HiTS light curve characterization

Image subtraction between DECam and SOI/Du Pont

Alessandro Razza & Francisco Förster

University of Chile/Millennium Institute of Astrophysics/Center for Mathematical Modeling

arazza@das.uchile.cl

Abstract

The High cadence Transient Survey (HiTS) makes use of a novel pipeline to perform real-time image subtraction and detection of SN candidates. Discoveries are performed with Dark Energy Camera (DECam) mounted on the 4-m Blanco Telescope at Cerro Tololo, but the full characterization of SN light curves requires follow-up by a combination of telescopes, including both the early rise (provided by DECam) and the later time evolution (e.g. provided by SOAR). By developing a modified pipeline we performed image subtractions between DECam and SOI data in order to extract more complete SN light curves. HiTS is making a transition from being a monochromatic survey, looking for shock breakouts, to a multi-band experiment looking for very young SN rising light curves, which makes this work more relevant for building the light curves to probe different aspects about the progenitors of these cosmic explosions.

Introduction

A supernova (SN) light curve can be used to constrain the progenitor star physical parameters. Although models show that the observation of SN shock breakout would directly probe the progenitor radius (Tominaga et al., 2011), its detection is challenging many surveys (Förster and et al, 2016 submitted). A viable method to estimate progenitor star parameters has been fitting the bolometric light curves, inferred from multi-band observations, with models from hydrodynamical and radiative transfer simulations (Bersten, 2013). According to these models, pre-SN stellar radius, progenitor initial mass, explosion energy and ejected nickel mass are the main parameters affecting the shape of bolometric light curves at later phases. Therefore, by a full characterization of SN light curves, i.e including plateau luminosity and duration, luminosity and slope of nickel powered tail, one can determine the main properties of the exploded star. The High cadence Transient Survey (HiTS) samples the sky through a wide-field camera (DECam) with a cadence of 40 fields every two hours, for 5 consecutive nights, in g-band. Once a SN is confirmed, other observations are triggered with other instruments such as SOAR Optical Imager (SOI) at Cerro Pachon or the imager at Du Pont telescope in Las Campanas. Accordingly, we used DECam observations both to trace the early rise of SN light curves and to obtain later time photometry of SNe subtracting DECam pre-explosion images.

Main Objectives

1. Characterize the late phases of HiTS SN light curves.
2. Build a tool that can be adapted to subtract images from DECam and other cameras.
3. Perform image difference SN photometric measurements.
4. Quantify the statistic and systematic errors.

Observations

HiTS has been performing the following observations over a span of three years (2014, 2015 and 2016):

- DECam real-time observations for a total of 5 consecutive nights in 2014A and 6 consecutive nights in 2015A followed by several half nights during the following days and weeks;
- Follow-up observations with several telescopes (SOI, DuPont, GROND, the Danish telescope), usually with a few observations per month after the main DECam real-time campaign and for selected SNe.

Image subtraction

A modified version of HiTS pipeline was developed for the purpose of subtracting DECam and SOI images. The main steps implemented in the pipeline can be summarized as follows:

1. SOI image detrend (bias subtraction and flat-fielding);
2. Generate a catalogue of sources with `SExtractor`;
3. Use `SExtractor` sources of both DECam and SOI images to match their pixel positions;
4. Project SOI image onto DECam through a non-linear coordinates transformation;
5. Remove cosmic rays with `crblaster` (Mighell, 2010);
6. Select bright isolated stars in both DECam and SOI images to train the convolution kernel;
7. Convolve one image onto the other depending on the worst PSF;
8. Compute the SN flux with the optimal photometry technique (Naylor, 1998).

The quality of the image subtraction was affected mostly by the type of stars selected for the empirical PSF estimation of each SOI and DECam image. Therefore, a particular attention was given to removing stars with no clean shape of their PSFs or "contaminated" by other close stars.

Results

Our modified pipeline has been tested with SOI images only. A satisfactory results was achieved for the image subtraction. Figure 1 shows how the host galaxy of SNHiTS14K was removed by the subtraction. It is important to note that, in this case, the worst PSF turned out to be the one of DECam image, hence the SOI image was convolved.

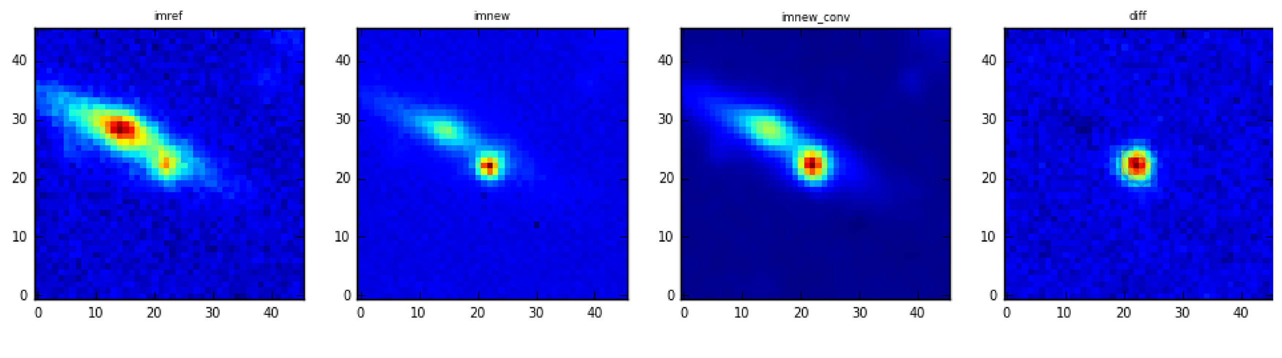

Figure 1: Image subtraction between SOI image in g-band, taken on March 24, 2014, and DECam reference image of SNHiTS14K. From left to right: DECam, SOI, convolved and subtracted image.

A major source of variability in the flux computed with our pipeline was the type of stars selected for training the kernel. We ran a preliminary test for the case of SNHiTS14K varying the number of selected stars and finding a relative error of 3.6% in the final flux, higher than the 1.3% error estimated by the pipeline. The implementation of a more robust error estimation, through the jackknife resampling technique, is in progress. Figure 2 shows an example of light curve characterization by using an observation taken on March 24, 2014 with SOI for SNHiTS14B.

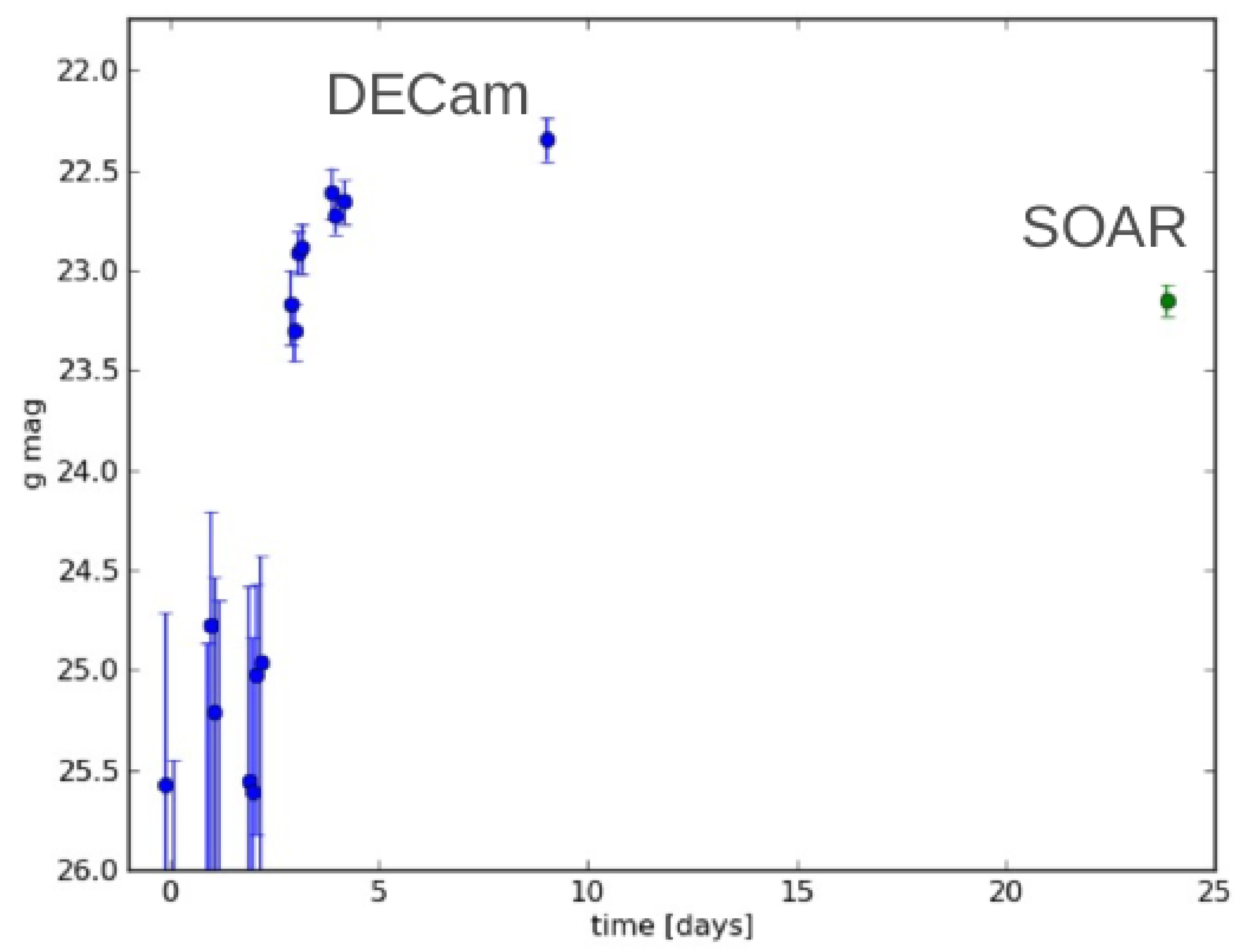

Figure 2: Light curve of SNHiTS14B. Blue points show early DECam observation, whereas the green one relates to SOI observation, 24 day after the discovery. Data before three days consist of non-detections.

Conclusions

Our image-subtraction pipeline enables obtaining SN photometry from images taken with different instruments. This was achieved by subtracting DECam observation from SOI images in order to remove the host galaxy flux from our measurements. Error in the calculated fluxes appears to be dominated by the sample of stars used for the convolution and their selection is then treated with particular attention. With this tool and the HiTS follow-up strategy we can investigate SN progenitor parameters through characterizing later phases of the SN light curves, especially when the forthcoming multi-band DECam observations will be operated. Similar tools are likely to be required for LSST telescope in combination with other follow-up resources.

Forthcoming Work

- An absolute astrometric solution will be added instead of the pixel-based transformations from one image to another. Although we do not expect significant changes for this particular dataset, it will make the pipeline more versatile.
- A left-one-out jackknife resampling technique or other similar techniques will be implemented to constrain the flux error.
- The pipeline will be adapted to compute image subtraction with other instruments.

References

N. Tominaga, T. Morokuma, S. I. Blinnikov, P. Baklanov, E. I. Sorokina, and K. Nomoto. Shock Breakout in Type II Plateau Supernovae: Prospects for High-Redshift Supernova Surveys. ApJS, 193:20, 2011.

F. Förster and et al. . ApJ, 2016 submitted.

M. C. Bersten. Comparing Hydrodynamic Models with Observations of Type II Plateau Supernovae. *ArXiv e-prints*, 2013.

K. J. Mighell. CRBLASTER: A Parallel-Processing Computational Framework for Embarrassingly Parallel Image-Analysis Algorithms. PASP, 122:1236–1245, 2010.

T. Naylor. An optimal extraction algorithm for imaging photometry. MNRAS, 296:339–346, 1998.

Acknowledgements

We acknowledge support from Conicyt through the infrastructure Quimal project No. 140003.
Powered@NLHPC: this research was partially supported by the supercomputing infrastructure of the NLHPC (ECM-02).