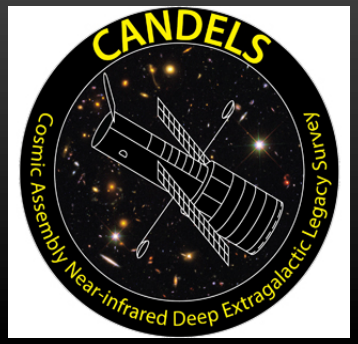

PCA Classification of CANDELS Non-Parametric Galaxy Morphologies

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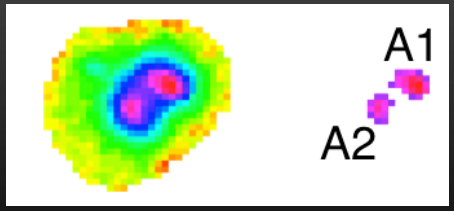
Motivation

- How can we best classify galaxies across redshift?
- What processes grow and quench galaxies? And are these processes different for elliptical, spiral and irregular galaxies?
- What Morphologies correspond to which mechanisms?
  - Bin galaxies into disks, spheroids and irregulars
  - Rare and subtle features that are lost in such a generic classification scheme are important for characterizing the evolution of galaxy morphology.

Non-Parametric Morphologies

- Concentration
- Asymmetry
- Gini Coefficient
- M_{20}
- Plus 3 newer statistics…

Non-Parametric Quantitative Morphology (Freeman et al. 2013)



Multi-mode (M)

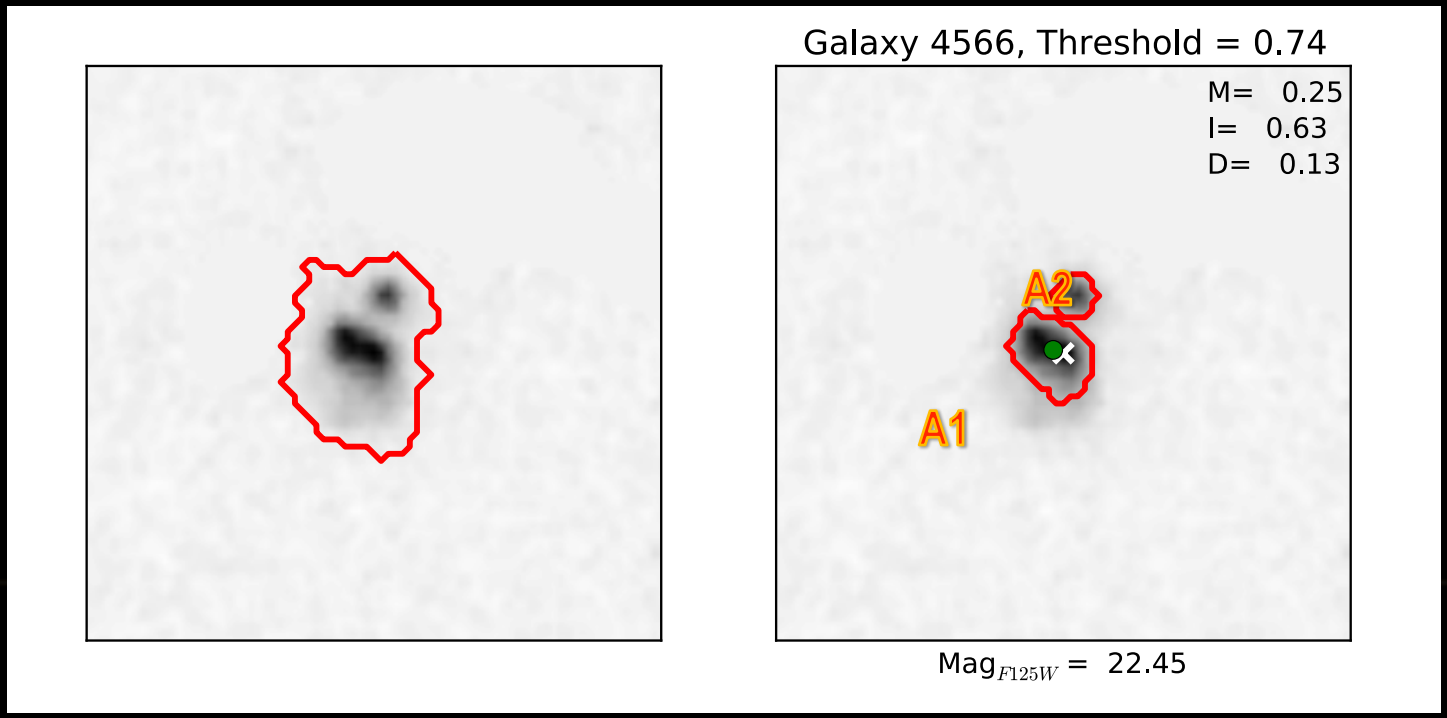
Ratio of size (in pixels) of 1st and 2nd brightest regions

Intensity (I)

Ratio of flux in 1st and 2nd brightest regions

Segmentation Map based on Petrosian Radius

Segmentation based on M calculation



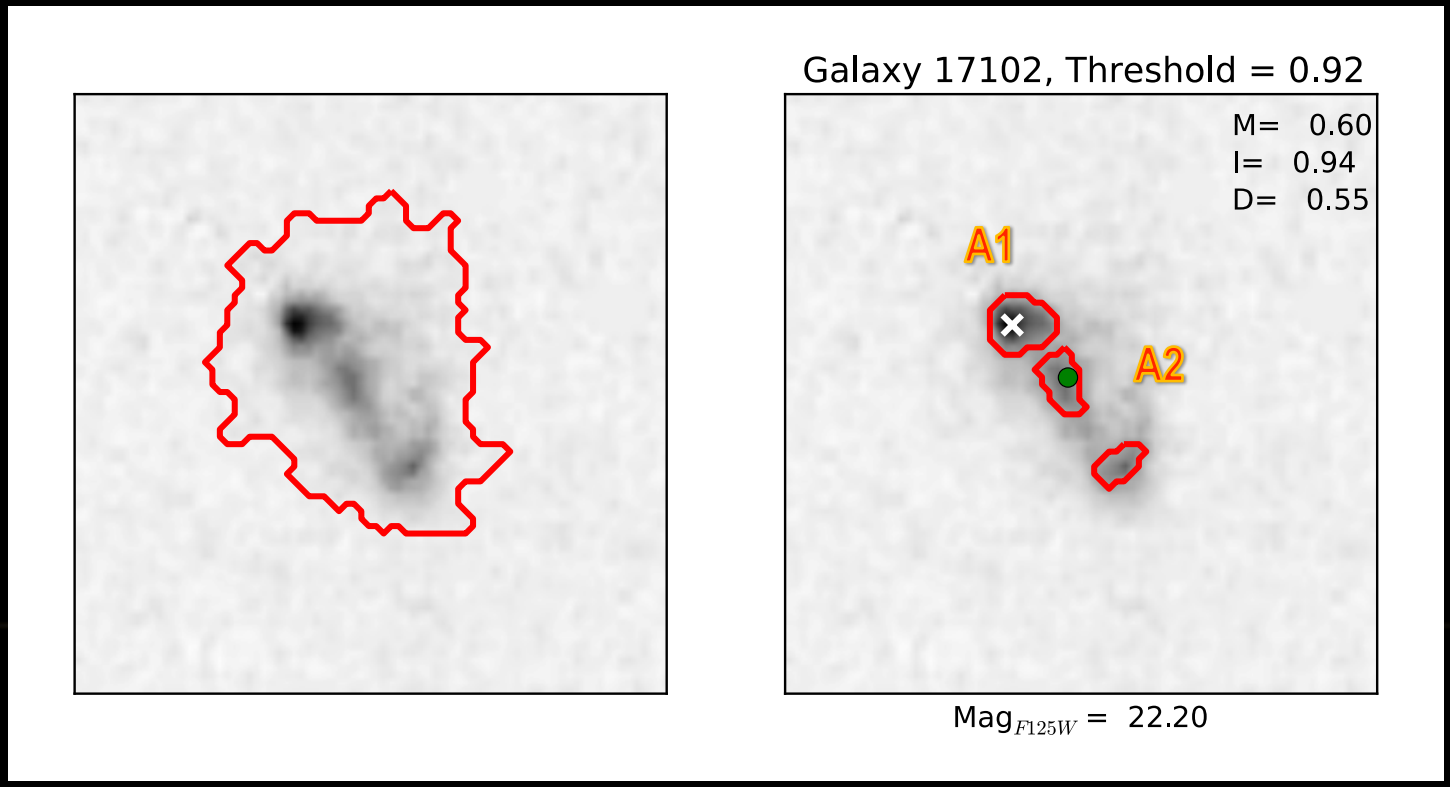
Non-Parametric Quantitative Morphology (Freeman et al. 2013)

Deviation (D)

Distance between center of brightest region and intensity centroid of galaxy

Segmentation Map based on Petrosian Radius

Segmentation based on M calculation



Principal Component Analysis

- PCA using the 7 non-parametric morphology parameters as measured in CANDELS UDS galaxies. Focus on F125W $1.36 < z < 1.97$ galaxies ($>10^{10}$ $M_{\odot}$)
- PCA outputs the eigenvector solutions of a singular value decomposition, which show the importance and internal correlation of each parameter.
- PCA previously used to classify galaxies using morphologies (ZEST; Scarlata et al. 2007)
  - However, this work covered galaxies $z \leq 1$, included Sersic-n, didn't include MID

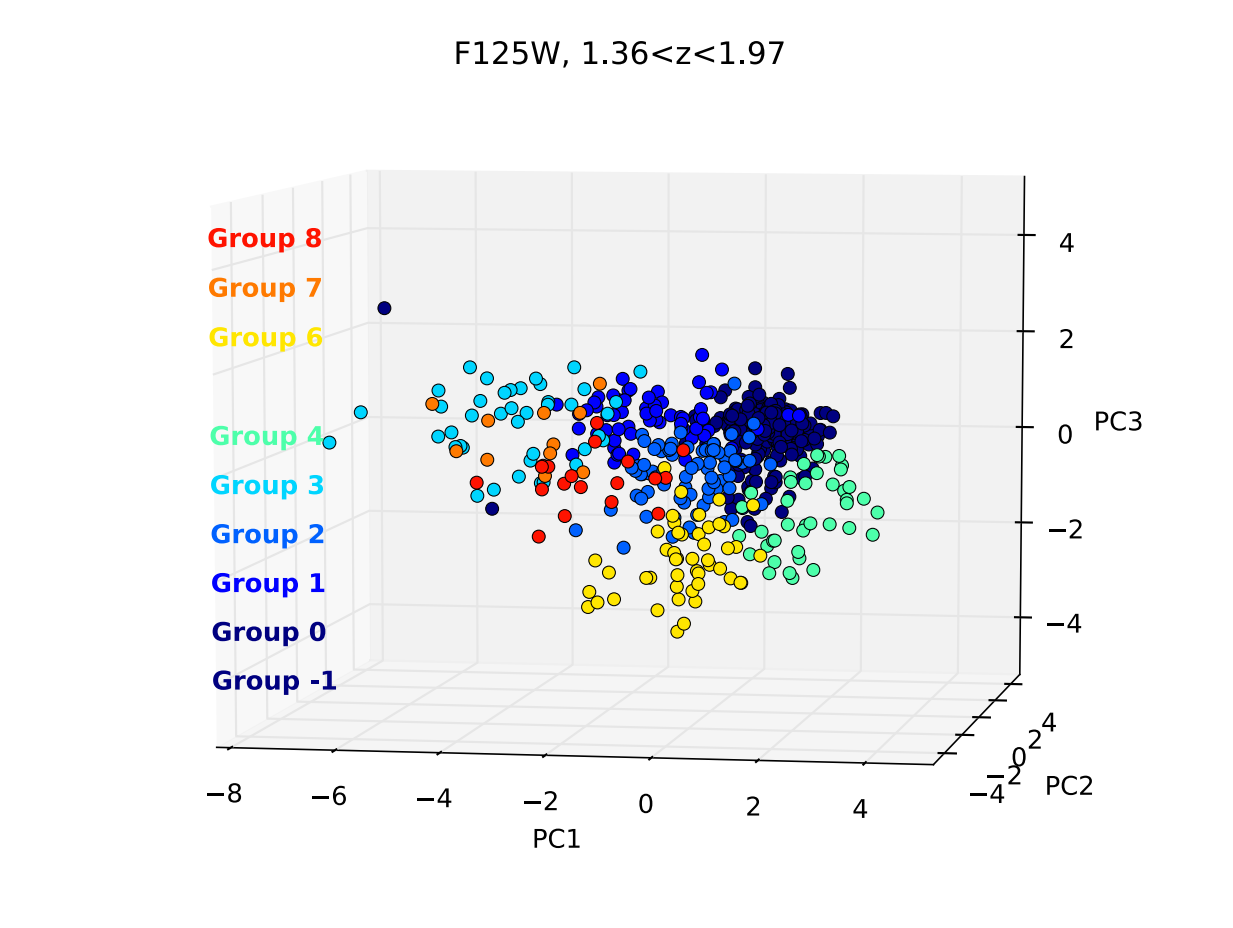
We discover:

- PC1: Finds *G*-M_{20} anti-correlated, *MID* correlated
- PC2: Asymmetry, PC3: Concentration

PARAMETER	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigenvalue	0.453	0.158	0.144	0.083	0.078	0.053	0.030
Concentration	0.0802	0.2308	-0.9446	0.0125	-0.0925	0.1825	0.0779
M20	-0.4337	-0.0903	-0.1952	-0.5807	0.0536	-0.6516	0.0313
Gini	0.4267	0.3038	0.0226	0.2886	-0.4584	-0.6357	-0.1659
Asymmetry	0.0521	0.8708	0.2045	-0.3053	0.3051	0.0836	0.0621
M'	-0.4741	0.1793	0.0496	0.487	-0.0815	-0.1316	0.6924
I	-0.4676	0.1559	-0.0988	0.4569	0.3171	-0.0932	-0.6552
D	-0.4209	0.1776	0.1231	-0.2006	-0.7604	0.3239	-0.2299

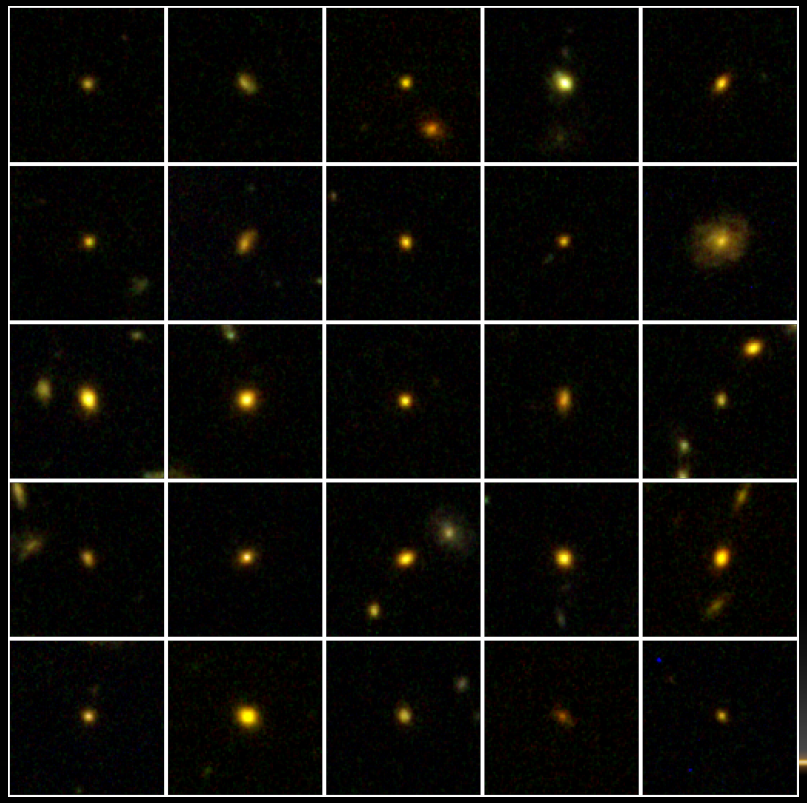
Agglomerative Hierarchical Clustering

Data points clustered minimizing in-cluster variance

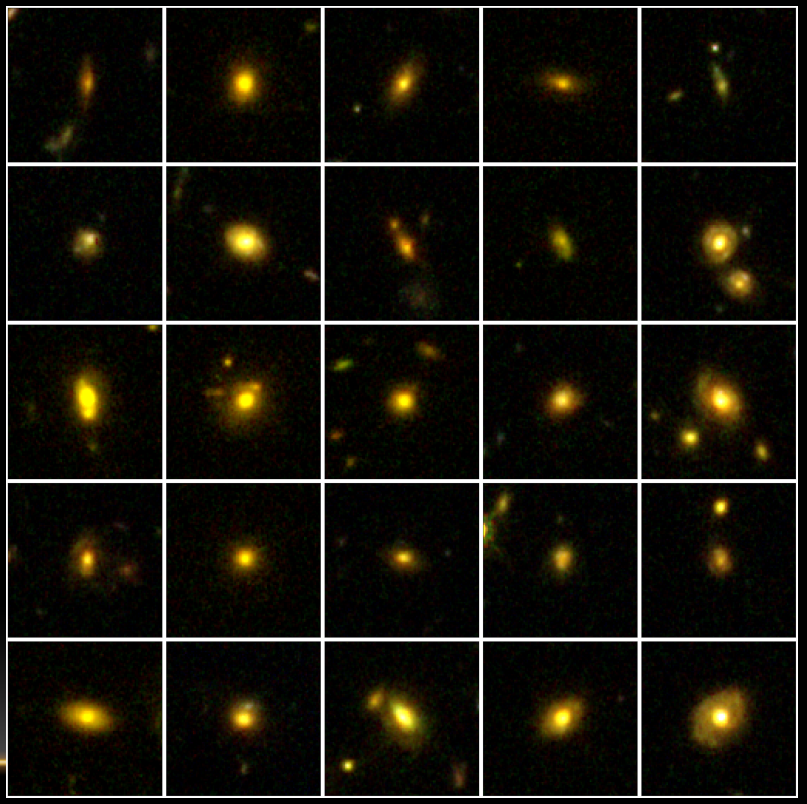


Comparisons of PCA Groups

Group 0: Compact, very small

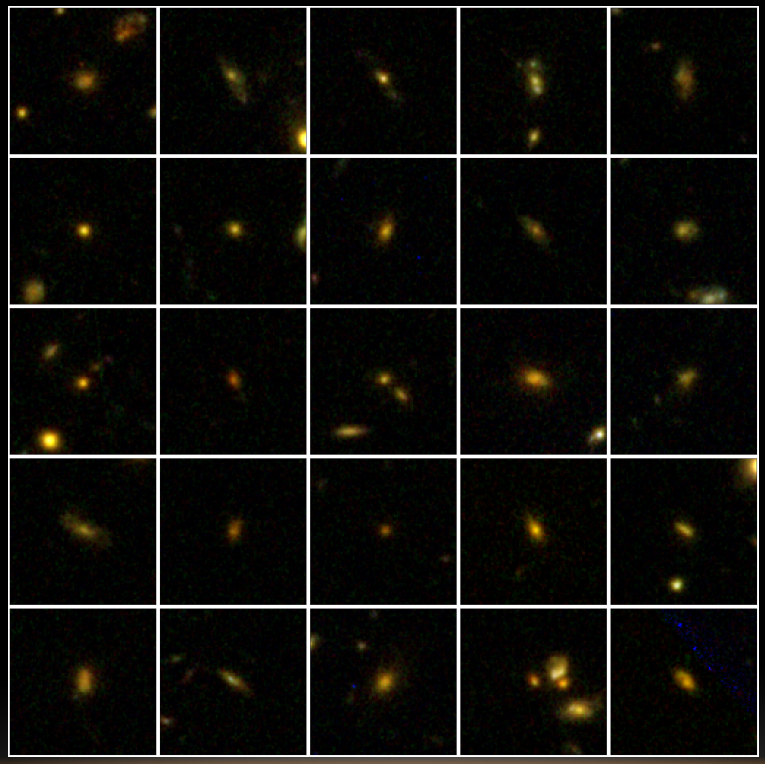


Group 4: Bulge dominated with disk



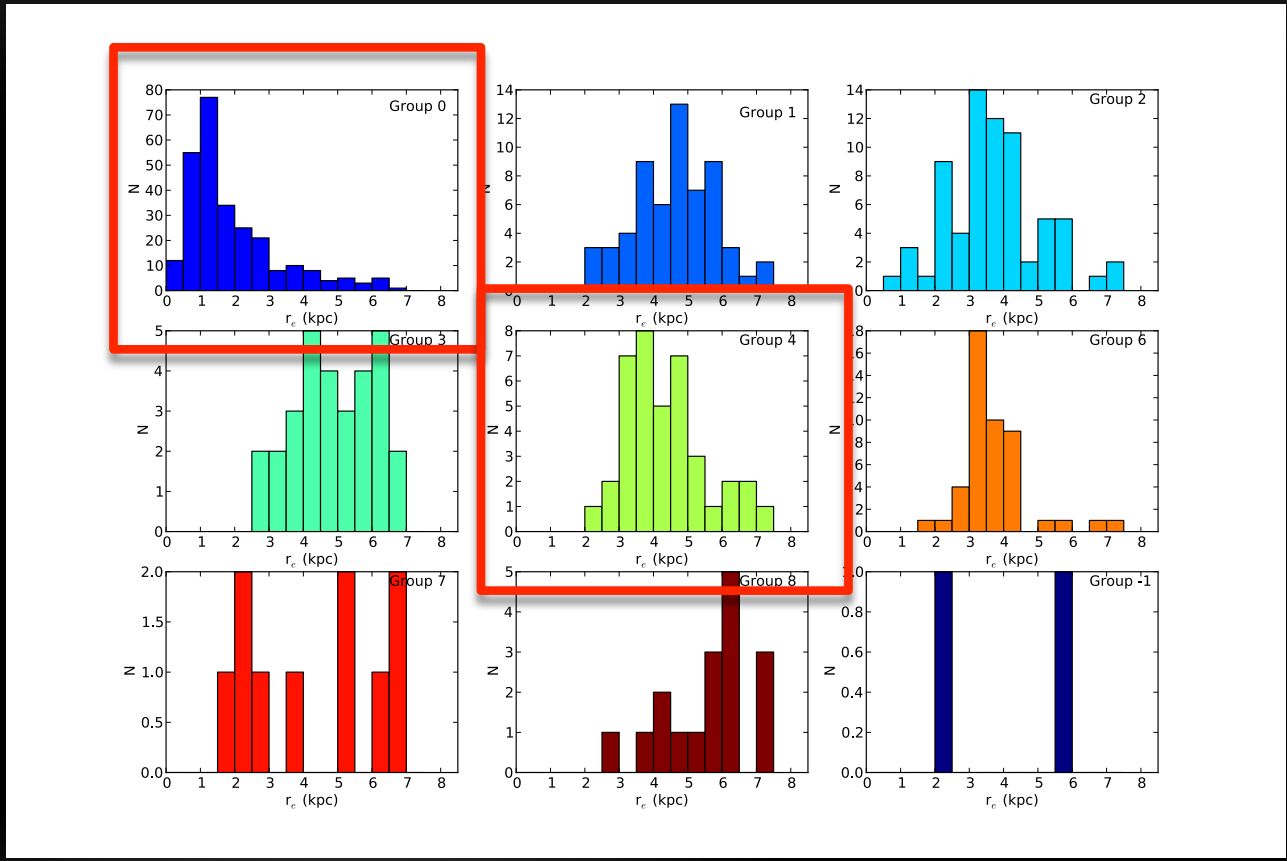
Comparisons of PCA Groups

Group 2: Appear to share certain elements of 0 and 4



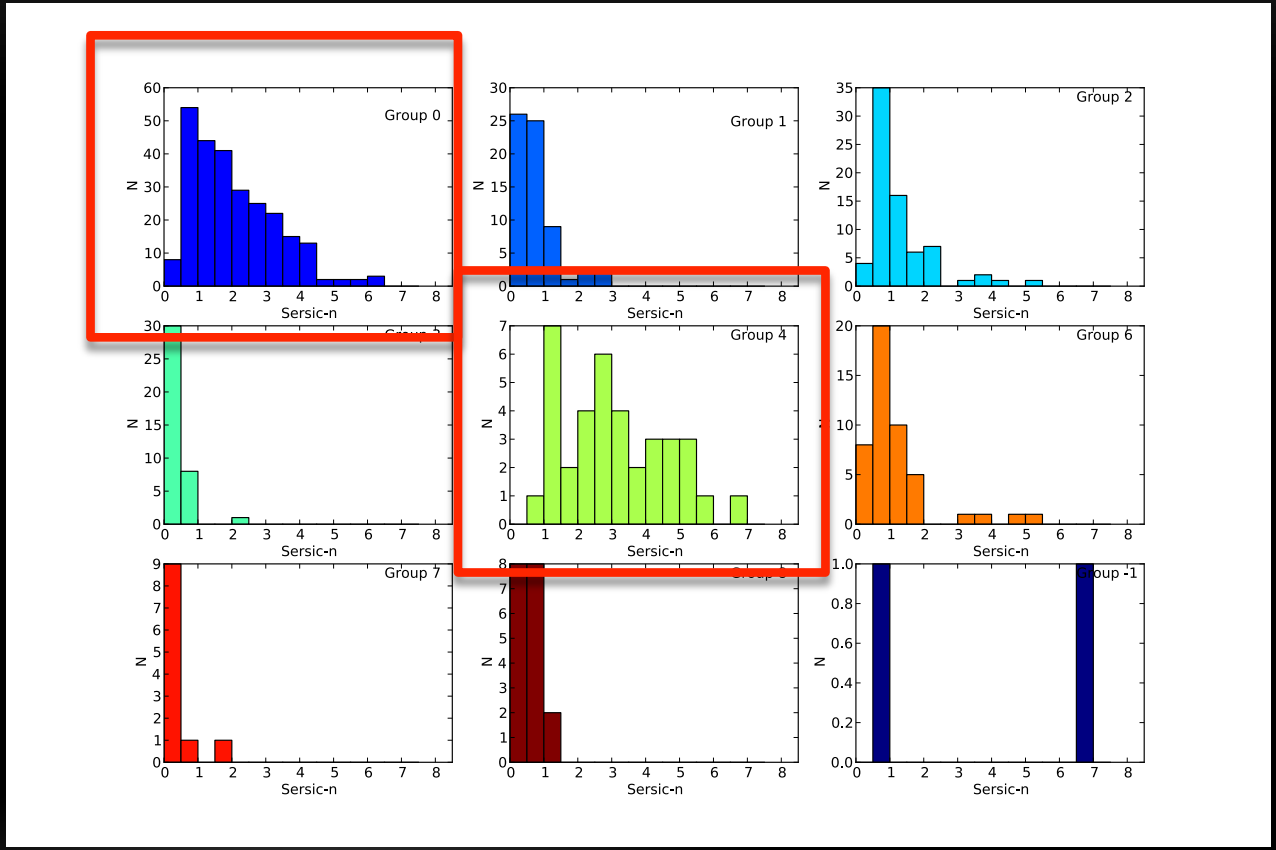
Effective Radii Histogram

- Group 0 is dominated by small galaxies (r_{eff} < 2 kpc)
- Whereas, group 4 has no small galaxies
- Effective radius not an input for PCA



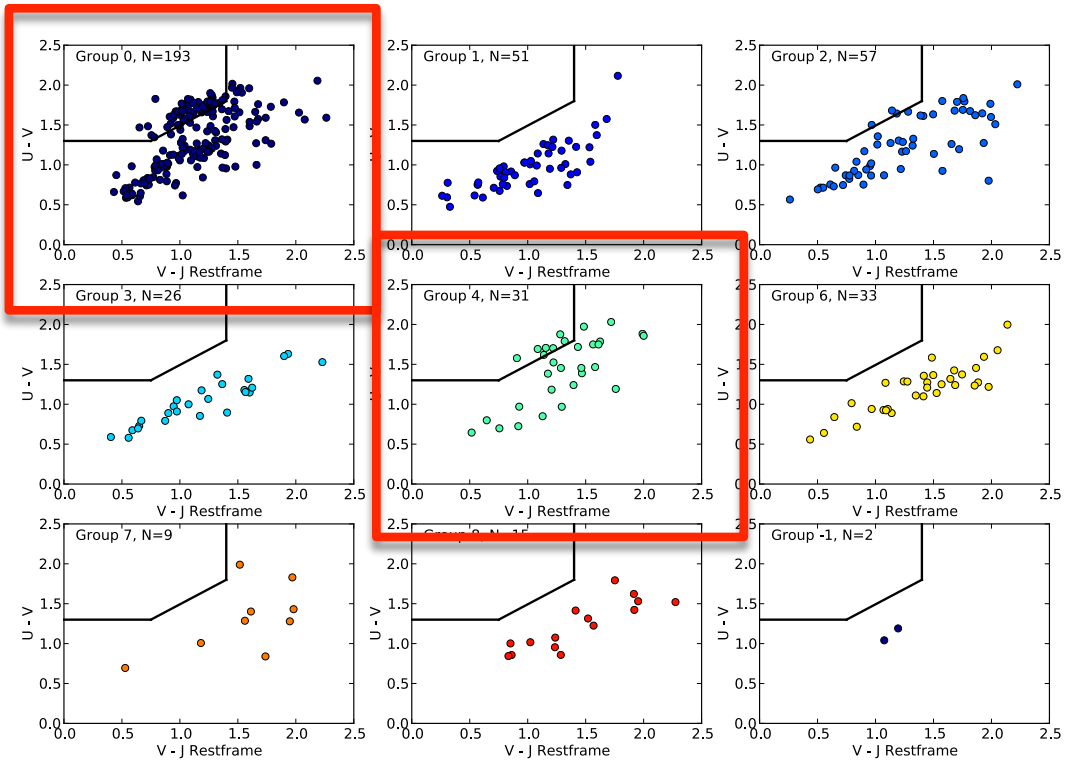
Sérsic Index

- Sérsic index not a great way to characterize these galaxy groups
- Many groups have similar distribution of Sérsic indices but have different non-paramatric morphologies (as we'll see later)



UVJ Color-Color Diagram

- Group 0 with vast majority of quenched galaxies, only group 4 also has a sizable amount



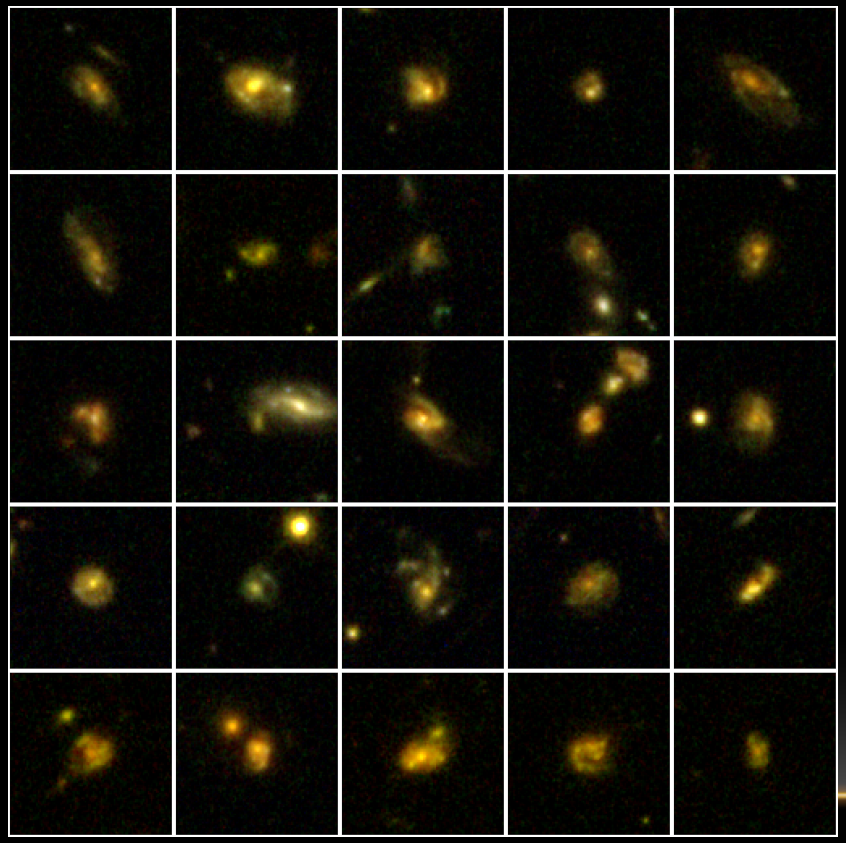
Quenched Fractions of Group Membership

	Quenched		Star Forming	
	of Group	of Total	of Group	of Total
Group -1	0.00	0.00	100.00	0.48
Group 0	34.72	83.75	65.28	30.22
Group 1	1.96	1.25	98.04	11.93
Group 2	5.26	3.75	94.74	12.95
Group 3	0.00	0.00	100.00	6.24
Group 4	25.81	10.00	74.19	5.52
Group 6	0.00	0.00	100.00	7.91
Group 7	11.11	1.25	88.89	1.92
Group 8	0.00	0.00	100.00	3.60

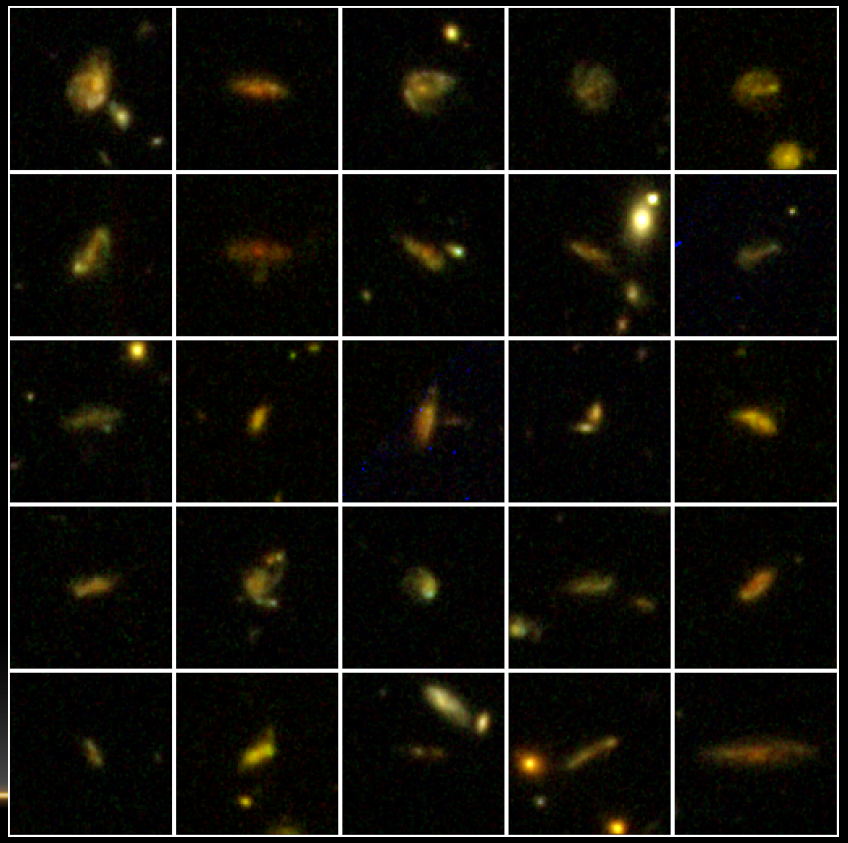
Keep in mind:
$1.36 < z < 1.97$

Comparisons of PCA Groups

Group 1: Most asymmetric. “Clumpy disks”?

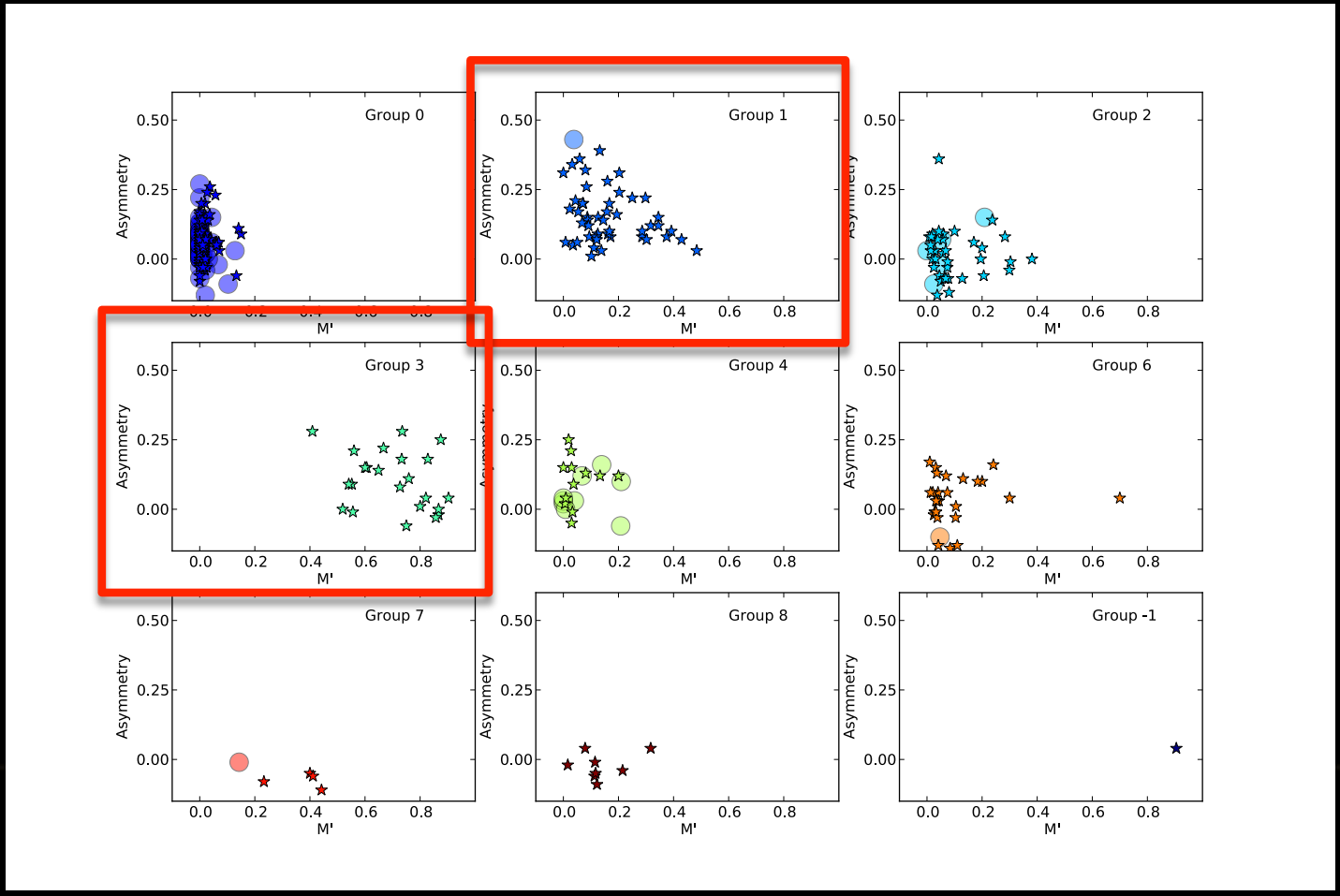


Group 3: Asymmetric, but very concentrated



Multi-Mode - Asymmetry

Group 1 and 3 separate cleanly by M and Asymmetry



What the Future Has In Store

- The next step will be to expand our analysis to:
  - All CANDELS fields
  - Multiple HST bands (i, v, Y, J and H) and redshift ranges ($0.4 < z < 3$)
    - Using groups and PCs defined by F125W $1.36 < z < 1.97$ morphologies (Jen's talk will cover this!)
    - Assign probability for classifications
  - Simulated Galaxies (Hydro-ART, Illustris)
- Use diffusion mapping (among other techniques) to find non-linear relations

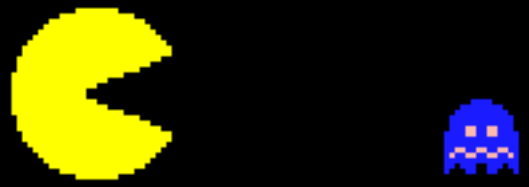
Summary

- **Group galaxies using a more descriptive schema than the traditional spiral, elliptical, and irregular categories.**
- Principal component analysis of non-parametric morphology measurements
  - Which is then grouped using Agglomerative Clustering, defining 10 groups
- Group 0: Largest Group, also largest Spheroidal and Quenched galaxy fraction. Very compact and small galaxies
- Group 2: Shares characteristics with both 0 and 4.
- Group 1: Very asymmetric, large percentage are irregular. Clumpy disks (?)
- Group 4: The other group with a substantial spheroid/quenched population. Large bulge+disk percentage
- Group 3: High percentage of irregulars, not as asymmetric as group 1. But more concentrated

Thanks!

Name ideas?

PACMAN?



MIRAGE?

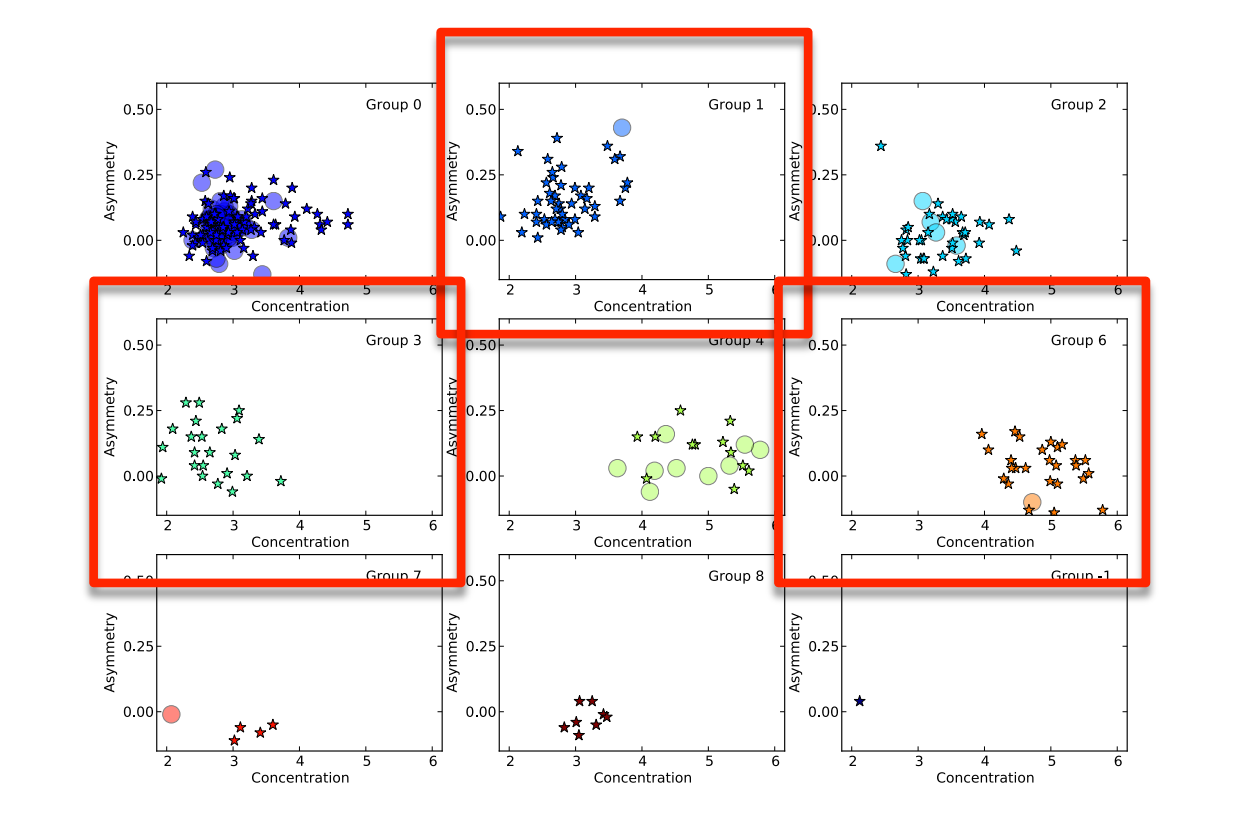
The Visual Classifications of Group Members

Demographics of Visual Classifications of Group Membership

	Disks		Spheroids		Irregulars		Disks+Spheroids	
	of Group	of Total	of Group	of Total	of Group	of Total	of Group	of Total
Group -1	0.00	0.00	50.00	0.80	0.00	0.00	0.00	0.00
Group 0	33.95	29.49	39.48	85.00	1.85	12.82	18.82	65.38
Group 1	73.85	15.38	1.54	0.80	23.08	38.46	1.54	1.28
Group 2	75.32	18.59	3.05	5.60	3.90	7.69	10.39	10.26
Group 3	70.73	9.29	2.44	0.80	19.51	20.51	2.44	1.28
Group 4	39.02	5.13	14.63	4.80	9.76	10.26	36.59	19.23
Group 6	83.33	12.82	4.17	1.60	6.25	7.69	4.17	2.56
Group 7	90.91	3.21	0.00	0.00	9.09	2.56	0.00	0.00
Group 8	100.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00

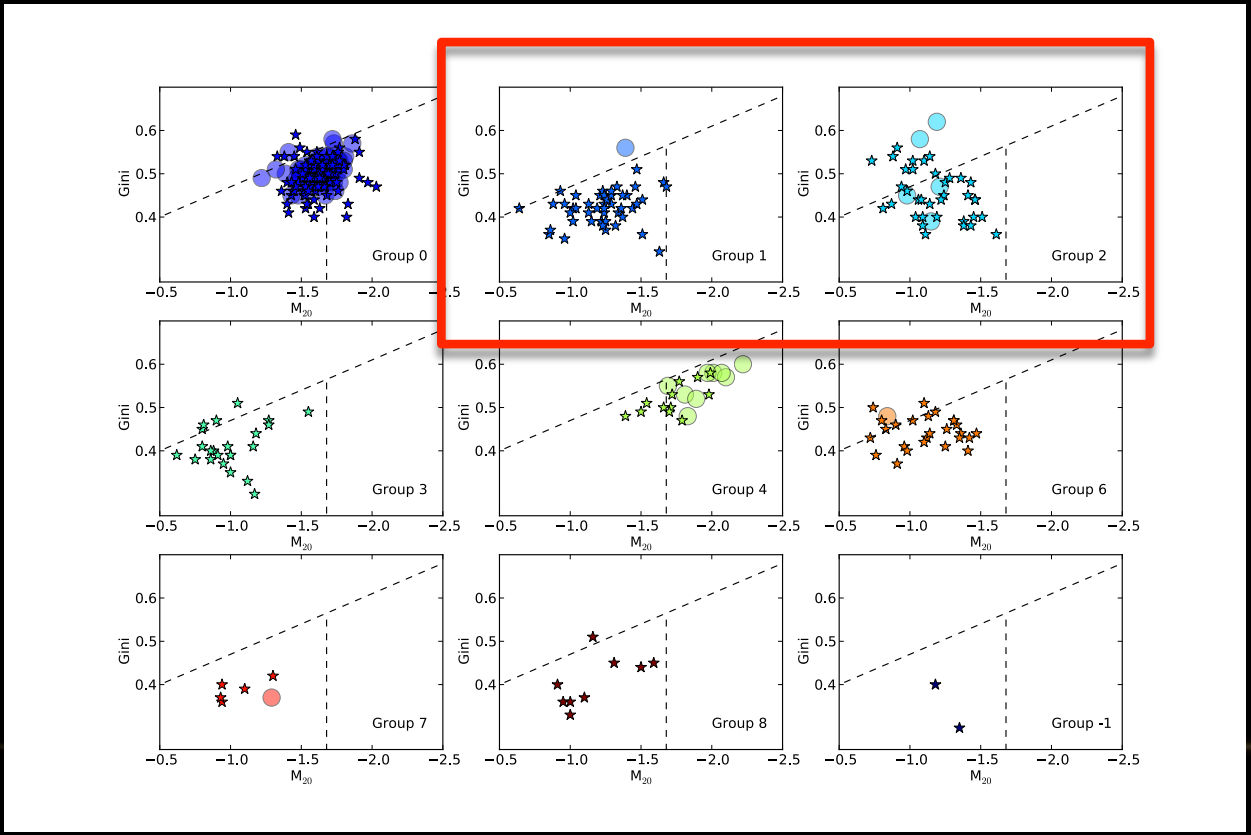
Concentration - Asymmetry

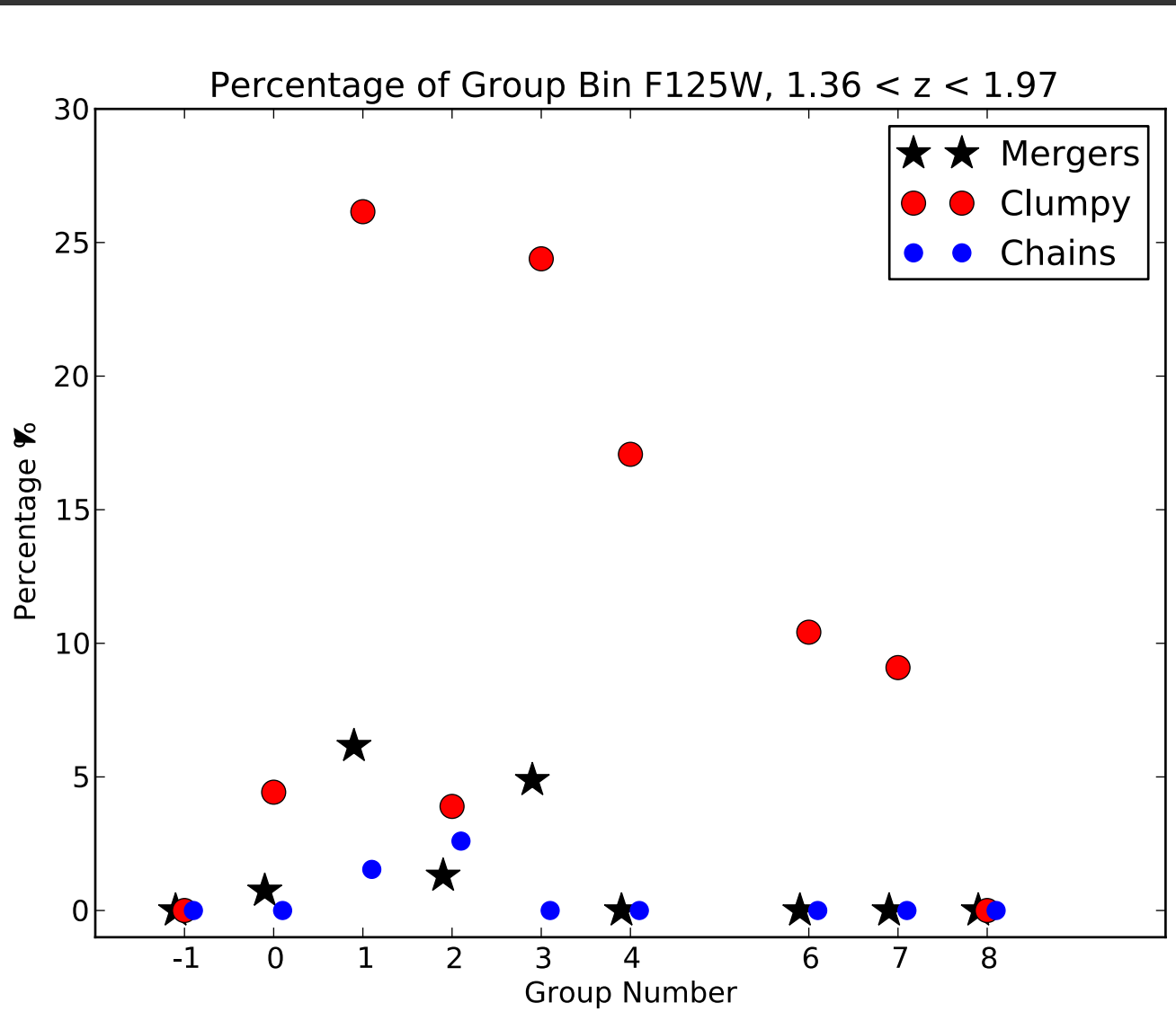
- Group 1 is the most asymmetric
- Group 3 very concentrated
- Concentration cleanly separates e.g. groups 1 and 6



Gini – M_{20} Diagram

- Group 2 with most G-M_{20}-classified irregular galaxies, even though visually Group 1 has the most




Percentage of Group Bin F125W, 1.36 < z < 1.97
Mergers
Clumpy
Chains
Percentage %
Group Number
30
25
20
15
10
5
0
-1
0
1
2
3
4
6
7
8