

# Measuring Cosmological Parameters with High-Z Supernovae

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Scientific category: SUPERNOVAE  
Instruments: NIR/CAM, NIR/SPEC, NIR/MSPEC  
Days of observation: 0

## Abstract

Type Ia supernovae are the best extragalactic standard candles. NGST exposures that are obtained as part of the deep imaging surveys (with AB-magnitude limits below 28) for galaxies and for gravitational lenses will include distant supernovae ( $z > 1$ ) in J, K, and M-band frames with no extra observing. Typical exposures could easily contain 5-36 SN Ia in a single frame, and judicious timing of the exposures could lead to adequate knowledge of the supernova light curves to reconstruct the flux at maximum light. With this information, plus a redshift obtained for the host galaxy at a later time, the Hubble diagram for SN Ia could be constructed at high redshift. At lower redshift ( $0.5 < z < 0.97$ ), this approach has already shown that cosmologies with a significant contribution from the cosmological constant ( $\Omega_\Lambda > 0$ ) are favored by the observations (Riess et al. astro-ph/9805201; Perlmutter et al 1998). This surprising result needs to be extended to higher redshift, where the detailed predictions of  $\Lambda$  cosmologies can be compared with the data. High redshift observations will help separate the effect of cosmology from the effects of stellar age, composition, and interstellar or intergalactic dust. They will also provide leverage on the problem of finding  $\Omega_\Lambda$  and  $\Omega_m$  separately. Those results could be compared with the results of precision Cosmic Microwave Background measurements to provide powerful and redundant determinations of the cosmological parameters.

ASWG DRM Proposal  
Measuring Cosmological Parameters with High-Z Supernovae

**Observing Summary:**

Target	RA	Dec	K <sub>AB</sub>	Configuration/mode	Days
					0
					0
				Grand total days	0

**NOTE:** The search for SNe is a by-product of the deep galaxy and gravitational lens surveys that are also part of the DRM.

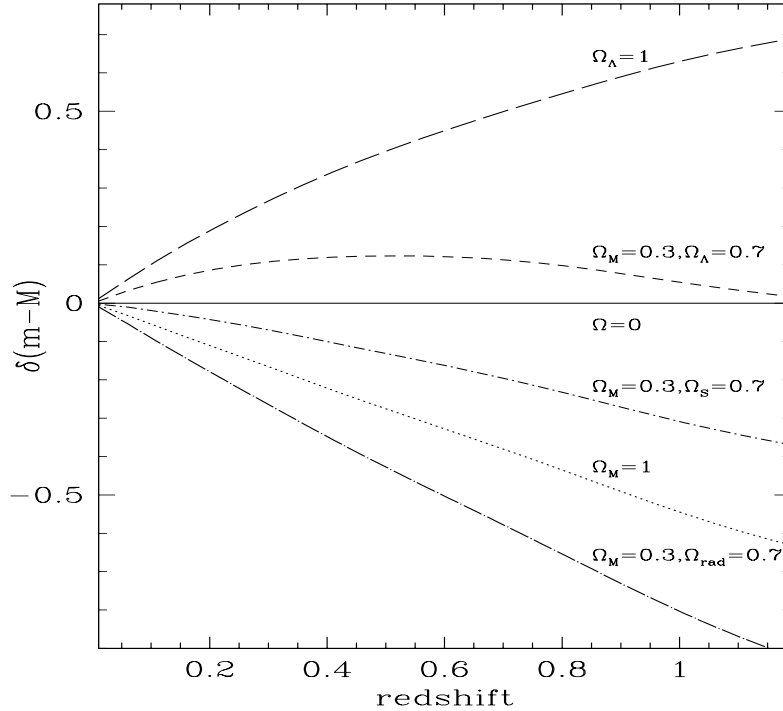


Figure 1: *The differences in the luminosity distance–redshift relation for various cosmological models expressed as the difference in distance modulus from an empty Universe,  $\Omega = 0$  (from Schmidt et al 1998).*

## ■ Scientific Objectives

The goal of this investigation is to determine the global geometry of the Universe and to measure the energy density in matter of all forms ( $\Omega_m$ ) and the contribution of vacuum energy, characterized by the contribution of a cosmological constant ( $\Omega_\Lambda$ ). The idea is to use the luminosity of Type Ia supernovae, which are thought to be exploding white dwarfs, as standard candles to measure the relation between redshift and distance. There is evidence that SN Ia have a modest range of luminosities, and a growing body of work shows how to reduce the scatter by using information about the supernova’s light curve shape (Phillips 1993; Hamuy et al 1996; Riess, Press, & Kirshner 1996). When these corrections are applied, they reduce the distance uncertainty for a single SN Ia to about 8%, which makes them the best extragalactic distance indicators. The objective of this program is to gather enough light-curves for SN Ia to measure the relation between redshift and luminosity distance over the range from  $z = 1$  to  $z = 1.5$ , where the near-infrared surveys for galaxies and for gravitational lenses carried out with NGST will also be peppered with newly erupting supernovae. A reasonable goal would be to gather 50 such objects, which would provide an adequate sample for investigating its systematic properties. A complementary DRM program

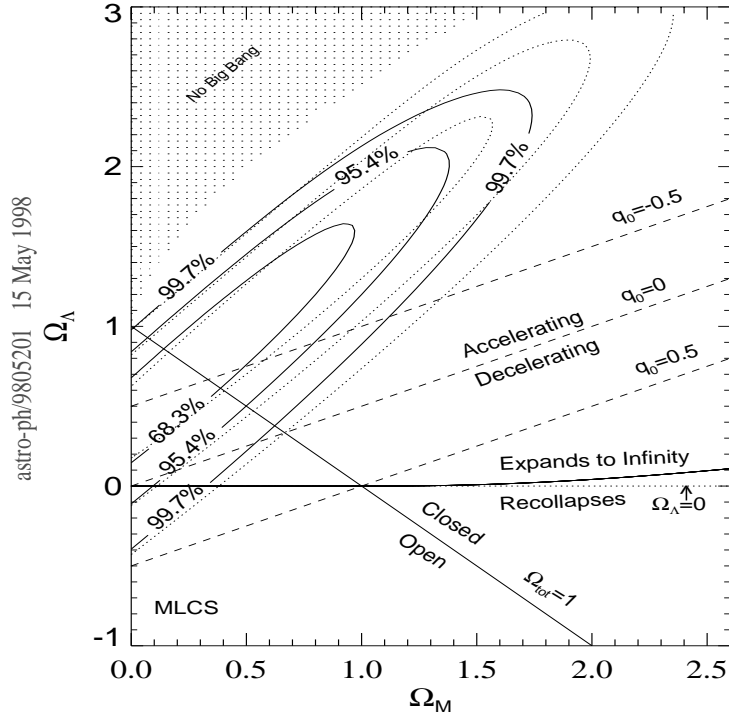


Figure 2: *Joint confidence intervals for  $(\Omega_m, \Omega_\Lambda)$  from SN Ia (from Riess et al 1998). Regions representing specific cosmological scenarios are illustrated.*

emphasizes Type II and Type Ia SNe as probes of the instantaneous and past stellar birth rate in the Universe, respectively.

## ■ NGST Uniqueness/Relationship to Other Facilities

Work from the ground with large-format CCD's can find supernovae to redshift 1.0, as has already been demonstrated (Garnavich et al 1998, astro-ph/9710123). This is exactly where the cosmological effects begin to become large. Unfortunately, very little energy from SN Ia is emitted in the rest-frame ultraviolet, so the problem of discovering, and subsequently making good flux measurements for these objects shifts squarely into the near infrared. Since our understanding of low redshift supernovae, and the use of light curve shapes to decrease the scatter for SN Ia, rests on observations in rest-frame B and V, it is essential to make observations at J-band and beyond to interpret the measurements of high- $z$  objects. While ground-based discovery, followed by HST (if NICMOS is restored) or 8-m IR photometry of single objects will lead to some progress in the redshift range from  $z = 1.0$  to 1.2 before NGST is launched, there is not much prospect of finding supernovae with  $z > 1.2$  in the IR without the large field and low background that the NIR camera on NGST will bring. Measurements of the luminosity distance-redshift relation provide a complementary

set of cosmological constraints to the inferences that can be drawn from measurements of the Cosmic Microwave Background by MAP (Eisenstein, Hu, & Tegmark 1998, astro-ph/9807130). So it will be particularly helpful to have data from both supernovae and from measurements of the CMB to pin down the separate contributions of the  $\Omega_m$  and of  $\Omega_\Lambda$ , and to see if they are consistent with the Euclidean geometry ( $\Omega_{\text{total}} = 1$ ) favored by inflationary models. Preliminary attempts to do this (Garnavich et al 1998b, astro-ph/9806396) are very encouraging, but far from conclusive.

Observations of supernovae at high redshift are also important because we do not really know the whole story about how stellar evolution, chemical evolution, or the history of cosmic dust can affect the inferences drawn from observations of SN Ia (Hoefflich, Wheeler, & Thielemann 1998). These systematic effects would be expected to grow in importance as we look back to earlier epochs. Surprisingly, for the presently favored values of  $\Omega_\Lambda = 0.7$  and  $\Omega_m = 0.3$ , the cosmological effect on apparent magnitude as a function of redshift will grow larger only up to about  $z = 0.5$  and then decrease. So a definite signature that we are observing cosmology and not systematic error will be a maximum in the deviation from the Hubble line at a redshift that should be well within the observed range opened up by NGST. This would be the most convincing demonstration that we are truly observing the effects of global geometry and deceleration, not of a drift in the properties of a stellar population.

## ■ Observing Strategy

The search for high- $z$  supernovae can be part of the observational program for deep surveys of galaxies and for measurement of the gravitational lensing properties of matter that are also part of the DRM. As long as the individual observing at each epoch reaches a limiting magnitude of  $AB = 28$ , we expect to see many SN Ia in the redshift interval of interest in each of the J, K, and M bands. The computations of Dahlen and Fransson (1998) show that, for reasonable assumptions, a K' filter could show between 5 and 36 simultaneously observed SN Ia in a single exposure. The only additional constraint to maximize the utility of these observations for the discovery of SN Ia is that not all the observations for a field be obtained at the same time. By spacing out the visits, the new supernovae will be revealed as new point sources in the images. Roughly speaking, the optimum spacing of observations in the rest frame is the time for a SN Ia to rise from obscurity to maximum light—about 3 weeks. Since time dilation stretches this by a factor of  $(1 + z)$  (see Leibundgut et al 1996), observations which are spaced by 6–8 weeks would provide the best chance of detecting new events when they are near maximum light. At least 3 visits to each survey field would make the evidence for each event much cleaner and would provide a little information on the ascent and decline rates which could be used to improve the measurement of the light curve peak. Supernovae discovered in this way would then provide a list of targets for spectroscopic studies. These would include measuring the redshift for the host galaxies of supernovae that had been observed in previous visits. A single low-dispersion ( $R = 300$ ) spectrum would be adequate. The most profitable way to use these spectroscopic visits would be to use a multi-object spectrometer to gather simultaneous information on other galaxies in the field

which would be the targets of interest for the follow-up of the galaxy survey.

In the course of building up the exposures for the deep imaging surveys for galaxies and for dark-matter lensing, a sample of about 50 fresh SN Ia could be constructed. Because of the great leverage of high-redshift events, this would be a powerful data set for deriving the global space curvature and the cosmic deceleration from supernova data alone. In concert with CMB measurements, it would give a robust way to determine the properties of the Universe, including the possible role of a cosmological constant.

Another possible way to proceed, which bears further investigation, would be to use imaging measurements of a deep field which had been constructed with a Michelson interferometer. Then, for appropriate spacing in the interferograms, you could derive the spectrum for every object in the field, including Type Ia supernovae. Since we have developed a reasonably effective way to estimate the age of a SN Ia from its spectrum (Riess et al 1998, astro-ph/9804065), this measurement would be enough to classify the supernova and to infer its age. With the age in hand, we could make a good extrapolation back to maximum light. Since we would already have the redshift from the supernova spectrum, this data cube would have in it all the information for constructing the Hubble diagram from SN Ia. If there were as few as 5 fresh SN Ia in each field, a statistical sample could be built up in 10 fields, with exposures of about 1 day each, and an effective resolution in the near-IR of 300. No repeat images would be needed, since the young SN Ia would be recognizable from their spectra, and no subsequent spectra would be required since we could get the redshift from the supernova spectrum.

## ■ Special Requirements

If the observations are carried out with a conventional camera, then we need to ensure that we get information on the ages of the supernovae from the exposures themselves by spacing them appropriately. A deep galaxy field could be constructed by making 3 visits with an interval of 6–8 weeks in between. This would have enough information to infer the age of the supernova. A subsequent visit for spectroscopy would be included in the plan of the galaxy survey anyway, so it would be no extra effort, with a multi-object spectrometer, to include the supernova parent galaxies in that measurement. If there is a Michelson interferometer on NGST, this could ideal for the problem of finding supernovae, determining their ages, magnitudes and redshifts all in a single blow.

Maximum FWHM:	100 mas at 2 $\mu\text{m}$
Minimum Spectral Resolution:	300 at 2 $\mu\text{m}$
Minimum FOV:	4' at 2 $\mu\text{m}$
Maximum time until replanned science followup:	50 days

## ■ Precursor/Supporting Observations