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Statistical analysis of the physical properties of the 6.7 GHz methanol maser features based on VLBI data

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Abstract. Methanol masers observed at high angular resolution are useful tool to investigate the processes of high-mass star formation. Here, we present the results of statistical analysis of the 6.7 GHz methanol maser structures in 60 sources observed with the EVN. The parameters of the maser clouds and exciting stars were derived. There is evidence that the emission structures composed of larger number of maser clouds are formed in the vicinity of more luminous exciting stars.

Keywords. stars: formation, ISM: molecules, masers.

1. Context and Methods

High-mass stars play important role in the Galactic evolution and the methanol masers are well known tracer of their formation. Studies of the 6.7 GHz maser emission give us unique insights into regions where processes of accretion and interaction of outflows with the ambient gas are still active. VLBI observations provide the data which allows us to analyze the properties of individual clouds at milliarcsecond scales.

In the present study we used the data from several experiments carried out at 6.7 GHz with the EVN (Bartkiewicz *et al.* 2009, 2014, 2016). Individual maser spots were grouped into the maser cloud structures then their brightness and angular size were measured. We defined cloud size as a distance between the extreme spots projected on a straight line matched to the position of the spots weighted by their brightness. Linear size, luminosity and velocity gradient of maser clouds were determined.

For each source we measured the total spatial size, defined as the diameter of the circle containing all spots. This circle was based on the positions of 2 or 3 extreme spots in the source depending on whether the circle which diameter was equal to the distance of two most extreme spots contains all other spots.

The infrared photometry data of publicly available surveys (2MASS, WISE, GLIMPSE, MSX, MIPSGAL, AKARI, IRAS, Hi-GAL, ATLASGAL, Bolocam) for a total of 33 bands were used to obtain the spectral energy distribution (SED). The package for the SED fitting tool by Robitaille *et al.* (2007) was used. In order to check a quality of IR data, a visual inspection of maps at 23 bands was made.

2. Results and conclusions

Basing on the SED fit, we could verify the distances calculated using Reid *et al.*'s (2009) recipe. Objects with the kinematic distance significantly different from the matched distance were excluded from further analysis or flagged as untrusted. Calculation of typical size of the maser region for objects with well determined distances allowed verification

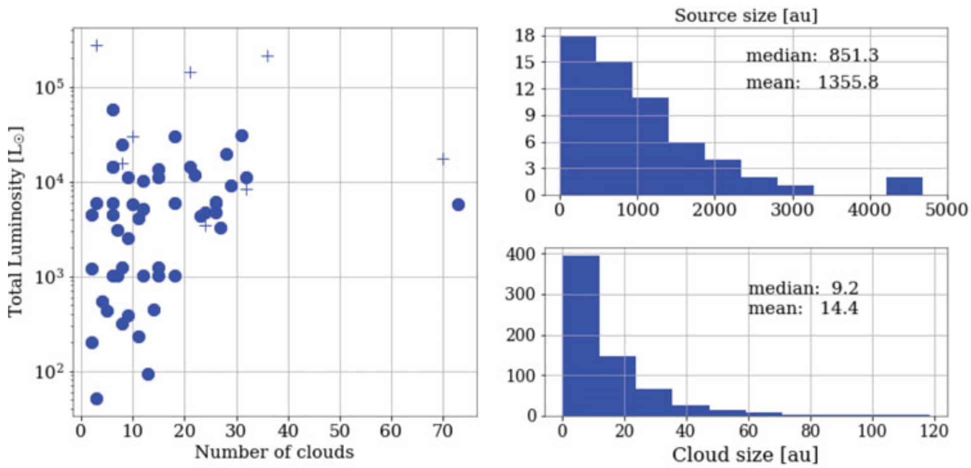

Figure 1. Left: Total luminosity of exciting star vs. the number of maser clouds in the source. Crosses indicate the sources with unreliable SED fit. **Right:** (upper) The histogram of the linear size of methanol maser sources. The extremely large values are not shown. (lower) The histogram of measured sizes of maser clouds.

of possible distance errors for the rest of objects and to identify double or multiple maser sources for which the SED fitting would not be reliable.

Figure 1 shows the total luminosity of exciting star as a function of the number of maser clouds. There is a tendency that the maser sources exciting by less luminous stars have smaller number of the clouds than those powering by more luminous objects. Typical 6.7 GHz methanol maser source size is ∼1000 au. The objects of size larger than 2000 au are either double or have an overestimated distance. The mean size of maser cloud is 14.4 au. Weak clouds with a brightness of less than 10 Jy beam^{-1} and typical size of 5-10 au predominate.

We found that the vast majority of maser clouds show linear alignment in spot locations and velocities. Directions of the velocity gradients of maser clouds have been analyzed and for some targets. There is a partial convergence of these velocity gradient vectors with the proper motion measured with the VLBI. The SED analysis revealed that most of the examined objects have accretion discs with a high accretion rate.

Acknowledgements

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