TFOSC AND COUDE SPEKTROSCOPY OF FAINT AND BRIGHT TARGETS AT RTT150

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Abstract

In this report we give some results of positional and spectro-photometric calibrations of TFOSC and Coude-echelle spectrometer instruments at 1.5-meter Russian-Turkish Telescope as well as examples of individual spectra from the scientific programs realized at RTT150.

1. Scientific equipments of RTT150.

RTT150 is a well-equipped telescope amongst the moderate size, 1-3-meter, telescopes of the world: the scientific equipments of RTT150 consist of 3 main instruments, two at F/8 Cassegrain focus and one at F/48 Coude focus:

1. CCD-photometer contains thermoelectrically cooled (-60 C) back-illuminated 2048 x 2048 pixels (13.5μm) CCD (manufactured by ANDOR firm, Northern Ireland) and two sets of 50 x 50 x 5 mm standard filters – BESSELL (UBVRcIc) and SDSS (u'g'r'i'z'). Its field of view is 8′ x 8′, sampling is 0″.24 per pixel. Binning 2 x 2 (0″.48/ pixel) is available to get better Signal-to-Noise ratio. It was found that targets of R ~ 23.5- 24 magnitudes could be detected and measured with an accuracy 0.2-0.3 mag (at 1-1.5 arcsec seeing and 1-3 hours total exposures in dark Moon period). A one percent accuracy is achievable in differential photometry with this photometer with single exposure times of 10 to 30 sec single for 12 -15 mag stars. The high (0″.24/pixel) angular scale allows one to get astrometric accuracy of about 0″.05 in any coordinate for objects with R ~ 12-19 mag.

2. TFOSC, manufactured at the Copenhagen University Observatory, Denmark, is a powerful faint object spectrometer and camera, with direct imaging of objects down to 22-24 magnitudes, and with low (5-15 A) and medium (2-3 A, echelle mode) resolution spectroscopy of faint (10-18 mag) targets. It can be changed from imaging mode to spectroscopic mode within seconds. It has a focal reducer to convert RTT150 F/8 beam to F/5.5 beam, increasing the field of view to 14′ x14′ with 0.39″/pixel sampling. TFOSC is equipped with a set of UBVRI filters for photometry and with a number of grisms and entrance slits providing a set of spectral resolutions depending on seeing and scientific task. The detector is nitrogen cooled, back illuminated CCD chip with 2048 x 2080 pixels (15 μm). In 2006, TFOSC was supplied with an autoguider system, operating with telescope control system and fine drive motors to eliminate telescope tracking inaccuracies and atmospheric differential refraction effects at medium and high zenith distances (Z ~ 30-65 degrees). It was

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found that long single exposures up to 30 min each could be realized with the TFOSC + autoguider system when obtaining spectra of faintest targets of 17-19 mag.

3. Coude echelle spectrometer (CES) is a high resolution spectrometer installed in the special coude-room at the second floor of RTT150 building. Construction of coude-room was designed specially to provide very high positional and temperature stability within it. The Coude-spectrometer consists of 7-meter focal length collimator mirror, large echelle-grating and cross-disperser prisms, and two spectral cameras, providing spectral resolutions of R = 40000 (short focus camera) and R = 100000 (long focus camera). Normal width (2 pixel resolution) of entrance slit is 1.5 arcsec for R = 40000 mode, permitting to use almost all light collected by telescope mirror at median seeing quality of 1.2-1.5 arcsec. This Coude echelle-spectrometer was fully designed and manufactured in Russia. Only the short camera with R = 40000 resolution is used at the moment, which is equipped with 1160 x 1040 pixels front illuminated (16 μm) nitrogen cooled CCD. With this CCD spectral range of 3900-8700 A is registered simultaneously (with some gaps in between echelle orders in yellow and red part of the spectrum due to limited size of the CCD chip). With 2k x 2k CCD, full range of 3500-10000 A could be registered simultaneously at R = 40000 camera and with 4K x 2K CCD at R = 100000 camera.

The limiting magnitude is 8-9 at R = 40000 with 2 hours total exposure and Signal-to-noise Ratio of ~ 100 per resolution element.

Knowing that proper calibration is an important step before scientific use of any instrument, we give here main results of the TFOSC and Coude-spectrometer calibrations.

2. Accuracy of radial velocity measurements with Coude spectrometer.

Spectra of radial velocity standard stars were obtained by using a new list of very accurate (~ 50 meter/sec) radial velocity (RV) determinations. This list is based on observations obtained with ELODIE Coude echelle-spectrometer (Baranne et al, 1996) attached to the 1.93-m telescope of Haute Provence Observatory (France). The ELODIE spectrometer is the best of the world's coude-spectrometers and is used for searching new planetary systems orbiting nearby solar-type stars.

Processing of the RTT150 data have shown the following results of RV measurements (see Table 1):

1) RV zero point of RTT150 CES is -0.5 km/s. This systematical value has to be added with proper sign to the results of Vr measurements based on CES data. The accidental error of radial velocity measurement is +/- 0.1 km/s (100 m/s). This error of 100 m/s is comparable to the accuracy of ELODIE standards (~ 50 m/sec), which shows the very high accuracy of RV measurements and positional stability of the CES. This allows us to realize many interesting programs at RTT150, involving accurate radial velocity measurements of single, binary or multiple stellar systems to investigate stellar dynamics in multiple systems or atmospheric motions (stellar winds) in single stars.

Table 1. Results of radial velocity measurements of Vr standard stars by ELODIE spectrometer and RTT150 CES.

Date/Star, HD	Vr, ELODIE	Vr, RTT150	RTT - ELODIE	(RTT-ELO)-0.5
May 06, 2004	km/s	km/s	km/s	km/s
101177	-16.95	-16.61	+0.34	-0.14
109358	+ 6.25	+ 6.62	+0.37	-0.11
139323	-67.20	-66.79	+0.41	-0.07
May 07, 2004				
131977	+26.85	+27.45	+0.60	+0.12
140538	+19.00	+19.53	+0.53	+0.05
May 08, 2004				
90343	+ 9.55	+10.14	+0.59	+0.11
140538	+19.00	+19.41	+0.41	-0.07
145742	-21.85	-21.32	+0.53	+0.05
June 06, 2004				
140538	+19.00	+19.47	+0.47	-0.01
164922	+20.15	+20.80	+0.65	+0.17
168009	-64.65	-64.22	+0.43	-0.05
182488	-21.55	-21.14	+0.41	-0.07
			+0.48 mean	+/-0.10 rms

3. Tests of spectro-photometric accuracy of equivalent widths (EW) measurements.

In astrometry and photometry, astronomical communities have created systems of astrometric (radio-galaxies, HIPPARCOS) and photometric (Johnson, Landolt, SDSS) international standards. Unfortunately, there are no lists of published "standard" equivalent widths (EW) of spectral lines of "EW standard" stars. This being the case, we have compared our EW data measured from RTT150 CES spectra and those measured from spectra of high quality spectrometers like ELODIE (for the common stars). This comparison is shown in Fig.1, which indicates a very high systematic agreement (at the 1 percent level) between RTT150 CES and ELODIE. Parts of the spectrograms of the same star obtained with ELODIE (Bruntt et al, 2004) and RTT150 CES is compared in Fig. 2.

These results of test observations with the RTT150 CES shows that it possible to detect week spectral lines and measure their EWs with systematic errors within 1-2 percent and rms errors within 0.002-0.004 Angstroms in the EW "working range" of 0.010 – 0.300 A, which is the working range for the study of chemical abundances in stellar atmospheres.

We should mention that there is a difference between the EW systems for echelle-spectrometers and classical coude spectrometers. It was found that classical spectrometers with RETICON arrays underestimated EW values by 5-15 percent as compared to modern echelle-spectrometers. (Adelman et al, 2003). In Fig.3, the equivalent widths for the bright star Omicron Pegasi measured from the spectra of Dominion Observatory classical coude spectrometer (Gilliver et al., 2004) are plotted against those from RTT150 CES. It is clearly seen that Dominion spectra shows underestimation of EWs by 7 to 8 percent. This systematic effect in EW might produce corresponding errors in the determination of the main physical parameters of stellar atmospheres (Teff, logg, chemical abundances) as the latter are based on **measured** EW values of spectral lines.

All data reductions have been made by using DECH software written for echelle spectra by Dr. G. Galazutdinov (1992). We highly recommend this PC based software for RTT150 CES data reductions. This DECH software is freely distributed now at the web-site (`http://www.kasi.re.kr/~gala/dech.htm`).

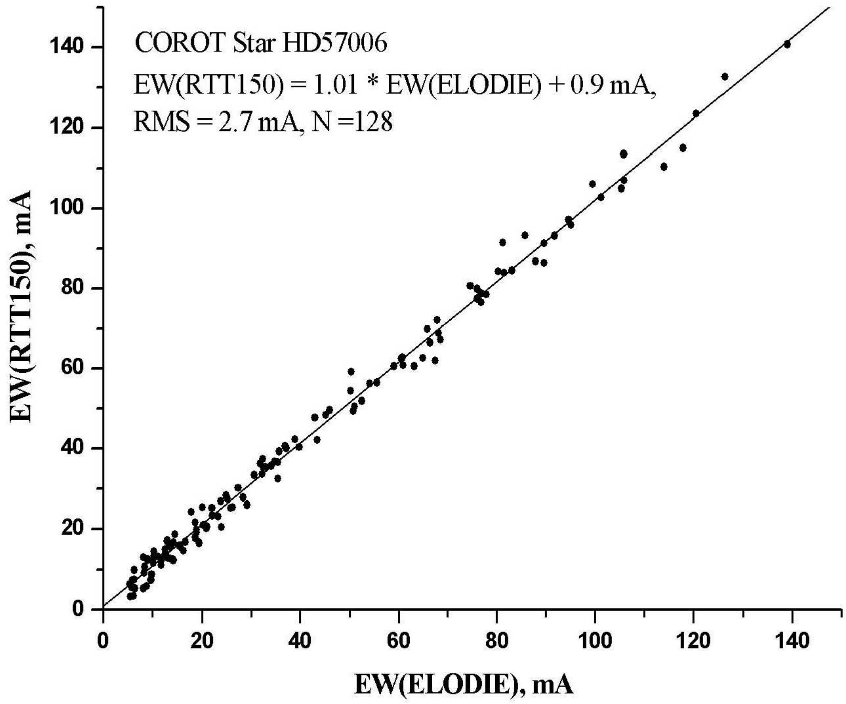

Fig.1. Comparison of EWs measured from ELODIE spectra (Bruntt et al., 2004) and from RTT150 CES echelle spectra of the same star.

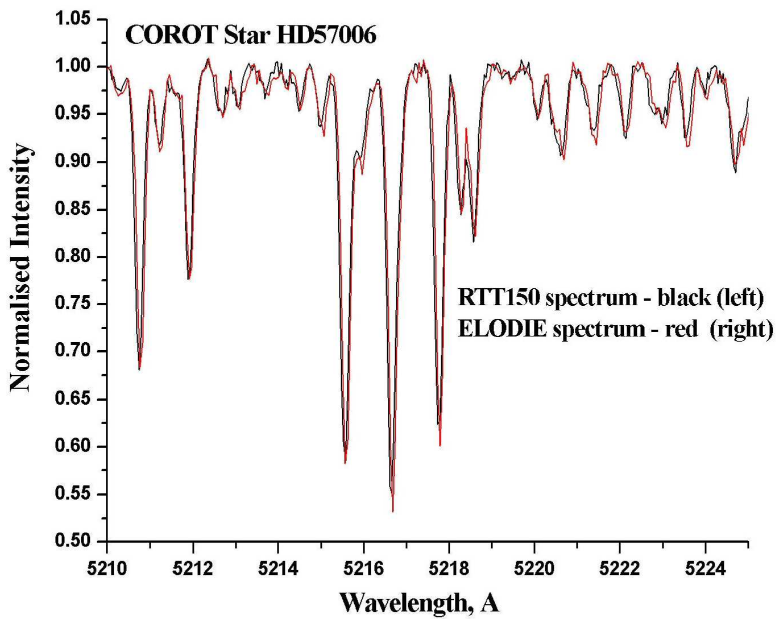

Fig. 2. Example of a direct comparison of RTT150 and ELODIE spectrograms of the same F-star.

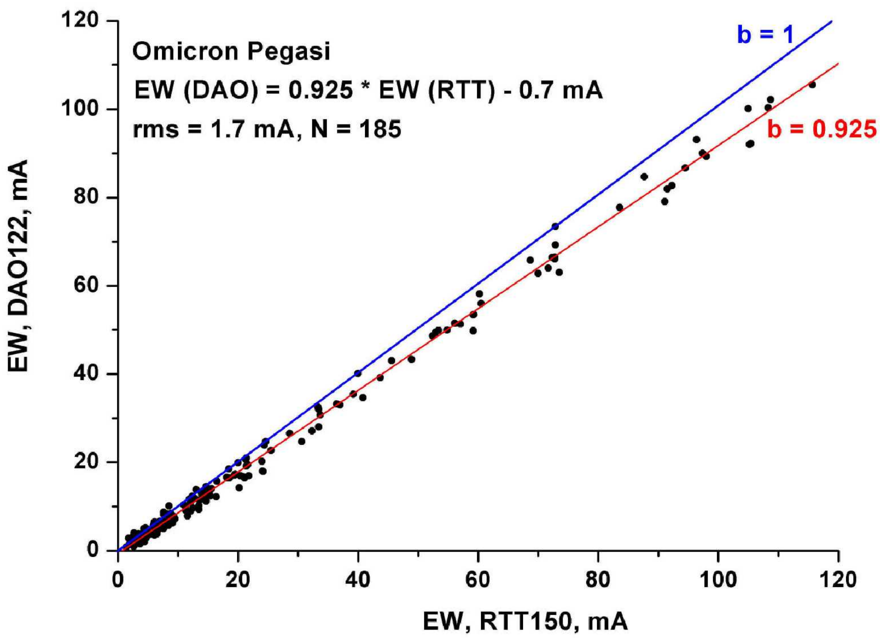

Fig.3. Example of EW comparison for the star Omicron Pegasi (Gulliver et al., 2004) as measured from Dominion Observatory 1.22-m telescope and RTT150 CES spectra. A systematic difference in EW is clearly seen (as compared to Fig.1), $Y = bX + a$, $b < 1$.

Fig.4 shows part of the spectrum of the binary star SZ Psc obtained with CES. The lines of both components are clearly seen, fast and slowly rotating components showing different line profiles – broad and narrow. We plan to investigate radial velocity changes of both stars and search for possible variations of the center of mass velocity (due possibly to the presence of a third component in the system) as a joint TUG+KSU project together with Prof. Z. Tunca.

In March 29, 2006, during the two minutes of the Total Solar Eclipse at Bakirlitepe, two unique spectra of the Solar Corona have been obtained with RTT150 CES (with the assistance of Dr. Irek Khamitov, who operated the telescope mirror shutters to protect from the sunlight). These spectra are subject of proper processing and scientific analysis now. The main goal was to find weak lines of solar coronal spectrum, to measure exact line wavelengths with an accuracy of 0.01 A, and to investigate line profiles of strong and weak emission lines. Fig. 5 shows an example of such weak emission lines of Argon X, whose even accurate wavelength was unknown.

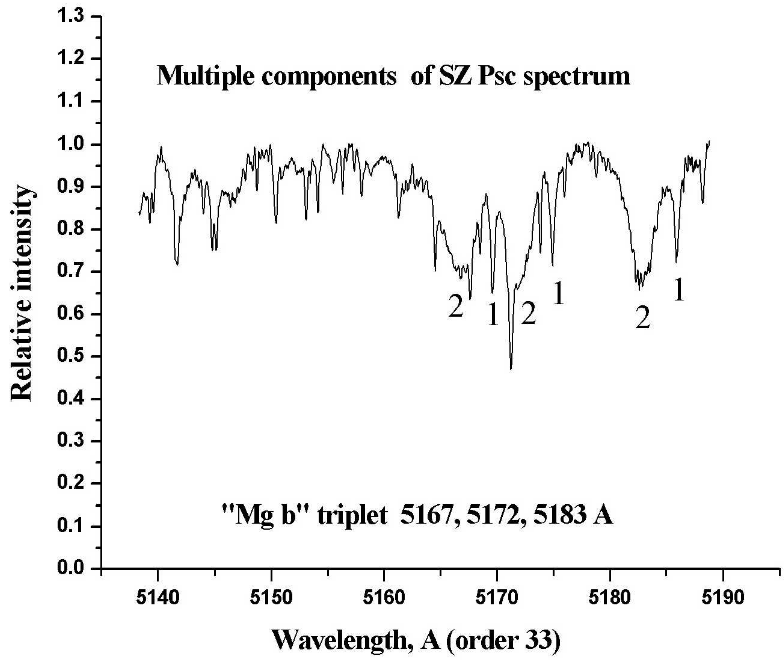

Fig.4. Part of the spectrum of the binary system SZ Psc (RS CVn type). Lines of both components are clearly seen at R = 40000 resolution and high S/N ratio.

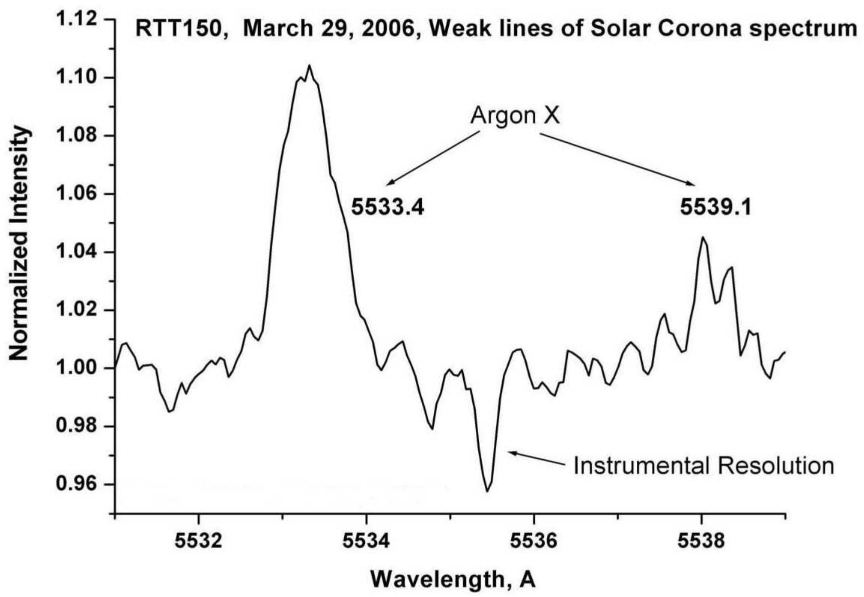

Fig.5. Part of the Solar coronal spectrum showing weak ArX lines. It is seen that wavelength of 5539.1 is uncertain by about 1 Angstrom.

4. Results of TFOSC calibrations.

To test the highest accuracy of radial velocity measurements with TFOSC, spectra of ELODIE radial velocity standard stars have been obtained in echelle-mode of TFOSC with resolution of 2-3 Angstrom. Echelle grating N 9 and cross-disperser grating N 11 have been used. This combination provides simultaneous coverage of the spectral range 3800-9000 A. Table 2 gives the results of radial velocity measurements with TFOSC of four RV standards. It is clearly seen that an accuracy of 1 km /s is potentially achievable with TFOSC in echelle mode for relatively bright targets when S/N ~ 100-300 is reached. Telluric H_2O molecular lines have been used to eliminate TFOSC instrumental shifts in Radial Velocity data of the standard stars. It was found that 1 km/sec accuracy of RVs and instrumental shifts of order ~ 10 km/sec are in good agreement with spectral resolution of 2-3 A (100-150 km/s). For Coude spectrometer RVs accuracies of 0.1 A and instrumental shifts of ~ 1 km/s are realized at 0.1-0.2 A resolution (5-10 km/s).

Table 2. Results of Radial Velocity measurements with TFOSC of RV standard stars in echelle-mode with spectral resolution of 2-3 A and 1 arcsec entrance slit.

Star	V	Sp.Type	TFOSC RV, km/s	Standard RV, km/s **	Difference, TFOSC–Standard RV, km/s
HD 114762	7.3	F9V	+47.6	+49.4	- 1.8
HD 144579	6.7	G8V	-59.5	-59.5	0
HD 182572	5.2	G8IV	-101.5	- 100.4	-1.1
HD 184499	6.6	G0V	-166.6	- 166.1	-0.5

** http://www.phys.unm.edu/~cpo/html/twhtml/standards/rv/elodie.html
http://obswww.unige.ch/~udry/std/stdcor.dat

It should be stressed that real accuracy of radial velocity measurements with TFOSC is strongly dependent on spectral resolution, S/N ratio, entrance slit width, brightness of the target and exposure time, etc.

Fig 6. demonstrates the result of time-dependent RV measurements of the new close binary system JGR J00234+6141, detected in X-Ray by INTEGRAL Satellite and optical counterpart discovered by RTT150 and TFOSC (Bikmaev et al., 2006b). This target has R ~ 16.7 mag and radial velocity have been measured from emission lines of H-alpha and H-beta originated in the accretion disk. Estimated orbital period of the system is about 4-5 hours. It is seen that the accuracy of radial velocity measurements is about 20-30 km/s, from single narrow emission line in this case.

Fig. 7 shows the averaged spectrum of IGR J00234 + 6141 with a total exposure of 1 hour. Almost all disk emission lines are identified in this spectrum.

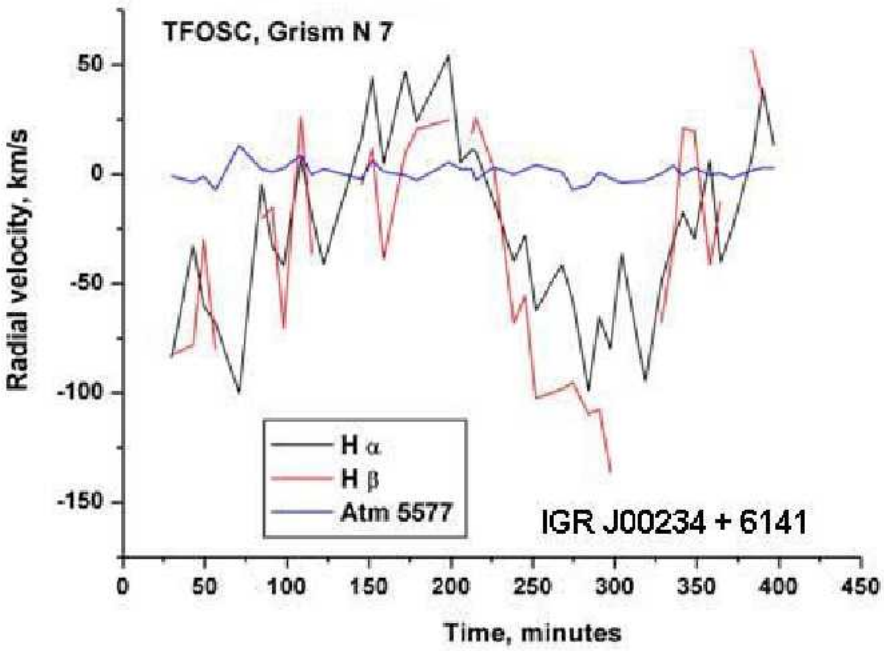

Fig. 6. Radial velocity variations of newly discovered close binary system IGR J00234+6141 with possible orbital period of 4-5 hours.

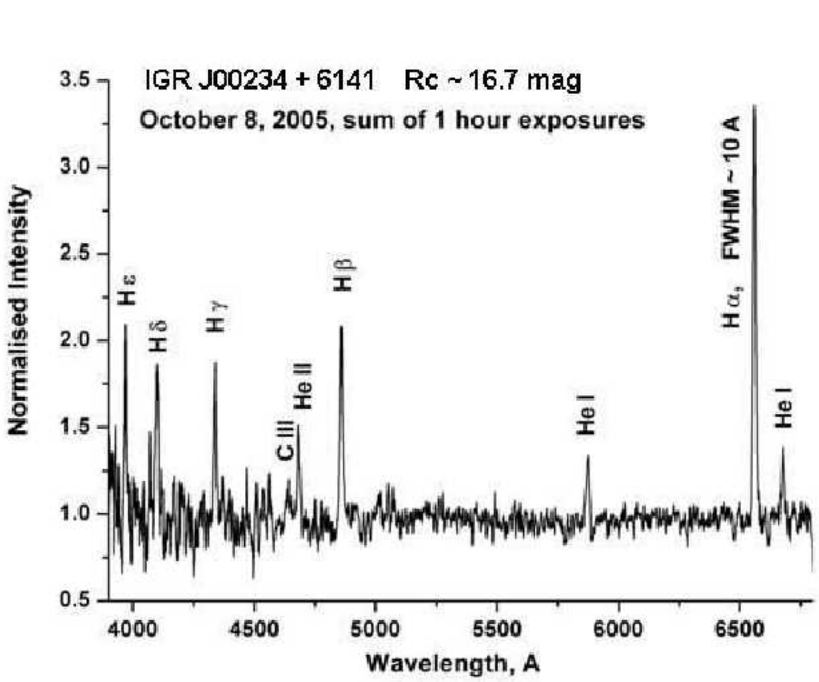

Fig. 7. Averaged spectrum of IGR J00234 + 6141 obtained with TFOSC grism N 7 and spectral resolution of 5-7 Angstrom.

At the lowest resolution of 10-15 A with Prism N 15, TFOSC has been used for optical discovery and identifications of new nearby galaxies with active nuclei (AGN) detected in Hard X-Ray with INTEGRAL and RXTE Space satellites. Results of these identifications are published in the paper of Bikmaev et al., (2006a) and full version of the paper could be found at TUG web-page. Fig. 8 shows an example of TFOSC spectrum of classical Seyfert galaxies obtained with resolution of 15 A. In spite of low resolution, main spectral features (H-alpha + [NII], [SII], [OIII], H-beta, etc) are clearly detected and their intensities and redshifts could be measured with an accuracy allowing us to properly classify the object and measuring distance to it. Using TFOSC and prism N 15, it was found possible to detect emission line objects down to R ~ 18-18.5 magnitudes.

We should note that at this very low signal level of the target, the proper subtraction of the relatively high brightness of the night sky becomes very important during processing procedures. Fig.9 shows the relative level of signal from R ~ 19.5 mag target and Night Sky emissions, the former being several times lower than the level of night sky parasitic lights.

Fig. 10 shows line identifications of Night Sky (Oxygen), Antalya City Hg and Na lamps and interstellar lines. We note in passing that TFOSC has a great potential possibility of detecting and measuring position and intensities of interstellar lines with angular resolution of 1-10 arcsec (as compared to 4 arcmin angular resolution of the DEPFOS instrument).

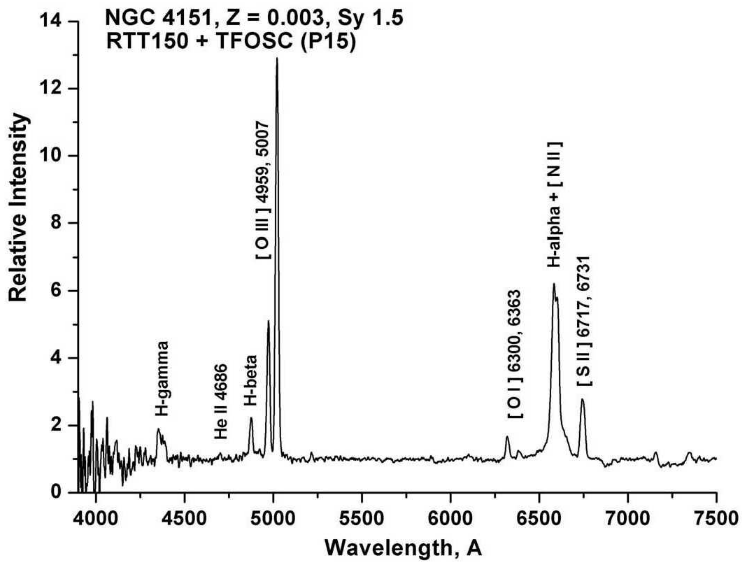

Fig. 8. Example of TFOSC spectrum of classical Seyfert galaxy NGC 4151.

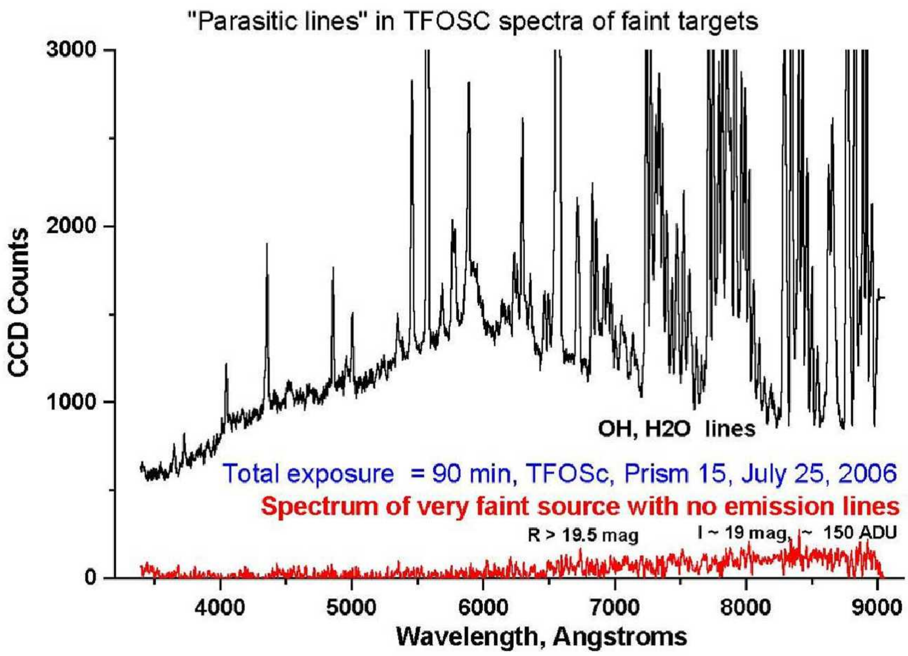

Fig.9. Example of signal levels from R ~ 19.5 mag targets and Night Sky.

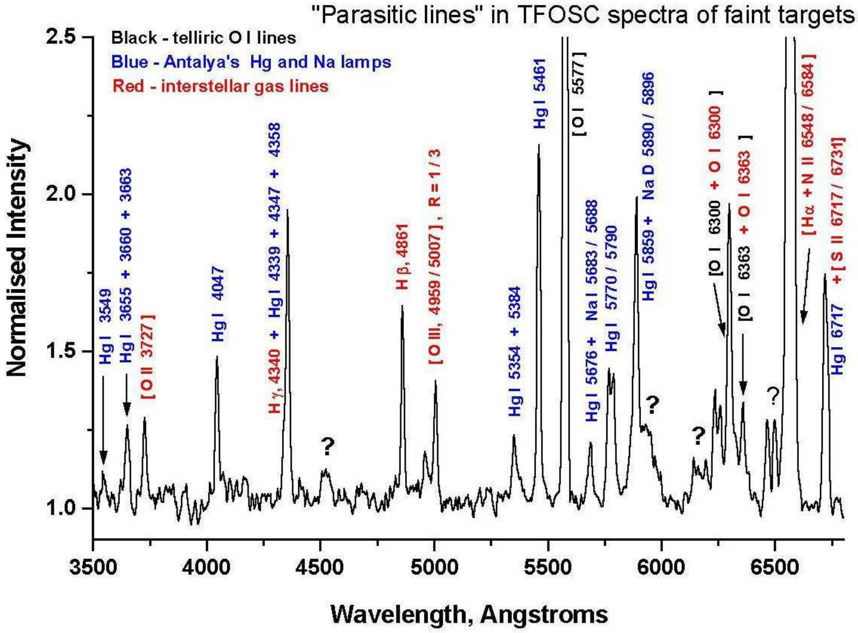

Fig. 10. Line identification of "parasitic lines" in low resolution TFOSC spectrum of very faint target (R ~ 19.5 mag) due to Night Sky, city lamps and interstellar lines.

5. Conlusions.

TFOSC and Coude positional and spectro-photometric calibrations have shown that both instruments fulfill their specifications with high accuracy. This will permit many new spectroscopic programs and tasks to be carried out at a high scientific level.

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