Photometric classification and basic parameters of type I supernovae

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Uniform determinations of the photometric class (rate of decline) are compared against other basic parameters of 54 type I supernovae. Spectrophotometric temperatures on successive dates and correlations between temperature and color index are obtained for several of these stars.

1. INTRODUCTION

In formulating a general description of the physical properties of supernovae, one finds that an important role is played by the "photometric class" β, a parameter the author has introduced to measure the rate at which the star fades in blue light (magnitudes per 100^d) during its fast postmaximum decline. The photometric class has proved sensitive to certain characteristics of supernovae and to the behavior of their light and color curves.[1–3] From the standpoint of classification, the parameter β has enabled the forms of type I and II supernova light curves to be put into a detailed and systematic scheme. That the photometric classification has some universal physical significance is indicated by the differing expansion velocities of the corresponding supernova remnants.[4]

2. UNIFORM PHOTOMETRIC CLASSIFICATION OF TYPE I SUPERNOVAE

In earlier papers the author did not attempt to differentiate between photographic and blue magnitude estimates of supernovae; as a result the classes assigned are subject to appreciable systematic error. Furthermore, the β values were determined quite roughly, with no rms error estimates. We have now introduced the appropriate refinements.

To ensure uniformity in the evaluation of β, we have considered for each supernova all available magnitude estimates between the epoch t_m of maximum light and the epoch t_b of the bend in the light curve where the decline slows down. An analogous parameter γ has been evaluated by considering all measurements after the bend point. Values of β and γ have been determined by least squares either in the B wavelength band or in the photographic, in which case the results have been reduced to the B system. If some magnitude estimates were quoted for the P photometric band, they were first converted to B magnitudes by the relation[5] $P - B = 0.18(B - V) - 0^m.29$ along with the type I supernova light curve, so that

$$\Delta B = \dot{B}\Delta t = \Delta P - (\dot{P} - \dot{B})\Delta t,\ \dot{P} - \dot{B} = 0.18(\dot{B} - \dot{V}).$$

Here ΔB, ΔP denote the B, P magnitude differences between the initial observation on the corresponding branch of the light curve and an observation Δt days later; $\dot{B}$, $\dot{P}$, $\dot{V}$ are the daily changes in magnitude. Denoting the three corresponding photometric classes by β, β_P, β_V, we obtain the following additional relations: for all β, $\dot{B} - \dot{V} \approx (0^m.06 \pm 0^m.004)/\text{day}$, $\beta_P - \beta = 100\ (\dot{P} - \dot{B}) \approx 1.1$, and $\beta - \beta_V = 6.0 \pm 0.4$. As the parameter γ, depending on $B - V$ we obtain from the color curves a small correction that ranges from $\gamma - \gamma_P = 0.5$ for $\beta = 5$ to $\gamma - \gamma_P = 0.06$ for $\beta = 17$.

In the case of conventional photographic magnitudes, the estimates at t_m, t_b were reduced to the B system by adding $+0^m.3$, $+0^m.1$, respectively.

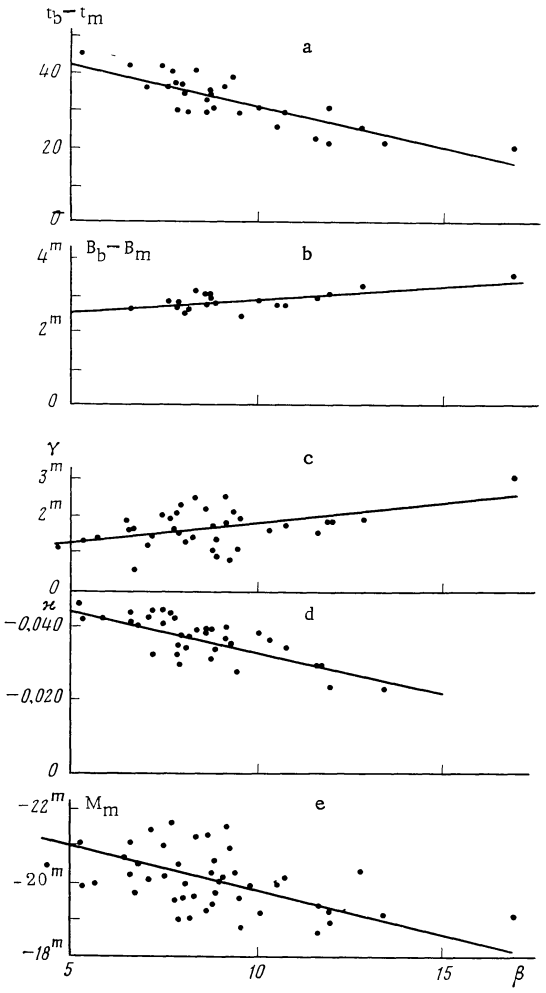

FIG. 1. Correlation of various parameters with the photometric class β. a) Time interval (days) between maximum light and the bend in the light curve; b) drop in B magnitude from maximum light to the bend point; c) the tail slope parameter γ (mag/100^d); d) expansion velocity $\varkappa = v/c$ of the absorption layer in the supernova envelope; e) absolute B magnitude at maximum light.

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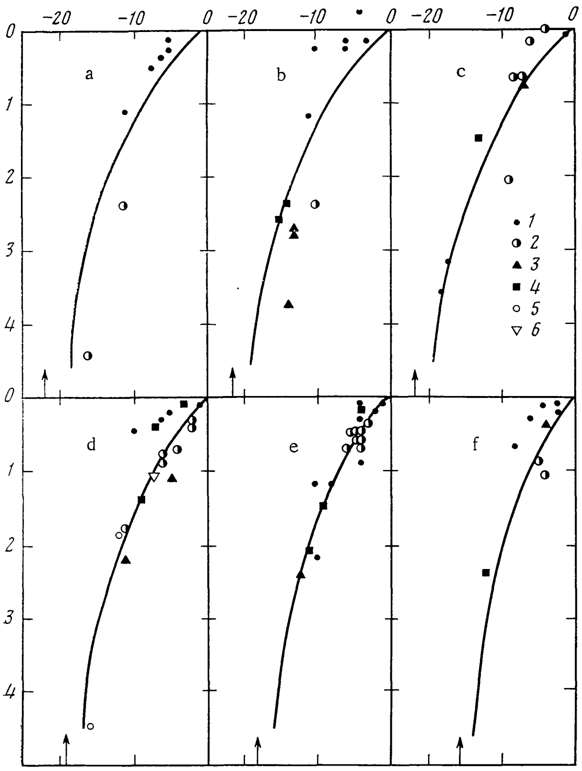

FIG. 2. Rising branch of the light curves for type I supernovae belonging to different photometric classes β. Abscissa, phase t (days); ordinate, B magnitude below maximum. In each panel the supernovae cluster around a different β value. a) β = 13.4: (1) SN 1972j, (2) SN 1963i; b) β = 12.0: (1) SN 1971i, (2) SN 1954a, (3) SN 1971g; c) β = 10.0: (1) SN 1965i, (2) SN 1939a, (3) SN 1937c, (4) SN 1980n; d) β = 9.2: (1) SN 1963p, (2) SN 1970)]. (3) SN 1964e, (4) SN 1981b. (5) SN 1979b, (6) SN 1973f; e) β = 8.0: (1) SN 1974g, (2) SN 1975n, (3) SN 1969c, (4) SN 1957b; f) β = 4.5: (1) SN 1961p, (2) SN 1920a, (3) SN 1963j, (4) SN 1962p.

Table I presents an inventory of type I supernovae with the elements of their light curves and their photometric classes and physical parameters. Successive columns contain: 1) the designation of the supernova; 2) the NGC or IC number of the parent galaxy; 3) the galaxy morphological type as coded by de Vaucouleurs in the Reference Catalog; 4) the Julian day of maximum light (§ denotes a date estimated from the spectrum[1]; * signifies a revised determination, in both column 4 and column 10); 5) the Julian day of the bend in the light curve; 6) the magnitude B_m at maximum light; 7) the magnitude B_b at the bend point (defined more carefully below); 8) the B-band photometric class β; 9) the corresponding parameter γ; 10) the expansion velocity $\varkappa$ relative to the speed of light, as estimated from the shift of absorption features in the supernova spectrum[1]; 11-14) quantities explained in Secs. 5 and 6; 15) references to the published photometry and spectra (further references are cited in the tables in my 1977 paper[1]; to save space these are not repeated here).

Actually the bend point does not lie on the light curve itself, since we define it by the intersection of the linear light-curve branches having slopes β and γ. Only one supernova, 1972e, has observations spaced closely enough to show that the light curve runs $0^m.3$ above the bend point; the supernova's epoch of greatest reddening leads the bend point by 3^d. For all other type I supernovae it is hard to make such an estimate due to the limited number of observations in this part of the curve. For type II supernovae, however, we know that the reddening maximum and the bend where the gentle tail of the light curve begins are spaced well apart.[4]

From the data in Table I the following correlations, illustrated in Fig. 1, can be obtained between the photometric class β and other parameters of the type I supernovae (subscripts m, b refer to maximum light and the bend in the light curve):

$$\begin{array}{rlll} t_b - t_m = 53 & -2.2\beta \text{ days} & (29 \text{ supernovae}) \\ \pm 3 & \pm 0.3 & \\ B_b - B_m = 2.2 & +0.065\beta \text{ mag} & (20 \text{ supernovae}) \\ \pm 0.1 & \pm 0.014 & \\ \gamma = 0.77 & +0.10\beta & (36 \text{ supernovae}) \\ \pm 0.29 & \pm 0.04 & \\ \varkappa = -0.055 & +0.0022\beta & (36 \text{ supernovae}) \\ \pm 0.003 & \pm 0.0003 & \end{array}$$

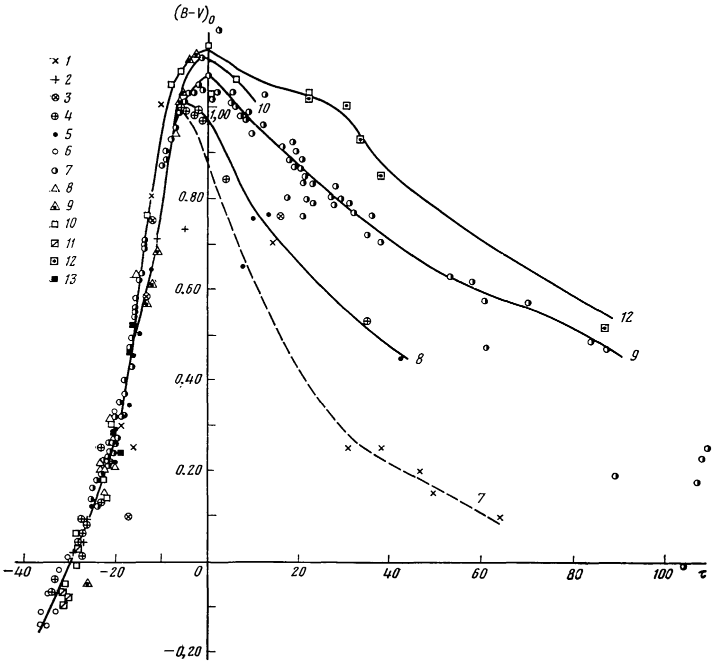

FIG. 3. Normal-color curves for type I supernovae. Abscissa, phase τ (days) relative to the bend in the light curve; ordinate, normal color index $(B-V)_0$. Each curve is labeled at the right with the approximate photometric class β. Colors are plotted for: 1) SN 1972h, 2) SN 1959c, 3) SN 1966j, 4) SN 1975n, 5) SN 1967c, 6) SN 1981b, 7) SN 1972e, 8) SN 1954b, 9) SN 1980n, 10) SN 1971i, 11) SN 1975a, 12) SN 1954a, 13) SN 1971g.

TABLE I. Photometric and Physical Parameters of Type I Supernovae

SN	NGC (IC)	Morph. type	JD − 2,400,000		B_b	B_m	β
			maximum light	bend point			
1	2	3	4	5	6	7	8
1895b	5253	0	13382§	–	8^m2	–	7.2±1.3
1919a	4486	−5	–	–	–	–	8.0±1.5
1920a	2608	3	–	22373	–	13^m7	4.7±1.0
1921c	3184	6	23031	–	11.3	–	5.6±1.1
1937c	(4182)	9	28769§	28798	8.5	11.2	10.8±0.3
1937d	1003	6	28794	28828	13.3	15.8	8.1±0.2
1939a	4636	−5	29290	29319	12.9	15.3	9.6±0.7
1939b	4621	−5	29389	29408	12.5	15.9	17±2
1954a	4214	10	34852§	34873	–	12.3	12.0±0.4
1954b	5668	7	–	34895	–	15.7	9.5±0.2
1956a	3992	4	–	35595	–	15.6	6.6±0.8
1957b	4374	−5	–	36002	–	15.3	7.9±0.2
1959c	Anon	5	36751§	–	14.1	–	6.8±0.2
1960f	4496	9	37039	37079	11.4	14.5	8.4±0.1
1960r	4382	−1	37283§	37323	–	14.8	7.8±0.2
1961h	4564	−5	37418	–	11.4	–	7.5±0.2
1961p	Anon	7	37552	37594	14.6	17.2	6.6±0.1
1962j	6835	1	37899§	37940	–	15.9	7.5±0.3
1962p	1654	–	–	38001	–	17.3	4.3±0.2
1963λ	4146	2	–	38034	–	18.9	8.3±0.4
1963i	4178	8	38158§	38179	–	15.7	13.5±0.3
1963j	3913	7	38175	–	13.4	–	5.8±0.2
1963p	1084	5	38301§	38330	14.0	17.0	8.8±0.4
1964e	Anon	6	–	38484	–	15.2	9.2±0.6
1965i	4753	0	38933	38963	12.5	15.6	10.1±0.2
1966j	3198	5	39453§*	39498	–	14.3	5.3±0.2
1966n	Anon	8	–	39454	–	17.6	6.5±0.3
1967c	3389	5	39544§	39582	–	16.0	8.0±0.3
1968e	2713	2	39924§	–	–	17.1	5.2±0.5
1969c	3811	6	40254	40290	14.0	16.8	7.7±0.2
1970j	7619	−5	40865	40895	14.3	17.0	8.9±0.2
1971g	4165	1	41055	41085	13.7	16.7	12.0±0.5
1971i	5055	4	41103	41125	12.0	14.9	11.7±0.4
1971l	6384	4	41133	41165	13.6	16.3	8.7±0.5
1971p	7319	4	41176§	41212	–	18.7	7.1±0.1
1972e	5253	0	41444§	41480	–	11.2	9.2±0.1
1972h	3147	4	–	41558	–	17.5	9.3±0.7
1972j	7634	−2	41553	41578	14.0	17.2	12.9±1.0
1973f	4944	0	41781	–	15.7	–	9.0±0.7
1973n	7495	5	–	41960	–	18.7	9.3±0.5
1974g	4414	5	42168	42197	12.2	14.8	8.2±0.2
1974j	7343	4	42335	42371	15.9	18.7	7.9±0.1
1975a	2207	4	42434	–	14.6	–	11.7±1.1
1975g	Anon	0	42575	42610	14.9	17.8	8.8±0.3
1975n	3723	3	42720	42750	13.5	16.1	7.9±02
1975o	2487	3	–	42775	–	18.2	8.9±0.3
1975s	1325	4	–	–	–	–	15.1±0.1
1976g	488	3	–	43100	–	17.4	8.6±0.1
1976j	977	1	–	43160	–	17.6	9.1±0.2
1978e	Anon	9	43815	–	15.3	–	7.8±0.2
1979b	3913	7	43948§	43986	–	15.7	9.4±0.2
1980n	1316	−5	44581	–	12.5	–	9.8±0.2
1981b	4536	4	44673	44707	12.0	15.0	8.8±0.1
1982b	2268	4	45019	45044	13.5	16.2	10.6±0.3

Using these relations we have recovered the dates and magnitudes of maximum light and the bend point for supernovae whose light curves are incomplete.

3. INITIAL RISE IN LIGHT CURVE

We adopt the Branch–Patchett relation[42] between the variations in the magnitude and photospheric temperature and radius of a supernova, assuming that prior to maximum the photosphere has a high temperature that remains practically constant until maximum is reached (see Sec. 7). The following relation will then yield the phase $t_0 - t_m$ when the supernova starts to expand, measured in days from the epoch of maximum light:

$$t - t_m = [1 - 10^{-0.2(B - B_m)}]\,(t_0 - t_m).$$

Here B is the apparent magnitude at phase t. Figure 2 as well as the summary data

β	4.5	8.0	9.2	10.0	12.0	13.4
$t_0 - t_m$	−16±2	−18±1	−19±1	−22±2	−21±2	−22±2.

illustrate how the initial rise depends on the photometric class for type I supernovae. We obtain the correlation

$$\begin{array}{l} t_0 - t_m = 0.7\,\beta \;\; + 13 \\ \qquad\qquad\; \pm 0.2 \;\; \pm 2. \end{array}$$

4. COLOR CURVES

In view of our refinements of the photometric classes of type I supernovae we have reconsidered their general color curves. Since photographic color indices are subject

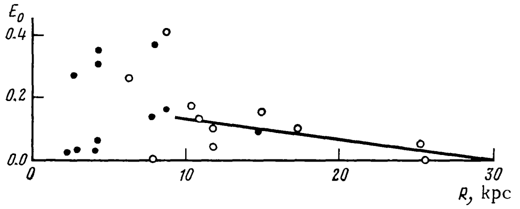

FIG. 4. Relation between the reddening (color excess E_0) of supernovae in spiral galaxies and the distance from the center. Circles, Sb galaxies; dots, Sc galaxies.

TABLE I (continued)

γ 9	ϰ 10	m_0—M 11	R, kpc 12	E 13	M_M 14	References 15
1.4	−0.044	$29^m\!.49$	—	$0^m\!.016$	$-21^m\!.4$	[1]
—	—	—	—	—	—	[6]
1.4:	—	—	—	—	—	[1]
—	—	30.94	18.0	0.1	−20.0	[7]
1.7	−0.034	28.49	—	0.000	−20.1	[1]
1.3	−0.034	30.27	2.8	0.70	−19.9	[1]
1.9	—	31.48	—	0.006	−18.7	[1]
3.0	—	31.48	—	0.005	−19.1	[1]
1.8	−0.023	28.49	—	0.000	−19.2	[1, 8]
1.1	−0.028	32.47	3.0	0.05	−19.6	[1, 9]
1.6	−0.041	31.80	8.8	0.65	−21.1	[1]
2.1	−0.034	31.48	—	0.018	−18.9	[1]
—	−0.040	33.81	4.2	0.20	−20.5	[1]
2.4	−0.039	32.59	—	0.003	−21.2	[1, 10]
1.6	−0.042	31.48	—	0.003	−19.5	[1, 10]
—	−0.040	31.48	—	0.019	−20.2	[1, 10]
1.6	−0.043	34.43	19.8	0.1	−20.2	[1]
2.0	−0.044	32.92	11.2	0.3	−21.0	[1]
1.4	—	34.74	10.8	0.1	−20.4	[1]
1.4	—	35.70	26.8	0.0	−19.6	[1]
—	−0.023 *	31.48	2.4	0.05	−19.0	[1, 10]
—	−0.042	—	—	—	—	[1, 11]
2.2	−0.038	32.22	8.7	0.3	−19.4	[1]
2.5	−0.039	—	—	—	—	[1, 10]
1.5:	−0.038	31.48	—	0.001	−19.0	[1, 12]
1.3	20.042	30.94	14.7	0.20	−19.9	[1, 13, 14]
1.3	—	34.83	11.3	0.2	−20.7	[1]
2.3	−0.037	31.78	7.9	0.10	−18.9	[1]
—	−0.046	34.33	10.8	0.35	−21.1	[1]
1.9	−0.043 *	33.97	4.3	0.40	−21.6	[1]
1.3	−0.034	34.49	—	0.051	−20.6	[1, 15]
1.8	—	32.26	—	0.05	−18.8	[1, 10, 16]
1.5	−0.029	29.93	11.7	0.17	−18.6	[1 ,10]
2.5:	−0.039	32.78	6.3	0.50	−21.2	[1, 17, 18]
1.2	−0.042	35.69	22.7	0.1	−20.1	[1, 19]
1.8	−0.036	29.49	—	0.016	−21.4	[1, 20–23]
0.5	—	33.80	14.9	0.20	−19.7	[1, 24]
1.9	—	34.13	—	0.038	−20.3	[25]
—	—	35.69	—	0.007	−20.0	[26]
0.8	−0.035	35.04	8.0	0.45	−20.9	[25]
3:	−0.037	30.78	4.3	0.10	−19.0	[1, 25]
1.5	−0.032	—	—	—	—	[25]
—	−0.029	33.46	25.5	0.10	−19.3	[1, 27, 28]
1.0	−0.031	—	—	—	—	[29]
2.4:	−0.03	32.97	10.4	0.25	−20.5	[17, 29–31]
0.9	—	34.97	17.4	0.15	−19.7	[29]
—	—	—	—	—	—	[30]
—	—	33.30	25.3	0.10	−19.2	[32]
2.2:	—	34.73	—	0.05	−20.1	[29, 32]
—	—	—	—	—	—	[11]
2.1	−0.032	31.89	4.4	0.35	−20.2	[11]
—	—	32.36	—	0.000	−19.9	[33, 34]
1.7	−0.039	31.48	11.8	0.17	−20.2	[35–39]
1.6	—	31.45	7.9	0.00	−19.9	[29, 32,40, 41]

to substantial error we have used only photoelectric measurements, except that for the "junior" supernovae, those not provided with photoelectric estimates, we have had to accept photographic B − V colors. As previously,[1] we neglect internal reddening in elliptical, lenticular, and irregular Magellanic-type galaxies; for supernovae in such galaxies we have computed the color excesses due to interstellar matter in the Milky Way.[43] For all other supernovae the reddening has been determined by comparing the mean color indices with the normal colors for SN 1972e on the rising branch of the color curve.

In Fig. 3 the normal-color curves are plotted against the phase $\tau = t - t_b$ relative to the bend point t_b. These curves display a similar increase in reddening for all photometric classes; the maximum reddening does depend somewhat on β, and there is a strong β-dependence for the declining branch of the color curve.

5. MEAN COLOR EXCESSES OF TYPE I SUPERNOVAE IN SPIRAL GALAXIES

If a type I supernova is observed in the outer part of a spiral galaxy one can make a rough estimate of the color excess without having a color-index measurement. Assuming that the supernova lies in the system's central

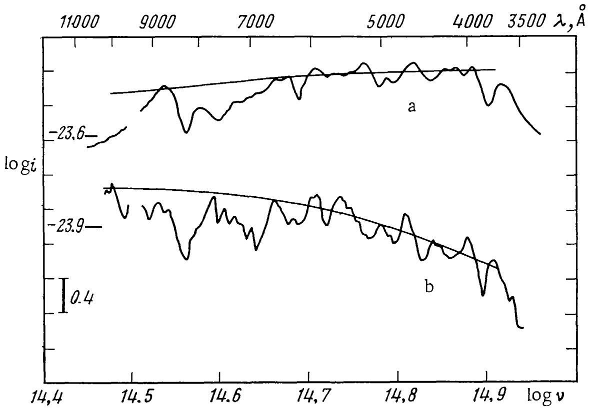

FIG. 5. Spectral energy distribution[51] of supernova 1972e, compared with a blackbody distribution. a) Phase at JD 41456, T_3 = 13; b) JD 41494, T_3 = 5.

TABLE II. Temperature Determinations [10^3 °K]

JD − 2,400,000	Phase τ, days	T_3 at wavelength [μ]									$\bar{T}_3$ 1,0—0,39	$\bar{T}_3$ 0.7—0.39	$\bar{T}_3^{-1}$	$(B-V)_0$	Δ	$(B-V)_{00}$
		1.0	0,87	0.77	0,65	0,63	0,59	0,55	0,52	0,39						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SN 1972e β=9.2 E=0.016 [51, 53]																
41454	−26	–	21	–	12 *	10.5*	9.5	–	20	6.5	15±2	12±2	0.067±0.009	0.09	0,08	0.01
41455	−25	–	26	–	13 *	10.5*	10	–	17	6.5	16±3	12±1	0,083±0.009	0.12	0.06	0.06
41456	−24	–	14	–	13.5 *	12.5*	12	–	17	6.5	13±1	13±1	0.076±0.005	0.14	0.06	0.08
41456	−24	–	–	–	–	15.5*	13.5	–	15	5.5	13±2	14.7±0.6	0,068±0.003	0.14	0,07	0.07
41459	−21	–	10.5	–	12 *	10.5*	11,5	–	11	6	10.6±0.6	11.2±0.4	0.088±0.003	0.24	0,05	0.19
41461	−19	–	9	–	11.5 *	9.5*	11	–	12	5.5	10±1	11.5±1.0	0.100±0.010	0,31	0,05	0.26
41462	−18	–	14	–	8.5 *	9*	10.5	–	6.5	7.5	11±1	8.9±0.7	0.112±0.009	0.37	0.03	0.34
41470	−10	–	8	7 *	6	–	6	4	–	5	6.7±0.5	5.6±0.6	0.179±0.019	0,80	0.01	0.79
41473	−7	–	9.5	5 *	5.5	–	5	4.5	–	6	6.6±0.9	5.1±0.3	0.186±0,012	0.95	0.00	0.95
41476	−4	6	6.5	6.5 *	5	4,5	4.5	5	–	5.5	5.7±0.2	4.8±0.2	0.208±0.009	1.03	0.00	1.03
41485	5	4.5	5	4.5 *	5.5	–	4.5	4.5	–	4.5	4.7±0.1	5.0±0.4	0.218±0.005	1.02	0.00	1.02
41489	9	–	7	9.5 *	5	–	5	4	–	5	6.8±0.8	4.8±0.3	0.208±0.013	0.98	0.00	0,98
41494	14	5.5	5.5	5 *	5.5	–	5	5	–	4.5	5.3±0.3	5.2±0.2	0.192±0.007	0.93	0.00	0.93
41505	25	6	6	6.5 *	5.5	–	5	5.5	–	4	5.8±0.2	5.3±0.2	0.189±0.007	0.83	0.01	0.82
41508	28	6.5	6.5	6.5 *	6.5	–	4.5	4.5	–	4.5	6.2±0.3	5.4±0.7	0.185±0.024	0.80	0.01	0.79
41530	50	7.5	–	6 *	7.5	–	8	8	–	–	7.3±0.4	7.8±0.1	0.126±0.002	0.64	0,02	0.62
SN 1971i β=11.7 E=0.17 [51]																
41120	−5	5	6.5	4,5	–	5	4	4	–	5	5.1±0.3	4.5±0.1	0.222±0.004	1.10	0.00	1.10
41135	10	5	6.5	5	–	5	4.5	4.5	–	5.5	5.3±0.2	4.8±0.2	0.207±0.009	1.06	0.00	1.06
41160	35	5.5	5.5	5,5	–	4.5	5	4	–	8	5.2±0.3	5.1±0.7	0.192±0.011	0.91	0.00	0.91
SN 1971l β=8.7 E=0.10 [51]																
41135	−30	–	16	–	17*	–	10	8	25	6.5	18±2	12±4	0.085±0.030	−0.01	0.06	−0.07
41160	−5	5.5	5	–	4.5	4.5	–	4.5	4.5	4.5	4.9±0.2	4.5±0.1	0.222±0.005	1.01	0.00	1.01
41178	13	–	7	–	5.5	5	–	4.5	6	5	5.8±0.4	5.1±0.6	0.196±0.023	0.94	0.00	0.94
SN 1975a β=11 7 E=0.10 [28]																
42429	−32	–	13.5	–	–	11*	20	–	24	7.5	14±2	16±4	0.071±0.010	−0.06	0.07	−0.13
42429	−32	–	–	–	–	–	10.5	–	16.5	9	12±2	13±3	0.083±0.014	−0.06	0.06	−0.12
42430	−31	–	–	–	–	10.5*	13.5	–	15	9.5	12±1	12±1	0.083±0.009	−0.03	0.06	−0.09
42432	−29	–	16	–	–	10 *	13	–	25	7.5	14±2	14±4	0.074±0.010	+0.01	0.07	−0.06
SN 1981b β=8.8 E=0.17 [39]																
44670	−37	–	–	–	–	12.5*	12	9	11	11.5	–	11.6±0.5	0.086±0.004	−0.12	0.05	−0.17
44687	−20	–	–	–	10.5*	–	13.5	–	10.5	11.5	–	11.5±0.7	0.087±0.005	0.27	0.05	0.22
44690	−17	–	–	–	6*	–	7	8	–	7.5	–	6.9±0.4	0.146±0.008	0.42	0.02	0.40
44694	−13	–	–	–	5	–	4.5	6.5	–	5,5	–	5.6±0.5	0.179±0.016	0.74	0.01	0.73
44698	−9	–	–	–	–	–	5.5	4	–	4	–	4.7±0.6	0.214±0.027	0.90	0.00	0.90
44705	−2	–	–	–	–	–	4.5	4	–	–	–	4.3±0.5	0.233±0.027	1.06	0.00	1.06
44719	12	–	–	–	5,5	–	5	4	–	–	–	5.0±0.4	0.200±0.016	0.95	0.00	0.95
44728	21	–	–	–	–	–	–	8	–	4	–	6±2	0.161±0.050	0.86	0.00	0.86
44765	58	–	–	–	–	–	13	9.5	–	7	–	10.5±0.4	0.095±0.004	0,61	0.04	0.57
44786	79	–	–	–	–	–	–	22	–	–	–	22±5	0.045±0.010	0.52	0.11	0.41
SN 1960f β=8,4 E=0.003 [54, 55]																
33747	−32	–	–	–	–	12*	16	8.5	14	–	–	13±1	0.076±0.008	−0.06	0.06	−0.12
33750	−29	–	–	–	–	11,5*	14	11.5	11.5	–	–	12±1	0.083±0.005	0.01	0.06	−0.05
33752	−27	–	–	–	12,5*	10,5*	10	–	20	–	–	12±2	0.083±0.012	0.07	0.06	+0.01
33756	−23	–	–	–	9,5*	8,5*	9	–	29	–	–	11±4	0.089±0.029	0.18	0.05	0.13
33758	−21	–	–	–	–	–	9	–	8	—	–	8.7±0.5	0.115±0.007	0.24	0.03	0.21

plane, we can use the observed excess E to determine the reddening E_0 in that plane along the normal direction:

$$E_0=(E-E_G)\,b/a, \tag{1}$$

where E_G denotes the interstellar reddening in the Galaxy, while b, *a* are the minor and major semiaxes of the parent galaxy's image.

Allowing for the inclination of the central plane to the line of sight, the distance d of the supernova from the center of the image in arc seconds and its distance R in kiloparsecs will be given by

$$d^2=(\Delta\delta\cos\varphi+\Delta\alpha\sin\varphi)^2+(\Delta\delta\sin\varphi-\Delta\alpha\cos\varphi)^2a^2/b^2,$$
$$R=d(\arcsin 1'')^{-1}\cdot 10^{0.2(m_0-M)-2}, \tag{2}$$

where Δα, Δδ are the equatorial coordinates of the supernova relative to the center of the galaxy,[44] φ is the position angle of the major axis,[45,46] and m_0-M is the true distance modulus.

Values of m_0-M, R, and E are given in columns 11-13 of Table I. In particular, column 11 makes use of redshift distances for the galaxies based on H_0 = 50 km · sec^{-1} · Mpc^{-1}, as well as mean distances for the parent clusters.[47,48] Column 12 gives the galactocentric distance R of the supernova. The color excesses in column 13 quoted to three decimal places are taken from Burstein and Heiles[43] (reddening in the parent galaxy is neglected); those with two decimal places are based on comparison of the supernova's color index with the corresponding color shown in Fig. 3; and entries given to one decimal place are derived from the linear correlation between E_0 and R, and Eqs. (1), (2). This correlation is plotted for nine supernovae in Fig. 4. It manifests itself for R ≥ 10 kpc, and takes the form

$$E_0=\underset{\pm0.04}{0.19}\;\underset{\pm0.003}{-0.006R}\quad\text{(9 supernovae).} \tag{3}$$

There does not seem to be any systematic disparity in the E_0 value for Sb and Sc galaxies. We have used Eqs. (1)-(3) to obtain the estimates of E for the nine supernovae quoted in Table I.

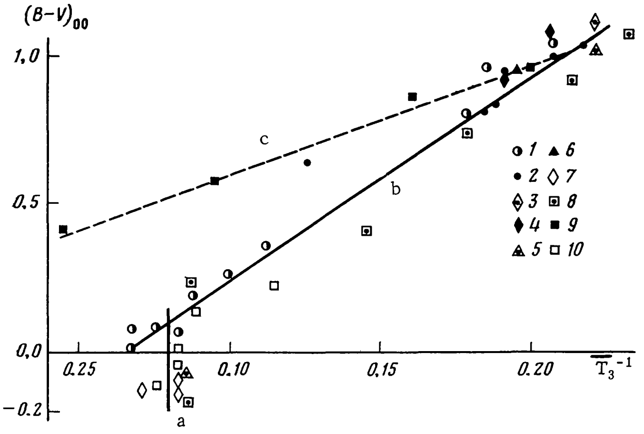

FIG. 6. Correlation between $\overline{T}_3^{-1}$ and $(B-V)_{00}$ for phases: a) $\tau < -23^d$; b) $-23^d < \tau < 0^d$; c) $\tau > 0^d$. 1) SN 1972e, $\tau < 0^d$; 2) SN 1972e, $\tau > 0^d$; 3) SN 1971i, $\tau < 0$; 4) SN 1971i, $\tau > 0$; 5) SN 1971l, $\tau < 0$; 6) SN 1971l, $\tau > 0$; 7) SN 1975a, $\tau < 0$; 8) SN 1981b, $\tau < 0$; 9) SN 1981b, $\tau > 0$; 10) SN 1960f, $\tau < 0$.

6. ABSOLUTE MAGNITUDES

Branch et al.[39] point out the conflict between the predictions of the radioactive ^{56}Ni decay hypothesis and the observed photometric-class dependence of the absolute magnitude M_m of type I supernovae at maximum light. Accordingly this dependence warrants the most careful confirmation. Data on the absolute magnitude at maximum light are given in column 14 of Table I. We find the following correlation between M_m and β (see also Fig. 4):

$$M_m = \begin{matrix} -22.1 \\ \pm 0.3 \end{matrix} \quad \begin{matrix} +0.23\beta \\ \pm 0.03 \end{matrix} \quad \text{(46 supernovae).}$$

It is worth recalling here that a correlation between M_m and the rate of decline of supernovae was first derived by Kopylov[49] in 1955.

7. SPECTROPHOTOMETRIC TEMPERATURES

The author's identification of features in supernova spectra[50] some years ago revealed continuous emission in the stellar envelopes. But a mere glance at the spectrum tracings suffices to show that supernova spectrophotometric temperatures can only be estimated roughly, and that one needs a method which will avoid arbitrariness and will indicate the level of random error in the results. We have worked out such a method for tracings of the SN 1972e spectrum and have applied it to several other spectra. Kirshner et al.[52] have demonstrated that on four dates the 0.33-2.3 μ spectrum of SN 1972e had a near-blackbody average energy distribution. In taking advantage of the more extensive material available for the 0.39-0.7 μ wavelength range, our aim has been to search for a well-defined distribution of this kind in a uniform manner.

We have proceeded as follows. Detailed tables of the logarithmic relative Planck intensities B_λ, B_ν were computed for temperatures of $(4\text{-}60)\cdot 10^{3\circ}$K at wavelengths corresponding to the peaks of each type I supernova spectrum. As the unit of intensity we have taken the value at the 0.46-μ peak. From the spectra we then determined the logarithmic relative intensities of the peaks and of the adjacent minima. These values were corrected for interstellar reddening, as computed from the standard empirical relation $A_\lambda = a + b/\lambda$ and from $\gamma_\lambda = A_\lambda/E$, setting $\lambda_B = 0.46$ μ, $\lambda_V = 0.55$ μ, and $\gamma_V = 3$. The resulting correction to the logarithmic intensity is

$$\Delta \lg i_\lambda = 0.4\,A_\lambda = (0.6-0.99\,\lambda^{-1})E \sim E/\lambda.$$

The corrected values for the logarithmic relative intensity i_λ of the spectrum peaks were now compared with the corresponding values in Table I, and the brightness temperature T_3 [in $10^{3\circ}$K] was determined for each wavelength.

Estimates of T_3 from the spectrum peaks alone and from the mean intensities for the peaks and the neighboring absorption troughs (this mean value is approximately the same as the intensity at the short-wave side of the absorption feature, unless it is distorted) show that as the phase τ of the supernova grows longer, the T_3 values derived from the peaks continue to rise, and are not correlated with the changes in color index. This behavior testifies to a steady increase in the intensity of the emission components. Since the T_3 values have a larger scatter when estimated from the peaks than from the mean intensities, the latter more accurately reflect the behavior of the continuum and yield more reliable T_3 estimates. We would point out, however, that the absorption edges marked by asterisks in Table II (see below) all have equal intensities, indicating that the emission components are inconsequential.

In selecting peaks and absorptions we have recognized that the infrared spectra of supernovae contain some excess intensity, serving to elevate T_3, while the opposite is true in the ultraviolet. Hence the brightness temperatures show a systematic trend at successive phases, although a perfectly satisfactory weighted mean can be obtained. As a weight we have adopted the difference between the peak wavelength and 0.46 μ. This weighted mean in effect gives not a brightness temperature but a spectrophotometric temperature $\overline{T}_3$. The Planck distribution corresponding to that temperature closely fits the observed supernova spectrum (Fig. 5).

In Table II we present comprehensive determinations of brightness temperatures T_3 and mean spectrophotometric temperatures $\overline{T}_3$ for six type I supernovae. Each section of the table is headed with the supernova name, its photometric class β, its color excess E, and references to the spectroscopic material. Successive columns give: 1) the Julian day when the spectrum was taken; 2) the phase τ; 3-11) the T_3 values at nine wavelengths (values based only on the peaks are marked *); 12-13) the weighted mean $\overline{T}_3$ values for the 0.39-1.0 μ and 0.39-0.7 μ intervals; 14) the inverse temperature $\overline{T}_3^{-1}$; 15) the normal color index $(B-V)_0$, read from Fig. 2; 16) the correction $\Delta \approx 0.0045\overline{T}_3$ to $(B-V)_0$ due to introduction of the Planck factor into the Wien formula[56]; 17) the correspondingly corrected index $(B-V)_{00}$.

Comparing the $\overline{T}_3$ values in columns 12, 13, we see that in some cases they differ significantly because of the spread of T_3 in the infrared, where the intensity excess raises the temperature estimates. In the remaining cases there is little disparity. In computing $\overline{T}_3^{-1}$ we have chosen the $\overline{T}_3$ value (columns 12, 13) having the smaller rms error.

Figure 6 shows the relation between $(B-V)_{00}$ and $\overline{T}_3^{-1}$ for several phase intervals:

$$\overline{T}_3^{-1}=0.080\pm0.002 \text{ , or } \overline{T}_3=12.5\pm0.3 \quad (\tau<-23^d), \tag{4}$$

$$\overline{T}_3^{-1}=\underset{\pm0.004}{0.132}\,(B-V)_{00} \underset{\pm0.002}{+0.066} \quad (\tau<0^d), \tag{5}$$

$$\overline{T}_3^{-1}=\underset{\pm0.02}{0.27}\,(B-V)_{00} \underset{\pm0.02}{-0.06} \quad (0<\tau<80^d), \tag{6}$$

By using Eqs. (4)-(6) one can estimate $\overline{T}_3$ from observed color indices $B-V$ and excesses E.

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