Daily Monitoring of the Variability of the Cepheus A Methanol Maser at 6.7 GHz

***Koichiro SUGIYAMA**, Kenta FUJISAWA, Kiyoaki WAJIMA, and Satoko SAWADA-SATOH*

Department of Physics, Faculty of Science, Yamaguchi University,
1677-1 Yoshida, Yamaguchi, Yamaguchi 753-8512
j011vc@yamaguchi-u.ac.jp

Abstract

We detected a rapid variability of 6.7-GHz methanol maser for Cepheus A (Cep A) using Yamaguchi 32-m radio telescope. Two of five spectral features decrease in flux density down to 50% for 27 days, while flux density of other three features increase up to 300%. The time variation of this maser flux density showed a clear inverse correlation between the decayed and the rising features. The synchronous of the variation would suggest that the Cep A methanol maser was excited by infrared radiation from a common exciting source. Given an isolation in a point of view of radial velocities and a spatial distribution in each feature, the inverse correlation would be caused by a variation of the suitable dust temperature in the regions producing methanol maser emission with accompanying a variation of flux density of the exciting source radiation.

1. Introduction

The methanol maser at 6.7 GHz traces just before or early stage of ultra-compact HII region phase [1-3], and this maser is a useful probe for the investigation of massive star formation.

A number of the 6.7-GHz methanol maser emission have been found to represent a long-term variability [4-6]. In the sample observed by [6] Goedhart et al. (2004), the G9.62+0.20E methanol maser showed the periodic variation, which were discovered at the first time in massive star forming regions. Its variation and the periodicity were thought to be caused by a change in either the seed or pump photon levels and by a binary system [7]. Their monitoring were conducted at typically intervals from a few weeks to a few years.

We have conducted the daily monitoring for four 6.7-GHz methanol maser sources to investigate a short time-scale variability from August 2007 using Yamaguchi 32-m radio telescope. Cepheus A (Cep A) was observed as one of our sample sources. In this paper, we present the rapid variability for the Cep A methanol maser at 6.7 GHz and discuss some interpretations of the rapid variability.

2. Observations and Data Reduction

The daily monitoring programme using Yamaguchi 32-m radio telescope have started from August 4 2007 (the days of year 216). The full-width at half maximum (FWHM) of the beam is 5 arcmin and the pointing error of the antenna is about 1 arcmin. We used the coordinates determined by fringe-rate mapping with an accuracy of 100 milli-arcsecond (mas) in [8] Sugiyama et al. (2008a), as shown in table 1. Both left and right circular polarizations were recorded and were averaged to advance sensitivities and sampling in 2-bit was conducted. The recorded data with a bandwidth of

Table 1. The sample of 6.7-GHz methanol masers. Col. 1 is source name; Col. 2 and 3 indicate observational coordinates; Col. 4 and 5 are a flux density and a radial velocity of a peak spectral feature; Col. 6 is radial velocity range; Col. 7 is reference for coordinates.

Source	Coordinates (J2000)		S_p	V_p	V_{ran}	Ref.
	RA (h m s)	Dec (° ' ")	(Jy)	(km s^{-1})	(km s^{-1})	
Cep A	22 56 18.095	+62 01 49.45	445.8	-2.7	-5.4, -1.3	2
G12.91-0.26	18 14 39.50	-17 52 00.3	289.9	39.6	34.7, 41.5	1

Reference --- (1) Goedhart et al. (2004); (2) Sugiyama et al. (2008a).

4 MHz covering a velocity range of 180 km s^{-1} were divided into 4096 channels, yielding a velocity resolution of 0.044 km s^{-1}. The radial velocities were assumed with respect to Local Standard of Rest (LSR). Note that the error in the LSR velocity was potentially to be 0.3 km s^{-1}. The bandwidth was centered at the LSR velocity of -2.6 km s^{-1}. An amplitude and gain calibration was performed by continuously measuring system noise temperatures by injecting the signal from noise source of known temperature. The accuracy of the calibration was 10%. The integration time is 14 minutes until the days of year (DOY) 244, and then 10 minutes from the days of year 245. The rms noise level was typically 1.2 Jy and 1.4 Jy with an integration time of 14 min and 10 min, respectively. The behavior of the system was checked by daily monitoring the G12.91-0.26 methanol maser emission, which is found to be relatively small valiability [6]. A standard deviation of the source was 5-6%.

3. Results

We detected a rapid variability of 6.7-GHz methanol maser at time-scales of 27 days for Cep A. Five spectral features, at radial velocity of -1.9, -2.7, -3.8, -4.2, and -4.9 km s^{-1}, were identified in each observation. The maser feature was labeled as I, II, III, IV, and V, respectively, as shown in figure 1. The maser features with the variability are divided into two groups. Two of the five features decrease in flux density down to 50%, while flux density of other three features increases. Especially, the feature V showed a remarkable rising up to 300% in the period. The decayed (I, II) and rising features (III, IV, V) are isolated in a point of view of radial velocities in the spectrum.

Correlation coefficients in each feature are showed in table 2. The feature II particularly shows a strong correlation with the feature I, while a clear inverse correlation with the feature III, IV, and V, whose correlation coefficient is 0.89, -0.91, -0.50, and -0.68, respectively.

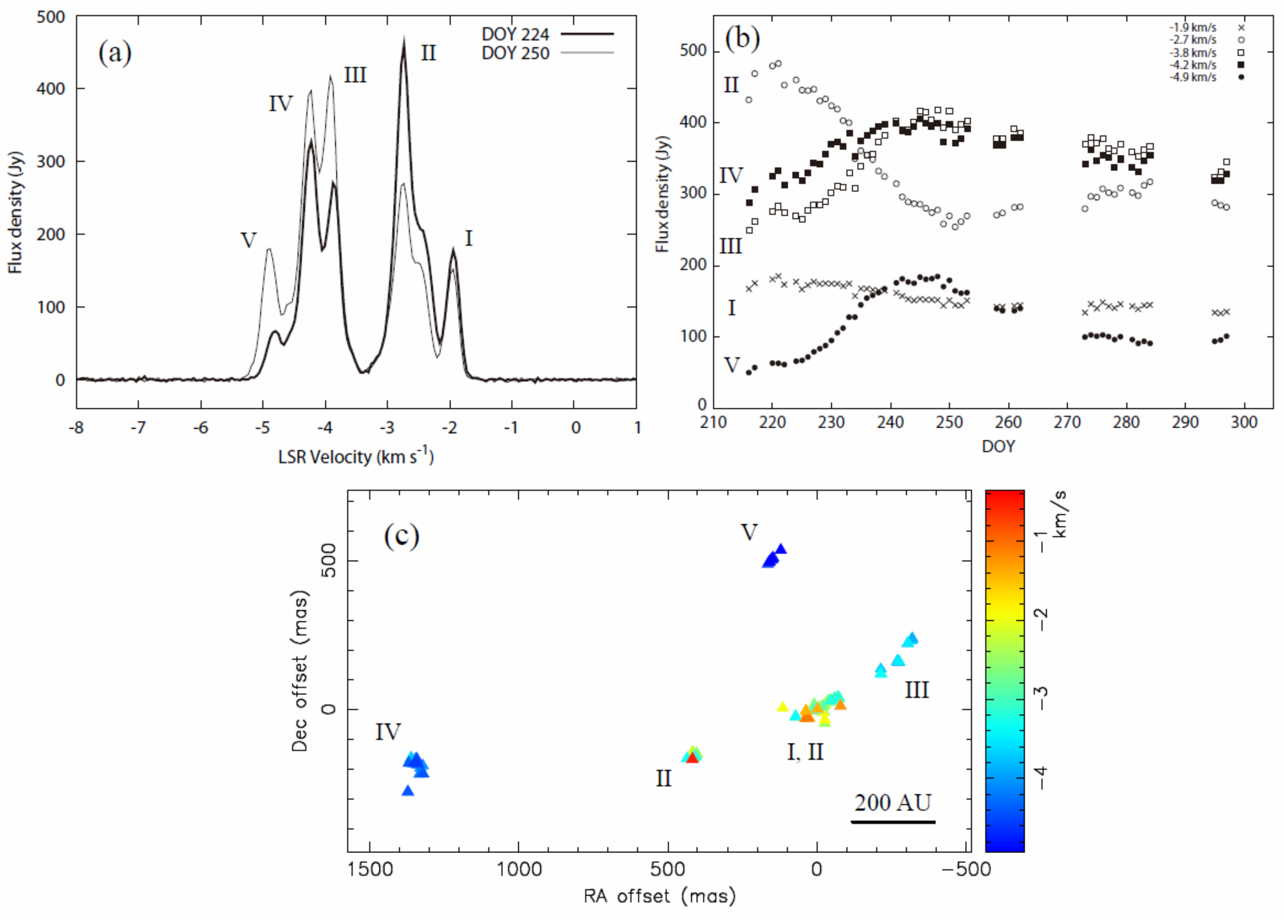

Fig. 1. The 6.7-GHz methanol maser in Cep A. The label numbers, which are I-V, corresponds to each spectral feature in each panel. (a) The thick and thin line shows the spectra obtained on DOY 224 and 250, respectively. (b) Time variation of flux densities for identified each spectral feature. (c) A spatial distribution of this maser spots obtained by other observation [9]. The spot color indicates the radial velocity (see color index at the right).

Table 2. Correlation coefficients for all spectral features

Feature	Spectral feature			
	I	II	III	IV
I				
II	0.89			
III	-0.65	-0.90		
IV	-0.08	-0.50	0.77	
V	-0.28	-0.68	0.84	0.92

4. Discussions

As can be seen in the previous section, the variation of the Cep A methanol maser flux densities was synchronized between the rising features and the decayed features. These features are isolated in a point of view of radial velocities in the spectrum. Compared with the VLBI map of the Cep A methanol maser [9] obtained with the Japanese VLBI Network (JVN), these spectral features are also isolated in the spatial distribution. Given the isolation in radial velocities and the spatial distribution of synchronizing features, a collisional excitation by a shock wave could not be a mechanism exciting the Cep A methanol maser. This hypothesis is consistent with the excitation model that class II methanol masers is excited by infrared radiation from nearby warm dust (e.g., [10]). The time variation of the Cep A methanol maser flux density could be produced by a common exciting source.

The time variation of the Cep A methanol maser flux density showed a clear inverse correlation between the decayed features (I, II) and the rising features (III, IV, V). Given the 6.7-GHz methanol maser distribution in Cep A of ~1400 Astronomical Unit (AU) or eight light-day, time-lag by a difference of light-travel time would not affect the methanol maser time variation. We suggest that the inverse correlation is caused by a variation of the suitable environment, especially dust temperature, in the regions producing methanol maser emission. A time-scale of a temperature variation in the regions producing methanol maser emission by radiative pumping is enough short to cause the time-variation of the Cep A methanol maser flux densities obtained by our observations. Current methanol excitation models [11] predict that methanol maser emission is produced by radiative pumping in warm regions of ~100-200 K. The dust temperature in the regions producing methanol maser emission varies as $R^{-1/2}$, where R is a distance from an exciting source. As it is assumed that an exciting source isotropically radiates and the flux density of the source increases, flux densities of the features locating at relatively near from the exciting source would decrease due to an excess for the suitable dust temperature. On the other hand, flux densities of the features locating at more far than the former features would increase by reaching the suitable dust temperature. However, it is not clear that a luminosity of the exciting source varies for several days.

In one-epoch VLBI observation, it is not clear for an order of rising or decaying of the Cep A methanol maser spots flux densities in the spatial distribution. VLBI-monitoring observations over the period of flux densities variation are required to investigate relation between the order and a distance from an exciting source.

Acknowledgments

The authors wish to thank the research group in department of physics in Yamaguchi University and also the JVN team for observing assistance and support. The JVN project is led by the National Astronomical Observatory of Japan (NAOJ) that is a branch of the National Institutes of Natural Sciences (NINS), Hokkaido University, Gifu University, Yamaguchi University, and Kagoshima University, in cooperation with Geographical Survey Institute (GSI), the Japan Aerospace Exploration Agency (JAXA), and the National Institute of Information and Communications Technology (NICT).

References

1. Walsh, A. J., Burton, M. G., Hyland, A. R., & Robinson, G. 1998, Monthly Notices of the Royal Astronomical Society (MNRAS), 301, 640

2. Minier, V., Conway, J. E., & Booth, R. S. 2001, Astronomy & Astrophysics (A&A), 369, 278

3. Ellingsen, S. P. 2006, Astrophysical Journal (ApJ), 638, 241

4. Caswell, J. L., Vaile, R. A., Ellingsen, S. P., Whiteoak, J. B., & Norris, R. P. 1995, MNRAS, 272, 96

5. Szymczak, M., Hrynek, G., & Kus, A. J. 2000, A&A Supplement, 143, 269

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

7. Goedhart, S., Minier, V., Gaylard, M. J., & van der Walt, D. J. 2005, MNRAS, 356, 839

8. Sugiyama, K, et al. 2008a, Publications of the Astronomical Society of Japan (PASJ), 60, 1

9. Sugiyama, K, et al. 2008b, in preparation

10. Sobolev, A. M., Cragg, D. M., & Godfrey, P. D. 1997, MNRAS, 288, L39

11. Cragg, D. M., Sobolev, A. M., & Godfrey, P. D. 2005, MNRAS, 360, 533