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# Associating Sites of Methanol Maser Emissions at 6.7 GHz

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We have carried out VLBI observations of some methanol maser sources at 6.7 GHz with the Japanese VLBI Network (JVN) using phase-referencing techniques. We superposed the methanol masers on water, hydroxyl masers, radio continuum, and various molecular line emissions with an accuracy of a milliarcsecond (mas) scale, which is enough for investigating a positional relation with a central or exciting star. In this paper, we report results of the superposition in massive star-forming regions (SFRs) Cepheus A (Cep A) and Onsala 1 (ON 1). The methanol maser spots of Cep A showed an arched structure with a scale of 1400 AU. This structure was roughly perpendicular to a radio continuum jet, having an exciting star near the center of the arch, and was coincident with the $CH_3CN$, $NH_3$ disks. It is easy to explain that the Cep A methanol masers are associated with a circumstellar disk around a massive young stellar object (YSO). The methanol maser spots of ON 1 formed two main clusters isolated 1800 AU from each other, which corresponded to a red- and a blue-shifted spectral feature, respectively. The direction of the elongation of the isolated clusters coincided with the $H^{13}CO^+$, SiO molecular outflows, although each spatial size is quite different. Also, the position-velocity diagram along the direction of the molecular outflows roughly coincided. The ON 1 methanol masers may trace an outflow ejected from a massive YSO, while it is also thought to be possible that the masers of this source may trace an expansion of an Ultra-compact (UC) HII region by superposing on the hydroxyl masers.

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## 1. Introduction

The methanol masers at 6.7 GHz were detected only in massive SFRs and these were thought to trace pre- or early UC HII region phase. This maser, therefore, could be a useful tool for investigations of star-formation around massive YSOs. The site of this maser, however, is still unclear and depends on whether this maser is associated with a circumstellar disk around a massive YSO or shock regions which are formed by outflows ejected from the YSO.

We have carried out VLBI observations of some methanol maser sources at 6.7 GHz with the Japanese VLBI Network (JVN) using phase-referencing techniques. We report results of superposition on water, hydroxyl masers, radio continuum, and various molecular line emissions with an accuracy of a milliarcsecond (mas) scale in the massive SFRs Cep A and ON 1. The VLBI map of methanol masers for Cep A was already obtained with the JVN using phase-referencing techniques [10]. A VLBI observation of methanol masers at 6.7 GHz for ON 1 was carried out on 11 May 2008 using five JVN stations (Yamaguchi, VERA-Mizusawa, -Ogasawara, -Iriki, and -Ishigaki).

## 2. Results and Discussions

The spatial distribution of the Cep A methanol maser spots showed an arched structure with a scale of 1400 AU, which was consistent with the result of [13]. The result of superposition on various emissions is shown in Fig. 1(a). The peak of 43 GHz continuum emission, which may be an exciting star [2], was located near center of the arched structure. The elongation of the arched structure was nearly perpendicular to the radio jet (e.g., [2], [11]) at difference of position angle $\sim$70 degree. The overall distribution of the maser spots coincided with the $CH_3CN$ and $NH_3$ disks ([8] and [12]) and the velocity range of the spots is similar to that of these disks. The methanol distribution also roughly coincided with the water maser and $SO_2$ disks ([11] and [5]), although the sizes of these disks are about 2 times smaller. It is easy to explain from these results that the Cep A methanol masers are associated with a circumstellar disk. However, a simple velocity gradient like Keplerian rotation was not detected in the methanol maser spots. The disk may rotate with infall or expansion.

The methanol maser spots of ON 1 formed two main clusters isolated 1800 AU from each other, which corresponded to a red- (15 km $s^{-1}$) and a blue-shifted (0 km $s^{-1}$) spectral feature, respectively. The result of superposition on various emissions based on the absolute coordinates obtained by [4] is shown in Fig. 1(b). First, exciting stars are probably different between water masers [7] and methanol masers, and the methanol masers were associated with the UC HII region [1]. The direction of the elongation of the isolated clusters was parallel to the $H^{13}CO^+$, SiO molecular outflows, although each spatial size is quite different. Also, the position-velocity diagram along the direction of the molecular outflows roughly coincided. The ON 1 methanol masers may trace a molecular outflow. On the other hand, the methanol masers coincided with the hydroxyl masers which traced an expansion of the UC HII region by measuring internal proper motions [3]. The ON 1 methanol masers may also trace an expansion of the UC HII region.

We have conducted multi-epoch VLBI observations of 6.7 GHz methanol masers with the JVN in order to measure internal proper motions and will report the results for discussing the associated sites of this maser in a forthcoming paper.

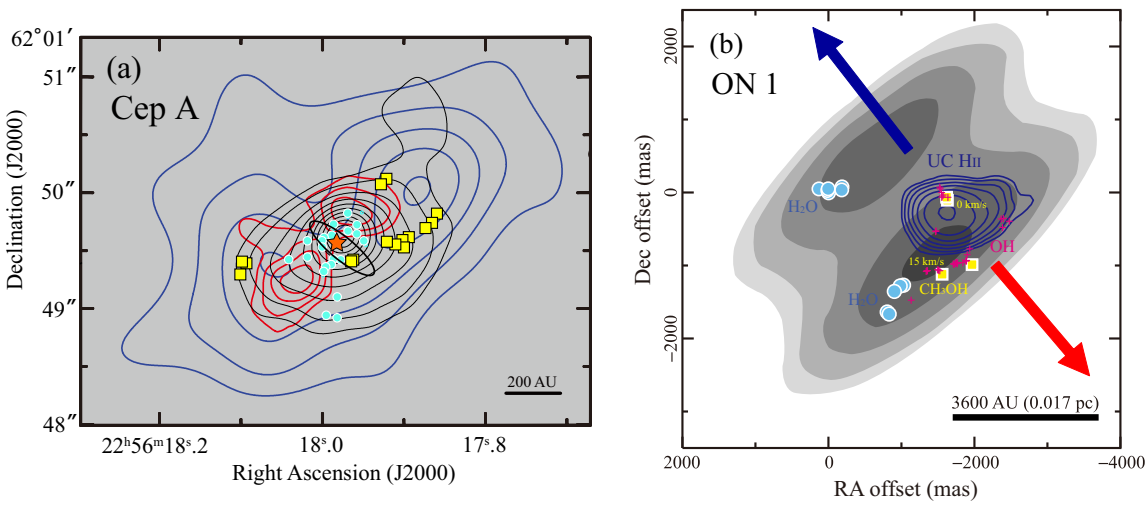


**Figure 1:** (a) The methanol maser spots for Cep A (square [10]) superposed on water maser (circle: with VLA [11]), 335 GHz continuum (black contours [12]), $NH_3$ (4, 4) emission (blue contours [12]), and $SO_2$ emission (red contours [5]). A thick inclined ellipse shows a radio jet at 22 GHz ([2], [11]), and a star-symbol indicates the peak of 43 GHz continuum emission [2]. (b) The methanol maser spots for ON 1 (square) superposed on water maser (circle [7]), hydroxyl maser (cross [3]), 8.4 GHz continuum (blue contours [1]), and 345 GHz continuum (gray scale [9]). Arrows indicate the direction of $H^{13}CO^+$ and SiO bipolar outflow [6] and colors correspond to red- and blue-shifted features. The numbers show approximately radial velocities of each methanol maser spot.

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