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FAR-INFRARED AND CO OBSERVATIONS OF THE W33 COMPLEX

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ABSTRACT

We present multi-band far-infrared (20–250 μm) and CO observations of the giant H II region W33. At a resolution of $\sim 1'$, we resolve the complex into four distinct far-infrared (far-IR) sources, derive their color temperatures and optical depths, and examine their relationship to the molecular and radio continuum properties. Most of the W33 radio continuum features observed at 3.5 cm have far-IR counterparts. The source W33C (W33 Main) has a total IR luminosity of $1.4 \times 10^6\ L_\odot$. The northern source (W33 A) has a high far-IR luminosity ($\sim 10^5\ L_\odot$) but is undetectable in the radio continuum. This source is either a normal ZAMS O7 star with an optically thick H II region of density 10^5–10^6 cm^{-3} or a 30–50 $M_\odot$ protostar in its gravitational contraction stage with a surface temperature of $< 15{,}000$ K.

Subject headings: infrared: sources — interstellar: molecules — nebulae: H II regions — nebulae: individual

I. INTRODUCTION

Although the giant H II region W33 is a strong radio continuum source (Westerhout 1958), it has received little attention compared to the nearby M17 region. In this paper, we present results of $1'$ resolution far-infared (far-IR) and CO observations of the W33 region. We have resolved the complex into several components at the far-IR wavelengths and obtained spectral information in the range 20–250 μm. We examine the nature of the individual W33 sources and their relationship to the radio sources and the molecular clouds. In particular, we discuss the nature of the unusual source W33 A which has a very high ratio of far-IR to radio luminosity.

II. OBSERVATIONS

a) Broad-Band Far-Infrared

The broad-band far-IR observations of W33 were made on 1977 April 26 with the Center for Astrophysics/University of Arizona 1.02 m balloon-borne telescope and a 40–250 μm photometer. Stier (1979) gives a detailed description of the telescope, photometer, and observing procedure. Briefly, three bolometers, each with a field of view of $1'.3$ in elevation and $0'.8$ in cross-elevation, are separated by $1'.5$ in elevation. We mapped by making a series of $100'$ long cross-elevation scans separated by $1'.3$ in elevation. The telescope scan rate was $3'.3$ s^{-1}. The 16 Hz oscillations of the secondary mirror produced a beam separation of $5'.4$ in cross elevation. An optical camera co-aligned to the telescope and sensitive to stars brighter than 6.5 mag provided far-IR source positions with rms uncertainties of about $0'.6$ (Stier *et al.* 1982).

We calibrated the experiment by observing Mars for which we adopted the brightness distribution of Wright (1976). For an assumed source blackbody temperature of 50 K the effective wavelength was 77 μm. The source sizes were determined by deconvolution of Gaussian fits to scans. The total uncertainty in the far-IR photometry, dominated by calibration uncertainty, was about 30%. The system noise equivalent flux density was 40–70 Jy Hz$^{-0.5}$.

b) Four-Band Far-Infrared Photometry

We also observed W33 with a four-band photometer located at the focal plane of the telescope described above, in a balloon flight on 1979 April 24. The photometer which has been described in detail by Daneu *et al.* (1978) takes in a single entrance field of $0'.95 \times 1'.2$, separates the different wavelengths by a series of reflecting and transmitting restrahlen filters, and reimages the entrance aperture onto four bolometers. The system enables us to observe the same sky field simultaneously in four different spectral bands. The effective wavelengths (bandwidth) in microns are 21(2.5), 42(5.5), 73(22), and 135(56), respectively. These values are rather insensitive to changes in source blackbody temperature for $T > 30$ K.

We used Jupiter as the calibration source. Its brightness temperature in the four bands was computed from the results of Orton *et al.* (1982). The noise equivalent flux densities were 375, 440, 260, and 320 Jy Hz$^{-0.5}$, respectively, for the four bands. The absolute error was about $\pm 20\%$.

c) CO Observations

We observed the $J = 1$–0 transition of ^{12}CO (115.271 GHz) in 1979 May and December, and ^{13}CO (110.201 GHz) in 1979 December with the NRAO 11 m telescope at Kitt Peak.[7] At these frequencies, the full width to half-power of the telescope beam was about $64''$. We observed by position switching. The reference positions, which we had previously determined to be free of CO emission, were $\sim 5°$ from the source positions. Peak-to-peak noise was < 2 K for the ^{12}CO observations and < 0.5 K for the ^{13}CO observations. The spectrometer had a free spectral range of 167 km s^{-1} and a channel spacing equal to 1.3 km s^{-1}. We observed with the center channel of the filter bank at a frequency corresponding to a velocity of 40 km s^{-1} with respect to the local standard of rest (LSR). The pointing accuracy was $\sim \pm 30''$ ($1\ \sigma$). We calibrated the spectral line data using the chopper wheel method of Ulich and Haas (1976) with the peak of M17 SW as a reference source.

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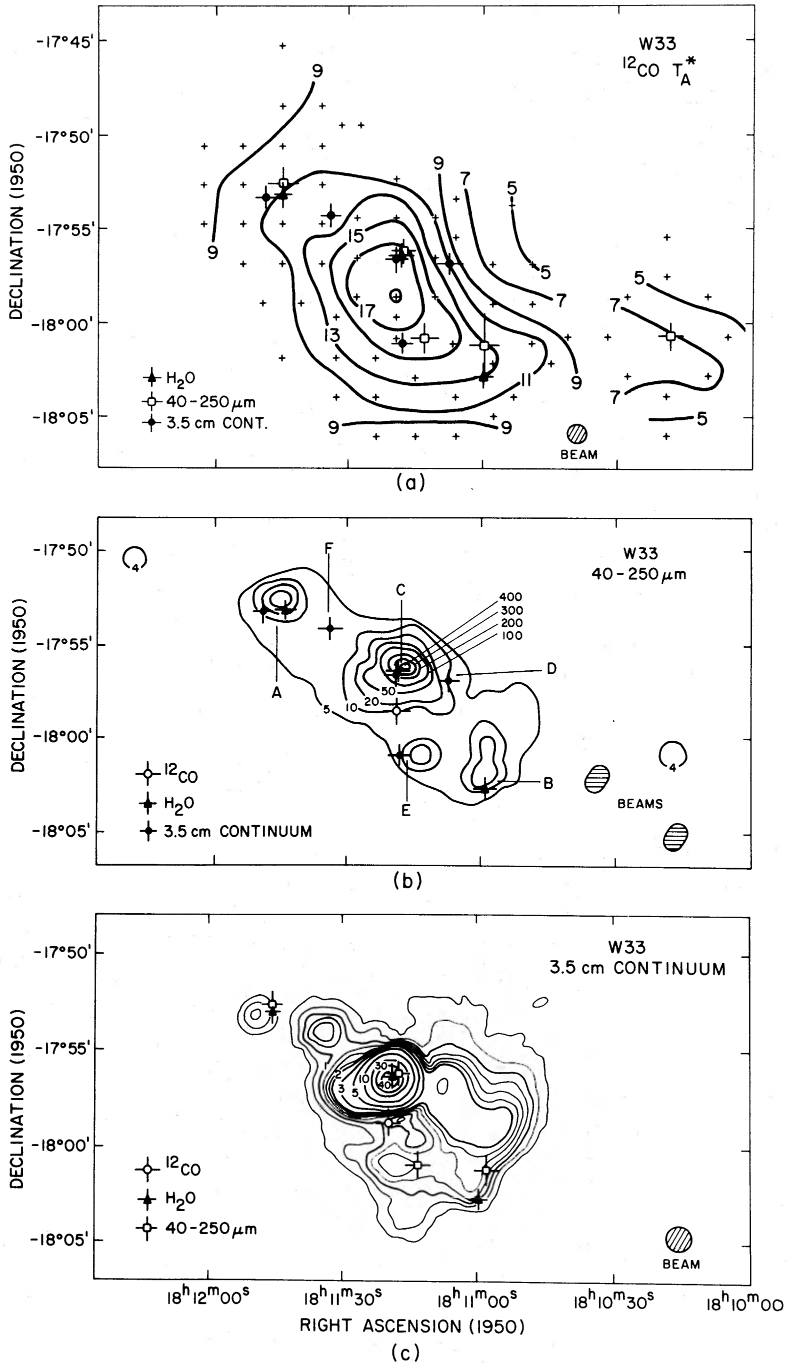

FIG. 1.—(*a*) Map of the 36 km s^{-1} component of ^{12}CO peak T_A^* toward the W33 complex. The HPBW was 1′.1. The crosses denote positions at which the data were taken. (*b*) Map of the 40–250 μm emission from the W33 complex. The contour unit is 5.8×10^{-18} watts m^{-2} Hz^{-1} sr^{-1} or 51 Jy per beam. The HPBW was 0′.8 × 1′.3. The orientation of the far-IR beams during the observations is shown. (*c*) Map of the 3.5 cm radio continuum emission from the W33 complex, adapted from Bieging, Pankonin, and Smith (1978). The contour unit is beam smoothed temperature in units of kelvins. The lowest contour is 0.50 K. The HPBE was 1′.5. The observations were confined to the range 18^{h}10^{m}30^s to 18^{h}12^{m}00^s.

III. RESULTS

In Figure 1, we present $\sim 1'$ resolution maps of ^{12}CO T_A* at 36 km s^{-1} (Fig. 1*a*), 40–250 μm far-IR emission (Fig. 1*b*), and 8.6 GHz continuum emission (Fig. 1*c*, adapted from Bieging, Pankonin, and Smith 1978) of the W33 complex. Each map contains symbols denoting the positions of peak emission at other wavelengths. Individual sources will be referred to by their far-IR designation as in Figure 1*b*.

In Figure 2, we present maps of 73 μm emission (Fig. 2*a*), 135 μm emission (Fig. 2*b*), color temperature as derived from 73 and 135 μm data (Fig. 2*c*), and the derived optical depths at 73 μm (Fig. 2*d*). For deriving the optical depth, we have assumed a source solid angle corresponding to the beam size and a dust emissivity dependence of λ^{-1}. The results from the broad-band 77 μm survey and the narrow-band 73 μm survey are in good agreement. The broad-band survey, however, is more sensitive.

Our ^{12}CO observations are in good agreement with the results of Goldsmith and Mao (1983), who have observed the region extensively in J = 2–1 line of ^{12}CO and selectively in the J = 1–0 transition.

In Table 1, we list the coordinates of the four far-IR sources and their sizes at 42, 73, and 135 μm. None of the sources was resolved at 21 μm. The 73 μm size given is an average of the two surveys. In Table 2, we present the peak and total fluxes of the four sources in the four spectral bands, the ^{13}CO column densities derived for W33 B and W33 C and the total bolometric luminosity of the sources. The bolometric luminosity was calculated for sources A and C by integrating the observed spectrum up to 1 mm using the present data and those of Dyck and Simon (1977) for short wavelengths and of Cheung *et al.* (1980) and Jaffe *et al.* (1984) for millimeter and submillimeter wavelengths. For sources B and E, a blackbody spectrum of 40 K and λ^{-1} emissivity law were assumed. Sources A, C, and E were assumed to be at the kinematic distance of 3.7 kpc (Jaffe, Stier, and Fazio 1982), while for source B a distance of 4.9 kpc corresponding to the 55 km s^{-1} velocity feature was used (Jaffe *et al.* 1984). The values given for W33 C are for the central compact source.

In Figure 3 we have plotted the total fluxes of W33 A and W33 C (compact) as a function of wavelength. Besides the data of the present study, results from others at wavelengths shorter than 20 μm and longer than 100 μm are also shown.

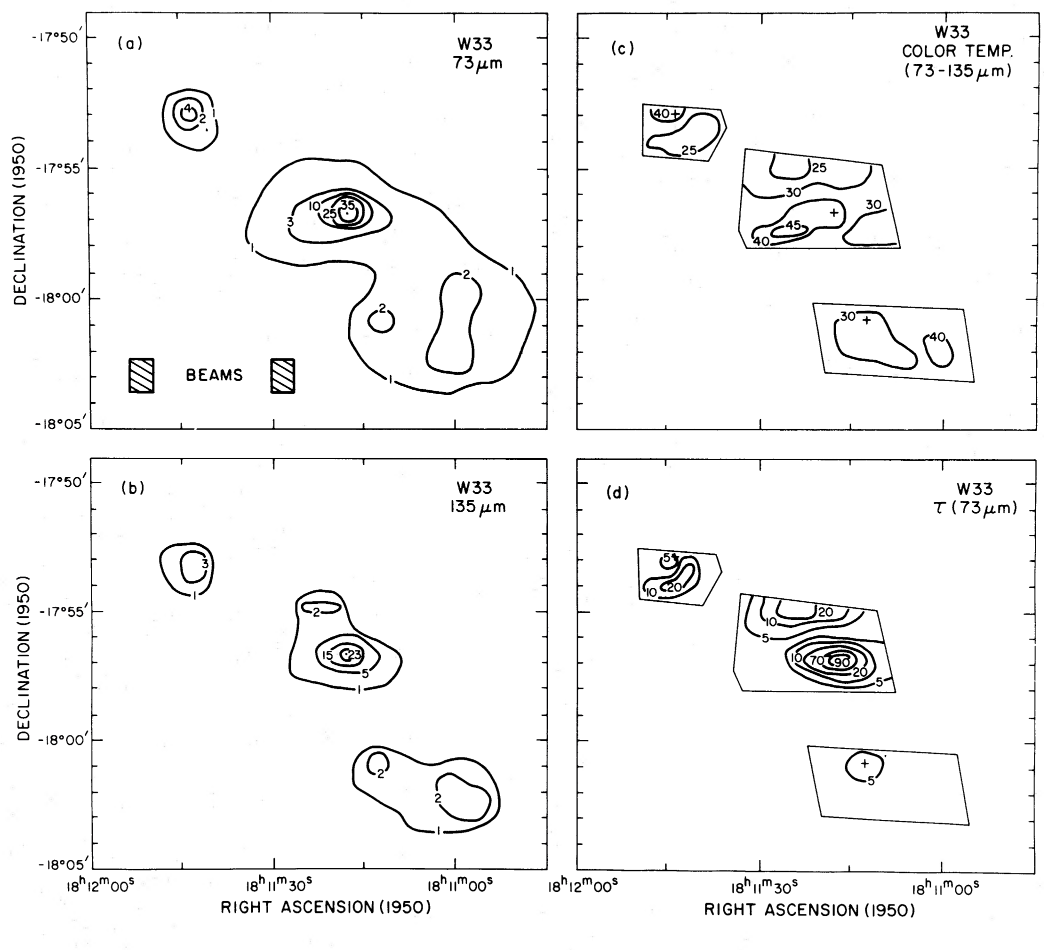

FIG. 2.—(*a*) Map of 73 μm (62–84 μm) emission from W33 complex. The contours are in units of 670 Jy per beam. The beam size was 0.′95 × 1.′2. The orientation of the far-IR beam during scan is shown. (*b*) Map of 135 μm (107–163 μm) emission. The contour unit is 1200 Jy per beam. (*c*) Map of color temperature obtained from the ratio of 73 μm and 135 μm fluxes assuming beam filling and dust emissivity dependence of λ^{-1}. The numbers shown are in degrees kelvin. (*d*) Map of τ_{73}, optical depth at 73 μm derived for the same assumption as in Fig. 2*c*. The numbers shown are in units of 0.01.

TABLE 1

FAR-INFRARED POSITIONS AND SIZES

SOURCE (1)	GALACTIC COORDINATES (2)	α (1950) (3)	δ (1950) (4)	SOURCE SIZE (arcmin) 42 μm (5)	73 μm (6)	135 μm (7)
A	12°91 − 0°26	18h11m44s8	−17°52′40″	<0.4	<0.4	0.7 ± 0.2
B	12.70 − 0.17	18 10 58.6	−18 01 20	...	1.5 × 3.5[a]	2.0 × 2.0
C	12.81 − 0.19	18 11 17.4	−17 56 16	0.6 ± 0.2	0.9 ± 0.1	0.9 ± 0.2
E	12.73 − 0.22	18 11 12.9	−18 01 00	...	0.6 ± 0.2	0.7 ± 0.2

NOTES.—(Explanation of column headings) (1) Source designation as in Fig. 1*b*; (3) Right ascension (±2s5); (4) Declination (±25″); (5)–(7) Full width at half-power of the deconvolved source. The 73 μm size is the mean from broad-band and narrow-band measurements.

[a] Undeconvolved size from 77 μm observations.

IV. DISCUSSION

a) *W33 A*

i) *Size, Temperature, and Optical Depth*

The W33 A far-IR source is coincident (within the positional uncertainties of ±36″) with a type I OH maser (Wynn-Williams, Werner, and Wilson 1974) and an H_2O maser (Genzel and Downes 1977). It also coincides with a compact near-infrared source which has very deep 3 μm and 10 μm absorption features (Dyck 1980; Capps, Gillett, and Knacke 1978; Willner *et al.* 1982). The source is unresolved at 73 μm; however, at 135 μm its deconvolved FWHM size is 0′.7 ± 0.2. Jaffe *et al.* (1984) who have observed W33 A with beam sizes of 30–50″ also find that the FWHM size increases from about 15″ at 60 μm to 45″ at 400 μm. The peak and total flux measurements of Cheung *et al.* (1980) imply a size of ∼60″ at 1 mm.

The ^{12}CO, $J = 1$–0 line is probably very thick toward W33 A since it does not appear as a line temperature peak in our observations. Goldsmith and Mao (1983) who have observed in the $J = 2$–1 line also do not find any enhancement either in the ^{12}CO temperature or in ^{13}CO column density. Jaffe *et al.* (1984) who have mapped W33 A in ^{13}CO and $^{12}C^{18}O$ lines find a possible self-reversal in ^{13}CO line coincident with a peak in $C^{18}O$. They compute a column density of 7×10^{16} cm^{-2} for $C^{18}O$ leading to a H_2 column density of 4.5×10^{23} cm^{-2}.

The 42 μm and 73 μm fluxes imply lower limits to the brightness temperature of 41 K and 34 K, respectively. Combining our measurement at 135 μm and those of Jaffe *et al.* (1984) at 400 μm and Cheung *et al.* (1980) at 1 mm, we find that the data can be fitted by a source temperature of 50 K and a dust emissivity law of λ^{-1}. The 135 μm optical depth implied by this is 0.1.

Using the relationship between $C^{18}O$ column density and visual extinction, A_v, of Frerking, Langer, and Wilson (1982), and the observed $C^{18}O$ column density of Jaffe *et al.* (1984), we derive for W33 A, $A_v \approx 200$. Using our observed 135 μm optical depth, we then get, for τ_v/τ_{135}, the ratio of optical depth at visual wavelength to that at 135 μm, a value of 1800. This is in the same range of 1000–2500 derived for sources like NGC 7023 and NGC 2023 (Whitcomb *et al.* 1980, and references therein). We can also infer the column density of dust from the observed silicate optical depth. Using $\tau_{9.7} = 7.8$ (Willner *et al.* 1982) and an average value of 12 for $A_v/\tau_{9.7}$ (Rieke 1974; Gillett *et al.* 1975; Becklin *et al.* 1978) we derive $A_v = 100$. This is, within a factor of 2, the same as derived above. Thus, within the uncertainties of the various estimates the dense matter around W33 A seems to have a normal gas-to-dust ratio and standard molecular abundances.

ii) *Radio and Total Luminosities*

The total integrated luminosity of W33 A is 10^5 $L_\odot$ for $d = 3.7$ kpc. If this is provided by a single ZAMS star, the

TABLE 2

FAR-IR FLUXES

SOURCE	PEAK FLUXES (10^3 Jy)[a] (Integrated Flux) 77 μm	21 μm	42 μm	73 μm	135 μm	L_{bol}[b]($L_\odot$)	$N(^{13}CO)$ cm^{-2}
A	4.1	...	1.30	3.4	4.0		
	(4.1)		(1.30)	(3.4)	(6.0)	1.0 E5	
B	1.7	...	...	1.7	2.8		
	(7.5)			(7.5)	(11.0)	2.0 E5	4.8 E16
C[c]	28.5	1.3	8.0	27.0	31.0		
	(59.0)	(1.3)	(11.5)	(56.0)	(64.0)	1.0 E6	2.2 E17
E	1.7	...	...	1.5	2.0		
	(2.9)			(2.0)	(2.6)	5.0 E4	

[a] Peak flux for a 50 K blackbody spectrum. Integrated fluxes are given in parentheses. The 77 μm result refers to 40–250 μm broad-band data. The statistical errors in peak fluxes are 45, 300, 500, 200, and 350 Jy, respectively, for cols. (2)–(6). The systematic errors are ±25%.

[b] Bolometric luminosity for a kinematic distance of 3.7 kpc (4.9 kpc for W33 B). See text for details.

[c] Central compact source only.

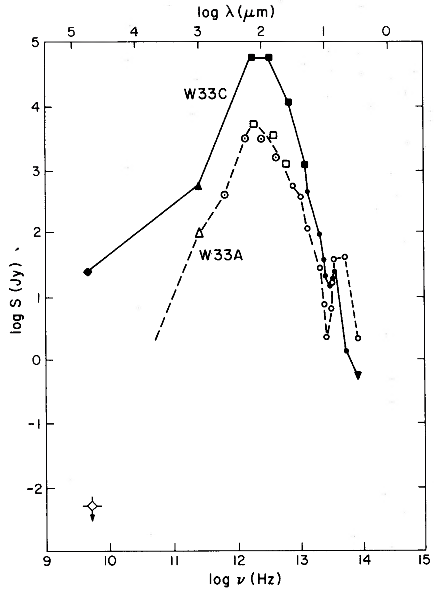

FIG. 3.—Spectra of emission from W33 C Core (*filled symbols*) and W33 A (*open symbols*). References for symbols are: ▽ Frogel and Persson 1974; ○ Dyck and Simon 1977; □ this work; ⊙ Jaffe *et al.* 1984; △ Cheung *et al.* 1980; ◇ Wynn-Williams *et al.* 1981; ◆ Bieging *et al.* 1978. The lines joining the points are only for eye guidance.

expected thermal radio emission from a normal optically thin H II region is 3.4 Jy whereas VLA measurements give an upper limit of 5 mJy for the 5 GHz emission (Wynn-Williams, Beichman, and Downes 1981). Thus, W33 A has one of the largest observed ratios for bolometric luminosity to the luminosity inferred from the radio flux. There are four possible ways to understand this.

1) The energizing source is one or more normal ZAMS stars, but the Lyman continuum photons are absorbed by the dust before ionizing the gas.

This solution does not seem probable since a source with $\sim 10^5\ L_\odot$ luminosity and circumstellar density of $n_H \sim 2 \times 10^5$ cm^{-3} will expel, by radiation pressure, the surrounding dust to radii of the order of 10^{16} cm (Davidson 1970).

2) The energizing source has a low surface temperature so that the flux of ionizing photons is low.

The observed limit to the ratio of luminosity inferred from radio continuum flux to the total luminosity implies $T < 15{,}000$ K which corresponds to B3 or later stars. From the tables of Panagia (1973) we then find that, even taking giants, 10 or more sources are needed to provide the total luminosity. This seems unlikely. However, it is possible that a single B3–B4 supergiant can give the requisite luminosity. If so, this is a rare case of the presence of a supergiant in a young star-forming region.

3) W33 A is a protostar in the gravitational contraction stage; such a star can have high luminosity, but low surface temperature.

From the models of Ezer and Cameron (1967) we find that a star of 30–50 $M_\odot$ can have the requisite luminosity of $10^5\ L_\odot$, and a surface temperature of $< 15{,}000$ K for a period of about 2000–3000 years. The time taken for such an object to reach ZAMS stage is 10^5–2×10^4 years. Thus if W33 A is indeed a protostar, it is a rare event.

4) W33 A is powered by one or more normal O stars, but is optically thick at radio wavelengths.

From the limit of 5 mJy at 6 cm, we can derive an upper limit of 0".2 to the angular size of the H II region, if it were optically thick. Assuming a Strömgren sphere of this size, the electron density is $> 2 \times 10^5$ cm^{-3}. We also derive $n_e > 5 \times 10^5$ cm^{-3} under the assumption that the energizing source is an O7 ZAMS star and the H II region size is 0".2. These values are not much larger than the H_2 density of 2×10^5 cm^{-3} derived from $C^{18}O$ column density.

W33 A has properties somewhat similar to the compact infrared source IRC 2 in Orion which has a deep silicate absorption feature and no detectable radio emission and is a maser source (Aitken *et al.* 1981; Moran *et al.* 1982; Genzel *et al.* 1982). However, no enhancement is seen in 34 μm emission for IRC 2 (Werner 1982); hence, its bolometric luminosity is, most probably, much less than $10^5\ L_\odot$. W33 A also resembles W3(OH). Dreher and Welch (1981), using the VLA, find that W3(OH) starts to become optically thin at 1.3 cm and has a total luminosity of about $1.5 \times 10^5\ L_\odot$ and an electron density of $(1.6–3.3) \times 10^5$ cm^{-3}. High-frequency radio observations of W33 A will be helpful to establish the presence of ionized gas.

b) W33 B

The far-IR source W33 B consists of a ridge of emission on the boundary of a diffuse 3.5 cm emission region and peaks $\sim 1'$ north of W33 B OH/H_2O maser positions (Wynn-Williams, Werner, and Wilson 1974). CO and NH_3 observations indicate that while the dominant velocity feature in the W33 complex is at 36 km s^{-1}, W33 B is predominantly seen at 55 km s^{-1} (Ho, Martin, and Barrett 1981; Goldsmith and Mao 1983; Jaffe *et al.* 1984). Observing with a 30" beam Jaffe *et al.* found a compact far-IR source coincident with the maser position. Our maps of W33 B, both at 73 μm and 135 μm, show the far-IR source to be extended; further, the profiles are different at the two wavelengths. Wynn-Williams, Beichman, and Downes (1981) have mapped the W33 B region with 4" × 6" beam at 5 GHz with the VLA. They found a ridge of emission about 3' long, coincident with the far-IR ridge and peaking about 30" northeast of the maser position. The far-IR source is, most likely, a superposition of a core at 55 km s^{-1} and a halo at 36 km s^{-1} or 55 km s^{-1} or at both velocities.

Taking the central 1' of the far-IR peak we derive from the 73 μm and 135 μm observations, a value of 30 K for the color temperature and $\tau_{135} = 0.09$.

c) W33 C (W33 Main)

W33 C is the strongest source in the W33 complex both in the far-IR and at cm wavelengths. Bieging, Pankonin, and Smith (1978) have observed it at 1.7, 5, and 8.6 GHz; Wynn-Williams, Beichman, and Downes (1981) at 5 GHz with the VLA; and Haschick and Ho (1983) at 20, 6, and 2 cm continuum using the VLA as well as in NH_3 lines. Dyck and Simon (1977) have found a cluster of 20 μm sources within a 30" region.

Our far-IR observations show that W33 C consists of a compact central source and an extended halo. The size of the core source is 0'.6 at 42 μm and 0'.9 at 73 and 135 μm. From the multi-band observations we also find that the emission-peaks at all four bands occur at the same sky position (within $\sim 10''$). This makes it unlikely that the increase in size observed at longer wavelengths is due to superposition of emission from two or more unresolved compact sources separated by $> 30''$. It may be noted that Cheung *et al.* (1980) who have observed W33 C at 1 mm with a 65" beam find a size of 2' (undeconvolved) and no significant offset between the 1 mm and 3.5 cm peaks. The far-IR size is roughly the same as that observed by Bieging, Pankonin, and Smith (1978) at 8.6 GHz with a 1.'5 beam.

The 135 μm surface brightness of the source implies a brightness temperature of 40(+8; −5) K. In order that the emissivity does not increase with λ in the 42–135 μm range we need to have $T_d < 60$ K. A reasonable fit to the 42 μm, 73 μm, and 135 μm surface brightness data is obtained with $T_d = 50$ K., $\tau_{135} \approx 1$, and a dust emissivity dependence of λ^{-1}. However, the ratio of surface brightness at 135 μm and 1 mm implies a λ^{-2} emissivity dependence for the same temperature. If we take into account the fact that, because of gradients in density and temperature, the average density and temperature for the region emitting millimeter radiation is less than the values for the region emitting far-IR, the emissivity index will be <2. Since millimeter emission extends to ~1.'7 (Cheung *et al.* 1980), the density gradient cannot be too steep. Taking a r^{-1} dependence for the density and following the formalism of Scoville and Kwan (1976) for the radiation transfer, we estimate that the emissivity index in the range 135 μm–1 mm is ~1.5.

Our ^{12}CO observations show that the temperature peak occurs ~2′ south of the 3.5 cm radio continuum peak. This is also confirmed by the observations of Goldsmith and Mao (1983). These authors further find that the ^{13}CO column density has a maximum near the radio continuum peak with an additional peak near the ^{12}CO maximum. This reflects the complex matter distribution in the region. Our estimate of 2.2×10^{17} cm^{-2} for ^{13}CO column density toward W33 C is about twice that obtained by Goldsmith and Mao using the more optically thick $J = 2$–1 line. Even this column density is likely to be an underestimate, because of optical depth effects; the H_2 column density implied by the far-IR optical depth is $\sim 1.5 \times 10^{24}$ cm^{-2}.

The total luminosity of W33 C (core + halo) obtained by integrating the observed spectrum and assuming a distance of 3.7 kpc is $1.4 \times 10^6\ L_\odot$, ~80% of which comes from the core source. Hauser *et al.* (1983) who observed the region with a 10′ beam found a flux density of 8.2×10^4 Jy at 150 μm. Since we observe 7.5×10^4 Jy at 135 μm within ~3′, it is clear that most of the emission is from the compact source; with $\tau_{135} \approx 1$ for the central source, the extended emission observed can be explained as due to dust heated by re-radiation from the central source.

Haschick and Ho (1983) from their VLA observations have resolved the cluster of sources powering the W33 C H II region. They find a total of about 10 stars ranging in spectral type of O5.5 to O7.5. Adopting a distance of 3.7 kpc and $T_e = 10^4$ K, we derive from their data an L_α luminosity of $3 \times 10^5\ L_\odot$. Combined with our derived IR luminosity, this leads to infrared excess (IRE) $= L_{IR}/L_\alpha = 4.7 \pm 1.5$ for the cluster. The total and L_α luminosity of the cluster can be calculated by integrating the expected luminosities from a star of mass M_m down to stars of mass M_l, if one assumes a mass function. In the past, the Salpeter initial mass function has been used (Mezger, Smith, and Churchwell 1974; Stier 1979). Following Haschick and Ho, we make use of the more recent present-day mass function (PDMF) listed by Miller and Scalo (1979). The total luminosity of the cluster is given by

$$L_{IR} = \int_{M_l}^{M_m} \phi(M) L(M) dM ,$$

where $\phi(M)$ is the number of stars per unit mass interval at M and $L(M)$ is the luminosity of a star of mass M. The L_α luminosity of the cluster can be evaluated in a similar manner replacing $L(M)$ with $L_\alpha(M)$. Using the total and L_α luminosities tabulated by Panagia (1973) for various spectral types, we find that to fit the observed L_{IR}/L_α ratio, $M_l = 30\ M_\odot$. If we take IRE = 6.2, corresponding to the higher 1 σ limit, $M_l = 21\ M_\odot$. These limits refer to a situation where there is no absorption of L_α photons by the dust in the H II region. Since even a single O5.5 star has an IRE of 4.2, and stars of spectral type later than O5.5 are seen, the observed IRE limits the fraction of L_α photons that can be absorbed to ≤20%. One may argue that the observed IRE is low because of an underestimate of the extended long wavelength IR emission. We find the fraction of total luminosity for $\lambda > 135$ μm to be ~15%. Making use of the 10′ beam observations of Hauser *et al.* in the range 150–300 μm, we get almost the same luminosity. Further, it may be noted that the L_α luminosity we have used may be an underestimate if the electron temperature in W33 is indeed 5000 K as concluded by Bieging, Pankonin, and Smith (1978) instead of 10^4 K used.

Taking the number of stars in the mass range 50–30 $M_\odot$ to be 10 as observed by Haschick and Ho (1983) and using the PDMF of Miller and Scalo (1979), we calculate the total luminosity of the cluster to be $1.6 \times 10^6\ L_\odot$ very close to the value of $L_{IR} = 1.4 \times 10^6\ L_\odot$. If lower mass stars down to 20 $M_\odot$ were present with the same PDMF, the total luminosity would be $2.8 \times 10^6\ L_\odot$, almost twice that observed. Thus the star-forming region in W33 C is characterized by an absence of low mass ($M \lesssim 20\ M_\odot$) stars and very little absorption of L_α photons by dust within the H II region, probably resulting from the expulsion of dust by radiation pressure.

d) W33 E

The deconvolved far-IR size of W33 E is 0.'6 ± 0.'2 and it does not change between 73 μm and 135 μm. Assuming a λ^{-1} emissivity law we obtain a color temperature of 40 K, $\tau_{135} = 0.1$, and a total luminosity of $5 \times 10^4\ L_\odot$.

The far-IR size of W33 E is about a third of the deconvolved 3.5 cm radio continuum size of 2.'1. The luminosity derived from radio continuum emission assuming the energy source to be a single ZAMS star is $10^5\ L_\odot$. The reduced far-IR size and luminosity, along with a possible offset of 70″ (2 σ significance) between the peaks of far-IR and radio continuum emission, indicate that W33 E may be a "blister" source somewhat similar to G14.43−0.69 seen in M17 SW cloud (Jaffe, Stier, and Fazio 1982).

V. CONCLUSIONS

1) In this paper we have presented 40–250 μm broad-band far-IR, narrow band 21 μm, 42 μm, 73 μm, and 135 μm continuum observations, and CO $J = 1$–0 observations of the W33 complex. Sizes, color temperatures, and far-IR optical depths have been determined for the four sources.

2) The size of source W33 A increases with increasing wavelength. It has a total luminosity of $10^5\ L_\odot$, but its radio continuum emission is ~600 times less than that expected for a standard optically thin H II region. Three possibilities are suggested to understand this: (*a*) the energizing source is a low surface temperature supergiant, (*b*) it is a normal O7 star surrounded by an optically thick H II region, (*c*) it is a 30–50 $M_\odot$ protostar in its gravitational contraction stage.

3) The most luminous source W33 C (W33 Main) has a

core-halo structure, with the core source accounting for $\sim 80\%$ of the far-IR flux. The size of the core source increases with wavelength. The 135 μm brightness temperature for the core source is 40 K, implying $\tau > 1$ for $\lambda = 42$ μm and 73 μm. The energy input for the extended emission can be provided by re-radiation from the central source. The total IR luminosity of the cluster is 1.4×10^6 $L_\odot$. The ratio of total luminosity to L_α luminosity for the cluster is 4.7 ± 1.5, which sets limits of $M > 20$ $M_\odot$ for the lowest mass star present, if the mass distribution follows the present day mass function of Miller and Scalo (1979). Further, there is very little absorption of L_α photons by dust within the H II region, probably due to expulsion of dust by radiation pressure.

4) A dust emissivity dependence of λ^{-1} is a good fit to W33 A data up to 1 mm; however, for W33 C, a steeper dependence of $\sim \lambda^{-1.5}$ is indicated for wavelengths between 135 μm and 1 mm.

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REFERENCES

Aitken, D. K., Roche, P. F., Spenser, P. M., and Jones, B. 1981, *M.N.R.A.S.*, **195**, 921.
Becklin, E. E., Mathews, K., Neugebauer, G., and Willner, S. P. 1978, *Ap. J.*, **220**, 831.
Bieging, J. H., Pankonin, V., and Smith, L. F. 1978, *Astr. Ap.*, **64**, 341.
Capps, R. W., Gillett, F. C., and Knacke, R. F. 1978, *Ap. J.*, **226**, 863.
Cheung, L. H., Frogel, J. A., Gezari, D. Y., and Hauser, M. G. 1980, *Ap. J.*, **240**, 74.
Daneu, V., Maxson, C., Peres, G., Serio, S., and Vaiana, G. 1978, *Infrared Astronomy*, ed. G. Setti and G. G. Fazio (Dordrecht: Reidel), p. 335.
Davidson, K. 1970, *Astr. Space Sci.*, **6**, 422.
Dreher, J. W., and Welch, W. J. 1981, *Ap. J.*, **245**, 857.
Dyck, H. M. 1980, *A.J.*, **85**, 891.
Dyck, H. M., and Simon, T. 1977, *Ap. J.*, **211**, 421.
Ezer, D., and Cameron, A. G. W. 1967, *Canadian J. Phys.*, **45**, 3429.
Frerking, M. A., Langer, W. D., and Wilson, R. W. 1982, *Ap. J.*, **262**, 590.
Frogel, J. A., and Persson, S. E. 1974, *Ap. J.*, **192**, 351.
Genzel, R., and Downes, D. 1977, *Astr. Ap. Suppl.*, **30**, 145.
Genzel, R., Reid, M. J., Moran, J. M., Downes, D., and Ho, P. T. P. 1982, *Symposium on the Orion Nebula*, ed. A. E. Glassgold *et al.*, *Annals New York Acad. Sci.*, **395**, 142.
Gillett, F. C., Jones, T. W., Merrill, K. M., and Stein, W. A. 1975, *Astr. Ap.*, **45**, 77.
Goldsmith, P. F., and Langer, W. D., 1978, *Ap. J.*, **222**, 881.
Goldsmith, P. F., and Mao, X. J. 1983, *Ap. J.*, **265**, 791.
Haschick, A. D., and Ho, P. T. P. 1983, *Ap. J.*, **267**, 638.
Hauser, M. G., *et al.* 1983, preprint.
Ho, P. T. P., Martin, R. N., and Barrett, A. H. 1981, *Ap. J.*, **246**, 761.
Jaffe, D., Hildebrand, R. H., Keene, J., Harper, D. A., Loewenstein, R. F., and Moran, J. M. 1984, *Ap. J.*, **281**, 225.
Jaffe, D. T., Stier, M. T., and Fazio, G. G. 1982, *Ap. J.*, **252**, 601.
Mezger, P. G., Smith, L. F., and Churchwell, E. 1974, *Astr. Ap.*, **32**, 269.
Miller, G. M., and Scalo, J. M. 1979, *Ap. J. Suppl.*, **41**, 513.
Moran, J. M., Garay, A., Reid, M. J., Genzel, R., Wright, M. C. H., and Plambeck, R. C. 1982, *Ap. J.* (*Letters*), **271**, L31.
Orton, G. S., Aumann, H. H., Martonchik, J. V., and Appleby, J. F. 1982, *Icarus*, **52**, 81.
Panagia, N. 1973, *A.J.*, **78**, 929.
Rieke, G. H. 1974, *Ap. J.* (*Letters*), **193**, L81.
Scoville, N. Z., and Kwan, J. 1976, *Ap. J.*, **206**, 718.
Stier, M. T. 1979, Ph.D. thesis, Harvard University.
Stier, M. T., Jaffe, D. T., Fazio, G. G., Roberge, W. G., Thum, C., and Wilson, T. L. 1982, *Ap. J. Suppl.*, **48**, 127.
Ulich, B. L., and Haas, R. W. 1976, *Ap. J. Suppl.*, **30**, 247.
Werner, M. W. 1982, in *Symposium on the Orion Nebula*, ed. A. E. Glassgold, *et al.*, *Annals New York Acad. Sci.*, **395**, 79.
Westerhout, G. 1958, *Bull. Astr. Inst. Netherlands*, **14**, 215.
Whitcomb, S. E., Gatley, I., Hildebrand, R. H., Keene, J., Sellgren, K., and Werner, M. W. 1980, *Ap. J.*, **246**, 416.
Willner, S. P., *et al.* 1982, *Ap. J.*, **253**, 174.
Wright, E. L. 1976, *Ap. J.*, **210**, 250.
Wynn-Williams, C. G., Beichman, C. A., and Downes, D. 1981, *A.J.*, **86**, 565.
Wynn-Williams, C. G., Werner, M. W., and Wilson, W. J. 1974, *Ap. J.*, **187**, 41.

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