

The structure of the Onsala 1 star forming region

M. S. N. Kumar¹, M. Tafalla², and R. Bachiller²

¹ Centro de Astrofísica da Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal
e-mail: nanda@astro.up.pt

² Observatorio Astronómico Nacional, Alfonso XII, 3, 28014 Madrid, Spain

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Abstract. We present new high-sensitivity high-resolution mm-wave observations of the Onsala 1 ultra-compact HII region that bring to light the internal structure of this massive star forming cloud. The 1.2 mm continuum map obtained with the IRAM 30-m radiotelescope ($\sim 11''$ resolution) shows a centrally peaked condensation of $1'$ size (~ 0.5 pc at the assumed distance of 1.8 kpc) which has been further investigated at higher resolution in the 3 mm continuum and in the emission lines of H^{13}CO^+ $J = 1-0$ and SiO $J = 2-1$ with the IRAM Plateau de Bure interferometer. The 3 mm data, with a resolution of $\sim 5'' \times 4''$, display an unresolved continuum source at the peak of the extended 1.2 mm emission and closely associated with the ultra-compact HII region. The H^{13}CO^+ map traces the central condensation in good agreement with previous NH_3 maps of Zheng et al. (1985). However, the velocity field of this central condensation, which was previously thought to arise in a rapidly rotating structure, is better explained in terms of the dense and compact component of a bipolar outflow. This interpretation is confirmed by SiO and CO observations of the full region. In fact, our new SiO data unveil the presence of multiple (at least 4) outflows in the region. In particular, there is an important center of outflow activity in the region about $1'$ north of the UCHII region. Indeed the different outflows are related to different members of the Onsala 1 cluster. The data presented here support a scenario in which massive star formation begin much later in the evolution of a cluster and/or the phases of UCHII regions last for much longer than 10^5 yr.

Key words. stars: formation – ISM: jets and outflows – HII regions – ISM: clouds

1. Introduction

Onsala 1 (ON 1) is an ultra-compact HII (UCHII) region situated in the densest part of the Onsala molecular cloud (Israel & Wootten 1983). It is one of the most compact and isolated UCHII regions known to be associated with several signposts of massive star formation such as dense gas, high velocity gas, masers, and near-infrared sources. However, a single luminous ($10^{4.2} L_{\odot}$) far-infrared (FIR) point source, IRAS 20081+3132, is associated with this UCHII region. The luminosity estimated from FIR data and the centimeter (radio) emission agree well, within a factor of 100 L_{\odot} , and indicate a spectral type of B0.3-B0.6 (MacLeod et al. 1998). At a spatial resolution of $0.7''$ – $1.5''$, the UCHII is detected as an unresolved source at 2 cm and 3 cm wavelengths (Kurtz et al. 1994). Higher angular resolution ($0.1''$) observations at 1.2 cm resolve the UCHII region into an approximate shell structure of size $0.6''$ (Turner & Matthews 1984). This source is placed at a distance of 1.3–6 kpc by various authors in the literature. However, a distance of less than 2 kpc is favored by most authors for many valid reasons (see e.g. MacLeod et al. 1998; Watson et al. 2003). We therefore adopt the near-distance of 1.8 kpc to this source for the purposes of this work.

Several masers such as OH (Ho et al. 1983), H_2O (Downes et al. 1979), CH_3OH (Menten 1991) and HCHO (MacLeod et al. 1998) are known to coincide with ON 1. Spatially

separated blue and red shifted OH maser spots around ON 1 have been identified by Desmurs & Baudry (1998) using VLBI techniques. Observations using dense gas and dust tracers have showed a compact, nearly circular dense core surrounding ON 1. Maps of $350 \mu\text{m}$ continuum emission (Mueller et al. 2000) and CS $J = 5-4$ emission (Shirley et al. 2003) show dense circular condensations around the source. Emission from transitions of CH_3CN $J = 12-11$ (Pankonin et al. 2001) and HNCO (Zinchenko et al. 2000) are also found to peak on ON 1. Using VLA observations at $11''$ resolution in the $(J, K) = (1, 1)$ line of NH_3 , Zheng et al. (1985, hereafter ZHRS85) argued for the presence of a rapidly rotating gas condensation centered on ON 1. However, regions of massive star formation often possess an intricate kinematic behavior involving motions of rotation, infall, and outflow, and the actual existence of a rapid gas condensation in ON 1 needed confirmation with higher resolution observations. In this paper, we present high-sensitivity high-resolution ($\sim 5''$) line and continuum observations that are used to investigate in detail the dense core and outflowing gas associated with ON 1.

2. Observational data

The IRAM 30 m radiotelescope at Pico Veleta (near Granada, Spain) was used to map the λ 1.2 mm continuum emission from

the ON 1 region in December 2000. We used the MAMBO 1 bolometer array to produce an on-the-fly map with a scanning speed of $4'' \text{ s}^{-1}$, a wobbler period of 0.5 s, and a wobbler throw of $53''$. The central frequency of the detectors was ~ 240 GHz, and the bandwidth was ~ 70 GHz. Sky dips made immediately before and after the map were used to correct for the atmospheric extinction, and a global calibration factor of 15 000 counts per Jy (based on an observation of Uranus) was applied to the data. The resulting map (produced with the IRAM NIC software) has an angular resolution of $11''$.

High resolution interferometric observations of ON 1 region were carried out using the IRAM Plateau de Bure (PdB) interferometer (near Grenoble, France) in its D (5 antennas) and C (6 antennas) configurations. Observations using the compact D array configuration were carried out on the nights of 28 May 2002 and 20 July 2002 for two adjacent fields; one field centered on the ON 1 FIR point source/UCHII region and another at offset $1'$ north. The C array configuration observations for the same fields were obtained during the nights of 9 and 10 January 2003. Each field was a mosaic of 9 pointings arranged in a 3×3 matrix with a spacing of $12''$ which is roughly equal to half the primary beam size. We used the SIS heterodyne receivers both at 87 GHz and 230 GHz. The 230 GHz data were mostly unusable due to summer weather conditions. Six spectral correlators were used to select three spectral lines, namely, SiO $J = 2-1$ ($\nu = 86.846891$ GHz), $\text{H}^{13}\text{CO}^+ J = 1-0$ ($\nu = 86.754330$ GHz) and CO $J = 2-1$ ($\nu = 230.538$ GHz) and two continuum bands centered at 1.2 mm and 3 mm wavelengths. The system temperature was typically 100 K at 3 mm and >400 K at 1.2 mm with a phase noise of $\sim 25^\circ-35^\circ$ at 3 mm and $>40^\circ-50^\circ$ at 1.2 mm. The D configuration provided baselines of 24 m–82 m while the C configuration gave a baseline range of 48 m–229 m. We used the sources 2023+336 and 2013+370 as the primary phase calibrators and MWC 349, 2013+370 and 3C 345 for flux calibration. Synthesized clean beams at 3 mm measured $\sim 5.35'' \times 3.7''$ (PA = 56°) which represents the typical resolution of the interferometric data presented here. The resulting maps does not include any short spacing data from single dish observations and thus filter out all large scale structures.

3. Results

3.1. Continuum observations

In Fig. 1 we depict the results of observations that represent the dense gas and dust in the region of ON 1. The star symbol shows the coinciding position of the UCHII region, the luminous IRAS point source and all the maser spots that represent the massive young stellar object, which we shall henceforth refer to as ON 1. The 1.2 mm continuum emission is extended over $\sim 70''$ and elongated in the North-East direction. The 1.2 mm continuum emission is a sensitive tracer of the warm dust and therefore indicates the dense cloud surrounding ON 1. The spatial extent and morphology of the 1.2 mm continuum map is very similar to that of the $350 \mu\text{m}$ map (Mueller et al. 2000), the CS emission line maps (Shirley et al. 2003) and also the integrated NH_3 emission (ZHR85) which has

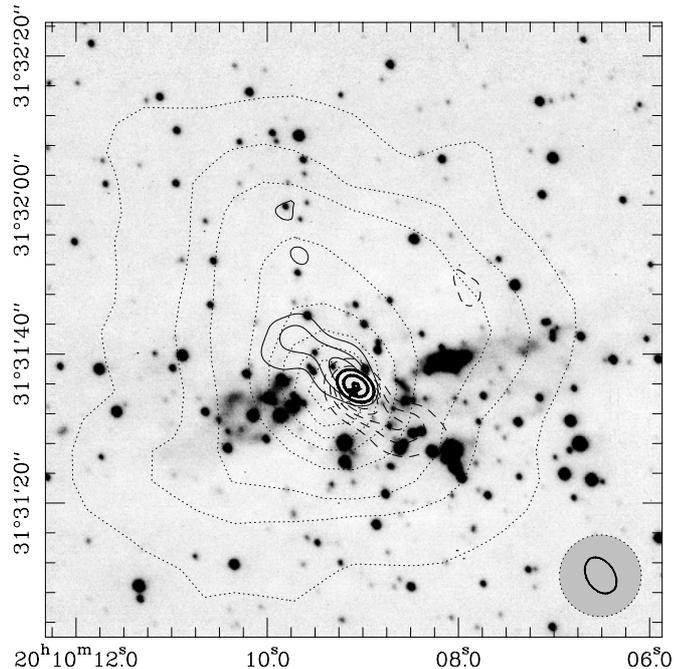


Fig. 1. 1.2 mm continuum emission (dotted contours) mapped with the IRAM 30 m telescope overlaid on a K -band image (Kumar et al. 2003) of the Onsala 1 region. Contour levels are 1, 2, 3, 6, 9, 12, 15, 18 and 21 Jy/beam with an rms of 140 mJy/beam. Thick contours enclosing grey shades represent the 3 mm continuum emission mapped with the IRAM PdB interferometer. Levels are 0.1, 0.15 and 0.2 Jy/beam (rms = 1.6 mJy/beam). The star symbol represents the position of the FIR sources and the UCHII region. Solid lines represent blue-shifted and dashed lines represent red-shifted $\text{H}^{13}\text{CO}^+ J = 1-0$ emission, integrated over the velocity range $V_{\text{lsr}} \pm 4.5 \text{ km s}^{-1}$. In both cases, the contour levels start at 0.5 K km s^{-1} (rms = 0.06 K km s^{-1}) and increase in steps of 0.5 K km s^{-1} . The beam sizes of the 1.2 mm data (dotted circle) and the 3 mm data (bold ellipse) are shown enclosed in grey shades at the bottom right corner of the figure.

been thought to represent a rapidly rotating condensation. The source ON 1 and the surrounding embedded cluster all appear well immersed in the observed 1.2 mm emission. Therefore the 1.2 mm emission region in Fig. 1, which is representative of the condensation unveiled by all other dense gas tracers, can be considered as the dense core in which the ON 1 cluster has been forming. The 3 mm continuum emission reveals an unresolved source centered on ON 1. The interferometric observations filter out the extended emission and show the underlying small scale structure. Therefore the 3 mm continuum emission centered on ON 1 is indicative of the major condensations within the more extended clump traced by the 1.2 mm emission. However, $10 \mu\text{m}$ observations (Kumar et al. 2003) reveal two closely situated sources coinciding with the unresolved 3 mm source indicating that ON 1 is likely to harbor a binary protostar.

The 1.2 mm emission maps can be used to estimate the mass of the ON 1 clump and the 3 mm continuum emission to estimate the mass of the unresolved central source(s). The black-body fit to the Far-Infrared (FIR) flux density distribution of ON 1 indicates a dust temperature of 57 K (Mueller et al. 2000). Since the peak of the dust condensation coincides with

an UCHII region, this value is likely an upper limit. If we assume a dust absorption coefficient of $\kappa_{1.2\text{ mm}} = 0.0005\text{ kg}^{-1}\text{ m}^2$ (Henning et al. 1985) and a distance of 1.8 kpc to the source, the observed 1.2 mm continuum emission represents a cloud mass of $\sim 3860 M_{\odot}$ for $T = 50\text{ K}$ and $5000 M_{\odot}$ for $T = 40\text{ K}$. The source averaged flux density (3.6 Jy/beam) implies hydrogen column densities of $1.4 \times 10^{24}\text{ cm}^{-2}$ resulting in $A_v \sim 700\text{ mag}$. The peak column density is even higher at $8.2 \times 10^{24}\text{ cm}^{-2}$ implying a few thousand magnitudes of visual extinction. However, these numbers are to be treated with caution because of the presence of the UCHII region. The observed emission does not faithfully represent the temperature of the warm dust since the heating effects of the UCHII region can contribute to the majority of the emission close to the peak. The 3 mm emission from the unresolved source represents a mass of $\sim 400 M_{\odot}$, where we have used $\kappa_{3\text{ mm}} = 6.6 \times 10^{-5}\text{ kg}^{-1}\text{ m}^2$. This value of $\kappa_{3\text{ mm}}$ is obtained by assuming a spectral emissivity index $\beta = 2$. There is increasing observational evidence that suggest that the value of β is likely much lower ($\beta \sim 1$) around massive protostellar sources (ex: Hunter et al. 2000). If we assume $\beta \sim 1$ then the resulting estimates of the embedded mass in the observed 3 mm emission will be lower than quoted above. In any case, the derived mass from 3 mm emission is probably an overestimate since 3 mm continuum emission is known to trace free-free emission also and may not be a good tracer of the dust alone (Downes et al. 1992). In view of these points we can safely assume that the enclosed mass in the unresolved central object is not greater than $\sim 300\text{--}400 M_{\odot}$. Thus about 6–8% of the overall dense core mass seems to be in the form of protostellar material at the center.

3.2. $\text{H}^{13}\text{CO}^+ J = 1\text{--}0$ emission

In Fig. 1 solid and dashed contours show blue and red shifted $\text{H}^{13}\text{CO}^+ J = 1\text{--}0$ emission, respectively, integrated over the velocity range $V_{\text{LSR}} \pm 4.5\text{ km s}^{-1}$. As is evident from the figure, the H^{13}CO^+ emission is centered on the source ON 1 and reveals a spatially resolved bipolar structure. The position angle (PA) of the axis of this well-collimated bipolar structure is $\sim 44^\circ$ and roughly coincides with the elongation displayed by the 1.2 mm contours. The H^{13}CO^+ emission also coincides well with the NH_3 condensation mapped by ZHRS85. The projected length of this bipolar emission is $\sim 30''$ corresponding to about 0.27 pc at the assumed distance of 1.8 kpc. Each lobe of this compact feature appears to consist of two distinct clumps.

In Fig. 2 we show a velocity-position map obtained along the axis (PA $\sim 44^\circ$) of this bipolar feature which reveals a structure that is distinctly different from earlier claims of ZHRS85. The vertical line represents the systemic LSR velocity at 12 km s^{-1} . The red-shifted southern lobe and the blue-shifted northern lobe can be seen clearly separated into two components on the PV diagram. A main component of the emission (denoted by A and B in Fig. 2) stretches to a radius of $\sim 5''$ and a satellite component comprising of two knots (denoted by C and D) extends to a radius of $\sim 10''$. These 4 clumps correspond to the clumps found in the images (Fig. 1). As can be seen from Fig. 2, all of the found emission is spread along a straight line

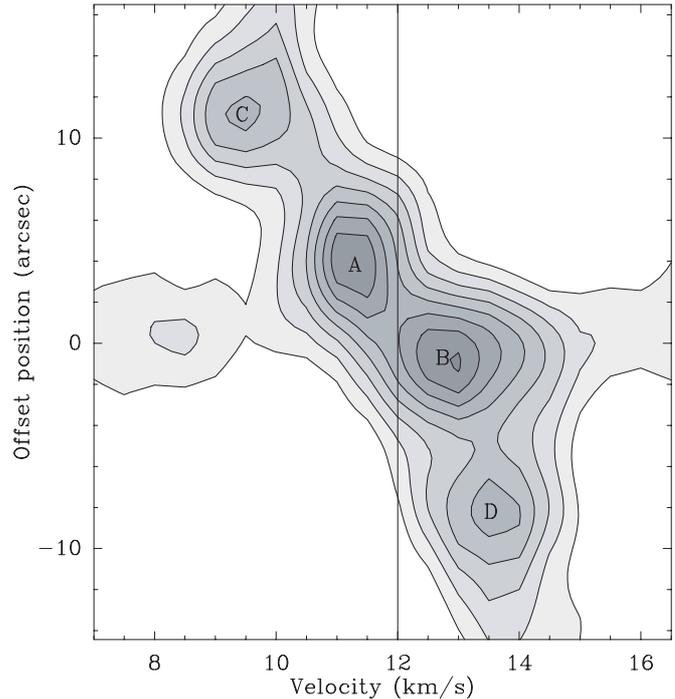


Fig. 2. Velocity-Position diagram for the $\text{H}^{13}\text{CO}^+ J = 1\text{--}0$ emission shown in Fig. 1, obtained along the axis of the bipolar emission at PA $\sim 44^\circ$. The contour levels start at 1 K and increase in steps of 1 K.

in the PV-plane showing increasing velocity with increasing distance from the central position following a Hubble law. We have not subtracted the bright continuum emission from these data. The continuum emission can therefore be seen close to the source (offset = 0) extending on either side of the V_{LSR} , up to the limits of our observing setup with the spectrometers.

Since the $\text{H}^{13}\text{CO}^+ J = 1\text{--}0$ emission is symmetrical both in position and velocity with respect to the central position and velocity, it is natural to conclude that this emission arises in a bipolar outflow emerging from the central object. Note that the observed kinematical structure cannot be easily explained with a rotating disk. First of all, the total size of this structure ($>0.2\text{ pc}$) is too large to be a disk and, moreover, a disk would produce just two peaks of emission in the PV diagram, not four peaks as the A, B, C, and D peaks which are actually observed in Fig. 2. The Hubble-like velocity law distribution which is observed in Fig. 2 (velocity proportional to the distance) is also very typical of young bipolar outflows. A straight line fit through all the knots shows a gradient of $\sim 30\text{ km s}^{-1}\text{ pc}^{-1}$ at the assumed distance of 1.8 kpc. These velocity limits and the velocity gradient are similar to the values obtained from NH_3 observations by ZHRS85 except that the gradient of $\sim 11\text{ km s}^{-1}\text{ pc}^{-1}$ estimated by ZHRS85 is due to their adopted distance of 3.5 kpc. The interpretation that the H^{13}CO^+ emission arises in the compact component of a bipolar outflow is confirmed by the SiO high-velocity data shown in the following section.

Assuming standard LTE conditions, the observed H^{13}CO^+ emission can be used to compute the column densities and enclosed mass. If we assume a dipole moment of $\mu = 4.08\text{ debye}$ (Haese & Woods 1979) and an $\text{H}^{13}\text{CO}^+/\text{H}_2$ ratio

of 3.3×10^{-11} (Blake et al. 1987; in OMC1), the observed fluxes indicate an enclosed mass of $\sim 280 M_{\odot}$ – $330 M_{\odot}$ for temperatures of 40 K–50 K. The estimated mass is uncertain by a few hundred solar masses depending on the assumed value of $\text{H}^{13}\text{CO}^+/\text{H}_2$ ratio and excitation temperature. In any case, the estimated H^{13}CO^+ mass is of the same order as the mass evaluated from the 3 mm continuum emission.

3.3. SiO and CO observations

In Fig. 3 we present the results of the SiO $J = 2-1$ and CO $J = 2-1$ high-resolution observations in the whole region around ON 1 including the north zone in which the 1.2 mm emission is significant. The SiO emission is found at velocities of $V_{\text{lsr}} \pm 4-5 \text{ km s}^{-1}$, with respect to the systemic velocity, whereas the CO emission appears to extend up to $V_{\text{lsr}} \pm 12 \text{ km s}^{-1}$. The CO $J = 2-1$ data at 1.2 mm are quite poor due to summer weather conditions, but the knots shown in Fig. 3 have high signal to noise ratio ($10-15\sigma$). Based on complementary blue and red shifted components we can identify at least four main outflows in the region. However, we caution that these maps do not reveal most of the large scale structures in the region, since we do not have any short spacing data from single dish telescopes included in the maps.

The first outflow is seen close to the central FIR source. The most internal component of this outflow is at PA $\sim 45^\circ$, in good agreement with the H^{13}CO^+ outflow component discussed in Sect. 3.2. As for the H^{13}CO^+ data, the blue-shifted emission is located at the NE of the source, while the red-shifted emission is located at the SW. We believe that the SiO and the H^{13}CO^+ high velocity emission are tracing the same compact bipolar outflow which is emerging from the very vicinity of the FIR object.

Most remarkably, the region $40''$ north of ON 1 FIR appears to be an important center of outflow activity: a prominent high-velocity SiO feature which is marked as A_{blue} in Fig. 3 stretches approximately $30''$ in the north-south direction forming a kind of highly-collimated jet. The red-shifted counterpart to this jet-like structure is not so obvious. We think that the bright red knot (A_{red}) on the south may be associated with A_{blue} because both structures are well aligned and because there is no other equally prominent blue component in the region. If these two features A_{red} and A_{blue} were actually part of the same outflow, this would have a total size of at least $1'$ or 0.5 pc . We caution however that it is difficult to identify bipolar counterparts on large scale in such complex regions.

A smaller outflow denoted by B shows both blue and red shifted lobes and extends to about $25''$ in the east-west direction. This flow is traced even by the poor quality CO data appearing as spatially separated blue and red knots. The driving source of this outflow has not been identified either in the near-infrared or in the mm-wave observations. The 3σ noise limit of 5 mJy of our 3 mm continuum maps imply a limiting detectable mass of $5-6 M_{\odot}$. Therefore this outflow is likely driven by a low mass object.

Finally, a short east-west jet-like feature, denoted by C , emerging from the dense blob of SiO emission surrounding

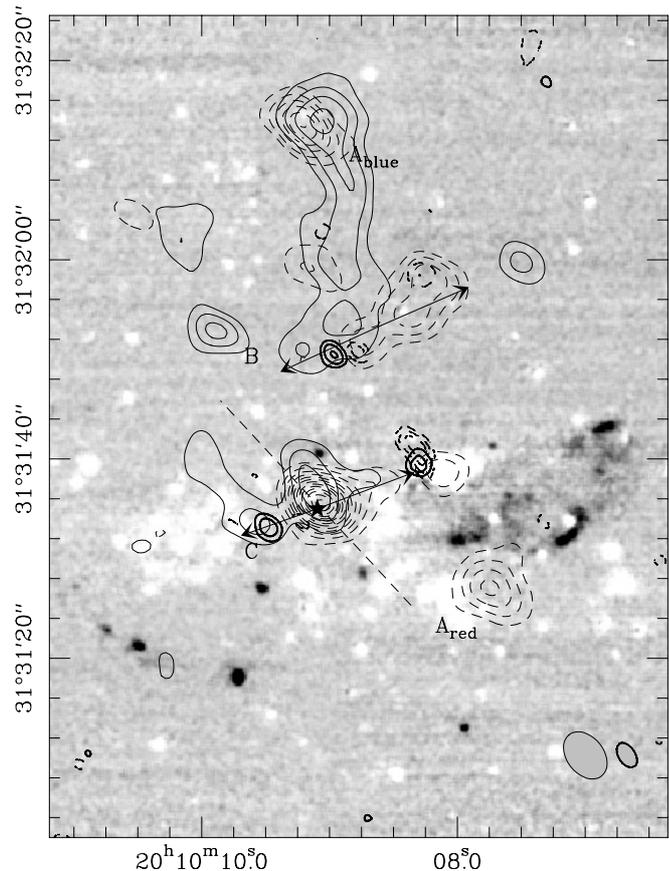


Fig. 3. SiO $J = 2-1$ (thin lines) and CO $J = 2-1$ (thick lines) integrated emission overlaid on a continuum-subtracted H_2 narrow band image at $2.122 \mu\text{m}$. SiO emission was integrated with a velocity interval of $V_{\text{lsr}} \pm 4 \text{ km s}^{-1}$ and CO emission was integrated in the range $V_{\text{lsr}} \pm 12 \text{ km s}^{-1}$. Solid lines represent blue-shifted and dotted lines represent red-shifted emission. SiO contour levels start at 0.2 K km s^{-1} ($\text{rms} = 0.06 \text{ K km s}^{-1}$) and increase in steps of 0.15 K km s^{-1} . CO contours levels start at 2 K km s^{-1} ($\text{rms} = 0.22 \text{ K km s}^{-1}$) and increase in steps of 1 K km s^{-1} . The star symbol represents the position of the FIR sources and the UCHII region as in Fig. 1. The dotted straight line represents the axis of the H^{13}CO^+ outflow. The beam sizes of the 3 mm and 1 mm data are shown by filled ellipses at the bottom right corner of the figure.

the ON 1 source represents another distinct bipolar outflow. Indeed, this flow is traced more prominently by the symmetrically placed CO knots on an axis that closely matches the axis of the overall bipolar distribution of near-infrared H_2 emission. It is unclear if this outflow arises from the same object as the dense and compact NE-SW outflow seen in H^{13}CO^+ and SiO, which has been discussed above. Since the FIR object is probably a binary system (Kumar et al. 2003), it may be not surprising to find two different outflows emanating from its vicinity.

It appears anyway that high velocity emission is spread all over the cluster-forming molecular cloud. Although our observations indicate the presence of real multiple outflows, it is also likely that some of these outflows have interacted with the surrounding cluster and broken into multiple components. This may be particularly true for the east-west flow which is

traced by the CO knots, a faint SiO jet and largely by the NIR H₂ emission.

4. Discussion

ON 1 was described to be a rapidly rotating condensation by ZHR85 based on NH₃ observations. The higher-resolution data presented here along with other dense gas and dust tracing observations indicate that the NH₃ condensation described by ZHR85 actually corresponds to an outflow. The H¹³CO⁺ observations discussed in Sect. 3.2 have orientation and velocity ranges similar to the NH₃ features. However, for the first time, our observations show a spatially resolved bipolar feature whose PV diagram is typical of outflows. Perhaps the H¹³CO⁺ observations alone would not have resolved the issue of whether this is an outflow or a rapidly rotating envelope, particularly because of the velocity structure close to the source and the low values of $\Delta v = V_{\text{lsr}} \pm 2\text{--}3 \text{ km s}^{-1}$. But the SiO emission which traces other outflows in the region show only slightly higher values of $\Delta v = V_{\text{lsr}} \pm 4\text{--}5 \text{ km s}^{-1}$. The symmetrical lobes of H¹³CO⁺ emission indicate that the outflow has a small inclination angle with respect to the plane of the sky. This implies small line-of-sight velocities of the H¹³CO⁺ structure in comparison to the SiO data. Indeed all other dense gas tracers from this region such as CS (Shirley et al. 2003), CH₃CN (Pankonin et al. 2001) and HNC (Zinchenko et al. 2000) display similar $V_{\text{lsr}} \sim 11\text{--}12 \text{ km s}^{-1}$ and $\Delta v \sim 4\text{--}5 \text{ km s}^{-1}$. Therefore it is clear that the H¹³CO⁺ presented here spatially resolves the NH₃ data from ZHR85 and reveals an outflow well placed in the plane of the sky and possibly moving slowly. A similar example where a large scale coherent NH₃ structure (Jackson et al. 1988) is aligned well with an outflow (Bachiller & Cernicharo 1990) is found in NGC 6334I.

In the light of above results, the following scenario appears the most plausible for the ON 1 region. The UCHII region ON 1 is a relatively isolated massive star forming region associated with a small embedded cluster, all of which is immersed in a molecular clump of a few thousand solar masses. The vicinity of the UCHII region appears to drive at least two (the H¹³CO⁺ compact outflow, the flow traced by CO knots and H₂) and likely three (SiO flow A) major outflows indicating multiple embedded sources of similar evolutionary states. While the exact driving sources for each of these flows are not clear, it is very likely that the H¹³CO⁺ flow originates from one of the two mid-infrared (10 μm) sources (Kumar et al. 2003) centered on ON 1. These two mid-IR sources are neither visible at 3.8 μm nor distinguishable in the millimeter observations. However, given that both sources show 10 μm emission and are associated with an unresolved mm continuum peak, and likely drive outflows, they may be at a similar evolutionary state. Thus the ON 1 source could harbor a massive binary protostar.

The H¹³CO⁺ and SiO outflows display very low line-of-sight velocities. Low values of line of sight velocities in outflows can be expected if they lie in the plane of the sky as appears to be case for H¹³CO⁺ flow. However, the SiO flow does not obviously appear to be oriented in the plane of the sky, thereby indicating that the low line-of-sight velocities are

representative of the region. The outflow traced by H¹³CO⁺ does not seem to show any obvious SiO counterparts. SiO production requires violent shocks and dust grain destruction while H¹³CO⁺ outflow emission only requires the acceleration of the dense core material (commonly traced by H¹³CO⁺). Given the high density of the central regions of this symmetric clump, the outflow traced by H¹³CO⁺ is likely encountering viscous forces, and thus only able to accelerate the gas rather than produce violent shocks. Further, since all dense gas tracers also display a similar range of low velocities such as the observed outflows, this is suggestive of the outflows experiencing an opposing force in its passage through the very dense, cluster forming core. Since the jet/outflow experiences the viscous forces uniformly from the point of ejection, the force only makes the flow have much lower velocities in comparison to other outflows.

The presence of an embedded cluster surrounding the ON 1 UCHII region represents a low mass stellar population that could be anywhere from Class I to pre-main sequence phases. If we consider that low mass stars form in $\sim 10^6$ yr and massive stars form in $\sim 10^5$ yr, the simultaneous presence of two massive outflows and the central location of the luminous sources provide two alternative scenarios. Either the massive star formation began much later than low mass star formation in this cluster-forming core or the formation of massive star/UCHII region phases lasts much longer than $\sim 10^5$ yr. While Herbig (1962) suggested that massive stars form *preferentially* late in the evolution of a cluster, Stahler (1985) argued that it is indeed so due to statistical reasons. In a related context, de Pree et al. (1995) suggest that the life times of the UCHII regions can be much longer than a few thousand years if they form and exist in dense and warm environments. The black-body fit to the FIR flux densities of several relatively isolated massive star forming regions (e.g. Hunter et al. 2000; Mueller et al. 2000; Beuther et al. 2002) suggest high temperatures between 50–100 K and densities $\geq 10^5 \text{ cm}^{-3}$ supporting the scenario predicted by de Pree et al. (1995). This is also true for ON 1 in view of the high estimated column densities and temperatures. However these observations cannot effectively rule out the possibility that massive star formation began much later than the formation of the surrounding cluster of low mass stars.

The FIR and radio flux of the ON 1 source and the mass estimates from this work suggest that ON 1 is among the early B type candidate massive protostars. This source can be compared to other well studied massive protostars such as IRAS 05358+3843 (Beuther et al. 2002), IRAS 18556+0136 (Fuller et al. 2001) or W75N (Shepherd et al. 2003). While W75N and IRAS 18556+0136 have UCHII regions, IRAS 05358+3843 has none and is likely about the same age as the massive protostars such as IRAS 20126+4104 (Cesaroni et al. 1999) and IRAS 23385+6053 (Fontani et al. 2004). Among all these, ON 1 is a neat example of a circularly symmetric molecular condensation with a centrally placed massive binary protostar which is driving multiple outflows and is surrounded by a young stellar cluster.

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