A NEARBY SUPERNOVAE SEARCH: EROS2

N. REGNAULT

Laboratoire de l’Accélérateur Linéaire, IN2P3-CNRS et Université de Paris-Sud, BP 34, F-91898 Orsay Cedex

Type Ia supernovae (SNIa) have been used as approximate standard candles to measure cosmological parameters such as the Hubble constant and the deceleration parameter. These measurements rely on empirical correlations between peak luminosities and other features that can be observed in the supernovae spectra and their light curves. Such correlations deserve further study since they have been established from small samples of nearby SNIa. Two years ago, the EROS2 collaboration launched an automated search for supernovae with the 1m Marly telescope operating at La Silla. In all, 57 SNe have been discovered in this EROS2 search and spectra have been obtained for 26 of them. We found that 75% were of type Ia and 25% of type II. Using this sample, a preliminary SN explosion rate has been obtained. Our most recent observation campaign took place in February and March 99. It was performed in the framework of a large consortium led by the Supernova Cosmology Project. The aim of this intensive campaign was to provide an independent set of high quality light curves and spectra to study systematic effects in the measurement of cosmological parameters. We will briefly describe our search procedure and present the status of our ongoing analysis.

1 Type Ia supernovae and cosmology

Supernovae are classified in different subtypes, according to their spectral features. Type Ia supernovae (SNIa) are believed to be explosions of carbon-oxygen white dwarfs. SNIa progenitors are likely to be binary systems, composed of a red giant and an old C/O white dwarf. The latter accretes matter from its companion until it reaches the Chandrasekar mass (~ $1.4M_\odot$), and then becomes unstable. This process leads to the total thermonuclear explosive burning of the white dwarf. Thus, the total energy released should be nearly constant from one SNIa to another. These objects may therefore be used as standard candles. Indeed, photometric and spectroscopic studies have shown that SNIa compose an homogeneous sample and their peak magnitudes present a small scatter (~ 20%) in all colors. Furthermore, these objects are very luminous — they have been detected up to redshifts $z \sim 1.2$ (Aldering et al.). Thus they constitute powerful cosmological distance indicators.

It has been shown that the absolute maximum luminosities of SNIa correlate with other observables, like the post maximum decline rate, the color at maximum, the SN spectral features, or the galaxy type. When corrections based on such correlations are applied, the relative dispersion of the peak luminosities of SNIa can be reduced to 10% (Hamuy et al.).

Measurements of the cosmological parameters $H_0$, $\Omega_0$ and $\Lambda$ have been made by analysing the apparent peak magnitude versus redshift relation (Perlmutter et al., Schmidt et al.).

* on behalf of the EROS2 Collaboration.
These analyses rely heavily on the standardization procedure outlined above. For example, the evidence for a non-zero $\Lambda$ arises from a 20% flux decrease with respect to a $(\Omega = 0.2)$ universe, which is comparable to the intrinsic luminosity spread. However, our SNIa knowledge is based on few objects, namely the 17 SNIa ($z < 0.1$) discovered before maximum during the Calan-Tololo search. This is why a number of nearby SN searches have been launched in order to increase the set of well sampled SNIa and study further the standardization corrections mentioned above.

Supernovae rates as a function of redshift are a useful tool for studying the star formation history, or constraining the galactic chemical evolution scenarios. While probing the stellar evolution, they also bring valuable information on the SNIa progenitor system, and allow us to get a better insight into the physics processes involved in these events. SNIa rates have been measured at low redshift (see e.g. Cappellaro et al.\(^5\)) with SNe discovered using photographic plates, and at high redshift ($z \sim 0.4$), with automatic subtraction of CCD images by Pain et al.\(^6\). EROS2 has obtained the first determination of the SNIa rate at $z \sim 0.15$ (Hardin et al.\(^7\)).

2 The EROS2 nearby supernovae search

The EROS2 experiment is mainly devoted to the search for microlensing events towards the Magellanic clouds, and towards the Galactic bulge and disk. For this purpose, the collaboration operates a 1 meter telescope, installed at the European Southern Observatory of La Silla (Chile). This instrument was specially refurbished and automated in view of a microlensing survey. It is equipped with a dichroic beam splitter and two cameras to take images simultaneously in two wide pass-bands. Each camera comprises a mosaic of $8 \times 2k$ thick CCD’s, covering a field of view of $0.7^\circ(\alpha) \times 1.4^\circ(\delta)$ with a pixel size of 0.6 arcseconds.

Since this setup is particularly well suited for discovering supernovae at $z \sim 0.05$ – 0.2, the EROS2 collaboration launched in 1997 a systematic nearby SN search aimed at the measurement of the nearby SN explosion rates and a detailed study of the correlations between the SNIa light curve shapes and their peak absolute luminosities.

2.1 The search strategy

Our SN search technique consists in comparing an image of a given field with a reference image of the same field taken two or three weeks before. For this purpose, we subtract the reference frame from the search frame, after a geometric and a photometric alignment, and a matching of the seeing. We then perform an object detection on the subtracted frame. Genuine candidates are selected among these objects by applying cuts tuned with a Monte-Carlo simulation, in order to reject variable stars, asteroids and subtraction artifacts. Finally, a visual scan allows us to eliminate the last spurious candidates.

2.2 The first stage: 1997-1998

During the first two years, 7 search campaigns have been conducted. We monitored fields from both celestial hemispheres. In order to avoid dust absorption they were chosen far from the Galactic plane. During these first searches, 35 SNe have been discovered. Spectra could be obtained for 10 of them with the ESO 3.6m and the ARC 3.5m telescopes. 7 of the SN were of type Ia, 1 of type Ic and 2 of type II. Using this first sample, a preliminary SNIa rate at $z \sim 0.15$ has been obtained (see section \(^3\)).
2.3 A worldwide SNIa search campaign

In the spring of 1999, we participated in a worldwide search campaign[^1], led by the *Supernovae Cosmology Project* and coordinated by Greg Aldering (SCP). The search involved 9 groups listed below.

EROS2 discovered a subset of 16 SN among the 41 supernovae found in this campaign. Among them, 19 (7 from EROS2) turned out to be of type Ia, discovered near maximum. An overview of the follow-up data for each SN can be found in table 1. Photometric and spectroscopic data from both these SN together with discoveries announced in the same period in IAU circulars are currently being analysed.

| SN   | 99aa | 99ao (††) | 99ac (††) | 99af (†) | 99ar (†) | 99at (⊥) | 99au (†) | 99av (†) | 99aw (†) | 99ax (▽) |
|------|------|-----------|-----------|----------|----------|----------|----------|----------|----------|----------|
| U    | 22   | 17        | 23        | 8        | 6        | 7        | 10       | 15       | 19       | 13       |
| B    | 27   | 16        | 27        | 9        | 11       | 11       | 8        | 13       | 19       | 18       |
| V    | 27   | 16        | 28        | 11       | 11       | 9        | 12       | 18       | 19       | 16       |
| R    | 27   | 15        | 27        | 10       | 11       | 9        | 12       | 17       | 19       | 15       |
| I    | 22   | 14        | 19        | 7        | 5        | 6        | 12       | 11       | 13       | 9        |

99be (+) 99bf (+) 99bh (††) 99bi (‡) 99bk (‡) 99bm (‡) 99bn (‡) 99bp (‡) 99bq (‡) 99by (††)

| U    | 7    | –       | 7        | 9        | 5        | 1        | 5        | 10       | 1        | 9        |
| B    | 12   | 4       | 12       | 9        | 7        | 7        | 11       | 10       | 4        | 15       |
| V    | 12   | 5       | 11       | 8        | 12       | 6        | 9        | 10       | 5        | 9        |
| R    | 11   | 3       | 12       | 9        | 10       | 4        | 7        | 11       | 2        | 9        |
| I    | 8    | 1       | 8        | 7        | 8        | 1        | 6        | 6        | 2        | 9        |

3 A first measurement of the SNIa rate at \(z \sim 0.15\)

Our preliminary determination of the SNIa rate at \(z \sim 0.15\) relies on a sample of type Ia supernovae discovered during 2 search campaigns led in October and November 1997. 120 square degrees have been covered, 8 supernovae discovered. Among them, 4 were of type Ia.

Supernovae rates \(R\) in the rest frame are usually expressed in SNe/10^10 \(L_{\odot}/100\ yr\). The number of supernovae of a given type discovered during a search is related to the rate \(R\) of this type of SNe through

\[
N \sim R \times \sum_{gal} L_{gal} \times T_{gal}
\]

where \(L_{gal}\) is the absolute luminosity of the galaxy \(gal\), and \(T_{gal}\) is the control time during which a SNIa could have been detected. If \(\varepsilon(t, z, \ldots)\) is the search efficiency, i.e. the probability to detect a SNIa with redshift \(z\) whose maximum occurred at a time \(t\) before the observation, \(T_{gal}\) can be written as \(T_{gal} = \int_{-\infty}^{+\infty} \varepsilon(t, z, \ldots) dt\).

The sum \(S = \sum_{gal} L_{gal} \times T_{gal}\) is computed by Monte-Carlo integration. Firstly the galaxies in the search fields are detected using the program *sextractor* (Bertin et al. [8]). Their apparent magnitudes are derived in the \(R_c\) band from the EROS2 magnitudes. Since the redshift of each galaxy is not known, a value of \(z\) is generated in the Monte-Carlo procedure, using a \(p(z|R_{gal})\) pdf derived from the Schechter law with parameter values measured by the LCRS (Lin et al. [10]).

[^1]: 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 & Rabinowitz), *QUEST* (⊤) (Schaefer et al.), *SpaceWatch* (+) (McMillan & Larsen), *The Tenagra Observatories* (⊙) (Schwartz), and *The Wise Observatories Supernovae Search* (▽) (Gal-Yam et al.).
The absolute luminosities of each galaxy can then be calculated. The detection efficiency is fully simulated. The SN rate we thus obtain is

$$ R = 0.44^{+0.35}_{-0.21} \pm 0.13 \, h^2 \, h_{\text{SNu}}. \hspace{1cm} (2) $$

By multiplying this value by the luminous density of the universe $\rho_L = 1.4 \pm 0.1 \, 10^8 \, hL_\odot \, Mpc^{-3}$ (Lin et al.\cite{lin}) we obtain the rate expressed in $h^3 \, Mpc^{-3} \, \text{year}^{-1}$

$$ R = 0.62^{+0.49}_{-0.29} \pm 0.19 \, 10^{-4} \, h^3 \, Mpc^{-3} \, \text{year}^{-1}. \hspace{1cm} (3) $$

**Conclusion**

Since 1997, the EROS2 collaboration has conducted several campaigns of supernovae searches. Our discovery rate is about 1 SN every two hours of observations, which makes us competitive with respect to other teams carrying on searches at the same $z$. In a first stage, 35 SNe were discovered, the light curves of 7 SNIa were studied, and a first SNIa explosion rate at $z \sim 0.15$ was derived. In Spring 99, EROS2 participated in a worldwide search led by the *Supernovae Cosmology Project*, and discovered 8 of the 19 SNIa near maximum found by the consortium. Photometric and spectroscopic follow-up data are currently been analyzed, and results are expected to come out soon.
References

1. M. Hamuy et al., *The Astronomical Journal* **112**(6), 2391 (1996).
2. G. Aldering et al., *IAUC* 7046 (1998).
3. S. Perlmutter et al., *Astrophysical Journal* **517**, 565P (1999).
4. P. Schmidt et al., *Astrophysical Journal* **507**, 46S (1998).
5. E. Cappellaro et al., *Astronomy & Astrophysics* **322**, 431C (1997).
6. R. Pain et al., *Astrophysical Journal* **473**, 356P (1996).
7. D. Hardin et al., Type Ia supernovae rate at $z \sim 0.15$, in preparation.
8. G. Bertin et al., *Astronomy & Astrophysics Suppl. Ser.* **117**, 393-404 (1996).
9. P. Madau et al., *Mon. Not. R. Astron. Soc.* **297**, L17-L22 (1998).
10. H. Lin et al., *Astrophysical Journal* **464**, 60L (1996).
11. D. Hardin, *PhD Thesis* DAPNIA/SPP 98-1002 (CEA 1998).
12. J.-C. Hamilton, *PhD Thesis* PCC 99-T1 (1999).