Classifying z>1 SNe Ia progenitor environments with HST obervations of cluster red sequences.

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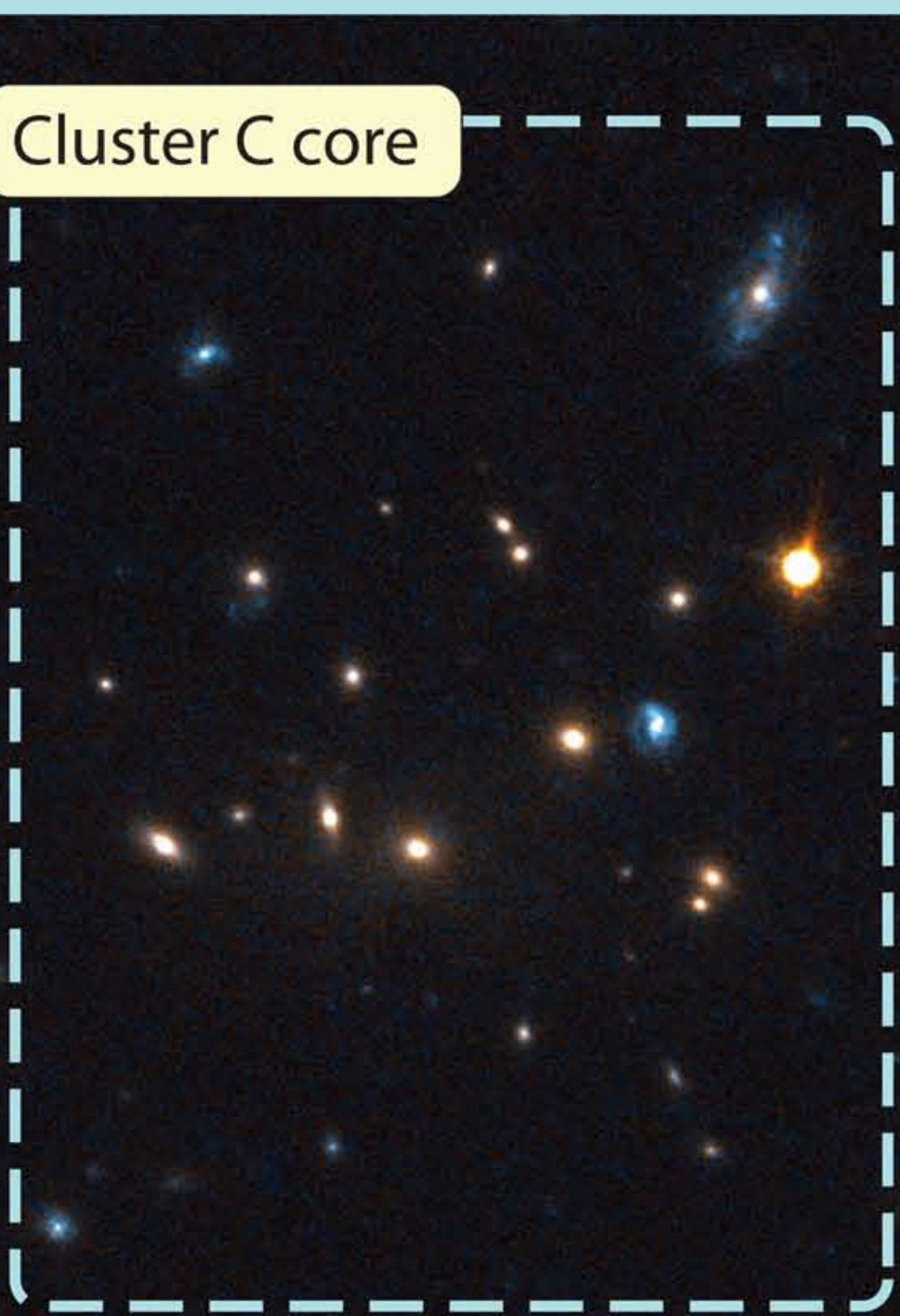
Introduction

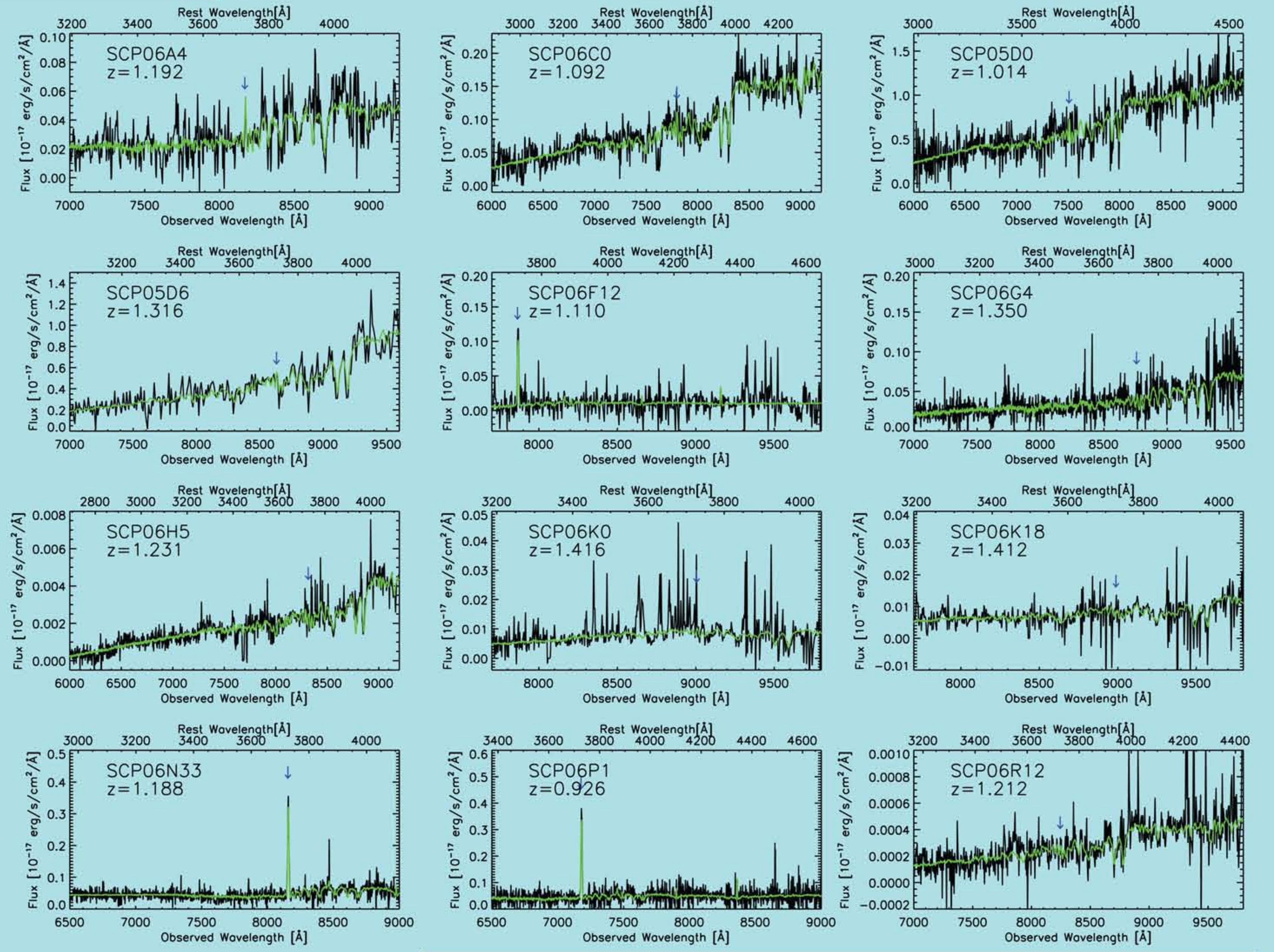
The use of Type Ia supernovae (SNe Ia) as standard candles in estimating astronomical distances has proven indispensable to modern cosmology, leading to the discovery that the expansion of the Universe is accelerating and the existence of dark energy (Riess et al. 1998; Perlmutter et al. 1999). Hundreds of SNe Ia have now been measured at low and intermediate redshifts (Amanullah et al. 2010), but only a handful have been observed at z>1 where expansion transitions from deceleration to acceleration. At all redshifts SNe and their hosts must be studied to minimize systematic uncertainty due to the evolution of dust or intrinsic SN properties; this is particularly important at high redshift.

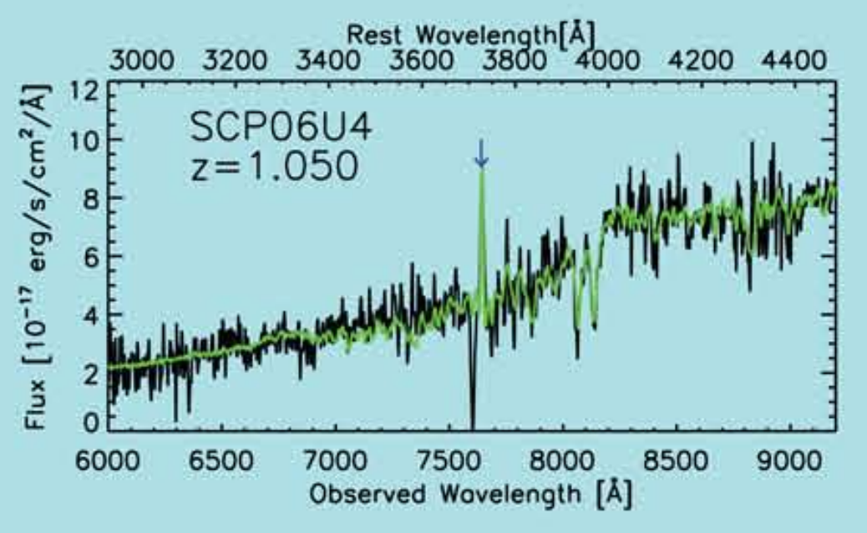
The HST Cluster SN Survey has exploited the overdensity of early-type galaxies in massive clusters to observe a uniformly hosted sample of minimally dust-contaminated SNe in the redshift range 0.9<z<1.5 (PI:Perlmutter; see Dawson et al. 2009). Twenty-five high redshift galaxy clusters drawn from the IRAC Shallow Cluster Survey (Eisenhardt et al. 2008), the Red Sequence Cluster Survey (Gladders & Yee 2005), the XMM Cluster Survey (Sahlen et al. 2008), the Palomar Distant Cluster Survey (Postman et al. 1996), the XMM-Newton Distant Cluster Project (Bohringer et al. 2005), and the ROSAT Deep Cluster Survey (Rosati et al. 1999) were selected for this survey, which yielded twice as many high redshift SNe Ia as would be expected from a comparable blank field survey. We have identified fourteen z>0.9 SNe Ia, seven of which are hosted by cluster members. Here we present the host properties of these SNe.

Cluster C core



Spectroscopy

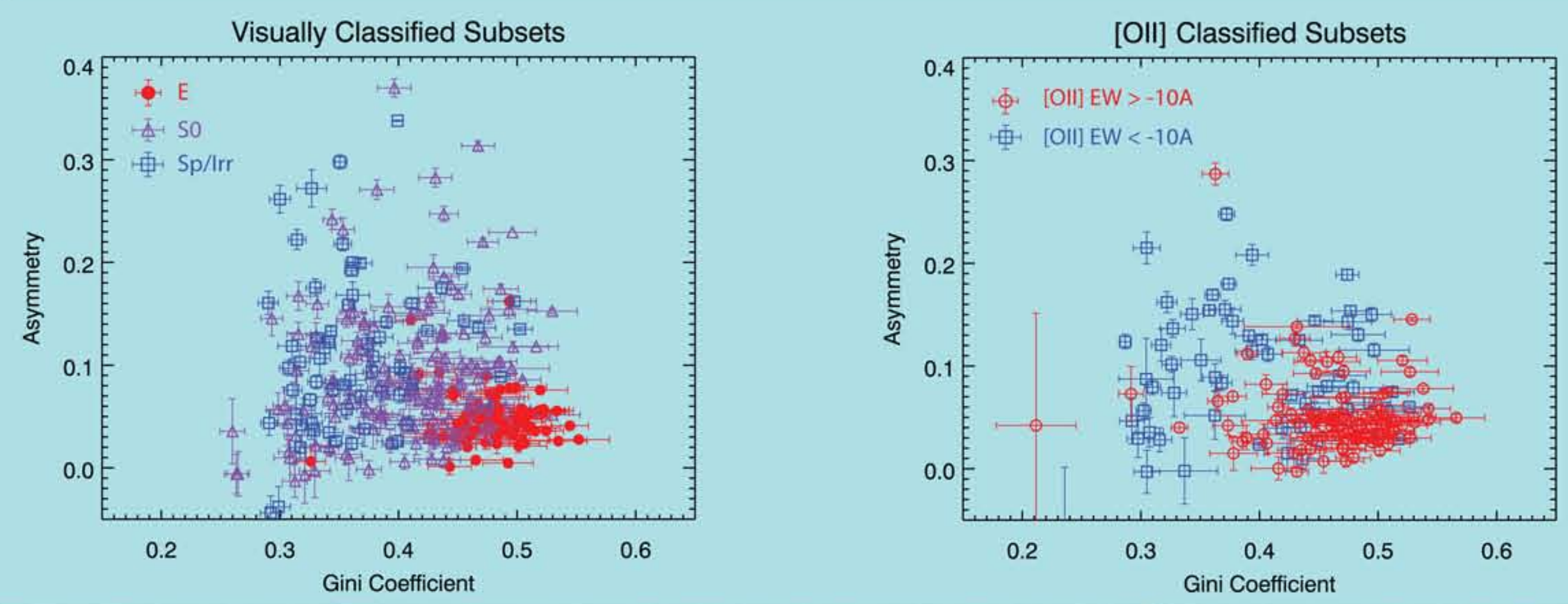




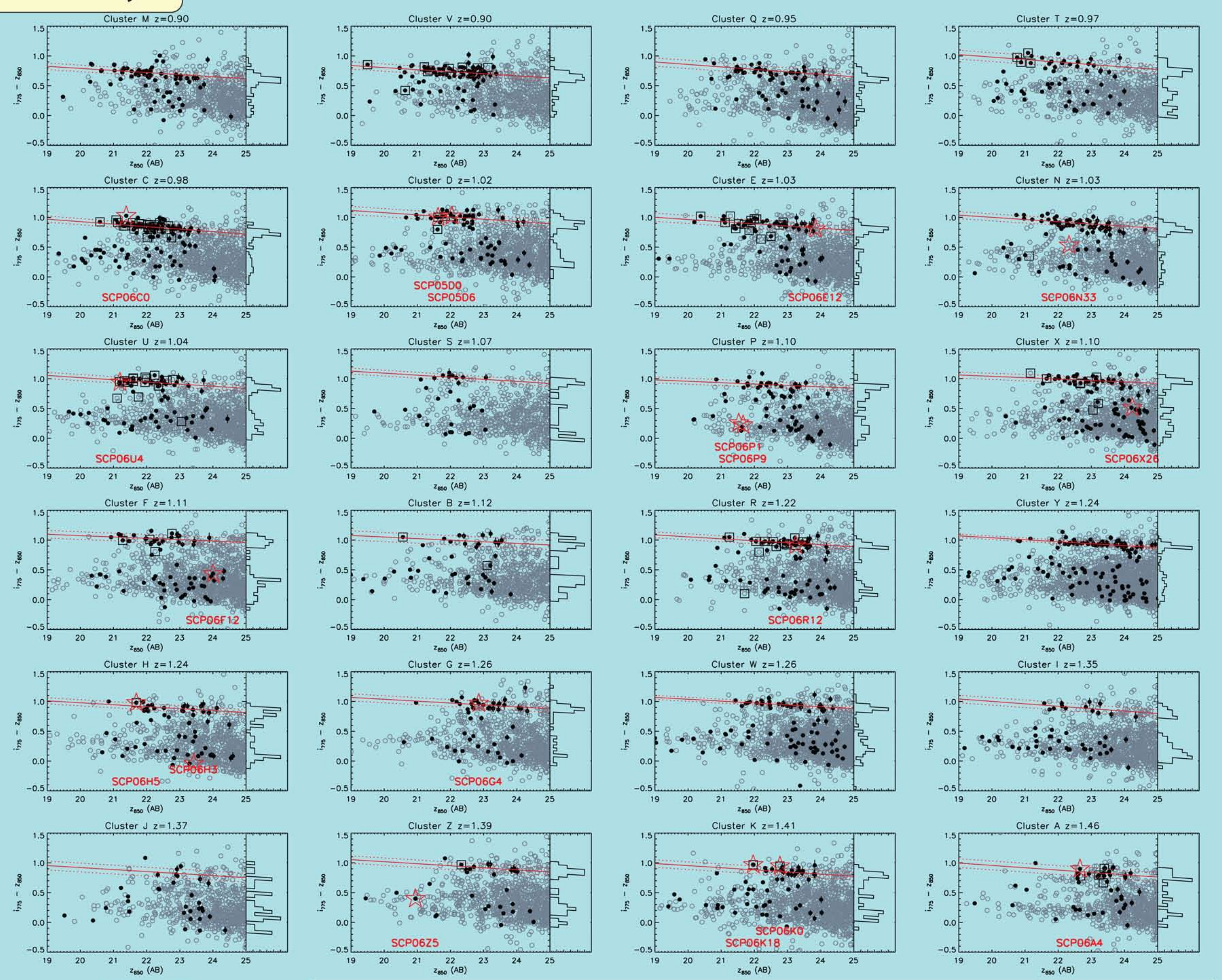
Spectroscopy of z>0.9 SNe Ia host galaxies. SNe hosts were targeted for spectroscopy using DEIMOS at Keck, FOCUS at Subaru and FORS1/2 at the VLT. The green spectra overplotted on the black data are the best fitting linear combinations of SDSS eigenspectra for each spectrum used to establish host galaxy redshifts. The blue arrow in each plot indicates the wavelength of the [OII] 3727 emission line doublet. The hosts of eight SNe show no significant [OII] emission. The hosts of the remaining five SNe: SCP06A4, SCP06F12, SCP06N33, SCP06P1, and SCP06U4 show varying degrees of [OII] emission, which may indicate star formation, but in certain circumstances may instead be attributed to LINER activity in otherwise passively-evolving galaxies (Yan et al. 2006).

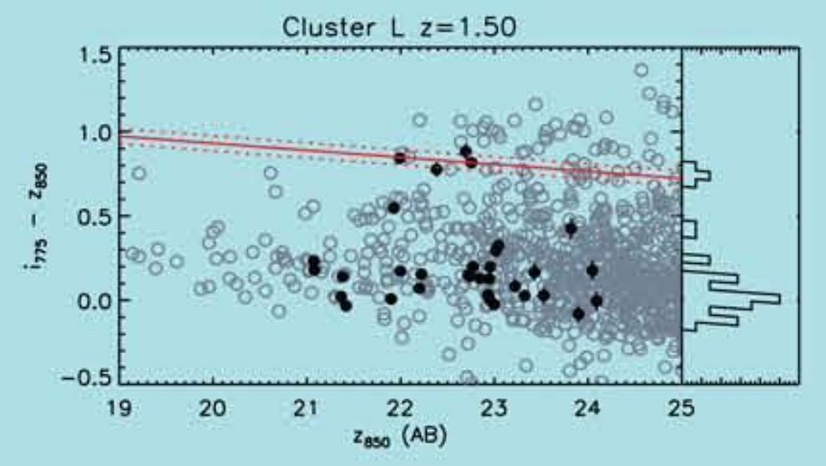
Morphology

We use quantitative morphology parameters to make an automated selection of galaxies likely to be visually classified as elliptical and likely to lack significant [OII] emission in their spectra. The Gini coefficient measures the inhomogeneity in the distribution of galaxy light, and the asymmetry index measures the degree of difference between a galaxy image and its 180 degree rotation (Abraham 2007). We have established cuts on these parameters allowing us to select ~90% of visually classified ellipticals while suffering only ~5% contamination by visually classified spirals and irregulars.



Photometry



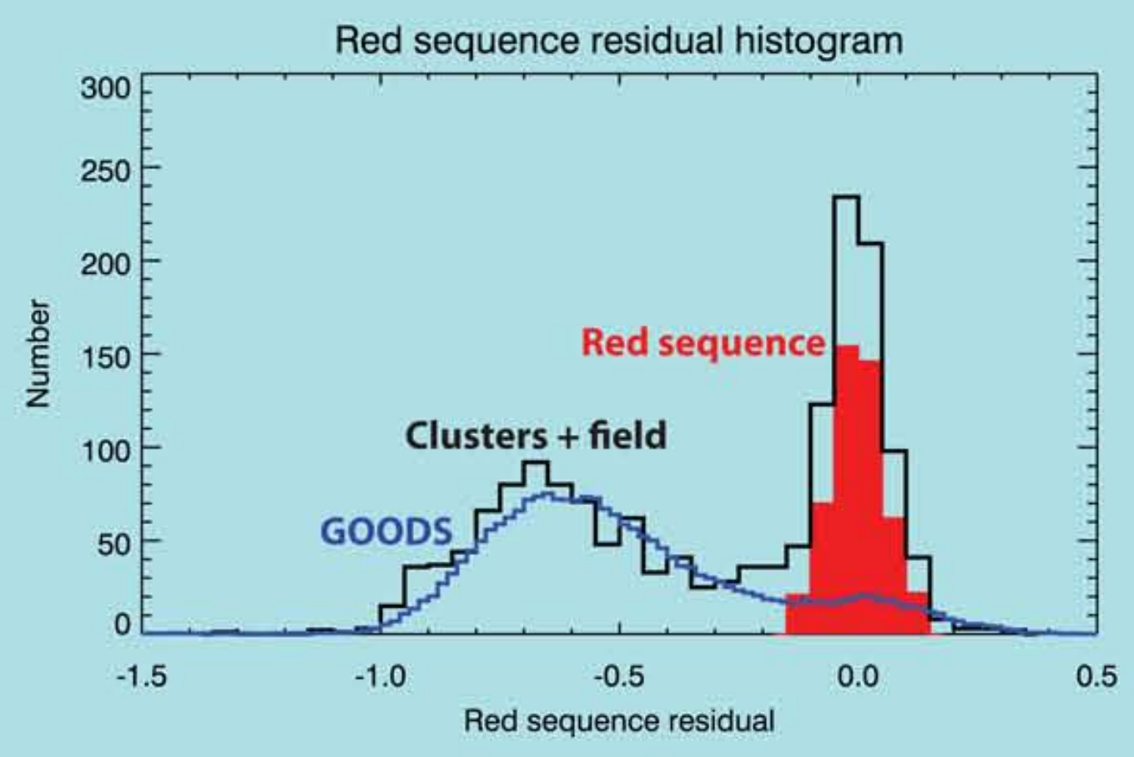


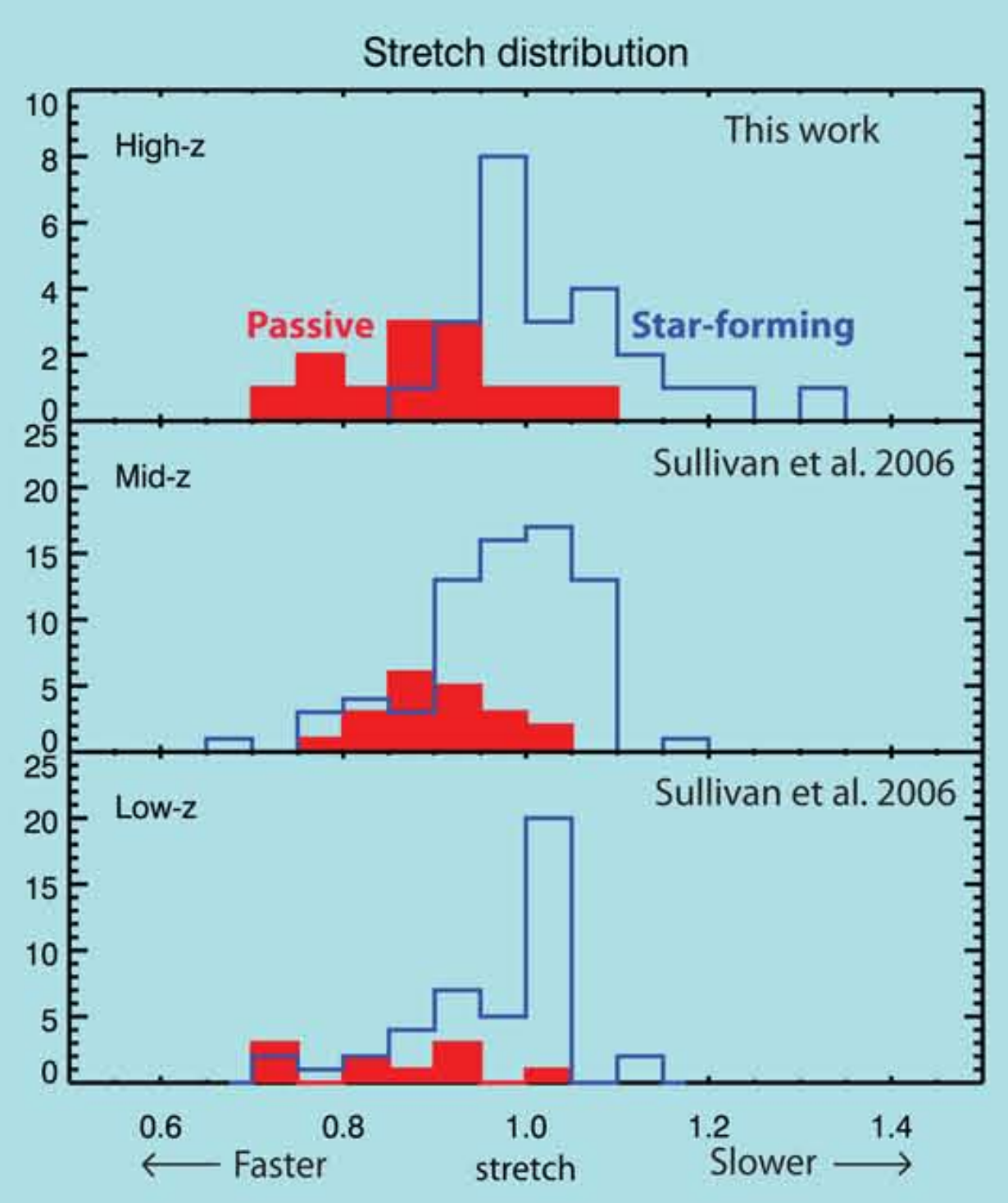
Cluster color-magnitude diagrams. We use SExtractor (Bertin and Arnout 1996) to detect galaxies in the z_{850} filter. Colors are measured within apertures defined by the effective radii of Sersic profiles fit using GALFIT (Peng et al. 2002). Dark filled circles indicate galaxies passing our elliptical morphology cut. Squares indicate spectroscopically confirmed cluster members with weak or no [OII] emission. Stars indicate the host galaxies of SNe Ia. Although not all clusters were specifically targeted for their red galaxy populations, in most of the CMDs the red sequence is clearly visible. The red lines are linear fits (and 1-sigma scatters) to the red sequences of clusters used to compute the red sequence residuals of cluster SNe hosts. To measure the red sequence residuals of field-hosted SNe, we compute an evolution corrected and k-corrected red sequence from the composite sample of spectroscopically confirmed red sequence members.

Results

z > 0.9 SNe hosts

	Name	z_{host}	$z_{cluster}$	Gini Coefficient	Asymmetry	red sequence residual	[OII] EW
Cluster	SCP05D0	1.014	1.02	0.498	0.081	-0.013	− 4.1 ± 1.5
	SCP06F12	1.110	1.11	0.423	0.015	-0.531	− 75.3 ± 206.0
	SCP06H5	1.231	1.24	0.517	0.031	0.062	0.2 ± 0.8
	SCP06K0	1.416	1.41	0.371	0.036	0.081	− 7.0 ± 1.0
	SCP06K18	1.412	1.41	0.446	-0.001	0.076	− 3.2 ± 1.3
	SCP06R12	1.212	1.22	0.448	0.090	-0.031	0.5 ± 2.4
	SCP06U4	1.050	1.04	0.451	0.035	-0.029	− 14.1 ± 1.0
Field	SCP06A4	1.193	1.45	0.420	0.033	-0.096	− 5.0 ± 1.4
	SCP06C0	1.092	0.98	0.470	0.046	0.013	− 3.0 ± 4.0
	SCP05D6	1.314	1.02	0.500	0.032	0.095	− 0.8 ± 1.0
	SCP06G4	1.350	1.26	0.470	0.023	0.054	− 0.3 ± 1.2
	SCP06N33	1.188	1.03	0.424	0.123	-0.474	− 39.7 ± 2.4
	SCP06P1	0.926	1.1	0.288	0.122	-0.585	− 48.6 ± 6.1





The median intrinsic scatter we measure for cluster red sequences is 0.048 magnitudes, though clusters hosting SNe Ia have a typical intrinsic scatter of 0.04 mag. Almost all of this scatter can be attributed to differences in galaxy age and metallicity, leaving little room for reddening by dust. **Lower Left:** The composite sample of red sequence members from all clusters also shows a small intrinsic scatter of 0.048 mag. (Note that for consistency at different redshifts, we limit red sequence members' magnitudes from m*-2.0 to m*+0.8, which somewhat diminishes the solid red histogram compared to the black histogram).

We classify z>0.9 SNe hosts as passively-evolving early-types if their quantitative morphology is consistent with visually identified ellipticals, their color is consistent with the red sequence, and their spectra are consistent with early-type spectra. From this survey, five out of seven cluster hosts and three out of six field hosts meet these criteria. Omitting the spectroscopic requirement we additionally classify six SNe Ia hosts from the GOODS SN surveys as passively-evolving early-types (Riess et al. 2004; Riess et al. 2007). **Lower Right:** Compared to non-passively-hosted SNe, the light curves of these fourteen SNe have a different distribution of light curve width, measured by the SALT parameter stretch, matching results obtained at lower redshift (Sullivan et al. 2006).

Acknowledgements

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For more information about this survey see: http://supernova.lbl.gov/2009ClusterSurvey/