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Isotopic SiO Maser Emission from the BAaDE Survey

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Abstract. The Bulge Asymmetries and Dynamical Evolution (BAaDE) project aims to map the positions and velocities of up to ~20,000 late-type stars with SiO maser emission along the full Galactic plane, with a large concentration in the Galactic Bulge and inner Galaxy. Both $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ transitions using the Very Large Array (VLA) and the Atacama Large Millimeter Array (ALMA) are being observed.

In the VLA observing setup, in addition to the ^{28}SiO, $v = 1$ and $v = 2 J = 1 \rightarrow 0$ maser transitions, the bandwidth was wide enough to include the $J = 1 \rightarrow 0$ transitions of the rare isotopologues of the SiO molecule in both the ground and vibrationally excited states: ^{29}SiO, $v = 0$, ^{30}SiO, $v = 0$, ^{29}SiO, $v = 1$, and ^{29}SiO, $v = 2$. Approximately 10% of the initial ~3500 targets of the project show maser emission from at least one of these lines. Some of these stars (with isotopic maser emission) show high radial velocities which implies that they are indeed in the Galactic Bulge or inner Galaxy (i.e. not foreground objects).

We present line profiles, refined detection statistics, and the implications of the detection of the isotopic maser emission on pumping schemes that have been previously presented.

Keywords. masers, stars: AGB and post-AGB, survey

1. Introduction

The Bulge Asymmetries and Dynamical Evolution (BAaDE) project aims to survey up to ~34,000 SiO maser stars along the Galactic Plane, concentrating in the Bulge and Inner Galaxy. The primary purpose is to study the dynamics and kinematics of the Galactic Bulge and Bar. The stars are color-selected from the MSX survey on their 8 - 15 μm color. Previous studies have shown that given a specific color selection, a detection rate of SiO masers greater than 50% is achieved. BAaDE was begun in 2013 on the VLA, using the **D** and **C** configurations, with a spectral setup shown in Fig. 1 and with 250 kHz resolution (~1.7 km s^{-1}). The central velocities of detected masers can thus be estimated to ~0.1 km s^{-1}. The VLA part of the BAaDE survey was completed earlier this year. The detection rate for SiO masers is ~70%.

The VLA observing setup was arranged for observing not only the ^{28}SiO masers at 7mm (four vibrational states), but also the ^{29}SiO $v = 0$ (42.88 GHz), ^{29}SiO $v = 1$ (42.58 GHz) and the ^{30}SiO $v = 0$ (42.37 GHz) in the lowest rotational transition.

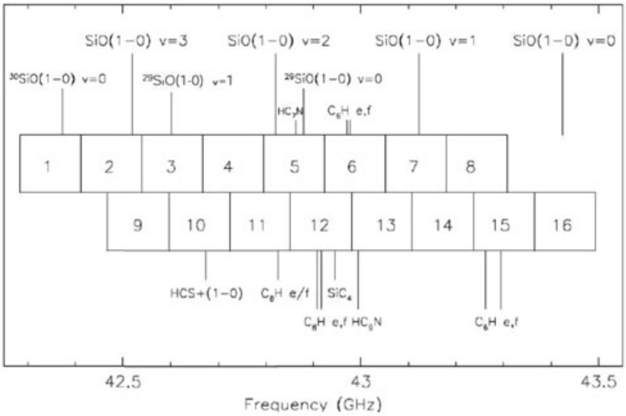

Figure 1. The spectral setup at the VLA for the BAaDE survey.

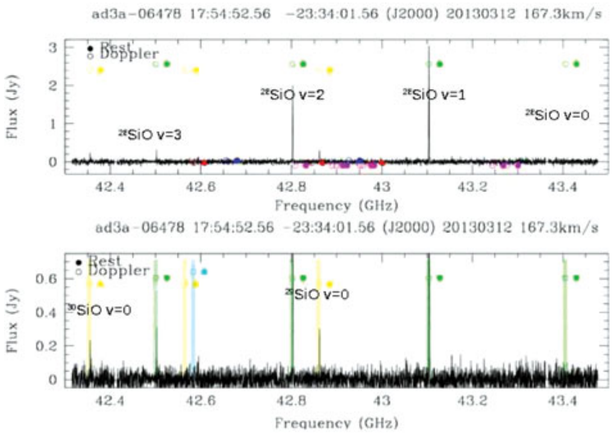

Figure 2. A spectrum of all the emission lines detected toward a target with LSR velocity +167.3 km s^{-1}.

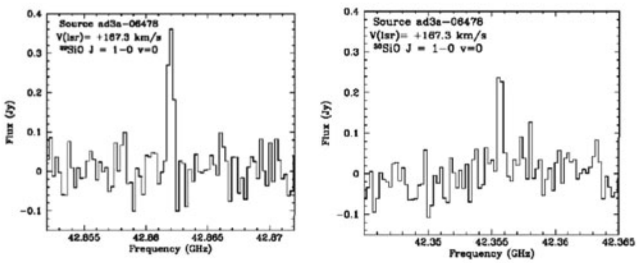

Figure 3. “Zoom-in” spectra of the isotopic SiO emission from the target with LSR velocity +167.3 km s^{-1}.

2. Background

Since the early 1990’s it has been clear that there have been problems with the pumping schemes for isotopic maser species (e.g. Cernicharo, Bujarrabal, & Lucas 1991). Olofsson *et al.*, as far back as 1981, introduced the hypothesis of line-overlap pumping, and several papers in the 1990’s investigated the importance of line overlaps (e.g. Gonzalez-Alfonso & Cernicharo 1997 developed a non-local radiative transfer code). Herpin & Baudry 2000

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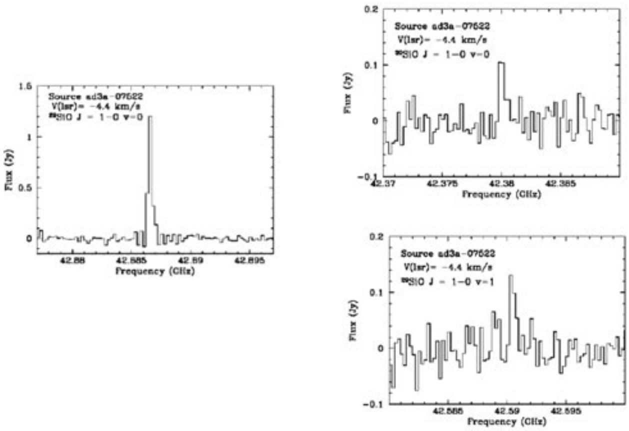

Figure 4. "Zoom-in" spectra of the isotopic SiO emission from a different target, with LSR velocity -4.4 km s^{-1}.

used LVG code and 40 rotational levels for each of $v = 0$ to 4 vibrational states and each of the isotopic species and found that they could explain a lot of the observed line intensities and made new predictions. For ^{29}SiO, they found that infrared line overlaps could explain the observations.

In the mid-to-late 2000s, VLBI observations of isotopic lines (Soria-Ruiz *et al.* 2005, 2007) found that the VLBI maps of the ^{29}SiO $v = 0, J = 1 \rightarrow 0$ lines in evolved stars were similar in nature to ^{28}SiO maps, i.e. they showed tangential amplification. These investigators suggested that a larger sample of VLBI maps of the isotopic masers will help to understand the line-overlap pumping of the SiO masers.

3. Example Spectra

Fig. 2 and Fig. 3 show some example spectra; Fig. 2 shows a spectrum with all lines detected for a target with an LSR velocity of $+167.3$ km s^{-1}. Fig. 3 shows the ^{29}SiO $J = 1 \rightarrow 0, v = 0$ and the ^{30}SiO $J = 1 \rightarrow 0, v = 0$ emission in "zoom-in" spectra (i.e. with the full resolution of the survey). Fig. 4 shows similar "zoom-in" spectra, with ^{29}SiO, ^{30}SiO, $v = 0$, and ^{29}SiO, $v = 1$ emission (for a different target, at -4.4 km s^{-1} LSR velocity).

4. Statistics and Summary

Of ~3600 targets in the 2013 VLA observations, ~360 or 10% show isotopic maser emission. This 10% reflects the ^{29}SiO $v = 0$ transition (i.e. detected in ~360 objects. The ^{30}SiO $v = 0$ transition is detected in ~4% of the targets (~ 150 objects), and the ^{29}SiO $v = 1$ transition is detected in ~0.8% of the targets (~30 objects). If these statistics hold over the entire VLA-BAaDE sample (~20,000 targets) then we would have:

- ~2000 objects detected in ^{29}SiO $v = 0$
- ~800 objects detected in ^{30}SiO $v = 0$
- ~150 objects detected in ^{29}SiO $v = 1$

Some fraction of these objects will be observable with VLBI techniques.

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The BAaDE survey is already very successful. Lorant Sjouwerman has a detailed paper on the survey in this volume. Luis Henry Quiroga Nunez (JIVE) presented a poster (Poster 43, and thus a poster paper in this volume) on BAaDE and GAIA comparisons (poster 43) and Michael Stroh (UNM) presented a poster (Poster 45, and thus a poster paper in this volume) on a comparison of 43 GHz (BAaDE-VLA) and 86 GHz masers ($J = 2 \rightarrow 1$) (BAaDE-ALMA).

We have examined the silicon isotopic SiO masers from the first (2013) part of BAaDE at 7 mm wavelength – ^{29}SiO $v = 0$, ^{29}SiO $v = 1$, and ^{30}SiO $v = 0$ in the ground rotational state. By number, the detection rates for these isotopic masers is $\sim$10%, with the ^{29}SiO $v = 0$ maser being the most prevalent, and generally the strongest, of these three isotopic species. With this sample, either BAaDE data or follow-up VLA and VLBI observations, will provide a large number of evolved SiO maser stars to study the pumping of SiO masers, including the effects of line overlaps.

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