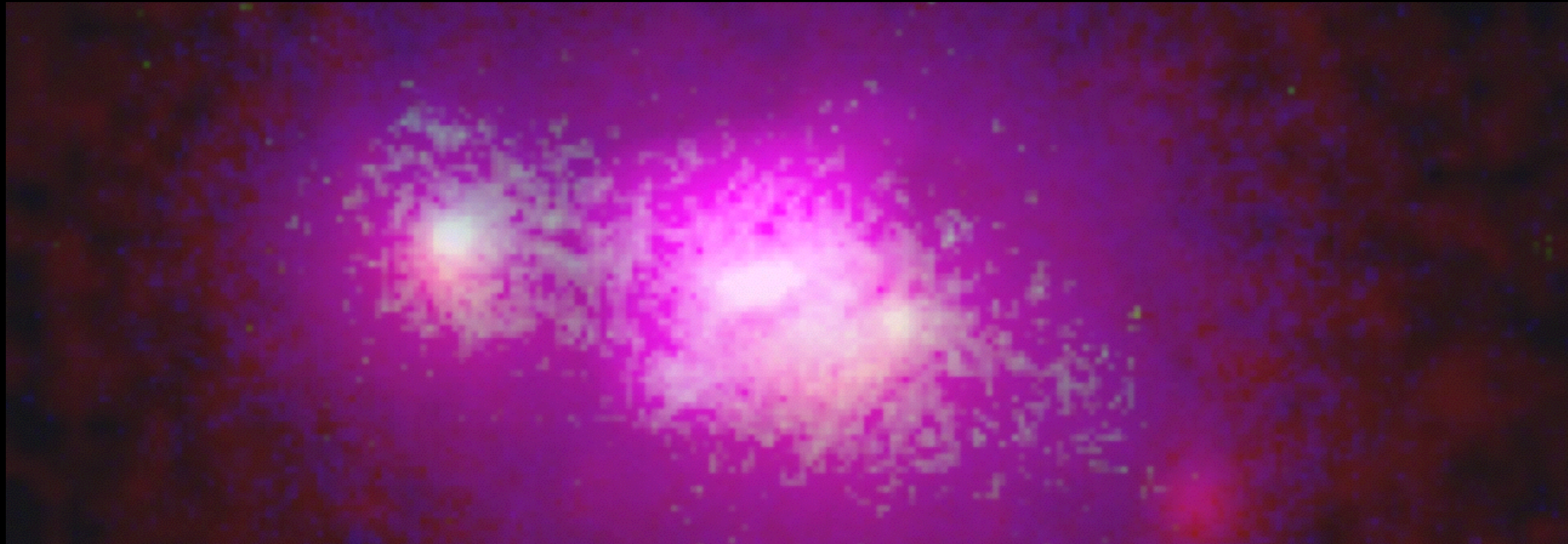


The Conditions of Single and Dual AGN Formation in Late-Stage Galaxy Mergers

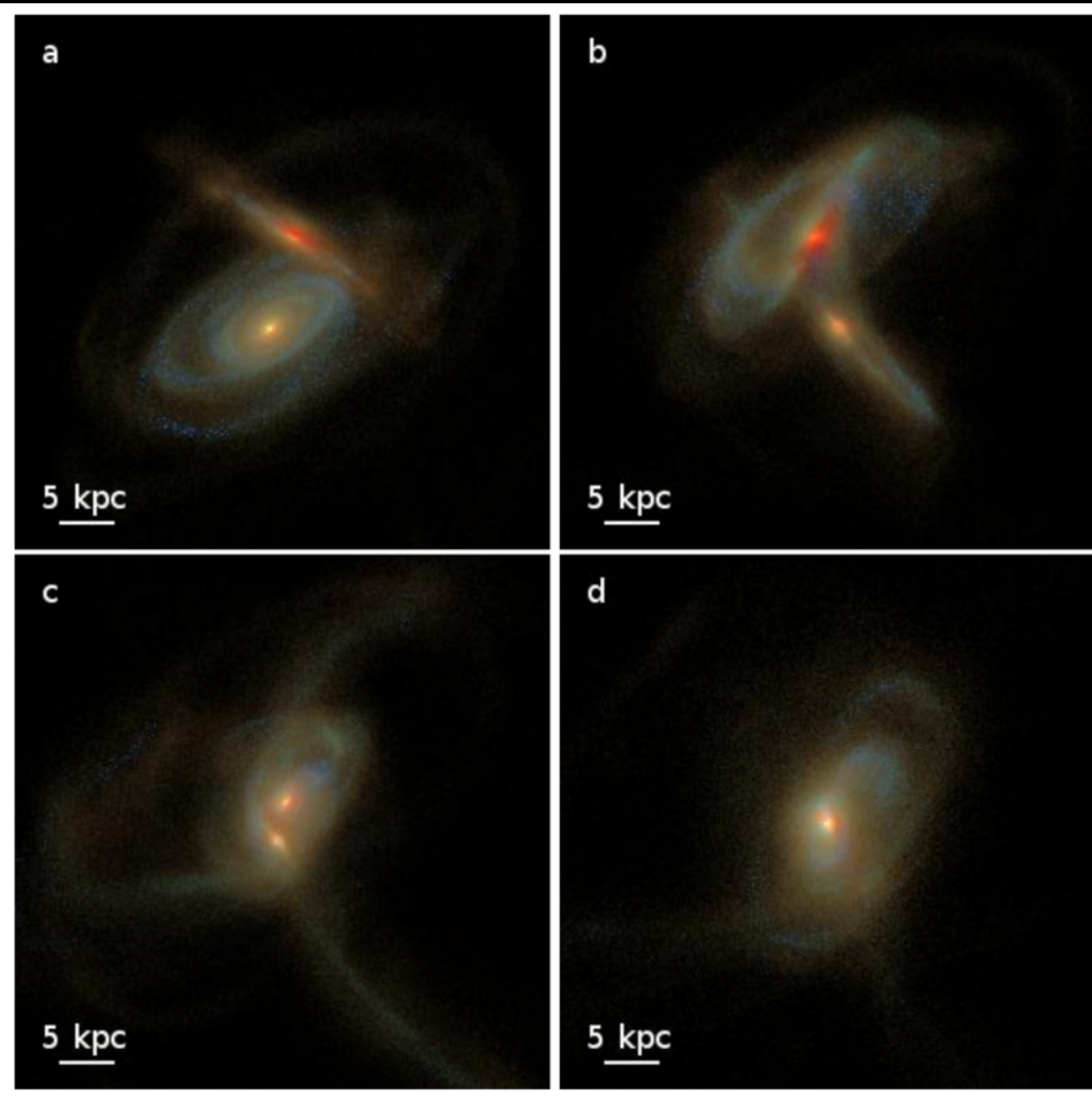


Scott Barrows
University of Colorado, Boulder

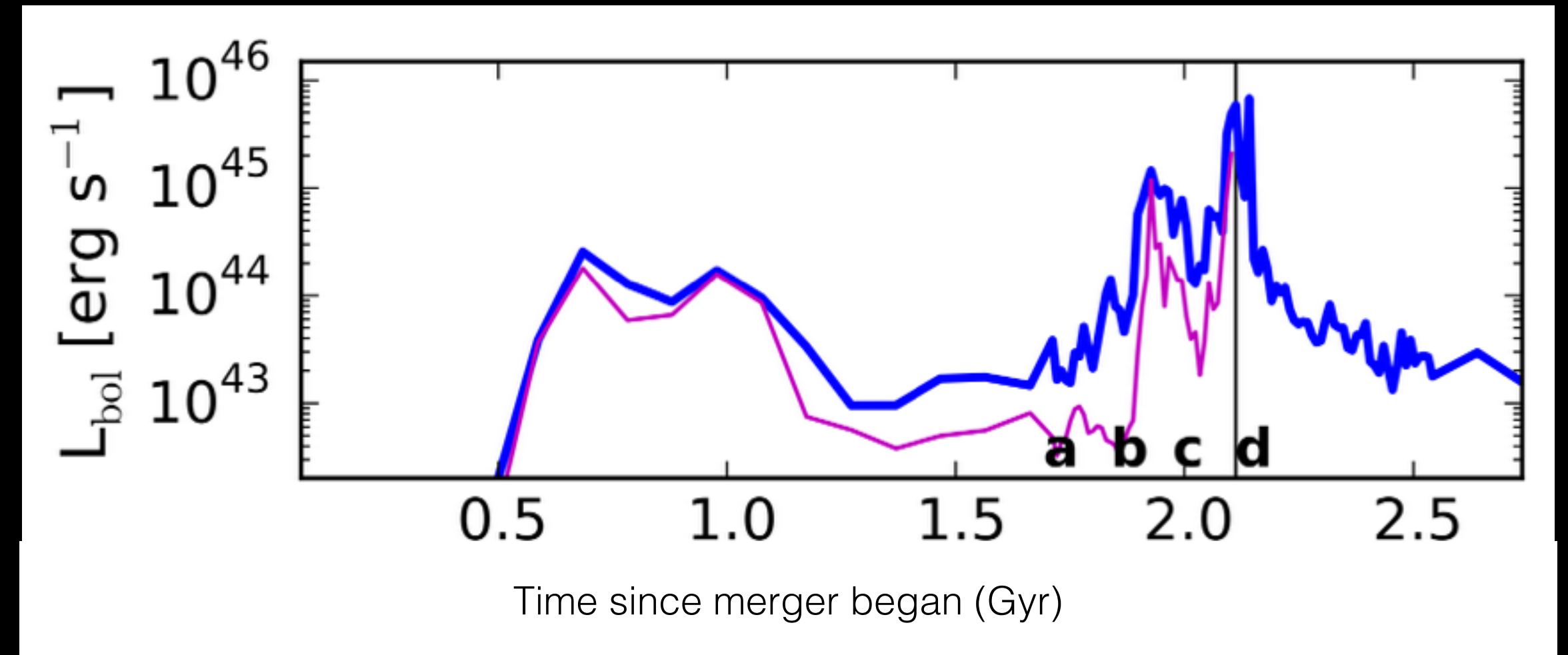
Collaborators: Julie Comerford, Jenny Greene, and David Pooley

Are AGN Special?, Durham, 2018

Galaxy mergers can trigger AGN



Simulations from Blecha *et al.*, MNRAS, 2018

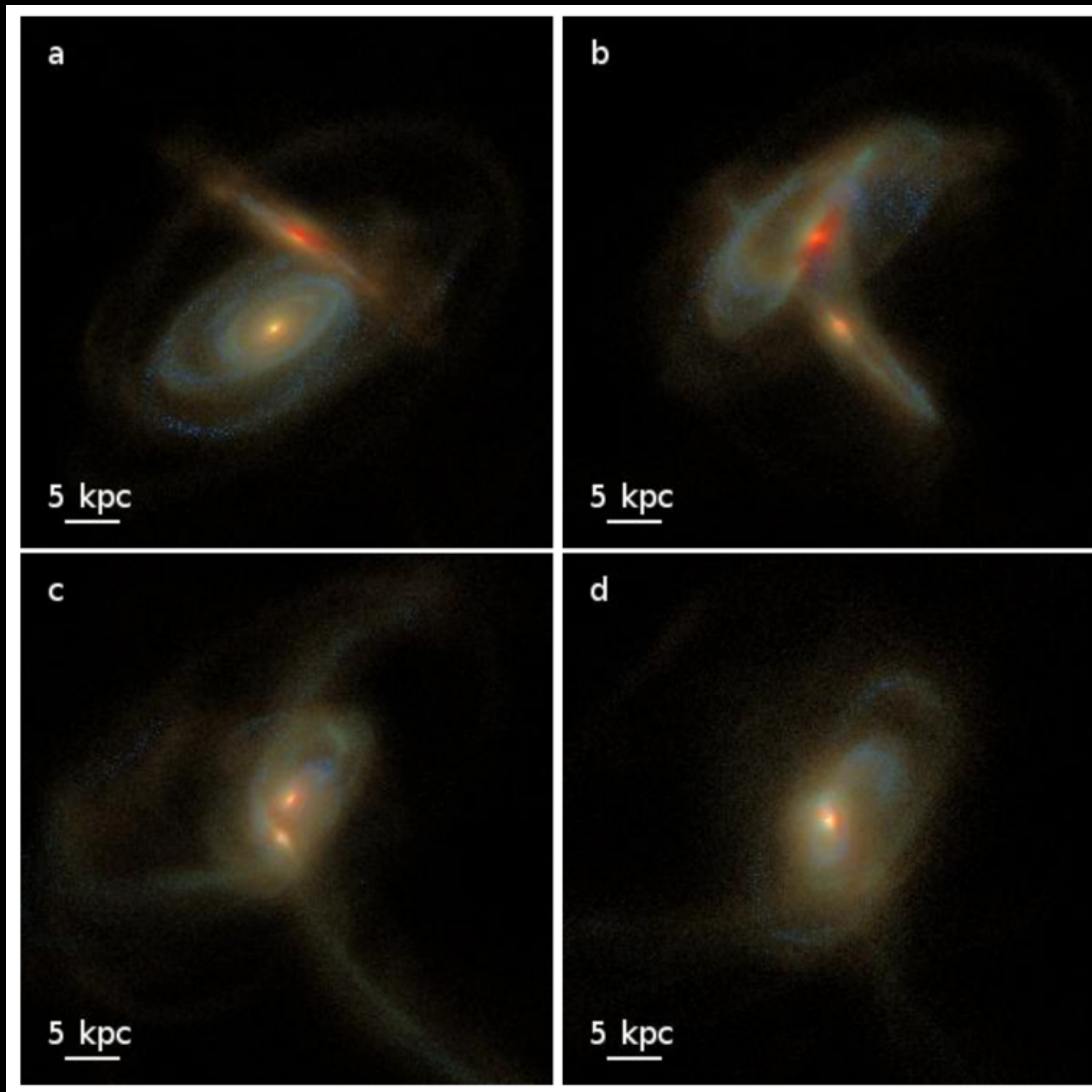


Simulations from Blecha *et al.*, MNRAS, 2018

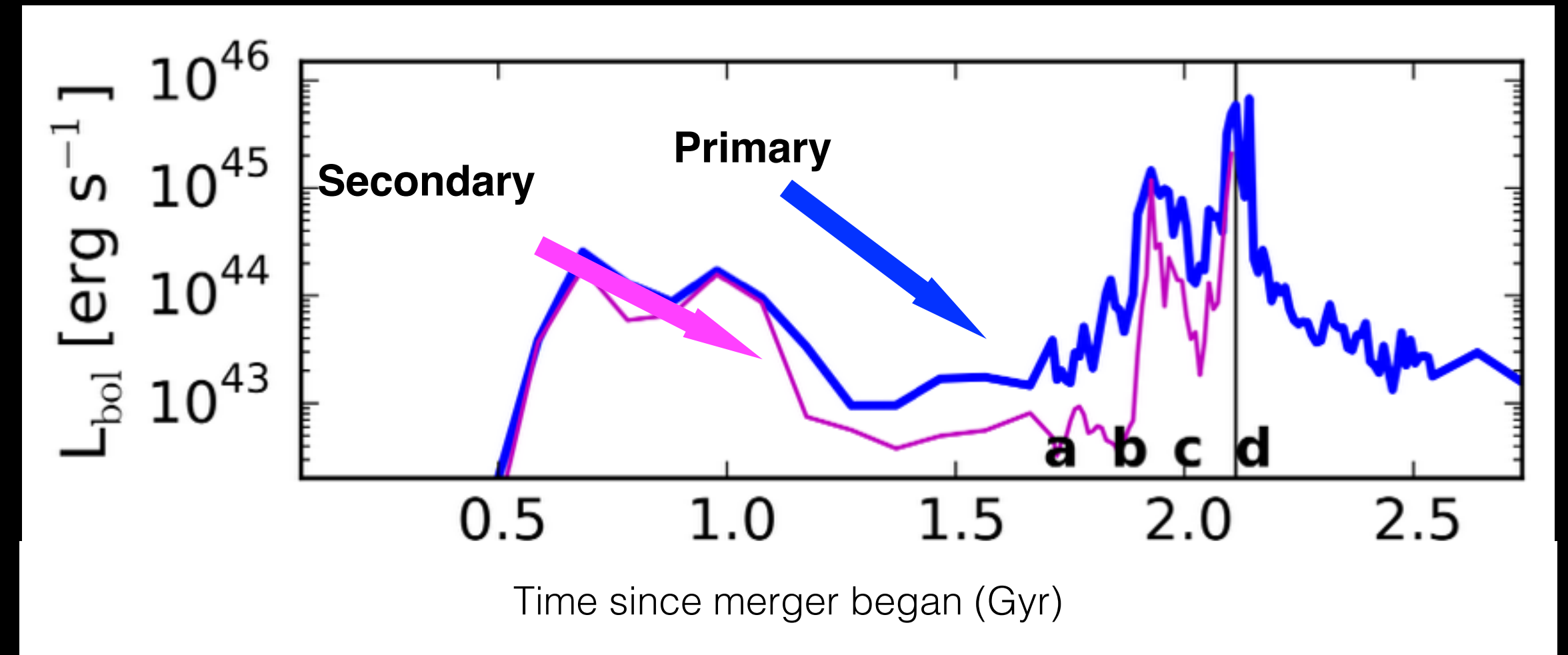
Not important for many (most?) AGN

Potentially important for triggering some AGN
(which ones?)

Galaxy mergers can trigger AGN



Simulations from Blecha *et al.*, MNRAS, 2018



Simulations from Blecha *et al.*, MNRAS, 2018

Not important for many (most?) AGN

Potentially important for triggering some AGN
(which ones?)

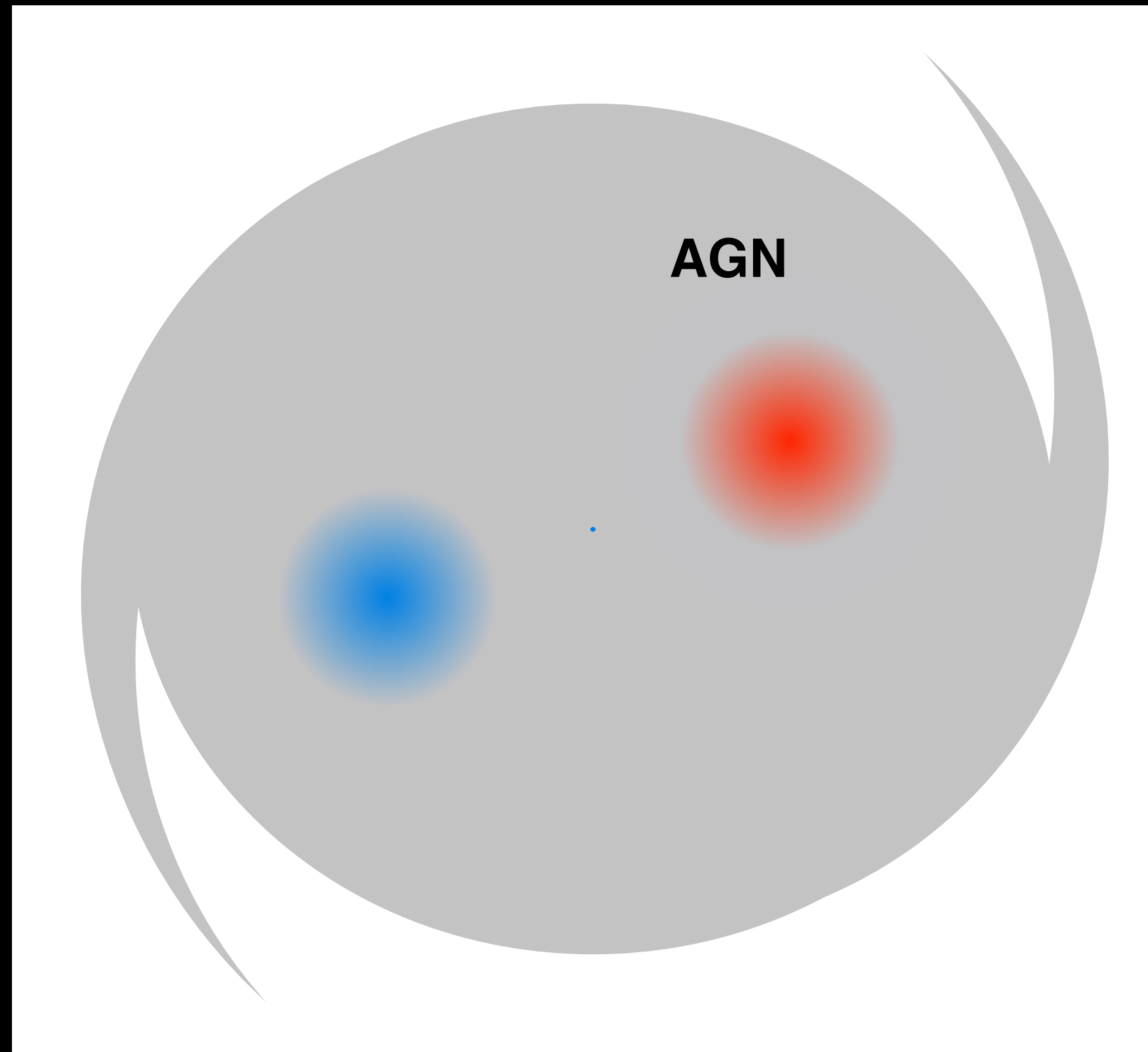
AGN triggering can happen for the SMBH in
one or both of the galaxies.

Offset AGN V.S. Dual AGN

In an on-going galaxy merger:

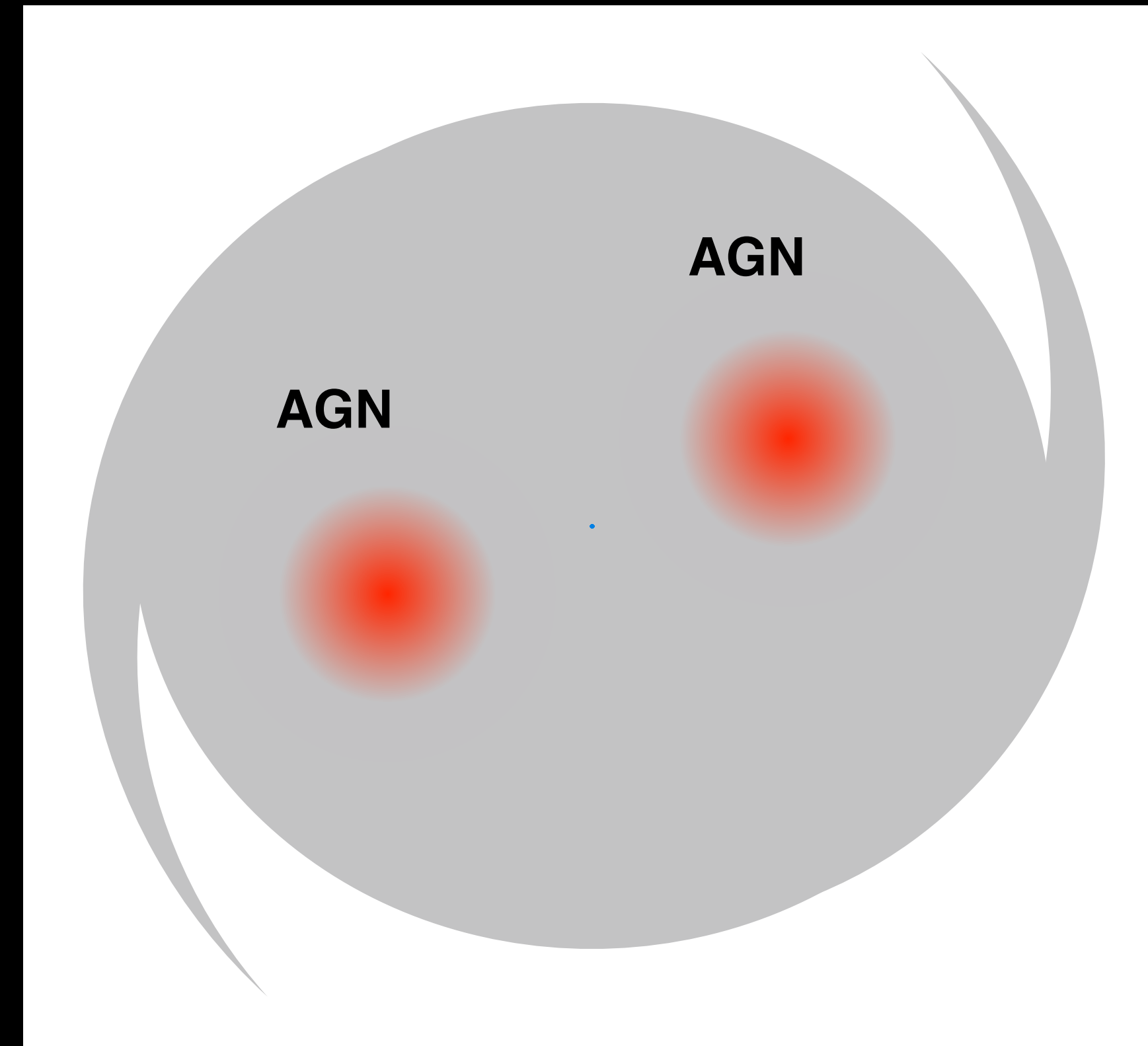
If only a single SMBH is active

.....**Offset AGN**



If both SMBHs are active

.....**Dual AGN**



Note:

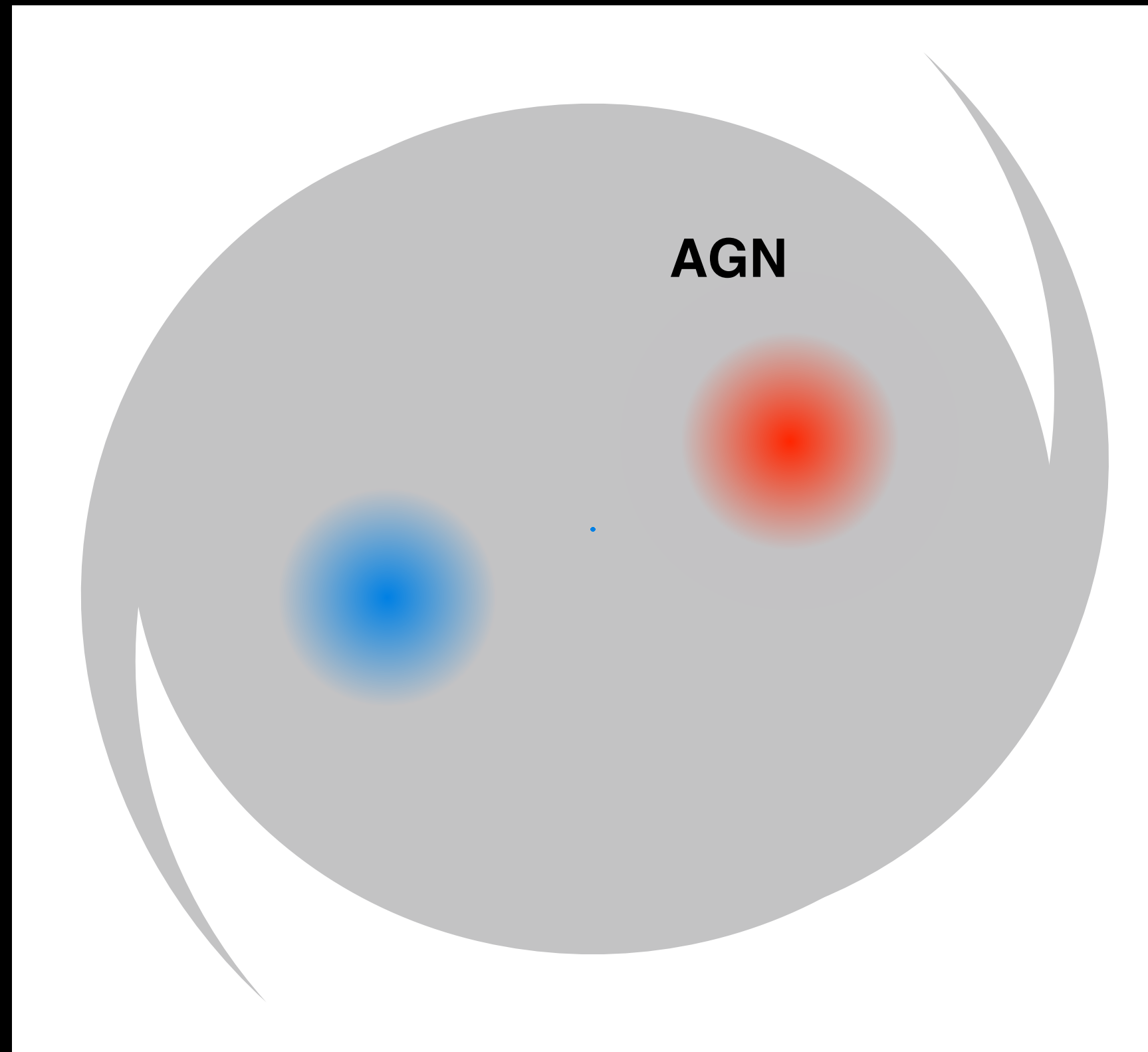
AGN 'presence' depends on the method of detection used and the adopted threshold

Offset AGN V.S. Dual AGN

In an on-going galaxy merger:

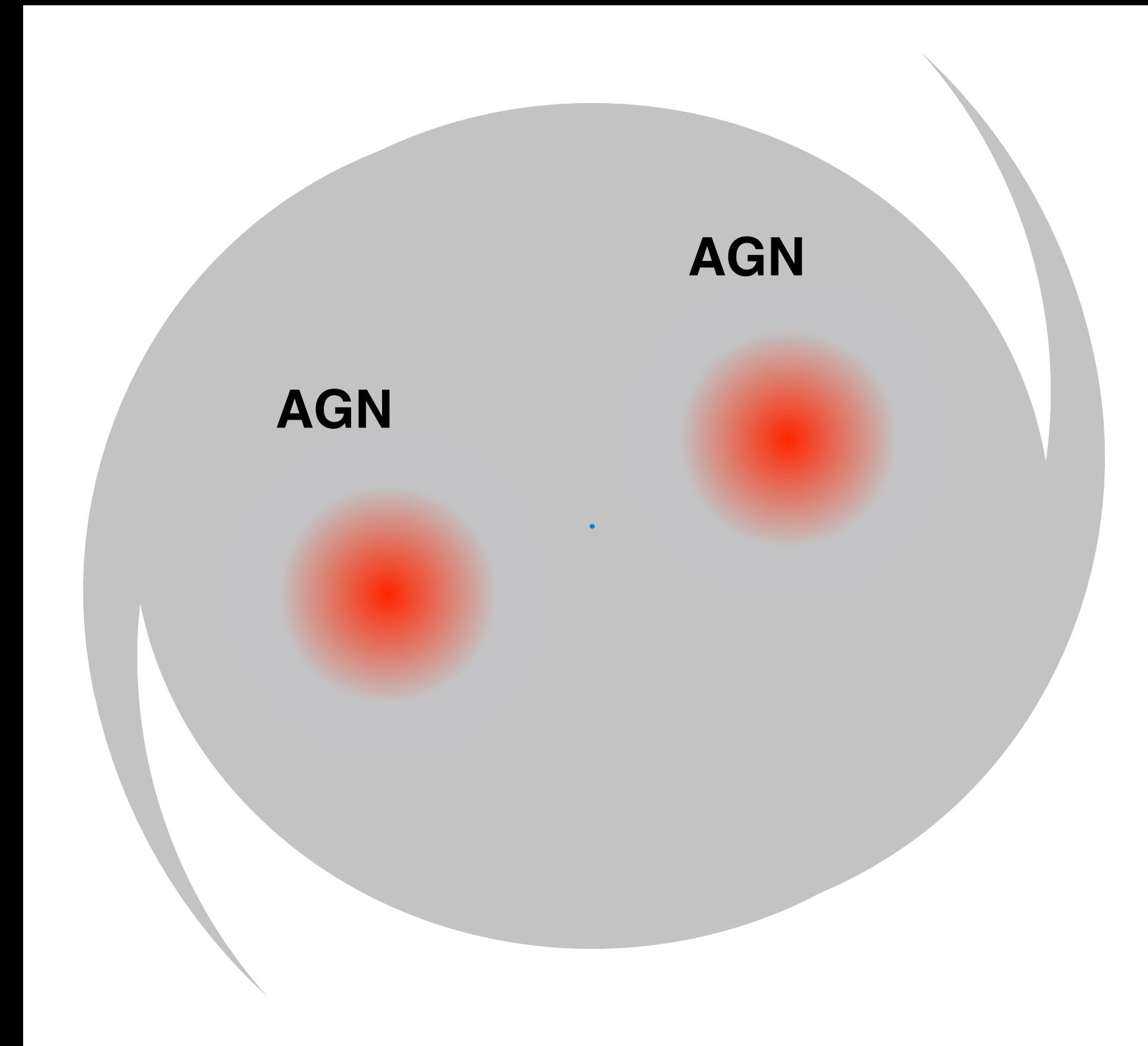
If only a single SMBH is active

.....**Offset AGN**



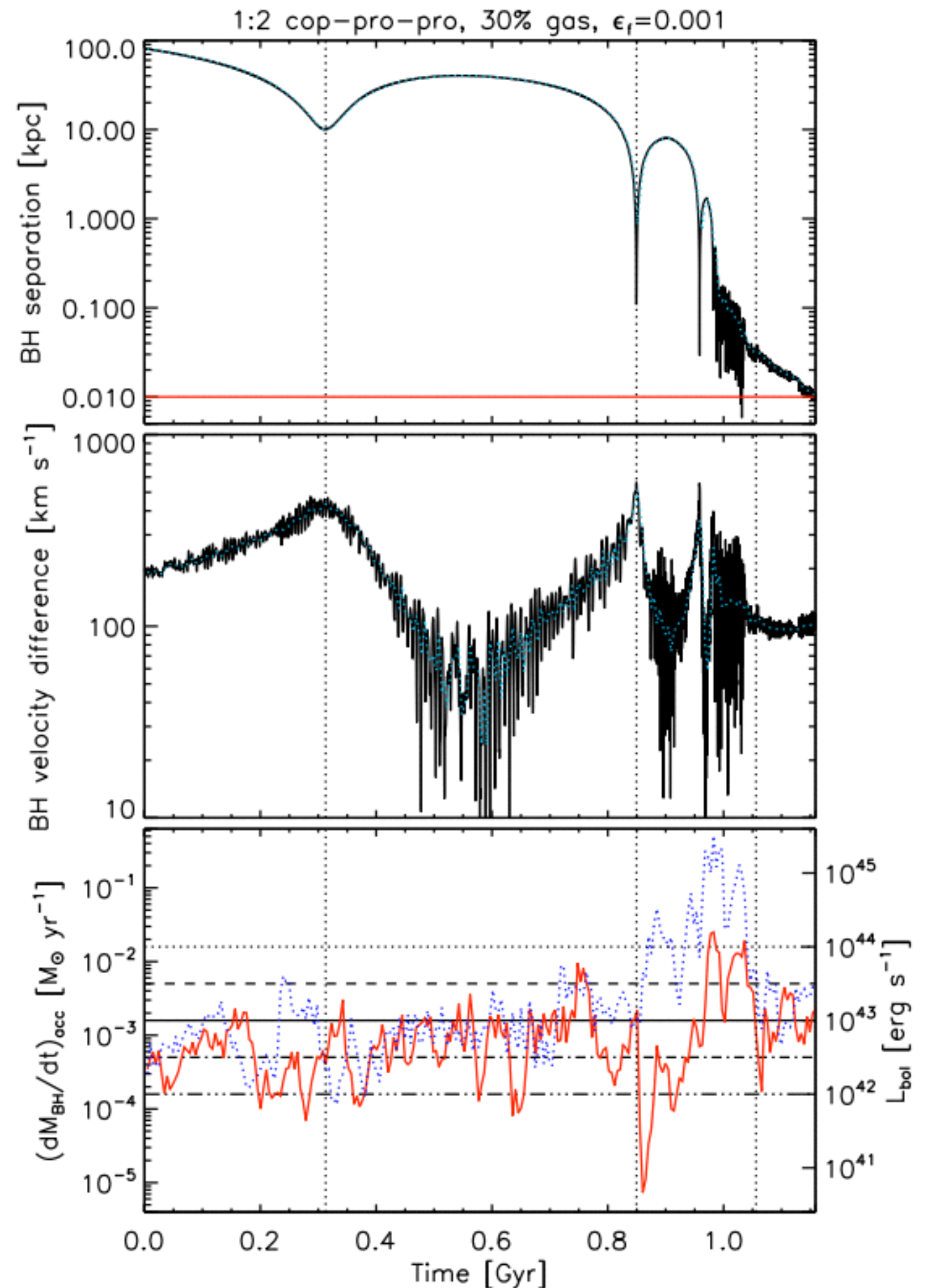
If both SMBHs are active

.....**Dual AGN**



Do offset AGN or dual AGN require *special* conditions in mergers?

Numerical Predictions: Temporal Evolution of Mergers



SMBHs grow by accretion in mergers

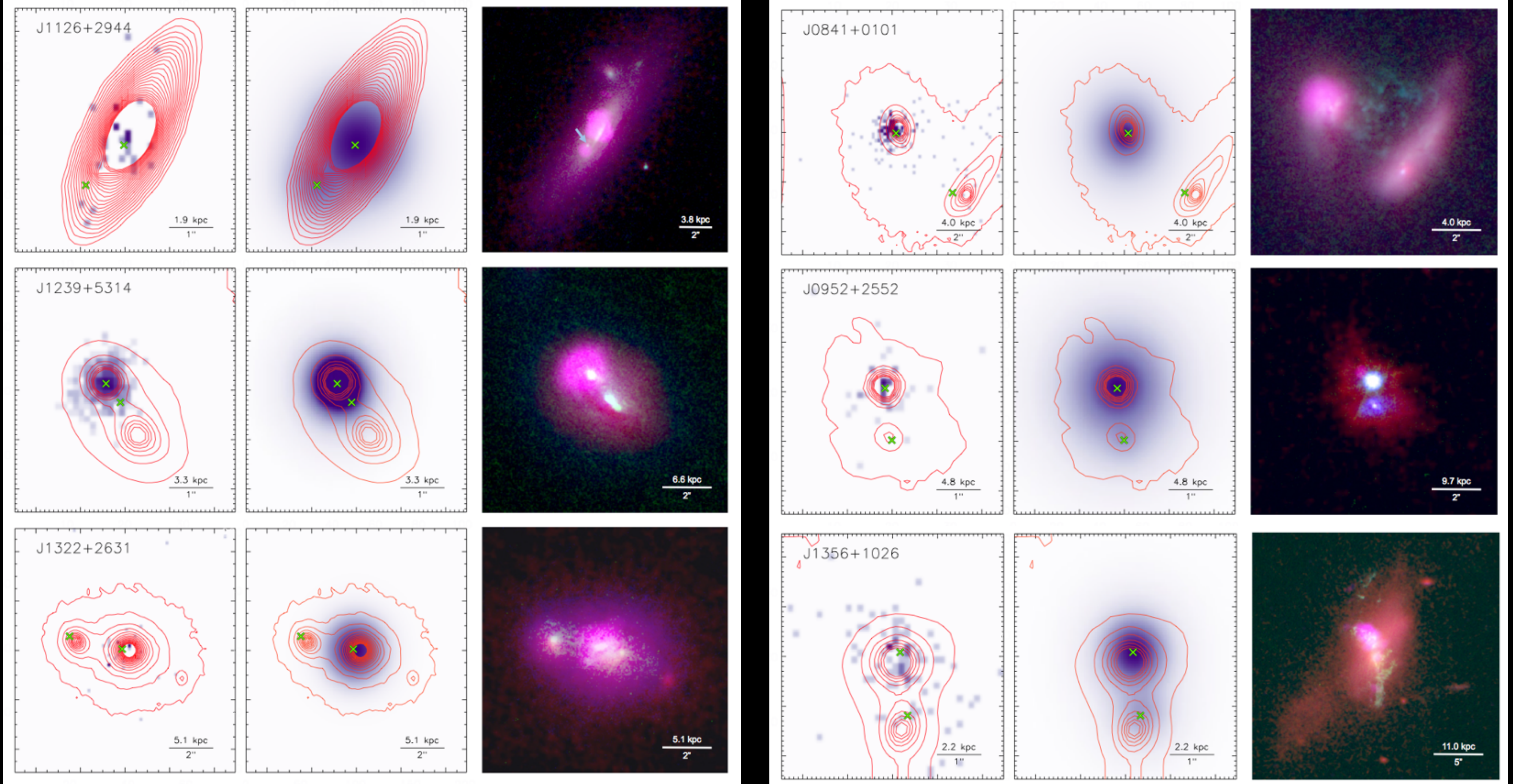
Offset vs Dual AGN:

distinction is important for merger-driven SMBH growth

Most of the action may occur at late merger stages:

Accretion rates peak at < 1 kpc

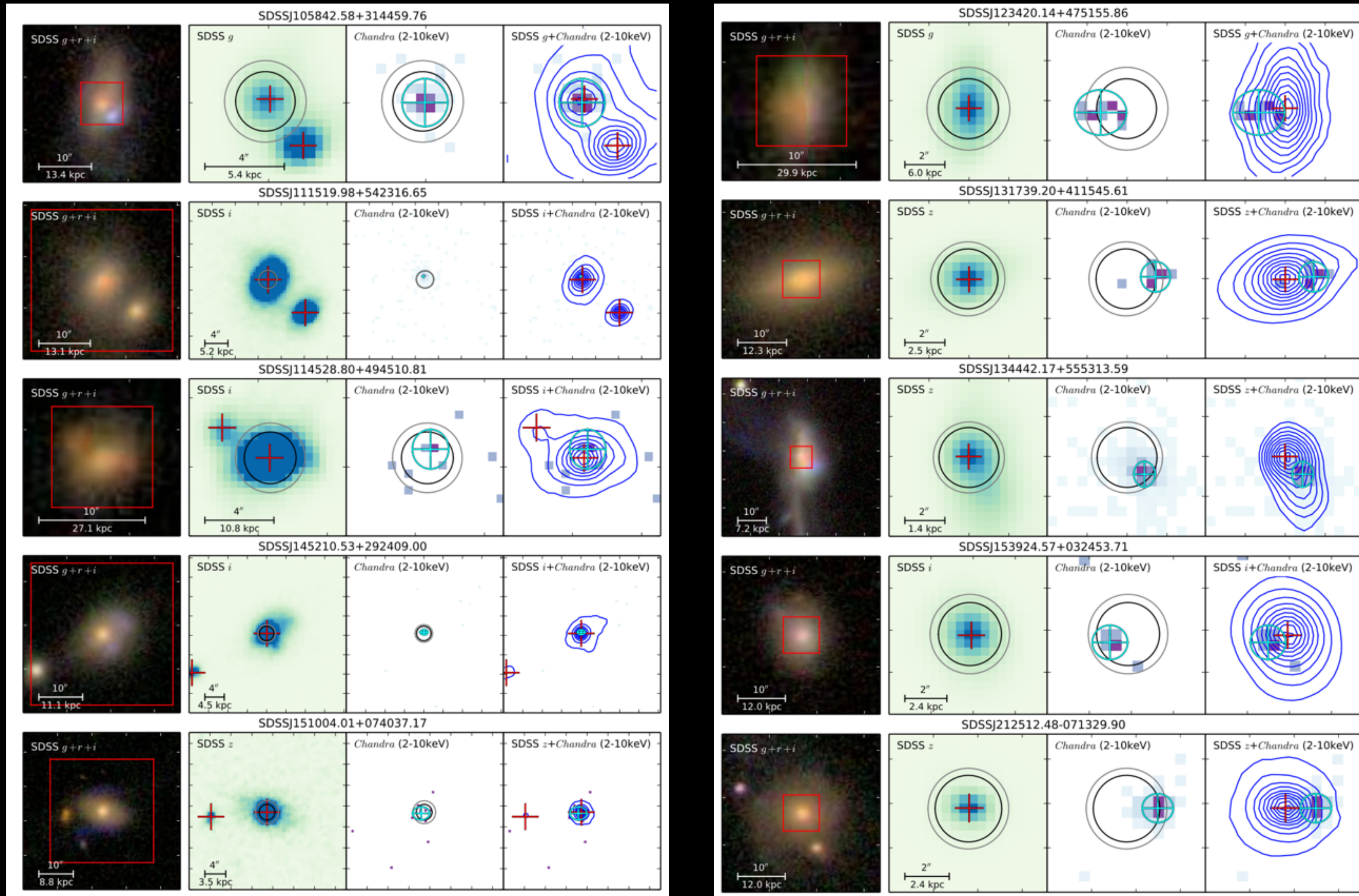
Dual AGN



Physical Separations of 2-8 kpc

Comerford et al. 2015

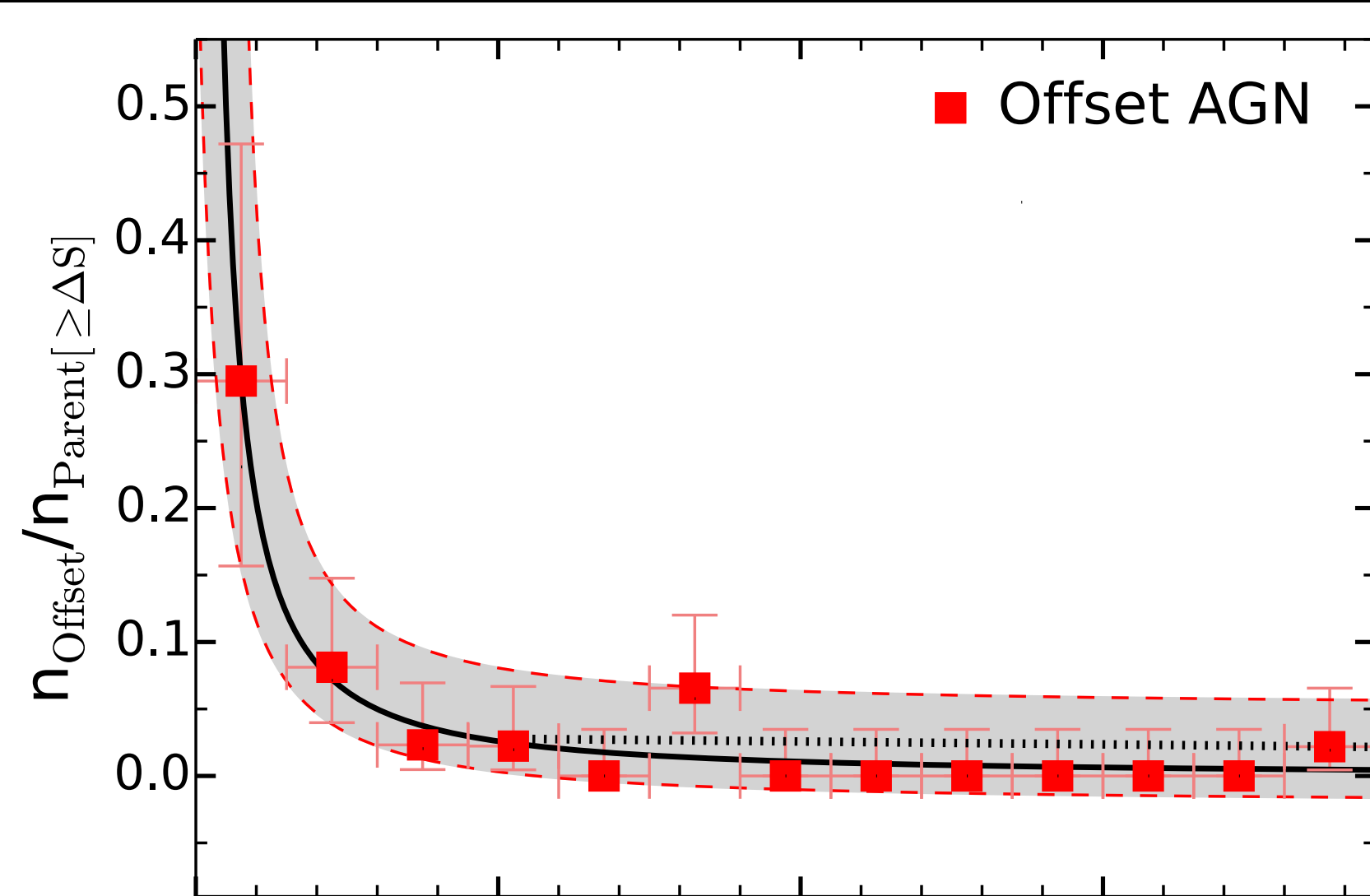
Offset AGN



Physical Separations of 0.8-19 kpc

Barrows et al. 2016

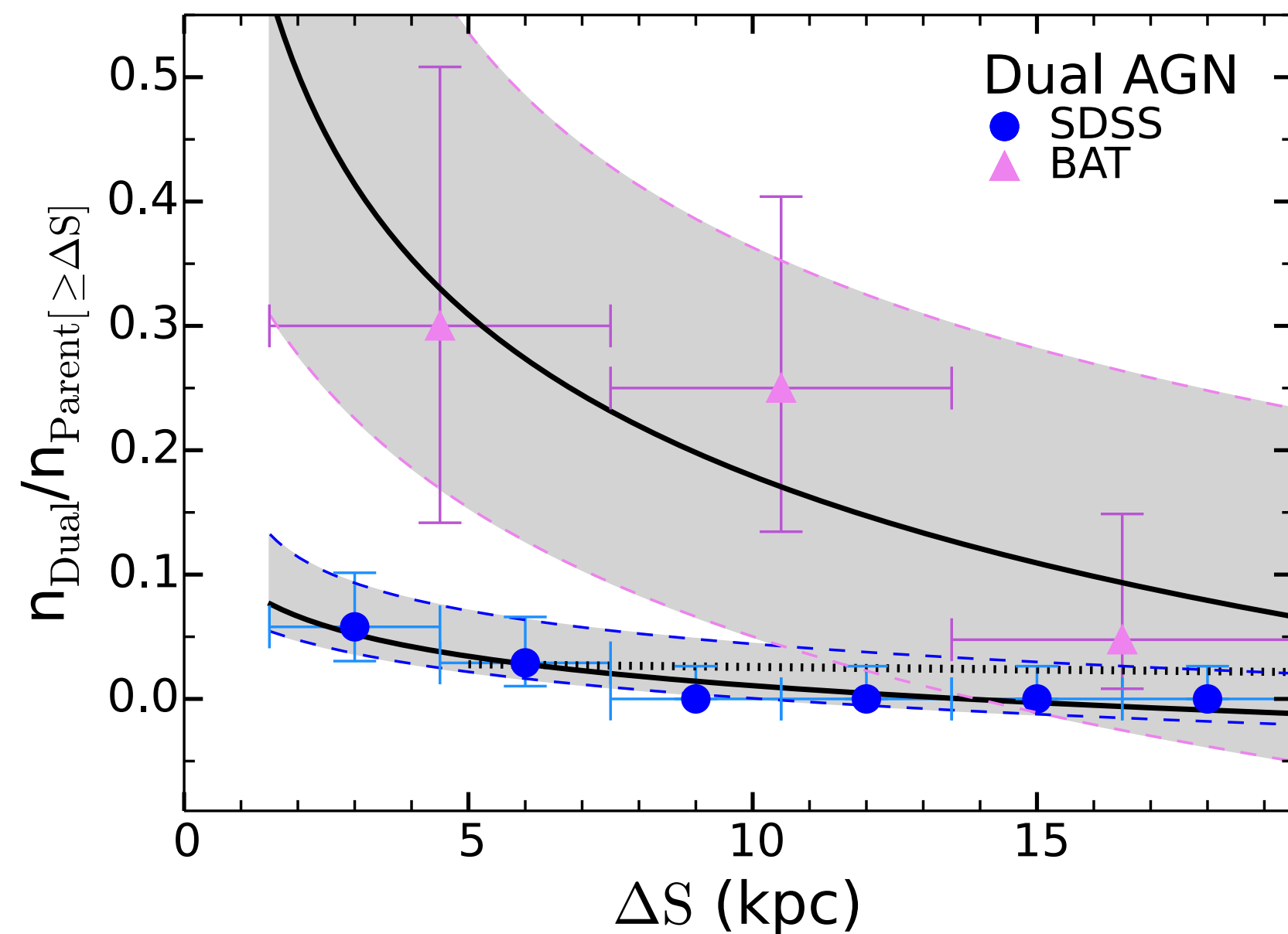
AGN Merger Fraction Versus Nuclear Separation



All Separations:

AGN merger fraction increases with decreasing nuclear separation ($\sim 3\sigma$)

General trends similar to larger scale pairs for both offset AGN and dual AGN (Ellison+2011, Satyapal+2014)

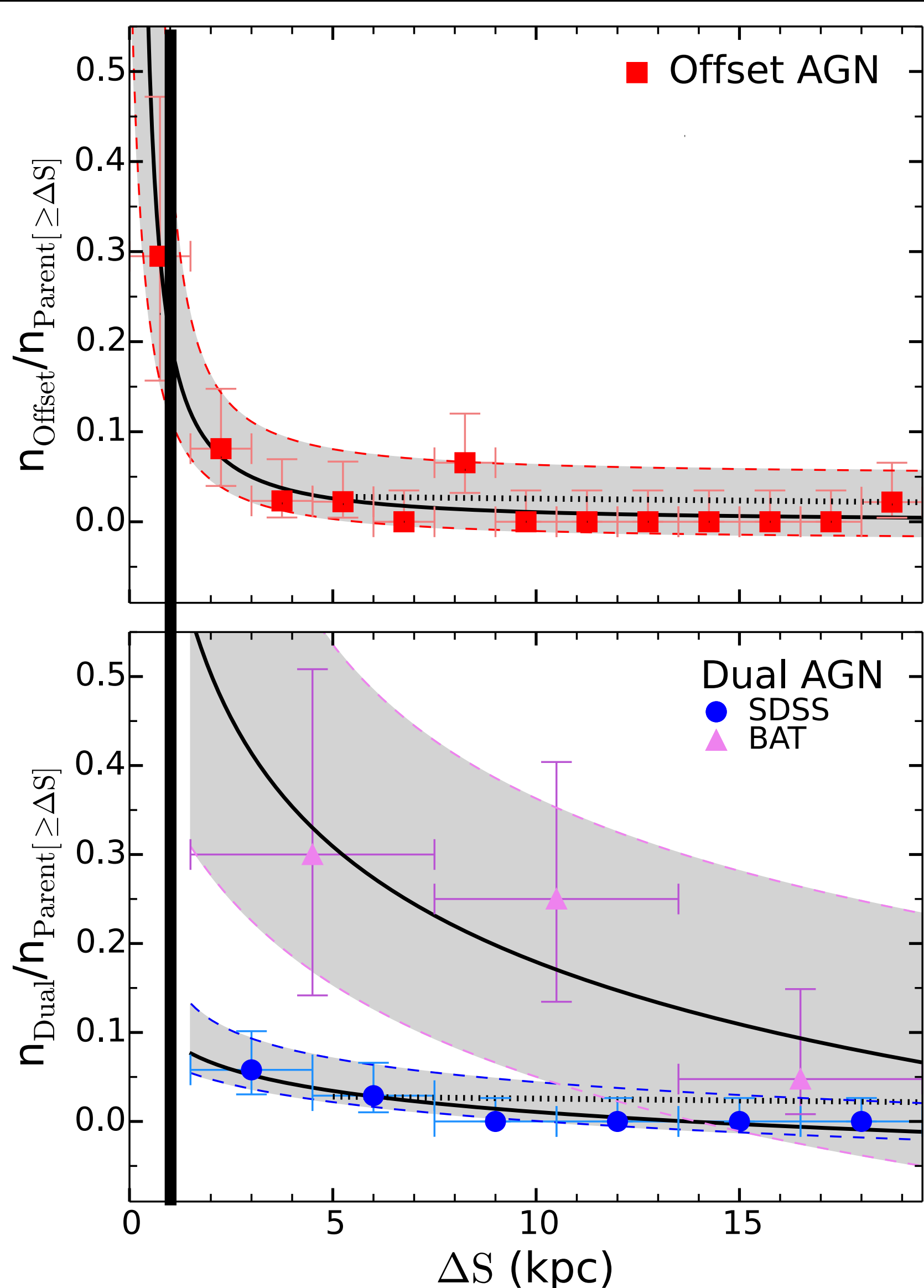


Small Separations (<1 kpc):

Offset AGN merger fraction rises most strongly and peaks
Probably similar or stronger evolution for dual AGN

Consistent with numerical predictions that frequency of AGN triggering peaks near nuclear coalescence

AGN Merger Fraction Versus Nuclear Separation



All Separations:

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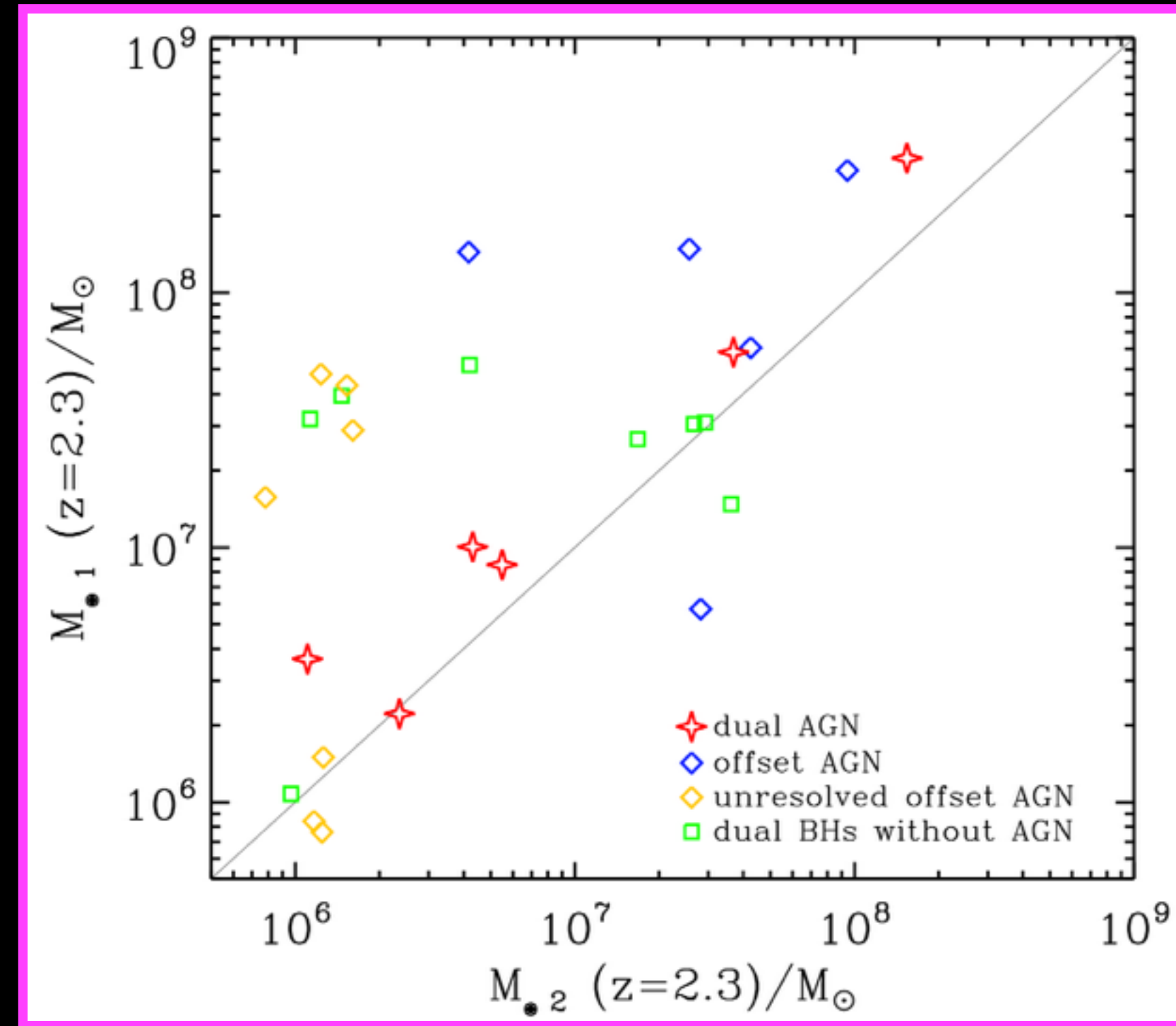
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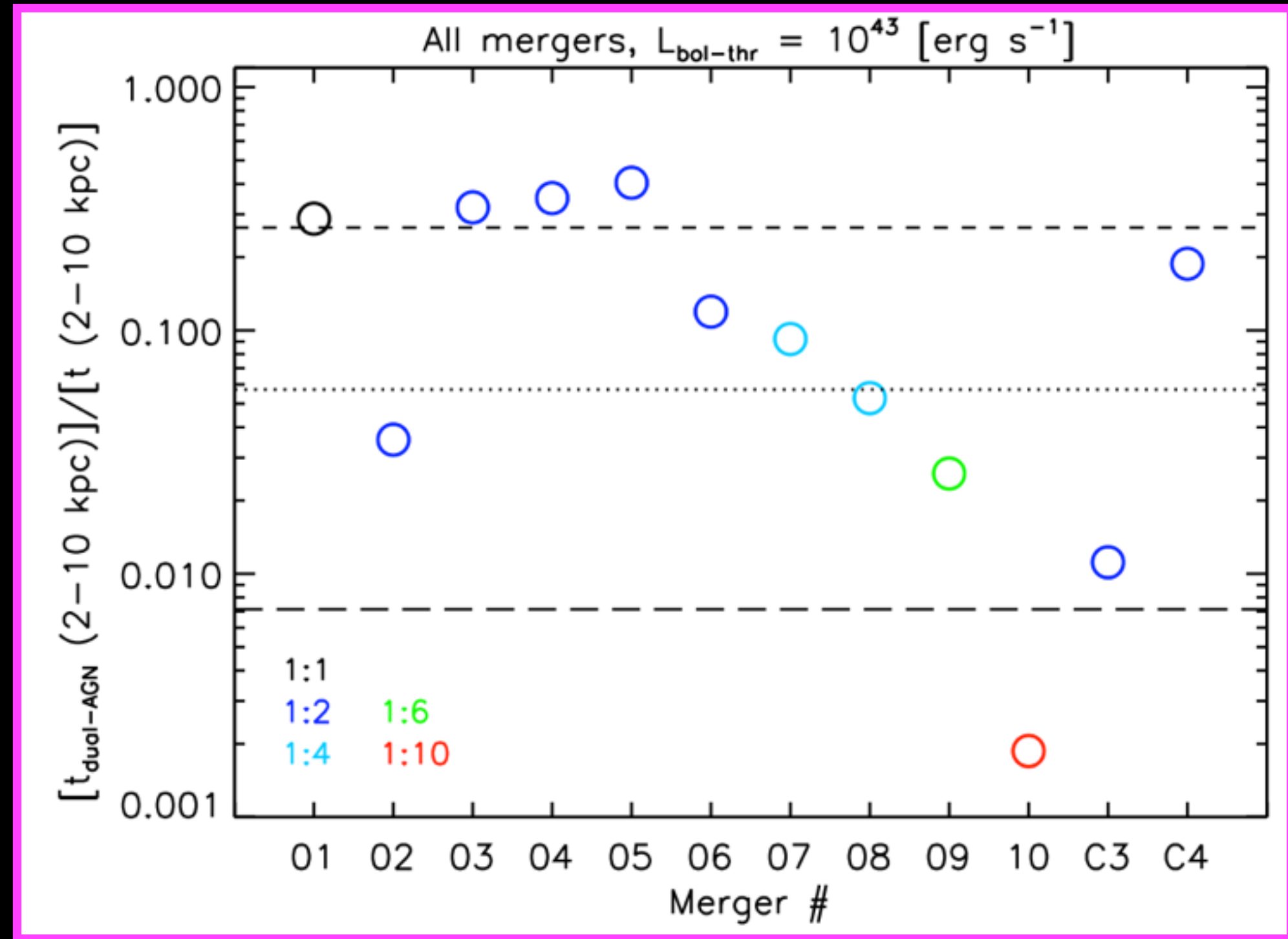
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Numerical Predictions: The Effect of Mass Ratio

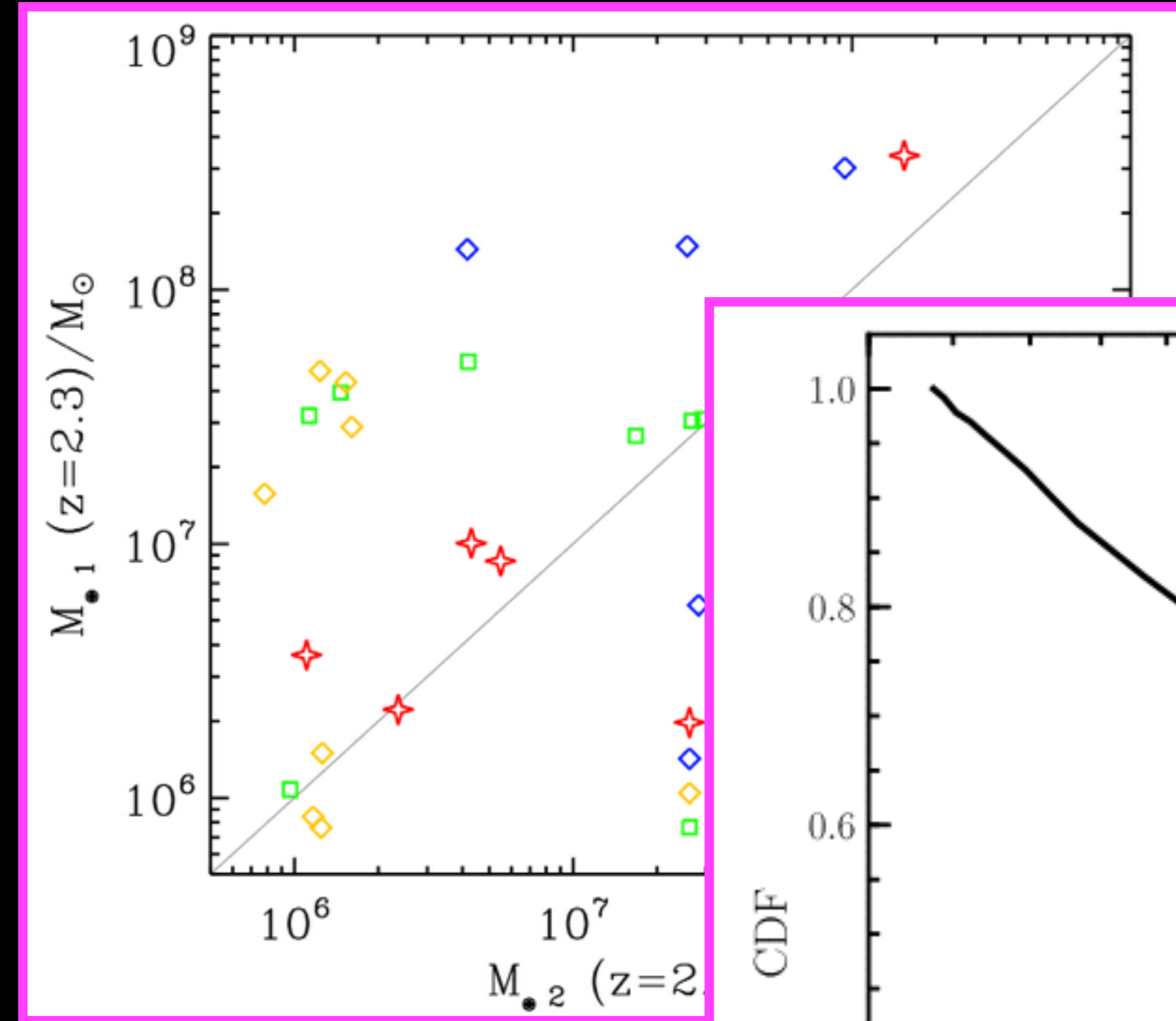


Steinborn et al. 2016

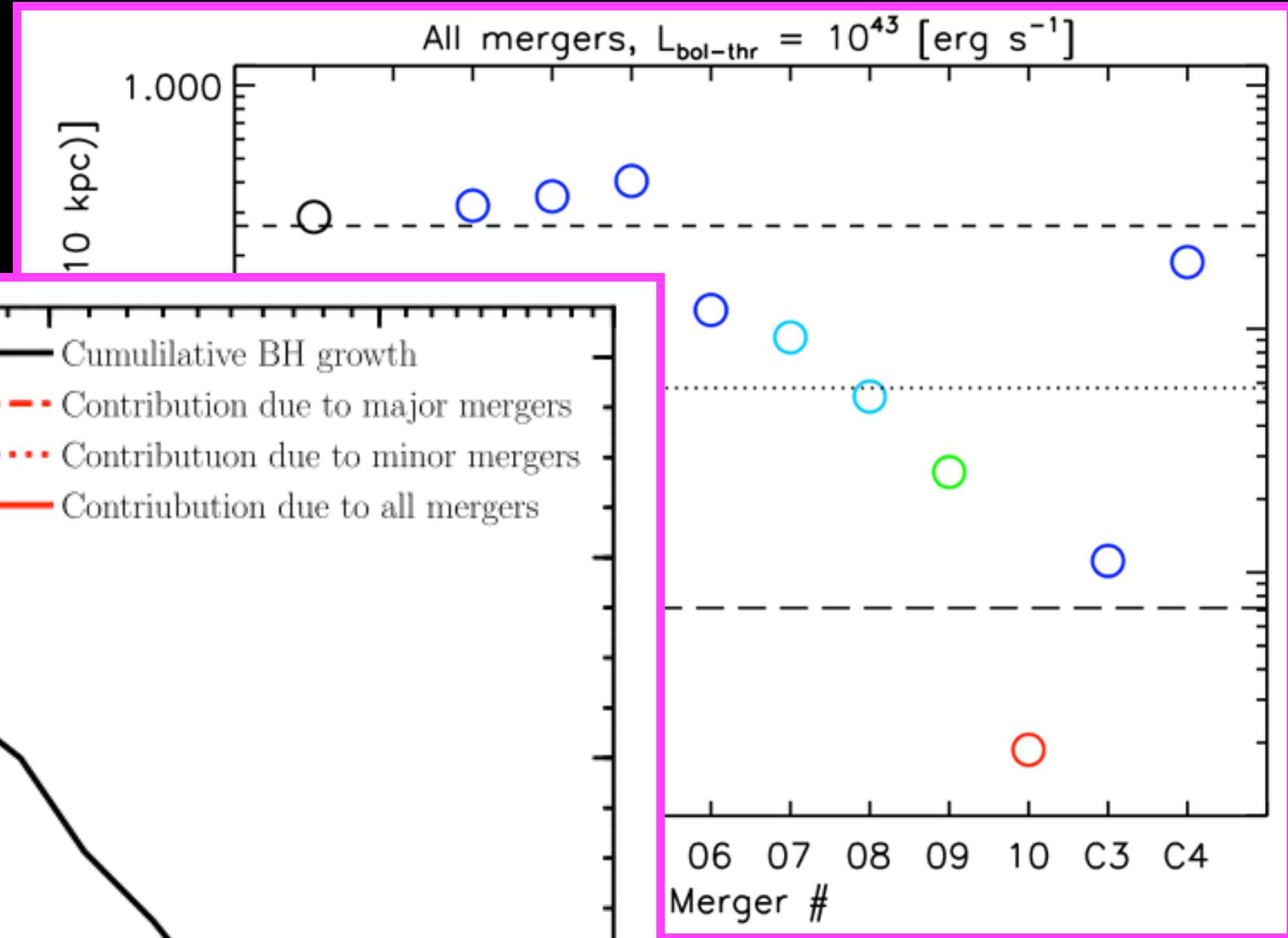


Capelo et al. 2017

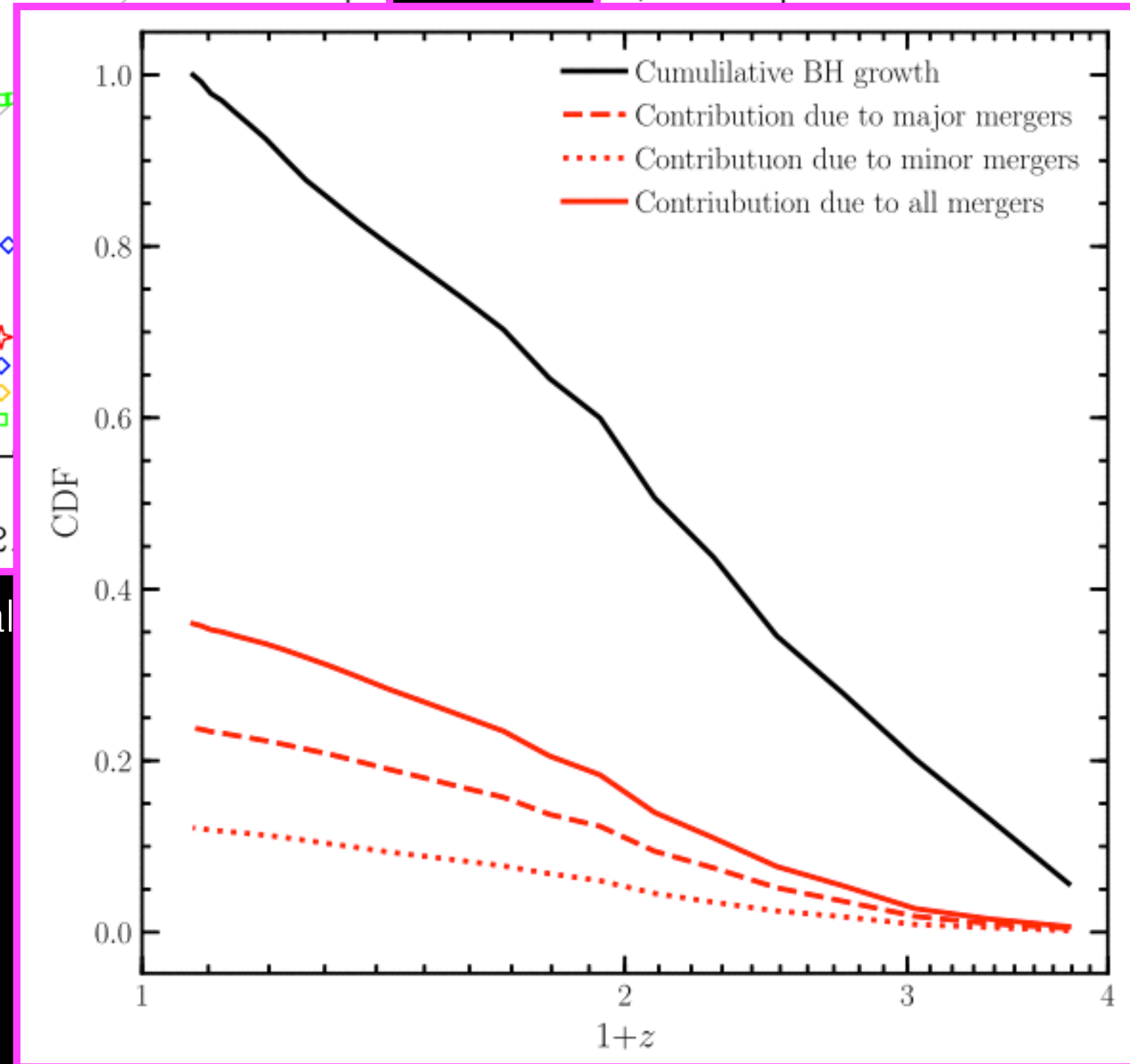
Numerical Predictions: The Effect of Mass Ratio



Steinborn et al.

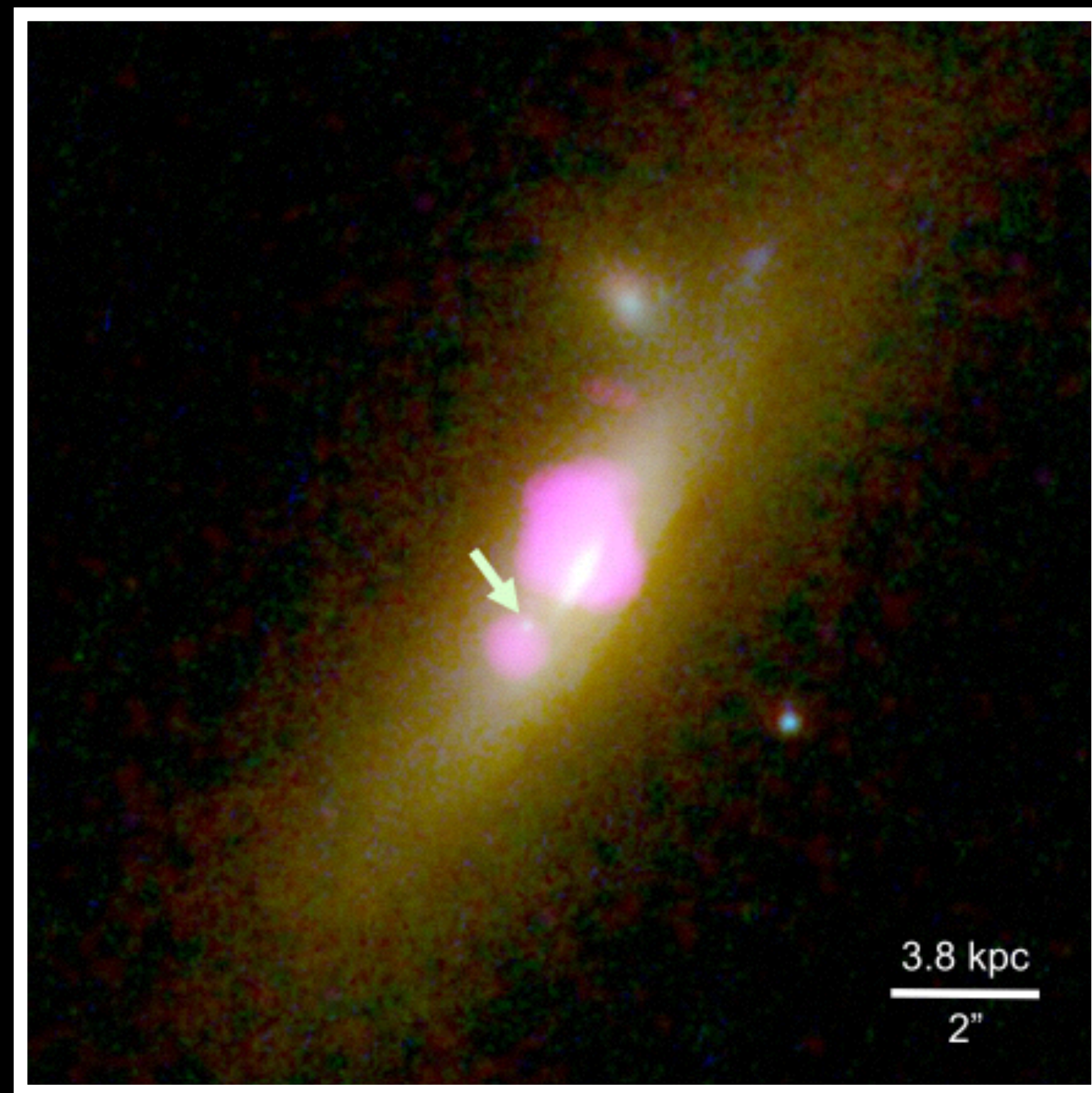


al. 2017

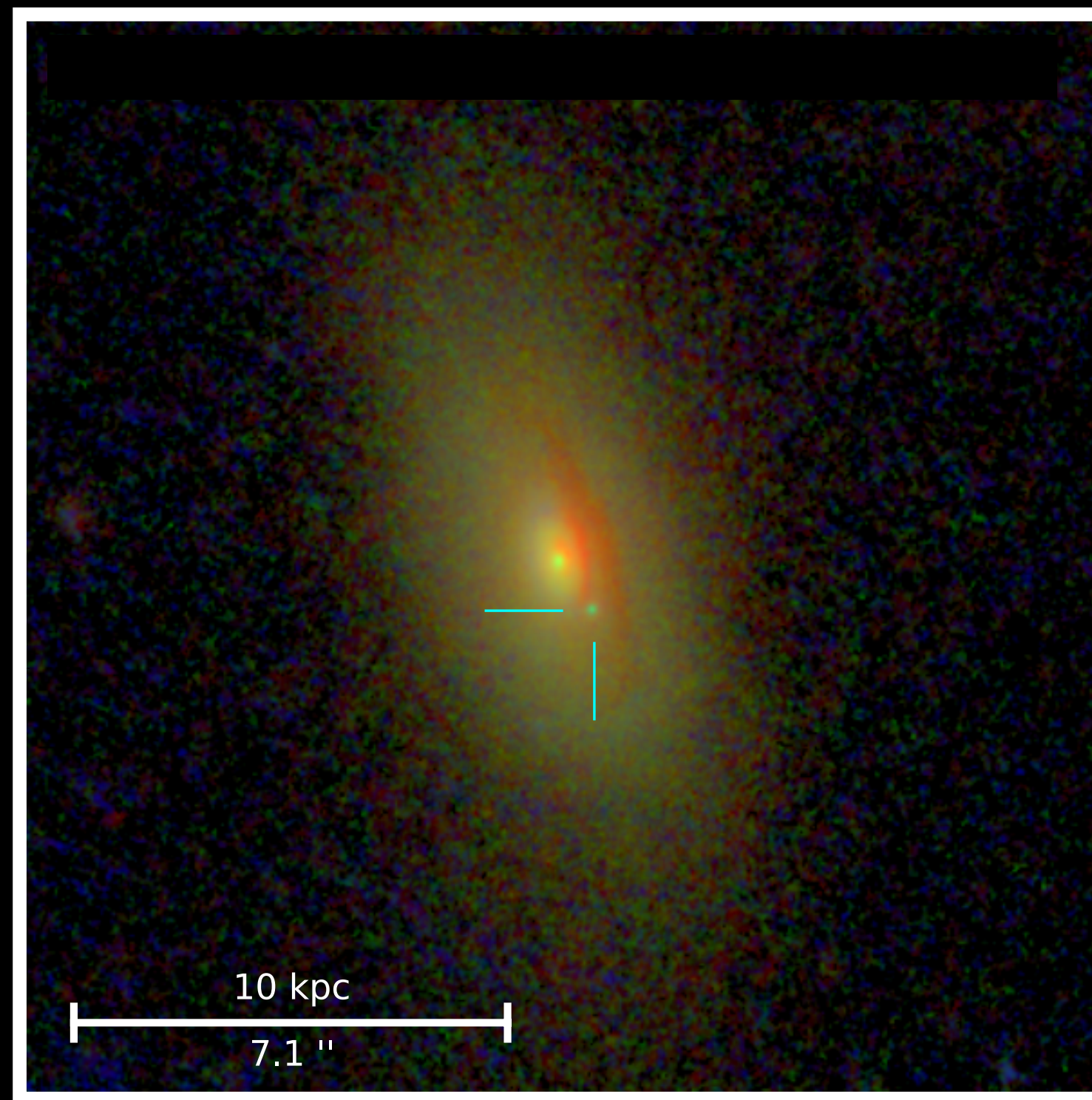


Martin et al. 2018

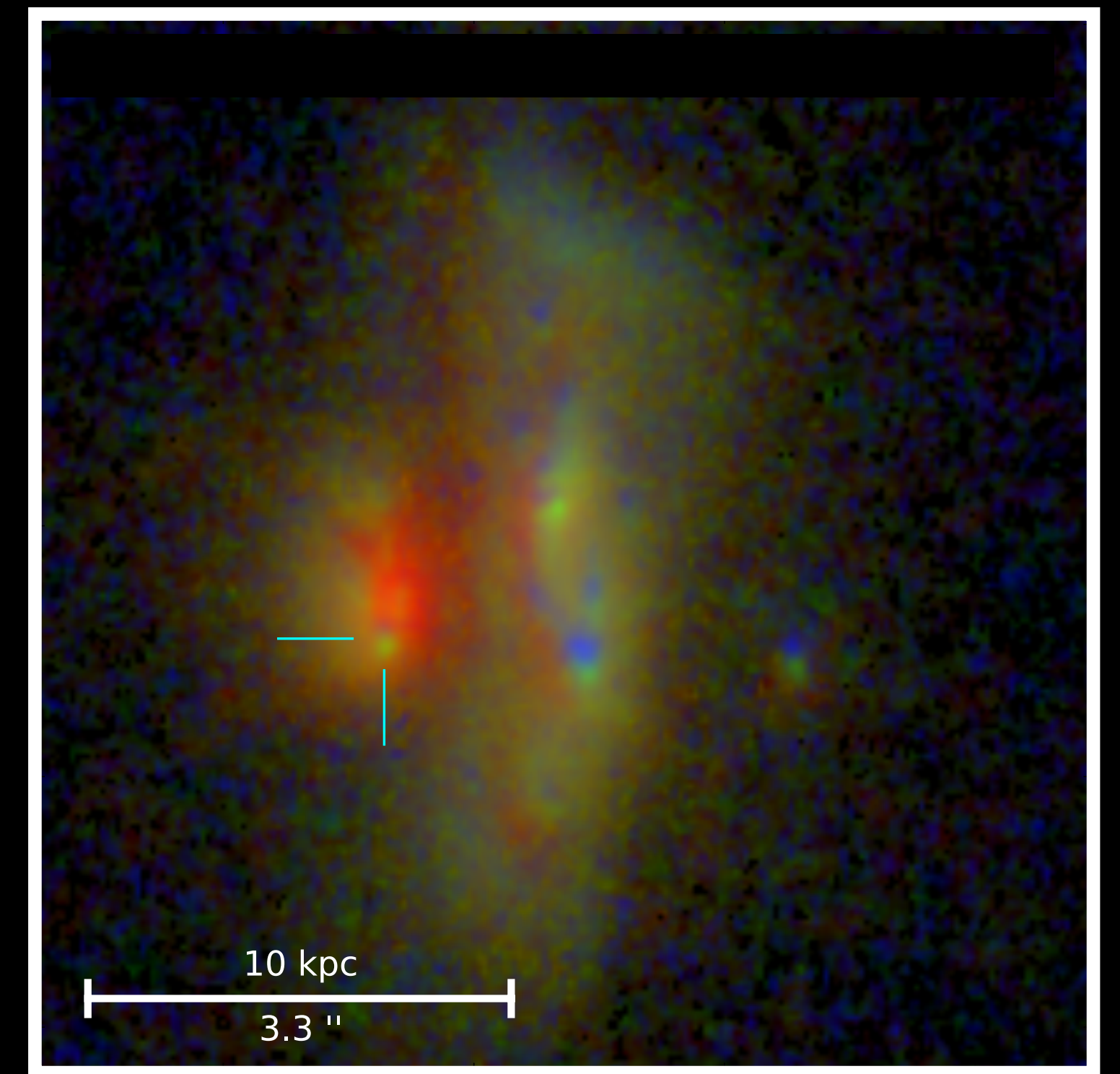
Mass Ratios of Offset AGN and Dual AGN in Late Stage Mergers



Mass Ratio $\sim 460:1$



Mass Ratio $\sim 50:1$



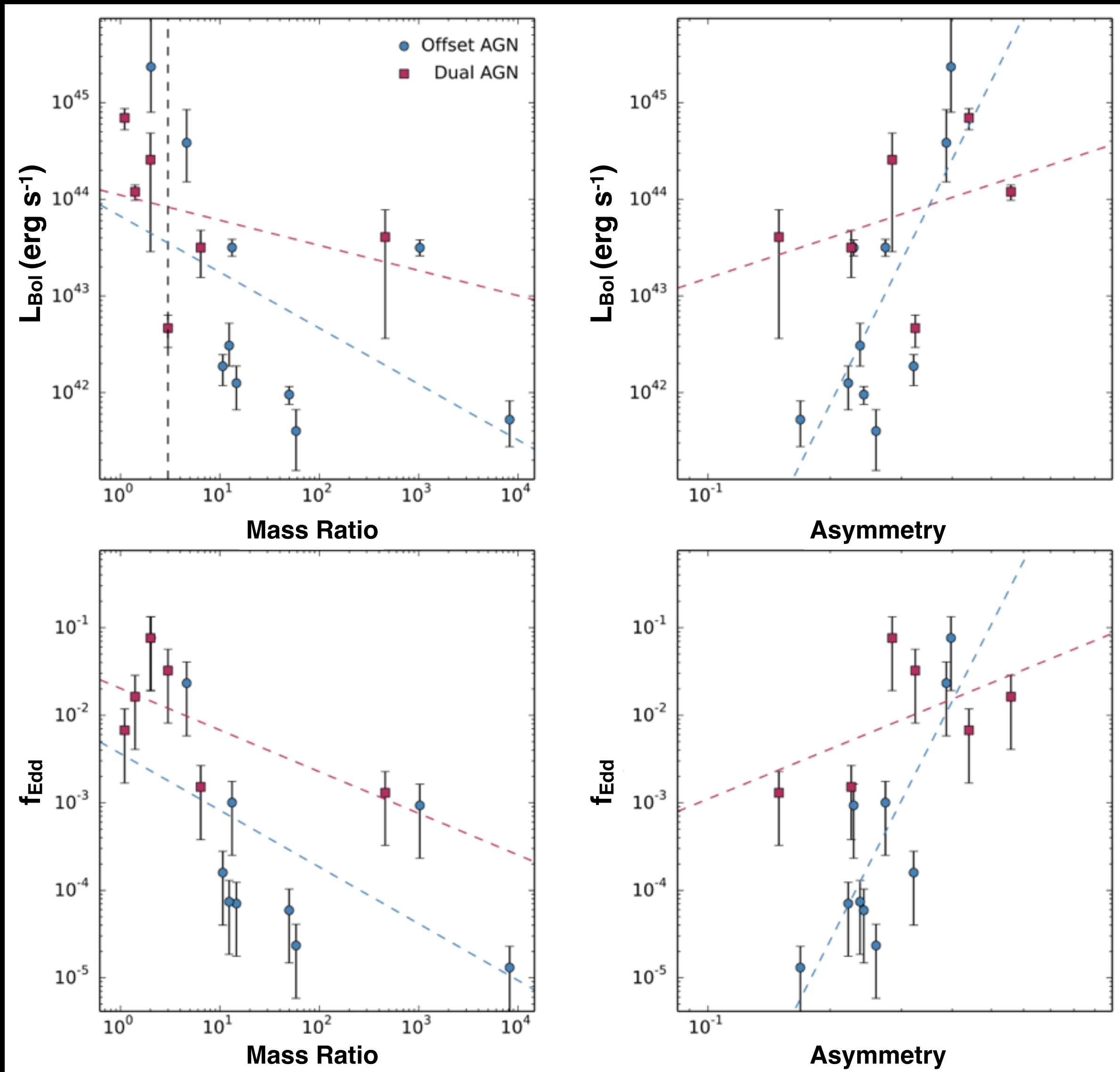
Mass Ratio $\sim 2:1$

Selection insensitive to merger mass ratio

Includes major mergers and minor mergers with large ratios

- dependence of mass ratio can be tested over a large dynamic range

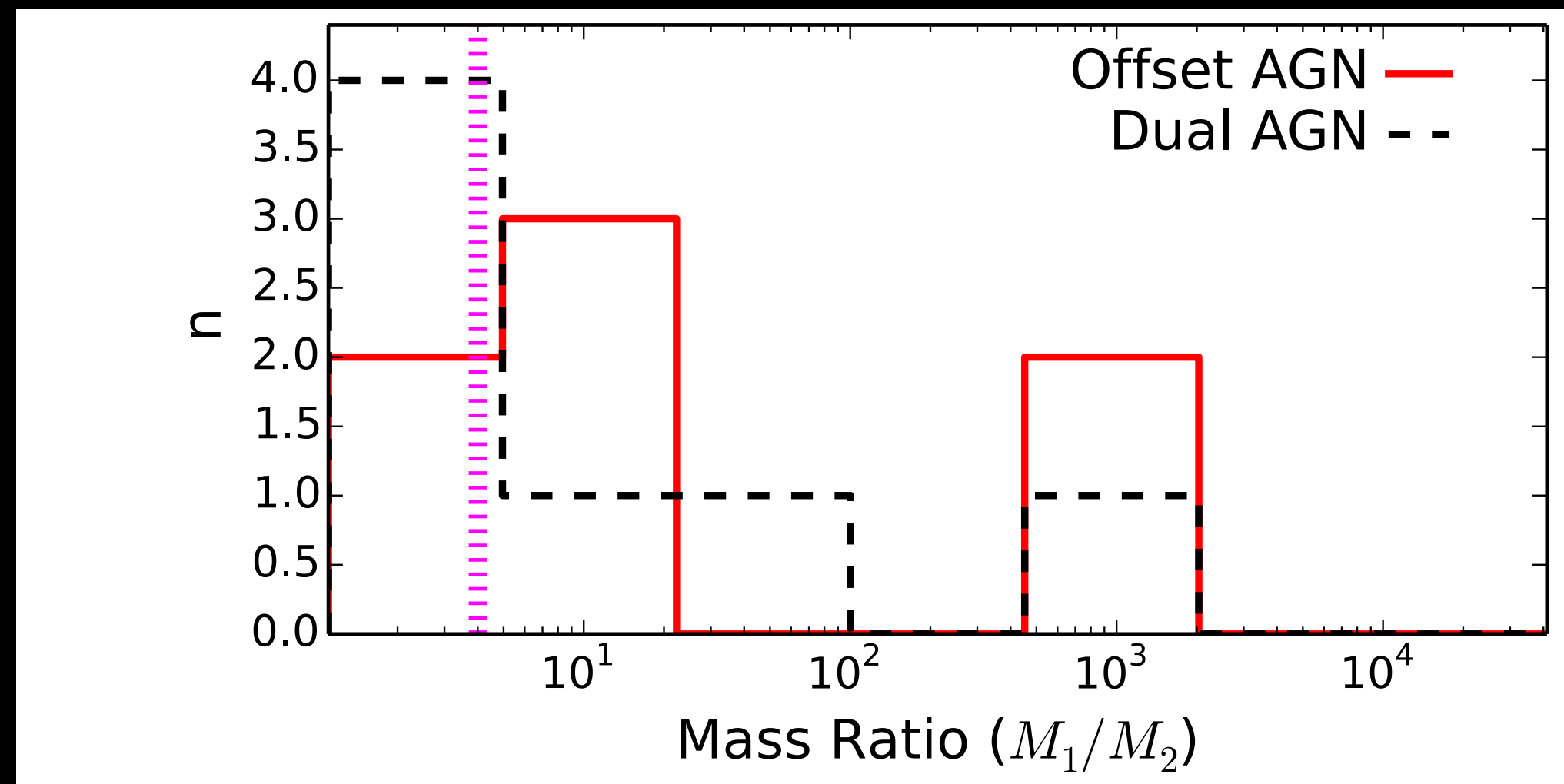
Dependence of AGN Triggering on Merger Morphology



General increase in accretion level and efficiency with merger morphology

Suggests that the AGN may remember they are in mergers (at least during late merger stages)

Offset AGN V.S. Dual AGN



Barrows et al. 2018, *in prep*

Offset AGN:

Mean Value: 70

Minor Mergers: 86%

Dual AGN:

Mean Value: 7

Minor Mergers: 43%

Offset AGN have similar minor and major merger fractions as galaxy mergers without AGN: 90% minor, 10% major (Lotz et al. 2011)

Single AGN are not so special among mergers

By comparison, dual AGN may preferentially form in major mergers

Offset AGN V.S. Dual AGN

By comparison with offset AGN, dual AGN may be special:

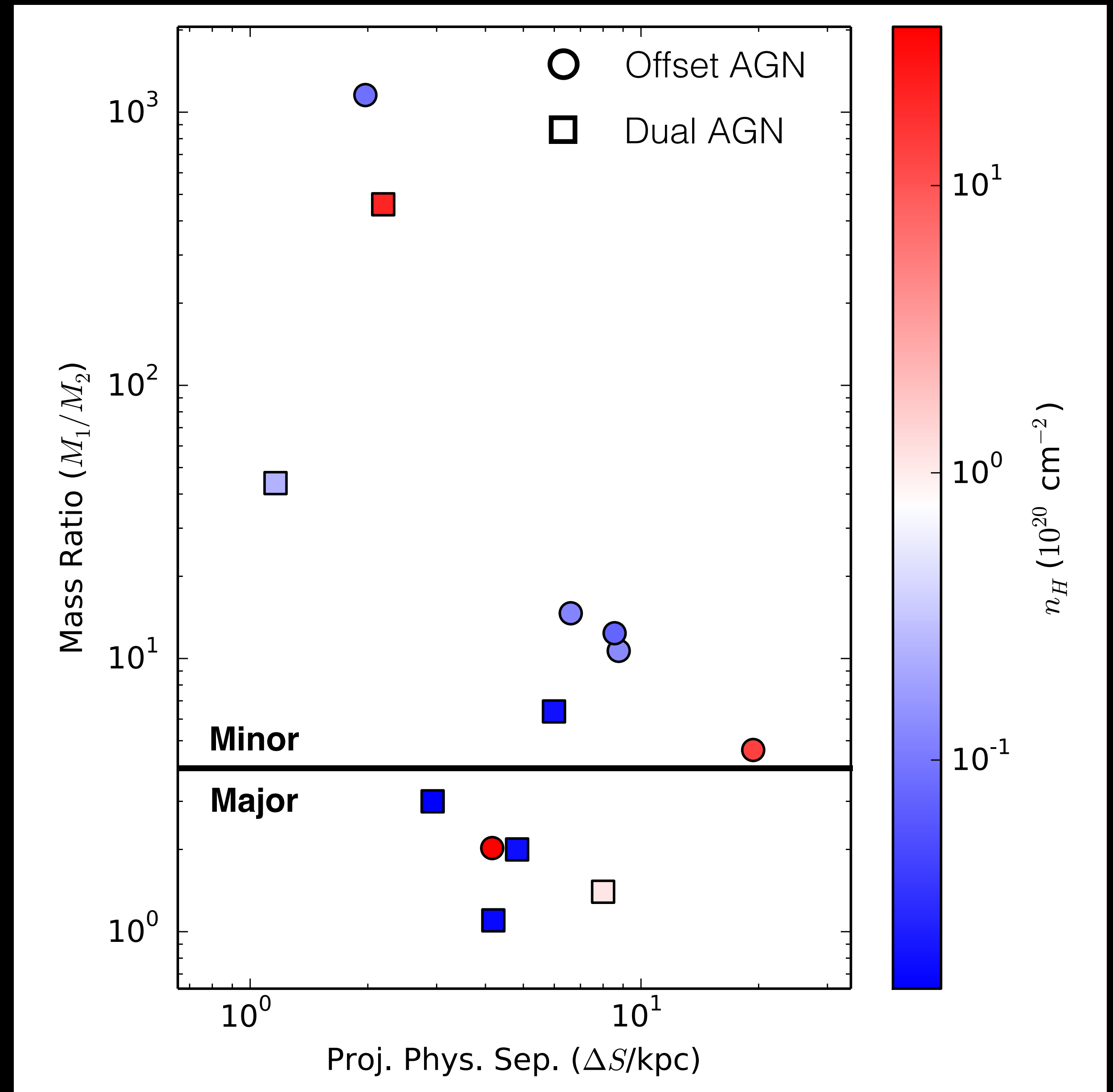
- major mergers

(extreme tidal forces)

- Smaller nuclear separations

(migration of gas and dust to nuclei)

- Large supplies of gas and dust



Offset AGN V.S. Dual AGN

By comparison with offset AGN, dual AGN may be special:

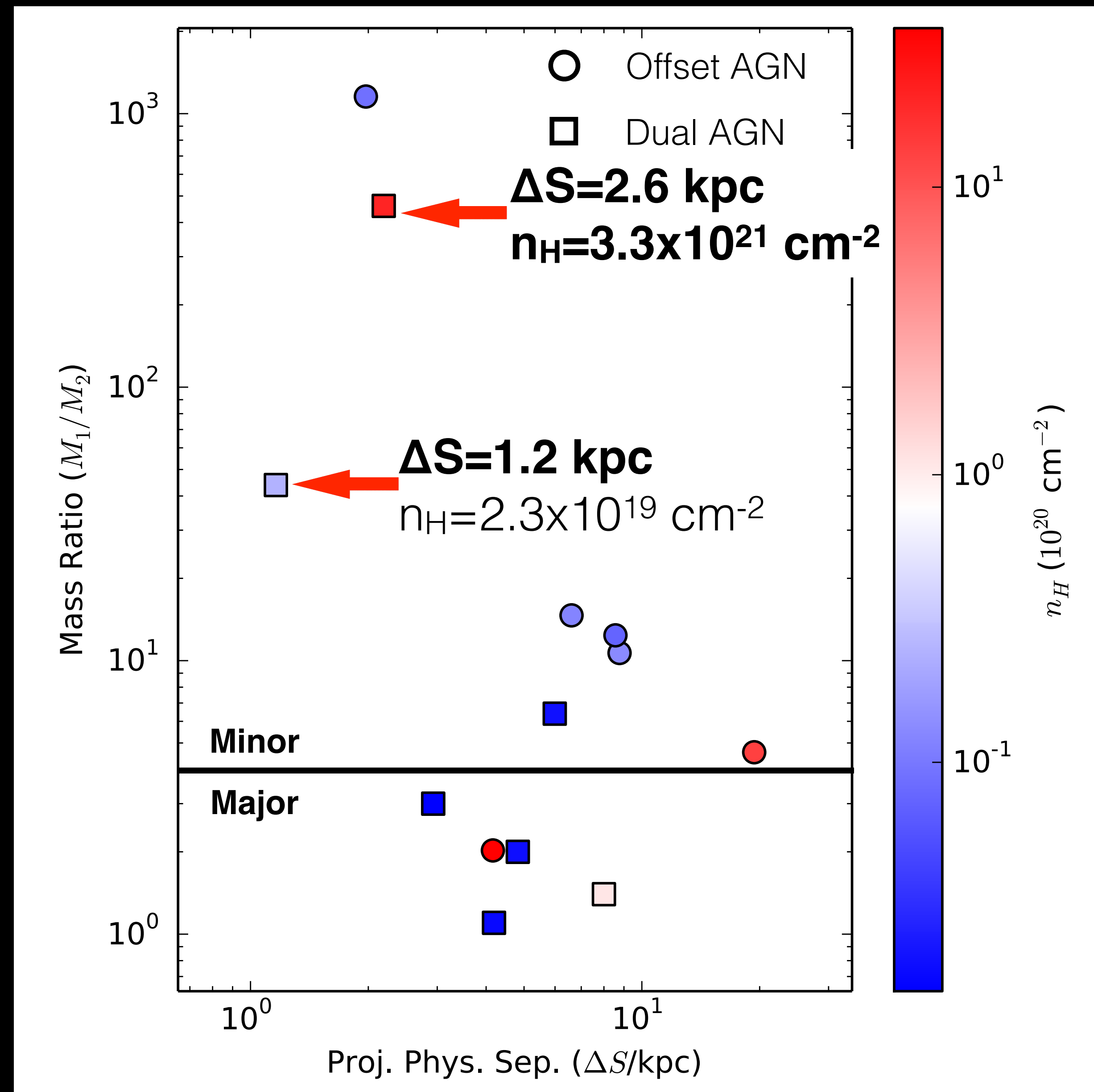
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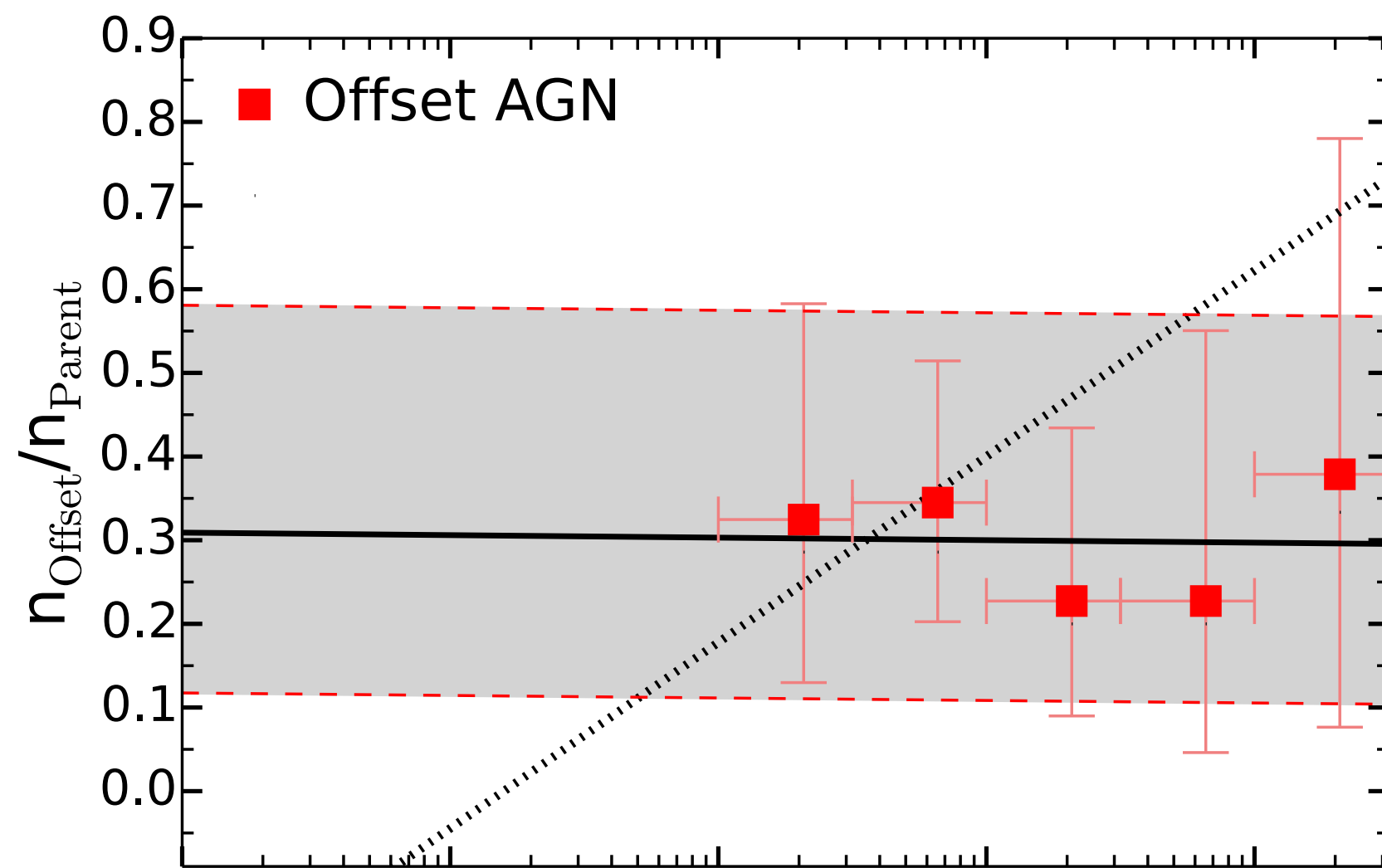
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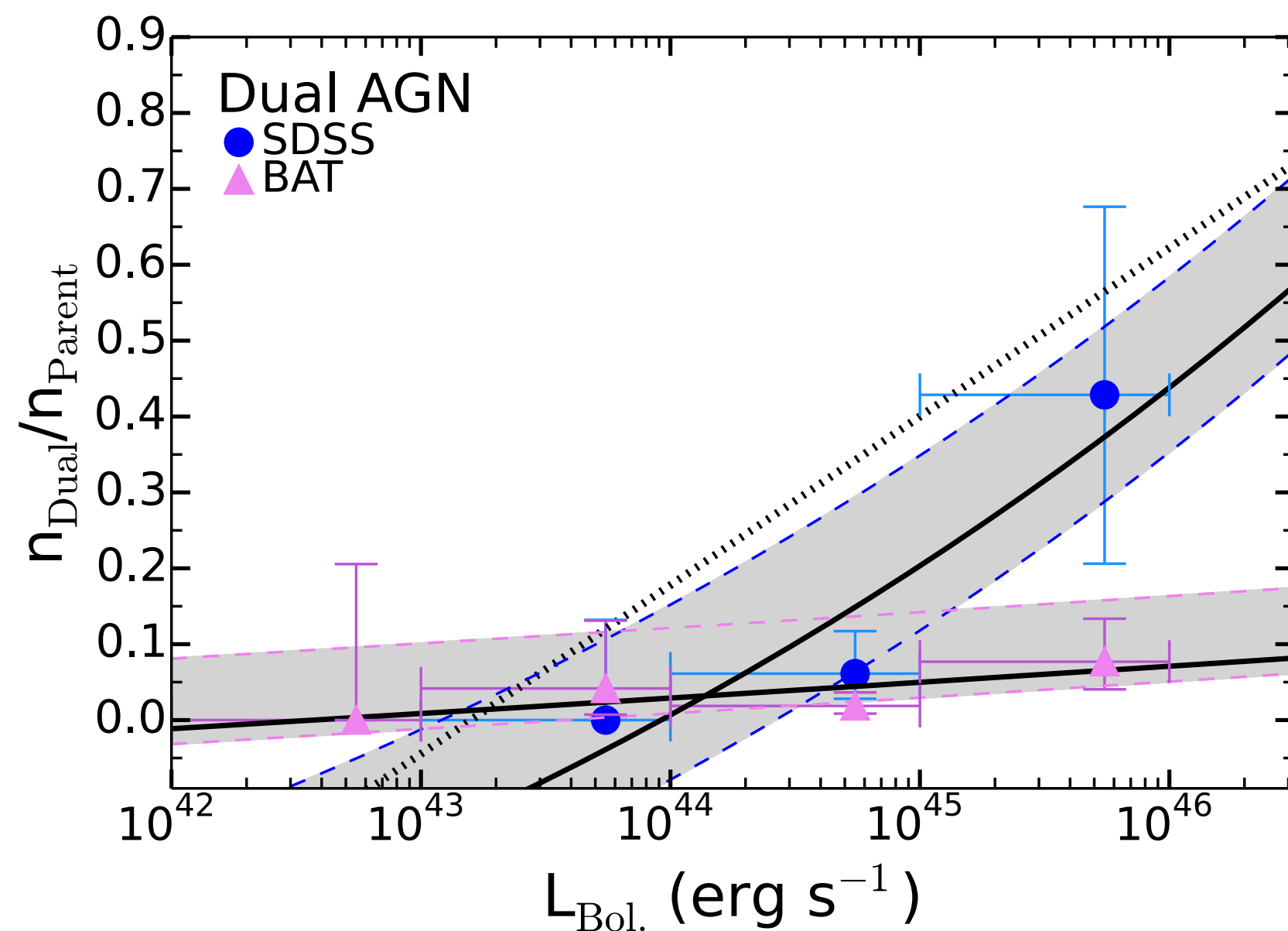
- Large supplies of gas and dust



AGN Merger Fraction Versus Nuclear Separation



Single AGN:
no correlation ($<1\sigma$)



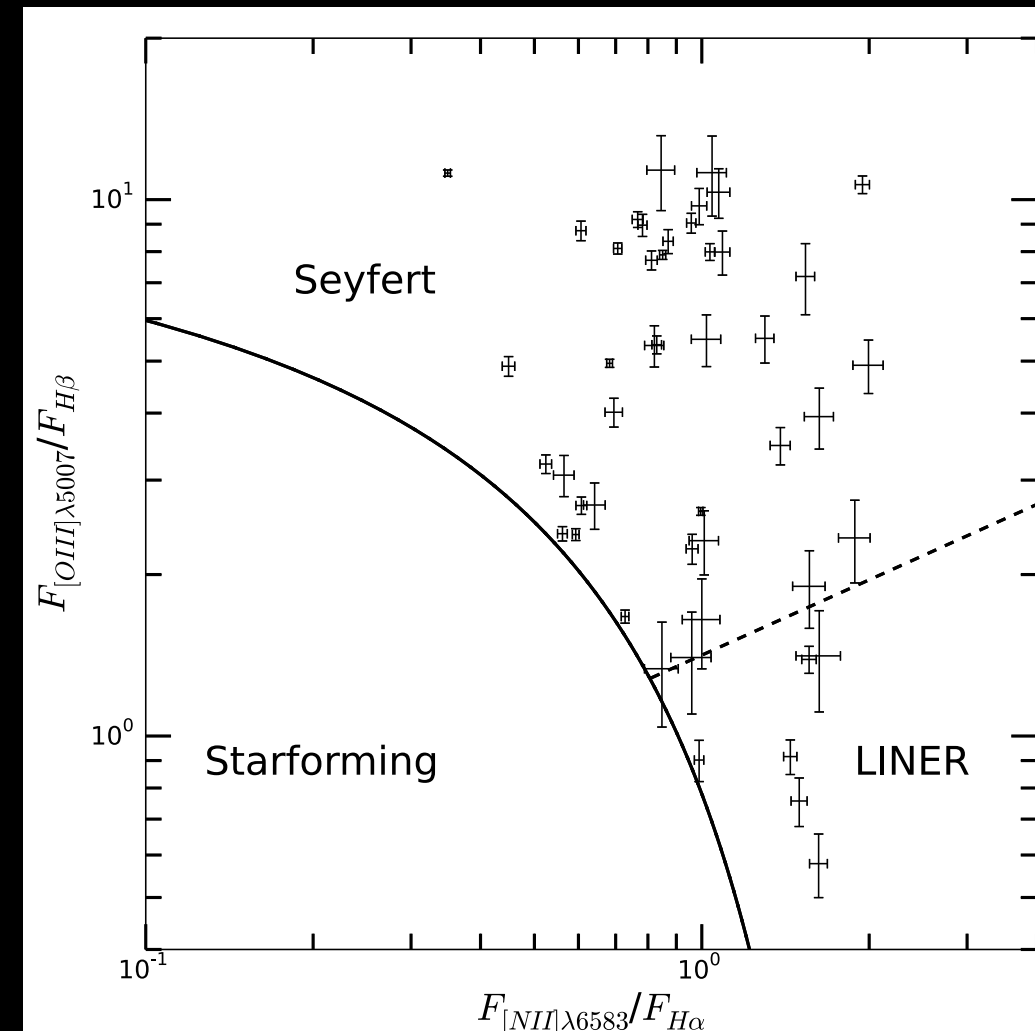
Dual AGN:
positive correlation ($\sim 3\sigma$)

Conditions that form dual AGN are different from those of offset AGN

Selection Effects

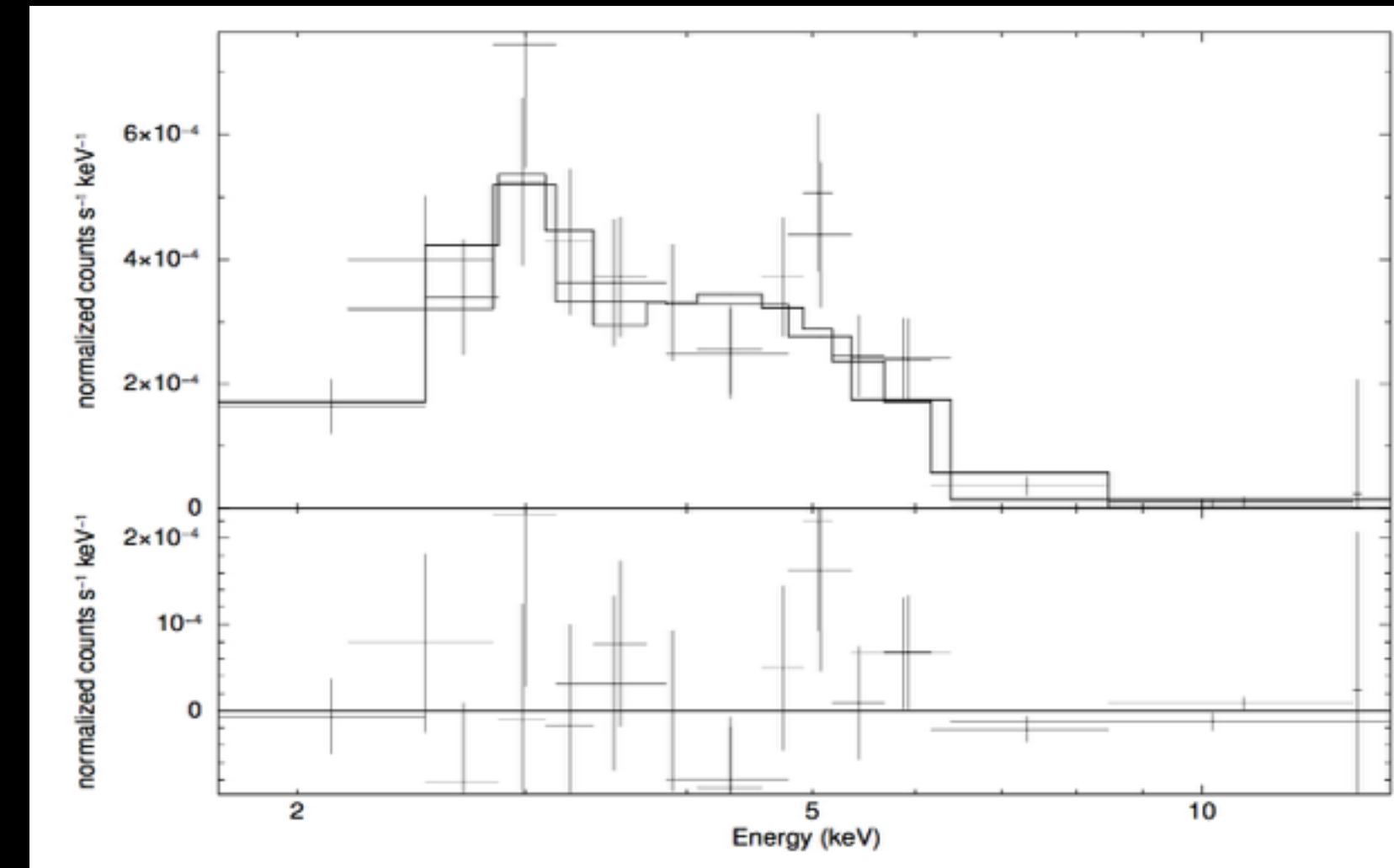
These AGN are all selected optically and detected in hard X-rays

Optical:



Barrows et al. 2016

X-ray:



Sensitive to relatively unobscured AGN

- X-ray selected dual AGN with small separations may be rare events
- Dual AGN may be more common if including more obscured systems (e.g. in ULIRGs)

Take-Away Points:

Offset AGN *and* dual AGN:

Observed frequency increases toward late merger stages

- Peaks at sub-kpc separations

Activity increases toward disturbed morphologies

- Suggests some information about the dynamics of late stage mergers is preserved

Take-Away Points:

Offset AGN V.S. Dual AGN:

Offset AGN morphologies similar to most mergers

- Majority reside in minor mergers

Dual AGN formed in special conditions:

(caveat: this applies to X-ray selected AGN)

Dual AGN show a preference for major mergers

Transition from offset AGN to dual AGN:

- toward late merger stages
- increased gas supplies