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Authors

Bailey, S
Aldering, G
Antilogus, P
et al.

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Initial Hubble Diagram Results from the Nearby Supernova Factory

S. Bailey, P. Antilogus, R. Pain, R. Pereira, P. Ripoche, and C. Wu
LPNHE, Paris, France
G. Aldering, C. Aragon, S. Bongard, M. Childress, S. Loken, P. Nugent, S. Perlmutter, K. Runge, and R. C. Thomas
LBL, Berkeley, CA
C. Baltay, D. Rabinowitz, and R. Scalzo
Yale University, New Haven, CT
C. Buton, Y. Copin, E. Gangler, G. Smadja, and C. Tao
IPNL, Lyon, France
E. Pecontal and G. Rigaudier
CRAL, Lyon, France

The use of Type Ia supernovae as distance indicators led to the discovery of the accelerating expansion of the universe a decade ago. Now that large second generation surveys have significantly increased the size and quality of the high-redshift sample, the cosmological constraints are limited by the currently available sample of ∼50 cosmologically useful nearby supernovae. The Nearby Supernova Factory addresses this problem by discovering nearby supernovae and observing their spectrophotometric time development. Our data sample includes over 2400 spectra from spectral timeseries of 185 supernovae. This talk presents results from a portion of this sample including a Hubble diagram (relative distance *vs.* redshift) and a description of some analyses using this rich dataset.[1]

1. INTRODUCTION

The method of using supernovae to constrain dark energy hinges upon comparing the brightnesses of distant and nearby supernovae. By using the ratio of luminosities of distant and nearby supernovae, the uncertainties in the Hubble constant H_0 and the absolute magnitude of Type Ia supernovae (SNe Ia) are cancelled, allowing measurements of the dark energy fraction Ω_Λ and the equation of state parameter w. Through the success of multiple observational programs, the high redshift supernova sample is now considerably larger than the nearby sample [1]. In addition to the statistical imbalance of the low- and high-redshift samples, the cosmology fits are now dominated by systematic errors related to the intercalibration of the nearby and distant samples and the lightcurve modeling of supernovae. Fortunately, these issues are addressable through improved measurements of nearby supernovae.

2. THE NEARBY SUPERNOVA FACTORY

The Nearby Supernova Factory (SNfactory) is a program to discover, observe and analyze nearby supernovae to improve both the statistical and systematic limits of cosmological measurements using supernovae. It is comprised of two main components: a large area supernova search followed by spectrophotometric observations of the development of the supernovae.

The search uses the 112 CCD QUEST-II camera [2] on the Palomar Oschin 1.2-m telescope. The observing pattern covers 350 to 850 square degrees per night, repeating fields with a median cadence of 5 days. Coadded stacks of previous observations are subtracted from the new images and remaining objects are identified and ranked as possible supernovae. Selected candidates are screened using the SuperNova Integral Field Spectrometer (SNIFS) [3], mounted

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[1] This is an abridged version of this paper, trimmed to meet the page length requirements of the ICHEP08 proceedings; see arXiv:0810.3499v1 for a more detailed writeup.

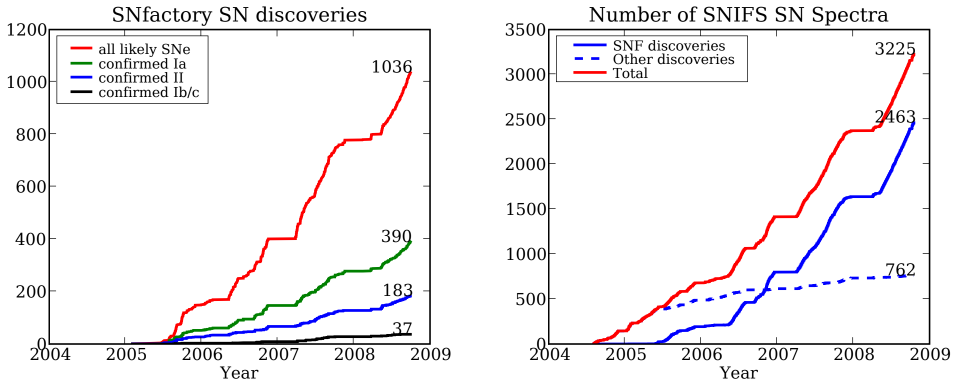

Figure 1: Number of supernovae discovered (left) and supernova spectra obtained (right) by the Nearby Supernova Factory as a function of time. These plots include data obtained after ICHEP 2008. Flat regions reflect the Winter shutdowns each year when we did not search or follow supernovae.

on the University of Hawaii 2.2-m telescope on Mauna Kea. Type Ia supernovae discovered before or at maximum brightness with redshift $0.03 < z < 0.08$ are followed with additional measurements by SNIFS every 2-3 nights until they are 45 days past maximum brightness (near the end of their lightcurve, observations are obtained less frequently). This redshift range limits the uncertainties from peculiar velocities while maximizing the lever arm for cosmology fits with the high redshift sample.

Figure 1 (left) shows the number of supernovae discovered as a function of time. The SNfactory search finished in September 2008 with over 1000 supernovae discovered, including 390 spectrally confirmed Type Ia supernovae, 183 Type II, and 37 Type Ib/c. The remainder have photometric confirmation as likely supernovae but do not have a spectral type confirmation. Figure 1 (right) shows the number of supernova spectra obtained with SNIFS as a function of time. Approximately 3/4 of these spectra are from 185 supernovae for which we have a spectral timeseries.

The Nearby Supernova Factory search is the largest supernova search ever performed in terms of both sky area and data volume. The computational scaling and false-positive object identification issues faced by the SNfactory are relevant to the upcoming transient search pipelines of the Palomar Transient Factory, PanSTARRS, and LSST, who intend to generate transient alerts within minutes of first discovery [4].

The unique screening and followup instrument SNIFS was custom designed by the SNfactory for the purpose of observing nearby supernovae. Members of the Nearby Supernova Factory collaboration remotely operate this telescope every 2 to 3 nights [5]. Within SNIFS, a photometric channel is used for initial target field acquisition, telescope guiding during an exposure, and for monitoring the field stars around a target to calibrate the nightly atmospheric extinction. A prism redirects the light from a 6x6 square arcsecond field around the supernova, followed by a dichroic which splits this light to separate blue ($320 - 520$ nm) and red ($510 - 1000$ nm) spectrograph channels. Within each channel, a 15 x 15 lenslet array focuses the light which is then dispersed into individual spectra. These 225 spectra form a datacube of spectra *vs.* position of the supernova and its surrounding field. These individual spectra are used to deconvolve the contributions from the supernova, its host galaxy, and the night sky background. The lenslets capture all the light from the supernova, enabling absolute flux calibration of the spectra when combined with observations of spectrophotometric standard stars and the surrounding field stars from the photometric channel.

This absolute flux calibration of spectral timeseries is a unique feature of these supernova observations. It allows synthesized photometry in any filter from 350 nm to 950 nm, eliminating the significant systematic which arises from intercalibrating the different filtersets used by current nearby and distant supernova observations. These data also contain far more information than the datasets used to build current SN lightcurve models; it will enable more accurate models, reducing another significant systematic.

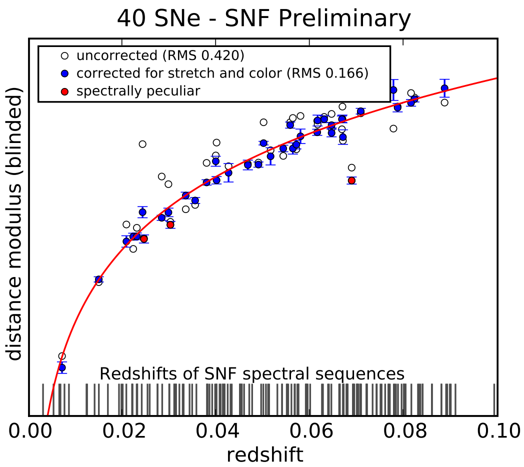

Figure 2: Preliminary SNfactory nearby Hubble diagram with 40 supernovae. Open circles show the uncorrected peak magnitudes; filled circles show peak magnitudes after corrections for color and lightcurve stretch. Spectrally peculiar supernovae are highlighted in red. The redshifts of additional SNfactory spectral timeseries measurements are also marked.

3. SNFACTORY DATA ANALYSES

Figure 2 shows a Hubble diagram with 40 supernovae from the Nearby Supernova Factory. This is $\sim 1/4$ of the total SNfactory dataset of supernovae with spectral timeseries. The remaining supernovae await additional data processing, final reference observations, and/or improved algorithms under development for disentangling host galaxy backgrounds with complex spatial structure. Before unblinding the cosmology we are performing additional systematics cross checks, improving the data extraction and calibration algorithms, and quantifying the full error chain including remaining systematics. Before the absolute flux calibration is finalized, a variety of analyses may be performed using the relative calibration (and thus the relative residuals of the nearby Hubble diagram). A few of these are highlighted below.

Three spectrally unusual SNe in figure 2 are highlighted in red. The largest outlier is SNF20070825-001, a SN whose spectra are a close match to the super-Chandrasekhar mass supernova SNLS-03D3bb [6]. The SNfactory observations of this target are the first spectral timeseries measurements of this class of supernova; we have also discovered and observed another supernova with similar spectra. The two other highlighted SNe have spectra similar to SN1991T, a known subclass of SNe Ia which are brighter than typical. These 3 supernova are well fit by the SALT2 lightcurve model yet their absolute magnitudes are not well corrected by standard stretch[1] and color corrections. We are studying their spectra to better understand SNe Ia intrinsic diversity and discover better ways of calibrating their peak magnitudes.

There are several ratios of spectral features which are known to correlate with supernova lightcurve width [9, 10, 11]. They may enable improved brightness calibration, but their correlation with absolute magnitude has only been studied with small statistics and it has never been established whether they contain information beyond what is contained in lightcurve shape and color. Using the SNfactory dataset, large statistics correlations of these metrics with absolute magnitude can be directly measured. Most importantly, this dataset enables for the first time a direct correlation of spectral indicators with Hubble diagram residuals, *i.e.*, testing correlations for information beyond stretch and color. A preliminary analysis was done as a Master's thesis [12]; this work is now being expanded with larger statistics and

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[1] In [7], "stretch" has a specific technical meaning relating to the Philips relationship [8] that broader lightcurves tend to have brighter peak magnitudes. Other SN fitters have different parameters which describe the same effect (ΔM_{15} for MLCS2k2; x_1 for SALT2). Here, "stretch" refers generically to this correction, not a specific definition or fitter.

improved Hubble diagram residual measurement errors.

Classic spectral metrics focus on specific spectral features and were usually discovered by their correlation with stretch (or equivalent) rather than what would be most cosmologically useful — a correlation which contains information beyond that of stretch and color. The SNfactory is performing a generalized correlation analysis of our supernova spectra, focusing on features which correlate with absolute magnitude in ways which stretch and color do not. The results of this study will be reported at an upcoming conference.

Previous SNfactory publications have contributed to the understanding of SNe Ia progenitor environments and the physics of their explosions [13, 14]. Ongoing studies include observations of the SNfactory discovered SN SNF20080720-001 [15], the most reddened normal SN Ia ever observed. An analysis of this supernova is being performed using a spectroscopic "twin" with less reddening to disentangle the contributions from dust *vs.* intrinsic SN properties. We have also undertaken a program to obtain measurements of host galaxy properties to study the connection between SN Ia properties and their stellar environments.

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