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The methanol maser ring G23.657−00.127 after 9 years

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We report about a multi-epoch study of the 6.7 GHz methanol masers toward the high-mass, young stellar object, G23.657−00.127. Its maser distribution shows a peculiar ring-like morphology that we re-observed after 8.5 years, in order to measure the internal kinematics of the ring. A preliminary result of the maser proper motion studies suggests a combination of an expansion and rotation along the ring. These results are at variance with the expectations for an infalling envelope, and support a scenario where the masing gas emerges at the base of the inner outflow.

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1. Introduction

The methanol masers at 6.7 GHz are indicators of an early stage of high-mass star-formation [6]. By means of VLBI observations, they enable us to study the neutral gas at milliarcsecond (mas) scales in close vicinity of forming massive stars. The spatial distributions of methanol maser spots are known to show different morphologies, from compact to arc-like or irregular structures (e.g. [7], [10], [16]). Using the EVN[1], 31 methanol sources towards the Galactic plane were imaged with a few mJy sensitivity and a few mas angular resolution [2]. Among that sample one source, G23.657−00.127, showed nearly-circular symmetric structure and became a prototype of the (so called) *ring-like* morphology of methanol masers [2]. Such symmetric structures suggested that: i) there is a central object(s) at the origin of the ring; ii) in these sources, methanol masers are likely associated with gas in a circumstellar disc or torus. However, by applying a simple model for a rotating and expanding thin disc (e.g. [15]), we showed that such ring-like structures are not dominated by rotation [2]. Instead expanding or infalling motions seem to dominate the maser kinematics, suggesting that the methanol masers are rather related to outflows and/or the interaction zone between the outflow and the accretion disc (e.g. [14]).

In order to address the question, *what kind of kinematics are methanol rings tracing?*, we started a systematic campaign of proper motion measurements of such ring-like structures as the most direct investigation of their nature. VLBI observations are a powerful tool to trace the 3D kinematics of the masing gas over time baselines of a few years (e.g. [8], [9]). Rotation combined with expansion around the jet/outflow axis, or the infall of a molecular envelope, were recently reported for some HMSFRs (e.g. [11], [12], [4]).

Here, we present preliminary results of a systematic, proper motion study of the maser kinematics in G23.657−00.127, as part of a large-project which targets the whole sample of methanol maser rings reported by [2]. Up to now, we have collected two epochs of EVN observations separated by 8.5 years. Such time baseline is appropriate to detect even small shifts in the position of single maser spots, as expected for maser velocities as small as a few km s^{-1} at the distance of the source of 3.19 kpc [1]. A third epoch of EVN observations toward G23.657−00.127 is expected in 2015 (EVN session I).

2. Observations

The first epoch data were observed in the EN003 project taken on 11 November 2004 that was reported by [2]. The second epoch data were observed on 2 March 2013 (project code EB052) using the EVN with the following antennas: Jodrell Bank, Effelsberg, Medicina, Noto, Onsala, Torun, Westerbork and Yebes. The observations were phase−referenced using J1825−0737 with a switching cycle of 175 s+95 s (maser+phase–calibrator) giving a total on-source time of 1.4 h. Using the EVN Mk IV Data Processor at JIVE, we set a spectral resolution on the maser lines of 0.1 km s^{-1}, across a bandwidth of 2 MHz divided into 1024 spectral channels. In order to increase the signal-to-noise ratio on the phase-reference source, we used eight BBCs per polarization for a second correlator pass with 128 channels per BBC (each 2 MHz wide).

[1]The European VLBI Network is a joint facility of European, Chinese, South African and other astronomy institutes funded by their national research councils.

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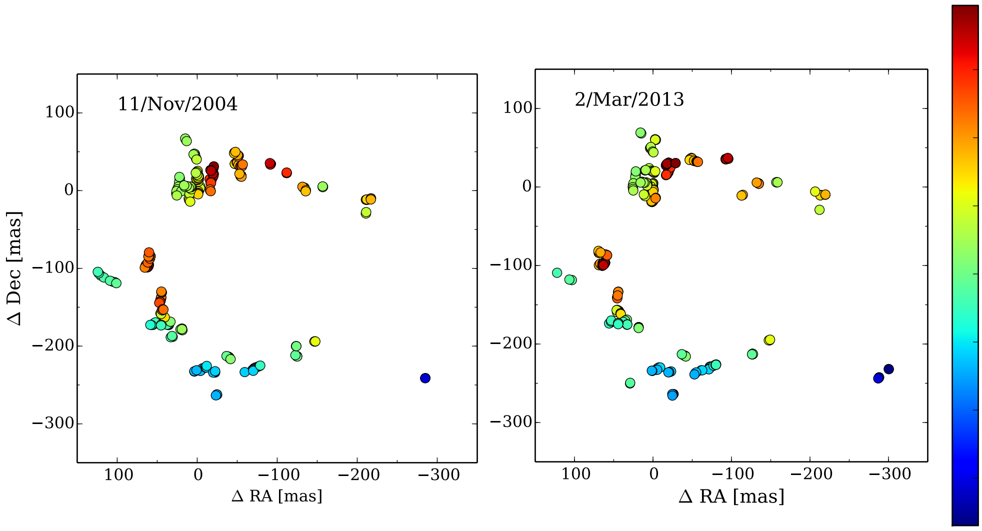

Figure 1: The 6.7 GHz methanol maser spot distributions towards G23.657−00.127 obtained using the EVN at two different epochs, separated by 8.5 years.

The data reduction was carried out in AIPS, employing the standard procedures for spectral line observations. Phase calibration was performed on the strongest maser channel at a V_{LSR} of 82.5 km s^{-1}. Finally, we searched for maser emission within a radius of about 1 arcsec (or about 3200 AU) around the strongest maser spot, by using the task SAD of AIPS and a cutoff of 7 σ on each channel map.

3. Results and Discussion

In total, we registered 325 methanol maser spots towards G23.657−00.127 in the second epoch data; the brightest spot was 2.2 Jy $beam^{-1}$ while the weakest one was 0.026 Jy $beam^{-1}$. Fig. 1 compares the spot distributions from 2004 and 2013 by aligning the brightest spot at each epoch, at a V_{LSR} of 82.5 km s^{-1}, with the (0,0) point. The overall structure clearly persisted for 8.5 years, covering both the same V_{LSR} and brightness ranges. The centres of best fitted ellipses to the data from both epochs (excluding the blueshifted spots at 73.6 km s^{-1}) differ by 0.2 mas and 0.1 mas in RA and Dec, respectively. Their major and minor semi–axes were 129.7 mas, 135.1 mas (2004) and 130.7 mas and 135.3 mas (2013), respectively. The position angles of the major axes were 66^{o} (2004) and 63^{o} (2013) (north to east), respectively.

In order to derive the internal kinematics of the methanol maser ring, we firstly aligned the centres of the best fitted ellipses. This approach removes any bulk motion of the ring in the plane of the sky. Next, we identified 198 pairs of spots that appeared at both epochs at the same LSR velocity (within two spectral channels) and at the same relative position on the sky (within 10 mas). These pairs were distributed along the whole ring and belonged to 34 maser groups (i.e. *features*) clearly separated each one from the other. We built up the *proper motion vector* taking the average of the positional shifts between corresponding pairs in each feature. The final plot is presented in Fig. 2, where we show the barycentre of each feature (dots) and its proper motion vector (arrows).

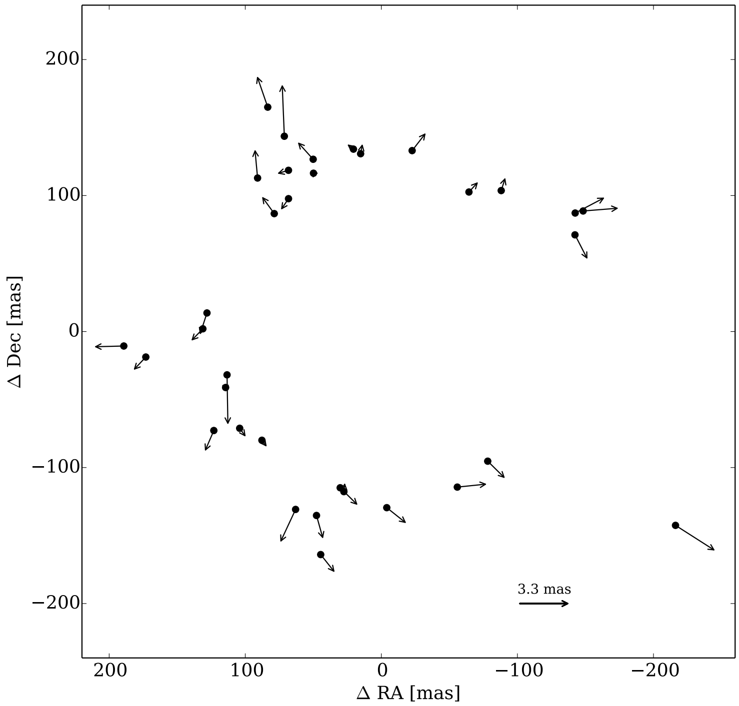

Figure 2: Proper motion vectors of the 6.7 GHz methanol maser features in G23.657−00.127 in the period from 2004 to 2013. The (0,0) point corresponds to the centre of the best fitted ellipse to the data from 2013.

This result clearly shows that the maser kinematics in G23.657−00.127 cannot be explained by an infalling motion of the ring (e.g. [4], [13]).

Then, we compared for each feature the difference between its position vector (relative to the centre of the best fitted ellipse) and the direction of its proper motion vector. A coincidence between these two vectors would suggest radial motion (expansion or infall), while a difference of 90^{o} would suggest rotation. The mean value is θ=38^{o} with a standard deviation of 5^{o}. A possible explanation would be a combination of rotation and expansion. We also checked the dependence of the magnitude of the proper motion vectors with the position of each feature along the ring. We do not note any particular direction where the motion would be either significantly greater or smaller (Fig. 3). The mean shift after 8.5 years is 1.53 mas with a standard deviation of 0.13 mas. At the source distance of 3.19 kpc [1], this corresponds to 4.9 AU and 2.7 km s^{-1}. Taking the value of θ of 38^{o}, as calculated above, one can derive the two components of the mean velocity that are a mean radial velocity of 1.7 km s^{-1} and a mean rotation velocity of 2.13 km s^{-1} as sine and cosine functions of θ, respectively. These values are smaller than the best fitted parameters obtained with the first epoch only, by assuming a thin Keplerian disc model [2].

A similar trend was previously reported toward the HMSFR G23.01−0.41. In this source, 6.7 GHz methanol masers emerge from the inner portion of a molecular toroid with velocities of a few km s^{-1}, tracing a combination of rotation around the outflow axis and expansion along this

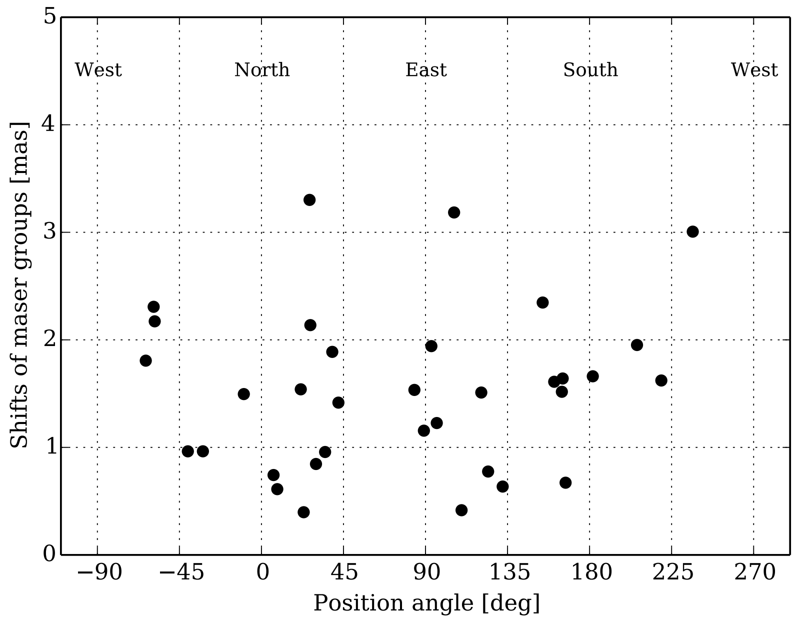

Figure 3: Position shift of maser features between 2004 and 2013 versus their position angle with respect to the centre of the best fitted ellipse.

axis [12].

Moreover, we also note that the northern features in G23.657−00.127 show the rotation components oriented clockwise, while the southern anticlockwise (Fig. 2). This change takes place at the position angle of ca. 50^{o} and might be related to the outflow since such direction points to the centre of a nearby infrared source located at the SW of the ring centre [3].

The third epoch of data will improve the accuracy of the proper motions and help to discriminate between these two scenarios described above.

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