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Letter to the Editor

Are low-order resonances observed in Mira pulsation?*

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Abstract. The possibility of a low-order, two-mode resonance in the pulsation of LPVs is investigated by means of Fourier analysis of lightcurves, supplemented by spectral types and by kinematic population analysis based on HIPPARCOS astrometric data. The question might be positively answered.

Key words: stars: AGB – stars: oscillations – stars: variables: long-period variables

1. Introduction

Theoretical works have shown the importance of resonances between radial pulsation modes in the case of Cepheid (including BL Her-type) and RR Lyrae stars (Buchler & Kovács 1986, Buchler et al. 1990, Buchler & Moskalik 1992, Moskalik & Buchler 1993). The Fourier parameters and shapes of the light- or velocity-curves appear very sensitive to whether the pulsation is close to a resonance of two or several pulsation modes. As a consequence, they are accurate indicators of mass and metallicity, provided that reliable nonlinear pulsation models are available. These results have been extensively confirmed by observations (Simon & Lee 1981, Hodson et al. 1982, Petersen & Diethelm 1986, Antonello et al. 1990, Kovács et al. 1990).

The present paper investigates the possible occurence and detection of 2:1 resonances between the predominant pulsation mode of Mira-type Long-Period Variables and a higher overtone, playing a role in the shaping of the light curves, as already found in the case of Cepheids.

Nonlinear models of Mira pulsation are still far from being reliable. One can of course not simply extrapolate from what is known about Cepheids to the case of red, inflated stars such as Miras. However, we may state that, if a similar resonance does occur, a strong, steep variation of the phase-lag and amplitude-ratio of the predominant Fourier component and its first harmonic must be observed, when approaching then going through the resonance. The shape of the lightcurve is expected to strongly dependent on the distance to the resonance center. Moreover, for a star of given mass and metallicity, a correlation is expected between the phase-lag and the effective temperature, and thus the spectral type. Last, the period and phase-lag at the resonance center should depend on the mass and metallicity.

After analyzing and confronting data of various types, we find that the stars of our sample seem to behave consistently with our expectations. Discussion of the possibility of circumstellar effects leads us to the conclusion that they are a less likely explanation than resonance of internal pulsation modes.

2. Data

In preparing the HIPPARCOS mission, we have analyzed the AAVSO lightcurves of 150 Miras-type LPVs by means of Fourier transform, deconvolution, then nonlinear fit of the most significant components (Barthès 1995). Among these, we have selected the largest-amplitude one (frequency ν_p, corresponding to the obvious "period" of the star) and its first harmonic ($2\nu_p$). This was possible for 105 stars; the others had either no first harmonic at all, or a component which could be identified to this harmonic, but with a frequency error (> 0.5%) making its amplitude and phase very uncertain. The Fourier parameters used in the following study are the phase-lag between the two components ($\phi_{21} = \phi(2\nu_p) - 2\phi(\nu_p)$), the period $P = 1/\nu_p$, and the amplitude ratio $R_{21} = A(2\nu_p) \,/\, A(\nu_p)$. Both the phase lag and the amplitude ratio are expected to exhibit significant variations near a resonance.

In addition to the Fourier parameters, our work is based on the spectral types at maximum visual brigthness, taken from the General Catalogue of Variable Stars (Kholopov et al. 1985). They give us some information on the effective temperatures, though their relationship is far from being accurate.

Another source of information is the mean shape of the lightcurve (presence or absence of a bump, flatness of the maximum) as given by Campbell (1955).

The fourth set of data was provided by luminosity calibration (Alvarez et al. 1997) performed by applying the maximum likelihood LM method (Luri, Mennessier et al. 1996) to HIPPARCOS proper motions and parallaxes (Perryman et al. 1997), supplemented by radial velocities and AAVSO visual magnitudes. As part of the calibration process, the stars are automati-

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* Based on data from the HIPPARCOS astrometry satellite.

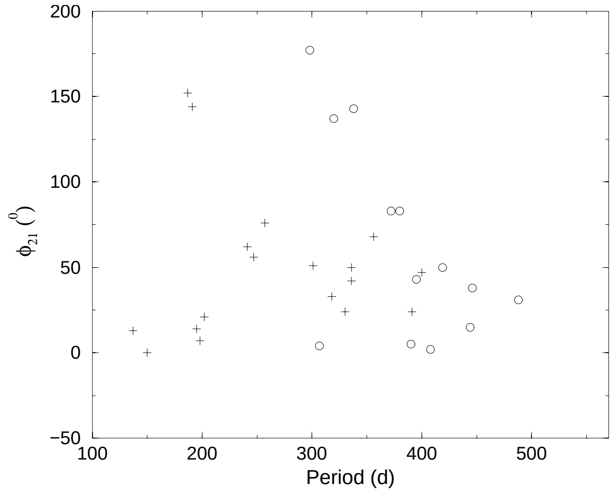

Fig. 1. Phase lag ϕ_{21} as a function of the period, with indication of spectral types

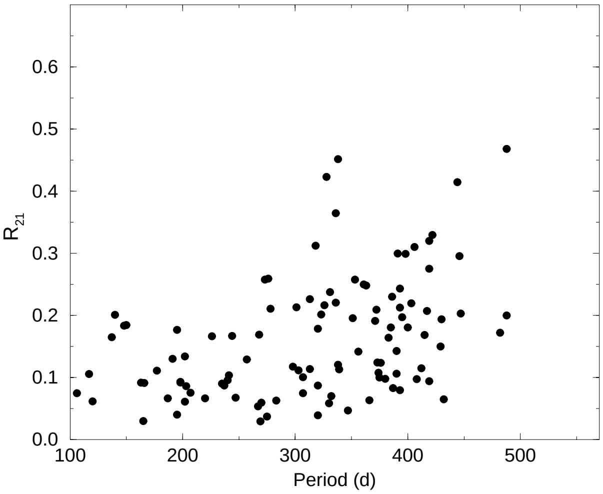

Fig. 2. Amplitude ratio R_{21} as a function of the period

cally separated into several groups with different mean absolute magnitudes and/or kinematics. In the case of our Mira sample, the stars were respectively assigned to three groups, kinematically interpreted as:
– old disk population;
– thin-disk population (stars with larger initial masses);
– extended-disk/halo population (stars with lower metallicity and initial masses).

3. Results

Figure 1 shows the phase lag ϕ_{21} as a function of the period, together with the spectral types. The first information is that, though most stars exhibit a phase lag close to zero, many depart from this value by significant amounts and some reach almost π. Stars with $\phi_{21} \approx \pi/2$, seem to be concentrated around two periods (260 and 375 days).

Moreover, the spectral type evolves towards later values from left to right. It also tends to get later along imaginary lines going from the bottom-left to the top-right of the figure. Last, S and C stars are concentrated in the top-right half.

It is also important to note that stars with a phase lag close to zero or π (e.g. T Ari, S Car, W Cas, R Cnc, RU Her, S Lib, Z Oph, S Ser...) exhibit bumps, humps, shoulders or flat maxima in their lightcurves, whereas stars with much smoother lightcurves (e.g. RR Aql, *o* Cet, S CrB, R Gem, R Leo, R Lyn, R UMa, T UMa...) are found in the range $\pi/4 \leq \phi_{21} \leq \pi/2$.

At this stage, one may risk doing the following conjecture: at fixed mass, luminosity and metallicity, stars with decreasing temperatures (thus increasing periods) would be distributed along an arccotangent-like line of increasing phase-lag: this would be consistent with second-order (but not with higher-order) nonlinear calculations of Buchler & Kovács (1986) concerning classical Cepheids; this would also be consistent with dynamical calculations of Moskalik & Buchler (1993) concerning BL Her stars. This phase-lag sequence would cross a 2:1 resonance of the predominant mode with a higher harmonic. Any change of mass or metallicity would, of course, shift the sequence (thus the center of resonance) towards longer or shorter periods (and also shift the spectral type at given P and ϕ_{21}). The concentrations around P =260 and 375 days (if not due to sampling bias) would be due to the coexistence of populations with different masses and/or metallicities. On the right side of each of these features, the sequences would be interrupted at the limit of the instability strip corresponding to each population.

Figure 2 displays the amplitude ratio against the period. From what is known about Cepheids, one might expect a broken-shaped relation between R_{21} and P which, in fact, is not observed. Adding spectral types does not help. Nevertheless, this is not so surprising. As in Fig. 1, the variety of masses, luminosities and metallicities, thus resonance center periods, must result in mixing up the expected sequences. Moreover, V amplitudes and their ratios are very sensitive to the steepness of the continuum and to the intensity of molecular bands, thus much more closely related to the effective temperature and metallicity than the bolometric or radial-velocity amplitudes. As a consequence, the expected features are blurred when visual magnitudes are used.

In Fig. 3, one of the two causes of blurring (the period dispersion of the resonance center) is suppressed by plotting the phase lag against the amplitude ratio. The result seems consistent with our hypothesis: if one draws two broken lines between which the data are enclosed, then the general aspect of the figure is compatible with a sort of W-shaped or inverse-Z-shaped relation between the phase-lag and the amplitude-ratio. In the former case, R_{21} would reach maxima at $\phi_{21} = 0$, $\phi_{21} \simeq 0.45\pi$ and $\phi_{21} = \pi$, and minima at $\phi_{21} \simeq 0.3\pi$ and $2\pi/3$. In the latter case, the maxima would occur at $\phi_{21} \simeq 0.45\pi$ and $\phi_{21} = \pi$, and the minima at $\phi_{21} = 0$ and $\simeq 2\pi/3$. The dashed part of the right–hand line would correspond to the limit of the instability strip, interrupting the sequences. Indeed, the 18 stars lying below this line appear in the bottom-right corner of Fig. 1; moreover, all but one have a spectral sub-type equal to or later than M5 or C5.

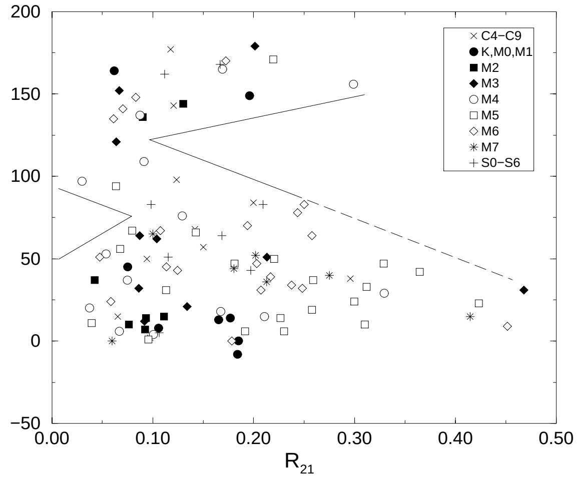

Fig. 3. Phase lag ϕ_{21} as a function of the amplitude ratio R_{21}, with indication of spectral types

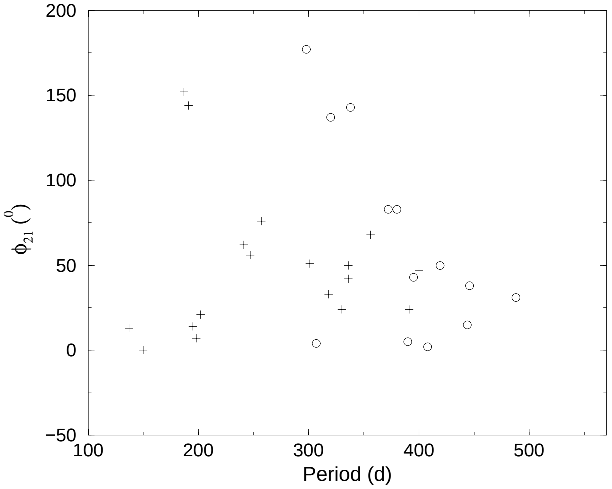

Fig. 4. Phase lag ϕ_{21} as a function of the period for stars belonging to the thin-disk (circles) or extended-disk/halo (crosses) populations

Figure 4 shows the $\{\phi_{21},\, P\}$ distribution of the stars that were found belonging to the thin disk and to the extended disk/halo, i.e. two extreme populations which respectively have the highest and lowest mean masses and metallicities. As expected, these groups are clearly separated by a diagonal line. Stars belonging to the old disk population are spread over the whole period range, with a majority in the region intermediate between the two extreme groups. All this is consistent with the hypothesis that stars are distributed along arccotangent-like lines, which get period-shifted according to the mass and metallicity. The two concentrations around 260 and 375 days may thus be an effect of the local superposition of the main population and the two extreme ones, as different evolutionary tracks lead these stars of different M and Z to resonance at the same period.

According to linear, nonadiabatic pulsation modelling (Barthès & Tuchman 1994, Barthès & Mattei 1997, Barthès 1998), and assuming metallicities typical of the galactic disk and halo, 2:1 resonances may occur in the period range where ϕ_{21} significantly differs from 0 or π. They concern either the fundamental and first overtone modes, if the stars pulsate on the fundamental mode, or the first and third overtones in the case of first-overtone pulsators.

4. Discussion

According to the data that we have collected and confronted, the two main Fourier components of the visual lightcurves of Mira stars seem to be related to each other and to the main period, the spectral type and the galactic population, in a way that suggests a 2:1 resonance between the predominant mode and a higher overtone, significantly contributing to the shape of the lightcurves.

One may object that the period-dependence of ϕ_{21} does not follow the characteristic "bell curve" found in third-order classical Cepheid calculations, but rather the arccotangent curve found in second-order calculations, which is surprising for stars which are expected to have a strongly nonlinear behaviour. This suggests that the observed phenomenon is perhaps not due to resonances in the interior pulsation, but rather to a modulation of the lightcurve by the dynamics of the dust-rich circumstellar envelope. However, the well-known correlation between the circumstellar envelope ([8]–[22], [12]–[25] or [3.5]–[60] excess) and the shape of the visual lightcurve (Vardya et al. 1986, Vardya 1989, Onaka et al. 1989, Little-Marenin & Little 1990) is a correlation with the asymmetry, i.e. with the higher-order harmonics. The first harmonic is thus expected to be the least affected by dust shells. Moreover, the ϕ_{21} "bell curve" does not appear in the case of the observed and theoretical lightcurves of BL Her stars too, though it does appear in the radial velocity (Buchler & Moskalik 1992, Moskalik & Buchler 1993). We thus conclude that circumstellar effects (though necessarily present) are a less likely explanation of the observed behaviour than interior resonances.

The origin of the difference with classical Cepheids may be three-fold: (1) in contrast to the latter case, both 2:1 resoning modes are linearly excited; (2) other low-order modes, too, are close to resonances (Barthès & Mattei 1997); (3) Miras are characterized by strong convection, with significantly varying flux and velocity along the pseudo-cycle. All these peculiarities are likely to significantly perturb the higher-order terms prior to the second-order.

It will be possible to check our conjecture as soon as reliable hydrodynamical modelling of Mira pulsation is achieved. Confrontation with the observation will be facilitated if radial velocity curves of a significant number of stars, by means of spectroscopic monitoring, are made available by that time. In case of positive results, this would be an efficient way to accurately determine the masses of these stars.

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