FIRST PROOF

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A COMPARATIVE STUDY OF TYPE I AND TYPE II SUPERNOVAE

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Abstract. Revised photometric data are used to ompare the light and colour curves of type I and type II supernovae (SNe I, SNe II); their statistical properties are also compared. No significant difference between SNe I and SNe II has been found in their radial distribution and frequency of outbursts in spiral galaxies. The comparison of light and colour curves reveals several features common to both types and the possibility of transition between types. √

1. Introduction

Although in recent years considerable progress has been achieved in understanding the phenomenon of supernovae, the nature of supernova progenitors remains a challenge. It is now commonly accepted that SNe II come from short-lived massive stars; the nature of SNe I is more controversial. Their occurrence in E–SO galaxies suggests low mass long-lived Population II precursors, but Oemler and Tinsley (1979) showed that in spiral galaxies SNe I may be associated with young Population I.

The radioactive decay models of SNe I give a fair approximation to the observed light curves (Wheeler, 1982; Shurmann, 1983), but they face difficulties in explaining some observed correlations, for example, between the luminosity at maximum light and rate of brightness decline (Pakovskii, 1977, 1984; Branch, 1982). Besides, the maximum light √ spectra of SNe I showed element abundances which are inconsistent with some radioactive models (Branch *et al.*, 1983).

Barbon *et al.* (1973, 1979) have shown that all SNe I have similar light curves, while SNe II can be roughly divided into two subclasses: with linear decline (SNe II–L) and with the plateau (SNe II – P). Investigations of light curves have led Pskovskii (1977, 1978a, 1984) to a continuous classification of supernovae according to the rate of brightness decline. This rate was shown to correlate with the Doppler shift of absorption features in spectra, with absolute magnitude at maximum and some other parameters of light curves.

In this paper we compare the light and colour curves of SNe I and SNe II, using the photometric data, revised and compiled by Tsvetkov (1986) and analyse spatial distribution and frequency of outbursts of SNe I and SNe II.

2. Light and Colour Curves of SNe I and SNe II

We have recently collected and analysed photometric data on 56 SNe I and 22 SNe II. All available data for these supernovae have been reduced to a single photometric

Astrophysics and Space Science **000** (1986) 000–000.

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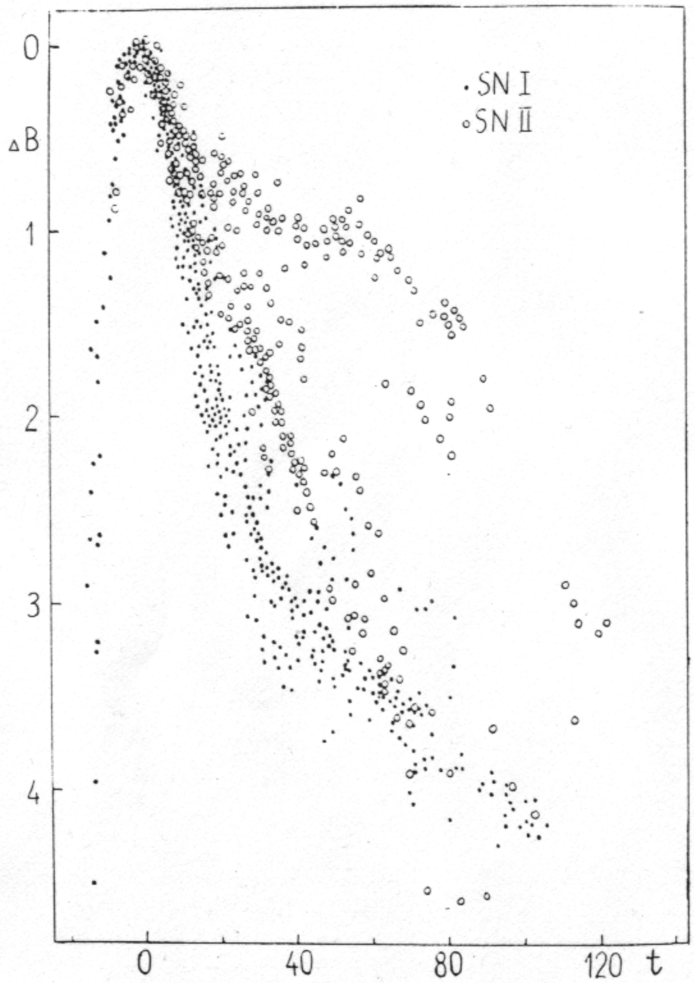
The comparison of SNe I and SNe II light and colour curves reveals the following common features:

(a) The light curves of SNe I and SNe II in *U* have similar shape, which resembles the shape of SNe I blue light curves. Even SNe II 1969l, which has on blue and visual light curves a plateau, lasting about 80^{d}, shows no sign of a plateau on the light curve in *U*.

(b) The composite blue light curves and colour curves of SNe I and SNe II practically coincide until the phase $\sim 15^{\mathrm{d}}$ past maximum, after this point the difference of blue light curves between SNe II–P and SNe I becomes evident, but SNe II–P have in general



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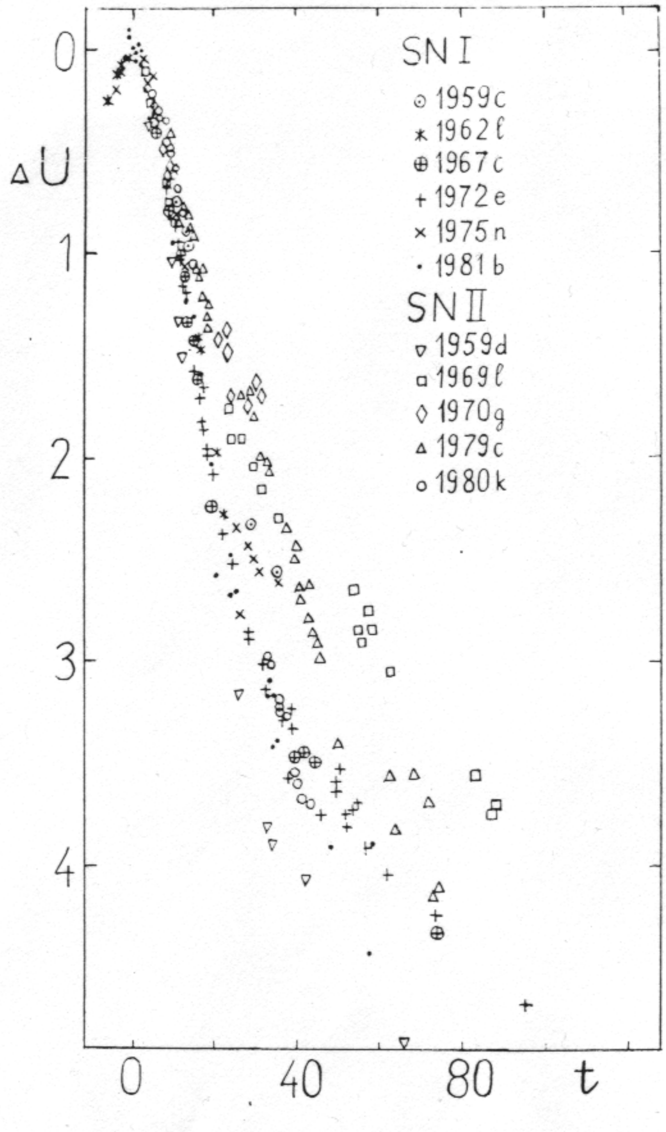

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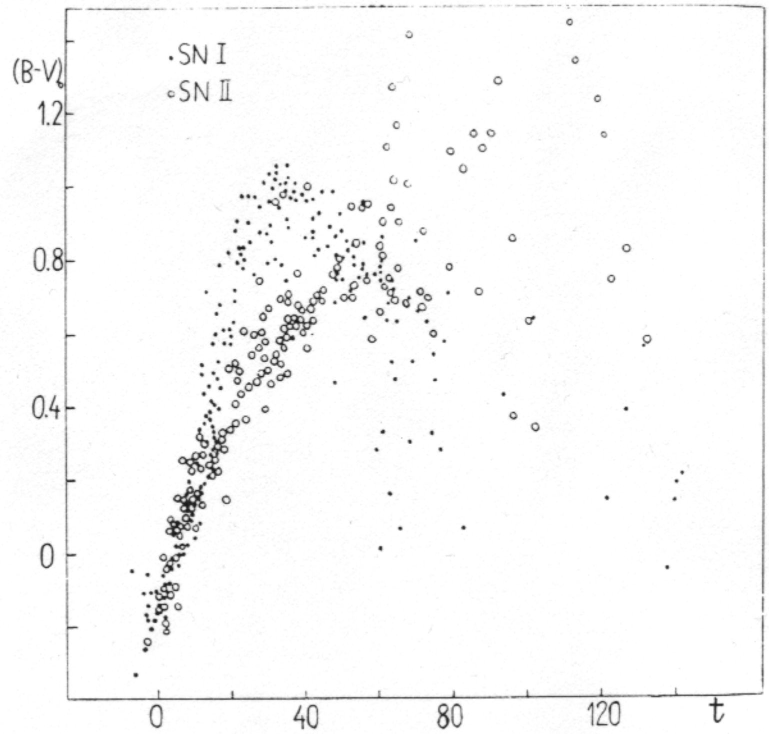
(c) Figures 4 and 5 show the supernova light curves which extend over a time interval exceeding 100^d. The final exponential decline is present for both SNe I and SNe II, as was recently emphasized by Barbon *et al.* (1984a). On the *B* light curve of SNe I the slope does not change after the first inflection point (point K, about 30^d past maximum), but the visual and especially infrared (Elias and Frogel, 1983) light curves show a second



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(d) The bolometric light curves for 2 SNe I and 3 SNe II are reproduced in Figure 6. The bolometric luminosity of supernovae was deduced from spectral scans of SNe 1972e and 19691 by Krishner *et al.* (1973) and from multicolour photometry. The spectral energy distribution has been integrated over the interval 3000–22000 Å for SNe I and 1000–22000 Å for SNe II. In the regions not covered by observations the energy distribution was approximated by the Planck function, best fitting the observed part of the spectrum. The accepted distances and reddening corrections are: for SN 1972e: $E_{B-V} = 0^m.05$, $D = 4$ Mpc; SN 1981b: $0^m.18$, 16 Mpc; SN 19691: $0^m.06$, 11 Mpc; SN 1979c: $0^m.02$, 16 Mpc; SN 1980k: $0^m.40$, 5 Mpc.

The shapes of bolometric light curves for SNe I and SNe II–L are similar, while SN II–P 19691 is distinguished from them by a plateau, which has the shape like on the *B* light curve. The interesting fact is the absence of any peculiarity on SNe I bolometric light curves at point K. The exponential decline sets at about 100^d after maximum light for all supernovae.

The already mentioned phase about 15^d after maximum is marked by several features on light and colour curves and in the spectral evolution of SNe I:

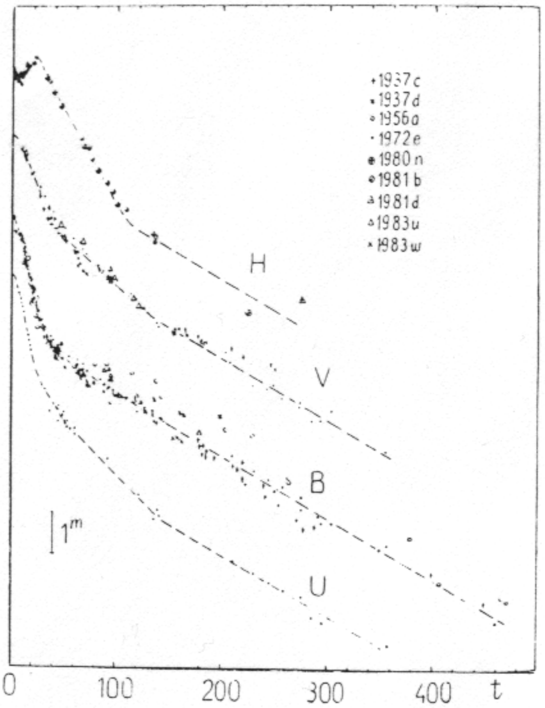


Fig. 4. Light curves of SNe I extending to ~400^d past maximum.

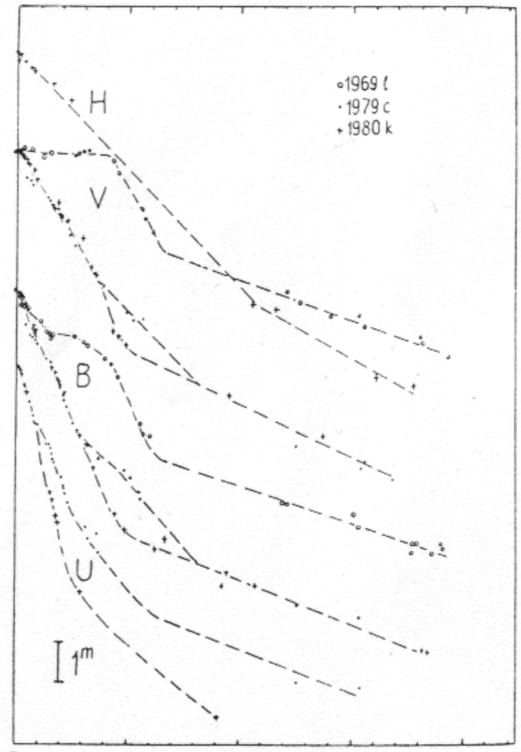


Fig. 5. Light curves of SNe II extending to ~400^d past maximum.

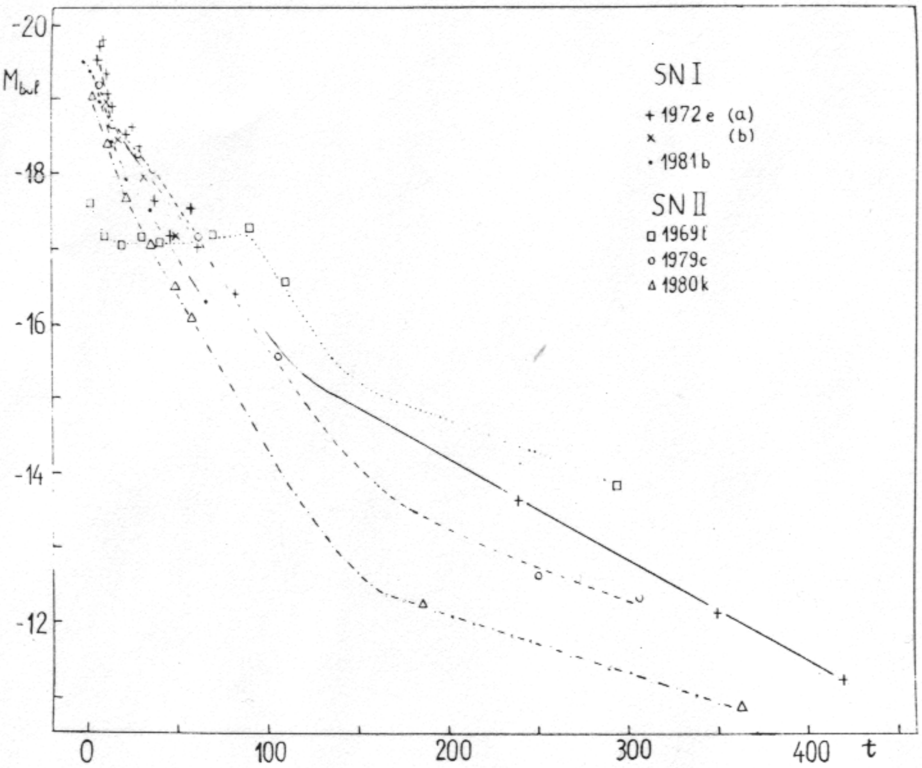


Fig. 6. Bolometric light curves of SNe I and SNe II. For SN I 1972e; *a*, data from Weaver *et al.* (1980); *b*, our data.

(a) Change of slope of $B - V$ colour curve, which is clearly seen on the best studied curve for SN 1972e.

(b) Minimum on infrared light curves (Elias *et al.*, 1981).

(c) The divergence of light and colour curves of SNe I and SNe II.

(d) Two emission peaks and four absorption troughs disappear and two new features appear in the spectrum of SN 1972e at J.D. 2441460 (phase about 15^{d}); the feature at λ 4600 Å drifts in wavelength at that time (Kirshner *et al.*, 1973). The drift of λ 4600 Å feature is also observed for SN 19621 (Bertola, 1964) and SN 1981b (Branch *et al.*, 1983).

(e) The radius of the photosphere, determined from $(B - V)_0$ vs temperature relation (Pskovskii, 1984) and absolute magnitude begins to increase with greater velocity than before (Bartunov and Tsvetkov, 1985).

The mentioned above facts allows to conclude that the phase $\sim 15^{d}$ past maximum, designated as 'point Λ' by Bartunov and Tsvetkov (1985) marks significant changes in physical parameters of SNe I envelopes.

3. Absolute Magnitudes of SNe I and SNe II at Maximum Light

Absolute magnitudes of 48 SNe I and 17 SNe II have been recently determined by Tsvetkov (1986). Distance estimates by de Vaucouleurs (1979, 1982) and de Vaucouleurs *et al.* (1981) were used; for galaxies not listed in these works we have used the radial velocity and the value of the Hubble constant $H_0 = 75$ km s^{-1} Mpc^{-1} to determine the distance. The absorption corrections were based on new estimates of colour excess E_{B-V}. The distribution of M_B^0(max) for SNe I and SNe II is shown in Figure 7. The dispersion of M_B^0(max) is larger for SNe II, but the scatter of M_B^0(max) for SNe I is also quite large and certainly exceeds 2^m. This cannot be explained by observational errors and by the errors in distance determination, because SNe I with the lowest and highest values of M_B^0(max) belong to the Virgo cluster and have small or zero values of E_{B-V}. Our conclusion is contrary to that of Cadonau *et al.* (1984) that SNe I are nearly perfect standard candles.

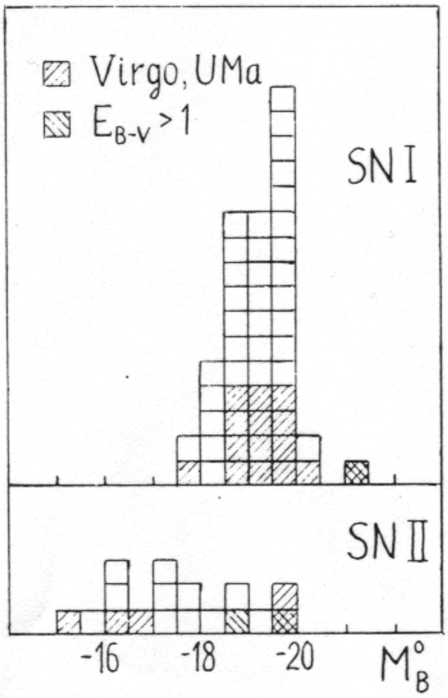


Fig. 7. The distribution of M_B^0(max) for SNe I and SNe II. Supernovae in Virgo and Ursa Major clusters of galaxies and with $E_{B-V} > 1^m$ are designated by hatched squares.

4. The Spatial Distribution of Supernovae

Radial distribution of SNe I and SNe II in spiral galaxies has been studied by Iye and Kodaira (1975), Guseinov *et al.* (1980), Tsvetkov (1981). Now we have collected data on 68 SNe I and 47 SNe II from Barbon *et al.* (1984b) and *IAU Circulars*, this is nearly

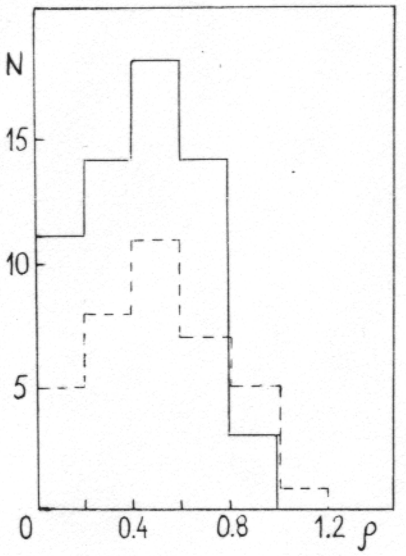


Fig. 8. The radial distribution of SNe I (solid line) and SNe II (dashed line) in spiral galaxies.

two times more than was used in previous studies. The relative radial distance of supernovae ρ was calculated using optical radii of galaxies from de Vaucouleurs *et al.* (1976), the correction for inclination was adopted following Iye and Kodaira (1975). The radial distributions of SNe I and SNe II are represented in Figure 8, they are practically identical. In Figure 9 the logarithm of supernovae surface density σ is plotted against ρ; for comparison the distributions of Novae in M31 and of blue supergiants in M33 are plotted. The first is different from the distribution of SNe I and SNe II, while the second is similar to them.

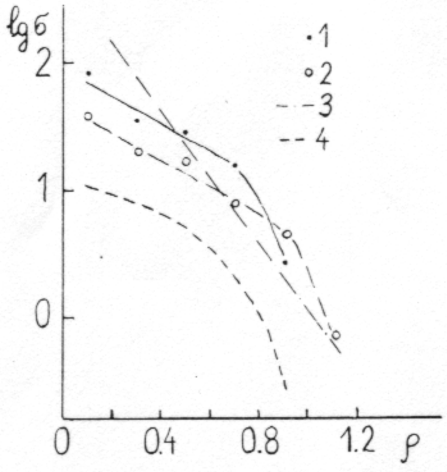


Fig. 9. The surface density of SNe I (1) and SNe II (2) in spiral galaxies as a function of ρ, compared with the surface density distribution of Novae in M31 (Sharov, 1982) (3) and of blue supergiants in M33 (calculated according to the data from Humphreys and Sandage, 1980) (4).

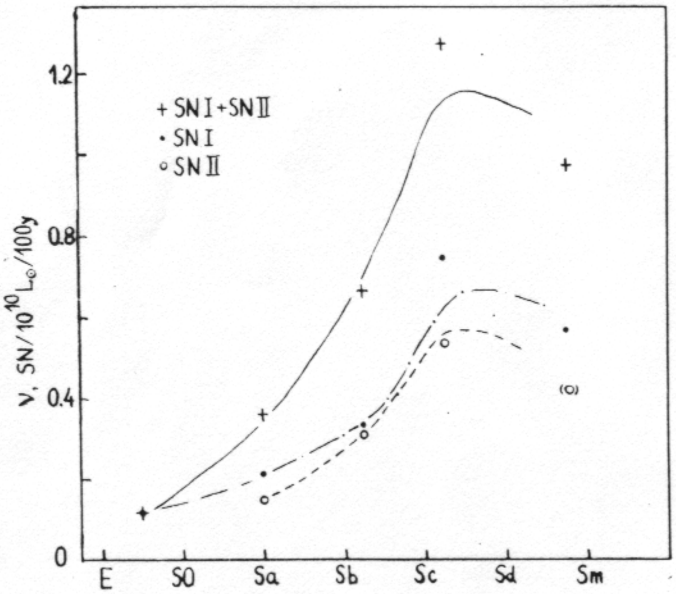
The comparison of mean *z*-coordinates of SNe I and SNe II by Tsvetkov (1981) also showed absence of difference; this result was confirmed on the basis of more large and homogeneous data (Tsvetkov, 1985).

5. The Frequency of SNe I and SNe II

We have recently obtained estimates of supernova frequency in galaxies of different morphological types on the basis of the observational data of supernova search at Sternberg Astronomical Institute Crimean station and at Asiago Astrophysical Observatory (Tsvetkov, 1983, 1985). Figure 10 shows the frequency of SNe I, SNe II, and all supernovae as the function of morphological type of galaxies. In Sa, Sb, and Sc galaxies the frequencies of SNe I and SNe II are nearly equal, only in E galaxies SNe II have not been detected (recently SNe II 1985g was discovered in SO galaxy NGC 4451), and in Sm–Im galaxies the SNe II frequency is likely to be lower than the frequency of SNe I (see also Oemler and Tinsley, 1979; or Tammann, 1982).

6. Summary and Discussion

The similarity of SNe I and SNe II in many aspects is the main conclusion of this work. This confirms earlier results of Oemler and Tinsley (1979) on frequency of supernova outbursts; Iye and Kodaira (1975) and Guseinov *et al.* (1980) on spatial distribution. The similarity of light curves of SNe I and SNe II–L was recently notices by Doggett and Branch (1985). This is important for attempts to classify the historical supernovae



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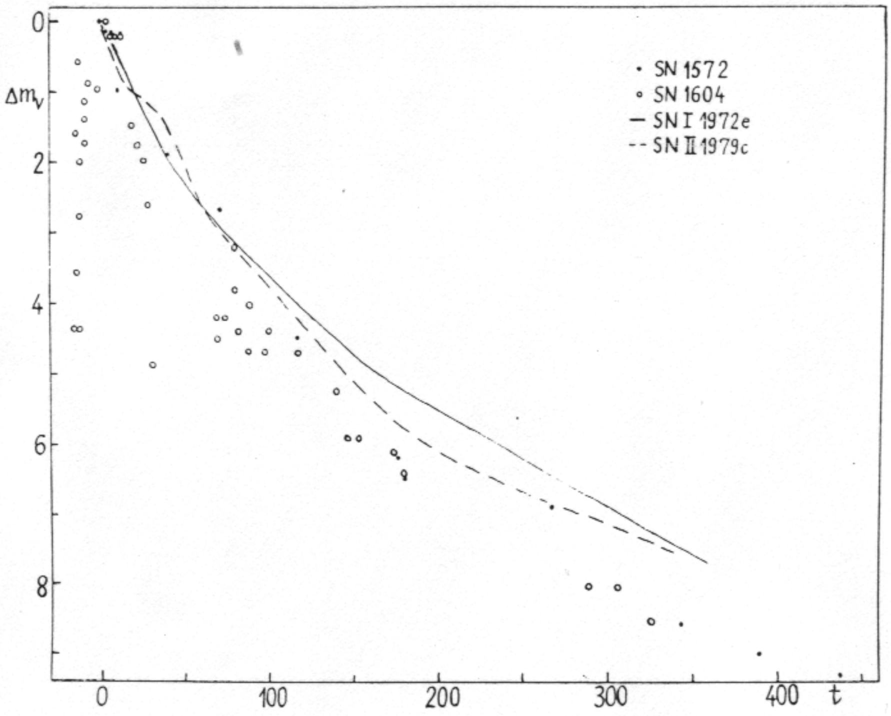

Fig. 11. Comparison of the visual light curves of 1572 and 1604 supernovae with the V light curves of SNe I 1972e and SNe II–L 1979c.

of 1572 and 1604. Figure 11 shows visual light curves of these supernovae (Pskovskii, 1978b) compared with the V light curves of SNe I 1972e and SNe II–L 1979c. No distinction between type I and type II–L can be made for these historical supernovae, the same conclusion was reached by Doggett and Branch (1985).

We should also note that the light curves in Figure 1 show the gradual transition from SNe I to SNe II–L and SNe II–P.

The comparison of SNe I and SNe II spectra by Krishner *et al.* (1973) revealed that the strongest features (except hydrogen lines) are the same, but the relative strength is different: the lines are stronger and more numerous in SNe I spectra. Kirshner *et al.* (1973) suggested that the main difference between SNe I and SNe II is in the chemical composition of their envelopes. We should like to note that SNe I have a deficit of ultraviolet radiation and so the ionization temperature is less than the temperature of the photosphere. When the temperature is higher than 10^4 K and $n_e \sim 10^{10}$, the elements like calcium, silicon, sodium are twice ionized, and the lines which belong to neutral and singly ionized atoms should be weak: this is the case of SNe II. SNe I have even at maximum light lower ionization temperature $\sim 5\text{–}7 \times 10^3$ K and the lines of Ca II, Si II, Fe II are stronger than for SNe II.

The similarity of SNe I and SNe II in statistical properties should indicate that the precursors of type I and type II supernovae have similar ages and initial masses. The opposite opinion is based mainly on results of Maza and van den Bergh (1976) who have found that SNe II are concentrated in spiral arms while SNe I show no preference for spiral arms. However, in earlier investigations by Johnson and McLeod (1963) and Bertola and Sussi (1965) SNe I were found to be associated wiht spiral structure, but less tightly than SNe II. Some SNe I discovered recently are clearly associated with spiral arms (SNe I 1974j, 1975p, 1975o, 1981b, 1983i). Our opinion is that the problem of association of SNe I with spiral arms is not yet resolved and new investigations are needed.

The connection between type of supernova and type of its remnant is also not clear. It was shown that the classification of supernovae of 1572 and 1604 as type I is doubtful, even less can be said on other historical supernovae. We have no reason to suppose that SNe II leave neutron stars while SNe I do not. The recent peculiar supernova 1985f in NGC 4618 (Filippenko and Sargent, 1985), which probably never exceeded absolute magnitude $\sim -14^m$ may be the type of supernova which produced the remnant Cas A, and we may expect more peculiar and faint supernovae to be discovered with the help of automated supernova search.

The difference between SNe I and SNe II may be due to different chemical composition, mass and structure of envelopes of their progenitors, but the mentioned above similar features show that these differences should not be very large. They may be caused by different intensity of mass loss, by evolution in close binary systems and other reasons. The outbursts of SNe I in elliptical galaxies may be due to star formation in some of them, this is supported by the results of Caldwell and Oemler (1981) and Guseinov *et al.* (1980).

References

Barbon, R., Cappellaro, E., and Turatto, M.: 1984a, *Astron. Astrophys.* **135**, 27.

Barbon, R., Cappellaro, E., Ciatti, F., Turatto, M., and Kowal, C. T.: 1984b, *Astron. Astrophys. Suppl.* **58**, 735.

Barbon, R., Ciatti, F., and Rosino, L.: 1973, *Astron. Astrophys.* **25**, 241.

Barbon, R., Ciatti, F., and Rosino, L.: 1979, *Astron. Astrophys.* **72**, 287.

Bartunov, O. S. and Tsvetkov, D. Yu.: 1985, *Astrofizika* **23**, 319.

Bertola, F.: 1964, *Ann. Astrophys.* **27**, 319.

Bertola, F. and Sussi, M. G.: 1965, *Contr. Asiago*, No. 176.

Branch, D.: 1982, in M. J. Rees and R. J. Stoneham (eds.), *Supernovae: A Survey of Current Research*, D. Reidel Publ. Co., Dordrecht, Holland, p. 267.

Branch, D., Lacy, C. H., McCall, M. L., Sutherland, P. G., Uomoto, A., Wheeler, J. C., and Wills, B. J.: 1983, *Astrophys. J.* **270**, 123.

Cadonau, R., Sandage, A., and Tammann, G. A.: 1984, Preprint No. 7, Astron. Institute Univ. Basel.

Caldwell, C. N. and Oemler, A.: 1981, *Astron. J.* **86**, 1424.

De Vaucouleurs, G.: 1979, *Astrophys. J.* **227**, 729.

De Vaucouleurs, G.: 1982, *Astrophys. J.* **253**, 520.

De Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G.: 1976, *Second Reference Catalogue of Bright Galaxies*, Univ. Texas Press, Austin.

De Vaucouleurs, G., Peters, W. L., Bottinelli, L., Gouguenheim, L., and Paturel, G.: 1981, *Astrophys. J.* **248**, 708.

Doggett, J. B. and Branch, D.: 1985, *Astron. J.* (in press).

Elias, J. H. and Frogel, J. A.: 1983, *Astrophys. J.* **268**, 718.

Elias, J. H., Frogel, J. A., Hackwell, J. A., and Persson, S. E.: 1981, *Astrophys. J.* **251**, L13.
Filippenko, A. V. and Sargent, W. L.: 1985, *Nature* **316**, 407.
Guseinov, O. H., Kasumov, F. K., and Kalinin, E. V.: 1980, *Astrophys. Space Sci.* **68**, 385.
Humphreys, R. and Sandage, A.: 1980, *Astrophys. J. Suppl.* **44**, 319.
Iye, M. and Kodaira, K.: 1975, *Publ. Astron. Soc. Japan* **27**, 411.
Johnson, H. M. and McLeod, J. M.: 1963, *Publ. Astron. Soc. Pacific* **75**, 123.
Kirshner, R. P., Oke, J. B., Penston, M. V., and Searle, L.: 1973, *Astrophys. J.* **185**, 303.
Maza, J. and van den Bergh, S.: 1976, *Astrophys. J.* **204**, 519.
Oemler, A. and Tinsley, B. M.: 1979, *Astron. J.* **84**, 985.
Pskovskii, Yu. P.: 1977, *Astron. Zh.* **54**, 1188.
Pskovskii, Yu. P.: 1978a, *Astron. Zh.* **55**, 350.
Pskovskii, Yu. P.: 1978b, *Astron. Zh.* **55**, 737.
Pskovskii, Yu. P.: 1984, *Astron. Zh.* **61**, 1125.
Sharov, A. S.: 1982, *Tumannost' Andromedy*, Nauka, Moscow.
Shurmann, S. R.: 1983, *Astrophys. J.* **267**, 779.
Tammann, G. A.: 1982, in M. J. Rees and R. J. Stoneham (eds.), *Supernovae: A Survey of Current Research*, D. Reidel Publ. Co., Dordrecht, Holland, p. 371.
Tsvetkov, D. Yu.: 1981, *Pis'ma v Astron. Zh.* **7**, 463.
Tsvetkov, D. Yu.: 1983, *Astron. Zh.* **60**, 37.
Tsvetkov, D. Yu.: 1985, *Astron. Zh.* (in press).
Tsvetkov, D. Yu.: 1986, *Peremennye Zvezdy* (in press).
Weaver, T. A., Axelrod, T. S., and Woosley, S. E.: 1980, in J. C. Wheeler (ed.), *Type I Supernovae*, Univ. Texas Press, Austin, p. 113.
Wheeler, J. C.: 1982, in M. J. Rees and R. J. Stoneham (eds.), *Supernovae: A Survey of Current Research*, D. Reidel Publ. Co., Dordrecht, Holland, p. 167.

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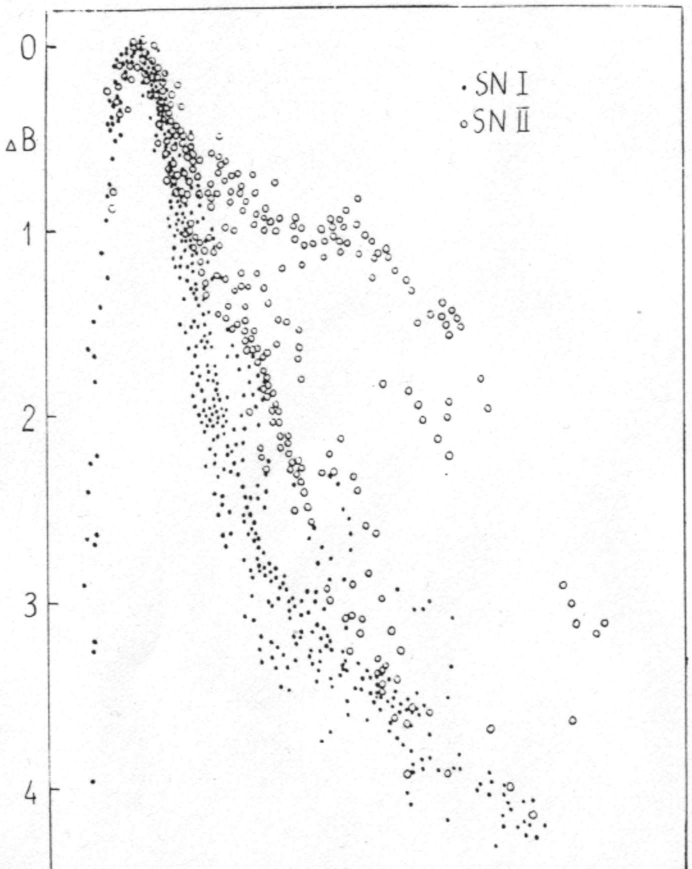

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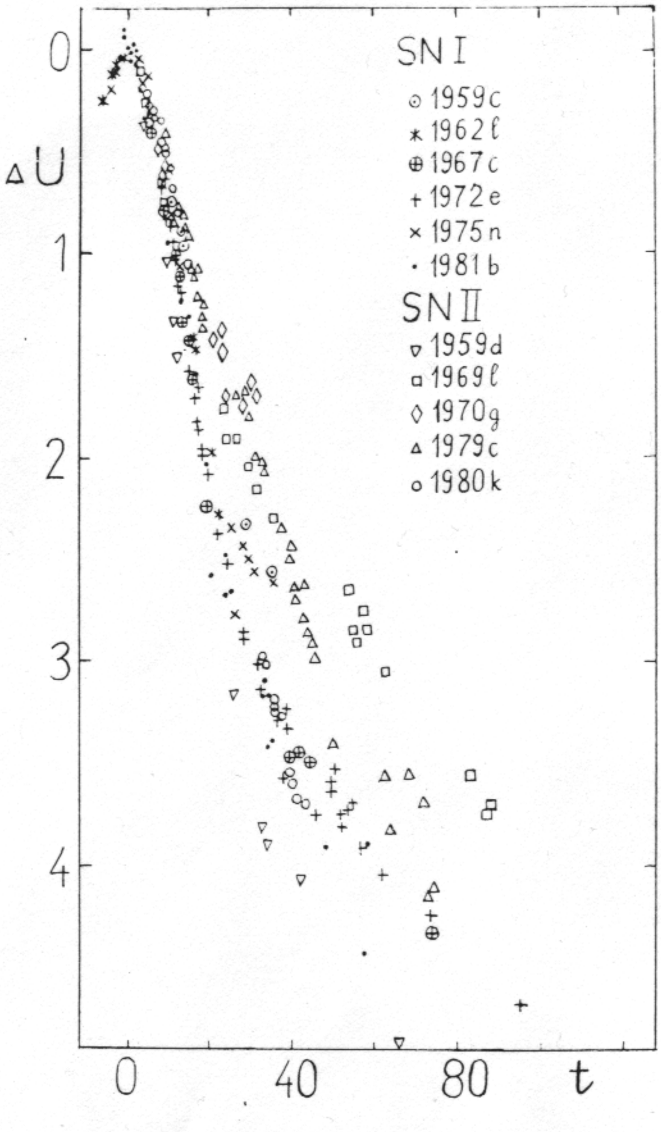

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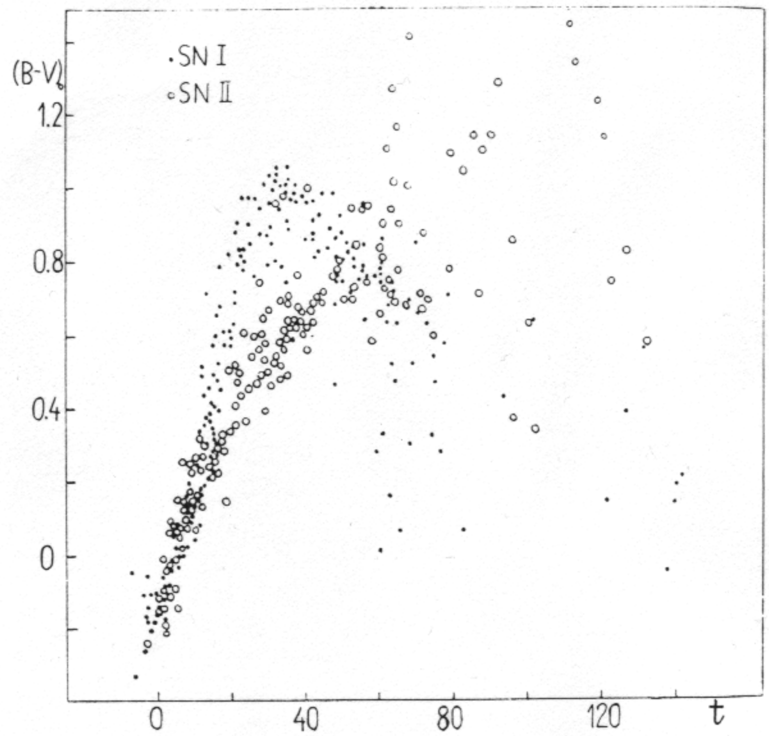

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The shapes of bolometric light curves for SNe I and SNe II–L are similar, while SN II–P 19691 is distinguished from them by a plateau, which has the shape like on the *B* light curve. The interesting fact is the absence of any peculiarity on SNe I bolometric light curves at point K. The exponential decline sets at about 100^d after maximum light for all supernovae.

The already mentioned phase about 15^d after maximum is marked by several features on light and colour curves and in the spectral evolution of SNe I:

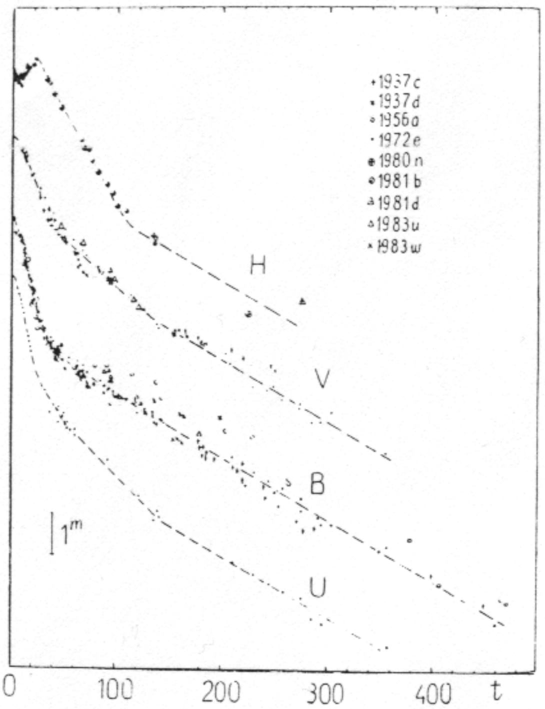

Fig. 4. Light curves of SNe I extending to ~400^d past maximum.

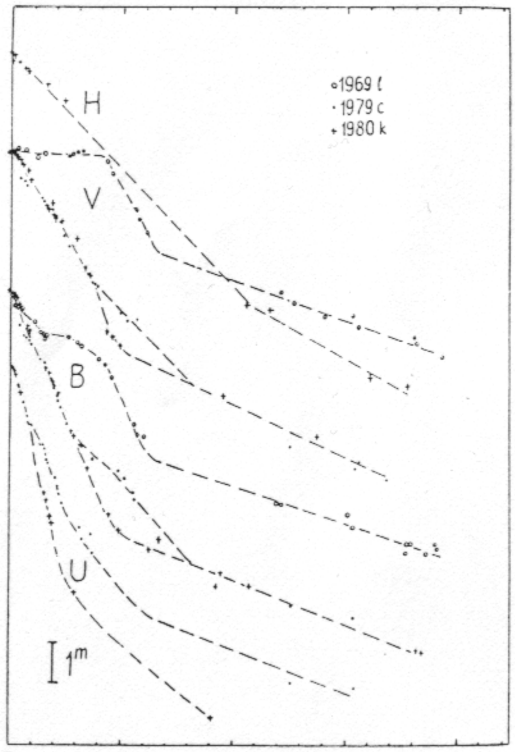

Fig. 5. Light curves of SNe II extending to ~400^d past maximum.

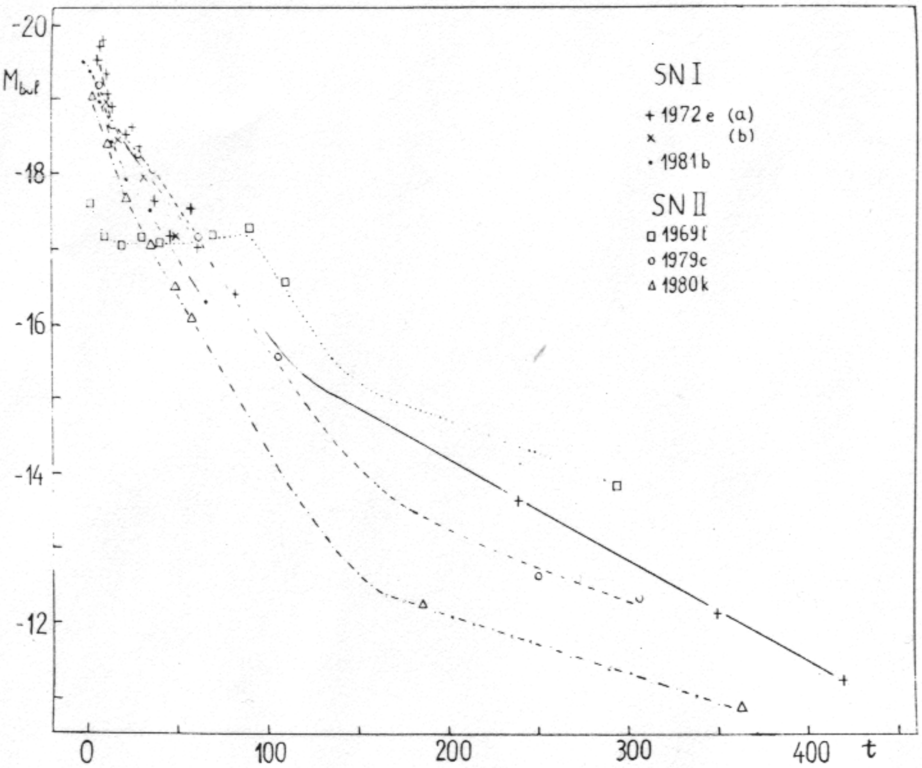

Fig. 6. Bolometric light curves of SNe I and SNe II. For SN I 1972e; *a*, data from Weaver *et al.* (1980); *b*, our data.

(a) Change of slope of $B - V$ colour curve, which is clearly seen on the best studied curve for SN 1972e.

(b) Minimum on infrared light curves (Elias *et al.*, 1981).

(c) The divergence of light and colour curves of SNe I and SNe II.

(d) Two emission peaks and four absorption troughs disappear and two new features appear in the spectrum of SN 1972e at J.D. 2441460 (phase about 15^{d}); the feature at λ 4600 Å drifts in wavelength at that time (Kirshner *et al.*, 1973). The drift of λ 4600 Å feature is also observed for SN 19621 (Bertola, 1964) and SN 1981b (Branch *et al.*, 1983).

(e) The radius of the photosphere, determined from $(B - V)_0$ vs temperature relation (Pskovskii, 1984) and absolute magnitude begins to increase with greater velocity than before (Bartunov and Tsvetkov, 1985).

The mentioned above facts allows to conclude that the phase $\sim 15^{d}$ past maximum, designated as 'point Λ' by Bartunov and Tsvetkov (1985) marks significant changes in physical parameters of SNe I envelopes.

3. Absolute Magnitudes of SNe I and SNe II at Maximum Light

Absolute magnitudes of 48 SNe I and 17 SNe II have been recently determined by Tsvetkov (1986). Distance estimates by de Vaucouleurs (1979, 1982) and de Vaucouleurs *et al.* (1981) were used; for galaxies not listed in these works we have used the radial velocity and the value of the Hubble constant $H_0 = 75$ km s^{-1} Mpc^{-1} to determine the distance. The absorption corrections were based on new estimates of colour excess E_{B-V}. The distribution of M_B^0(max) for SNe I and SNe II is shown in Figure 7. The dispersion of M_B^0(max) is larger for SNe II, but the scatter of M_B^0(max) for SNe I is also quite large and certainly exceeds 2^m. This cannot be explained by observational errors and by the errors in distance determination, because SNe I with the lowest and highest values of M_B^0(max) belong to the Virgo cluster and have small or zero values of E_{B-V}. Our conclusion is contrary to that of Cadonau *et al.* (1984) that SNe I are nearly perfect standard candles.

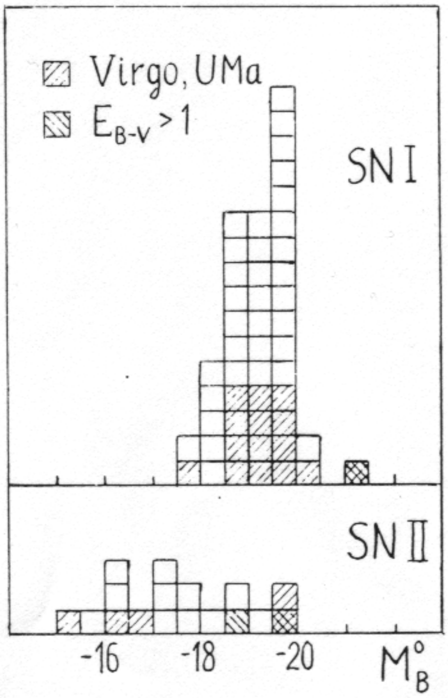

Fig. 7. The distribution of M_B^0(max) for SNe I and SNe II. Supernovae in Virgo and Ursa Major clusters of galaxies and with $E_{B-V} > 1^m$ are designated by hatched squares.

4. The Spatial Distribution of Supernovae

Radial distribution of SNe I and SNe II in spiral galaxies has been studied by Iye and Kodaira (1975), Guseinov *et al.* (1980), Tsvetkov (1981). Now we have collected data on 68 SNe I and 47 SNe II from Barbon *et al.* (1984b) and *IAU Circulars*, this is nearly

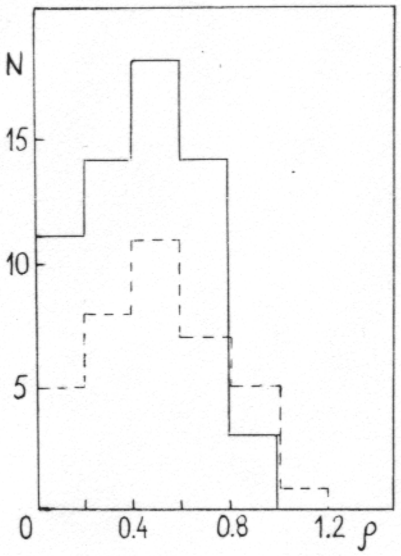

Fig. 8. The radial distribution of SNe I (solid line) and SNe II (dashed line) in spiral galaxies.

two times more than was used in previous studies. The relative radial distance of supernovae ρ was calculated using optical radii of galaxies from de Vaucouleurs *et al.* (1976), the correction for inclination was adopted following Iye and Kodaira (1975). The radial distributions of SNe I and SNe II are represented in Figure 8, they are practically identical. In Figure 9 the logarithm of supernovae surface density σ is plotted against ρ; for comparison the distributions of Novae in M31 and of blue supergiants in M33 are plotted. The first is different from the distribution of SNe I and SNe II, while the second is similar to them.

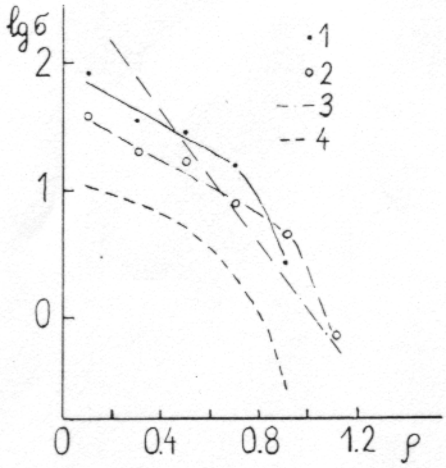

Fig. 9. The surface density of SNe I (1) and SNe II (2) in spiral galaxies as a function of ρ, compared with the surface density distribution of Novae in M31 (Sharov, 1982) (3) and of blue supergiants in M33 (calculated according to the data from Humphreys and Sandage, 1980) (4).

The comparison of mean *z*-coordinates of SNe I and SNe II by Tsvetkov (1981) also showed absence of difference; this result was confirmed on the basis of more large and homogeneous data (Tsvetkov, 1985).

5. The Frequency of SNe I and SNe II

We have recently obtained estimates of supernova frequency in galaxies of different morphological types on the basis of the observational data of supernova search at Sternberg Astronomical Institute Crimean station and at Asiago Astrophysical Observatory (Tsvetkov, 1983, 1985). Figure 10 shows the frequency of SNe I, SNe II, and all supernovae as the function of morphological type of galaxies. In Sa, Sb, and Sc galaxies the frequencies of SNe I and SNe II are nearly equal, only in E galaxies SNe II have not been detected (recently SNe II 1985g was discovered in SO galaxy NGC 4451), and in Sm–Im galaxies the SNe II frequency is likely to be lower than the frequency of SNe I (see also Oemler and Tinsley, 1979; or Tammann, 1982).

6. Summary and Discussion

The similarity of SNe I and SNe II in many aspects is the main conclusion of this work. This confirms earlier results of Oemler and Tinsley (1979) on frequency of supernova outbursts; Iye and Kodaira (1975) and Guseinov *et al.* (1980) on spatial distribution. The similarity of light curves of SNe I and SNe II–L was recently notices by Doggett and Branch (1985). This is important for attempts to classify the historical supernovae

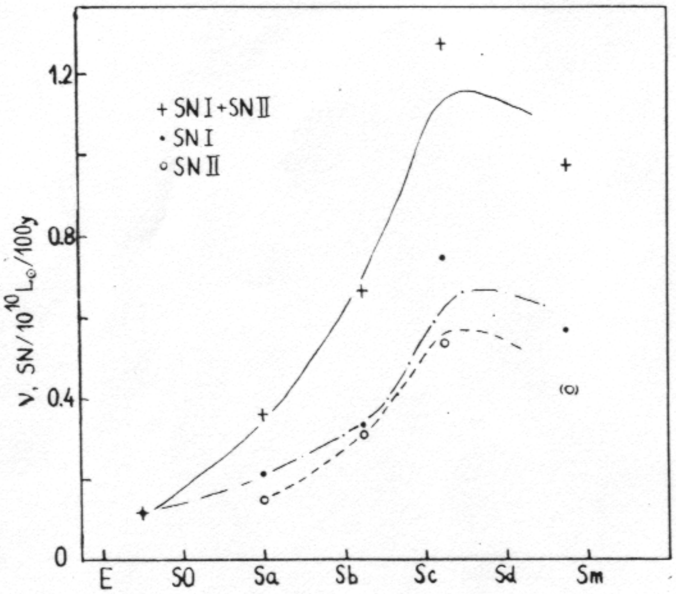

Fig. 10. Frequency of SNe I and SNe II as a function of morphological type of galaxies.

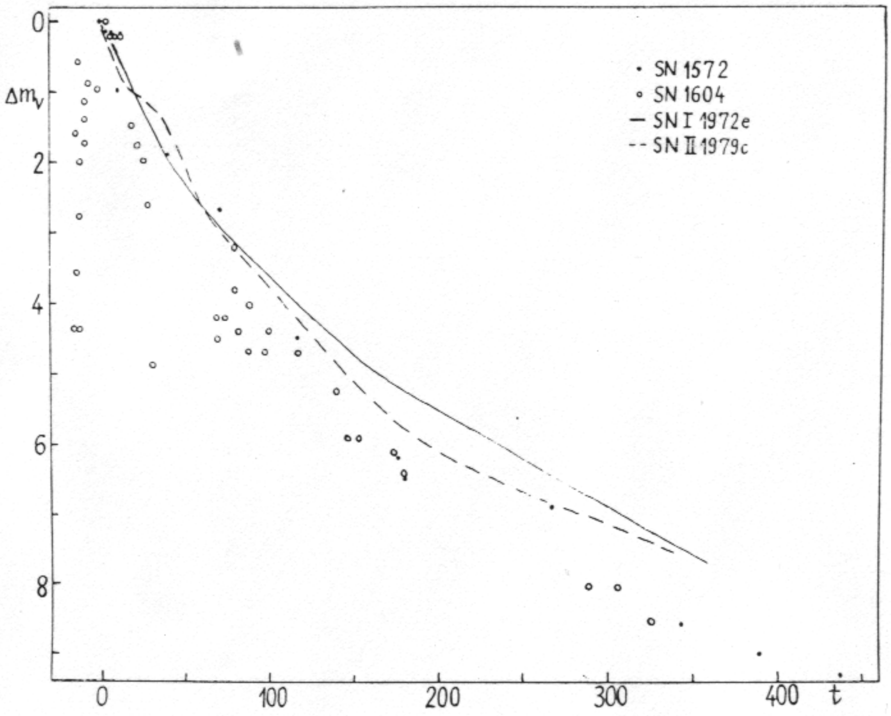

Fig. 11. Comparison of the visual light curves of 1572 and 1604 supernovae with the V light curves of SNe I 1972e and SNe II–L 1979c.

of 1572 and 1604. Figure 11 shows visual light curves of these supernovae (Pskovskii, 1978b) compared with the V light curves of SNe I 1972e and SNe II–L 1979c. No distinction between type I and type II–L can be made for these historical supernovae, the same conclusion was reached by Doggett and Branch (1985).

We should also note that the light curves in Figure 1 show the gradual transition from SNe I to SNe II–L and SNe II–P.

The comparison of SNe I and SNe II spectra by Krishner *et al.* (1973) revealed that the strongest features (except hydrogen lines) are the same, but the relative strength is different: the lines are stronger and more numerous in SNe I spectra. Kirshner *et al.* (1973) suggested that the main difference between SNe I and SNe II is in the chemical composition of their envelopes. We should like to note that SNe I have a deficit of ultraviolet radiation and so the ionization temperature is less than the temperature of the photosphere. When the temperature is higher than 10^4 K and $n_e \sim 10^{10}$, the elements like calcium, silicon, sodium are twice ionized, and the lines which belong to neutral and singly ionized atoms should be weak: this is the case of SNe II. SNe I have even at maximum light lower ionization temperature $\sim 5–7 \times 10^3$ K and the lines of Ca II, Si II, Fe II are stronger than for SNe II.

The similarity of SNe I and SNe II in statistical properties should indicate that the precursors of type I and type II supernovae have similar ages and initial masses. The opposite opinion is based mainly on results of Maza and van den Bergh (1976) who have found that SNe II are concentrated in spiral arms while SNe I show no preference for spiral arms. However, in earlier investigations by Johnson and McLeod (1963) and Bertola and Sussi (1965) SNe I were found to be associated wiht spiral structure, but less tightly than SNe II. Some SNe I discovered recently are clearly associated with spiral arms (SNe I 1974j, 1975p, 1975o, 1981b, 1983i). Our opinion is that the problem of association of SNe I with spiral arms is not yet resolved and new investigations are needed.

The connection between type of supernova and type of its remnant is also not clear. It was shown that the classification of supernovae of 1572 and 1604 as type I is doubtful, even less can be said on other historical supernovae. We have no reason to suppose that SNe II leave neutron stars while SNe I do not. The recent peculiar supernova 1985f in NGC 4618 (Filippenko and Sargent, 1985), which probably never exceeded absolute magnitude $\sim -14^m$ may be the type of supernova which produced the remnant Cas A, and we may expect more peculiar and faint supernovae to be discovered with the help of automated supernova search.

The difference between SNe I and SNe II may be due to different chemical composition, mass and structure of envelopes of their progenitors, but the mentioned above similar features show that these differences should not be very large. They may be caused by different intensity of mass loss, by evolution in close binary systems and other reasons. The outbursts of SNe I in elliptical galaxies may be due to star formation in some of them, this is supported by the results of Caldwell and Oemler (1981) and Guseinov *et al.* (1980).

References

Barbon, R., Cappellaro, E., and Turatto, M.: 1984a, *Astron. Astrophys.* **135**, 27.

Barbon, R., Cappellaro, E., Ciatti, F., Turatto, M., and Kowal, C. T.: 1984b, *Astron. Astrophys. Suppl.* **58**, 735.

Barbon, R., Ciatti, F., and Rosino, L.: 1973, *Astron. Astrophys.* **25**, 241.

Barbon, R., Ciatti, F., and Rosino, L.: 1979, *Astron. Astrophys.* **72**, 287.

Bartunov, O. S. and Tsvetkov, D. Yu.: 1985, *Astrofizika* **23**, 319.

Bertola, F.: 1964, *Ann. Astrophys.* **27**, 319.

Bertola, F. and Sussi, M. G.: 1965, *Contr. Asiago*, No. 176.

Branch, D.: 1982, in M. J. Rees and R. J. Stoneham (eds.), *Supernovae: A Survey of Current Research*, D. Reidel Publ. Co., Dordrecht, Holland, p. 267.

Branch, D., Lacy, C. H., McCall, M. L., Sutherland, P. G., Uomoto, A., Wheeler, J. C., and Wills, B. J.: 1983, *Astrophys. J.* **270**, 123.

Cadonau, R., Sandage, A., and Tammann, G. A.: 1984, Preprint No. 7, Astron. Institute Univ. Basel.

Caldwell, C. N. and Oemler, A.: 1981, *Astron. J.* **86**, 1424.

De Vaucouleurs, G.: 1979, *Astrophys. J.* **227**, 729.

De Vaucouleurs, G.: 1982, *Astrophys. J.* **253**, 520.

De Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G.: 1976, *Second Reference Catalogue of Bright Galaxies*, Univ. Texas Press, Austin.

De Vaucouleurs, G., Peters, W. L., Bottinelli, L., Gouguenheim, L., and Paturel, G.: 1981, *Astrophys. J.* **248**, 708.

Doggett, J. B. and Branch, D.: 1985, *Astron. J.* (in press).

Elias, J. H. and Frogel, J. A.: 1983, *Astrophys. J.* **268**, 718.

Elias, J. H., Frogel, J. A., Hackwell, J. A., and Persson, S. E.: 1981, *Astrophys. J.* **251**, L13.
Filippenko, A. V. and Sargent, W. L.: 1985, *Nature* **316**, 407.
Guseinov, O. H., Kasumov, F. K., and Kalinin, E. V.: 1980, *Astrophys. Space Sci.* **68**, 385.
Humphreys, R. and Sandage, A.: 1980, *Astrophys. J. Suppl.* **44**, 319.
Iye, M. and Kodaira, K.: 1975, *Publ. Astron. Soc. Japan* **27**, 411.
Johnson, H. M. and McLeod, J. M.: 1963, *Publ. Astron. Soc. Pacific* **75**, 123.
Kirshner, R. P., Oke, J. B., Penston, M. V., and Searle, L.: 1973, *Astrophys. J.* **185**, 303.
Maza, J. and van den Bergh, S.: 1976, *Astrophys. J.* **204**, 519.
Oemler, A. and Tinsley, B. M.: 1979, *Astron. J.* **84**, 985.
Pskovskii, Yu. P.: 1977, *Astron. Zh.* **54**, 1188.
Pskovskii, Yu. P.: 1978a, *Astron. Zh.* **55**, 350.
Pskovskii, Yu. P.: 1978b, *Astron. Zh.* **55**, 737.
Pskovskii, Yu. P.: 1984, *Astron. Zh.* **61**, 1125.
Sharov, A. S.: 1982, *Tumannost' Andromedy*, Nauka, Moscow.
Shurmann, S. R.: 1983, *Astrophys. J.* **267**, 779.
Tammann, G. A.: 1982, in M. J. Rees and R. J. Stoneham (eds.), *Supernovae: A Survey of Current Research*, D. Reidel Publ. Co., Dordrecht, Holland, p. 371.
Tsvetkov, D. Yu.: 1981, *Pis'ma v Astron. Zh.* **7**, 463.
Tsvetkov, D. Yu.: 1983, *Astron. Zh.* **60**, 37.
Tsvetkov, D. Yu.: 1985, *Astron. Zh.* (in press).
Tsvetkov, D. Yu.: 1986, *Peremennye Zvezdy* (in press).
Weaver, T. A., Axelrod, T. S., and Woosley, S. E.: 1980, in J. C. Wheeler (ed.), *Type I Supernovae*, Univ. Texas Press, Austin, p. 113.
Wheeler, J. C.: 1982, in M. J. Rees and R. J. Stoneham (eds.), *Supernovae: A Survey of Current Research*, D. Reidel Publ. Co., Dordrecht, Holland, p. 167.