Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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A sensitive search for SiO maser emission in planetary nebulae

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Abstract. Eight planetary nebulae (PNe) are known to emit OH and/or H_2O masers, but there is no report of an SiO maser in this type of objects. We present a search for SiO masers in 16 confirmed and candidate PNe, carried out with the Australia Telescope Compact Array. We found no evidence of association between SiO masers and PNe in our data. Previous detections of thermal SiO emission in PNe show that these molecules can be present in gas phase in this type of objects, but it is not yet clear whether they can be found where the physical conditions are appropriate for maser pumping. We suggest that the best candidates for a new search would be PNe showing high-velocity outflows.

Keywords. masers, planetary nebulae: general, stars: AGB and post-AGB, stars: mass loss

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1. Introduction

Maser emission of SiO, H_2O, and OH is widespread in Asymptotic Giant Branch (AGB) stars with Oxygen-rich circumstellar envelopes. However, it is expected that it quickly disappear after the end of strong mass-loss (up to 10^{-4} $M_\odot$ yr^{-1}, Blöcker 1995) of the AGB phase, with timescales $\simeq 10 - 10^4$ years, depending on the molecular species (Gómez *et al.* 1990). Planetary nebulae (PNe) bearing maser emission are, therefore very scarce, and are considered to be nascent PNe. So far, only eight PNe are confirmed to emit OH and/or H_2O masers (see Cala *et al.* 2022, and references therein). No SiO-maser-emitting PN has ever been found. We present here a sensitive search for SiO masers in PNe in two carefully selected samples.

2. Source selection and observations

We carried out interferometric observations of SiO masers at 43 GHz with the Australia Telescope Compact Array. Four SiO transitions (v=0,1,2,3 of J=1-0), as well as radio continuum emission (4 GHz total bandwidth) were covered simultaneously. We selected two source samples, based on different criteria, in order to maximize the probability of detection.

For the first sample, we selected all PNe with known masers of OH and H_2O, as well as some candidate PNe with masers (sources for which the PN nature is still not confirmed). The sample comprises 11 sources. The angular resolution of the observations was $\simeq 7''$.

For the second sample, we cross-matched detections of SiO masers (obtained with single-dish radio telescopes) with catalogs of known PNe and of radio continuum sources.

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PNe show prominent radio continuum emission, due to free-free processes in the photoionized gas, so this emission may pinpoint a PN. We selected those cases in which a radio continuum source or a catalogued PN is within the beam of the reported single-dish SiO detection. Our sample comprised five sources. The angular resolution of these observations was $\simeq 0.5''$.

3. Results

In the first sample (confirmed and candidate PNe with masers of other species), no SiO detection was obtained, with 3σ upper limits $\simeq 7$ mJy. This is a much more stringent constraint than in previously reported SiO observations toward five of our sources ($\simeq 1$ Jy, Nyman *et al.* 1998). All sources in the sample, however, show radio continuum emission at 43-45 GHz. In some of these sources, ours is the first report of continuum emission at this frequency band.

In the second sample (single-dish SiO detections near radio sources and PNe), we detected SiO emission in four out of our five targets. In none of them we could confirm that the maser emission is associated with a radio continuum source. These four SiO emitters are most likely to be AGB stars. We obtained accurate positions for the SiO masers in these sources. The only case in which we still cannot completely rule out the association of SiO with radio continuum emission is IRAS 17390-3014. We did not detect any radio continuum emission at 7mm in that source, but there is an extended continuum source (NVSS 174218-301526), detected at 1.4 GHz (Condon *et al.* 1998), with a deconvolved size of $80'' \times 34''$, whose association is unclear and that seems to engulf the position of the evolved star. Our observations, with an angular resolution of $0.5''$ do not seem to have enough sensitivity to detect such an extended source. Further observations are needed to confirm the existence of this continuum source, its nature, and its putative association with the SiO masers.

4. Discussion

Our non-detection of SiO masers in the sampled PNe could be due to several reasons. One is that the SiO abundance in gas phase may be too low to provide the necessary column density for a detection. Even if SiO is present in gas phase, it may be located in regions where the physical conditions are not appropriate for population inversion.

The SiO abundance in gas phase tends to drop in circumstellar envelopes at increasing distances from the central star, because the molecule accretes into dust grains, but it may be released again in the presence of shocks. In the particular case of PNe, however, SiO molecules could be photodissociated by the hot, central star. There are some reports on thermal SiO emission using single-dish telescopes (e.g., Edwards & Ziurys 2014), and our ALMA observations of the young PN IRAS 15103-5754 also show thermal SiO emission located at < 400 AU from the central star (Gómez et al. in preparation). While this indicates that SiO molecules can be found in gas phase in PNe, there is still no data showing their presence at the locations where SiO masers are typically found in AGB stars (a few stellar radii). Of course, SiO masers may be pumped by different mechanisms from those of in the AGB, and thus be found farther away from the central star. We note, for instance, that SiO masers can be excited at the base of high-velocity outflows in the case of post-AGB stars (Imai *et al.* 2005), at distances $\simeq 10$ AU. Assuming the same may happen in PNe, promising candidates for a new SiO maser search could be objects showing fast outflows, which may be even more evolved than PNe harboring OH and H_2O masers.

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