CNO-CYCLED MATERIAL EJECTED BY ETA CARINAE

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Eta Carinae has provided more incisive clues to the evolution of the most massive stars than any other individual object. Its luminosity is comparable to that of a very massive O3 star, but it appears to have evolved beyond the O3 stage, to the limit where its surface is rather unstable. We think that it has begun to lose mass semi-catastrophically, in outbursts which may recur at intervals of perhaps several hundred years. The suspected binary nature of Eta Carinae introduces some conceptual uncertainty but is most likely not crucial.

It is an interesting fact that our knowledge of Eta Carinae is largely independent of the methods used for most other stars discussed in this symposium. The luminosity is observed as dust-re-radiated infrared emission and does not depend upon a conventional bolometric correction; the suspected "surface temperature" of roughly 30 000 K is based on non-standard arguments (see K. Davidson, 1971, M.N.R.A.S. 154, 415); and the surface composition -- the main topic of our work -- is estimated from nebular emission lines rather than from analyses of a photosphere or a stellar wind. Eta Carinae is clearly special from more than one point of view.

The spectrum of the star itself, plus its surrounding dense halo of ejecta from the outburst observed in 1837--1858, is intractably complicated. But farther out, at distances of the order of 0.15 pc from the star, are some lower-density condensations with nebular emission-line spectra. These condensations have measurable proper motions and certainly were ejected from the star during the past two centuries, "apparent time" (see N.R. Walborn, B.M. Blanco, and A.D. Thackeray, 1978, Ap.J. 219, 498). The brightest condensation, denoted "S", is quite unusual among nebular objects in that it has prominent emission lines of 5 successive ionization stages of nitrogen (NI through NV) but scarcely any carbon or oxygen emission (see K. Davidson, N.R. Walborn, and T.R. Gull, 1982, Ap.J. Letters 254, L47). The implication is clear: CNO-cycle-processed material has been mixed to the surface of the star and then ejected.

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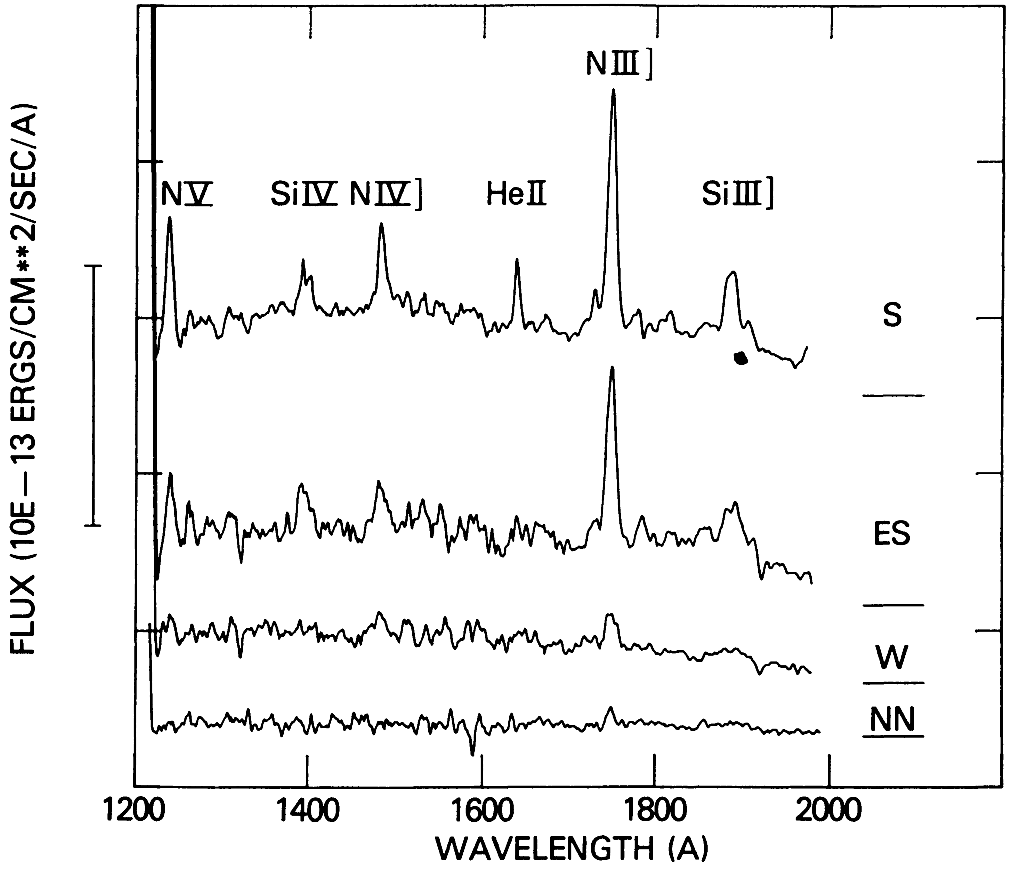
We have made some improved observations. K.D., N.R.W., and T.R.G. have used several shifts of IUE time to observe additional condensations and to obtain better UV data on the "S" condensation. R.J.D. has used the Cerro Tololo 4-m telescope and SIT vidicon system to obtain quantitative visual-wavelength spectral data on "S". Here we can offer only a preliminary, somewhat qualitative account of the results.

The figure below shows tracings of the UV spectra of condensations "S", "ES", "W", and "NN". These appear to show the same sets of emission lines. In each case there is a significant UV continuum, which seems stronger (relative to the lines) in condensation "NN". Generally, though, we can take "S" to be representative, aside from its greater brightness.



Tracings of short-wavelength IUE data on several condensations around Eta Carinae. Condensations are labelled (S, ES, W, and NN, see Ap.J. 219, 498) on the right side, with the zero level for each tracing marked by a horizontal line under each label.

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There are several difficulties in analyzing the ionization structure, which we can only mention briefly here. Corrections for interstellar and circumstellar reddening are uncertain. The UV continua mentioned above may be largely due to scattering by dust grains within the condensations; therefore, internal extinction within each condensation may affect the UV emission lines. If our preliminary UV/visual-wavelength relative intensity calibration is valid, the intrinsic He II λ1640/λ4686 line ratio greatly exceeds the "Case B recombination" value. This probably indicates (along with other arguments) that the gas is shock-heated and has a complicated ionization structure with strong temperature gradients. Pending appropriate theoretical calculations, we tentatively think that the bulk of the gas contains moderate ionization stages (H^+, He^+, N^{++}, some He^0 and N^+) at temperatures only modestly above 13 000 K.

With the most plausible assumptions regarding ionization structure, our data suggest that the nitrogen mass fraction is roughly 0.005, of which about 70% is doubly ionized. This mass fraction, while less than the total CNO mass fraction in the Sun, is large enough to be consistent (within the uncertainties) with the idea that most of the CNO nuclei are nitrogen. Weak C IV, C III], and [O II] emission lines appear to be present; these suggest that the C/N abundance ratio is of the order of 0.01, and O/N is even smaller, in the observed gas. We suspect that most of the oxygen in each condensation is in silicate dust grains. Silicon emission lines are prominent in the spectra of the condensations and of the gas nearer the star; this may imply that some silicon was "left over" after the formation of silicate grains, which must therefore have been limited by the supply of oxygen. Thus we conjecture that the oxygen abundance (including grains as well as gas) is less than about twice the silicon abundance. This would correspond to $O/N < 0.15$, roughly.

With the same ionization assumptions, we estimate that the helium mass fraction is $Y = 0.42 \pm 0.04$, which of course is larger than the Solar value. While the nitrogen overabundance is qualitatively significant because it indicates that the star has evolved and that mixing has occurred, the helium abundance may be quantitatively significant because it must be related to the degree of evolution.

...While working on this problem, K.D. and N.R.W. have been guest observers with the IUE (supported by NASA) and R.J.D. has been a guest observer at Cerro Tololo Inter-American Observatory (supported by NSF). N.R.W. is a National Research Council Senior Associate in the Lab. for Astronomy and Solar Physics at GSFC. The figure was designed by Nolan Walborn and kindly executed by Joy N. Heckathorn at the GSFC Regional Data Analysis Facility.

DISCUSSION

Spruit: If the oxygen is bound in dust, can the carbon be bound in dust as well?

Davidson: In principle, yes; there may be carbon grains. Note, however, that the O/N ratio must be low, because gaseous oxygen is thoroughly "depleted" by silicate grain formation, with some gaseous silicon left over. If O/N is low, we tend to expect low C/N also (unless some triple-alpha carbon nucleosynthesis has occurred). Eventually, we hope the 2200 Å extinction feature may give information about carbon grains in the relevant gas. A significant part of the observed reddening is due to grains associated with Eta Carinae itself, rather than ordinary interstellar dust; and the 2200 Å feature is only moderately strong in the "S" condensation UV continuum. But we cannot yet promise you any particular results.