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INFRARED OBSERVATIONS OF ETA CARINAE *†

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INTRODUCTION

Eta Carinae is a non-stellar object less than 5″ in diameter seen projected on a region of dense nebulosity. Spectroscopic observations, reviewed by Rodgers and Searle (1967) and Aller (1966) have shown strong emission lines superimposed on a smooth continuum. This continuum contributes about 60 per cent of the visual energy and rises steeply into the infrared; no entirely satisfactory mechanism for producing this radiation has been proposed. In this Letter photometric data which extend the continuum observations to 1.65, 2.2, and 3.4 μ are presented.

OBSERVATIONS

Figure 1 shows the average flux densities in the wavelength intervals 1.5–1.8 μ, 2.0–2.4 μ, and 3.1–3.8 μ observed in December 1967 with a 20″ diameter aperture centered on η Car. The observations were made using a double-beam infrared photometer attached to the 60-inch telescope at Cerro Tololo, Chile. A similar photometer and detection system are described by Becklin and Neugebauer (1968). The observed signals were converted to flux densities by comparision with stars previously measured by Johnson *et al.* (1966) and with the absolute energy calibration by Becklin (1968). The signal-to-noise ratios of the observations exceeded 50:1; the errors assigned are standard deviations and reflect the uncertainty in the absolute calibration and in the sensitivity at the time of measurement.

The flux densities of the visual continuum measured in 1964 and 1965 by Rodgers and Searle (1967) for an area 17″ in diameter around η Car are also included in Figure 1. Although η Car has shown large, irregular fluctuations in brightness in the past (Gratton 1963), there is evidence that the recent infrared and visual data can be compared directly. Feinstein (1967) has found that during the period 1963–1967 the visual magnitude of η Car has remained within 0.2 mag of 6.2, in good agreement with the brightness obtained by Rodgers and Searle (1967). Furthermore, Walker (1967) obtained a value of $V = 6.12$ mag at the time the infrared measurements were made. Since there are no known strong emission lines within the wavelength intervals observed, it is assumed that the measurements reported here represent an extension of the continuum.

In addition to the measurements with a 20″ aperture, observations of the flux density within 40″, 30″, 10″, and 5″ apertures were made at 1.65 and 2.2 μ. The results are shown in Figure 2 together with similar measurements made at an effective wavelength of 0.54 μ by Visvanathan (1967) in 1963 and 1964. The observed close agreement can be taken as evidence that the infrared and visual energy originates in the same region of space. An integration of the visual intensities derived by Thackeray (1953) from the isophotes obtained photographically by Gaviola (1950) in 1945 is also in good agreement with the data of Figure 2.

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INTERSTELLAR EXTINCTION

In order to find the true shape of the energy distribution of η Car, differential interstellar extinction must be considered. By observing stars in the cluster Trumpler 16, Feinstein (1963) has estimated the reddening (E_{B-V}) of η Car to be in the range $0.36 \leq E_{B-V} \leq 0.50$ mag; Faulkner (1963) observed O and B stars in the neighborhood of η Car and found that E_{B-V} ranged from 0.20 to 0.67 mag. Rodgers and Searle (1967) published a value $E_{B-V} = 0.69$ mag on the basis of the observed Balmer decrements in the spectrum of the H II region near η Car and assumed it also applies to η Car itself; Searle (1968) has re-examined the data and concludes that less reddening is in better agreement with the observations.

The data have been corrected for interstellar extinction by adopting $E_{B-V} = 0.6$ mag and an extinction curve following Johnson and Borgman (1963) and Whitford (1958).

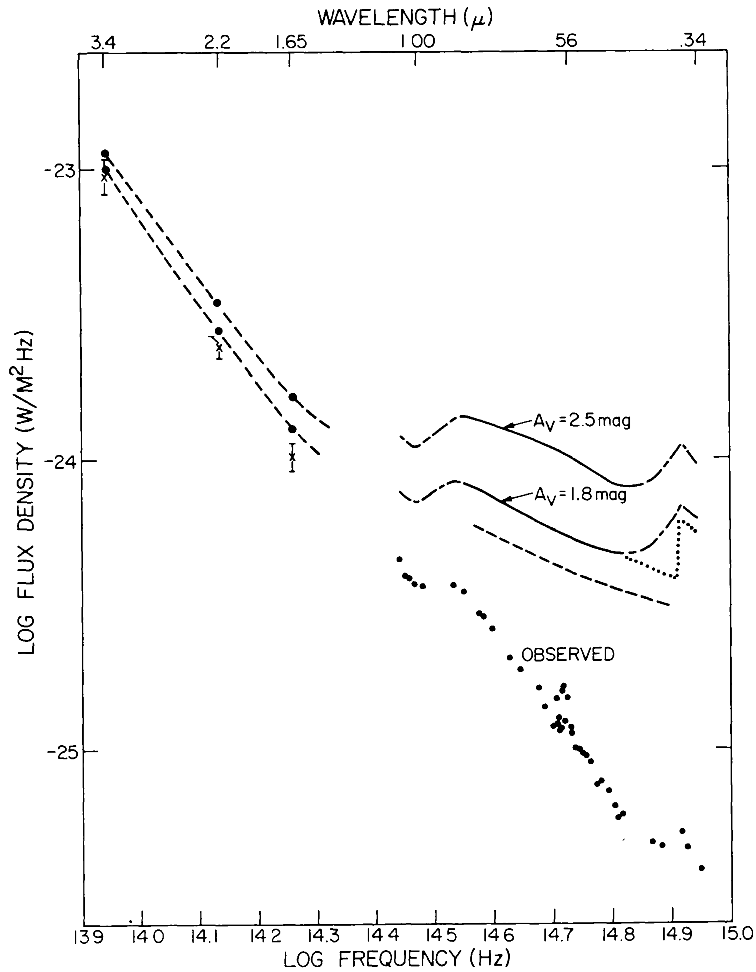

FIG. 1.—The observed energy from η Car. The crosses are new infrared data reported here. The medium dots are data of Rodgers and Searle (1967); those for $\log \nu$ (Hz) > 14.85 represent an upper limit to the continuum while those for $\log \nu$ < 14.53 are uncertain because of difficulties in removing emission features (Searle 1968). Rodgers and Searle (1967) indicate that the inflection at $\log \nu$ (Hz) $\sim$ 14.5 is not a Paschen discontinuity. The solid lines above the visual data and the heavy dots above the infrared points show the data corrected for interstellar absorption. The dashed line below the $A_V = 1.8$-mag curve is the remainder after hydrogen free-free plus recombination radiation has been subtracted from the continuum with $A_V = 1.8$ mag. The fine dots show the Balmer discontinuity expected when this component is extrapolated smoothly beyond $\log \nu$ (Hz) = 14.8.

This extinction curve agrees with calculations by van de Hulst (1949) for dielectric grains (curve No. 15). The visual absorption was taken to be $A_V = 1.8$ mag, corresponding to a ratio of total to selective absorption of $R = A_V/E_{B-V} = 3$; the corrected data are included in Figure 1. If a smaller E_{B-V}, such as 0.45 mag, is used, the corrected data are qualitatively the same.

Rodgers and Searle (1967) have compared the 11-cm radio brightness of the H II region surrounding η Car to the brightness in Hα light of the same region and find more absorption than 1.8 mag. For comparison, the data have also been corrected assuming a visual absorption of 2.5 mag and an extinction curve similar to that found for the Orion Nebula (Sharpless 1952; Johnson 1968). As is seen from Figure 1, the assumption of increased absorption flattens the spectrum in the visual region but does not radically change the spectrum in the infrared which is quite insensitive to the assumed absorption.

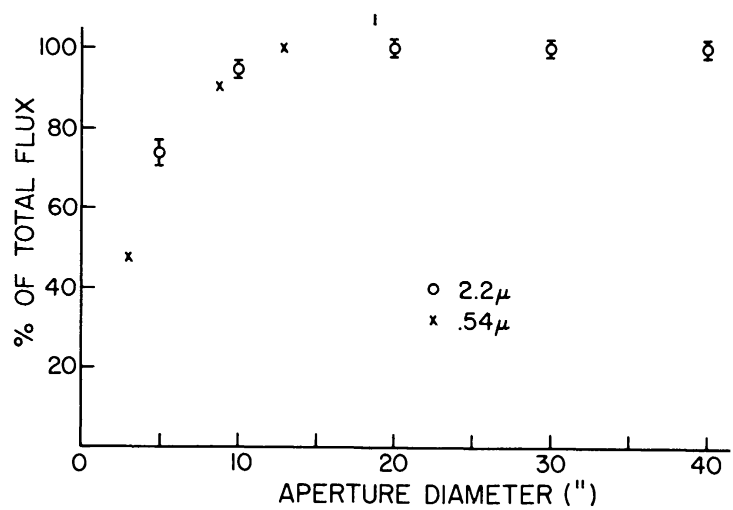

FIG. 2.—The percentage of total flux included within various-sized apertures at 2.2 and 0.54 μ (Visvanathan 1967). The infrared points were obtained by locating the aperture to maximize the observed signal.

DISCUSSION

The results of the absorption calculations establish that the steep increase toward the infrared is a real feature of η Car and not a consequence of interstellar reddening, so that the continuum spectrum of η Car presented in Figure 1 can be broken up into (*a*) an infrared component plus (*b*) a flatter component in the visual region.

The fraction of the continuum radiation which is produced by hydrogen recombination can be estimated by adjusting the continuum so that the ratio of the Hβ line intensity to the continuum intensity agrees with recombination theory. Analyses of line intensities by both Aller (1966) and Rodgers and Searle (1967) indicate the existence of an ionized region at electron temperatures around 20000° K; at this temperature the equivalent width of the Hβ line is approximately 500 Å (Oke and Sargent 1968; Searle and Sargent 1968). Since the equivalent width observed by Rodgers and Searle (1967) is 114 Å, hydrogen free-free plus recombination radiation accounts for only approximately 23 per cent of the observed continuum at the wavelength of Hβ. The contribution of hydrogen recombination radiation to the observed continuum with an assumed absorption $A_V = 1.8$ mag has been calculated following Seaton (1960) for the range $14.58 < \log \nu$ (Hz) < 14.82. The remainder, derived by subtracting this contribution from the observed continuum, is shown in Figure 1. If this presumably non-thermal component is extrapolated smoothly beyond $\log \nu$ (Hz) $= 14.8$, the predicted Balmer discontinuity is in good agreement with the observed discontinuity (Fig. 1) which is, in fact, an upper limit. The predicted observable Paschen discontinuity, again assuming a smooth extrapolation, is log $\Delta f_\nu \simeq 0.04$ in agreement with the absence of an observed discontinuity. At frequencies below the Paschen discontinuity, the extrapolated hydrogen free-free plus recombination radiation makes a negligible contribution to the observed continuum. Thus the lower dashed curve in Figure 1 is probably a reasonable estimate of the non-hydrogen recombination component of the radiation emitted by η Car.

The source of the infrared component has been discussed by Searle *et al.* (1965), Rodgers and Searle (1967), McCray (1967), and others as being the result of s achrotron radiation. A severe limitation on this interpretation is imposed by the measurements of

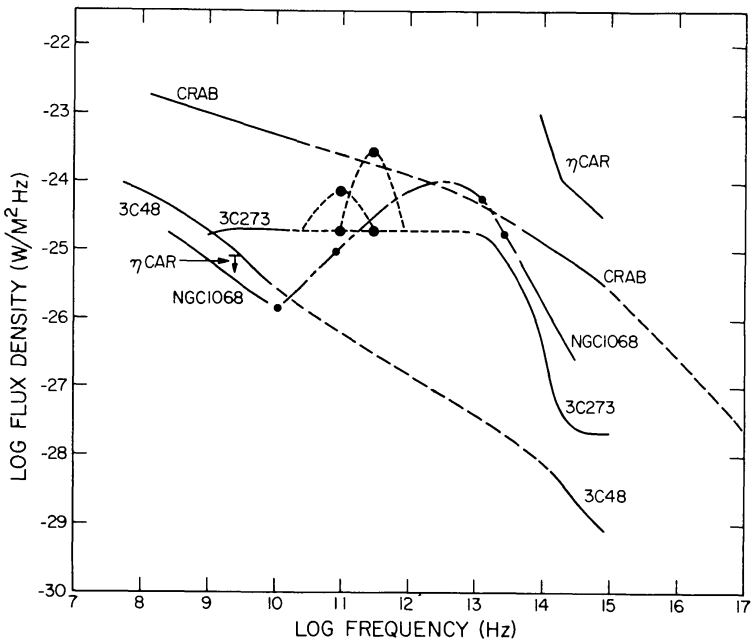

FIG. 3.—A comparison of the approximate spectral energy distribution of various sources. The curves are solid in regions where data are closely spaced and dashed in regions with few data points. The latter lines are included to ease confusion rather than as an indication of the actual distribution. The two curves with 3C 273 indicate the observed variability of that source. Data have been taken from the following references: η Car at log ν (Hz) = 9.4, Beard and Kerr (1967); Crab Nebula, summary by Becklin and Kleinman (1968); NGC 1068, summary by Becklin and Neugebauer (1968) and Low (1968*a*); 3C 273, summary by Low (1968*b*); 3C 48, Dent and Haddock (1966), and unpublished measurements of Oke, Neugebauer, and Becklin.

Beard and Kerr (1967) which set an upper limit of 11-cm flux from η Car of $(8 \pm 2) \times 10^{-26}$ W m^{-2} Hz^{-1}, well below the value predicted from simple synchrotron theory. The Tsytovich-Razin effect, i.e., the decrease of synchrotron radiation which results because the index of refraction is less than unity (Scheuer 1965), has been invoked to explain the low radio flux (Rodgers and Searle 1967; McCray 1967). As pointed out by Rodgers and Searle (1967), however, this explanation would require a serious violation of the equipartition of kinetic and magnetic energy; the large index to the power-law spectrum of -2.85 observed in these measurements emphasizes the seriousness of this objection. On the other hand, a model invoking the free-free absorption by a gas cloud surrounding the emitting region can be adjusted to agree qualitatively with the limited observations (McCray and Rees 1968).

It is possible that the infrared component of η Car is thermal. Thermal radiation from dust grains has been advanced by Low and Smith (1966) to explain the infrared excess of R Monocerotis and by Gillett, Low, and Stein (1967) and Krishna Swamy and O'Dell (1968) to explain the infrared radiation from the planetary nebula NGC 7027. A complex model incorporating regions of various temperatures, which may be quite consistent with the complex structure observed optically, can, of course, be adjusted to fit the limited observations. The shape of the infrared rise observed from η Car, however, precludes the radiation being thermal emission from an optically thick configuration characterized by a single temperature. Again, the data are probably not complete enough to warrant detailed model calculations.

The similarity between the spectra of η Car and other objects which have apparently had a violent history has been pointed out by Searle *et al.* (1965). In Figure 3, the energy distributions of η Car, the Crab Nebula, the Seyfert galaxy NGC 1068, and the quasi-stellar sources 3C 48 and 3C 273 are shown. Although the spectra of these sources differ at the radio wavelengths, all share the property of a large increase of the continuum into the infrared. However, η Car, 3C 273, and NGC 1068 have a much larger spectral index in the near-infrared than do the Crab Nebula and 3C 48. It is interesting to speculate that if the spectrum of η Car were to follow that of NGC 1068 to 22μ, η Car would be among the brightest objects outside the solar system observed at these wavelengths. Although the ratio of radiation from gas, stars, and non-thermal sources may differ in the objects shown, it seems possible that the striking similarity of the observed infrared energy distribution is indicative of a common form of energy production. Further measurements of η Car, potentially the brightest of these sources, may thus be of general importance to the understanding of this broad category of objects.

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