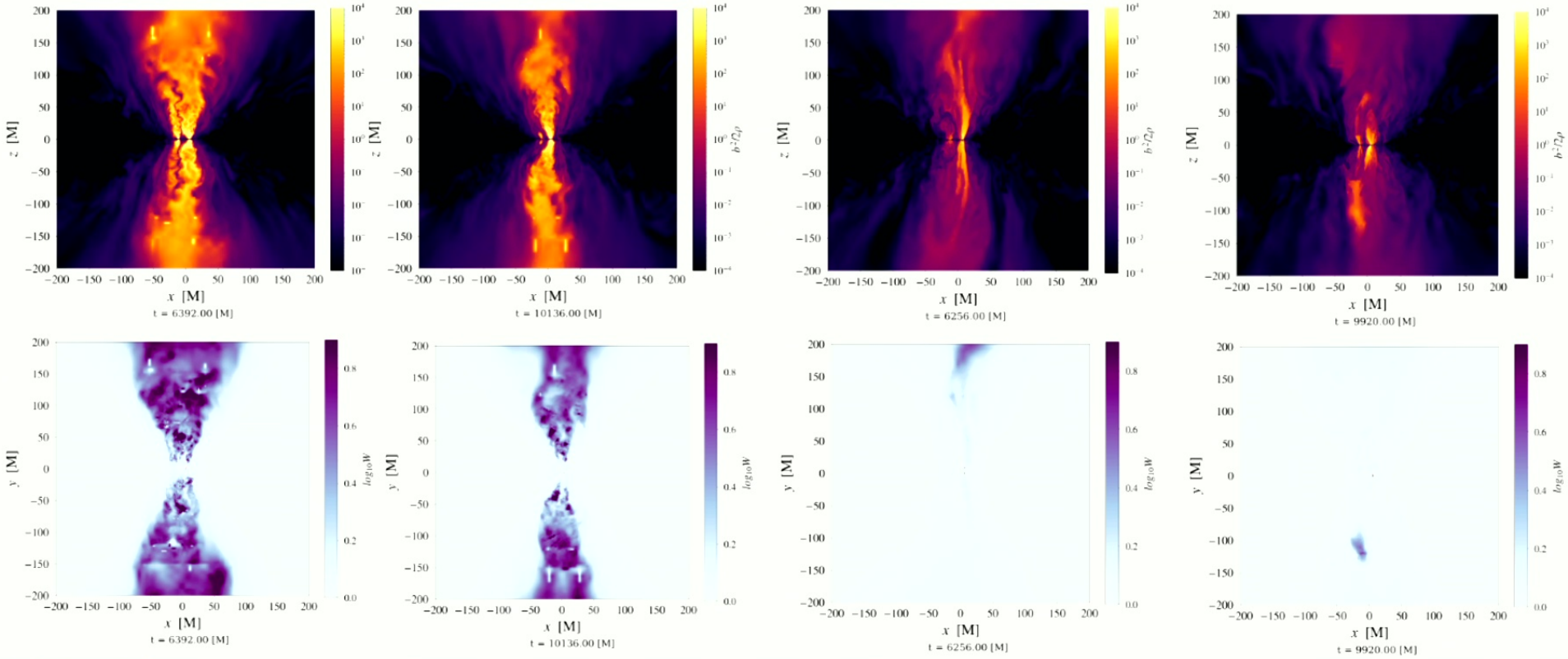
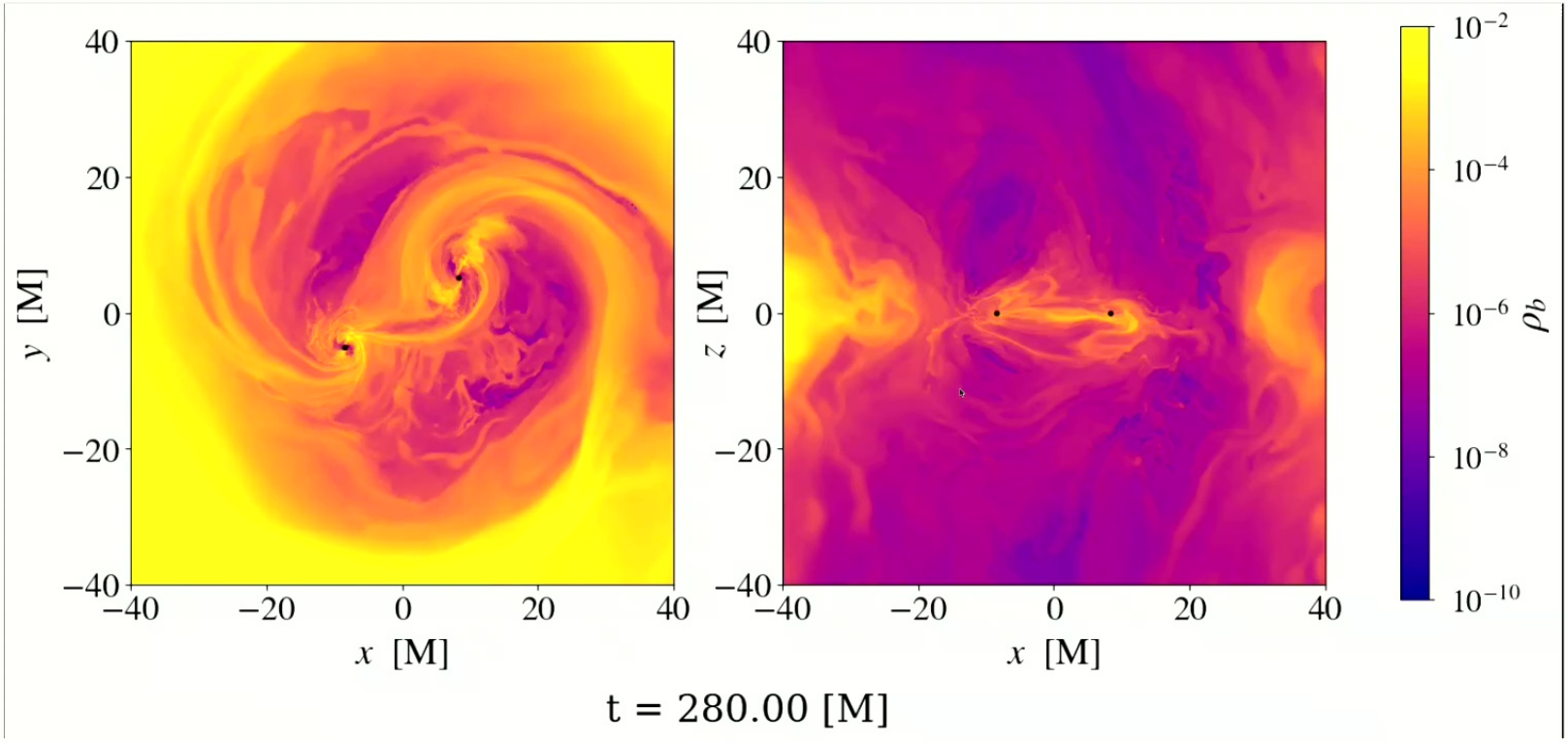
$q = 0.5\ a_{spin} = 0.8$

$q = 0.5\ \ a_{spin} = 0$



Preliminary results

HUK



potential **jet-jet** interaction!

Maximum recoil ~ **5000** km/s

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Conclusions

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Summary

- Preferential accretion rate onto the smaller black hole in unequal mass SMBBHs
- Minidisk structure and evolution depends on the BHs mass-ratio, spin orientation and orbital dynamics
  - Simulations underways!

Future work

- Explore the parameter space: larger separations and smaller mass ratios, other recoiling SMBBH configurations
- More accurate radiation transport models (leakage + full transport)
- Improve computational efficiency with GPU enabled codes: **AsterX** (*Kalinani+2024,* AMReX/CarpetX based)