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86 GHz SiO Masers in Late-type Galactic Bulge Stars

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Abstract. We present 86 GHz ($v = 1, J = 2 \rightarrow 1$) SiO maser line observations with the 30-m IRAM telescope of a small sample of late-type stars in the inner Galaxy. The stars were selected on basis of their infrared magnitudes and colors, and our first results show an instantaneous detection rate of ∼65%. The derived SiO maser fluxes and line-of-sight velocities indicate that the stars are located in the Galactic Bulge.
The goals of the project are to study the relation between 86 GHz SiO maser emission and infrared properties of the stars, and to enlarge the number of known stellar line-of-sight velocity measurements. Combining the detections with measurements from other surveys (e.g. OH maser surveys) will allow a kinematic analysis of stellar orbits, and probe the dynamics of the inner Galaxy and its probable triaxial mass distribution.

1. Introduction

Many independent observations support the existence of a triaxial potential in the Milky Way: non-circular motions in the gas (De Vaucouleurs 1964), asymmetry in the brightness distribution as seen in the COBE/DIRBE and DENIS maps (Weiland et al. 1994; López-Corredoira et al. 2001), and gravitational micro-lensing experiments (Alcock et al. 1997). However, model parameters of the bar, i.e. length, strength, pattern speed, and position angle, are still poorly constrained.

A number of studies have been undertaken to characterize both the kinematics and the distributions of stars in the central part of the Galaxy. Unfortunately the number of known stellar velocities is still too small, so that a detailed quantitative analysis of Galactic structure is not possible (Vauterin & Dejonghe 1998). An excellent method to measure radial velocities is to locate circumstel-

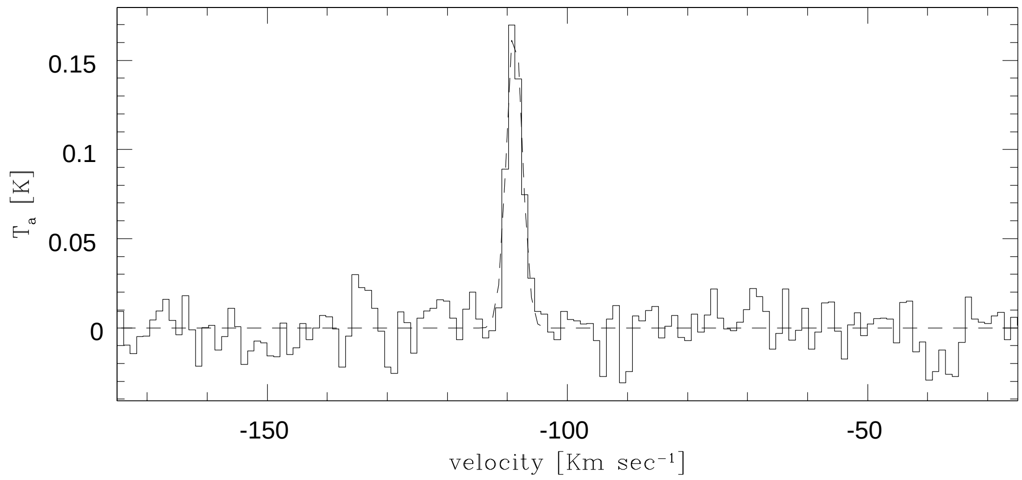

Figure 1. Typical observed line profile. Dashed is the best gaussian fit

lar masers associated with AGB stars, as previous SiO (43 GHz) and OH (1612 MHz) masers surveys in the Galactic disk and bulge demonstrate (e.g. Sevenster et al. 1997; Sjouwerman et al. 1998; Deguchi et al. 2000). Maser observations can penetrate the Galaxy uniformly, also at very low latitudes, while optical spectroscopy is extinction limited. OH and SiO maser lines give the line-of-sight velocity of the central star to within a few km s^{-1} (Jewell et al. 1991). But it remains problematic to identify enough sources for quantitative studies since the maser phenomenon is rare among AGB stars.

SiO maser emission has been detected in different transitions toward oxygen-rich AGB stars, i.e. Mira variables, semi-regular variables, and OH/IR stars. The relative strengths of different SiO maser lines have been observed to change strongly going from Mira to OH/IR stars (Lane 1982; Nyman et al. 1986, 1993). In particular, the ratio of the SiO flux at 43 and at 86 GHz is between 2 and 10 in OH/IR stars, but only ∼0.4 in Miras and in supergiants. Thus, in particular for Mira like stars, the 86 GHz ($v = 1, J = 2 \rightarrow 1$) SiO transition is a powerful tool to derive stellar line-of-sight velocities. This is confirmed by Haikala et al. (1994) who obtained a detection rate of 69 % on Mira stars from a sample of IRAS point sources observed at 86 GHz.

Aiming to enlarge the number of stellar line-of-sight velocities, complementary to the previous OH-maser searches, we started a survey for 86 GHz ($v = 1, J = 2 \rightarrow 1$) SiO maser line in late type stars selected from the mid-infrared ISOGAL catalogue (Omont et al. 1999) in the inner Galaxy.

2. The ISOGAL selection criteria

ISOGAL is a 7 and 15 μm survey of ∼15 square degrees in selected fields along the Galactic plane, mostly concentrated towards the Galactic center. The combination of the ISOCAM data with the I, J, K_S photometric catalogue from DENIS allows a good determination of the nature of the stars and shows that, with near arcsec spatial resolution and a sensitivity of ∼10 mJy, ISOCAM was able to detect the entire AGB population in the Bulge region (Omont et al. 1999): from the highly obscured, very bright OH/IR stars, to the low mass stars at the RGB tip (K_0 ~8.2 for D = 8.0 kpc).

The sample for our SiO program was chosen from the DENIS-ISOGAL catalog. In fact, we located known LPV's and variable candidates (taken from Glass et al. (2001) and Schultheis et al. (2000)) in the ISOGAL-DENIS color-magnitude diagrams, and selected all the ISOGAL stars detected at both 7 and 15μm, with a DENIS counterpart, and with intrinsic colors similar to the two samples above $(1.0 < [15]_o < 3.85), 0.7 < ([7]-[15])_o < 2.3, 1.95 < (K-[15])_o < 4.85)$; known OH/IR stars were removed. For the extinction correction we used the extinction map derived from the DENIS database by Schultheis et al. (1999), and the extinction law from Glass (1999); at 7 and 15 μm we used the relation $A_V : A_7 : A_{15} = 1 : 0.020 : 0.025$ (Hennebelle et al. 2001; Teyssier et al. 2001). The final DENIS-ISOGAL sample contains 245 objects within $-4° < l < +10°$, and $|b| < 1°$.

3. Observations

The observations were carried out with the IRAM 30m telescope (Pico Veleta, Spain) in August 2000 and December-February 2001. Two receivers were used simultaneously to observe the SiO ($v = 1,\ J = 2 \rightarrow 1$) transition at 86.24335 GHz. The system temperature ranged between 100 to 300 K. Depending on the source elevation, on-source times of 5-15 minutes were used, and tentative detections were observed more than once. In December 2000, the forward efficiency of the telescope varied from about 0.92 to 0.95, changing the conversion factor from 5.98 to 6.18 Jy/K. For the spectral analysis we used analog filters with low resolution (3.5 km s^{-1}), and the AOS autocorrelator with a resolution of 312 kHz (1 km s^{-1}). The observations covered a velocity range of $\pm$440 km s^{-1} with respect to the Local Standard of Rest. The spectra were reduced using CLASS. The receivers were added, yielding a typical rms of 0.017 K, and only a signal higher then 3 σ in both the analog filter and autocorrelator was considered as a detection. The line parameters were determined by fitting the data from the autocorrelator with a gaussian after subtracting a linear baseline.

4. Discussion

Up to now we have detected 36 new SiO ($v = 1, J = 2 \rightarrow 1$) maser lines in 56 Galactic bulge AGB stars selected from the DENIS-ISOGAL catalogue. In particular 7 of the 8 observed long period variables were detected and 9 of the 15 DENIS candidate variables. The line width ranges between 2 and 7 km sec^{-1} as is expected for SiO maser lines in AGB stars. Also, radial velocities of sources spread from -273 to 248 km/s, which is typical for stars in the Bulge. The detection rate is 65% and it tends to increase with the 7 and 15 μm flux.

The average ratios between the 86 GHz SiO peak intensity flux and the extinction corrected ISOCAM fluxes are: $I_{15}/I_{SiO} \sim 3.62$ ($\sigma = 2.04$); I_7/I_{SiO} ~ 3.88 ($\sigma = 2.34$). These results confirm the expected correlation between the mid-infrared flux of the star and the maser intensity. Furthermore, the small dispersion indicates that, according to Nyman et al. (1986), we have selected a sample of stars homogeneous in mass-loss rate. Previously, this correlation is not accurately determined; improving it is a further step toward understanding the maser pump mechanism. Our results are consistent with the ~ 5.3 ($\sigma = 4.4$) obtained by averaging the 12 μm IRAS flux and the 86 GHz SiO peak intensity from Mira stars (Haikala et al. 1994). But then, some of our non-detections (3 sources, or 5% overall) can be explained by a SiO flux below our detection limit ($3\sigma = \sim 0.3$ Jy). Taking this 5% into account, the resulting 30% non-detections may be partly due to the probable variable nature of the sources, and thus variable SiO line emission, and partly due to sources without SiO masers; the ratio between these two still remains to be determined.

Summarizing, first results confirm that the 86 GHz SiO maser is a powerful tool to derive radial velocities of Mira-like stars. The new detections will be combined with data from previous OH and SiO maser surveys for a quantitative analysis of stellar kinematics in the inner Galaxy.

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