Effects of Eccentricity on Accreting Binary Black Holes

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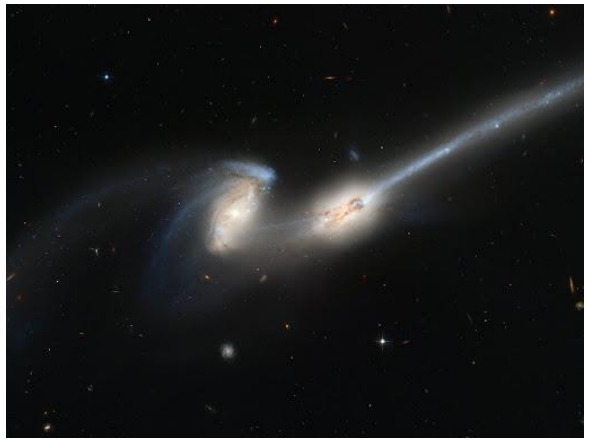
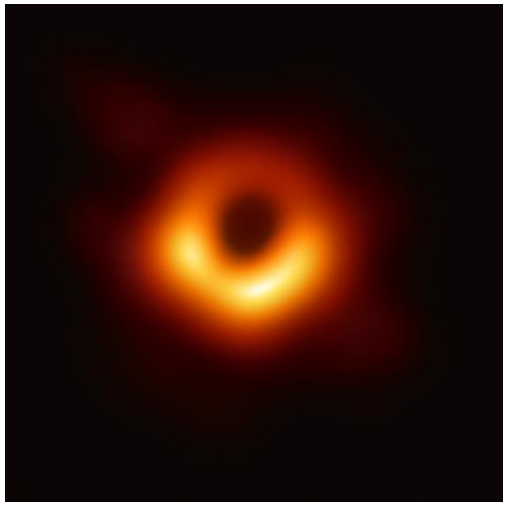
SMBBHs Expected to be Ubiquitous Multi-messenger Sources

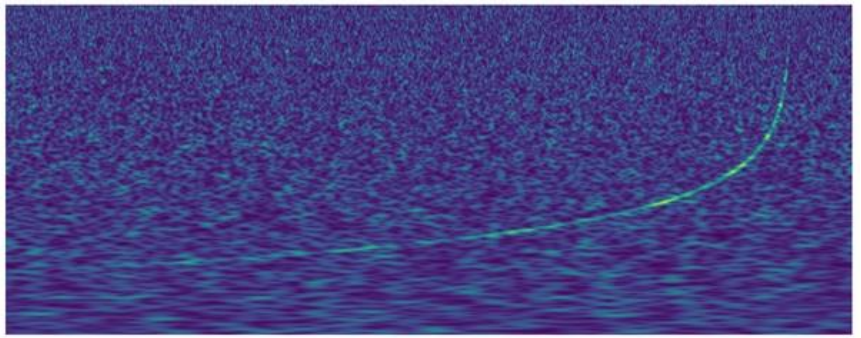
- Product of galaxy mergers (Begelman+1980)
- GWs from inspiral and EM emission from accretion (Bogdanovic+2022, LISA+2023)
- Understanding large-scale structure (Kormendy+2013, Heckman+2014)
- Probing H0 and universe's expansion (Schulz 1986, Holz+2005)



NGC 4676, Credits: NASA/ESA



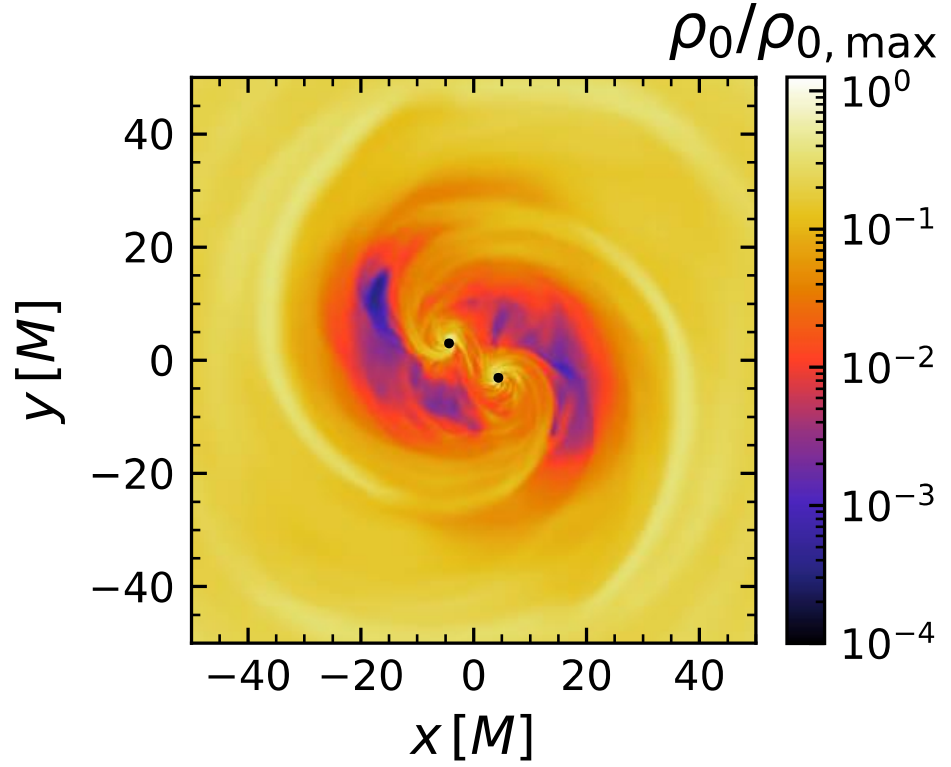
M87*, EHT Collaboration



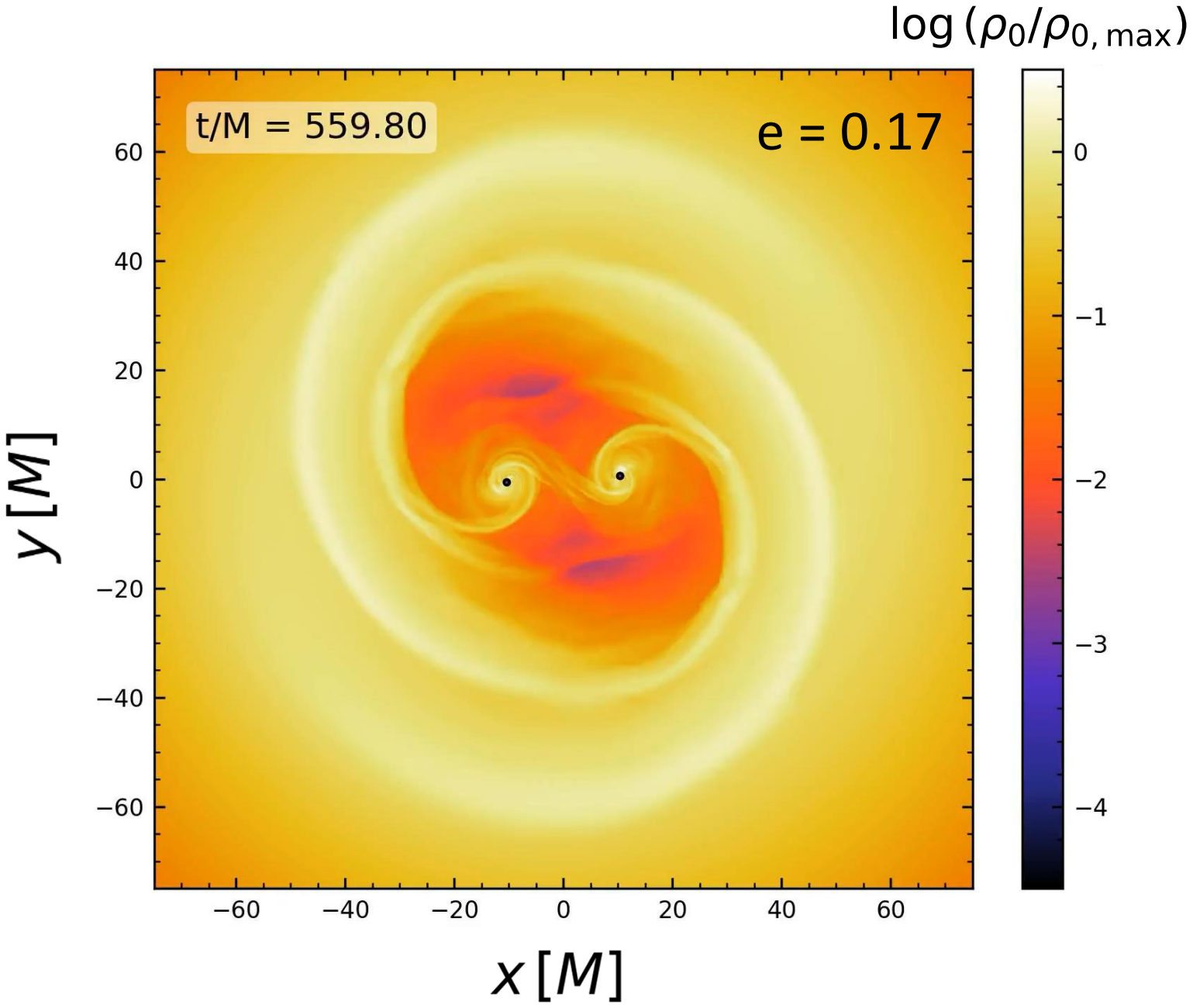
LIGO, GW170817 chirp signal

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

- Einstein Toolkit: Full general relativity (LeanBSSN) & Ideal Magnetohydrodynamics (IllinoisGRMHD)
- Eccentricities: e = 0.00, 0.17, 0.31 (Roedig+2011, Siwek+2024)
- Initial major axis: a = 20 M
- Equal mass, non-spinning BBH

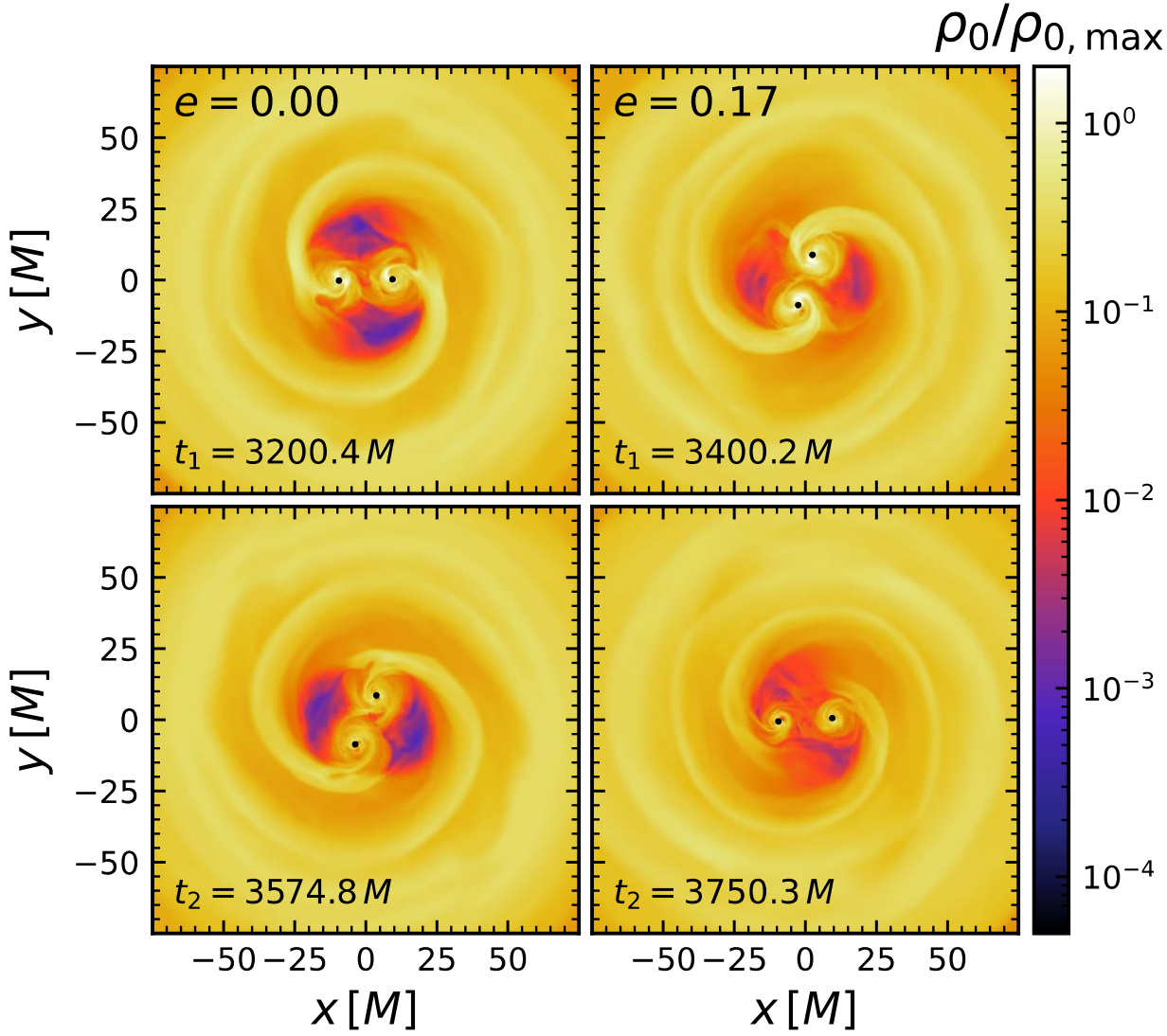


First GRMHD simulations of accreting, eccentric binaries

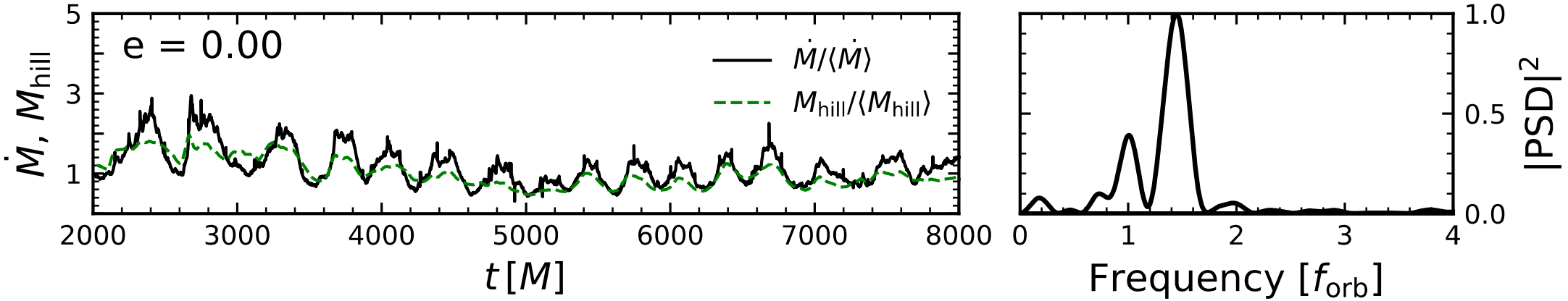


Eccentric Binaries don't Sustain Minidisks

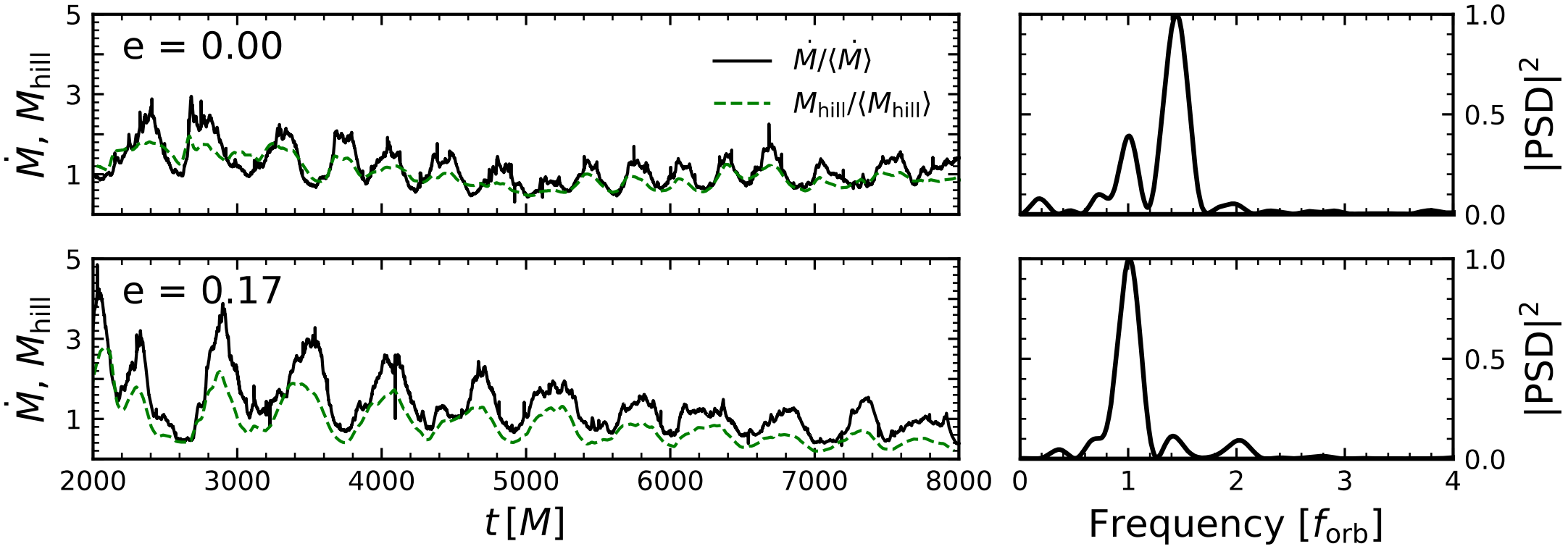
- Tidal streams circularize around BBH
- Form minidisks and then accrete
- Quasi-circular binary has persistent structure
- Eccentric Binaries don't sustain minidisks (at these separations)



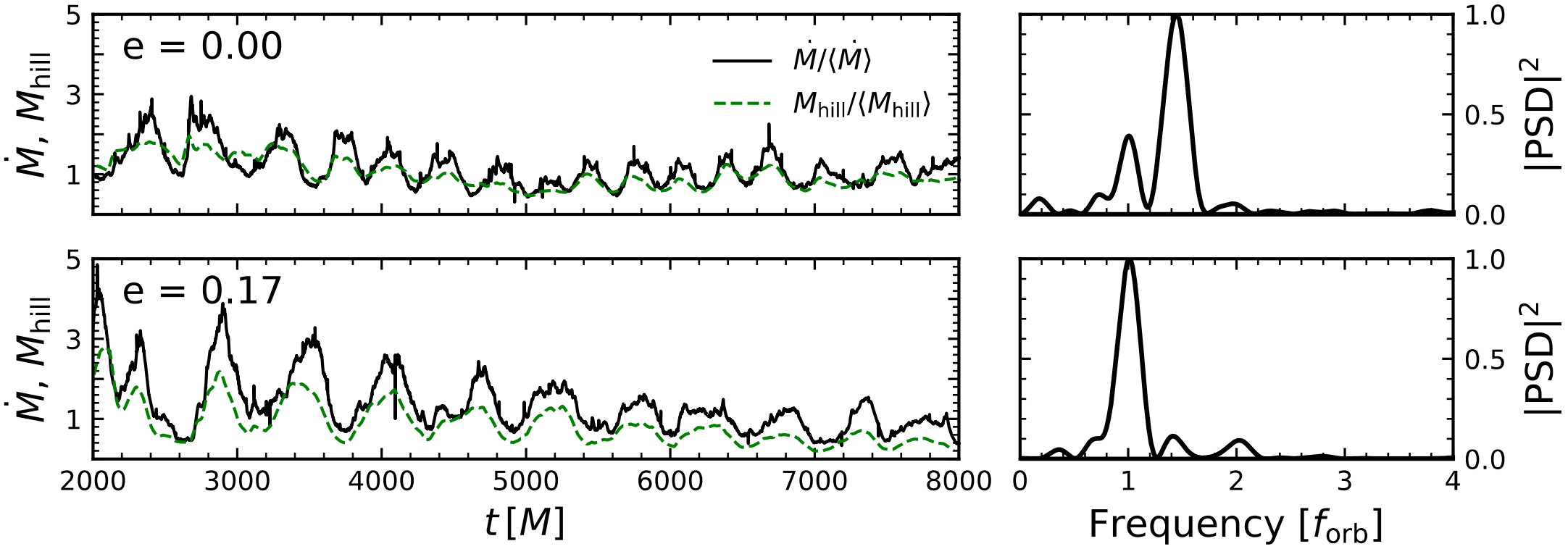
Quasi-circular binaries accrete at ~1.4 f_{orb}



Eccentric Binaries Accrete at their Orbital Frequency



Accretion is Driven By Pericenter Approach



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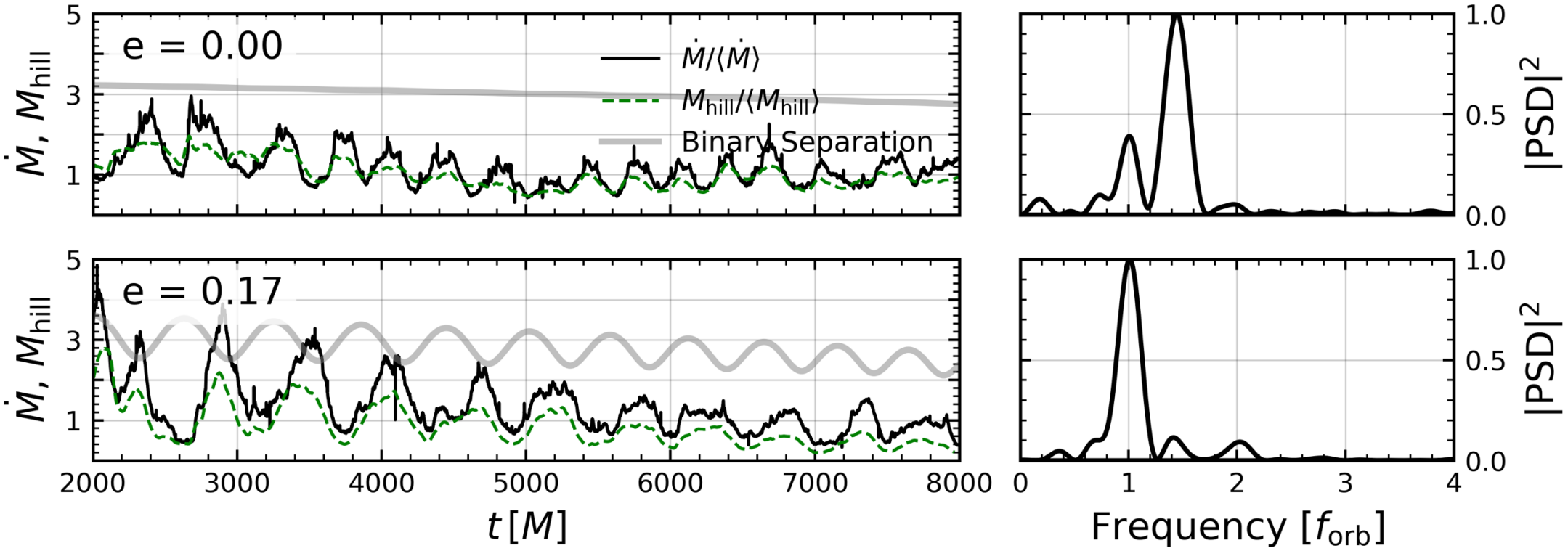
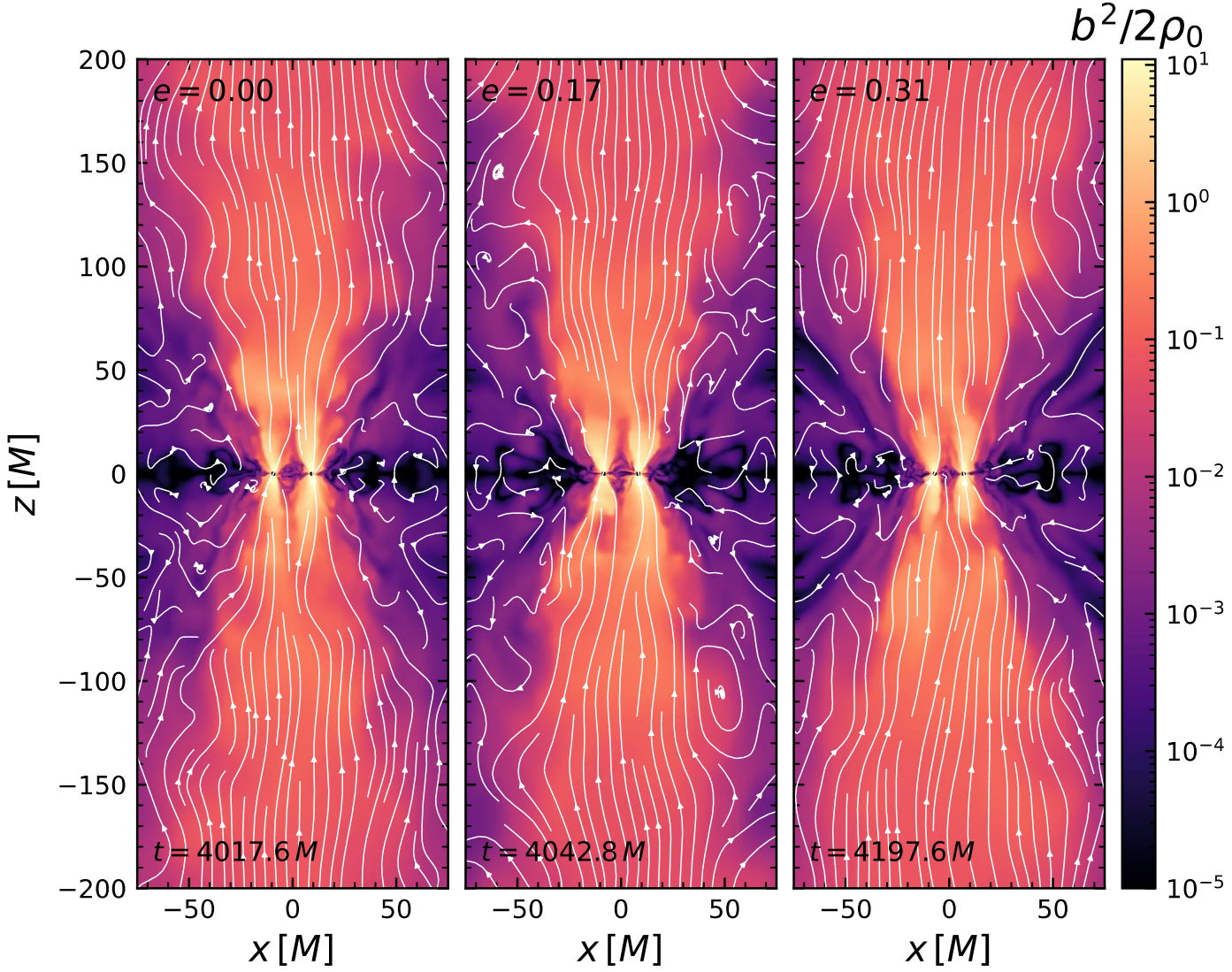
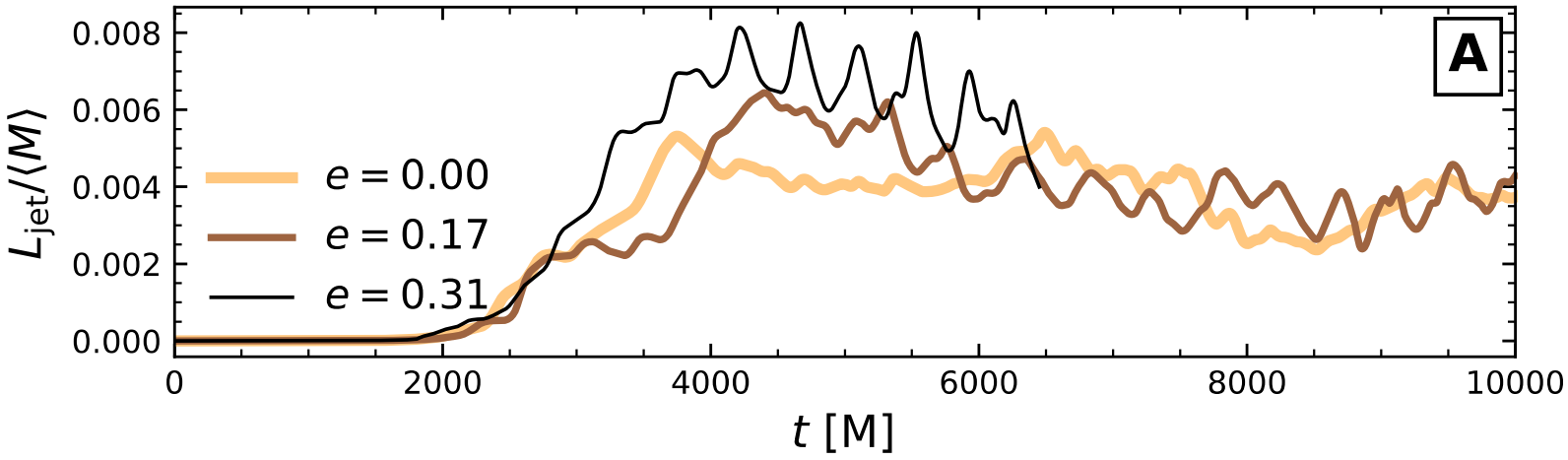


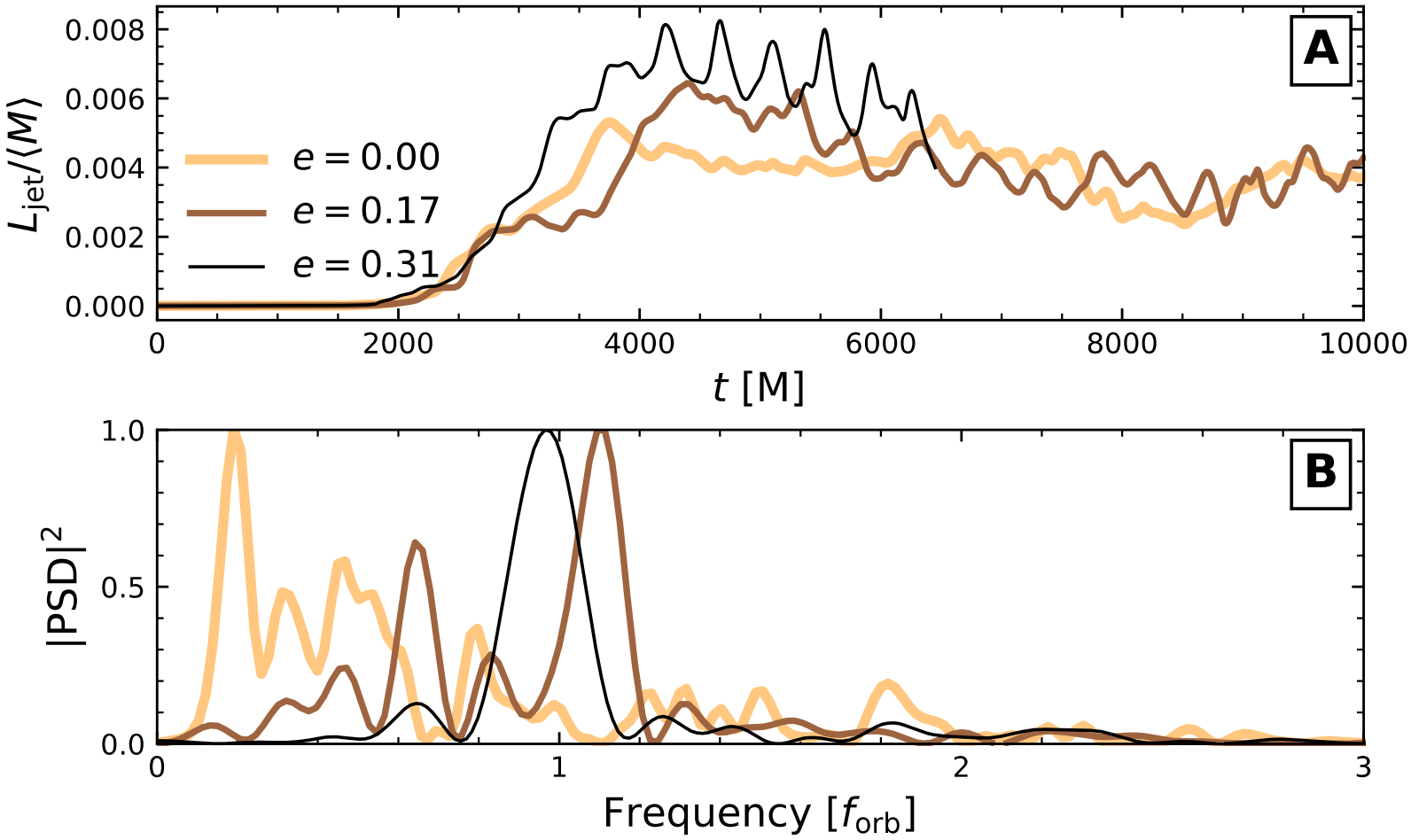
Ubiquitous Jet Launching from Non-spinning BBH



Eccentric binaries have variable jets

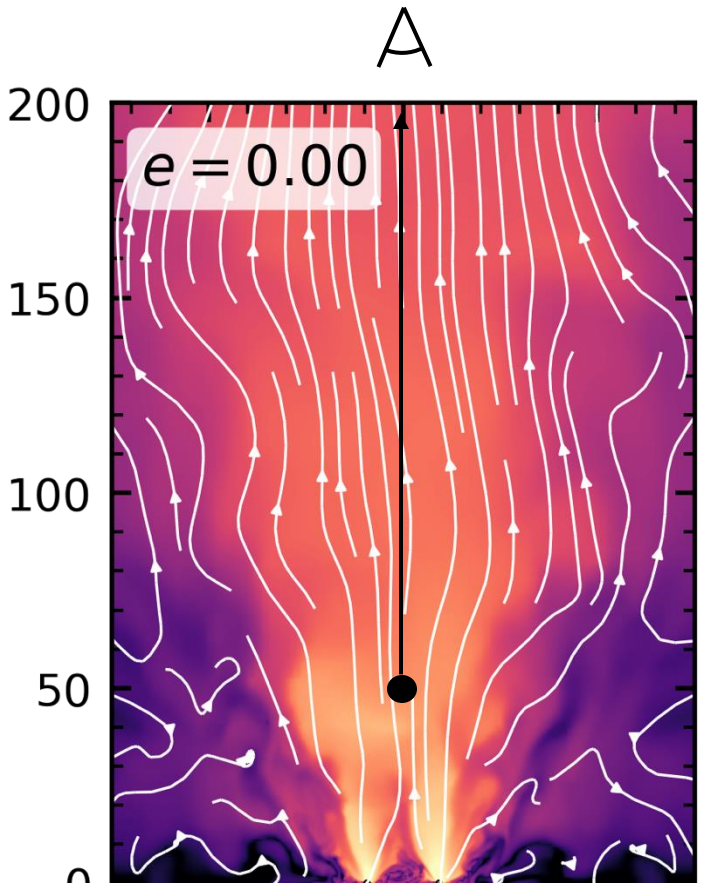


Eccentric binaries have variable jets

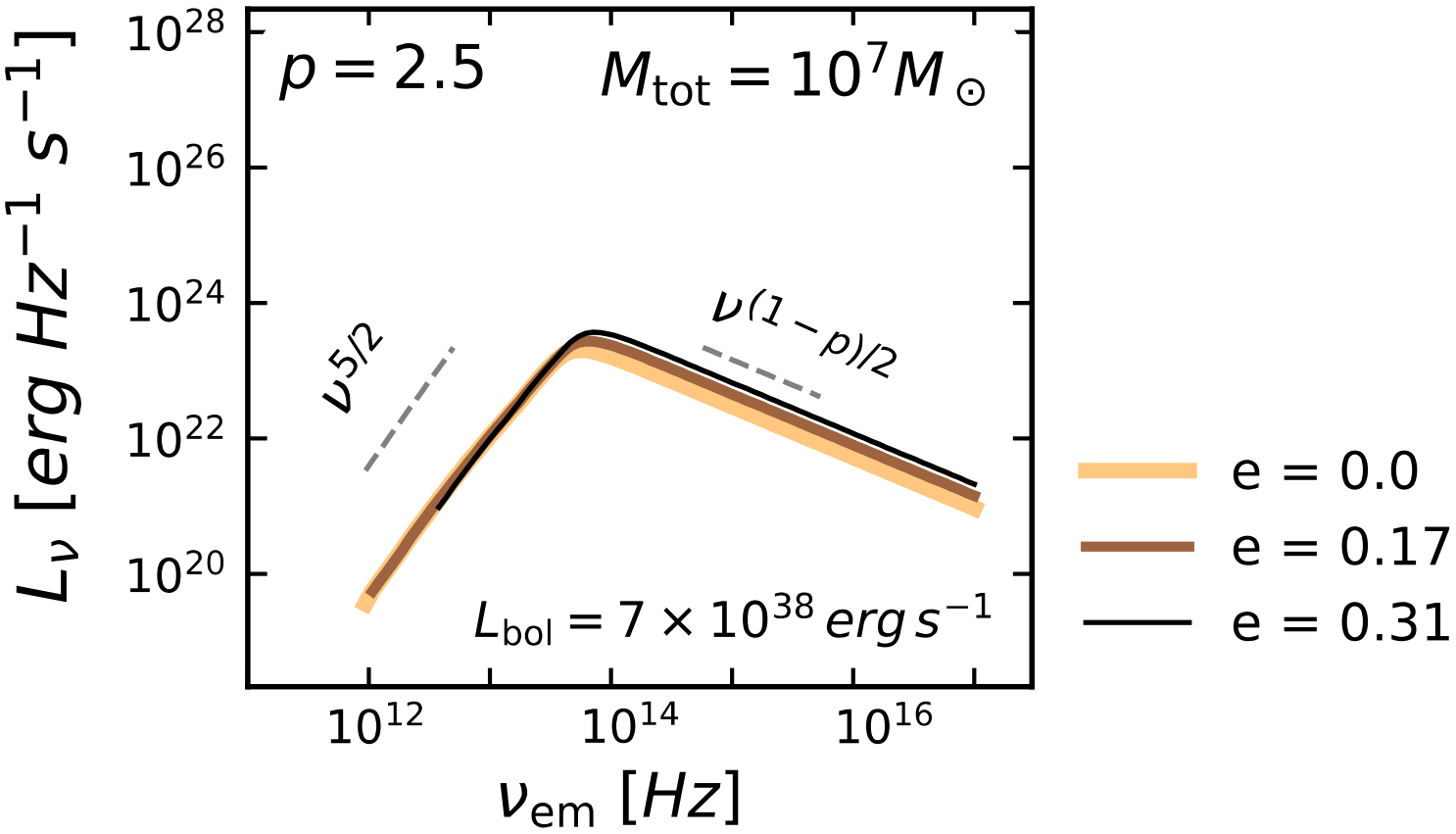


Synchrotron Radiative Transfer

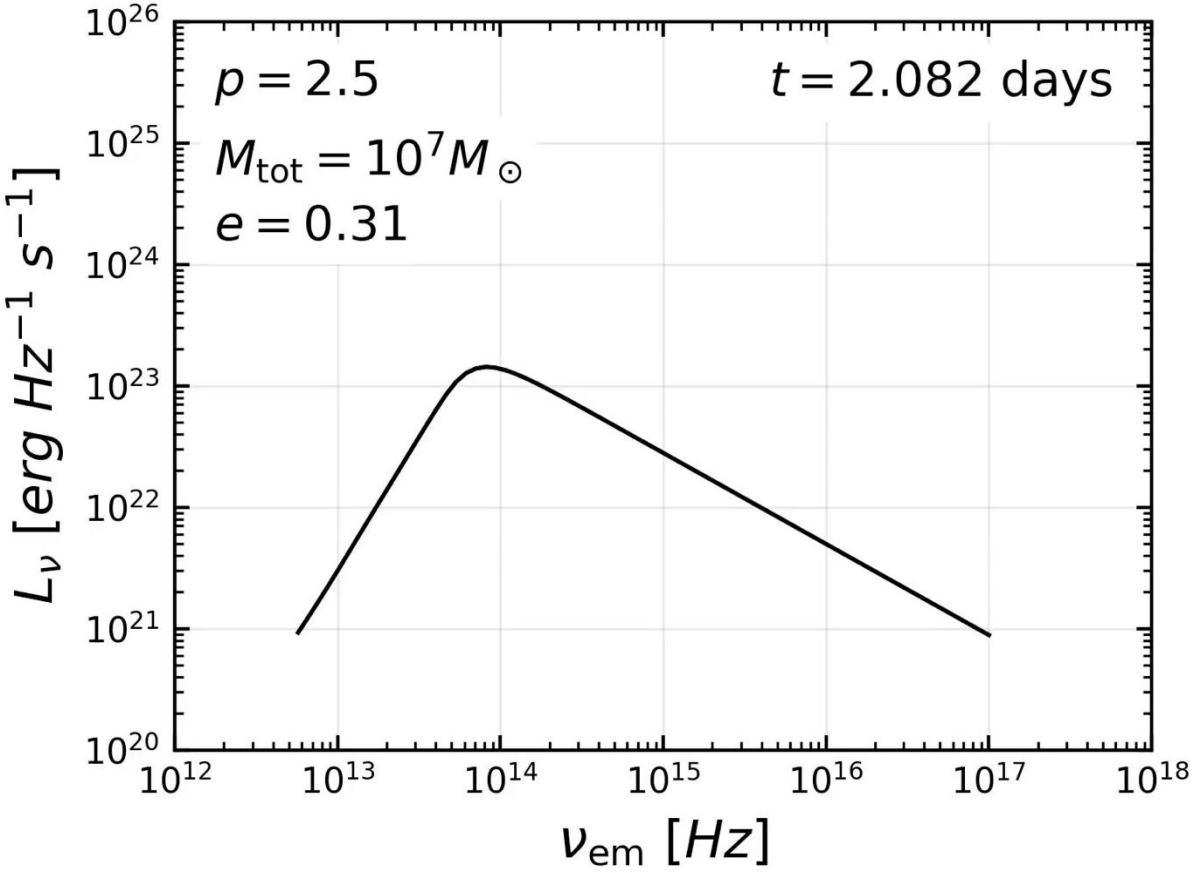
- Choose a line of sight
- Choose electron distribution
- Rybicki & Lightman synchrotron coefficients
- Assumptions:
    1. Fast-light
    2. Non-relativistic
    3. z > 50 M
    4. 10% Eddington
    5. 10% radiative efficiency



Recover the Typical Synchrotron SED



Time-dependent SED are Variable



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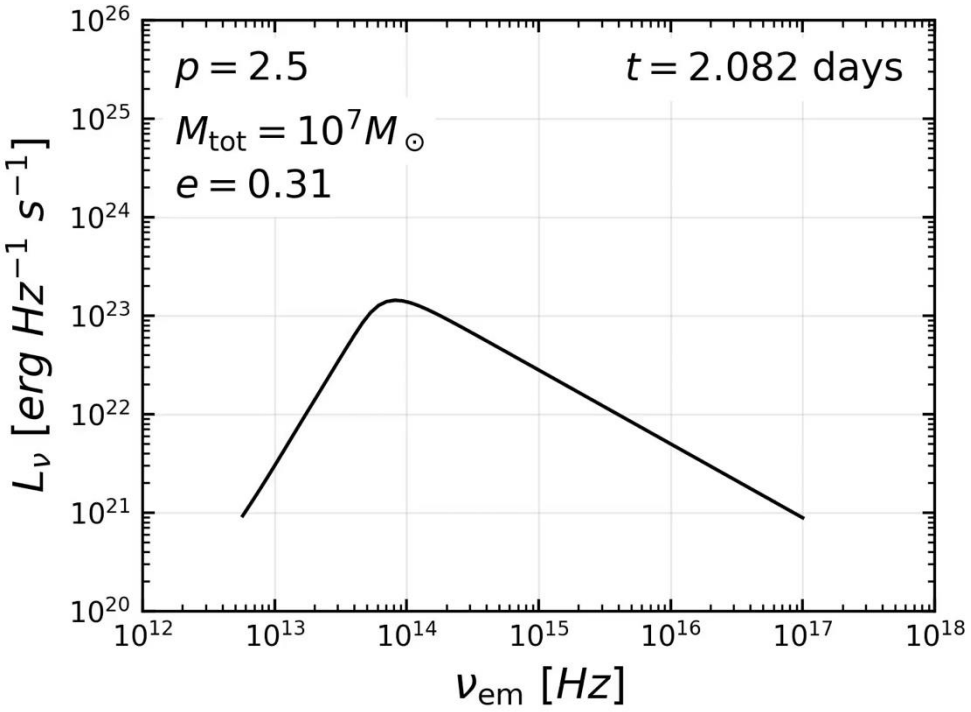
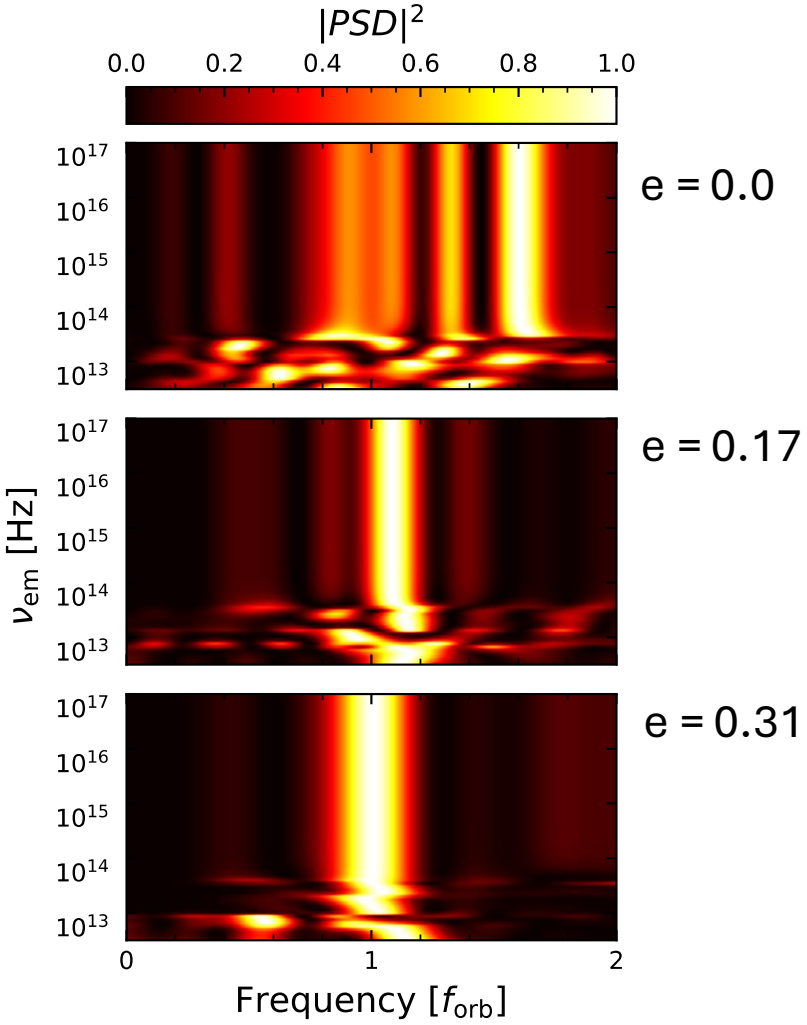
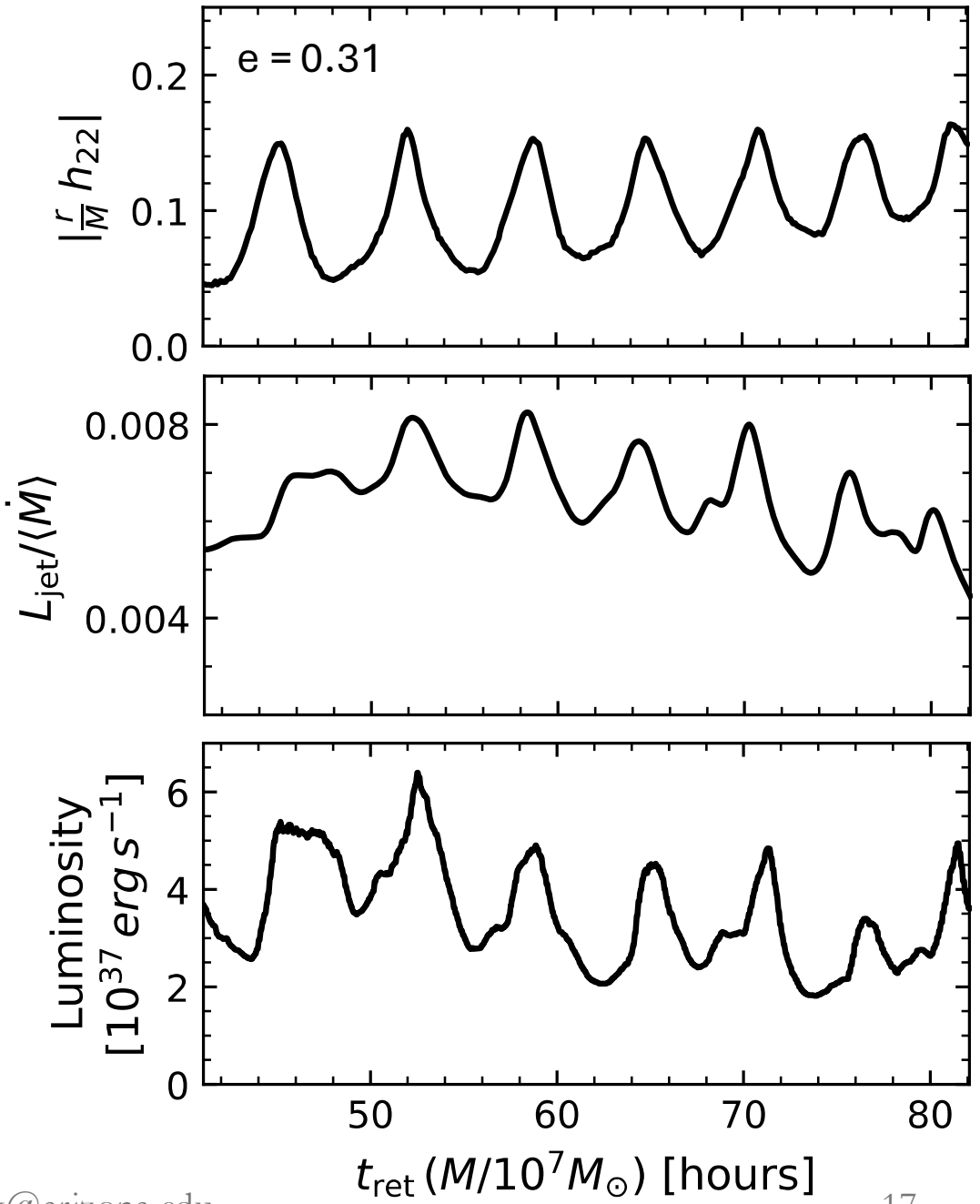




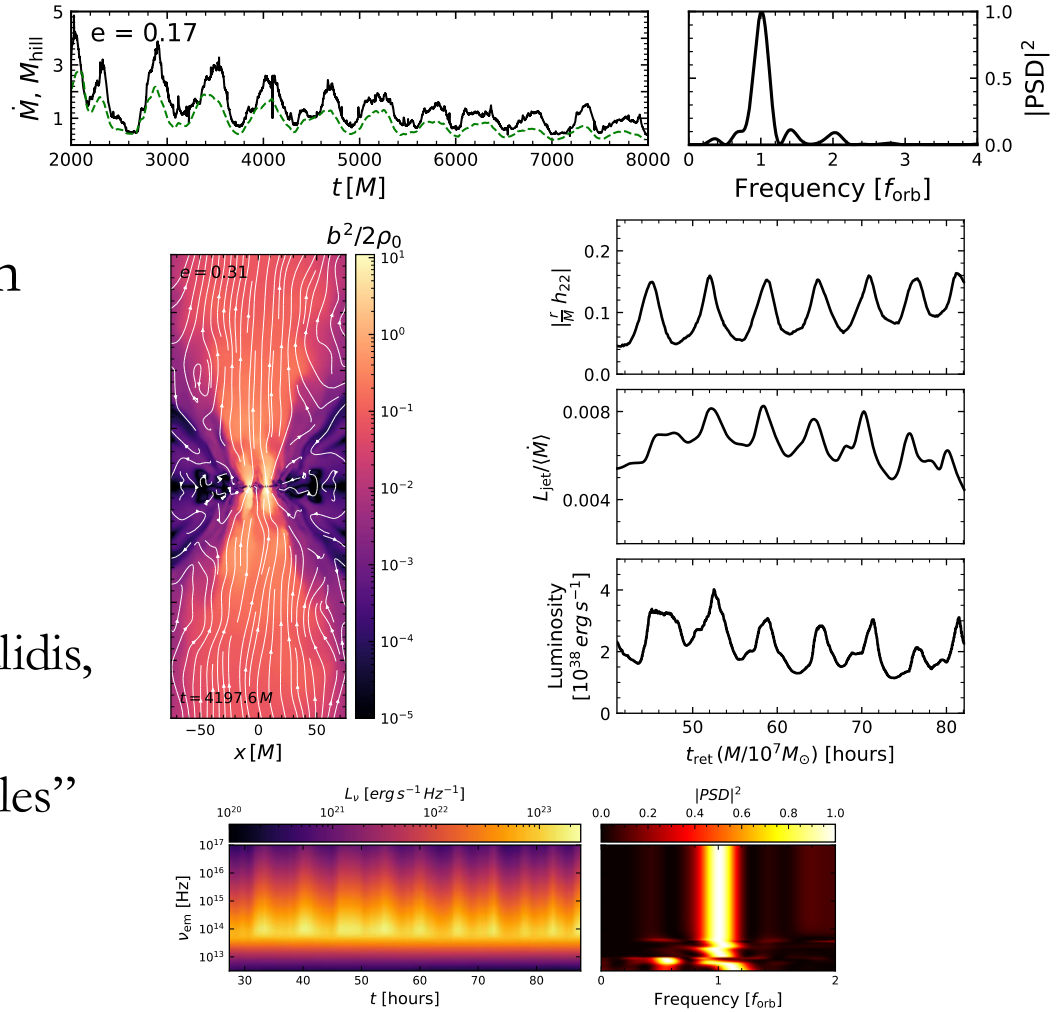
Coincident EM and GW Bursts

- Gravitational waves
- Jet power
- Synchrotron emission
- 'Burst' at the same time and at equal intervals



Eccentric SMBBHs are Uniquely Identifiable

- Eccentric BBHs accrete at $\sim f_{orb}$
- Their jets are variable on $\sim f_{orb}$
- This variability is reflected in their synchrotron emission
- Coincident GW and EM bursts



- "Coincident Multi-messenger Bursts from Eccentric Supermassive Binary Black Holes" Manikantan, Paschalidis, Bozzola, arXiv:2411.11955
- "Effects of Eccentricity on Accreting Binary Black Holes" Manikantan, Paschalidis, Bozzola, on arXiv next week

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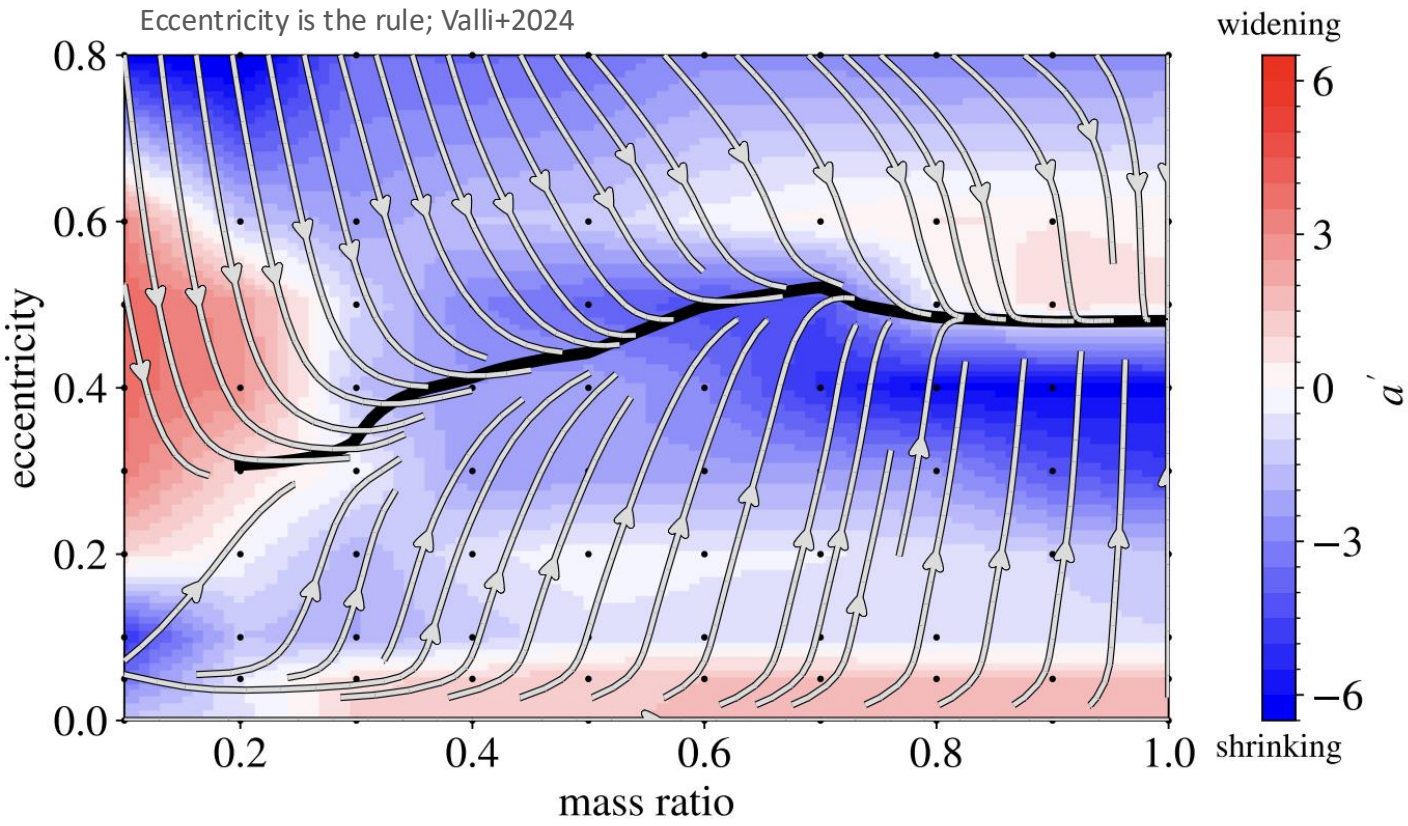
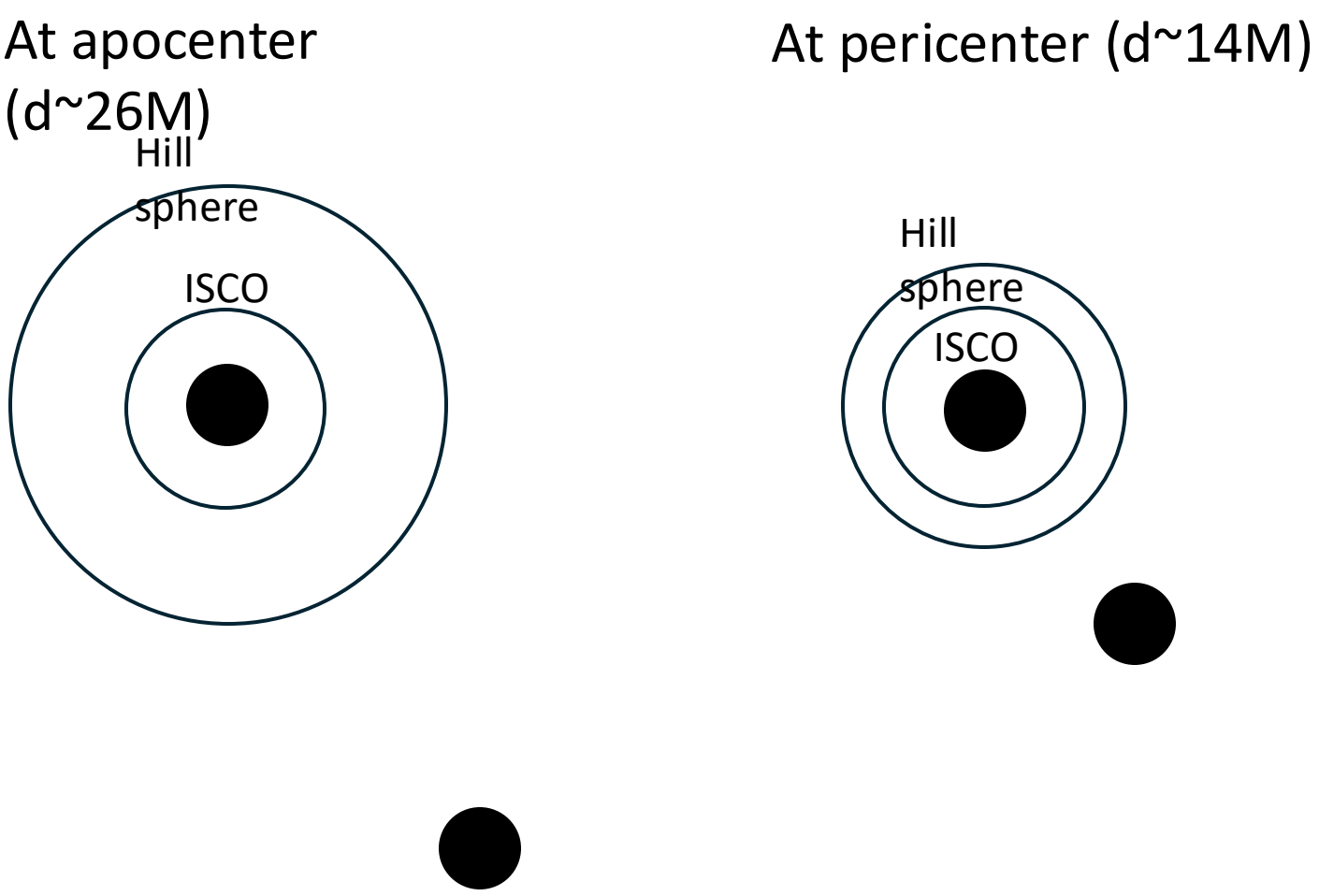
Eccentricity is expected to be common

- Galaxy mergers are eccentric; SMBBHs preserve that eccentricity (Gualandris+2022)
- CBD-binary interactions induce long-term eccentricity (Valli+2024)
- SMBBH 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



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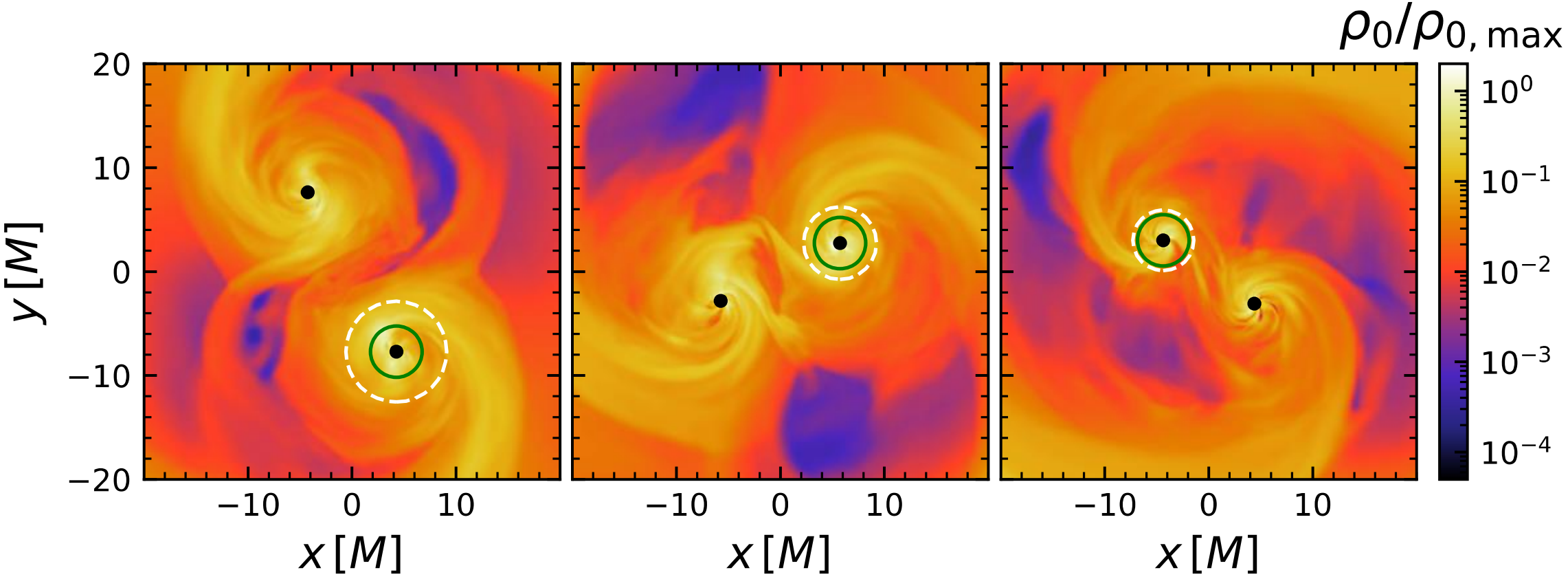
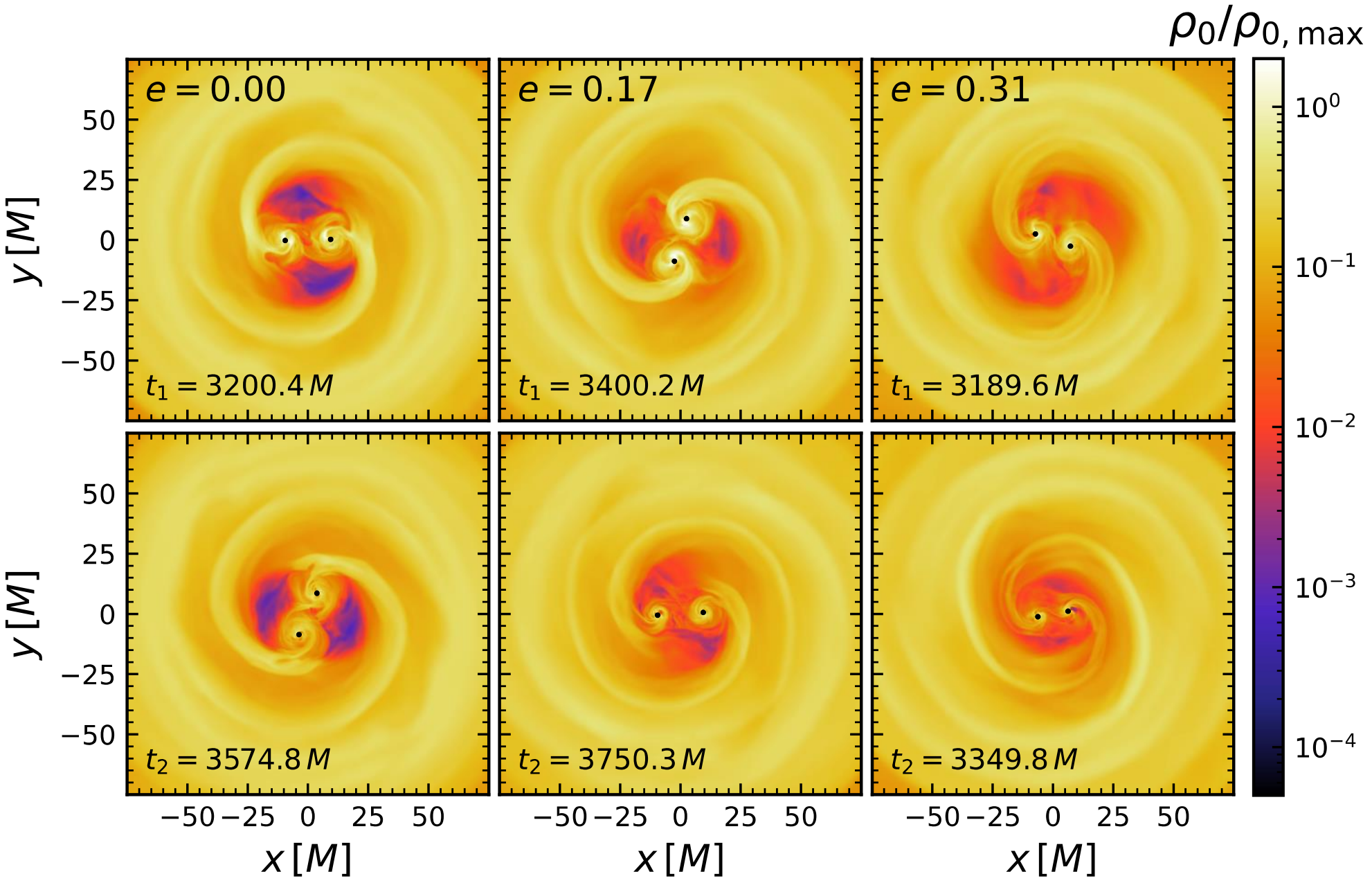
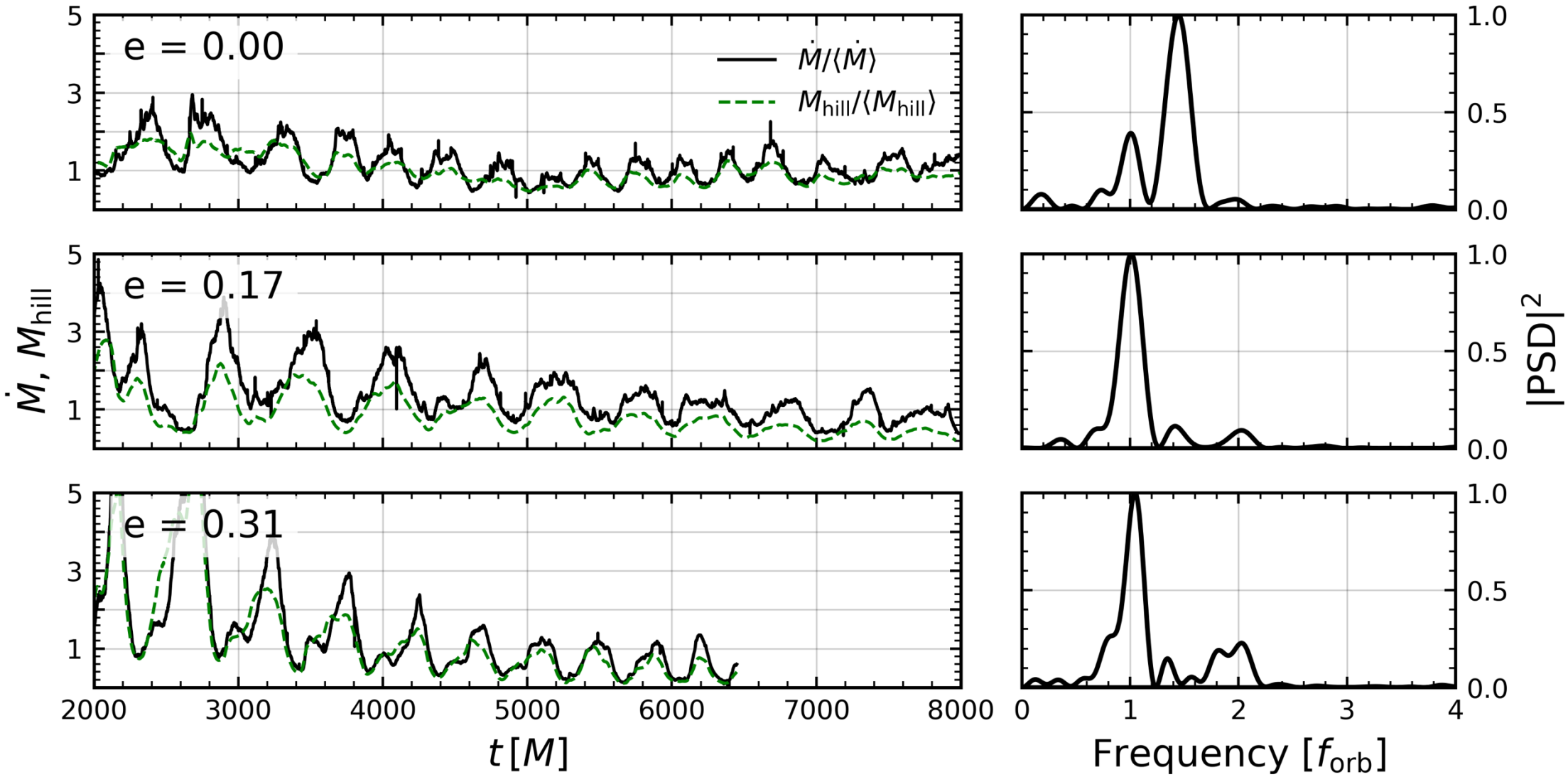
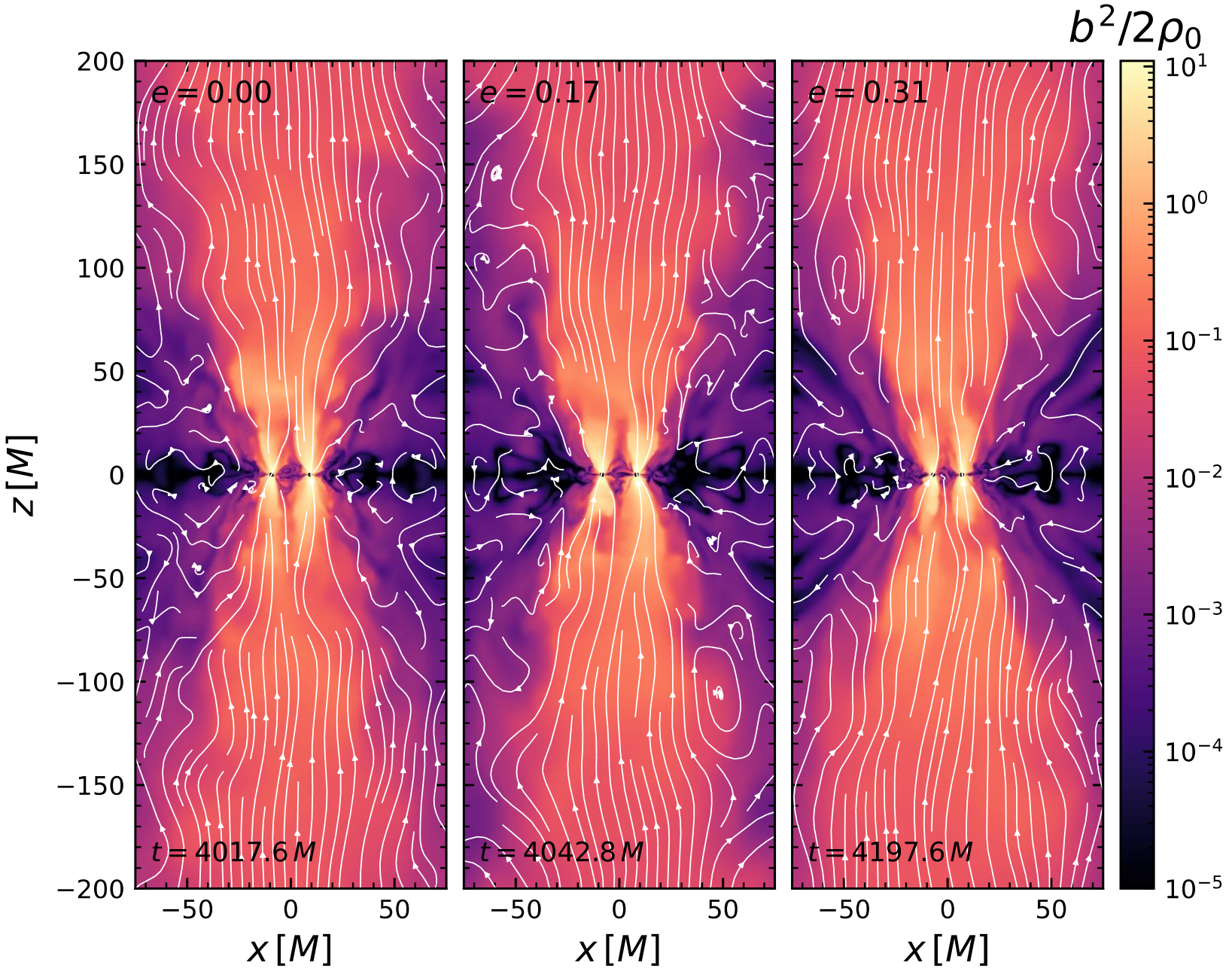



$\rho_0/\rho_{0,\max}$
$e = 0.00$
$e = 0.17$
$e = 0.31$
$t_1 = 3200.4\,M$
$t_1 = 3400.2\,M$
$t_1 = 3189.6\,M$
$t_2 = 3574.8\,M$
$t_2 = 3750.3\,M$
$t_2 = 3349.8\,M$
$y\,[M]$
$x\,[M]$
50
25
0
−25
−50
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}


e = 0.00
e = 0.17
e = 0.31
$\dot{M}/\langle\dot{M}\rangle$
$M_{\rm hill}/\langle M_{\rm hill}\rangle$
$\dot{M}$, $M_{\rm hill}$
$t\,[M]$
Frequency $[f_{\rm orb}]$
$|{\rm PSD}|^2$


$b^2/2\rho_0$
$e = 0.00$
$e = 0.17$
$e = 0.31$
$t = 4017.6\,M$
$t = 4042.8\,M$
$t = 4197.6\,M$
$z\,[M]$
$x\,[M]$
200
150
100
50
0
−50
−100
−150
−200
−50
0
50
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

Time-dependent SED are Variable