Do δ Sct - γ Dor hybrid stars form a distinct group of variables?

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Abstract

Investigation of main sequence A and F stars have shown that γ Dor - δ Sct hybrid stars do not concentrate in the overlapping region within the HRD, where the δ Sct and γ Dor Instability strips (IS) overlap, but rather the hybrid stars follow basically the δ Sctf Instability strip.

High order g mode pulsation of γ Dor stars require a certain depth of the base of the convective envelope in order to drive those g modes. This condition is fulfilled near the red border of the δ Sct IS, where the γ Dor stars are located. In contrast, hybrids exhibit as well g modes, but their frequencies cannot easily be explained by the same mechanism as the γ Dor stars.

Moreover, a statistical comparison of the p mode pulsation to δ Sct stars shows a different behaviour. When plotting 1) the dominant pulsation mode of each of these two groups against their effective temperature, the δ Sct stars show a correlation of their main pusation period with T_{eff}.
2) If the average of the three dominant modes is considered the same evidence is present. Both relations are not followed by hybrids.

Hybrid stars are known, which exhibit three distinct groups of frequencies (e.g. HD 8801, HD 114839, BD +18 4914). They exhibit a narrow range of excited modes with gaps in between. The intermediate group could probably be explained by low-order g modes (in contrast to γ Dor stars which have high-order g modes excited).

On the other hand, classification spectroscopy has shown that these stars are not giants nor subdwarfs, but coincide well with the δ Sct and γ Dor stars. Do hybrid stars comprise a distinct class of pulsators within the δ Sct instability strip?

Introduction

δ Sct are main sequence A to F type stars pulsating with p modes within the extended Cepheid instability strip (IS). The driving mechanism of their pulsation is the κ-mechanism acting in the He II ionisation zone.

γ Dor stars are late A to early F type stars located at the red edge of the δ Sct IS on the main sequence. The class of γ Dor stars was defined by Kaye et al. (1999). These stars pulsate in contrast to the δ Sct stars in high-order low-degree g-modes.

The instability domains of both groups overlap, hence hybrid stars, pulsating like δ Sct in the high frequency domain and like γ Dor in the low frequency regime are expected and discovered.

Studies of large samples of γ Dor, ds and hybrids were carried out (Hareter, PHD thesis, Uytterhoeven & WG10, KASC 2011) where surprisingly, the hybrid stars are not confined to the overlapping region in the HRD, but spread over the whole ds IS, including the γ Dor IS.

CoRoT LRa01 data

For this study, we concentrate on the stars observed in the CoRoT LRa01. The sample was selected by visual inspection of all the 11400 light curves and the determination of the fundamental parameters was performed on the AAOmega classification spectra.

The CoRoT light curves were corrected for discontinuities and outliers. If resampled light curves were encountered, they were rebinned to 8 minute sampling for increasing the speed of the frequency analysis using SigSpec.

The careful analysis of the SigSpec output for our program stars resulted in 90 γ Dor, 30 γ Dor candidates, 59 hybrids, 57 hybrid candidates and 90 δ Sct stars. The high number of candidates is due to ambiguous identifiactions of the low frequencies. Generally their number of potential g modes is low and they may be caused by rotation, binarity, residual instrumental effects, or other effects than g mode pulsation.

Temperature Determination and Instability Domains

The AAOmega spectra (Sebastian et al. 2012) were used for the determination of temperature and log g. This was achieved by fitting synthetic spectra to four temperature-sensitive spectral regions: Ha, Hb, Hg and the Ca K line at 3933 A.

The synthetic spectra were calculated from ATLAS9 (Kurucz 1993) model atmospheres and line lists extracted from VALD (Ryabchikova et al. 1997; Kupka et al. 1999; Piskunov et al. 1995) using the synth3 code (Kochukhov 2007). solar abundances were assumed for all stars.

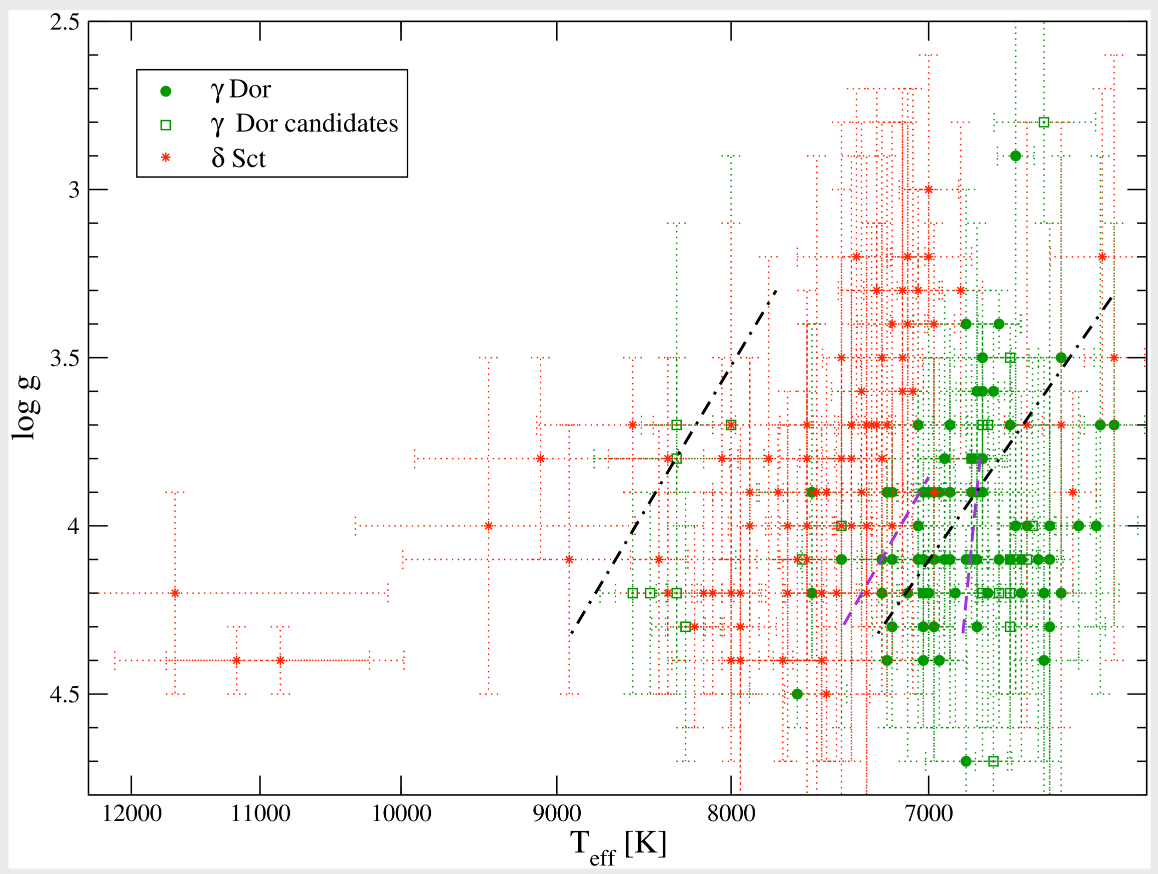

Fig. 1. T_{eff} - log g diagram for δ Sct (red asterisks) and γ Dor (green filled circles) stars. The black dash dotted lines indicate the δ Sct IS and the dashed purple lines that of the γ Dor stars .

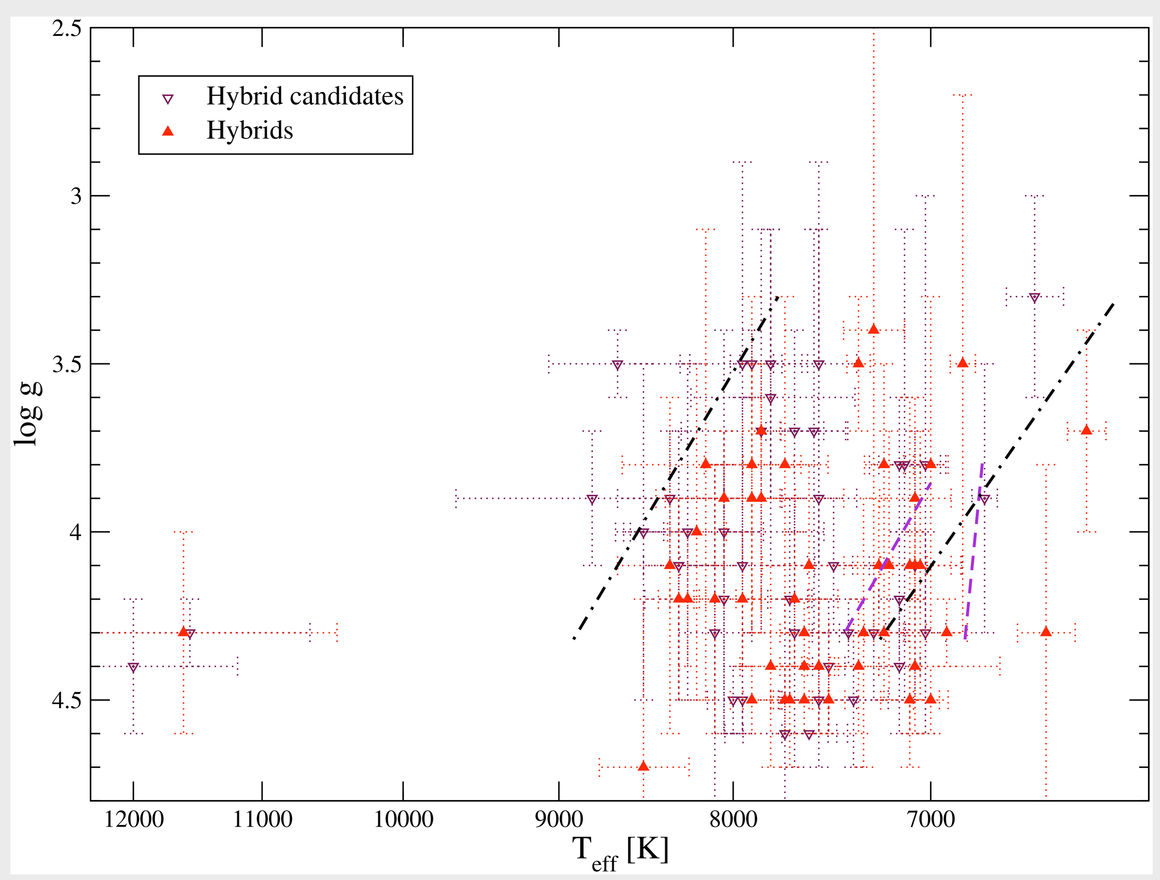

Fig.2. Same as Fig. 1. but now for hybrids (red upward triangles) and hybrid candiates (purple open downward triangles).

g modes

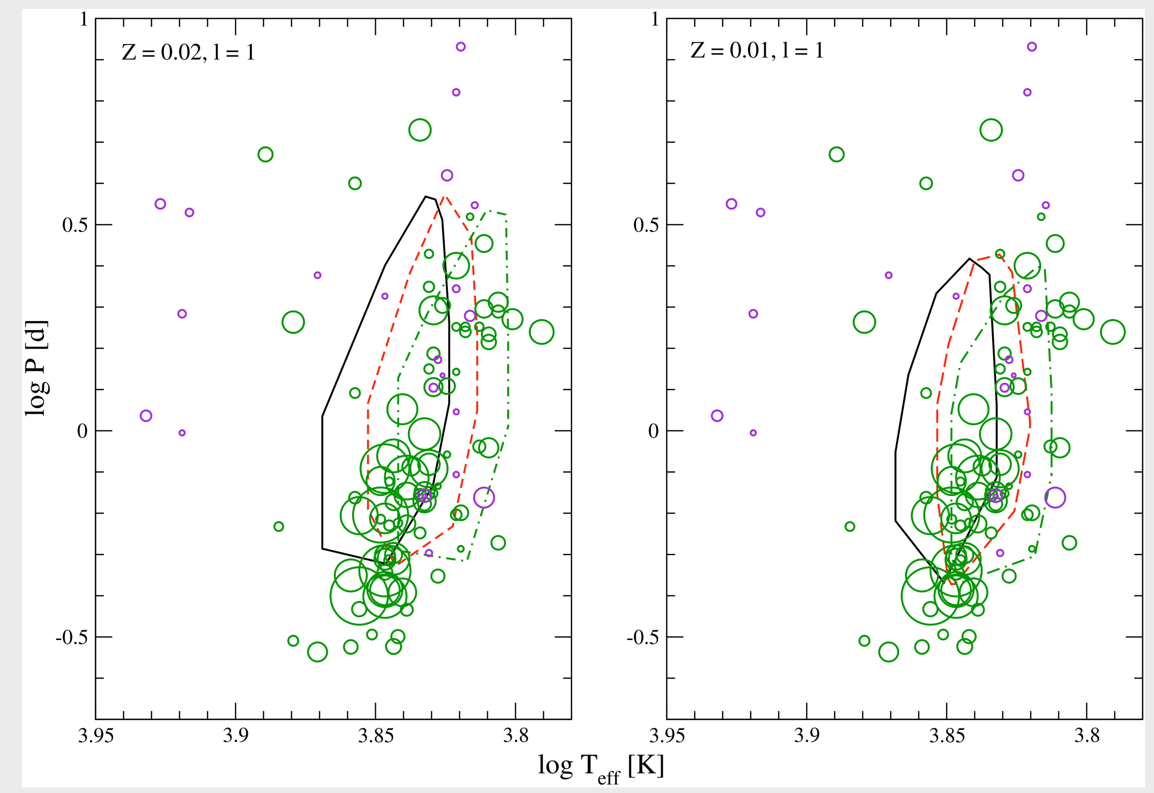

Fig. 3. Comparison of observed frequencies of pure γ Dor stars to unstable theoretical frequencies (l =1) of different mixing length. Black full lines: α_{MLT} = 2, red dashed lines: α_{MLT} = 1.7, green dash dotted lines: α_{MLT} = 1.4. The green circles represent the γ Dor stars and the purple circles the γ Dor candidates. The symbol sizes correspond to the amplitudes. The left panel shows the comparison for Z = 0.02, the right panel for Z = 0.01.

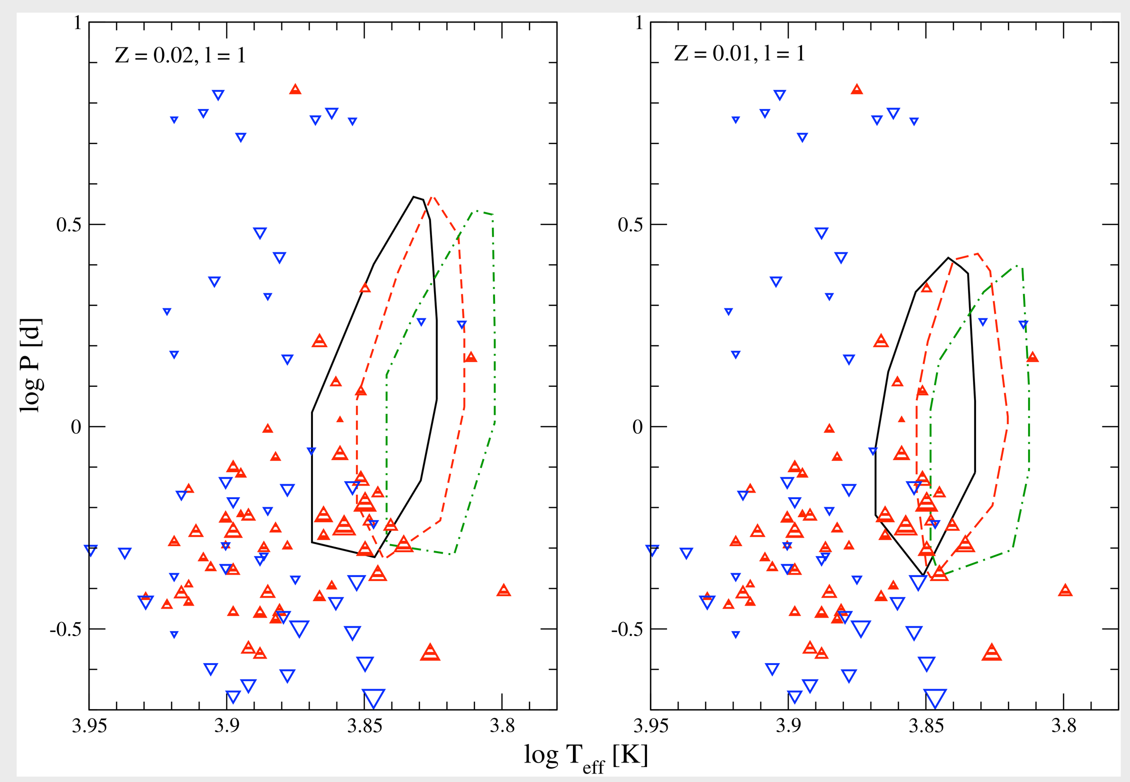

Fig. 4. Same as Fig.3. but for the g modes of hybrid (red hatched upward triangles) stars and candidates (blue open downward triangles).

Theoretical g mode Frequencies

The frequencies of γ Dor models were provided by A. Miglio (private communication). The stellar models were calculated using the codes CLÉS and the adiabatic oscillation frequencies were calculated by the code LOSC (Scuflaire et al. 2008a,b). The computation of these frequencies were done for two different metallicities (Z = 0.01 and Z=0.02) and three different mixing-length parameters α_{MLT} = 2.0, 1.7 and 1.4.

p modes

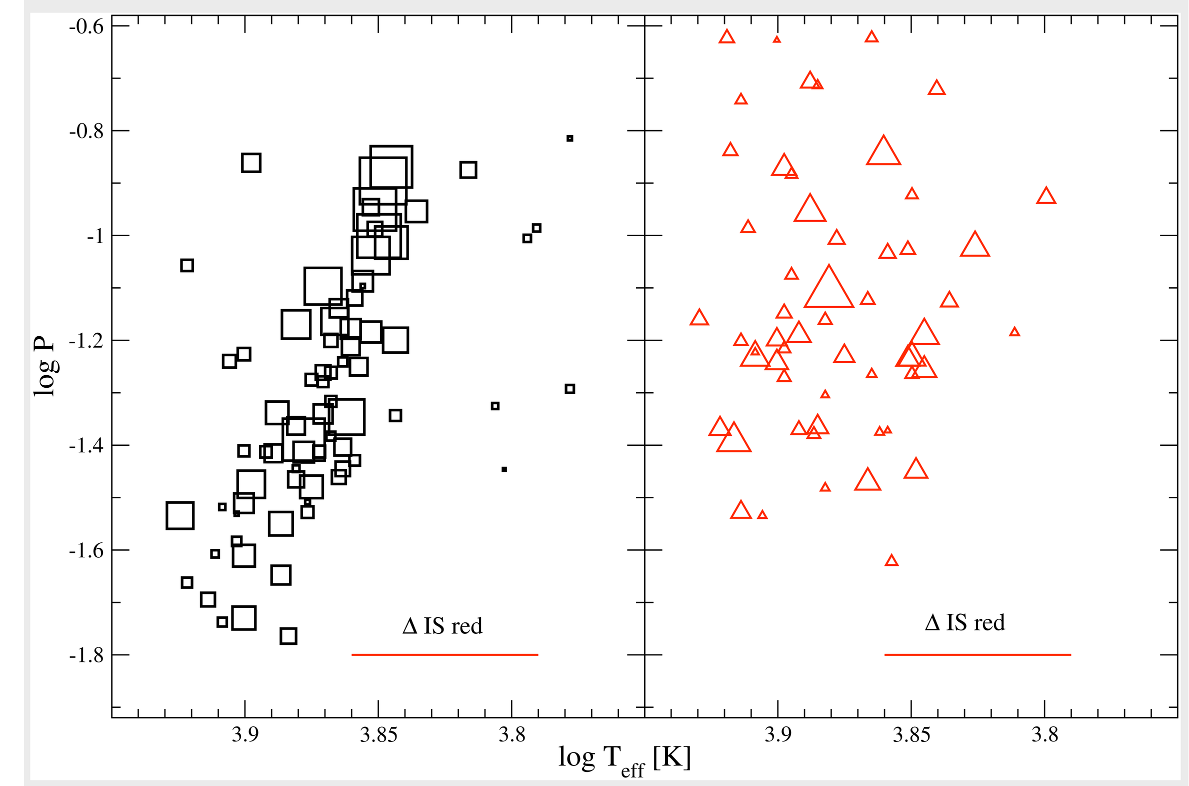

Fig. 5. Comparison of the observed p mode periods of the δ Sct stars (left panel) to that of hybrids (right panel). The symbol sizes correspond to the amplitudes.

Discussion & Conclusions

Fig. 1 and 2 show the instability domains of γ Dor, δ Sct, and hybrid stars. Hybrids are not confined or concentrated at the overlapping ISs of γ Dor and δ Sct but rather spread the whole δ Sct IS.

For the following comparisons T_{eff} was plotted against log P, where P is the average period of the three periods with the stronges amplitudes for each star.

Fig. 3 compares the g modes of the pure γ Dor stars to theoretical frequencies of l=1 and shows a good agreement for frequencies calculated with α_{MLT} = 2.0 and 1.7. Fig. 4. compares the g modes of hybrids to the same theoretical frequencies and shows that the g modes of hybrids cannot be expained in the same way as that of pure γ Dor stars.

If the same analysis is employed for p modes of δ Sct and hybrid stars, the picture even gets more complicated. From Fig.3 to 5 we conclude that:
1.) the g modes of the hybrid stars cannot be explained by the convective flux blocking mechanism, since these stars are on average too hot.
2.) The p modes of hybrids give also a different picture than that of pure δ Sct stars.

Thus, the question arises if in fact the hybrids are a different group of pulsators. A recently published theory by Shiode et al. 2012 predicts stochastically excited g modes of massive stars (2 - 3 Msun). Possibly, we have detected such g modes. The question for the p modes is at this stage still open.

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