The Nançay and Stockert stellar OH Maser monitoring program

A status report

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Summary

The variability properties of OH/IR stars obscured at optical and often also at near-infrared wavelengths can be studied by following their OH maser emission at 1612 MHz. With the Nançay radio telescope (NRT) we are conducting a monitoring program of more than hundred OH/IR stars to study the transition from large amplitude, long-period variability on the AGB to the small-amplitude, irregular variability in the early post-AGB phase. The program is complemented with observations by the Stockert radio telescope to follow selected OH/IR stars over several variability cycles. We find few candidates that can be identified unambiguously as transition objects. OH masers seem to fade away within a few hundred years after departure from the AGB.

Introduction

Stars evolving on the Asymptotic Giant Branch (AGB) can achieve mass-loss rates in the range $10^{-8}–10^{-4}$ $M_{\odot}yr^{-1}$ (De Beck et al. 2010, and references therein), which lead to the formation of circumstellar envelopes (CSE) 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: 1−5 µm). Variable OH/IR stars with high mass-loss rates ($\geq 10^{-6}$ $M_{\odot}yr^{-1}$) are examples of such obscured stars in their final stage of AGB evolution.

After that most of their mass is lost during the AGB phase, the 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 $10^{-7} - 10^{-8}$ $M_{\odot}yr^{-1}$ (Miller Bertolami 2016). Because of the short time scales and the obscuration of the stars, the details of the transition process from the AGB to the post-AGB phase are not well constrained. There is growing evidence accumulating that following variations of the IR, the H_2O and the OH maser on timescales of decades allows to study aspects of this transition process in real time (Wolak et al. 2014; Orosz et al. 2019; Kamizuka et al. 2020; Uno et al. 2021).

In general, 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 ~400 − ~2000 days and in part small-amplitude irregular or almost non-variable stars (hereafter S-pAGB stars). Studying the variability properties of OH/IR stars, we wish to identify stars losing currently their L-AGB variability and are in the transition process to the post-AGB stage.

The bright OH/IR star sample

The core sample monitored 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_{ν} > 4 Jy). The brighter masers of the sample have been monitored before by Herman & Habing (1985), who reported several sub-groups with different amplitudes and periodicity among S-pAGB stars. In addition, another 7 stars located outside the area surveyed by Baud et al. were monitored.

The stars are observed typically every two months with the NRT using the Low-Frequency receiver. The digital autocorrelator is split into eight banks with a bandwidth of 1.56 MHz centered on the 1612 and 1667 MHz OH maser transitions. The velocity resolution is 0.28 km/s. Typical integration times are 8 minutes on source, which yield a noise level of ~0.1 Jy.

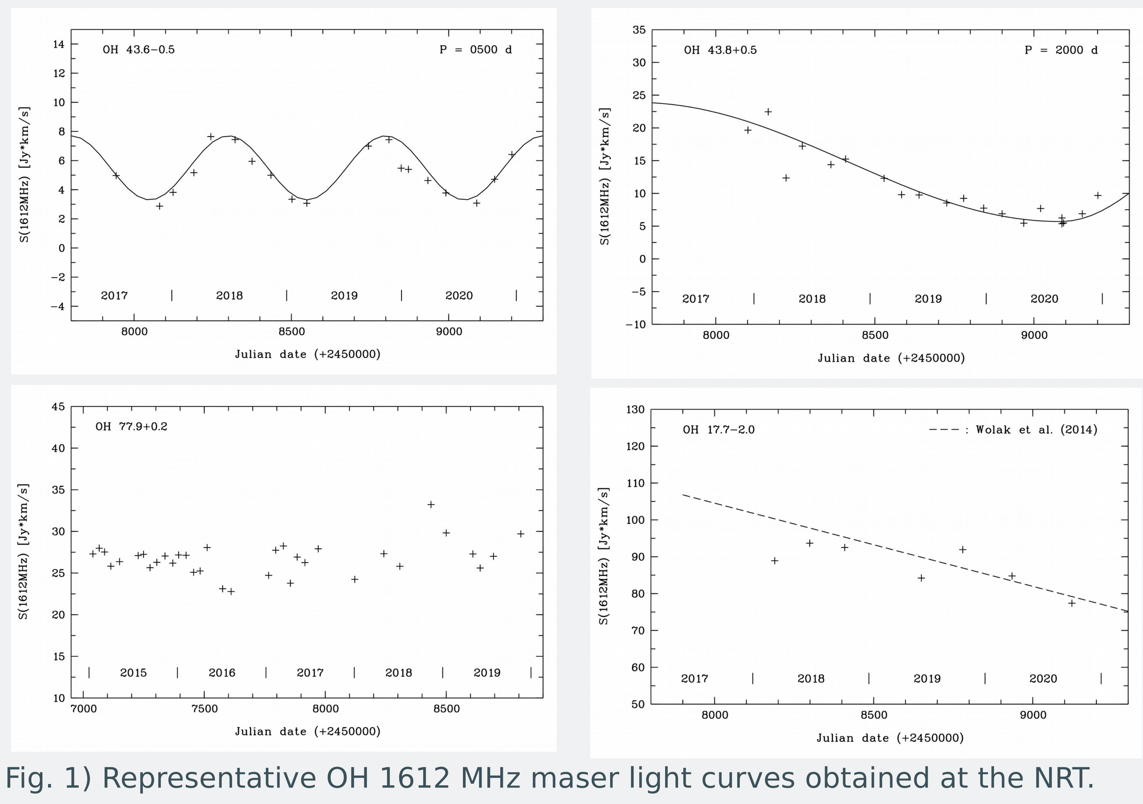

Fig. 1) Representative OH 1612 MHz maser light curves obtained at the NRT. Monitoring of the L-AGB stars OH 43.6-0.5 (P = 500 days) has been finished, while OH 43.8+0.5 (P~2000 days) will be monitored for another ~4 years to cover a complete variabilty cycle. OH 77.9+0.2 is classified as S-pAGB star, and OH 17.7-2.0 shows a steadily declining integrated flux (see text).

NRT results

As of end of 2020, variability characteristics are available for 107 OH/IR stars (88%) of the sample. Their status is preliminary, as for part of them the monitoring program has not been completed. To cover also the longest periods monitoring for six and more years is required.

The majority of the OH/IR stars are L-AGB stars (N=70, 57%) of which periods have been determined for 56 stars. We have classified 37 stars (30%) as S-pAGB stars, while the rest (N=15, 12%) still need to be monitored. Examples of light curves obtained are shown in Fig. 1. The full set of continuously updated light curves is available on the project webpage.

A large fraction of L-AGB stars do show rather long periods (P > 800 days) compared to AGB samples selected optically (Mira variables) or in the infrared. In Fig. 2 we compare their period distribution with the one of N = 348 IRAS selected OH/IR stars of the Arecibo sample (Jimenez-Esteban et al. 2021). The stars with long periods make up only a small minority among the Arecibo OH/IR stars. Compared to the Arecibo sample, the L-AGB sample is likely biased toward more massive stars in their final stages of AGB evolution, as almost all are located close to the Galactic plane.

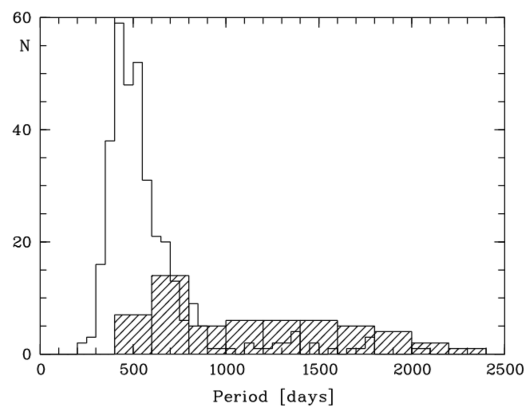

Fig. 2) Period distribution of the ‚Arecibo sample of OH/IR stars' (Jiménez-Esteban et al. 2021) (open bars) and of the ‚Bright OH/IR star sample' (shaded bars).

The light curves of S-pAGB stars show small-amplitude variability but no periodicity (see OH 77.9+0.2 in Fig. 1, lower left panel). Wolak et al. (2014) pointed out that the post-AGB star OH17.7-2.0 (IRAS 18276-1431) is continuously decreasing its OH maser brightness and predict disappearance by 2030. We can confirm this conclusion as the maser decreased as predicted during the last 3 years (Fig. 1, lower right panel). We continue to monitor several other S-pAGB stars, where a similar fading of the maser may happen currently as well. The observations suggest that the OH masers are lost on timescales of hundreds of years after that the stars have left the AGB.

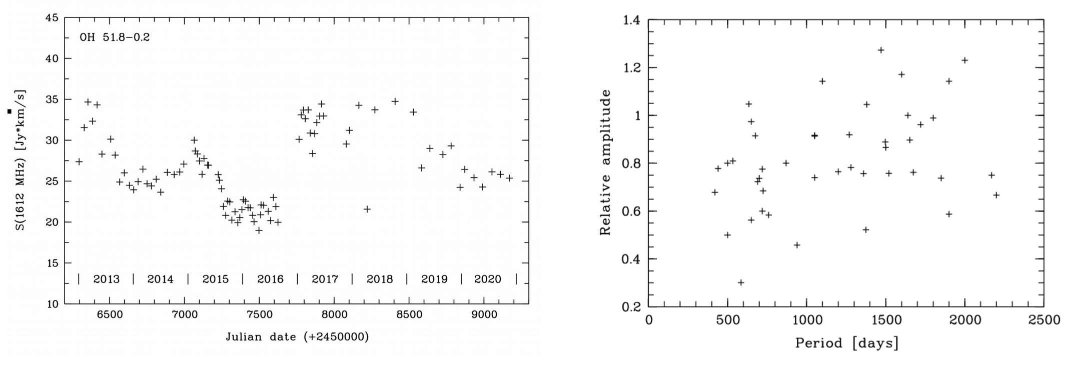

Fig. 3) Left: Transition candidate OH 51.8-0.2; Right: Relative OH maser lightcurve amplitudes as function of periods of the ‚Bright OH/IR star sample'.

Our best candidates for a star losing its L-AGB status is OH 51.8-0.2, which has a peculiar light curve with small amplitude variations on top of a possibly long-period large-amplitude variation (see Fig. 3, left panel). Our previous analyses of the light curves led to the conclusion that the fading out of pulsations with steadily declining amplitudes would be a viable transition process (Engels et al. 2019). However, with more light curves characterized we do not find correlations between the OH maser light curve amplitudes and periods, which would allow to constrain this hypothesis further (Fig. 3, right panel).

Stockert Observations

Since 2017 we are using the 25-m Stockert Radio Telescope to follow variations in the 1612 OH maser line of selected OH/IR stars. The Stockert RT was inaugurated in 1956 and was the first large radio telescope in Germany. It was decommissioned in 1995 but has been modernized and put back into operation again in 2011. It is now operated by a volunteer organization "Astropeiler Stockert e.V.". As it stands today, it is the largest and most capable radio astronomy facility which is in the hands of amateurs worldwide.

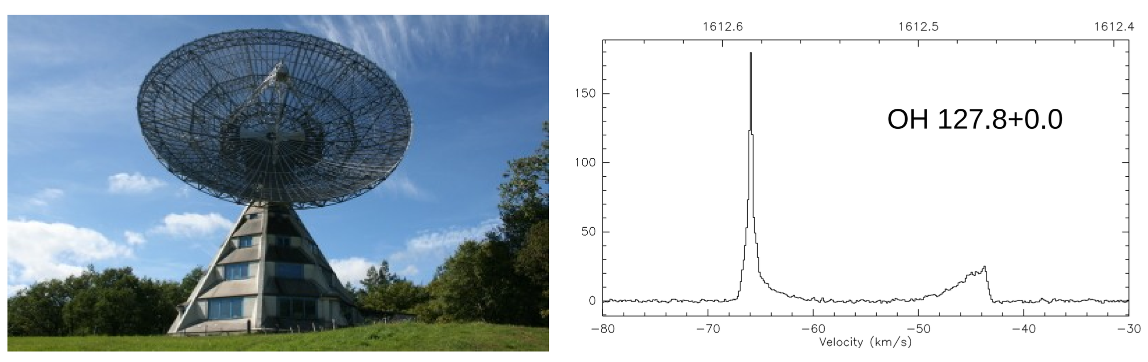

Fig. 4) Stockert Radio Telescope and sample 1612 MHz OH maser spectrum.

Astropeiler Stockert Website: http://www.astropeiler.de

For the OH maser observations (an example is shown in Fig. 4) the 25m telescope is equipped with an L-Band receiver covering the frequency range 1600 – 1730 MHz. Integration times used are 0.5 – 1.5 hours. The spectral resolution is set to 0.14 km/s resulting in a rms noise of ≥0.5 Jy. For calibration, we use transit scans of flux calibrators from the list of Baars et al. (1977).

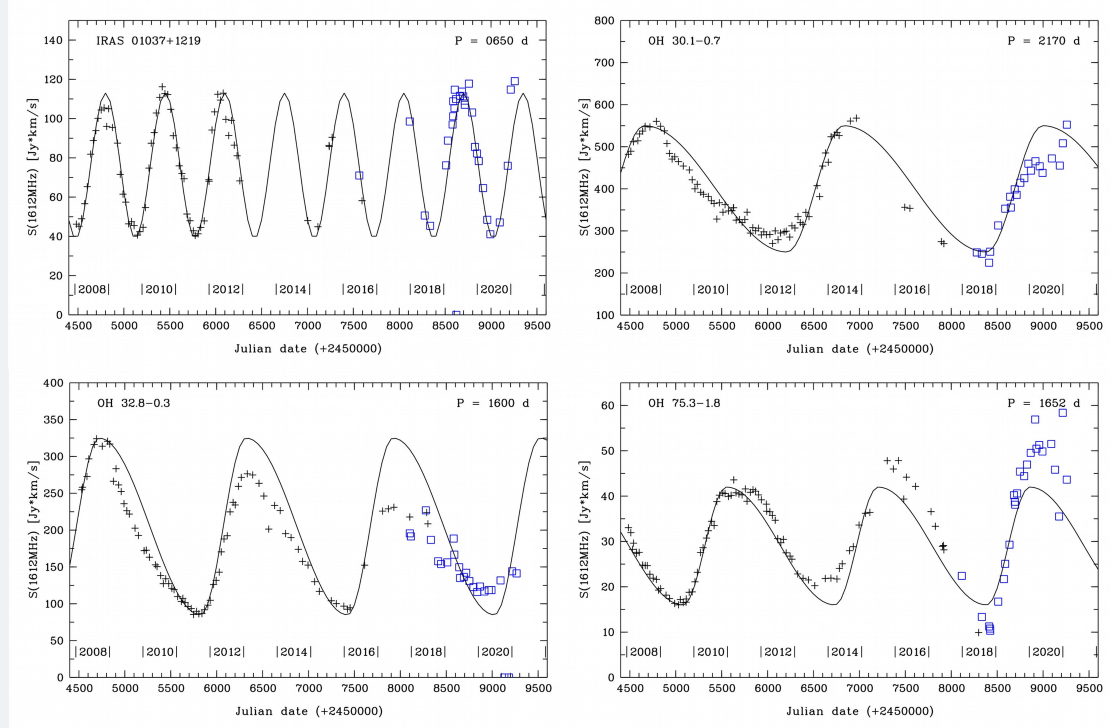

Fig. 5) OH 1612 MHz maser light curves. Observations are from the Nançay (+) and Stockert (blue squares) radio telescopes. The model asymmetric sine-curves are eye-fits to the 2008 - 2012/2014 data and should only be used to guide the eye.

OH maser light curves

A more or less continuous coverage of observations between 2008 and 2021 has been obtained for a couple of L-AGB OH/IR stars. They have periods 400 < P < ~2400 days (1.2 – ~6.5 yr). While earlier OH monitoring programs lacked the cadence of observations required, the Nancay-Stockert program allows to analyze in detail the properties of the light curves.

We find that the stars with periods <~800 days are rather regular with fixed periods and amplitudes. The shapes can be represented reasonably with asymmetric sine-functions, where the rising branch is steeper than the decreasing one. An example is IRAS 01037+1219 (WX Psc, IRC+10011) with a period of 650 days (Fig. 5, upper left panel). For longer periods the regularity is kept, but the periods can vary from cycle to cycle by ~10%. As shown in the remaining panels of Fig. 5, the amplitudes do vary as well. Remarkable are the light curves from OH 32.8-0.3 and OH 75.3-1.8. The amplitude of the former star seems to decrease systematically, while in OH 75.3-1.8 the opposite behaviour is observed. The number of cycles observed is still too small to draw final conclusions, but the light curve of OH 32.8-0.3 would meet expectations, if the pulsations of the star currently die out before entering the post-AGB stage. During the final stage of AGB evolution the mass of the pulsating envelope may have decreased so much that the pulsations become unstable, and allow the amplitude temporarily to increase as observed in OH 75.3-1.8.

More Nançay-Stockert light curves:
www.hs.uni-hamburg.de/nrt-monitoring/stockert.html

Conclusions

The long-term monitoring of obscured variable OH/IR stars in the 1612 MHz line shows light curves which can vary from cycle to cycle lasting up to six years each. If the OH/IR stars with P>800 days are assigned to the latest phase of AGB evolution then the loss of the pulsation may be connected to irregular fluctuations (OH 51.8-0.2) or to fading of the pulsations (OH 32.8-0.3). After the loss of pulsations, the OH masers show low-amplitude fluctuations. Due to the short transition time, objects currently in transition between L-AGB and S-pAGB type variability may be difficult to identify unambiguously. In some cases a long-term fading of the OH maser brightness is seen in S-pAGB stars. These stars may lose their OH maser within a few hundred years.

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DELVE: The Death-Throes of Evolved Stars, a Virtual Encounter, Online Conference: April 12-16, 2021, https://fys.kuleuven.be/ster/events/conferences/2021/delve