Title
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Publication Date
1988-05-01

LBL-25262
Preprint

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UNIVERSITY OF CALIFORNIA

Physics Division

Submitted to the Astronomical Journal

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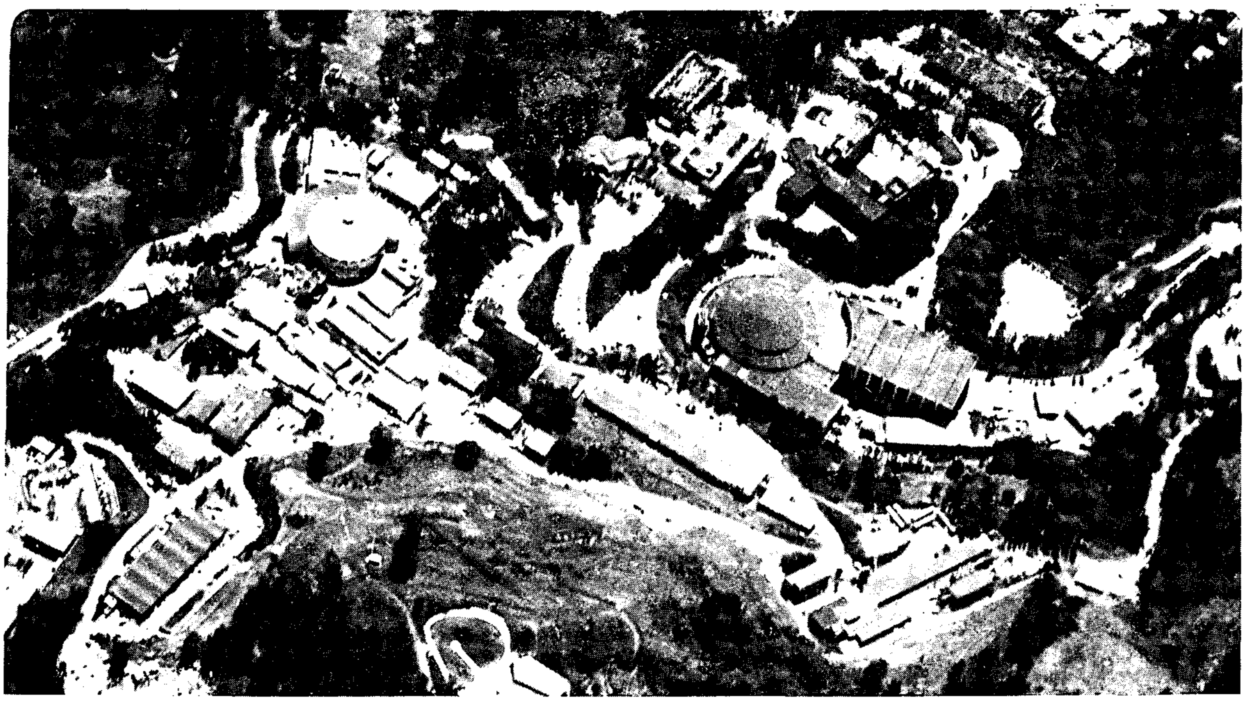
May 1988



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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Submitted to *Astronomical Journal*

Abstract

We report spectroscopic and photometric results on a supernova in M99, SN1986I, from first detection to several months after the explosion. This supernova is distinct from other supernovæ (except possibly SN1987A in the LMC) in that it exhibits strong Hα emission in the early spectra, less than 10 days after it exploded. The spectra also show an ultraviolet deficit below the blackbody extrapolated from longer wavelengths. The light curves in V, R, and I dropped slowly during the first few months after detection, resembling a Type II "plateau" supernova, and dropped precipitously near 200 days past maximum. We have also measured the wavelengths and velocities of the stronger emission and absorption features, with tentative identifications.

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I. Introduction

On May 17, 1986 (UT), an m_V ~14 magnitude supernova was discovered at Leuschner Observatory as part of a systematic search by the Berkeley Automated Supernova Search team (the search is described in Kare, et al, 1988). It was known from a search image taken May 8.3 (UT) that the supernova was younger than nine days. Follow-up spectra obtained on May 20, with the Cryogenic Camera on the KPNO 4-meter telescope showed broad hydrogen (Hα) emission; hence this was a Type II supernova. Spectroscopic and photometric observations at other observatories were arranged, which spanned the period from the explosion to nine months later. This paper reports the early photometric and spectroscopic results. Later papers will report analysis and interpretation of these data, and second epoch results.

II. Photometry

Search data from May 8.3 showed no object brighter than about m_V ~ 16.6 (95% confidence level) at the supernova's position, and the supernova was first recorded on May 17.3, 1986 UT. The brightness of SN1986I was measured by comparing it to stars in the same CCD field. After the photometric suitability of stars in the same CCD frame was established, one star located ~68" E and ~40" S of the supernova was chosen as the standard of comparison, and calibrated against a standard star (UBVRI standard star #4752, *Astronomical Almanac*, 1985, a type A0p) under photometric conditions at the same air mass. Photometric observations were made over the period from the discovery date until the supernova was inaccessible behind the sun. Our present CCD has little blue sensitivity, so we did not obtain blue light curves.

Since the supernova search uses the broad-band wavelength response of the CCD, the initial photometric datum was obtained as a broad band "CCD magnitude", which is a mixture of V,R, and I magnitudes. The light curve in Figure 1a includes the pre-discovery and discovery data. Subsequent measurements were made using this broad-band magnitude in addition to the normal bandpasses, for consistency. The "CCD magnitude", like others, was normalized to A0 stars.

The CCD magnitude light curve brightened at least three magnitudes to 13.8±0.06 in less than 10 days, reached a maximum of 13.7 a week or two later, and then gradually faded at 0.003±0.001 magnitude per day for the next few months. By six months after discovery, SN1986I had dimmed by two magnitudes; it dropped ~1.5 magnitudes below a linear extrapolation of the light curve at early times. The brightness of the supernova in the later epoch was 15.89 magnitude at 200 days after discovery.

The V-magnitude light curve rose to 14.2±0.2 magnitude, and then dimmed at an average rate of 0.01 ±0.003 magnitude per day during the first 100 days. By day 200 the supernova dropped about two magnitudes compared to the discovery brightness, very roughly at the same time (within our sampling window) the observed CCD magnitude dropped. The visual light curve dropped 1.5 mag. below the light curve linearly extrapolated from the early rate.

The R and I light curves rose to 14.5±0.06 and 14.0±0.09 magnitudes, respectively, and then exhibited more gradual declines (rates of ~1/4 of the visual light curves) of 0.0028±0.009 and 0.0022±0.0018 magnitudes per day after observed maximum light. The late-time photometric points for R and I magnitudes are about 1.5 -- 2 magnitudes below the curves extrapolated from the earlier data.

III. Spectra

A) The Continuum

The spectra in Fig. 2 and Table 2 show the evolution of the supernova from ~ 10 - 60 days after explosion . During this interval the spectra can be approximately characterized as a thermal continuum upon which are superimposed a number of P Cygni profiles. If these spectra are heavily smoothed, one concludes that the lines (with the exception of the feature at 6560Å) merely redistribute the flux and make an insignificant contribution to the net flux. Hence, during this phase of the supernova evolution, the continuum carries nearly all of the radiant energy . The spectra blueward of 4000Å indicate that there is an ultraviolet flux deficit compared to a blackbody which fits the longer wavelength data. In another study of supernovæ, Kirshner et al. (1973) note that the blackbody which best fits the flux between 5000Å and 10,000Å is generally too bright in the UV. A UV deficit is reminiscent of Type I supernovae (Wheeler, Harkness, and Swartz, 1986). This UV deficit was also seen in the LMC (SN1987A) supernova (see, e.g., Wheeler, Harkness, and Barkat 1988). Many Type II supernovæ show a UV excess which may be indicative of an extended envelope or circumstellar shell.

SN1986I was observed by one of us (G.B.) on May 25 UT at the Lick 3 meter telescope with the Hamilton echelle spectrograph using a resolution of ~0.1 Å a. Three components of interstellar Na I D λ5889 Å lines were observed at velocities of 2367, 2395, and 2502 km/sec, with respective equivalent widths of 0.15, 0.10, and 0.15Å (uncertainty of 0.04Å); for comparison, the systematic velocity of M99 is listed as 2413 kilometers per second by Sandage and Tammann (1981). The total equivalent width of the Na I D lines is 0.8 ± 0.1Å, which corresponds to a reddening within M99 of E(B-V) = 0.09±0.1 mag. (c.f. Penston and Blades, 1980). The Galactic reddening towards M99 (de Vaucouleurs et al.,1976) is E(B-V) = 0.045 (assuming R = 3.1), and so we estimate that the total reddening to the supernova is E(B-V) = 0.14, and the total visual extinction is $A_V = 0.42$ mag.

B) Hydrogen Lines

The hydrogen Balmer lines Hα, Hβ, Hγ, and possibly Hδ are present in the spectra. Hα is strong even in the first spectrum, less than 12 days from the explosion date, and shows clear P Cygni structure with an absorption minimum at -11,400 km/s, with repect to the rest frame of M99. The emission to the red of the absorption line center indicates material expanding at a velocity of +12,000 km/s. The Hα features evolves significantly during the period of our observations; as the supernova ages the Hα feature becomes more prominent and the absorption shift to the blue drops to 4700 km/s on 6 July. The maximum equivalent width of Hα is 120Å; it was recorded around 7 June. On this date the ratio of the equivalent widths of the absorption to emission was ~1/4. By 6 July the equivalent width of the Hα emission had fallen to 70Å, and the ratio of absorption to emission was ~1/2.

It is difficult to establish the location of the continuum near Hβ, and therefore to measure its equivalent width as well. Nevertheless it is clear that any Hβ emission is significantly weaker than the Hα emission, although in early June the depth of Hβ is comparable to Hα. The velocity derived from the minimum of the Hβ absorption tracks that derived from Hα, but the velocity remains ~1000 km/s lower; Hβ is formed deeper within the ejecta because its optical depth is lower.

The absorption which one would naively attribute to Hγ is probably blended with other lines, (most likely Fe II), that became increasingly strong, since the velocity derived from identification with Hγ does not compare well with the velocities derived from Hα and Hβ.

C) Tentative Identifications of Other Lines

The absorption minimum at 3850Å, the most prominent non-hydrogen feature, is consistent with the CaII λλ3934,3968 resonance doublet (Kirshner et al. 1973). The May 20 spectrum shows that the IR CaII triplet λ8600Å is not present. Since the strength of these two CaII lines should be comparable, CaII λλ 3934,3968 must have developed between May 20 and June 5, presumably reflecting a rapid change in the ionization state during this interval. Unfortunately, none of our later spectra recorded the subsequent development of the infrared triplet. The July 6 spectrum shows very marginal evidence for CaII λλ7291+7323; however, a continuum is clearly present on this date, and the supernova is still too young to show distinct forbidden line emission.

Another resonance line, Na I D λ5890, is a likely identification for the 5700Å absorption. The structure of the absorption in the early June spectra is unlike the other P Cygni profiles. This may simply be because the line is broader; the Na I D line profile implies a velocity 2000 km/s greater than the velocities from any of the other identifications considered here. We do not understand this difference.

Less confident identifications have been made for most of the remaining lines by attributing them to FeII; specifically FeII λ4352 (blended with Hγ), 4583, 5018, 5215, and 5581. Identifications have been guided by the FeII lines identified in the type I supernova 1981b by Branch et al. (1983).

The velocity evolution shows appartently linear behavior -- subsequent data shows a departure from this behavior. A more detailed analysis of the hydrogen lines and the distance to this supernova using the Baade method are presented elsewhere (Perlmutter et al., 1988).

D) Formation of Hα emission.

The large net emission often seen in the Hα line is a persistent problem to those who study the atmospheres of type II supernovae, and SN1986I is no exception. One can easily show that the rate of mass (m) flowing through the photosphere at time t is given by

$$\frac{dm}{dt} = 8\pi(1-n)\, v_p \frac{dv_p}{dt} \frac{t^2}{3k},$$

where n is the index of the assumed power-law density distribution, v_p is the photospheric velocity, and k is the opacity, here set to be 0.4 cm^2/gm (probably somewhat too large a value because of non-hydrogenic contributions to the opacity, but not large enought to affect the following argument). If we assume that the Hα emission feature is due to the recombination of H ions flowing through the photosphere, then we can calculate the expected Hα luminosity. (This is a plausible assumption since the photospheric temperature corresponds roughly to the temperature at which H recombines.) With typical numbers for this explosion, we calculate $\sim 10^{49}$ atoms per second flow through the photosphere, whereas there are $\sim 10^{52}$ Hα photons per second arising in the envelope. This indicates that an additional source of ionization or excitation is required. Perhaps a substantial population is maintained in the n = 2 level by some mechanism (such as Lyman α trapping), so that the radiation field from the photosphere can cause ionization. Another possibility is the direct excitation of n=3 by electron collisions (Kirshner et al. 1973, Branch et al. 1981).

IV. Comparison with other Supernovæ

SN1986I resembles SN1969L (Ciatti, et al. 1971) photometrically, and shows some of the same lines. Photometrically SN1969L evolved a little more rapidly. The V magnitude plateau of SN1986I either lasted ~ 40 days longer, or the decline from the plateau was less precipitious. Both spectra exhibit clear P Cygni Hα profiles a few weeks after detection (unlike SN1979C for example). However, the Hα emission early on in the spectra of SN1986I is markedly different from that in SN1969L SN1987A does show the early strong Hα feature, and the comparison between these two supernovæ might be more appropriate in some ways.

SN1986I also resembles SN1969L in the velocities derived from the spectra. The Hα velocity near maximum light in SN1969L is 12, 000 km/s declining to 7,000 after 50 days (Ciatti et al. 1971). Given this similarity it is interesting to speculate whether the presence of an Hα P Cygni absorption is correlated with this photometric class of the SN. Both SN1969L and SN1986I are plateau type whereas SN1979C is a linear type.

The differences between SN1986I and others indicate the importance of discovering more supernovæ and acquiring frequent spectra, from pre-maximum through the nebular phase. The early strong Hα feature distinguishes this from others, except for SN1987A. Future work will help us understand the underlying physics of the explosion.

Acknowledgements:

This work has been partially supported under Dept. of Energy contract DEAC03-76F000098.

References

Branch, D., Falk, S. W., McCall, M. L., Rybski, P., Uomoto, A. K., & Wills, B. J.. 1981, *Ap. J.*, 244, 780.
Branch, D., Submitted to *Ap. J. Letters*, May 14, 1987.
Ciatti, F., Rosino, L., & Bertola, F. 1971, *Mem,.Soc. Astr. Italia*, 42, 163.
Kare, J., et al. To Be Published, *Reviews of Scientific Instruments.*,1988.
Kirshner, R. P., Oke, J. B., Penston, M. V., & Searle, L. 1973, *Ap. J.* 185, 303.
Penston, M.V. and Blades, J.C., 1980, *M.N.R.A.S.*, **190**, p51.
Perlmutter, S., et al., submitted to *ApJ. Letters*, 1988.
Sandage, A.,and Tammann, G.A., 1981*A REvised Shapley-Ames Catalog of Bright Galaxies,* (Washington, Carnegie Institution of Washington).
Wheeler, J. C., Harkness, R. P., Swartz, D., 1986, *PASP,* **98,** p1018.
Wheeler, J.C., Harkness, R.P., and Barkat, Z., 1988, *IAU Colloquiom 108,* in press.
De Vaucoulers, G. 1976, *Ap.J.*, 205, 13.

Figure Captions

Figure 1(a-d): Light curves of SN1986I. The supernova was calibrated against the standard star 4752. "CCD magnitude" is a non-standard, unfiltered response of the CCD, and is a weighted sum of V,R, and I photometric bands. The lines are fit to the early data (hollow points), and the data points noted with the solid symbol are not included in the linear fit.

Figure 2: Representative spectra of SN1986I, with identification of absorption minima (for the earlier spectra) of $H\alpha$ and $H\beta$. The spectra for the various dates have been multiplied by the number printed below the date, and then plotted. For example, to find the measured flux from the May 20th data, read the flux from the ordinate and divide by 1000.

Figure 3(a-b): Gas velocities determined from $H\alpha$ and $H\beta$. Other lines exhibit similar velocity evolution.

Table Captions

Table 1: Measured magnitudes of SN1986I for "CCD" (see section II), V,R, and I magnitudes.

Table 2: Observing Log of Spectra taken of supernova 1986I in M99.

Table 3: Absorption minima and emission maxima; tentative identifications of strong spectral features.

	date (UT)	epoch (days)	CCD(mag)	V(mag)	R(mag)	I(mag)
1	5/8/86	8.	>15.6			
2	5/17/86	17.	13.88			
3	5/20/86	20.	13.88			
4	5/24/86	24		13.00	14.52	14.01
5	5/25/86	25	13.72			
6	5/26/86	26	13.82			
7	5/27/86	27	13.66			
8	5/28/86	28	13.72			
9	5/29/86	29	13.88	14.47	14.57	14.14
10	5/30/86	30	13.74	14.28	14.57	14.11
11	6/4/86	35	13.64	14.45	14.57	14.14
12	6/9/86	40	13.93	14.42	14.65	13.98
13	6/10/86	41	13.90	14.50	14.60	13.96
14	6/13/86	44	13.93			
15	6/17/86	48		14.53	14.65	14.01
16	6/20/86	51	13.85	14.56		13.96
17	6/29/86	60	13.96	14.64	14.70	
18	7/3/86	64	13.82	14.50	14.76	14.01
19	7/7/86	68.	13.77	14.42	14.65	14.14
20	7/9/86	70.	13.88	14.56	14.62	14.11
21	7/17/86	78.	13.99	15.15	14.81	14.25
22	7/20/86	81	14.09	14.81	14.88	
23	7/31/86	92.	13.74	14.68		
24	8/3/86	95		14.64		13.96
25	8/5/86	97.	13.96	14.93	14.60	14.01
26	8/11/86	103.	14.28	14.64		14.55
27	10/25/86	178	15.62	15.93	16.40	16.25
28	11/12/86	196	16.00	16.88	16.61	16.00
31	11/30/86	214	16.04	16.89		16.21
32	12/7/86	221	15.99	17.07	16.73	16.21

Table 1: Light Curve Data

Table 2:

Records of Spectra of SN 1986I in M99

Observ. UT Date	Band [Å]	Resolution [Å]			Observer
			Instrument	Telescope	
20 May	6041-9463	12-15	Cryogenic Camera	4m Kitt Peak	Junkkarinen
27 May	6139-7485	≈6	IIDS	2.1m Kitt Pk	Kennicutt
5 June	3591-6603	≈10	IDS Spectrometer	2.7m McDonald	Wills
7 June	4041-7225	≈4	Schmidt Spectrograph	3m Lick	Spinrad
9 June	3200-7600	≈4	MMT Spectrograph	MMT	Foltz
30 June	4056-5723	1.3 - 8	CCD Spectrograph	1m Lick	Bixler
6 July	3200-7600	≈4	MMT Spectrograph	MMT	Foltz

Table 3: 1986I Rest Wavelengths

Date	Epoch	Feature	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
		Tentative I.D.'s	Ca II 3933	$H\gamma$ 4340	Fe II 4583	$H\beta$ 4861	Fe II 5018	Fe II 4924	Fe II 5215	Na I 5889	Fe II 5581	$H\alpha$ 6563
May 20	20	Min:*										6313
		Max:										6530
May 27	27	Min:										6339
		Max:										
June 5	36	Min:	3844	4221	4444	4737	4908		5056	5693		6380
		Max:	3949	4399	4576	4859	4961		5152			
June 7	38	Min:		4227	4447	4732	4918		5064	5687		6373
		Max:		4388	4586	4853	4972		5150			6522
June 6/9	38.5	Min:	3851	4222	4460	4746	4925		5071	5691		6380
		Max:	3953	4338	4587	4870	4971		5157			6522
June 30	61	Min:		4235	4483	4797	4954	4866	5102		5458	
		Max:		4297		4828	5012	4903	5186		5516	
July 6	67	Min:	3863	4252	4497	4804	4963	4868	5112	5827	5474	6459
		Max:	3950	4307		4837	5015	4913	5189	5884	5519	6537

*Absorption Minimum and Emission Maximum

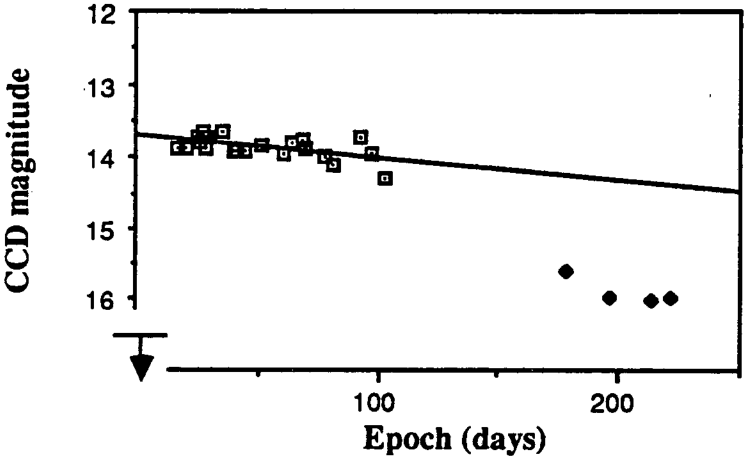

Fig. 1a: CCD Light Curve

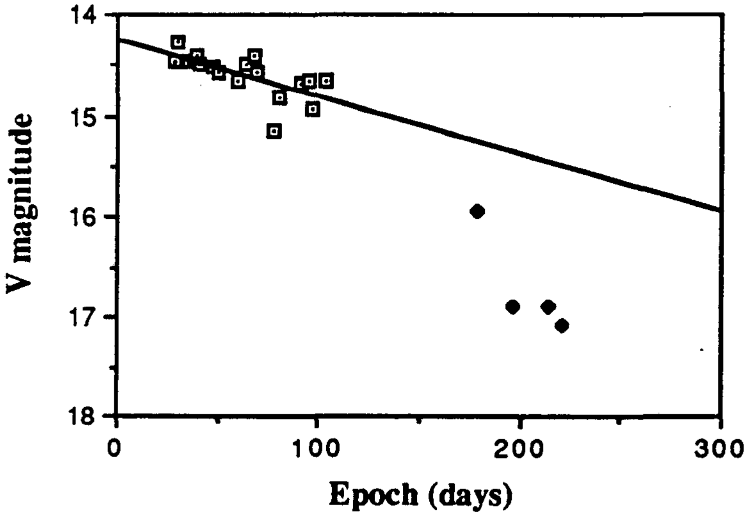

Fig. 1b: V Light Curve

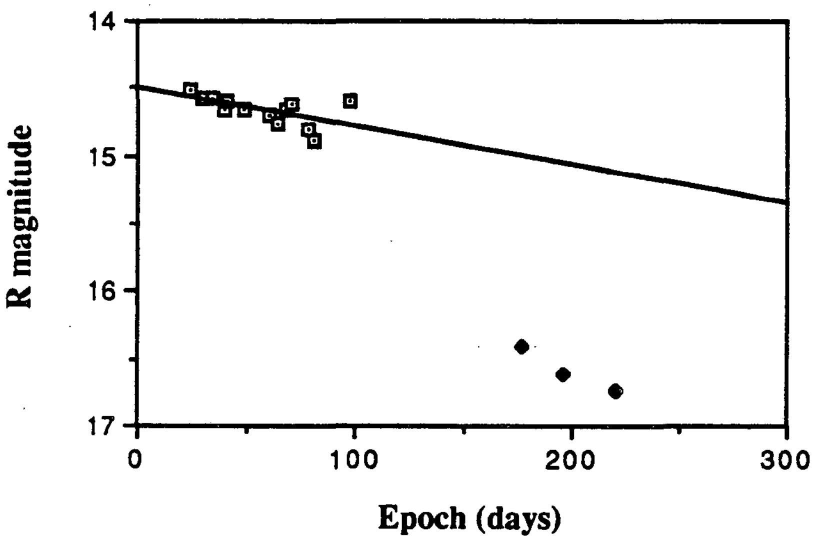

Fig. 1c: R Light Curve

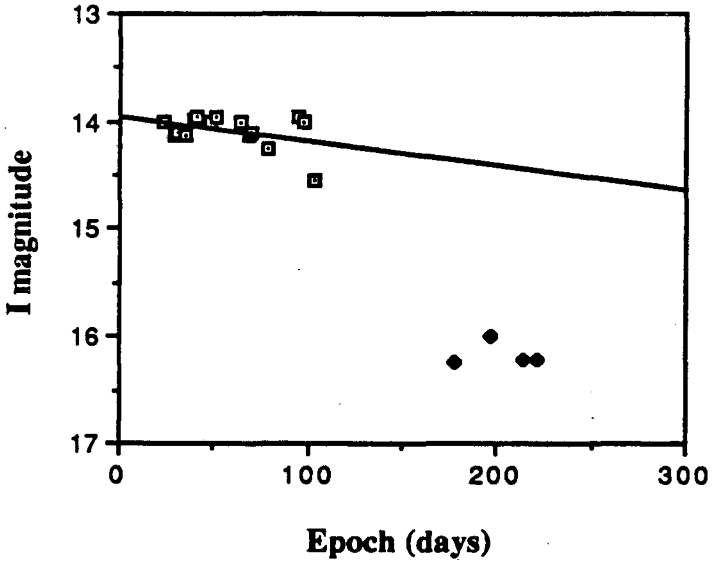

Fig. 1d: I Light Curve

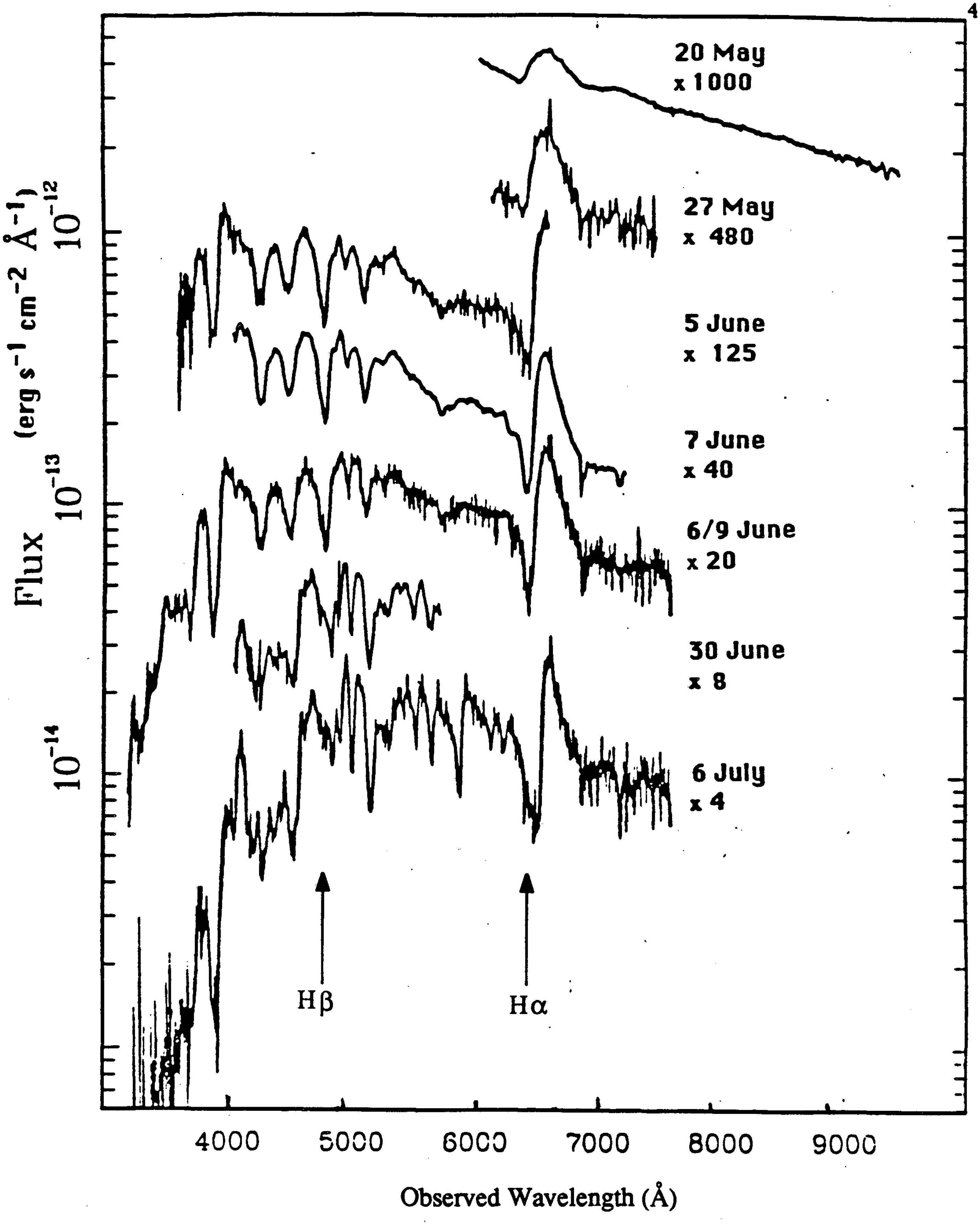

Figure 2
Spectra of SN 1986I

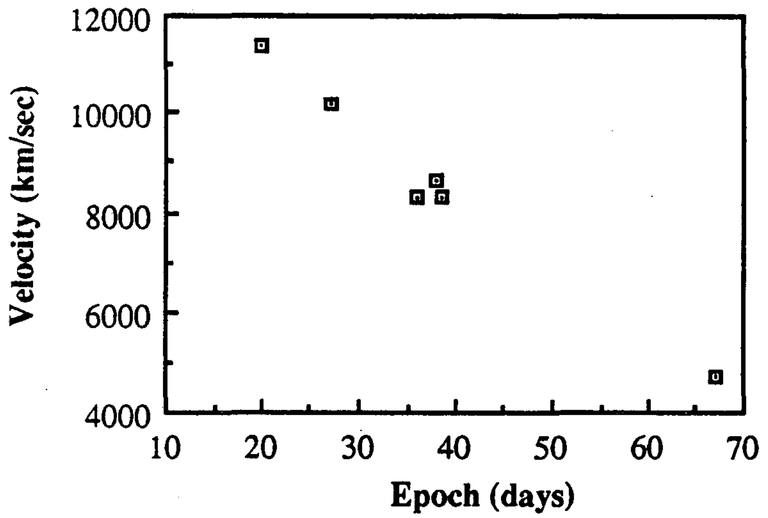

Fig. 3a: Velocity of H αLine

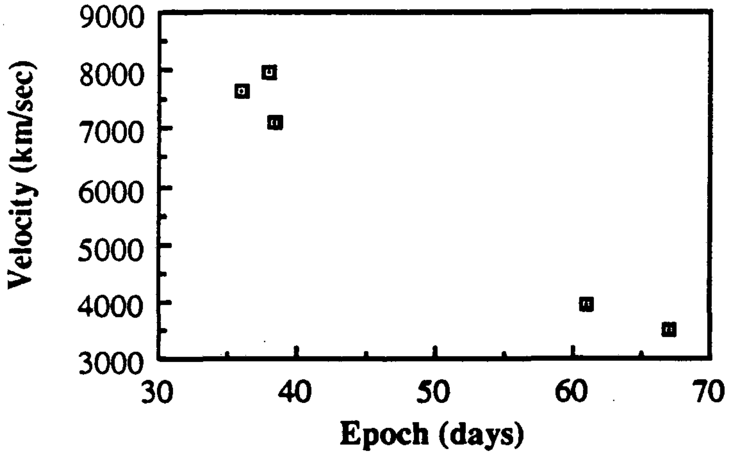

Fig. 3b: Velocity of H βLine

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