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Absolute Magnitudes of Supernovae

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The maximum indicative absolute magnitudes of 33 supernovae are derived. For supernovae of type I, the average absolute magnitude is $M_{pg}=-18.6+5\log(H/100)$. For type II, the average is $M_{pg}=-16.5+5\log(H/100)$. These values are lower limits, which neglect the effects of absorption within the parent galaxies. The redshift–magnitude relation for type I supernovae is shown, and the usefulness of these supernovae as distance indicators is discussed.

SEVERAL attempts have been made in the past to obtain the average absolute magnitudes of supernovae (Baade 1938; van den Bergh 1960a; Minkowski 1964). These attempts were hampered by the scarcity of complete light curves, so that the results depended heavily on extrapolated magnitudes. Now, however, almost 40 light curves are available which provide reasonably reliable magnitudes for the supernova maxima. By using luminosity classifications of galaxies, or by other techniques, we can estimate the distances, and therefore the absolute magnitudes of the supernovae, in terms of an assumed Hubble constant.

Table I lists the data for all supernovae that have well-determined maxima. The maxima were seldom extrapolated by more than $0^m.25$; exceptions are listed in the notes. Sources of the light curves are given at the end of this paper. The magnitudes have been corrected for galactic absorption by 0.25 csc$b$. The radial velocities were corrected for solar motion with respect to the local group of galaxies. For five supernovae without spectra, the types were assumed on the basis of their magnitudes alone. Elimination of these five supernovae, however, makes little difference in the average magnitudes. No attempt was made to correct for absorption within the parent galaxies of the supernovae, since the procedures for this are highly uncertain. The average magnitudes derived, should therefore be regarded as lower limits to the true brightness. Most of the distance moduli are from van den Bergh (1960a,b,c), and are based on a Hubble constant of 100 km/sec/Mpc. A modulus of 30.3 was used for members of the Virgo cluster. The average absolute photographic magnitude so derived is -18.6 for type I, and -16.5 for type II. In both cases the dispersion is about $0^m.6$. It should be remembered that the dispersion is caused by uncertainties in the distance moduli, different absorptions in the parent galaxies, and errors in the light curves, as well as by the intrinsic dispersion in the maximum magnitudes of the supernovae. There is therefore considerable hope that the magnitudes of type I supernovae, at least, can be used as reliable distance indicators, presumably free of such complications as evolutionary effects, and visible at very great distances. For very distant supernovae, corrections will, of course, have to be made for the redshifting of the emission bands into or out of the bandpass of the filters used. No such correction was attempted in the present study.

I. PHOTOMETRIC CHARACTERISTICS OF THE DIFFERENT TYPES OF SUPERNOVAE

Type I: Light curves are available for 22 supernovae of this type, and distance moduli have been obtained for 19 of these. For supernovae 1961d, and 1963p, the photographic magnitudes were obtained by applying the average color indices from Table II. The average photographic magnitude of the 19 supernovae is $M_{pg}=-18.56$, with a dispersion $\sigma=0^m.77$. Eliminating the four supernovae whose absolute magnitudes are parenthesized in Table I, we obtain an average of -18.67, and a dispersion of $0^m.61$. If we also eliminate the two supernovae that were only assumed to be of type I (type parenthesized in Table I), we obtain an average of -18.59. We therefore adopt as the final result for supernovae of type I

$$M_{pg}=-18.6+5\log(H/100).$$

Type II: Although the light curves of type II supernovae show considerable variation in shape, the absolute magnitudes at maximum do not vary as much as one might expect. However, the number of good light curves is still small. Also, absorption in the parent galaxies may be large in some cases. The average photographic magnitude at maximum of nine type II supernovae is

$$M_{pg}=-16.5+5\log(H/100), \quad \sigma=0^m.6.$$

Eliminating the three supernovae that were only assumed to be of type II gives an average of -16.7. The average of -16.5 agrees well with the result obtained by van den Bergh, (1960a), but is considerably fainter than Minkowski's (1964) result, since the latter introduced large corrections for absorption within the parent galaxies.

Type IV: Only one supernova of this type is known; SN 1961f in NGC 3003. Its absolute magnitude of -16.9 is similar to the average magnitude of type II supernovae.

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TABLE I. Supernova data.

SN	NGC IC*	Type	V_0	Cluster	Corrected maxima m_{pg}	m_B	m_V	$(m-M)_0$	M_{pg}	Notes
1895b	5253	(I)	+ 229	NGC 5236 Comp.	7.5			27.2	−19.7	
1921c	3184	(I)	+ 418		10.7			29.4	−18.7	
1923a	5236	Pec.	+ 335	NGC 5253 Comp.	13.5			27.2	−13.7	
1936a	4273	II	+2192	NGC 4273 Gr.	14.1			30.4	−16.3	
1937c	4182*	I		(Canes Ven.)	8.2		8.3	(28.2)	(−20.0)	*
1937d	1003	I	+ 741	NGC 1023 Gr.	12.0		11.4	29.2	(−17.2)	*
1937f	3184	(II)	+ 418		13.2			29.4	−16.2	
1939a	4636	I	+ 778	Virgo	11.9			30.3	−18.4	
1939b	4621	I	+ 345	Virgo	11.6			30.3	−18.7	
1939c	6946	(II)	+ 371		11.8			28.3	−16.5	
1940a	5907	II	+ 725		14.0			29.7	−15.7	
1940b	4725	II	+1109	Ursa Major	12.6			30.2	−17.6	
1941a	4559	II	+ 852		12.8			29.2	−16.4	*
1954a	4214	I	+ 311	Canes Ven.	9.5			28.2	−18.7	
1954b	5668	I	+1732		12.0			31.2	−19.2	
1955b	Anon.	...			15.5			...	...	
1956a	3992	I	+1147	Ursa Major	12.0			30.4	−18.4	*
1957a	2841	II pec.	+ 671		13.6		13.3	29.6	−16.0	
1957b	4374	I	+ 878	Virgo	12.2			30.3	−18.1	
1959c	Anon.	I	+2910		13.3	13.8	13.6	32.3	−19.0	
1959d	7331	II	+1072	NGC 7217 Comp.	12.7	13.0	13.0	29.9	−17.2	
1960f	4496	I	+1665		11.3			31.1	−19.8	*
1961d	Anon.	I	+7706	(Coma)	(16.1)		16.3	34.1	(−18.0)	*
1961f	3003	IV	+1429		12.8			29.7	−16.9	
1961h	4564	I		Virgo	11.9			30.3	−18.4	
1961p	Anon.	I			13.6			30.8	−17.2	
1961u	3938	II	+ 919		13.5			30.5	−17.0	
1961v	1058	V	+ 624	NGC 1023 Gr.	11.5			29.2	−17.7	
1962a	Anon.	I	+6152	Coma	15.4		15.5	34.1	−18.7	*
1962j	6835	I			12.9			...	...	
1962l	1073	I pec.	+1893		...	13.6	13.0	29.4	...	
1963c	Anon.	I	(+6920)	Coma	15.4		15.7	34.1	−18.7	
1963d	4146	I			15.5			...	...	
1963j	3913	I			13.4			...	...	
1963p	1084	I	+1448		(13.3)	13.7		30.8	(−17.5)	
1964l	3938	I pec.	+ 919		13.1			30.5	−17.4	
1966e	4189	(II)		Virgo	14.6		14.7	30.3	−15.7	
1967c	3389	I	+1145		12.7	13.0	12.8	31.1	−18.4	*

SN 1937c—After comparison with other light curves, the adopted maximum magnitude of this supernova has been changed slightly from the value originally determined by Baade and Zwicky (1938). The uncorrected photographic magnitude is 8.4 instead of 8.2. Since this supernova is 1.3 mag brighter than SN 1954a in NGC 4214, IC 4182 may not be a member of the Canes Venatici Group. (See van den Bergh 1960c and Minkowski 1964.)

SN 1937d—The red color and relative faintness of this supernova may indicate that it was considerably obscured by matter within NGC 1003. Minkowski (1964) estimates that the photographic absorption amounts to 1.3 mag.

SN 1941a—The magnitude is from Zwicky (1965) and is $0^m.5$ brighter than reported by Minkowski (1964).

SN 1956a—The magnitude has been extrapolated by $0^m.75$. The uncorrected magnitude at maximum was determined to be at $m_{pg}=12.3$, after comparison with other light curves of type I.

SN 1960f—The distance modulus here was determined only from the radial velocity of the galaxy. de Vaucouleurs (1961) states that NGC 4496 is a member of the "X-Cloud" of the Virgo cluster, in which case the distance modulus would be 30.6. No attempt has been made here to separate the supernovae of the Virgo cluster into the different clouds, and indeed, their apparent magnitudes do not confirm such a differentiation.

SN 1961d—Note that this supernova is considerably fainter than others in the Coma cluster. It appeared rather far from the nucleus of an E0 galaxy, so obscuration of the supernova is likely to be small. Therefore, its magnitude may be an indication of the intrinsic dispersion of supernova maxima, or the galaxy may actually be more distant than the Coma cluster. It is located two degrees from the center of the cluster.

SN 1962a—The photographic magnitude has been extrapolated by $0^m.5$, and the visual magnitude by $0^m.2$.

SN 1967c—The distance modulus is from de Vaucouleurs (1968).

Type V: SN 1961v in NGC 1058 is the only supernova of this type which has been thoroughly studied. Its absolute magnitude can be determined in two ways: by the luminosity classification of NGC 1058, and by its membership in the NGC 1023 group. NGC 1003, which contained SN 1937d, is also a member of this group. For NGC 1003, van den Bergh obtained an apparent distance modulus of 30.2, which corresponds to a true modulus of 29.4. From the luminosity of NGC 1058 we obtain a true modulus of 29.0. In Table I we have adopted the value of 29.2 for both galaxies. The absolute photographic magnitude of SN 1961v at maximum is therefore −17.7. This is not far from the maximum magnitudes of type I supernovae. In addition, SN 1961v was seen for about 30 yr at an absolute magnitude of −11.9. (See Bertola 1964 and Zwicky 1964.)

II. REDSHIFT–MAGNITUDE RELATION FOR TYPE I SUPERNOVAE

Figure 1 shows the redshift–magnitude relation for 16 supernovae of type I. The crosses represent the average velocity and average supernova magnitude in the Virgo and Coma clusters.

For Virgo: $V_0=1136$ km/sec and $m_{pg}=11.9$.

For Coma: $V_0=6920$ km/sec and $m_{pg}=15.4$.

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TABLE II. Colors of type I supernovae at maximum.

SN	NGC IC*	Corrected maxima m_{pg}	m_B	m_V	$m_{pg}-m_V$	$B-V$	Notes
1937c	4182*	8.2		8.3	−0.1		
1937d	1003	12.0		11.6	(+0.4)		*
1959c	Anon.	13.3	13.8	13.6	−0.3	+0.2	*
1962a	Anon.	15.4		15.5	−0.1		
1963c	Anon.	15.4		15.9	−0.5		
1967c	3389	12.7	13.0	12.9	−0.2	+0.1	

Adopted averages: $m_{pg}-m_V=-0.2$
$B-V=+0.15$

*SN 1937d—This supernova may have been reddened by matter within NGC 1003. Its color index was not used in determining the adopted average.
*SN 1959c—The visual magnitude, and therefore the color indices given here, differ from those given by Mihalas (1962). It is believed that the values stated above are more in accord with other light curves, but the extrapolation to maximum is rather arbitrary, and Mihalas' value of $B-V=-0.25$ must be considered. See also Pskovskii (1968).

A 45° straight line has been drawn to fit these two points best. The equation of the line is

$$m_{pg}=5\log V_0-3.59. \quad (1)$$

This agrees exactly with the value derived by Zwicky (1961, 1965) from the estimated magnitudes and individual velocities of seven supernovae in the Virgo cluster. A least-squares fit for 15 supernovae in Fig. 1 (omitting SN 1939b), without regard to cluster membership, gives

$$m_{pg}=5\log V_0-3.27. \quad (2)$$

Equation (1) is probably preferable, because of the great scatter in $\log V_0$ for nearby galaxies, but the two equations give an indication of the general degree of uncertainty in the (m_{pg}, $\log V_0$) relation. At present, we can say that Eq. (1) is probably accurate to within $\pm 0^m.3$. This uncertainty can be reduced considerably when more supernovae are found at distances comparable to that of the Coma cluster. It may even be possible to determine the second-order term in the redshift–magnitude relation when light curves become available for very distant supernovae.

III. SUPERNOVAE AS DISTANCE INDICATORS

As shown earlier, the observed dispersion in the maximum magnitudes of supernovae of type I is about $0^m.6$, and the intrinsic dispersion should be even smaller. It is obvious, therefore, that these supernovae could be exceedingly useful indicators of distance. It should be possible to obtain average supernova magnitudes in clusters of galaxies to an accuracy of 0.1 or 0.2 mag, which corresponds to accuracies of 5% to 10% in the distances. The main problem now is one of calibration. It is not yet possible to determine the Hubble constant by means of supernovae alone, since no reliable distance moduli are available to calibrate the absolute magnitudes of the nearer supernovae. The currently proposed moduli for the Virgo cluster range from 30.0 to 30.8. A search for supernovae in galaxies of various distances is being carried out at Palomar and other observatories, in the hope of further refining the redshift–magnitude relation. Distances of the parent galaxies of the nearer supernovae may soon become available through studies of Cepheid variables, H II regions, or red supergiant stars.

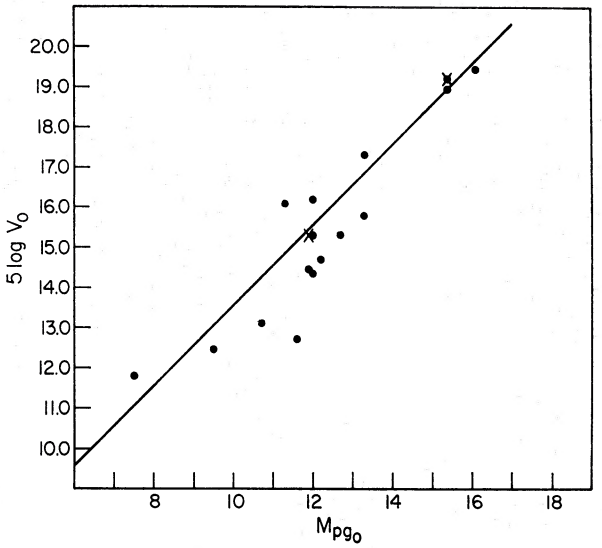

FIG. 1. The redshift–magnitude relation for supernovae of type I. The dots refer to individual supernovae, and the crosses represent averages for the Virgo and Coma clusters, as explained in the text.

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The Eclipsing Binary System AU Puppis

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The eclipsing binary AU Puppis was studied photoelectrically in yellow and blue light in New Zealand in 1965–66 and in Australia in 1967. The period is found to have decreased by 1.3 sec during the last 40 yr. The variation of light outside eclipses is extremely great. The value of the coefficient of the $\cos 2\theta$ term A_2 is -0.18 or -0.19. This is larger than that found in any W Ursae Majoris-type system. No completely consistent solution is found for the orbital elements of AU Puppis. Both components seemingly fill their inner zero-velocity lobes, thus making AU Puppis a contact system. The interactions between the components must be very large, and both components are presumed to deviate substantially from ellipsoidal shape.

I. INTRODUCTION

IN Sydney, Australia (1935), AU Puppis was first noted as being variable by O'Leary and O'Connell of the Riverside College Observatory. The star was recognized as an eclipsing binary of the beta Lyrae type. Its spectral type and apparent photographic magnitude are given as A0 and +8.5, respectively, in the *Henry Draper Catalogue*.

The author undertook this photoelectric study of AU Puppis at the Mount John University Observatory in New Zealand from December 1965 to June 1966, and later at the Mount Stromlo Observatory in Australia during February and March of 1967. Although AU Puppis has been known to be variable for more than thirty years, this is the first photoelectric study of this star.

TABLE I. AU Puppis and its comparison and check stars.

Star	CPD No.	HD No.	R.A. (1966)	Dec. (1966)	Spec. (HD)
AU Puppis	−41°2337	69951	$8^h16^m28^s$	−41°35′.6	A0
Comparison	−41°2351	70024	$8^h16^m54^s$	−41°59′.7	B8
Check	−41°2366	70217	$8^h17^m51^s$	−41°51′.9	B9

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II. OBSERVATIONS

AU Puppis was observed in New Zealand and Australia with the standard B, V filters. The New Zealand observations were made with a 16-inch, $f/25$ Cassegrain reflector, while the Australian observations were made using a 30-inch, $f/18$ Cassegrain reflector. The photomultipliers used at both locations were RCA 1P21 tubes. In New Zealand no refrigeration was used, while in Australia the cell was refrigerated with dry ice.

AU Puppis was observed alternately with a comparison star HD 70024 (Table I). Thus small changes in seeing conditions could be detected, and extinction coefficients for the night of observation could be calculated. HD 70217 was used as a check on the comparison star. HD 70024 and HD 70217 have apparent visual magnitudes of +9.0 and +8.7, respectively, and both lie within one-half degree of AU Puppis. The three stars have approximately the same color indices, and the comparison star has a brightness which is nearly identical to the mean brightness of AU Puppis. The New Zealand observations yielded mean values of Δm (check–comparison) of $-0^m.256\pm0^m.004$ in yellow light and $-0^m.365\pm0^m.003$ in blue light. The Australian data yielded mean values of $-0^m.283\pm0^m.004$ for yellow light and $-0^m.373\pm0^m.005$ for blue light. The blue means are in good agreement, but the means for yellow

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