Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Signposts of transitional phases on the Asymptotic Giant Branch

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Abstract. When low- and intermediate-mass stars pass through the Asymptotic Giant Branch (AGB) they experience dramatic changes in their circumstellar shell (CSE) influenced by their mass loss, the possible presence of a (closeby) companion and the magnetic field. Masers, well spread in this environment, provide a powerful tool to reveal the CSE changes occurring when the stars undergo a transitional phase on the AGB. These can be indirect, via for instance the modification of the pumping conditions or a direct consequence of e.g. a companion and/or of the magnetic field. Evidences of such changes have been observed towards Miras, materialized by strong - both in intensity and degree of polarisation - (OH) flaring events and towards stars believed to be transitioning from the Mira to the OH/IR phase, showing an unusual high degree of polarisation. How OH maser emission can be used as a signpost of transitional phases along the AGB is explored.

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

1. Introduction

When low and intermediate stars (i.e., less than 8 $M_{\odot}$) leave the Main Sequence, they head to the Asymptotic Giant Branch (AGB). This is associated with a dramatic increase of mass-loss rates, reaching typical values ranging from 10^{-6} to $10^{-4}\,M_{\odot}\ yr^{-1}$. As a consequence, the star surrounds itself with a circumstellar shell (CSE) of gas and dust of varied opacity. The AGB is populated with Miras, Semi-Regulars (SRs) and OH/IR stars, but their actual relation in terms of their original mass and evolution is still a matter of debate. In particular, it has been shown that the oxygen-rich (variable) Miras and OH/IR stars lay in a continuous sequence in the IRAS colour-colour diagram built from their 12, 25 and 60μm emission while the "non-variable" OH/IR stars (in essence the OH/IR stars leaving the AGB), having the highest [12]-[25] colour, deviate (i.e., depart) from this sequence (van der Veen & Habing 1988). Though originally interpreted as an evolutionary consequence, this "sequence" is most likely a mix of both evolution and masses to reconcile with the associated mass-ranges of Miras and OH/IR stars (Etoka & Le Squeren 2004) As it is based on FIR measurements, the IRAS colour-colour diagram and the "sequence" itself are a powerful tool to characterize the CSE (i.e., "filtering out the star") with amongst other properties, both the expansion velocity and the mass-loss rate increasing along the "sequence" (cf. Fig. 1).

OH maser is well spread in these objects and long-term monitoring of this emission provides dynamical information of the CSE (Etoka & Le Squeren 2000). OH is a para-magnetic molecule and is consequently particularly well suited for the retrieval of both the magnetic field strength and structure (Etoka & Diamond 2010).

Here we concentrate on the evolution of Miras and OH/IR stars. The transitional phase between (variable) OH/IR stars and the (non-variable) post-AGB stage is discussed in

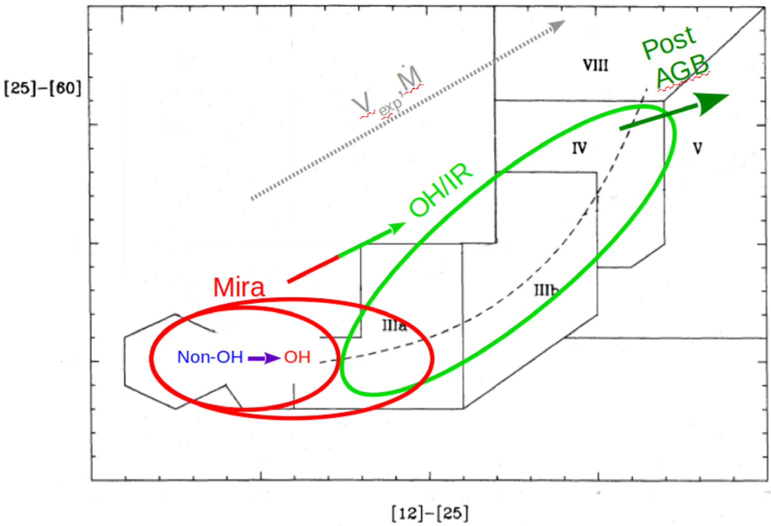

Figure 1. Schematic view of the Mira, OH/IR and post-AGB location on the IRAS colour-colour diagram.

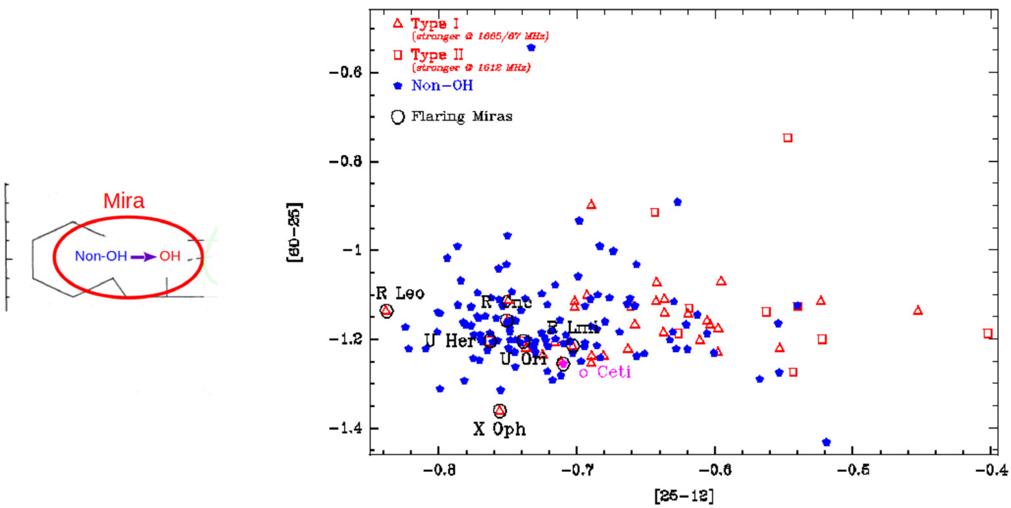

Figure 2. Non-OH → OH Mira transitional phase: Location of the flaring Miras in the IRAS-colour-colour diagram.

"The loss of OH maser emission in the early stage of Post-AGB evolution" (Etoka et al. these proceedings). The study presented here is based on OH-maser survey and long-term monitoring programmes performed at the Nançay radio telescope (NRT).

2. Non-OH→OH: Flaring Miras

The first OH flaring event in a Mira was recorded towards U Ori (Pataki & Kolena 1974). Successive detections were made toward X Oph (Etoka & Le Squeren 1996), U Her, R Leo, R LMi, R Cnc, (Etoka & Le Squeren 1997) and recurrently towards *o* Ceti (Dickinson *et al.* (1975), Gérard & Bourgois (1993), Etoka *et al.* (2017)). Figure 2 presents their location in the IRAS Colour-Colour diagram.

The flaring Miras are all found to be scattered into the non-OH maser area characterised by very thin CSEs as a clear signature of the non-OH → OH transitional phase

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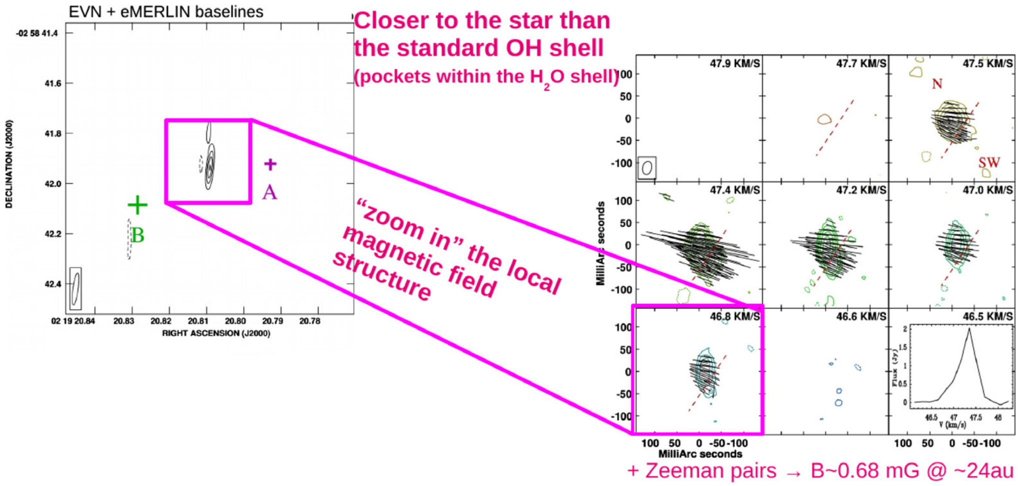

Figure 3. *o* Ceti flaring event: location of the flare with respect to the 2 stars of the binary system (i.e., Mira A & B) and polarimetric characteristics of the emission.

in which the CSE fills itself with enough dust to produce {just} enough IR radiation for the necessary radiative pumping of this emission. Added to the location of these Miras in the IRAS colour-colour diagram, all the flaring events display common features: the flaring components are spectrally compact (in terms of velocity range), peaking close to the stellar velocity and exhibiting systematically a very high degree of polarisation. Because of these characteristics, VLBI is mandatory for their mapping. The latest of such event observed towards *o* Ceti is summarized in Figure 3. It confirmed for the first time that indeed such emission is very localised and compact. The associated pocket(s) of OH emission, located much closer to the star than the standard OH masers, at H_2O region's radii, provide(s) an insight into the local magnetic fields structure of these regions. Zeeman pairs revealed line-of-sight local magnetic field strengths of $\sim$0.70 mG at $\sim$25 AU from the central star (Etoka *et al.* 2017). The long-term monitoring of this event revealed changes in the polarimetric properties of the emission as the flaring event progressed (attested by a slow change in velocity) including a dramatic flip in the strength of the dominating circular polarisation. The latter is most probably related to the complexity of magnetic field lines' direction/orientation probed by the flaring maser progressing away from its original location.

3. Mira→OH/IR

In a survey towards sources distributed along the IRAS colour-colour diagram so as to investigate the spectral evolution of the mainline transitions with the CSE thickness, 2 objects located in the lower part of the diagram with very atypical polarimetric signatures were discovered (Etoka & Le Squeren 2004).

Figure 4 presents their location in the colour-colour diagram, along with their mainlines spectra. Both objects show a wide range of very highly polarised features in the 2 mainlines with hints of potential Zeeman pairs. Because these features are spread over a wide velocity range, it is clear that a good fraction of the CSE is consequently affected. The location of these objects in the colour-colour diagram corresponds to intermediate expansion velocities and mass-loss rates and their CSE is anticipated to be between $\leq$1 and a few arcsec (hence needing "intermediate-baseline" interferometric mapping).

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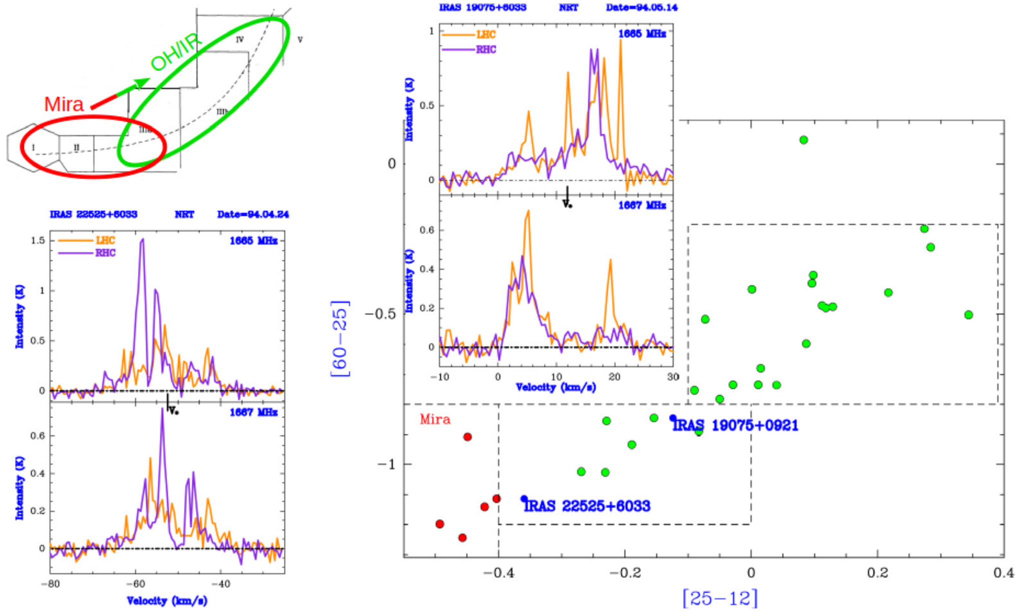

Figure 4. Mira→OH/IR: Location in the colour-colour diagram and {spectral} characteristic features.

4. Conclusion

In order to characterise the evolutionary path of a star on the AGB, it is important to understand the transitional phases that some of the stars will experience before turning into a planetary nebula. OH-maser emission has proved to be a very sensitive signpost of such objects with (a mix of) variability, spectral and polarimetric signatures, the latter allowing insight into the local magnetic field structure. Surveys and long-term monitoring are crucial for their identification and follow up. Concerted monitoring programmes with dedicated instruments located at different latitudes like e.g. the NRT and the new NARIT Thai National Radio Telescope would allow a greater number of sources and location in the Galaxy to be investigated. These need to be supplemented with interferometric observations, with VLBI for the compact events such as those associated with the Non-OH→OH Mira transitional phase and intermediate-baseline mapping (e.g. eMERLIN; SKA in the future) for the transitional phases Mira→OH/IR→post-AGB as related to more extended objects.

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