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THE PHOTOMETRIC PROPERTIES OF SUPERNOVAE

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A detailed summary is compiled of the photometric parameters for 60 type I, II, and V supernovae. Means are determined for each type, including the mean absolute photographic magnitude M_{SN} at maximum light. The relation is found between M_{SN} and the type of galaxy where each type I supernova outburst occurred. All three types of supernova exhibit a common correlation between the brightness decline rate β and M_{SN}. For type II supernova β is correlated with the time required for a "hump" to appear in the light curve.

1. General Description of the Photometric Material for Supernovae

Supernovae constitute a topic in modern astrophysics that is closely interlaced with such problems as the radiation of massive nonstationary stars, the formation of heavy elements, cosmic rays, intense radio emission of nonthermal character, magnetohydrodynamic processes in the interstellar medium and in envelopes containing relativistic particles, the replenishment of the interstellar medium with hydrogen, and its enrichment with heavy elements.

In contradistinction to the great interest in supernovae from the theoretical side, the situation is unsatisfactory regarding observational data on these stars. Thus far, information on the supernova outburst stage has been acquired only by optical techniques – photometry, colorimetry, and spectroscopy. Because of the rarity of supernova outbursts in the galaxies closest to us, no opportunity has yet arisen to observe the supernova outburst stage with a radio telescope.

Although the number of extragalactic supernovae observed since 1885 is rapidly approaching 200, estimates of spectral type are available for only 60 of them, and certain vital photometric elements (the shape of the light curve, the rate of brightness variation, the magnitude at maximum) have been secured and published for only 65. This fairly modest material may, however, serve as a basis for analyzing the photometric properties of supernovae.

The procedure for measuring the brightness of supernovae is no different from the procedure for ordinary variable stars, yet the photometric material does have distinctive features due to the uniqueness of the phenomenon. Since the outburst occurs only once, any phases of the phenomenon which may have been missed for various reasons are irretrievably lost. The quality of the observational material is naturally related to the experience of the investigator, the capabilities of the instrument, the observing conditions, and the status of standardization for photometric measurements at the epoch of observation. These circumstances are common to those encountered for other nonstationary stars. But whereas for novae (which appear rather frequently in the Galaxy) the observational material can be renewed comparatively quickly with time, the process of renewing and completing the observational data for supernovae operates immeasurably more slowly because of the rarity of the supernova phenomenon.

The quality of the photometric material for supernovae has increased by discrete jumps. Beginning in 1926 observers undertook to refer their measurements to the international system of Standard Areas, as published by the Mount Wilson Observatory. In 1936 Baade [1] placed on the international system the data on the brightness of all supernovae known at that time. In 1944 Baade [2] discovered a systematic underestimate in the faint magnitudes on the scale of area SA 68. In 1950 this finding was confirmed [3] by photoelectric measurements of the same area and two others. Since that time measures have been taken in the photometry of stars fainter than 15^{m} to eliminate the systematic errors in the old photometric scales by tie-ins to newly calibrated areas or to other new photoelectric standards in the vicinity.

As for the reduction of supernova observations prior to 1950 to accurate scales, this can only be carried out if the magnitudes of the comparison stars originally used are known. A procedure of this type – a redetermination of comparison-star magnitudes on the modern scale – so far has only been applied to the 1937 supernova in IC 4182 [4]. A complete redetermination of the brightness of a supernova could also be made from old plates that have been retained, but so far no such redeterminations have been made.

2. Summary of Photometric Properties of Type I, II, and V Supernovae

The appreciable dispersion in the optical properties of supernovae suggests that the properties should be analyzed according to individual spectral types. The supernova classes having the most representatives are types I and II, introduced in 1940 by Minkowski [5], and type V, introduced in 1961 by Zwicky [6] (the latter class evidently corresponds to Minkowski's type III). The types are characterized by the following brightness behavior [6]:

Type I: a rapid decline in brightness after maximum, and a slower decline after about 30 days.

Type II: a more gradual brightness decline, sometimes with a temporary delay.

Type III: a lengthy maximum (50 days) followed by a rapid weakening.

Type IV: a sharp drop in brightness in two steps – first by 3^{m} in 50 days, then a pause in the decline of the same duration, and finally another sharp drop.

Type V: a slow rise and fall in brightness.

Since Zwicky's types III and IV are so far represented only by a single supernova each, we can only analyze the properties of the other three types with any confidence.

We would point out that the first attempt to classify supernovae by the shape of their light curve was made by Kulikovskii [7] in 1944.

Tables 1 and 2 summarize the available photometric and other data on type I, II, and V supernovae

TABLE 1

N	Galaxy						Supernova							Reference
	NGC (IC)	Type	$m_0 - M$	a_p	A_p	M_n	Year	m_{SN}	M_{SN}	α	β	γ	Δm	
* 12	4486	E0	$30^{m}.4$ *V*	$0^{m}.3$	—	$-20^{m}.6$	1919	$11^{m}.5$	$-19^{m}.2$	—	10^{m}	$1^{m}.4$	—	[1]
30	4636	E0	30.4 *V*	0.3	—	—19.9	1939	12.5	—18.2	15^{m}	10	—	—	[18, 19]
* 31	4621	E5	30.4 *V*	0.3	—	—19.3	1939	11.8	—19.1	15	17	1.5	$3^{m}.5$	[18]
* 56	4374	E1	30.4 *V*	0.3	—	—19.8	1957	12.2	—18.5	15	10	2.0	3	[20]
86	4382	S0	30.4 *V*	0.3	—	—20.2	1960	12.0	—18.7	—	8	1.3	2.5	[20, 21]
87	*An*	E0	34.2 *C*	0.3	—	—20.0	1961	16.3	—18.4	—	8	—	—	[22]
* 88	*An*	S0	35.5 *Z*	0.3	—	—20.4	1961	17.0	—19.1	—	—	—	—	[8]
92	4564	E7	30.4 *V*	0.3	—	—18.6	1961	11.2	—19.5	—	8	—	—	[23]
106	*An*	E	34.2 *C*	0.3	—	—19.1	1962	16.5	—18.2	—	—	—	—	[8]
125	*An*	E	34.2 *C*	0.3	—	—19.2	1963	15.6	—19.1	15	—	—	—	[24]
* 135	*An*	S0$_p$	34.2 *C*	0.3	—	—18.4	1963	16.5	—18.2	—	—	—	—	[8]
* 140	*An*	S0	34.3 *L*	1.0	—	—	1963	16.8	—18.7	—	—	—	—	[8]
* 141	*An*	S0	33.2 *L*	0.5	—	—	1963	15.0	—18.8	—	10	—	—	[25]
* 142	*An*	S0	34.7 *L*	0.8	—	—	1963	17.5	—18.2	—	—	—	—	[8]
* 3	5253	Im	27.9 (*H*)	0.6	—	—17.5	1895	8.0	—20.3	19	8	1.2	3	[1.19]
25	(4182)	Im	28.7 *S*	0.3	—	—15.5	1937	8.2	—20.8	—	11	1.4	3	[18]
50	4214	Im	29.1 (*H*)	0.3	—	—18.7	1954	9.0	—20.7	10	12	1.7	3	[26]
107	*An*	Im	36.0 *	0.4	—	—19.0	1962	16.0	—20.4	—	—	—	—	[8]
26	1003	Sc	30.4 *H*	0.6	0.7	—18.6	1937	12.8	—18.9	15	9	1.0	3.5	[18]
51	5668	Sc	31.2 *Z*	0.4	0.3	—19.5	1954	12.0	—19.5	—	8	1.5	3.5	[26]
62	*An*	SBc	32.3 *Z*	0.3	1.3	—18.0	1959	13.6	—20.4	—	8	1.7	3	[27]
69	4496	SBc	30.4 *V*	0.3	0.4	—19.1	1960	11.0	—20.1	—	10	2.0	3	[21, 28]
100	*An*	Sc	31.9 *L*	0.6	0.6	—	1961	14.3	—18.8	10	8	1.0	3	[21]
119	1073	SBc	31.4 *Z*	0.4	0.3	—20.1	1962	12.0	—20.1	—	7	—	—	[29]
* 128	*An*	Sc	35.6 *B*	0.3	0.3	—20.0	1963	18.5	—19.2	—	—	—	—	[8]
131	4178	SBc	30.4 *V*	0.3	0.8	—18.6	1963	12.6	—18.9	—	11	—	—	[30]
132	3913	Sc	32.9 *L*	0.3	0.3	—	1963	13.7	—19.9	—	5	—	—	[31]
138	1084	Sc	31.0 *Z*	0.5	0.9	—21.2	1963	14.0	—18.4	—	6	—	3.5	[25]
150	*An*	SBc	32.1 *L*	0.3	0.3	—	1964	12.0	—20.7	—	6	—	3	[32, 33]
54	3992	SBc	30.3 *Z*	0.3	0.7	—20.1	1956	12.5	—18.8	10	8	2.0	2.5	[34]
* 65	*An*	Sb	35.5 *L*	0.3	0.4	—	1960	16.0	—19.5	—	—	—	—	[8]
* 97	*An*	Sb	33.7 *P*	0.8	0.5	—20.8	1961	17.0	—18.1	—	—	—	—	[8]
124	*An*	Sb	35.4 *Z*	0.4	0.9	—20.7	1963	17.0	—20.0	—	—	—	—	[8]
127	(1703)	Sb	33.8 *Z*	0.3	0.5	—19.9	1963	16.5	—18.3	—	—	—	—	[8]
* 133	3656	Sb	32.5 *L*	0.3	0.3	—	1963	15.0	—18.0	—	—	—	—	[8]
* 137	5905	Sb	31.8 *L*	0.4	0.9	—	1963	15.0	—18.1	—	—	—	—	[8]
* 53	*An*	SBa	33.6 *L*	0.4	0.3	—	1955	15.8	—18.9	—	—	—	—	[8]
* 90	*An*	Sa	35.7 *L*	0.3	0.3	—	1960	16.5	—2[illegible].2	—	—	—	—	[8]

TABLE 2

N	Galaxy						Supernova					Reference
	NGC	Type	$m_0 - M$	a_p	A_p	M_n	Year	m_{SN}	M_{SN}	α	β	
*1	224	Sb	$24\overset{\mathrm{m}}{.}2$	$0\overset{\mathrm{m}}{.}6$	$1\overset{\mathrm{m}}{.}0$	$-21\overset{\mathrm{m}}{.}5$	1885	$7\overset{\mathrm{m}}{.}2$	$-18\overset{\mathrm{m}}{.}6$	—	6^{m}	[8]
18	4303	Sc	30.4 *V*	0.3	0.3	−20.1	1926	14.3	−16.7	—	5.4	[1]
21	4273	Sc	30.4 *V*	0.3	0.4	−18.7	1936	14.4	−16.7	15	3.5	[18, 19]
23	4157	Sb	30.7 *L*	0.3	1.8	—	1937	15.5*	−17.3	10	4.0	[35]
32	6946	Sc	27.5 *H*	1.2	0.3	−18.0	1939	13.2	−15.9	—	5.6	[36]
34	5907	Sb	29.2 *H*	0.4	0.9	−18.7	1940	13.4	−17.1	—	6.3	[18]
35	4725	SBb	28.1 *S*	0.3	0.6	−18.2	1940	12.8	−16.2	15	2.2	[18]
39	4559	Sc	29.6 *Z*	0.3	0.8	−20.0	1941	13.5	−17.2	10	6.2	[18]
45	3177	Sb	30.0 *Z*	0.4	0.3	−17.9	1947	—	—	—	2.3	[37]
47	6946	Sc	27.6 *H*	1.2	0.3	−18.0	1948	12.8*	−16.3	—	2.0	[38]
52	5879	Sb	30.2 *Z*	0.4	1.7	−20.2	1954	14.9	−17.4	—	3.3	[27]
55	2841	Sb	29.0 *Z*	0.4	0.9	−19.8	1957	14.5	−15.8	—	8.0	[39]
63	7331	Sb	30.4 *H*	0.7	1.2	−21.1	1959	13.6	−18.7	—	6.0	[40]
*66	An	Sb	34.1 *Z*	0.3	0.3	−19.4	1960	17.0	−17.9	—	3.5	[41]
105	3938	Sc	29.8 *Z*	0.3	0.3	−18.8	1961	13.8	−16.6	—	4.0	[42]
*115	5134	Sb	29.4 *L*	0.4	0.6	—	1962	13.0	−17.4	—	—	[8]
120	1313	SB	28.2 *H*	0.4	0.4	−18.2	1962	11.2*	−17.8	—	2.8	[43]
*136	536	SBb	31.0 *L*	0.8	1.3	—	1963	17.7	−15.4	—	—	[8]
*7	5457	Sc	27.3 *H*	0.3	0.3	−19.0	1909	12.1	−15.8	—	1.0	[1.8]
96	1058	Sc	27.6 *S*	0.6	0.3	−15.8	1961	12.2	−16.0	1.0	0.9	[44]
146	3631	Sc	30.4 *Z*	0.3	1.0	−19.9	1964	17.0	−14.7	—	—	[8]

as published up to the beginning of 1966. In Table 1 the supernovae are arranged by the type of galaxy in which they were observed. All supernovae are represented for which coherent data on the light curve are available such that one can reliably establish the brightness of the supernova at maximum and the rate of brightness variation in at least one segment of the light curve. Unfortunately, for some supernovae only estimates from the first observation, close to maximum, have so far been published (these magnitudes are given in columns 9), and there are also supernovae for which no spectral type estimates are available but which can evidently be assigned to type I from indirect evidence (for example, if the supernova appeared in an elliptical galaxy or an irregular galaxy, where other types of outbursts have not yet been observed), or to type II (if the rate of brightness decline definitely indicates this classification). Provisional assignments of this type are indicated by an asterisk in columns 1 of the tables. The columns in Tables 1 and 2 have the same arrangement since they give similar data. The columns contain the following information: 1) the number of the supernova in Zwicky's list [8]; 2) the NGC (or IC) number of the galaxy where the outburst appeared; 3) the morphological type of the galaxy; 4) the true distance modulus $m_0 - M$, and a letter designating the method by which it was determined (see below); 5) the interstellar photographic absorption a_p in our galaxy in the direction of the supernova, according to Sharov [9]; 6) the mean photographic absorption A_p along the line of sight, for the case of spiral galaxies, according to [10]; 7) the absolute integrated photographic magnitude M_n of the galaxy, according to [8] and columns 4-6; 8) the year the supernova appeared; 9) the photographic magnitude m_{SN} of the supernova at maximum light, according to [8], with values redetermined (extrapolated) by the author indicated by an asterisk; 10) the absolute photographic magnitude M_{SN} of the supernova at maximum light, corrected for absorption in our galaxy and in its own galaxy and for the redshift effect, according to [11]; 11) the rate α of increase in supernova brightness on the rising branch, expressed in stellar magnitudes per 100-day interval; 12) the rate β of brightness change after maximum in the rapid-decline segment; 13) the rate γ of brightness change in the slow-decline region; 14) the difference Δm in brightness at the beginning and end of the rapid-decline segment; and 15) references to papers giving estimates for the supernova brightness.

The distance moduli in columns 4 have been obtained by various methods, but in accordance with Sandage's system [12]. The notation in these columns is as follows: Z, from redshifts with a Hubble constant $H = 100$ km·sec^{-1}·Mpc^{-1} (or from mean redshifts for clusters, with Z replaced by the following: V, Virgo cluster; C, Coma Berenices cluster; P, Pisces cluster; B, Corona Borealis cluster); H, from the angular dimensions of H II regions, using Sandage's calibration estimates and a revision of Sersic's determination [13] by means of the formulas $m - M = 33.8 - 5.5 \log d_3 = 28.3 - 5.5 \log d_5$ (here d_3 and d_5 denote respectively the angular dimensions of the third and fifth largest H II regions), with d taken from [14, 15] for NGC 6946 and NGC 1313; (H), from membership in clusters and groups of galaxies where different H II regions are encountered; S, from estimates for the brightest stars, with $M_S = -9^m.2$; and L, from the mean absolute photographic magnitude of the galaxies in a given luminosity class, according to van den Bergh [16] and de Vaucouleurs' calibration [17], with $M_n = -18^m.0$ adopted for S0 galaxies from the mean absolute magnitude of these galaxies in the Virgo cluster.

3. Photometric Properties of Type I Supernovae

As the author has pointed out previously [45], a correlation is found for type I supernovae between the absolute photographic magnitude at maximum light and the absolute integrated photographic magnitude of the galaxy in which the outburst occurs. Because of the large dispersion in M_{SN} and the lack of data on supernovae in low-luminosity galaxies, the correlation is not reliably determined.

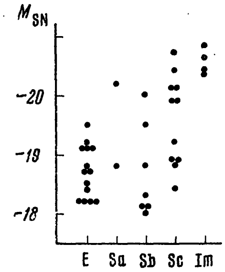

Fig. 1. Correlation between the absolute magnitude of a type I supernova at maximum and the type of the galaxy where the outburst appeared.

Table 3 presents mean estimates for the photometric parameters of supernovae in different types of galaxies. The columns contain the following data: 1) the type of the supernova and of the galaxy; 2) the number of supernova outbursts considered in obtaining the mean value $\overline{M}_{SN}$; 3) the mean absolute magnitude for the galaxies of the given type in this sample (for those galaxies where no individual determinations are given in Tables 1-2, mean values of M_n have been adopted from the galaxy type, according to [17]); 4) the mean absolute photographic magnitude for the supernovae at maximum light; 5-7) the mean values of α, β, and γ; 8) the mean value of Δm; and 9) the range in the values of M_{SN} for the sample used. Table 3 and Fig. 1, which illustrates the table, indicate that $\overline{M}_{SN}$ increases with transition from elliptical to spiral and irregular galaxies. One should note that the distance moduli in Tables 1-2 have been derived in different ways, and this fact should be reflected in the dispersion. It is therefore interesting to observe that the mean $\overline{M}_{SN}$ for supernovae in field galaxies do not differ from the $\overline{M}_{SN}$ in cluster galaxies, and that the estimates of $\overline{M}_{SN}$ from redshifts do not differ in any systematic way from the estimates obtained from distance indicators other than the redshift. The absence of differences in the $\overline{M}_{SN}$ determined in this manner apparently means that the photometric properties of type I supernovae are homogeneous, and that no large errors have been made in determining the relative distances of the galaxies where the supernovae were observed. Internal absorption is insignificant in elliptical and irregular galaxies, so that the difference in the mean $\overline{M}_{SN}$ in these galaxies is free from the influence of absorption inside the systems, and thus is evidently real. But in spiral galaxies there is considerable internal absorption which is difficult to correct for perfectly. The so-called correction for the inclination of a galaxy to the plane of projection is actually a rough approximation corresponding to a model spiral galaxy screened from us by a uniform, plane-parallel "umbrella" of absorbing material whose plane is parallel to the principal plane of the spiral system. In reality, however, the absorption in spiral galaxies is highly nonuniform. Hence the mean estimates for A_p are formal, to a large extent, and introduce

TABLE 3

Supernova and galaxy types	n	$\overline{M}_n$	$\overline{M}_{SN}$	α	β	γ	Δm	Range in M_{SN}
Type I								
E	14	$-19^m.2$	$-18^m.7$	15^m	10^m	$1^m.6$	$3^m.0$	$-18^m.1$; $-19^m.5$
Sa	2	−18.9	−19.5	—	—	—	—	−18.8; −20.2
Sb	7	−20.2	−18.7	10	8	2.0	2.5	−18.0; −20.0
Sc	11	−19.5	−19.6	10	8	1.4	3.2	−18.4; −20.7
Im	4	−17.7	−20.5	10	10	1.4	3.0	−20.3; −20.8
Type II	18	−19.1	−16.9	12	4.3	—	—	−15.8; −18.7
Type V	3	−18.2	−15.5	1.0	1.0	—	—	−14.7; −16.0

a considerable scatter into M_{SN}. But since supernovae are most often encountered or discovered more easily at the periphery of a galaxy, where the absorption is in general more uniform and closer to the model "umbrella"; it is in fact appropriate to correct for absorption by means of the "inclination effect". There simply is no other way so far. As Table 3 indicates, the mean $\overline{M}_{SN}$ for supernovae in spiral galaxies occupy an intermediate position between the $\overline{M}_{SN}$ estimates for supernovae in elliptical and irregular galaxies.

The high frequency of supernova outbursts in irregular galaxies still remains a puzzle [45-47]. Four outbursts are already known. The absolute magnitude of supernova No. 107 has been estimated from the absolute magnitude of its irregular galaxy, using the correlation between the absolute magnitude and surface brightness of Magellanic-type irregular galaxies.

There is one other characteristic relationship, between M_{SN} and the rate β of brightness decline (Fig. 2); it seems to be a general tendency for type I, II, and V supernovae. We discuss this behavior below. Supernova No. 31 does not conform to the relationship; its spectral type has not been determined, and it may therefore be premature to assign it to type I.

The question arises: Since it is generally recognized that the light curves of type I supernovae are similar to one another, does not the (M_{SN}, β) relation contradict this fact? Table 3 provides a clear answer to these doubts. Most type I supernovae have similar β, and the small dispersion distinctly evident in Fig. 3 cannot succeed in "breaking down" the light curves. In extrapolating to maximum we are therefore fully entitled to use the standard light curve, as characterized by mean values of α, β, γ, and Δm. Only in the case of irregular galaxies do the light curves of type I supernovae differ somewhat in the mean from the light curves of supernovae in other types of galaxies.

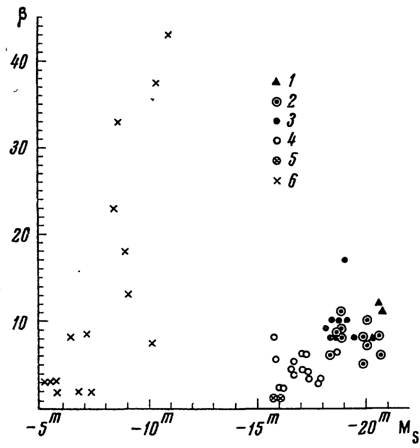

Fig. 2. Diagram showing the rate β of brightness decline after maximum as a function of the absolute magnitude at maximum for novae and type I, II, and V supernovae. 1) Type I supernovae in irregular galaxies; 2) type I supernovae in spiral galaxies; 3) type I supernovae in elliptical galaxies; 4) type II supernovae; 5) type V supernovae; 6) novae, according to [51].

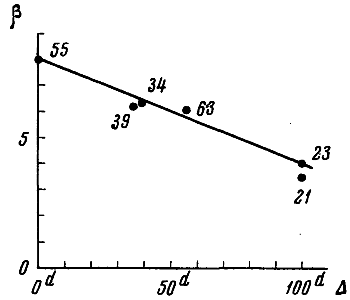

Fig. 3. Relation between the rate β of brightness decline for type II supernovae and the elapsed time Δt for appearance of the hump on the descending branch of the light curve. The numerals indicate the supernova number.

4. Photometric Properties of Type II and V Supernovae

The photometric material for type II supernovae collected in Table 2 is much less extensive and considerably more uncertain than the material for type I supernovae. This circumstance arises not only from the comparatively low luminosity of type II supernovae, but from the fact that they are observed in type Sb and Sc spiral galaxies which, as pointed out above, have considerable internal interstellar absorption for which the correction is unreliable. But in most cases the absorption in the vicinity of type II supernova outbursts is moderate. Since an "avoidance" by supernovae of regions of high absorption would seem improbable physically, the behavior is evidently an effect of observational selection, so that the observed frequency of type II supernova outbursts may be an underestimate of the real value.

To what extent do the light curves of type II supernovae differ from those of type I supernovae, and to what extent do they differ within the type? The observational material exhibits a great variety for the light curves of type II supernovae [48]. Two distinctive features are apparent, however. First, the rate of brightness decline of type II supernovae ranges from $\beta = 8^m$ to $\beta = 2^m$; secondly, the light curves of a number of type II supernovae have a "hump" 40-100 days after maximum. The presence of the hump facilitates extrapolation of type II supernovae to maximum light, similar to the role of the place where the rate of brightness decline changes in the light curves of type I supernovae. However, a comparison of the rate of brightness decline and the time of appearance of the hump shows that the two are closely related. Figure 3 presents a graph for the relationship between these characteristics. Unfortunately, the periods at 100 days and more after maximum are not covered by observations, but if the appropriate observational data are secured in the future the correlation could be verified. At present, however, from an estimate of β one may use Fig. 3 to determine the time Δt of appearance of the hump, and thereby reliably establish the epoch of maximum light in the event that no observations had been made at that time. As an approximate formula one may use the relation

$$\Delta t = 200 - 25\beta \text{ (days)}.$$

In view of the behavior demonstrated above, we cannot agree with Bertaud's claim [48] that the descending branch of the light curve should be divided into three parts – fast, slow, and again fast decline. Evidently the hump in the curve is a local phenomenon occurring at a definite phase in the development of the supernova. The spectrophotometric significance of the hump has not yet been investigated.

Despite the variety of brightness decline rates for type II supernovae, in most cases one can definitely state that, judging from its light curve, a supernova should be assigned to type II. But for supernovae with an extremely rapid brightness decline, the classification is more ambiguous. One example is the well-known supernova No. 55. According to its light curve it should be regarded as a type I supernova, but spectroscopic and colorimetric observations have shown that it was a rapid type II supernova. The absolute magnitude of the supernova was very low ($-15^m.8$). Interestingly enough, the visual light curve of this supernova is remarkably similar to the light curves of the familiar faint galactic supernovae of Tycho and Kepler (Fig. 4)!

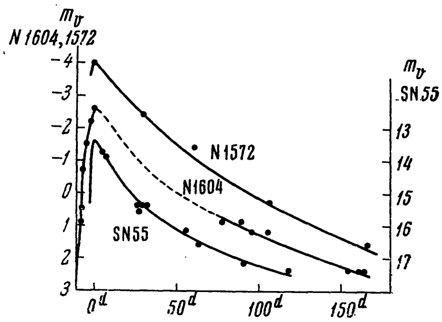

Fig. 4. Visual light curves for the faint galactic supernovae of Tycho and Kepler (left-hand magnitude scale), according to Baade [49], and the light curve of the rapid type II supernova No. 55 (right-hand magnitude scale), according to Zwicky [39].

Evidently one should also assign S Andromedae to type II; its mean brightness decline rate was 5^m per 100 days in the visual system [50], or 6^m in the photographic. Correspondingly, there was a small hump on the light curve at about 50 days after maximum.

We turn now to the type V supernovae. These differ from type II supernovae in their smaller absolute magnitude at maximum, smaller brightness decline rate, and lower envelope expansion velocity. Figure 2 gives the (β, M_{SN}) diagram for type I, II, and V supernovae as well as for galactic novae, according to [51]. One first notices the marked difference between supernovae and novae. There are no grounds for believing that any class of nonstationary stars having any kind of intermediate properties exists. The brightest novae differ materially from the faintest supernovae not only in luminosity but in the characteristics of their brightness decline. The whole problem has been discussed quite definitively by Payne-Gaposchkin [51].

On the other hand, it is curious that supernovae having fairly distinct photometric and spectral properties form a single sequence, although with some scatter. But the expansion velocity of type I and V supernova envelopes is of order 1000-2000 km/sec, whereas for type II supernovae, which happen to occupy an intermediate position in the (β, M_{SN}) diagram, the expansion velocity is 4000-8000 km/sec. An interpretation of the (β, M_{SN}) diagram would be of extreme interest.

We wish to point out that the relation between the absolute magnitude of a supernova at maximum light and the rate of brightness decline after maximum was investigated in 1955 by Kopylov [52] from data on 19 supernovae.

The treatment presented in this paper suggests that even the material already available would be adequate to support a study of the physical factors operative in a supernova outburst.

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