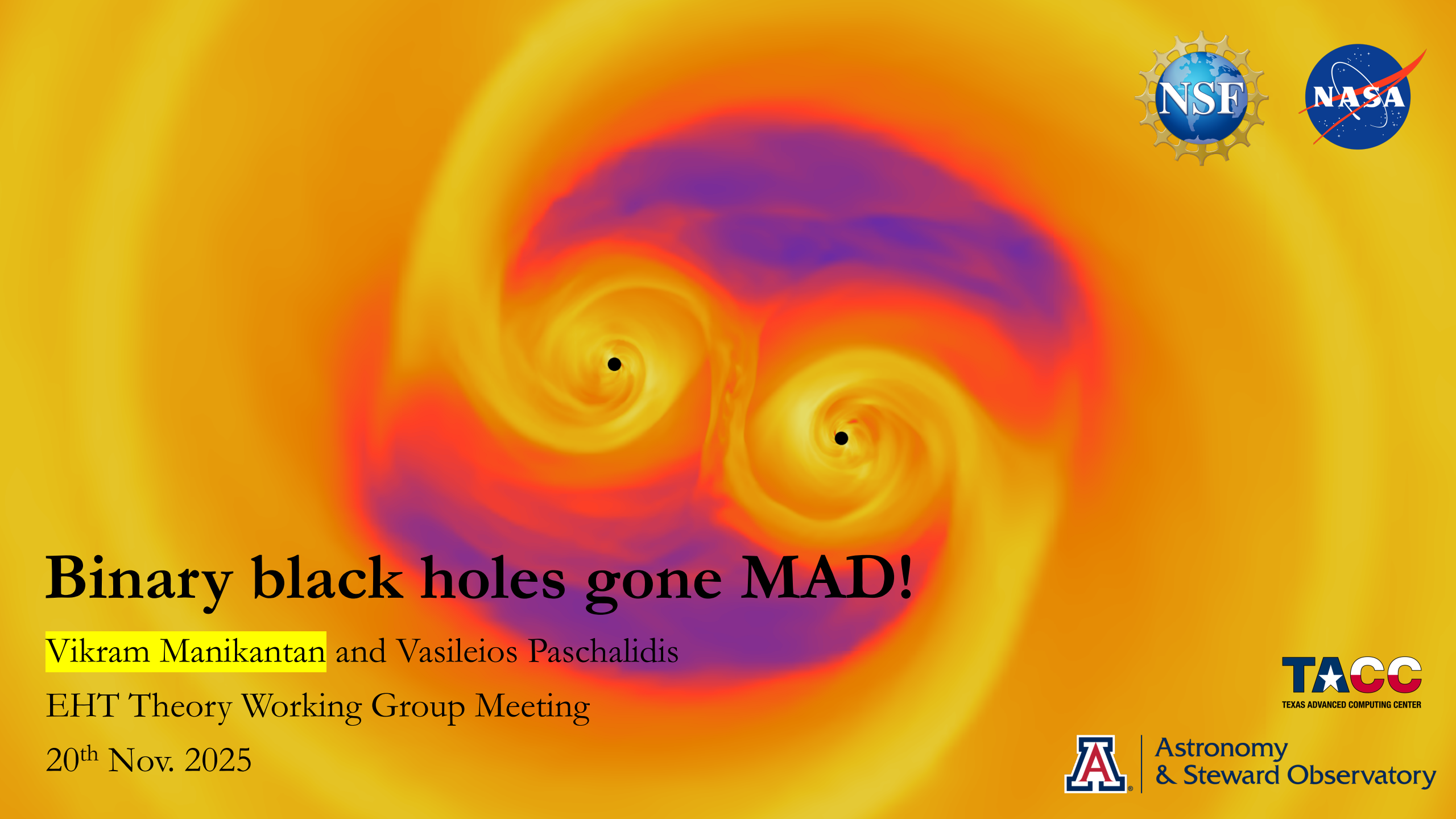


Binary black holes gone MAD!

Vikram Manikantan and Vasileios Paschalidis

EHT Theory Working Group Meeting

20th Nov. 2025

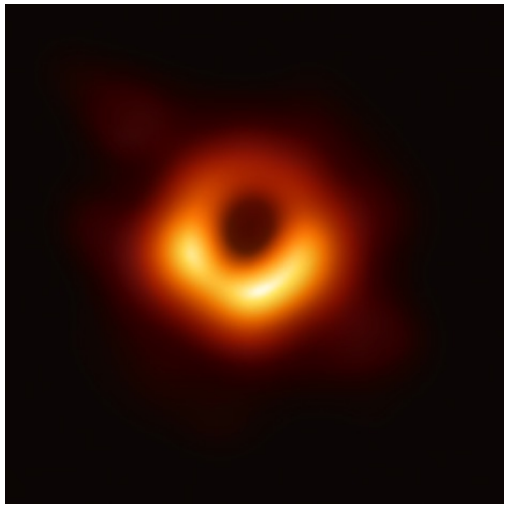
TACC
TEXAS ADVANCED COMPUTING CENTER

Astronomy
& Steward Observatory

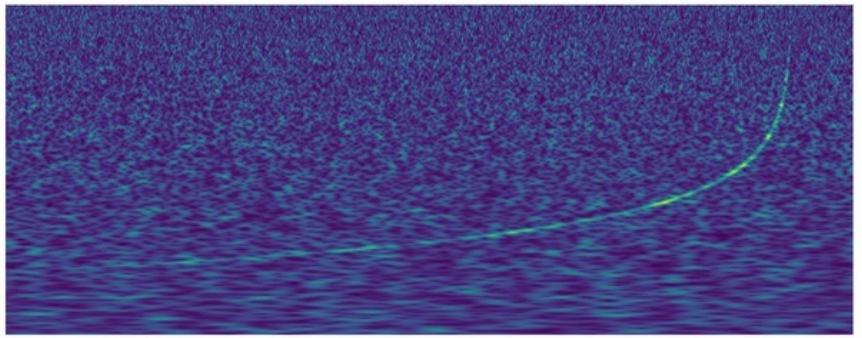
SMBBHs Expected to be Ubiquitous Multi-messenger Sources

- Product of galaxy mergers (Begelman+1980)
- GWs from inspiral and EM emission from accretion (Bogdanovic+2022, LISA+2023)
- Understanding large-scale structure (Kormendy+2013, Heckman+2014)
- Probing H0 and universe's expansion (Schulz 1986, Holz+2005)

NGC 4676, Credits: NASA/ESA



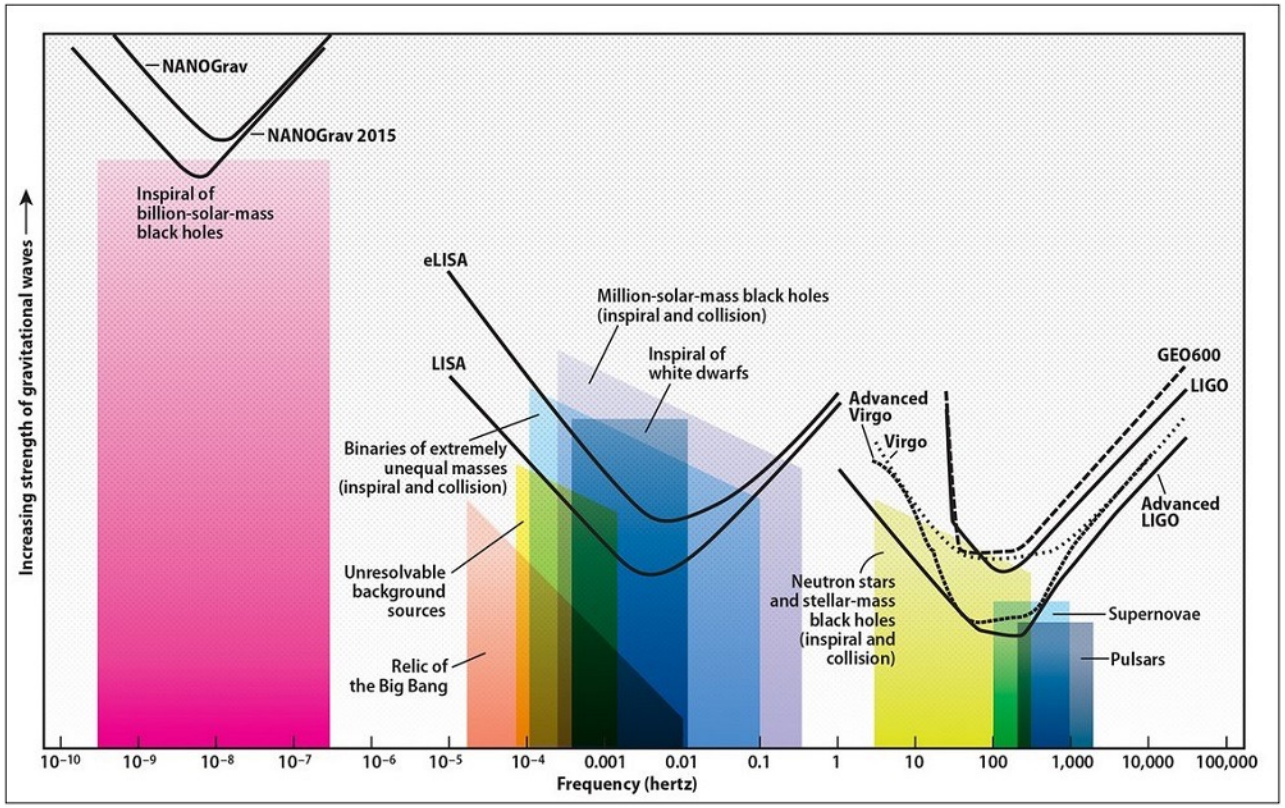
M87*, EHT Collaboration



LIGO, GW170817 chirp signal

Gravitational wave observations with LISA and PTAs

- LISA will target low-frequency sources, including SMBBHs
- PTAs have evidence for a stochastic background

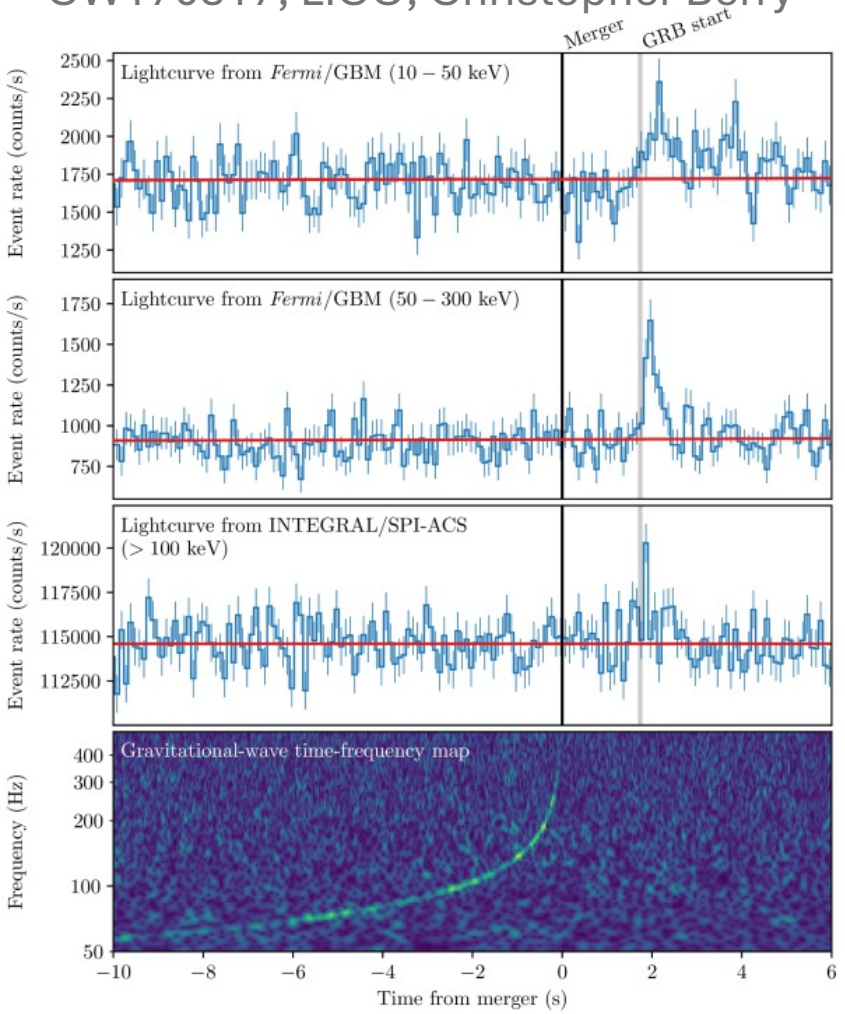


GW Sensitivity Curves; Moore+2014

Goal of MMA with LISA/PTAs

- Multimessenger astronomy (GW + EM) has been starved since GW170817
- Goal is to have coincident multiwavelength and GW observations
- Aid with fundamental physics and astronomy (incl. cosmology, SMBH seeds, etc.)
- How do we uniquely identify SMBBHs?
- Multiwavelength and multimessenger modelling of SMBBHs has to start now!

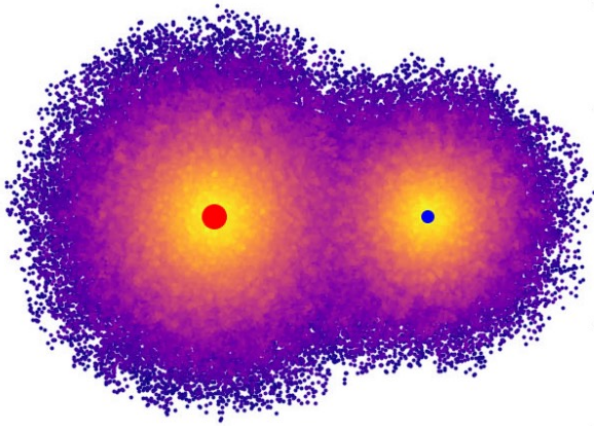
GW170817, LIGO; Christopher Berry



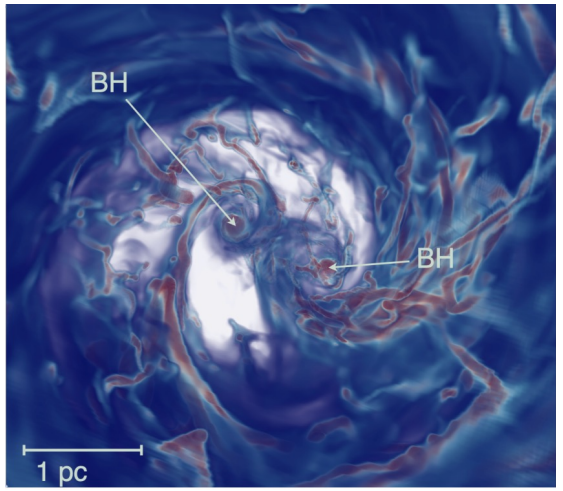
SMBBH evolution spans ~10 orders

NGC 4676, Credits: NASA/ESA

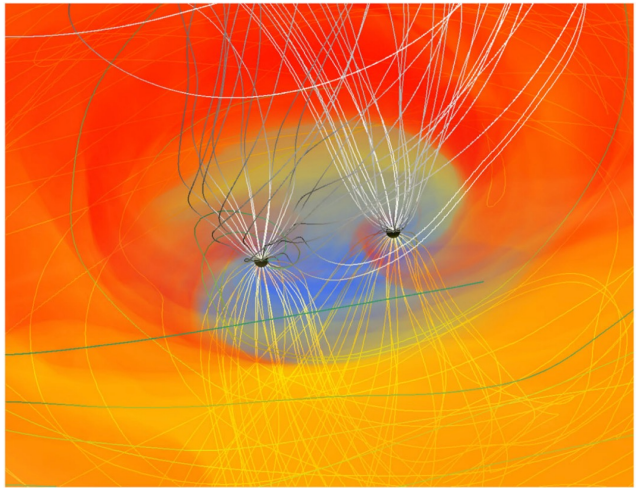
Sobolenko+2021



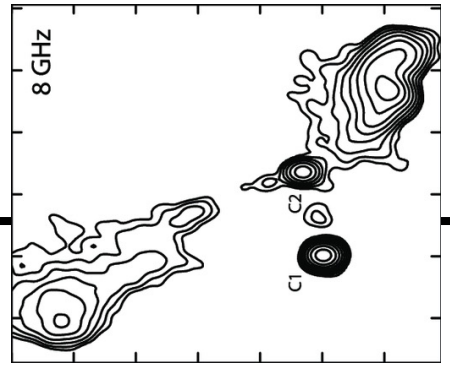
Wang+2025



Gold, Paschalidis+2014



Rodriguez+2009



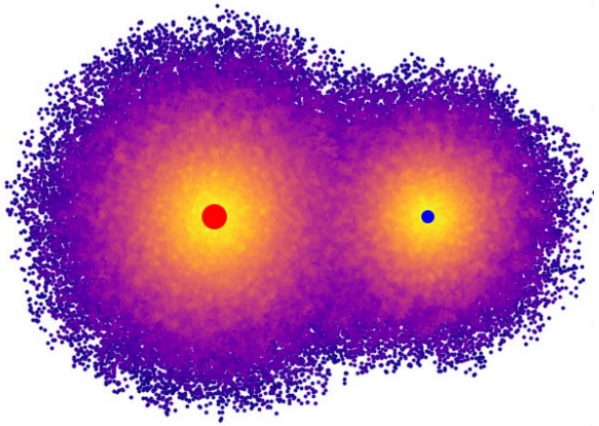
Galactic scales
> 10 kpc

Horizon scales
~ 1 μpc

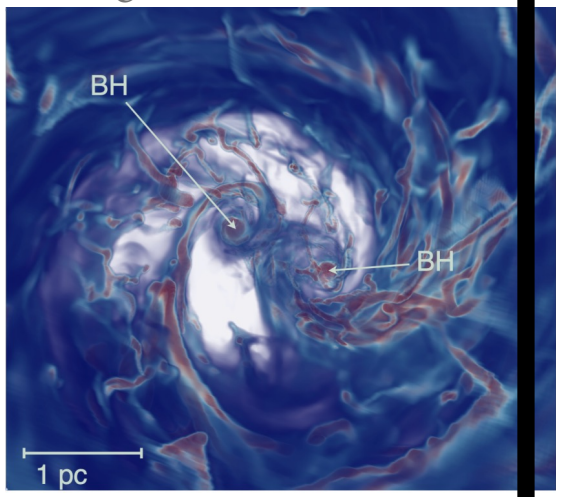
I study the late inspiral, dynamical spacetime regime

NGC 4676, Credits: NASA/ESA

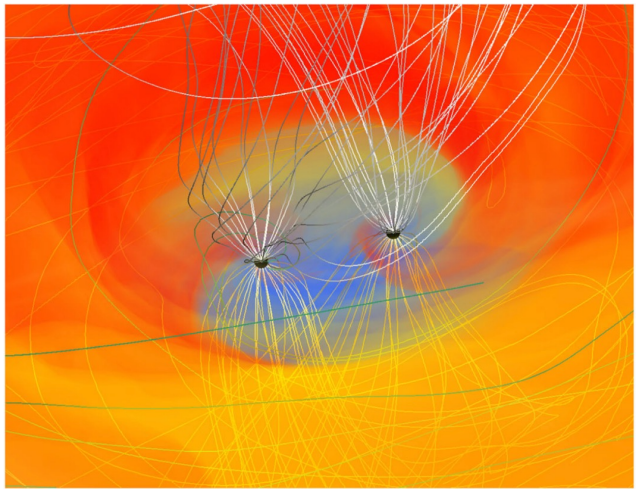
Sobolenko+2021



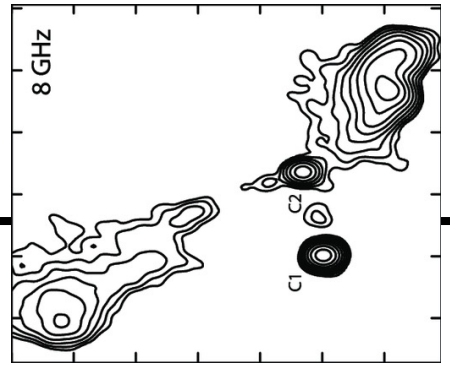
Wang+2025



Gold, Paschalidis+2014



Rodriguez+2009



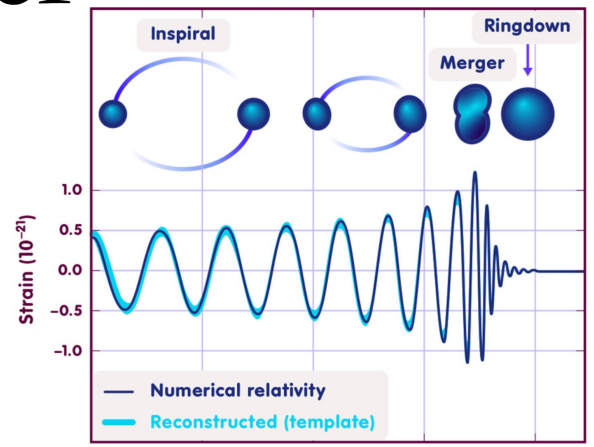
Galactic scales
> 10 kpc

Horizon scales
~ 1 μpc

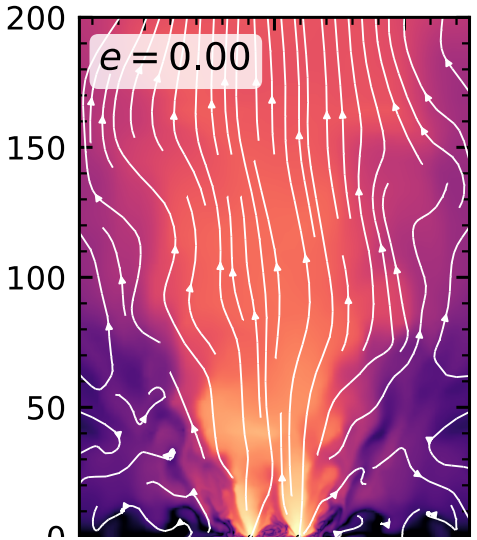
Multiwavelength and Multimessenger modelling of SMBBHs

- Modelling gravitational waves requires evolving Einstein's equations
- Modelling electromagnetic emission requires understanding the accretion flow and outflows
- Therefore, magnetohydrodynamics

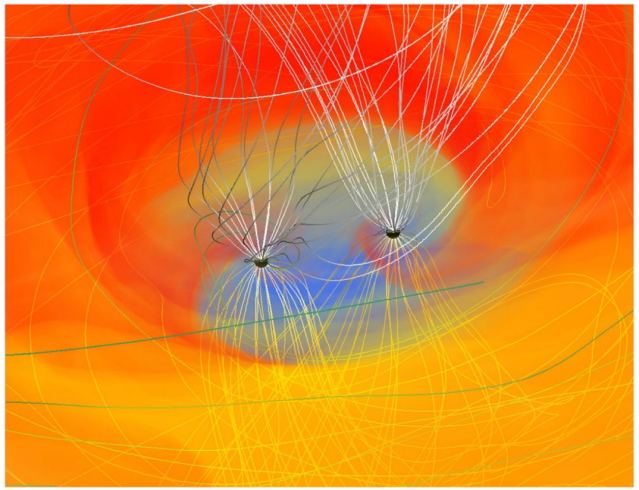
LIGO, Daniela Leitner



Manikantan+2025

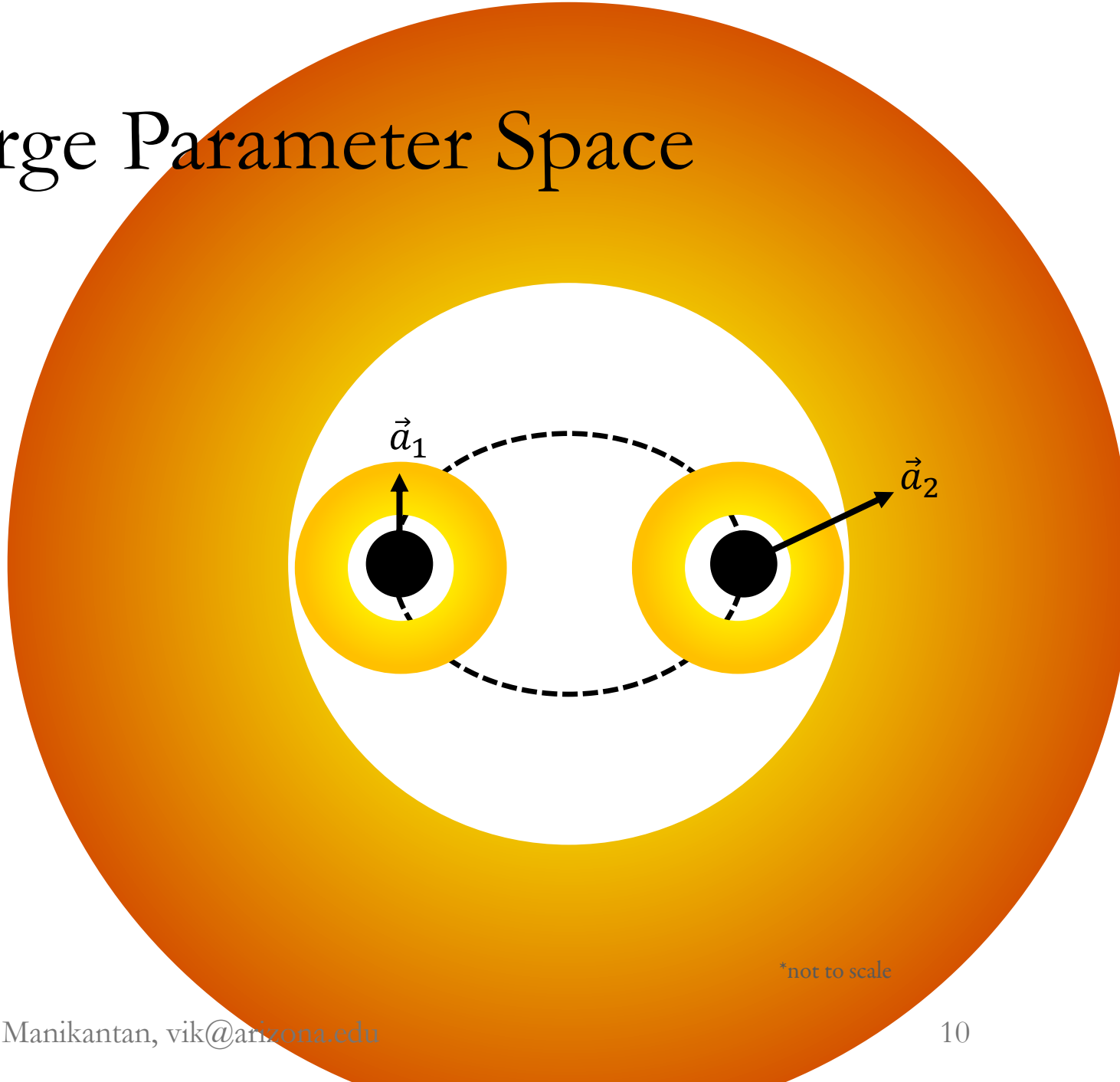


Gold, Paschalidis+2014



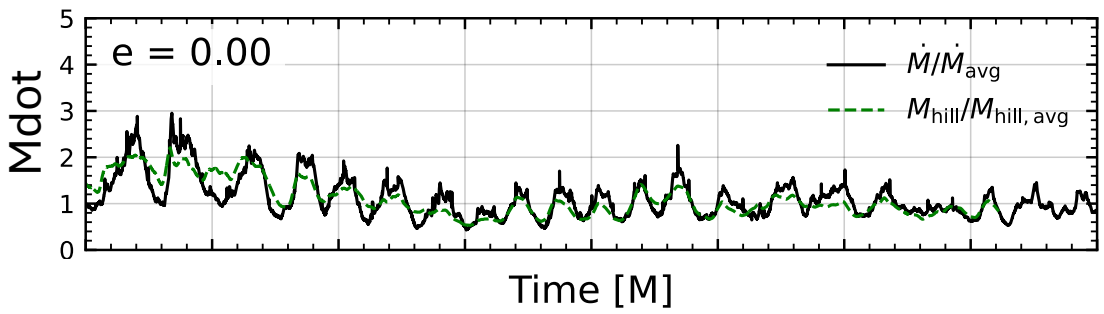
SMBBHs have a Large Parameter Space

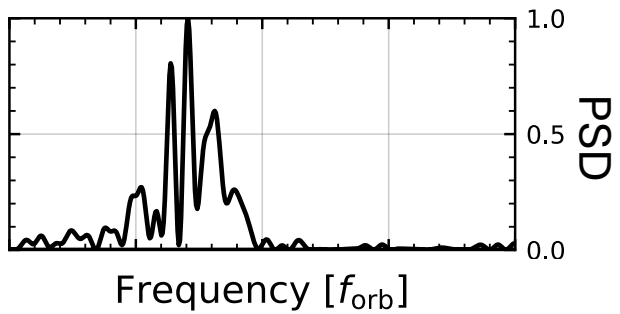
- Parameters Include:
  - Mass ratio
  - Relative spin magnitudes
  - Relative spin orientation
  - Orbital eccentricity
  - Separation
- We haven't even talked about the accretion disk
  - Thickness
  - Magnetic fields
  - Radiation Transport



Previous work at smaller separations

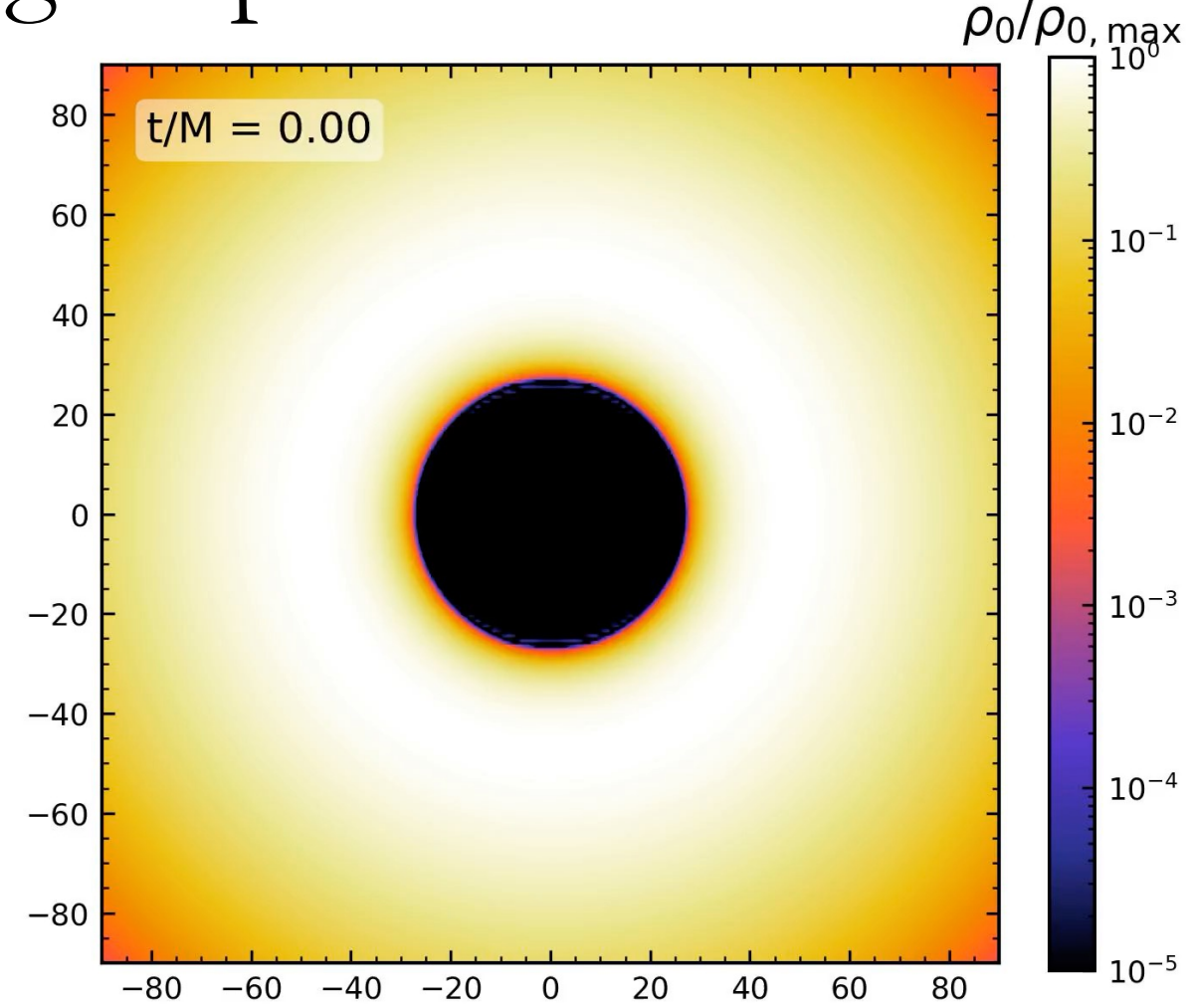
- Binary separation sets the orbital time, which sets the simulation length
- Accretion is periodic, set by the orbital period
- Previous work starts BBH at d=20M





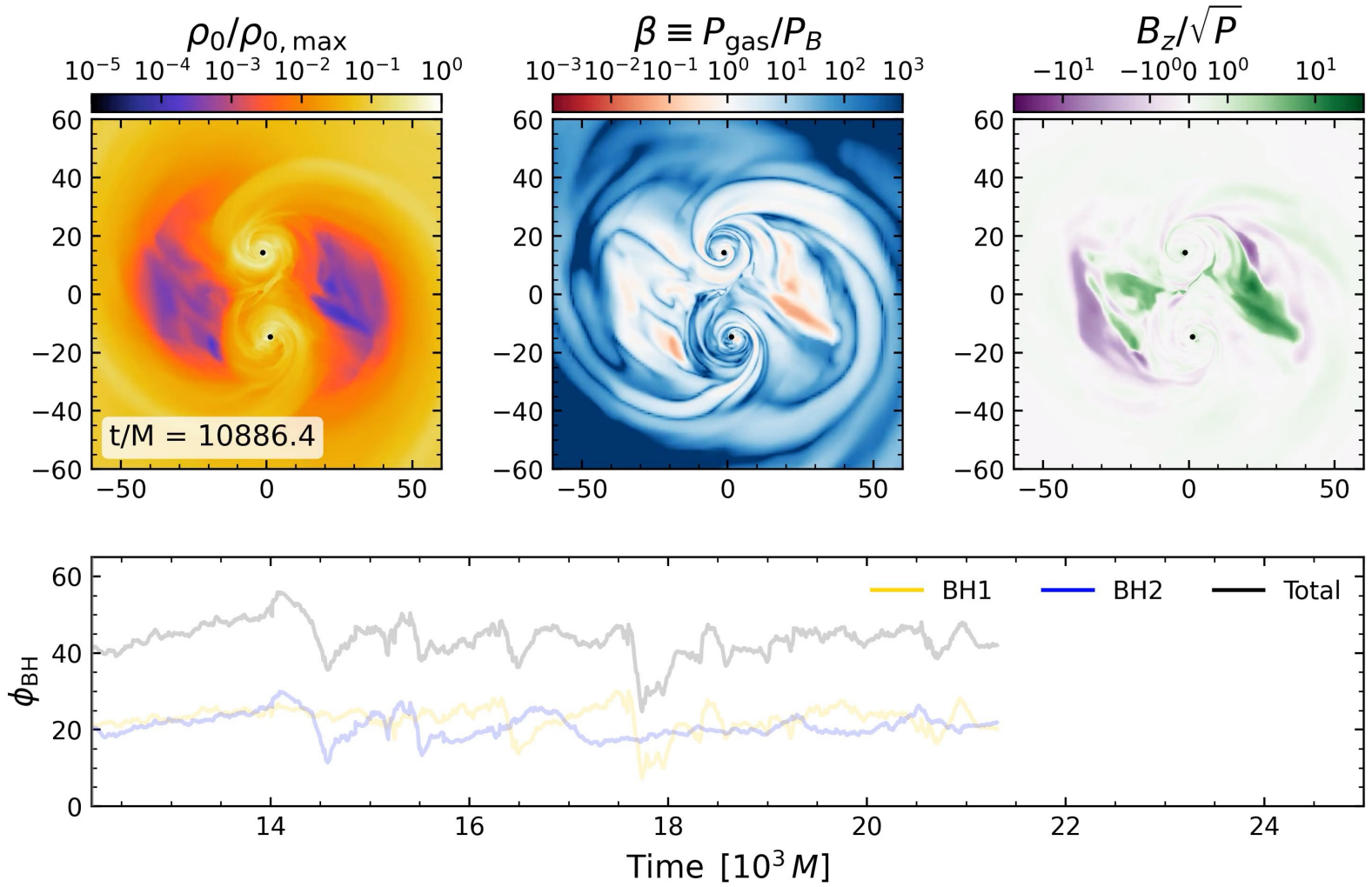
Goal of this work: Large separation

- Binary now at d=30M
- Nonspinning, quasicircular, equal mass
- Initialize binary with magnetized circumbinary disk
- Tidal streams circularize to form minidisks
- Minidisks accrete onto each BH



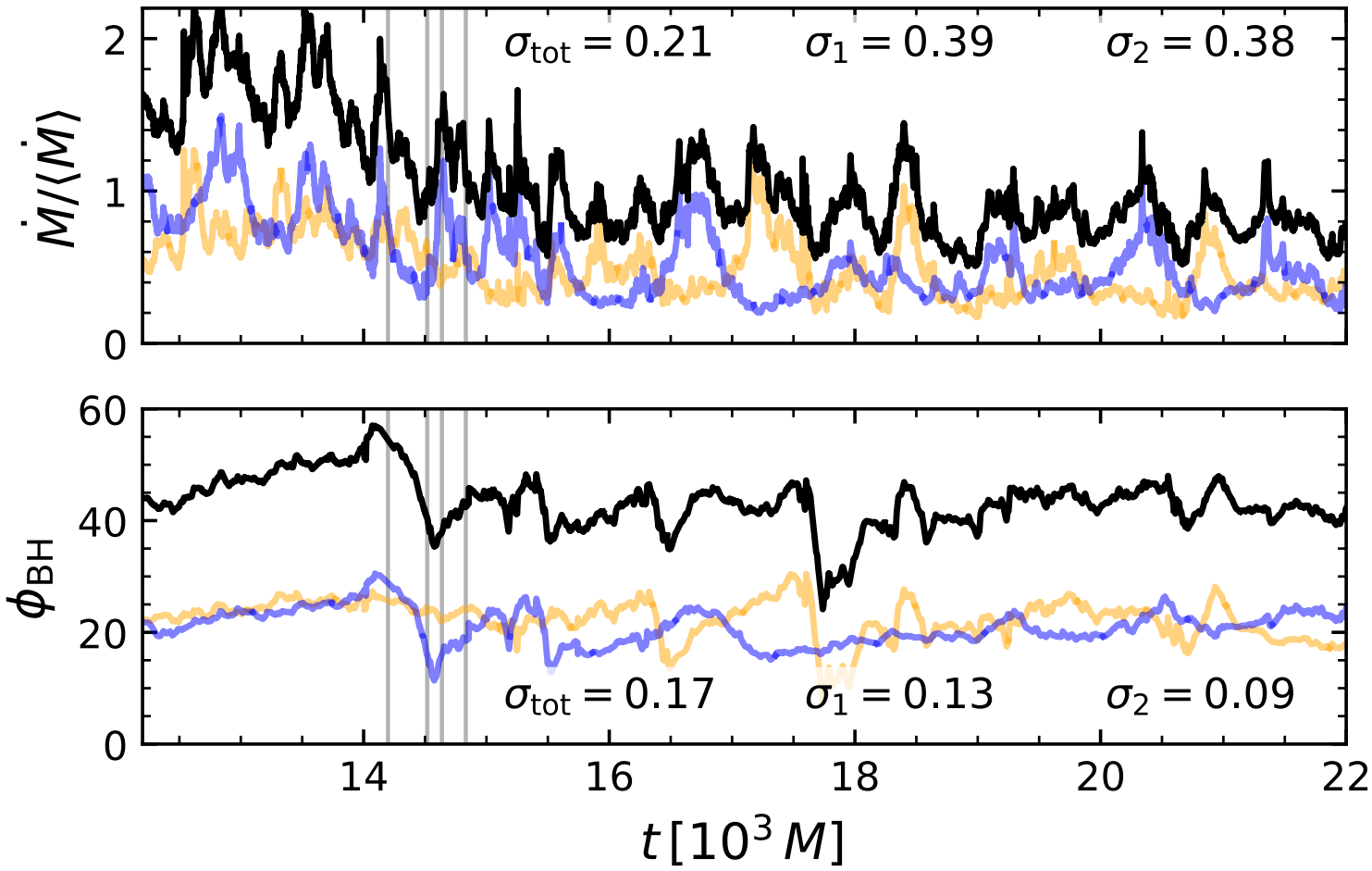
Magnetically Arrested Minidisks

- Minidisks bring magnetic flux to the horizons and saturate the horizons!
- Flux erupts from the horizon, proceeds through the minidisk and into the cavity

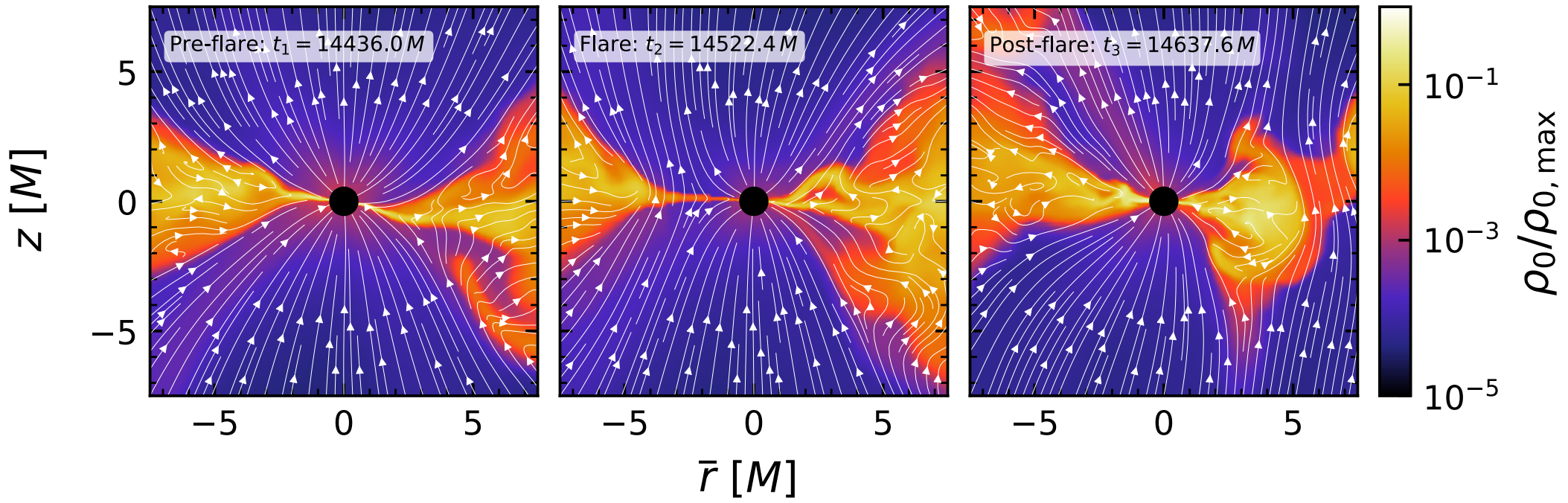


Horizon flux and accretion rate

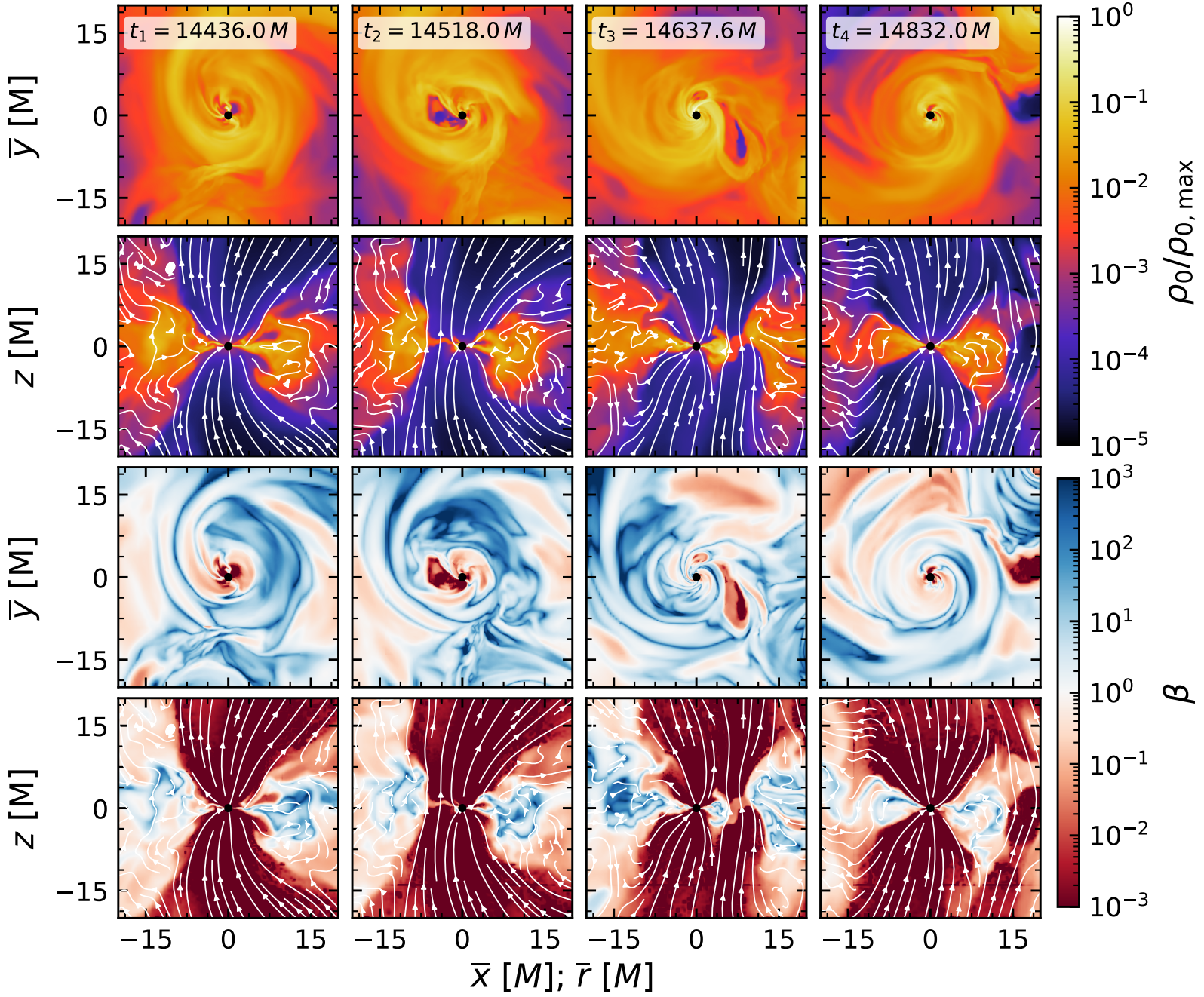
- Accretion is periodic still
- Horizon flux saturates, but at a lower value than a lot of single SMBH simulations



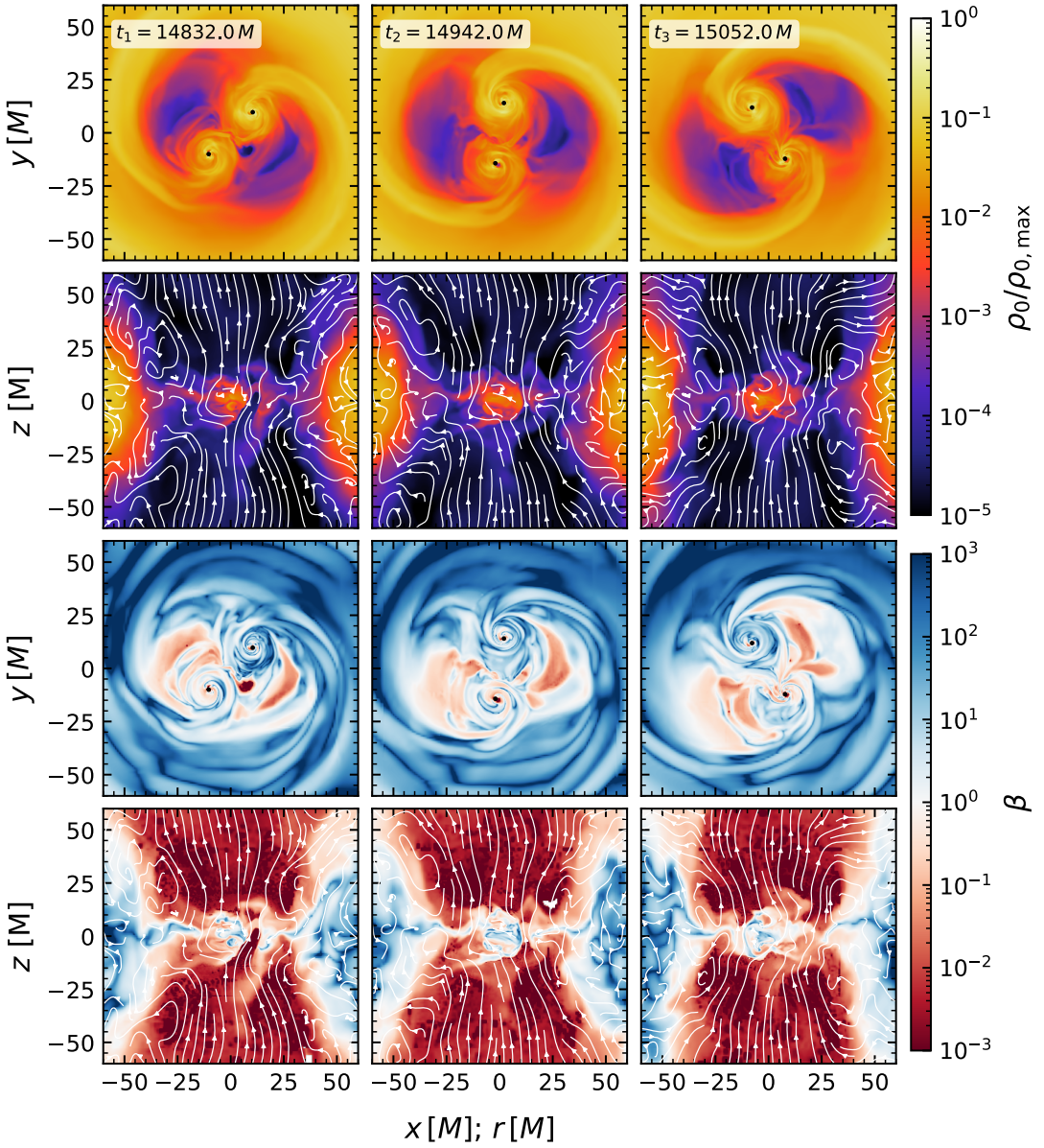
Horizon scale flux eruption



Journey through the minidisk

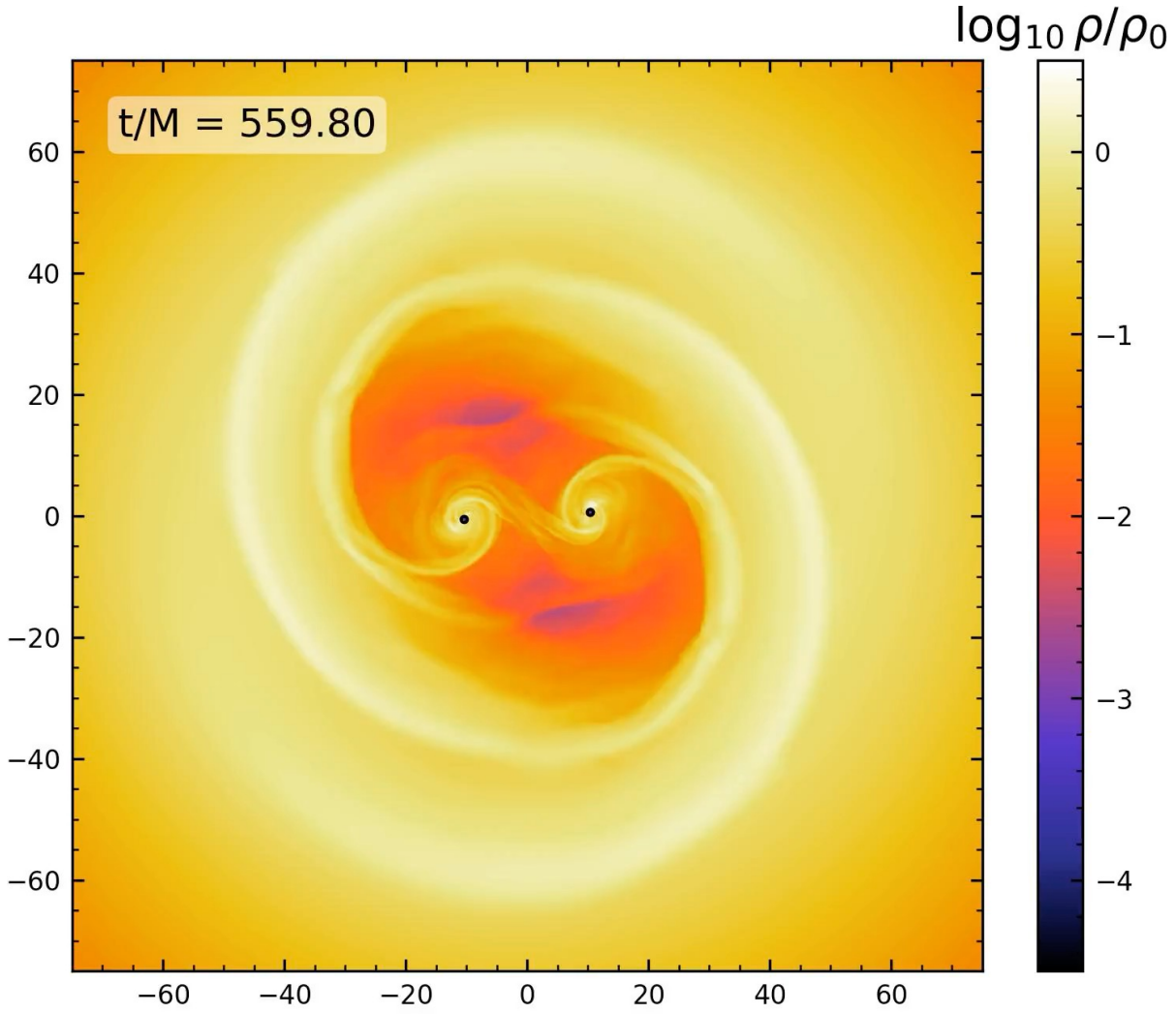


…into the cavity



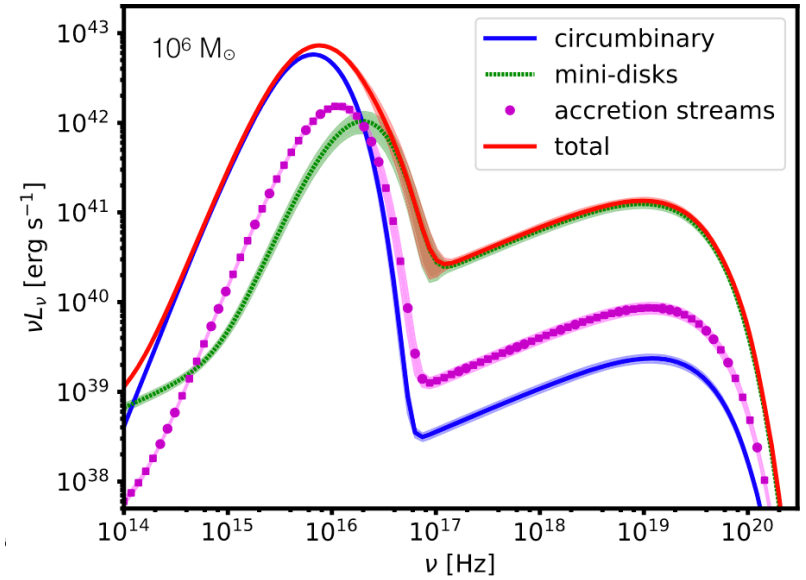
Flux eruptions in other simulations

- Magnetic flux eruptions approaching merger
- Remnant will likely be born in magnetic field, promptly launching a jet

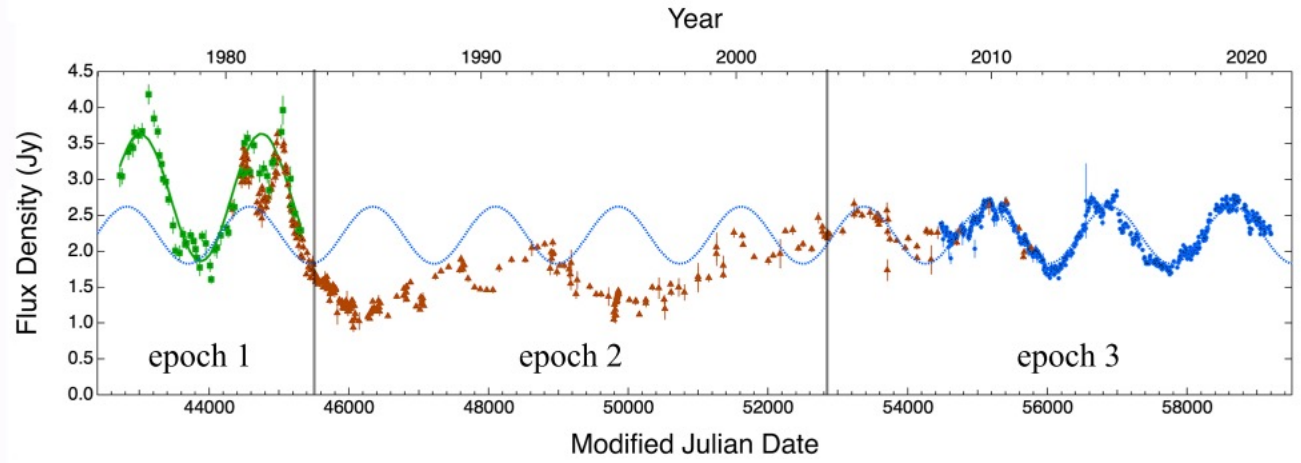


Implications for MMA

- Observations (confirmations) of SMBBH rely on periodicity
- Flux eruptions will have an impact on accretion and the observed light curve/SED



Expected emission from CBD and minidisks; adapted from d'Ascoli+2018

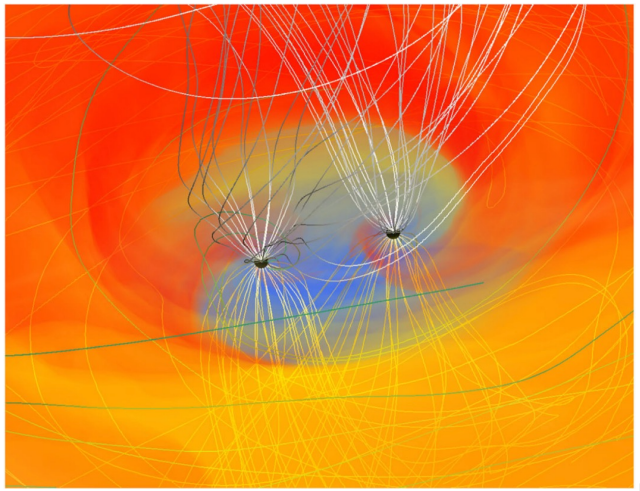


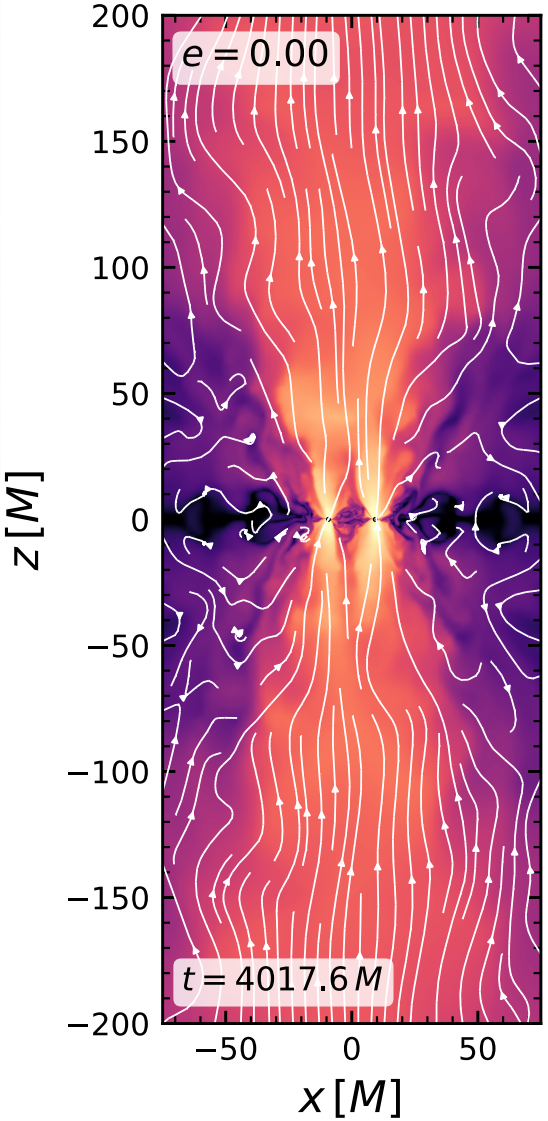
15GHz light curve of PKS 2131-102, O'Neill+2022

Future work

- What role will jets have to play?
- What about binary mass ratio?
- We need longer simulations, and a ‘relaxed’ circumbinary disk?
- Need to explore disk parameters!
- What is the effect of flux eruptions on observables?

Gold, Paschalidis+2014





Magnetically Arrested Minidisks

- Binary black holes at separation d/M > 30 will form large minidisks
- With enough magnetic flux, they will become magnetically arrested minidisks
- Significant implications for the evolution of the accretion flow and for observable signatures of SMBBHs

- "Binary black holes gone MAD: Magnetically arrested minidisks around nonspinning black holes" Manikantan & Paschalidis, 2025, accepted to PRD, arXiv:2509.18254.