OBSERVATIONS OF SUPERNOVA 1979c IN M 100

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ABSTRACT

The IUE observations of supernova 1979c in M 100 are presented and discussed. The main results are:

1) The bulk of the energy is in the form of continuous emission which is radiated by the main SN envelope.
2) The absorption features originate mostly in both the disks and the haloes of our Galaxy and M 100.
3) The emission lines are produced in a highly ionized shell which has a radius greater than twice the radius of the main envelope and consists of compressed circumstellar material in which the abundance ratio N/C is about 30 times higher than solar.

INTRODUCTION

On April 19, 1979 Johnson (Ref. 1) discovered a bright supernova (denoted as 1979c, $m_B \simeq 12^m$) in the spiral galaxy M 100 (= NGC 4321).

The behavior of the light curve and the optical spectrum have indicated this SN to be a Type II (Ref. 2).

In the framework of a joint ESA-SRC target-of-opportunity program, on April 22, 1979 a series of low resolution spectra were taken in both short and long wavelength ranges. Observations were repeated at several subsequent epochs (April 24 and 27, May 1, 7 and 18, June 4, 15 and 28, and August 4).

In addition, simultaneous observations in the visual, radio and X-ray domains were also made resulting in a rather complete coverage and a thorough follow-up of the SN explosion and its time evolution. Detailed account of the first six weeks observations can be found in an article presently in the press (Ref. 3)

Here, I will present and briefly discuss the IUE observations with some reference to the optical results.

THE CONTINUUM AND THE TOTAL LUMINOSITY

The UV spectrum of the SN taken on April 22 is shown in Fig. 1. The bulk of the energy is radiated in the form of continuous emission which runs smoothly from 1600 to 3200 Å corresponding to a color temperature of $T_c \simeq 11000$ K.

The emission lines are estimated to contribute less than $\sim$ 15% of the total flux.

As seen in Fig. 2, which presents the observations made during the first four weeks, the continuum decreases steadily and becomes steeper with time, corresponding to a decrease of the color temperature from about 11000 K on April 22 to $\sim$ 7400 K on May 7. Starting in mid-May the decline in the UV bands becomes shallower and becomes similar to that observed in the optical range. This suggests an almost constant photospheric temperature after the middle of May.

Integrating over the whole optical and UV spectrum of April 22, after correction for extinction, the total flux is estimated to be $F_{tot} = 7.9 \times 10^{-10}$ erg $cm^{-2}s^{-1}$. Adopting a distance of 16 Mpc for M 100, the absolute luminosity on April 22, 1979 is L (April 22) = 2.4×10^{43} erg s^{-1} = $6.3 \times 10^{9} L_{\odot}$. By integrating the observed spectra over time and frequency the total radiative energy released by the Supernova explosion has been estimated to be E_{rad} (1979c) = 7×10^{49} erg.

THE ABSORPTION LINES

Superimposed on the continuum are many absorption and emission features. In absorption one can easily identify (cf. Fig. 1 and 2) lines of low ionization ions such as CI, CII, OI, NaI, MgII, SiII, SII, as well as some resonance transitions of highly ionized species (e.g. SiIV, CIV, AlIII).

The absorptions extend from approximately zero velocity up to velocities of about 1600 km s^{-1} and can be produced in the interstellar media of both M 100 and our own Galaxy. The interstellar origin of all these absorption features is confirmed by the constancy of their widths and strengths in spectra taken at different epochs (cf. Fig. 2).

The velocity dispersion implied by the absorption features due to neutral and once ionized atoms observed between 1250 and 1350 Å is found to be in the range of 14-26 km s^{-1}. This estimate agrees very well with the more direct determination by Penston & Blades (Ref. 4) of 15 (+11, -6) km s^{-1} obtained from measurements of the absorption of the Ca II 3934-68 and Na I 5890-96 doublets.

Similarly, the absorption lines of highly ionized atoms imply the presence, in both galaxies, of a medium where the gas is highly ionized and the velocity dispersion is 50 km s^{-1} at least. Evidence for the presence of such a halo in our Galaxy has been found in the direction of 3C 273 and towards some high z stars (Ref. 5) as well as towards stars of the LMC (Ref. 6).

THE EMISSION LINES

The strongest emission features present in the April 22 spectrum can be identified with resonant transition of N V (1238.8-42 Å), Si IV (1393.7 - 1402.7 Å), C IV (1548.2-50.8 Å) and the intercombination transitions of N IV]

1486 Å, N III] 1750 Å, C III] 1909 Å. The intercombination lines of O III] 1663 Å and of O IV] 1406 Å, cannot be discerned in the spectrum. The He II 1640 Å line is neither clearly present in this spectrum nor in those taken at later epochs. On the other hand, in the spectrum one can clearly see the line 1718.5 Å of N IV which corresponds to a permitted transition between excited levels (2p $^1P^0$–$2p^2$ ^1S). This immediately tells us that nitrogen must be present largely in the form of N IV in order to produce such a strong line.

As seen in Fig. 2, the spectrum appears to contain several other lines which are somewhat weaker. However, they are severely blended with each other so that the identification of individual lines and a quantitative estimate of their intensities is impossible.

The same crowding of lines makes it difficult to properly determine the profile of the major features and to measure their intensities to accuracies better than, say, 30%. Nevertheless, by studying the spectrum observed on April 22 as well as those obtained at later epochs (cf. Fig. 2) the following is apparent:

1) The line profiles are sharply peaked at a velocity displacement of 1800 ± 300 km s^{-1} with respect to the laboratory wavelength. This velocity is only marginally higher than the radial velocity of M 100 and confirms that the emission lines originate in the SN envelope.
2) The wings of the individual emission features extend to no more than 4000 km s^{-1}.
3) The emission profiles appear to be symmetric with respect to the emission peak.

The peaked profiles indicate that the lines are formed in an expanding envelope in which a velocity gradient exists and the maximum expansion velocity is $v_{max}(UV) \approx 4000$ km s^{-1}.

The symmetric extension of the line wings to the red and to the blue indicates that the UV emitting layers are far enough from the SN "photosphere" that any occultation of the receding part of the shell is negligible. From simple geometric arguments the average distance of the UV emitting shell from the SN surface can be estimated to be at least 2 photospheric radii (i.e. R (UV shell) $\geq 2.5 \times 10^{15}$ cm). Therefore, the UV emission line layers must be well separated from those which produce the continuous spectrum, i.e. the SN photosphere. Moreover, inspection of Fig. 2 shows that the line-to-continuum ratio increases with time. This is further confirmation that they evolve independently and, thus, are formed in different zones.

On the other hand, the optical lines display very asymmetric profiles (Ref. 3), with the blue portion being twice as extended as the red one. This indicates that the optical lines are formed in the main envelope which has been ejected in the SN explosion. Also the MgII λ2800 Å line presents similar characteristics in both profile and time evolution. Thus, this line too originates in the top layers of the SN photosphere.

The UV shell is likely to consist of gas originally ejected by the stellar progenitor, a red supergiant, as a more or less continuous wind. The wind material must have subsequently been compressed and accelerated as a result of the SN explosion, possibly by the radiation pressure of an initial soft X-ray burst (Ref. 7). The UV shell mass can be estimated to be approximately $M(\text{UV shell}) \approx 10^{-2} M_\odot$. This may be the result of steady mass loss of $\dot{M} \approx 10^{-4}\ M_\odot/\text{year}$. From the intensities of the emission lines of C and N, as well as the upper limits to the O lines, it is estimated that the number abundance ratios of N/C and O/C are 7 and <4, respectively. This corresponds to a strong overabundance of nitrogen relative to both carbon and oxygen by a factor of 10-30. The high enrichment of N and/or the possible depletion of C and O are indicative of nuclear processing through CNO cycle. This can have occurred in an H-burning shell during the red giant phase of the progenitor star. Subsequently the material has been brought up to the surface and ejected from the star in the form of stationary wind. It is clear, then, that the anomalous CNO abundances found in the UV shell provide further evidence for the accumulation of circumstellar material prior to the SN explosion.

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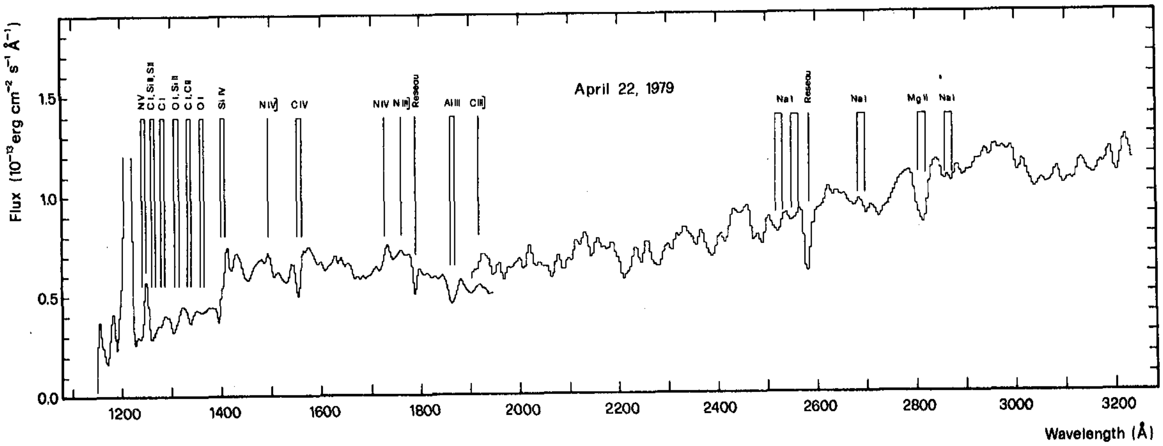

Figure 1. Ultraviolet spectrum of the supernova taken on April 22.3, 1979. The identifications of some relevant features either in absorption or in emission are given. The average wavelengths for components at zero velocity and at the M 100 radial velocity (z = 0.0054) are shown for absorption features. Only the red-shifted wavelength is indicated for emission lines.

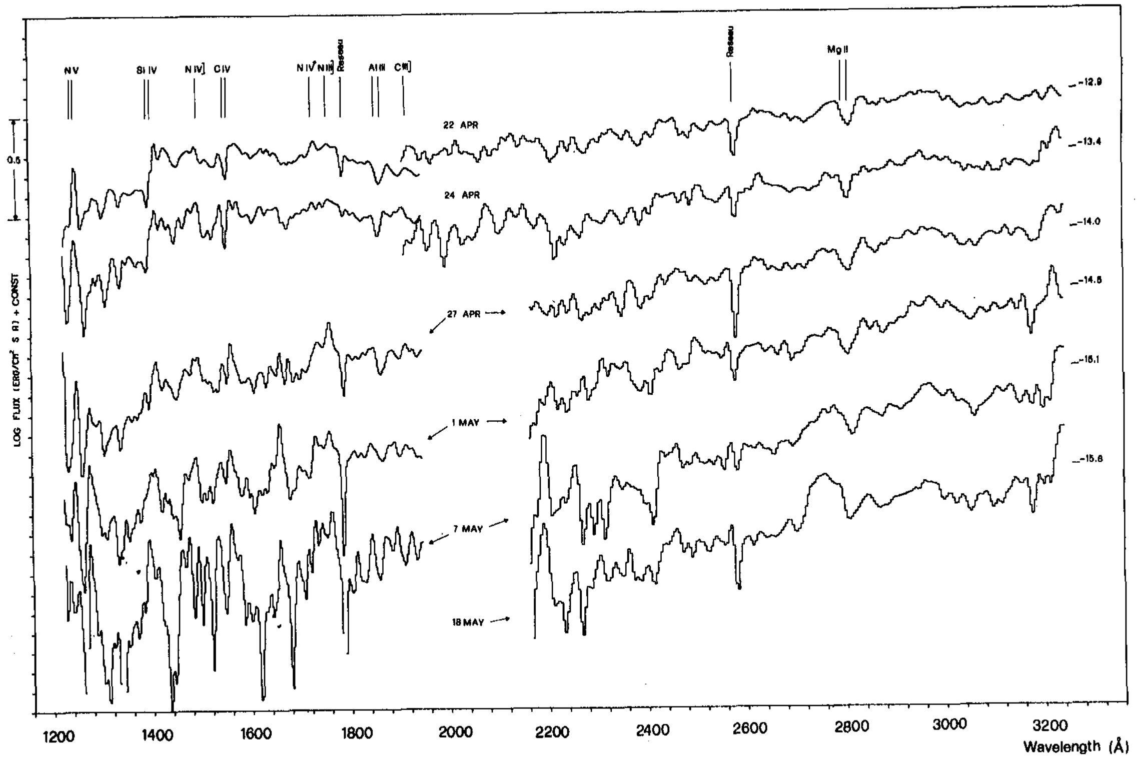

Figure 2. Evolution of the ultraviolet spectrum from April 22 to May 18. Note the increasing prominence of the far UV lines with time. Also noteworthy, is the development of the Mg II λ2800 Å line.