Onsala Proposal

Humphreys 0108.F-9321

Revising the norms for research using water masers?

Semester: may2021 **Science Cat.: ISM and star formation**

Abstract

Water masers are used to probe a range of environments from evolved stars and star-forming regions, to extragalactic megamasers. Over the years several rules of thumb / paradigms have become accepted. For example, it is said that some of the best lines for blind searches are those at 22 and 183 GHz, to stay away from 321 GHz as it can be highly variable, and to avoid using the 437 and 658 masers to study star-forming regions since they are either absent or rarely present. However, some of the maser paradigms are built upon the pioneering maser discovery observations now about 30 years ago. The upper limits are high relative to what can be done with today's receivers. In addition, maser positions have now been refined using interferometric observations in some cases. Here, we seek to revisit 437 and 658 GHz observations of star-forming regions to put stringent limits on their presence / detections. This ties into work we are doing more generally at 437 GHz and other frequencies to understand ortho-para line overlap in the pumping.

Applicants

Name	Affiliation	Email	Country		Potential observer
Dr. Elizabeth Humphreys	European Southern Observatory	ehumphre@eso.org	Germany	Pi	
Per Bergman	Chalmers University of Technology (Space, Earth and Environment)	per.bergman@chalmers.se	Sweden		

Contact Author

Title	Dr.	***Institute***	European Southern Observatory
Name	Elizabeth Humphreys	***Department***	
Email	ehumphre@eso.org	***Address***	
Phone(first)	00498932006912	***Zipcode***	
Phone(second)		***City***	
Fax		***State***	
		Country	Germany

Is this a long term proposal: No

Overall scheduling requirements

None.

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	nFLASH460 (385-500 GHz)	5h (1h)	439.0	< 0.5mm	02-08, 15-23	The observations are of water lines at 437 and 439 GHz, which will both be included in this setup.
B	APEX	SEPIA660 (581-727 GHz)	1h (1h)	658.0	< 0.5mm	0-10	

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
SGRB2-N-K2	17:47:19.88	-28:22:18.4	J2000	0.0	72	A	Position from Higuchi et al. 2015
W49N-G1-G2	19:10:13.41	+09:06:12.8	J2000	0.0	72	A	Position from De Pree et al. 2000
Orion-SrcI	05:35:14.51	-05:22:30.4	J2000	5.0	72	A	Position from Matthews et al. 2010
NGC-6334I-MM1	17:20:53.38	-35:46:55.7	J2000	-10.0	138	A B	Position from Brogan et al. 2018

Scientific Rationale

Over the years, several rules of thumb for observing astrophysical masers have come to pass. However, some of these paradigms rely on data taken about 30 years ago, when upper limits for typical maser observations were much higher than what is possible today. For example, the pioneering work discovering water masers at 321, 325, 437, 439, 471 & 658 GHz had upper limits of 60 Jy, and above, in some cases (Menten et al. 1990; Menten & Melnick 1991; Melnick et al. 1993; Menten & Young 1995).

We have recently become interested in whether it is time to look again at some of the generally-accepted paradigms. This is in light of the fact we have been studying water masers at 437, 439, 471 & 474 GHz towards evolved stars using APEX (Bergman & Humphreys 2020; Figure 1). In these observations, the 437 GHz is often strong towards AGB stars, such as Miras. Yet, to date, it has never been detected (as far as we know) towards star-forming regions (SFRs). The work we have performed towards evolved stars indicates that line overlaps between ortho and para water, which can come into play in gas at >10 kms^{-1}, may be important in pumping strong 437 GHz masers. If the 437 GHz masers are truly absent from SFRs, then this could be linked to why it has not been observed e.g. if there is insufficient water column for maser emission in gas components 10 kms^{-1} apart. However, it will not be known for sure that these masers do not exist in SFRs without new observations with more meaningful/stringent upper limits.

In this proposal, we therefore request to observe the 437 GHz water maser towards four SFRs which are known to host other strong water masers: Orion, W49N, NGC 6334I and Sgr B2 N. The water masers in these regions also have more accurate positions in recent years due to interferometric observations (Orion Source I: Matthews et al. 2010; W49N-G1-G2: De Pree et al. 2000; NGC 6334I-MM1: Brogan et al. 2018; SgrB2-N-K2: Higuchi et al. 2015). In addition, we request to observe NGC 6334I at 658 GHz. Until recently, 658 GHz water masers had not been detected towards star-forming regions. With the detection towards Orion Source I by Hirota. et al. (2016; Figure 2) using ALMA, we would like to search for this maser towards the next most nearby target in our sample: NGC 6334I.

Note that, this proposal deliberately asks for observations towards a relatively small number of targets in case the observations would indeed all result in non-detections. If the observations result in non-detections, we would still publish them with the improved upper limits. If they result in detections, we can increase sample size in a followup proposal. The total time request for the proposed project is 5.9 hours.

Facilities Requested

This proposal requests APEX observations using nFLASH460 and SEPIA660. Single-dish observations are ideal for performing the initial detection of these lines in star-forming regions. Detections can be followed up later at higher angular resolution using ALMA Bands 8 and 9.

Observing Requirements

437 & 439 GHz Observations: The main maser of interest for detection using nFLASH460 is that at 437 GHz. As far we are aware, this maser line has never been detected to date towards a SFR. On the other hand, the 439 GHz maser - which we will get for free in the same tuning - was detected towards at least three high-mass SFRs with peak flux densities in the range 100 to 500 Jy (Melnick et al. 1993).

We request a 1σ rms of 20 mK ($\sim$1 Jy, the Jy/K factor for the nFLASH460 receiver is $\sim$ 55) in 3 kms^{-1} in the observations at 437.347 GHz, in pwv=0.5 mm weather. This sensitivity was chosen in order to be able to make a 5σ detection of a maser as weak as 5 Jy. The central

tuning will be at 439.0 GHz. We note that the 439.151 GHz maser frequency is in significantly worse atmospheric transmission than that at 437 GHz, nonetheless the rms achieved at 439 GHz will be ∼55 mK (∼ 3 Jy). This is easily sufficient to make high signal-to-noise detections for the types of maser strengths already detected at 439 GHz towards SFRs, see above. The time needed for each one of the four targets is 1.2 hours.

658 GHz Observations: The nearby Orion Source I has already been detected at 658 GHz, where it is a strong maser. The peak flux density was ∼1000 Jy (Hirota et al. 2016, see Figure 2). This is the only detection of the 658 GHz maser towards a SFR to date.

In these observations we seek to observe this line towards only NGC 6334I-MM1, since this target is significantly closer than the other star-forming regions in the proposal that do not have the 658 GHz maser already detected. We base the sensitivity request for NGC 344I-MM1 on the detection that was made towards Orion Source I (d=414 pc; Kim et al. 2008). If Orion Source I were shifted to the distance of NGC 6334I (d=1.3 kpc; Chibueze et al. 2014) the 658 GHz maser would have a peak of ∼100 Jy.

We request a 1σ rms of 20 mK (∼1 Jy, the Jy/K factor for the SEPIA660 receiver is ∼ 55) in 2 kms^{-1} in the observations at 658.007 GHz, in pwv=0.5 mm weather. If a 658 GHz water maser exists towards NGC 6334I-MM1 and is Orion-like, we will detected it with an SNR of 100. This also provides a good margin for the maser to be weaker and we will still detect it. The time needed for the 658 GHz observation is 1.1 hours.

Observing Plan

We used the APEX Sensitivity Calculator to perform the sensitivity calculations and establish the time request. We will use beam-switching. We will observe at highest spectral resolution available and smooth in post-processing to a suitable level.

Scheduling Requirements

There are no special scheduling requirements for these observations.

References

[1] Bergman, P. & Humphreys, E. M. L., 2020, A&A, 638

[2] Brogan, C. L., Hunter, T. R., Cyganowski, C. J., et al. 2018, ApJ, 866, 87

[3] Chibueze, J. O., Omodaka, T., Handa, T., et al. 2014, ApJ, 784, 114

[4] De Pree, C. G., Wilner, D. J., Goss, W. M., et al. 2000, ApJ, 540, 308

[5] Higuchi, A. E., Hasegawa, T., Saigo, K., et al. 2015, ApJ, 815, 106

[6] Hirota, T., Kim, M. K., & Honma, M. 2016, ApJ, 817, 168

[7] Kim, M. Y., et al. 2008, PASJ, 60, 991

[8] Matthews, L. D., Greenhill, L. J., Goddi, C., et al. 2010, ApJ, 708, 80

[9] Melnick, G. J., Menten, K. M., Phillips, T. G., & Hunter, T. 1993, ApJ, 416, L37

[10] Menten, K. M. & Melnick, G. J. 1991, ApJ, 377, 647

[11] Menten, K. M., Melnick, G. J., Phillips, T. G. & Neufeld, D. A. 1990, ApJ, 363, L27

[12] Menten, K. M. & Young, K. 1995, ApJ, 450, L67

Figures

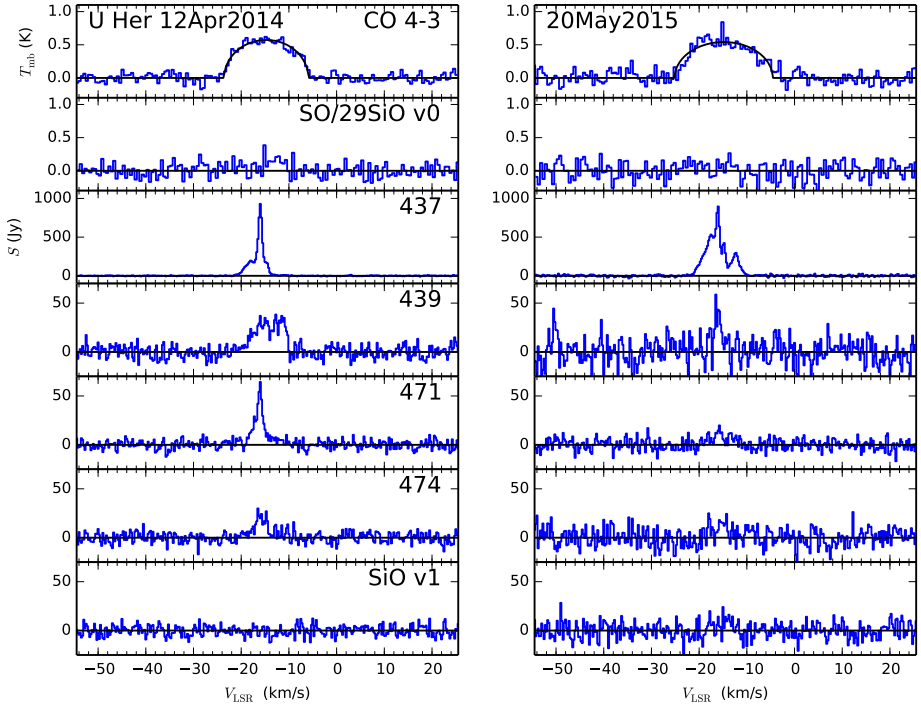

Figure 1: APEX observations of U Her at two different epochs (Bergman & Humphreys 2020).

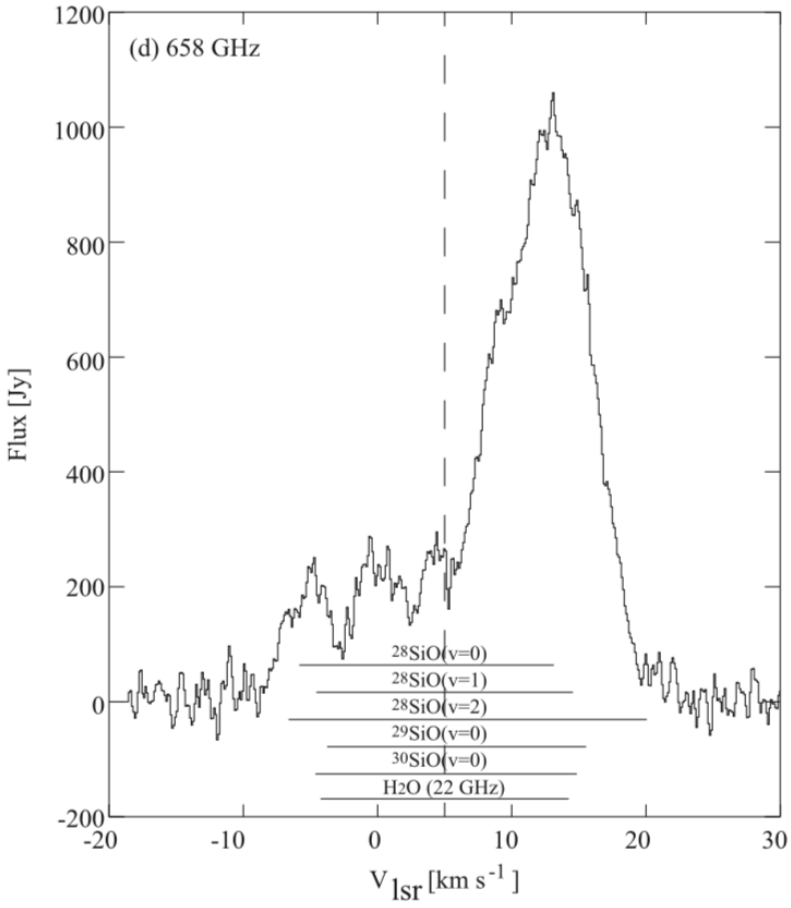

Figure 2: ALMA observations of Orion Source I at 658 GHz (Hirota et al. 2016).

No PhD Students involved

Linked proposal submitted to this TAC: Yes

We have resubmitted a partially-related proposal (0107.F-9306) that also studies the 437 GHz maser, but in evolved stars (0108.F-9301).

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

In Bergman & Humphreys 2020, A&A, 638, 19 we published results from previous allocations: 091.F-9329, 093.F-9315 and 095.F-9313.

Additional remarks

ehumphre

Observing run info :