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Mapping the Non-Radial Pulsations

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Abstract. We apply the surface imaging technique to high-resolution spectra of the rapidly rotating β Cep-type star ω^1 Sco. Assuming only temperature fluctuations due to pulsations, we obtain a map of the surface corotating with the dominant pulsation mode. From the map we identify the dominant mode and find traces of a second pulsation mode. We conclude that the traditional surface imaging technique can be successfully used for mapping stellar non-radial pulsations.

1. Introduction

In the early 1980s, systematic line-profile variations (*lpv*) were discovered in a number of O and B stars. A pioneer study by Vogt & Penrod (1983) suggested that the *lpv* arise in photospheric non-radial pulsations (NRP). With the common Fourier analysis of time series of profiles, dominant frequencies of pulsations can be found from *lpv*. Then, the pulsational degree ℓ, the azimuthal order m and the velocity amplitude of the pulsations can be found as well (Schrijvers et al. 1997; Telting & Schrijvers 1997; Schrijvers & Telting 1999). Difficulties arise when one determines the value of $\mid m \mid$; sectoral and tesseral modes have to be distinguished. In this paper, we show that a great help in the identification of the pulsation modes can be provided by the technique of surface imaging.

2. The Technique of Surface Imaging

Let us assume for simplicity that the *lpv* are caused by the temperature fluctuations. This assumption is in good agreement with the results by Lee et al. (1992) who found that the effects of temperature variation can in some cases exceed that of velocity variation in the *lpv* of the Si III 4553 Å and He I 6678 Å lines. No assumption is made about the origin of the temperature variations. If the

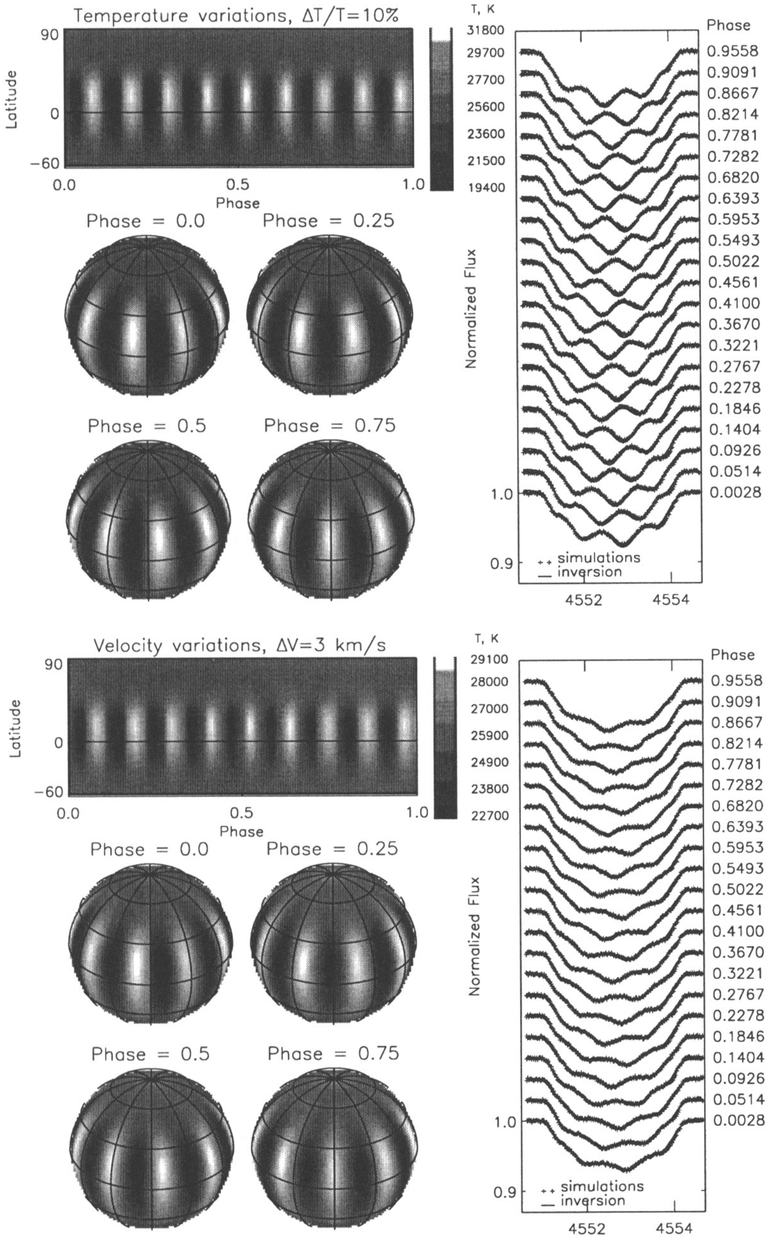

Figure 1. The test star images and line profile variations. The star assumed to have either velocity or temperature fluctuations due to pulsations, although the images were calculated under the assumption of only temperature variations in both cases.

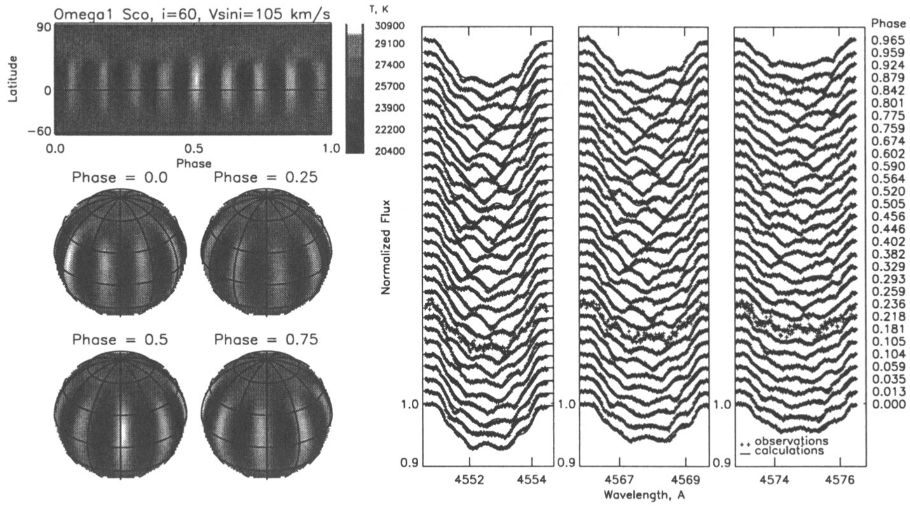

Figure 2. The image of ω^1 Sco, recovered under the assumption of only temperature variations, and fits to the observed line profiles.

star rotates rapidly enough that the rotational broadening of the profile is significantly larger than the local line profile at a single point on the stellar surface, then a temperature fluctuation on the stellar surface will result in a "bump" in the profile. This "bump" moves across the profile, as the star rotates, with the amplitude depending on the latitude of the fluctuation. Inversion of a time series of stellar line profiles results in a map, or image, of the stellar surface. Here, we use the Occamian approach to inverse problems which was applied to the surface imaging problem by Berdyugina (1998). This approach was successfully used for temperature mapping of cool stars (see e.g. Berdyugina et al. 1998).

To demonstrate the capability of the method for mapping the NRP, we calculated a set of the profiles of the Si III triplet (λ 4552, 4567, 4574 Å) for a test star with the following parameters: $T_{\rm eff}$=25000 K, log$g$=4.0, $v\sin i$=100 km s^{-1}, i=60°, ΔT=2500 K, $\Delta\, v$=3 km s^{-1}. The star is assumed to have sectoral pulsational modes of $\ell = |\, m\, |$=9 with either temperature or velocity field fluctuations. The profiles were simulated with S/N=500 for 22 rotational phases covering a whole rotation. The recovered image of the test star shows distinctly the sectoral structure of pulsations for the both cases (Fig. 1). Thus, we conclude that the applied technique can indeed serve as a helpful diagnostic of the pulsation modes.

3. Mapping the Surface of ω^1 Sco

ω^1 Sco (HD144470, B1 V) was recently discovered by Telting & Schrijvers (1998) as a rapidly rotating β Cephei star showing remarkable line-profile variations in the Si III triplet. They interpreted *lpv* in terms of non-radial pulsations, found a single significant frequency, 15 cycles/day, and determined a pulsational degree

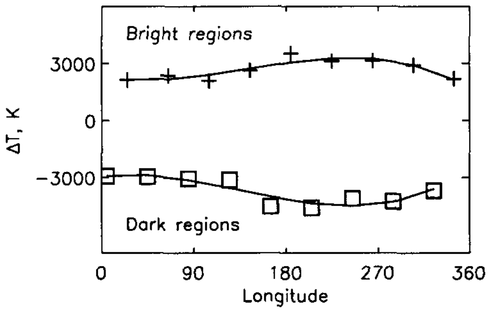

Figure 3. Amplitudes of the pulsation “bumps” measured in temperatures from the image presented in Fig. 2.

of the dominant mode, $\ell = 9 \pm 1$. Comparing the *lpv* with models, they derived the mode to be prograde and sectoral, i.e. $m = -9$.

Here, we apply the surface imaging inversion technique to the same time series of profiles and obtain a temperature map of the surface corotating with the dominant pulsation mode. All needed parameters were the following: $T_{\rm eff}$=26000 K, $\log g$=4.0, $v\sin i$=105 km s^{-1}, i=60°. A set of the local line profiles was calculated for the temperature range of 20000–30000 K with the models by Kurucz (1993). A recovered image of ω^1 Sco and fits to the observed profiles are shown in Fig. 2. A clear sectoral mode of $\ell = | m | = 9$ is read from the image. The temperature fluctuations are concentrated in the equatorial zone in good agreement with predictions of NRP.

An analysis of the map reveals amplitude modulation of the pulsations in the opposite stellar hemispheres (Fig. 3). This suggests the presence of another sectoral mode with ℓ close to the dominant mode. This gives a ’beating’ pattern where on one side of the star the amplitudes add constructively, and on the other side they cancel out. We find that a mode of $\ell = 8$ is appropriate: its expected frequency of 13.33 cycles/day coincides well with the low-power frequency of 13.6 cycles/day which was found in the data with Fourier transforms by Telting & Schrijvers (1998).

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