HST Cluster Supernova Survey

Nao Suzuki[1], G. Aldering[1], R. Amanullah, K. Barbary[1,2], L. Barrientos, M. Brodwin, N. Connolly, K. Dawson, R. de Jong, A. Dey, M. Doi, M. Donahue, P. Eisenhardt, E. Ellingson, L. Faccioli[1], V. Fadeyev, H. Fakhouri[1,2], A. Fruchter, D. Gilbank, M. Gladders, G. Goldhaber[1,2], A. Gonzalez, A. Goobar, A. Gude[1,2], J. Hennawi, H. Hoekstra, E. Hsiao[1], X. Huang[1,2], Y. Ihara, B. Jannuzi, M. J. Jee, B. Koester, M. Kowalski[2], C. Lidman[1], B. E. Linder[2], L. Lubin, J. Meyers[12], T. Morokuma, S. Perlmutter[1,2], M. Postman, J. Rhodes, P. Rosati[2], P. Ripoche[1], D. Rubin[12], D. Schlegel[1], A. Spadafora[1], A. Stanford, D. Stern, N. Yasuda, H. Yee,

Supernova Cosmology Project

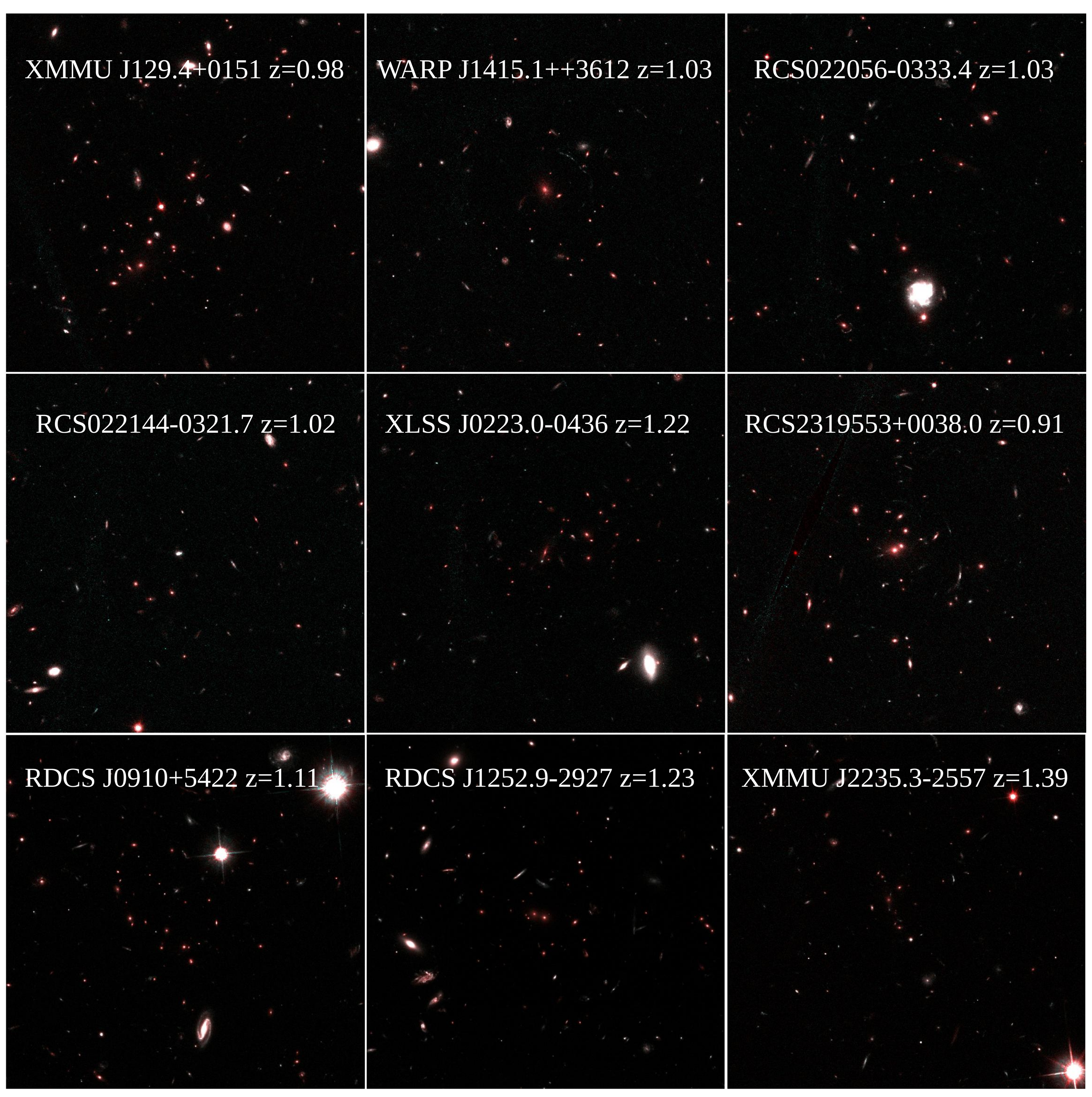
[1]Lawrence Berkeley National Laboratory, [2]University of California, Berkeley

A Novel Strategy

We report on results from the Hubble Space Telescope (HST) Cluster Supernova Survey with the Advanced Camera for Surveys (ACS) (PI: Perlmutter; see Dawson et al. AJ, 2009), where we introduced a novel approach to discover and follow high-redshift Type Ia supernovae (SNe Ia). With HST, we monitored 25 massive galaxy clusters spanning the redshift interval $0.9 < z < 1.5$. In total, 39 SNe of all types were discovered. Of these, 16 SNe Ia have both lightcurves of sufficient quality and spectroscopic redshifts (obtained at the Subaru, VLT and Keck observatories) for use on the Hubble Diagram. Eight of these – half the sample - occurred in early-type galaxies. Using high-redshift clusters to find SNe Ia has two major advantages. First, this is the most efficient way of finding supernovae at targeted redshifts, and second, SNe Ia in galaxy clusters are found primarily in early type galaxies.

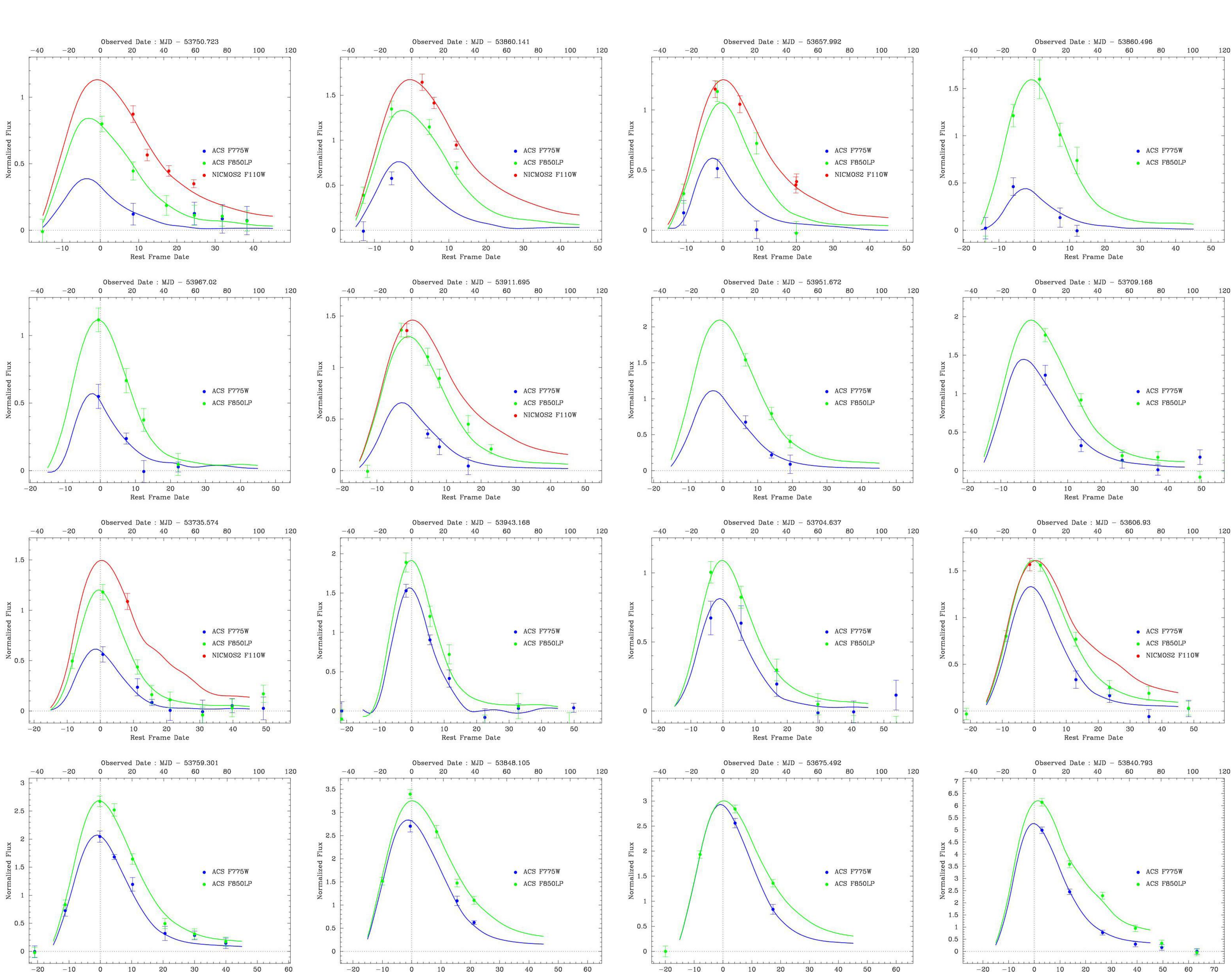
The largest astrophysical systematic uncertainty in using SNe Ia for cosmology stems from the nature of the color correction that is used to standardize luminosities. The observed color of a SNe Ia is the sum of two effects: the intrinsic color and reddening by dust. By comparing subsets of SNe Ia that are likely to be unaffected by dust (e.g., SNe Ia in early-type galaxies) with those in dusty environments, we can more accurately quantify the nature of the correction and reduce the systematic error that is associated to it. Furthermore, early-type galaxies have simpler star formation histories and more aged stellar populations than galaxies of other types, thus possibly leading to a more uniform progenitor population and a better SNe Ia standard candle.

SN Ia Discoveries in Clusters



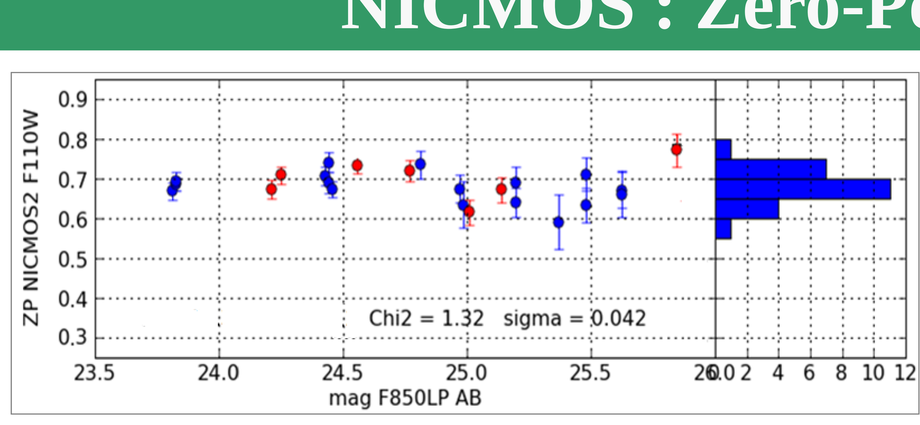
Galaxy cluster examples from this HST cluster supernova survey. Note the red-sequence galaxies show similar colors. We monitored 25 clusters of galaxies and discovered more than 50 variable objects from which we identified 26 SNe Ia, 14 AGNs and 8 core collapse supernovae. From the deep stacked images, we study the colors and morphologies of SN host galaxies (see Josh Meyers et al. poster: 461.01).

SN Ia Light Curves



SNe Ia light curves for the 16 SNe Ia shown above. Images with the HST ACS F775W and F850LP filters are taken approximately once every 3 weeks in the observer-frame, which corresponds to a 7-10 day cadence in the rest-frame. Once a likely $z > 0.95$ SN Ia is identified in early-type host galaxy, we obtain additional HST NICMOS F110W observations to further constrain the rest-frame B-V color. We use SALT2 for the light curve fitting and adopt a revised NICMOS F110W zero-point.

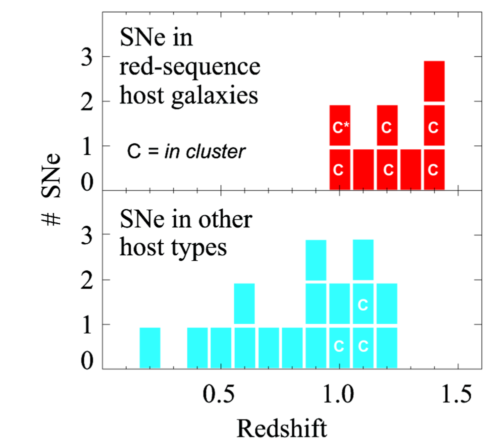
NICMOS : Zero-Point Calibration



The NICMOS F110W filter observations are very important for the measurement of SNe Ia colors at $z > 1$. However, the calibration of NICMOS at low count rates has proven to be extremely uncertain. We have re-determined the NICMOS zero-point using observations of high redshift cluster ellipticals (see Ripoche et al. poster 462.01 for details).

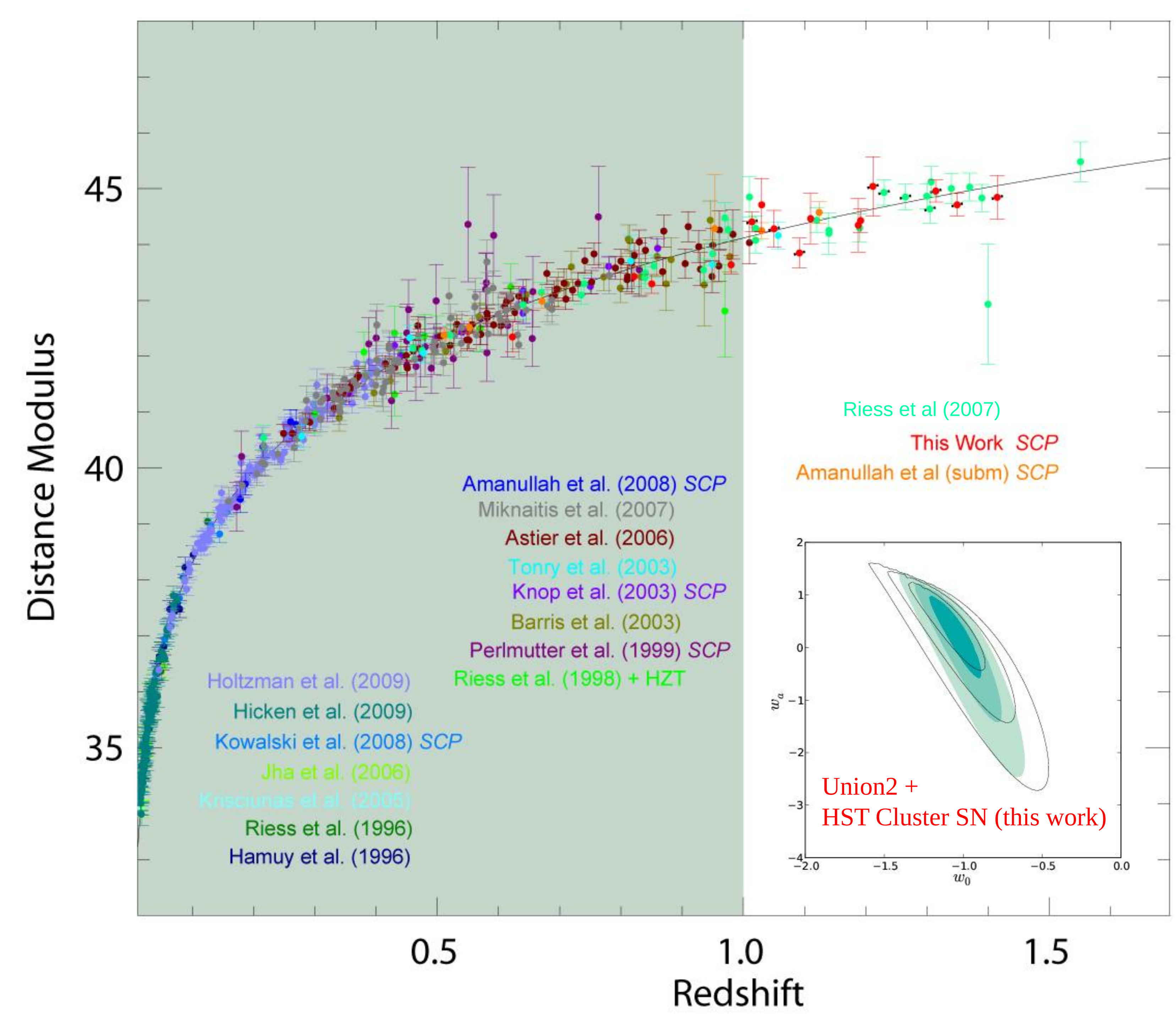
Our preliminary results suggest that the F110W zero-point differs from the standard zero-point by approximately 10%.

SN Ia Statistics

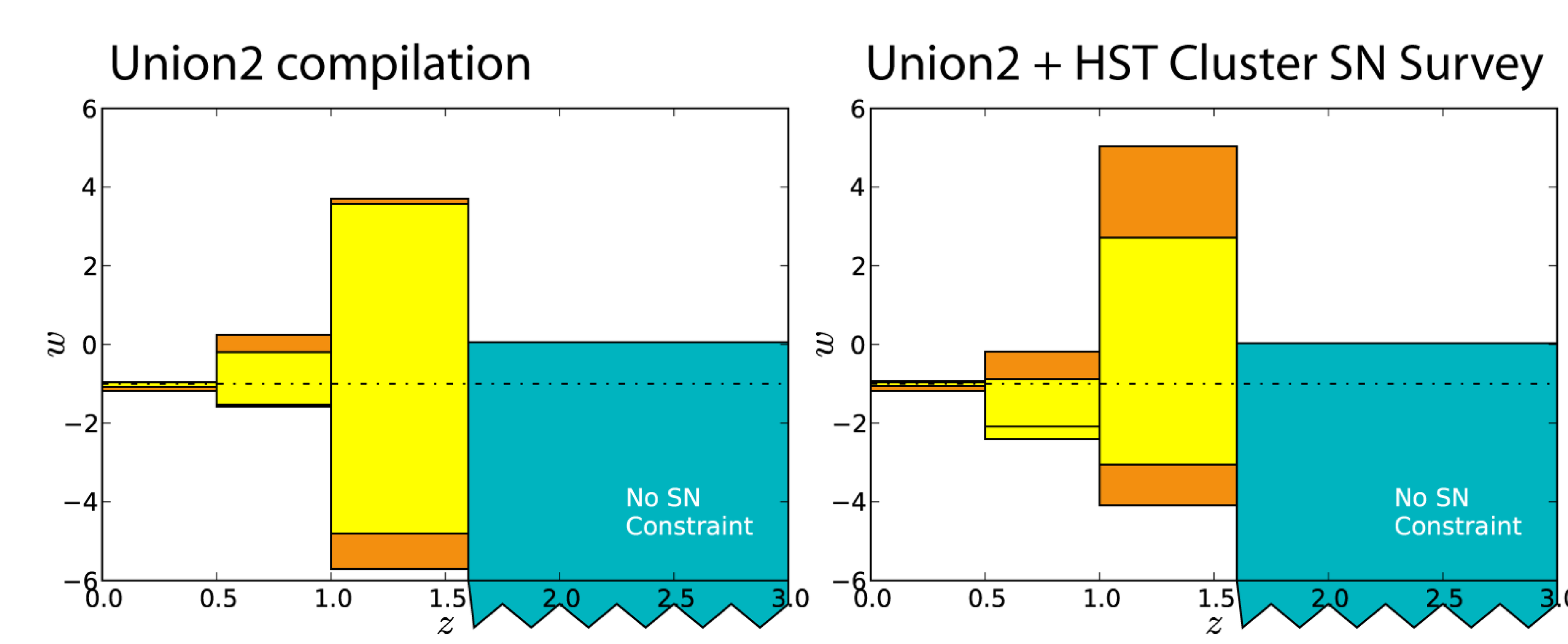


The redshift distribution of SNe discovered in our ACS program. The upper panel shows the distribution of red-sequence galaxies that had SNe Ia, with the cluster members marked with the letter 'C'. The asterisk indicates [OII] emission in the spectrum of a galaxy that lands on the red-sequence and is morphologically an early type galaxy. The lower panel shows the distribution for the other SN hosts. For $z > 0.95$, the number of SNe in cluster galaxies (9) is comparable to the number of SNe in field galaxies (7).

Results



A Hubble Diagram showing the Union2 sample (555 SNe Ia) together with the data (shown in red) from the HST Cluster Supernova Survey. These data sets almost double the number of the supernovae at $z > 1$. The $z > 1$ SNe Ia that occurred in early-type galaxies are marked with small arrows on either side. The inset shows constraints on the dark energy equation of state paramaters w_0 and w_a. The filled contours include statistical errors but not systematic errors. The empty contours include both.



Constraints on the equation of state parameter, w(z), where w(z) is assumed to be constant in each redshift bin. The results were obtained assuming a flat universe for the joint data set of supernovae, BAO, CMB, and H_0 and the width in w represents the 68% probability with and without systematic errors (orange and yellow bars, respectively). The left panel is from UNION2 compilation (Amanullah et al. submitted to ApJ and see Rubin et al. poster 461.01), and the right panel is UNION2 plus this cluster supernova data set. We reduce the statistical error for the $1 < z < 1.6$ redshift bin by a factor of two.

Publications from the HST Cluster Supernova Survey

The HST cluster supernova survey has resulted in numerous publications. Here is a list of results that have been published or are about to be published..

Supernovae Science

- The Type Ia Supernova Rate in High Redshift Galaxy Clusters — Barbary et al. in prep. (oral 343.03)
- Constraining z>1 SN Progenitor Environments with HST Observations of Cluster Elliptical Galaxies — Meyers et al. in prep. (poster 461.02)
- Absolute Calibration of the HST NICMOS F110W Using High-z Red-Sequence Galaxies — Ripoche et al. in prep. (poster 462.01)
- An Intensive HST Survey for z > 1 Supernovae by Targeting Cluster of Galaxies — Dawson et al. 2009, AJ, 138, 1271
- Subaru FOCAS Spectroscopic Observations for High-Redshift Supernovae — Morokuma et al. 2009, arxiv:0911.1258
- Discovery of an Unusual Optical Transient with the Hubble Space Telescope — Barbary et al. 2009, ApJ, 690,
- Rest-Frame R-band Light Curve of a z ~ 1.3 Supernova Obtained with Keck Laser Adaptive Optics — Melbourne et al. 2007, AJ, 133, 2709

Gravitational Lensing

- Discovery of a z=3.9 Multiply Imaged Galaxy behind the Cluster Lens WARPS J1415+36 at z=1.026 — Huang et al. 2009, ApJL, 707, 12 (poster 461.03)
- HST Weak-Lensing Study of the Galaxy Cluster XMMU J2235.3-2557 at z=1.4 — Jee et al. 2009, ApJ, 704, 672

Cluster Science

- The Beginning of the End: Pinpointing the Galaxy Cluster Red Sequence from 0.1 < z < 1.0 — Koester et al. in prep. (poster 602.23)
- Multi-Wavelength study of XMMU J2235.3-2557 : The study of Massive Cluster at z > 1 — Rosati et al. 2009, A&A, 508, 583
- Multiwavelength observations of a rich galaxy cluster at z = 1 — Santos et al. 2009, A&A, 501, 49
- Galaxy Morphologies and the Color-Magnitude Relation in XMM J2215.9-201 at z = 1.46 — Hilton et al. 2009, ApJ, 497, 436
- Clusters of Galaxies in the First Half of the Universe from the IRAC Shallow Survey — Eisenhardt et al. 2008, ApJ, 684, 905
- The XMM Cluster Survey: The Dynamical State of XMM J2215.9-1738 at z = 1.457 — Hilton et al. 2007, ApJ, 670, 1000

Web Site : http://supernova.lbl.gov/2009ClusterSurvey

Acknowledgement
This work has been supported by the Office of Science, U.S. Department of Energy, through contract DE-AC02-05CH11231 and in part by NASA through grants associated with HST-GO-10496 and HST-GO-11799.