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ON THE SPECTRUM OF SUPERNOVA 1972e IN NGC 5253

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ABSTRACT

Photoelectric scans of the spectrum of SN 1972e are presented. The observations were obtained at the McDonald Observatory between 15 and 50 days after maximum light with a spectral resolution ranging from 4 to 20 Angstroms. Line identifications (Ca II, Fe II, Si II, and possibly He I) are discussed briefly. It is suggested that the emission feature identified by Kirshner and Oke as Hα may have been produced by Fe II.

I. INTRODUCTION

Absolute spectral-energy distributions for the bright ($V \gtrsim 8$ mag) Type I supernova of 1972 in NGC 5253 have been published by Kirshner, Oke, Penston, and Searle (1973) and Kirshner and Oke (1975). The observations range from about 10 to 700 days after maximum light, and provide the best quantitative description now available of the evolution of the spectrum of a supernova. The data are not ideal for comparison with synthetic spectra; however, owing to the fairly low spectral resolution (from 20 Å in the blue and 40 Å in the red at early times to 80 and 160 Å at late times).

Photoelectric scans obtained at the McDonald Observatory between about 15 and 50 days after maximum light are presented in this paper. The coverage in terms of time and wavelength is less extensive than that provided by the Palomar data but the resolution, ranging from 4 to 20 Å, is higher and the spectra are plotted on a scale which is suitable for comparison with synthetic spectra. In the light of these additional spectra, line identifications are discussed briefly.

II. THE OBSERVATIONS

Observations were obtained by R. G. Tull, E. S. Barker, and G. L. Chincarini with the coude scanner on the 2.7-m telescope and the Cassegrain scanner on the 2.1-m telescope. Spectra based on the 2.7-m observations are shown in Fig. 1. The data points are at 4 Å intervals with a resolution of 8 Å; no smoothing has been applied. The relative flux distributions (per unit wavelength interval) are based on the absolute calibration of α Lyrae given by Oke and Schild (1970). When converted to flux per unit frequency interval and plotted on a logarithmic scale the spectra agree well with those shown by Kirshner *et al.* except for small differences in the line profiles which can be attributed to the differences in resolution. Narrow terrestrial features have not been removed; atmospheric absorptions near 6900, 7200, and 7600 are clearly visible.

The spectrum shown in the top panel of Fig. 1 is for May 18, 1972, 15 days after maximum light. (For purposes of discussion the date of maximum light will be taken to be May 3 although it is actually uncertain by several days.) At this point the supernova was in its early photospheric phase, which lasts until about 25 days after maximum. The spectrum shown in the lower panel is a composite, made by summing scans obtained on June 21, 22, 23, 25, and 29. The individual spectra for these nights were practically indistinguishable so they were combined to achieve a good signal-to-noise ratio. Kirshner *et al.* also commented on the remarkably constant appearance of the spectrum between 30 and 60 days after maximum. The composite spectrum in Fig. 1 refers to about 50 days after maximum.

Spectra based on the 2.1-m observations are shown in Fig. 2. These were obtained at 8 Å resolution on May 20, 1972, at 4 Å on May 21, and at 20 Å on May 23, June 2 and June 3. The plotted curves are the result of a power-spectrum smoothing procedure applied to the original data, which had a signal-to-noise ratio considerably better than that of the 2.7-m data. The first three spectra are for 17, 18, and 20 days after maximum, and the last two for 29 and 30 days. This figure provides the best available account of the changes which occur in the blue part of a Type I spectrum at the end of the early photospheric phase.

III. LINE IDENTIFICATIONS

According to the thermal interpretation of supernova light (Pskovskii 1969; Mustel 1971; Branch and Patchett 1973; Kirshner *et al.* 1973), the spectrum during the early photospheric phase consists of a thermal continuum

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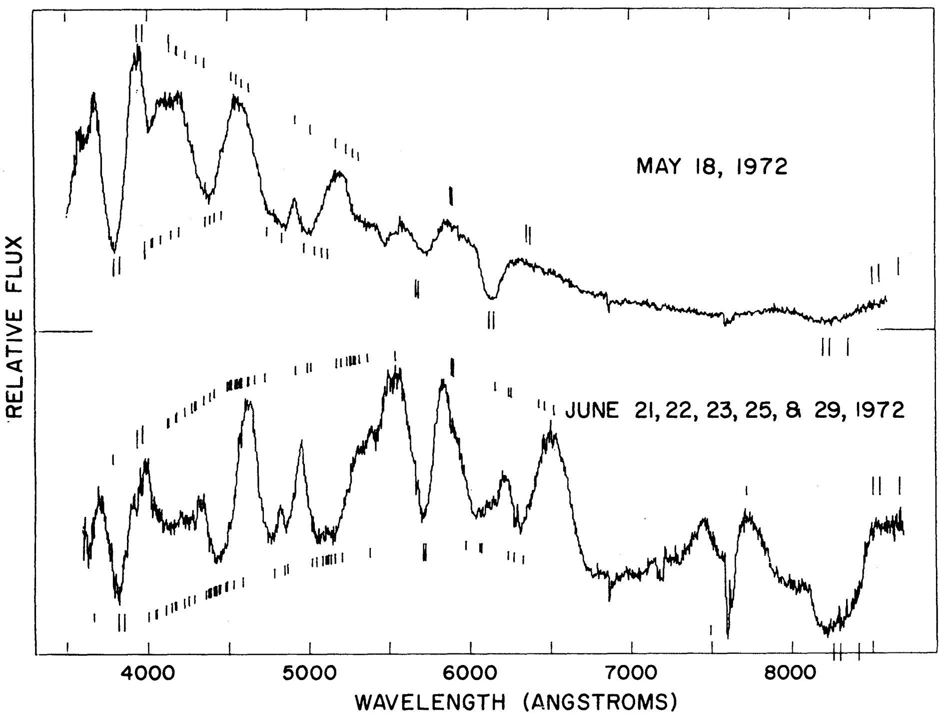

FIG. 1. Spectra of SN 1972e obtained with the 2.7 m telescope. The spectrum shown in the lower panel was made by summing individual spectra obtained on the indicated dates.

with superimposed line features formed near the photosphere. Emission lines are expected to occur at their rest wavelengths in the frame of the supernova, and absorption components should be blueshifted by an amount which corresponds roughly to the velocity of material at the photosphere. In the top panel of Fig. 1, the expected emission and absorption wavelengths are shown for some lines of interest: the *H* and *K* lines (λ3934 and λ3968 Å) and the infrared triplet (λ8498, λ8542, λ8662) of Ca II, the red doublet (λ6347, λ6371) and the blue doublet (plotted as a single line, λ4129 Å) of Si II, the Na I *D* lines (plotted as a single line, λ5892 Å), the strongest optical line of He I (λ5876), and the 15 strongest lines of Fe II. The Fe II lines were selected according to their optical depths computed for Boltzmann excitation at a temperature of 10,080 °K and the oscillator strengths given by Phillips (1979). For clarity, the positions of the Fe II lines are shown by shorter lines than are used for the other lines. Emission wavelengths, plotted above the spectrum, have been redshifted by 400 $\mathrm{km\,s^{-1}}$ to allow for the radial velocity of NGC 5253. Absorption wavelengths, beneath the spectrum, have been blueshifted by 10,900 $\mathrm{km\,s^{-1}}$, which, on the assumption that the absorption feature observed at 6125 Å is indeed the red Si II doublet, is the mean blueshift for Type I supernovae (Branch 1977).

In the physical conditions of Type I supernova envelopes two weeks after maximum light, Ca II, Fe II, and Si II are the ions which are expected to contribute the strongest lines (Branch 1980). The case for their presence is, in our opinion, strong. It should be noted that the emission peak due to the Ca II *H* and *K* lines is distorted by interstellar absorption by the same lines in our galaxy and NGC 5253 (Sistero and Castore de Sistero 1972; Wallerstein, Conti, and Greenstein 1972). Synthetic spectrum calculations are being carried out to determine whether all of the spectral features between 4200 and 5300 Å can be explained as complex blends of emission and absorption lines of Fe II. (For an attempt to match a Type I spectrum to a pure Fe II emission spectrum, see Assousa *et al.* 1976.) The fact that the observed absorption feature near 5750 Å occurs at a longer wavelength than expected for either the Na I lines or the He I line may be a clue that the line is actually He I. If the line were Na I it would be hard to understand why it is blueshifted less than the other lines. The He I line is strongly temperature-dependent and its optical depth would fall off rapidly with height above the photosphere. Calculated line profiles for weak lines with steeply decreasing optical depths do show reduced absorption blueshifts (Branch 1977).

In the lower panel of Fig. 1, emission and absorption wavelengths are shown for the lines of Ca II, Na I, He I, and the 50 strongest lines of Fe II. The absorption blueshift has been decreased to the value inferred by Branch and Patchett (1973) for Fe II lines at late phases, 7000 $\mathrm{km\,s^{-1}}$. There is an apparent discrepancy between the expected emission wavelength for Na I or He I and the wavelength of the observed emission peak, but this may be spurious because the observed feature is affected by interstellar absorption by the Na I lines (Wallerstein *et al.* 1972) and by atmospheric H_2O absorption between

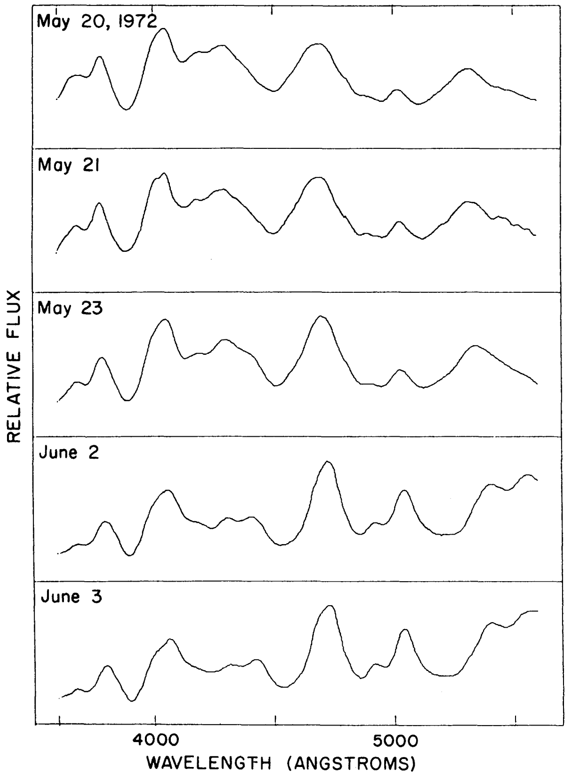

FIG. 2. Spectra of SN 1972e obtained with the 2.1 m telescope.

about 5900 and 6000 Å. At 50 days after maximum, conditions in the envelope are non-equilibrium, the photosphere having retreated with respect to the material, so we have no particular preference for either Na I or He I for the identification. Again, it seems plausible, although unproven, that most of the blue-green part of the spectrum can be explained by Fe II blends. The coincidences between observed features and predicted Fe II wavelengths are especially striking when the spectrum is viewed in terms of absorption. For a discussion of a possible mechanism for Fe II emission and absorption at late phases, see Meyerott (1978).

Kirshner and Oke (1975) have discussed a rough model of the physical conditions in the envelope of this supernova, based on their tentative identification of Hα in emission. However, it is clear from Fig. 1 that the observed feature is centered on 6500 Å rather than on the expected wavelength, after allowing for the redshift of NGC 5253, of 6572 Å. We have no reason to suspect that this discrepancy is spurious. As noted by Kirshner and Oke there is a weak emission peak at the expected position of Hγ, but there is a minimum instead of a peak at the expected position of Hβ. Thus the direct evidence for the presence of hydrogen emission is weak. The observed feature may in fact be due to Fe II, as argued, for example, by Mustel (1972). The three lines which appear near it in Fig. 1 are λ6417 and λ6457 of multiplet 74 and λ6516 of multiplet 40. Lines of these multiplets are strong in emission in the spectrum of the Type I Seyfert galaxy I Zw 1 (Phillips 1978; Oke and Lauer 1979). Friedjung (1975) has presented an argument against the Fe II identification of this feature in the spectrum of SN 1972e, but it rests on his conclusion that at 65 days after maximum the optical depth in the strongest Fe II lines was on the order of unity. If the features in the blue-green are due to Fe II, as they appear to be, then his conclusion is probably incorrect. The presence of hydrogen emission in the spectrum of SN 1972e is certainly an open question.

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REFERENCES

Assousa, G. E., Peterson, C. J., Rubin, V. C., and Ford, Jr., W. K. (1976). Publ Astr. Soc. Pac. **88,** 828.
Branch D. (1977). Mon. Not. R. Astr. Soc. **179,** 401.
Branch, D., and Patchett, B. (1973). Mon. Not. R. Astr. Soc. **161,** 71.
Friedjung, M. (1975). Astron. Astrophys. **44,** 431.
Kirshner, R. P., and Oke, J. B. (1975). Astrophys. J. **200,** 574.
Kirshner, R. P., Oke, J. B., Penston, M. V., and Searle, L. (1973). Astrophys. J. **185,** 303.
Meyerott, R. E. (1978). Astrophys. J. **221,** 975.
Mustel, E. R. (1971). Sov. Astron-Astron. J. **15,** 1.
Mustel, E. R. (1972). Sov. Astron-Astron. J. **16,** 10.
Oke, J. B., and Lauer, T. R. (1979). Astrophys. J. **230,** 360.
Oke, J. B., and Schild, R. (1970). Astrophys. J. **161,** 1015.
Phillips, M. M. (1978). Astrophys. J. Suppl. **38,** 187.
Phillips, M. M. (1979). Astrophys. J. Suppl. **39,** 377.
Pskovskii, Yu. P. (1969). Sov. Astron.-Astron. J. **12,** 750.
Sistero, R. F., and Castore de Sistero, M. E. (1972). Astrophys. J. Lett. **176,** L123.
Wallerstein, G., Conti, P. S., and Greenstein, J. L. (1972). Astrophys. Lett. **12,** 101.