Non-adiabatic analysis: activity and progress report

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1 Introduction

To make things clear, I would like to outline the limits of what, in my opinion, is to be included in the theme *Non-adiabatic analysis*. The classical problem of the vibrational instability induced by the κ-mechanism, as in the variables of the instability strip, is of course a central problem of non-adiabatic analysis. But I also include all kinds of problems linked to the departure of the eigenfunctions of oscillation from their adiabatic description.

On the contrary, the study of the stochastic excitation of the pulsation by convective motions, as in solar-like stars, and the prediction of the amplitudes require another sort of expertise and I consider that problem as a distinct one.

I will try to give you a brief survey of the abilities and tools available in the COROT SWG. Then I will describe recent progress in non-adiabatic computations and examine the prospects of studies in this domain in the frame of the COROT mission.

2 The teams

Two teams have expressed their interest in using COROT data for non-adiabatic analysis: one in Granada, around Rafael Garrido and one in Liège leaded by Arlette Noels.

In Granada, they use models computed either by the stellar evolution code of Antonio Claret or by CESAM written by Pierre Morel (Nice). In close collaboration with Marie-Jo Goupil (Meudon), Rafael Garrido plans to include the coupling of modes due to rotation in his non-adiabatic code (Daszyńska-Daszkiewicz et al. 2002). A few students are also involved in the project: Andres Moya, Juan Carlos Suarez and Ahmed Grigahcene.

In Liège, two stellar evolution codes are available, an updated version of the Henyey code and CLÉS (Code Liégeois d'Évolution Stellaire), still in development. Marc-Antoine

Dupret is at the center of the work on non-adiabatic analysis. His treatment of the non-adiabatic pulsation in the external layers of the star has brought significant progress in the computation of the observables of pulsating stars. The future work will be carried out in collaboration with Arlette Noels, Anne Thoul, Josefina Montalban, Maryline Briquet, Joris De Ridder (Leuven) and Richard Scuflaire. Two PhD students, Benjamin Vatovez and Pierre-Olivier Bourge will be involved in non-adiabatic analysis.

3 Classical non-adiabatic analysis

A classical non-adiabatic analysis is in principle able to predict which modes will be excited by the κ-mechanism. To validate a theoretical model, we must be reasonably sure that we have detected all the modes excited in the star. We may hope that the data that will be obtained from the COROT mission will be more exhaustive than that obtained from the ground.

Let me give a simple example of the information which can be obtained in this way. It is well known that in β Cephei variables, the excitation by the κ-mechanism depends critically on the metallicity of the star. In a recent work on the β Cep variable 16 Lac (EN Lac), we were able to obtain by this way a lower bound on the metallicity of the star.

4 Recent progress in the computation of non-adiabatic eigenfunctions

M.-A. Dupret has recently achieved a decisive progress in the computation of the non-adiabatic eigenfunctions (Dupret 2001 and Dupret et al. 2002a). His treatment gives a special care to the modelling of the pulsation in the external layers of the star. It is based on the remark that the thermal relaxation time in these layers is much shorter than the period of the pulsation. It is then justified to use a temperature distribution $T(\tau, t)$ variable with time but given, at each time, by a model atmosphere in thermal equilibrium. This progress has an impact on the mode identification method based on multicolor photometry. It is also the starting point of a technique of investigation of the properties of the external layers of variable stars that I will call, following M.-A. Dupret, *Non-adiabatic asteroseismology.*

Both non-adiabatic codes of Liège and Granada have benefited of this improvement.

4.1 Mode identification

An important problem of asteroseismology is the identification of the observed modes. It is known that multicolor photometry can help to obtain the degree ℓ of the spherical function describing the angular dependency. The new treatment of the external layers results in more reliable identifications (Dupret et al. 2002b and 2002c). You can see an application of the method in the poster presented by Dupret et al. at this meeting. The identification of modes of pulsating B stars and δ Scuti stars will benefit from this progress. The method is, in principle, applicable to γ Doradus and solar-like variables, but some progress has to be made in our understanding of the interaction between pulsation and convection.

4.2 Non-adiabatic asteroseismology

With a good description of the behaviour of the non-adiabatic pulsation in the atmosphere of the star, we are now able to make safe predictions of the variations of the line profiles and colors of the star during the pulsation. Of course, these observables are dependent on the structure of the external layers. Detailed modelling and analysis of the observations offer a powerful tool to investigate the properties of the layers where the pulsation acquires its non adiabatic features. I will give two examples of non-adiabatic asteroseismology applications based on multicolor photometric data (Dupret 2002, Dupret et al. 2002d).

1) The study of models of the β Cephei variable 16 Lac (EN lac) shows that the amplitude ratios are very dependent on the metallicity. The fit to the observations has provided us with an upper bound for the metallicity. (Dupret, 2002)

2) In models of δ Scuti stars, it was found (Dupret, 2002) that the amplitude ratios are dependent on the thickness of the thin convective zone present in the external layers (itself depends on the value of the convection parameter α). The comparison with observations will give us important information on the structure of the convective zone.

It has been shown recently (Samadi et al. 2002) that δ Scuti variables can present solar-like oscillations. If pulsations of this type could be observed, the information deduced from the frequencies of both types of modes by classical seismological methods, supplemented by the information on the thickness of the convective zone deduced by non-adiabatic asteroseismology techniques will put unprecedented constraints on the models of this type of stars.

Expected theoretical benefits (speculation)

Non-adiabatic asteroseismology applied to δ Sct variables probably offers a unique opportunity to study the interaction between convection and pulsation. This problem is certainly an important one, but it is also a very difficult one. The treatment of the convection in the external layers of a static star is already a problem. In a pulsating star the convective elements cannot adapt instantaneously to the varying physical conditions. During their finite life-time, they integrate, in some way, the fluctuating physical conditions they undergo. But nobody knows exactly how. Because of the lack of a satisfactory theory, simple approximations have been used. Non-adiabatic asteroseismology may certainly be used to validate them and maybe will guide future progress in our understanding of this problem.

5 Discussion

During the discussion that followed the presentation of this report, the following point was raised. Classical non-adiabatic analysis (computation of the excited modes) requiring data from the seismology field is a matter for the asteroseismology core program. On the contrary, projects needing multicolor photometric data from the exoplanet field should be the subjects of additional programs.

6 References

Daszyńska-Daszkiewicz J., Dziembowski W.A., Pamyatnykh A.A., M.-J. Goupil, 2002, A&A, 392, 151–159.

Dupret M.-A., 2001, A&A, 366, 166–73.

Dupret M.-A., 2002, PhD Thesis.

Dupret M.-A., De Ridder J., Neuforge C., Aerts C., Scuflaire R., 2002a, A&A, 385, 563–571.

Dupret M.-A., De Ridder J., De Cat P., Aerts C., Scuflaire R., Noels A., Thoul A., 2002b, A&A, accepted for publication.

Dupret M.-A., Scuflaire R., Noels A., Thoul A., Garrido R., Moya A., De Ridder J., De Cat P., Aerts C., 2002c, In Asteroseismology across the HR diagram, Porto Asteroseismology Conference, 1-5 July 2002.

Dupret M.-A., Scuflaire R., Garrido R., De Ridder J., Aerts C., De Cat P., Moya A., Montalban J., Noels A., Thoul A., 2002d, in COROT Week 3, Liège, 4-7, December 2002.

Samadi R., Goupil M.-J., Houdek G., 2002, A&A, 395, 563–571.