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Studies of circumstellar shells in AGB stars by multifrequency (sub)mm-VLBI observations of maser emission

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Abstract

VLBI observations of maser emission are a basic tool to study the circumstellar envelopes (CSEs) around evolved stars, mainly around AGB and post-AGB stars. The maser lines of water and silicon monoxide are particularly intense. They provide us with high spatial resolution data on the very inner CSEs around AGB stars, including the pulsating layers previous to grain formation and outer regions where the fast expansion characteristic of such envelopes is already present. The analysis of the pumping mechanism of SiO masers and of the physical conditions in the emitting clumps requires accurate maps of the various lines, which show different excitation requirements. A large observational effort is being done to obtain (quasi-)simultaneous multiline data at the highest spatial resolution, using VLBI techniques, which makes possible to compare the relative distribution of the maser lines. We present the state-of-the-art in the field, and discuss preliminary results of SiO masers observed with the Global Millimeter VLBI Array (GMVA) which provide a new view into the physics of these AGB envelopes. The participation of ALMA in these VLBI arrays will boost the study of these masers, at higher frequencies.

1 Introduction

Observations of SiO masers performed in various vibrational and rotational transitions by very long baseline radiointerferometric techniques (VLBI) have provided extremely valuable information on the spatial structure and dynamics of the inner circumstellar shells around AGB stars. More generally, comparison of models of SiO emission (including models combining SiO excitation and dynamic evolution of circumstellar atmospheres) with VLBI data and single dish SiO observations allows us to specify the physical conditions in the circumstellar environment of late-type stars and to discern the main mechanisms at work for the vibrational/rotational excitation of the SiO molecule.

VLBI mapping systematically shows emission clumps distributed in a ring-like structure consistent with tangential ray amplification at about 10^{14} cm from the star (equivalent to about 23 stellar radii). The structure and dynamics of the SiO inner shells have been studied in great detail with the VLBA instrument for the 43 GHz (λ = 7 mm) of the SiO J=1-0 maser lines in the v=1 and v=2 vibrationally excited states at a resolution of about 2 10^{12} cm for the typical distance to these objects (see e.g. [15] [6] [9] [18] [19] [11] [1]). Comparing the observed brightness distributions in different vibrational/rotational states should be indicative of which excitation mechanisms dominate. The v=1,2 J=1-0 maser lines often occupy similar regions, but their clumps are rarely spatially coincident and the v=2 emission ring tends to be closer to the star. These relative separations are an argument in favor of dominant radiative excitation models (e.g. [6] [7] and Fig. 1) although observation of globally similar emitting regions tends to favour collisional excitation. The v=2 masers tend to be located slightly closer to the star whereas at other epochs several maser clumps overlap suggesting that stellar shocks are playing a role in the collisional/radiative pumping scheme.

The SiO J=2-1 lines, around 86 GHz (λ = 3 mm), are often strong masers, especially in the v=1 state, but they have been much less studied with VLBI techniques than the J=1-0 lines. The standard theoretical models predict that the v=1 J=1-0 and v=1 J=2-1 lines, with nearby energy levels and thus requiring a similar pumping mechanism, must come from the same clumps (e.g. [16] [3]). However, observations of AGB stars such as IRC+10011, R Leo and chi Cyg have shown that these two lines exhibit a ring morphology but are not coincident at all. In fact, the J=2-1 maser clumps occupy a clearly larger shell in the circumstellar envelope ([18] [19]; see also R Cas data in [17]). As for the 43 GHz transitions, it is impossible to reconcile all 86 GHz observational results with the general features predicted by theoretical models of SiO masers, at least under the standard collisional and radiative excitation scenarios. Other mechanisms may also be at work, and [18] [19] argue that the overlap of two infrared lines of SiO and water affects the SiO maser pumping, explaining, at least qualitatively, the relative J=1-0 and J=2-1 distributions. In this complex theoretical and observational situation, new detailed and sensitive mapping of the SiO lines undertaken with the most sensitive interferometric baselines will bring very useful information.

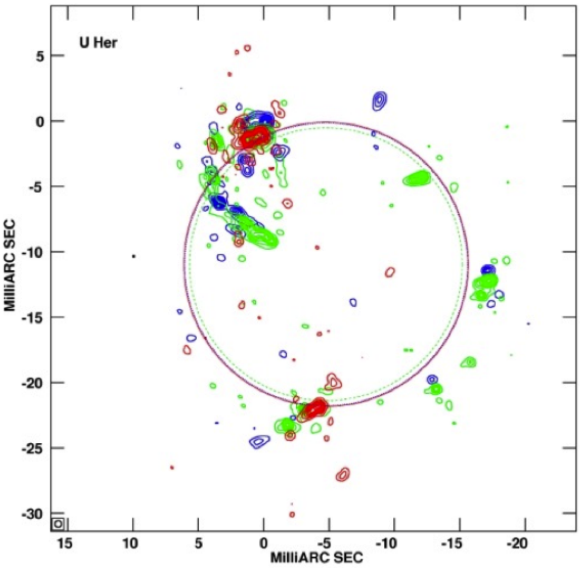

Figure 1: Map of the SiO J=1-0 maser emission around U Her, in the v=1 (blue), v=2 (green) and v=3 (red) states [7].

2 GMVA new results

In the quest for obtaining maps of SiO emission in AGB circumstellar envelopes with higher resolution and sensitivity, we performed a VLBI study with the European telescopes of the Global Millimeter VLBI Array (GMVA; in particular Effelsberg, IRAM phased-Plateau de Bure, IRAM Pico de Veleta, Yebes, Onsala and Metshovi however the data of the last two instruments could not be used). Fig. 2 shows one example of SiO detection. It is specially interesting the fact that up to 40% of the maser flux is recovered in some frequency channels. Previous observations of the 86 GHz v=1 J=2-1 SiO masers in R Cas with the GMVA had demonstrated that there is very compact emission, since it is detectable even with the longest VLBI baselines [5]. Similarly, maser spots as small as 0.2 mas were observed in v=1 at 43 GHz (see e.g. [8]). It is however well known that a large amount of SiO emission, which is present in the single dish data (upper pane in Fig. 2), is missed with current arrays and/or filtered out with the longest VLBI baselines (see e.g. VLBA maps by [18] [19] [1], where a ratio of correlated to total SiO maser flux at 86 GHz of no more than 10% is shown). In order to better compare the SiO maser distributions at 43 and 86 GHz, it is crucial to improve the fraction of flux recovered in VLBI maps, particularly at 86 GHz. The large amount of missing flux at this frequency has been preventing any sensible comparison of both distributions. Good quality maps of the 86 GHz SiO v=1 J=2-1 line are needed to compare these with the existing 43 GHz SiO distributions in a physically meaningful way. Our new data is very promising; in Fig. 3 there are many regions of SiO emission identified probably due to the larger sensitivity of our VLBI baselines; further investigations are needed to clarify if these are weaker features not seen in previous studies, and responsible of the larger recovered flux in this map.

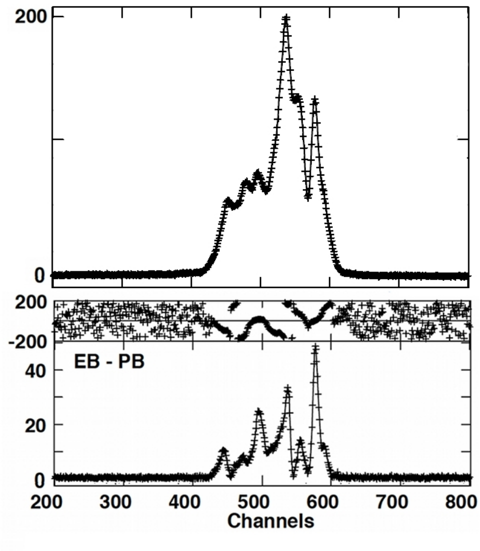

Figure 2: Spectra of the SiO v=1 J=2-1 maser emission at 86 GHz towards chi Cyg (top) and crosscorrelation in the Effelsberg-Plateau de Bure GMVA baseline (bottom). Fluxes are in Jy.

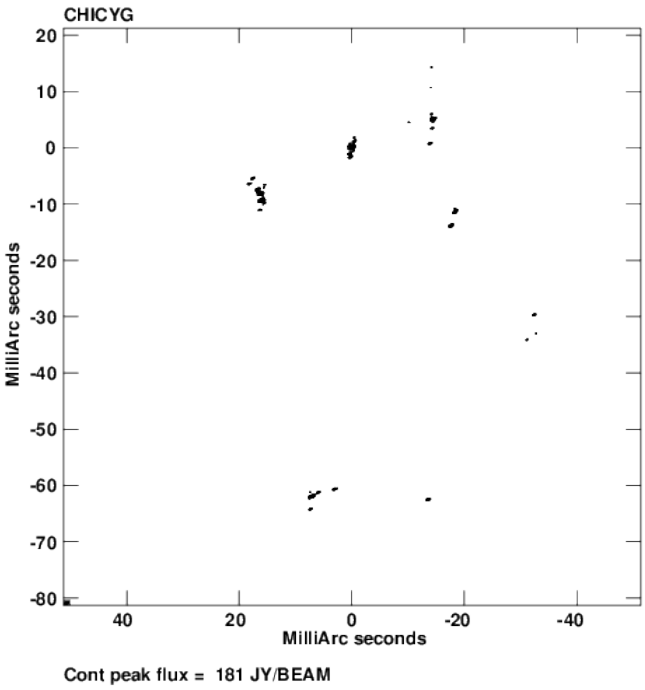

Figure 3: Integrated GMVA flux map of the SiO v=1 J=2-1 maser emission at 86 GHz around chi Cyg. The minimum flux showed is 9 Jy/beam.

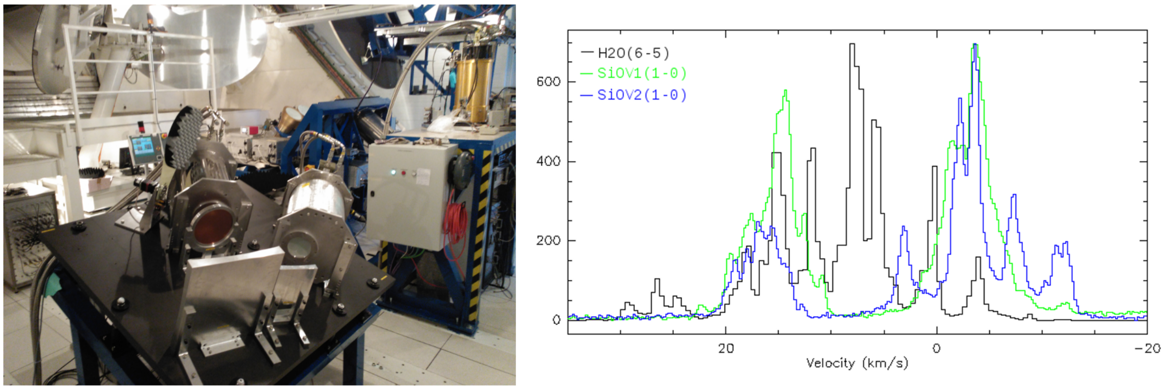

Figure 4: *Left*: Receivers installed at the Yebes 40-m radio telescope that allows the simultaneous observation of the frequency bands centered at 22 and 43 GHz. *Right*: example of obtained spectra.

3 Multifrequency observation scenarios

A new scenario for multiline studies arises thanks to the technological development in broadband receivers and the capability to perform simultaneous observations in different frequency bands. One very successful case is the Korean VLBI Network (KVN, [13]), where a setup of receivers centered at 22, 43, 86 and 129 GHz allow to study H_2O and several lines of SiO at the same time. This instrument is producing a great advance in the observational field of masers in AGBs (see the many maps of SiO in e.g. [20]). However it lacks very long baselines; in this respect we have installed a system at the IGN Yebes 40-m radio telescope (in Guadalajara, Spain) that allows the simultaneous observation of the frequency bands centered at 22 and 43 GHz (see Fig. 4). The receiver for 86 GHz is expected to be installed shortly, which will enhance the technical capabilities for this kind of studies.

Acknowledgments

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