The Interplay Between Black Holes and their Hosts during Unequal Mass Galaxy Mergers

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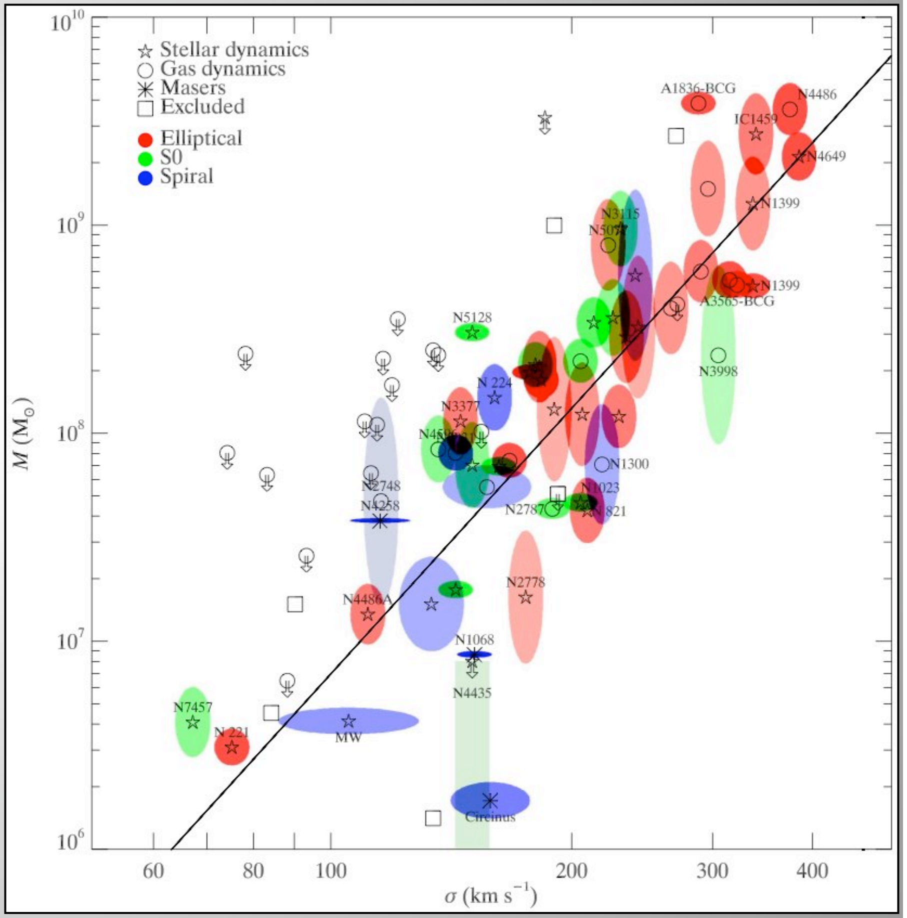
BH Galaxy Coevolution

- Black holes are found in the centers of most nearby galaxies
- Scaling relations between BHs and host galaxies provide evidence for co-evolution (M_{BH}-σ, M_{BH}-L, M_{BH}-M_{bulge})
- Important to understand how BH and galaxy interact under typical conditions and what BH observables tell us about their environment



Gultekin et al. 2009

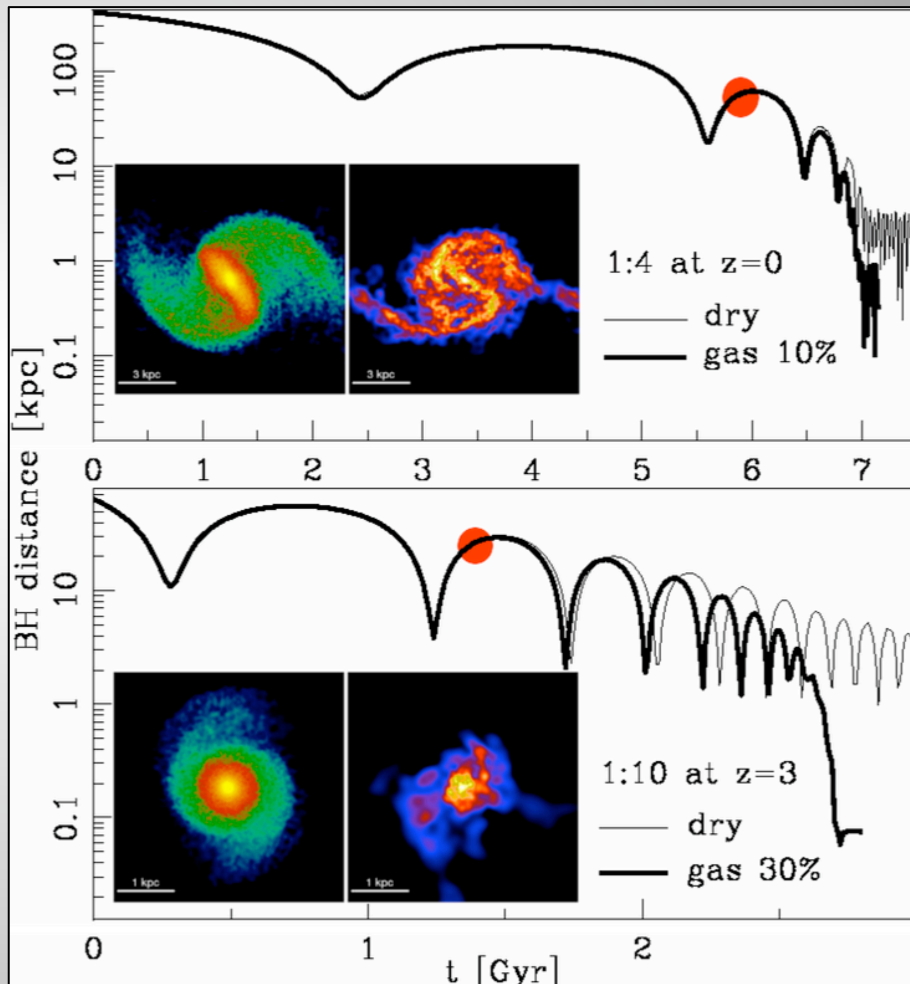
Pairing in Unequal Mass Galaxy Mergers

Callegari et al. 2009, 2011

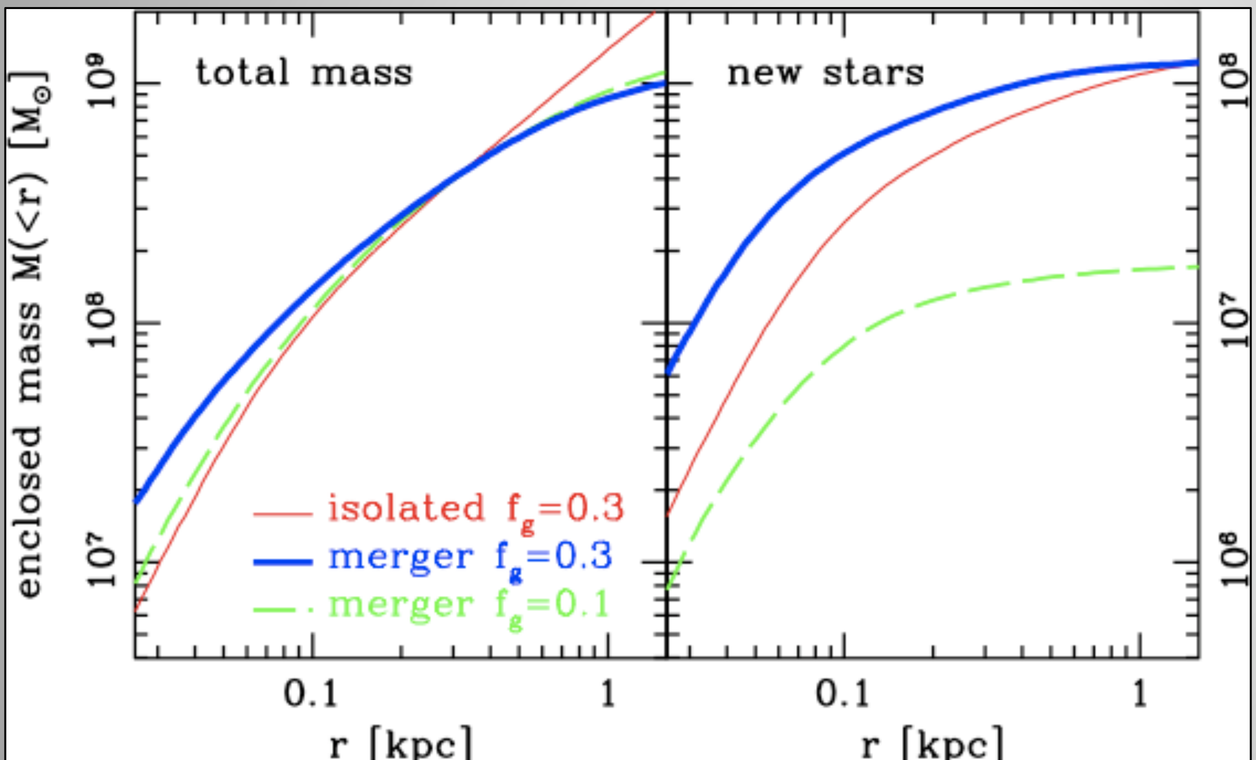
Table 1
Summary of Simulations

q	SF	f_g	z	BH final distance[a]
0.25	No	0	0	2–4 kpc
0.25	Yes	0.1	0	200 pc
0.1	No	0	3	1–6 kpc
0.1 (Hi-Res)	No	0	3	1–5 kpc
0.1	Yes	0.1	3	400 pc
0.1	Yes	0.3	3	70 pc

- 1:4 and 1:10 spiral-spiral mergers at z=0 and z=3
- Pairing more efficient in disks with a high gas fraction
- Merger proceeds more quickly at high redshift



The Importance of a Stellar Cusp



Callegari et al. 2009

Tidal torques concentrate gas in secondary galaxy, creating a burst of star formation

Formation of a stellar cusp protects the MBH from tidal stripping, allowing pairing to proceed down to small separations

Dynamical friction timescale shorter for a more massive surviving cusp

Simulation Outline

- BH pairing successful in high redshift gas-rich mergers
- We study here the impact of the morphology and gas content of the primary galaxy on accretion and pairing
- Primary: gas-poor elliptical or gas-rich spiral
- Secondary: gas-rich spiral
- Focus on 1:2 mass ratio mergers at z=3

Simulation Parameters

- Simulations use the N-body/SPH code Gasoline
- Star formation, supernova feedback, radiative cooling, BH accretion and feedback included
- Gravitational softening lengths 10-30 pc

Bondi-Hoyle-Lyttleton accretion

$$\dot{M}_{BH} = 4\pi G \frac{M_{BH}^2 \rho_g}{\left(V^2 + c_s^2\right)^{3/2}}$$

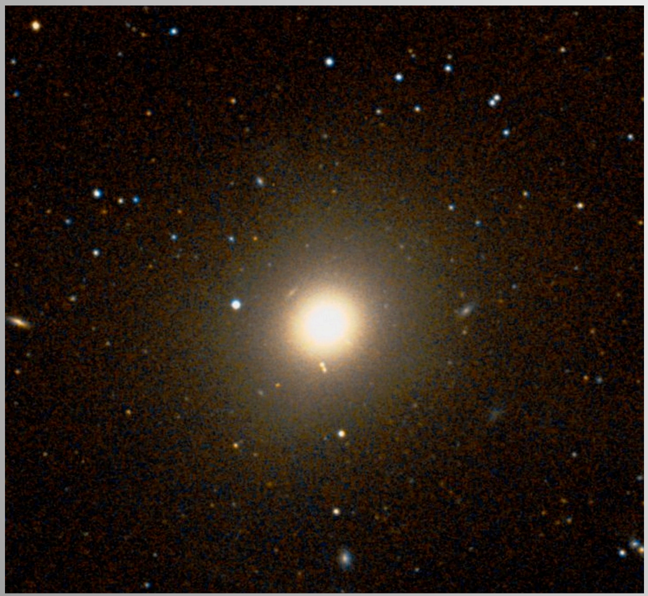
ε_{fb} = 0.001 of accreted energy deposited in nearby gas

Galaxies placed on nearly parabolic orbits initially, with pericentric passages ~20% the virial radius of the primary galaxy

Galaxy Initial Conditions

Spiral:

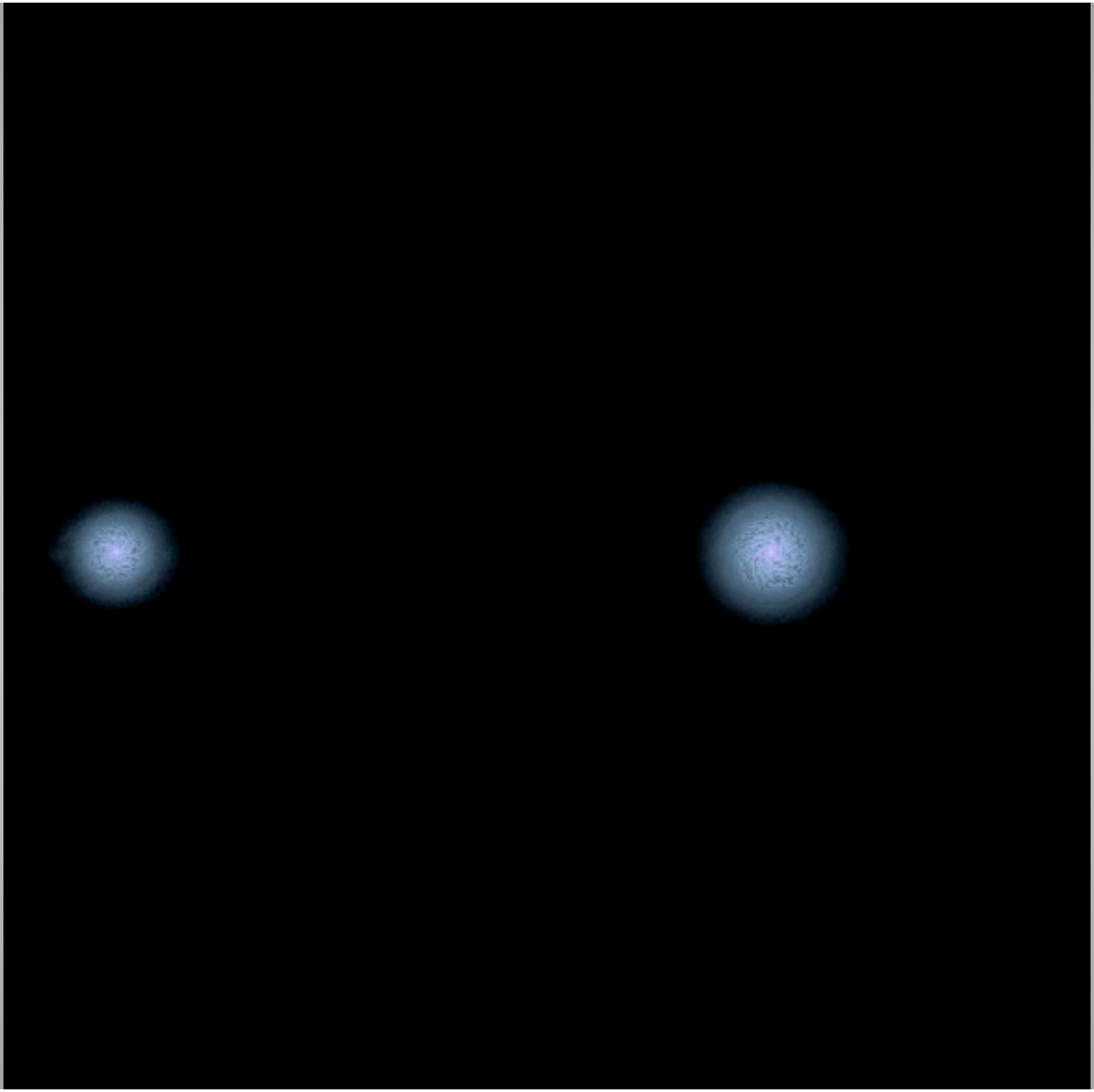
- NFW Halo, exponential disk, and Hernquist bulge
- Gas fraction of 30%



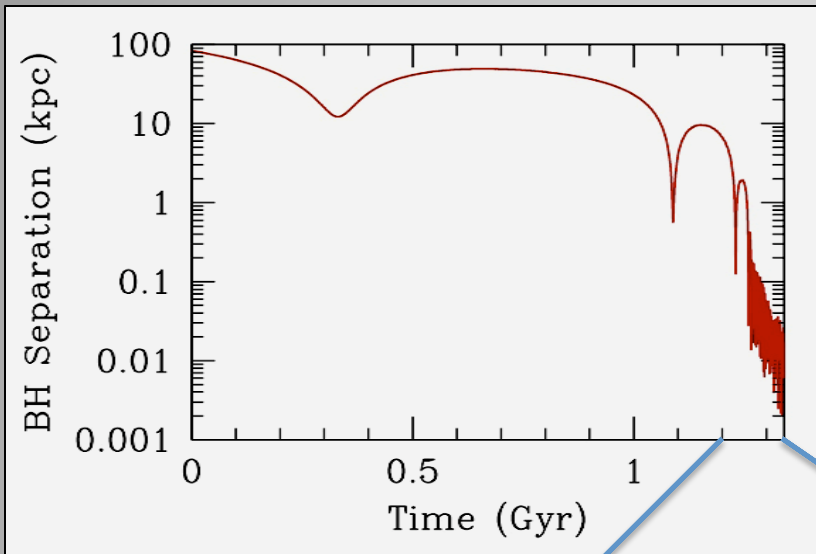
Elliptical:

- Nested Hernquist halos of stars and dark matter
- No gas
- Axisymmetric profiles

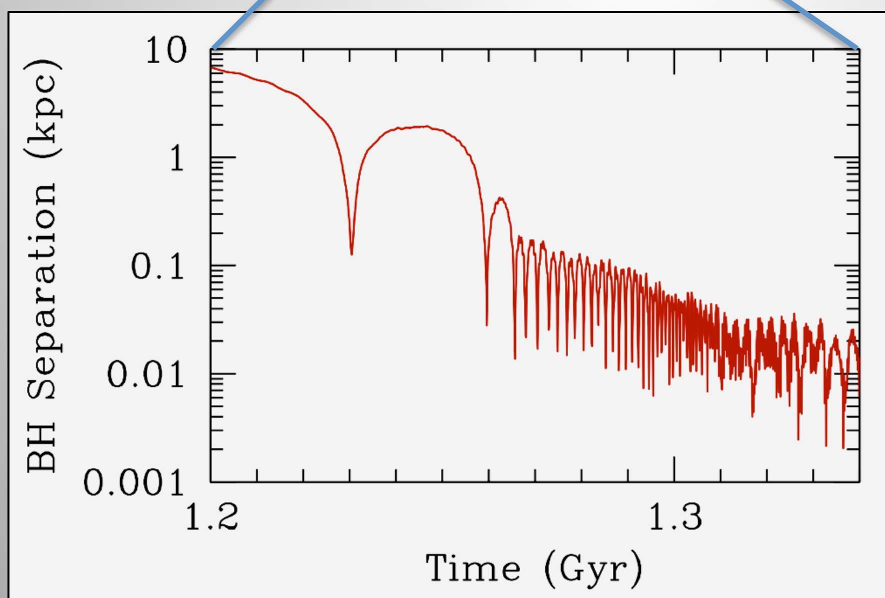
(Hernquist 1993, Mo, Mao & White 1998, Springel et al. 2005)



BH Pairing, Spiral-Spiral Merger



Following 5th pericenter passage, the stars and gas surrounding the primary BH are disrupted, leaving the BH orbiting in the gas rich merger remnant



Final Separation: < 20 pc
At the resolution limit of the simulation

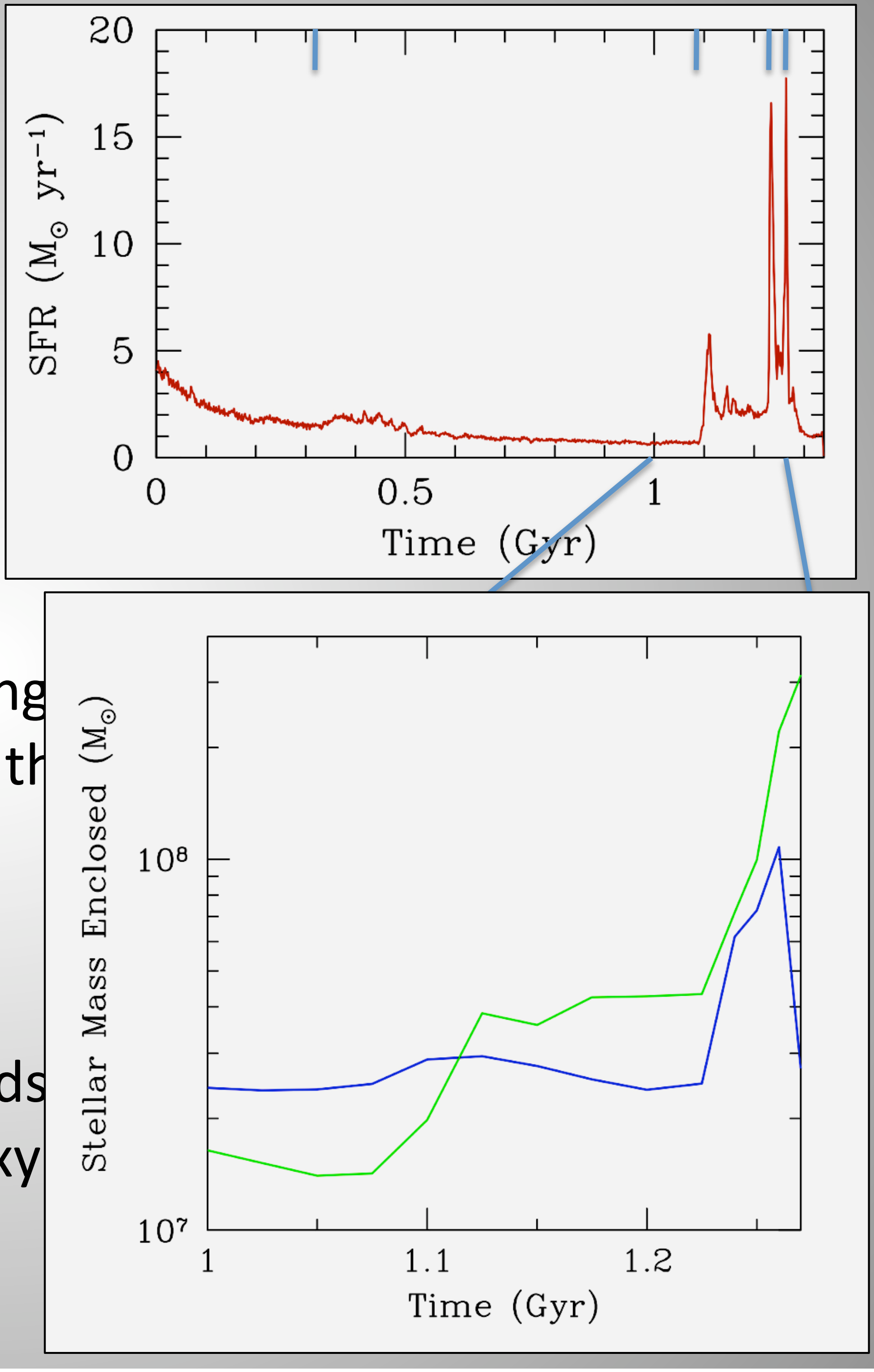
Time to reach resolution limit following disruption of primary galaxy: < 100 Myr

Star Formation History

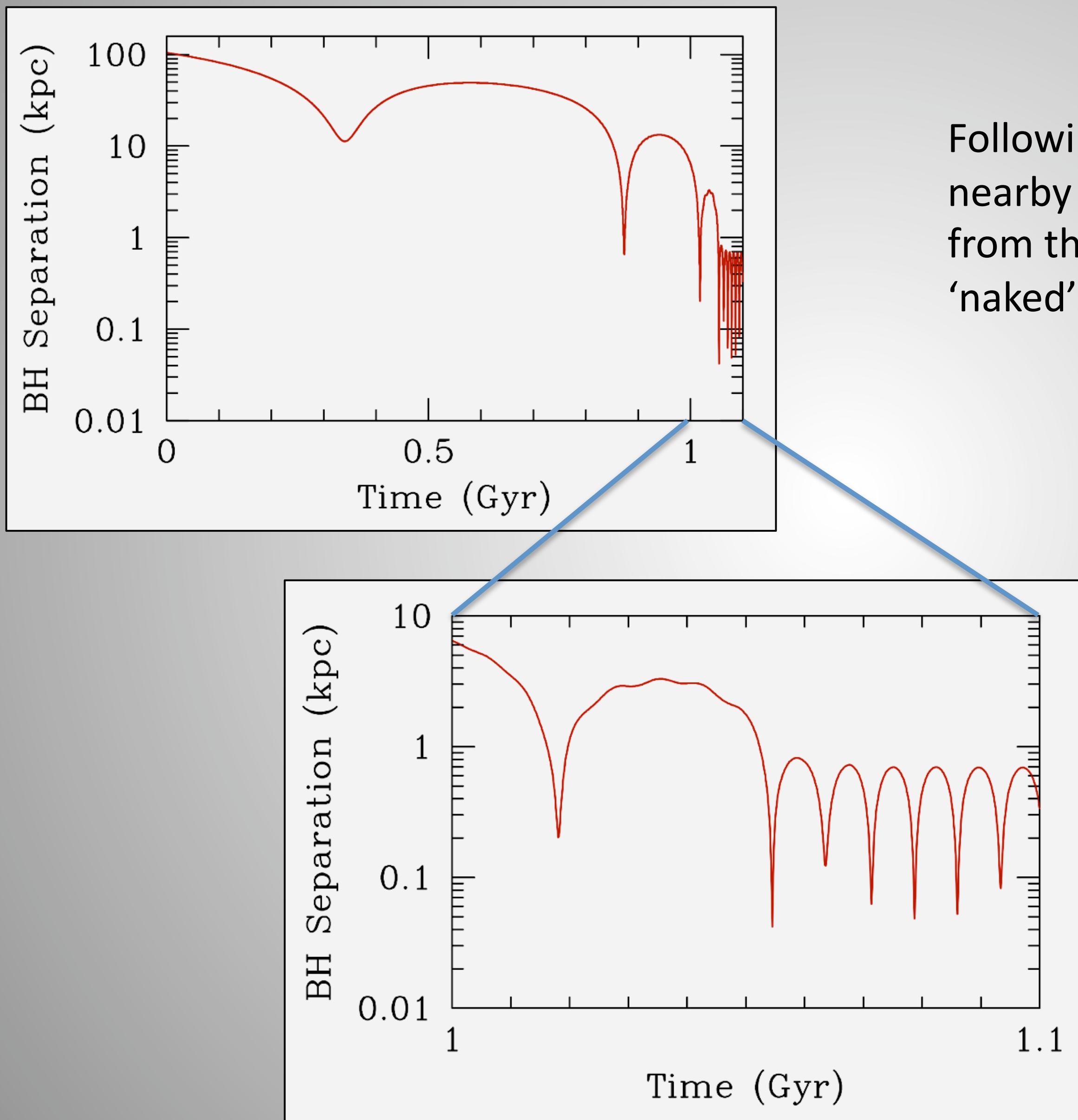
Global star formation peaks following pericenter passages

Secondary galaxy experiences strong SF in its central 100 pc throughout th merger

Central SF in secondary galaxy builds denser cusp than the primary galaxy



BH Pairing, Elliptical-Spiral Merger



Following 4th pericenter passage, nearby stars and gas are stripped from the secondary BH, leaving it 'naked'

Final Separation:
Pericenter: 50 pc
Apocenter: 700 pc

Prospects for BH-BH Merger

Spiral-Spiral

- Final separation of 10-20 pc
- Merger remnant:
  gaseous disk
  mass: 3 x 10^8 M_{sun}
  radius: 1 kpc
- Binary may form within a few Myr

(Mayer 2007)

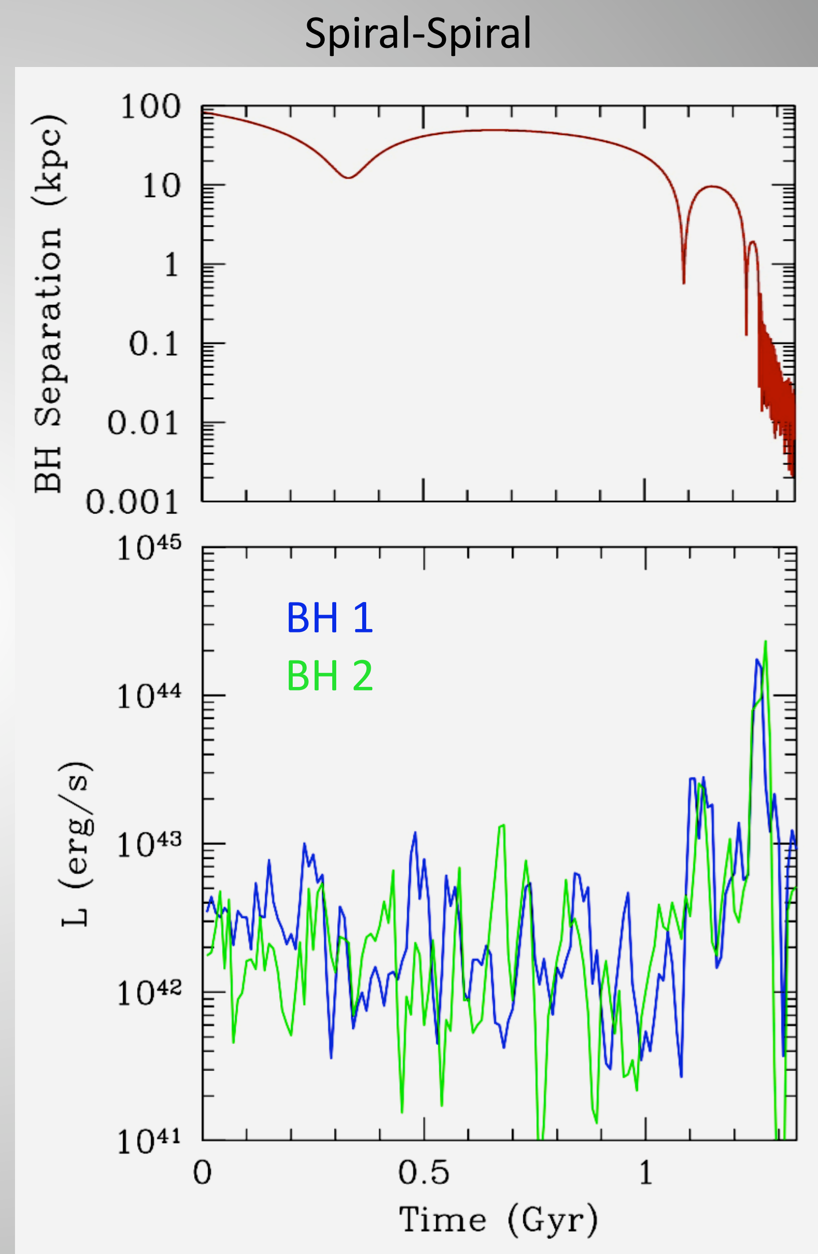
Elliptical-Spiral

- Final separation of 50-700 pc
- Merger remnant:
  gaseous disk
  mass: 10^8 M_{sun}
  radius: 200 pc
- Binary will form within a Hubble time

MBH Accretion

$$L = \varepsilon_r \dot{M} c^2$$

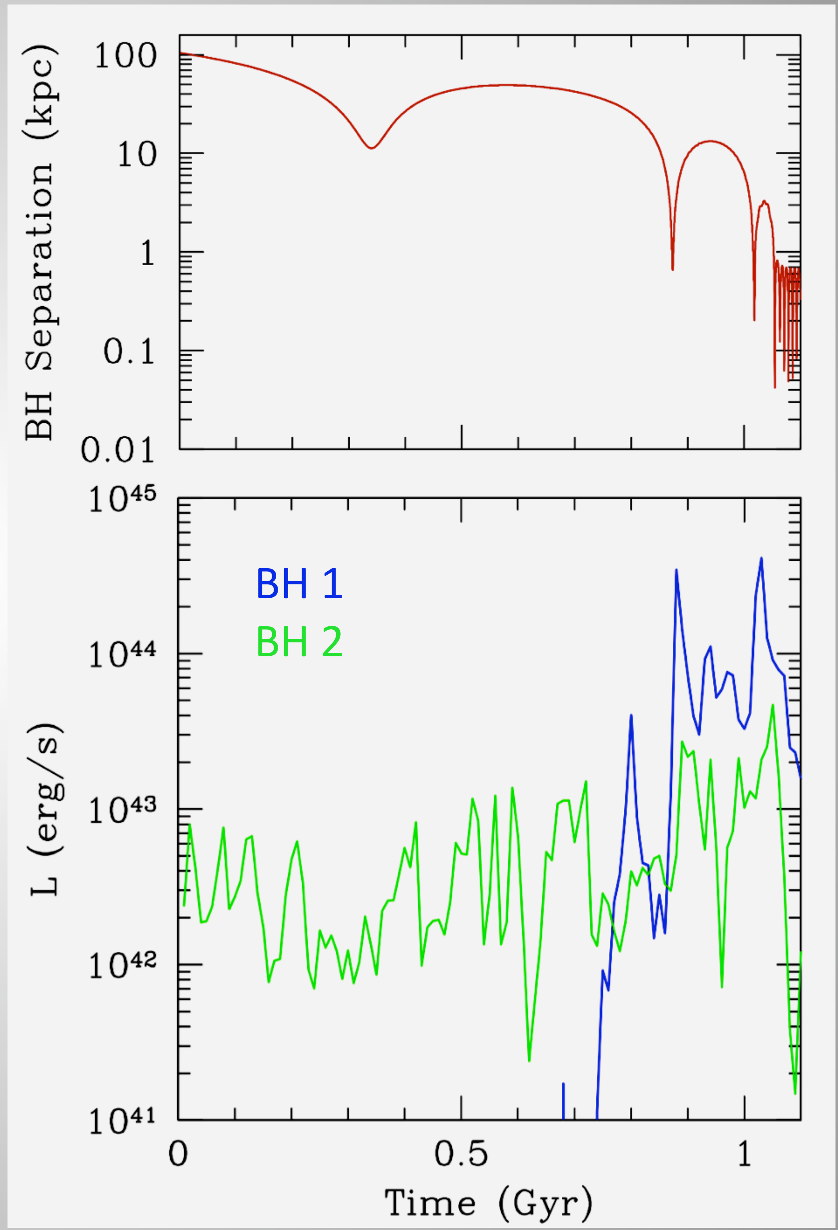
- No obscuration considered here
- Strongest accretion in both BHs occurs following 2nd and subsequent pericentric passages



MBH Accretion

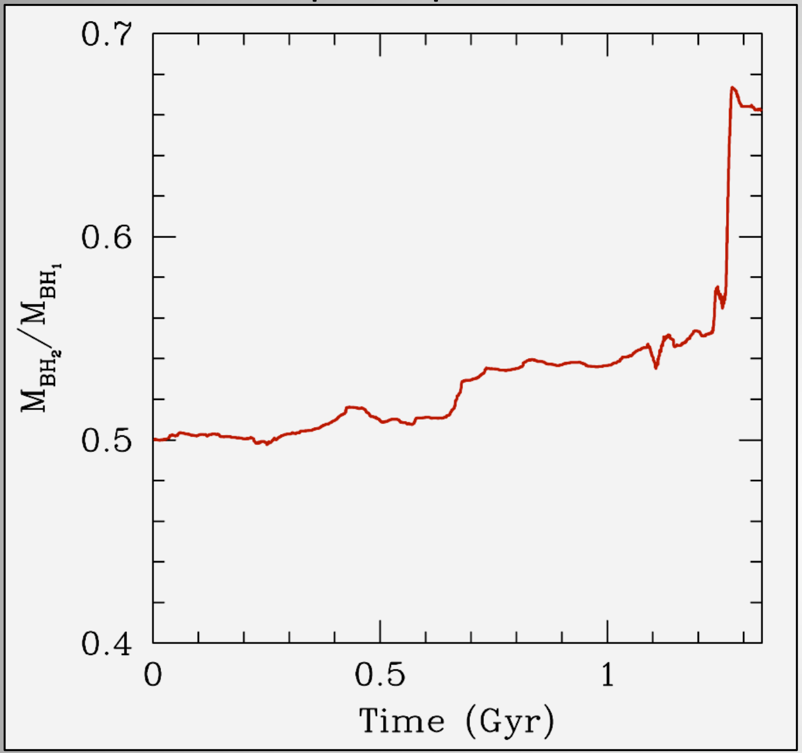
- Elliptical initially completely gas-poor
- Gas stripped from companion at pericenter passages
- With an older stellar population, gas cools more efficiently and forms stars/accretes

Elliptical-Spiral

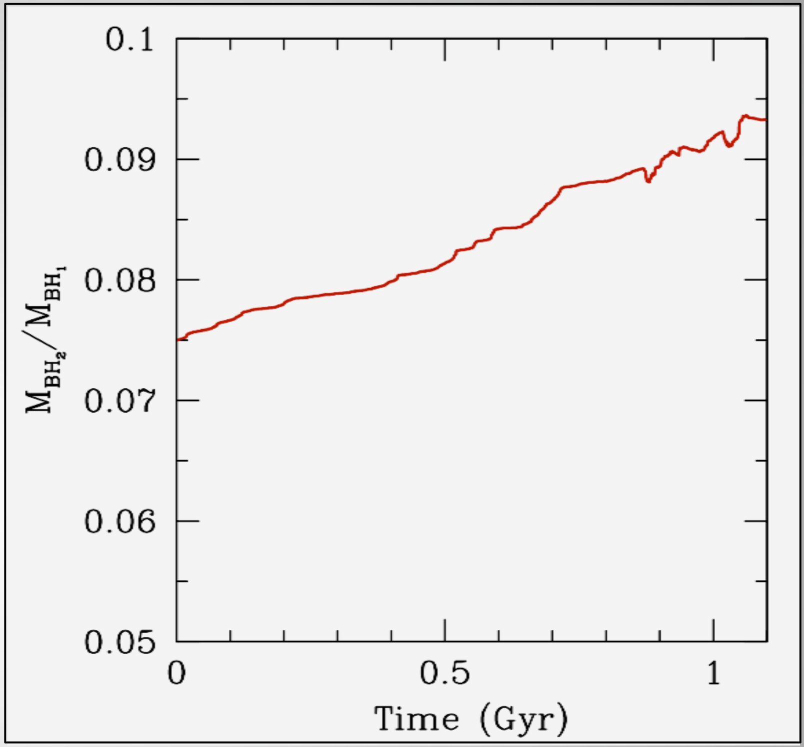


Evolution of the BH Mass Ratio

Spiral-Spiral



Elliptical-Spiral



Following disruption of the gas and stars around the primary BH, the secondary experiences near Eddington accretion

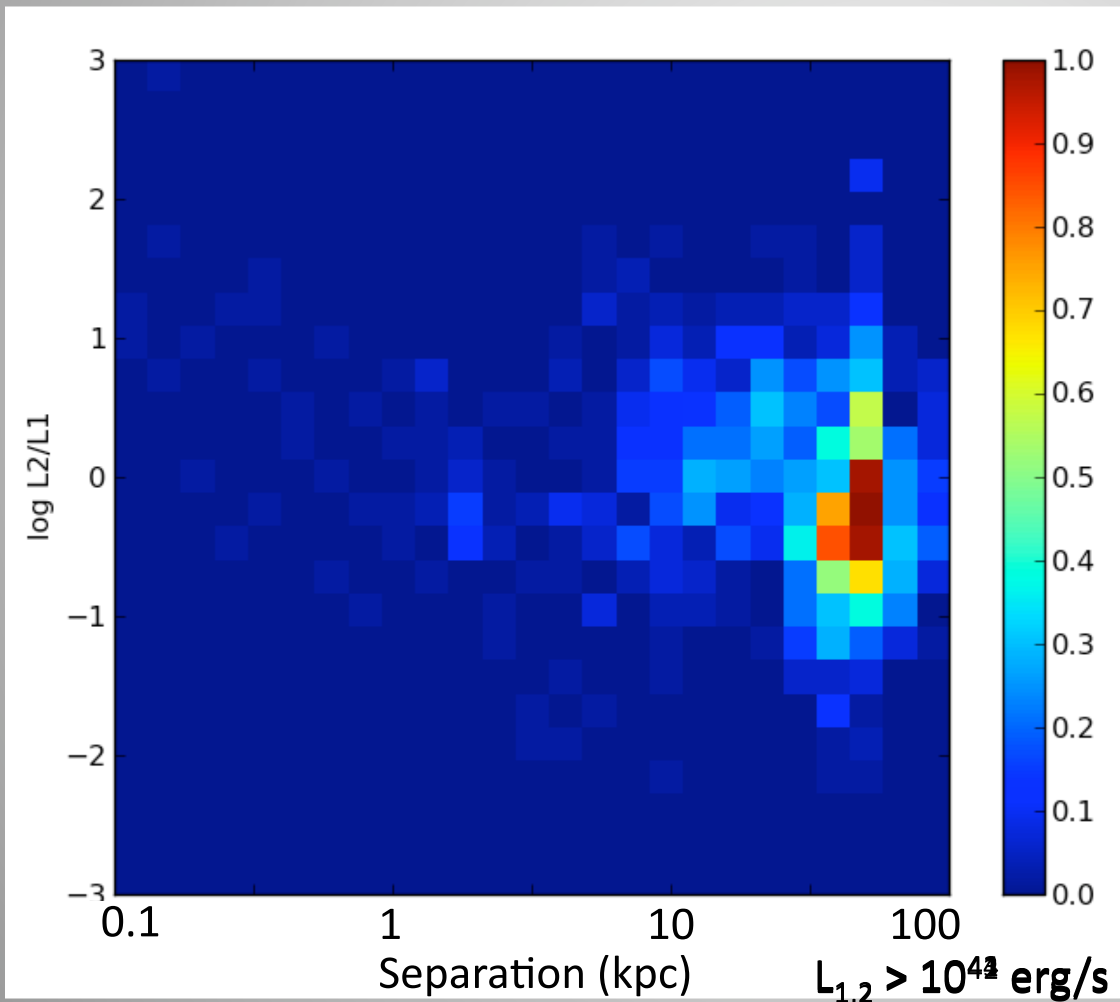
No strong bursts of accretion; secondary ceases accreting efficiently following disruption

Final BH mass ratio differs from initial conditions

Very important for gravitational wave emission or kicks from a successful merger!

Dual AGN Activity

Spiral-Spiral



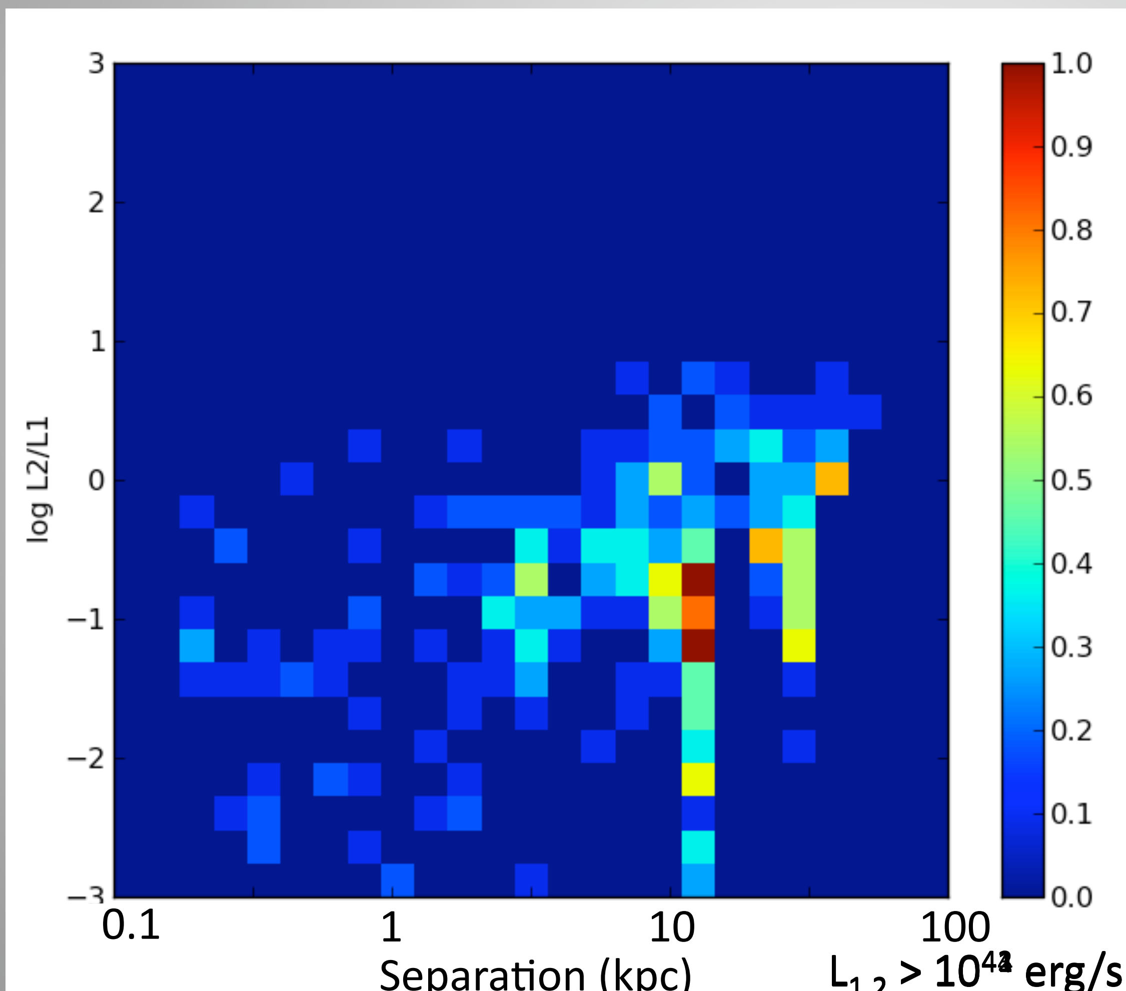
- Galaxies spend most of their time near apocenter, so we see most of the dual AGN activity at large separations

- Using a higher cutoff in luminosity moves us to smaller separations – strong accretion following 2nd and 3rd pericenter passages

- Strongest accretion seems to occur simultaneously, weaker accretion is less correlated

Dual AGN Activity

Elliptical-Spiral



- No accretion onto primary BH until shortly before second pericenter; this moves dual AGN activity to smaller separations

Summary

- Performed 1:2 galaxy mergers at z=3, varying the morphology and gas content of the primary
- Studied efficiency of BH pairing and accretion
- Pairing proceeded quickly in spiral-spiral merger due to build-up of a dense stellar cusp in the secondary
- Pairing much slower in elliptical-spiral merger due to tidal stripping by the primary galaxy
- Mass ratio of two black holes evolves prior to BH merger
- Most of time spent as a dual AGN is at the largest separations (~10-50 kpc), but the strongest accretion occurs at smaller separations (<10 kpc)

Discussion Questions

- What is the structure of a typical galaxy at high redshift? How do they differ from galaxies in the local universe?
- How do scaling relations evolve during a merger – do the BHs or galaxies grow first?
- How do BH dynamics evolve following the pairing phase? Is the final parsec problem still an issue?
- Why are AGN pairs rare observationally? Is merged induced accretion simultaneous in both BHs?