

# Using WISE To Find Obscured AGN Activity in SDSS Mergers & Interactions

Madalyn E. Weston

Daniel H. McIntosh

University of Missouri – Kansas City

Galaxy Evolution Group

# Galaxy merging plays an important role in massive galaxy buildup and in triggering new SF and black hole growth activity

Hopkins et al. 2008, Kauffmann et al. 1996 & 2003, Filho et al. 2014  
McIntosh et al. 2014, Barnes 1988, Springel et al. 2005,  
DeBuhr et al. 2011, Volonteri et al. 2003, Toomre & Toomre 1972

# Simulations show....

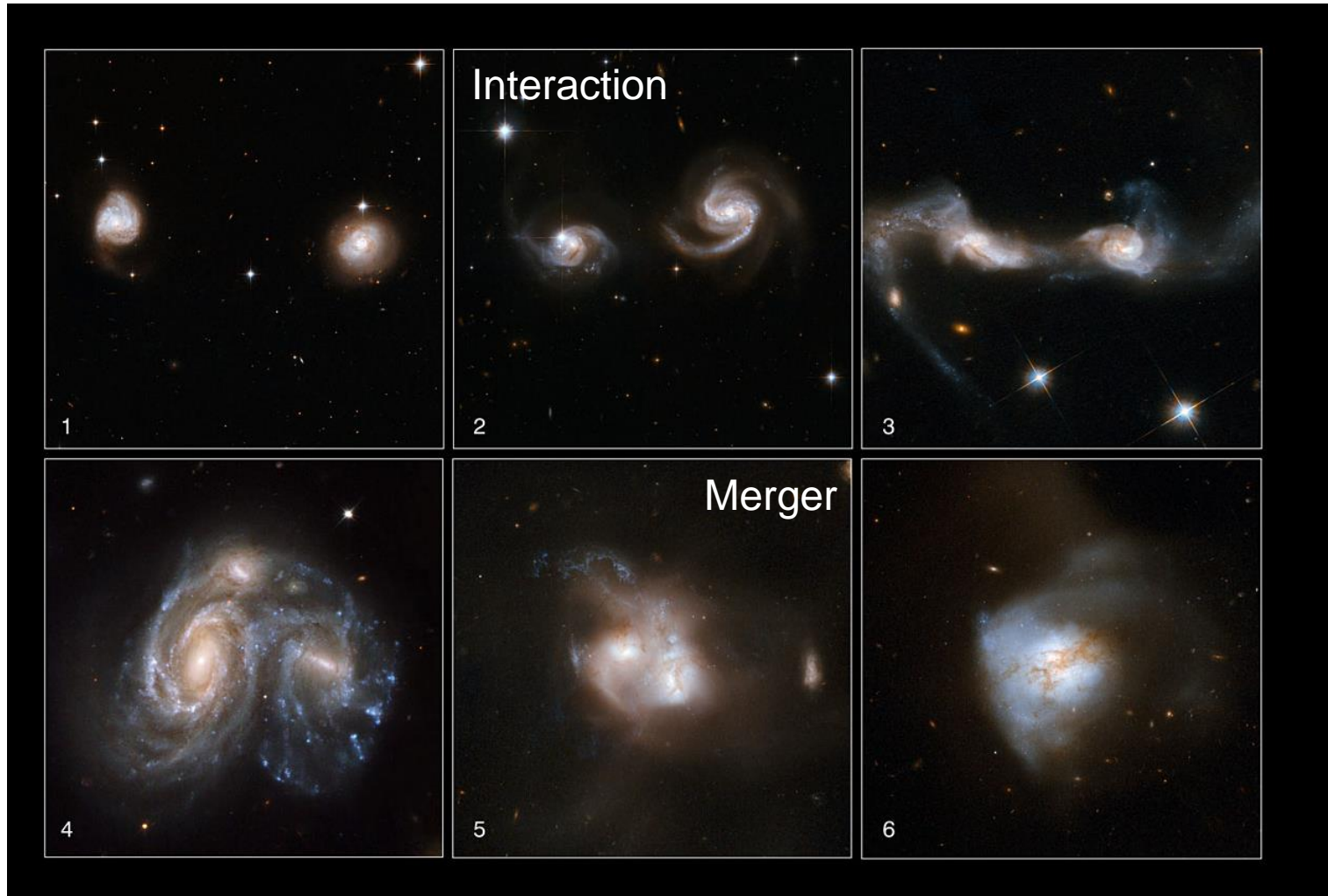


Image Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University), K. Noll (STScI), and J. Westphal (Caltech).

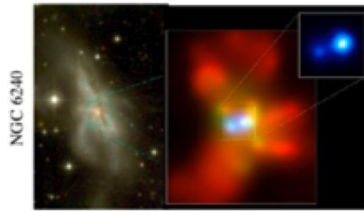
Barnes & Hernquist 1996

(c) Interaction/"Merger"



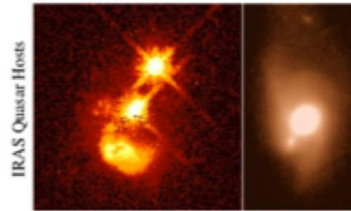
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



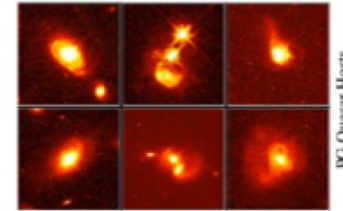
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



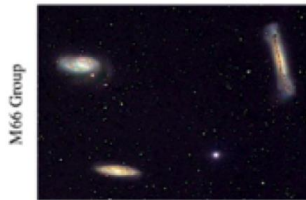
- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



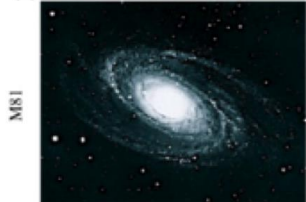
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

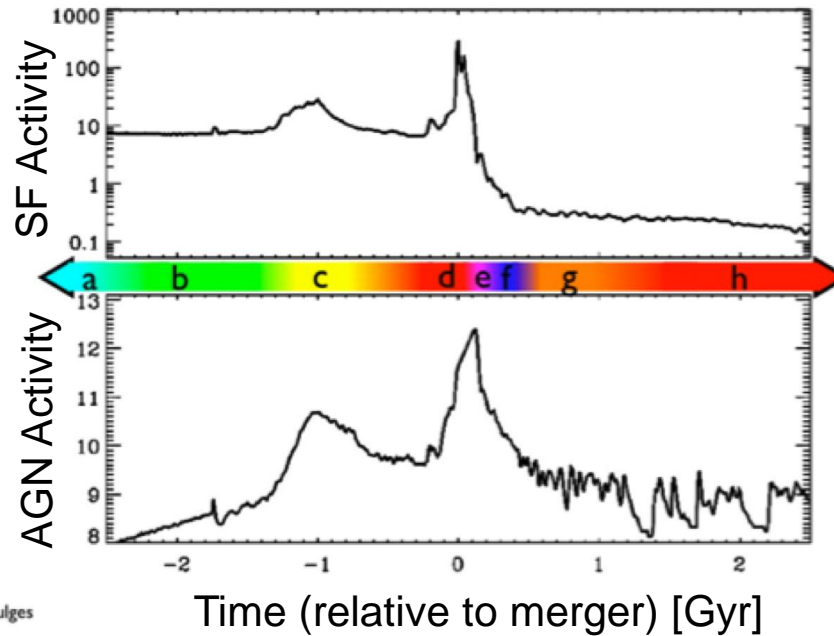


- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- $M_{halo}$  still similar to before: dynamical friction merges the subhalos efficiently

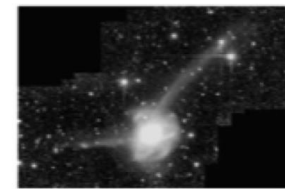
(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with  $M_b > 23$ )
- cannot redden to the red sequence



(g) Decay/K+A



- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

(h) "Dead" Elliptical

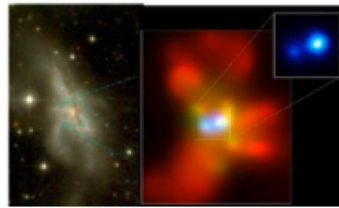


- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

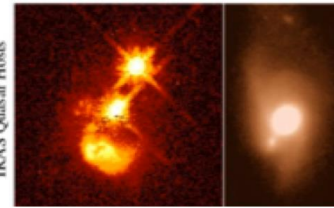
(c) Interaction/"Merger"



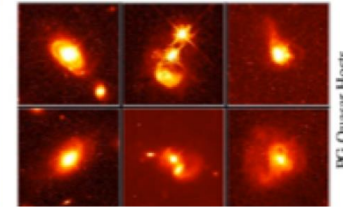
(d) Coalescence/(U)LIRG



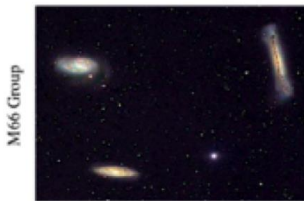
(e) "Blowout"



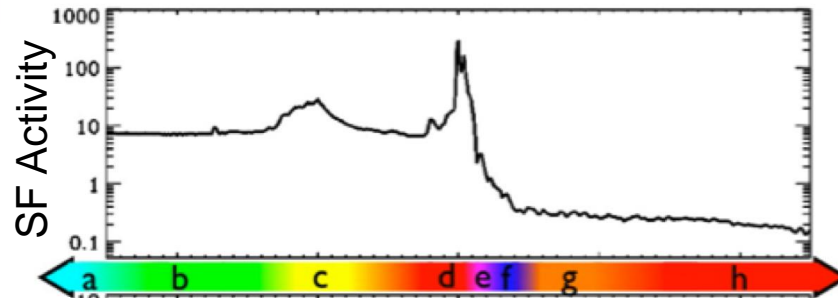
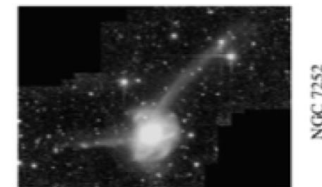
(f) Quasar



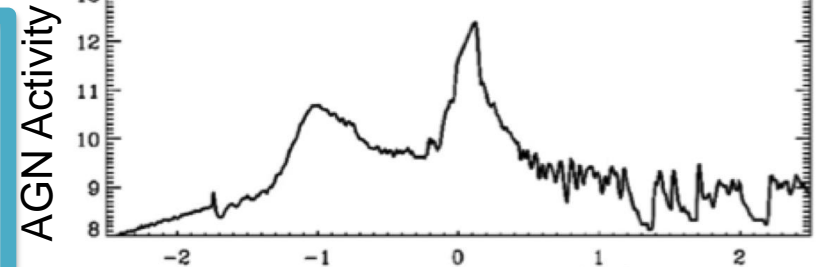
(b) "Small Group"



(g) Decay/K+A



(a) Isolated Disk



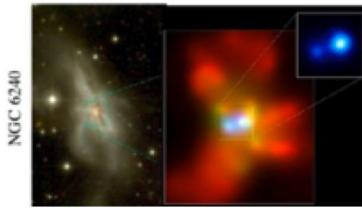
(h) "Dead" Elliptical



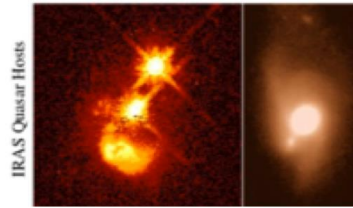
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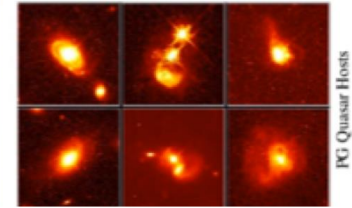
(d) Coalescence/(U)LIRG



(e) "Blowout"



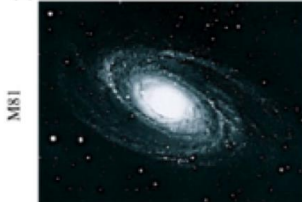
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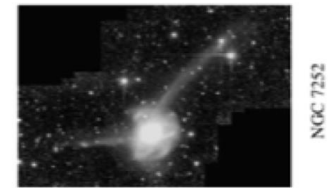
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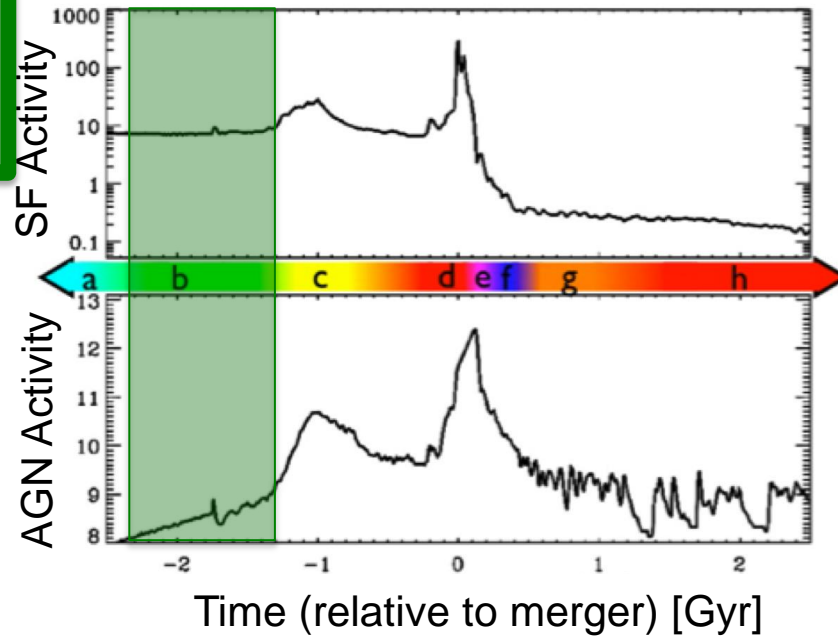
(a) Isolated Disk

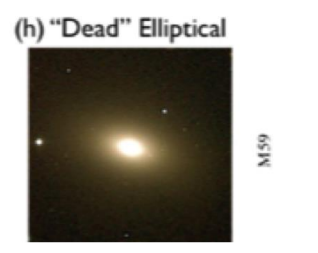
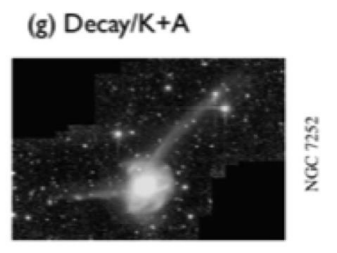
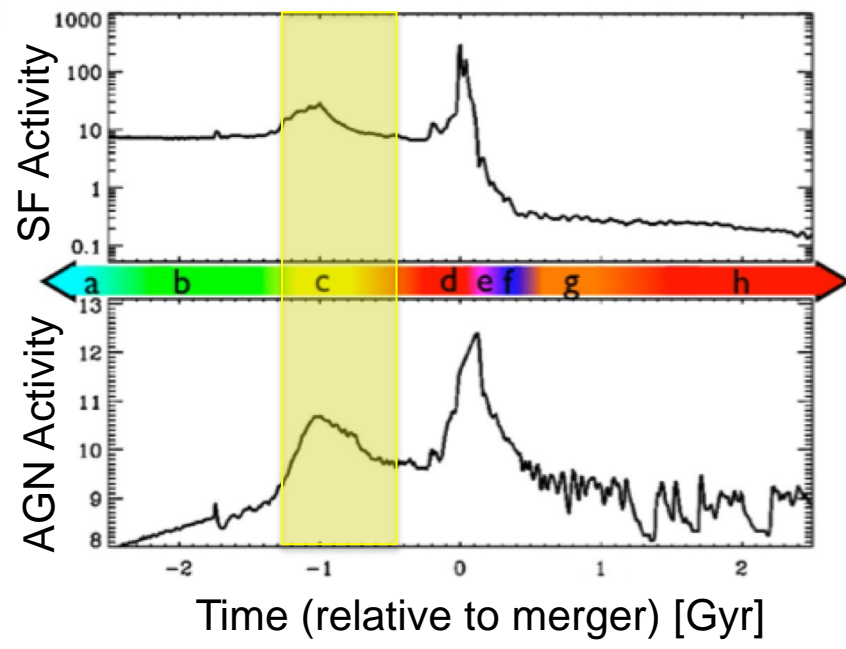
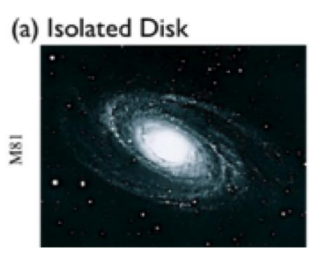
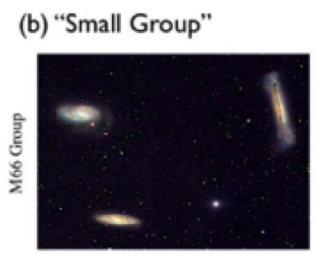
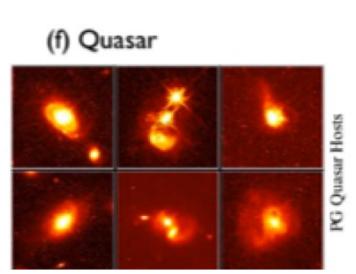
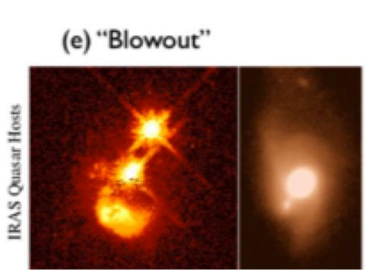
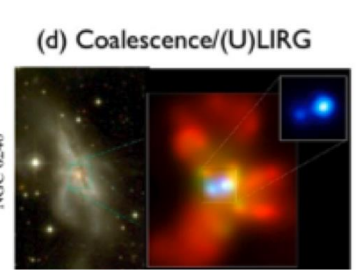


(g) Decay/K+A



(h) "Dead" Elliptical

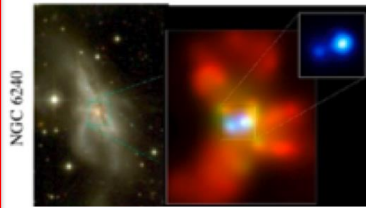




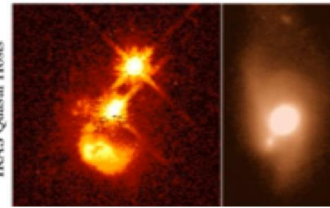
(c) Interaction/"Merger"



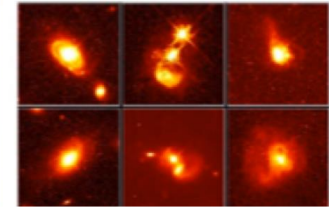
(d) Coalescence/(U)LIRG



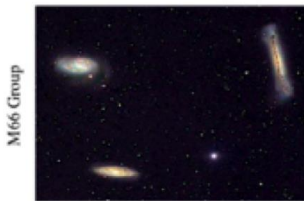
(e) "Blowout"



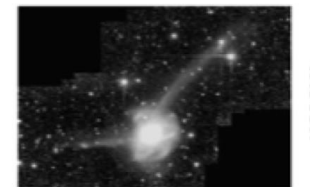
(f) Quasar



(b) "Small Group"



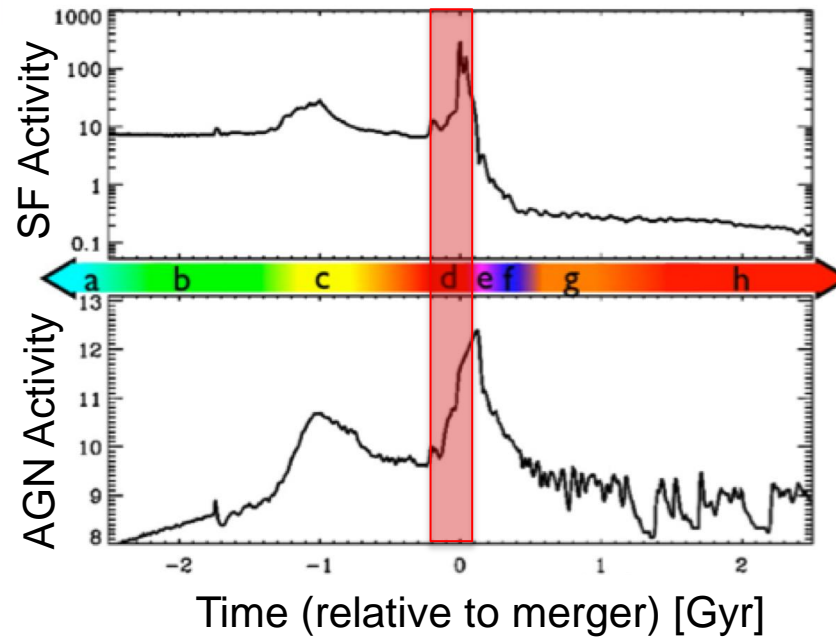
(g) Decay/K+A



(a) Isolated Disk



(h) "Dead" Elliptical

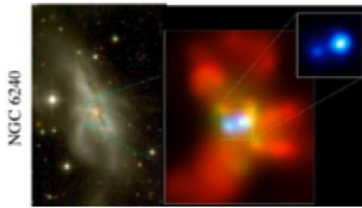




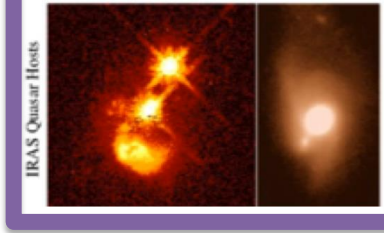
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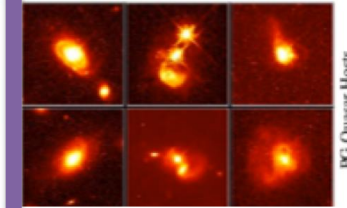
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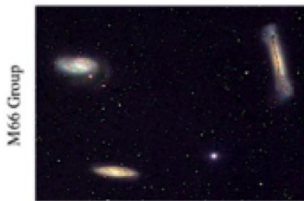
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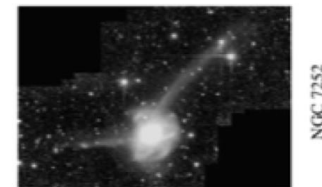
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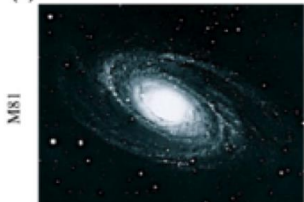
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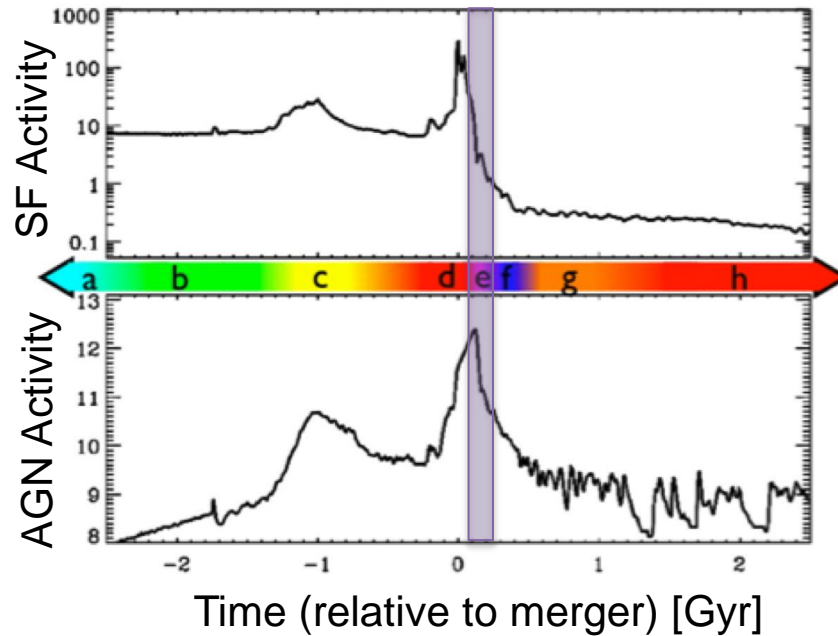
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(a) Isolated Disk



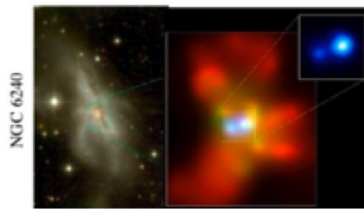
(h) "Dead" Elliptical



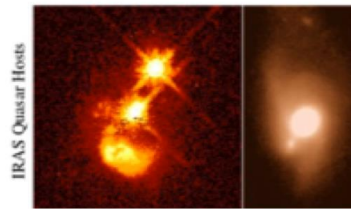
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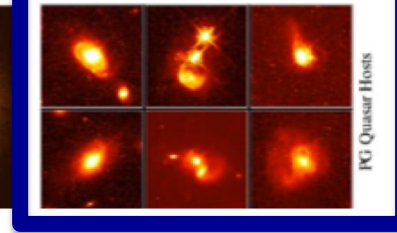
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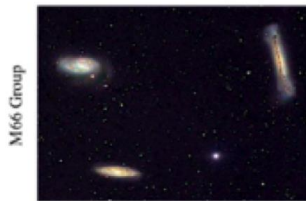
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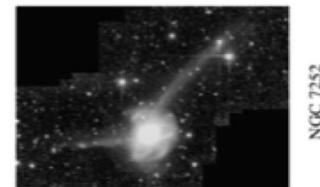
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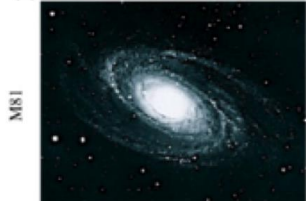
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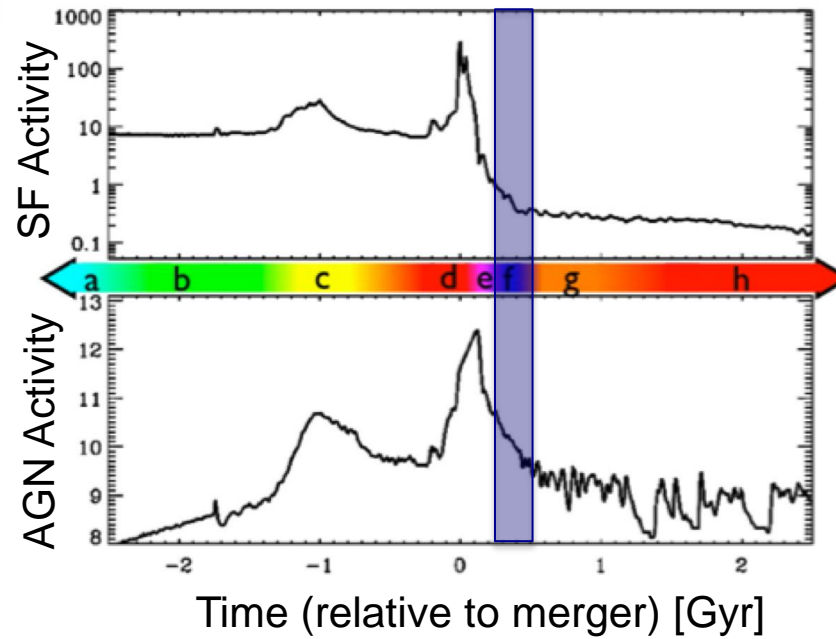
(g) Decay/K+A



(a) Isolated Disk



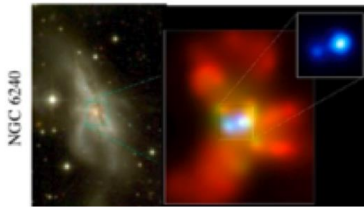
(h) "Dead" Elliptical



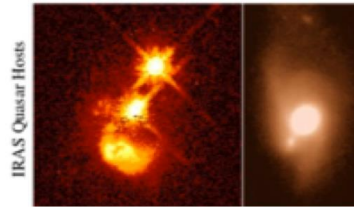
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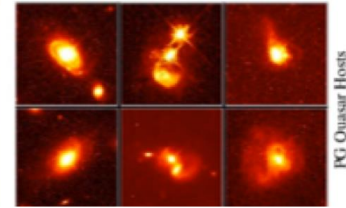
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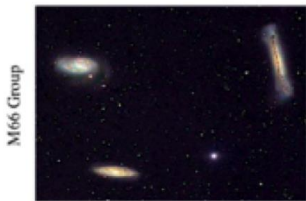
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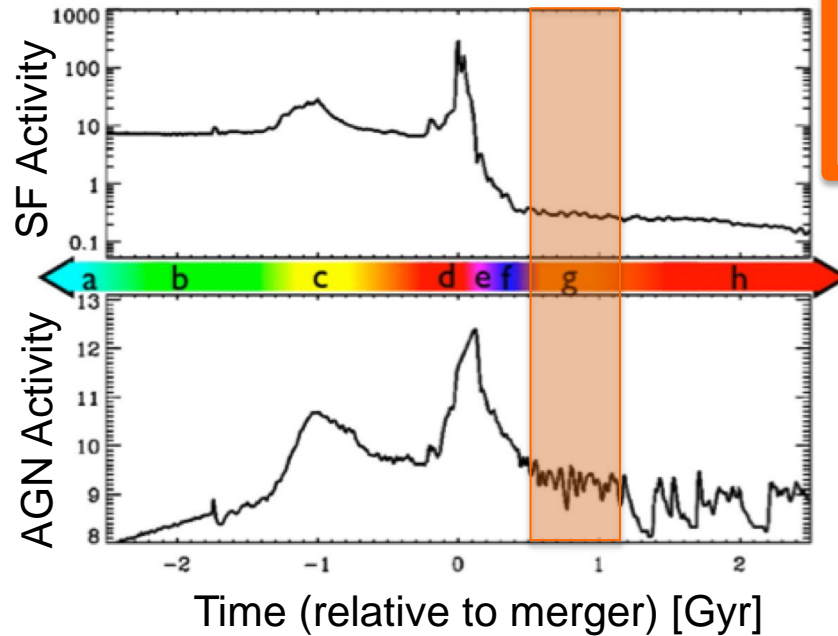
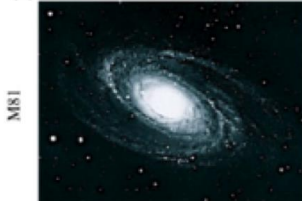
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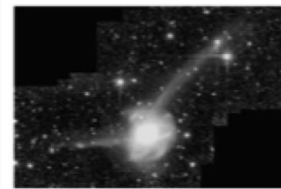
(b) "Small Group"



(a) Isolated Disk



(g) Decay/K+A



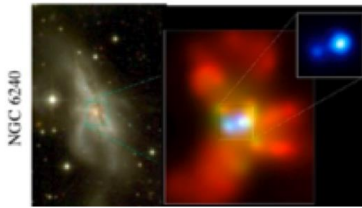
(h) "Dead" Elliptical



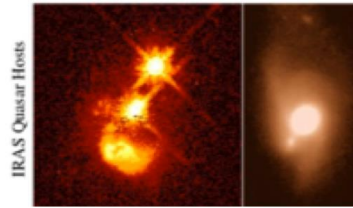
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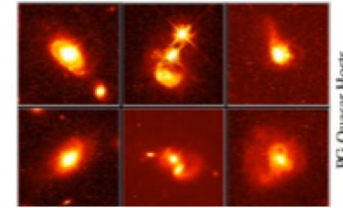
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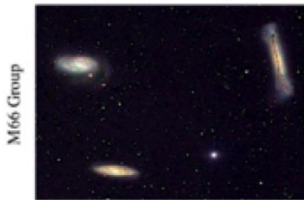
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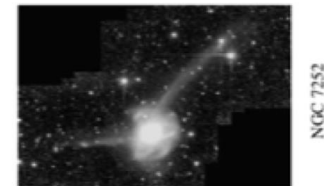
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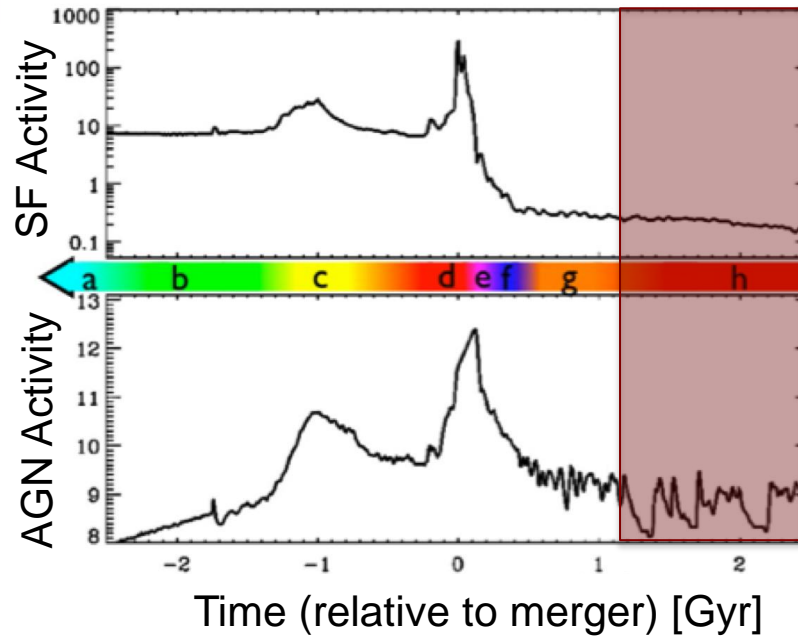
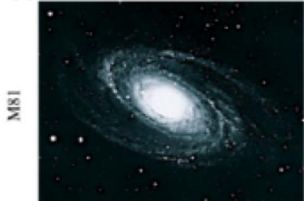
(b) "Small Group"



(g) Decay/K+A



(a) Isolated Disk

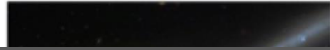


(h) "Dead" Elliptical

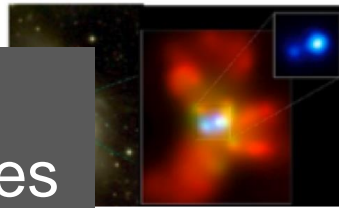


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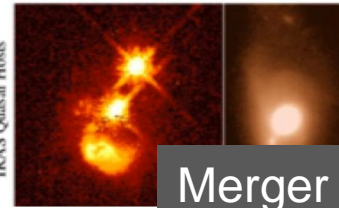
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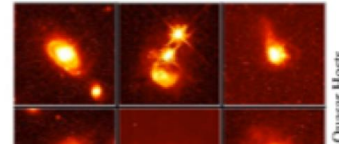
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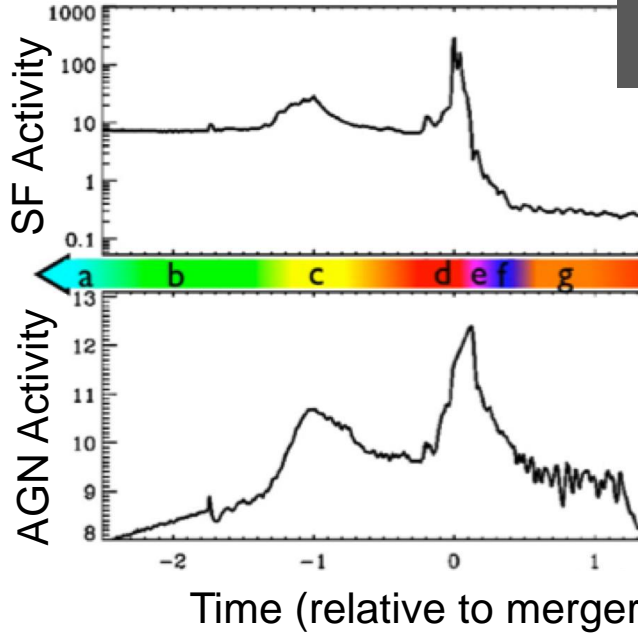
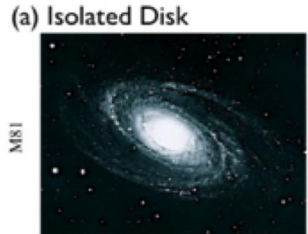
(f) Quasar



There are many observational studies that support this process.

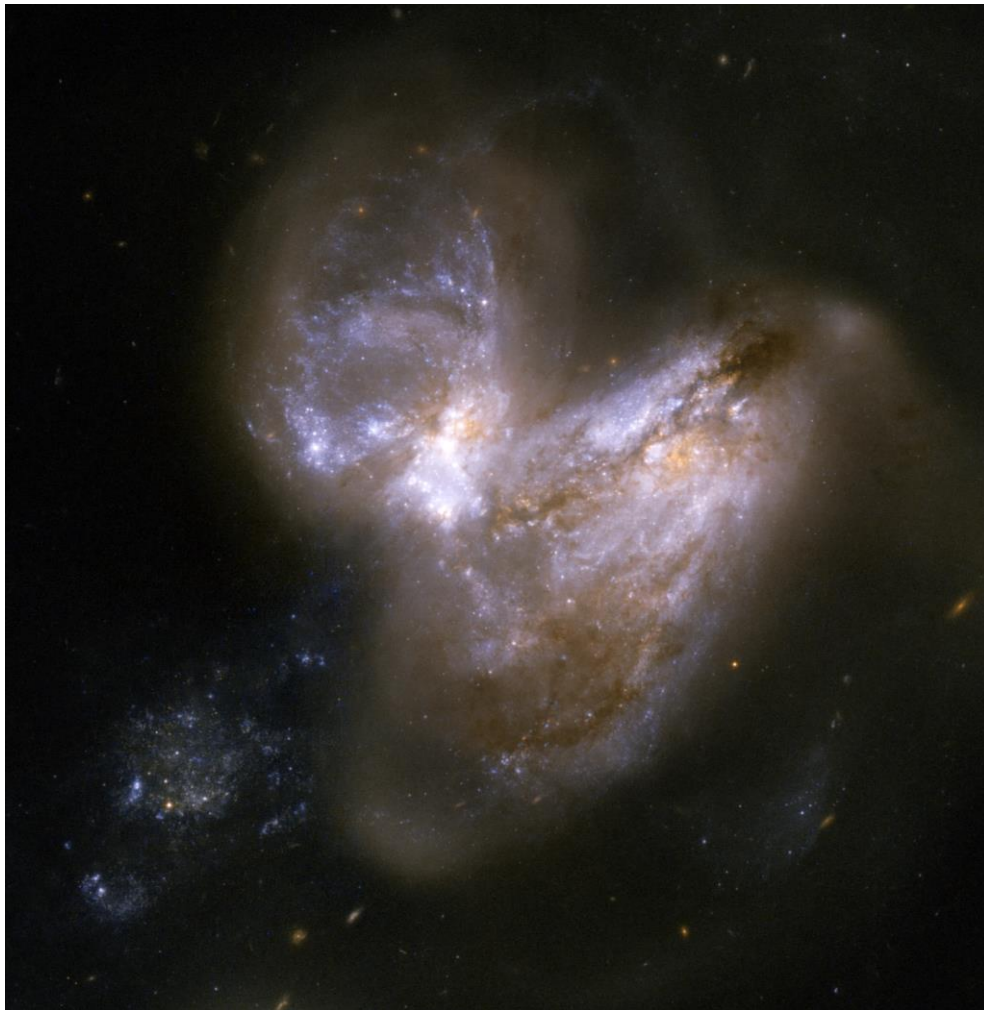
Merger – SF Connection:

- Kauffmann et al. 2003
- Darg et al. 2010
- Kampczyk et al. 2012
- Ellison et al. 2013
- Puech et al. 2014



Merger – AGN Connection:

- Kauffmann et al. 2003
- Treister et al. 2012
- Ellison et al. 2013
- Cotini et al. 2013
- Nazaryan et al. 2014
- Satyapal et al. 2014



Arp 299, HST

Why don't all studies  
find an AGN-merger  
connection?

Cisternas et al. 2011

Fan et al. 2014

Scott et al. 2014

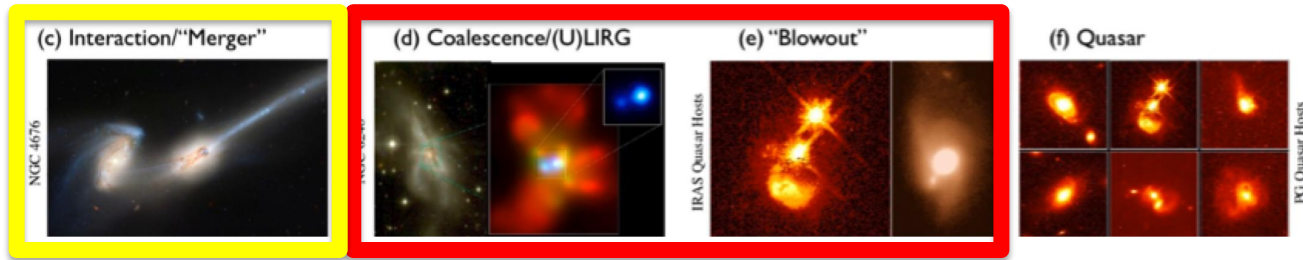
Villforth et al. 2014

**Strong star formation  
produces dust which  
obscures the AGN.**

Kennicutt 1998, 2009

Goulding et al. 2009, 2011

# Sample Description



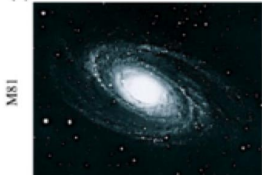
**Interactions**

**Mergers**

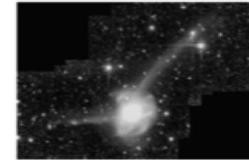
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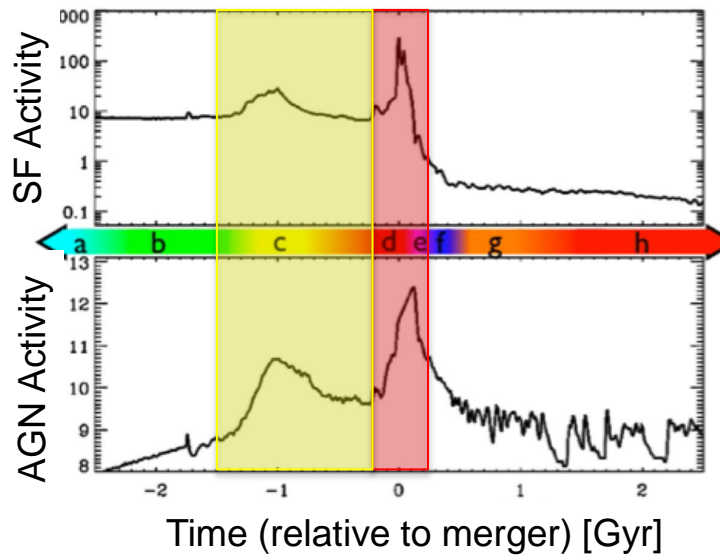
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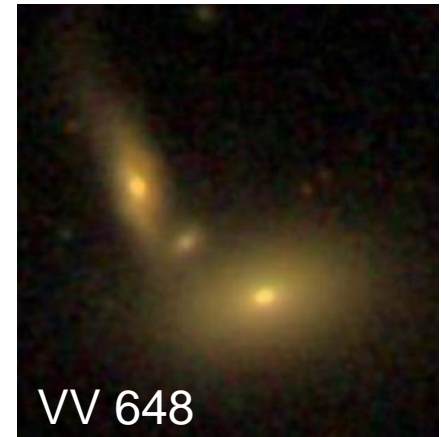
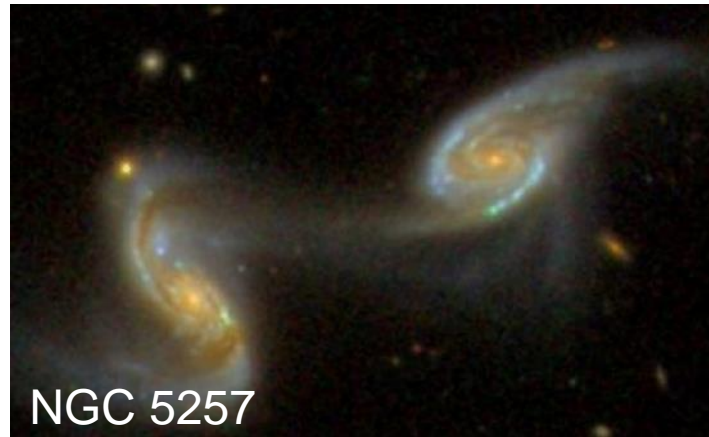
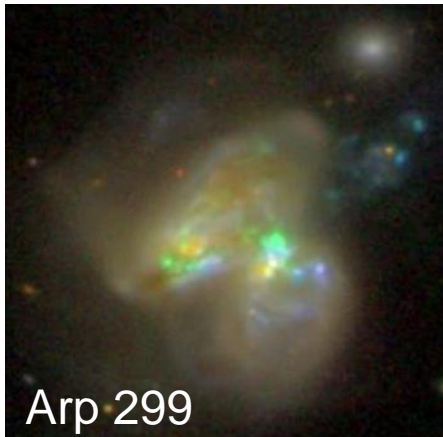
(g) Decay/K+A



(h) "Dead" Elliptical



# Sample Description



Parent Sample of 60k galaxies from the SDSS  
Main Spectroscopic Sample (Strauss et al. 2002)  
described in McIntosh et al. 2014

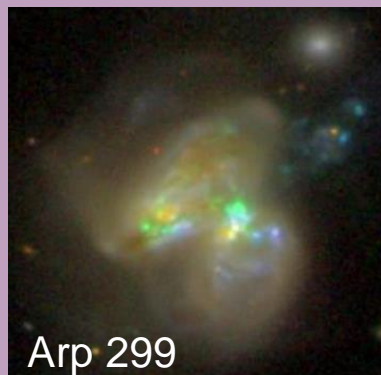
- $z \leq 0.08$
- $M_{\text{star}} > 2 \times 10^{10} M_{\text{sun}}$
- Complete in mass & redshift

Images from SDSS Image Tool



# Sample Description

130 Mergers (m)



307 Interactions (i)



762 Possible Interactions (i?)



# Many studies have used WISE colors to isolate AGN

Jarrett et al. 2011

Mateos et al. 2012

Stern et al. 2012 & 2014

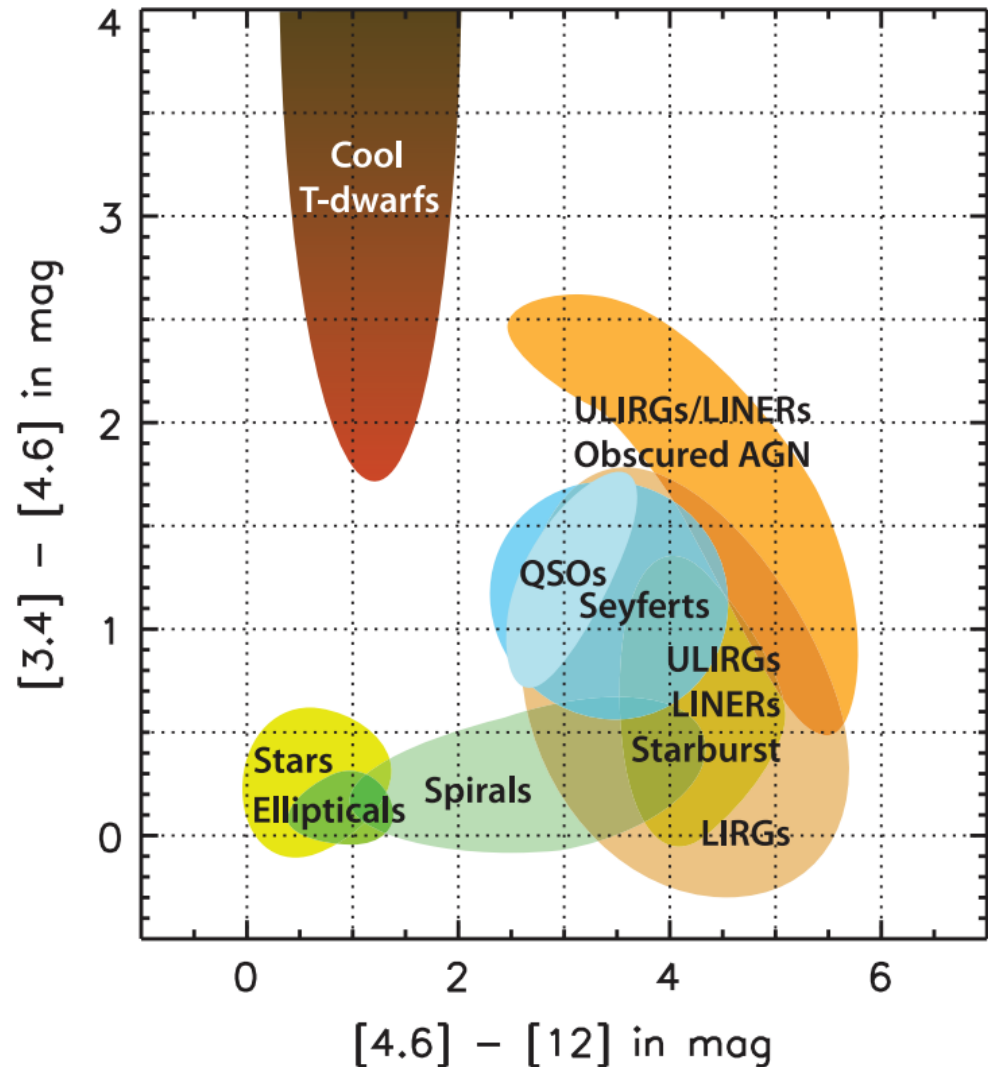
Assef et al. 2013

Gürkan et al. 2013

Shao et al. 2013

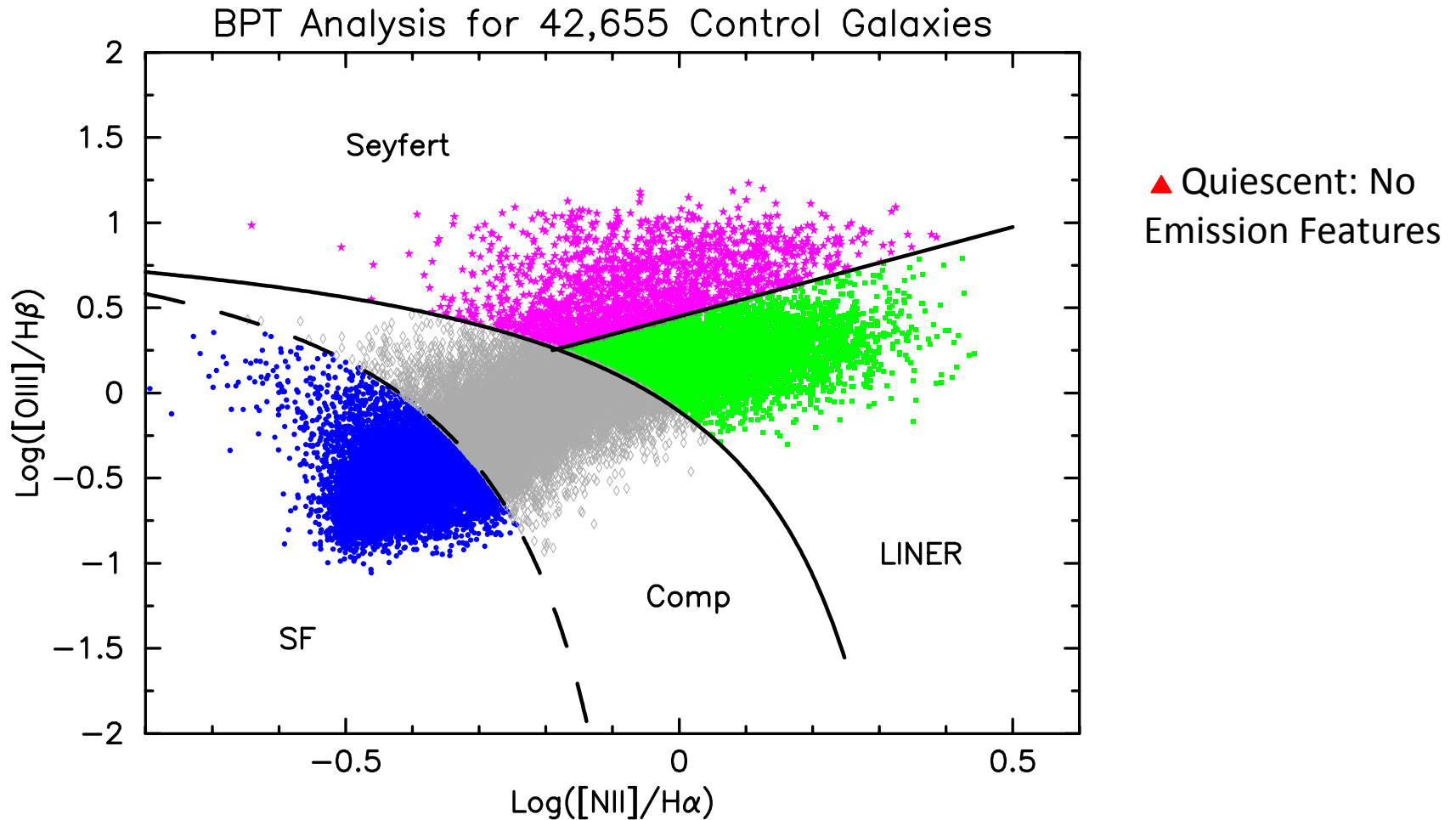
Yan et al. 2013

Satyapal et al. 2014



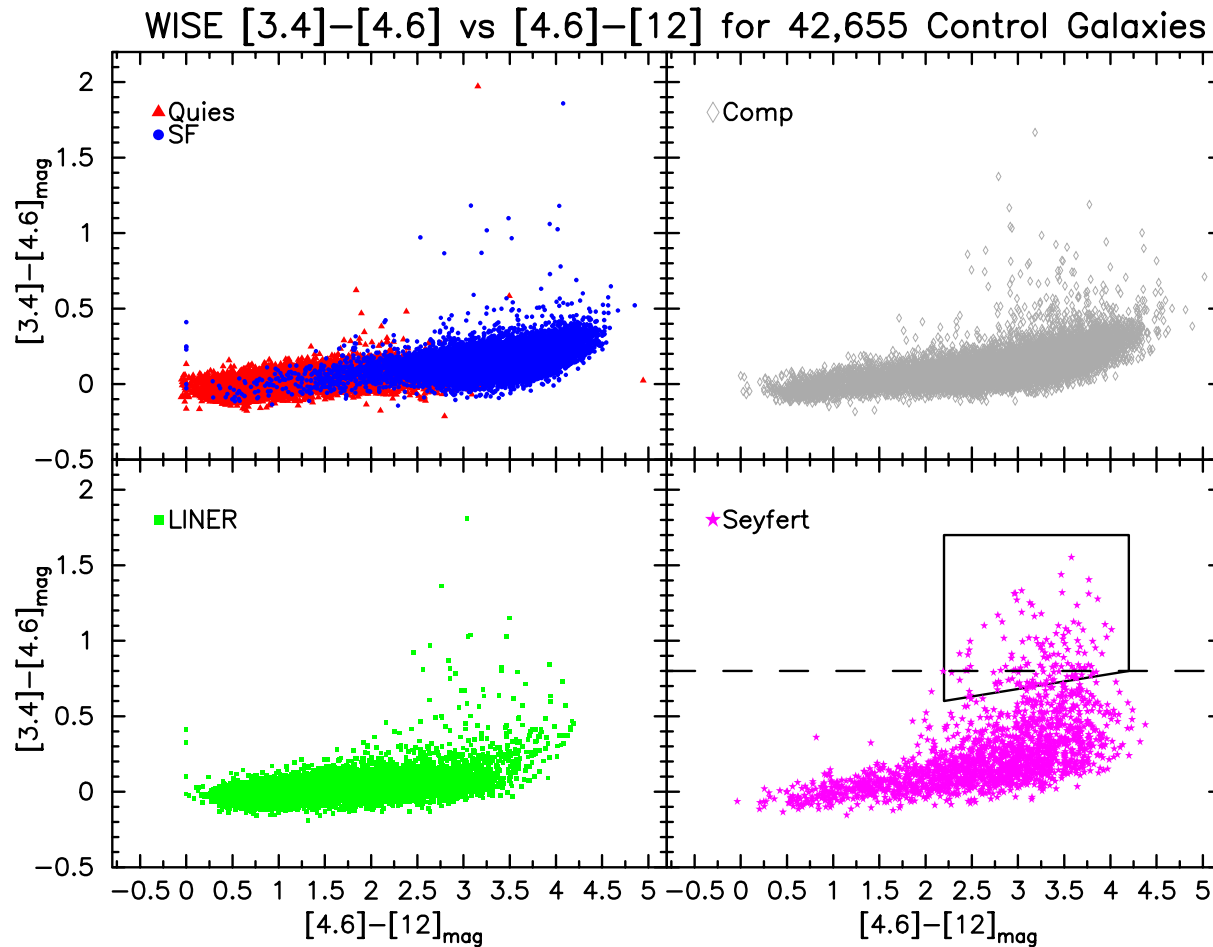
Wright et al. 2010

# Emission Type Analysis of WISE Color Space

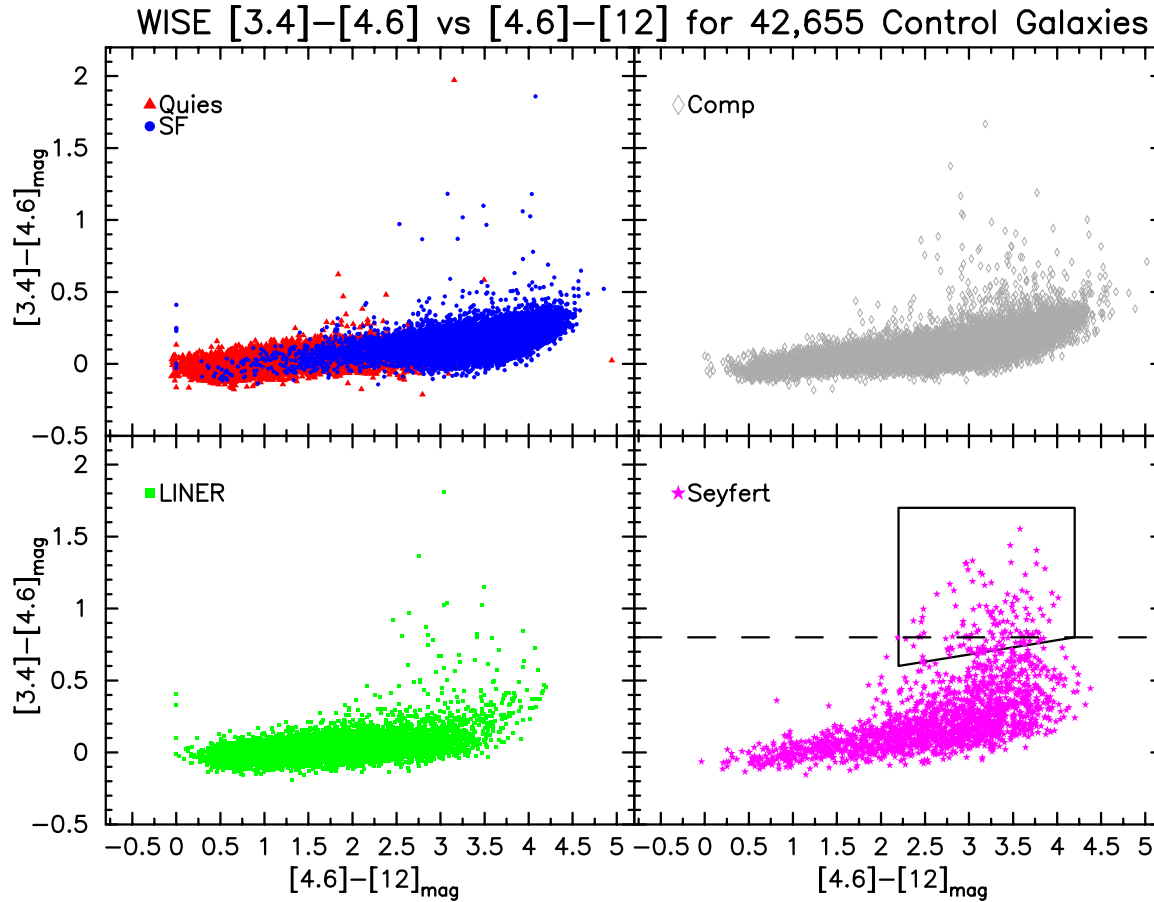


BPT Selection: Baldwin et al. 1981, Kauffmann et al. 2003, Kewley et al. 2001, Schawinski et al. 2007

# Emission Type Analysis of WISE Color Space



# Emission Type Analysis of WISE Color Space



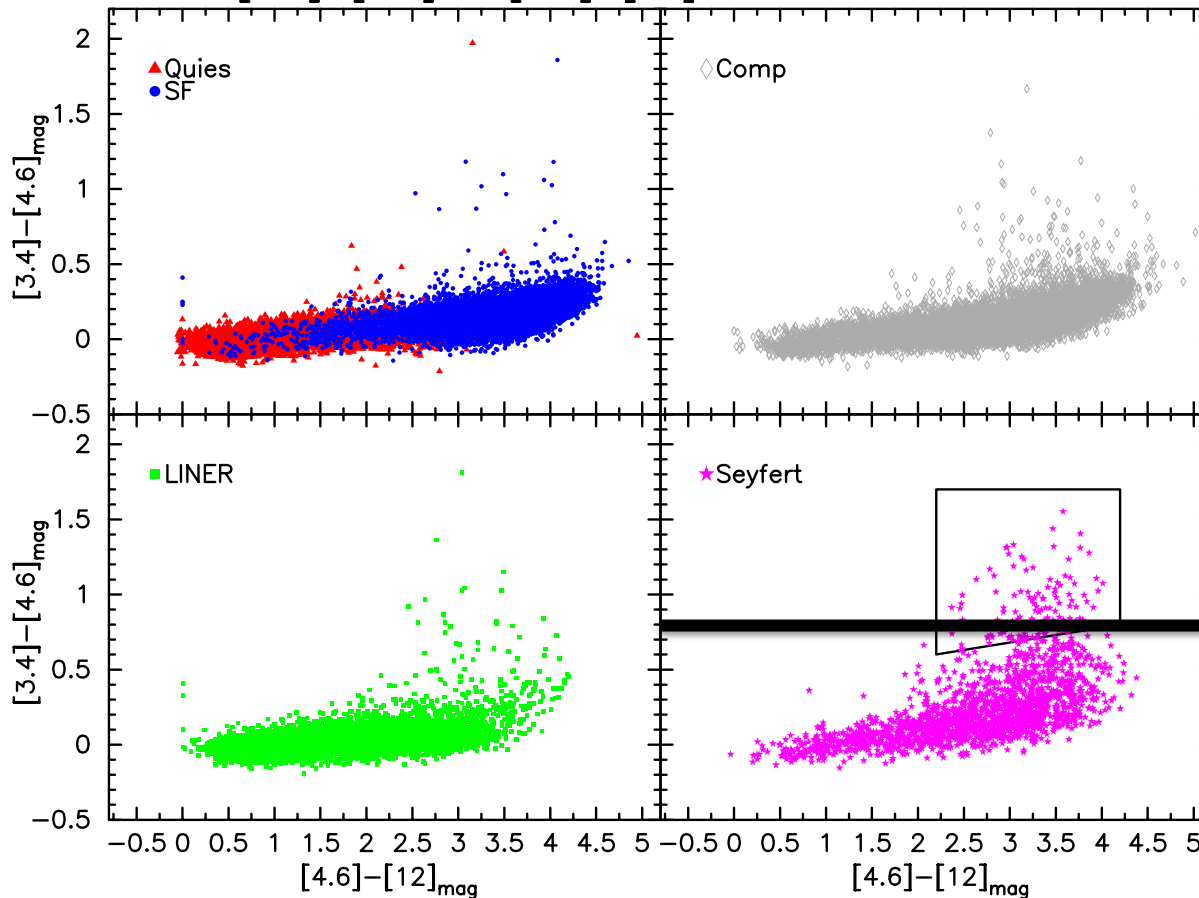
Warmer dust from AGN

Dust Heating by SF



# Three Ways to Isolate AGN

WISE [3.4]–[4.6] vs [4.6]–[12] for 42,655 Control Galaxies

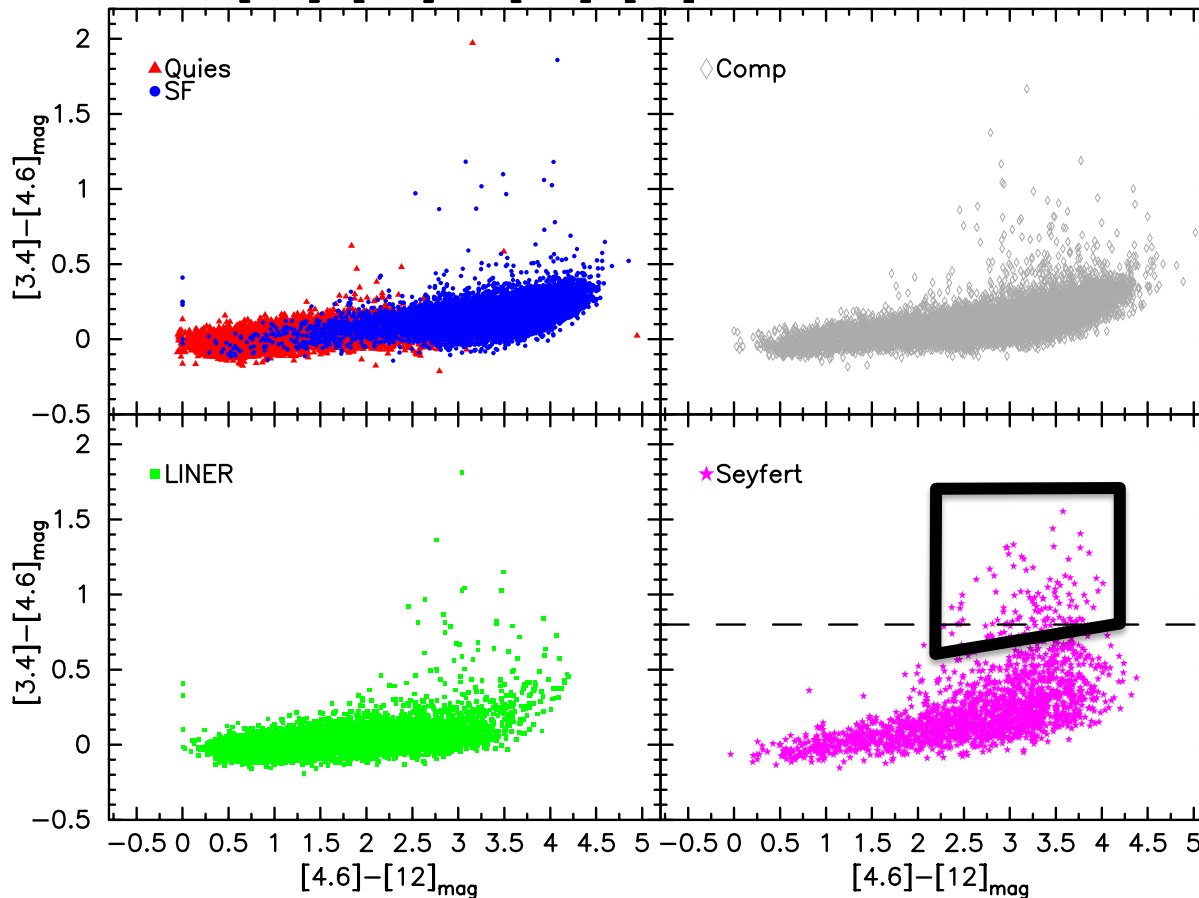


1.  $[3.4] - [4.6] \geq 0.8$   
Yan et al. 2013,  
Assef et al. 2013,  
Stern et al. 2012
- 66% of galaxies above  $[3.4] - [4.6] \geq 0.8$  are Seyfert galaxies

5% of Seyferts have  $[3.4] - [4.6] \geq 0.8$

# Three Ways to Isolate AGN

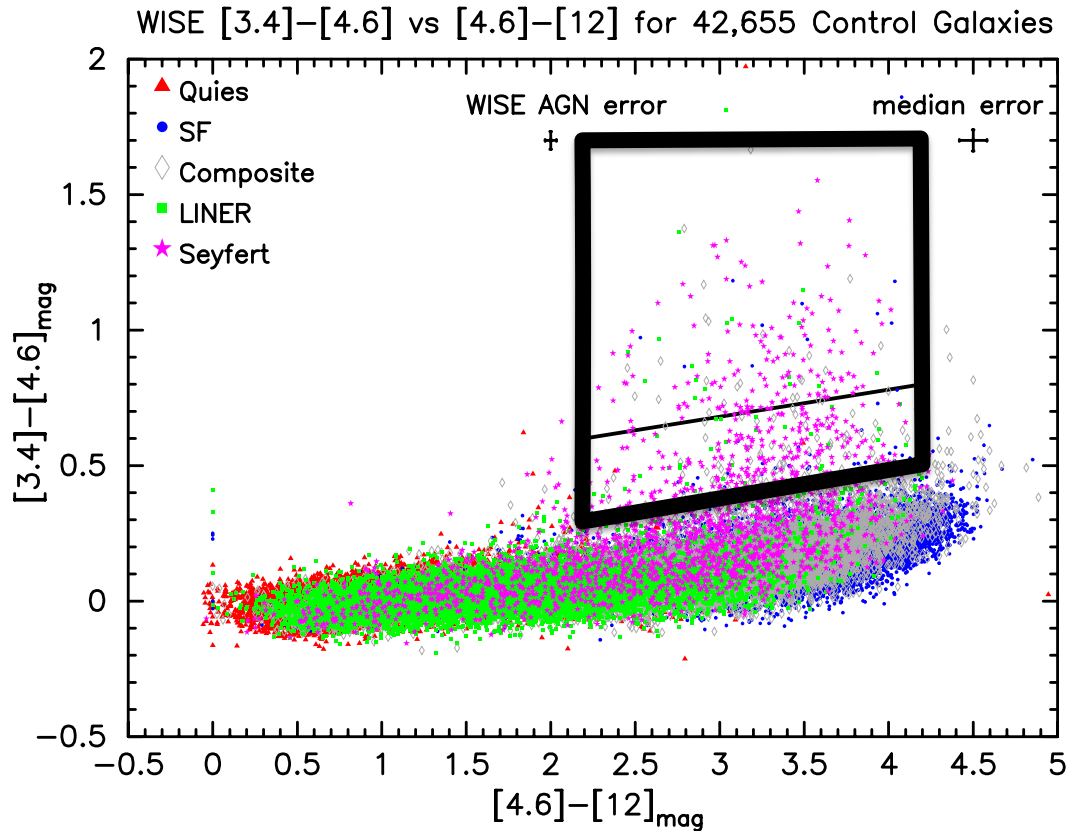
WISE [3.4]–[4.6] vs [4.6]–[12] for 42,655 Control Galaxies



1.  $[3.4] - [4.6] \geq 0.8$  – 66%
2. WISE AGN Box defined by Jarrett et al. 2011
  - 73% of galaxies in the Jarrett+11 box are Seyfert galaxies

7% of Seyferts are in Jarrett+11 box

# Three Ways to Isolate AGN

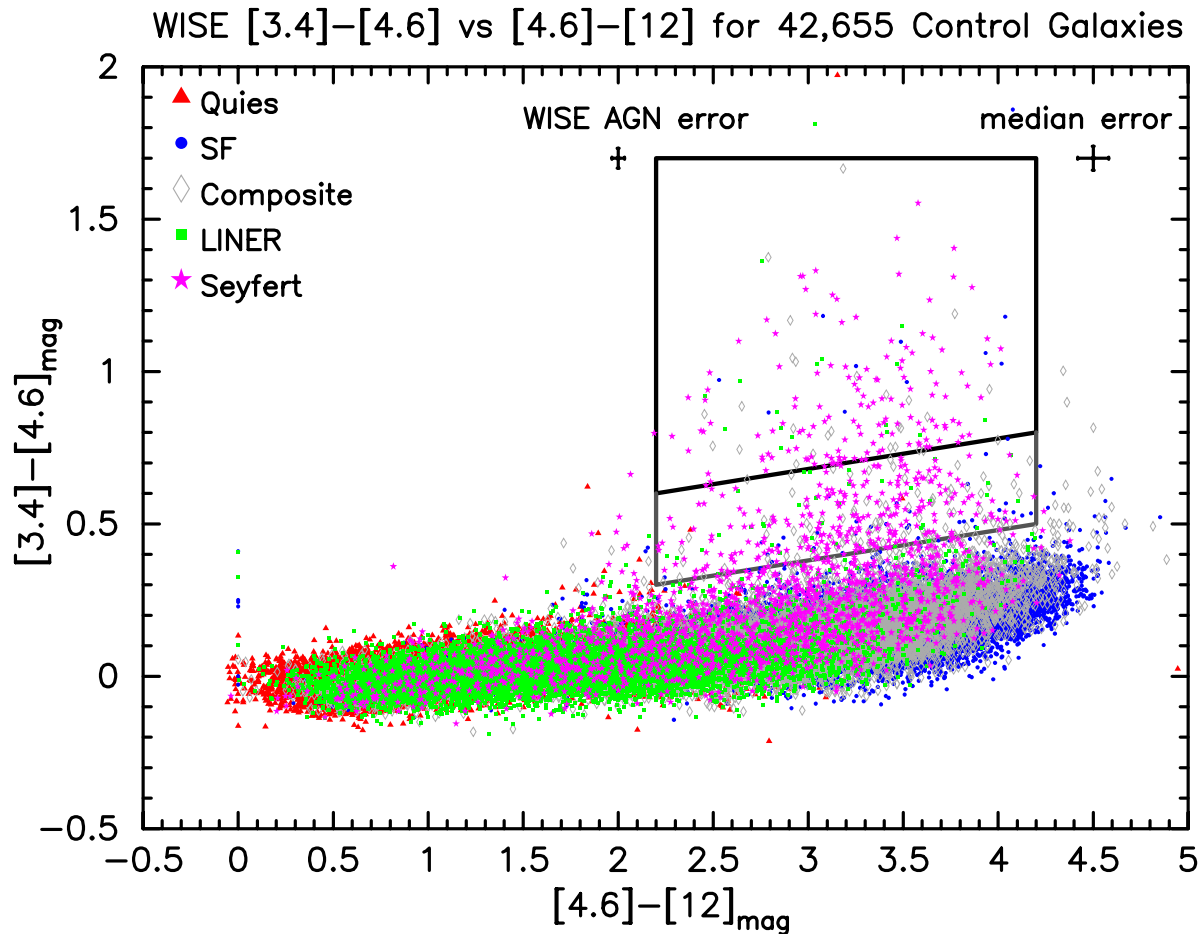


21% of Seyferts are in Extended Jarrett+11 box

1.  $[3.4] - [4.6] \geq 0.8$  – 66%
2. WISE AGN Box defined by Jarrett et al. 2011 – 73%
3. Extended WISE AGN Box:  
Extension of the WISE AGN Box defined by Jarrett et al. 2011
  - 64% of galaxies in the Extended Jarrett+11 box are Seyfert galaxies



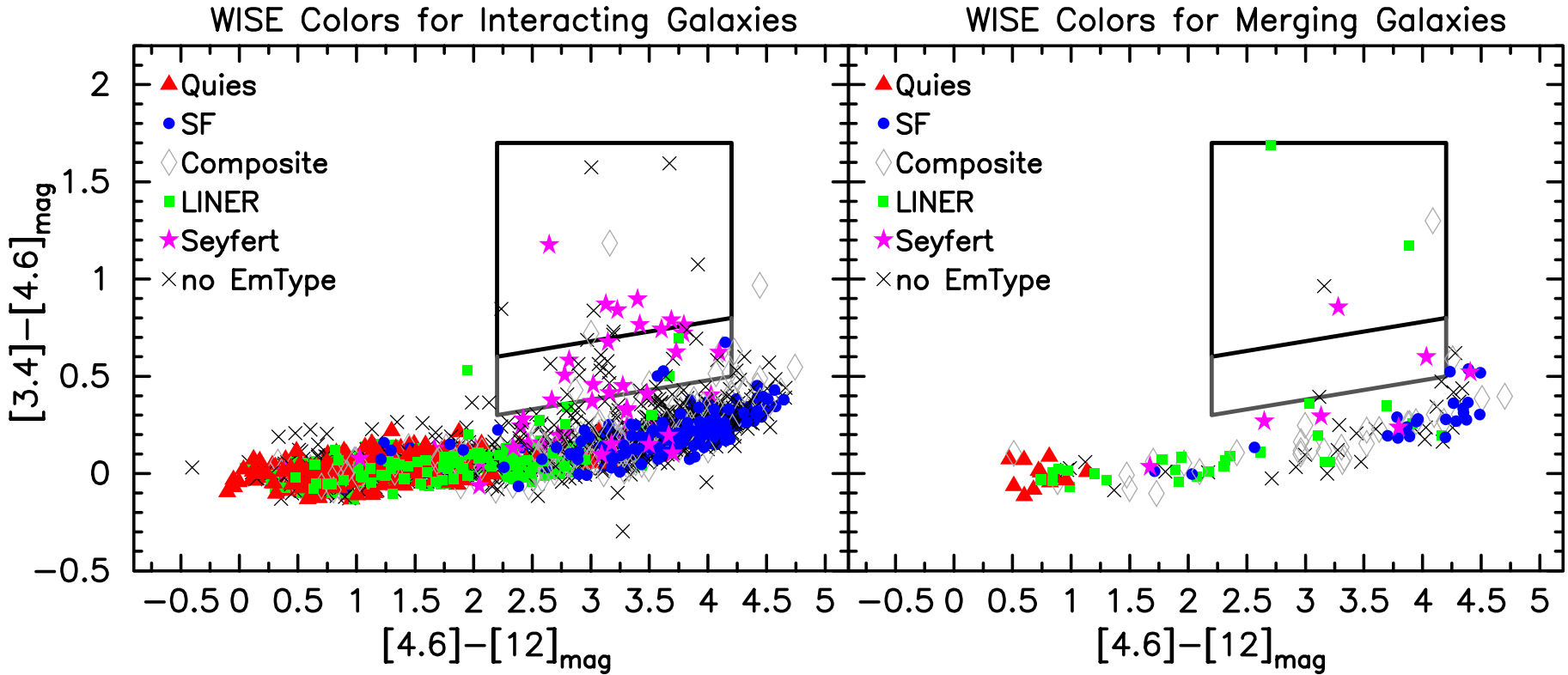
# Incidence of Dusty AGN in Control Galaxies



0.38 – 0.51% of  
Control galaxies  
are a WISE AGN  
(Jarrett+11 Cut)

1.33 – 1.55% of  
Control galaxies  
are an Extended  
WISE AGN  
(Extended Cut)

# Incidence of Dusty AGN in Mergers & Interactions



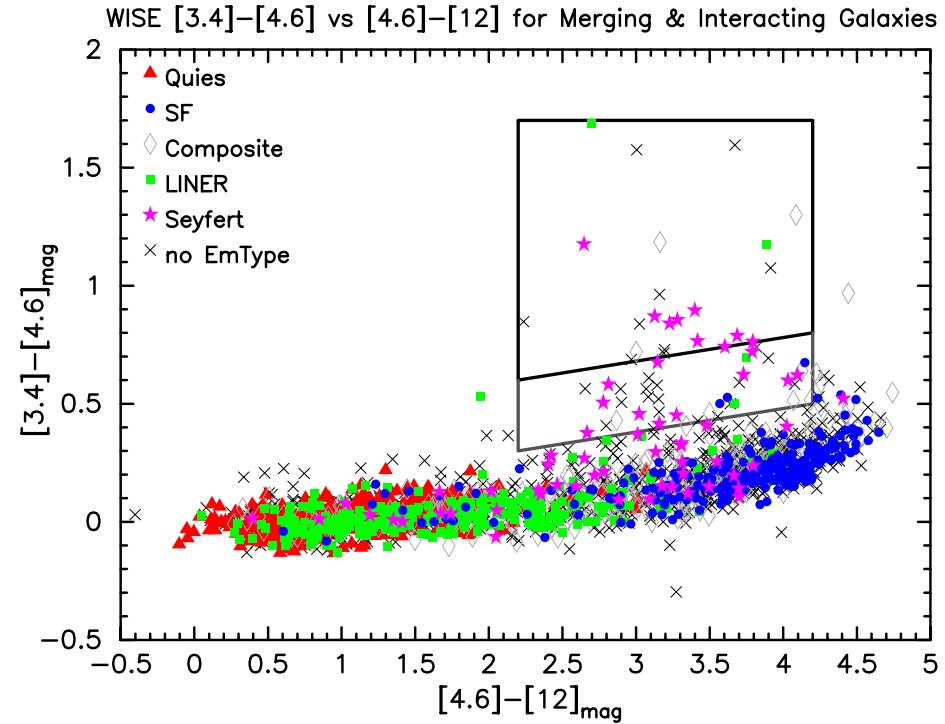
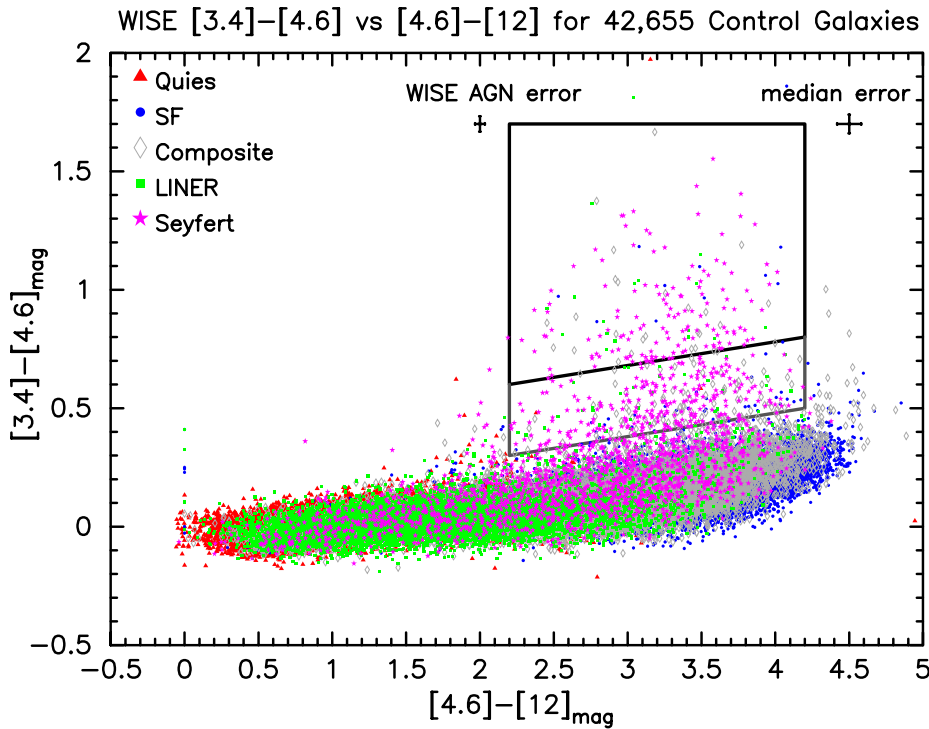
1.0 – 2.5% of Interacting Pairs  
have a WISE AGN  
(3.9 – 6.5% Extended)

2 – 9% of Merging Systems  
are a WISE AGN  
(3 – 10% Extended)

0.38 – 0.51% Control galaxies

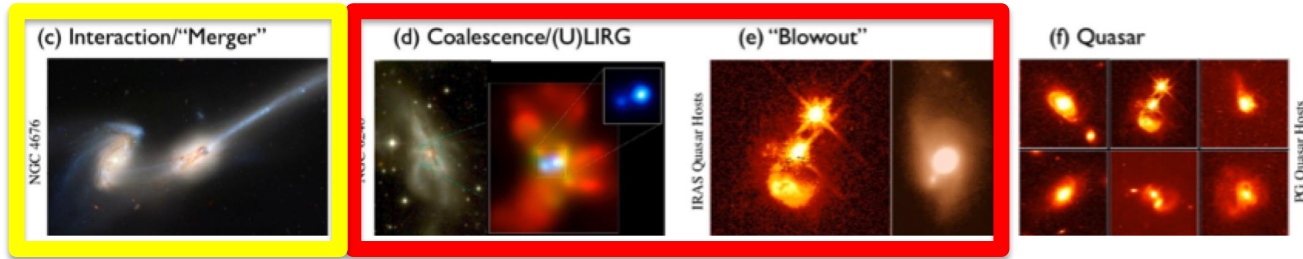
2 – 9% Mergers

1.0 – 2.5% Interactions



Mergers are 5 – 20 times more likely to be obscured AGN than normal galaxies.

# Why don't all mergers make a WISE AGN?



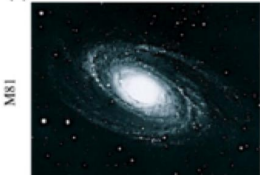
**Interactions**

**Mergers**

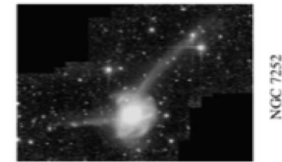
(b) "Small Group"



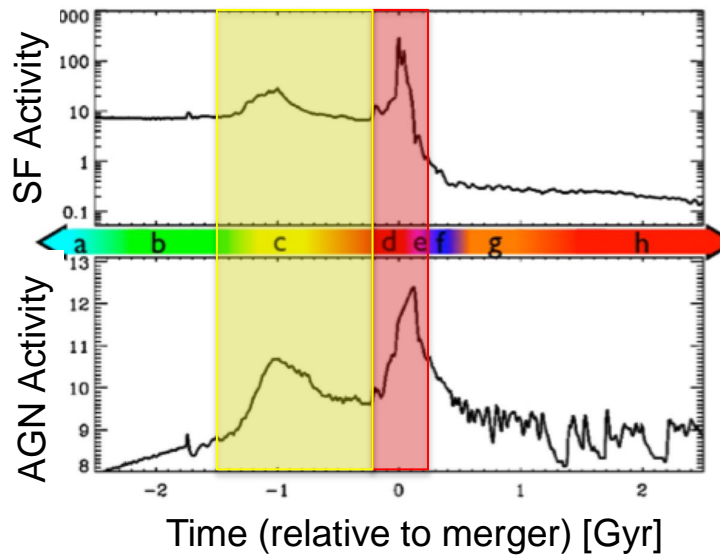
(a) Isolated Disk



(g) Decay/K+A



(h) "Dead" Elliptical

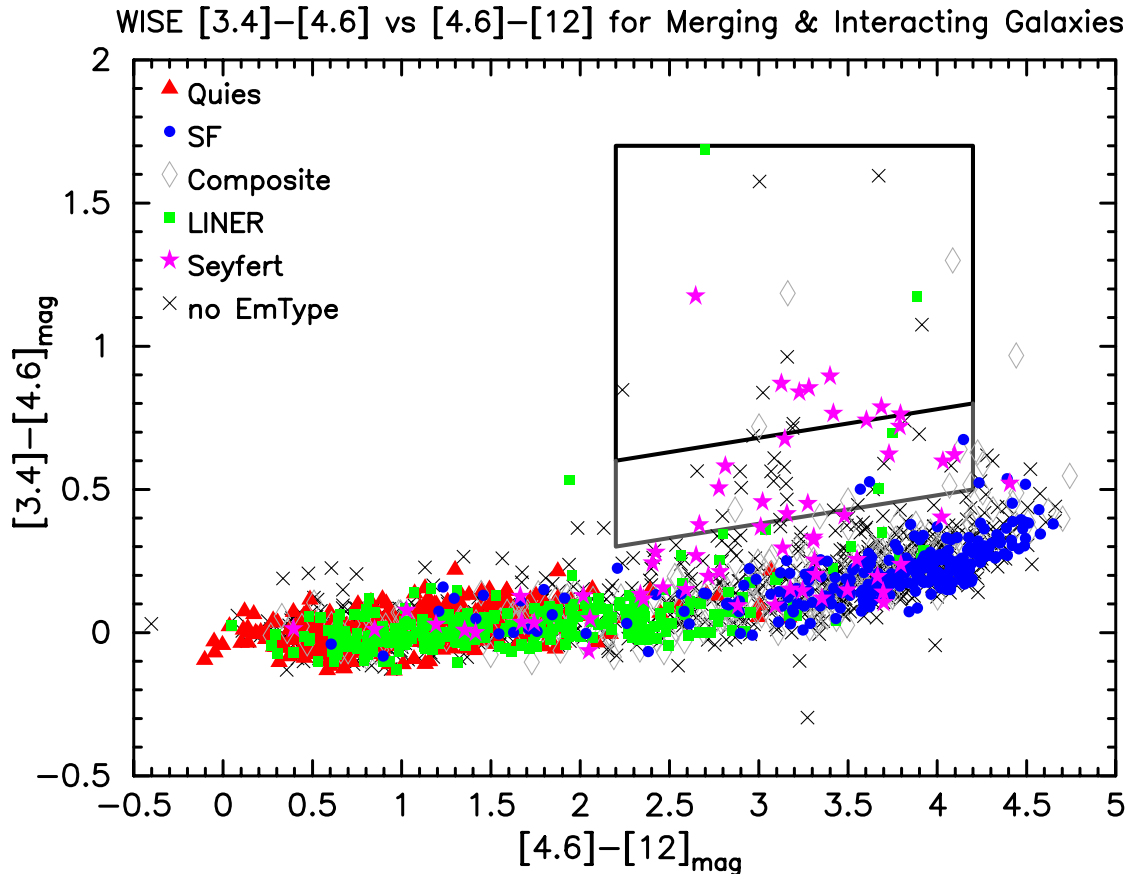


# Now that we've found these WISE AGN mergers & interactions, is there anything special about them?

Other studies have found that AGN can relate to:

- **Stellar Mass** Sabater et al. 2013
- **Mass Ratio (interactions)** Capelo et al. 2014, Ellison et al. 2011
- **Pair Separation (interactions)** Ellison et al. 2011, Satyapal et al. 2014
- **Group Parameters** Yang et al. 2007
- **L[OIII] – AGN Power** Satyapal et al. 2014, Toba et al. 2014
- **Star Formation** Kauffmann et al. 2003, Hickox et al. 2014

# What is special about these mergers & interactions?

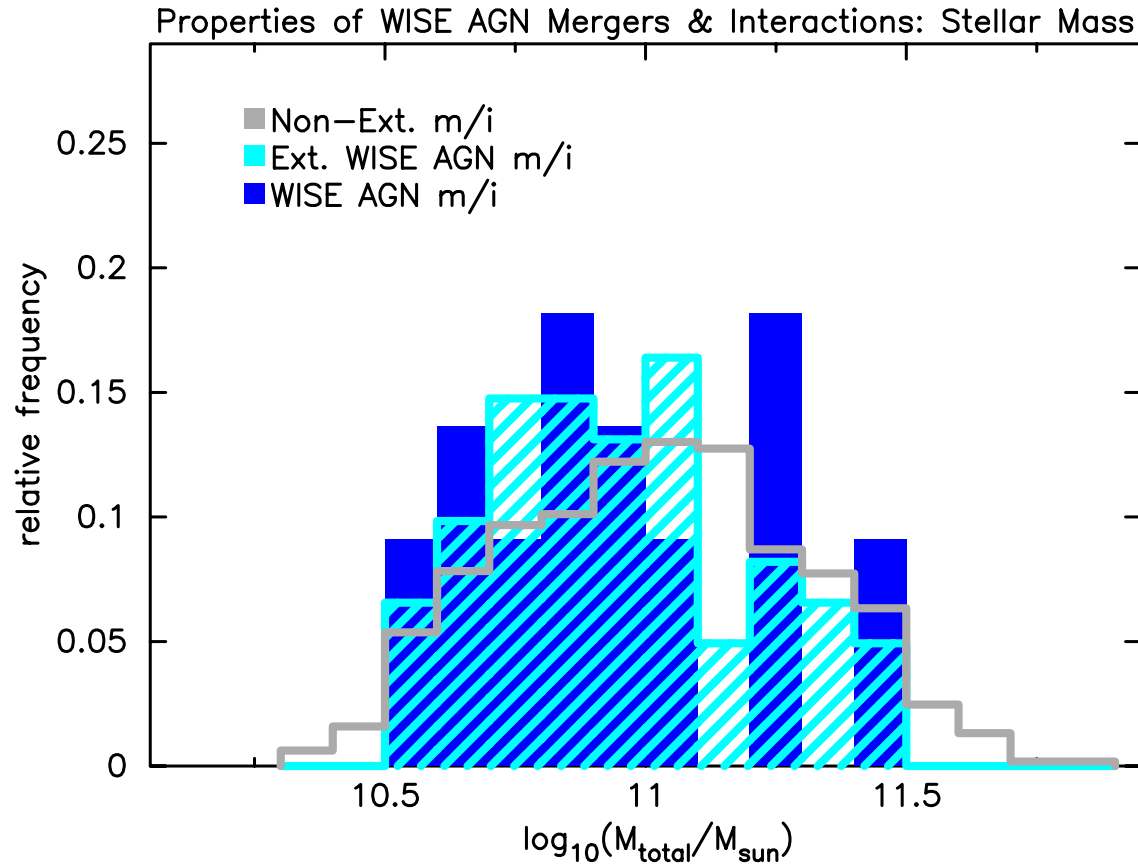


K-S Tests to compare properties of normal (non-Ext. WISE AGN) mergers & interactions to WISE AGN mergers & interactions

Two cuts:

1. WISE AGN box by Jarrett+11
2. Extended WISE AGN box

# What is special about these mergers & interactions? Stellar Mass

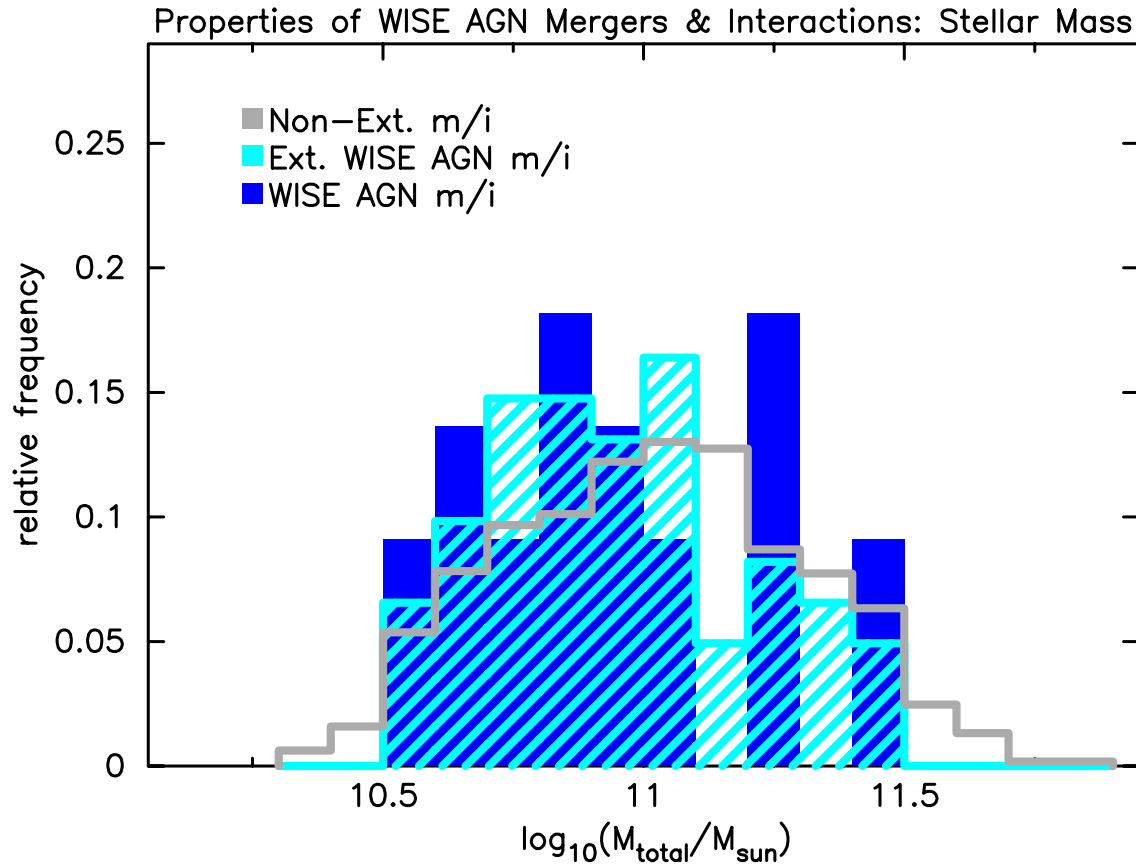


## K-S Test p-values for Stellar Mass

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WISE AGN:	0.695
Extended Cut:	0.127

# What is special about these mergers & interactions? Stellar Mass



K-S Test p-values for  
Stellar Mass

WISE AGN: 0.695

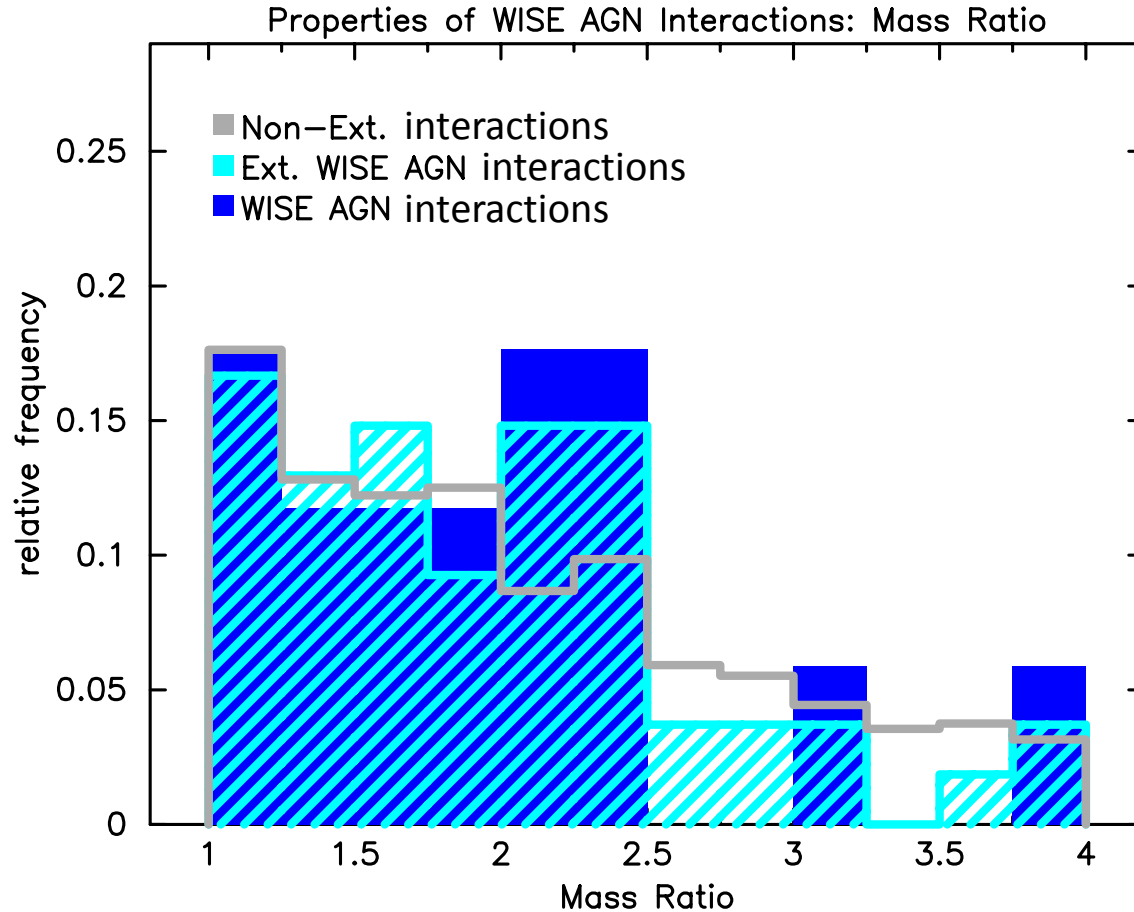
Extended Cut: 0.127

No dependence on  
Stellar Mass



# What is special about these mergers & interactions?

## Mass Ratio of Interactions



### K-S Test p-values for Mass Ratio of Interactions

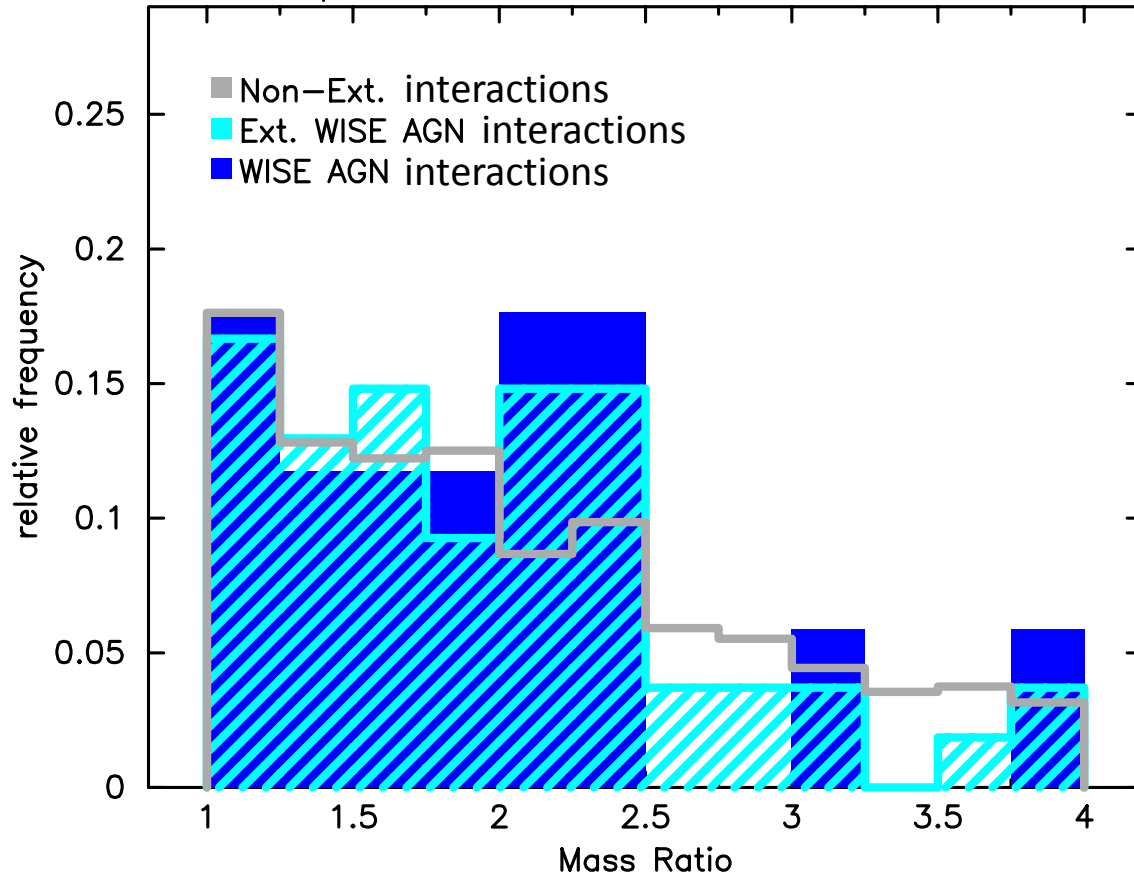
WISE AGN: 0.913

Extended Cut: 0.489

# What is special about these mergers & interactions?

## Mass Ratio of Interactions

Properties of WISE AGN Interactions: Mass Ratio



### K-S Test p-values for Mass Ratio of Interactions

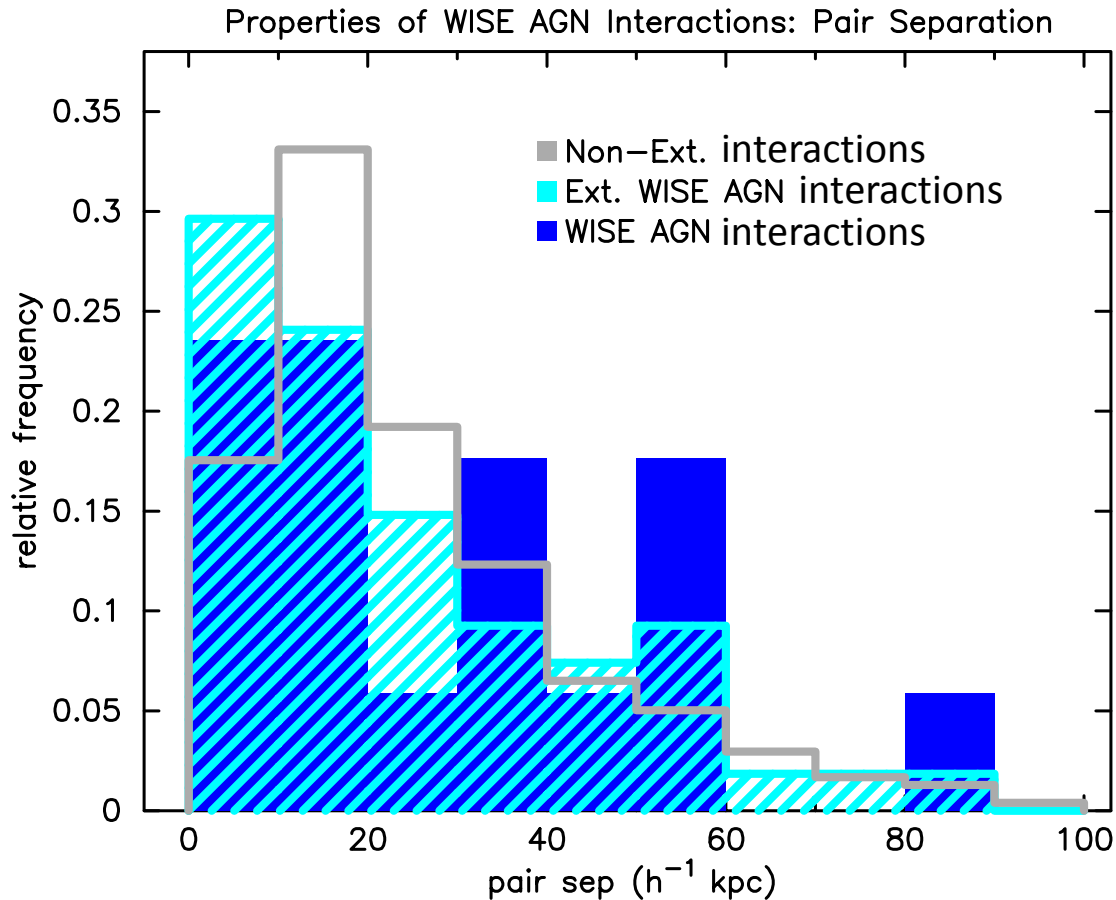
WISE AGN: 0.913

Extended Cut: 0.489

No dependence on  
Mass Ratio

# What is special about these mergers & interactions?

## Pair Separation of Interactions



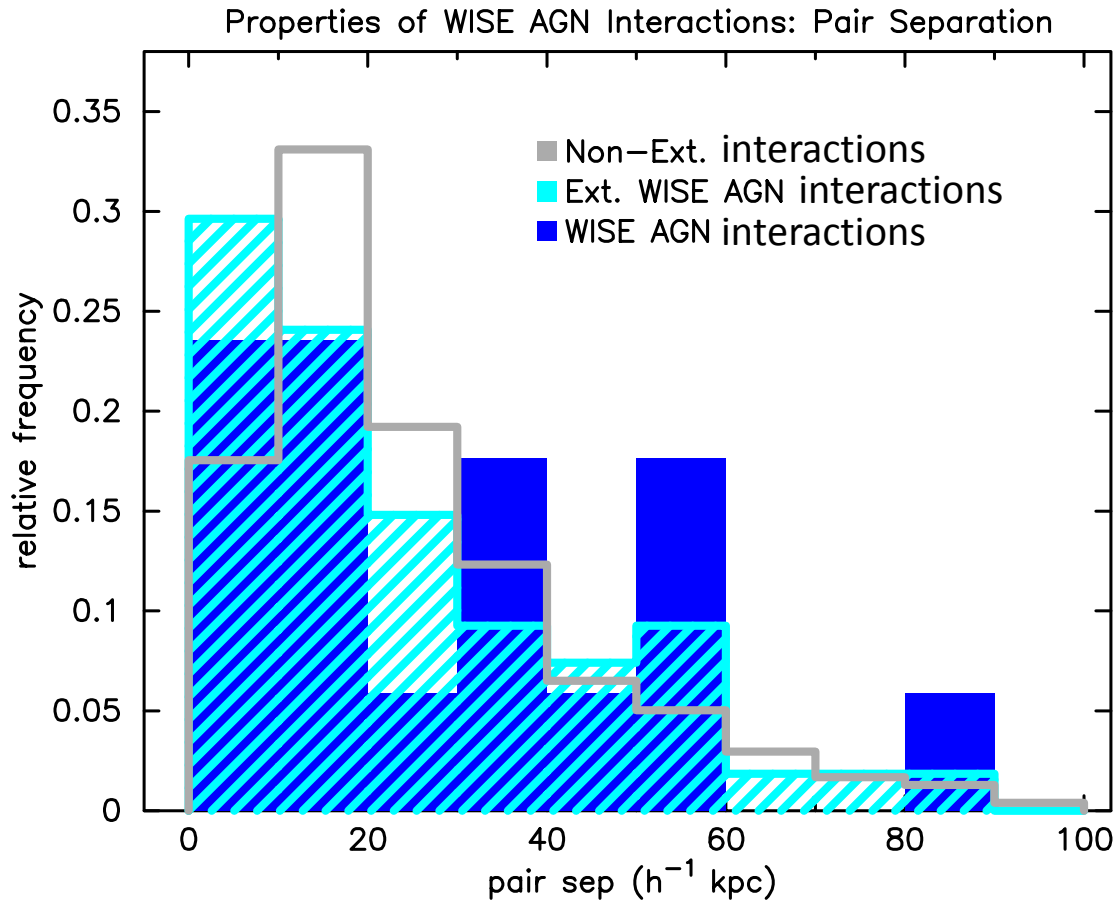
### K-S Test p-values for Pair Sep. of Interactions

WISE AGN: 0.063

Extended Cut: 0.031

# What is special about these mergers & interactions?

## Pair Separation of Interactions



### K-S Test p-values for Pair Sep. of Interactions

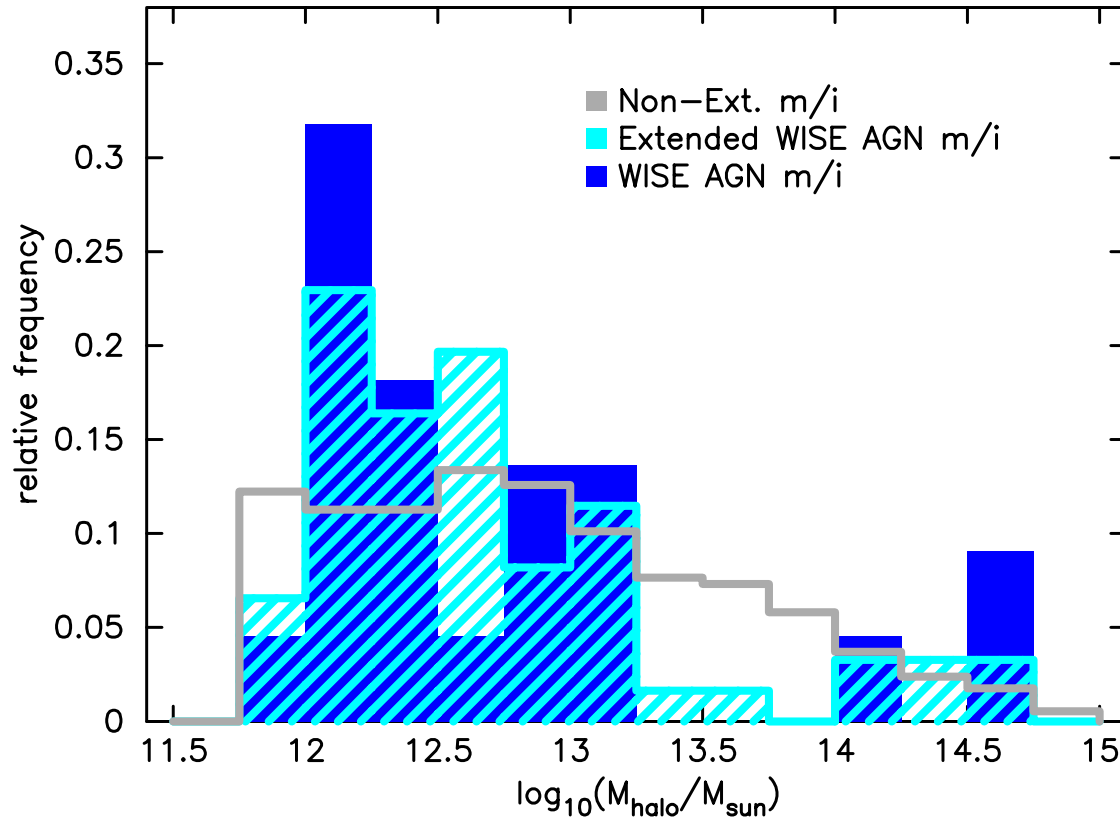
WISE AGN: 0.063

Extended Cut: 0.031

Marginal dependence  
on Pair Separation

# What is special about these mergers & interactions? Halo Mass

Properties of WISE AGN Mergers & Interactions: Halo Mass



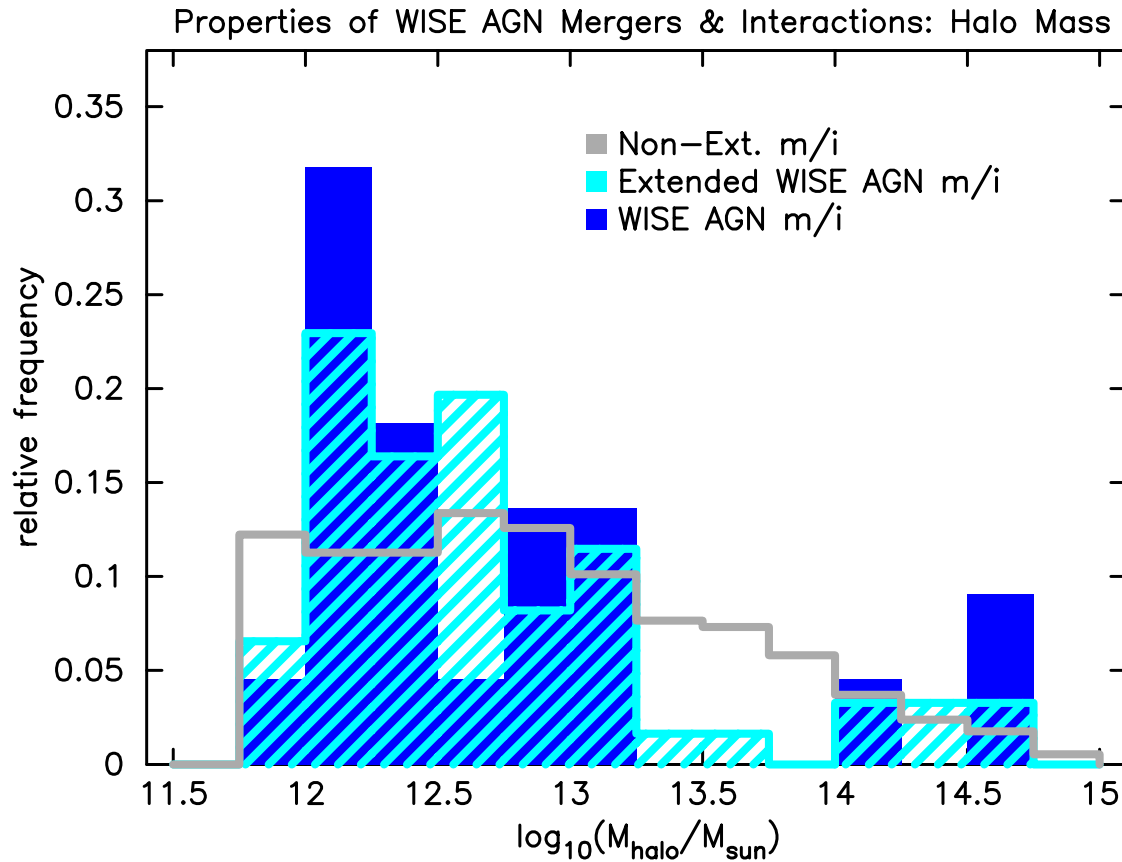
K-S Test p-values for  
Halo Mass

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WISE AGN:	0.211
Extended Cut:	0.025

Yang et al. 2007 Group Catalog

# What is special about these mergers & interactions? Halo Mass



K-S Test p-values for  
Halo Mass

---

WISE AGN:	0.211
Extended Cut:	0.025

Possible dependence  
on Halo Mass

# What is special about these mergers & interactions? Central Fraction

The brightest galaxy in a galaxy group is assumed to be the most massive, and thus the center of the dark matter halo.

Other galaxies in the group are considered satellites.

## Percent of Centrally-Located Galaxies

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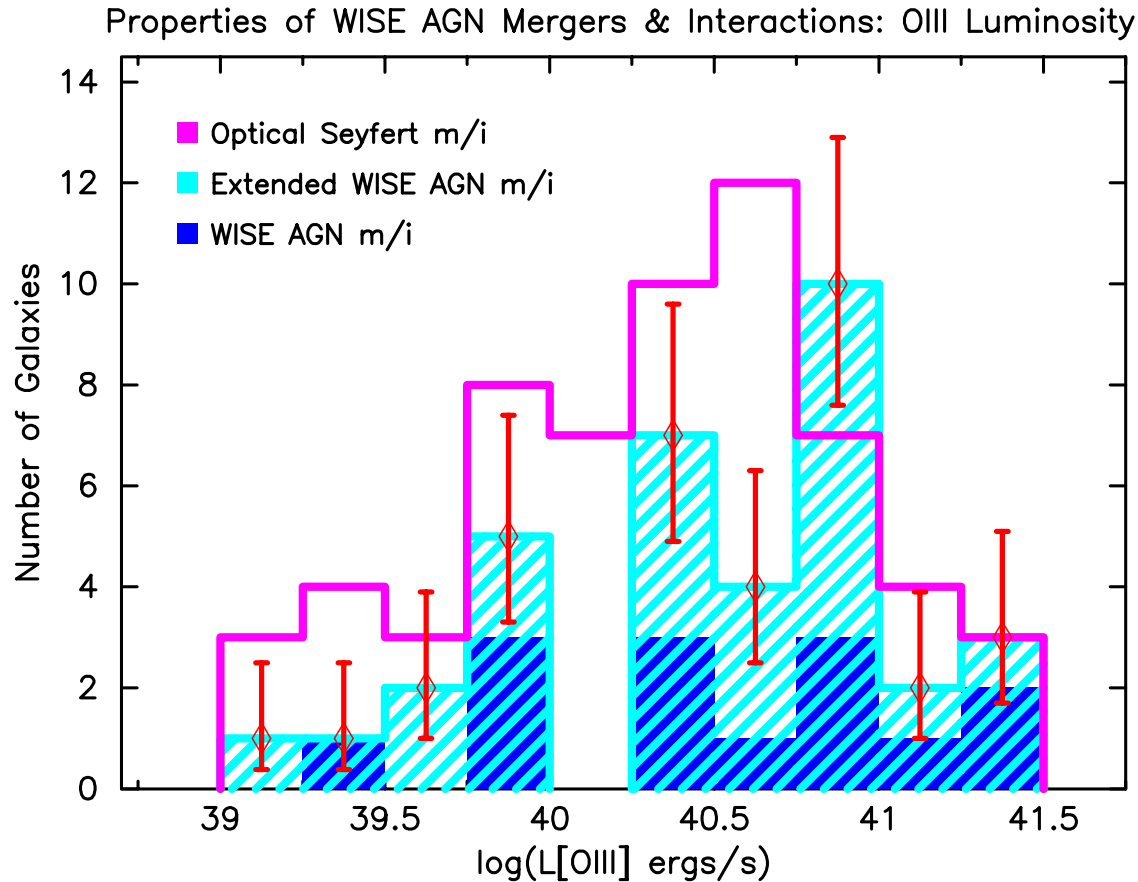
Non-Ext. m/i:	78%
WISE AGN:	81%
Extended Cut:	80%

No dependence on Halo Location

Yang et al. 2007 Group Catalog

# What is special about these mergers & interactions?

## AGN Power



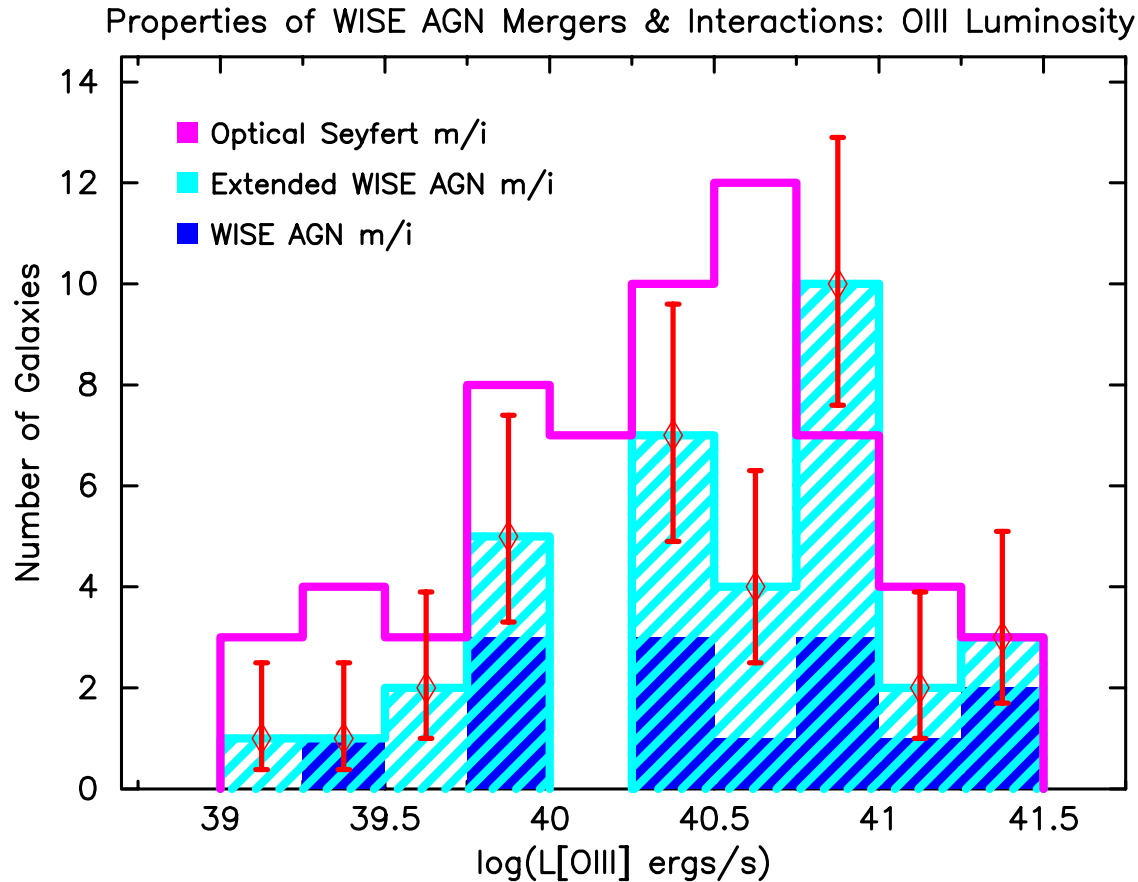
K-S Test p-values for  
[OIII] Luminosity  
(compared to m/i Seyferts)

WISE AGN: 0.280

Extended Cut: 0.180



# What is special about these mergers & interactions? AGN Power



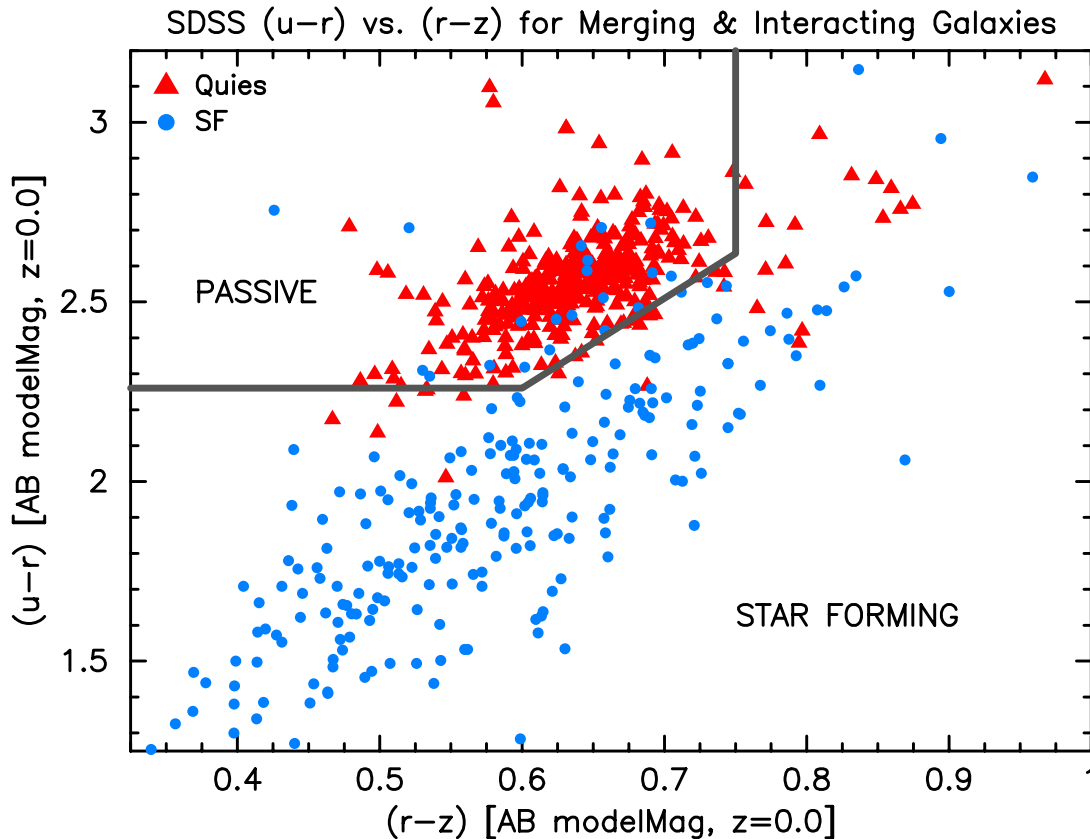
K-S Test p-values for  
[OIII] Luminosity  
(compared to m/i Seyferts)

WISE AGN: 0.280

Extended Cut: 0.180

No dependence on  
AGN Power

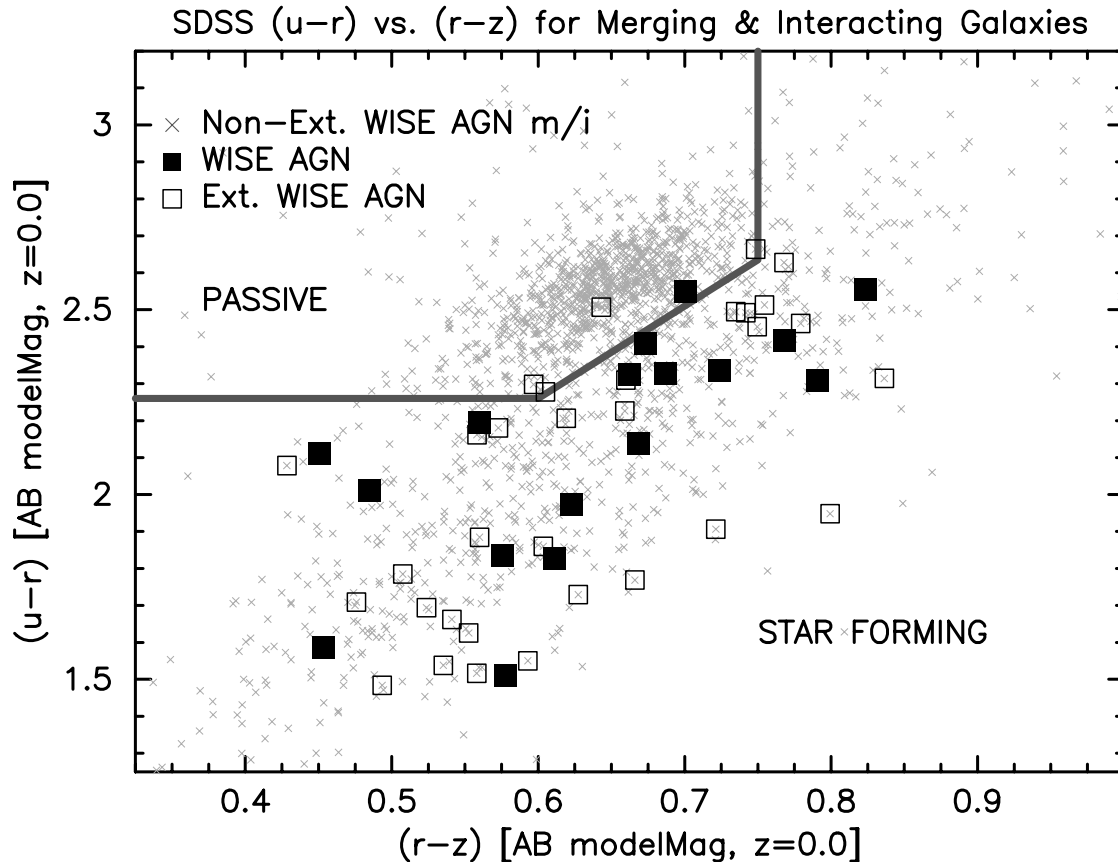
# What is special about these mergers & interactions? Star Formation



SDSS urz-color diagrams are an effective way of isolating passive (non-SF) galaxies from the SF population.

Holden et al. 2012

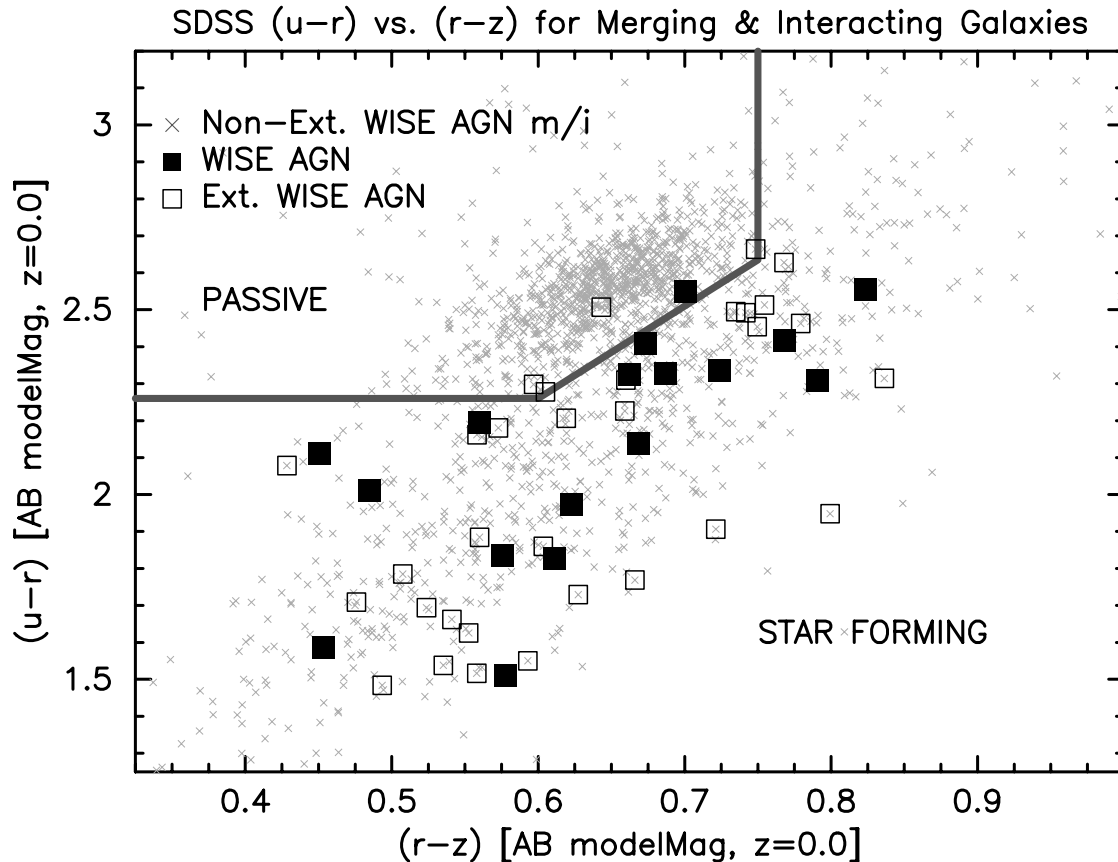
# What is special about these mergers & interactions? Star Formation



## Percent of SF Galaxies

Non-Ext. m/i:	57%
WISE AGN:	94%
Extended Cut:	90%

# What is special about these mergers & interactions? Star Formation

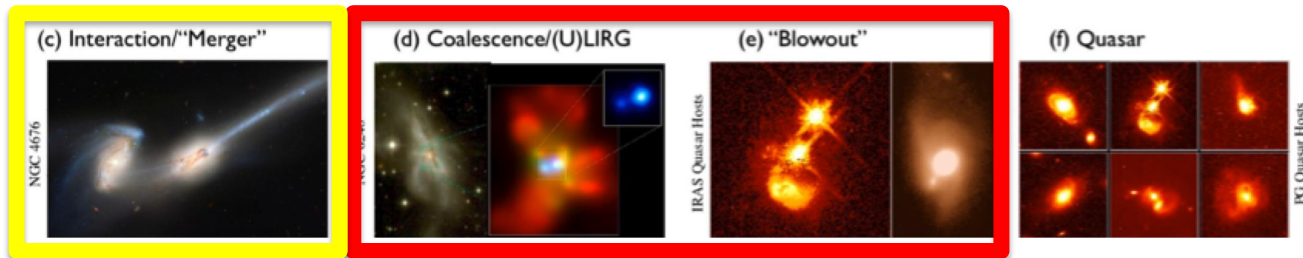


## Percent of SF Galaxies

Non-Ext. m/i:	57%
WISE AGN:	94%
Extended Cut:	90%

There is a correlation between WISE AGN and SF

# Dusty AGN & SF



Interactions

Mergers

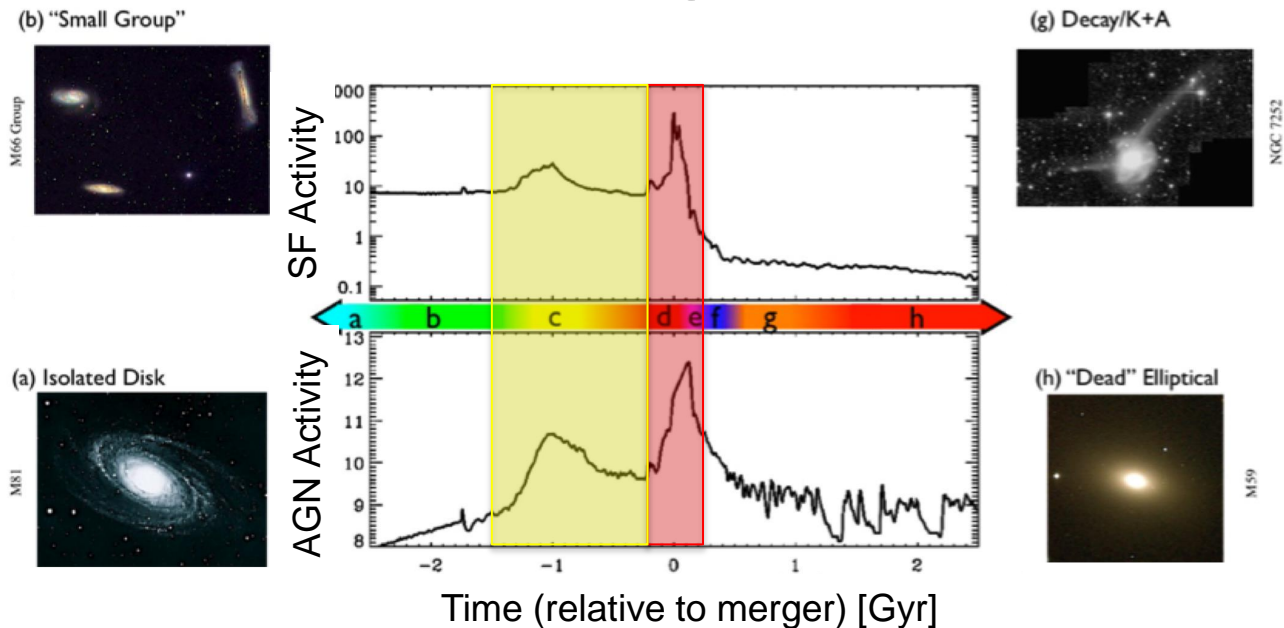


Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

# Summary

We compare selection methods of AGN in WISE color space and use the WISE AGN box by Jarrett et al. 2011 to isolate dusty AGN in merging and interacting galaxies.

**Mergers are 5 – 20 times more likely to be a dusty AGN than non-interacting galaxies.**

WISE AGN mergers/interactions are most likely to be found in a star forming galaxy.

**All of this is consistent with the major merger model.**

# Summary

**Mergers are 5 – 20 times more likely to be a dusty AGN than non-interacting galaxies.**

**This is consistent with the major merger model.**

**Thank you!**

**Questions?**

MEW & DHM gratefully acknowledge support from NASA grant NNX13AE96G