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Pulsation in Herbig stars: an idea of Francesco and its realization

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Abstract. We first briefly recall the importance of studying pulsating stars to infer stellar properties and then focus on pulsating Herbig Ae stars, expected to cross the instability strip during their evolution towards the Main Sequence. We illustrate the first theoretical prediction of the instability strip for these stars as based on an idea of Francesco and the huge impact of these results for subsequent observational ground and space-based studies, as well as for further theoretical investigations. Finally we discuss how pulsating Herbig Ae stars can be used to infer individual ages of young stars in clusters and associations, an application that has been fascinating Francesco during the last few years of his activity in the field.

Key words. Stars: variables: delta Scuti – Stars: pre-main sequence – Stars: fundamental parameters – Stars: evolution

1. Introduction

Pulsating stars are intrinsic variables showing cyclic or periodic variations on a time scale of the order of the free fall time. In the simplest case they are radial pulsators, simply varying their volume and brightness but with approximately constant spherical shape. Among the various classes of pulsating stars, the most studied in the literature are Cepheids and RR Lyrae but there are many other classes associated to different evolutionary phases in the Hertsprung-Russell (HR) diagram. Pulsating stars are easily recognized thanks to their light variation. Moreover, the pulsation periods and amplitudes have the great advantage of being unaffected by distance and reddening uncertainties and are instead related to the intrinsic stellar parameters. In particular, the well known Period-(Mean) Density relation, combined with the Stefan Boltzmann law, imples a tight correlation connecting the pulsation period to luminosity, mass, and effective temperature of the pulsator. Then, a theoretical and observational study of pulsating stars allows us to constrain their intrinsic properties and to use them both as tracers of stellar populations, of different age and chemical composition, and as distance indicators. Pulsating stars lie within an almost vertical region in the HR diagram called instability strip. Figure 1 shows the location of the most common classes of pulsating stars in the HR diagram. Among these, classical δ Scuti are Main-Sequence and post-Main-Sequence stars that cross the pulsation instability strip during their evolution from the Zero Age Main Sequence (ZAMS) (see e.g. McNamara et al. 2007, and references therein).

But the real first crossing of the instability strip occurs earlier in the evolution, when young stars contract from the birthline to the ZAMS on the Kelvin-Helmholtz time scale. Indeed, during their evolution toward the

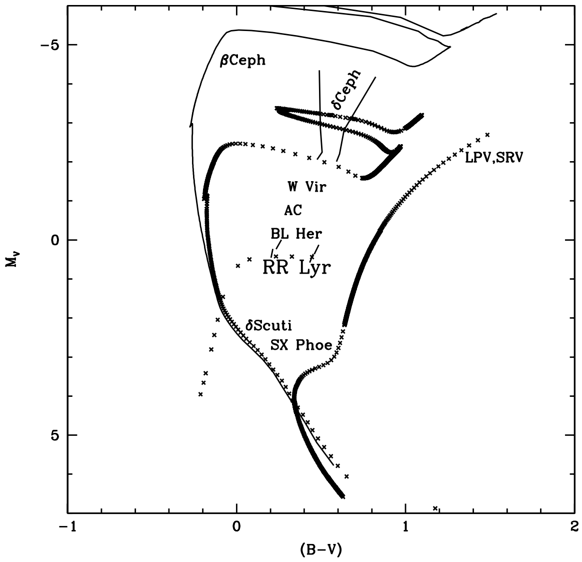

Fig. 1. The instability strip of most common pulsating stars.

ZAMS, intermediate mass ($1.5 \leq M/Mo \leq 4.0$) Pre-Main Sequence (PMS) stars can cross the instability strip of more evolved δ Scuti.

2. Francesco's idea

The presence of Scuti-like pulsation among Herbig Ae stars was originally suggested by Breger (1972) who discovered two candidates (V588 Mon and V589 Mon). However, this evidence was based on only few hours of observation in 3 nights separated by several months. Subsequent observations by Kurtz & Marang (1995) for HR5999 and Donati et al. (1997) for HD104237 seemed to confirm the existence of δ Scuti like pulsation among intermediate mass PMS stars.

In those years Francesco's had the idea of producing the first theoretical prediction for this still almost unexplored class of pulsating stars. In fact, we computed the first theoretical instability strip (Marconi & Palla 1998) for the first three radial modes on the basis of nonlinear convective radial pulsation models selected along the PMS evolutionary tracks by Palla & Stahler (1993).

In our paper (Marconi & Palla 1998) we evaluated the nonlinear modal stability for the Fundamental, the First and Second Overtone modes and estimated the crossing time of the produced instability region to be of the order of 5-10 % of the total contraction time towards the MS ($10^5 \div 10^6$ years).

This theoretical paper triggered a burst of activity both from the observational and the theoretical point of view, as outlined in the following two subsections.

2.1. Observational follow up

The theoretical investigation presented in Marconi & Palla (1998) stimulated the selection of Herbig Ae stars (infrared excess, H emission), expected to lie between the predicted boundaries of the instability strip. Herbig Ae/Be stars are young intermediate mass stars ($1.5 - 2 < M/M_{\odot} < 8.0$) showing some (or all) of the following features: spectral type B-A/F(early), strong IR (and/or UV) excess, H_α emission (Balmer lines), photometric and spectroscopic variabilities (time scale from hours to years), interaction with the stellar environment.

Several pulsating Herbig Ae candidates have been studied both from the ground and from the space (see e.g. Marconi et al. 2000, 2001; Ripepi et al. 2002, 2003; Pinheiro et al. 2003; Zwintz et al. 2005, and references therein) and after about six years the number of PMS δ Scuti stars had increased by 15 (see e.g. Marconi & Palla 2003, 2004; Marconi et al. 2004, and references therein).

The ground based investigations of PMS δ Scuti candidates also aimed at identifying possible targets for space missions. As an example, Cusano et al. (2011) performed a a photometric and spectroscopic follow-up of the star forming complex Sh 2-284 using VIMOS, identifying 8 very good candidates for PMS δ Scuti-type pulsation. One of them was then observed by CoRoT (target CoRoT 102699796) and found to lie at the intersection between δ Sct and γ Dor stars, likely representing the first PMS hybrid γ Dor – δ Sct pulsator (see Ripepi et al. 2011, for details).

Similarly, following Francesco's suggestion, a number of $A - F$ pre-main-sequence stars in the Upper Scorpius association was selected to be observed by the Kepler satellite. As a result 6 new PMS δ Scuti and 1 PMS γ Dor were identified (Ripepi et al. 2015), as represented in Figure 2.

In general, using photometric time series from ground and space (MOST, CoRoT, Spitzer and Kepler), in some cases complemented by spectroscopic investigations, the number of confirmed PMS δ Scuti stars has increased up to about 50 (see e.g. Bernabei et al. 2007; Cusano et al. 2011; Marconi et al. 2000, 2001, 2002; Marconi & Palla 2003; Marconi et al. 2004; Pinheiro et al. 2003; Ripepi et al. 2002, 2003, 2006, 2007, 2010, 2011, 2014, 2015; Zwintz et al. 2005; Zwintz & Weiss 2006; Zwintz et al. 2009, 2011, 2013, 2014).

2.2. Theoretical follow up

From the theoretical point of view, on the basis of the empirical evidence of pulsating stars bluer than the second overtone blue edge predicted by Marconi & Palla (1998), the effect of possible metallicity variations was investigated. However, also decreasing the metallicity by a factor 2 was not enough to reproduce the location of observed pulsators in the blue region of the HR diagram. On this basis, it was early hypotesized the occurrence of higher radial modes, then observationally confirmed in many δ Scuti stars and predicted by various authors (see e.g. Grigahcene et al. 2006, and references therein). Moreover, PMS δ Scuti stars have been found to pulsate both in radial and nonradial modes (Suran et al. 2001; Ruoppo et al. 2007; Degl'Innocenti et al. 2008; Di Criscienzo et al. 2008; Guenther et al. 2009; Marconi et al. 2008) and specific tools have been developed to use the observed large frequency separation to constrain the position in the HR diagram (see e.g. Ruoppo et al. 2007; Di Criscienzo et al. 2008; Casey et al. 2013, and references therein).

3. PMS δ Scuti as age indicators

In the latest years of his activity Francesco was particularly fascinated by the idea of using seismic analysis to identify young stars and their evolutionary status. In a paper with Steven Stahler (Stahler & Palla 2014), they nicely introduced a work by K. Zwintz (Zwintz et al. 2014) on the variation of the oscillation frequencies with ages.

As a consequence of the well known Period-Density relation, in a given cluster or association, the hottest and most evolved stars have the highest maximum frequency values and pulsate with the shortest periods.

For a sample of nine pulsating pre-MS stars in the young cluster NGC2264 investigated with MOST and CoRoT, Zwintz et al. (2014) find that the least-evolved stars pulsate slower than do the objects that are already located closer to the ZAMS. This occurrence implies sequential star formation in NGC2264 with a dispersion in age of about 5 Myr. This approach has also been applied to the Upper Scorpius association (Ripepi et al. 2015) but, differently from the case of NGC2264, the maximum oscillation frequency is similar for all the investigated Upper Scorpius members, likely implying a small age dispersion.

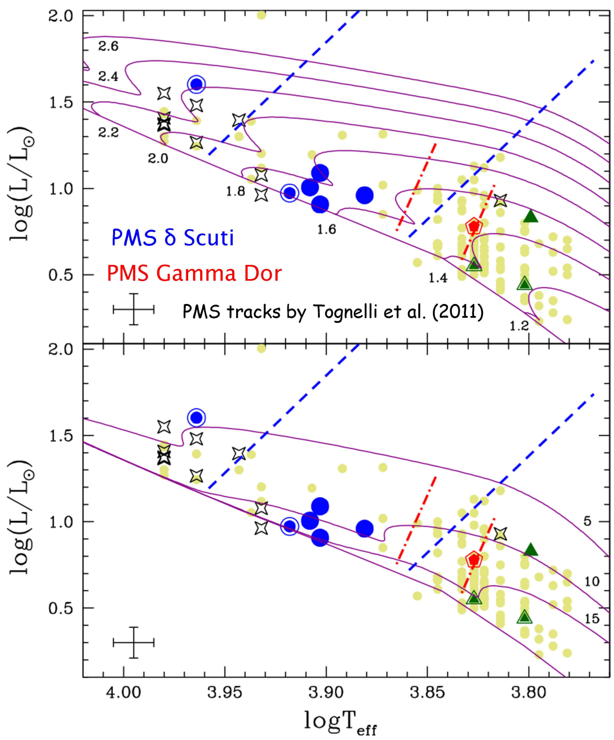

Fig. 2. Identification of the new PMS δ Scuti (circles) and PMS γ Dor (pentagon) in Upper Scorpius. The instability strips of δ Scuti (dashed lines) and γ Dor (dot dashed lines) are overimposed to the PMS evolutionary tracks predicted by Tognelli et al. (2011).

4. Conclusions

PMS δ Scuti stars are Herbig Ae stars crossing the instability strip while evolving towards the ZAMS and the investigation of their pulsation properties is important to constrain PMS structure and evolution. Francesco had the successful idea of theoretically predicting the Instability Strip for the first three radial modes of candidate PMS δ Scuti.

This theoretical result had a significant impact on the study of young pulsating stars with many new observational and theoretical works that produced an impressive increase of the number of known PMS δ Scuti stars as well as significant progress in our knowledge of young stars.

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