Radial velocity performance of the coudé-spectrograph of 2-m RCC telescope: a concise reliability test

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Abstract. We report on the results of a reliability test concerning radial velocity performance of the coudé spectrograph of 2-m RCC telescope. During 90 months five bright radial velocity standard stars have been observed in five spectral regions of common use. The set-up of the spectrograph has included "small" B&L (22°.3) grating and 200-mm collimator. Standard IRAF routines and the "classical" line-by-line method of measuring radial velocities have been used to obtain 44 individual measurements. Mean value of the difference between measured and "standard" velocities for the second grating order (4500 – 7500 ÅÅ) is evaluated as $+0.4 \pm 0.3$ km/s. The same value for the first order (> 7500 Å) is -2.0 ± 0.7 km/s. Using cross-correlation methods can improve substantialy the accuracy of measured radial velocities.

Key words: high-precision radial velocity measurements

Измерване на лъчеви скорости на звезди с куде-спектрографа на 2-м РКК телескоп

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Съобщава се за резултатите от измерването на лъчеви скорости с куде-спектрографа в НАО "Рожен". Пет ярки звезди-стандарти за лъчеви скорости бяха наблюдавани в течение на 90 месеца в пет спектрални участъка. Използвана е "малката" решетка B&L (22°.3) и колиматор с диаметър 200 мм. Стандартен IRAF и класическата методика "линия-по-линия" са използвани за да се проведат общо 44 измервания на лъчевите скорости. Средното значение на разликата между измерените и "стандартните" лъчеви скорости във втори порядък (4500 – 7500 ÅÅ) е $+0.4 \pm 0.3$ km/s. Същото значение за първи порядък (> 7500 Å) е -2.0 ± 0.7 km/s. По-широкото използване на крос-корелационни методи може да доведе до подобряване на точността на измерване на лъчевите скорости.

When measuring stellar radial velocities one of the most important questions is how reliable is the spectrograph. Can the results be repeated? Is it possible to get any reproducible data? Are there any systematics? This is crucial especially for many long-term observational programs like radial velocity monitoring of binary systems with unknown periods. By default all coudé spectrographs have to be mechanically very stable. There are no moving parts, and all heavy details are fixed. Some peculiarities in the way we used to use coudé-spectrograph of 2-m RCC telescope require the Photometrics CCD camera to be mounted and dismounted from its mechanical unit many times during the work with the telescope. To be more precise - it happens approximately 15 times every year.

In order to carry out a performance check of the coudé-spectrograph in NAO Rozhen, we put additionally in our observational program five radial velocity standard stars (Stefanik et al. [1999], Udry et al. [1999]). They are: HD 22484 (10 Tau), F9IV-V, $V \sim 4\overset{\mathrm{m}}{.}3$, $R.V. = +27.8 \pm 0.1$ km/s; HD 102870 (β Vir), F9V, $V \sim 3\overset{\mathrm{m}}{.}8$, $R.V. = +4.1 \pm 0.1$ km/s; HD 136202 (5 Ser), F8III-IV, $V \sim 5\overset{\mathrm{m}}{.}0$, $R.V. = +54.2 \pm 0.1$ km/s; HD 187691 (o Aql), F8V, $V \sim 5\overset{\mathrm{m}}{.}1$, $R.V. = -0.2 \pm 0.1$ km/s and HD 222368 (17 Psc), F7V, $V \sim 5\overset{\mathrm{m}}{.}4$, $R.V. = +5.4 \pm 0.1$ km/s. All common data are from SIMBAD. Radial velocities are taken from Nordstöm et al. [2004]. High-precision spectrograph CORAVEL has been used to produce hundreds of individual measurements for each star.

Our observations have a time span of about 90 months, from December 1999 to March 2007. Just like in our regular coudé-runs we used "small" B&L (22°.3) grating and 200-mm collimator. Spectroscopic CCD-observations were carried out in five wavelength regions, centered at λ4500 Å, λ5890 Å, λ6420 Å, λ6440 Å (all of them are 100 Å large), and λ8550 Å (200 Å large). Only the last region lies in the first grating order, the rest are in the second. Standard IRAF routines and the "classical" line-by-line method of measuring radial velocities have been used all the time. The data thus obtained are summarized in the following Table 1.

Table 1. Radial velocities of five standard stars. eRV denotes r.m.s. error, while N is the number of measured spectral lines. The values of RV_{std} are from Nordstöm et al. [2004].

Star	RV_{std}, km/s	RV, km/s	eRV, km/s	N	SpReg	Star	RV_{std}, km/s	RV, km/s	eRV, km/s	N	SpReg
10 Tau	+27.8	+23.7	0.2	19	8550	o Aql	−0.2	+0.4	0.3	20	8550
		+27.0	0.2	19	5890			−4.1	0.3	20	8550
		+27.5	0.2	18	5890			−4.3	0.3	20	8550
		+28.6	0.3	15	4500			+3.3	0.2	14	5890
								+3.3	0.2	13	5890
5 Ser	+54.2	+56.6	0.2	12	5890			+0.6	0.2	21	8550
		+54.7	0.1	12	5890			−1.2	0.3	19	8550
		+54.2	0.1	12	5890			+1.6	0.4	18	8550
		+54.7	0.1	12	5890			+0.0	0.2	12	5890
		+49.7	0.3	16	8550			+2.0	0.6	19	8550
		+49.8	0.5	16	8550			−2.7	0.4	18	5890
		+53.9	0.3	10	6420			+1.1	0.4	13	6440
		+54.5	0.2	12	6440			+0.9	0.4	15	6440
		+54.9	0.3	11	6420			−1.2	0.4	18	8550
		+52.4	0.4	15	8550			−0.7	0.2	13	5890
		+56.1	0.3	10	6440			−0.8	0.3	13	6440
		+53.9	0.2	12	5890			+0.6	0.3	13	6440
								+0.7	0.3	12	6440
β Vir	+4.1	−0.7	0.3	20	8550			−1.9	0.3	12	6440
		+7.3	0.2	19	8550			−1.5	0.3	13	6440
		+3.6	0.4	19	8550						
		+1.3	0.4	19	8550	17 Psc	+5.4	+5.8	0.3	13	6440
		+4.2	0.2	10	5890			+5.2	0.3	12	6440
								+4.9	0.4	14	5890

The statistics collected by us is quite enough to make some basic conclusions about the possible systematic shifts, and to study the reliability of the spectrograph. The differences D between every particular measurement listed in the Table and the appropriate value of $\mathrm{RV_{std}}$ have been thoroughly probed. Sixteen measurements in the first order gave mean value of $< D_I > = -2.0$ km/s, with a r.m.s. error of 0.7 km/s. There are twenty eight measurements made in the second order. The mean value in this case is $< D_{II} > = +0.4$ km/s, while the r.m.s. error is 0.3 km/s. The value of $< D_{II} >$ is much less than the typical error we can reach in almost all of the observational programs implemented at the telescope. In other words - the systematic shift of the coudé-spectrograph can be neglected beyond the limit of 1 km/s, and for the spectral range 4500 – 7500 ÅÅ. A simple Student's t-test has demonstrated, however, that the difference between $< D_I >$ and $< D_{II} >$ is statistically significant. Radial velocities measured in the near-infrared appeared to be about 2.5 km/s smaller than those taken in the optical region. This difference has remained even during our special experiments when the transition between the two spectral regions has been provided just by exchanging the order separation filters only. In such cases the wavelengths from the first order reference spectrum have been computed via dispersion curve obtained from the second order reference spectrum and vice versa. Large r.m.s values in both orders can be addressed most probably to the limited capabilities of the mechanical unit used for mounting the CCD camera to the spectrograph.

Our experience shows that a substantial improvement of the accuracy can be achieved by using cross-correlation methods. Successful application of suitable synthetic templates has been described in details in Dümmler et al. [1997], and Zverko et al. [2007]. The ultimate approach, to have at least two radial velocity standard stars in every night of observation has been performed by Dümmler et al. [2002].

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