Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
Proceedings IAU Symposium No. 380, 2024
T. Hirota, H. Imai, K. Menten, & Y. Pihlström, eds.
doi:10.1017/S1743921323001941

Ultra-precise monitoring of a class I methanol maser

M. A. Voronkov[1], S. L. Breen[2], S. P. Ellingsen[3], J. A. Green[4], A. M. Sobolev[5], S. Yu. Parfenov[5] and D. J. van der Walt[6]

[1]CSIRO Space & Astronomy, PO Box 76, Epping, NSW 1710, Australia.
email: Maxim.Voronkov@csiro.au

[2]SKAO, Jodrell Bank, Lower Withington, Macclesfield, Cheshire SK11 9FT, UK

[3]School of Natural Sciences, University of Tasmania, Private Bag 37, Hobart, Tasmania 7001, Australia

[4]SKAO, SKA-LOW Science Operations Centre, ARRC Building, 26 Dick Perry Avenue, Technology Park, Kensington WA 6151 Australia

[5]Ural Federal University, 19 Mira street, 620002 Ekaterinburg, Russia

[6]Centre for Space Research, North-West University, Potchefstroom 2520, South Africa

Abstract. We report the results of a 7-year monitoring program using the Australia Telescope Compact Array (ATCA) for the 9.9 GHz class I methanol maser in G331.13-0.24 where a periodic class II methanol maser is present. The great deal of the project was to control systematics at an unprecedented level. Although no periodic flux variation was found, the maser shows a very stable decline of 166±7 μJy/day. The radial velocity of the maser is stable down to 1 m/s level. We also report a marginal periodic signal in radial velocity (comparable to the level of systematics) of about 20±7 cm/s with the period of 475±22 days, close to that of the 6.7-GHz maser in the source. No hyperfine split was detected which suggests preferential excitation of a single hyperfine transition.

Keywords. masers, stars: formation, HII regions

1. Introduction

Periodic variability of radiatively pumped (or class II) methanol masers has recently become a hot topic as limited number of astrophysical phenomena can give rise to periodic flux variations (e.g., Goedhart *et al.* 2014; Parfenov & Sobolev 2014, and references therein). The collisionally pumped (or class I) methanol masers are often present in the same region, although usually believed not to originate in the same volume of gas (e.g., Voronkov *et al.* 2014). We carried out a long-term monitoring campaign of G331.13−0.24, observing it simultaneously at 6.7 and 9.9-GHz (convenient transitions with different pumping for ATCA monitoring observations) approximately every 20 days in order to probe the effects of the seed radiation on maser variability (both masers amplify the emission of an HII region, see the map of Voronkov *et al.* in this volume, and would vary in sync if the flux density of the HII region varies). The 6.7-GHz maser in the selected source has a period of about 500 days (Goedhart *et al.* 2014). No results of long term monitoring of the 9.9-GHz maser (or any other class I maser in any source) have previously been reported.

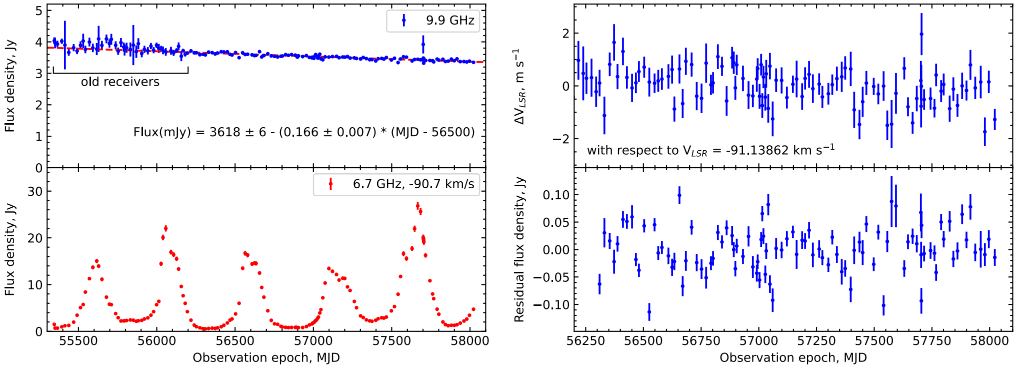

Figure 1. Left panel: flux density time series for the 9.9-GHz maser (top) and the most periodic feature of the 6.7-GHz maser (bottom). Note, the two masers are not co-located, but seen projected onto the same HII region (see Voronkov *et al.* in this volume for a map of the region). Right panel: time series of the radial velocity (top) and de-trended flux density (bottom). There could be a periodic wobble with the period close to that of the 6.7-GHz maser in the radial velocity. The weak variations in flux density are believed to be instrumental and may have a component with one year period.

2. Results

No periodic variability was found for the 9.9-GHz maser at a similar period to the 6.7-GHz maser (there could be a weak annual variation believed to be instrumental). Instead, the maser showed a steady decline in flux density (see Fig. 1). In addition, the 9.9-GHz spectrum turned out to be rather simple with just a single feature well described by a Gaussian. Combined with high 488 Hz spectral resolution (<15 m/s at 9.9 GHz) and a good signal-to-noise ratio this enabled very accurate radial velocity measurement (down to m/s accuracy, see the right-hand panel of Fig. 1). On the other hand, we can confidently exclude hyperfine split for the 9.9-GHz transition ($9_{-1}-8_{-2}$ E) at kHz level. The split expected following Belov *et al.* (2016) would be comparable to the FWHM of the maser line and, therefore, easily detectable. This suggests that preferential pumping of a single hyperfine transition may take place.

The predictable behaviour and simplicity of the maser along with a large number of epochs allowed us to reveal many low-level systematics in the data. This investigation resulted in a number of software fixes (bugs in MIRIAD's Doppler regridding code), workarounds (external barycentric correction model) and improvements to the data reduction procedure (new methods for the absolute flux scale calibration and flux estimation which are less sensitive to weather effects, gain-elevation correction). The resulting radial velocity time series (top right in Fig. 1) has a marginal periodic wobble (20 ± 7 cm/s). It is comparable to the level of systematics but has the period (475 ± 22 days) close to that of the 6.7-GHz maser. Otherwise, the radial velocity is remarkably stable at the level of m/s, and the lack of observed acceleration over the 7-year period implies the minimum distance between the maser and the YSO ranging from 120 to 4300 au for a 10 $M_\odot$ YSO depending on the orientation (the strongest limit is when the maser and the central mass are aligned along the line of sight), provided there is no other mechanism at play counteracting gravity in this system. The residual (after the linear trend is removed) flux density variations (bottom right in Fig. 1) are likely to be dominated by systematics of unknown nature (resulting in a weak spurious annual periodicity).

https://doi.org/10.1017/S1743921323001941 Published online by Cambridge University Press

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1743921323001941

References

Belov, S. P., Golubiatnikov, G. Yu., Lapinov, A. V. *et al.* 2016, *J. Chem. Phys.*, 145, 024307

Goedhart, S., Maswanganye, J. P., Gaylard, M. J., van der Walt, D. J. 2014, *MNRAS*, 437, 1808

Parfenov, S., Yu., Sobolev, A. M. 2014, *MNRAS*, 444, 620

Voronkov, M. A., Caswell, J. L., Ellingsen, S. P., *et al.* 2014, *MNRAS*, 439, 2584

https://doi.org/10.1017/S1743921323001941 Published online by Cambridge University Press