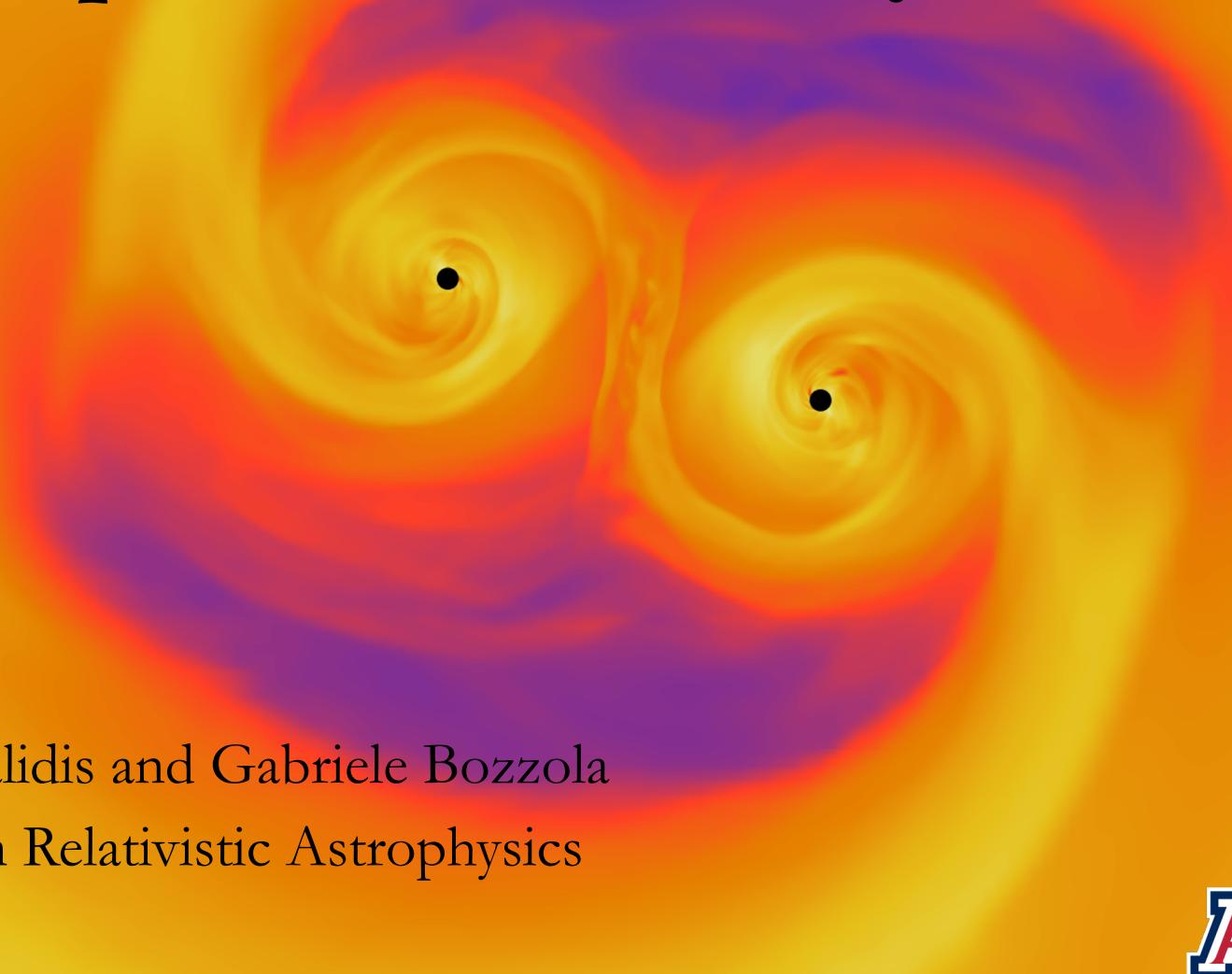


Coincident Multimessenger Bursts from Eccentric Supermassive Binary Black Holes

(SMBBH)



Vikram Manikantan

with Vasileios Paschalidis and Gabriele Bozzola

Texas Symposium on Relativistic Astrophysics

10th Dec. 2025



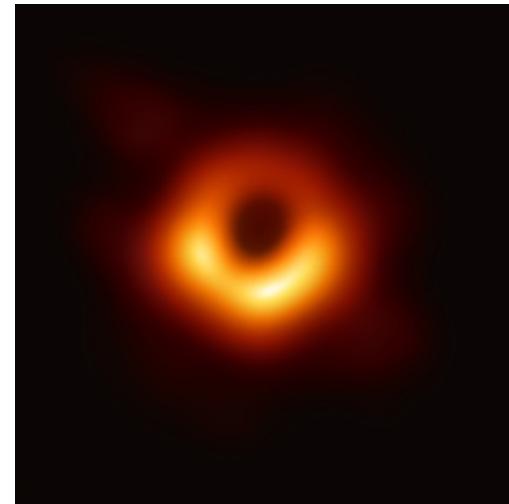
Astronomy
& Steward Observatory

SMBBHs Expected to be Ubiquitous Multimessenger Sources

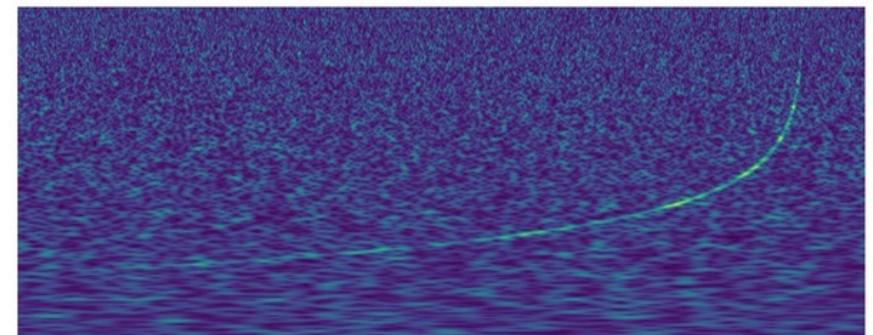
- Product of galaxy mergers (Begelman+1980)
- Gravitational waves (GW) from inspiral and electromagnetic (EM) emission from accretion (Bogdanovic+2022, LISA+2023)
- Extremely useful sources, e.g. providing an independent measure of H0 and universe's expansion (Schulz 1986, Holz+2005)



NGC 4676, Credits: NASA/ESA



M87*, EHT Collaboration



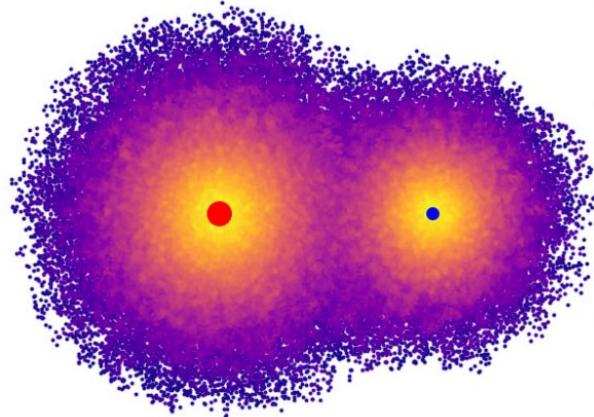
LIGO, GW170817 chirp signal

SMBH evolution spans \sim 10 orders of magnitude

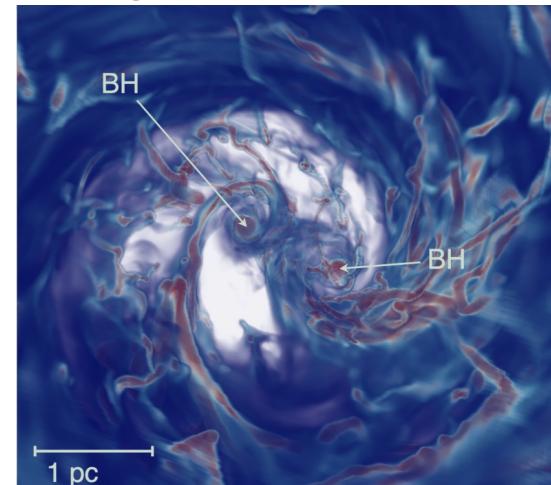
NGC 4676, Credits: NASA/ESA



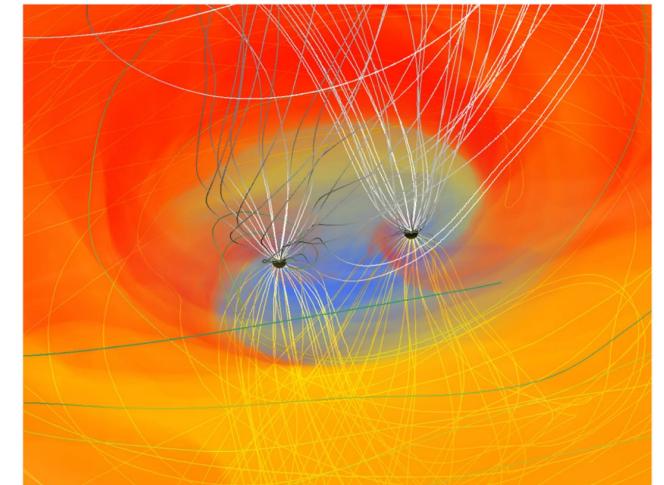
Sobolenko+2021



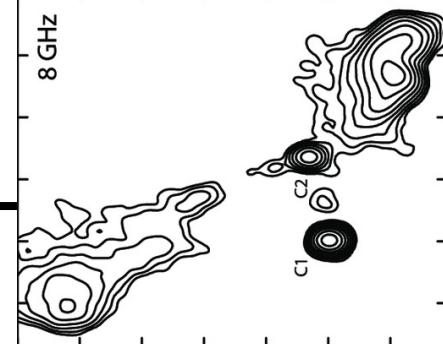
Wang+2025



Gold, Paschalidis+2014



Galactic scales
 > 10 kpc



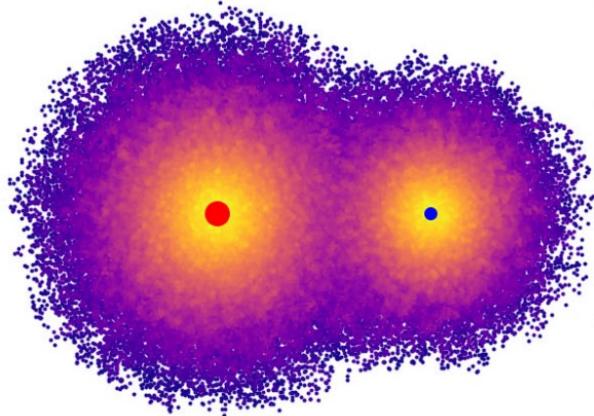
Horizon scales
 $\sim 1 \mu\text{pc}$

I study the late inspiral, dynamical spacetime regime

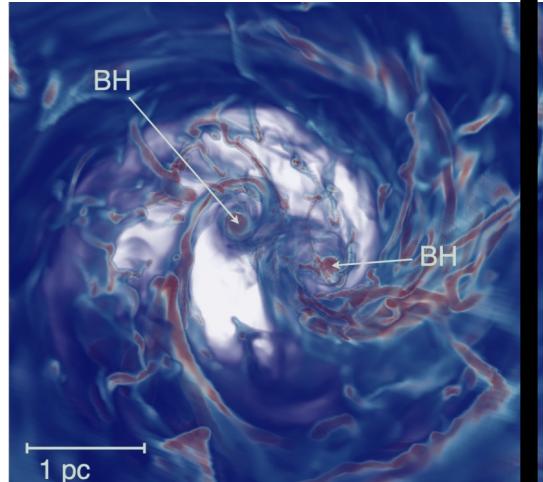
NGC 4676, Credits: NASA/ESA



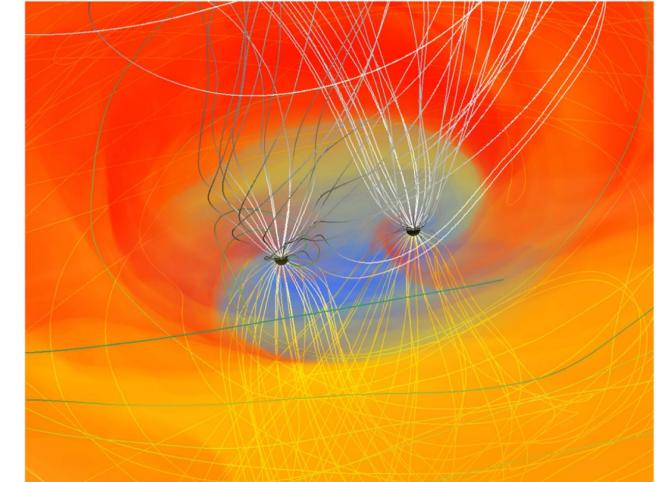
Sobolenko+2021



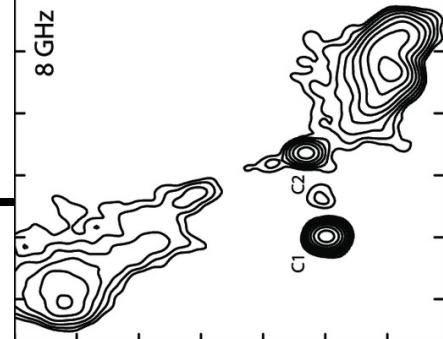
Wang+2025



Gold, Paschalidis+2014



Galactic scales
 > 10 kpc

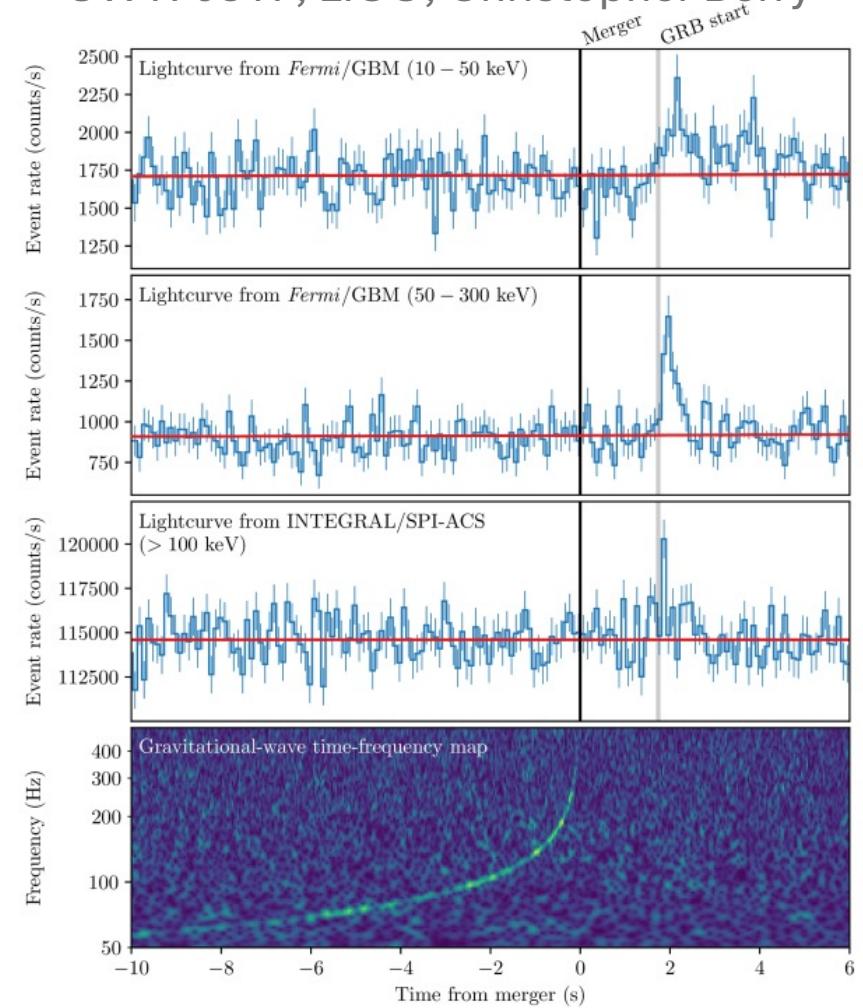


Horizon scales
 $\sim 1 \mu\text{pc}$

Looking forward to Multimessenger Astronomy with LISA/PTAs

- Multimessenger astronomy (GW + EM) has been starved since GW170817
- Goal is to have coincident multiwavelength electromagnetic and GW observations
- Localizing GW sources is difficult (see S250818k)
- How do we uniquely identify SMBBHs?
- Multiwavelength and multimessenger modelling of SMBBHs has to start now!

GW170817, LIGO; Christopher Berry

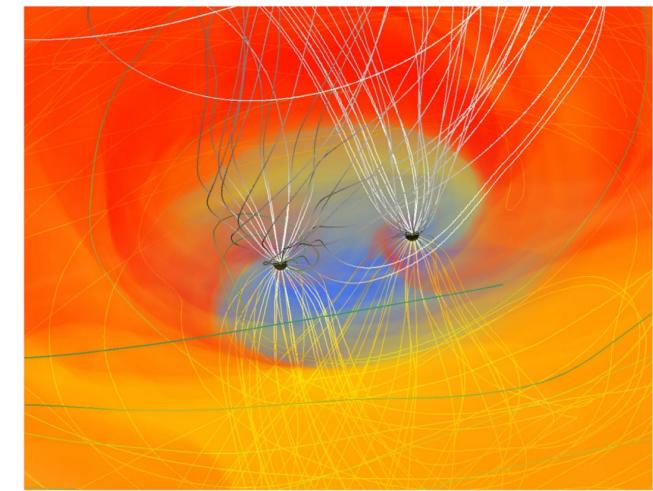


Multiwavelength and Multimessenger modelling of SMBHs

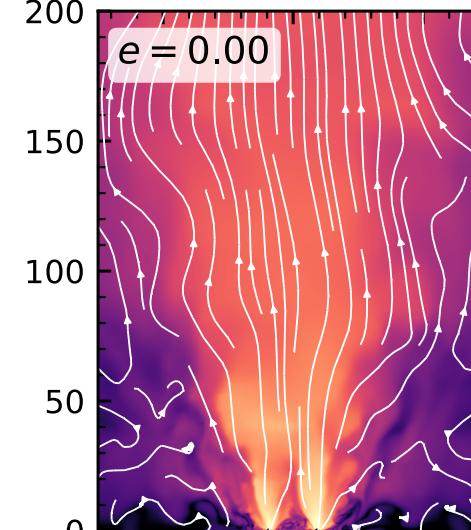
- Modelling gravitational waves requires evolving Einstein's equations
- Modelling electromagnetic emission requires understanding the magnetized accretion flow and outflows
- Therefore, we run fully general-relativistic magnetohydrodynamic simulations
- Using the Einstein toolkit



Gold, Paschalidis+2014

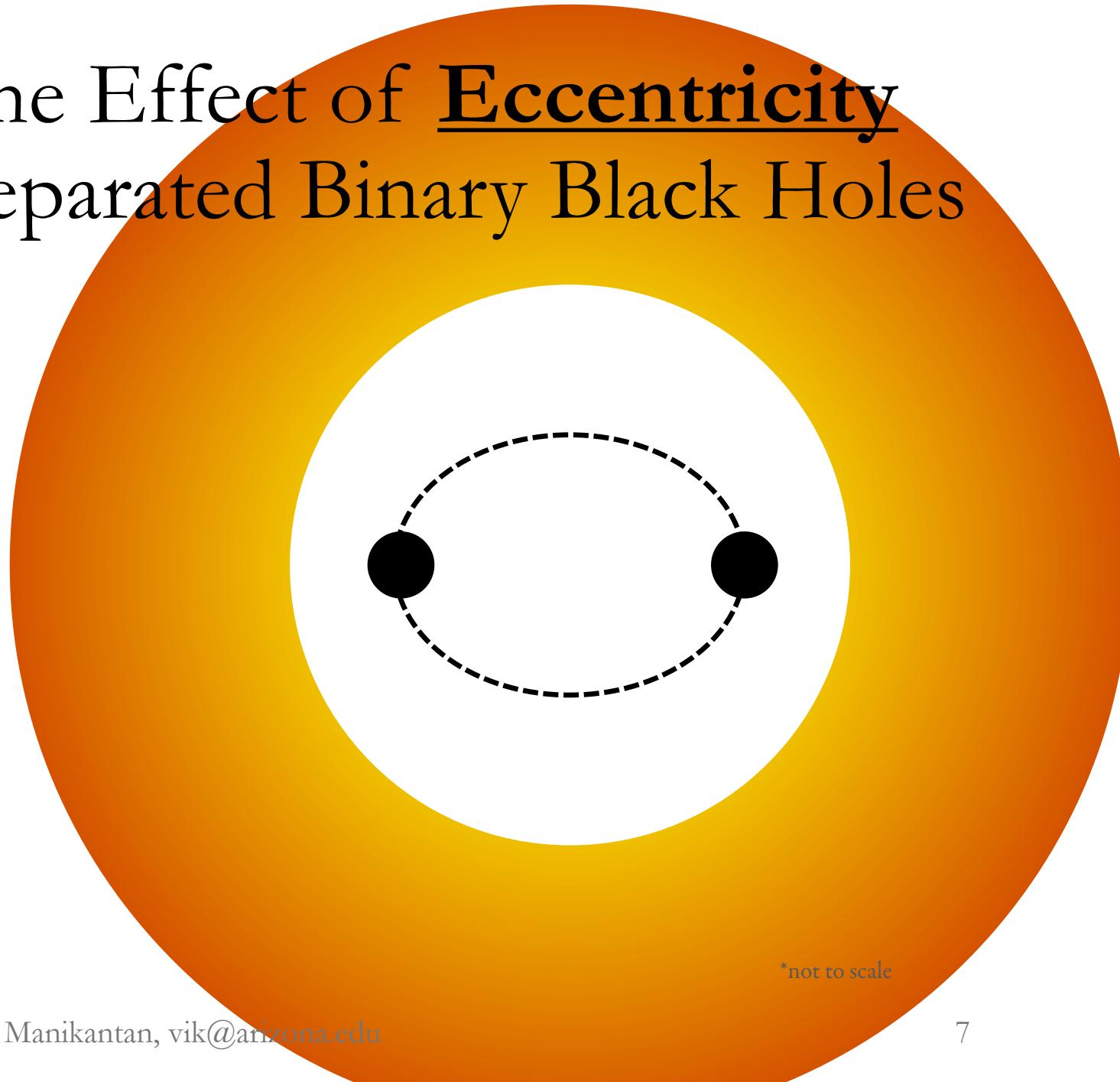


Manikantan+2025

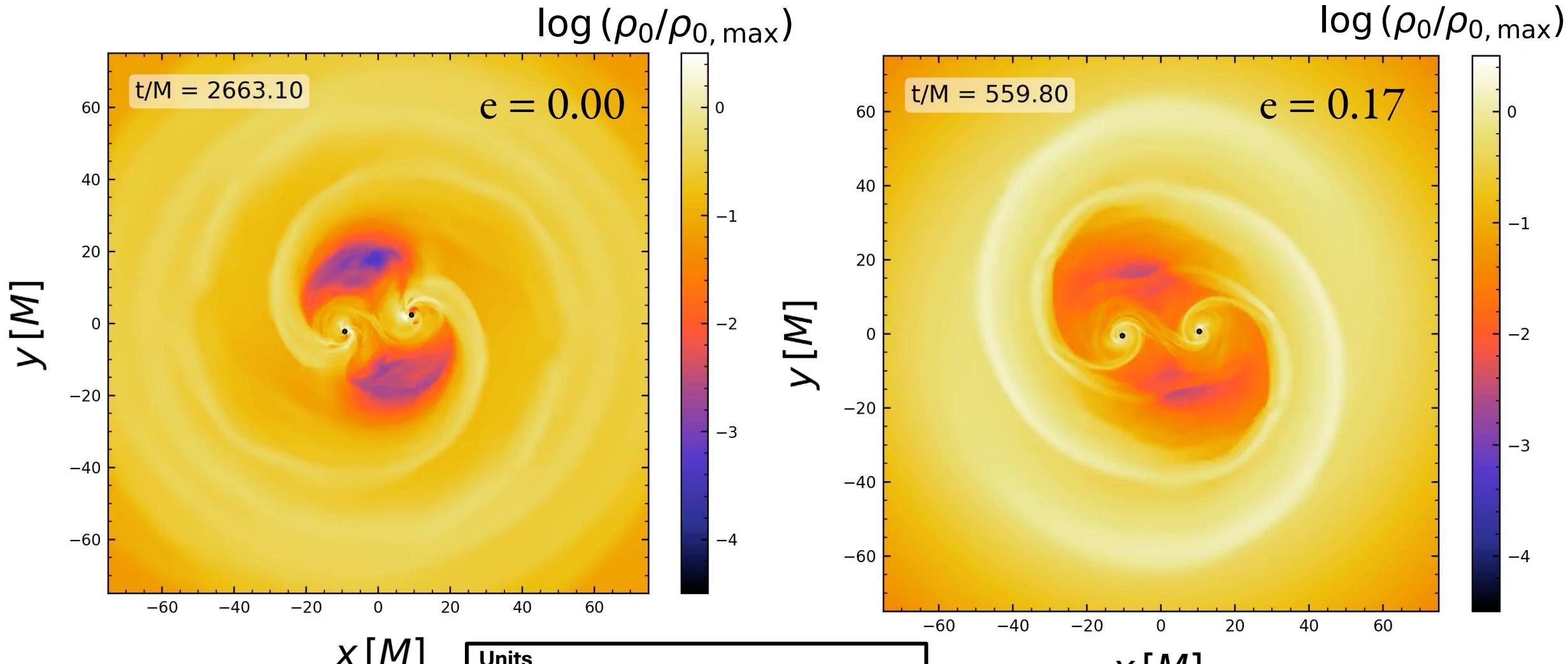


Goal: Understand the Effect of Eccentricity on Relativistically Separated Binary Black Holes

- Binary black holes are equal mass and have no spin
- Eccentricities: $e = 0.00, 0.17, 0.31$ (Roedig+2011, Ryu+2018, Siwek+2024)
- Separation of $\sim 20 \text{ GM}/c^2$ (~ 25 orbits from merger)
- Circumbinary disk with poloidal magnetic field



*not to scale



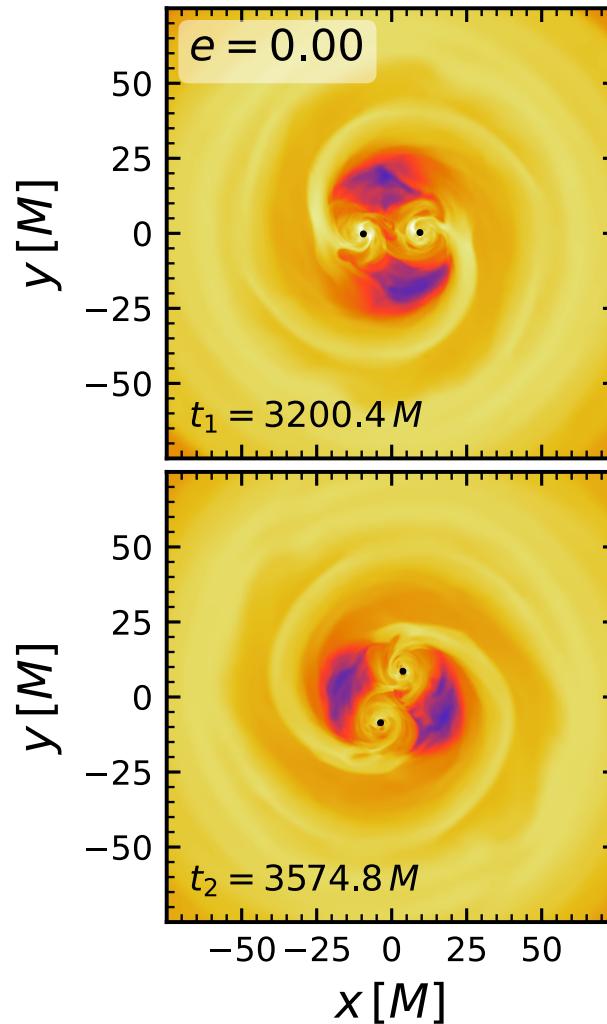
Units

Time: $1M \sim 0.84 (M_{tot}/10^7 M_\odot)$ minutes

Space: $1M \sim 4 \times 10^{-4} (M_{tot}/10^7 M_\odot)$ mpc

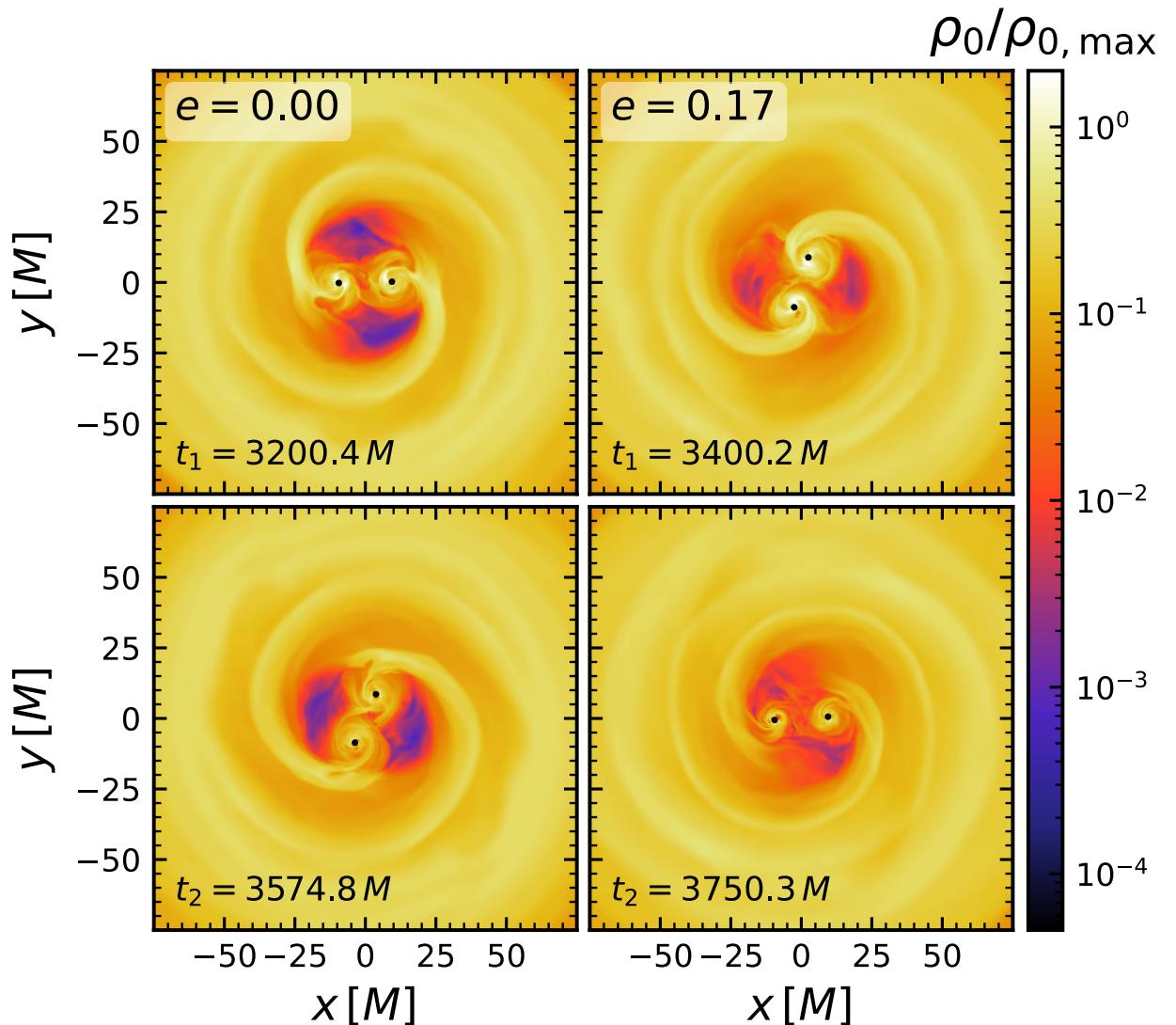
Quasicircular binaries form minidisks

- Tidal streams circularize around BBH
- Form minidisks and then accrete
- Quasicircular binary has persistent structure

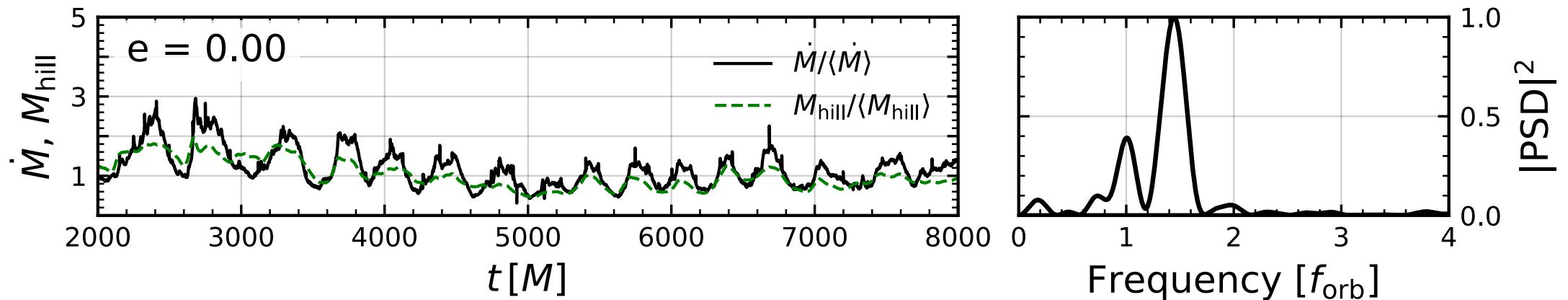


Eccentric Binaries don't Sustain Minidisks

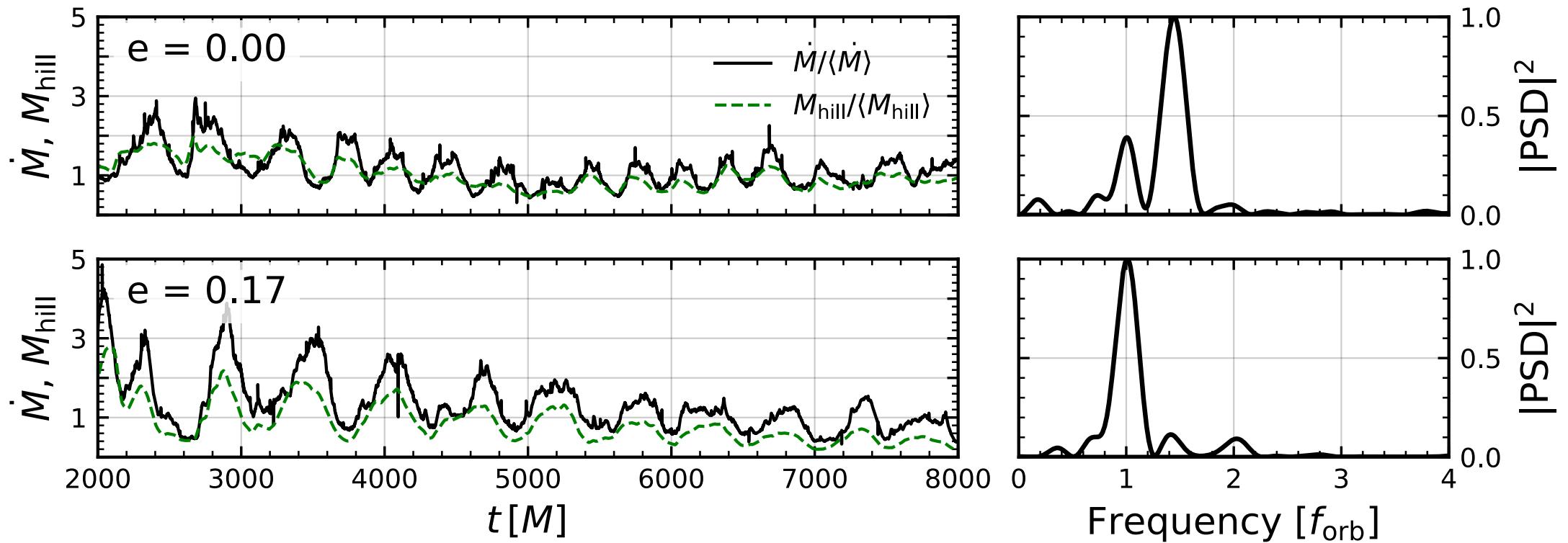
- Tidal streams circularize around BBH
- Form minidisks and then accrete
- Quasicircular binary has persistent structure
- Eccentric Binaries don't sustain minidisks (at these separations)



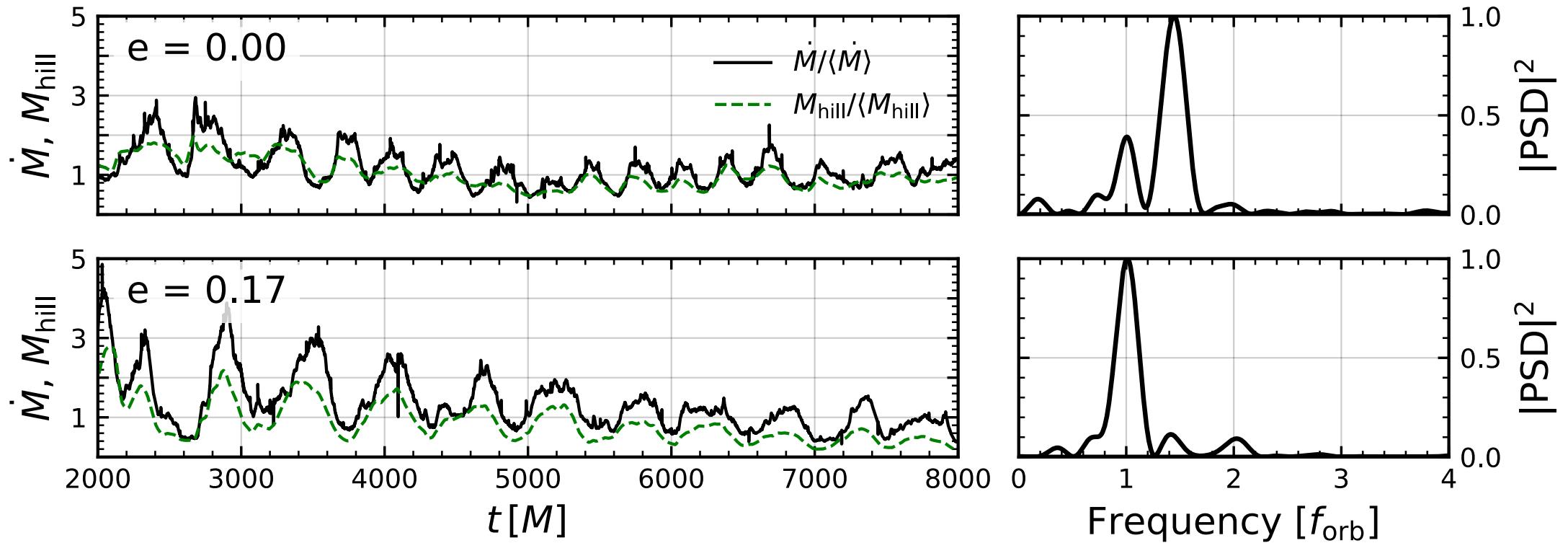
Quasicircular binaries accrete at $\sim 1.4 f_{\text{orb}}$



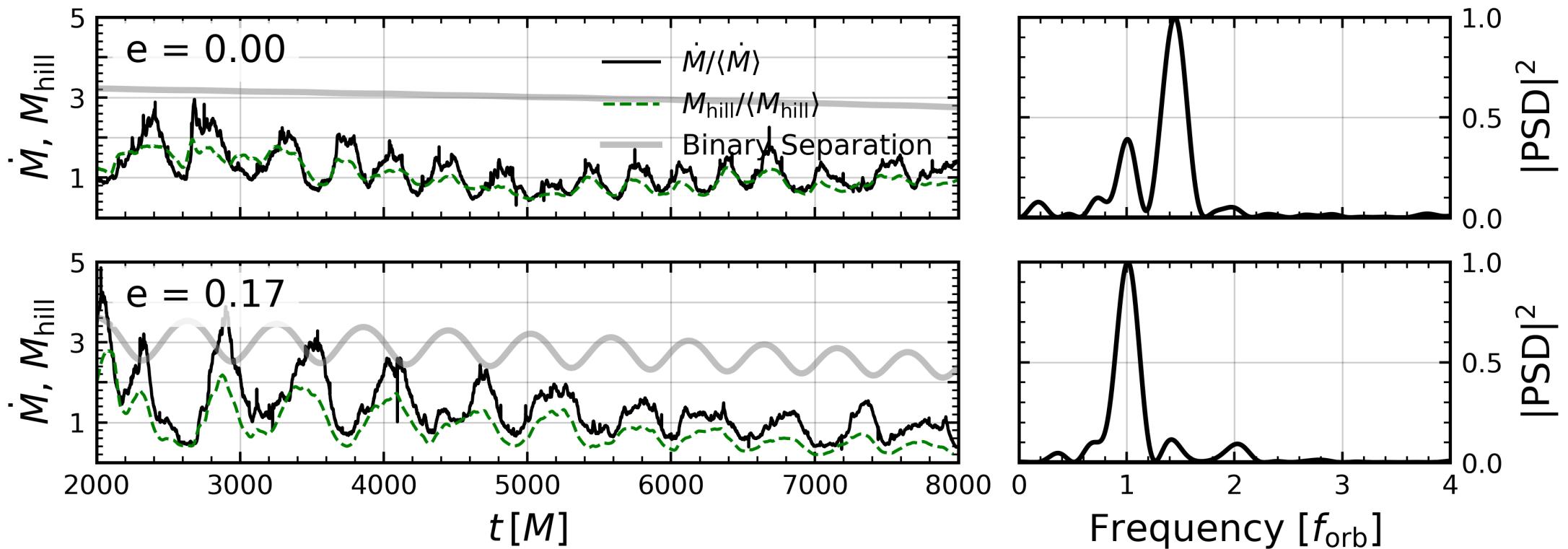
Eccentric Binaries Accrete at their Orbital Frequency



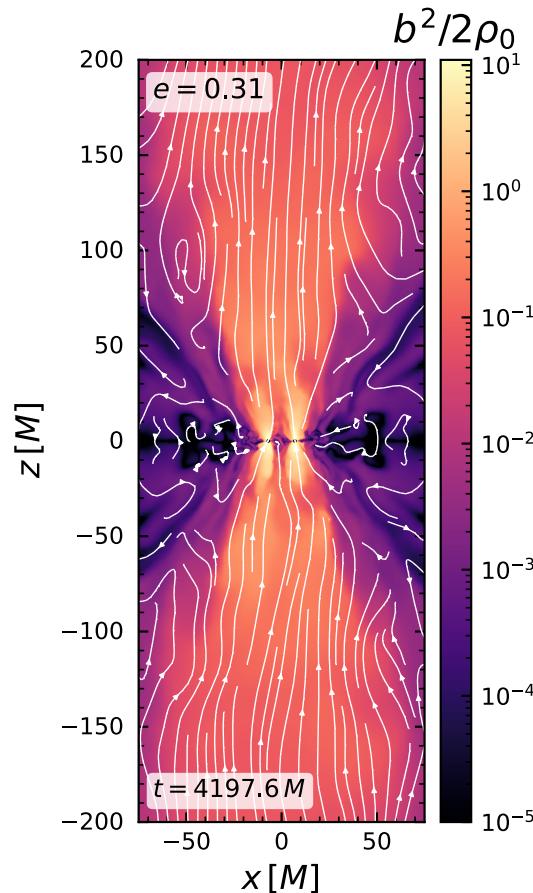
Accretion is Driven By Pericenter Approach



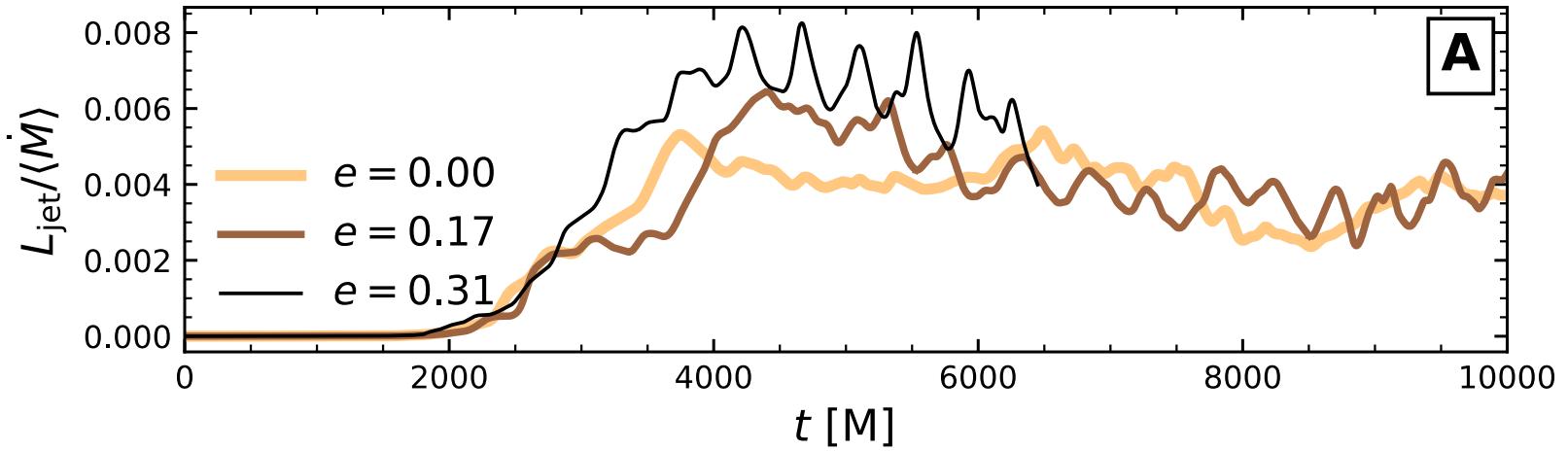
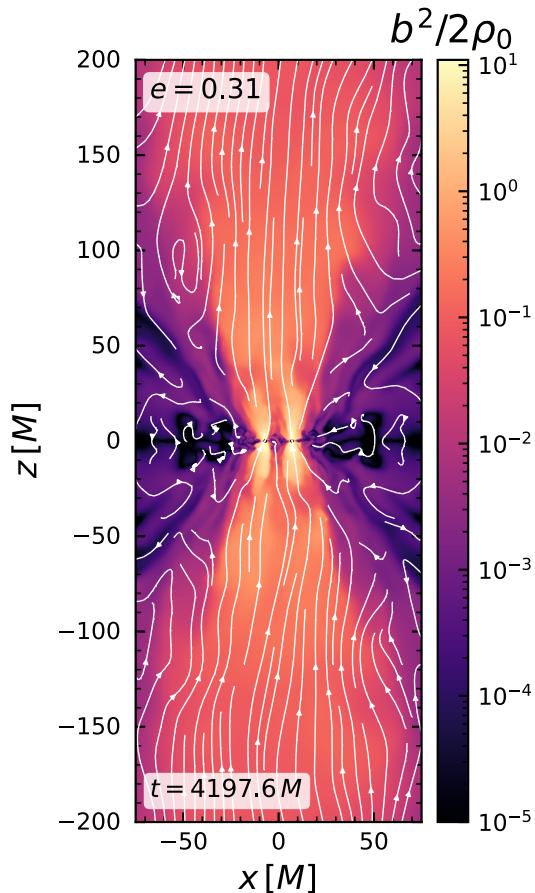
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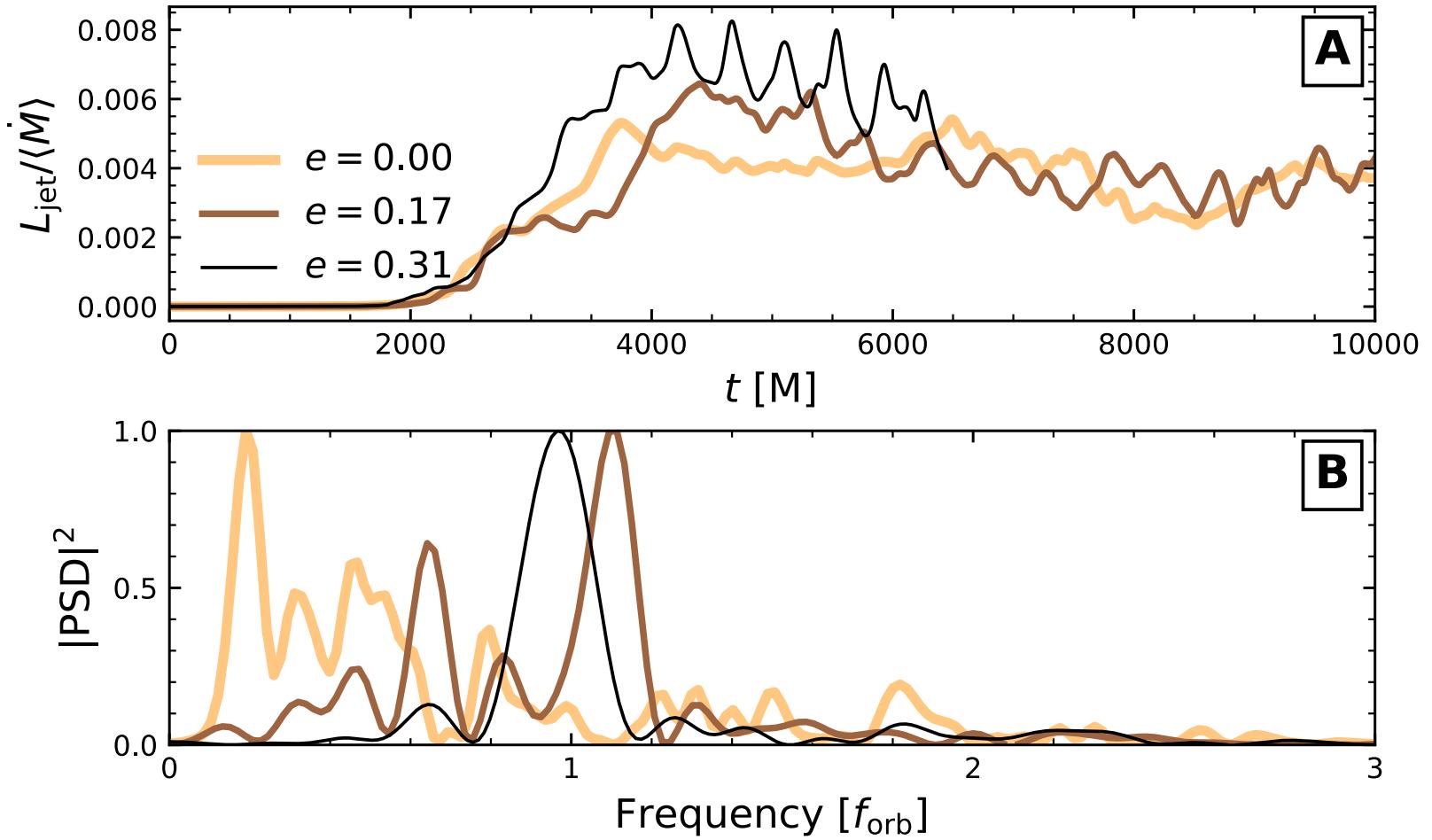
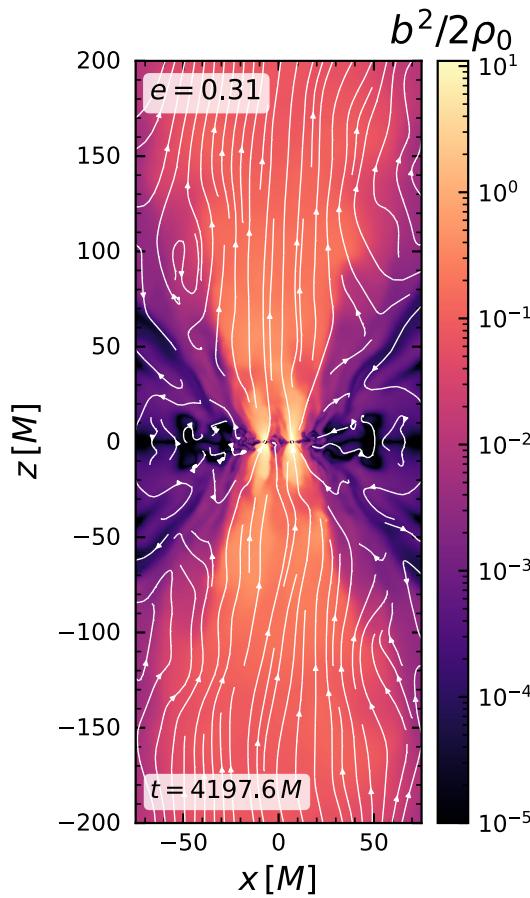
Eccentric binaries have variable jets



Eccentric binaries have variable jets

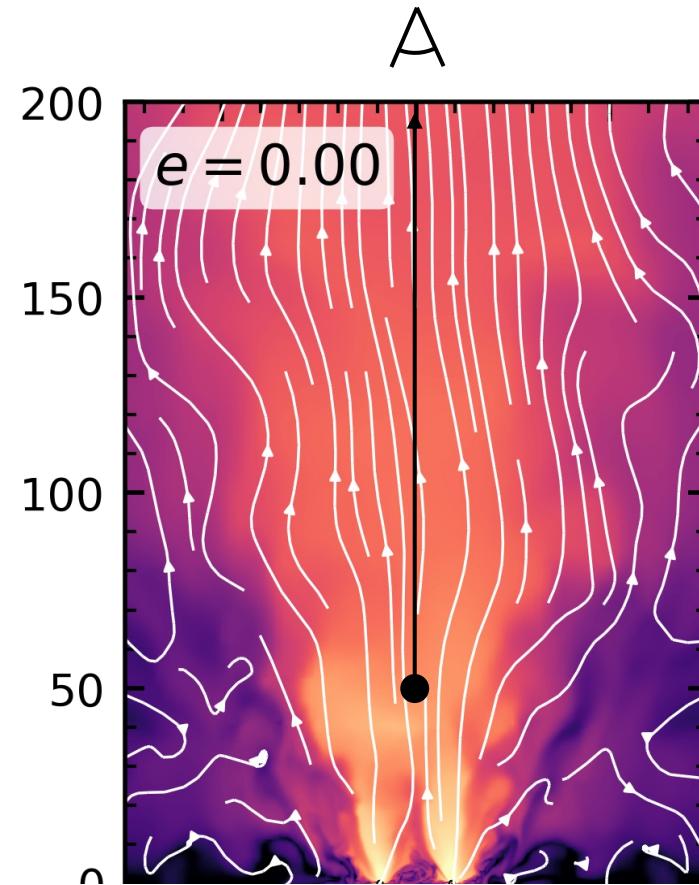


And, jet variability is on the orbital period

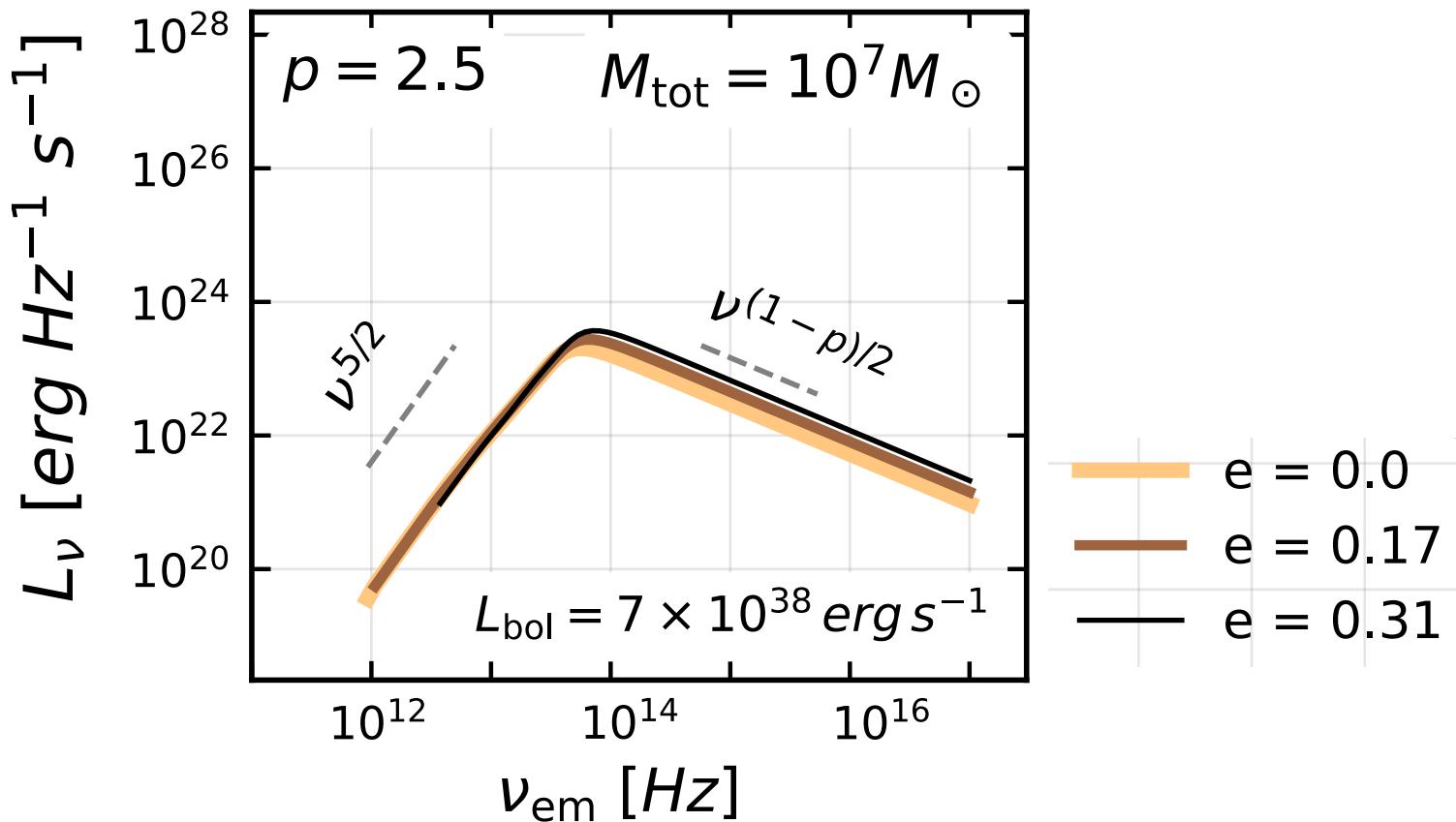


Synchrotron Radiative Transfer of Jet Emission

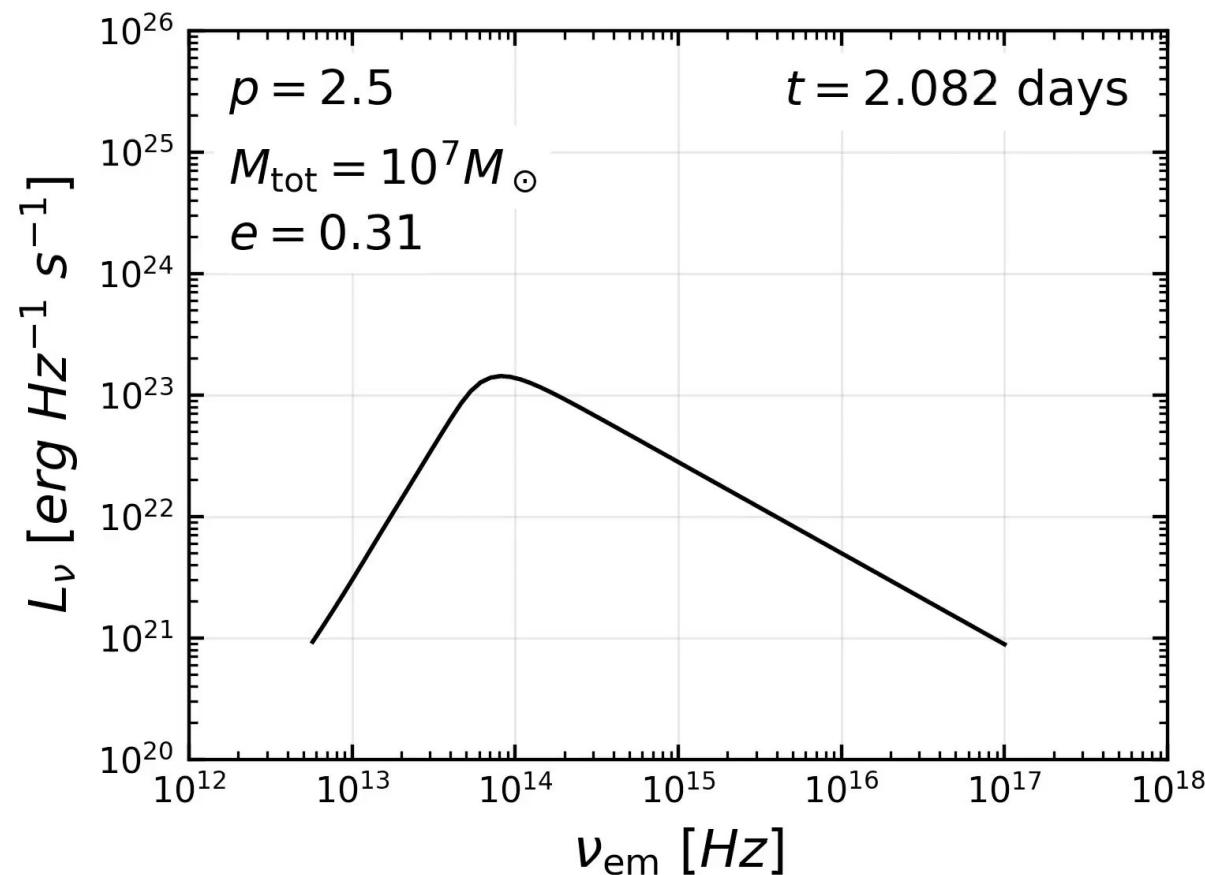
- Looking down the barrel of the jet (i.e. blazar)
- Powerlaw electron distribution in equipartition with the magnetic field energy density
- Assumptions:
 1. Fast-light
 2. Non-relativistic
 3. height $> 50 \text{ M}$
 4. 10% Eddington
 5. 10% radiative efficiency



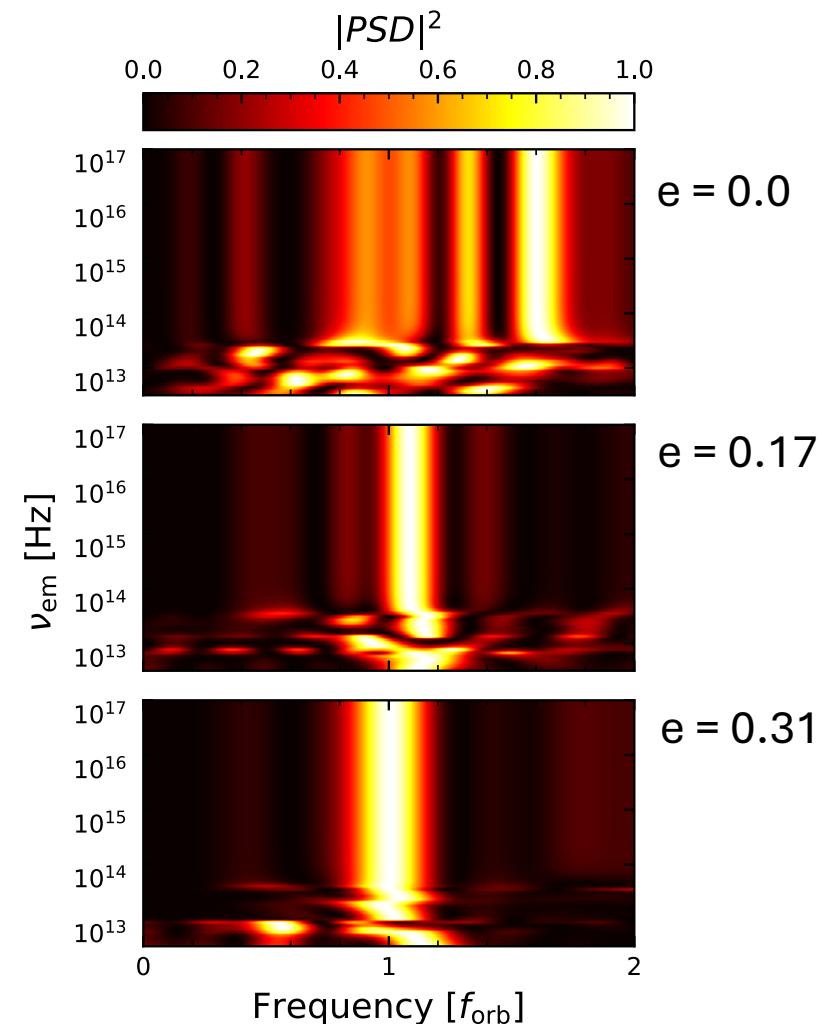
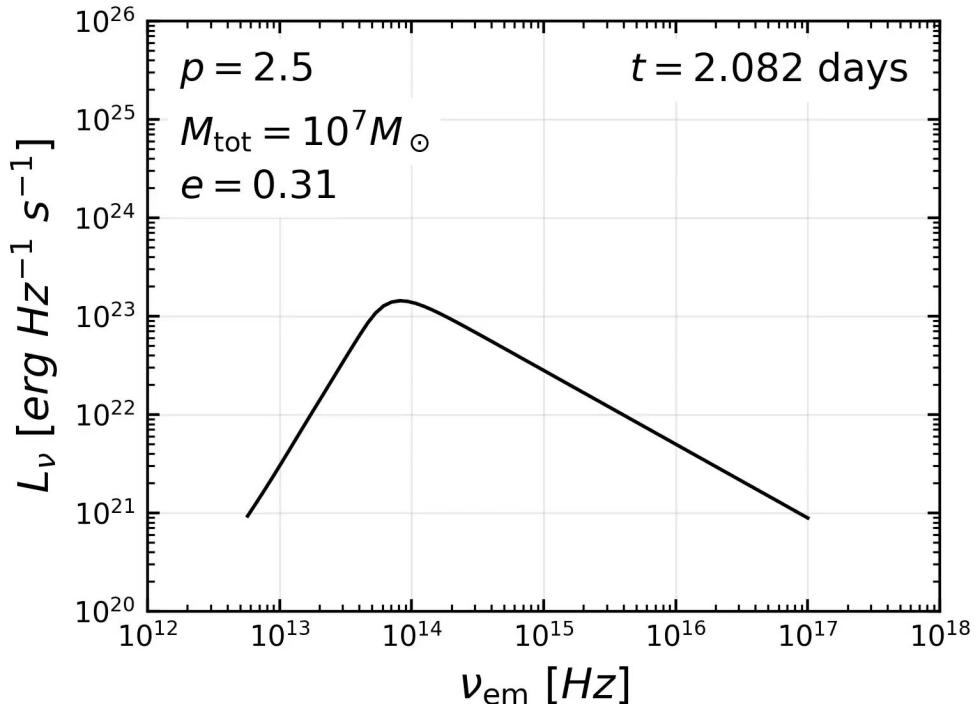
Recover the Typical Synchrotron SED



Time-dependent SED are Variable



Time-dependent SED are Variable



Coincident EM and GW Bursts

- Gravitational waves, jet power, and synchrotron emission all ‘burst’ at the same time and at equal intervals
- Not sinusoidal
- Smoking gun signature of eccentric SMBBHs

arXiv: 2411.11955

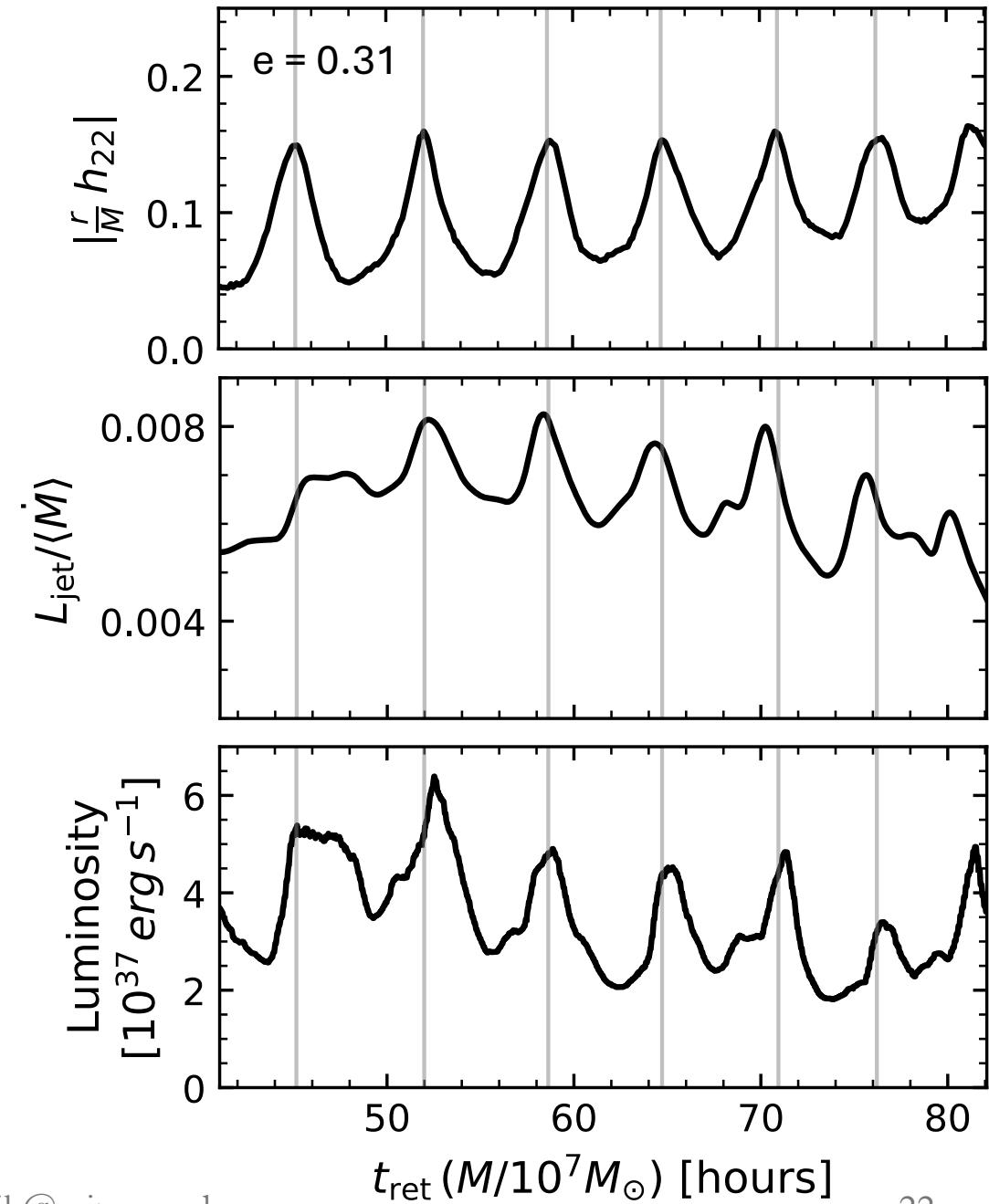


ApJL, 984 L47

arXiv: 2504.12375

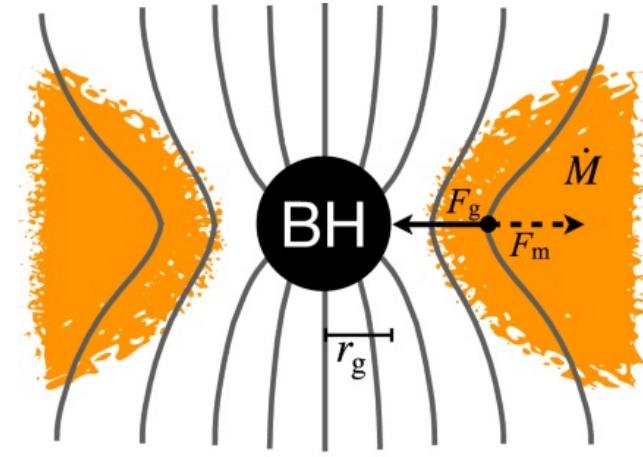


PRD, 112, 043004



Since I have more time... magnetically arrested minidisks

- Magnetic flux accumulates on the horizon and regulates accretion (Narayan+2003)
- Magnetically arrested disks (MAD) are a common end state in single BH accretion (Jacquemin+2022, Begelman+2022, Gottlieb+2023, Lalakos+2024)
- Can power flares in infrared and X-ray (Dexter+2020, Scepi+2022)
- Can binary black holes have magnetically arrested disks? Yes!

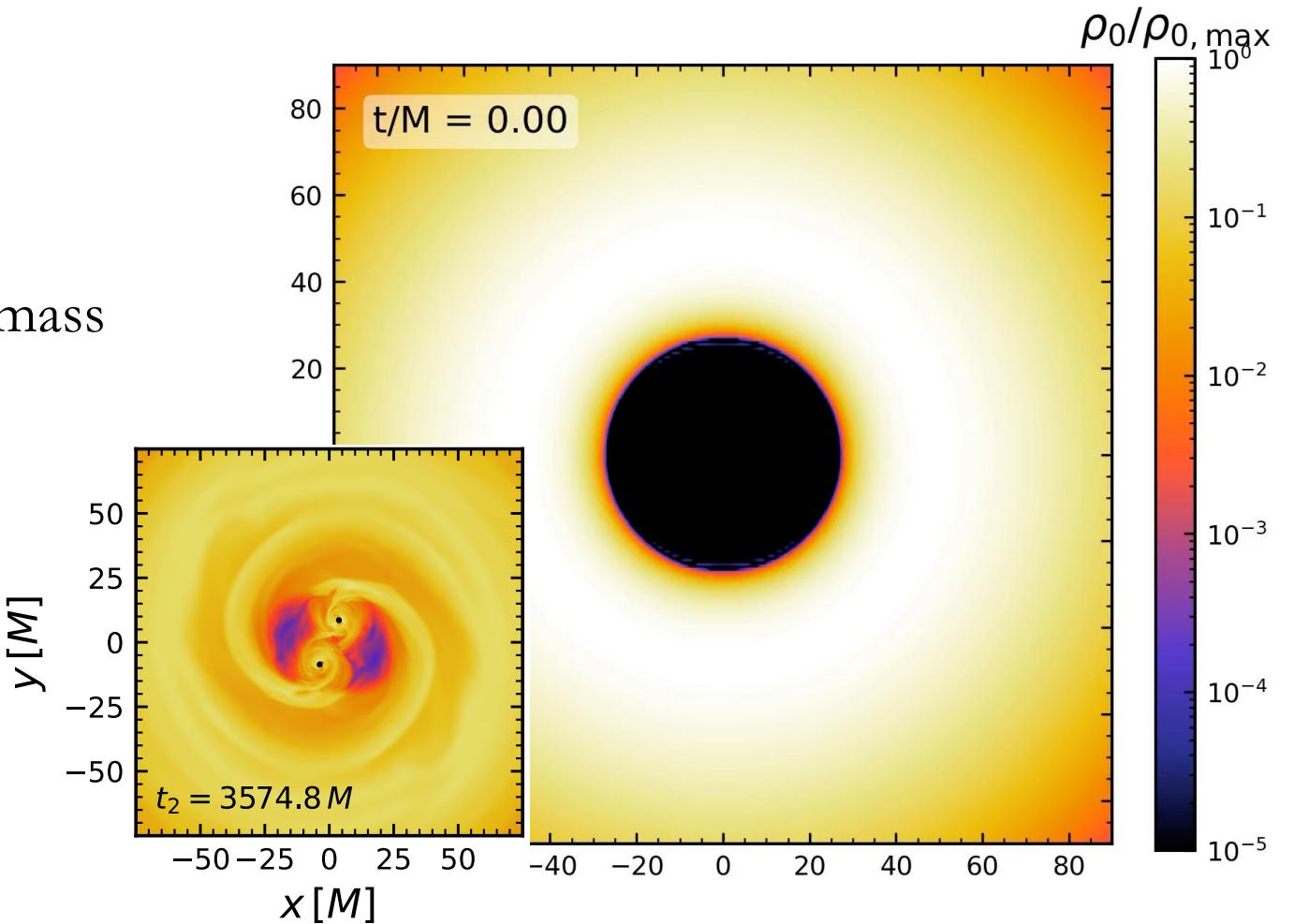


Hada+2024

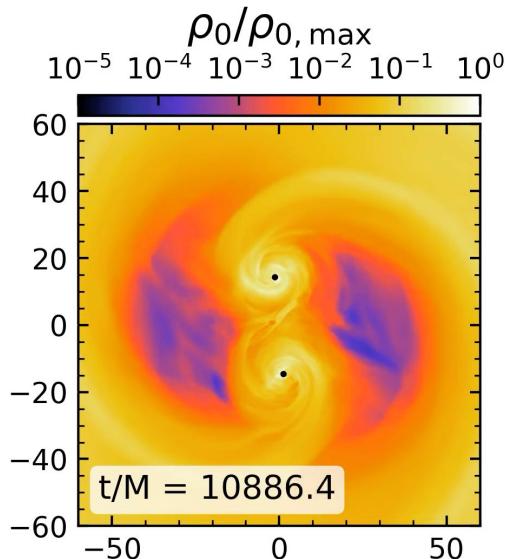
$$\phi_{BH} = \frac{\int B \, dS}{\sqrt{\dot{M}}}$$

BBHs at large relativistic separations form large minidisks

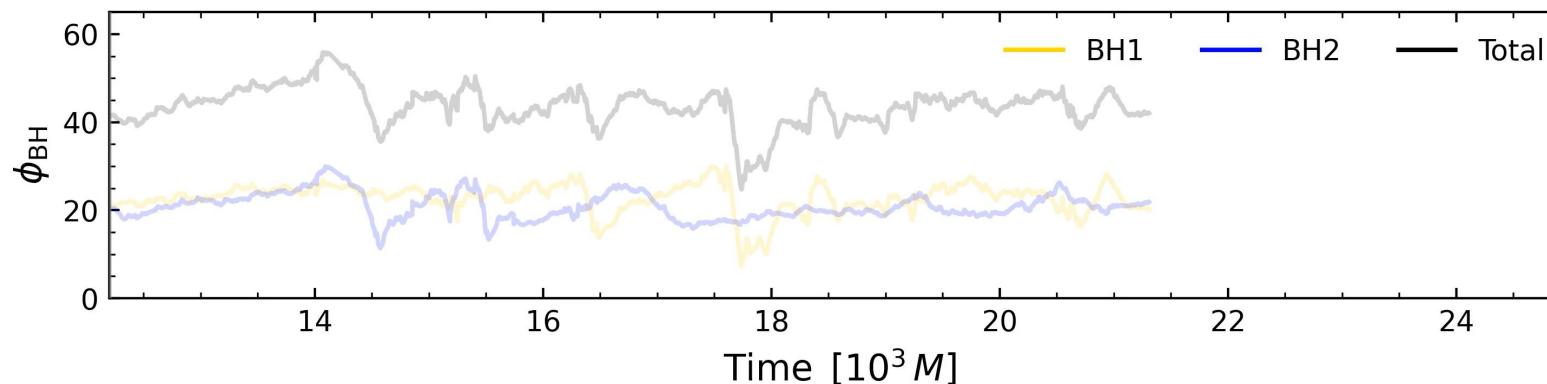
- Largest binary separation (~ 30 GM/c^2) studied in full general relativity and MHD
- Nonspinning, quasicircular, equal mass
- Initialize with a magnetized circumbinary disk
- Tidal streams circularize to form minidisks
- Minidisks accrete onto each BH



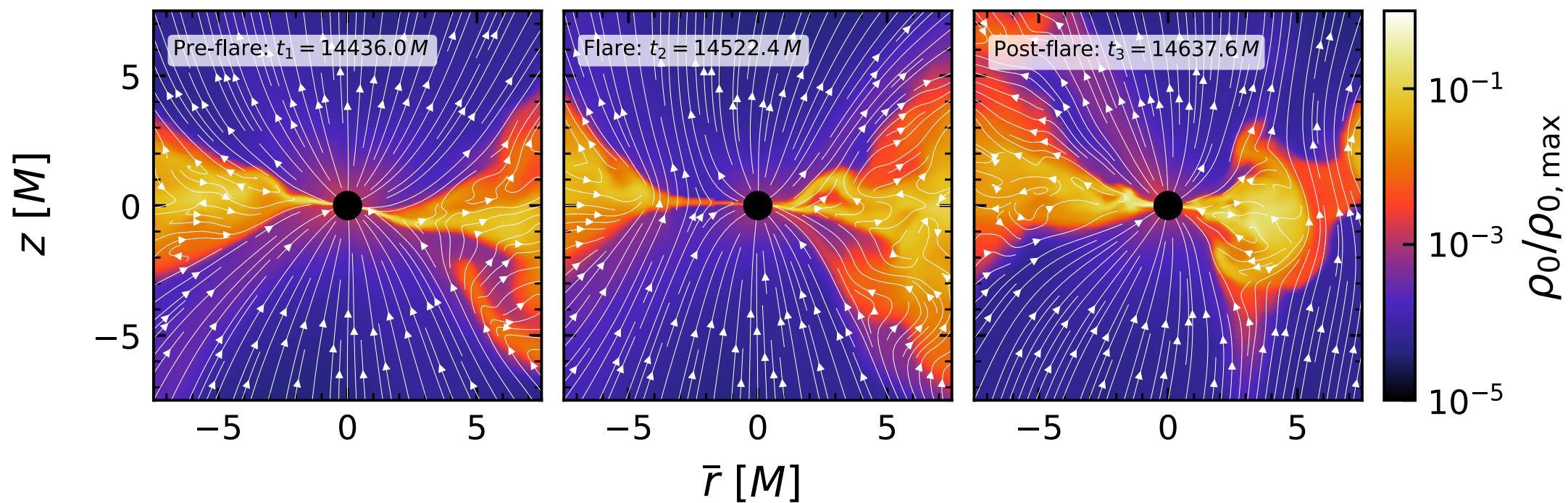
Those minidisks become magnetically arrested



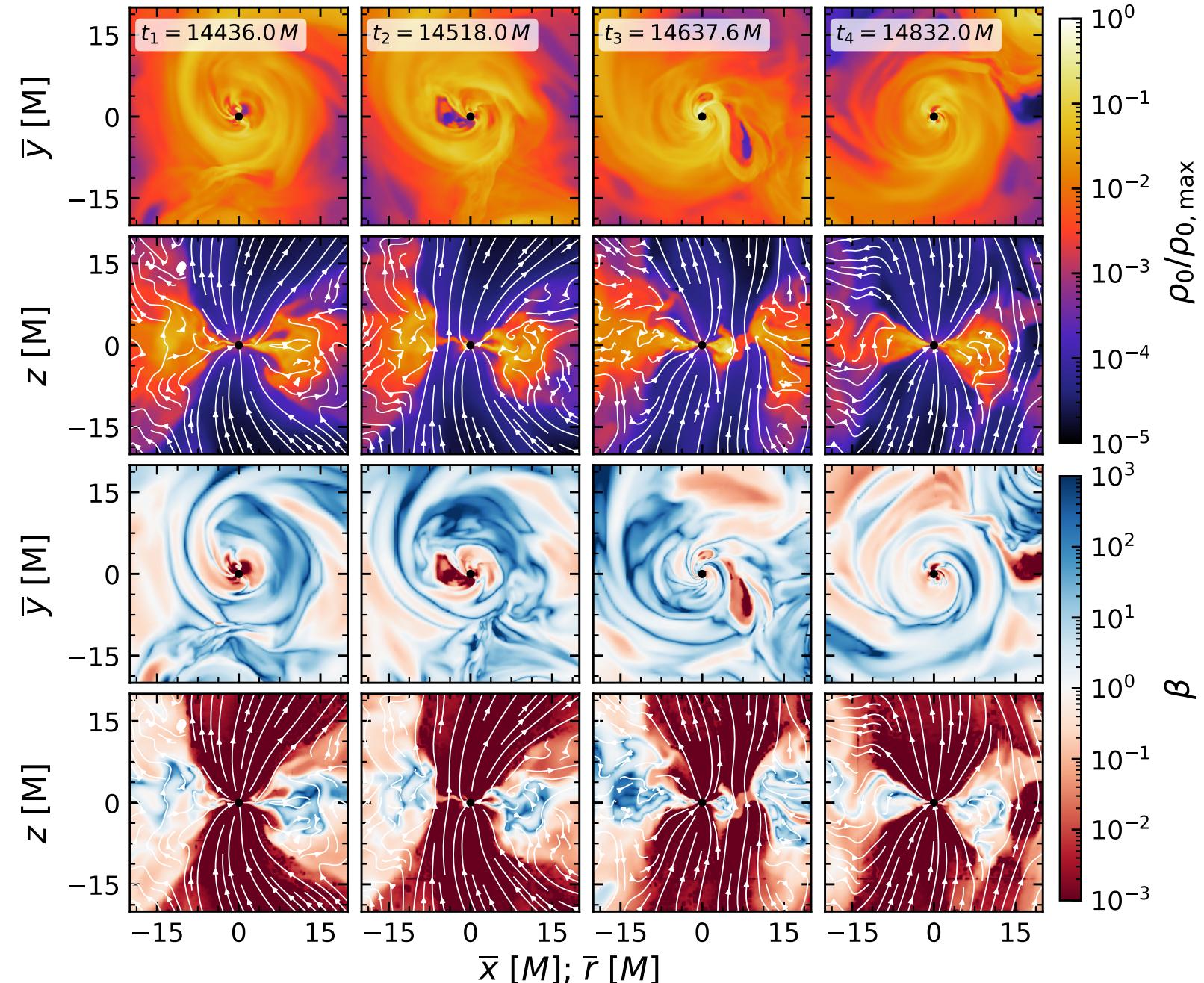
- Minidisks bring magnetic flux to the horizons and saturate the horizons!
- Flux erupts from the horizon, proceeds through the minidisk and into the cavity



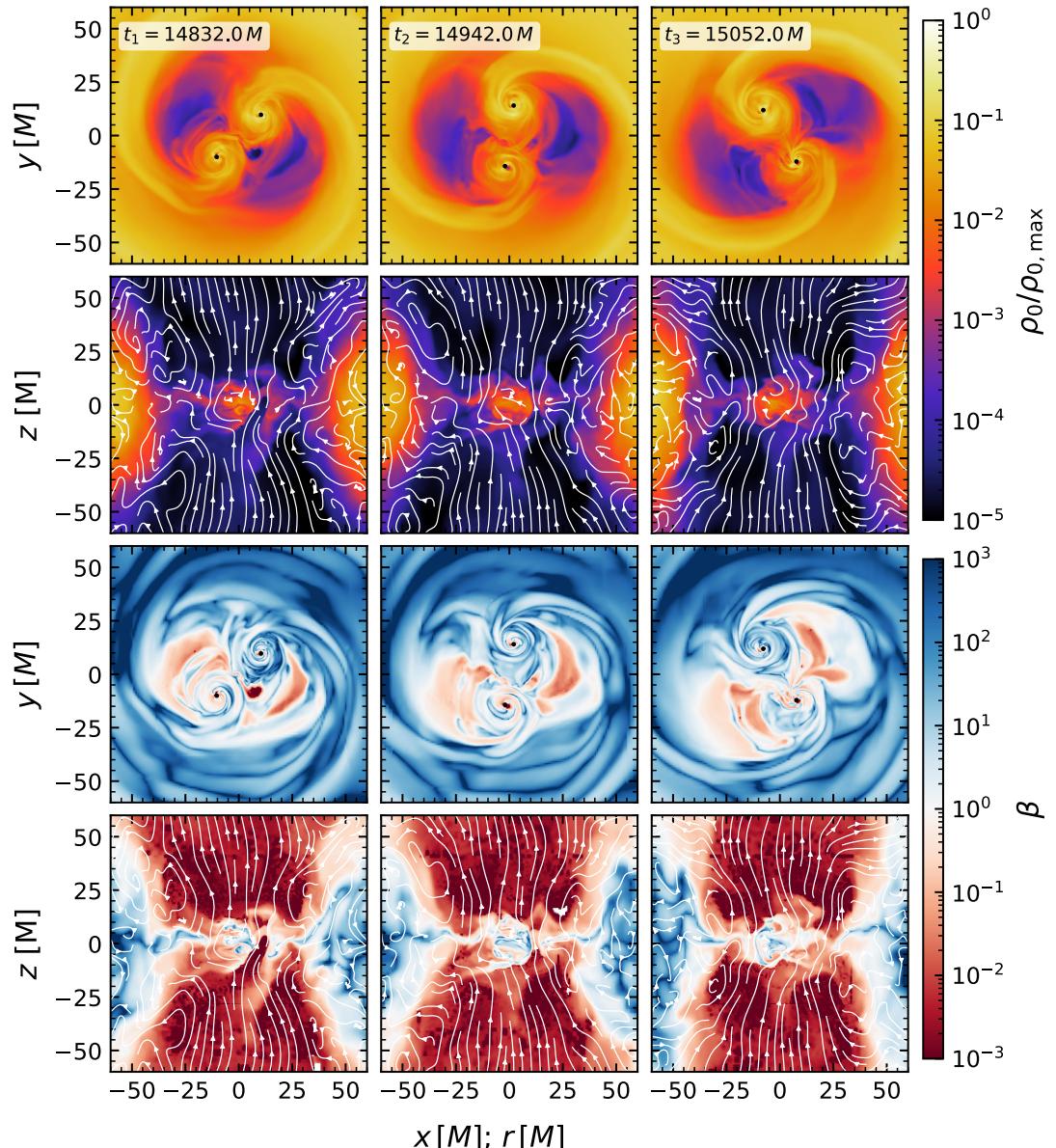
Forming the magnetic flux bundle at the horizon



Journey through the minidisk

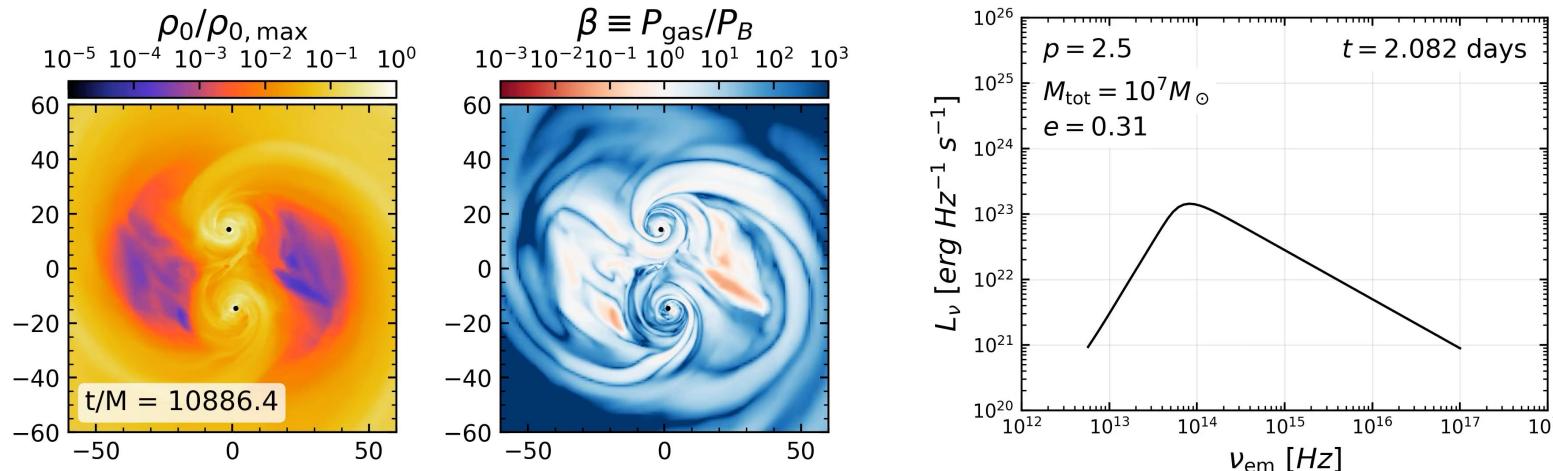


...into the cavity



Multimessenger emission from eccentric black hole binaries and magnetically arrested minidisks

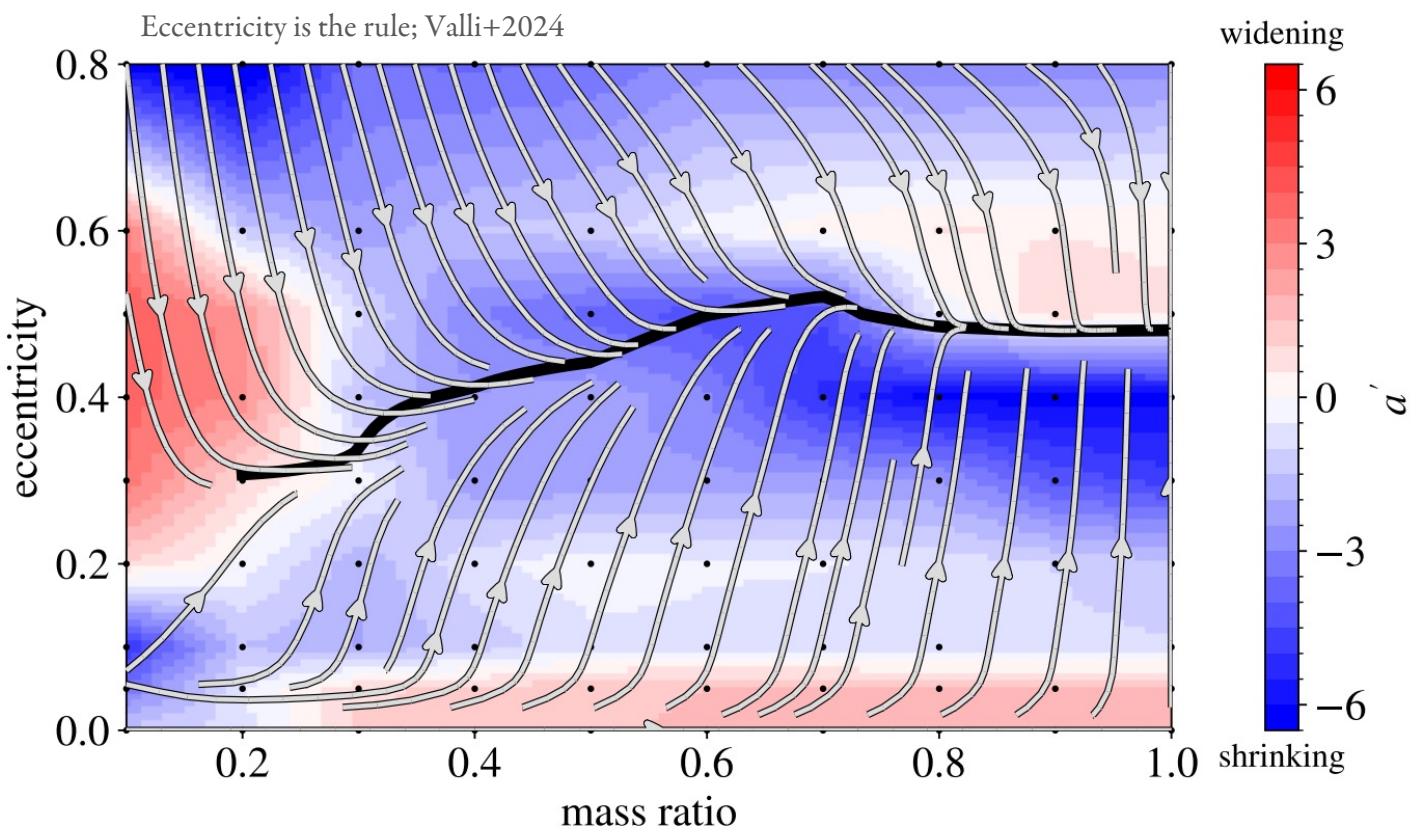
- Eccentric black hole binaries will launch **jets variable on the orbital timescale** with a **smoking gun quasiperiodic EM emission** (ApJL, 984 L47 and PRD, 112, 043004)
- Binary black holes at large relativistic separations will form **magnetically arrested minidisks** with expected flaring in infrared and X-ray bands (PRD 112, 103050)



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Eccentricity is expected to be common

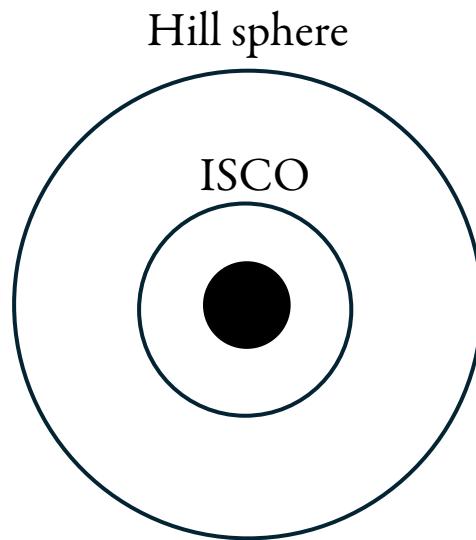
- Galaxy mergers are eccentric; SMBBHs preserve that eccentricity (Gualandris+2022)
- CBD-binary interactions induce long-term eccentricity (Valli+2024)
- SMBH eccentricity is the norm, and up to $e=0.5$ (Siwek+2024)



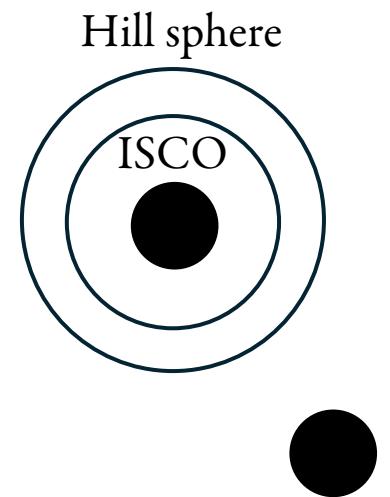
Accretion is Driven By Pericenter Approach

- ISCO: plunging radius
- Hill sphere-ISCO ratio determines presence of minidisks

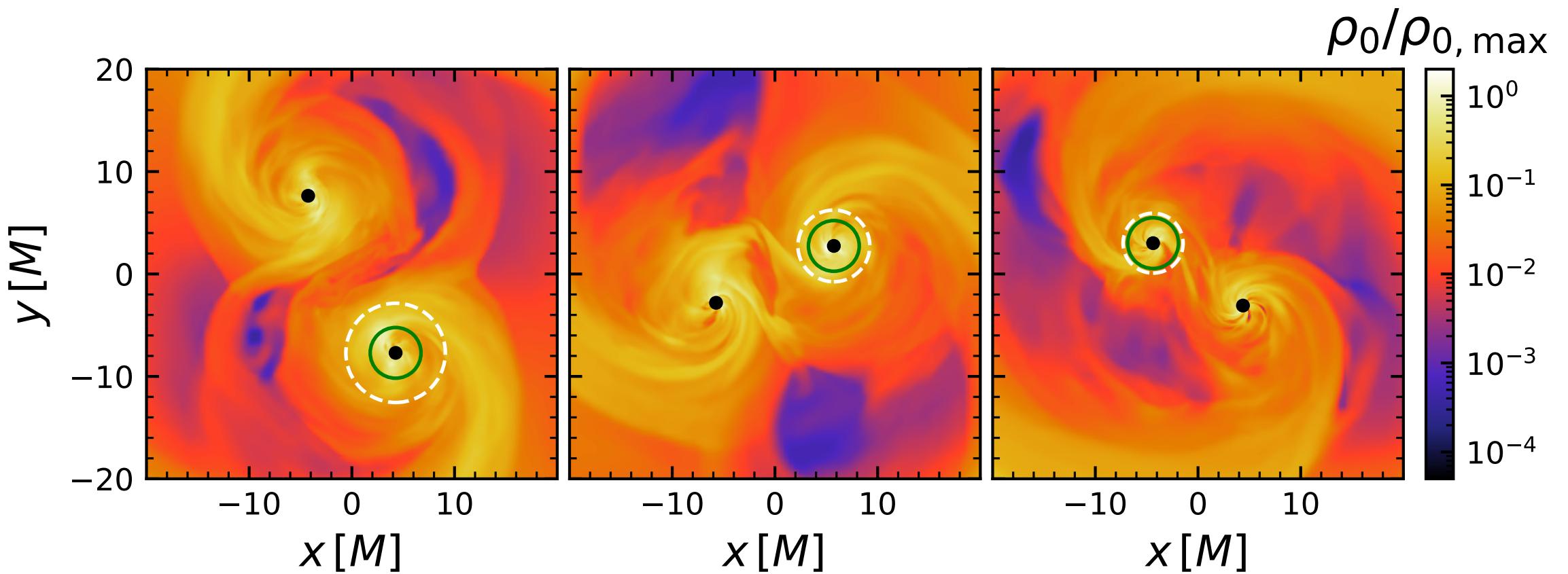
At apocenter ($d \sim 26M$)

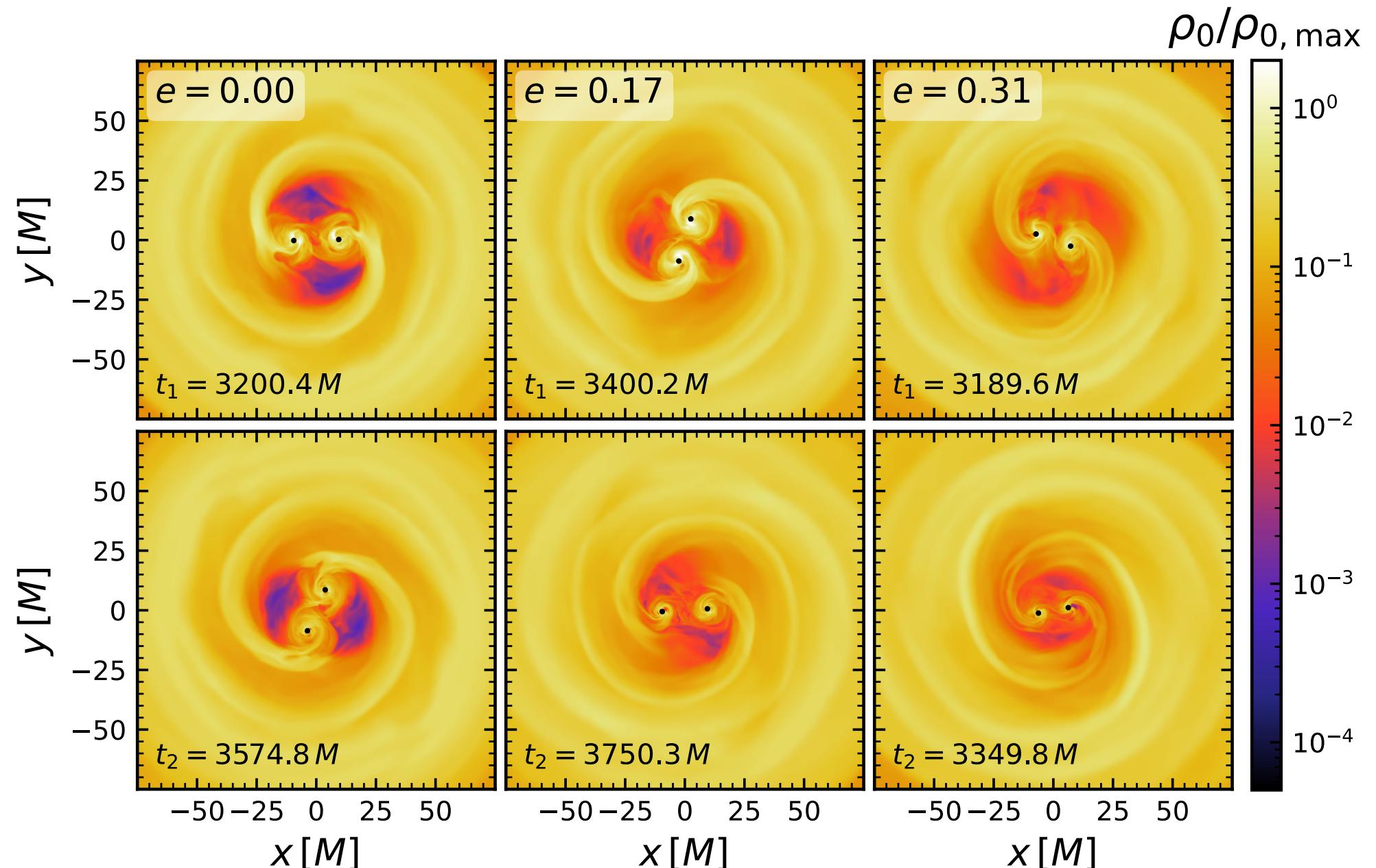


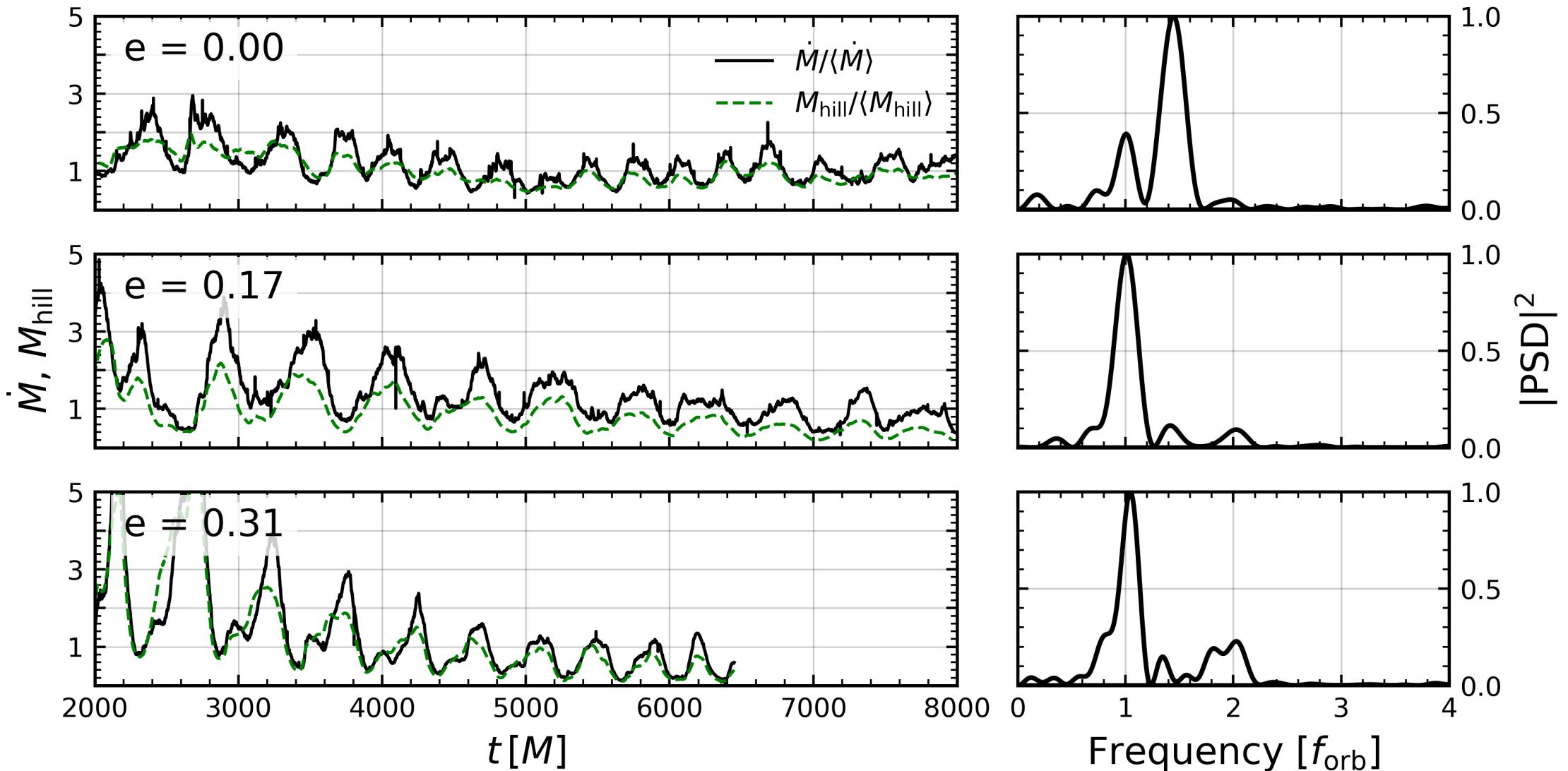
At pericenter ($d \sim 14M$)

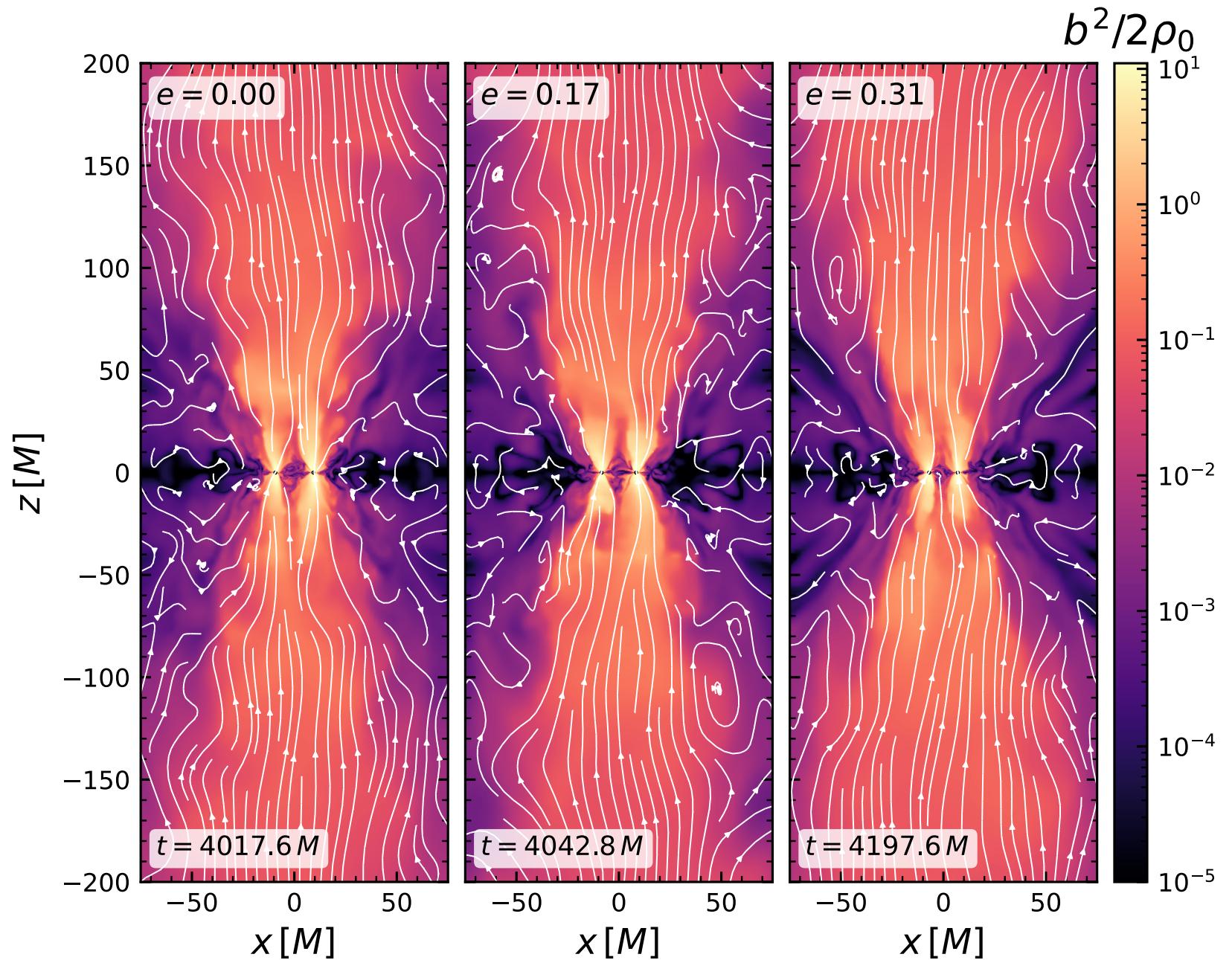


Accretion is Driven By Pericenter Approach









Time-dependent SED are Variable

