ESO Participation in the Nearby Supernova Factory

1 Overview

The Nearby Supernova Factory (SNfactory) is a project to discover and obtain detailed lightcurve and spectral observations for over 300 nearby supernovae during the period 2002—2006. This project has been initiated by scientist at Lawrence Berkeley National Lab (LBNL) in the United States; IN2P3, Observatories Lyon, and INPL in France; Stockholm University in Sweden; and Centro Multidisciplinar de Astrofisica at the Instituto Superior Tecnico in Portugal. The SNfactory will concentrate on Type Ia supernovae (SNe Ia), the type which have recently been used to determine that the expansion of the universe is accelerating. Type II supernovae (SNe II) will also be developed as more reliable distance indicators. Several aspects of the SNfactory set it apart from other supernova projects. Foremost among these is that supernovae will be discovered using a blind wide-area CCD-based survey; other nearby supernova projects target known galaxies but there is now evidence that this approach misses an important subset of supernovae. In addition, the SNfactory will coordinate discovery and follow-up observations, eliminating the delays and spotty early lightcurve coverage which typically results from follow-up of supernovae listed in the IAU Circulars. It is expected that with the SNfactory detailed follow-up of supernova candidates can begin within as little as 12 hrs of the discovery observations. Finally, SNfactory follow-up observations will use an integral field unit spectrograph, data from which can be used to construct both detailed flux-calibrated spectra and broadband images. The regular photometric spectral time series for nearby supernovae the SNfactory will generate will revolutionize the study of supernovae. This dataset will also eliminate several limitations (bandpass mismatch, wavelength-dependent slit losses, etc.) of all other currently available instrumentation used to study supernovae.

2 Goals

The primary goal of the SNfactory is to determine those properties of SNe Ia affecting their use for cosmology. The most critical of these will be the search for deviations or extra parameters not accounted for by the lightcurve width — brightness relations currently used to standardize SNe Ia for use as cosmological distance indicators. If such deviations are found, it is expected that exclusion criteria or improved standardization methods based on lightcurve shapes and/or spectral features will be found to ameliorate the effect of deviant SNe Ia on measurements of the cosmological parameters. Well-observed nearby SNe Ia, especially in host galaxies spanning a wide range in metallicity and star-formation histories, are essential for testing for possible deviations. It is possible that the discovery of new luminosity-related parameters will actually allow the standardization of SNe Ia to be further improved, making them even better tools for cosmology.

A number of sample-size and technical issues related to the use of SNe Ia as distance indicators for cosmology will also be addressed by the SNfactory. These include:

- securing the low-z portion of the SNe Ia Hubble diagram (Fig 1) — which serves as the zero-point for high-z cosmological measurements — using this large, less biased, sample of nearby SNe Ia.
- obtain $UBVRI$ lightcurves beginning well before maximum — data currently available for only a handful of nearby SNe Ia, and needed to fit the lightcurves of high-z SNe Ia for which there is now have extensive data prior to maximum (see Fig 2).
- test and refine the lightcurve width vs. brightness relation used to standardize SNe Ia luminosities, (to ~ 0.1 mag after extinction correction), for which a wide range of lightcurve widths is essential.
- construct a U-band template lightcurve and a U-band lightcurve width vs. brightness relation to allow U and U-B lightcurves to be used to correct $z > 0.75$ SNe Ia observed with, e.g., HST.
- obtain spectral coverage with lightcurve phase, and thereby determine accurate K-corrections as a function of lightcurve width and time (see Fig 2).
- determine intrinsic (unreddened) SNe Ia color-curves needed to establish the correct color zeropoints for host-galaxy extinction corrections.
- test for the existence of abnormal host-galaxy extinction laws.

The uniquely large sample of nearby SNe Ia expected from the SNfactory will allow these standardized candles to be studied at a level of detail heretofore impossible. Indeed, there are enough plausible luminosity-related parameters that a large sample intentionally covering a wide range of such parameters (or their surrogates) is essential (and can only be carried out with the large discovery overcapacity possible with the SNfactory). This level of scrutiny is demanded by the remarkable evidence for an accelerating universe and by plans to refine and expand such measurements using much larger (thousands) samples of high-redshift SNe Ia.

The resulting SNfactory dataset on SNe Ia will also allow detailed exploration of SNe Ia properties never before possible, which will almost certainly lead to a better understanding of SN physics and place strong constraints on progenitor models. It will enable us to determine:

- the intrinsic luminosity function of SNe Ia
- new relations between lightcurve shapes, spectral diagnostics (such as UV continuum slope, Si5180/Si6150 line ratios), etc., and luminosity.
- SNe properties in different host galaxy environments (as a surrogate for progenitor age, mass, and metallicity).
- the rates of SNe of all types (presently uncertain by at least 2x for nearby galaxies), including rates as a function of host galaxy properties.

3 Components of the Nearby SNfactory

3.1 Discovery

The SNfactory will search for supernovae using CCD images obtained by JPL's Near Earth Asteroid Team (NEAT). A proof-of-concept search conducted using two nights of NEAT data found 4 confirmed supernovae. NEAT has since expanded it's operation to include a 1.2-m telescope (at the 10,000 ft summit of Haleakala, Hawaii) working 18 nights per month. NEAT has agreed to examine supernova search fields three times during each month, giving the SNfactory the potential to find many supernova shortly after explosion. (Risetime — the time from explosion to peak brightness — is considered one possible parameter that could affect peak luminosity). In addition, since this search covers large portions of the sky irrespective of known galaxies, it will be rid of the biases to which pointed searches are subject due to their reliance on existing galaxy catalogs. NEAT will soon quadruple it's capacity, with a second 1.2-m telescope operating at Mt. Palomar with a large CCD camera, so we expect to discovery several supernovae per night.

As with the proof-of-concept search, NEAT data will be transferred in near realtime via high-speed Internet connection to Lawrence Berkeley Nation Lab (LBNL, where 1 Tb of NEAT data is already archived). Once there, the images will be processed and searched using automated software developed by the Supernova Cosmology Project (SCP) and further refined by the SNfactory. Candidate supernovae will be screened interactively and assigned a preliminary follow-up priority. An important aspect of the SNfactory is that the selection of supernova candidates will be quantitative and traceable, something current surveys completely lack and which makes calculations of supernova rates and peculiarity fractions extremely difficult.

3.2 Follow-up — Lightcurves and Spectroscopy

The most revolutionary aspect of the SNfactory — aside from the huge numbers of supernovae it will find — is the coordinated follow-up using instrumention tailored to the study of supernovae. Candidate supernovae found in the NEAT images must first be screened with spectroscopy to confirm the supernovae and reveal its type (Ia, II, Ib, Ic) and redshift. The SNfactory will not only discover supernovae closer to explosion that other surveys do, with a 12 hr turn-around it will also begin the follow-up much much sooner. Typically candidate supernovae are confirmed with imaging on subsequent nights, then reported to the IAU Circulars, and then observed spectroscopically with regular – but infrequently — scheduled time or director's discretionary time (requiring a proposal for each supernova and the availability of the right instrumentation). This process can easily stretch on for a week or more after discovery. The SNfactory plans to have at least two telescopes with optimal instrumentation available every night, waiting to be fed by the stream of supernova candidates coming from the two NEAT sites. Indeed, realizing this capability is the main reason the SNfactory is seeking significant regular access to an ESO telescope.

Traditionally supernovae have been followed with $BVRI$ photometry, and spectra beyond the initial confirmation spectrum are rare. The SNfactory will change all that. Using a integral field unit on a two-channel (blue & red) optical spectrograph, the SNfactory's **S**uper**N**ova **I**ntegral **F**ield **S**spectrograph (**SNIFS**; under construction at Observatorie Lyon) equipped with LBNL's red-enhanced CCD's, will allow spectroscopy of supernovae at all epochs. Because these spectra will be spectrophotometric, $UBVRIZ$ photometry can be synthesized from these spectra, without the uncertainties due to photometric color terms and K-corrections (the latter usually based on non-spectrophotometric spectra). **SNIFS** will retain one advantage of the traditional approach, which allows surrounding field stars to be used for flux scaling when conditions are non-photometric, by also having an imager which integrates on the field immediately surrounding each supernova and having the exact same exposure as the integral field unit.

4 More about SNIFS

The opto-mechanical layout of **SNIFS** is shown in Fig. X. The operation of **SNIFS** is intended to be fully automated. An observer/technician is needed to prepare the telescope for observing, point the telescope to targets designated by the SNfactory, close the telescope, and possibly ensure that the **SNIFS** dewars are supplied with LN2. **SNIFS** is intended to be capable of focusing the telescope, recognizing star fields near requested targets using it's own imager, adjusting the telescope pointing to place the desired target on the integral field unit, and acquire and guide on a suitable star. It will then execute an observing sequence for the spectrograph and imager, read out the date, determine the quality of the data, and take it's own calibration (afternoon dome flats may also be required on occasion). Moving parts on **SNIFS** are limited to a shutter, filter wheel, and pick-off mirror (feeding the spectrograph). The electronic components consist of detector readout (for 4 CCD's), a shutter, filter wheel, calibration lamps, and status-monitoring. Software interface to the telescope control system to execute pointing and focus adjustments, and to obtain information for the data headers and control software will be necessary. An additional software interface to the Internet is required to transfer the imager and spectrograph data (at most 64 Mbytes every 10 minutes, and that only during the fraction of time **SNIFS** is operating) to Europe and the United States so that the observing program can be revised as needed based on the new observations.

The **SNIFS** spectrograph continuously covers a $6'' \times\ 6''$field of view with a sampling of $0.4''$. It has blue and red channels, which are operated simultaneously, generating spectra on 2k×4k LBNL red-enhanced CCD's at resolutions of 4.5Å and 6.6Å, respectively. The imager consists of a 2k×4k LBNL red-enhanced CCD with 15μmpixels, which views the sky surrounding the spectrograph pick-off mirror. The built-in guider/focuser consists of a second identical CCD. (If designed for a telescope which provided guiding, the guider channel on **SNIFS2** could be modified to serve as an imager.) The imager and guider are used directly, without re-imaging optics.

5 A Role for ESO:

The SNfactory currently has plans to place the first **SNIFS** on the University of Hawaii 2.2-m telescope on Mauna Kea. It will be permanently mounted, and continuously available for use of up to 20% of the night. **SNIFS** is under construction at Observatorie Lyon, and is expected to begin operations on Mauna Kea in early 2002. We are now seeking a significant fraction of time on a second telescope at a comparably good site to be the home of **SNIFS2** (which could be available as early as mid-2002). The ESO 2.2-m could be such a telescope if significant time can be obtained and arrangements can be made to permanently mount a second **SNIFS**. The ESO NTT or 3.6-m are other possible options. The membership of the SNfactory is predominantly European, with more than 10 scientists (and several students) from ESO nations such as France, Sweden, and Portugal. This, it is only fitting that an approach be made to ESO for its assistance in realizing the full potential of the SNfactory. In an age where 8-m telescopes like the VLT dominate, smaller telescopes like the ESO 2.2-m must seek roles for themselves that capitalize on their ability to be dedicated to large and unique projects. We seek suggestions from ESO on how it can contribute to a program — the SNfactory — which will revolutionize the study of supernovae.

Below we have listed some possible arrangements for **SNIFS** at La Silla, in order of preference:

1. **SNIFS** permanently mounted on the ESO 2.2-m and used for the SNfactory at least 20% of the time.
2. **SNIFS** mounted at a Nasymth port on the NTT (possibly as a replacement for SuSI2), and available at least 10% of the time for the SNfactory.
3. **SNIFS** mounted on the ESO 2.2-m for at least 2 nights each week, during which time it would be used mainly for the SNfactory.

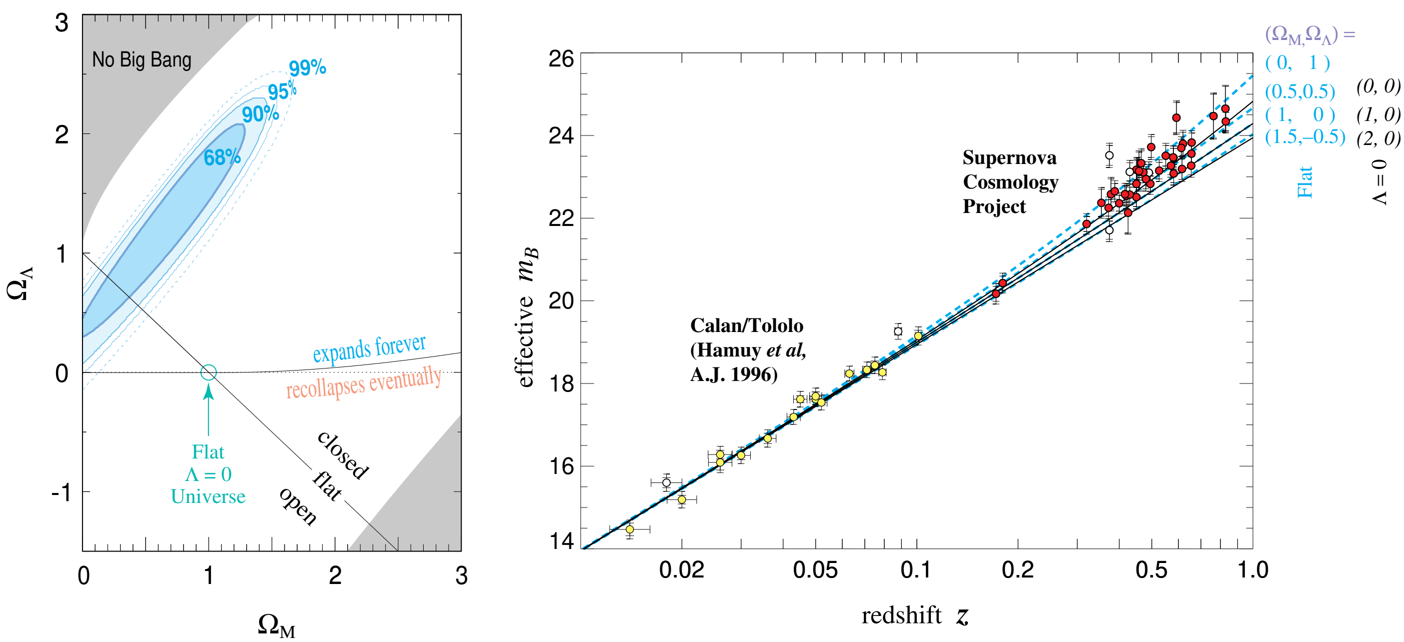

Figure 1: **Cosmological constraints from Type Ia supernovae:** Hubble diagram and resulting constraints on Ω_M and Ω_Λ from 42 high-z Type Ia supernovae from Perlmutter *et al* 1998b. At left, the 68%, 90%, and 99% confidence regions for an unconstrained fit for Ω_M and Ω_Λ are shown. At right, the low-z SNe Ia are those from Hamuy *et al* 1996a which are suitable for analysis using the same methods as used for the high-z SNe Ia.

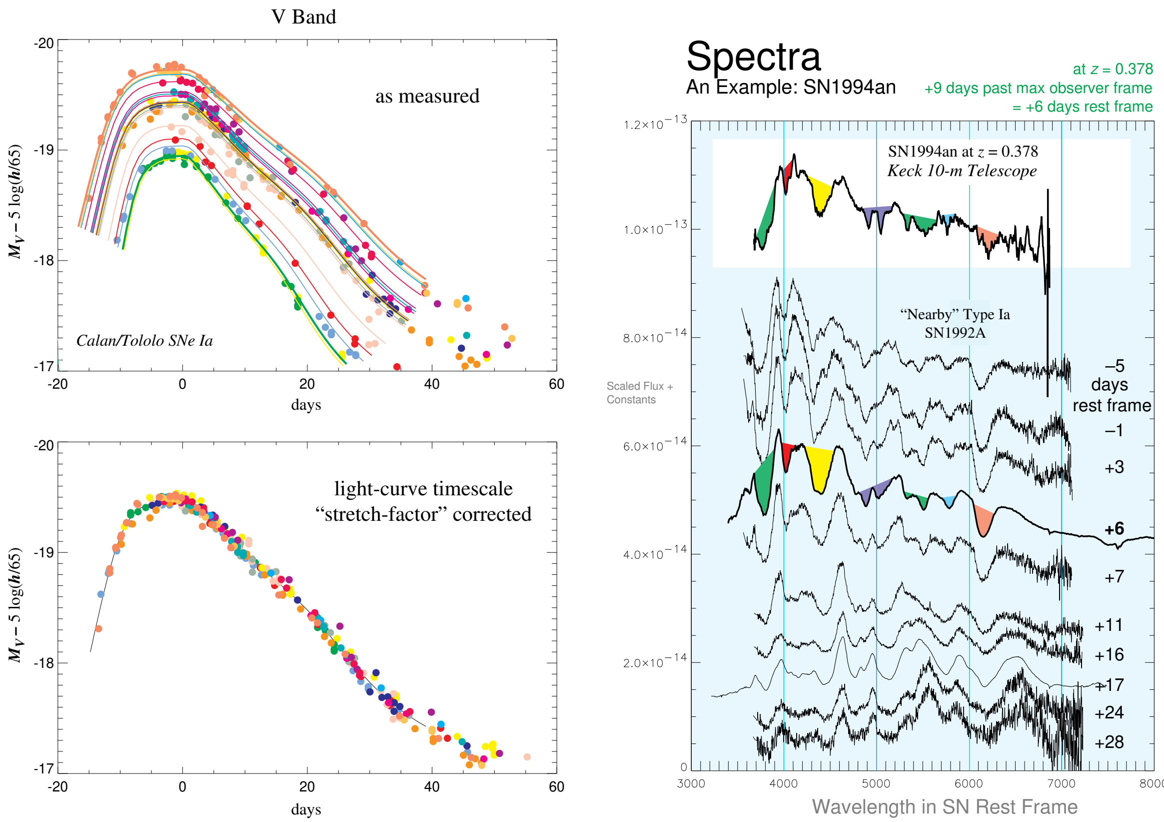

Figure 2: **Photometric and Spectral Time Evolution of Type Ia supernovae:** At left, V-band lightcurves for nearby SNe Ia from Hamuy *et al* 1996b. The upper panel shows lightcurves for individual SNe Ia, with absolute magnitudes derived assuming pure Hubble flow and $H_o = 65$ km/s/Mpc. Template lightcurves from Leibundgut *et al* 1991 have been fit to the lightcurve for each SN. Note that the brighter SNe have lightcurves which are broader and decline more slowly. Also notice that very few of these SNe have data well before maximum light. The lower panel at left shows the superposition of these data after using a linear correction for stretch, S, and scaling the time axis (with maximum at t = 0) by the same stretch-factor. We have found that the lightcurves for a given filter for most SNe Ia can be represented by a single stretched template. We have also found that this stretch factor is linearly proportional to the intrinsic luminosity (in magnitudes). At right is the evolution of the spectrum of a Type Ia supernova as the explosion ages. This was constructed using spectra from different SNe Ia obtained at different epochs. The shaded regions highlight portions of the spectra which are seen to evolve with time. Some of these can also be used as luminosity indicators.

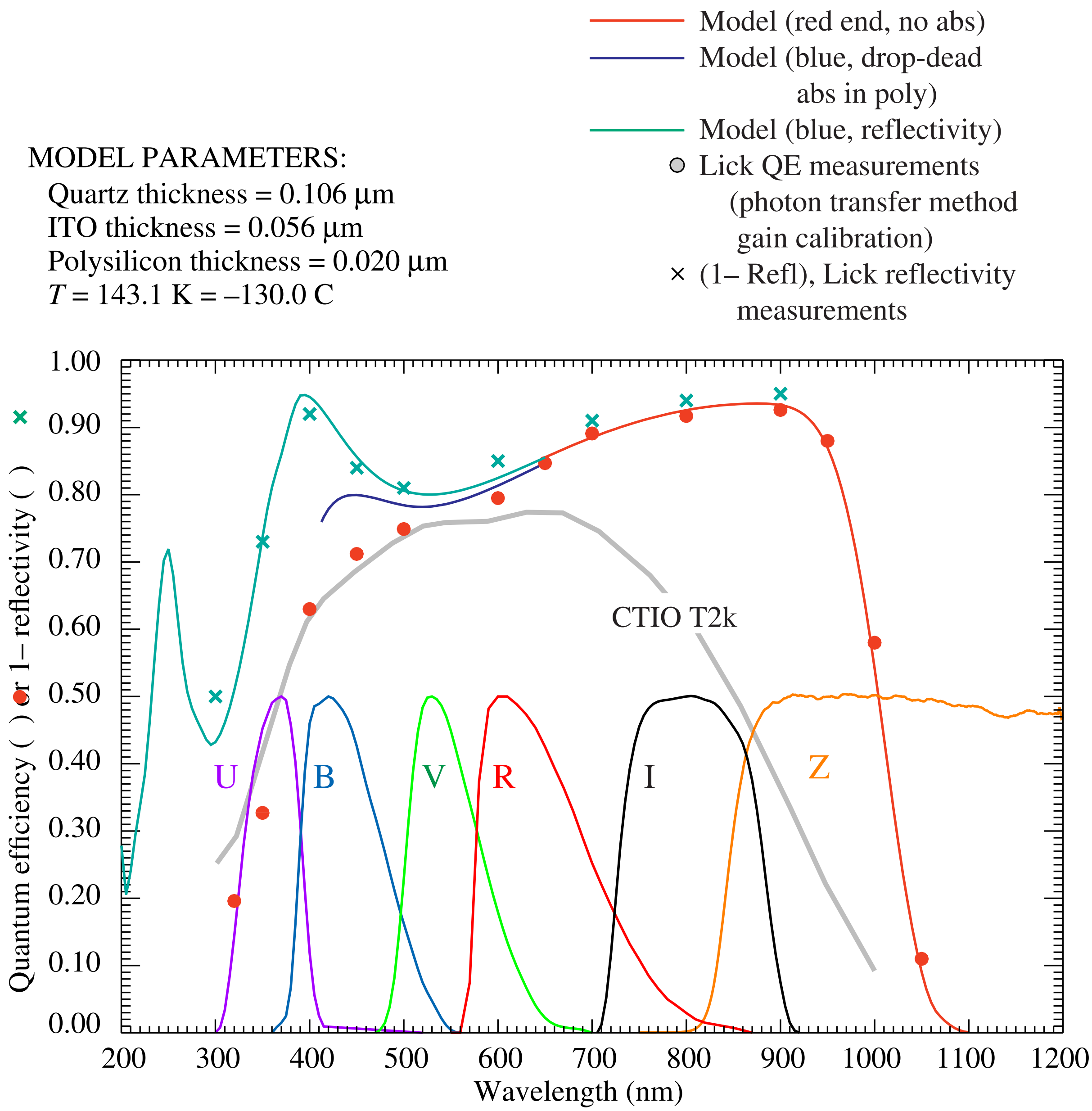

Figure 3: **Measured QE of LBNL red-enhanced CCD:** The black solid circles show the measured QE as a function of wavelength for a LBNL 2k×2k CCD. The red crosses show 1−reflectance as a function of wavelength for the same device. Overlaid on these measurements are model calculations derived from the known physical parameters of the CCD's. Also overlaid as a thick gray line is the QE for a good imaging CCD from Cerro Tololo Interamerican Observatory. The standard $UBVRIZ$ bandpasses are also shown for reference. Note that this CCD has enhanced QE in at longer wavelengths than conventional thinned CCD's due to it's greater thickness (300μm, which is fully deleted). The anti-reflection coating is also optimized for red wavelengths. These devices are free of fringing, which plagues other CCD's at red wavelengths. The difference between 1−reflectance and the QE indicates losses in the polysilicon gettering layer. An anti-reflection coating optimized for blue wavelengths would improve the blue performance slightly. Alternatively, **SNIFS** may use an EEV CCD for the blue channel.