Redshift Errors and the Supernova Magnitude Error Budget

A. Kim[1]

ABSTRACT

The two fundamental measurements needed by SNAP to build a Hubble diagram are of the supernova redshifts and corrected peak magnitudes. In this paper we explore the effects of redshift error, not only through the luminosity distance but also through propagated stretch, K-correction, and extinction errors.

1. Introduction

The measurement of the cosmological parameters using standard candles requires both the magnitude and redshift of the object in question. In supernova studies the redshift measurement is typically taken from the spectrum of the host galaxy, either from sharp emission lines or from the 4000 Å break. For high-redshift objects, redshift measurement errors dwarf the magnitude errors. As we enter an era of high-precision supernova cosmology we need to explore the effects of redshift measurement error on the determination of cosmological parameters.

2. Observed Supernova Brightness Model

The expected observed magnitude of a Type Ia supernova is given as:

$$m_X = M_B + \mu + K_{BX} - \alpha(s-1) + R_B E(B-V). \tag{1}$$

The filter X used for the observation is taken to be the redshifted B filter for each redshift considered in the following analysis. The absolute magnitude M_B is for an $s=1$ supernova. The distance modulus μ is a function of redshift and the cosmological parameters. The K-correction is K_{BX}. We take the empirically derived $\alpha = 1.9$ stretch–magnitude relation found by the SCP's study of forty two high-redshift supernovae. The extinction is assumed to be in the host galaxy with a standard $R_B = 4.1$ dust model.

An error in the redshift measurement enters the expected observed magnitude error via each of these terms (except the first). A positive dz incorrectly gives a smaller universe when the supernova exploded and a larger distance modulus. The supernova spectrum is incorrectly shifted redder than it should be and thus affects the K-correction. The stretch s of a supernova is obtained from the observed width w of a supernova using the formula $s = w/(1+z)$, the error in s is then $ds = -s\,dz/(1+z)$. The supernova will have an underestimated s and thought to be intrinsically overly faint. Supernova colors at differing redshifts are different; color measurements with a fixed pair of filters near the restframe B and V are bluer for slightly higher redshift supernovae. There will thus be an observed color excess making the expected brightness of the supernova fainter.

Figure 1 shows dm/dz for each of the above terms as well as their sum. A cosmology of $\Omega_M = 0.28$ and $\Omega_\Lambda = 0.72$ is assumed. Stretch and K-correction errors are found to contribute negligibly. The distance modulus term is dominant at the very lowest redshifts whereas extinction errors dominate for almost all of the redshift range considered. Except for the K-correction, a positive redshift error produces a positive magnitude shift for all effects, compounding the total error.

Redshift error measurements are expected to be random Gaussian from supernova to supernova. The SNAP experiment's target corrected observed magnitude uncertainty is to be ~ 0.1 magnitudes

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[1] Lawrence Berkeley National Laboratory

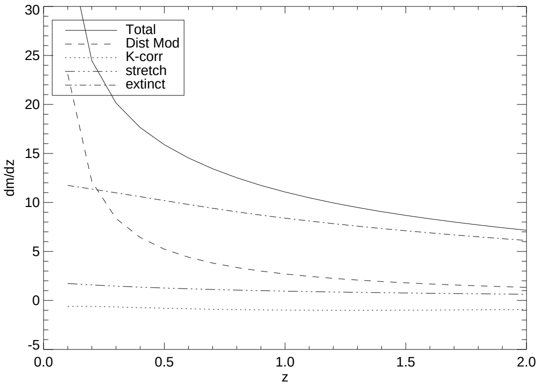

Fig. 1.— Given an error in redshift, the expected observed magnitude changes due to the error in the distance modulus, K-correction, stretch correction, and extinction correction. Plotted is dm/dz for these different terms as a function of redshift.

for an individual object. The redshift measurement requirement to ensure a redshift uncertainty contribution that is of this order is plotted in Figure 2. The requirement is looser for increasing redshifts.

3. Conclusion

We find that fairly precise redshift measurements, $dz \sim 0.005 - 0.01$, are necessary to maintain measurement errors comparable to the intrinsic corrected supernova magnitude dispersion. SNAP would like to do an order of magnitude better so that redshift errors contribute negligibly to the error budget. Obtaining redshifts of this precision is standard for current high-redshift supernova searches. We need to determine whether a very low dispersion spectrograph $R \sim 75$ can obtain these kinds of measurements. Low-redshift supernovae have more stringent redshift measurement requirements, but fortunately spectra are easier to obtain at these lower redshifts. Photometric redshifts will have to be shown to work beyond the 1% level if they are to be applied to supernovae at redshifts below one.

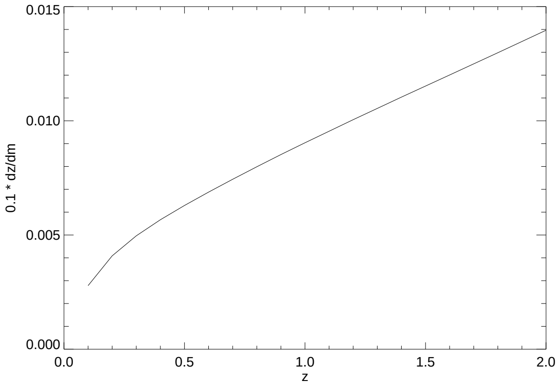

Fig. 2.— The necessary accuracy of the redshift measurement for an effective 0.1 magnitude error for each supernova is plotted as a function of redshift. Larger redshifts can accommodate larger redshift measurement uncertainty.