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MULTICOLOR PHOTOELECTRIC PHOTOMETRY OF SN 1993J

We present $UBV(RI)_c$ photometry of supernova 1993J which erupted in the spiral galaxy M81 (NGC 3031) during late March 1993. The supernova was discovered on 28 March 1993 by Francisco Garcia during the star's initial rapid rise (Garcia *et al.*, 1993). This was the brightest supernova in the northern hemisphere in about 40 years and because of its brightness ($m_{v(max)} \simeq +10.3$) and high declination of +69°, SN 1993J has been extensively observed with ground based instruments and orbiting satellites over a wide range of wavelengths. Thus, SN 1993J has joined SN 1987A as one of the most extensively observed supernovae.

Table 1

HJD (2449000+)	U	B	V	R_c	I_c
79.6292	+11.02	+11.69	+11.42	+11.26	+10.87
80.6343	+11.42	+11.95	+11.63	+11.30	+10.99
81.6344	+11.67	+12.18	+11.82	+11.43	+11.14
82.6353	+11.79	+12.23	+11.84	+11.44	+11.17
84.6339	+11.77	+12.17	+11.69	+11.32	+11.09
86.6368	+11.71	+11.94	+11.50	+11.11	+10.96
88.6377	+11.54	+11.72	+11.28	+10.92	+10.80
93.6400	+11.33	+11.40	+10.89	+10.57	+10.53
94.6448	+11.36	+11.40	+10.86	+10.53	+10.50
96.6366	+11.48	+11.47	+10.86	+10.52	+10.46
97.6371	+11.60	+11.53	+10.89	+10.54	+10.48
101.6337	+12.41	+12.08	+11.19	+10.72	+10.56
102.6342	+12.64	+12.24	+11.28	+10.79	+10.64
103.6348	+12.76	+12.37	+11.37	+10.85	+10.67
105.6358	+13.08	+12.61	+11.54	+10.97	+10.77
106.6354	+13.33	+12.73	+11.61	+11.02	+10.80
107.6329	+13.45	+12.86	+11.68	+11.07	+10.86
109.6330	+13.47	+13.00	+11.82	+11.16	+10.93
110.6335	+13.81	+13.19	+11.91	+11.25	+10.95
111.6350	+13.61	+13.10	+11.91	+11.23	+10.97
112.6346	+13.91:	+13.15	+11.91	+11.27	+10.95
113.6352	+13.60:	+13.19	+12.00	+11.32	+11.02
114.6358	+13.86:	+13.14	+12.00	+11.29	+11.10
115.6363	+14.04:	+13.27	+12.09	+11.44	+11.17
116.6368	+13.96:	+13.31	+12.12	+11.51	+11.26
117.6375	+13.82:	+13.34	+12.15	+11.49	+11.27
118.6388	+13.95:	+13.34	+12.17	+11.49	+11.15
120.6400	+14.21:	+13.43	+12.21	+11.51	+11.12
121.6406	+14.28:	+13.37	+12.23	+11.53	+11.17

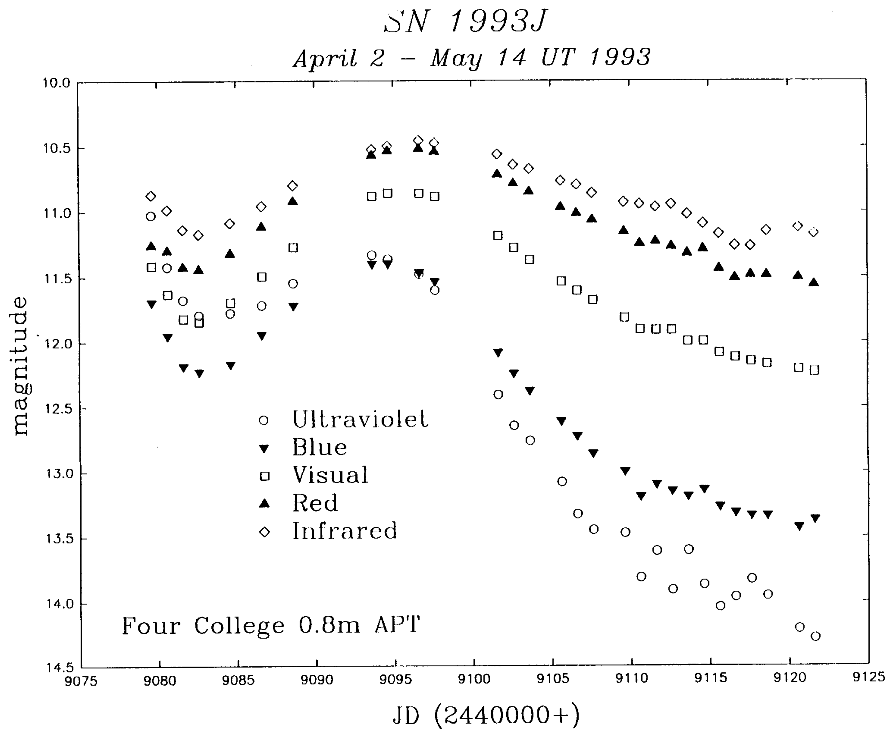

Figure 1. A plot of our data from Table 1.

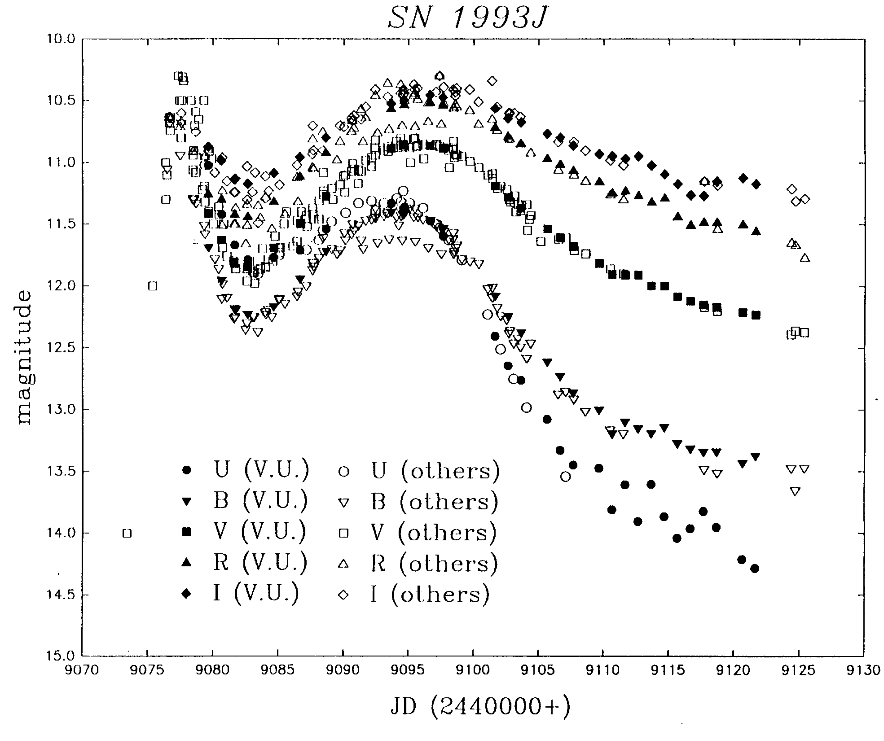

Figure 2. A plot of all the data collected from the literature, including our own observations, to create a single light curve of SN 1993J in the $UBV(RI)_c$ bandpasses.

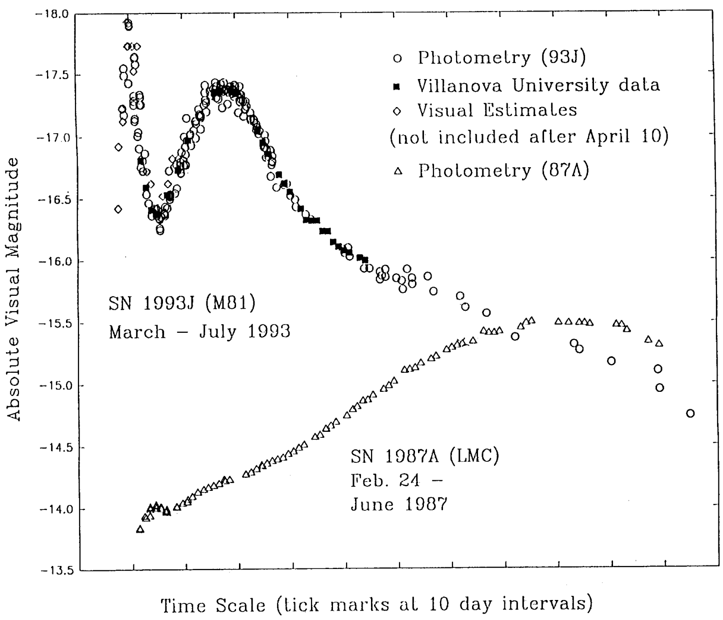

Figure 3. A plot comparing SN 1993J and SN 1987A by plotting the absolute visual magnitude vs. time using the same time scale for both objects. A distance modulus of 27.8 mag and an intermediate value for interstellar absorption, $A_v \simeq 0.5$ mag (see Richmond *et al.*, 1994) were used for calculating the absolute magnitude of SN 1993J. For SN 1987A, a distance modulus of 18.5 mag and an A_v of 0.25 mag (see Menzies *et al.*, 1987) were used. SN 1993J's light curve developed much more rapidly than SN 1987A's light curve. Also, SN 1993J was about 2 magnitudes brighter in absolute magnitude than SN 1987A at their respective peaks.

We carried out $UBV(RI)_c$ photoelectric photometry from early April through May 1993 using the Four College Consortium 0.8m Automatic Photoelectric Telescope (FCC 0.8m APT) located at Mt. Hopkins, AZ. Differential photometry was conducted through a 40 arcsec diaphragm using the following comparison stars: HD 85458 (F5, V = +8.7, B−V = +0.5), HD 86677 (F5, V = +7.876, B−V = +0.510); and HD 85828 (K0, V = +8.0, B−V = +1.0) served as a check star. Because of the faintness of the supernova, blind offsets were made to the position of the supernova. The supernova was observed using the usual pattern of *sky - comparison - check - variable - comparison - sky* with an integration time of 20 seconds. The data were reduced using software developed at Villanova University by G.P. McCook. The details of the reduction procedure have been described elsewhere by Guinan *et al.* (1987). The data were then transformed to the $UBV(RI)_c$ system and corrections were made to account for the effect of fainter stars included in the aperture with the supernova as it faded. In order to fully correct for stars included in the diaphragm with the supernova, we observed the same field one year later, after the supernova had faded below the telescope's limiting magnitude, to measure the background light directly. We computed nightly means from the individual measures of SN 1993J and these values are tabulated in Table 1 and a plot of our observations vs. Heliocentric Julian Day number is given in Figure 1. The estimated errors of the observations in the $BV(RI)_c$ are on the order of 0.01–0.02 magnitudes; the scatter in the U observations was similar until the star rapidly faded in this bandpass and the errors became large. We included these U-band measures in Table 1 with colons after the magnitude values.

We also collected all the available visual and photometric measurements of SN 1993J from the *IAU Circulars*, those published in the literature, and other sources through the end of 1994. Extensive compilations of optical photometry of SN 1993J are given by Lewis *et al.* (1994) and Richmond *et al.* (1994). After removing some obviously inaccurate measures, these data are included in Figure 2 along with our own observations. A comparison of the absolute visual magnitudes of SN 1993J is made to the LMC supernova SN 1987A in Figure 3 where both stars are plotted on the same magnitude and time scales.

The rapid expansion of the progenitor star's interior and the interaction of this shock front with its envelope and photosphere caused the initial rapid rise of SN 1993J to a peak magnitude of V = +10.3. The first decline in brightness occurred in early April 1993, dropping to V = +11.9, as the thin envelope of the star lost heat from the shock wave. During mid-April there was a second increase in brightness to V = +10.5; this time the increase was powered by the energy released by the decays of radioactive cobalt into nickel and iron. As the energy from these short-lived decay products decreased, the star slowly dimmed and cooled. By December 1993, the supernova's magnitude had decreased to approximately V = +17.

The progenitor of SN 1993J has been identified as a late G or early K supergiant (Aldering, Humphreys, Richmond, 1994) with $V_{mag} \simeq +20.75$. The progenitor appears to be a member of a binary or multiple star system having fainter nearby blue components. The spectroscopic and photometric behavior of SN 1993J indicate that the progenitor star had its hydrogen envelope partially stripped away by strong winds, or more likely, by a close binary companion. Possible analogs of SN 1993J could be ζ Aurigae systems which are composed of K-supergiant components and early B-main sequence companions.

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