UKRAINE IN INTERNATIONAL ASTEROSEISMIC PROJECTS

D. E. Mkrtichian[1], A. V. Kusakin[2], A. P. Hatzes[3], A. Kanaan[4], V. E. Panchuk[5], W. W. Weiss[6], E. Paunzen[6], V. Koval[1], A. Gamarova[1], E. B. Janiashvili[7]

[1] *Astronomical Observatory of Odesa National University, T. Shevchenko Park, 27014 Odesa, Ukraine*
e-mail: davidm@te.net.ua

[2] *Sternberg State Astronomical Institute, Universitetsky prospect, 13, Moscow, 119899, Russia*

[3] *Thüringer Landessternwarte Tautenburg, D-07778 Tautenburg, Germany*

[4] *Departamento de Física, Universidade Federal de Santa Caterina, Campus Universitário 88040-900, Florianópolis, Brazil**

[5] *Special Astrophysical Observatory, Russian Academy of Sciencies, Nijnij Arkhuz, Russia*

[6] *Institut für Astronomie der Universität Wien, Türkenschanzstr. 17, A-1180 Wien, Austria*

[7] *Abastumani Astrophysical Observatory, Mt. Kanobili, Abastumani, Georgia*

This brief summarizes the results of international asteroseismic projects with Ukrainian participation on pulsating λ Bootis, rapidly-oscillating Ap stars, and pulsating components of eclipsing binaries.

INTRODUCTION

Application of seismic techniques to A–F spectral type pulsating stars is possible if the dense spectrum of opacity driven acoustic and gravity modes can be detected and their spatial structure (which is determined by the ℓ, m, n quantum numbers of spherical harmonics) be identified, as was done for the majority of convection driven modes in the Sun. The detection and identification of excited modes in pulsating stars require high-quality, continuous photometric and spectroscopic data obtained from space or from the ground, of which the latter requires the organization of international world-wide asteroseismic campaigns from observatories at good weather sites distributed uniformly in geographic longitudes. In 1994 Ukraine started an active participation in such projects.

THE CENTRAL ASIAN NETWORK COLLABORATION

In 1994 the newly created Central Asian Network (CAN) collaboration of astronomers (Mkrtichian *et al.*, 1998a) informally began activity among scattered groups of the former SU astronomers within the framework of asteroseismic campaigns and networked observations of variable stars. The coordinated rapid-response (Euro)Asian network includes astronomers from the Astronomical Observatory of Odesa National University (Ukraine), Sternberg State Astronomical Institute (Russia), Tien-Shan Astronomical Observatory (Kazakhstan), Mt. Dushak-Erekdag Observatory (Turkmenistan) and Abastumani Astrophysical Observatory (Georgia). They effectively cover the Central Asian gap in distribution of observatories over the northern hemisphere. The main objectives of CAN are deep investigations of the spectra of oscillating stars and the development of approaches for understanding their internal structure and evolution. These objectives are approached by carrying out continuous multi-longitude, global asteroseismic photometric and spectral observations on target stars. The first worldwide campaigns organized by Central Asian Network collaboration showed highly effective collaboration between the Eastern and Western European, Asian, North America institutions, and other international groups (see Weiss *et al.*, 1998; Mkrtichian *et al.*, 1998b).

ASTEROSEISMOLOGY OF λ BOOTIS STAR 29 CYG

The 29 Cyg is the first among λ Boo-type stars in which the well defined pulsations were detected and studied (Gies & Percy, 1977; Kusakin & Mkrtichian, 1996). 29 Cyg was selected as a key object to investigate the pulsational characteristics of λ Boo–type stars. The 1996, 1997 and 1998 global multisite campaigns were initiated by CAN in a wide international collaboration of institutes from Austria, Canada, Hungary, Mexico,

*CNPq Fellow.

Russia, Spain, Turkey, Ukraine, and USA. As a result, CAN's strategy led to significant progress in the detection and study of the seismic spectra of λ Boo stars. The first results on this project, which are based mainly on results of the 1996 campaign, can be summarized as follows:

- We established a multiperiodicity in 29 Cyg and determined frequencies and amplitudes for 10 high-amplitude (A$>$ 1 mmag) modes. These are related to consecutive $2, 3, 4$ and 5 overtone low-degree ℓ modes (see Fig. 1).
- We found in 29 Cyg the long-term and short-term variability of amplitudes for all of these modes.
- For the first time in λ Boo stars we detected pulsational multiperiodic radial velocity variations (Mkrtichian *et al.*, 1998b). Based on spectroscopic radial velocity and line-profile data obtained during 1996, 1997 and 1998 campaigns we found that both low and high–degree nonradial modes are excited.
- For the first time in λ Boo stars, based on multicolor W, B, V, R photometry, we determined the amplitude-wavelength dependency for high-amplitude low-degree modes in 29 Cyg.
- The photometric behavior of the 29 Cyg shows a close similarity to the pulsational characteristics δ Scuti-type stars.

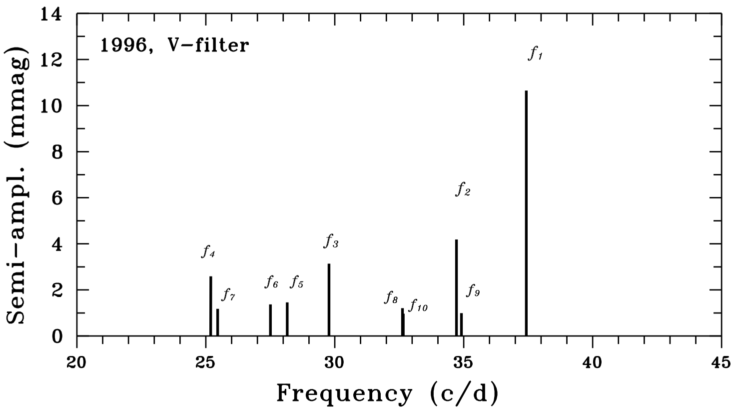

Figure 1: The schematic of pulsation frequency spectrum detected during 29 Cyg 1996 global campaign

ASTEROSEISMOLOGY WITH SPATIAL RESOLUTION

The rapidly oscillating magnetic chemically-peculiar (roAp) stars exhibit low-amplitude photometric variations ($<$ 2–5 mmag) with periods ranging from 5 to 15 minutes. These variations are thought to be due to low order ($\ell < 4$) nonradial pulsations, but the excitation mechanism remains unknown (Kurtz, 2000). Like their non-oscillating Ap counterparts these stars have strong chemical anomalies that are distributed inhomogeneously on the stellar surface (Hatzes, 1993) and a large, global dipole (quadruple and more complex in some cases) magnetic field whose axis is inclined with respect to the rotation axis. roAp stars (as the eclipsing binaries) are unique objects for which the technique of spatial filtration of nonradial modes is applicable (Mkrtichian, 1994).

We began the "Asteroseismology with Spatial Resolution" program for use of the precise stellar radial velocities (RV) to study rapidly oscillating Ap stars (roAp). This program united for the first time astronomers from the U.S.A. (McDonald Observatory, The University of Texas at Austin), Ukraine (Astronomical Observatory of Odesa State University), Brazil (Departamento de Física, Universidade Federal de Santa Caterina), and Russia (Special Astrophysical Observatory), in a collaborative effort for studying an important class of objects to understand the basic stellar problems such as origin of strong chemical anomalies and rapid pulsations. We were one of the first researchers to use an iodine gas absorption cell to study the pulsational RV behavior of roAp stars over a wide spectral range and with a high precision. Our RV measurements can achieve a velocity precision of 10-30 m/s for the brighter roAp stars. Some of the highlights of the first results from this ongoing project include:

- The first detailed investigation in 33 Lib of atmospheric standing acoustic waves – a new phenomenon for stellar atmospheres (Hatzes *et al.*, 2001).

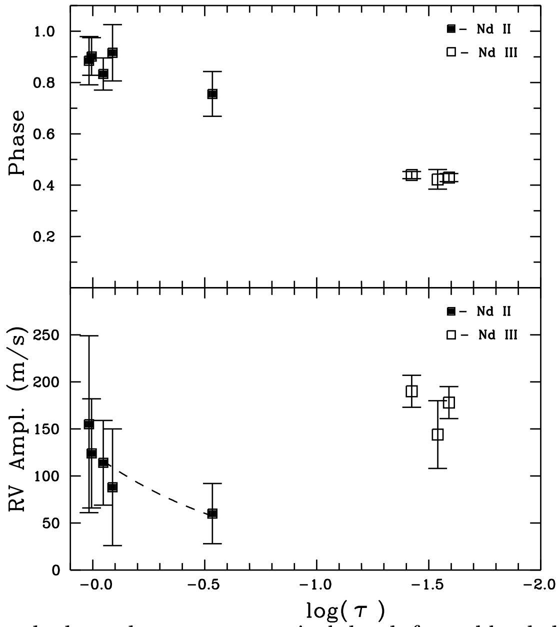

Figure 2: The phase and amplitude dependence versus optical depth for unblended or weakly blended Nd II and Nd III lines showing the acoustic cross-section of the atmosphere in 33 Lib. We can see the different formation heights for Nd II and Nd III lines. The latter shows a very small phase scatter that may be a strong indication of formation of Nd III lines in a thin upper atmospheric layer on another side of vertical pulsation node, which have the opposite pulsation phase respect lower layers where the Nd II lines are formed

- The detection of pulsational radial velocity variations in three roAp stars for which the RV variations have been found in the past but with better precision. The detection of RV variations in two additional roAp stars HD 122970 and HD 134214 (Hatzes *et al.*, 1999b).
- The oscillation spectrum of HR1217 entirely from RV data are derived.
- It is established that the pulsation RV amplitude depends on the spectral line strength and thus the depth of formation of the line. It has been seen in all roAp stars and indicates the presence of a radial node in the stellar atmosphere.
- We were the first to establish that the pulsation RV amplitude depends on the atomic species, which is interpreted as arising from the inhomogeneous distribution of elements in atmospheres of roAp stars. This gives a firm basis to our concept of periodic spatial filters.
- Two-site high-resolution spectroscopic campaign on γ Equ using the 2.7 McDonald and 6.0-m SAO telescopes were successfully performed.
- For the first time we detected that the pulsational phase of spectral lines depends on the Lande factors in 33 Lib (Hatzes *et al.*, 2001). This indicates strongly the influence of the magnetic field on the effective heights of formation of spectra lines and also reflects the existence of a radial node in stellar atmosphere. Investigations of the Lande g-factor versus pulsation phase in other roAp stars may prove fruitful.

SURVEY OF PULSATING ECLIPSING BINARY STARS

The asteroseismology of pulsating components (PC) in eclipsing binary systems (EBS) is expected to be very powerful and attractive tool for investigation of the inner structure of these stars. The advantages of studying PC in EBS with respect to single stars are the high accuracy in determination of the basic stellar parameters of components that is necessary for the precise tuning of theoretical models and also for the possibility of spatial filtration and identification of modes during the eclipse phases. Only five firm discoveries of δ Scu–type PC in EBS until 2000 year were made, among them only three stars are in the semi-detached (SD) systems.

The remarkable peculiarity of PCs in SD systems is a mass accretion on a pulsating gainer in an SD system. The mass accretion may lead to accretion-driven period changes of the pulsation modes. The observed period changes may be used as a tool for asteroseismic accretion rate estimation in binary system (Mkrtichian, 2001).

This expected phenomenon needs more detailed theoretical and comparative observational investigations in components of SD and detached systems. The pulsation spectra of stars in these sub-groups have not been studied well. Within the frames of CAN collaboration we started a project on an asteroseismic study and survey for new PC in the detached and SD eclipsing binary stars. The first results of our project on the study of PC in EBS can be summarized as follows:

- During the first stages of our survey we discovered the 24.4 min pulsations in A3 V primary, component of SD EBS AS Eri (Gamarova *et al.*, 2000). The calculated pulsation constant Q = 0.01194 relates this pulsation mode to the sixth-seventh overtone of low degree modes.
- We discovered the 67.89 min first overtone pulsations in a primary F0 V component of the well studied semi-detached EBS R CMa (Mkrtichian and Gamarova, 2000).
- During the survey we also confirmed the rapid pulsations in a primary A3 V component of SD EBS RZ Cas with a period 22.43 min and interpreted the excited mode as sixth overtone of low degree modes.
- We have carried out the intensive set of theoretical modeling of nonradial pulsations demonstrating the effect of apparent changes in the pulsation amplitude and phase during the eclipse of the pulsating component. This confirms the possibility and the high efficacy of using a spatial filtration of modes during the eclipse.

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