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Relevant issues in the study of Pre-Main Sequence δ Scuti stars

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Abstract

We will review the theoretical and observational developments in the study of Pre-Main Sequence (PMS) δ Scuti stars and point out some current open problems. In particular, we stress the strong need for multi-site and/or space-based observations and for nonradial pulsation modelling. The most recent observations of the best studied object, V351 Ori, and the preliminary results of the application of a nonradial code to PMS δ Scuti stars will also be discussed.

Introduction

The PMS evolutionary phase starts when a stellar structure becomes optically visible at the end of the protostellar phase and ends with the arrival on the Main Sequence. Usually, PMS stars are characterized by a high degree of surface activity and mass loss which is the manifestation of the interaction with the circumstellar environment (disks, envelopes) and by photometric and spectroscopic variability occurring on time scales from minutes to years.

The first PMS stars discovered were the low-mass T Tauri stars ($0.1 \le M/M_{\odot} \le 1.5$). The more massive ($1.5 \le M/M_{\odot} \le 8.0$) counterparts were identified in the 1960s by G. Herbig who searched for stars of spectral type A or B with emission lines, located in obscured regions and associated with reflection nebulosities. A modern classification of these Herbig Ae/Be stars requires: 1) Spectral type A or B with emission lines and variable Hα; 2) infrared excess due to hot or cool circumstellar dust or both; 3) luminosity class from III to V; 4) association with molecular clouds and/or young stellar clusters.

During the contraction phase toward the Main Sequence, intermediate-mass stars cross the pulsation instability strip of more evolved variables, suggesting that, in spite of the relatively short time spent in the strip ($\sim 10^5$-10^6 years), at least part of the observed activity could be due to intrinsic variability.

The first observational evidence for such variability is due to Breger (1972) who detected δ Scuti-like pulsations in two Herbig stars of the young cluster NGC2264, namely V588 Mon and V589 Mon. More than 20 years later the topic was reconsidered by Kurtz & Marang (1995) and Donati et al. (1997) who observed δ Scuti-like variability in the Herbig stars HR5999 and HD104237. Since then there has been a renewed interest in the study of these young pulsators, both from the observational and theoretical point of view. For the latter, using convective nonlinear models, Marconi & Palla (1998) computed the first theoretical instability strip for PMS δ Scuti stars. They also identified a list of candidates with spectral types in the range of the predicted instability region. This theoretical investigation stimulated new observational programs carried out by various groups with the result that the current number of known or suspected candidates amounts to at least 13 objects.

There are at least three reasons for studying pulsation in young stars. 1) The relation between the pulsation period and the intrinsic stellar parameters allows to independently constrain the evolutionary properties and in particular the stellar mass of observed objects[1]. 2) On the basis of experience with other classes of variable stars, we know that asteroseismological techniques allow to derive information on the inner structure of observed pulsators; for example, Suran et al. (2001) made a comparative analysis of the seismology of pre- and post-MS stars of the same mass (1.8 $M_{\odot}$) and found that some non-radial unstable modes are very sensitive to the deep internal structure that is profoundly different in the two evolutionary phases (see also Templeton & Basu 2003). 3) At least in principle, PMS stars could be used to search for mode frequency changes due to the rapid evolution of their interior (Breger and Pamyatnykh 1998 and Catala 2003).

A census of PMS δ Scuti stars is given in Sect. 2, whereas the comparison with the prediction of pulsation models is shown in Sect. 3. In Sect. 4 we discuss the observational and theoretical limitations affecting our results and show the specific case of V351 Ori.

The observed PMS δ Scuti stars

In Table 1 we show the present census of known (or suspected) PMS δ Scuti stars. The first column reports the identification, whereas frequencies are given in the following five columns. The last three columns give the visual amplitudes, the visual magnitudes and the spectral types.

We note that many pulsators show multifrequency behaviour and that for the monoperiodic objects data are often affected by uncertainties due to the short time coverage, so that other frequencies could be discovered with more accurate observations. This means that asteroseismological techniques are in principle useful for these variables.

Table 1: Observed pulsational properties for all the 13 known or suspected PMS δ Scuti stars. Note that, in order to save space, the sixth frequency (27 c/d) found for IP Per has not been reported in the table.

VAR	f1 c/d	f2 c/d	f3 c/d	f4 c/d	f5 c/d	ΔV mag	V mag	S.T.
V588 Mon[1]	7.1865	?				0.04	9.7	A7
V589 Mon[1]	7.4385	?				0.04	10.3	F2
HR5999[2]	4.812					0.02	7.0	A7
HD104237[3]	33					0.02	6.6	A7
HD35929[4]	5.10					0.02	8.1	A5
V351 Ori[5]	15.687	13.331	12.754	15.885	12.817	0.045	8.9	A7
BL 50[6]	13.9175	9.8878				0.02	14.5	
HP 57[6]	12.72557	15.52437				0.03	14.6	
HD142666[7]	21.43					0.01	8.8	A8
V346 Ori[8]	35.3	22.6	45.5	18.3		0.015	10.1	A5
H254[9]	7.41					0.02	10.6	F0
NGC6383 4[10]	14.376	19.436	13.766	8.295	17.653	0.014	12.61	A7
IP Per[11]	30.45	22.88	34.64	42.27	48.31	0.006	10.4	A7

Sources: (1) Breger (1972), Peña et al. (2002); (2) Kurtz & Marang (1995), Kurtz & Catala (2001); (3) Donati et al. (1997), Kurtz & Muller (1999); (4) Marconi et al. (2000); (5) Ripepi et al. (2003); (6) Pigulski et al. (2000); (7) Kurtz & Müller (2001); (8) Pinheiro et al. (2003); (9) Ripepi et al. (2002); (10) Zwintz & Weiss (2002); (11) Ripepi et al. in preparation.

[1] The other direct way to infer the stellar mass is based on the small number of spectroscopic eclipsing binaries that are young enough to contain Herbig stars.

Comparison with the pulsation models

The pulsation periods can be predicted by radial linear nonadiabatic pulsation models for each selected mode (Marconi & Palla 1998, 2003) as a function of mass, luminosity and effective temperature. In addition, the evolutionary prescriptions provide constraints on the luminosity level for each mass and effective temperature. This implies that the comparison between empirical and theoretical periods, for a given set of evolutionary tracks, allows to estimate the mass, luminosity and effective temperature of the pulsators. However, if only one period is observed, different combinations of luminosity and effective temperature can simultaneously reproduce the pulsation relation for the period and the evolutionary properties. In this case, independent information (e.g. empirical values from the literature) is needed in order to remove the degeneracy. If more than one period is observed, and the accuracy is high enough, the comparison with model predictions should be able to provide a unique solution for the position of the star in the HR diagram.

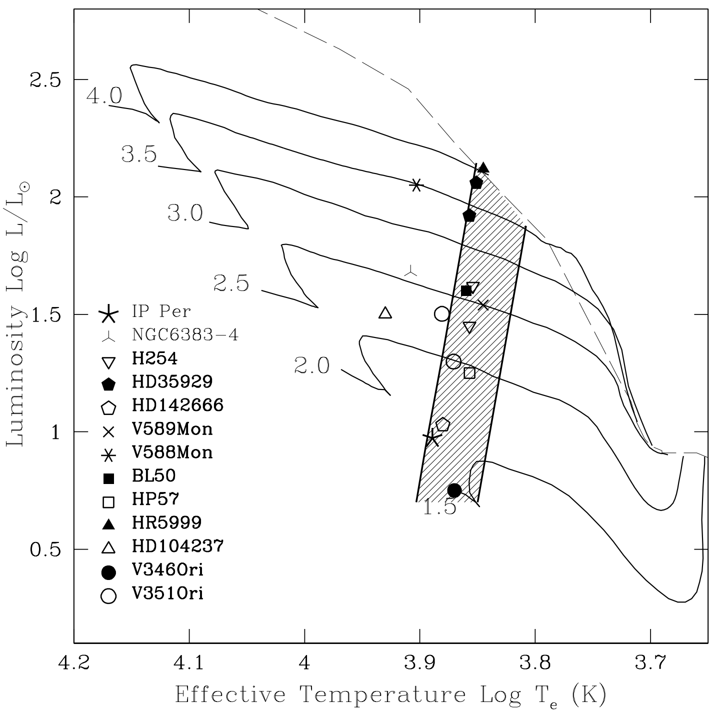

Figure 1: Position in the HR diagram of known PMS δ Scuti stars. The predicted instability strip is represented by the shaded region, whereas solid and dotted lines are PMS and post-MS evolutionary tracks respectively. The dashed line represents the birthline (see Marconi & Palla 1998 for details)

By comparing the observed frequencies of the PMS δ Scuti stars reported in Table 1 with the predictions of linear nonadiabatic pulsation models (see Marconi & Palla 1998 and references therein for details on the models), we can derive their position in the H-R diagram and make a comparison with the predictions of the nonlinear instability strip (see Fig. 1). Even if this result is heavily dependent on the assumption of radial pulsation, the agreement is quite satisfactory: only three pulsators are found to be bluer than the second overtone blue edge and indeed they are predicted to pulsate in higher overtones.

Open problems: the case of V351 Ori

The main limitations of the method illustrated in the previous section are: 1) the uncertainties still affecting many of the observed frequencies, due to poor data quality and/or the aliasing problem; 2) the difficulty to discriminate between PMS and post-MS evolutionary phases on the basis of models with radial modes only, in particular for pulsators that are predicted to be located close to the MS; 3) the fact that the likely presence of nonradial modes is not taken into account.

Concerning the first point, significant improvements can be obtained by means of multisite campaigns and will be obtained with future satellite missions (e.g. EDDINGTON and COROT). As for the last two issues, it is clear that both radially and nonradially pulsating models should be computed in order to understand the intrinsic properties of the rather unexplored class of young variable stars better.

To illustrate how the observational and theoretical limitations affect a specific case, we discuss the best studied PMS δ Scuti star, V351 Ori. This is a Herbig Ae star that has been discovered to pulsate as a δ Scuti PMS star by Marconi et al. (2000) and confirmed to be a multiperiodic pulsator by Marconi et al. (2001, hereinafter M01) and by the more accurate photometric and spectroscopic investigation of Balona et al. (2002, hereinafter B02).

Even if it has been suggested in the literature that V351 Ori is not a PMS star (e.g. Koval'chuk & Pugach 1998), the spectroscopic study by B02 has shown the presence of characteristic features of Herbig stars in its spectrum (Hα emission, sharp and broad NaII absorption components and weak HeI absorption). From the theoretic al point of view, it is difficult to establish the evolutionary phase of this object on the basis of radial pulsation analysis, given its position near the MS in the HR diagram, in a region where PMS and post-MS evolutionary tracks tend to intersect each other (see Fig. 1). On the other hand, a comparative asteroseismological analysis, such as the one performed by Suran et al. (2001), should allow to confirm the PMS nature of this star. For this purpose, accurate frequency measurements are critical.

In order to confirm the frequencies found by M01 and B02, a multisite campaign on V351 Ori has been recently organized (see Ripepi et al. 2003, hereinafter R03), involving 7 telescopes and 180 hours of observation distributed over 29 nights in a 2 year period. The Fourier analysis of this data set (Fig. 2) confirms the multiperiodic nature of V351 Ori. The five frequencies of pulsation reported in Table 1 are measured (four of them with high accuracy). The last one is more uncertain even if it results to be "good" according to the Scargle (1982) test and the Breger et al. (1993) criterion (see R03 for details).

The comparison of these frequencies with the predictions of linear nonadiabatic pulsation models indicates that no solution can match simultaneously all the observed periodicities, while only two solutions can reproduce f_1 and f_3. The latter correspond to a double mode pulsation either in the first and second ($2M_\odot$ PMS model) or in the second and third overtone modes ($2.3M_\odot$ PMS model, see open circles in Fig. 1 and R03 for details). The inability to fit all the frequencies with radial pulsation models clearly points out to the need for a nonradial analysis of V351 Ori.

In order to cope with this problem, we have applied Christensen-Dalsgaard's adiabatic nonradial code (Christensen-Dalsgaard 1982) to the same PMS evolutionary models for which we reproduce f_1 and f_3 by means of radial pulsation analysis. As a result, we find that, at least in the case of the $2M_\odot$ model, f_2 can be associated to a nonradial l=1 mode, whereas f1 and f3 could be radial modes of consecutive radial order. For the $2.3M_\odot$ model the interpretation

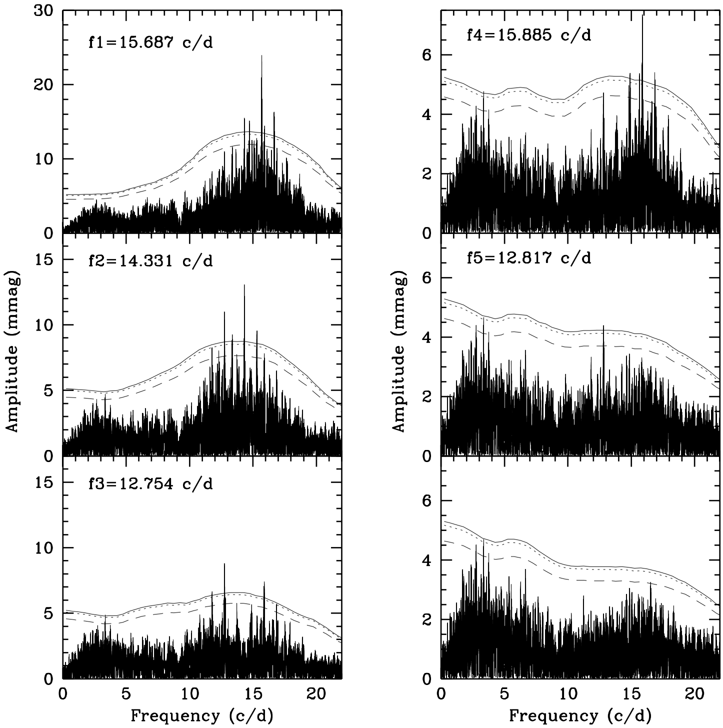

Figure 2: Frequency analysis of the multisite campaign dataset. Each panel shows the Fourier Transform after the subtraction of a pulsation frequency. The solid line corresponds to S/N=4. The dotted and dashed lines show the 99% and 90% significance levels, resp., calculated from the Scargle (1982) test.

is more difficult and no clear identification of f_2 with a nonradial mode is possible. A detailed analysis of the dependence of the nonradial mode analysis on the stellar mass is in progress.

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