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INFRARED LINE OBSERVATIONS OF DR 21, W75N, AND K3-50

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ABSTRACT

We present hydrogen Brackett α line observations of obscured and very compact radio components in the regions of DR 21, W75N, and K3-50, and of the [Ne II] 12.8 μm line of DR 21. We derive the extinction to these components. In DR 21, the extinction varies markedly from $A_v \sim 18$ mag to the infrared source DR 21(S) to 120 mag and greater to radio components A, B, and C which we suggest form an ionization blister at the far side of the DR 21 molecular cloud. Through the core of DR 21, the ratio of A_v to ^{13}CO column density is $\sim 1 \times 10^{-15}$ mag cm^2 which is larger than the corresponding ratio in cooler, less dense clouds. The extinction is $A_v = 4(+6; -4)$ to the H II region W75N. In the K3-50 region, the extinction varies from $A_v = 4 \pm 2$ mag to radio component A to $\sim$100 mag to radio component C1.

Subject headings: infrared: sources — infrared: spectra — nebulae: general

I. INTRODUCTION

The association of very compact H II regions with infrared sources and molecular clouds is well established. The optical counterparts of such H II regions often are very heavily obscured by dust within the H II region and the associated molecular clouds. The infrared recombination lines and fine-structure lines emitted by the ionized gas are a powerful probe for the study of obscured H II regions. We have obtained hydrogen Bα line observations of very compact H II regions in the areas of DR 21, W75N, and K3-50. For DR 21 we have also measured the 12.8 μm [Ne II] flux. With the available radio flux densities, we use these data to determine the line-of-sight extinction to the regions of ionized gas and hence to estimate their locations within the respective molecular clouds.

II. OBSERVATIONS

The Brackett line observations were obtained at 11″ angular resolution and $\lambda/\Delta\lambda = 500$ spectral resolution with the InSb-equipped cooled grating spectrometer at the 1.3 m telescope of the KPNO. Beam chopping was in declination with 1′ amplitude. The performance of the spectrometer was checked each night by observation of the Bα and Bγ lines of NGC 7027. Flux calibration was obtained by observing ϵ Cyg at the Bα and Bγ wavelengths. The flux density of ϵ Cyg at Bα and Bγ was obtained by smooth interpolation of its H, K, L, and M band flux densities. Supporting observations were also obtained at the 1.3 m telescope by using the variable aperture, InSb-equipped, broadband photometer and the circular variable filter spectrometer.

The [Ne II] line observations were obtained with a piezoelectrically scanned Fabry-Perot spectrometer at the 1.5 m telescope of the Mount Hopkins Observatory, Arizona. Spectral resolution at the 780 cm^{-1} frequency of the [Ne II] line was typically 1 cm^{-1}. Two different beam sizes were used: a 30″ field of view in 1977 June, and a 15″ field of view in 1977 September.

The Bα observations were generally made at the peaks of the radio emission of the compact H II regions mapped by radio interferometer observations. In the DR 21 region, our observations included the radio components A, B, C, and D identified by Harris (1973). Wynn-Williams, Becklin, and Neugebauer (1974) found two infrared sources in this region: DR 21(S) located approximately 10″ to the northwest of radio component A and DR 21(N) at approximately the same position as radio component D. We mapped the region of the infrared source DR 21(S) in the L (3.5 μm) band at 5″ resolution and observed in Bα (Fig. 1) at the peak of the 3.5 μm emission. The coordinates of this position, and of the other positions at which we observed Bα, are given in Table 1. In W75N we observed at the peak of the relatively weak radio continuum source (Harris 1974), which is essentially the same as the position of the 20 μm source (Wynn-Williams, Becklin, and Neugebauer 1974). Our observations in the K3-50 region were made at the positions of the radio components A, C1, and C2 (Harris 1975; Israel 1976; Colley and Scott as quoted by Wynn-Williams *et al.* 1977). Infrared studies of this region are described by Wynn-Williams *et al.* (1977).

Our Bα results are listed in Table 1 (col. 4) (the listed upper bounds are at the 3 σ level). The 5 GHz radio flux density within the 11″ field of view of our Bα observations is listed in column (5). For the regions whose radio emission extends over an area larger than

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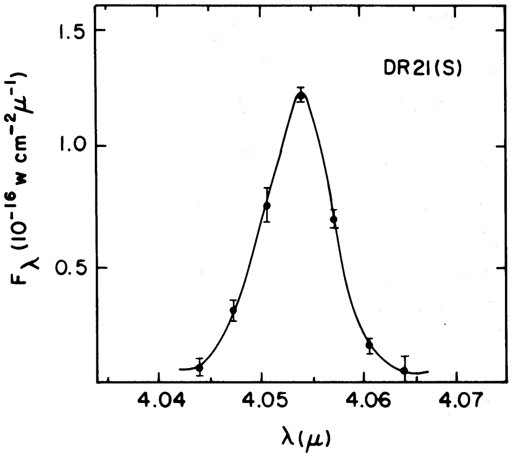

FIG. 1.—The Bα line profile measured in an 11″ beam at DR 21(S) at the peak of the 3.5 μm continuum emission (Table 1) at spectral resolution $\lambda/\Delta\lambda \sim 500$. At this resolution the line is not resolved.

our beam, we have integrated the contours of the radio maps over the area enclosed by our 11″ beam. Both the 30″ beam and the 15″ beam observations of DR 21 in the [Ne II] line were centered at radio component B (α[1950] = 20^{h}37^{m}14^s.0; δ[1950] = 42°09′03″). The flux observed in the line with the 30″ beam is $(3.5 \pm 0.6) \times 10^{-17}$ W cm^{-2}. Subsequent observations of DR 21 with a 15″ beam failed to show [Ne II] emission greater than 3×10^{-18} W cm^{-2} (3 σ). This apparent discrepancy is most easily understood in terms of spatial variations of the extinction, as discussed in § III.

III. DISCUSSION

a) DR 21 and W75N Regions

We estimate the extinction to the compact H II regions by comparing the observed line fluxes with values predicted on the basis of the radio free-free emission and recombination theory. If one assumes that the ionized gas is pure hydrogen and uses the departure coefficients calculated by Giles (1977) for Baker-Menzel Case B at temperature 10^4 K and electron density 10^4 cm^{-3}, the predicted Bα line flux is

$$I(\mathrm{B}\alpha) = 1.6 \times 10^{-18} S(5\ \mathrm{GHz})(10^4/T_e)\ \mathrm{W\ cm^{-2}},$$

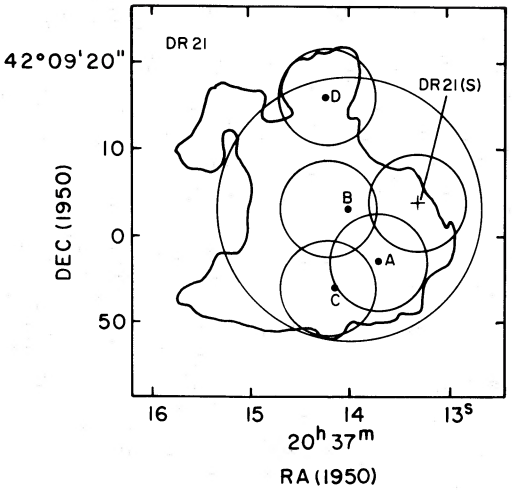

FIG. 2.—A schematic map of the DR 21 region, adapted from Harris (1973). The outermost contour of the 5 GHz continuum is shown. The positions of the radio components A, B, C, D are shown (*solid black dots*). The small circles represent the 11″ beam of the Bα observations and are centered at the positions given in Table 1. The large circle, centered at component B, represents the 30″ beam width of the [Ne II] observation.

where S(5 GHz) is the radio flux density in janskys as given in Table 1. The predicted values of I(Bα) are given in Table 1 (col. 6). For the DR 21 region we used T_e = 8000 K as determined by Harris (1973), and for all the other regions $T_e = 10^4$ K was assumed. The ratio I_{obs}(Bα)/I(Bα) yields the extinction at Bα. We estimated the corresponding visual extinction by use of the van de Hulst No. 15 extinction curve (Johnson 1968), which gives $A_v = 30\ A(4\ \mu\mathrm{m})$. Obviously, the applicability of this extinction curve to very dense molecular clouds is uncertain. The derived A_v's are listed in Table 1 (col. 7). The Bα results for the DR 21 region are summarized in Figure 2, which shows the relationship of the several positions observed. It is evident that the extinction to the regions of ionized gas in DR 21 varies considerably—the lowest values are obtained in the directions of the infrared sources DR 21(S) and DR 21(N), while the visual extinction is ~120 mag or greater to radio components A, B, and C.

TABLE 1

Bα LINE RESULTS

Source (1)	α(1950) (2)	δ(1950) (3)	I_{obs}(Bα) (10^{-19} W cm^{-2}) (4)	S(5 GHz) (Jy) (5)	I(Bα) (10^{-19} W cm^{-2}) (6)	A_v (mag) (7)
DR 21(S)–3.5 μm peak	20^{h}37^{m}13^s.3	42°09′04″	9.8 ± 0.3	0.89	17	18 ± 1
Radio component A	20 37 13.7	42 08 57	1.8 ± 0.3	3.4	68	118 ± 6
DR 21, radio component D	20 37 14.2	42 09 16	1.4 ± 0.3	1.1	21	90 ± 6
0^s.2 E of radio component B	20 37 14.2	42 09 03	< 1.0	2.6	52	> 130
0^s.1 E of radio component C	20 37 14.2	42 08 54	< 1.7	3.5	70	> 120
W75N	20 36 51.1	42 27 19	1.4 ± 0.3	0.1	1.6	4(+6; −4)
K3-50, radio component A	19 59 50.1	33 24 19	57 ± 4	4.0	64	4 ± 2
Radio component C1	19 59 58.4	33 25 49	0.58 ± 0.13	0.8	13	100 ± 7
Radio component C2	19 59 59.7	33 25 52	2.9 ± 4	0.4	6.4	25 ± 4

References for positions of radio components: DR 21: Harris 1973; W75N: Harris 1974; K3-50: Harris 1975.

We use our [Ne II] measurement in a similar manner to estimate an average extinction to the regions of ionized gas included within the 30″ beam. Since this beamwidth included nearly the entire area of Harris's (1973) radio map, it is appropriate to use the 18.5 Jy integrated flux density of the region. With Petrosian's (1970) analysis of the [Ne II] line strength, the assumption of "normal" Ne abundance (Ne/H = 10^{-4} [Auer and Mihalas 1973]), and assuming that all the Ne is in the form of Ne II, which is appropriate at 8000 K, we obtain 5.7×10^{-16} W cm^{-2} for the flux of the [Ne II] line in a 30″ beam in the absence of extinction. Comparison with the observed flux yields $A(12.8\ \mu\mathrm{m}) \approx 3.0$ mag. Using the van de Hulst No. 15 curve to estimate the visual extinction, according to $A_v \sim 100\ A(12.8\ \mu\mathrm{m})$, yields $A_v = 300$ mag.

Apart from the uncertainty in this estimate because of our ignorance of the actual Ne II abundance, this A_v estimate is very likely to be an overestimate because it neglects contribution to the 12.8 μm extinction of the broad silicate absorption feature centered at ~9.8 μm. Observations of the silicate feature in compact H II regions by Gillett *et al.* (1975) suggest that the extinction at 12.8 μm is greater than would be expected from the van de Hulst law. These authors find that $A_v \approx 50\ \tau(12.8\ \mu\mathrm{m})$ gives reasonable agreement with the observations. For DR 21, then, we obtain $A_v \approx 150$ mag for the *average* extinction to the region. The actual extinction to the core of DR 21 may, in fact, be much higher, since the [Ne II] emission may be "leaking out" from the region of lower extinction associated with the near-infrared source. In the direction of the compact H II region W75N our Bα measurements yield $A_v = 4(+6; -4)$ mag.

The extinction that we have inferred to the several components of DR 21 and W75N is likely to arise in the giant molecular cloud complex associated with the DR 21–W75 region. By CO observations, Dickel, Dickel, and Wilson (1978) have delineated two molecular clouds in this region, one at $V_{\mathrm{LSR}} = -3$ km s^{-1}, primarily associated with DR 21, and the other at $\sim +9$ km s^{-1}, primarily associated with W75N, and suggest that the two clouds are interacting. From submillimeter observations of DR 21, DR 21(OH), and W75N, the dust column density through these sources is known to be very large and comparable: at 350 μm and 1 mm the dust optical depths (derived from observation with ~1′ resolution) of the cores of these three sources are the same to a factor of 2 (Westbrook *et al.* 1976; Righini-Cohen and Simon 1977; Righini-Cohen, Simon, and Cassar 1979 in preparation). Our Bα observations indicate that the dust column density through DR 21 leads to at least $A_v \sim 120$ mag, thus indicating that a comparable value pertains through the W75 molecular cloud. It follows then either that the H II region W75N is located deep within its molecular cloud but we are seeing it through a "hole" of lower extinction, or that it is near the surface of the molecular cloud on the near side. The center of the submillimeter source is separated by ~20″ from the H II region/near-IR source (Harvey, Campbell, and Hoffmann 1977). It is evident that the dust column density to the near-IR source is much less than to the submillimeter source.

In DR 21, the analysis summarized in Table 1 indicates that components A, B, and C are deeper, along our line of sight, within the molecular cloud than is component D. It is possible that A, B, and C are in fact on the far side of the cloud and that A_v in the range 120–150 mag is a measure of the extinction through the entire cloud. It is interesting to note that the velocity of the H109α recombination line peaks at $V_{\mathrm{LSR}} \sim +2$ km s^{-1} (Mezger *et al.* 1967), while the velocity of the DR 21 molecular cloud is ~ -3 km s^{-1}. It is reasonable to associate the H109α line emission with components A, B, and C because they are far stronger free-free emission sources than D. It is plausible then to conjecture that components A, B, and C form an ionization blister on the far side of the molecular cloud with the ionized gas flowing away from the cloud surface. Radio component D is at approximately the same position as the infrared source DR 21(N) and the peak of 53 μm emission (Harvey *et al.*). The extinction $A_v \sim 90$ mag to component D indicates that it has less foreground absorption than components A, B, or C. As indicated by Table 1 (col. 5), the emission measure of the ionized gas within our beam is the smallest at the position of DR 21(S), where we measured the largest Bα line flux. Clearly, the Bα line flux is strong at this position because of the relatively low extinction to the ionized gas. This suggests that the near-infrared radiation at this position is emitted by relatively warm dust associated with the ionized gas, and it is detectable because it is not attenuated to levels below the sensitivity limits by the overlaying colder dust as it is elsewhere in this region.

The ^{13}CO column density through the core of DR 21 is $\sim 1.2 \times 10^{17}$ cm^{-2} (Dickel *et al.*; Righini-Cohen, Simon, and Cassar, in preparation). Since it appears that $A_v \approx 120$–150 mag through the DR 21 molecular cloud, we obtain that $A_v/N(^{13}\mathrm{CO}) \approx 1 \times 10^{-15}$ mag cm^2. This value is somewhat higher than the

$$A_v/N(^{13}\mathrm{CO}) \sim 4 \times 10^{-16}\ \mathrm{mag\ cm}^2$$

in the cooler and less optically thick Bok globules (Dickman 1978) and the similar ratio determined in our study of the globule B361 (Fischer *et al.*, in preparation).

b) K3-50 Region

K3-50 is one of several H II regions of very high radio-surface brightness within the radio source W58 (see, e.g., Israel 1976). K3-50 is associated with a molecular cloud revealed by CO observations (Wilson *et al.* 1974). We detected Bα radiation from K3-50 radio component A and also the radio components C1 and C2 that have no optical counterparts. The low extinction to K3-50 $A_v = 4 \pm 2$ mag derived from our Bα observations is consistent with absence of extinction at 7.5 μm inferred by Puetter *et al.* (1979) from their measurement of the hydrogen Pfund α line strength, but is surprising if the distance to K3-50 is ~8 kpc as usually adopted. The low extinction supports the model for K3-50 described by Wynn-Williams *et al.* (1977) of a partially ionization-bounded H II region at the edge of the molecular cloud. From infrared photometry of C1 these authors inferred that it must be heavily obscured. Our observations show that the extinction to it, $A_v \sim 100$ mag, is the largest of the components we have studied in this region. C2 is a near-infrared source, while C1 has not been detected at wavelengths below 20 μm. The intermediate extinction to C2, $A_v \sim 25$ mag, confirms the conclusion drawn from our observations of the DR 21 region that H II regions that are detectable as near-infrared sources have less overlying material than those that are not detectable in the near-infrared, and that the lower absorption accounts for their detectability in the near-infrared.

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Note added in proof.—Colley and Scott (1977, *M.N.R.A.S.*, **181**, 703) measured 6 Jy at 15 GHz from K3-50A. With this density, and our measured Bα intensity, we obtain $A_V \sim 17$ mag to K3-50A.

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