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

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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….

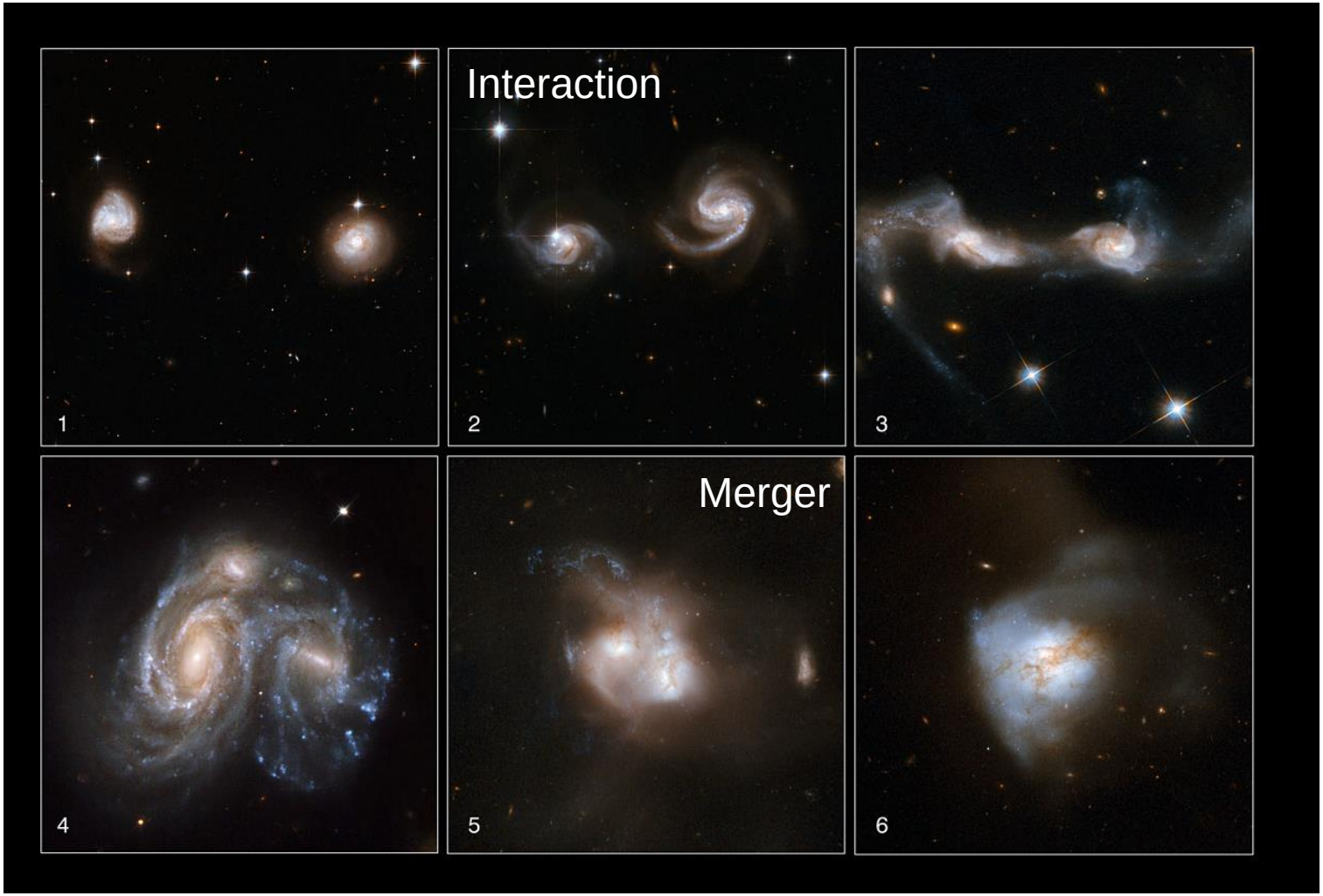

Image Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University), K. Noll (STScI), and J. Westphal (Caltech).

Barnes & Hernquist 1996

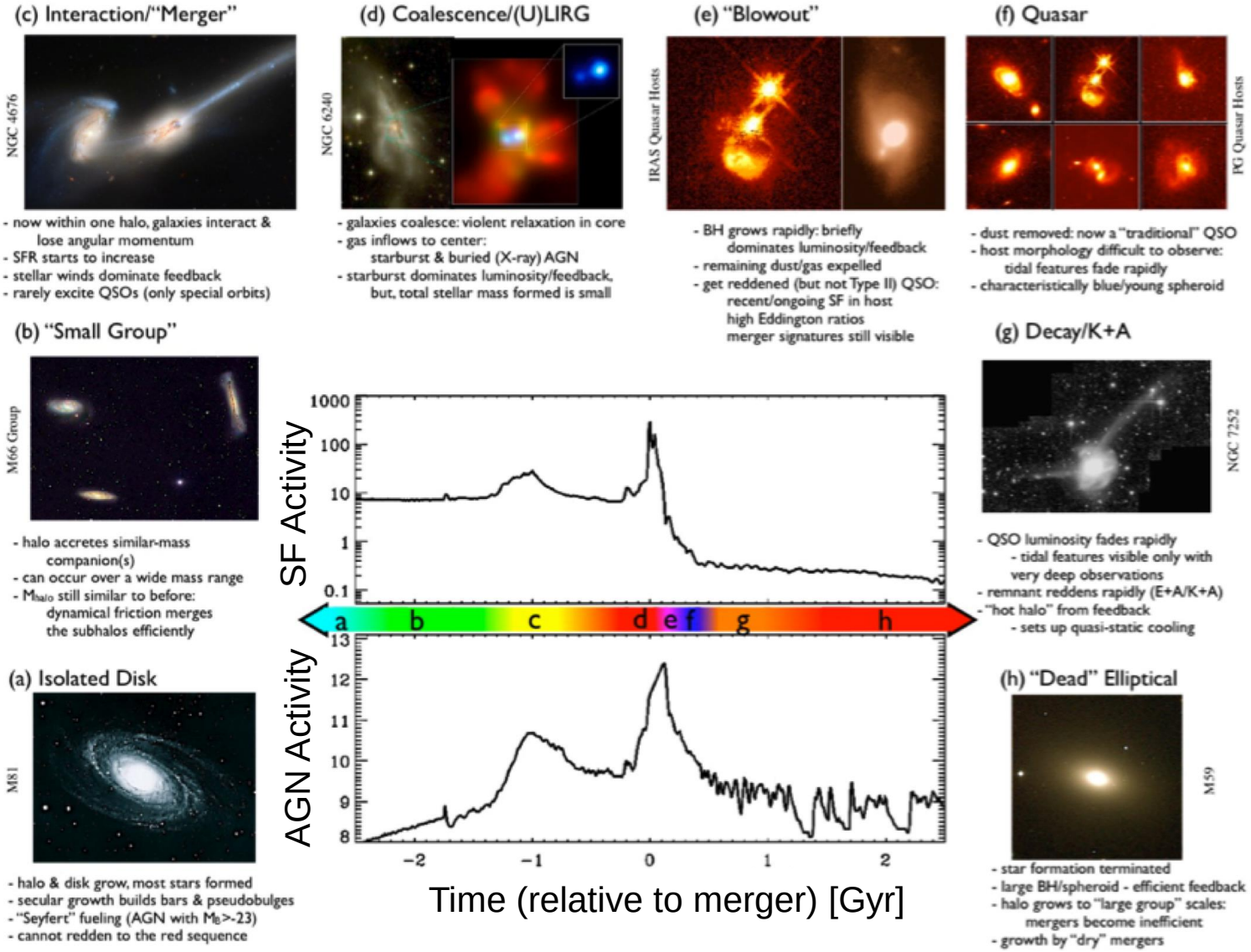

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

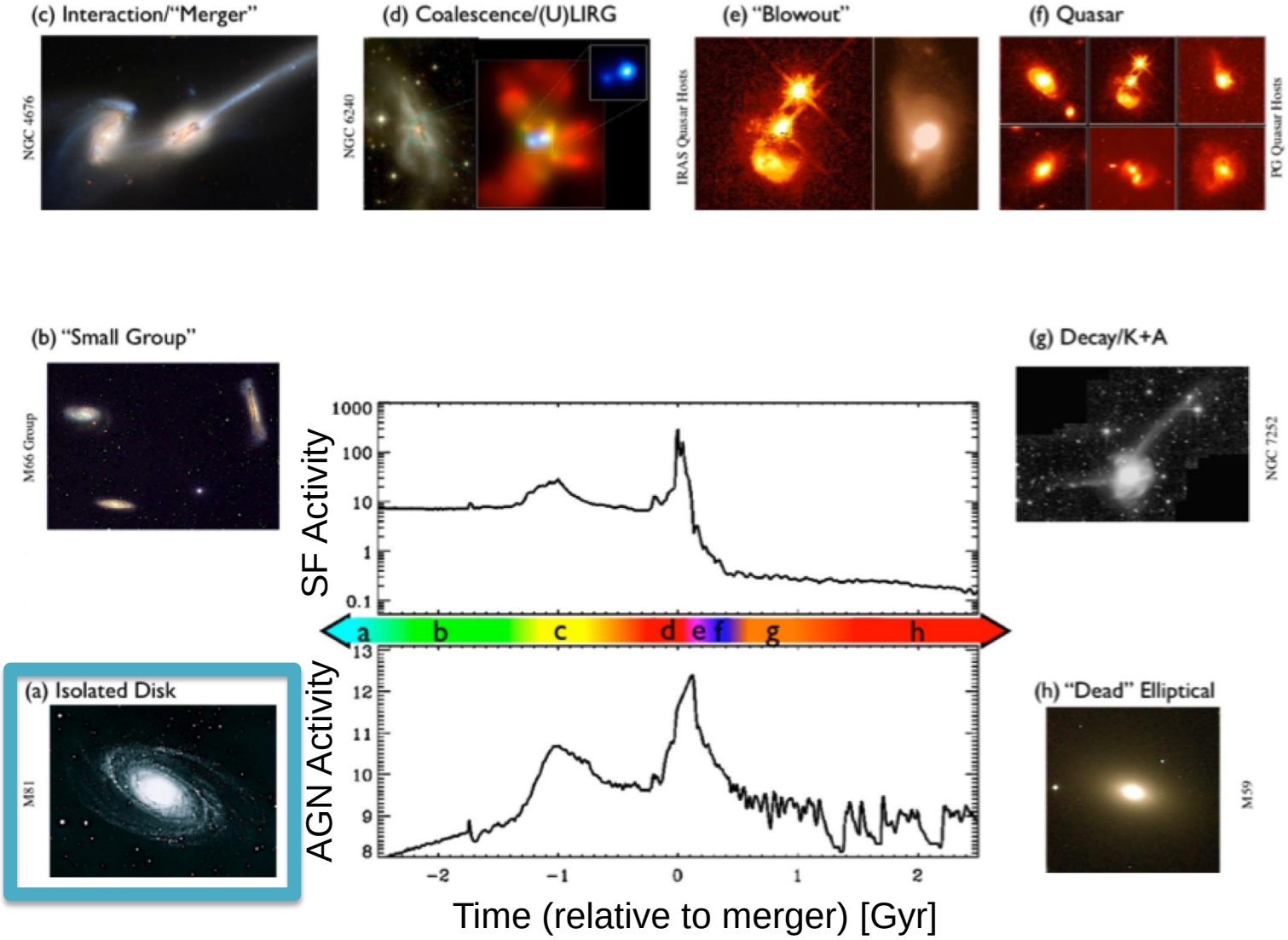

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

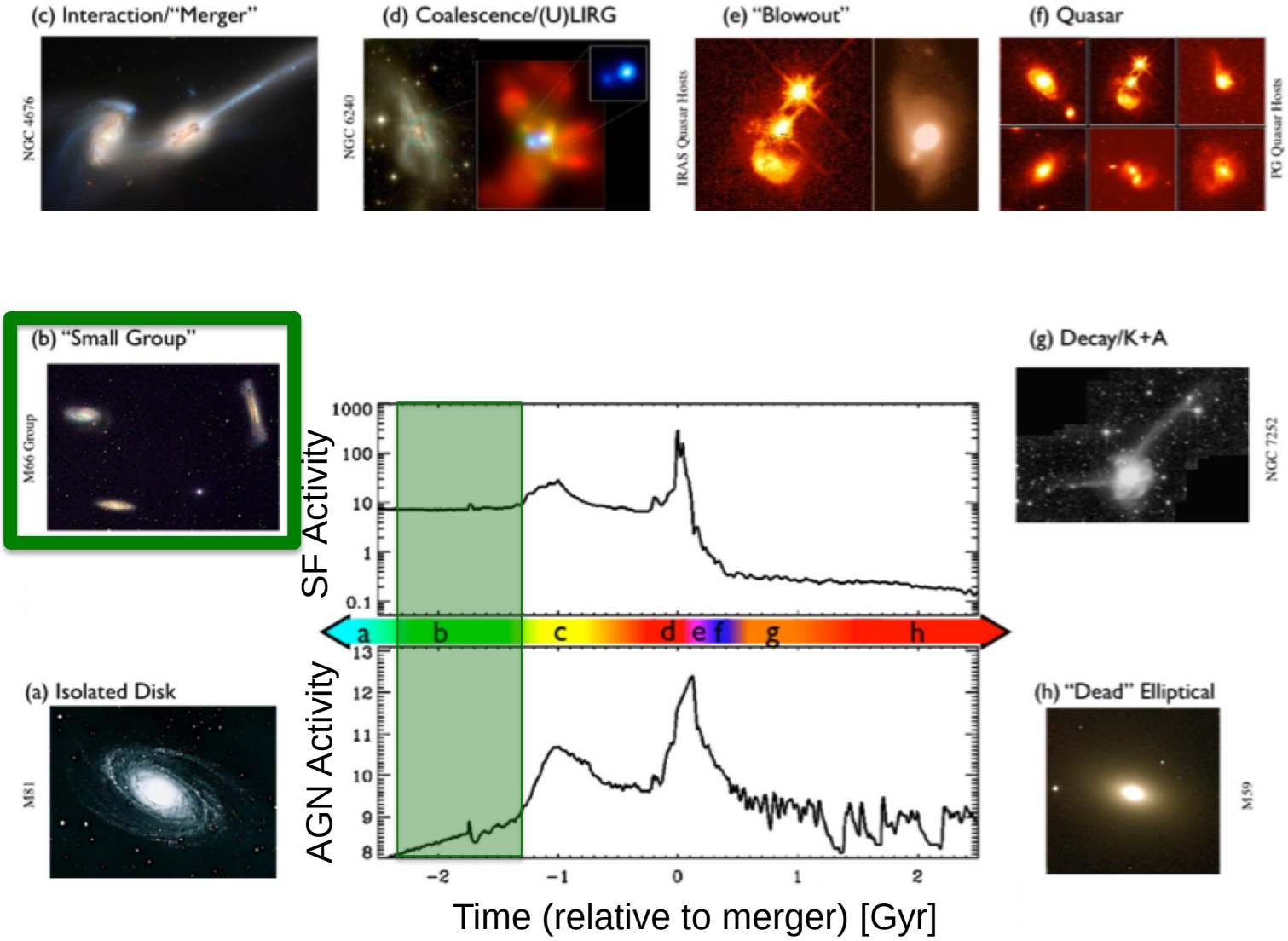

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

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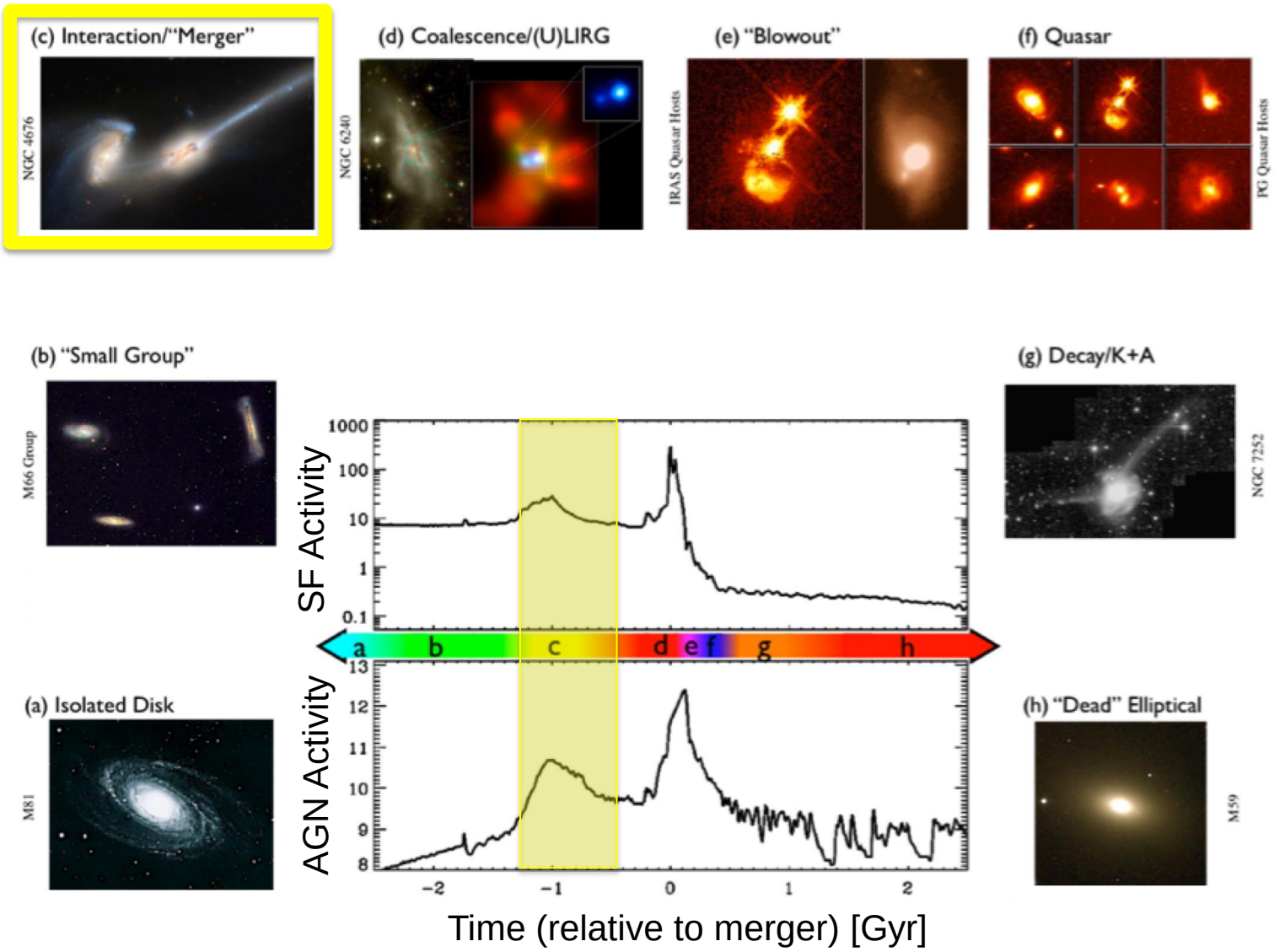

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

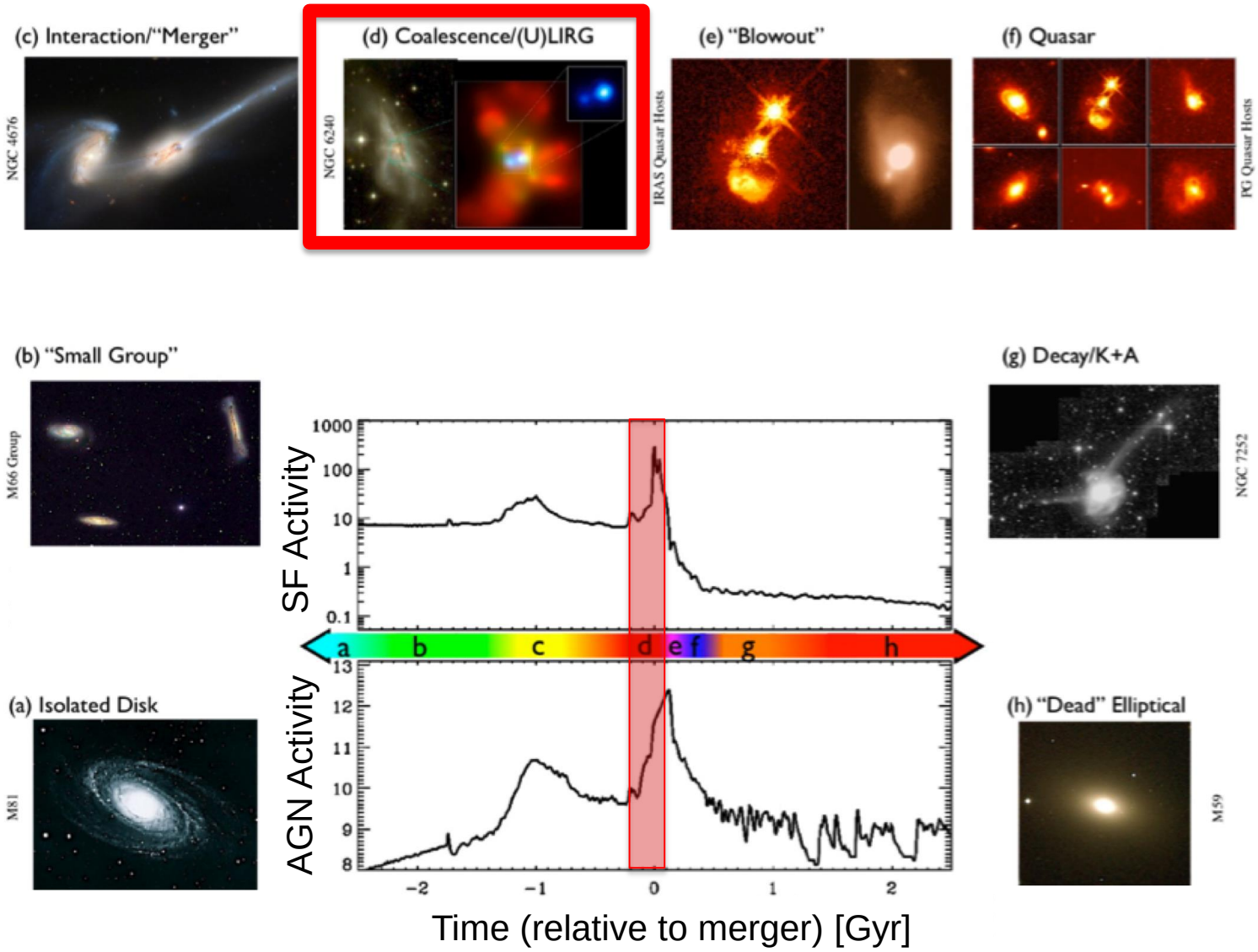

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

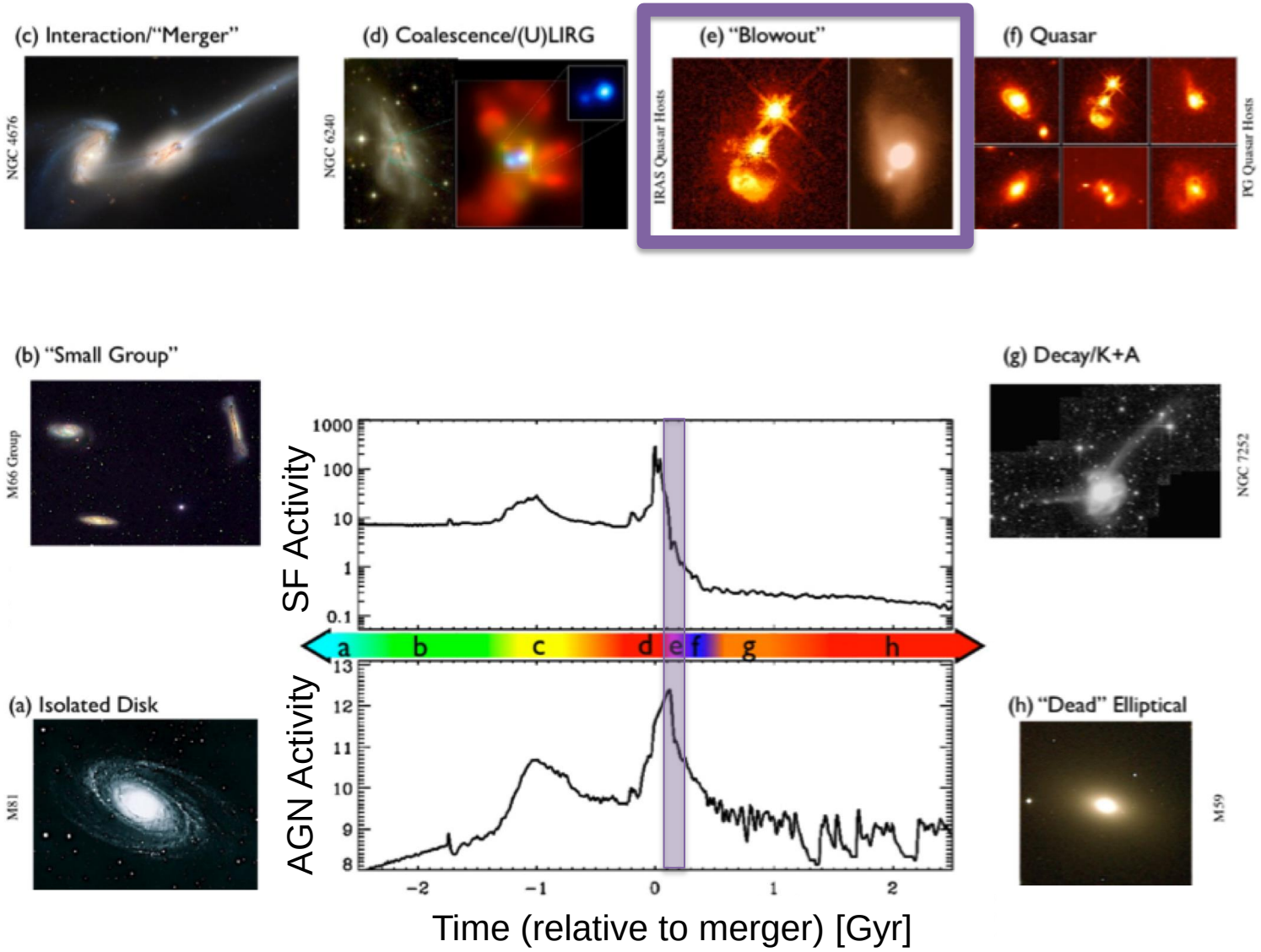

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

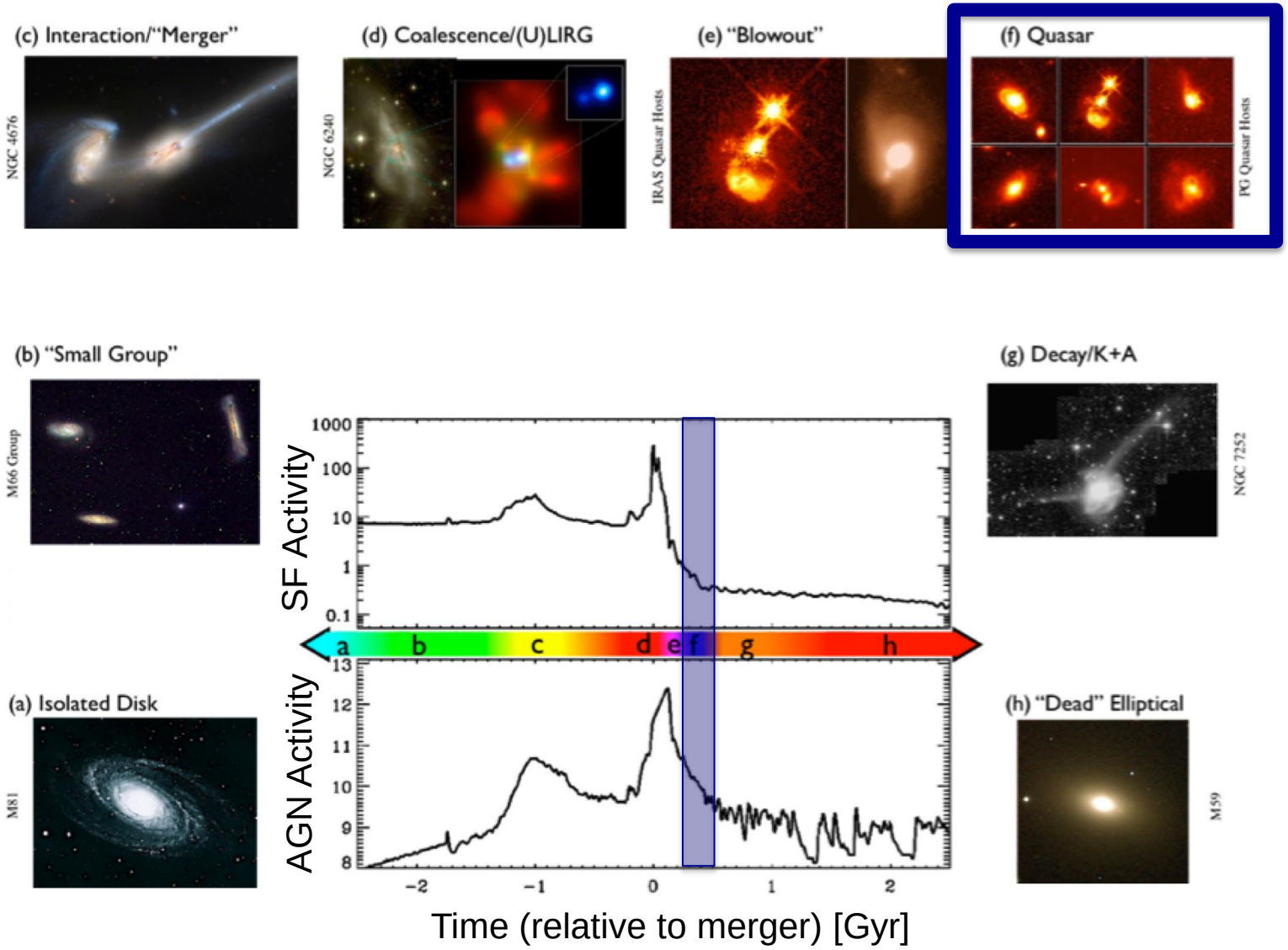

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

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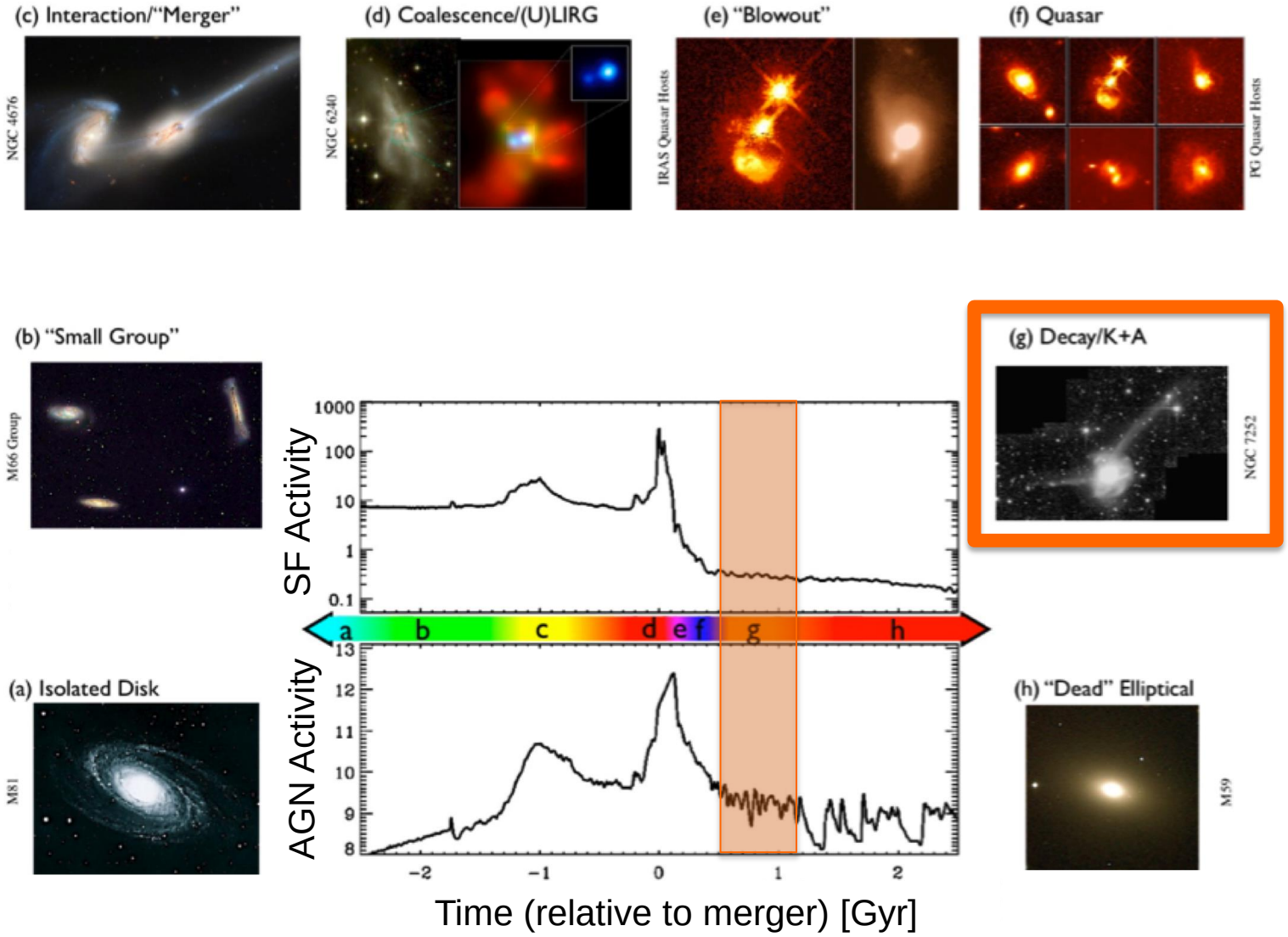


Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

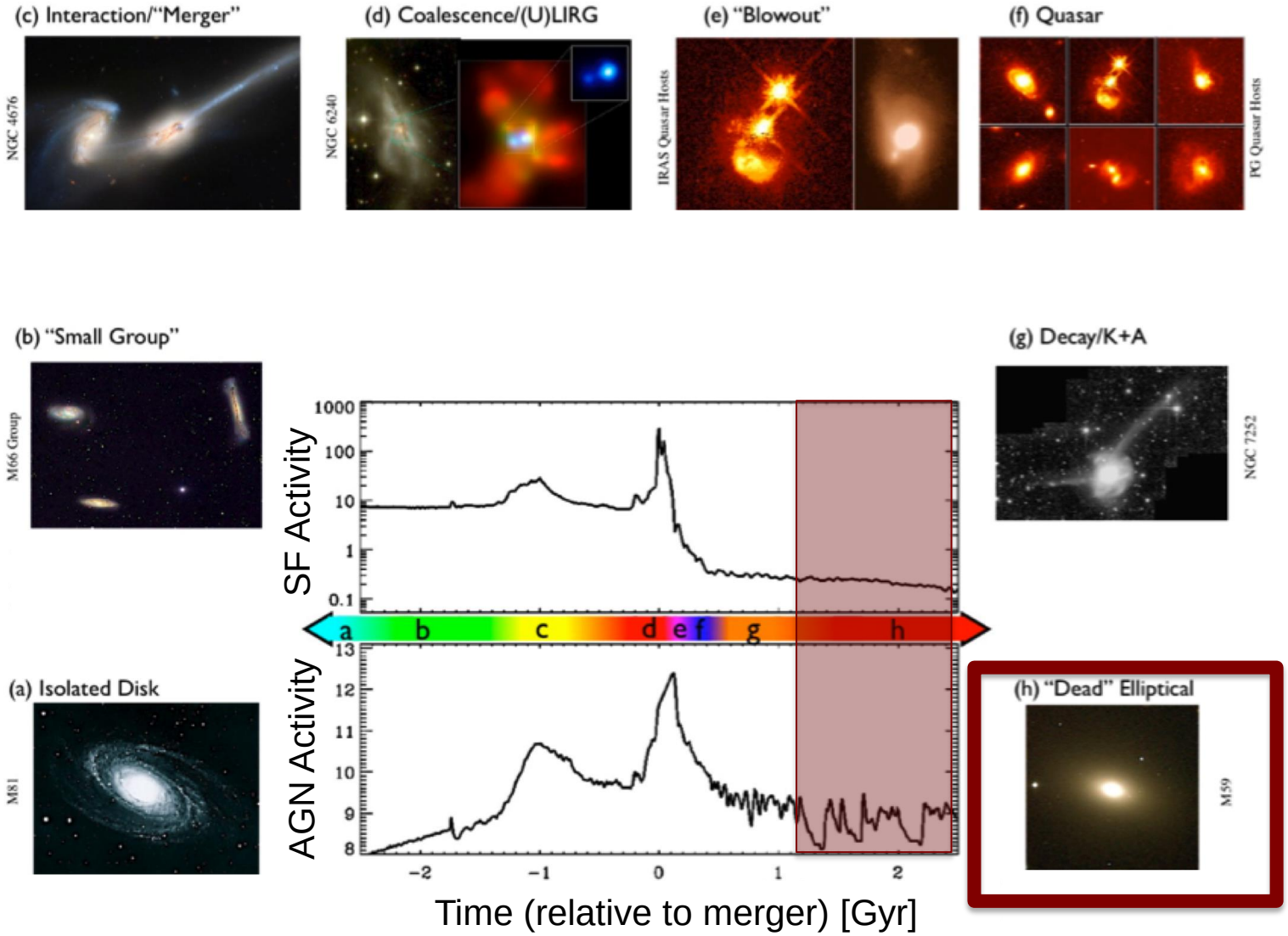
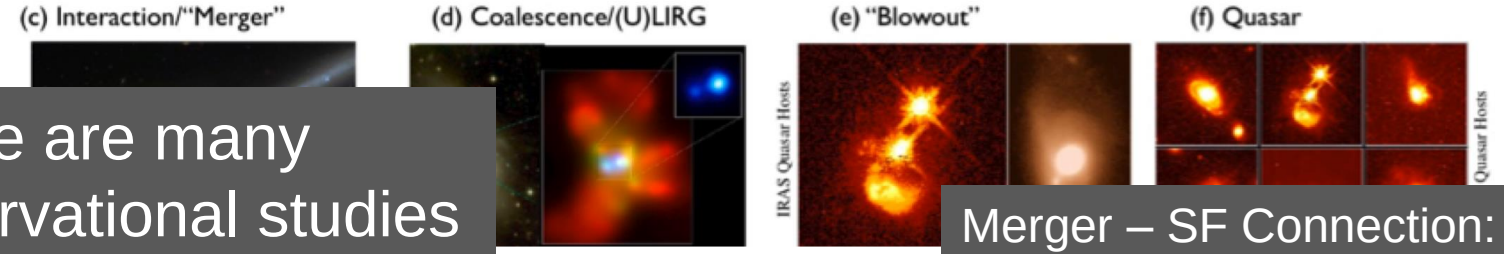


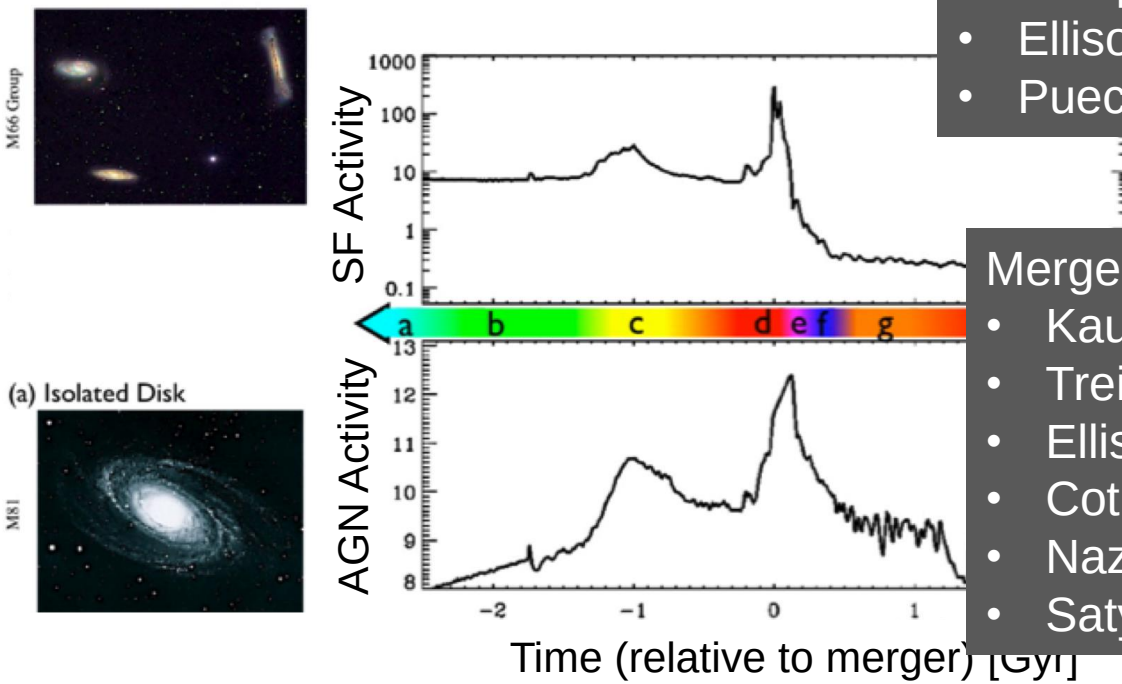
Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

There are many observational studies that support this process.



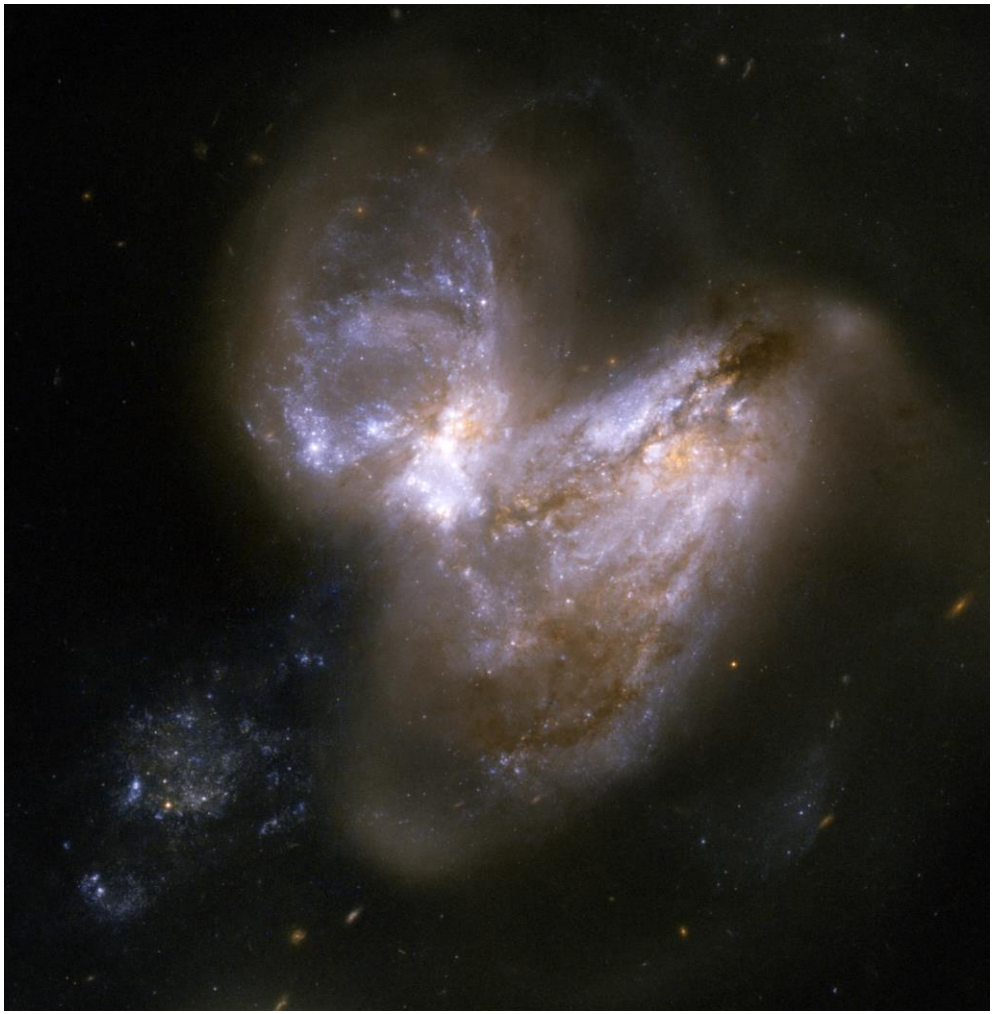
Merger – SF Connection:
- Kauffmann et al. 2003
- Darg et al. 2010
- Kampczyk et al. 2012
- Ellison et al. 2013
- Puech et al. 2014



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

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

Hopkins et al. 2008



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

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Sample Description

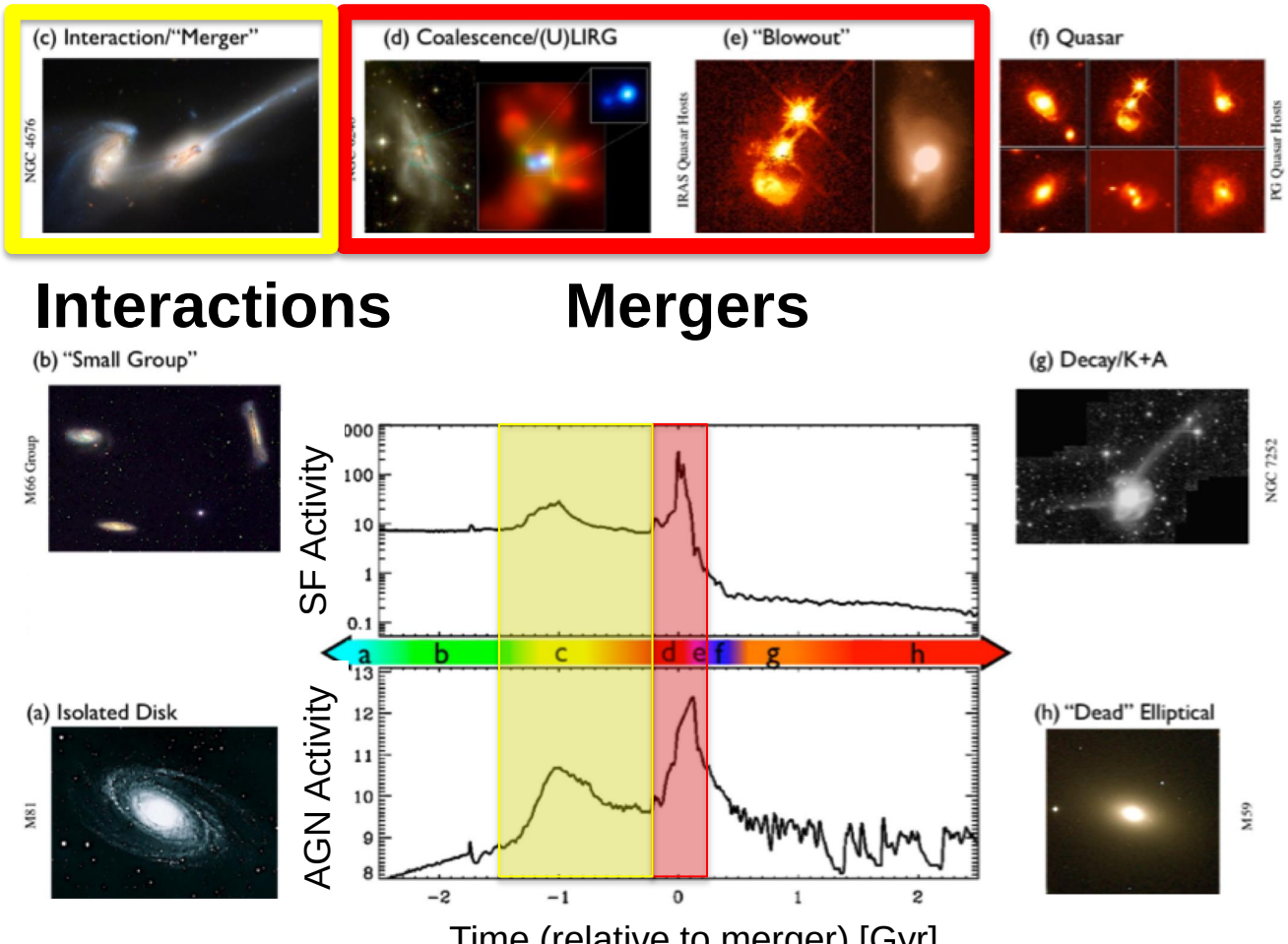
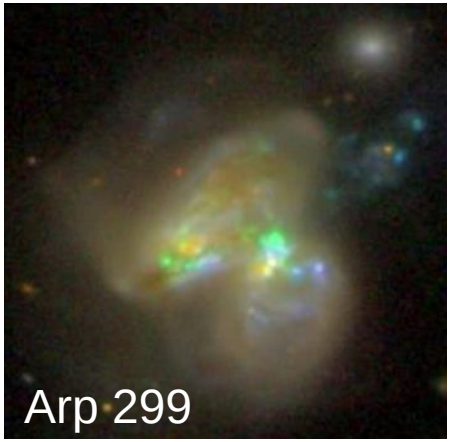
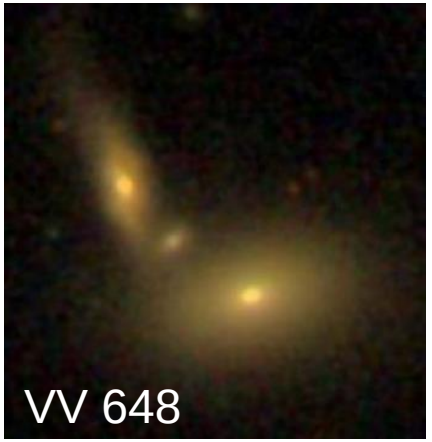


Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

Sample Description





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

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

Images from SDSS Image Tool

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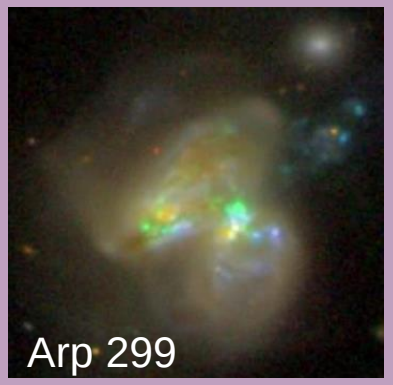
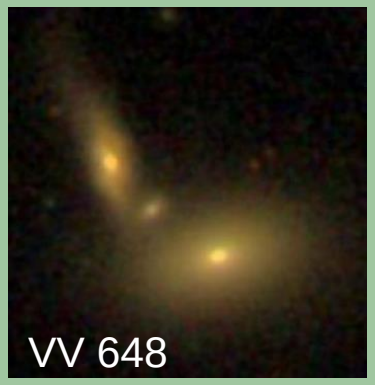
Sample Description

130 Mergers (m)



307 Interactions (i)

762 Possible Interactions (i?)

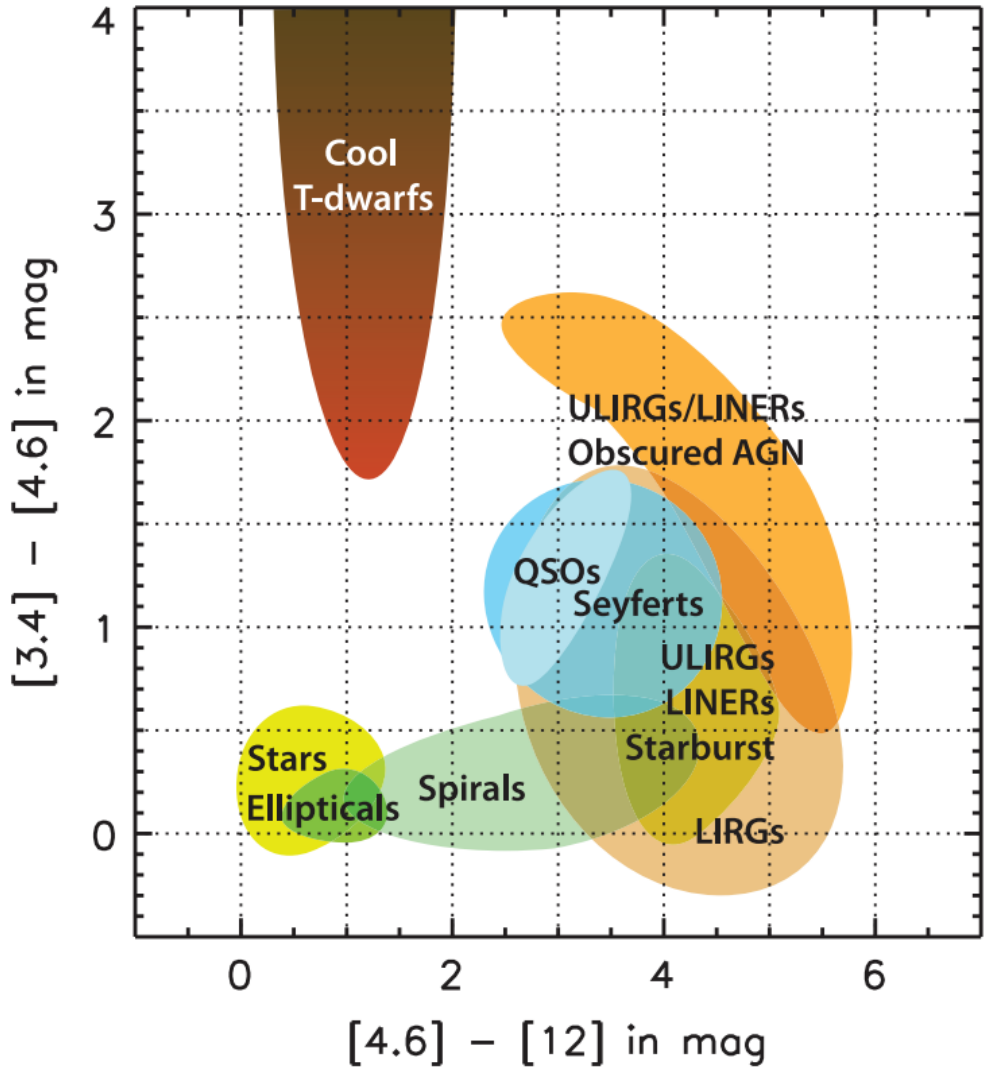


Images from SDSS Image Tool

McIntosh et al. (in prep)

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

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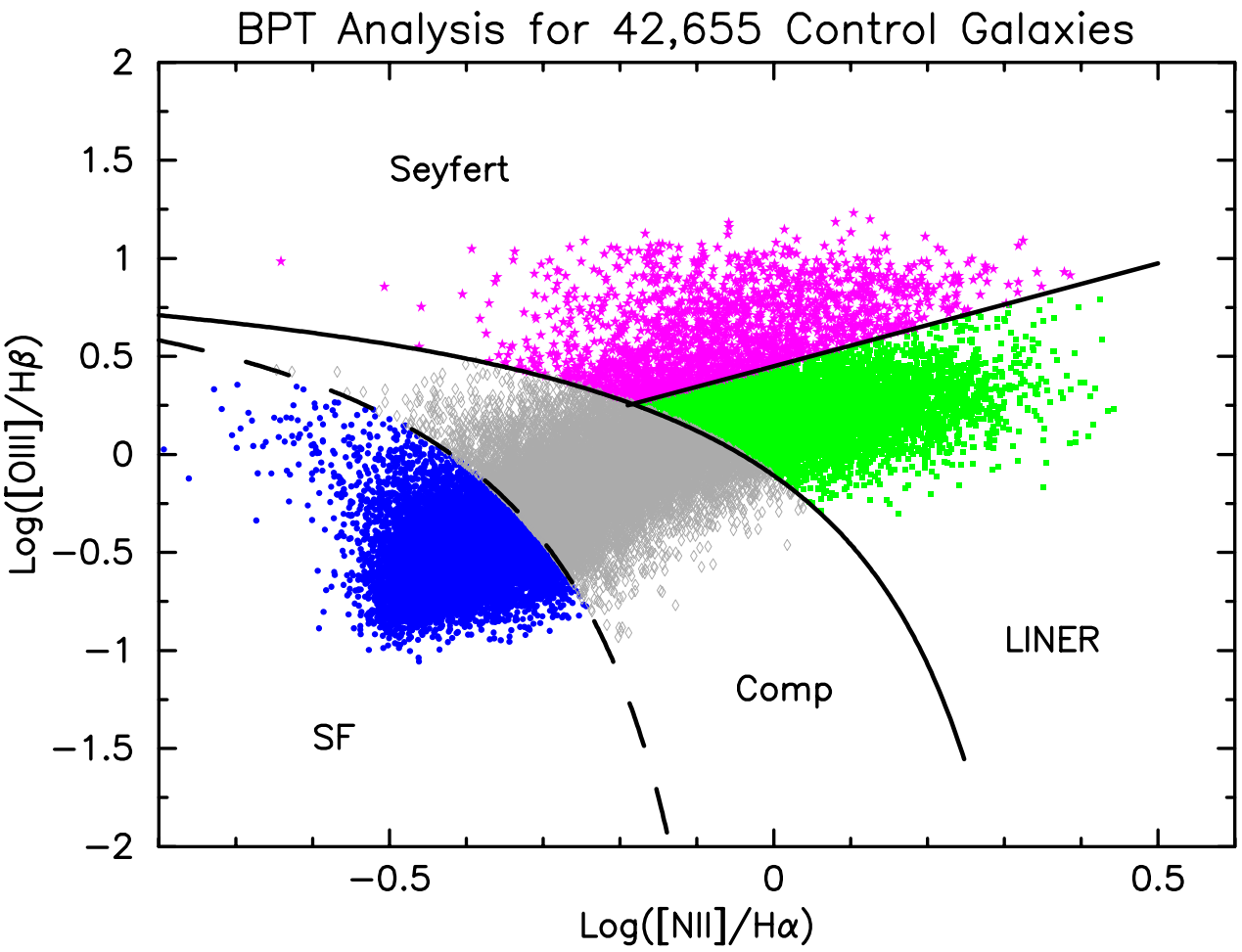
Emission Type Analysis of WISE Color Space



▲ Quiescent: No Emission Features

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

Weston et al. (in prep)

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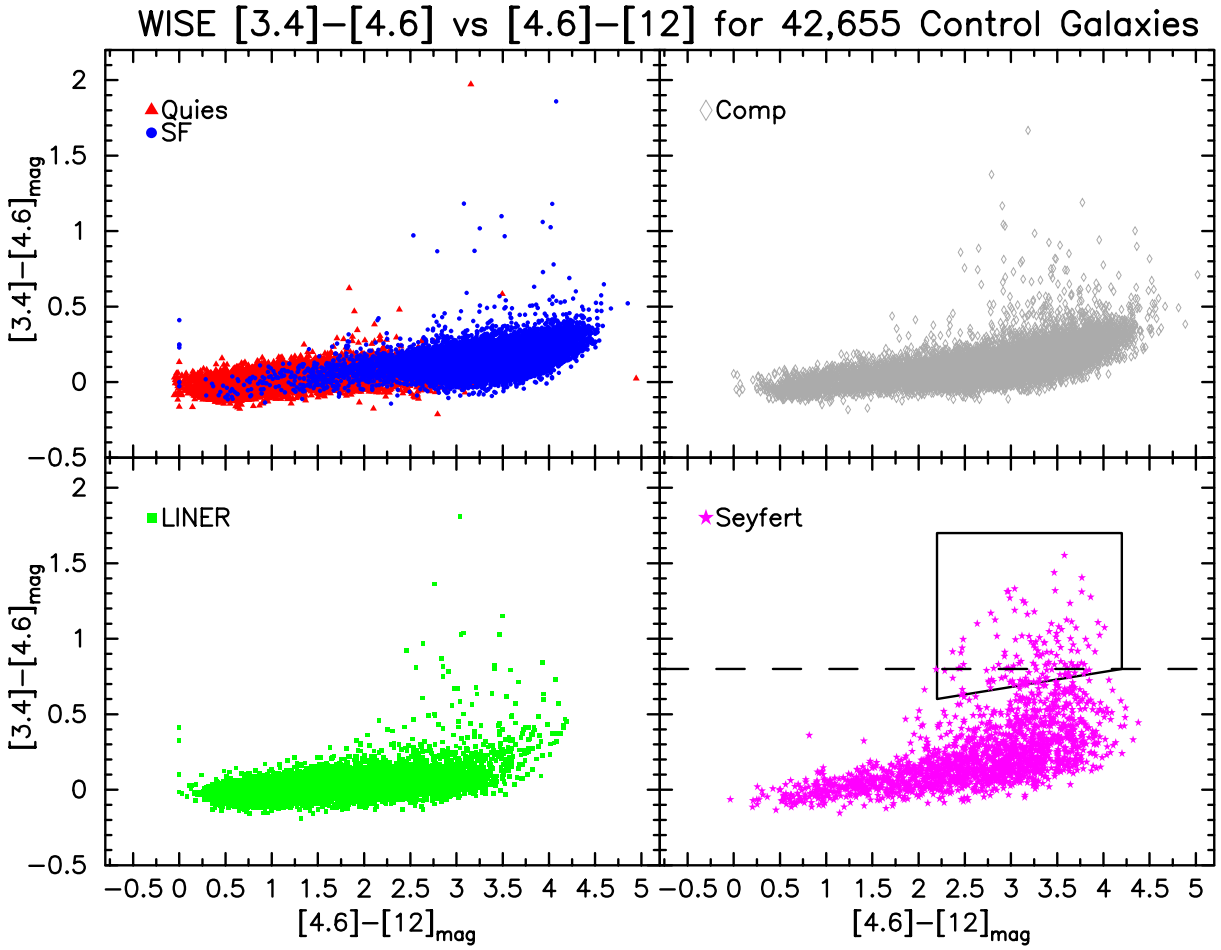
Emission Type Analysis of WISE Color Space



Weston et al. (in prep)

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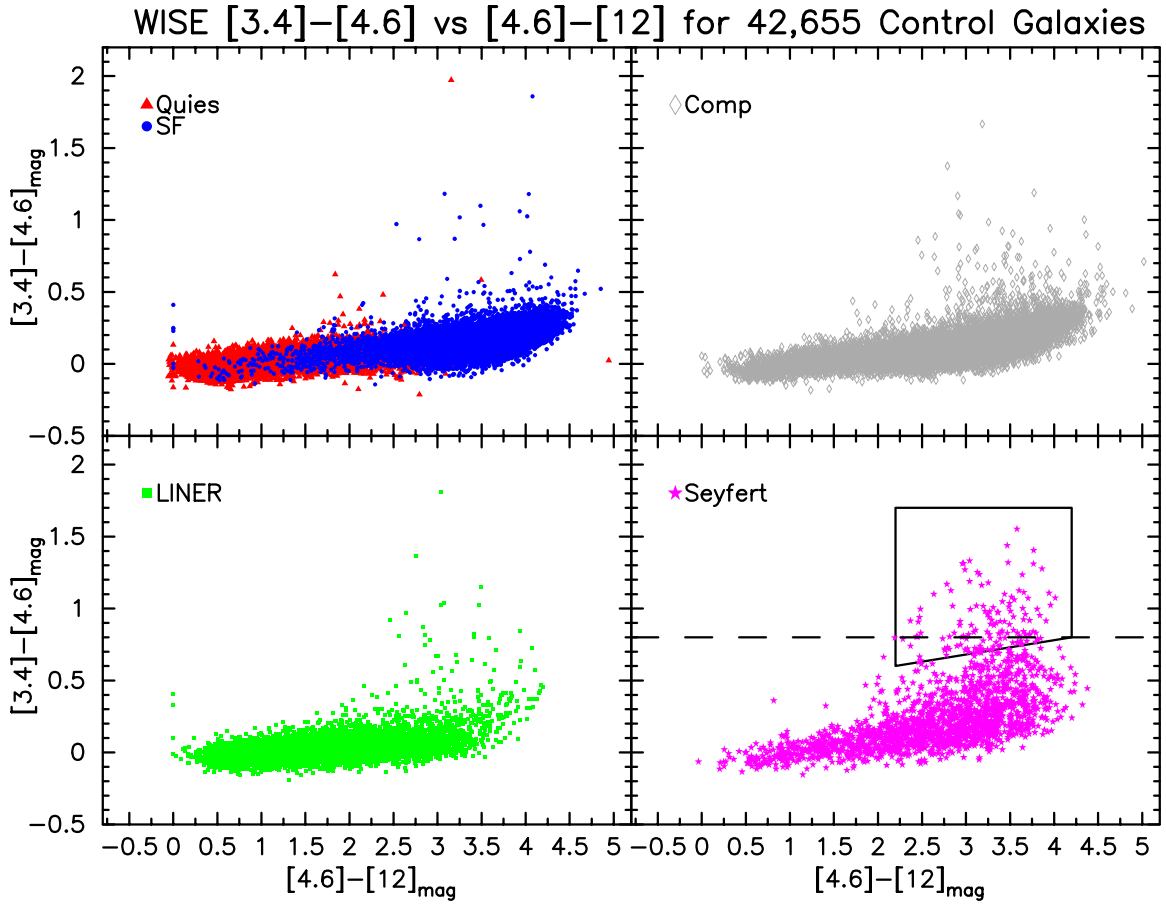
Emission Type Analysis of WISE Color Space



Warmer dust from AGN

Dust Heating by SF

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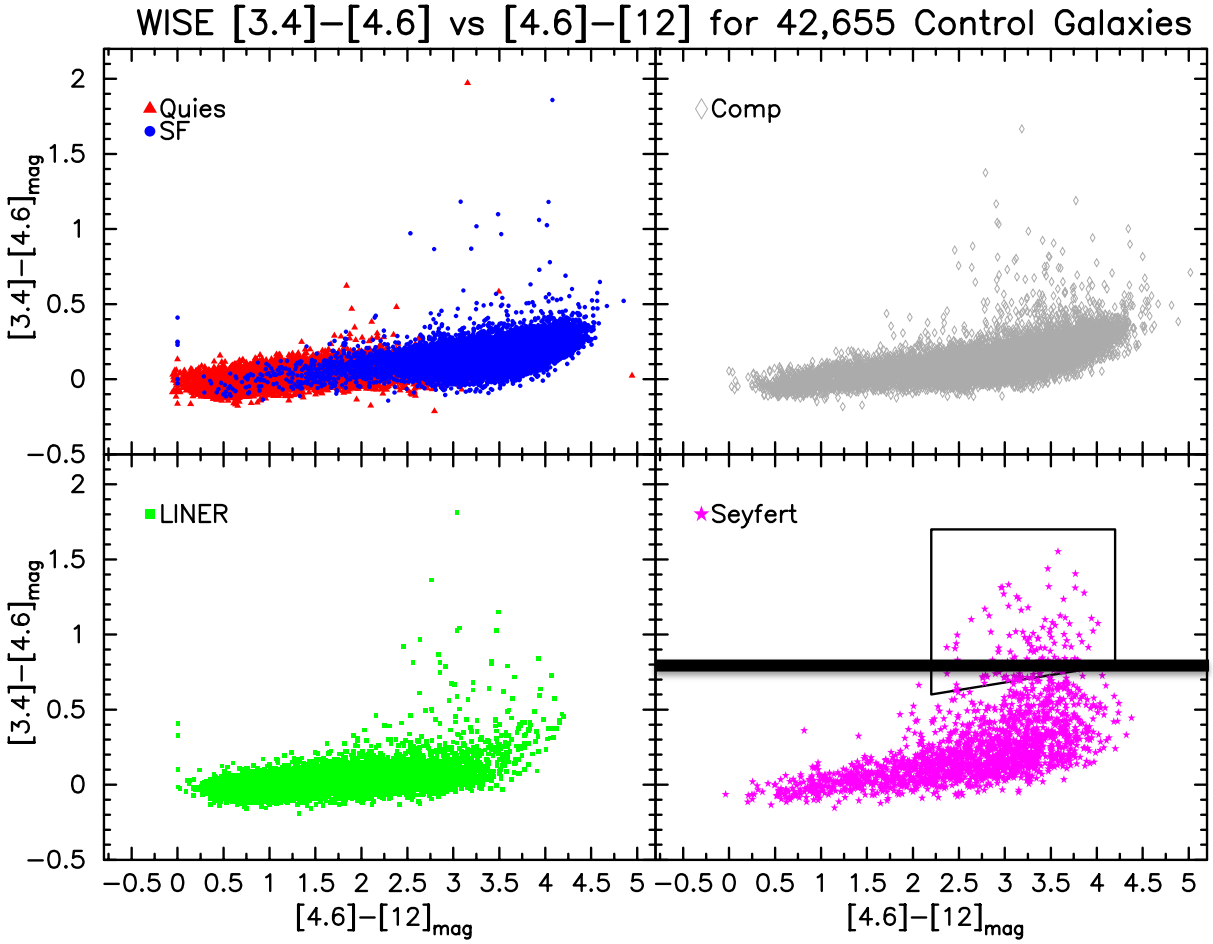
Three Ways to Isolate AGN



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

5% of Seyferts have [3.4] – [4.6] ≥ 0.8

Weston et al. (in prep)

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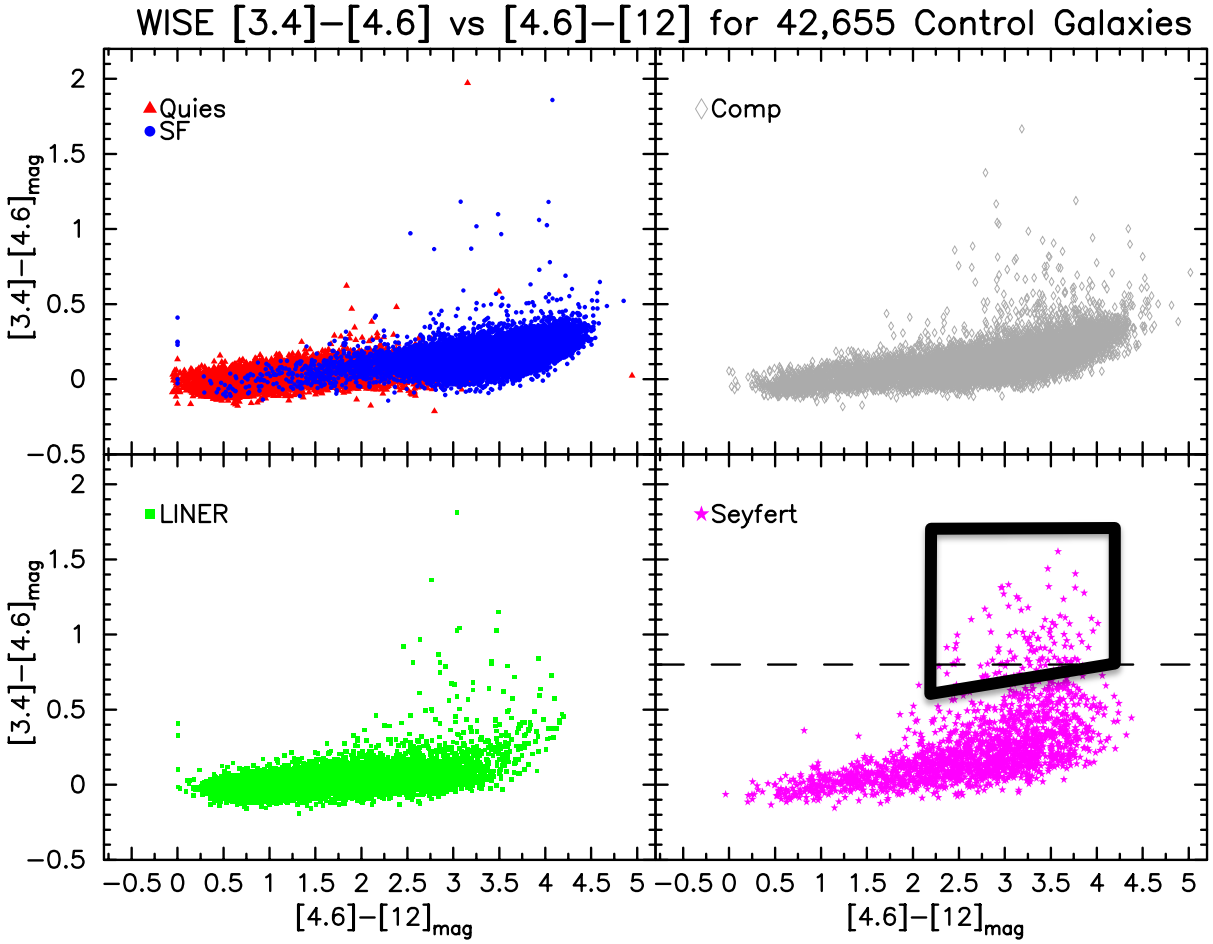
Three Ways to Isolate AGN



1. [3.4] – [4.6] ≥ 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

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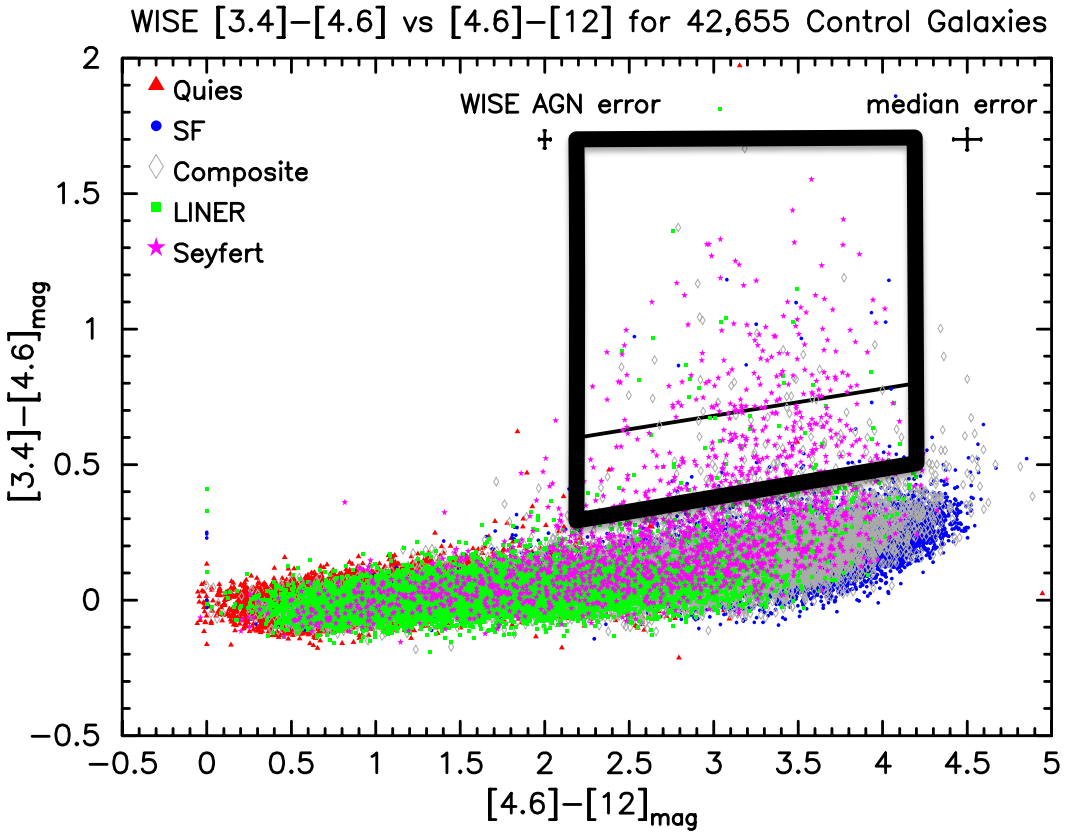
Three Ways to Isolate AGN



21% of Seyferts are in Extended Jarrett+11 box

1. [3.4] – [4.6] ≥ 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

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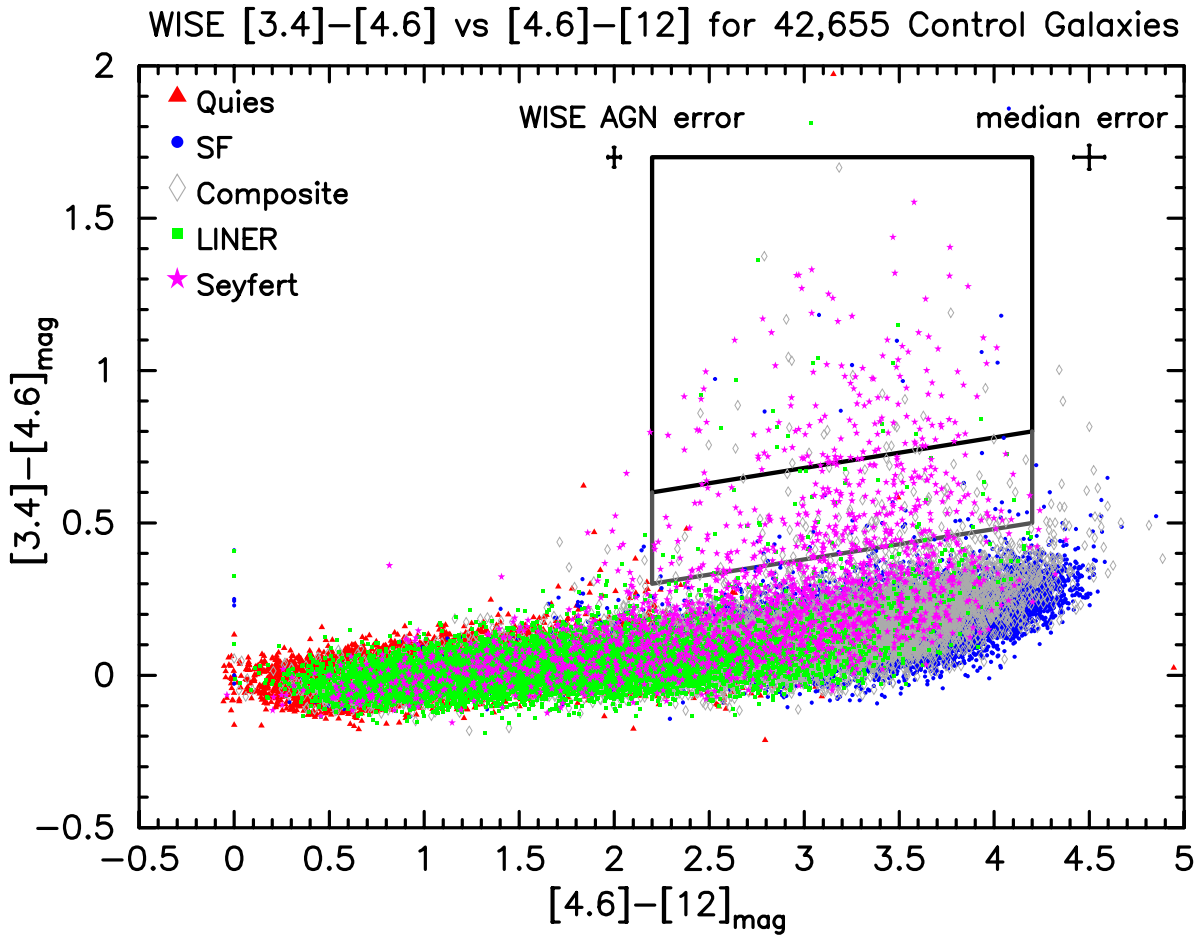
Incidence of Dusty AGN in Control Galaxies



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)

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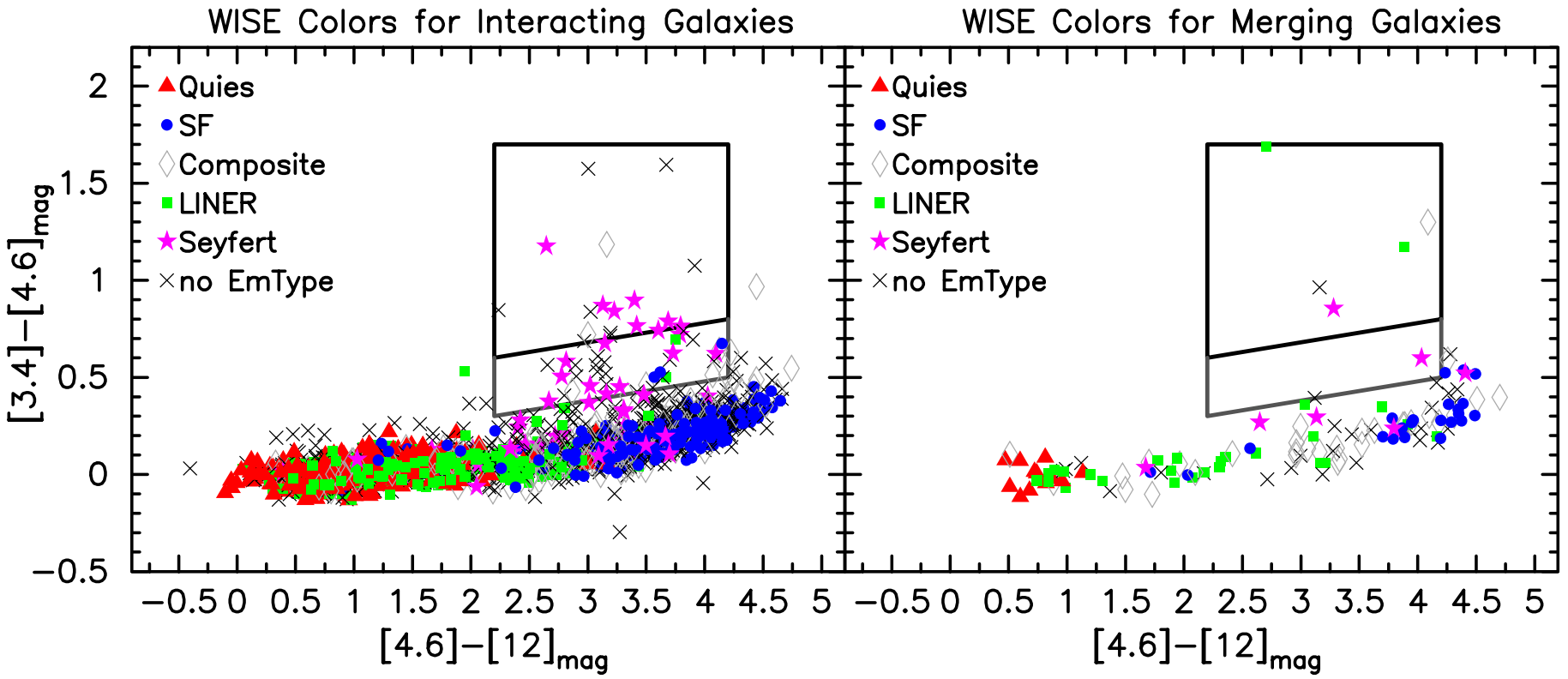
Incidence of Dusty AGN in Mergers & Interactions



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)

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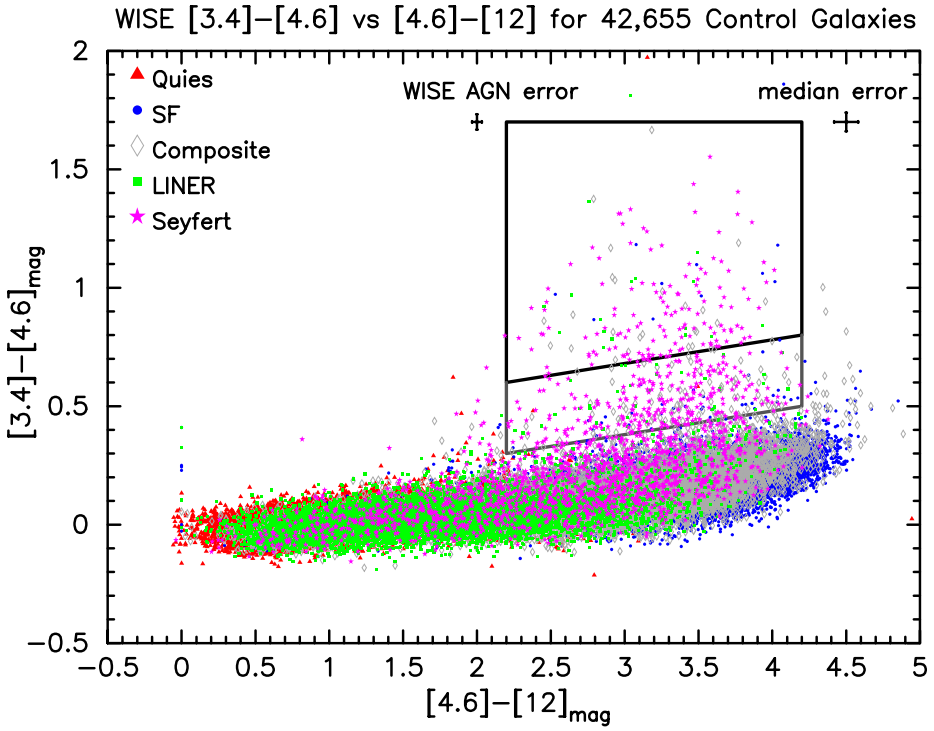
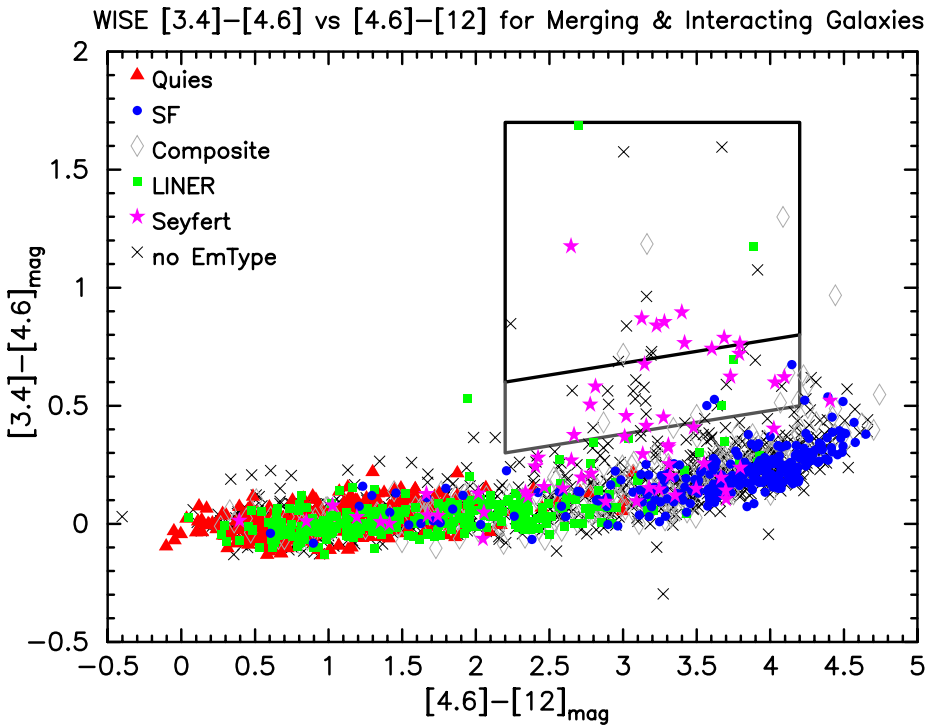
0.38 – 0.51% Control galaxies

2 – 9% Mergers
1.0 – 2.5% Interactions





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

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Why don't all mergers make a WISE AGN?

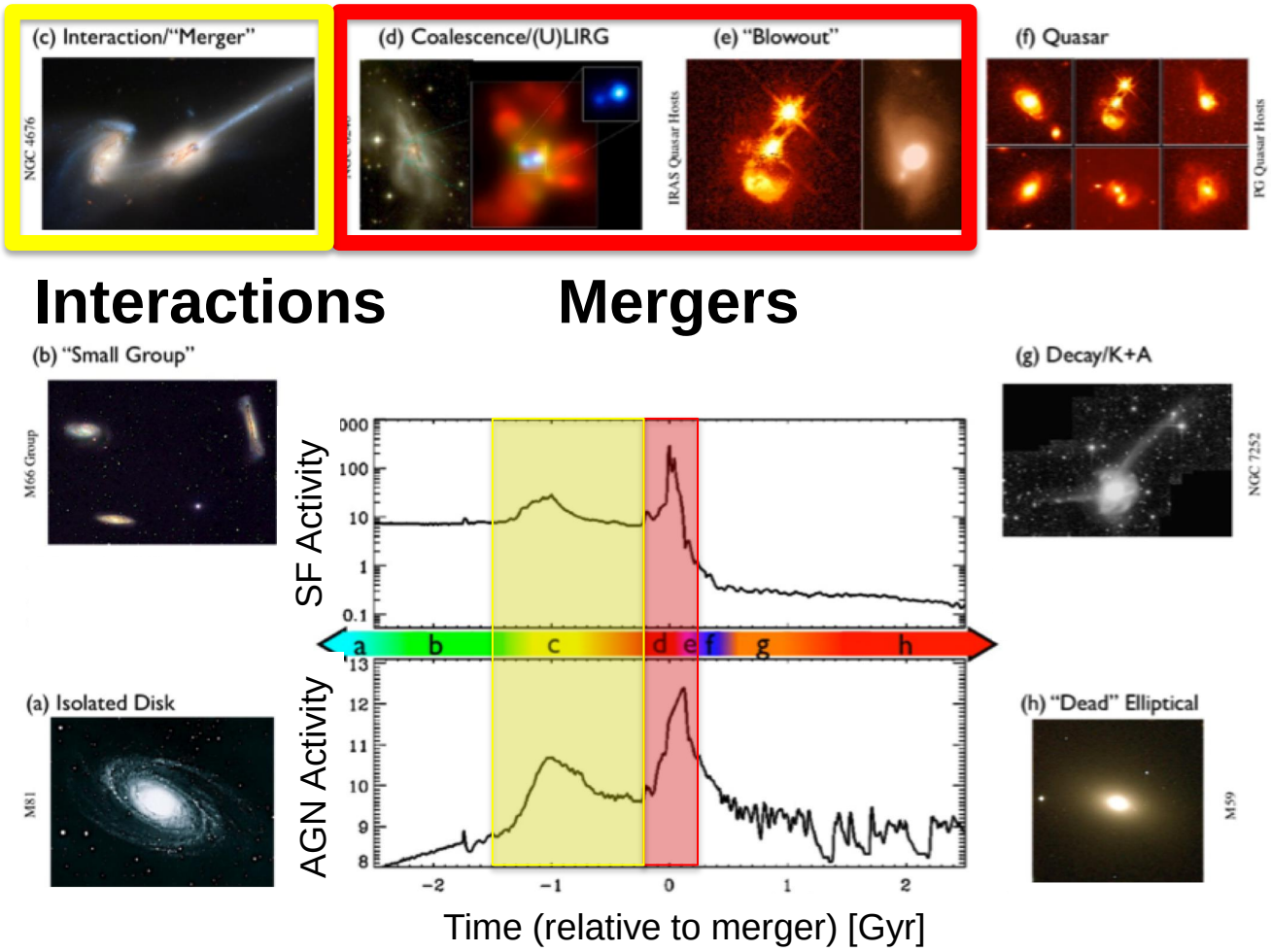

Image Credit: Hopkins, et al., NOAO/AURA/NSF

Hopkins et al. 2008

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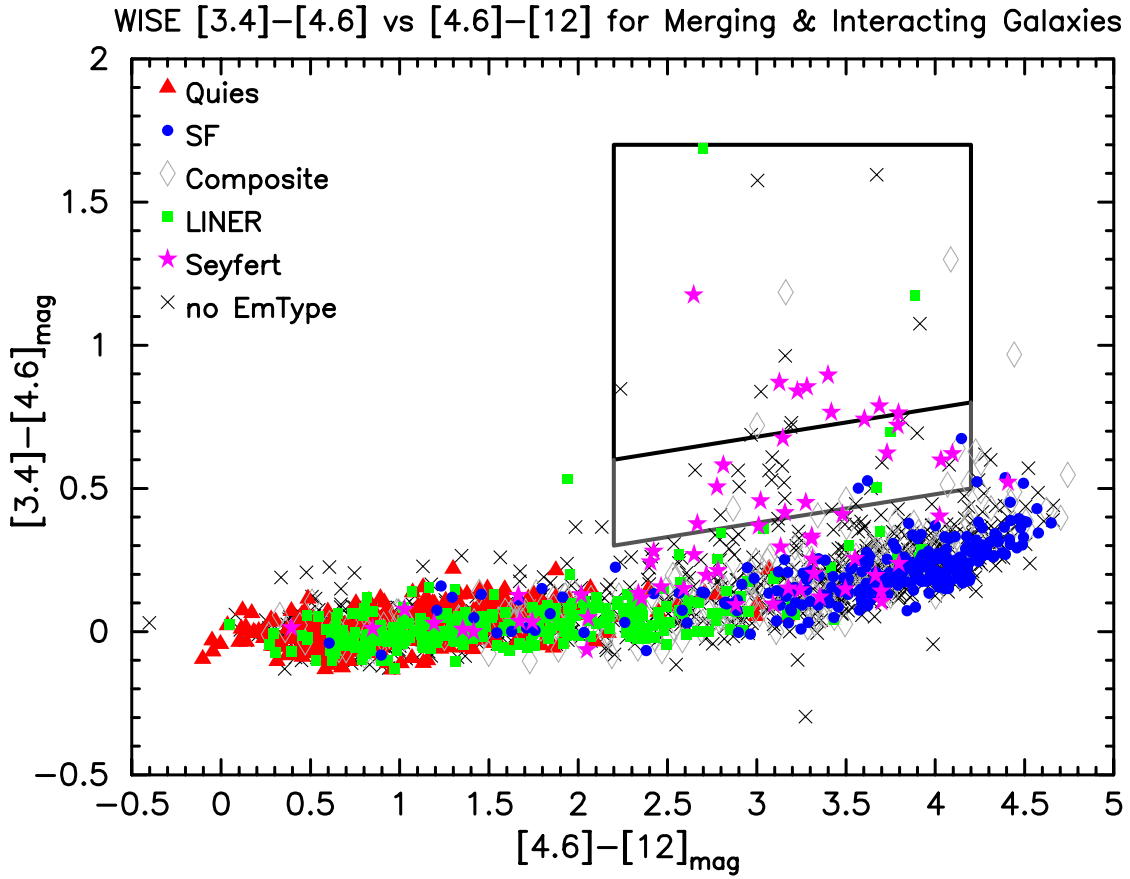
Now that we've found these WISE AGN mergers & interactions, is there anything special about them?

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

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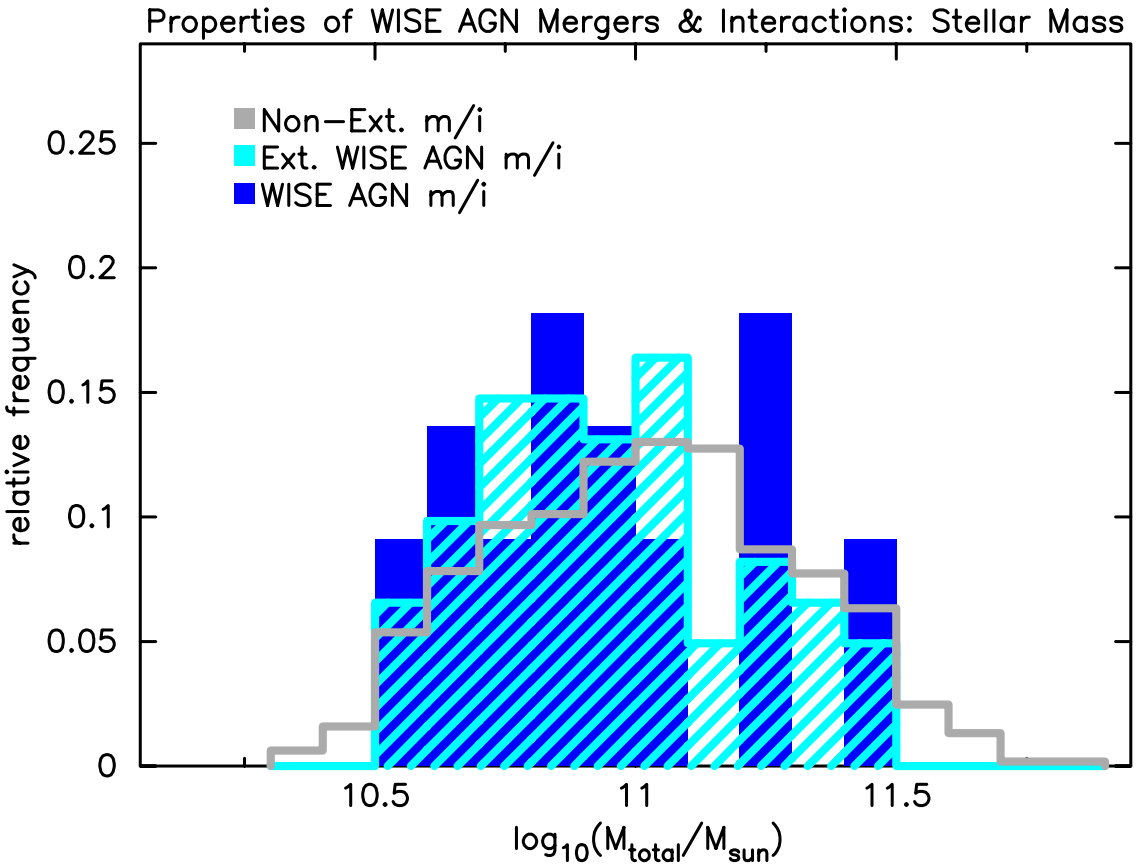
What is special about these mergers & interactions? Stellar Mass



K-S Test p-values for Stellar Mass

WISE AGN:	0.695
Extended Cut:	0.127

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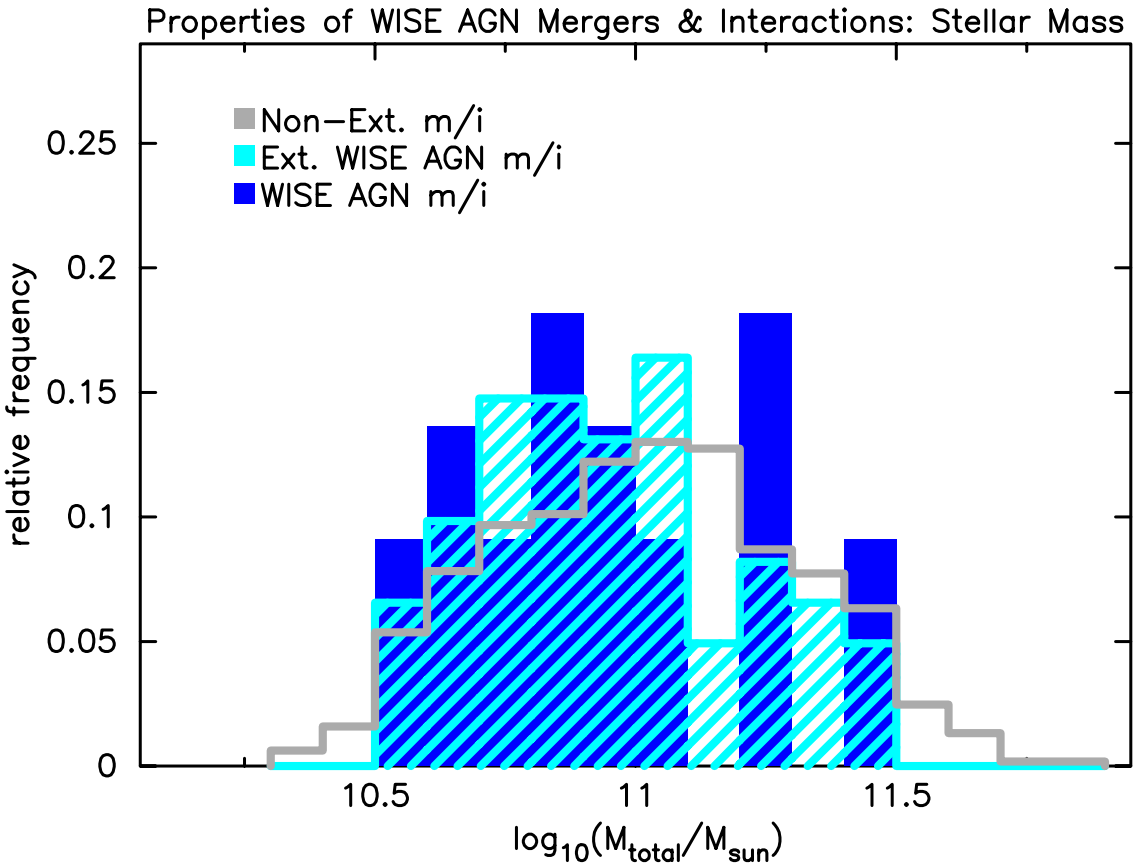
What is special about these mergers & interactions? Stellar Mass



K-S Test p-values for Stellar Mass

WISE AGN:	0.695
Extended Cut:	0.127

No dependence on Stellar Mass

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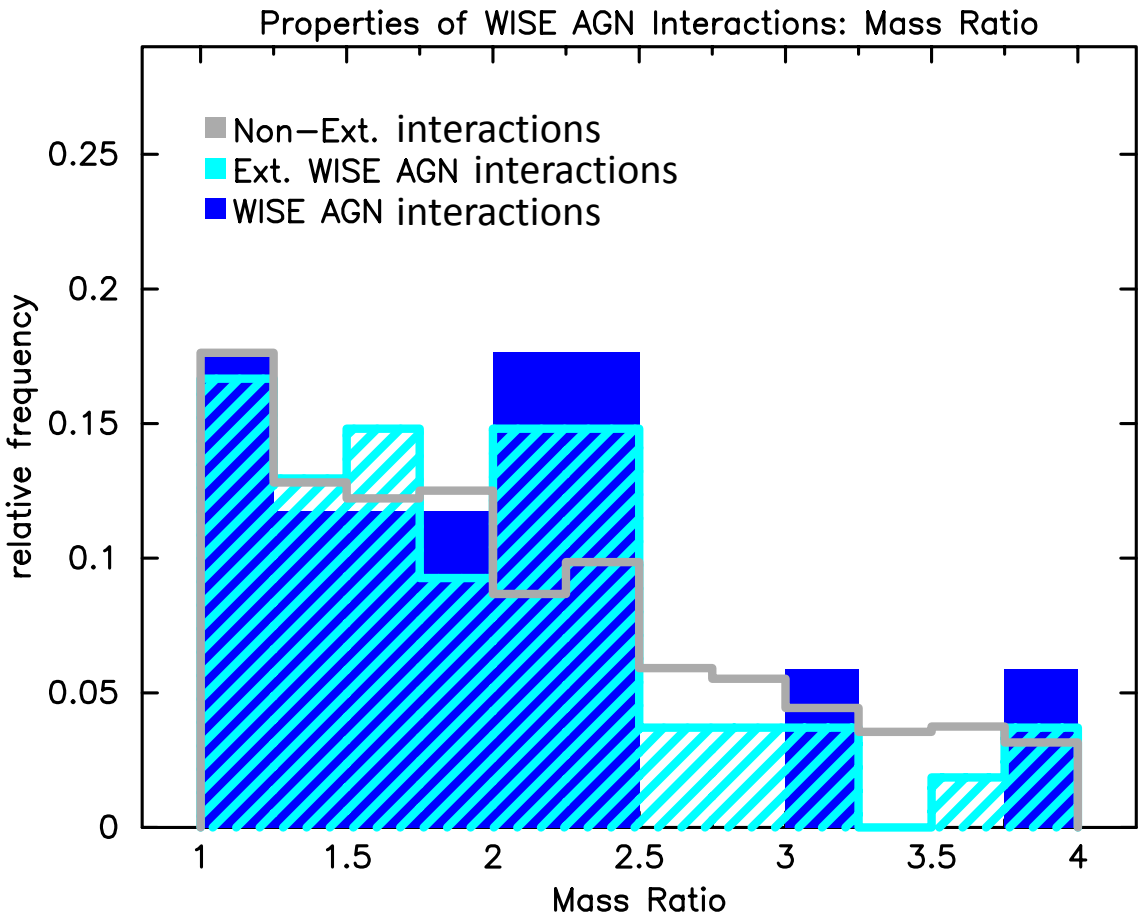
What is special about these mergers & interactions?
Mass Ratio of Interactions



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

WISE AGN:	0.913
Extended Cut:	0.489

Weston et al. (in prep)

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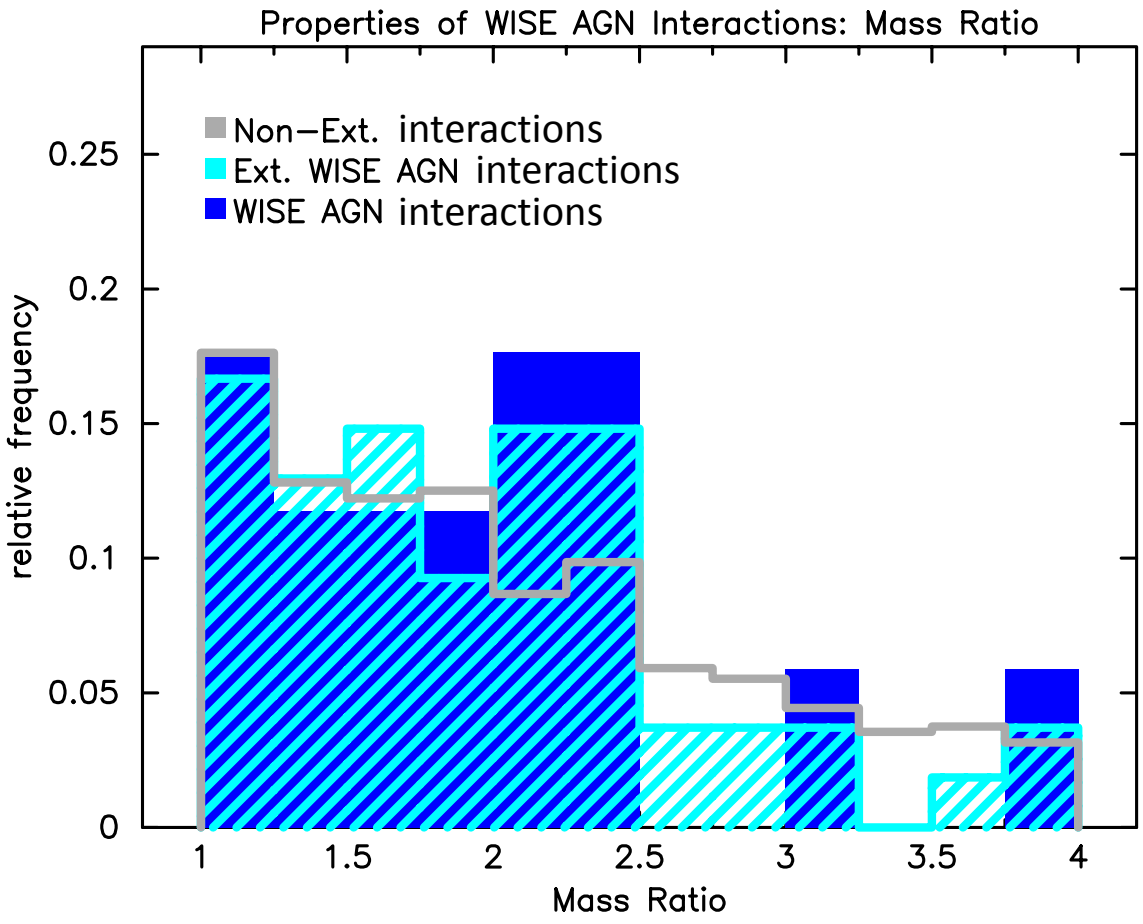
What is special about these mergers & interactions?
Mass Ratio of Interactions



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

WISE AGN:	0.913
Extended Cut:	0.489

No dependence on Mass Ratio

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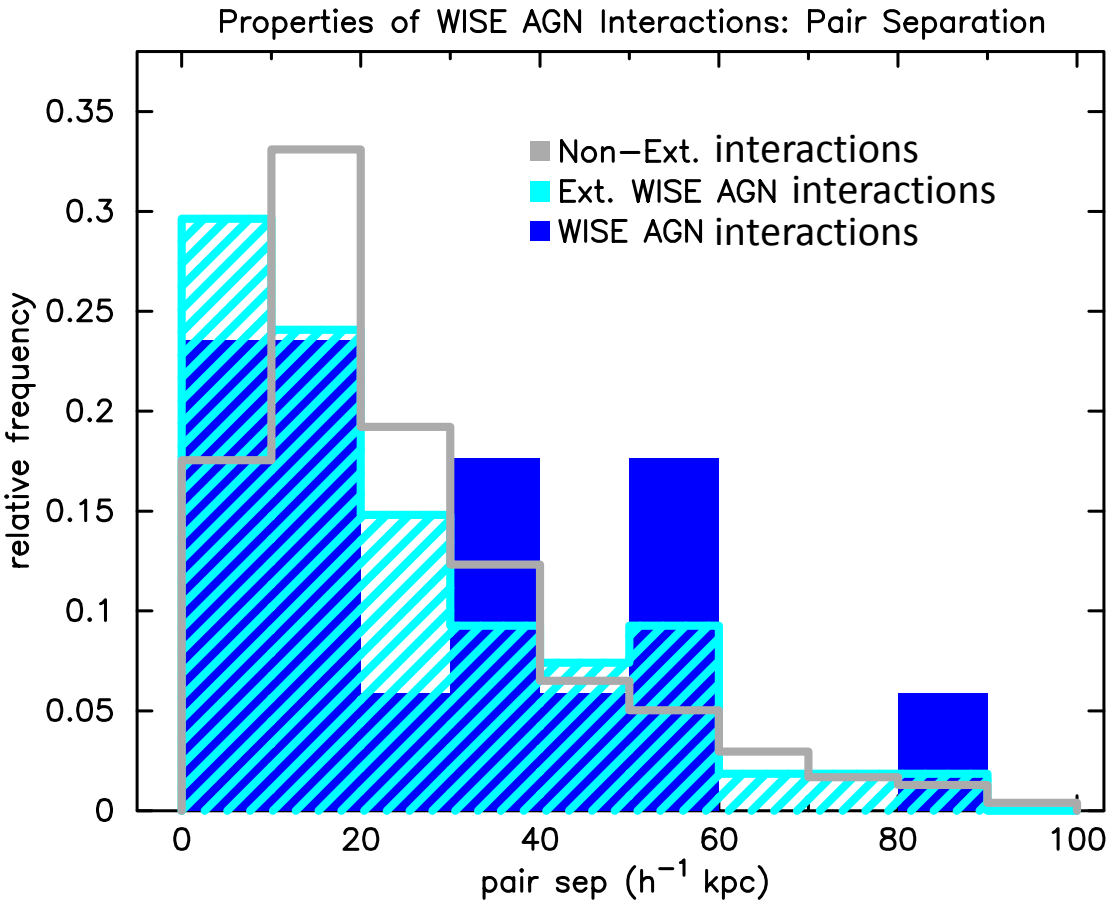
What is special about these mergers & interactions?
Pair Separation of Interactions



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

WISE AGN:	0.063
Extended Cut:	0.031

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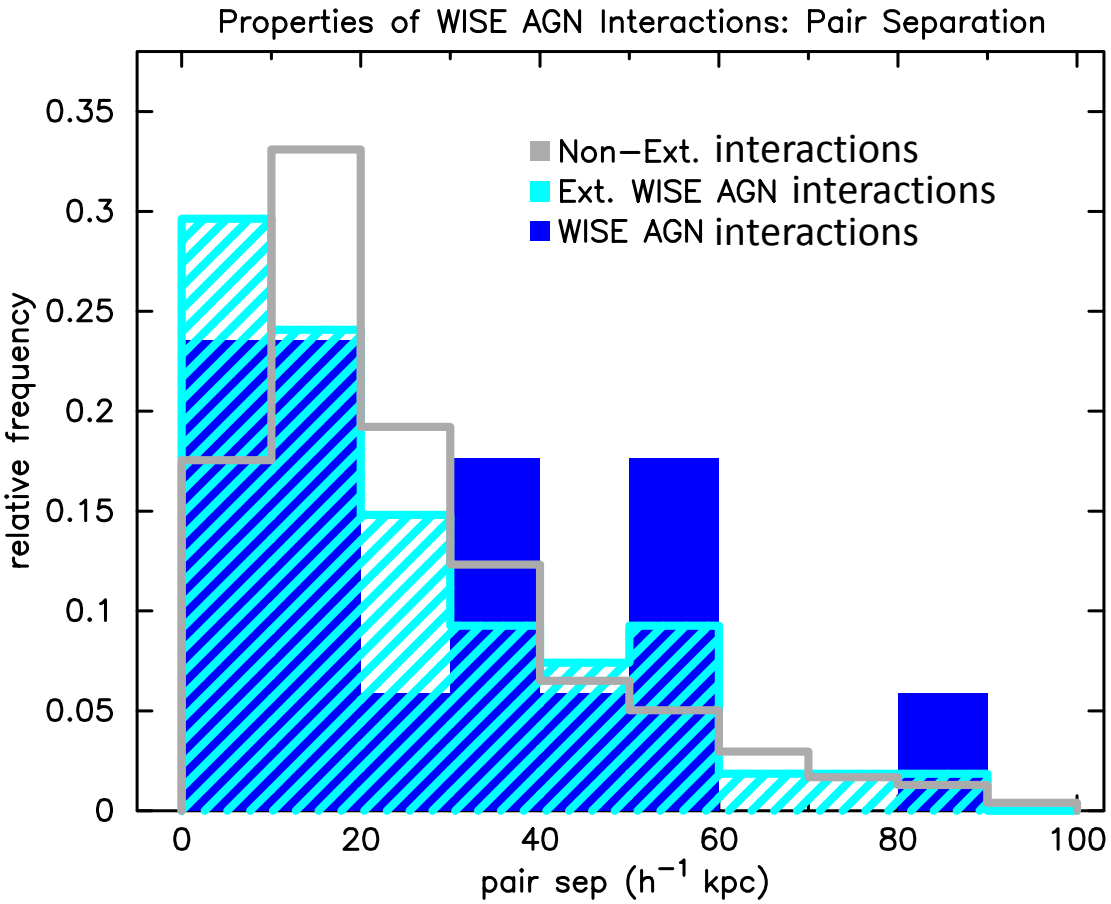
What is special about these mergers & interactions?
Pair Separation of Interactions



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

WISE AGN:	0.063
Extended Cut:	0.031

Marginal dependence on Pair Separation

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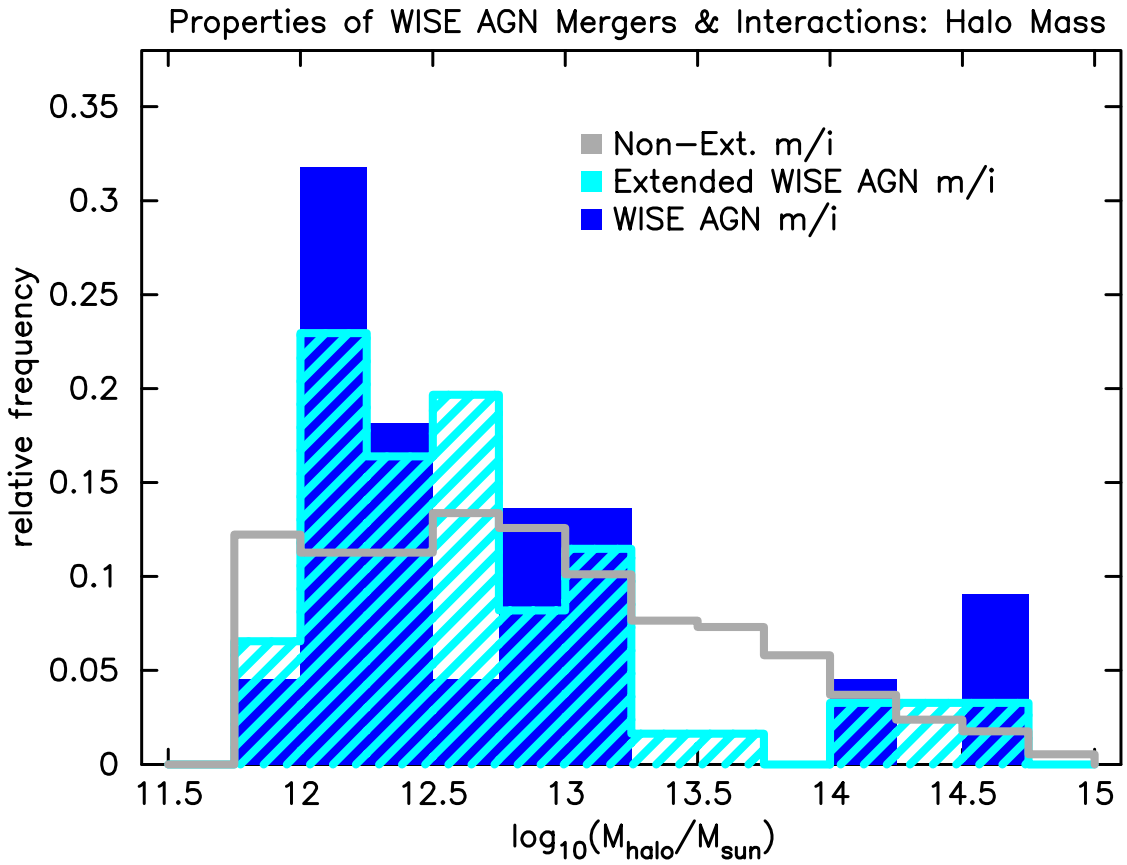
What is special about these mergers & interactions? Halo Mass



K-S Test p-values for Halo Mass

WISE AGN:	0.211
Extended Cut:	0.025

Yang et al. 2007 Group Catalog

Weston et al. (in prep)

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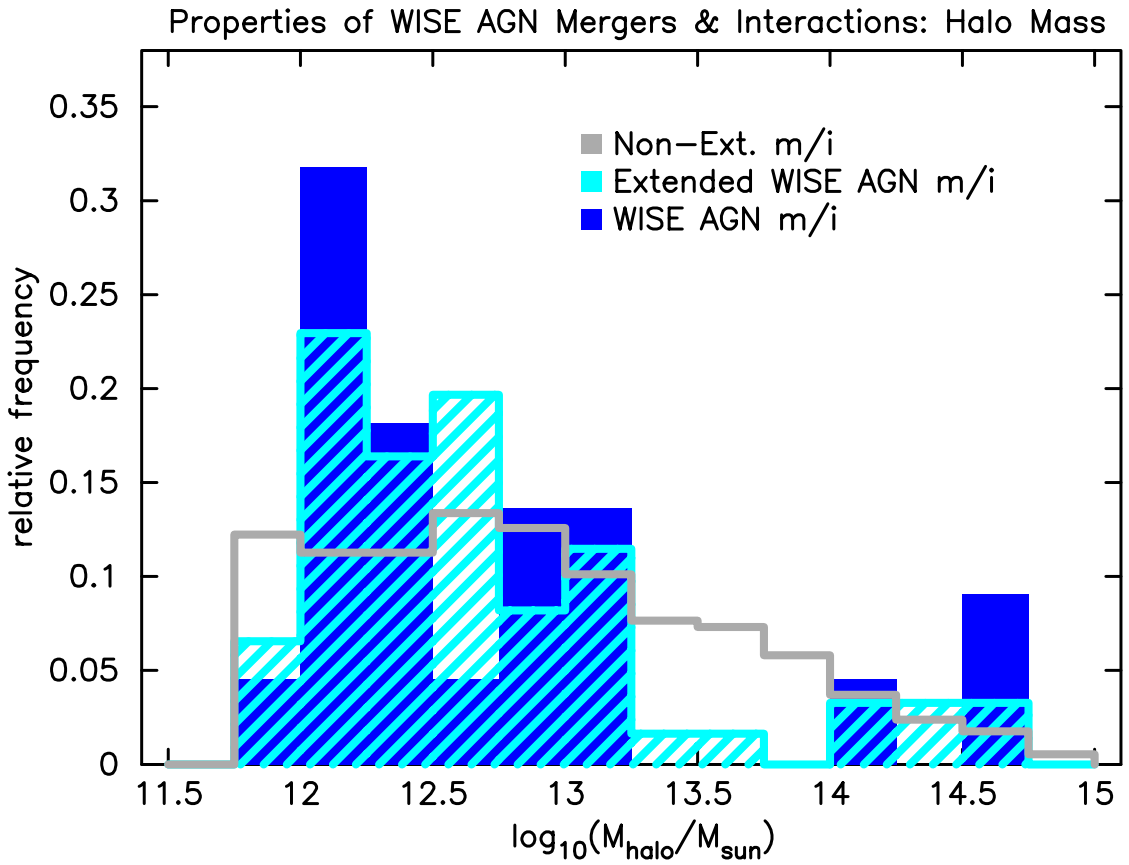
What is special about these mergers & interactions? Halo Mass



K-S Test p-values for Halo Mass

WISE AGN:	0.211
Extended Cut:	0.025

Possible dependence on Halo Mass

Weston et al. (in prep)

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

No dependence on Halo Location

Yang et al. 2007 Group Catalog

Weston et al. (in prep)

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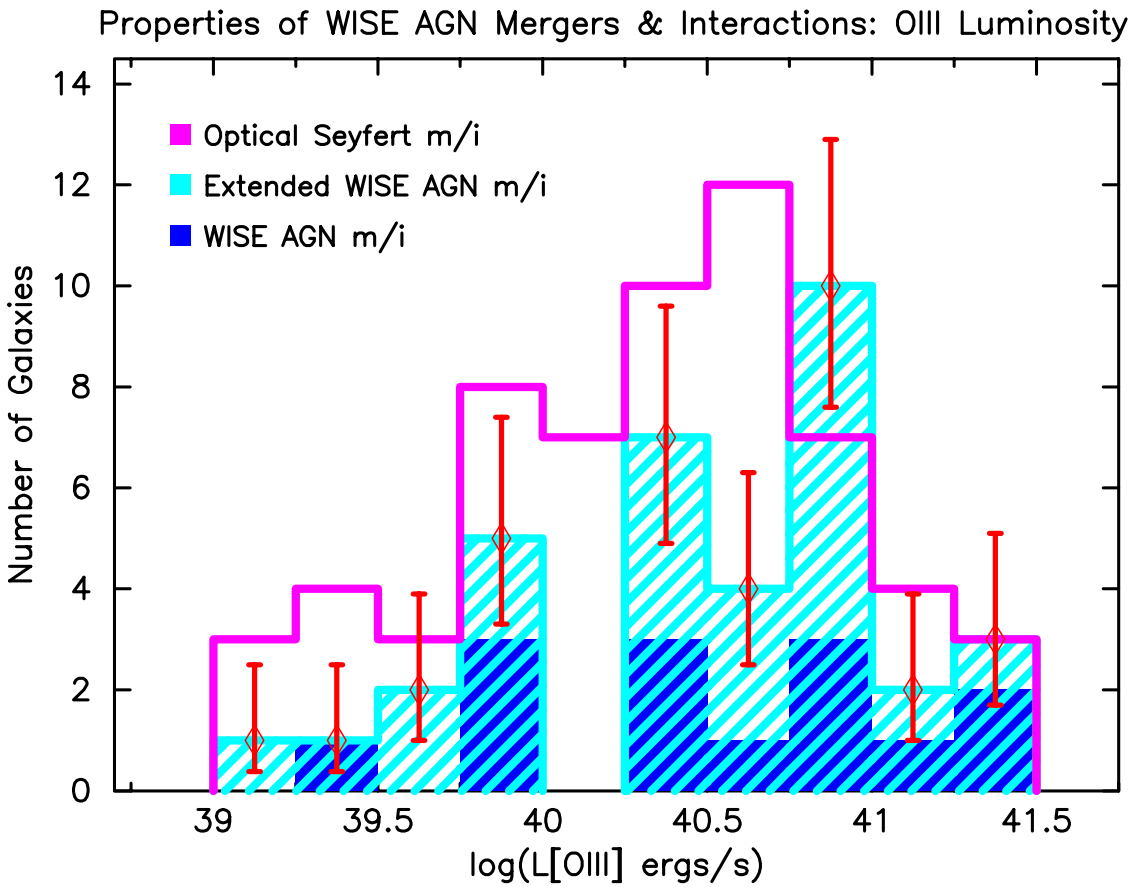
What is special about these mergers & interactions? AGN Power



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

WISE AGN:	0.280
Extended Cut:	0.180

Weston et al. (in prep)

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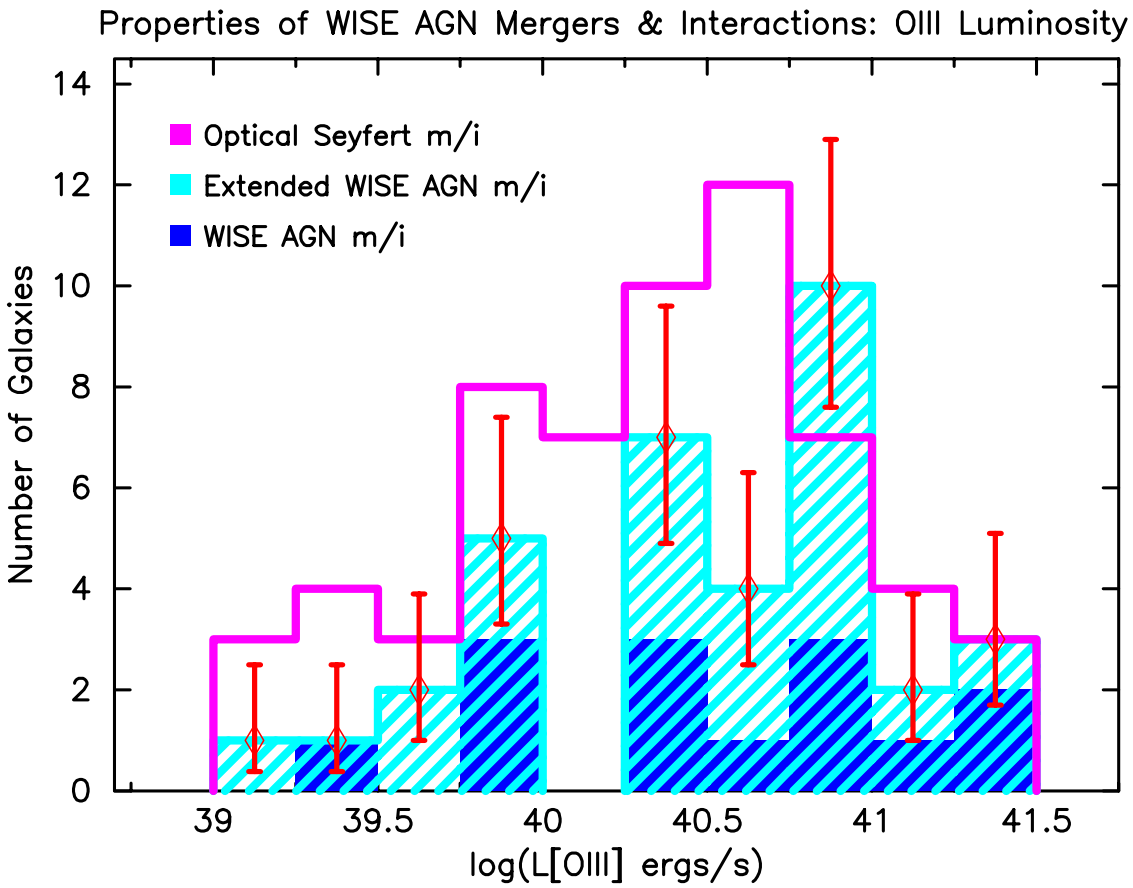
What is special about these mergers & interactions? AGN Power



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

Weston et al. (in prep)

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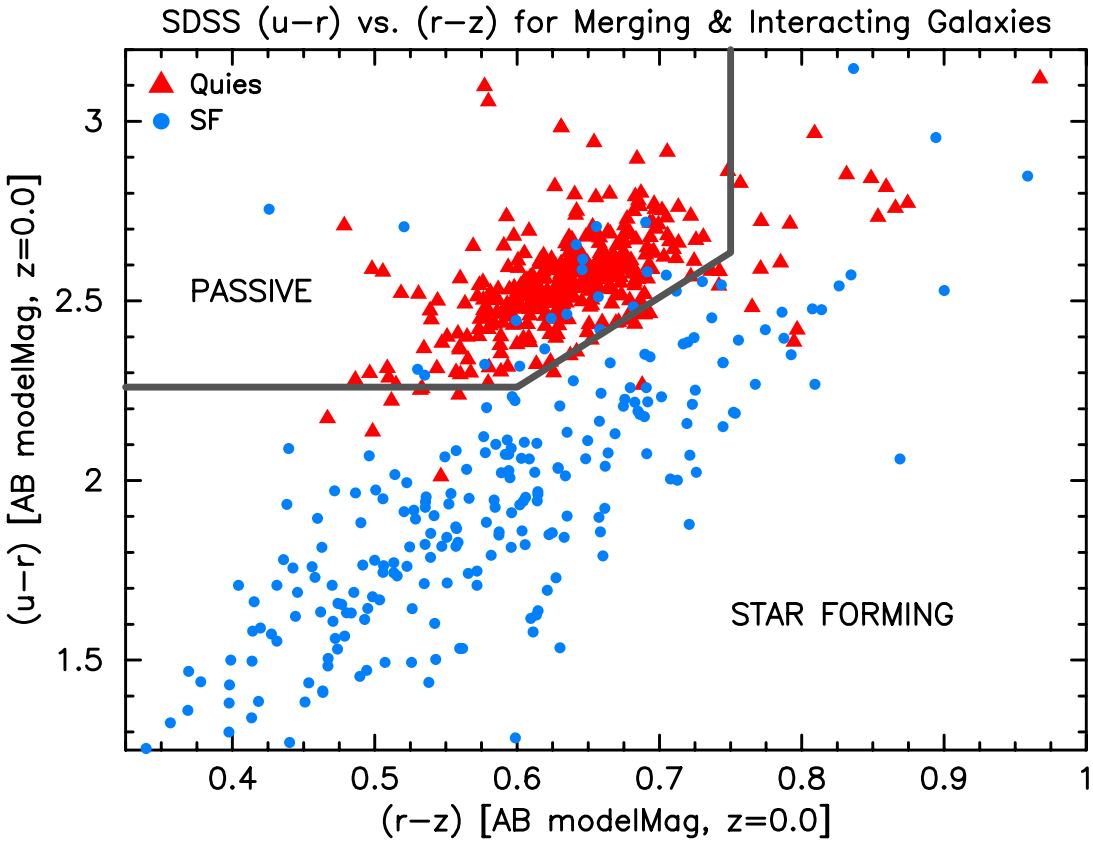
What is special about these mergers & interactions? Star Formation



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

Holden et al. 2012

Weston et al. (in prep)

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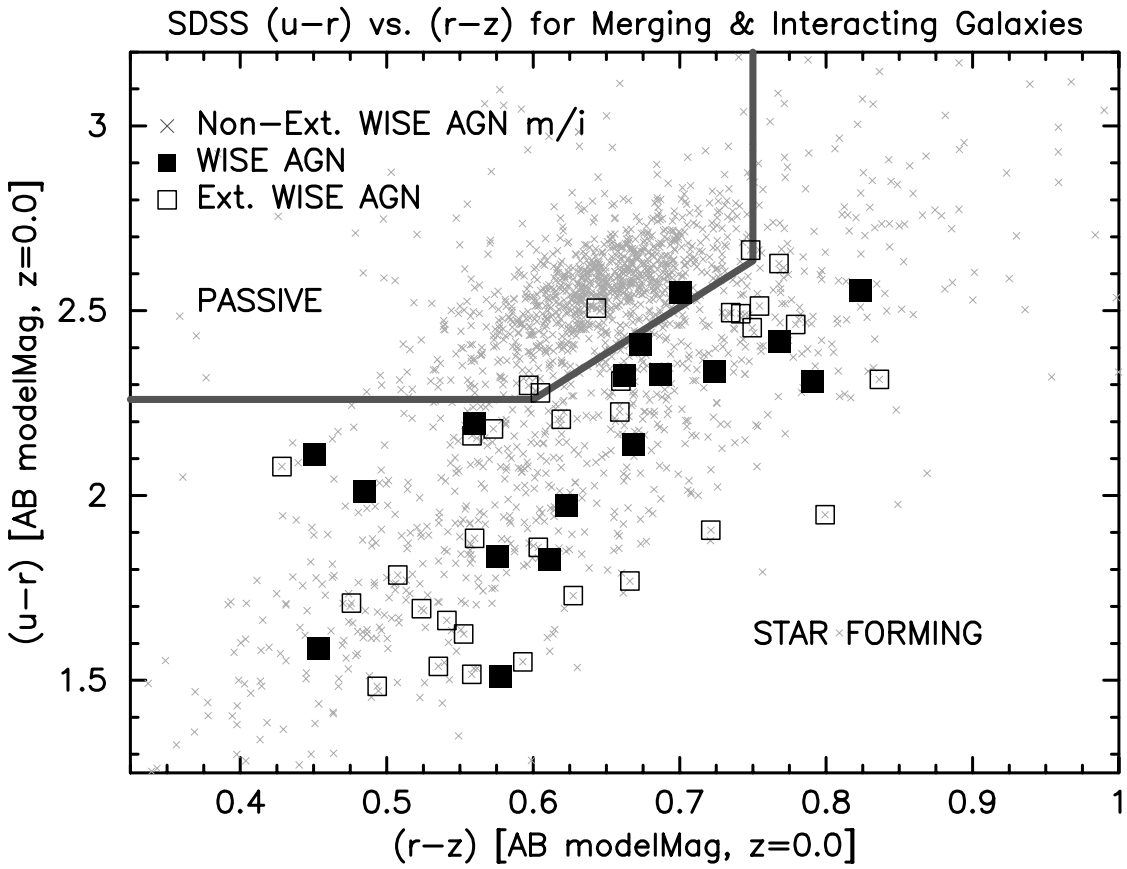

Percent of SF Galaxies

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

Weston et al. (in prep)

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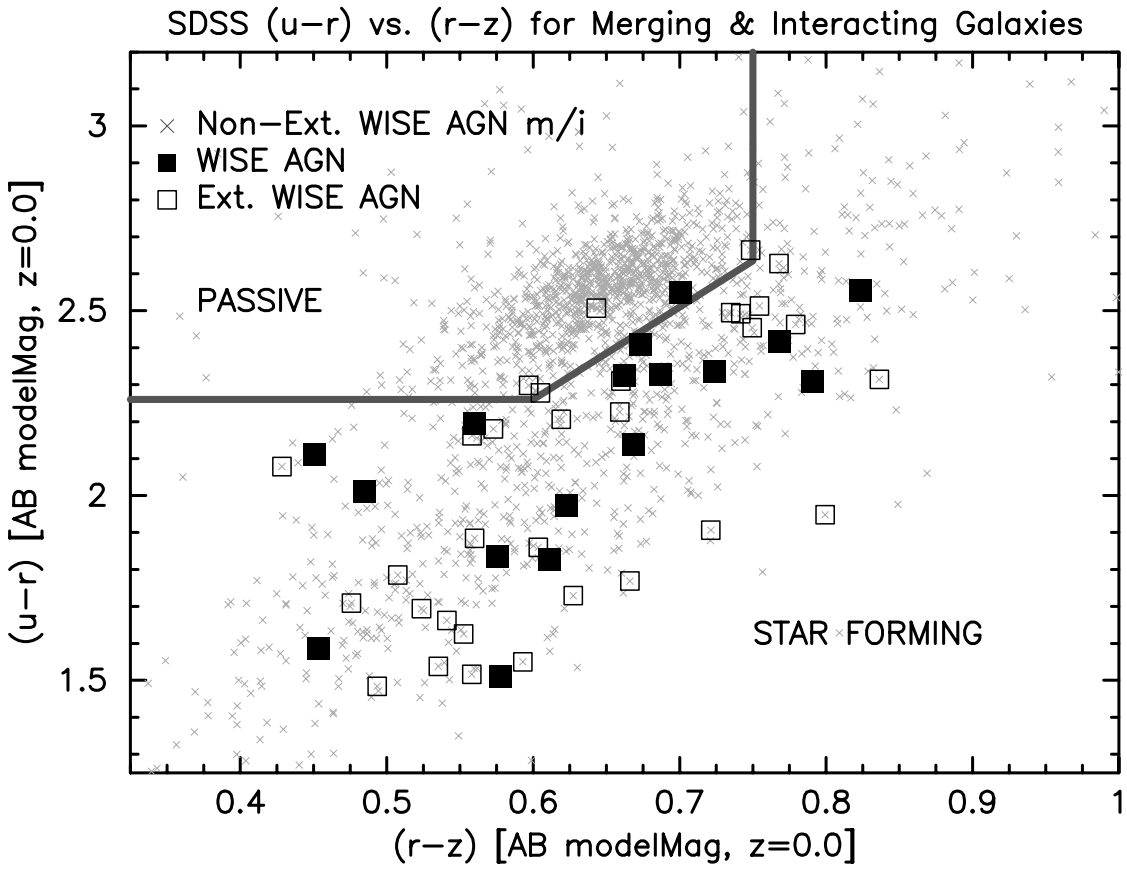

Percent of SF Galaxies	
Non-Ext. m/i:	57%
WISE AGN:	94%
Extended Cut:	90%

There is a correlation between WISE AGN and SF

Weston et al. (in prep)

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Dusty AGN & SF

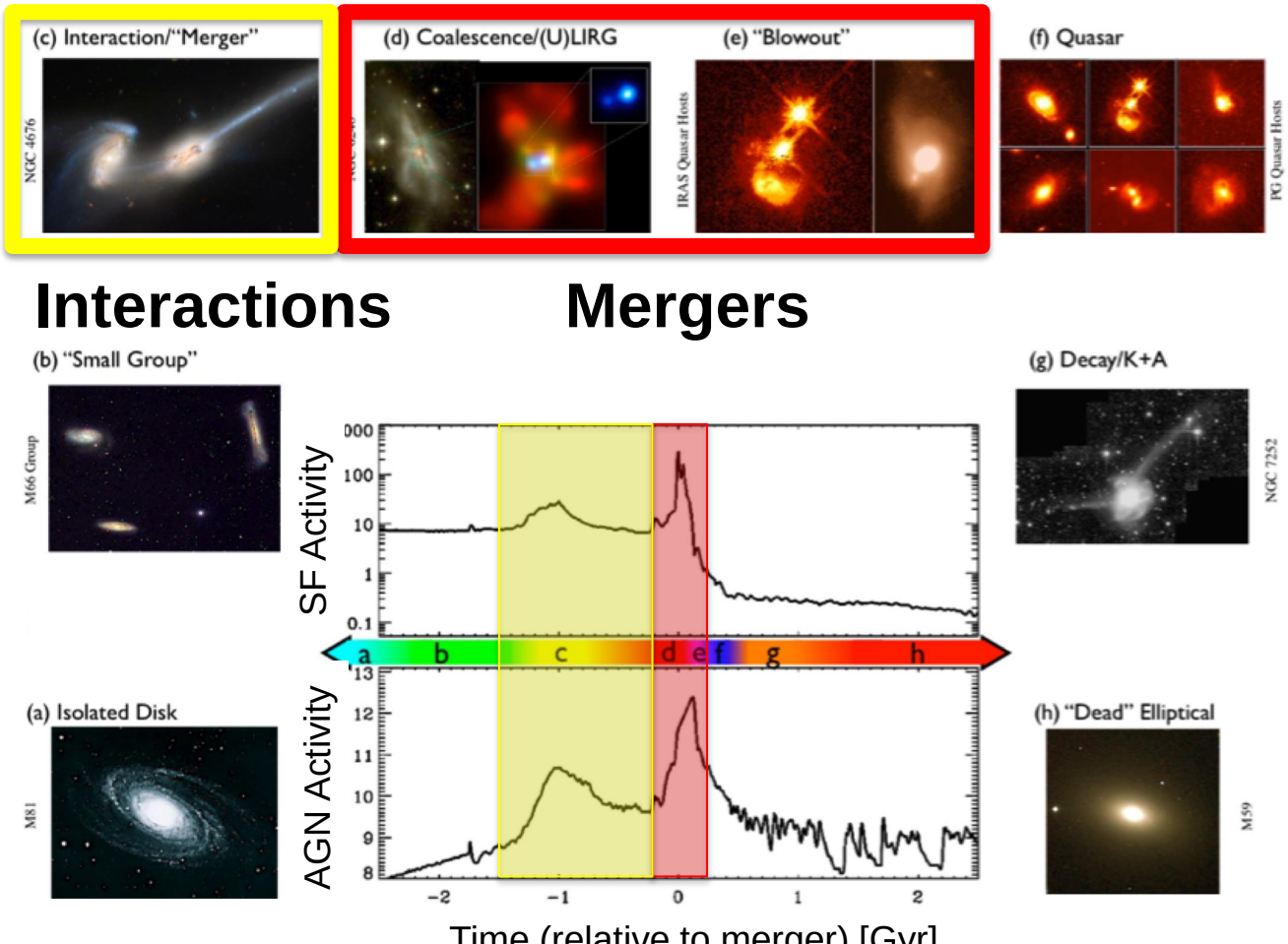

Image Credit: Hopkins, et al., NOAO/AURA/NSF

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

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