CONSTRAINTS ON TERMINAL AGB EVOLUTION FROM PROPERTIES OF MIRAS AND OH-IR SOURCES

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Near the tip of the AGB we find the optical Mira variables and also the OH-IR stars. Observational data on the luminosities, periods, and population membership of the OH-IR sources are beginning to be available; in principle this information should constrain AGB models very strongly. In practice, current data are found to be insufficient to unambiguously determine the relation between Miras and these sources; in fact three very different interpretations are currently possible.

Three currently available period-luminosity relations for the OH-IR sources and Miras are compared in Figure 1. These give very different pictures of the relationship between Miras and OH-IR sources.

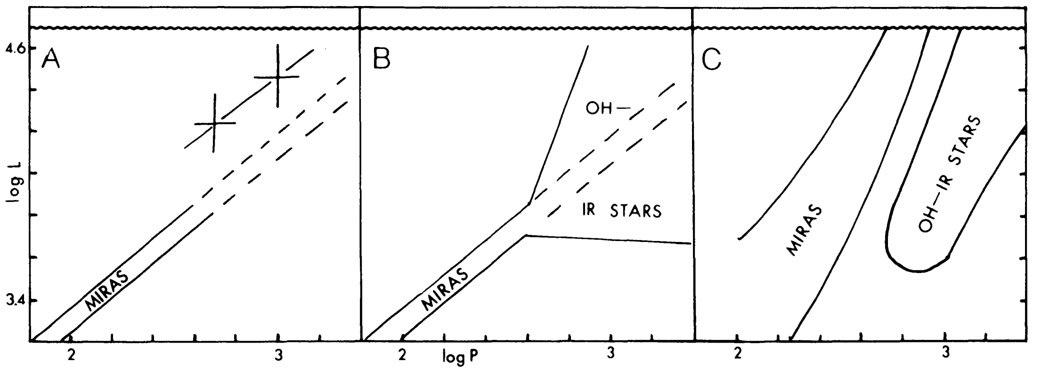

Figure 1. Period - luminosity relations for Miras and OH-IR sources based on A: an analysis of radio luminous IR sources by deJong, (1983); B: observations and analysis of galactic sources by Engels et. al. (1983 = EKSS); C: observations and analysis of red stars in the LMC by Wood, Bessell, and Fox (1981 = WBF). The AGB limit log $L/L_\odot$ = 4.7 is indicated. In A, B the Mira period-luminosity relations are from Glass and Lloyd-Evans (1981).

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deJong selected radio-luminous infrared sources with periods near 500, 1000^d; in Fig. 1A his derived luminosities are compared with the period-luminosity relations of Glass and Lloyd-Evans (1981) for the LMC (upper line) and galactic Miras. The OH-IR sources studied by deJong lie above the extrapolated Mira relation; a similar result is obtained if M_{ms} is plotted against P for the same data. One interpretation of these plots is that for fixed luminosity, P(OH-IR) / P(Mira) ~ 1/3 -- as would result from fundamental mode pulsation for the Miras and first overtone pulsation for the OH-IR sources.

In contrast, Engels (EKSS and this volume) finds a period-luminosity relation for the OH-IR stars which is continuous with that of the Miras (Figure 1B). The scatter in luminosity, particularly at the longer periods, is very large; this may be a reflection of observational uncertainty, or it may represent a real range of L for fixed P. The simplest interpretation of this relation is that the Miras and at least most of the OH-IR stars are pulsating in the same mode.

Finally, WBF found for the long period sources in the LMC and SMC a discontinuity between the "Miras" and the longer period sources, which they interpret as a shift from overtone "Mira" pulsation to fundamental mode pulsation for the longer period objects (Figure 1C). However their definition of "Mira" variables is less strict than that usually used. Strictly, a Mira is a variable with visual amplitude >2.5 mag, emission lines of hydrogen at least part of the time, and a light curve with constant mean magnitude which is regular in timing and amplitude from cycle to cycle to within 15%. Other red long period variable belong to various semiregular (SR) classes; it is not yet known what relation the SRs are to the Miras. If questionable "Miras" are eliminated from WBF's data, and if the same bolometric corrections and distance modulus are used, then the Glass and Lloyd-Evans relation is recovered, at least for $P < 350^d$ (Lloyd-Evans, this volume).

What can be done both observationally and theoretically to select the correct picture from among the three? First, we need to know whether there is in fact a discontinuity in the properties of Miras and OH-IR sources -- and in what properties this discontinuity can be seen. Second, sorting properties by period may not produce groups of sufficient homogeneity for the statistical analyses usually undertaken. The expected range of L at fixed P is very large even if only one mode is present, because stars of differing M reach the same P at different L. Ultimately, direct comparison of the distribution of L vs. P with theoretical predictions will be required to sort rigorously among the models.

Theoretical calculations as well as observations of red LPVs in globular clusters indicate that as a star evolves up the AGB it first pulsates in an overtone, then converts to fundamental mode pulsation at some critical (L,T,M). This has led to two evolutionary scenarios including Miras and OH-IR sources, in both of which the more evolved OH-IR sources are fundamental mode pulsators (e.g. Willson 1982, Wood 1982). Figure 1C is consistent with Wood's scenario, where OH-IR sources are the result of a mode switch from overtone Mira pulsation to fundamental mode. Figure 1B is consistent with the Willson scenario, where both OH-IR sources and Miras pulsate in the fundamental mode. If Figure 1A applies, however, that is if there is a distinct group of high-luminosity overtone pulsating OH-IR stars, then a mechanism must be found for a second mode switch, and/or for more massive, more luminous stars to develop rapid mass loss while remaining overtone pulsators.

A possible mechanism is inherent in the mass loss process itself: When the star's mass loss rate exceeds some critical value, probably around 10^{-5} $M_{\odot}$/ yr , the star develops an optically thick dust shell. This produces the characteristic appearance of the OH-IR source; it must also have some effect on the temperature boundary condition at the surface of the star. If we model the circumstellar dust shell very simply, as a spherical "blanket" several stellar radii out, then we can calculate the backwarming effect in two simplified cases. If the stellar radiation is absorbed by the blanket without scattering, and re-radiated at the equilibrium Planck temperature (near 1000K), then the effect on the boundary temperature will be small -- less than 1% for stars above 2500K. However if scattering is important, so that perhaps 50% of the photons are scattered back towards the star without change in energy, then the boundary temperature will be raised by 10% -- easily enough to move the star back across the boundary in (L,T,M) between fundamental and overtone pulsation.

Further model calculation efforts should focus on determining (a) the dependence of the preferred pulsation mode on (L, T, M_{*}, M_{core}, Y, Z); (b) the scaling law for pulsation enhanced mass loss from Miras; (c) the effects of such a mass loss process on the evolutionary tracks and in particular (d) the effects of an opaque, scattering circumstellar envelope on the stellar characteristics and pulsation mode. At the same time, better observational constraints are needed, particularly luminosities, mass loss rates and current masses of Miras and OH-IR sources as a function of at least two observable parameters -- period and probably infrared amplitude or expansion velocity.

Bibliography

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DISCUSSION

Frogel: How high an albedo does the dust need to give sufficient backscattering?

Willson: I assumed 50 % backscattering, that is a very high albedo; I also assumed single scattering of photons. These effects are in opposite directions. The purpose of this calculation is just to show that a 10 % effect is reasonable; this is very large in relation to the pulsation mode and the HR diagram tracks for these stars.

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