Physical Properties of SNe IIP Derived from a Comparison of Theoretical Models with Observations

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Abstract

The hydrodynamical modelling of Type II plateau supernova light curves predicts a correlation between three observable parameters (the plateau duration, the absolute magnitude and photospheric velocity at the middle of the plateau) on the one side and three physical parameters (the explosion energy E, the mass of the envelope expelled M, and presupernova radius R) on the other side. The correlation is used to estimate E, M, and R for a dozen of well-observed SNe IIP. For this set of supernovae, the resulting value of E varies within a factor of 5 $\left(0.5 \lesssim E/10^{51}\mathrm{erg} \lesssim 2.7\right)$, whereas the envelope mass turns out to be within the limits $10 \lesssim M/M_{\odot} \lesssim 30$. The presupernova radius is typically about $200 - 600\,R_{\odot}$ and seems to be as large as about $1000\,R_{\odot}$ or even larger for the brightest supernovae from the set (e.g., SN 1992am).

A new method of determining the SNe IIP distance is proposed. It based on an additional assumption of a possible correlation between the explosion energy E and the mass of ^{56}Ni produced to power the post-plateau light curve tail by means of the ^{56}Co decay. The method is thought to work for the SNe IIP with well-observed bolometric light curves both during the plateau and radioactive tail phases. The results are discussed in the context of cooperation between theoretical and observational projects in studying of supernovae.

Introduction

The plateau Type II supernovae (SNe IIP) are believed to come from the explosion of massive supergiant stars whose envelopes are rich in hydrogen. Their light curves are easy to identify by a long (sometimes up to 120–150 d) plateau which is the result of the propagation of a cooling-and-recombination wave (CRW) through the supernova envelope that is in state of free inertial expansion ($u = r/t$). The CRW physics is discussed in detail by Imshennik & Nadyozhin (1964), Grassberg et al. (1971), and Grassberg & Nadyozhin (1976). It propagates supersonically downward through the expanding supernova envelope and separates almost recombined outer layers from still strongly ionized inner ones. During the plateau phase, the photosphere seats on the upper edge of the CRW front. Since the CRW downward speed turns out to be close to the velocity of the outward expansion, the photosphere radius changes only slowly during the plateau phase. If one takes into account that the effective temperature does not change appreciably too (it approximately equals to the recombination temperature 5000–7000 K), the approximate constancy of the luminosity becomes quite clear.

The supernova outburst properties are determined mostly by three physical parameters: the explosion energy E, the mass M of the envelope expelled, and initial radius R of the star just before the explosion (presupernova). Litvinova and Nadyozhin (1983, 1985) have undertaken an attempt to determine these parameters from the comparison of the hydrodynamical supernova models with observations. They constructed simple approximation formulae which allow to estimate E, M, and R from the observations of individual SNe IIP. At that time, only one or two supernovae were observed at length enough to apply these formulae. At present, there exist detailed observational data for, at least, a dozen of such supernovae which we use below to estimate E, M, and R by means of the formulae mentioned above. Then we propose a new method of distance determination for those individual SNe IIP which are well-observed both at the plateau and radioactive-tail phases.

Hydrodynamic models versus observations

Figure 1 shows schematically the general view of the SNe IIP light curve. The plateau is defined as part of the light curve on which the supernova brightness remains nearly constant (more precisely, deviates from the certain mean value no more than 1^{m} on both sides). For some supernovae, the plateau begins almost immediately after the onset of the explosion ($t = 0$) whereas for others a short luminosity peak can precede the plateau. The peak either appears owing to a shock wave breakout in the case of presupernovae of not very large initial radii ($R \lesssim 1000\, R_{\odot}$) or, according to Grassberg et al. (1971), originates from the emergence of a thermal wave precursor for presupernovae of very large radii ($R \approx (2000 - 5000)\, R_{\odot}$) and of moderate explosion energies ($E \lesssim 1 \times 10^{51}$ erg), or at last may occur as a result of interaction between the supernova envelope and dense stellar wind (Grassberg & Nadyozhin 1987). For some SNe IIP the peak duration δt is only a few days long and can be hardly seen in observations (shock wave breakout), for others it could be as large as 10–20 days (thermal wave or dense wind)— perhaps, for such supernovae as SNe 1988A, 1991al, and 1992af (see below).

It is quite clear that the middle of the plateau is to be used as the main reference point to compare the theoretical models with observations. Litvinova and Nadyozhin (1983, 1985) (LN83 and LN85, hereafter) calculated a grid of the supernova models for E, M, and R changing within the limits $(0.18 - 2.91) \times 10^{51}$ erg, $(1 - 16)\, M_{\odot}$, $(300 - 5000)\, R_{\odot}$, respectively. They found E, M, R to be strongly correlated with the plateau duration Δt, and the middle-plateau values of the absolute V-magnitude M_V, and the expansion velocity

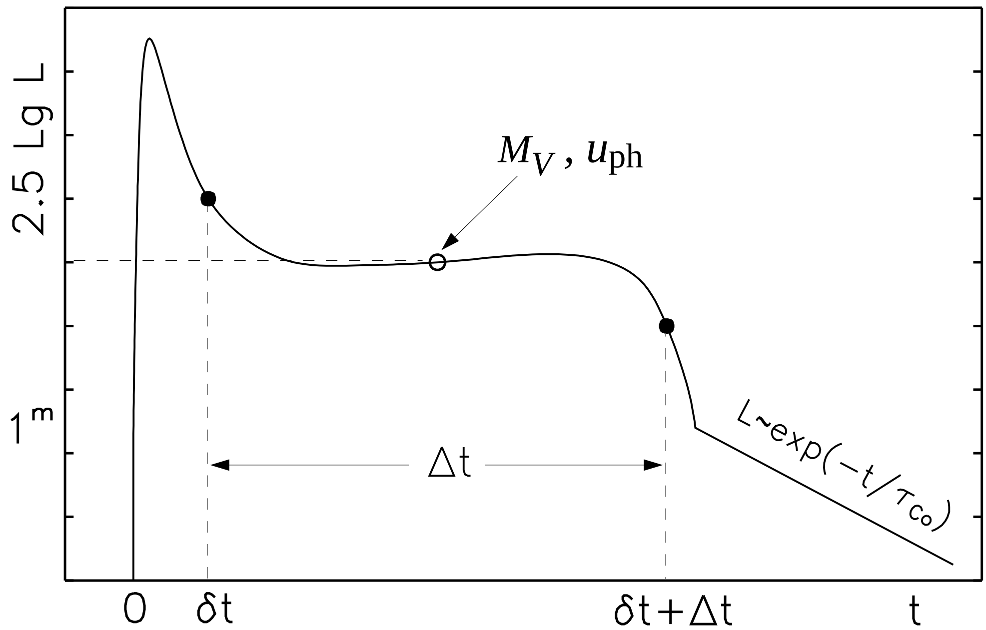

Figure 1: A schematic plot of the SN IIP light curve. An open circle marks the middle of the plateau whereas two black circles show the plateau boundaries. The light curve tail powered by the ^{56}Co decay is also shown ($\tau_{\rm Co} = 111.3\,$d)

$u_{\rm ph}$ at the level of photosphere (Fig. 1). According to LN85, the following approximate relations can be used to derive E, M, and R from observations:

$$\lg E = 0.135\, M_V + 2.34 \lg \Delta t + 3.13 \lg u_{\rm ph} - 4.205\,, \tag{1}$$
$$\lg M = 0.234\, M_V + 2.91 \lg \Delta t + 1.96 \lg u_{\rm ph} - 1.829\,, \tag{2}$$
$$\lg R = -0.572\, M_V - 1.07 \lg \Delta t - 2.74 \lg u_{\rm ph} - 3.350\,, \tag{3}$$

where E is expressed in units of 10^{51} erg, M and R are in solar units, Δt in days, and $u_{\rm ph}$ in $1000\,{\rm km\,s^{-1}}$. Here M_V can be expressed through the apparent magnitude V by the relation:

$$M_V = V - A_{V{\rm tot}} - 5 \lg(D/1{\rm Mpc}) - 25\,, \tag{4}$$

where D is the distance to a supernova and $A_{V{\rm tot}}$ is the total absorption on the way to the supernova. One can find from Eqs. (1)–(3) that E, M, and R scale with the distance as:

$$E \sim D^{-0.675}, \qquad M \sim D^{-1.17}, \qquad R \sim D^{2.86}\,. \tag{5}$$

Thus, it is very important to know D with as high accuracy as possible. We have chosen 14 supernovae whose observational data, relevant to our analysis, are collected in Table 1. The last column gives the references which served as the main sources to assume for each supernova just the data listed in columns 2–7. The heliocentric recession velocities $v_{\rm rc}$ of host galaxies (column 3) were used to determine the supernova distances D. First, $v_{\rm rc}$ was converted into v_{220} — the recession velocity corrected for a Virgocentric infall of

$220\,\mathrm{km\,s^{-1}}$ as provided by Kraan-Korteweg (1986), and then the distance D was calculated as $D = v_{220}/H_0$ with $H_0 = 60\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. The corresponding values of v_{220} and D are

Table 1: Input data

SN	Host galaxy	$v_{\rm rc}$ km s^{-1}	$A_{V\rm tot}$ mag	V mag	Δt days	$u_{\rm ph}$ km s^{-1}	Ref.
1968L	NGC 5236	516	0.219	12.0	80	4100	1, 2, 3
1969L	NGC 1058	518	0.203	13.4	100	4000	1, 2
1986L	NGC 1559	1292	0.099	14.7	110	4000	4
1988A	NGC 4579	1519	0.136	15.0	110	3000	1, 2, 4, 5, 6
1989L	NGC 7339	1313	0.423	16.5	120	2700	4, 7
1990E	NGC 1035	1241	1.083	16.0	120	4000	2, 4, 8, 9
1991al	LEDA 140858	4572	0.318	17.0	90	6000	4
1992af	ESO 340-G038	6000	0.171	17.3	90	6000	4, 7
1992am	anon 0122-04	14600	0.464	19.0	110	4800	4, 10
1992ba	NGC 2082	1104	0.193	15.43	100	2900	4, 7
1999cr	ESO 576-G034	6069	0.324	18.6	100	3600	4
1999em	NGC 1637	717	0.314	14.0	110	3000	4, 11, 12, 13, 17
1999gi	NGC 3184	592	0.65	15.0	110	2900	14, 15, 16, 18
1987A	LMC	278	0.60	3.3	110	2800	4

References.— (1) Patat et al. 1993; (2) Schmidt et al. 1992; (3) Wood & Andrews 1974; (4) Hamuy 2001; (5) Ruiz-Lapuente et al. 1990; (6) Turatto et al. 1993; (7) Schmidt et al. 1994a; (8) Schmidt et al. 1993; (9) Benetti et al. 1994; (10) Schmidt et al. 1994b; (11) Hamuy et al. 2001; (12) Haynes et al. 1998; (13) Baron et al. 2000; (14) Schlegel 2001; (15) Smartt et al. 2001; (16) Li et al. 2002; (17) Abouazza et al. 2002; (18) Leonard et al. 2002

given in columns 2 and 3 of Table 2. Now we have everything necessary to implement Eq. 4 and then Eqs. (1)–(3). The results are given in columns 4–7 of Table 2. The last column presents the mass of ^{56}Ni, ejected by some supernovae, which was estimated by reducing the radioactive-tail luminosities, measured by Hamuy (2001), to the distances given in column 3.

We have included also SN 1987A in our analysis although it is certainly beyond the scope encompassed by Eqs. (1)–(3) as far as it concerns the presupernova radius which, as is well known, was as small as $\approx 50\,R_\odot$. Moreover, the major part of the SN 1987A plateau (about 70 of 110 d) was powered by the ^{56}Co-decay (Imshennik & Nadyozhin 1989). Nevertheless, the resulting values of E and M (Table 2) differ no more than by a factor of 1.5 from current estimates based on a detailed study of SN 1987A. However, the presupernova radius turned out to be too large. This happened because the LN85 approximations do not take into account the radioactive heating. A special study (Grassberg & Nadyozhin 1986) demonstrates that the radioactive heating influences only weakly on E and M furnished by

Table 2: The supernova physical properties

SN	v_{220} km s^{-1}	D Mpc	M_V mag	E 10^{51}erg	M $M_\odot$	R $R_\odot$	$M_{\rm Ni0}$ $M_\odot$
1968L	291	4.85	−16.65	0.83	10.3	286	
1969L	766	12.77	−17.33	1.05	13.0	595	
1986L	1121	18.68	−16.76	1.56	23.5	251	0.027
1988A	1179	19.65	−16.60	0.67	14.5	452	0.080
1989L	1556	25.93	−16.69	0.57	14.5	618	
1990E	1238	20.63	−16.66	1.98	31.9	200	0.047
1991al	4476	74.60	−17.68	2.61	17.6	347	0.11
1992af	6000	100.00	−17.87	2.46	15.9	445	0.22
1992am	14600	243.33	−18.40	1.66	13.9	1321	0.36
1992ba	1096	18.27	−16.07	0.57	13.7	272	0.027
1999cr	6069	101.15	−16.75	0.90	14.5	368	0.080
1999em	743	12.38	−16.78	0.63	13.2	569	0.051
1999gi	707	11.78	−16.01	0.72	18.7	226	0.025*
1987A	—	0.05	−15.79	0.69	19.6	188	0.065

*Derived from $V = 17.^{\rm m}86$ at $t = 174.3$ d (Leonard et al. 2002), and Hamuy's recipe (section 5.3 of his Thesis) to convert V into luminosity L.

Eqs. (1)–(3), whereas the R-values can be overestimated by a factor of 3. In this connection, one should have in mind that for some supernovae the R-values from Table 2 can be larger than actual presupernova radii. By its physical properties, SN 1999gi proves to be the closest to SN 1987A.

According to Table 2, the resulting values of E, M, and R seem to be reasonable enough: the expelled mass, explosion energy, and presupernova radius remain approximately within the limits $(10 - 30)\,M_\odot$, $(0.6 - 2.6)\times 10^{51}$ erg, and $(200 - 1300)\,R_\odot$, respectively. Hamuy (2001) argued that SNe 1991al, 1992af were discovered several weeks after explosion. Their plateau, therefore, could last for $\Delta t \approx 110$ d. It is quite probable, however, that $\delta t \approx 20$ d for these supernovae by the reasons mentioned above. Having this in mind, we have chosen (Table 2) $\Delta t = 90$ d which results in $u_{\rm ph} = 6000$ km s^{-1}. In the case $\Delta t \approx 110$ d we would have to assume also $u_{\rm ph} = 7000$ km s^{-1} and would obtain from Eqs. (1) and (2) very large values of E and M for both the supernovae: $E \approx 7\times 10^{51}$ erg and $M \approx 40\,M_\odot$. No other special adjustments of the observational data were made.

Plateau-Tail Distance Determination

The SN IIP light curve tails are believed to be powered by the ^{56}Co decay. The temporal behavior of the luminosity is given by (see, e.g. Nadyozhin 1994):

$$L = 1.45\times 10^{43}\ \exp\left(-\frac{t}{\tau_{\rm Co}}\right)\frac{M_{\rm Ni0}}{M_\odot}\,{\rm erg\ s}^{-1}\,, \qquad (\tau_{\rm Co} = 111.3\,{\rm d})\,, \tag{6}$$

where t is measured from the moment of explosion ($t = 0$) and $M_{\rm Ni0}$ is the total mass of ^{56}Ni at $t = 0$ which decays with a half-life of 6.10 d into ^{56}Co.

Equation (6) can be written in the form

$$M_{\rm Ni0} = \frac{D^2}{145}\,Q, \qquad Q \equiv F_{41}(t)\exp\left(\frac{t}{111.3}\right), \tag{7}$$

where $M_{\rm Ni0}$ is in $M_\odot$, t in days and D in Mpc. The quantity $F_{41}(t)$ is the tail luminosity measured at time t in units $10^{41}\,{\rm erg\,s}^{-1}$ under an assumption that the supernova is at the distance $D = 1$ Mpc. Equation (7) contains a single observational parameter Q that depends neither on t nor on D. Thus, it is absolutely unimportant at which t the luminosity is actually measured — one has only to be sure that the supernova really entered its tail phase. The last 3 columns of Table 3 give t and corresponding values of $F_{41}(t)$ and Q derived from Hamuy's (2001) Figures 5.7 and 5.8 excluding SN 1999gi for which the values were calculated from the data of Leonard et al. (2002).

If the value of $M_{\rm Ni0}$ were known, one would easily find the distance D from Eq. (7). So, we have to look for a way to estimate $M_{\rm Ni0}$ independently. Having this in mind, we put forward a hypothesis that the supernova explosion energy E should correlate with $M_{\rm Ni0}$ produced during the explosion. This means that

$$E = f\,(M_{\rm Ni0}) = f\left(\frac{D^2}{145}\,Q\right), \tag{8}$$

where under f we mean *a statistically admissible correlation function* rather than a strict mathematical relation. Inserting this expression for E into Eq. (1) and using Eq. (4) for M_V, we obtain an equation which can be solved for D when such quantities as $V - A_{V{\rm tot}}$, $u_{\rm ph}$, Δt, and Q are known from observations. Then for given D, we can find E, M, R, and $M_{\rm Ni0}$ from Eqs. (1)–(3), Eq. (4), and Eq. (7), respectively.

What we can say about the function $f\,(M_{\rm Ni0})$ at present, when the details of the SN II mechanism remain still ambiguous? First of all, we believe that a good amount of E might have come from the recombination of free neutrons and protons into ^{56}Ni just at the bottom of the envelope to be finally expelled (Nadyozhin 1978, Bethe 1996). Such a correlation should exist at least for typical SNe IIP with not very low explosion energies E, say $E \gtrsim 0.2\times 10^{51}$ erg.

The energy released in such a recombination, when an amount $M_{\rm Ni0}$ of ^{56}Ni produced, is given by

$$E_{\rm np\to Ni}\ =\ 1.66\times 10^{52}\,\frac{M_{\rm Ni0}}{M_\odot}\,{\rm erg}\,. \tag{9}$$

So, the production of only $\approx 0.06\,M_\odot$ of ^{56}Ni turns out to be sufficient to provide the standard explosion energy of 10^{51} erg. The current hydrodynamic models of the SN II explosions (Woosley & Weaver 1995; Rauscher et al. 2002) do not show a certain correlation between E and $M_{\rm Ni0}$ because in these models ^{56}Ni comes from explosive silicon and carbon-oxygen burning nearby the envelope bottom and its yield is sensitive to the mass-cut point. We bear in mind, however, a neutron-proton layer which is located somewhat deeper and recombines into ^{56}Ni providing a good amount of energy to convert a steady-state accretion shock into the outgoing blast wave.

Table 3: The tail-calibrated supernova physical properties ($\xi = 1$)

SN	D Mpc	M_V mag	E 10^{51}erg	M $M_\odot$	R $R_\odot$	$M_{\rm Ni0}$ $M_\odot$	$F_{41}(t)$ 10^{41}erg/(s Mpc^2)	t days	Q
1986L	29.67	−17.76	1.14	13.7	944	0.067	2.25×10^{-3}	180	0.0113
1988A	15.21	−16.05	0.79	19.6	217	0.048	4.96×10^{-3}	200	0.0299
1990E	29.16	−17.41	1.57	21.3	539	0.094	2.67×10^{-3}	200	0.0161
1991al	85.31	−17.97	2.38	15.0	509	0.14	8.13×10^{-4}	140	0.00286
1992af	86.45	−17.55	2.71	18.8	293	0.16	9.02×10^{-4}	140	0.00317
1992ba	19.85	−16.25	0.53	12.4	346	0.032	1.97×10^{-3}	200	0.0119
1999em	11.08	−16.54	0.68	15.0	414	0.041	1.26×10^{-2}	150	0.0485
1999gi	14.53	−16.46	0.63	14.5	411	0.038	5.41×10^{-3}	174	0.0259

Let us assume now that E is proportional to $E_{\rm np\to Ni}$:

$$E = \xi\, E_{\rm np\to Ni} = 16.6\,\xi M_{\rm Ni0} = 0.1145\,\xi\, D^2\, Q\,, \tag{10}$$

where, as usual, E is in 10^{51} erg, $M_{\rm Ni0}$ in $M_\odot$ and D in Mpc. This equation implies that the function f, introduced in Eq. (8), reads as $f(x) = 16.6\,\xi\, x$ where ξ is an adjustable parameter.

Inserting E from Eq. (10) and M_V from Eq. (4) into Eq. (1) and solving for D, we obtain:

$$\lg D = -0.374\ \lg(\xi\, Q) + 0.0505\,(V - A_{V{\rm tot}}) + 0.875\ \lg \Delta t + 1.17\ \lg u_{\rm ph} - 2.482\,, \tag{11}$$

where D is in Mpc, Δt in days, and $u_{\rm ph}$ in $1000\,{\rm km\,s^{-1}}$. The resulting distances D, $M_{\rm Ni0}$, and all others values in question are given in Table 3 for 8 supernovae selected from Table 2. We did not include SNe 1992am and 1999cr in our analysis because their light curve tails were observed only at one time t and it is not yet clear whether they were already in the tail phase. Hence, the $M_{\rm Ni0}$-values for these SNe in Table 2 are actually the upper limits.

The distance D, defined by Eq. (11), weakly depends on V and $A_{V{\rm tot}}$: an error in $(V - A_{V{\rm tot}})$ of ±1 mag changes D only by $\pm12\%$. The dependence on Q is also not very strong, for instance the decrease in Q by a factor of 2 results in *increase* in D by 30% only.

Comparing the distances D from Table 3 (designated as $D_{\rm tail}$ hereafter) with D from Table 2 we can see a wonderful coincidence. For 6 SNe from the list, $D_{\rm tail}$ coincide with D

within the limits $\pm 23\%$ and only for two SNe (1986L and 1990E) $D_{\rm tail}$ are by a factor of 1.5 larger than D. The two SNe differ from others in Table 2 by having the largest masses M. In Table 3, their masses already are not so prominent. The coincidence seems to be really remarkable because $D_{\rm tail}$ come from the intrinsic supernova properties, and have nothing to do with the recession velocities and Hubble constant. We could even reduce the mean difference $(D_{\rm tail} - D)$ by optimising the coefficient ξ. However the value $\xi = 1$, assumed for Table 3, seems to be not so far from the optimal choice. Fortunately, the dependence of $D_{\rm tail}$ on ξ is not very strong: $D_{\rm tail} \sim \xi^{-0.374}$. So, the variation of ξ within a factor of 1.5 does not change appreciably the supernova physical properties in comparison with those listed in Table 3.

Discussion and conclusions

We have obtained a rather homogeneous set of the SN IIP presupernova properties listed in Tables 2 and 3. The explosion energy, envelope mass, and presupernova radius vary within reasonable limits: $(0.53-2.71)\times 10^{51}$ erg, $(10.3-31.9)\,M_{\odot}$, and $(200-1321)\,R_{\odot}$, respectively. We believe that these results can serve as a good guiding line in the elucidation of the intrinsic supernova properties by means of a tight interaction between the observational and theoretical projects.

We have to notify, however, that the results, obtained here with the aid of the correlations demonstrated by our hydrodynamical models and approximated by Eqs. (1)–(3), should be considered carefully as far as it concerns individual supernovae: the corresponding rms deviations for this approximation are about $\pm 30\%$ for E and M. The errors in the observational values (especially in $u_{\rm ph}$ and Δt) could modify E and M by another factor of 1.3. So, it seems reasonable to assume an uncertainty factor of ~ 1.5 for the *individual* values of E and M in Tables 2 and 3. As to the presupernova radius R, it can be overestimated by a factor of 2–3 for the SNe with large values of $M_{\rm Ni0}$ such as 1991al, 1992af, and perhaps 1992am; this can happen because Eqs. (1)–(3) do not take into account the radioactive heating consistently.

Inspecting Tables 2 and 3, one can observe that the explosion energy E does not correlate with the presupernova mass M (the difference of $1.5-2\,M_{\odot}$ between a presupernova mass and expelled envelope mass M is unimportant here). This is clearly seen in Fig. 2 which also demonstrates that the radioactive-tail calibration does not improve the situation. For nearly the same mass $M \approx 15\,M_{\odot}$, the explosion energy E can differ by a factor of 4 – compare, for instance, the SN 1991al with SN 1999em. It is hard to impute this result only to the statistical errors mentioned above. So, it is reasonable to expect another parameter to be involved in the supernova mechanism. It could be the rotation (and magnetic fields) inherited by the collapsing stellar core or nonspherical jet-like perturbations of a random nature arising from the macroscopic neutrino-driven advection below the accretion shock which could launch the outgoing blast wave earlier when the recombination nuclear energy stored in a hot neutron-proton gas is not yet as large as it should be in the case of spherical symmetry. If this is correct one may expect that the asphericity of the

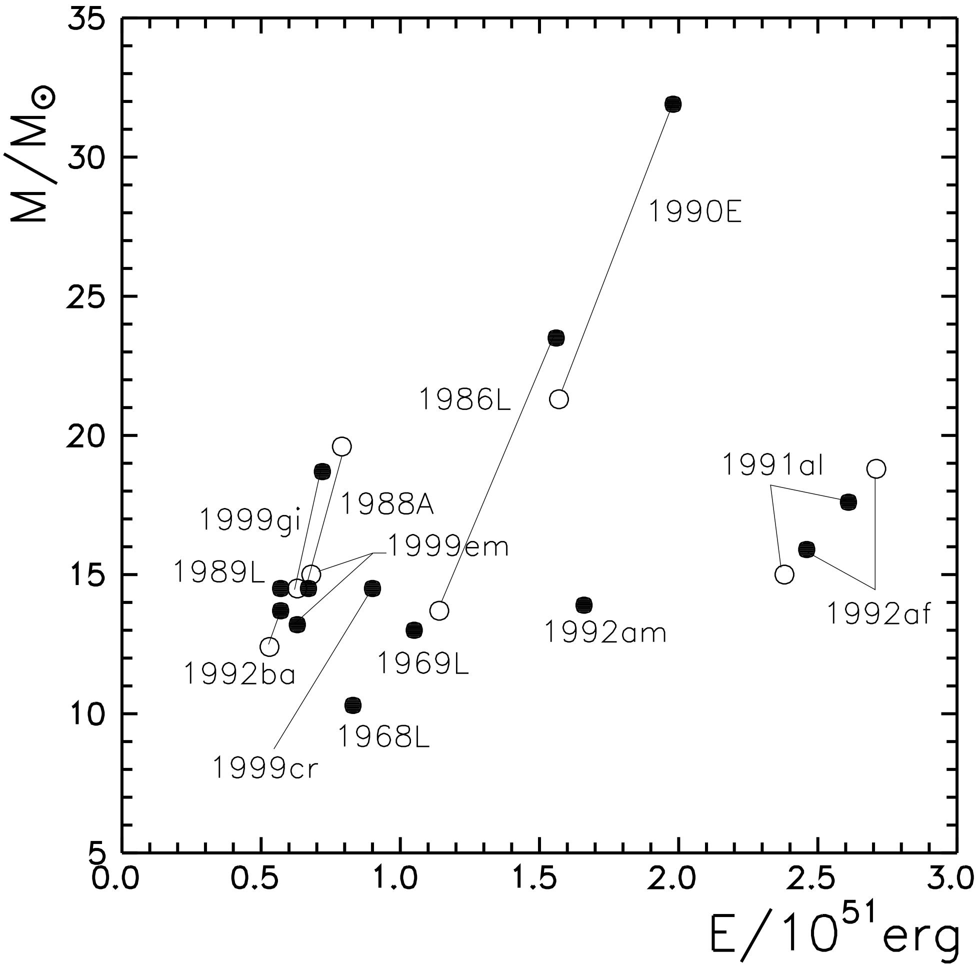

Figure 2: The explosion energy – envelope mass diagram for the supernovae listed in Table 2 for the case of Hubble distances (black circles) and in Table 3 for the case of radioactive-tail calibrated distances (open circles)

explosion *anticorrelates* with the explosion energy.

Recently, a promising project has been started by Smartt et al. (2001, 2002) with an ultimate aim to discover the supernova progenitors (presupernovae) or at least to impose conclusive constraints on their properties by inspecting the prediscovery images of stellar environment nearby supernovae. In particular, they derived the upper mass limits of $12\,M_{\odot}$ and $9\,M_{\odot}$ for the progenitors of the SNe 1999em and 1999gi, assuming the corresponding distances D for the host galaxies NGC 1637 and NGC 3184 of 7.5 Mpc and 7.9 Mpc, respectively. Note that these upper limits depend on D and have to be changed for other D to $12\,M_{\odot}(D/7.5\,\mathrm{Mpc})^{0.6}$ and $9\,M_{\odot}(D/7.9\,\mathrm{Mpc})^{0.6}$. This follows from the fact that the mass-luminosity relation can be approximated as $L \sim M^{3.3}$ in the mass interval $(10-15)\,M_{\odot}$. For the distance of 12.4 Mpc, assumed in Table 2 for SN 1999em, we have $16.2\,M_{\odot}$ as the upper mass limit. From the other side, if we assumed $D(1999\mathrm{em}) = 7.5\,\mathrm{Mpc}$ we would obtain $M \approx 24\,M_{\odot}$ [see Eq. (5)] in an obvious contradiction to the observations. Hence, our result

$M = 13.2\,M_\odot$ or even $M = 15.0\,M_\odot$ from Table 3 does not contradict to the observations *as long as* $D(1999\text{em}) \gtrsim 10\,\text{Mpc}$. We have similar situation also with the SN 1999gi. The upper mass limit for $D(1999\text{gi}) = 11.78\,\text{Mpc}$ (Table 2) is $M < 9 \times (11.78/7.9)^{0.6} = 11.4\,M_\odot$ that is not yet in a serious contradiction but, we would say, in a stimulating confrontation with our M-value of $18.7\,M_\odot$ from Table 2. There is no serious contradiction with the upper mass limit of $15^{+5}_{-3}\,M_\odot$ for the SN 1999gi progenitor imposed recently by Leonard et al. (2002) who argued the SN 1999gi distance to be of 11.1 Mpc that is nearly the same as in Table 2.

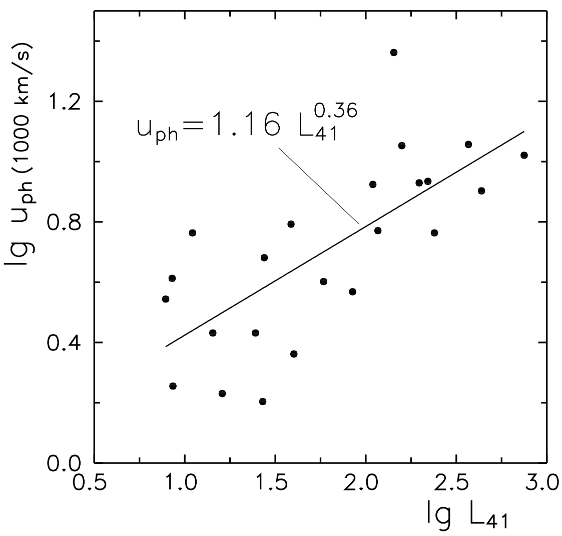

Figure 3: The $(L - u_{\rm ph})$ correlation

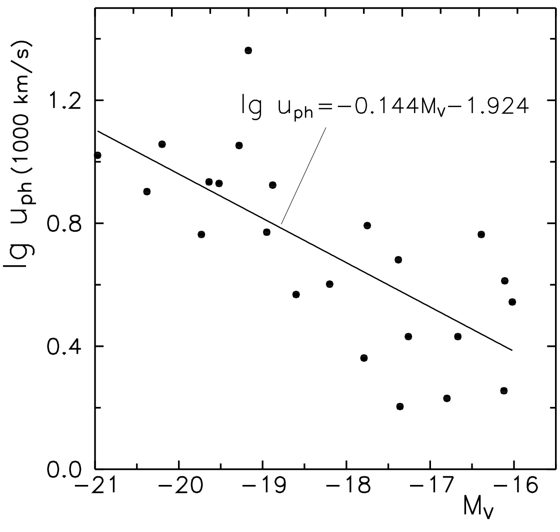

Figure 4: The $(M_V - u_{\rm ph})$ correlation

Equations (1)–(3) in no circumstances exhaust all possible correlations between various physical properties of SNe IIP. Theorists should follow astronomers which are so inventive in finding the correlations of different kinds. Recently, Hamuy & Pinto (2002) found a correlation between expansion velocities $u_{\rm ph}$ and bolometric luminosities L of the SNe IIP nearby the middle of their plateau phase and proposed to use the correlation for the distance determination. We looked into the hydrodynamical supernova models in LN83 and LN85 and found there the very same correlation. Figures 3 and 4 show this correlation and also an equally strong $(M_V - u_{\rm ph})$ correlation for all the 23 models used for creating Eqs. (1)–(3). The models are shown as black dots whereas the straight lines show the mean-square fits:

$$u_{\rm ph} \;=\; 1.16\,L_{41}^{0.36}\,, \qquad\qquad \lg u_{\rm ph} \;=\; -0.144\,M_V\,-1.924\,, \qquad (12)$$

where $u_{\rm ph}$ is in $1000\,\text{km}\,\text{s}^{-1}$. Our $(L - u_{\rm ph})$ correlation from Eq. (12) virtually coincides with that of Hamuy & Pinto (2002): $u_{\rm ph} \sim L^{0.33\pm0.04}$.

In conclusion we emphasize the necessity of constructing a new grid of the SN IIP hydrodynamic models based on current evolutionary presupernova models and taking into account ^{56}Ni as an additional parameter in a consistent way. Such a grid would allow to create more precise analytic approximations for a number of correlations between supernova physical parameters and observable properties of the SN IIP.

The "plateau-tail" method of distance determination needs, of course, further thorough calibration that requires a close collaboration between astronomers observing supernovae and theorists modelling their explosions.

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