Investigating methanol maser observation of massive star forming region IRAS18144-1732 and IRAS20198+3716

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Contents

1. Introduction
   * About massive star formation
   * Purpose

2. Observations
   * JVN observation & Archive data of VLA

3. Source selection

4. About distribution
   * About IRAS20198+3716
   * methanol maser and molecular line
   * About IRAS18144-1723

5. Future

6. Summary
Classification by mass of stars

- Low mass star $M < 8M_\odot$
- Massive star $8M_\odot < M$
  - $M_\odot$: solar mass $\sim 2.0 \times 10^{30}$ kg

Massive star formation region

- We do not fully understand the formation scenario
  - Distance is far
  - Usually complicate situations because of multiple stars formation
  - Protostars embedded in dense dust clouds
  - We cannot observe at high spatial resolution
  - We cannot observe in shorter wavelengths than infrared.
Purpose

How are massive stars formed? (What is the formation scenario?)

How are accretion disks and outflows formed in massive star formation regions?

Immediate objective

To determine the structure, we analyze methanol maser associated with a disk or/and outflow.
Observation & Archive data

- VLBI observations of the 6.7GHz CH$_3$OH maser
  - Date: Sep. 15, 16, 2012
  - Radial velocity resolution: 0.176[km/s]
  - Frequency: 6.668GHz

- Observation data of 44GHz CH$_3$OH maser
  - Date: Sep, 15 1997
  - Frequency: 44.067GHz
  - Spatial resolution: 0.47 arcsec
  - Field of view: 1.0 arcmin
As a result of having observed it in a single dish, we can detect it at both frequency, and intensity is strong

- IRAS18089-1732
- IRAS20198+3716
- IRAS18144-1723
- IRAS18117-1753
About IRAS20198+3716
About IRAS20198+3716

*This region is also known as ON2.
*Estimated distance: $3.83 \pm 0.13\text{kpc}$
  (Ando et al. 2011)
*Bolometric luminosity:
  $20,605 \times 10^3 \text{ L}_\odot$
  (Varricatt et al. 2010)
*Molecular lines:
  SiO(2-1) (Fig. 5)
  H$_2$O maser (Ando et al. 2011)
  H$^{13}$CO$^+$ (Shepherd et al. 1997)
  6.7GHz CH$_3$OH maser (classII)
  (Menten et al. 1991) etc.

Fig 1: $^{13}$CO emission (contours), integrated SiO emission (gray scale)
(Shepherd et al. 1997)

Fig 2: Distribution of H$_2$O maser and continuum emission
(Ando et al. 2011)
44GHz methanol masers distribution of IRAS20198+3716

✓ Relative position:
  (20h21m44.0s +37d26’37.7”)
✓ Systemic velocity: -1.2km/s
  (ref. Ando et al.2011)
✓ 44GHz: 3 spots
44GHz methanol maser and molecular line

Fig 3: $^{12}$CO emission (contours), integrated SiO emission (gray scale); UCHII region, ++OH maser, ··H2O maser (Shepherd et al. 1997)
Structure of outflow

- Structure of outflow
  - 44GHz methanol maser: outside
  - 22GHz water maser: inside
  - We can elucidate the outflow structure of one source with each maser

Fig 4: Internal motion vectors of H2O maser (Ando et al. 2011)
6.7GHz methanol masers distribution of IRAS20198+3716

- Relative position: (20h21m44.0s +37d26’37.7’’)
- Systemic velocity: -1.2km/s (ref. Ando et al. 2011)
- 6.7GHz: 11 spots
- About velocity
  - Red spots: Red shift
  - Blue spots: Blue shift
- It is possible that 6.7GHz methanol maser is associated with outflow.
About IRAS18144-1723
**About IRAS18144-1723**

*This region is also known as Mol45.*
*Estimated distance: 4.33 kpc*
(Varricatt et al. 2010)
*Bolometric luminosity:*
\[ 21.2 \times 10^3 \, L_\odot \]
(Varricatt et al. 2010)
*Molecular lines:*
\[ \text{NH}_3 \] (Molinari et al. 1996)
\[ \text{H}_2\text{O} \] maser (Molinari et al. 1996)
\[ 6.7\text{GHz CH}_3\text{OH} \] maser (class II)
(Menten et al. 1991)
\[ \text{N}_2\text{H}^+ (3-2) \] (Fig. 8) etc.
6.7GHz methanol masers distribution of IRAS18144-1723

- Relative position:
  (18h17m24.5s -177d22’13.0”)
- Systemic velocity: 47.3km/s
  (ref. Kurtz et al. 2004)
- 6.7GHz: 5 spots
- About velocity
  - Red spots: Red shift

\[
\begin{array}{|c|c|}
\hline
\text{R.A. offset [mas]} & \text{Dec. offset [mas]} \\
\hline
51.1\text{km/s} & \\
52.0\text{km/s} & \\
49.7\text{km/s} & \\
49.2\text{km/s} & \\
50.0\text{km/s} & \\
\hline
\end{array}
\]
Future

- Because 44GHz methanol maser in redshift from distribution from Ando et al. 2011, we can measure the three-dimensional structure from now on.
- We will investigate the relative distribution of both maser classes in further 1 source.
- We increase the sources to take the statistics:
  - Observation of 44GHz methanol maser by KVN +VERA, VLA
  - Observation of 6.7GHz methanol maser by JVN
We made IRAS 20198-1723 methanol maser image with high resolution.

- we considered 44GHz methanol maser and the relations with the molecular line spectrum
  - We understood that 44GHz methanol maser was at the base of the outflow
    → Structure from the outside of the outflow to the inside was identified as a methanol maser and other molecular line spectra

- We made IRAS 18144+1723 methanol maser image with high resolution.
  - Distribution of 6.7GHz methanol masers were divided into red shifts
Methanol masers distribution of IRAS20198+3716

- Relative position: (20h21m44.0s +37d26'37.7")
- Systemic velocity: -1.2 km/s (ref. Ando et al. 2011)
- 6.7GHz: 11 spots
- 44GHz: 3 spots
- About velocity
  - Red spots: Red shift
  - Blue spots: Blue shift
44GHz methanol maser and molecular line (1)

- The distribution of the 44GHz methanol maser is associated with 111GHz and 86GHz.

- 44GHz methanol maser is emitted in this star formation region.

Fig 9: 86GHz (contours) and 111GHz continuum emission (gray scale) \( \oplus \); UCHII region, \( +; \) OH maser (Shepherd et al. 1997)
44GHz methanol maser and molecular line (2)

Fig. 10 : H$^{13}$CO$^+$ emission (gray scale and thin lines), SO$_2$ emission (thick lines) ⊕; UCH II region (Shepherd et al. 1997)

Fig. 11 : SiO emission (gray scale and thin lines), SO$_2$ emission (thick lines) (Shepherd et al. 1997)