Imaging and Spectroscopy of Active Galactic Nuclei with Double-Peaked Emission Lines:

Searching for Dual AGN

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Outline

- Why do we expect to see dual AGN?
- At what separations have AGN pairs been found already?
- Our Data and Analysis
  - Sample selection
  - NIRC2 images
  - OSIRIS spectra
- Conclusions

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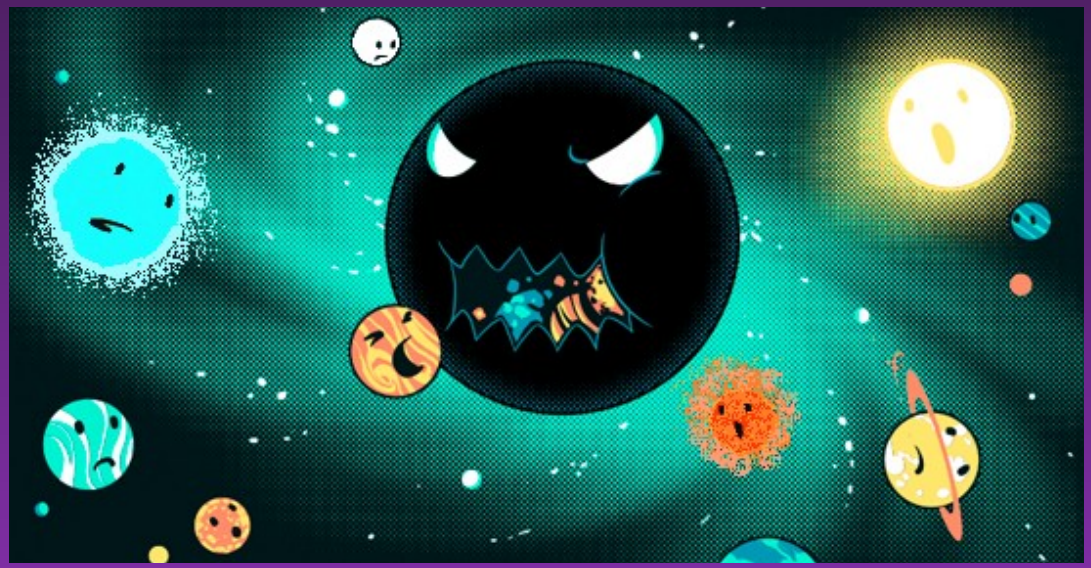
Most Massive Galaxies Harbor Supermassive Black Holes

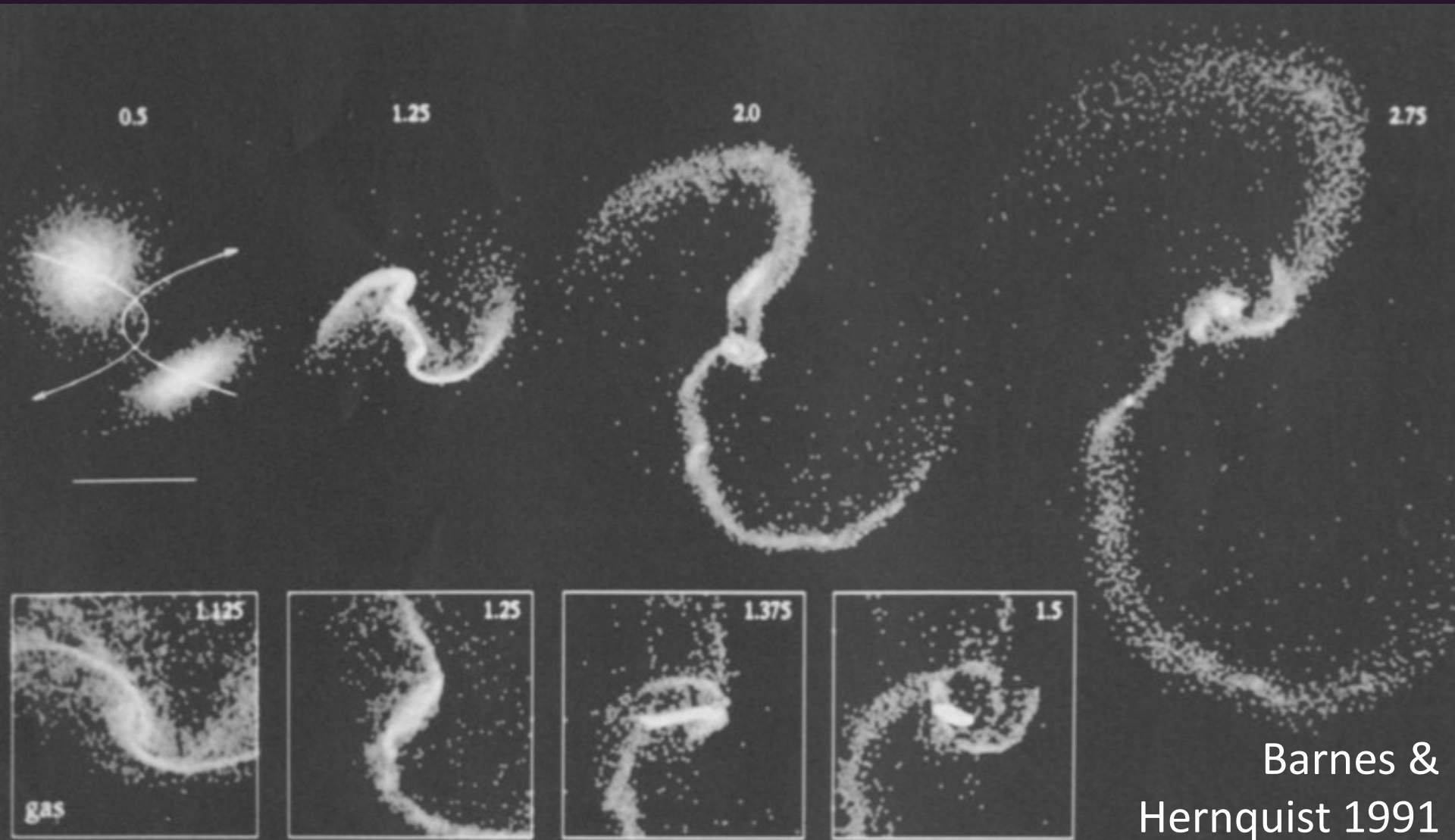
– Richstone et al. 1998
– Kormendy & Richstone 1995

Sometimes not actively accreting

Sometimes actively accreting = Active Galactic Nuclei (AGN)



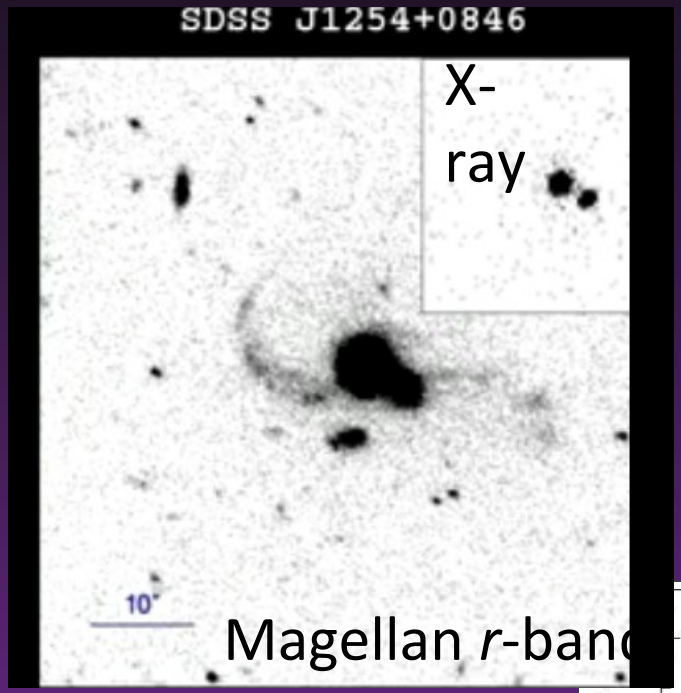
Mergers Cause Gas to Flow to Galaxy Centers, Trigger BH Accretion

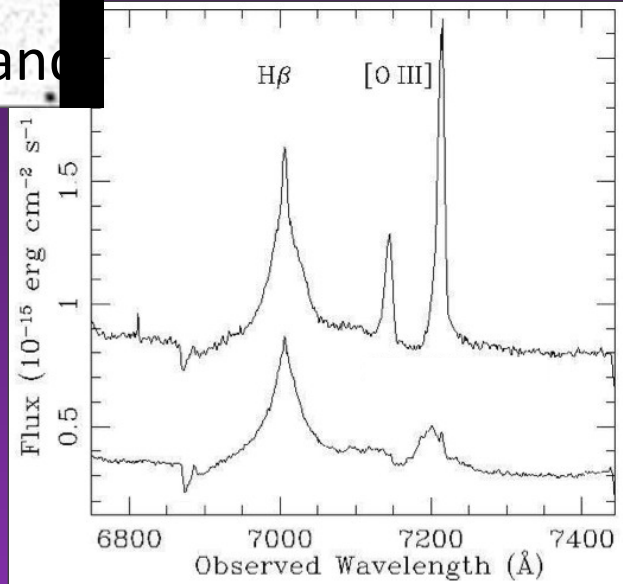


Barnes & Hernquist 1991

AGN pairs from galaxy mergers should be observable

- Example of a double AGN discovered by Green et al. 2010
  - Separation = 21 kpc





Dimmer galaxy

Brighter galaxy

Why are dual AGN important?

- the existence and statistics of dual AGN provide a probe into:
  - hierarchical galaxy formation models
  - accretion-triggering mechanisms
  - galaxy merger rates
  - AGN duty cycles

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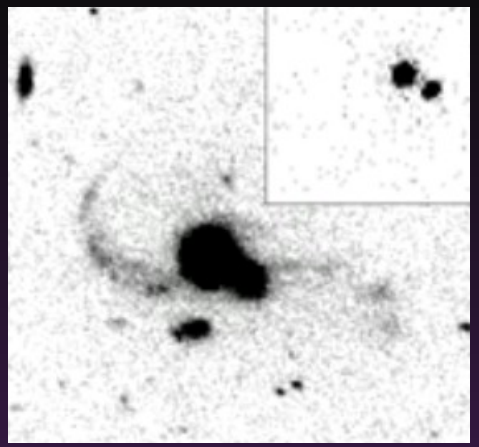
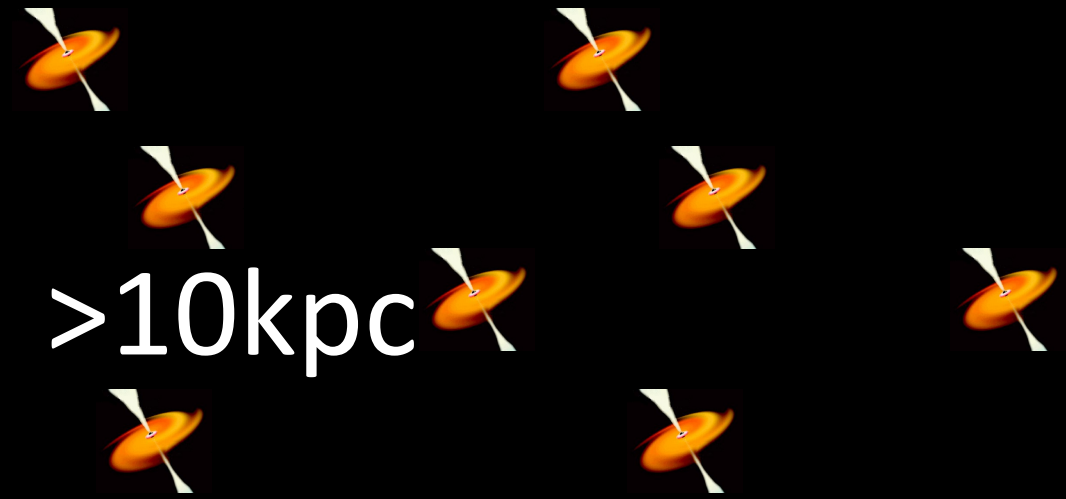
Most Observed AGN Pairs Have Separations > 10 kpc



Paper	Number of AGN Pairs	Separations (kpc)	Z
Myers et al. 2007	72	12 < R < 49	0.5-2
Myers et al. 2008	11	23.7 < R < 30	1.7-2
Hennawi et al. 2010	24	10 < R < 650	3-4.3
Green et al. 2010	1	21	0.44

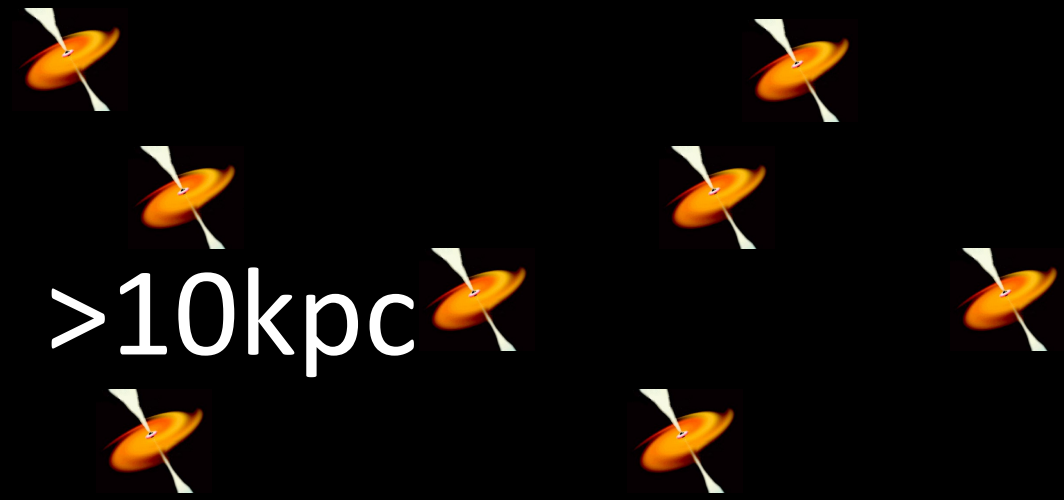
Green et al. 2010



At what separations are AGN pairs found?

Not Many Candidate AGN Pairs Have Separations < 0.01 kpc

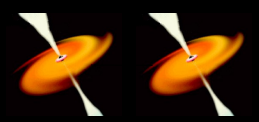
Paper	Number of AGN Pairs	Separations (kpc)	Z
Rodriquez et al. 2006	1	0.0073	0.06
Boroson & Lauer 2009	1	0.0001	0.39
Decarli et al. 2010	1	0.00006	0.42



>10kpc

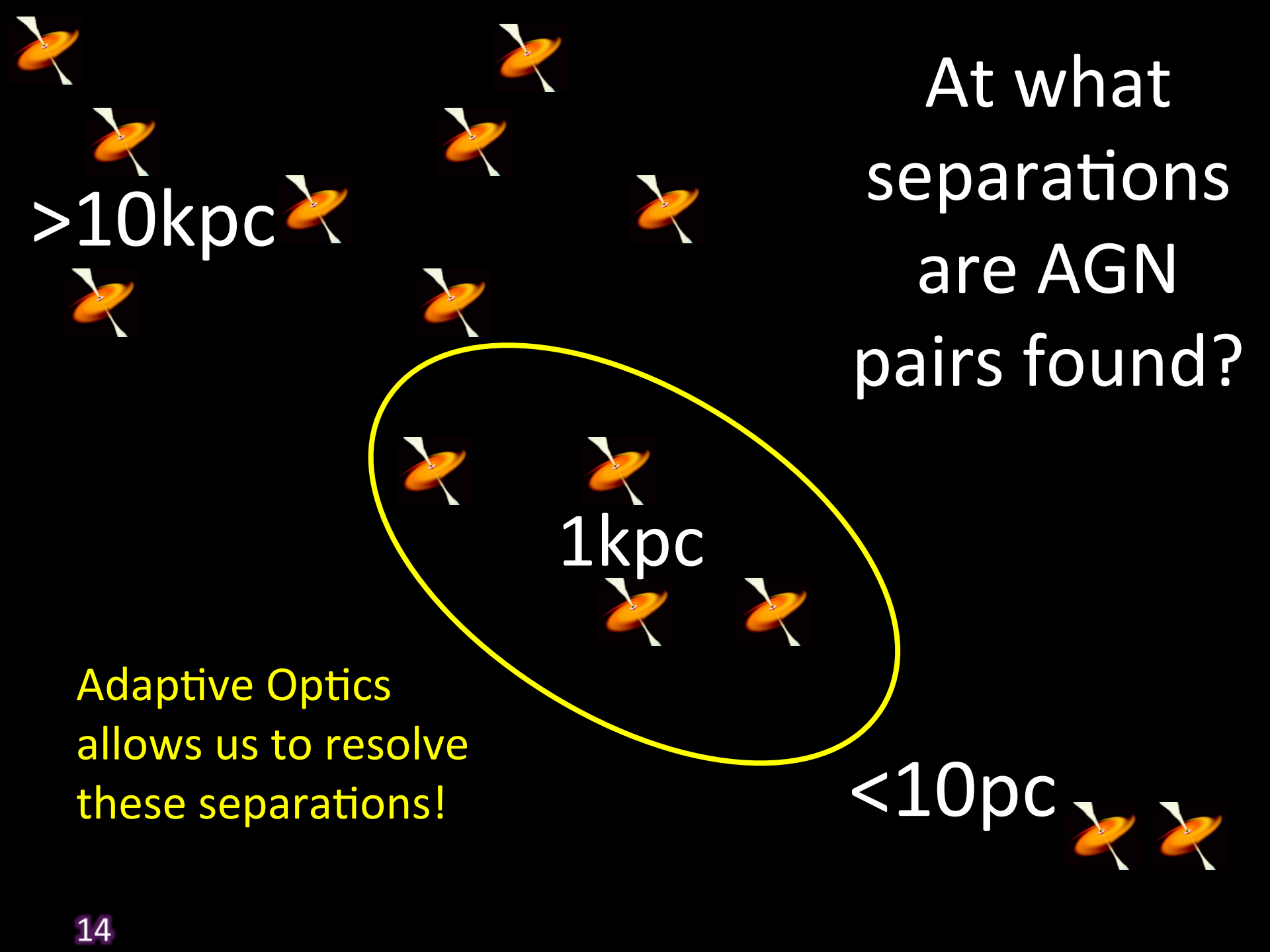
At what separations are AGN pairs found?

<10pc



0.1 kpc < Separations < 10 kpc Confirmed AGN Pairs

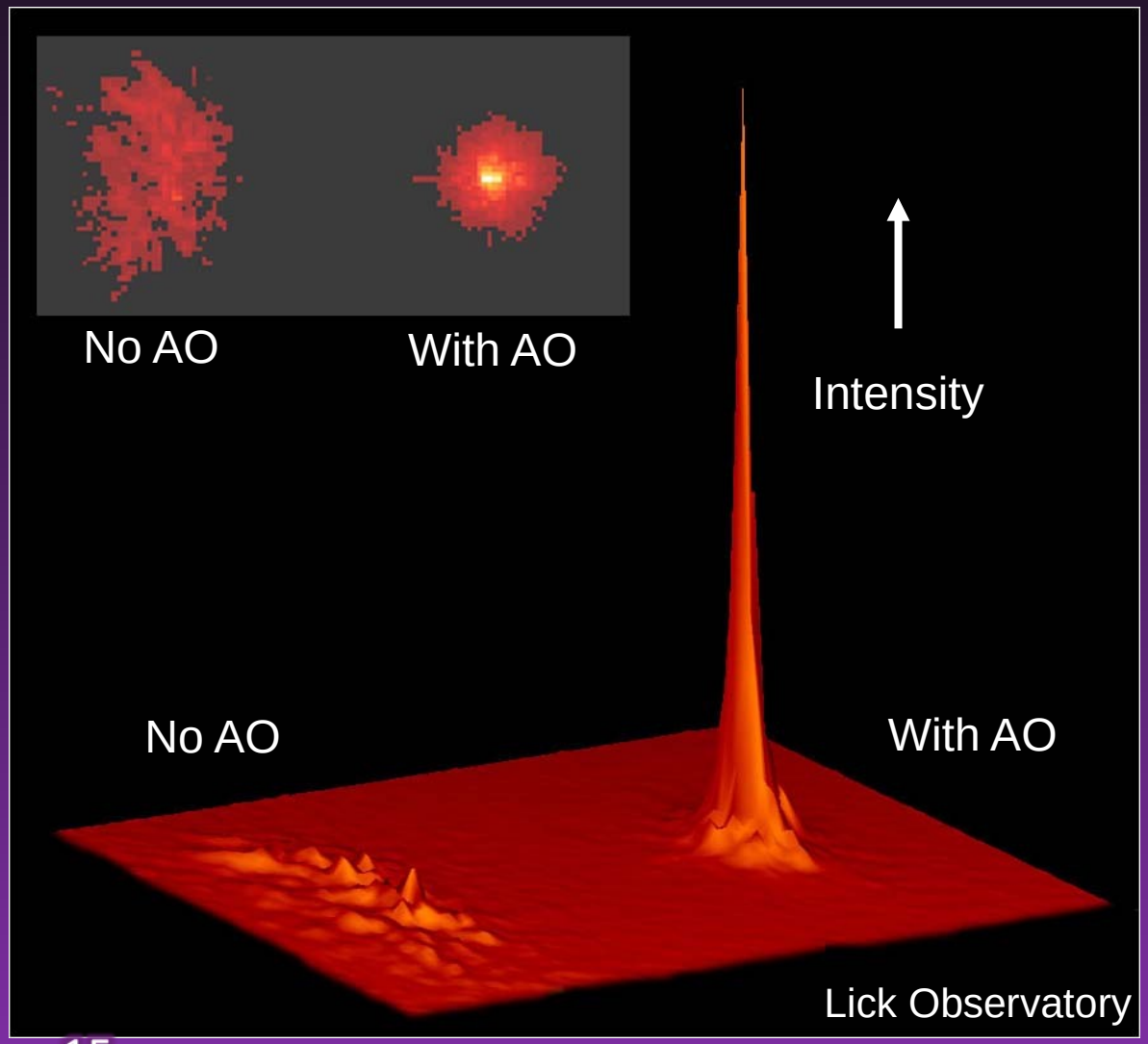
Paper	Number of AGN Pairs	Separations (kpc)	Z
Junkkarinen et al. 2001	1	2.3	0.85
Komossa et al. 2003	1	0.75	0.02
Ballo et al. 2004	1	4.6	0.01
Gerke et al. 2007	1	1.2	0.71
Bianchi et al. 2008	1	3.8	0.05
Liu et al. 2010	4	1.5 < R < 6.3	0.07
Koss et al. 2011	1	3.4	<0.2



At what separations are AGN pairs found?

Adaptive Optics allows us to resolve these separations!

Why is Adaptive Optics (AO) needed?



- Adaptive Optics
  - Increases peak intensity
  - Creates tight cores

Needed to resolve dual AGN at 0.1 < z < 0.6 with 1 kpc separations

0.1 kpc < Separations < 15 kpc

Candidate AGN Pairs

Paper	Number of AGN Pairs	Separations (kpc)	Z
Fu et al. 2011b	31	0.5 < R < 18	<0.6
Rosario, **McGurk** et al. 2011	6	3.5 < R < 12	<0.6

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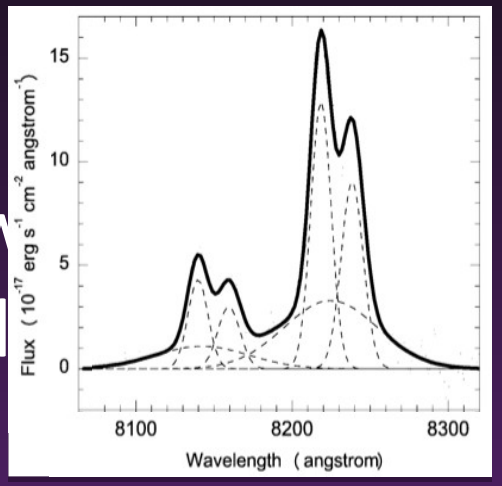
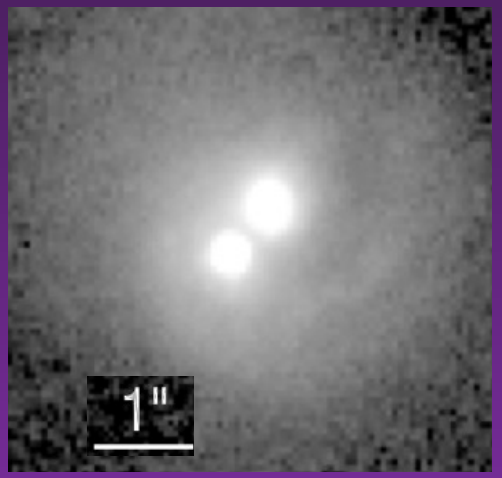
Two Ways to Select Potential AGN Pairs

Potential AGN Pairs

bserving velocity offsets between tw
emission lines (e.g. [O III]), potential
from two AGN



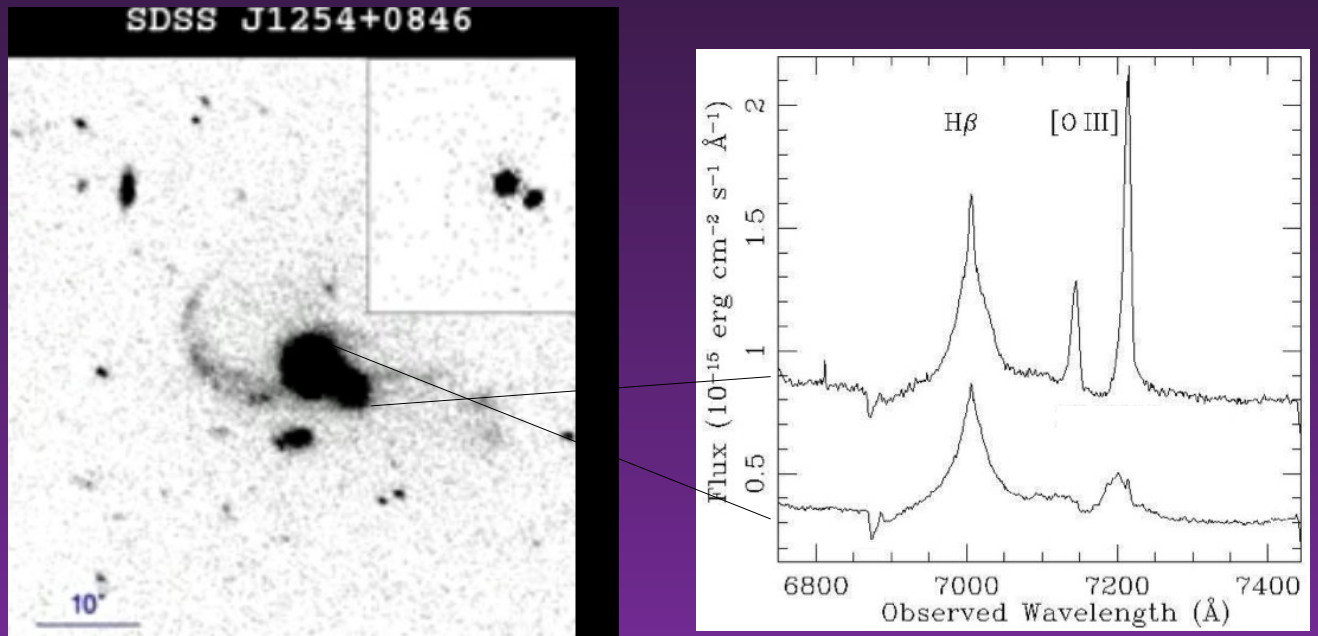
maging of multiple AGN in a single
host galaxy



Top: Zhou et al. 2004
Bottom: Comerford et al.

To Confirm a Dual AGN…

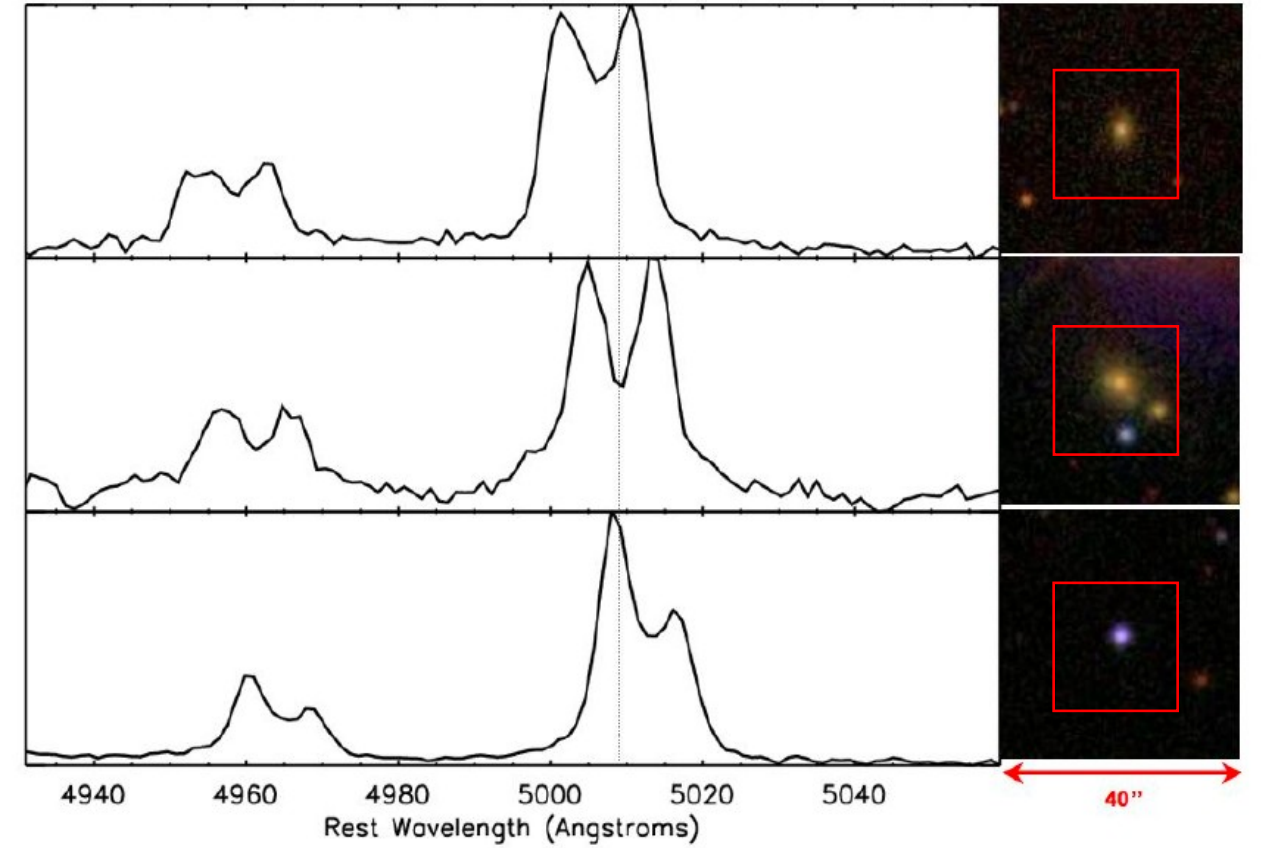
- Each spatially resolved component must have a unique AGN spectrum



Green et al. 2010

We chose our sample spectroscopically from Smith et al.

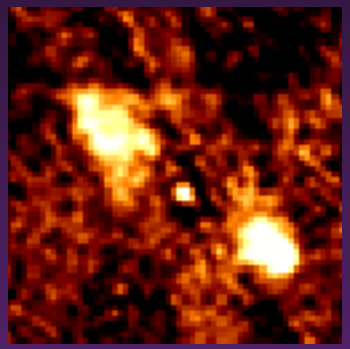
- SDSS spectra
- Primary criteria:
  - double in both [O III] λ5007 and λ4959
  - consistent with 3:1 intensity ratio



Smith et al. 2010

We require our targets to be Type 1 and Radio-Quiet to avoid Jet Interactions

- FIRST radio survey detects radio flux for:
  - 9% of overall SDSS quasar catalogue
  - 27% of Smith et al. objects



- Radio-loud quasars are 3x more likely to be double-peaked than radio-quiet quasars
  - Suggests jet interactions produce some double structure (as discussed in Rosario et al. 2009)

Smith et al. 2010

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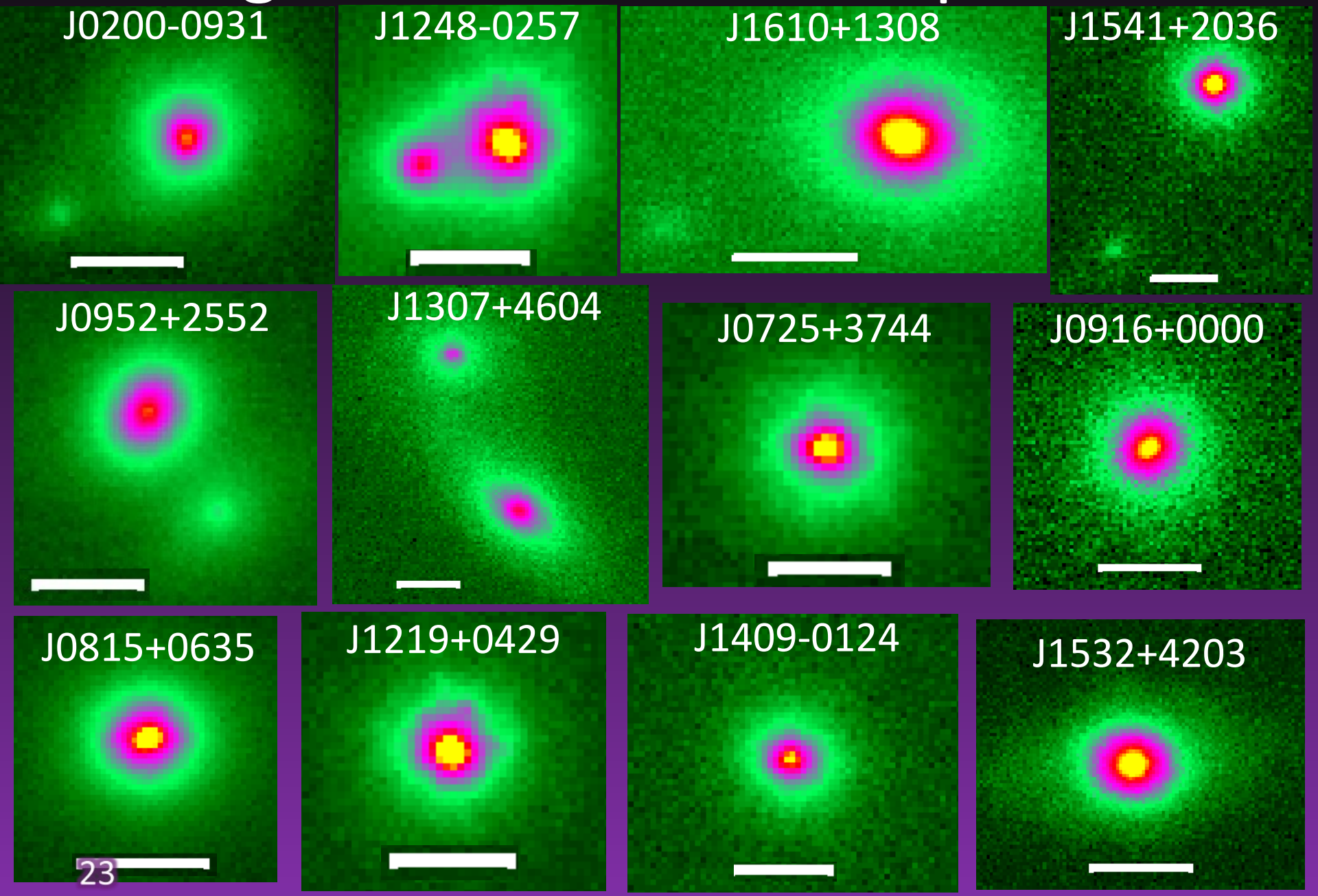
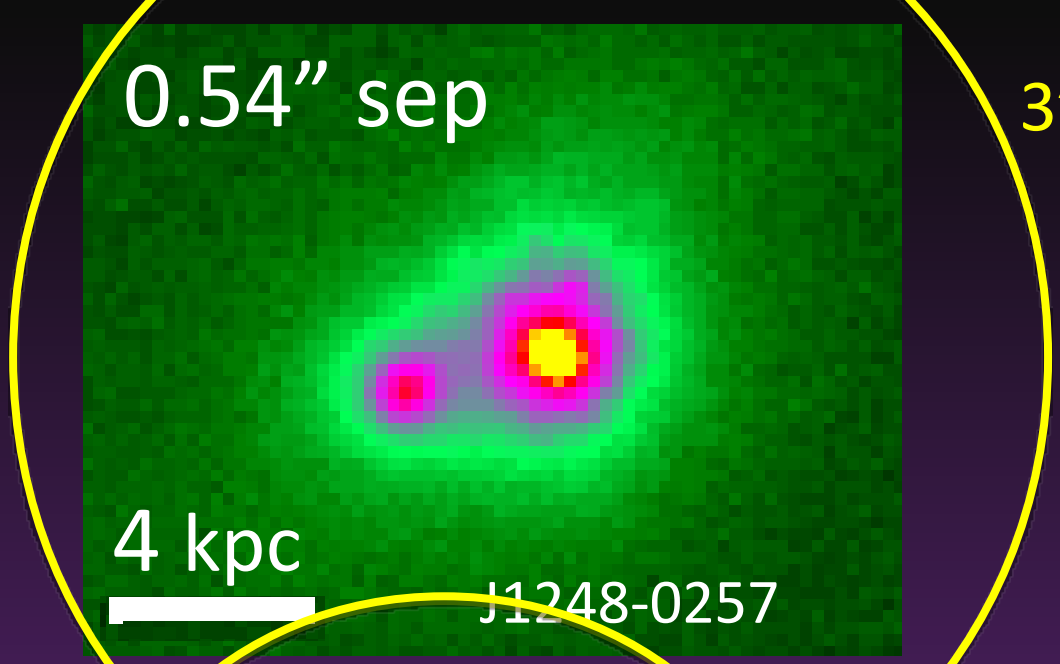
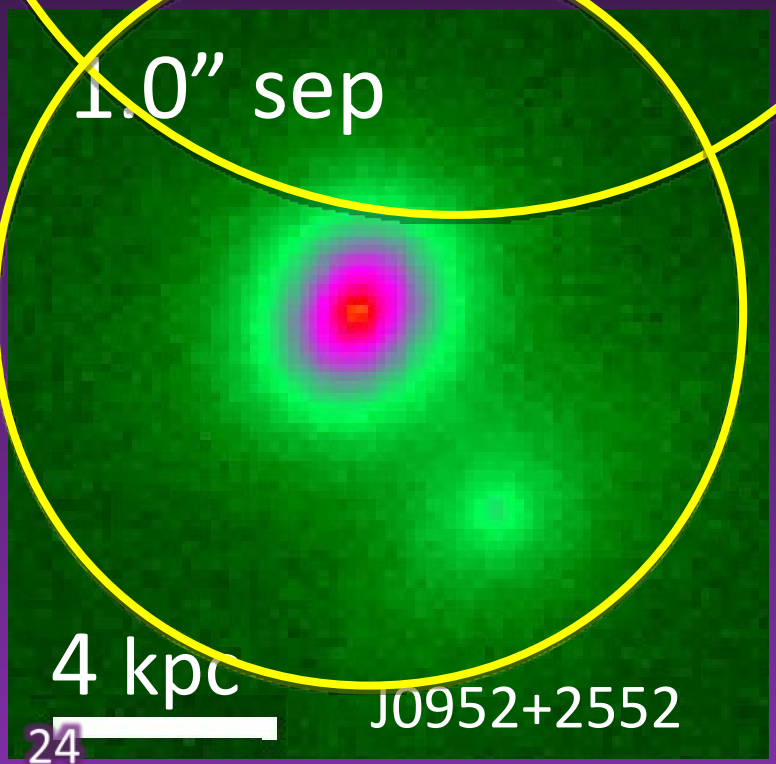
12 Images of Potential AGN pairs

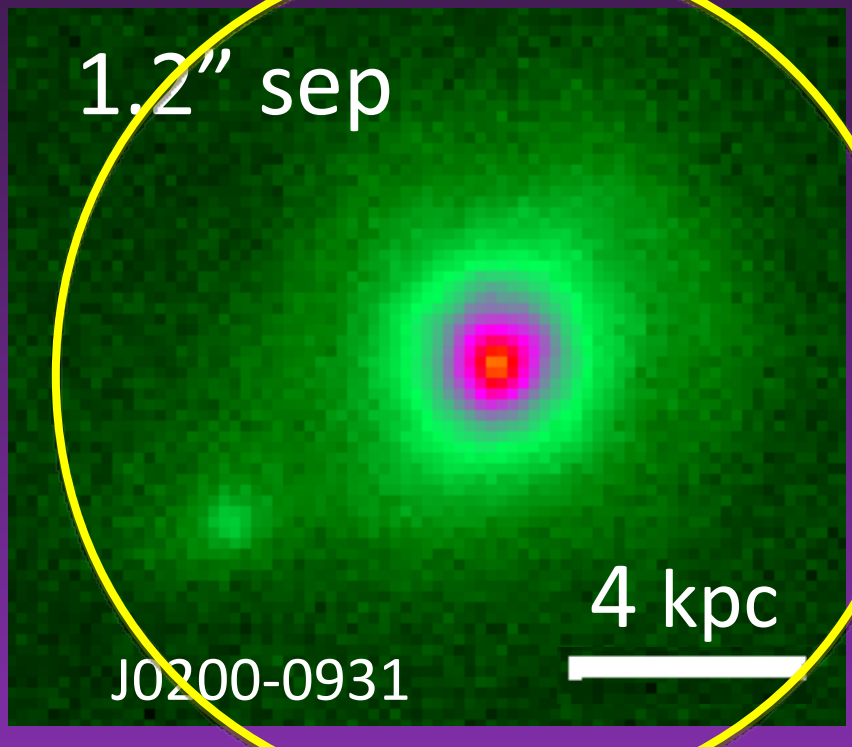




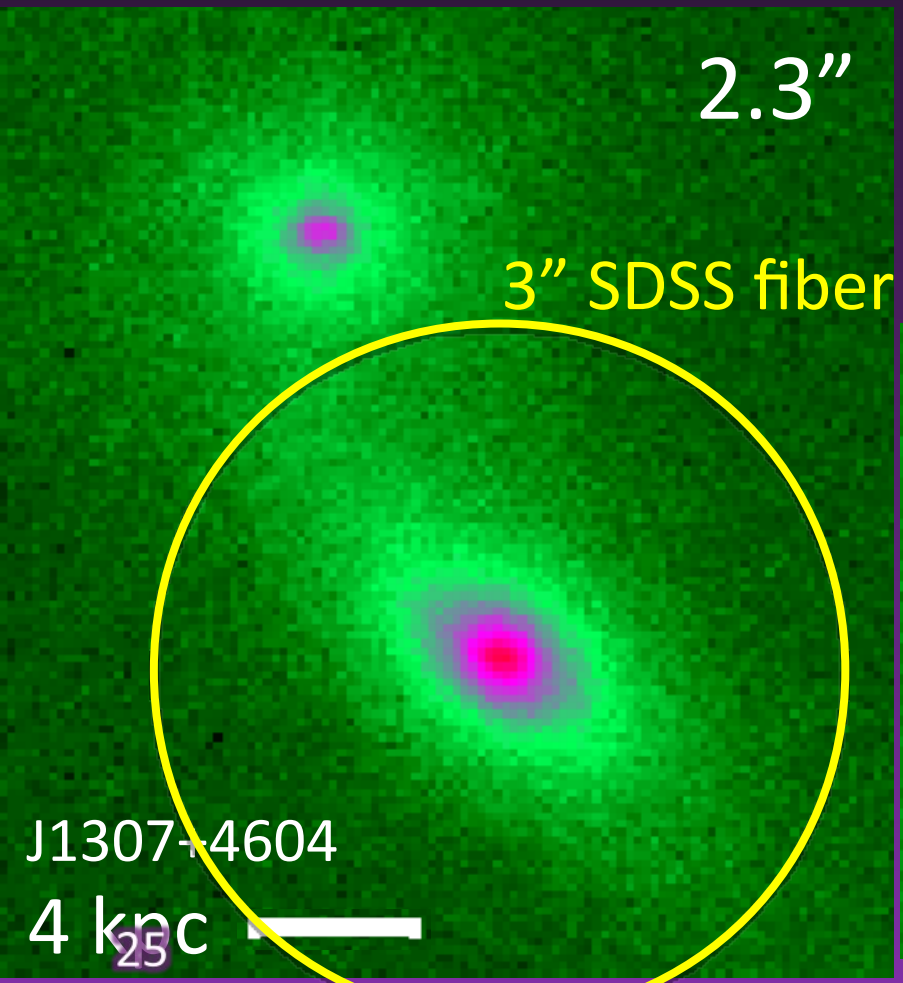
3” SDSS fiber

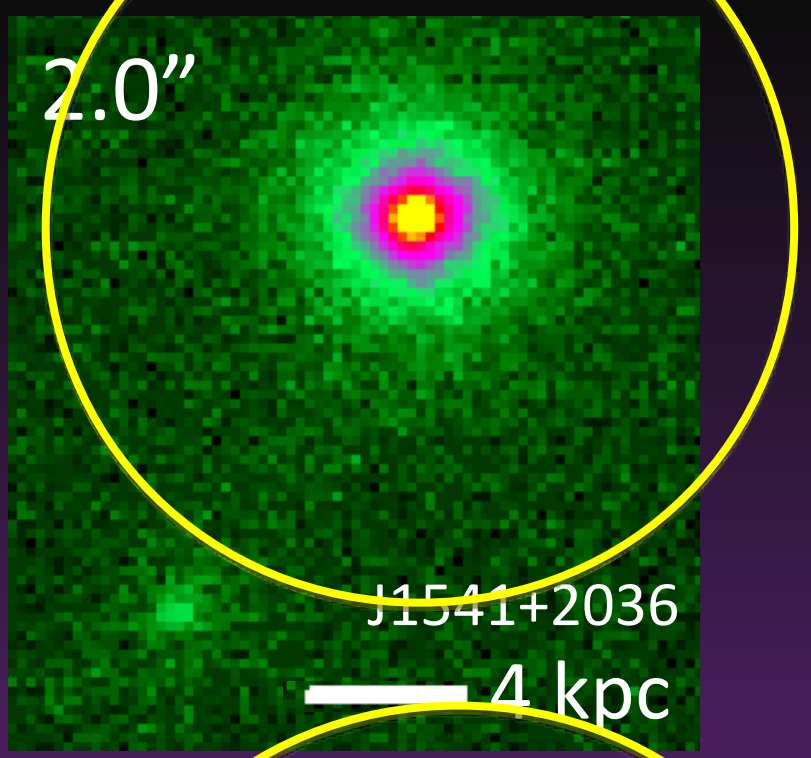
Close Doubles

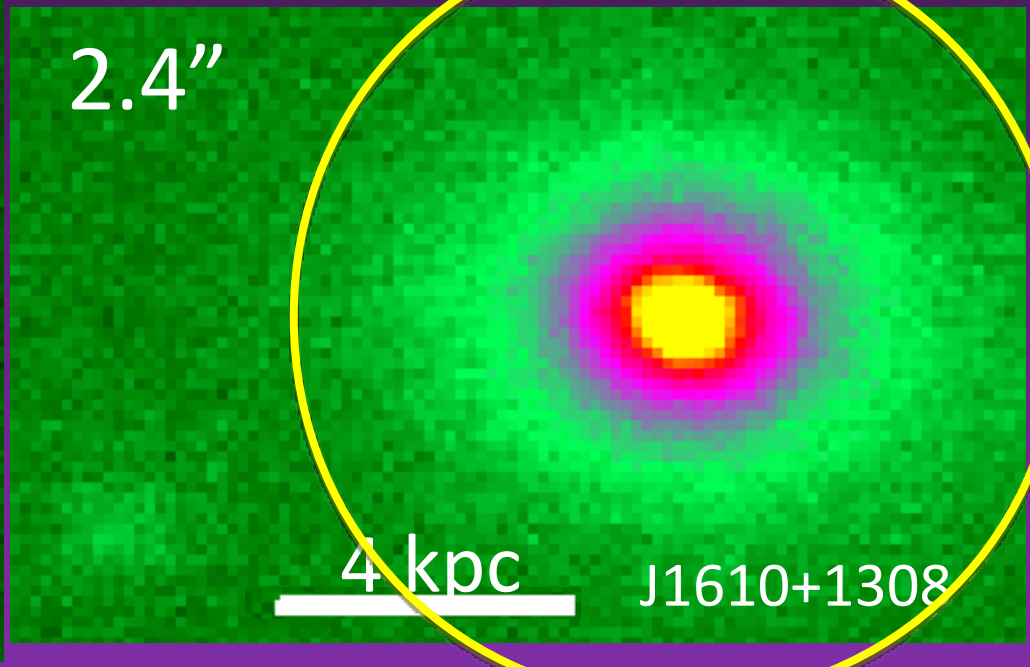




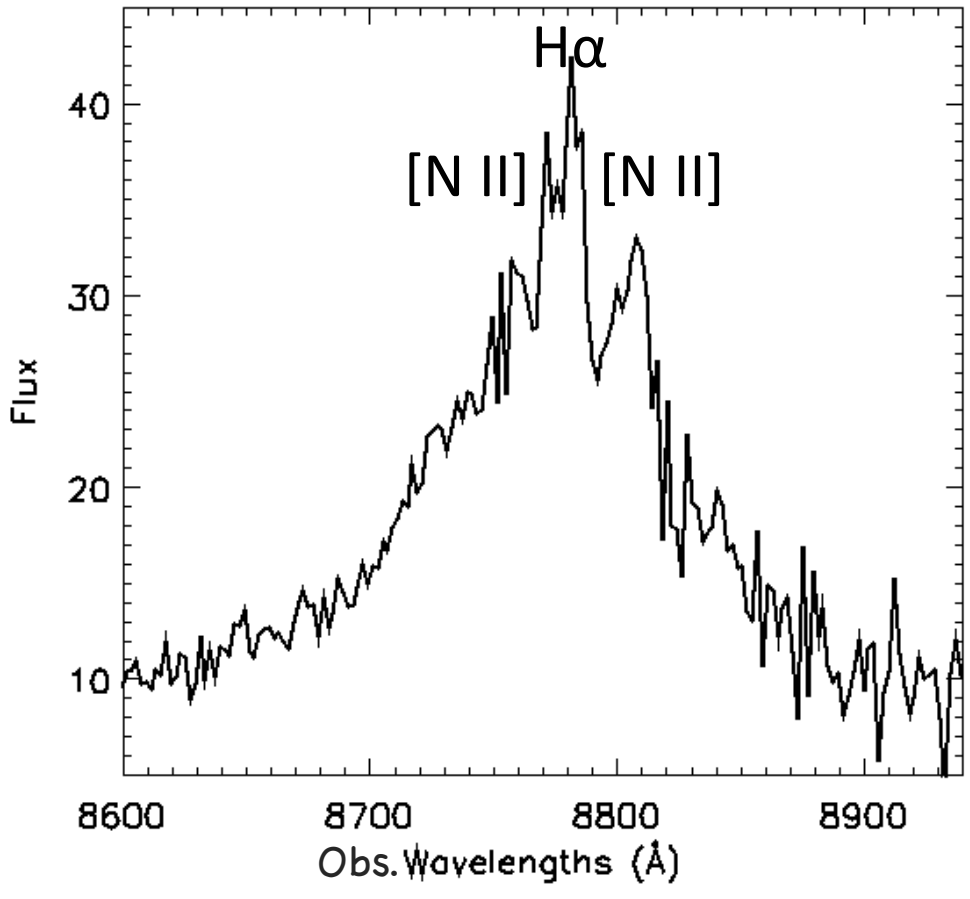
More Separated Doubles

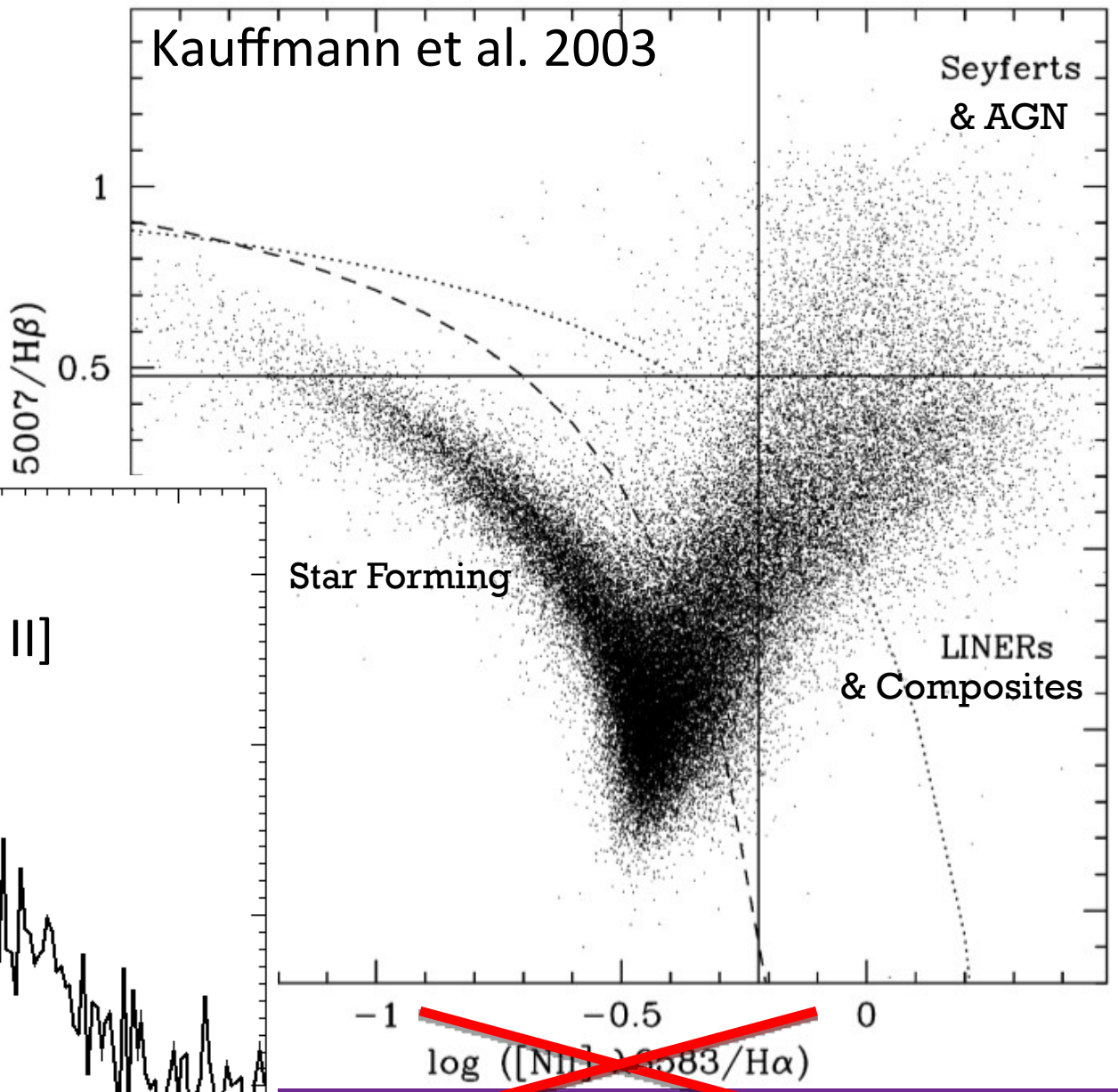






To Distinguish Between AGN and Star Formation,





- Can't disentangle [N II] and Hα for our objects

Instead… collapse horizontally to the [O III]/Hβ ratio

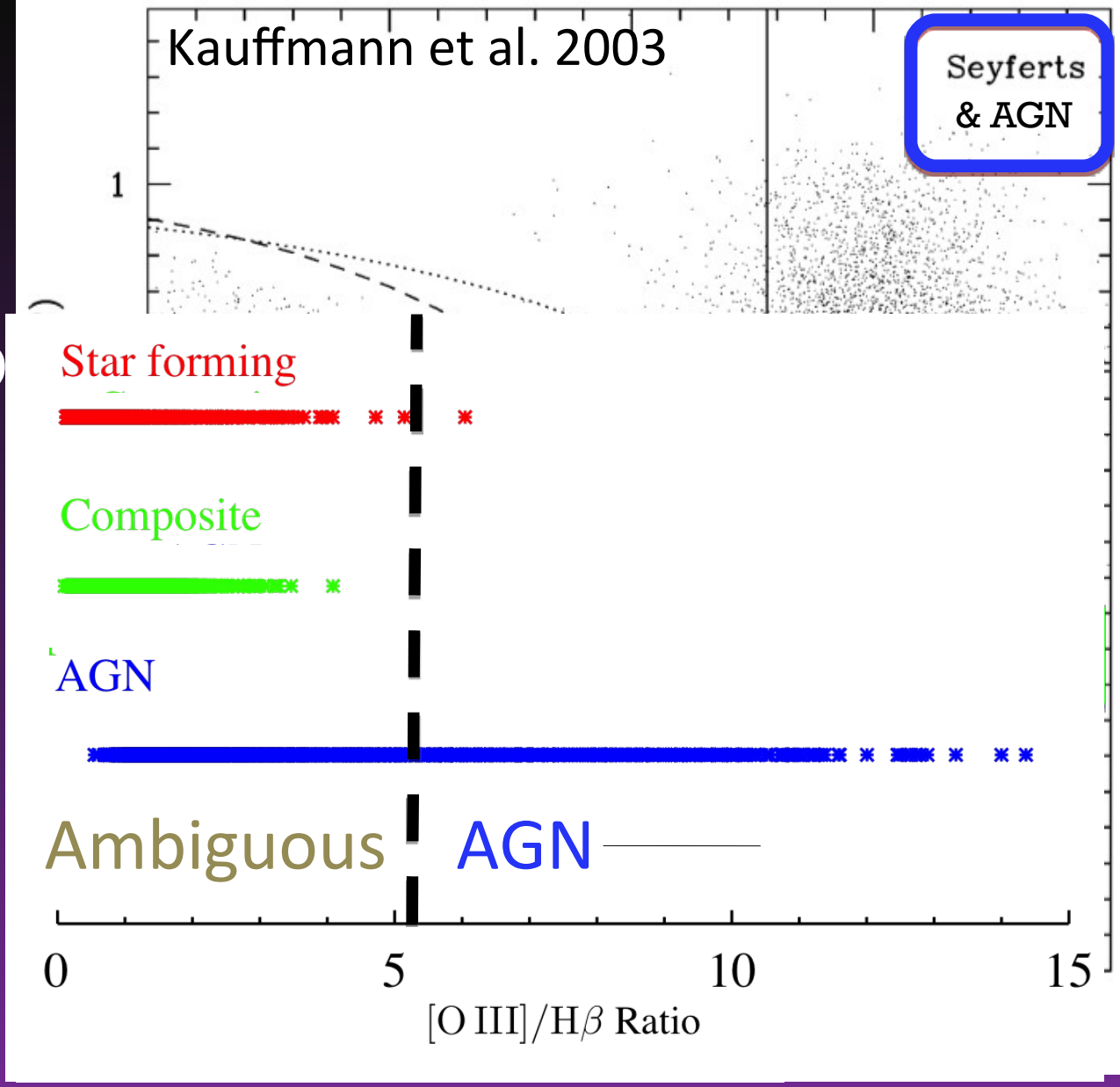


Figure courtesy of Jerome Fang

Major mergers

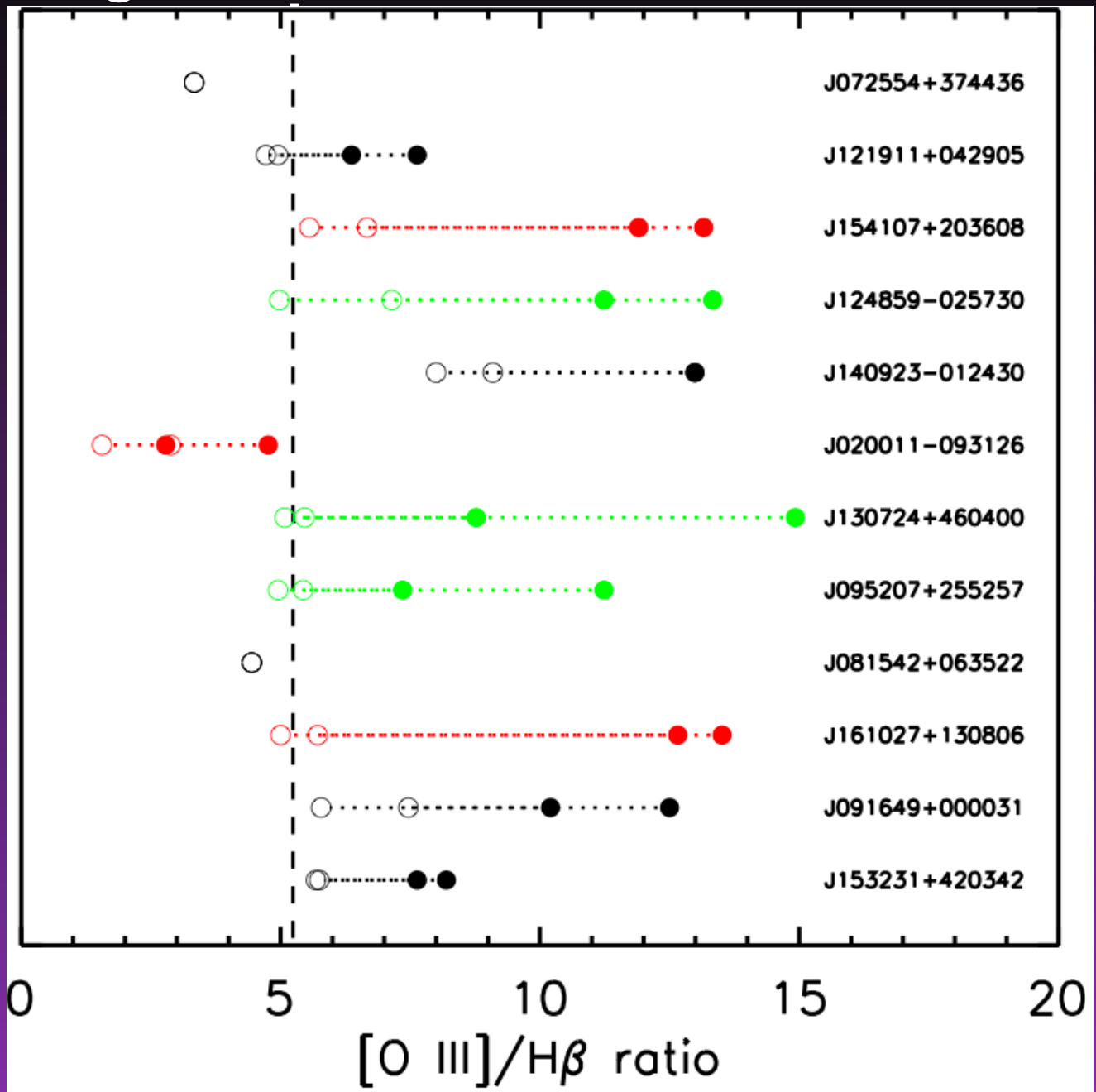
Minor mergers

No double spatial structure

● = best estimate

○ = 2σ lower limit

Both spectral components of our merger candidates are AGN (with one exception)



Combining Samples for Better Statistics

- Our sample:
  - 6/12 Type 1 radio-quiet AGN are doubles (≈50%)
- When I combine our sample with Fu et al. 2011:
  - 9/28 Type 1 radio-quiet AGN are doubles (≈32%)

- 1% of SDSS AGN have double-peaked [OIII]
- 0.3% of SDSS AGN have two spatially-separated components
- Agrees with predictions by Yu et al. 2011

In the next section I will discuss how to confirm spatially-separated components as actual dual AGN

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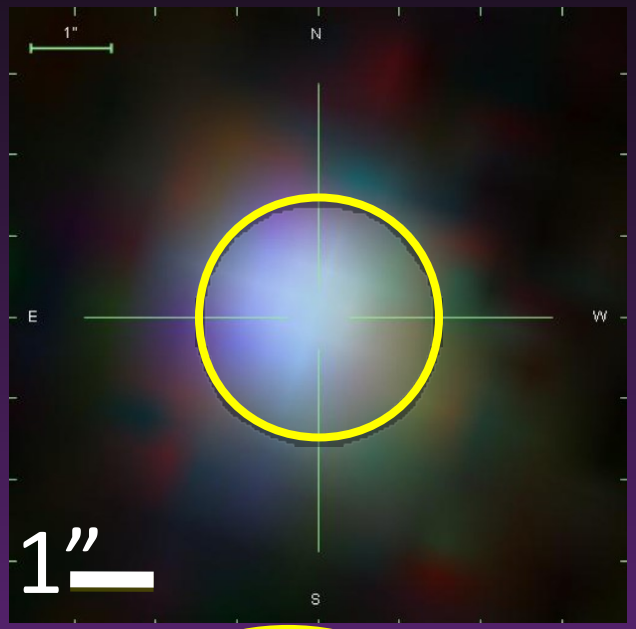
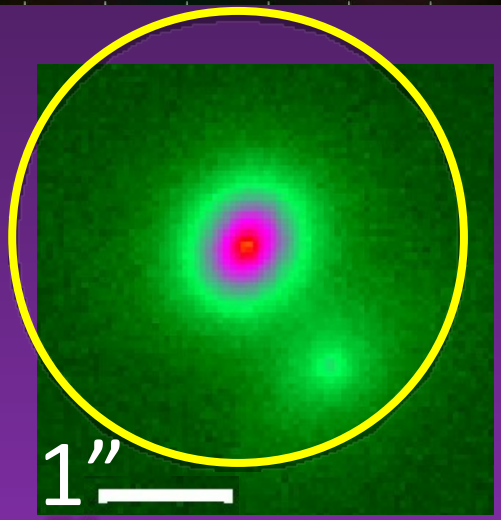
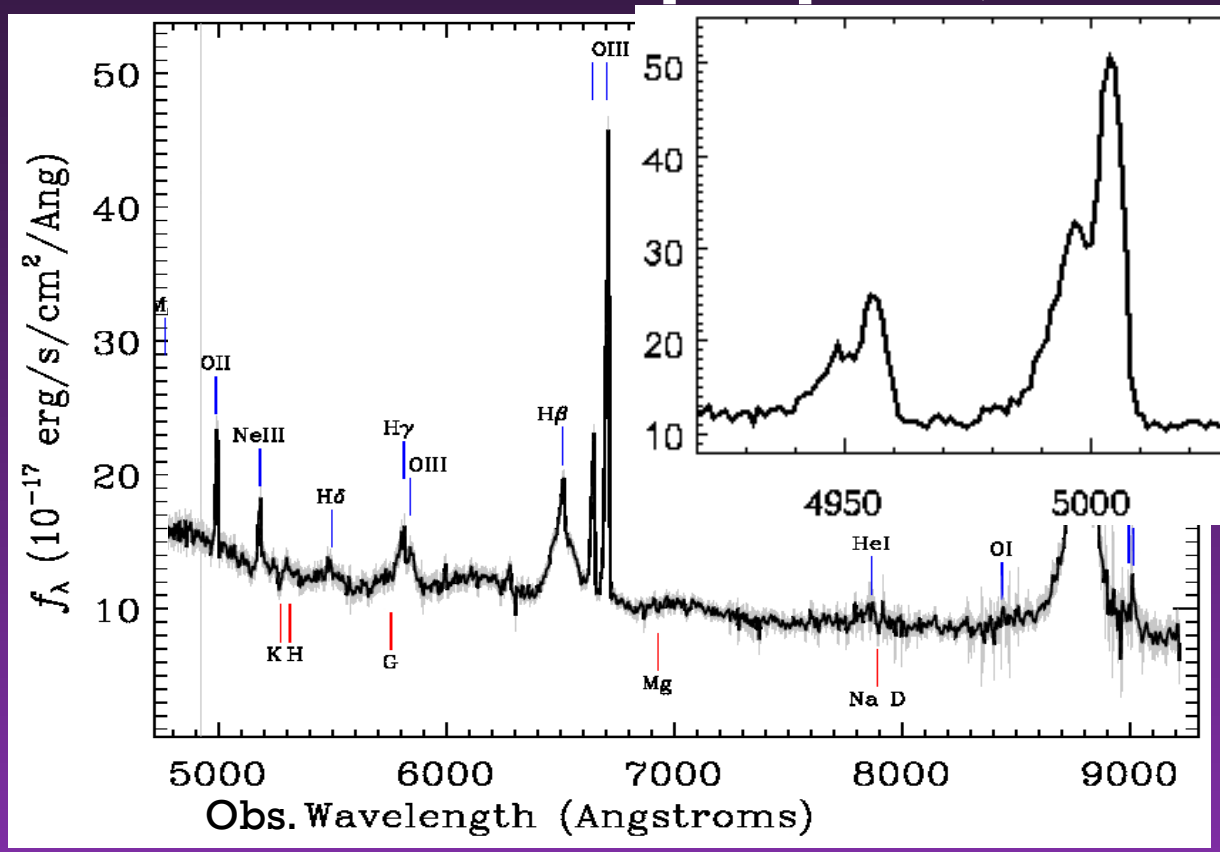
Why are spatially resolved spectra needed?





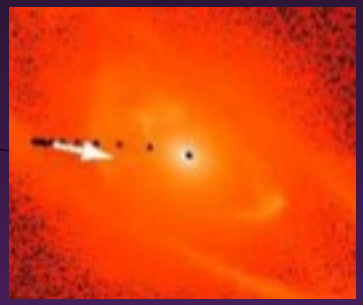
- SDSS spectra are spatially unresolved

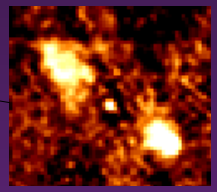
[O III] 4959, 5007Å

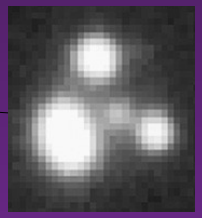


What else can candidate dual AGN be?

- Chance superposition of two objects
- Recoiling SMBH
- Jets interacting with the surrounding medium
- Outflows
- Gravitational lenses
- Starburst



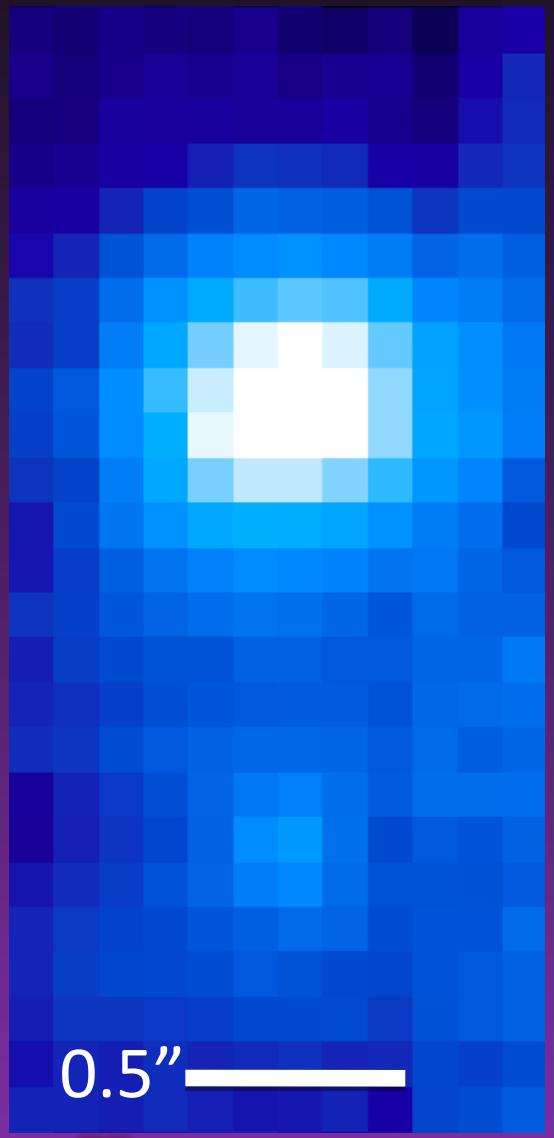




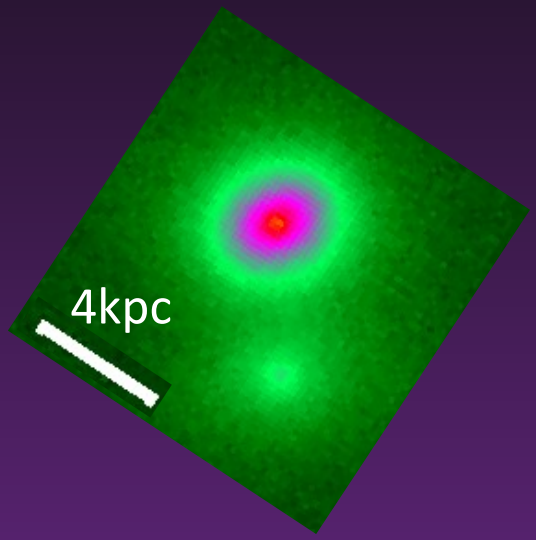
Spatially resolved spectroscopy is needed to distinguish between them

Guedes et al. 2010

We observed J0952+2552 with OSIRIS



- Separation = 1.0” = 4.81 kpc
- $M_{BH} = 1x10^8 M_\odot$
- Redshift = 0.339



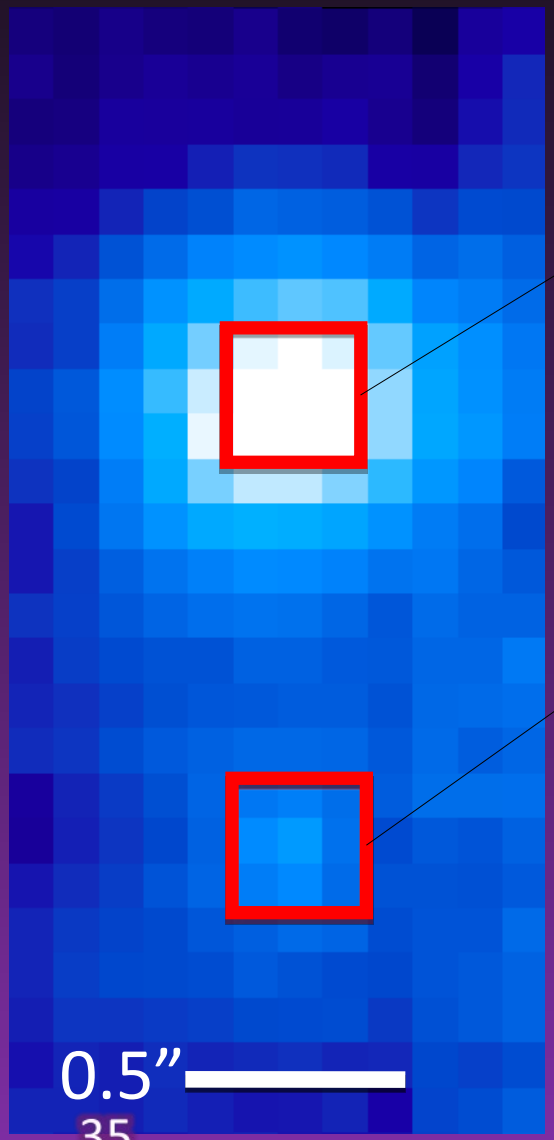
- Spectra taken at every pixel
- J, H broadband

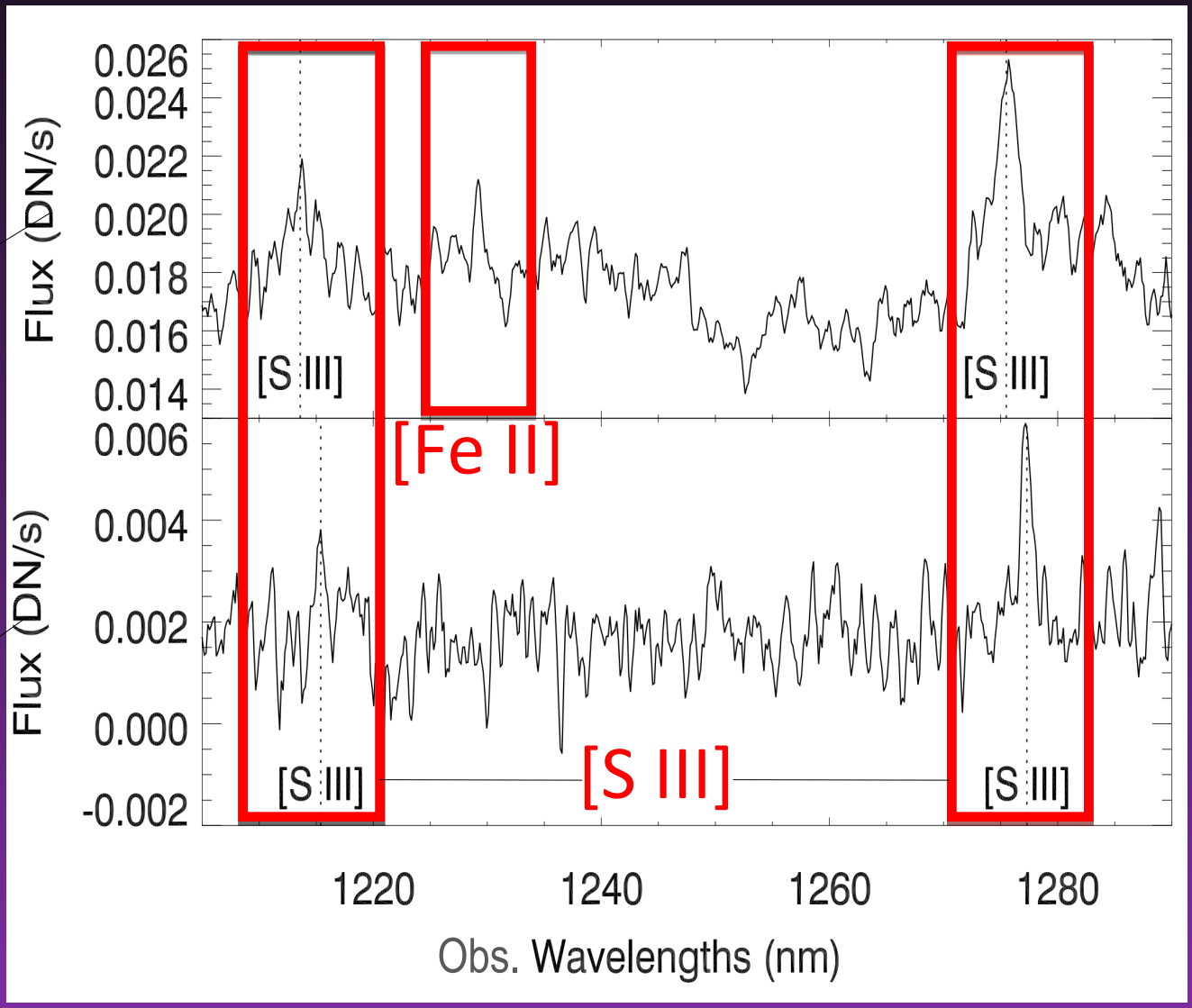
OSIRIS spectra will answer two questions:

1. Do the redshifts of the visible spatial structures match the double peaks of the SDSS emission lines?

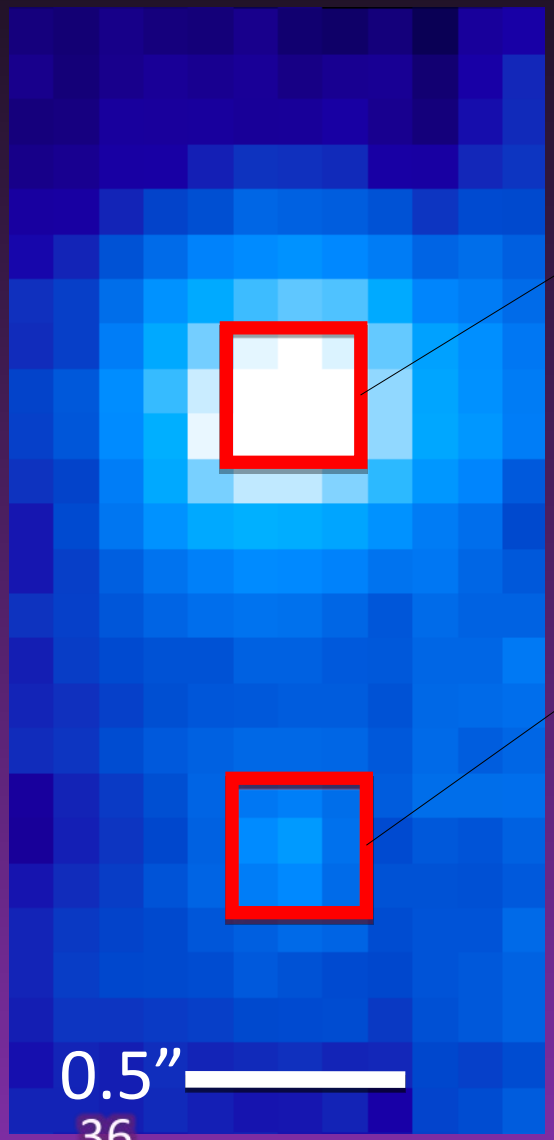
2. What types of objects are the bright galaxy and the companion: Type 1 or 2 AGN, or a starburst?

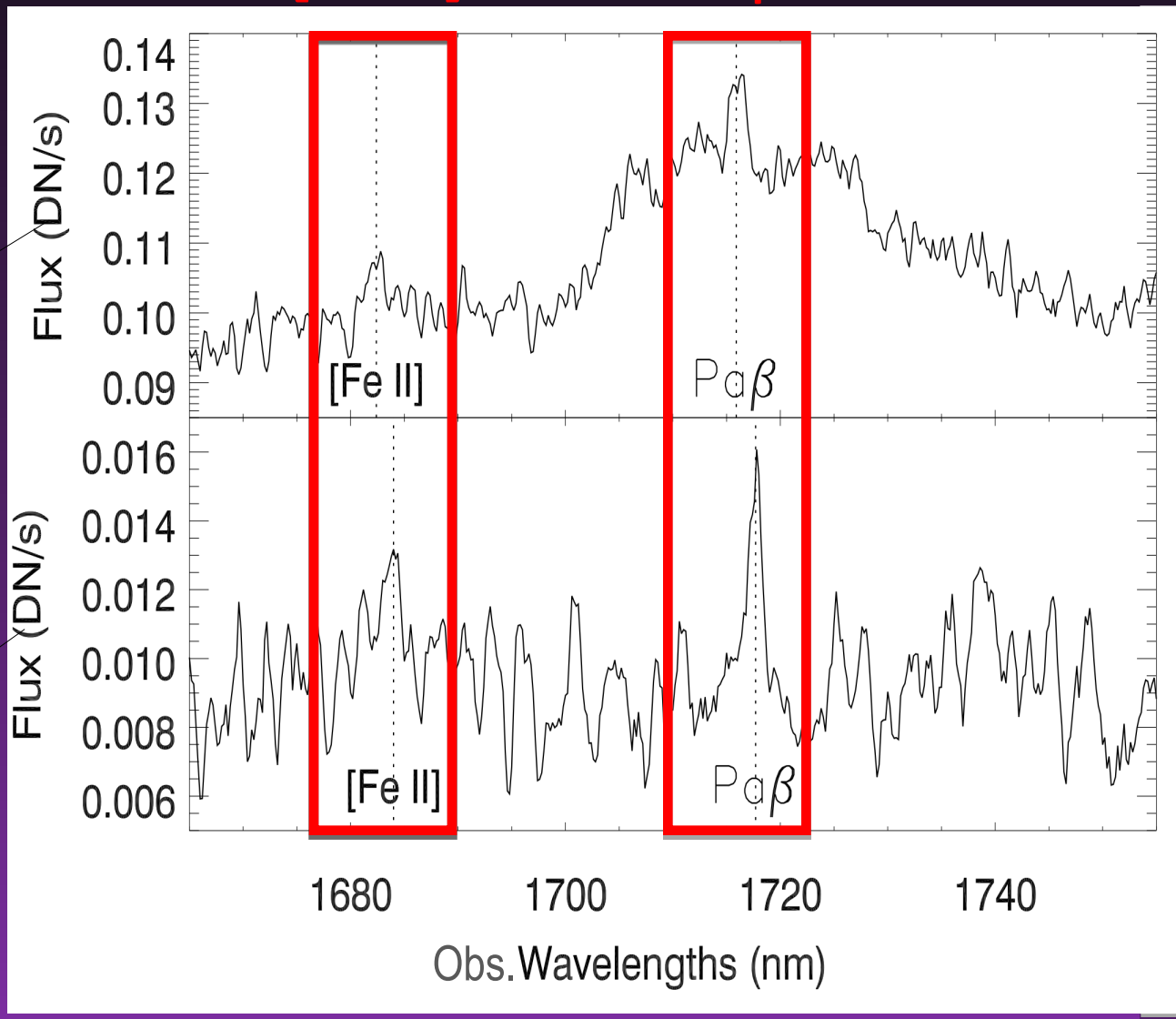
[S III] λ953.4 and λ907.3 nm in J...





And Paβ and [Fe II] λ1257nm in H.





Using the narrow lines to measure redshifts…

Redshift error = ±0.00014

Spectral line:	Bright Galaxy	Companion
[S III] 9073 Å	0.33797	0.3398
[Fe II] 9188 Å	0.33786	---
[S III] 9534 Å	0.33792	0.3397
[Fe II] 1.2570 μm	0.33842	---
Pa β	0.33840	0.3397
SDSS [O III] red		0.3399
SDSS [O III] blue	0.3380	

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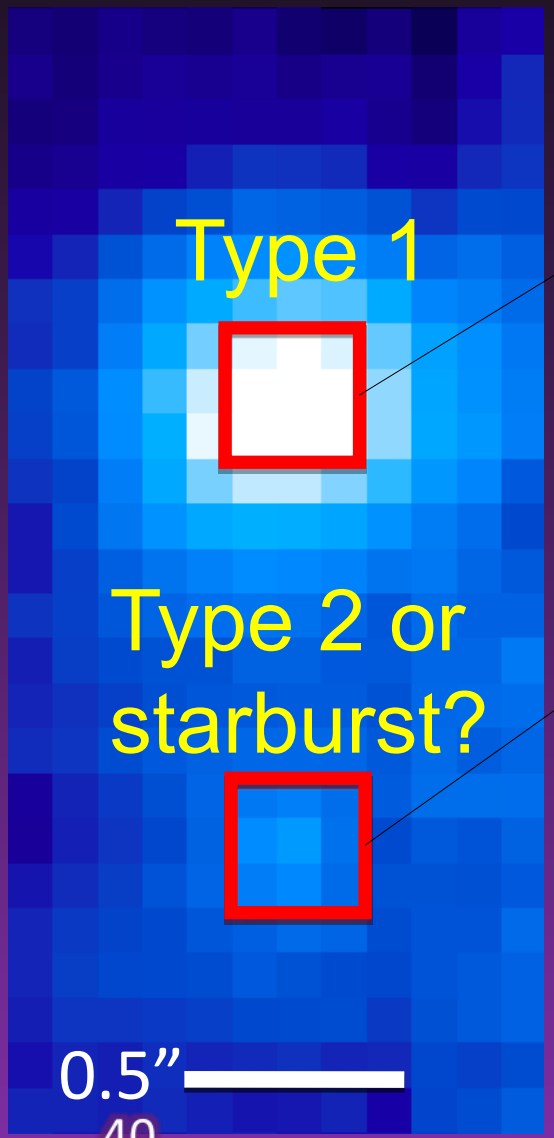
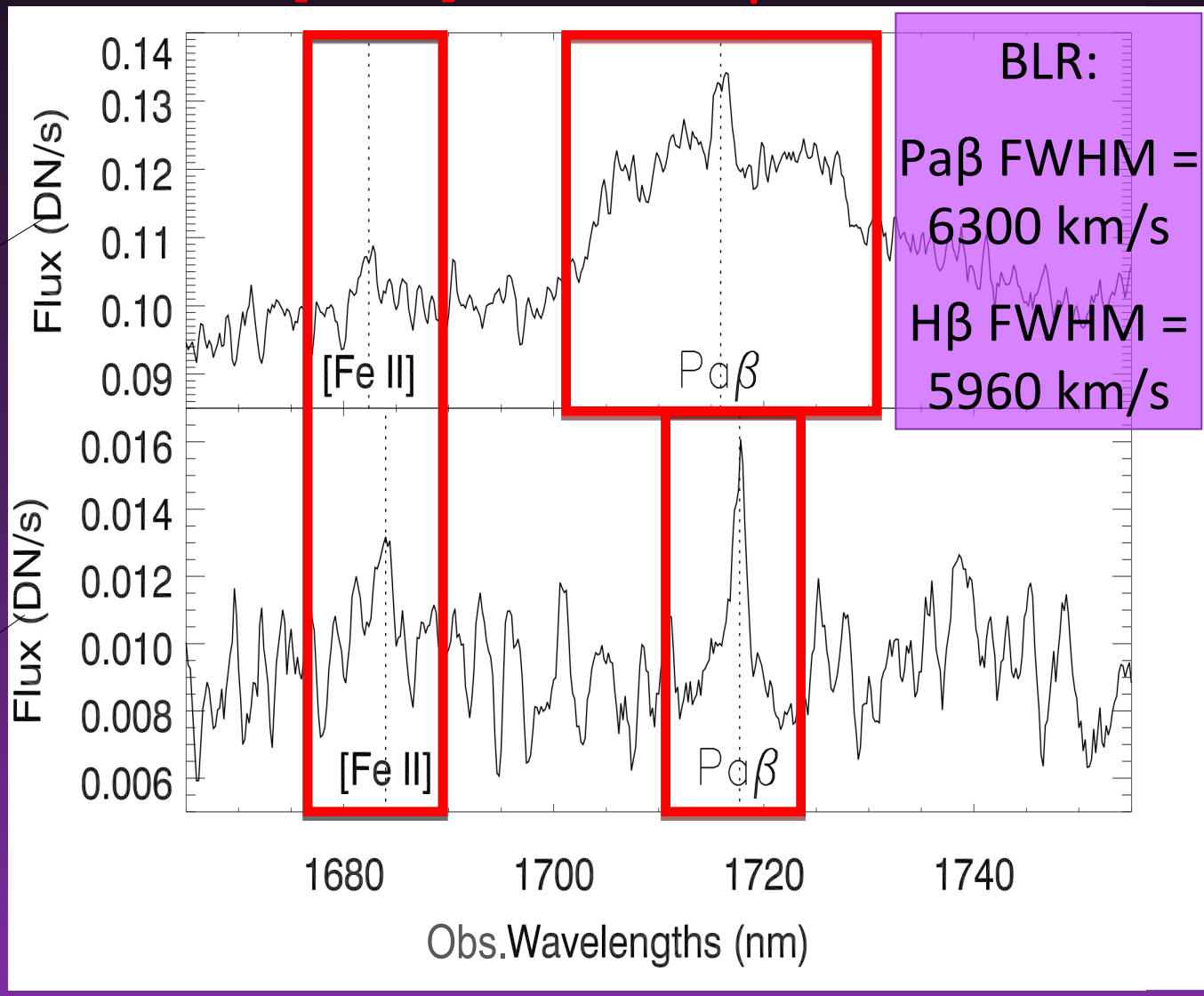
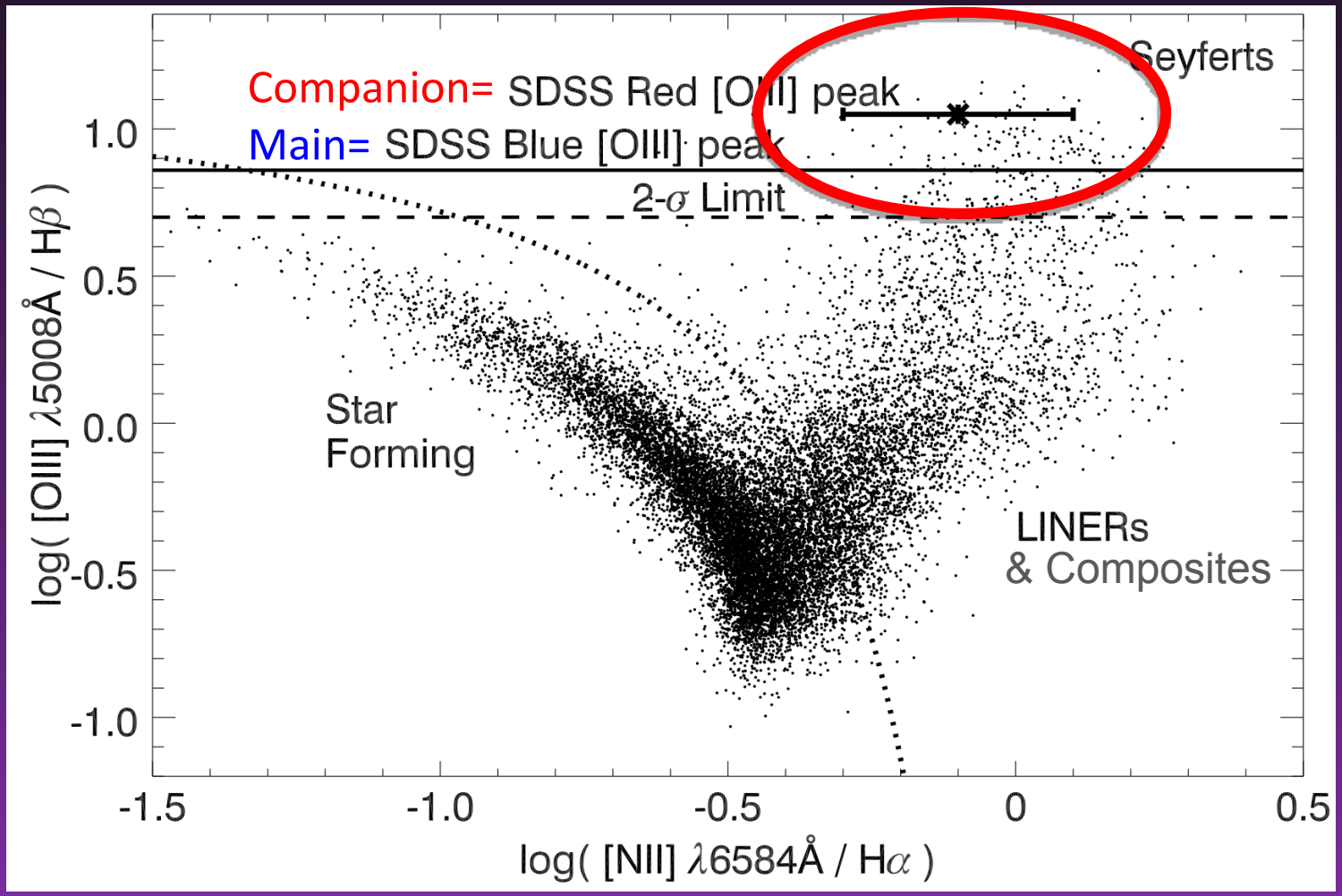
The double spatial structure corresponds to the SDSS double-peaked emission lines!

Broad Paβ and AGN type





Is the companion an AGN or a starburst?



McGurk et al. 2011

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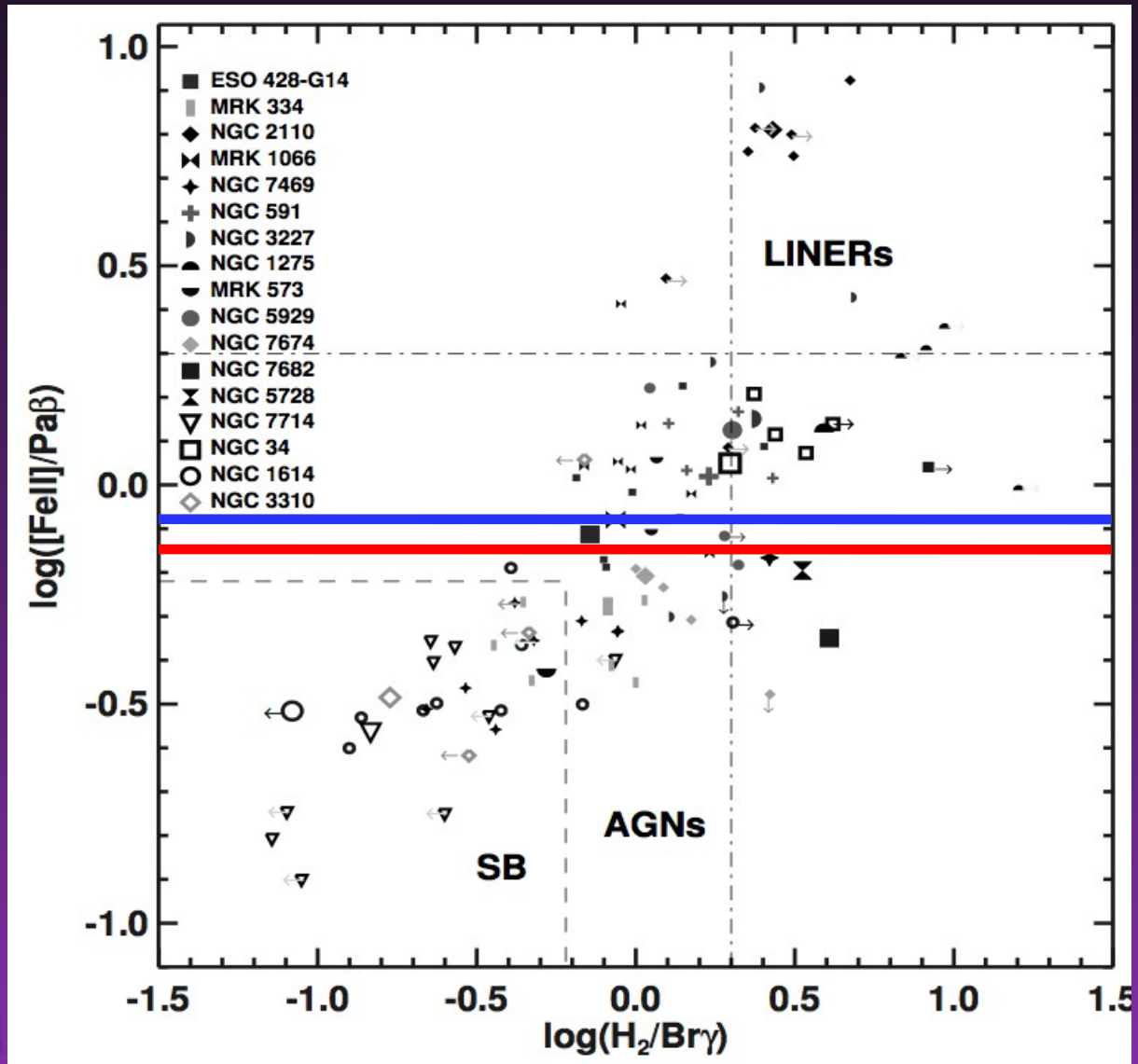

Main galaxy

Companion galaxy

McGurk et al. 2011

Rodriquez-Ardila et al. 2008

Conclusions for J0952+2552

- Bright galaxy and companion correspond to double [O III] peaks
- Main = Type 1 AGN
- Companion = Type 2 AGN

- Confirmed 1 Dual AGN!

- Now repeat for other objects!

Conclusions

- Imaging:
  - Of the 12 Type 1 radio-quiet AGN examined, 50% have merger activity
  - Based on the SDSS emission line ratios, both spectral components are AGN

- Spatially Resolved Spectroscopy:
  - Bright galaxy and companion correspond to the double [O III] peaks
  - J0952+2552 is a dual AGN!

Open Questions:

- How does the AGN duty cycle affect the detectability of dual AGN? At what separations are both of the AGN bright, and for how long?
- What indicators should be used to find more close dual AGN?
- What fraction of AGN are actually in mergers?