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INFRARED EMISSION FROM THE SOUTHERN H II REGION H2-3

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ABSTRACT

The H II region H2-3 has been found to have a large infrared flux with a luminosity of 1 to 2 x 10^5 $L_\odot$ between 1.65 and 25 μ. Most of this flux comes from a single component with a diameter of 110" (2 pc). At 2.2 μ there is an unresolved source which is identified as the exciting star of the nebula; it can provide the required ionization and the total luminosity observed at infrared wavelengths. The 3- to 25-μ radiation is shown to be consistent with dust heated by Lα radiation within the nebula, but much of the 40- to 350-μ radiation probably originates from outside the H II region.

I. INTRODUCTION

The small optical H II region H2-3 (RCW 117, G345.4-0.9) is a bright radio source at 2 cm (Rubin 1970). Radial velocities have been determined from observations of hydrogen recombination lines (Rubin and Turner 1971) and of 21-cm absorption and emission lines (Radhakrishnan et al. 1972). Discrepancies in the results are large, but an estimate of 4 kpc for the distance to H2-3 is not unreasonable. Intense 40- to 350-μ emission has been measured by Emerson, Jennings, and Moorwood (1973) with a spatial resolution of 5'.

II. OBSERVATIONS

The 1.65- to 20-μ photometry discussed in this paper was obtained on the 36-inch (92-cm) telescope at Cerro Tololo Inter-American Observatory in 1971 April, on the 24-inch (61-cm) telescope at Mt. Wilson in 1971 May, on the 40-inch (102-cm) telescope at Las Campanas Observatory in 1972 April and September, and on the 88-inch (224-cm) telescope at Mauna Kea Observatory in 1973 May. The data consist of spatial scans plus photometry at selected points. From right ascension and declination scans at

2.2, 3.5, 10 and 20 μ with 15" and 45" apertures, the source was found to be roughly circularly symmetric with a full width of approximately 110" at all observed wavelengths. The infrared source appears to be of the same order of size as the image of H2-3 on the Whiteoak extension of the Sky Survey. There is also good agreement between the position of the center of the optical image on the survey print and the extended infrared source (table 1). A careful search of the central region of the nebula with 10" resolution at 2.2 μ revealed one discrete source with flux densities (10^{-26} W $m^{-2}Hz^{-1}$) of 0.12 ±0.02 at 1.65 μ, 0.16 ±0.02 at 2.2 μ, and less than 10 at 10 μ. The position of this latter object, which in § IVb we identify as the exciting star of the nebula, is given in table 1.

The results of the scans and of photometry with various sized apertures are summarized in figure 1. All of the observed infrared colors are constant as a function of nebular radius to within the errors, although point photometry at 2.2 and 3.5 μ with a 23" aperture shows that the outer regions of the nebula at a radius of 44" are 0.7 ±0.2 magnitude redder than the center of the nebula.

Figure 1 has been used to obtain the total fluxes within the central 110" area of H2-3; these fluxes are shown in figure 2.

III. SUMMARY OF PROPERTIES

1. H2-3 consists of a single extended 2-pc diameter source with a luminosity of $(1.8 \pm 0.5) \times 10^5 L_\odot$ between 1.65 and 25 μ. This radiation appears to originate from within the optical nebula.

2. The infrared surface brightness of the source increases towards the center.

3. At 1.65 and 2.2 μ there is an unresolved source within the nebula. The [1.65 μ] - [2.2 μ] color of this source is 0.4 magnitudes bluer than that of the extended nebula.

4. Longward of 3.5 μ there is a considerable excess of emission compared with that predicted from the radio data by use of the extrapolation formulae of Willner, Becklin, and Visvanathan (1972). Shortward of 3.5 μ the opposite is true, and there is a deficiency.

5. The infrared colors are independent of aperture size, to within the errors of the measurements, except perhaps in the outermost regions of the nebula.

IV. DISCUSSION

a) The Reddening

By comparing the [1.65 μ] - [2.2 μ] color and the 1.65-μ flux with the values expected on the basis of recombination emission (Willner et al. 1972), we obtain visual absorptions of 8 and at least 7 magnitudes, respectively. These values were computed by using the van de Hulst reddening law (Johnson 1968). If, as will be shown in § IVb, the discrete source seen at 2.2 and 1.65 μ is the exciting star of H2-3, then its observed colors lead to a visual absorption of 15 magnitudes. These values for the absorption are not necessarily inconsistent because of unknown contributions from dust emission to the nebular and stellar fluxes.

b) The Exciting Star

The discrete source observed at 1.65 and 2.2 μ can probably be identified as the exciting star in H2-3 because (a) it has a small diameter, (b) it has a much bluer color in the 2-μ region than the nebula itself and, (c) it is

located within 20" of the geometric center of the nebula (table 1).

If the discrete source is at the distance adopted for H2-3 and its extinction is as discussed in the previous section, then its absolute magnitude at 2.2 μ is -5.0. For it to be the exciting star of H2-3 it must be an O star, so that V - [2.2] = -0.96 magnitudes (Johnson 1966) and $M_V \approx -6$ magnitudes; the apparent visual magnitude of such a star would be about 17. As will be shown below, both the ionizing flux and the total luminosity from H2-3 can be provided by such an early-type star; the unlikely possibility that the object is a very late-type M star unassociated with the nebula will not be considered.

c) The Dust Temperature

The 3.5- to 20-μ energy distribution shown in figure 2 cannot be fitted by a single temperature black-body curve; if this radiation arises from hot dust there must be a range of dust particle temperatures within the nebula. To within the errors of the measurements, the 3.5- to 20-μ energy distribution does not change over the face of the object, indicating that the range in dust temperatures varies little throughout the nebula. The dust temperature as characterized by the 10- and 20-μ fluxes is about 170°K; the central 30"

has an optical depth at 20 μ of approximately 5×10^{-4}.

d) Mechanism for Heating the Dust

If the 2-μ point source is the exciting star of the nebula, then, as pointed out in § IVb, its absolute visual magnitude is -6. A zero-age main sequence star of this magnitude would have a spectral type O4 (Conti and Alschuler 1971) and a surface temperature of 50,000°K (Conti 1973). Using the latest model atmospheres of Mihalas (1972), Westbrook (private communication) has calculated the total luminosity of such a star to be 1.4×10^6 $L_\odot$. Since Emerson et al.'s (1973) 40-350 μ flux density indicates a luminosity of 1.0×10^6 $L_\odot$, assuming a distance of 4 kpc, it is very likely that all of the infrared emission from H2-3 is the result of heating of dust particles either directly or indirectly by stellar energy.

Where are these particles? Observations have shown that the infrared energy in the range 1 to 25 μ is all being emitted from within the ionized region. Because of poorer resolution at longer wavelengths it cannot be directly determined from the observations whether this is also true for the remaining 85 % of the total power from H2-3, or whether the bulk of the 100-μ emission is being radiated from a neutral region outside the H II region. The crucial factor is the relative density of the dust and ionized gas within the H II region. If the dust density is

low enough, only the resonantly scattered Lα radiation will be absorbed by dust within the ionized region, and all the optical photons will escape into the surrounding neutral gas (see, e.g., Harwit et al. 1972). From the radio flux density (Caswell 1972) and Rubin's (1968) formula, it may be deduced that 7×10^{49} s^{-1} photons are necessary to ionize H2-3. On the assumption that each of these photons creates a Lα photon, the power available as Lα photons is 3×10^5 $L_\odot$. This value is in excess of the 1.8×10^5 $L_\odot$ known to be emitted from within the H II region itself at $\lambda \leq 25$ μ; this model therefore presents no conflict with observations.

If the dust density in the H II region is sufficiently high, on the other hand, some ionizing photons will be absorbed within the H II region by dust rather than by gas. An 04 zero-age main-sequence star emits about 10^{50} s^{-1} ionizing photons (Westbrook, private communication); a later-type star satisfying the 2-μ observations would emit fewer. As discussed above, about 7×10^{49} s^{-1} photons are required to maintain the ionization in H2-3. Consequently, no more than half of the ionizing photons can be absorbed by dust grains within the H II region; thus the optical depth is less than unity at 900 Å (Petrosian, Silk, and Field 1972) and, therefore, much smaller at visual wavelengths. Most of the visible photons, both from the star and the nebula, will be able to escape the ionized region and be

absorbed in the surrounding neutral gas. This second model, therefore, like the first, leads to the prediction that a significant amount of the radiation at $\lambda > 25\ \mu$ will be emitted from outside the nebula (cf. Lemke and Low 1972). Size measurements at 100 μ and a flux density measurement at 35 μ with a small aperture would obviously be desirable.

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TABLE 1

H2-3 POSITIONS

	Right Ascension (1950)	Declination (1950)
Center of 10-μ emission	$17^h06^m01.5\pm1^s.0$	$-41^\circ32'20\pm10''$
Center of optical emission	17 06 02.5±1.0	-41 32 18±10
Discrete 2-μ source	17 06 02.3±0.4	-41 32 04±5

FIGURE CAPTIONS

Fig. 1 - The flux density-aperture diameter relations for H2-3. The filled circles denote direct photometric observations; the crosses indicate data obtained by integrating under the spatial scans. The dashed line through the 20-μ points shows the relationship for a model in which the volume emissivity E is inversely proportional to the physical central distance r. Also shown is the relationship for a surface of uniform surface brightness.

Fig. 2 - The infrared energy distribution of H2-3 obtained by assuming circular symmetry and integrating the total flux under the spatial scans out to the full 110" diameter of the source. The dashed line represents the infrared fluxes extrapolated from the 2-cm observation of Rubin (1970), with the formula of Willner *et al*. (1972).

REFERENCES

Becklin, E. E., Frogel, J. A., Neugebauer, G., Persson, S. E., and Wynn-Williams, C. G. 1973, Ap. J., 182 (in press).

Caswell, J.L. 1972, Australian J. Phys., 25, 443.

Conti, P. S. 1973, Ap. J., 179, 181.

_____, and Alschuler, W. R. 1971, Ap. J., 170, 325.

Emerson, J. P., Jennings, R. E., and Moorwood, A. F. M. 1973, Nature Phys. Sci., 241, 108.

Harwit, M., Soifer, B. T., Houck, J. R., and Pipher, J. L. 1972, Nature Phys. Sci., 236, 103.

Johnson, H. L. 1966, Ann. Rev. Astr. and Ap., 4 193.

_____. 1968, Nebulae and Interstellar Matter, ed. B. M. Middlehurst and L. H. Aller (Chicago: University of Chicago Press), p. 167.

Lemke, D., and Low, F.J. 1972, Ap. J. (Letters), 177, L53.

Mihalas, D. 1972, Scientific and Technical Report No. 76 (National Center for Atmospheric Research, Boulder).

Petrosian, V., Silk, J., and Field, G. B. 1972, Ap. J. (Letters), 177, L69.

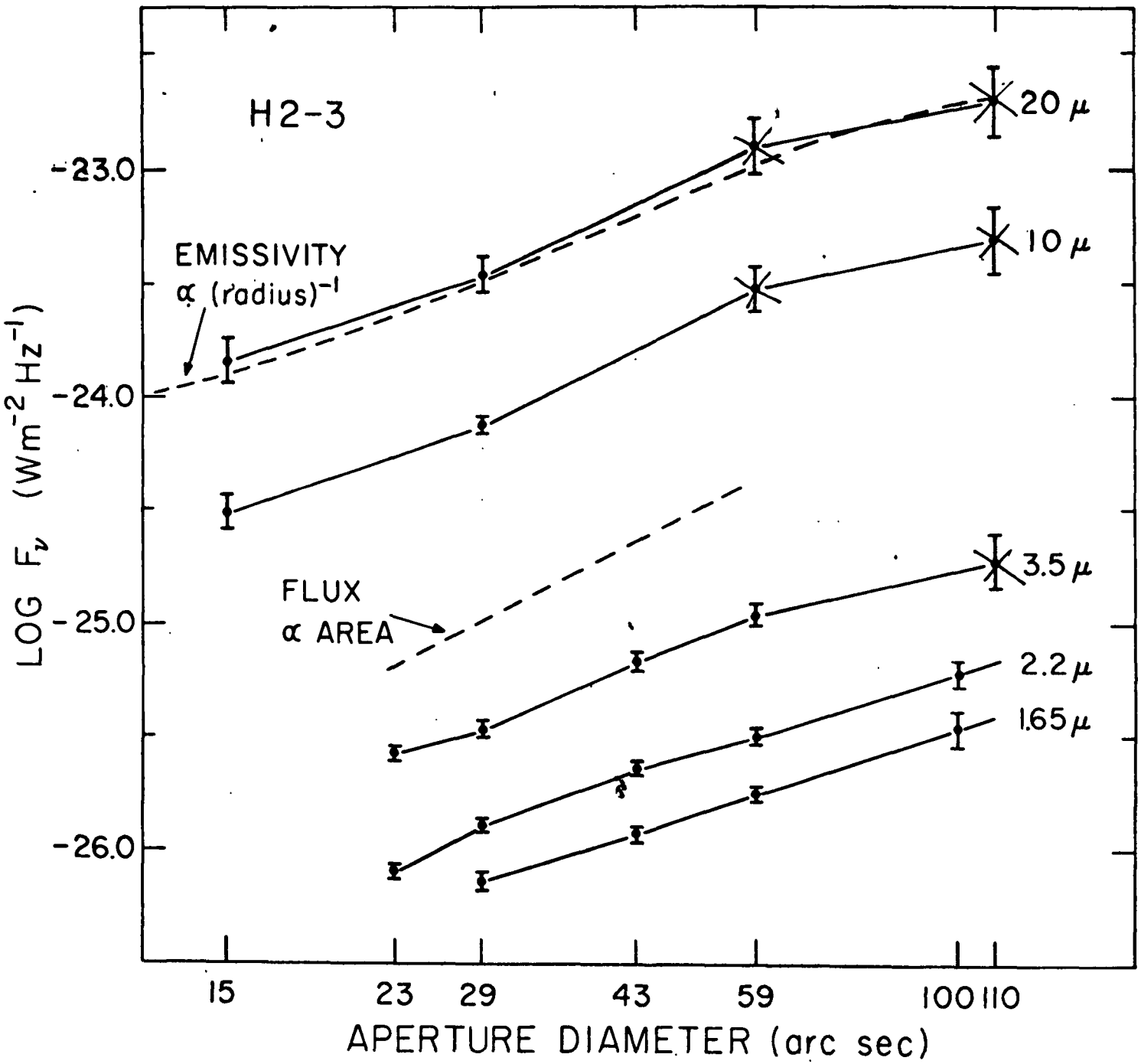
Radhakrishnan, V., Goss, W. M., Murray, J. D., and Brooks, J. W. 1972, Ap. J. Supp., 24, 49.

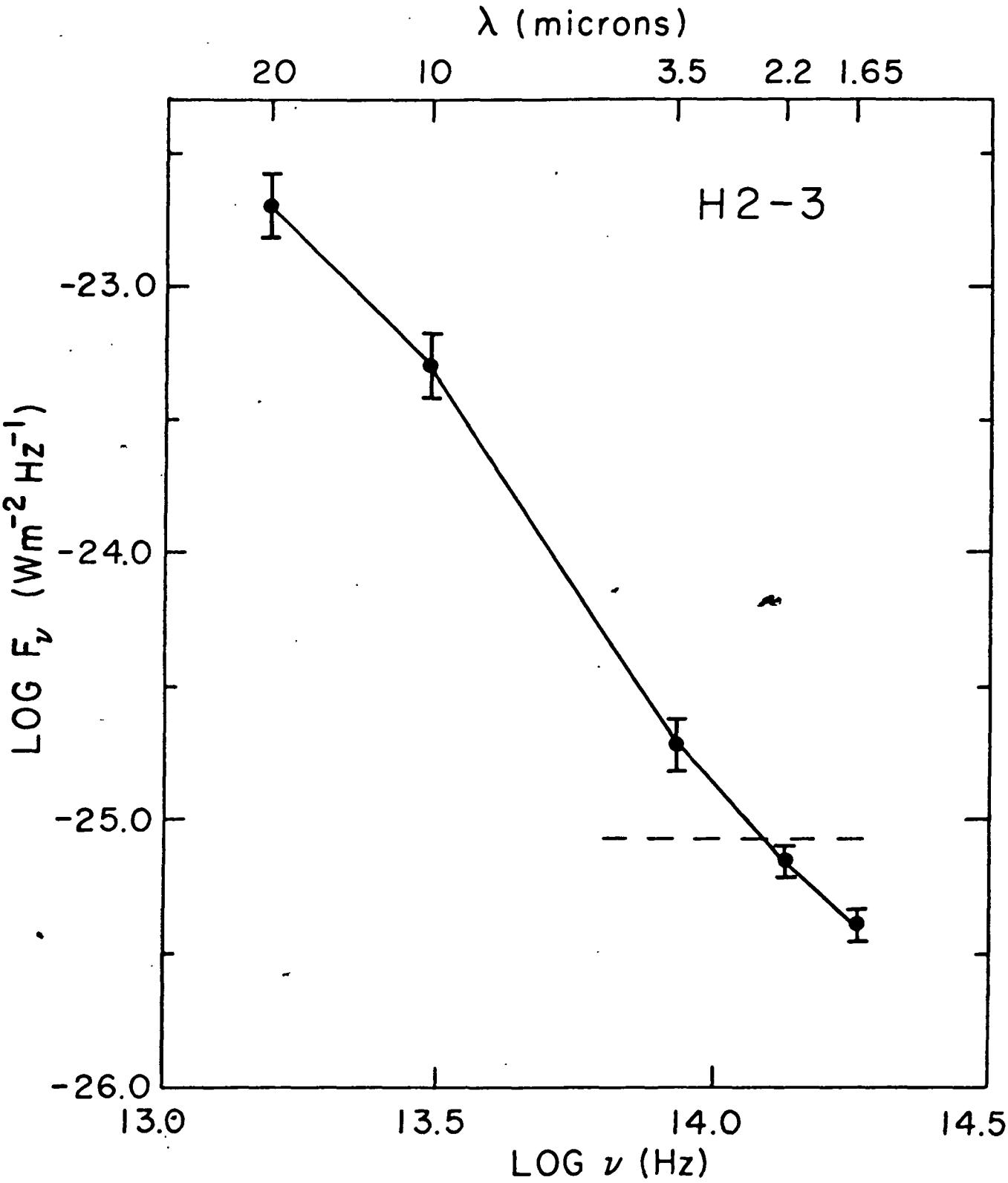
Rubin, R. H. 1968, Ap. J., 154, 391.

_____. 1970, Astr. and Ap., 8, 171.

_____, and Turner, B. E. 1971, Ap. J., 165, 471.

Willner, S. P., Becklin, E. E., and Visvanathan, N. 1972, Ap. J., 175, 699.


H2-3
20 μ
10 μ
3.5 μ
2.2 μ
1.65 μ
EMISSIVITY
∝ (radius)$^{-1}$
FLUX
∝ AREA
-23.0
-24.0
-25.0
-26.0
LOG F_ν (Wm^{-2}Hz^{-1})
15
23
29
43
59
100
110
APERTURE DIAMETER (arc sec)


λ (microns)
20
10
3.5
2.2
1.65
H2-3
-23.0
-24.0
-25.0
-26.0
LOG F_ν ($Wm^{-2} Hz^{-1}$)
13.0
13.5
14.0
14.5
LOG ν (Hz)