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VLBI observations of H_2O masers in the LkHα 234 star-forming region

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Abstract. We made observations of H_2O masers in the LkHα 234 star forming region using the Japanese domestic VLBI network (J-Net). We first present spatial and velocity structures of the maser sources of C1 and C3 which are detected by Tofani et al.(1995). The distribution of H_2O maser components in C1 shows an extent of 300×150 AU. On the other hand, it shows a compact and linear extent of 15×3 AU in C3 , and its position angle (P.A.=232 °) roughly agrees with that of the H_2 jet (P.A.=226 °). Moreover, the most blue-shifted and red-shifted maser components are located at both ends of the linear extent, indicating that this might be a very small jet ejected from the deeply embedded protostar. However, it is difficult to explain the distribution of intermediate velocity components by a simple jet model. We will discuss whether the H_2O masers originate in a jet or a disk.

1. Introduction

From recent investigations of the spatial and kinematic structure of H_2O masers around the protostars by VLA and VLBI observations, H_2O masers are likely to be due to the shock by infalling material onto the disks (e.g., Feibig et al. 1996; Imai et al. 1999), or by interaction of outflows (jets) from protostars with the parent clouds (e.g., Patel et al. 2000; Furuya et al. 2000). High

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spatial resolution such as milliarcsecond (mas) which will be acquired by VLBI observations of H_2O masers is critical in resolving the detailed structure and kinematics of protostellar disks and jets in a radial distance of 1-10 AU. In order to elucidate the dynamics of the circumstellar environment very close to the protostar and also the generation mechanism of the outflow, we conducted VLBI observations of H_2O masers in the LkHα 234 star-forming region.

LkHα 234 is a Harbig Ae/Be star located in the NGC 7129 star-forming region at a distance of 1 kpc. It is associated with a molecular outflow with an axis of NE-SW direction (Edwards & Snell 1983; Mitchell & Matthews 1994; Fuente et al. 2001), an optical jet (P.A.= 252°: Ray et al. 1990), and a deeply embedded H_2 jet (P.A.= 226°: Cabrit et al. 1997). However, there is an another deeply embedded infrared source IRS6 at 10μm at 2.7″ west from LkHα 234 (Cabrit et al. 1997). This is coincident with a radio continuum source (Tofani et al. 1995) and a millimeter-wave dust continuum source (Fuente et al. 2001), suggesting that it is a driving source of the outflow. Four H_2O maser spots are detected by VLA observations of Rodrigeuz et al. (1987) and Tofani et al. (1995). One spot, C3, is coincident with the deeply embedded source IRS6. Only C1 located at about 1″ away from C3 is resolved by VLBA observations of Migenes et al. (1999), but other maser spots are spatially unresolved into several velocity components.

2. Observations and data analysis

We performed VLBI observations of H_2O maser at 22.23508 GHz on May 28 and 29, 1997 using J-Net. J-Net has the minimum fringe spacing of 2.1 mas at 22 GHz band. The received signals were recorded using K-4 backend system, which has 16 video channels with 2 MHz bandwidth each. The correlation process was accomplished by the Mitaka FX correlator which has 256 points resolution in each channel corresponding to 0.105 km s^{-1} velocity resolution at 22 GHz. Data were edited and calibrated using the AIPS package of NRAO. We took uniform weighting. Synthesized beam size (FWHM) was 4.6×4.2 mas in P.A. = 138°.

3. Results

3.1. Detection of emission from C1 and C3

We detected H_2O maser emission from 2 spots, C1 and C3 by VLBI observations. C1 is at (ΔRA, ΔDec)=(-1.119″, 0.883″) from C3. C3 is coincident with a deeply embedded source IRS6. Our results are consistent with previous studies. Water maser emission appeared in the V_{LSR} velocity range from −18.2 km s^{-1} to −2.8 km s^{-1} at C1 and from −17.8 km s^{-1} to +1.7 km s^{-1} at C3 in this epoch.

3.2. Spatial and velocity structure of C1 and C3

We first present the spatial and velocity structure of the maser sources in C1 and C3 which were detected by Tofani et al.(1995). C1 is resolved into 9 components and its distribution shows an extent of 300×150 AU. This is roughly consistent with that by Migenes et al. (1999). Proper motion study of C1 can be done by comparing our position of each component with that by Migenes et al. (1999).

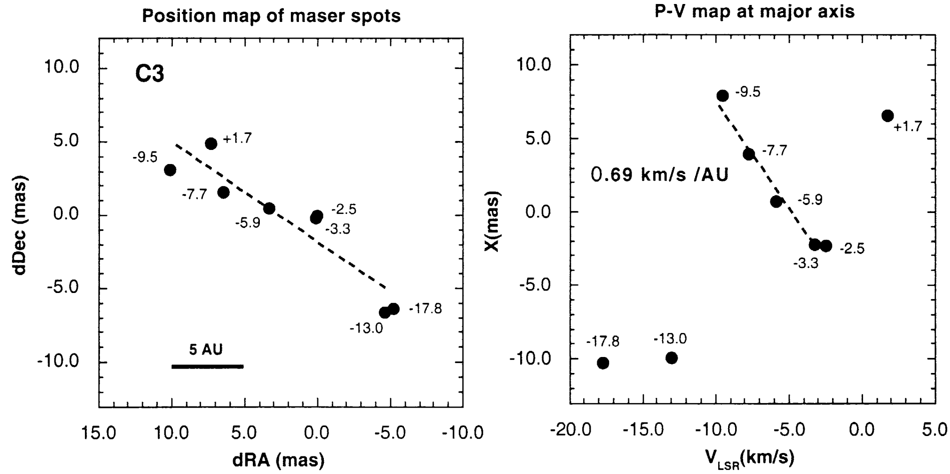

Figure 1. Positions of water maser spots in C3 (left) and position-velocity map along the major axis (right). Line-of-sight velocities are indicated by numerical value.

They observed in June 5, 1996 by VLBA and found 6 components. Only three components (–8.3, –9.7, –18.2 km s^{-1}) were available for proper motion study because the time interval between the two observations is too long for maser spots to survive. The spatial and velocity structure is roughly consistent with the large scale outflow, but its kinematics is very complicated, so it is difficult to explain it by any ordered motion.

On the other hand, C3 is resolved into 8 components and it shows a compact and linear (jet-like) structure with an extent of 15×3 AU as shown in Figure 1(left). Its position angle (P.A.=232 °) nearly agrees with that of the H_2 jet (P.A.=226 °). Moreover, the most blue-shifted and red-shifted maser components are located at both ends of the linear extent, while the large scale outflow has the blue-shifted component in SW. This indicates that it might be a very small jet ejected from the deeply embedded protostar inside the large scale outflow (cf. Furuya et al. 2001: this symposium)

4. Discussions

We show a position-velocity map along the major axis of the maser spots in C3 in Figure 1(right). It shows a linear velocity gradient of 0.69 km s^{-1} AU^{-1} of intermediate velocity components along the major axis, but an opposite velocity gradient to the most blue and red-shifted maser components (1.25 km s^{-1} AU^{-1}). It is difficult to explain the distribution of intermediate velocity components by a simple jet model.

The linear velocity gradient was thought to be due to the acceleration in jets (Patel et al. 2000) and the rotating motion of protostellar disks (e.g., Torrelles et al. 1998; Slysh et al.1999). There are two possible explanations for the velocity structure in C3: (1) the precession of the outflow and (2) a rotating protostellar disk.

The dynamical times are 6.9 and 3.8 yrs for the masers of intermediate velocity components and the most blue and red-shifted components, respectively. This could mean that two groups of maser components are produced by two independent ejection events. Several studies for molecular outflows show that the outflow axis is changed by precession (e.g., Imai et al. 2001:this symposium). If we assume that the jet axis is almost perpendicular to the line-of-sight, the velocity structure can be explained by a change of the jet direction during two ejection events. However, it is uncertain whether or not it is possible to achieve such a short precession period (3 yrs).

When we assume a rotating protostellar disk with the rotating axis (P.A.=–45°) perpendicular to the axis of the large scale outflow, then the velocity structure can be explained by an infall or expanding motion of the disk. Assuming Keplerian motion, an enclosed mass was calculated to be 0.1-1 $M_\odot$ ($\lesssim$ 5 AU) from the velocity gradient. This is not inconsistent with the mass of the less luminous embedded source (Fuente et al. 2001). From the highest resolution observation by the VLA, the 3.6 cm radio continuum source is resolved into two sources with $0.1''$ separation (Curiel et al. 2001: private communication). One of these sources is associated with the H_2O masers, which are probably produced in a rotating disk with its axis perpendicular to that of the large scale outflow, and another one could be the driving source for the large scale outflow independent of the maser emission. However, there is no evidence for another outflow perpendicular to the large scale outflow so far.

In any case, proper motion studies are highly required to decide the origin of the H_2O masers. We are planning to make multi-epoch observations by J-Net and the VLBA to elucidate the dynamics of the circumstellar environment very close to the protostar.

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