SEARCH FOR TYPE Ia SUPERNOVAE AT REDSHIFT $z \sim 0.1$ WITH EROS2

N. REGNAULT[a]
Laboratoire de l'Accélérateur Linéaire,
IN2P3-CNRS et Université de Paris-Sud, BP 34, F-91898 Orsay Cedex

Type Ia supernovae (SNIa) are powerful cosmological distance indicators and have been used for measuring cosmological parameters such as the Hubble constant, H_0, and the deceleration parameter, q_0. These measurements rely on empirical correlations between absolute peak luminosities and other observables, like the postmaximum decline rate, or the color at maximum. Since the total number of well observed nearby SNIa is still small, these correlations are not yet fully understood. In 1997, the EROS2 Collaboration launched an intensive search for SNIa at $z \sim 0.05 - 0.2$. Our last search, in the spring of 1999 was performed in the framework of a worldwide consortium led by the *Supernova Cosmology Project*. It aimed at providing an independent set of high quality light curves and spectra, to study further the SNIa properties. In the following, we briefly describe our search procedure and the status of our analysis of the photometric data.

1 Type Ia supernova

Type Ia supernovae (SNIa) seem to form a nearly homogeneous class of objects, with almost identical spectra and light curves. Their absolute magnitude at maximum shows a dispersion of less than 25%. Progenitors are likely to be binary systems involving a C / O white dwarf, accreting matter from a companion which may be a red giant. When the white dwarf reaches the Chandrasekhar mass ($\sim 1.4\ M_{\odot}$) its collapse ignites the carbon thermonuclear fusion, which leads to the explosive disruption of the white dwarf. This model involving the thermonuclear burning of a Chandrasekhar-mass white dwarf explains that the total amount of energy released during the explosion is nearly constant from one SNIa to another. However, the physics of the explosion as well as the exact nature of the progenitor system are still beeing discussed.

Thanks to their high brightness and the small scatter of their peak absolute luminosity, SNIa can be used as standard candles to measure cosmological distances. It has been shown (Hamuy *at al.*[1] ; Phillips *et al.*[2]) that SNIa peak absolute luminosities correlate in each color with other observables, among which the postmaximum decline rate, the color at maximum, and some spectral features. Once corrections based on these correlations are applied, the peak luminosity dispersion can be reduced to 10%. However these correlations require further investigation, since they have been established on a small number of SNIa.

SNIa have been used for measuring the cosmological parameters H_0, Ω_m and Ω_Λ, by studying how their apparent luminosity varies with their redshift (Perlmutter *et al.*[3] ; Schmidt *et al.*[4]). These analyses indicate a low value for Ω_m, and a non zero cosmological constant. However,

[a]on behalf of the EROS2 Collaboration.

they rely heavily on the standardization mentionned above. Indeed, the evidence for a non zero Λ comes from a 20% flux deficit with respect to a $\Lambda = 0$ flat universe, which is of the same size as the instrisic luminosity dispersion. Therefore, many groups — EROS2 among them — have launched nearby supernovae searches in order to build large samples of well studied nearby SNIa.

2 The EROS2 nearby Supernova Search

The EROS2 Collaboration, whose program is mainly devoted to the search for microlensing events operates a 1 meter telescope, installed at the *European Southern Observatory* of La Silla (Chile). This instrument is equipped with a dichroic beam splitter and two cameras to take images simulteanously in two wide non-standard pass-bands. Each camera contains an 8 thick $2k \times 2k$ CCD mosaic, covering a field of view of $0.7^o(\alpha) \times 1.4^o(\delta)$, with a pixel size of 0.6 arcsecond.

This setup is well adapted for discovering SNIa at $z \sim 0.05 - 0.2$, the expected discovery rate beeing of 1 SNIa every three hours of observation. Hence, in the spring of 1997, the EROS2 Collaboration launched a systematic search for nearby supernovae. The goal of this program was to constitute a large sample of well observed nearby SNIa in order to measure the SNIa explosion rate at $z \sim 0.15$ and to study the correlations mentioned above between the SNIa light curve shapes and their absolute maximum luminosities.

2.1 The search strategy

We search for supernovae by comparing an image of a given field with a *reference image* of the same field, taken two or three weeks before. The comparison is made by subtracting the former from the latter, after a geometric and a photometric alignment, and a convolution to match the seeings. We then perform an object detection on the subtrated frame. The resulting candidates are then filtered by applying cuts tuned using a Monte-Carlo simulation. This procedure rejects variable stars, asteroids and subtraction artifacts. Finally, the last spurious candidates are eliminated through a visual scan.

2.2 The first stage : 1997-1998

During the first two years, 7 search campaigns have been undertaken by the collaboration, and 35 supernovae have been discovered. Unfortunately, due to the lack of follow-up time, spectra could be obtained for only ten SNe, using the ESO 3.60m and the ARC 3.50m telescopes. 7 of these were of type Ia, 1 of type Ic, and 2 of type II. Using this first sample a SNIa rate at $z \sim 0.15$ has been determined (Hardin *et al.*[5]).

2.3 A worldwide supernova search

In the spring of 1999, a worldwide search[b], conducted by the *Supernova Cosmology Project* and coordinated by Greg Aldering (SCP) resulted in the discovery of 41 supernovae. Among these, 19 turned out to be SNIa discovered within 10 days from maximum. EROS2 participated in this search, and discovered 7 of these 19 SNIa.

[b] Involving the following 9 groups : **The Nearby Galaxies SN Search Team** (Strolger, Smith *et al.*), **EROS2** (Spiro *et al.*), **KAIT** (Filippenko *et al.*), **The Mount Stromlo Abell Cluster Supernovae Search** (Schmidt, Germany & Reiss), **NEAT** (Helin, Pravdo & Rabinovitz), **QUEST** (Schaefer *et al.*), **SpaceWatch** (McMillan & Larsen), **The Tenagra Observatories** (Schwartz), and **The Wise Observatories Supernovae Search** (Gal-Yam *et al.*).

Large amounts of photometric and spectroscopic follow-up time were available to the consortium. All of the 19 SNIa near maximum discovered during the search, as well as 1 SNIa published in an IAU circular at the same time have been followed up. On average, 12 photometric points per color could be collected for each SNIa. In addition, the spectroscopic follow-up produced an average sample of 10 spectra per supernova.

Photometric and spectroscopic data from these SNe are currently being analysed. The physics output will include a new measurement of the SNIa rate at $z \sim 0.15$, computed with the larger sample of SNIa discovered by EROS2, as well as systematic studies of SNIa light curves and spectra. In the following, we present an overview of the analysis of the photometric data.

3 Analysis of the photometric follow-up

The photometric follow-up of the 20 SNIa has been conducted with twelve different telescopes. The resulting data diversity, especially the slight passband differences from one telescope to another complicates the analysis quite a lot.

The photometric follow-up and calibration data represent a total amount of 7,000 images. After a first reduction, objects are detected on each image, using the program `sextractor` (Bertin *et al.*[6]), which also provides a star versus galaxy discrimination. We then perform a geometrical alignment, and we identify the supernova and its host galaxy on each image.

3.1 Photometry methods

The follow-up images have been analysed using three different photometry methods. The first one consists in modelling the galaxy luminosity profile locally around the supernova with a bilinear function. The SN flux is then computed by summing the fluxes of the pixels within an aperture centered on the supernova, whose radius is a function of the seeing.

In another method, we model the whole galaxy luminosity profile, after having removed the noise, using spline functions. For this purpose, we use a *reference image*, taken once the supernova has faded with an exposure time long enough to obtain a good signal to noise ratio. On the follow-up images, this galaxy background model is then fitted simultaneously with a model of the PSF describing the flux coming from the supernova.

The last method consists in subtracting from the current image a *reference image*. The subtraction algorithm used is taken from (Alard & Lupton[7]). In addition, we have to correct for pixel size differences, when both current and reference images have been taken with two different telescopes.

The first method is well suited for studying SNIa whose host galaxy luminosity profile presents smooth variations, *i.e.* nearby supernovae ($z < 0.05$), lying at the periphery of their host galaxy. The second method can be used for supernovae which can be well distinguished from their host galaxy, while the third method can be applied to all supernovae.

3.2 Intercalibration and first light curves

At this stage, we have obtained the instrumental fluxes of the supernovae and those of the surrounding field stars. These fluxes must now be expressed in standard magnitude systems in order to obtain calibrated light curves. As standard stars could not be observed every night, we used the field stars to intercalibrate the follow-up images on the reference image. The reference image is in turn absolutely calibrated with standard stars taken during the same night.

The calibration relation comprises two terms. The first term corrects for the mirror diameters and CCD sensitivity differences between telescopes, and for atmospheric absorption. The

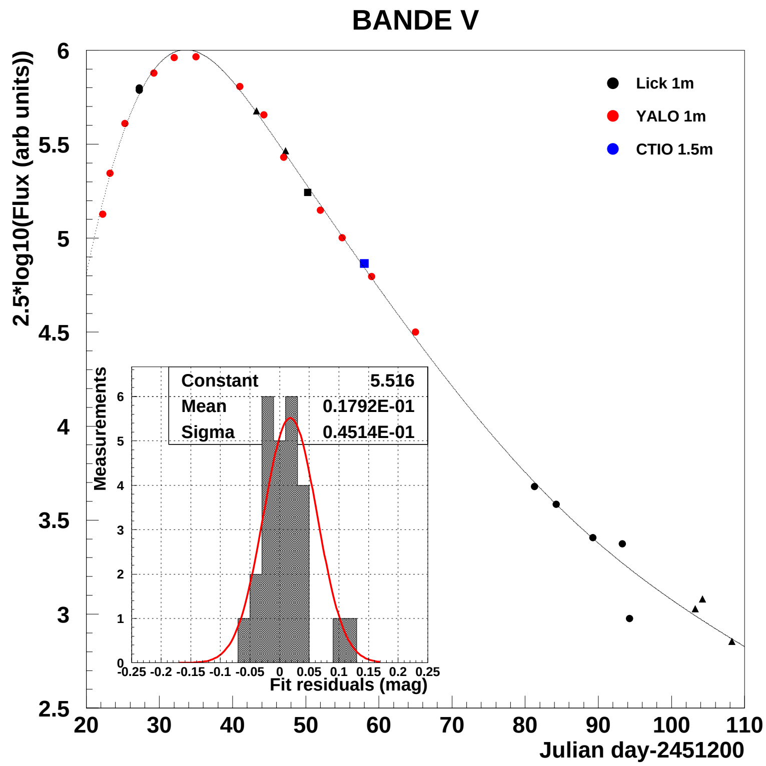

Figure 1: Light curve of the supernova `1999ac` in the V band. The flux is expressed in arbitrary units.

other term is a function of the color of each object, and corrects for passband differences between the telescopes. To apply the latter correction to the SNIa, we have to take into account the color variation of these objets, using a color evolution model.

3.3 Determination of the peak luminosity

We finally determine the peak luminosity of each SNIa, for each passband, using a semi-analytical model. An analytic function which involves 7 parameters is first fitted to well sampled type Ia supernovae in order to obtain a light curve template library. These templates are then fitted to each SNIa light curve.

Conclusion

Since 1997, the EROS2 Collaboration has been devoting 10% of its observation time to the search of nearby supernovae. Up to now, 60 SNe have been discovered. In the spring of 1999, we joined a worldwide consortium search for nearby SNIa. We found 7 of the 19 SNIa discovered less than 10 days after their peak luminosity. We have presented an overview of our analysis, for which we have developped three different photometry methods. We are now taking reference images in order to perform an absolute calibration of our light curves. Once this absolute calibration done, it will be possible to compare this sample with other sets of nearby well observed SNIa.

References

1. M. Hamuy *et al.*, *The Astronomical Journal* **112(6)**, 2391 (1996)

2. M. Phillips *et al.* *The Astronomical Journal* **118**, 1766 (1999)
3. S. Perlmutter *et al.*, *Astrophysical Journal* **517**, 565P (1999)
4. P. Schmidt *et al.*, *Astrophysical Journal* **507**, 46S (1998)
5. D. Hardin *et al.*, *Type Ia supernovae rate at* $z \sim 0.15$, *in preparation*.
6. G. Bertin *et al.*, *Astronomy & Astrophysics Suppl. Ser.* **117**, 393-404 (1996)
7. C. Alard & R. H. Lupton, *Astrophysical Journal* **503**, 325 (1998)