IUE OBSERVATIONS OF SUPERNOVA REMNANTS*

J.C. Raymond

Harvard-Smithsonian Center for Astrophysics

ABSTRACT

We discuss the UV emission spectra of several filaments in the Cygnus Loop and the Vela Supernova Remnant, including several which are anomalously bright in the optical O III lines. The effects of internal and interstellar resonance line scattering are estimated. Shock velocities, elemental abundances, and in some cases filament ages are given.

INTRODUCTION

Detailed discussions of IUE spectra of supernova remnants have been given by Benvenuti, D'Odorico and Dopita and Benvenuti, Dopita and D'Odorico (refs. 1,2). Raymond et al (ref. 3) considered long and short wavelength spectra of a bright filament in the Cygnus Loop which had been studied optically by Miller (ref. 4; his position 3). Here we compare that spectrum with two other filaments for which we have long exposures in both the long and short wavelength cameras.

Miller's position 3 is anomalously bright in the [O III] optical lines compared with models (refs. 5-7) and with most of the other bright optical filaments. Raymond et al.(ref. 3) inferred for this filament 1) a shock velocity of about 130 $km\ s^{-1}$, significantly faster than had been estimated from optical spectra; 2) weakening of the resonance lines of C II and C IV by up to a factor of ten by resonant scattering, either intrinsic to the filament or in the interstellar gas along the line of sight; 3) carbon and silicon only slightly depleted ($\approx$ a factor of 1.5) compared with oxygen; and 4) departure from steady-flow, in the sense that the recombination region is incomplete, implying an age for the filament of $\approx$ 200 yrs.

CONCLUSIONS

Table 1 compares the IUE spectrum of Miller's position 3 with the spectrum of another Cygnus Loop filament and that of a filament in the Vela Supernova Remnant. The Cygnus Loop filament has been studied optically by R. Fesen and R. Kirshner and called position "yellow". Its optical spectrum resembles those of

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Miller's positions 1 and 2. The filament selected for study in the Vela Supernova Remnant was a sharp, bright [O III] filament near the center of the remnant chosen from interference filter photographs provided by T. Gull. It is probably similar to Miller's position 3 in its relatively great [O III] / Hβ ratio. The fluxes listed in Table 1 for the Cygnus Loop have been corrected for reddening E(B-V) = 0.08 (refs. 8,9). Reddening is not obviously required by the optical spectra of the Vela Supernova Remnant (refs. 10,11), and no reddening correction was made, but we cannot exclude the possibility of significant extinction in the UV.

The emission in the bright lines at Miller's position 3 appears to be uniform over the large aperture, so interpretation in terms of a single velocity shock is at least reasonable. The other two spectra reported here show clear structure within the large aperture, and full interpretation will require separation of two or three spatial regions in each. Thus we will not attempt a serious fit of these spectra to individual shock models, but instead give a general comparison with Miller's position 3.

The three spectra are basically quite similar in the lines present. The outstanding difference between the two Cygnus Loop spectra is the strong Mg II emission at position "yellow" and the lack of Mg II at position 3. This confirms the hypothesis that the recombination zone, where Mg II emission is expected to arise, is almost absent at position 3, while more of a steady-flow shock has developed at "yellow". While this is expected from the optical spectra, there is a conceivable alternative explanation. It is possible that the Doppler velocities of the two filaments are such that the Mg II lines from position 3 coincide with the strong interstellar Mg II absorption, while those at "yellow" do not. A hit at the position of C II λ1335 prevents more than a lower limit to the factor by which resonant scattering reduces that line. The C IV / O III] ratio is larger at "yellow" by a factor of two, giving some indication that resonant scattering may be less severe. Either less severe scattering or a slightly higher shock velocity may account for the greater strength of N V at position "yellow", but the likelihood of a mixture of shock velocities makes even this uncertain.

In the coming year we will be studying the interstellar absorption lines in the vicinity of the Cygnus Loop and the Doppler velocities of the filaments under study in order to distinguish between interstellar resonant scattering and intrinsic scattering. In the latter case, resonance line photons tend to be scattered out the faces of a sheet of gas; the choice of bright optical filaments for study tends to select sheets of gas seen on edge, so the resonance lines appear to be weak relative to forbidden and intercombination lines. If the resonance line scattering is intrinsic, the ratio C II / C II] yields a column density, and consequently a density estimate.

The Vela SNR filament is much like position 3 of the Cygnus Loop in that the low temperature lines, C II and Mg II are relatively weak, again indicating a departure from steady flow. The weakness of N V indicates a slightly smaller shock velocity. The N III] and N IV] lines are rather strong compared with O III]. Since there is no optical evidence for an unusual abundance ratio (refs. 10,11), it seems likely that this is a result of the mixture of shock velocities. The C II / C II] ratio is only about a factor of 2 below those predicted by the models. The interstellar C II absorption has been studied extensively (ref. 12), and it seems that a Doppler shift of around 50 $km\ s^{-1}$ is needed to shift the emission lines away from the interstellar absorption.

One comparison of interest between the Cygnus Loop and Vela SNR is the relative abundances of carbon and silicon, since these elements are most strongly affected by grain depletion. Jenkins, Silk and Wallerstein (ref. 12) concluded from *Copernicus* observations of absorption lines that there was no significant depletion in shocks associated with the Vela SNR. The IUE spectra seem to indicate depletion of carbon and silicon by about a factor of 1.5 in both remnants as compared with the ratios of these elements to oxygen given by Allen (ref. 13), but further observational and theoretical study is required to confirm this result.

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LINE EMISSION

Relative to λ 1666

ION	λ	Cygnus Loop Miller 3	Cygnus Loop "Yellow"	Vela SNR
N V	1240	19	42	11*
C II	1335	10*	62**	23
O V	1371	6*	-	-
O IV, Si IV	1400	73	115	148
N IV	1485	11	-	55
C IV	1550	108	266	205
He II	1640	27	38	40
O III	1666	100	100	100
N III	1745	52**	63	76
Si II	1818	6*	-	-
Si III	1890	27	128	73
C III	1909	181	424	293
C II	2325	102	240	74
Ne IV	2420	37	23*	47
O II	2470	21*	23*	20*
Mg II	2800	-	40	-
I(1666)†	-	2.5(-4)	5.4(-5)	3.9(-5)

* Estimated uncertainty greater than 30%

** Particle noise contributes up to 50% of this value.

† Ergs cm^{-2} s^{-1} sr^{-1}.