Onsala Proposal

Humphreys 0108.F-9301

Resubmission of The Enigma of the 437 GHz Water Maser

Semester: may2021 **Science Cat.: Late stages of stellar evolution**

Abstract

Since Melnick et al. (1993), it has been apparent that there is a difference between the 437 GHz water maser and other water masers. In general, water masers can be strongly detected both towards evolved stars and star-forming regions. However, this does not appear to be the case at 437 GHz, which is only detected in evolved stars. Moreover, in our recent APEX paper we have narrowed down the occurrence of the 437 GHz maser to a sub-set of evolved stars only - it is not present in the lower amplitude pulsators, the semi-regular variables. We believe we have a reason for this behaviour. There is a line overlap between ortho and para-water which only comes into play at gas velocities of 10 km/s. Therefore in evolved stars with lower amplitude pulsations it is not observable. Here, we propose to observe additional maser lines towards three evolved stars with different pulsation amplitudes. This will enable constraint for which lines this overlap could play a role.

This is a resubmission of the 0107.F-9306 proposal.

Applicants

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Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA180 (159-211 GHz)	7h (3h)	183	< 0.5mm		
B	APEX	SEPIA345 (277-371 GHz)	10h (5h)	321	0.5-1 mm		
C	APEX	SEPIA660 (581-727 GHz)	5h (2h)	658	< 0.5mm		
D	APEX	nFLASH460 (385-500 GHz)	7h (3h)	437	< 0.5mm		
E	APEX	nFLASH460 (385-500 GHz)	14h (7h)	472	0.5-1 mm		

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
UHer	16:25:47.50	+18:53:33.0	J2000	-14.5	426	A B C D E	
RTVir	13:02:37.98	+05:11:08.4	J2000	18.2	426	A B C D E	
VXSgr	18:08:04.05	-22:13:26.6	J2000	5.3	426	A B C D E	

Scientific Rationale

Immediate Objectives

The aim of this work is to observe water masers at 183, 321, 325, 437, 439, 471, 474 and 658 GHz towards evolved stars with different pulsation amplitudes. We will use the results to constrain and inform radiative transfer modelling in which line overlap between the ortho and para water species has been incorporated. This will help confirm whether line overlaps requiring a gas velocity of up to >10 km/s are needed to produce strong 437 GHz water maser emission. We will also determine if line overlaps between ortho and para water can be important in the pumping schemes of other masers.

Previous Results

We used APEX to observe submillimetre water transitions at 437, 439, 471 and 474 GHz and the CO (4-3) line towards eleven evolved stars (Bergman & Humphreys 2020). The sample included semi-regular and Mira variables, plus a red supergiant star. We performed radiative transfer modelling for the water masers. We also used the CO observations to determine mass loss rates for the stars. From the sample of eleven evolved stars, seven stars displayed one or more of the masers at 437, 439, 471 and 474 GHz. We therefore found that these masers are common in evolved star circumstellar envelopes. The fact that the maser lines were detected near the stellar velocity, rather than in double-peaked line shapes bracketing the stellar velocity, indicates that they are likely to originate from the inner circumstellar envelopes of the stars. We also tentatively linked the presence of the masers to the degree of the target star variability, i.e. that they are more likely to be present in Mira variables than in semi-regular variables, at least as strong masers.

Typically, the 437 GHz was the strongest maser line by far in those studied. However, we could not reproduce this finding in our radiative transfer models, in which it is was weakest line. We propose that line overlap both within the para-water species and between the para and ortho species plays an important role in producing strong maser emission at 437 GHz, and identified the lines of possible importance in the overlap. As some of the line overlaps require gas at 10 km/s, this could explain the absence of the line in the low amplitude pulsators, the semi-regular variables. It may also be linked to why this line has not been observed as a strong maser in star-forming regions, e.g. if there is insufficient water abundance for maser emission in gas >10 km/s.

This proposal

We propose to take some targets from our previous study with a range of pulsation amplitudes and study an expanded range of water masers towards each. To help make sure we understand which results are related to variability, we request two epochs of data. We will use the data to test the hypothesis outlined in the abstract, that line overlap between the ortho and para species is important for production of the 437 GHz maser and to determine the role of line overlaps in other masers. Overall we plan to perform a 3-step process: (i) incorporate line overlap between the ortho and para species in our radiative transfer model - we think may be the first time line overlap between these species is included. This work is ongoing. (ii) observe more maser lines towards a few evolved stars with different pulsation amplitudes, at two epochs - we want to constrain for which masers line overlap could play a role. (iii) In a proposal at the next deadline, we also want to perform a sensitive survey the 437 GHz maser towards a variety of star-forming regions, to check the hypothesis holds. This proposal is to obtain the evolved star data. We aim to followup on the APEX results using ALMA.

Facilities Requested

APEX is the only single-dish telescope that can observe at all the frequencies we propose to study: 183, 321, 325, 437, 439, 471, 474 and 658 GHz. The 321 and 325 GHz lines can be observed in a single tuning, as can the 437 and 439 GHz, as well as the 471 with the 474 GHz lines i.e. these observations would require 5 tunings only per target. Using nFLASH460, we will detect CO 4-3 in the other sideband from the water lines (at 471/474 GHz) and using SEPIA180 we will detect a number of SiO lines in the other sideband.

Observing Requirements

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 e.g. 0.2 km/s. The time needed per source (for the given sensitivity) and per observing epoch is listed in the table below. We here aim for an rms of 5 Jy (as judged from our previous observations) for all setups except for 321 GHz setup in which our rms goal is 1 Jy (to give a reasonable sensitivity at 325 GHz). The Jy/K conversion factor is also listed as is the required pwv. The amount of time needed per source and occasion is 7.1 hr. For three sources, each observed at two epochs, this amounts to about 43 hrs.

Observing Plan

The observing plan is to obtain as many line detections as possible towards each of our targets. Ideally the lines towards each target would be observed close by in time (within days) due to the variable nature of masers. We request two epochs of data for each target, with the epochs separated in time by at least one week. However, we can still perform much of the science outlined in this proposal if a subset of the observations only can be obtained.

Scheduling Requirements

We have chosen targets in the RA range 12 to 24 hours, suitable for the anticipated range of observation dates. The targets chosen formed part of the previous APEX study published in Bergman & Humphreys (2020). We request two epochs of data for each target in order to check variability of the maser lines.

References

[1] Bergman, P. & Humphreys, E., 2020, A&A, 638, 19

[2] Melnick, G., Menten, M., Phillips, T., Hunter, T., 1993, ApJ, 416, L37

Table 1: Water maser lines of interest and time estimates

Line(s) GHz	Flux density rms Jy	pwv mm	Time h	Notes
183	5	0.5	1.1	SEPIA180, 35 Jy/K
321/325	1	1.0	1.7	SEPIA345, 40 Jy/K
437/439	5	0.5	1.1	nFLASH460, 48 Jy/K
471/474	5	0.7	2.4	nFLASH460, also CO 4-3 in LSB
658	5	0.5	0.8	SEPIA660, 65 Jy/K
			7.1	

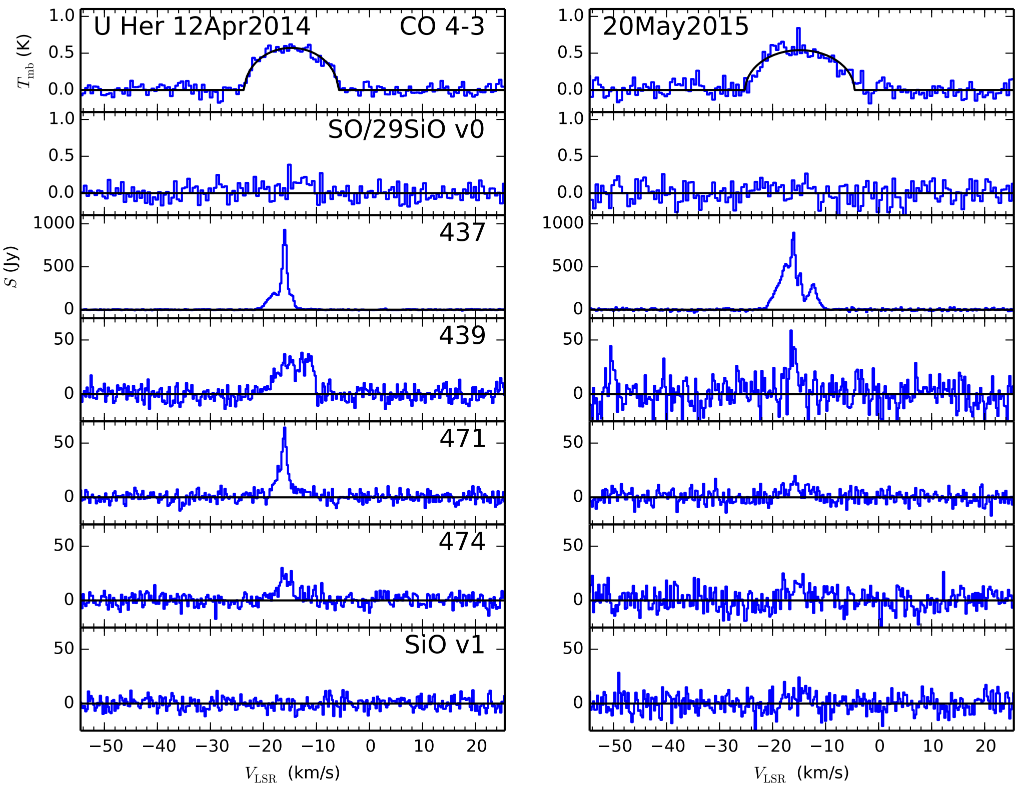

Figure 1: APEX observations of U Her at two different epochs

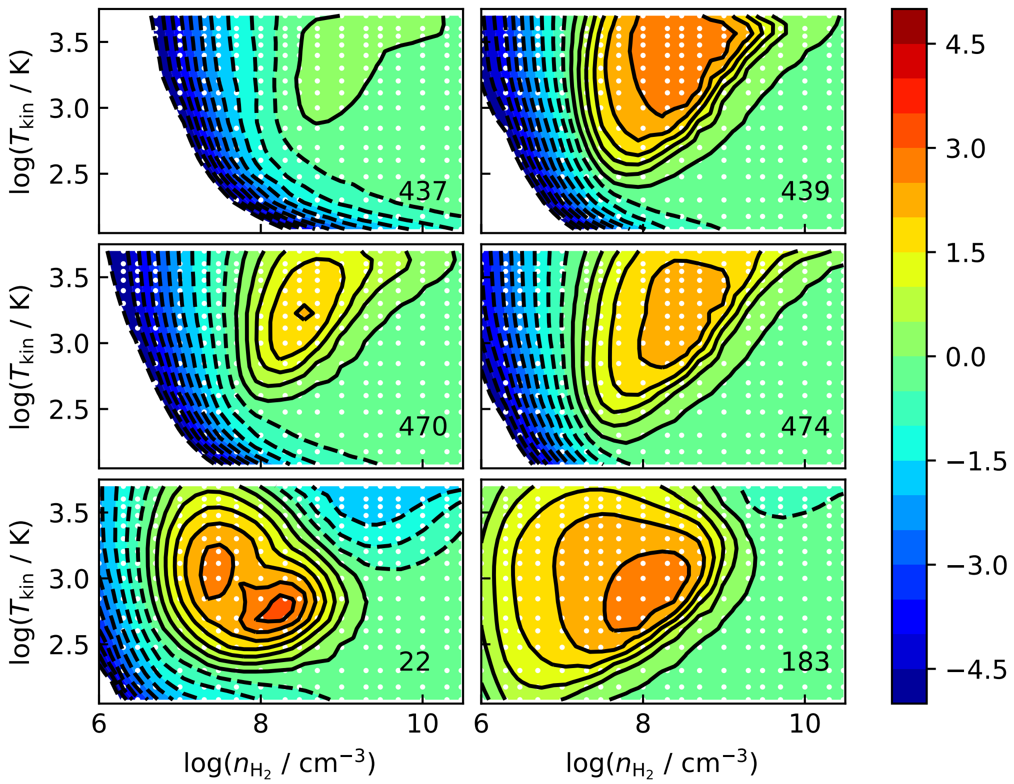

Figure 2: Radiative transfer modelling results from Bergman & Humphreys (2020). The contour plots show the logarithmic ratio of the maser line (frequency in GHz is indicated) relative the 557 GHz thermal line. Note that the 437 GHz maser line is typicallly the weakest of the 400-GHz lines - opposite to what is observed.

No PhD Students involved

Linked proposal submitted to this TAC: No

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.
Because of the current pandemic situation in Chile, this is a resubmission of a proposal 0107.F-9306 with a recommended time of 43 hrs. If this P107 proposal cannot be completed in P107 we would like to have the option to complete the observations in P108 if needed.

Additional remarks

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Observing run info :