L. Kewley

Extreme Starbursts in Merging Galaxies

I present new results from our large multiwavelength survey of nearby infrared merging galaxies. We show that metallicity gradients in galaxy pairs provide a "smoking gun" for large-scale gas inflows in merging galaxies and are intricately connected to extreme central bursts of star formation. At first close pass, gas inflows dramatically flatten metallicity gradients which do not recover until very late merger stages. We use optical, infrared and X-ray diagnostics to investigate the evolution of starburst and AGN activity as a function of merger progress. We show that the galaxies form a clear merger sequence where fuel boths starburst and AGN are fueled, and where the AGN becomes increasingly dominant during the final merger stages of the most luminous IR objects. Our results indicate that identification of the "diffuse merger" stage is critical for understanding the connection (if any) between starburst and AGN activity. In this stage, extreme starburst and AGN activity co-exist, yet the presence of compact radio cores indicative of AGN disappears. We discuss these results in terms of thermal free free absorption caused by large amounts of merger driven gas inflows.

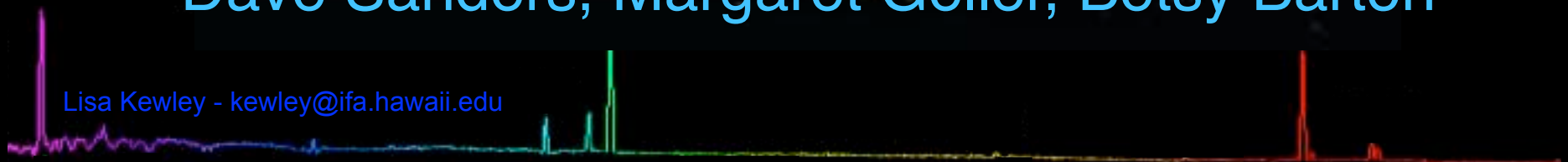
Extreme Starbursts and galaxy mergers

Lisa Kewley

U. Hawaii

Tiantian Yuan, Jeff Rich, David Rupke

Dave Sanders, Margaret Geller, Betsy Barton



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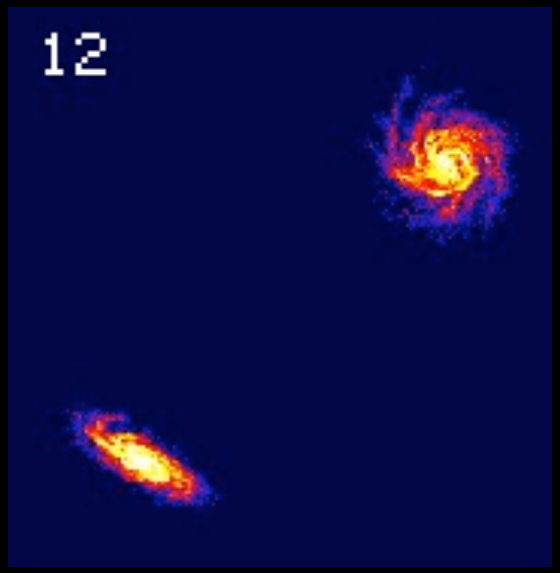
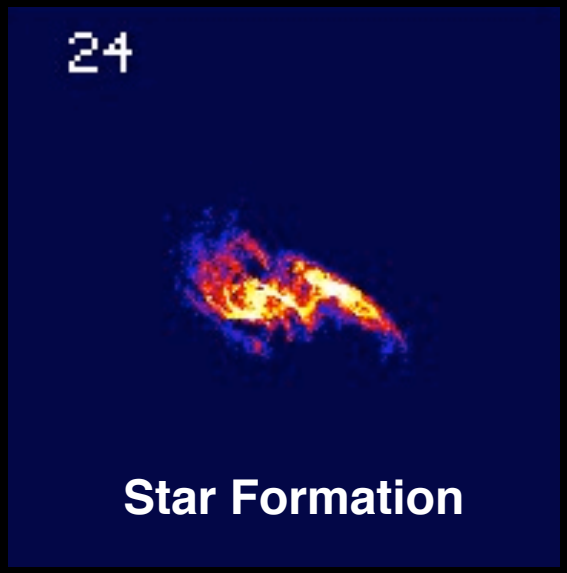
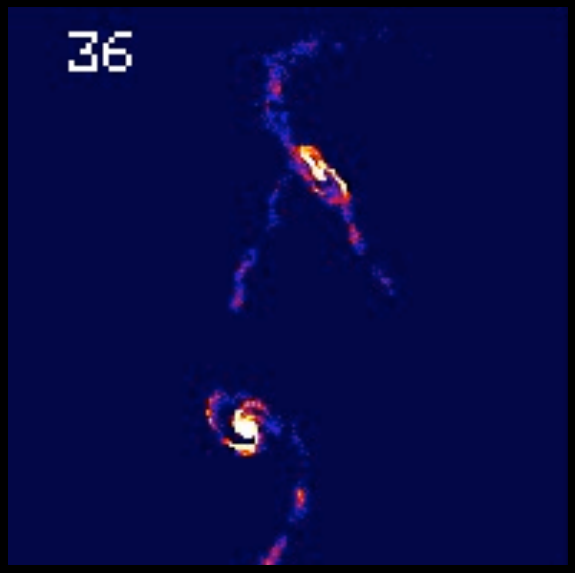
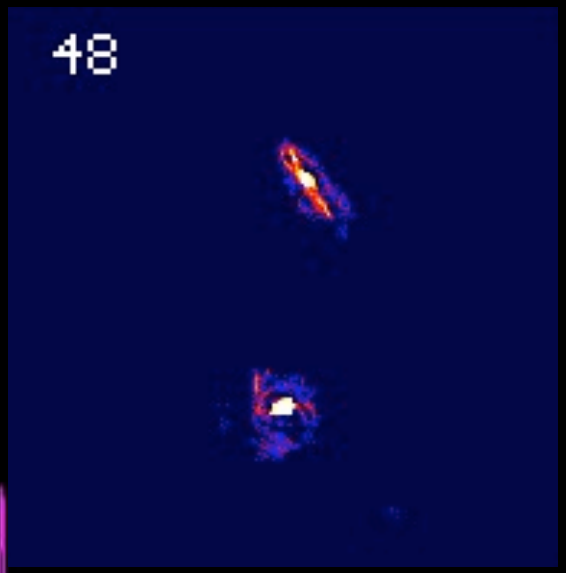
Merger Scenario

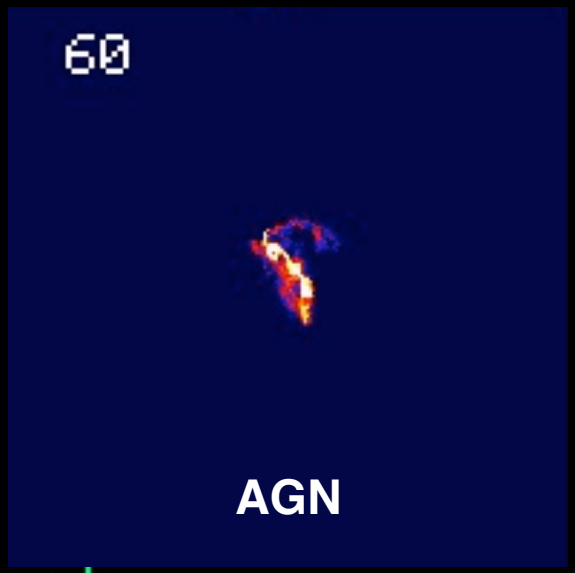
e.g., Sanders & Mirabel (1996)
Barnes & Hernquist (1996)











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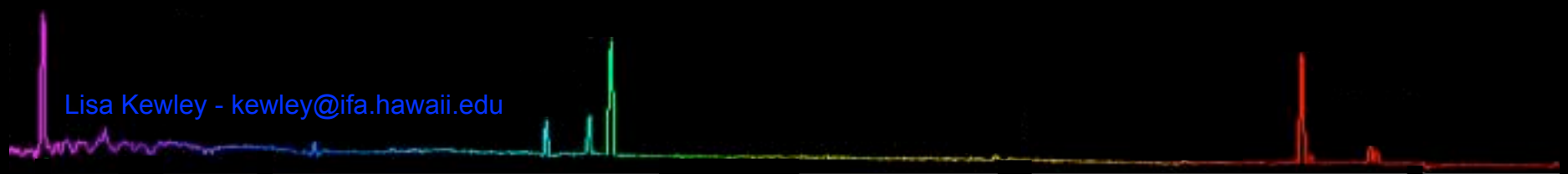
Images Courtesy Chris Mihos

Outstanding Questions

- Do such large-scale gas flows occur?
- Is the Sanders merger scenario correct?
- Connection between starbursts & AGN?



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Galaxy Pairs

Luminosity-metallicity Relation

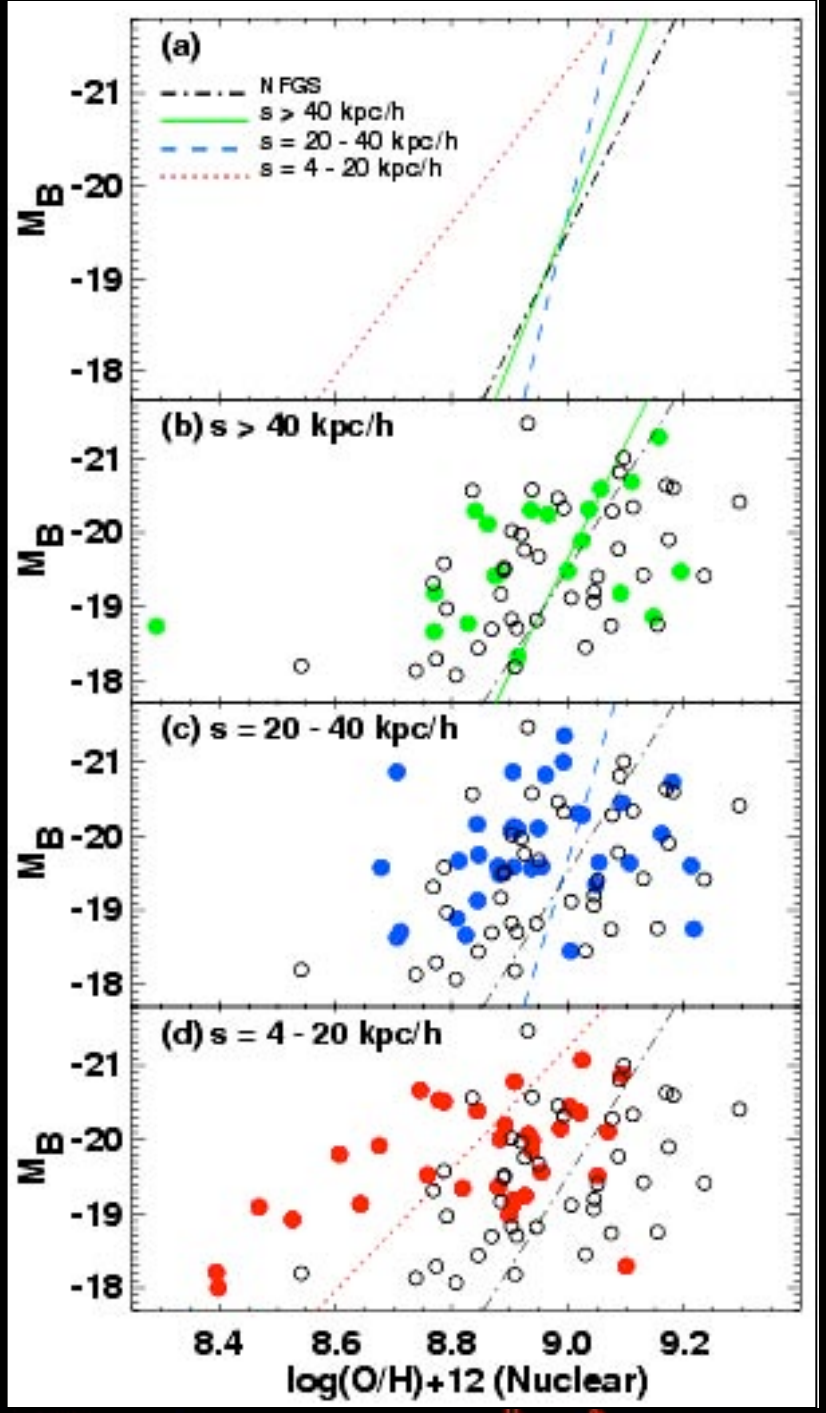
1. shifts for close pairs
2. correlated with central burst

   strength

⇩

Evidence for Gas Infall

Kewley, Geller, & Barton (2006, AJ, 131, 2004)



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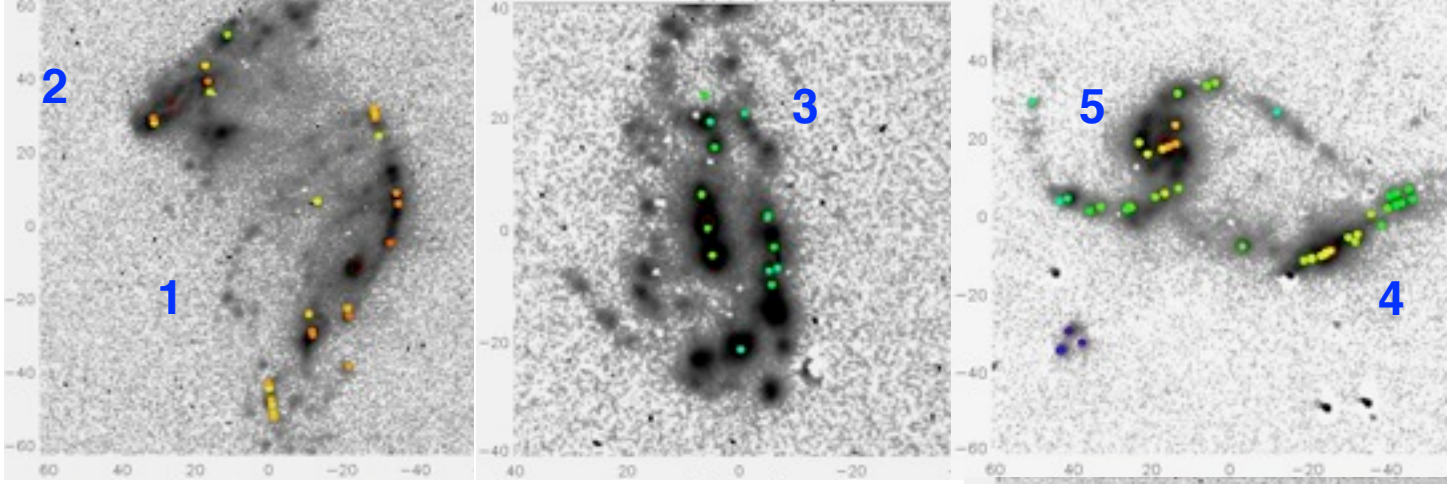
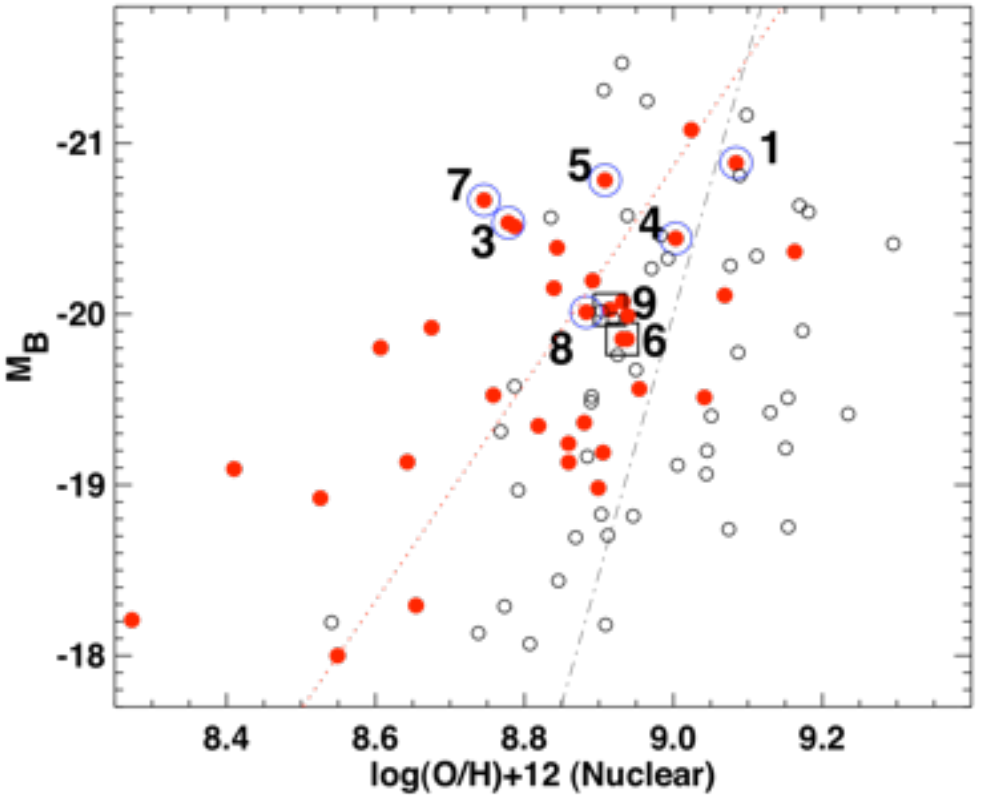
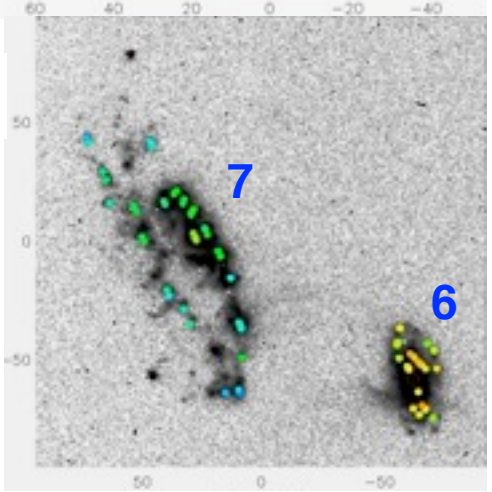
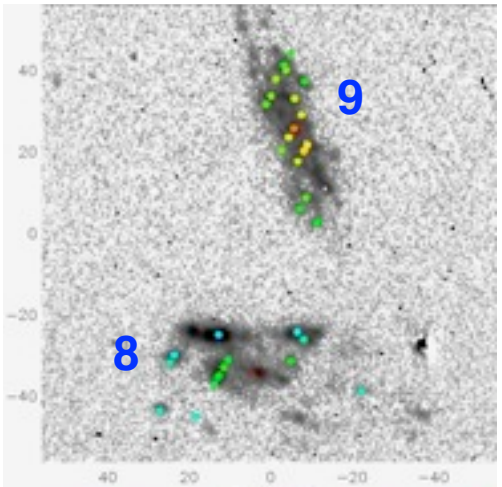






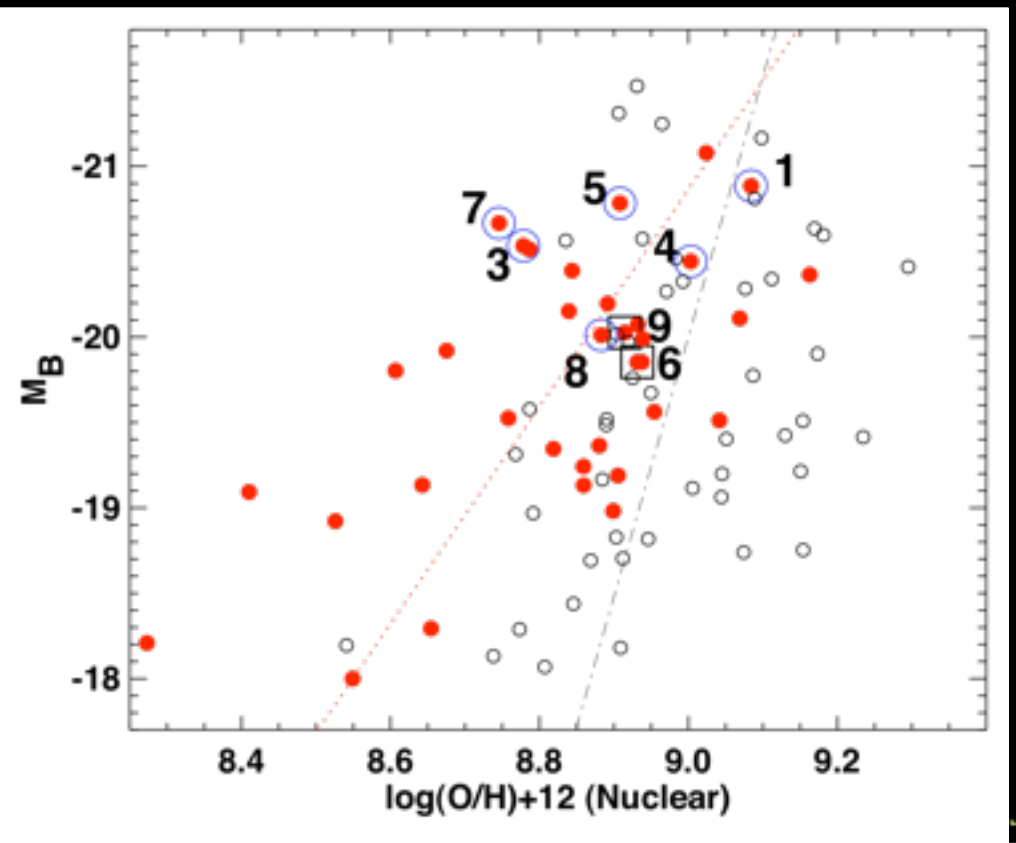


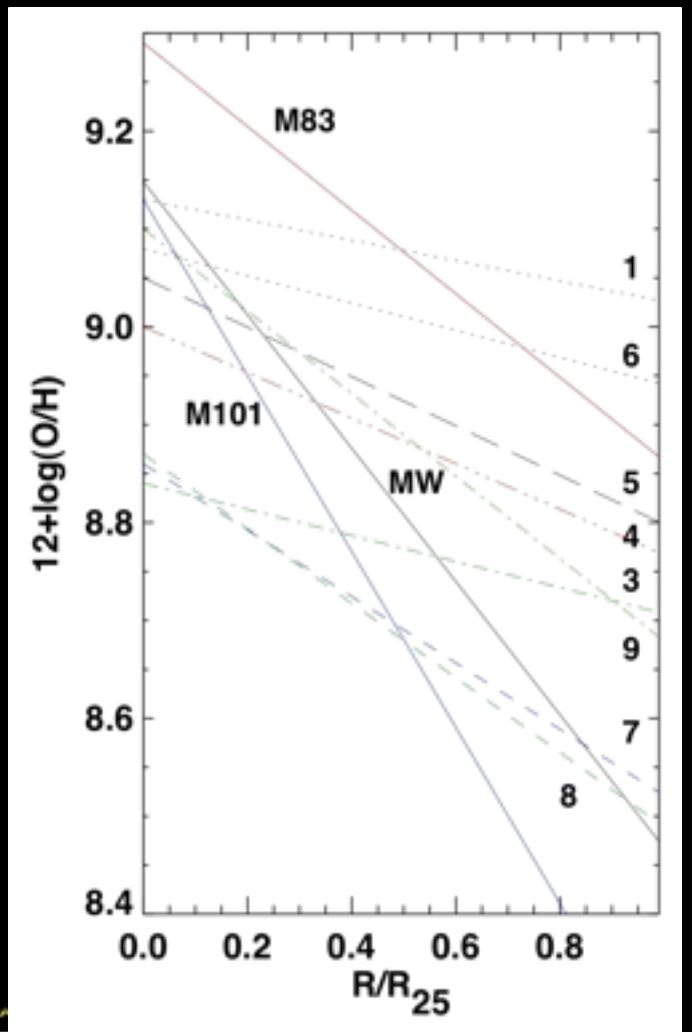
Kewley et al. (2010, ApJL, submitted),

Rupke, Kewley & Barnes (2010, ApJ, submitted)

Metallicity Gradients: A Smoking Gun for large merger-driven gas inflows.

Kewley et al. (2010, ApJL, submitted)
Rupke, Kewley & Barnes (2010, ApJ, submitted)





Outstanding Questions

- Do such large-scale gas flows occur?

  Yes & can be traced with metallicity

- Is the Sanders merger scenario correct?

- Connection between starbursts & AGN?

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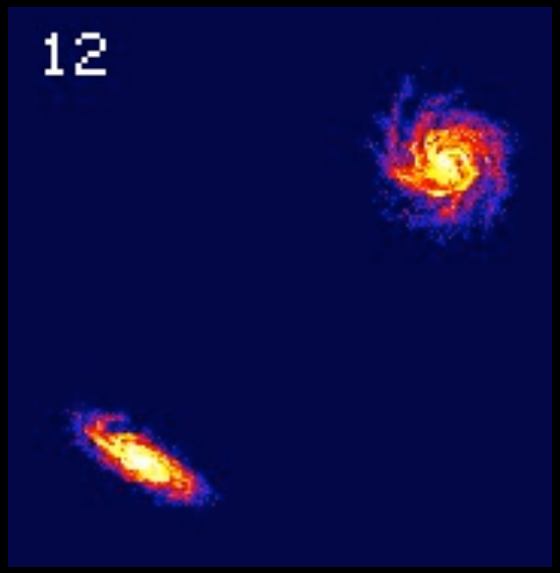
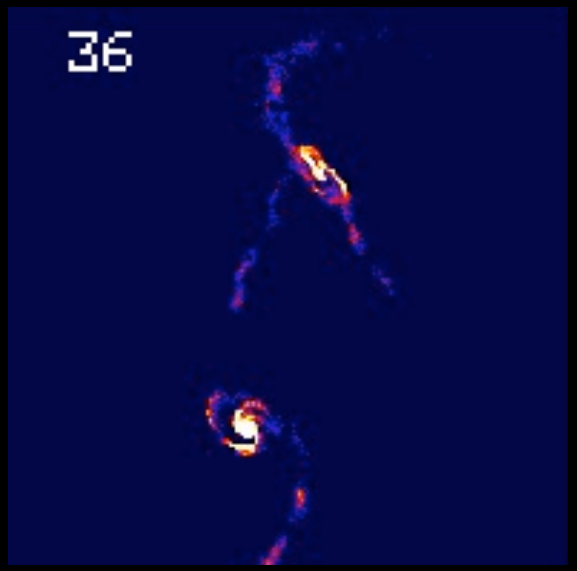
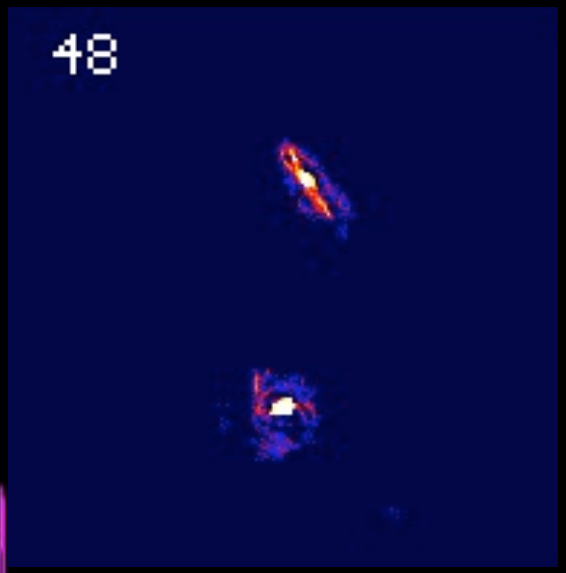
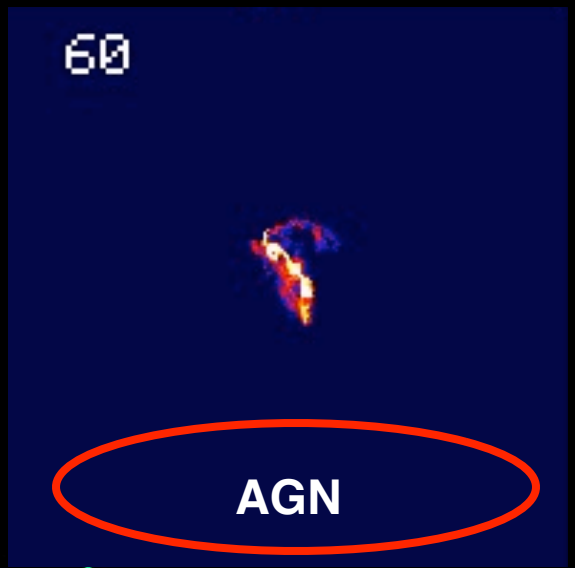
Merger Scenario

e.g., Sanders & Mirabel (1996)
Barnes & Hernquist (1996)









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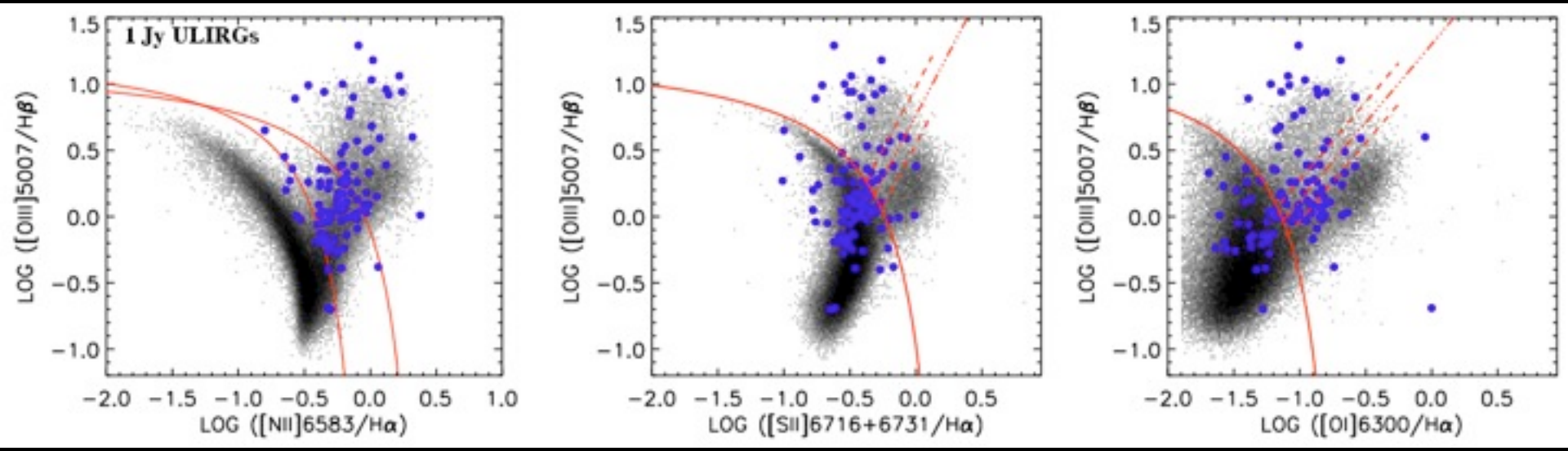
Images Courtesy Chris Mihos

Spectral Classification

ULIRGs (blue) - $L_{IR} > 10^{12} L_{sun}$



Yuan, Kewley, & Sanders (2010, ApJ, 209, 884)

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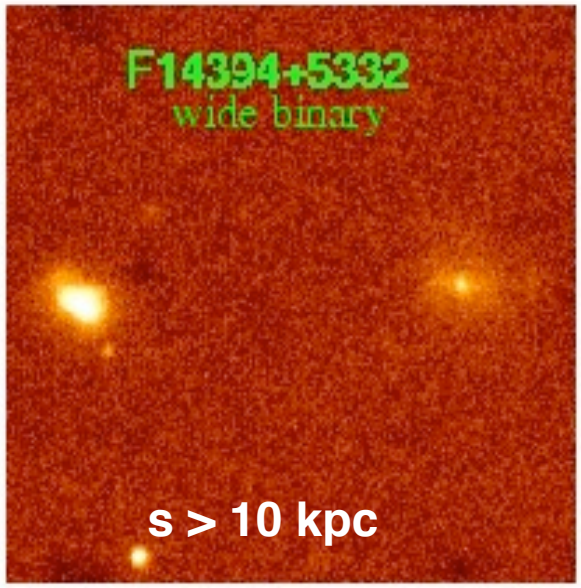
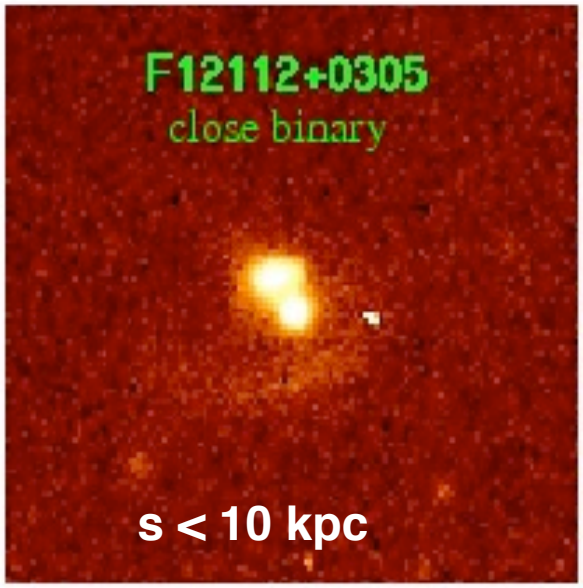
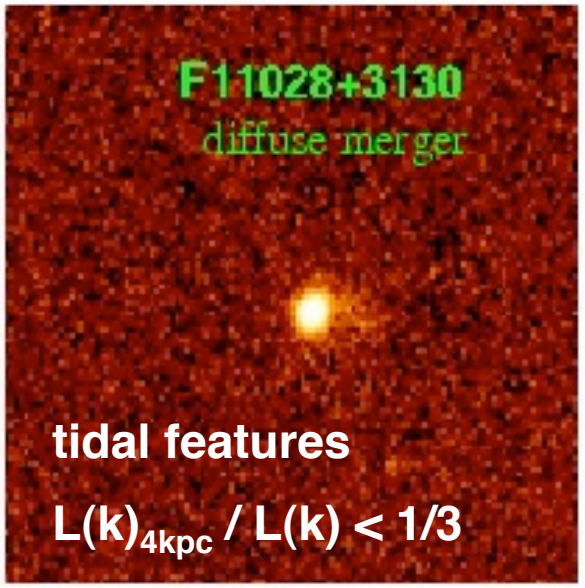
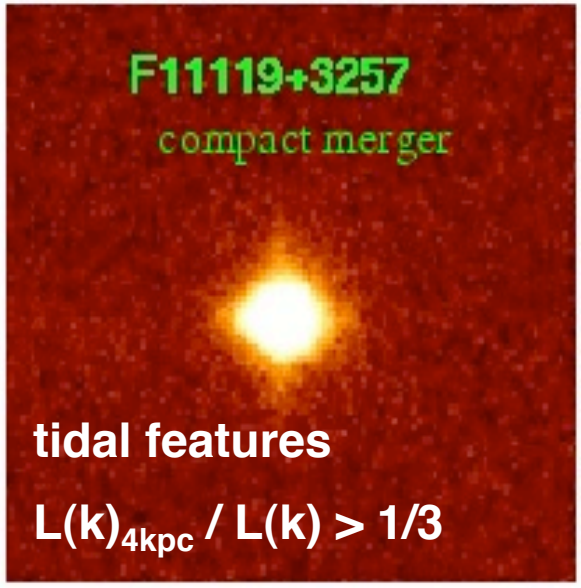
Merger Progress





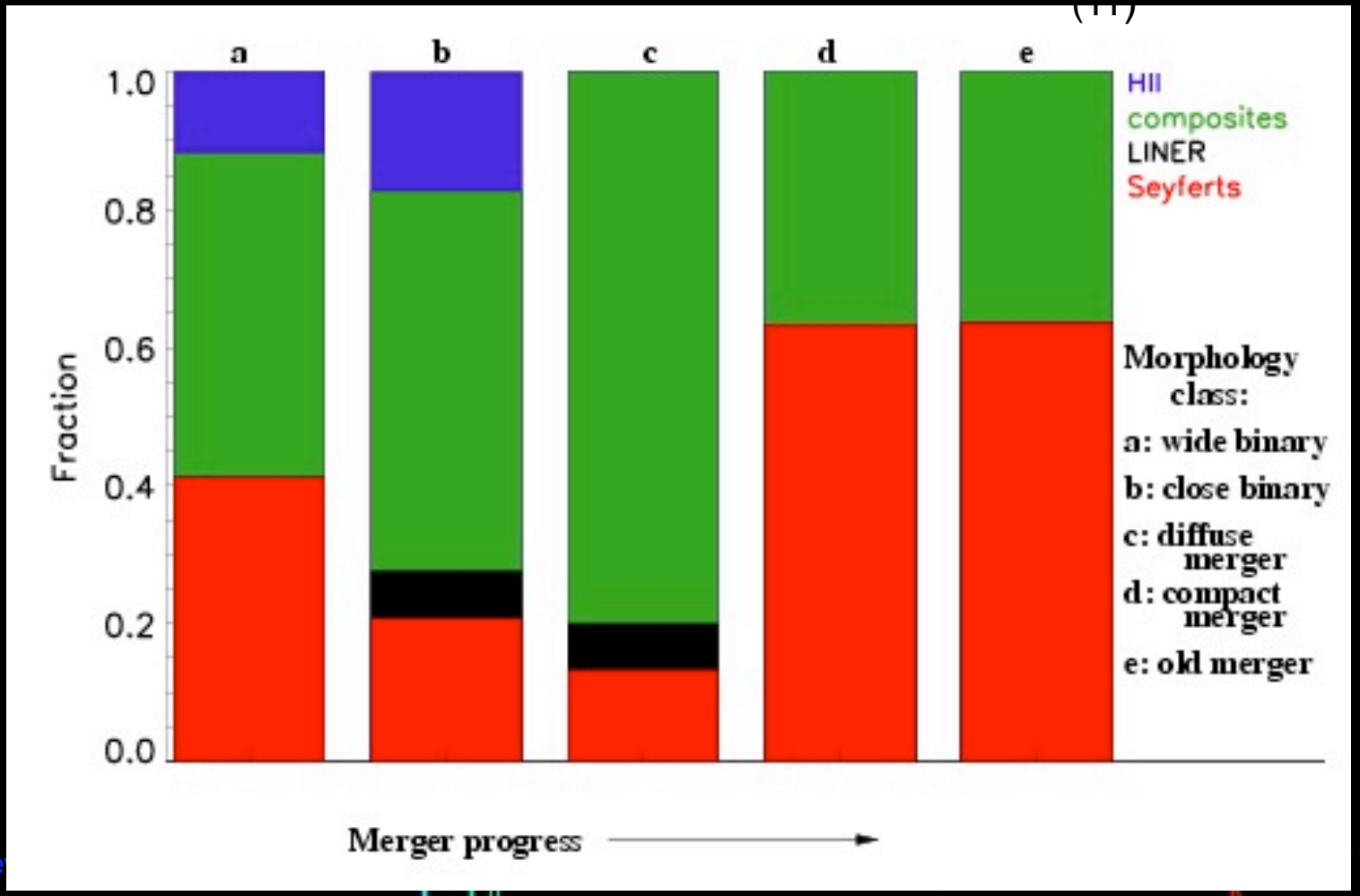




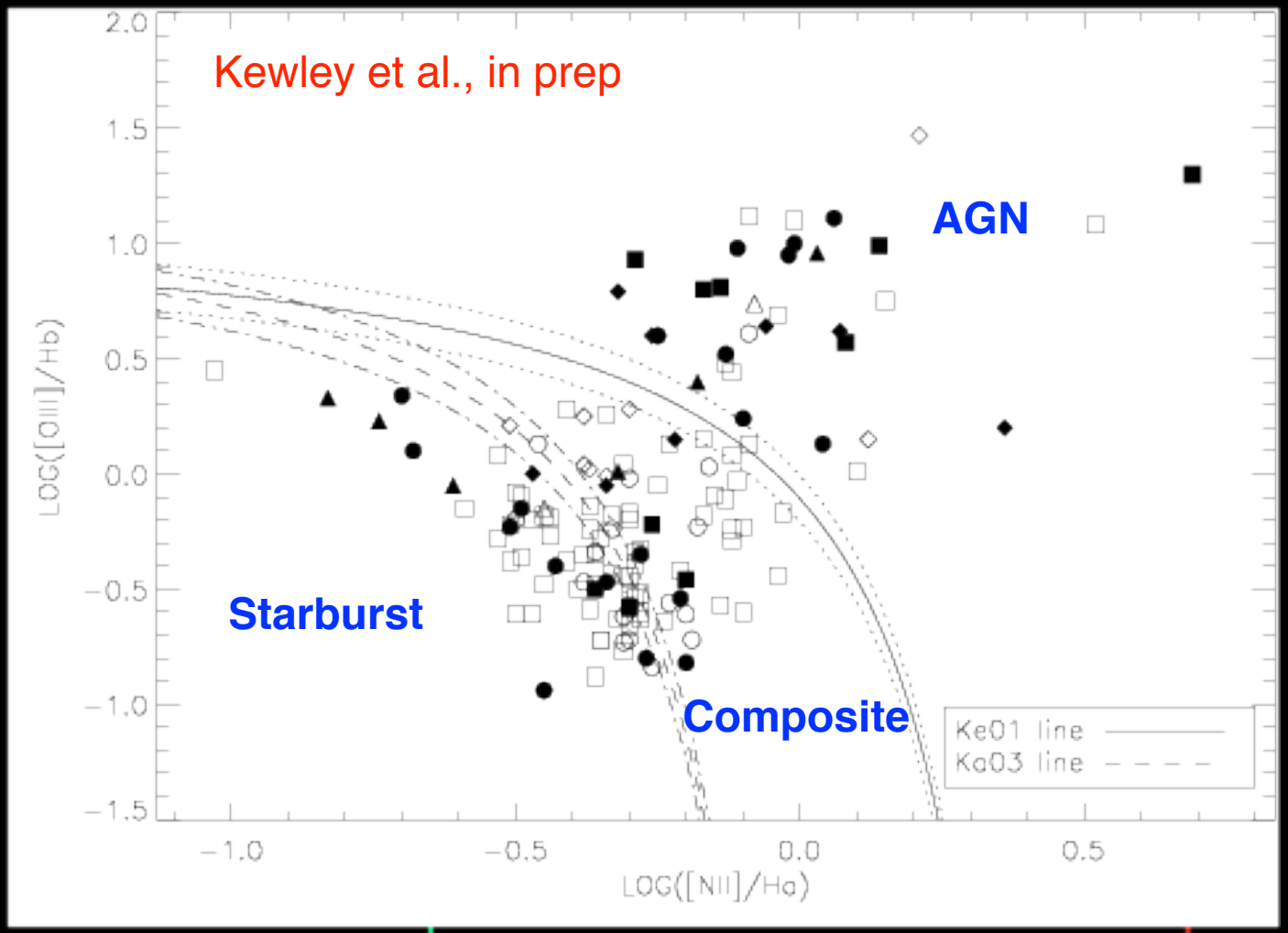
Morphological Class based on Veilleux et al. 2002

Spectral Class & Merger Progress

ULIRGs Yuan, Kewley, & Sanders (2010, ApJ, 209, 884)



Compact Radio Cores in Composites



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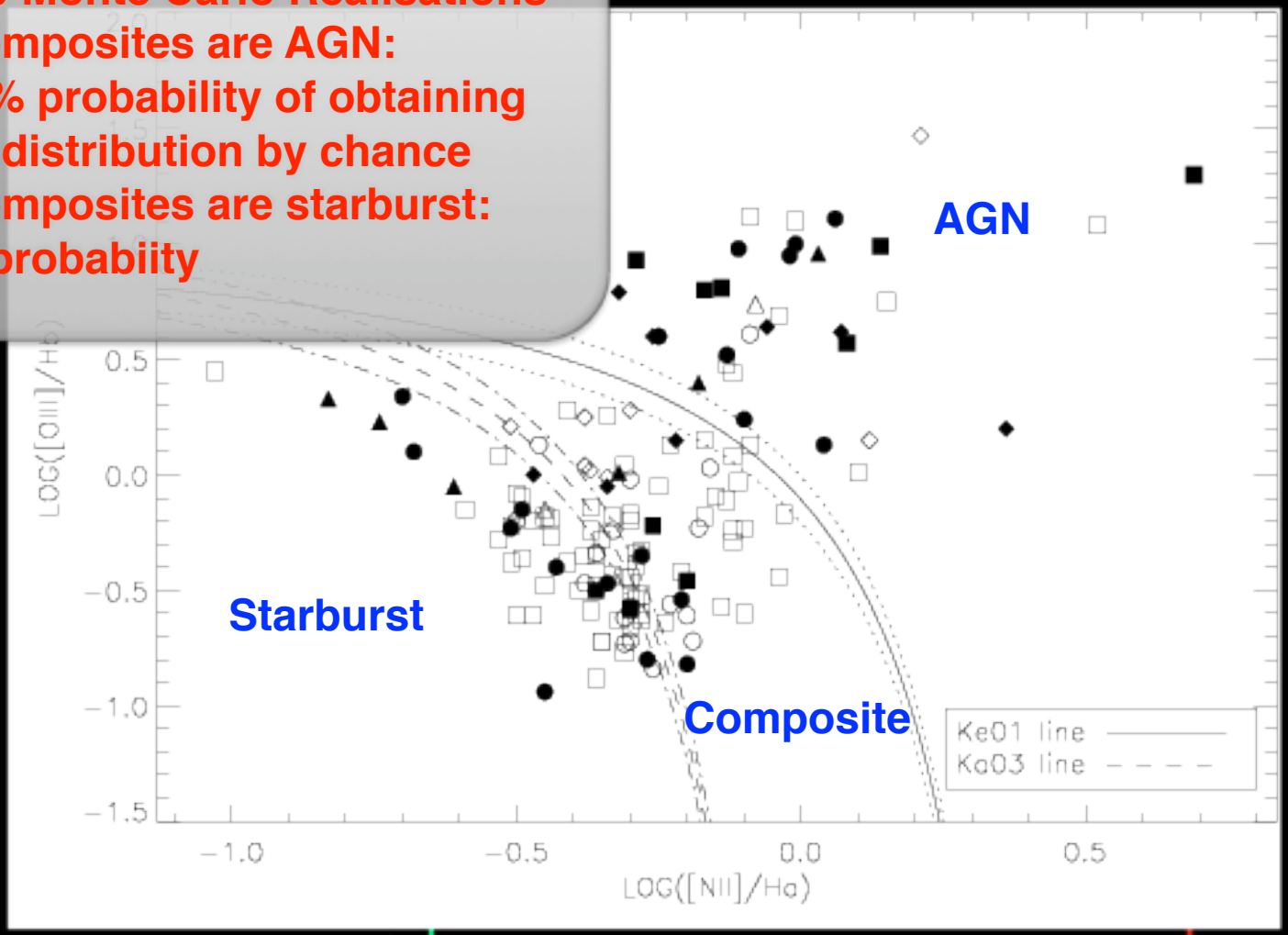
Compact Radio Cores in Composites

1000 Monte Carlo Realisations
If composites are AGN:
< 1 % probability of obtaining this distribution by chance
If composites are starburst:
7% probabiity



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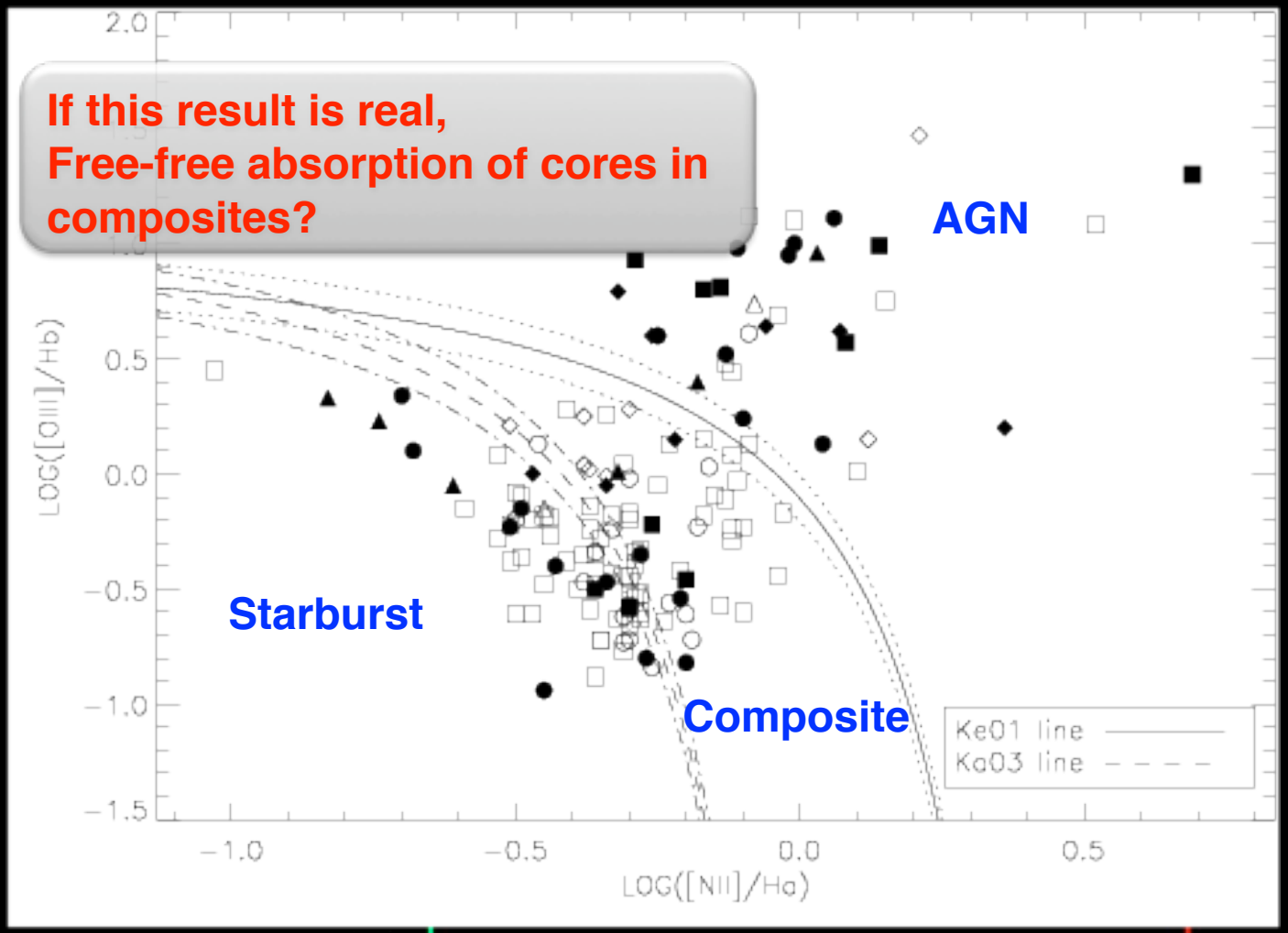
Compact Radio Cores in Composites



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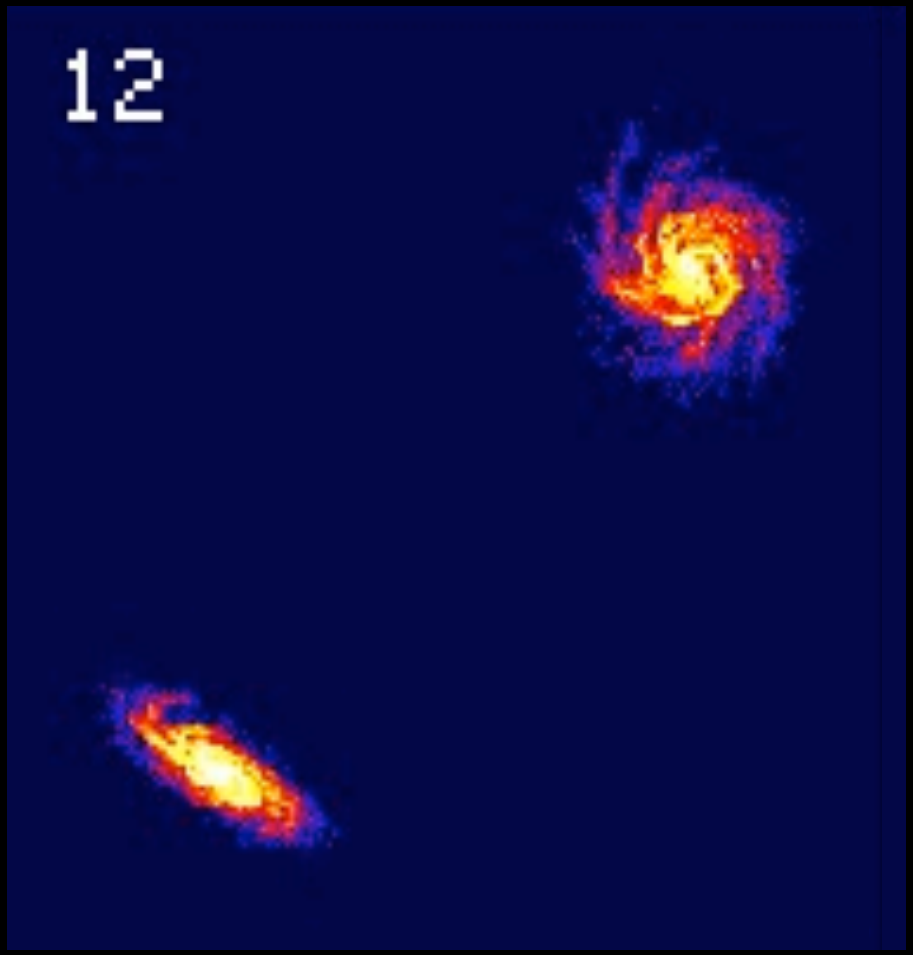
New Merger Scenario

Initial stages

AGN may be visible in some galaxies



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Images Courtesy Chris Mihos

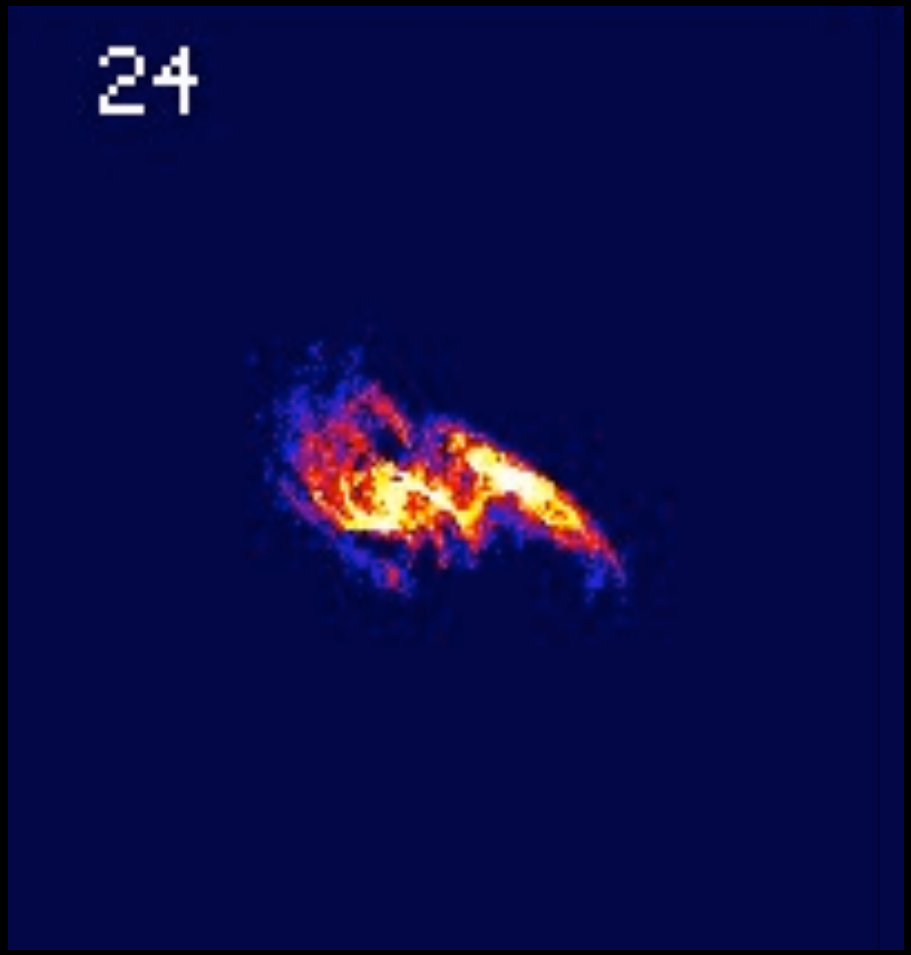
Merger Scenario

First close pass

Large gas inflows

Starburst triggered

Metallicity gradient disrupted



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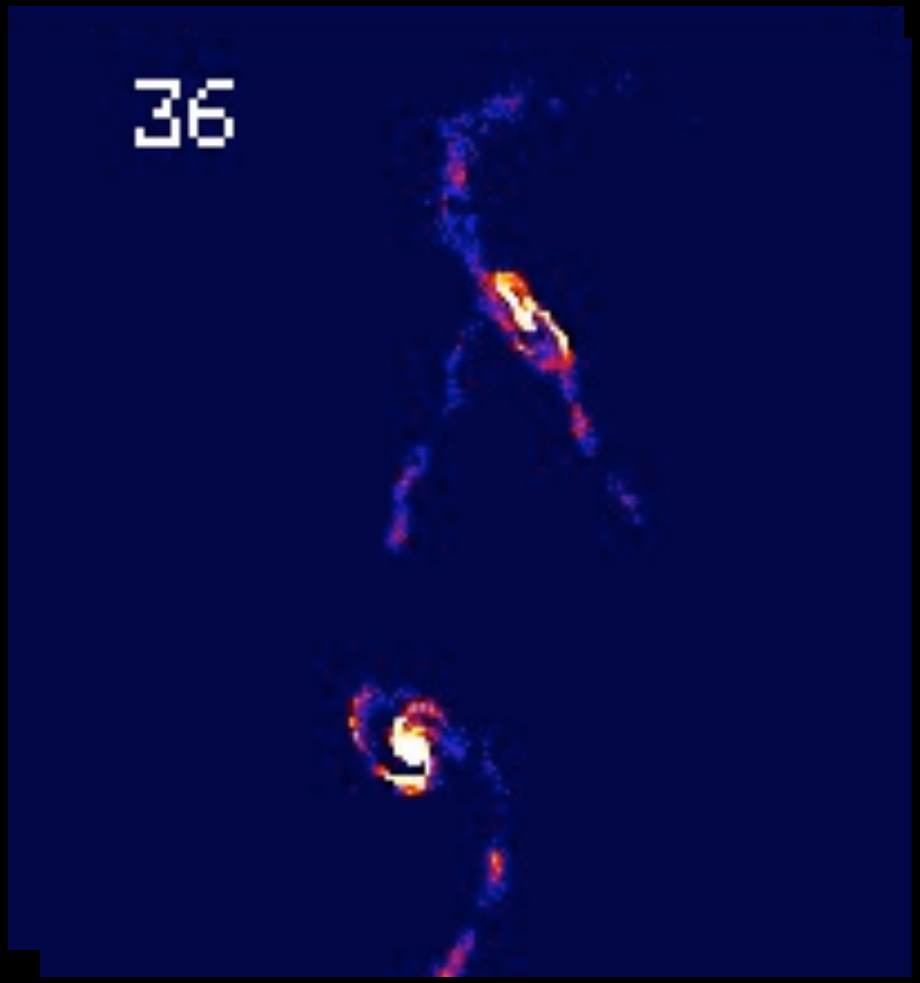
Images Courtesy Chris Mihos

Merger Scenario

After first close pass

Large gas inflows
& star formation continue



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Images Courtesy Chris Mihos

Merger Scenario

Final coalescence
(diffuse merger stage)

Starburst and AGN
visible

Composite spectral
class dominant

F-F absorption of radio cores?

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Images Courtesy Chris Mihos

Merger Scenario

Nuclei forms core
(compact merger stage)

Starburst subsides,
nuclear dust clears

AGN activity dominant

Yuan, Kewley, & Sanders (2010, ApJ, 209, 884)

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Images Courtesy Chris Mihos

Merger Scenario & Composites

- Merger scenario assumes composites are starburst + AGN

- What about alternative ionization sources (e.g., shocks)?

- What about aperture effects? (our spectra cover ~ 1 kpc)

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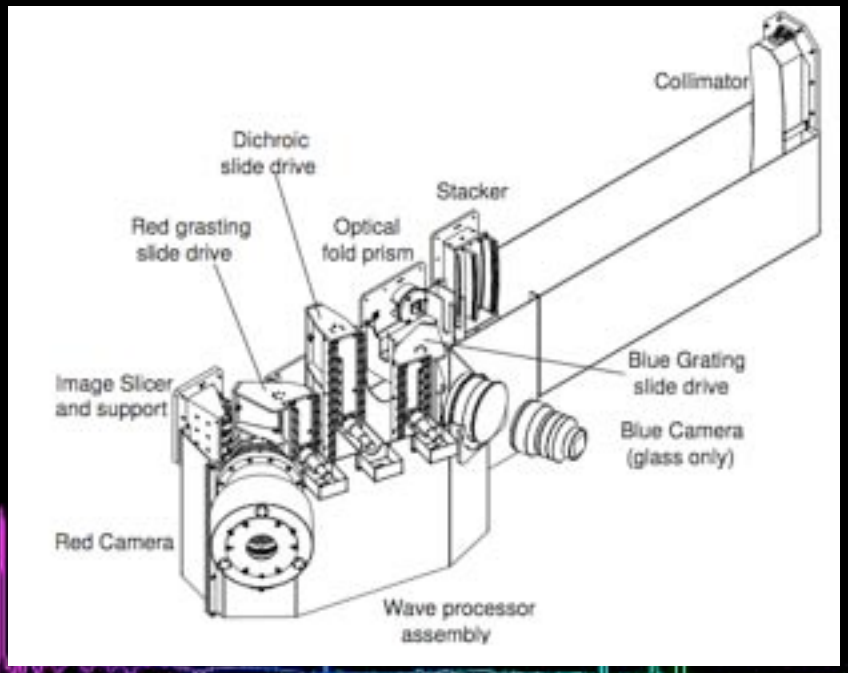
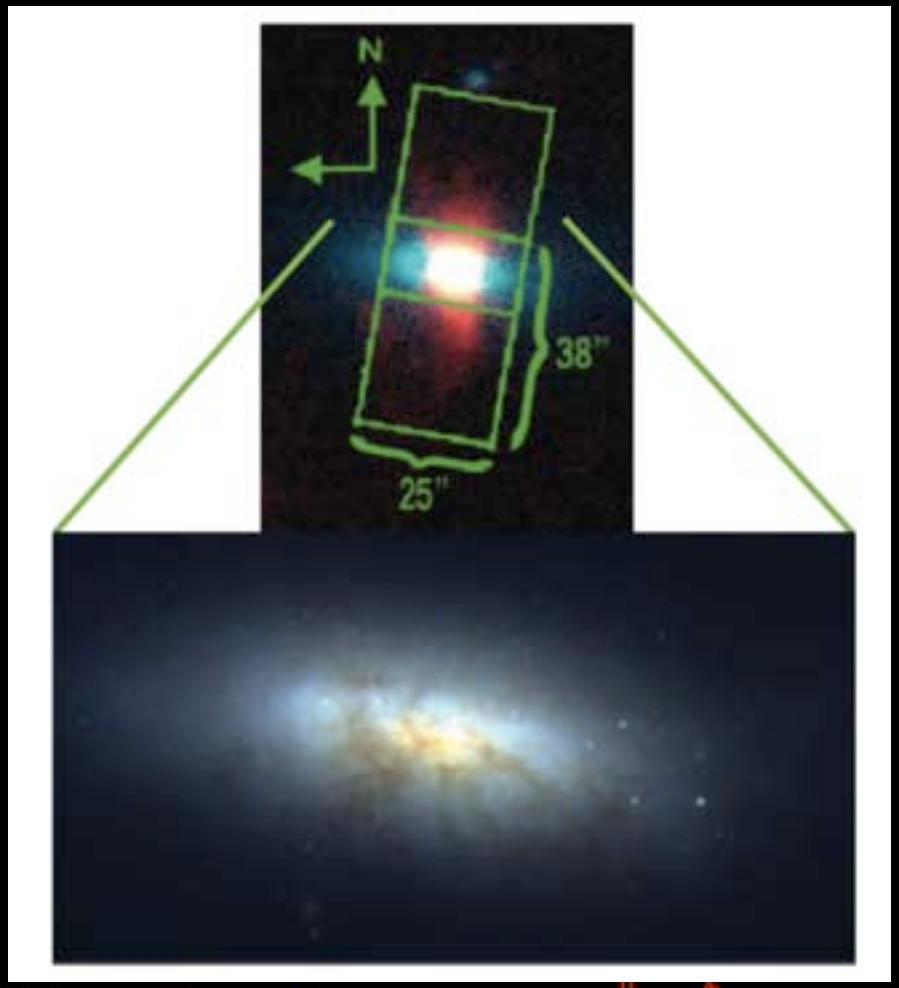
Integral Field Spectroscopy of nearby U/LIRGs

~25 LIRGS & ULIRGs from GOALS

IFU observations obtained with WiFES (PI Dopita)

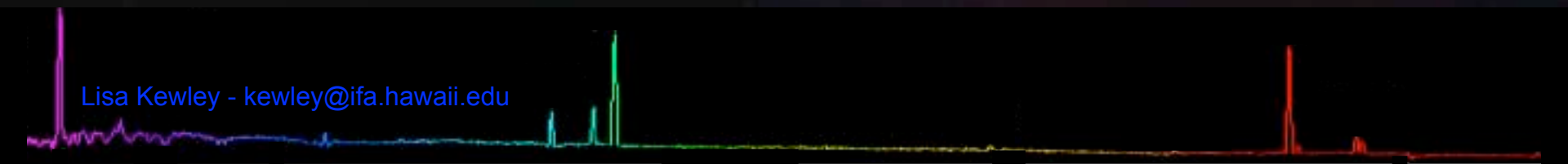




Integral Field Spectroscopy of nearby U/LIRGs

M82

NGC 839



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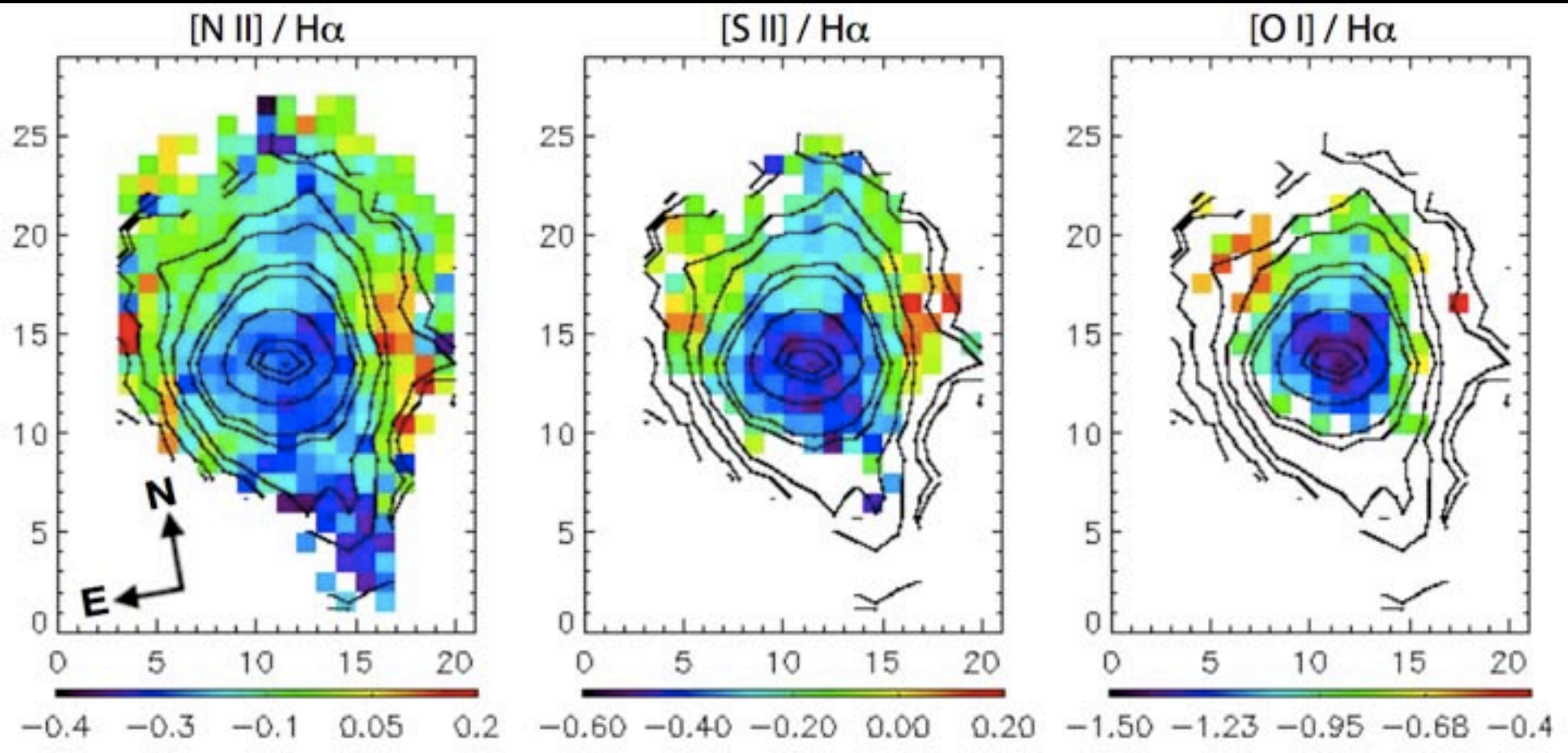
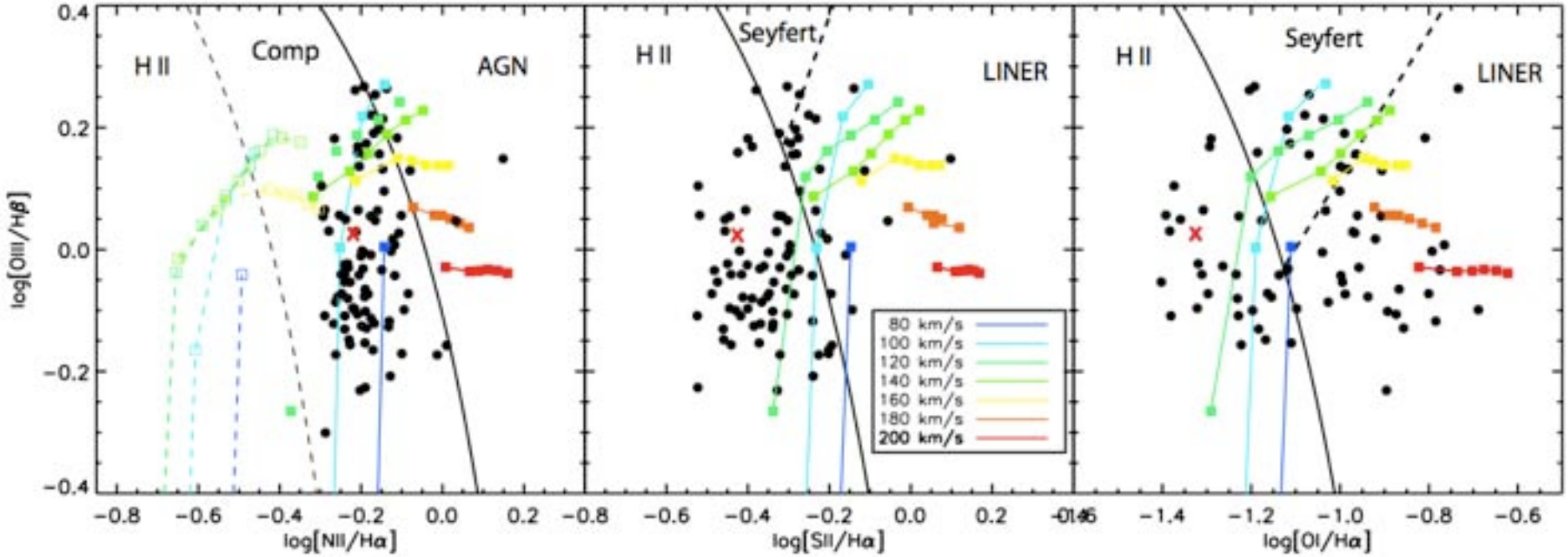
Integral Field Spectroscopy of nearby U/LIRGs

NGC 839: Line Ratio Maps



Integral Field Spectroscopy of nearby U/LIRGs

NGC 839: Line Ratio Maps & low velocity shock models



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Outstanding Questions

- Do such large-scale gas flows occur?

  Yes & can be traced with metallicity

- Is the Sanders merger scenario correct?

  Yes, according to optical classification

- Connection between starbursts & AGN?

Composites, Diffuse Merger Stage is Critical
=> X-ray, VLBI, IFU investigations ongoing

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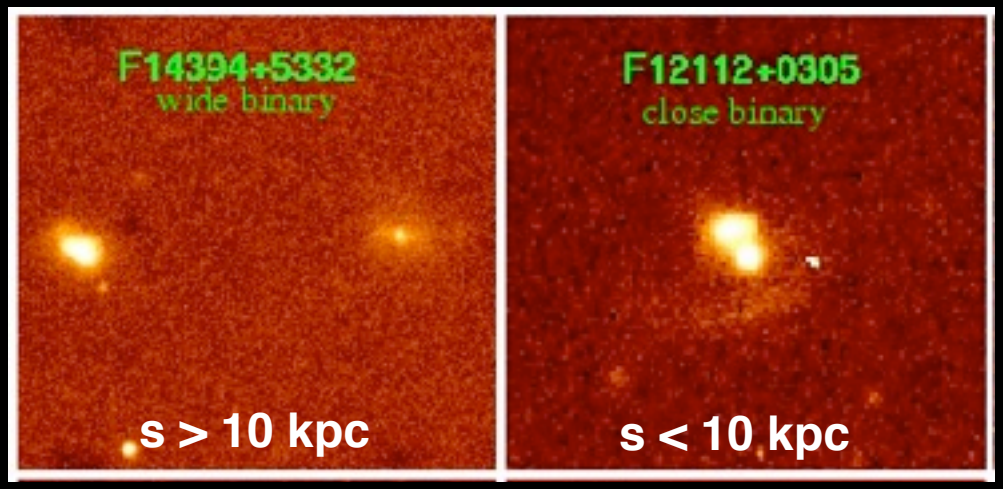
Merger Progress

- Morphological Classification (Veilleux et al. 2002)



- Projected Separation

UH88 K band images (ULIRGs), 2MASS

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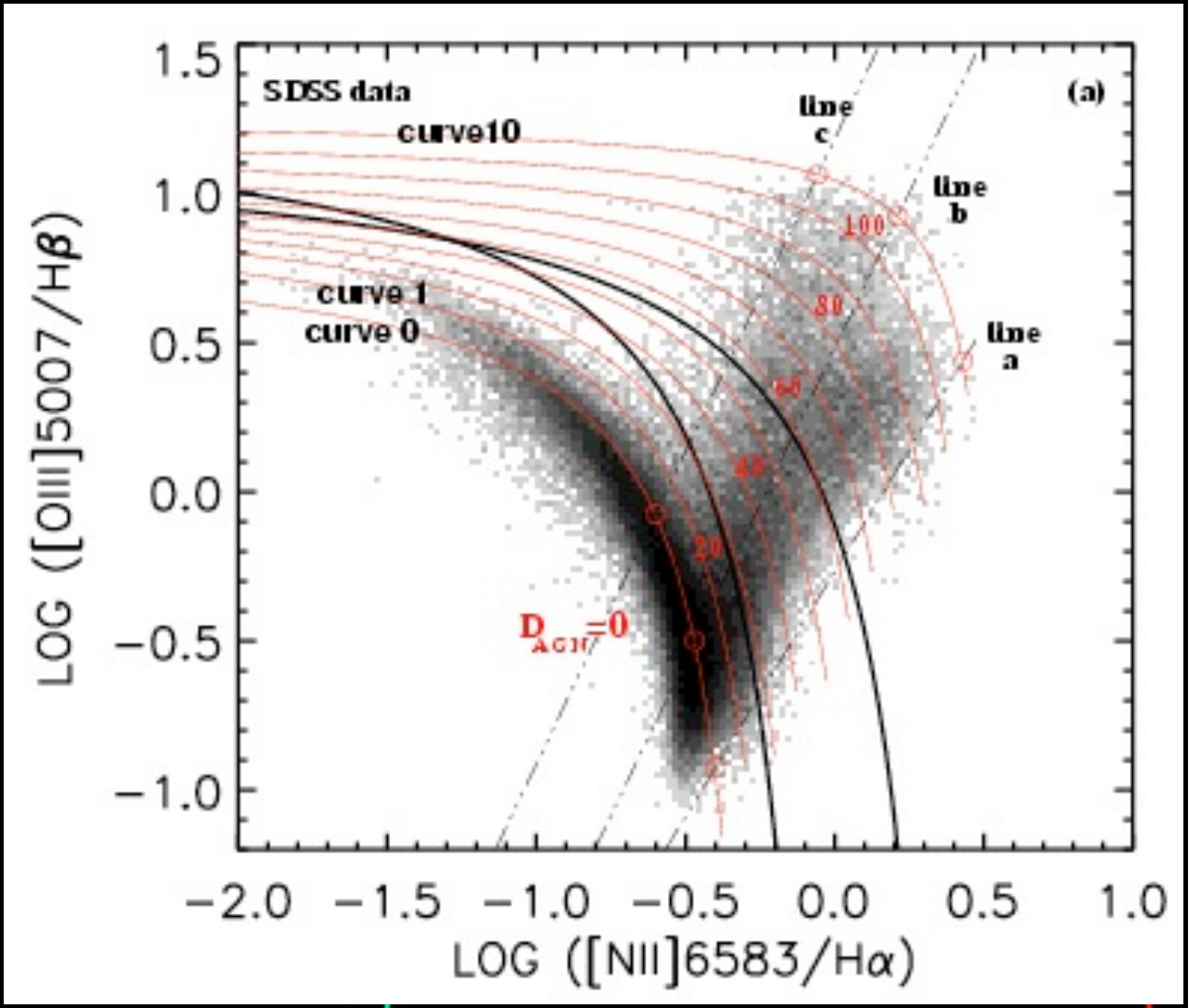
AGN contribution



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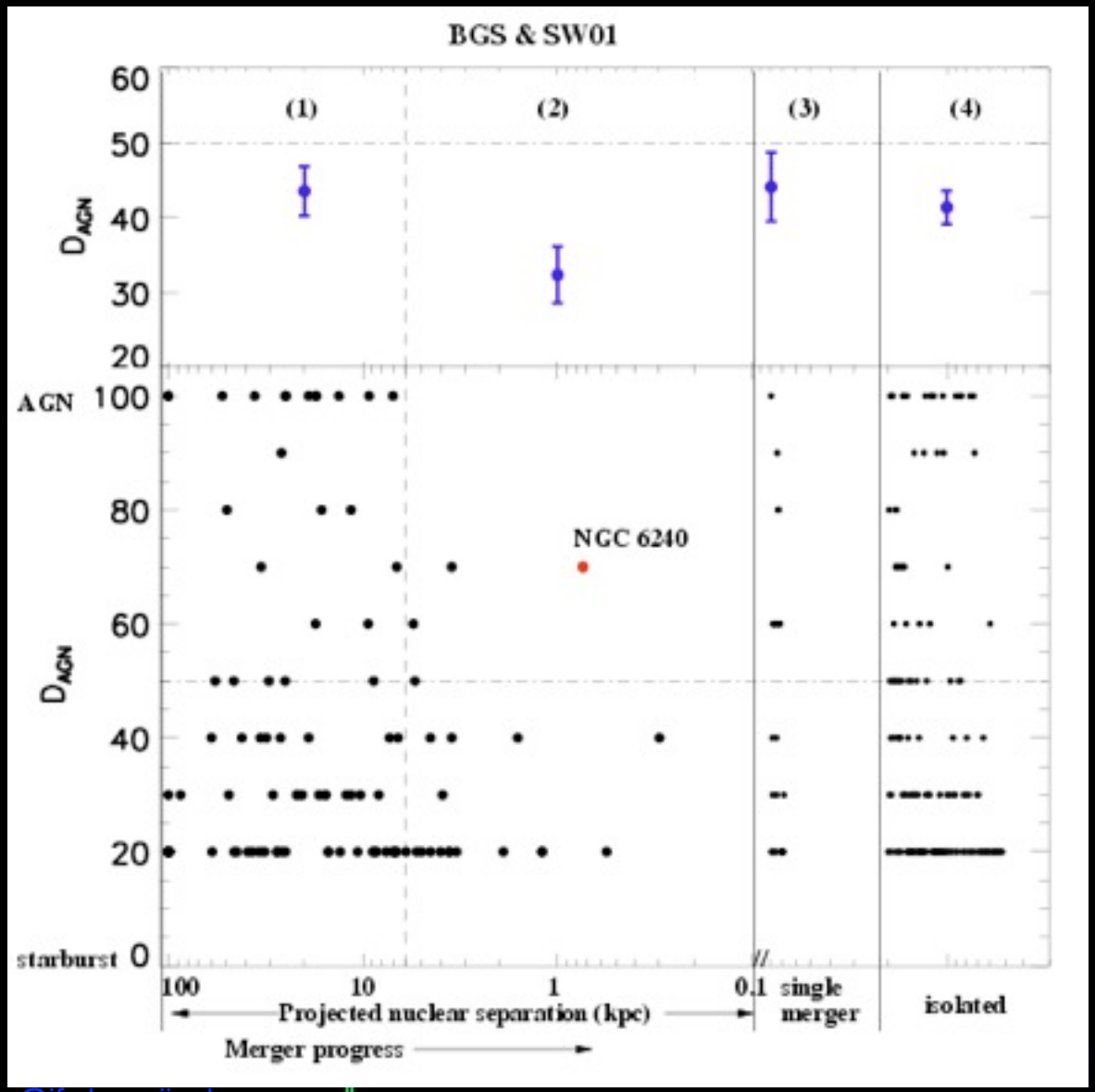
AGN contribution vs projected separation



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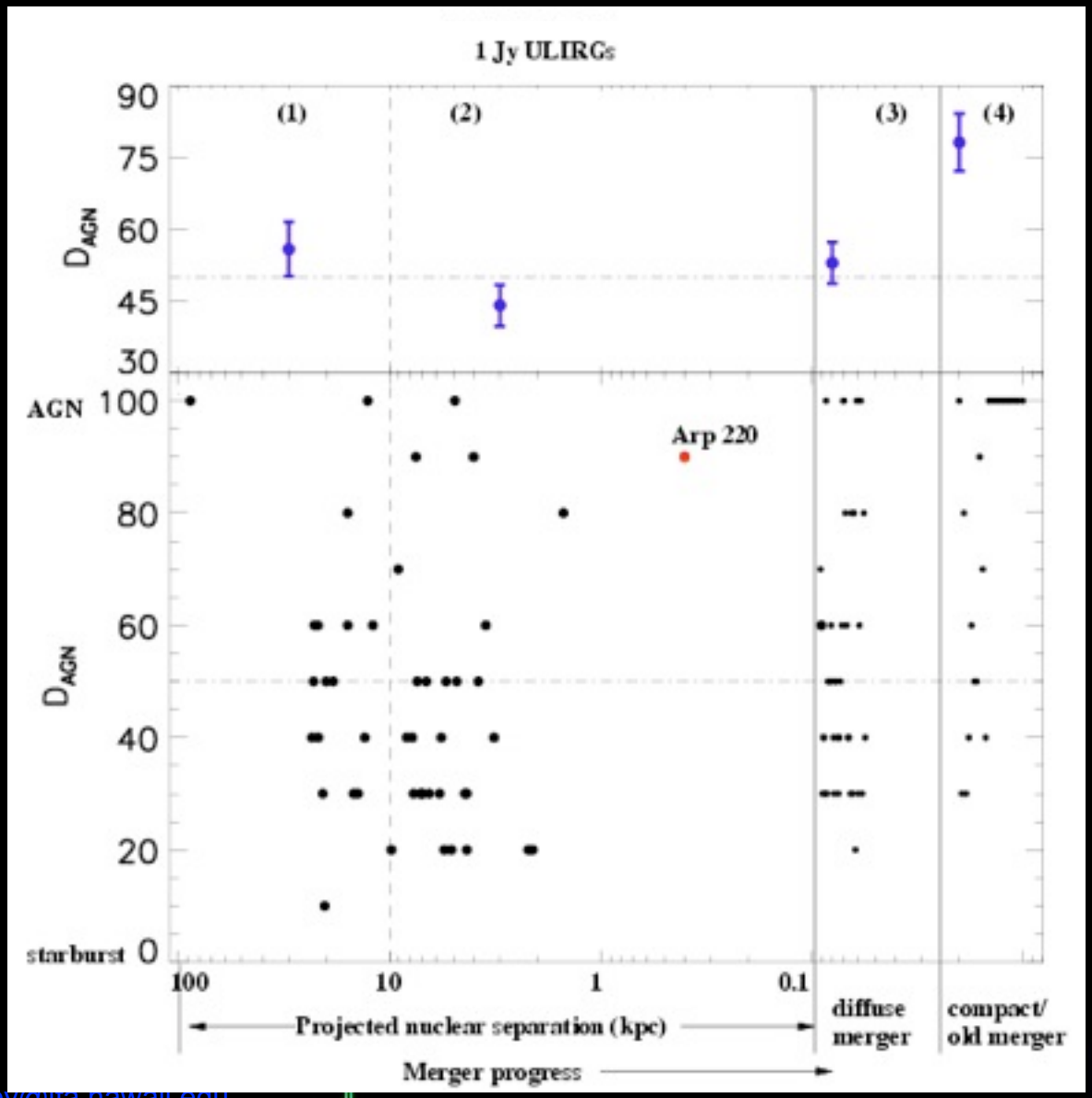
AGN contribution vs projected separation



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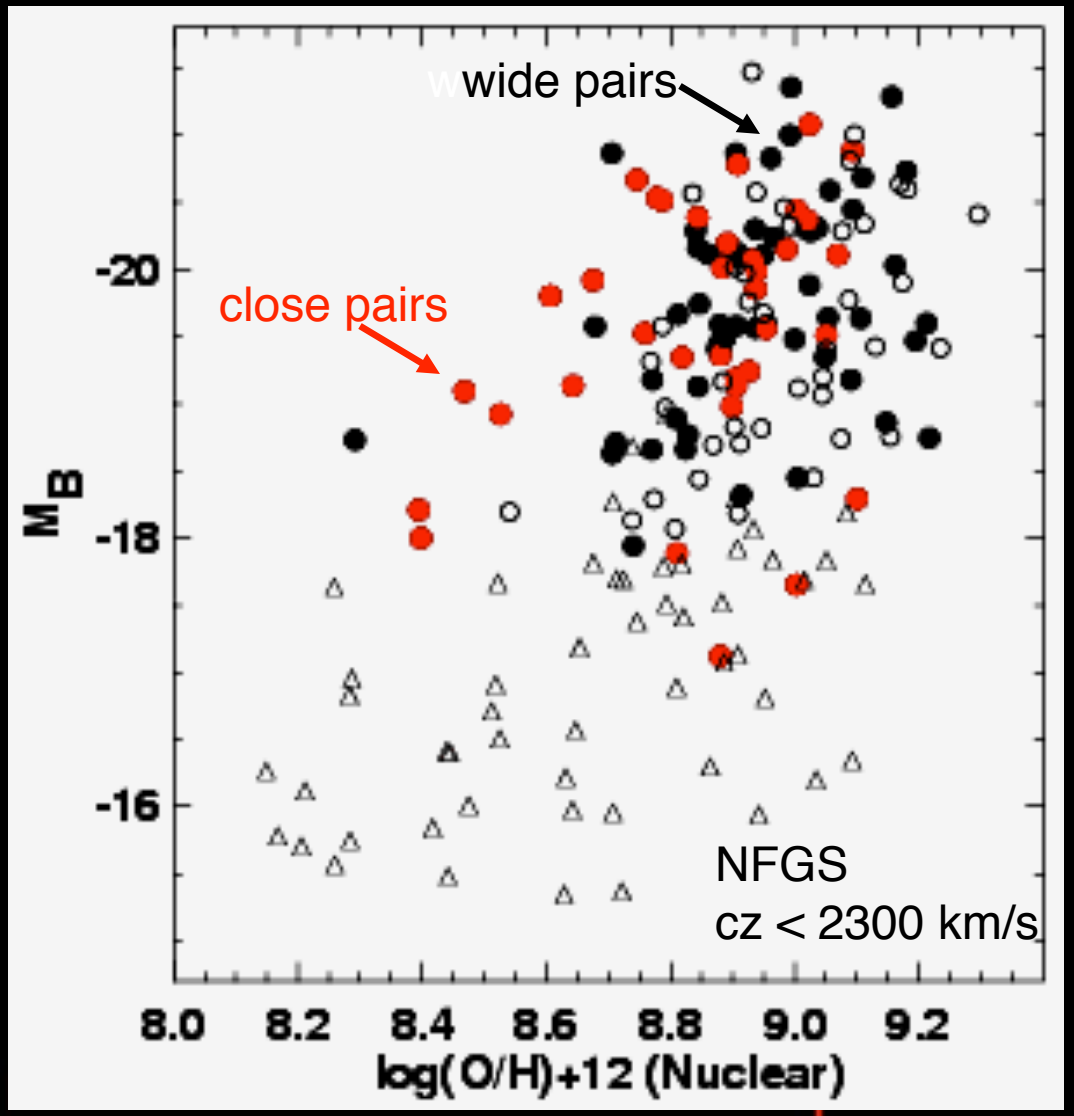
Luminosity Effect?

Need 1-2 Mag rise



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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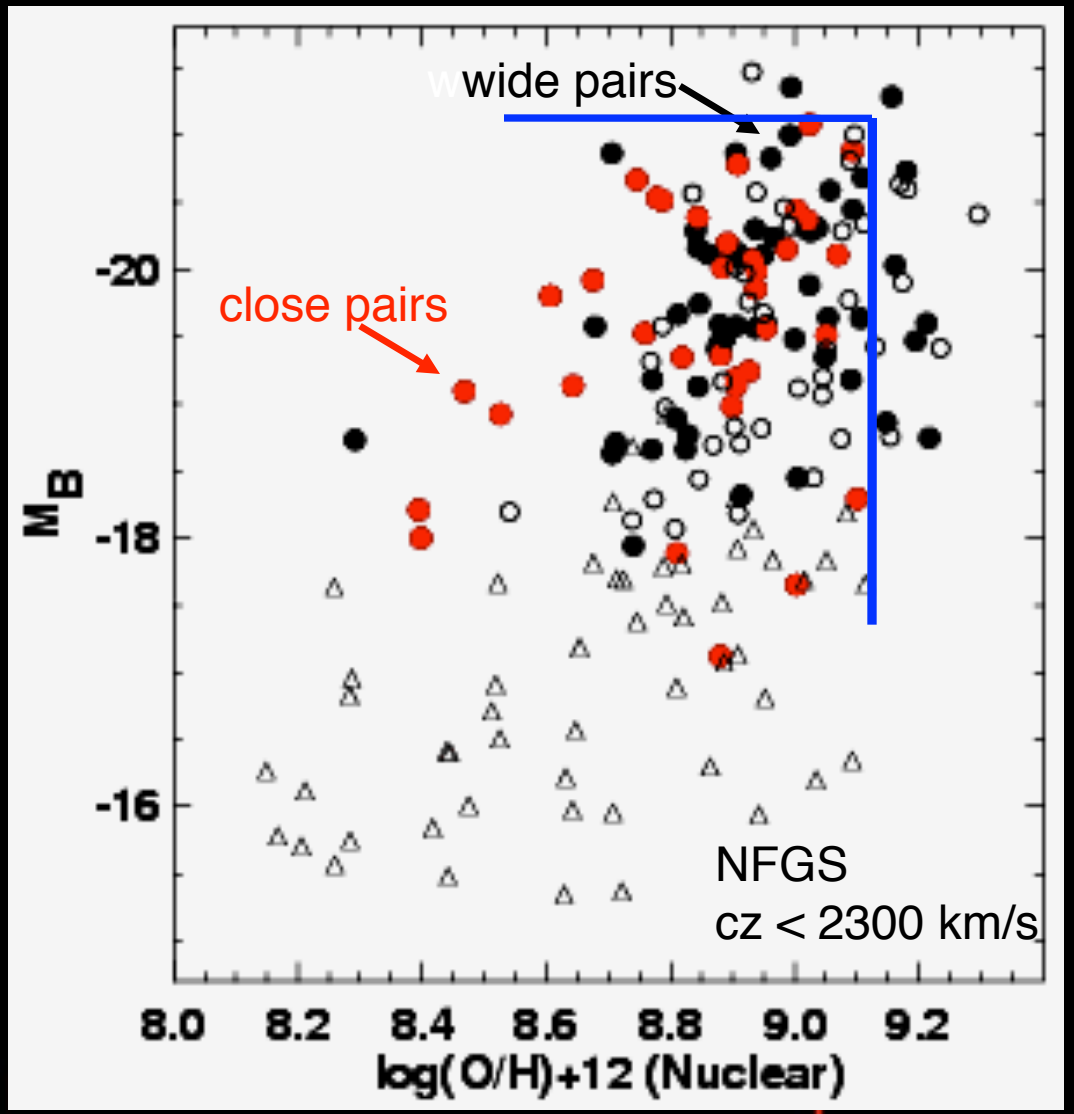
Luminosity Effect?

No shift in upper bound : M_B

Negative shift in right bound: metallicity



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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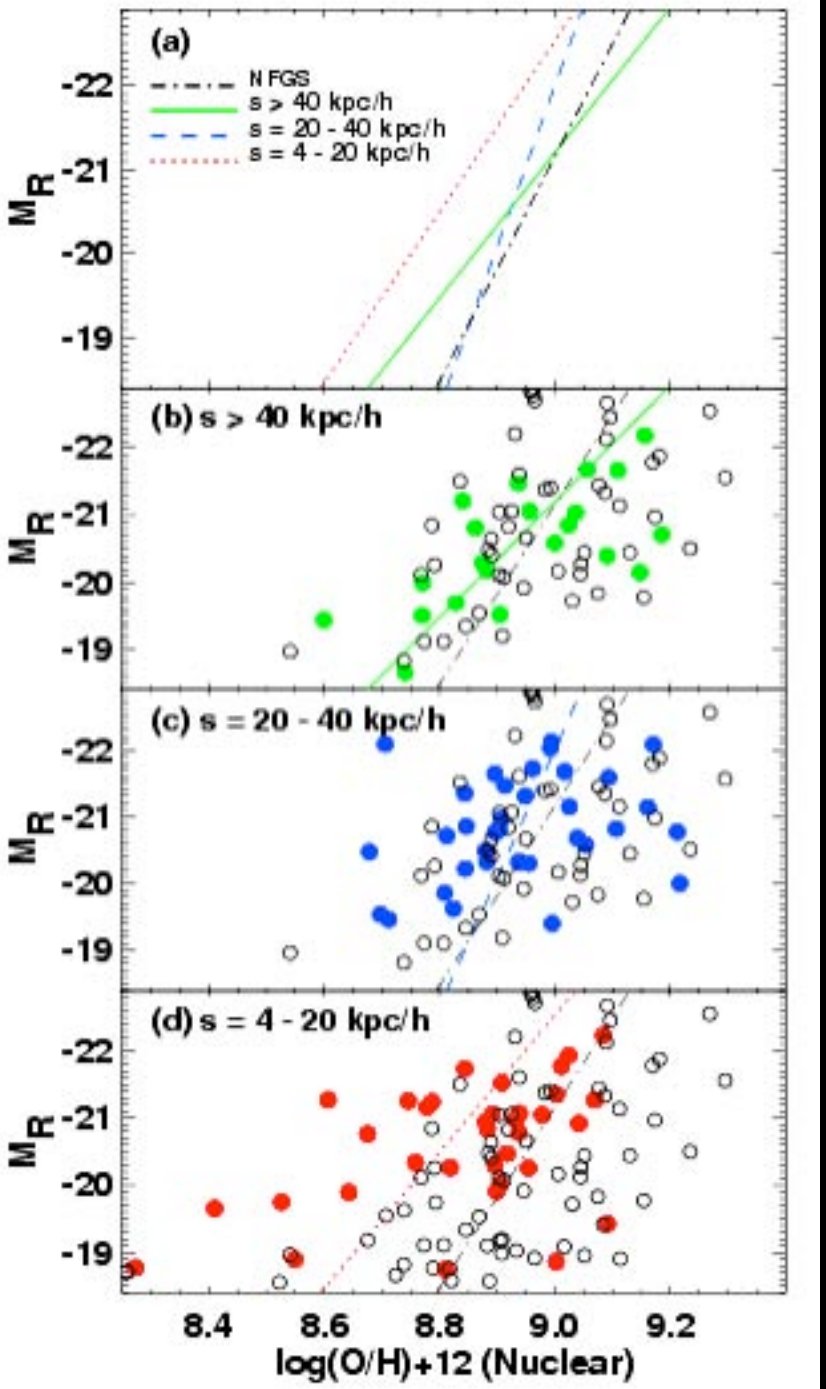
Luminosity Effect?

R-Band Luminosity-metallicity Relation

1. still shifts for close pairs



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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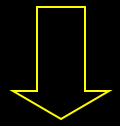
Central Burst Strength, $S_R(t)$

Barton, Geller & Kenyon (2003):

Stellar population synthesis models + colors + EWs assuming 2 populations (old & young)



$S_R(t)$ = current fraction of R-band light from young burst

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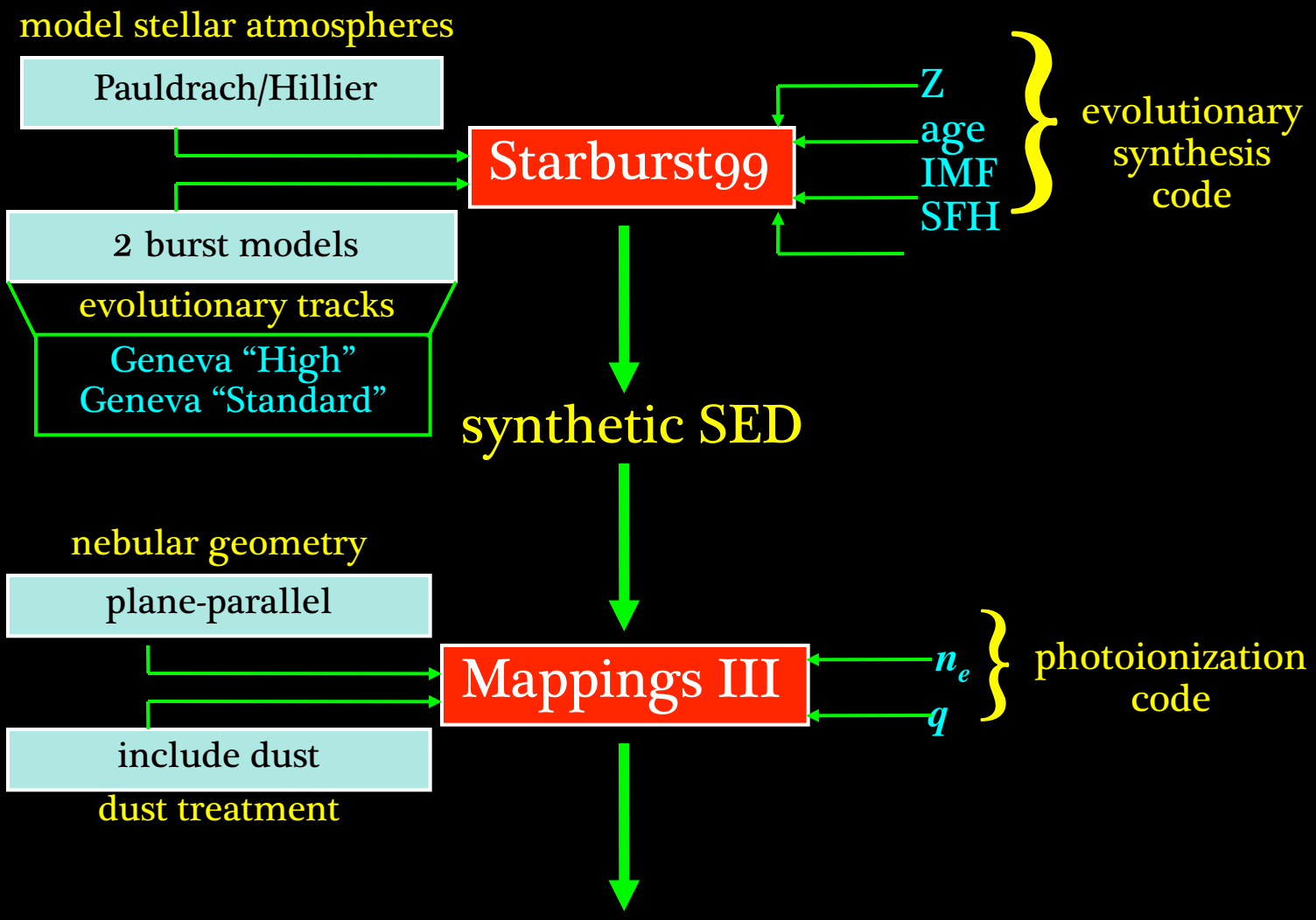
Photoionization Models



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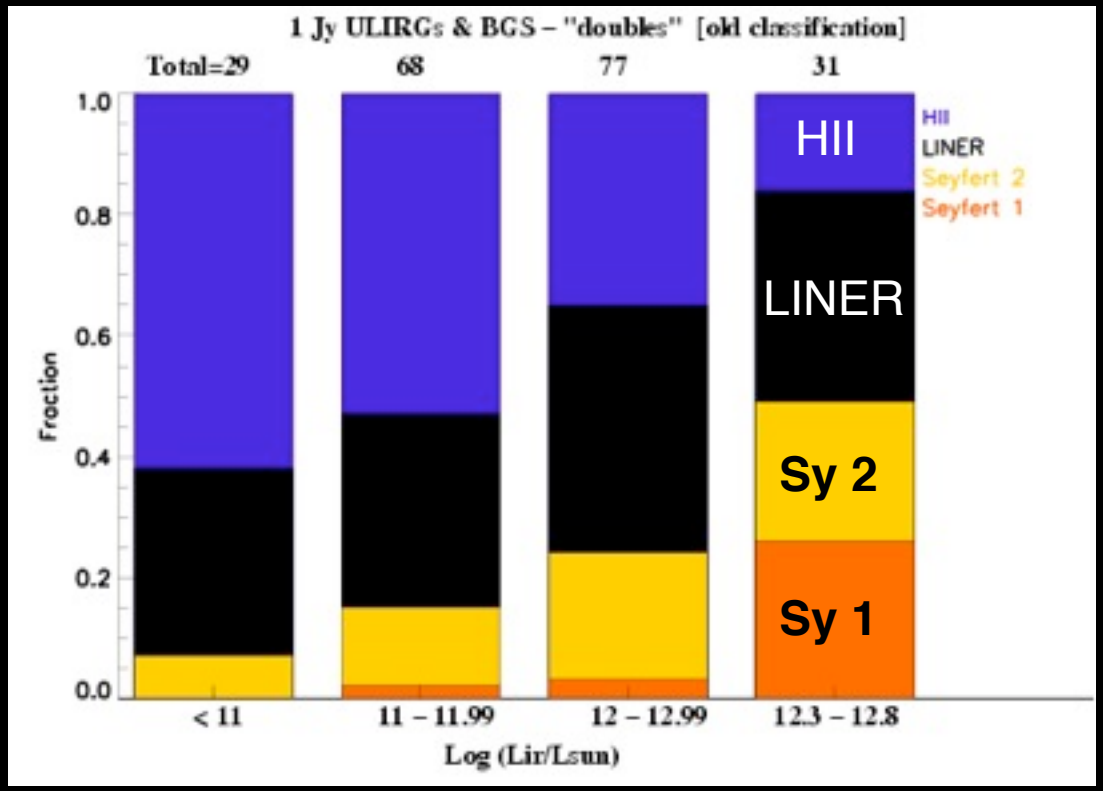
Spectral Classification

Previously:



Veilleux et al. (2005)

Yuan, Kewley, & Sanders (2007)

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Merger Scenario

Assuming:

1. Gas inflow rate ~ 7 $M_\odot$/yr
2. Normal Spiral Metallicity gradient

How much central dilution is required?

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Merger Scenario

Assuming:

1. Gas inflow rate ~ 7 $M_\odot$/yr
2. Normal Spiral Metallicity gradient

How much central dilution is required?

50-60%

Merger models predict: 60% infall

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Merger Scenario

Assuming:

1. Gas inflow rate ~ 7 $M_\odot$/yr
2. Normal Spiral Metallicity gradient
3. Central Gas Mass 10^8 - 10^9 $M_\odot$

ave v. high

How long will it take to infall?

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Merger Scenario

Assuming:

1. Gas inflow rate ~ 7 $M_\odot$/yr
2. Normal Spiral Metallicity gradient
3. Central Gas Mass 10^8 - 10^9 $M_\odot$

How long will it take to infall?

9×10^6 - 9×10^7 years

Merger models predict: within 1×10^8 years

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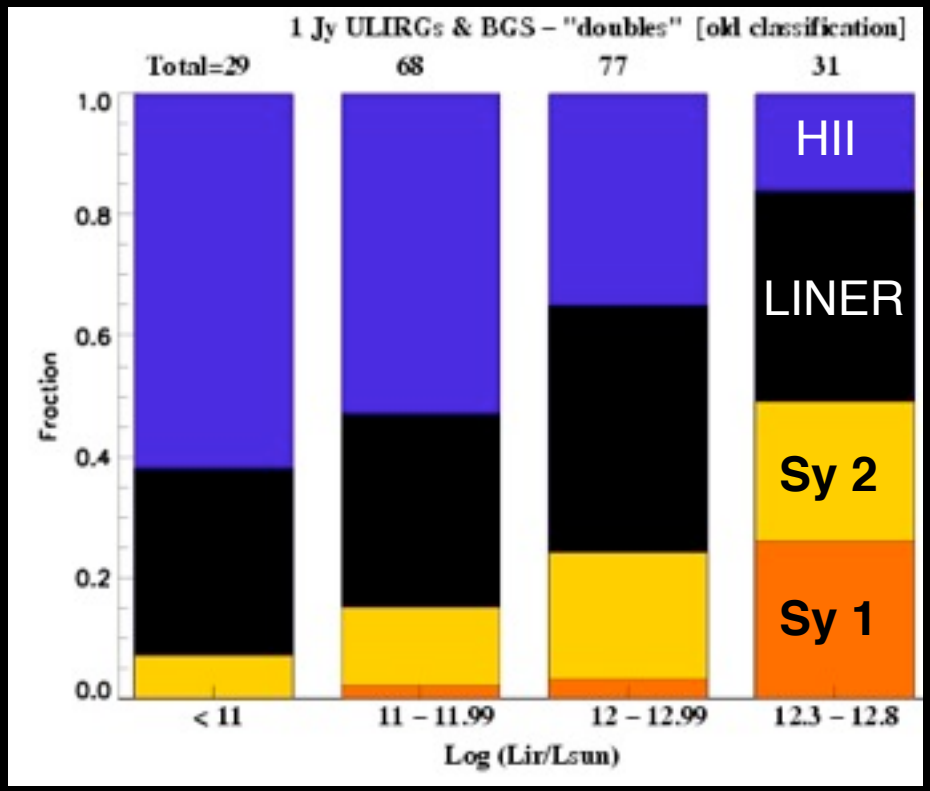
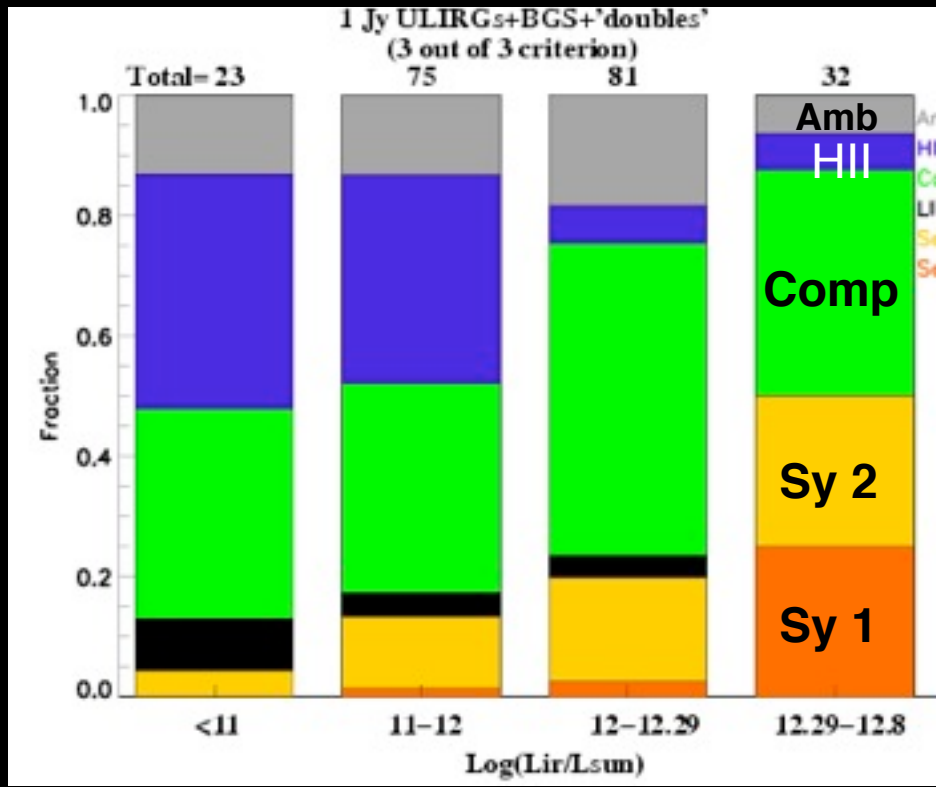
Spectral Classification

Previous:



Veilleux et al. (2005)

Now:



Yuan, Kewley, & Sanders (2007)

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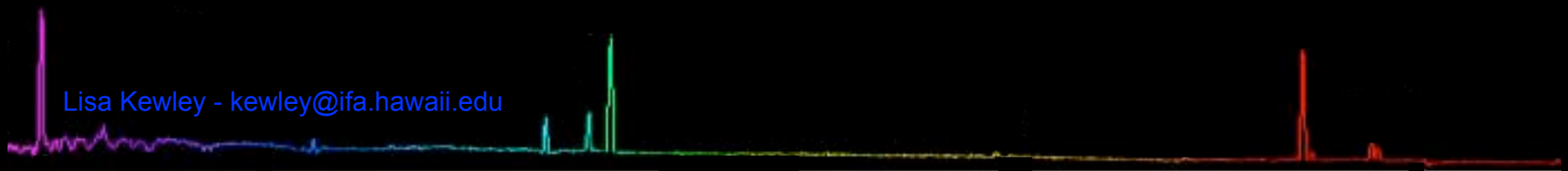
Summary



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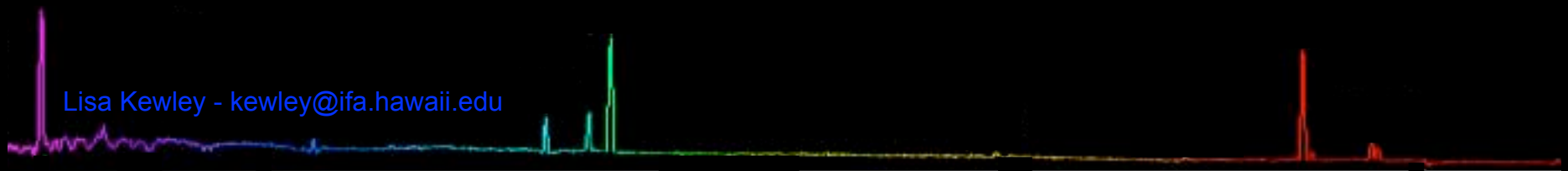
Summary



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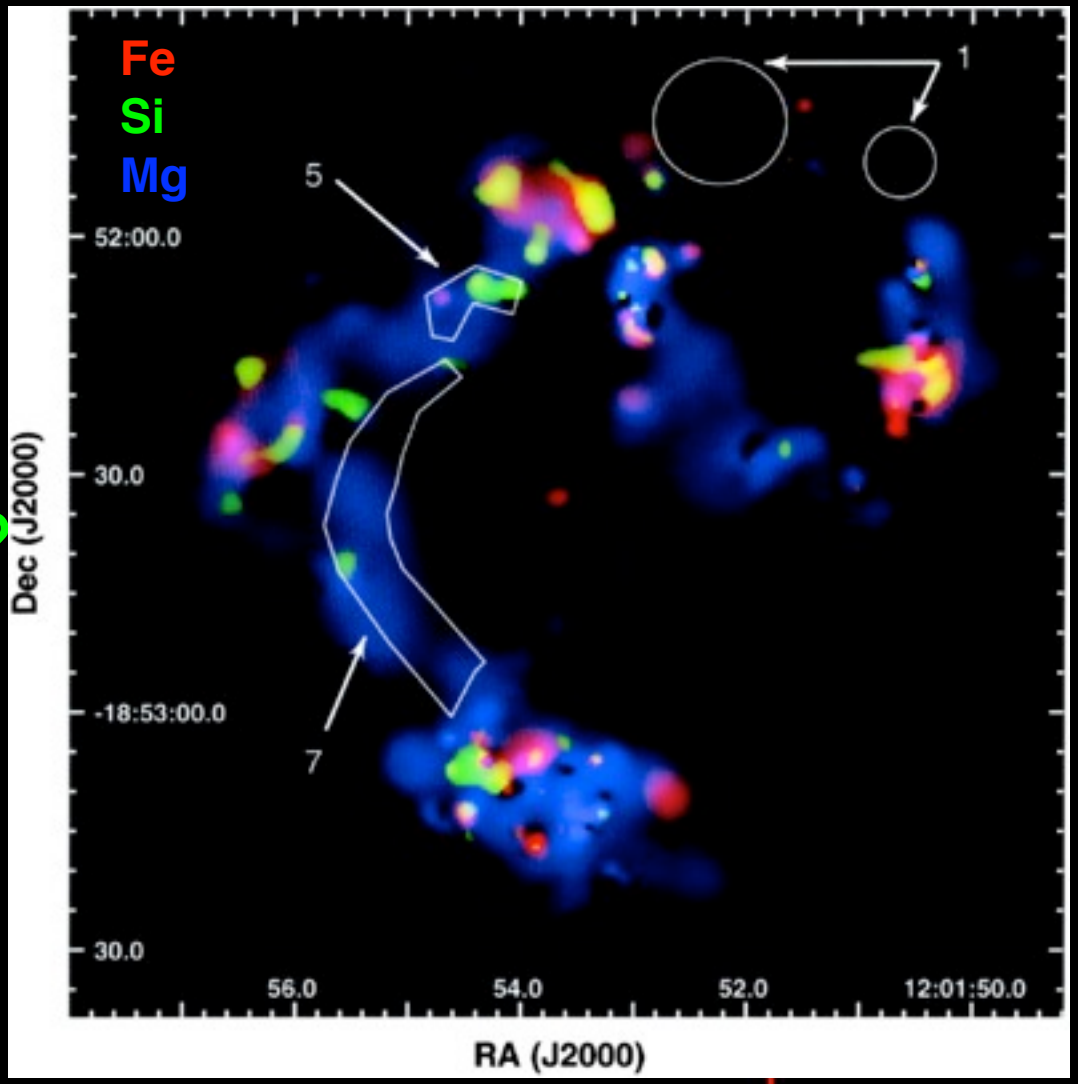
Motivation

Effect of mergers on metallicity?
unknown

Predicted gas flows?
elusive



Fabbiano et al. (2004)

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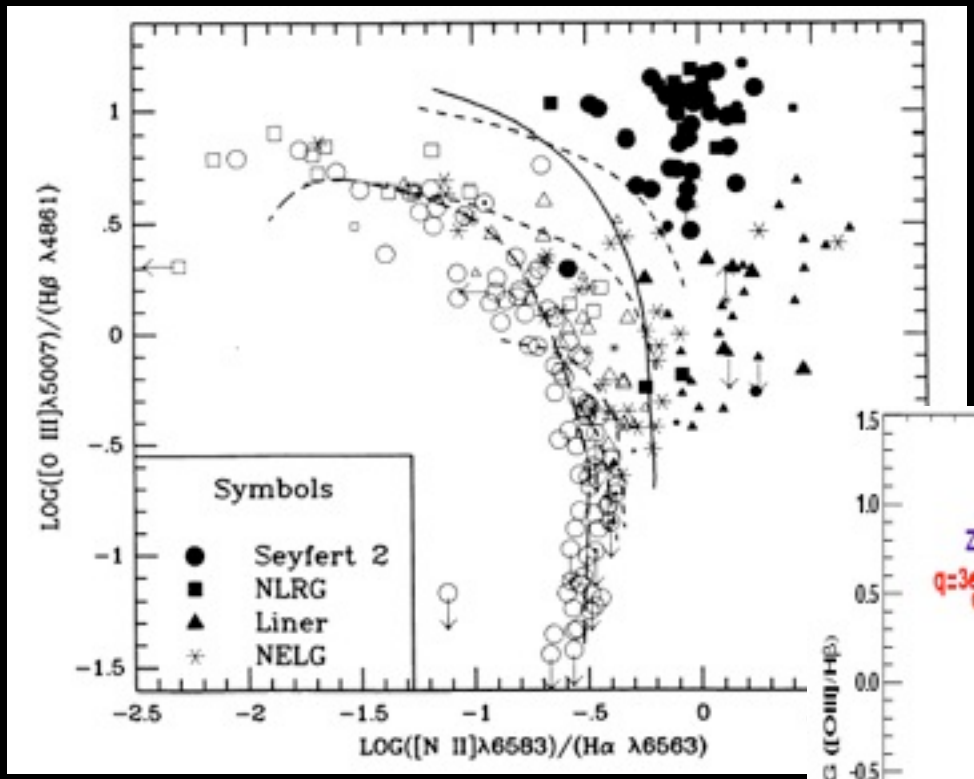
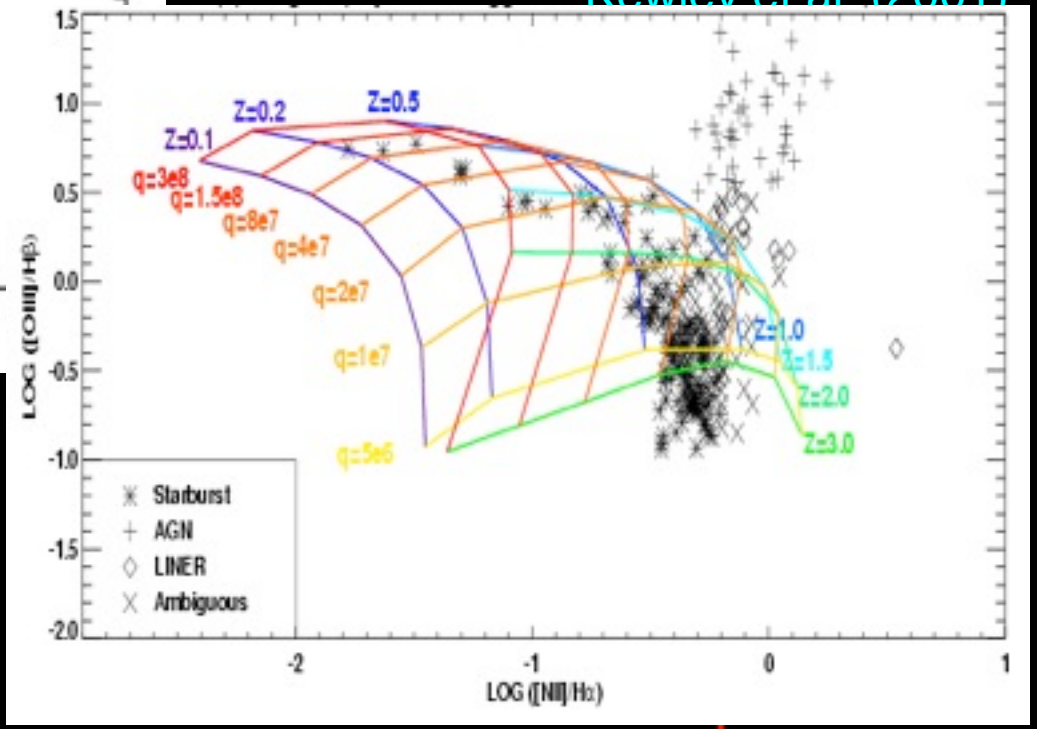
Ionizing Source: AGN vs Star Formation



Semi-empirical:
Veilleux & Osterbrock (1987)

Theoretical:
Kewley et al. (2001)



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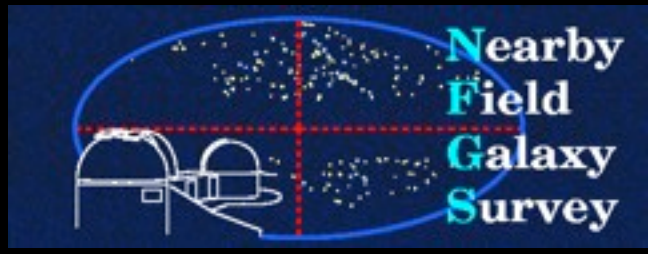
Galaxy Pairs

- 502 galaxies from the CfA redshift catalog
  ($v > 2300$ km/s, $\Delta v < 1035$ km/s, $\Delta D < 77$ h^{-1} Mpc)
- Nuclear spectra for ~200 galaxies in pairs
  (Barton et al. 2000)

Field Galaxies



- 198 galaxies from the CfA redshift catalog
- full range in Hubble type & Magnitudes in CfA survey

(Jansen et al. 2000)
http://cfa-www.harvard.edu/~jansen/nfgs/nfgssample.html

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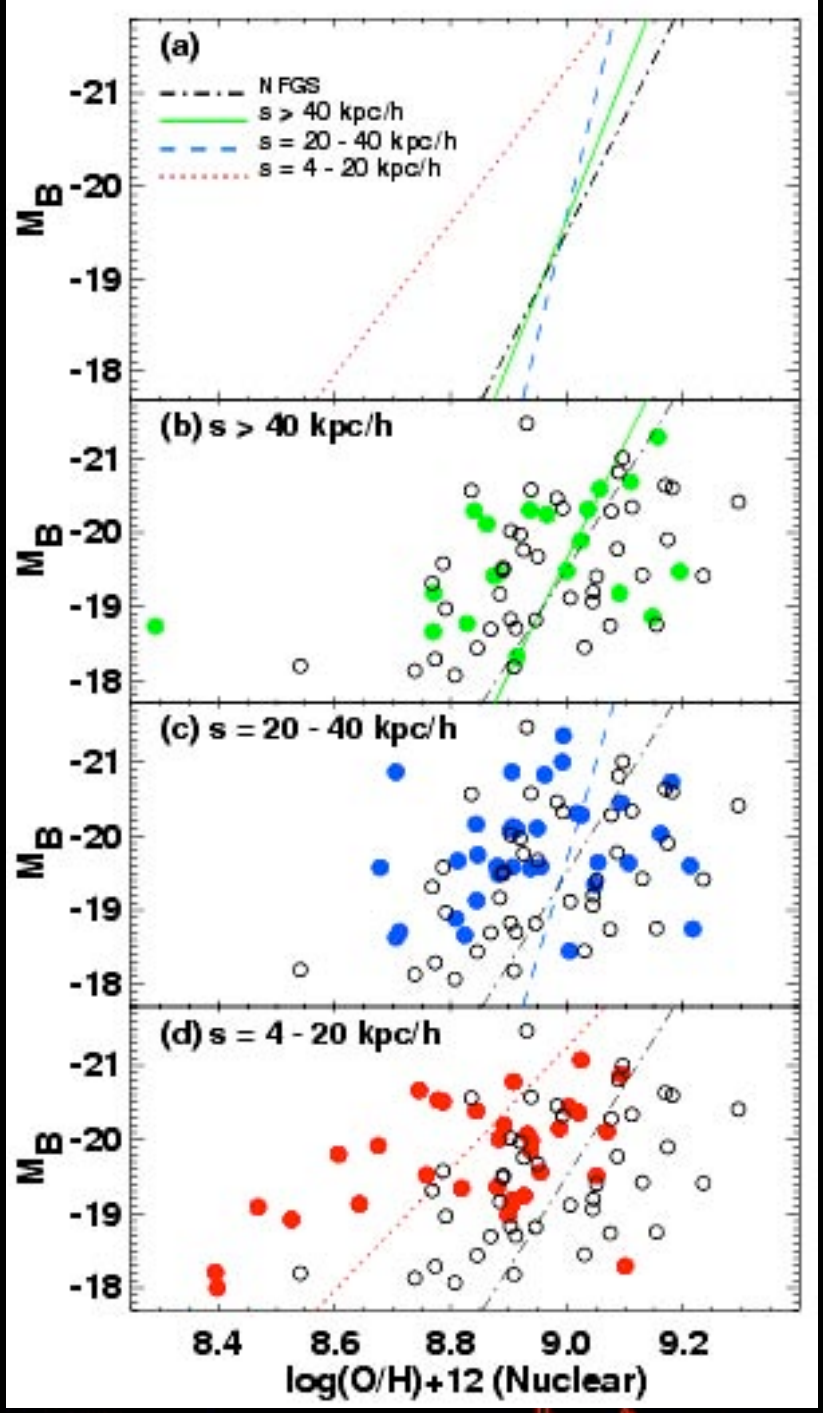
Galaxy Pairs

Luminosity-metallicity Relation

1. shifts for close pairs



Kewley, Geller, & Barton (2005, AJ, 131, 2004)

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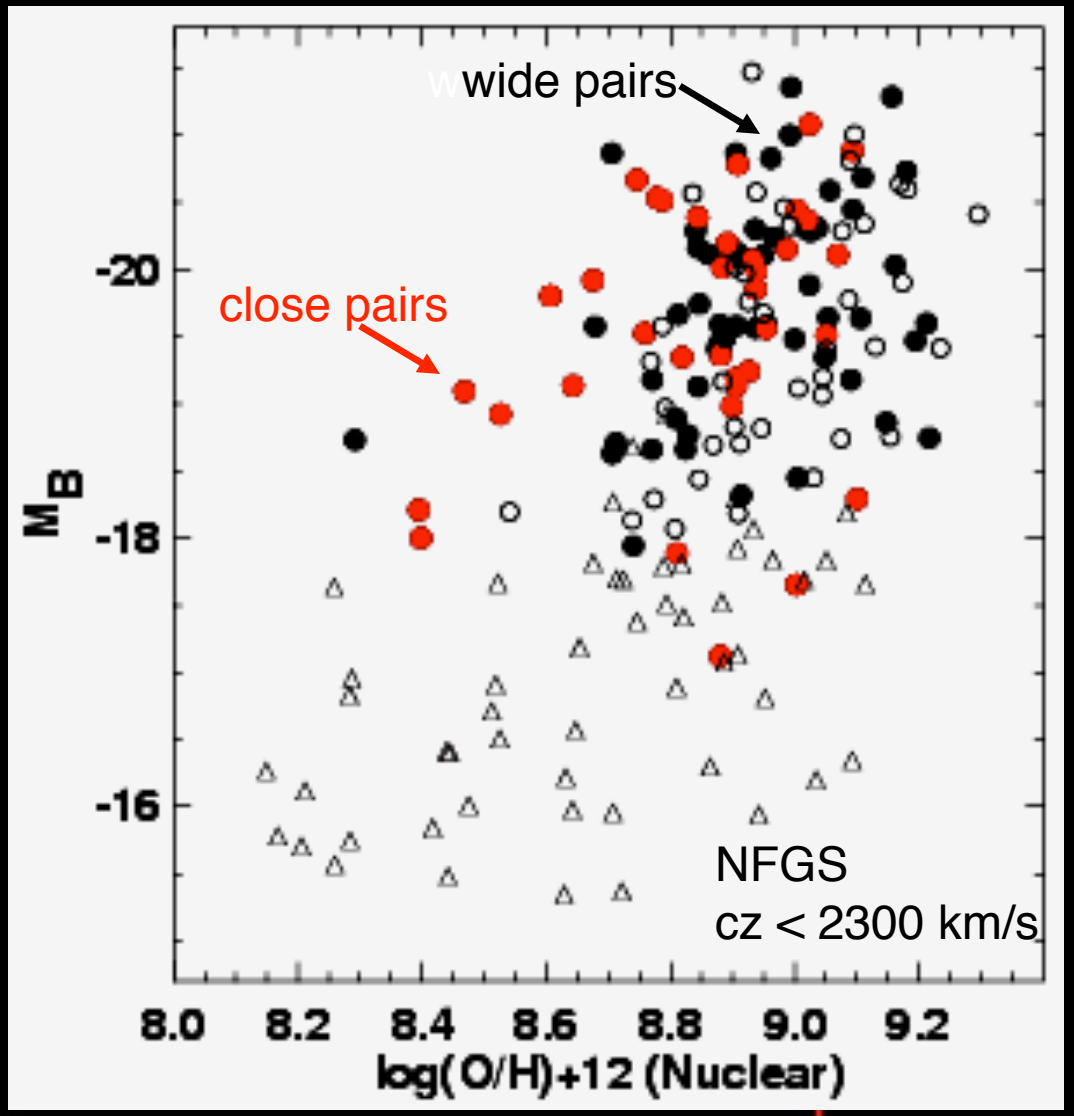
Luminosity Effect?

Need 1-2 Mag rise



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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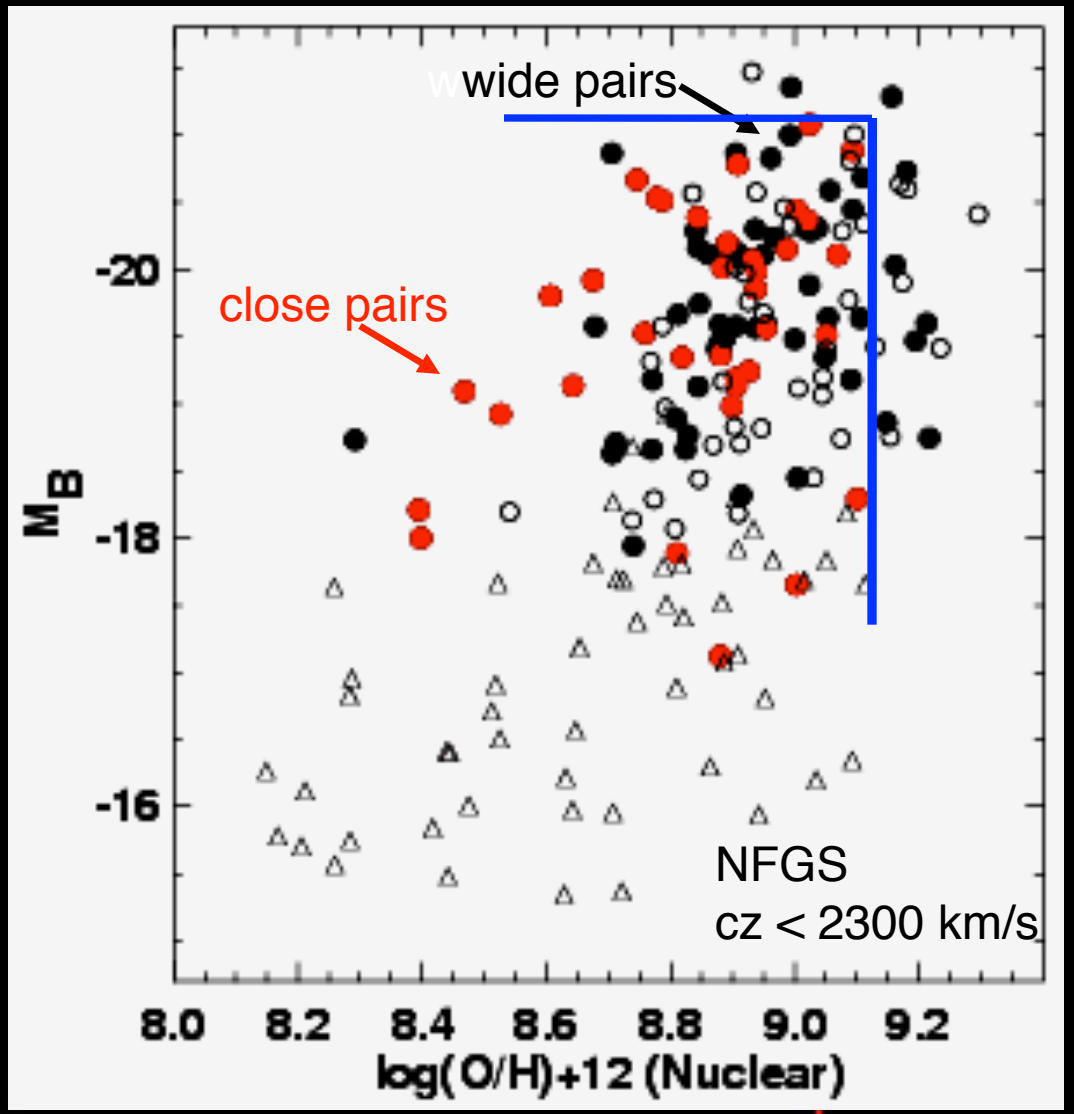
Luminosity Effect?

No shift in upper bound : M_B

Negative shift in right bound: metallicity



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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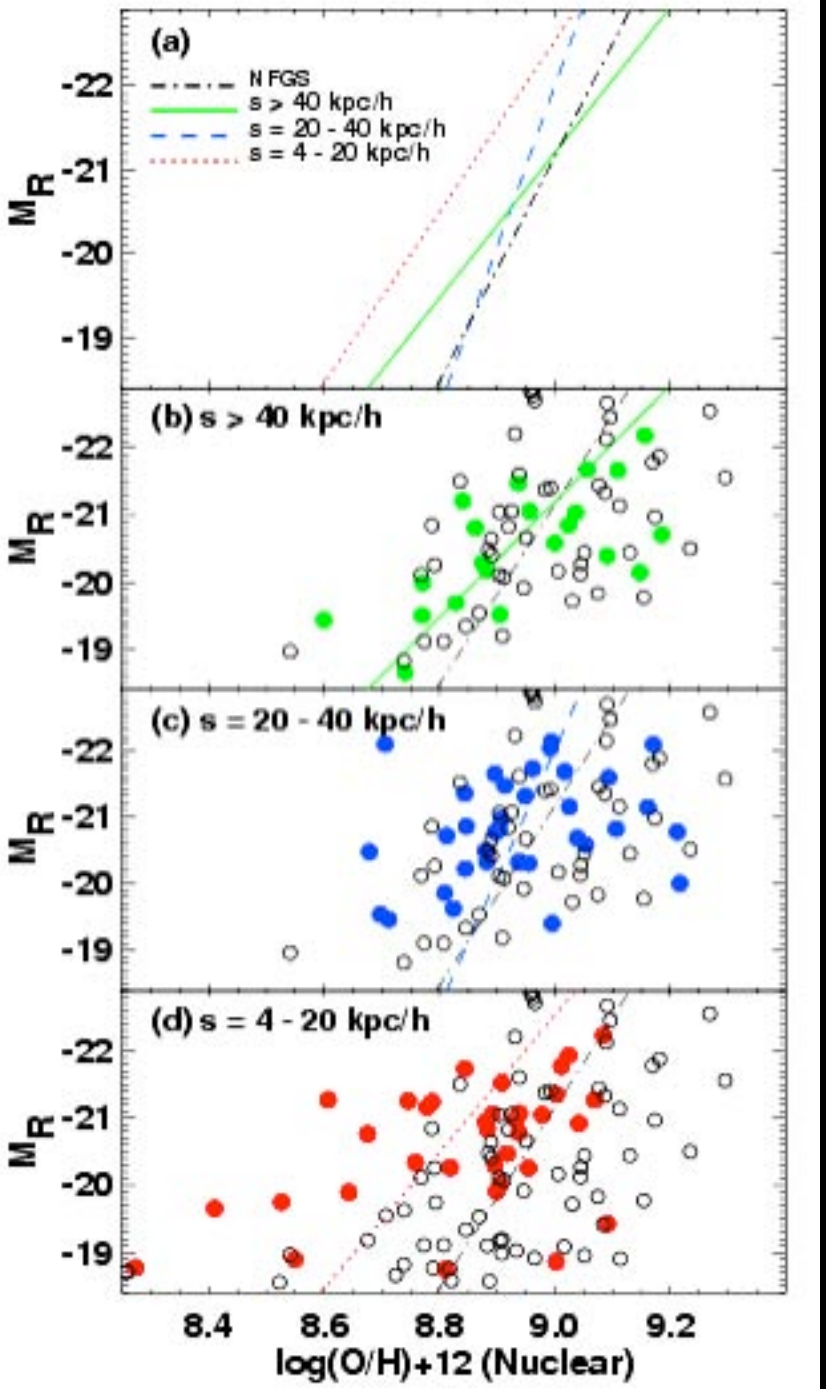
Luminosity Effect?

R-Band Luminosity-metallicity Relation

1. still shifts for close pairs



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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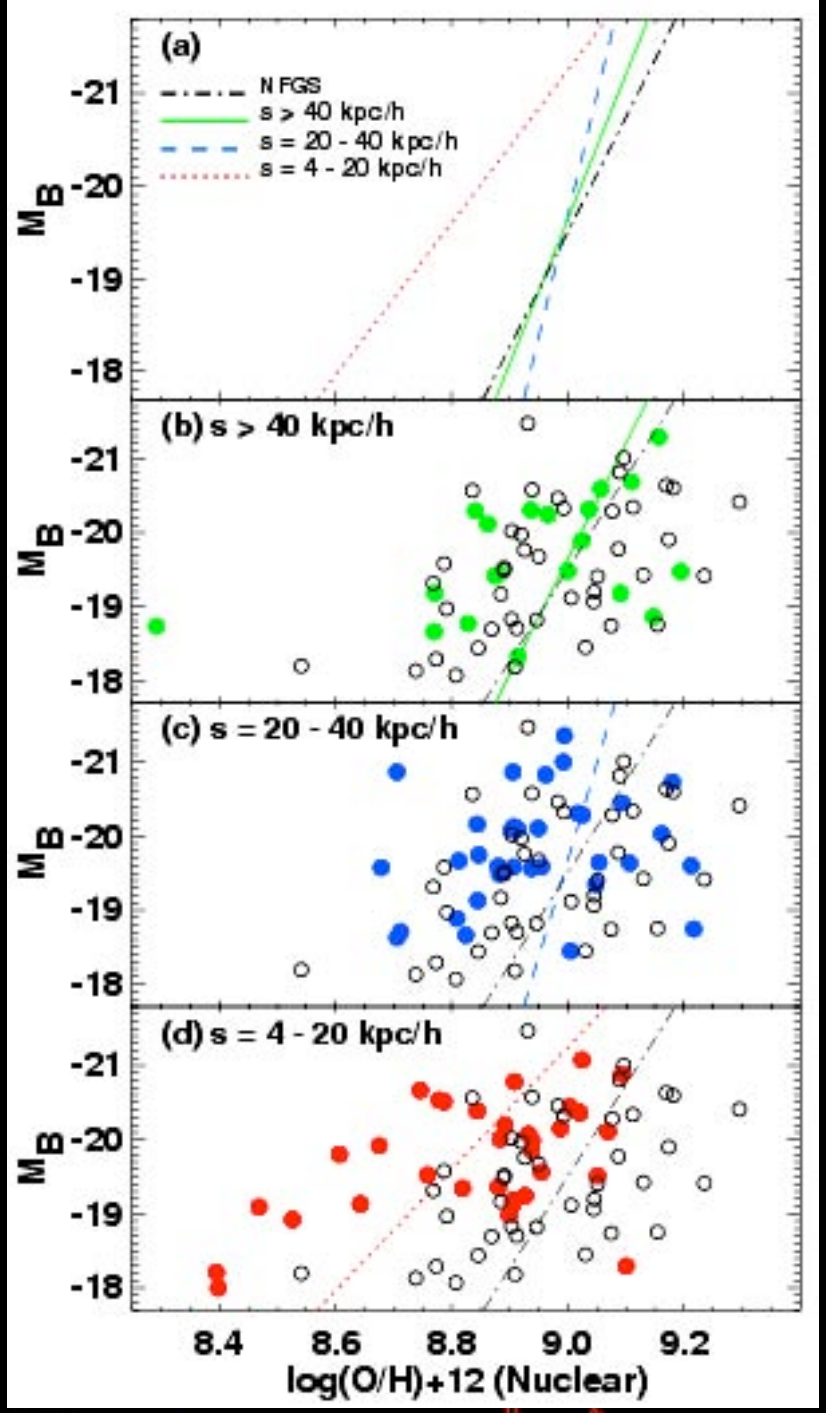
Galaxy Pairs

Luminosity-metallicity Relation

1. shifts for close pairs

   metallicity effect?
   gas infall?



Kewley, Geller, & Barton
(2006, AJ, 131, 2004)

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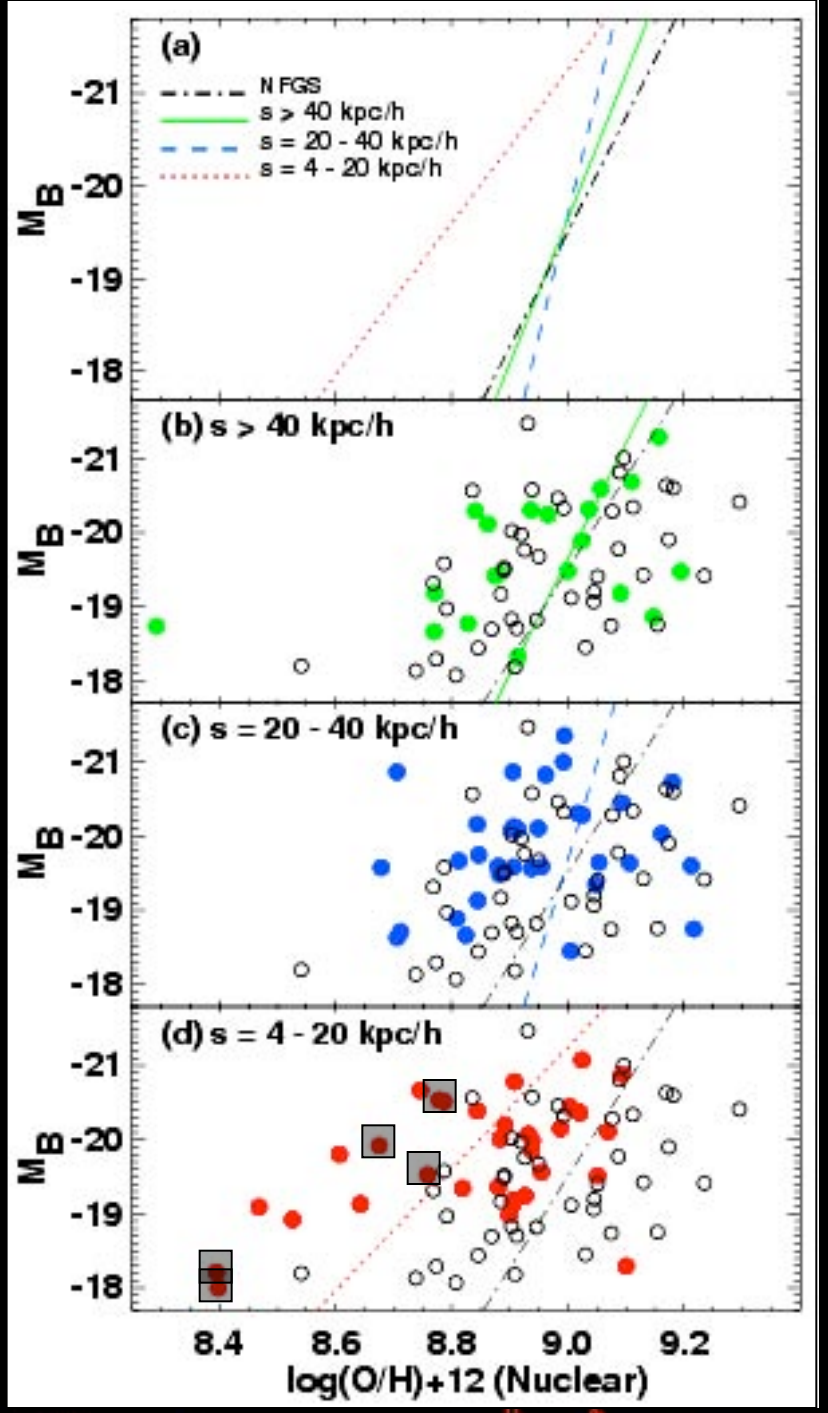
Galaxy Pairs

Luminosity-metallicity Relation

1. shifts for close pairs
2. correlated with central burst strength



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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Galaxy Pairs

Luminosity-metallicity Relation

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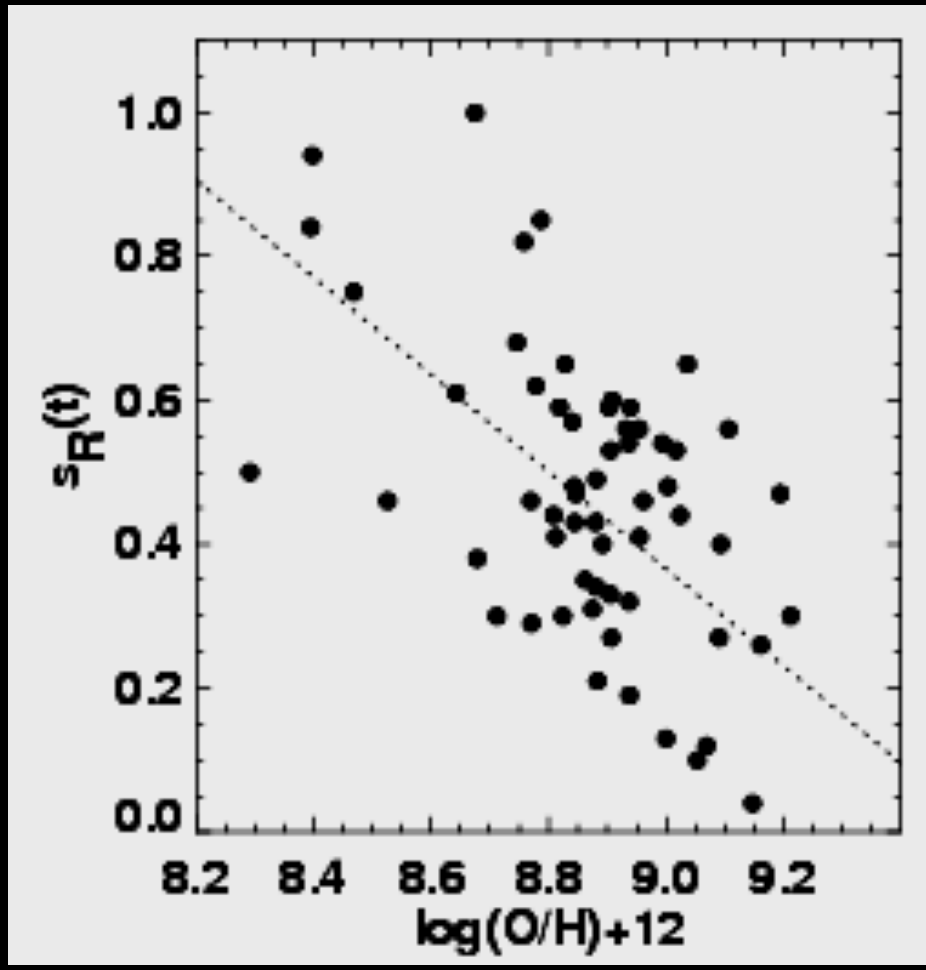

Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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Blue Bulges

Kannappan et al. (2003): "blue bulge parameter"

$$\Delta(B\text{-}R) = (B\text{-}R)_{outer} - (B\text{-}R)_{inner}$$

where

$(B\text{-}R)_{outer}$ = (B-R) at 75% light radius

$(B\text{-}R)_{inner}$ = (B-R) at 1/2 light radius

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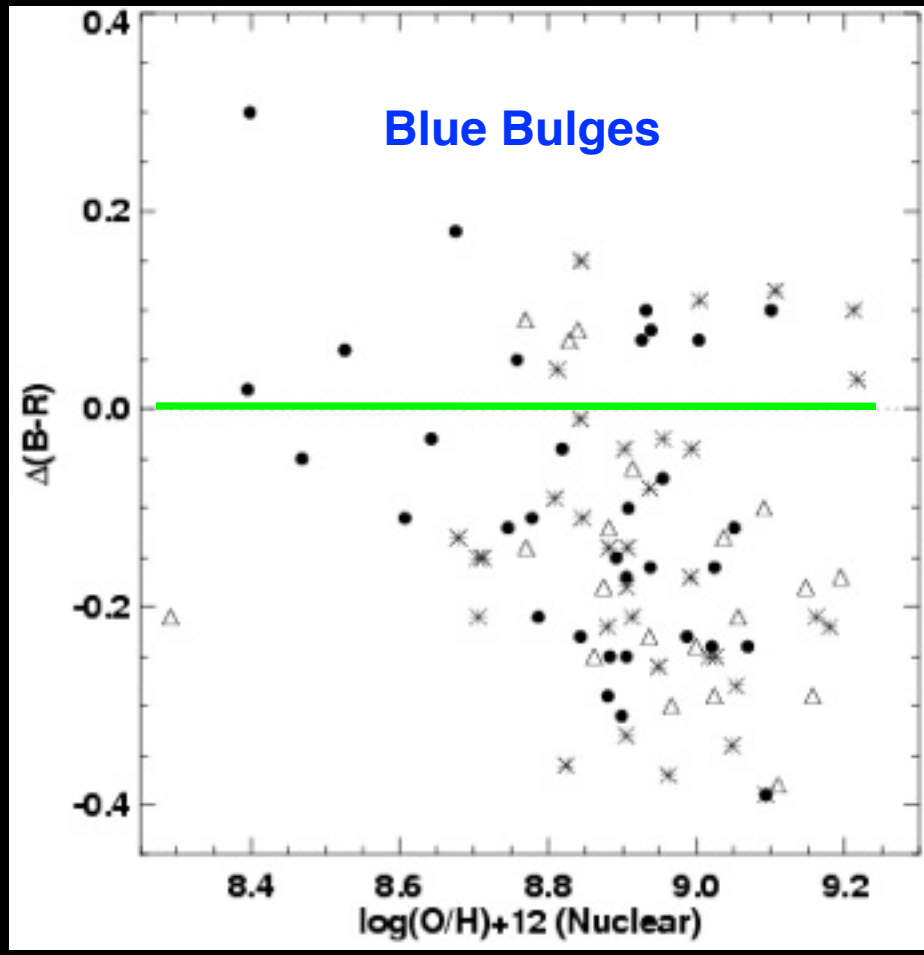
Galaxy Pairs

Luminosity-metallicity Relation

1. shifts for close pairs
2. correlated with central burst strength
3. correlated with blue bulges



Kewley, Geller, & Barton (2006, AJ, 131, 2004)

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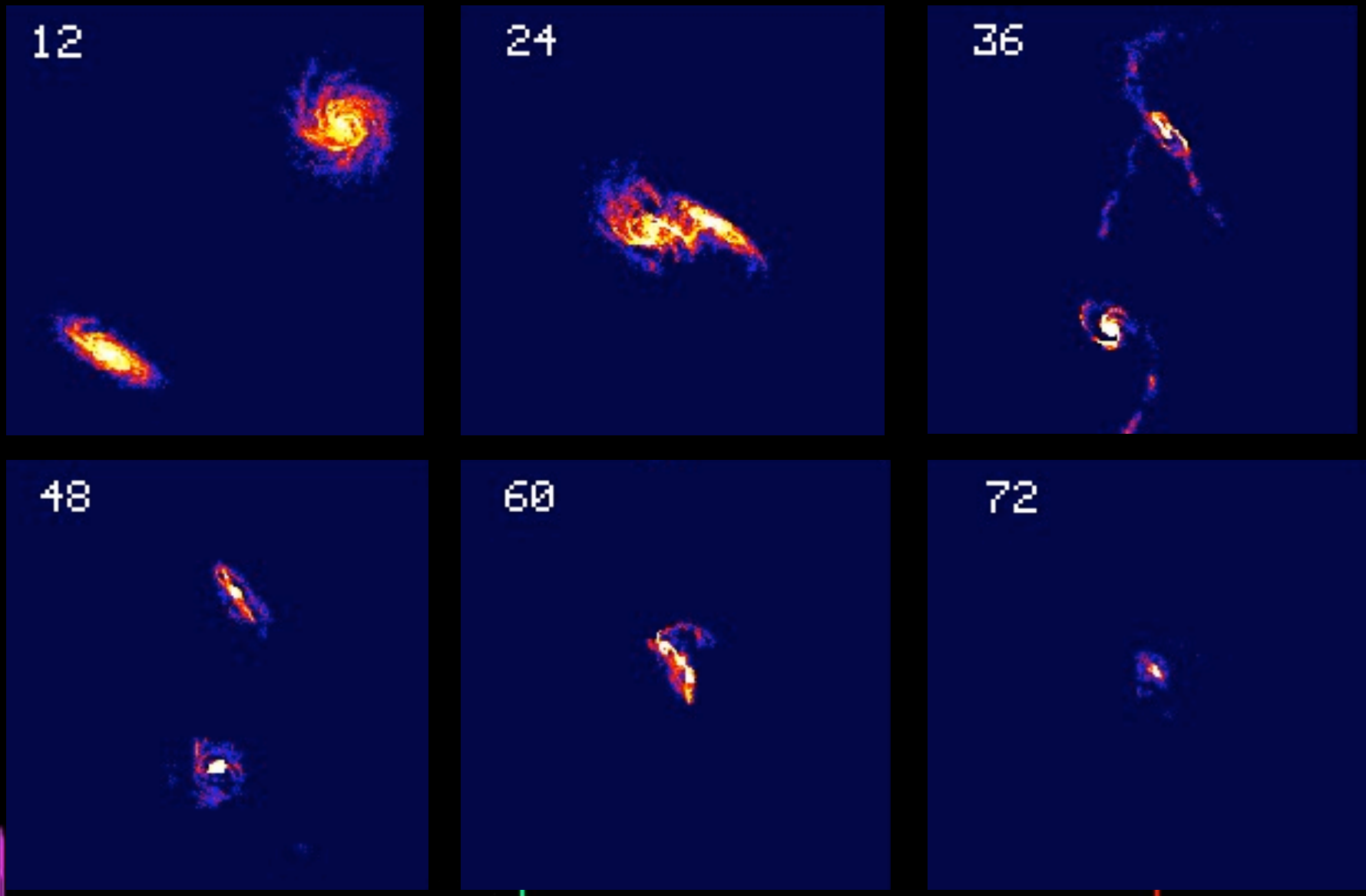
Merger Scenario



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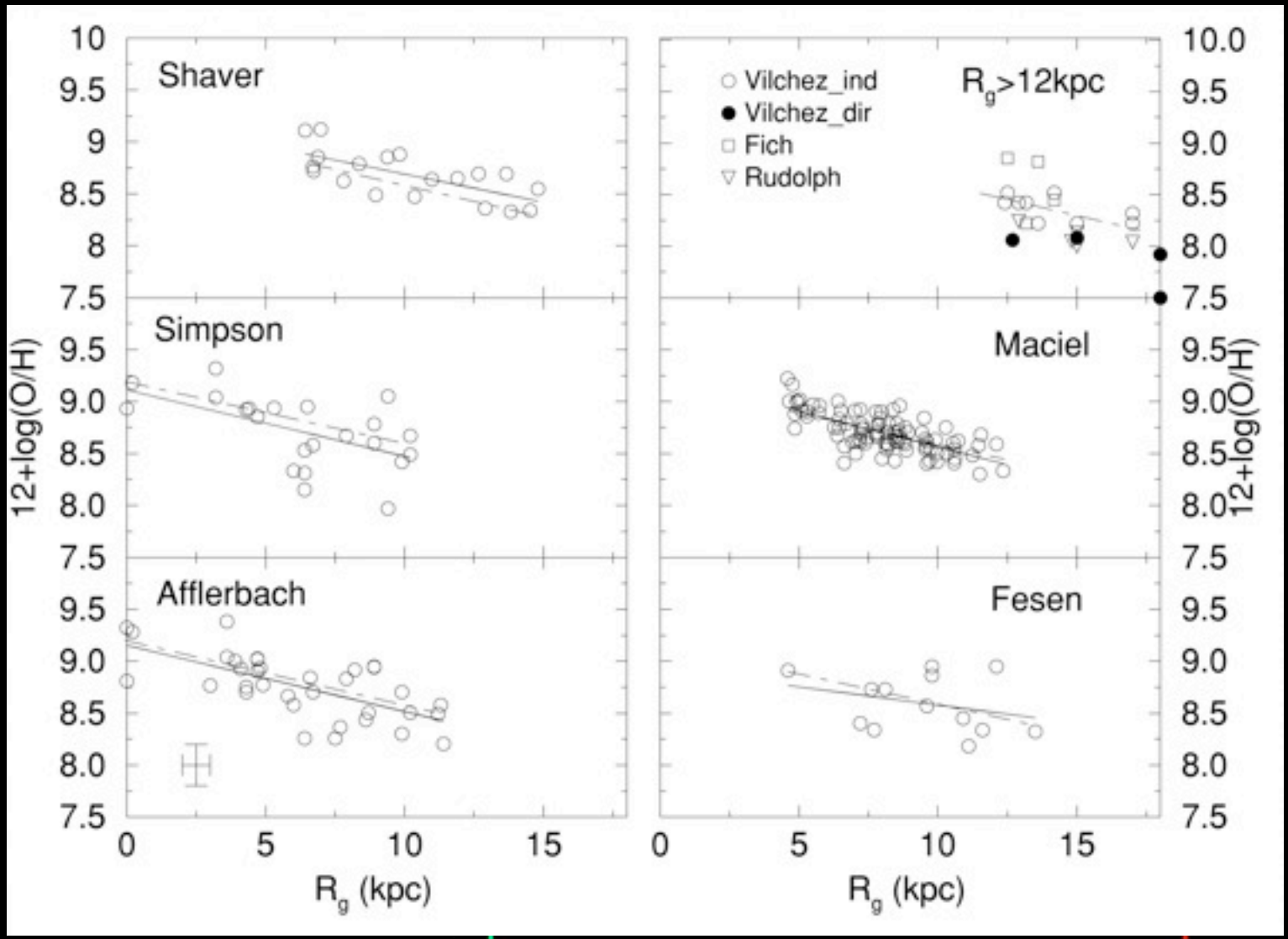
Images Courtesy Chris Mihos

Metallicity Gradients



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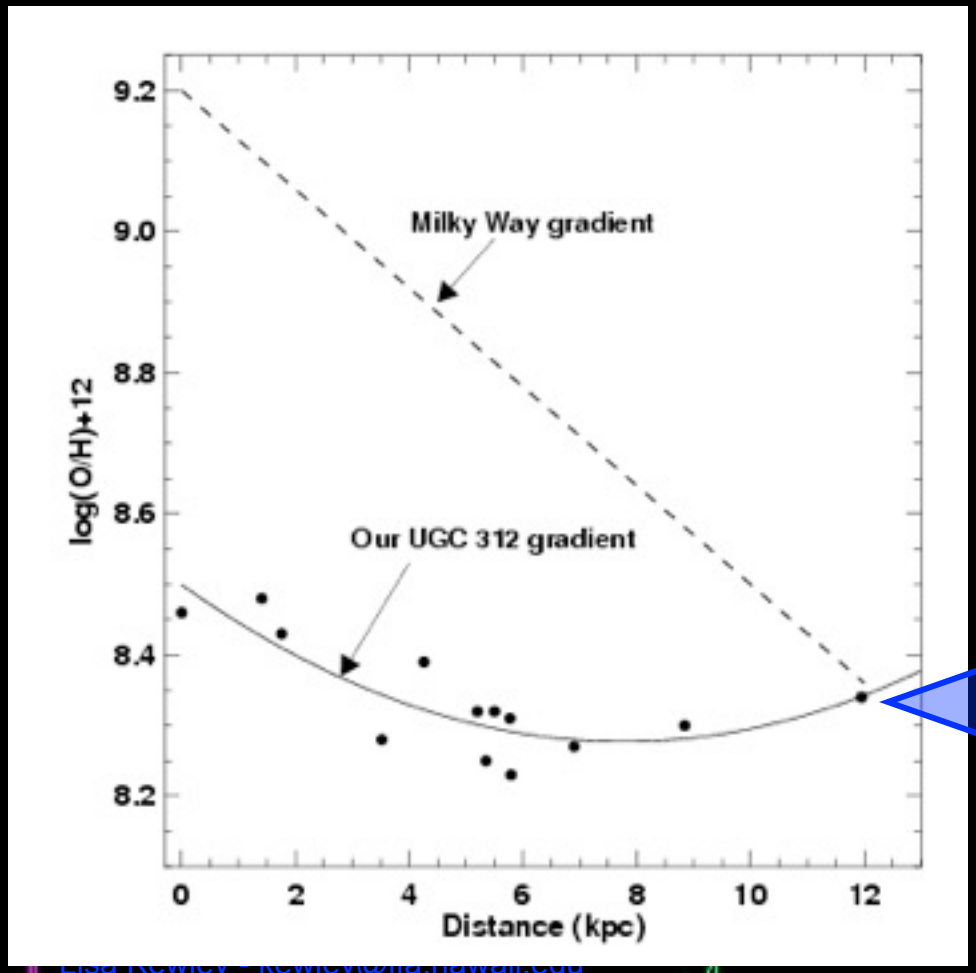
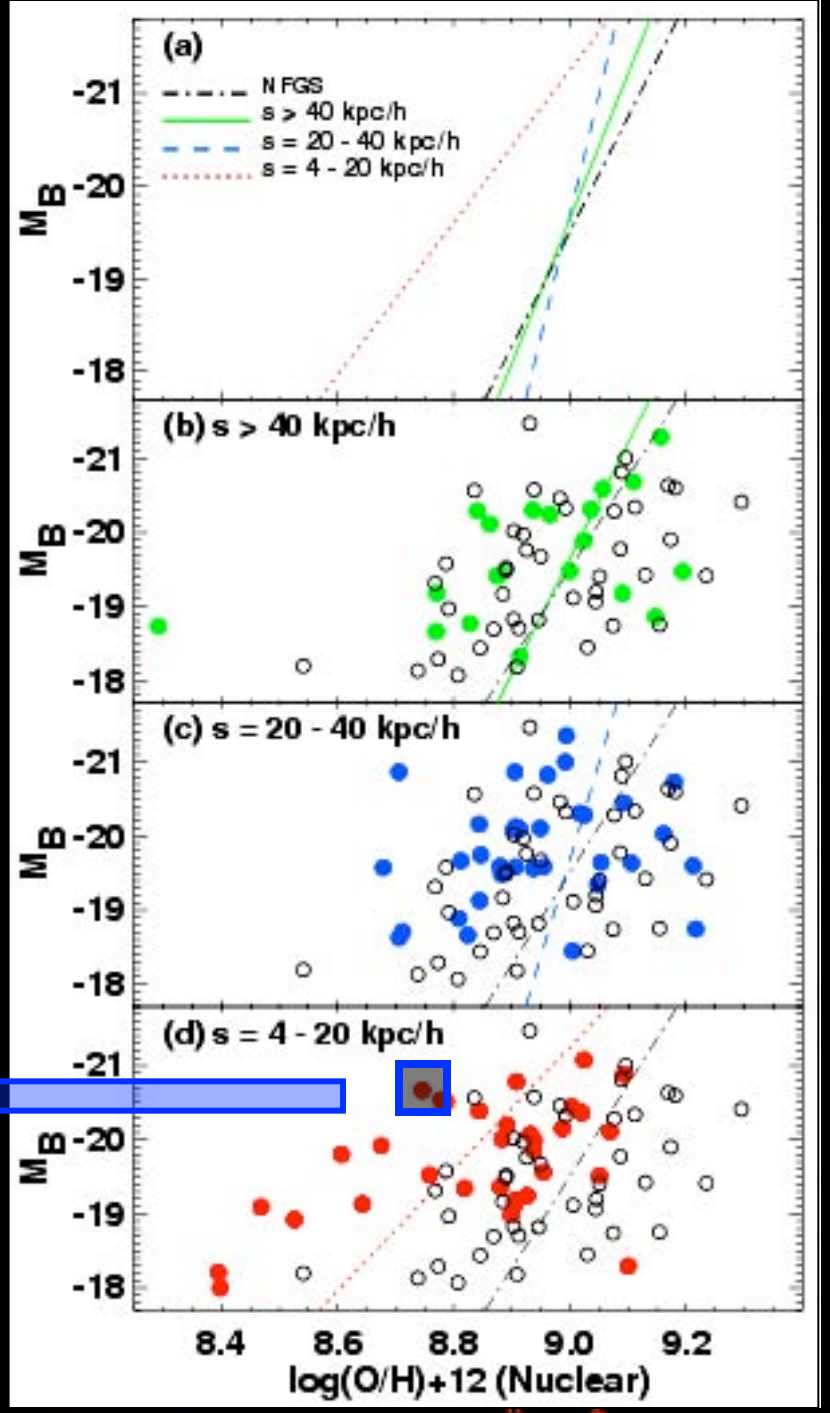
Metallicity Gradient

Keck LRIS Spectroscopy





Galaxy Pairs

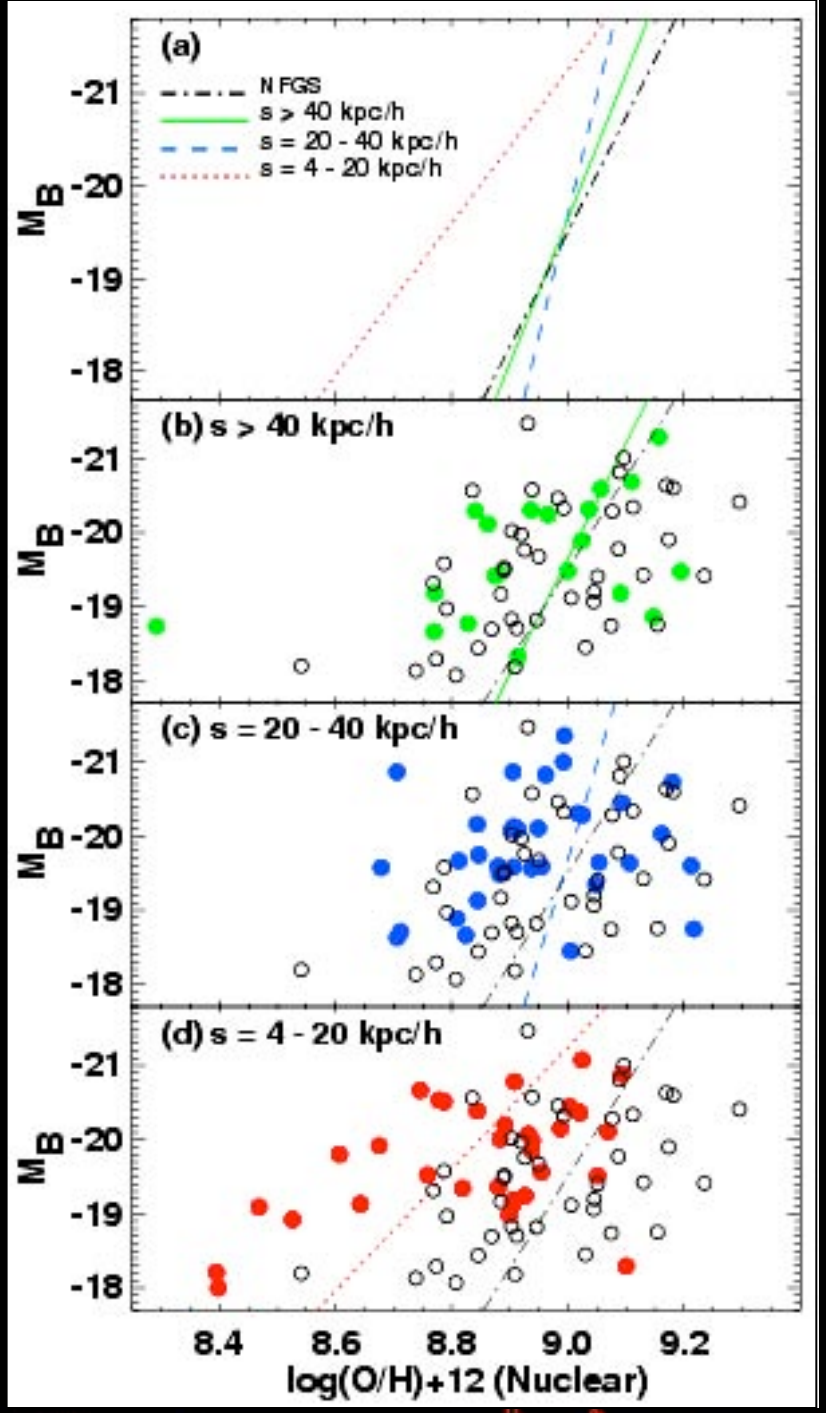
Luminosity-metallicity Relation

1. shifts for close pairs
2. correlated with central burst strength
3. correlated with blue bulges

⇩

Evidence for Gas Infall

Kewley, Geller, & Barton (2006, AJ, 131, 2004)



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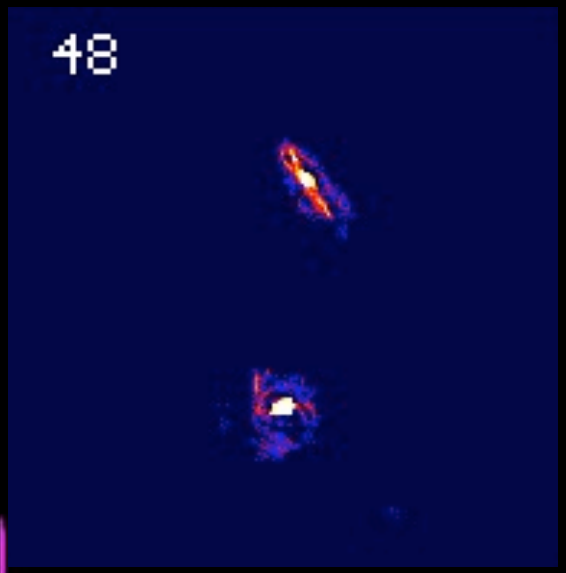
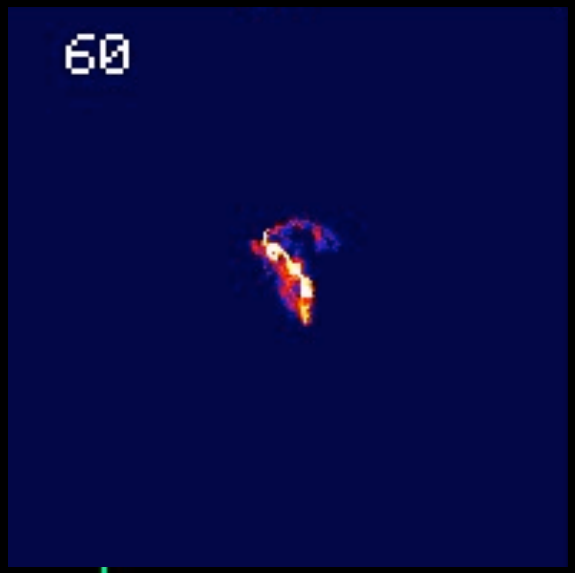
Merger Scenario

Iono et al. (2004): Simulations predict:

1. Gas inflow rate ~ 7 $M_\odot$/yr

2. Gas flows within 1st 100 Myr
but before disk merger





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Merger Scenario

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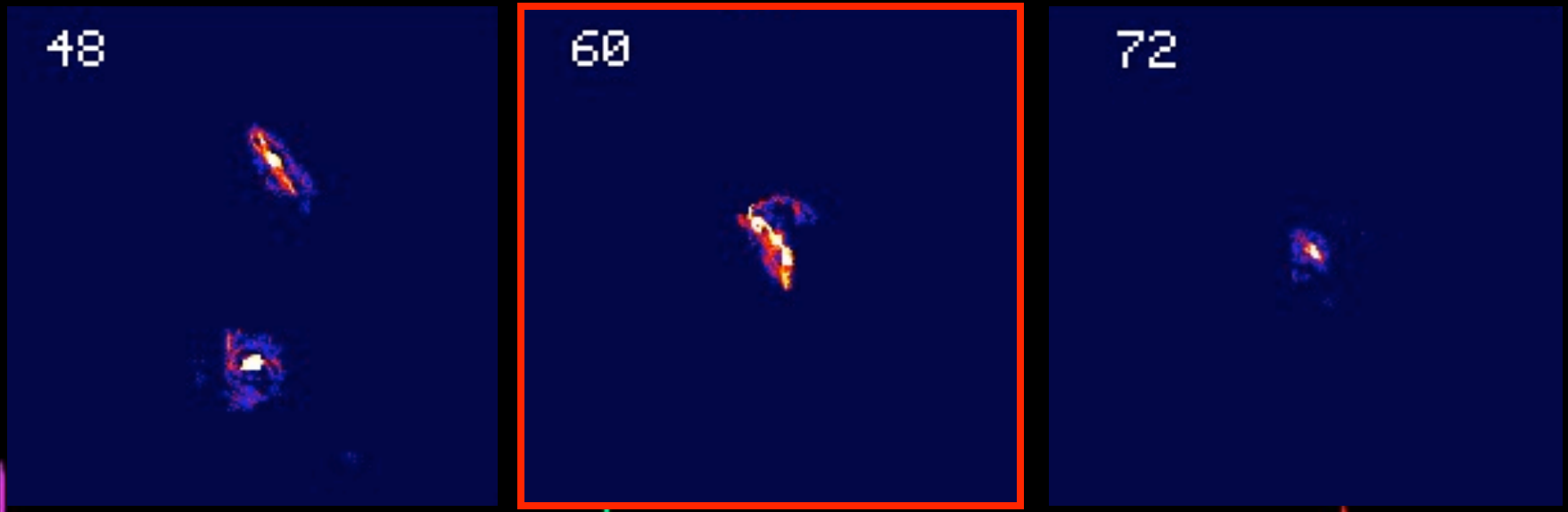

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Conclusions

- Close galaxy pairs have lower than field central metallicities

⇩

"Smoking gun" for gas infall during merger?

- Central metallicity correlates with:
  - central burst strength
  - blue bulges
- Timescale consistent with current merger simulations

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Future Directions

- Keck LRIS spectra of matched pair members
  - Lisa Chien (PhD student, U. Hawaii)
- Merger simulations of metallicity gradients

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Available Now!

Starburst99-Mappings On-Line

L. Kewley & C. Leitherer

Starburst99-Mappings Interface:
http://www.stsci.edu/science/starburst99/
Mappings Interface:

http://www.ifa.hawaii.edu/~kewley/Mappings

Pre-run model grids

Interactive web form to run models

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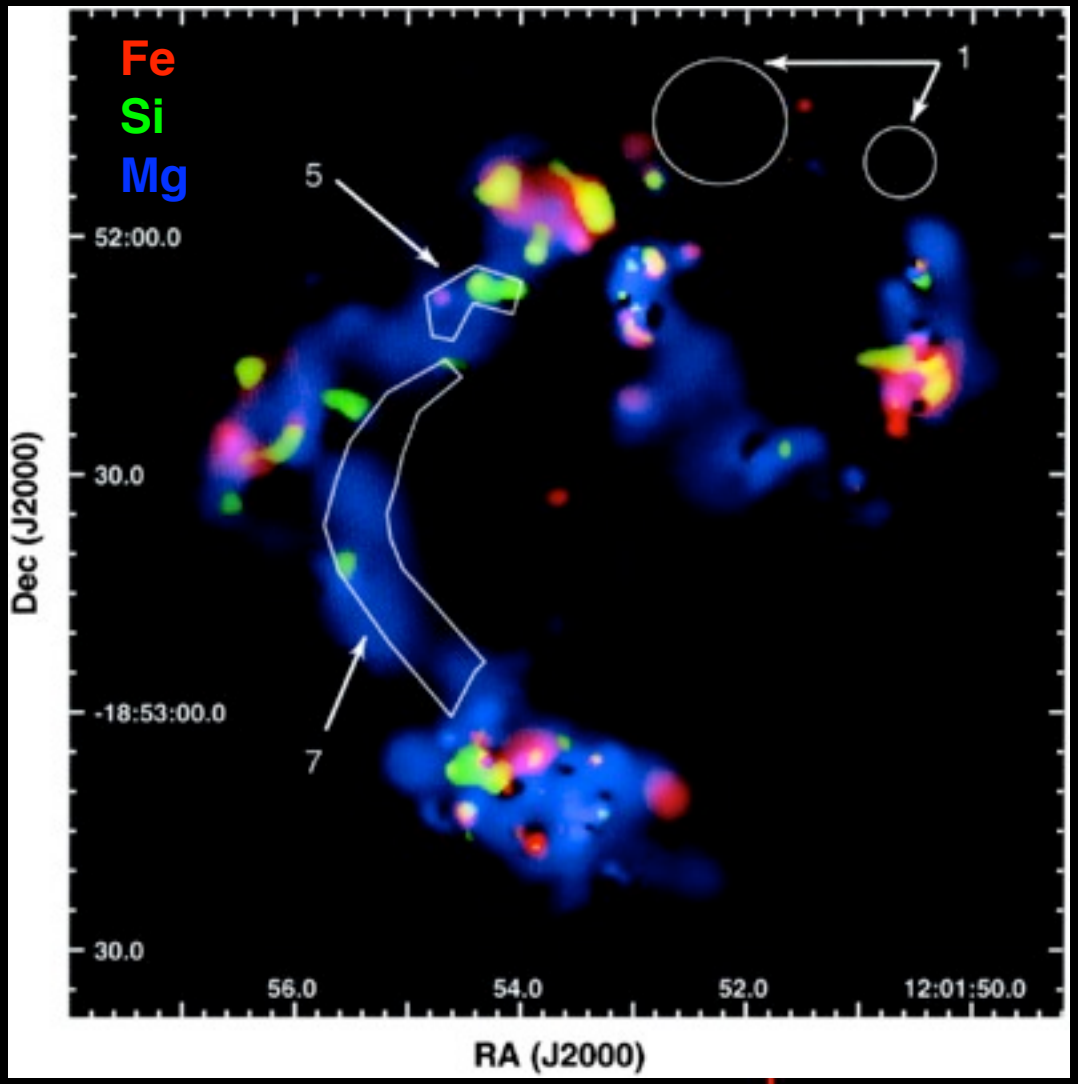
Motivation

Effect of mergers on metallicity is unknown



Fabbiano et al. (2004)

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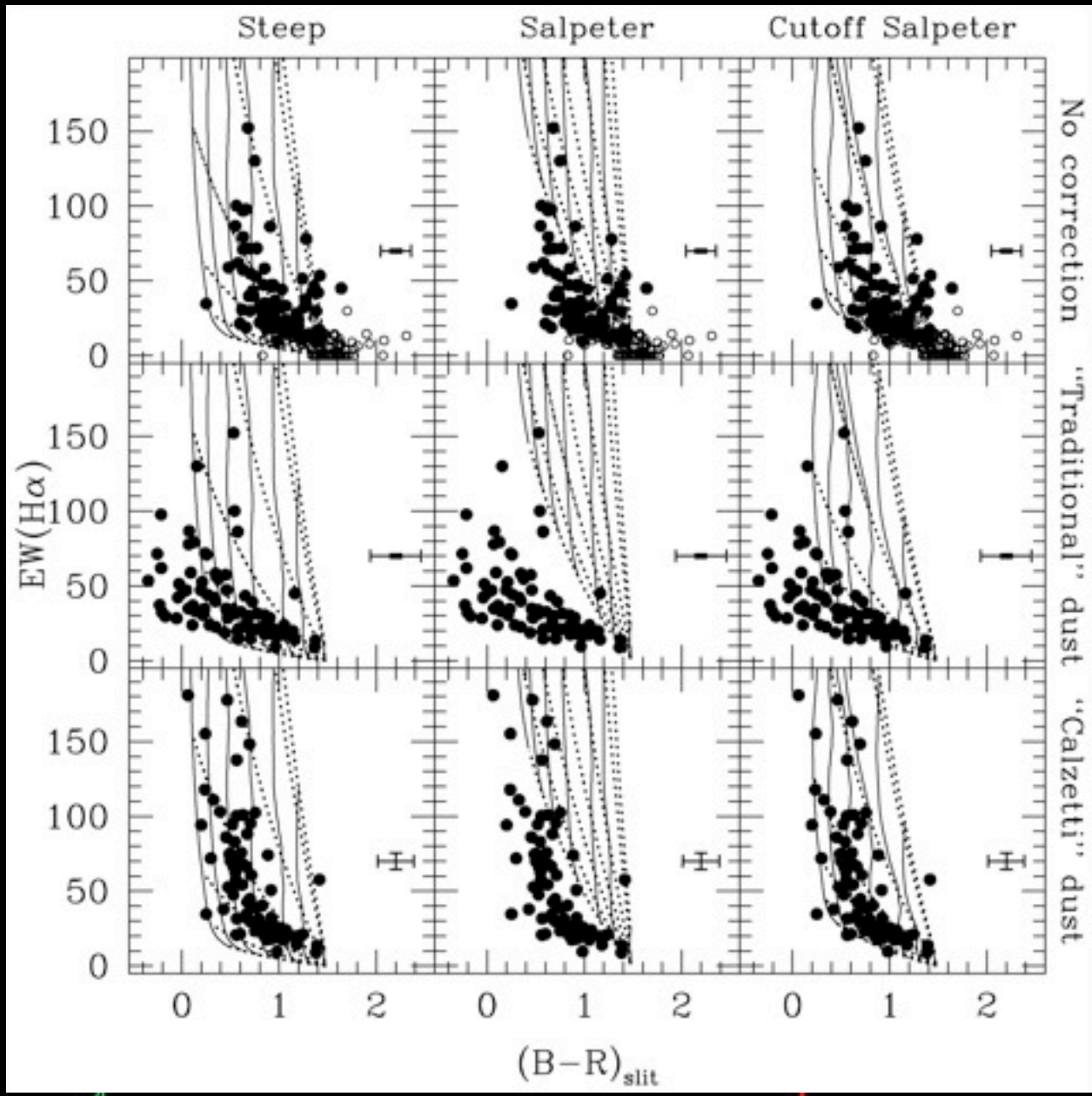
Central Burst



Barton, Geller & Kenyon (2003)

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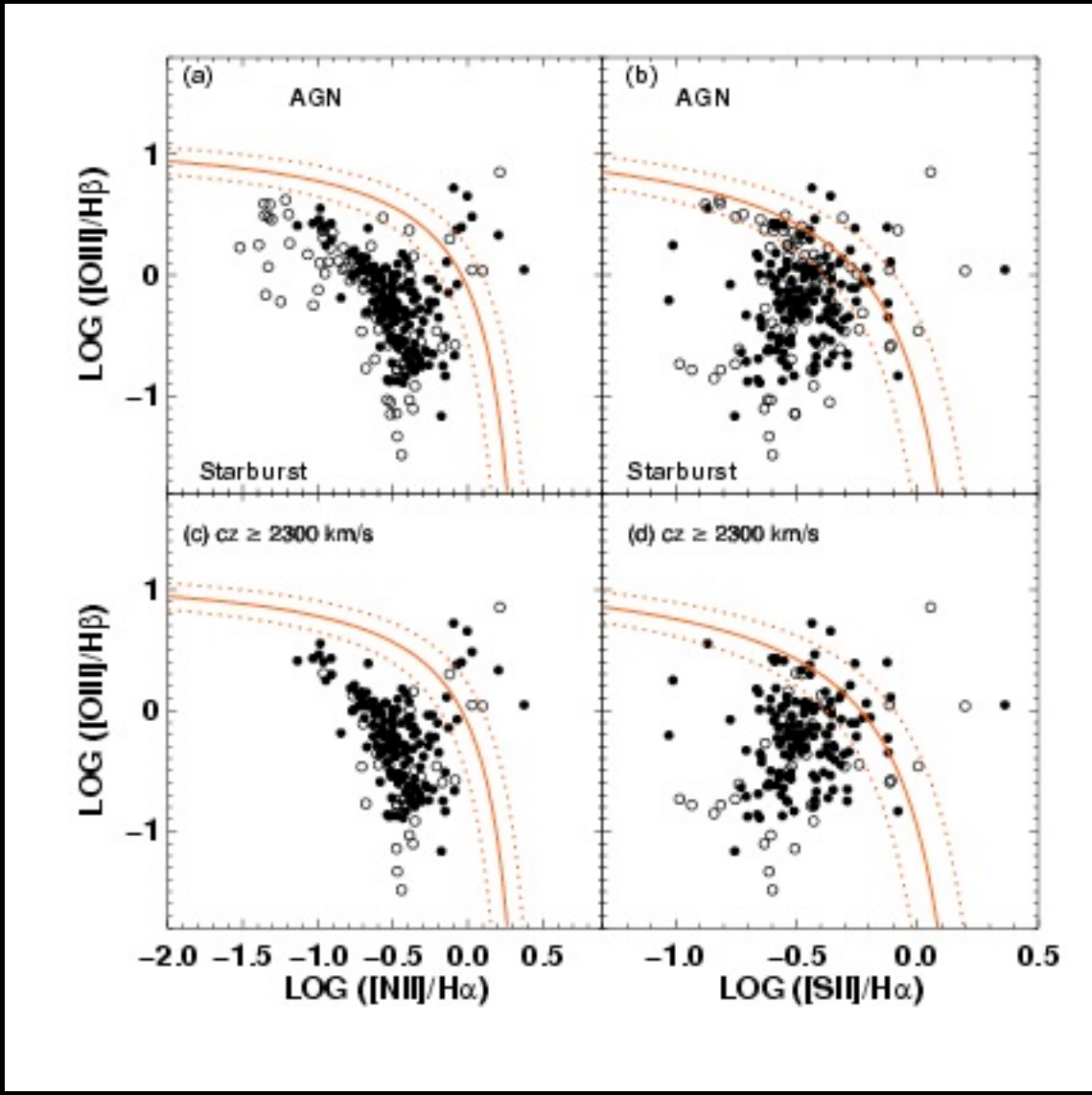
Classification Scheme



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New Theoretical Models

Josefa Perez et al. (2006, astro-ph/0605131)

- Chemical evolution model (Scannappieco et al. 2005)
- Λ–CDM model (GADGET-2; Springel & Hernquist 2003)
- Lower mean central (O/H) in pairs from inflows

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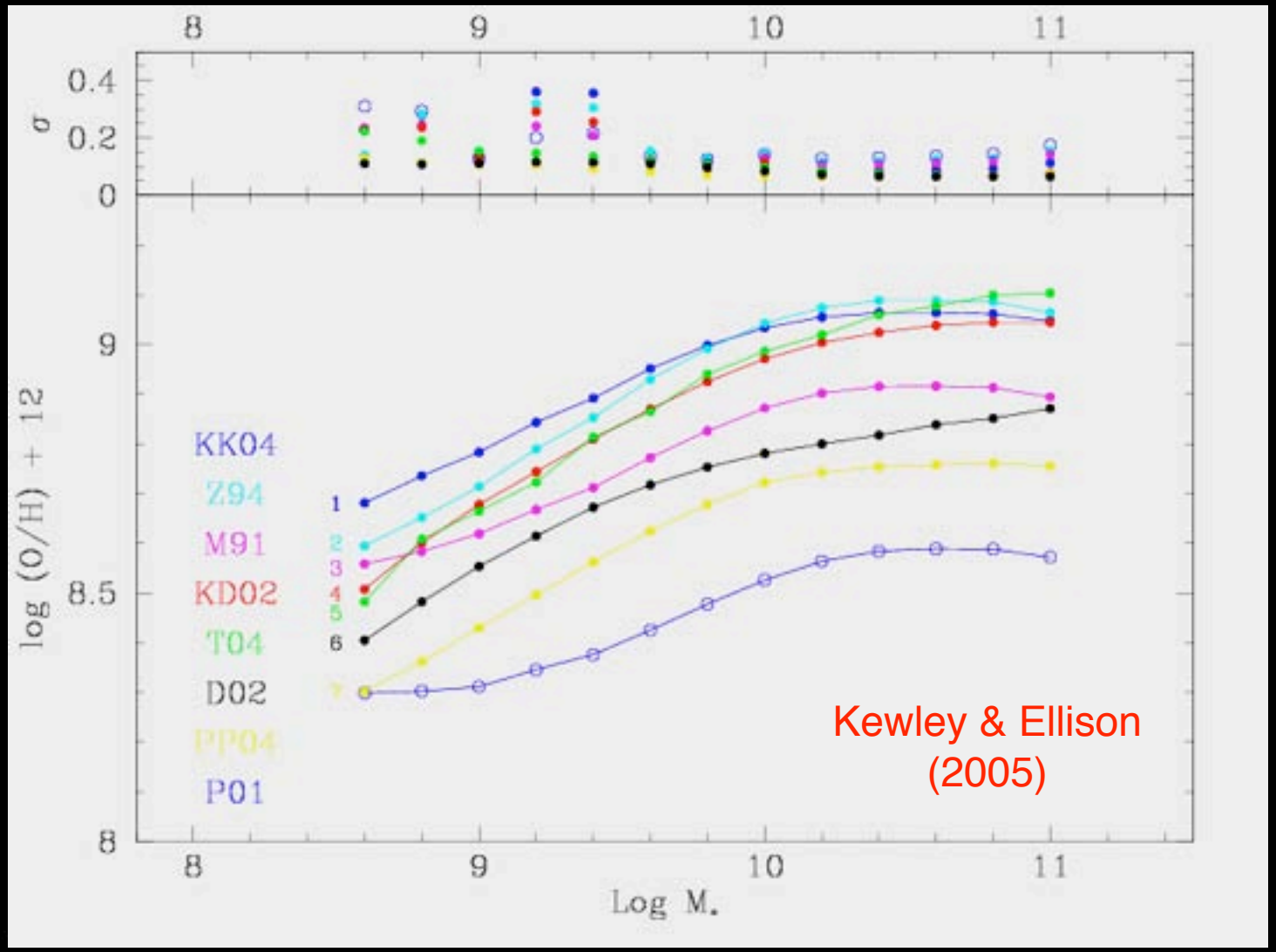
Metallicity Diagnostic Comparisons



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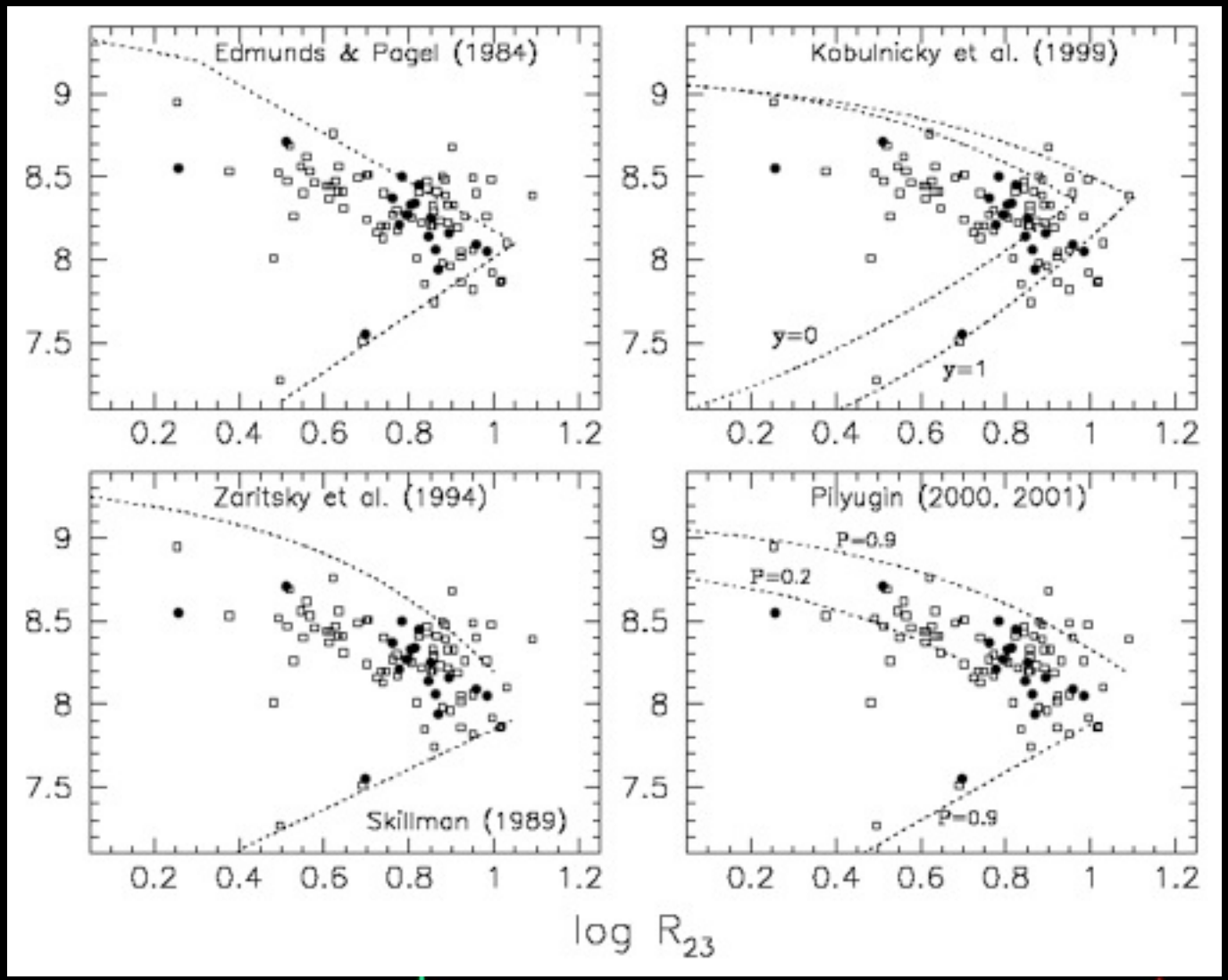
Metallicity: Strong lines vs Auroral Lines



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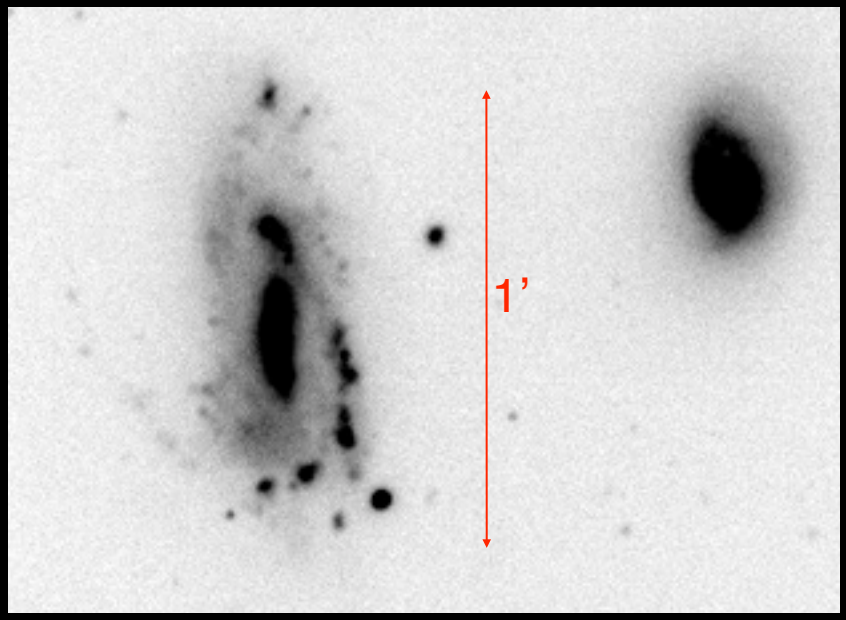
Garnett, Kennicutt, Bresolin

Galaxy Pairs



Luminosity-metallicity Relation

1. shifts for close pairs
2. correlated with central burst strength
3. correlated with blue bulges

⇩

Evidence for Gas Infall

Kewley, Geller, & Barton (2005, AJ, submitted)

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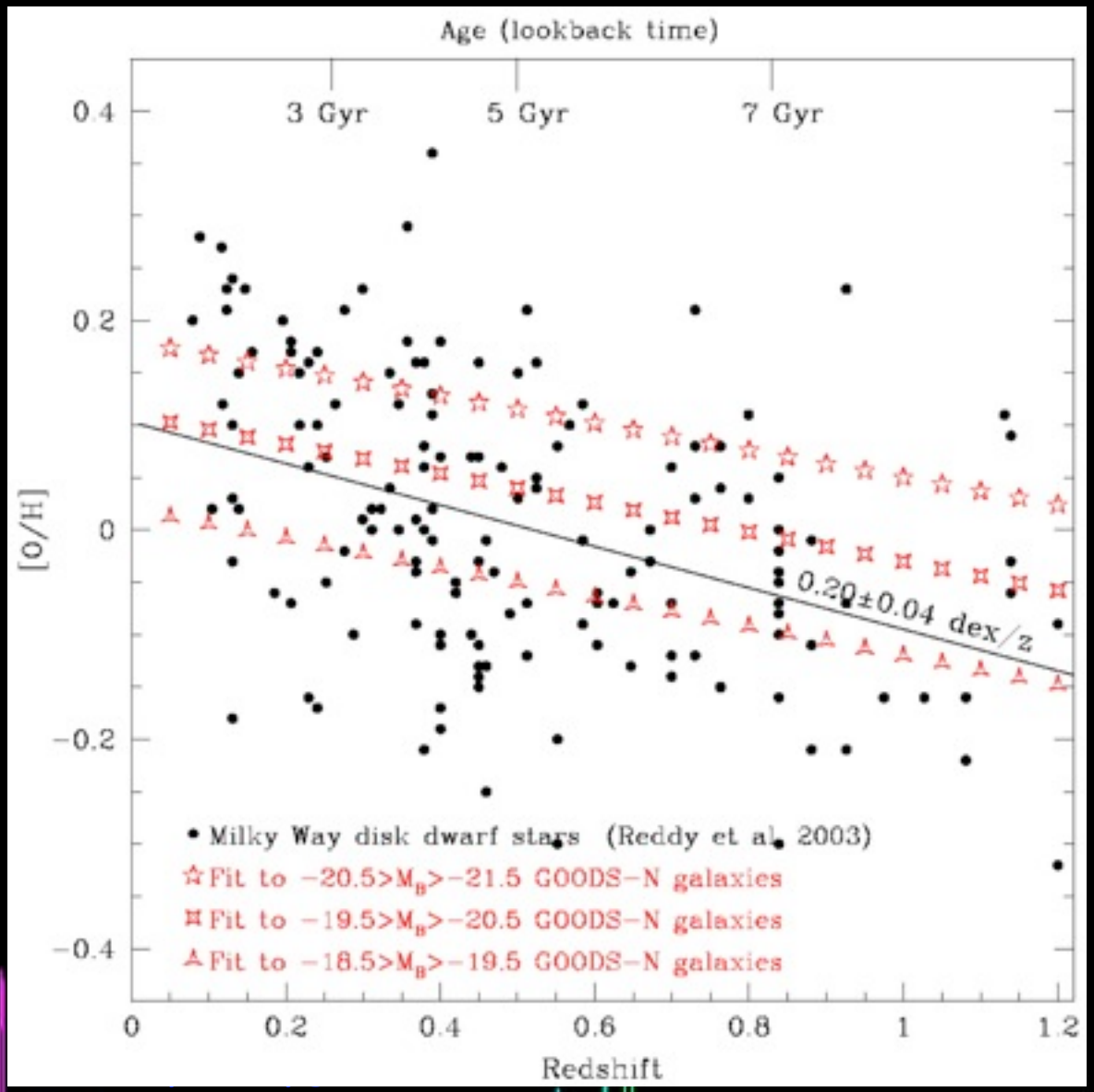
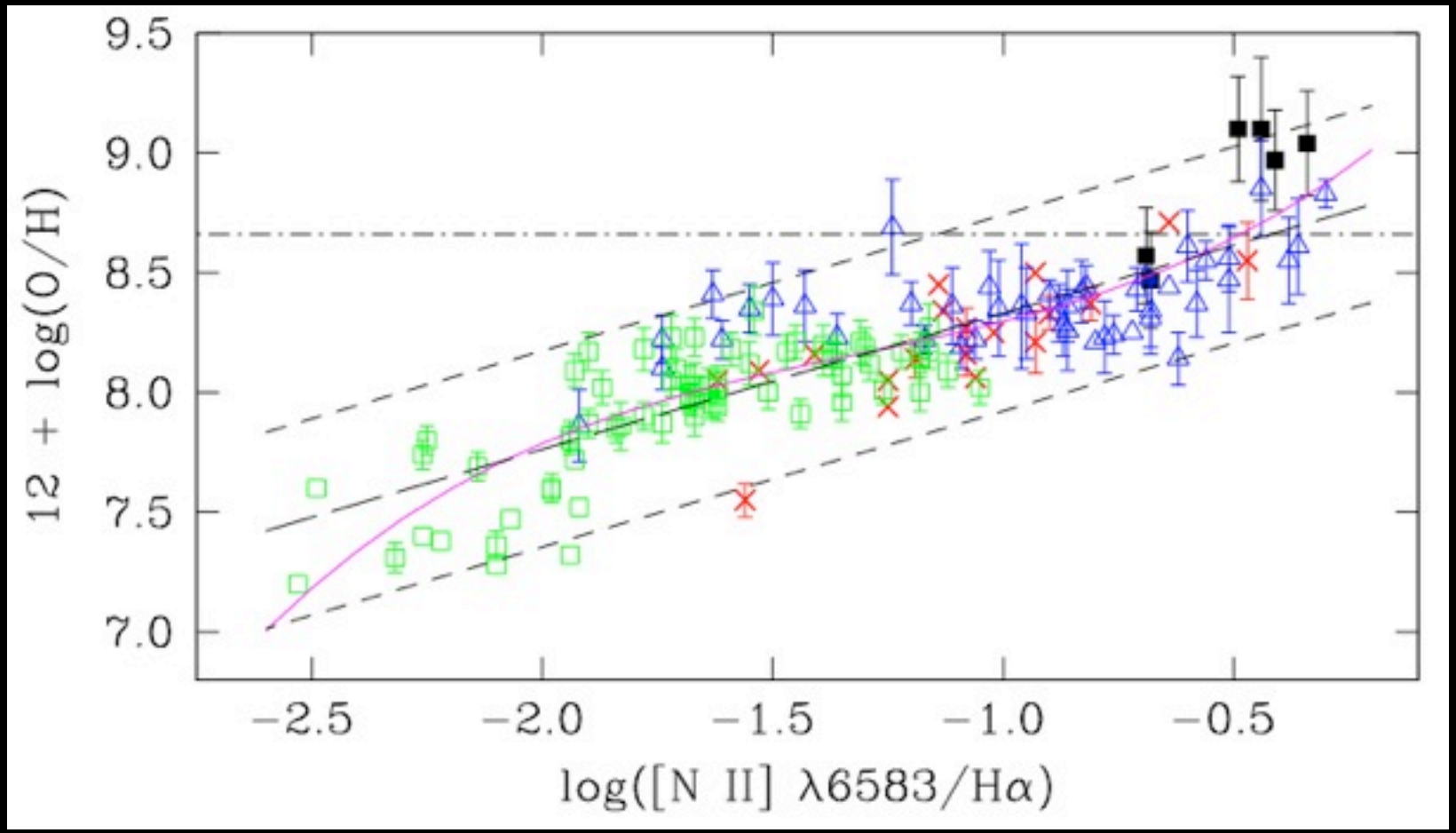
GOODS Survey: 0.3 < z< 1



Kobulnicky & Kewley (2004, ApJ, 617,240)

Metallicity - [NII]/Ha



Pettini & Pagel (2004)

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Metallicity Diagnostics

1. Theoretical - photoionization models

   e.g., McGaugh (1991), Kewley & Dopita (2002), Tremonti et al. (2004)

2. Empirical - fit to T_e metallicities

   e.g., Pilyugin (2000), Pettini & Pagel (2004)

- Combination - fit to T_e method + theoretical metallicities

  e.g., Denicolo, Terlevich & Terlevich (2002)

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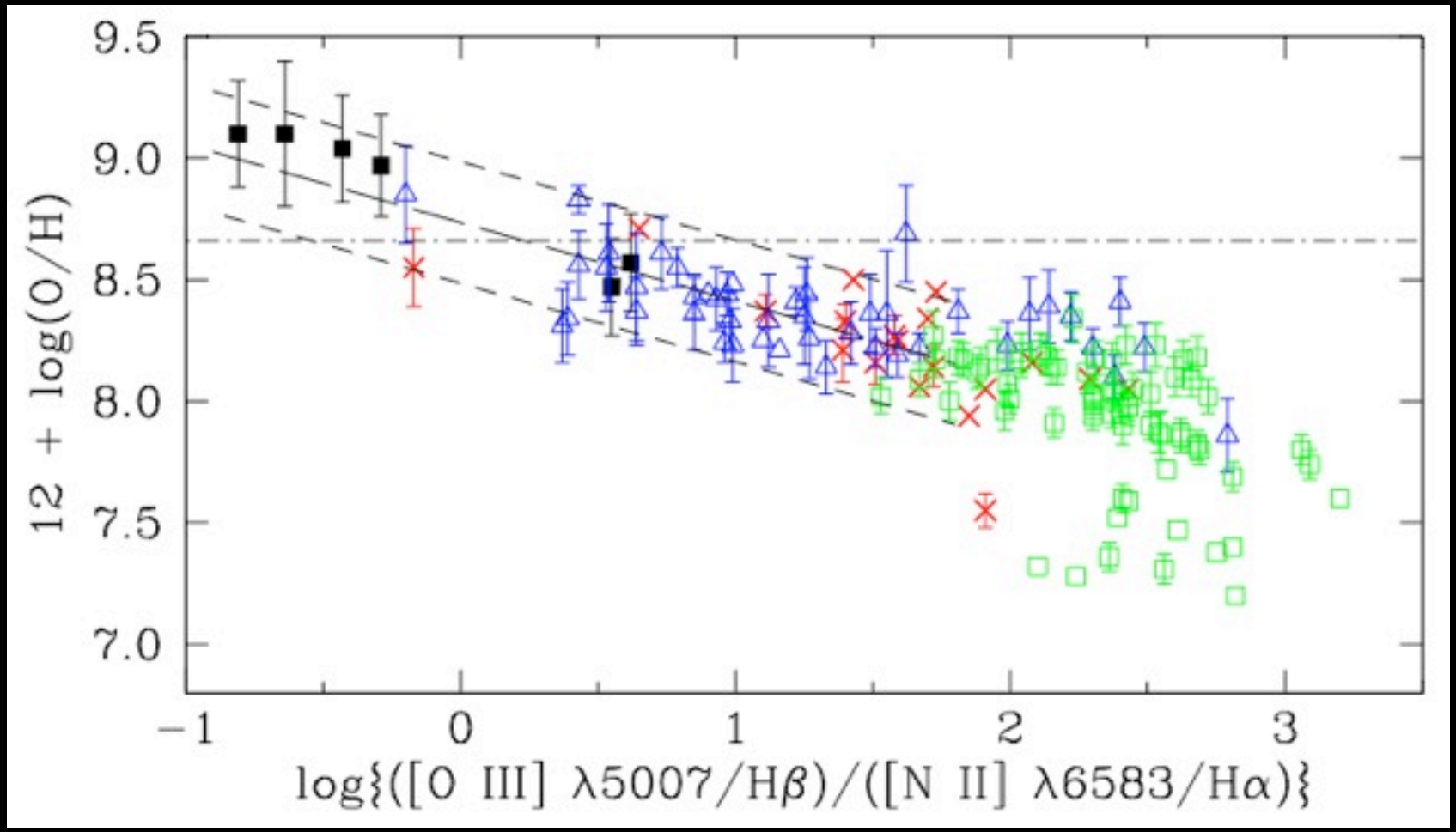
Metallicity - [OIII]/Hb,[NII]/Ha



Pettini & Pagel (2004)

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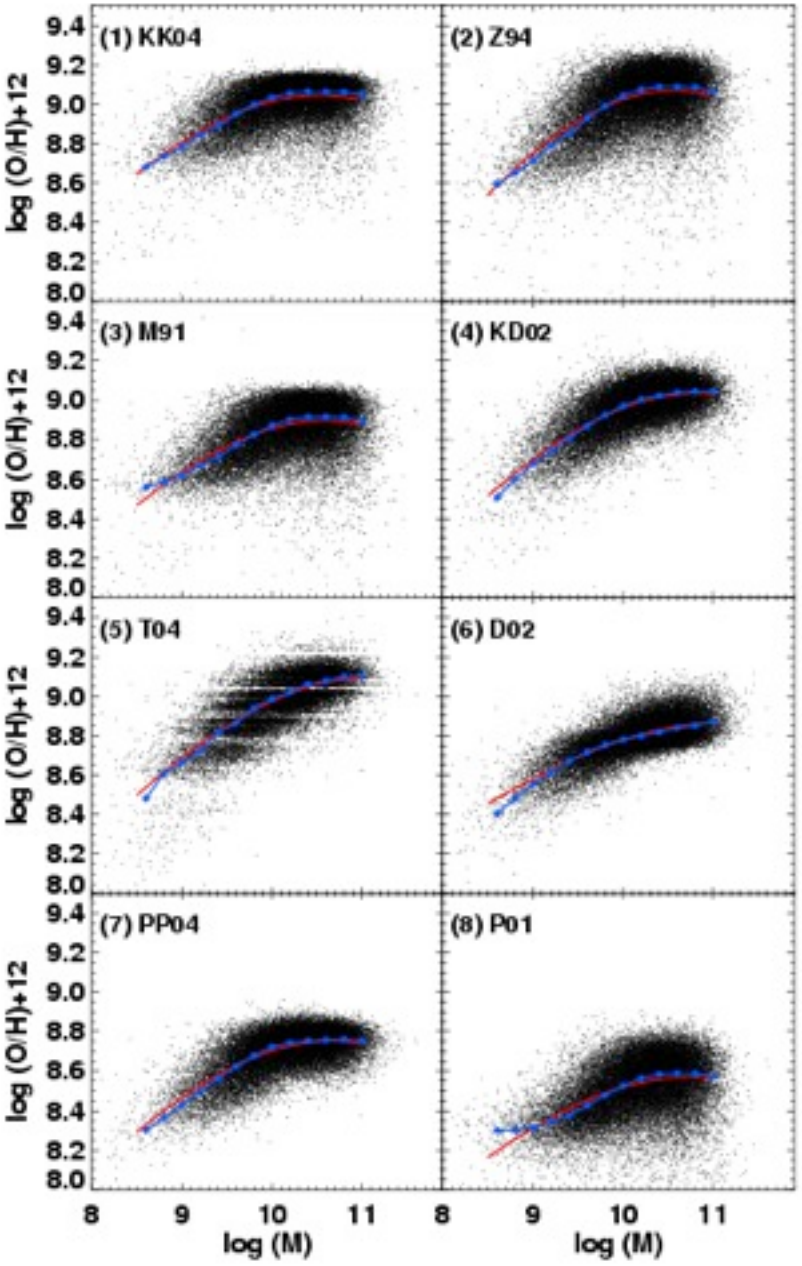
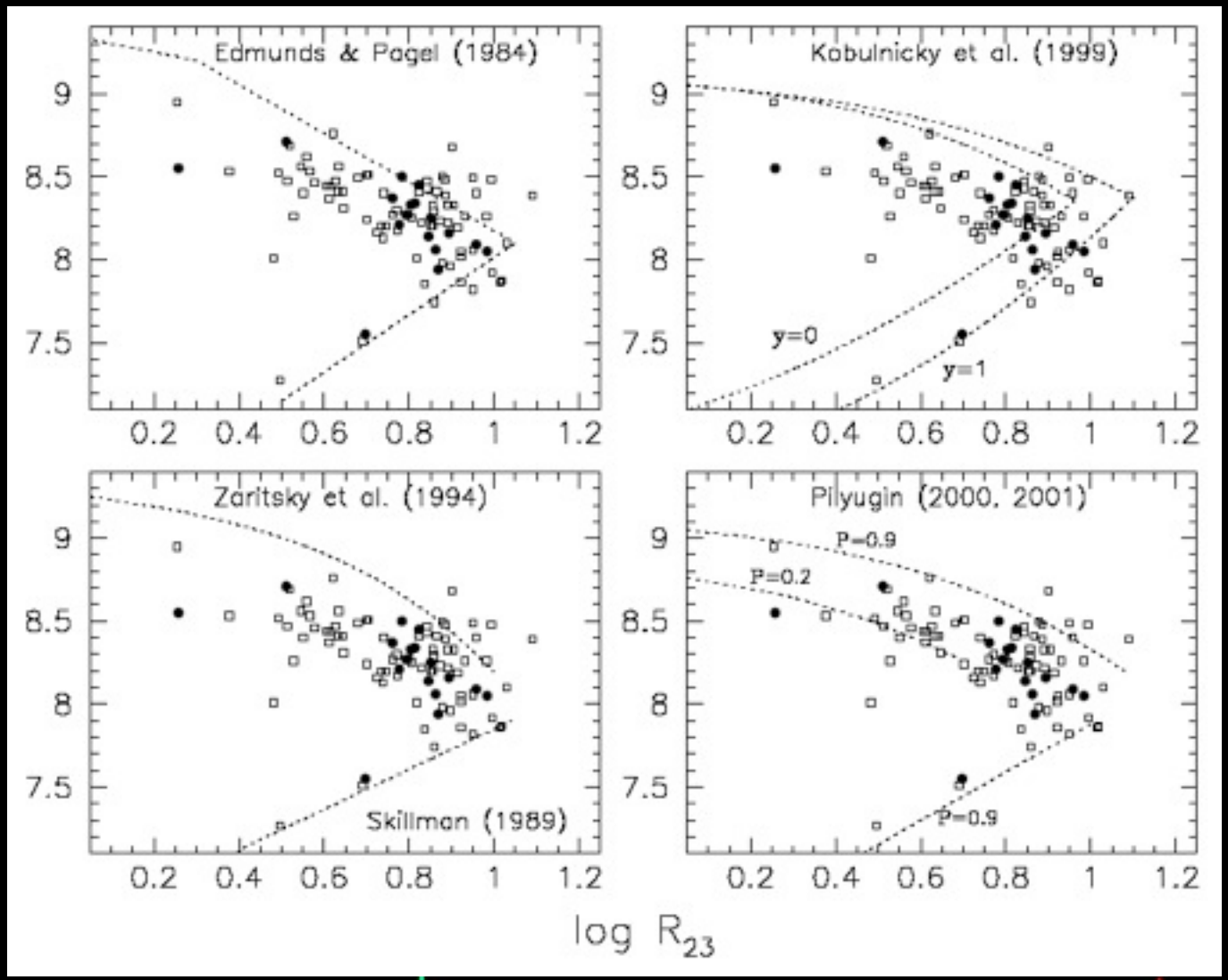
Metallicity Diagnostic Comparisons



Kewley & Ellison (2005, in prep)

Metallicity: Strong lines vs Auroral Lines



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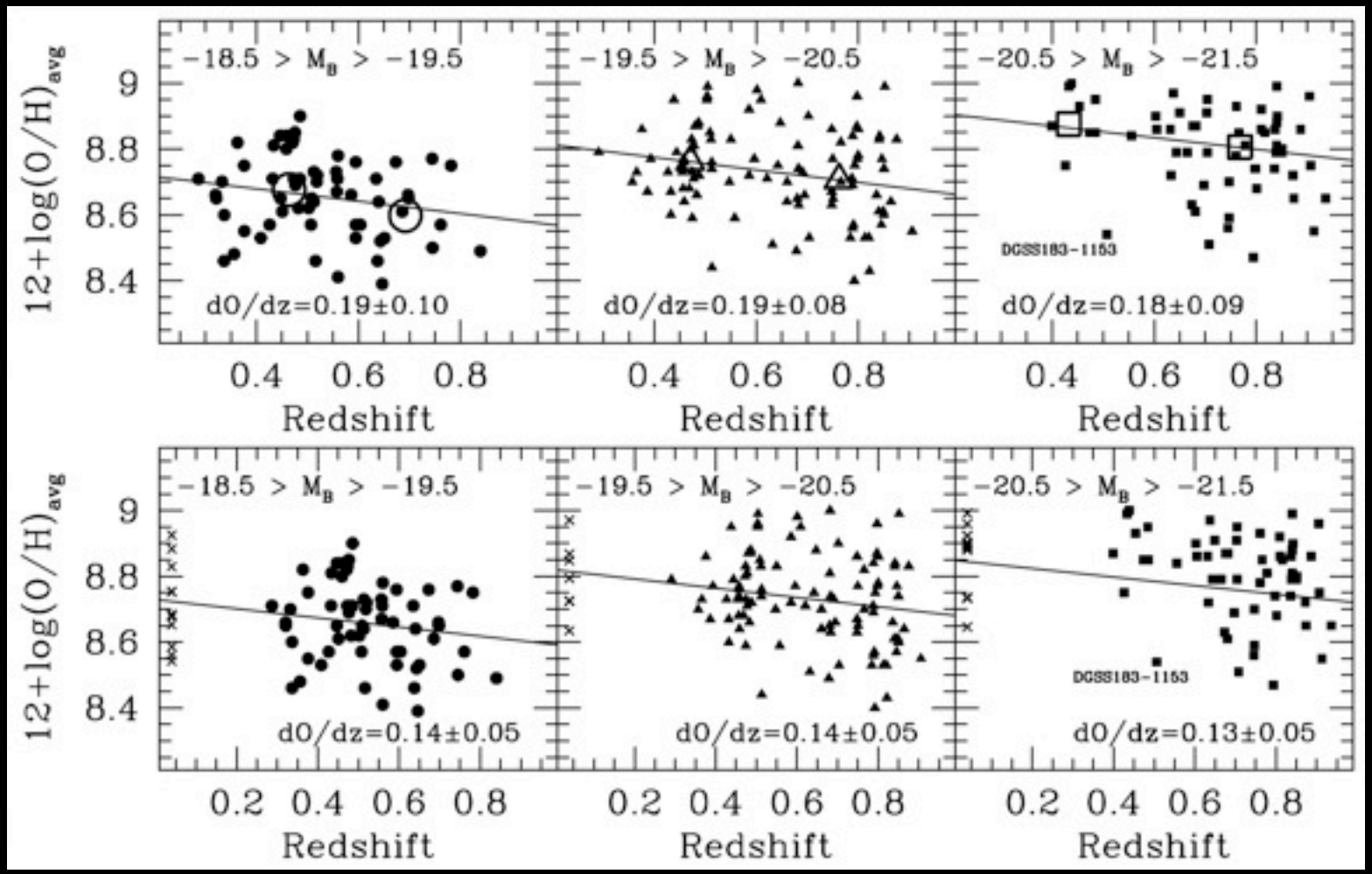
Garnett, Kennicutt, Bresolin

GOODS Survey: 0.3 < z< 1



Kobulnicky & Kewley (2004, ApJ, 617, 240)

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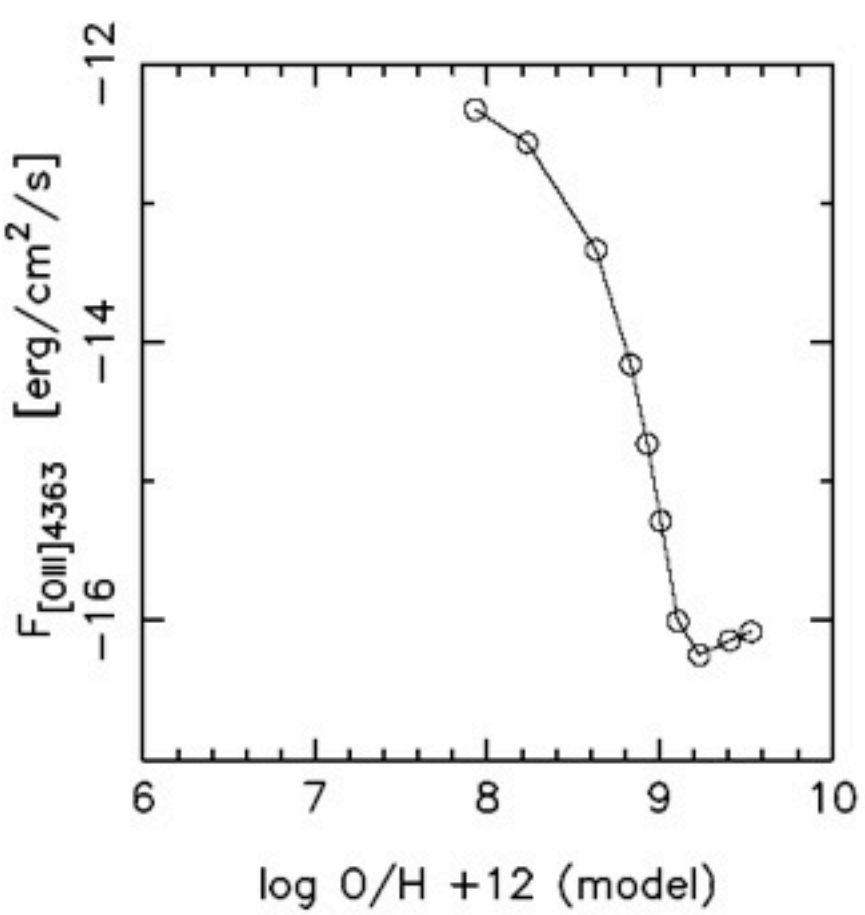
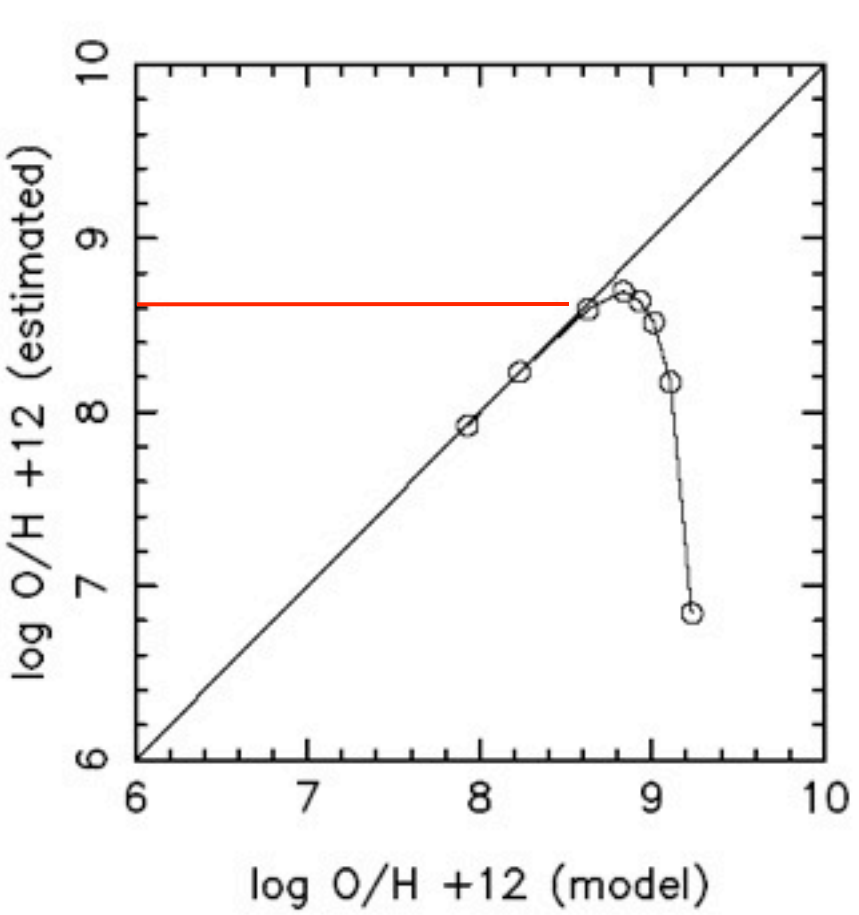
Auroral Line Saturation





Stasinska (2002,2005)

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