PRELIMINARY REPORT ON IUE SPECTRA OF THE CRAB NEBULA

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ABSTRACT

The Crab Nebula is marginally observable with the IUE. Observations of the optically brightest filamentary regions, made with IUE in August 1979, show the C IV λ1549, He II λ1640, and C III] λ1909 emission lines. The intensities of these lines have been compared with visual-wavelength data. It appears that carbon is not overabundant in the Crab; carbon/oxygen is approximately "normal" and oxygen is slightly scarcer than "normal" as a fraction of the total mass.

INTRODUCTION

The Crab Nebula is the only young supernova remnant (i.e., one composed of supernova ejecta rather than of swept-up interstellar matter) which can be detected with the IUE. In August 1979, several IUE shifts were devoted to surveying a few spots in the nebula, using the large (10X20 arc sec) apertures, at low dispersion. The brightest spot found in this preliminary work will be further observed in 1980. The results of the 1979 work, described here, are preliminary. It appears that only near the brightest spot does the nebula produce ultraviolet emission line fluxes that are bright enough to be measured with the IUE. This is a region of superimposed "filaments" southwest of the pulsar, near the "bright filament" of Davidson (ref. 1) and "position 2" of Miller (ref. 2).

OBSERVATIONS

The present results are based on two exposures with the short-wave spectrograph, with integration times of 260 and 420 minutes, respectively (Figures 1 and 2). At the bright region that we observed, the C IV λ1549, He II λ1640, and C III] λ1909 lines appear to have been detected; radiation hits also affected the data shown in the Figures.

The He II λ1640 brightness is essential, because it allows comparison with relative line intensities in the visual wavelength region, thanks to the theoretical intrinsic relation (ref. 3) between the He II recombination lines,

$$I(\lambda 1640)/I(\lambda 4686) \approx 7.$$

No observations reported in refs. 1 and 2 were taken at positions that coincide exactly with the location in the nebula that was observed with IUE. However, for the purpose of the present preliminary analysis, we may average these previous results for the bright filamentary region. The lines that we take into account here are listed in Table I, where we have assumed a reddening for the Crab,

$$E_{B-V} = 0.5 \text{ mag}$$

from ref. 4. The adopted reddening was used to correct the visual line ratios, [O III]/Hβ/He II/He I, and separately to correct the ultraviolet line ratios, C III]/He II/C IV; then the previously-mentioned intrinsic ratio of the He II λ1640/λ4686 recombination lines was used to combine all of the relative intensities on the common scale of Table I.

The visual wavelength data of Table I were taken from refs. 1 and 2. Differences between these two references are less than 20 percent and probably real, due to the slightly different locations that were observed. The ultraviolet data (present work) in Table I must be regarded as very rough estimates, with errors as large as a factor of 1.5 quite possible.

DISCUSSION

Ultimately, appropriate photoionization calculations will be required to support a full analysis of the data in Table I and the further measurements to be obtained this year. In the meantime, some rough estimates will be instructive.

Theoretically, each blob or filament in the Crab Nebula is expected to have a stratified structure in photoionization equilibrium (ref. 5). An illustrative model is shown in Figure 3. The scheme shown in the figure is supported, to some extent, by temperature estimates from the lines of [S II] and [O III] (refs. 2 and 6). Zones B and C in the model are too cool to contribute significantly to the ultraviolet lines that we observed. Therefore, in this analysis, we consider only zone A. The [O III] λ4363/λ5007 temperature estimates generally give values around 14,000 - 15,000 K for this zone. (Actually these are averages, since there must be a temperature gradient within the zone.)

The intensity ratio of the He II λ4686/He I λ4471 recombination lines in the Crab Nebula shows that most of the helium in zone A is in the form of He^{+}, not He^{++}, in particular,

$$n(He^{++})/n(He^{+}) \sim 0.1.$$

This probably means that O^{3+} and C^{4+} are negligible compared with O^{++} and C^{3+}, respectively. Thus, in zone A we have C^{++}, C^{3+}, O^{+}, and O^{++}. It is very unlikely that more than 50 percent of the oxygen in zone A is O^{+}. Most likely, in zone A, at least 60 percent of the oxygen is O^{++} (see ref. 6). In the following discussion, we keep this in mind and consider only the C III], C IV, and [O III] lines.

Using conventional values for collision strengths (ref. 8),

$$\frac{I(\text{C III] } \lambda 1909)}{I(\text{[O III] } \lambda\lambda 4959,\ 5007)} \approx 13\ e^{-\left(\frac{46{,}500\ \text{K}}{T}\right)} \frac{n(C^{++})}{n(O^{++})}$$

and

$$\frac{I(\text{C IV } \lambda 1549)}{I(\text{[O III] } \lambda\lambda 4959,\ 5007)} \approx 50\ e^{-\left(\frac{64{,}400\ \text{K}}{T}\right)} \frac{n(C^{3+})}{n(O^{++})}$$

The line intensities reported in Table I then imply ionic abundance ratios for various representative temperatures, as listed in Table II. Note that the most likely temperature is around 15,000 K.

It seems clear that the carbon/oxygen ratio in the Crab is not very large. Also included in Table I are the observed relative line intensities in the high-excitation planetary nebula NGC 7662 (ref. 7), normalized to Hβ. The intensities of the lines observed in the Crab, which are attributed to zone A, are remarkably similar to those found in the planetary nebula. Since NGC 7662 was extensively modeled in ref. 7, an idea of the abundances in the Crab may also be obtained under the assumption that the physical conditions are similar. For NGC 7662, the carbon abundance was found to be solar and the C/O ratio was equal to unity, with the oxygen abundance less than solar. The temperature of the inner zone of NGC 7662, where the C IV line is formed, was 14,000 K. It is somewhat surprising that the C IV line is so strong in the Crab, since the C^{3+} ions are reduced by dielectronic recombination and by charge transfer on neutral hydrogen, which is much more abundant in the Crab. The inferred carbon/oxygen ratio in the Crab does not confirm the prediction of Arnett's (ref. 9) Case B, in which the supernova ejected all mass above the helium-burning shell, nor does it confirm the suspicion of Davidson (ref. 6). It is consistent with the Arnett Case A, in which all mass above the oxygen-burning shell is ejected. There are, however, a variety of models for the presupernova star and not all have been accompanied by explicit abundance predictions for the remnant nebula. Considering that some O^{+} must be present, but has been omitted from this analysis, it is probable that

$$\frac{n(\text{carbon})}{n(\text{oxygen})} \approx \left[\frac{n(C^{++}) + n(C^{3+})}{n(O^{+}) + n(O^{++})}\right] \quad \text{zone A}$$

$$\approx 1 \quad \text{within a factor of two}$$

It is important to recall that in the Crab Nebula, the abundance of oxygen by mass is lower than solar (ref. 6). Incidentally, note that the C IV/C III] ratio is considerably higher (perhaps by 3 to 5 times) than anticipated from the simplest photoionization calculations. It is too soon to say whether this indicates a serious difficulty for such calculations. It is unfortunate that the O III] λ1663 line cannot be measured as a check on this matter. The line is expected to be faint and its position corresponds to a reseau mark; a similar comment applies to N III near λ1750.

The interstellar absorption feature at λ2200 was observed in the continuum and will provide an independent determination of the extinction along the line of sight to the Crab Nebula. The extinction also can be independently determined from the ratio of the He II recombination lines, which is known from theory, once the absolute fluxes are available.

REFERENCES

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TABLE I. SOME RELATIVE LINE INTENSITIES IN THE BRIGHT FILAMENTARY REGION OF THE CRAB NEBULA

(corrected for interstellar reddening)

Identification		Crab Nebula	NGC 7662
[O III]	4959, 5007	16.	15.5
Hβ	4861	1.0	1.0
He II	4686	0.7	0.4
He I	4471	0.3	0.03
C III]	1909	7.5	5.5
He II	1640	5.	3.0
C IV	1549	5.	7.3

Crab Nebula Data: Visual lines from refs. 1 and 2.
NGC 7662 Data: From ref. 7.

TABLE II. C/O IONIC ABUNDANCE RATIOS IN THE CRAB NEBULA ZONE A

T (K)	$\frac{n(C^{++})}{n(O^{++})}$	$\frac{n(C^{3+})}{n(O^{++})}$
12,000	1.74	1.29
14,000	1.00	0.60
16,000	0.66	0.34
18,000	0.48	0.22

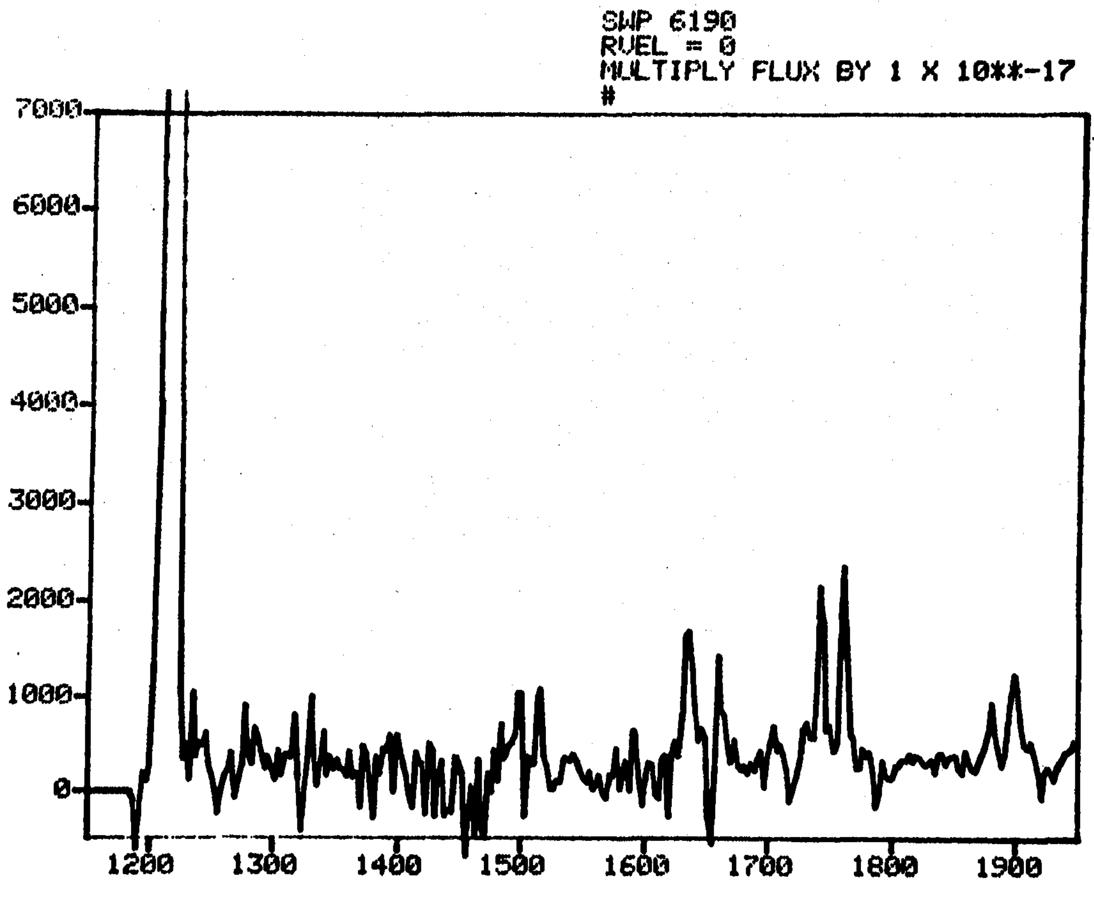


Figure 1. Results of 260-min exposure initiated at 02:51 G.M.T. on August 15, 1980.

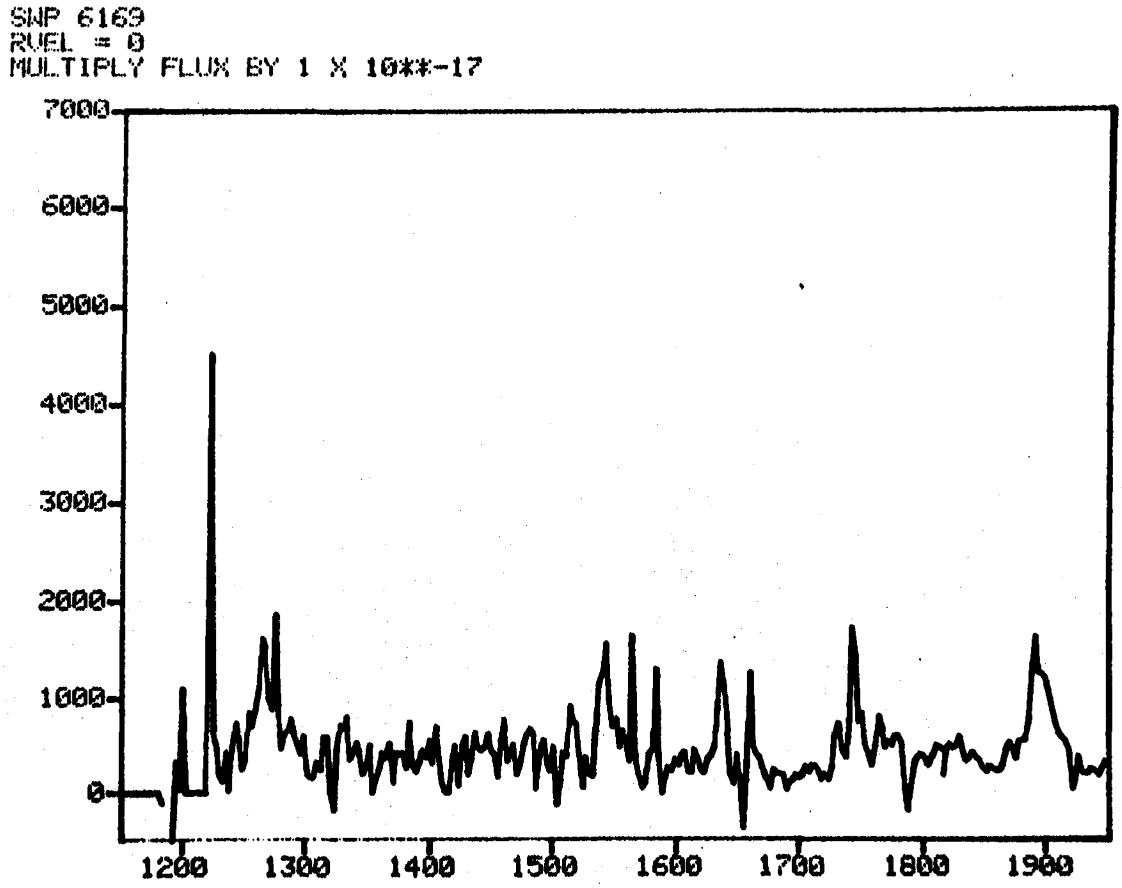
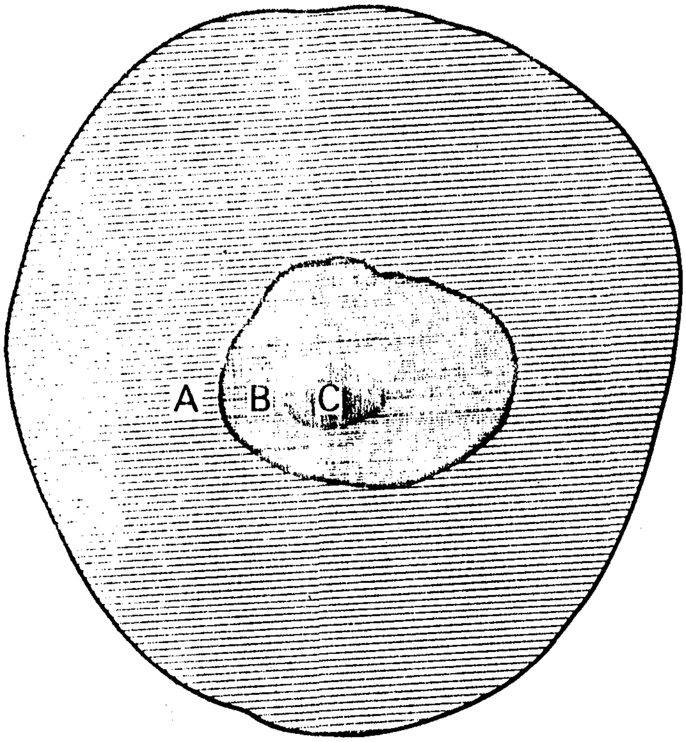


Figure 2. Results of 420-min exposure initiated at 02:55 G.M.T. on August 13, 1980.

STRATIFIED FILAMENT IN PHOTOIONIZATION EQUILIBRIUM



ZONE A

H^+, He^+, some He^{++}

C^{++}, some C^{+++}

O^{++}, some O^{+++} & O^+

$T \approx 12{,}000 - 18{,}000$ K

ZONE B

H^+, He, C^{++}, O^+

$T \approx 6{,}000 - 10{,}000$ K

ZONE C

H, He, ...

Figure 3. Schematic model for stratified filament in photoionization equilibrium in the Crab Nebula.