PMS versus Post-MS

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Abstract

Close to the main sequence the HR diagram is confusing, as stars of similar global properties but with different stages of evolution occupy the same position. Pulsating stars (both PMS and Post-MS) were discovered in this area. In some cases the young PMS stars are recognized through specific characteristics - for instance the presence of nebulosity or high degree of activity. An alternative is to take advantage of seismological information whenever it is possible. In this case the discrimination between PMS and Post-MS can be made using differences in their oscillatory frequency distributions in the low frequency range.

1. Introduction

In the vicinity of the main sequence, the HR diagram is confusing as stars of similar global properties but different stages of evolution lie at the same position. The outer layers of PMS and Post-MS stars having the same effective temperature and gravity are very similar. For pulsating stars, as these layers drive the pulsation in this range of temperature, it is reasonable to expect that PMS stars in the instability strip are also destabilized by a classical opacity mechanism with a similar range of unstable modes as for the Post-MS stars. This supports the vibrational instability as explanations for few stars which are suspected to be in the PMS stage (HAEBE type stars).

Differences, on the other hand, exists (in the deep interior) between the two stages: whereas PMS are relicts of the gravitational contraction phase, the Post-MS stars develop chemical inhomogenities. What is the imprint of these differences on the observable (near-surface *f*-, *p*- modes) modes of the stars? Is it possible to decide the evolutionary status of the stars using only the asteroseismological data? Some of the answers will be given in this paper.

2. Evolutionary tracks

In the early stages of PMS evolution, rapid dynamical and thermal processes occur which modify the internal structure of the protostar. By the time when a 1.8$M_{\odot}$ protostar reaches the classical instability strip on its way towards the main sequence, these complex phenomena have long disappeared and the evolution has considerably slowed down. The usual quasi-static approximation then holds and it is assumed here. Rotation is not considered and the star is modeled in the spherically symmetric equilibrium state.

Equilibrium models have been computed with the **CESAM code** (Morel [1])), an evolutionary code with a numerical accuracy of first order in time and third order in space. The evolutionary model is built with ~300 mesh points in mass, but to perform detailed pulsation calculations, the mesh has been extended to 2400 mesh points, using spline interpolation functions. An EFF equation of state (Eggleton et al. [2]) , opacities from Livermore Library (Iglesias & Rogers[3]) completed at low temperature (T<10000K) by Alexander & Ferguson [4], nuclear reaction rates of Caughlan & Fowler ([5]), standard mixing length treatment of convection with solar α=1.67, X=0.71, Y=0.27, Z=0.02, and a standard solar mixture of heavy elements (Grevesse & Noels [6]) are used in our calculations (as sufficient approximations for an 1.8$M_{\odot}$ star).

Fig. 1 shows the evolutionary track running from the latest PMS stages to the early Post-MS ones for our 1.8$M_{\odot}$ star. We plot results from two different evolutionary codes – CESAM code (C, already discussed) and Henyey code (B, based on classical ‘old‘ libraries and equation of state) - both implemented on a **Silicon Graphics ALTIX system**.

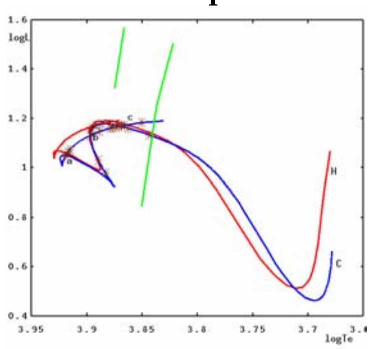

Figure 1. The evolutive tracks of 1.8 $M_{\odot}$ star in the HR diagram using CEASAM(C) and HENYEY(B) codes. We have labeled the common points (PMS,Post-MS) as a.,b.,c. The edges of the instability strip are also shown.

On the track, three common points of the PMS and Post-MS (labeled as a-, b-, c-) can be found for both C and B models (see Tab. 1).
The comparative physical structures of the $1.8M_{\odot}$ in the point **c.** (both the PMS and Post-MS evolutive stages) are shown in Fig.2. We choose point **c.** because here the differences between PMS and Post-MS stages are maximal (far stellar evolutive points on each branches). As expected, the outer layers of associated models are very similar (practically the same κ- and Γ_1 profiles). On the other hand, the central regions differ significantly (differences in ε- profile). The PMS model is still contracting and *remains chemically homogeneous.* By contrast, the Post-MS model *has already developed,* in the central region *a μ chemical gradient.* The signature of this chemical gradient (due to hydrogen depletion and the fully mixing in the central core) on the Post-MS stage is clearly seen on the profile of th Brünt Vaissälä frequency, N.

	Log T	Log L	R	Age	X_c	r_{conv}
a.M13	3.919	1.050	1.621	4.8	0.7134	0.186
M16	3.920	1.044	1.608	300.	0.6383	0.204
b.M8	3.897	1.129	1.970	1.25	0.7142	0.221
M19	3.897	1.131	1.978	900.	0.4355	0.191
c.M4	3.872	1.170	2.319	0.7	0.7142	0.068
M23	3.872	1.167	2.312	1160.	0.3132	0.180

Table 1. Common PMS and Post-MS points on the track of an $1.8M_{\odot}$ star. Ages are in Myr, luminosities and total stellar radius, in solar units, convective radii r_{conv} in unit of the total stellar radii and X_c (the central hydrogen content) in percentage.

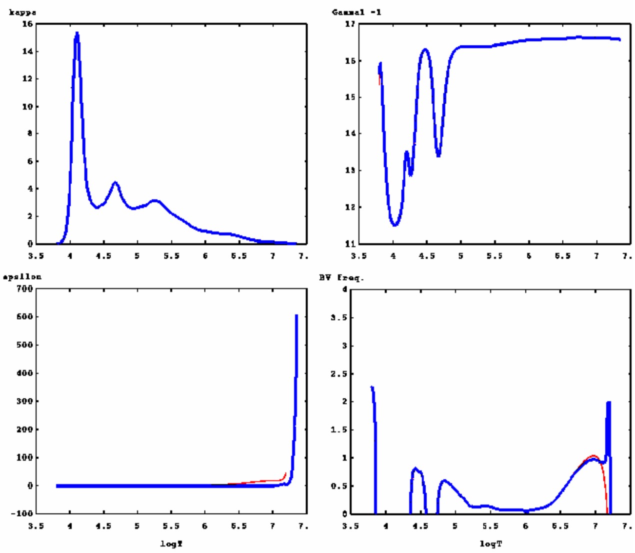

Figure 2. The structure of the stars in the common point c. Thin line-PMS star, thick line– Post-MS star. We have represented (from top left): κ, Γ_1, ε, and Brunt-Vaissala frequency.

3. Nonradial pulsations

The question which we address is: would it be possible to discriminate the evolutive stage using only asteroseismological data (frequency differences), even though the stellar surface parameters for the three points are the same? If YES, which kind of different phenomena can be inferred in the PMS and Post-MS stages.

This problem can be understood more easely comparing the nonradial pulsationary properties (the power spectrum) for the $1.8M_{\odot}$ star during the whole stellar evolutionary track (see Fig.3).

For the calculation of the nonradial pulsations we use a **LNAWENANR code** (a linear, non adiabatic, non radial code) implemented also on the **SGI ALTIX platform**. We use an eigenfrequency range $0 \leq \omega_R \leq 16$ (which include *g-, f-, p-* modes, *n ranging from -10 to 10*), a spectrum range *l* = 0-2, with *κ-, Γ_1- and ε- pulsation mechanisms inferred*, and in place of ω_I we use the Dziembowski unitary parameter η.

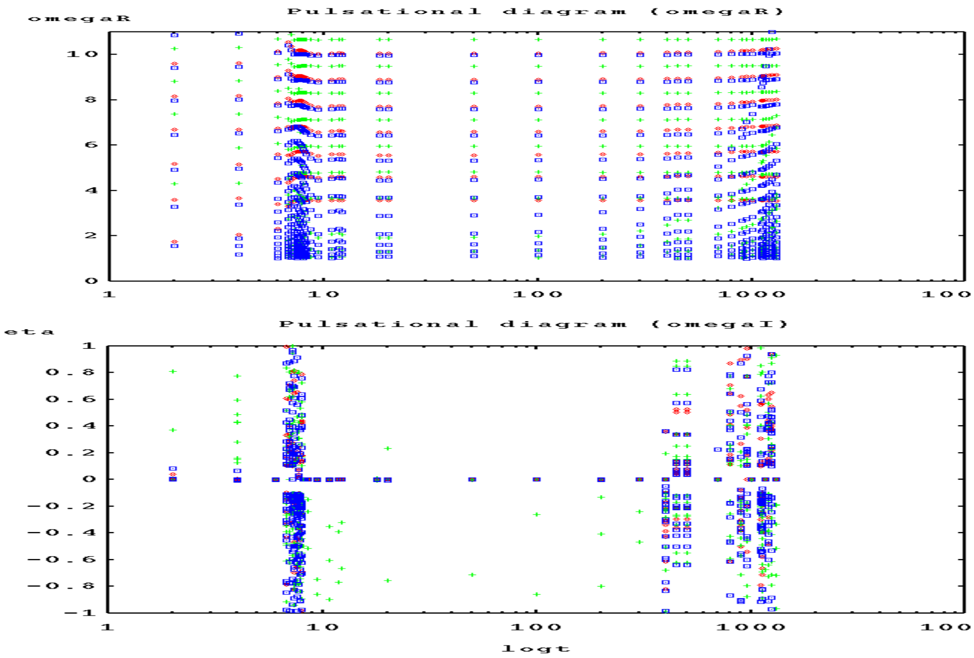

Figure 3. The evolutive power spectrum. Top: ω_R; bottom: ω_I. Time in Myr.

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Our calculations show that in the instability strip (both in the PMS and the Post-MS regions) the main destabilizing pulsationary mechanism remains the κ- mechanism. The ZAMS and post-MS pulsationary region is occupied by well known δ Scuti stars, and the PMS pulsationary region is occupied by HAEBE (Herbig Ae/Be) stars. Our point **c.** and possible **b.** point (depending on the location of the blue limit of the instability strip) lies in this region.

Another instability region is present near ZAMS (including PMS, ZAMS, Post-MS phases), our point **a.** lying to this region. This zone represents a prolongement of the instability region which extends between β-Cephei (destabilizing κ- mechanism, high *g*-modes) to Sun-like pulsators (chaotic surface excitation mechanism, *p-* modes).

In the present paper we restricted only to the instability strip. Two distinct disturbative phenomena can be seen on the [evolutive] power spectrum, one in the PMS region and other in the Post-MS region. If in the latest Post-MS stages the well known *effect of avoid crossing* (mode penetrating) is present, new phenomena are seen in the PMS region: *the bump of modes* and *the occurrence of strange modes*. These phenomena are related both to the complicate interaction of convection and pulsation for the PMS stars. Indeed the transaction from the convection to the radiation and the interaction with pulsation in a PMS star are complicated (and not yet well explained!) phenomena. Finally, the frequency calculations show the existence of strange modes, *i.e.* surface modes trapped in the very superficial outer layers. Whether these modes are excited or are not is probably strongly dependent on the convection-pulsation interaction, which is very approximately taken into account in our paper.

The comparison between the pulsational properties (l = 2), for the three common points a-,b-,c-, are presented in Fig.4. The differences between modes are due to the presence of that two disturbing phenomena - bumps of modes in the PMS region and avoid crossing/penetrating modes in the post-MS stages.

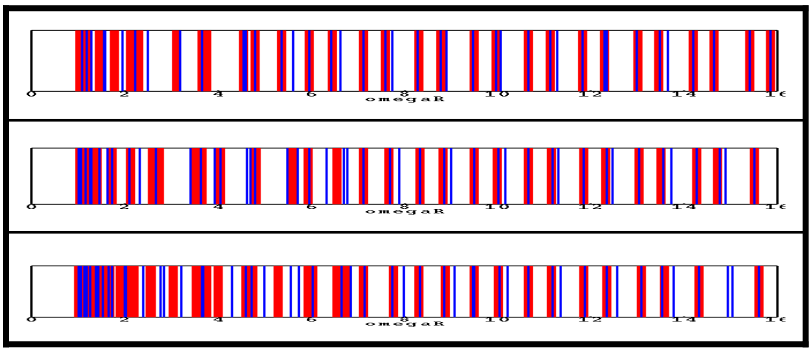

Figure 4. The comparative power spectrum (l=2) in points a-, b-, c- (from top to bottom).Thin line – PMS star, thick line – Post-MS star.

4. Conclusions

PMS star of 1.8M$_{\odot}$ crossing the classical instability strip on the way to the ZAMS, are found to be vibrationally unstable (HAEBE stars), destabilized by the same mechanism as for the δ Scuti stars, indicated as ZAMS or Post-MS stars. The asteroseismological differences between the PMS and Pot-MS stars are due to two different mechanisms which are present during the evolution of the $1.8M_{\odot}$ star.

One is the well known avoid crossing phenomenon for the Post-MS evolution, which gives birth to the penetrating modes. The other, is a new discovered phenomenon (Suran et al. [7]), the bump of pulsating modes for PMS stars which gives birth to different hieratic, strange, modes. These modes are complicated and represent the interaction of convection with the pulsation in the early stages of the stellar evolution.

Our results could be directly applied to the star V351 Ori, a prototype of such a PMS/Post-MS star, which has an estimated mass of $\sim 1.8M_{\odot}$, and lies very close to our point **c.** on the HR diagram

On the other hand, we must find out observationally more PMS/HAEBE and POST-MS/δ Scuti stars sharing the same HR region. The future asteroseismological COROT mission – in which our team intends to participate – could be such a good observational opportunity.

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