Mem. S.A.It. Vol. 77, 506

Memorie della

Evolutionary stages and dominant modes in δ Scuti stars

M. Paparó

Konkoly Observatory of Hungarian Academy of Sciences – Budapest, Konkoly Thege u. 15-17, H-1121, Hungary e-mail: paparo@konkoly.hu

Abstract. An examination has been done on the contribution of dominant modes to the star's light variation. A sample of δ Scuti stars (altogether 30 stars) with well-determined frequency solution (based mostly on multisite international campaigns) are overviewed. Correlation of the dominant (highest amplitude) modes and evolutionary stages have been investigated. Attention is called to the importance of dominant modes in the theoretical investigations.

Key words. Stars: variables – Stars: δ Scuti stars – Stars: Dominant modes – Galaxy: open clusters

1. Introduction

It is our dream that asteroseismology, as a diagnostic tool for the inner structure of pulsating stars, can be widely used all over the Hertzsprung-Russell Diagram. However, there are only two cases where asteroseismology has had really great success. These are the Sun and the white dwarfs. In both cases many modes are known. Regular spacing appears in frequencies (like in the Sun) or in periods (white dwarfs). The diagnostic potential of large and small separation is well-known. We obtain extremely detailed information for the inner structure of the Sun based on millions of excited modes. The radial distribution of pressure, temperature, density, hydrogen content and sound speed are derived. In white dwarfs triplets and trapped modes give information on the structure of the star. Thanks to the many modes and regularities, there is no problem in identifying the modes.

Stars are more distant than our Sun and their structure are more complex than the white dwarfs' structure. We can see only a few modes and there are no dominant regularities among the excited modes. There is a few hope to observe modes with low amplitude and with high precision. The present paper calls the attention to the diagnostic importance and the potential of the dominant modes in asteroseismology as soon as we put theory behind them.

2. δ Scuti stars

δ Scuti stars are located near the Sun on HR diagram. We would expect that the standard solar model with small modification can work for these stars. It seems that the existence of the inner convective layer, the convective core, leads to great differences in the asteroseismological behaviour of the Sun and δ Scuti stars.

Send offprint requests to: M. Paparó

2.1. As asteroseismological targets

δ Scuti stars are regarded as perfect targets for asteroseismological studies for decades. The low amplitude δ Scuti stars pulsate in both radial and non-radial modes. The number of the excited modes seems to be enough for asteroseismological purposes. There are well-observed stars in multisite campaigns with long time base. However, only the low order modes can be seen in these stars, at least by photometry. With such a great effort the number of modes is only slightly increasing. There is no dominant regularity. The mode identification is a hard task. The theory predicts many more modes than that we observe. It has been expressed for a long time that some kind of mode selection and/or amplitude limiting mechanism is missing from the models. Only the distribution of frequencies is used for mode identification and we give equal weight to each modes (see Figures for XX Pyx, FG Vir and 4CVn: (Breger 2000)).

3. Amplitudes as additional constrains for excited modes

We can get not only the frequencies but the amplitudes of each observed mode from the observation. We are able to recognize that not only different frequency ranges exist for different stars but modes are excited on different amplitude levels in different stars. What is more, modes are excited on different amplitude levels in a certain star. Dominant modes are immediately and easily recognized by observation. These are the frequencies determined with the highest precision. These are the modes where in the amplitudes we may follow the non-linear effects acting during the pulsation.

Comparing the different type of pulsating stars, the amplitudes contain important information for the pulsation. Why are the radial modes excited on so different amplitude levels? Radial modes have much higher amplitudes in the classical (radial) variable stars (RR Lyraes, Cepheids and High Amplitude δ Scuti stars) than in stars pulsating also in non-radial modes. The amplitude and phase modulation of the radial modes, the Blazhko-effect is well-known in RR Lyrae stars. More and more cases have been reported in the last years in which such amplitude modulation was found in different type of pulsating stars (Cepheids, even low amplitude δ Scuti stars). Non-linear effects are as important in non-radial models as in the radial ones. In the light of the unified pulsation model, the same physical processes are going on in the different types of stars but the different circumstances strengthen the different aspects of the pulsation.

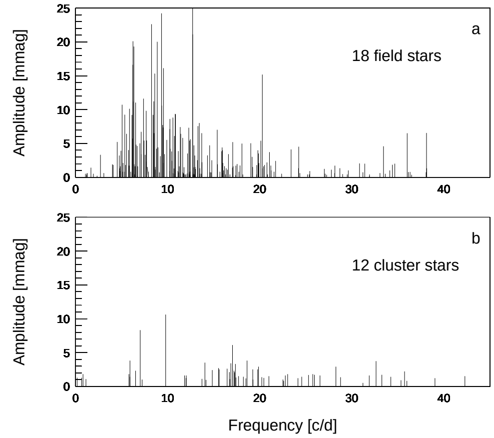

Fig. 1. Composite schematic amplitude spectrum of **a.** 18 field δ Scuti stars, **b.** 12 cluster δ Scuti stars

If we accept that the amplitude of the excited mode corralates with the kinetic energy of that mode then we may declare that the dominant modes of a star contain most of the kinetic energy of the pulsation. It seems to be plausible that the dominant modes contain most of the information for the pulsation. They exhibit strong constrains for the pulsating models as soon as we are able to give the theoretical amplitude of an excited mode and we can say why these modes are excited and why we can see the certain amplitudes.

4. Observed amplitudes of δ Scuti stars

The concept of unification suggests a new type of investigation for δ Scuti stars. If we suppose that pulsation is working in the same way, a comparison of different δ Scuti stars

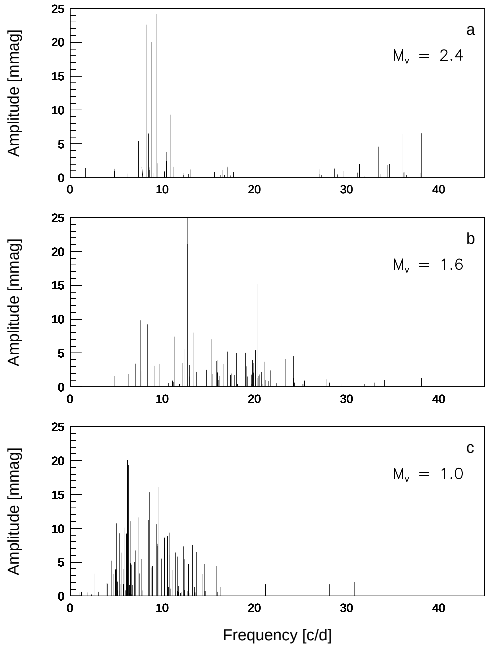

Fig. 2. Differences in the composite schematic amplitude spectrum according to the luminosity

has to present some similarity, some general behaviour. I have made an investigation concerning the general behaviour of the observed dominant modes in the best-studied δ Scuti stars. The list of stars involved in the investigation and the references are published in (Paparó 2004). The selection criterion was that the stars were observed in multisite campaign, they were studied on a long time base. Many modes were recognized. Thanks to the observer's decision, stars with different evolutionary stages are represented in the sample. Evolutionary stages were separated according the absolute magnitude. Location in the instability strip was derived according to the temperature. Physical parameters were taken from the literature. Some stars are a single star but many of them are involved in binary sytems. Both field stars (18) and cluster stars (12) were involved in the sample.

5. Composite spectra

5.1. For 18 field δ Scuti stars

In panel **a** of Fig. 1 we presented the schematic frequency spectrum of all stars in a single diagram. The dominant modes are located in a narrow frequency range. A long tail to higher frequency with low amplitude modes is connected to the narrow range. Only some peak with high amplitude can be seen in the low amplitude region. These belong to two stars, XX Pyx and θ Tuc. Both stars are in binary systems.

5.2. For 12 cluster δ Scuti stars

The amplitude behaviour of the δ Scuti stars in clusters (panel **b** of Fig. 1) seems to be different from that of the field stars. The amplitudes of the excited modes are lower than for field stars. Stars from three clusters were involved in the sample. No amplitude dependence seems to exist on the cluster, that is, on the initial chemical composition.

5.3. Separation according to M_v (2.4, 1.6 and 1)

We have only a few main sequence stars (XX Pyx, BI CMi and UV Tri) but we can draw some conclusions (panel **a** of Fig. 2). According to the theory a simple frequency distribution can be expected on the main sequence. If we look at the modes with the largest amplitude, this is true. However, in BI CMi we see modes with lower amplitude, too. In this case we may not say that the frequency spectrum is simple. We definitely see that XX Pyx is a special case comparing to the other two stars. Main frequency range is 7-11 cycles/day.

In panel **b** (Fig. 2) the frequency spectrum is more complex, the range is wider. The main range is shifted to higher frequencies (10-25 c/d). The amplitude value of the lower level is higher than in the previous group.

In panel **c** (Fig. 2) we present a large sample of evolved stars. According to the theory more complex frequency spectrum is expected.

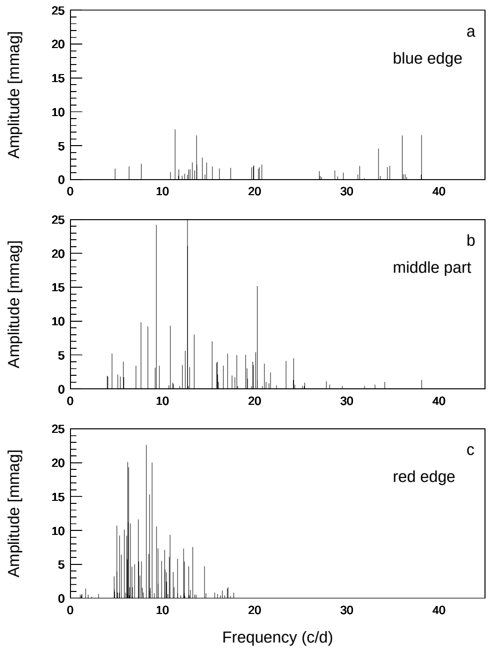

Fig. 3. Differences in the composite schematic amplitude spectrum according to the temperature

The dominant modes in each star are located in the same frequency region (5-14 c/d).

5.4. Separation according to temperature (blue, middle and red)

Near the blue edge of the instability strip high order modes are expected with high frequencies (panel **a** of Fig. 3). However, modes are widely separated in our sample. It is hard to define a main range even, if we leave out XX Pyx as a special case. It is certanly sure that the amplitudes are lower for the dominant modes than in the other groups.

The frequency distribution is also wider for the middle part of the instability strip (panel **b** of Fig. 3). The high peak at high frequency belongs to θ Tuc, a δ Scuti star in binary system.

We also have a large sample near the cool edge of the instability strip (panel **c** of Fig. 3). The frequency distribution is more compact and the amplitudes are higher. It agrees with the theory that modes with lower radial order are expected near to the cool edge, that is, frequency values are lower.

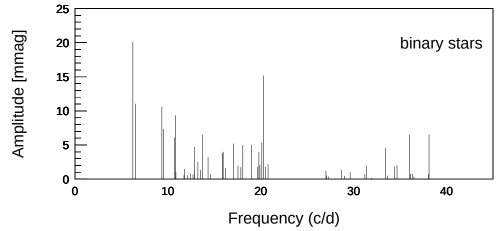

Fig. 4. Composite schematic amplitude spectrum of δ Scuti stars in binary systems

5.5. δ Scuti stars in binary systems

The pulsation is affected by external gravitational field in binary systems. It has been presented years ago that there is resonance between the period of dominant pulsation mode and the orbital period in the case of θ Tuc. There are regular frequency spacing around 2 c/d for both Θ Tuc and XX Pyx. The increased amplitude value of the dominant modes break the general regularity of the low amplitude region (Fig. 4).

6. Conclusions

Frequency distribution alone is not enough for seismic investigation for δ Scuti (and for other type of non-radially pulsating) stars. I guess, the situation will be the same even with the datasets coming soon from space. However, the amplitudes have diagnostic power for the inner structure of stars if we put theory behind them. To reach this level, an improvement on non-radial, non-linear modelling is needed.

Acknowledgements. I am grateful to LOC for the excellent organization and the very helpful attitude. Many thanks to M. Breger for his figure on evolutionary stages of some stars. Financial support from Hungarian OTKA Grant T046207 is acknowledged.

References

Breger, M., 2000, ASP Conf. Ser. 210, 3
Paparó, M., 2004, Proc. of the SOHO14/Gong 2004 Workshop, ESA SP-559, 201