Photometry and Light Curves for the SDSS–II Supernova Survey

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The SDSS–II Survey

In its second phase of operations, the Sloan Digital Sky Survey (SDSS) 2.5m telescope has been used to attack several different scientific goals. One of these is a supernova survey that will run for three years (2005-2007) and will target supernovae in the redshift range $0.05 < z < 0.35$. The scientific motivation for doing so is to:

- take advantage of the large area that can be covered by the large format cameras and drift scanning of SDSS to fill in a redshift regime where other surveys have not been efficient in finding supernovae
- take advantage of the well-understood photometric system of SDSS to minimize calibration errors and other systematics.

Operationally, two strips (denoted strips 82N and 82S) located along the celestial equator are monitored over a period of three months from September through November. These two strips lie along a region for which many previous SDSS scans were obtained as part of the original SDSS survey. The survey alternates between these two strips on successive clear nights. Potential supernovae are identified by subtracting a deeper coadded frames from previous images and inspecting the subtracted frames to find new objects. Candidate supernovae are followed up spectrocsopically using a range of different telescopes to confirm their status as supernovae and to determine the supernova type. Details of the object selection and spectroscopic followup procedure are given in companion posters and in talks during the AAS special sesssion on the SDSS Supernova survey.

While the vast majority of the supernova imaging for the SDSS-II SN survey is done with the SDSS 2.5m telescope, some additional imaging followup has been performed with other telescopes, including the MDM 2.4m, UH 88inch, ARC 3.5m, NMSU 1.0m, WIYN 3.5m, Maidanak 1.5m, and FLWO 1.2m. The main purpose of these additional observations is to complete light curves of supernovae identified towards the ends of the SDSS-II SN seasons and to fill in the SDSS 2.5m light curves if there are periods of bad weather at the SDSS telescope.

This poster discusses the techniques used to extract the supernovae light curves and present light curves obtained from the fall 2005 season.

Photometry Techniques

We have developed a technique to do the final supernova photometry that we call *scene modelling photometry*. The basic idea is similar to that used by the Supernova Legacy Survey (SNLS, Astier et al. 2006), where we model the host galaxy background as a grid of squares with indendependent surface brightnesses. We simultaneously solve for the supernova position and brightnesses and background surface brightnesses on the entire stack of images of the field; the pre-supernovae images constrain the background brightnesses. This technique has two primary advantages:

- No pixel resampling is ever performed. Because of this, errors on each pixel are uncorrelated and well characterized. This leads to robust error estimates.
- Observations from multiple telescope/filter configurations can be reduced using a single set of template images so long as the filter response is not dramatically different, as we allow for color terms in the calibration of the individual frames that are applied to the galaxy background (see additional discussion in non-2.5m section).

The basic technique is PSF-fitting photometry; a single PSF is determined for a ~ 400 arcsec region on each SDSS frame centered around the SN. Photometric solutions for each individual frame are derived using a set of pre-calibrated stars (see calibration section). Relative linear astrometric solutions for each frame are determined from these stars as well; the relatively long baseline of the SDSS survey observations allow us to detect and include proper motion effects. Distortions in the SDSS 2.5m frames are included using the measured distortion coefficients from the SDSS pipeline.

In addition to the final scene modelling photometry, several other stages of photometry are used for various purposes:

- *survey photometry*, which makes quick measurements on pipeline frame subtraction images using an image centroid; this is used for target selection for spectroscopic followup.
- *forced photometry*, which works on pipeline frame subtraction images using a fixed position derived from an average of multiple survey photometry positions.
- *cross-convolution photometry*, where an independent frame subtraction is done by subtraction a template images convolved with the search image PSF from the search image convolved with the template image PSF.

The latter two methods were developed independently from the scene-modelling photometry in our effort to develop the optimum technique. In general, they agree well, but the scene-modelling photometry appears to give slightly smoother light curves and better error estimates, leading to better fits to the light curves.

Photometric Calibration

The SDSS supernovae runs are taken on all fall nights during which the telescope can be operated; hence, most of the data is taken under non-photometric conditions. However, all of the data on strips 82N and 82S taken as part of the standard SDSS survey were taken under photometric conditions, with simultaneous monitoring of atmospheric transmission using the Sloan photometric monitor telescope. As a result, the standard SDSS imaging provides multiple photometric measurements of all stars along these strips.

Ivesic et al. (2006) have taken the repeat observations along the equatorial strips and constructed a master catalog of standard stars in the SDSS system using these measurements. Variable stars are flagged by comparing the multiple measurements, and final median magnitudes for all non-variables with good S/N were compiled into the master catalog. We use the Ivesic et al. (2006) catalog to calibrate the supernovae frames using all stars within about 200 arcsec of each supernova. The fit constrains the relative brightness of all of these stars to be the relative brightnesses from the catalog, and solves for a single frame zeropoint. Along with the derived zeropoint, the scatter of the observed star brightnesses vs. the catalog brightnesses is computed to determine how well a single zeropoint matches the frames; with the drift scanning that is used for the survey, stars at different right ascensions are observed over different time intervals, so the zeropoint can vary as a function of row position on the frames. Frames with larger than expected scatter are flagged as potentially bad.

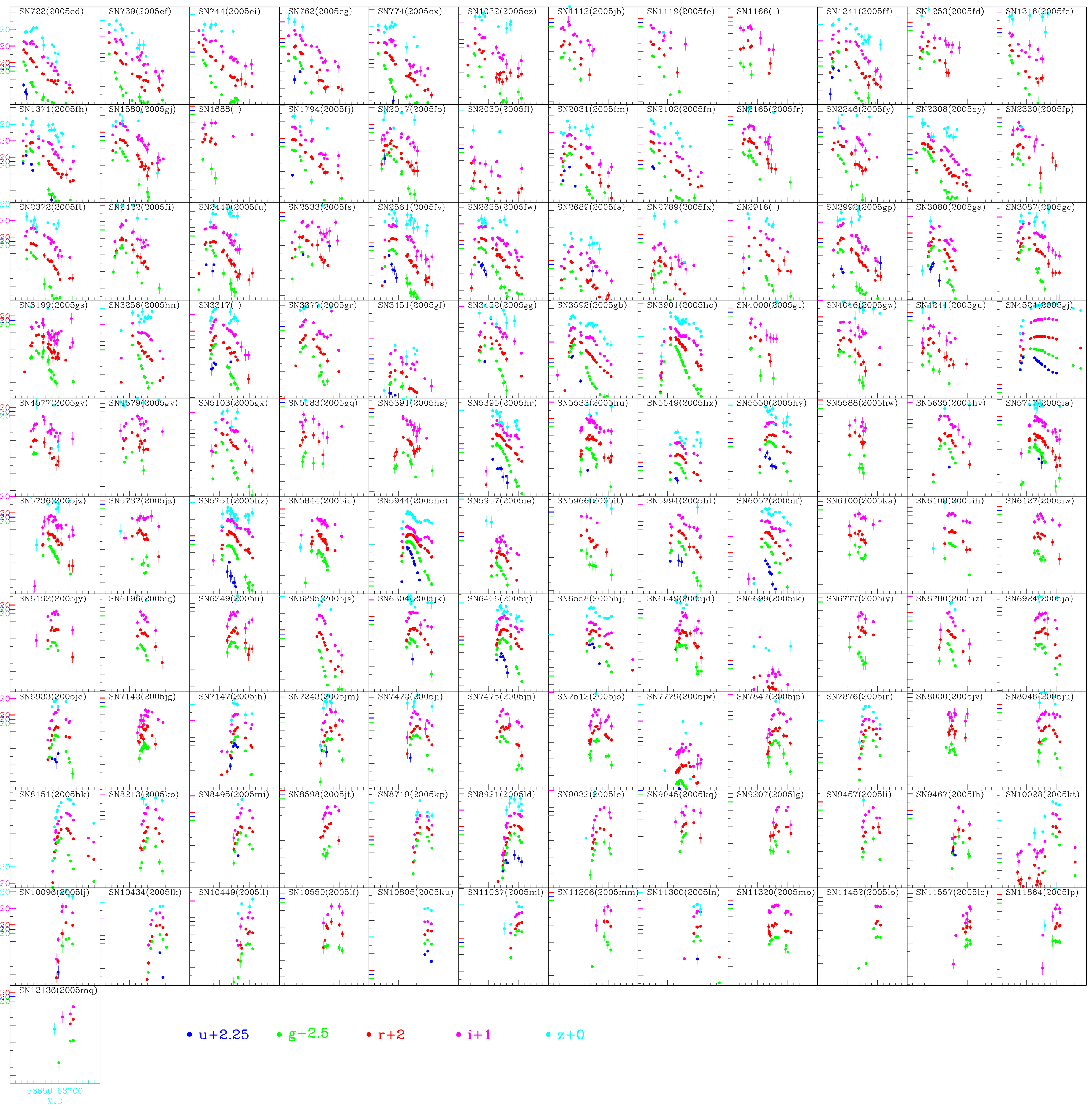
For absolute calibration, we are compiling various techniques that have been used to understand the SDSS system, and we believe we are converging on an absolute calibration that is good to about 1 percent.

In addition, we take advantage of the well understood system response of the SDSS system; this is critical to accurately be able to compare supernovae at different redshifts.

Non 2.5m photometry

The scene modelling technique allows for supernova observations from multiple telescopes to be combined with template observations from a single telescope, so long as the filter responses are not dramatically different. This is done by allowing for color terms in the solution for the photometric zeropoints for each frame. These color terms are then applied to the model of the galaxy background, so that small mismatches in filter response between template and supernova frames do not lead to significant host galaxy subtraction problems. Of course, this is valid only to the extent that the color terms (derived from stars) accurately match color terms for the background galaxy; this breaks down as the filter responses deviate more and as the galaxy spectral energy distribution deviates more from that of the stars used to determine the color terms.

Since the supernovae spectra, in general, deviate significantly from stellar spectra, application of the stellar color terms to the supernova measurements is, in general, inaccurate. As a result, the details of the filter response for each telescope is still required to merge observations from multiple telescopes via so-called S-corrections. However, scene modelling at least obviates the requirement of obtaining separate template observations with each telescope.



Light Curves

In the 2005 season, the SDSS SN survey identified 129 SN that were confirmed spectroscopically as type Ia. The figure above shows light curves for 121 of these; the remaining 8 either fell outside of the calibration star catalog (we can still calibration these, but the calibration rests on fewer SDSS runs than were required to make the catalog) or had a fit convergence problem. In addition, we have light curves from scene modelling photometry for:

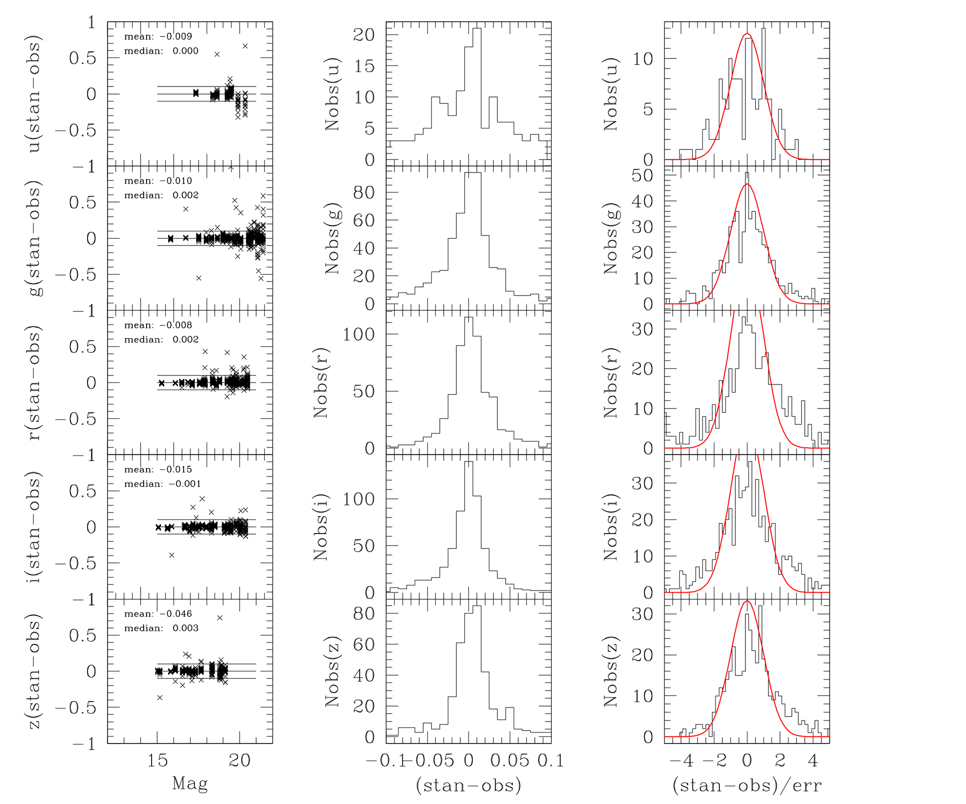
- 16 additional supernovae that were ranked as probable Ia from spectroscopic followup,
- 60 supernovae with light curves that are well fit with Ia template light curves when the fit is constrained by spectroscopically measured host galaxy redshifts
- several hundred additional objects with no followup spectroscopy. We are investigating to what degree we can classify these supernovae on the basis of light curves alone.

Photometry Tests

Several experiments have been performed to test the accuracy of the scene modelling photometry:

- Calibration stars near several supernovae have been treated as variable objects, and their recovered brightnesses compared with the calibration catalog brightness.
- A calibration star near several supernovae has been treated as a supernova: in pre-SN epochs, a patch including these stars was replaced by a nearby patch of sky. The reduction proceeded as for the true supernovae, allowing for an underlying galaxy model to be fit to the data.
- SN brightnesses have been determined in all frames after 90 days before estimated peak. Since the SN have short rise times, observations more than 30 days before peak should yield SN brightness of 0 within errors.
- Fake SN have been inserted into the data and recovered by the photometry.

Results from all of the tests are very encouraging. The following plots shows the results from stars near several supernovae being treated as supernovae, allowing for a host background to be fit underneath the star. The left panels shows the recovered stellar brightnesses compared with the known brightnesses; central panels show the histograms of recovered-known brightnesses. The right panels show the deviations of recovered-known divided by the estimated errors on the recovered brightnesses; perfect behavior should give a gaussian of unit width, shown in red.



Future Work

A paper presenting the photometry techniques and the 2005 light curves should be submitted shortly, at which point these light curves will become public.

Some improvements to the current photometry may still be possible and are being investigated, including astrometric improvements, PSF modelling improvements, improved sky determination, and careful analysis of the performance of the technique for faint objects.