# The Union2 Supernova Compilation: Construction and Cosmology

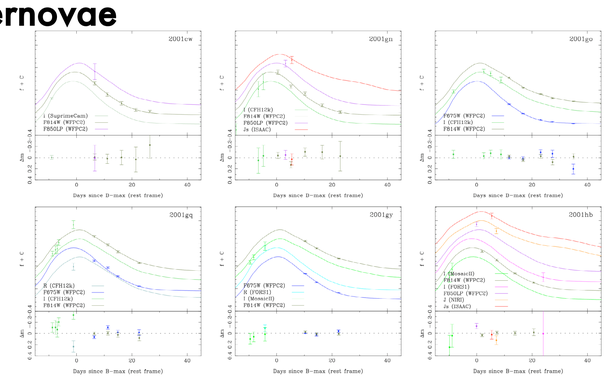
**D. Rubin**[1,2], R. Amanullah, C. Lidman, G. Aldering, P. Astier, K. Barbary, M. S. Burns, A. Conley, K. S. Dawson, S. E. Deustua, M. Doi, S. Fabbro, L. Faccioli, H. K. Fakhouri, G. Folatelli, A. S. Fruchter, H. Furusawa, G. Garavini, G. Goldhaber, A. Goobar, D. E. Groom, I. Hook, D. A. Howell, N. Kashikawa, A. G. Kim, R. A. Knop, M. Kowalski, E. Linder, J. Meyers, T. Morokuma, S. Nobili, J. Nordin, P. E. Nugent, L. Östman, R. Pain, N. Panagia, S. Perlmutter, J. Raux, P. Ruiz-Lapuente, A. L. Spadafora, M. Strovink, N. Suzuki, L. Wang, W. M. Wood-Vasey, N. Yasuda

**Supernova Cosmology Project**

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

We present a complete update of the Union Supernova compilation (Amanullah et al., submitted), including new SNe at redshift > 1 with high-quality ground-based near-IR data. We improve the cosmological constraints from the original Union compilation by 10-30%, including systematic errors, which are now handled via a detailed covariance matrix. We also provide constraints on the existence and nature of dark energy in separate redshift bins. While the data favor some form of dark energy below redshift 1, no real constraint can be placed above this redshift.

## New Supernovae




We add a new sample of six HST-observed SNe, extending to $z > 1$. Two of these at $z > 1$ have ground-based NIR data and provide a measurement of supernova color at these redshifts that is independent of NICMOS calibration uncertainties (see poster 462.01).

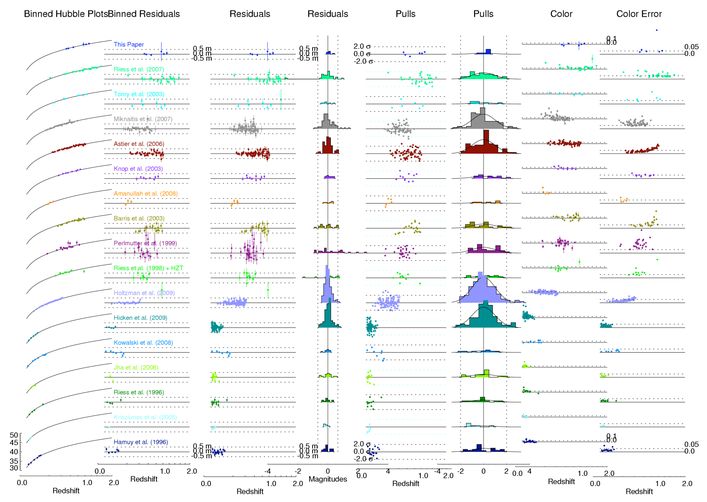
## Updated Systematics Analysis

Effect on $w$ (includes BAO+CMB)

| Source | Error on $w$ |
|---|---|
| Zero point | 0.042 |
| Vega | 0.040 |
| Galactic Extinction Normalization | 0.010 |
| Rest-Frame $U$-Band | 0.008 |
| Contamination | 0.021 |
| Malmquist Bias | 0.026 |
| Intergalactic Extinction | 0.008 |
| Light curve Shape | 0.010 |
| *Quadrature Sum (not used)* | *0.069* |
| Summed in Covariance Matrix | 0.059 |

We consider both sample composition systematics and photometry and model systematics. The former category is still taken into account as a sample-by-sample covariance, while the latter is handled with a separate covariance for every filter band (see below). Evolution and peculiar velocity uncertainties are sub-dominant systematics. Each systematic error has different redshift-dependent effects; the proper way to sum them is in a covariance matrix, not in quadrature.

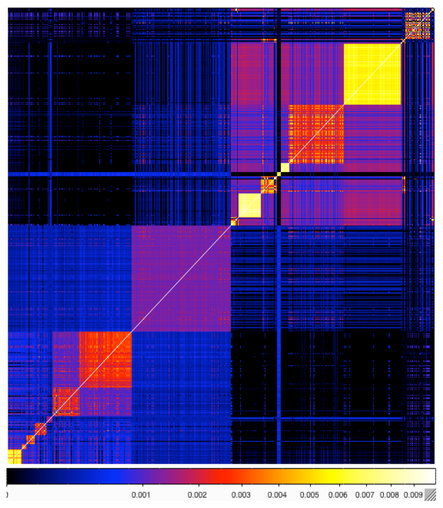
## Updated Union Compilation and Analysis




All lightcurves fit consistently with SALT2 in natural systems (when data is available). 555 supernovae pass the cuts for inclusion in cosmology fits ($z > 0.015$, measured color, at least five data points, the first of which must be less than six days after $B$-band maximum).

These new supernovae were combined with new supernovae from Amanullah et al. (2008), Kessler et al. (2009), and Hicken et al. (2009).

## Covariance Matrix

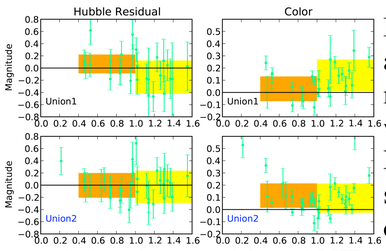



The distance modulus covariance matrix is generated with:

$$V_{ij} = \sum_{\text{band}} \frac{\partial \mu_i}{\partial(\text{band})} \frac{\partial \mu_j}{\partial(\text{band})} d(\text{band})^2$$

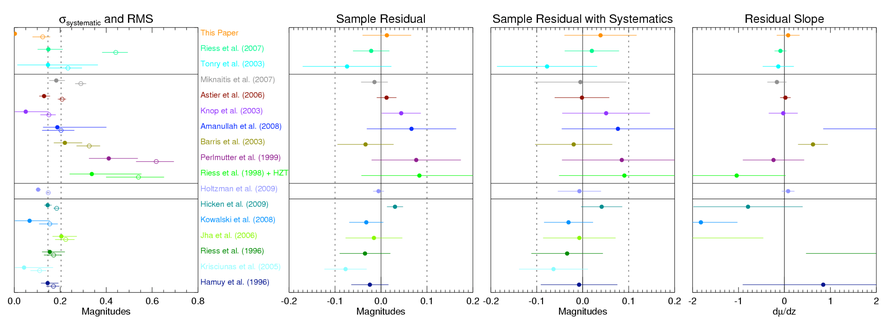
The supernova subsets are arranged in the same order listed in the left panel (Updated Union Compilation and Analysis), generally low redshifts in the lower left and higher redshifts in the upper right. Distance modulii from each subset co-vary, as do supernovae from similar redshift ranges, appearing as blocks in this figure. Brighter colors indicate subsets with more systematic error.

## Reduced Color and Hubble Residual Offsets for z > 1 SNe



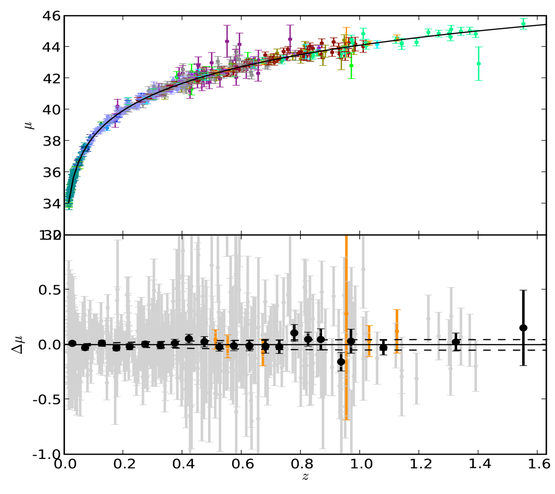

In Union, we noted a significant offset in color and residual of SNe at $z > 1$, where the supernovae begin to rely on NICMOS for color measurements. (If not for concerns about calibration, these offsets would have had important implications for dark energy.) Updates to HST calibration have improved compatibility with ΛCDM, but supernova colors remain slightly redder than average for supernovae observed with NICMOS. Interestingly, the two new supernovae we added with ground-based NIR have normal colors. We are re-determining the NICMOS zero point at low flux levels, independent of the current extrapolation to the NICMOS low-count non-linearity correction (see poster 462.01).

## Testing for Tension Between Subsets

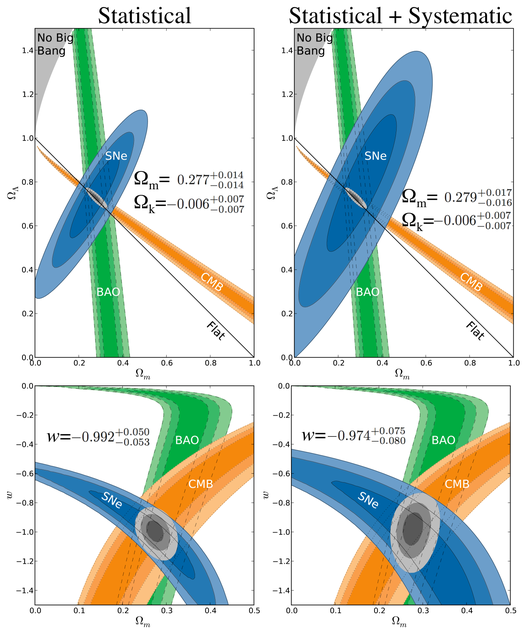



Computing the weighted mean of residuals for each subset can reveal systematic errors (as can comparing photometry on supernovae in common between subsets). We do note some statistical tensions (Sample Residual plot, second from left) which are reduced when we include calibration uncertainties (Sample Residual with Systematics, second from right).

## Cosmology Constraints from 555 SNe

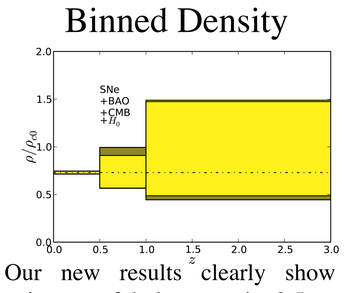



Hubble diagram and residuals for the Union2 compilation. The two new $z > 1$ supernovae have comparable measurement errors to existing supernovae with NICMOS measurements.



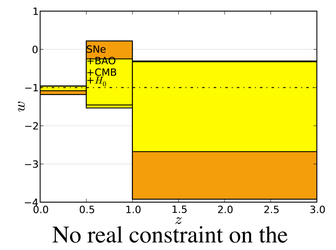

Including systematic errors, the Union2 constraint on Omega_m, improves by 26% compared to the previous Union compilation; for $w$, the improvement is 13%.

### Binned Density

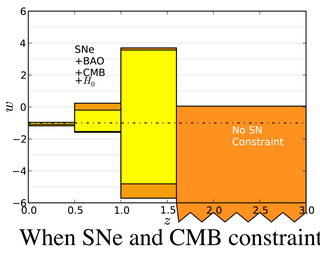



Our new results clearly show the existence of dark energy in $0.5 < z < 1$; constraint for $z > 1$ is very weak.

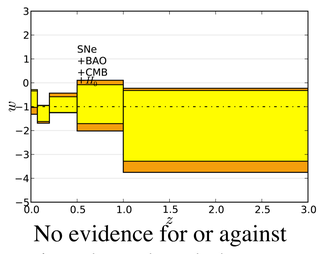
### Binned $w$




No real constraint on the equation of state for $z > 0.5$.




When SNe and CMB constraints are separated, no constraints on the equation of state or even the *existence* of dark energy for $z > 1$.




No evidence for or against time-dependent dark energy.

### Union2 Availability

The new Union2 compilation will be available (redshifts, distances, and covariance matrices, with a module for CosmoMC) at:

www.supernova.lbl.gov/Union

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