The Dynamics of the Outflow Structure in W49 N

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Abstract

We present the current study of the proper motions of 22 GHz water masers towards W49 N that were observed by the KaVA telescope during February to May 2017. We found 263, 268, and 310 features in 3 successive epochs; they were distributed in a region of size 4×4 arcsec^2. For 102 H_2O maser features, proper motion was detected across all 3 epochs. The average proper motions in right ascension offset and declination offset were -0.352 and +0.890 mas per year, respectively. The morphology of the distribution of the H_2O maser features was found to be a bipolar outflow structure with an inclination angle of 37±13 degrees to the line of sight, and the features were expanding from a well-defined outflow centre. A model of the source combining expansion and rotation yielded a distance to W49 of 11.12±0.96 kpc that is consistent with results from trigonometric parallax. We compare the H_2O maser features with SiO v=0 J=5-4 emission observed with ALMA. The PV diagram of the SiO emission shows structure of bipolar outflow and has a face-on orientation with the inclination angle of 36.4±0.4 degrees with respect to the line of sight of the observer and we also discuss the dynamics of its outflow.

Introduction

W49 North (W49 N or G043.16+0.01) is a region inside the high-mass SFR, W49A. It is the most luminous and complex SFR with H_2O masers in our Galaxy [1,2]. An H_2O maser parallax distance of $11.11^{+0.79}_{-0.69}$ kpc has been measured [3]. De Pree et al. (2020 and reference therein)[4] defined 23 distinct ultracompact sources in W49 N, definitions that were newly upgraded in observations using the 3.6 cm and 7 mm wavebands of the VLA and also IRAM Northern Extended Millimeter Array (NOEMA), e.g. A1, A2, B1, B2, B3, C, C1, D, E1, E2, E3, F, G1, G1 south, G2a, G2b, G2c, G3a, G3b, G3c, G3d, G4, and G5. Mostly, the H_2O maser emission in W49 N is found closely associated with the G1/G2 sources and strongest flux is observed around there. Many previous works have been discussed and proposed that the maser emission arises from an outflow centre near the G region, e.g., [5], [6], and [3]. [7] suggested an extremely energetic outflow which is traced by the HCN v2=1 (3-2) line, and the most energetic molecular outflows in the Milky Way.

The proper motion, flux variability of 22 GHz H_2O maser and its bipolar outflow were presented in Asanok et al. 2023 [9]. In this work, we will report only the current updated of SiO outflow towards the W49 N star-forming region by using the calibrated data obtained from the ALMA archive. We also compare the distribution of H_2O maser features with the molecular line emission in the SiO v=0 J=5-4 transition which will be the first report of this line emission and the 1.4-mm continuum data that were observed with the ALMA at band 6.

Info.	ALMA01421348	ALMA01421322
Band:	6	6
Date of observations:	2018-09-29	2018-09-29
Data type:	image	cube
	1.4 mm continuum	SiO v=0 J=5–4
Image size(arcmin^2):	2.21×2.53	2.21×2.53
Image scale and beam size. : (arcsec)	0.074, 0.301×0.277	0.074, 0.343×0.280
Freq. range. (GHz):	217.033 – 234.664	216.967 – 218.840

Table 1 Information about datasets ID:ALMA01421348 and ID:ALMA01421322, obtained from the JVO portal.

Observation and the calibrated data from JVO portal

Observations of the H_2O ($6_{1,6}$-$5_{2,3}$) line at 22.235080 GHz were carried out with KaVA, which consists of four 20-m antennas of the VERA in Japan and three 21-m antennas of the KVN. The maximum baseline length of KaVA is 2,270 km, providing the highest angular resolution of 1.2 mas.

The pointing and phase-tracking center position of the target source, W49 N was taken to be RA(J2000) = 19h10m13.41s, Decl(J2000) = $+09^{\circ}06'14.3''$. We observed W49 N in 3 epochs, each of which consisted of a time from horizon to horizon of 4.5 hours on two consecutive days. In the `doy' (day of the year) system, these epochs were 058-059, 102-103, and 130-131 in 2017. The net on-source time was 3.2 hours per epoch. Left-handed circular polarization data were recorded on the hard disk devices at 1 Gbps. The total bandwidth of each session was 8×32 MHz, and a spectral resolution for the 22-GHz maser line was set to be 31.25 kHz, which corresponded to a total velocity coverage and velocity resolution of 430 km s^{-1} and 0.42 km s^{-1}, respectively. The systemic velocity of W49 N is equal to +10.0 km s^{-1}. We observed a nearby calibrator, DA406, for bandpass and delay calibration once every hour. Phase calibration was done by using the strongest H_2O maser spot in the first epoch and it was the same position for every epoch in W49 N by fringe fitting and self-calibration. Software "AIPS" was used to calibrate the data. We have developed and employed the python script for classifying the maser features. We used calibrated data that were obtained from the the Japan Virtual Observatory (JVO) portal service under the project code ALMA#2016.1.00620.S; the datasets are ID:ALMA01421348 and ID:ALMA01421322. Both datasets belonging to the ALMA observation and can be summarized as shown in table 1.

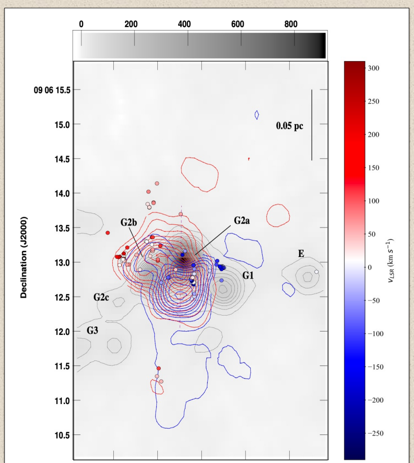

Figure 3 The calibrated continuum data was obtained from the JVO portal service as the dataset ID:ALMA01421348, which was observed at band 6 of the ALMA telescope. Red and blue lobes are SiO outflow. Contour levels for grey scales and red and blue lobes are at 1, 2, ..., 15 $\times\sigma_{rms}$. The subset of the 22 GHz H_2O maser features that were observed in all 3 epochs by the KaVA are overlaid on the 1.4-mm continuum contours. The color shades denote the epoch-averaged V_{LSR} in the range from -290 to +310 km s^{-1} of the maser features. Sources G1, G2a, G2b, G2c, G3 and E are defined by [4]. The vertical dotted line is a cut line for measuring the position-velocity diagram in figure 2.

The association between the 1.4mm continuum sources, 22 GHz H_2O masers, and the SiO outflow emission

We plotted the contours of the SiO v=0 J=5-4 outflow emission overlaid on the 1.4-mm continuum data, and also together with the 22 GHz H_2O maser features which were observed by the KaVA (see figure 3). Red and blue colors represent redshifted and blueshifted velocities from the H_2O maser features and the same manner with the contours of the SiO outflow. Almost the H_2O maser were found toward G1, G2a, and G2b sources. The SiO lobes appear to have the clear structure of a bipolar outflow with some inclination respect to the face-on direction to the observer on the Earth. We calculate the inclination angle of this outflow by estimating from the projection of redshifted and blueshifted contours and use a simple trigonometric expression to calculate the value i.e., its inclination angle is 36.4±0.4 degrees.

Acknowledgement

We would like to thank KVN, VERA array (KaVA) for the observation data, and the ALMA data: ADS/JAO.ALMA#<2016.1.00620.S>. This project is fully supported by Thailand Research Foundation, NARIT and KKU Thailand during the fiscal year 2018-2020.

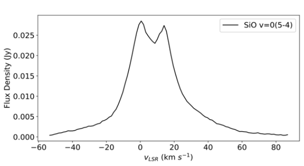

Figure 1 Total power spectrum of the SiO v=0 J=5-4 line emission, which was taken from the JVO portal service under the project code named ALMA#2016.1.00620.S.

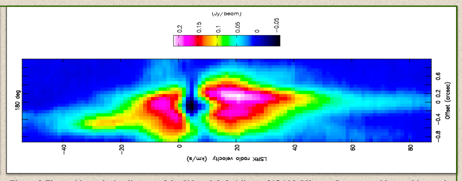

Figure 2 The position-velocity diagram of the SiO v=0 J=5–4 line at 217.105 GHz rest frequency with a position angle +180 degrees. Color shades represent the specific intensities in Jy beam^{-1}.

The SiO v=0 J=5-4 outflow and its dynamics

- ***The SiO v=0 J=5-4 line emission***: the total power spectrum of SiO v=0 J=5-4 line emission is measured by using the spectral profile tool of the CASA software. Two peaks of spectrum are blueshifted [-54.7:+8.6] km s^{-1} and redshifted [+10.0:+74.7] km s^{-1} as shown in figure 1, respectively. The velocity ranges of these lobes are 63.5 km s^{-1} and 64.7 km s^{-1}, respectively, and they give rise to nearly symmetrical velocity structures in the spectrum velocity of 8 km s^{-1}.
- ***PV diagram***: the position-velocity diagram of the SiO v=0 J=5-4 line emission in the W49 N region (see figure 2) by measuring in the respective directions along position angle 180 degrees. It shows the clear structure of a bipolar outflow with a compact sizes of diameter (1.5×0.5) arcsec^2 in each lobe. These lobes are formed by gas ejected from the outflow core that subsequently reaches speeds sufficient to generate shocks.
- ***Physical properties of the SiO outflow***: we have adapted the equations which were taken from [7,10] and computed the physical parameters of the SiO v=0 J=5-4 line emission by following (1) the column densities within a main beam (N_{SiO}) = $1.6\times10^{11}\ cm^{-2}\times\frac{(T_{ex}+0.35)exp\{31.26/T_{ex}\}}{exp\{10.4/T_{ex}\}-1}\times\frac{1}{J_\nu(T_{ex})-J_\nu(T_{bg})}\int T_{mb}dv$ where $J_\nu(T)=\frac{\frac{h\nu}{k}}{\exp(\frac{h\nu}{kT})-1}$, T_{ex} and T_{bg} are the excitation temperature of the gas and background radiation temperatures; (2) the luminosity (L_{SiO}) = $2.3\times10^{-4}L_\odot\times\left(\frac{d}{6\ kpc}\right)^2\frac{\int T_{mb}dv}{1\ K\ km\ s^{-1}}$ where d is the distance of W49 N, $L_\odot$ is the luminosity of the sun and $\int T_{mb}dv$ is the velocity integrated intensity inside the main beam; (3) the gas mass in the outflow (M_{out}) = $N_{SiO}\left[\frac{H_2}{SiO}\right]\mu_g m_H d^2\Omega_A$ where $\Omega_A=\frac{\pi}{4\ln(2)}\theta^2_{FWHM}$, μ_g = 1.36 is the mean molecular mass per hydrogen atom, m_H is the hydrogen atom mass, and the ratio [H_2/SiO] has a large uncertainty which is depended on the SiO abundance and types of sources; (4) if we assume the outflow is powered by winds driven therefore the mass lost rate ($\dot{M}_{out}$) $=\frac{P}{t_{dyn}V_{wind}}$ where V_{wind} is the wind velocity; (5) the momentum (P) = $M_{out}\times V_{char}$ where the characteristic outflow velocity (V_{char}) is defined as $V_{char}=V_{flow}-V_{sys}$, V_{sys} is the systemic velocity and V_{flow} is the intensity-weighted velocity of high-velocity emission corrected with the projection effect; (6) the momentum rate ($\dot{P}$) $=\frac{P}{t_{dyn}}$; (7) the kinetic energy (E) $=\frac{1}{2}M_{out}\times V^2_{char}$; (8) the mechanical luminosity (L_{mech}) $=\frac{E}{t_{dyn}}$; and (9) the dynamical time scale (t_{dyn}). All those calculated physical parameters were presented in table 2.
- ***Protostars?:*** we found two strong negative blobs that are shown by the dashed lines in figure 4. The first blob is at the position RA(J2000)=19h10m13.373s, Decl(J2000)=$+09^{\circ}06'12.63''$, which is associated with the position of the ultra-compact source G1, and can be found within the velocity range [+11.3:+8.6] km s^{-1}. The second blob is at RA(J2000)=19h10m13.422s and Decl(J2000)= $+09^{\circ}06'13.03''$, which is associated with the ultra-compact source G2a, and can be detected over the large velocity range [+8.6:-0.8] km s^{-1}. These blobs could be the position of protostars. However, this hypothesis should be clarified by following up with other observations at different wavelengths and high resolution.
- ***The association between the hot molecular cores and the SiO outflow***: [11] confirmed that G:IRS1 is an infrared source inside W49 N that is coincident with a hot molecular core, which is driving an outflow and is the origin of a larger bipolar cavity and CO outflow inside W49 N. We have found two cores in this outflow i.e., G:IRS1 or MCN-b at RA(J2000) = 19h10m13.424s, Decl(J2000) = $+09^{\circ}06'12.47''$ and MCN-c at RA(J2000) = 19h10m13.407s, Decl(J2000) = $+09^{\circ}06'10.53''$, respectively. The MCN-b source is more likely to be associated with the blueshifted lobe of the SiO outflow and its extended structure than with the redshifted lobe.

	Red lobe:	Blue lobe:
Velocity Interval (km s^{-1}):	[+10.0 : +74.7]	[−54.7 : +8.6]
V_{char} (km s^{-1}):	52.6	17.3
l_{lobe} (10^3AU):	12.2	9.2
t_{dyn} (yr):	1104±9	2532±28
M_{out} ($M_\odot$):	41.5±5.9	51.1±7.2
$\dot{M}_{out}$ ($10^{-4}M_\odot yr^{-1}$):	39.5±4.6	7.0±1.0
P ($M_\odot$ km s^{-1}):	2180±308	884±125
$\dot{P}$ ($M_\odot$ km s^{-1}yr^{-1}):	2.0±0.2	0.4±0.1
E (10^{47}erg):	11.4±1.6	1.5±0.2
L_{mech} ($10^2 L_\odot$):	84.0±11.1	4.8±0.6
N_{SiO} (10^{14}cm^{-2}):	1.4	1.8
L_{SiO} ($10^{-2}L_\odot$):	7.4	9.1

Table 2 Physical parameters of the outflow derived from the SiO v=0 J=5-4 emission.

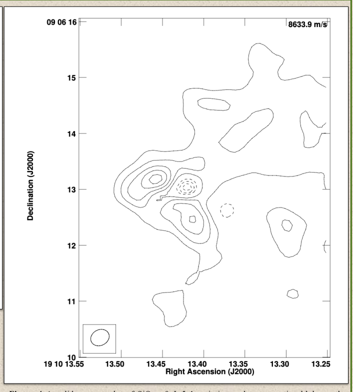

Figure 4 A solid contour plot of SiO v=0 J=5-4 emission and two negative blobs as the dashed-line contours in W49 N at the V_{LSR} velocity of +8.63 km s^{-1}. The image cube data were taken from the JVO portal service under the project in a code named ALMA#2016.1.00620.S. Contour levels are at -10,-9,..., 10 times 0.03 Jy beam^{-1}. The ellipse at the bottom left of its panel shows the beam size of the telescope.

Summary

We have studied the proper motions of 22 GHz H_2O masers towards the W49 N region using the KaVA over epochs during February to May 2017 (see the first paper in [9]) and compare our results together with band 6 of the ALMA data.

❒ The SiO v=0 J=5–4 outflow is detected in W49 N and oriented face-on with the inclination angle of 36.4±0.4 degrees with respect to the line of sight to the observer.

❒ At least one protostar is found at the G2a source and a YSO candidate with an envelope remnant is at the G1 source. However, these results need to clarify by following up other observations at different wavelengths with high resolution.

❒ The evolutionary time scale in each lobe of the SiO outflow, especially the redshifted lobe, is rather short when compared to other bipolar outflow regions. This suggests a highly energetic outflow is still active inside the W49 N region.

❒ The dynamics of the SiO outflow shows associated with the hot core MCN-b and is the most powerful which can be driven by the young sources or clumps in that region.

References

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