Quenched Spirals:
Star Formation Histories and AGN Abundance Across the LoCuSS Sample of z~0.2 Clusters

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Galaxy Evolution & Environment
Kuala Lumpur April 3rd, 2009

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LoCuSS: Local Cluster Substructure Survey

- 100 Clusters at 0.15<z<0.3
- Subsample of 25 with Subaru-based WL maps
- For these:
  - GALEX NUV & FUV 1.5-6ks per cluster
  - Spitzer MIPS imaging
  - SDSS coverage for ~half
  - XMM or Chandra
  - UKIRT/other deep J & Ks imaging
  - Herschel key program
  - Spectra from MMT/Hectospec

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Today's Special: Results on 14 clusters with: SDSS photometry

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Today's Special: Results on 14 clusters with: MMT Spectra

Redshifts with MMT Hectospec

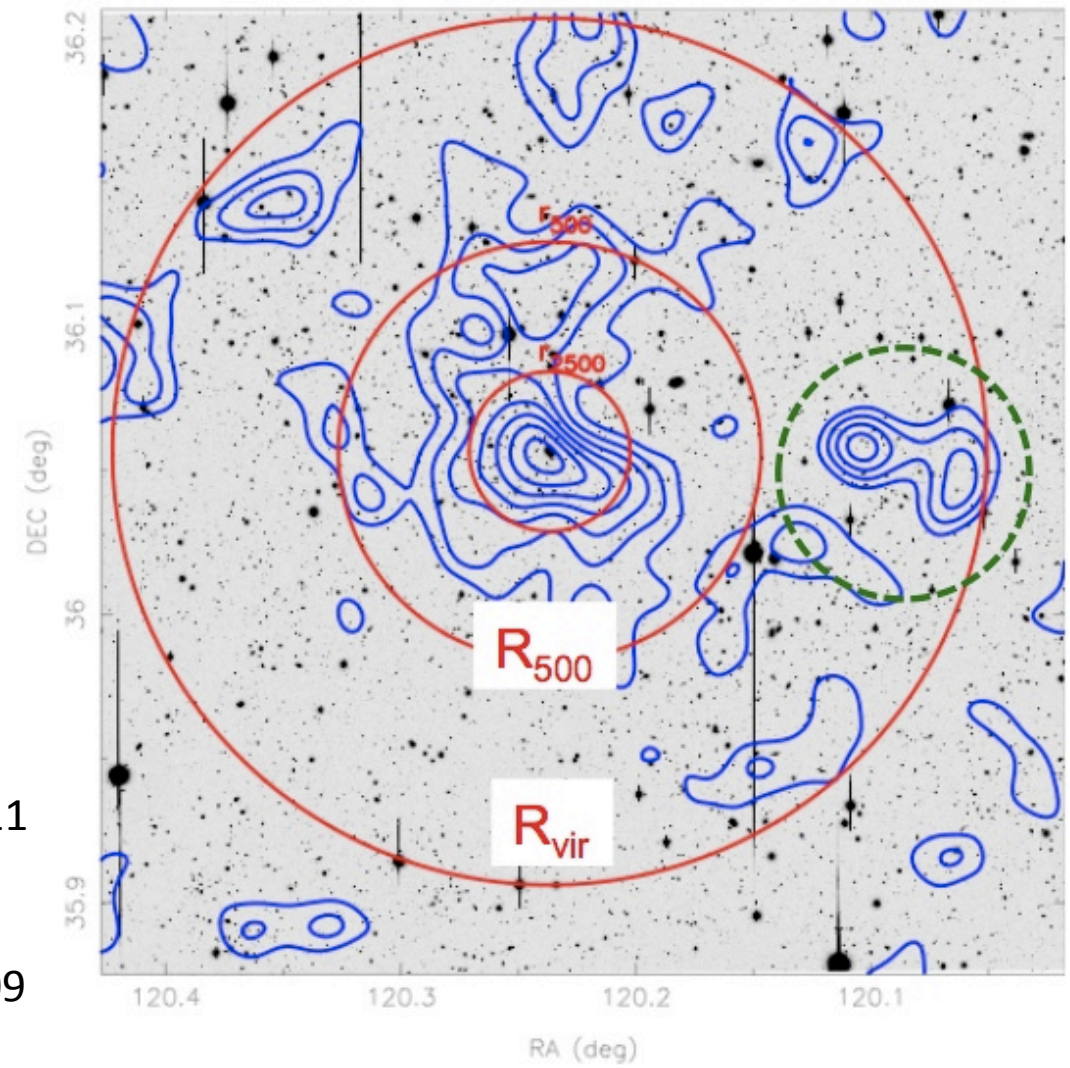
- Results: In just 3 nights equivalent, have ID'ed over 3400 cluster members across 12 clusters (+3 more partially complete), to K_*+1.5 to 2
- Previously, remarkably few known redshifts, even for well-known Abell clusters
  - Should make for a useful legacy catalog!
- Spectra provide decent em. & abs. line measures
- **Hot off the press; more redshifts coming soon!**

- But what makes LoCuSS a special cluster sample?
  - Local environment, Global environment, and "Super-environment" (1 deg FOV)

A Wider View of Environment: Global Cluster Properties

#cluster	ra	dec	redshift	L_x	f_sub	Z(XMM)	T(XMM)	Lbol(XMM)	n_e0	r500	M500X	f_gas,500	XMorph	Cool-Core?	r500_YX	M500_YX	SDSS?
A383	42.00833	-3.53750	0.187	5.27	0.06	0.18	5.3	3.6	54.8	0.98	3.17	0.104	0	1	1.02	3.30	1
A611	120.23300	36.06100	0.288	8.05	-1	-1	-1	-1	-1	1.37	-1	-1	-1	-1	-1	-1	1
A665	127.73900	65.85400	0.182	9.66	-1	-1	-1	-1	-1	1.38	-1	-1	-1	-1	-1	-1	1
A697	130.74038	36.36625	0.282	9.64	-1	-1	-1	-1	-1	1.51	-1	-1	-1	-1	-1	-1	1
A963	154.25500	39.02900	0.205	6.16	0.06	0.28	6.3	7.4	14.3	1.14	5.19	0.120	0	0	1.16	5.28	1
A1758	203.18529	50.54181	0.280	6.64	-1	0.19	7.6	9.4	2.4	1.43	11.15	0.077	2	0	1.18	8.46	1
A1763	203.81800	40.99600	0.228	8.83	0.15	0.20	6.3	14.1	6.5	1.12	4.96	0.178	1	0	1.25	6.11	1
A1835	210.26000	2.88200	0.253	22.80	0.06	0.23	8.0	22.5	63.9	1.30	8.01	0.148	0	1	1.36	8.43	1
A1914	216.49908	37.82475	0.171	10.88	-1	0.19	8.6	9.7	10.5	1.71	16.76	0.071	3	0	1.37	11.56	1
A2218	248.97000	66.21400	0.171	5.50	0.27	0.21	7.4	9.0	5.8	1.07	4.18	0.147	0	0	1.13	4.47	0
A2219	250.09400	46.70600	0.228	12.07	0.20	-1	-1	-1	-1	1.49	-1	-1	-1	-1	-1	-1	1
R1720	260.04225	26.62525	0.164	9.54	-1	-1	-1	-1	-1	1.53	-1	-1	-1	-1	-1	-1	1
Z348	16.70625	1.05614	0.254	5.80	-1	-1	-1	-1	-1	1.0	-1	-1	-1	-1	-1	-1	1
Z1693	126.49100	4.24653	0.225	4.41	-1	-1	-1	-1	-1	1.0	-1	-1	-1	-1	-1	-1	1
Z2089	135.15358	20.89444	0.235	6.40	-1	-1	-1	-1	-1	1.02	-1	-1	-1	-1	-1	-1	1
Z7160	224.31346	22.34278	0.258	7.80	-1	0.32	5.0	6.7	65.1	0.87	2.39	0.161	0	0	1.04	2.85	1

A Better(?) View of Local Density: Weak Lensing Maps of Substructure



A611

Okabe et al. 2009

Wide enough
to probe
Super-environment?

Outline

- Identifying Galaxies in Transition: Green Valley
- Recent SFHs vs. environment for the ensemble of cluster members
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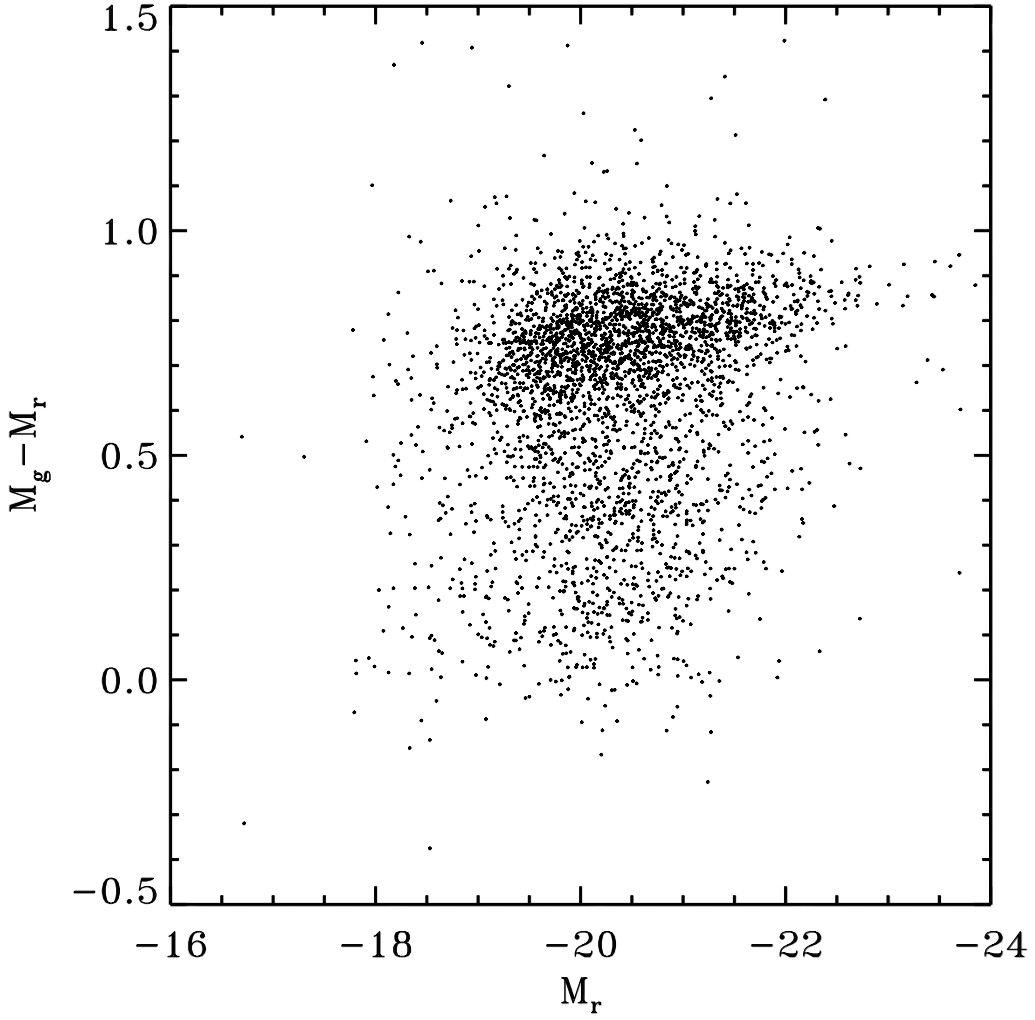
SDSS g-r CMR

- 12 of the clusters (+2 partially) finished so far have SDSS coverage
- These 14 constitute my main sample for initial analysis
- Matching to SDSS photometry, rest g-r vs M_r CMR for 3000+ cluster members



NUV-r CMR

•~1100 out of 3400 cluster members overall have a UV detection

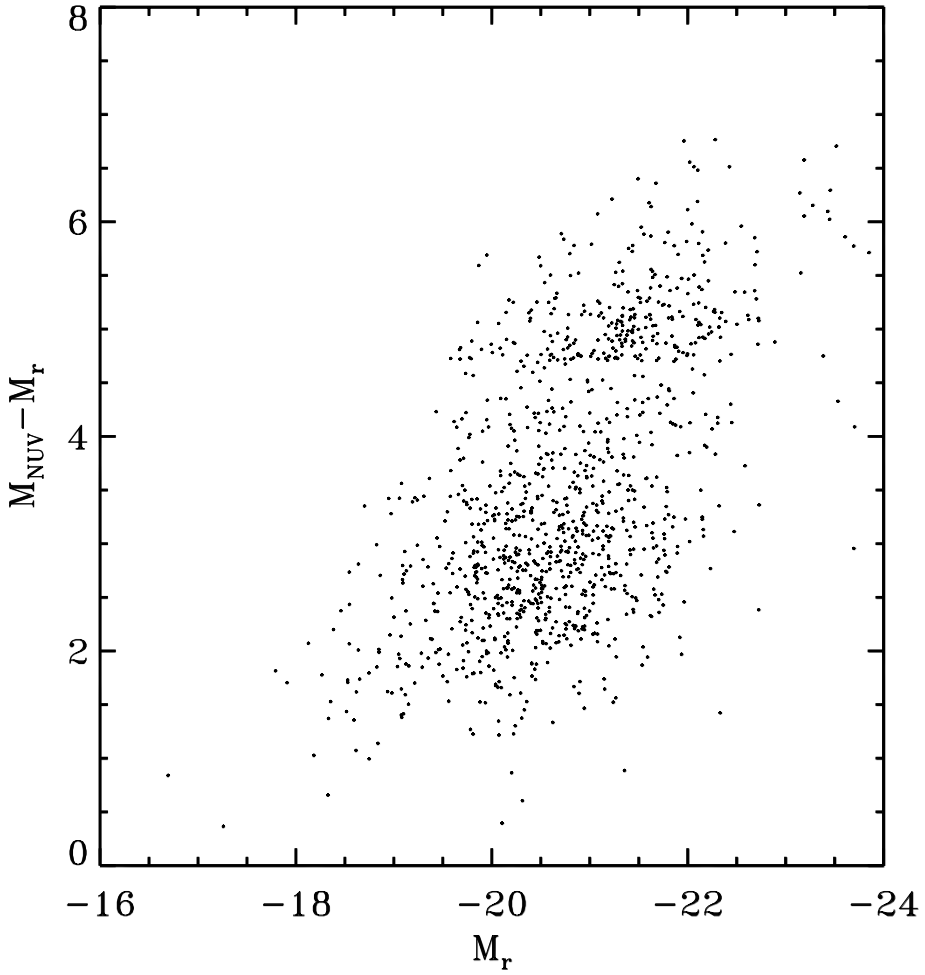
•Classifiying the sample:

•SF=NUV-r < 3.7, defined by looking at the NUV-r colors of galaxies in the g-r blue cloud

•Green Valley= NUV-r 3.7-4.7 (arbitrary 1 mag width)

•Passive=NUV-r>4.7, plus all GALEX non-detections with limit > 4.7

•~300 Green Valley galaxies



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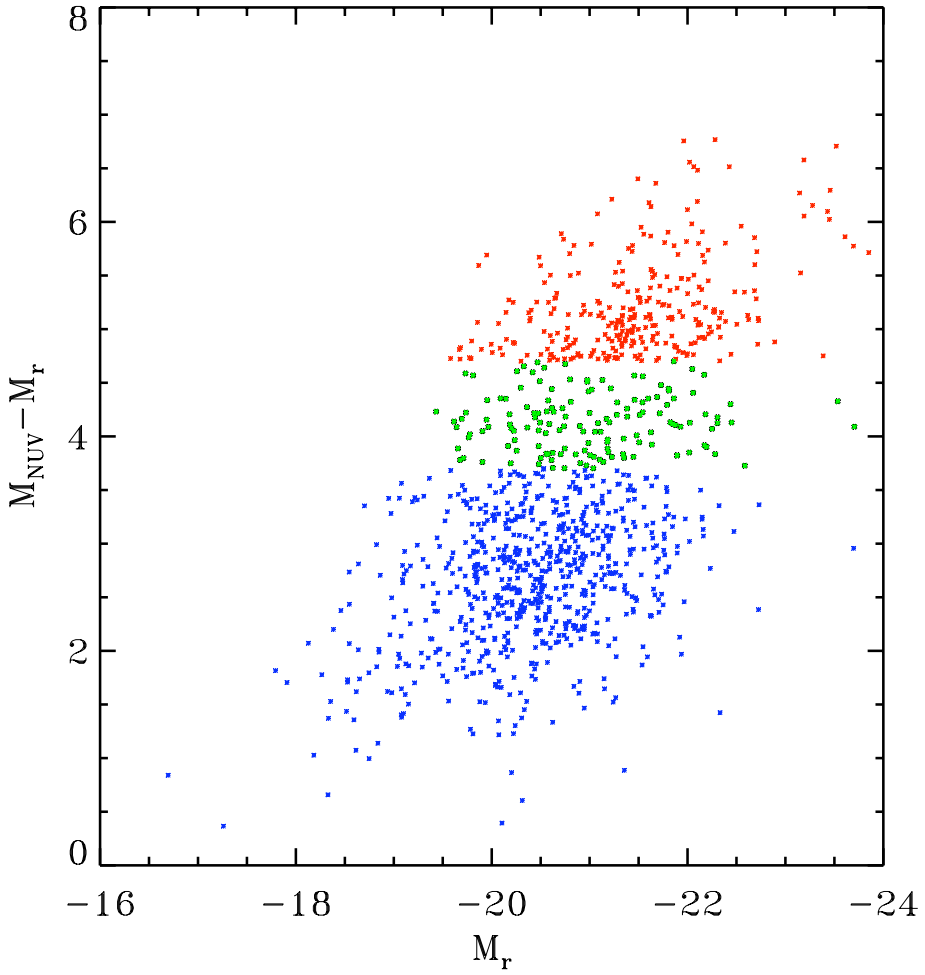

Actually, use M_K<-20.5

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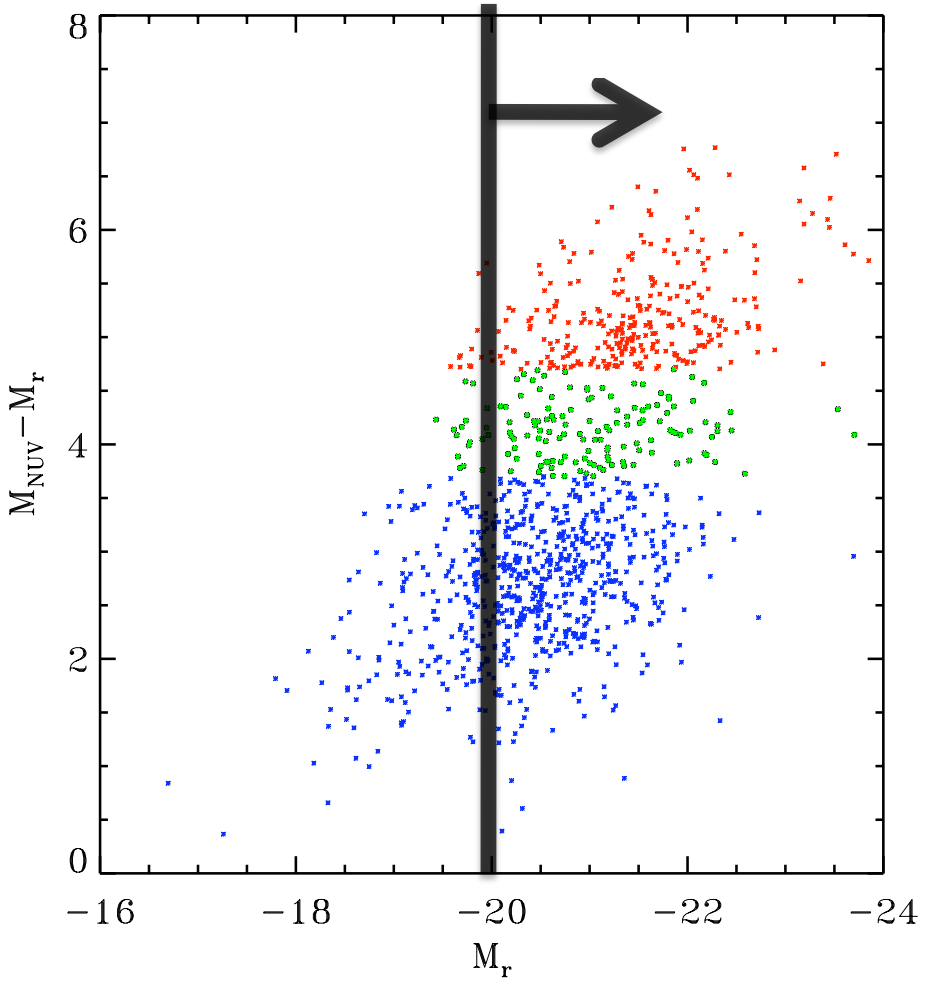

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Sample probes M_*s near the transition mass

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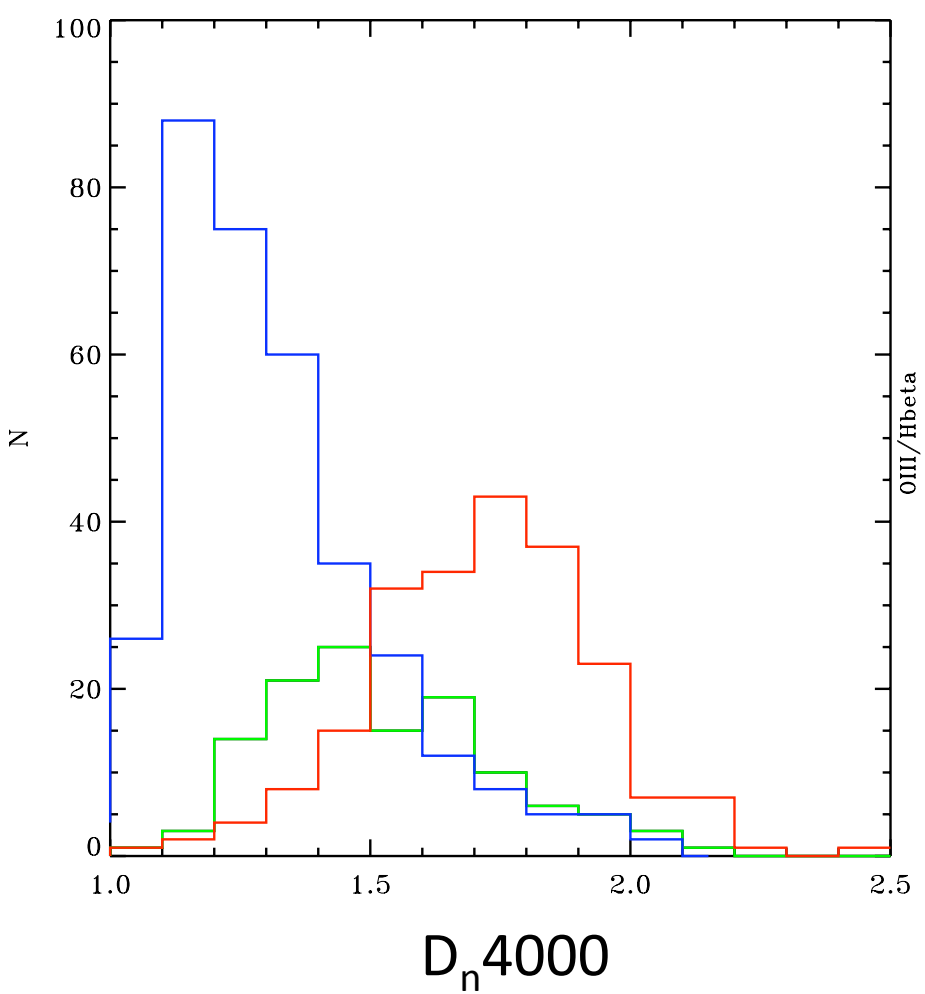
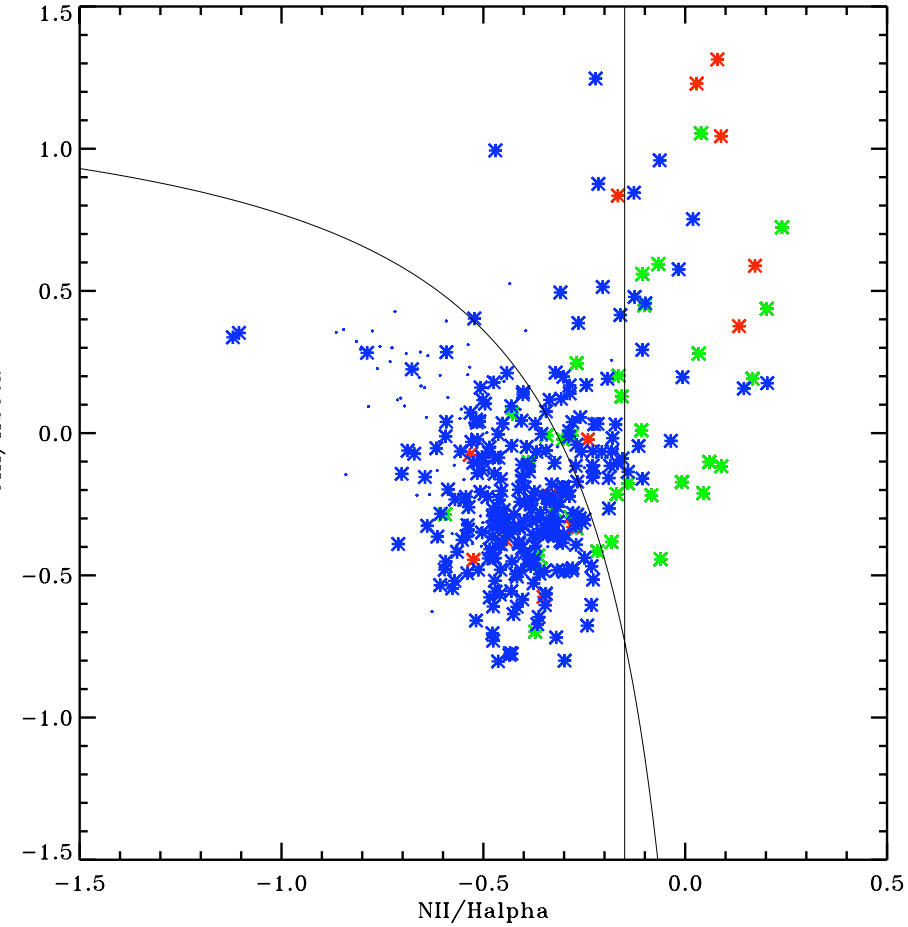
Green Valley Galaxies are Transition Galaxies and Many are AGN

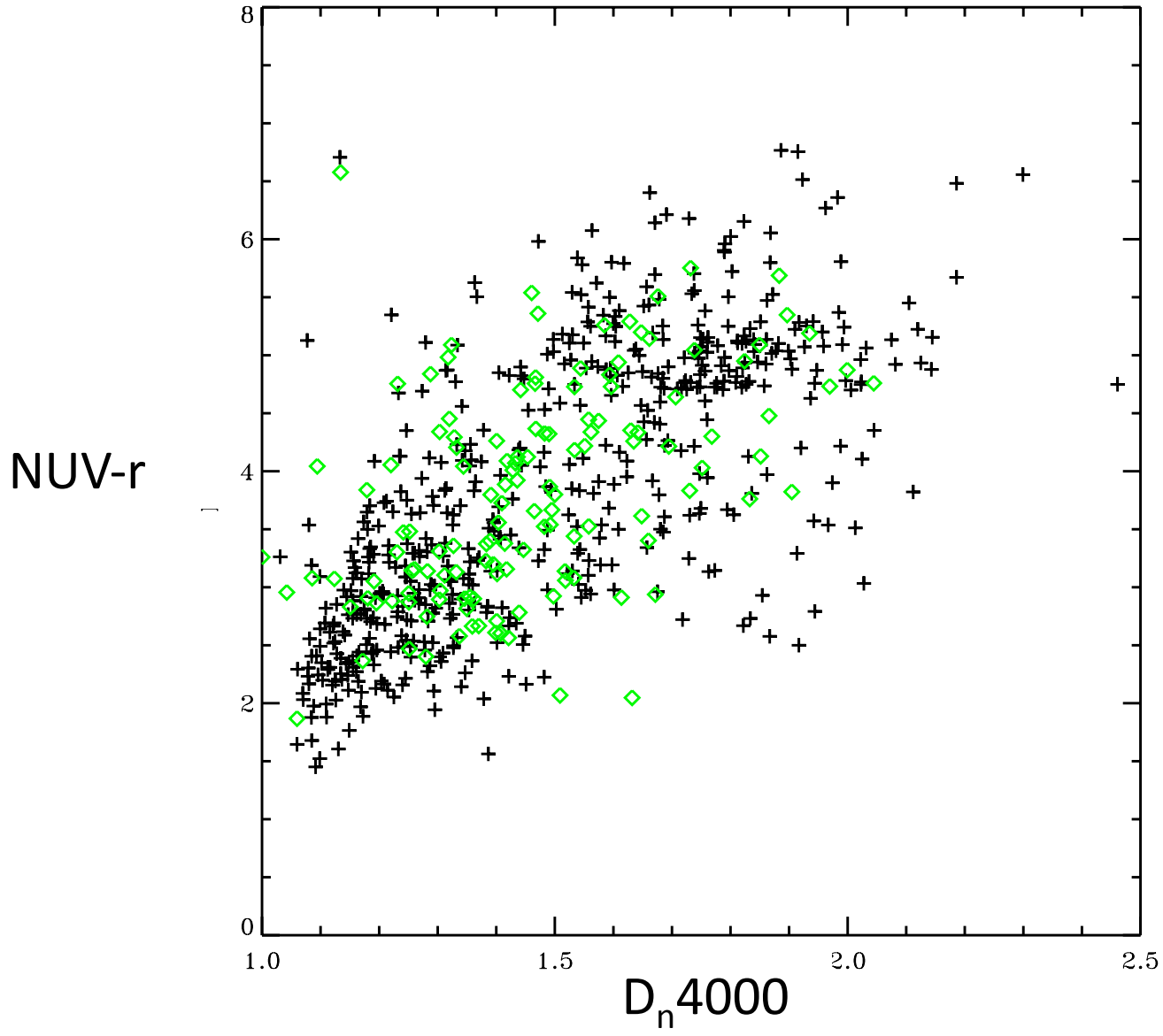




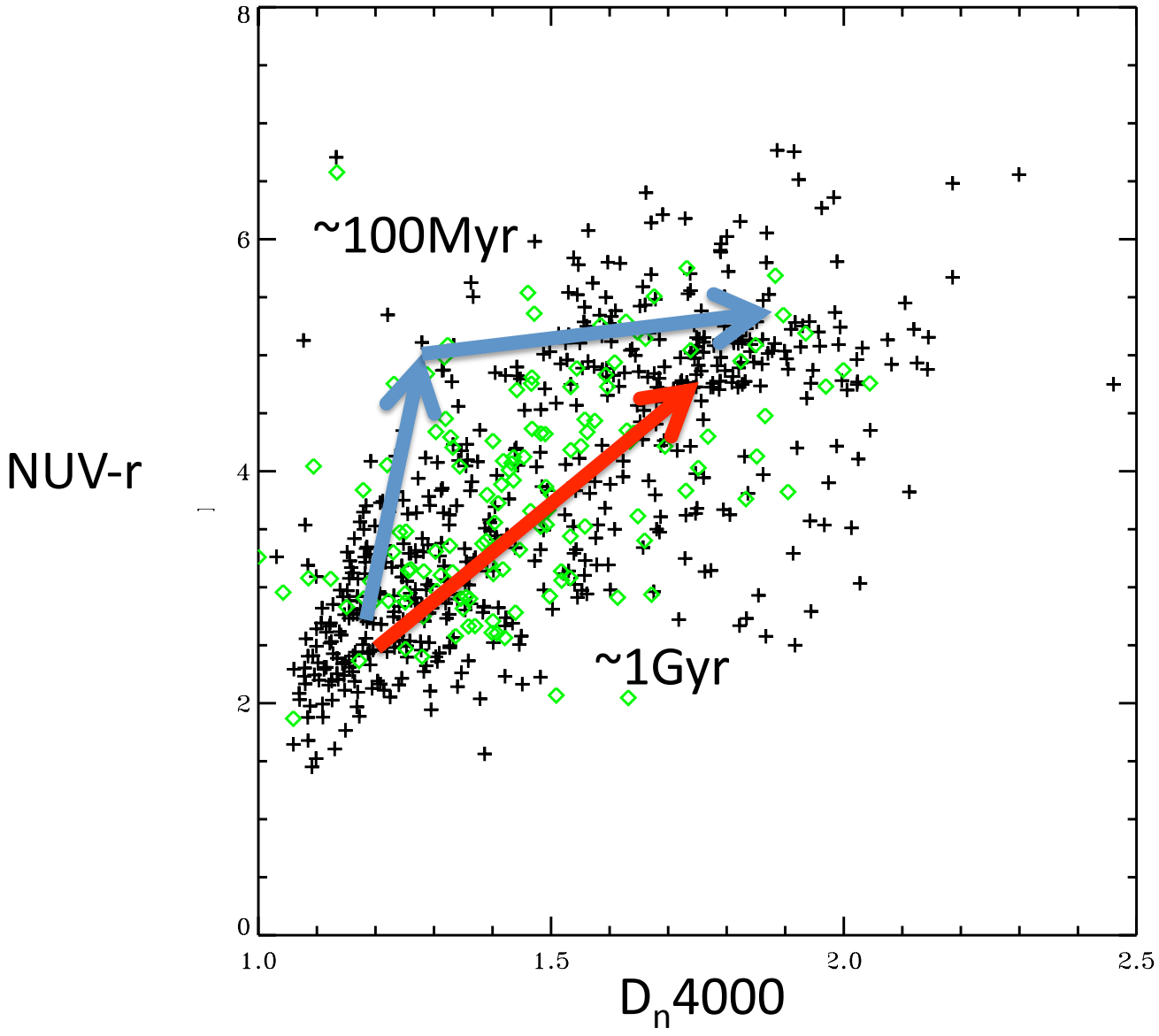
AGN Fractions	All	$R<R_{500}$	$R>R_{500}$
Red	13±2%	11±4%	14±3%
Green	31±5%	29±9%	31±6%
Blue	16±2%	28±5%	13±2%

- AGN fraction in Green Valley very high!
- Similar to lower density environments (e.g., talk by Jong-Hak Woo), sometimes used to argue in favor of AGN feedback
- Numbers cut in ~half if I only include galaxies with all 4 emission lines measured (vs. also cutting on NII/Halpha), but same trends

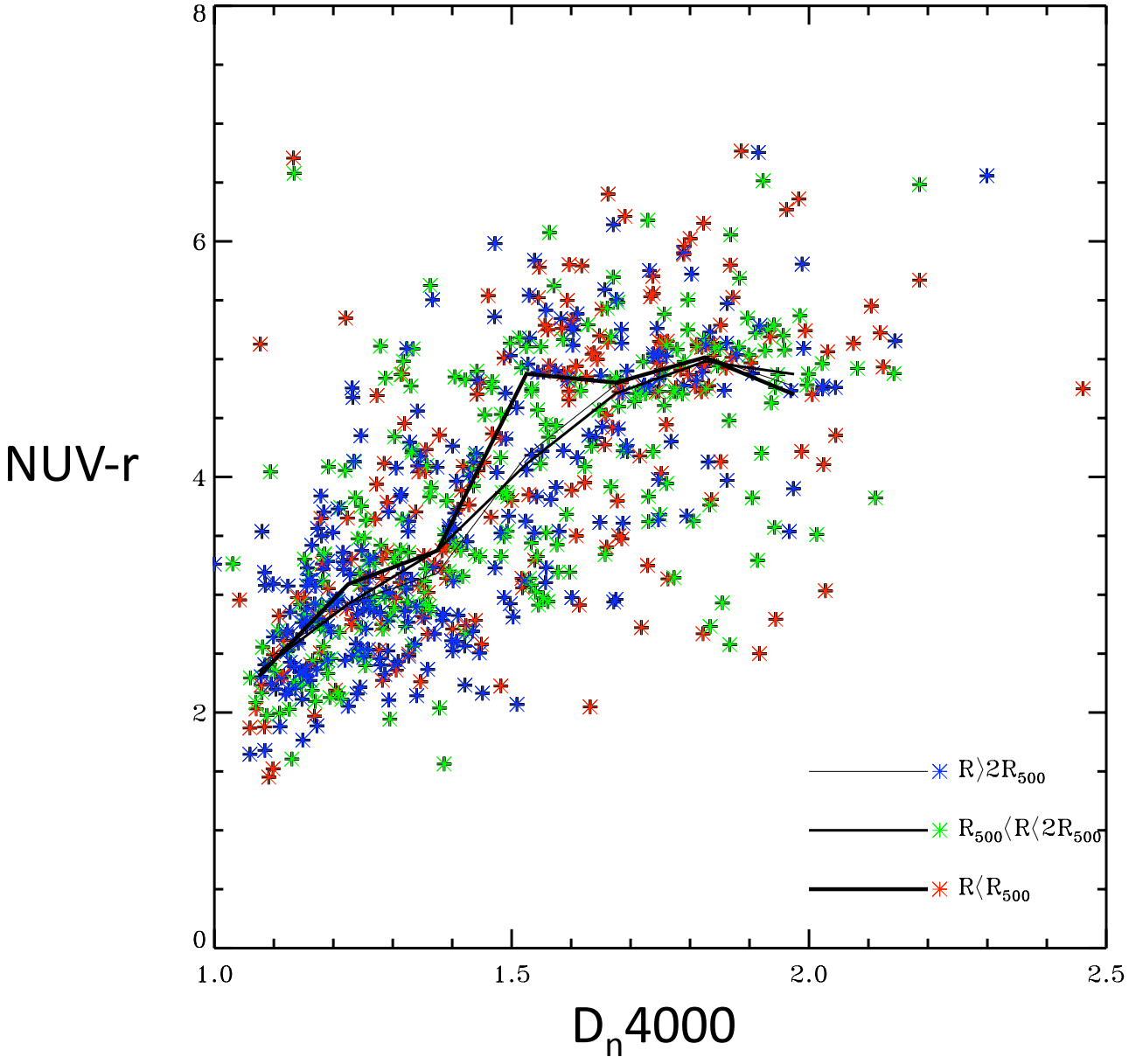
Measuring the Quenching Timescale



Measuring the Quenching Timescale



Environmental Variation in Quenching Timescales



Ram pressure stripping (presumably) causes a faster median timescale for galaxies at $R<R_{500}$

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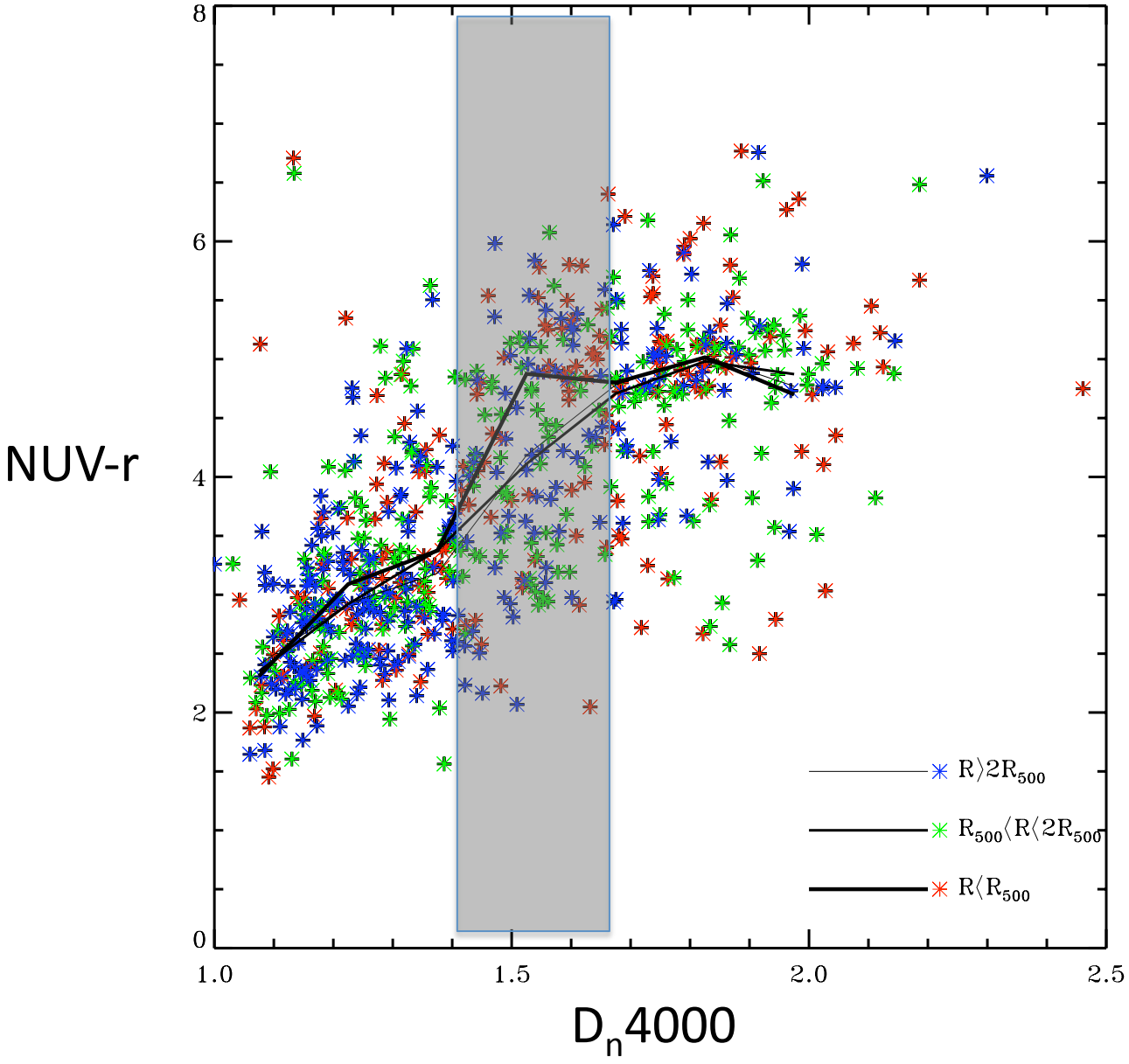
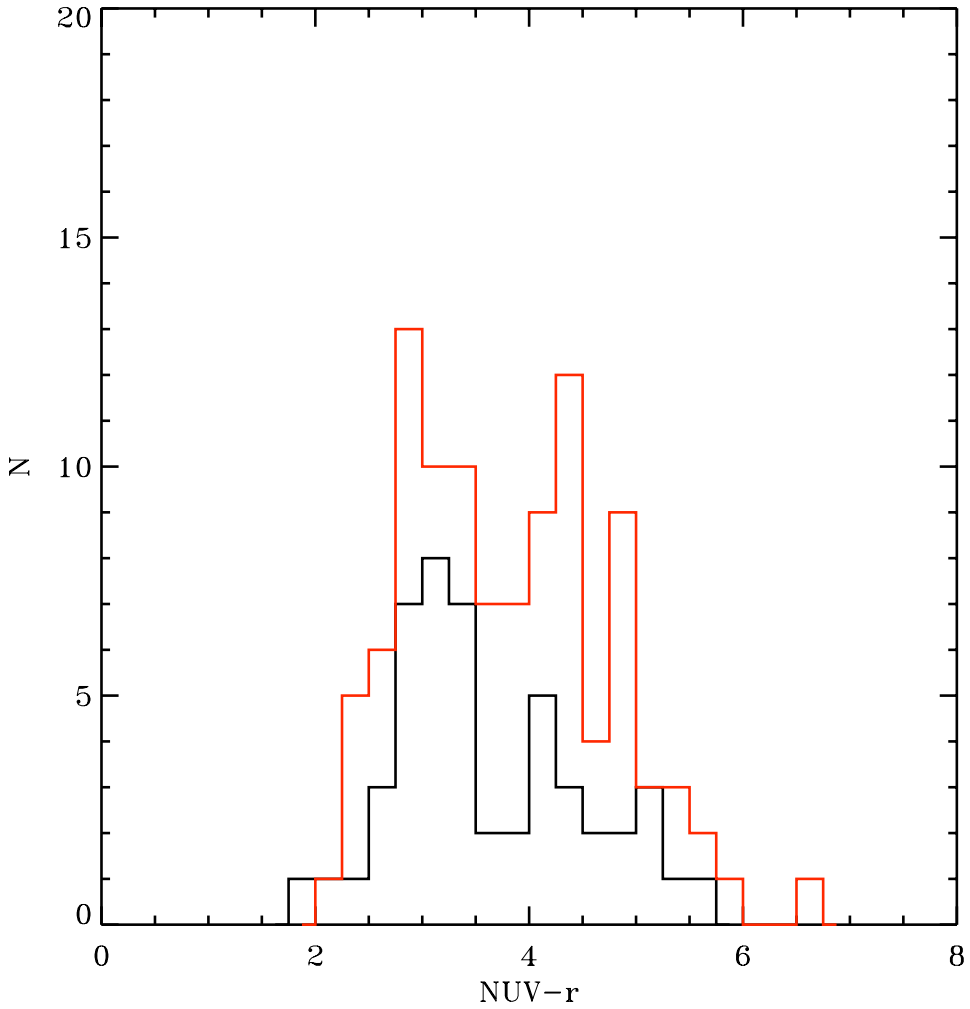


KS test indicates this is a significant difference (marginally)

Can use this difference to help answer: Does the 30% AGN fraction reflect a duty cycle of the AGN?

Are there extra red AGN inside R_{500}?



$R>R_{500}$

$R<R_{500}$

Maybe…

But not significant

According to KS test

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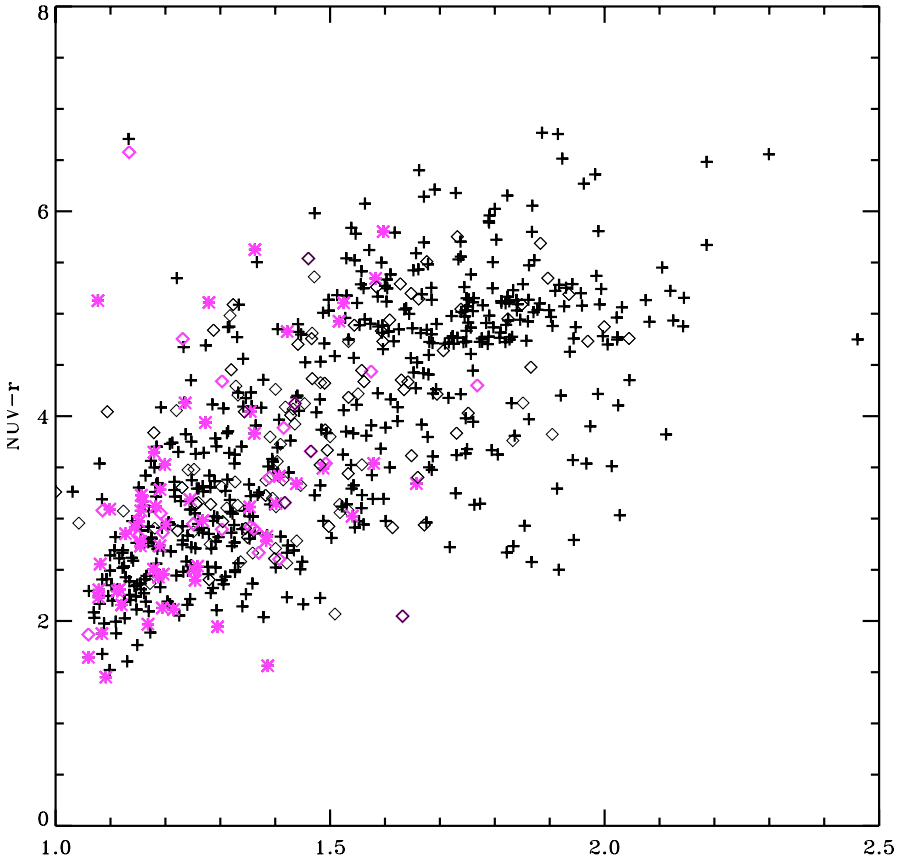
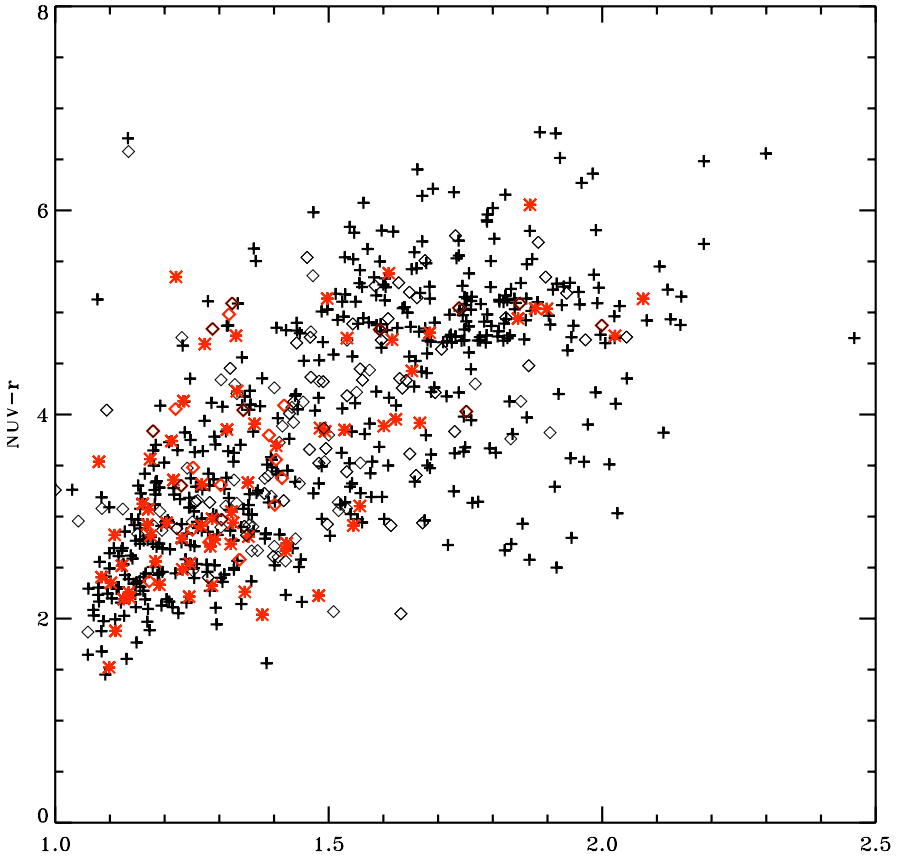
Dusty Star-Formers



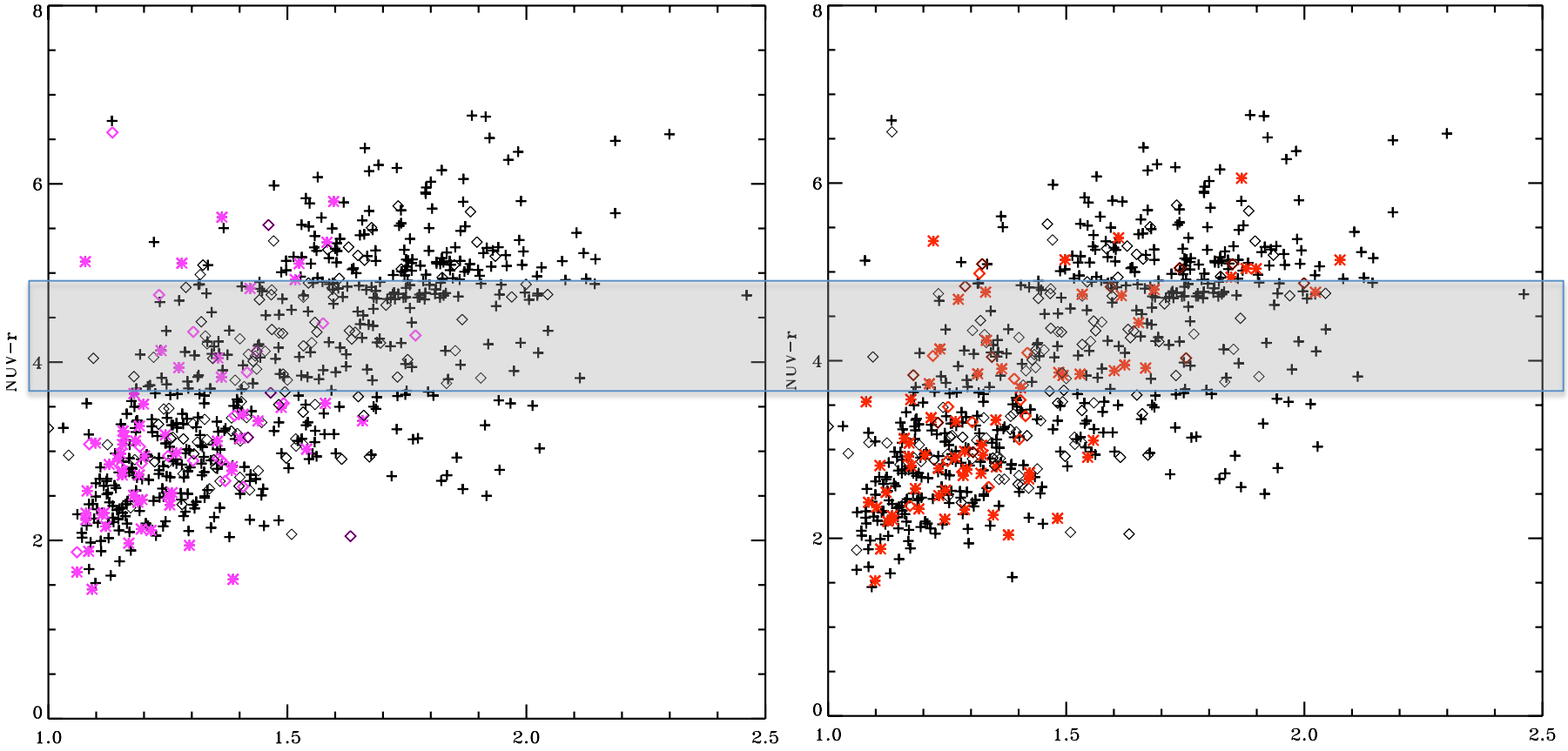
LIRGS



IR detected, moderate luminosity

Wilman et al., Wolf et al., Gallazzi et al.,(2008):
How much of the green valley is contaminated by obscured SF?

Dusty Star-Formers



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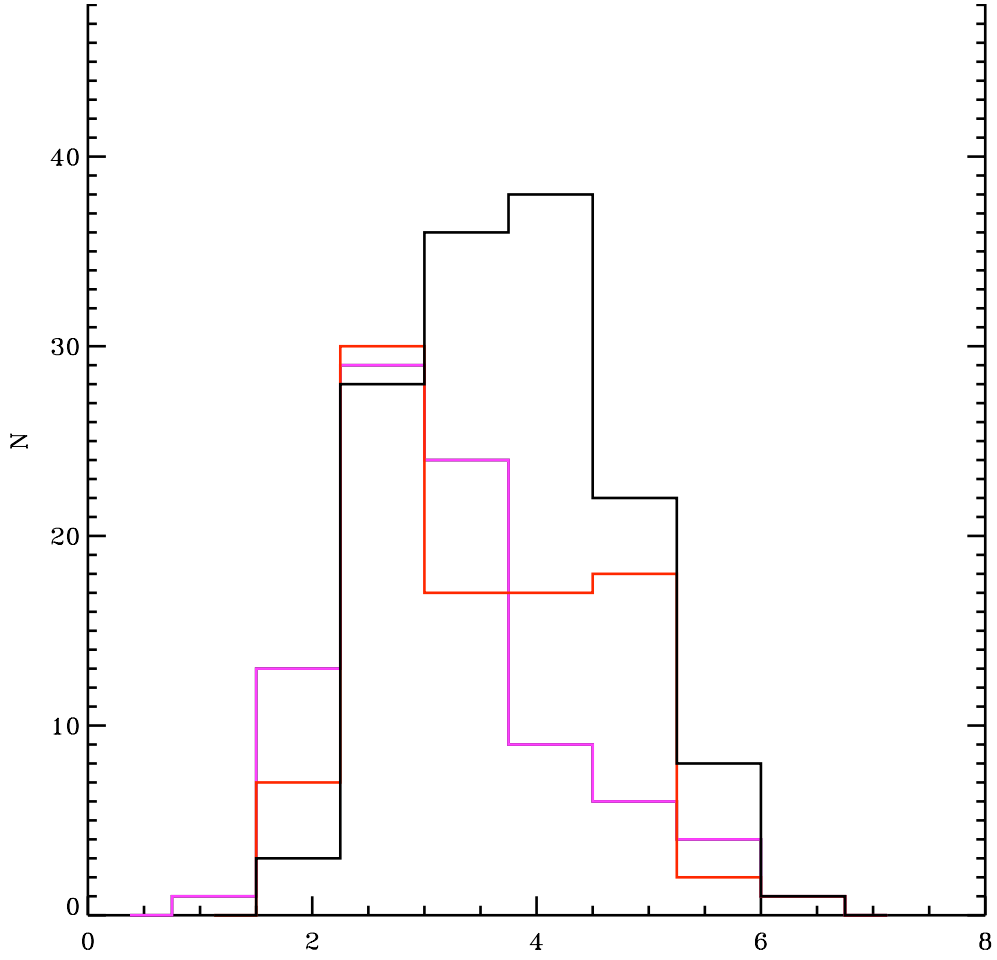
Some Green Valley Contamination from Dusty (Moderate) SF



IR Detected
LIRGs

10-20% of Green Valley shows an IR excess
-Consistent with Wilman et al.'s numbers For z~0.4 groups
-Lower than STAGES? (Wolf, Gallazzi et al. 08), But less sensitive to low levels of SF.

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Differences between clusters: Why?

We see cluster to cluster variations in both slope (quenching timescale) and scatter (spread in quenching timescales)

But these don't yet seem to correlate with

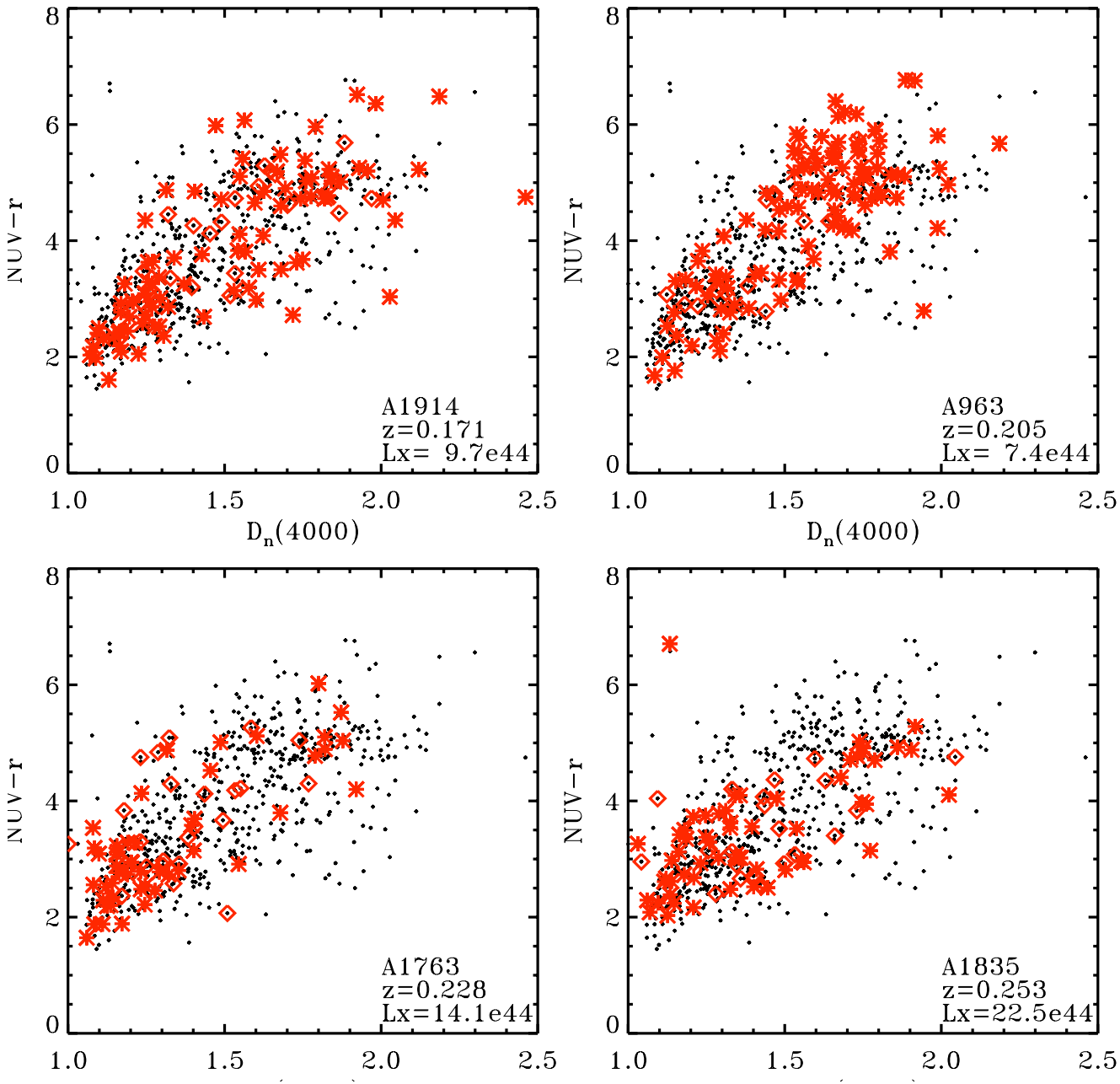
-Redshift

-Cluster Mass

-Smooth/Complex X-ray morphology

Does this simply reflect that whatever is going on in filaments in the outskirts is relatively unaffected by central cluster? (e.g., Rasmussen, Haines, Poggianti et al 2006, poster by D. Just)

Do these galaxies **know** what type of cluster they are falling into?

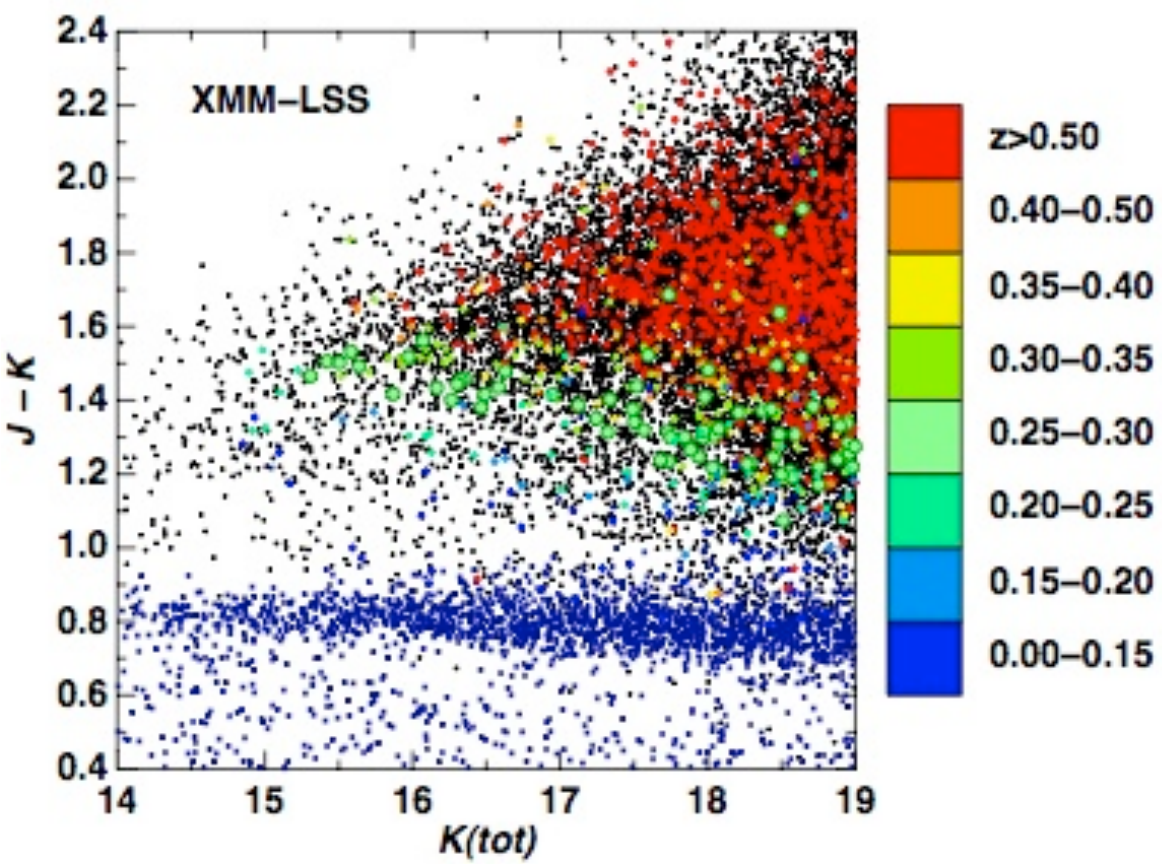


Conclusions

- LoCuSS sample allows us to examine timescale of SF quenching in Green Valley
  - By examining AGN in `prematurely quenched' systems, can learn about duty cycles & feedback
  - Moderate luminosity dusty systems do contaminate the Green Valley & red sequence
- Cluster to cluster variation in quenching is strong, but correlations with global or "super-environment" are elusive so far

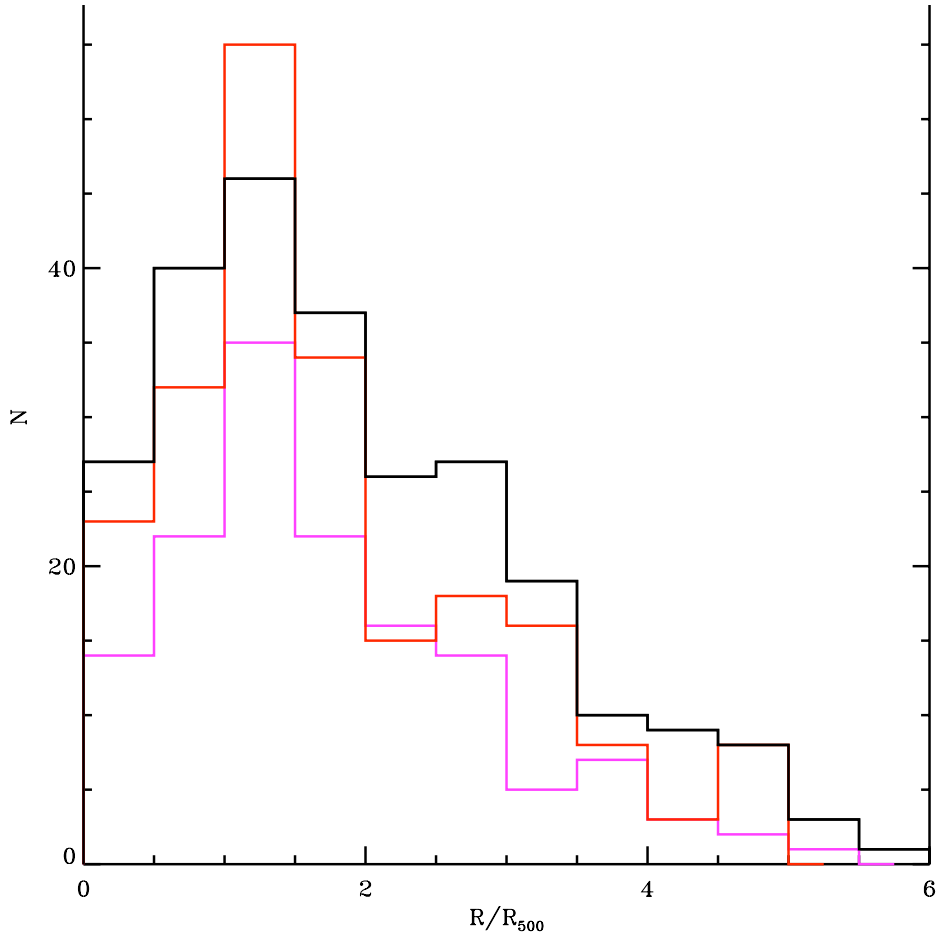
Redshifts with MMT Hectospec

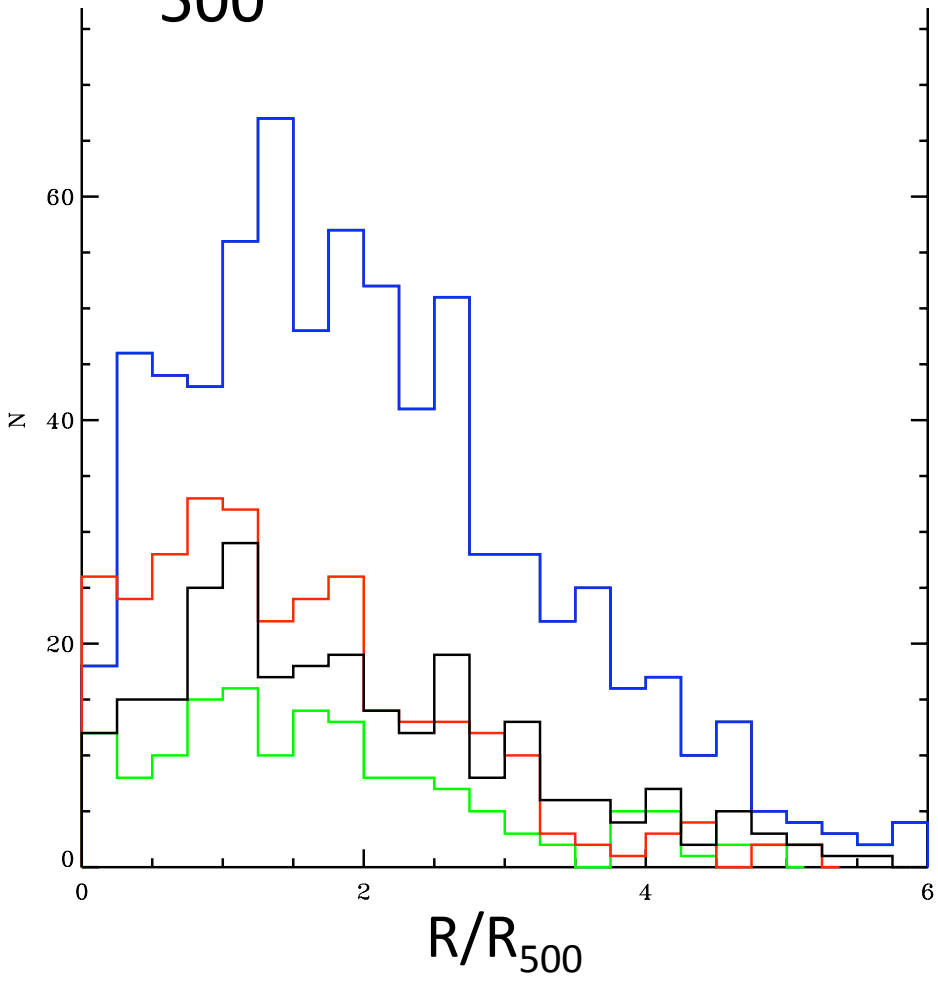
- At z<0.3, J-K color nearly monotonic with redshift
- Use this to efficiently select cluster targets:
- >70% complete, but only ~40-80% clean
- Should be relatively unbiased
- Beyond this, targets selected to K*+1.5-2



Haines et al. 2008

IR luminous galaxies are largely outside R_{500}





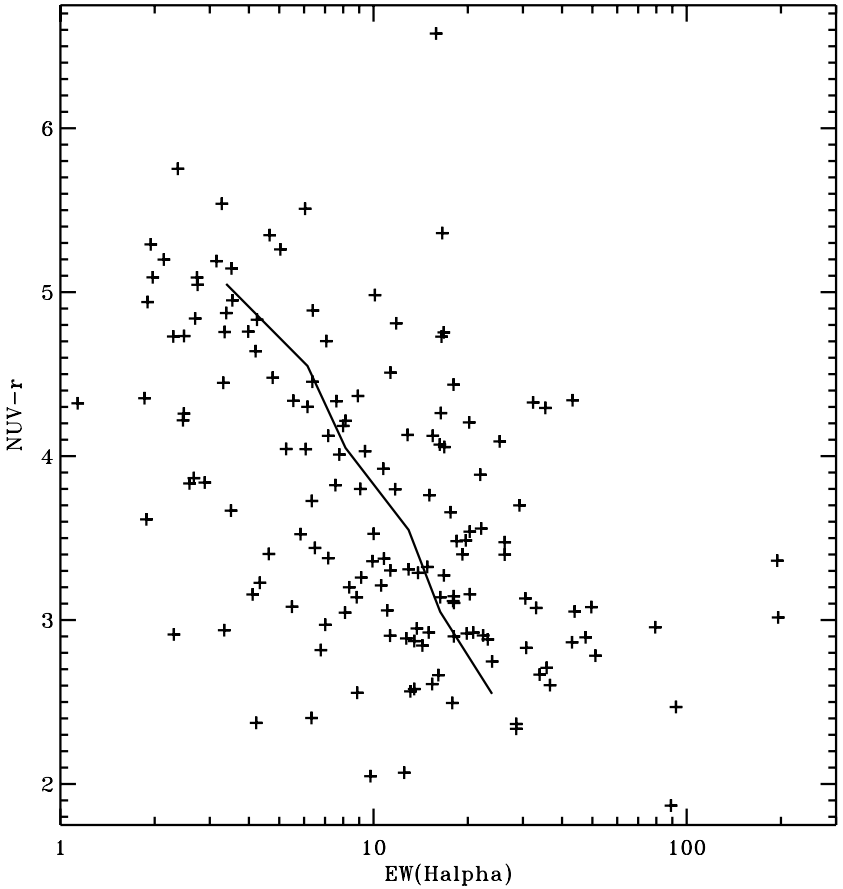
But their distribution is not too different from that of AGN

AGN

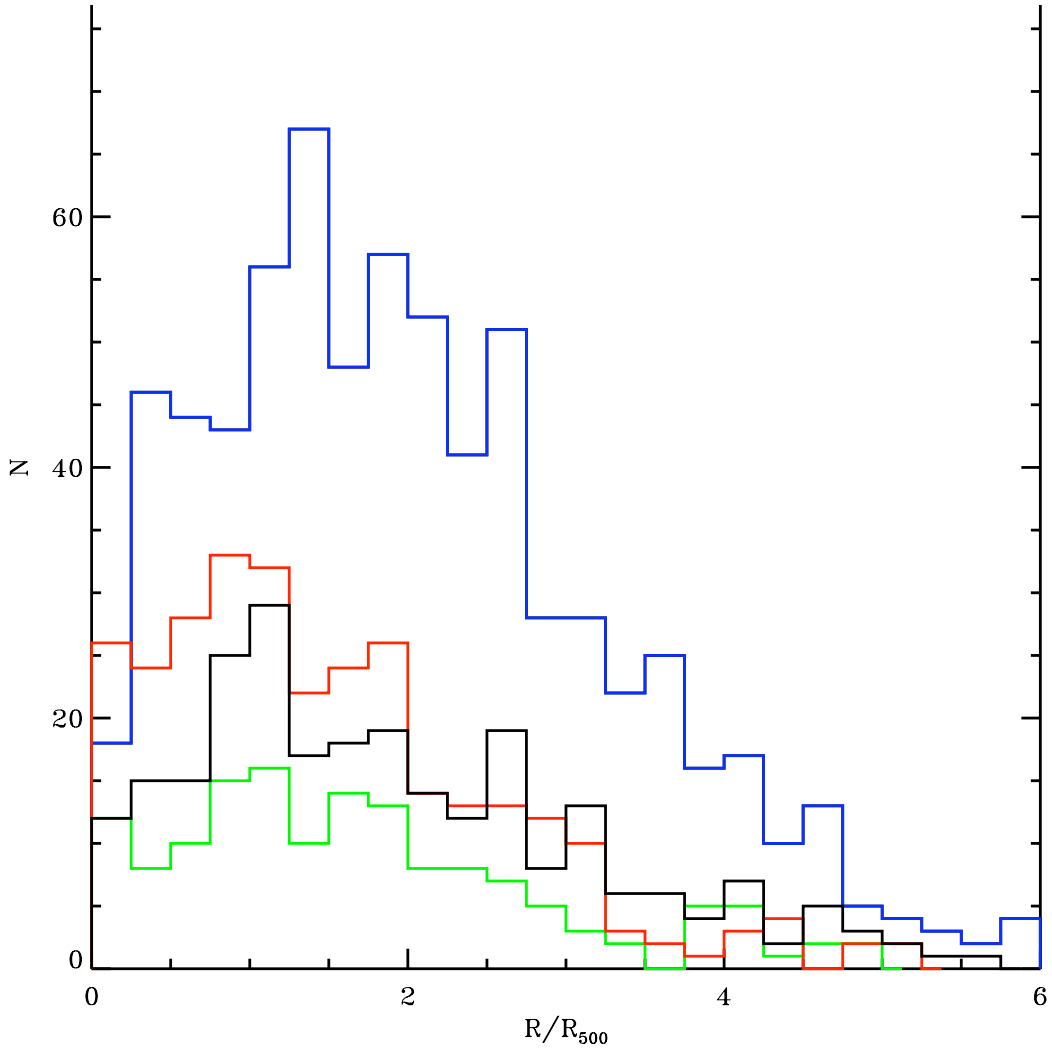
IR detected

LIRG

But the Gr Val. AGN are not too strong!



Environments of Green Valley and AGN



CAUTION:
NUV upper limits

Due to mix of redshifts, exposure times, and archival data use, the limiting mags vary considerably between clusters.

This should improve as we obtain the remainder of the GALEX imaging

For now→ comparision across clusters is complicated. **Grain of salt!**