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PHOTOMETRY OF THE SUPERNOVA SN 2002ap IN M 74 DURING 2002

V. T. Doroshenko,[1] S. G. Sergeev,[2] N. I. Merkulova,[2] and E. A. Sergeeva[2] UDC: 524.35; 520.82

$UBVR_cI_c$ observations of SN 2002ap during February, October, and November 2002 at the Crimean Astrophysical Observatory are reported. An examination of our photometric data, along with published data, shows that over a period of about a year from the day the SN 2002ap supernova burst, the light curve passed through three developmental stages: a sharp rise, followed by a stage of rapid exponential decrease, and then a slower fading. Based on the shape of the light curve, this supernova is of type SN I, but according to the variation in its color indices, it more likely belongs to the SN Ic supernovae. In the premaximum stage, the energy distribution from λ 3000 Å to λ 6000 Å resembles the emission from a star of spectral class F5V. In the second stage of the light curve evolution, when the brightness falls off rapidly, the changes in the color indices are associated with a change in the radiation temperature indicative of rapid cooling of the ejected material. Taking the effective radiation temperature in the premaximum stage to be $T_{eff} \approx 6500\,\mathrm{K}$, we estimate the expansion velocity of the quasiphotosphere to be about 9700 km/s.

Keywords: *stars:Supernovae - stars:photometry - stars:individual: SN 2002 ap*

1. Introduction

On 29 January 2002 (29.4 UT) the amateur astronomer Yoji Hirose observed a $14^m.5$ star in the interior portion of the spiral M74 galaxy a distance of 4'38" from its center [1]. According to Lee of the University of California [1], there was no star brighter than 18^m at this position as late as 25 January. The newly discovered star was named SN 2002ap. The next day its visual magnitude was estimated to be $13^m.7$. Thus, the supernova was discovered in the rising brightness stage almost immediately after it exploded. Because of its brightness and possible connections with GRB sources, this supernova attracted the attention of many researchers. At the assumed distance of D = 7.3 Mpc to the galaxy [2,3], the supernova lies a distance of 9.8 kpc from its center. The total absorption to the supernova, i.e., in our galaxy and in the M74 galaxy is low [4] at $E(B\text{-}V)=0^m.08$, so that the extinction in the U, B, V, R_c, and I_c bands corresponding to this color

[1] P. K. Shternberg State Astronomical Institute, Russia, and Crimean Branch of the Chilean Isaac Newton Institute. e-mail: doroshen@sai.crimea.ua;
[2] Crimean Astrophysical Observatory, Ukraine, and Crimean Branch of the Chilean Isaac Newton Institute. e-mail: sergeev@crao.crimea.ua.

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excess is $A_U = 0^m.43$, $A_B = 0^m.37$, $A_V = 0^m.28$, $A_{R_c} = 0^m.21$, and $A_{I_c} = 0^m.14$ [4]. A study of deep UBVRIH a K images of M74 [5] taken several years before the supernova explosion yielded no traces of a precursor exploding star brighter than $U \approx 21^m.5$, $B \approx 23^m$, $V \approx 22^m.6$, $R_c \approx 22^m.2$ or $I_c \approx 21^m.5$. The spectral properties of the supernova immediately after its discovery indicated that the star may belong to the class of hypernova stars with a explosion kinetic energy $E > 10^{52}$ erg. It turned out that the kinetic energy was somewhat lower than this value at $E \simeq 4-10 \times 10^{51}$ erg [6]. Both photometric BVR_cI_c and polarization *UBVRI* observations of SN 2002ap have been made at the Crimean Astrophysical Observatory. We shall discuss only the photometric data in the following.

2. Observations

The photometric observations of SN 2002 ap were made in the direct focus of the AZT-8 (f = 282 cm) telescope with a mirror diameter of 70 cm, equipped with a CCD photometer that has an AP7p 512×512 pixel array. Observations with *B, V, R,* and *I* filters were reduced to the standard Johnson-Cousins system. The coefficients for converting the instrument system to the Johnson-Cousins system were obtained from a special photometric analysis of 32 stars in the NGC 7790 cluster and their standard B, V, R_c, and I_c stellar magnitudes were taken from Stetson [8]. Star No. 1, located 65" to the west and 8" to the north with coordinates $\alpha = 01^h36^m19^s$, $\delta = +15°45'22''$ (2000) and stellar magnitudes $V = 13^m.061$, $B = 13^m.844$, $R_c = 12^m.618$, and $I_c = 12^m.148$ [7], was used as a comparison star in the photometric measurements of the supernova during February. In October-November, when the brightness of the supernova had decreased significantly, we used star No. 2, which has $\alpha = 01^h36^m23^s.04$, $\delta = +15°47'45''.4$ (2000) and magnitudes $V = 14^m.611$, $B = 15^m.190$, $R_c = 14^m.273$, and $I_c = 13^m.913$ [7]. A program developed by S. G. Sergeev was used for photometric data processing, including corrections for bias, dark current, and flat field, which last was obtained in the dawn sky, as well as aperture measurements including an accounting for errors associated with the charge accumulation statistics and the peculiarities of array detection. An aperture diameter A = 15" was used for the photometric measurements. The results of our observations are shown in Table 1, in which the first column lists the year, month, and date, the second, the Julian date, the third, the stellar magnitude, the fourth, the probable error, and the fifth, the number of the comparison star that was used.

Yu. S. Efimov has made polarization measurements on the 125-cm telescope (AZT-11) at the Crimean Astrophysical Observatory and, as a byproduct of these observations, we have obtained estimates of the brightness in the U, B, V, R_c, and I_c bands over 4 nights at the beginning of February. They are included in Table 1 with the kind permission of Yu. S. Efimov.

3. $UBVR_cI_c$ light curves

In order better to represent the changes in the brightness of the supernova, we have combined our data with published data [4,9,10-13]. The very latest observation in the *V*-band is that of Henden [14] for 31 December 2002 ($V = 19^m.5$). The summary light curves are shown in Fig. 1, where our data are indicated by solid circles and the other data by open circles. The dimensions of the circles for the February observations are much greater than the measurement errors and are taken this way only to illustrate the localization of our data in the overall pattern of decaying brightness

TABLE 1. $UBVR_cI_c$ Magnitudes of SN 2002 ap

YYmmdd.UT	JD2450000+	U	err$U$	Cs
020203.735[a]	2309.2293	13.29	0.04	1

YYmmdd.UT	JD2450000+	B	err$B$	Cs
020201.739[a]	2307.2391	13.43	0.03	1
020201.800	2307.2996	13.440	0.009	1
020202.718	2308.2175	13.289	0.005	1
020203.676	2309.1763	13.192	0.013	1
020203.719[a]	2309.2194	13.18	0.03	1
020204.734[a]	2310.2345	13.11	0.03	1
020204.737	2310.2373	13.125	0.004	1
020205.794	2311.2942	13.106	0.008	1
020207.714[a]	2313.2142	13.13	0.04	1
020207.723	2313.2234	13.162	0.004	1
020208.693	2314.1929	13.222	0.005	1
020210.694	2316.1936	13.397	0.004	1
020212.700	2318.1997	13.596	0.006	1
020216.704	2322.2041	13.984	0.004	1
020217.715	2323.2151	14.069	0.004	1

YYmmdd.UT	JD2450000+	V	err$V$	Cs
020201.742[a]	2307.2415	12.92	0.03	1
020201.800	2307.2998	12.901	0.007	1
020202.720	2308.2200	12.724	0.004	1
020203.677	2309.1772	12.602	0.011	1
020203.730[a]	2309.2300	12.60	0.03	1
020204.738[a]	2310.2382	12.47	0.03	1
020204.740	2310.2402	12.497	0.004	1
020205.798	2311.2976	12.425	0.006	1
020207.714[a]	2313.2136	12.39	0.03	1
020207.724	2313.2236	12.368	0.004	1
020208.695	2314.1946	12.368	0.004	1
020210.694	2316.1936	12.421	0.004	1
020212.701	2318.2012	12.525	0.005	1
020216.705	2322.2048	12.786	0.004	1
020217.716	2323.2158	12.856	0.004	1
021009.995	2557.4951	18.435	0.057	2
021017.034	2565.5339	18.680	0.091	2
021102.886	2581.3862	18.952	0.259	2
021114.913	2593.4133	18.809	0.180	2
021128.879	2607.3787	18.925	0.204	2

YYmmdd.UT	JD2450000+	R_c	errR_c	Cs
020201.742[a]	2307.2422	13.00	0.03	1
020201.800	2307.3003	13.037	0.007	1
020202.721	2308.2209	12.862	0.004	1
020203.678	2309.1777	12.711	0.011	1
020204.729[a]	2310.2351	12.57	0.03	1
020204.742	2310.2415	12.610	0.004	1
020205.800	2311.3000	12.526	0.005	1
020207.715[a]	2313.2148	12.30	0.03	1
020207.723	2313.2231	12.404	0.004	1
020208.696	2314.1958	12.375	0.004	1
020210.694	2316.1938	12.361	0.004	1
020212.704	2318.2039	12.401	0.004	1
020216.706	2322.2056	12.568	0.004	1
020217.717	2323.2166	12.619	0.004	1
021009.007	2557.5066	17.554	0.045	2
021017.035	2565.5354	17.714	0.090	2
021102.896	2581.3955	17.930	0.184	2
021114.916	2593.4155	17.998	0.159	2
021128.881	2607.3809	18.191	0.236	2

YYmmdd.UT	JD2450000+	I_c	errI_c	Cs
020201.801	2307.3013	13.013	0.010	1
020202.731	2308.2307	12.847	0.005	1
020203.680	2309.1797	12.688	0.016	1
020204.735[a]	2310.2356	12.66	0.03	1
020204.743	2310.2427	12.569	0.004	1
020205.799	2311.2993	12.449	0.006	1
020207.722	2313.2222	12.302	0.004	1
020208.696	2314.1956	12.253	0.005	1
020210.695	2316.1946	12.207	0.004	1
020212.705	2318.2046	12.206	0.006	1
020216.706	2322.2063	12.294	0.004	1
020217.718	2323.2175	12.315	0.004	1
021009.001	2557.5010	17.461	0.063	2
021017.037	2565.5366	17.611	0.082	2
021102.892	2581.3923	18.081	0.225	2
021114.918	2593.4177	18.000	0.133	2
021128.883	2607.3831	19.229	0.291	2

[a] Observations of Yu. S. Efimov on the 125-cm telescope.

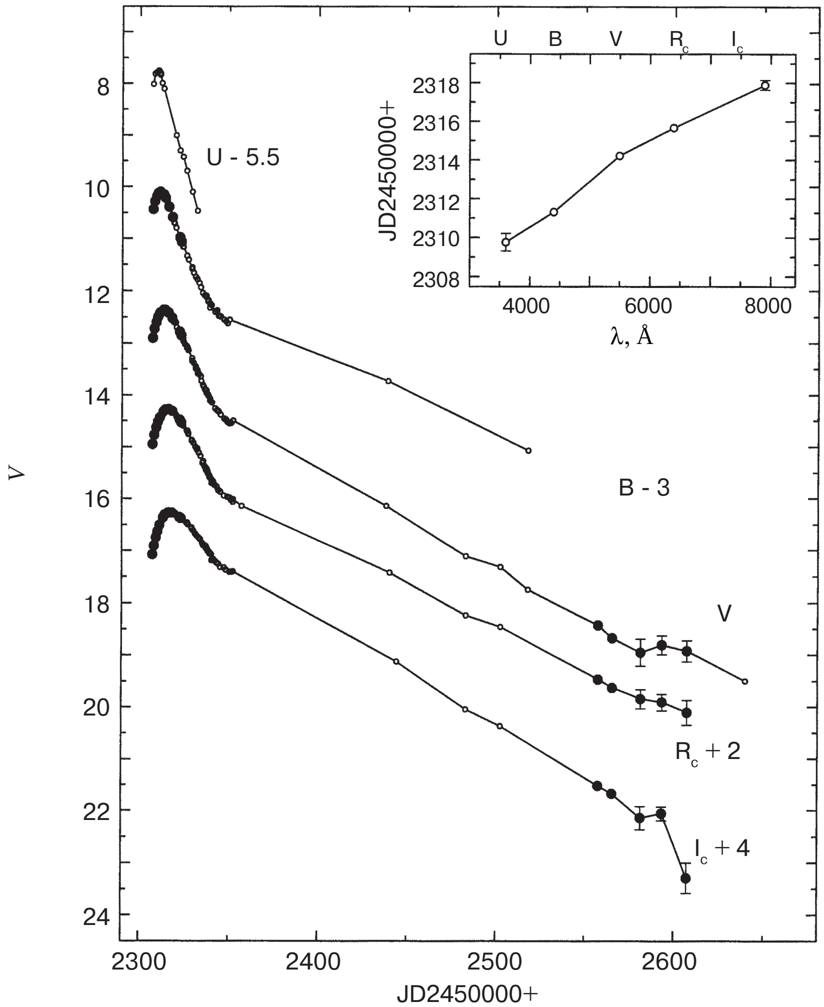

Fig. 1. Summary light curves of SN 2002 ap in the *U*, *B*, *V*, R_c, and I_c bands. The solid circles indicate our observations. The errors in the early stage of the observations are much smaller than the dimensions of the circles. The hollow circles indicate data obtained from the literature. The light curves in the *U*, *B*, R_c, and I_c bands are shifted relative to that in the *V* band. The numbers next to the filter designations represent the offsets of the curves in stellar magnitudes. The inset shows the onset time of the maximum brightness as a function of the filter wavelength.

of the supernova. For greater clarity the light curves obtained with the different filters are offset in the figure with a shift relative to the *V*-filter light curve. The shifts in stellar magnitude are indicated in the figure. This figure shows that the changes in brightness take place in three stages: a rise (until the first decade or the middle of February), then a sharp drop (to the first decade of March), followed by a slower decrease in brightness through the end of 2002. In the first 30-36 days the highest rate of decrease in brightness occurred in the *U* filter, 0.122 m/day, while in the *B*, *V*, R_c, and I_c the rates of decrease were 0.066, 0.064, 0.055, and 0.036 m/day, respectively. Over the next 240-290 days, the rate of decrease in the brightness was roughly the same in the *B*, *V*, R_c, and I_c bands, at 0.015-0.20 m/day. The light curve of SN 2002ap is very similar to that of I-type supernovae. The transition points from rapid fall to slow decrease in the

TABLE 2. Characteristics of the light curve at its maximum

	U	B	V	R_c	I_c
λ_{eff}, Å	3600	4400	5500	6400	7900
Maximum brightness					
Date	04.02.2002	05.02.2002	08.02.2002	10.02.2002	12.02.2002
UT	06:05	19:12	17:14	03:36	09:22
JD2450000+	2309.753	2311.300	2314.218	2315.650	2317.890
Magnitude	13.262	13.103	12.377	12.255	12.262

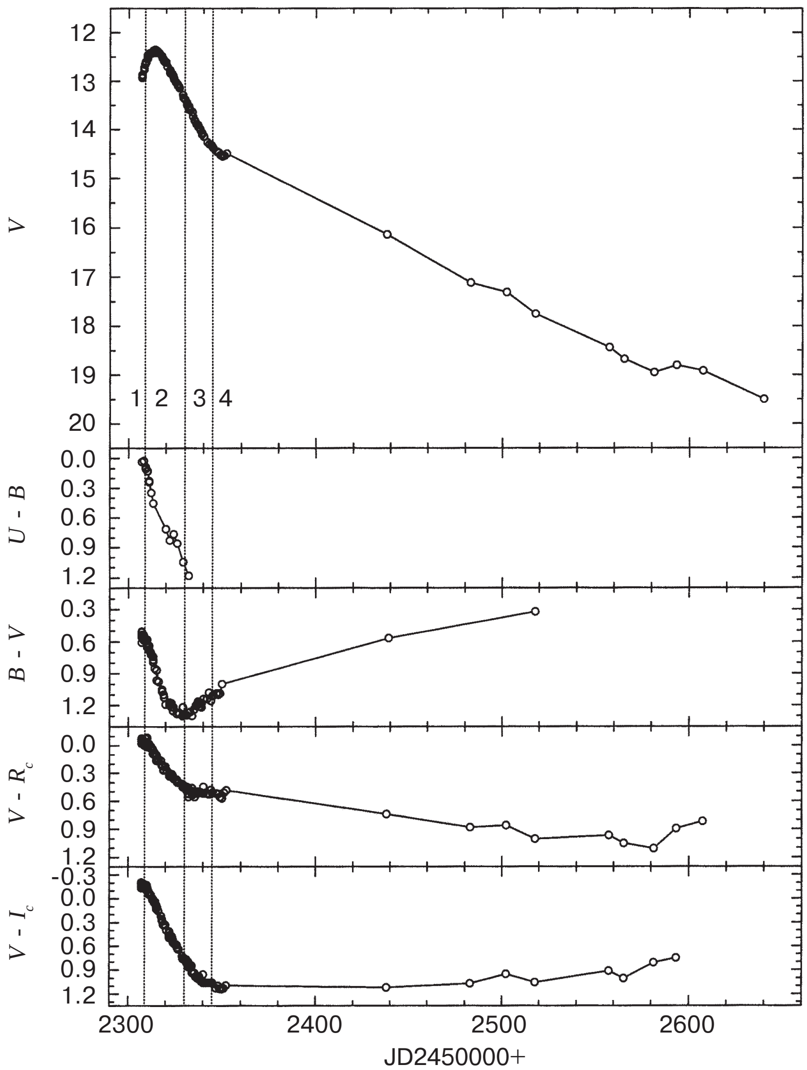

Fig. 2. The changes in the color indices with time. The dotted lines separate the different portions of the light curves, which are indicated by numbers 1 through 4.

brightness in the different spectral bands correspond to slightly different times. The brightness peaks in the different spectral bands also occur at different times. This has been noticed by all observers. A similar effect has been observed in all supernovae which could be observed using different filters during the rising brightness stage. The observers usually report this fact without an explanation. The inset to Fig. 1 shows the times of maximum brightness in the *U, B, V,* R_c, and I_c filters which we determined from the summary brightness curve by approximating the brightness curve with high order polynomials. Our values for the times of peak brightness are in good agreement with the estimates of Ref. 4. Some characteristics of the light curves, such as the time of occurrence of the maximum brightness and the peak stellar magnitude are listed in Table 2.

4. Evolution of the color indices

The color indices of the supernova varied in an odd fashion. In terms of their variation and for convenience of further analysis, we separated the light curves into 4 segments, as indicated by the dotted lines in Fig. 2. In the first stage (labelled 1) the color indices were essentially constant. In the second stage (2), all the color indices increased and the supernova became "redder." In the third stage (3) the color indices behaved in different ways: $B - V$ decreased, $V - R_c$ stabilized, and $V - I_c$ continued to increase. Finally, the section in which the supernova is decaying slowly was considered as the fourth stage (4). In this section there were few observations, since the supernova could not be observed through most of the summer. During this time the color index $B - V$ continued to decrease, $V - R_c$ again increased after sort of stopping during the third stage, and $V - I_c$ stabilized or even began to decrease somewhat. Plots of the variation in the color indices as functions of the brightness in the *V* - band, shown in Fig. 3, had very interesting and complicated behavior. Here the stages in the variation of the color indices are all quite apparent.

5. Two-color diagrams

Many physical mechanisms for radiation are characterized just by their inherent color indices. Thus, an analysis of the color indices of a supernova on two-color diagrams, which is often carried out in stellar astronomy, may be extremely useful. Figure 4 contains the following two-color diagrams: (*U-B*), (*B-V*); (*B-V*), (V-R_c); and (*B-V*), (V-I_c), which we shall refer to as *UB-BV*, BV-VR_c, and BV-VI_c for brevity in the following. The numbers correspond to the segments of the light curve of the supernova that were discussed above. It should be noted that the color indices have been corrected for the interstellar and intergalactic reddening, the value of which [4] we gave in the introduction. The thick line indicates the position of the color indices for a power-law (synchrotron) spectrum $F_\nu \sim \nu^\alpha$. The thinner continuous curve indicates the main sequence, i.e., the color indices for normal stars. The dashed curve indicates the color indices for black body radiation at different temperatures.

Several conclusions may be drawn from an examination of this figure. In the *UB - BV* diagram it is clear that the color indices of the supernova vary along the main sequence. At the earliest observation times (first days of February), *U-B* and *B-V* correspond to F5V stars. At the end of February these color indices correspond to stars in spectral class K7V. Thus, it is evident that the change in the color indices *U-B* and *B-V* are associated with a change in the radiation temperature. In the BV-VR_c and BV-VI_c diagrams the location of the color indices corresponds neither to normal (main sequence) stellar radiation nor to black body radiation, but their time variation is parallel to both stellar and black body

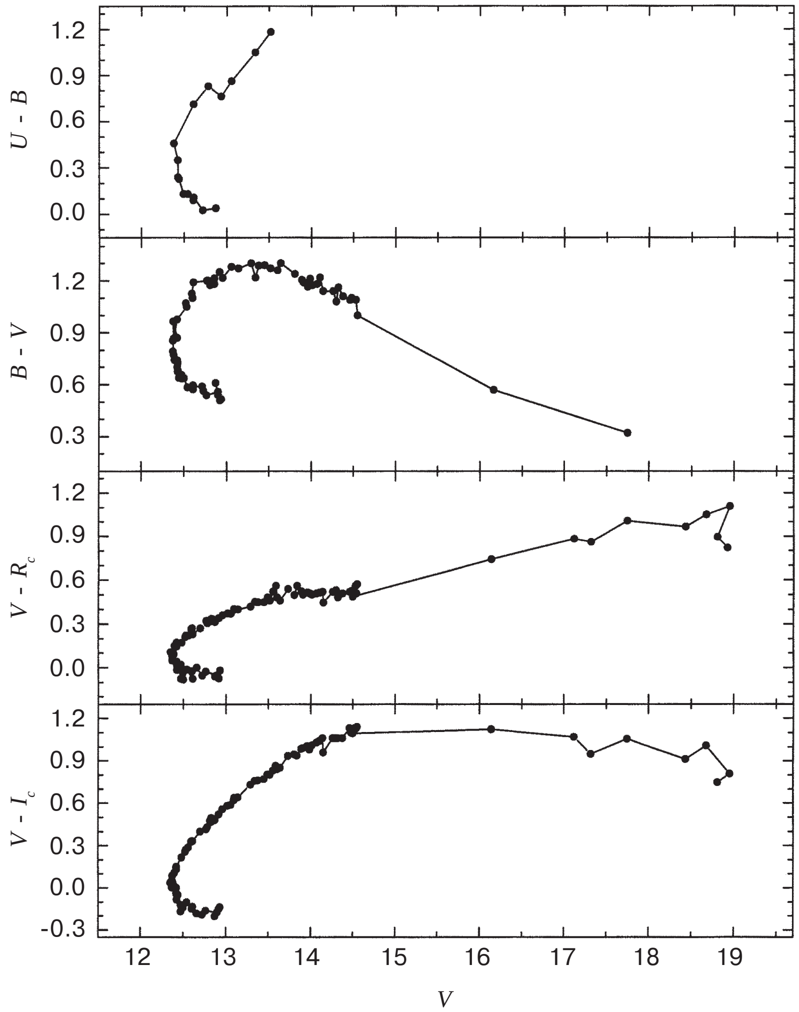

Fig. 3. Evolution of the color indices as a function of the change in the *V* - band brightness of the supernova.

radiation. It appears that the evolution of the color indices V-R_c and V-I_c in the first 30-40 days after the burst follows the temperature variations and is indicative of cooling of the radiation matter in the supernova. The color indices in the last stage of observation (October-November 2002), denoted by the labels 4, behave entirely differently and appear to be associated with a transition to other radiation mechanisms. During this time the radiation from the supernova is more like the radiation from a hot plasma. Thus, the position of the color indices of the supernova in the two color-diagrams is evidence of the extremely complex processes that accompany powerful explosions of this type.

Recently, entirely automatic telescopes with highly sensitive detectors, CCD arrays, have come into wide use for astronomical observations. This has led to major advances in spectral and photometric studies of supernovae. A large number of supernovae have been observed, and their spectra and brightness evolution with different filters have been obtained. Here has become necessary to derive color indices from observations of the spectra of various types of supernovae. The driving motive for this work has been the desire to find ways of classifying supernovae in terms of their color indices, as well as in terms of their spectral data or light curves. Poznanski et al. [15] refer to the color indices derived from spectra as synthetic color indices. Different two-color diagrams were constructed for typical supernovae of

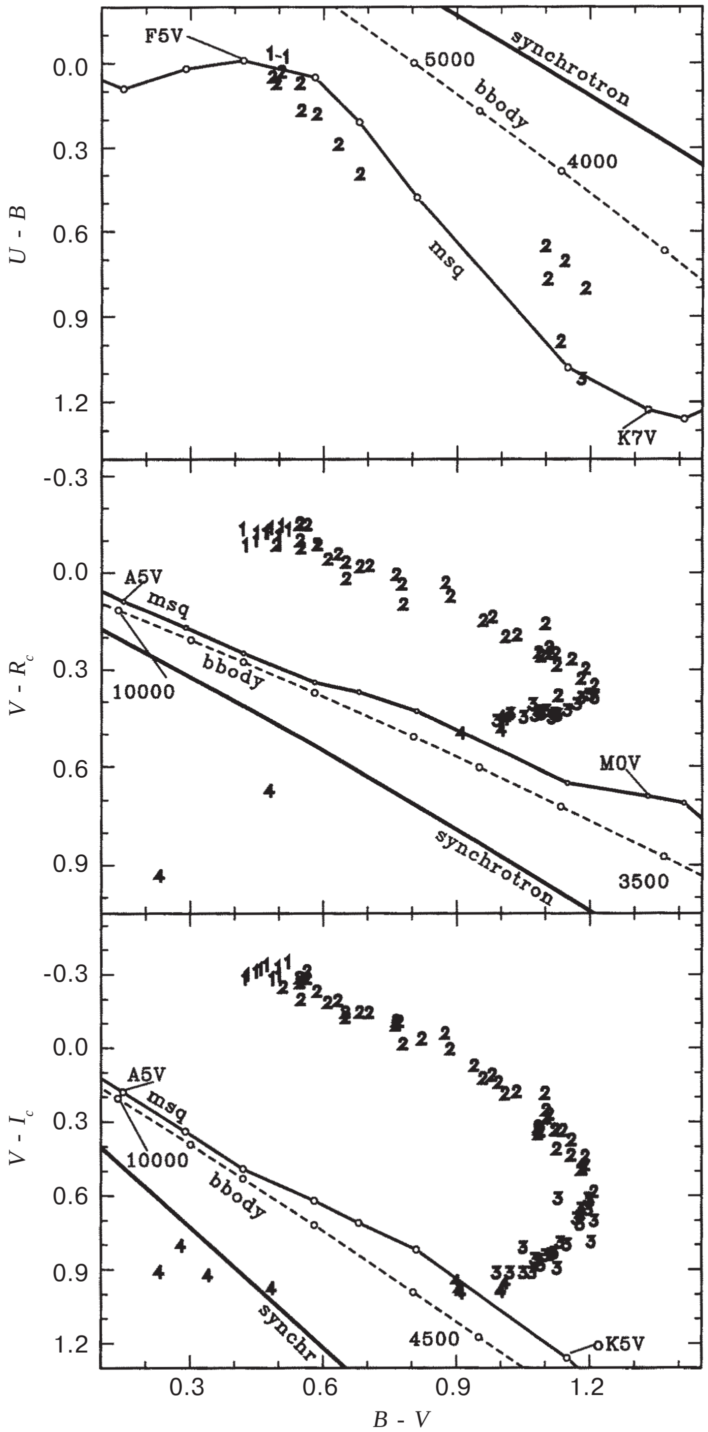

Fig. 4. Two-color diagrams. The numbers indicate the color indices of the supernova in the different stages of its evolution indicated in Fig. 2. In addition, various curves represent the color indices of black bodies at different temperatures, the color indices of main sequence stars as functions of spectral class, and the color indices of a power-law (synchrotron radiation) spectrum as functions of the

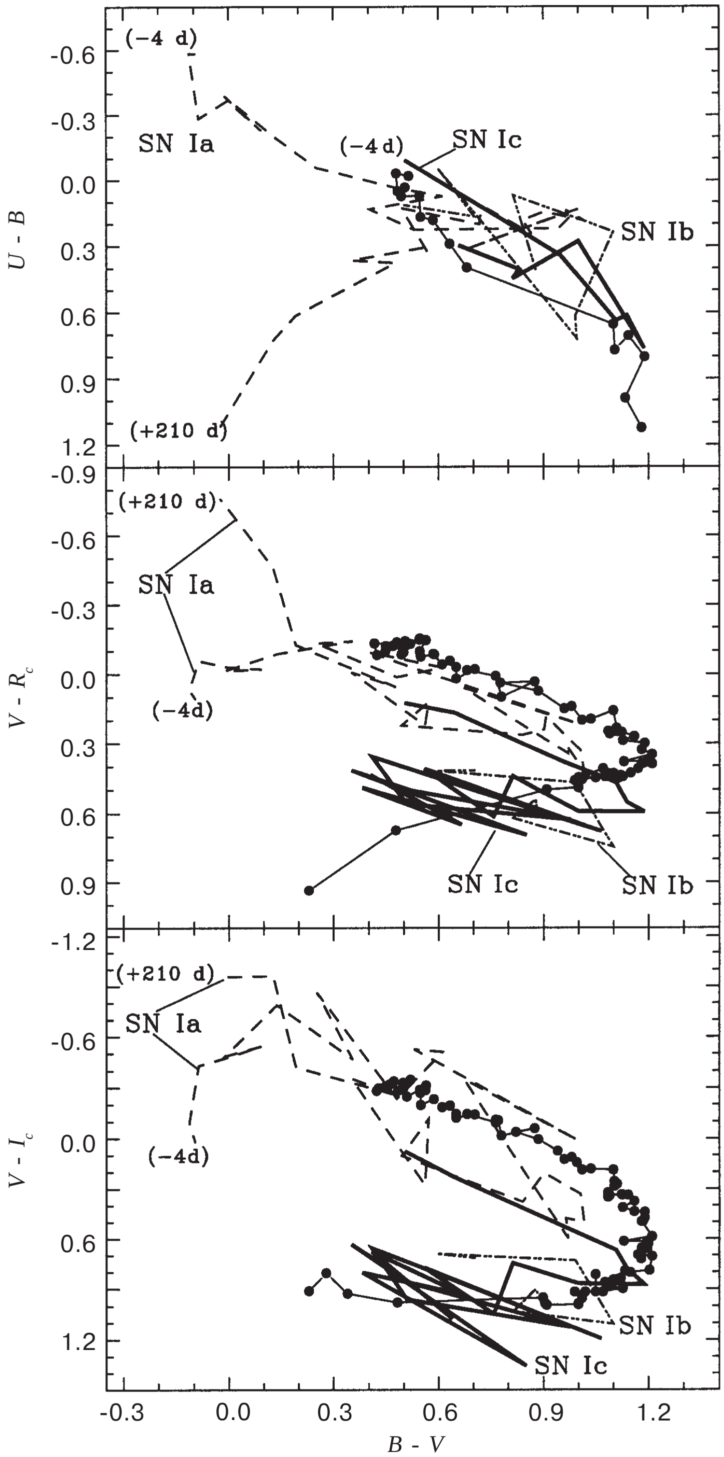

Fig. 5. Two-color diagrams for SN Ia, SN Ib, and SN Ic supernovae as functions of time following the time of their peak B-band brightness. The data were taken from the web site http://wise-obs.tau.ac.il/~dovip/typing. The solid circles illustrate the evolution of the color indices of SN 2002ap.

all types. In these diagrams the variable is the age of the supernova or the time since the peak brightness in the *B* band. In principle, two-color diagrams of this type for supernovae are analogous to those for stars of different spectral types. These synthetic color indices are available on the internet. Tables of the evolution of the color indices for various types of supernovae are freely available at the site http://wise-obs.tau.ac.il/~dovip/typing. *UB-BV*, $BV\text{-}VR_c$, and $BV\text{-}VI_c$ two-color diagrams from these tables are shown in Fig. 5, where the dashed, dot-dashed, and smooth curves illustrate the evolution of the color indices for Ia, Ib, and Ic supernovae. The numbers in parentheses denote the number of days since the brightness peak in the *B* band, i.e., each of the synthetic color index curves shows the development of the color characteristics of the different types of supernova with time since the date of the maximum in the *B* band. The solid circles are the observed color indices for SN 2002ap, also in terms of the time of its discovery. A comparison of the color indices of the supernova under study with typical plots for type SN Ia, Ib, and Ic supernovae shows that, first, the observed development of the color indices of SN 2002ap is not in any way unusual among supernovae. Second, the color characteristics of SN 2002ap are most similar to those of type Ic supernovae and, perhaps at some times, to those of SN Ia, as well. If, however, wee compare the position of the color indices on the *UB-BV* diagram, then the similarity with SN Ia vanishes. Thus, the unusual position of the color indices compared to normal stars, black body radiation, or synchrotron radiation seen in Fig. 4 becomes entirely ordinary if we compare SN 2002ap with other supernovae. A comparison of the color indices implies that the supernova we are studying belongs to type SN Ic. Other researchers [4-6] have reached the same conclusion based on studies of the spectral characteristics of this supernova.

6. Energy distribution in the spectrum from photometric data

As noted above, even in the first days after its discovery when its brightness was still rising, the color indices of the supernova SN 2002ap did not match either black body radiation or the emission from any normal stars. The actual

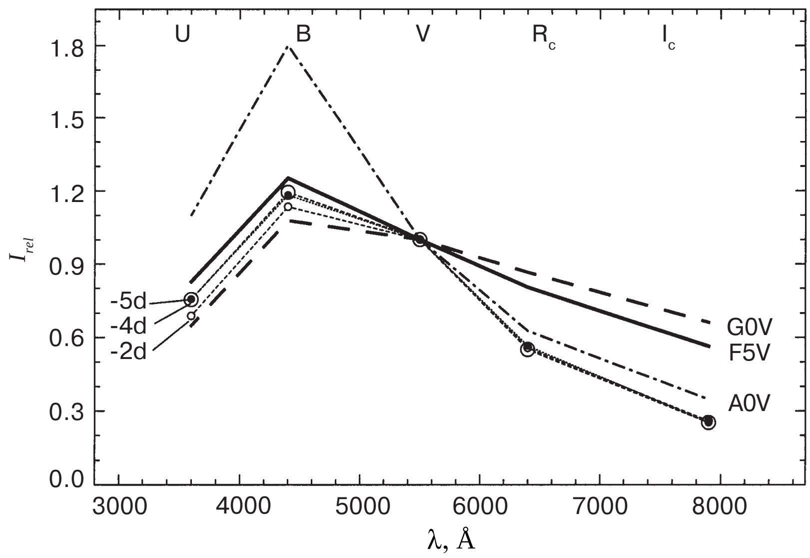

Fig. 6. The energy distribution in the spectrum of SN 2002ap 5, 4, and 2 days prior to the *B* - band brightness peak. As a comparison the thicker curves (smooth, dashed, and dot-dashed) curves show the energy distributions in A0V, F5V, and G0V stars. The energy distributions are all normalized at λ 5500 Å.

situation is shown in Fig. 6. All the fluxes plotted in Fig. 6 are normalized to those in the *V* band, i.e., to the fluxes at a wavelength λ 5500 Å. The energy distribution in the spectrum of a typical F5V star is plotted as a thick continuous curve, that of G0V stars as a thick dashed curve, and that of A0V stars as a dot-dashed curve. The energy distribution of the SN 2002ap supernova is plotted there for the very first day of photometric $UBVR_cI_c$ observations (1 February 2002, JD = 2452307.3), i.e., five days before the peak in the *B* band. These data are indicated by large open circles. The solid circles correspond to observations made 4 days before the brightness maximum (2 February 2002, JD = 2452308.3) and the small open circles, to observations of the supernova two days before the maximum with the *B* filter (4 February 2002, JD = 2452309.8). Interstellar extinction has been taken into account. The "age" of the supernova, i.e., the number of days from the brightness peak in the *B* band, is indicated next to each of the actual energy distributions of the supernova. This figure shows how difficult it is to describe the actual energy distribution in terms of the energy distributions of ordinary stars.

It should be noted that absorption bands are essentially undetectable in the supernova spectrum of 1 February (t = -5 d). The maximum continuum radiation is observed in band *B*, which corresponds to an effective temperature $T \approx 6600\mathrm{K}$ if this emission corresponded to black body radiation. It is also evident from Fig. 6 that the energy distribution changed little over these dates, so that the assumed effective temperature also was essentially constant. On these days the color indices *U-B* and *B-V* are localized near the F5V stars in the two-color diagram; this also indicates an effective temperature $T \approx 6500\mathrm{K}$.

7. Estimate of the rate of expansion of the photosphere of SN 2002ap from photometric data

Very broad absorption structures were observed in published spectra at the brightness peak (7 February 2002) of SN 2002ap. These have been attributed to blends of CoII, NiII, FeII, and SiII lines. Based on the observed wavelength of the minimum of the absorption blend, SiII with λ_0 = 6355 Å, Kinugasa et al. [16] have determined the expansion velocity of the material and, according to their measurements, on 31 January 2002, it was equal to 35000 km/s. Other observers obtain estimates ranging from 30000 to 38000 km/s from the same blend of SiII for the same observation date. On the next day, 1 February 2002, the expansion velocity was 30000 km/s [16]. It fell to 16000 km/s by 6 February 2002 and then decreased exponentially with time [16].

The spectra of SN 2002ap in the article of Kinugasa et al. [16], however, show that most of the radiated energy on 31 January and 1 February 2002 was in the continuum. The spectrum for 31 January is essentially structureless. It is difficult to see any absorption or emission features in it. Some sort of structure (perhaps broad absorption features) begins to show up in the spectrum of 1 February. But these features are still undetermined. On the other hand, by 6 February the structure clearly has structure and absorption features are quite noticeable. Strong blending of shallow lines and the extreme width of the absorption bands make an estimate of the velocity rather uncertain, although the authors indicate that the typical uncertainty in their determination of the displacement velocity of the line is ±1000 km/s.

Since the spectrum of SN 2002ap prior to the brightness maximum, i.e., 31 January-2 February, was essentially continuous with no noticeable absorption features, it may be assumed that at this time we were observing layers of the expanding shell whose opacity was very high, i.e., the photosphere of the star. The outer layers of the shell, which might be regarded as a reversing layer, begin to show up somewhat later, at times near the brightness maximum. The velocities of the outer layers determined from the absorption lines may differ significantly from the velocity of the deep layers which make up the photosphere. It is precisely the presence of a large velocity gradient that makes the absorption features shallow. One of the assumptions in models of the spectra of supernovae is usually that the velocity varies in proportion to the radius [17]. Thus, a comparison of the velocities of the outermost parts of the shell, which are determined from the shift of the absorption lines, with the expansion velocity of the photosphere layers, i.e., the deeper layers, may yield interesting material for discussion, provided, of course, that the expansion velocity of the photosphere is determined independently.

Thus, if we assume that at times prior to the brightness maximum of SN 2002ap the continuum radiation corresponds to an effective temperature $T \approx 6500\mathrm{K}$, then we can try, even if crudely, to estimate the expansion velocity of the photosphere relying solely on the photometric data. We shall assume that on the days preceding the brightness maximum of supernovae, when only a continuum spectrum is observed, we can use the black body radiation formula: $M_V = 28400/T - 5\log(r_{ph}) - 0.19$, where M_V is the absolute magnitude in the V band, T is the temperature of the photosphere in degrees, and r_{ph} is the radius of the photosphere expressed in terms of solar radii. Knowing the absolute magnitude of the supernova, as well as the temperature of the photosphere from the energy distribution in the spectrum of the supernova before the brightness peak, we can estimate the radius. From the size of the photosphere at two times (t_1 and t_2), we obtain its expansion velocity. Of course, this estimate is fairly crude, since, as we saw above, the energy distribution in the optical region of the spectrum cannot be described by a single temperature.

The distance to the supernova (7.3 Mpc) and the absorption up to it ($A_V = 0^m.28$) are known. Then, for two times prior to the brightness peak, specifically t_1 = JD2452307.3 and t_2 = JD2452308.3 (1 and 2 February 2002), we obtain absolute stellar magnitudes of $M_{V1} = -16^m.70$ and $M_{V2} = -16^m.87$, corresponding to the observed magnitudes $V_1 = 12^m.89$ and $V_2 = 12^m.87$. Taking $T \approx 6500\mathrm{K}$, we find $r_{ph}1 = 15010 r_{\odot}$ and $r_{ph}2 = 16210 r_{\odot}$, for an expansion velocity of the photosphere of v_{ph} = 9700 km/s. This value is approximately a factor of three smaller than the value determined from the SiII absorption line, i.e., than the velocity of a layer outside the boundary of the photosphere.

8. Conclusion

An examination of Johnson-Cousins $UBVR_cI_c$ system photometric data from our observations and published data has shown that over an interval of about one year from the date of the burst of the supernova SN 2002ap the light curve passed through three stages in its development: a sharp rise, followed by a stage of rapid exponential decay, and then a slower decay stage. In terms of the shape of its light curve, this supernova is a typical representative of class SN I. The delay in the time of maximum brightness in the I band relative to the U band was about 8.1 days for this supernova. It appears that the dependence of the optical thickness of the shell on frequency and on the time after the explosion, together with a drop in the temperature of the ejected material, creates the effect of a delay in the brightness maximum with increasing wavelength. In terms of the change in its color indices, it can most likely be assigned to the supernova class SN Ic. In the second stage of the evolution of the brightness, when the luminosity falls rapidly, the changes in the color indices are caused by changes in temperature indicative of rapid cooling of ejected material. If we assume that in the premaximum brightness stage the energy distribution in the range from λ 3000 Å to λ 6000 Å is similar to the emission from a spectral class F5V star with an effective temperature $T_{eff} \approx 6500\mathrm{K}$, then the expansion velocity of the layer responsible for the continuum emission is about 9700 km/s.

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