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High Amplitude δ Sct-type variables

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Abstract

Historically, the high amplitude δ Sct-type variables (δ Sct pulsators with full amplitudes larger than $0.^{m}3$) have been considered as a separated group from the "normal" low amplitude δ Sct variables on the basis, mainly, of their pulsation amplitudes. This has been a subject of controversy by a number of authors. After the review papers by Breger (1979, 1980), the commonly accepted idea is that, independently of the amplitude, the δ Sct variables are normal Population I stars in, or evolving off, the main sequence according to standard stellar evolution theory. This excludes the recently discovered pre-main sequence δ Sct pulsators. Nevertheless, some differences remain and some interesting aspects make these high amplitude objects very useful.

Introduction

High amplitude δ Sct (HADS) stars are a subgroup of the δ Sct-type variables formed by those stars with full amplitudes larger than about $0.^{m}3$, peak to peak. Presently, there are about 150 members catalogued in this group (Rodríguez et al. 2000). Similar to the δ Sct variables with lower amplitudes, they are of Population I. However, by tradition, a few variables of Population II showing similar light curves have also been included into the same group for a long time. They are known as SX Phe variables. Only 13 of these objects are catalogued in the list of Rodríguez et al. (2000) and all belong to the field. Some of them (8) display also high pulsational amplitudes. During the last few years, a great number of these Population II variables were discovered in globular clusters. The subject of the present work is to review the present status of the HADS variables, however some aspects dealt here with will also be applicable to the field high amplitude (HA) SX Phe stars.

Similar to the normal δ Sct variables, the HADS stars represent evolutionary stages of normal Population I stars in main sequence or just post-main sequence phases with radii of about 2-3 $R_\odot$ and masses of 1.5-2.5 $M_\odot$, with solar abundances and low spatial motions typical of Population I. The HADS variables also show period distributions, period-gravity relations and period ratios similar to the δ Sct variables with low amplitudes. However, their rotational velocities are very low ($vsini \leq 45$ Km/s in all cases) as compared with the values ($<vsini>=109$ Km/s) derived from the δ Sct pulsators with amplitudes smaller than $0.^{m}03$ (Rodríguez et al. 2000).

In the following, we consider the term low amplitude δ Sct (LADS) stars for those stars with full amplitudes lower than about $0.^{m}1$ and the term medium amplitude δ Sct (MADS) stars for those variables with amplitudes between about 0.1 and 0.3 mag.

Light curves

Concerning stability of the light curves, it is well known that multiperiodic LADS variables commonly show variations in the amplitude of a number of modes over long time scales (years). This is also shown in some monoperiodic (or nearly monoperiodic) LADS stars as τ Peg (Breger 1991), BP Phe (Poretti et al. 1996) or 28 And (Rodríguez et al. 1993, 1998). Figure 1 shows the case of 28 And where strong amplitude variations take place. Extreme amplitude variations are also found in the multiperiodic LADS star V663 Cas (Mantegazza & Poretti 1990, Poretti et al. 1996) where no detectable or very small variations were found in the period 1999-2003 (Rodríguez et al. 2003). Amplitude variations are also seen in some multiperiodic MADS variables as AN Lyn (ΔV$\sim$0.^{m}20) (Rodríguez et al. 1997) and V1162 Ori (ΔV$\sim$0.^{m}20) (Arentoft et al. 2001).

However, no significant amplitude variations are found in any HADS variable (Rodríguez 1999). Possible exceptions are: the double-mode HADS star AE UMa (Zhou 2001, but not confirmed by Pócs & Szeidl 2001) and the monoperiodic field HA SX Phe variable XX Cyg (Zhou et al. 2002, but not confirmed by Blake et al. 2003).

Concerning multiperiodicity, the LADS stars present very complex pulsational spectra with many independent frequencies and commonly nonradial modes. One example is XX Pyx where 30 frequencies were detected with 22 of them being independent (Handler et al. 2000). In the case of some MADS stars as AN Lyn, 3 independent frequencies were detected by Rodríguez et al. (1997), with at least one being nonradial or V1162 Ori where 6 independent frequencies were detected with most of them likely nonradial (Arentoft et al. 2001). However, if we are dealing with HADS pulsators, they are always monoperiodic or double-mode variables with only radial modes mostly pulsating in the fundamental mode or/and first overtone of radial pulsation. The unique exception seems to be V974 Oph (ΔV$\sim$0.^{m}5) where Poretti (2003) finds five independent frequencies with several likely nonradial modes.

On the other hand, microvariability takes also place in HADS variables. Besides the main periodicities which come from the radial modes, their harmonics and combinations, additional modes with very small amplitudes have also been detected in some HADS stars when analysing the residuals. Commonly, these modes are nonradial. Some examples are the cases of AI Vel (Walraven et al. 1992) where three of such modes were detected with at least one being nonradial or SX Phe (Garrido & Rodríguez 1996) with two additional frequencies and at least one being nonradial. Recently, such kind of microvariability has also been discovered in RV Ari (Pócs et al. 2002) and BL Cam (Zhou et al. 1999).

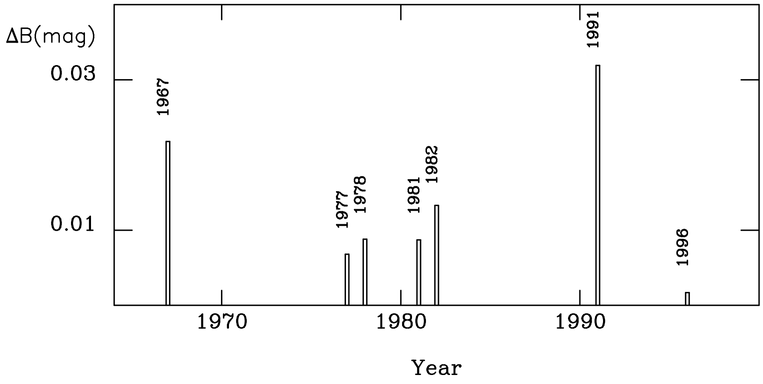

Figure 1: B amplitudes of 28 And in different years.

Phase shifts between light curves

Elst (1978) found phase shifts between light curves collected in different filters, using Johnson UBV photometry, for the variable SX Phe itself. This author found that the light maxima occur later when the corresponding wavelength is longer. Later, phase shifts have also been detected in a number of δ Sct variables. In particular this effect is observed in a large sample of HADS stars, including some field HA SX Phe variables, using both Johnson UBV and Strömgren *uvby* photometry.

In the case of Strömgren photometry, it is also found that the "amplitude ratios versus phase shifts" diagrams for the (v,y) and (b,y) pairs of bands are discriminant between radial and low order nonradial pulsation (Garrido et al. 1990). This discrimination is also valid for the pair ((b-y),y). However, the expected phase shifts, in the case of radial pulsation, are very small (only a few thousandths of period in the case of *vb* filters with respect to the *y* filter). Therefore, very good precision is necessary in order to get reliable mode identifications.

In this way, the HADS variables are very good targets for this kind of mode identification because they present very simple spectra and also the precision in "phase" is much better than in LADS variables (this is inversely proportional to the pulsation amplitude). In this sense, an investigation was carried out by Rodríguez et al. (1996) for all the HADS and field HA SX Phe variables with reliable multicolor Johnson and Strömgren photometry available in the bibliography, concluding that, in all the cases (at least the main periodicities), they are radial pulsators.

m_1-index curve

In Strömgren photometry, the m_1 index is related to metallicity. Moreover, in some pulsating stars in the lower part of the Instability Strip, this index shows variation along the pulsation cycle which is connected with the location of the variable in the Hertzsprung-Russell (H-R) diagram and with its metal content. This offers a possibility to check the atmosphere grids using pulsating variables, but only objects with large amplitudes of luminosity are suitable for this task because of the commonly very small variation taking place in the m_1 index. This is the case of the RR Lyr, HADS and HA SX Phe variables. The HA SX Phe variables always show a large variation of the m_1 index in the same sense of the light curve (that is, m_1 increases when temperature also increases), but no homogeneity is found for the HADS and RR Lyr stars.

This behaviour can be explained when the (β, m_1) versus (T_e, log g) grids are taken into account for different metallicities, in the sense that the $\beta - m_1$ slopes are larger when the metal content is lower (Rodríguez et al. 1991). Moreover, the temperature and surface gravity of the star have to be also taken into consideration, specially for solar abundances or cool objects in the case of low abundances. Figure 2 shows the observed and predicted m_1 index curves for several HADS and field HA SX Phe variables. This allows to build grids relating directly the observations (β-index and Δm_1) with the metal content [Me/H] of the variables.

Period changes

It is well known for HADS variables, from classical O-C analyses of the times of light maximum, that their periods are not constant. The same is true for the known field HA SX Phe pulsators. These variables are very good targets for this analysis because of their very simple spectra and high amplitudes and, hence, very good precision in determining the times of maximum. On the other hand, period changes are expected to reflect the evolutionary changes in radius. Thus, it is a good tool to test the evolutionary status of these stars and the evolutionary tracks across the H-R diagram.

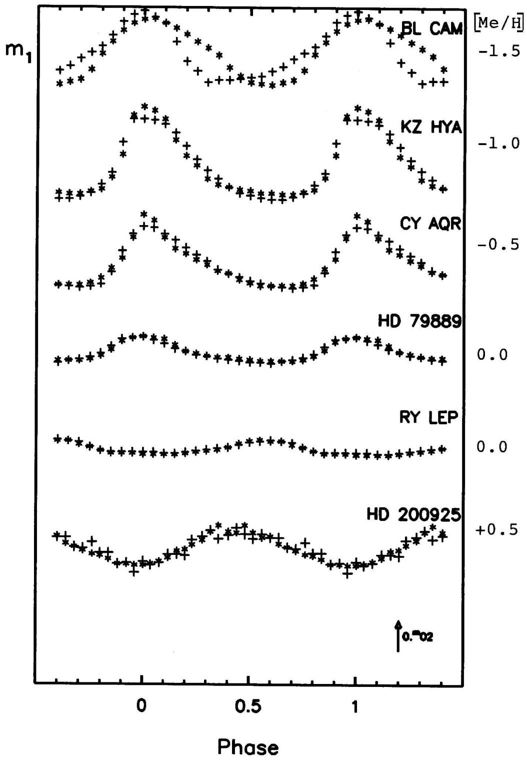

Figure 2: Observed (+) and predicted (*) variations of the m_1-index over the pulsation cycle for several stars using the grids of Kurucz (1979) at the corresponding metal abundances: BL Cam, [Me/H]=−1.5; KZ Hya, [Me/H]=−1.0; CY Aqr, [Me/H]=−0.5; HD 79889 and RY Lep, [Me/H]=−0.0; HD 200925, [Me/H]=+0.5.

The period changes predicted by evolution models within the boundaries of the δ Sct instability strip are always positive, except in the zone of the overall contraction phase where the evolutionary periods are decreasing. However, the evolution in this zone is very quick and, hence, the probability of finding a star there is very small. In the rest of the δ Sct region, typical period increases of $\sim 10^{-9}y^{-1}$, in units of dP/Pdt, are predicted for main sequence stars and of $\sim 10^{-7}y^{-1}$ for post-main sequence stars.

However, these predictions are not in good agreement with the changes derived from the observations (Rodríguez et al. 1995, Breger & Pamyatnykh 1998). In fact, the observational characteristics can be summarized as follows: a) positive and large period changes in HADS stars with the shortest periods, b) negative changes in HADS stars with long periods, c) negative changes in HA SX Phe variables, d) possible sudden jumps in a number of stars and e) different rates of variation for different modes of the same star. None of these observational features are explained by evolution. Hence, the observed period changes are not caused by stellar evolution alone.

It should be very interesting to study the period changes taking place in pre-main sequence

δ Sct variables because the predicted evolutionary period changes are negative with rates of 10-100 times larger than those occurring in main sequence and post-main sequence stars. Thus, the period changes caused by evolution should not be hidden by other effects. However some caution is necessary for these stars because none of them is, up-to-date, known to be of high amplitude and the frequency spectra are, in general, more complex. Moreover, the evolution within the instability strip as a pre-main sequence star is very rapid. Hence, the probability of finding a star in this phase of evolution is very small as compared with that of finding it in a main-sequence stage.

Multiplicity can also be derived through the residuals remaining from the O-C analysis of light maxima. Sometimes, these residuals can be attributed to the light-time effect produced in a binary system. Nevertheless, such detections are very difficult and only analyses with data of high quality and very long time baseline are reliable for this task. Therefore, only pulsators with high luminosity amplitudes and simple frequency spectra (only one or two periods) are good candidates for such studies.

Period-Luminosity relation

Period-Luminosity-Colour (P-L-C) relations are very important as they provide distance scales into the Universe. In the case of the HADS stars, only a P-L relation is needed because the width of the HADS strip is very small, less than 500 K (McNamara 1997). Another advantage of these stars concerns the fact that they are mostly known as radial pulsators with very simple spectra (monoperiodic or double-mode pulsators) and that they are pulsating in the fundamental mode and/or first overtone of radial pulsation. Then, the pulsational mode identification is relatively easy.

Moreover, the HADS variables provide a new distance scale which is independent from the classical existing ones, such as from classical Cepheids and RR Lyr stars. However, there is some problem because of the faintness of a lot of these variables, which implies that only very few of them are known with accurate luminosities. This will be solved, for example, with the parallaxes to be obtained by the GAIA satellite to be launched in a few years. Nevertheless, precise P-L and P-R (radius) relations have recently been obtained for HADS or HADS/classical Cepheids variables (McNamara 2002; Laney et al. 2002, 2003).

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