

# The Role of Major Mergers in (obscured) Black Hole Growth and Galaxy Evolution

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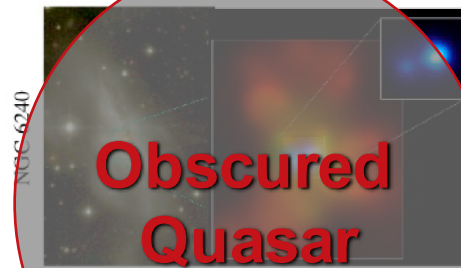
**Collaborators:** Franz Bauer (PUC), George Privon (PUC), Claudio Ricci (PUC), Kevin Schawinski (ETH), Mike Koss (ETH), Francisco Muller-Sanchez (Colorado), Julie Comerford (Colorado), Dave Sanders (Hawaii), Nick Scoville (Caltech), Meg Urry (Yale), Vivian U (UCR), Anne Medling (Caltech), Patricia Arevalo (UV) and others...



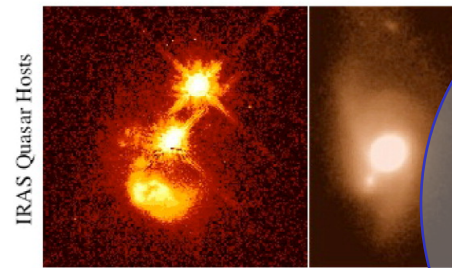
(c) Interaction/"Merger"



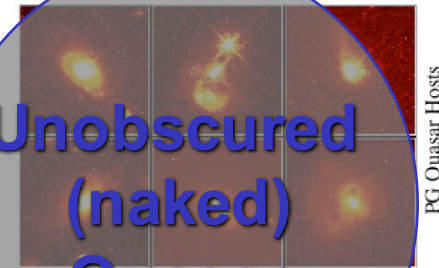
(d) Coalescence/(U)LIRG



(e) "Blowout"



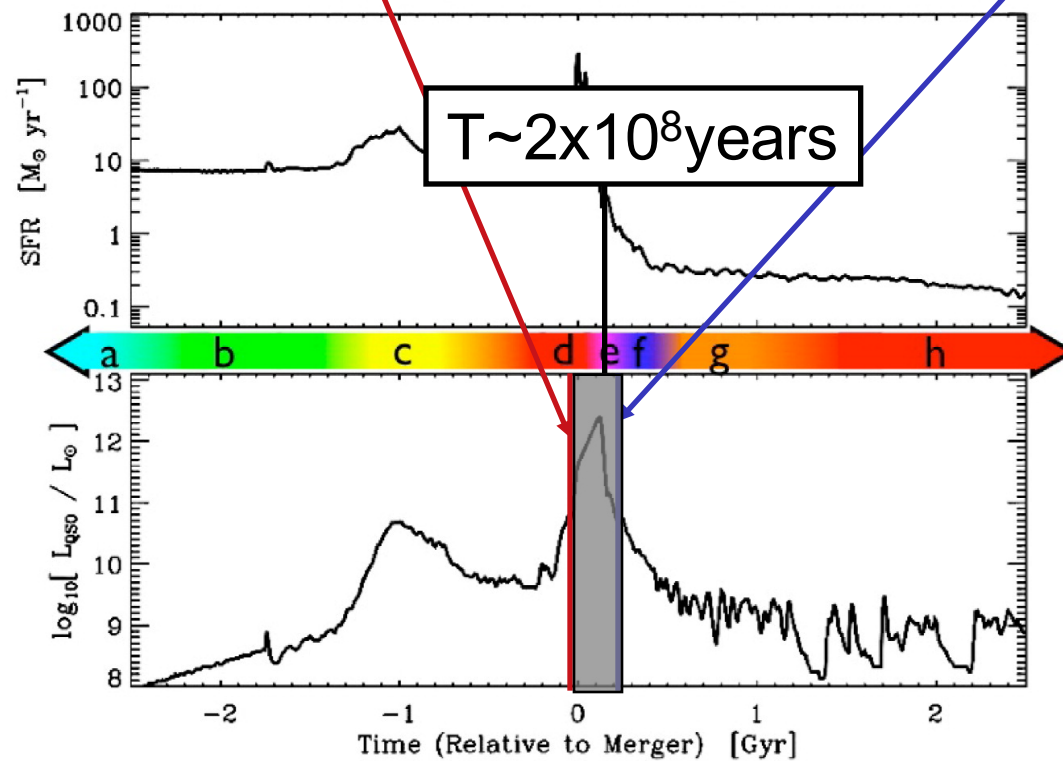
(f) Quasar



(b) "Small Group"



(a) Isolated Disk

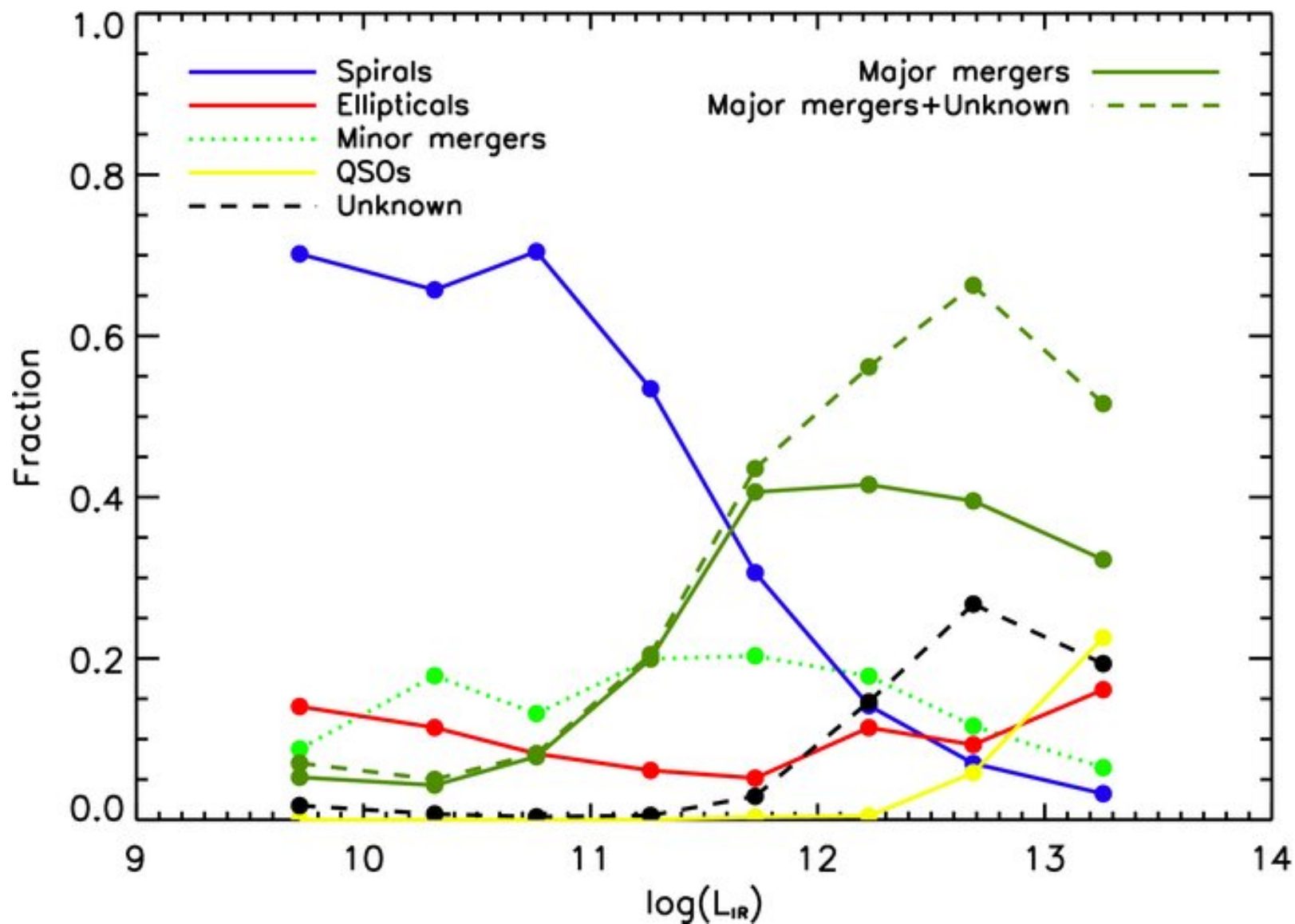


(h) "Dead" Elliptical



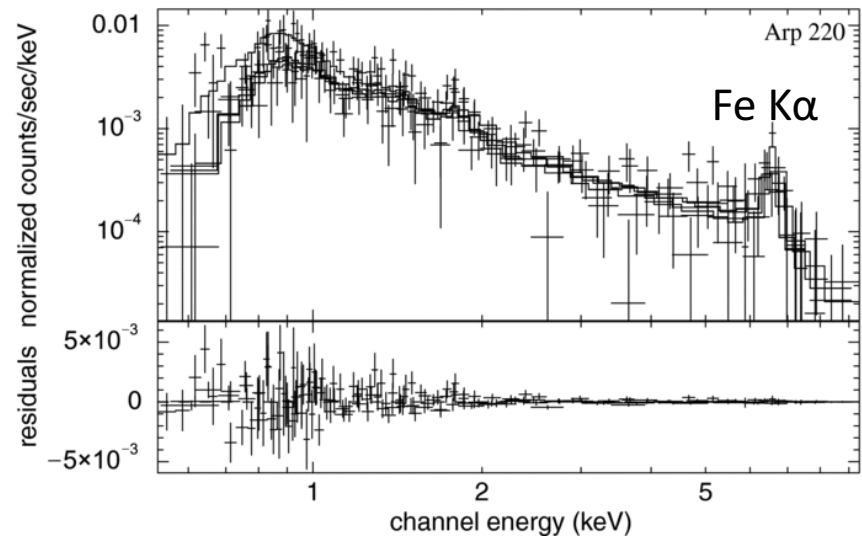
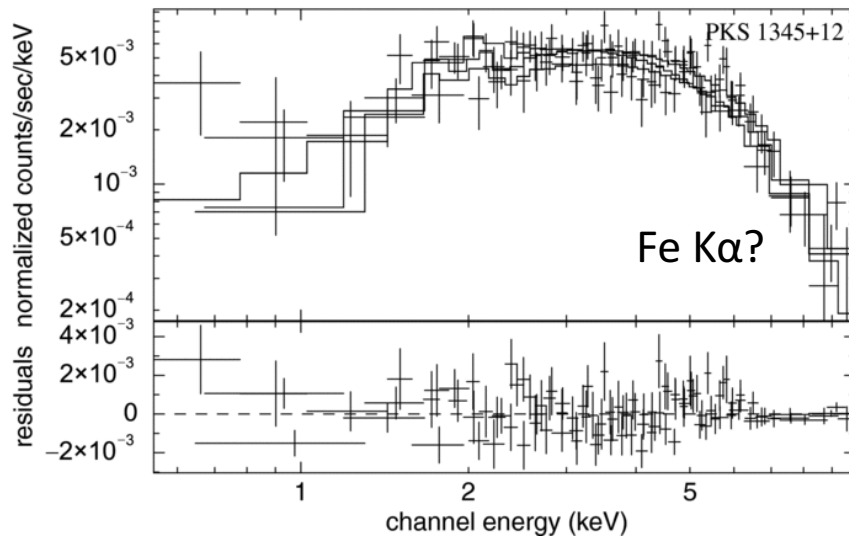
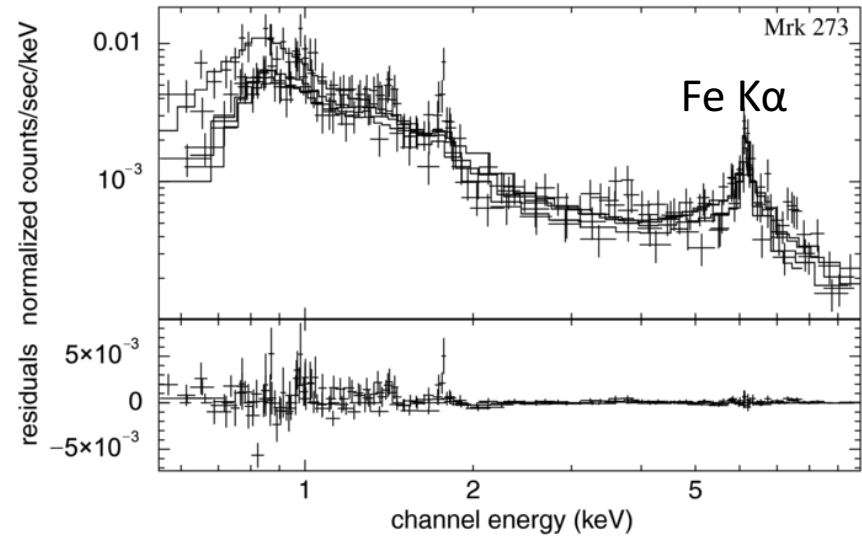
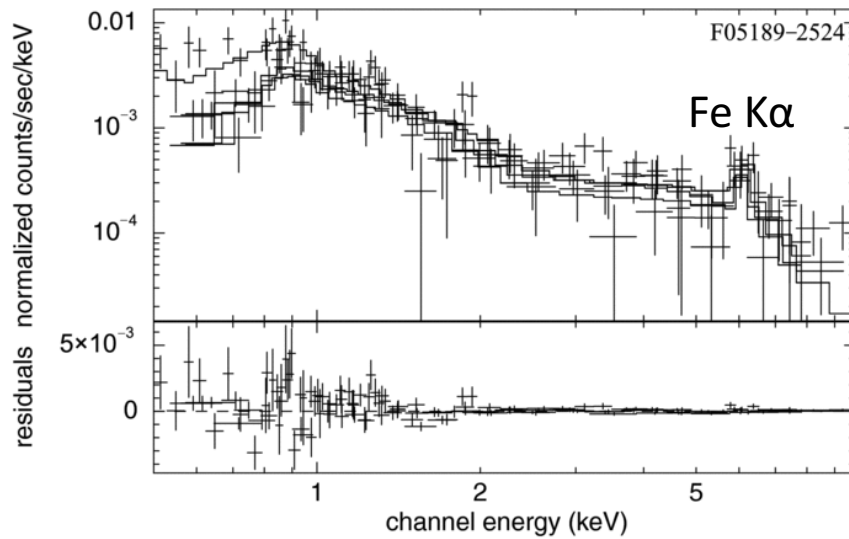
Hopkins et al. (2008)

# Morphologies at $z \sim 1$

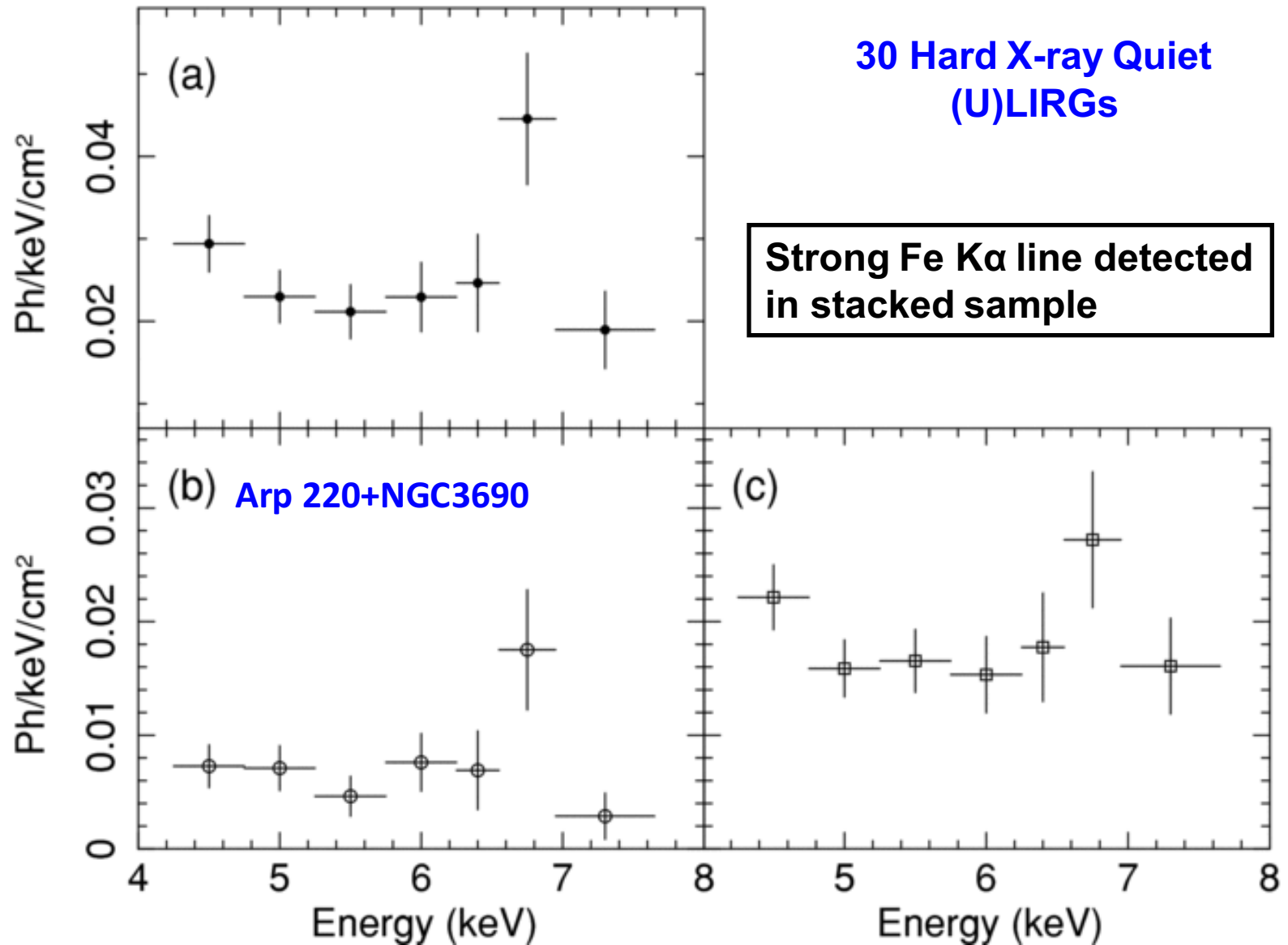


Kartaltepe et al. 2010

# Suzaku X-ray Observations

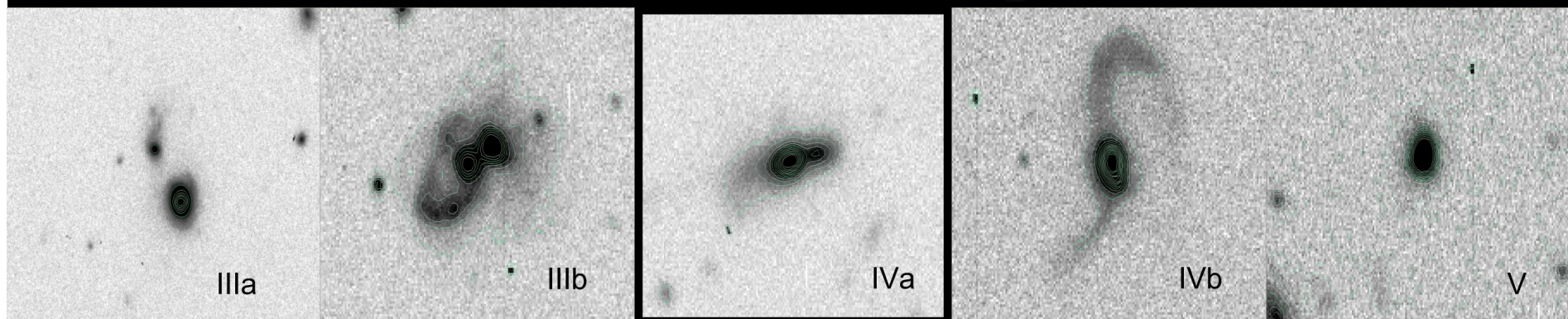


# The Chandra Perspective



Iwasawa et al. 2009, 2011

# Evolutionary Sequence

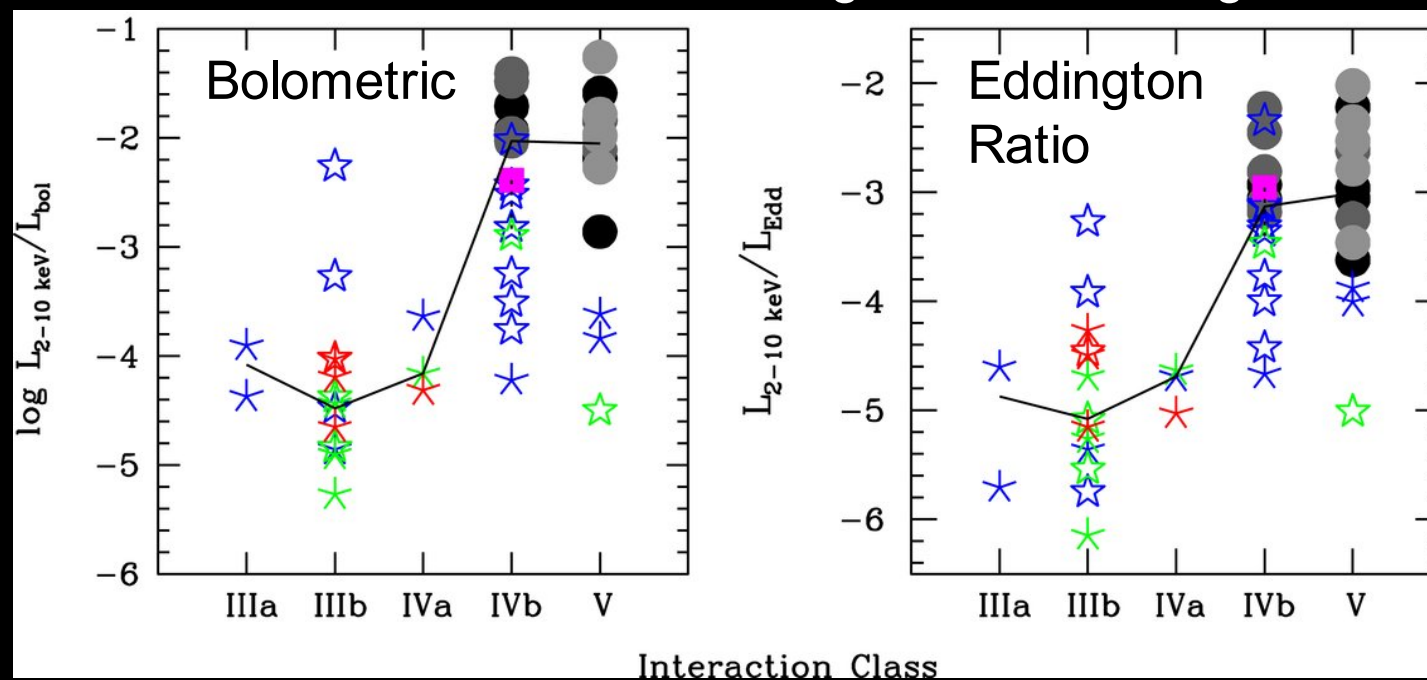


pre-merger

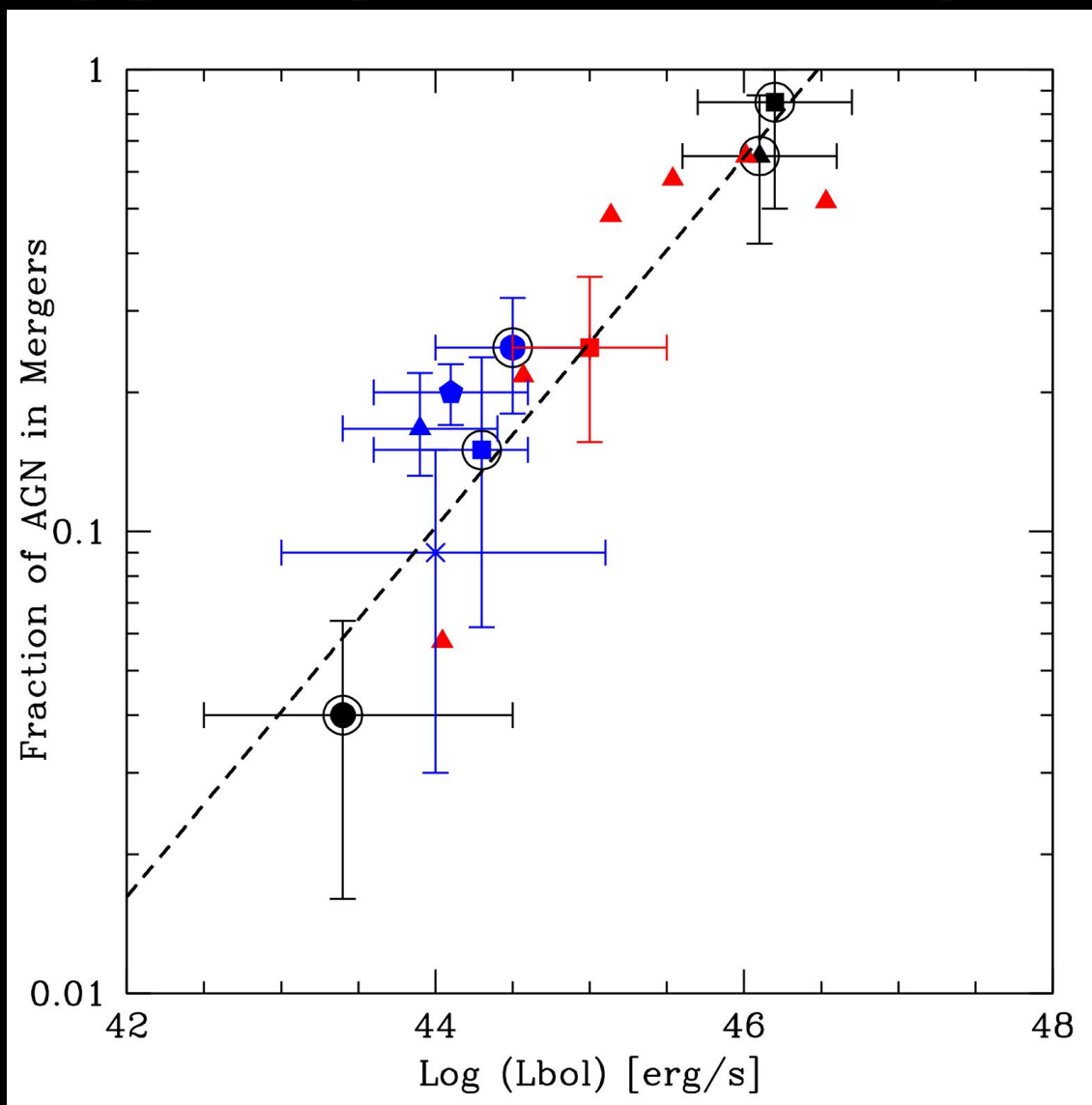
diffuse  
merger

compact  
merger

old merger

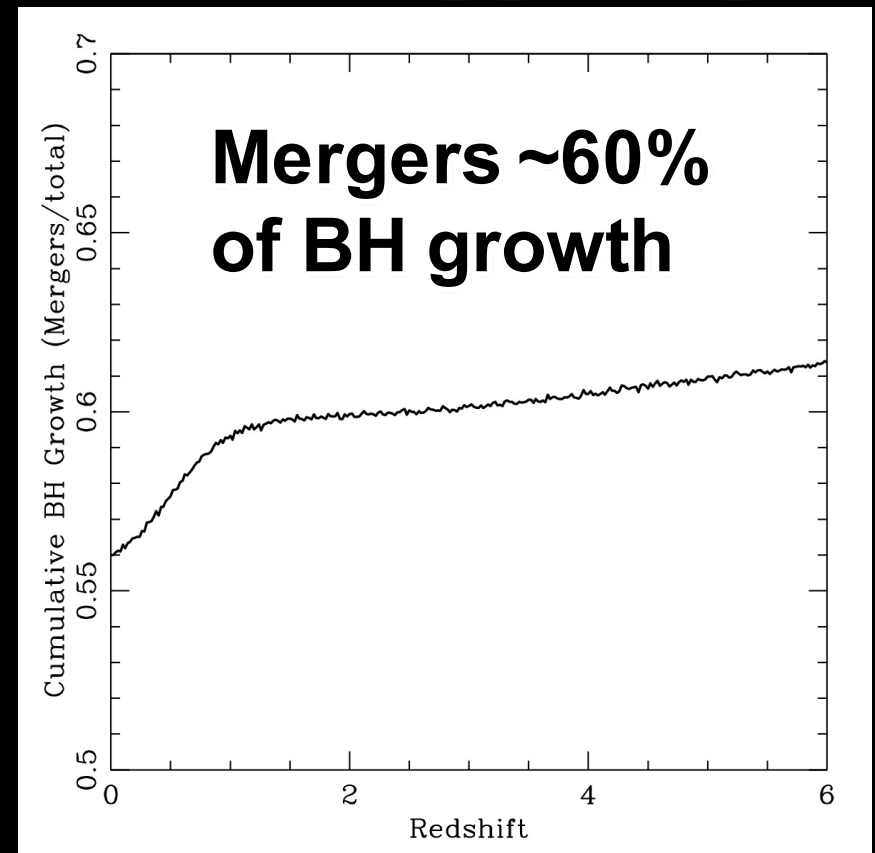
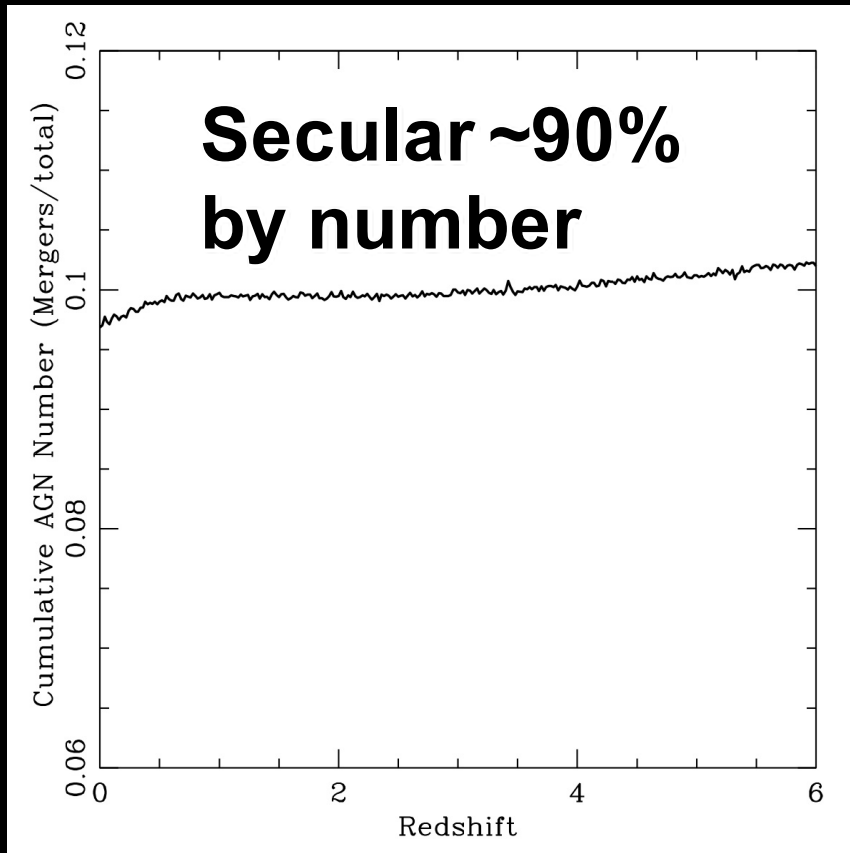


# AGN Triggering is Luminosity Dependent



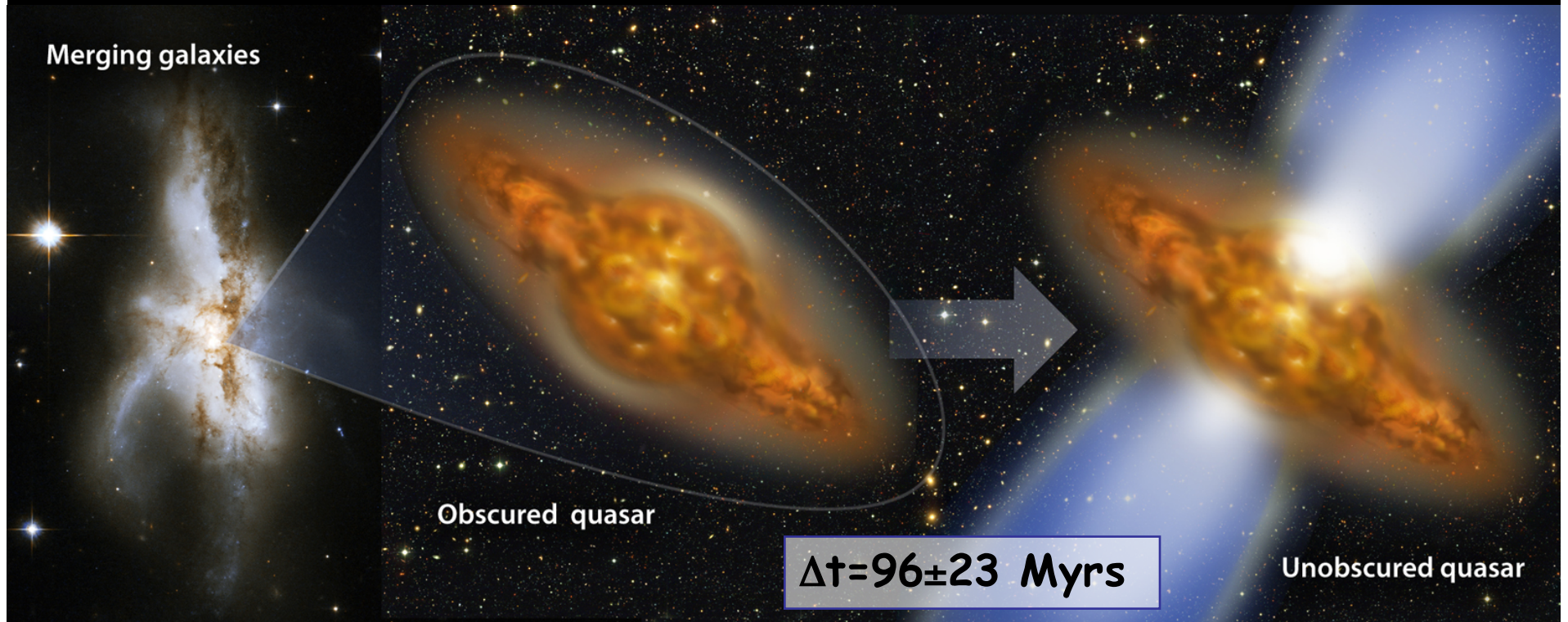
Treister et al. 2012

# AGN Contributions Versus Triggering



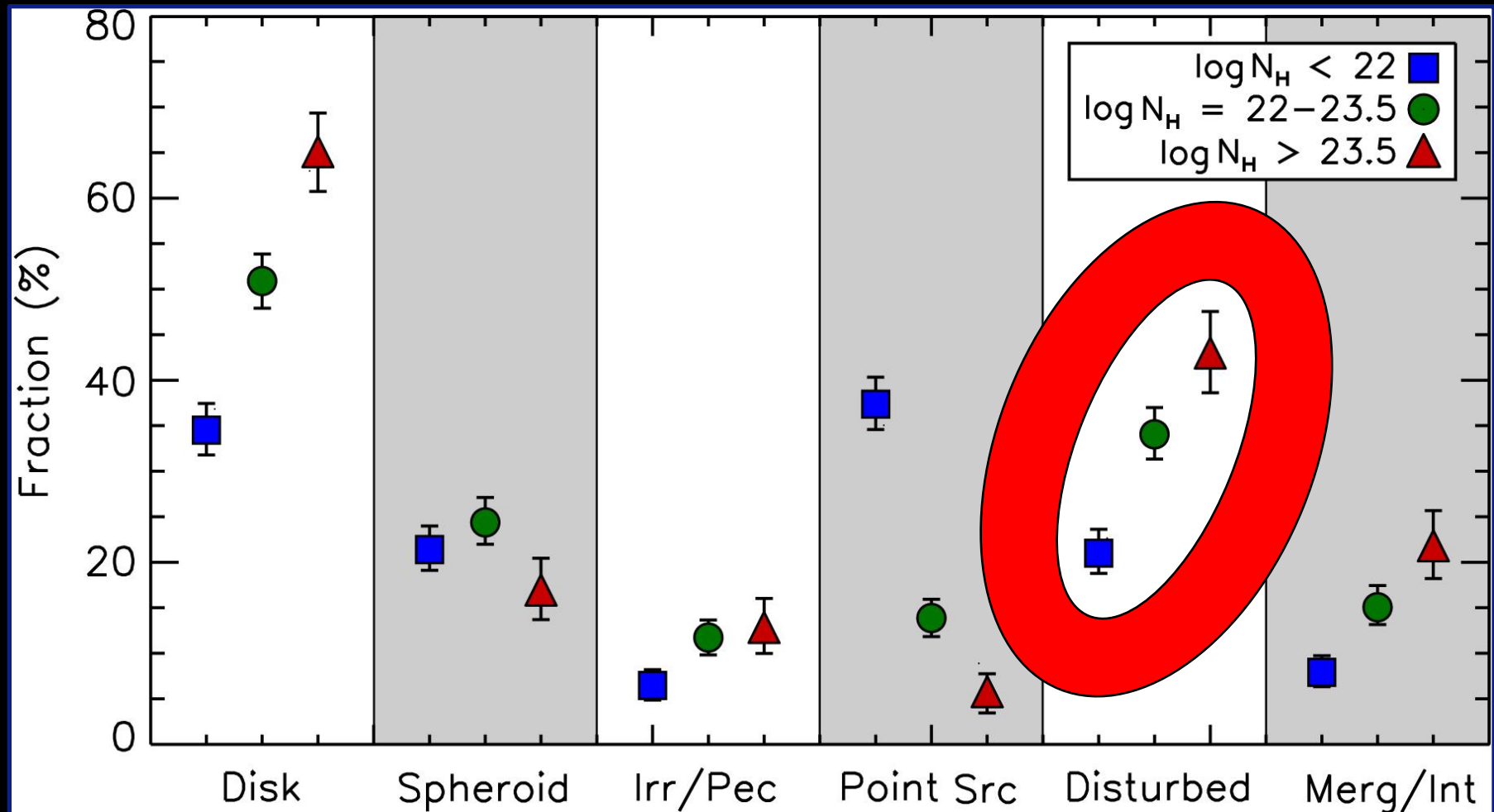
**Major mergers/ULIRGs are responsible for 60% of the total black hole growth across cosmic history**

# Merger-Quasar Connection



The obscured phase represents ~30% of total accretion onto supermassive black holes

# Heavily Obscured AGN are in Disk and Disturbed/Merger Galaxies



Kocevski et al. 2015

# NuSTAR

Part of the SMEX NASA program

Weight: 350 kilos

Size: 1,2x10 meters

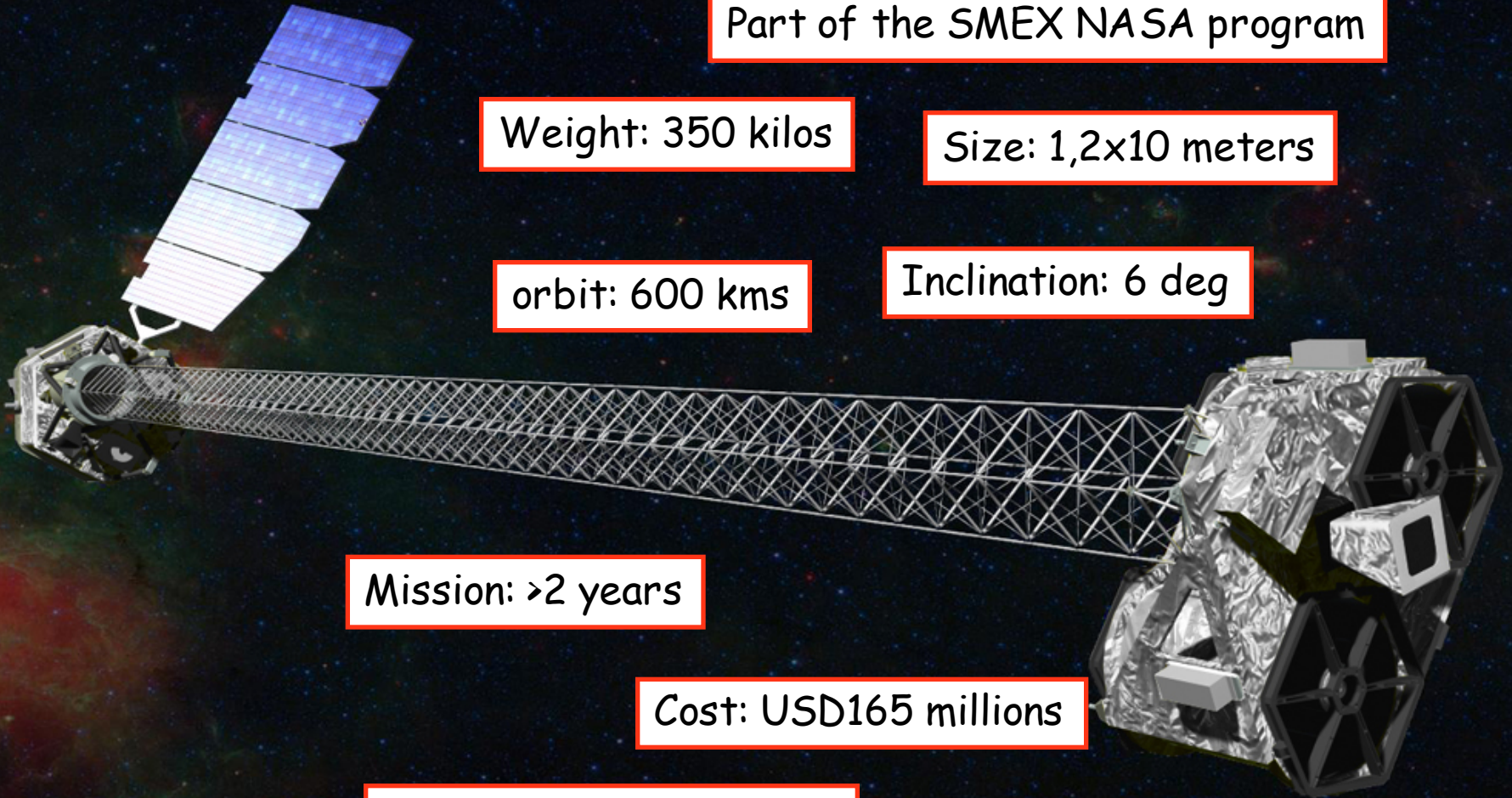
orbit: 600 kms

Inclination: 6 deg

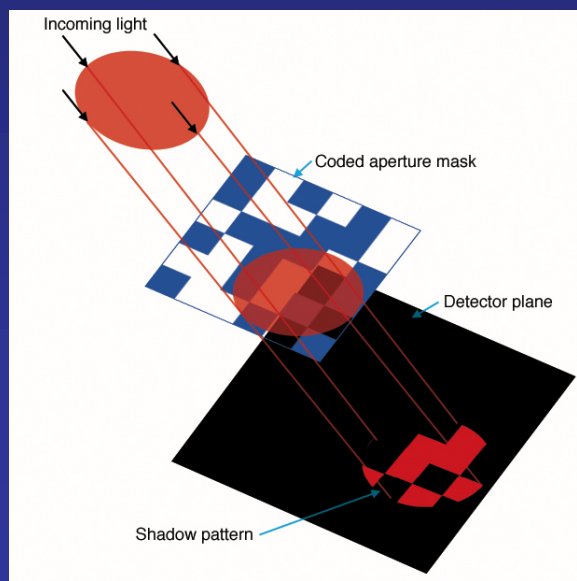
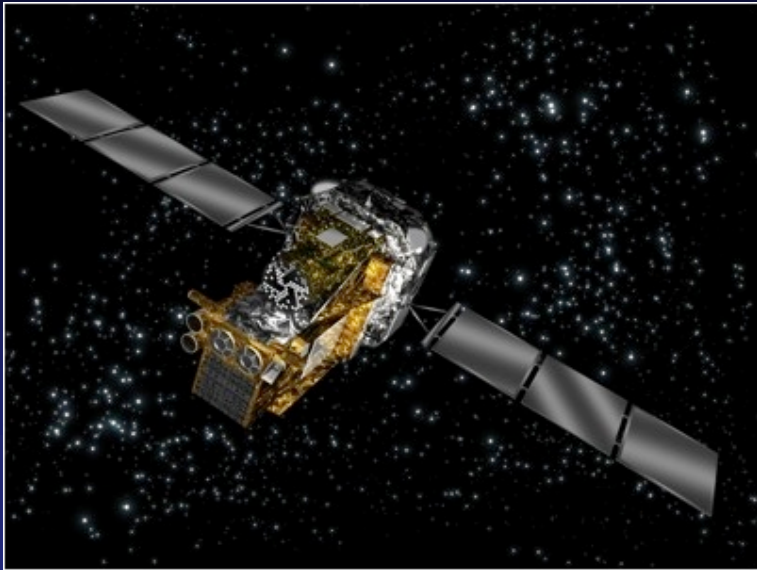
Mission: >2 years

Cost: USD165 millions

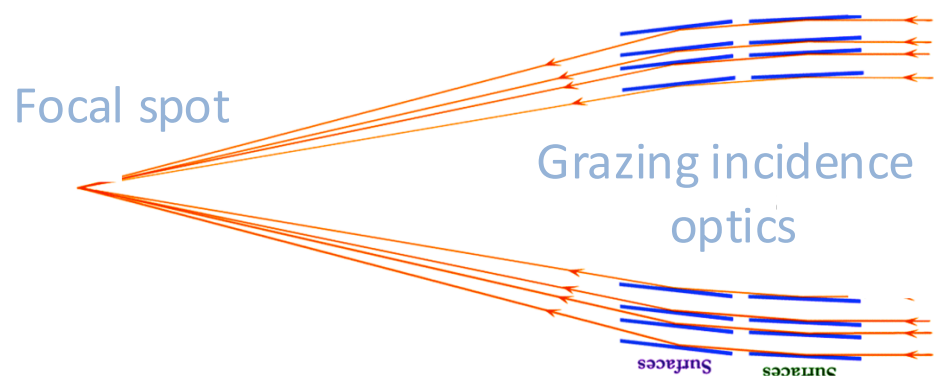
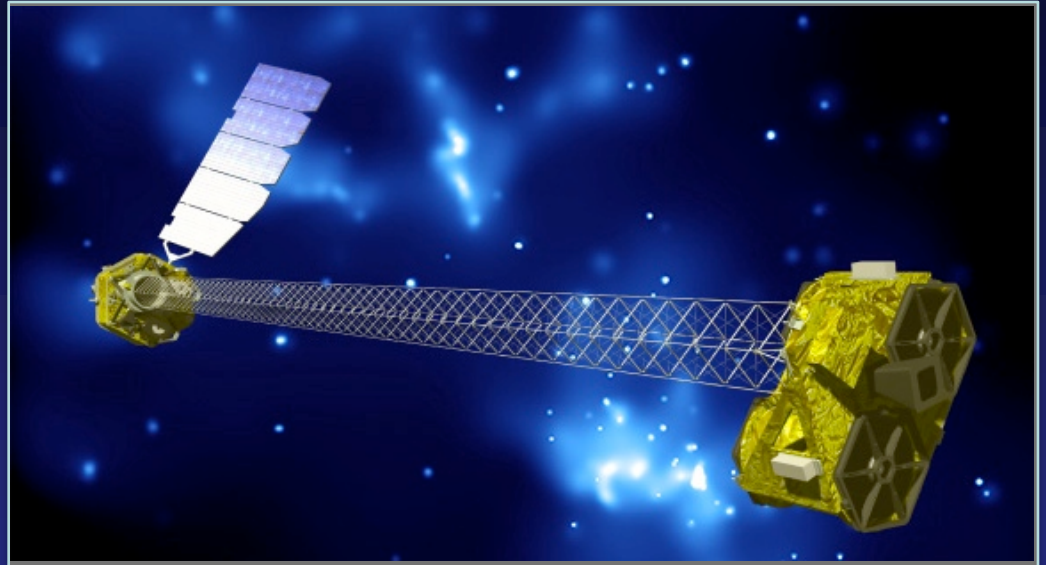
Launch: June 13th, 2012



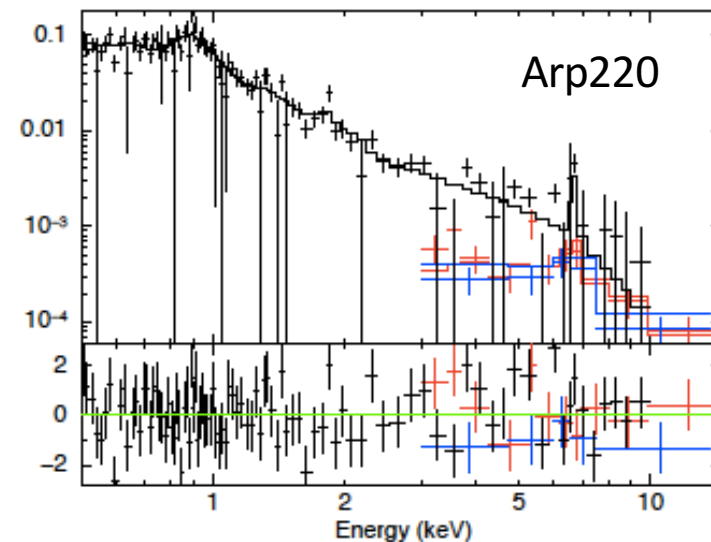
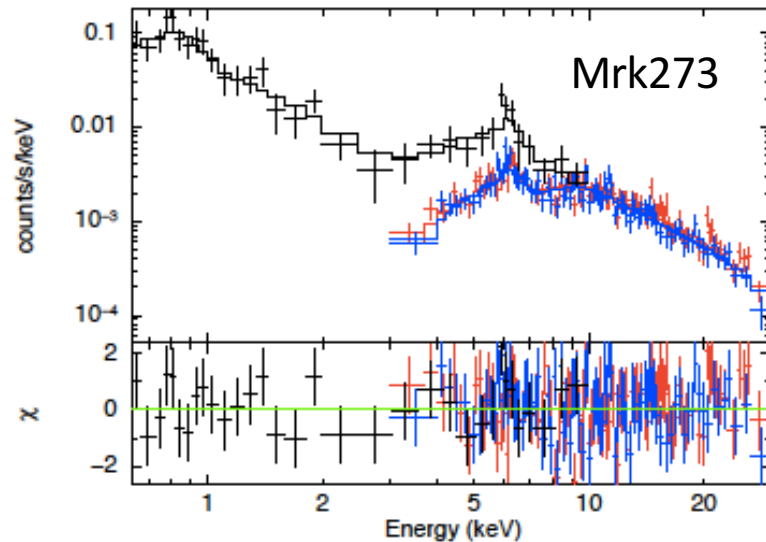
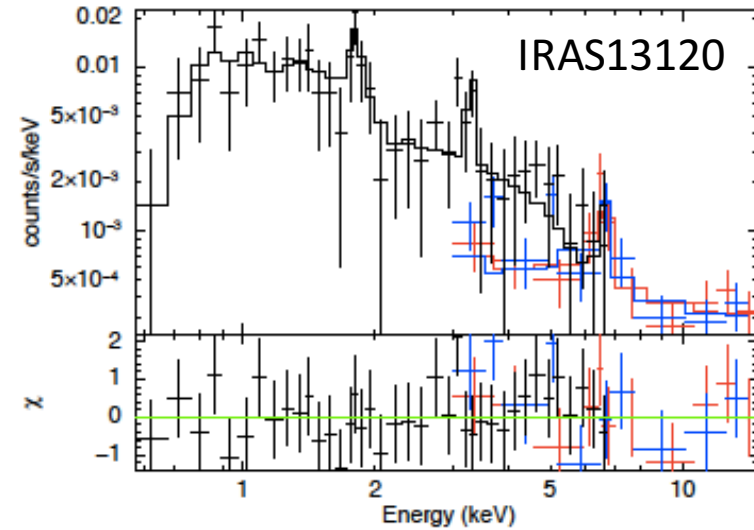
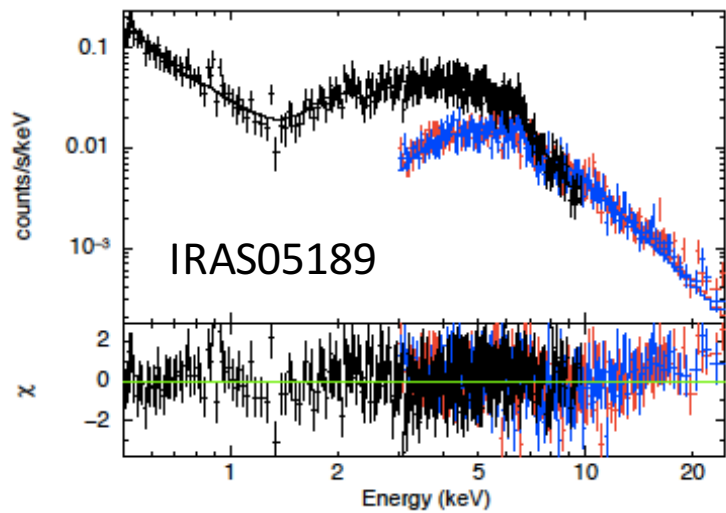
## INTEGRAL, Swift BAT



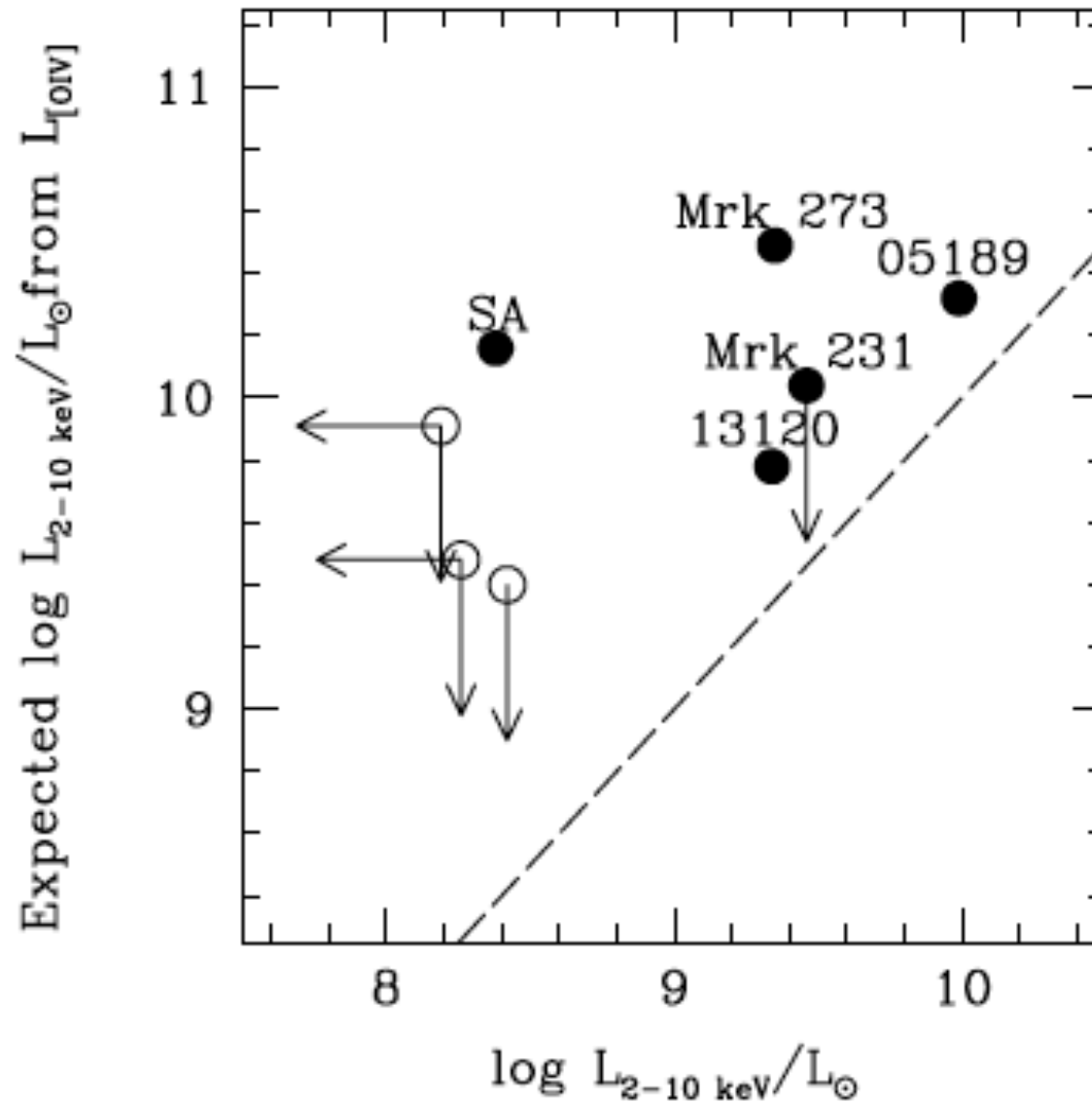
## NuSTAR



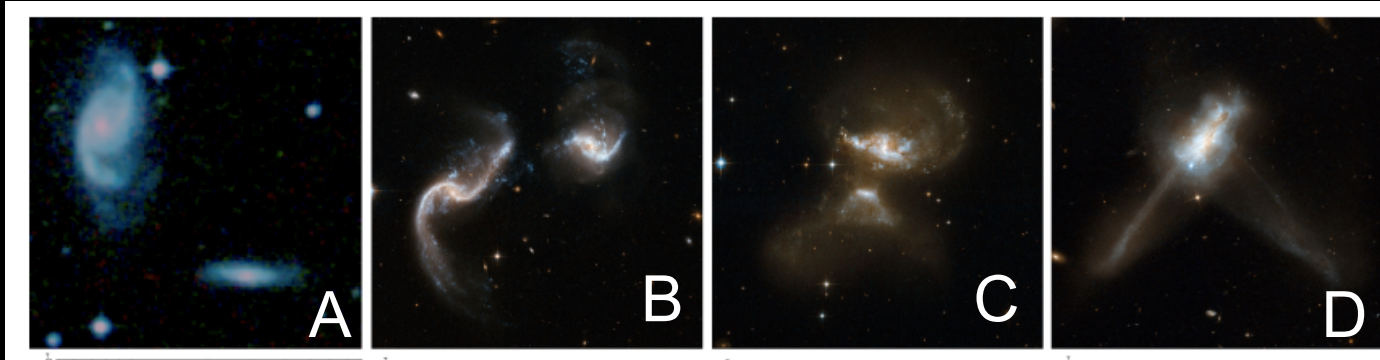
# NuSTAR ULIRGs Observations



# ULIRGs Are X-ray Underluminous



# Complete Sample of nearby (U)LIRGs



Nearby (U)LIRGs spanning the merger sequence following the Stierwalt et al. 2013 morphological classification.

NuSTAR Cycle 1 GO Program  
200 ksec, 12 targets

- Have existing Chandra Observations
- <120 Mpc away
- $\log L_{\text{FIR}} > 11.3 L_{\odot}$

| Name            | $\log L_{\text{IR}}$<br>(erg/s) | Merger<br>Stage |
|-----------------|---------------------------------|-----------------|
| MCG+08-18-013   | 11.34                           | A               |
| NGC3110         | 11.37                           | A               |
| Arp256          | 11.48                           | B               |
| ESO440-IG058_N  | 11.43                           | B               |
| ESO440-IG058_S  | 11.43                           | B               |
| NGC6286_N       | 11.37                           | B               |
| NGC6286_S       | 11.37                           | B               |
| MCG+12-02-001   | 11.50                           | C               |
| NGC4922         | 11.38                           | C               |
| IRASF18293-3413 | 11.88                           | C               |
| NGC0034         | 11.49                           | D               |
| IRASF17138-1017 | 11.49                           | D               |

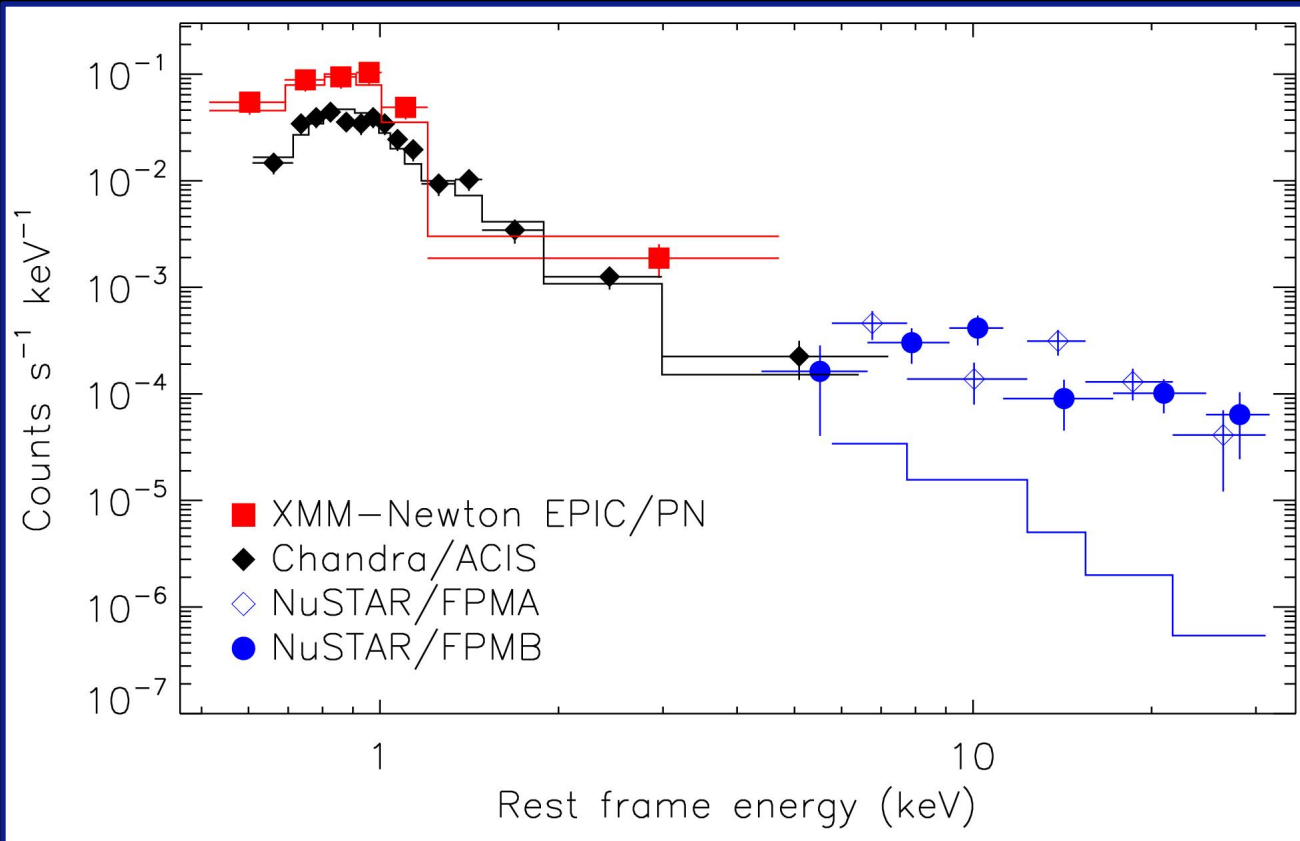
# Complete Sample of nearby (U)LIRGs

NGC6286 (stage B)



# Complete Sample of nearby (U)LIRGs

## NGC6286 (stage B)



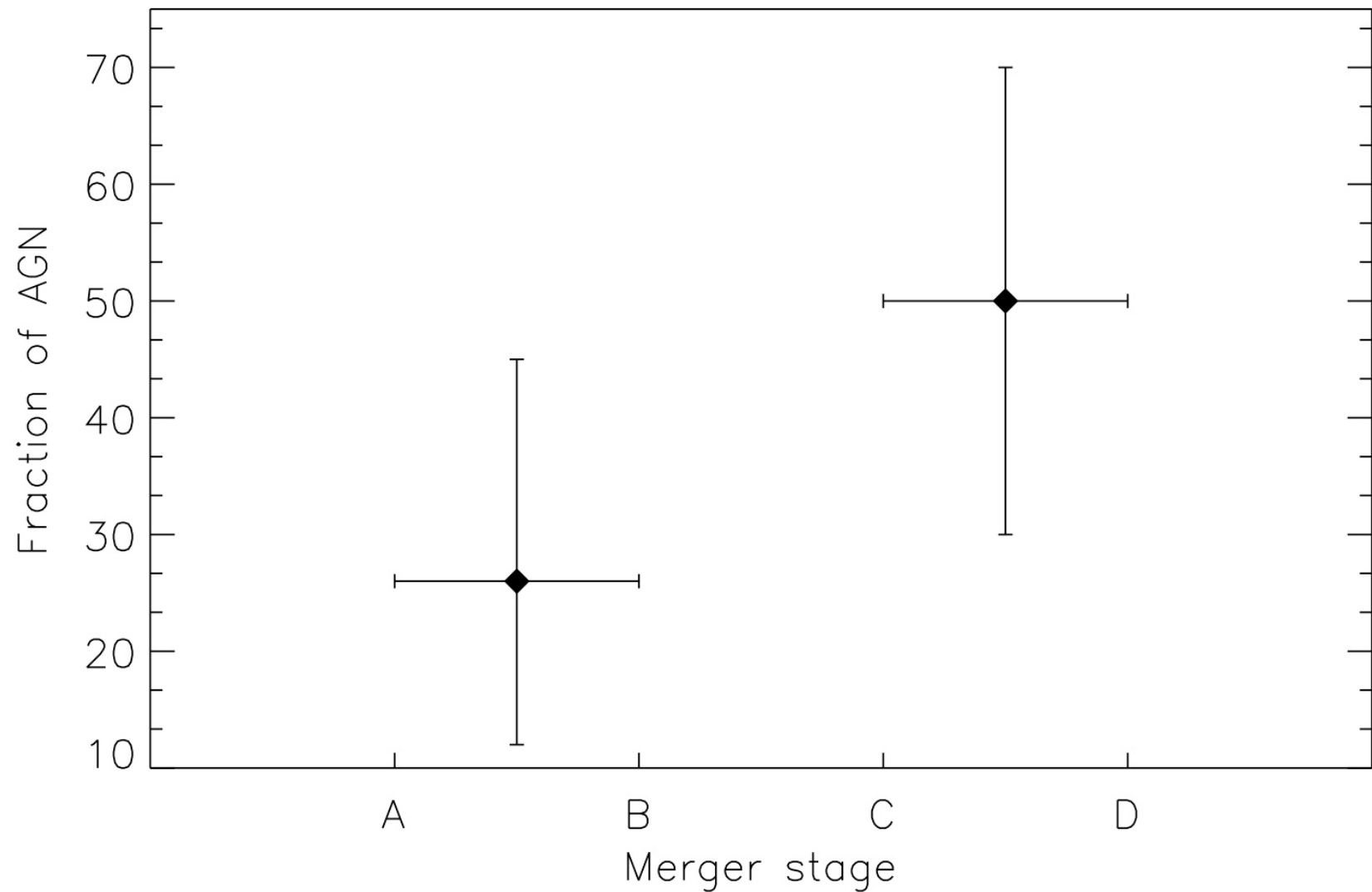
Ricci et al., 2016

New heavily-obscured AGN confirmed by NuSTAR observations.

$$N_H \sim 6 \times 10^{23} - 1.3 \times 10^{24} \text{ cm}^{-2}$$

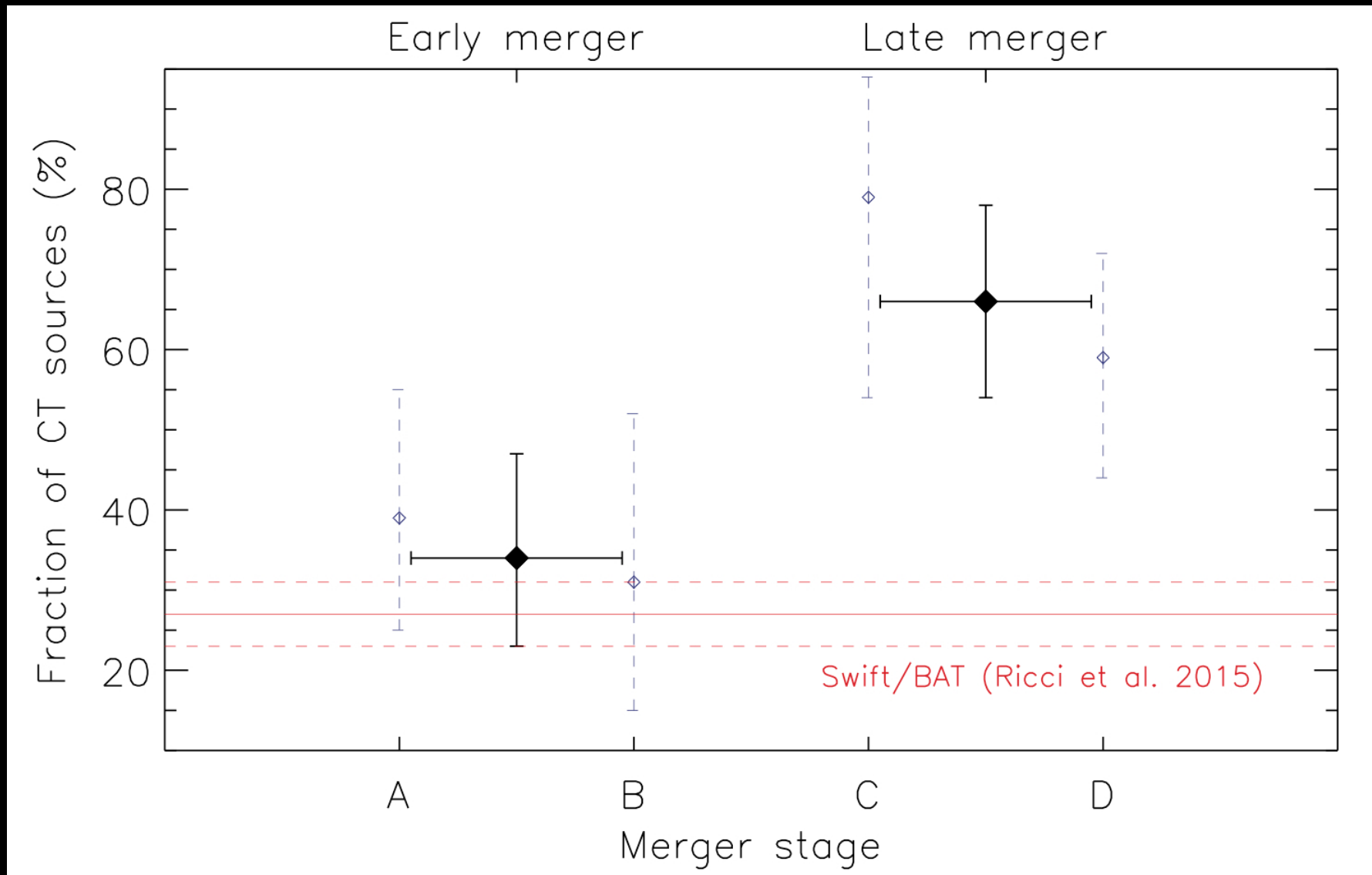
$$L_X(10-50 \text{ keV}) \sim 10^{42} \text{ erg/s}$$

# AGN Fraction Versus Merger Stage

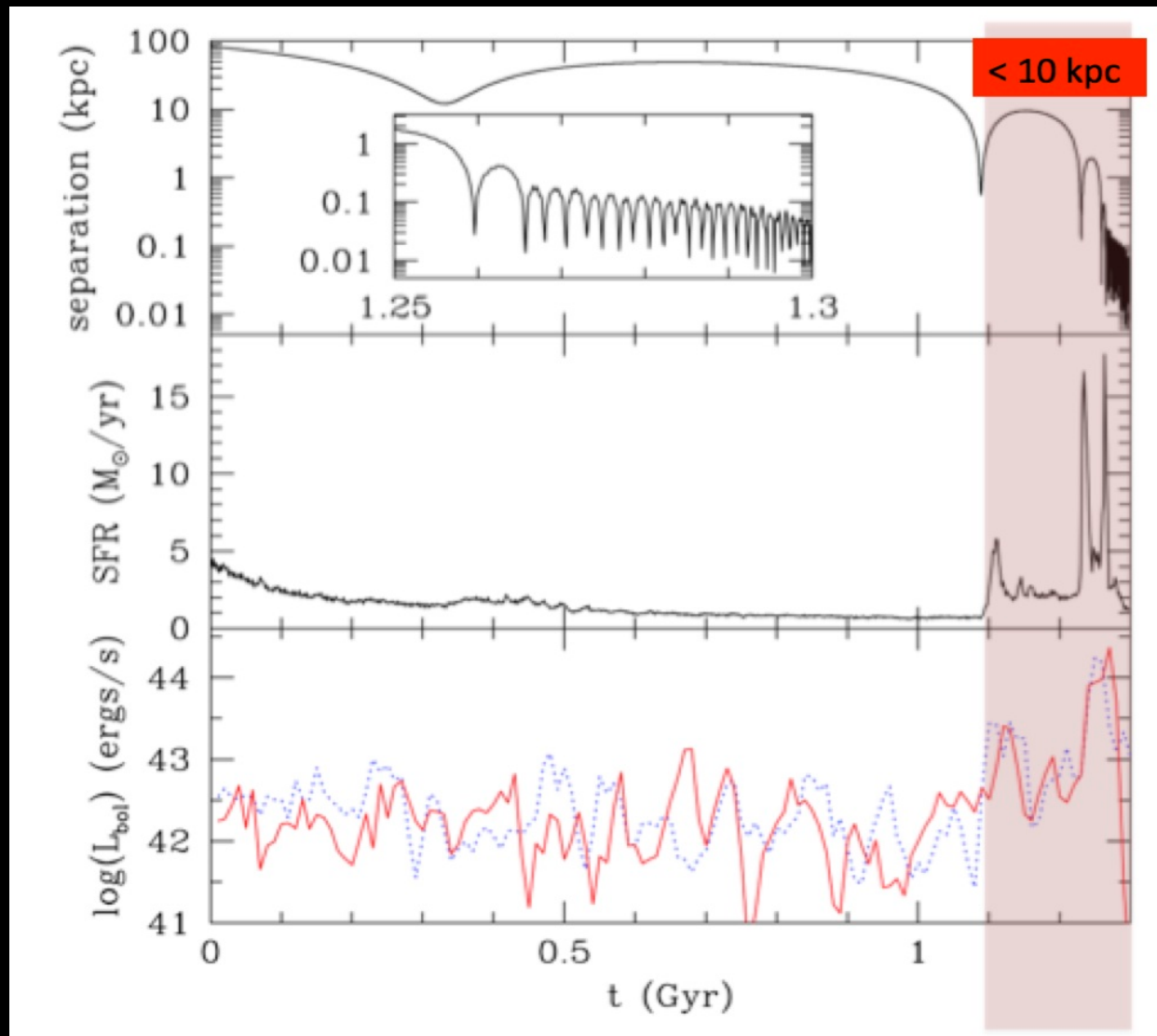


Ricci et al., in prep.

# Compton Thick AGN Fraction



# The Dual AGN Phase



Van Wassenhove et al. (2012)

# ALMA and IFU Observations of Nearby Dual AGN

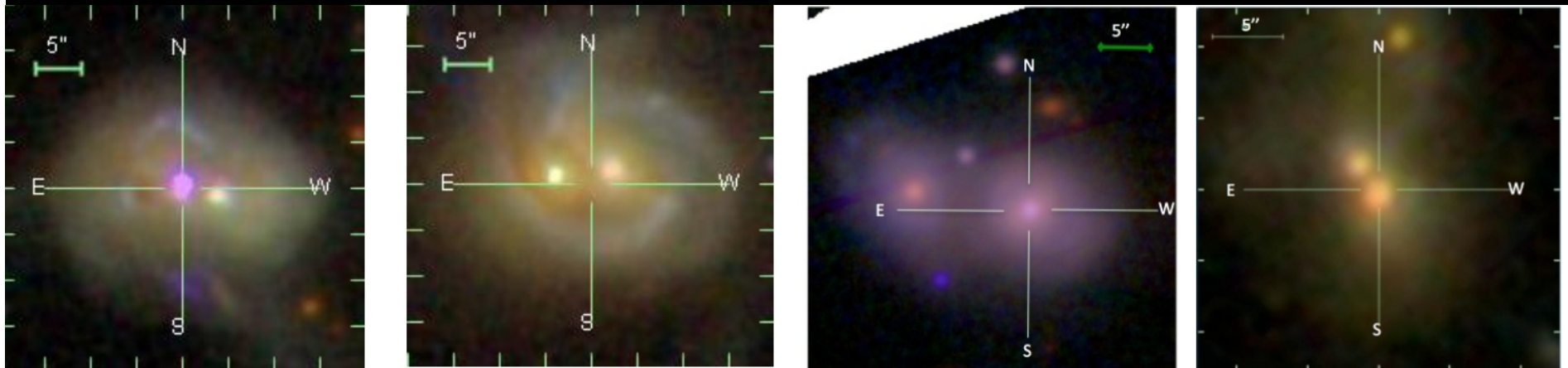
Tracing the gas distribution in merging galaxies with:

- ALMA (Cycle 2, PI: E. Treister, band 6, CO(2-1), 5 hours, Cycle 3 High resolution CO(2-1) NGC6240)
- VLT/MUSE (P95, PI: Treister, 9 hours)
- VLT/SINFONI (P93, PI: S. Cales, 16 hours)

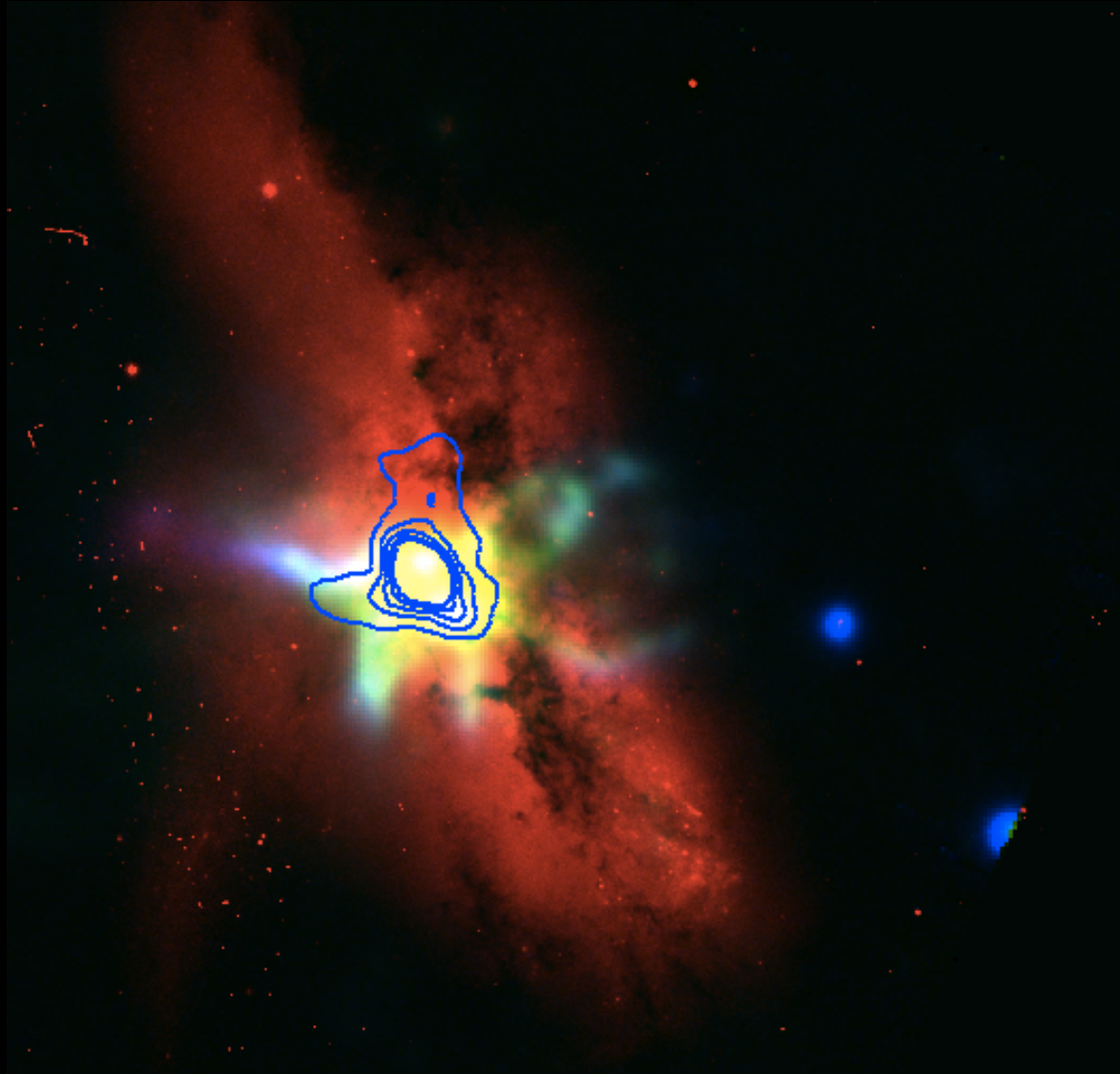
Mrk 463

Mrk739

ESO 509    2MASX J1611554

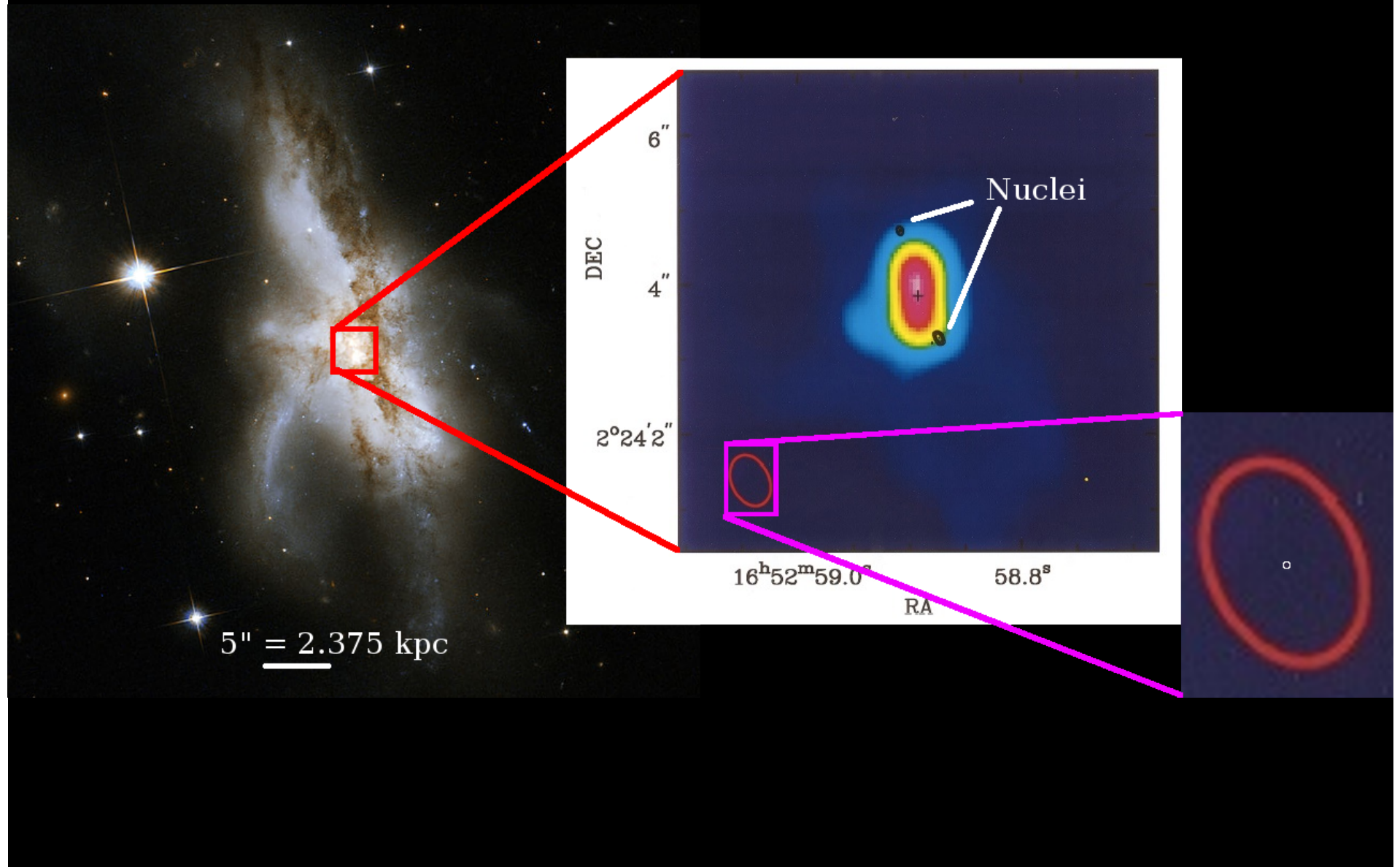


# H $\alpha$ , [OIII] and CO Emission in NGC6240



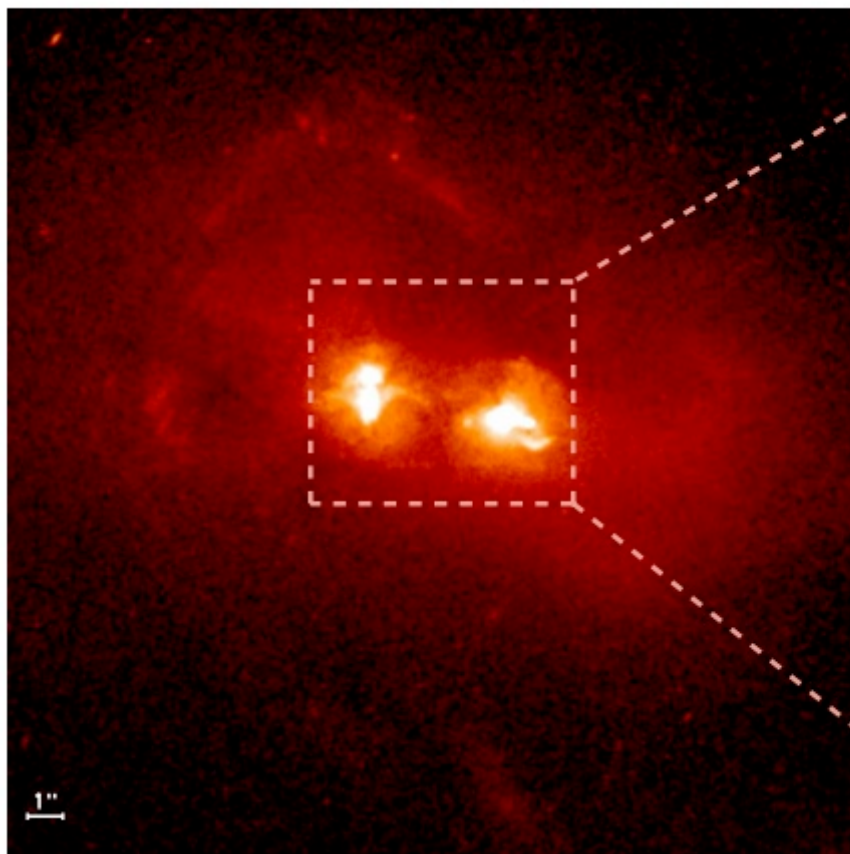
Privon et al., in prep.

# ALMA Cycle 3 Observations of NGC6240

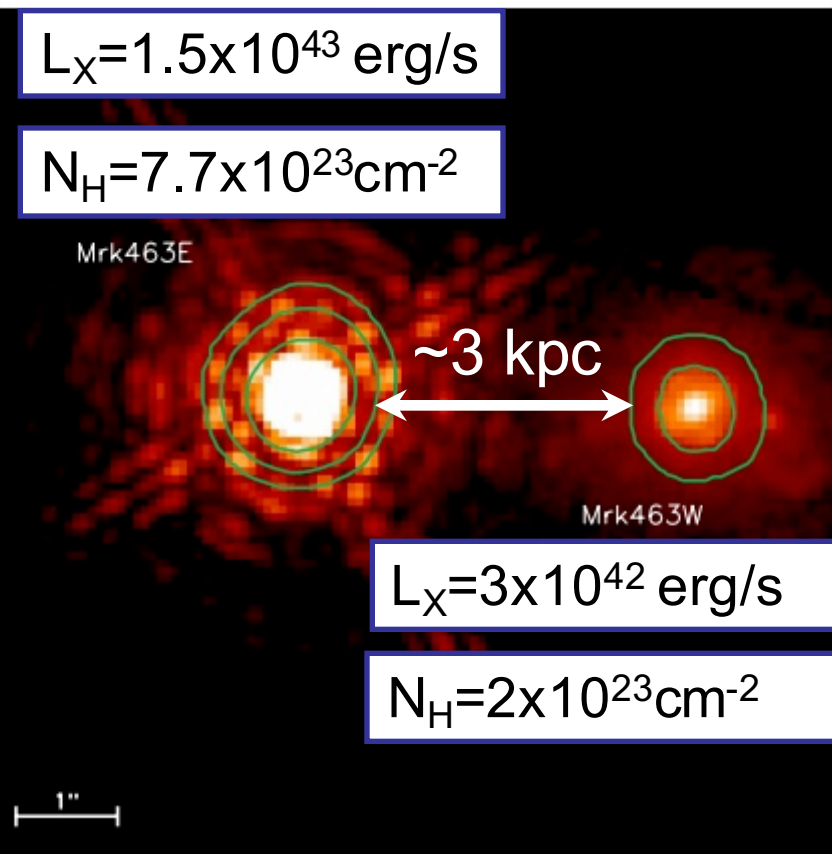


# Mrk 463 Chandra

Optical galaxy



X-ray/NIR Nuclei

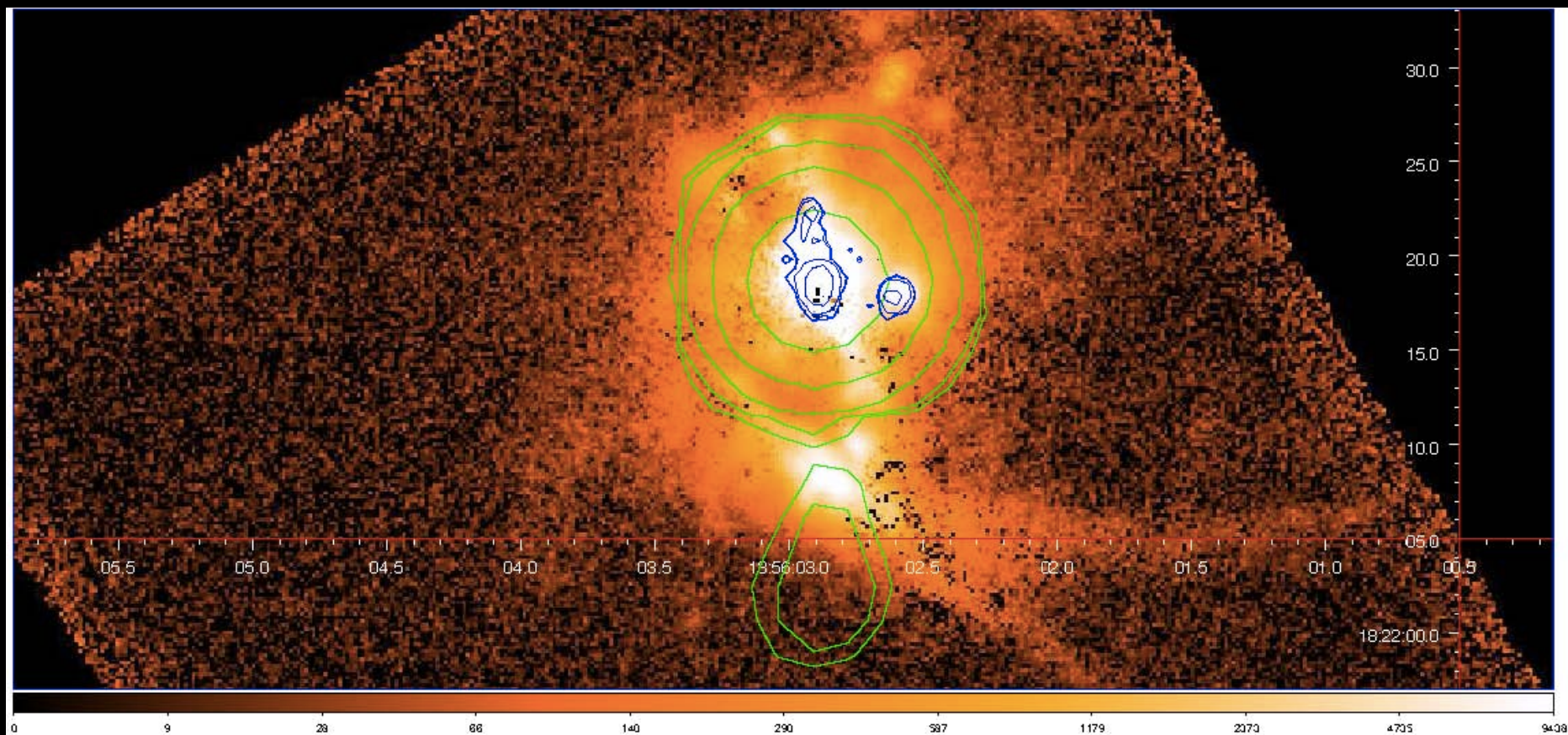


# Mrk 463 MUSE Image



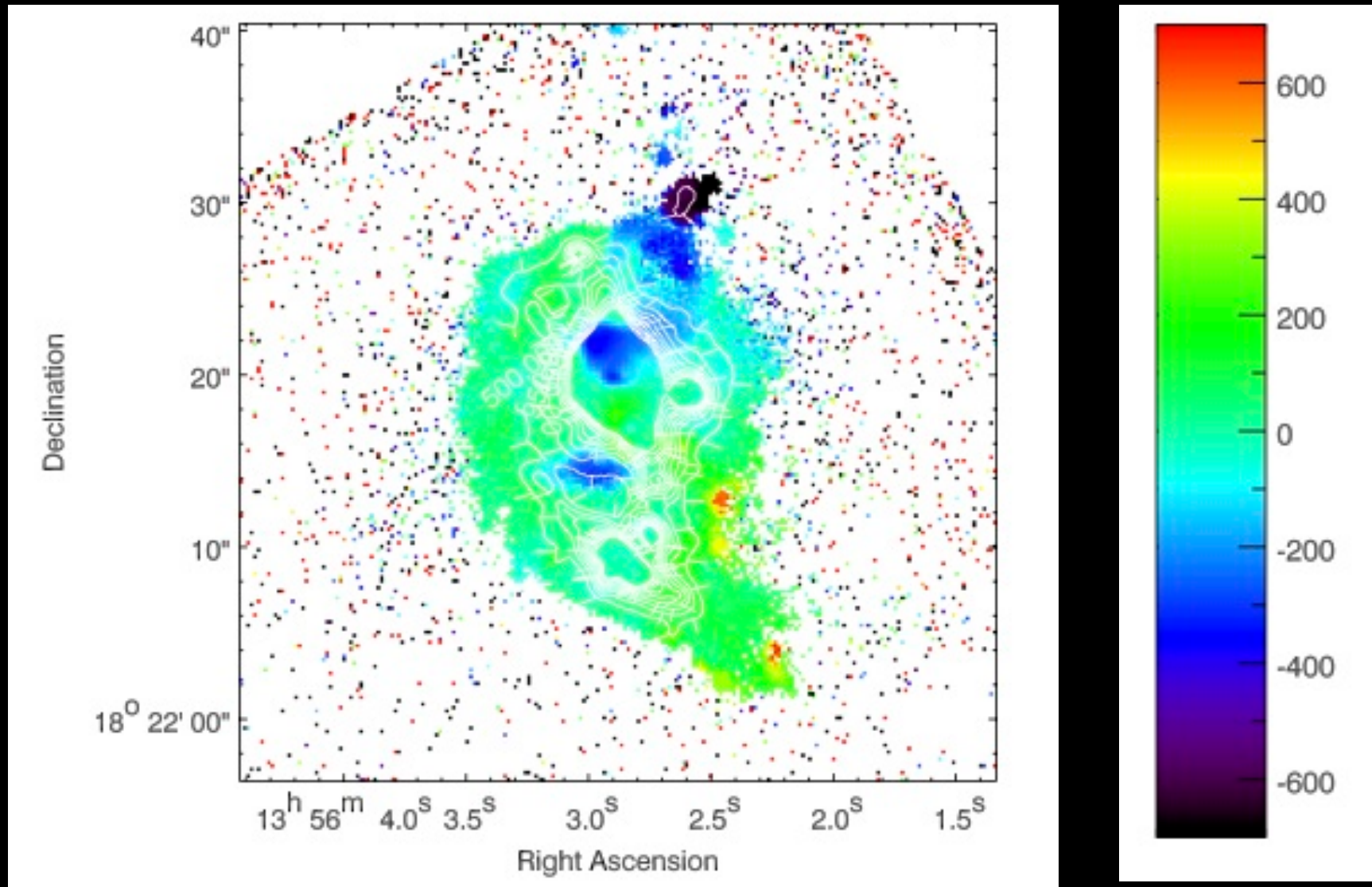
Treister et al., in prep.

# Mrk 463 [OIII] Emission



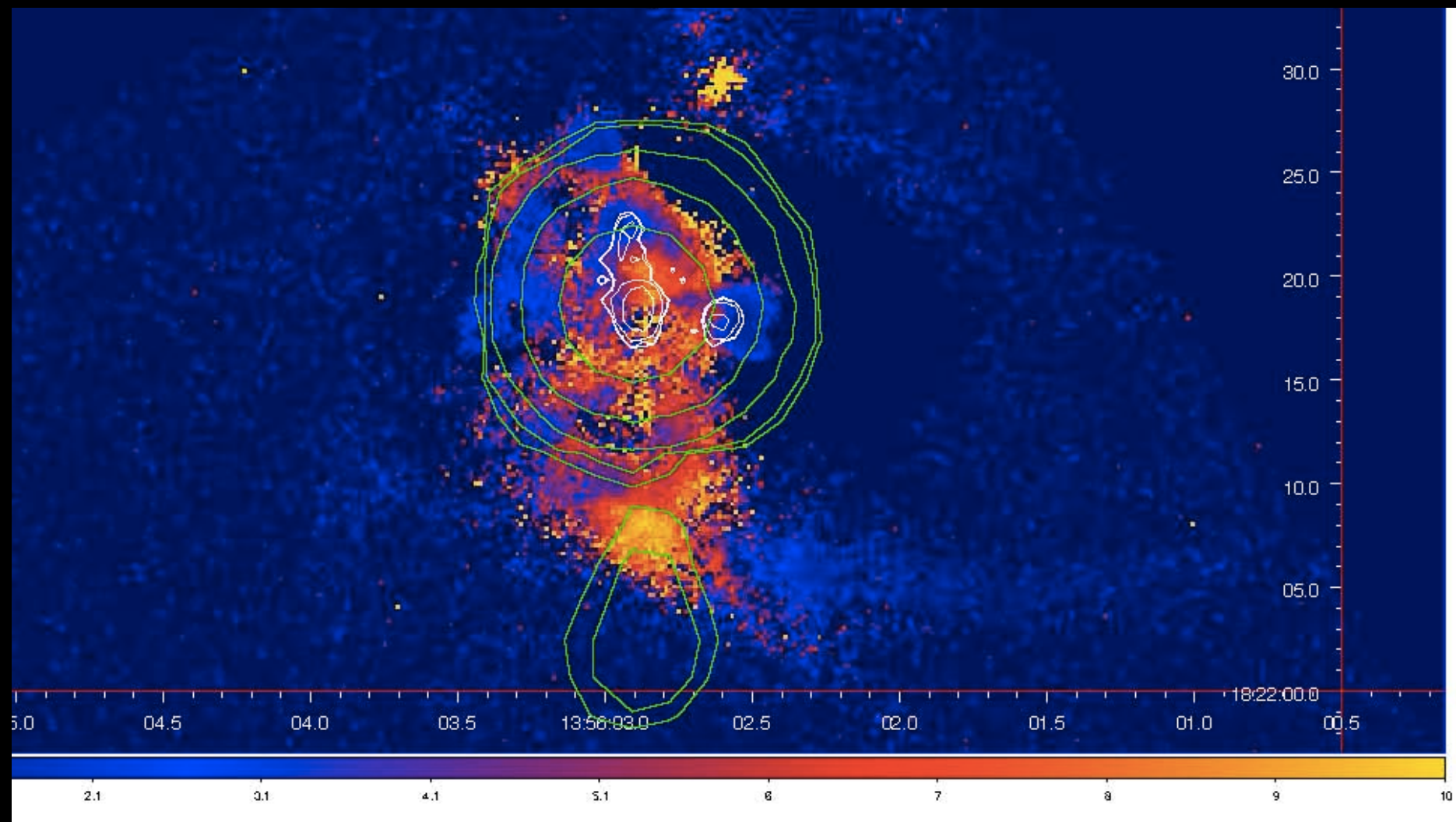
Treister et al., in prep.

# Mrk 463 Velocity Profile



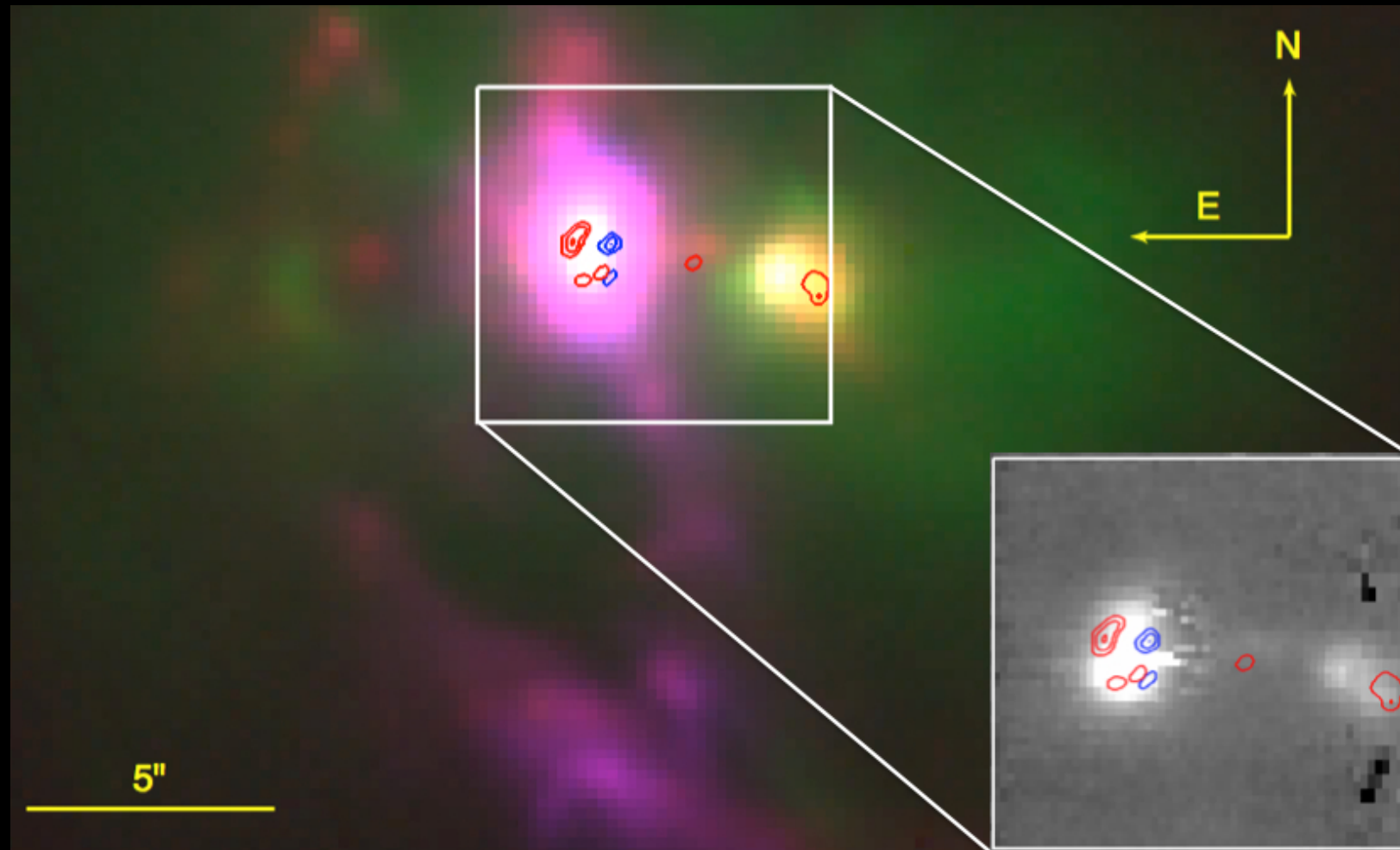
Treister et al., in prep.

# Mrk 463 [OIII] to H $\beta$



Treister et al., in prep.

# Mrk 463 MUSE+SINFONI+ALMA



Treister et al., in prep.

# Summary

Clear connection between galaxy mergers and the most luminous AGN activity, which can account for  $\sim 60\%$  of the total SMBH growth.

Heavily Obscured (Compton-thick) phase can be  $\sim 30\%$  of total BH growth.

Higher (obscured) AGN fraction when the two galaxies are near coalescence.

ALMA and IFU studies of dual AGN show evidence of outflows and potentially feedback effects. These are the sources in which the SMBH-galaxy co-evolution takes place.