THE 1974 TYPE I SUPERNOVA IN NGC 4414

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SUMMARY

Spectra of Miss Burgat’s supernova in NGC 4414 were taken with the Isaac Newton 2·5-m reflector during 1974 April and May. The spectra cover the period from just before maximum light to 20 days post-maximum, and show many features typical of Type I supernovae. In addition secondary features in the spectrum indicate the presence of thin shell or filamentary structure. A photographic light curve and direct plate are presented.

1. INTRODUCTION

The spectra of Type I supernovae near maximum light are now generally accepted as being composed of low excitation, singly ionized, metallic lines. Kirshner et al. (1973) have shown from spectral scans of several supernovae that a thermal continuum exists and emits a large percentage of the visible light during this period.

Following the work of Pskovskii (1971), Branch & Patchett (1973) identified much of the visible spectrum by using a simple model atmosphere for the supernova, and adjusting expansion velocity and line profile parameters to give the best fit with the observed spectra. In the present paper we adopt their line list to identify the major features, and also retain their simplification of assuming that only absorption lines are present in the early post-maximum period. Kirshner et al. (1973) have shown that P Cygni profiles, typical of expanding, somewhat rarefied, atmospheres, are in fact present even near maximum light. However, the relatively narrow absorption components of such profiles make for much easier identification in the crowded visible region.

2. OBSERVATIONS AND REDUCTION PROCEDURE

A total of 12 spectra was secured with the Image Tube Spectrograph at a dispersion of 210 Å mm⁻¹ and using the 2·5-m Isaac Newton reflector at Herstmonceux; details are listed in Table I.

All the spectra were well exposed and several night-sky plates were taken during the run. Microphotometry was carried out using a Boller and Chivens PDS measuring machine, and the intensity calibration and plotting on the ICL 1903T computer at Herstmonceux.

Figs 2, 3 and 4 show the final relative intensity tracings obtained (the last spectrum in Fig. 4 being a night-sky spectrum taken at bright of Moon). The EMI

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Table I

<table>
<thead>
<tr>
<th>Plate No.</th>
<th>Detector</th>
<th>Emulsion</th>
<th>Date</th>
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<td>Spectrocon</td>
<td>XM (nuclear)</td>
<td>April 29–30</td>
<td>22.15</td>
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<td>XM (nuclear)</td>
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<td>XM (nuclear)</td>
<td>April 30– May 1</td>
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<td>IIIaJ</td>
<td>May 11–12</td>
<td>21.08</td>
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<td>IIIaJ</td>
<td>May 11–12</td>
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<td>IIIaJ</td>
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<td>IIIaJ</td>
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</table>

Fig. 1. The photographic light curve for the supernova, the arrows indicating dates when spectra were obtained.

tube suffers to some extent from both ion-spots and blemishes in the phosphor screen, and where noticeable these have been identified by a X marked above the intensity tracing (note that the blemish at around 4300 Å is in fact present on all of the EMI spectra).

No attempt was made to deconvolve the instrumental function from the spectra, and distortions necessarily occur in the absolute energy distribution.
Fig. 2. Relative intensity tracings of the supernova spectra at around maximum light taken with the spectrocon tube. The major features are identified on the tracing of plate 819 and the more tentative identification on that of 814.

3. Notes on the Spectral Features

The overall shape of the spectra of supernovae of Types I and II has been accounted for (Branch & Patchett 1971; Patchett & Branch 1972) in terms of a large number (~60) blue-shifted absorption lines of Fe II, Ti II, Si II, Sc II and Mg II seen against a continuum. In the present case identifications for some of the stronger, individual lines are given in Fig. 2.
3.1 Spectrocon films

Fig. 2 shows intensity tracings from the three spectrocon films taken at around maximum light. The large absorption features are identified on the lower spectrum, all the wavelengths having been blue-shifted by 10,000 km s\(^{-1}\) in order to give the best fit.
FIG. 4. Relative intensity tracings of spectra taken between 1974 May 14 and 18 using the EMI image tube. The tracing at the foot of the diagram is of a typical night sky spectrum.
The most prominent absorption features appear to be Si II 4130 Å, Mg II 4481 Å, and the three strongest members of Fe II multiplet (42); all are typical of Type I supernovae spectra near maximum light.

The proposed identification of the '5300' dip is with Fe II 5335 Å and Sc II 5527 Å, though the positional agreement is not in fact very good. This feature is noted for its apparent shift towards the red in the early post-maximum period, similar in fact to the Si II and Mg II features, both of which are shown clearly in the wavelength-time diagram (Fig. 5). Explanations for such shifts can generally be found in the relative fading of the strong permitted lines with respect to the metastable lines (Branch & Patchett 1973). However, it is not at all clear which line would be responsible in the case of '5300'.

An interesting feature occurs at around 5460 Å (coinciding with a prominent night sky line). This has been previously noted as typical of Type I within 10 days of maximum light (Branch & Patchett 1971) and as such is very useful as an indicator of this phase. The disappearance after 10 days suggests a strong permitted line, and yet a feature reappears in this position some 60 days after maximum.

The large absorption features are clearly present on all three of the spectrocon films. On close examination however it appears that there also exists a system of weaker absorption lines to the blue of the main features; this is particularly apparent in the case of the Fe II multiplet (42). The strongest lines have been identified in the top spectrum appearing in Fig. 2 with lines blue-shifted by 12 200 km s⁻¹. It is not possible to say with certainty that such weak features are real and not merely a statistical quirk in the photometry. However, the two exposures taken on the night of April 29–30 do show considerable similarity in this respect. The spectrum taken on the following night has a rather smoother appearance, though in fact the instrumental resolution was identical; encouragingly, however, there does still appear to be an indication of the secondary absorptions.

Additional weak features occur in all three spectra at around 4550 Å and 4690 Å, and it is tempting to suppose that Hβ is responsible for the latter. In the top spectrum both Hβ and Hγ are shown blue-shifted by 11 500 and 13 000 km s⁻¹ in order to coincide with the two rather prominent absorption lines around 4690 Å. A suitable feature does occur close to the projected position of Hγ; the agreement however is by no means perfect. Note that the average of these two velocities is almost exactly equal to the 12 200 km s⁻¹ proposed for the Fe II secondary absorption. Because of the high densities on the electronographic spectrograms it has not been possible to reproduce photographs of them which show the detailed structure convincingly: the case for the existence of the shell structure rests heavily on the fact that the features are seen in all three tracings in Fig. 2.

The line at 4550 Å is tentatively attributed to Fe II 4731 Å. An interesting point about this line is that it appears to be double on all three of the spectrocon films.

Spectra kindly supplied by Professor Rosino of the Asiago Observatory were investigated to see if any trace of Hα could be found. Unfortunately the dispersion was rather low at this wavelength (being prism spectra) and, though the Hβ feature was clearly visible, it was not possible to say whether Hα was visible or not. Certainly if present it was very faint, but in any case would probably be submerged in the extensive absorption feature present at around 6150 Å.

3.2 EMI spectra

The nine spectra taken using the EMI tube are shown in Figs 3 and 4. They
cover a period of six days starting some 10 days after maximum light, during which
time the relative intensity in the red is seen to increase steadily, and is presumably
the effect of the cooling continuum. A major feature of the spectra is the peak at
4600 Å; undoubtedly this is accentuated by the combined response function of
the image-tube and the spectrograph, and is not in fact seen to be abnormally
strong in the scans of 1972e by Kirschner et al. (note 1972e was a Type I supernova
appearing in NGC 5253).

There is considerable detail around the 4600 peak which is present on most of
the spectra. Of particular interest is the line at 4690 Å which has been previously
mentioned as occurring on the spectracon films. In spectra 823A, B, C and 824,
this feature is relatively strong, but in later spectra is seen only as a point of inflexion.
The behaviour of the 4550 feature is very similar to this (see Fig. 5).

Both 5300 Å and 5640 Å features have apparently disappeared, and a very broad
absorption is now present centred upon 5080 Å. Several of the spectra (823A, B, C)
appear to show this latter feature as double, which would explain its unusual width,
and it is most probably a combination of Fe II 5169 Å and Fe II multiplet (48).

Finally, both the Mg II and Si II permitted lines have rapidly faded, and are
not visible on these spectra. The rapid increase in strength of the forbidden lines
accounts for the apparent shift of the Mg II line to the red (see Fig. 5).

4. Photometry

Experience with the 66-cm refractor at Herstmonceux has shown (Penston &
Cannon 1970) that exposures on unfiltered Kodak IIaO emulsion give magnitudes
very close to Johnson’s B. Such exposures of the field of the supernova were
obtained on 21 nights between 1974 April 26 and June 21, after which the object
was setting in the twilight.

A sequence of 11 reference stars, extending both brighter and fainter than the
extremes of the supernova brightness, was chosen by visual inspection of the
plates. The images of all the stars and of the supernova were measured on each
plate using a Sartorius Iris Photometer. Magnitudes for these reference stars were
derived by means of a photographic transfer from Selected Area 57 using the
sequence given by Purghatofer (1969); equal exposures of the supernova field and
the Selected Area were obtained at identical zenith distances and on the same plate.
The reference stars and the supernova are identified on Plate I. The supernova lies
56° S and 23° E of the nucleus of the galaxy.

The iris measures were reduced using the computer program (Penston &
Cannon 1970) developed for the Herstmonceux quasar monitoring program. In
this procedure the magnitudes of the reference sequence are first smoothed (these
smoothed values are listed in Table II) and the supernova measures reduced
against a mean iris curve defined by all the plates (see Penston & Cannon (1970) for
full details).

The reference star magnitudes, derived as they are from a single transfer,
may well have a zero point error of \( \pm 0^m.2 \) or \( \pm 0^m.3 \). However, the self consistency
of the supernova values is better than this and the relative magnitudes are probably
good to \( \pm 0^m.1 \).

The light curve, plotted as Fig. 1, shows a shape typical of Type I supernovae.
The date of maximum light is quite well defined at May 1, and is followed by the
usual sharp drop of 3 mag in 30 days which precedes the slow linear decline.
The phases at which spectrograms were taken are indicated by arrows. The good fortune of securing spectra and direct plates at maximum light owes much to the promptness of Miss Burgat in forwarding her discovery to the IAU telegram bureau and the rapidity with which the details were sent to Herstmonceux.

5. CONCLUSION

The spectra and light curve are in general typical of Type I supernovae. The relatively high resolution spectra taken at maximum light indicate however that a secondary shell or filament is contributing its own set of absorption lines. The velocity of the shell is found, by considering the three features associated with the Fe II multiplet (42), to be 12 200 km s$^{-1}$ (compared with 10 000 km s$^{-1}$ for the primary shell).

It appears possible that hydrogen is present, an assumption which rests largely upon identifying the 4690 Å absorption feature with blue-shifted H$\beta$. H$\alpha$ is not visible in the spectra, and if present would most probably be lost in the extensive 6150 Å absorption. However, there may be a physical explanation for this lack if we assume the atmosphere to be optically thick in Lyman $\alpha$. Under scattering conditions the second level of the hydrogen atom would act as a pseudo-ground-state, and lead to enhancement of H$\alpha$ emission with a subsequent reduction in the observed absorption.

Apart from the first two spectra, both with pronounced shell structure, Fig. 5 indicates that a velocity of 10 000 km s$^{-1}$ would be adequate to explain the absorption at 4690. It would seem, therefore, that any hydrogen would be associated with the main body of the supernova rather than an isolated shell or filament.

In a recent paper Kirshner & Oke (1975) have identified hydrogen in emission in the spectrum of the 1972 Type I supernova in NGC 5253. They saw features at H$\alpha$ and H$\gamma$ which first appeared at about 20 days post maximum and strengthened considerably thereafter; the complexity of their spectra at H$\beta$ precluded them from making any identification of an emission feature there. All of the spectrograms discussed in the present paper predate this phase and the suggested hydrogen absorption (seen with the superior resolution of the photographic technique) might be expected to occur before the onset of any P Cygni structure in the lines. Friedjung (1975) has also discussed Kirshner et al. data from the standpoint of the conditions for excitation of Fe II in the supernova ejecta and has concluded that these conditions, together with a modest mass of ionized hydrogen above the photosphere, could well give rise to H$\alpha$ emission.
Plate I. The field of NGC 4414. The galaxy appears to be an irregular spiral with two possible associated compact objects. The supernova, marked SN, is at the position 23° east and 56° south of the central nucleus. The photograph is reproduced from a plate taken with the 66-cm refractor at Herstmonceux on Kodak IIaO emulsion.
PLATE II. Enlarged section of Plate I showing details of the structure of NGC 4414. The supernova is indicated by the letters SN.
The 1974 Type I supernova in NGC 4414

Fig. 5. A wavelength-time diagram for the absorption features: ○, represents weak absorption; ●, strong absorption. Line identification markers have been blue-shifted by 10 000 km s\(^{-1}\).

It is, perhaps, important to retiterate the desirability of obtaining concurrent spectroscopic and photometric observations of supernovae so that distances may be determined using a modified Baade–Wesselink method (Branch & Patchett 1973; Kirshner & Kwan 1974). It is unfortunate that in the present case only \(B\) magnitudes are available, which precludes the determination of continuum temperatures.

ACKNOWLEDGMENTS

We thank the observers on the Isaac Newton telescope who so willingly gave up part of their own observing time in allowing us to exercise the override granted by the LTUP. We are grateful to our colleagues at the Royal Greenwich Observatory who helped by taking some of the direct plates used in determining the light curve, and in measuring them. We must acknowledge our debt to Dr M. V. Penston for helpful discussions and to Professor Rosino for communicating his spectra in advance of publication. The comments of a referee were helpful in clarifying several points.

REFERENCES