UNVEILING A COMPACT CLUSTER OF MASSIVE AND YOUNG STARS IN IRAS 17233-3606

Luis A. Zapata\(^1\), Silvia Leurini\(^2\), Karl M. Menten\(^1\), Peter Schilke\(^1\), Rainer Rolffs\(^1\), and Carolin Hieret\(^1\)

\(^1\) Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121, Bonn, Germany
\(^2\) ESO, Karl Schwarzschild Str. 2, 85748 Garching bei München, Germany

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ABSTRACT

We have analyzed sensitive high spatial resolution archival radio continuum data at 1.3, 2.0, 3.6, and 6.0 cm as well as the H\(_2\)O maser molecular line data obtained using the Very Large Array (VLA) in its hybrid AB configuration toward the high-mass star-forming region IRAS 17233-3606 (G351.78-0.54). We find nine compact radio sources associated with this region, six of them are new radio detections. We discuss the characteristics of these sources based mostly on their spectral indices and find that most of them appear to be optically thin or thick ultra- and hyper-compact H\(_\II\) regions ionized by B zero-age main-sequence stars. Furthermore, in a few cases the radio emission may arise from optically thick dusty disks and/or cores; however more observations at different wavelengths are necessary to firmly confirm their true nature. In addition, we compared our centimeter maps with the mid-infrared images from the Spitzer Space Observatory GLIMPSE survey revealing a cluster of young protostars in the region together with multiple collimated outflows, some of which might be related to the compact centimeter objects. Finally, we find that one of these centimeter objects, VLA2d, is well centered in an apparent strong and compact north–south bipolar outflow traced by OH masers and we therefore suggest that this object is energizing the latter.

Key words: H\(_\II\) regions – ISM: jets and outflows – masers – radio continuum: stars – stars: individual (IRAS 17233-3606, G351.78-0.54) – stars: pre-main sequence – techniques: interferometric

1. INTRODUCTION

Attention to the high-mass star-forming region IRAS 17233-3606 (or G351.78-0.54) was first garnered by the detection of very strong maser emission from various species e.g., hydroxyl (OH) and water (H\(_2\)O) (Caswell & Haynes 1980, 1983). At the time of the detection (1980), it possibly contained the strongest known interstellar hydroxyl maser in the sky, with a peak intensity of 1000 Jy (Caswell & Haynes 1980). Later on, intense Class II methanol (CH\(_3\)OH) maser emission was detected (Menten 1991). From the IRAS fluxes and assuming a distance of 2 kpc, it has been estimated that IRAS 17233-3606 has a bolometric luminosity of \(\sim 1.5 \times 10^9 L_\odot\) (Hughes & MacLeod 1993). However, more recent measurements with a better estimation of its kinematic near distance (of about 1 kpc) suggest a luminosity of \(2.5 \times 10^4 L_\odot\) (MacLeod et al. 1998). Here, we adopt a distance to IRAS 17233-3606 of 1 kpc, the near kinematic distance to the object reported by MacLeod et al. The reason that the far distance appears unlikely is because the source is located at an angular separation of more than 0.5\,″ from the Galactic plane.

Using VLA and VLBA radio observations of the four hyper-fine structure lines of hydroxyl (OH) around 1.6 GHz, Argon et al. (2000, 2002) and Fish et al. (2005) revealed that the maser spots clearly show a velocity gradient with a north–south orientation and in the range \(-10.4\) and \(7\,\text{km}\,\text{s}^{-1}\). The masers are centered in the position right ascension (R.A.) = 17h26m42.7s, declination (decl.) = \(-36°09'17''\) (J2000.0) (Fish et al. 2005). The large broad velocity gradient displayed by the OH masers, which is several times larger than in most sources (Argon et al. 2000), indicates that they could be tracing a compact bipolar outflow.

Norris et al. (1998) found methanol maser spots coincident with the location of the OH masers that also appear to display a well-defined north–south velocity gradient. Forster & Caswell (1989) and Forster et al. (1990) detected water maser spots about 3\,′′ west of the hydroxyl and methanol maser location. The water masers cover a much broader velocity range, between \(-38\) and +22\,km\,s\(^{-1}\), and seem to be tracing an “expanding ring” possibly surrounding a central massive protostar. Forster & Caswell (1989) proposed that the compact size (\(\sim 2''\)), wide velocity spread in the masers, and a lack of strong continuum emission indicate that this “ring” might be produced by a star in its early expansion phase. However, they also suggested that the geometry could be due to one or multiple outflows.

A few radio sources have been found in this region; Haynes et al. (1979) and Caswell & Haynes (1980) reported for the first time the possible presence of an H\(_\II\) region using observations at 2 cm. Subsequent observations at 2 cm by Fix et al. (1982) confirmed this detection and found that this continuum source is extended and bright (310 mJy at 2 cm) and is located almost 10\,″ east of the OH/CH\(_3\)OH/H\(_2\)O maser zone. Later radio observations at 3.6 cm with a better angular resolution also detected this extended continuum source and slightly resolved it in a compact H\(_\II\) region with a cometary morphology (Walsh et al. 1999a). Fix et al. (1982) and Hughes & MacLeod (1993) report the detection of a very weak radio continuum source near the location of the OH/CH\(_3\)OH/H\(_2\)O masers. The observations made by Hughes & MacLeod (1993) at 2 cm with a resolution of 0.3 revealed that this object is actually a radio binary and that it is located very close to the maser positions.

Fix et al. (1982) and Walsh et al. (1999b) detected 2.0 \(\mu\)m infrared sources toward IRAS 17233-3606. Fix et al. (1982) reported an infrared object close to the location of the masers. Images by Walsh et al. (1999b) find a source coincident with the OH/CH\(_3\)OH/H\(_2\)O masers and a source coincident with the extended H\(_\II\) region to the east. Finally, De Buizer et al. (2000) detected a compact and faint infrared object at 10\,\mu\m at about 10\,″ east of the position of the masers. They also detected very diffuse and extended 18\,\mu\m infrared emission about 3° northeast of the OH/CH\(_3\)OH/H\(_2\)O maser location.

In this paper we present radio continuum observations made with the Very Large Array (VLA) toward the massive star-forming region IRAS 17233-3606. We report the detection of...
new radio sources associated with this zone which are distributed among a cluster of strong infrared sources detected by the Spitzer Space Telescope. We discuss the nature of these radio objects based mainly on their radio spectral indices and counterparts at other wavelengths. In addition, we present imaging of H$_2$O maser emission associated with IRAS 17233-3606.

2. OBSERVATIONS

From the NRAO$^3$ VLA archival database we retrieved continuum data of the IRAS 17233-3606 region at wavelengths of 1.3, 2.0, 3.6, and 6.0 cm and spectral line data of the 22.2 GHz water maser transition (Project number AG502). The data were taken with the VLA in its hybrid AB configuration. The region was observed between 1997 January 26 and 28 using the 27 antennas of the array. The phase center was R.A. = $17^h26^m42.s5$, decl. = $-36^\circ09'17''.38$ (J2000.0). The amplitude calibrator was 1328+307 (3C286) and the phase calibrator was 1622−05 (3.6 cm). The flux densities for 1328+307 were 2.5 Jy (2.0 cm), 0.8 Jy (3.6 cm) and 0.3 Jy (6.0 cm), while the bootstrapped flux densities for 1622−05 were 3.0 Jy (2.0 cm), 2.8 Jy (3.6 cm), and 1.4 Jy (6.0 cm).

For the maser observations the frequency was centered on the H$_2$O ν = 1 J = 6$_1$−6$_2$ and F = 5−5 at 22.235077 GHz, while the correlator was configured in line mode with a band of 64 channels over 6.25 MHz, which provided 97.6 kHz (1.3 km s$^{-1}$) resolution.

The data were analyzed in the standard manner using the AIPS package of the NRAO. The data were also self-calibrated in phase and amplitude for each band and for the H$_2$O maser data. Most of the images were made with the ROBUST parameter of the task IMAGR set to 0, to obtain an optimal compromise between sensitivity and angular resolution. However, in some cases we used ROBUST set to −5 to get a better angular resolution, sacrificing some sensitivity. The resulting rms noise levels and angular resolution for each band are listed in Table 1. In this table we also include the largest scale structure to which the array is sensitive. We assume that the systemic LSR velocity of the molecular cloud associated with IRAS 17233-3606 is $-4$ km s$^{-1}$.

3. RESULTS AND DISCUSSION

In a region of about $1' \times 1'$, we detected a total of five compact sources in one or more of the individual bands, as well as 16 water maser spots (see Figures 1−3). However, two of the radio sources, VLA1 and VLA2, were resolved into two (VLA1a, b)
Figure 2. VLA 1.3 cm continuum gray-scale image overlaid with a blue-contour image at 2.0 cm of a central region of IRAS 17233-3606. The contours are $-3, 3, 6, 9, 12, 15, 18, 20$ and $25$ times $0.30$ mJy beam$^{-1}$, the rms noise of the image. The half-power contour of the synthesized beam is shown in the bottom left corner of the image. The size of the synthesized beam is $0.51 \times 0.42$ with a P.A. of $9.7^\circ$ E of N. The gray-scale bar on the top indicates the 1.3 cm continuum emission on mJy beam$^{-1}$. The crosses indicate the positions of the multiple radio and infrared sources presented in Figure 1. The 1.3 cm image was convolved to the same angular resolution as the 2.0 cm image, using the parameter “UVTAPER” from the task “IMAGER” of AIPS.

Figure 2, VLA 1.3 cm continuum gray-scale image overlaid with a blue-contour image at 2.0 cm of a central region of IRAS 17233-3606. The contours are $-3, 3, 6, 9, 12, 15, 18, 20$ and $25$ times $0.30$ mJy beam$^{-1}$, the rms noise of the image. The half-power contour of the synthesized beam is shown in the bottom left corner of the image. The size of the synthesized beam is $0.51 \times 0.42$ with a P.A. of $9.7^\circ$ E of N. The gray-scale bar on the top indicates the 1.3 cm continuum emission on mJy beam$^{-1}$. The crosses indicate the positions of the multiple radio and infrared sources presented in Figure 1. The 1.3 cm image was convolved to the same angular resolution as the 2.0 cm image, using the parameter “UVTAPER” from the task “IMAGER” of AIPS.

and four (VLA2a, b, c, d) compact sources, respectively (see Figures 2 and 3). The observed parameters were determined from a linearized least-squares fit to an elliptical Gaussian using the task IMFIT of AIPS.

Infrared two-color band (8 and $4.5 \mu m$) images from the Spitzer Space Observatory’s GLIMPSE survey (Benjamin et al. 2003) overlaid with our 6 cm radio image of the IRAS 17233-3606 region (both with similar angular resolutions) are presented in Figure 1. In this image a cluster of 10 bright 8 $\mu m$ infrared sources is detected. We give the positions and sizes of the sources in Table 2 obtained using the task IMFIT of AIPS. These infrared sources are possibly associated with the objects detected by Fix et al. (1982), Walsh et al. (1999b), and De Buizer et al. (2000) at IR wavelengths. In a similar manner we give the observed parameters of the radio sources and the masers in Tables 3 and 4.

As can be seen, some of these infrared sources appear to be related to the centimeter objects. However, the nature of these infrared objects will not be discussed in this article, but the sources are presented here only for reference.

In what follows, we discuss separately each of the nine radio sources detected in this region. Our discussion of the spectral indices is based on the assumption that the flux densities did not change between the 1997 January 26 and 28 observations. Furthermore, since the spectral index measurements presented here can be very sensitive to the largest angular size and the angular resolution of the observations, matching-beam observations of the sources at several frequencies are required to discuss them in a very reliable way.

| IRAC | Position | Size | P.A. |
|------|----------|------|------|
|      | $\alpha_{2000}$ | $\delta_{2000}$ | (arcsec) | (deg.) |
| 1    | 17 26 42.845 | −36 08 35.23 | 3.3 $\times$ 2.9 | 16$^\circ$ |
| 2    | 17 26 42.529 | −36 09 46.16 | 9.2 $\times$ 7.3 | 49$^\circ$ |
| 3    | 17 26 42.946 | −36 09 40.65 | 6.1 $\times$ 5.2 | 22$^\circ$ |
| 4    | 17 26 42.950 | −36 09 37.69 | 6.3 $\times$ 4.6 | 164$^\circ$ |
| 5    | 17 26 43.030 | −36 09 18.38 | 3.6 $\times$ 3.1 | 155$^\circ$ |
| 6    | 17 26 43.075 | −36 09 14.02 | 3.2 $\times$ 3.2 | 82$^\circ$ |
| 7    | 17 26 43.082 | −36 09 46.48 | 12.5 $\times$ 9.8 | 27$^\circ$ |
| 8    | 17 26 43.555 | −36 09 18.48 | 7.4 $\times$ 5.8 | 69$^\circ$ |
| 9    | 17 26 43.708 | −36 09 17.94 | 5.8 $\times$ 5.2 | 14$^\circ$ |
| 10   | 17 26 43.920 | −36 09 10.84 | 6.0 $\times$ 5.7 | 12$^\circ$ |

Notes. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

3.1. Classical Ultra-Compact H ii Regions

3.1.1. VLA5

As already mentioned in the introduction, this source was discovered and reported as a faint H ii region for the first time by Haynes et al. (1979) and Caswell & Haynes (1980). Later observations with a better signal to noise and angular resolution by Fix et al. (1982), Walsh et al. (1999b), and Argon et al.
Figure 3. VLA 1.3 cm continuum image of the maser zone. The contours are $-3, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,$ and $15$ times $0.43 \, \text{mJy \, beam}^{-1}$, the rms noise of the image. The half-power contour of the synthesized beam is shown in the bottom-left corner of the image. The size of the beam is $0\farcs27 \times 0\farcs25$ with a P.A. of $7.1^\circ$.

The gray-scale bar on the top indicates the 1.3 cm continuum emission on mJy beam$^{-1}$. The blue and red dots indicate the positions of the blue- and red-shifted OH maser spots, respectively (Fish et al. 2005). Note that these masers appear to be tracing the innermost part of a north–south compact outflow that shows a moderate velocity gradient, going from $-10.4$ to $7$ km s$^{-1}$ (Fish et al. 2005) and that seems to emanate from the radio source VLA2d. The blue and red open squares (about $3''$ west from the OH center maser) indicate the position of the water masers presented in this article (see Table 4) and that seem to be tracing an “expanding ring” (Forster et al. 1990). The two black crosses mark the position of the objects VLA1a and b. (2000) confirm its detection. However, this source is not related to the center of the OH, CH$_3$OH, and H$_2$O masers (the maser zone), but rather it is offset by about $10''$ east; see Figures 2, 3, and the images from Walsh et al. (1999a) and Argon et al. (2000).

Figure 2 shows the 1.3 and 2 cm continuum emission from the central portion of the IRAS 17233-3606 region, and the H ii region and the radio binary system reported by Hughes & MacLeod (1993) are shown in this image. The H ii region is resolved and shows a very clumpy cometary morphology. We give its deconvolved dimensions and flux densities for all bands in Table 3.

The total 2 cm flux densities for this source reported by Fix et al. (1982) and our Table 3 are 310 and 330 mJy, respectively, and we consider the agreement to be very good. Furthermore, the 3.6 cm peak flux densities reported by Walsh et al. (1999a) and Argon et al. (2000) also seem to be consistent with our measurements.

Taking the flux densities at 2 and 1.3 cm from Table 3, which both have a similar angular resolution (see Table 1), we estimated a very flat spectral index for this object, equal to 0.06, indicating thus that the emission might come from an optically thin UCHII region.

Following the derivation of van der Tak & Menten (2005), and assuming that the free–free emission at 2 cm is optically thin (which must be the case for the above calculation), that the ionized gas has a temperature of $10^4$ K, that this source is located at a distance of 1 kpc, and taking the values of the number of ionizing photons corresponding to the spectral type for a young star from Panagia (1973), we estimate that possibly the UCHII region is ionized by a B0.5 zero-age main-sequence (ZAMS) star. This is again in very good agreement with the values and spectral types reported in Walsh et al. (1999a) and Hughes & MacLeod (1993).

From Figure 1 we can see that this H ii region is coincident with the compact infrared sources, IRAC 8 and 9, suggesting that they may be the stars responsible for its ionization. However, both infrared sources seem to lie south and east of the UCHII region.

3.1.2. VLA3

This source is first detected here and is imaged at 6 cm in Figure 1. We note that VLA 3 at this wavelength is resolved and turns out to be an UCHII region with a shell-like morphology. We give its deconvolved dimensions and flux densities for all bands in Table 3.
### Table 3
Parameters and Tentative Nature of the Centimeter Sources

| Wavelength (cm) | Position \( \alpha_{\odot 2000} \) | Position \( \delta_{\odot 2000} \) | Flux Density (mJy beam\(^{-1}\)) | Deconvolved Size\(^a\) (arcsec) | P.A.\(^b\) (deg.) |
|----------------|-----------------------------------|-----------------------------------|----------------------------------|-------------------------------|------------------|
| 6.0            | 17 26 42.446                     | −36 09 14.89                     | 7.3 ± 0.3                       | \( \leq 1 \)                  | 42 ± 1           |
| 3.6            | 17 26 42.378                     | −36 09 15.80                     | 4.8 ± 0.3                       | \( 4.4 \pm 0.5 \times 0.24 \pm 0.05 \) | 41 ± 1           |
| 2.0            | ...                              | ...                              | \( \leq 1 \)                     | ...                           | ...              |
| 1.3            | ...                              | ...                              | \( \leq 2 \)                     | ...                           | ...              |

VLA1a

| 6.0            | 17 26 42.543                     | −36 09 17.92                     | 11.4 ± 0.1                      | \( 1.0 \pm 0.1 \times 0.31 \pm 0.05 \) | 40 ± 1           |
| 3.6            | 17 26 42.418                     | −36 09 15.24                     | 3.2 ± 0.3                       | \( 1.8 \pm 0.5 \times 0.34 \pm 0.05 \) | 41 ± 1           |
| 2.0            | ...                              | ...                              | \( \leq 1 \)                     | ...                           | ...              |
| 1.3            | ...                              | ...                              | \( \leq 2 \)                     | ...                           | ...              |

VLA1b

| 6.0            | 17 26 42.540                     | −36 09 17.95                     | 4.0 ± 0.3                       | \( \leq 2 \)                  | ...              |
| 3.6            | 17 26 42.529                     | −36 09 18.14                     | 12.3 ± 0.3                      | \( 1.1 \pm 0.5 \times 0.35 \pm 0.05 \) | 43 ± 1           |
| 2.0            | 17 26 42.514                     | −36 09 18.10                     | 10.1 ± 0.5                      | \( 0.28 \pm 0.05 \times 0.19 \pm 0.05 \) | 49 ± 18          |
| 1.3            | 17 26 42.508                     | −36 09 18.04                     | 11.8 ± 0.7                      | \( 0.10 \pm 0.05 \times \leq 0.05 \) | ...              |

VLA2a

| 6.0            | 17 26 42.540                     | −36 09 17.95                     | 4.0 ± 0.3                       | \( \leq 2 \)                  | ...              |
| 3.6            | 17 26 42.526                     | −36 09 18.18                     | 2.7 ± 0.3                       | \( \leq 2 \)                  | ...              |
| 2.0            | 17 26 42.518                     | −36 09 18.10                     | 3.4 ± 0.5                       | \( 0.53 \pm 0.05 \times 0.25 \pm 0.05 \) | 49 ± 18          |
| 1.3            | 17 26 42.508                     | −36 09 18.04                     | 3.0 ± 0.5                       | \( 0.34 \pm 0.05 \times 0.10 \pm 0.03 \) | 153 ± 63         |

VLA2b

| 6.0            | ...                              | ...                              | \( \leq 0.1 \)                   | ...                           | ...              |
| 3.6            | ...                              | ...                              | \( \leq 0.2 \)                   | ...                           | ...              |
| 2.0            | ...                              | ...                              | \( \leq 1 \)                     | ...                           | ...              |
| 1.3            | 17 26 42.609                     | −36 09 17.35                     | 3.7 ± 0.8                       | \( 0.29 \pm 0.05 \times \leq 0.1 \) | 34 ± 11          |

VLA2c

| 6.0            | ...                              | ...                              | \( \leq 0.1 \)                   | ...                           | ...              |
| 3.6            | ...                              | ...                              | \( \leq 0.2 \)                   | ...                           | ...              |
| 2.0            | ...                              | ...                              | \( \leq 1 \)                     | ...                           | ...              |
| 1.3            | 17 26 42.686                     | −36 09 17.05                     | 2.7 ± 0.7                       | \( 0.18 \pm 0.05 \times \leq 0.1 \) | 46 ± 24          |

VLA2d

| 6.0            | 17 26 42.934                     | −36 09 39.87                     | 11.2 ± 0.3                      | \( 2.2 \pm 0.1 \times 2.0 \pm 0.1 \) | 53 ± 13          |
| 3.6            | 17 26 42.922                     | −36 09 39.97                     | 5.3 ± 0.3                       | \( 1.9 \pm 0.5 \times 1.0 \pm 0.1 \) | 42 ± 6           |
| 2.0            | ...                              | ...                              | \( \leq 1 \)                     | ...                           | ...              |
| 1.3            | ...                              | ...                              | \( \leq 2 \)                     | ...                           | ...              |

VLA3a

| 6.0            | 17 26 42.940                     | −36 09 09.31                     | 9.8 ± 0.1                       | \( 1.2 \pm 0.2 \times \leq 1 \) | 65 ± 5.5         |
| 3.6            | 17 26 42.933                     | −36 09 09.48                     | 0.8 ± 0.05                      | \( 0.90 \pm 0.05 \times 0.30 \pm 0.05 \) | 38 ± 17          |
| 2.0            | ...                              | ...                              | \( \leq 1 \)                     | ...                           | ...              |
| 1.3            | ...                              | ...                              | \( \leq 2 \)                     | ...                           | ...              |

VLA4

| 6.0            | 17 26 43.621                     | −36 09 16.31                     | 330 ± 5                         | \( 3.1 \pm 0.1 \times 2.9 \pm 0.1 \) | 112 ± 1          |
| 3.6            | 17 26 43.691                     | −36 09 16.46                     | 252 ± 5                         | \( 3.1 \pm 0.1 \times 2.9 \pm 0.1 \) | 103 ± 2          |
| 2.0            | 17 26 43.699                     | −36 09 16.37                     | 211 ± 5                         | \( 3.1 \pm 0.1 \times 2.2 \pm 0.1 \) | 105 ± 3          |
| 1.3            | 17 26 43.696                     | −36 09 16.27                     | 300 ± 5                         | \( \leq 3 \)                   | ...              |

VLA5
In a similar way as VLA 5, taking the flux densities at 2 and 1.3 cm from Table 3 for VLA3 (both measurements with similar angular resolution), we estimated a spectral index for this object of \( \leq 1.1 \), consistent with the emission also coming from an optically thin \( \text{H}\alpha \) region.

In addition, assuming again that the free–free emission at 2 cm is optically thin, that the ionized gas has a temperature of \( 10^{4} \) K, and that this source is located at a distance of 1 kpc, we estimate that this \( \text{H}\alpha \) region is possibly ionized by a B2-type ZAMS star.

From Figure 1, we also see that this UCHII region is coincident with one compact infrared source, IRAC 3.

### 3.2. On the Nature of VLA1 and VLA4

These sources were only detected in our more sensitive maps at 6 and 3.6 cm (see Figure 1 for an image at 6 cm). VLA4 is very compact and faint, while VLA1 is quite elongated in northeast–southwest orientation at 6 cm. Furthermore, VLA1 is resolved into two sources (VLA1a, b) in our 3.6 cm map with a better angular resolution. We give their flux densities and deconvolved sizes at this wavelength in Table 3.

From the values of the flux densities at 6 and 3.6 cm presented in Table 3, which also both have a similar angular resolution (see Table 1), we estimate a spectral index for VLA4 of \( \leq 1.0 \), and for VLA1a and b of \( \leq -0.8 \) suggesting that possibly the emission arises from optically thin \( \text{H}\alpha \) regions or from ionized stellar winds (the latter case is more likely for VLA4). The radio emission from VLA1a and b might also be associated with synchrotron emission. This kind of emission is believed to trace gyrosynchrotron emission from active magnetospheres of young, low-mass stars. However, similar negative spectral indices have also found in sources associated with high- and low-mass stars and are believed to be produced in strong shocks, see Garay et al. (1996).

However, these flattened spectral indices could also be due to missing flux density in the higher angular resolution and
higher frequency observations; see Table 1 where we include the largest-scale structure to which the array is sensitive.

None of these radio sources has a counterpart at infrared wavelengths (8.0 and 4.5 μm), see Figure 1.

3.3. Radio Objects Associated with The Master Zone

In Figure 3 we show the 1.3 cm radio emission together with the position of the OH, CH₃OH, and H₂O masers spots reported by Fish et al. (2005), Forster et al. (1990), and Caswell (1997). We found six compact radio sources in this region, VLA2a, b, c, d (VLA2a, b were detected for the first time by Hughes & MacLeod 1993 at 6 cm) and VLA1a, b. In Figure 2 we also show the radio sources detected by Hughes & MacLeod (1993), VLA2a and VLA2b, where they appear to form a binary system with a spatial separation of about 800 AU. However, the new observations show that possibly these sources are part of a multiple system. The sources VLA2c and d are only detected in our 1.3 cm images.

Figure 4 shows the SEDs for the centimeter compact sources VLA2a, b, c, and d. The flux density values for the four wavelengths were obtained from Table 3; however the values at 2 and 1.3 cm were obtained using a convolved map at a resolution of 1″, i.e. with a angular resolution similar to those at 3.6 and 6 cm (see Table 1). We convolved the maps using the parameter “UVTAPER” from the task “IMAGER” of AIPS. This parameter set a Gaussian taper to weigh down long-baseline data points.

VLA2c and d have steeper spectral indices, \( \geq 2.2 \) consistent with either optically thick hyper-compact H II regions or with optically thick thermal dust emission from massive dusty cores and/or disks. If the emission arises from thermal dust, the spatial sizes (about 300 AU) of these sources indicate that they are more likely to be compact circumstellar disks rather than dusty cores. VLA2b shows a negative spectral index \( \leq -0.15 \), possibly associated with synchrotron emission. The spectrum of the source VLA2a can also be modeled by a two-component spectrum where for the centimeter wavelengths is dominated for a classical H II region, while on the millimeter wavelengths is dominated by a component that rises rapidly with frequency. This component is likely...
to be associated with dust emission from a core or disk, see Figure 4.

From Figure 3 we note that the radio source VLA2d is well centered in an apparent compact bipolar north–south outflow traced by the OH maser spots. This again suggests that VLA2d may be a compact circumstellar disk rather than an hyper-compact H II region. We also note that there is a strong bow-shock about 40° north of this compact outflow which is quite well aligned to this compact outflow traced by OH masers, see Figure 1. Possibly this bow shock is part of an older ejection of this compact outflow. If this is the case, the outflow should have a dynamical age of the order of 10^4 years, assuming a velocity of 10 km s^{-1}. Furthermore, Leurini et al. (2008) found a strong north–south ^{12}CO outflow using the Atacama Pathfinder EXperiment (APEX) radiotelescope which is emanating from the maser zone. It is likely that this molecular compact outflow forms part of this bow shock and the very compact outflow traced by the OH maser.

Finally, there is another highly collimated northwest–southeast jet that seems to be emanating from this region (see Figure 1), possibly also associated with these compact radio objects.

We do not find any 8 µm infrared source associated with these four radio objects, indicating that they may be highly embedded in the molecular cloud. The extended 4.5 µm source associated with this zone (see Figure 1) seems to be more likely associated with shocked gas possibly from the multiple outflows originating here.

3.4. An Expanding Ring?

As first suggested by Forster & Caswell (1989), and as can be observed in Figure 3, the water maser spots located at the east of the OH masers appear to be tracing a “ring” centered on the position R.A. = 17°26′42″ decl. = −36°09′17.5″ (J2000.0) with a radius of approximately 1°.5. The maser spots associated with the “ring” display broad redshifted (−4 to 22.5 km s^{-1}) and blueshifted velocities (−4.5 to −19.5 km s^{-1}), see Table 4. Moreover, systematically the blueshifted maser spots are located to the northeast, while the redshifted masers to the southwest. The velocities and size are in good agreement with those reported by Forster & Caswell (1989) and Forster et al. (1990). However, we think that such large radial velocity gradients (AV ∼ 40 km s^{-1}) observed in the masers are too large to be explained in terms of a ring in expansion produced by an energetic stellar homogeneous wind that compresses the ambient medium and drives a shock into it, particularly since there is no radio or infrared source. A possibility is that these large gradients are due to multiple outflows. Torrelles et al. (2001) and Uscanga et al. (2005) reported the presence of “rings” in expansion (on much smaller scales) traced by water masers in the high-mass star-forming regions Cepheus and W75N, respectively. The radial velocities of the masers are close to the ambient cloud velocity.

We therefore suggest that possibly the radio sources VLA2a and VLA1a that are well centered on the positions of the water masers might be exciting them. These radio sources thus perhaps are driving northeast–southwest compact outflows.

4. SUMMARY

We have analyzed 1.3, 2, 3.6, and 6 cm continuum and water maser line archival data from the VLA toward the massive star-forming region IRAS 17233-3606. Comparing our results with mid-infrared images from the Spitzer Observatory’s GLIMPSE survey revealed a cluster of young protostars associated with this region and multiple outflows, some of them possibly related with the compact centimeter objects. We have summarized the tentative nature of every radio source in Table 3.

The specific results and conclusions of this study are as follows.

1. We report the detection of nine compact radio sources, six of which are new detections. We found that they are embedded in a cluster of infrared sources associated with multiple outflows. Most of these radio objects appear to be ultra- and hyper-compact optically thin and thick H II regions ionized by early B-type ZAMS stars; however, in a few cases (VLA2c and VLA2d) they could be optically thick compact (∼300 AU) and dusty circumstellar disks that might be powering a strong bow shock and a collimated outflow observed in the infrared wavelengths and that appear to emanate from this region.

2. We found that the object VLA2d is well centered in a putative low-velocity, strong and compact north–south bipolar outflow that is traced by OH masers, and we suggest that this object could be powering it.

3. We suggest that the sources VLA2a and VLA1a might be energizing two northeast–southwest outflows traced by H2O maser emission and which appear to form an “expanding ring.”

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