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UBVRI Photometry and Polarimetry of SN 1993J in the Galaxy M 81

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Abstract – *UBVRI* photometric and polarimetric observations of SN 1993J in M 81, conducted with the 125-cm telescope at the Crimean Astrophysical Observatory and with the 60-cm telescope at the Crimean Station of the Sternberg Astronomical Institute within 206 days after the time of explosion, are presented. The *U–B* and *B–V* color variations between April and June 1993 are shown to be mainly associated with temperature variations in the envelope. Emission lines also affect the color variations, although to a lesser degree. Over the period from the end of April till June 1993, these lines had the strongest effect on the *V–I* or *R–I* colors. An abrupt reversal of the decrease in the color indices 40 days after the explosion can be explained by a substantial increase in the transparency of the envelope. The frequency dependence of the envelope optical depth along with the temperature drop cause the secondary maximum to be delayed with increasing wavelength. A polarization of ~0.6% in *V* was detected near the secondary maximum. The shape of the wavelength dependence of the degree of polarization changed with time. These changes suggest that it is most likely initially, the polarization arose from light scattering in an asymmetric nonuniform envelope produced by the explosion, and, subsequently, on the 40th - 50th day after the explosion, it could have resulted from the scattering of the supernova light in the circumstellar medium.

INTRODUCTION

SN 1993J, one of the brightest supernovae in the northern sky, was discovered on March 28, 1993 in the fairly nearby spiral galaxy M 81 (Garcia 1993). Like SN 1987A, the brightest in the southern sky, this supernova was detected when it was at the stage of initial rise in brightness. SN 1993J cannot be unambiguously classified. Most authors believe that some of its features suggest that the supernova has evolved from SN II to SN Ib. On this basis, a number of authors classified it as SN IIb or as of intermediate type between SN II and SN Ib. Presently, more than one year after its discovery, a large number of photometric observations of SN 1993J have been published, and its bolometric light curve has been constructed using some of our data (Ray *et al.* 1993). Models, which are generally consistent with the bolometric light curve within the interval 3 - 50 days after the time of explosion, were calculated by Nomoto *et al.* (1993) and Utrobin (1994). Studies show that the primary brightness maximum was a result of the explosion of a red supergiant surrounded by a low-mass hydrogen–helium envelope. The secondary maximum was caused by radioactive decay of ^{56}Ni, synthesized during the explosion, and its subsequent conversion to the radioactive isotope ^{56}Co and then to the isotope ^{56}Fe.

Additional information on the emission mechanisms and properties of supernova envelopes (e.g., on the presence of dust in the envelopes or their asymmetry) can only be obtained from polarization observations. However, polarization data on supernovae are extremely scarce. Although a few hundred of such stars are now known, only seven supernovae have been measured so far for polarization because these observations are very complicated; these are SN 1968L (Serkowski 1970), SN 1970G (Shakhovskoi and Efimov 1972), SN 1972E (Lee *et al.* 1972; Wolstencroft and Kemp 1972), SN 1975N (Shakhovskoi 1976), SN 1981B (Shapiro and Sutherland 1982), SN 1983G (McCall *et al.* 1984), and SN 1987A (Jeffery 1991). The polarizations of the supernovae were typically less than 1% and varied only slightly with wavelength. The presence of rapid variations in the polarization parameters with time were reported for SN 1972E (Lee *et al.* 1972). Variations in the polarization parameters with wavelength and time were most thoroughly traced for SN 1987A. One of the possible mechanisms for the formation of polarization of the SN 1987A light may be asymmetry of its envelope, ≈10% (Jeffery 1991). Another mechanism, coupled with asymmetry in the ^{56}Ni distribution, was considered by Chugai (1992a).

We are aware of only two short communications that report the polarization estimates for SN 1993J made on April 7, 20, and 26, 1993 in *V* and over the broad spectral range λ4200 - 6900 and λ4000 - 7300, respectively (Trammell *et al.* 1993; Jannuzi *et al.* 1993).

In this paper, we present our photometric and polarimetric *UBVRI* observations of SN 1993J, which complement the data already published.

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