Precise Stellar Radial Velocities
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Radial Velocity Variations of the Rapidly Oscillating Ap Star 33 Lib

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Abstract. We present precise stellar radial velocity (RV) measurements of the rapidly oscillating Ap (roAp) star 33 Lib taken in rapid succession over a 3-hr time span. A Fourier analysis of the data clearly shows the 8.2 min. pulsation period found previously by photometric investigations and gives a peak-to-peak ($2K$) amplitude of about 80 $\mathrm{m\,s^{-1}}$. We find, like in other roAp stars we have studied, that the RV amplitude depends on the spectral region used for measuring the pulsational RV amplitude and is as high as 57 ± 4.7 $\mathrm{m\,s^{-1}}$ in the region 5411–5500 Å and as low as 7 ± 3 $\mathrm{m\,s^{-1}}$ in the 5877–5976 Å region. An analysis of individual spectral lines show considerable scatter in the RV amplitude, ranging as high as 320 $\mathrm{m\,s^{-1}}$ and as low as 7 $\mathrm{m\,s^{-1}}$. There is an overall trend of increasing RV amplitude with decreasing line strength. We also found that spectral lines due to nickel have a higher mean RV amplitude than chromium lines. We believe that the line strength variations result from the vertical atmospheric structure of the pulsations and that the elemental differences are related to the inhomogeneous distribution of elements known to occur on Ap stars. Precise stellar radial velocity studies of roAp stars may be a powerful tool for studying both the spatial (surface) and vertical structure to the pulsational velocity field.

1. Introduction

The rapidly oscillating Ap stars (roAp) represent a class of stars pulsating in nonradial p-modes with periods of 4–15 min. These star also possess global dipole magnetic fields and the pulsational axis is aligned with the magnetic axis rather than the rotation axis (oblique pulsator).

Most of what we know about roAp stars have been gleaned from photometric studies. We have begun a program of using precise stellar radial velocity (RV) measurements to study these pulsations. Here we present RV measurements for the roAp star 33 Lib. This star is a cool roAp star with a magnetic field

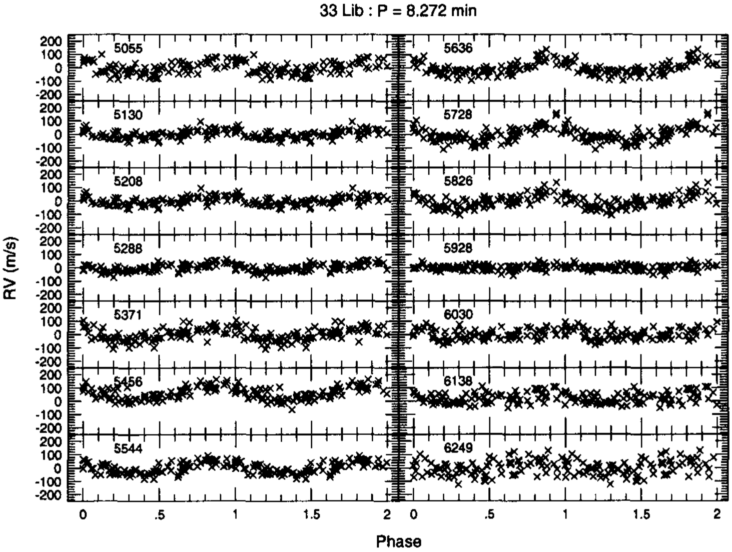

Figure 1. The discrete Fourier transform of the 14 spectral orders of 33 Lib that were examined for RV variations. The number in each panel refers to the central wavelength of each spectral order. The wavelength coverage in each order is about 110 Å.

strength of +1600 gauss that is mildly variable and with no reversal of sign (i.e. we only view one magnetic pole). The photometric period is 8.272 min with a peak-to-peak amplitude of $\Delta B = 1.5$ mmag.

2. Observations

Spectra were taken with the 2-d coudé spectrograph of the McDonald Observatory 2.7-m telescope. This instrument along with a Tektronix 2048×2048 CCD detector provided a wavelength coverage of 3500 Å – 1μm at a resolving power of $R = (\lambda/\Delta\lambda) = 60\,000$. The wavelength reference for the RV measurements was provided by an iodine absorption cell. To minimize the CCD readout time the detector was binned a factor of two perpendicular to the dispersion and only a sub-frame of 1000 rows spanning the wavelength interval 4500–7000 Å was read. The total deadtime between exposures was 38 seconds. The exposure time for each observation was 50 s and observations were made in rapid succession for a total 3 hours (80 observations). The typical signal-to-noise ratio for each observation was about 75.

3. Results

Fourteen spectral orders spanning 5000–6300 Å were used for the radial-velocity measurements. The RV was computed using each full spectral order as well as individual spectral lines.

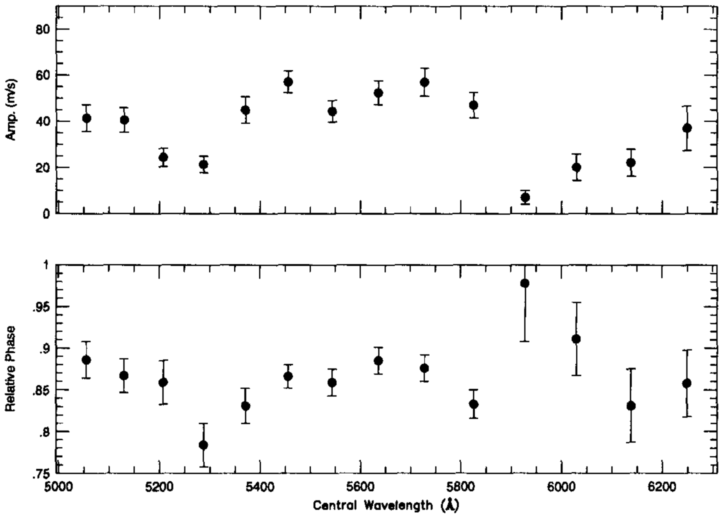

Figure 2. (Top) The pulsational RV amplitude as a function of the central wavelength of the spectral order. (Bottom) The phase of the pulsations as a function of the central wavelength of the spectral order. The phase represents the time of RV maximum phased from the time of the first observation.

Fig. 1 shows the discrete Fourier transform of the RV measurements from each of the spectral orders. The vertical dashed line indicates the photometric frequency. The pulsational RV amplitude varies significantly from order to order being as high as 57 m s^{-1} in the spectral order centered on 5728 Å and virtually absent (7 m s^{-1}) in the spectral order centered on 5928 Å.

The top panel of Fig. 2 shows the least squares RV amplitude as a function of the central wavelength of each spectral order. The lower panel shows the relative pulsation phase for each spectral order (the time of RV maximum phased from the time of the first observation).

Fig. 3 summarizes the results of the RV measurements from individual lines. It shows the pulsational RV amplitude as a function of line strength for four atomic species: iron, chromium, titanium, and nickel. Because of an insufficient number of spectral lines, both neutral and once ionized lines were averaged together, except for iron. Each point represents an average of 1–4 individual lines and the error bars represent the rms scatter of the measurements used in computing the average. It is not known if the one discrepant point at EW = 200 mÅ in the nickel panel is due to misidentification of the line or blending. We should note that this point is an average of two individual measurements.

4. Conclusions

Our RV measurements for 33 Lib reveal that the pulsational amplitude depends on the spectral region that is examined. A detailed line-by-line analysis shows

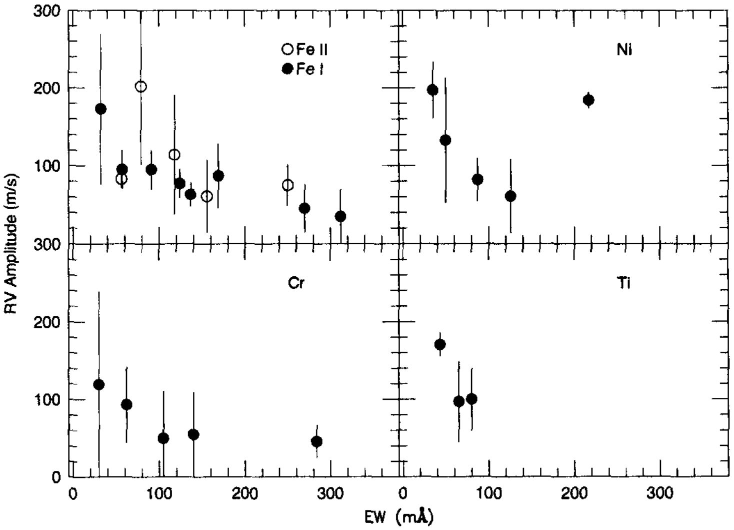

Figure 3. The RV amplitude as a function of line strength for four atomic species: iron, nickel, chromium and titanium.

that this RV amplitude depends both on the atomic species of the spectral line as well as the line strength. Lines of nickel have the highest mean amplitude (137 ± 60 m s^{-1}) whereas chromium has the lowest (87 ± 45 m s^{-1}). For a given atomic species the pulsational amplitude increases with decreasing line strength. A similar RV behavior has been seen in γ Equ (Kanaan & Hatzes 1998), HR 1217 (Hatzes & Kanaan 1998) and α Cir (Baldry et al. 1998).

These results are interpreted in the context of the oblique pulsator model and the inhomogeneous distribution of elements on the surface of the star. Elements concentrated near the magnetic poles (vertical field lines) have a higher RV amplitude than those concentrated near the magnetic equator (horizontal field lines, nodal lines for pulsations). The equivalent width effect may be due to vertical structure of the pulsations. Weaker spectral lines are formed deeper in the atmosphere, possibly closer to the excitation region. Consequently these lines have higher amplitude than strong lines that are formed higher in the atmosphere. If true, then roAp stars may represent a unique opportunity for studying both the vertical and horizontal structure of stellar oscillations.

References

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