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SUPERNOVA LEGACY SURVEY 5 YEARS : FINAL TYPE IA SUPERNOVA SPECTROSCOPIC SAMPLE

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Abstract. The SuperNova Legacy Survey (SNLS) is a five-year project aiming at constraining the equation of state of the dark energy using a type Ia supernova (SNIa) Hubble diagram. To construct this diagram, a spectroscopic program is essential to secure the type and redshift of the SNIa candidates. SNLS benefited from large time allocated on 8-m class telescopes with 1500 hours of observations. In this talk, I will describe the steps of the data processing and spectral analysis what have allowed to build the full spectroscopic sample with 427 SNeIa. In addition to be used for the final SNLS cosmology analysis, this spectroscopic sample is a rich source of physical information about the SNeIa to test the evolution of their population with redshift.

Keywords: Type Ia supernova, SuperNova Legacy Survey, spectroscopy, dark energy

1 Introduction

Using type Ia supernovae (SNe Ia) as standardisable candles has lead to the discovery of the acceleration of the universal expansion (Perlmutter et al. 1999; Riess et al. 1998). This acceleration is nowadays attributed to a dark energy component that contributes to more than 70% to the energy budget of the Universe. To characterize the nature of this component, a combination of various probes has been used. Among those, the measurement of luminosity distances to SNe Ia provides perhaps the simplest and most direct way of probing dark energy. For this purpose, low and high redshift SNe Ia are compared in a Hubble diagram. Combining the SuperNova Legacy Survey (SNLS) 3 year SNe Ia with low-redshift SNe Ia from the literature, intermediate redshift SNe Ia from the SDSS-II Supernova Survey and high-redshift from the Hubble Space Telescope, Conley et al. (2011) have produced the most advanced supernova Hubble diagram to date with 472 SNe Ia in total. With its 235 SNe Ia in the range $0.15 < z < 1.1$, SNLS is the most comprehensive supernova survey at high redshift to date.

After the publication of the SNLS 3 year cosmological analysis, the effort are now focusing on the SNLS 5 year analysis. Spectroscopy is essential for this analysis to secure the nature of the SN Ia candidates and measure their redshift to build the Hubble diagram. The present article focuses on the spectroscopic analysis of the SNLS 5 year data set to build of the full SNe Ia spectroscopic sample. This new sample will allow us to investigate a key question for cosmology : as SNe Ia are used over a large redshift range, we will test if the SN Ia populations evolve with the redshift. This study is fundamental to validate the used of SNe Ia in cosmology.

2 The SuperNova Legacy Survey experiment

The SNLS is a 5 year experiment conducted from 2003 to 2008. It is a spectro-photometric progam aiming at detecting and following a large number of SNe Ia at intermediate to high redshift in order to measure their luminosity distance and constrain cosmological parameters. The experiment was split in two surveys : an imaginig survey and three spectroscopic programs.

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2.1 The imaging survey

A photometric program at the Canada-France-Hawaii Telescope implemented a rolling search technics that allowed for the detection of new SN Ia candidates as well as the follow-up of their light curves in several photometric bands. The objects are detected in four 1 square degree field observed every 3-5 nights during 5-6 lunations per years. During the survey, more than 1000 SNe Ia candidates with well sampled multi-bands light curves have been optained (Guy et al. 2010).

2.2 The spectroscopic programs

To assess the type of the candidates and estimates their redshift, spectroscopic follow-up programs have been performed on three 8-10m class telescopes : the Very Large Telescope (VLT), Gemini-North & South and Keck I & II. SNLS benefited from 1500h of observation on these telescopes and spectra have been measured for around half of photometric SN Ia candidates :

- 35% of the SNe Ia have been measured by the Gemini telescopes (Howell et al. 2005; Bronder et al. 2008; Walker et al. 2011) where SNLS benefited from 60 hours of observation per semester during 5 years. Gemini observed preferentially high redshift candidates ($z > 0.6$) in the four SNLS fields,

- the VLT measured 45% of the SNe Ia (Balland et al. 2009; Cellier-Holzem & the SNLS collaboration in prep) during two ESO large programs, corresponding to 60 hours per semester from June 2003 to September 2007. The VLT is a southern telescope and thus observed preferentially the equatorial SNLS fields.

- the remainder of the candidates were sent to the Keck telescopes, in particular the objects of the high latitude fields and candidates with a redshift around 0.5 for dedicated studies. These telescopes measured around 20% of the SNe I (Ellis et al. 2008; Fakhouri & SNLS collaboration in prep).

3 Building the final spectroscopic sample of SNLS

3.1 Redshift estimates

The first step to build the full spectroscopic sample is the redshift estimates of the SN Ia candidates. Redshifts are estimated from strong host features if present (e.g. [O II] at 3727Å or H_β at 4861Å emmission lines or Ca II H&K at 3934Å and 3968Å absorption lines). To estimates the redshift, we perform a gaussian fit of each identified host feature. We assign an error of 0.001 on the redshift, typical of the uncertainty obtained on redshift derived from host lines.

If no apparent host line is present, the redshift is estimated from the supernova features themselves. First a rough estimate is inferred from one of the large absorption line of the supernova (e.g. Ca II around 3700Å or Si II at 4000Å). To refine the redshift, we performed a combined fit of the observed light curves and spectrum with the spectro-photometric model of SN Ia, SALT2 (Guy et al. 2007). A galaxy template representing the host contribution is added to the model to take into account the host contamination and recover the SN Ia signal. As the supernova feature are larger than the host lines, we assign a higher error of 0.01 on the supernova redshift.

3.2 SNe Ia identification

The second aim of the spectroscopy is the SN Ia identification to include only SNe Ia to the Hubble diagram. To assess the nature of the candidates, we inspect the SALT2 fit of the spectrum after the host subtraction. If at least one typical features of SN Ia is seen (e.g. Si II at 4000Å or 6150Å), or if the spectral fit is good over the entire spectral range, the object is certainly a **SN Ia**. For some cases, the candidate is likely a SN Ia but other types can not be excluded given the signal-to-noize and the quality of the SALT2 fit : we classify these objects as **SN Ia**$\star$. To not contaminate the SN Ia sample with other types, only SNe Ia and SNe Ia$\star$ (which represent 70% of candidates) are considered for inclusion in the Hubble diagram. The objects where a supernova signal is not clearly visible, or with a not SN Ia spectrum are excluded.

3.3 Results : full spectroscopic sample

The final spectroscopic sample of SNLS contains 427 objects, with 76% of SNe Ia and 24% of SNe Ia⋆. These SNe Ia and SNe Ia⋆ subsamples have very similar photometric properties (color, stretch and absolute magnitude at maximum in B-band) on average, which suggest that the SNe Ia⋆ sample is not contaminated by non-Ia-objects with respect to the SN Ia sample.

This pure data set is the largest sample of SNe Ia at intermediate and high redshift to date. Among this sample, two independant sub-samples (two different extractions and without common SNe Ia) of spectra measured by the VLT existe : the VLT 3 year (Balland et al. 2009) and the VLT 5 year (Cellier-Holzem & the SNLS collaboration in prep) samples. These two sub-samples can allow us to test the calibration and the identification in SNLS. For this purpose, we compare the raw data building the mean spectrum for each VLT sub-sample. To build the mean spectra, spectra are first de-redshifted and rebinned to 5Å. We normalize the spectra fixing the flux integral over a wavelength range 4000-4500Å. The average weighted flux and its corresponding uncertainty (1σ error) are then computed in each wavelength bin. The two mean spectra are overlapped in Fig. 1 and are remarkably similar. We conclude the SNe Ia of the two subsamples are identical in average and the spectra are calibrated at 5%.

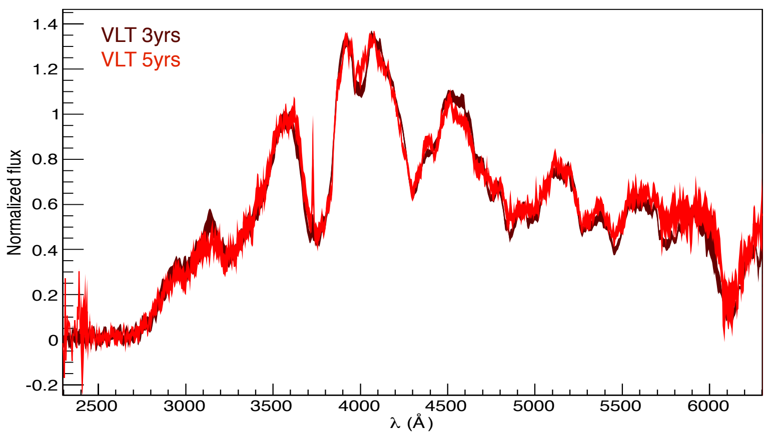

Fig. 1. Mean spectra from VLT 3 year (in dark red) and VLT 5 year (in light red) samples

4 Testing the evolution of SNe Ia properties with the redshift

With this exeptional sample, we can investigate some key questions for cosmology. In particular, as SNe Ia are used over a large redshift range, we have to determine if the SN Ia population properties evolve with redshift to validate the used of SNe Ia in cosmology. Several studies (e.g. Sullivan et al. 2009 or Maguire et al. 2012) investigated this question, comparing low and high redshift spectra and they remarked spectral differences localized in UV : low redshift spectra have depressed flux compared to higher redshift. Several interpretation existe in literature : it could be explained by a demographic evolution of the SN Ia population (Sullivan et al. 2009) or a consequence of the galactic evolution (Maguire et al. 2012) for example. In this controversial context, the SNLS spectra can shed a new light on this key question.

For this purpose, we build mean spectra at low and high redshift from VLT spectra using SNe Ia (not SNe Ia⋆ to limit the bad signal-to-noise spectra) around light maximum ($-4 <$ phase < 4 days) with a cut in color ($-0.2 <$ color < 0.2) to exclude peculiar SNe Ia. Spectra are split into two redshift bins : 15 with $z < 0.5$ and 56 with $z > 0.5$. Mean spectra are built using the previous methode, with a color correction of the spectra to take into account the diversity of SN Ia colors, and are overlapped on the left panel of Fig. 2. Spectra are similar but absorption depth differences are visible : low redshift spectra have deeper absorption lines due to intermediate mass elements (Ca II at 3700Å and Si II at 4000Å). This is consistent with higher SNe Ia beeing bluer (flux excess in UV), brighter and hotter and thus ionasing more intermediate mass elements. Indeed, when we select two sub-samples with similar photometric properties (on the right panel of Fig. 2), the differences are significantly reduced. We conclude that the differences bewteen low and high redshift SNe Ia are consistent with a selection effect : we select preferentially brighter (bluer and hotter) SNe Ia at high redshift and we do not highlight a demographc evolution of SNe Ia.

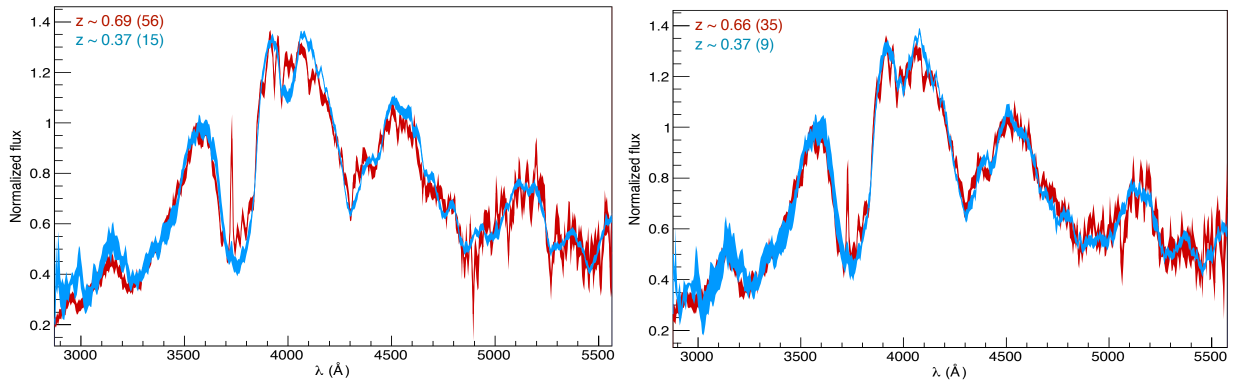

Fig. 2. Mean spectra at low (in blue) and high (in red) redshift built from **Left:** the VLT sample (15 low z and 56 high z spectra), **Right:** from two VLT sub-samples with similar photometric properties in average (9 low z and 35 high z spectra).

5 Conclusions

Spectroscopy is essential in cosmology to estimate the redshift and assess the nature of the SN Ia candidates. For this purpose, SNLS benefited from exceptional spectroscopic surveys with 1500h of observation on 8-10m class telescopes. During the survey, the SNLS collaboration has identified 427 SNe Ia and SNe Ia⋆. This is the largest intermediate to high redshift SN Ia sample to date. The final SNLS cosmology analysis will rely on this spectroscopic sample, after photometric cuts are made.

This exceptional sample can be used to investigate the key question of the evolution of SNe Ia with redshift. Using the VLT spectra, we find evidence for differences in the intermediate mass element absorptions between low and high redshift SN Ia. These differences are consistent with a selection effect and we do not need to invoke a demographic evolution of SNe Ia, which legitimates the use of SNe Ia as ”calibrated candels” in cosmology.

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