Starburst Activity in High Redshift Galaxy Clusters

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Cluster Evolution with Redshift

* At higher redshifts, significant evolution observed in cluster galaxies.
* Increased fraction of blue, star-forming, late-type galaxies.
* Increased fraction of post-starburst (k+a) galaxies.
* **Suggests high-z cluster galaxies experience temporary increase in star formation. This is not seen at lower redshifts.**
* Controversial as starbursting progenitors have yet to be found. Could be hidden by dust obscuration.

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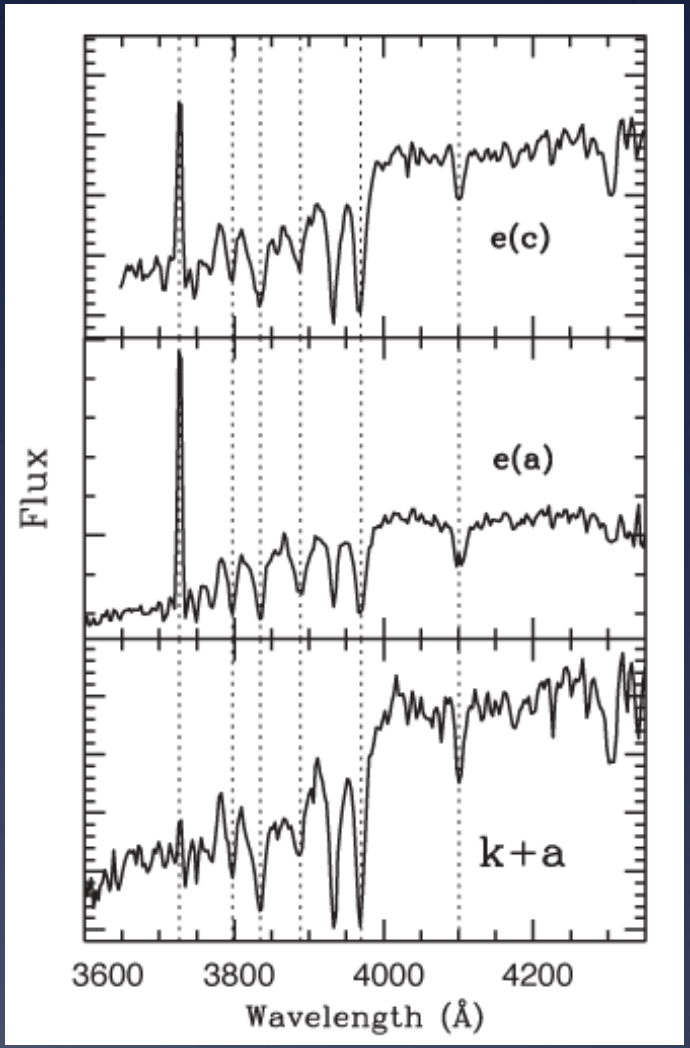
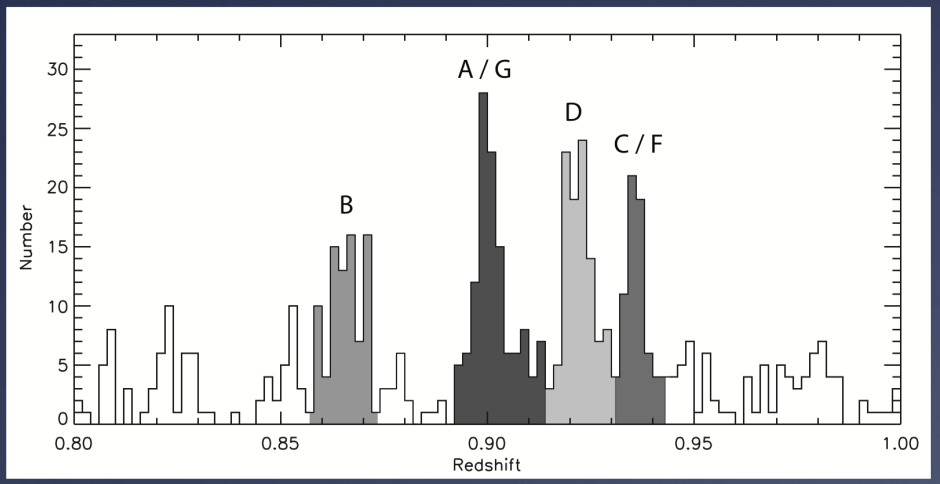
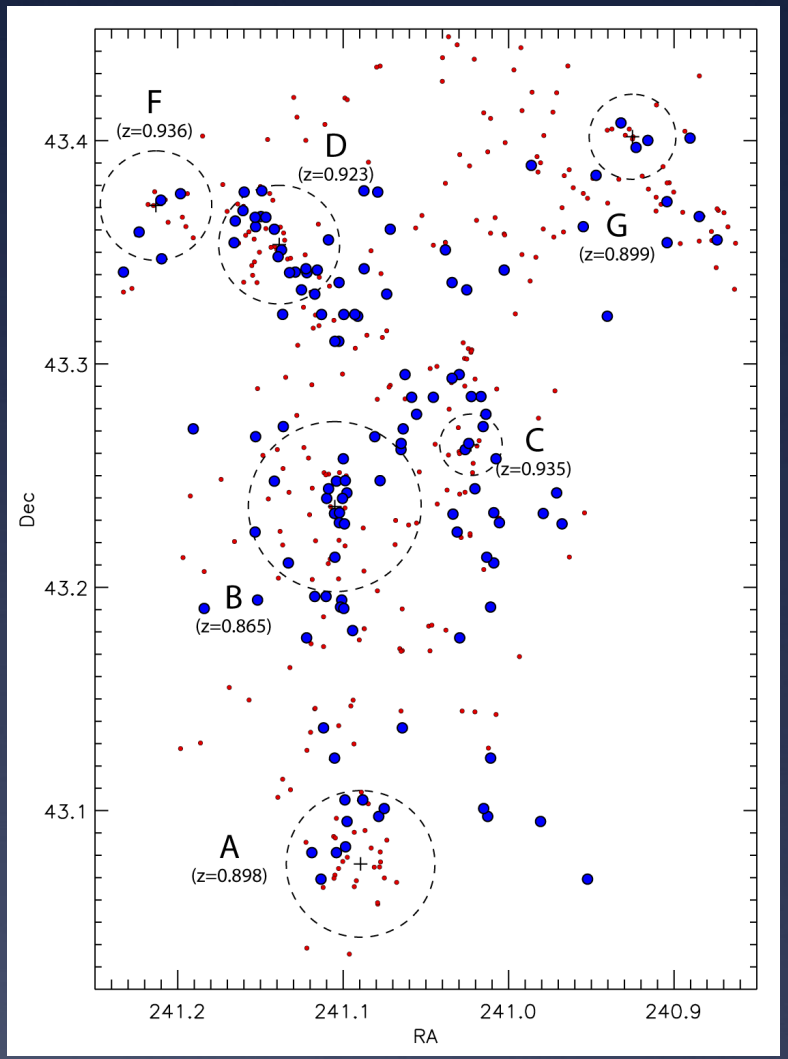


Poggianti et al. 2009

Spitzer Observations of Cl1604

* Spitzer MIPS 24μm Observations:
  * Sensitive to stellar radiation reprocessed by dust
  * Able to detect starburst galaxies otherwise optically obscured
* The Cl1604 Supercluster:
  * 3 Clusters + 5 Groups at z~0.9
  * 1789 redshifts obtained, 517 confirmed members





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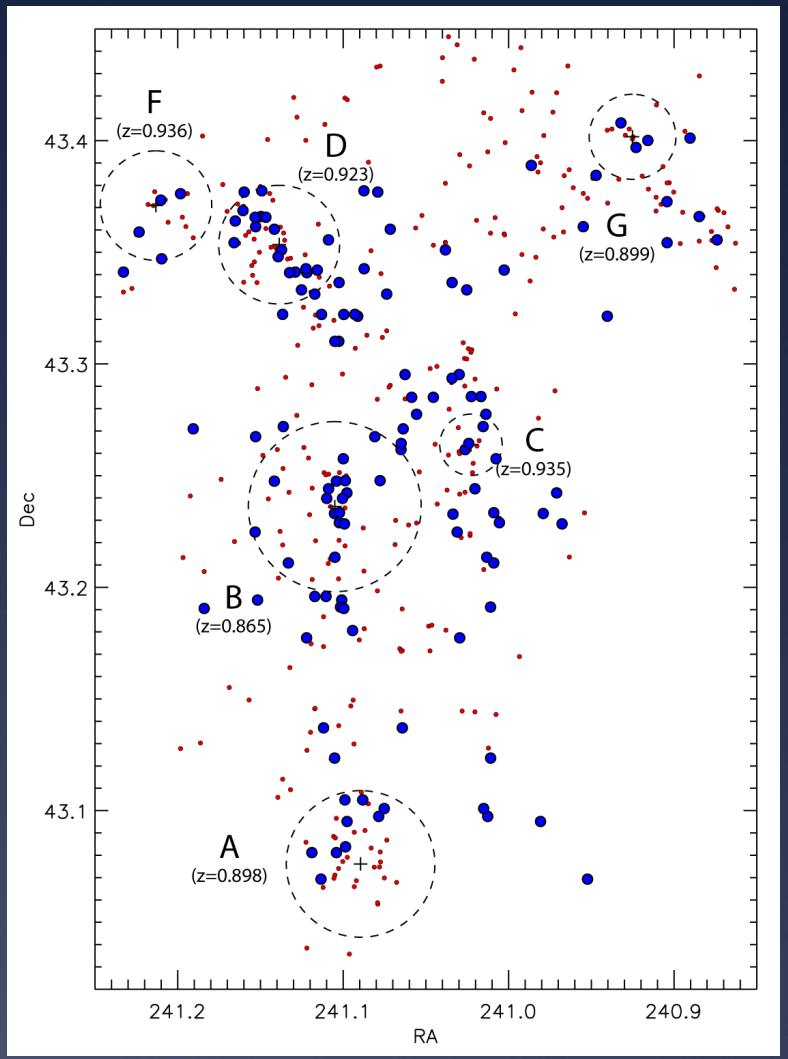
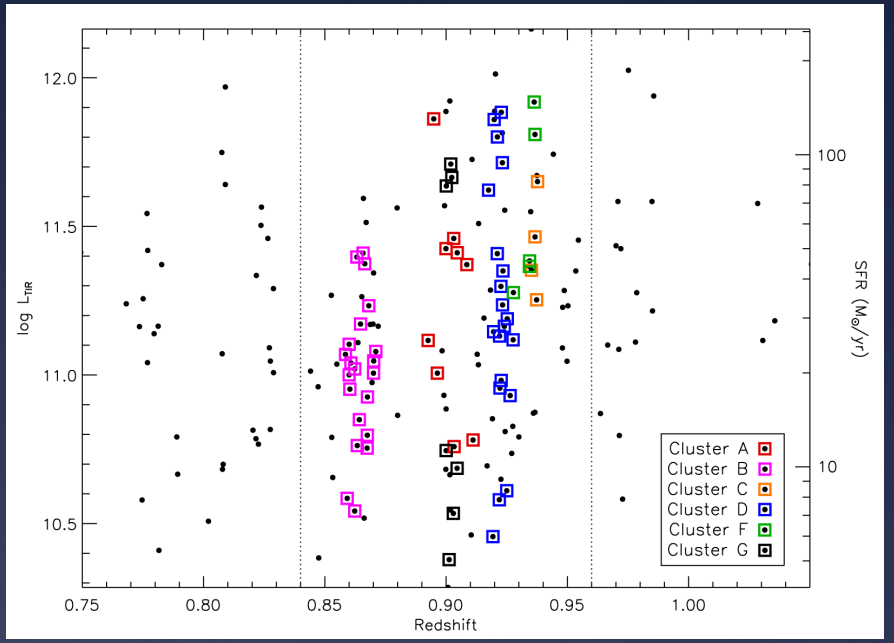
* The Cl1604 Supercluster:
  * 3 Clusters + 5 Groups at z~0.9
  * 1789 redshifts obtained, 517 confirmed members
* Cross-correlating MIPS detections with redshift catalog: 126 24μm detected galaxies at $0.84 < z < 0.96$.



Optical vs IR SFR

* L_{IR} derived from measured redshift and 24μm flux using templates of Chary & Elbaz (2001).
* Can compare IR to optical SFR using Kennicutt (1998) relations.
* Optical SFR indicators such as [OII] would severely underestimate the activity of these galaxies.
* Reason why identifying starburst galaxies in high-z clusters has been so difficult.



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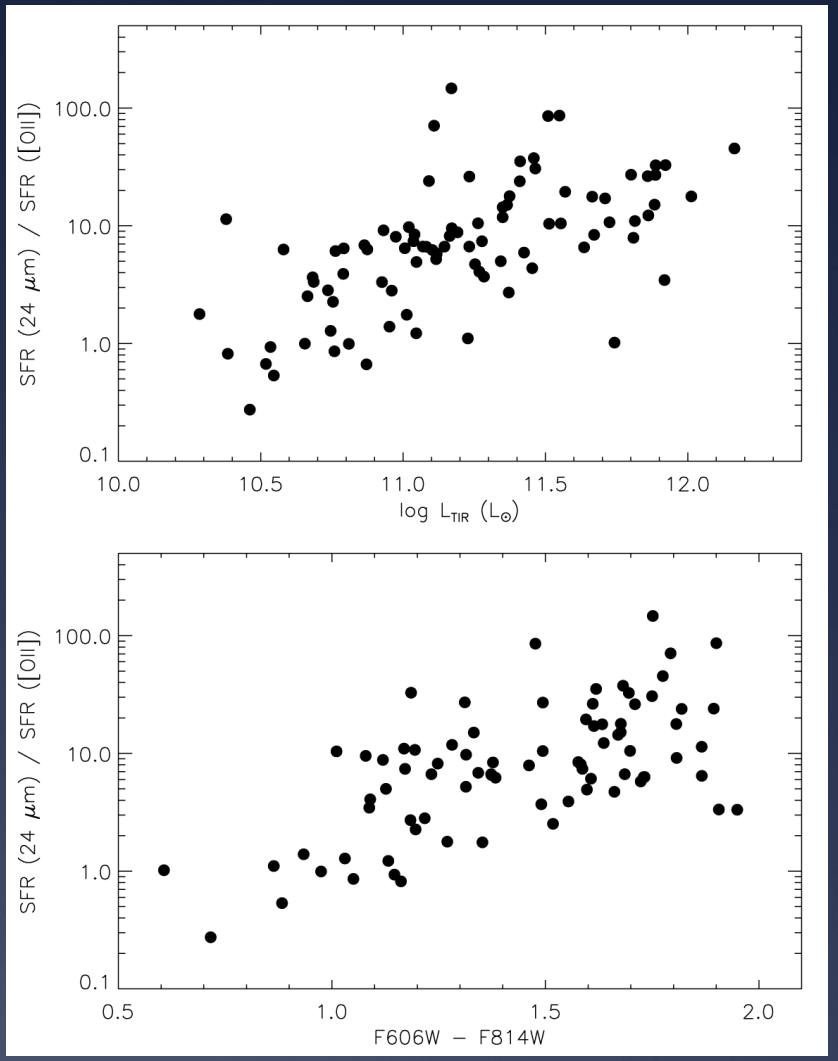
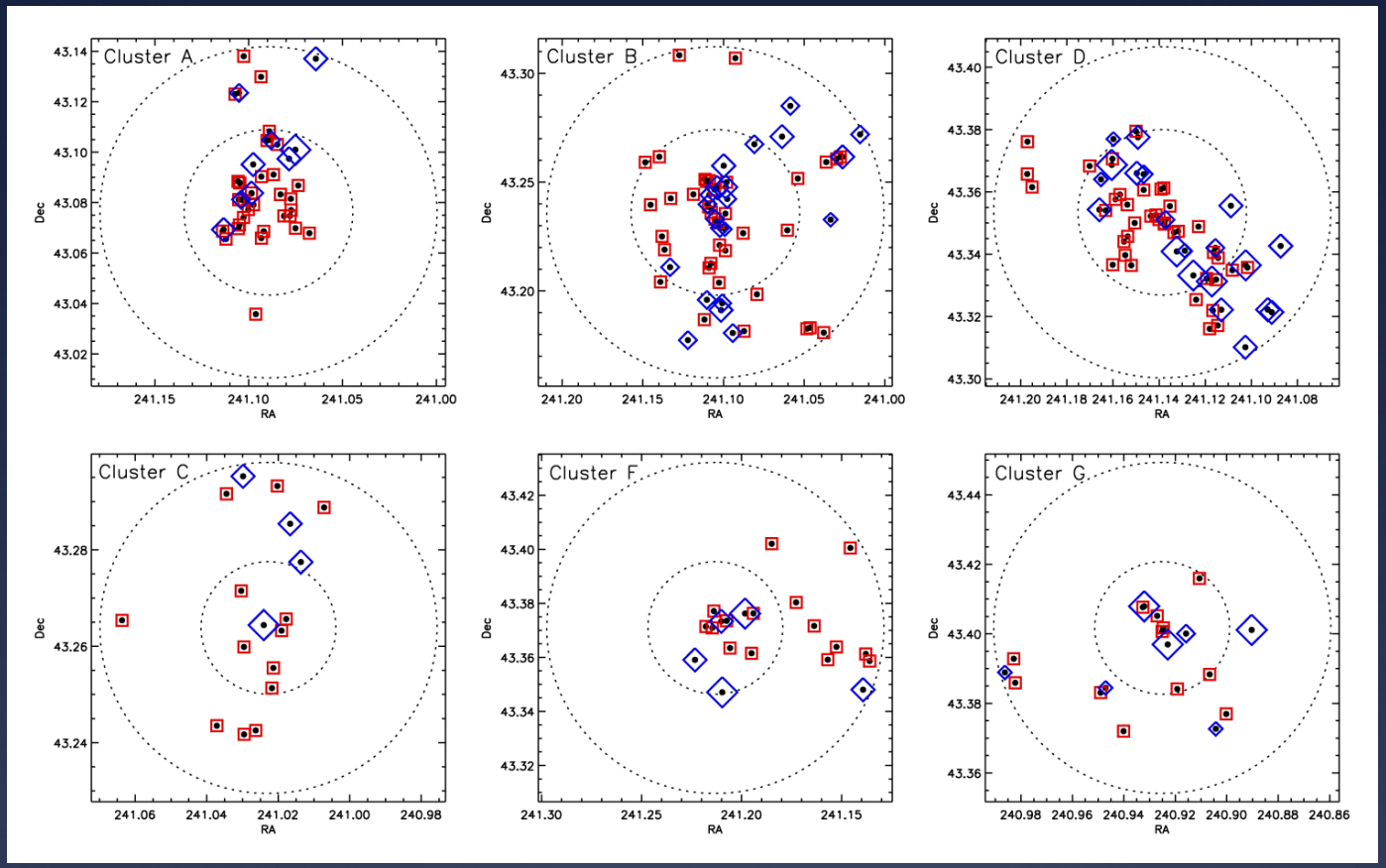


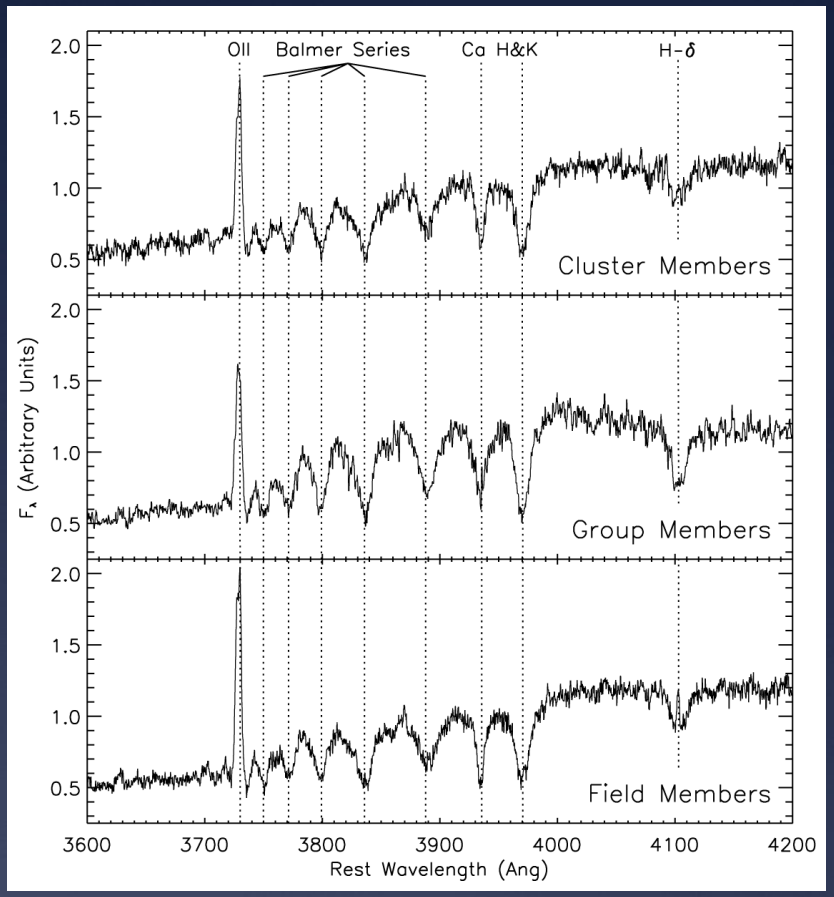
Spatial Distribution



* Increased star formation activity associated with dynamically unrelaxed clusters.
* 24μm sources in Cluster D associated with infalling filament.

Spectral Properties

* Spectra show moderate [OII] line strengths and strong Balmer abs.
  * Mix of e(b) and e(c) spectral types. Few e(a) (i.e starburst) spectra.
  * Moderate [OII] likely due to selective dust extinction.
  * Cluster and group members show stronger Balmer abs than field.
* Continuous or bursty activity?
  * [OII] and Hδ line strengths correlated for normal continuous star formation.
  * Bursty activity leads to excess Balmer absorption.
* **Star formation is burstier in cluster and group members than in field galaxies with similar IR luminosities.**



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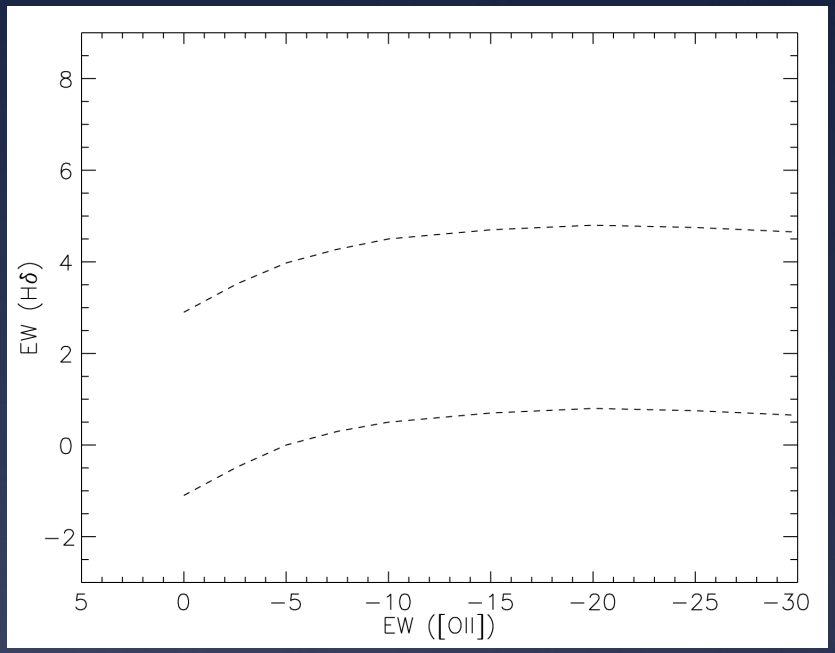

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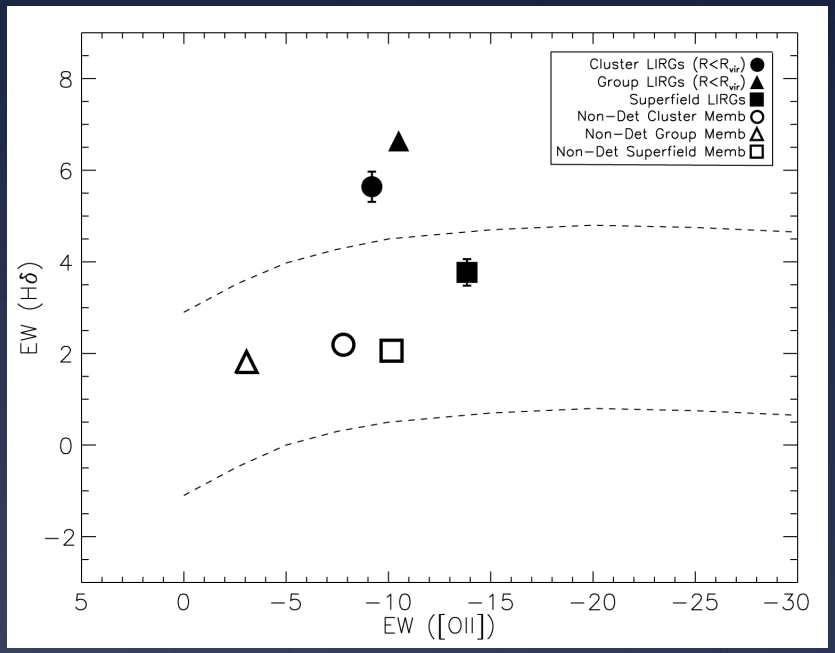
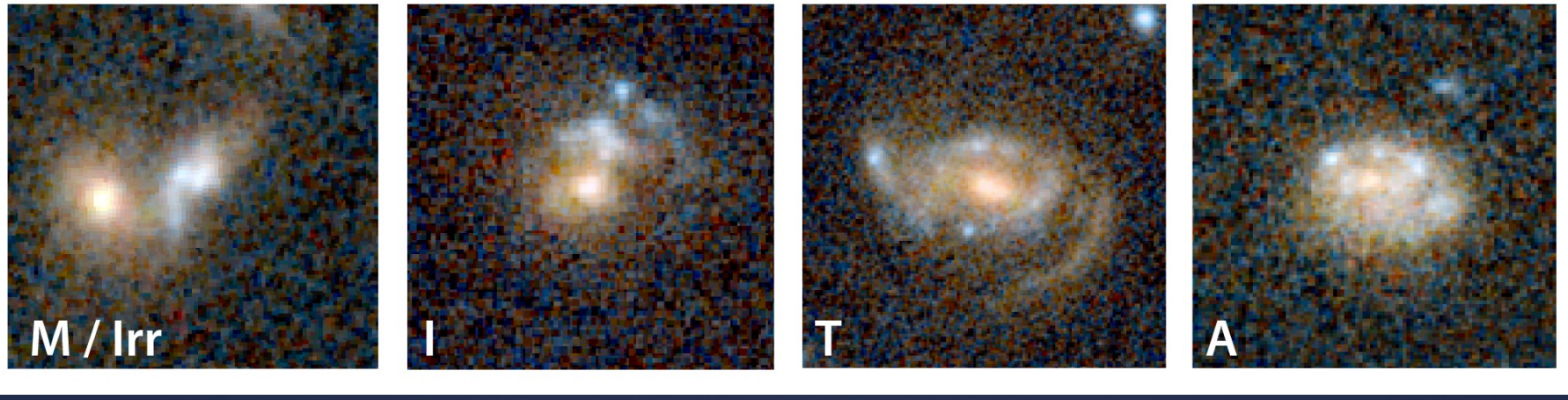


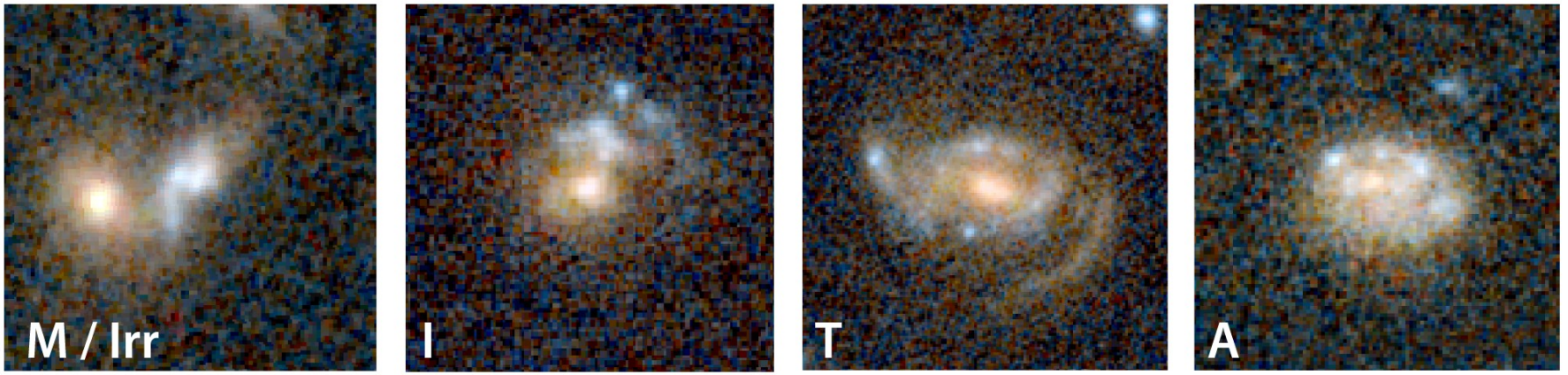
Morphologies



Interaction Classification	Starburst / Passive $R < R_{vir}$	Starburst / Passive $R > R_{vir}$
Irr + MIT	65.8% / 20.2%	35.7% / 39.0%

* Interaction Classification: Mergers, Interactions, Tidal Tails, Asymmetries.
* Majority of 24μm sources in cluster/group centers show disturbances.
  * Disturbances three times as common in detected vs non-detected galaxies.
  * Interactions more common in cluster centers than outskirts.

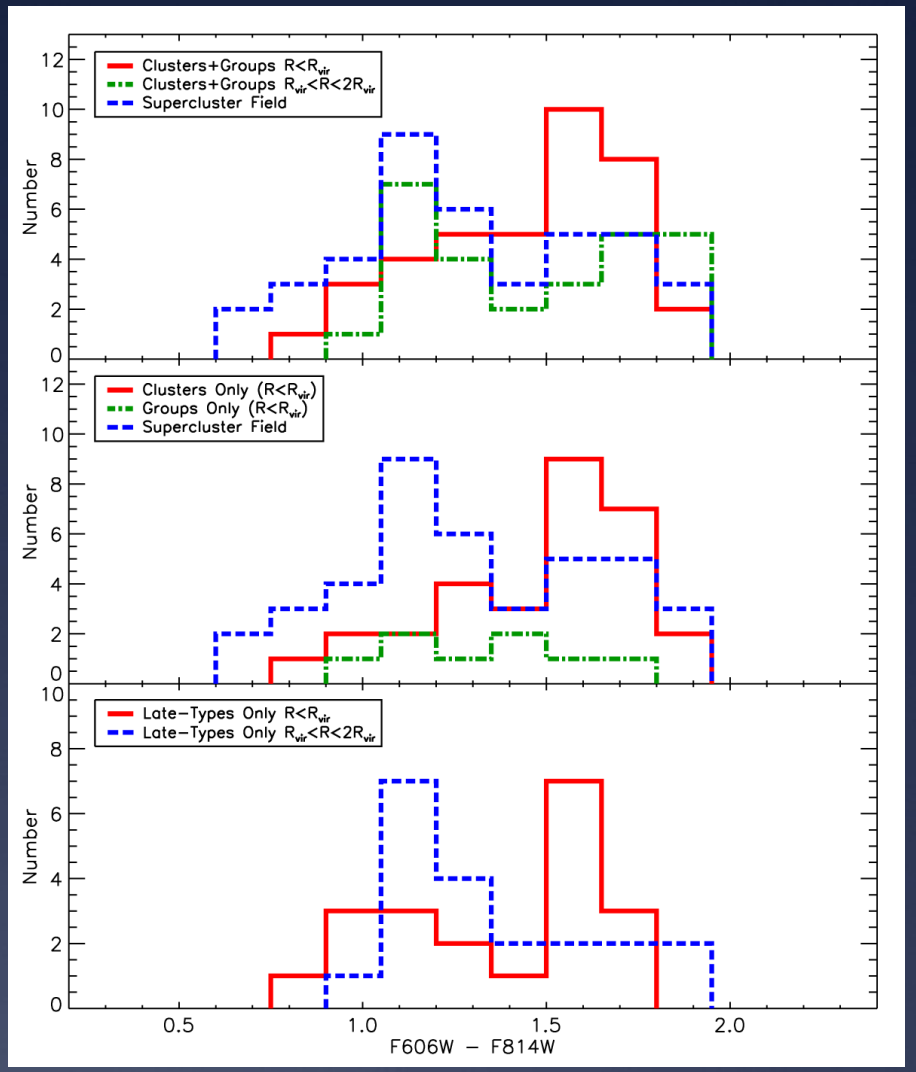
Morphologies



- **Galaxy interactions likely contribute to the increased activity of the starburst galaxies.**
- Since many are found within R_{vir}, where mergers are not likely, this may point to harassment or group compression as mechanism that triggers these interactions.

Optical Colors

* Field: Optical colors of 24μm detected galaxies peak in the blue cloud, small subset of red galaxies.
* Cluster/Group Centers: 24μm Galaxies have colors that peak in the red.
* Color difference remains when we consider only late-type galaxies.
* **Optical colors indicate starburst galaxies in cluster centers cannot simply be infalling field galaxies that have yet to be quenched.**



Summary

* We find that the density of 24um sources in clusters is nearly twice that of the surrounding field and that the overdensity scales with the cluster's dynamical state.

* Spatial distribution suggests 24um-bright galaxies are an infalling population, but they are not simply field galaxies that have yet to be quenched.

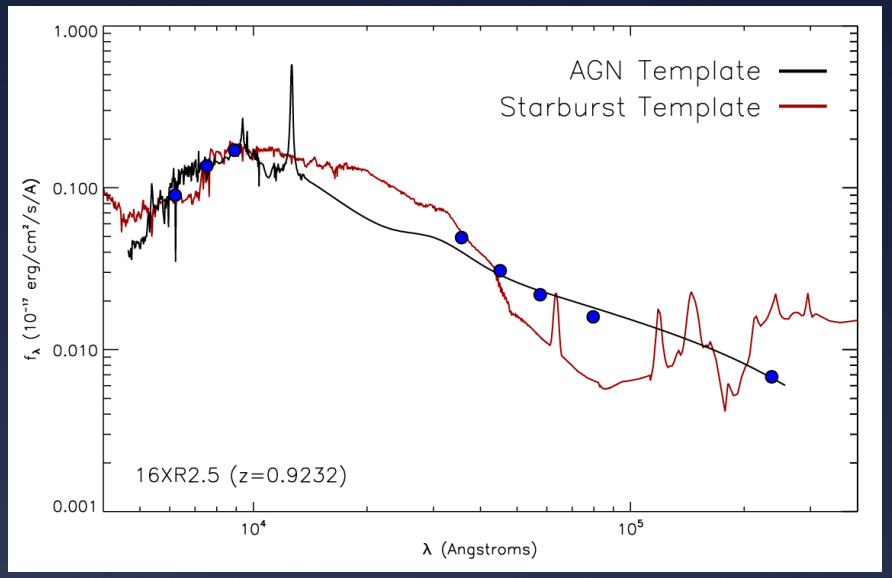
* **24um-bright cluster and group galaxies are experiencing burstier star formation compared to their counterparts in the field at the same redshift.**

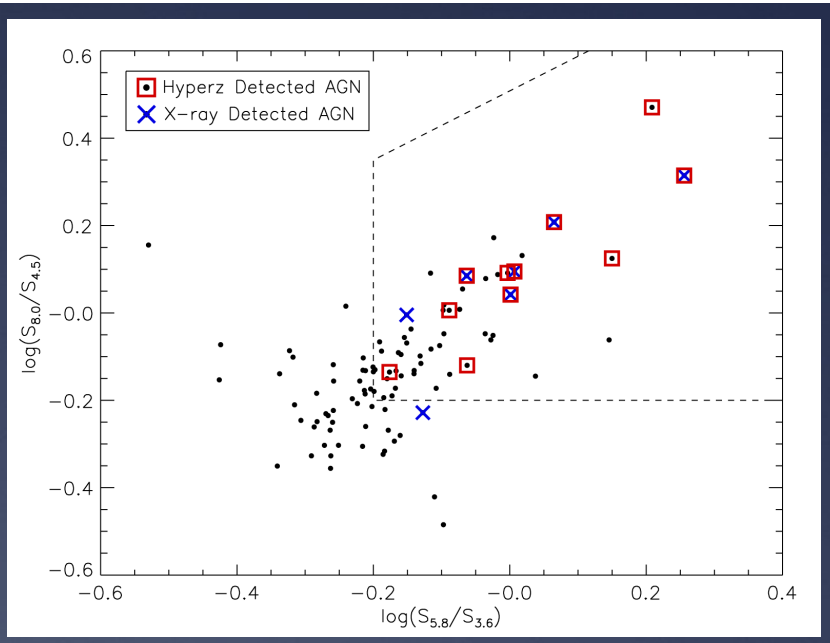
* They exhibit redder colors and presumably higher extinctions than field galaxies: centrally concentrated burst.

* Morphologies indicate interactions / mergers may be triggering this activity.

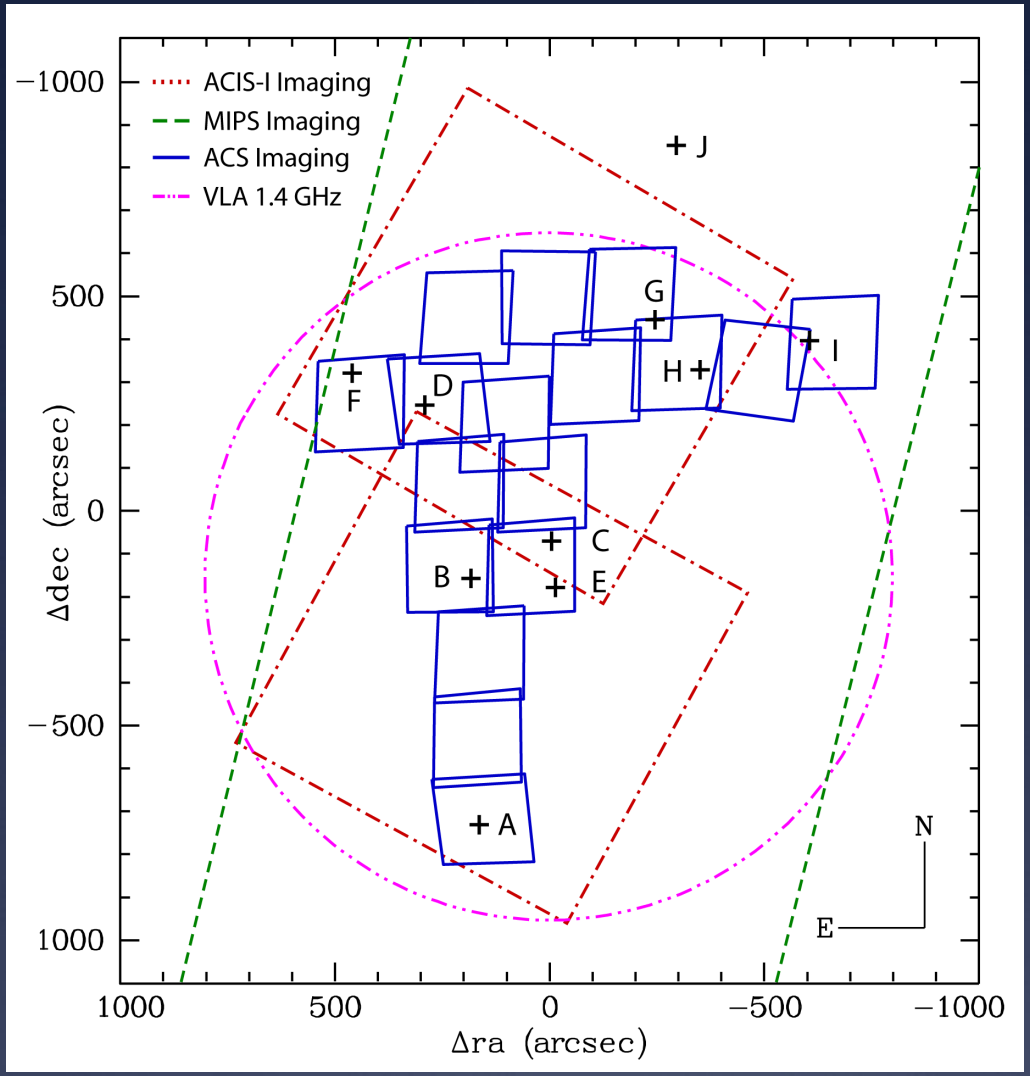
AGN Contamination

* 24μm sources contaminated by AGN emission selected using two methods.
  * SED fitting of starburst and AGN templates to optical & MIR photometry. Used Hyperz + SWIRE template library.
  * AGN detected in our Chandra X-ray imaging.
* In total 13 / 98 sources found to be AGN ~ 13% contamination.
* All but two X-ray detected AGN found via SED fitting method.
* Most have IRAC colors consistent with sources having negative power-law spectral slopes in the Mid-IR (i.e. Donely et al. 2008).

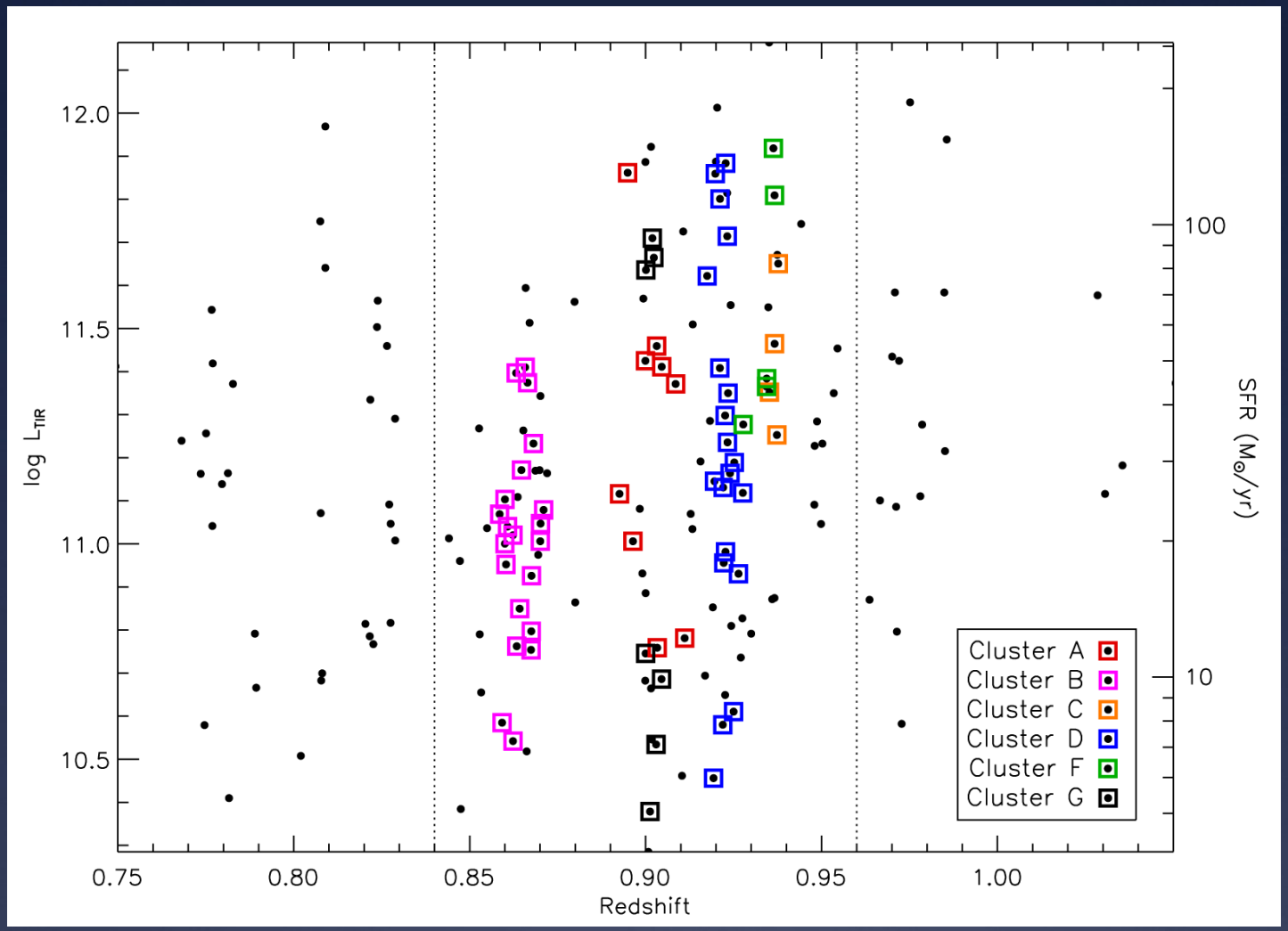




The Cl1604 Supercluster



Calculating L_{IR} & SFR



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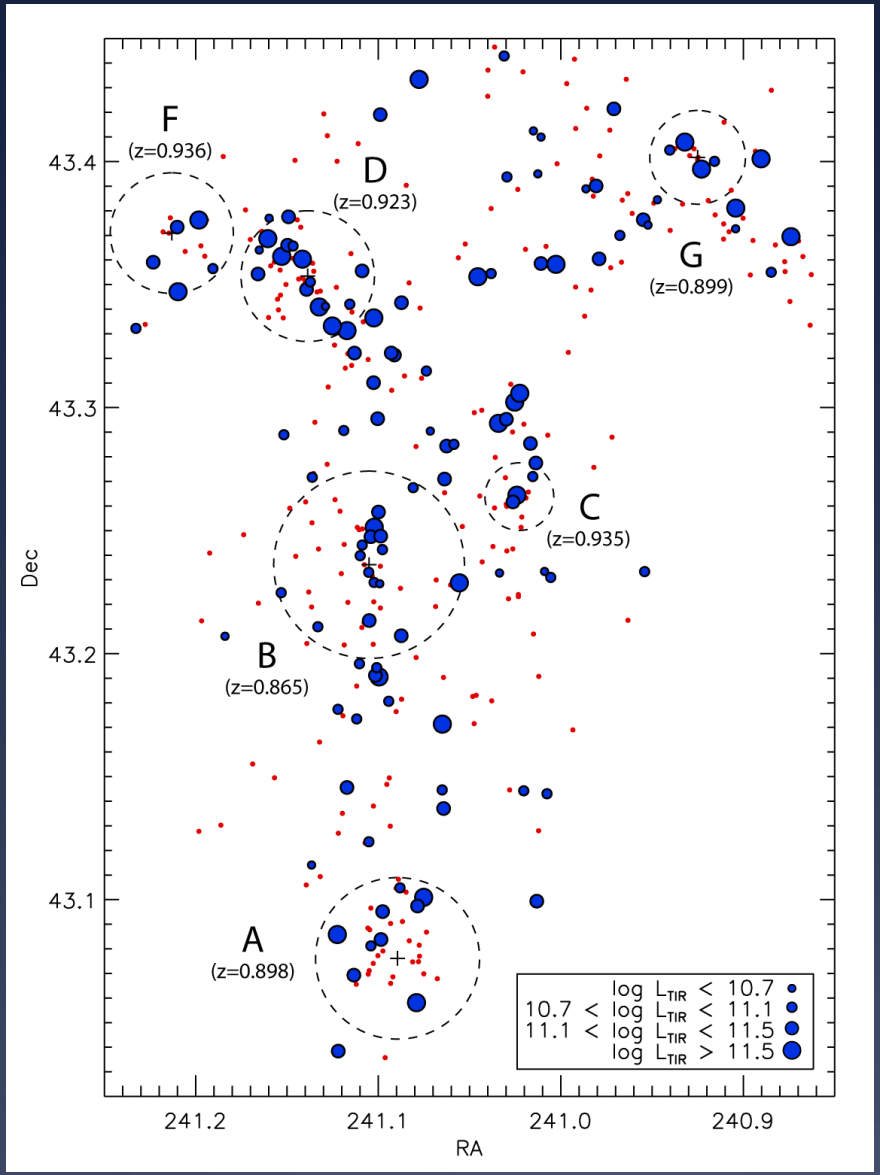


Optical vs IR SFR

* Can compare IR to optical SFR (Kennicutt 1998):

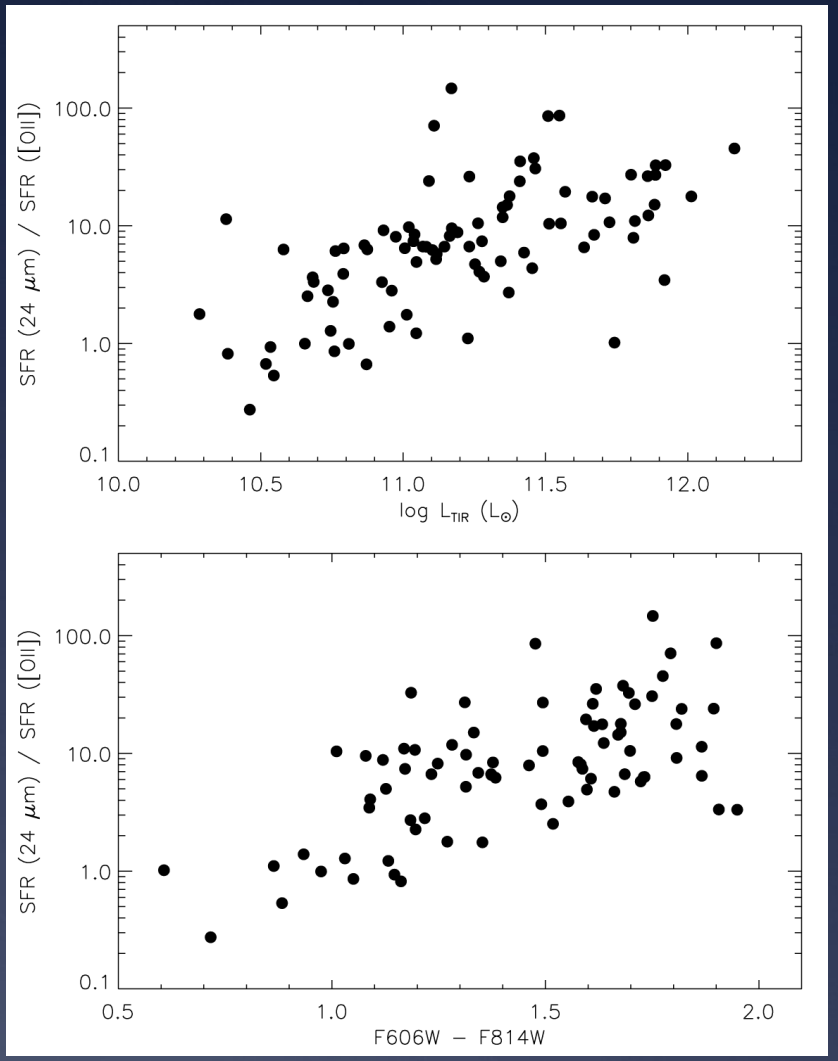
$$SFR_{opt} = 1.4 \times 10^{-41} L[OII]$$

$$SFR_{IR} = 4.5 \times 10^{44} L_{IR}$$

* Optical SFR indicators such as [OII] would severely underestimate the activity of these galaxies.

* Find heavy extinction in 24μm detected population that is well correlated with IR luminosity.

* Reason why identifying starburst galaxies in high-z clusters has been so difficult.



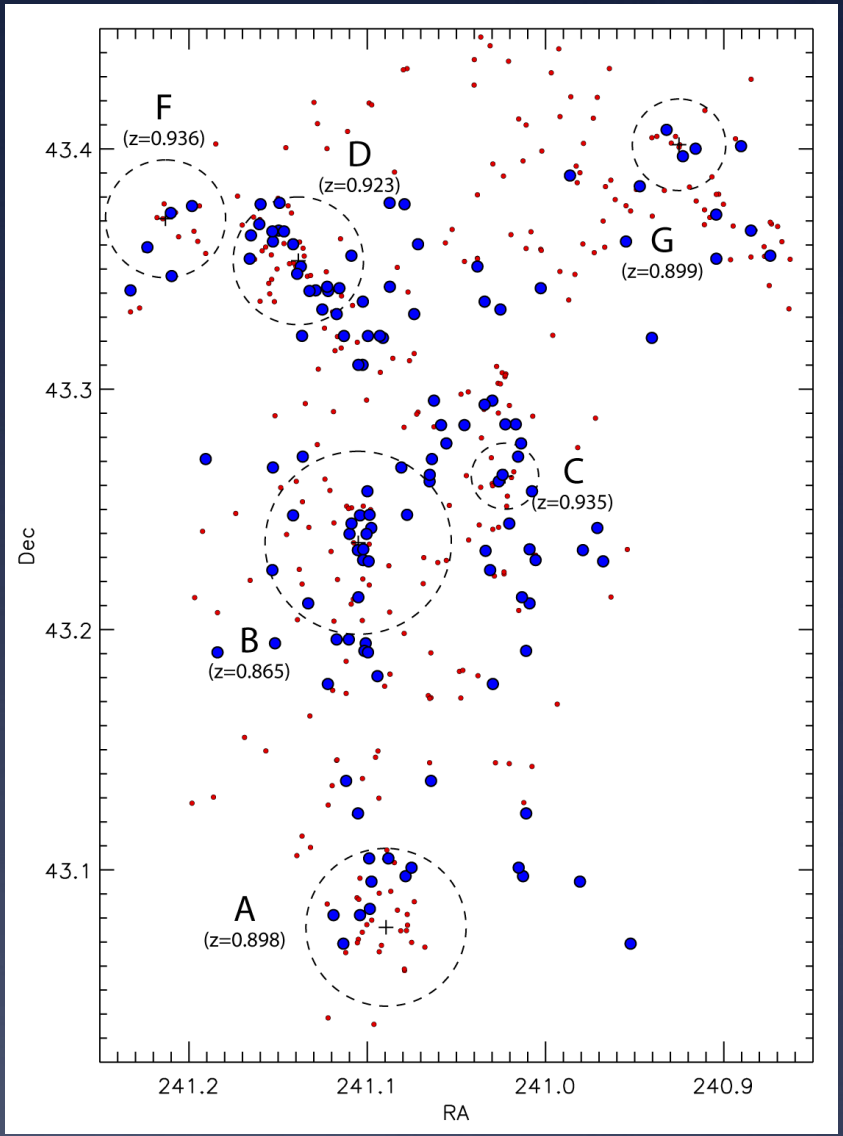
Cluster & Group Subsamples

* Cluster & group subsamples allow us to examine properties of starburst galaxies relative to their host systems.

* Cluster / Group membership determined via conditions:
  * Galaxy located within two projected virial radii (R_{viral}) of a cluster / group center, where:

    $R_{viral} = \sqrt{(3\sigma_v)} / 8.8\ H(z)$

  * Comoving velocity is less than three times the systemic cluster / group velocity dispersion: $dz < 3\sigma_v$



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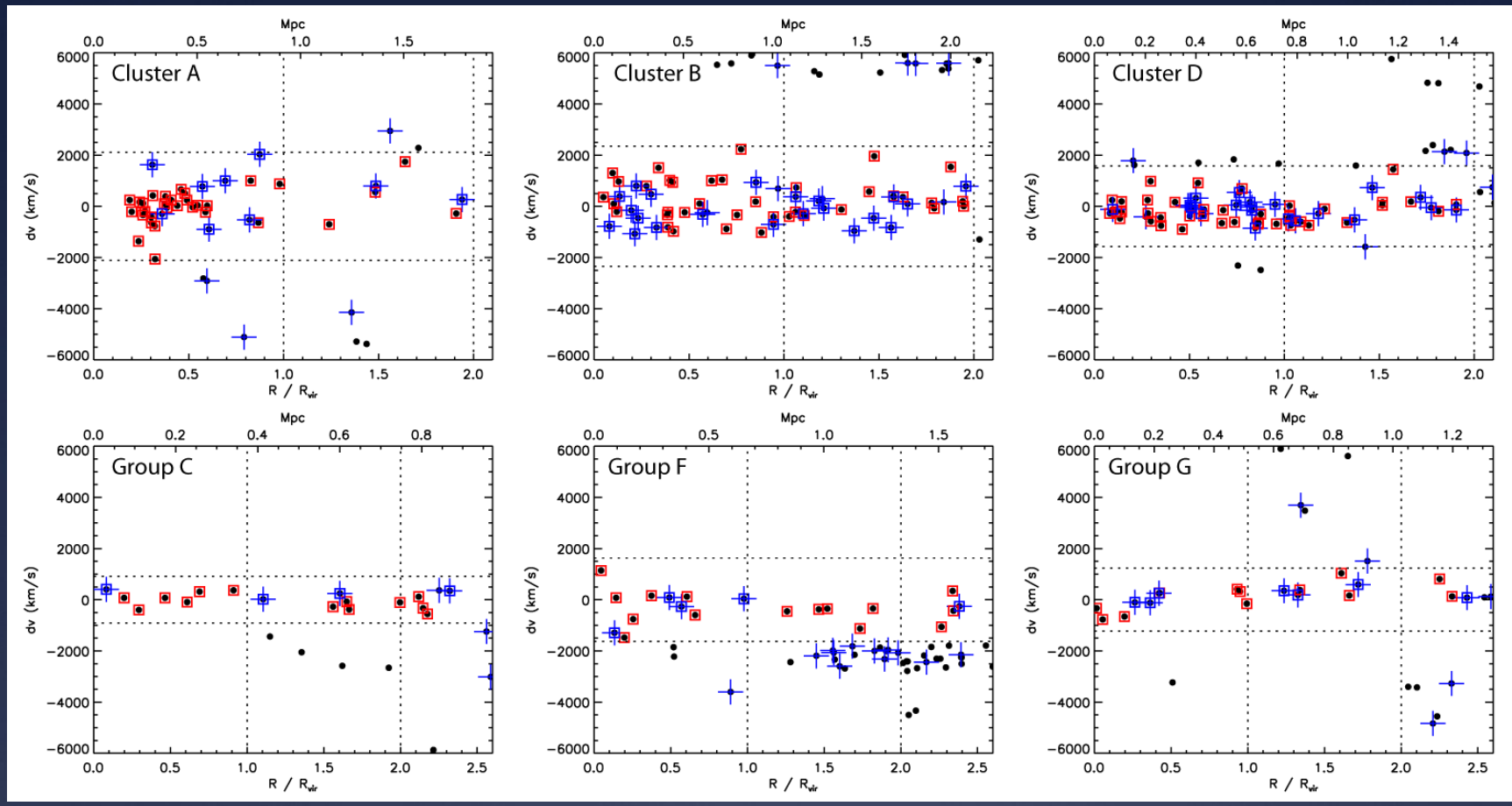
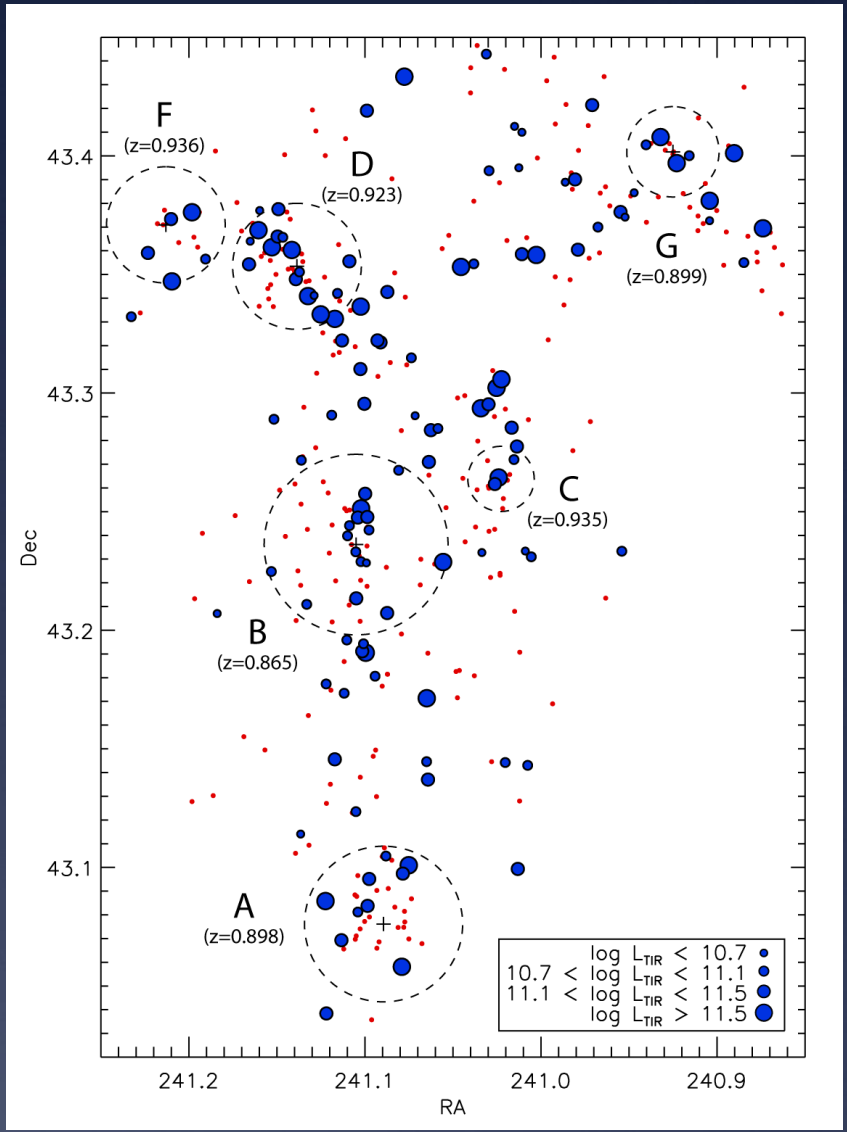


- 50 Galaxies in Clusters A, B, and D ($R < 2R_{vir}$).
- 16 Galaxies in Groups C, F, and G ($R < 2R_{vir}$).

Cluster & Group Subsamples

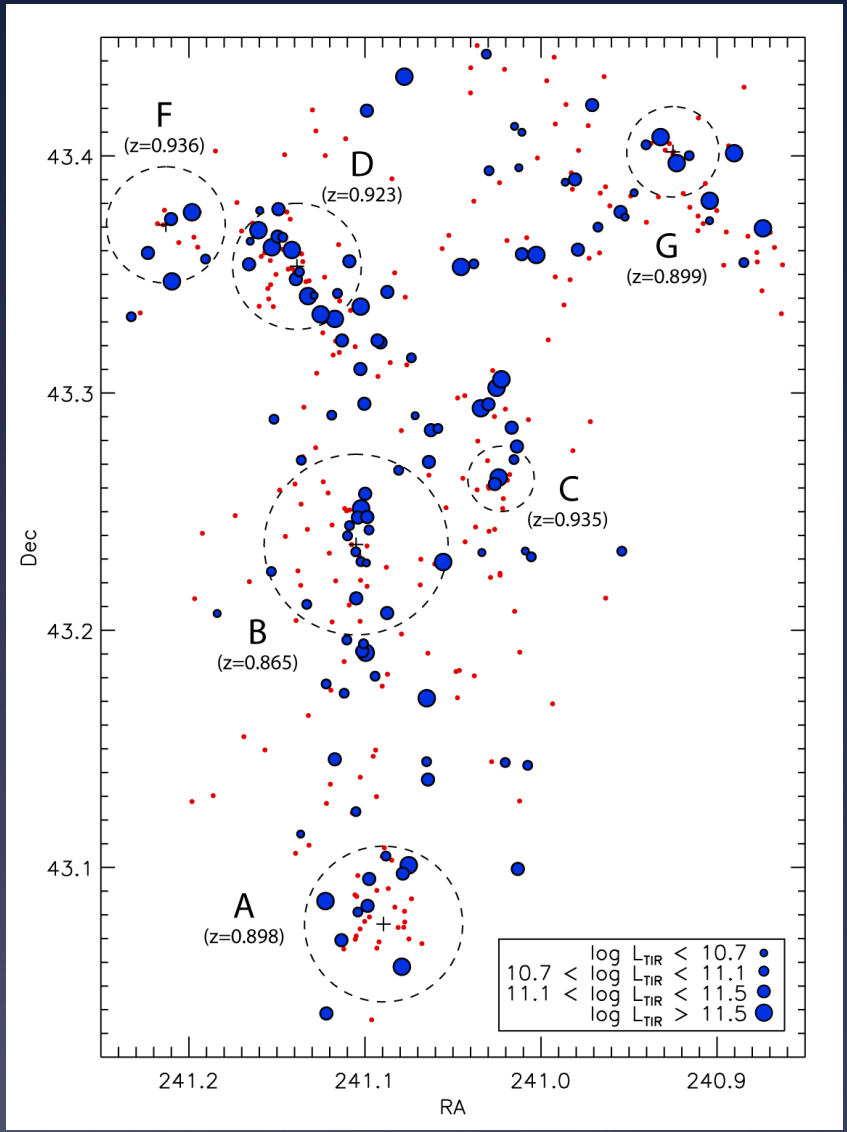
* Number of 24μm sources within $2R_{vir}$:
  * 50 Galaxies in Clusters A, B, and D.
  * 16 Galaxies in Groups C, F, and G.
* Defined three subsamples:
  * Cluster/Group Center: $R < R_{vir}$
  * Cluster/Group Outskirts: $R_{vir} < R < 2R_{vir}$
  * Supercluster Field: $R > 2R_{vir}$ ($0.84 < z < 0.96$)
* Number in each subsample
  * Center: 38 Galaxies
  * Outskirts: 28 Galaxies
  * Field: 47 Galaxies



Spatial Distribution

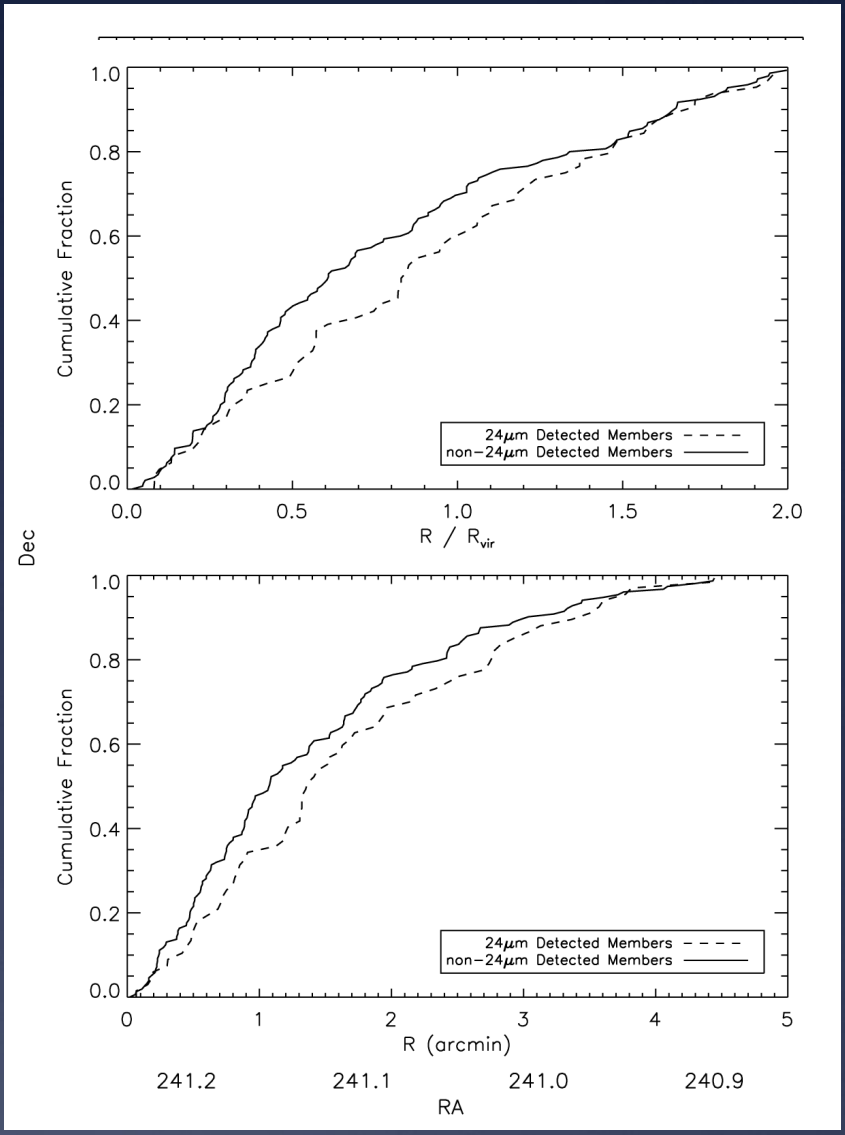
* Increased fraction of members detected in dynamically active clusters:
  * 22.5% detected in Clusters A
  * 36.4% in Cluster B
  * 34.5% in Cluster D
* Increased surface density of 24μm sources in Clusters B and D relative to Cluster A and the field:

Cluster A	1.235 gal/arcmin^2
Cluster B	1.568
Cluster D	2.338
Cluster Avg	1.625
Field Avg	0.881



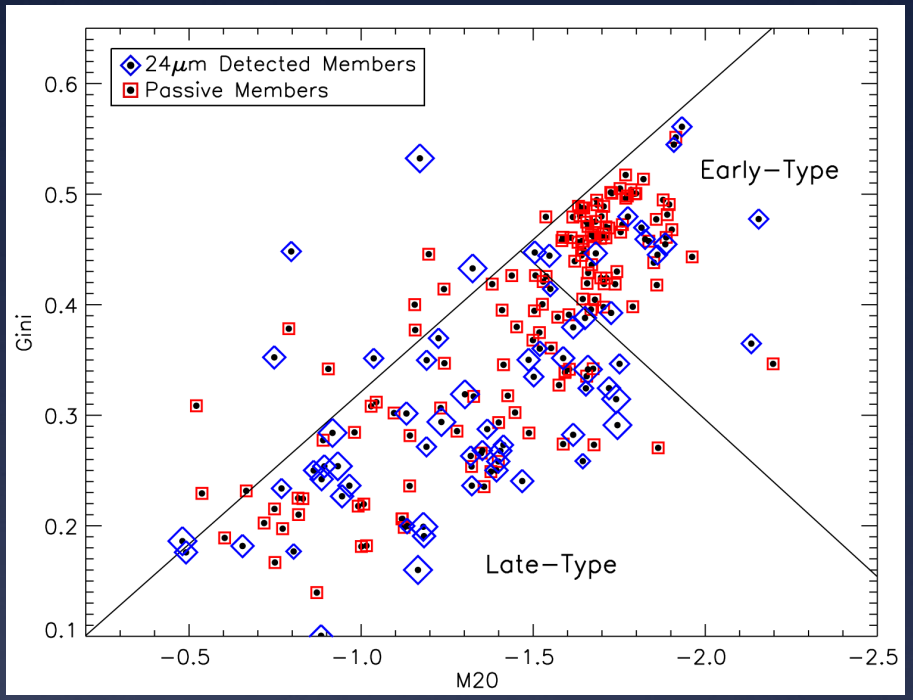
Spatial Distribution

* High density of 24μm sources in filament associated with Cluster D.
* 24μm bright members are less centrally concentrated than non-detected members.
  * KS Test finds only 14% probability that active and passive populations are drawn from same distribution.
* **Spatial distribution indicates 24μm detected galaxies are an infalling population.**



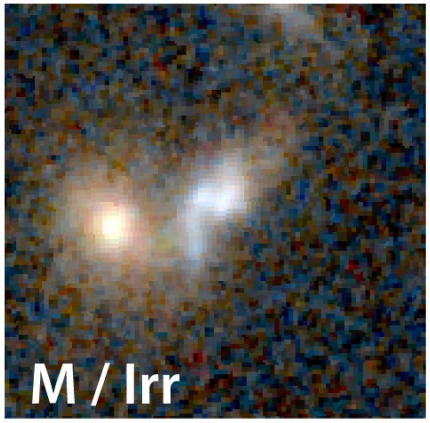
Morphologies

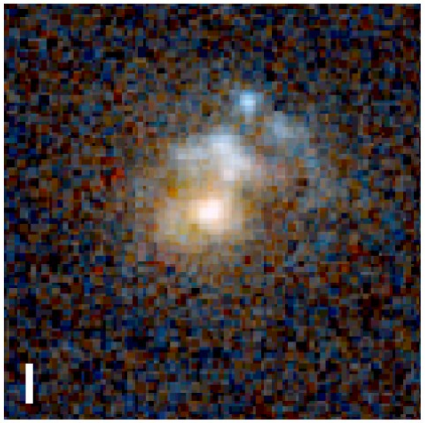
* Do galaxy interactions cause this increased activity?
* Gini-M20: Majority have late-type morphologies. Opposite true for non-detected members
* Visual Classification: Irregular morphs more common in 24μm bright cluster and group members.

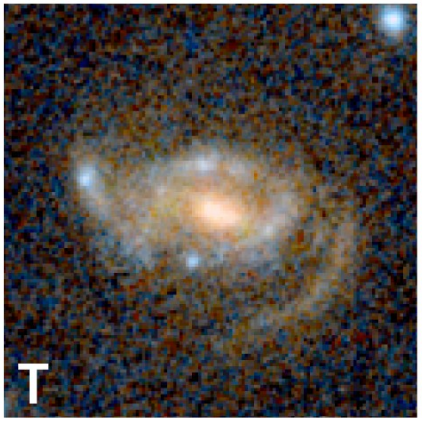


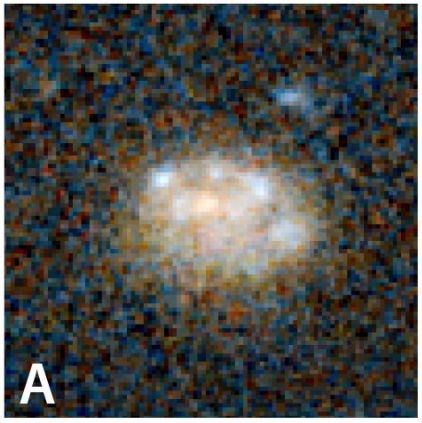
Morph	Starburst / Passive
E / S0	34.2% / 76.6%
Late-Type (Sa-Sd)	52.6% / 21.3%
Irregular	13.2% / 2.2%

Morphologies









Interaction Classification	Starburst / Passive $R < R_{vir}$	Starburst / Passive $R > R_{vir}$
Irr + M	42.1% / 13.8%	25.0% / 29.3%
Irr + MIT	65.8% / 20.2%	35.7% / 39.0%
Irr + MITA	78.9% / 26.6%	53.6% / 46.3%

* Interaction Classification: Mergers, Interactions, Tidal Tails, Asymmetries.
* Majority of 24μm sources in cluster/group centers show disturbances.
  * Disturbances three times as common in detected vs non-detected galaxies.
  * Interactions more common in cluster centers than outskirts.

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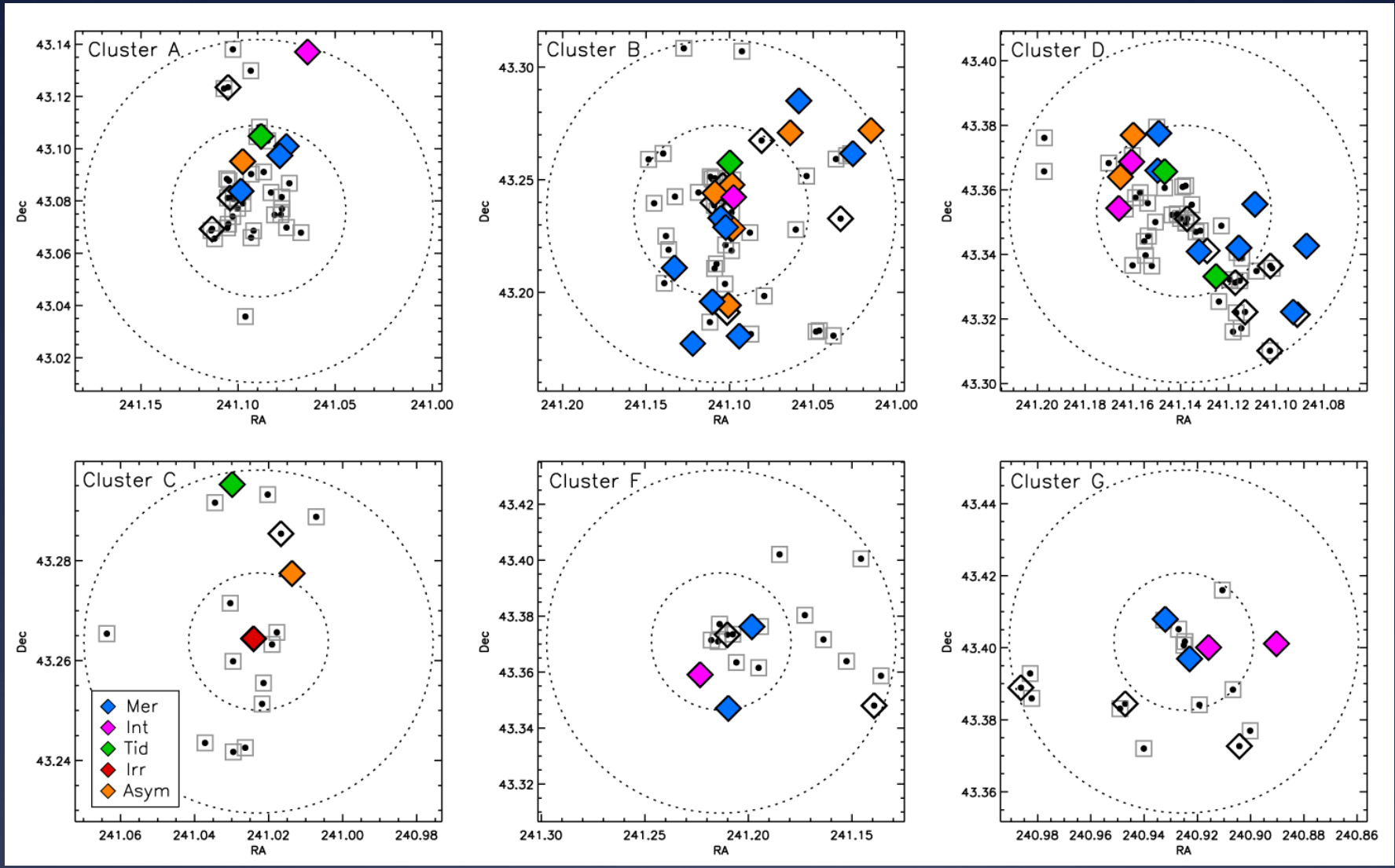
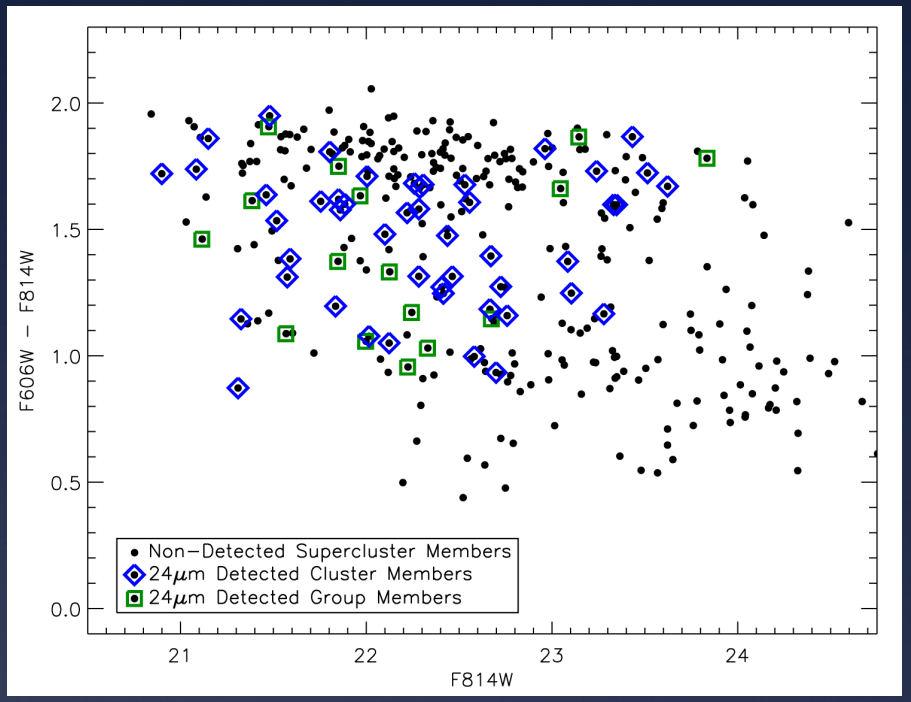
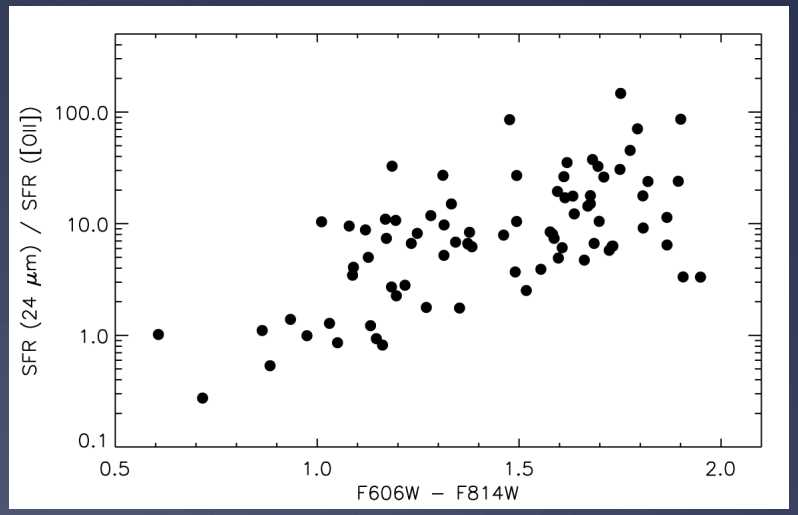


Optical Colors

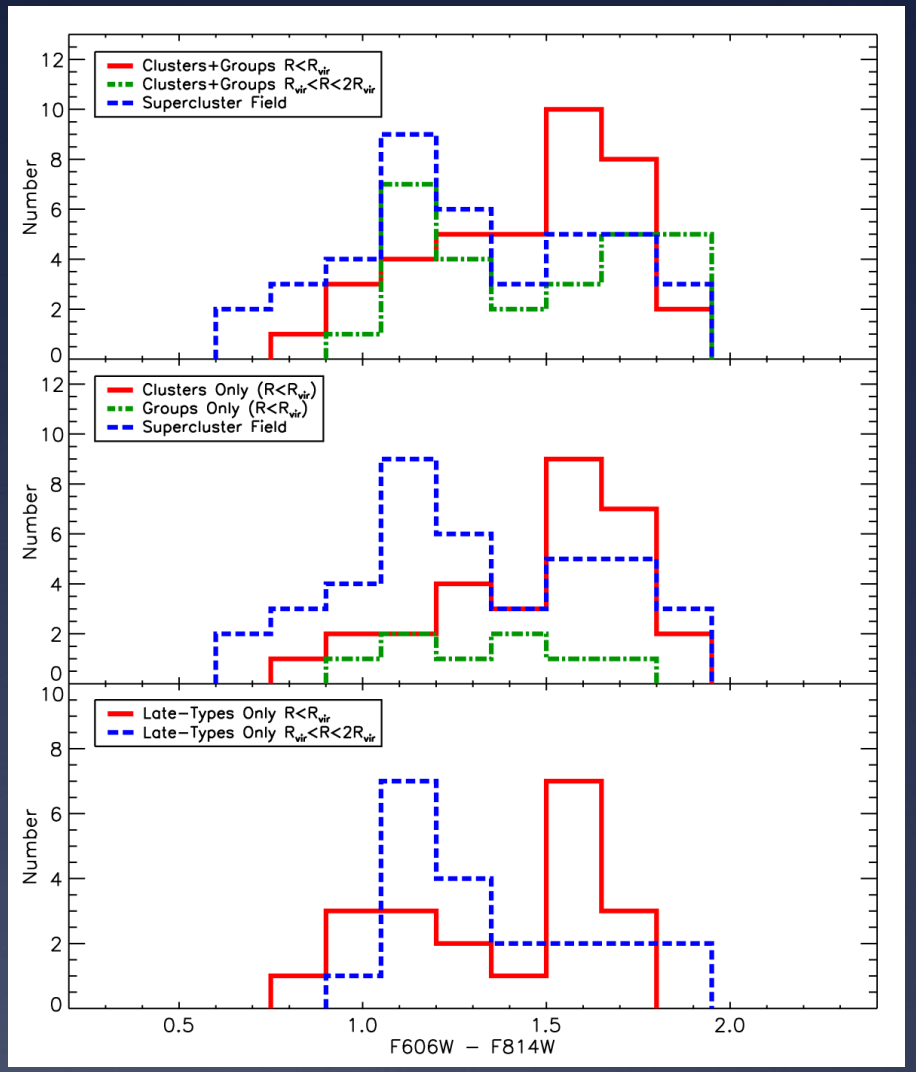
* Optical colors (U-B) redder than Blue Cloud - peak in Green Valley.
* Optical vs IR derived SFRs indicate this is largely the result of dust extinction.
* Pronounced differences in color appears when 24μm sample split by cluster-centric distance.





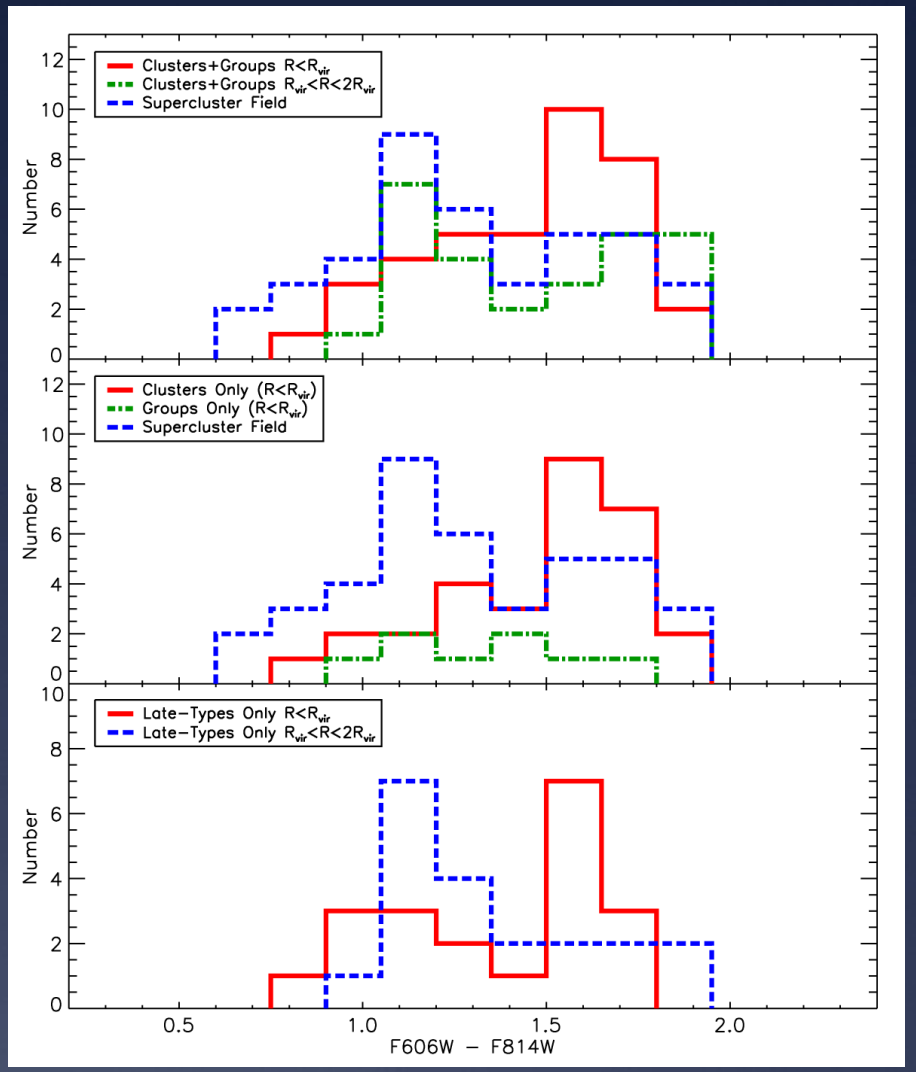
Optical Colors

* Field: Optical colors of 24μm detected galaxies peak in the blue cloud, small subset of red galaxies.
* Cluster/Group Outskirts: Colors evenly distributed between blue and red.
* Cluster/Group Centers: 24μm Galaxies have colors that peak in the red.
* Largely due to cluster galaxies, as group galaxy colors are evenly distributed.



Optical Colors

* Field / Cluster color dichotomy not due to increase in early-type fraction within clusters.
* Color difference remains when we consider only late-type galaxies.
* **Optical colors indicate starburst galaxies in cluster centers cannot simply be infalling field galaxies that have yet to be quenched.**



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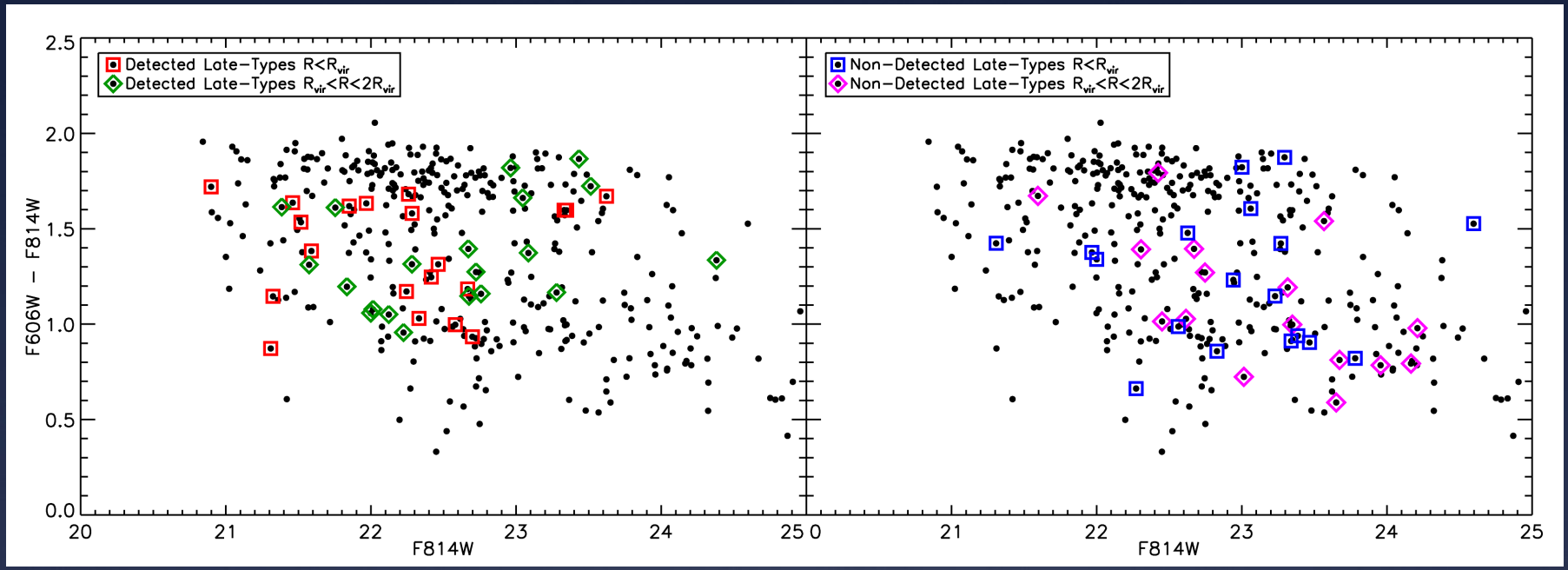

* In addition, 24μm detected cluster/group spirals tend to be brighter and redder than their non-detected counterparts.

* Colors could be explained if 24μm detected cluster / group galaxies are experiencing centrally concentrated burst of star formation.

Central Concentration

* Circumnuclear starbursts buried beneath higher column densities of obscuring dust.
* Gas funneled toward galaxy centers may trigger such activity.
* 24μm detected members have higher central concentrations compared to non-detected members.
* Not due to greater fraction of early-type galaxies in cluster centers.