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THE LIGHT CURVE OF SUPERNOVA 1971 I

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Light and color curves are presented for the 1971 supernova in NGC 5055. The light curves were derived from photoelectric observations, and photographic observations calibrated with a photoelectric sequence. The dates and B, V magnitudes of maximum light are established. The form of the light curve is consistent with previous spectrographic determinations that the supernova was of type I. Evidence is presented, however, to suggest that the spectroscopic behavior of the supernova was anomalous. The date of maximum in the light curve does not correspond to the date which would be indicated by the appearance of characteristic type I spectral features. A $(B-V)$ color curve is presented and is used to derive a reddening of $0^{m}35$ for the supernova. The consequent visual absorption of $1^{m}05$ is used to obtain an absolute visual magnitude for the supernova of -18.6.

Key words: supernovae — NGC 5055 — light curves

Introduction

Supernova 1971 I, in NGC 5055, was discovered at Corralitos Observatory by G. Jolly on 24 May 1971 UT. At the time of discovery the photovisual magnitude was estimated at 11.8. The supernova was not present at a limiting magnitude of 17 when NGC 5055 was monitored at Corralitos two weeks earlier. An independent discovery of the supernova was made on 29 May UT by Roger Clark at the Manasstash Observatory. A prediscovery observation was reported by G. van Herk and A. A. Schoenmaker of the Leiden Observatory (van Herk and Schoenmaker 1971). Van Herk and Schoenmaker gave the photographic magnitude as 13.0 on 20.95 May UT. A number of magnitude estimates were reported on the I.A.U. Circulars following No. 2330. A light curve for the supernova was published by Bertaud and Pollas (1972), who argue that the supernova reached maximum light on 17 May UT, at a visual magnitude of 11.3. They derived a peak absolute visual magnitude for the supernova of -18.2.

Spectrographic observations of the supernova were reported by Kikuchi (1971), by Wray and Rybski (1971), and by Barbon and Ciatti (1971). All spectrographic observations indicate the supernova to be of type I. The supernova was further discussed in a review article in *Sky and Telescope*, August 1971.

NCG 5055 is listed by Humason, Mayall, and Sandage (1956) as an Sb spiral with an integrated photographic magnitude of 9.0 and a corrected symbolic velocity of recession of 616 km sec^{-1}. An extensive study of the luminosity distribution in NGC 5055 was made by Fish (1961). Burbidge, Burbidge, and Prendergast (1960) studied the distribution of mass in NGC 5055 and derived a total mass for the system.

The Observations

Observations of this supernova began at the Prairie Observatory of the University of Illinois on 30 May 1971 UT. The object was observed both photographically and photoelectrically with the 102-cm Ritchey-Chrétien reflector, and photographically with a 10-cm Ross camera.

The photoelectric observations were made with a single-channel photometer with digital output and standard B and V filters of the UBV system. The technique employed in the observations was to measure the supernova with respect to a comparison star 01′57″ north and $41^{s}2$ west of the supernova. The comparison star is number 2 in Table I. Sky deflections for the supernova were taken 10 seconds east, where inspection of the Palomar Sky Survey indicated that the background due to NGC 5055 was about

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TABLE I

Photoelectric Magnitudes for the Stars Numbered on Plate I

Star	V	$B-V$	Nights
1*	9.24	0^m48	2
2	10.85	0.77	3
3	11.57	0.51	1
4	12.42	0.65	2
5	12.80	0.75	1
6	12.99	0.50	2
7	13.04	0.51	2
8†	13.89	1.51	1
9	13.95	0.84	2
10	14.20	1.13	1
11	15.39	0^m41	2

*HD 115270. HD spectral type is incorrect. Actual spectral type is F6.

†Possibly variable in B.

as bright as at the position of the supernova. All observations were made with a 40 arc-second focal plane diaphragm. Thirty-second integrations were used and it was found that the mean error of a single set of 30-second integrations was typically 0^m10 in both B and V. Since at least four sets of supernova and sky integrations in each color were taken on all nights but one (29 June), a single observation has an associated uncertainty of 0^m05 in both B and V. No corrections were made for the color difference between the supernova and the comparison star, or for the small difference in air mass between the supernova and the comparison star, since these corrections were found to be substantially smaller than the error of a single observation. The photoelectric observations are included in Table II.

Most of the supernova observations were photographic. The photographic observations with the 102-cm telescope were made at the $f/7.6$ Cassegrain focus on Kodak 103a-O or IIa-O emulsion behind a Schott GG13 filter (B) and on Kodak 103a-D emulsion behind a Schott GG11 filter (V). No filter was employed with the Ross camera and therefore the derived magnitudes were on the m_{pg} system. They were transformed to B through the relation $m_{pg} = B - 0.29 + 0.18(B-V)$, as given by Arp (1961). This relation is valid for main-sequence stars and is thus not necessarily valid for the supernova. However there seems to be no systematic difference between the m_{pg} magnitudes transformed to B, and B magnitudes derived directly. The $(B-V)$ color indices of the supernova were taken from nearly concurrent photoelectric or photographic observations. In addition to the Ross plates, two plates taken with the 102-cm telescope were on unfiltered IIa-O emulsion and were reduced in the same manner as the Ross camera plates.

Photographic magnitudes for the supernova were obtained using a sequence of eleven comparison stars, indicated on Plate I. Both V magnitudes and $(B-V)$ color indices for the comparison stars were obtained photoelectrically with the 102-cm telescope on four nights in the spring of 1972. The resulting magnitudes and color indices are given in Table I. Standard UBV stars given by Johnson (1963) were observed to determine extinction and transformation coefficients for each night. The average mean error for the standard stars was 0^m025 in V and 0^m019 in $(B-V)$. The stars in Table I are all fainter than the standard stars, yet were observed with longer integration times and were observed more than once per night, so the errors of a single night's observation are comparable. From a comparison of values obtained on different nights

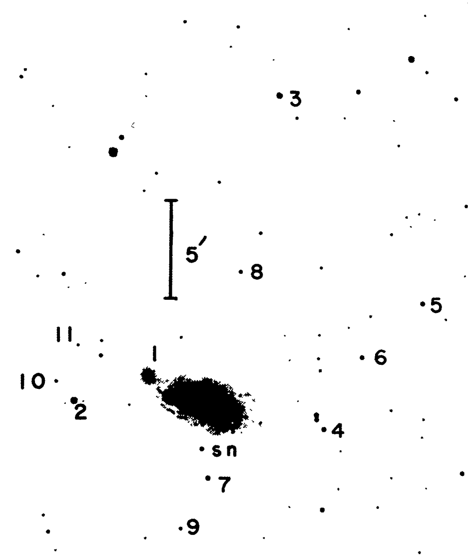

PLATE I

A V plate of the supernova taken 22 June UT with the 102-cm telescope. The comparison stars used in obtaining the photographic magnitudes are numbered, and photoelectric data for these stars are given in Table I. SN marks the supernova. North is towards the top and east is to the right.

we feel that the magnitudes given in Table I are accurate to $\pm 0^{m}03$ in V and $\pm 0^{m}02$ in $(B-V)$. Star number 7 in Table I has been measured by Ishida (1971) who derives $V = 12.98 \pm 0.01$ and $(B-V) = 0.55 \pm 0.02$.

All plates were measured with an Astromechanics iris photometer. The supernova magnitude was estimated to the nearest $0^{m}05$. In the case of the Ross camera plates, m_{pg} magnitudes for the comparison stars were calculated from their B magnitudes and $(B-V)$ color indices, using $m_{pg} = B - 0.29 + 0.18(B-V)$, and an m_{pg} magnitude was determined for the supernova. The m_{pg} magnitudes for the supernova were then converted back to B. Table II summarizes the observed B and V magnitudes of the supernova. The B and $(B-V)$ light curves are shown on Figure 1. The $(B-V)$ curve was constructed from both photoelectric and photographic observations. In addition to our observations, two other observations are plotted: the observation of van Herk and Schoenmaker (1971) and a photoelectric observation by Ishida (1971). The photographic magnitude given by van Herk and Shoenmaker cannot be unambiguously converted to B since the color index of the supernova at the time of their observation is not known. However, inspection of the available color curve indicates that the color index of the supernova at the time was probably less than $0^{m}16$ and thus the B magnitude of the supernova must have been several tenths of a magnitude fainter than 13.0.

Discussion

The light curve is typical of type I supernovae as discussed by Zwicky (1965). The initial decline of type I supernovae is followed by a long period of linear decline at a rate of $0^{m}01$ to $0^{m}02$ per day (Baade and Zwicky 1938; Mihalas 1963). The light curve presented here, however, does not include this linear section.

It is apparent from the B light curve that the supernova must have reached maximum in the blue about 29 May 1971 UT. At maximum light the B magnitude was probably close to 11.90. There is a suggestion in the V light curve that the visual maximum may have occurred three days later, on 1 June UT, although the data are not reliable enough to establish this with certainty. The V magnitude at maximum, however, must have been close to 11.50. It is unlikely that these magnitudes are in error by more than $0^{m}20$.

However, spectrograms of the supernova obtained by Kikuchi (1971) and by Barbon and Ciatti (1971) indicate that the supernova should have attained maximum about 16 May UT, in conflict with the light curve. The observation by van Herk and Schoenmaker is particularly definite in showing that the supernova had not yet reached maximum on 20 May UT. Van Herk and Schoenmaker have published the photographic magnitudes, obtained by photographic transfers, of comparison stars used in reducing their observation (van Herk and Schoenmaker 1972). Four of these stars are included in our photoelectric sequence. We find that the magnitudes of van Herk and Schoenmaker are in good agreement with ours, and we conclude that their supernova magnitude is reliable. In addition, the photoelectric observation of Ishida (1971) shows the supernova still before maximum on 25 May UT. Bertaud and Pollas (1972) have published a light curve for the supernova and have taken 17 May UT as the date of maximum, yet they have included a number of magnitude estimates by visual observers which increase the scatter in the light curve sufficiently that a later date could equally well be taken. In Figure 1, however, we have plotted only observations which we know to be consistent with our photoelectric sequence. It does not seem possible that the maximum of the light curve could have occurred as early as 17 May UT. One possible explanation is that transitory emission bands in the B and V spectral regions could have seriously affected the light curve. However this seems insufficient to explain a discrepancy which would amount to more than a full magnitude in the case of van Herk and Schoenmaker's observation. In addition, Rust (1973) has estimated the date of maximum m_{pg} using an extrapolation technique which is a combination of two techniques originally developed by Pskovskii (1971). These techniques are based on the point of inflection in the m_{pg} light curve and on average m_{pg} light curves. Rust estimates that the peak m_{pg} was 11.7, on 27 May UT.

The balance of the evidence thus seems to indicate that the maximum of the light curve must have been near 29 May 1971 UT. The supernova exhibited anomalous behavior in the sense that

TABLE II

OBSERVATIONS

1971 Date, UT	Receiver	B	V	B-V	Remarks
May 30.16	102 cm telescope photoelectric		(12.10)	0.35	
May 30.22	10 cm Ross camera IIaO, unfiltered	11.98			transformed from m_{pg} = 11.75
May 31.21	102 cm telescope photoelectric		(11.98)	0.31	
May 31.23	10 cm Ross camera IIaO, unfiltered	11.83			transformed from m_{pg} = 11.60
June 01.16	102 cm telescope photoelectric		11.74	0.48	
June 01.18	10 cm Ross camera IIaO, unfiltered	11.90			transformed from m_{pg} = 11.70
June 03.42	10 cm Ross camera IIaO, unfiltered	12.35			transformed from m_{pg} = 12.15
June 09.15	102 cm telescope IIaO + GG13	13.15			
June 09.18	102 cm telescope 103aD + GG11		12.20		
June 09.22	102 cm telescope IIaO + GG13	13.10			
June 10.23	102 cm telescope IIaO + GG13	13.45			
June 10.24	102 cm telescope 103aD + GG11		12.30		
June 14.23	102 cm telescope IIaO + GG13	13.90			
June 14.24	102 cm telescope 103aD + GG11		12.70		
June 14.32	102 cm telescope 103aD + GG11		12.65		
June 16.20	102 cm telescope IIaO + GG13	14.00			
June 16.22	102 cm telescope 103aD + GG11		12.75		
June 17.19	10 cm Ross camera IIaO, unfiltered	14.12			transformed from m_{pg} = 14.05
June 22.18	102 cm telescope IIaO, unfiltered	14.65			transformed from m_{pg} = 14.60
June 22.20	102 cm telescope 103aD + GG11		13.35		
June 22.22	102 cm telescope IIaO + GG13	14.65			

TABLE II (Continued)

1971 Date, UT	Receiver	B	V	B-V	Remarks
June 23.25	102 cm telescope photoelectric		13.39	1.19	
June 29.18	102 cm telescope photoelectric		13.83	1.23	
July 03.21	102 cm telescope photoelectric		13.97	0.86	
July 14.19	102 cm telescope photoelectric		14.05	1.20	
July 16.17	102 cm telescope 103aO + GG13	15.40			
July 16.20	102 cm telescope 103aD + GG11		14.50		
July 16.23	102 cm telescope 103aO, unfiltered	15.33			transformed from m_{pg} = 15.20
July 29.17	102 cm telescope 103aO + GG13	15.35			
July 29.19	102 cm telescope 103aD + GG11		14.90		
July 31.15	102 cm telescope 103aO + GG13	15.50			
July 31.17	102 cm telescope 103aD + GG11		14.90		
August 02.14	102 cm telescope 103aO + GG13	15.35			
August 02.17	102 cm telescope 103aD + GG11		14.85		
August 03.13	102 cm telescope 103aD + GG11		14.95		
August 03.15	102 cm telescope 103aO + GG13	15.10			
August 14.11	102 cm telescope 103aO + GG13	15.8			plate taken at large air mass, estimated uncertainty is ± 0.3 magnitude

the appearance of characteristic type I spectral features was not well correlated with the light curve. This possibility was first suggested by van Herk and Schoenmaker (1972).

The Absolute Magnitude of the Supernova

Pskovskii (1968) has discussed the $(B-V)$ color index of type I supernovae as a function of time. He gives the reddening-free color curve, based on well-observed and nominally unreddened supernovae. Our $(B-V)$ curve, given in Figure 1, can be roughly matched to the curve given by Pskovskii. We can derive the reddening of the supernova in NGC 5055 by assuming that its $(B-V)$ curve conforms to the curve given by Pskovskii, with the addition of a constant amount of reddening to all points of the curve. A shift along the $(B-V)$ axis of 0^m35 is necessary to match the two curves and we can then adopt 0^m35 as the total reddening along the line of

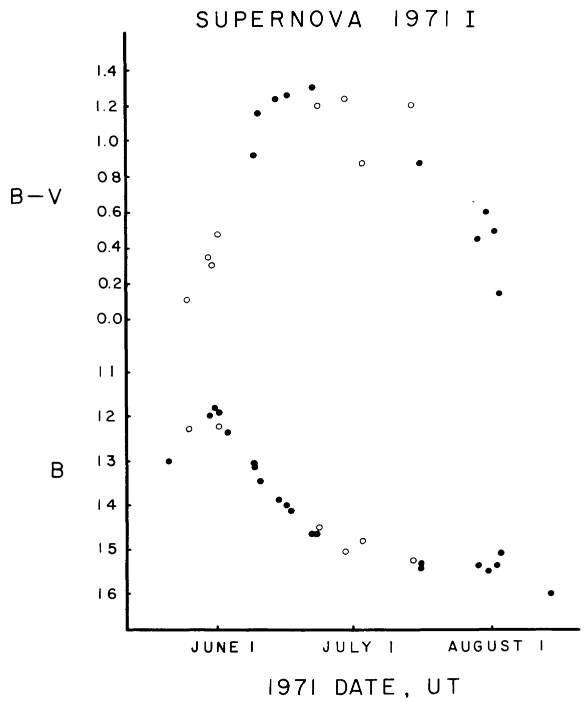

FIG. 1 — The B light curve and $(B-V)$ color curve of the supernova. Photoelectric observations are plotted as open circles and photographic observations as filled circles. In addition to our observations the observations of Ishida (25 May) and of van Herk and Shoenmaker (20 May) are plotted, as explained in the text. It should be noted that the observation of van Herk and Schoenmaker is on the m_{pg} system, the corresponding B magnitude will be fainter than the point which is plotted.

sight to the supernova. With a ratio of total to selective absorption of 3.0 the total visual absorption is 1^m05. This procedure, however, must be used with caution since an anomalous spectroscopic behavior of the supernova would be accompanied by anomalies in the color curve. Indeed, both the color curve and the spectroscopic behavior seem to be out of phase with the observed light curve by the same amount. If the color curve is not anomalous along the $(B-V)$ axis, the above reddening is probably reliable. A reliable method for determining the absorption suffered by type I supernovae is to be greatly desired since this will allow improved determinations of type I absolute magnitudes and will enhance the possibility of an eventual use of type I supernovae as extragalactic distance indicators. The method of fitting an observed color curve to a reddening-free color curve seems to us to hold the most promise for determining the absorption suffered by type I supernovae and has been used extensively by Rust (1973). However the method is speculative in the sense that a ratio of total to selective absorption must be assumed for the parent galaxies of the supernovae.

To obtain a distance modulus for NGC 5055 we have used three methods: the symbolic velocity of recession and a Hubble parameter of 100 km^{-1} sec^{-1}mpc^{-1}; the Hubble type and Holmberg luminosity function (Holmberg 1965), and the DDO type and van den Bergh luminosity function (van den Bergh 1960). These three methods give, respectively, $m - M = 28.95$, 29.87, 28.27. The mean distance modulus from these three methods is $m - M = 29.05$ and the absolute visual magnitude of the supernova, corrected for absorption, is then -18.6. The greatest source of uncertainty in this value is the distance modulus of NGC 5055, more recent values of the Hubble parameter giving a greater luminosity for the supernova.

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