UBVRI Photometry of SN 2002er around Maximum Light

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ABSTRACT

With the aim of studying in great detail the physics of type Ia supernovae (SNe), all major European institutes working in this field have submitted a joint proposal for a EU Research Training Networks (RTN) under Framework 5 in spring of 2001. The application was successful and the RTN, also named "European Supernova Collaboration (ESC)", officially started its operations in July, 2002. But already a couple of months earlier the collaboration began to collect data for nearby SNe Ia, leaning on a large number of observatories world wide.

In this paper we present preliminary results for SN 2002er in UGC 10743, which was one of the first targets followed up by the RTN. This object was observed at different sites, including Calar Alto, where we could make use of the 2.2m telescope equipped with CAFOS, which played a fundamental role in securing a very good time coverage, both for photometry and spectroscopy.

1 Introduction

Even though significant progress has been made in recent years, many of the properties of SNe Ia remain largely uncertain. To address this problem, all European institutes working in this field have successfully applied for a Research Training Network ("The Physics of Type Ia Supernova Explosions", P.I.

W. Hillebrandt)[1]. One of the main targets of this project is the collection of a large and homogeneous database of optical and IR SN Ia light curves and spectra at low redshifts ($v_{gal} \leq 4000$ km s^{-1}). This is necessary in order to be able to search for systematic differences, evolution and/or environmental effects, and for the comparison with model predictions. All these points are crucial in the use of these objects as cosmological probes. In fact, a serious problem which one has to face when dealing with SN Ia, is that the data-base on which the light curve shape-luminosity relation is based, includes both high and low red-shift objects. This implicitly assumes that SN Ia properties are the same, no matter what the age of the universe is. This hypothesis is rather weak and still far from being definitely demonstrated. Moreover, in the SNe sample there are only few objects with excellent phase coverage, a fact which is crucial for looking at possibly small differences caused by the SN evolution.

SN 2002er ($\alpha = 17^h11^m29^s.88$, $\delta = +7°59'44''.8$, J2000) is one of the first targets of the RTN (see Fig. 1). It was discovered on August 23.2 in UGC 10743, 12''.3 West and 4''.7 North of the galaxy nucleus, during the LOTOSS-KAIT SN search (Li et al. 2002). On the basis of a low resolution spectrum taken at La Palma with the INT on August 26.9 UT, the SN candidate was classified by some of the RTN members as a type Ia, approximately 10 days before maximum brightness (Smartt, Patat & Meikle 2002).

Considering the early epoch of the discovery and the proximity of the host galaxy ($v_r = 2568 \pm 7$ km s^{-1}, Falco et al. 1999), this SN fully satisfied the criteria that were agreed upon for an object to be suitable for the RTN project. Therefore, target of opportunity observations were immediately triggered at all available telescopes and, mainly thanks to the contribution of Calar Alto Observatory, almost a daily coverage could be achieved, both for photometry and spectroscopy.

In this paper we present the preliminary photometric results from the first epoch until 20 days past maximum light. Final results, including the analysis of the bolometric light curve, will be discussed in a forthcoming paper (Pignata et al., in preparation), while we will devote another work to spectroscopy (Kotak

[1]More information about the project and participating institutes can be found at the following URL: `http://www.mpa-garching.mpg.de/~rtn/`

et al., in preparation).

2 Observations and Data Reduction

Photometry of SN 2002er around maximum brightness was obtained mainly using the 2.2-m telescope at Calar Alto, equipped with a LORAL 2048×2048 px CCD (0.53 arcsec px^{-1}) and SiTe 2048×2048 pixel CCD (0.33 arcsec px^{-1}). Additional photometry was collected at the 1-m JKT telescope at La Palma (0.33 arcsec px^{-1}), 0.8-m Wendelstein telescope on the Bavarian Alps (0.50 arcsec px^{-1}), 1.54-m Danish telescope at ESO La Silla (0.39 arcsec px^{-1}) and the 1.82-m telescope at Asiago Observatory (0.34 arcsec px^{-1}).

Basic data reduction (bias and flat-field correction) was performed using standard routines in IRAF. Selected observations of standard fields (Landolt 1992) during photometric nights have been used to calibrate a local standard sequence and to compute the color terms for each instrument.

Photometry was performed using the PSF fitting technique, because the SN was projected on a region with quite a complicated background.

3 Interstellar Extinction

Already from the spectrum which was used to classify the SN it was clear that a significant amount of extinction along the line of sight was present both in the host galaxy and in the Milky Way (Smartt et al. 2002). This was somehow expected because of the SN position within UGC 10743 (see Fig. 1) and its relatively low galactic latitude (b=+26°).

In order to estimate the intrinsic luminosity of the SN it is crucial to correct for this effect. For this purpose we have assumed the intrinsic color at B maximum to be that of *standard* type Ia's, namely $(B-V)_0 = -0.07 \pm 0.03$ (Leibundgut 2000). Since the observed $B-V$ color at B max is 0.38±0.05, the corresponding color excess turns out to be $E(B-V)$ =0.45±0.06. A similar result is obtained with the overall comparison to the $B-V$ color curve of SN 1994D (see Fig. 2), which suffered a small extinction (Patat et al. 1996).

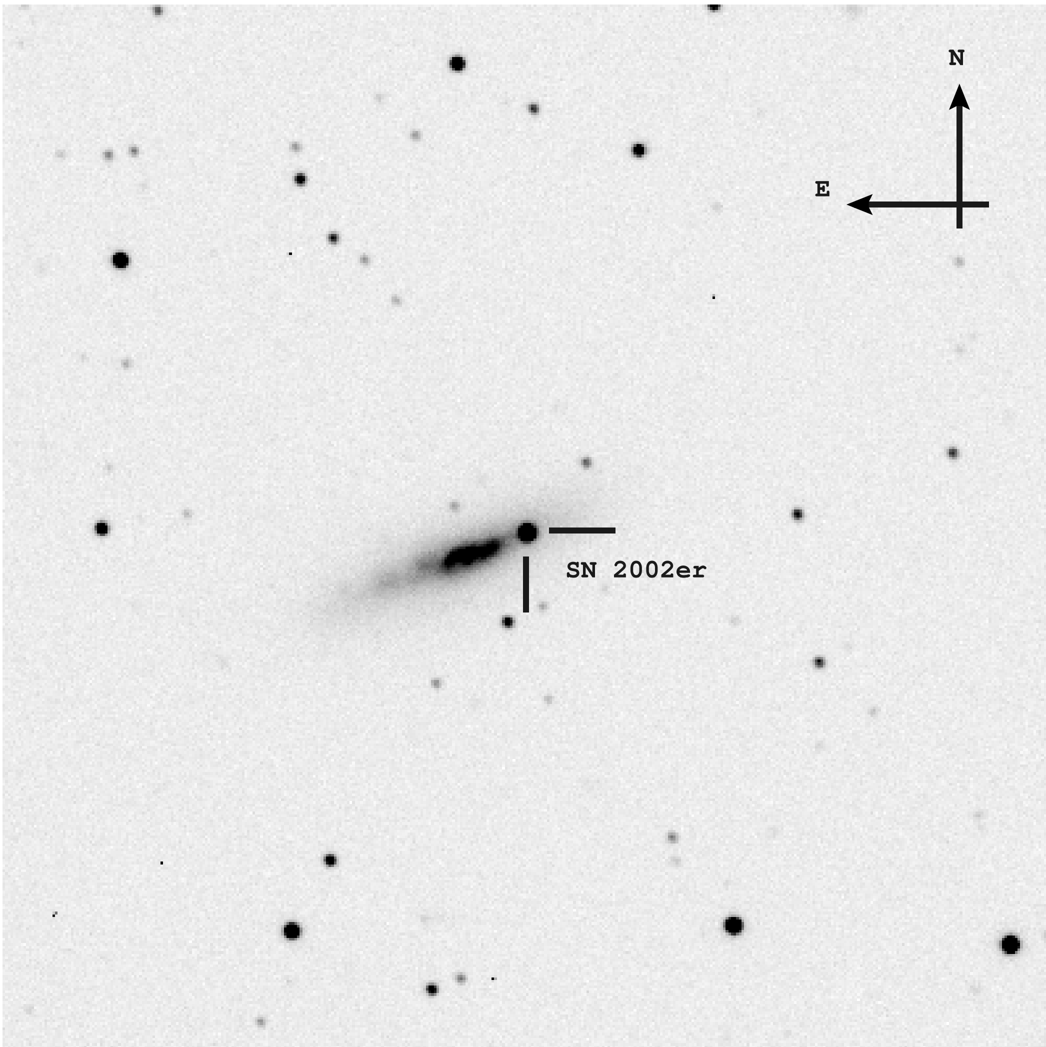

Figure 1: Image of SN 2002er in UGC 10743 obtained at Calar Alto with 2.2-m+CAFOS in the V passband on August 30, 2002.

Now, since the color excess produced by the Milky Way along the line of sight to SN 2002er is 0.16 (Schlegel et al. 1998), this implies that the SN is strongly absorbed by host galaxy, with $E(B-V)_{host} \approx 0.3$.

This is not surprising, since the SN appears projected onto the disk of UGC 10743, which has been recently classified as a Sc (Christensen et al. 2003), and therefore is believed to be rich in dust and gas. Adopting the canonical relation $A_B/E(B-V)$=4.32 (Schlegel et al. 1998) we get A_B=1.9±0.3 for SN 2002er. We note that the uncertainty on the A_B estimate is probably larger than the quoted error. In fact, as we have seen before, roughly 65% of the color excess is produced within the host galaxy and, as usual, there are no evidences that the Schlegel ratio, which was found for our galaxy, holds for UGC 10743 as well.

As we have already mentioned, clear indications of a strong absorption in the host galaxy are also present in the spectra of SN 2002er. As a matter of fact, Smartt et al. (2002) measured an interstellar Na ID lines equivalent widths of 1.1±0.1 Å for the Milky Way and 1.2±0.1 Å for UGC 10743. Applying the empirical relation found by Barbon et al. (1990) one gets a global $E(B-V) \simeq$0.58, a value which is higher than that obtained from the color curve fitting. Nevertheless, we must note that the use of this empirical relation implicitly assumes that the gas-to-dust ratio in the Milky Way and UGC 10743 is the same, a hypothesis which is by no means necessarily true.

Unfortunately, the large uncertainty on the extinction suffered by SN 2002er has a strong impact on the estimate of its intrinsic luminosity. In the following we will adopt the extinction derived assuming an intrinsic color at maximum.

4 *UBVRI* Light Curves

The *UBVRI* light curves of SN 2002er are shown in Fig. 3. For comparison, the light curves of SN 1994D (Patat et al. 1996), which is commonly believed to be a *standard* SN Ia, are also sketched. In the U, B and V passbands the light curves of the two SNe are rather similar, while in R and I filters some differences seem to be present, in the sense that the light curve peak appears to be broader in SN 2002er. However, before drawing any firm conclusion we

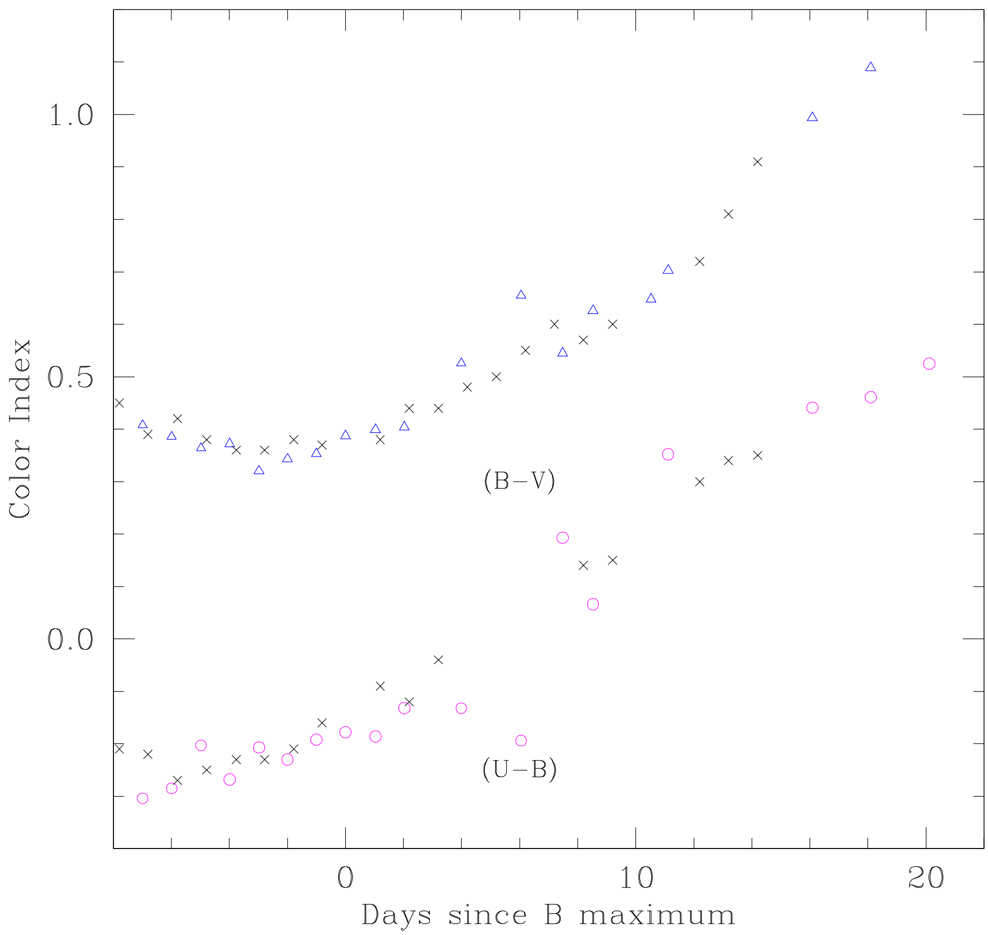

Figure 2: Colour curves for SN 2002er. Triangles indicate $B - V$ color and circles refer to $U - B$ color. The crosses trace the color curves of SN 1994D (Patat et al. 1996), shifted by +0.45 $(B - V)$ and +0.35 $(U - B)$ magnitudes respectively.

prefer to complete the reduction of the whole data set, which will extend the time coverage to 40 days past maximum, and hence will include the secondary maximum.

As usual, the widths of the light curves core increase going from U to I and a hint of secondary maximum is perceivable in the reddest wavelengths at about 20 days past B maximum, which was reached on September 6, 2002 (JD=2452523.9) at a magnitude B=14.90±0.02.

Another fundamental parameter to be computed is the so-called Δm_{15} which, for a given passband, is the luminosity decrease during the first 15 days after maximum light expressed in magnitudes. Since the SN is reddened and Δm_{15} is known to depend on extinction (Phillips et al. 1999), it is necessary to apply a correction to the observed value. In the case of B passband and adopting the relation found by Phillips et al. (1999)

$$\Delta m_{15}(B) \simeq \Delta m_{15}(B)_{obs} + 0.1 \times E(B-V)$$

one gets $\Delta m_{15}(B)$=1.27±0.1. This value is indeed very similar to that found for SN 1994D (1.26, Patat et al. 1996), not too a surprising result, since the light curves of the two SNe are pretty similar (see Fig. 3); the higher slope shown by SN 1994D is in fact compensated by correction implied by the large reddening which affected SN 2002er.

These similarities between the two targets suggest that the intrinsic luminosities should also be comparable.

5 The Absolute Magnitude of SN 2002er

With the data available so far, the absolute magnitude of SN 2002er can be derived in two ways:

1. Assuming H_0=65 km s^{-1} Mpc^{-1} we can derive a distance modulus of 33.0±0.4 for host galaxy. Then, taking into account the estimated A_B, we obtain $M_B^{max} = -20.0 \pm 0.5$.

2. Alternatively we can use the relation between M_B^{max} and Δm_{15} found by Hamuy et al. (1996):

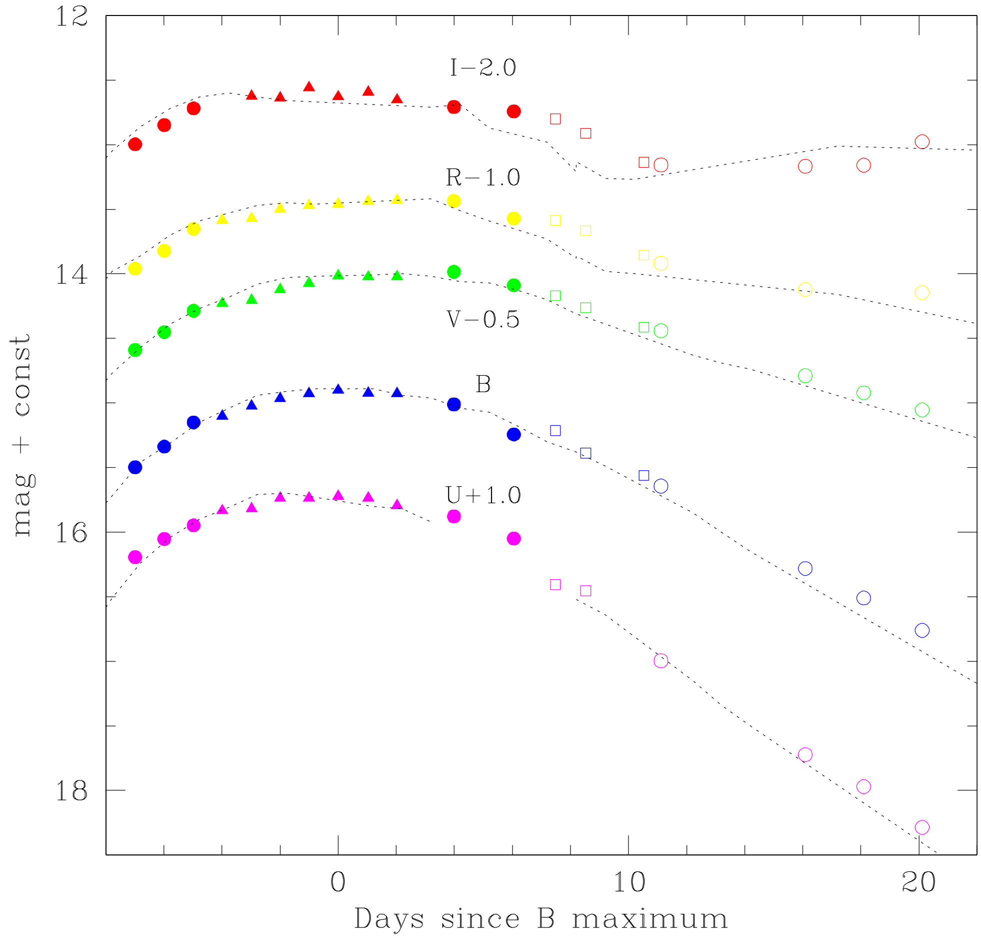

Figure 3: *UBVRI* broad-band light curves of SN 2002er. Different symbols refer to different observatories: Calar Alto (2.2m+CAFOS, filled triangles and circles), La Silla (1.54+DFOSC, empty circles) and La Palma (JKT+JAG, empty squares). The dashed lines represent the light curves of SN 1994D.

$$M_B^{max} = -19.256 + 0.860 \times [\Delta m_{15}(B) - 1.1]$$

This equation, applied to the case of SN 2002er, gives $M_B^{max} = -19.1 \pm 0.2$.

The value derived with the second method is indeed very similar to that of SN 1994D, which was obtained using a distance modulus inferred from the SBF method. We note that this result is not really useful for our purposes, since it is based on a relation that we actually want to check, and this has to be done with independent luminosity estimates.

Taken at face value, the result from the assumption of an intrinsic color (which seems reasonable due to the fair resemblance between the light curves of SNe 1994D and 2002er) seems to tell us that SN 2002er is brighter than predicted by the Pskowski-Phillips relation.

6 Light Curve Models

Observed light curves and spectra provide the most direct test of explosion models. According to "Arnett's Law" light curves measure mostly the amount and spatial distribution of radioactive ^{56}Ni in type Ia supernovae, and spectra measure the chemical composition in real and velocity space.

The standard model of a type Ia supernova is a white dwarf, composed of carbon and oxygen, near the Chandrasekhar mass, disrupted by thermonuclear burning. Recent explosion models (Reinecke et al. 2002) are essentially free of non-physical parameters. They can only vary the ignition conditions and the composition of the exploding white dwarfs and then allow to predict light curves and spectra.

Sorokina & Blinnikov (2002) have used the results of a typical 3-dimensional explosion model of Reinecke et al. (2002) (averaged over spherical shells) to compute colour light curves in the UBVI-bands. Their code assumes LTE radiation transport and loses reliability at later times (about 4 weeks after maximum) when the supernova enters the nebular phase. Also, this assumption and the fact that the opacity is not well determined at longer wavelength

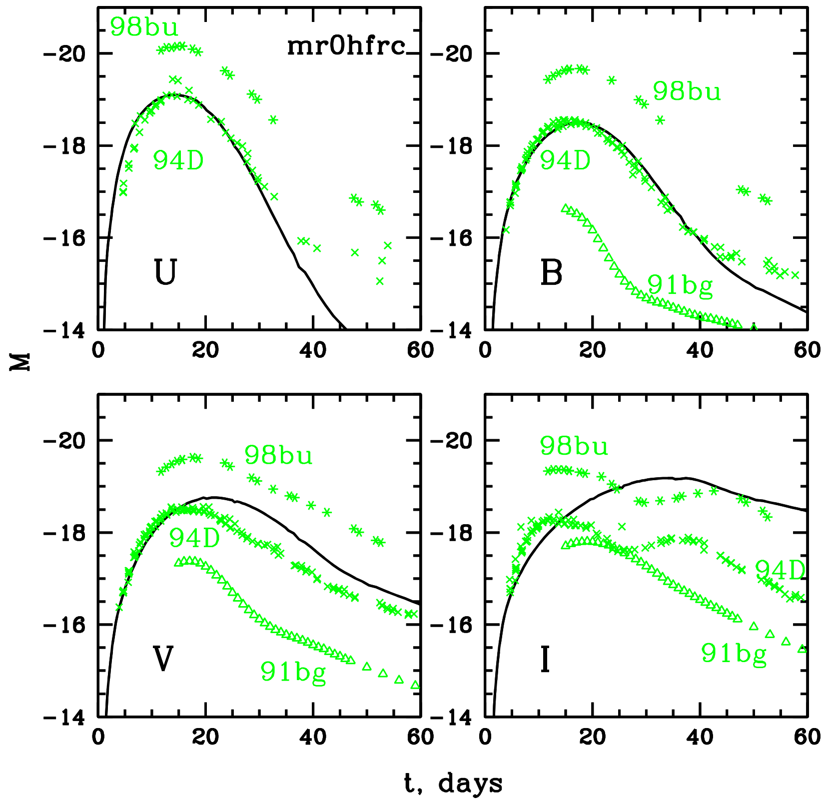

Figure 4: UBVI-colour lightcurves predicted by a centrally ignited 3D model (solid lines) in comparison with observed data for a bright (98bu), a "normal" (94D), and a subluminous (91bg) supernova. Note that the model had no adjustable parameters!

make I-light curves less accurate. Keeping this in mind, the light curves shown in Fig. 4 look very promising. The main reason for the good agreement between the model and SN 1994D (which had colour light curves very similar to SN 2002er) is the presence of radioactive Ni in outer layers of the supernova model at high velocities which is not be predicted by spherical models and, therefore, gives for the first time clear evidence for the 3-dimensional nature of the explosions.

7 Discussion and Conclusions

The availability of target of opportunity time allocated at different observatories, including Calar Alto, allows us to secure quite a good time coverage, which is one of the main goals for the observational part of the RTN project.

In fact, the use of SNe Ia in Cosmology heavily depends on the light curve shape vs. intrinsic luminosity relation which, in turn, is based on a small number of fiducial objects. Moreover, this relation remains totally empirical and no physical explanation has been given yet. For this reason there is a strong need of both verifying the validity of such relation with larger high quality data samples and to approach the problem from a theoretical point of view, starting with different explosion scenarios and going all the way through the spectrum and light curve synthesis. The comparison between well sampled data and the models is probably the only way for understanding what hides behind the so-called Pskowski-Phillips relation and, in the end, it will give the grade of reliability in the use of Ia's as cosmological probes.

SN 2002er is a nice example of what we want to achieve. Spectroscopic and photometric coverage is rather good, also thanks to Calar Alto Observatory, whose staff has greatly contributed to the observational campaign. We are still in the process of reducing the data collected from other observatories, an operation which is complicated by the different photometric systems.

In this paper we have presented the preliminary results with the reduced data available so far. The SN appears to be heavily reddened and shows probable deviations from SN 1994D in the shape of the secondary maximum, even though the values of Δm_{15} are very similar in the two objects.

As we have shown, the luminosity implied by the the distance modulus obtained from the Hubble law and the extinction derived from the assumption of an intrinsic color at maximum is larger than the one we get using the Phillips relation. This results is of course prone to the large uncertainty in the amount of interstellar absorption suffered by the SN and further work is required.

In particular, the analysis of spectroscopic data by means of synthetic spectra will give independent estimates for reddening and intrinsic luminosity and it will show other possible deviations in expansion velocities, line profiles and so on.

Based on our models we can *predict* light curves, spectra, and abundances, and the first preliminary results look promising. In particular, the lightcurves seem to be in very good agreement with observations. Of course, the next step to compare a grid of models with the increasing data base of well-observed type Ia supernovae. The hope is that this will give us a tool to understand their physics.

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