Part 6. Asteroseismology from Space and from the Ground

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Requirements for Future Photometric and Spectroscopic Observations for Asteroseismology: One Observer's Perspective

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Abstract. We discuss prospects for asteroseismology in stars for which the frequencies of pulsation lie outside the asymptotic regime. The problem of mode identification in this case is the major obstacle. Mode identification techniques from photometric and spectroscopic observations are discussed.

1. Introduction

Asteroseismology requires a good starting model, a method of mode identification and as many observed periodicities as possible. In the near future one can look forward to the detection and analysis of solar-type oscillations. Provided rotation is negligible, mode identification in these stars should be relatively easy as the frequencies lie in the asymptotic regime. The same applies to the pulsating white dwarfs, which have been the only successful asteroseismological targets apart from the Sun. In most other types of pulsating stars very few modes are observed. While it might be possible to determine the mean density or the ages for these stars, they are unlikely to provide the detailed information required to test stellar structure. Exceptions can be made for a few B-type subdwarfs and δ Scuti stars in which as many as 50 periodicities have been detected. These stars are promising targets for asteroseismology were it not for the problem of mode identification.

2. Photometric mode identification

The expression for the monochromatic amplitude, ΔL_λ, at wavelength λ for a star of radius r, surface gravity g, angle of inclination i, pulsating with angular frequency ω is (Watson, 1988):

$$\frac{\Delta L_\lambda}{L_\lambda} = \sqrt{4\pi}\epsilon N_\ell^m P_\ell^m(\cos i) b_{\ell\lambda} \left\{T_1 + T_2 + T_3\right\} e^{i\omega t}, \tag{1}$$

$$T_1 = -(\ell - 1)(\ell + 2), \qquad T_2 = -\left(\frac{\omega^2 r}{g} + 2\right)(\alpha_{g\lambda} + \beta_{g\lambda}),$$

$$T_3 = \frac{1}{4}(\alpha_{T\lambda} + \beta_{T\lambda}) f e^{i\psi}.$$

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T_1 describes the geometric variation, while T_2 and T_3 are the gravity (pressure) and temperature terms. In this equation, ϵ is the relative radial displacement amplitude, P_ℓ^m is the associated Legendre polynomial of degree ℓ, azimuthal order m, and $b_{\ell\lambda}$ is an integral involving limb darkening. The α and β terms are partial derivatives which can be computed from static model atmospheres. The complex coefficient, $fe^{i\psi}$, is the ratio of relative flux to relative displacement evaluated at the surface (Dziembowski, 1977). It is determined by the solution of the equations for nonadiabatic oscillations.

It is apparent from Eq. (1) that the amplitude is independent of azimuthal order, m, except through the constant factor $N_m^\ell P_m^\ell(\cos i)$. This implies that line profile variations are independent of m, which is clearly incorrect. An additional term describing the Doppler displacement needs to be added to take this into account. The equation, as given above, is valid when convolved with a sufficiently large wavelength region and for modes of relatively low radial order for which the assumption of static model atmospheres is a good approximation.

The usefulness of Eq. (1) in mode identification is due to the two terms which depend on ℓ: T_1 and $b_{\ell\lambda}$. Non-adiabatic models show that T_3 is normally an order of magnitude larger than T_1 or T_2. In the visible region $b_{\ell\lambda}$ is almost independent of wavelength and has a negligible effect on mode identification. The result is that the relative amplitude and phase differences are almost entirely determined by the small geometric factor, T_1, giving rise to small observable effects. Very accurate photometry is required to discriminate between various values of ℓ. Because they are faint, obtaining the required accuracy will not be easy for the pulsating B-type subdwarfs.

Most attempts at mode identification in the δ Sct stars have used the Johnson B and V bands or Strömgren b and y. Balona et al. (2001) have shown that a considerable improvement in the significance of the results can be obtained by using a longer wavelength base. If one extends the wavelength range to include the far UV, mode discrimination is greatly increased, as shown in Fig. 1. The figure shows model calculations for a δ Sct star with $M/M_\odot = 1.8$ near the middle of the main sequence band (left panels) and near the end of core hydrogen burning (right panels).

Calculations of non-adiabatic models corresponding to δ Sct stars show instability of large numbers of modes of high degree within the same frequency range as the more easily observed modes of low degree. Some modes of high degree are indeed seen in many δ Sct stars (e.g. Kennelly et al., 1998; Balona, 2000a). Because rotation perturbs the frequency in proportion to m, such modes are sensitive probes of rotation. However, unique mode identification is extremely difficult (Balona & Kambe, 1999). Balona & Dziembowski (1999) conclude that a very large number of modes of high degree may be detected in δ Sct and other variables from accurate photometric observations from space. The reason is that the T_1 term in Eq. (1) increases geometrically with ℓ. In this case the low-degree modes could be lost or severely distorted in frequency and amplitude by the forest of rotationally split high-degree modes.

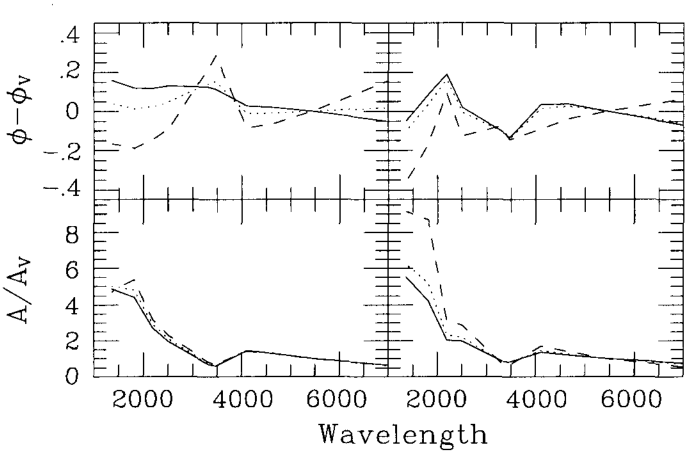

Figure 1. The amplitude ratio and phase difference (radians) relative to the V band for $\ell = 0$ (solid line), $\ell = 1$ (dotted line) and $\ell = 2$ (dashed line) as a function of wavelength (in Å) for two δ Scuti models.

3. Mode identification from line profile variation

Viskum et al. (1998) have used the equivalent width variation of a temperature sensitive line for mode discrimination. While the method is somewhat more sensitive than the photometric method, the temperature term, T_3, still dominates the variation. The increased sensitivity is offset to some extent by the requirement of a larger telescope.

Line profile variations are necessary to determine the azimuthal number, m. Spectra of high S/N are required which restricts the method to the brightest stars. It is important to determine the full set of pulsational parameters for each mode in order to test a particular solution. At present, only the method of moments (Aerts et al., 1992) and the direct fitting method (Balona, 2000b) are capable of providing this information. The moment method becomes less sensitive for high ℓ, while the direct fitting technique requires further development to handle multiperiodic stars. In spite of the large amount of line profile data to be fitted, Balona (2000b) has shown that a unique solution may still not be possible. The combination of photometric and spectroscopic techniques is particularly useful in resolving possible ambiguities.

To date, only a small number of δ Sct stars have been observed for line profile variations (see Mantegazza, 2000, for a review). While these observations are unlikely to yield identifications for more than a few of the strongest modes, the information can be crucial to resolving ambiguities. Even if only a few modes are positively identified, these can serve as markers from which the remaining modes may be found by frequency matching. Identification of radial modes, which are least affected by rotation, and the determination of ℓ and m of at least one non-radial mode (to determine the rotational splitting) would be particularly important.

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Discussion

P. Moskalik : Being in the asymptotic regime is not always enough for easy mode identification. For example, even if all theoretically unstable modes are detected in a SPB star, we are still in trouble. The reason is that in these stars neighbouring triplets start to overlap already for rotational velocities as low as $5 - 10$ km s^{-1}. This makes mode identification from the frequency pattern virtually impossible.

L. Balona : I agree. Mode identification in the asymptotic regime is easy only if the rotational velocity is near zero.

M. Jerzykiewicz : I would like to defend β Cep stars as targets for asteroseismology as many more frequencies than presently observed may well be discovered. These stars have not been as well observed as the δ Sct variables. The β Cep stars also have the advantage that there is no outer convection zone.

L. Balona : It is, of course, important to pursue observations in other stars, including the β Cep variables, and it is certainly true that convection plays a much larger role in the δ Sct stars. Until more periodicities are detected in β Cep variables, however, the δ Sct stars remain more promising candidates.