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Internal proper motion of 6.7-GHz methanol masers in an HII region S269

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We present the first internal proper motion of the 6.7-GHz methanol maser within S269, an HII region in the outer Galaxy, which have been carried out in 2006 and 2011 using the Japanese VLBI Network (JVN). Several maser groups and weak isolated spots are detected in an area spanning by $\sim$ 200 mas (1000 AU). Three remarkable maser groups are aligned at a position angle of 80°. Two of three maser groups are also detected by a previous observation in 1998, which allow us to study a long-term position variation of maser spots from 1998 to 2011. Angular separation between the two groups increased $\sim$ 10 mas, which corresponds to an expansion velocity of $\sim$ 10 km s^{-1}. Some velocity gradient ($\sim 10^{-2}$ km s^{-1} mas^{-1}) in the overall distribution was found.

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1. Introduction

The 6.7-GHz methanol maser emission is known to be closely associated with high-mass star forming regions, and it is thought to probe very early stages of star formation (e.g. [2, 11, 22]). Various morphologies of the 6.7 GHz methanol masers have been obtained with past interferometric and VLBI observations. The linear distribution and velocity gradient of the masers have often been explained as an edge-on rotation disk (e.g. [13]). Such a rotation disk hypothesis is supported by detections of ring-like distribution of masers [1, 18, 21], and detections of internal motions surrounding a radio continuum source [5, 12, 16, 17]. On the other hand, shock-wave model has been presented to explain the maser location in several sources [4, 14, 23]. De Buizer (2003) [3] searched for H_2 outflow signatures in massive young stellar objects with the linear distribution of methanol masers to test whether the outflows are perpendicular to the linear distributions. Their search revealed that H_2 emission is distributed almost parallel to the distribution of methanol masers in their sample sources. Moreover, multi-epoch VLBI observations have shown the internal motions of methanol masers in massive star-forming region ON1, which suggested that the masers trace the expansion of the UC HII region or a bipolar outflow [15, 19]. Thus, the 6.7 GHz methanol maser emission is detected on size scale of 1000 AU, and is a powerful tool to investigate the environment close to the forming high-mass protostar. However, internal motions of the 6.7 GHz methanol masers have been reported in limited number of sources so far.

S269 is a small HII region in the outer Galaxy, and harbors two bright near-infrared (IR) sources separated by $\sim 30''$, IRS 1 and IRS 2 [24]. Recent near-IR images imply that several H_2 knots are distributed across IRS 2, which suggest two bipolar outflows, powered by sources in IRS 2 [8]. The 6.7-GHz methanol maser emission has been also found in S269 [9, 20]. The past VLBI observations of the 6.7-GHz methanol maser in S269 detected two groups (A & B), separated by ~ 55 mas in 1998 November [10].

2. Observations

We observed 6.7-GHz methanol masers in S269 using the Japanese VLBI Network (JVN) on 2006 September (Epoch 1) and 2011 October (Epoch 2), eight and thirteen years after the past VLBI observation. Observation parameters for the JVN observations are summarized in table 1.

We have also carried out single-dish observations toward 6.7-GHz methanol maser emission of S269 with Yamaguchi 32-m telescope almost simultaneously with each JVN observation, for the absolute flux calibration to the VLBI data. The observations were performed for four days from

Table 1: Observation parameters

Epoch	Date (yyyy/mm/dd)	Telescopes	Synthesized beam (mas, mas, deg)	On-source time (hr)	$I_{\rm rms}$ (mJy beam^{-1})
1	2006/09/10	Y, U, M, I	23×3, −34	2.1	110
2	2011/10/22	Y, U, H, M, R, O, I	8×3, −46	6.5	10

Column 3: Y for Yamaguchi, U for Usuda, H for Hitachi, M for VERA-Mizusawa, R for VERA-Iriki, O for VERA-Ogasawara, I for VERA-Ishigaki.

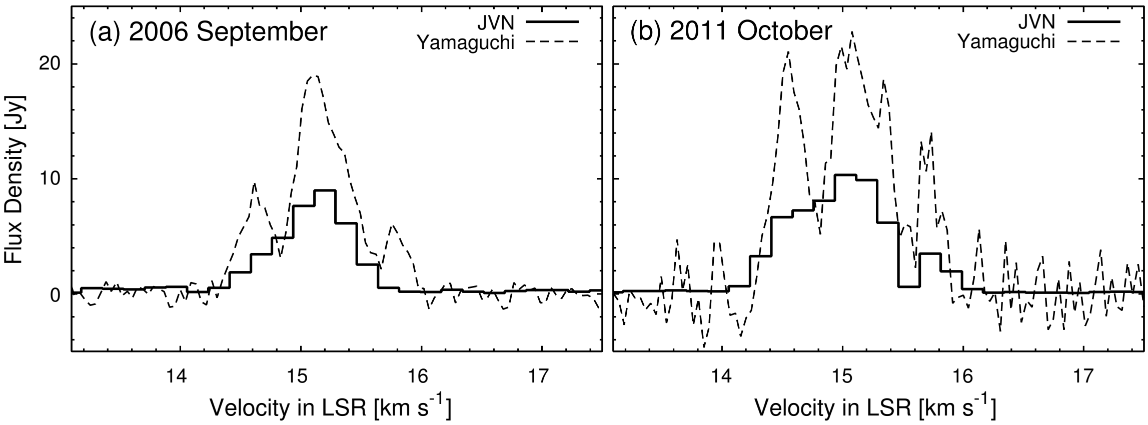

Figure 1: Comparison of the cross-power spectrum (vector average) obtained from our JVN observations (Solid line) and the spectral profile measured with the Yamaguchi 32-m telescope (Dashied line) in (a) 2006 September and (b) 2011 October Velocity resolution is 0.178 km s^{-1} and 0.044 km s^{-1}, respectively.

2006 September 4, and one day on 2011 October 22 just after the JVN observations toward S269. We adopt $D = 5.28$ kpc to S269[7], and hence 1 mas corresponds to 5.27 AU.

3. Results

The maser emission was detected at velocity range of 14.0–16.5 km s^{-1} (figure 1). The spectrum detected with the Yamaguchi 32-m telescope reveals the brightest peak at velocity of 15.2 km s^{-1}, and blue-shifted and red-shifted spectral components at peak velocity of 14.7 and 15.9 km s^{-1}, which is consistent with the past single-dish observations [6, 20].

The maser distribution is organized by several maser groups and some weak isolated spots (figure 2). The most luminous maser spot at 15.2 km s^{-1} belongs to group B. The group A is the second brightest, which locates $\sim$ 55 mas east from the group B. The group C is located, 95 mas west from the group B. In 2011, the group D is seen at 70 mas west and 60 mas north from the group A. The group D consists of several maser spots with velocities of 16.00 and 16.17 km s^{-1}. And also, several prominent maser spots at velocity of 14.8–15.3 km s^{-1}, distributed $\sim$ 170 mas in a line at southeast–northwest direction, almost parallel to the dashed line in figure 2b.

We here describe the relative position of the maser spots with respect to the barycentric point among maser spots within the group A for each epoch. The spatial and velocity structure of the groups A, B and C are consistent during the period 1998–2011. The angular separation between the barycentric points of the groups A and B increases $\sim$10 mas for thirteen years from 1998 to 2011. If we assume that it increases at a constant rate, the velocity of the internal motion is estimated to be 10 km s^{-1}. We note that maser distribution and velocity range of the group A in 2011 (Epoch 2) changed from two previous VLBI observations in 1998 and 2006 (Epoch 1), and there could be uncertainty about the reference point in 2011. If we exclude the results at Epoch 2 for estimation of the internal motion between the group A and B, the velocity of the motion would be 13 km s^{-1}. It is difficult to discuss about the motion of the group C, because the velocity range of the group C at Epoch 1 and 2 is not same, and therefore the maser spots in the group C in different epochs can not be identified as the same.

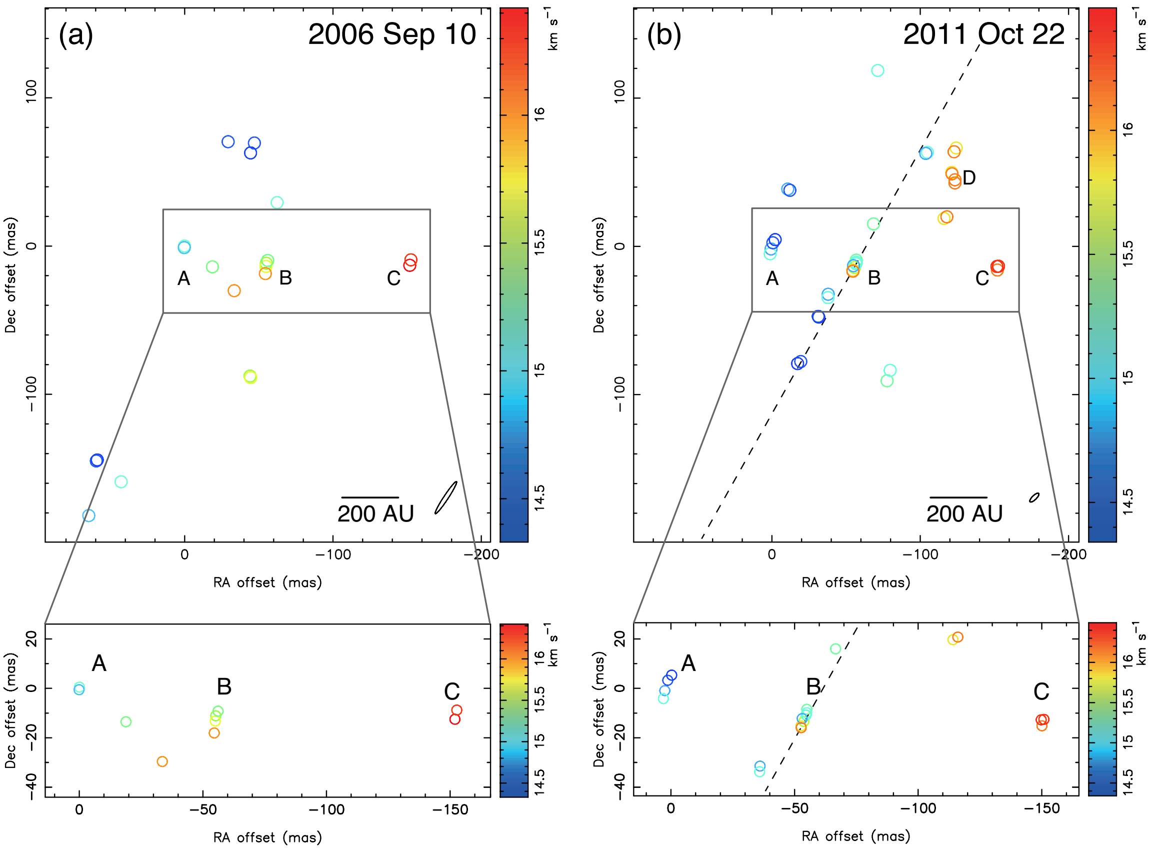

Figure 2: Maser positions for S269 on (a) 2006 September 10 and (b) 2011 October 22. Color indicates the LSR doppler velocity of the spectral channel. The synthesized beam size is shown at the lower right in wide-field view.

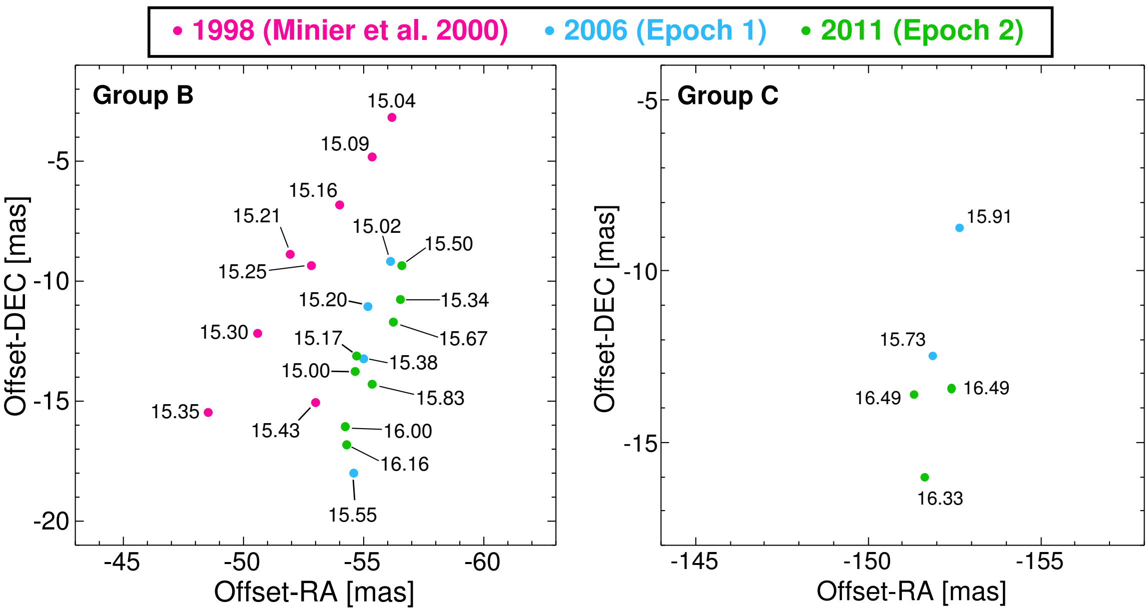

Figure 3: Superposed maps of 6.7-GHz methanol maser distribution in the groups B and C with respect to the group A.

Velocity gradient in the overall distribution could roughly be seen along the alignment of the groups A, B and C at position angle of $\sim 80^\circ$. In 2011, another obvious linear structure was seen along the southeast–northwest direction (P.A. $\sim 135^\circ$) with a velocity gradient. Some trends of velocity gradients of $\sim 10^{-2}$ km s^{-1} mas^{-1} are determined by a linear fitting along the directions at P.A. of 80° and 135°.

4. Discussion

The bipolar outflow scenario is the simplest explanation for the increase of the angular separation between two maser groups A and B. The axis of outflow would be a line joining the two maser groups A and B, in the direction at position angle of $\sim 80^\circ$. Viewing angle of the outflow is estimated to be 87° from the projected relative velocity of 13 km s^{-1} and the velocity difference between the groups A and B of 0.6 km s^{-1}. Therefore, the outflow axis is almost parallel to the sky plane, and absolute velocity of the expansion between the groups A and B is estimated to be nearly 13 km s^{-1}. The group C is also located on the extension of the line, and the groups A, B and C could be associated with the same outflow. However, the direction at position angle of $\sim 80^\circ$ is not consistent with a large-scale bipolar outflow in the southeast–northwest direction traced by several H_2 knots (Knots 1, 2, 3, 4, 5; [8]). Therefore, the internal motion of groups A and B could be driven by another outflow. The near-IR images have suggested the existence of a second outflow with a different axis traced by H_2 knot 6 as well[8]. If the second outflow is powered by sources in IRS 2, the outflow axis would be a line connecting IRS 2 and H_2 knot 6. We note that the direction of the outflow axis is nearly parallel to the position angle of 80°, which is the alignment of the maser groups A, B and C.

The disk scenario has often been proposed to interpret the maser distribution in linear distribution with a velocity gradient, and could be another candidate to explain the observational results of the methanol masers. If the velocity gradient of the methanol maser emission is due to a Keplerian rotation disk, the enclosed mass is estimated to be $\sim 1 M_\odot$, assuming edge-on view of the disk with a disk radius of 1000 AU, defined by the total extent of the methanol masers. However, the estimated value is too small for a high-mass star forming region, in which 6.7-GHz methanol maser emission is observable.

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References

[1] Bartkiewicz, A., Szymczak, M., van Langevelde, H. J. 2005, A&A, 442, L61

[2] Caswell, J. L., Vaile, R. A., Ellingsen, S. P., Whiteoak, J. B., Norris, R. P. 1995, MNRAS, 272, 96

[3] De Buizer, J. M. 2003, MNRAS, 341, 277

[4] Dodson, R., Ojha, R., Ellingsen, S. P. 2004, MNRAS, 351, 779

[5] Goddi, C., Moscadelli, L., Sanna, A., 2011, A&A, 535, L8

[6] Goedhart, S., Gaylard, M. J., van der Walt, D. J. 2004, MNRAS, 355, 553

[7] Honma, M. et al. 2007, PASJ, 59, 88

[8] Jiang, Z., Yao, Y., Yang, J., Baba, D., Kato, D., Kurita, M., Nagashima, C., Nagata, T., Nagayama, T., Nakajima, Y., Ishii, M., Tamura, M., Sugitani, K., 2003, ApJ, 596, 1064

[9] Menten, K. M. 1991, ApJ, 380, L75

[10] Minier, V., Booth, R. S., Conway, J. E. 2000, A&A, 362, 1093.

[11] Minier, V., Ellingsen, S. P., Norris, R. P., Booth, R. S. 2003, A&A, 403, 1095

[12] Moscadelli, L.; Cesaroni, R.; Rioja, M. J.; Dodson, R.; Reid, M. J. 2011, A&A, 526, A66

[13] Norris, R. P., Byleveld, S. E., Diamond, P. J., Ellingsen, S. P., Ferris, R. H., Gough, R. G., Kesteven, M. J., McCulloch, P. M., Phillips, C. J., Reynolds, J. E., Tzioumis, A. K., Takahashi, Y., Troup, E. R., Wellington, K. J. 1998, ApJ, 508, 275

[14] Phillips, C. J., Norris, R. P., Ellingsen, S. P., McCulloch, P. M. 1998, MNRAS, 300, 1131

[15] Rygl, K. L. J., Brunthaler, A., Reid, M. J., Menten, K. M., van Langevelde, H. J., Xu, Y. 2010, A&A, 511, A2

[16] Sanna, A., Moscadelli, L., Cesaroni, R., Tarchi, A., Furuya, R. S., Goddi, C. 2010a, A&A, 517, A71

[17] Sanna, A., Moscadelli, L., Cesaroni, R., Tarchi, A., Furuya, R. S., Goddi, C. 2010b, A&A, 517, A78

[18] Sugiyama, K., Fujisawa, K., Doi, A., Honma, M., Isono, Y., Kobayashi, H., Mochizuki, N., Murata, Y. 2008, PASJ, 60, 1001

[19] Sugiyama, K., Fujisawa, K., Doi, A., Honma, M., Isono, Y., Kobayashi, H., Mochizuki, N., Murata, Y., Sawada-Satoh, S., Wajima, K. 2011, PASJ, 63, 53

[20] Szymczak, M., Hrynek, G., Kus, A. J. 2000, A&AS, 143, 269

[21] Torstensson, K. J. E., van Langevelde, H. J., Vlemmings, W. H. T., Bourke, S. 2011, A&A, 526, A38

[22] Walsh, A. J., Hyland, A. R., Robinson, G., Burton, M. G. 1997, MNRAS, 291, 261

[23] Walsh, A. J., Burton, M. G., Hyland, A. R., Robinson, G. 1998, MNRAS, 301, 640

[24] Wynn-Williams, C. G., Becklin, E. E., Neugebauer, G. 1974a, ApJ, 187, 473

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