

Light Curves of Five Supernovae

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Photographic light curves for the supernovae found in NGC 2841, 4374, 4496, 4382 and in an anonymous galaxy have been derived. The shape of the light curves shows that all of them are of type I. With exclusion of the supernova in NGC 2841, which is peculiar for its low luminosity, the average absolute photographic magnitude at maximum is $M_{pg} = -17.9$. The linear decrease in the light curve of the supernovae in NGC 4382 and in the anonymous galaxy is $0^m.013$ per day.

IN this paper are described photographic observations of five supernovae which recently appeared in NGC 2841, NGC 4374, NGC 4496, NGC 4382, and in an anonymous galaxy at $\alpha(1950) = 2^h32^m5$ and $\delta(1950) = +37^\circ25'$. The material concerning the two supernovae of 1957 was obtained with the 24-inch reflector of the Loiano Observatory, while the remaining material was obtained at Asiago with the 20/16-inch Schmidt telescope and with the 48-inch reflector (observations with the latter instrument are indicated by an asterisk in Tables IV–VI). The plates were blue sensitive and no filter was used. The reduction of most of the photographic material was made with the Becker iris diaphragm photometer; in some cases the magnitudes of the supernovae were determined by visual estimation on the photographic plates. Table I gives the data on the five galaxies and on the supernovae.

SUPERNOVA OF 1957 IN NGC 2841

This supernova was found at Bern by Schürer (1957) on 1 March 1957; it was located in or near a spiral arm $2'$ NW of the nucleus of the SA(r)b galaxy NGC 2841. The observations with the 24-inch reflector

of Loiano are listed in Table II. The comparison stars (Fig. 1a) are based on seven photographic transfers, three with the Schmidt telescope and four with the 48-inch reflector, from the stars of SA 51, whose magnitudes have been measured by Baum (1963). In Fig. 2 the full dots represent our observations and the circles those of Wenzel (1957). The latter were corrected by $+0.20$ mag. because Wenzel's (1963) comparison stars are systematically brighter than those of Asiago by this amount. The light curve in Fig. 2 resembles that of type I supernovae in the period immediately after the maximum; it includes the initial rapid decline and the beginning of the straight-line region. By comparing it with the light curve of the supernova in the anonymous galaxy, on which the maximum is well defined, we can extrapolate the observations of this supernova to find the date and the magnitude at maximum. The maximum was reached on or about 27 February 1957 with a photographic magnitude $m_{pg} = 14.50$. The corresponding absolute magnitude is $M_{pg} = -15.5$ (using the distance modulus in column 10 of Table I), a value much lower than the mean for type I supernovae (Zwicky 1958; van den Bergh 1960b). Since the supernova is in a spiral galaxy, it is possible to explain this

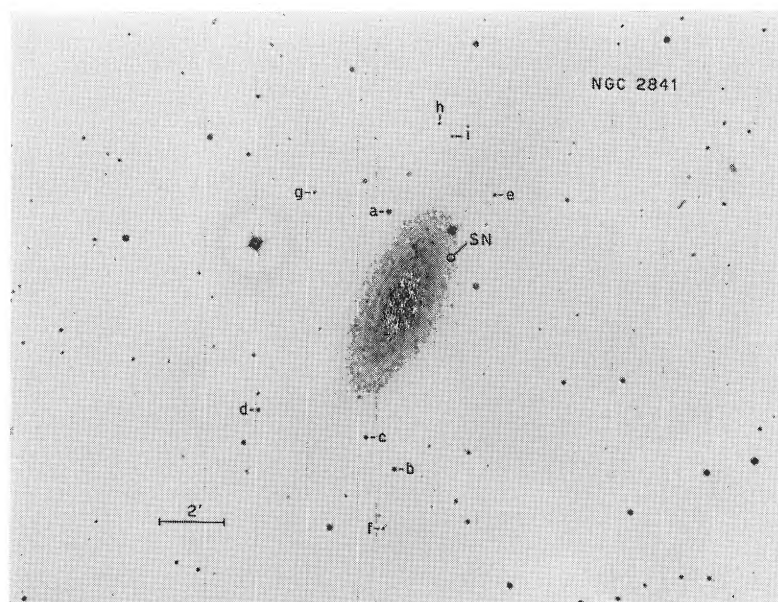


FIG. 1 (a). NGC 2841 ($a=14.85$, $b=15.60$, $c=15.96$, $d=16.37$, $e=17.25$, $f=17.78$, $g=17.96$, $h=18.13$, $i=18.22$). North is at the top.

TABLE I. Data on galaxies and supernovae.

(1) Galaxy	(2) α	(3) δ	(4) III	(5) bII	(6) m_{pg}	(7) Type	(8)	(9) Cluster	(10) $m-M$	(11) Max. date	(12) m_{pg}	(13) M_{pg}	(14) m/d	(15) ρ	(16) D	(17) Type
NGC 2841	9 ^h 18 ^m 6	+51°12'	166°44'	+44°15'	10.10	SA(r)b	704	Virgo, E	29.7	Feb. 27, 1957	14.8	-15.5		120"	5060	I:
NGC 4374	12 22.6	+13 10	278.27	+74.48	10.21	E+1	880	Virgo, E	29.4	May 10, 1957	12.6	-17.0		60	2210	I
NGC 4496	12 29.1	+4 12	280.57	+66.32	11.93	SB(rs)m	1665	Virgo, X, NW	30.6	Apr. 16, 1960	11.6	-19.2		54	3450	I
NGC 4382	12 22.8	+18 28	267.61	+79.22	10.05	SA(s)0 ⁺ p	721	Virgo, E	29.4	Dec. 19, 1960	12.0	-17.6	0.013	120	4420	I
An. gal.	2 32.5	+37 25	144.76	-20.78	14.2:	SA(rs)cd			31.5	Sept. 11, 1961	14.3	-17.9	0.013	36	3490	I

- NOTES
- (1)-(5) Identification, right ascension, and declination (1950), galactic longitude and latitude.
- (6) Integrated photographic magnitude of the galaxy by Holmberg (1958), except for An. gal. which is by Zwicky (1961).
- (7) Revised morphological type according to de Vaucouleurs (1963).
- (8) Corrected recession velocity by Humason *et al.* (1956) (NGC 2841, 4374, 4382) and by Mayall and de Vaucouleurs (1962) (NGC 4496). For NGC 2841 the mean of Lick and Mount Wilson velocities was taken.
- (9) Cluster to which galaxy belongs, according to de Vaucouleurs (1961).
- (10) Corrected distance modulus adopted: for NGC 2841 mean from the redshift value and luminosity class, according to van den Bergh (1960), for NGC 4374, 4496, and 4382 according to de Vaucouleurs (1961) for an. gal. from luminosity class, according to van den Bergh (1963).
- (11) Date of the maximum for the supernovae.
- (12) Photographic apparent magnitude at maximum.
- (13) Absolute magnitude at maximum corrected for galactic absorption, using the distance modulus in Column 10.
- (14) Slope of the light curve in the straight-line region in mag./day.
- (15), (16) Distance of the supernova in seconds from the nucleus and the corresponding distance in parsecs.
- (17) Type of the supernovae.

TABLE II. Supernova in NGC 2841.

Plate No.	Date (1957)	UT	Exposure	m_{pg}
8015	April 18	23 ^h 09 ^m	16 ^m	17.40
8027	23	00 15	16	17.45
8035	23	22 43	16	17.40
8049	26	23 25	16	17.65
8059	May 5	01 53	16	17.75
8096	22	23 30	16	18.00
8102	June 1	22 40	18	18.20
8127	19	23 06	18	[18.00

fact by assuming strong absorption by interstellar matter in NGC 2841. Nevertheless, since spectroscopic data and a more complete light curve are not available, it is not possible to state definitely that the supernova in NGC 2841 belongs to type I. It would be the first case of a type I supernova with such a low luminosity. It should be noted that this is the second supernova observed in NGC 2841. The first one is described by Pease (1912).

SUPERNOVA OF 1957 IN NGC 4374

This supernova was discovered independently by Romano (1957) at Treviso, Italy, on 18 May 1957, and by Gates at Mount Palomar Observatory on 28 April 1957; it is one minute of arc north of the nucleus of the E+1 galaxy NGC 4374, which is a member of the E cloud in the Virgo Cluster (de Vaucouleurs 1961). In Table III the observations with the 24-inch reflector of Loiano are listed. The comparison stars (Fig. 1b) are based on seven photographic transfers at Asiago, three with the Schmidt telescope and four with the 48-inch, from the stars of SA 57, whose magnitudes are given by Stebbins, Whitford, and Johnson (1950). In Fig. 3 the full dots represent our observations, the circles those of Götz (1958) and the crosses those of Romano (1957). While Götz's observations are in agreement with ours, it was necessary to apply a correction of +0^m.8 to the zero point of Romano's observations. The four observations of Gaposchkin (1958) are also in agreement with ours after an appropriate correction for the zero point. The light curve has the shape characteristic of the type I supernovae. It shows the period around the maxi-

TABLE III. Supernova in NGC 4374.

Plate No.	Date (1957)	UT	Exposure	m_{pg}
8094	May 21	23 ^h 17 ^m	3 ^m	13.20
8095	22	22 59	10	13.30
8101	31	23 01	10	14.45
8103	June 1	23 06	10	14.60
8116	17	22 46	10	15.20
8117	17	23 12	10	15.15
8137	28	22 30	10	15.60
8167	July 20	22 01	12	15.90
8197	30	21 46	12	16.00

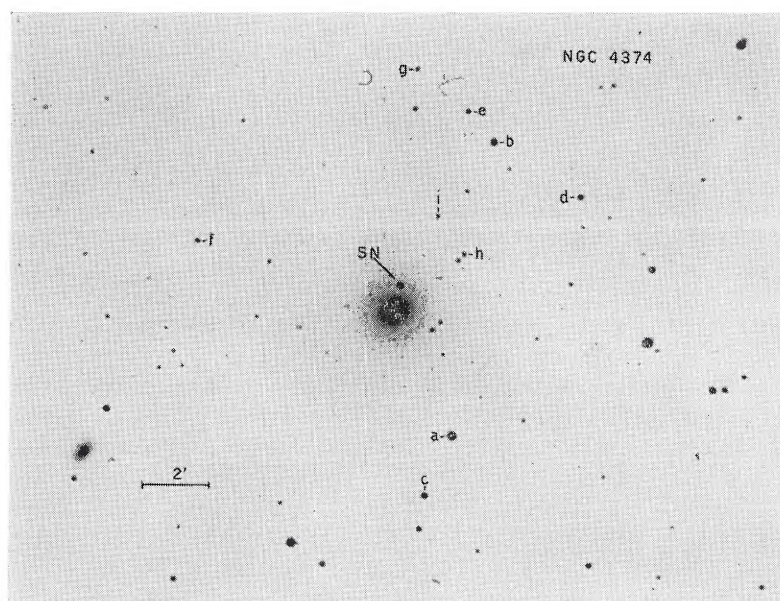


FIG. 1 (b). NGC 4374 ($a=12.40$, $b=13.83$, $c=14.20$, $d=14.88$, $e=15.45$, $f=15.75$, $g=16.06$, $h=16.24$, $i=16.68$). North is at the top.

mum and the beginning of the straight-line region. By means of the light curve of the supernova in the anonymous galaxy, it is possible, by extrapolation, to establish that the supernova in NGC 4374 reached its maximum on or about 10 May 1957, with a photographic magnitude $m_{pg}=12.6$. The corresponding absolute photographic magnitude is $M_{pg}=-17.3$, using the distance modulus in column 10 of Table I. Romano's two observations on the 26th and 28th of April allow one to establish the rate of brightening of a type I supernova in the days immediately preceding the maximum. This gives 0^m.6 magnitudes in two days. Two observations of Götz on the 6th and 16th of June show that the supernova flared; it should be noted that the

same phenomenon has been observed at the same phase by Pietra (1955) in the supernova in NGC 5668. Photoelectric observations of other supernovae will be needed in order to decide if this is a real phenomenon or if it is due to errors of observation.

SUPERNOVA OF 1960 IN NGC 4496

This supernova was discovered by Humason (1960) at Mount Palomar on 17 April 1960; it was 47'' east and 27'' north of the SB(rs)m galaxy NGC 4496, a member of the NW half of the "X" cloud of galaxies South of the Virgo Cluster (de Vaucouleurs 1961). NGC 4496 is a system of two galaxies. The supernova

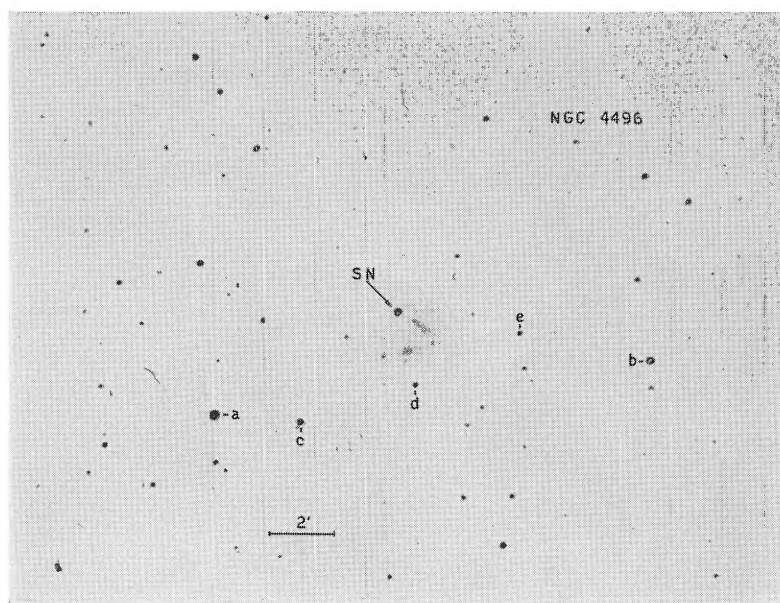
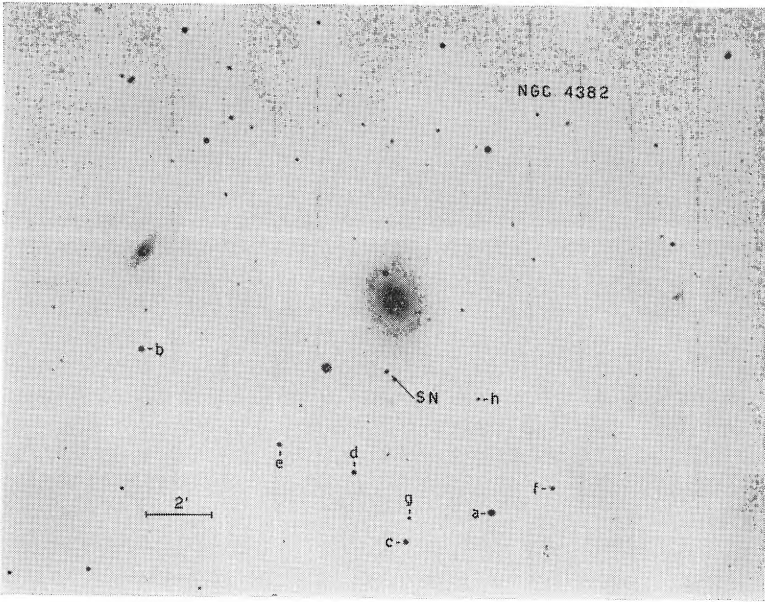


FIG. 1 (c). NGC 4496 ($a=9.76$, $b=12.45$, $c=12.73$, $d=14.53$, $e=15.50$). North is at the top.

FIG. 1 (d). NGC 4382 ($\alpha=12.45$, $b=13.40$, $c=14.10$, $d=14.50$, $e=14.68$, $f=14.92$, $g=15.94$, $h=16.25$). North is at the top.



flared up at a point in line with the bar in or near a spiral arm of the brighter galaxy. In Table IV the Asiago observations are listed. The comparison stars (Fig. 1c) a , b , c , and d were obtained with a photoelectric transfer from stars A and B in the region of supernova 64 (Mihalas 1962); the magnitude of star e was obtained by extrapolation on the photographic plates. In Fig. 4 the full dots represent our observations, the

agreement with that deduced from the spectroscopic observations. The apparent photographic magnitude at maximum was $m_{pg}=11.6$ and the absolute magnitude $M_{pg}=-19.2$ using the distance modulus in column 10 of Table I. Fluctuations in the magnitudes of Huth, when the supernova was at maximum, should be noted. From a spectrophotometric study, Vorontsov-Velyaminov and Saveleva (1961) found for this supernova, near the maximum, an energy distribution corresponding to a blackbody at 6550° .

TABLE IV. Supernova in NGC 4496.

Plate No.	Date (1960)	UT	Exposure	m_{pg}
4068*	April 21	20 ^h 17 ^m	30 ^m	11.60
852	May 1	21 00	15	12.55
862	16	22 21	15	14.10
905	26	22 58	15	14.48
4093*	June 26	21 28	6	15.20
4094*	26	21 40	16	15.20
4099*	27	21 46	40	15.20

SUPERNOVA OF 1961 IN NGC 4382

This supernova was independently discovered by Rosino (1961) at Asiago on 18 January 1961, and by

circles those of Kulikov (1960), to which 0^m25 was added to correct to our zero point, and the crosses those of Huth (1960), adapted to our observations by adding 0^m85. With appropriate corrections for the zero point, the observations of Tempesti (1961) and of Kuzmin and Eelsalu (1960) may be fitted to ours, while for those of Mannino (1962), it is necessary to make a scale correction below 14^m65. The shape of the light curve shows that the supernova is of type I, in agreement with the spectroscopic observations (Rosino and Bertola 1961). At first there is a decline of 0^m1 per day, and after approximately 40 days the linear decline begins. By extrapolation, using the light curve of the supernova in the anonymous galaxy, it is possible to establish that the supernova in NGC 4496 reached its maximum on or about 16 April 1960. This date is in

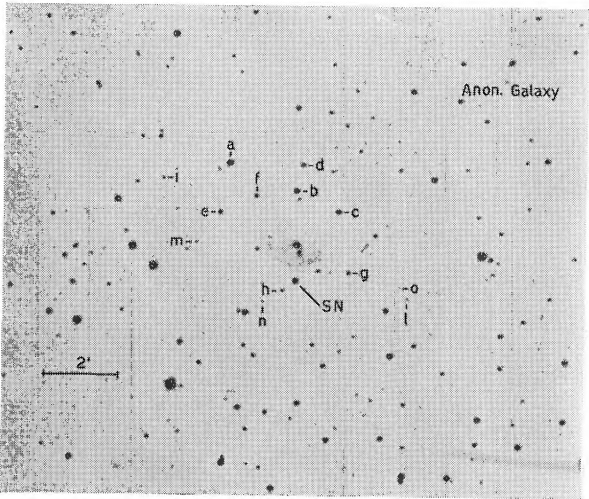


FIG. 1 (e). Anonymous Galaxy at $\alpha(1950)=2^h32^m5$ and $\delta(1950)=+37^{\circ}25'$ ($a=13.96$, $b=14.69$, $c=15.20$, $d=15.63$, $e=16.13$, $f=16.58$, $g=17.00$, $h=17.22$, $i=17.62$, $l=17.81$, $m=18.04$, $n=18.29$, $o=18.45$). North is at the top.

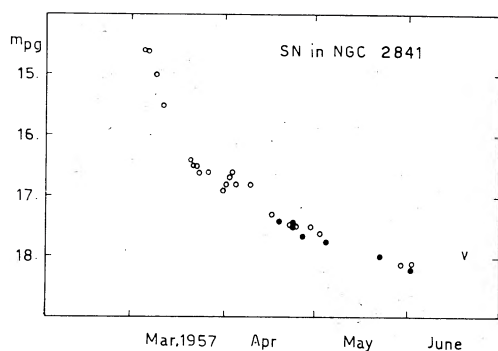


FIG. 2. Light curve of the supernova in NGC 2841.

TABLE V. Supernovae in NGC 4382.

Plate No.	Date (1961)	UT	Exposure	m_{pg}
1312	Jan. 19	00 ^h 55 ^m	15 ^m	14.28
1329	22	00 02	15	14.55
4372*	22	02 01	30	14.40
1337	23	00 34	15	14.65
1340	27	03 09	15	14.60
4378*	27	03 34	20	14.58
1344	28	03 42	15	14.70
1376	Feb. 8	22 36	10	14.90
1388	10	22 00	10	14.82
1399	11	22 18	10	15.00
1407	12	22 20	10	14.93
1418	14	00 56	10	14.80
1426	14	22 11	10	14.85
4481*	Mar. 23	22 47	20	15.63
1658	26	01 39	15	15.20
1666	April 6	23 04	10	15.57
1671	7	23 39	10	15.60
1679	8	23 28	10	15.65
4483*	19	20 41	40	15.80
1689	19	23 55	10	15.78
1695	May 2	19 47	10	15.90
1701	5	21 56	12	16.03
1707	7	22 37	10	15.93
4494*	7	23 25	30	15.90
1716	9	23 06	10	15.95
1725	10	23 21	10	15.98
1735	13	00 25	10	16.05
1747	June 7	23 00	10	16.00
1763	15	22 58	10	16.00
1784	18	22 45	10	16.00

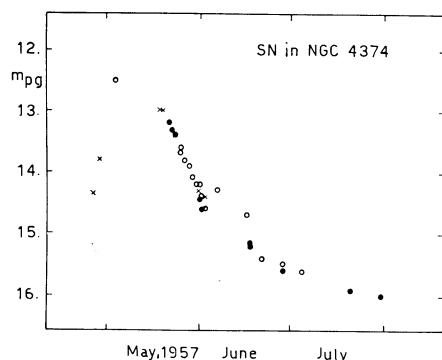


FIG. 3. Light curve of the supernova in NGC 4374.

Gates (1961) at Mount Palomar; it is 2' south of the SA(s)0+p galaxy NGC 4382, belonging to the E Cloud of the Virgo Cluster (de Vaucouleurs 1961). In Table V the Asiago observations are listed. The magnitudes of the comparison stars are based on five transfers, two with the 48-inch and three with the Schmidt telescope, from the stars of SA 81 (Mount Wilson magnitudes were used). In Fig. 5 the full dots represent our observations, the circles, those of Zaitseva (1961), and the two crosses are Mount Palomar observations (Gates 1961) in the *B* system. The magnitudes of the comparison stars and of the supernova determined by Zaitseva are in perfect agreement with ours. The light curve shows that the supernova is of type I, as was indicated also by our spectroscopic observations (Bertola 1962). The Asiago observations cover the linear portion of the curve well, but there is a gap in the first period after the maximum. An extrapolation by means of the light curve of the supernova in the anonymous galaxy indicated that the date of maximum was on or about 19 December 1960, in agreement with

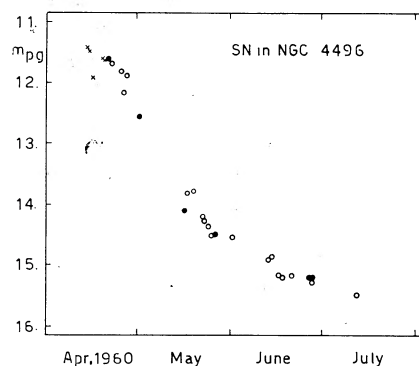


FIG. 4. Light curve of the supernova in NGC 4496.

that deduced from the spectrum, and the apparent photographic magnitude was $m_{pg} = 12.0$. The corresponding absolute magnitude is $M_{pg} = -17.6$ using the distance modulus in column 10 of Table I. In the linear part of the curve the supernova declined at a rate of 0^m013 per day, which corresponds to a luminosity decline of 50% every 58 days.

SUPERNOVA OF 1961 IN AN ANONYMOUS GALAXY

This supernova was discovered by Wild (1962) at Bern on 9 September 1961; it was 0.6 south of the nucleus of an anonymous SA(rs)cd galaxy at $\alpha(1950) = 2^h32^m5$ and $\delta(1950) = +37^\circ25'$. In Table VI the Asiago observations are listed. The magnitudes of the comparison stars (Fig. 1e) are based on six photographic transfers with the 48-inch reflector from SA 68, magnitudes according to Stebbins, Whitford, and Johnson (1950). The light curve (Fig. 6) has the characteristic shape of type I supernovae. It defines the interval around the maximum well, and also the successive

TABLE VI. Supernova in the Anonymous Galaxy.

Plate No.	Date (1961-62)	UT	Exposure	m_{pg}
1976	Aug. 19	01 ^h 03 ^m	10 ^m	[17.00
2002	Sept. 1	22 36	10	14.95
2007	3	21 14	10	14.63
2018	4	23 58	10	14.40
2028	6	23 24	10	14.50
2036	8	00 46	10	14.42
2046	9	23 02	10	14.05
2055	10	22 59	10	14.35
2062	13	22 25	10	14.28
4622*	13	23 07	15	14.35
2069	15	23 00	10	14.32
2076	16	22 58	10	14.32
2083	17	23 59	10	14.38
4639*	18	01 50	30	14.45
2088	19	00 25	10	14.48
2097	20	01 09	10	14.68
2106	21	01 57	10	14.70
2112	22	02 10	10	14.70
2127	Oct. 2	22 27	10	15.63
2146	9	22 48	10	16.28
2157	10	23 20	10	16.18
2164	11	23 49	10	16.23
2186	31	21 03	10	17.12
2189	Nov. 1	19 19	10	17.30
2190	1	19 58	10	17.30
2199	2	23 40	10	17.25
2204	5	18 07	10	17.20
2209	10	23 12	10	17.32
2210	14	22 15	10	17.30
2211	15	22 18	10	17.30
4748*	15	22 55	20	17.25
2225	17	01 18	10	17.35
4764*	17	19 03	16	17.35
2231	18	01 17	10	17.52
2238	19	02 13	10	17.55
2243	28	17 36	10	17.50
2265	Dec. 8	20 22	10	17.48
2279	11	17 13	10	17.75
2292	12	17 46	10	17.65
4817*	15	00 42	20	17.90
2364	Jan. 6	17 22	10	18.00
2403	8	17 44	10	17.90
4837*	8	21 55	20	17.95
2448	24	18 41	10	18.10
2454	25	19 09	10	18.10
2524	31	18 47	10	18.10
4905*	Feb. 6	21 37	40	18.42
4929*	Mar. 28	20 38	40	[18.00

rapid drop of $0^m1/\text{day}$ and the linear part, in which there is a decrement of 0^m013 per day; the corresponding half-life is 58 days. The spectrum (Bertola 1962) exhibited by this supernova was characteristic of type I. Note the observation on 9 September; it is displaced from the mean curve, and would indicate fluctuations in the luminosity of the supernova at the maximum. It is possible to fix the date of the maximum on or about 11 September with a photographic magnitude $m_{pg}=14.3$. The corresponding absolute magnitude is $M_{pg}=-17.9$ using the distance modulus in column 10 of Table I.

CONCLUDING REMARKS

The preceding observations indicate the following:

(a) The light curves of type I supernovae have a

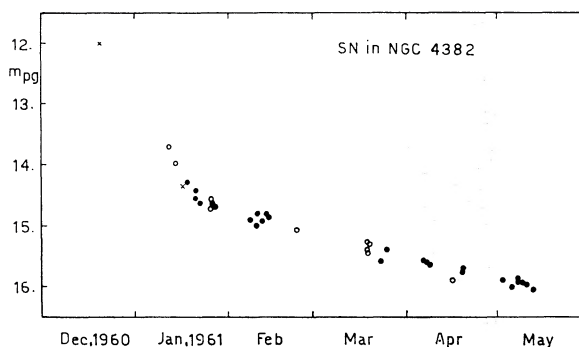


FIG. 5. Light curve of the supernova in NGC 4382.

shape like that described by Baade and Zwicky (1938) for the supernova in IC 4182.

(b) Within a period from 20 to 40 days after the maximum the slope of the light curve changes abruptly. There is a corresponding change in the slope of the curve which gives the redshift of the $4600 \text{ \AA}$ band in the spectrum as a function of phase, and also a change of the structure in the red region (Bertola 1962).

(c) About 40 days after the maximum the light curve becomes linear. In the photographic region the corresponding half-life varies from 43 days for the supernova studied by Wild (1960) in NGC 4214 to 58 days for the supernovae in NGC 4382 and in the anonymous galaxy studied in this paper. In the light of these results, the theory (Baade *et al.* 1956) which attempts to explain the linear part of the light curve in terms of the decay of the radioactive element Cf^{254} (half-life 55 days) seems to be inadequate.

(d) The mean photographic absolute magnitude of the supernovae studied in this paper (excluding the supernovae in NGC 2841, which is peculiar for its low luminosity) is $M_{pg}=-17.9$, if our extrapolations are valid. Assuming that the absolute magnitudes at maximum are the same, this value is strongly dependent on the uncertainties which exist in the determination of the distances of the galaxies and, in the case of galaxies of advanced type, on internal absorption. In this connection there is a need for observations in the *UBV* system in order to establish a two-color diagram for unreddened type I supernovae.

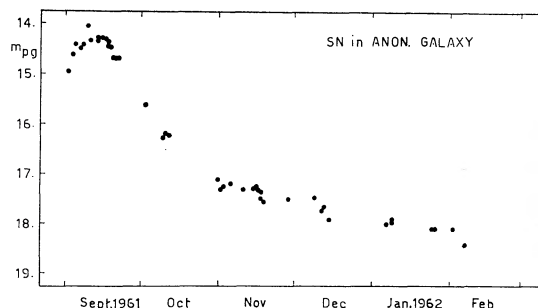


FIG. 6. Light curve of the supernova in Anonymous Galaxy.