A New Signpost for Galaxy Mergers: Offset AGN in Galaxy Merger Remnants

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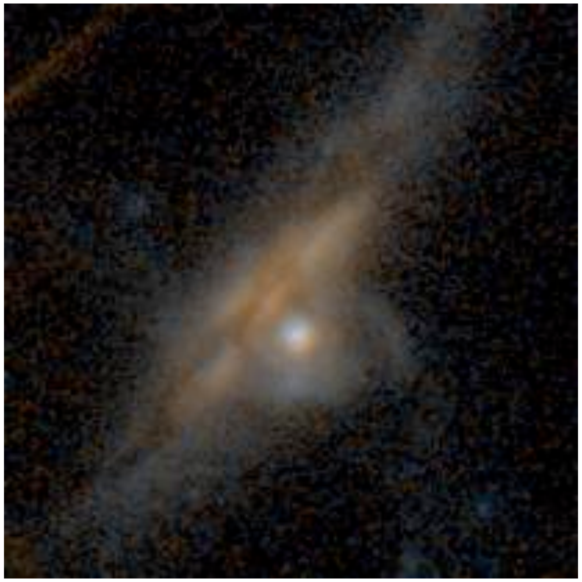
Difficulty of Measuring Merger Rates

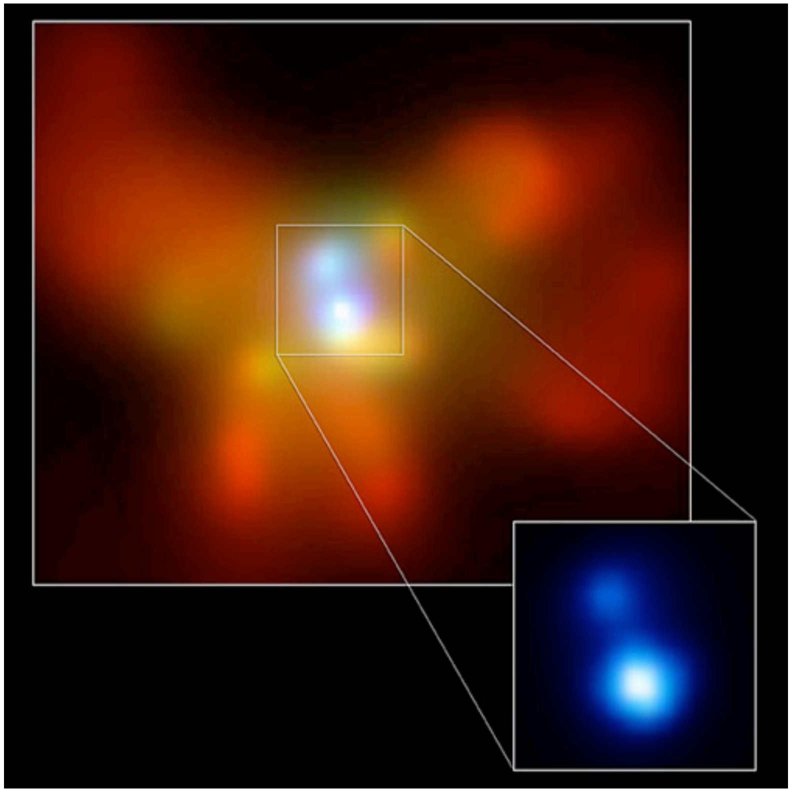
Galaxy merger rates measured via:

<u>Close dynamical pairs of galaxies</u>
May not be good proxies for mergers, simulations show (e.g., Berrier et al. 2006)



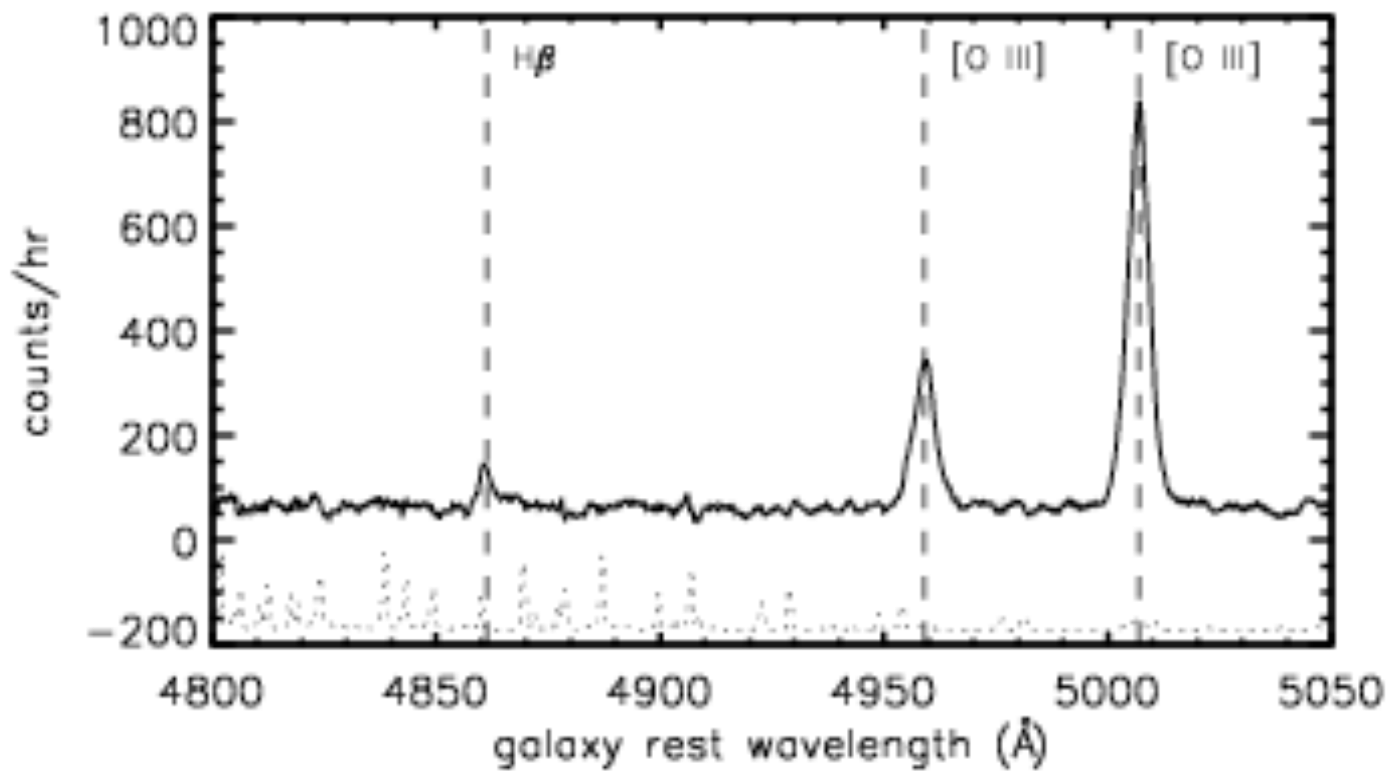
<u>Galaxy morphologies</u>
Percentage of galaxies are misclassified
(e.g., Lotz et al. 2008)

Merging Black Holes in Galaxies



Komossa et al. 2003

Typical AGN Spectrum



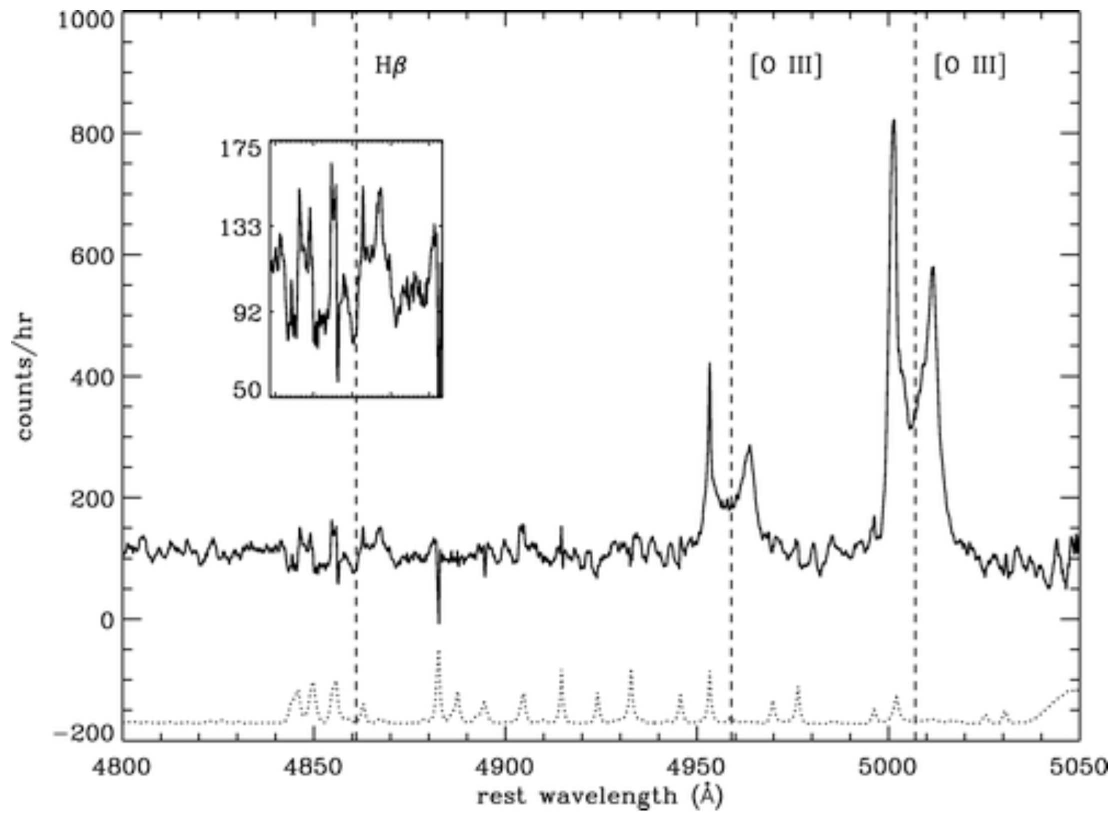
AGN is at rest with respect to the host galaxy

Dual AGN

Early-type galaxy at z = 0.709

Double-peaked [O III] emission lines separated by 630 km/s

Galaxy hosts a <u>dual AGN</u>: Two AGN moving within the host



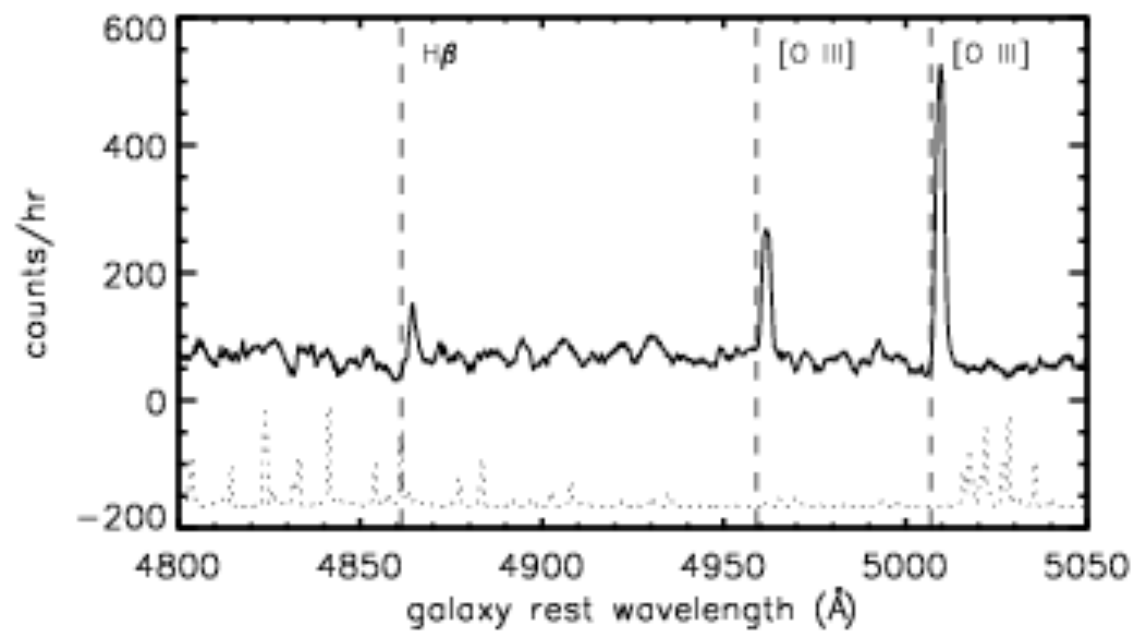
Gerke et al. 2007

Offset AGN

<u>Offset AGN</u>:
One set of AGN emission lines offset in velocity from the galaxy's stars

Implies that galaxy hosts an AGN and a quiescent SMBH

Early-type galaxy spectrum:



Systematic Search for Dual and Offset AGN in DEEP2

DEEP2 Galaxy Redshift Survey

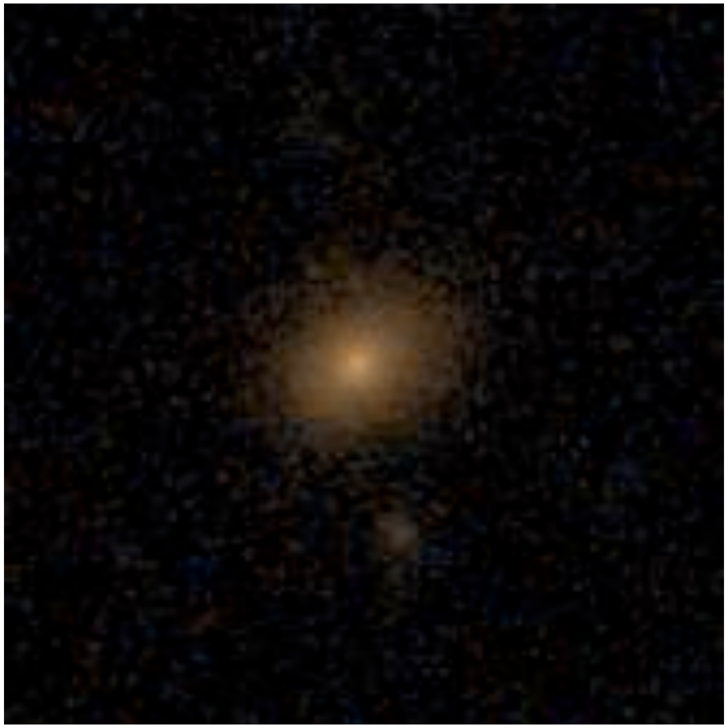
Spectra for 50,000 galaxies out to $z = 1.4$ with DEIMOS spectrograph on Keck II

DEIMOS

Select Early-type Galaxies

We want [O III] emission from an AGN, not from star formation, so we select only early-type galaxies

- Early-type galaxies based on color cut of Willmer et al. 2006
- Spectra where both [O III] and Hβ are covered; this limits the redshift range to $0.34 < z < 0.82$

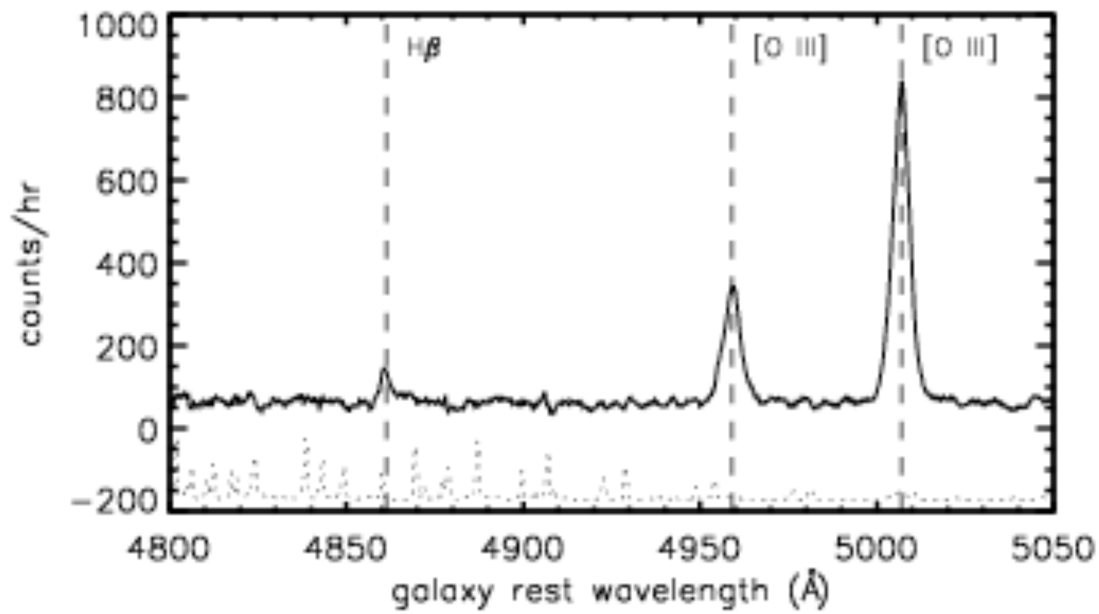


Result: 1881 early-type galaxies at $0.34 < z < 0.82$

Select Early-type Galaxies Hosting AGN

- Significant [O III] detection: at least 3σ
- $\lambda 5007/H\beta > 3$ to distinguish Seyferts from other emission-line galaxies (Kauffmann 2003; Yan et al. 2006)

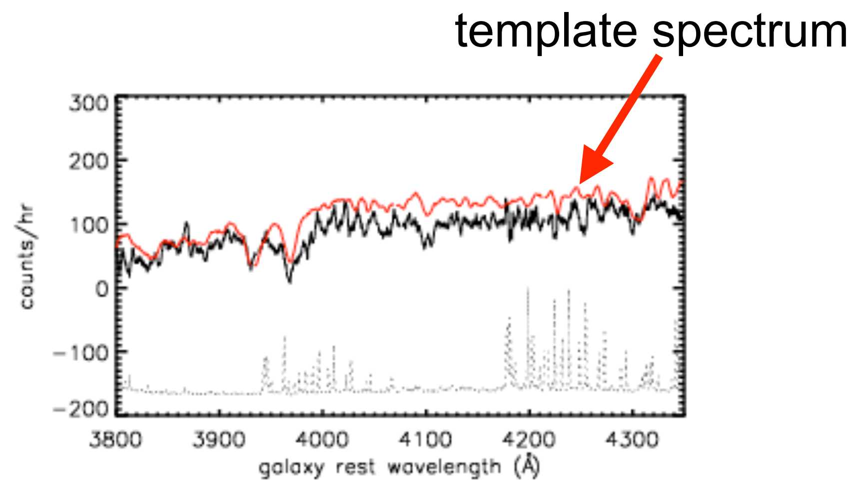
Result: 107 early-type galaxies hosting AGN at $0.34 < z < 0.82$

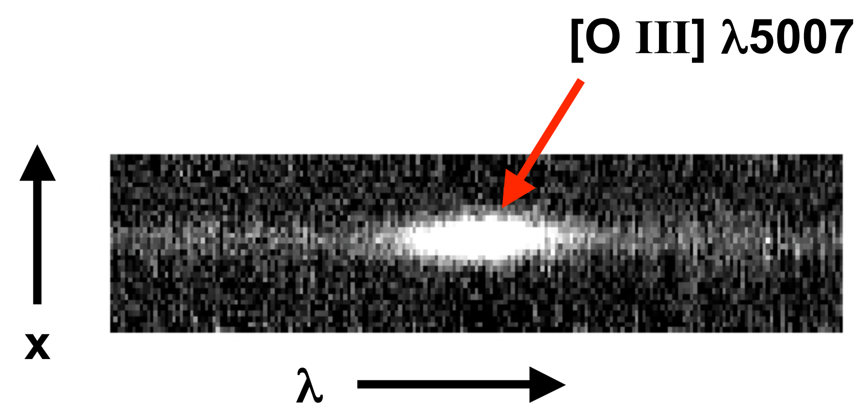


Offset and Dual AGN Found by a Discrepancy between Absorption and Emission Redshifts

Mask out emission lines and fit an early-type galaxy template spectrum
→ measure the absorption redshift

Fit Gaussian to a window around the peak of the [O III] emission line
→ measure the emission redshift



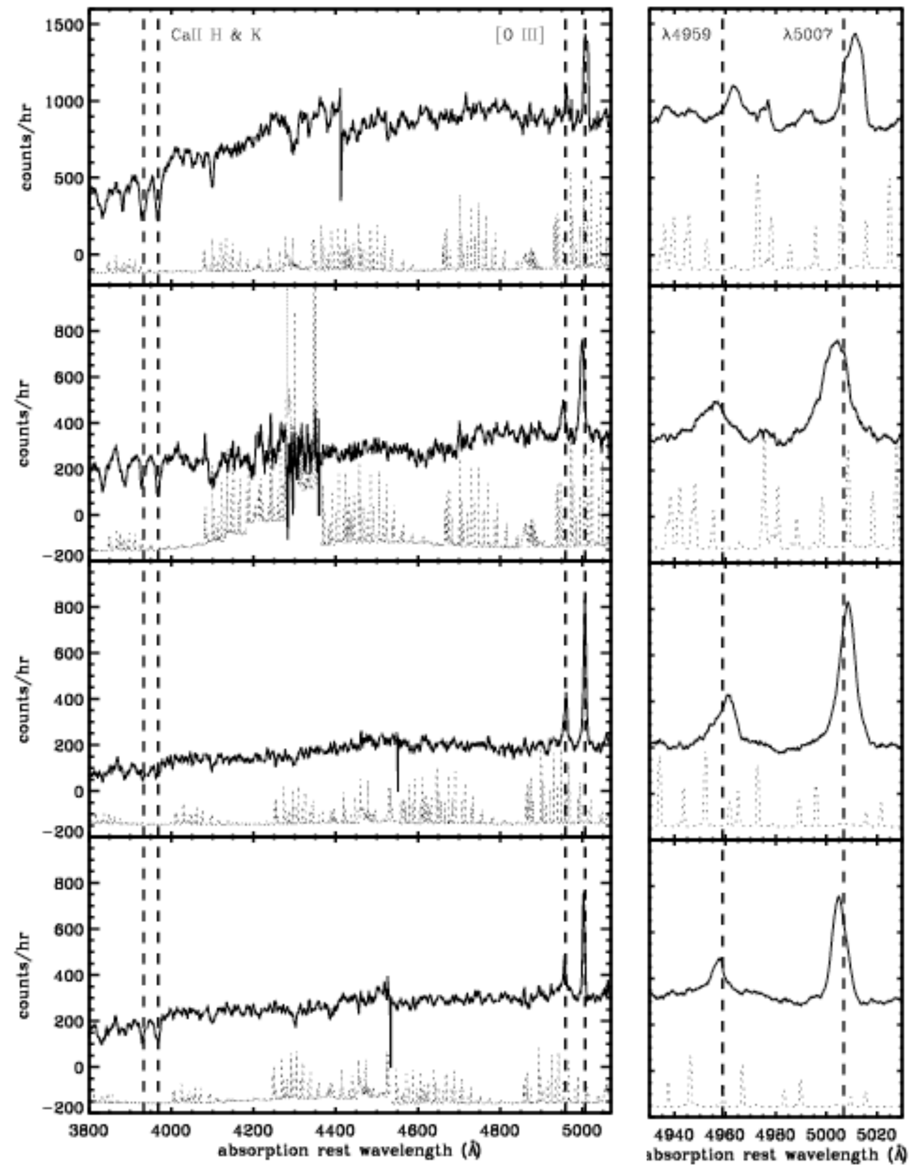


Redshift Discrepancies

Inconsistent absorption and emission redshifts show the [O III] emission component (AGN) is moving with respect to the absorption component (host galaxy)

Convert redshift difference to a velocity separation

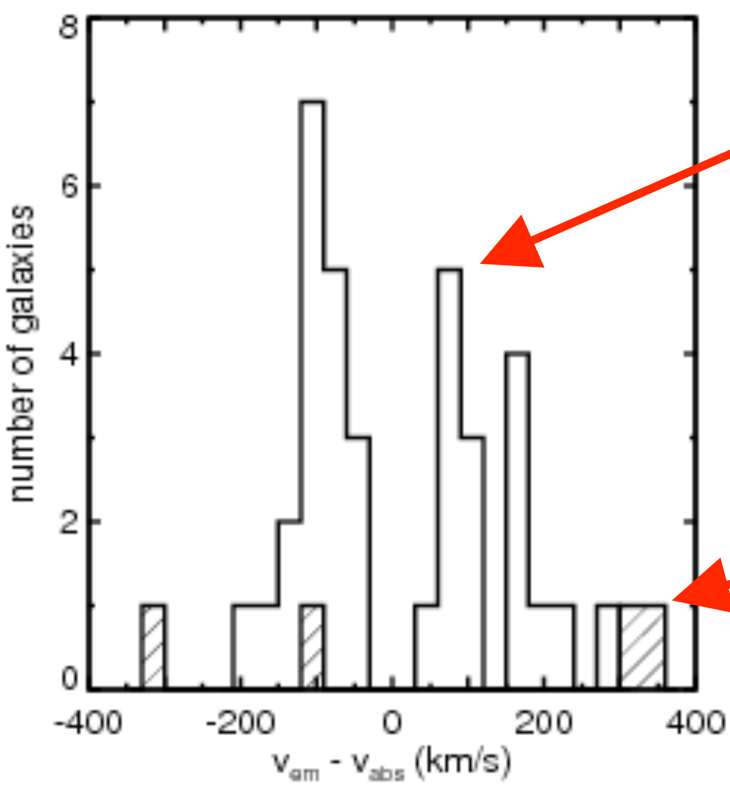
$\Delta z \rightarrow \Delta v$



Found 37 Dual or Offset AGN

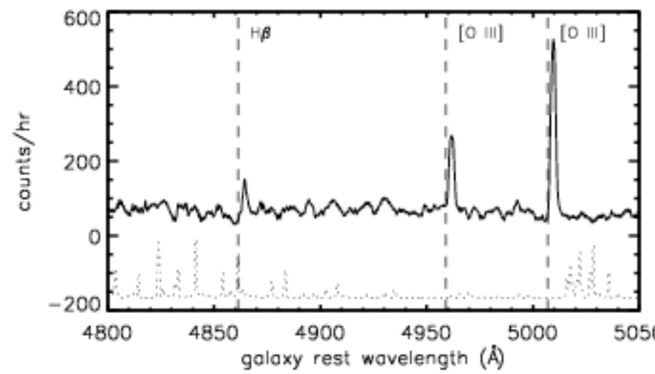
Eliminate objects with <3σ velocity difference

Leaves 2 dual AGN and 35 offset AGN

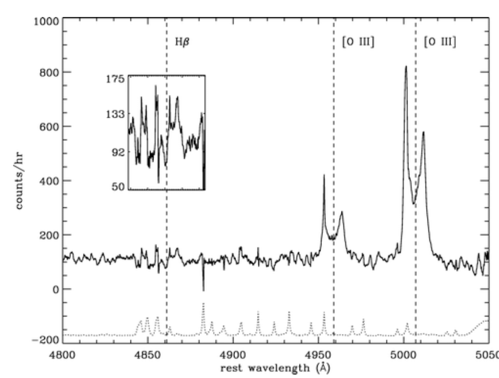


Comerford et al. 2008

Offset AGN:

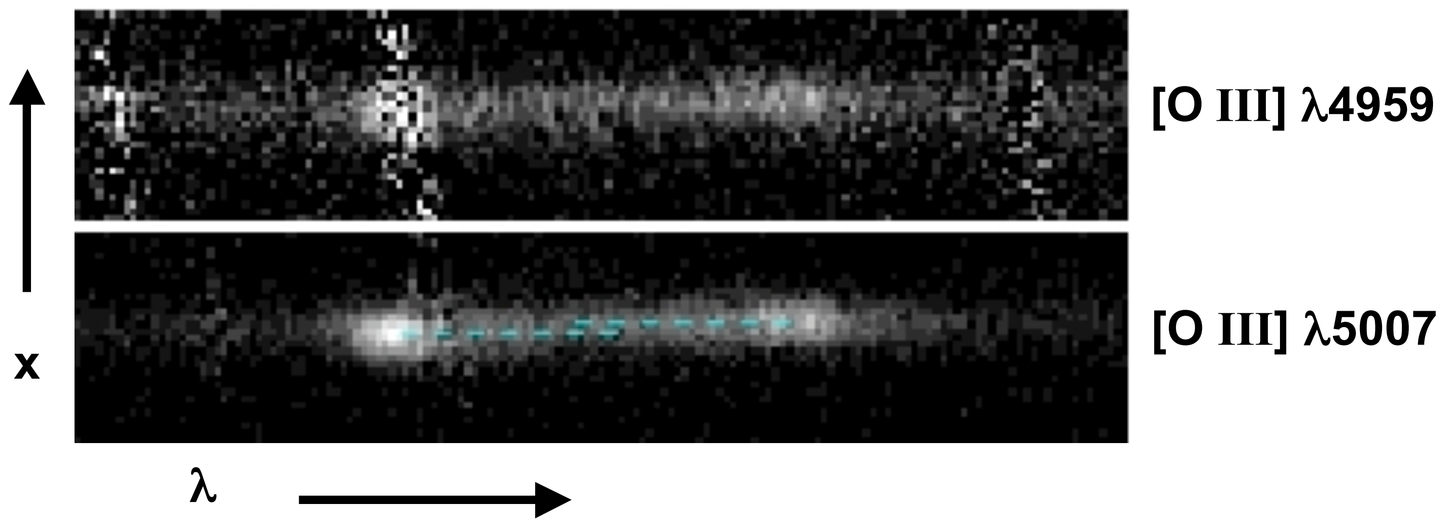


Dual AGN:

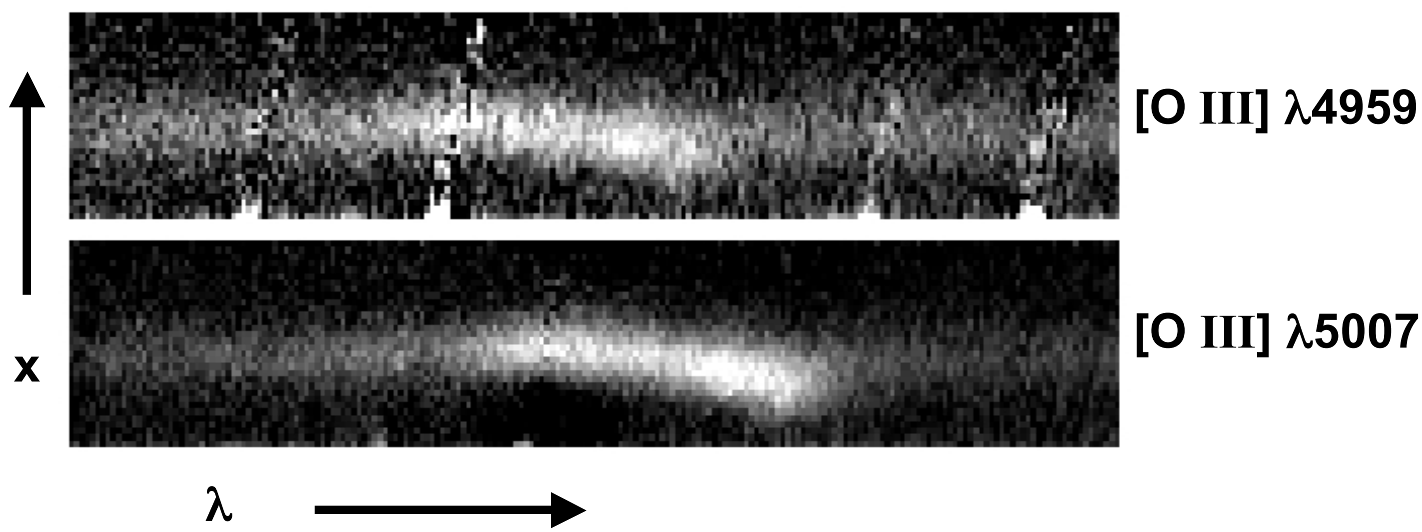


2 Dual AGN

z = 0.709
Δv = 630 km/s
Δr = 1.2 kpc

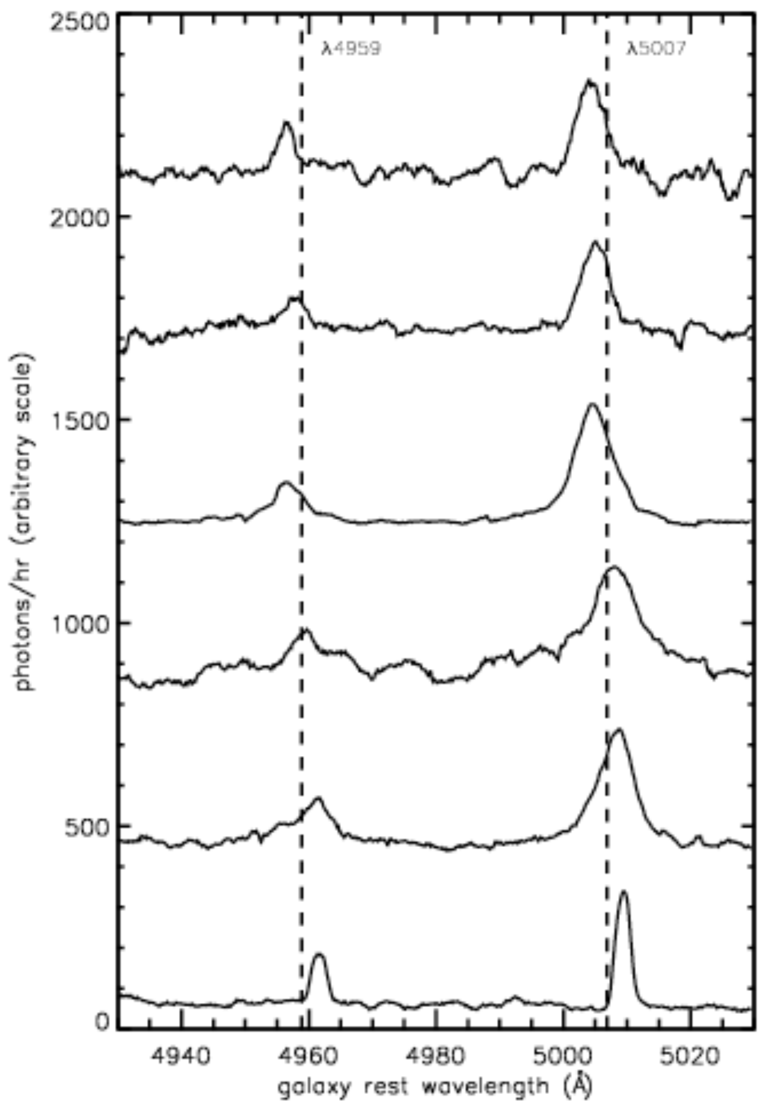


z = 0.619
Δv = 430 km/s
Δr = 2.3 kpc



35 Offset AGN

$\Delta v = v_{em} - v_{abs}$



Δv = -146 km/s

Δv = -115 km/s

Δv = -94 km/s

Δv = 90 km/s

Δv = 110 km/s

Δv = 170 km/s

Comerford et al. 2008

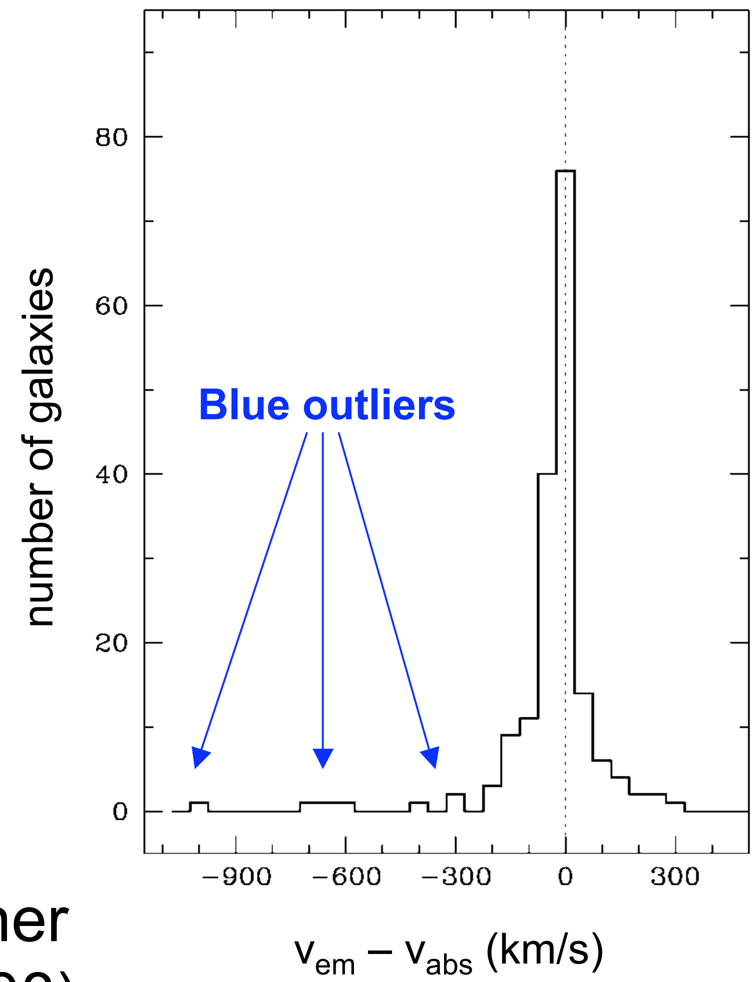
What Causes AGN Velocity Offsets?

Zamanov et al. (2002) measure [O III] λ5007 velocity offsets for ~200 AGN at z < 0.8

Factor of 3 more blueshifts than redshifts in 100 km/s < |Δv| < 200 km/s

Blue outliers but no red outliers

Offsets caused by:
• Outflows in inner NLR of AGN (Zamanov et al. 2002)
• Strong, decelerating wind in inner NLR of AGN (Komossa et al. 2008)

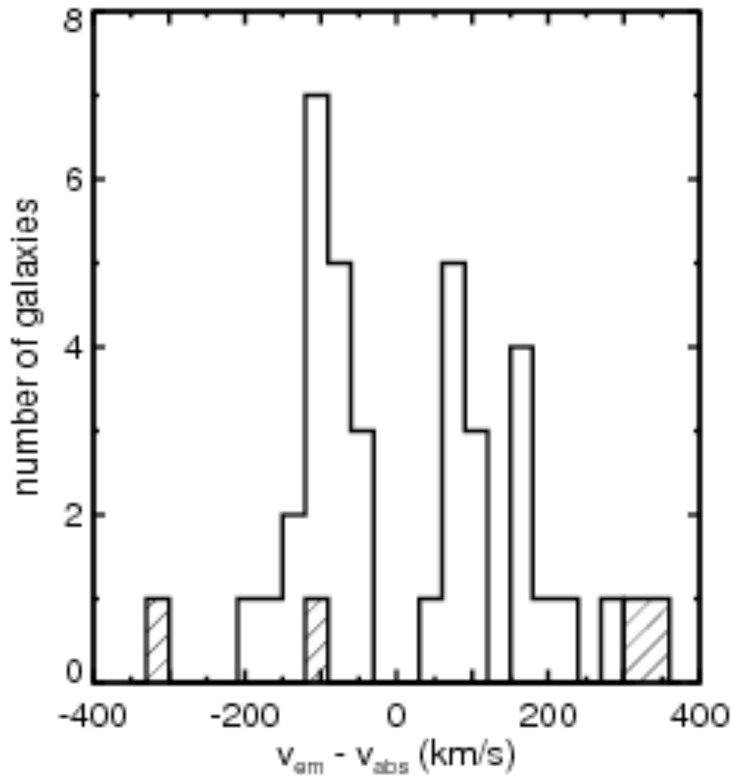


Our Distribution of Offset AGN

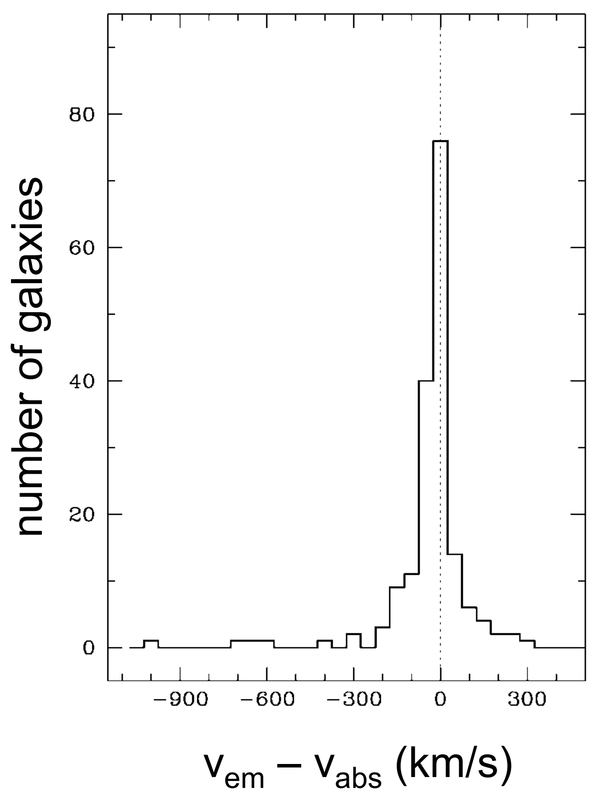
~Same number of blueshifts as redshifts

Blueshifts and redshifts have similar Δv range

Physical explanation for offsets in our sample is likely different



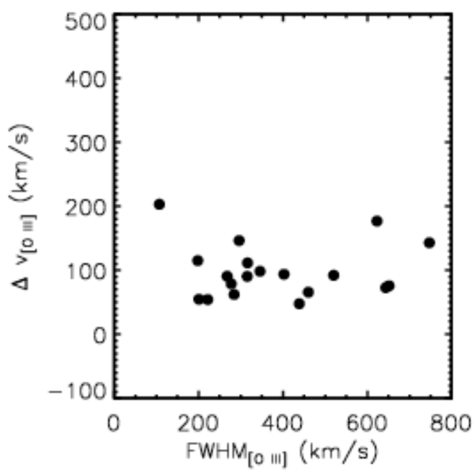
Comerford et al. 2008



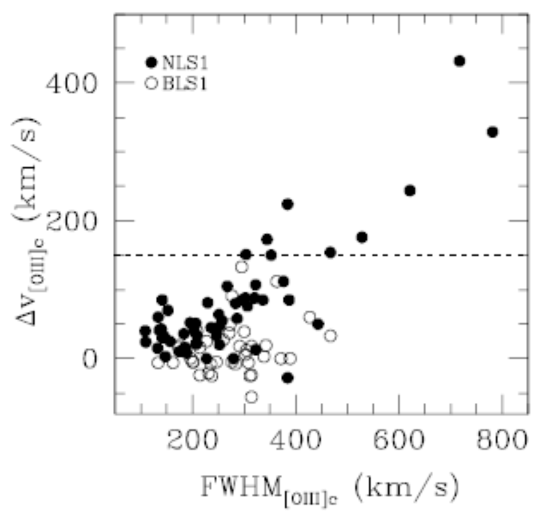
Zamanov et al. 2002

Outflows Cannot Explain Our Offsets

Outflows are believed to cause a strong correlation of increasing [O III] line width with [O III] blueshift, as seen in Komossa's sample but not ours



Correlation coefficient = 0.009



Komossa et al. 2008

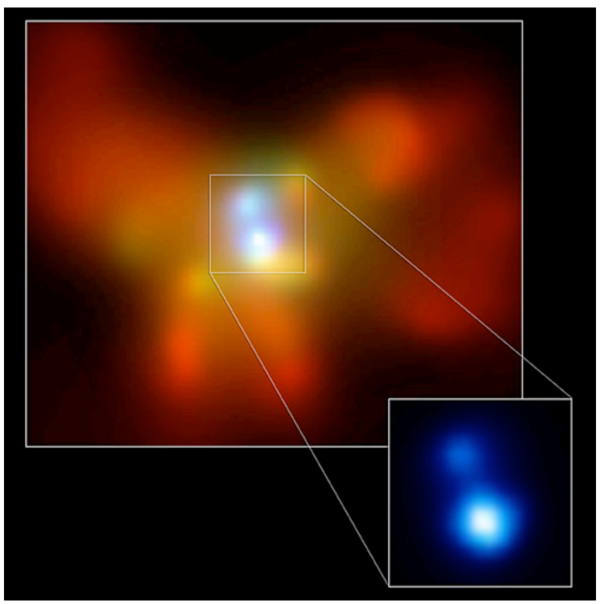
High-ionization outflows would shift [O III] emission lines but not low-ionization lines such as [O II] and Hβ, as seen in Komossa's sample but not ours

Galaxies Hosting Dual SMBHs

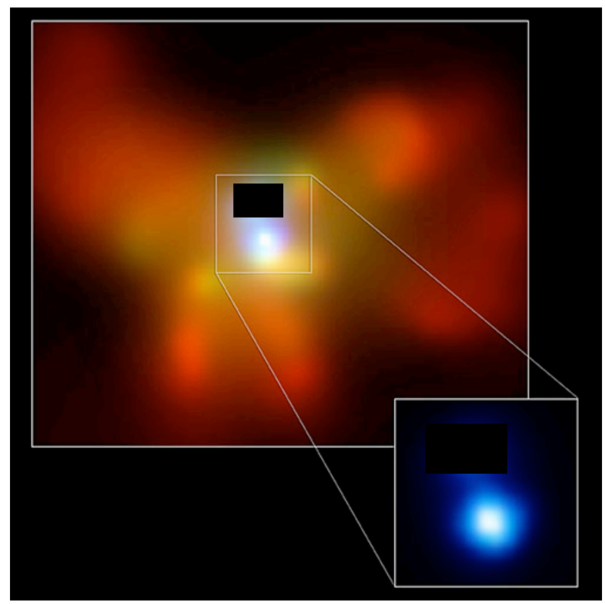
Most plausible explanation for offset [O III] lines in our sample: AGN moving within the host galaxy

Our sample consists of merger remnant galaxies hosting dual SMBHs, where one or both are powering AGN

Dual AGN:



Offset AGN:

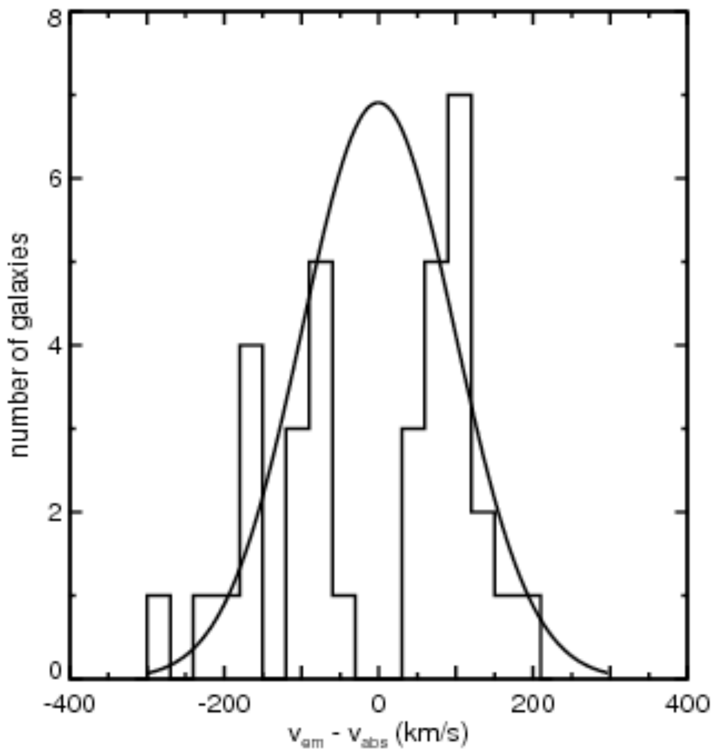


Komossa et al. 2003

Half of AGN Hosts Are Merger Remnants

After adding an interpolated number of low velocity separation objects, we expect there to be 49-59 offset or dual AGN in our sample

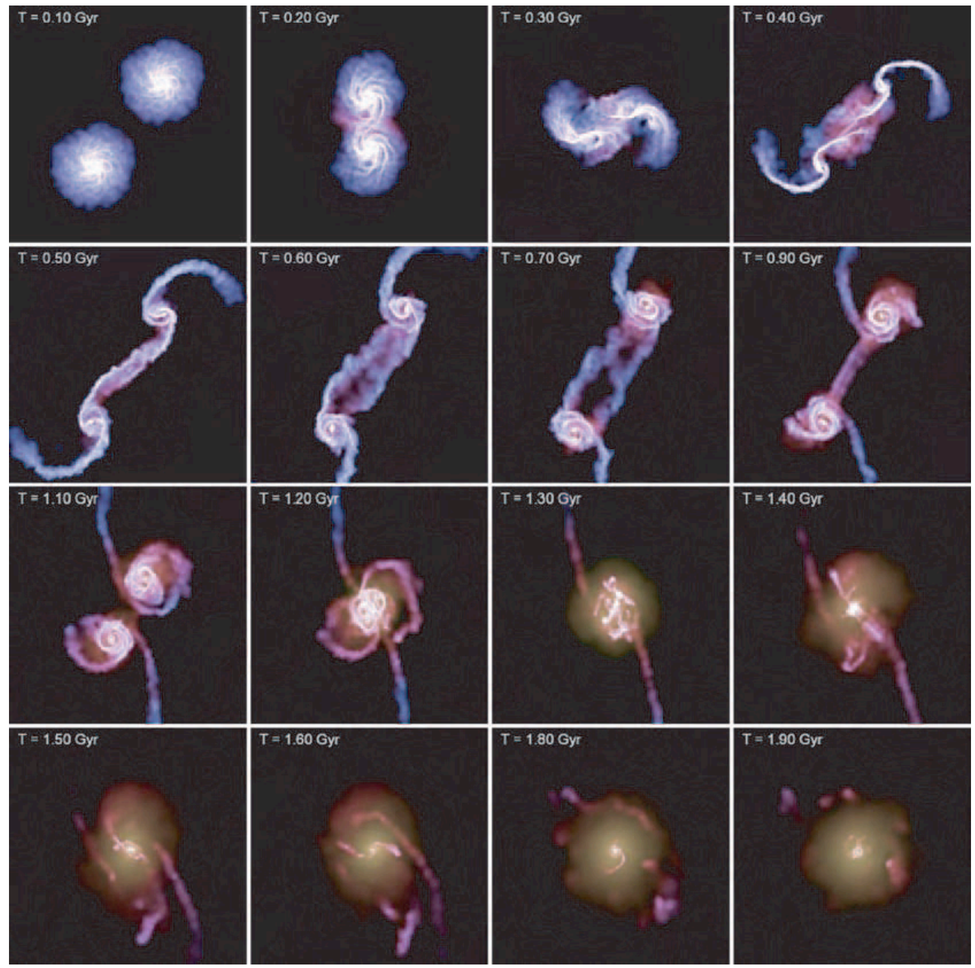
Of the 107 early-type galaxies hosting AGN, roughly half are moving within the host galaxy due to a recent merger



We Find a Strong Link between AGN Activity and Galaxy Mergers

That half of early-type galaxies hosting AGN are also merger remnants signals a strong connection between AGN and mergers

Mergers between late-type galaxies can trigger nuclear gas inflows that power AGN -- may also be true for early-type galaxies



Springel et al. 2005

Galaxy Merger Rate

Number of dual and offset AGN we find suggests a lower limit that > 2% of early-type galaxies $0.34 < z < 0.82$ are undergoing mergers

We find luminous fraction f_{lum} = 2/37 = 5% of SMBHs are fueling AGN

Convert our 49 – 59 expected dual or offset AGN to a merger rate of

5.4 – 6.6 mergers/Gyr (100 Myr / $t_{combine}$) (5% / f_{lum})

for early-type galaxies $0.34 < z < 0.82$

Conclusions

- We find 2 dual AGN and 35 offset AGN in DEEP2 early-type galaxies
- Half of early-type galaxies hosting AGN are also merger remnants, signaling a strong link between AGN activity and galaxy mergers
- Merger rate ~6 mergers/Gyr for early-type galaxies 0.34 < z < 0.82
- A powerful new way of identifying galaxy mergers