Astrophysical Masers:
Unlocking the Mysteries of the Universe
Proceedings IAU Symposium No. 336, 2017
A. Tarchi, M.J. Reid & P. Castangia, eds.

doi:10.1017/S174392131800011X

Periodic masers in massive star forming regions

S. Goedhart[1], R. van Rooyen[1], D. J. van der Walt[2], J. P. Maswanaganye[2], G. C. MacCleod[3] and A. Sanna[4]

[1]SKA SA, The Park, Park Rd, Pinelands, Cape Town, 7405, South Africa
email: `sharmila@ska.ac.za`

[2]Space Research Unit, Physics Department, North-West University, Potchefstroom, South Africa

[3] Hartebeesthoek Radio Astronomy Observatory, PO Box 443, Krugersdorp, 1740, South Africa

[4]Max-Planck-Institut für Radioastonomie, Auf dem Hügel 69, D-53121 Bonn, Germany

Abstract. The first periodic Class II methanol maser was reported on in 2003. Since that time, a number of different monitoring programmes have found periodic masers, as well as other modes of variability. In a few cases, periodicity has been found in other maser species such as formaldehyde and water. Several distinct characteristics of light curves have been noted, possibly pointing to different underlying mechanisms for periodicity if one assumes a linear response to incoming radiation. I will give a brief overview of the known periodic sources, discuss current theories, and present new results obtained from monitoring mainline hydroxyl masers using the seven-element Karoo Array Telescope (KAT-7) during its science verification phase.

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

1. Introduction

The first periodic masers were found by Goedhart, Gaylard & van der Walt (2004) while comducting a large scale monitoring programme of 6.7 GHz methanol masers. An extension of the programme found correlated variations at 12.2 GHz, in cases where the masers were detected (Goedhart *et al.* 2014). In other studies, correlated periodic variability in other maser molecules was found in a single source in formaldehyde (Araya *et al.* 2010), Green & Caswell (2012) found a faint hint that the hydroxyl maser in G12.89-0.49 may undergo a dip in flux density at the onset of the methanol maser flare, while anti-correlated variability in a water maser compared to methanol in G107.298+5.639 was recently reported by Szymczak *et al.* (2016). Two more large scale monitoring programmes have been reported on during this conference (Sugiyama *et al.*, Szymczak *et al.*, this volume), bringing the number of periodic masers now known to exceed 50. Thus periodic variability may not be as unusual as initially thought.

The sample of periodic masers show a range of profiles, many of which are similar to each other. By analogy with optical variability studies, one could argue that the shape of the light curves could hint to the origin of the periodic modulation, if there is a direct relation of the maser output to the incoming radiation. A number of mechanisms have been proposed to explain the periodic masers. This includes

- Colliding-wind binary system producing shocks which leads to increased ionisation of the background HII region (van der Walt, 2011).
- Dust temperature variations in an accretion disk around a binary system, modulating the pump rate (Parfenov & Sobolev, 2014).

- Pulsational instability in a bloated protostar during rapid accretion (Inayoshi *et al.* 2013).
- Eclipsing binary system modulating the infrared radiation (Maswanganye *et al.* 2015).

Thus far, no conclusive way has been found to verify any of these hypotheses, but monitoring at other wavelengths, particularly of the radio continuum or the infrared, may help solve this question.

Hydroxyl and methanol masers are thought to have a common pump mechanism (Cragg *et al.* 2002) but, up to now, no conclusive evidence has been found of correlated variability in methanol and hydroxyl. A sample of seven periodic methanol maser sources were monitored in the hydroxyl main lines using the KAT-7 telescope, while the methanol and water transitions were monitored using the HartRAO 26m telescope. Thus far only two of the sources have been analysed and have been confirmed to show periodic variability in the hydroxyl masers. Here we present the results on G9.62+0.20E, which was the first periodic source discovered. The masers towards G9.62+0.20E have been accurately mapped relative to each other and the background HII region (Sanna *et al.* 2015), giving us a unique opportunity to study the relation of the various maser species given high cadence monitoring of as many transitions as possible.

2. Observations

The 7-dish Karoo Array Telescope (KAT-7) (Foley *et al.* 2016), built as an engineering prototype for the 64-dish MeerKAT Array, consists of 12m prime focus dishes equiped with L-band receivers covering 12.2 to 1.95 GHz. The shortest and longest baselines are 26m and 186 m, respectively. The system temperature, when the cryostats were functional, was approximately 30K, and the apperture efficiency is on average 65%. The OH maser observations were done as part of the KAT-7 science verification programme. We used the narrowest correlator mode, which gives a velocity resolution of 68 m s^{-1}. Observations were run at both 1665 and 1667 MHz, from February 2013 to June 2015. The typical rms noise achieved ranged from 0.15 to 0.2 Jy. The typical beam size (not all antennas were always available) was $\sim$ 3 arcmin, thus the masers are unresolved and relative positions cannot be measured since all spots are located within a single beam.

The 26m dish at Hartebeesthoek Radio Astronomy Observatory was used to concurrently monitor the associated methanol masers at 6.7 and 12.2 GHz, and the water masers at 22 GHz.

Observations were typically done on a weekly basis, with increased cadence when flares were expected.

3. Results

Figure 1 shows the spectra for each of the transitions monitored, with an indication of the range of variation by plotting the minimum, maximum and mean of the timeseries in each channel. The methanol and hydroxyl masers show periodic flaring behaviour in the same velocity ranges, while the water masers cover a different, slightly higher velocity range and, while variable, appear to be uncorrelated with the other two species.

Figure 2 shows the time-series for the strongest maser channel in each transition. Note that these results are for Stokes I only due to problems encountered in polarisation calibration of KAT-7. The most notable feature in the hydroxyl masers is the drop in flux density, which occurs at the same time as the start of the flare in methanol. The hydroxyl masers show a drop in intensity over a period of about 5 days, after which they continue

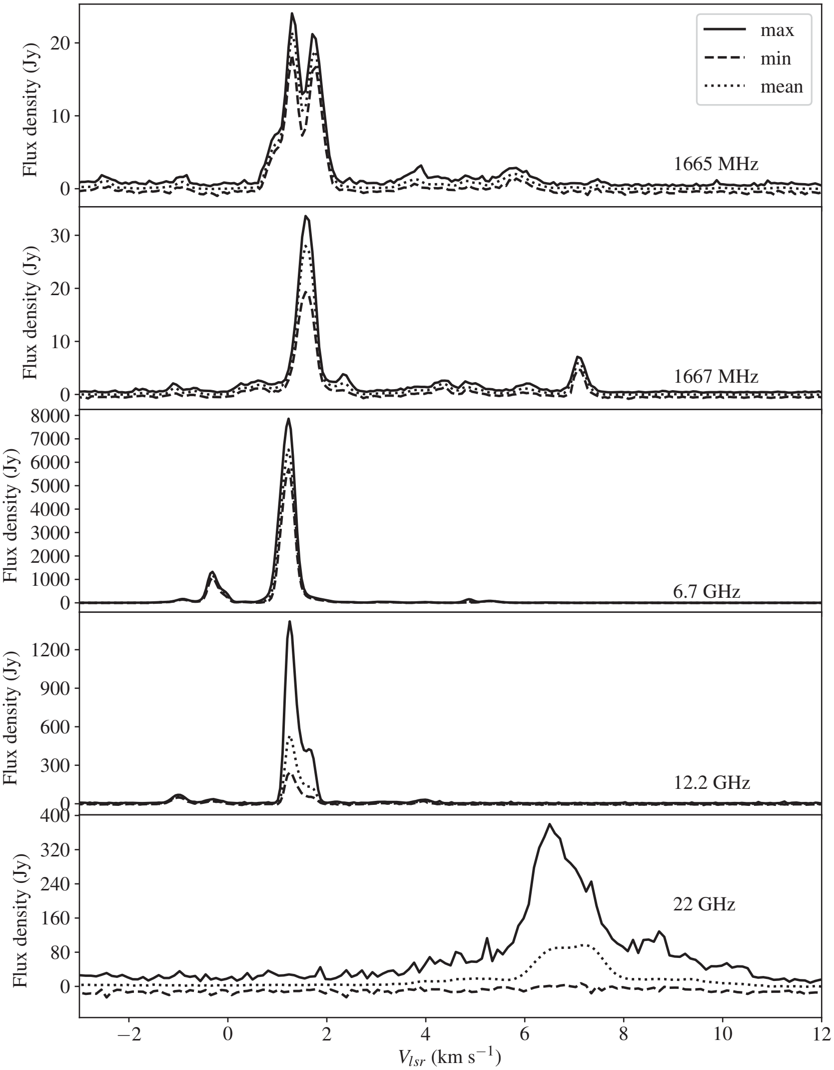

Figure 1. Spectra of the maser transitions monitored, showing the range of variation over the monitoring period, in each channel.

to increase in flux density, with the 1665 MHz transition peaking between ∼ 7–10 days after the methanol masers, which flare and peak simultaneously in both transitions, while the 1667 MHz masers peak ∼ 20 days later. The amplitude of the variation is higher in the 1667 MHz transition than for 1665 MHz. The 1667 MHz masers also show a steady rise in the baseline flux density over the course of the monitoring programme. Not all of the hydroxyl maser features behave in the same way. Some velocity features show very pronounced dips while others show stronger flaring behaviour and not as much of a dip (see Figure 3). Some features, which are spatially offset from the HII regions, do not show variations. The periodic variations occur only in the velocity ranges 1.2 to 1.8 km s^{-1} and 2.12 to 2.4 km s^{-1}. Examination of the VLBI spot maps and spectra indicates that the periodically flaring hydroxyl masers are situated to the north-east of the methanol masers, close to the HII region component E2 (as designated by Sanna *et al.* 2015). The

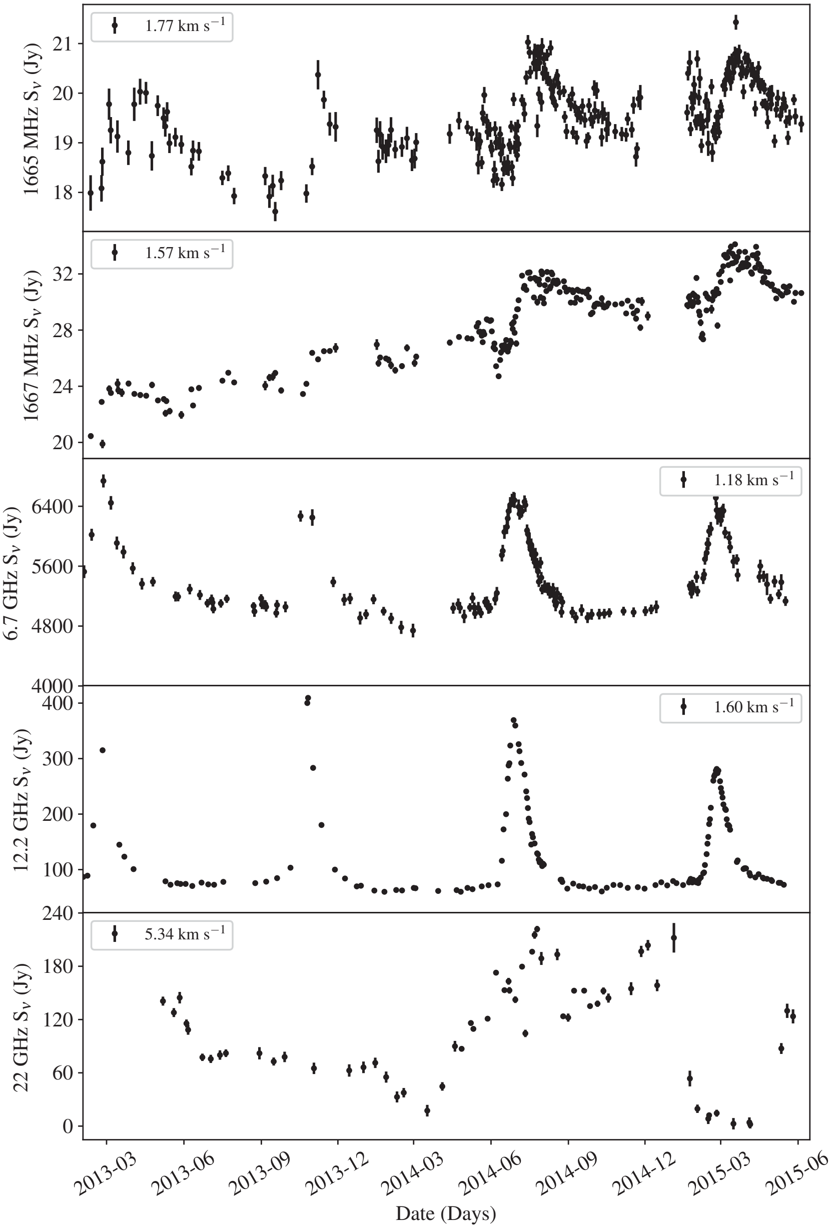

Figure 2. Comparison of the dominant velocity channel flux density as a function of time for each transition monitored.

hydroxyl masers to the west and south of the methanol maser group do not show periodic variability.

4. Discussion

The monitoring programme using KAT-7 covered four cycles of periodic flaring of G9.62+0.20. The first two cycles were not very well sampled but showed clear variability. The subsequent two cycles were then followed at a higher cadence, and a pronounced

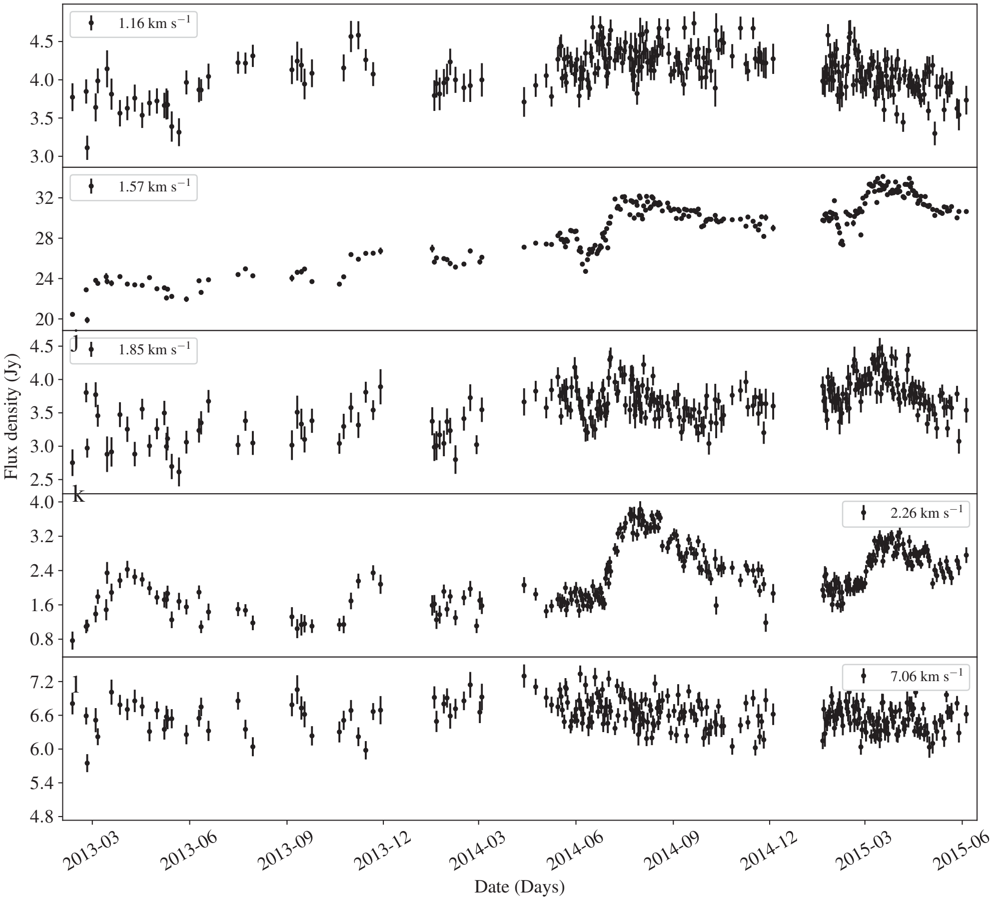

Figure 3. Examples of the differing behaviour of the different velocity features at 1667 MHz.

drop in the hydroxyl maser flux density is seen over a week, coinciding with the start of the flare in methanol. The hydroxyl masers are located approximately 300 mas from the methanol masers, which at a distance of 5.2 kpc corresponds to a projected distance of 1560 AU or 9 light days. For the masers to see an effect simultanously the source of the periodic phenomenon would have to be situated midway between the two locations, or the methanol masers are closer to us along the line of sight, as would be seen on a sphere. In any case, it is clear that the hydroxyl and methanol do not respond in the same way to the incoming impulse, whether it be in the background continuum flux or pump photons. The water masers, while they are variable, do not show any obvious correlated variability.

Maswanganye *et al.* (this volume, and PhD thesis) show that hydroxyl masers can react very differently to the same thermal profile, depending on the column density of the particular maser. Thus these very detailed pulse profiles could potentially be used to infer specific conditions in the maser locales.

5. Conclusions and recommendations

These results show that hydroxyl masers associated with periodic methanol maser sources can also show periodic variability, but there may not necessarily be a one-to-one correspondence in pulse profiles. Much more work needs to be done in simulating the radiative transfer in the different proposed mechanisms. It will also be helpful to increase the sample of masers monitored at multiple transitions, while having high angular resolution maps of their relative positions, in order to build up a global picture of the conditions around the young stellar object.

References

Araya, E., Hofner, P., Goss, W. M., Kurtz, S., Richards, a. M. S., Linz, H., Olmi, L., & Sewilo M., 2010, *ApJ*,717, L133

Cragg, D. M., Sobolev, A. M., & Godrey, P. D., 2002, *MNRAS*, 331, 52

Foley, A. R., Alberts, T., Armstrong, R. *et al.* 2016, *MNRAS*, 460, 1664

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

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

Green, J. A. & Caswell, J. L., 2012, *MNRAS*, 425, 1504

Inayoshi, K., Sugiyama, K., Hosokawa, T., Motogi, K., & Tanaka, K. E. I., 2013, *ApJ*, 769, L20

Maswanganye, J. P., Gaylard, M. J., Goedhart, S., van der Walt, D. J., & Booth, R. S., 2015, *MNRAS*, 446, 2730

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

Sanna, A., Menten, K. M., Carrasco-González, C., Reid, M. J., Ellingsen, S. P., Brunthaler, A., Moscadelli, L., Cesaroni, R., & Krishnan V., *ApJ*, 804, L2

Szymczak, M., Olech, M., Wolak, P., Bartkiewicz, A., & Gawroński M., 2016, *MNRAS*, 459, L56

van der Walt, D. J., 2011, *AJ*, 141, 152