How Can We Find Supermassive Binary Black Holes—**Now!**

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Or, What Kinds of Photons Should We Search For?

Why Supermassive Binary Black Holes Should Radiate More Photons Than Stellar Mass Systems

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+ Non-axisymmetric density after galaxy mergers, spiral shocks, etc.

Basic Problem: Distinguishing SMBBHs from AGNs

Energy from radiation comes from accretion;

Most of the energy is released near the ISCO;

For $a > 20-30\ r_g$, near-ISCO regions of minidisks look just like those in solitary AGN

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How can binary black holes be robustly distinguished from solitaries?

Basic Structure of Accreting Binaries

- For $q = M_2/M_1 >$ ~few%, accreting binary carves a low-density gap in the circumbinary disk, radius ~2a (quadrupole prevents closed orbits)

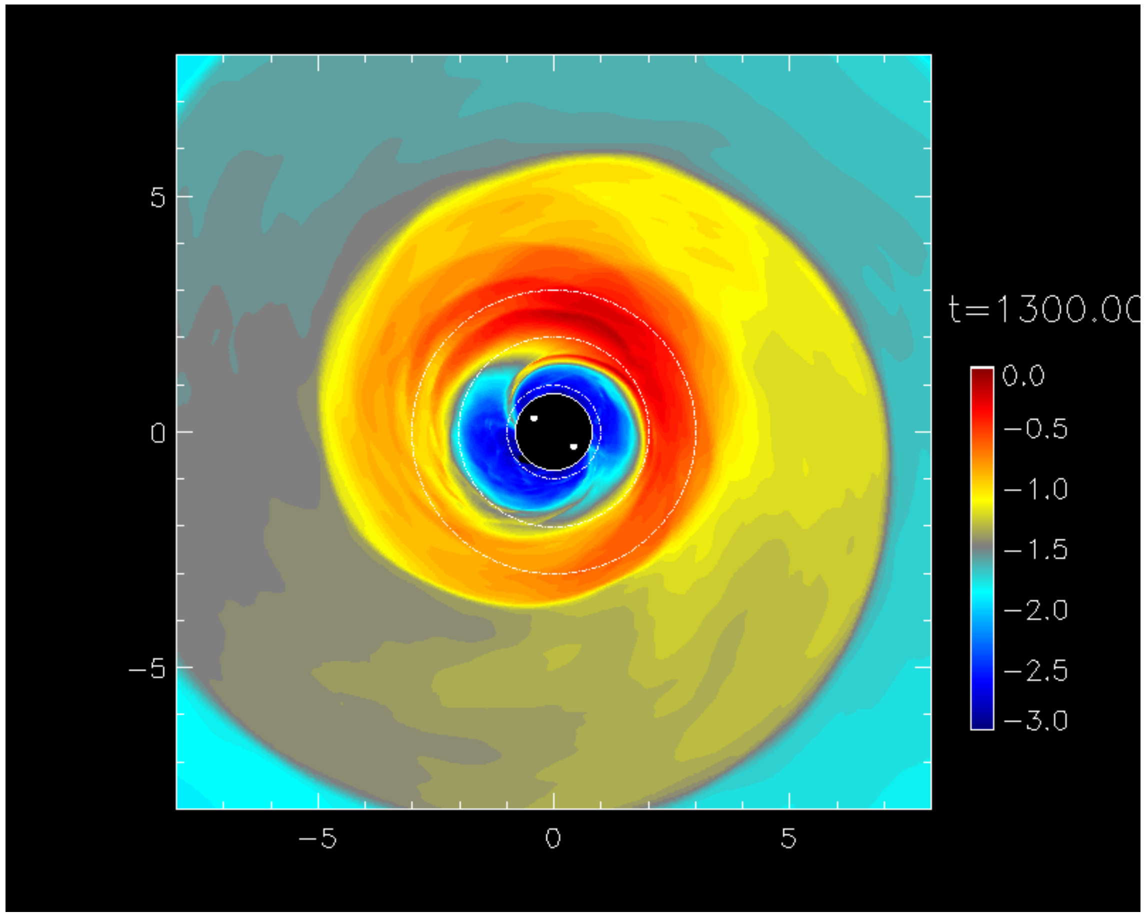
- Two streams leave circumbinary disk's inner edge: circ-j gas torqued and returns to cbd, low-j gas feeds minidisks

- For q >~0.1—0.2, cbd inner edge forms "lump", breaks stream symmetry, modulates inflow at Ω_{lump}

- Secondary captures more mass than primary

- Accretion streams shock at edges of minidisks, torqued gas at inner edge of cbd.

- Even when $t_{GW} < t_{inflow}$, accretion continues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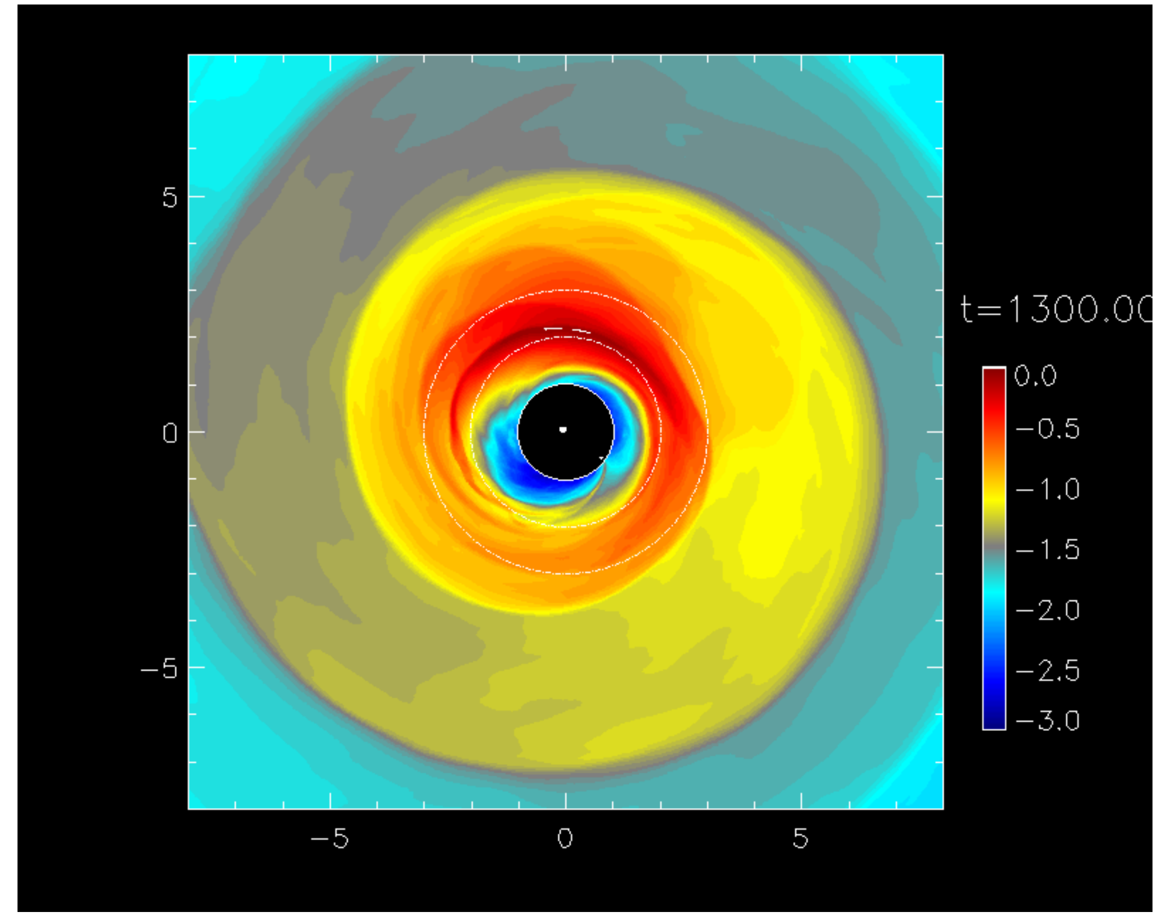
q=1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Potentially Distinctive Signals

- Alteration to continuum spectrum (radio/IR/optical/UV/X-ray?)
- Alteration to emission line profiles (optical/UV, X-ray)
- Periodic modulation of any property: which band? at which frequency? under which circumstances?

Generic Problems

Predictions:

How do any proposed signals relate **uniquely** to binarity?

Do we understand the emission physics well enough to be confident in the prediction?

Observations:

Are there enough examples sufficiently bright? Gap region associated with little energy unless a/r_g <~ 1000, but
$t_{\rm GW} \simeq 1.3 \times 10^5 \left[(1+q)^2/q\right] M_7 (a/1000 r_g)^4$ yr
Confirming periods can be difficult:

Red noise —> spurious periodicity at ~T/3

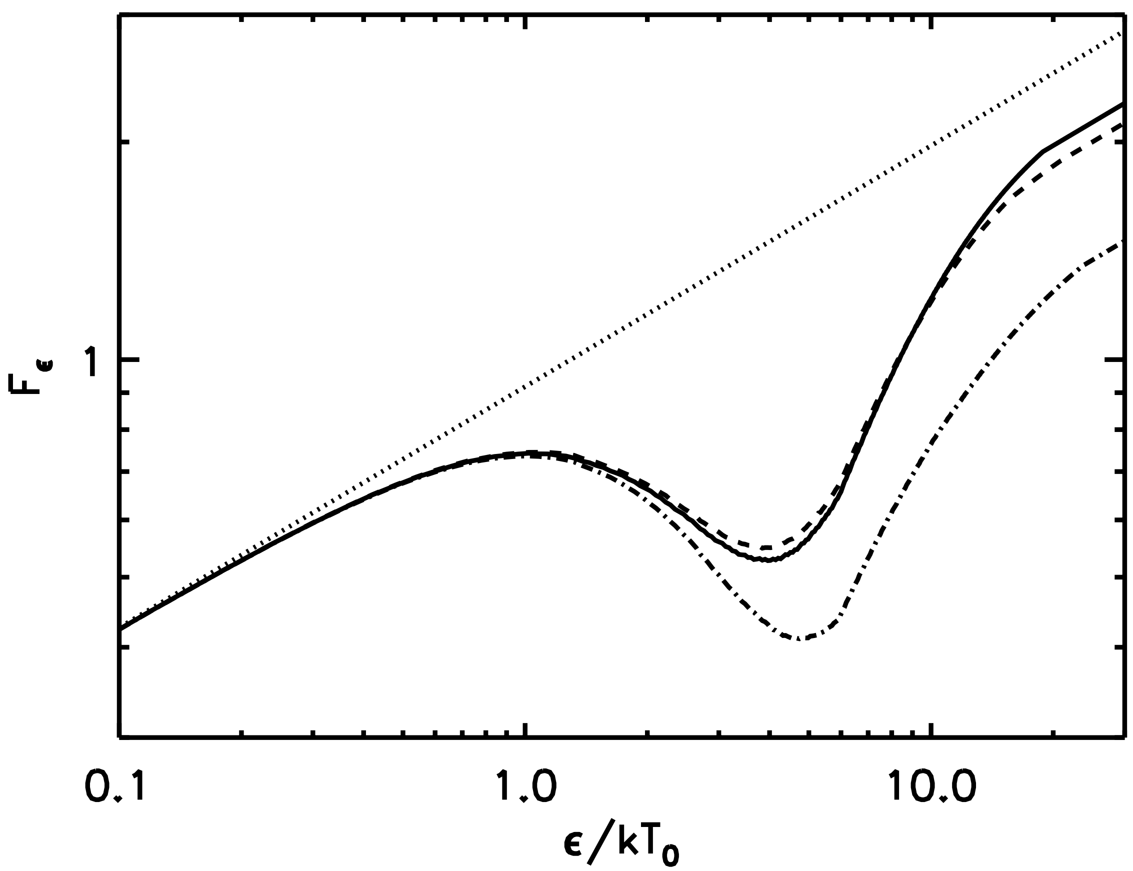
False alarm probabilities ("a posteriori statistics")

P ~ 0.3 $(a/1000\ r_g)^{3/2}$ M_7 yr; need multiple periods

Specific Proposals: Long-Lived Signals

Continuum Spectrum: the “notch”

Energy that might have been emitted in a thermal spectrum by matter accreting across r ~a instead radiated in shocks—> gap in gas produces gap in spectrum



Assumes:

- exact NT73 behavior in cbd and minidisks
- ignores stream shocks

Modified if t_{inflow}(minidisks) <~ P_{bin}

Unlikely to see both loss and recovery in single spectrum

Continuum Spectrum:
X-rays from Stream/Minidisk Shocks

Compton cooling implies hard, strongly
Comptonized spectrum, rapid post-shock cooling:

$$T_s \sim 6 \times 10^9 (a/1000 r_g)^{-1} [(q^{0.3}, q^{0.7})/(1+q)] \text{ K}$$

$$t_{\rm cool}\Omega \sim 1 \times 10^{-2} (\dot{m} f_{1,2})^{-1} (kT_e/m_e c^2)(a/1000 r_g)^{-1/2} (q^{0.15}, q^{1.35})/(1+q)^{3/2}$$

$$y \approx 5 (\dot{m} f_{1,2})^2 (a/1000 r_g)^{-1} (q^{0.3}, q^{-1.3})(1+q)$$

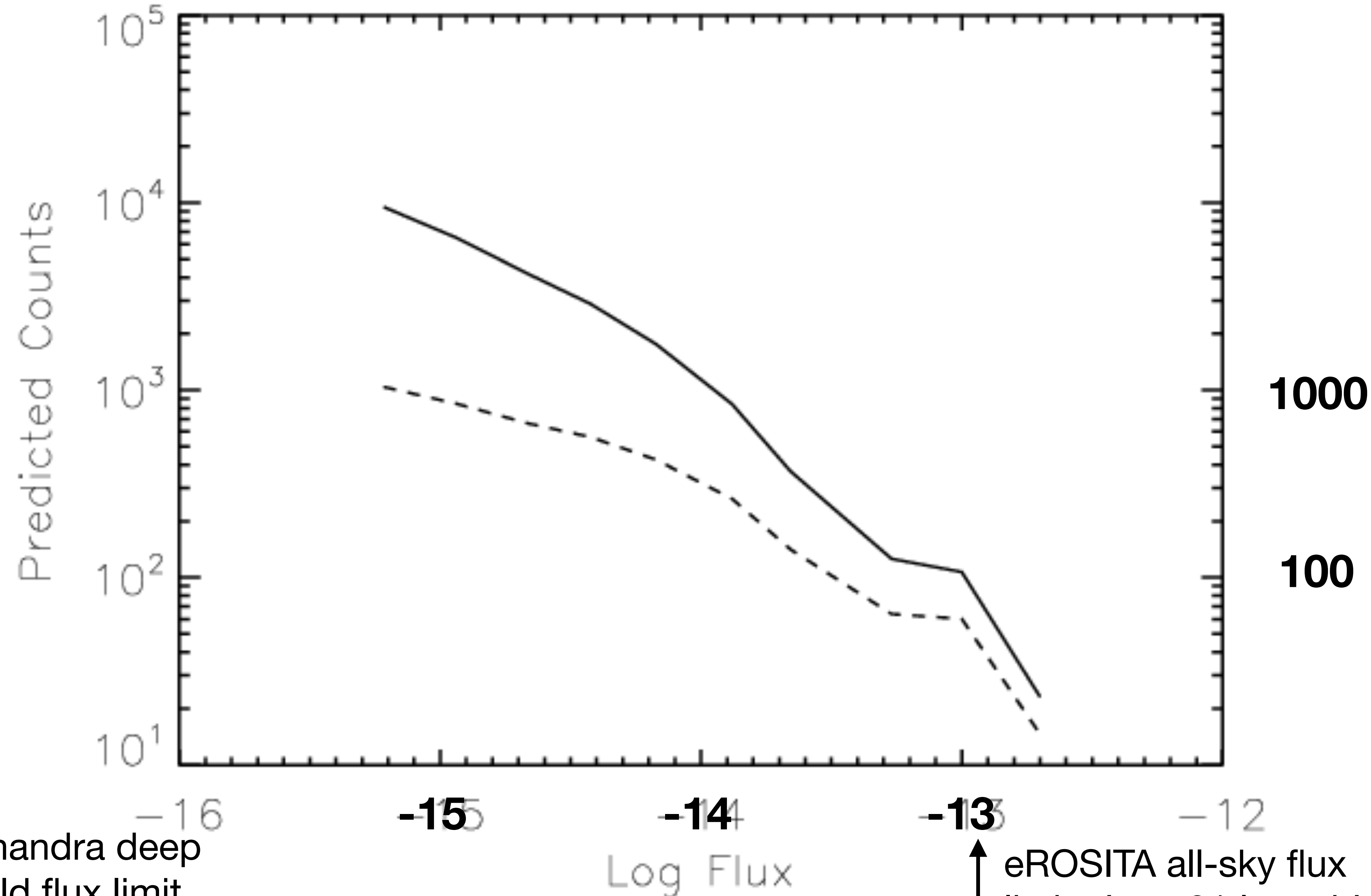
Accretion modulation —> hard X-ray modulation

Difficulties:

high bkgd., need multifoil mirrors for focusing (small FoV)

all the periodicity problems

Source Counts (?)



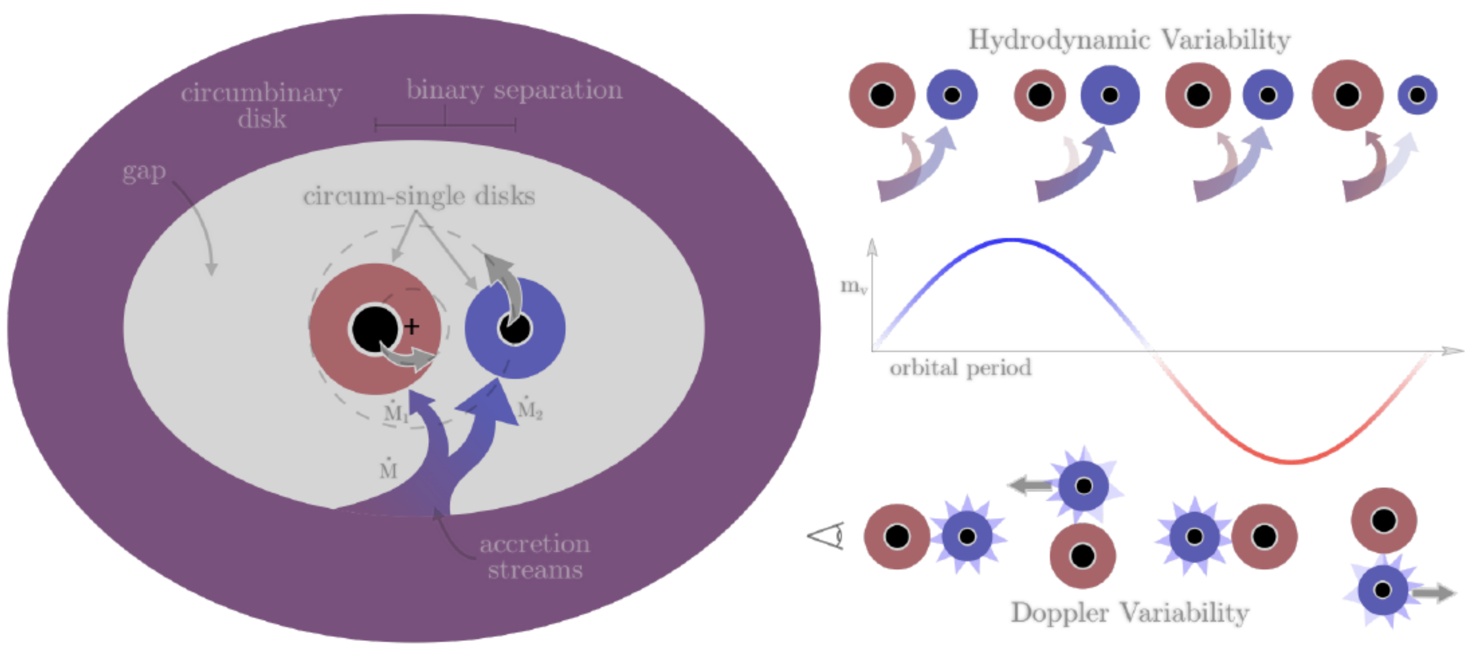
Chandra deep field flux limit

eROSITA all-sky flux limit: June 21 launch!

Thermal Continuum Periodicity

Mechanism either accretion stream modulation or Doppler boosting

Need $t_{inflow} \lesssim \Omega_{lump}^{-1}$ for former, which requires a <~ 20—30 r_g
Amplitude of latter small unless a <~ 100 r_g
And period measurement difficulties…



Broad Emission Line Profiles

Assumes:

- Black holes carry their own broad line regions, with structure roughly “normal”

Signature:

- double-peaked profile;
- or *periodically-varying* profile

- If BLR motions gravitational in scale, profiles superimposed unless a $<\sim r_{BLR}$
- How do binary illumination, binary potential, interacting BLR fluids, affect line emissivity, profiles?
- We don’t know geometry, dynamics of solitary BLRs; how to predict changes in binary?
- Plus the usual difficulties posed by period-hunting

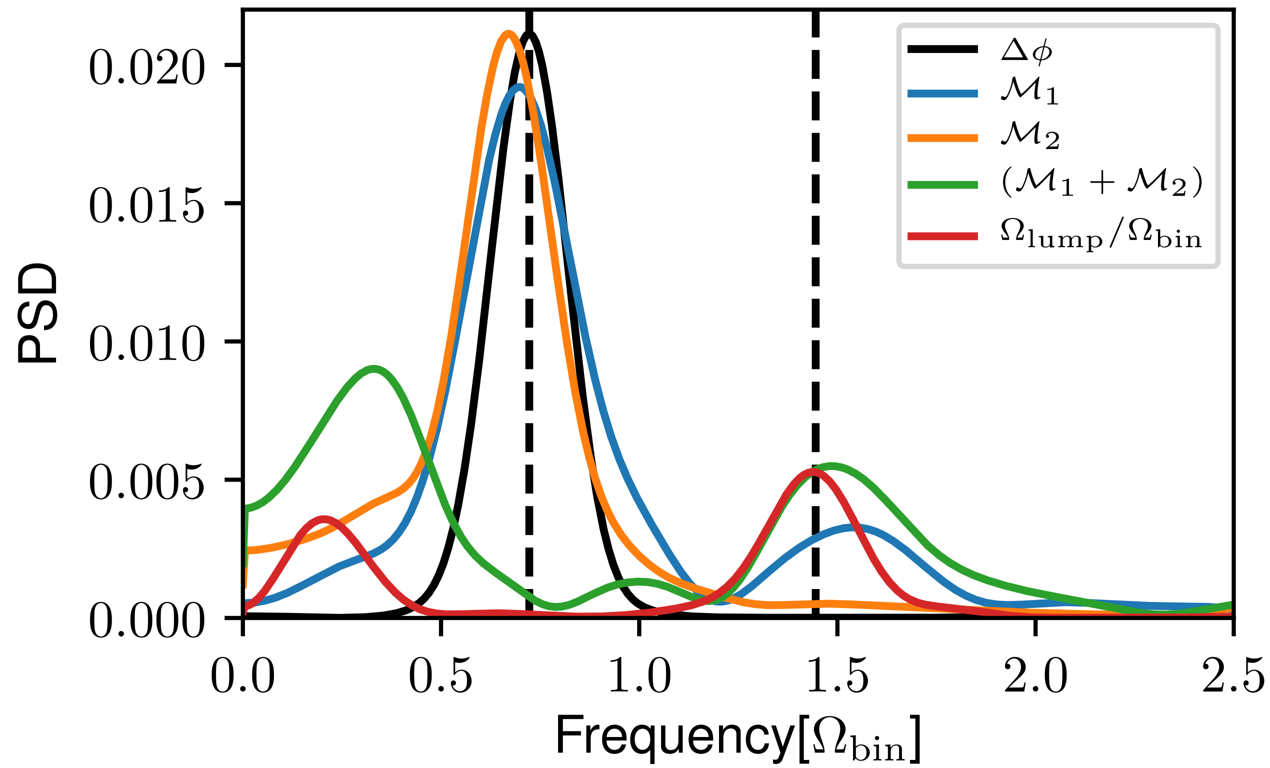
Specific Proposals: Event Signals

Systems Approaching Merger

$$t_{\rm GW} \simeq 8 \left[(1+q)^2/q\right] M_7 (a/20r_g)^4 \ {\rm d}$$

$r_{\rm minidisk}$ ~ few $r_{\rm ISCO}$ —> $t_{\rm inflow}$ <~ $P_{\rm bin}$ —> output follows accretion modulation

—> Strong accretion modulation
+ Doppler boosting, beaming



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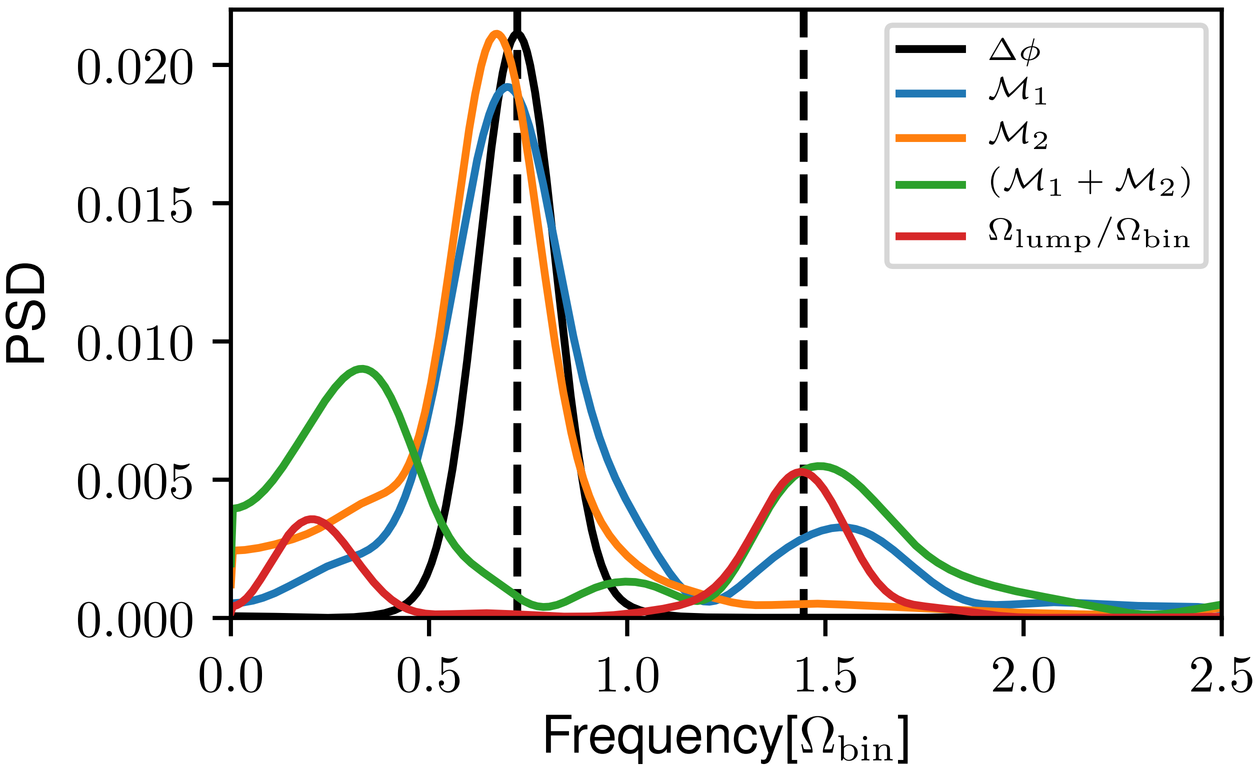
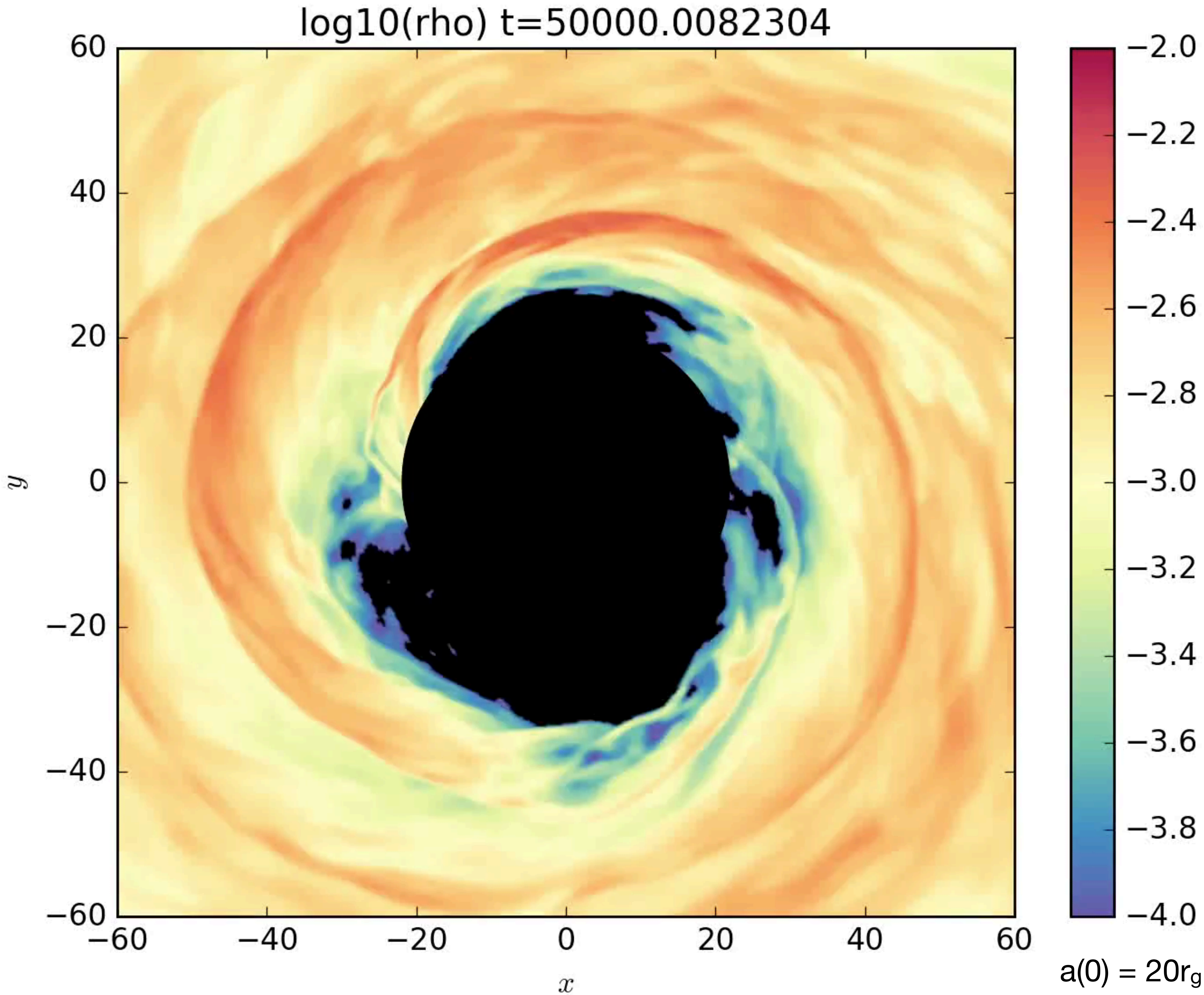
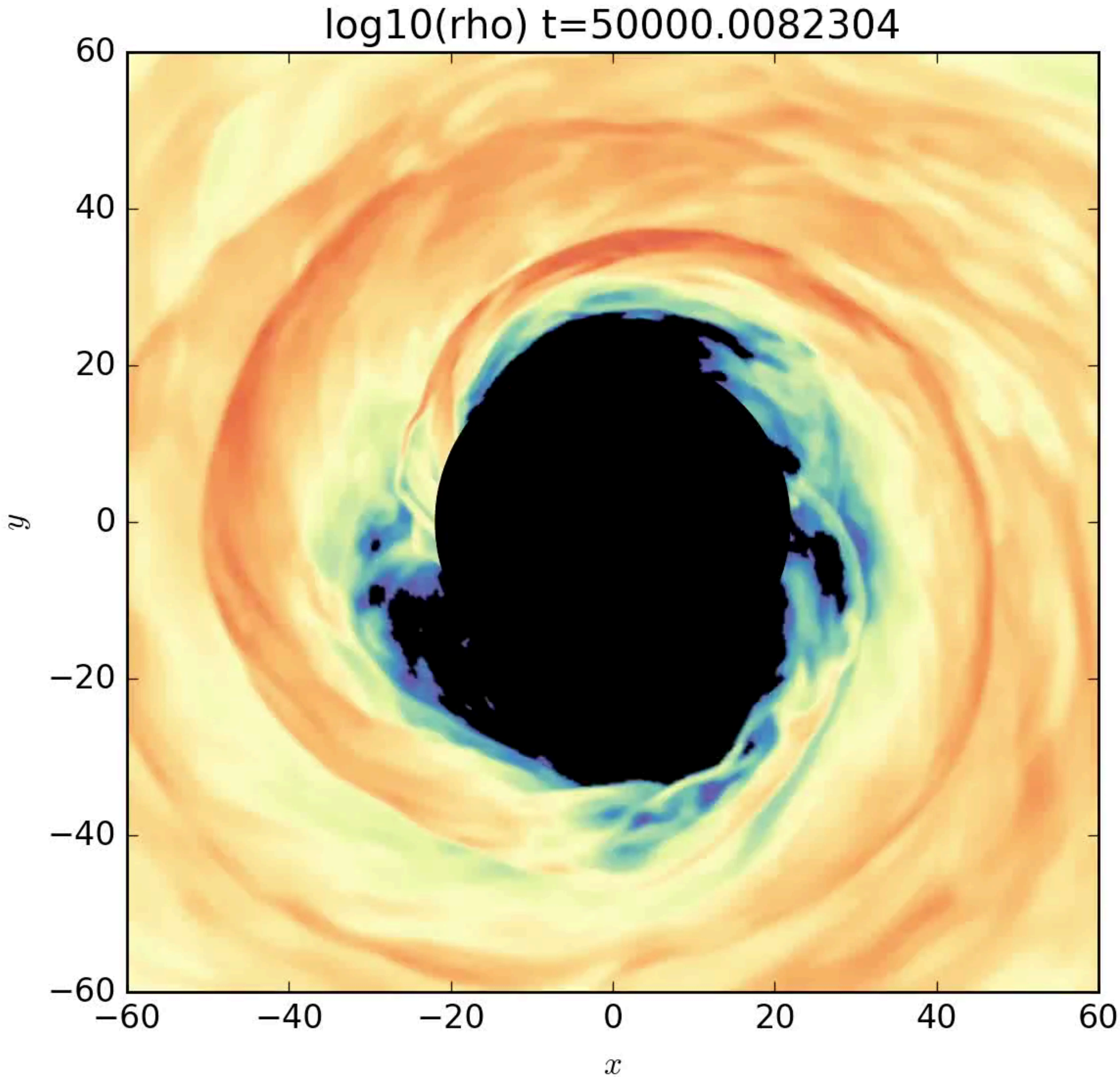


Leads to gas disposition immediately before merger proper



a(0) = $20r_g$; q=1
2.5pN + perturbed Schw.
3.5pN orbital evolution;
multipatch MHD



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