New Constraints on Ω_M, Ω_Λ, and w from an Independent Set of Eleven High-Redshift Supernovae Observed with HST

Supernova Cosmology Project

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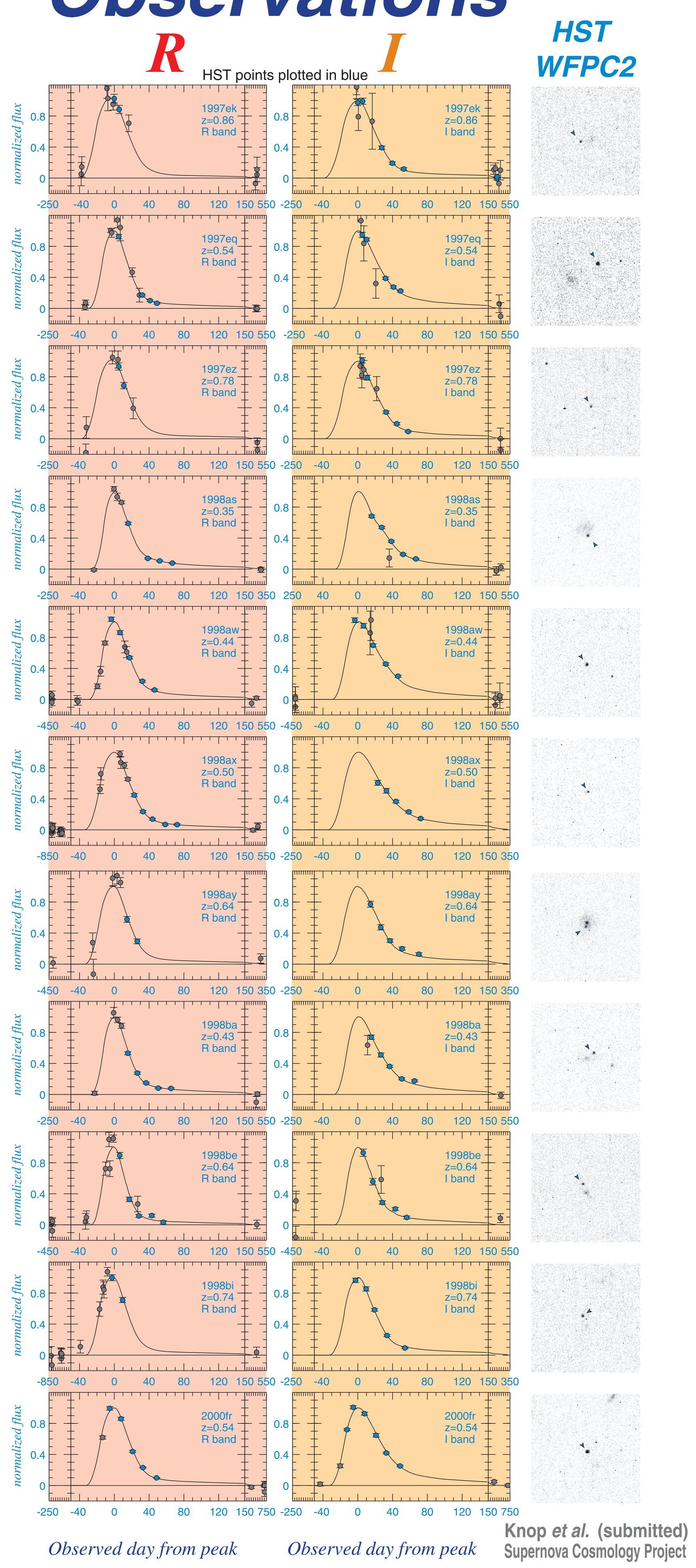
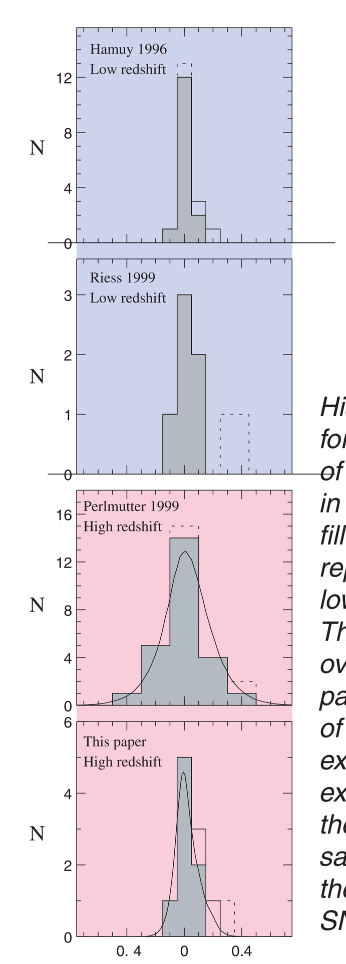
Abstract

We present measurements of Ω_M, Ω_Λ, and w from eleven supernovae at $z = 0.36$-0.86 with high-quality lightcurves measured using WFPC2 on the HST. This is an independent set of high-redshift supernovae that confirms previous supernova evidence for an accelerating Universe. The high-quality lightcurves available from photometry on WFPC2 mean that these eleven supernovae alone provide measurements of the cosmological parameters comparable in statistical weight to the previous results. Combined with earlier Supernova Cosmology Project data, the new supernovae yield a measurement of the mass density $\Omega_M = 0.25$ +0.07/-0.06 (statistical) +/-0.04 (identified systematics), or equivalently, a cosmological constant of $\Omega_\Lambda = 0.75$ +0.06/-0.07 (statistical) +/-0.04 (identified systematics), under the assumptions of a flat universe and that the dark energy equation of state parameter has a constant value $w = -1$. When the supernova results are combined with independent flat-universe measurements of Ω_M from CMB and galaxy redshift distortion data, they provide a measurement of $w = -1.05$ +0.15/-0.20 (statistical) +/-0.09 (identified systematic), if w is assumed to be constant in time. In addition to high-precision lightcurve measurements, the new data offer greatly improved color measurements of the high-redshift supernovae, and hence host-galaxy extinction estimates. These extinction measurements show no trend of anomalous E(B-V) at higher redshifts. The precision of the measurements is such that it is possible to perform a host-galaxy extinction correction directly to individual supernovae without any assumptions or priors on the parent E(B-V) distribution, yielding cosmological results consistent with current and previous results, and requiring dark energy with probability $P > 0.99$.

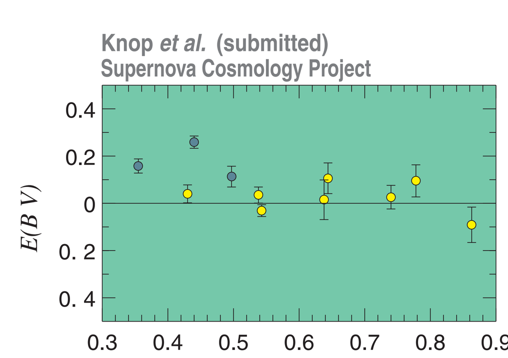
Observations



Extinction Measurements

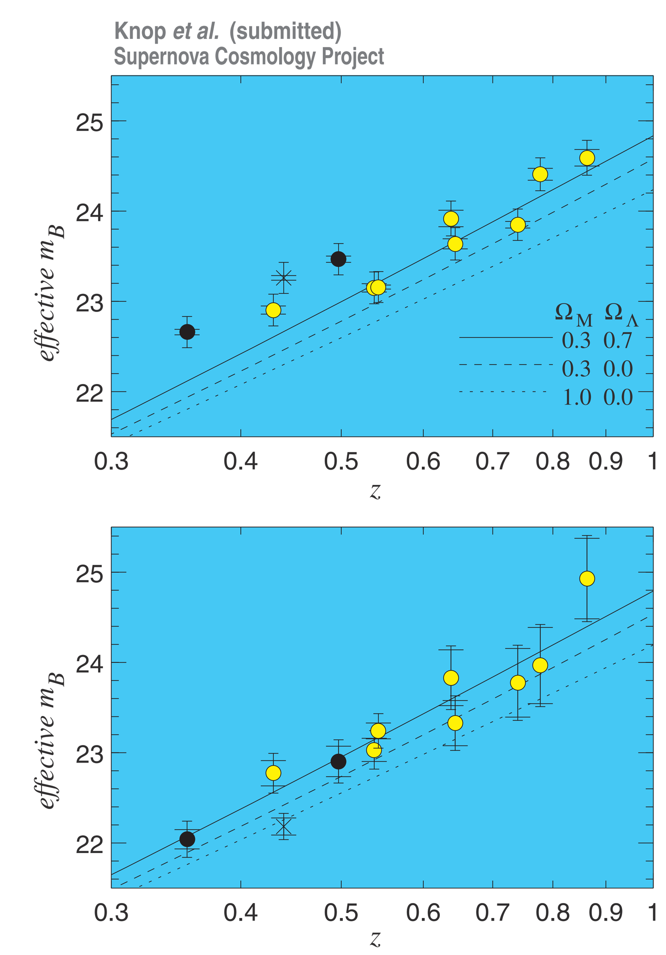


Histograms of E(B-V) for the four samples of supernovae used in this analysis The filled grey histogram represents just the low-extinction subset. The solid lines drawn over the bottom two panels is a simulation of the distribution expected if the low-extinction subset of the Hamuy 1996 sample represented the true distribution of SN colors.



A plot of E(B-V) as a function of redshift for the 11 HST-observed supernovae of this analysis shows that the blue edge of the distribution shows no evolution with redshift. The grey filled circles represent SNe removed from the low-extinction subset.

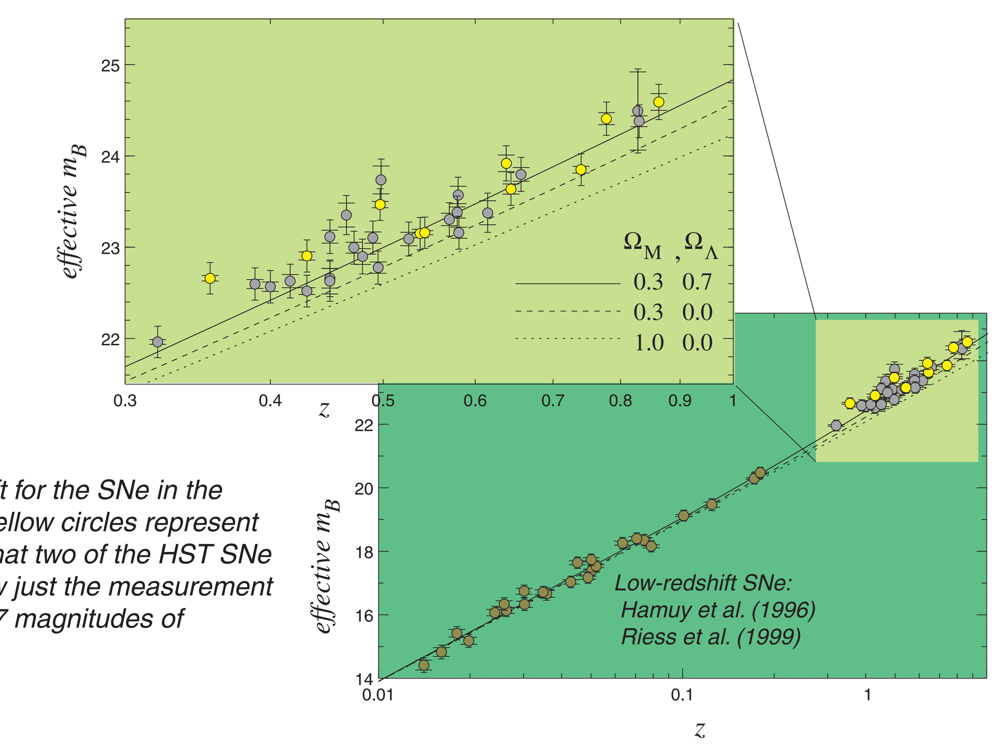
Hubble Diagram



Hubble diagram of effective m_B vs. redshift for the 11 new SNe observed with WFPC2. Reddened SNe are plotted as filled circles and (for a very reddened SN) a cross. These are omitted from the low-extinction primary subset.

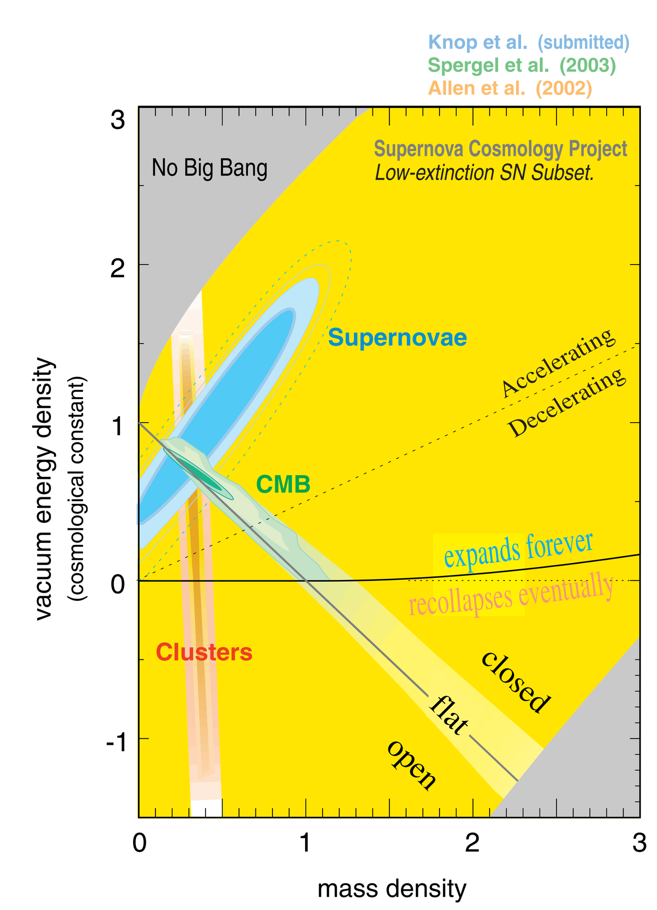
Upper plot: no host-galaxy E(B-V) extinction corrections have been applied. Inner error bars only include the measurement error. Outer error bars include 0.17 magnitudes of intrinsic dispersion.

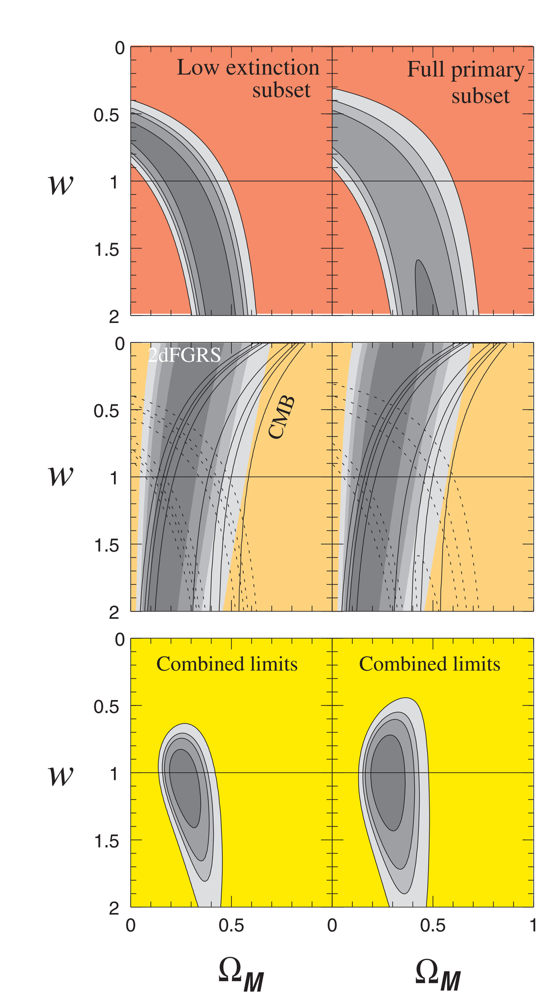
Lower plot: extinction corrections have been applied using the standard interstellar extinction law. Error bars have been increased by the uncertainty in this extinction correction. Here, outer error bars include 0.11 magnitudes of intrinsic dispersion.



Hubble diagram of effective m_B vs. redshift for the SNe in the SCP full primary subset of this analysis. Yellow circles represent the new HST SNe presented here. Note that two of the HST SNe are mildly reddened. Inner error bars show just the measurement uncertainties; outer error bars include 0.17 magnitudes of intrinsic dispersion.

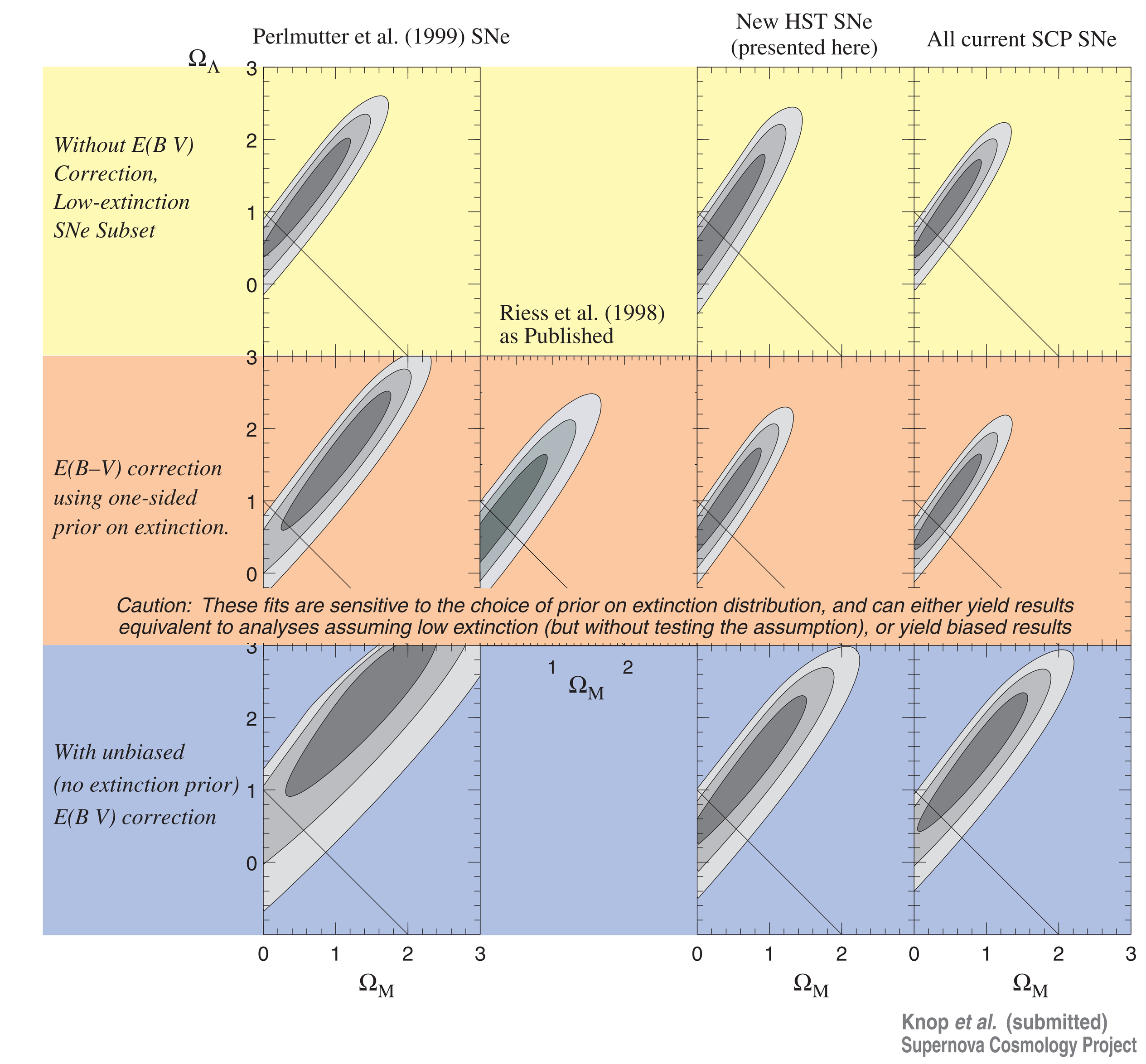
Cosmology Fits



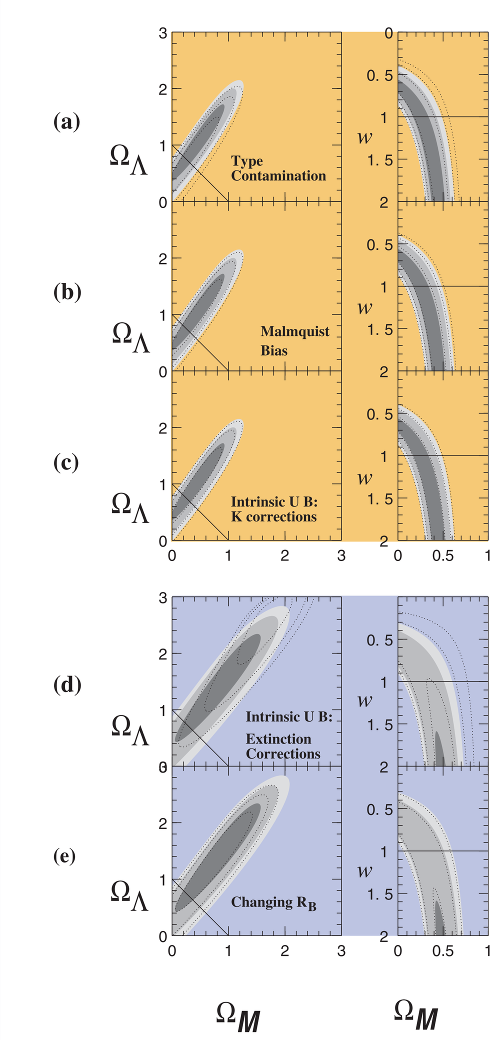


Measurements of Ω_M and w assuming $\Omega_M + \Omega_X = 1$ and that w is not time-varying. Confidence regions plotted are 68%, 90%, 95%, and 99%. The left column shows fits to the low-extinction SN subset; the right column shows fits to the primary subset with unbiased individual host-galaxy extinction corrections applied to each SN. The upper panels show the confidence intervals from the SCP SNe alone.The middle panels overlay this with measurements from 2dFGRS (Hawkins et al. 2002) and combined CMB measurements (Bennett et al. 2003; Spergel et al. 2003). The bottom plot combines the three confidence regions to provide a combined measurement of Ω_M and w.

Comparison of Fits



Systematics



Simulated effects of identified systematic errors on the cosmological parameters, estimated by applying the systematic effect to the supernova parameters used in the cosmological fits. The left column shows fits to Ω_M and Ω_Λ and the right column to Ω_M and the dark energy equation of state parameter w.

Rows (a)-(c) show the fit to the low-extinction subset in filled contours:
(a) The dotted contours show the results of a fit to only those SNe with the very most secure spectral identifications as Type Ia SNe.
(b) The dotted contours show a fit where the supernova magnitudes have been dimmed to correct for simulated Malmquist bias.
(c) The dotted contours show a fit where K-corrections have been applied using a template spectrum with the assumed intrinsic value of U-B shifted by 0.1 mag.

Rows (d) and (e) show, in filled contours, the fit to the full sample with host-galaxy extinction corrections applied :

(d) The dotted contours show a fit to the same Subset, but using a template spectrum with an assumed intrinsic value of U-B shift by 0.1 mag for estimating both K-corrections and color excesses.
(e) The dotted contours apply extinction corrections using a value of $R_B = 3.5$

Conclusions

- A new, independent set of supernovae observed with the HST confirm and strengthen previous supernova evidence for dark energy, yielding $\Omega_\Lambda = 0.75$ +0.06/-0.07.
- The evidence for dark energy is robust to host-galaxy extinction, and dark energy is still requird when unbiased, assumption-free host galaxy extinction corrections are made to the supernovae.
- Systematic uncertainties remain smaller than statistical uncertainties. The supernova systematics are largest along the major axis of the confidence intervals, and thus sytematics are not curerntly a significant limit in the measurement of the dark energy density where the supernovae have the greatest weight.
- Combined with CMB and galaxy redshift distortion measurements, the supernova data begins to provide a measurement of the equation of state parameter for dark energy, $w = -1.05$ +0.15/-0.20, under the assumption that w is constant in time.