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ABOUT THE STABILITY OF THE SPECTROGRAPH OF THE 1-M YALE TELESCOPE AT CERRO TOLOLO

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RESUMEN

Hemos medido velocidades radiales con el telescopio de 1-m de Yale y su espectrógrafo, de estrellas patrones de velocidad radial en el sistema de la *UAI*. Con los resultados discutimos correlaciones con la declinación de las estrellas, el ángulo horario y el producto del coseno del ángulo paraláctico y la tangente de la distancia zenital. No se ha podido establecer ninguna correlación cierta.

ABSTRACT

We have measured radial velocities with the 1-m Yale telescope plus spectrograph combination for several standard stars whose radial velocities in the *IAU* system are known. With the results we discuss correlations with the declination of the stars, the hour angle and with the quantity.

$$L = \mathrm{tg}\ z \cos q$$

where z is the zenith distance and q the parallactic angle. No correlation could be established.

Key words: **INSTRUMENTS**

I. INTRODUCTION

Some years ago Shawl, Hesser, and Meyer (1981) showed that the spectrograph used at the cassegrain focus of the 1-m Yale telescope at Cerro Tololo had a systematic effect in the radial velocities of the stars measured with it. The radial velocity was a mild function of the declination of the observed stars. Shawl *et al.* derived this result using observations taken before 1978 and they obtained the spectra with a *dispersion of 121 A mm*$^{-1}$ using the RCA image-tube. Very recently Bassino and Muzzio (hereinfter BM) (1984) re-investigated the systematic errors of the radial velocities observed with such instrumental configuration but using 43 A mm^{-1} and IIa-0 emulsion, they found errors that they thought are caused by the dispersion of the stellar light in the atmosphere of the Earth. This well known effect (guiding error) is enhanced, according the Bassino and Muzzio, due to the sensitivity of the image-tube eyepiece of the spectrograph to the red light (more sensitive than the eye).

In the meantime many papers have appeared in the literature using observations of the 1-m Yale spectrograph, and in general the authors agree about the stability of the instrumental configuration.

As part of our long range program on radial velocities among members of open clusters and associations we obtained a large number of spectra of standard stars since October 1982 until April 1984. We analyzed carefully this material because it is very important for our program to be sure about the radial velocity system in which we are working. In what follows we will describe our strictly empirical results.

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II. OBSERVATIONS

We observed during different observing runs six standard stars taken from the *IAU* list. Table 1 indicates the stars observed, their spectral types, declination and radial velocity in the *IAU* system. We obtained spectra at 43A mm^{-1}, on IIIa-J emulsion (this is a difference with BM data) using the RCA image-tube. The spectra were widened up to 1 mm, and all of them were measured with a Grant comparator using the Fe lines λλ4045, 4063, 4071, 4404 and 4415 and also Hγ, Ca I 4226 and Sr 4215 in some cases.

Table 2 provides the individual radial velocities measured for each spectrogram jointly with the Julian Dates and the internal probable errors. Table 3 gives the average radial velocity for each star observed in each observing run jointly with the probable error of the mean. Also this table provides the correction to the *IAU* system which is necessary to apply to our observations. From Table 3 it is clear that the correction is fairly constant during the period covered by our observations (October 1982-April 1984). Now let us consider in the next sections, the facts that may affect the above corrections.

III. LABORATORY WAVELENGTHS

To measure the radial velocities we adopted the laboratory wavelengths given by Moore's table (1945). However in late-type stars, as they are the *IAU* standards, some workers in radial velocity research have adopted the DAO (Batten *et al.* 1971) set of rest wavelengths.

Table 4 gives the spectral lines from Moore that we have used and the lines recommended by Batten *et al* (1971) which we have also used to compare the results.

TABLE 1

STANDARD STARS OBSERVED

Star Name	HD	Declination	Spectral Type	*IAU* Radial Vel.
6 Cet	693	– 15°45′	F6 V	+ 14.7
β Lep	36079	– 20°48′	G5 III	– 13.5
...	80170	– 39°11′	K5 III-IV	0.0
β Crv	109379	– 23°07′	G5 III	– 7.0
κ Ara	157457	– 50°35′	K1 III	+ 17.4
δ Sgr	168454	– 29°51′	K2 III	– 20.0

We reduced 10 spectra of β Leporis using the two different sets and we obtained average corrections as follows:

IAU – Tololo = + 13 ± 1.4 km s^{-1} (Moore's wavelength).

IAU – Tololo = + 7 ± 1.6 km s^{-1} (DAO wavelength).

Thus it seems that the *IAU* radial velocity system is better reproduced if the DAO wavelength set is used for late type stars (later than F5). There are many papers in the literature using radial velocity data obtained with the Yale 1-m telescope whose authors have reduced the plates with the DAO set of rest wavelengths and they obtained corrections around zero which seem to be very close to our results.

In the case of early type stars, the situation is more difficult because there are no recognized standards among them.

TABLE 2

INDIVIDUAL MEASUREMENTS

Julian Date 2440000	Radial Velocity km s^{-1}	e.p. km s^{-1}	Julian Date 2440000	Radial Velocity km s^{-1}	e.p. km s^{-1}	Julian Date 2440000	Radial Velocity km s^{-1}	e.p. km s^{-1}
β Lep = HD 36079			β Lep = HD 36079			β Lep = HD 36079		
5245.900	-31	4	5360.555	-41	3	5368.539	-32	4
5246.891	-30	3	5360.562	-39	4	5368.539	-32	3
5246.898	-34	2	5361.547	-29	4	5369.547	-37	5
5247.875	-30	4	5361.547	-27	3	5369.547	-25	3
5247.883	-28	3	5365.539	-37	4	5369.556	-39	4
5248.867	-29	4	5365.547	-32	5	5369.546	-23	4
5248.867	-26	2	5365.547	-24	4	5370.540	-21	4
5249.836	-25	3	5365.547	-31	4	5370.542	-19	6
5249.836	-27	4	5366.539	-23	4	5370.552	-30	5
5250.883	-25	2	5366.539	-30	4	5371.555	-22	2
5250.891	-28	3	5366.540	-36	6	5371.563	-44	4
5251.812	-26	4	5366.543	-30	4	5372.552	-19	4
5251.820	-32	3	5366.547	-24	4	5372.554	-22	3
5252.805	-31	3	5367.539	-35	4	5372.565	-17	3
5252.805	-29	3	5367.539	-27	4	5777.495	-24	3
5360.508	-31	4	5367.539	-33	3	5778.499	-35	3
5360.555	-35	4	5367.648	-29	3	5779.494	-12	2
5360.555	-34	5	5367.648	-41	6	5782.493	-28	3
						5783.496	-33	3

TABLE 2 (CONTINUED)

Julian Date 2440000	Radial Velocity km s^{-1}	e.p. km s^{-1}
6 Cet = HD 693		
5246.703	-1	3
5247.680	5	2
5250.656	-4	2
5250.750	4	2
5250.758	4	3
5250.758	4	3
5251.687	-3	3
5251.687	-4	3
5252.664	-7	3
HD 80170		
5360.109	-11	5
5359.875	-18	5
5359.875	-16	4
5360.867	-24	3
5360.875	-15	4
5361.828	-16	4
5361.828	-14	2
5361.836	-13	3
5361.875	-18	5
5365.703	-3	5
5365.703	-8	3
5365.852	-18	2
5365.859	-7	5
5366.703	-17	5
5366.711	-22	4
5366.711	-23	3
5366.852	-21	4
5366.852	-17	4
5367.656	-19	3
5367.656	-13	4
5367.789	-13	3
5367.992	-16	4
5368.727	-23	4
5368.734	-22	3
5368.734	-22	4
5369.703	-19	7
5369.706	-22	3
5369.709	-26	5
5369.890	-21	4
5369.894	-24	4
5370.680	-16	4
5370.687	-14	5
HD 80170		
5370.687	-17	4
5370.883	-14	3
5370.883	-12	5
5371.749	-24	4
5371.500	-22	5
5371.714	-20	3
5372.706	-21	4
5372.710	-25	5
5372.714	-25	5
5776.712	-25	4
5778.715	-26	3
5778.590	1	3
5780.648	-18	3
5780.652	-26	3
5781.574	-18	3
5782.676	-14	3
5783.646	-14	2
5783.651	-22	3
5784.610	-11	3
5785.579	-12	3
5785.583	-16	2
5786.581	-15	4
5786.585	-9	2
5787.639	-17	3
5787.642	-18	3
5788.592	-16	2
5789.672	-18	2
κ Ara = HD 157457		
5776.887	1	2
5776.898	-7	3
5777.908	-2	2
5779.908	4	2
5779.905	-4	3
5783.868	7	3
5783.907	3	3
5784.894	-2	4
5784.897	1	2
5786.904	-1	4
5786.907	1	3
5787.848	4	3
5787.851	5	3
5787.903	19	2
κ Ara = HD 157457		
5788.894	2	2
5788.896	5	2
5809.882	-2	3
5810.885	-2	3
5811.835	0	3
5812.858	2	2
5813.826	-1	2
β Crv = HD 109379		
5779.799	-22	3
5779.802	-22	3
5780.728	-18	3
5782.809	-26	4
5784.811	-25	3
5784.817	-29	2
5784.833	-20	2
5785.828	-24	2
5786.822	-25	3
5786.828	-22	3
5787.806	-21	3
5789.805	-20	3
5804.685	-24	3
5804.690	-24	2
5805.773	-27	1
5807.655	-23	4
5807.808	-21	2
5808.507	-20	2
5808.805	-25	3
5809.656	-26	2
5810.815	-21	2
5811.777	-20	1
5812.719	-24	2
5813.818	-21	3
δ Sgr = HD 168454		
5248.485	-35	5
5250.494	-36	4
5252.495	-37	4
5252.499	-34	6

But using observations of 24 *secondary standards* or bright stars extensively observed without any report of radial velocity variability, we found a correction to the *IAU* system which is 50% of the average correction that results from Table 3 (around 6 km s^{-1}). So the situation concerning the observed correction to the *IAU* system of radial velocities, for data obtained with the 1-m Yale Telescope using 43 A mm^{-1} dispersion on IIIaJ emulsion, seems to be the following: for late-type stars the *DAO* set of recommended lines reproduced better the *IAU* system than Moore's wavelengths. The average correction that we found is around 7 km s^{-1} and 16 km s^{-1} respectively. In the case of early-type stars there is no difference in the wavelengths sets and the correction to the Lick system seems to be around 6 km s^{-1}. In practice a null correction seems quite reasonable and this agrees with the findings of dozens of papers in the literature.

IV. CORRELATION WITH THE DECLINATION OF THE STARS

Shawl *et al.* (1981) and also BM found that the residduals of the radial velocity show a systematic trend with the declination of the stars.

TABLE 3

CORRECTIONS TO THE *IAU* SYSTEM FOR EACH OBSERVING RUN

Observing Run	Stars observed	Number of plates	R.V. ($km\ s^{-1}$)	p.e.	Correction to *IAU* system
October 1982	β Lep	15	28.7	1.8	+ 14.5
	6 Cet	9	− 0.2	3.0	+ 15
Feb/Mar 1983	β Lep	35	29.5	4.9	+ 16
	HD 80170	41	− 18.0	3.6	+ 18
March 1984	κ Ara	21	1.6	3.5	+ 16
	β Crv	24	− 22.9	1.8	+ 16
	δ Sag	4	− 35.5	0.9	+ 15.8
	β Lep	5	− 26.4	6.1	+ 13
	HD 80170	18	− 16.3	4.4	+ 16

TABLE 4

LABORATORY WAVELENGTHS

Moore's Set	*DAO* set
3933.664[a]	4005.59
4045.815	4045.61
4063.597	4077.71
4071.740	4101.69
4215.524[a]	4143.50
4226.728	4171.69
4340.468[a]	4226.64
4404.752	4271.63
4415.125	4383.82

a. Used only in a few cases.

Figure 1 shows the average correction to the *IAU* system of radial velocity (Δ V) for the six stars observed in this paper, using Moore wavelengths, plotted against the declination. The bars are probable errors of the mean. No systematic dependence can be inferred from this figure.

An important point to be noted in BM's Figure 1 is that if one eliminates the secondary standards and plots only the *IAU* standards the correlation with the declination cannot be established.

V. CORRELATION WITH AN EVEN FUNCTION OF THE HOUR ANGLE

We checked the correlation with an even function of the hour angle (cos t). Figure 2 shows the plot of V against cos t. From the figure no systematic trend can be inferred, however for those who like numbers, we computed the best fitting line and the correlation coefficient for this two variables obtaining a value of -0.016 ± 0.070 (standard error) which corresponds, using the Student's t distribution, to a very low probability (< 80%) that this value does not arise just from chance.

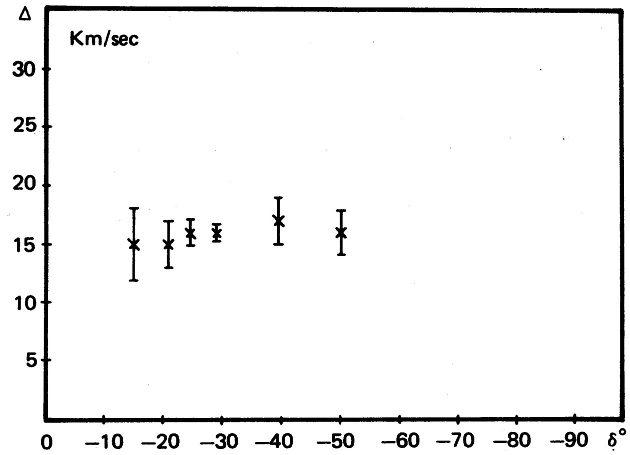

Fig. 1. Relation between the average correction to the *IAU* system for each star and the declination.

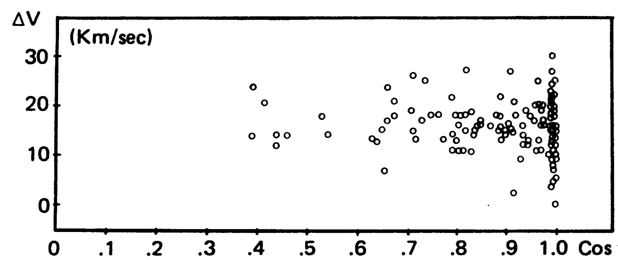

Fig. 2. Relation between the individual correction to the *IAU* system for each spectrogram and the cosine of the Hour Angle at mid-exposure.

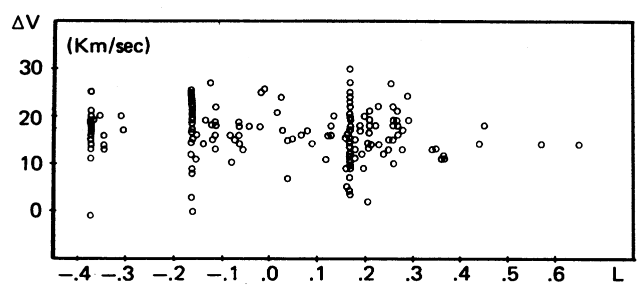

Fig. 3. Relation between the individual correction to the *IAU* system for each spectrogram and the quantity L = tg z cos q defined in the text.

VI. CORRELATION WITH ZENITH DISTANCE AND PARALLACTIC ANGLE

BM defined the quantity L = tg z cos q where z is the zenith distance and q the parallactic angle. Figure 3 shows our individual corrections to the *IAU* system plotted against the quantity L. Here again no relation can be noted and also we computed the coefficient of correlation of L with ΔV to be $r = -0.11 \pm 0.075$ (standard error). This corresponds to a value of $|t| = 1.44$ of the Student's t distribution and to a probability of less than 80% that such a value does not arise just from chance.

It is important to note that if in Figure 3 of BM's paper one considers only the *IAU* standards the very mild relation than can be derived from it disappears.

VII. DISCUSSION

It is clear from the above empirical analysis that with our data, taken between October 1982 and April 1984, we could not find any of the systematic effects mentioned in Shawl *et al.* and BM papers, for the radial velocities measured with the 1-m Yale spectrograph.

It is obvious that the guiding errors exist in radial velocity work but they are probably not so high as indicated by BM. Petrie (1964) experimentally guided on the blue and red images of a star and found, for such very extreme situation, a total radial velocity difference of ~ 15 km s^{-1} between the red and blue guided spectra.

When this paper was ready for being sent to publication we received the paper by Augensen (1985) in which this author presents a radial velocity analysis of the central stars of some southern planetary nebulae. The observations were made with the 1-m Yale telescope plus the image-tube spectrograph combination using 45 A mm^{-1}) and IIIa-J plates. The observations were taken in August 1981 and February 1982. The measurement of standard stars to fix the zero point correction gave a residual of + 9 and + 15 km s^{-1} to be applied to the observations of the 1-m Yale telescope. This is in excellent agreement with our results.

On the other hand during a new observing run at Cerro Tololo in April 1985, we took spectrograms of 40 Leo. The six plates obtained gave an average correction to the Lick system of $+ 13 \pm 1.4$ km s^{-1}. The standard star 40 Leo is located at a declination of $+ 20°$.

VIII. CONCLUSION

We must conclude on a strictly empirical basis that:

1) The correction to the *IAU* of the Lick system using the 1-m Yale spectrograph is very stable. The amount of the correction depends on the set of standard wavelengths used in the reduction: practically between 0 and 7 km s^{-1} for early type stars and between 7 and 16 km s^{-1} for late-type stars.

2) We could not find any significant correlation of the correction with Hour Angle or a even function of it.

3) We could not find any significant correlation of the correction with the quantity $L = \mathrm{tg}\, z \cos q$.

4) We could not find any correlation with declination.

5) Radial velocity work with the instrumental configuration described seems to be quite safe and reliable.

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