Precise Stellar Radial Velocities
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Limitations of Precise Radial Velocity Measurements in Pulsating Stellar Atmospheres

J. Vinkó[1,2]

Research Group on Laser Physics of the Hungarian Academy of Sciences, and Department of Optics & Quantum Electronics, JATE University, Szeged, POB 406 H-6701 Hungary

G. Kaszás[2]

Department of Optics & Quantum Electronics, JATE University

L. L. Kiss[2]

Department of Experimental Physics, JATE University, Szeged, Dóm tér 9, H-6720 Hungary

Abstract. We study the velocities of specific stellar absorption lines of Cepheid-type variable stars determining line bisector velocities from newly obtained high-resolution echelle spectra. We compare these velocities with recent CORAVEL measurements of Cepheids to reveal systematic differences of 2 – 3 km s^{-1}.

1. Introduction

Precise radial velocities are of great significance in the case of pulsating stars. This is basically due to the importance of radial velocities in Baade-Wesselink techniques to derive stellar radii and distances, in discovering binary companions and inferring stellar masses, and in verifying theoretical pulsational models via observations.

Cepheids play an essential role among pulsating variable stars as well as in almost every field of astronomy including stellar evolution and extragalactic distances. They are late-type giant or supergiant stars, they show very stable, radial pulsation with large amplitude which make them useful targets for obtaining precise radial velocities.

However, it has been known for a long time that there are problems with measuring Cepheid velocities. This is because different spectral lines have different velocities (level effect), the profiles of lines are asymmetric, and line doubling or emission may occur at certain phases. These effects arise from the presence

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[1] Magyary Fellow, Foundation for Hungarian Education and Science

[2] Visiting observer, David Dunlap Observatory, Richmond Hill, Canada

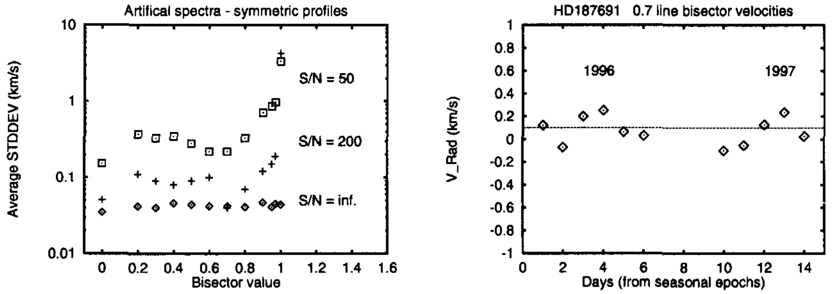

Figure 1. The standard deviation of bisector velocities of artificial spectra (left panel) and the 0.7-bisector velocities of the IAU velocity standard star HD 187691 (right panel).

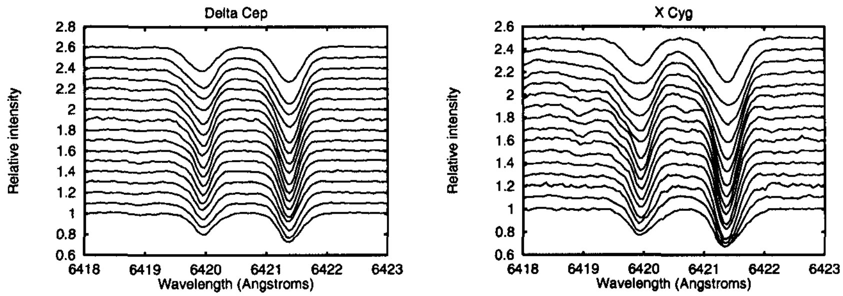

Figure 2. The line profiles of δ Cep and X Cyg. Phase is increasing from bottom to top.

of a velocity gradient in the pulsating atmosphere and changes of the location of the line-forming region during the pulsation cycle.

It was recently shown, e.g., by Butler (1993) and Butler, Bell, & Hindsley (1996) that these effects limit the precision of measured velocity curves to about 1 km s^{-1}.

2. New radial velocities of Cepheids

In this paper we present a progress report of a project of obtaining new high-resolution velocities of Cepheids. The observations were made at David Dunlap Observatory with the échelle spectrograph mounted on the 1.8-m telescope. The spectra had S/N ratios over 100 and the resolution was about 40 000. The covered spectral interval was between 5 800 – 6 600 Å.

We used both line bisector and digital cross-correlation techniques to derive radial velocities measuring Doppler shifts of unblended Fe I, Ni I and Si II lines in the 6 100 – 6 450 Å region. Fig. 1 summarizes the results of testing the velocity determination with artificial spectra containing Gaussian lines. It is seen that in the case of our resolution and S/N, the cross-correlation (given as 0 bisector) and the 0.7 bisector give the most accurate velocities. The right panel of Fig. 1

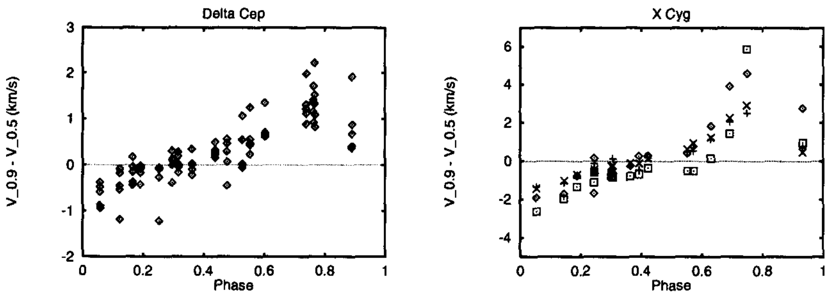

Figure 3. Bisector velocity differences computed using four Fe I lines with E.P. = 2 – 3 eV.

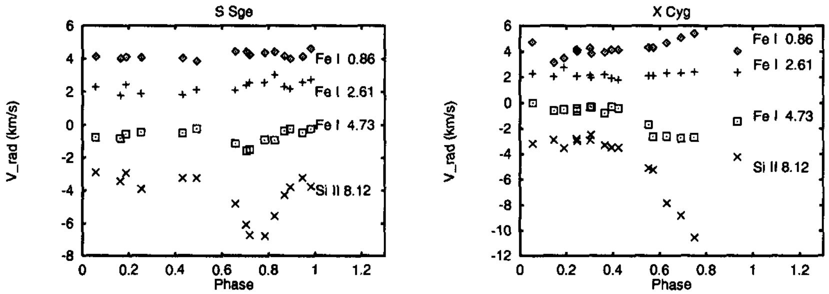

Figure 4. The deviations of velocities of selected lines from the average value. Excitation potentials are marked on the right-hand side of both panels.

displays the computed velocities of the IAU velocity standard star HD 187691 during the two seasons – the deviations from the standard value are about 100 – 200 $\mathrm{m\,s^{-1}}$. We adopt these values as the internal error of our velocity measurements.

The asymmetric shape of the spectral lines of Cepheids as well as its variation throughout the pulsational cycle can be observed in Fig. 2, while Fig. 3 illustrates the effect of line asymmetries on the inferred velocities.

Here we present the differences of the velocities of the 0.9 and the 0.5 bisectors of the same line as a function of phase. The difference between the velocities of the line center (0.9 bisector) and the line wings (0.5 bisector) depends on the phase of pulsation and the atomic parameters (strength, excitation potential) of the line chosen. The ambiguity of the velocity of a given line can be as large as 3 – 6 $\mathrm{km\,s^{-1}}$ in the case of X Cygni, while it is 1 – 2 $\mathrm{km\,s^{-1}}$ for δ Cephei.

Examples of line level effects for two long-period Cepheids are presented in Fig. 4. In these graphs the deviations of the velocities of selected individual lines from the average velocity are plotted against phase. The Si II 6347.1 Å line is a good indicator of the strength of level effects. Its deviations, however, cannot be explained by kinematic velocity gradients (Butler et al. 1996), because the γ-

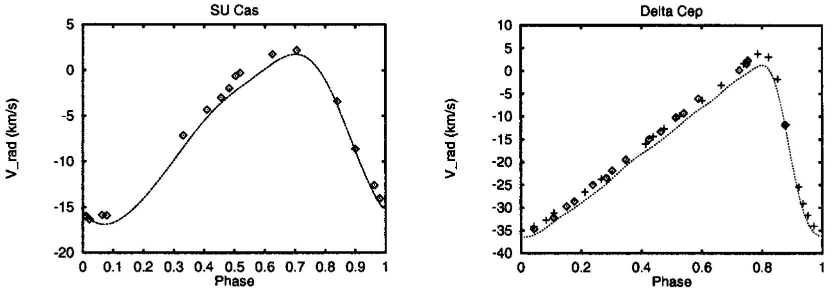

Figure 5. Comparison of our line bisector velocities (diamonds) with velocities from CORAVEL (dotted line). The right panel also shows the iodine-cell velocities from Butler (1993) as crosses.

velocity of the Si II velocities is quite different from the γ-velocity of the average velocity curve.

The average velocities for all lines (average E.P. is about 3 eV) are compared with the CORAVEL velocities of Bersier et al. (1994) in Fig. 5 for SU Cas and δ Cep. For δ Cep, the iodine-cell velocities of Butler (1993) are also plotted. It is visible that these agree quite well with our new velocities, while there is a clear disagreement both in shape and average value (γ-velocity) between the CORAVEL and bisector velocities. Note, that period variation was checked carefully and phase shifts were eliminated by matching light curves obtained at the same epochs as the velocities. The deviations can be as large as $2-3$ km s^{-1} and they are phase-dependent, so cannot be explained by, e.g., orbital motion.

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References

Bersier, D., Burki, G., Mayor, M., & Duquennoy, A. 1994, A&AS, 108, 25
Butler, R.P. 1993, ApJ, 415, 323
Butler, R.P., Bell, R.A., & Hindsley, R.B. 1996, ApJ, 461, 362

Discussion

Marcy: Martin Krockenburger and Paul Butler have done similar Cepheid line-profile work. Do your results agree with theirs, and does the distance scale to Cepheids change?

Vinko: Yes, we did similar work with more stars included in the sample, and the results agree very well. These effects probably do not disturb the calibration of the distance scale. However, they may considerably affect the results of Baade-Wesselink analyses.