Classifying $z > 1$ SNe Ia as progenitor environments with HST observations 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 $z > 1$ when expansion distances translate to distances at zero. At redshifts $z > 1$, their host galaxies and their environments must be studied to minimize systematic uncertainty due to the evolution of dust or intrinsic SNe properties, and this is particularly important for high-redshift SNe Ia.

The HST Cluster SN Survey has exploited the overdensity of nearby-type galaxies in massive clusters to obtain a uniformly hosted sample of minimally dust-contaminated SNe Ia in the redshift range 0.8 < z < 1.5 (Peirson et al. 2006). Twenty-five high-redshift galaxy clusters drawn from the HATN Cluster Survey (Einasto et al. 2008), the ReDFsequence Cluster Survey (Gladders & Yee 2000), the XMM Newton Cluster Survey (Schindler et al. 2000), the Palomar Distant Cluster Survey (Postman et al. 1996), the XMM-Newton Deep Cluster Survey (Borgani 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 one would expect 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.

Spectroscopy

Spectroscopy of $z > 0.9$ SNe Ia hosts galaxies. SNe hosts were targeted for spectroscopy using DEMS at Keck, DEEP2 at Subaru and FORS2 at the VLT. The green spectra overlaid on the black data are the best fitting linear combinations of E05 models 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 (SCP0407, SCP0412, SCP0414, SCP0416, SCP0418) 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 Gao 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 ~3% contamination by visually classified spirals and irregulars.

Acknowledgements

Amanullah, R., et al., 2011, submitted
Bohlinger, H., et al., 2003, The Messenger, 120, 33

Cluster color-magnitude diagrams. We use SExtractor (Bertin & Arnouts 1996) to detect galaxies in the 39P filter. Colors are measured within apertures defined by the effective radii of SExtractor profiles fit using GALFIT (Peng et al. 2010). Red boxes 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 clusters the red sequence is clearly visible. The red lines are the best fit to the observed color by the least-squares method to the red sequence of clusters used to compute the red sequence residuals of cluster SNe hosts. To measure the red sequence residuals of field-hosted SNe Ia, we compute an evaluation corrected and k-corrected red sequence from the composite sample of spectroscopically confirmed red sequence members.

Results

The median intrinsic scatter we measure for cluster red sequences is 0.048 mag, though clusters hosting SNe Ia have a typical intrinsic scatter of 0.054 mag. Almost all of this scatter can be attributed to differences in galaxy age and metallicity, leaving little room for redshift-driven 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 $m_e$-2.0 to $m_e$-0.8, which somewhat diminishes the solid red histogram compared to the black histogram). We classify all SNe Ia hosts as passively evolving early-type if their quantitative morphological description 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 are three out of six field hosts meet these criteria. Omitting the spectroscopic requirement we additionally classify six SNe Ia hosts from the GOODS-S cluster surveys as passively evolving early-type (Riess et al. 2004, Riess et al. 2007). Lower Right: Compared to ten passively-hosted SNe Ia, the light curves of these fourteen SNe Ia have a different distribution of light curve width, measured by the $\Delta F$ parameter stretch, matching results obtained at lower redshift (Sullivan et al. 2008).