Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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High resolution VLBI observations of 6.7GHz periodic methanol masers

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Abstract. In the last 20 years a small group of 6.7GHz methanol maser sources displaying periodic variability have been identified. This variability is thought to reflect local processes linked to star formation. A number of models have been proposed e.g. colliding wind binary, protostellar pulsation, accretion on binary system. Recent studies of known sources as well as non-periodic flaring masers suggest an episodic accretion as a driving mechanism. We present the results of VLBI observation program aimed at studying known periodic methanol maser sources. High resolution maps of emission, source morphology and evolution in time will be discussed. Those results will help us fully understand the nature of maser periodicity in star forming regions.

Keywords. masers, stars: formation, ISM: clouds, radio lines: ISM

1. Introduction

Periodicity in class II 6.7 GHz methanol masers was first reported in Goedhart *et al.* (2004). Since then 28 sources have been identified with periods ranging from 24 to 1260 days (Tanabe *et al.* 2023). Those masers display varied types of flare profiles: sinusoidal, asymmetric or gaussian like, with large range of length of activity compared to overall period and varied relative amplitude. Some of the sources have shown correlation in flux brightness changes of IR and 6.7 GHz emission (Olech *et al.* 2022). Due to variety of types of flare profiles and source characteristics different models have been proposed to explain this phenomena. Those can be divided into models where variability is caused by modulation of seed photon flux e.g. colliding wind binary (van der Walt *et al.* 2009) or models that consider changes in pumping efficiency of masing region. The latter can be caused by different processes e.g. modulated accretion on binary protostar (Araya *et al.* 2010), stellar pulsations (Inayoshi *et al.* 2013) or rotating spiral shocks (Parfenov & Sobolev 2014) to name a few.
In order to differentiate between proposed models and better understand behavior of periodic methanol masers, high resolution interferometric observations are needed. Those proceedings present the initial results of project using European VLBI Network (EVN) observations of selected 6.7 GHz periodic sources.

2. Observations and initial results

2.1. *Observations*

Source sample selected for Very Large baseline Interferometry (VLBI) observation program consisted of 13 periodic 6.7 GHz masers that were monitored by Torun 32m antenna. Observations were conducted in phase-referencing mode with a switching cycle of 180s + 120s (maser + phase calibrator), total on source time for each target was 2h. Due to time constraints of EVN observation campaign and quiescent nature of periodic sources

Table 1. Summary of observations.

Source	Date	Period (d)	Synthesized beam (mas x mas)	1 $\sigma_{\rm rms}$ (mJy beam^{-1})
G12.89+0.489	4.06.2019	29	10.02 x 3.14	30.0
G22.357+0.066	6.03.2020	178	6.04 x 3.09	9.3
G24.148−0.090	1.11.2019	185	5.28 x 4.15	9.2
G25.411+0.105	1.11.2019	243	4.95 x 4.31	12.4
G30.400−0.296	4.06.2019	220	8.31 x 2.89	13.3
G33.641−0.228	4.06.2019	570	8.10 x 4.80	33.5
G36.70+0.090	1.11.2019	52	4.74 x 3.67	10.7
G37.550+0.200	1.11.2019	247	5.09 x 3.60	10.3
G45.473+0.134	6.03.2020	198	5.89 x 2.57	10.9
G59.63−0.192	6.03.2020	149	4.34 x 2.72	9.5
G73.06+1.80	4.06.2019	159	5.59 x 2.91	18.4
G107.298+5.639	6.03.2020	34	4.58 x 3.02	6.1
G108.76−0.99	6.03.2020	163	5.22 x 3.51	5.9

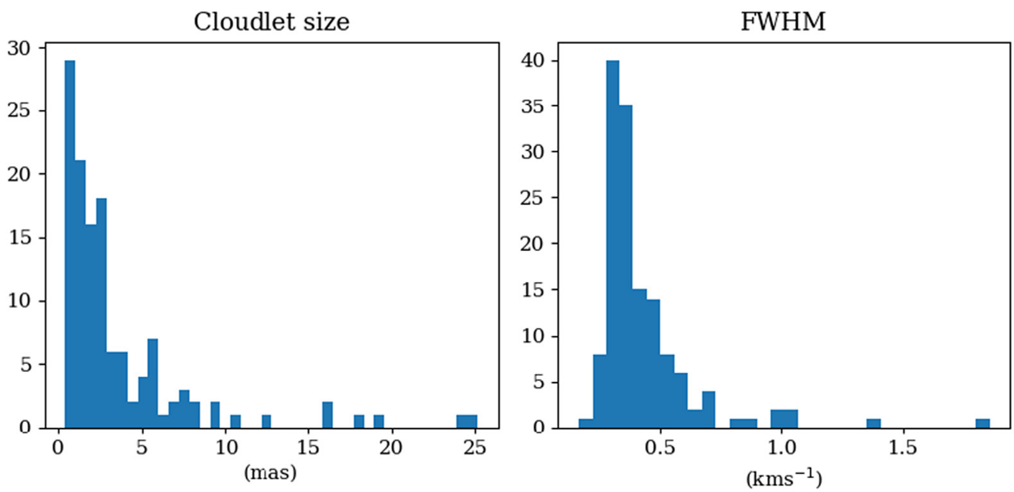

Figure 1. The statistics of measured *cloudlets* for all observed sources.

we divided the project into 3 epochs. This ensured that each source was observed during its active phase. Summary of observations is presented in Table 1.

Data was calibrated with AIPS package using with standard spectral line reduction procedure.

2.2. *Results*

For each source the *spot* emission of individual velocity channels was measured. For more physical representation of masering gas structure those *spots* were grouped into *cloudlets*: emission that's continuous in velocity and spatially within a beamwidth of adjacent channel. If there was more than 4 *spots* in group, gaussian function was fitted to the brightness distribution. This approach resulted in identification of 141 maser regions with the average *cloudlet* size of 3.61 ± 4.3 mas and 127 gaussian profiles with an average FWHM of 0.43 ± 0.22 kms^{-1}, results are shown in Figure 1. Those values are consistent with previous VLBI studies of 6.7 GHz methanol masers.

Maps of sources show varied morphology (Figure 2). Most prominent type is incomplete ring-like structure suggesting that the emission is located in well-defined region of accretion disk or at the interference between disk and envelope. Morgan *et al.*

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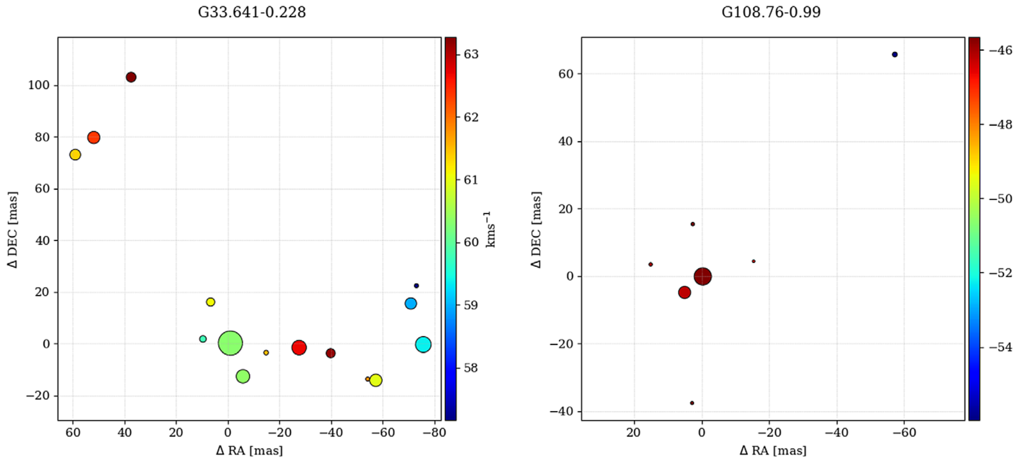

Figure 2. Example of 6.7 GHz emission maps for two periodic sources G33.641−0.228 (left) and G108.76−0.99 (right). Position is measured relatively to the brightest *spot*, color shows velocity and size of the circles scales logarithmically with *cloudlet* brightness.

(2021) argues that orientation of the disk on the sky-plane might have significant impact on observed flare profile. Other sources show core-halo or more complicated morphology.

3. Conclusions

We successfully conducted VLBI observations of 13 well known periodic 6.7 GHz methanol masers using EVN network. Initial results show mostly ring-like/disk morphologies with characteristics of individual masing regions consistent with previous studies. This work will be important to understanding of dependencies between source structure and observed periodicity.

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