# Onsala Proposal

# Olofsson 0115.F-9303

## OH/IR stars in the inner Galactic Bulge: constraining the mass-loss characteristics on the AGB

**Semester: feb2025** **Science Cat.: Late stages of stellar evolution**


### Abstract

Stellar mass loss on the AGB is well established, but not well quantified, e.g., its magnitude as a function of time, mass, etc.. This is problematic since the mass-loss evolution of AGB stars is an important input parameter, e.g., as a mass-loss-rate prescription in population synthesis and galactic chemical evolution models. Therefore, there is a strong need to empirically determine the mass-loss-rate evolution, especially on the upper AGB and the early post-AGB where most of the stellar mass is lost. We have a sample of 77 OH/IR stars at the distance of the inner Galactic Bulge, and have successfully detected essentially all of them in the 12CO(1-0,2-1,3-2) and 13CO(2-1,3-2) lines with ALMA. In order to constrain the circumstellar model to use we here request time to observe 7 of these objects in the 12CO(2-1,3-2,4-3) lines with APEX. This will provide total line flux densities as well as information on a line not observed with ALMA.



### Applicants

| Name | Affiliation | Email | Country | | Potential observer |
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Applicants are continued on the last page



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*Is this a long term proposal: No*

*No overall scheduling requirements*

## *Observing runs*

| run | telescope | instrument | time request (minimal) | frequency (GHz) | weather (pwv) | LST range | comments/constraints |
|---|---|---|---|---|---|---|---|
| A | APEX | SEPIA345 (277-371 GHz) | 23h (15h) | 345.79598 | 1-2 mm | 14-22 | Observe 12CO and 13CO 3-2 lines simultaneously |
| B | APEX | nFLASH460 (385-500 GHz) | 18h (12h) | 461.04076 | 0.5-1 mm | | Observe the 12CO 2-1 and 4-3 lines simultaneously |

## *Targets*

| Source | RA | Dec | Epoch | Vlsr (km/s) | Duration (min) | Runs | Comments |
|---|---|---|---|---|---|---|---|
| 359.23-1.87 | 17:51:12.20 | -30:33:40.0 | J2000 | -15.0 | 200 | A | |
| 359.48-2.94 | 17:56:04.40 | -30:52:57.0 | J2000 | 283.0 | 156 | B | |
| 001.23+1.27 | 17:43:37.40 | -27:13:08.9 | J2000 | 227.0 | 200 | A | |
| 359.03+1.93 | 17:35:46.60 | -28:43:44.9 | J2000 | -115.0 | 156 | B | |
| 359.14+1.13 | 17:39:07.70 | -29:04:02.9 | J2000 | -136.0 | 200 | A | |
| 357.81+1.99 | 17:32:33.90 | -29:43:13.6 | J2000 | -30.0 | 200 | A | |
| 359.14+1.13 | 17:39:07.70 | -29:04:02.9 | J2000 | -136.0 | 156 | B | |
| 001.23+1.27 | 17:43:37.40 | -27:13:08.9 | J2000 | 227.0 | 156 | B | |
| 000.81-1.95 | 17:55:13.30 | -29:14:40.3 | J2000 | -174.0 | 200 | A | |
| 359.03+1.93 | 17:35:46.60 | -28:43:44.9 | J2000 | -115.0 | 200 | A | |
| 357.81+1.99 | 17:32:33.90 | -29:43:13.6 | J2000 | -30.0 | 156 | B | |
| 359.48-2.94 | 17:56:04.40 | -30:52:57.0 | J2000 | 283.0 | 200 | A | |
| 000.81-1.95 | 17:55:13.30 | -29:14:40.3 | J2000 | -174.0 | 156 | B | |
| 359.23-1.87 | 17:51:12.20 | -30:33:40.0 | J2000 | -15.0 | 156 | B | |

# Mass loss on the AGB, inner Galactic Bulge OH/IR stars

There is strong evidence that as low- to intermediate-mass stars evolve up the asymptotic giant branch (AGB) a pulsation-driven mass loss, augmented by radiation pressure on dust, is initiated [1]. It is further believed that the mass-loss rate (MLR) increases as the object evolves, and that it is higher the more massive the star is. Apart from the fact that the more massive the star is the more mass is lost (e.g., the initial mass - final mass relation of [2]), and some progress on understanding the mass-loss dependence on stellar characteristics [3], there is very little evidence that supports these beliefs. In addition, it has been proposed, but not yet convincingly shown, that the MLR characteristics on the AGB are frequently affected by the presence of a nearby companion [4].

The MLR evolution of AGB stars is an important input parameter in population synthesis and galactic chemical evolution models. In such models, the MLRs of AGB stars follow prescriptions based on the expectations listed above. Different MLR prescriptions imply longer or shorter lifetimes on the AGB, affecting AGB gas and dust yields [5], the relation between AGB stars and planetary nebulae (PNe) [6], and even the expected infrared luminosity of a galaxy [7]. It is therefore of great importance to empirically determine the MLR evolution for a well-selected sample of AGB stars to improve the prescriptions so broadly employed. Of particular interest is the upper AGB where most of the stellar mass is expected to be lost. Some studies have been carried out for samples of equidistant AGB stars in the Magellanic Clouds [3], but MLRs can only be inferred from dust emission at those distances, and they are significantly more uncertain than those derived based on circumstellar CO lines [8].

It has recently been shown that a sample of equidistant AGB stars, detectable in circumstellar CO lines with ALMA, can be obtained through selecting OH/IR stars located in the inner Galactic Bulge (GB), i.e., within a few degrees of the Galactic Centre (GC) [9]. O-type (oxygen atoms more common than carbon atoms) AGB stars are believed to become OH/IR stars, if their MLR becomes high enough, characterized by strong OH 1612 MHz maser emission, and easily identified through the double-peaked line profile [10]. They reach MLRs in excess of $10^{-5}\,M_{\odot}\,\mathrm{yr}^{-1}$. These objects are expected to be located close to the tip of the AGB, and have thick circumstellar envelopes (CSEs). Some may even have stopped losing mass and evolved off the AGB within the last (few) thousand years. A study of such a sample provides an opportunity to reshape our knowledge of the mass-loss evolution on the AGB, constraining the phase of strongest mass loss, and the sharp decline in MLR expected to take place at the end of the AGB. This will provide a much-needed and unprecedented empirical picture of the evolution of AGB gaseous mass loss at its most extreme phases.

## The sample

A sample of 77 OH/IR stars (within 3° of the GC, except the central 0.3° where extinction is high) was selected from the catalogue of [11] based on four criteria: the sources are i) *equidistant*, ii) *relatively complete above a given MLR*, iii) *narrow range in mass* (minimizes effects on MLR due to stellar initial mass), and iv) *cover the MLR evolution also on the early post-AGB*. This provides a unique sample of enough sources to study in unprecedented detail the evolution of the circumstellar characteristics during the high-MLR phase on the AGB and (slightly) beyond.

ALMA observations in five lines, $^{12}$CO(1-0, 2-1, 3-2) and $^{13}$CO(2-1, 3-2), were highly successful, 74 of 77 objects detected in at least one line, and the far majority detected in all five lines. We have also performed APEX observations of the $^{12}$CO( 2-1, 3-2, 4-3) lines in 8 sources, providing, among other things, the important single-dish total line flux densities.

The ALMA data have been complemented with spectral energy distributions (SEDs) and light curve photometry for all objects. Radiative transfer analysis of the dust and CO line emission has been performed along the lines presented in [9]. The conclusion is that the 74 detected objects can be grouped into three classes:

i) 47 objects show AGB-like characteristics in their CO line emission (Fig. 1), their SEDs are well fitted assuming standard spherical dust envelopes with inner radii of a few stellar radii, and the majority of them are large-amplitude pulsators. *These objects are most likely on the upper AGB.*

ii) 8 objects show AGB-like characteristics in their CO line emission, but their SEDs are only well fitted if their dust envelopes have large inner radii (several hundred stellar radii), and none of them are variable. *These objects have most likely very recently left the AGB, embarking on the post-AGB evolution.*

iii) 19 objects show extended CO line brightness distributions with complex structures (Fig. 1), their SEDs are only well fitted if their dust envelopes have large inner radii (several hundred stellar radii), and none of them are variable. *These objects are most likely well into their post-AGB evolution.*

## The analysis

Our interest for the moment is focussed on classes i) and ii), and specifically to determine the best circumstellar model [basically determine which radial law to adopt for the kinetic temperature, $T_{\rm k}(r)$] to use for the CO line modelling, since this will determine the accuracy of the estimates of our primary goals, determinations of mass-loss rates and stellar $^{12}$C/$^{13}$C ratios. However, the observed lines are often affected by interstellar CO line emission and sometimes by CO line emission from circumstellar/interstellar media interaction. The latter is a phenomenon not previously seen in CO line emission. It is most likely due to these objects moving with high velocities through an interstellar medium denser than that in the solar neighbourhood. An excellent way to tackle these problems is to observe, with APEX, the objects brightest in the CO lines and without any contamination from interstellar or circumstellar/interstellar CO line emission. This will provide the *total* CO line fluxes, and a line not observed by ALMA, the 4–3 line. Based on this we ask for APEX time to observe 7 objects in the $^{12}$CO( 2–1, 3–2, 4–3) lines to constrain the circumstellar model.

## Observing request

An estimate of the required observing time in the $^{12}$CO(3–2 and 4–3) lines is obtained from the ALMA $^{12}$CO(3–2) data and the existing APEX data (the 2-1 line is observed simultaneously with the 4-3 line and its S/N ratio will be higher than that of the 4-3 line). The observed $^{12}$CO(3–2) ALMA lines lie in the flux density range 0.6–1.0 Jy (at 3" resolution). The APEX $^{12}$CO(3–2 and 4–3) lines are both expected to be stronger than this, by about 45 % as shown by the existing APEX data. Consequently, we base our time estimate on a line flux density of 0.9 (0.6 x 1.45) Jy for the 3–2 and 4–3 lines. This corresponds to antenna temperatures of about 26 and 19 mK, respectively. We aim for 10$\sigma$ detections in the 3–2 line and 5$\sigma$ detections in the 4–3 line. We have used the ON-OFF observing time calculator at APEX V7.3 to estimate the total time needed to achieve our goal. Using SEPIA345 and nFLASH460 tuned to 345 and 461 GHz in the LSBs, respectively, a spectral resolution of 5.0 km s$^{-1}$, assuming a typical source elevation of 45°, and a typical PWV of 1 and 0.5 mm (at 345 and 461 GHz, respectively), we get down to a noise of 2.6 and 3.8 mK [$T_{\rm A}^*$] in 3.3 and 2.6 hours, respectively (including telescope and calibration overheads). In total, we request 41 hours in the LST range 14 – 22. Two of these objects have already been observed with APEX in the 2–1, 3–2, and 4–3 lines, but the S/N ratios are limited (especially for the 4–3 line) and re-observing them will also give a measure of the repeatability of the APEX calibration.

## References

[1] Höfner S., Olofsson H., 2018, A&ARv 26, 1 • [2] Cummings J.D., et al., 2016, ApJ 818, 84 • [3] Prager H.A., et al., 2022, ApJ 941, 44 • [4] Decin L., et al., 2020, Science 369, 1497 • [5] Schneider R., et al., 2014, MNRAS 442, 1440 • [6] Jones D., Boffin, H.M.J., 2017, Nat. Astron., 1, 0117 • [7] Villaume A., et al., 2015, ApJ 806, 82 • [8] De Beck E., et al., 2010, A&A 523, A18 • [9] Olofsson H., et al., 2022, A&A 665, A82 • [10] Habing H.J., 1996, A&ARv 7, 97 • [11] Sevenster M., et al., 1997, A&AS 122, 79

Table 1: Sample sources

| Source | $\alpha$(J2000) [h:m:s] | $\delta$(J2000) [°:':"] | $v_{sys}$ [$\mathrm{km\,s^{-1}}$] |
|---|---|---|---|
| OH357.819+1.990 | 17:32:33.87 | –29:43:13.6 | –30 |
| OH359.033+1.938 | 17:35:46.59 | –28:43:44.9 | –115 |
| OH359.140+1.137 | 17:39:07.69 | –29:04:02.9 | –136 |
| OH359.233−1.876 | 17:51:12.15 | –30:33:40.0 | –15 |
| OH359.486−2.942 | 17:56:04.40 | –30:52:57.0 | 283 |
| OH000.810−1.959 | 17:55:13.27 | –29:14:40.3 | –174 |
| OH001.234+1.273 | 17:43:37.35 | –27:13:08.9 | 227 |

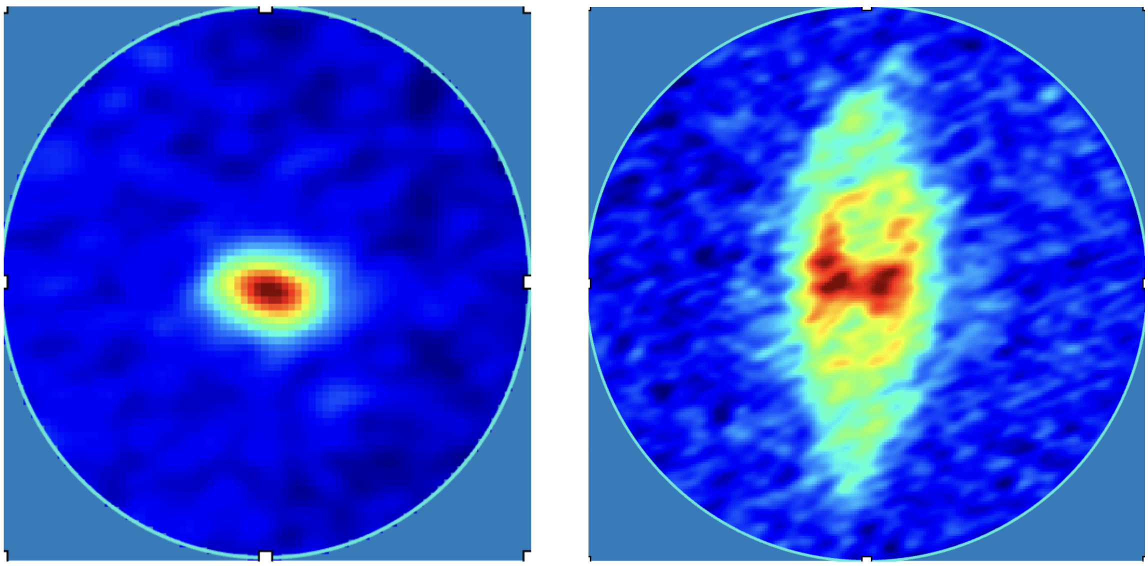

Figure 1: $^{12}$CO(3-2 brightness distributions, in the form of moment 0 images, obtained with ALMA. **Left:** A typical example of an object with AGB-like circumstellar characteristics, OH357.749+0.320. **Right:** An object with a complex circumstellar CO brightness distribution, OH359.750+2.629, most likely a post-AGB object.

*No PhD Students involved*

*Linked proposal submitted to this TAC: No*

*Linked proposal submitted to other TACs: No*

*Relevant previous Allocations: Yes*

O111-9304, ? hours

O113-9300, ? hours

These data will be part of a major publication on the ALMA data related to these observations.

*No additional remarks*

*Observing run info :*

*Applicants*

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