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OBSERVATIONS OF SUPERNOVAE: 1975a IN NGC 2207 AND 1975b IN THE PERSEUS CLUSTER

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ABSTRACT

Spectroscopic, spectrophotometric, and photometric observations demonstrate that supernova 1975a, located in the unusual system NGC 2207/IC 2163, was of Type I. Observations began about 7 days before maximum light and continued until shortly after maximum. The radius of the photosphere 5 days before maximum light was of order 1×10^{15} cm, at a temperature near 12,000 K. An attempt to find the distance through the Baade-Wesselink method is not successful due to inadequate data. Spectroscopic evolution, on the large scale, is similar to that observed previously, but features of small wavelength extent are also observed. These observations extend the comprehensive series of spectrophotometry obtained for supernova 1972e to the era before maximum light.

The supernova 1975b, in the Perseus cluster, was either of Type I, or of the class of peculiar Type I supernovae which lack the distinctive λ6115 feature. In either case, the observed magnitude is consistent with the distance of the cluster, despite the large redshift of the parent galaxy, and helps confirm the large velocity dispersion and mass discrepancy in the Perseus cluster.

Subject headings: galaxies: clusters of — galaxies: individual — stars: supernovae

I. OBSERVATIONS OF SUPERNOVA 1975a

The supernova 1975a was discovered by J. R. Dunlap and Yvonne Dunlap on 1975 January 15.323 (UT) using the image-orthicon system at the 30 inch (76 cm) reflector of Corralitos Observatory, near Las Cruces, New Mexico. The discovery image, shown in Figure 1, was the result of a systematic search for supernovae in nearby galaxies. Because a typical detection limit for this system is $m \approx 18$, and the observed galaxies are nearby ($m - M \approx 34.3$), typical Type I supernovae which attain $M \approx -19.9$ should be well above the detection limit long before (and after) maximum light.

The supernova was located 59″ east and 55″ north of the nucleus of the spiral NGC 2207, in a region that is not clearly associated with any spiral feature of the galaxy. NGC 2207 is 6^s west of IC 2163, and it is conceivable that the supernova belongs to that system. The apparent redshift of NGC 2207 is 2680 km s^{-1} (Humason, Mayall, and Sandage 1956), which corresponds to 2455 km s^{-1} when corrected for galactic rotation, or a distance modulus of $m - M = 33.3$ for $H_0 = 55$. IC 2163 has a redshift of 2965 km s^{-1}, and is presumably physically associated with NGC 2207 (Rubin 1976). Photometry of the supernova has been reported by R. Green (1974) on the *UBV* system, as shown in Table 1. In addition, instrumental magnitudes referring to the unfiltered S-20 cathode of the image orthicon have been derived, and are displayed in Figure 2. From these data we conclude that the date of maximum light was between 1975 January 21 and 1975 January 24. For concreteness, we adopt 1975 January 22.8.

We estimate the interstellar reddening in the direction of the supernova in three ways: the H I column density, the Ca II doublet ratio, and a model of galactic absorption. From the H I maps of Heiles and Habing (1974) at $l = 229$, $b = -18$, $N_H \approx 4 \times 10^{20}$ cm^{-2}. Using the gas-to-absorption ratios derived by Knapp (1975), $A_v \approx 0.2 \pm 0.2$ mag. One of the observations of this supernova was a spectrogram obtained at the 4 m Mayall telescope at Kitt Peak at 27 Å mm^{-1} near λ3900. It shows strong Ca II absorption at zero redshift, but no evidence of absorption at +2500 km s^{-1}. The H and K doublet ratio of 1.12 ± 0.05 implies an optical depth from 4 to 60. Because the corresponding absorption is so uncertain, no reasonable estimate of the absorption can be made in this way, but it is likely to be substantial in our Galaxy, while it is likely to be unimportant in the distant galaxy (equivalent width of K < 0.1 Å). For this galactic latitude, the "partly

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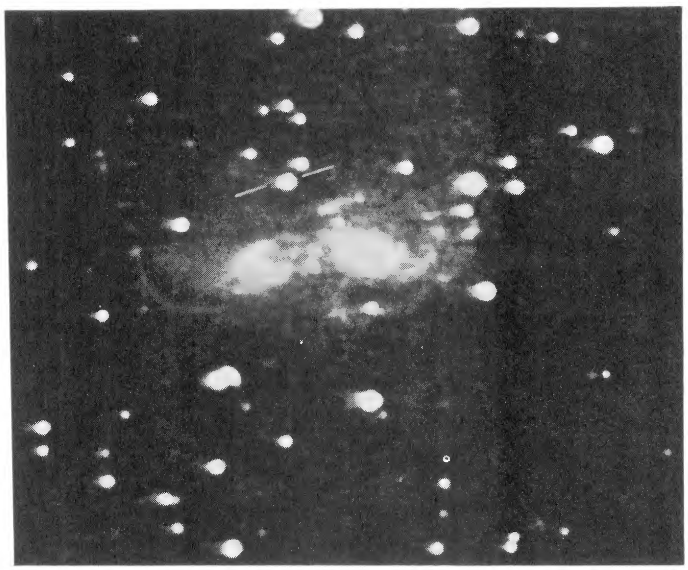

FIG. 1.—Print from image-orthicon frame obtained 1975 Jan. 17. Supernova 1975a is marked in this 1.5 s exposure.

TABLE 1
UBV OBSERVATIONS (Green 1975)

1975 UT DATE	EPOCH (DAYS)	OBSERVATIONS			INTRINSIC	
		V	*B* − *V*	*U* − *B*	$(B-V)_0$	$(U-B)_0$
January 17.260............	−5.5	14.90	−0.05	−0.36	−0.15	−0.43
January 18.281............	−4.5	14.72	−0.03	−0.29	−0.13	−0.36
January 20.278............	−2.6	14.66	+0.08	−0.14	−0.02	−0.21

cloudy" model of Sandage (1972) would give $A_v = 0.45$. It seems reasonable to suppose that $0.2 < A_v < 0.5$. We adopt $A_v = 0.3$.

The corresponding magnitude at maximum light can be estimated from Table 1 and Figure 2. On January 20.3 $m_B = 14.74$ and the increase to the maximum is about 0.1 mag. If we suppose $m_B(\max) = 14.6$, then with $A_B \approx 0.4$, $M_B \approx -19.1$. In view of the uncertainties of the absorption and the magnitude at maximum, this does not seem inconsistent with the value of $M_{pg} = -19.9 \pm 0.3$ derived for Type I by Kowal (1968) with $H_0 = 55$ km s^{-1} Mpc^{-1}.

The intrinsic colors derived with $A_v = 0.3$ are shown in Table 1. They are somewhat redder than the typical Type I color curve shown by Barbon, Ciatti, and Rosino (1973) or Psovskii (1968) of $B - V = -0.3$, a few days before maximum. This may indicate either that premaximum colors have some dispersion, or that our reddening value is too small. A value of $A_v \approx 0.5$ would give a better match to the colors and an absolute magnitude of $M_B \approx -19.4$.

In Figure 3, the multichannel spectrometer data for supernova 1975a are presented, along with the earliest scan of the extensive set of spectrophotometry of supernova 1972e in NGC 5253 (Kirshner *et al.* 1973*a*). Using the date of maximum for supernova 1972e inferred from the light curve by Aardeberg and de Groot (1974), the scan shown is at an age of about +15 days.

Some care must be employed in comparing these scans, because they were obtained with different bandwidths. Nevertheless, the overall energy distributions show a remarkable similarity, with the possible exception of new minima just shortward of 5000 Å. In the case of 1972e, the photospheric temperature was about (Kirshner *et al.* 1973*b*) 10,000 K and the photospheric radius about 1.1×10^{15} cm at about 15 days past maximum. For the observations in the present case, the best estimate of the temperature, including reddening effects, is $T = 12{,}000 \text{ K} \pm 2000$ and $R/D = 0.0237$ (10^{15} cm Mpc^{-1}) for the scan of 1975 January 17. For a distance of 45 Mpc, the photospheric radius was 1.06×10^{15} cm, and the energy output about 1.7×10^{43} ergs s^{-1}.

As pointed out by Leonard Searle, the change in photospheric radius from one scan to another can be compared with the photospheric velocity to give the distance to supernovae. This has been applied to individual Type II supernovae by Kirshner and Kwan (1974) and to Type I supernovae as a class by Branch and Patchett (1973).

In the present case, the time interval is very short—only 3 days—and the temperatures are not distinguishable, but the increase in flux can be accurately determined from Table 4 as 14 percent over the observed wavelength range. This implies $R_2/R_1 = 1.068$. Using the red edge of the absorption minimum at Ca II (feature 2 in Fig. 4) as done by Kirshner and Kwan, or the feature identified as Si II at λ6355 (No. 22) as done by Branch and Patchett, gives the same velocity of 11,600 km s^{-1}. With a time separation of 3 days, this implies $V\Delta t \approx 3.0 \times 10^{14}$ cm.

We can write a crude estimate of the distance as

$$D = \frac{D}{R_1} \frac{V\Delta t}{(R_2/R_1 - 1)} .$$

This gives $D = 187$ Mpc, an excessively large distance. The difficulty is in the determination of R_2/R_1. Since the time interval is short, R_2/R_1 is near 1 in any event, and the expression $R_2/R_1 - 1$ in the denominator is both poorly determined and very important. In particular, a decrease in temperature between scans of only 1000 K, which cannot be excluded from the data, could lead to a factor of 4 decrease in the determined distance. A longer time span is required to use the expanding photosphere method to determine distances to Type I supernovae.

II. SPECTROSCOPIC BEHAVIOR

Because the multichannel scans are reduced to the absolute flux scale of Oke and Schild (1970), and since some of the spectroscopic observations listed in Table 2 were obtained at the same times, the spectra can be converted to an absolute intensity scale. The spectra were obtained with image-tube spectrographs on baked IIIa-J emulsions. Calibration step-wedges using iconel films were obtained at the same time using a filter that mimics the image-tube phosphor, and developed with the spectra. The spectrograms were scanned using a $20 \times 20\,\mu$ aperture on the Kitt Peak PDS microphotometer, converted to intensity, and summed in columns of constant wavelength. The resulting intensity spectra were normalized to match the corresponding scan in each band. The results are shown in Figure 4, where the linear flux density, f_ν, is plotted against wavelength. In principle, it would be possible to use pure noise spectra, and to manipulate the mean

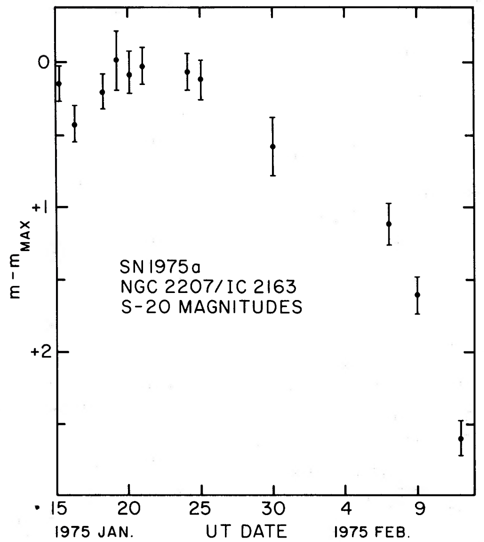

FIG. 2.—Unfiltered S-20 instrumental magnitudes from image orthicon.

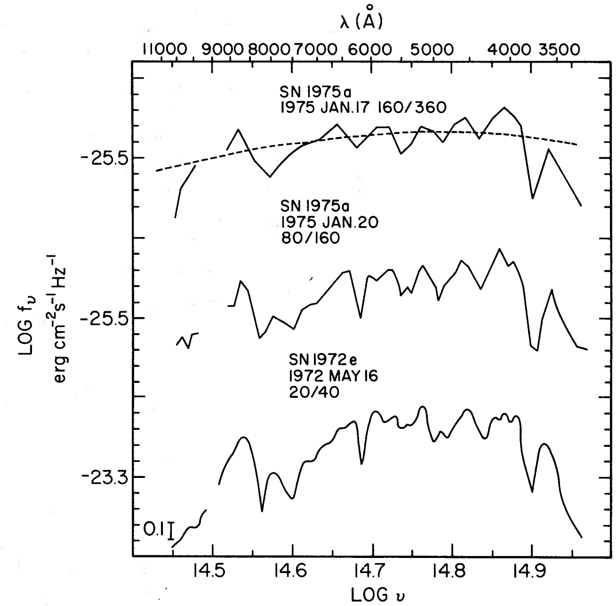

FIG. 3.—Energy distributions for early phases of Type I supernovae. Top scan shows (*broken line*) 12,000 K blackbody with $A_v = 0.3$. Top scan is at age -5 days, middle scan at -2 days, and bottom scan at age $+14$ days.

in any band to match any given flux distribution. We are confident that this has not happened here because the corrections applied are smooth, and because all the features seen in the normalized data are present in the original intensity tracings. We believe that the corrections applied correspond only to the atmospheric extinction, grating blaze, and cathode sensitivity, and that the resulting spectra give absolute flux densities accurate to about 10 percent with a wavelength resolution of about 2 Å. The main shortcoming of this technique is that the sky emission has not been subtracted: it is not important for an object as bright as this one, except near the emission lines of the night sky.

Wavelengths of several distinct maxima and minima have been measured, with an accuracy of 2 Å, and are presented in Table 3. The location measured for each feature, along with a serial number, is indicated on Figure 4. In general, the observed features agree well with those seen in other Type I supernovae (Oke and Searle 1974). The strong maxima of features 3, 5, 9, 14 + 16, and 21 and the distinct minimum at feature 22 are characteristic features of Type I SNs near maximum light. We would like to draw special attention to features of small wavelength extent which appear to be real. As seen in the supernova in NGC 4414 by Iye *et al.* (1976), the narrowest features have width of only 2000–3000 km s^{-1}. What is more significant is that many of the narrow features in the spectra of Iye *et al.* are the same features which are seen in the present data. In particular, features 6, 11, 12, 13, 14, and 18 are narrow, undoubtedly real, and seen in both sets of data. (The very sharp absorption splitting feature 3 is due to galactic Ca II.) In addition, features 7 and 8, which stand well out of the noise in the January 17 spectrum, appear to undergo an overnight change which may well be real.

Explanations for narrow features can be sought either in departures from spherical symmetry, or in

TABLE 2

SPECTROSCOPIC OBSERVATIONS

UT Date	Observatory and Telescope	Spectrogram Scan Number	Dispersion or Bandwidth	Useful Wavelength Range (Å)
1975 Jan. 17..............	Palomar 5 m	1A1	160/360 Å	3300–10500
	Kitt Peak 2.1 m	3163	100 Å mm^{-1}	3400– 6000
1975 Jan. 18..............	Kitt Peak 2.1 m	3169a	100 Å mm^{-1}	4900– 6400
			50 Å mm^{-1}	3400– 4400
	Kitt Peak 2.1 m	3169b	100 Å mm^{-1}	3400– 5300
1975 Jan. 20..............	Palomar 5 m	4A5	80/160 Å	3300–10500
	Kitt Peak 4 m	600	27 Å mm^{-1}	3500– 4300
		601	54 Å mm^{-1}	5000– 6600
1975 Jan. 21..............	Kitt Peak 4 m	605	27 Å mm^{-1}	3500– 4300
1975 Jan. 22..............	Kitt Peak 2.1 m	3194	200 Å mm^{-1}	5800– 6500

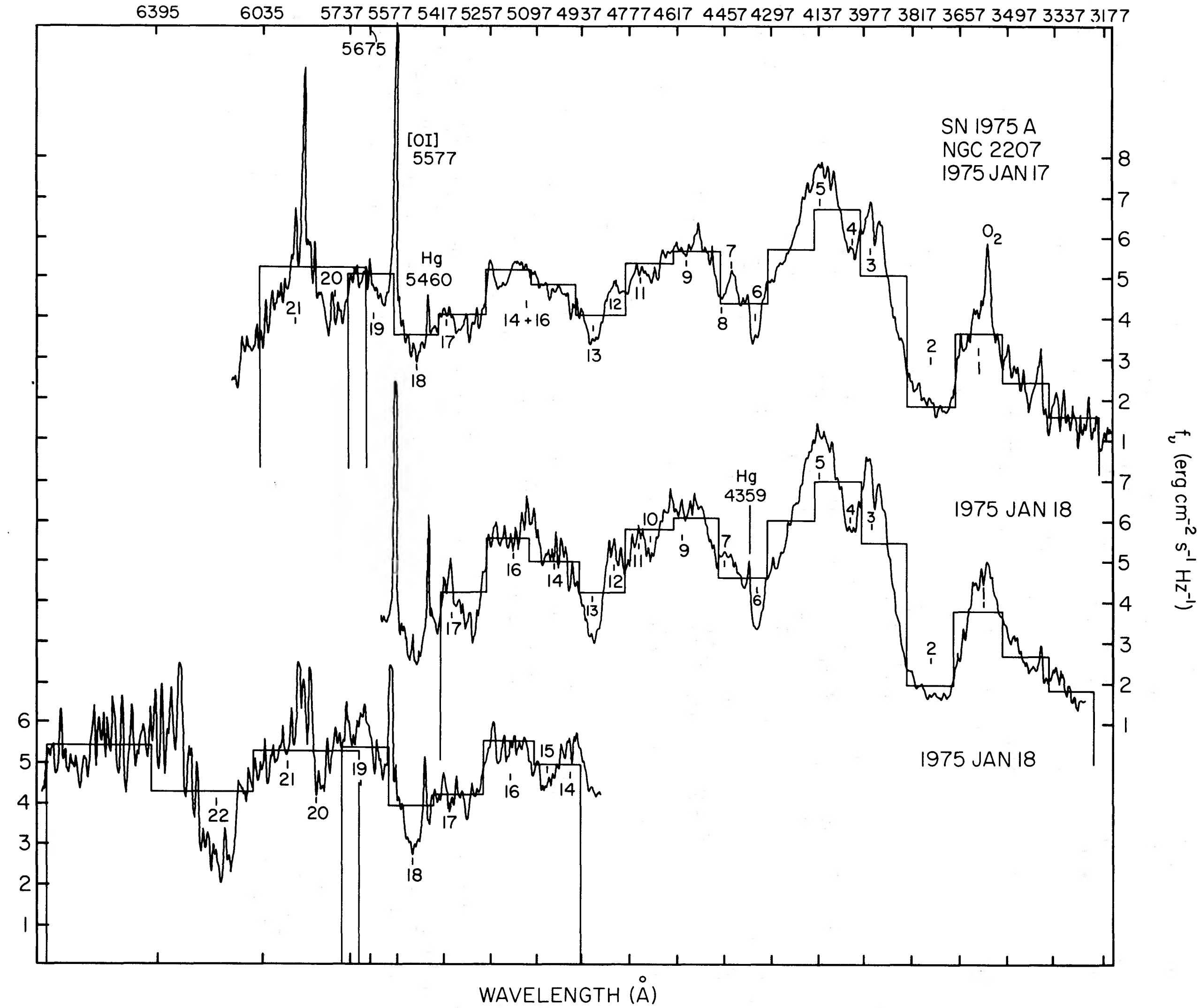

FIG. 4.—Spectroscopic observations of SN 1975a, placed on an absolute flux scale. Atmospheric emission has not been subtracted, but is marked. Numbers refer to measured wavelengths of Table 3. Solid line shows multichannel observations.

thin shells of absorbing material. Departures from symmetry would be unlikely to repeat from one supernova to the next, and cannot account for features such as 6 or 11 which are seen both in the supernova in NGC 4414 and in the present case. They may explain rapidly changing or unique features such as 7.

Thin shells of matter might be a natural outcome of the supernova explosion, but they must coexist with the very broad range of velocities seen in the Ca II lines: both feature 2 identified with H and K (Kirshner *et al.* 1973*a*), and the infrared triplet at λ8540 have similar profiles extending over 20,000 km s^{-1}. It may be possible to contrive density distributions in the expanding envelope so that it remains opaque in the strong resonance lines of Ca II over a wide velocity range while having only a narrow range in some weaker, and as yet unidentified, lines. This picture is unlikely, since the rapid expansion of the outer layers should cause the strong lines to narrow rapidly with time (see Mustel and Chugay 1975). This is not observed.

The proper explanation of the narrow features and their relation to the broad ones remains a puzzle.

III. SUPERNOVA 1975b

The supernova 1975b was discovered by Lovas (1975) at the Konkoly Observatory, Budapest, in an anonymous galaxy of the Perseus cluster at $\alpha = 3^h16^m.4$, $\delta = +41°27'$ (1950). The supernova, located 1″ east and 10″ north of the galaxy, was reported at photographic magnitude 15.5 on 1975 March 1.

On 1975 March 5, a spectrogram on baked IIIa-J emulsion was obtained with the image-tube spectrograph of the 4 m Mayall telescope at a dispersion

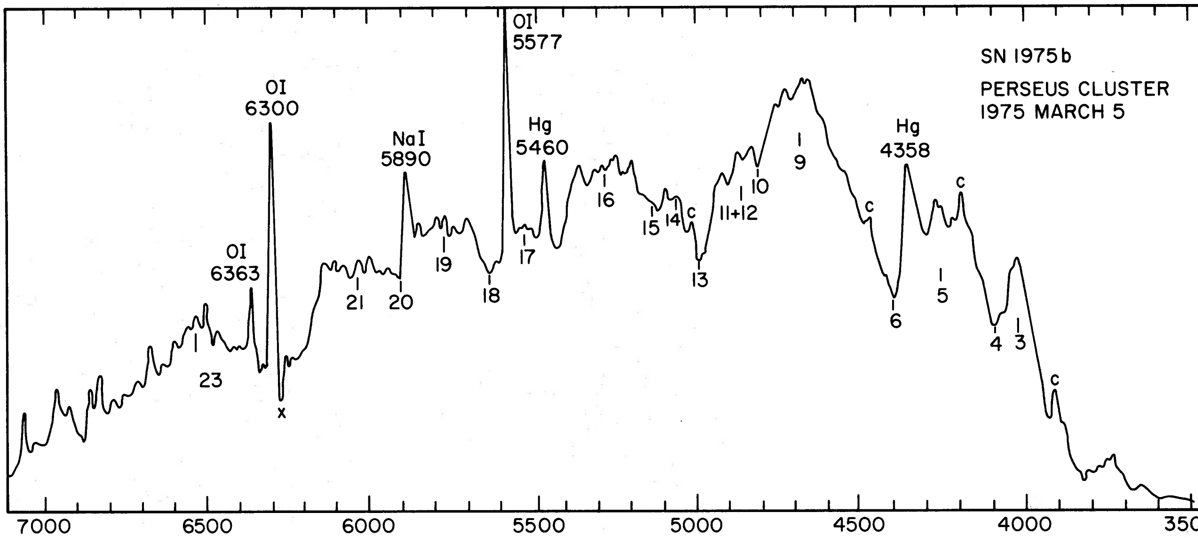

FIG. 5.—Intensity tracing of SN 1975b. Photographic effects have been removed, but the overall wavelength response of the spectrograph has not. Small "c" denotes comparison line which leaked across the spectrum. Missing feature with rest wavelength λ6115 should appear at λ6320, amid night-sky lines and emulsion defect (×).

of 200 Å mm^{-1}. A simultaneous sensitometer exposure provided the data to convert the photographic density, as measured in a 20 × 20 μ square with the Kitt Peak PDS microdensitometer, to the relative intensity plot shown in Figure 5. Unlike the data for supernova 1975a, no attempt has been made to reconcile these observations with an absolute flux scale. Due to an instrument malfunction, some comparison light fell across the spectrum: the spurious comparison features, as well as night-sky lines, are indicated on the figure.

The galaxy is one of those whose velocity is known from the work of Chincarini and Rood (1971) as $V_r \approx 8568$ km s^{-1} (galaxy 33). This should be compared to the mean velocity of the Perseus cluster of 5460 km s^{-1}. This galaxy makes a substantial contribution to the velocity dispersion of the cluster $\langle \Delta V^2 \rangle^{1/2} = 1420$ km s^{-1}, and is partly responsible for the cluster's large virial mass. Thus it is of more than passing interest to see whether this supernova can be used to decide whether galaxy 33 is truly a cluster member, or only a background galaxy.

As shown in Table 2, the wavelengths, corrected for the galaxy redshift, agree very well with those measured

TABLE 3

WAVELENGTHS IN SUPERNOVAE

Feature	Iye *et al.*	Observed Wavelength 1975a	Rest Wavelength 1975a	Rest Wavelength 1975b	Observed Wavelength 1975b
1 + ...	...	3575	3543	3547	3650
2 −	...	3748	3716	3712	3820
3 + ...	b	3948	3913	3912	4025
4 −	B	4010	3974	3980	4095
5 + ...	c	4122	4085	4130	4250
6 −	D	4333	4295	4275	4400
7 + ...	...	4430	4331	...	...
8 −	3	4450	4411	...	...
9 + ...	e_1, e_2	4580	4533	4558	4690
10 −	...	4695	4653	4679	4814
11 + ...	4	4735	4693 }	4728	4865
12 + ...	5	4820	4777 }		
13 −	E	4890	4847	4854	4995
14 + ...	f	5000	4956	4932	5075
15 −	F	5050	5005	4973	5117
16 + ...	g_1, g_2	5172	5126	5122	5270
17 + ...	h	5390	5342	5374	5530
18 −	H	5500	5451	5474	5633
19 + ...	i	5668	5617	5608	5770
20 −	I	5810	5759	5744	5910
21 + ...	j_1	5928	5876	5865	6035
22 −	J_1	6170	6115	...	...
23 + ...	...	...	...	6336	6520

TABLE 4

FLUXES FROM WN 1975a

1975 JANUARY 17			1975 JANUARY 20					
λ	Band	F_ν*	λ	Band	F_ν	λ	Band	F_ν
3257	160	1.64	3238	80	2.09	5876	160	5.45
3417	160	2.44	3318	80	2.20	6036	160	5.81
3577	160	3.66	3398	80	2.68	6196	160	3.23
3737	160	1.81	3478	80	3.49	6356	160	6.51
3897	160	5.05	3558	80	4.96	6516	160	6.07
4057	160	6.61	3638	80	3.27	6676	160	5.08
4217	160	5.64	3718	80	1.99	6836	160	3.41
4377	160	4.24	3798	80	2.29	6996	160	3.96
4537	160	5.59	3878	80	5.33	7156	160	3.92
4697	160	5.26	3958	80	7.00	7316	160	3.60
4857	160	4.02	4038	80	6.82	7476	160	2.68
5017	160	4.68	4118	80	8.63	7636	160	2.95
5177	160	5.03	4198	80	7.66	7956	160	3.32
5237	160	3.92	4278	80	5.96	8116	160	2.63
5487	160	3.42	4358	80	4.75	8276	160	2.40
5657	160	4.90	4438	80	5.72	8436	160	3.74
5855	360	5.04	4518	80	6.99	8596	160	4.92
6215	360	3.69	4598	80	7.33	8756	160	5.53
6575	360	5.12	4678	80	6.20	8916	160	3.76
6935	360	4.05	4758	80	5.59	9076	160	3.82
7295	360	3.85	4838	80	5.12	9396	160	5.18
7655	360	3.16	4918	80	4.17			
8015	360	2.39	4998	80	5.26			
8375	360	2.83	5078	80	5.87	9876	160	2.58
8735	360	4.97	5158	80	6.72	10036	160	2.54
9095	360	3.57	5238	80	6.37	10196	160	2.06
9455	360	4.44	5318	80	4.58	10356	160	2.43
9815	360	2.41	5398	80	4.96	10516	160	2.16
10175	360	2.46	5478	80	4.31			
10535	360	2.17	5558	80	5.37			
			5638	80	6.35			
			5718	80	6.29			

* 10^{-26} ergs cm^{-2} s^{-1} Hz^{-1}.

for supernova 1975a. From the wavelength agreement, the supernova is undoubtedly of Type I, and probably less than 10 days past maximum light. The only unusual feature is the absence of a clearly defined absorption at λ6115. This feature, redshifted to λ6320, is confused by night-sky emission and an emulsion defect. It is difficult to say whether it should have been seen.

Two peculiar Type I supernovae are known which do not show the λ6115 feature (Bertola 1964; Bertola, Mammano, and Perinotto 1965), and which do not exhibit the usual redward drift of emission wavelengths. The existence of this class of object, which in the case of Bertola (1964) has a very well observed and typical Type I supernova light curve, but does not show the shift of the peaks to the red, requires that the explanation of the line shifts and the photometric behavior must be in some sense separate. We can either conclude that the present supernova is a normal Type I supernova with the λ6115 feature obscured, or another member of this peculiar class. In either case, the absolute magnitude at maximum should have been $M_B = -19.9$.

If we assume that the supernova was discovered *at* maximum light, we can estimate an upper limit to the distance. Using $m_{pg} = 15.5$ and an absorption of $A_B = 0.4$ based on the colors of NGC 1275 (Sandage 1972), we find a value of $m - M \approx 35.0$. This should be compared to $m - M = 35.0$ for the Perseus cluster and $m - M = 35.9$ for a galaxy at $v_r = 8500$ km s^{-1}. If the supernova were intrinsically fainter at the time of observation, the galaxy would have to be even nearer.

The most likely interpretation is that supernova 1975b was a normal Type I supernova near maximum at the time of observation, and at the distance of the Perseus cluster.

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