Uncovering the Elusive Signatures of Obscured AGN in Mergers

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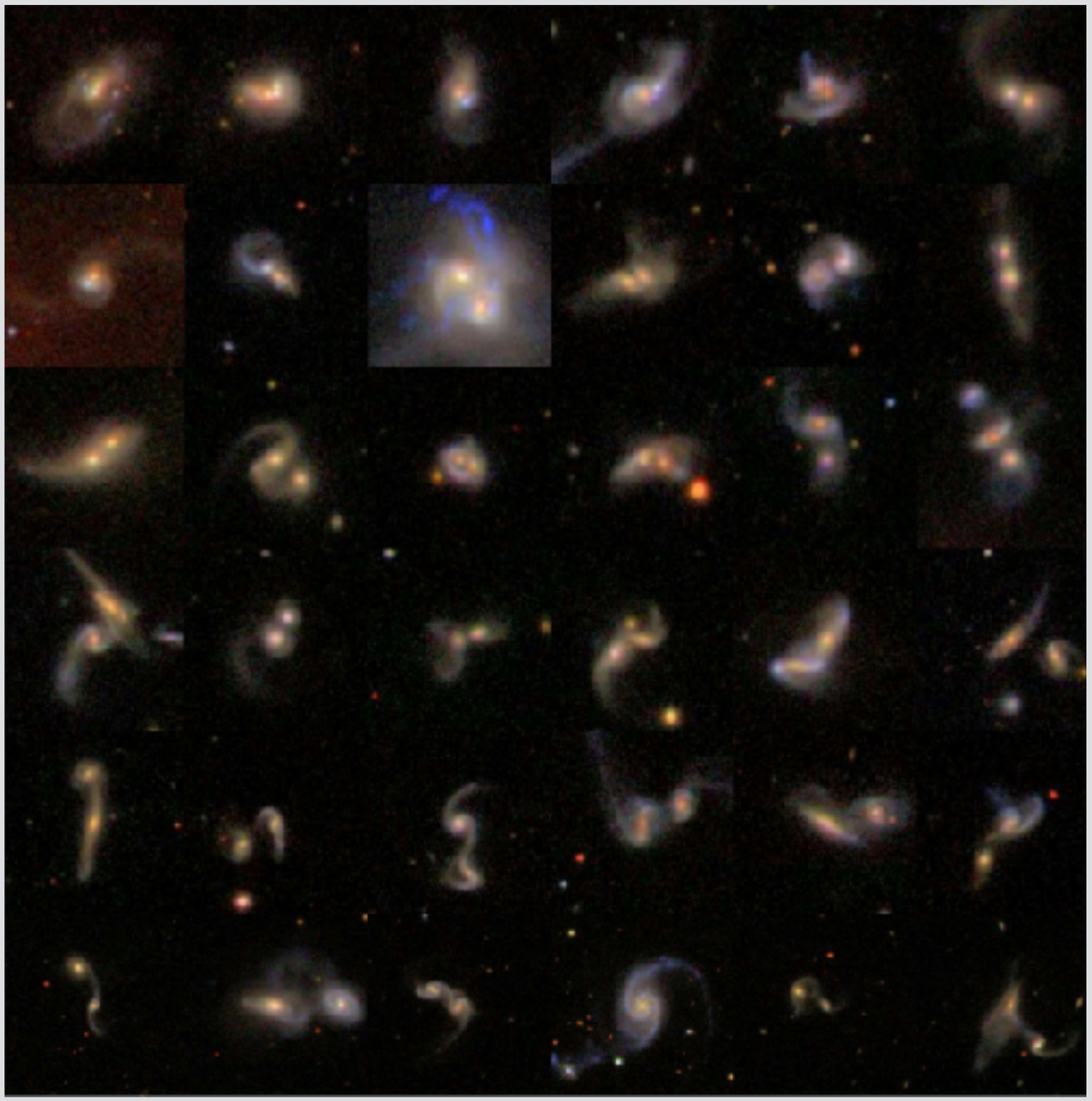
Elusive AGN Conference, George Mason Univ.

June 11-15, 2017

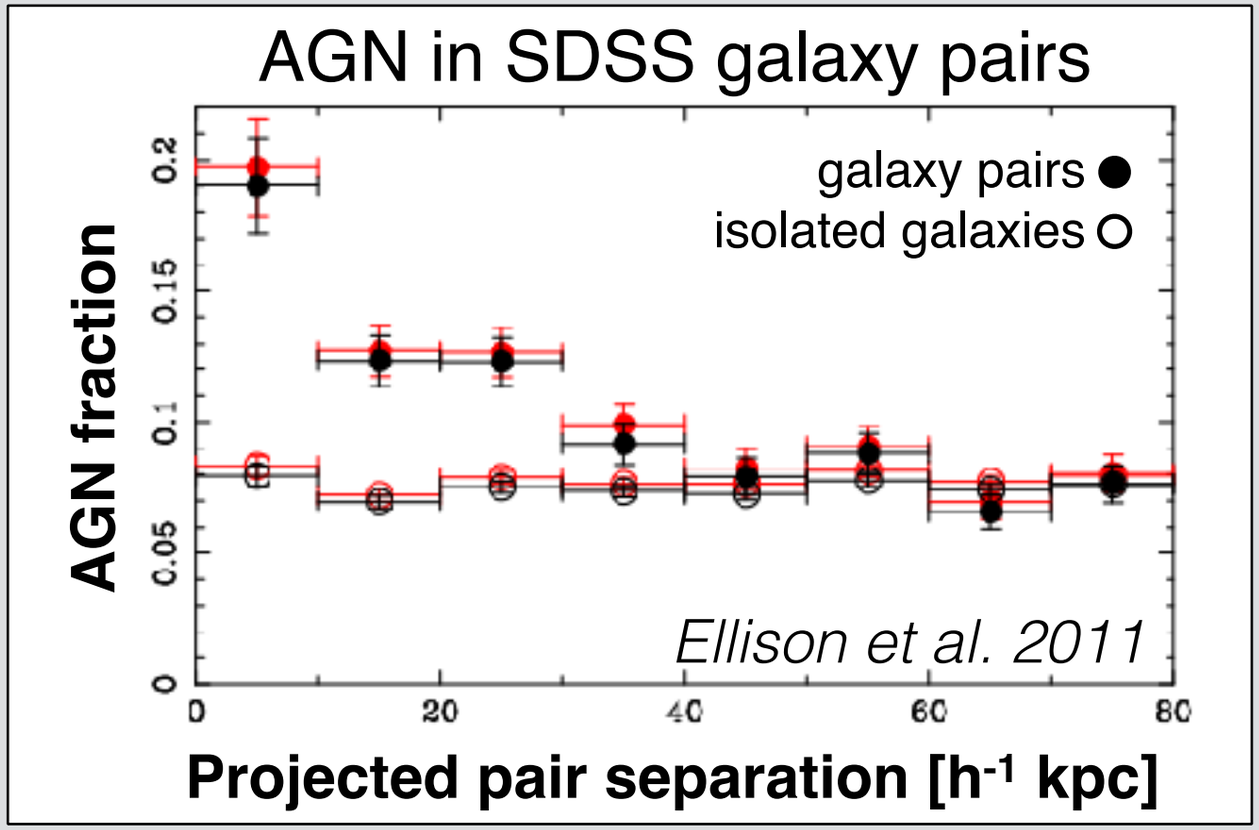
The elusive merger/AGN connection



(Liu et al. 2011)

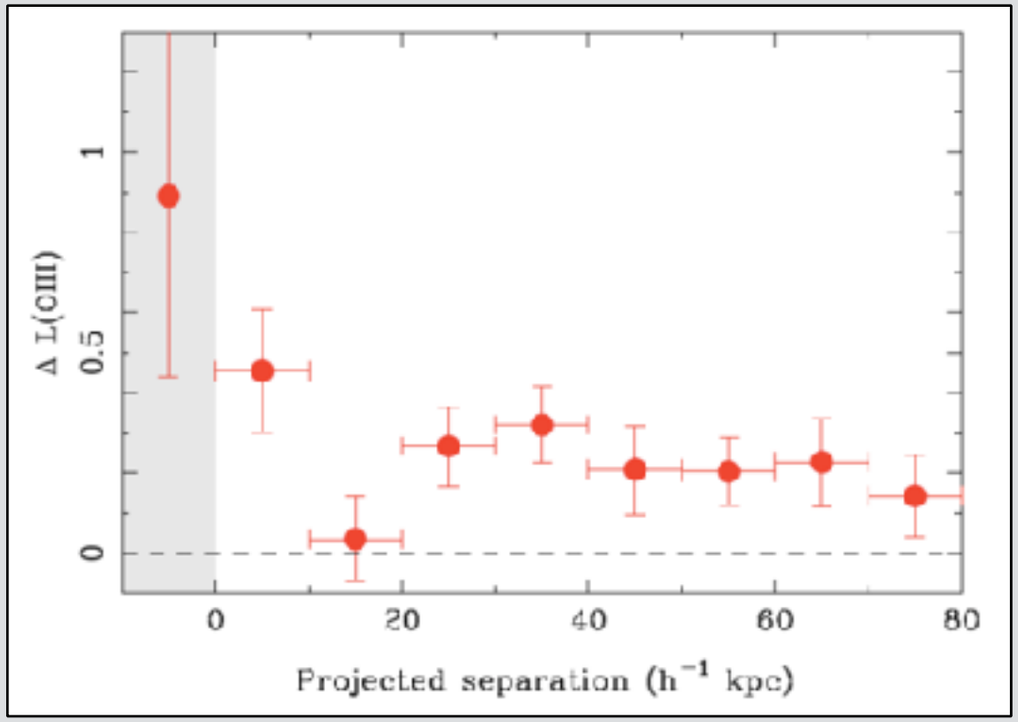
- A small minority of SDSS AGN are hosted in apparent mergers (~4% with companion within 100kpc, Liu et al. 2011)
- Most optically & (soft) X-ray selected AGN hosts show no signs of merger activity (e.g., Cisternas et al. 2011, Kocevski et al. 2012, Villforth et al. 2014)
- No evidence for a connection between mergers & AGN fueling?
- **Selection effects (e.g., merger stage, AGN luminosity, & nuclear obscuration)**

Mergers trigger AGN fueling

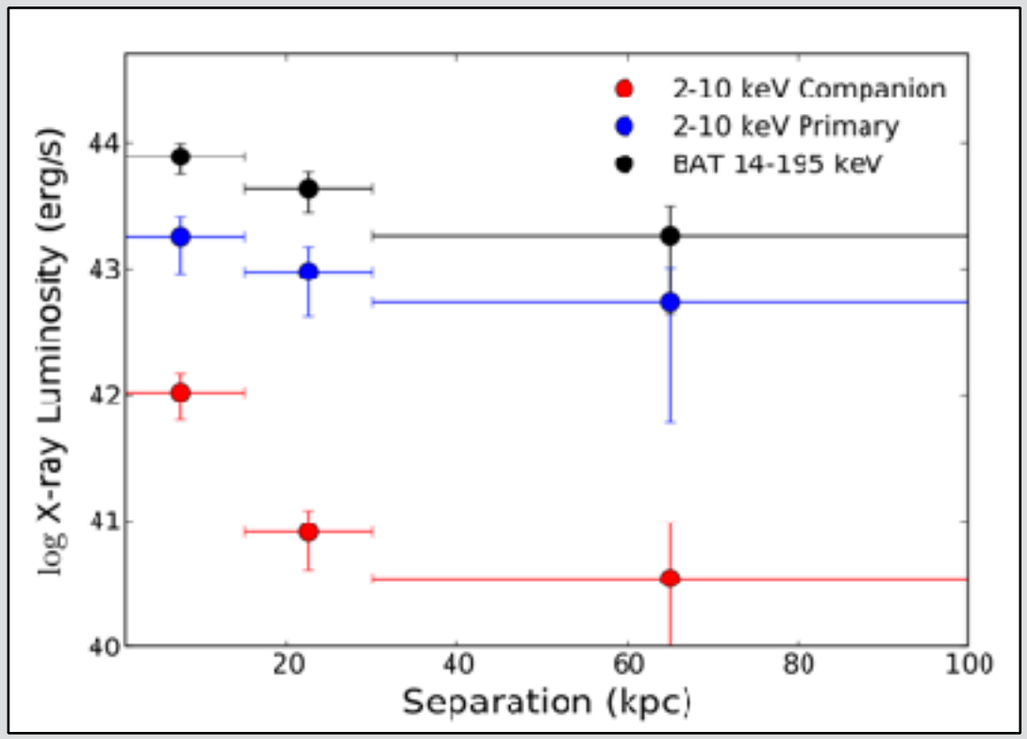


- AGN activity is enhanced in galaxy pairs
- Strongest enhancement in late-stage mergers

Mergers trigger *luminous* AGN

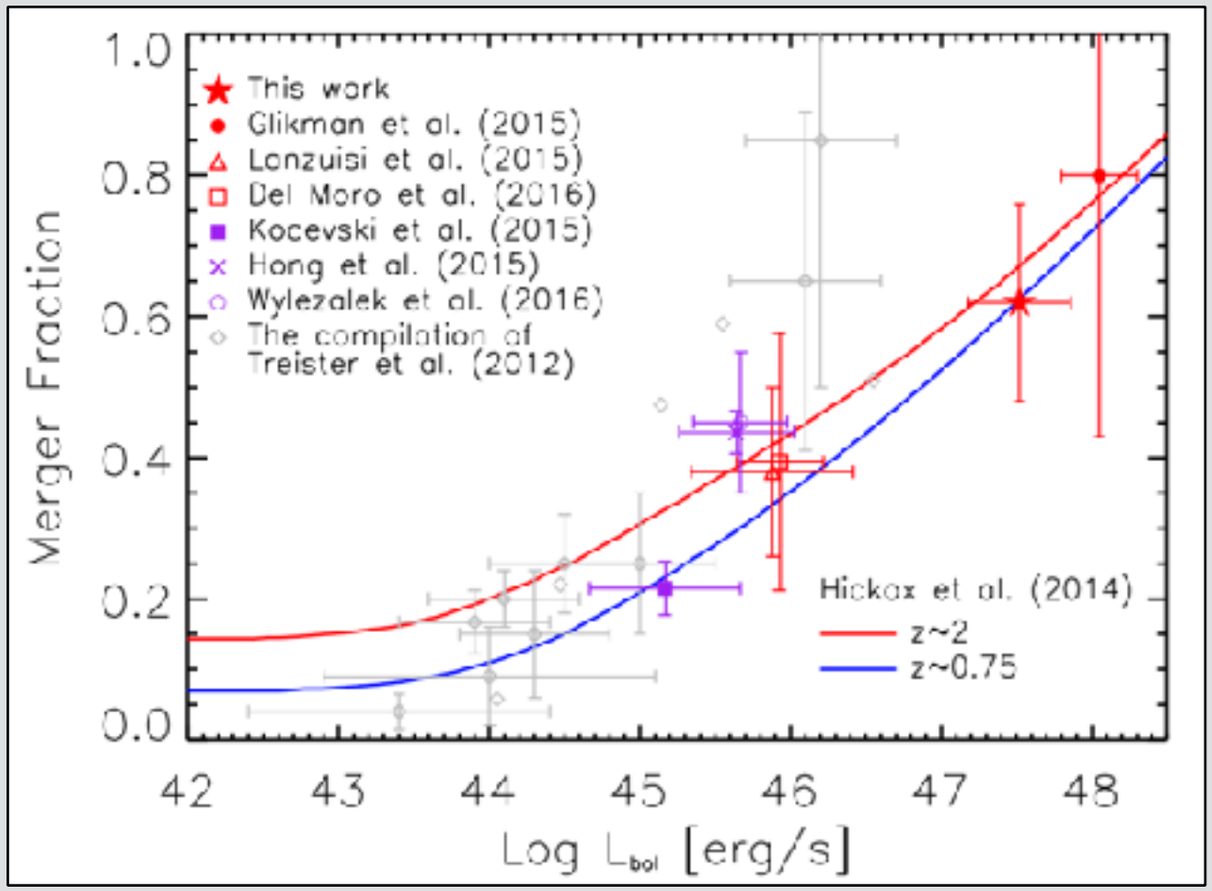


Ellison et al. 2013



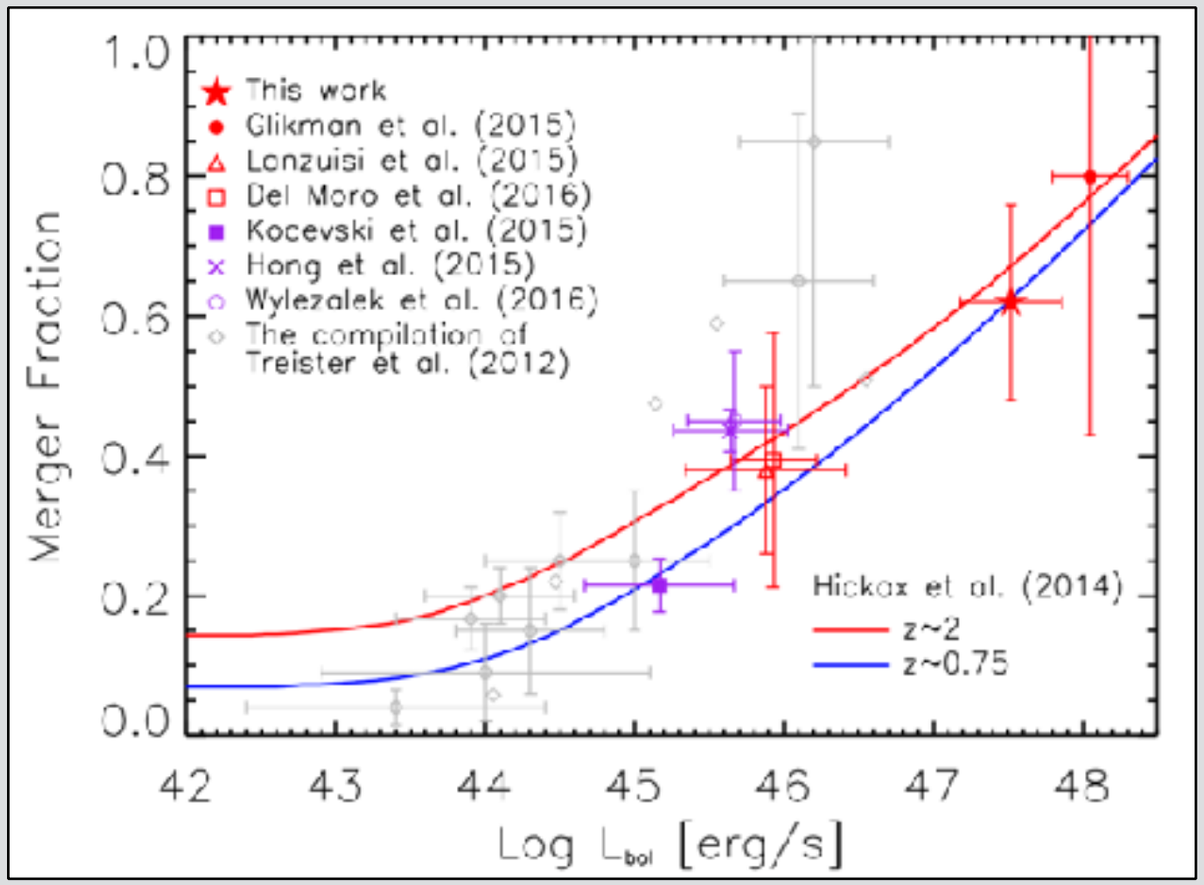
Koss et al. 2012

High merger fraction for hosts of the most luminous AGN:

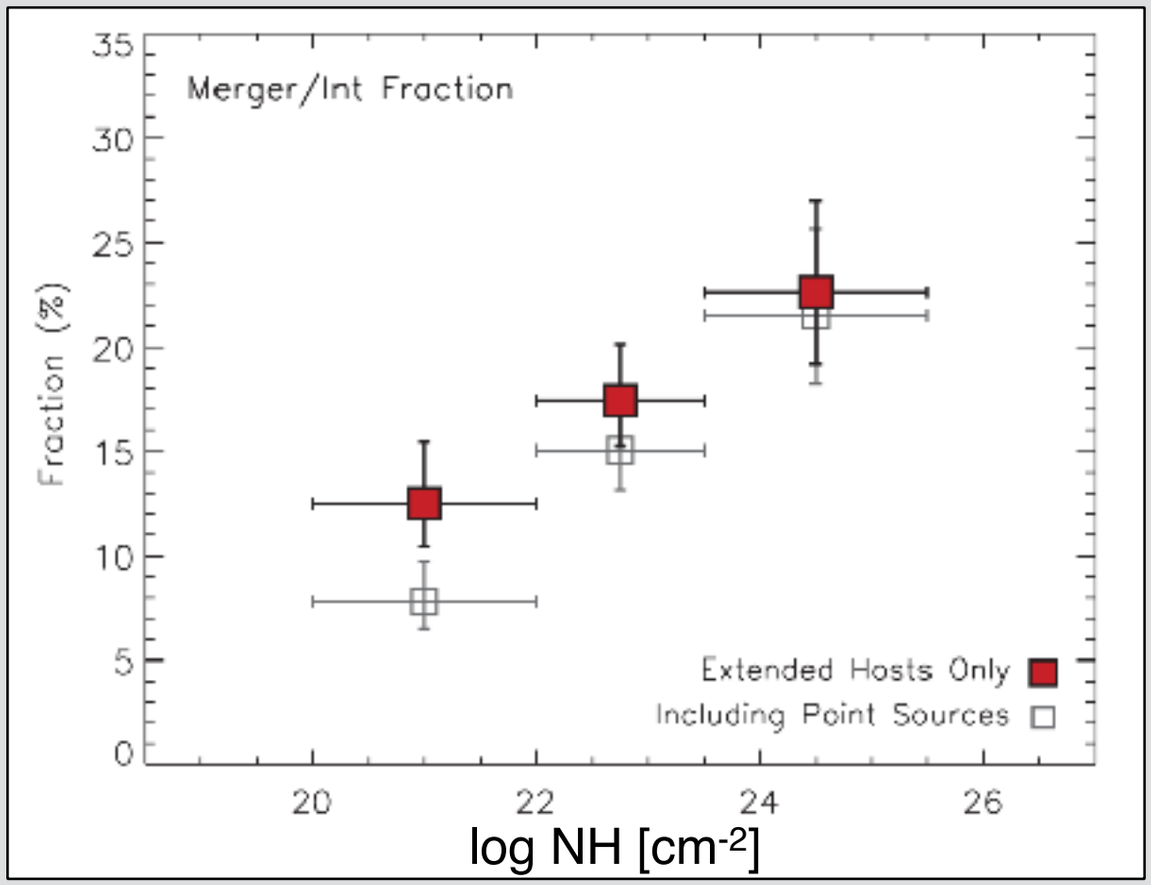


Fan et al. 2016

Mergers trigger *obscured, luminous* AGN

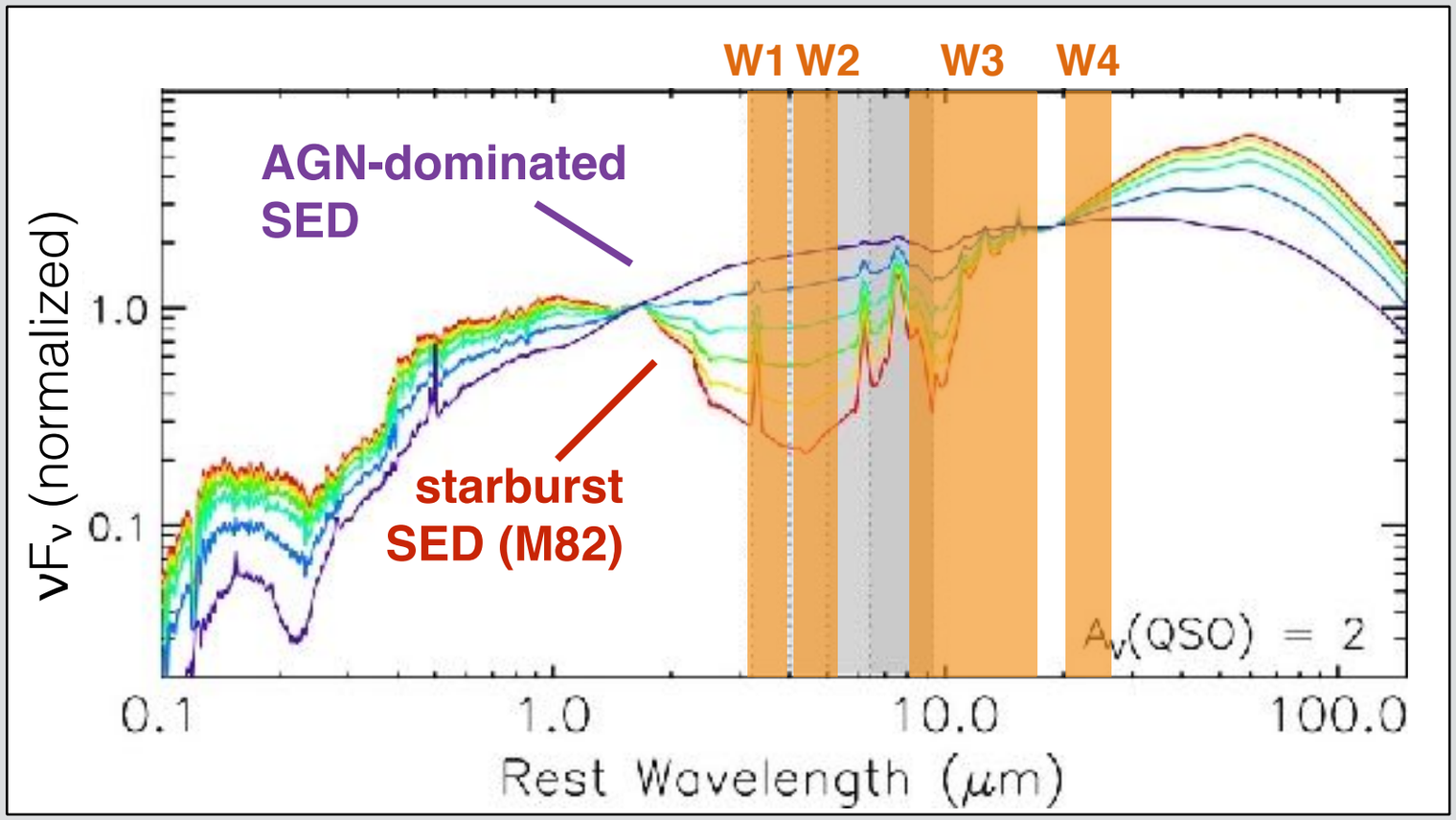


Fan et al. 2016



Kocevski et al. 2015

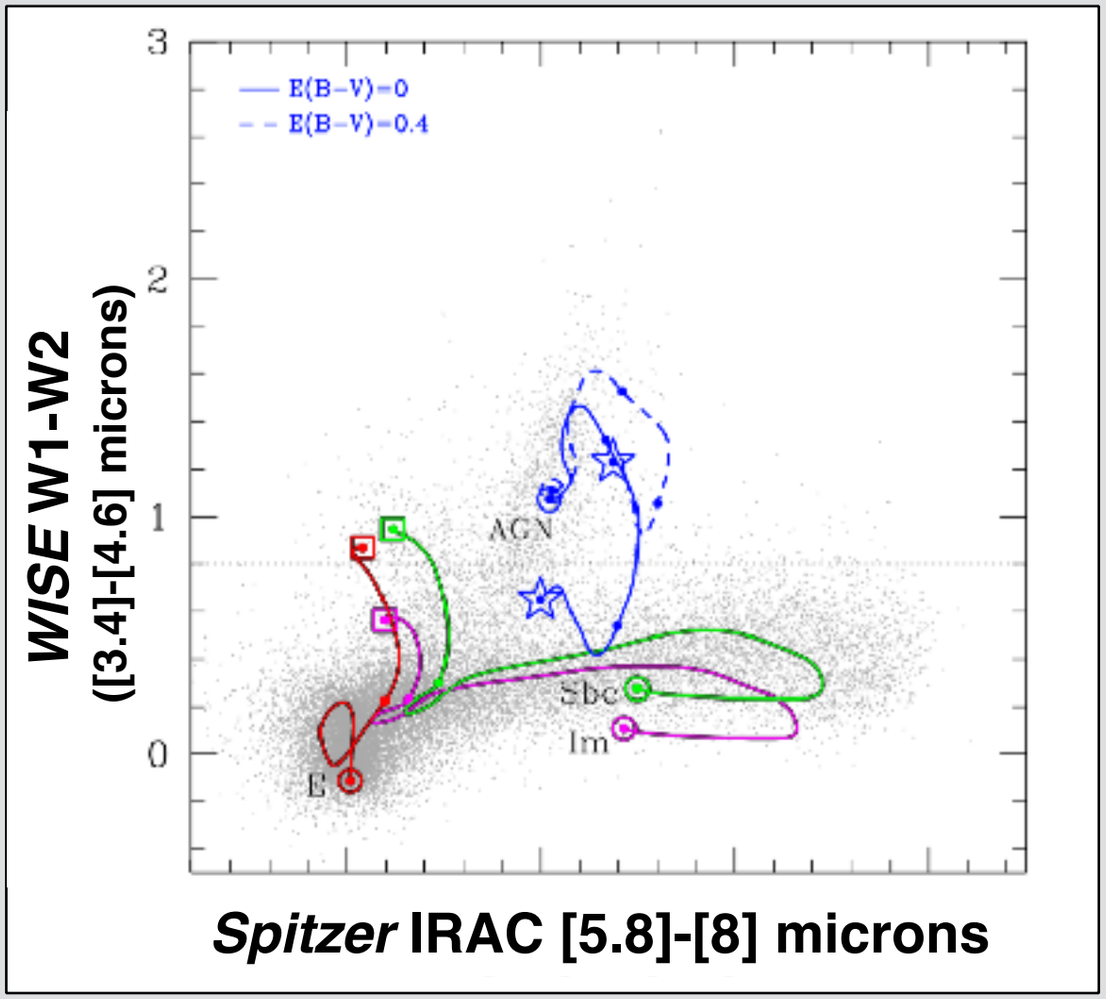
Mid-IR color selection of obscured, luminous AGN



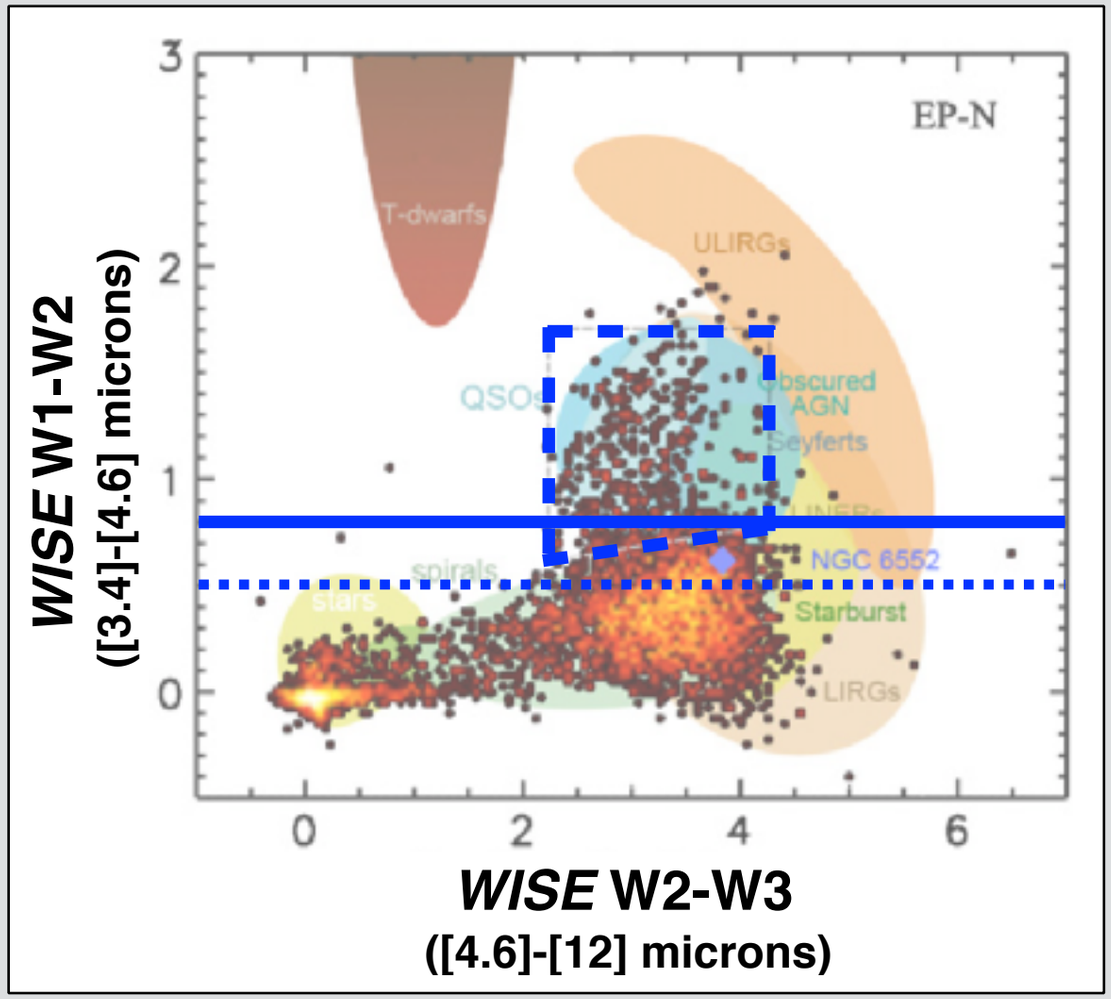
Donley et al. 2012

- Mid-IR SED sensitive to hot, AGN-heated dust
- But sensitive only to most luminous AGN (& contaminated by star-forming galaxies at high z)
- Large surveys possible (with e.g., *WISE)*

Mid-IR color selection of obscured, luminous AGN

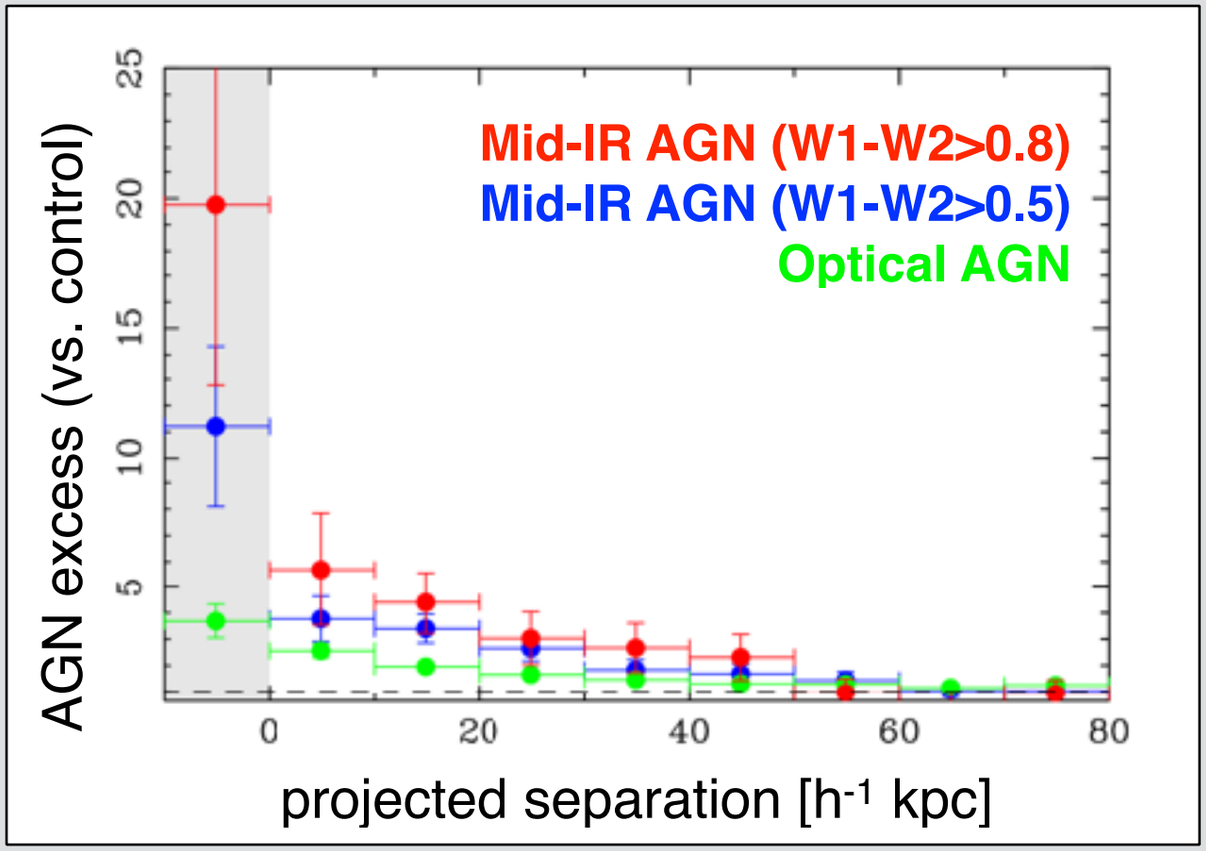


Assef et al. 2013



Jarrett et al 2011

Mid-IR color selection of obscured AGN



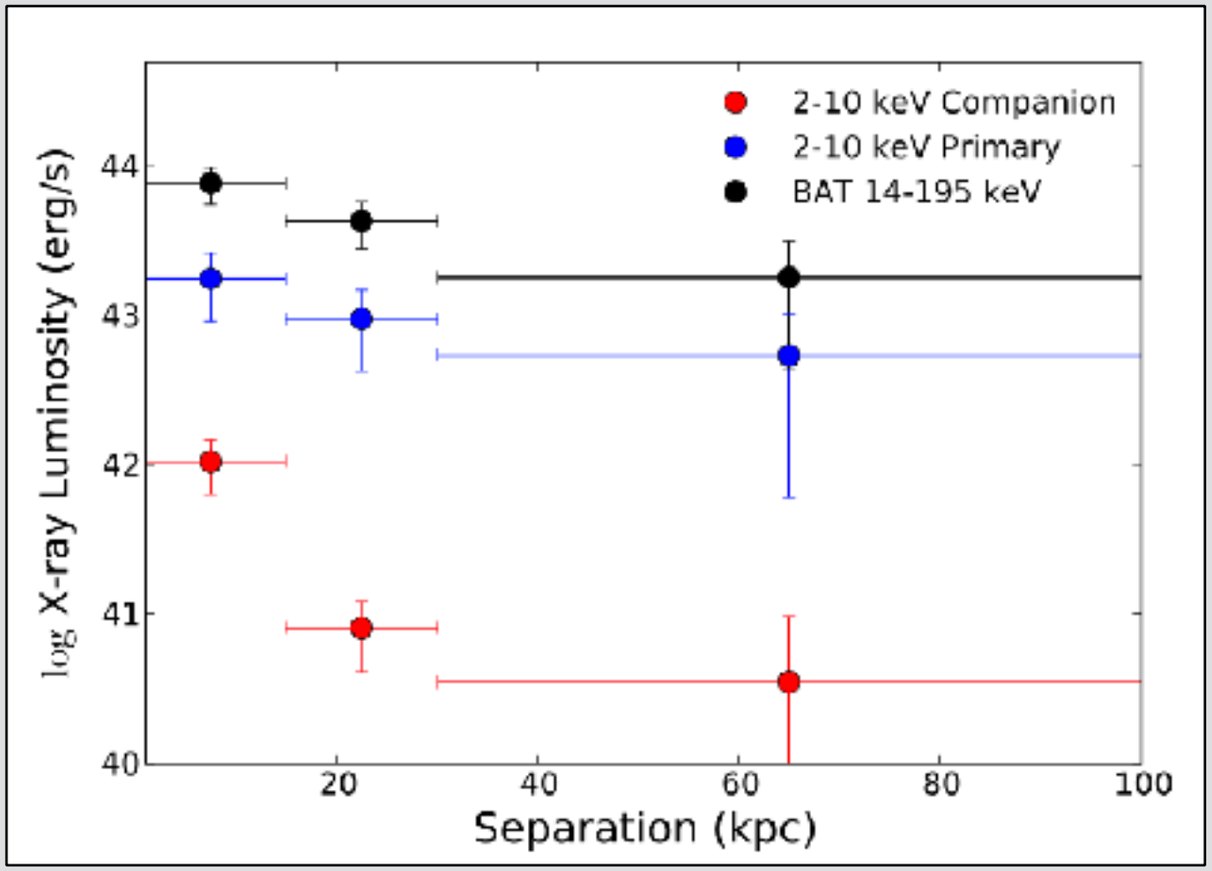
Satyapal et al. 2014

SDSS pair sample

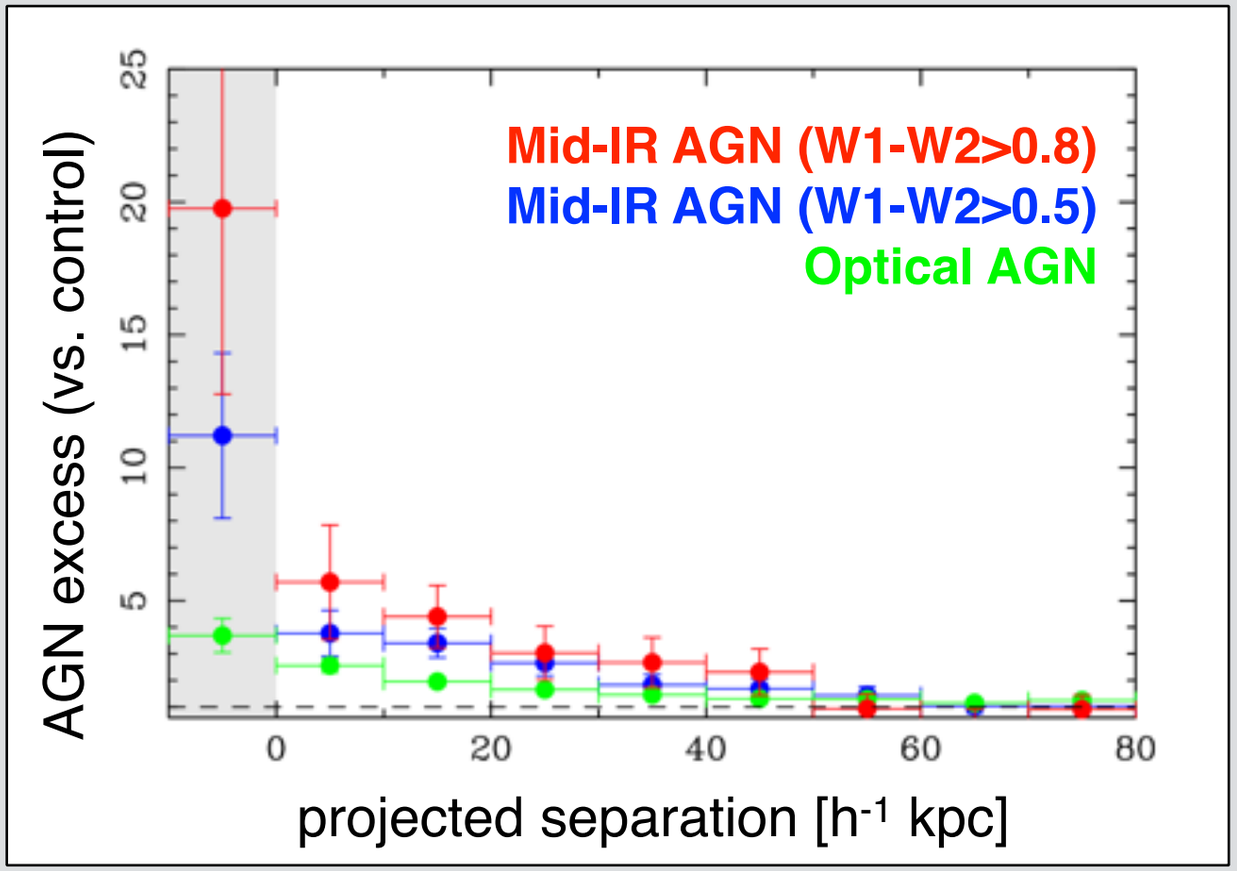
+

Galaxy Zoo ‘post-merger’ sample

X-ray vs IR diagnostics of obscured AGN



Koss et al. 2012



Satyapal et al. 2014

<u>Hard X-ray AGN selection</u>:

- Robust & insensitive to dust obscuration
- But only shallow surveys possible

<u>Mid-IR color selection</u>:

- Much larger surveys possible
- But sensitive only to most luminous AGN (& contaminated by galaxies at high z)
- **How do mid-IR colors (& completeness) evolve during the merger?**
- **When are they associated with dual AGN?**

Simulations & mock observations of AGN in merging galaxies

Hydrodynamic simulations with GADGET-3*:

**(Springel & Hernquist 2003, Springel 2005)*

- 6 major merger simulations
- init. gas fraction: 10 - 30 %
- init. bulge-to-total ratio: 0 - 0.2
- SMBHs with accretion & feedback

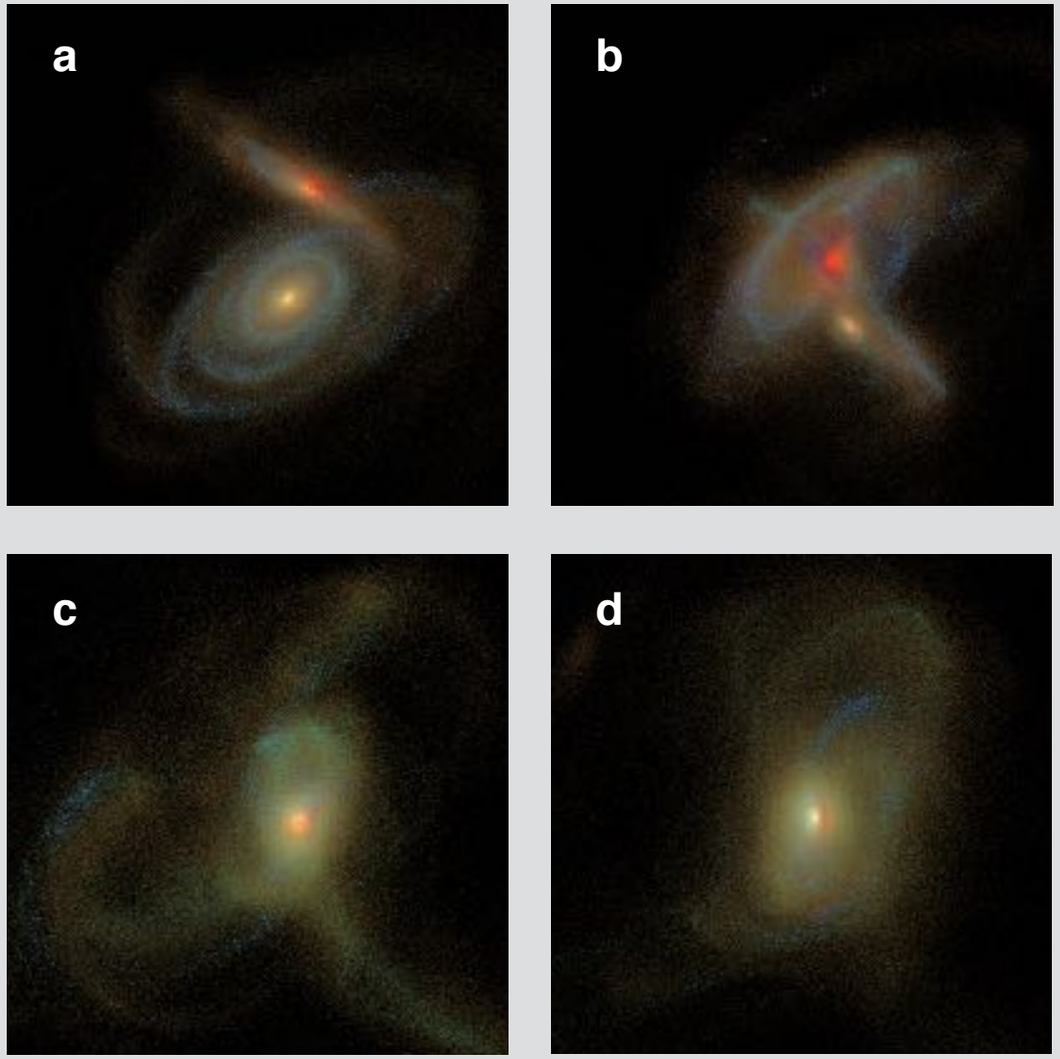
3-D dust radiative transfer with SUNRISE*:

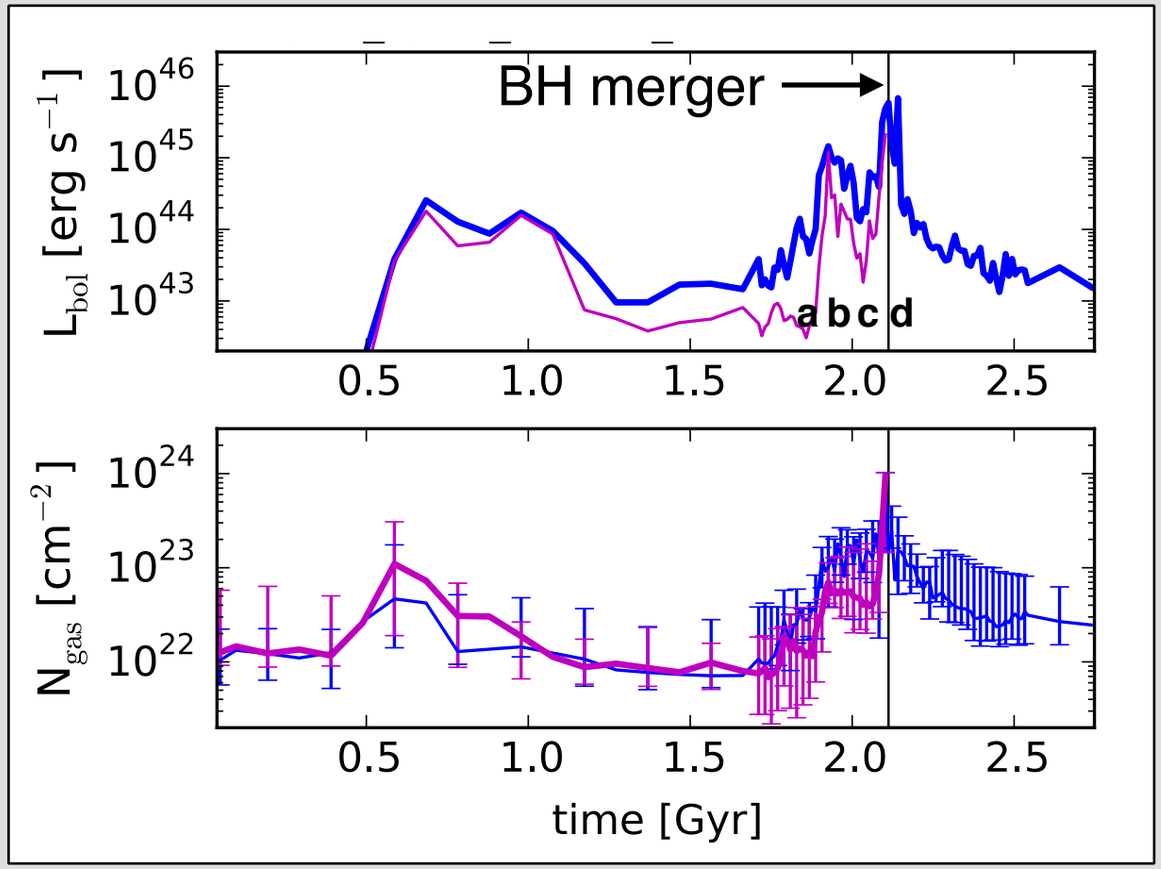
*(*Jonsson 2006, Jonsson+2010*)

- Use luminosity-dependent AGN SED template
- 7 viewing angles for each simulation
- Calculate resolved UV-IR spectra of galaxies at each timestep, incl. dust absorption/re-emission

credit: P. Jonsson

Simulating the mid-IR SED of merger-triggered-AGN

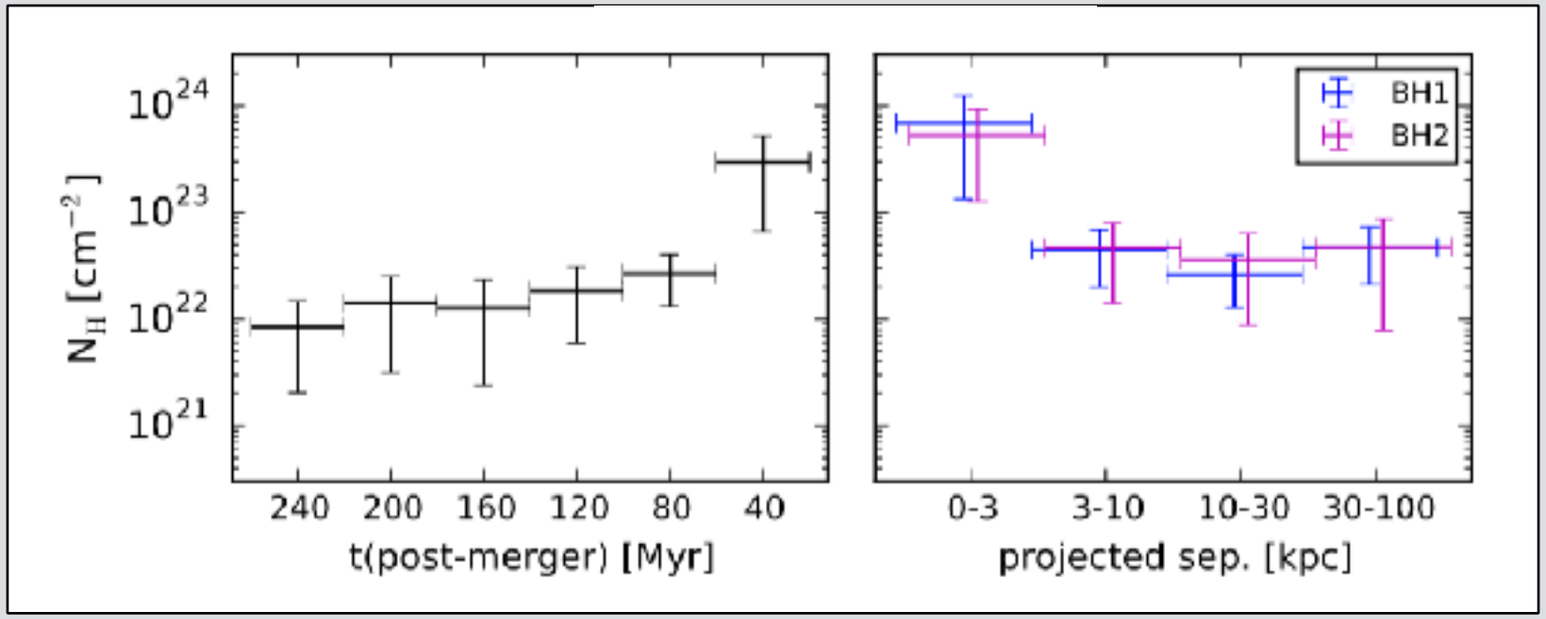




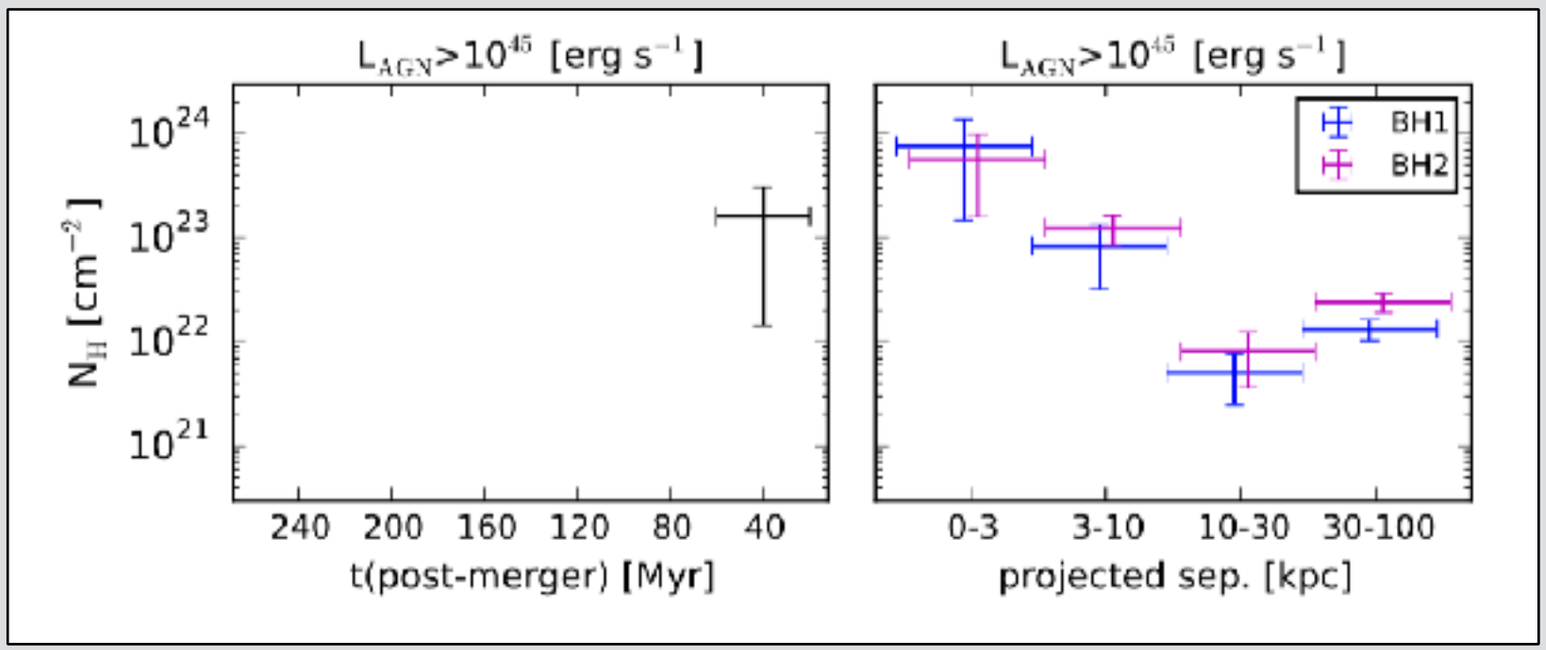
Blecha et al. 2017, in prep

Environmental obscuration in late-stage mergers

Major, gas-rich mergers



All mergers (luminous AGN only)



Blecha et al. 2017, in prep

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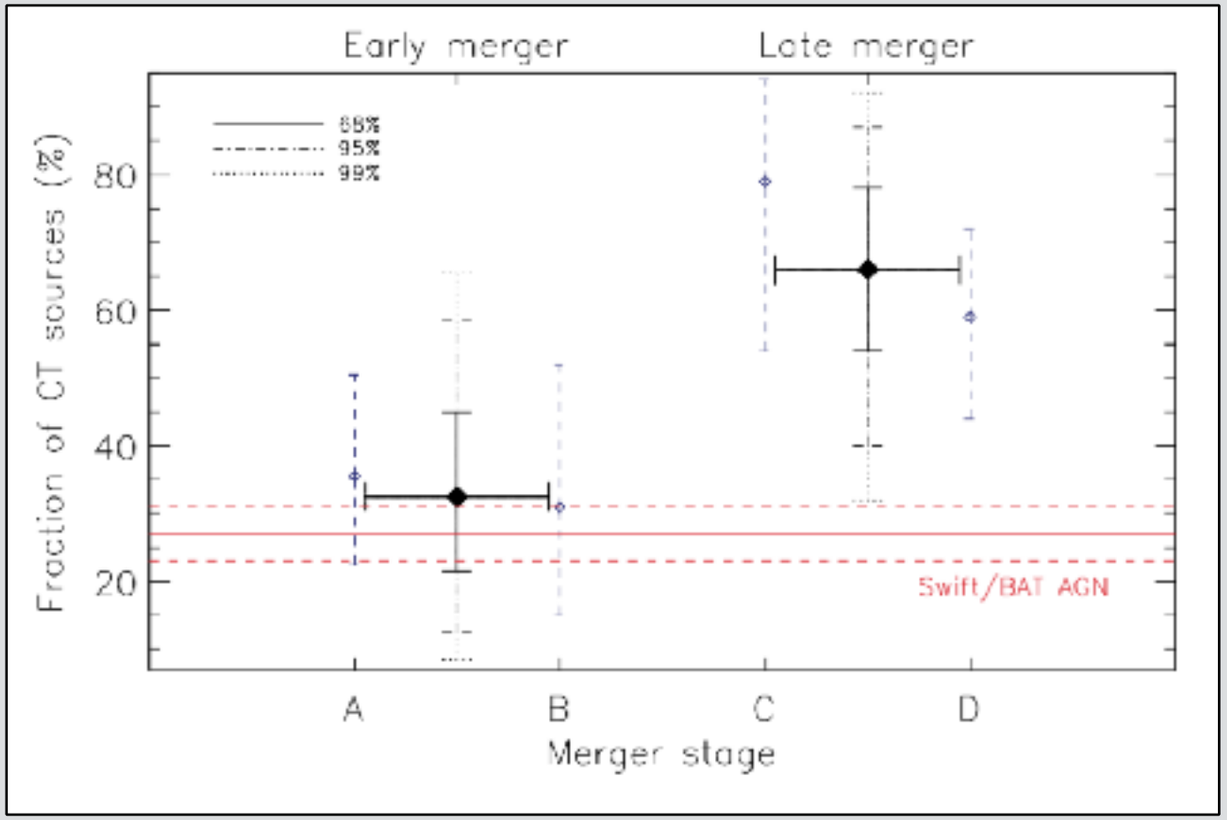
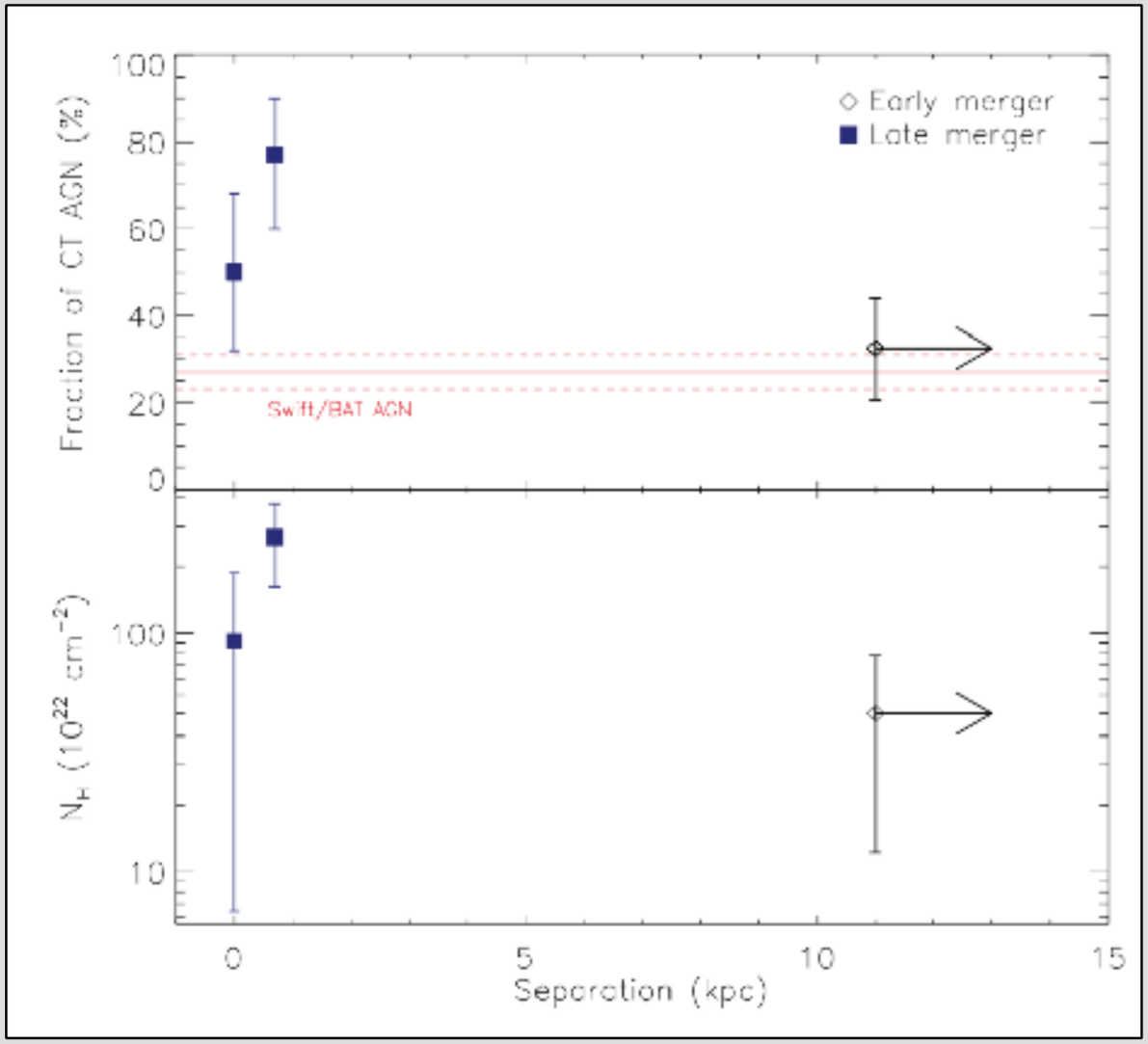
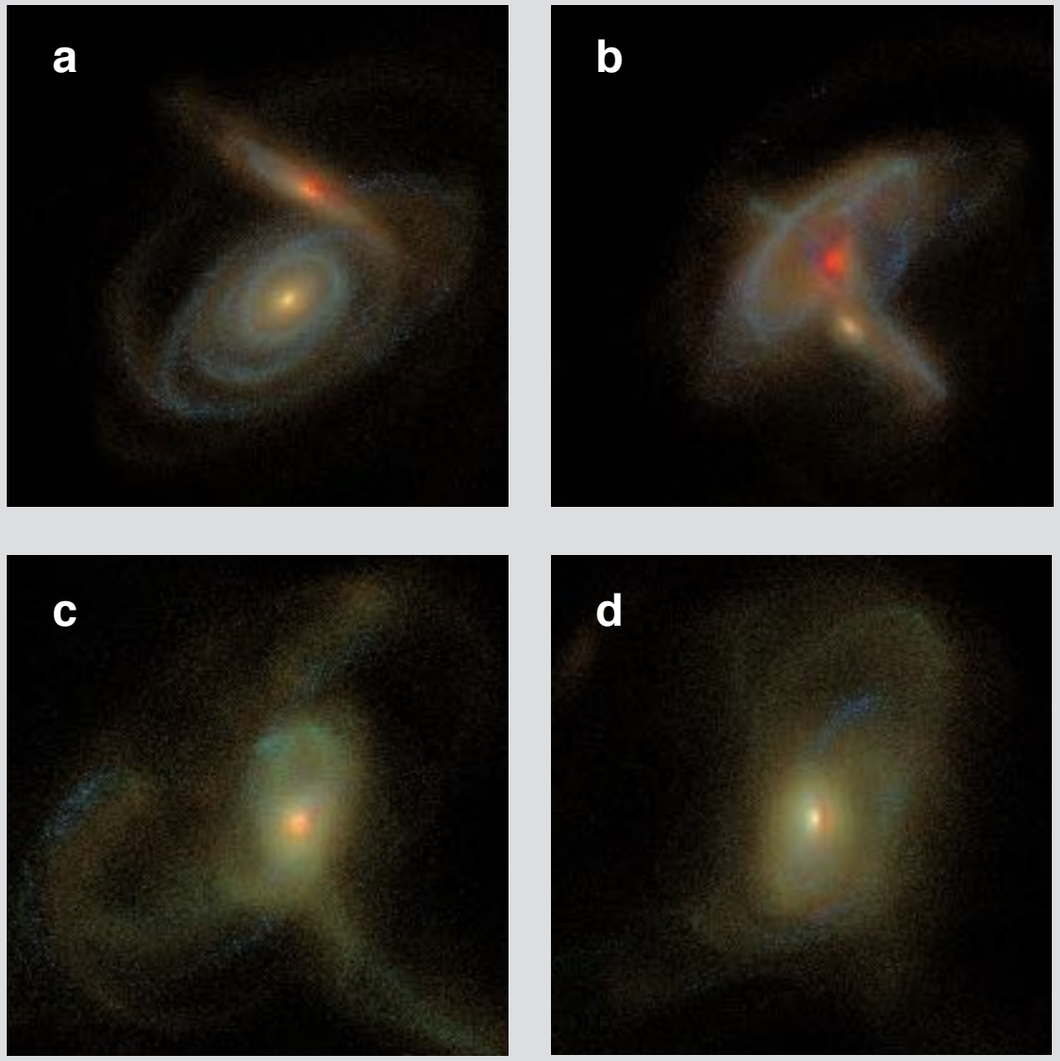
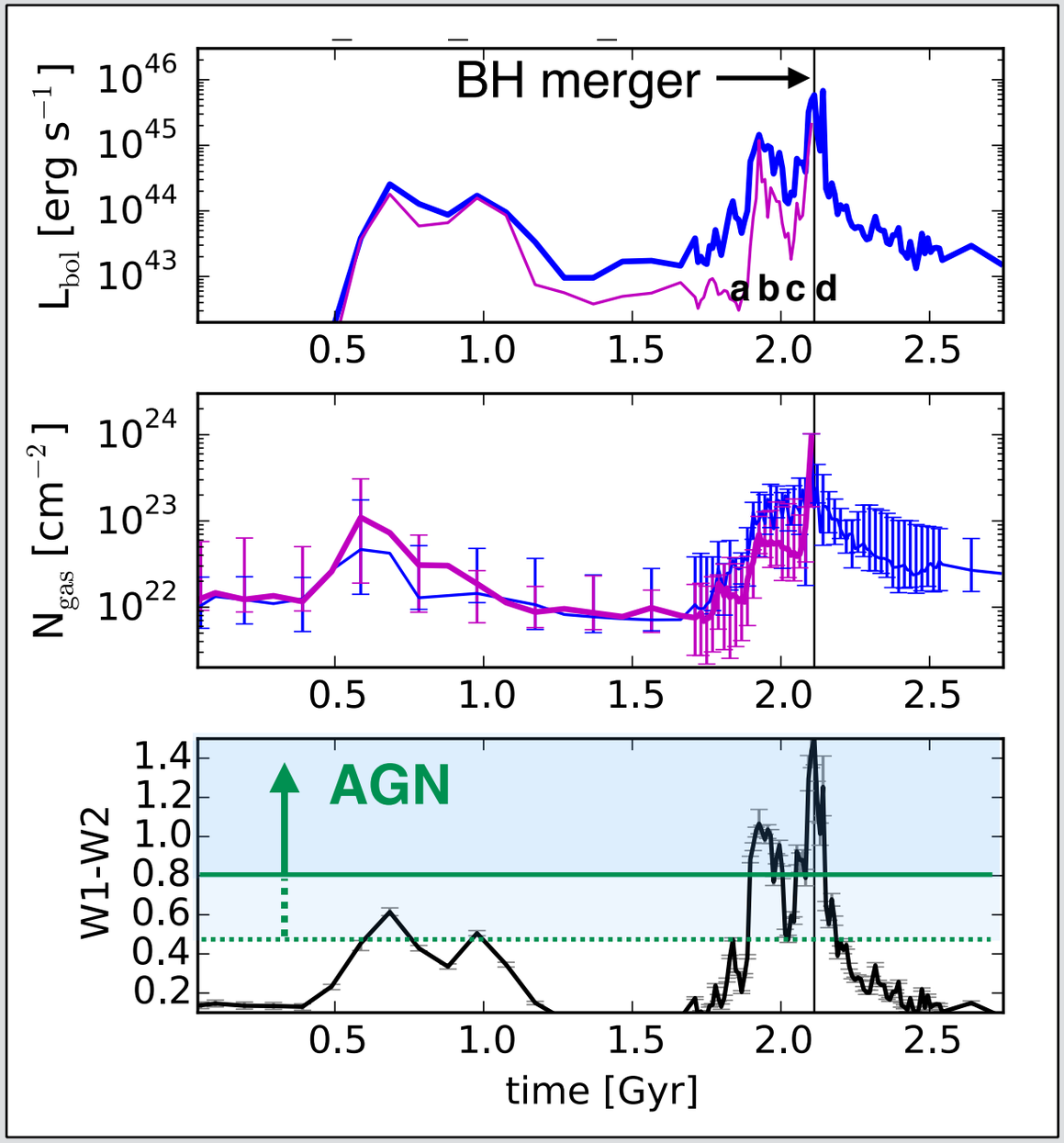


Ricci et al. 2017



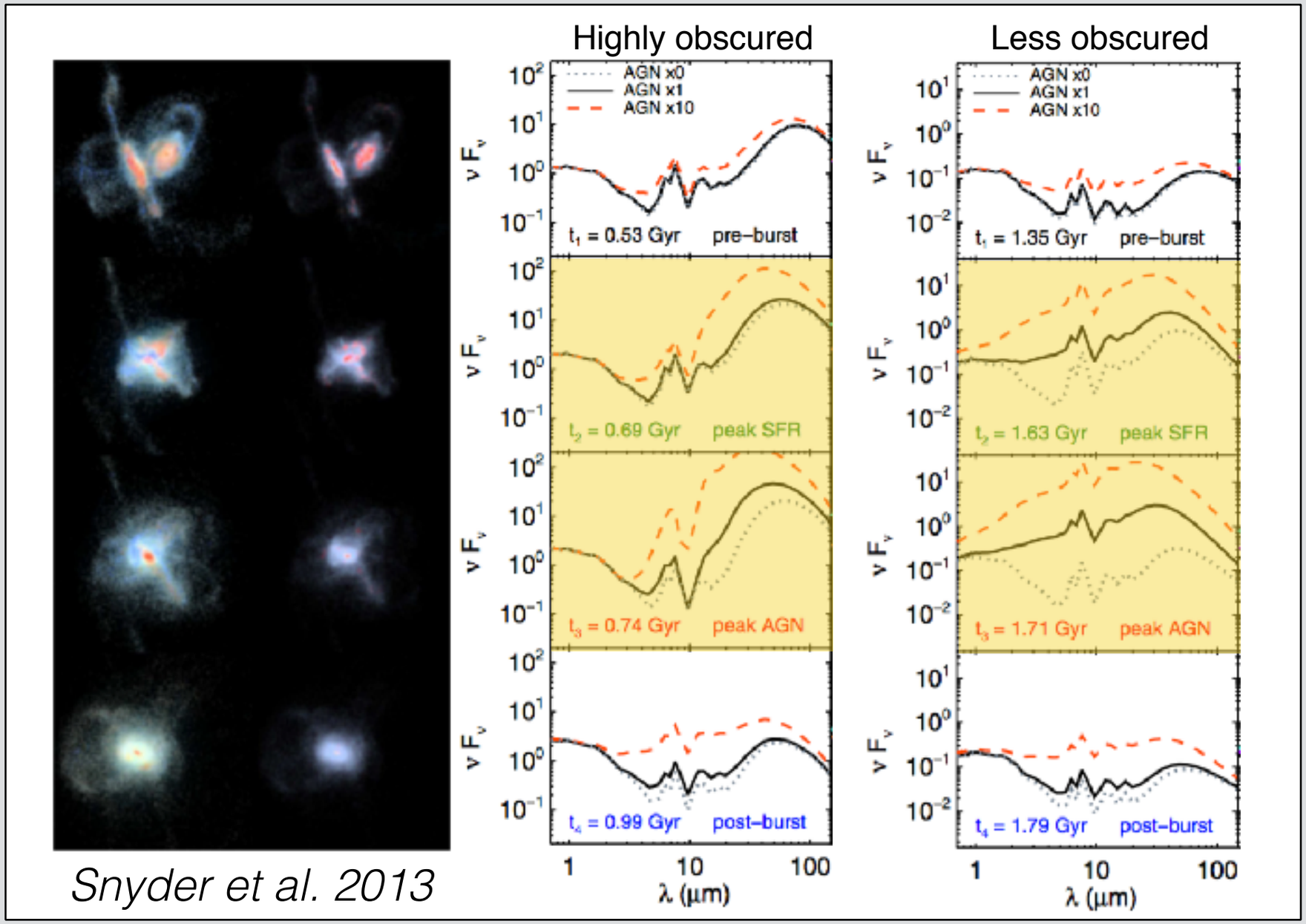
Simulating the mid-IR SED of merger-triggered-AGN





Blecha et al. 2017, in prep

Simulating the mid-IR SED of merger-triggered-AGN

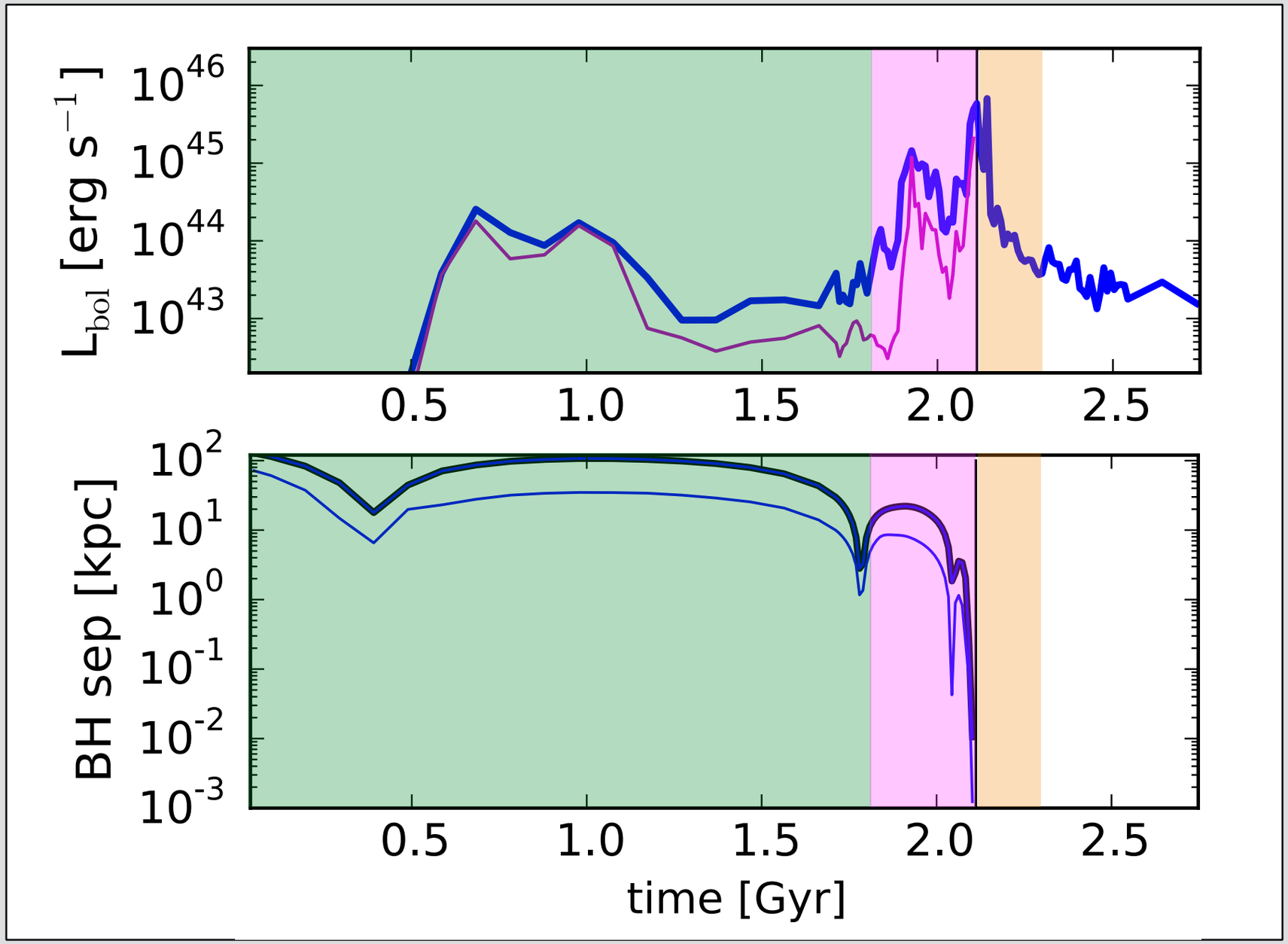


Snyder et al. 2013

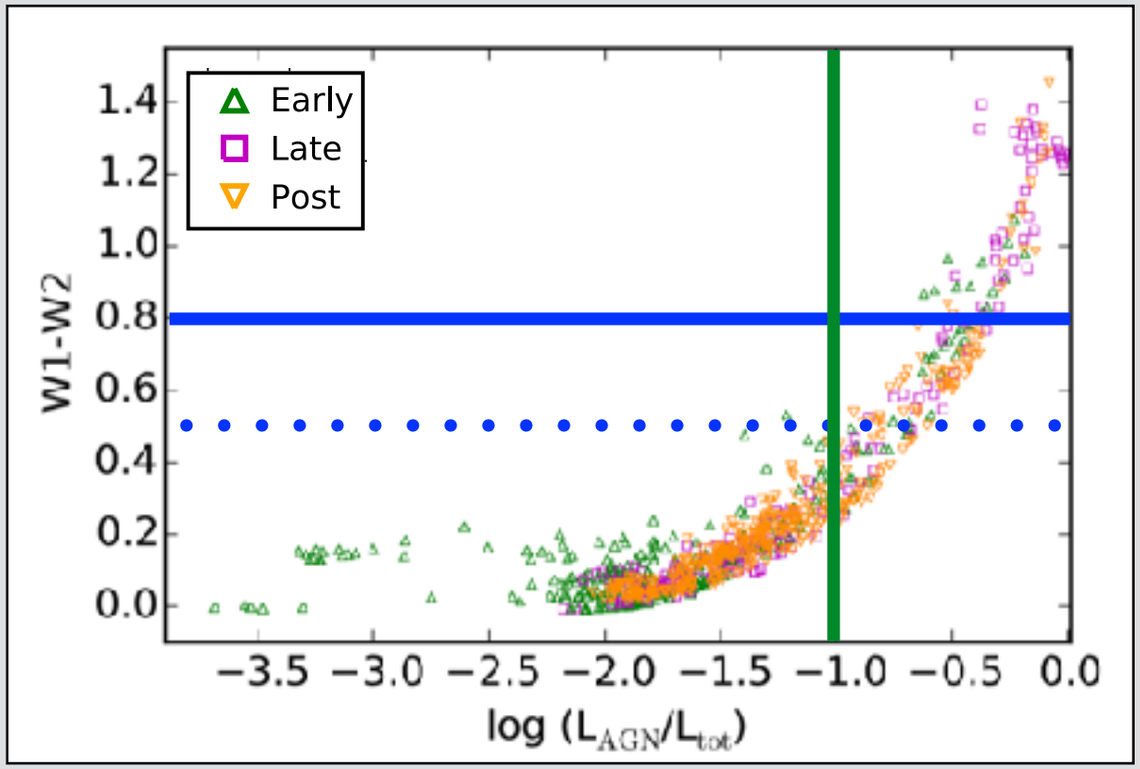
- Red mid-IR slope during coalescence in ‘normal’ gas rich mergers
- Mid-IR AGN signature obscured in extreme, high-z ULIRGs/HyLIRGs
- JWST spectral diagnostics (9.7 μm absorption + PAH strength + mid-IR slope) can constrain f_{AGN}

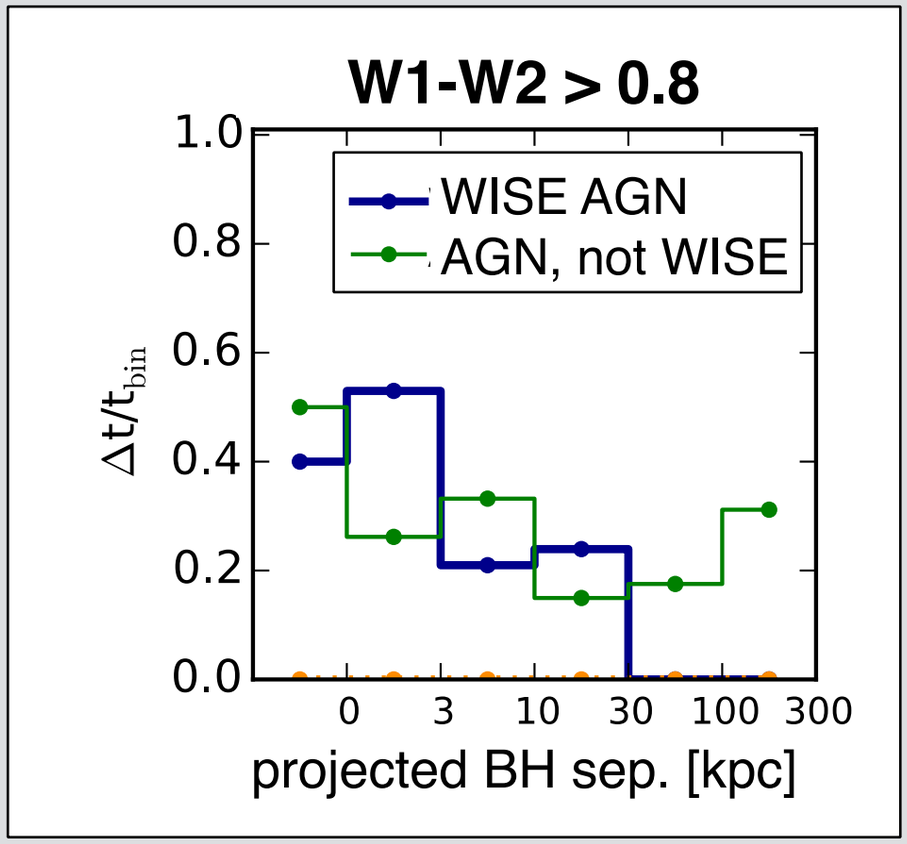
Definition of merger phases

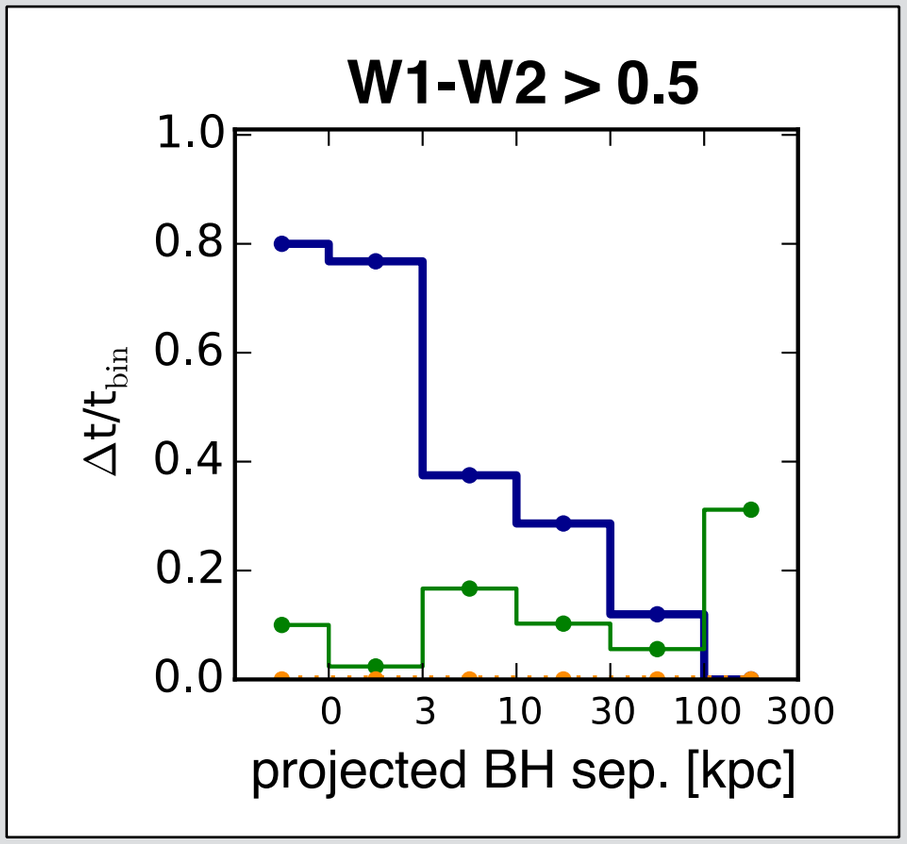
“Early” (a_{BH} > 10kpc)
“Late” (a_{BH} < 10kpc)
“Post” (after BH merger)



WISE mid-IR colors vs. AGN luminosity

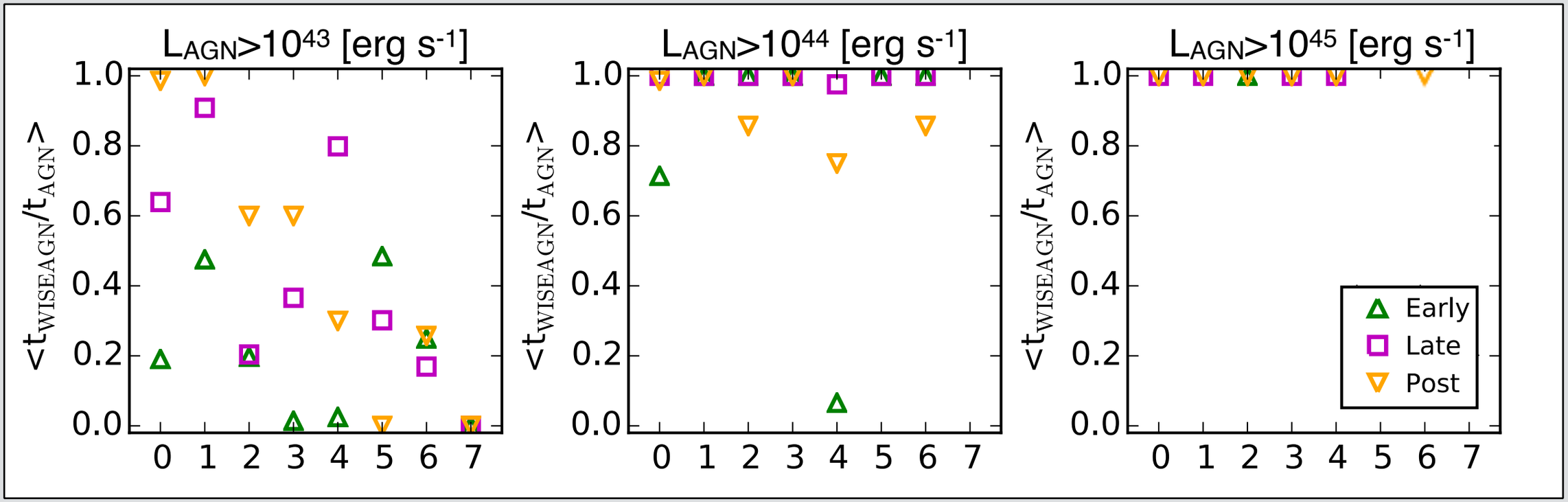






Blecha et al. 2017, in prep

WISE AGN fraction (W1-W2 > 0.5)



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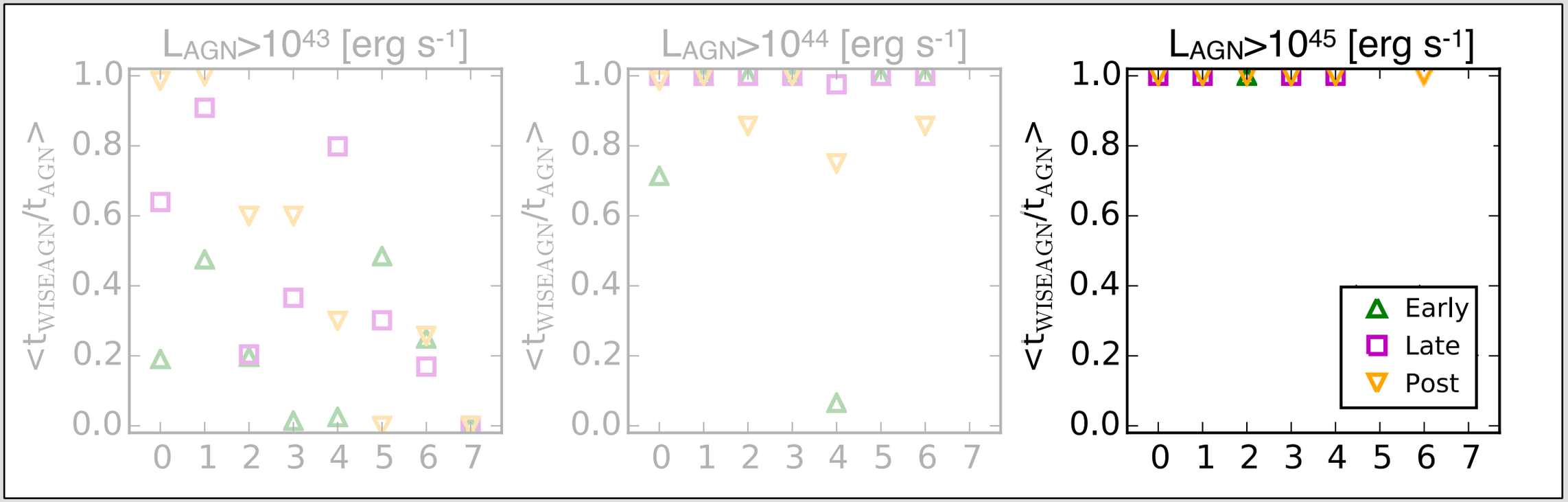
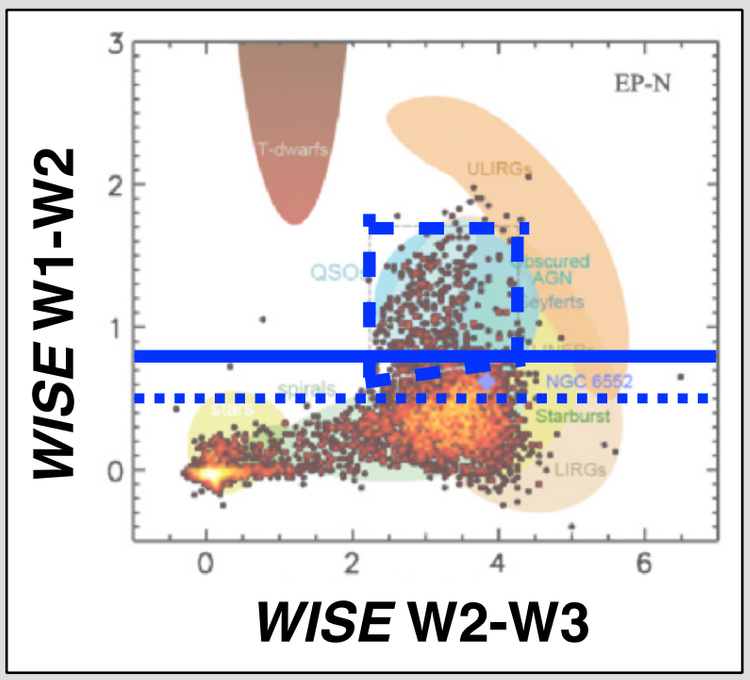
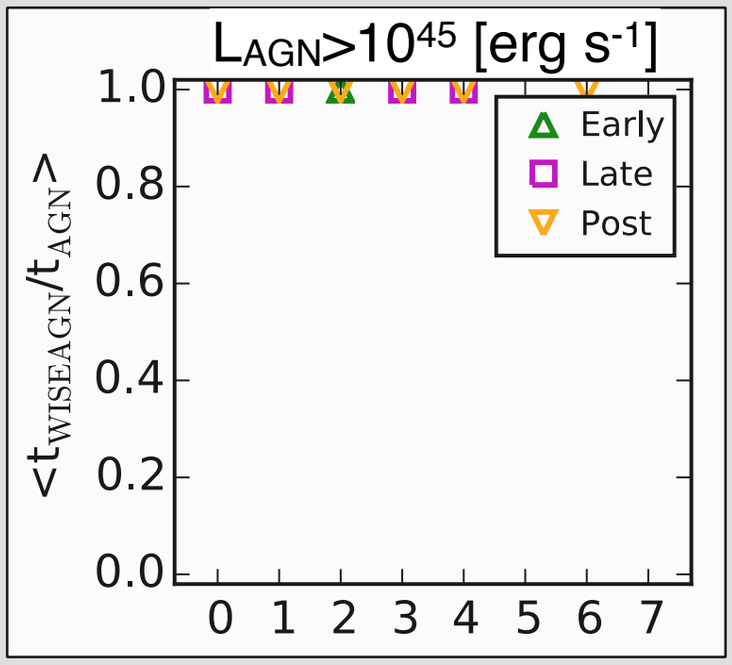
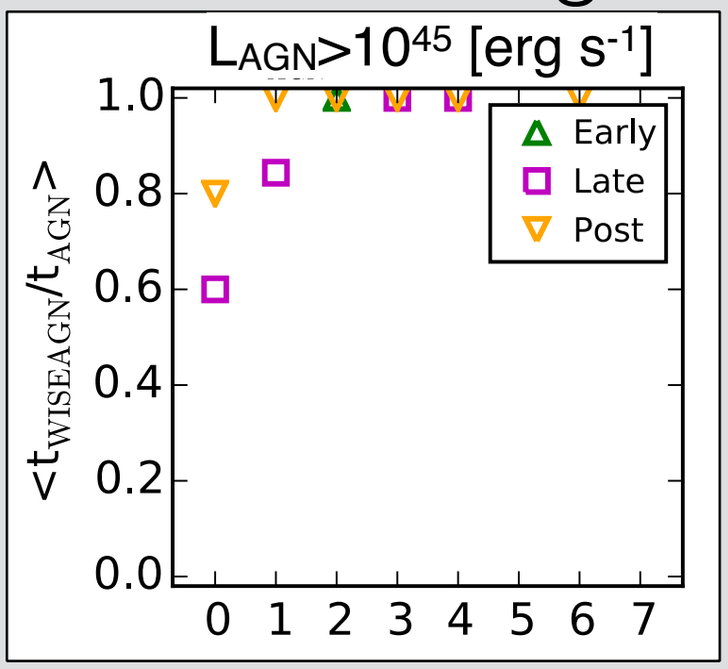




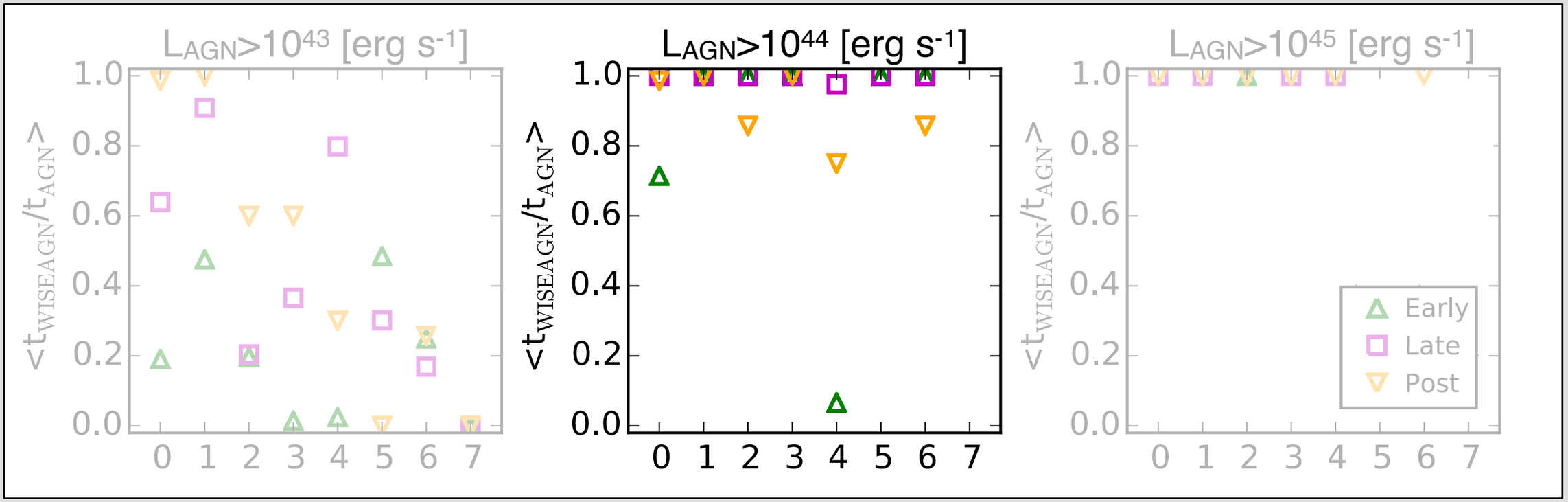
W1-W2 > 0.8

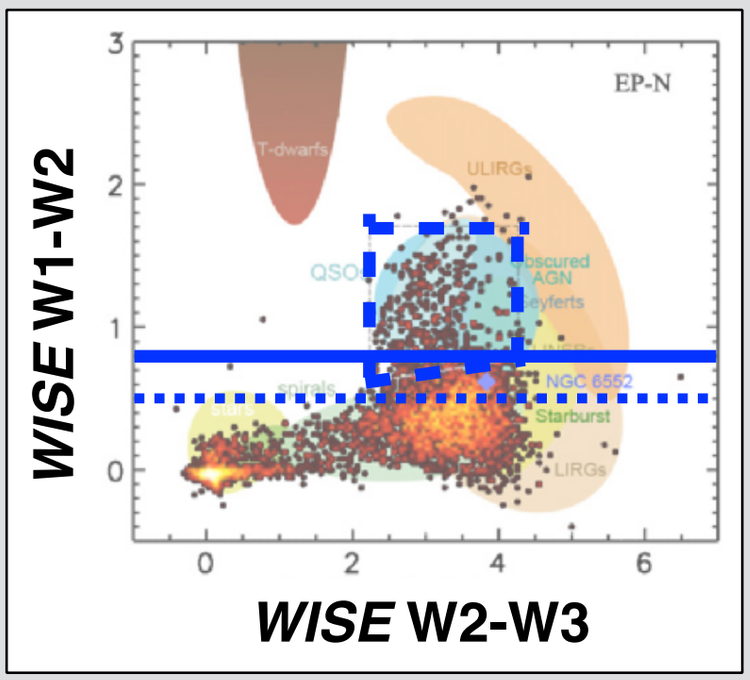


2-color ‘wedge’

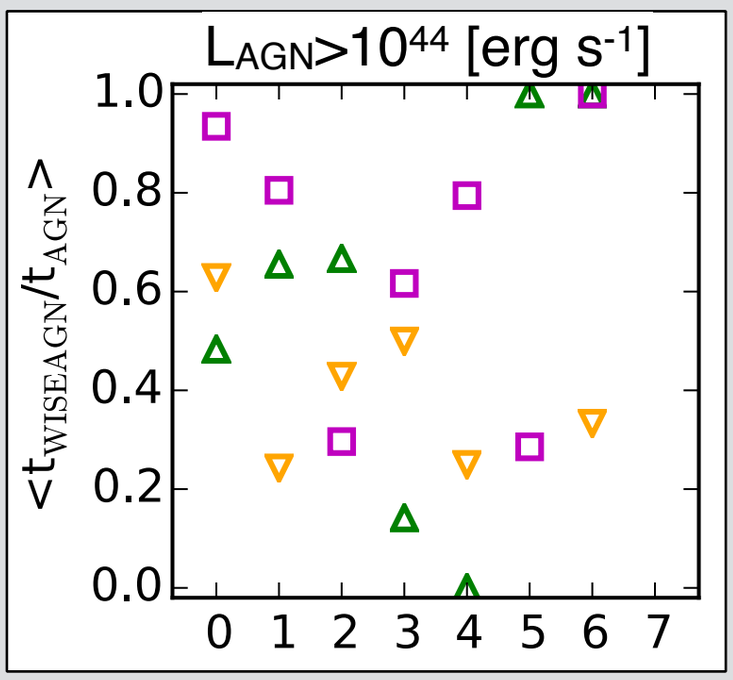


WISE AGN fraction (W1-W2 > 0.5)





W1-W2 > 0.8



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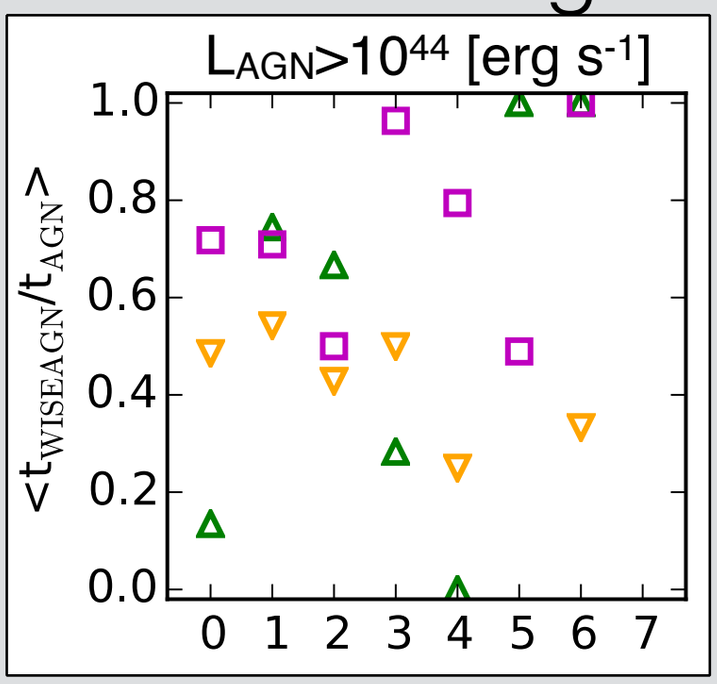
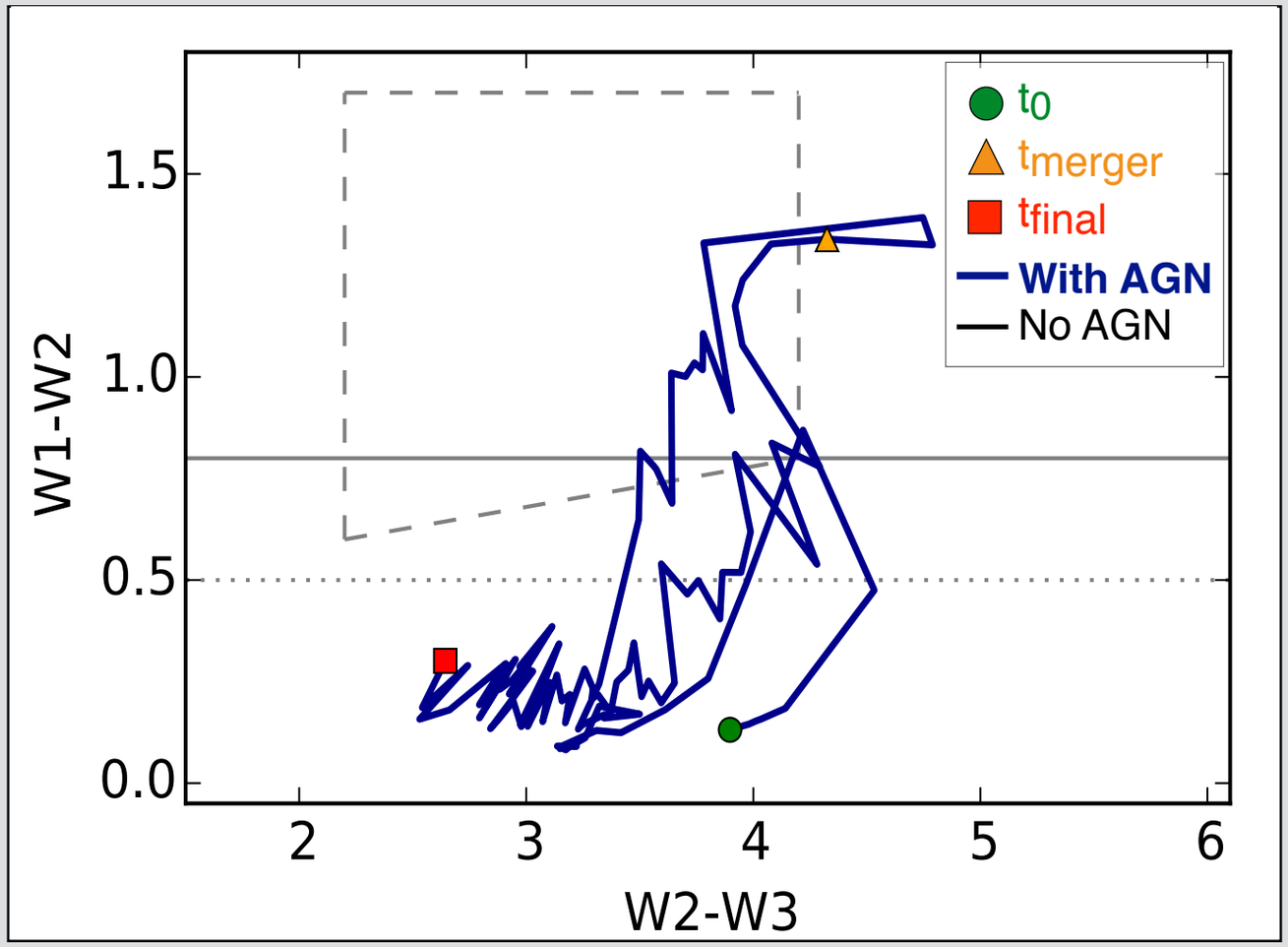
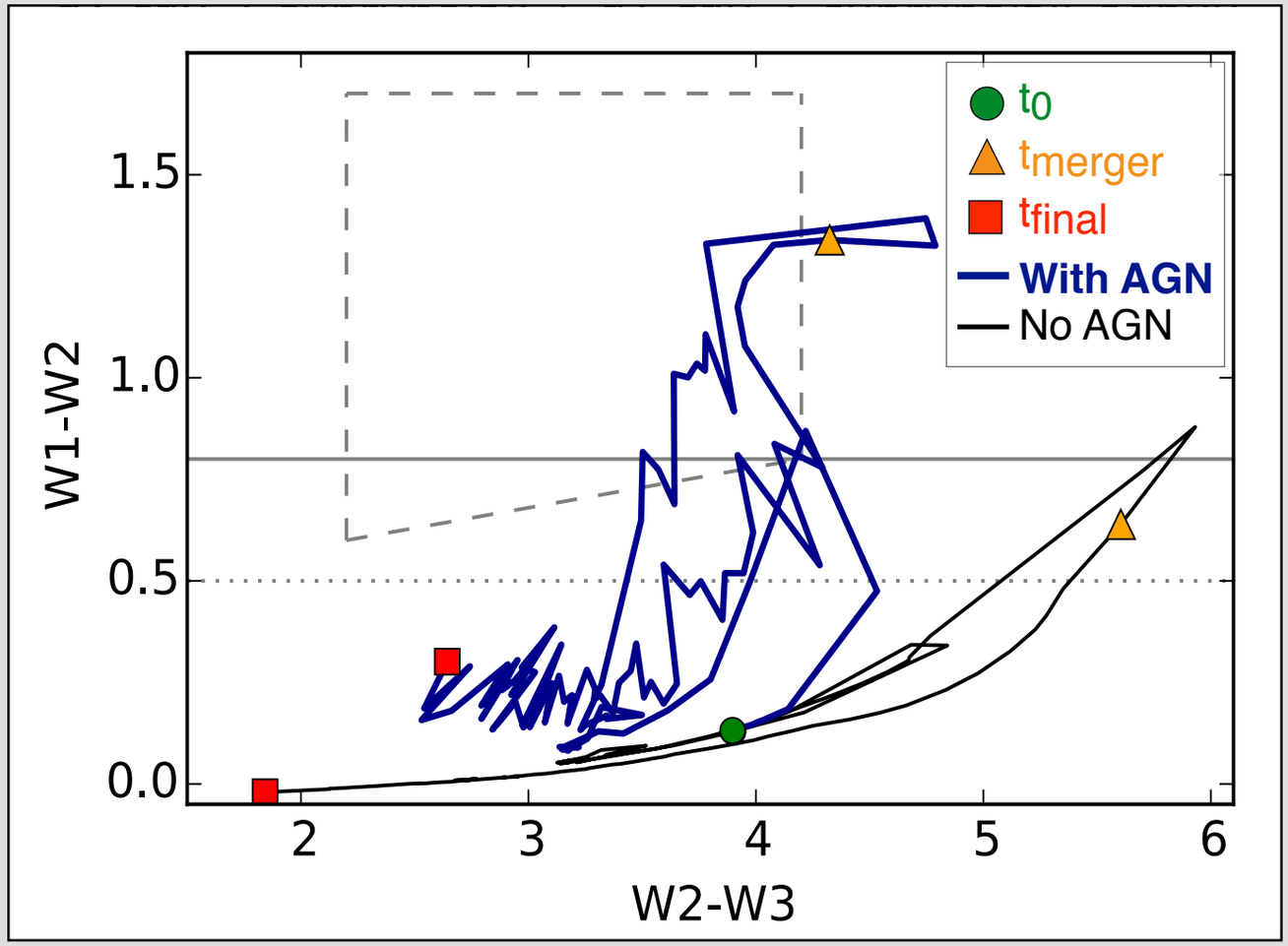


WISE mid-IR color evolution in mergers



Blecha et al. 2017, in prep

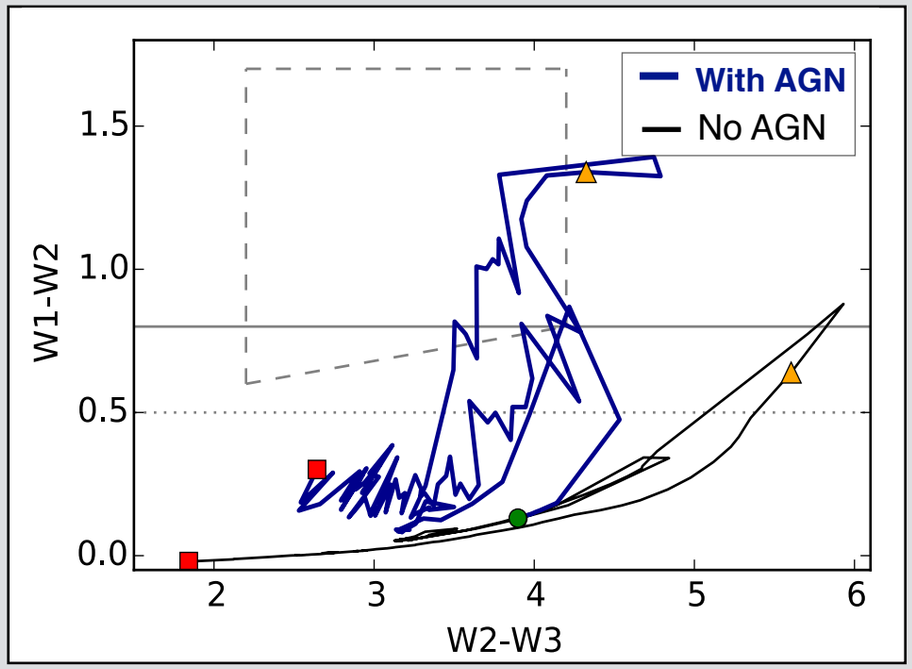
AGN vs. SF contribution to WISE colors



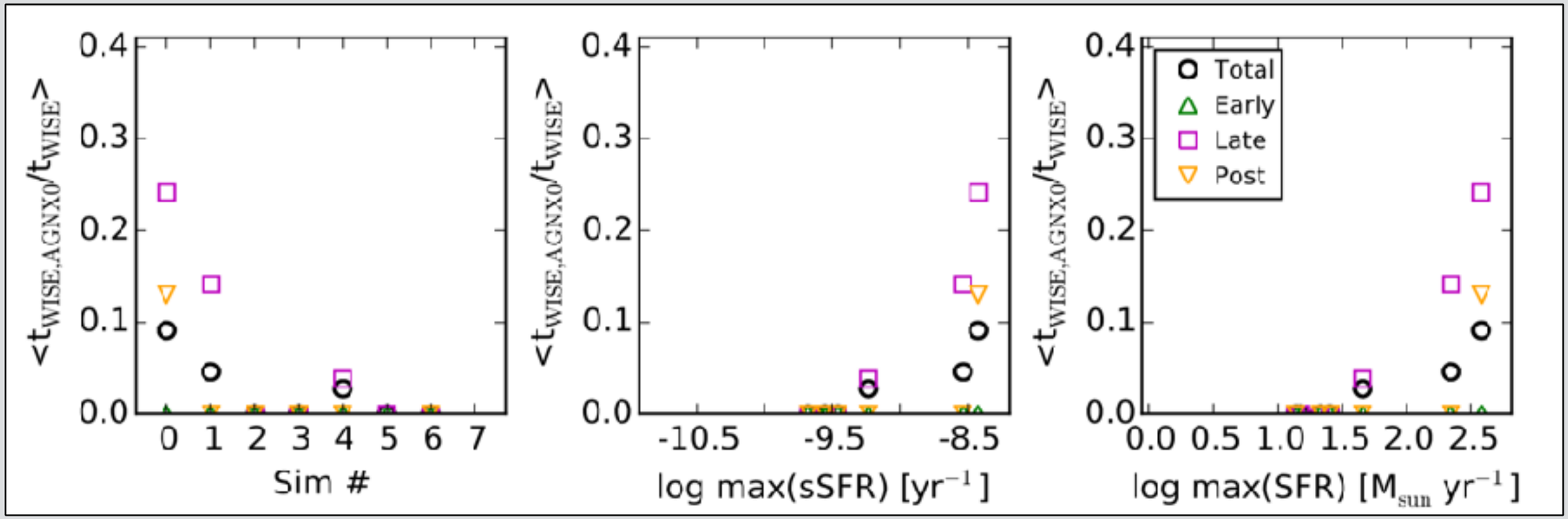
Blecha et al. 2017, in prep

- Peak SFR ~ 400 $M_\odot$ yr^{-1}, peak sSFR ~ $10^{-8.5}$ yr^{-1}
- Little contamination of *WISE* (W1-W2>0.5) colors, at *most* 15-20% of late/post-merger phase (at low z)
- Virtually no contamination in less-intense starbursts (or with standard color cuts)
- No contamination with 2-color selection

AGN vs. SF contribution to WISE colors

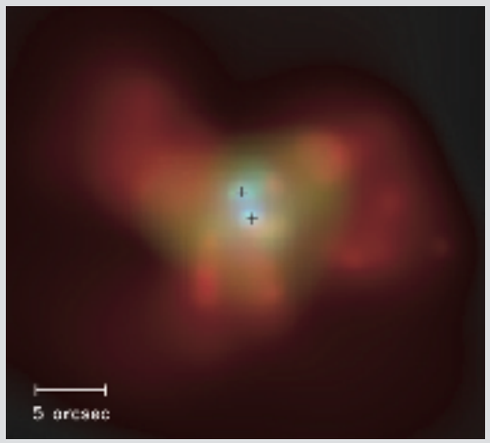


fractional "contamination" of WISE W1-W2 > 0.5 color by SF

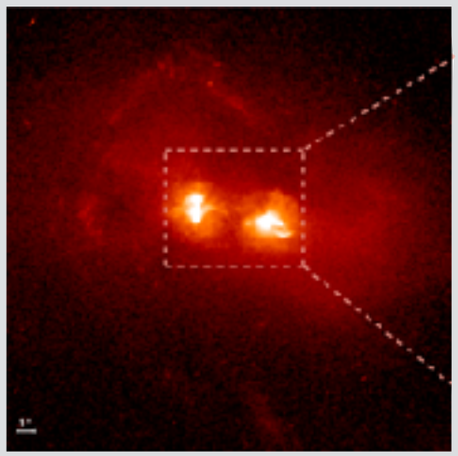


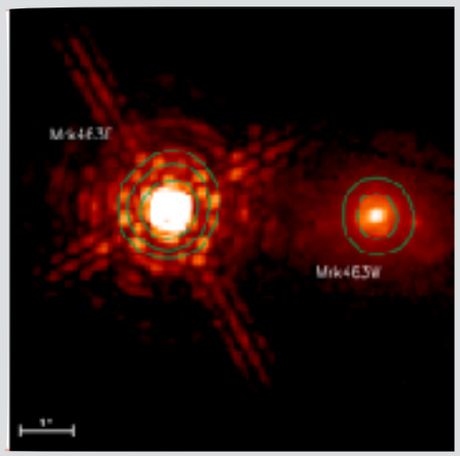
Blecha et al. 2017, in prep

Dual AGN:
unique probes of merger-triggered growth

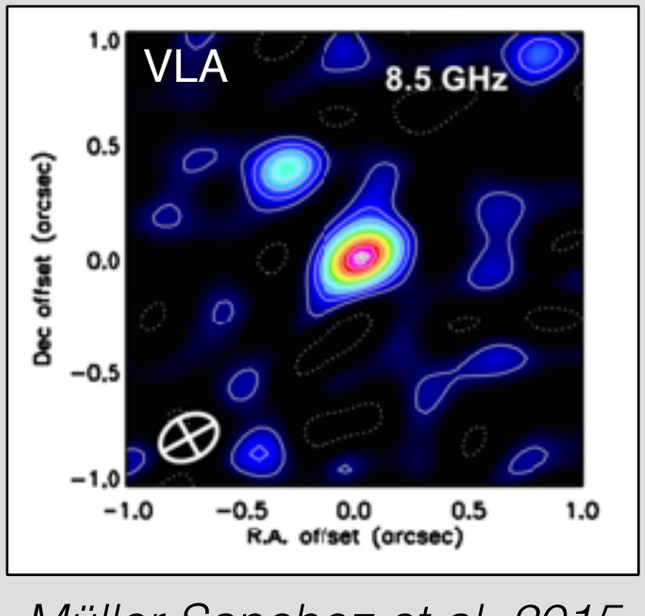


Komossa et al. 2003



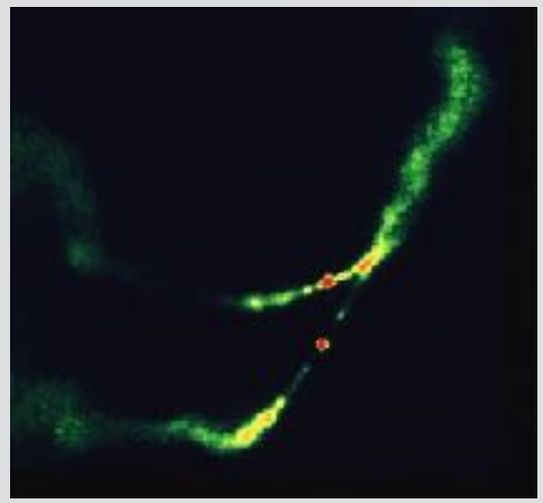


Bianchi et al. 2008



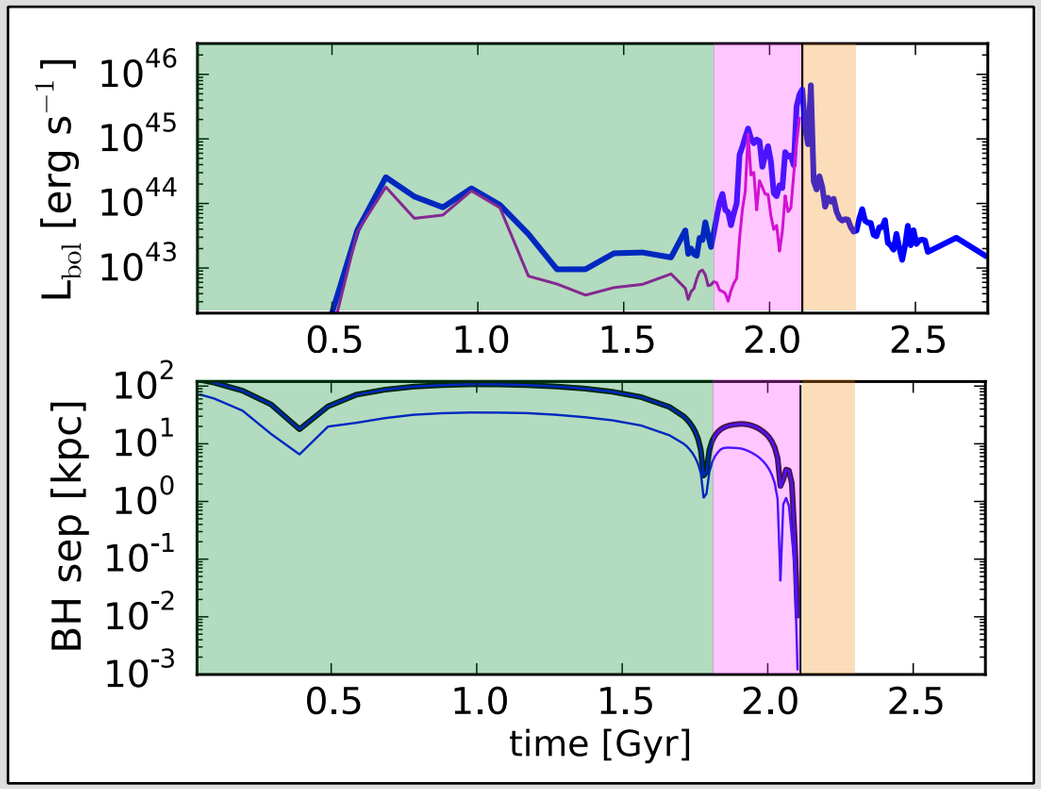
Müller-Sanchez et al. 2015

Koss et al. 2012

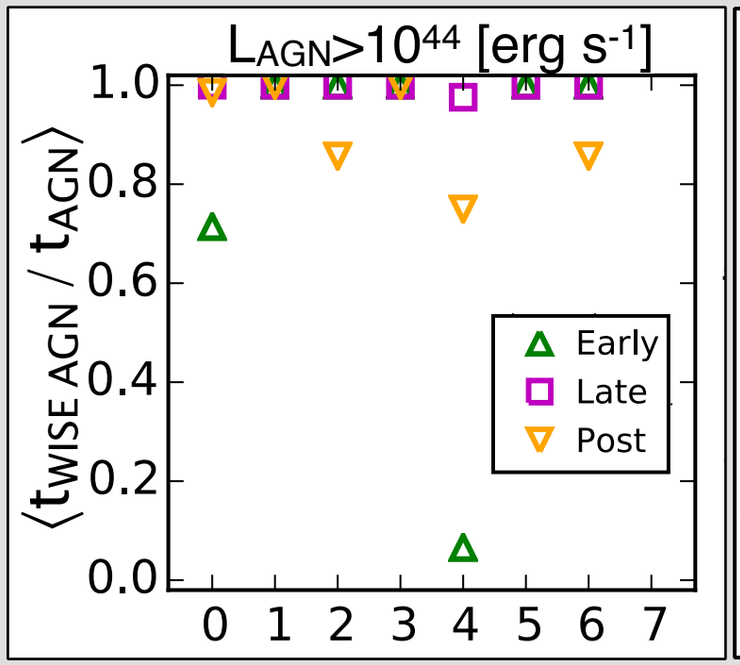


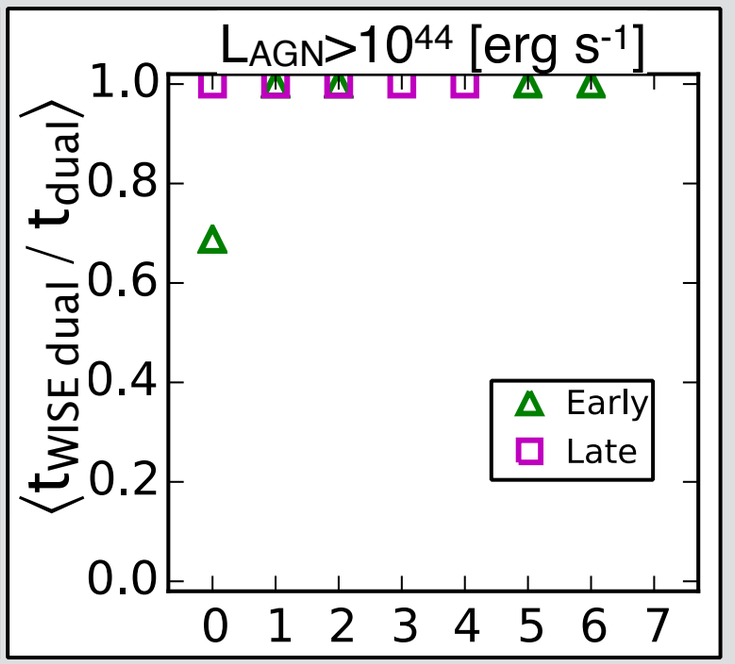
NRAO/AUI/F.N.Owen etal.

Uncovering dual nuclei in *WISE*-selected AGN



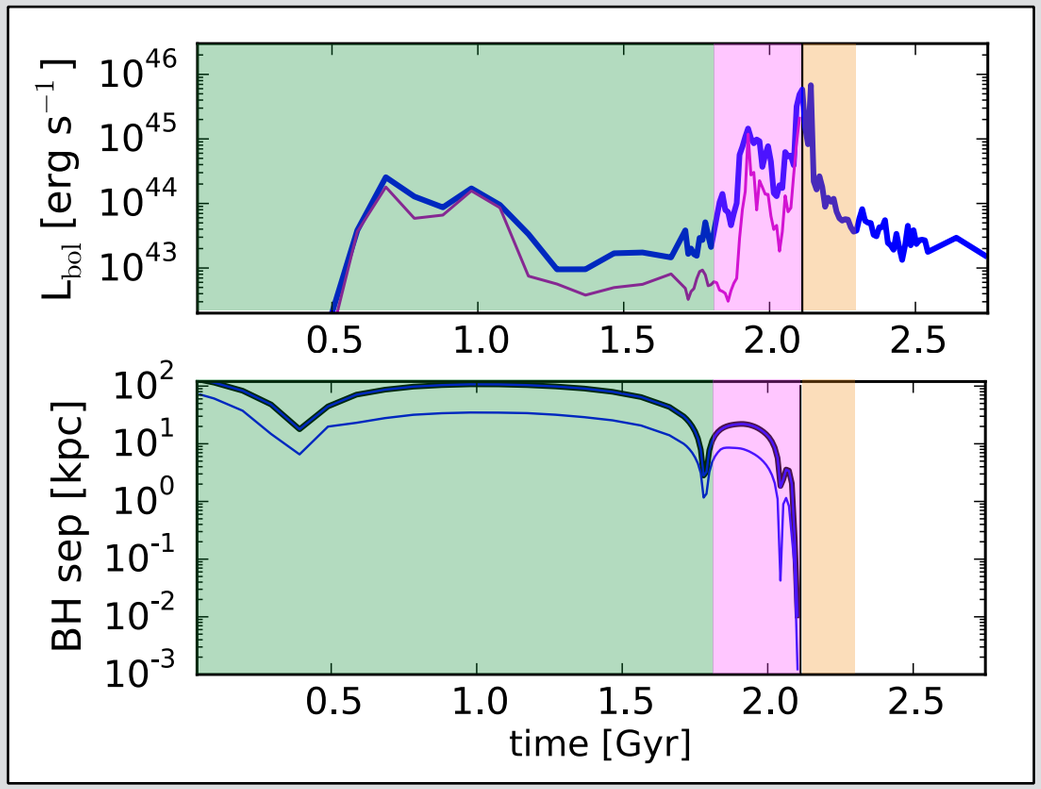
W1-W2 > 0.5





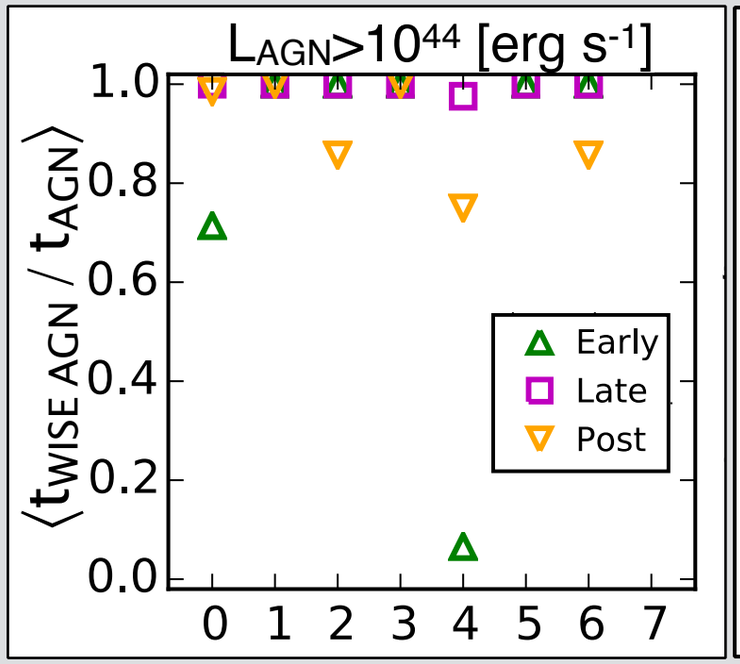
- Virtually all dual AGN in late-stage mergers are selected with W1-W2>0.5
- >~ 75% are selected with W1-W2>0.8

Uncovering dual nuclei in *WISE*-selected AGN

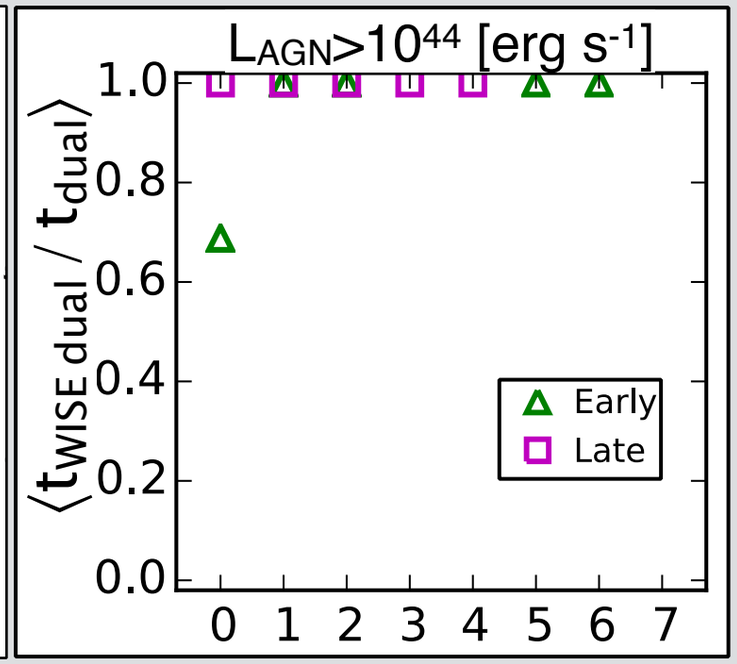


W1-W2 > 0.5

$t_{WISE\ AGN}$ / t_{AGN}

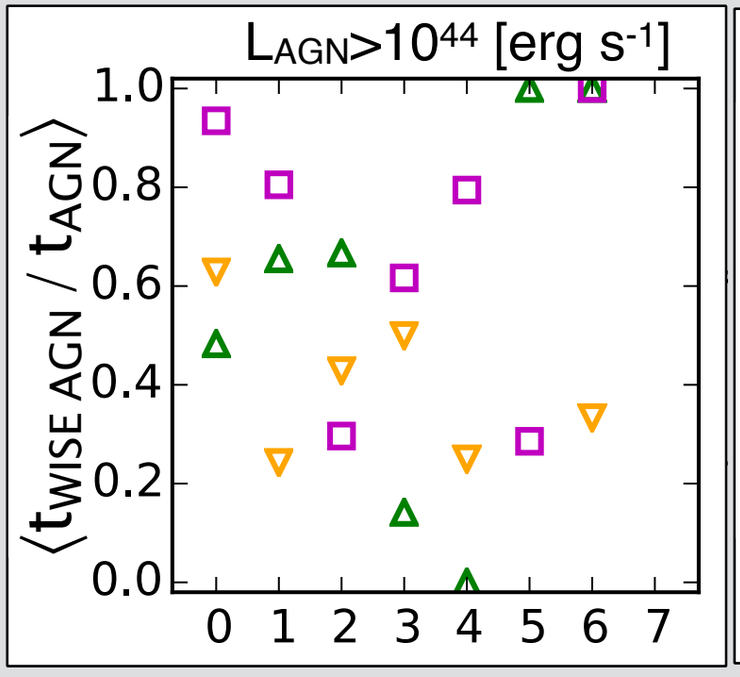


$t_{WISE\ dual}$ / t_{dual}

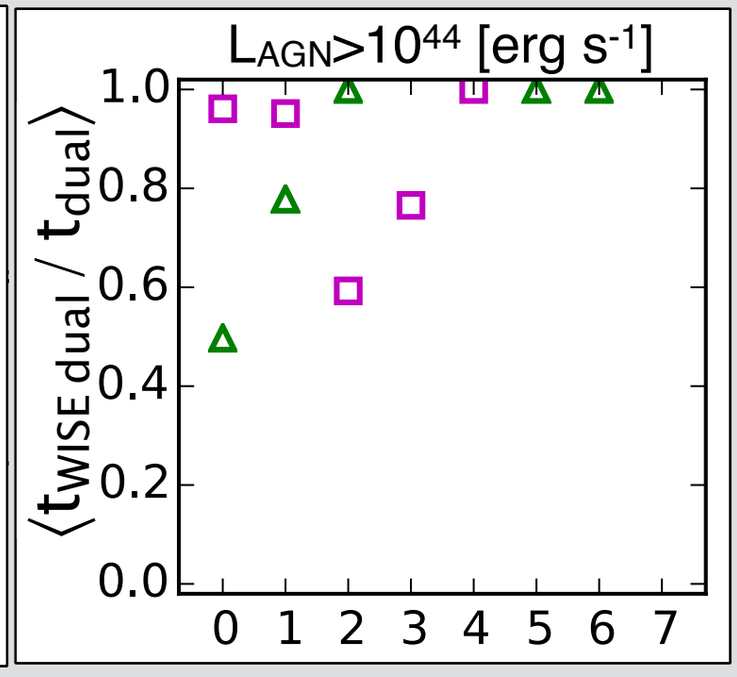


W1-W2 > 0.8

$t_{WISE\ AGN}$ / t_{AGN}



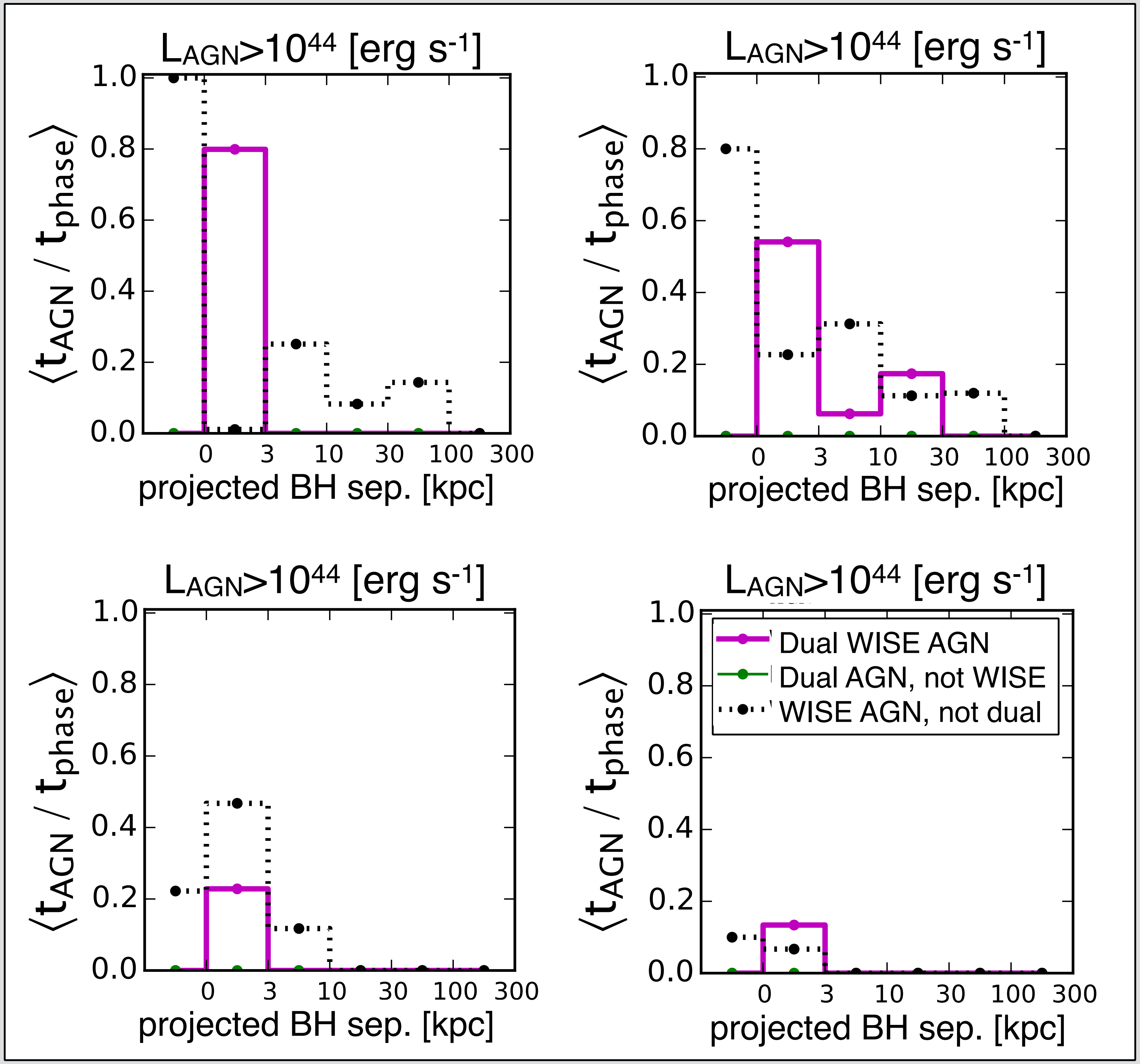
$t_{WISE\ dual}$ / t_{dual}



- Virtually all dual AGN in late-stage mergers are selected with W1-W2>0.5
- >~ 75% are selected with W1-W2>0.8

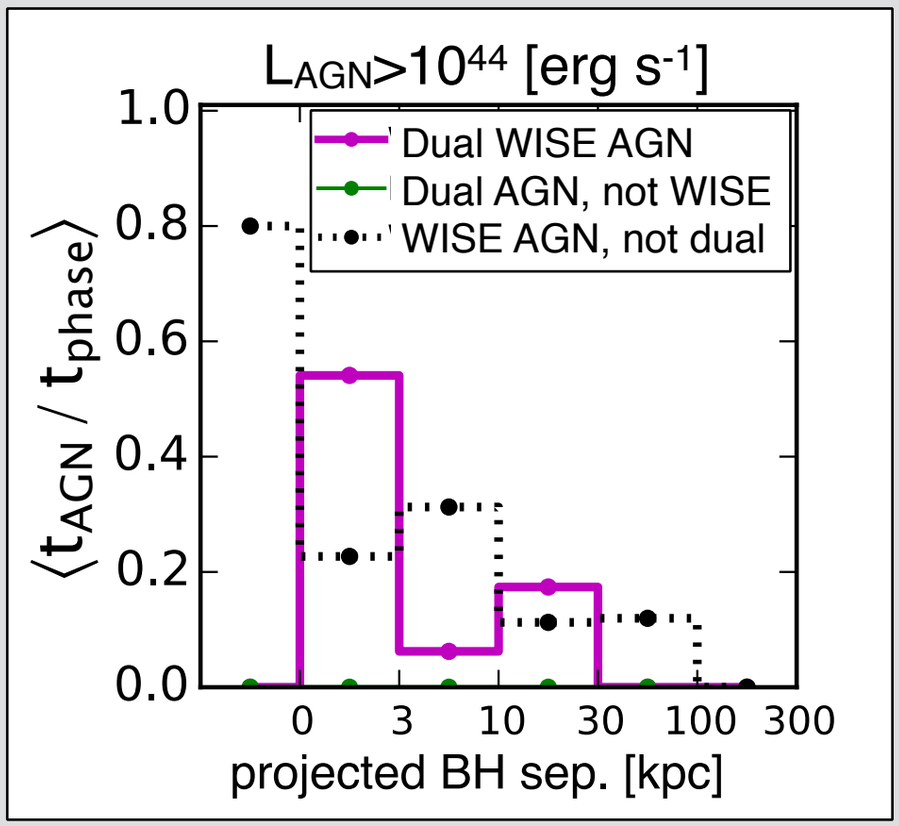
Uncovering dual nuclei in *WISE*-selected AGN

- >~30-40% of *all* WISE-selected AGN in mergers should contain duals (with L>~10^{43}-10^{44} erg/s)
- Many are likely still unresolved
- Prime targets for *JWST*



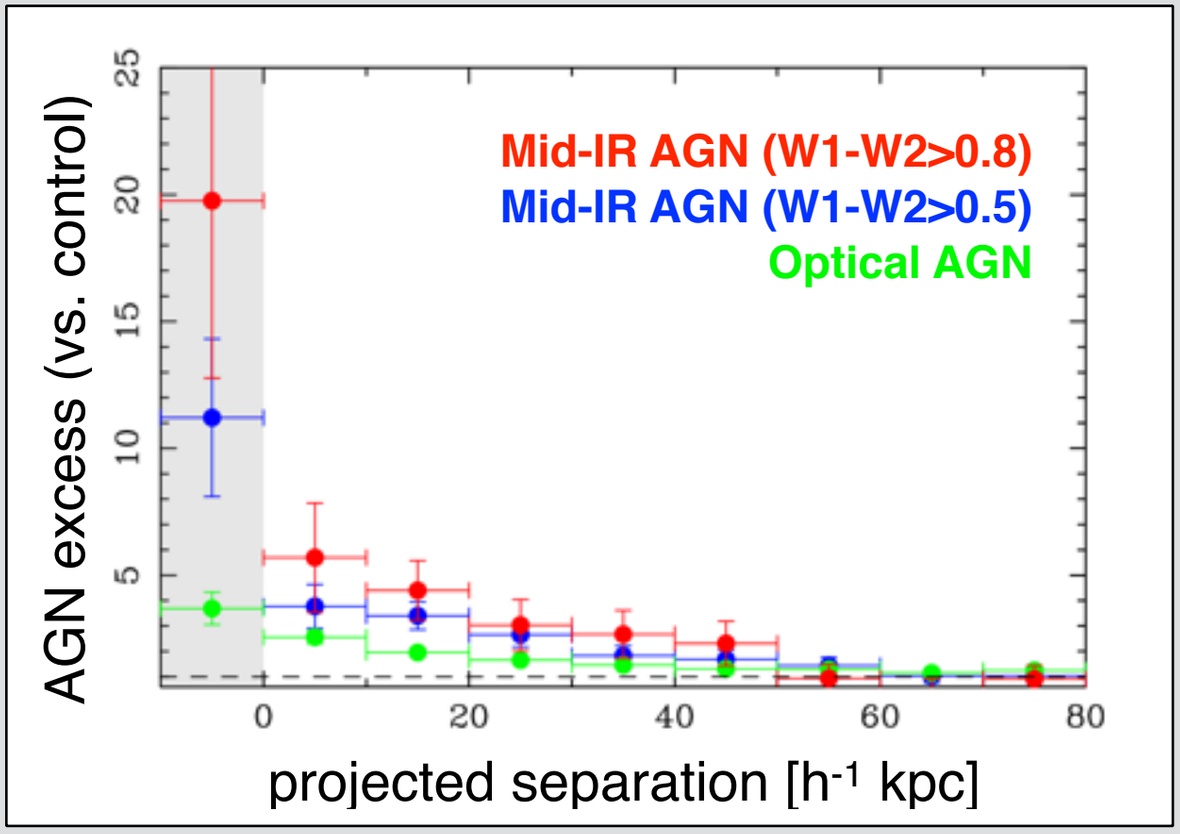
Uncovering dual nuclei in *WISE*-selected AGN

Simulated *WISE* **dual** AGN:



Blecha et al. 2017, in prep

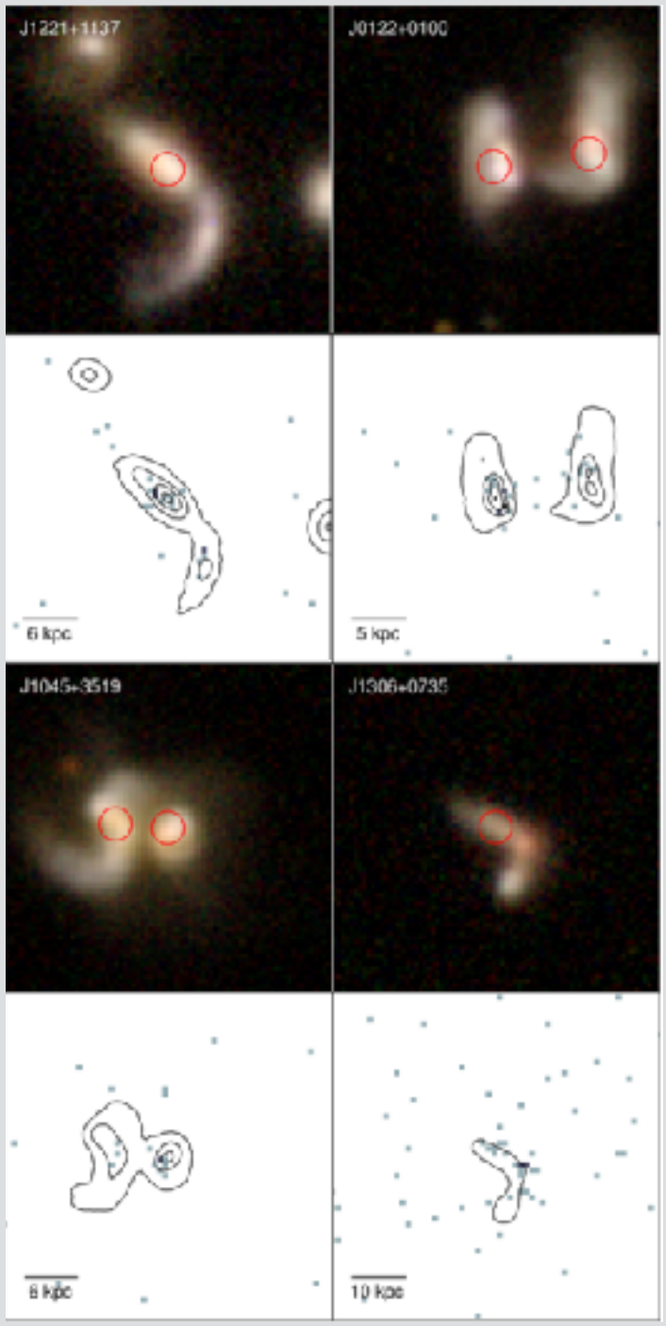
Candidate *WISE* **dual** AGN:



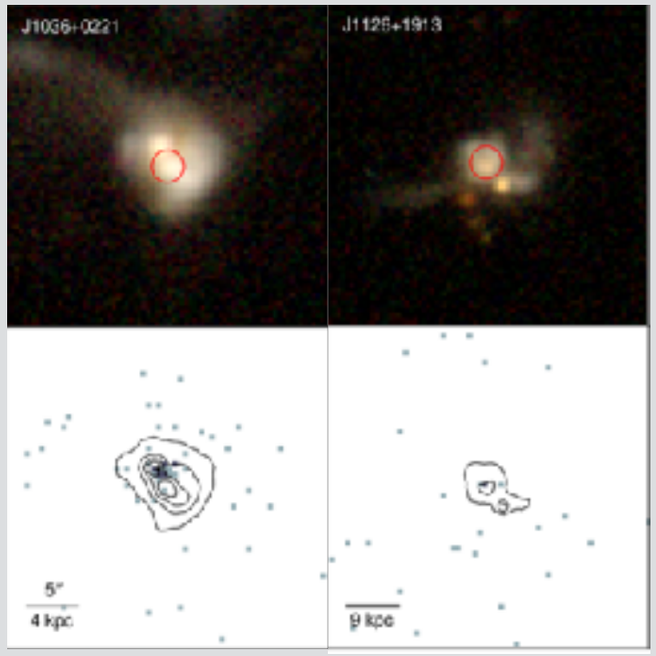
Satyapal et al. 2014

Uncovering dual nuclei in *WISE*-selected AGN

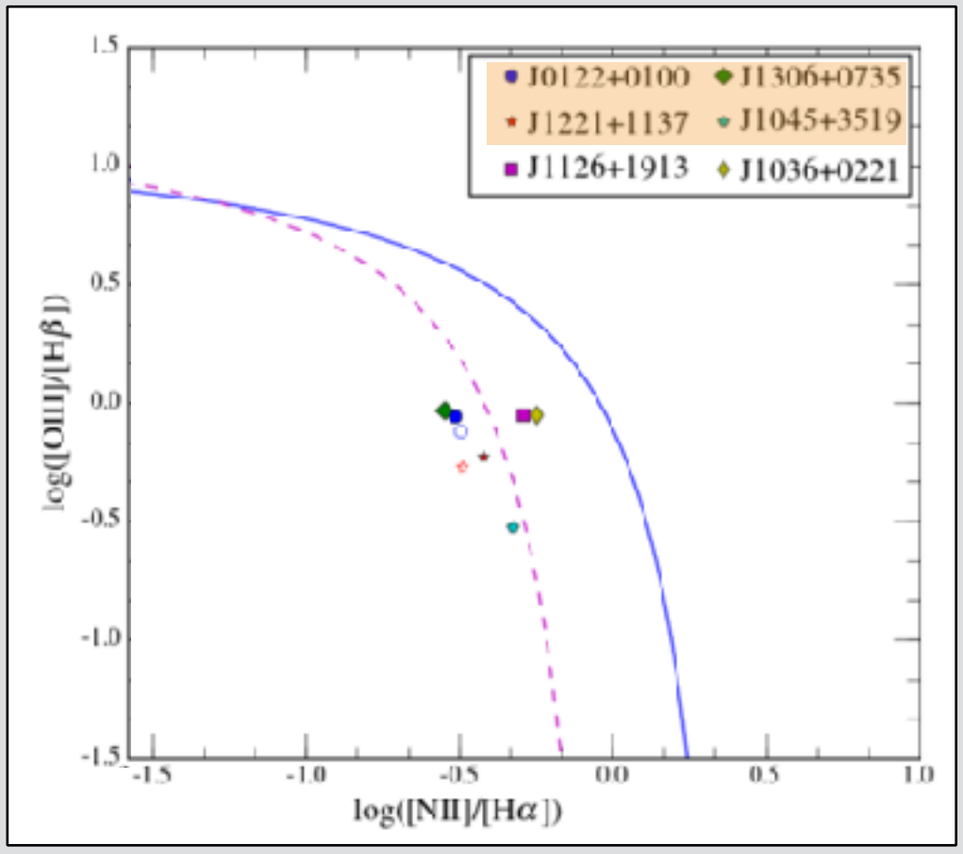
Candidate Dual AGN



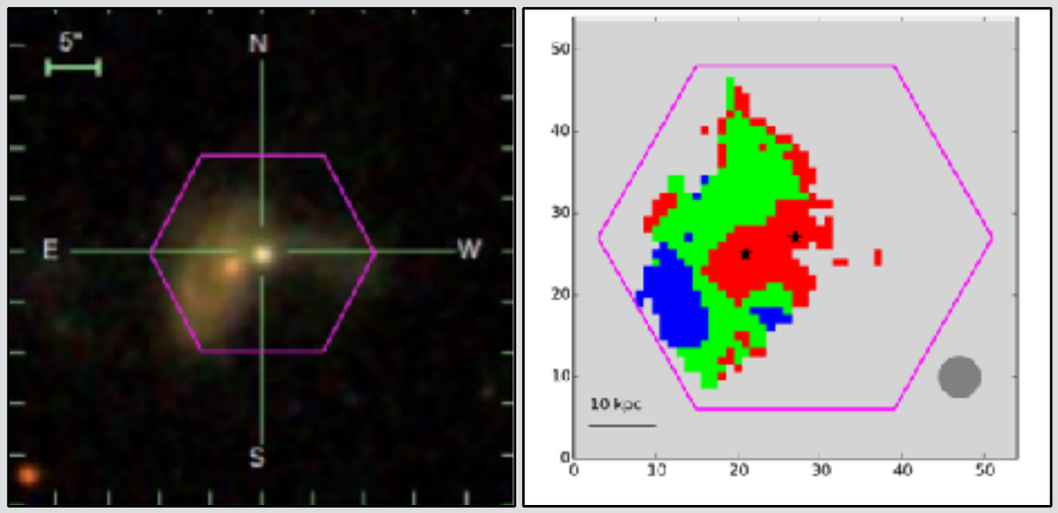
Single AGN



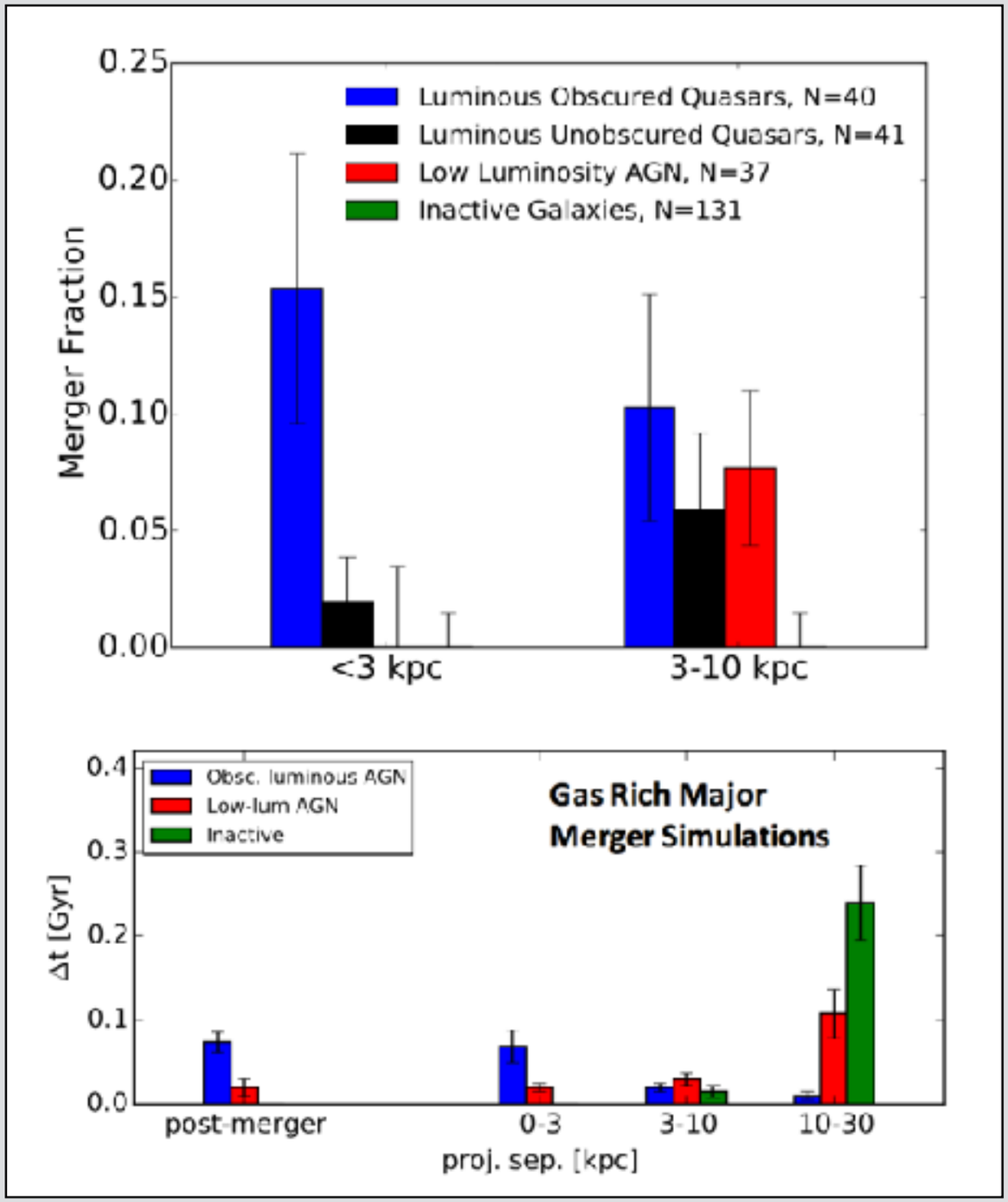
Satyapal et al. 2017

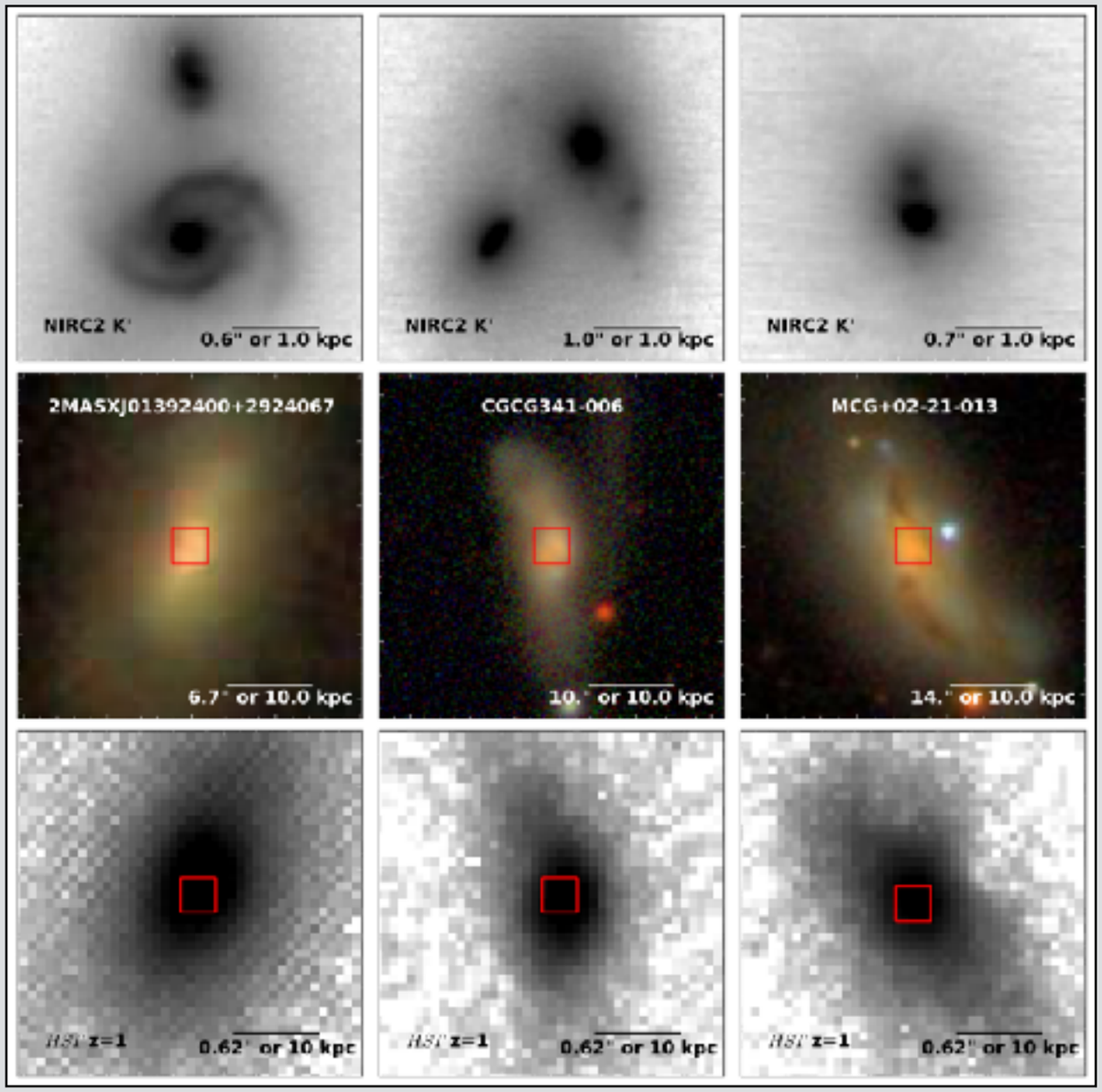


Ellison et al. 2017



More evidence for elusive dual nuclei
(in hard X-ray selected AGN)





Koss, LB et al. 2017

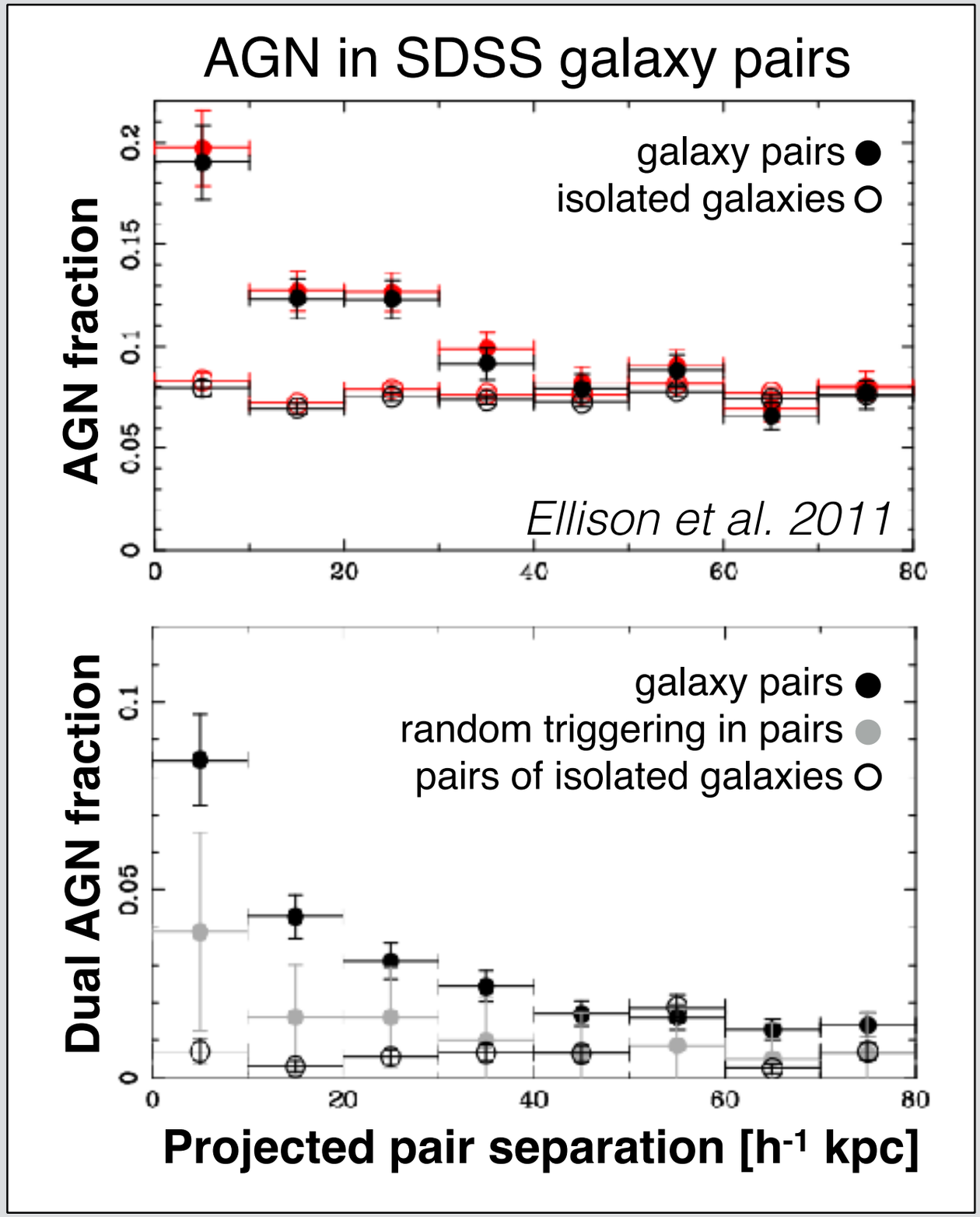
Summary

- Observed merger/AGN connection depends strongly on selection effects: **highest luminosity & obscuration in late-stage mergers**
- Significant environmental obscuration occurs in mergers, in contrast with AGN unification theories; peaks in the latest merger stages
- Standard mid-IR color selection identifies luminous merger-triggered AGN (L_{AGN}/L_{tot} > 30 - 50%), but **most AGN are missed, even in late stage mergers**
- Less stringent cut (W1-W2 > 0.5) selects merger-triggered AGN with high completeness **and high accuracy** (at low z)
- Very effective selection of **dual AGN**; many are likely still unresolved
- Mid-IR selected AGN (*and* hard X-ray selected AGN) are **promising targets for *JWST***; should uncover obscured, sub-kpc dual AGN in mergers

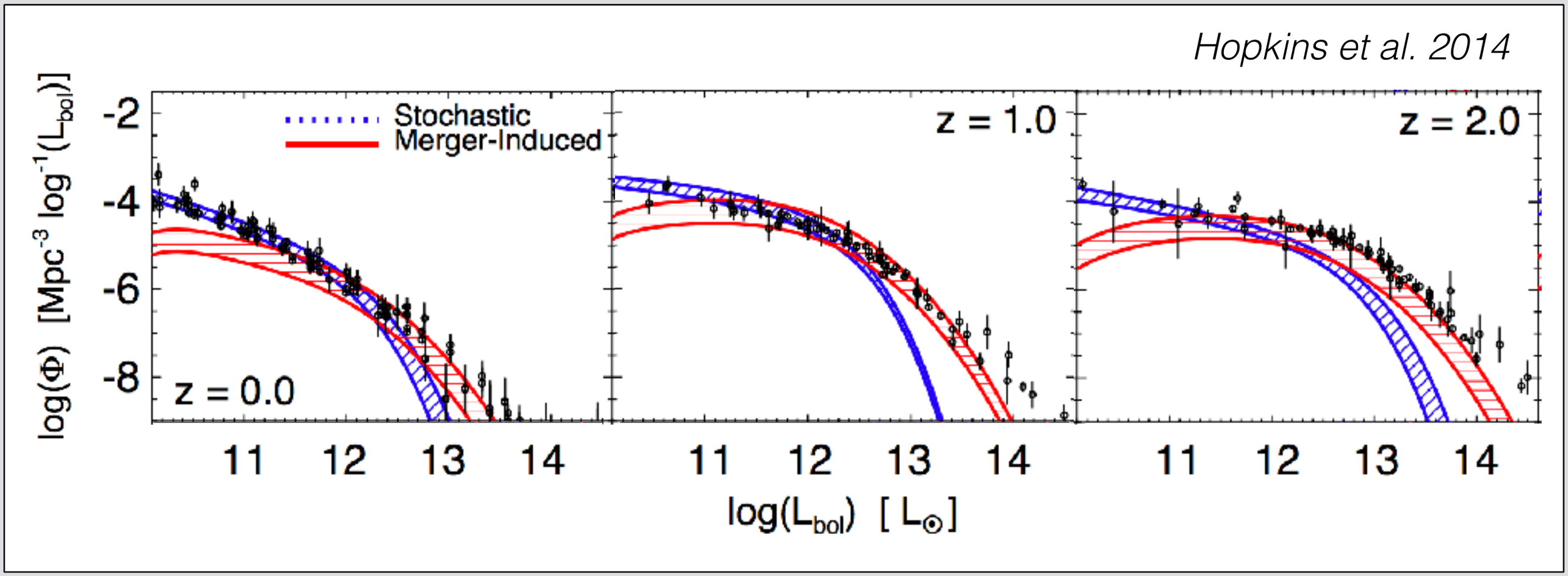
EXTRA SLIDES

Mergers trigger AGN fueling

- AGN activity is enhanced in galaxy pairs
- Strongest enhancement in late-stage mergers
- Dual AGN activity is enhanced even more strongly



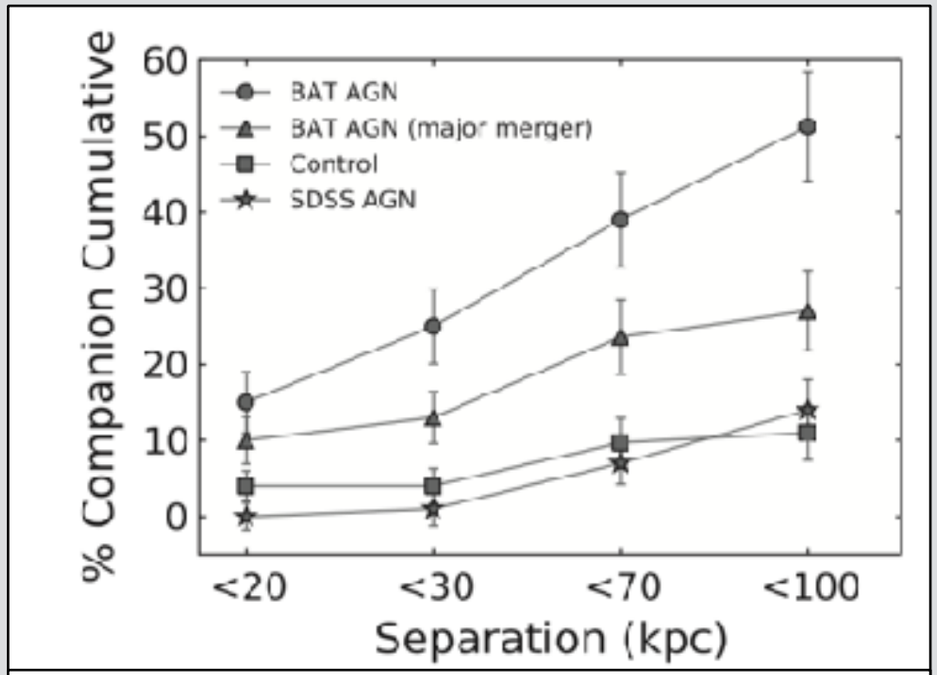
Mergers trigger *luminous* AGN

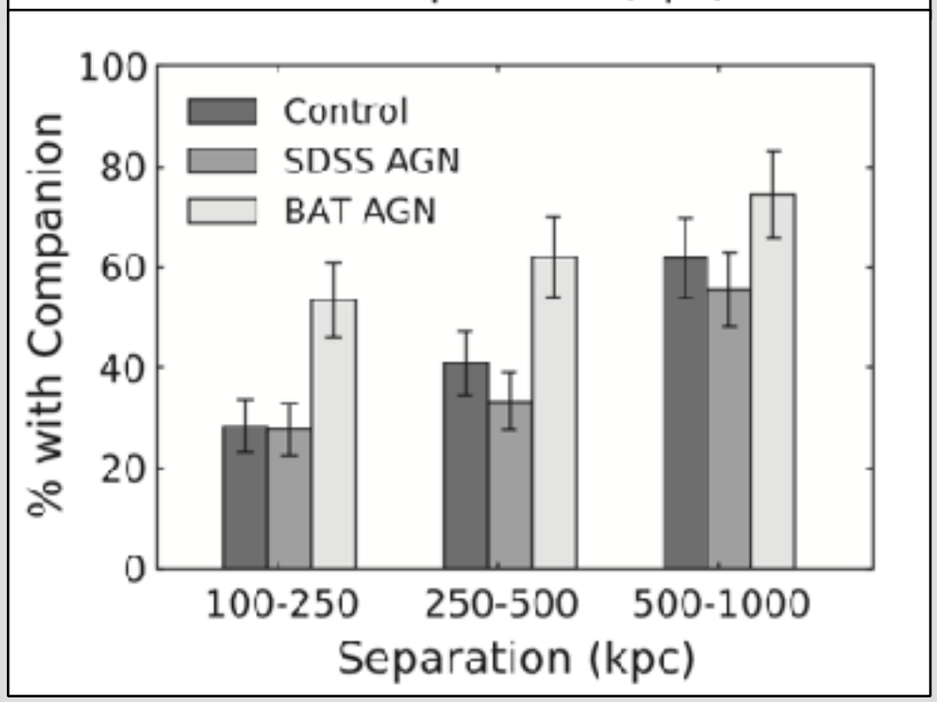


Mergers trigger *obscured, luminous* AGN

Higher merger fraction in hosts of AGN selected in ultra-hard X-rays (*Swift*/BAT):

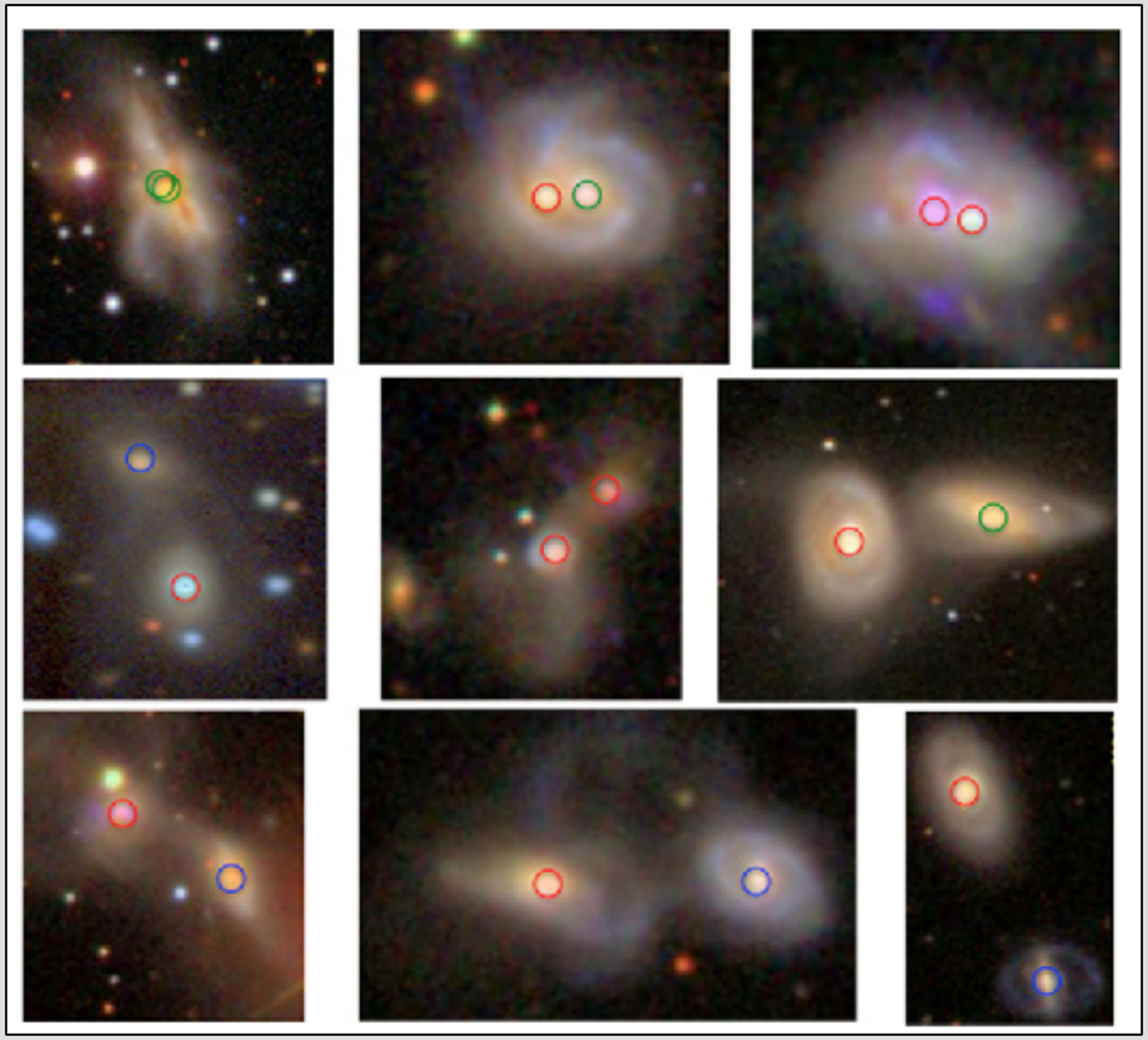
Koss et al. 2010





Mergers trigger *obscured, luminous* AGN

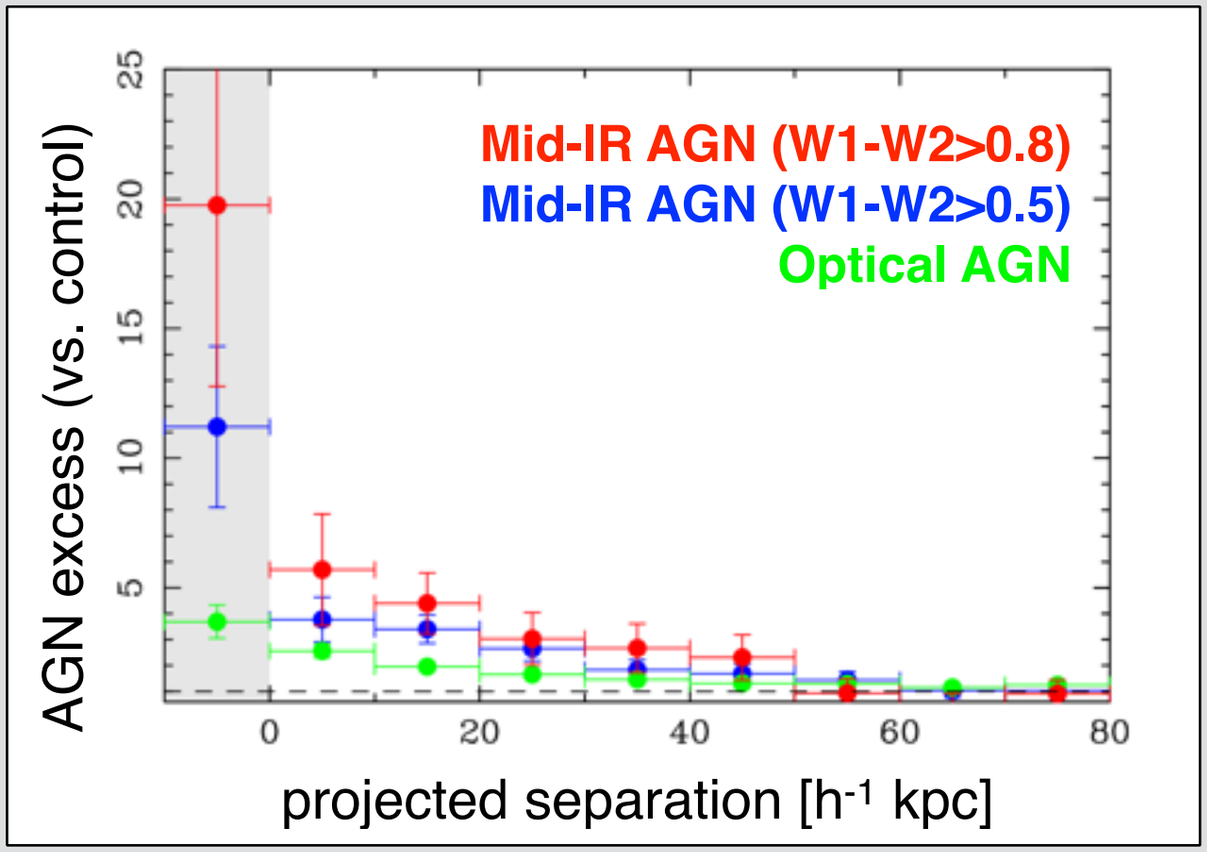
Koss et al. 2012

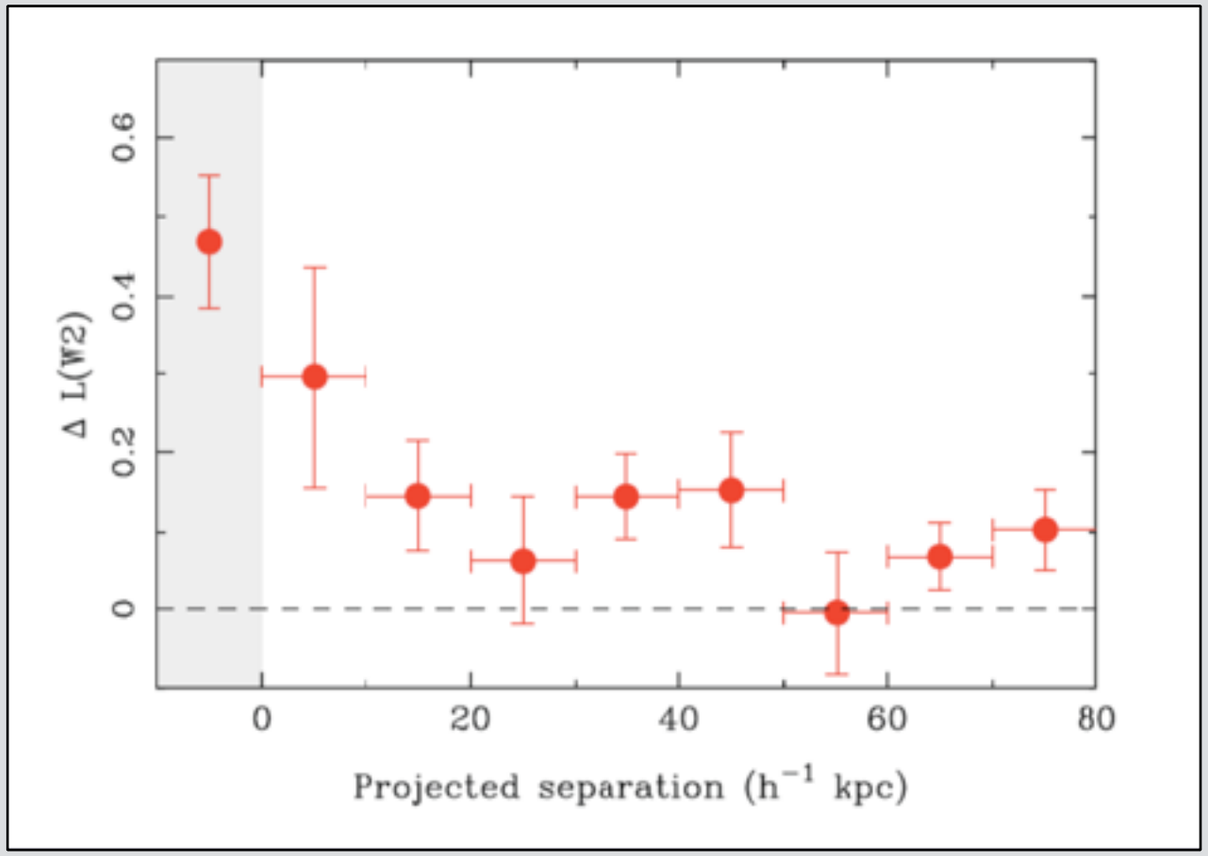


Ultra-hard X-ray (Swift-BAT) selected AGN:

- f_{pair} ~ 10% on < 100 kpc scales
- f_{pair} ~ 50% for < 15 kpc

Mid-IR color selection of obscured AGN





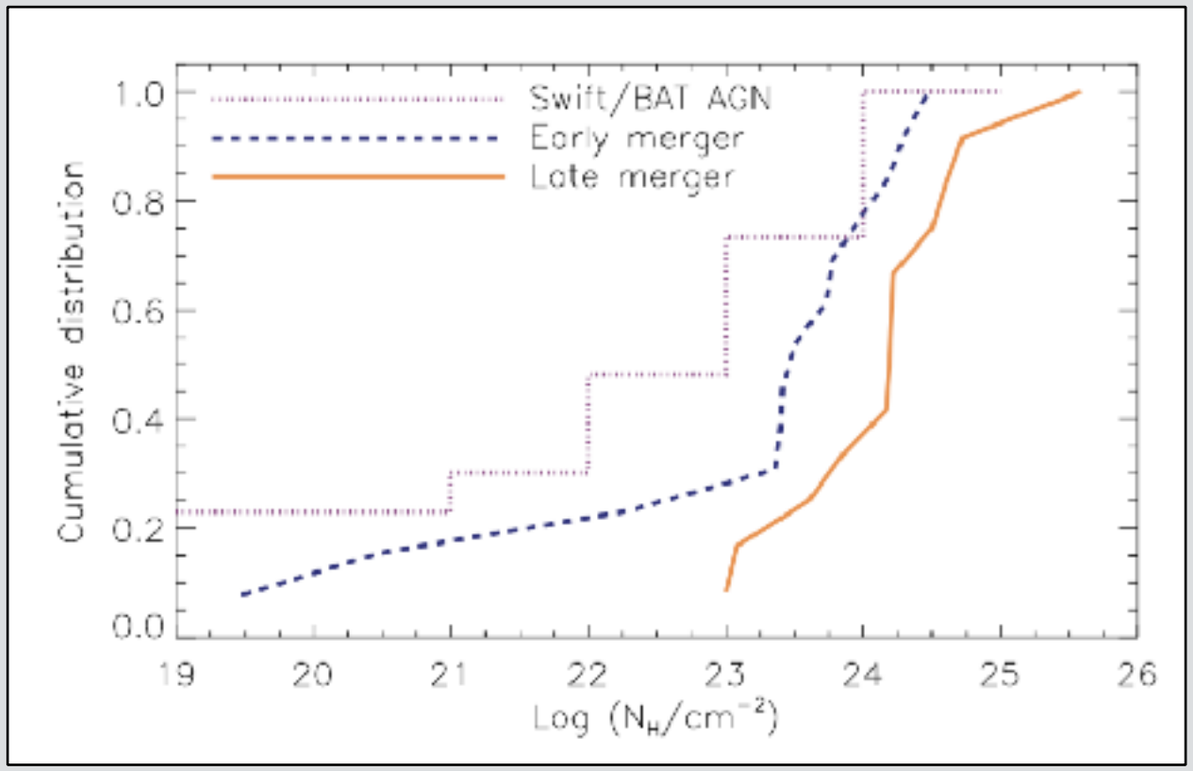
Satyapal et al. 2014

SDSS pair sample

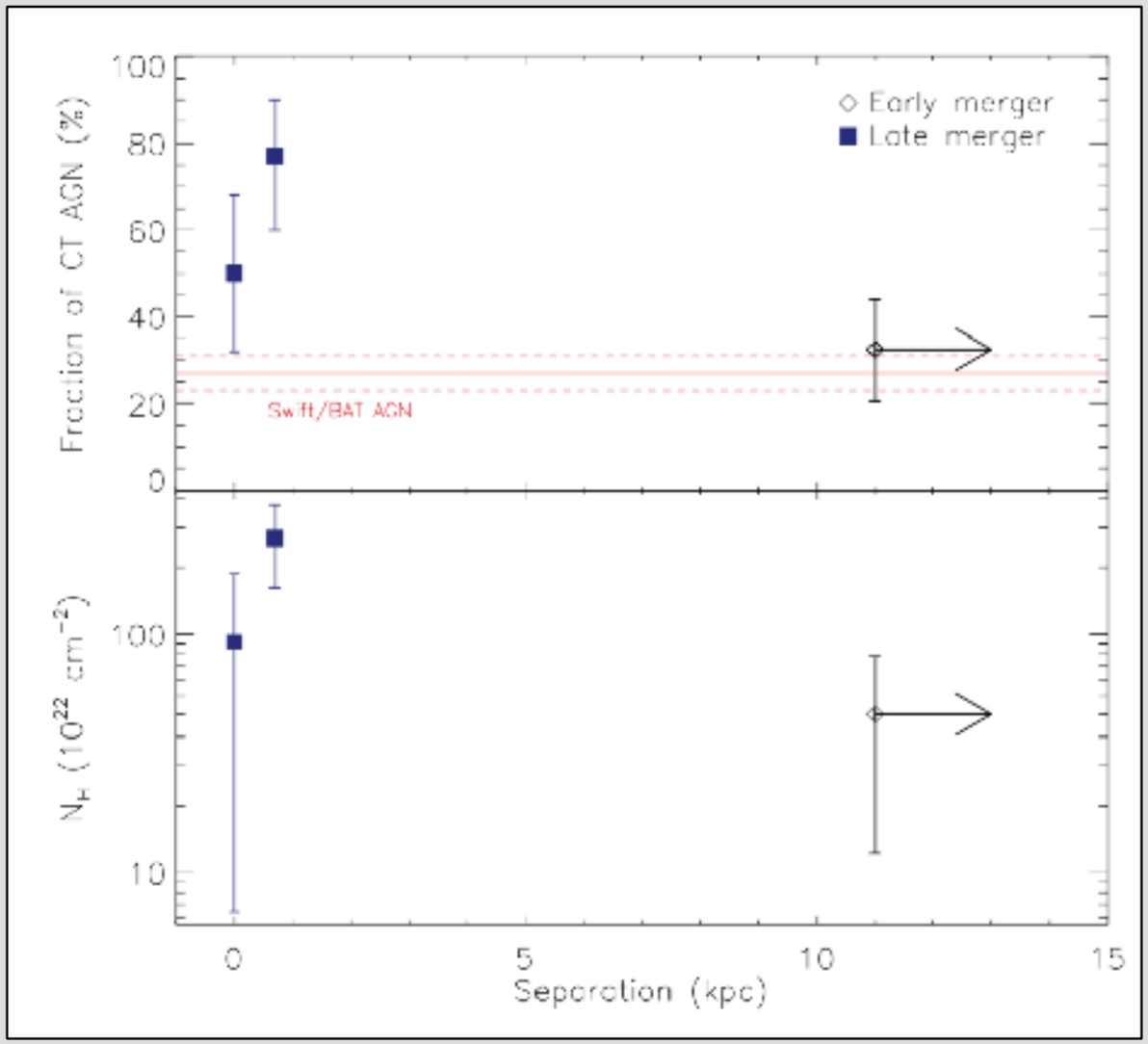
\+

Galaxy Zoo ‘post-merger’ sample

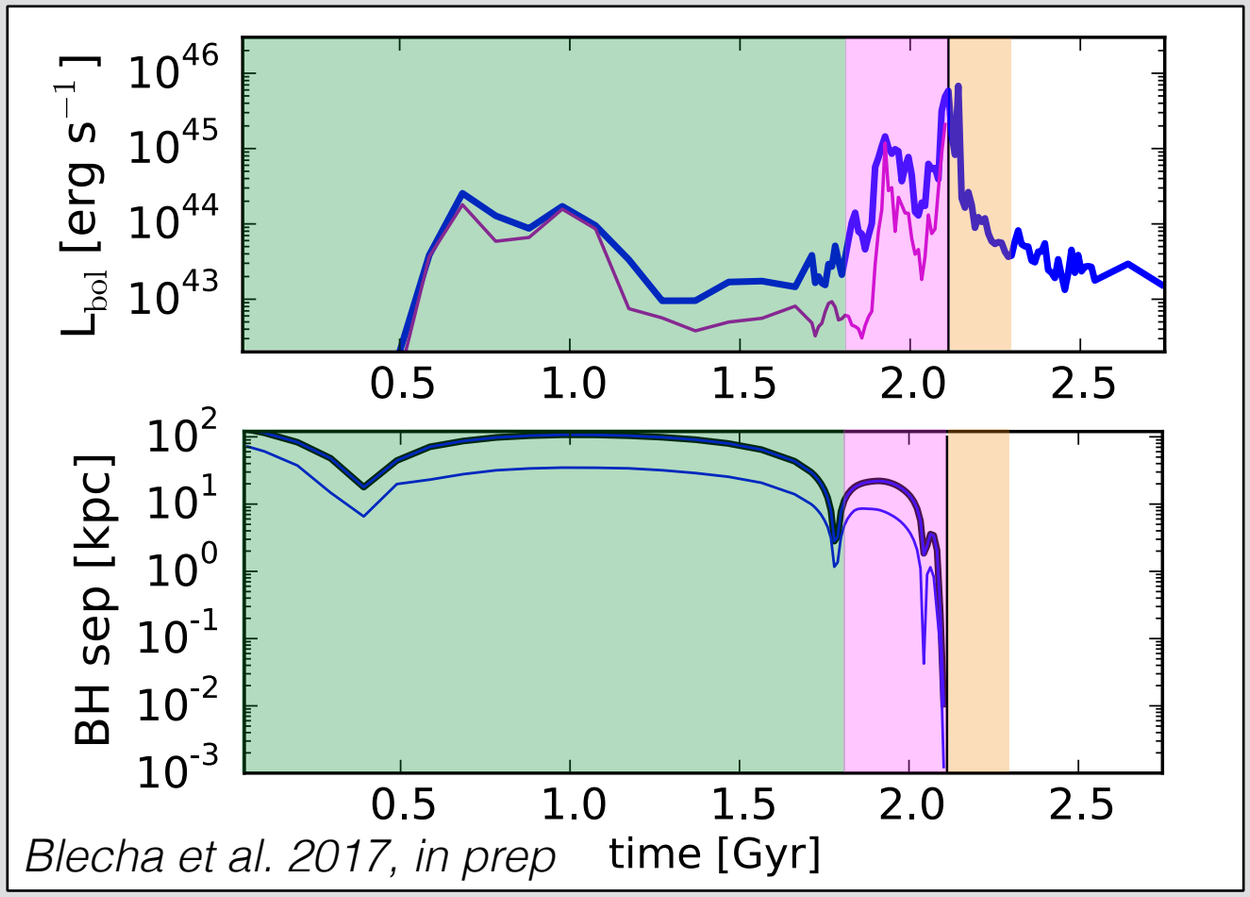
Environmental obscuration in late-stage mergers



Ricci et al. 2017

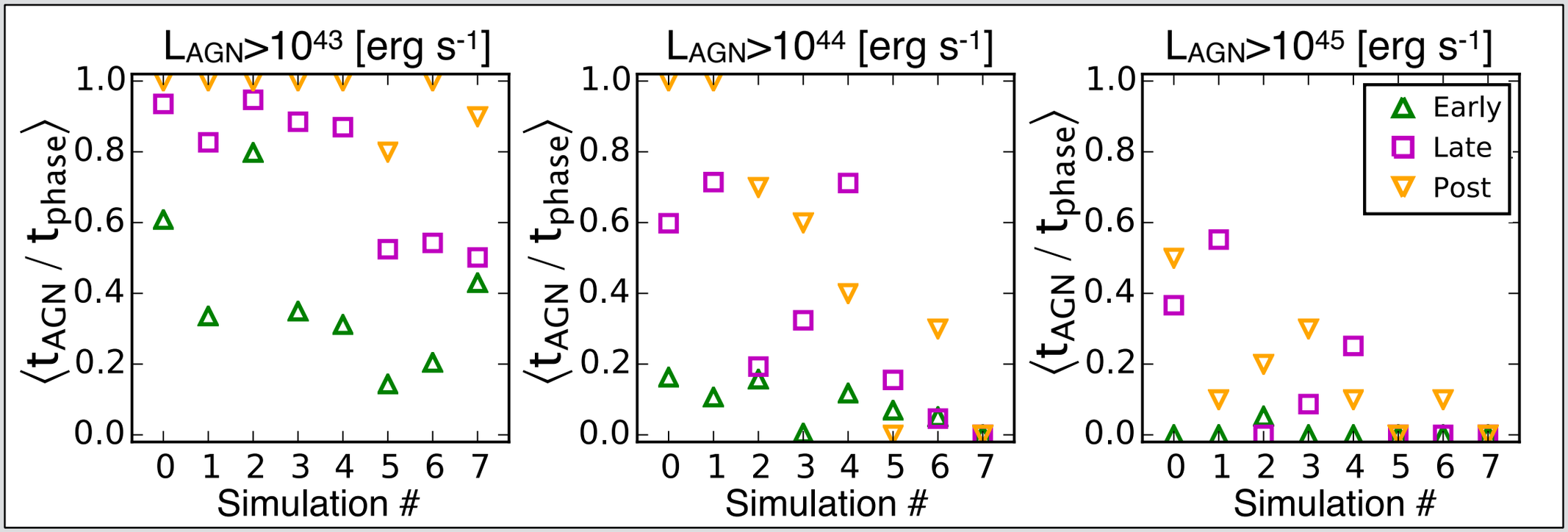


Active fraction vs merger phase

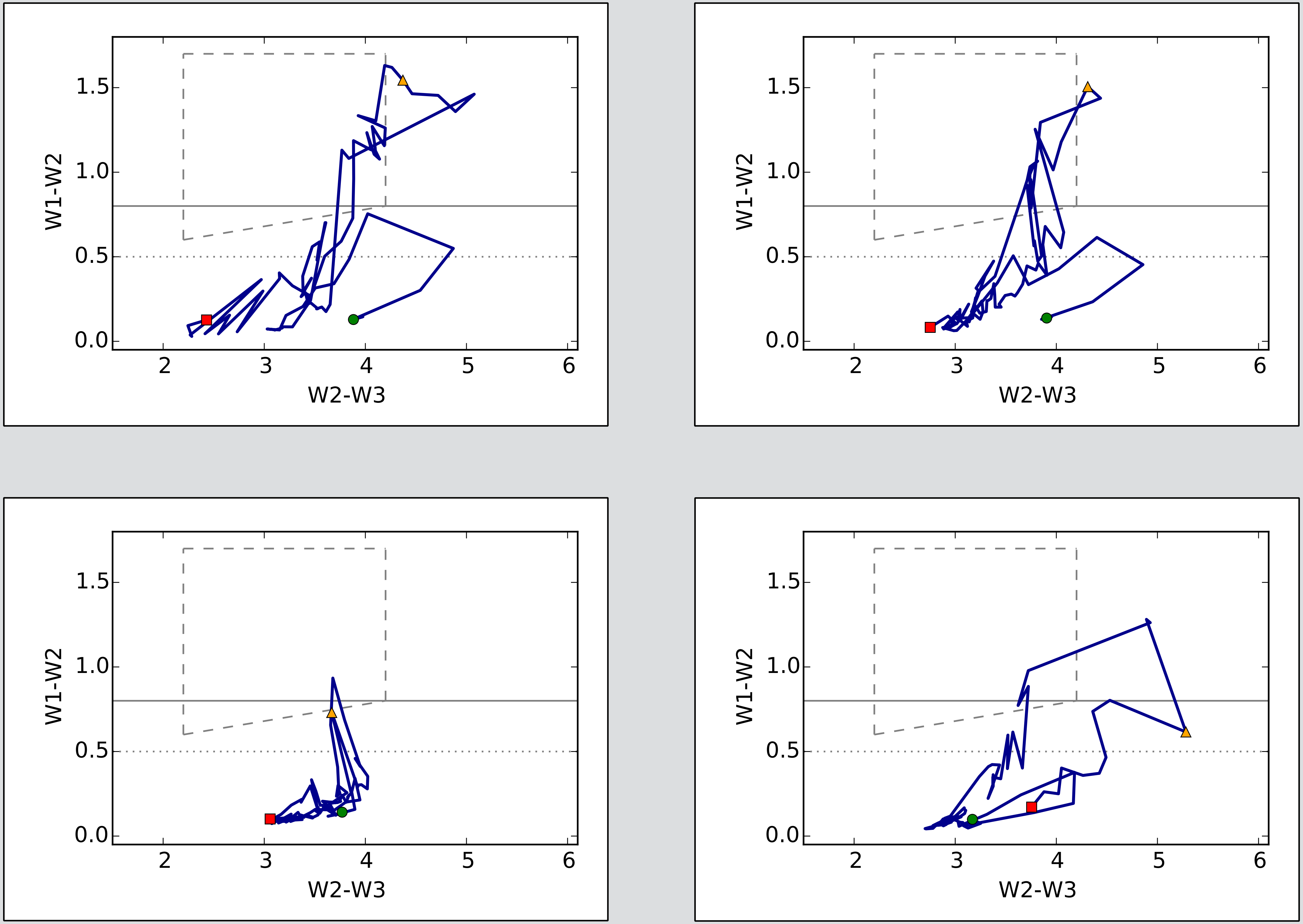


Blecha et al. 2017, in prep

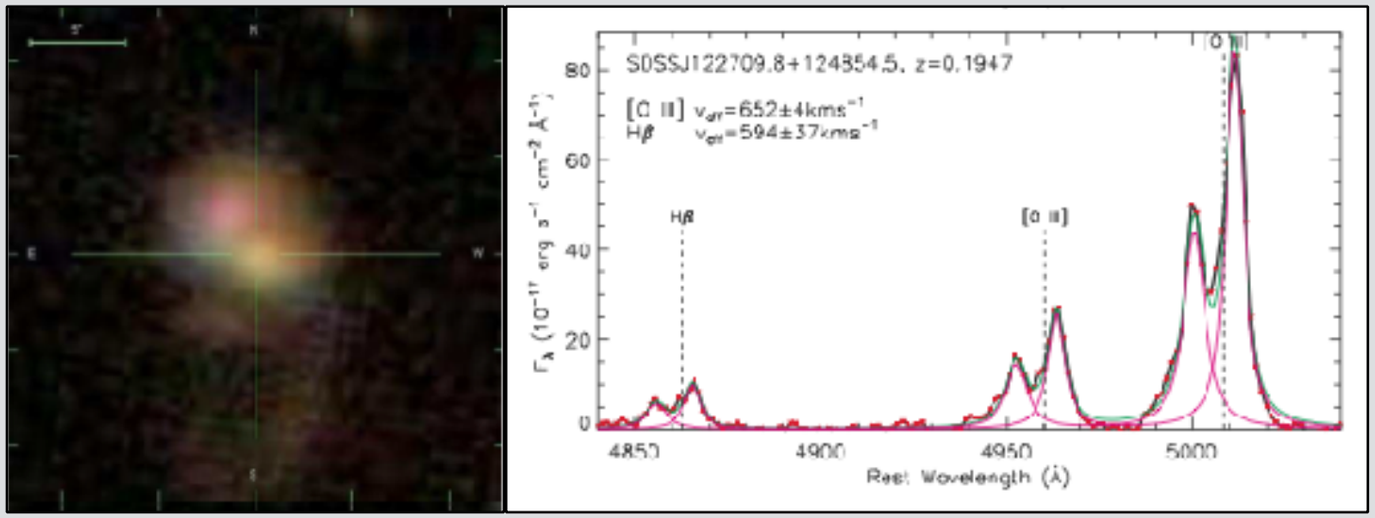
"Early" (a_{BH} > 10kpc)
"Late" (a_{BH} < 10kpc)
"Post" (after BH merger)



WISE mid-IR color evolution in mergers

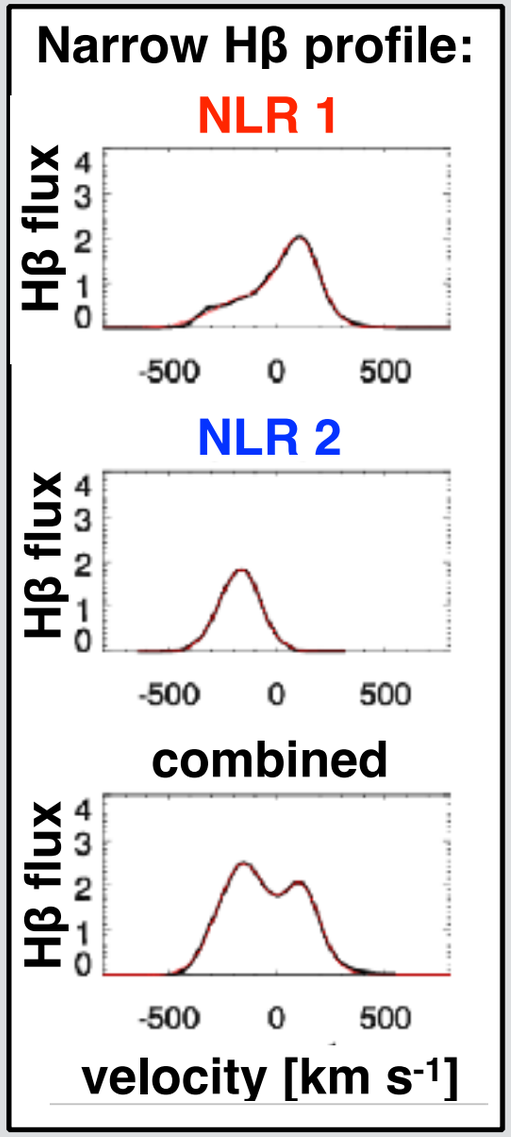


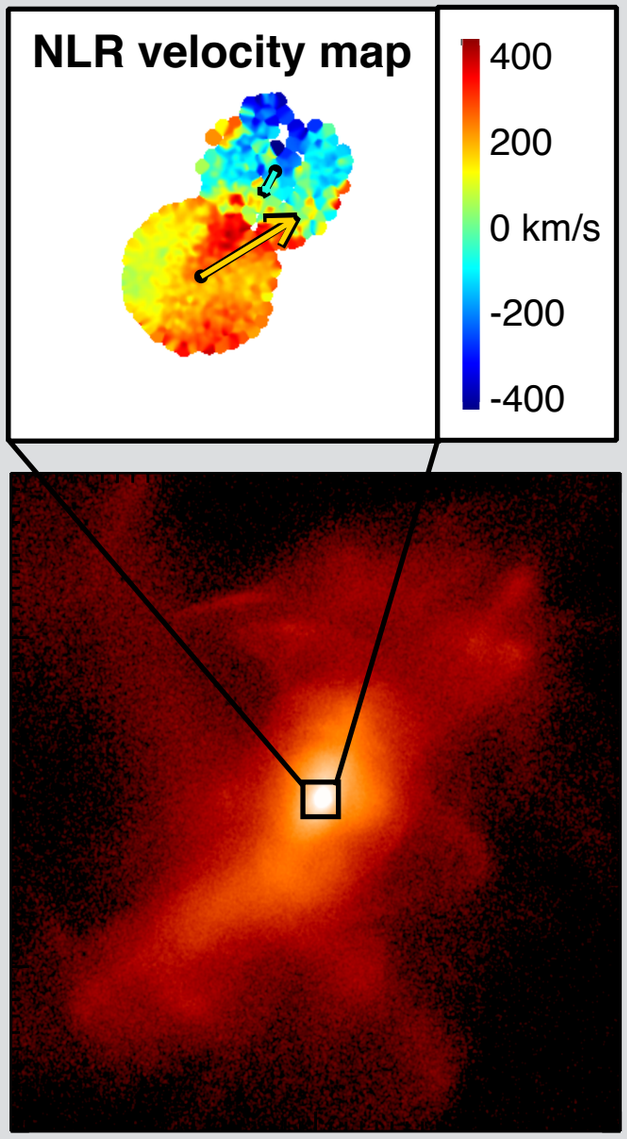
Optical searches for dual AGN: Double-peaked narrow lines



Liu et al. 2009

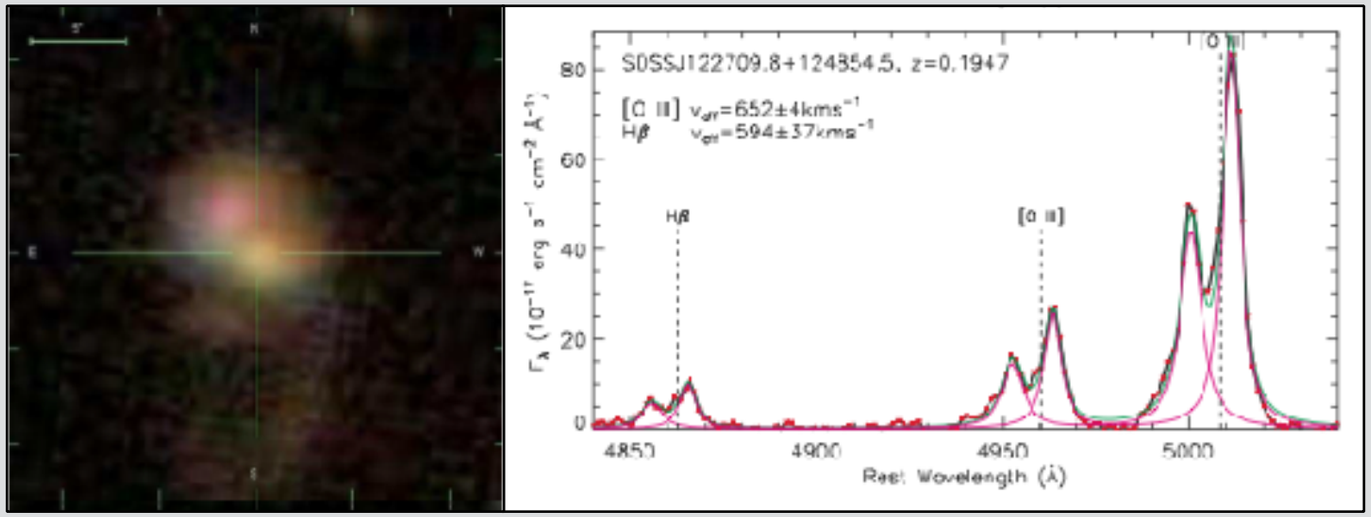
- SMBH orbital motion on kpc scales?
- ~ 1% of AGN have double-peaked NLs





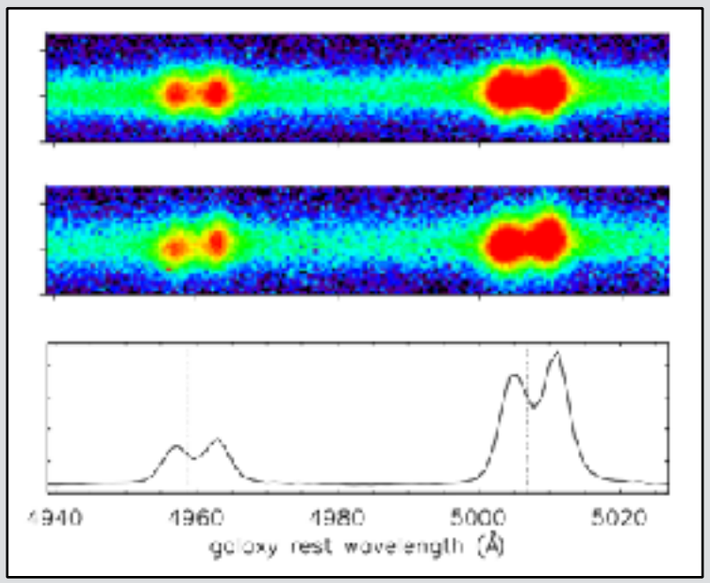
Blecha et al. 2013b

Optical searches for dual AGN: Double-peaked narrow lines

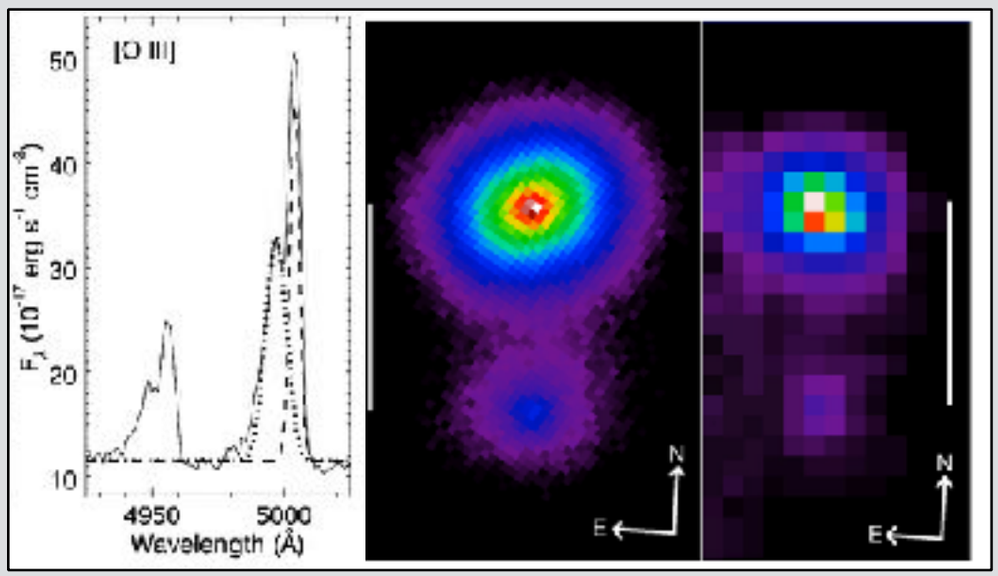


Liu et al. 2009

- SMBH orbital motion on kpc scales?
- ~ 1% of AGN have double-peaked NLs
- Follow-up observations: >10% are confirmed dual AGN or strong candidates



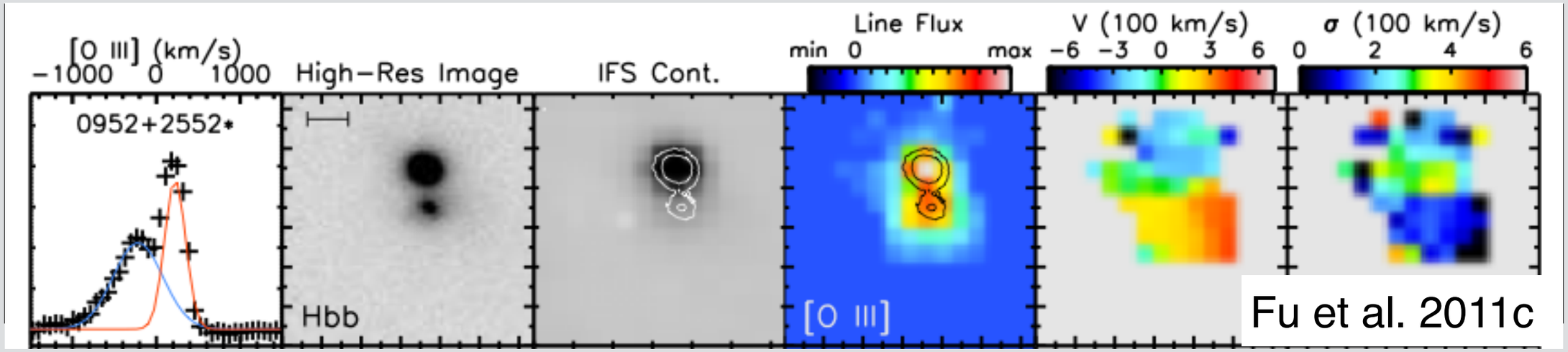
Comerford et al. 2012



McGurk et al. 2011

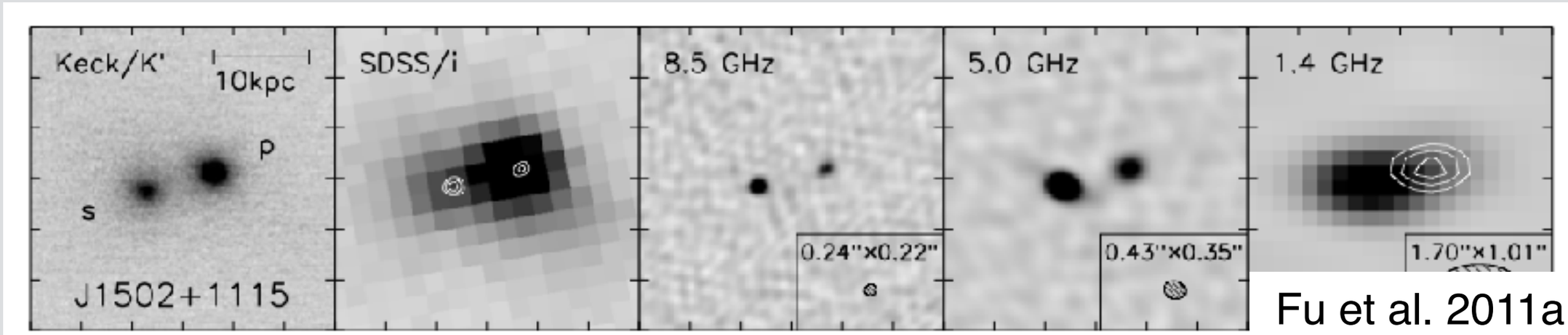
Follow-up of double-peaked NL AGN

Optical:



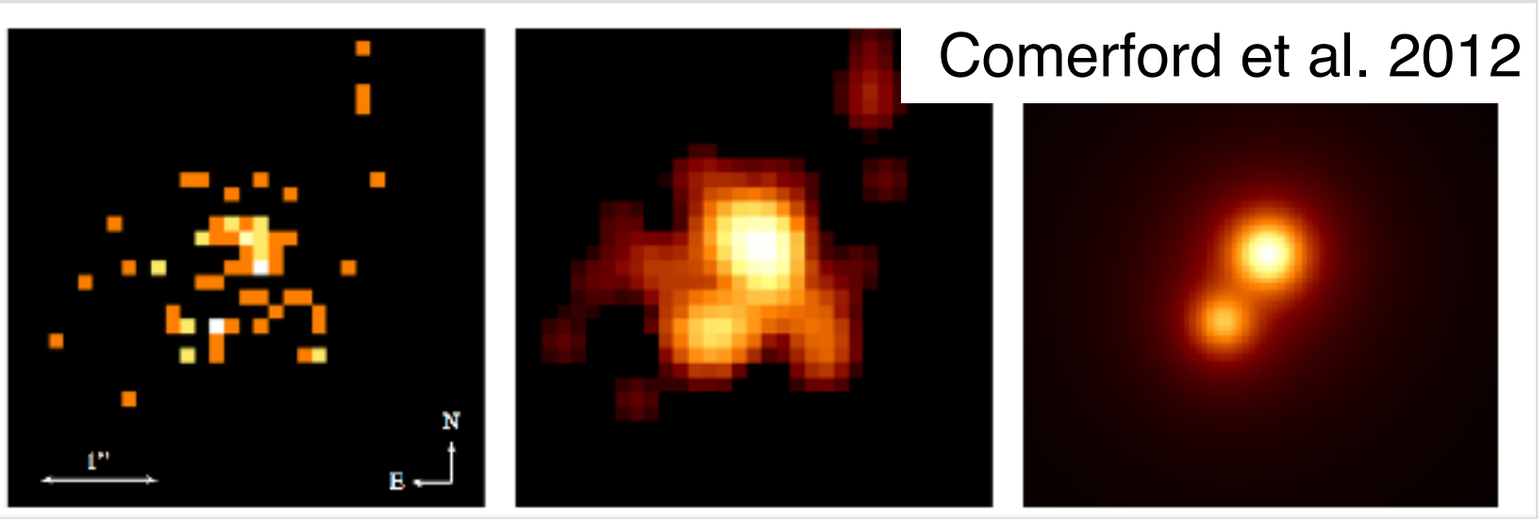
Fu et al. 2011c

Radio:



Fu et al. 2011a

X-ray:

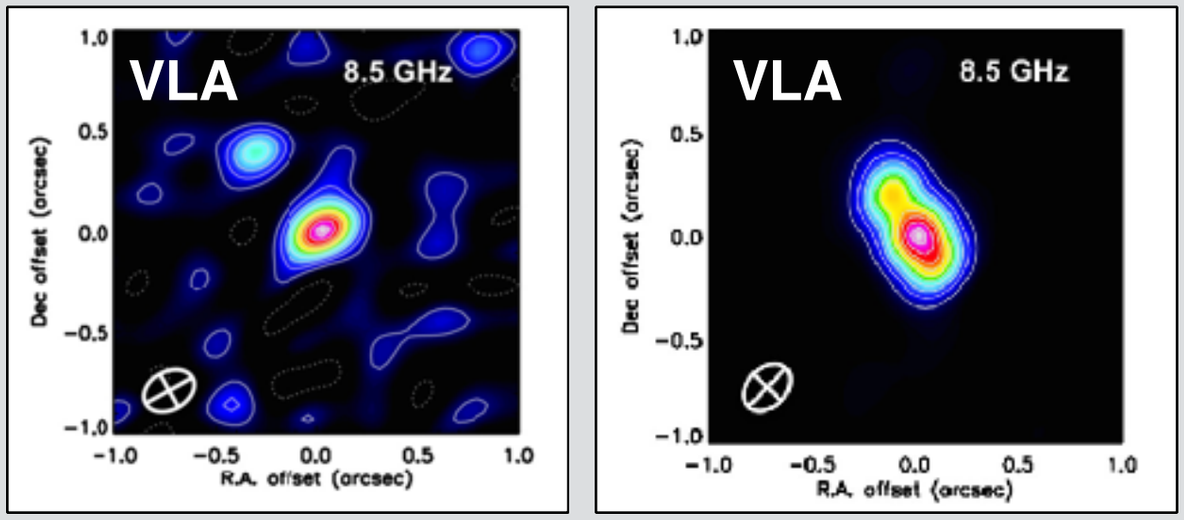


Comerford et al. 2012

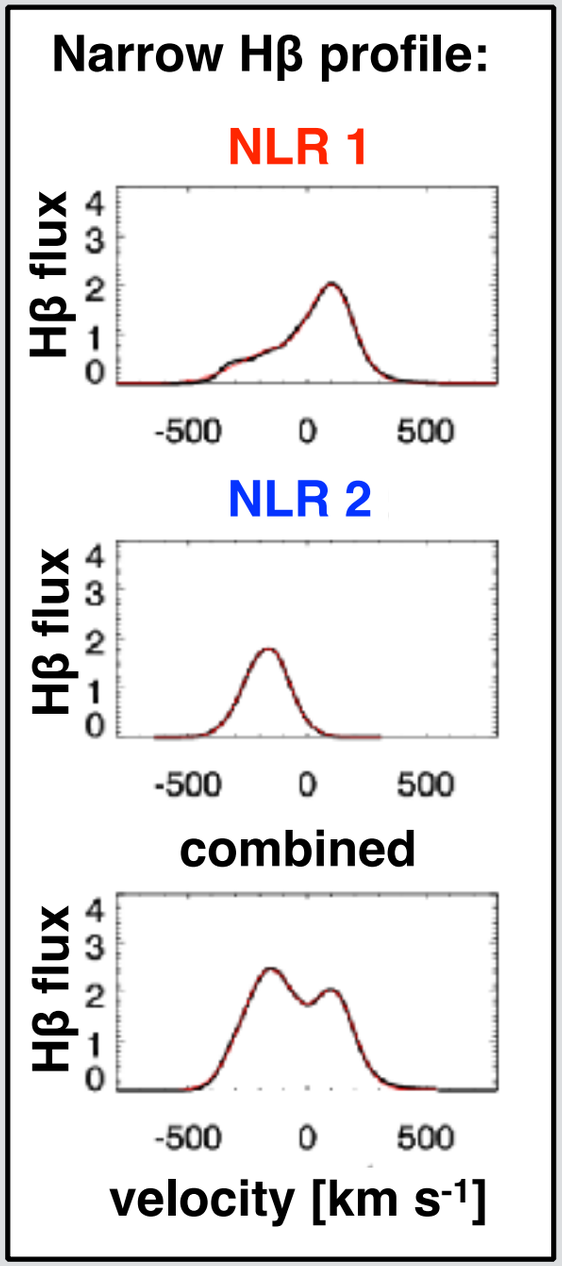
Optical spectroscopic searches for kpc-scale dual AGN

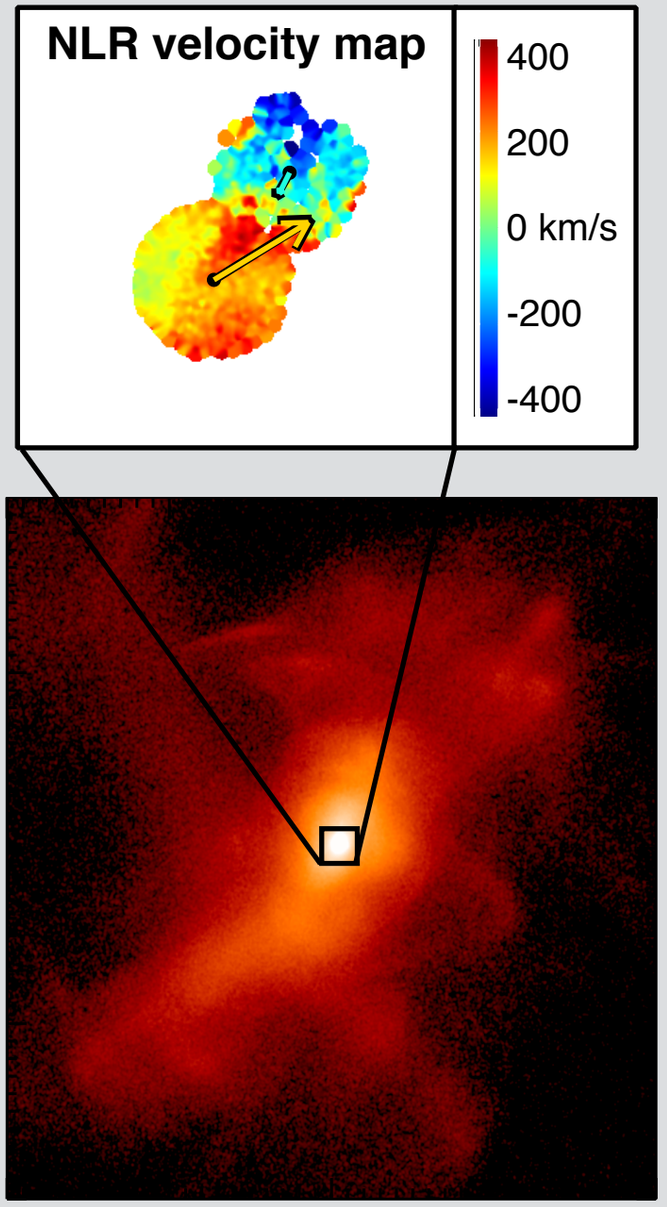
- Double-peaked NLs from dual SMBHs are ***generic*** to major mergers, but ***short lived*** (~ few Myr)
- Most double-peaked NLs produced by ***gas kinematics***, not SMBH motion

dual AGN **jet-driven outflow**



Müller-Sanchez et al. 2015



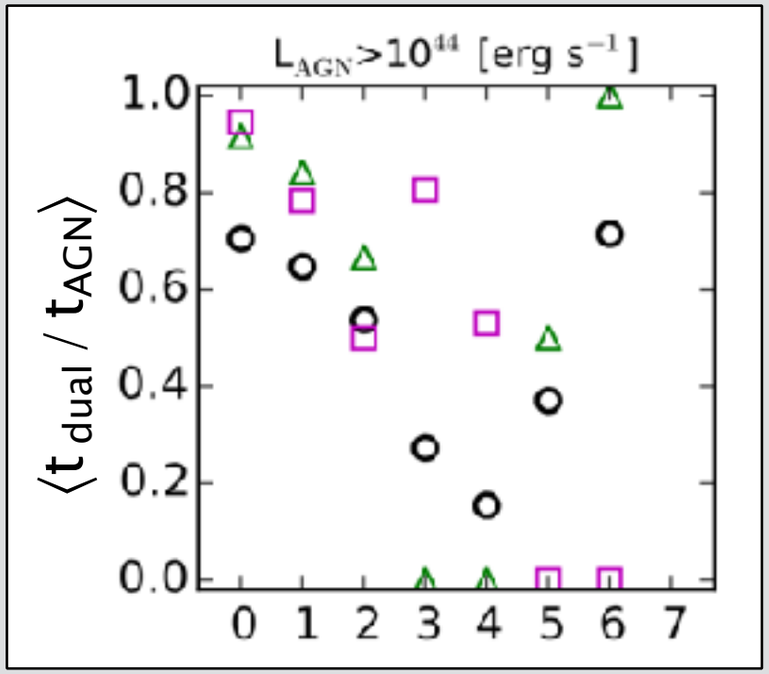


Blecha et al. 2013b

Uncovering dual nuclei in *WISE*-selected AGN

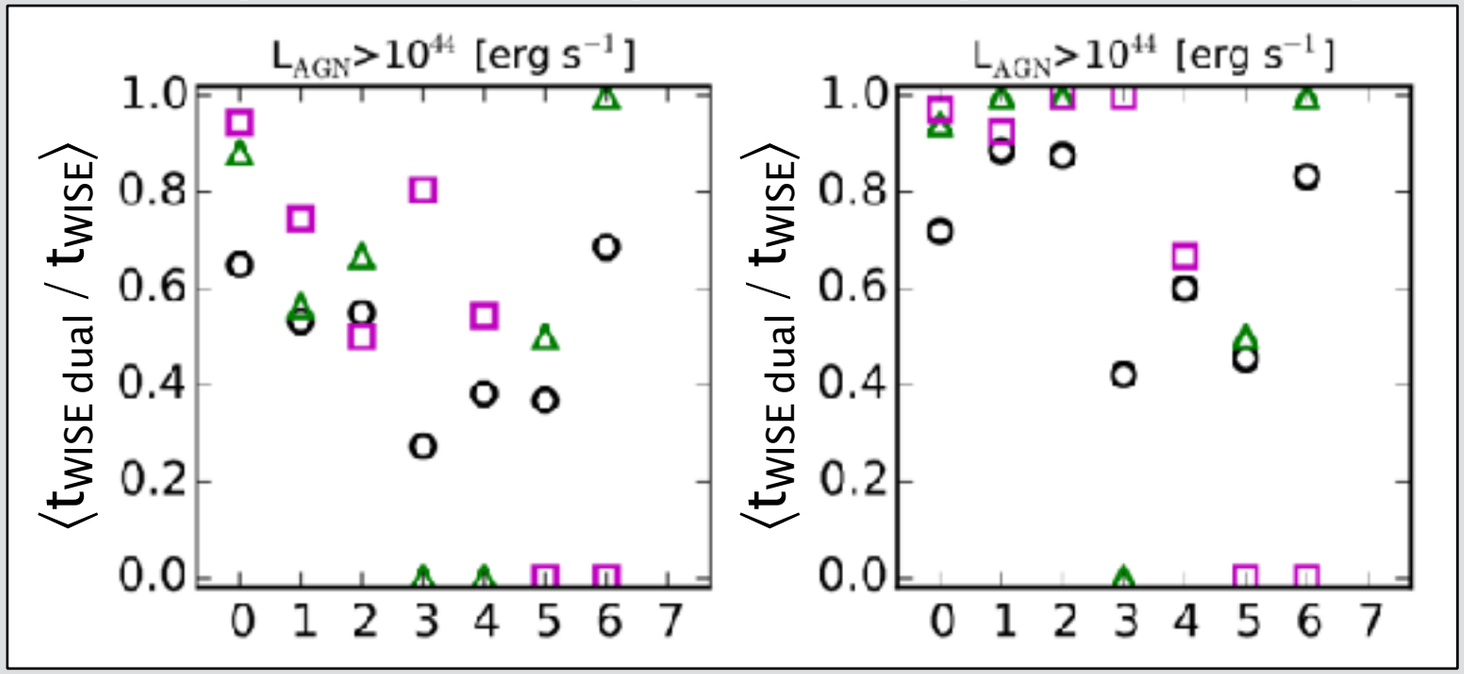
- >~30-40% of *all* WISE-selected AGN in mergers should contain duals (with L>~10^{43}-10^{44} erg/s)
- Slightly *higher* dual fraction for more stringent mid-IR criterion (W1-W2>0.8)
- Many are likely still unresolved
- Prime targets for *JWST*

t_{dual} / t_{AGN}

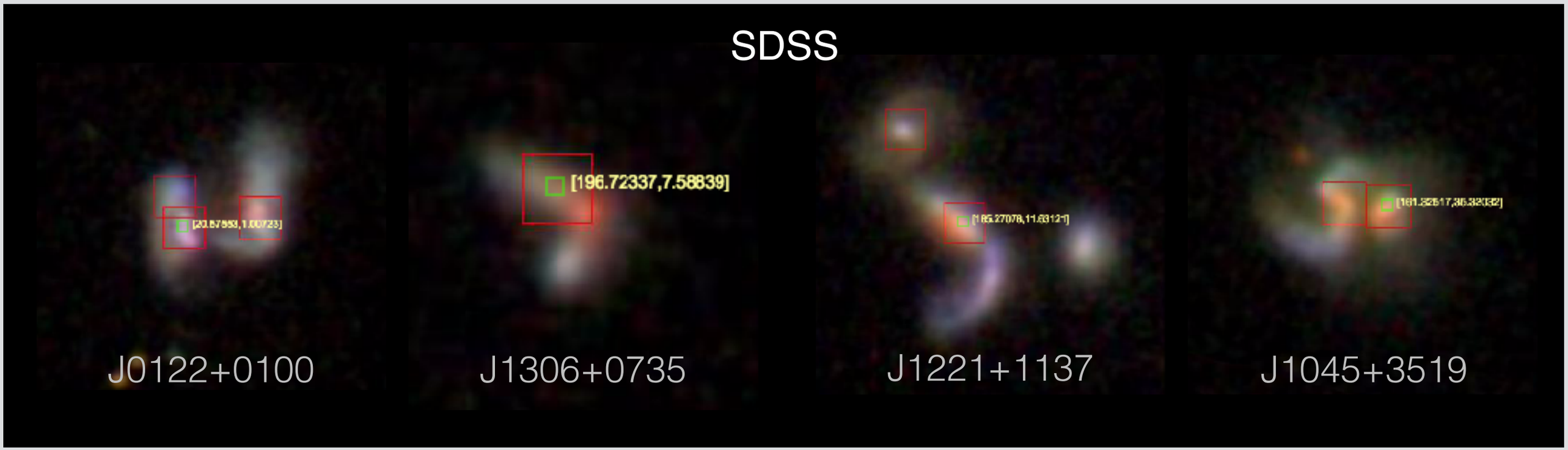


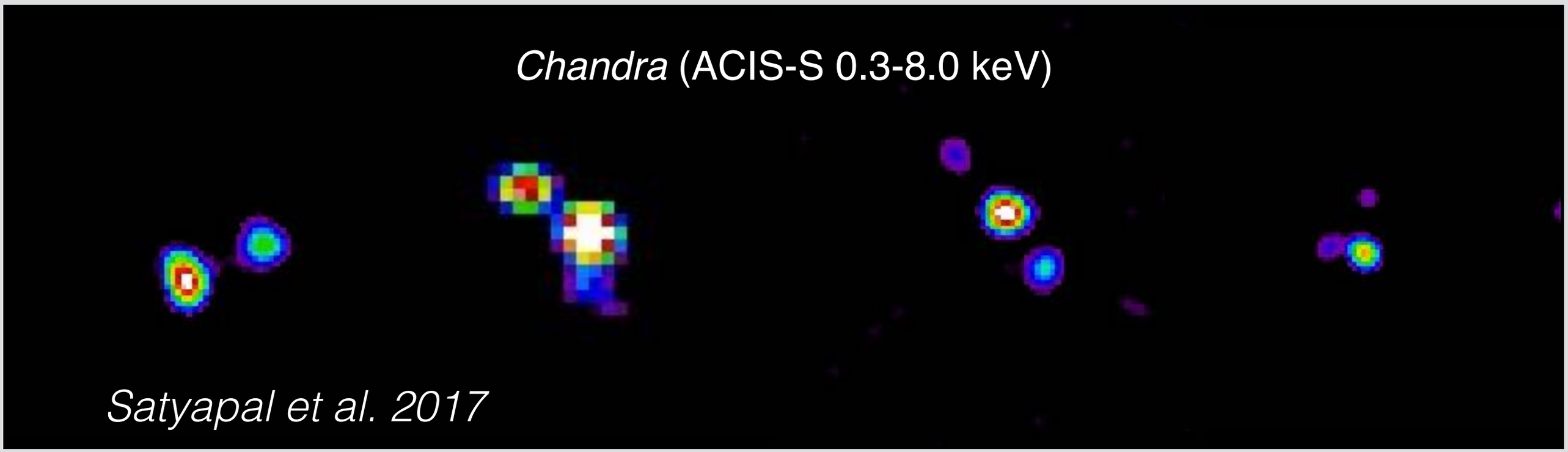
$t_{WISE\ dual}$ / t_{WISE} (W1-W2 > 0.5)

$t_{WISE\ dual}$ / t_{WISE} (W1-W2 > 0.8)

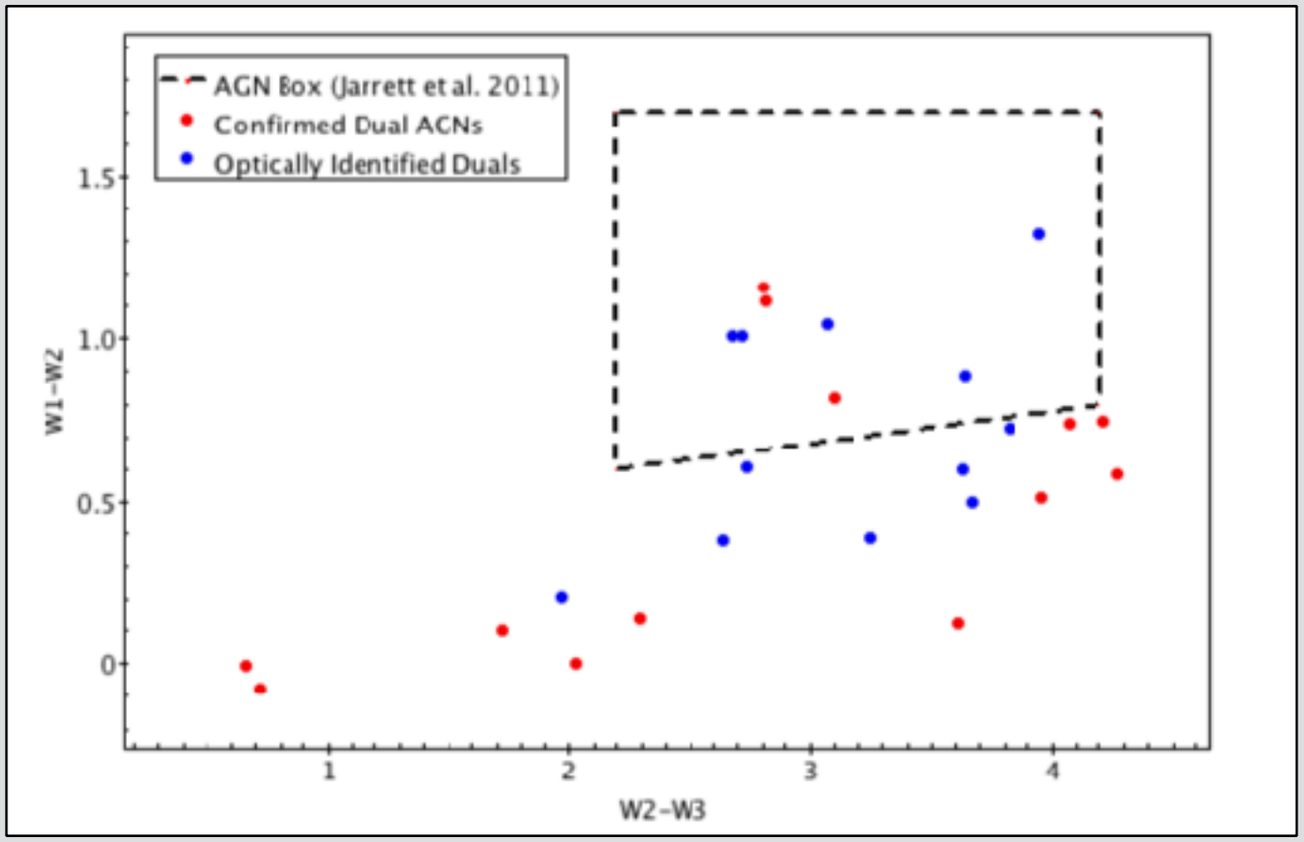


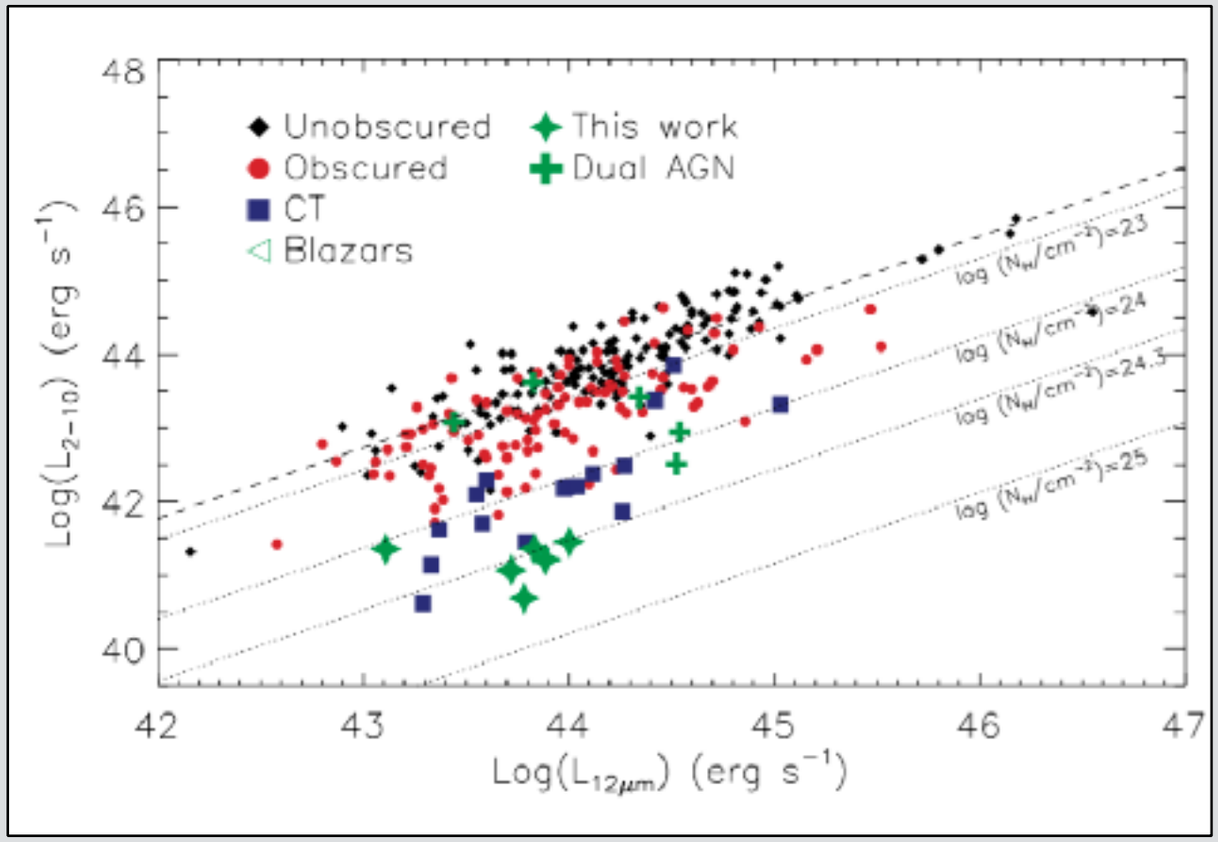
Uncovering dual nuclei in *WISE*-selected AGN





Evidence for obscuration in confirmed dual AGN





Satyapal et al. 2017