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THE EXCITING STAR OF HH 57

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ABSTRACT

We provide the first spectral classification for the exciting star of HH 57. The star is an F8 III and suffers about 5 mag of visual extinction, far greater than that toward the HH 57A knot, only a few arc seconds away. This difference supports the previous identification of a flattened geometry for the circumstellar dust around this star. Using *IRAS* photometry we determine a distance of 940 pc to HH 57 by bolometrically matching the observed luminosity of the star to those of FU Ori and V1057 Cyg.

Subject headings: stars: circumstellar shells — stars: pre-main-sequence — stars: spectral classification

I. INTRODUCTION

Graham (1983*a*, *b*) has reported the appearance of a recently brightened star within the HH 57 nebula. Graham and Frogel (1985) have presented red spectra and infrared photometry of this star, while Reipurth (1985) has obtained near-infrared spectrophotometry and an optical stellar spectrum, albeit unclassifiable. The star bears some resemblance to stars of the FU Ori class (Herbig 1977) by virtue of its multiple Hα P Cyg absorption components, the strength of Li I 6707, and its photometric history. Cohen *et al.* (1984) and Cohen, Harvey, and Schwartz (1985) have spatially resolved a flattened, 100 μm emitting structure centered on the star, with major axis elongated roughly east-west, orthogonal to the long axis of the HH 57 nebula (see Schwartz 1977 for a photograph of the nebular structure).

In this *Letter* we present a spectrum of the star within HH 57, adequate for its spectral classification and for the direct determination of its reddening. We comment briefly on the character of the "HH 57" nebulosity and of the nearby Reipurth 13 nebula (Reipurth 1981).

II. THE OBSERVATIONS

We obtained several long-split spectra of HH 57, its associated star, and Reipurth 13 using the Anglo-Australian 3.9 m telescope, coupled to the Image Photon Counting System (IPCS; Boksenberg 1972) on the nights of 1984 March 26 and April 1 and 2. All were taken with the 25 cm camera, using a 250 lines mm^{-1} grating blazed in the blue in its first order to obtain continuous coverage from 3500 to 7500 Å. The slit width was 2$''\!.$65 on the sky, wider than the seeing disk, and our resolution was 11 Å. The slit length was 115″, divided into 50 spatial elements. We coadded all relevant spectra corresponding to independent spatial elements in each exposure for increased signal-to-noise ratio. Figure 1 shows the sum of three independent, co-added spectra obtained on different nights (exposures of 1200, 1600, and 1400 s), uncontaminated by nebular emission lines. The inset illustrates an expanded version of a portion of the stellar spectrum, in the vicinity of Hγ and Hδ. We also use three other spectra of different locations in the "HH 57" nebulosity where a strong continuum is seen, to determine the colors of this scattered continuum, presumed stellar.

Figure 2 identifies HH 57A, B, and the direction to Reipurth 13, based on a synthesis of postbrightening images of the nebula presented by Cohen *et al.* (1984), and Graham (1984). HH 57A is a bona fide Herbig-Haro object, although a bright continuum is also present (Fig. 3). HH 57B shows only a continuum (Fig. 4), as Graham and Frogel (1985) also found.

The slit positions employed were (Fig. 2): through the star and HH 57A in p.a. 9°; through the star and Reipurth 13 (which lies 54″ west of the HH 57 star in p.a. 265°); and 3″ west of the star through "HH 57B", in p.a. 6°.

III. THE SPECTRA

We have followed the criteria for spectral classification established by Morgan, Keenan, and Kellman (1943) and elaborated by Yamashita, Nariai, and Morimoto (1977). The spectral type is F8 from the following line ratios: Ca I 4227/Hδ; Fe I 4144/Hδ; Fe I 4046/Hδ; Fe I + Fe II 4384, 5/Mg II 4481; 4384/Hγ; Fe I 4260/Ti II + Fe I 4290; and from the appearance and strength of the *G* band. The luminosity class is III from Fe I 4046/Sr II 4078 and Sr II 4078/Hδ; the faintness of Fe I 4444 compared with Hγ; the weakness of Ca I 4227; and the spectral structure near the *G* band (the latter two criteria discriminate between classes III and IV). Corroboration of this spectral type comes from two red criteria: namely the absolute strengths of the 6500 Å (later

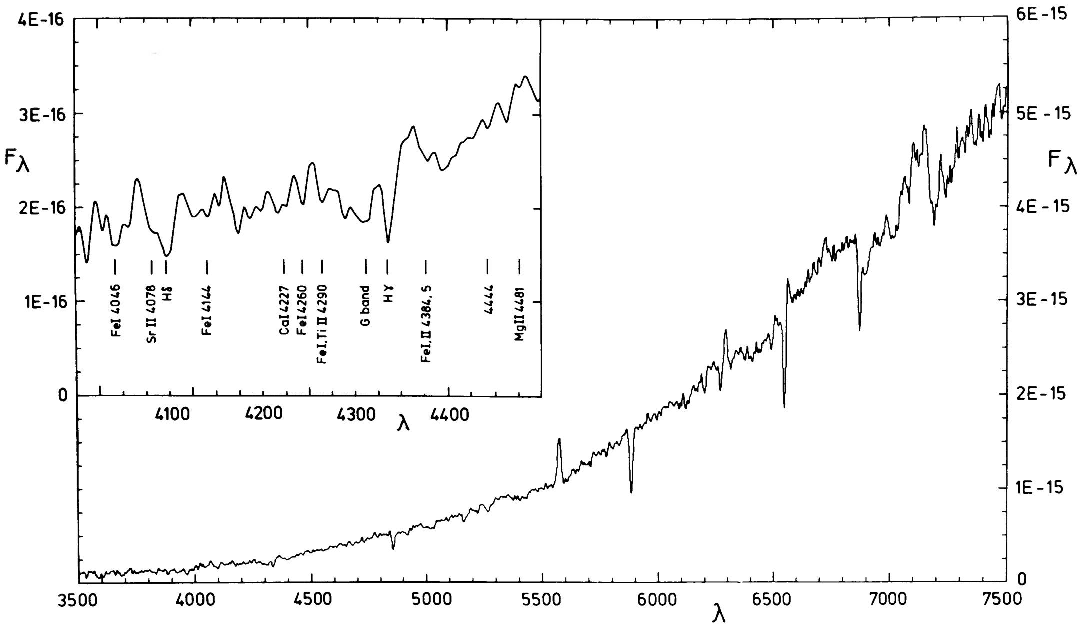

FIG. 1.—IPCS spectrum of the HH 57 star. Ordinate is F_λ in units of ergs cm^{-2} s^{-1} Å^{-1}; abscissa is wavelength in Å. (*Inset*): expanded spectrum in the region of Hβ showing some of the blue lines used for spectral classification.

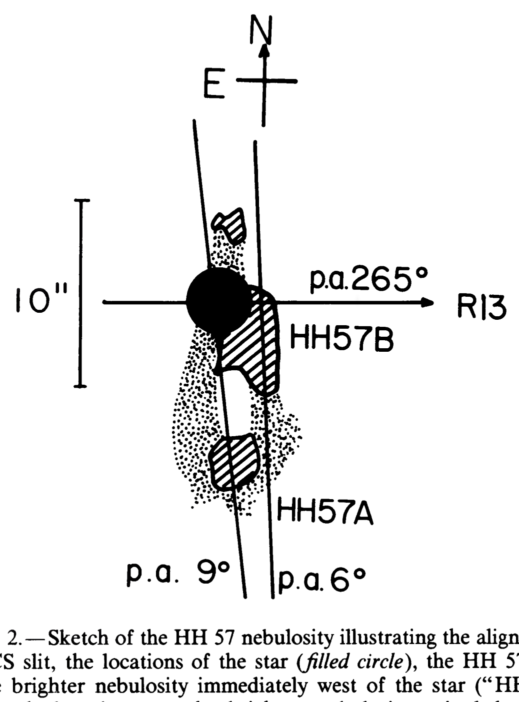

FIG. 2.—Sketch of the HH 57 nebulosity illustrating the alignments of the IPCS slit, the locations of the star (*filled circle*), the HH 57A knot, and the brighter nebulosity immediately west of the star ("HH 57B"). Cross-hatched regions are the brightest nebulosity; stippled areas are fainter nebulosity.

than F6 III) and 7200 Å photospheric blends (F8 III: Jacoby, Hunter, and Christian 1984).

With a type of F8 III, the HH 57 exciting star resembles the spectral types through which V1057 Cyg passed in the years following its outburst (Herbig 1977). Reipurth (1985) identifies the HH 57 star with the FU Ori class on the basis of its near-infrared steam absorptions (cf. FU Ori and V1057 Cyg; Cohen 1975) and its (slow) photometric brightening. We measured $B = 18.4$, $V = 16.3$, close to an extrapolation of the magnitudes in Table 1 of Graham and Frogel (1985), that extend only as far as 1984 March 10.

Some of the stellar absorption lines seem "washed out," as if broadened. We suggest that this effect arises through sizable rotation of the HH 57 star, a characteristic noted by Herbig (1977) in other FU Ori stars.

The P Cyg structure at Hα, described in detail by Graham and Frogel (1985), is very prominent. Deep sodium absorption occurs in the stellar spectrum, too strongly to be photospheric. Our spectra of HH 57A, B, and Reipurth 13 also reveal a definite sodium feature. We therefore identify this as interstellar in origin but cannot distinguish between material widely distributed along the line of sight and that present only in the dark cloud in which HH 57 lies. Reipurth (1985), too, concluded that this sodium feature is intrinsic to the star.

In HH 57A $\log I(\mathrm{H}\alpha)/I(\mathrm{H}\beta) = 0.72$, $\log I(\mathrm{H}\beta)/I(\mathrm{H}\gamma) = 0.51$. If these lines arise by collisional excitation in a typical Herbig-Haro object (with intrinsic ratio $I(\mathrm{H}\alpha)/I(\mathrm{H}\beta) = 3.2$) then the interstellar A_v is roughly 1.4.

Narrow-band continuum colors (Cohen and Kuhi 1976) between 5400, 6000, and 6700 Å indicate that $[54, 67] = 1.38 \pm 0.04$, $[60, 67] = 0.67 \pm 0.03$ for the star, compared with intrinsic colors for an F8 star of 0.31 and 0.07, respectively. A_v is equal to 3.94 * {color excess in [54, 67]} and 8.13 * {color excess in [60, 67]} which come from the Miller and Matthews (1972) approximations to the interstellar reddening law with R of 3.10. The continua in HH 57A, B, and Reipurth 13 are bluer than the star itself, so all three nebulae might reflect starlight to us along different indirect paths. Confirmation that the HH 57 nebula reflects starlight comes from the obvious absorption features near 4300 Å in HH 57A, and near 4310

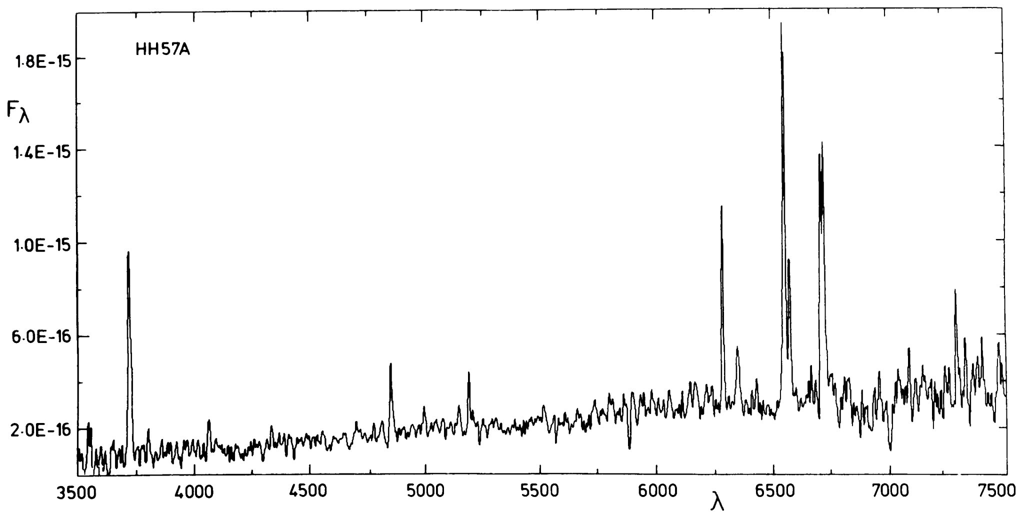

FIG. 3.—IPCS spectrum of HH 57A; details as in Fig. 1

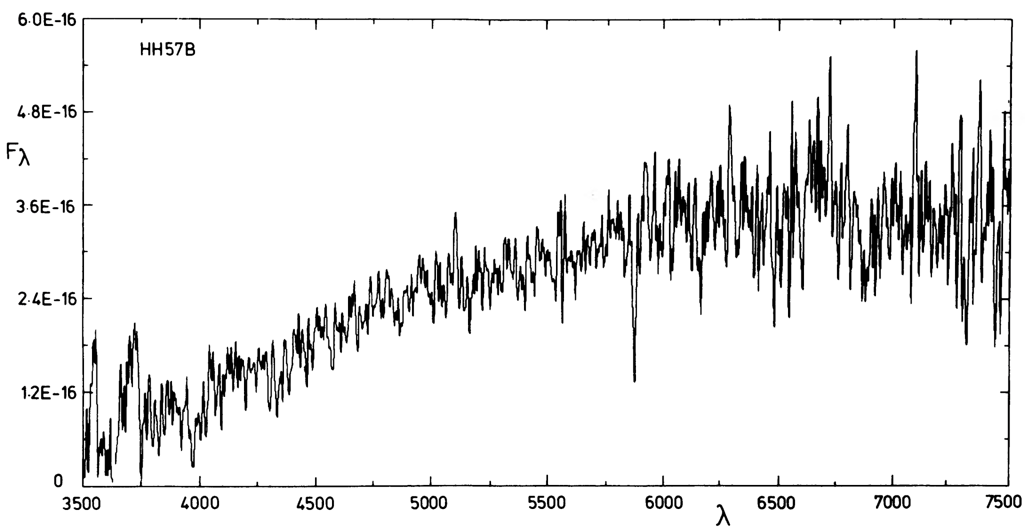

FIG. 4.—IPCS spectrum of HH 57B; details as in Fig. 1

and 4860 Å in HH 57B; probably the *G* band and Hβ. The observed colors signify extinctions, A_v, as follows: 4.6 $\pm$ 0.3 to the star directly: 0.35 $\pm$ 0.05 along the indirect paths within the HH 57A, B nebulosity; and 1.1 $\pm$ 0.2 by way of Reipurth 13, if all three nebulae truly reflect the same starlight.

IV. DISCUSSION

If circumstellar dust grains thermalize starlight then the ratio of stellar far-infrared to visual luminosities yields the stellar extinction. The observed energy distribution from 0.35 to 160 μm, from our optical, Graham and Frogel's (1985) near- and mid-infrared, and Cohen *et al.*'s (1984) far-infrared observations, indicates that thermal radiation dominates photospheric by 1.25 μm. The integrated, observed "optical" (between 0.35 and 1.25 μm) flux is 1.1($-$10) ergs cm^{-2} s^{-1}. The integrated observed infrared flux beyond 1.25 μm, extrapolated to infinity, is 7.9($-$9) ergs cm^{-2} s^{-1}. The ratio of luminosities therefore suggests that A_v is 4.7 mag.

This star is a bright *IRAS* source with fluxes (from the average of data in the *Point Source Catalog* and those derived from *Coadded Survey* data) of 8.6 Jy at 12 μm; 28 at 25 μm; 63 at 60 μm; and 87 at 100 μm. The color temperature is 41 K between 60 and 100 μm, assuming grains with 1/λ emissivity. *IRAS* clearly detects greater fluxes than ground-based or even airborne (with 45″ beams) measurements (Cohen *et al.* 1984), by a factor of 1.54 $\pm$ 0.10 (estimated from data between 10 and 160 μm). The color temperature of the airborne 47 and 95 μm fluxes (corrected for beam-size effects, 1/λ emissivity, and newly determined effective wavelengths since Cohen *et al.* 1984) is 57($+$11/$-$ 8) K, appreciably lower than *IRAS* sees. We feel that these differences are significant and indicate the presence of a spatially extended, low-temperature dusty envelope surrounding the HH 57 star. However, allowance for the extra *IRAS* flux increases the deduced luminosity only to 1.0(−8) ergs cm^{-2} s^{-1} whence A_v toward the star is 4.9 mag. This value agrees very well with the directly determined stellar extinction. Finally, were the star to have normal broad-band colors for an F8 III star, $(B - V)$ would be 0.55, whence $E(B - V) = 1.65$ and $A_v = 5.1$ (for $R = 3.10$).

All these estimates exceed the purely interstellar contribution, estimated from the Balmer lines in HH 57A, supporting the idea of thermal reradiation by circumstellar dust. Further, the difference between the reddening of the star, and of HH 57A just a few seconds of arc away, suggests that the distribution of circumstellar material is quite anisotropic, consistent with the identification of a dust "disk" within the HH 57 nebula (Cohen, Harvey, and Schwartz 1985).

Emission lines near the star come only from HH 57A, arguing that the dust disk lies in the plane normal to the flow from the star. The absence of emission lines from "HH 57B" speaks for anisotropic mass loss that has not emerged to the west of the star, but only to the south. The nebular morphology also supports this interpretation, since it shows a roughly north-south elongation.

Our composite spectrum of Reipurth 13 shows modest Hα emission and very weak [O I]. Without nebular spectropolarimetry we cannot identify the source of this emission. It cannot be reflection of HH 57A for we see no red [S II] lines; it might be from the HH 57 star but then the intensity of the light, at Reipurth 13, would be much greater than at HH 57B. We therefore surmise that Reipurth 13 reflects the light of a locally embedded emission-line star, of very low luminosity, for no obvious near-infrared source occurs there (Reipurth and Wamsteker 1983), nor any coincident *IRAS* object.

It is clearly important to determine the distance to HH 57. This is evidently difficult for a wide range in estimates exists in the literature: 200 pc (Cohen *et al.* 1984); 300 pc (Reipurth 1985); < 1100 and 700 pc (both by Graham and Frogel 1985). Now that L(bol) can be estimated accurately, the most reasonable method for assessing a distance to HH 57 would be based on the sole assumption that, bolometrically, the HH 57 exciting star is comparable to other FU Ori–type stars, namely FU Ori (250 $L_\odot$: combining *IRAS* data with those by Cohen 1973) and V1057 Cyg (470 $L_\odot$: data of Rieke, Lee, and Coyne 1972 and a distance of 575 pc Grasdalen 1973). Equating the luminosity of the HH 57 star [4.05(−4)D^2 (pc)] to the average of these two stars (360 $L_\odot$) suggests a distance of 940 pc. The spectroscopic parallax of a normal F8 III ($M_v = +1.7$), with $A_v = 4.9$ and $V = 16.3$, would be 870 pc, entirely consistent with the bolometrically determined distance. This large distance is also in keeping with the absence of significant proper motion for HH 57 (Schwartz, Jones, and Sirk 1984). At 900 pc, the flattened far-infrared structure resolved by Cohen, Harvey and Schwartz (1985) would have a semimajor axis ~ 17,000 AU, and the cooler *IRAS* emission would lie beyond ~ 30,000 AU from the star.

V. CONCLUSION

We have classified the exciting object of HH 57 as an F8 III star with an extinction, principally circumstellar, of 4.9 mag. The associated nebulosity is reflection rather than in emission in character. Circumstellar material is organized anisotropically, resulting in substantially greater stellar extinction than that toward the slightly displaced HH 57A knot. Star, HH object, and a flattened, resolved far-infrared structure are embedded in an extensive cooler region that we identify as a remnant of the still-infalling circumstellar envelope around this very young star (cf. Stahler, Shu, and Taam 1980).

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