Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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Does 3$^{\rm rd}$ dredge-up reduce AGB mass-loss?

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Abstract. We follow up on a previous finding that Miras containing the third dredge-up (3DUP) indicator technetium (Tc) in their atmosphere form a different sequence of $K-[22]$ colour as a function of pulsation period than Miras without Tc. A near-to-mid-infrared colour such as $K-[22]$ is a good probe for the dust mass-loss rate (MLR) of these AGB stars. Contrary to what one might naïvely expect, Tc-poor Miras show *redder* $K-[22]$ colours (i.e. higher dust MLRs) than Tc-rich Miras at a given period. In the follow-up work, the previous sample is extended and the analysis is expanded towards other colours and *ISO* dust spectra to check if the previous finding is due to a specific dust feature in the 22 μm band. We also investigate if the same two sequences can be revealed in the gas MLR. Different hypotheses to explain the observation of two sequences in the P vs. $K-[22]$ diagram are discussed and tested, but so far none of them convincingly explains the observations.

Uttenthaler (2013) demonstrated that two separate sequences of Miras exist in the P vs. $K-[22]$ diagram, if a distinction is made for the presence of Tc. Surprisingly, at a given period, Tc-poor Miras show *redder* $K-[22]$ colours (i.e. higher dust MLRs) than Tc-rich ones. Here, we report about the follow-up work Uttenthaler *et al.* (2018). Fig. 1 shows the updated P vs. $K-[22]$ diagram of our sample Miras. The two sequences have a tight correlation between $K-[22]$ and period. The $K-[22]$ sequence of Tc-rich Miras extends to longer periods and is much steeper. Also, the two groups are separated remarkably well in this diagram, most of the outliers can be explained by binarity or hot bottom burning.

To check if the two sequences are caused by a specific dust feature in the *WISE* 22 μm band, we expanded the analysis to other near-to-mid-IR colours and *ISO* dust spectra. Indeed, the two sequences can clearly be revealed with colours including bands as red as *Akari* 90 μm. Also *ISO* dust spectra reveal that Tc-rich Miras have much less dust emission than their Tc-poor siblings with similar periods. The previous finding based on the $K-[22]$ colour is thus not due to a specific dust feature. This could mean that, at a given period, Tc-poor Miras have a higher dust MLR than Tc-rich (post-3DUP) Miras.

An important question that arises from this is, if the two sequences can also be found in the gas MLRs? It would be important to know if only $K-[22]$ is affected by 3DUP, or also the gas MLR. This could help to identify the underlying process(es). We collected from the literature MLR data measured from CO radio lines to address this question. We confirm a clear increase of the gas MLR with increasing period, but unfortunately, the

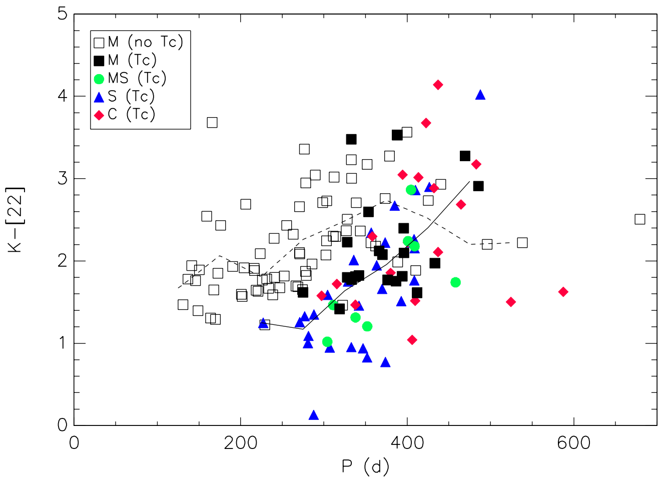

Figure 1. P vs. $K-[22]$ diagram of our sample Miras with and without Tc, see legend. The solid and dashed lines show a running mean of $K-[22]$ in 50 d period bins.

data are inconclusive on the existence of two sequences. Too few Miras with $P \lesssim 400$ d have been observed, there is little overlap between the Tc sample and CO observations, and large uncertainties attached to gas MLR measurements cause scatter. We encourage observers to target more short-period Miras with information on their Tc content in radio CO observations.

We put forward hypotheses to explain the surprising and unexpected observations:

H 1: *3DUP influences the pulsation period.* This is unlikely both on observational (Riebel *et al.* 2015) and theoretical (Scholz, Ireland & Wood 2014) grounds. This hypothesis can thus be discarded.

H 2: *The stars are groups of different masses that evolve differently in the P vs. $K-[22]$ plane.* We inspected the distance to the Galactic mid-plane and the radial velocity dispersion as indicators of age and hence mass (Feast 1963). None of them reveals a difference between Tc-poor and Tc-rich Miras at a given period.

H 3: *3DUP reduces MLR.* The decay of radioactively unstable isotopes could somehow reduce dust formation and thus MLR. Glassgold (1995) investigates the formation of ions in circumstellar shells of AGB stars by the decay of isotopes such as ^{26}Al. The effect on MLR is unclear, but ions could play a role in dust formation.

H 4: *3DUP reduces dust emissivity.* Similar to H 3, but only the dust emissivity (thus $K-[22]$) is reduced upon 3DUP, not MLR. Also here, the physical mechanism is unclear.

H 5: *Tc lines are unobservable in some stars.* This could be the case, if Tc line formation strongly depends on stellar parameters. Tc chemistry and line formation are indeed not well understood.

At the moment, none of the hypotheses satisfyingly explains the observations. Nevertheless, some of them deserve deeper investigation.

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