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ОБСЕРВАТОРИИ

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The Ural's fiber-fed echelle spectrograph (UFES) at the 1.2-meter telescope of the Kourovskaya astronomical observatory

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Аннотация. В Коуровской астрономической обсерватории в 2010 г. был установлен оптоволоконный эшелле-спектрограф (в фокусе Нэсмита 1.2-м телескопа). Прибор разработан и построен в лаборатории астроспектроскопии САО РАН. Спектральный диапазон прибора 3900–10500 Å, разрешение R = 30000, оптическая эффективность не меньше 2 %.

Найдено распределение рассеянного света (вклад в интенсивность 1–2 %), геометрическая и температурная нестабильности (средний сдвиг 1.8 px/°C), инструментальный профиль (FWHM = 4–6 px), точность измерения лучевых скоростей (0.3–0.4 km/s), величина отношения сигнал-шум в зависимости от времени экспозиции и звездной величины.

Также описаны потери света, возникающие вследствие атмосферной дисперсии, ошибок позиционирования объекта на входе оптоволокна. Описаны ошибки автогидирования, предлагаются возможные усовершенствования.

THE URAL'S FIBER-FED ECHELLE SPECTROGRAPH (UFES) AT THE 1.2-METER TELESCOPE OF THE KOUROVSKAYA ASTRONOMICAL OBSERVATORY, *by A.F. Punanova, V.V. Krushinsky.* A new fiber-linked echelle spectrograph constructed in the Laboratory of astrospectroscopy of the SAO RAS has been installed at the Nasmyth focus of the 1.2-meter telescope of the Kourovskaya astronomical observatory. The spectral range of the spectrograph is 3900 to 10500 Å with a resolution R = 30000 and optical efficiency at least 2 %.

In this article, we present results of calibration of the dispersion curve, ThAr atlas, tests on scattered light distribution (contribution to intensity 1–2 %), geometrical and temperature instability (average shift 1.8 $px/^\circ C$), signal-to-noise calculator, instrumental profile (FWHM = 4–6 px) and the determination of radial velocity accuracy (0.3–0.4 km/s). Also light losses such as atmosphere dispersion, errors of positioning of an object on the fiber entrance, auto guiding errors are described and probable improvements are discussed.

Key words: spectrographs, detectors, image processing, spectroscopic

1 Efficiency of the instrument

The manufacturer of the spectrograph (Panchuk et al., 2011) declared an optical efficiency of the instrument to be at least 2 % (optical design of the spectrograph is presented in Fig. 1). Basic features of the spectrograph according to the technical documentation (only the signal to noise ratio from our tests

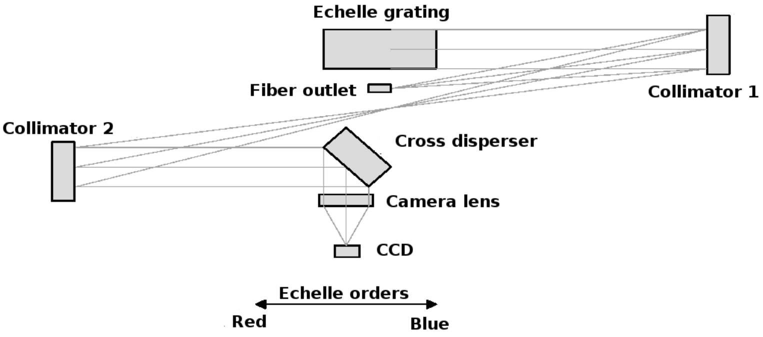

Fig. 1. Design of the optical bench of the spectrograph

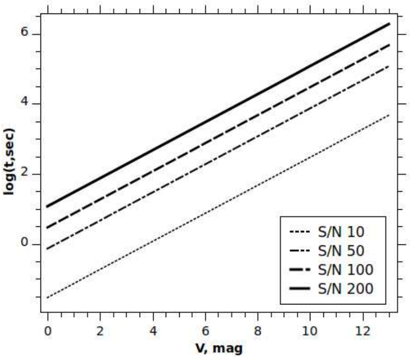

Fig. 2. Estimated S/N for various magnitudes

on sensitivity) one can find in Table 1. We investigated possible reasons of additional light losses. The investigation has been performed with IRAF software (Tody, 1993).

During the test observations of Procyon at relatively high altitude (35°) we found a significant influence of the atmospheric dispersion. The effect is clearly seen on the cross-dispersion profile of the echelle frame. The position of the flux maximum differs for various positions of the star on the fiber entrance.

Signal-to-noise

We derive the formula of a signal to noise ratio from a standard equation (Bolte, 2006):

$$\frac{S}{N} = \frac{R_* \cdot t}{\sqrt{(R_* \cdot t) + (R_{sky} \cdot t \cdot n_{pix}) + (RN^2 + (\frac{G}{2})^2 \cdot n_{pix}) + (D \cdot n_{pix} \cdot t)}} \qquad (1)$$

where S is signal, N – noise, t – exposure time, R_* – count rate from the object, R_{sky} – count rate from the sky, n_{pix} – number of pixels, RN – readout noise, G – inverse gain, D – dark current. The influence of the sky background is negligible for bright stars, dark current and readout noise (about 4 ADU/px) are negligible too. Consequently we can count the signal to noise ratio as $\frac{S}{N} = \sqrt{R_* \cdot t}$. The results of our tests on sensitivity are plotted in Fig. 2.

Temperature instability

During the test observations we found a shift of the wavelength scale correlated with temperature changes. To investigate the temperature instability five thermal elements (DS18b20) were installed in the optical bench of the spectrograph, three inside and two outside. An obvious correlation between the spectrum shift and bench temperature changes was observed.

Decreasing of temperature causes the spectrum redshift, while increasing – the blueshift. It is related to the temperature deformations of the optical bench of the spectrograph. The temperature inertia of the system is seen. Slow increasing of temperature after the steep drop still shifts the spectrum to the red side due to the fact that the inner parts of the optical bench are still cool down. The shift dependence is not linear and depends on the temperature gradient between inner and outer side of the bench. We suspect that such a significant shifts caused by bimetallic (Al+steel) construction of the bench. Thermal deformation occurs due to the fact that metalls have unequal thermal conductivity and coefficient of linear expansion. An average shift is about 1.8 $px/°C$, an average shift on the linear piece (temperature increase is 1.7$°C/hour$) is 1.64 $px/°C$. The random error of the line location in case of stable temperature ($\pm 0.06°C$) is 0.1 px which is a theoretical limit of the line centering error.

We tried to detect the correlation between wavelength shift and position of the telescope using ThAr lamp spectra got in short-time period (0.5 h) without steep temperature changes of the optical bench. The results show that motions of telescope increase the random RMS error of the wavelength scale shift by 2 times, up to 0.2 px. This effect is related to poor scrambling of light in a fiber.

Table 1. Basic features of the UFES

General	
telescope	1.2 m
design	echelle spectrograph, white pupil
focus	Nasmyth, $FL = 13\ m$
resolution	30 000
wavelength	4 000—10 500
N orders	60
sensitivity	$S/N \sim 50$, 9^m, 2900 *sec*
Telescope unit	
aperture on sky	4”
focal reducer	1/2
calibration lamp	ThAr
autoguide camera field	$6' \times 8'$
Optical fiber	
type	dry, step index
numerical aperture	0.12
diameter	150/180 μm
length	23 *m*
protection tube	PVC with Kevlar
micro lenses	BK7 output

Spectrograph	
optical bench	$2.4 \times 1.2 \times 0.5\ m$
echelle grating	R4 (76°), 37.5 g/mm
collimators	2 off-axis paraboloids $\lambda/10$, $FL = 1\ 000\ mm$
cross-disperser grating	150 g/mm
camera	CANON 200/1.8
CCD	DinaSystem2 (Advansed Lab SAO RAS)
CCD	
sensor	E2V CCD42-40-0-381
active pixels	2048×2052
pixel size	13.5×13.5 μm
image area	27.6×27.6
Blemish specification	Grade 1 sensor
cooling	Cryotiger
chip temperature	-110°*C*
dynamic range	10 000, 22 000
dark current	$3 \cdot 10^{-3}\ e/px/sec$
gain	$0.54, 2.17\ e/ADU$
readout noise	$3.16, 4.70\ e/px$

Accuracy of radial velocity measurements

We used the spectrum of Aldebaran ($V = 0.985^m$) to determine a radial velocity accuracy. The short exposure allowed the influence of temperature instability to be excluded. The radial velocity measured by 167 lines in several orders differs from the known data (Massarotti et al., 2008) by $-0.08\ km/s$, $RMS = 0.34\ km/s$.

Pipeline

The actual pipeline of UFES allows the observer to make a quick data reduction, visualize the data, and estimate the S/N of the data acquired at the telescope. The pipeline is based on standard IRAF functions. It works with datasets that include object images and calibration images (bias, flat, ThAr, usually 5 items of each one) obtained at the nearest to the object exposure time.

The on-telescope unit redesign

The existing autoguiding system of the spectrograph doesn't work properly. We developed a project of a new on-telescope unit. 8R/92T beam-splitter and fast CCD camera will be used for guiding system. The new device will enable usage of two fibers with different apertures (5 and 10 arcsec). These two configurations will provide spectral resolution 30000 and 15000 respectively. The new device will be available next year.

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