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BAaDE: The Bulge Asymmetries and Dynamical Evolution survey

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Abstract. The Bulge Asymmetries and Dynamical Evolution (BAaDE) survey aims to use circumstellar SiO maser line-of-sight velocities as probes for the Galactic gravitational potential and dynamical structure. The SiO masers are detected at a high rate in specific color-selected MSX infrared sources. Furthermore, the SiO maser properties and line ratios, in combination with infrared spectral energy distributions and location in the Galaxy, will statistically yield detailed information on population and evolution of low- to intermediate-mass evolved stars in the Galaxy.

Keywords. masers, surveys, stars: AGB and post-AGB, Galaxy: bulge, Galaxy: evolution, Galaxy: kinematics and dynamics, infrared: stars

1. Summary

The Bulge Asymmetries and Dynamical Evolution (BAaDE) survey builds upon highly successful surveys and studies of OH/IR stars in the past (e.g. Habing 1996).

In the class of Asymptotic Giant Branch (AGB) stars, the OH/IR stars differ from the optically identified Mira stars by their denser circumstellar envelope (CSE), causing the stellar optical light to be obscured and re-radiated in the infrared. Miras and OH/IR stars therefore are bright(est) in the infrared waveband, where they are relatively easy to identify. In general, the OH/IR stars are the more massive and more luminous among the oxygen-rich AGB stars (but not as massive or luminous as supergiants), allowing for a higher mass-loss rate (up to about $10^{-4}\mathcal{M}_\odot$/yr, instead of about $10^{-6}\mathcal{M}_\odot$/yr for Miras) and a thicker, more opaque CSE†.

In the obscuring, expanding and cooling CSE, molecules start to form. Rotational and vibrational transitions may be excited by the stellar and re-radiated CSE radiation upon which population inversion may occur. Typical molecular *maser* lines may be detected in the 1612 MHz OH, 22 GHz H_2O, and 43 or 86 GHz SiO transitions originating in the outer (~1000 AU from the central star), intermediate, and inner (few AU) regions of the CSE, respectively. As the masers are bright and not affected by interstellar extinction, they can be detected over the entire extent of the Galaxy while directly revealing their line-of-sight velocity. These point-mass like probes are thus excellent probes of the local Galactic gravitational field.

† Foreground extinction adds to the intrinsic stellar obscuration and may cause a genuine Mira star to appear as an OH/IR star, in particular in the optically obscured Plane and Bulge.

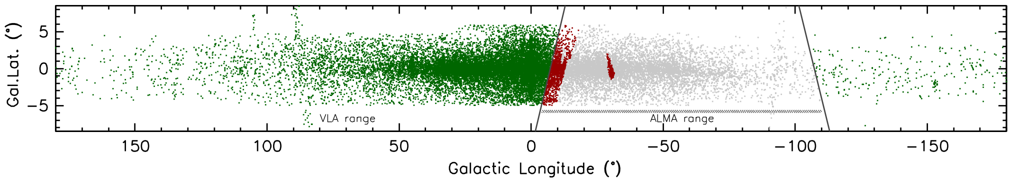

Figure 1. MSX color-selected sources in Galactic longitude and latitude. The northern Galactic Bulge and Plane (north of Declination −35 degrees) have all been observed with the VLA for J=1-0 SiO masers at 43 GHz (green; dark on the left). The (southern hemisphere, $\delta < -35°$) range between about −5 and −105 degrees longitude is observable with the ALMA for J=2-1 SiO masers at 86 GHz (gray; in the middle: planned, and red; darkest: observed).

The 1612 MHz line of the OH maser has been extensively used in Galactic dynamics studies (see, e.g., Habing *et al.* 2006 and references therein). However, the total sample of OH/IR stars has been stagnating at a few thousand; insufficient for a detailed analysis of Galactic dynamics in the highly (optically) obscured regions of the Bulge and Plane, where the dynamics are most revealing.

We have therefore embarked on a survey for the far more numerous SiO masers in Mira stars. Using color-selected infrared stars that predict a high (50-90%) detection rate (Sjouwerman *et al.* 2009), a sample of 28 000 Galactic Plane and Bulge objects is being observed with ALMA and the VLA (see Figure 1). The BAaDE survey itself is described in more detail in Sjouwerman *et al.* (2018) and Sjouwerman *et al.* (in prep.), with the individual VLA and ALMA surveys described in detail by Lewis *et al.* (in prep.) and Stroh *et al.* (2019), respectively.

Early stellar kinematic results have been published by Trapp *et al.* (2018), and other sideways connected checks and biases have been resolved in Pihlström *et al.* (2018) (positional information) and Stroh *et al.* (2018) (86 versus 43 GHz SiO, ALMA versus VLA bias). See also the contributions of Stroh *et al.* and Lewis *et al.* in these proceedings.

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References

Habing, H. J. 1996, *A&AR*, 7, 97
Habing, H. J., Sevenster, M. N., Messineo, M., van de Ven, G., & Kuijken, K. 2006, *A&A* 458, 151
Lewis, M. O., *et al.*, *in preparation*
Pihlström, Y. M., Sjouwerman, L. O., Claussen, M. J, Morris, M. R., Rich, R. M., van Langevelde, H. J., & Quiroga-Nuñez, L. H. 2018, *ApJ* 868, 72
Sjouwerman, L. O., Capen, C., & Claussen, M. J. 2009, *ApJ* 705, 1554
Sjouwerman, L. O., Pihlström, Y. M., Rich, R. M., Claussen, M. J., & Morris, M. R. 2018, *IAU Symposium* 336, 180
Sjouwerman, L. O., *et al.*, *in preparation*
Stroh, M. C., Pihlström, Y. M., Sjouwerman, L. O., Claussen, M. J., Morris, M. R., & Rich, R. M. 2018, *ApJ* 862, 153
Stroh, M. C., Pihlström, Y. M., Sjouwerman, L. O., Lewis, M. O., Claussen, M. J., Morris, M. R., & Rich, R. M. 2019, *ApJ*, accepted
Trapp, A. C., Rich, R. M., Morris, M. R., Sjouwerman, L. O., Pihlström, Y. M., Claussen, M. J., & Stroh, M. C. 2018, *ApJ* 862, 153

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