Accretion burst in G358.93-0.03

KVN observations of masers at K/Q/W/D bands

1 Topic: Massive star formation

The formation of massive stars stands as one of the many prominent branches of modern astronomy, as theory and observations are finally approaching consensus on how massive stars achieve their final masses. Non-continuous accretion mechanisms [1] are emerging as solutions to the luminosity problem [2], the issue of overcoming radiation pressure [3], and have been evinced directly in the case of massive protostars S255 [4] and NGC6334 [5] and indirectly via their ejection histories [6].

2 Masers emission during accretion bursts

Masers have emerged as powerful observational tools in understanding accretion events [7; 8; 9]. Maser emission is very sensitive to its environment; a change in physical conditions can selectively favor or unfavor the pumping/sink mechanism of different maser transitions [10].

Some methanol maser transitions are observed only during accretion flares of associated YSO (e.g. [11]) and can be considered as indicators of the flare phenomenon. This possibility has to be studied in more detail, because masers provide observational access to deeply embedded YSOs which are invisible even in the infrared and sub-mm ranges.

Information on multiple maser transitions can be used to constrain physical parameters and evolution of the region where the masers form and environment of this region because masers are sensitive to external radiation, its intensity and spectrum [12; 13; 14; 15]. In general, information on a greater number of transitions provide more constraints on models and allow analysis of the physical conditions with higher level of confidence.

At the same time, studies of some transitions are of special importance. For example, detection of the torsionally excited methanol masers indicate that the pumping is going through the levels of the torsionally excited states. Detection of the masers in highly excited transitions (like the methanol transition at 20.97 GHz) puts strong constraints on the temperature and the wavelength range of the pumping radiation.

3 G358.93-0.03

In the past month, the M2O reported a flare of the 6.7 GHz methanol maser in G358.93-0.03 (hereafter "G358"), detected by the Ibaraki 32m telescope [16] reported in ATel 12446. While not being a frequently studied source, pre-burst information for G358 exists as C-band VLA archival data and IR data from 2MASS, VVV, Spitzer, and Herschel, to provide comparison for new observations to confirm the burst event. New DDTs were taken at NIR on Feb 8, and with the JVLA at C, Ku, K and X bands on Feb 25th. Also, muti-epoch C and K-band data with the LBA, VERA and the EVN. DDTs to the VLBA and SOFIA are also underway.

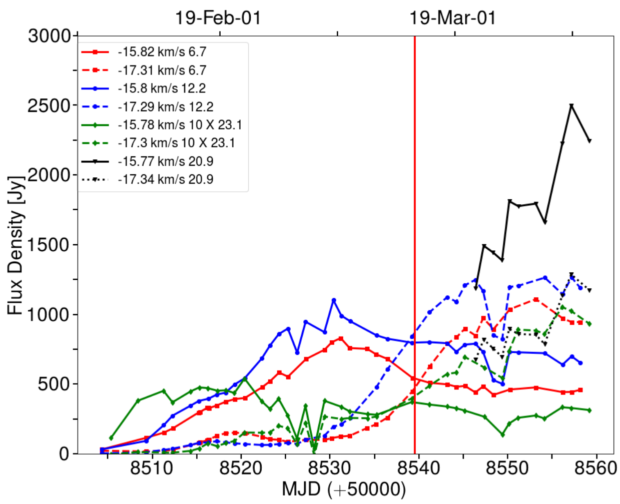

Fig 1. Evolution of individual spectral components - showing onset, subsequent decay, and delayed onset behaviors. The key denotes velocity component and transition in GHz. Note the 23.1 GHZ is x10 scale.

The initial G358 flare announcement triggered follow-up observations at HartRAO, SMA, Mopra and ATCA who reported the detections of not only previously known masers at 6.7, 12.2, 19.9, 23.1 and 37.7 GHz but also new maser lines at 6.2, 7.7, 7.8, 20.97, 45.8, 44.9, 199.6, 201.7 GHz and some others. Some of the aforementioned candidates for flare-tracing transitions were detected in the recent weeks of the ongoing G358 flare. Also, it is greatly unexpected that some of the new transitions occur between the levels of the highly excited rotational transitions of the torsionally excited state vt=1. Moreover, some of these transitions are now brighter than the 6.7 GHz transition which was previously considered as the brightest methanol maser. The 23.1 GHz methanol maser transition is very rare (only 3 previous sightings) and was described by [17] as *" favoured by conditions representing low gas temperature, high external dust temperature, low gas density and high column density of methanol; the scarcity of this maser indicates that such combinations of conditions are uncommon"*.

The 6.7, 12.2, 20.9 and 23.1 GHz methanol maser emission trace the G358 accretion burst (Fig 1).

4 KVN observations

All maser spectra in G358, have been evolving daily (Fig 1). Therefore the only possible way to compare the fluxes of multiple methanol transitions is to make simultaneous observation.

Relevant modelling requires confirmation that the various maser emitting sites are co-spatial, in addition to data on the spot sizes and brightness temperature estimates. Unusual flux ratios of the maser transitions during the G358 flare indicate that in this case we are dealing with the **previously unknown** methanol maser pumping regime which requires investigation and has its own high scientific importance.

The KVN is the only facility capable of conducting this investigation. If successful, the results would represent the first VLBI detection of the 23.1 GHz line, and many others. Previous maser flares were short lived [8; 7] therefore we request an urgent Target of Opportunity.

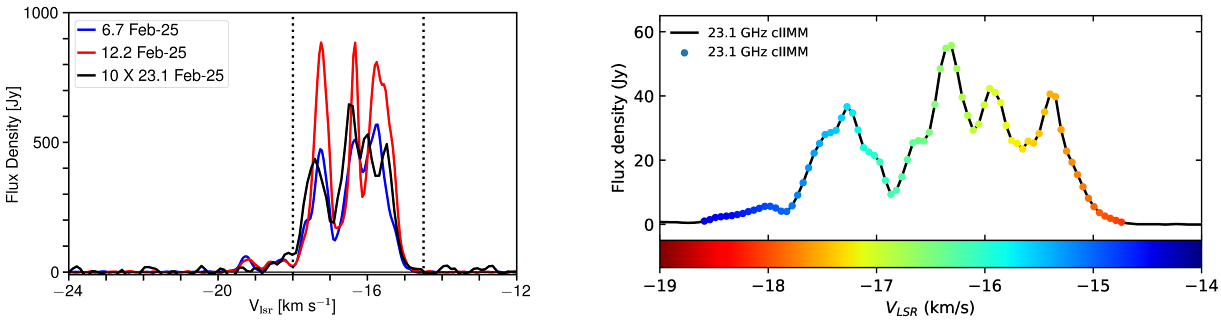

Fig 2 Comparison of the *Left* HartRAO (Single dish) and *Right* JVLA cross-correlation flux densities of the 23.1 GHz line in G358, indicating full flux recovery on interferometric scales.

5 Strategy

We propose simultaneous multi-band spectral line observations of methanol lines in G358 to model, and establish the physical parameters, of maser emission during the ongoing accretion burst.

Considering the current frequency limitations of the Tamna station, and considering the requirement of accessing lines within a 512 MHz frequency range in each band, the following maser lines selected by Prof. Andrej Sobolev based on maximizing modelling of the maser (see Fig 3).

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Target methanol lines:
****K-band****
9(2)-10(1)A+:                 23.12102420 GHz
10(1)-9(2)A-:                 23.44477800 GHz
****Q-band****
8(2,7)-9(1,8)A- 13CH3OH:      41.90433000 GHz
22(9)-22(8)A+-, vt=1:         42.03824500 GHz
****W-band****
1(0)-2(1)E, vt=1:             93.19667300 GHz
****D-band****
23(-2,22)-23(1,22)E:          140.0331440 GHz
18(0)-18(-1)E:                140.1510800 GHz
4(1)A- 4(0)A+ CH3OD           140.1752000 GHz
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The 23.1 GHz methanol maser is rarely detected. It has been observed with single dish and interferometers [18; 19], but has not been successfully observed with VLBI [18]. On Feb 25th the flux density of the 23.1 GHz methanol maser in G358 was measured to be ~60 Jy using the HartRAO 30m observatory. JVLA observations on the same date indicate a flux density of almost the same value, indicating emission to be unresolved on JVLA baseline scales (Fig 2). The flux has since **increased to 100 Jy** (Fig 1).

The KVN Status Report 2019 states a 12 mJy baseline sensitivity at K-band with 256 MHz bandwidth (1 Gbps). Multiplying by $\sqrt{4096}$ (0.48 km/s channels) gives 0.8 Jy/channel. Therefore, even if 90% of the JVLA flux is resolved out at KVN VLBI scales would achieve a $> 10\sigma$ detection.

Providing sufficient detection of the 23.1 GHz line (the brightest in our target line list) we would use this line to calibrate atmospheric fluctuations in order to increase the coherence time for the higher frequency lines via source frequency phase referencing.

Fig 3 illustrates the transition coverage and Fig 4 shows a preliminary KVN schedule summary showing source GST ranges.

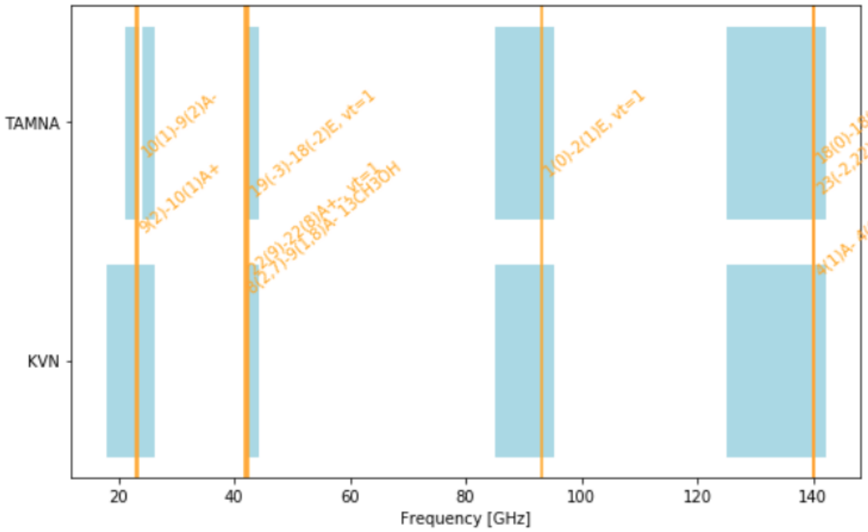

Fig 3. Frequency coverage of the KVN stations, considering the current state of the Tamna station. Over-plotted are the targeted methanol maser lines.

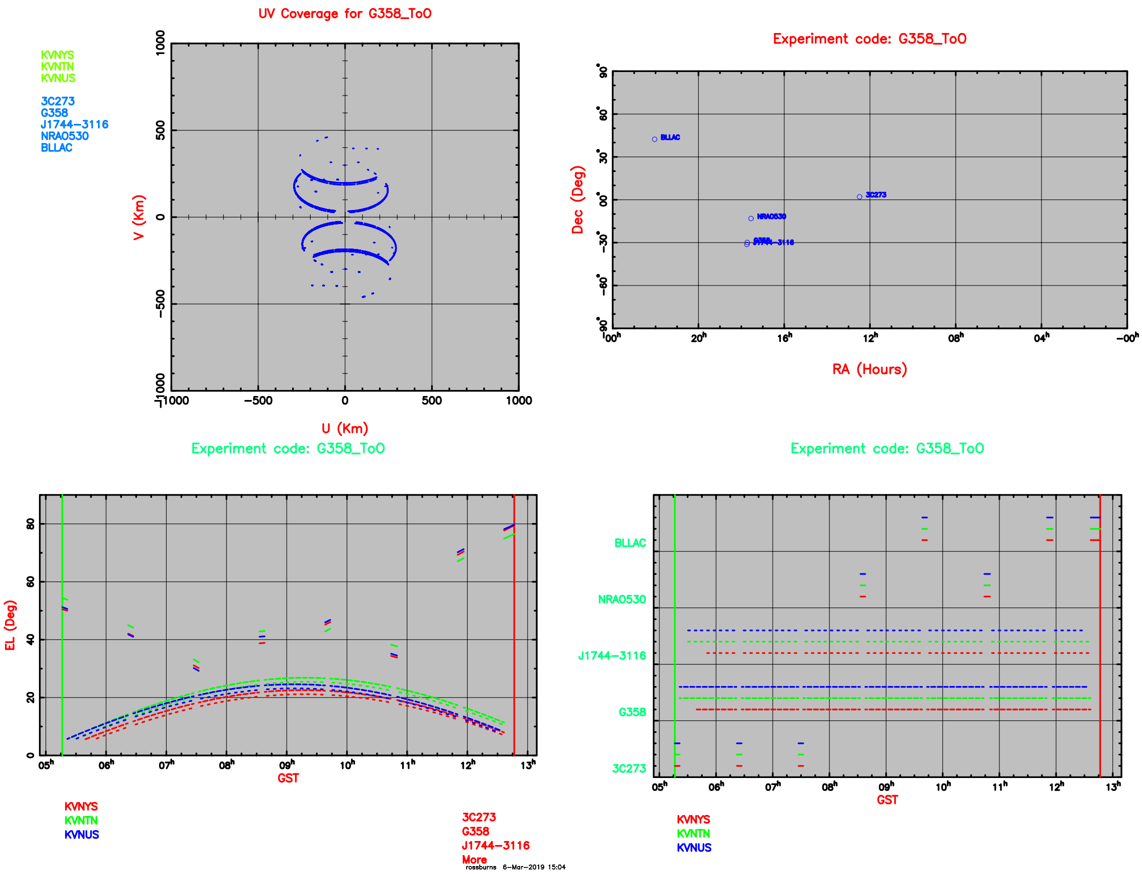

Fig 4. Preliminary schedule for proposed KVN observations of G358 indicating GST ranges

References

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