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Magnetoacoustic oscillations in Ap stars

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Abstract. In this paper I briefly summarize a number of robust results derived from observational and theoretical studies of roAp stars over the past three decades.

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1. Introduction

Rapidly oscillating Ap (or roAp) stars are chemically peculiar magnetic stars that exhibit pulsations with typical periods in the range of 5 to 20 minutes. Well below the photosphere the magnetic field is unlikely to play an important role in the dynamics of the oscillations. However, in the outer layers it influences the oscillations both directly, through the action of an additional restoring force, and indirectly, through the interaction with outer convection. As a result of this, asteroseismic studies of these pulsators provide a unique opportunity to infer about the properties of photospheric and subphotospheric stellar magnetic fields and about the interaction between the magnetic field, diffusion and convection, in stars other than the sun.

2. Observational results

roAp stars were first discovered and characterized through high-speed photometry Kurtz (1982). Despite some earlier attempts aiming at the detection of pulsational radial velocities in this pulsators e.g.]matthewsetal88,libbrecht88, it was with the advent of the high-spectral resolution spectrographs that the intense spectroscopic campaigns developed, providing a wealth of new data on these stars e.g. seefor a recent review]kochukhov09. From three decades of observations of roAp stars, a number of interesting and, in some cases, intriguing properties emerged, namely:

• roAp stars are found among the coolest chemically peculiar magnetic stars, having effective temperatures approximately within the range of 6400 K − 8200 K;

• The oscillations are of high frequency, often close to, or even above, the acoustic cutoff frequency for the corresponding stellar models;

• In some multiperiodic pulsators the frequencies of the oscillations are close to equally spaced, but in a number of stars that pattern is not present, or is restricted to a particular frequency range in the oscillation spectrum;

• The analysis of high-resolution spectroscopic time series of roAp stars reveled that the structure of the pulsations in the atmospheric layers is complex, often including running components, similarly to what is observed in regions of strong magnetic field of the solar atmosphere.

3. Theoretical results

Over the past two decades, theoretical studies of roAp stars for earlier results were aimed primarily at interpreting the observed oscillation spectra or at studying pulsation stability in models of these pulsators. Comparisons between model predictions and observations has also been carried out for a limited number of stars Cunha (2001), Cunha *et al.*(2003)Cunha, Fernandes, & Monteiro, Gruberbauer *et al.*, 2008, Huber *et al.*, 2008), Bruntt *et al.*, 2009. Some of the aspects in which progress has clearly been made, as well as some of the open questions that still remain can be summarized as follows:

• The oscillations in roAp stars are likely to be excited by the opacity mechanism acting in the region of hydrogen ionization. Nevertheless, in most cases such excitation requires the suppression of the thin outer convective region of the star by the action of the magnetic field. Moreover, the red edge predicted from models is significantly hotter than that derived from observations.

• The interaction between the magnetic field and pulsations in the outer layers of roAp stars results in energy being transferred between magnetic and acoustic waves. This provides a natural mechanism for mode reflection even for oscillations with frequencies above the acoustic cutoff. Nevertheless, part of the mode energy is expected to be dissipated by running acoustic waves in the atmosphere and running magnetic waves in the interior.

• The direct effect of the magnetic field on pulsations results in perturbations to the oscillation frequencies that in some cases are as large as tens of μHz. This provides a natural explanation to what is observed in the oscillation spectra of several multiperiodic roAp stars, in particular the significant deviations from the equally spaced pattern that would be expected in the absence of the magnetic field;

• The correct interpretation of the data acquired in recent high-resolution spectroscopic campaigns requires a detailed analysis of the eigenfunctions in the magnetic boundary layer, taking into account the horizontal and vertical structure of the oscillations, as well as the horizontal and vertical distribution of chemical elements.

4. Conclusions

This is a very exciting time for studies of magnetic pulsators. Recently, significant amounts of excellent seismic data of roAp stars have been acquired and additional high-quality data is envisaged as result of the recent launch of the NASA satellite Kepler. These observations posed new challenges to those attempting to model these pulsators. Ultimately, the correct modelling of these stars will provide a unique insight into important physical processes taking place inside the stars, such as diffusion and convection, and into the way they interplay with magnetic fields.

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