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SiO masers in evolved stars

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Abstract. We present preliminary results of a survey of SiO masers in evolved stars carried out with the Noto radiotelescope at 43 GHz. This project is intended to be a feasibility study for successive monitoring programs to be carried out with the Noto telescope, but it is also shown how, after a comparison between the Noto and the SRT sensitivities, the advent of SRT will open new perspectives in the study of the evolutive stages of stars of intermediate masses before the transition to Planetary Nebulae.

1. Introduction

Masers of SiO, H_2O and OH are often associated with stars of the asymptotic giant branch (AGB) or more evolved (post-AGB). The masers are located in the circumstellar envelopes (CSE), but at different depth: SiO masers in the innermost part, close to the central star, H_2O at half-way and OH, due to the dissociation of the H_2O by the interstellar UV radiation, in the outhermost part of the CSE. In the CSE of evolved stars with high mass loss, like Miras and OH-IR, all three kinds of masers are present. When the mass loss ends, the masers closer to the star, first SiO and later H_2O, disappear, while the OH masers can be found also in the latest evolutive phases post-AGB and later Proto Planetary Nebula (PPNs) (Lewis 1989).

While H_2O and OH masers have been intensively studied thanks to many surveys of AGB and post-AGB stars, the study of the SiO maser characteristics and evolution is still at the beginning, likely because there are few radiotelescopes in the world that can observe at 43 GHz. Here we present preliminary results of a survey of a sample of evolved stars in the two SiO maser transitions at 42.8 and 43.1 GHz, carried out with the Noto radiotelescope, recently equipped with a new primary mirror with a good surface accuracy, whose shape is kept parabolic by an active surface system, and a new 7-mm receiver (band 38-48 GHz).

2. Sample selection

Previous survey of SiO masers at 43 GHz in evolved stars have been carried out at Parkes (stars with $\delta < +5°$) by Nyman et al. (1993, 1998) and with the Nobeyama radiotelescope (Nakashima & Degughi 2003). The observed samples have been selected from the literature on the basis of the presence of other maser species, or from the IRAS catalogue on the basis of the color indices.

In order to extend the study of evolved stars with observable emission in the SiO maser lines, we selected a new sample starting from Allen's catalogue (Allen et al. 1993), which consists of the 300 brightest sources of the IRAS Point Source Catalogue, and selecting only the late type stars (spectral type M) that showed a higher variability in the infrared during the IRAS mission. Among them, we selected the oxygen rich ones on the basis of the low-resolution IRAS spectra (LRS class between 21 and 39) observable from Noto ($\delta > -30°$). Those criteria returned a sample of 69 evolved stars.

Previous surveys have pointed out that the probability of detection of SiO maser is related to the variability of the central star, whether it is an AGB star (Hall et al. 1990; Nyman et al. 1993), or a more evolved object, i.e. a post-AGB star or PPN (Nyman et al. 1998; Nakashima & Degughi 2003). However, it is still unclear how the variability of the star is linked to the maser emission.

3. Observations

The observations have been carried out with the 32-m Noto radiotelescope by using the new 43-GHz receiver. The total system noise is about 80-100 K at zenith, depending on weather, and the gain ranges from 0.05 to 0.08 K/Jy, leading to a system equivalent flux density (SEFD) of 1200-2000 Jy. Even if the receiver has a large bandwidth, from 38 GHz up to 48 GHz, the instantaneous tunable bandwidth is about 400 MHz; two circular polarizations are available.

The spectra have been acquired with the ARCOS autocorrelator. The maximum number of spectral channels is 1024, that can be split into two spectra, each with 512 channels. This gives the possibility to observe two spectral regions simultaneously provided that the frequency separation is less than the instantaneous bandwidth.

For each star we observed two SiO maser transitions at 43 GHz, $J = 1 - 0$, $v = 1$ (43122.079 MHz) and $J = 1 - 0$, $v = 2$ (42820.582 MHz) in the left circular polarization, with a bandwidth of 20 MHz per spectrum and a spectral resolution of 37 kHz that, at this frequency, corresponds to 0.25 km s^{-1} as velocity resolution. We observed in beam-switch mode, with 5 min of integration time both on-source and off-source. The spectra were reduced by using the software XSPETTRO for the on-off difference, then CLASS for baseline subtraction, temperature and flux calibration.

4. Results

In Fig. 1 we show as an example the spectra of some detected sources in the two transitions at 43.1 and 42.8 GHz. In the lower panels the spectra of one of the faintest detected sources indicate that the noise level that is possible to get with 5 min of integration is about 200 mJy. It is interesting to note that the sensitivity of the Noto telescope at this frequency, thanks to the new resurfacing and to the active optics, is comparable or better than the one achievable with the Nobeyama 45-m telescope.

Among the 69 stars of the sample, we detected 36 sources: 17 maser sources already known and 19 *new detections*, increasing by about 6% the number of evolved stars detected in the SiO maser; 33 observed sources have not been detected.

What is the difference between stars that present SiO maser emission and stars that do not show such kind of emission? The reason can be either in the physical characteristics of the circumstellar envelope or in the characteristics of the central star.

If the presence of maser emission is linked to the circumstellar envelope, detections and non-detections should be located in different regions of the infrared color-color diagram, because circumstellar envelopes with the same physical characteristics, like average temperature and density of the dust, size, total mass-loss, have the same infrared colors. But neither in the IRAS nor in the 2MASS colour-colour diagram there is a separation between detections and non-detections.

If the presence of the maser emission is due to the characteristics of the central star, we should see a trend in the detection probability as a function of the photospheric temper-

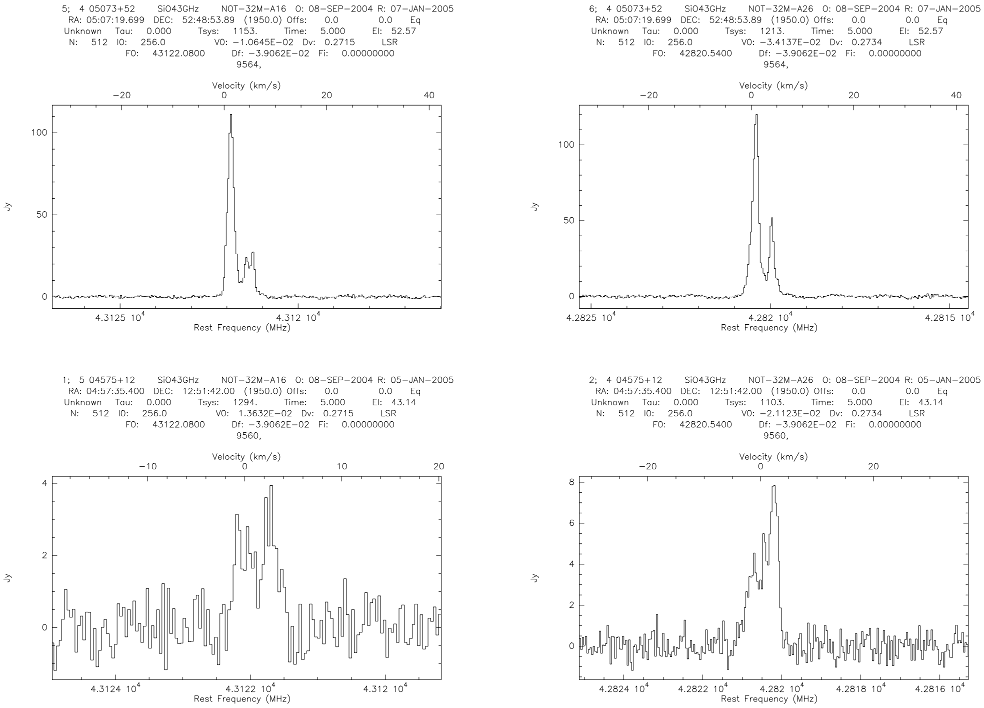

Fig. 1. Spectra of two detected sources at the two maser transitions; left panels: $J = 1-0, v = 1$(43 122.079 MHz) transition; right panels: $J = 1-0, v = 2$(42 820.582 MHz) transition; lower panel: a faint source to estimate the noise level achievable in 5 min of acquisition (about 200 mJy).

ature (or spectral type) or as a function of the pulsation of the star (or amplitude of the light curve in the visible), that is linked to the mass-loss. But also in this case, there is no clear evidence of any separation between detection and non detection, even if the data seem to indicate that the most intense emission occurs when the amplitude of the stellar pulsation is larger. No definitive conclusion can be drawn at this stage, and further investigations, with observations of a bigger sample of evolved stars and a monitoring program, will give important indications.

5. Comparison Noto-SRT

The advent of SRT, with the capability to observe with high sensitivity in the millimetre range up to 86 GHz, offers great opportunities for the observations of masers in the circumstellar envelopes of evolved stars. Masers of SiO can be observed both at 43 and 86 GHz and, thanks to the frequency agility, it will be possible to get spectra of different maser lines (OH, H_2O and SiO) almost simultaneously.

As already discussed in Sect. 3, the Noto telescope at 43 GHz has a very good performance, as reported in Table 1. Starting from Table 3.1 of the Report of the SRT Working Group (Brand et al. 2005), we computed the integration time to get the same r.m.s. of 200 mJy with SRT, getting an impressive result of a few seconds at 43 GHz and a few tens of seconds at 86 GHz. By adopting the same exposure time and spectral resolution as we did with Noto, the achievable r.m.s. in the two bands is 16 and 60 mJy, respectively. In addition, the large instantaneous bandwidth of 2 GHz will allow the simultaneous acquisition of the four SiO maser transition around 43 GHz (transitions $J = 1-0$ at $v = 0$ at 43423.864 MHz, $v = 1$ at

Table 1. Comparison Noto - SRT for SiO maser observations.

	Noto (43GHz)	SRT (43GHz)	SRT (86GHz)
Tsys (K)	100	60	170
gain (K/Jy)	0.08-0.05	0.61	0.46
SEFD (Jy)	1200-2000	100	370
Pol	L&R	L&R	L&R
Instantaneous BW (MHz)	400	2000	2000
N Simult. spectra	2	8	8
r.m.s. (mJy) (*)	200	16	60

(*) with 37 kHz resolution and 5 min integration time

43122.079 MHz, $v = 2$ at 42820.582 MHz and $v = 3$ at 42519.373 MHz) in the two orthogonal polarizations. And the same can be obtained for the observations of the several transitions lines $J = 2 - 1$ at different vibrational states ($v = 0, 1, 2$) around 86 GHz. This will give the possibility to get the line intensity ratios for the different transitions, and this will give the possibility to understand the physical conditions of the inner part of the CSE where SiO masers originate.

In conclusion, the high sensitivity of SRT at high frequency, the large instantaneous bandwidth and the frequency agility will allow:

- to observe in a short time large samples of evolved stars;
- to probe the circumstellar envelopes at different depths;
- to increase the monitoring frequency of the samples and to correlate the variability of the different maser lines with that in the optical or infrared.

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