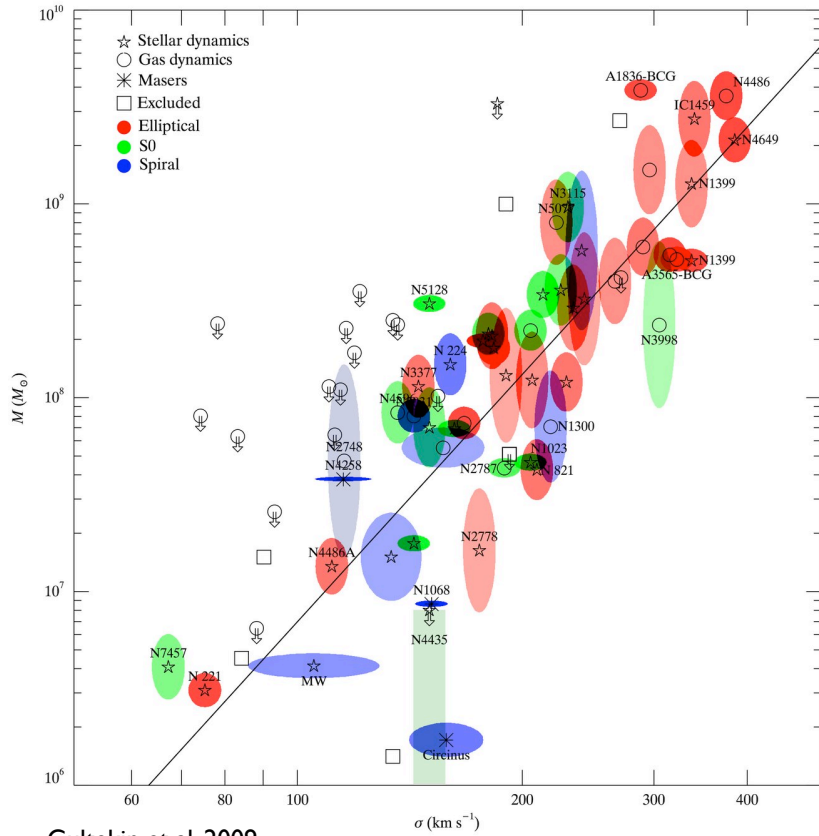


Nuclear Coups in Unequal Mass Galaxy Mergers

'Massive Black Holes: Birth, Growth and Impact' Conference
Kavli Institute for Theoretical Physics, Univ. of California, Santa Barbara, August 6, 2013

Pedro R. Capelo (University of Michigan, Ann Arbor)
Sandor Van Wassenhove, Marta Volonteri, Massimo Dotti, Jillian Bellovary, Lucio Mayer

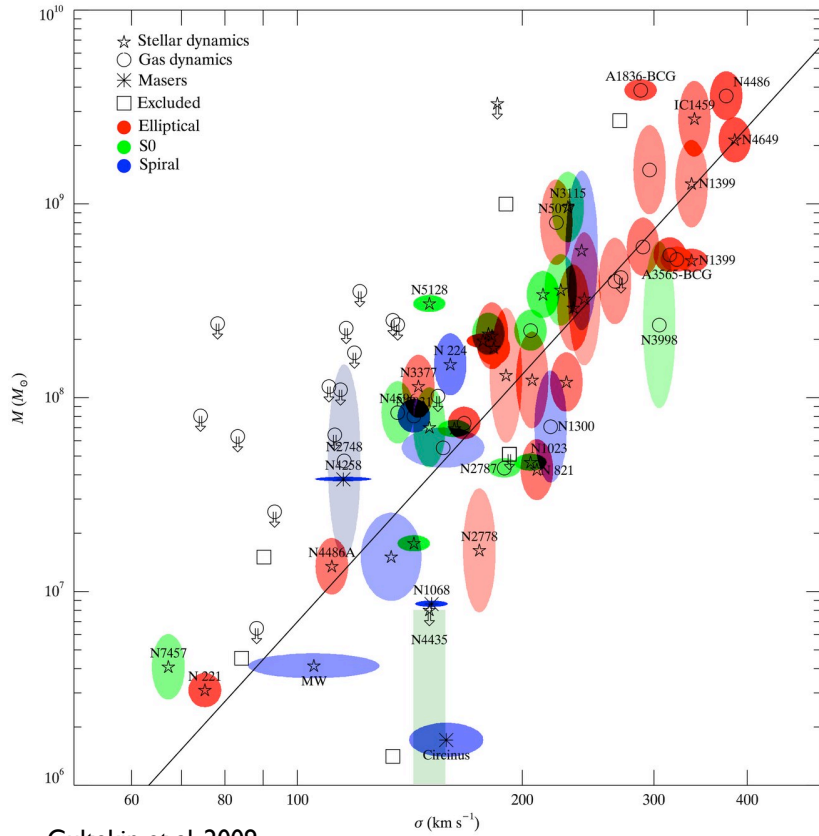
'Black hole – galaxy' coevolution



Scaling relations:

$M_{BH} - X$, where $X = \sigma, L, M... (bulge)$

'Black hole – galaxy' coevolution

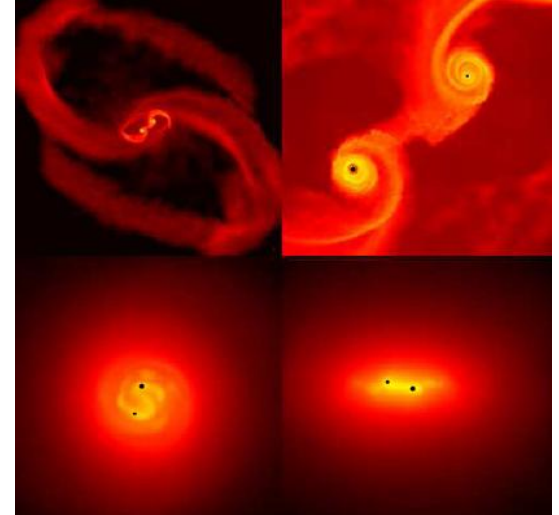


Gultekin et al. 2009

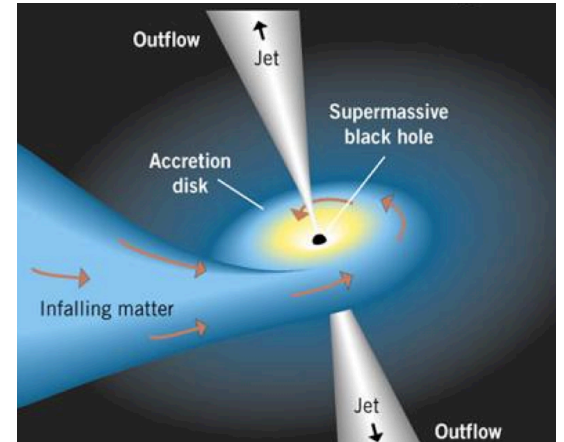
Scaling relations:

$M_{\text{BH}} \propto X$, where $X = \sigma, L, M \dots$ (bulge)

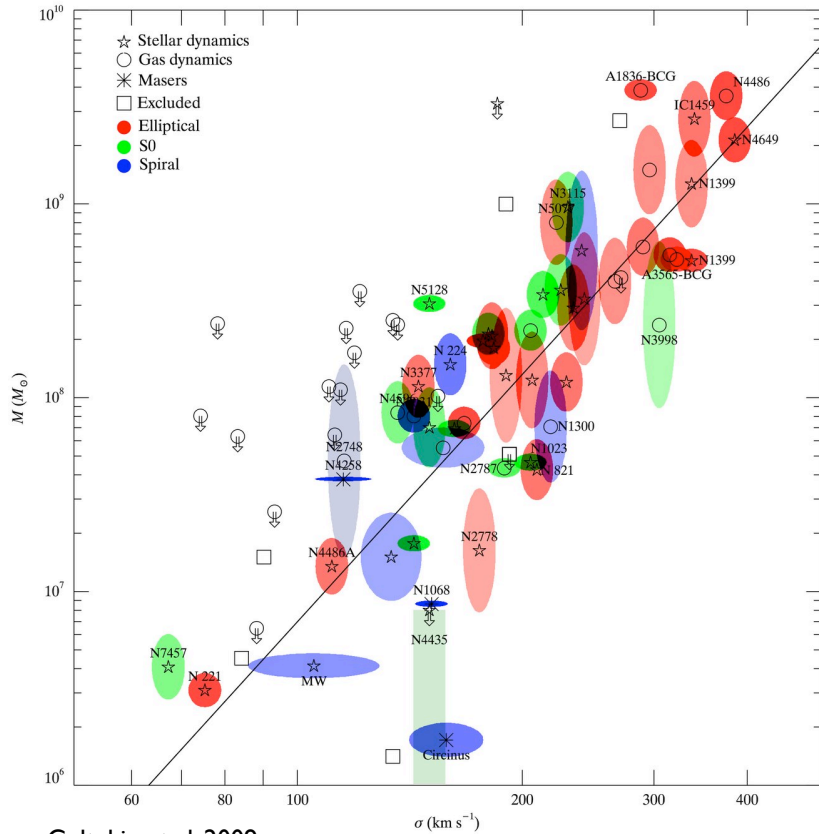
Mergers



Accretion



'Black hole – galaxy' coevolution

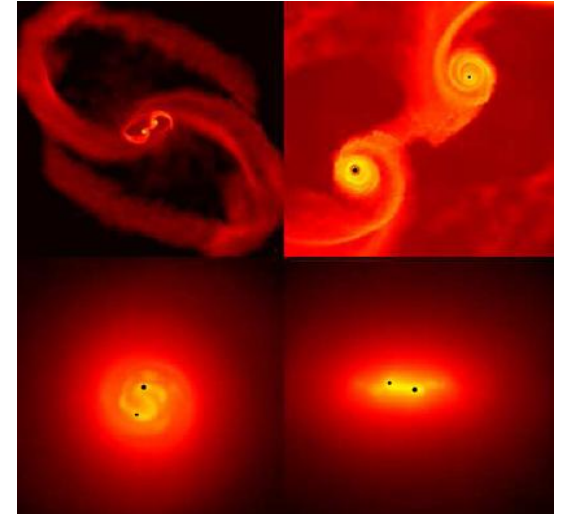


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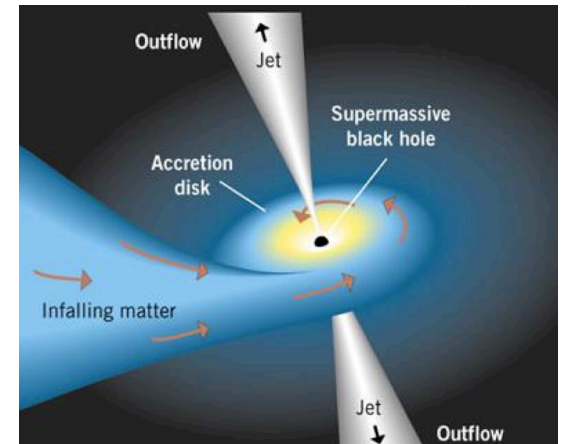
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Mergers



Accretion



- Feedback?
- How do scaling relations evolve during a merger?
- When do mergers trigger AGN activity?
- Do BHs merge as efficiently as their host galaxies?

Suite of merger simulations

- Merging galaxies using N-body SPH simulations (Gasoline)
- Star formation, supernova feedback, stellar winds
- Black hole accretion and feedback
- Isolated galaxies – dark matter, stars, gas, central black hole
- $z = 3$; Parabolic orbits ($R_i = R_{\text{vir},1} + R_{\text{vir},2}$; $R_p = 0.2 R_{\text{vir},1}$)

Thresholds for SF:

- 100 amu/cm³

- 6000 K

$$\frac{d\rho_*}{dt} = c^* \frac{\rho_{\text{gas}}}{t_{\text{dyn}}}$$

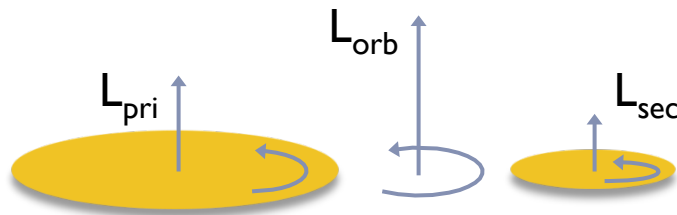
$c^* = 0.015$

Suite of mergers

Different morphologies: elliptical and disk galaxies

Different mass ratios: 1:2, 1:4, 1:6, 1:10

Different galactic angular momentum vectors: prograde, retrograde, inclined orbits



$$[\theta(L_{\text{pri}}), \theta(L_{\text{sec}})] = \begin{aligned} & [0, 0] \text{ (pro-pro)} \\ & [0, \pi/4] \text{ (inclined)} \\ & [0, \pi] \text{ (pro-ret)} \\ & [\pi, 0] \text{ (ret-pro)} \end{aligned}$$

Angle of L_{pri} and L_{sec} with L_{orb} : $\theta = 0, \pi/4, \pi$

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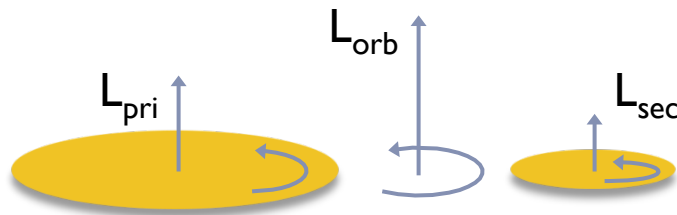
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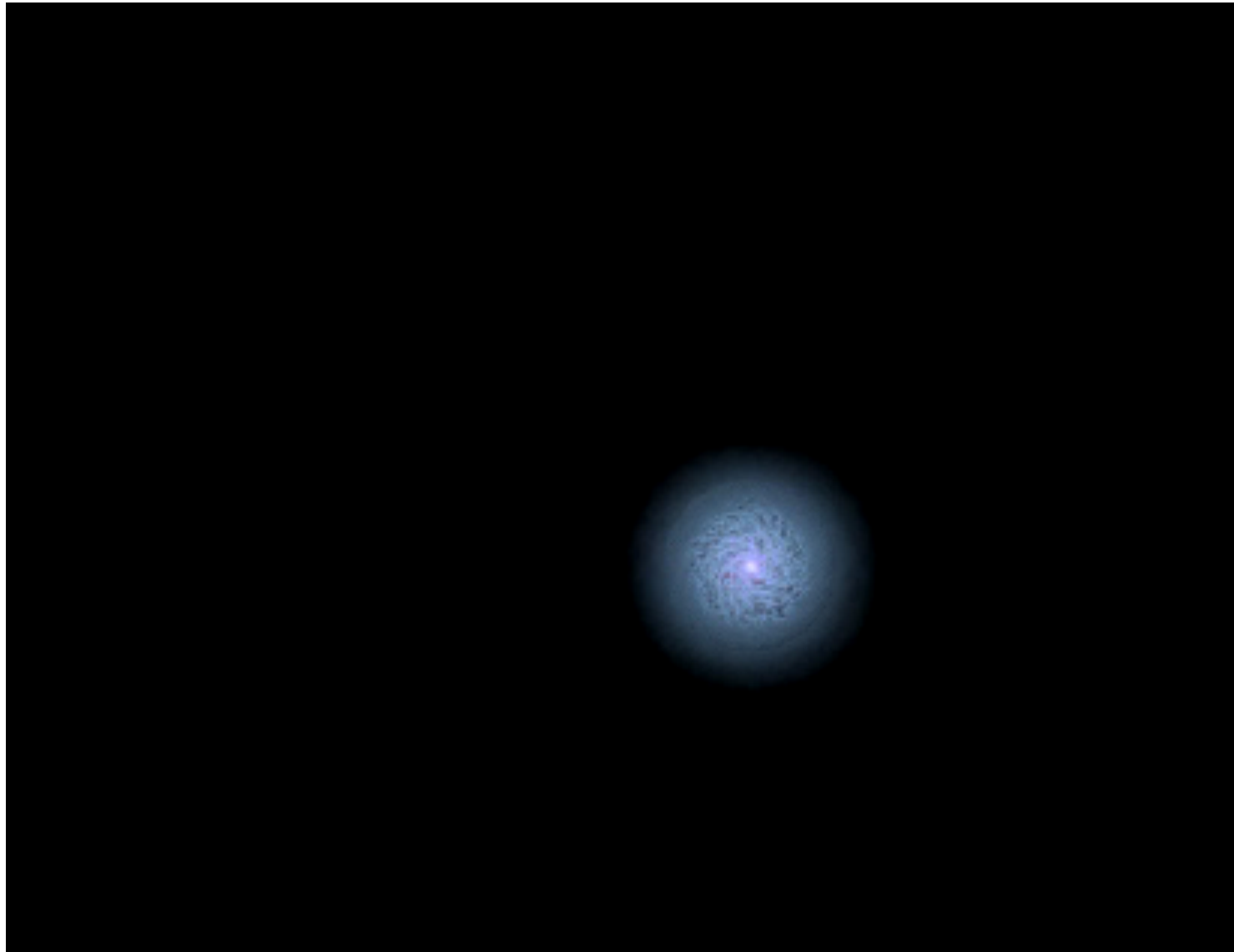
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This talk:

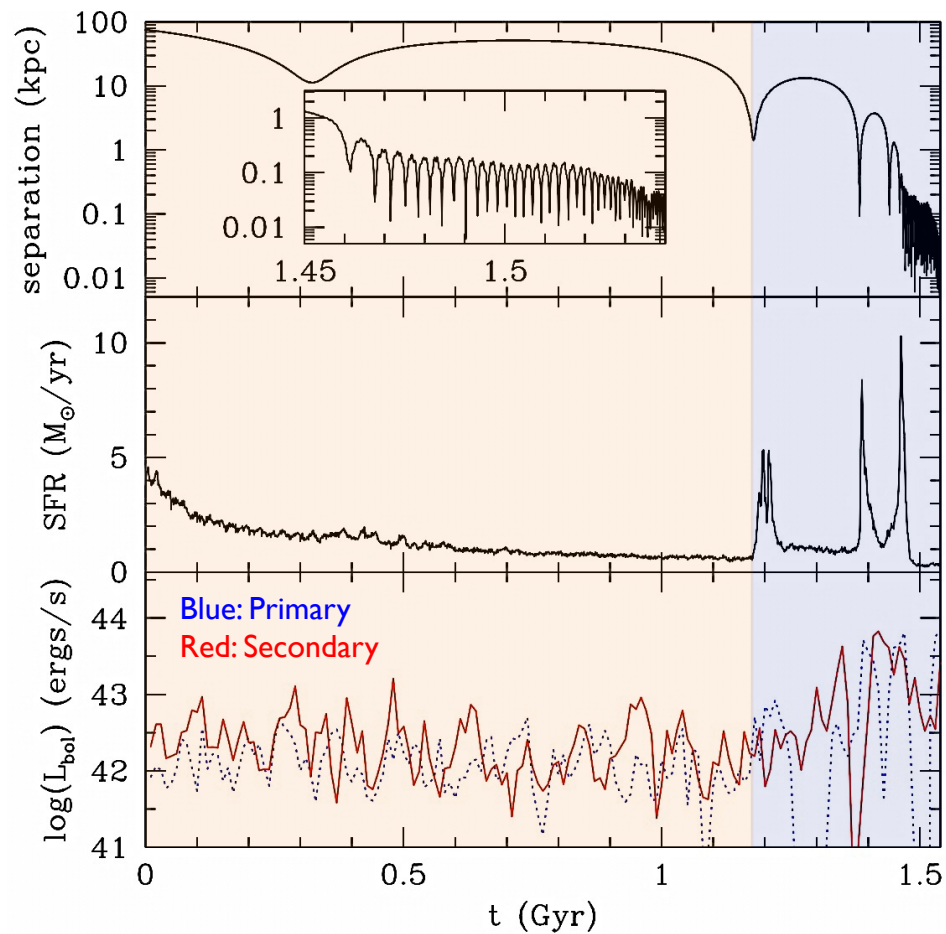
DISK-DISK, COPLANAR

(PROGRADE, RETROGRADE)

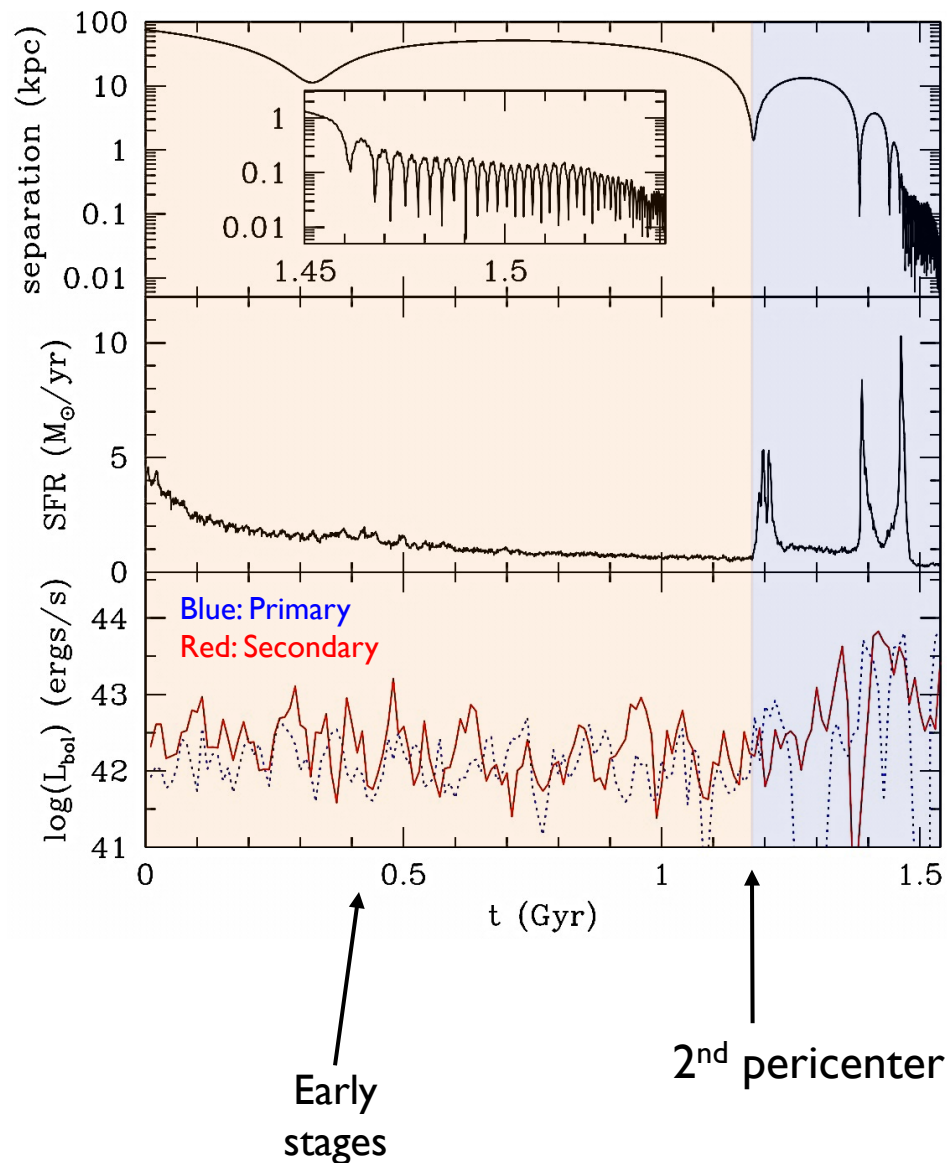
1:4 disk-disk, coplanar, prograde-prograde



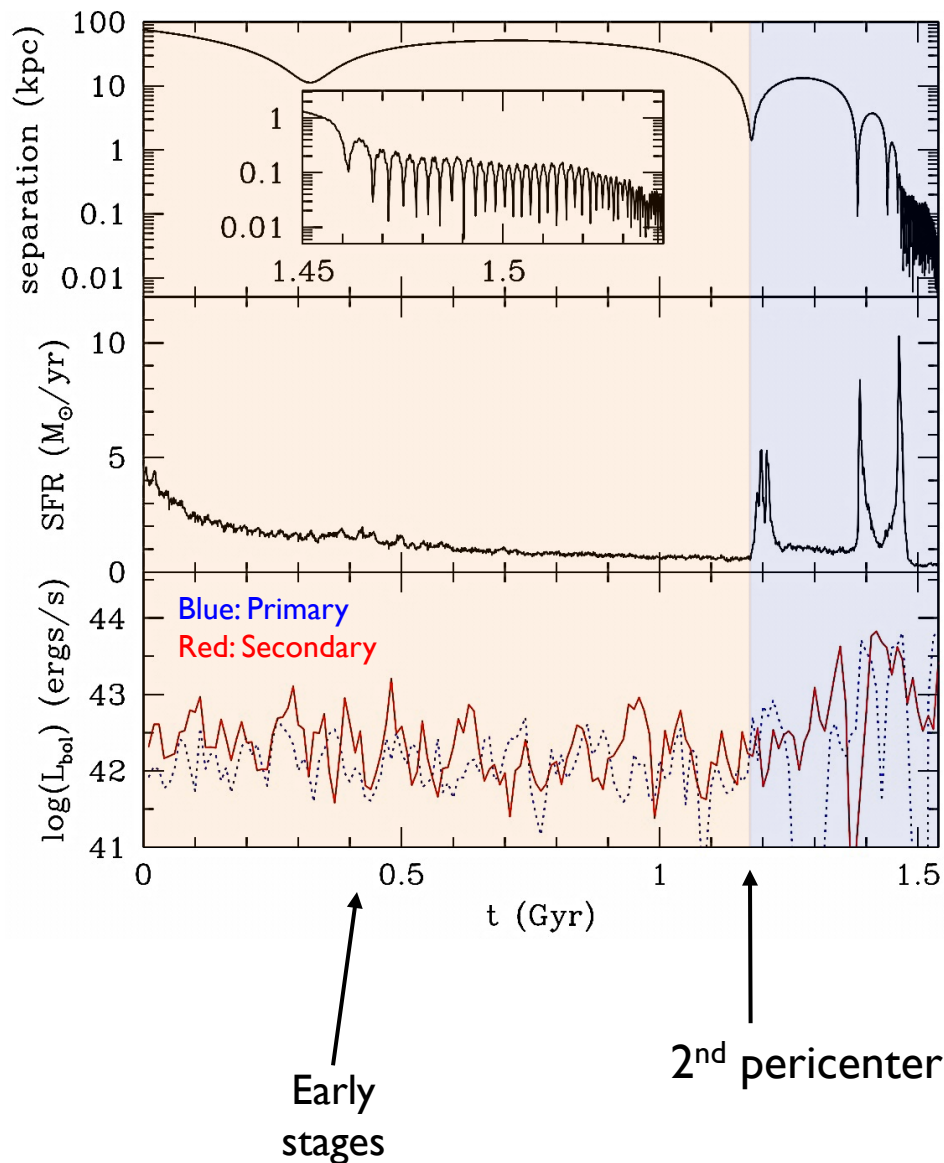
AGN activity: 1:4 disk-disk, coplanar, prograde-prograde



AGN activity: 1:4 disk-disk, coplanar, prograde-prograde

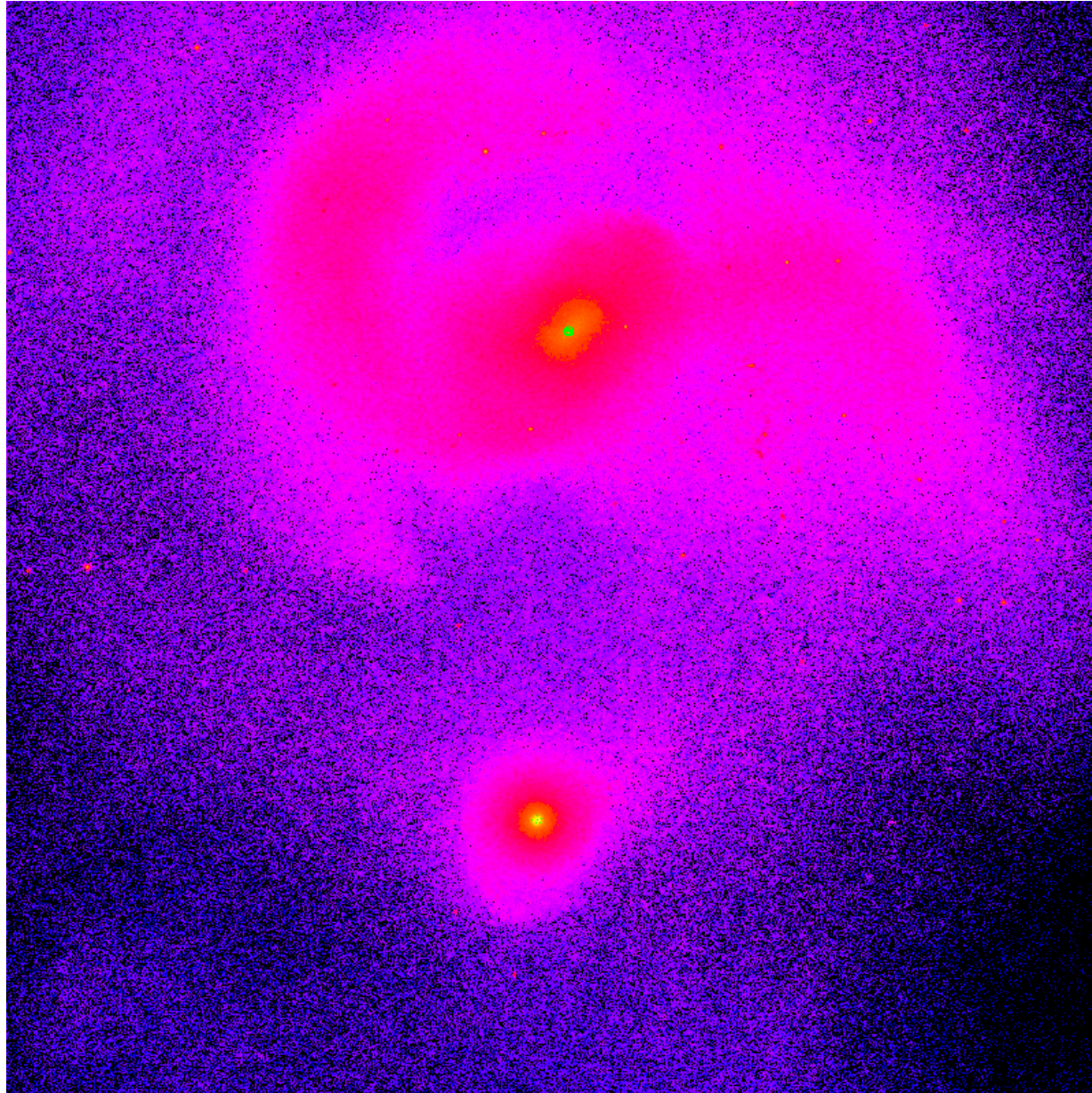


AGN activity: 1:4 disk-disk, coplanar, prograde-prograde



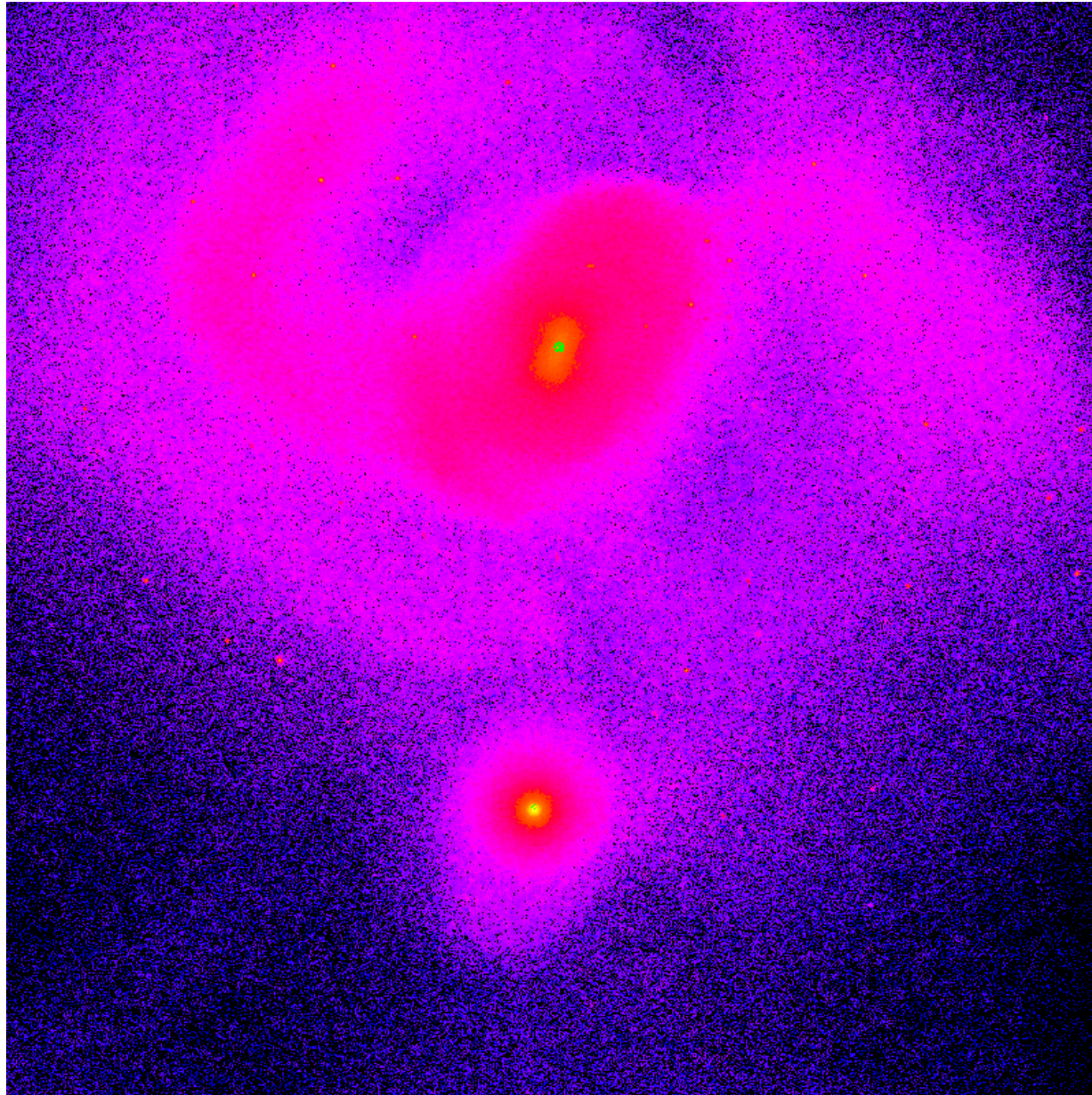
- Dual AGN activity: random vs correlated
- AGN activity dependence on BH separation, luminosity ratio, velocity offset
- Few % are 'dual AGN', in rough agreement with observations

Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro



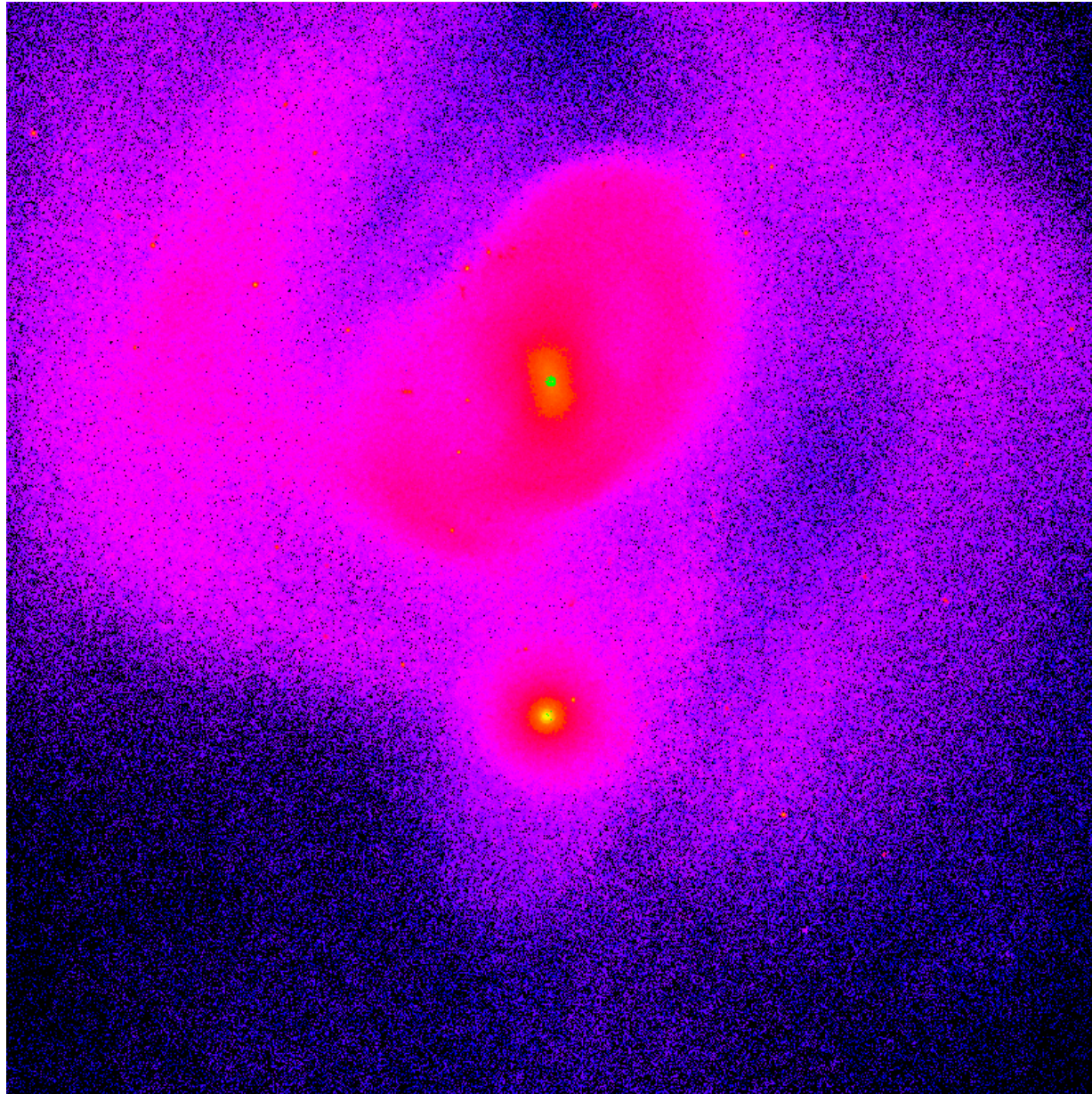
| 1 kpc

Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro



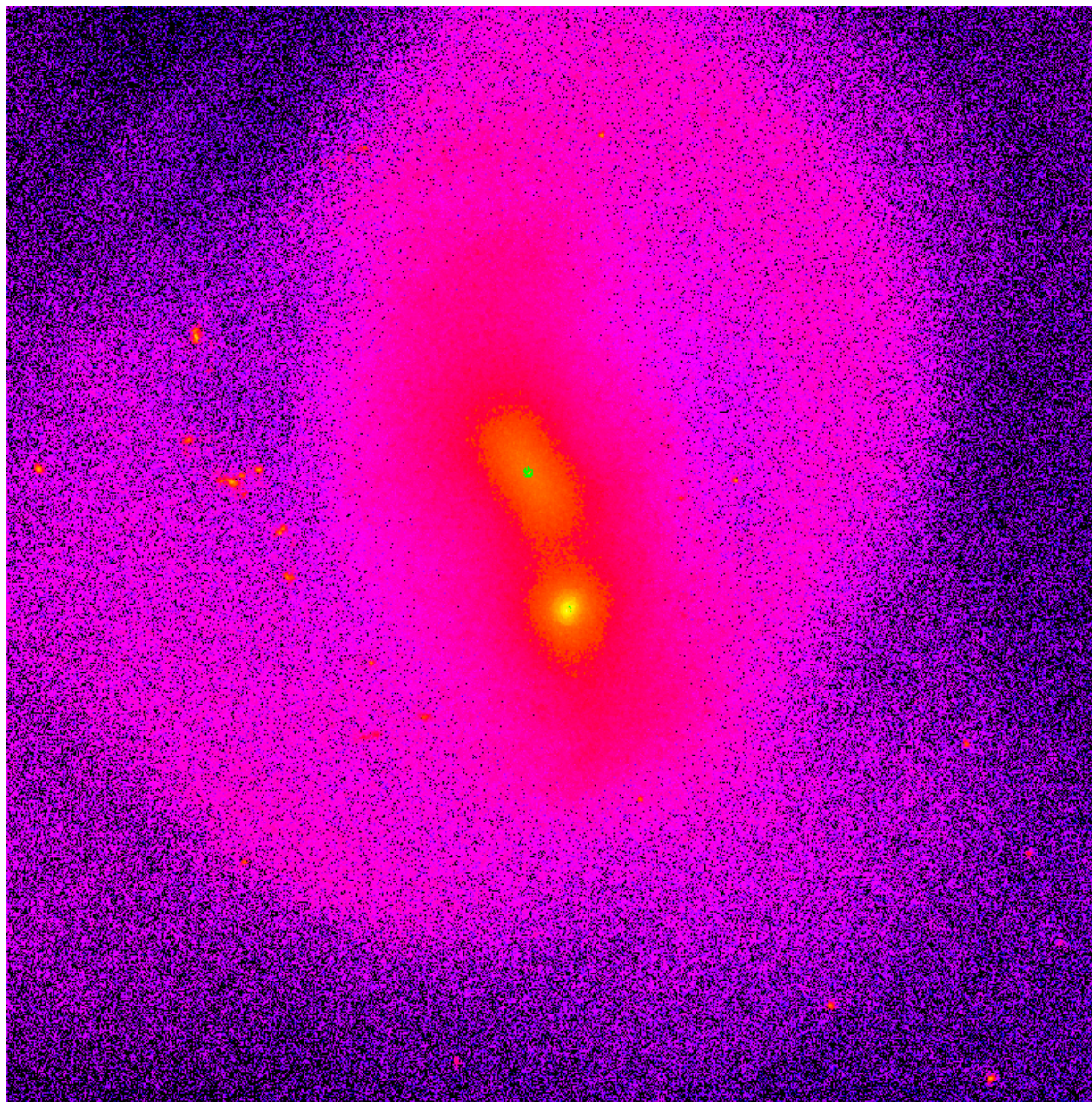
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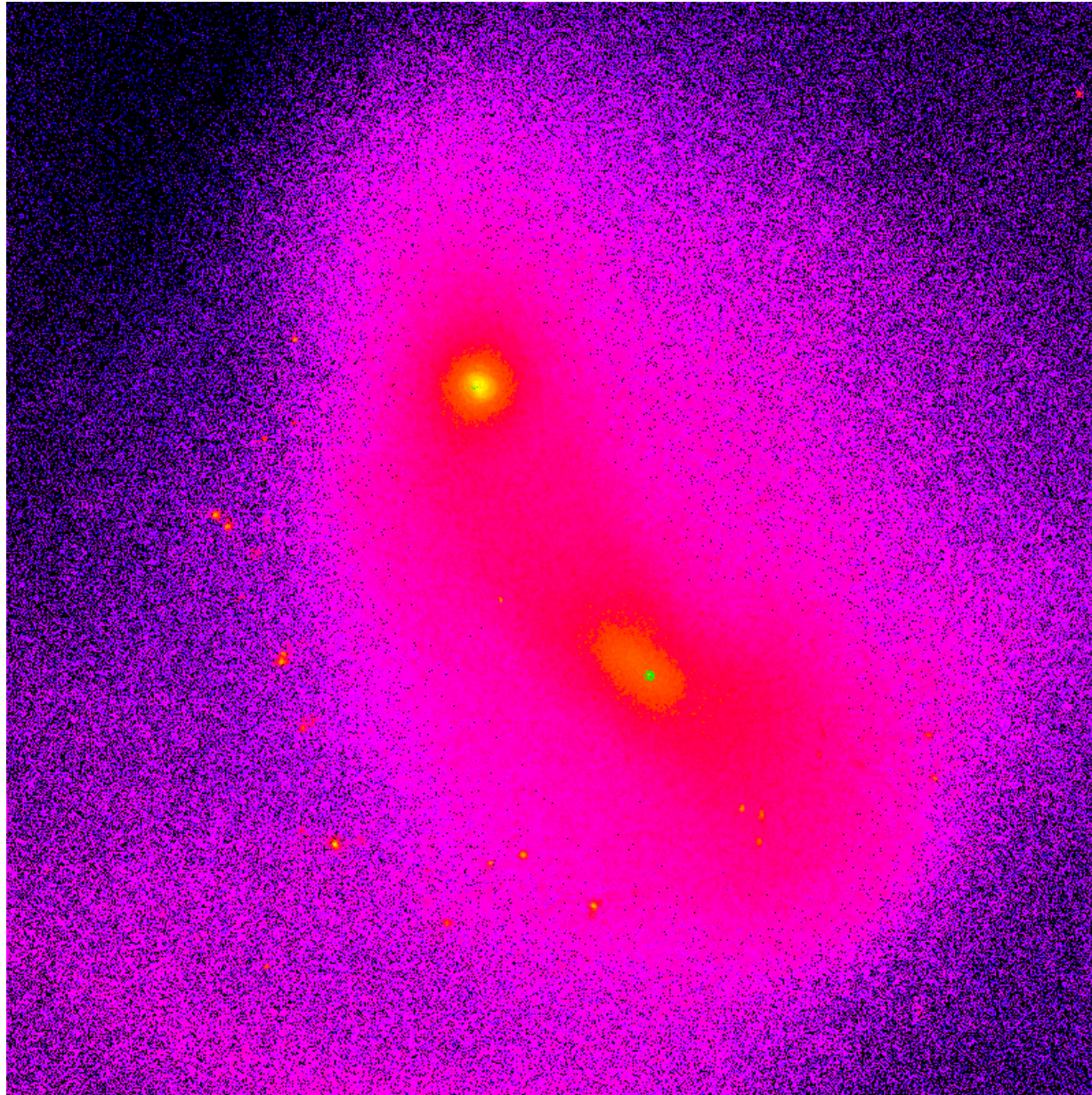


| 1 kpc

Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro

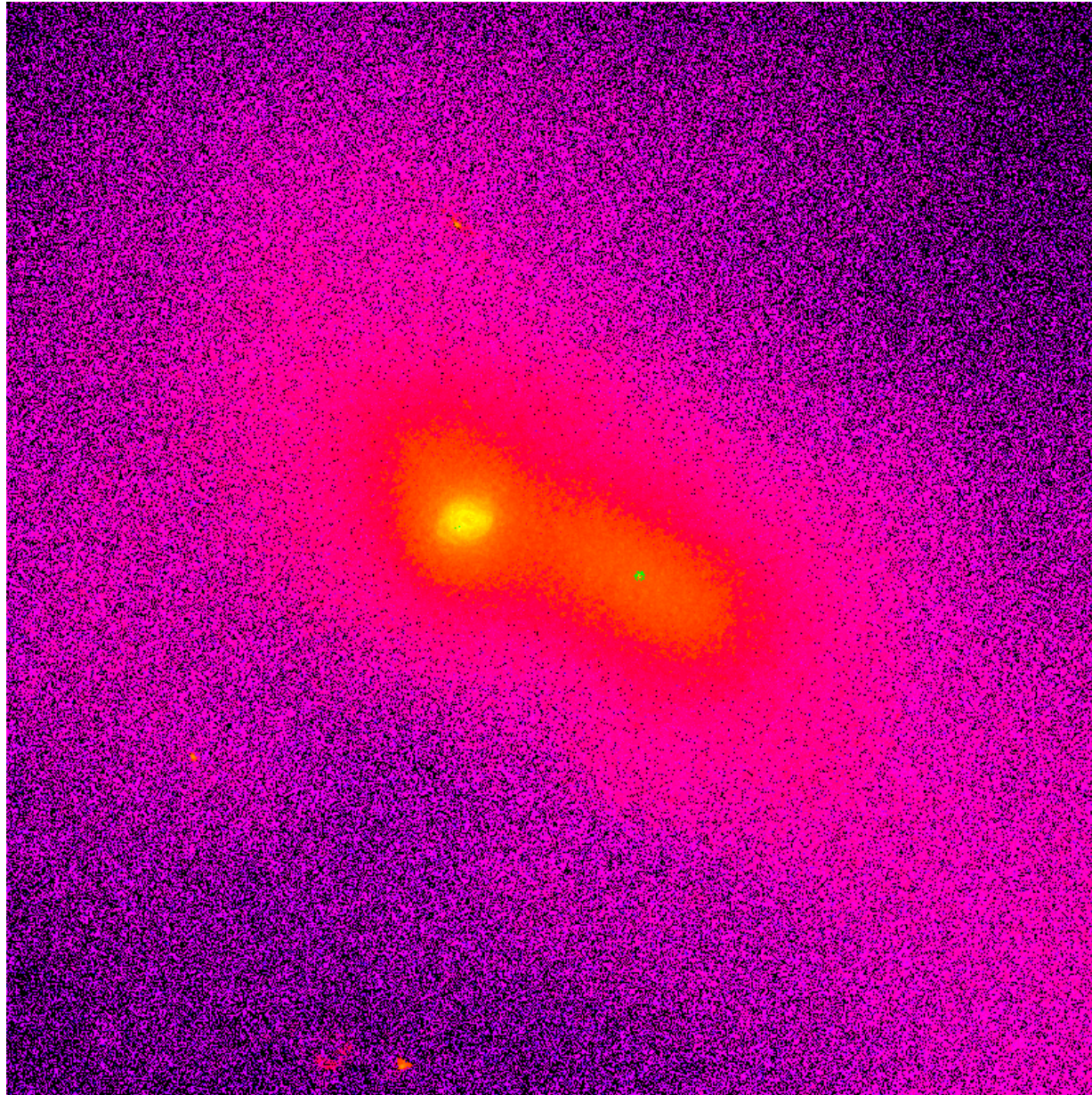


Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro



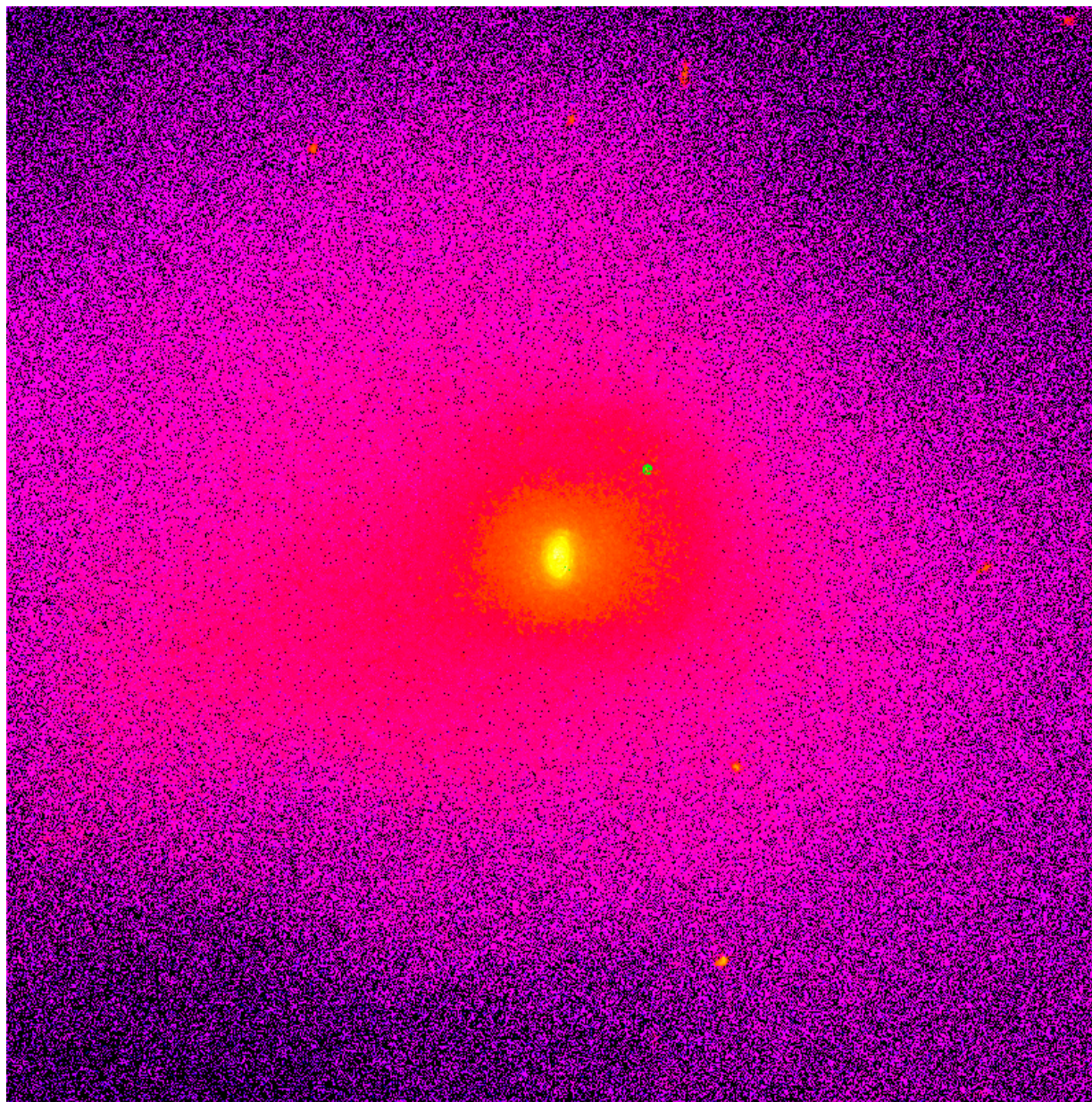
1 kpc

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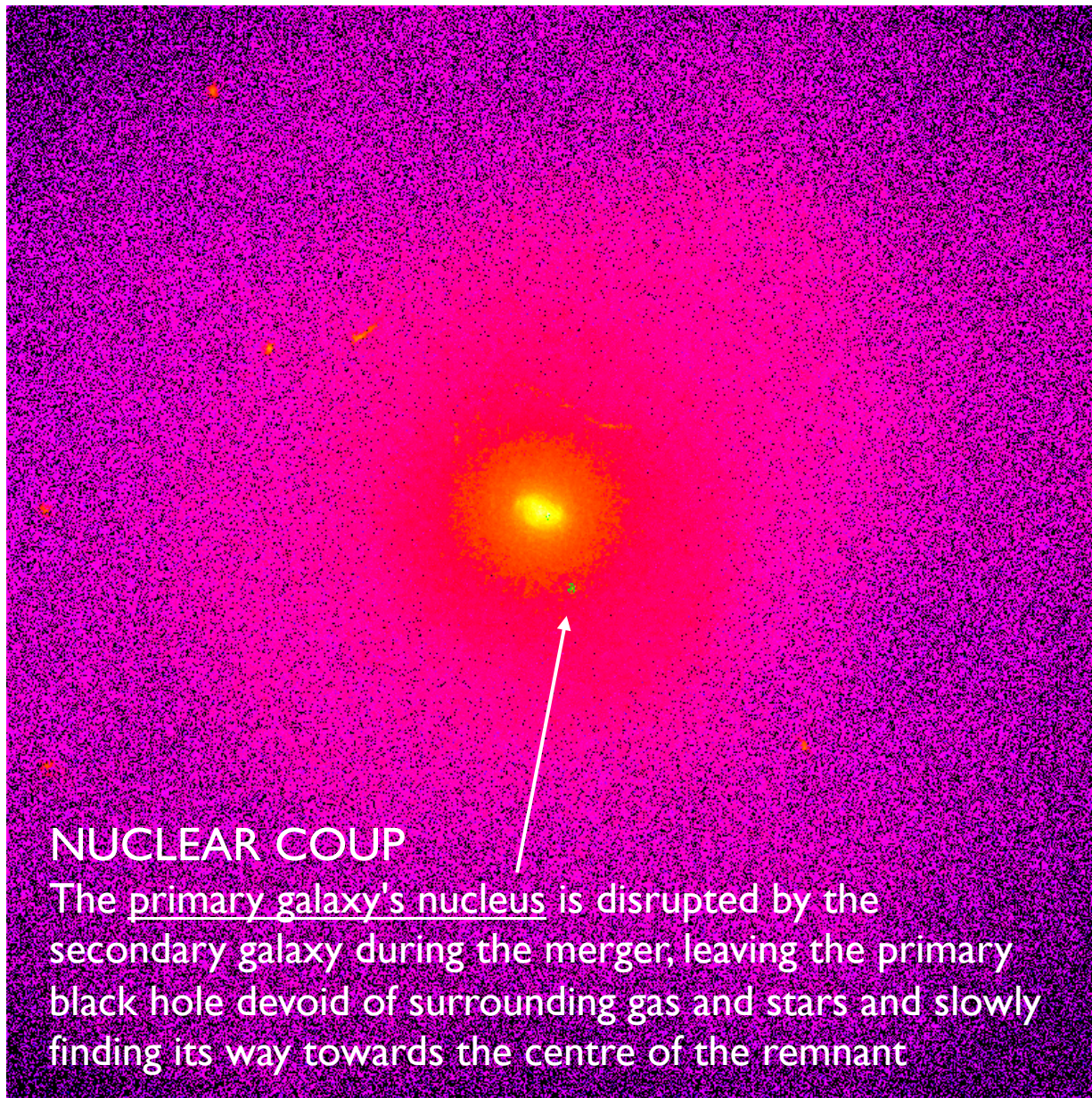
1 kpc

Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro

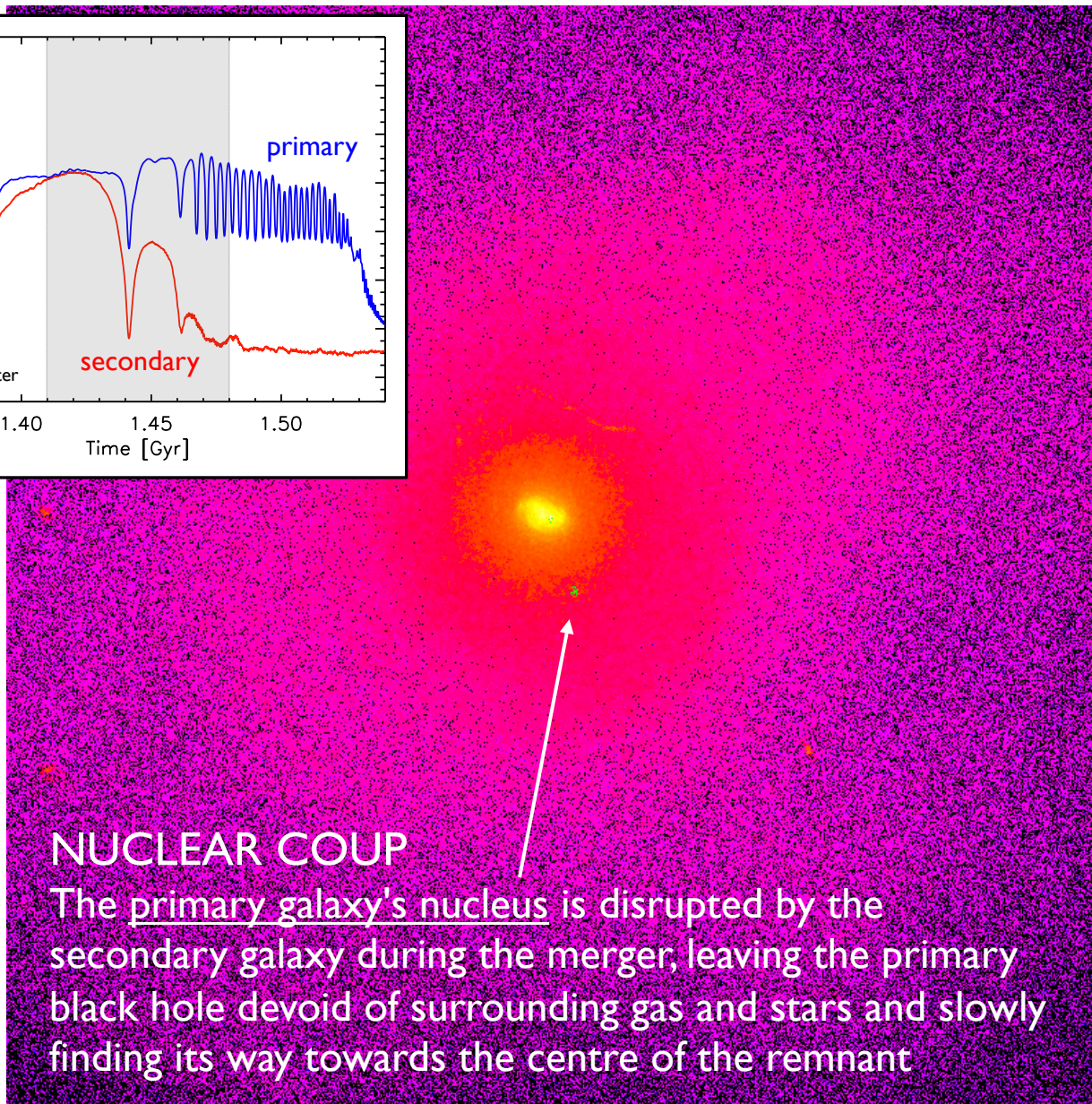
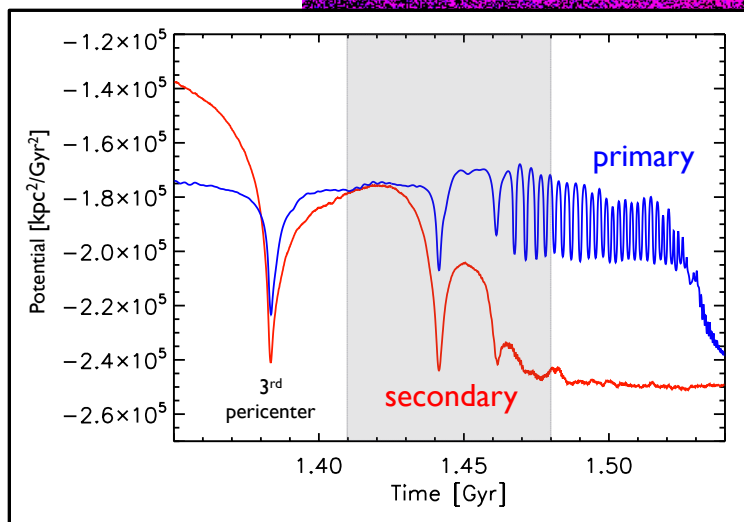


1 kpc

Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro



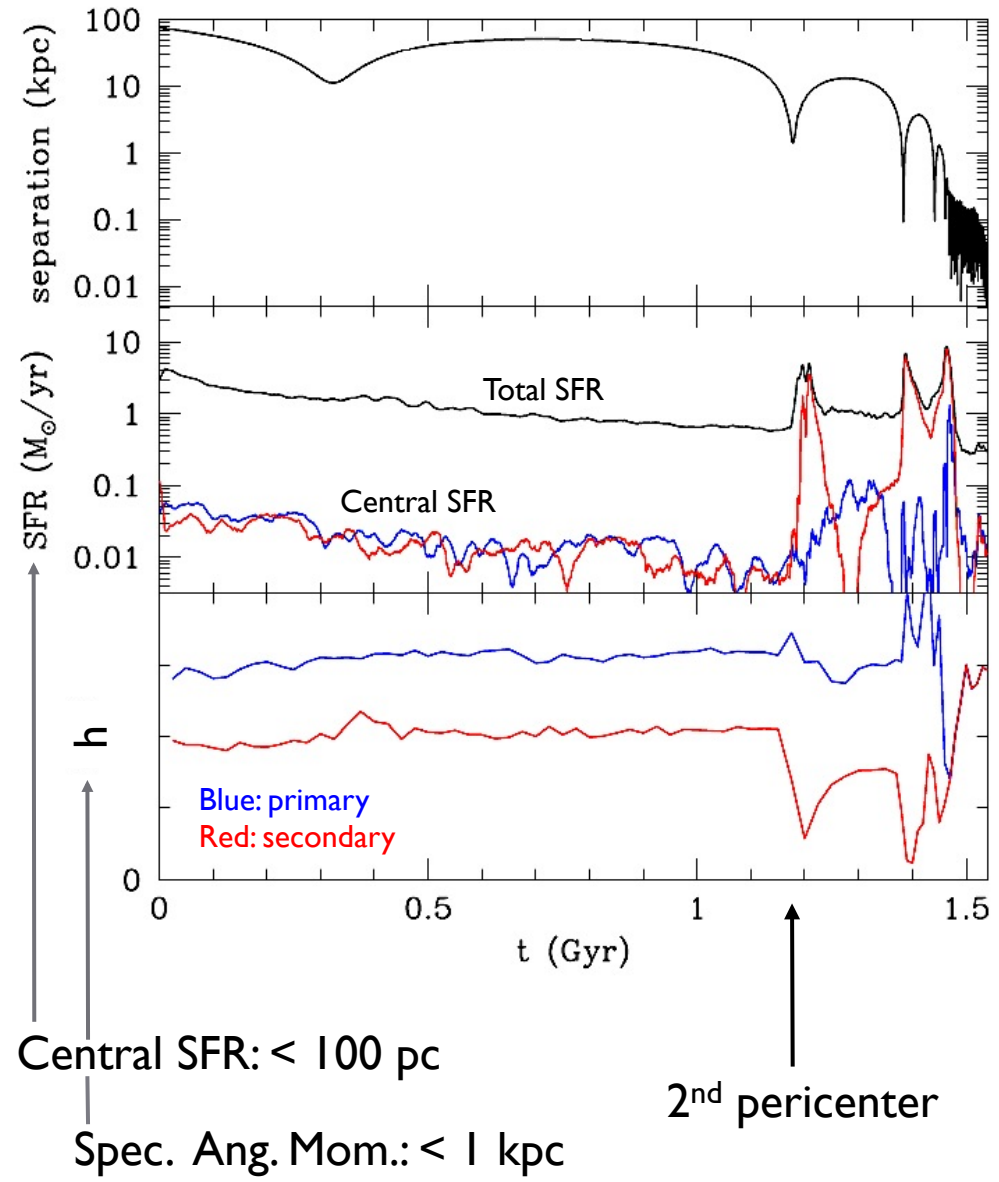
Primary nuclear disruption – 1:4 disk-disk, coplanar, pro-pro



NUCLEAR COUP

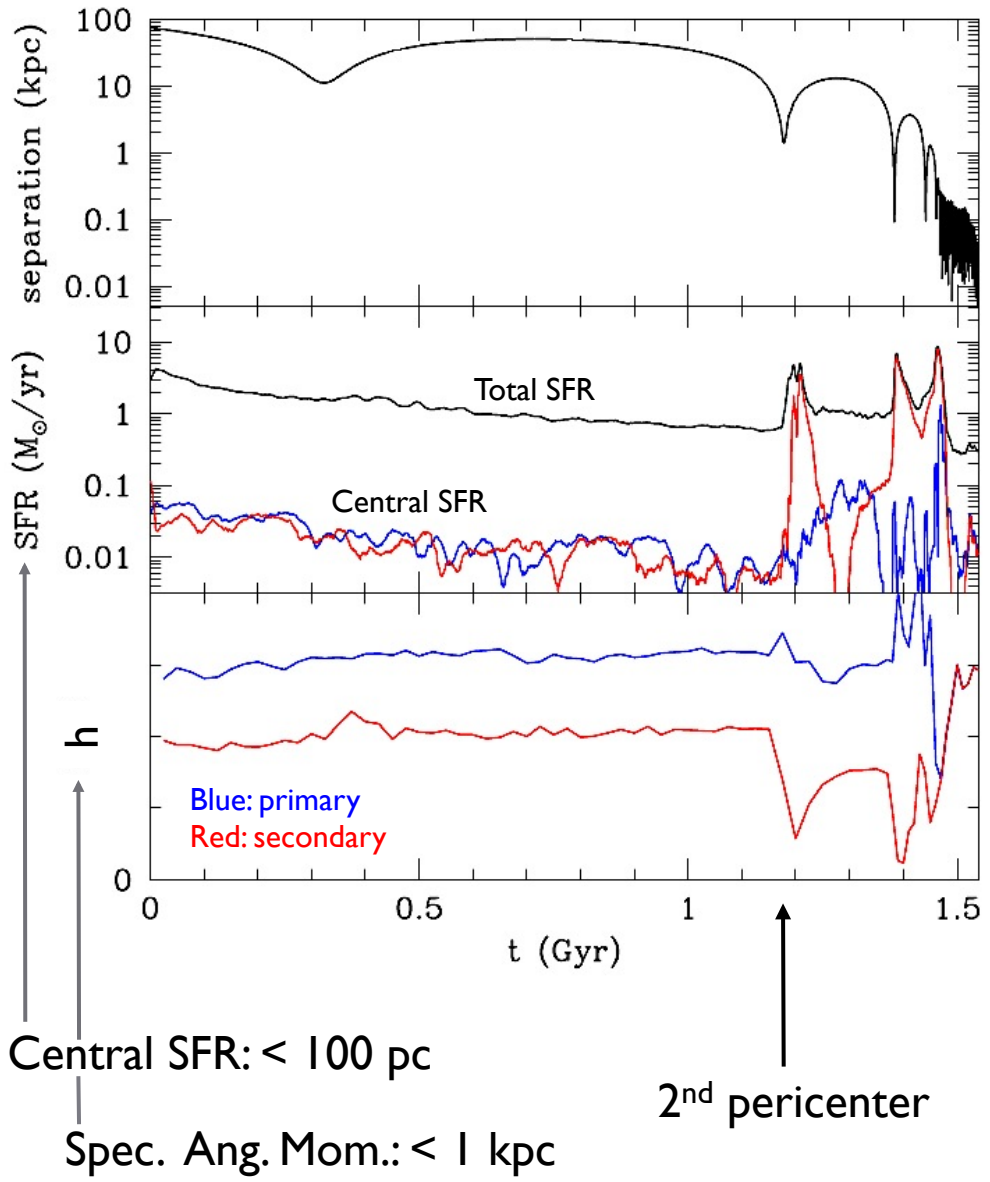
The primary galaxy's nucleus is disrupted by the secondary galaxy during the merger, leaving the primary black hole devoid of surrounding gas and stars and slowly finding its way towards the centre of the remnant

Why is there a nuclear coup?



1:4 disk-disk merger,
coplanar,
prograde-prograde

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1:4 disk-disk merger,
coplanar,
prograde-prograde

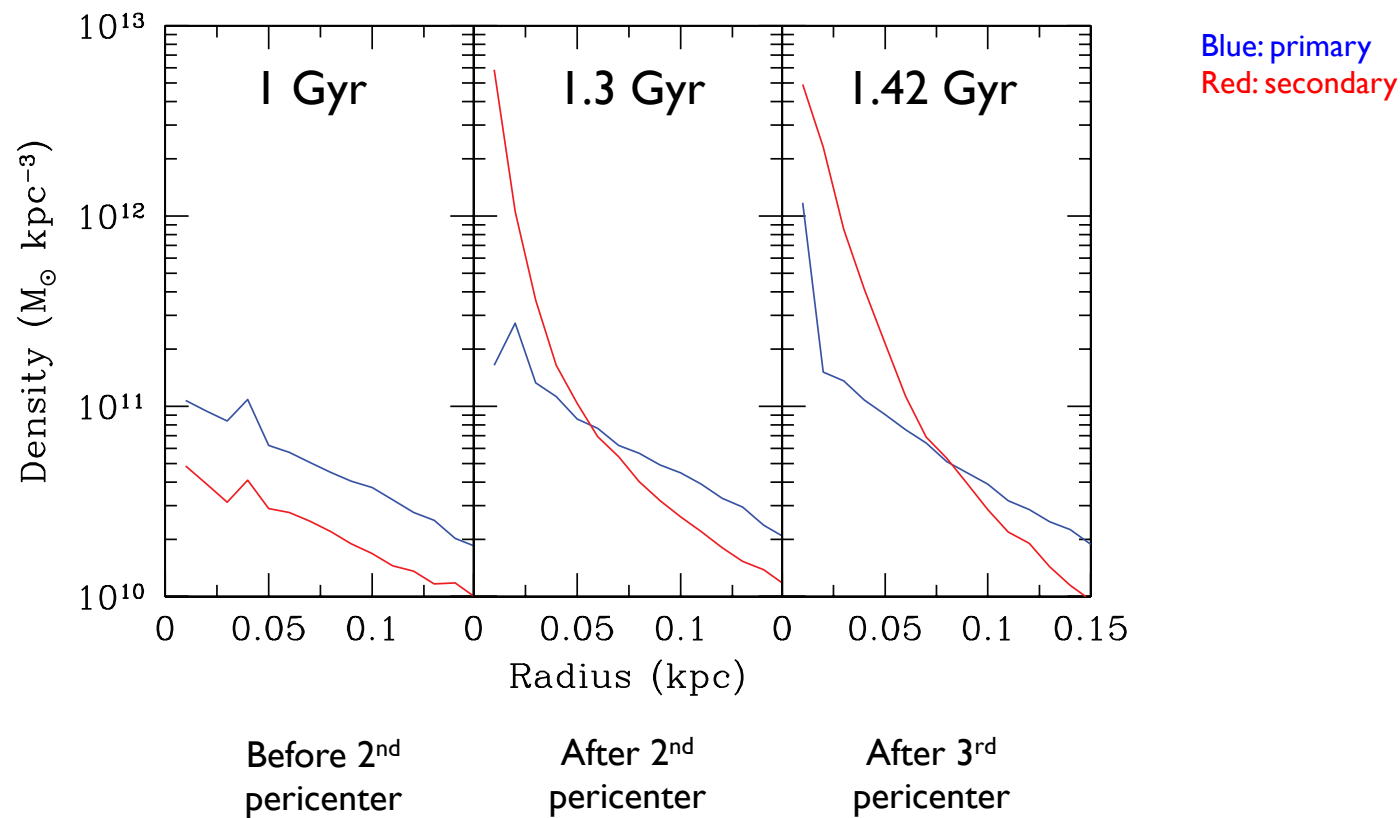
Merger dynamics

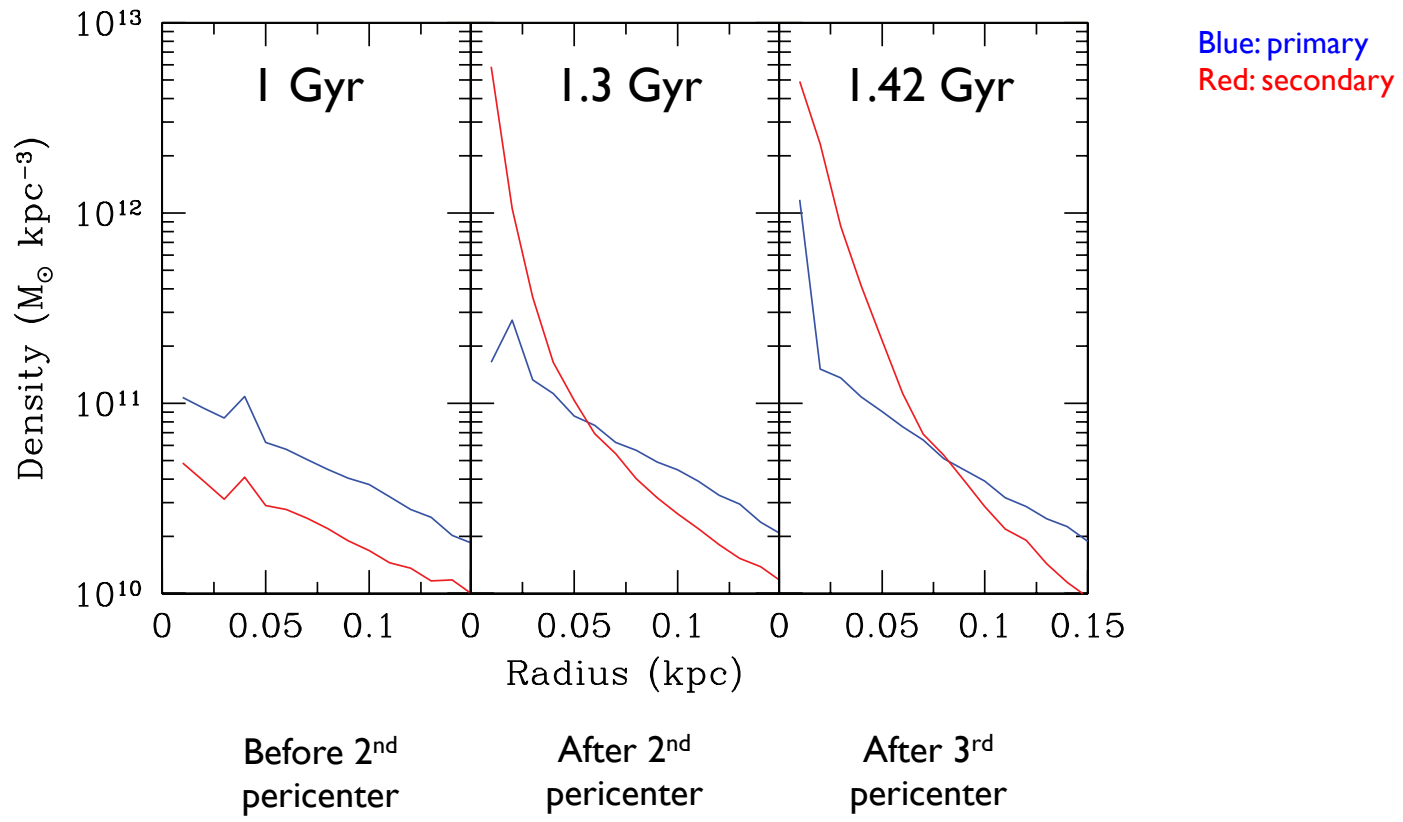
↓

- Loss of angular momentum;
- Gas inflows;
- Strong central star formation (esp. secondary)

Why is there a nuclear coup?

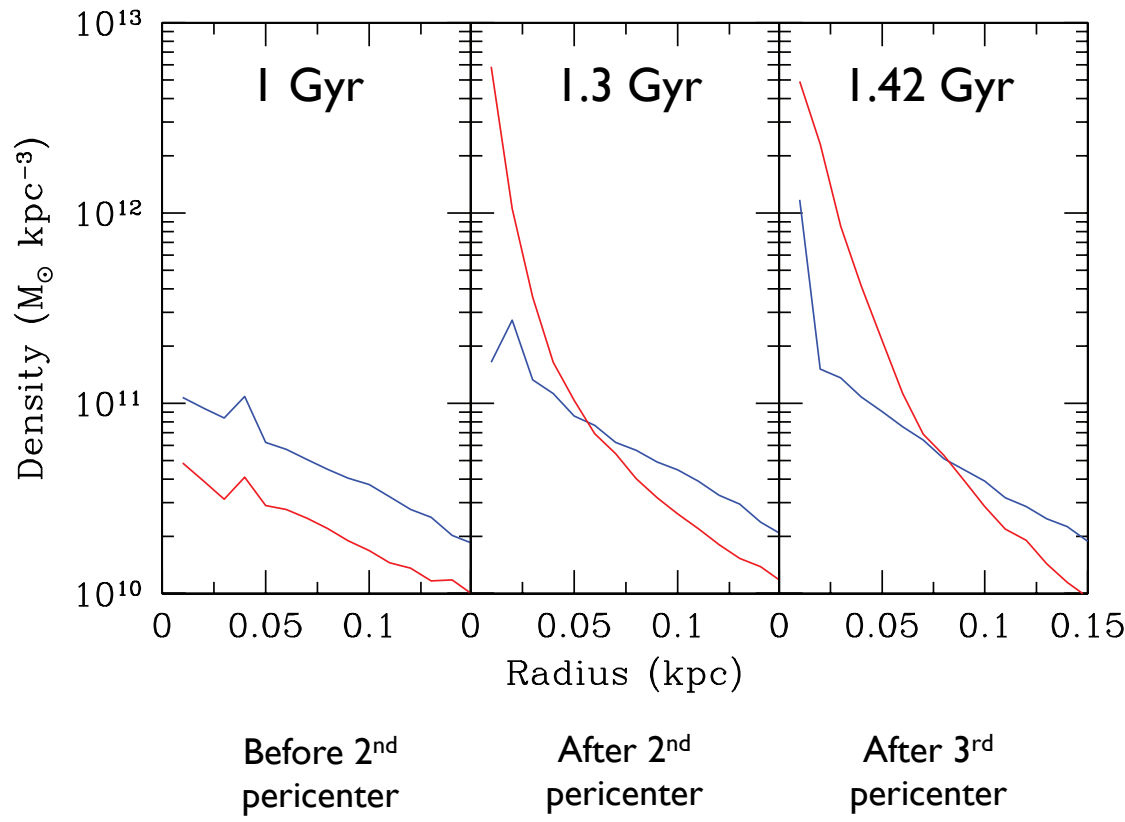
2/2



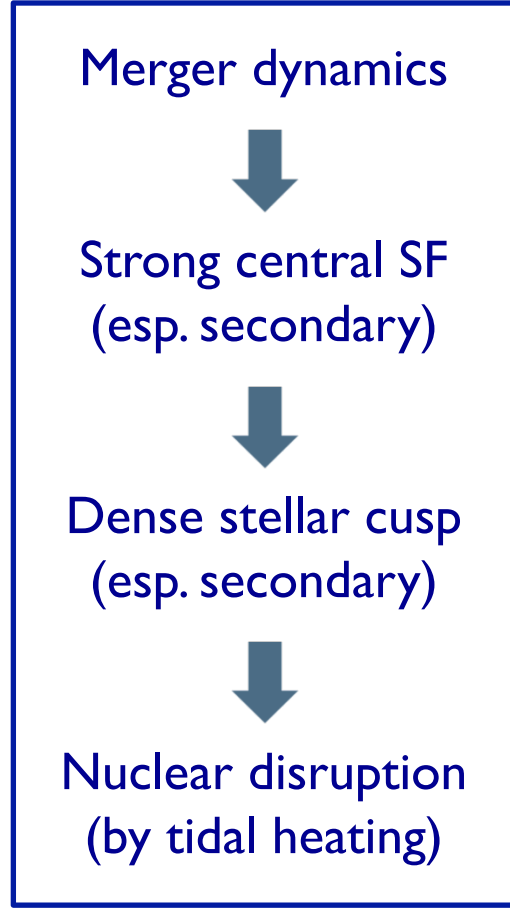


Tidal stripping? Encounters are too fast.

Tidal heating? Energy injected is \sim or $>$ binding energy.



Blue: primary
Red: secondary

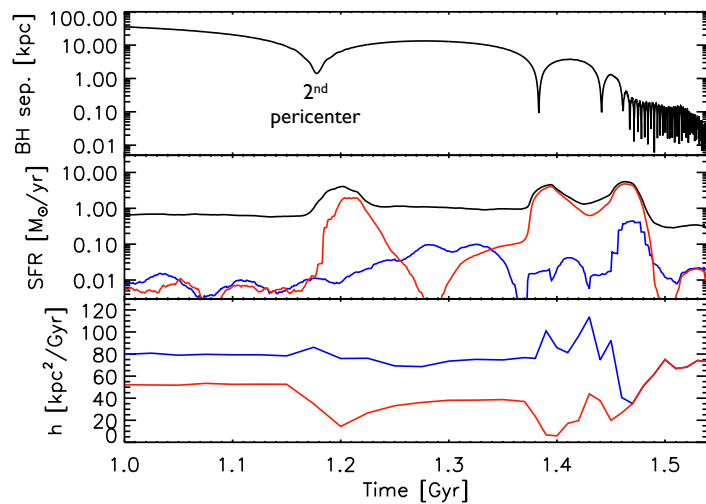


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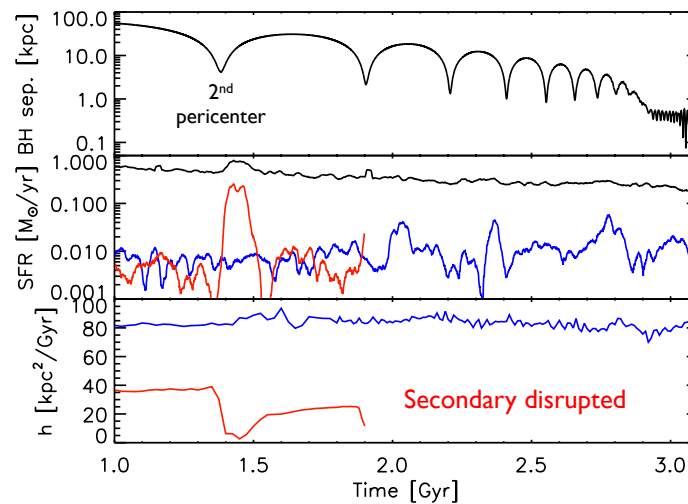
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Does the nuclear coup always occur?

1:4 disk-disk, coplanar, pro-pro
Clear nuclear coup

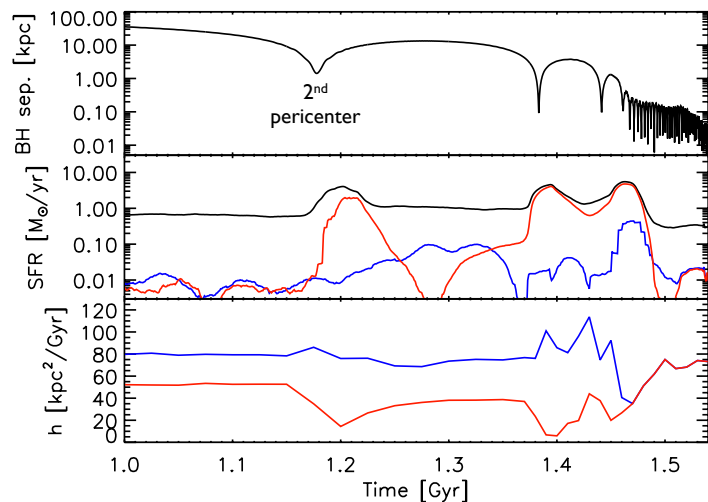


1:10 disk-disk, coplanar, pro-pro
No nuclear coup

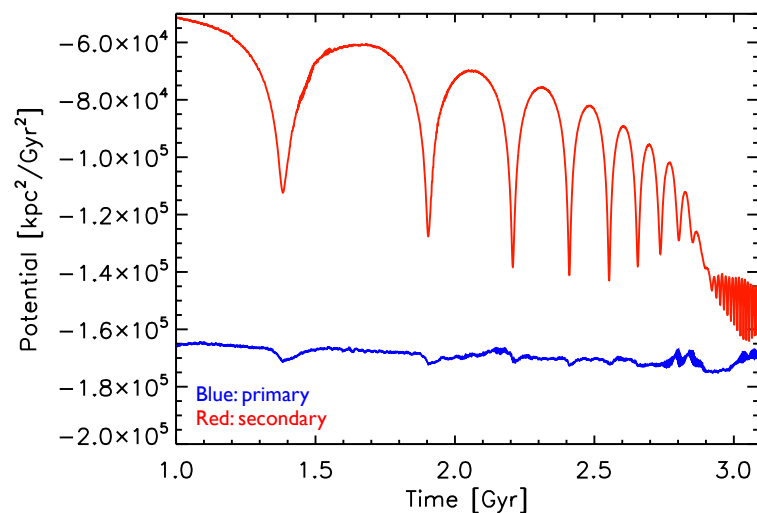
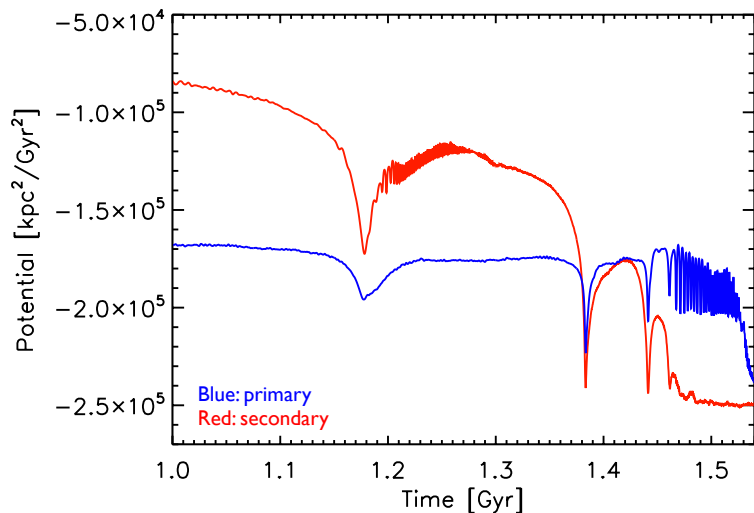
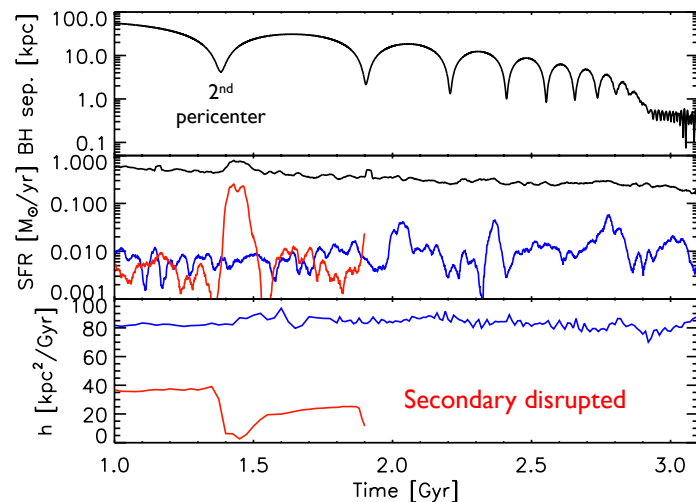


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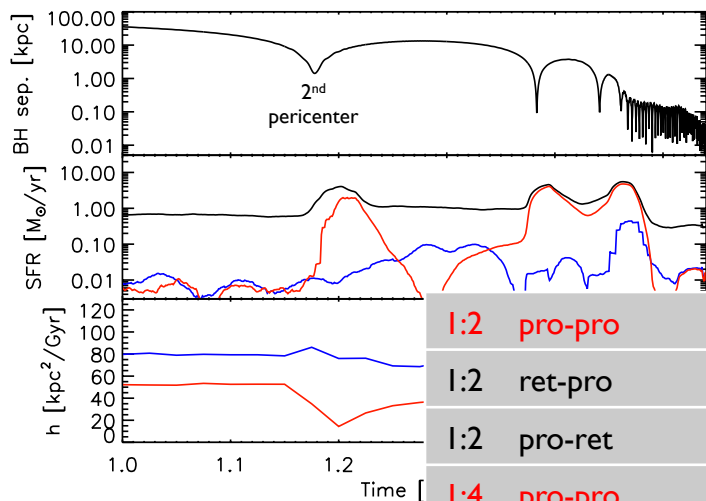


1:10 disk-disk, coplanar, pro-pro
No nuclear coup

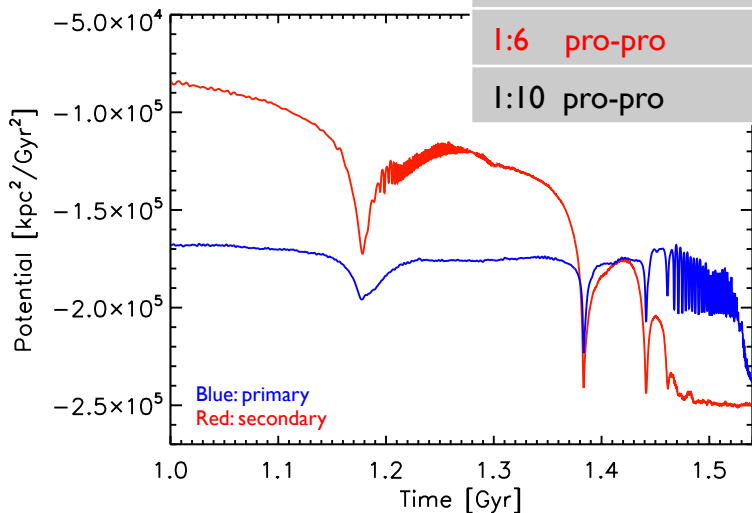


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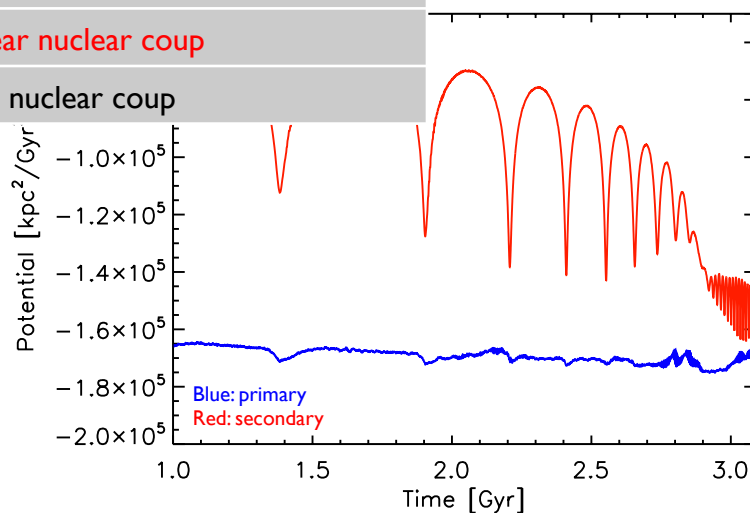
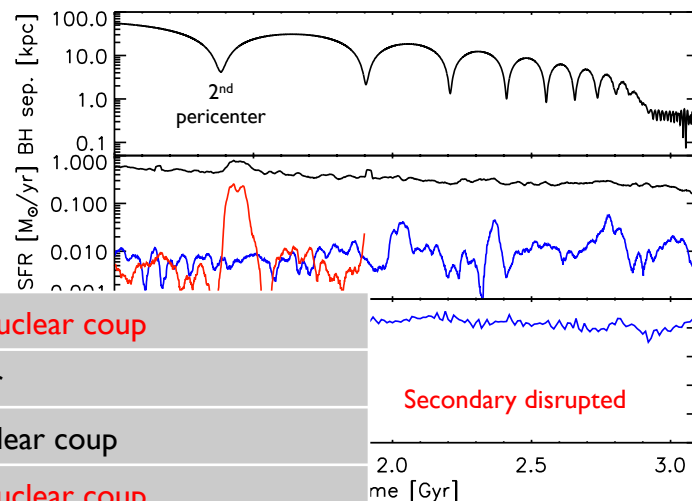
1:4 disk-disk, coplanar, pro-pro
Clear nuclear coup



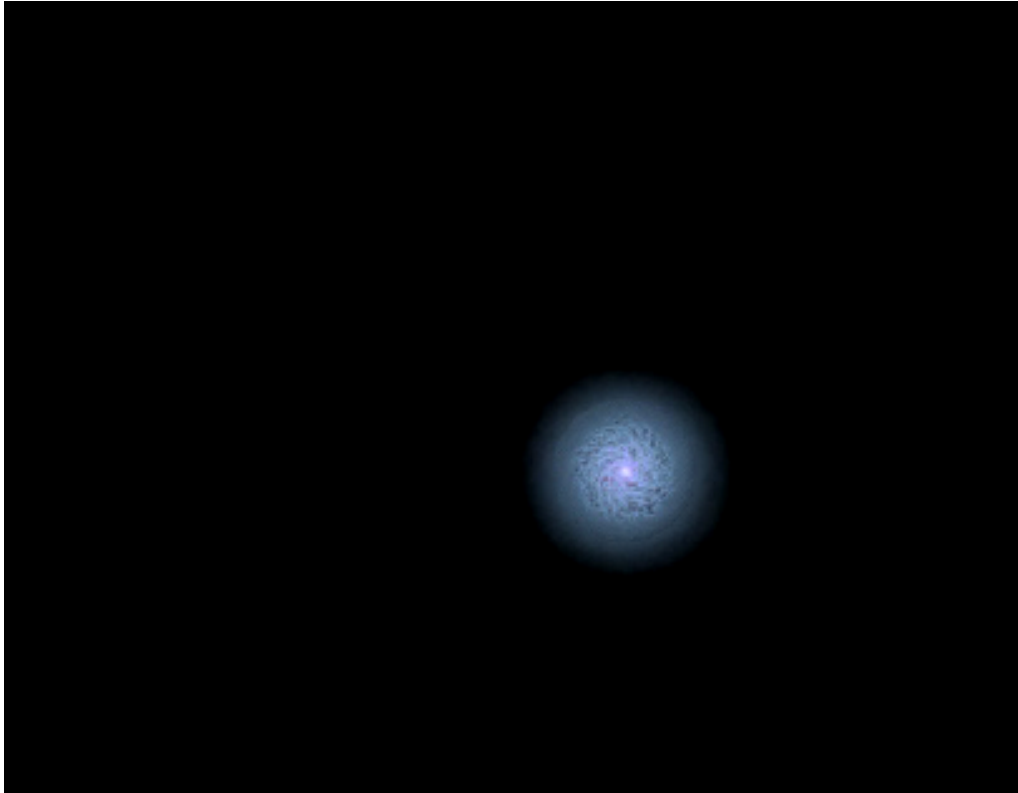
1:2 pro-pro	clear nuclear coup
1:2 ret-pro	unclear
1:2 pro-ret	no nuclear coup
1:4 pro-pro	clear nuclear coup
1:6 pro-pro	clear nuclear coup
1:10 pro-pro	no nuclear coup



1:10 disk-disk, coplanar, pro-pro
No nuclear coup

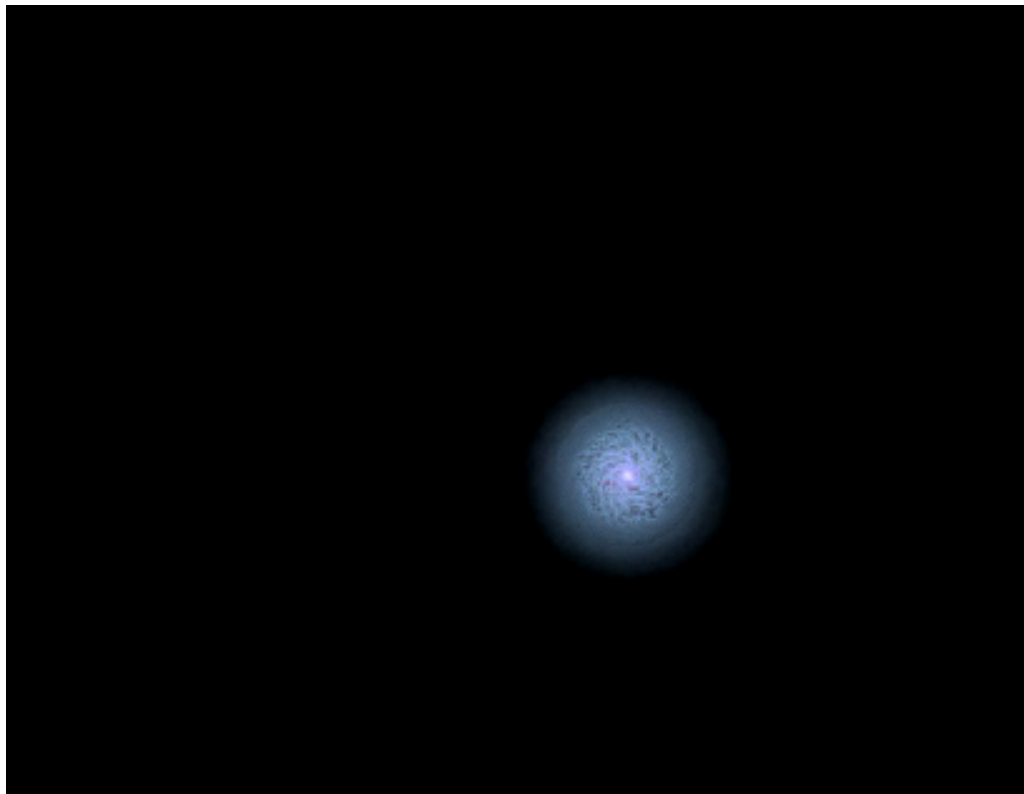


Angular momentum flip



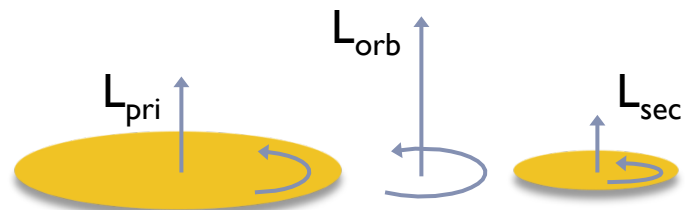
At 2nd pericenter
passage:
the secondary
galactic angular
momentum flips

Angular momentum flip

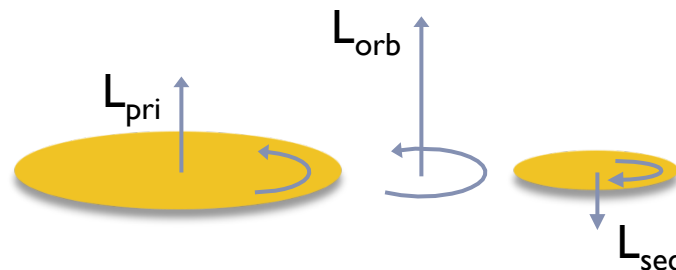


At 2nd pericenter passage:
the secondary galactic angular momentum flips

pro-pro orbit

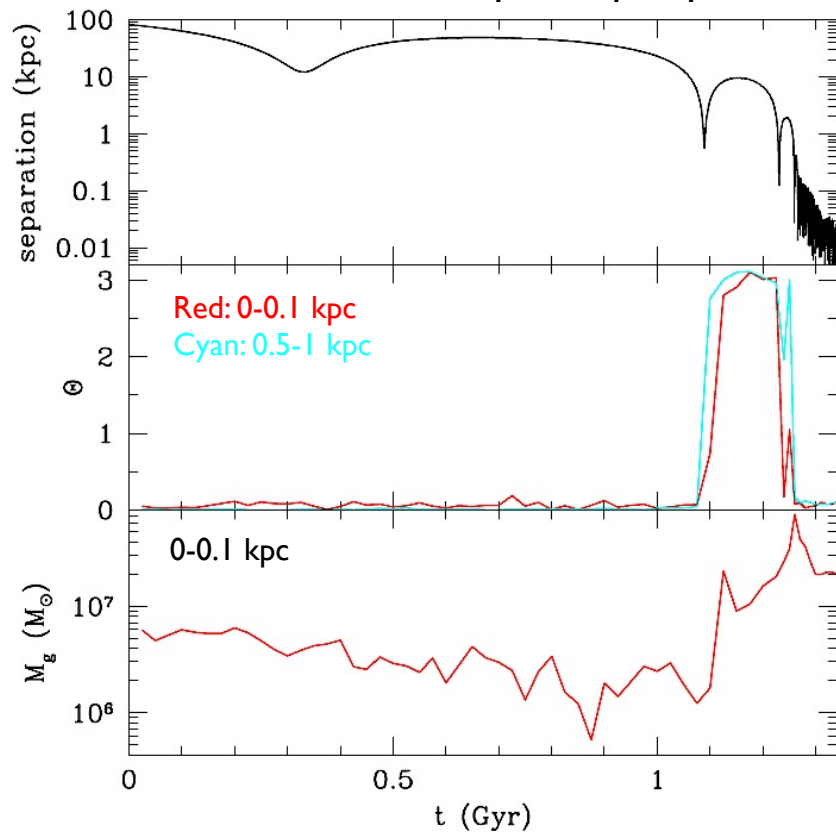


pro-ret orbit

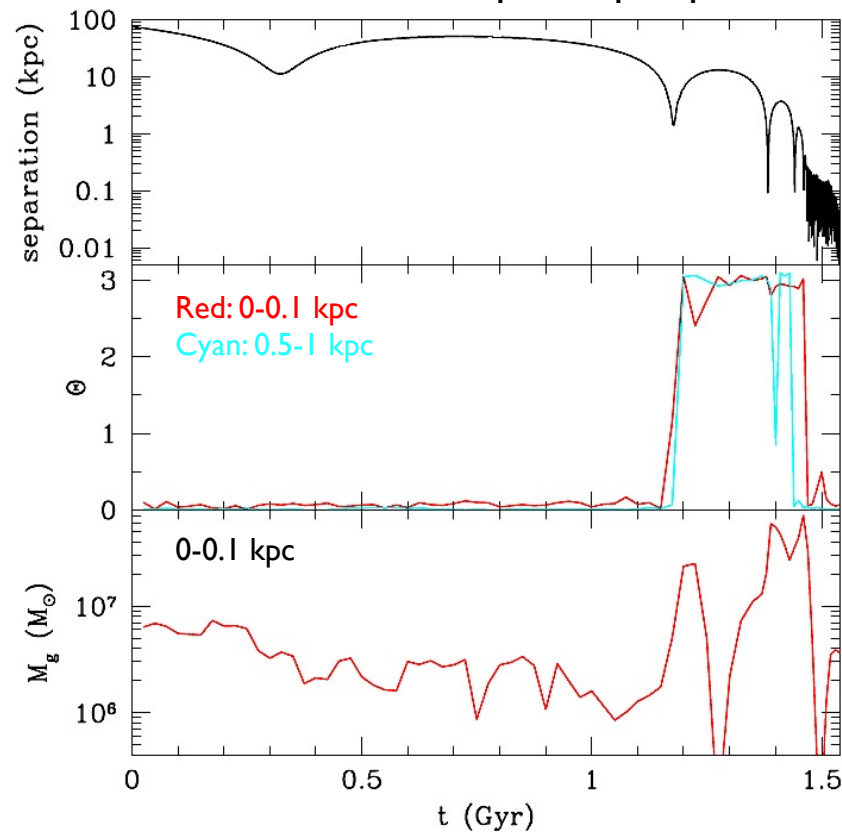


Angular momentum flip and counter-flip

1:2 disk-disk, coplanar, pro-pro

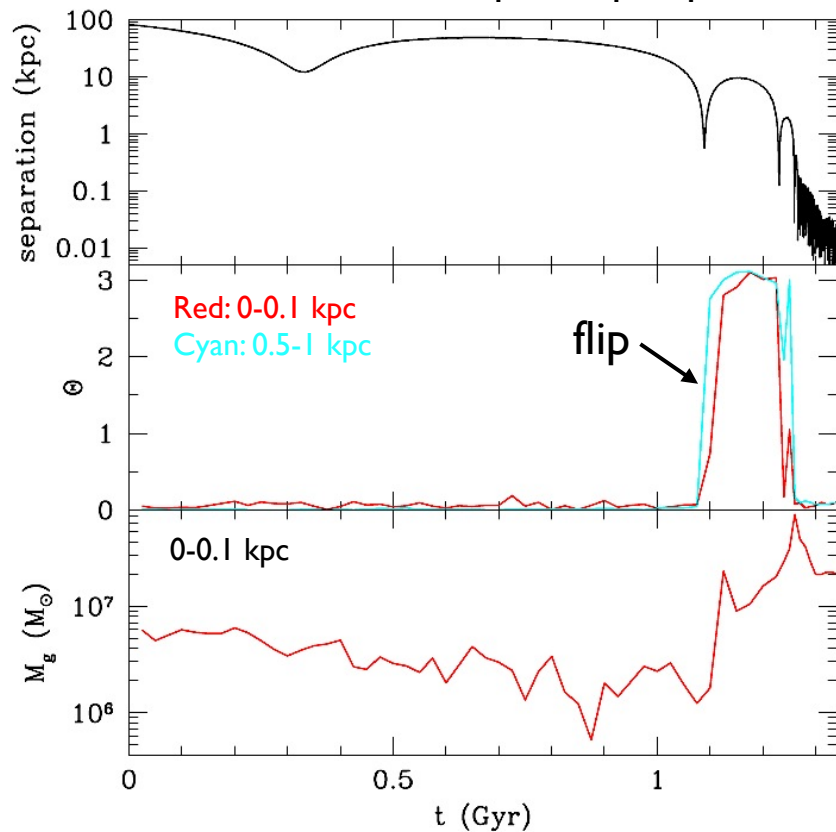


1:4 disk-disk, coplanar, pro-pro

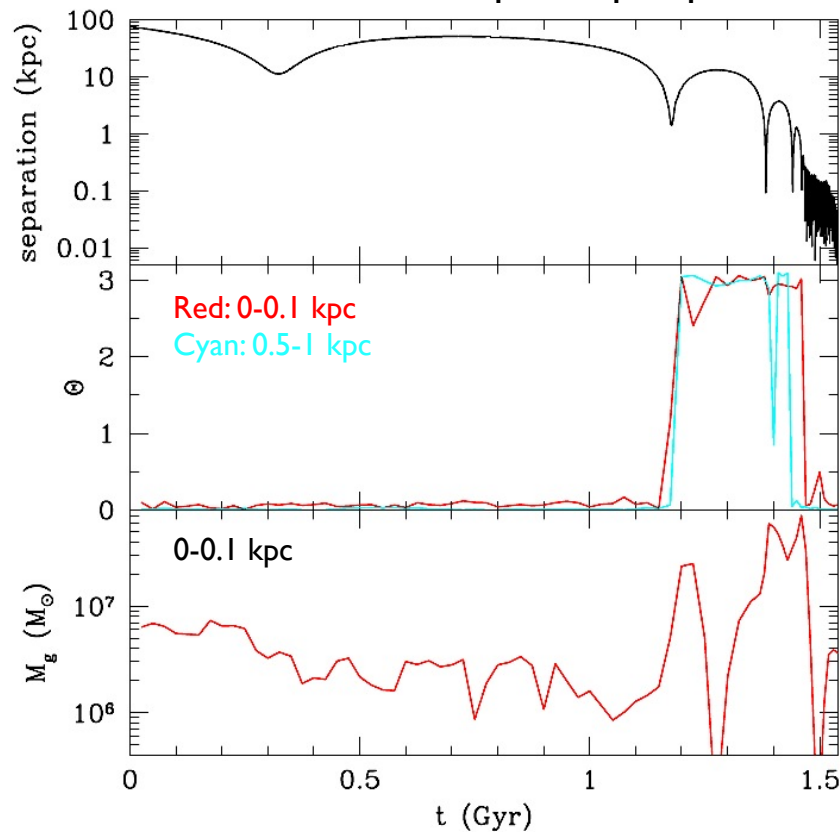


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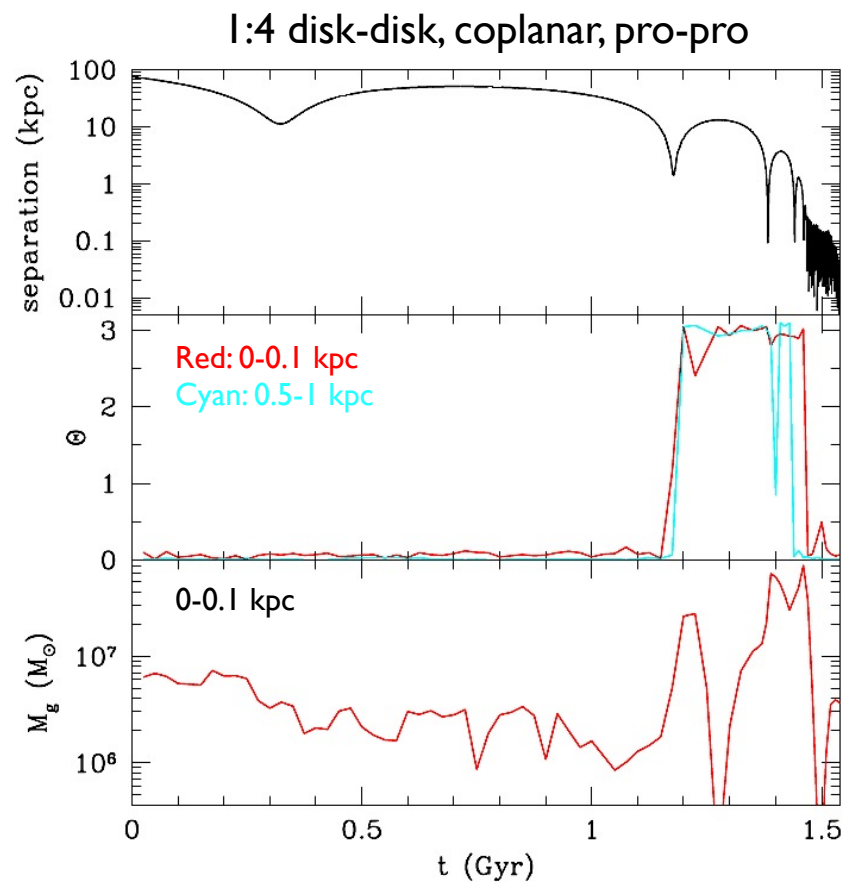
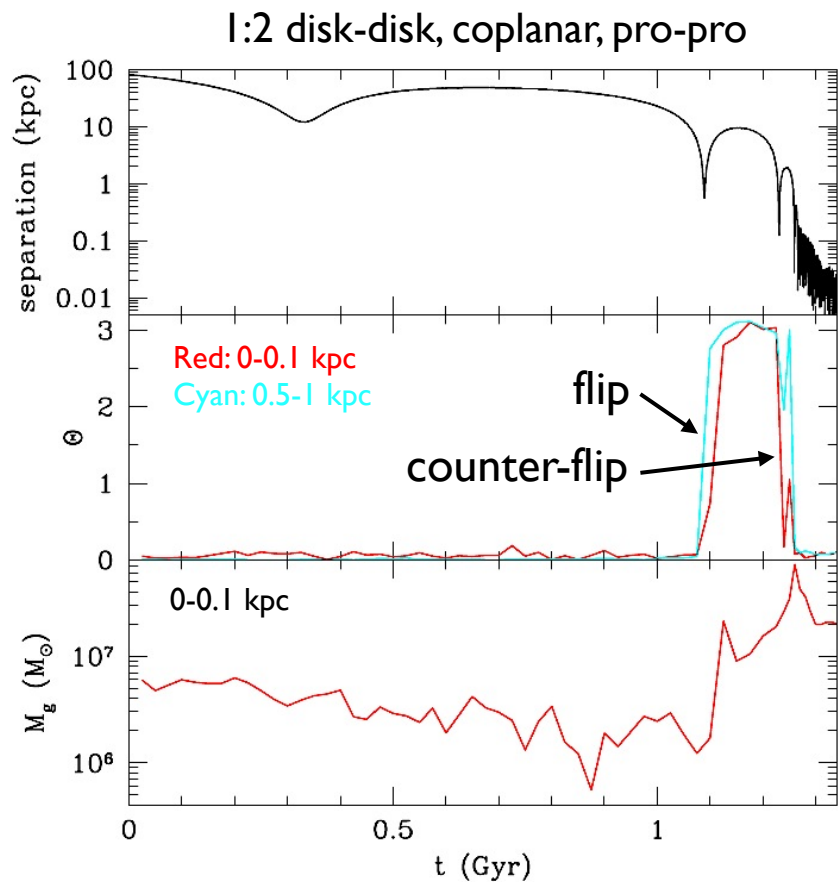
1:2 disk-disk, coplanar, pro-pro



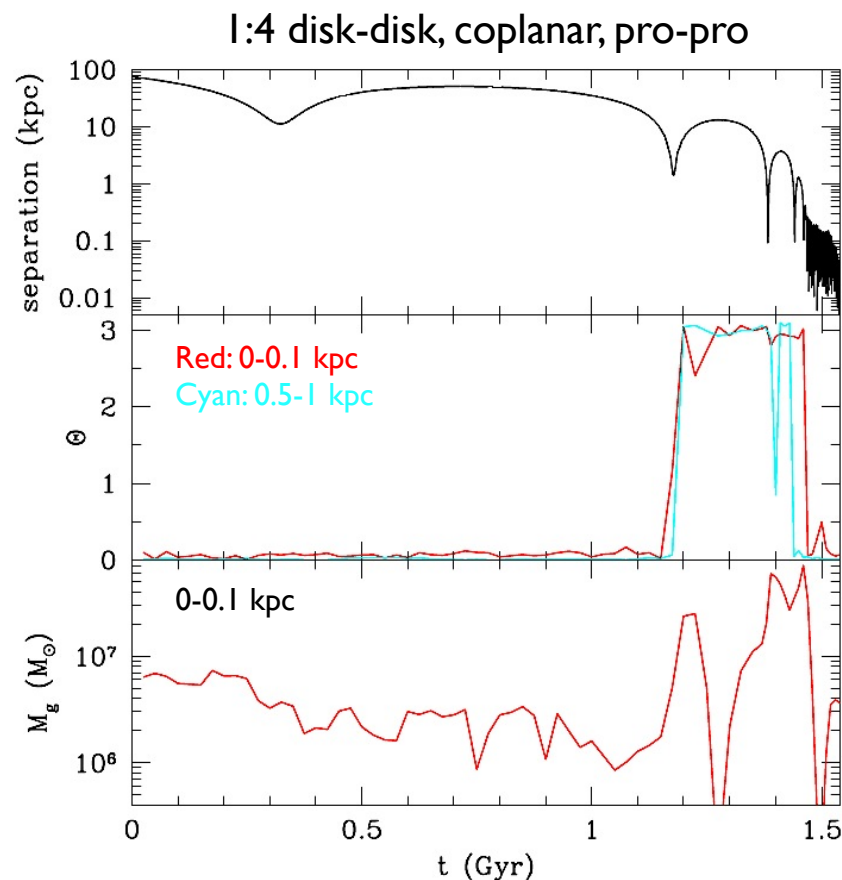
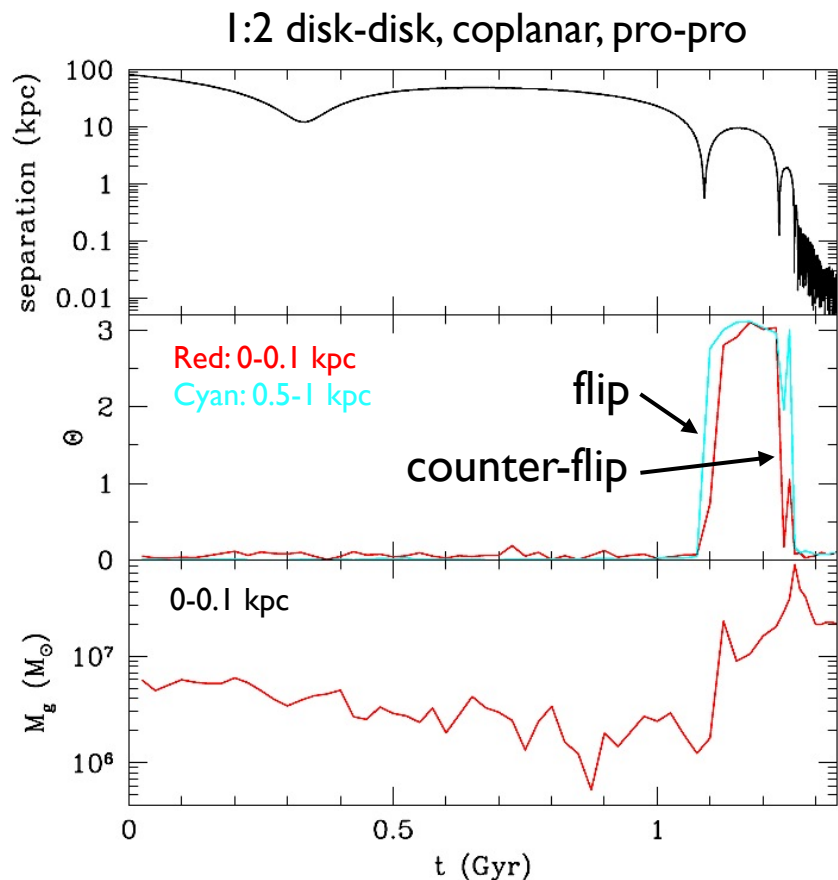
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Angular momentum flip and counter-flip

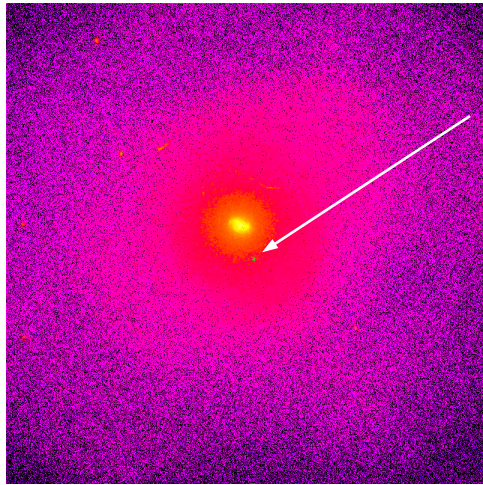


Angular momentum flip and counter-flip



1:2	pro-pro	clear nuclear coup	angular momentum flip
1:2	ret-pro	unclear	unclear
1:2	pro-ret	no nuclear coup	no angular momentum flip
1:4	pro-pro	clear nuclear coup	angular momentum flip
1:6	pro-pro	clear nuclear coup	angular momentum flip
1:10	pro-pro	no nuclear coup	no angular momentum flip

Summary



NUCLEAR COUP

The primary galaxy's nucleus is disrupted by the secondary galaxy during the merger, leaving the primary black hole devoid of surrounding gas and stars and slowly finding its way towards the centre of the remnant

Implications for:

- (dual) AGN activity
- Data off scaling relations
- BH pairing time-scales
- Getting to the final parsec for a BH binary

