The Local Cluster Survey

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The Collaboration

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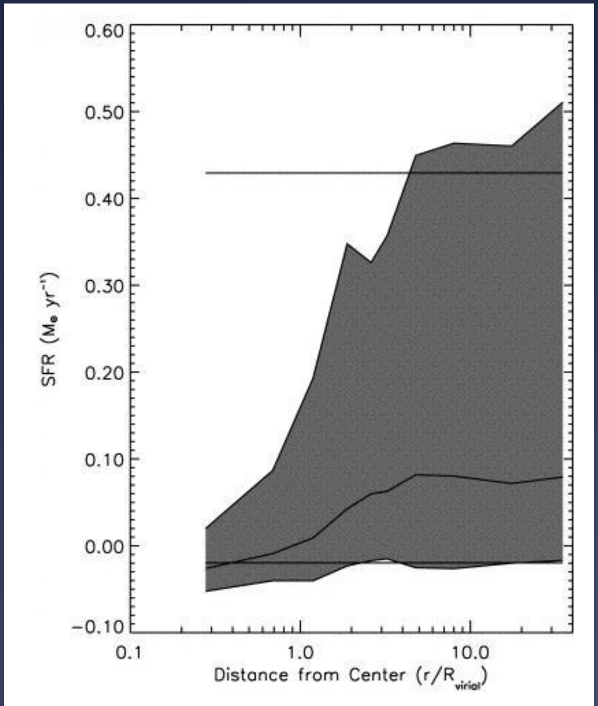
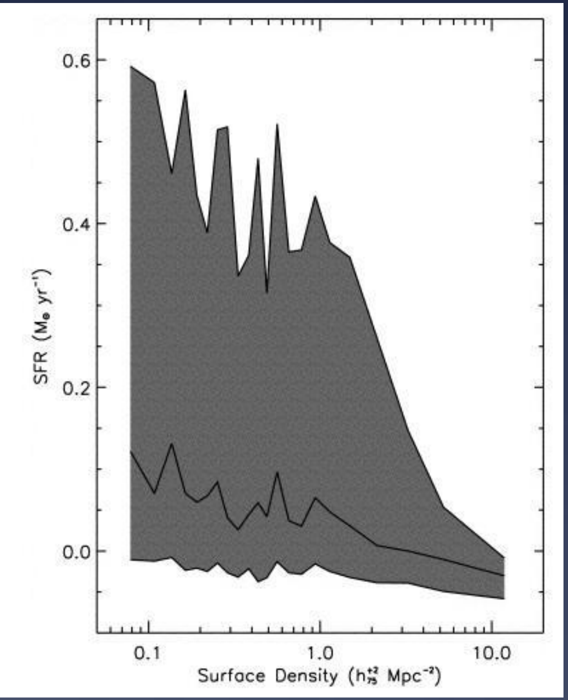
Scientific Motivation

* Galaxies in dense environments have lower average star-formation rates (SFRs) than field galaxies at least out to $z \sim 1$.
  (Balogh et al. 1997; Poggianti et al. 1999; Lewis et al. 2002; Gomez et al. 2003; Postman et al. 2005)
* Despite tremendous observational effort, it is not clear what physical mechanisms are driving this trend.
* Many mechanisms have been proposed for suppressing star- formation in galaxies, and their effectiveness varies with environment.

Conflicting Results from Local Surveys





- The SDSS and 2dF surveys show that the average SFR starts to decline at group densities, which are comparable to the density at 3 – 4 times the cluster virial radius (Lewis et al. 2002; Gomez et al. 2003).
- These results suggest a group-based mechanism is driving evolution from star-forming to quiescent, and that *clusters play a minimal role*.

A different view: The Virgo Cluster

- Spiral galaxies in the Virgo cluster show evidence of cold gas stripping and truncated star formation.
  (Koopmann & Kenney 1998, 2004; Dale et al. 2001; Crowl et al. 2005; Chung et al. 2007)
- Shows clearly that the cluster environment is actively altering the star-formation properties of infalling galaxies.

How star-formation rates are measured is important!

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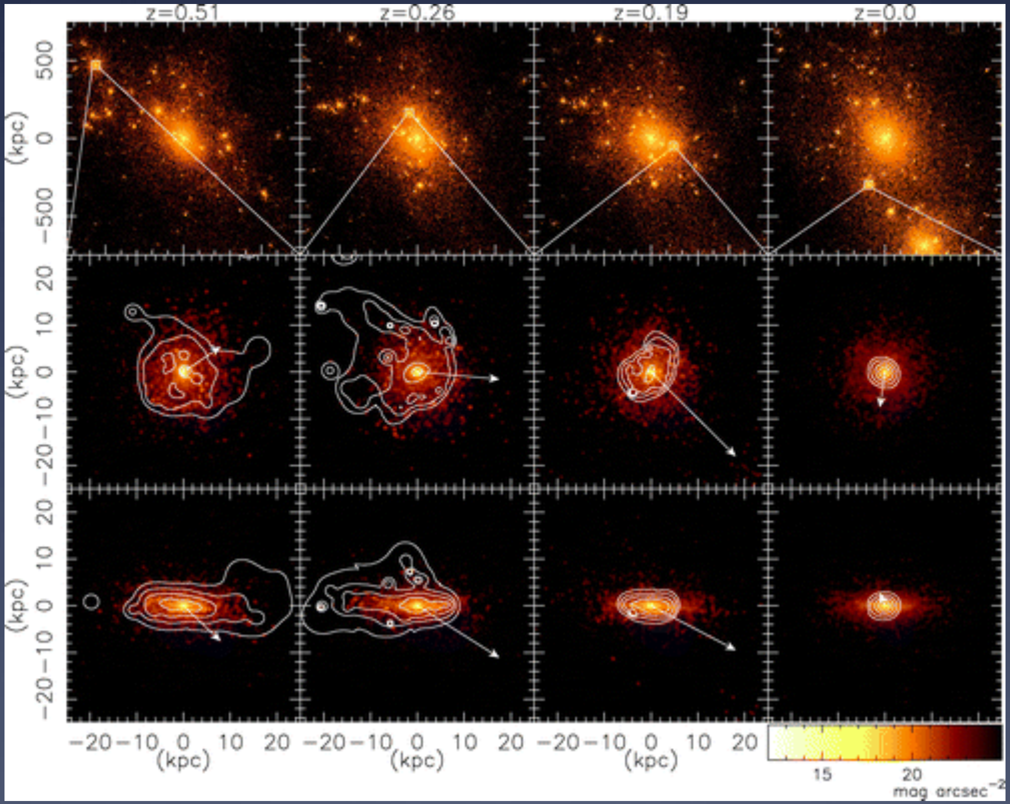
How to measure SFRs

* Virgo studies are based on resolved Hα or HI maps
* 2dF and SDSS determine star-formation rates from fiber spectroscopy
* This is significant because starvation and ram-pressure stripping of cold gas generically predict that star formation in the edges of galaxies will be affected more strongly than star formation near the centers of galaxies.

Simulations of Starvation

- Simulation of galaxy falling into a group from Kawata & Mulchaey (2008).
- Contours show cold gas.
- Perimeter of galaxy is most affected.



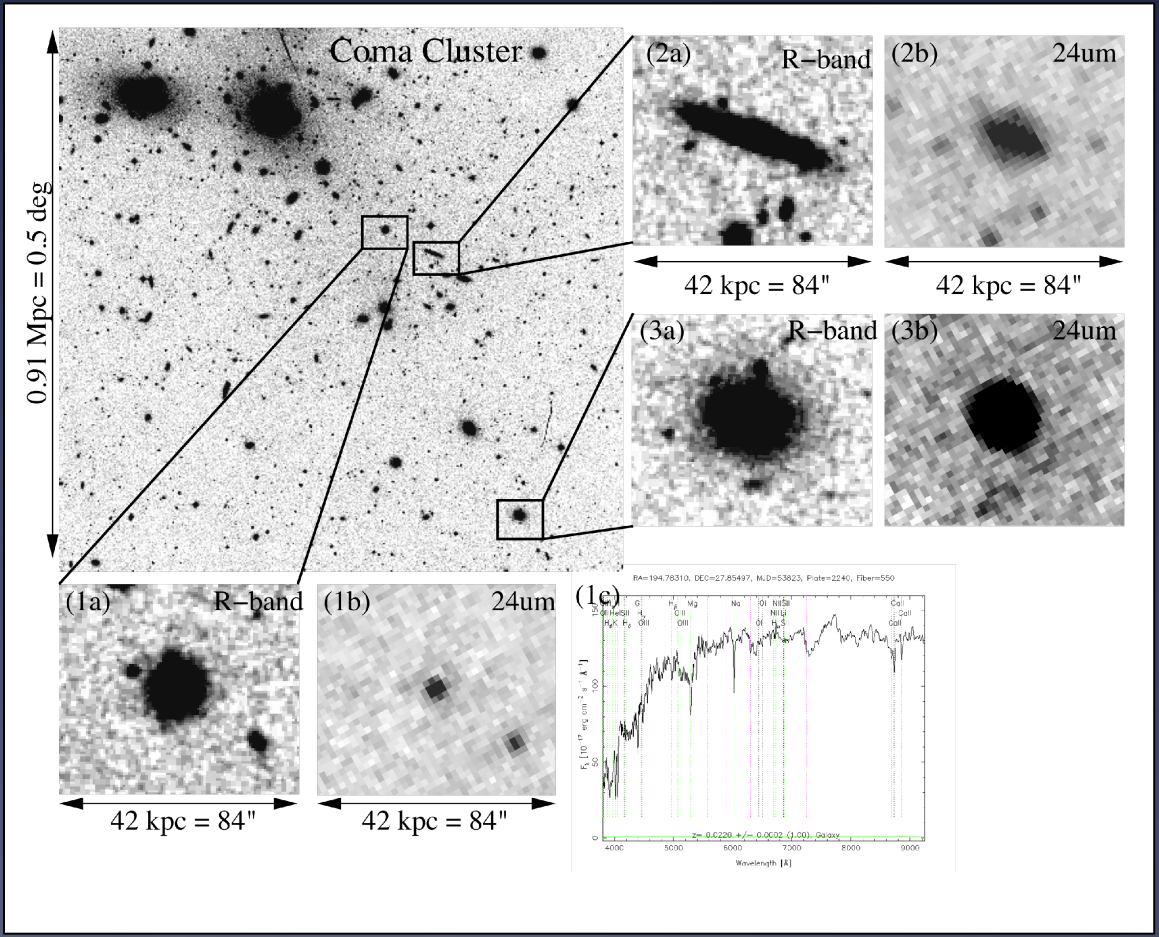
Face-on

Edge-on

Kawata & Mulchaey (2008)

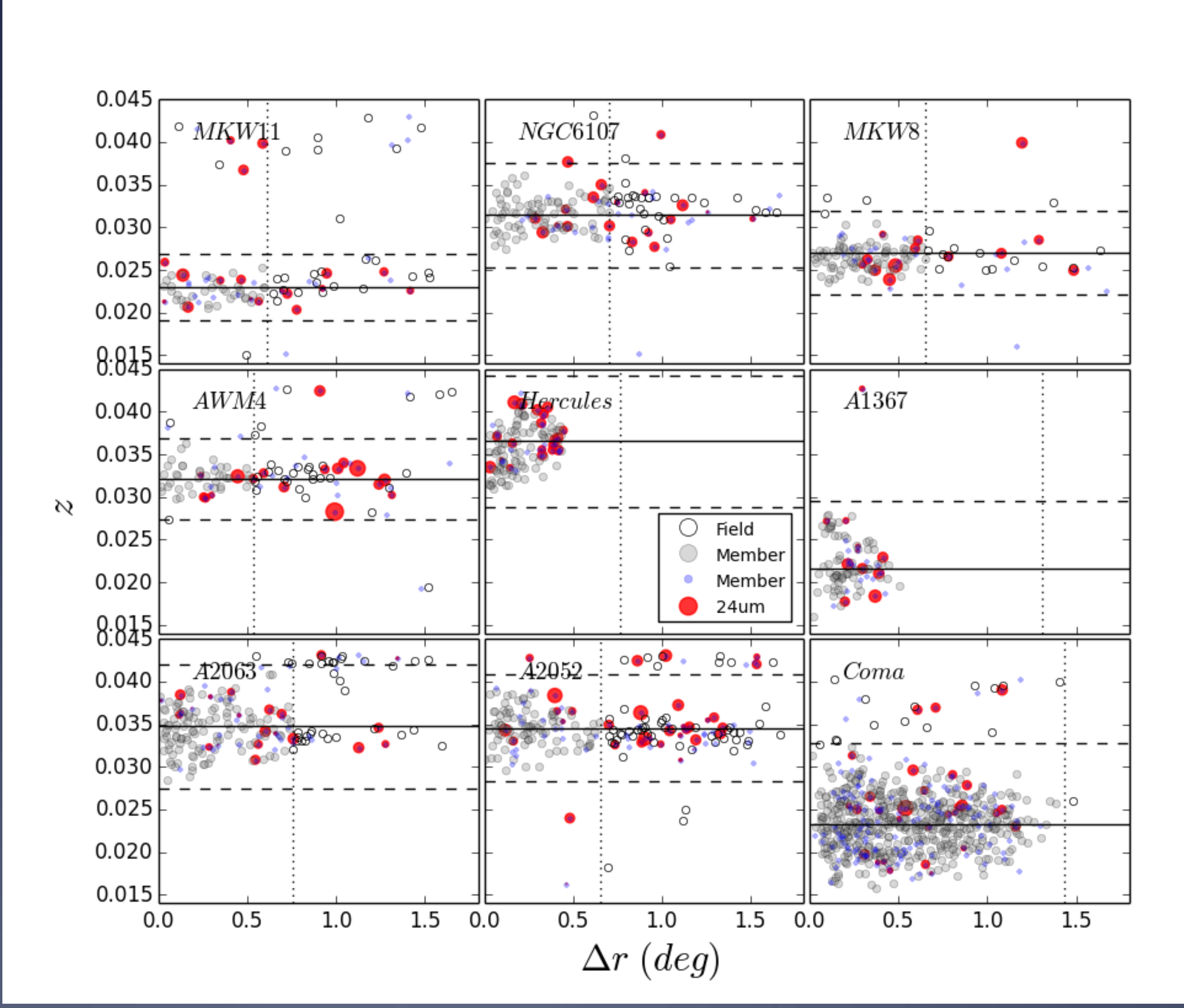
Approach

- Use 24-micron imaging to probe the spatial extent of cold gas relative to the stellar disk.
- Study the full range of galactic environments, including the cores of massive clusters, groups, and surrounding field.

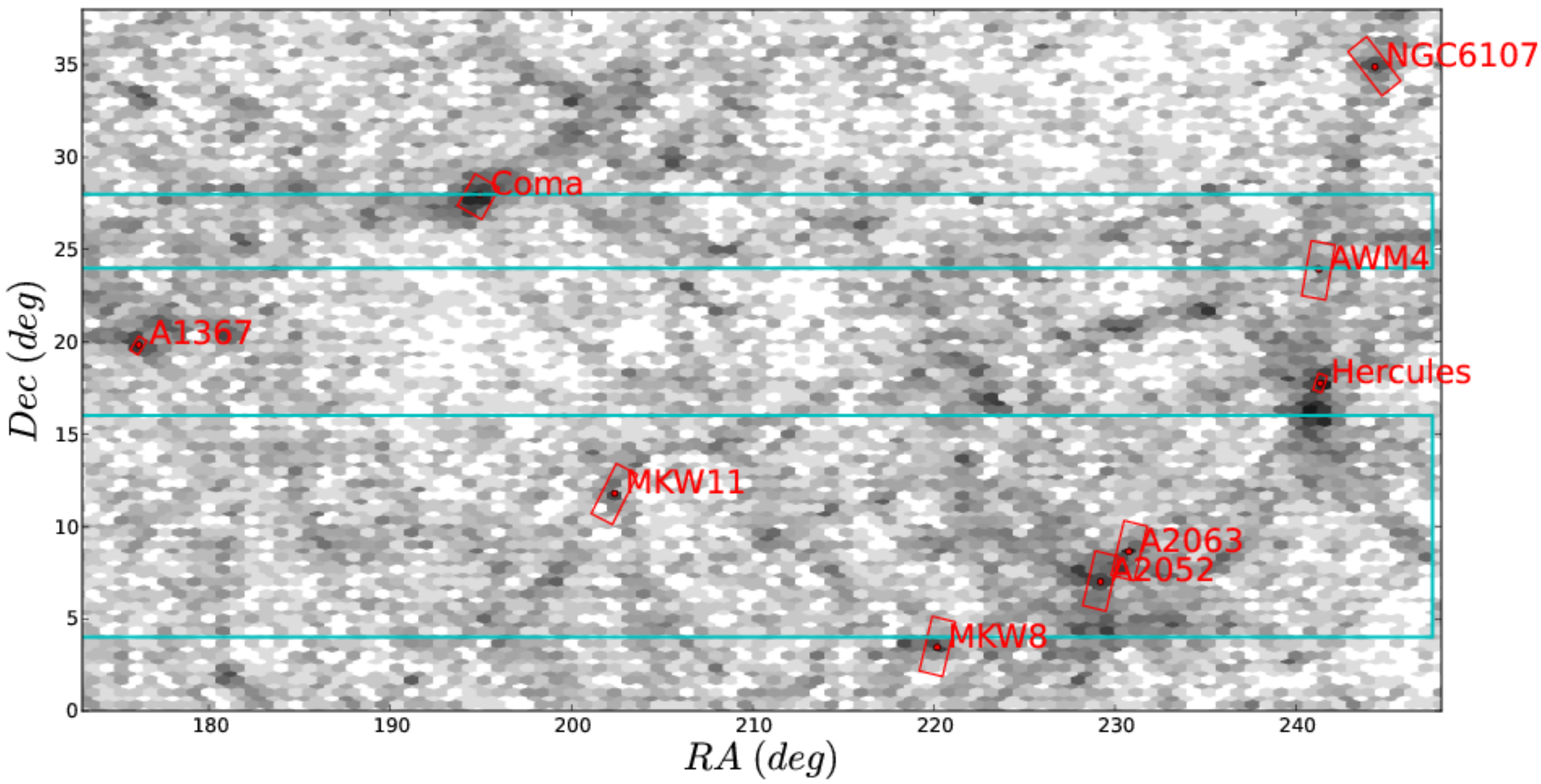


The Sample

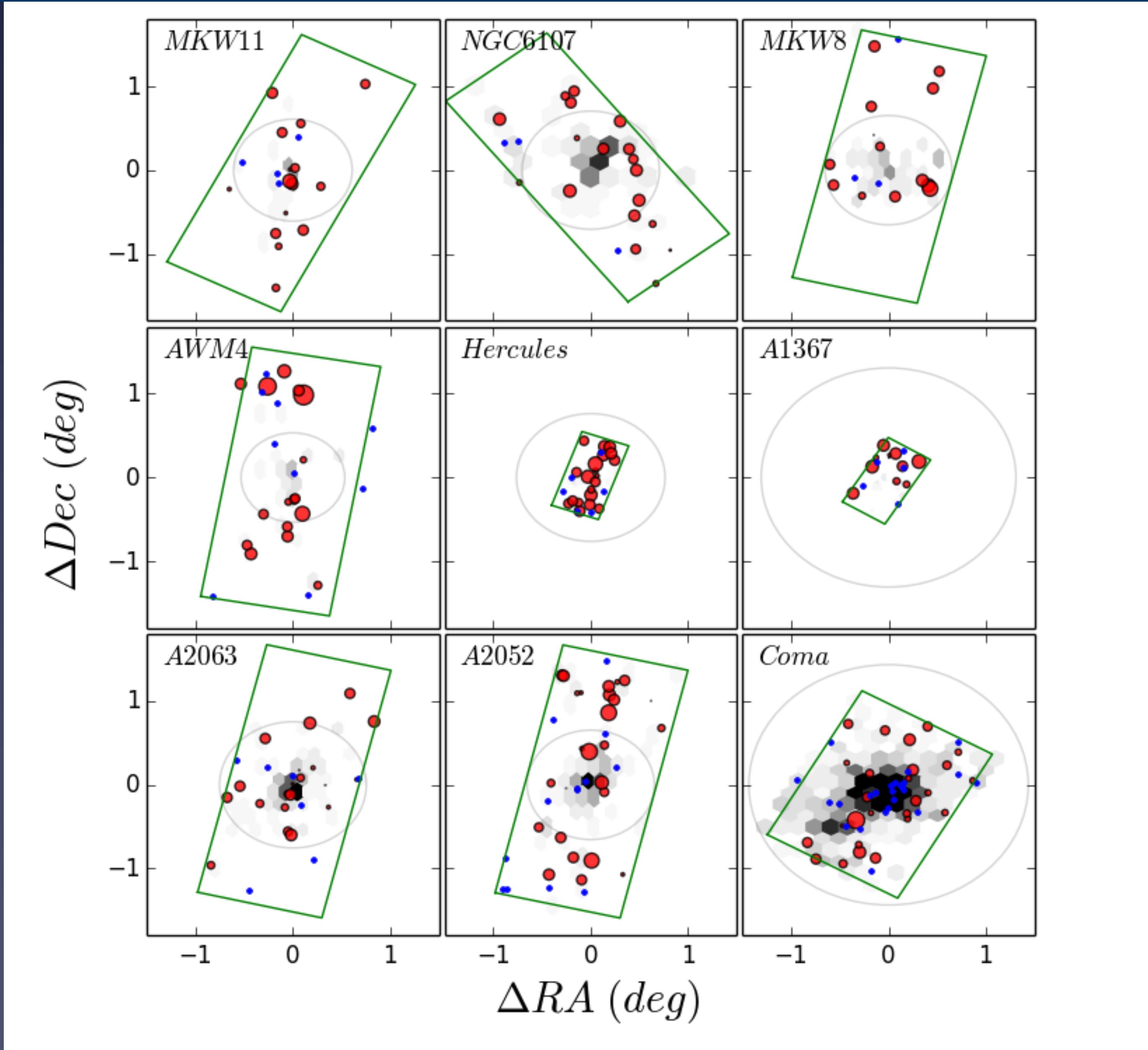
- The galaxy groups and clusters in our sample:
- (1) lie within SDSS and ALFALFA surveys
- (2) span a range of mass and X-ray luminosity
- (3) have wide-field Spitzer 24μm scans
- (4) 6,000 < v_r < 11,000 km/s



Location of LCS Clusters Relative to NASA-Sloan Atlas Galaxies

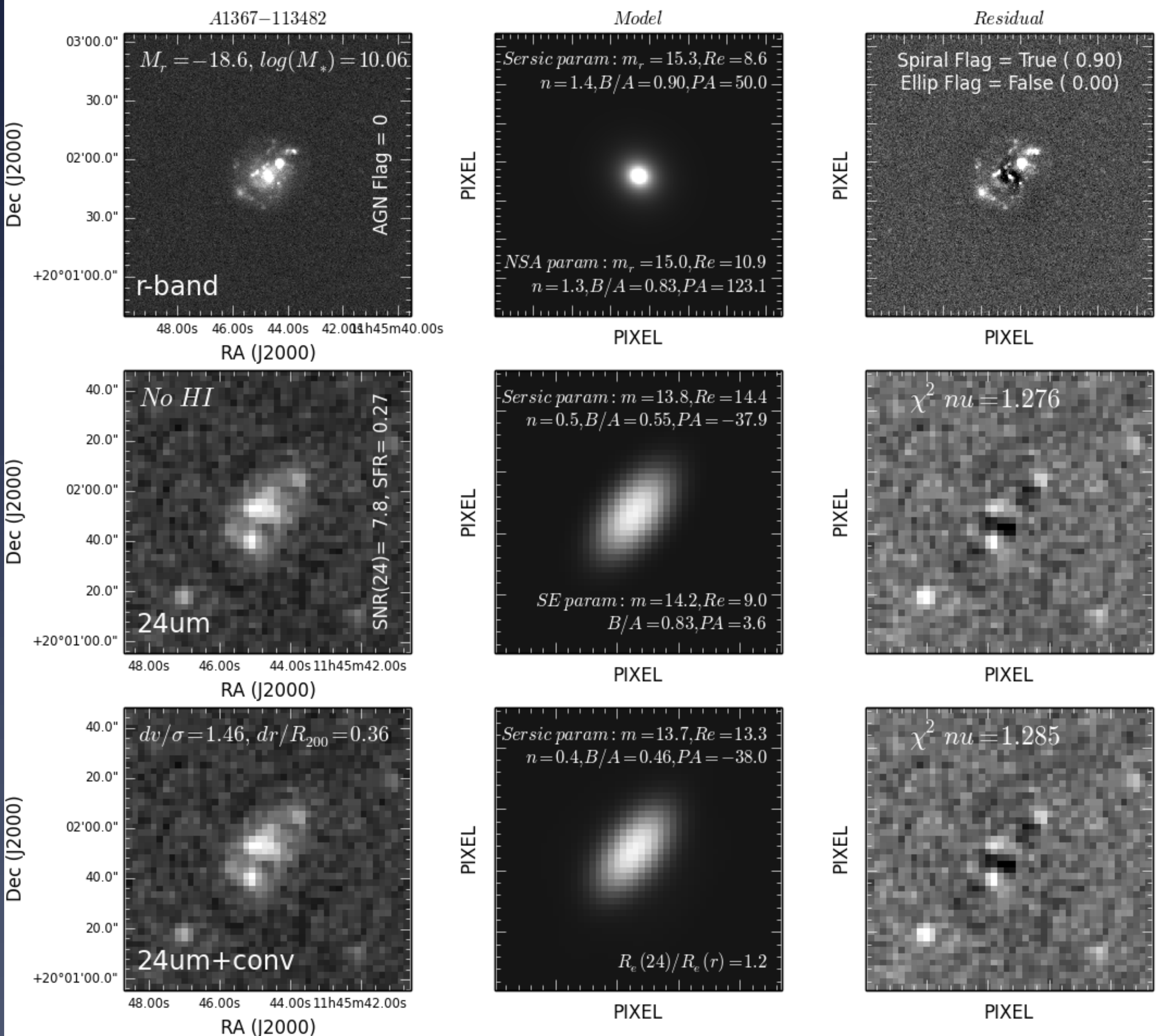


Size of MIPS Scans Relative to R200



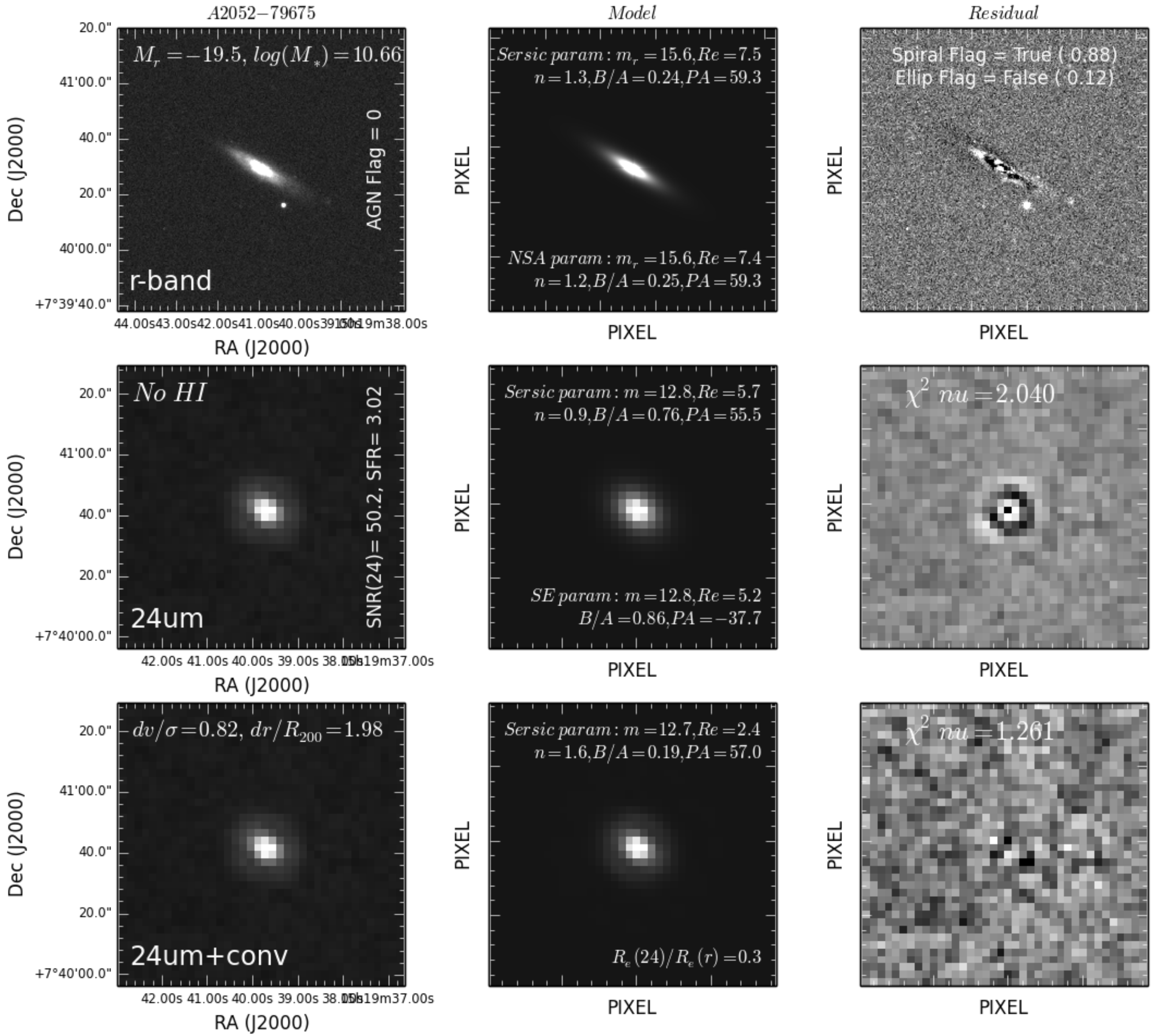
GALFIT Analysis

Example of a galaxy with extended 24um emission.

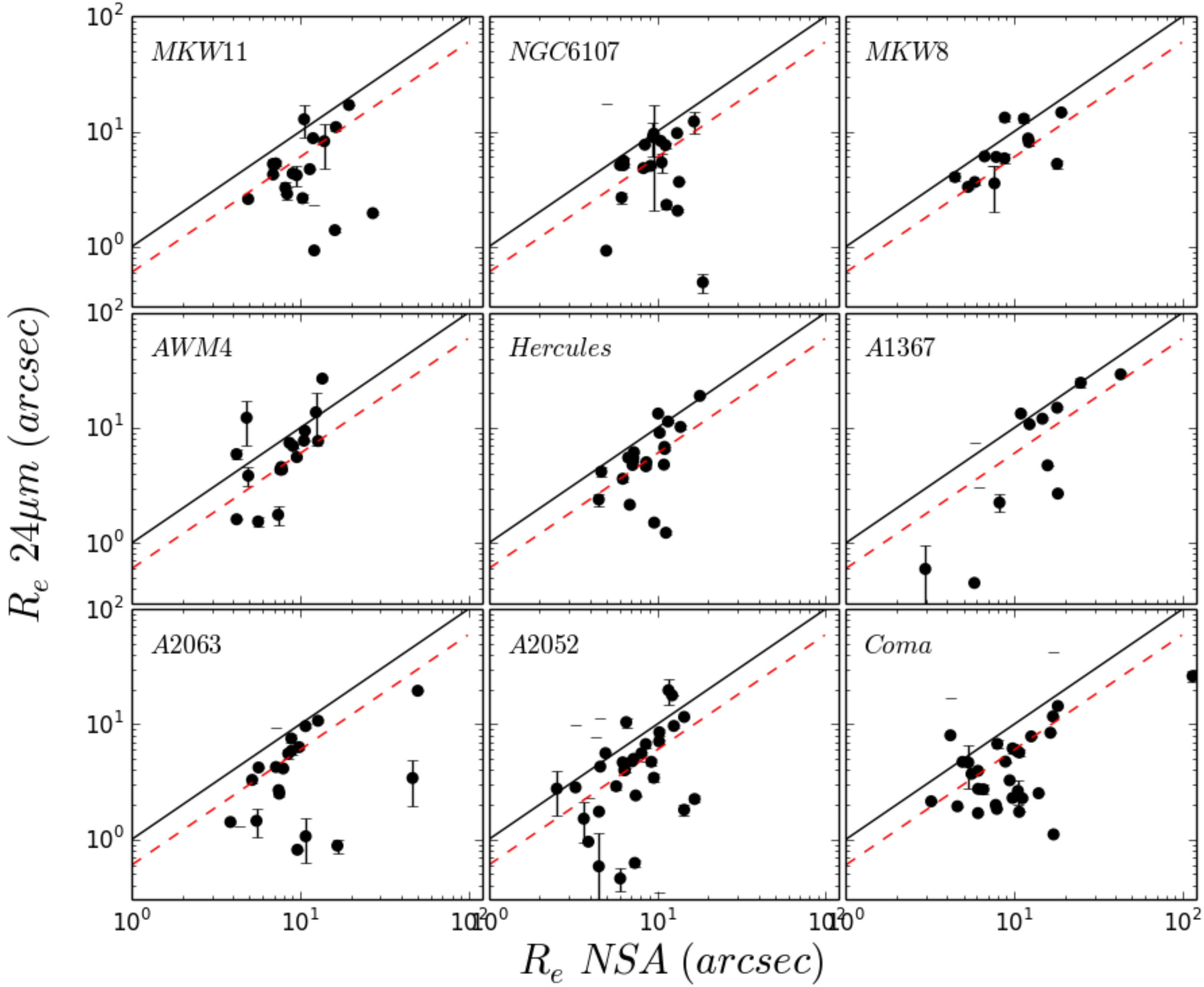


GALFIT Analysis

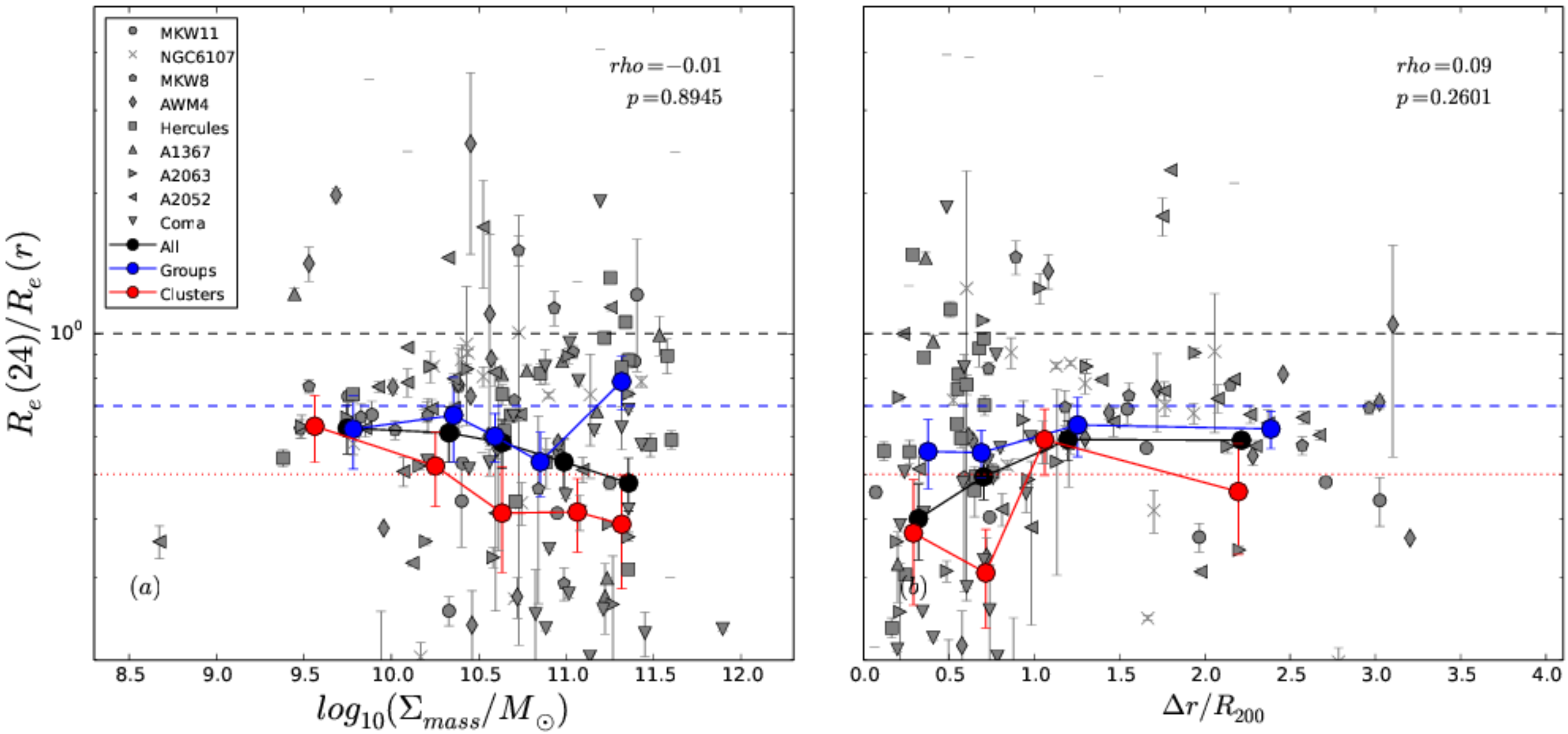
Example of a galaxy with *truncated* 24um emission.



Size Results: we find many truncated galaxies!

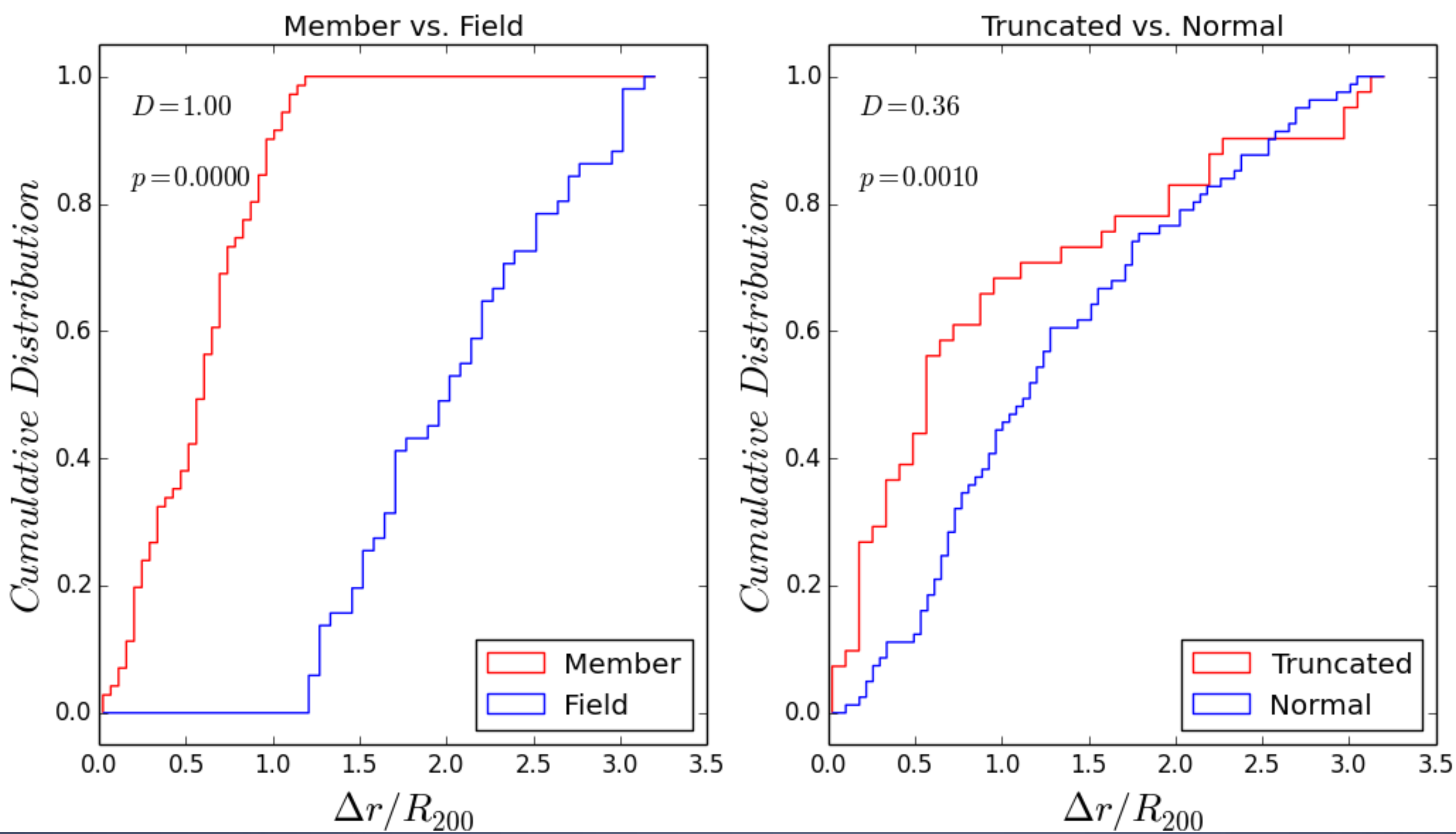


Relative Size of 24um Emission Decreases as Local Density Increases

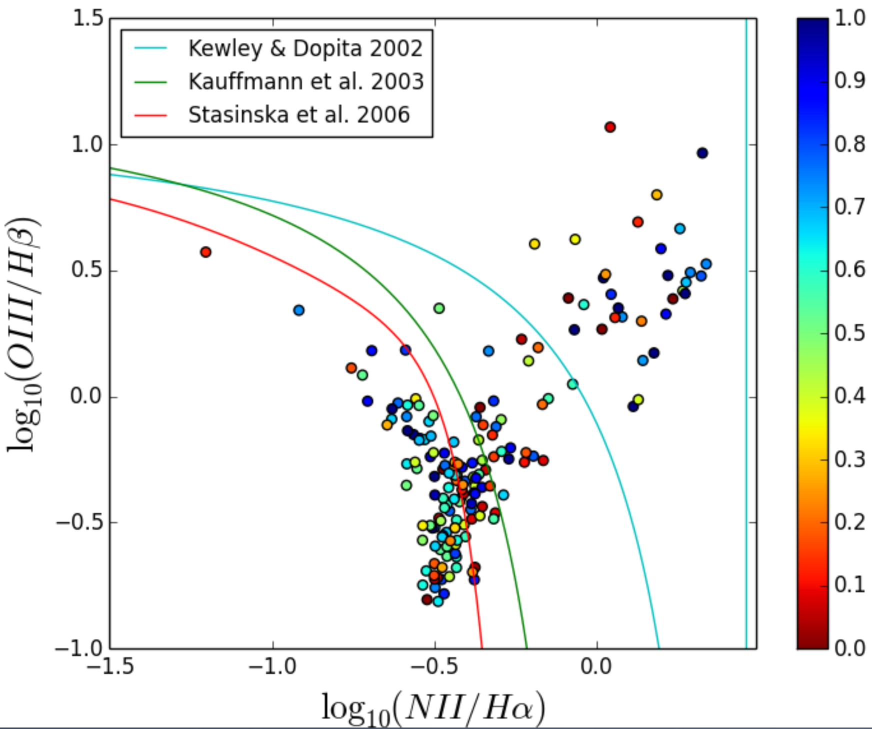


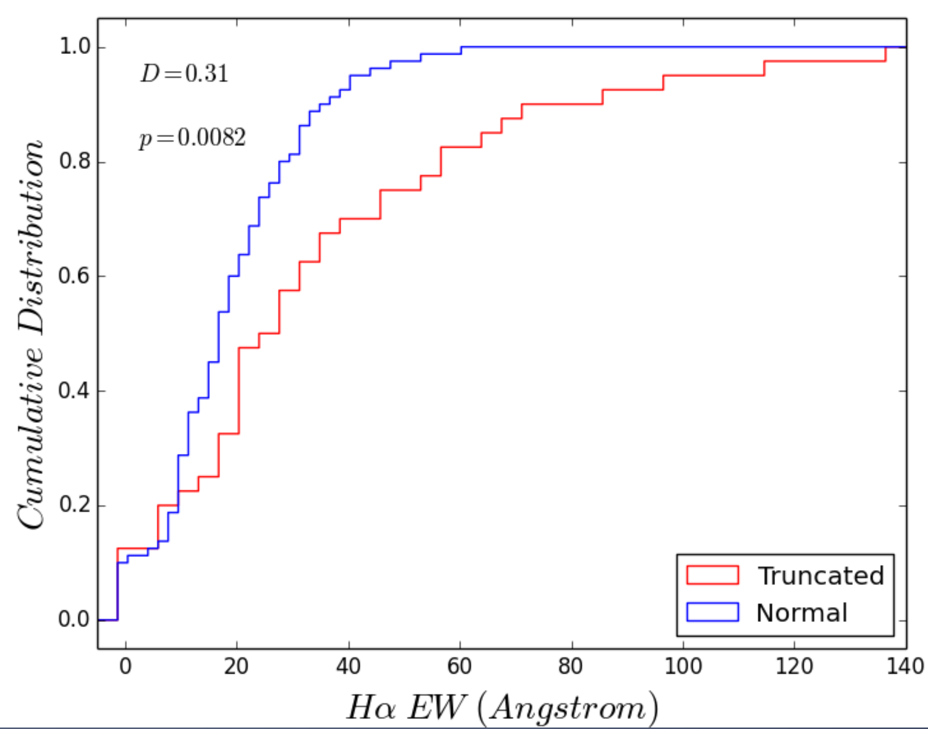
The effect is more pronounced in the clusters vs the groups.

Truncated spiral galaxies are at lower cluster-centric radii and higher local densities



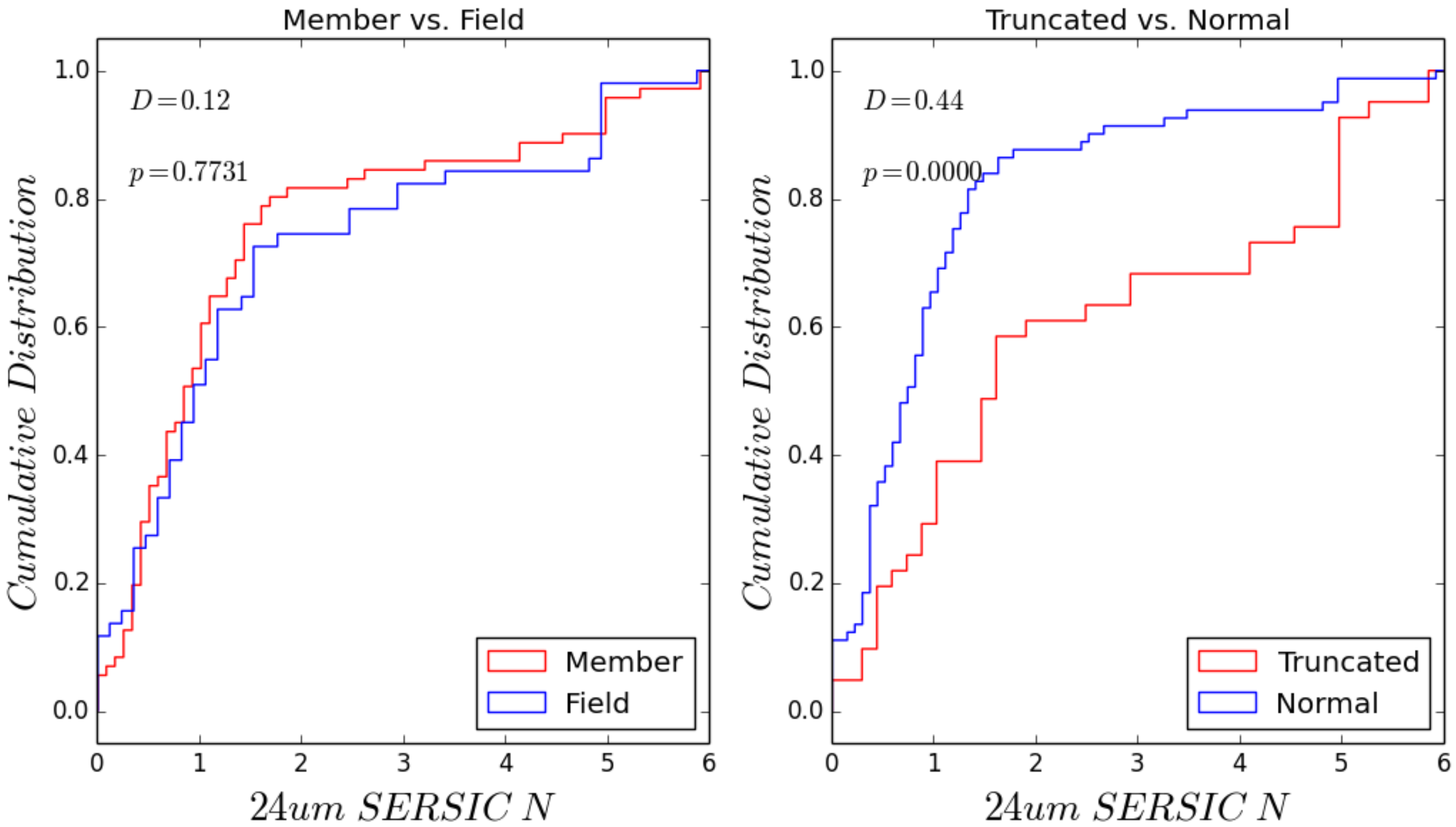
Truncated Galaxies Have Higher H-alpha Equivalent Width (nuclear emission)





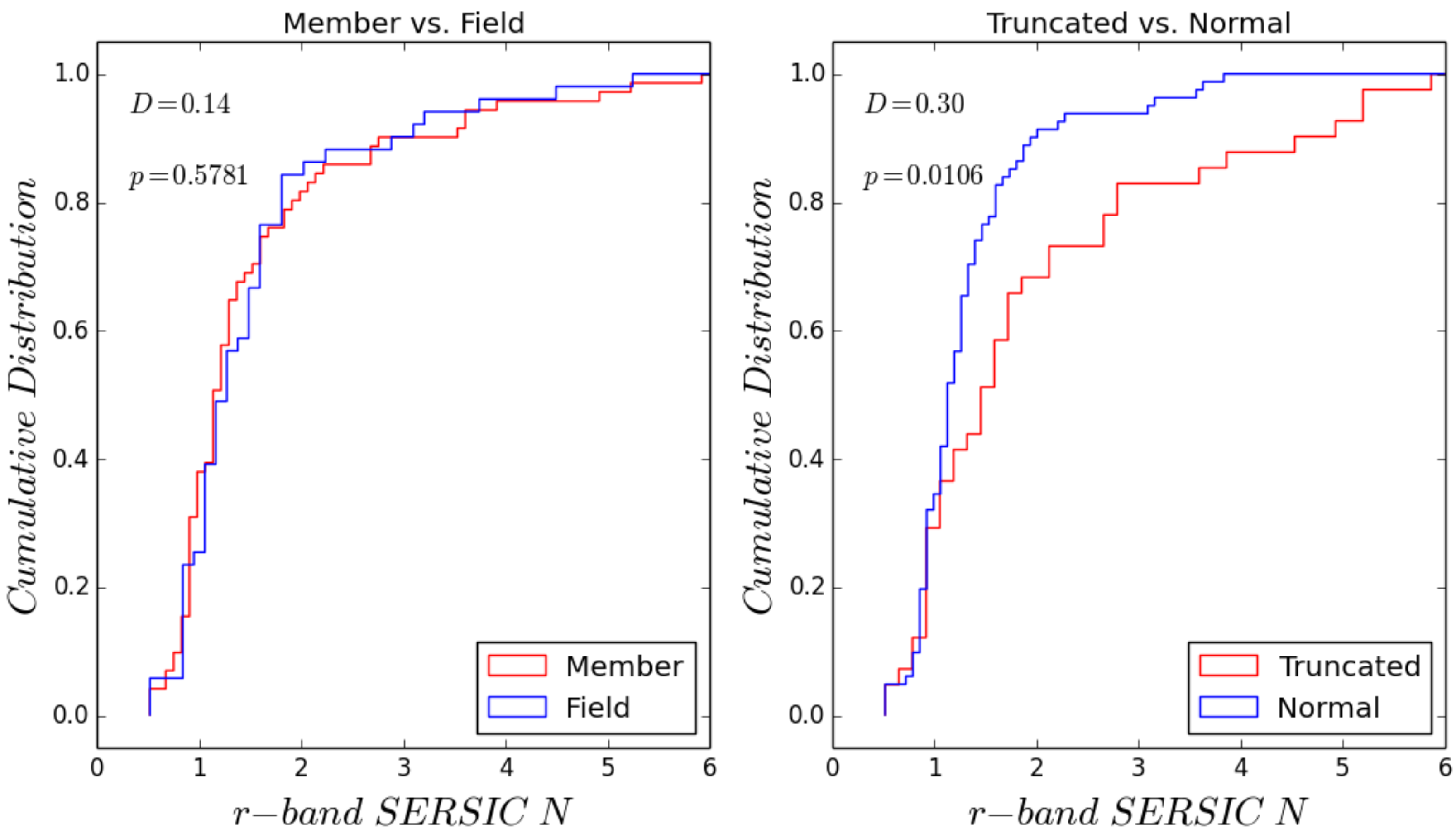
We use the most conservative criteria to identify AGN (Stasinka+06). After AGN are removed, the truncated spirals still have higher Halpha EW. More significant when comparing H-alpha flux, H-beta flux, and N2 flux.

Truncated spirals have higher Sersic index at optical and infrared wavelengths

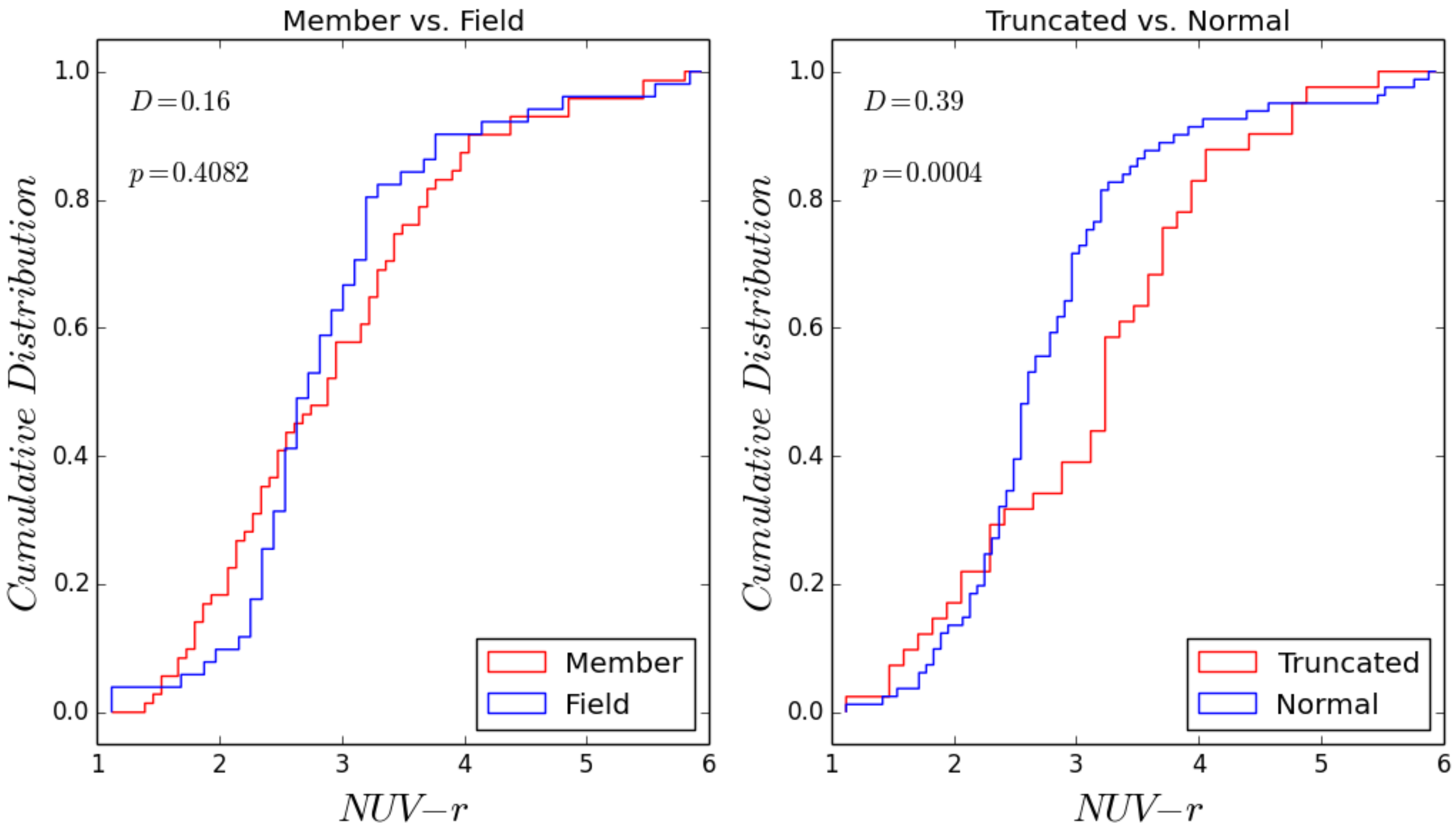


the difference is more significant at 24um

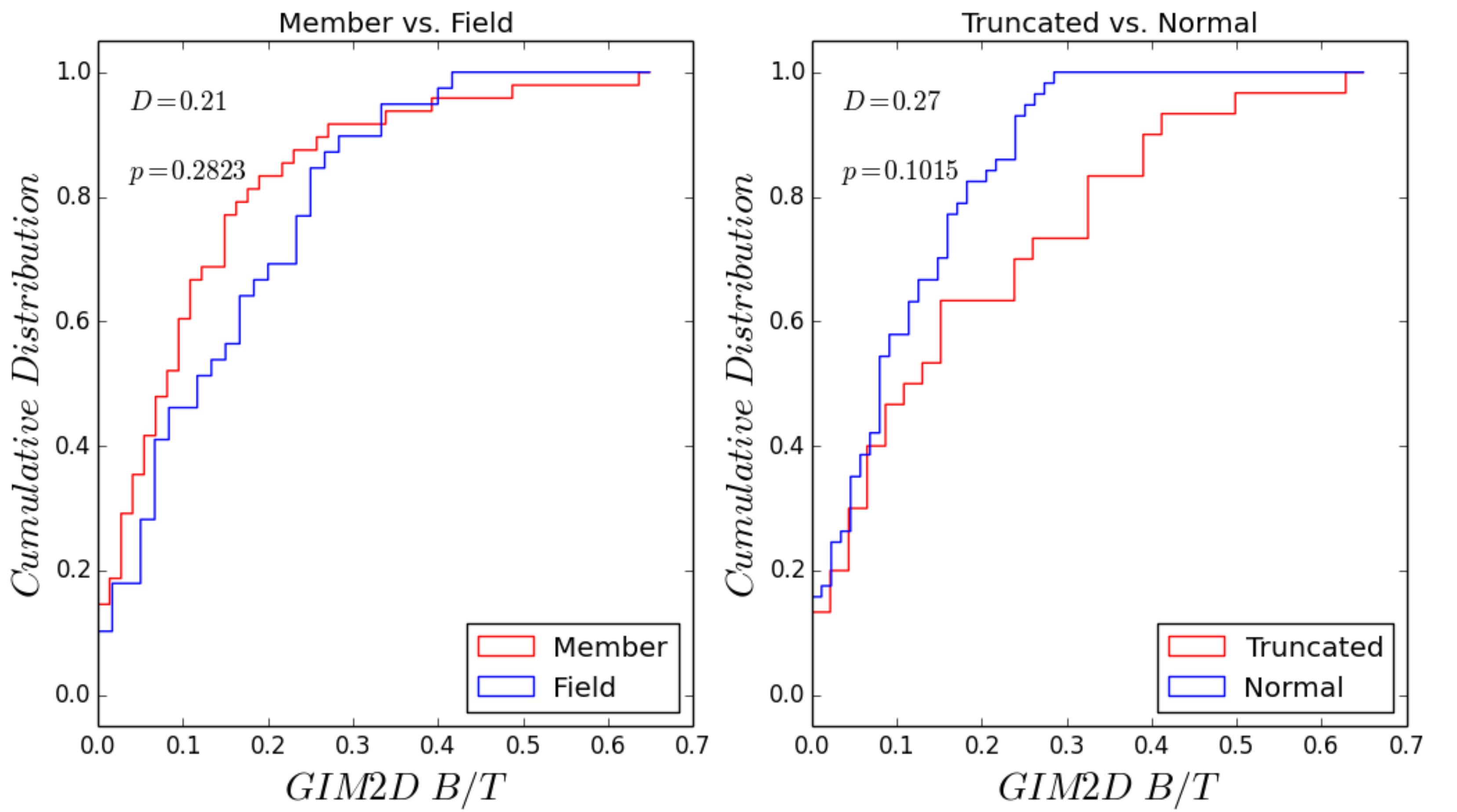
Truncated spirals have higher Sersic index at optical and infrared wavelengths



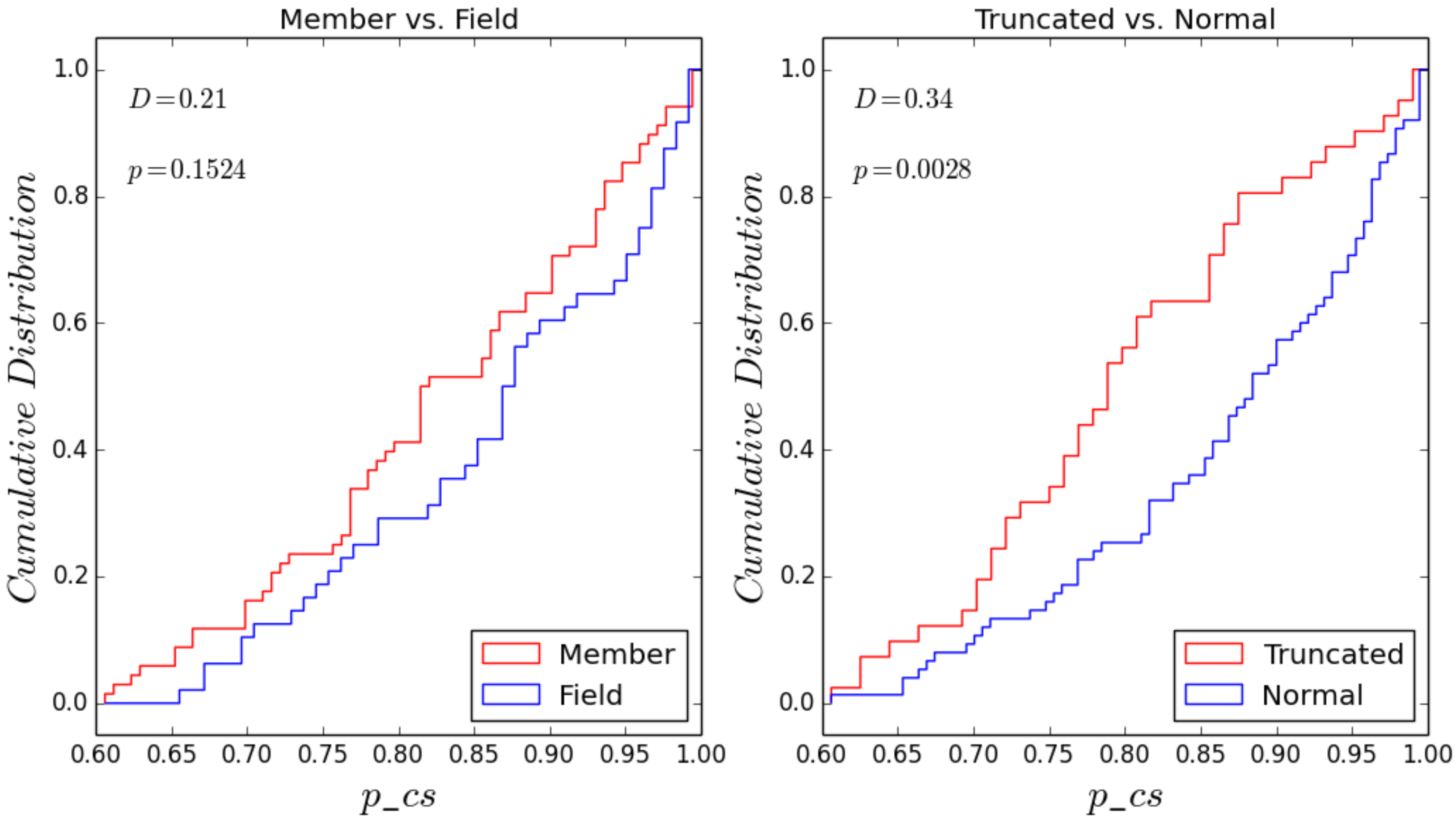
Truncated spirals are brighter at 24um and redder in NUV-r color



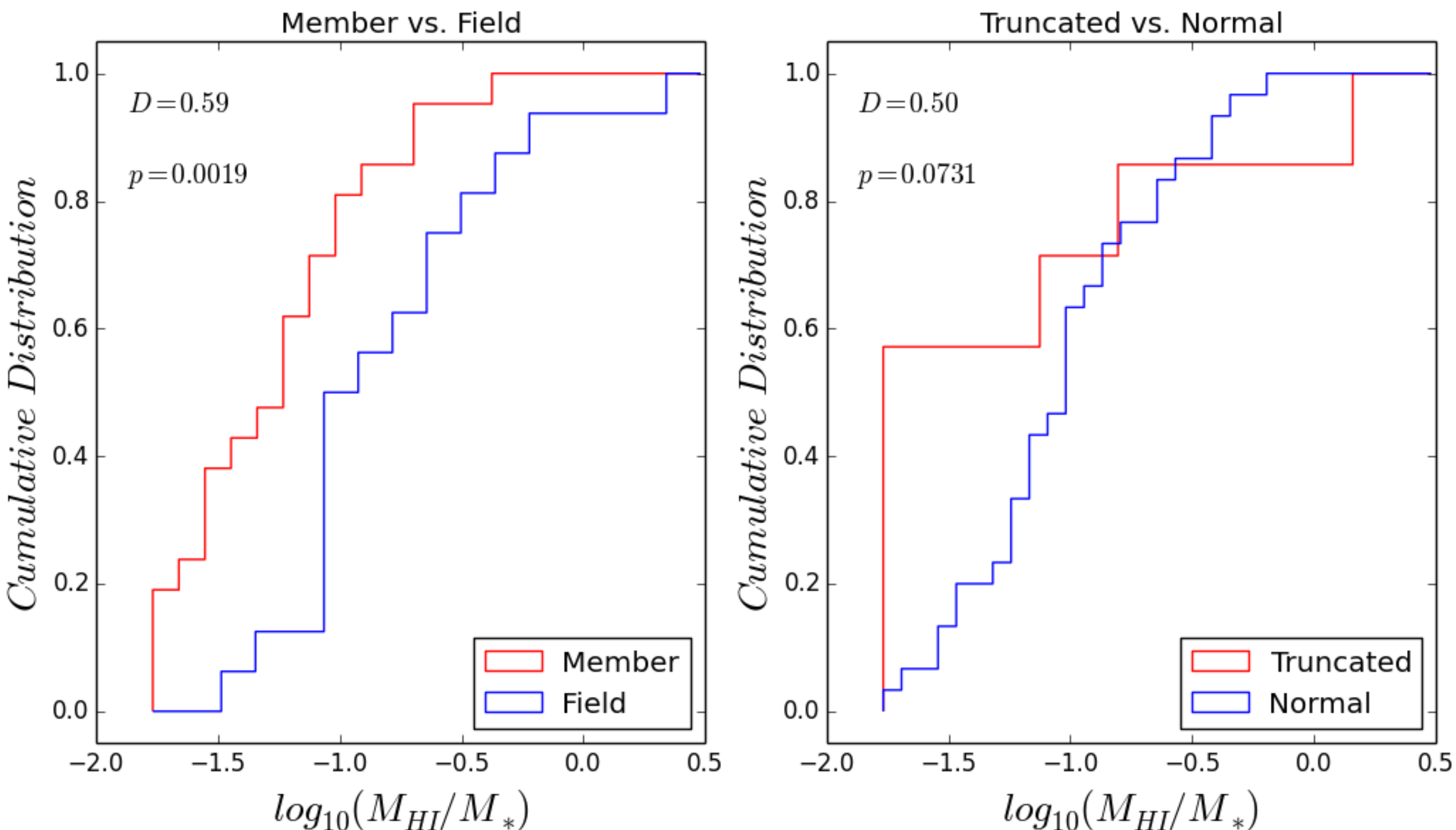
B/T is not significantly different for truncated spirals (or cluster spirals)



Truncated spirals have lower probability of being a spiral according to galaxy zoo



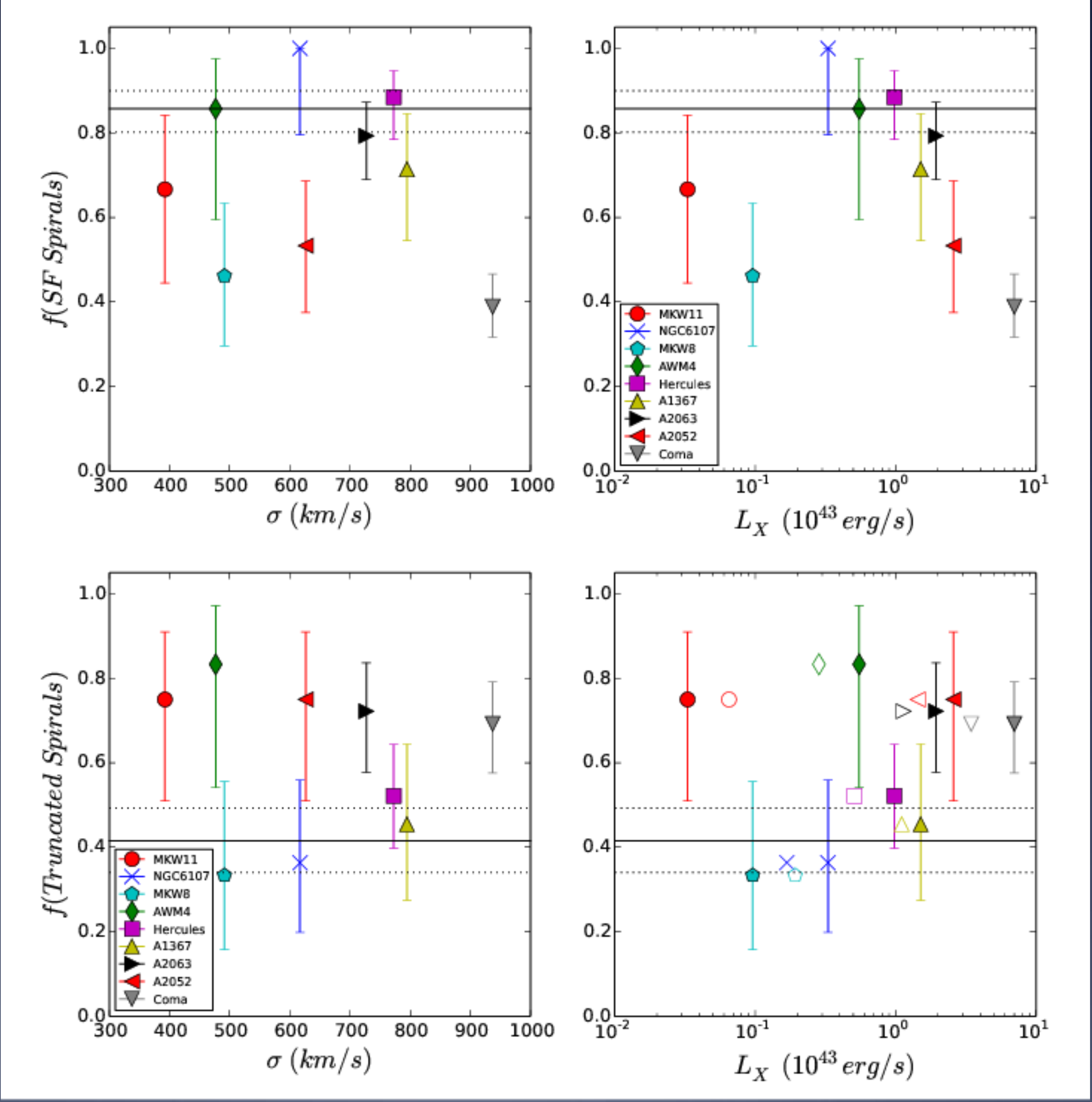
Gas fraction: smaller among cluster spirals; maybe smaller among truncated galaxies?



full ALFALFA survey data should help answer this more definitively

Fraction of star-forming spirals decreases as cluster L_X increases.

Trend is not significant with the fraction of truncated spirals.

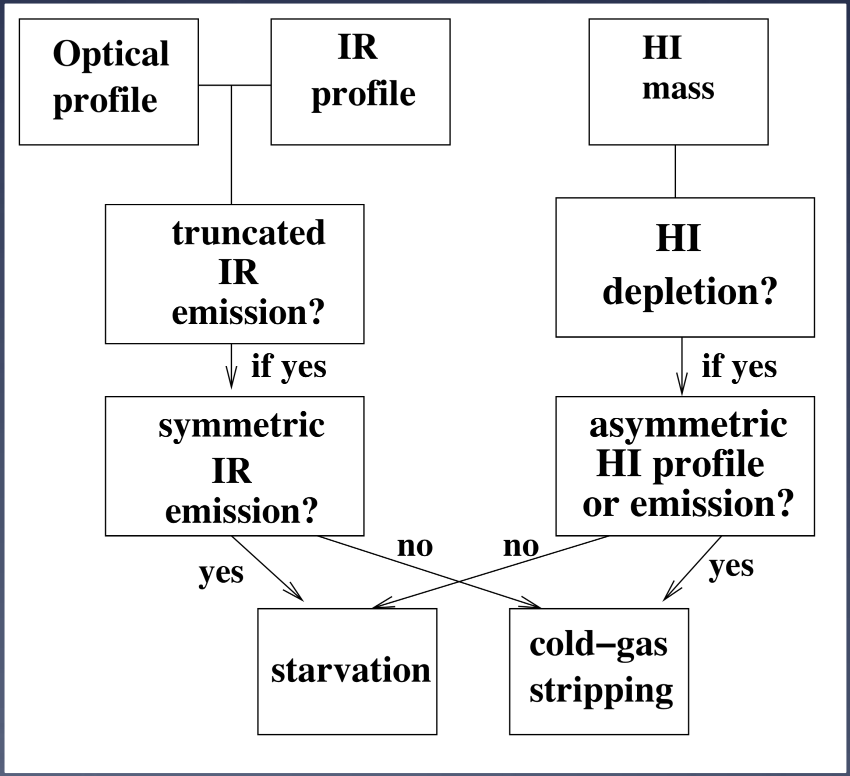


What does it all mean?

To be continued...

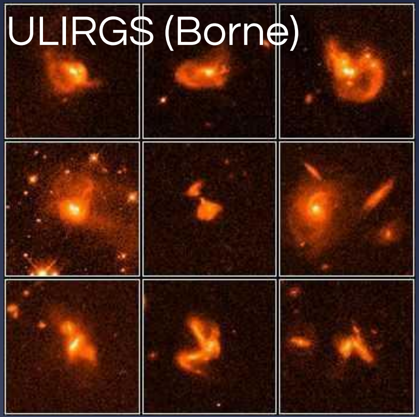
A Survey of Local Groups & Clusters

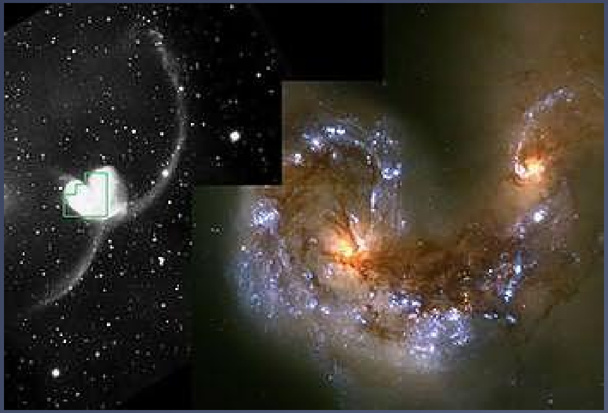
* We will map radial extent of IR and optical images.
* Look for truncation and asymmetry of the IR emission from gas relative to the stellar disk



Galaxy-Galaxy Interactions

* Galaxy-galaxy interactions:
  * exhaust the gas supply through a burst of star-formation
  * most effective in groups or cluster outskirts.





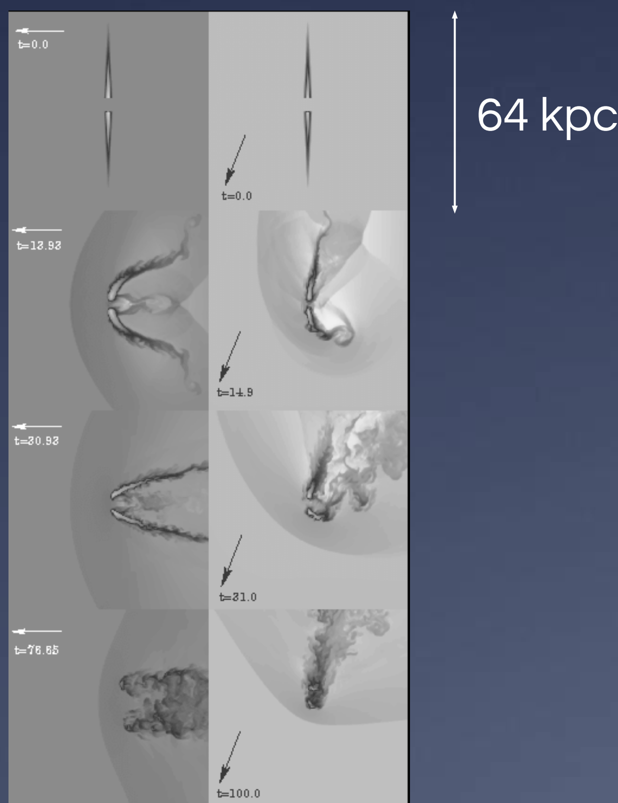
Antennae Galaxy (Whitmore)

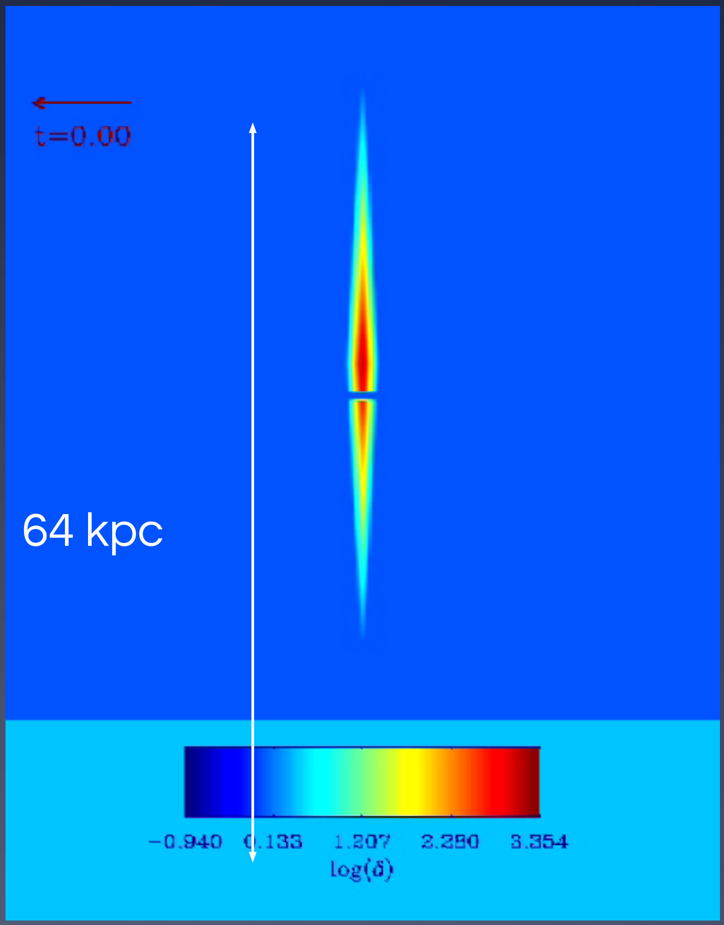
Ram-Pressure Stripping

* The removal of cold disk gas via ram-pressure stripping by the intra-cluster medium
* most effective near the core of galaxy clusters, where both the intra cluster medium density and galaxy velocities reach maximum (e.g. Gunn & Gott 1972).
* However, recent models show that outward-moving shocks from the formation of groups increase the relative velocity of group galaxies and the intragroup medium (Vollmer et al. 2006).
  * *cold gas stripping may occur in more environments than previously expected*.

Ram-Pressure Stripping of Cold Disk Gas

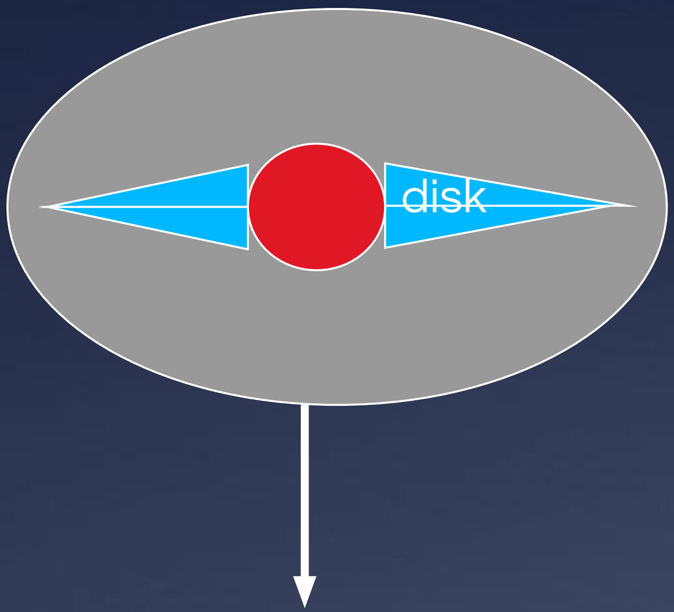
- Hot intracluster medium can strip gas from a galaxy (100 Myr)



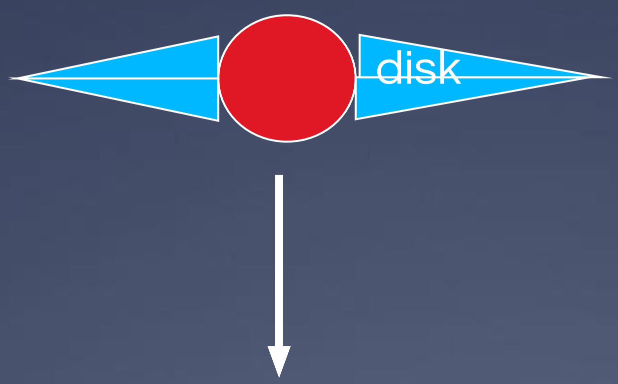


(Quilis, Moore & Bower 2000)

Starvation



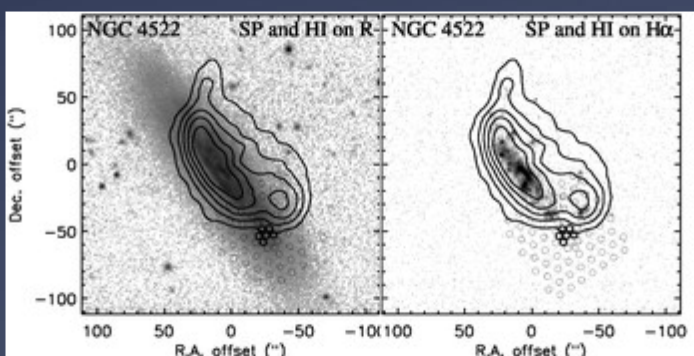
* Starvation describes a weaker version of ram-pressure stripping where a galaxy's hot, extended halo of gas is removed by the intra-group or intra-cluster medium (e.g. Larson et al. 1980).



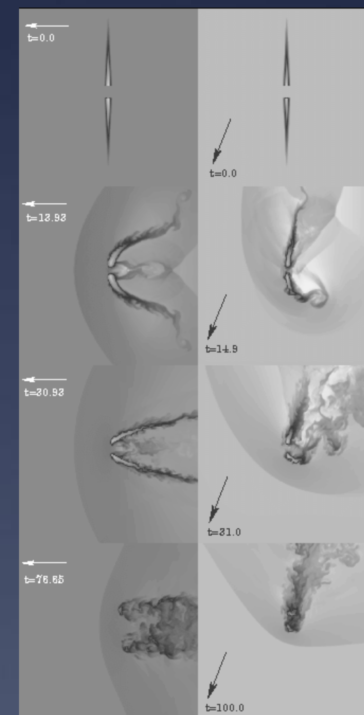
* The cold disk gas can no longer be replenished and star-formation shuts off on a 1-2 Gyr timescales.

Simulations of Ram-Pressure

* simulations and observations of ram-pressure stripping of the cold disk gas show that disk gas is compressed in the direction of motion and cupped in morphology, with the cup opening away from the direction of motion



Crowl et al. 2006



Quilis et al. 2000