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The CHilean Automatic Supernova sEarch

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Abstract. The CHilean Automatic Supernova sEarch (CHASE) project began in 2007 with the goal to discover young, nearby southern supernovae in order to (1) better understand the physics of exploding stars and their progenitors, and (2) refine the methods to derive extragalactic distances. During the first four years of operation, CHASE has produced more than 130 supernovae, being the most successful project of its type in the southern hemisphere. Here we describe the project and present illustrative examples of CHASE discoveries of particular relevance.

Key words. Stars: supernovae – Cosmology: observations

1. Introduction

Supernovae (SNe) correspond to the explosive ending of some types of stars. They are grouped in two general classes: core collapse and thermonuclear supernovae. Core collapse SNe are thought to be massive (M>8 $M_{\odot}$) stars that undergo the gravitational collapse of their Fe cores at the end of their lives. This type of objects is only found in star-forming galaxies and come in different spectroscopic subclasses. Type II SNe are those which were able to retain their H-rich envelopes prior to explosion, Type Ib SNe are those that lost their outermost layers but were able to keep their He-rich envelopes, while Type Ic SNe are those that expelled both their H and He layers.

Thermonuclear SNe, on ther other hand, occur in all types of galaxies and are thought to originate in white dwarf stars that explode upon reaching the Chandrasekhar limit after a period of accretion from a binary companion, leaving no compact remnant behind them.

The origin of the different SN types has been only partially confirmed for Type II SNe. In a handful of cases it has been possible to identify and measure the luminosity and colors of their progenitor stars from pre-explosion images. Such studies have confirmed that such

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objects are supergiants with masses between 8.5-16.5 $M_{\odot}$ (Smartt et al. 2009). The remaining SN types have no progenitors identified and the challenge to identify their origin still remains an unsolved problem.

In 2007 we started the CHilean Automatic Supernova sEarch (CHASE) program (Pignata et al. 2009) in order to discover young and nearby SNe for which we could directly identify their progenitors in pre-explosion images, or through the fingerprints left by the progenitor in the early phases of evolution of the SN. Intensive spectroscopic and photometric follow-up studies of selected CHASE SNe also allow us to test explosion models and learn about the complex physics involved in such phenomena. Last but not least, the CHASE SNe have constituted an important source of targets for the Carnegie Supernova Program (Hamuy et al. 2006) in order to calibrate the SN luminosities and refine methods to determine accurate and precise extragalactic distances. In this paper we present the main characteristics of the CHASE survey and some illustrative results obtained in the course of these first four years.

2. Observations

The CHASE survey uses five of the Panchromatic Robotic Optical Monitoring and Polarimetry (PROMPT) telescopes located on Cerro Tololo [1]. Each telescope has a 40-cm diameter mirror and is equipped with a CCD covering a 10×10 arcmin^2 field of view. These instruments are 100% computer controlled and have been developed by the University of North Carolina at Chapel Hill in order to get prompt follow-up observations of Gamma-Ray Burts. CHASE makes use of only 10% of the observing time that is reserved to Chilean astronomers.

We pre-selected 6300 nearby galaxies in the southern hemisphere with radial velocities <8000 km s^{-1}, from which we drew a golden subset of galaxies with cz<2000 km s^{-1} which we attempt to observe with a higher cadence. On average we observe ~250 galaxies per night and we take one 80-sec exposures of each galaxy. The data are immediately transferred to our computers located in our headquarters at Cerro Calán Observatory in Santiago, where a modified version of the pipeline used by the ESSENCE survey (Miknaitis et al. 2007) begins a comparison with a previous epoch image of the galaxy stored in our archive. The pipeline aligns the two images, balances their fluxes and point-spread-functions, and subtracts them. Then it searches for positive residuals in the difference image and uploads the three images to our web site [2].

Figure 1 shows an example of the images generated by the pipeline which corresponds to SN 2008bp. Every day, a team of students and asistants performs a careful visual inspection of hundreds of images of this type to screen real SNe from other objects (variable stars, asteroids, bad pixels, and other artifacts). When a SN candidate is found, we try to obtain a confirmation image with PROMPT on the following night as well as a spectroscopic observation with other telescopes available to us (VLT, Gemini South, Magellan, SOAR). The confirmed SNe are immediately reported to the Central Bureau for Astronomical Telegrams. CHASE was started on March 2007 and in four years of operation it has discovered more than 130 SNe of all types (40% of all nearby southern SNe), being the most successful program of its type in the southern hemisphere. Not only we discover large number of SNe, but we also find them in earlier stages than other competing teams (for example, 55% of the Type Ia CHASE SNe are found before maximum light).

3. Some illustrative CHASE results

Here we present some illustrative examples of CHASE discoveries of particular relevance.

[1] http://www.physics.unc.edu/~reichart/prompt2.html

[2] http://www.das.uchile.cl/proyectoCHASE/

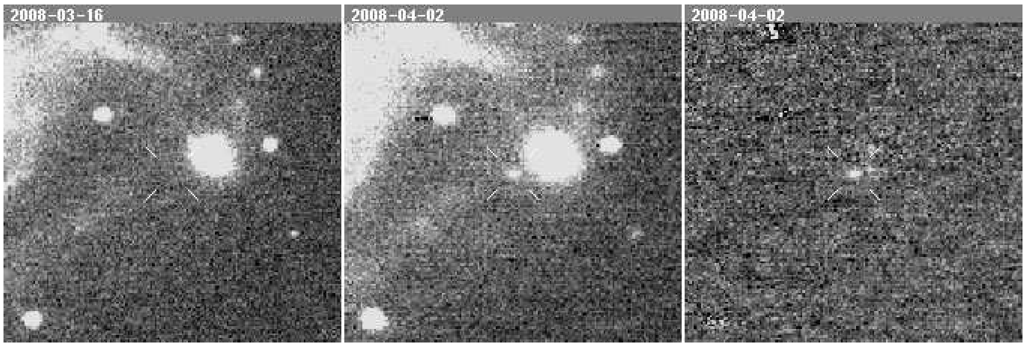

Fig. 1. An example of the three images generated by the pipeline. On the left if the pre-discovery image, in the middle is the new image, and in the right is shown the difference image. In this case the new object corresponds to SN 2008bp.

3.1. SN 2009bb

This object was an extremely young SN discovered on 2009 March 21.1 UT, only two days after explosion. Our initial spectroscopic observations revealed that SN 2009bb was a Type Ic supernova with very broad spectral lines, thus suggesting high expansion velocities. X-ray and radio observations provided firm evidence for a relativistic ejecta powered by a central engine (Sodergerg et al. 2010). Our modeling yielded an enormous explosion energy of $18{\times}10^{51}$ ergs and a large mass (0.22 $M_{\odot}$) of freshly synthesized radioactive ^{56}Ni. SN 2009bb became one of five relativistic SNe powered by a central engine but, intriguingly, the only one without a GRB (Pignata et al. 2011).

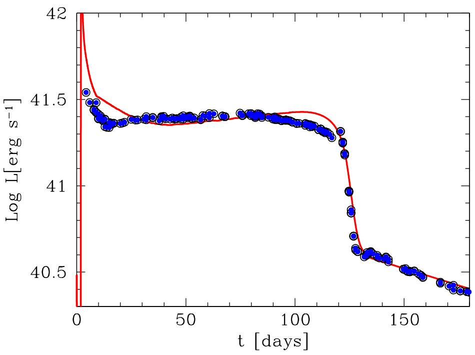

Fig. 2. Bolometric light curve of SN 2008bk (blue circles) and hydrodynamic model (red line). The horizontal axis shows the time since explosion.

3.2. SN 2008bk

This object was discovered by Monard (2008) on 2008 March 25.1 and independently confirmed by CHASE. Our initial spectroscopic observations demonstrated that SN 2008bk was a Type II plateau SN with very narrow spectral lines, thus suggesting very low expansion velocities (Morrell & Stritzinger 2008). Thanks to its short distance, we were able to measure a Cepheid distance modulus of 27.68±0.05 (Pietrzynski et al. 2010). The detailed optical lightcurves that we obtained with PROMPT allowed us to derive a bolometric lightcurve starting a few days after explosion, as can be seen in Figure 2. Our hydrodynamic models yield very good fits to our observations, from which we derive the following parameters: explosion energy of $0.25{\times}10^{51}$ ergs, progenitor mass of 12 $M_{\odot}$, initial radius of 500 $R_{\odot}$, and only 0.009 $M_{\odot}$ of freshly synthesized radioactive ^{56}Ni. An independent study by Van Dyk et al. (2011) of previously recorded images of the host galaxy taken with the Very Large Telescope and Gemini-South instruments, allowed them to identify the progenitor star and infer a ZAMS mass of 12$M_{\odot}$, in agreement with our hydrodynamic model. SN 2008bk belongs to the group of low energy and faint Type II plateau SNe, very similar to the propotype of this class, SN 1999br.

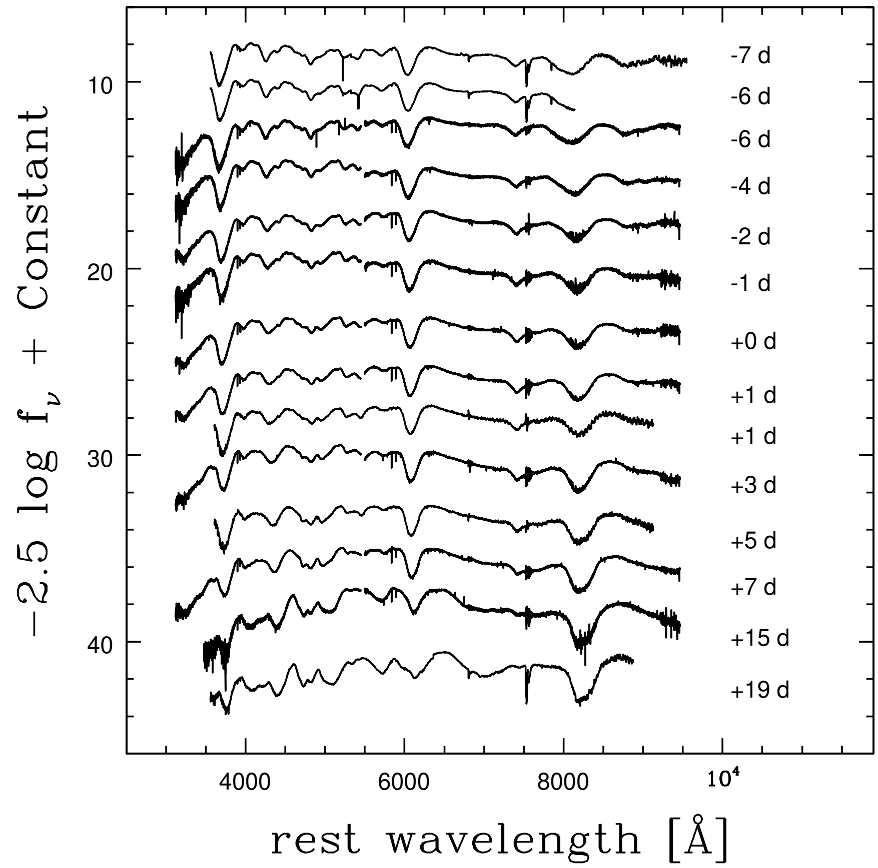

Fig. 3. Spectroscopic sequence of the Type Ia SN 2010ev, covering the first 26 days of its evolution. Each spectrum is labeled with the time since maximum light. The spectra were obtained with the VLT/XSHOOTER, Gemini-South/GMOS and Magellan instruments.

3.3. SN 2010ev

One of our approaches to better understand the SN progenitors and their explosion mechanism is the "mass tomography" technique, which requires a dense spectroscopic follow-up of the object over the first 30 days since explosion. With this kind of data and a detailed radiative transfer analysis, it is possible to reconstruct the chemical and density inner structure of the exploding star and constrain explosion models. Using a combination of instruments (VLT/XShooter, Gemini/GMOS, and Magellan/IMACS) in Target of Opportunity mode, our team has obtained dense spectroscopic sequences for nine CHASE SNe (five Type Ia: 2009le, 2010ae, 2010el, 2010ev, 2010gp; two Type II: 2009lq, 2009mw; one Type Ibc: 2010as; and one Ib/IIb: 2010cn). Figure 3 shows the spectroscopic evolution for one of such objects, SN 2010ev, a normal Type Ia SN caught 10 days prior to maximum light. A preliminary analysis of these data indicates that this is a high velocity gradient SN. In the context of the asymmetric explosion models of Maeda et al. (2010) our observations imply that the initial sparks were ignited at an offset from the center of the white dwarf nearly opposite to the line of view of the observer. We will soon be able to empirically check this prediction from the measurement of nebular emission lines in late-time spectra of SN 2010ev.

3.4. Spectropolarimetry

Another approach to study asymmetries in SN ejecta and determine the explosion geometry is through spectropolarimetric data of nearby SNe. Our team has been using the telescopes in Cerro Paranal Observatory to observe bright-nearby SNe. A sample of 11 SNe is under analysis.

3.5. The 50cm CHASE telescope

Since our priority in the PROMPT scale is low, we have little control on which galaxies are observed during a given night and this does not allow us to fully implement our search strategy. To address this problem we have been developing our own robotic telescope. We acquired a telescope mount manufactured in the USA, an optical tube with a 50 cm diameter primary mirror with Russian optics and Italian mechanics, a CCD camera with 2048×2048 pixels and several filters in the Johnson and SDSS systems. During 2009 we started the construction of a dome to host our telescope, in collaboration with engineers of the department of Mechanical Engineering at Universidad de Chile. During 2010 we integrated the telescope and mount at Cerro Tololo and adapted the existing telescope control software RTS2 (Kubanek et al. 2004) for the automatic control of the robotic instrument. The CHASE-500 telescope had its first light on November 2010 and is expected to begin scientific operations during 2011.

4. Conclusions

With 130 discoveries of nearby supernovae in four years of operation, the CHASE project is the most successful project of its type in the southern hemisphere. Not only we discover large number of SNe, but we also find them in earlier stages than other competing teams (for example, 55% of the Type Ia CHASE SNe are found before maximum light).

The discovery and subsequent followup (spectroscopy and photometry) observations of the CHASE nearby SNe have been very useful to (1) advance our understanding on the nature of these objects and the physics of the explosion (as illustrated here with SN 2008bk, SN 2009bb, and SN 2010ev) and (2) to refine the techniques for the measurement of extragalactic distances and figure out the origin of dark energy.

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