Constraints on Cosmological Parameters from HST Observations of High-z Supernovae

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ABSTRACT

We have coordinated *Hubble Space Telescope* photometry with ground-based discovery for three supernovae: two SN Ia near $z \sim 0.5$ (SN 1997ce, SN 1997cj) and a third event at $z = 0.97$ (SN 1997ck). The superb spatial resolution of *HST* separates each supernova from its host galaxy and leads to good precision in the light curves. We use these light curves and relations between luminosity, light curve shape, and color calibrated from low-z samples to derive relative luminosity distances which are accurate to 10% at $z \sim 0.5$ and 20% at $z = 1$. The redshift-distance relation is used to place constraints on the global mean matter density, Ω_m, and the normalized cosmological constant, Ω_Λ. When the *HST* sample is combined with the distance to SN 1995K ($z = 0.48$), it suggests that matter alone is insufficient to produce a flat Universe. Specifically, for $\Omega_m + \Omega_\Lambda = 1$, Ω_m is less than 1 with $> 95\%$ confidence, and our best estimate of Ω_m is -0.1 ± 0.5 if $\Omega_\Lambda = 0$. Although the present result is based on a very small sample whose systematics remain to be explored, it demonstrates the power of *HST* measurements for high redshift supernovae.

OBSERVATIONS

- The *HST*-coordinated search for distant SNe was conducted at the CFHT on 1997 April 29-30 using the UH8K CCD mosaic. Four fields each covering $0.25\,\square^\circ$ were searched by comparing with template images taken April 4 & 9.
- Spectra of eight SN candidates were obtained May 1-4 with the MMT and Keck. Four were classified as SNe Ia, one as a SN II, one as an AGN and two could not be identified. One target in each of the pre-planned *HST* fields, SNe 1997ca, 1997ce, 1997cj and 1997ck were selected for follow-up photometry with *HST*. The light curve of SN 1997ca appears to be that of a SN II so was not included in the analysis.
- The first WFPC2 images were obtained May 12, approximately two weeks after discovery. Data was taken in the F675W (R) and F814W (I) filters for the $z \sim 0.5$ SNe and in the F850LP filter for SN 1997ck at $z = 0.97$. Six epoch of *HST* photometry were obtained over approximately one month and combined with ground-based photometry to construct light curves shown in Fig. 1.

ANALYSIS

- Templates for galaxy subtraction were created from the *HST* images by using a PSF to remove the SN image from each epoch and then averaging the results.
- The Holtzman calibration was used as the zeropoint for the *HST* photometry and stars in the *HST* frames provided a calibration for ground based data. The new CTE corrections from Whitmore & Heyer were applied.
- The intrinsic brightness of the supernovae were corrected using the light curve decline rate. Both the MLCS (Riess, Press & Kirshner) and the template fitting (Hamuy *et al.*) methods were applied.

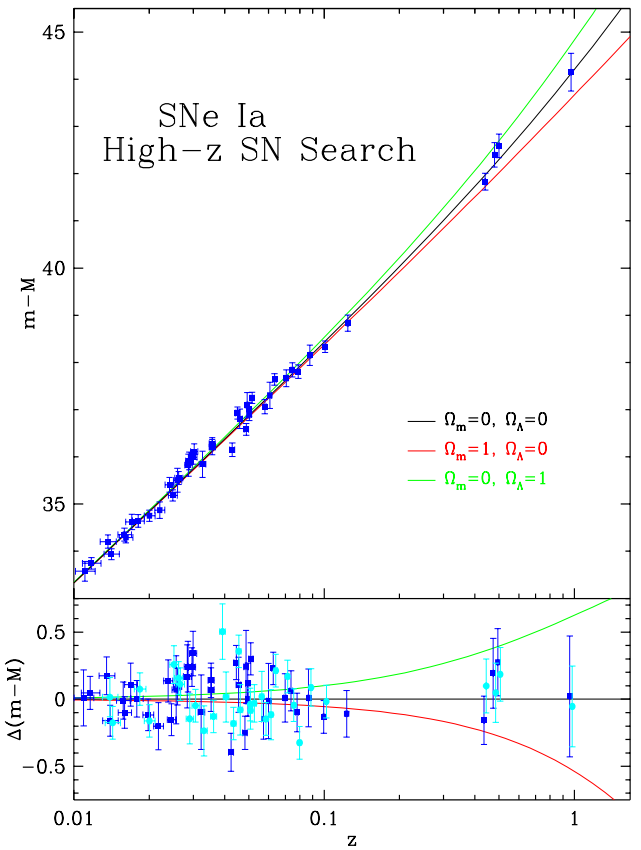

Fig. 2.—The Hubble diagram for SNe Ia. The top panel shows the MLCS distance modulus versus z for a large sample of low redshift events and the four (HST +SN 1995K) high-z SNe. The lower panel plots the magnitude difference between the observed SNe and the magnitude expected from a Universe with $\Omega_m = \Omega_\Lambda = 0$. The lighter points show the SNe distances estimated using the techniques and scale from Hamuy *et al.*. The redshift for SNe where both techniques have been applied has been slightly shifted for clarity.

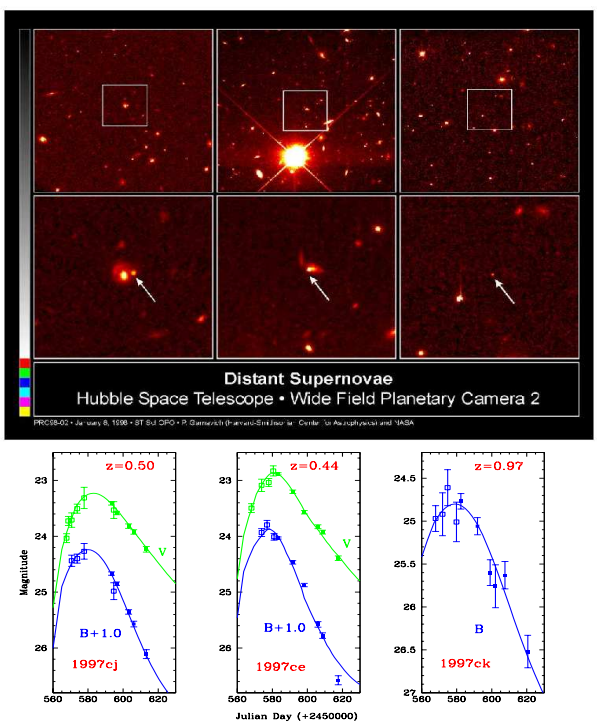

Fig. 1.—(top panel) *HST* images of the three SNe Ia, SN 1997cj (left), SN 1997ce (middle) and SN 1997ck (right). (bottom panel) Light curves of the SNe. Rest frame V is shown in green and B in blue. Filled points indicate *HST* observations.

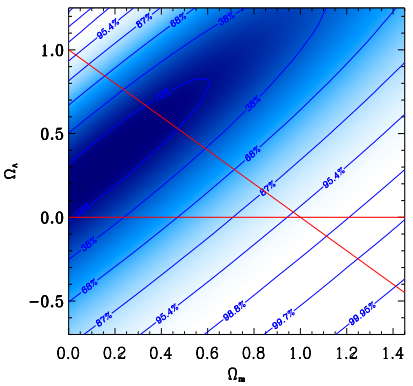

Fig. 3.— The joint likelihood distribution for cosmological models consisting of matter and a cosmological constant. The horizontal red line shows models with a cosmological constant of zero while the diagonal red line represents flat models.

CONCLUSIONS

- We show that it is possible to coordinate *HST* photometry with ground based discovery of SNe.
- It is possible to discover and study SNe at $z \sim 1$.
- Three SNe with $z \sim 0.5$ give, for a flat Universe, $\Omega_m = 0.4^{+0.3}_{-0.3}$.
- For a Universe with no cosmological constant, $\Omega_m = -0.1 \pm 0.5$.
- SN 1997ck at $z = 0.97$ has only a B light curve, so no reddening estimate could be made. However, including 1997ck (assuming no extinction) tightens the constraints on the matter density but does not change the estimated value.
- Preliminary results with a handful of supernovae indicate that the normalized matter density is low, either the Universe is open, or if flat, then a cosmological constant makes a considerable contribution.
- The SNe show little deceleration in the cosmic expansion rate which implies an age for the Universe close to the Hubble time. For $H_0 = 65$ km/s/Mpc the time since the Big Bang is ~ 15 Gyr, consistent with the nuclear burning ages for globular clusters.

Table 1. **Supernova Parameters and Error Budget**

SN	1995K[1]	1997ce	1997cj	1997ck
z	0.48	0.44	0.50	0.97
Error Budget (mag)				
CT Correction	0.00	0.02	0.02	0.02
Zeropoint	0.03	0.05	0.05	0.05
Evolution[2]	0.06	0.06	0.06	0.06
Selection Bias[3]	0.02	0.02	0.02	0.02
Weak Lensing[3]	0.02	0.02	0.02	0.04
K-corrections[4]	0.06	0.06	0.06	0.06
Light Curve Fit RPK[5]	0.21	0.08	0.19	0.42
Light Curve Fit H96[5]	0.13	0.11	0.11	0.21
σ of SNe Ia[6]	0.12	0.12	0.12	0.12
Parameters (mag)				
m_B^{max} (H96)	22.89	22.75	23.19	24.78
m_V^{max} (H96)	23.00	22.79	23.19	...
Δ (RPK)	−0.07	0.41	0.04	−0.01
Δm_{15} (H96)	1.15(09)	1.19(06)	1.16(03)	1.00(17)
A_V (RPK)	0.00	0.00	0.00	...
Galactic A_V	0.00	0.03	0.03	0.03
$m - M$ RPK	42.40(26)	41.83(18)	42.59(25)	44.15(45)
$m - M$ H96[7]	42.25(20)	42.06(19)	42.48(19)	44.06(27)

[1]From SSP98. [2]Current observational upper limit from SSP98. [3]From Wambsganss *et al.* 1997. [4]Includes propagated effect on extinction, $3.1\sigma E[B-V]$. [5]Includes uncertainty in light curve fit, extinction and background subtracti on. [6]Dispersion in local SN Ia distances after LCS correction (RPK). [7]Average of B and V.

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