At the crossroads of astrophysics and cosmology: Period–luminosity relations in the 2020s
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OH/IR stars and the Period-Luminosity Relation of Mira variables

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Abstract. The OH/IR stars evolving on the Asymptotic Giant Branch are large-amplitude variable stars with periods in the range of ∼400 to 2500 days, significantly longer than those of the related Mira variables. We use preliminary results from a monitoring program of the 1612-MHz OH maser variations of a sample of >70 OH/IR stars to study a possible extension of Mira Period-Luminosity Relations to longer periods. The period distribution of the sample is split around $P\sim1100$ days. Using WISE $W3$ absolute magnitudes as proxies for the luminosity and the best available distances, we found no convincing relation between periods and absolute magnitudes. A cause could be rapid evolution of the 'extreme OH/IR stars' (the group with $P>1100$ days) close to the tip of the AGB, where no increase of luminosity is expected on the short time-scales involved.

Keywords. masers, stars: AGB and post-AGB, circumstellar matter

1. Introduction

Stars evolving on the Asymptotic Giant Branch (AGB) can achieve mass-loss rates in the range $10^{-8}-10^{-4}$ $M_\odot\,\mathrm{yr}^{-1}$ (De Beck et al. 2010, and references therein), which lead to the formation of circumstellar envelopes composed of gas and dust. For the highest mass-loss rates, the dust becomes optically thick and the stars become obscured at visual light and, for the most extreme cases, also in the near-infrared (NIR: 1–5μm). Variable OH/IR stars with high mass-loss rates ($\geq10^{-6}$ $M_\odot\,\mathrm{yr}^{-1}$) are examples of such obscured stars in their final stage of AGB evolution. After most of their mass is lost during the AGB phase, the mass-loss rates drop on short timescales of a few thousand years from late AGB values of $10^{-5}-10^{-4}$ to post-AGB values of $10^{-8}-10^{-7}$ $M_\odot\,\mathrm{yr}^{-1}$ (Miller Bertolami 2016).

In general, evolved AGB stars are observed as large-amplitude variables with periods >1 year, while post-AGB stars have lost the large-amplitude pulsations, and are almost non-variable. The obscured OH/IR stars are in part large-amplitude periodic variables (hereafter L-AGB stars) with periods $\sim400-\sim2500$ days (fundamental mode pulsators) and in part small-amplitude irregular or almost non-variable stars (hereafter S-pAGB stars). The L-AGB stars can be considered as related to Mira variables. The designation

'OH/IR stars' stems from the way they were discovered (Wilson & Barrett 1970). Because of their optical obscuration, they were found only in the 1970s by searches among bright infrared sources or in blind OH maser surveys with counterparts identified subsequently in the near infrared. In the following, the latter objetcs were confirmed as long-period variable stars at infrared and radio wavelengths (Engels et al. 1983; Herman & Habing 1985).

The extension of the Period-Luminosity Relation (PLR) for Mira variables to the significantly longer periods of the OH/IR stars has been discussed since the first long OH/IR star periods (up to >5 year), were determined. An extended PLR would have been a comfortable tool to determine distances to OH/IR stars. Such a PLR was presented by Engels et al. (1983), but the relation was considered as tentative. As most of the energy is emitted in the mid-IR ($\lambda > 5\mu$m), and no mid-IR observations were available, the bolometric flux determination was rather uncertain. Also the kinematic distances used to determine the OH/IR star luminosities have caveats, because the movement of the OH/IR stars has peculiar velocity components on top of their participation to the Galactic rotation. Jones et al. (1983) argued for a different explanation for the long periods observed. The OH/IR stars in their view would have been former Mira variables, which had undergone a switch in pulsation mode from first overtone to fundamental mode without changing their luminosity.

Because of the large time and efforts to obtain periods for larger samples of OH/IR stars via NIR and radio monitoring programs, progress has been slow. Also the dearth of OH/IR stars in the Large Magellanic Cloud (LMC) (Goldman et al. 2017), where most of the PLR studies for Mira variables were focused on (see Iwanek et al. 2021) and references therein), inhibited progress.

To remedy this, we conducted an NIR monitoring program of the 'Arecibo sample of OH/IR stars' (Jimenéz-Esteban et al. 2021) and are conducting an ongoing monitoring program of the 1612-MHz OH maser emission of the 'Bright OH/IR star sample'†. Also, improved distances were determined for a couple of stars (Engels et al. 2015), using the phase-lag method (Etoka & Engels 2022). We will use the results of these observational programs to re-address the relation between periods and luminosties of OH/IR stars and to compare them with the most recent Mira PLR relations.

2. Variability properties of the 'Bright OH/IR star sample'

The 'Bright OH/IR star sample' comprises 115 stars, originally compiled by Baud et al. (1981) and updated by Engels & Jiménez-Esteban (2007). Almost all of them are located along the Galactic plane at $10 < l < 150°$, and $|b| < 4°$. It is quite complete for bright 1612-MHz OH masers ($F_\nu > 4$ Jy). The monitoring program started in 2008 is mainly made at the Nançay Radio Telescope (NRT) with a cadence of two months. After two years an initial classification (L-AGB, S-pAGB candidates) is made. L-AGB candidates are continued to be monitored until their period and amplitude are determined, while the cadence of observations of the S-pAGB candidates is decreased to 1–2 times a year. Since 2017 the program has been complemented with observations by the Stockert Radio Telescope to follow selected L-AGB stars over several variability cycles.

As of end of 2022, 80 OH/IR stars are classified as L-AGB variables (70%), while 30 (26%) are S-pAGB stars showing only irregular brightness variations. The remaining five objects are the red supergiant NML Cyg or are not classified so far. Two examples are shown in Figure 1. The brighter masers of the sample have been monitored before by Herman & Habing (1985), who reported several sub-groups with different amplitudes and

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† see https://www.hs.uni-hamburg.de/nrt-monitoring

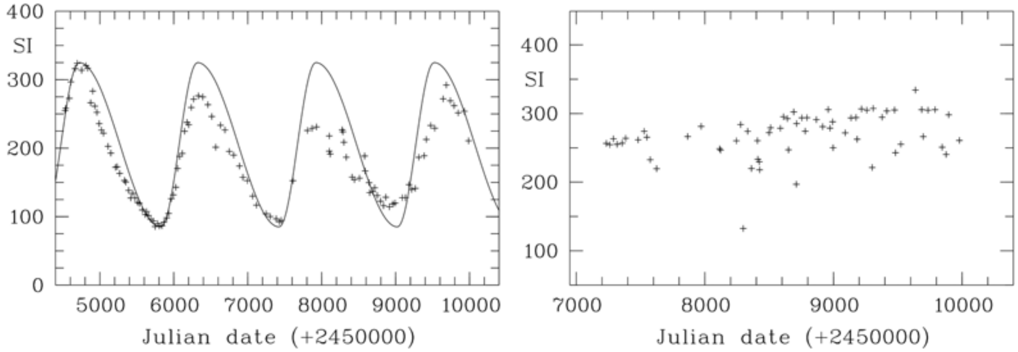

Figure 1. Examples of 1612-MHz OH maser light curves from the 'Bright OH/IR star sample'. Maser brightness SI is the integrated flux density given in units Jy km s^{-1}. *Left:* OH 32.8–0.3, a L-AGB star with a period of ≈4.4 years, observed between 2008 and 2022. *Right:* OH 31.0–0.2, a S-pAGB star, observed 2015–2022. The scatter of the integrated flux is caused by a mix of real fluctuations and calibration uncertainties.

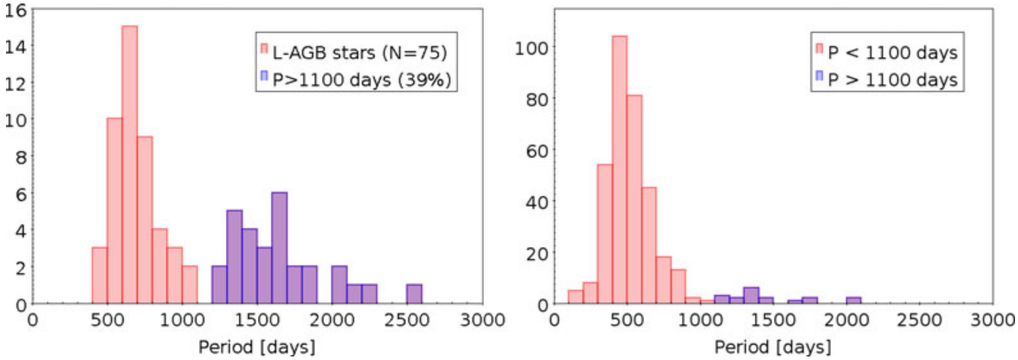

Figure 2. Period distributions. *Left:* 'Bright OH/IR star sample'. Periods are available for 75 OH/IR stars out of the 80 objects classified as L-AGB stars. 29 (39%) objects are 'extreme OH/IR stars' with P > 1100 days. *Right:* 349 OH/IR stars of the 'Arecibo sample of OH/IR stars', 18 with P > 1100 days.

periodicity also among S-pAGB stars. We found no periodicity in any of the S-pAGB stars.

Figure 2 shows the period distribution of the 'Bright OH/IR star sample' in comparison to the 'Arecibo sample'. In both samples two groups separated by period are discernible with the major group having periods $P \leq 1100$ days and a peak in the distribution between 500 and 700 days. The 'Bright OH/IR star sample' shows a prominent separate group of stars with $P > 1100$ days, which we call 'extreme OH/IR stars' hereafter. As the 'Arecibo sample' covers only a small part of the Galactic plane, it contains only few of the 'extreme OH/IR stars'. Of them, 9 (50%) are also in the 'Bright OH/IR star sample'. The confinement of the 'extreme OH/IR stars' to low latitudes suggests that their progenitors were relatively high main-sequence mass stars ($3 - 8\,M_{\odot}$).

3. OH/IR stars and WISE mid-IR Period-Luminosity Relations for Mira variables

Since several photometric surveys have been carried out in the mid-IR wavelength range (e.g. IRAS, MSX, AKARI, and WISE), the spectral energy distributions of OH/IR stars are now much better covered with observations, allowing us to determine more accurate bolometric fluxes than before. The other ingredient for the determination of luminosities is the distances to the OH/IR stars. Mostly kinematic distances are used, which can be obtained from the stellar radial velocities given by the center of the OH maser velocity range, and assuming that the stars follow closely the Milky Way's rotation curve. The latter assumption is probably not generally valid, as there are a fraction of OH/IR stars which have radial velocities incompatible with Galactic rotation. Also for a given radial velocity, in general two (the near- and far-kinematic) distances are possible making the distance determination ambiguous.

More precise distances can be obtained from the phase-lag technique (Etoka & Engels 2022), from radio parallax mesurements (Nakagawa et al. 2016), and also from GAIA (Bailer-Jones et al. 2021) for less obscured stars. Based on phase-lag distances of Van Langevelde et al. (1990) and average kinematic distances, Whitelock et al. (1991) found that OH/IR stars follow the same PLR as Miras in the LMC, albeit with substantial scatter. New phase-lag distances have been determined by Wolak et al. (2013) and Engels et al. (2015) and a few radio parallax distances have been published in recent years (Orosz et al. 2017; Nakagawa 2023), but the number of reliable distance determinations for OH/IR stars is still relatively small.

To determine luminosities for the 'Bright OH/IR star sample', we use preferentially the most recent phase-lag, radio parallax and GAIA distances. For the rest of the sample, we determined kinematic distances using the Bessel distance calculator V2† (Reid et al. 2019) and removed all OH/IR stars without a near-kinematic distance between 1 and 8 kpc. This left all in all 49 OH/IR stars with plausible distances.

To compare the location of the OH/IR stars in a period-luminosity diagram with Mira variables, we used the recently published PLRs for the LMC by Iwanek et al. (2021) and for Galactic Miras by Nakagawa (2023). Both use the absolute magnitude in the WISE $W3$ filter ($\lambda = 11.6\mu$m) as proxy for the luminosity, which is better suited for OH/IR stars, as the commonly used K filter ($\lambda = 2.2\mu$m) is more strongly affected by circumstellar extinction and brightness variations than the wavelength bands in the mid-IR. In Figure 3 we show the location of the OH/IR stars in the period-luminosity diagram together with the proposed WISE $W3$ PLRs. In the left panel only the OH/IR stars with phase-lag, radio astrometric and GAIA distances available are plotted, while in the right panel the remaining OH/IR stars with plausible near-kinematic distances are also included.

Taking into consideration only the OH/IR stars with distances based on (GAIA or radio) parallaxes or phase-lag determinations, we find that the extrapolation of the PLR of Iwanek et al. (2021) to periods > 1100 days predicts luminosities higher than observed, while the positions of the OH/IR stars are reasonably consistent with the Nakagawa PLR in this regime. However, if the OH/IR stars with (plausible) kinematic distances are also included, the consistency is lost. The distribution of luminosities is then consistent with an absence of relation between periods and luminosities.

4. Discussion

The absence of a significant PLR for the OH/IR stars in the period range $600 < P < 2500$ days in Figure 3 may be due to uncertainties of the distances used. However, the lack of relation could also be real. The most recent non-linear pulsation models of Trabucchi et al. (2021) do not predict periods $\geq$1000 days for the entire AGB mass range during the evolution on the AGB, so that the periods of the 'extreme OH/IR stars' remain unexplained. These stars may be at the tip of AGB evolution close to the

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† http://bessel.vlbi-astrometry.org/

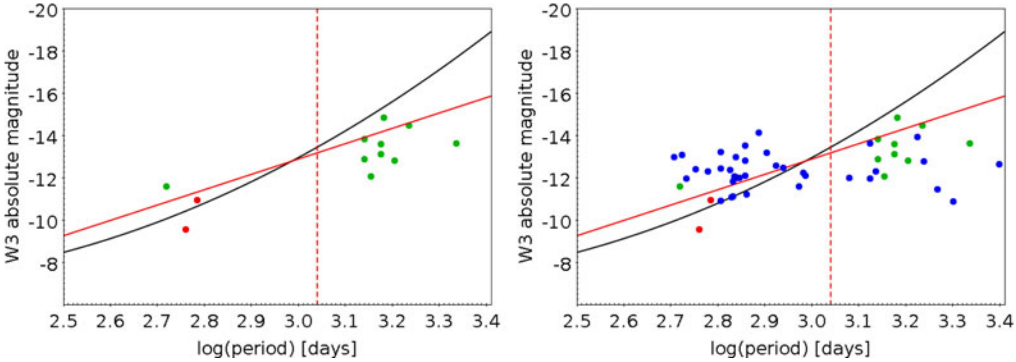

Figure 3. Positions of OH/IR stars from the 'Bright OH/IR star sample' in a period-luminosity diagram based on WISE $W3$ filter photometry and using distances obtained by different methods. Overplotted are the PLRs proposed by Iwanek et al. (2021) (black curve) and Nakagawa (2023) (red line). The vertical dotted line corresponds to a period P=1100 days. *Left:* Only OH/IR stars with distances based on GAIA parallaxes (red), or based on phase-lag determinations or radio parallaxes (green). *Right:* The same, but OH/IR stars added with kinematic distances (blue) between 1–8 kpc.

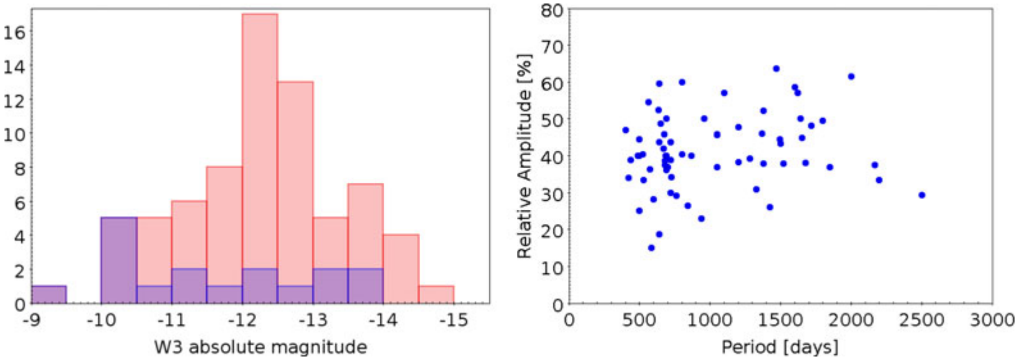

Figure 4. *Left:* WISE $W3$ absolute magnitude distribution of the 'Bright OH/IR star sample' with L-AGB stars shown in red and S-pAGB stars in blue. *Right:* Relative Amplitude (defined as 100 × amplitude / mean integrated flux density SI) of the integrated 1612-MHz OH maser flux density SI of the L-AGB stars in the 'Bright OH/IR star sample'.

transition into the post-AGB phase (Marini et al. 2023). The late AGB evolutionary phase and the early post-AGB phase likely lasts only a couple of thousand years, during which the luminosity does not change significantly. The $W3$ absolute magnitudes of the S-pAGB stars in the 'Bright OH/IR star sample' are similar to those of the L-AGB stars (Figure 4, left panel), corroborating the fact that the AGB maximum luminosity is reached before evolution in the post-AGB phase happens. The group of OH/IR stars with $P < 1100$ days may be ordinary Mira variables, as described by the above mentioned non-linear pulsation models, and may be still evolving on the AGB experiencing thermal pulse cycles increasing their periods and luminosities. On the other hand, the 'extreme OH/IR' stars may already be in their last thermal pulse cycle, with a relatively thin shell above the stellar core, and where the pulsation may appear with different periods and amplitudes for a short period of time (scale hundreds to thousand of years), before the pulsations die out. The star then evolves further as S-pAGB star and the OH masers fade away soon after the transition (Etoka et al. 2023). The cessation of the pulsation might be abrupt, as we have not detected any correlation between amplitudes and periods (Figure

4, right panel), which could be expected if the pulsation would cease slowly over a period of time.

If this scenario is right, then the ‘Bright OH/IR star sample’ may actually consist of three groups representing different evolutionary phases on the AGB and the early post-AGB phase. These are the Miras (L-AGB stars with $P < 1000$ days), the ‘extreme OH/IR stars’ stars with longer periods at the border between the AGB and the post-AGB phase, and the post-AGB OH/IR stars (S-pAGB). Maybe, only the first group is expected to follow PLRs derived from shorter-period Mira variables.

References

Bailer-Jones C. A. L., Rybizki J., Fouesneau M., Demleitner M., Andrae R., 2021, AJ, 161, 147

Baud B., Habing H. J., Matthews H. E., Winnberg A., 1981, A&A, 95, 156

De Beck E., Decin L., de Koter A. et al., 2010, A&A, 523, A18

Engels D., Kreysa E., Schultz G. V., Sherwood W. A., 1983, A&A, 124, 123

Engels D. & Jiménez-Esteban F., 2007, A&A, 475, 941

Engels D., Etoka S., Gérard E., Richards A., 2015, in Kerschbaum F., Wing R. F. & J. Hron J., eds., Why Galaxies Care about AGB Stars III: A Closer Look in Space and Time, ASP-CS, 497, 473

Etoka S. & Engels D., 2022, European VLBI Network Mini-Symposium and Users’ Meeting 2021, 12–14 July, 2021. Online at https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=399, id.12

Etoka S., Engels D., Ullrich T., González J. B., López-Martí B., 2023, in Hirota T., Imai H., Menten K. & Pihlstrom Y., eds., Cosmic Masers: Proper Motion toward the Next-Generation Large Projects, Proceedings of the IAU Symposium 380, in press

Goldman S. R., van Loon J. Th., Zijlstra A. A. et al., 2017, MNRAS, 465, 403

Herman J. & Habing H. J., 1985, A&AS, 59, 523

Iwanek P., Soszyński I., Kozłowski S., 2021, ApJ, 919, 99

Jiménez-Esteban F. M., Engels D., Aguado D. S., González J. B., García-Lario P., 2021, MNRAS, 506, 6051

Jones T. J., Hyland A. R., Wood P. R., Gatley I., 1983, ApJ, 273, 669

Marini E., Dell’Agli F., Kamath D. et al., 2023, A&A, 670, A97

Miller Bertolami M. M., 2016, A&A, 588, A25

Nakagawa A., Kurayama T., Matsui M. et al., 2016, PASJ, 68, 78

Nakagawa A., 2023, these proceedings

Orosz G., Imai H., Dodson R. et al., 2017, AJ, 153, 119

Reid M. J., Menten K. M., Brunthaler A. et al., 2019, ApJ, 885, 131

Trabucchi M., Wood P. R., Mowlavi N. et al., 2021, MNRAS, 500, 1575

van Langevelde H.J., van der Heiden R., van Schooneveld C., 1990, A&A, 239, 193

Whitelock P., Feast M., Catchpole R., 1991, MNRAS, 248, 276

Wilson W. J., Barrett A. H., 1970, A&A, 17, 385

Wolak P., Szymczak M., Gérard E., 2013, MNRAS, 430, 2499