VLBI Observations of Water Masers in Onsala 1: Massive Binary Star-Forming Site?

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Abstract

We present the proper motions of water masers toward the Onsala 1 star-forming region, observed with the Japanese VLBI network at three epochs spanning 290 days. We found that there are two water-maser clusters (WMC 1 and WMC 2) separated from each other by 1.6 (2900 AU at a distance of 1.8 kpc). A proper-motion measurement revealed that WMC 1 is associated with a bipolar outflow elongated in the east–west direction with an expansion velocity of $69 \pm 11$ km s$^{-1}$. WMC 1 and WMC 2 are associated with two 345 GHz continuum dust emission sources, which are located 2" (3600 AU) east from the core of an ultracompact H II region traced by 8.4 GHz radio continuum emission. This indicates that the star-formation activity of Onsala 1 could move from the west side of the ultracompact H II region to the east side of two young stellar objects associated with the water masers. We have also found that the WMC 1 and UC H II regions could be gravitationally bound. Their relative velocity along the line of sight is $\sim 3$ km s$^{-1}$, and the total mass is $\sim 37 M_\odot$. Onsala 1 seems to harbor a binary star at a different evolutionary stage.

Key words: ISM: H II region — ISM: individual (Onsala 1) — masers — stars: formation — VLBI

1. Introduction

Star-forming regions are often associated with water-maser emissions, and Very Long Baseline Interferometry (VLBI) monitoring observations of the water maser provide a unique tool to study the structure and kinematics of a star-forming region. Analyses of spatial positions, Doppler velocities, and proper motions of water masers have often revealed the 3-D gas kinematics in the vicinity of young stellar objects (YSOs) (e.g., Orion-KL: Genzel et al. 1981; Cepheus A: Torrelles et al. 2001; G192.16–3.84: Imai et al. 2006; G24.78–13: Moscadelli et al. 2007).

The Onsala 1 star-forming region (hereafter ON 1) has an ultracompact (UC) H II region observed in radio continuum emissions at 8.4 GHz and 23.7 GHz (Zheng et al. 1985; Argon et al. 2000). The centimeter radio continuum luminosity of this UC H II region is $10^{1.2} L_\odot$, which indicates an exciting star of the ZAMS type B0 (MacLeod et al. 1998). Kumar et al. (2004) reported the presence of multiple outflows from the UC H II region. One outflow traced by the $^{12}$CO $J = 2–1$ line is elongated in the east–west direction with a velocity of 12 km s$^{-1}$ (respect to the systemic velocity of ON 1 $V_{\text{LSR}} = 12$ km s$^{-1}$), and other possible outflow traced by the H$^{13}$CO$^+$ $J = 1–0$ line is elongated in the northeast–southwest direction with a velocity of 4.5 km s$^{-1}$ (Kumar et al. 2004). The H$^{13}$CO$^+$ outflow is, however, on the other hand, interpreted as being a rotating disk by observations in the NH$_3$ and the same H$^{13}$CO$^+$ lines (Zheng et al. 1985; Lim et al. 2002). These molecular line observations suggest that there are several YSOs in or around the UC H II region of ON 1.
observations with the Japanese VLBI network (JVN, e.g., Doi et al. 2006; Imai et al. 2006) and data reduction. Section 3 shows the distribution and proper motion of the water masers. Section 4 discusses the driving sources of water masers and the structure of ON 1 through comparisons with previous observations. Although the distance to ON 1 is uncertain, a near kinematic distance of 1.8 kpc is favored by most authors (e.g., MacLeod et al. 1998; Kumar et al. 2004). We therefore adopt a distance of 1.8 kpc to this source.

2. Observations

The VLBI observations of ON 1 were made on 2005 March 24, and June 1, and on 2006 January 8 using five or six telescopes of the JVN composed of four 20-m telescopes of the VLBI Exploration of Radio Astrometry (VERA), a 45-m telescope of the Nobeyama Radio Observatory (NRO), and a 34-m telescope of the National Astronomical Observatory of Japan (NAOJ), or six telescopes of the JVN composed of four 20-m telescopes. There are low-velocity components (\(V_{\text{LSR}} \approx 4-22 \text{ km s}^{-1}\)) near the systemic velocity of ON 1 observed in the NH\(_3\) line (\(V_{\text{LSR}} = 10-12 \text{ km s}^{-1}\); Zheng et al. 1985) and, in addition, high-velocity blue-shifted (\(V_{\text{LSR}} \approx -60 \text{ to } -20 \text{ km s}^{-1}\)) and red-shifted (\(V_{\text{LSR}} \approx 50-60 \text{ km s}^{-1}\)) components. The blue- and red-shifted components symmetrically appear around the systemic velocity. We have detected most of the velocity components seen in the previous observations (Downes et al. 1979; Kurtz & Hofner 2005).

3. Results

3.1. Water Maser Spectrum

Figure 1 shows the total power spectra of the ON 1 water masers obtained with the Nobeyama 45-m and Mizusawa 20-m telescopes. There are low-velocity components (\(V_{\text{LSR}} \approx 4-22 \text{ km s}^{-1}\)) near the systemic velocity of ON 1 observed in the NH\(_3\) line (\(V_{\text{LSR}} = 10-12 \text{ km s}^{-1}\); Zheng et al. 1985) and, in addition, high-velocity blue-shifted (\(V_{\text{LSR}} \approx -60 \text{ to } -20 \text{ km s}^{-1}\)) and red-shifted (\(V_{\text{LSR}} \approx 50-60 \text{ km s}^{-1}\)) components. The blue- and red-shifted components symmetrically appear around the systemic velocity. We have detected most of the velocity components seen in the previous observations (Downes et al. 1979; Kurtz & Hofner 2005).

The peak flux density of the low-velocity components is typically 100 Jy, and does not change from epoch to epoch. On the other hand, the fluxes of the high-velocity components are time-variable. The blue-shifted components had 8 Jy in 2005 March, and increased to more than 150 Jy in 2006 January. These blue-shifted components were already found about 30 years ago by a single-dish observation (Genzel & Downes 1977). However, they were too weak to be mapped by the VLBI in 1977 (Downes et al. 1979). The red-shifted
components were strong (approximately 100–150 Jy) during our first and second VLBI observations (2005 March–June). However, they decreased to 30 Jy in 2006 January. These redshifted components were not detected in 1977 and 1987 (Genzel & Downes 1977; Cesaroni et al. 1988), and detected for the first time in 1995 (Kurtz & Hofner 2005).

The statistics of water masers show that high-velocity components are generally highly variable, and are as weak as 0.1–10% of the low-velocity component (Genzel & Downes 1977). Similarly, the high-velocity component in ON 1 is also highly variable. However, the high-velocity component is sometimes stronger than the low-velocity component. Its intensity is 10–200% of the low-velocity component.

3.2. Water Maser Distributions

Figure 2 shows the distributions and the proper-motion vectors of water masers in ON 1 (for proper motions, see next subsection). Twenty one of the features detected at the first epoch are plotted. The color index denotes the LSR velocity range from −41.8 to 58.4 km s\(^{-1}\), where the 21 features are located. The map origin is located at the position of the reference maser feature at \(V_{\text{LSR}} = 16.5 \text{ km s}^{-1}\), which is estimated to be \(\alpha(2000) = 20^h 10^m 09^s 201 \pm 0^s 004\) and \(\delta(2000) = 31^\circ 31' 36" 02' 0' 08'\) from a fringe rate analysis. ON 1 has two clusters of water maser features located at \((X, Y) \approx (0^\circ, 0^\circ)\) (hereafter WMC 1 = water-maser cluster 1) and at \((X, Y) \approx (-0^\circ 9, -1^\circ 4)\) (hereafter WMC 2). The separation of WMC 1 and WMC 2 is 1.76, which corresponds to 2900 AU.

WMC 1 is distributed within a region of \(\sim 320 \times 50\) mas \((580 \times 90\) AU\). The blue- \((V_{\text{LSR}} = -41.8 \text{ to } -28.5 \text{ km s}^{-1}\) and red-shifted \((V_{\text{LSR}} = 52.4–58.4 \text{ km s}^{-1}\) maser features appeared in WMC 1. Their separation is 195 mas, which corresponds to 350 AU. The blue- and red-shifted maser features are distributed within areas of \(9 \times 11\) mas \((16 \times 20\) AU\) and \(5 \times 14\) mas \((9 \times 25\) AU\), respectively, and were not detected outside of these regions. The systemic velocity of WMC 1 is \(V_{\text{LSR}} = 9.3 \pm 6.8 \text{ km s}^{-1}\), derived from three mean velocities of blue-shifted \((V_{\text{LSR}} = -40.5 \pm 4.3 \text{ km s}^{-1}\) ), red-shifted \((V_{\text{LSR}} = 55.4 \pm 2.0 \text{ km s}^{-1}\) ), and low-velocity \((V_{\text{LSR}} = 13.1 \pm 3.2 \text{ km s}^{-1}\) ) features detected in three epoch observations.

WMC 2 is distributed within a region of \(\sim 160 \times 380\) mas \((290 \times 680\) AU\). Only the low-velocity features \((V_{\text{LSR}} = 7.2–14.8 \text{ km s}^{-1}\) ) were detected in WMC 2. The systemic velocity of WMC 2 is derived to be \(V_{\text{LSR}} = 11.3 \pm 2.3 \text{ km s}^{-1}\) from the mean velocity of low-velocity features detected in three epoch observations.

3.3. Proper Motions

Table 2 lists the observed proper motions of 14 maser features in ON 1. The maser features in different epochs were identified as the same feature, if their LSR velocities were equal to each other within 0.42 km s\(^{-1}\) (2-channel), and if their positions were coincident within 2.5 mas at the first to second epochs and 7 mas at the second to third epochs. The spatial ranges of 2.5 and 7 mas correspond to a proper motion of 100 km s\(^{-1}\) (12 mas yr\(^{-1}\) ). Based on these identification criteria, each maser feature was identified in at least two epochs. The proper motions were calculated by performing a linear least-squares fit of the positional offsets to the elapsed time. Figure 3 shows the observed time variations of right ascension and declination offsets (relative to feature “5”) of five features detected at all three epochs.

The proper motions of WMC 1 exhibit a bipolar outflow structure in the east–west direction. The proper motions show high \((69 \pm 11 \text{ km s}^{-1}\) ) and low \((\sim 10 \text{ km s}^{-1}\) ) expansion velocities. The blue- and red-shifted features represent the high-velocity and collimated outflow. For the blueshifted features, the proper motion of the brightest feature at \(V_{\text{LSR}} = -40.5 \text{ km s}^{-1}\) was obtained to be \((\mu_x, \mu_y) = (7.9, -3.3) \text{ mas yr}^{-1}\), which corresponds to \((V_x, V_y) = (68, -28) \text{ km s}^{-1}\). The mean proper motion of four redshifted features \((V_{\text{LSR}} = 52.4–58.4 \text{ km s}^{-1}\) ) is \((\mu_x, \mu_y) = (-3.0 \pm 0.7, 0.4 \pm 0.2) \text{ mas yr}^{-1}\), which corresponds to \((V_x, V_y) = (-25 \pm 6, 3 \pm 2) \text{ km s}^{-1}\). These proper motions appear to be associated with a common origin.

The simplest explanation for this fact is that the water masers in WMC 1 are associated with a bipolar outflow which is ejected from a YSO located at the midpoint of the blue- and red-shifted features. The expansion velocity between the blue- and red-shifted features was estimated to be \(69 \pm 11 \text{ km s}^{-1}\), from the differences of their proper motions \((\Delta V_x, \Delta V_y) = (93 \pm 6, 31 \pm 2) \text{ km s}^{-1}\) and LSR velocities \(\Delta V_{\text{LSR}} = 95 \pm 3 \text{ km s}^{-1}\). The inclination angle of the direction of expansion was determined to be \(44^\circ \pm 3^\circ\). The position angle and opening angle derived from the distributions of blue- and red-shifted features are \(92^\circ\) and \(10^\circ\), respectively. The LSR velocities of three low-velocity features \((V_{\text{LSR}} = 12.1, 15.0, 15.6 \text{ km s}^{-1}\) ) in WMC 1 show a low expansion velocity.
Fig. 2. (a) Observed water maser distributions (colored filled circle) superimposed on an 8.4 GHz radio continuum map (thick contour) of the UC H II region (Argon et al. 2000). The gray-scale map shows the 345 GHz radio continuum exhibiting dust emission (Su et al. 2004), where the lowest gray contour indicates half of the peak brightness. The crosses show the OH maser distribution (Fish et al. 2005) and the triangle indicates the 10 μm infrared source (Kumar et al. 2003). The map origin with RA and DEC offsets = (0, 0) is at \( \alpha (J2000) = 20^h 10^m 09^s 201 \pm 0^s 004 \) and \( \delta (J2000) = 31^\circ 31' 36'' 02 \pm 0'' 008 \). 1000 mas corresponds to 1800 AU at a distance of 1.8 kpc. (b), (c) Close-up to the two water-maser clusters (WMC 1 and WMC 2) with proper-motion vectors. The colored arrows and number added for each feature denote the LSR velocity. The arrows at the bottom-right corner in (b) and (c) indicate proper motions of 5.9 mas yr\(^{-1}\) and 1.2 mas yr\(^{-1}\) (50 km s\(^{-1}\) and 10 km s\(^{-1}\)), respectively. The dashed line in (b) indicates the axis of the bipolar outflow observed in the \(^{12}CO\ J = 2-1\) line (Kumar et al. 2004).
Table 2. Parameters of the water-maser features identified by proper motion toward ON 1.

<table>
<thead>
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<th>ID*</th>
<th>Offset (mas)</th>
<th>LSR velocity (km s(^{-1}))</th>
<th>Proper motion (mas yr(^{-1}))</th>
<th>Peak intensity at three epochs (Jy beam(^{-1}))</th>
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<td>X (\sigma)X</td>
<td>Y (\sigma)Y</td>
<td>(V_{\text{LSR}})</td>
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<td>-1267.26 0.03</td>
<td>7.27 0.52 0.11</td>
<td>0.66 0.00</td>
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* Feature ID number.
† Relative value with respect to the position-reference maser feature: ID 5.

Fig. 3. Observed relative proper motions of the water-maser features in ON 1. The proper motions of only the maser features detected at all three epochs are presented. The number added for each sub-panel shows the assigned one listed in table 2. The dash line indicates a least-squares-fitted line assuming a constant-velocity motion.

Water masers in ON 1 (\(\sim\) 10 km s\(^{-1}\)). Their LSR velocities are close to the LSR velocity of the quiescent molecular cloud observed in the NH\(_3\) line (\(V_{\text{LSR}}\) \(\sim\) 10 km s\(^{-1}\); Zheng et al. 1985). This may indicate an interaction between the outflow and the dense surrounding cloud (Genzel et al. 1981). Their proper motions are within \(\mu_x = 0.5\)–1.5, \(\mu_y = -0.5\) to \(-0.3\) mas yr\(^{-1}\), which correspond to \(V_x = 4\)–13, \(V_y = -4\) to \(-3\) km s\(^{-1}\).

The proper motion of WMC 2 shows \(\mu \sim 1\) mas yr\(^{-1}\) (\(V \sim\) 10 km s\(^{-1}\)). Although it is unknown what is associated with WMC 2, the proper motions of WMC 2 did not originate from WMC 1. This indicates the presence of a driving source that is different from WMC 1. Therefore, our proper-motion measurements show that there are at least two driving sources of water masers in ON 1.

4. Discussion

4.1. Driving Sources of Water Masers

Figure 2a shows the positions of the water masers relative to the 8.4 GHz continuum emission. The water masers are located at 2\(\arcsec\) east from the peak of the 8.4 GHz continuum emission with an absolute position accuracy of \(\approx 0.3\) (Argon et al. 2000). The water masers are not coincident with the UC H II region, and appear to be associated with the YSO formed on the east side of the UC H II region.

Submillimeter continuum emission traces dust emission around a YSO. The 345 GHz continuum emission observed with SMA has two components of north-eastern (SMA 1) and south-western (SMA 2) ones (Su et al. 2004). The water masers would be associated with SMA 1 and SMA 2. Water masers appear to have a position offset of approximately 1\(\arcsec\) south-east from both peak positions of the 345 GHz continuum emission. This offset would be due to an insufficient angular resolution of a 345 GHz continuum observation of \(\sim 3\)\(\arcsec\) and insufficient absolute position accuracy.

A 10.5 \(\mu\)m infrared source, which was not detected in the 2.2 \(\mu\)m and 3.75 \(\mu\)m emissions (Kumar et al. 2003), is situated near the center of the two WMCs and UC H II region.
et al. 2004). The dynamical age of CO 2–1 outflow is estimated by IRAM observations in the extended in the east–west direction by envelopes, emitting the 345 GHz submillimeter emission. (Shirley et al. 2003), and dust emission at 350 μm emission is extended in a 3″ × 3″ area, it is unclear whether this is associated with the present water maser features.

The total far-infrared luminosity of ON 1 derived from the IRAS data is $10^{4.1} L_\odot$, and the luminosity of the UC H II region observed in 1.3 to 20 cm radio continuum emission is $10^{4.2} L_\odot$ (MacLeod et al. 1998). The agreement of the luminosities of the far-infrared and radio continuum emissions indicates that ON 1 has a single luminous star of spectral type B0 ($L \geq 10^4 L_\odot$), which forms the UC H II region. The luminosities of YSOs in WMC 1 and WMC 2 seem to be lower ($<10^4 L_\odot$) than that of the B0 star exciting the UC H II region.

We may thus conclude that the water masers, WMC 1 and WMC 2, are associated with two YSOs on the eastern side of UC H II region. These two YSOs are still surrounded by dusty envelopes, emitting the 345 GHz submillimeter emission.

### 4.2. Outflow and YSO in WMC 1

The outflow of WMC 1 is coincident with a jet-like outflow extended in the east–west direction by ~0.07 pc, which was found by IRAM observations in the 12CO J = 2–1 line (Kumar et al. 2004). The dynamical age of CO 2–1 outflow is estimated to be $(5–7) \times 10^3 \text{yr}$ using the LSR velocity difference from the systemic velocity of CO 2–1 (12 km s$^{-1}$) and the inclination angle of the outflow obtained by the present work (44° ± 3°). The velocity spans in 12CO J = 1–0 and 2–1 lines are 35 km s$^{-1}$ and 24 km s$^{-1}$, respectively (Xu et al. 2006; Kumar et al. 2004). These values are smaller than the velocity span of water masers (~100 km s$^{-1}$). This may be because the size of the high-velocity outflow observed in the water masers (<0.2") is too compact to be detected with the beam of the CO 1–0 (~15") and CO 2–1 (~2") lines. The dynamical age of the CO outflow of $(5–7) \times 10^3 \text{yr}$ suggests that the age of the YSO in WMC 1 is about $10^4 \text{yr}$.

Water-maser features are most likely located in shock regions, where the outflow from YSO hits ambient gases. We derived the momentum rate of the outflow in WMC 1 using the method of Torrelles et al. (2003). The momentum rate is given by

$$\dot{P}_t = 2\Omega_r R^2 \rho_t V_r^2,$$

where $\Omega_r = 2\pi [1 - \cos(\theta_{op}/2)]$ is the solid angle of the outflow, $R$ the distance from the star, $\rho_t$ the mass density in the outflow, $V_r$ the expansion velocity of the outflow. Assuming a typical gas density necessary for water masering, $n(H_2) = 10^8 \text{cm}^{-3}$ (Elizur et al. 1992), the momentum rate of outflow can be estimated to be $(1–2) \times 10^{-3} M_\odot \text{yr}^{-1} \text{km s}^{-1}$ for the observed expansion velocity ($V_r = 69 \pm 11 \text{km s}^{-1}$), the distance from the star ($R = 175 \text{AU}/\cos 44° = 245 \text{AU}$), and the opening angle ($\theta_{op} = 10°$). In addition, using this momentum rate and dynamical age derived from the CO 2–1 outflow, we can estimate the momentum of the outflow in WMC 1 to be $5–14 M_\odot \text{km s}^{-1}$. This value is 10–30% of the momentum of the largest outflow in ON 1 with a size of 0.94 pc, found in the 12CO J = 1–0 line (Xu et al. 2006). Therefore, the outflow in WMC 1 would not mainly contribute to the formation of the CO 1–0 outflow.

### 4.3. Star Formation Activity of ON 1

Dense molecular gas, which is traced in the CS J = 5–4 line (Shirley et al. 2003), and dust emission at 350 μm (Mueller et al. 2002), extend to the east and north side of the UC H II region. The different locations of the UC H II region, submillimeter continuum emissions, water masers, and dense molecular cloud suggest that the star-formation activity of ON 1 moves from west to east. In table 3, we summarize the possible properties of a B0 star exciting the UC H II region as well as the YSO associated with WMC 1 and WMC 2. The mass of the star in UC H II region is $15 M_\odot$, which is indicated by a spectral type of approximatively B0 (MacLeod et al. 1998). The mass of YSO in WMC 1 would be $2–15 M_\odot$, because the momentum rate of the outflow in WMC 1 corresponds to a typical value of an intermediate-mass YSO (Shepherd 2005). The difference between WMC 1 and WMC 2 is only the expansion velocity of water masers. This velocity difference may reflect the difference of the outflow energy between WMC 1 and WMC 2. This indicates a lower power, implying a lower mass of the forming YSO in WMC 2 than in WMC 1.

Finally, we propose that the B0 star is the possible driving source of the CO 1–0 outflow. The dynamical age of the CO 1–0 outflow is estimated to be $7.3 \times 10^4 \text{yr}$ at our assumed distance (Xu et al. 2006). Thus, we think that the age of the B0 star is $10^5 \text{yr}$.

<table>
<thead>
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<th>No</th>
<th>Name</th>
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<th>Maser</th>
<th>Velocity span* (km s$^{-1}$)</th>
<th>Luminosity (L$_\odot$)</th>
<th>Age† (yr)</th>
<th>Mass‡ (M$_\odot$)</th>
</tr>
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<td>B0 star</td>
<td>Ionized gas$^\dagger$ + Dust$^\ddagger$</td>
<td>OH#</td>
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<td>$10^4 2^{\pm 2}$</td>
<td>~10$^5$</td>
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<td>~10</td>
<td>$&lt;10^{4^{\pm 1}}$</td>
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</tr>
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</table>

* LSR velocity span of masers.
† Estimated ages of B0 star and WMC 1 YSO (see subsections 4.2 and 4.3).
‡ Estimated masses (see subsection 4.3).
§ Traced by 8.4 GHz continuum emission (Argon et al. 2000).
∥ Traced by 345 GHz continuum emission (Su et al. 2004).
# Results obtained in OH maser observation (Fish et al. 2005).
** Luminosity obtained in 1.3 to 20 cm radio continuum emissions (MacLeod et al. 1998).
†† Luminosity estimated from the far-infrared and radio continuum emissions (see subsection 4.1).
that the WMC 1 and UC HII regions are gravitationally bound. Therefore, we may consider

\[ M = \frac{R^2 v^2}{G} \]

\[ \sim 4.1 \times \left( \frac{R}{3600 \text{ AU}} \right) \left( \frac{v}{1 \text{ km s}^{-1}} \right)^2 M_\odot, \]

where \( R \) is the separation of the WMC 1 and UC HII regions, and \( v \) is the relative velocity. This total mass is minimum value, because the separation along the line of sight and the relative velocity of the sky are still unknown. The total mass was derived as \( M_t \sim 37M_\odot \) from a separation of 3600 AU and a relative velocity of \( v = 3 \text{ km s}^{-1} \). The masses of a 345 GHz dust emission core associated with the WMC 1 and UC HII regions are estimated to be 6 \( M_\odot \) and 6 \( M_\odot \), respectively (Su et al. 2006). Therefore, the total mass of the YSO and B0 stars, and the accompanying dust-emission cores is \( \sim 29-42 M_\odot \). This value is consistent with the total mass estimated on the basis the assumption of a gravitationally bound system. Therefore, we propose that the YSO in WMC 1 and the B0 star exciting the UC H II region form a binary star. The LSR velocity of WMC 2 \( (V_{\text{LSR}} = 11.3 \pm 2.3 \text{ km s}^{-1}) \) indicates that the YSO in WMC 2 is a third object of this bound system.

In figure 4, we illustrate a possible structure of ON 1, as inferred from the present consideration based on figure 2a. A rotating disk is found in NH$_3$ \((J, K) = (1, 1)\), and H$^{13}$CO$^+$ \(J = 1-0\) lines with the VLA and the BIMA array (Zheng et al. 1985; Lim et al. 2002). The orbit shown in figure 4 is assumed to be at a position angle of 40°, which is seen in the velocity gradient in the H$^{13}$CO$^+$ line (Lim et al. 2002).

5. Conclusions

The following conclusions are drawn from this study:

1. We carried out three epoch observations of the ON 1 water masers with the JVN, and successfully measured the proper motions of ON 1 water masers for the first time.

2. ON 1 has two major water-maser clusters (WMC 1 and WMC 2), which are separated by 2900 AU. Both WMCs are located at 3600 AU from the UC H II region seen at 8.4 GHz continuum emission.

3. A proper-motion measurement reveals that WMC 1 is associated with a bipolar outflow elongated in the east–west direction with a high expansion velocity of \( 69 \pm 11 \text{ km s}^{-1} \). This outflow is coincident with a jet-like outflow found in the CO 2–1 line.

4. WMC 1 and WMC 2 are associated with two 345 GHz continuum sources on the east side of the UC H II region. These two YSOs are still surrounded by dusty envelopes.

5. The star-formation activity of ON 1 appears to move from the west side of the UC H II region to the east side of two WMCs and a dense molecular cloud is observed in CS lines.

6. We suggests that the WMC 1 and UC H II regions in ON 1 form a binary system. The relative velocity and total mass of the WMC 1 and UC H II regions are estimated to be \( \Delta V_{\text{LSR}} \sim 3 \text{ km s}^{-1} \) and \( M_t \sim 37M_\odot \), respectively.

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