Publ. Astron. Obs. Belgrade No. 98 (2018), 341 - 348 *Poster*

FIRST SPECTRA FROM THE TELESCOPE MILANKOVIĆ

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Abstract. Telescope Milanković is a 1.4m Nasmyth telescope that installed at Astronomical Station Vidojevica in May 2016. The telescope has 4 Nasmyth ports, thus it is suitable for using multiple instruments. Two Nasmyth ports are equipped with field de-rotators. While one port is used for photometrical/astrometrical measurements, the other was used to setup and calibrate a portable spectrograph SpectraPro 2750. In this paper, we present the first spectra obtained by this instrument.

1. INTRODUCTION

Astronomical Station Vidojevica (ASV) is an observational site of the Astronomical Observatory of Belgrade (AOB). It is located on the mountain Vidojevice (South-East Serbia) at altitude of about 1150 meters. ASV exist since 2003 but the first telescope, the 60cm Cassegrain telescope, was installed only in 2010 due to construction works on the site.

In line with preliminary plans, AOB purchased several CCD cameras for photometrical/astrometrical observations and one portable spectrograph for low resolution spectroscopy for the 60cm telescope. Using solar scattered light and HgAr calibration lamp Vince & Lalović (2005) tested the spectrograph for some basic spectral parameters - reciprocal linear dispersion and spectral resolution. They also proposed a method to link the spectrograph to the telescope using fibre optic bundle (FOB). However, the spectrograph has never been systematically used on 60cm telescope because of some technical difficulties out of which two most importants are: 1) relativelly small telescope primary mirror along with light losses that are common on spectrographs, it was usable only for very bright sources and 2) the optical connection between telescope and the spectrograph has never been solved properly.

However, with installation of the 1.4m telescope at ASV in May 2016, we have reconsidered the possibility to install again the spectrograph. We were motivated by the fact that primary mirror has much larger collecting area than the 60cm telescope and by the convenience to setup all the necessary equipment onto the Nasmyth platform.

In this paper we describe the spectrograph setup present the first spectra obtained on the 1.4m telescope Milanković

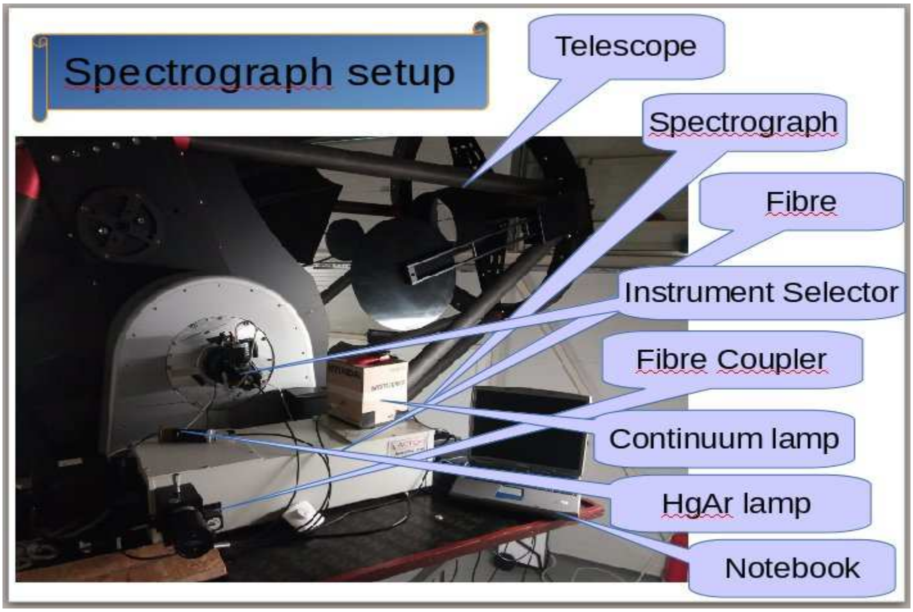

Figure 1: Spectrograph setup installed on the 1.4m telescope.

2. SPECTROGRAPH SETUP

The Figure 1 shows the spectrograph setup. Main element are labeled on the figure and they will be outlined in the following sections.

2. 1. TELESCOPE

Telescope Milanković is a 1.4m Nasmyth telescope which is thoroughly described in (at least) two papers in this proceedings - Vince et al. and Samurović et al. Therefore, only elements of the telescope that are specifically related to the spectrograph will be described in this section.

Milanković is a Nasmyth type of telescope and has 4 usable ports - two ports toward the telescope fork (classical Nasmyth) and two perpendicular to the fork (bent Cassegrain). The two classical Nasmyth ports are equipped with image de-rotator. While one of then is provided with field corrector, the other is free of any additional optics and is, therefore, suitable for installation of light-starwing instruments such as spectrograph. Additionaly, the port is oriented toward the telescope fork, so it is convenient to install a platform which can carry the portable spectrograph.

By design, the telescope was built to be a compact and easy-to-handle instrument. Therefore, all the electronics, along with the personal computer that run the telescope, are installed in the fork of the telescope. There are all souts of ports (ethernet, USB, power supply and so on) on the telescope that made easier to run the spectrograph.

2. 2. SPECTROGRAPH

Vince & Lalović (2005) described thoroughly the spectrograph, for that reason we only summarize its characteristics in this section as follows:

- The spectrograph is Cherny-Turner type.
- The focal ration of the spectrograph is 9.7.
- As a dispersion elements three gratings with different groove numbers are available - 300, 600 and 1200 grooves per millimeter. Gratings are installed on rotating turret and can be changed by software. Gratings are 68x68 square centimeters in size.
- Focal distances of both, collimator and camera mirrors are 750 cm.
- For detector, Spec-10 CCD camera from Princeton Instruments is used. The chip resolution is 1024x256 pixels and pixel size is 26 μm.
- According to specification, linear dispersion is 44, 22, and 10 $\AA$/mm for three gratings respectively.
- Spectral coverage with our detector is 1120, 560, 250 $\AA$ for the three grating modes.

The mechanical calibration of the spectrograph was performed in two steps:
- First, the CCD camera was focused and aligned with the entrance slit. The entrance slit was directly lightened by lamp for this calibrations. CCD adapter for the spectrograph allows both processes to be handled.
- Secondly, the FOB on the spectrograph side was focused and, since fibres are in slit arrangement, aligned with the entrance slit. For this purposes, the FOB was lightened by lamp.

The spectrograph was provided along with 32bit Windows software called WinSpec32. Except the entrance slit, all parts of the spectrograph are automated so it can be easily run remotely. Unfortunately, the software does not support FITS format but several non-commercial programs can be found on the internet. Unfortunately, the converter that we use for these purposes doesn't fill the FIST header with all parameters that are needed for later in image reduction (RA, DEC, OBS-TIME, DATE and so on). The observation time is the most critical one and must be recorded independently from the spectrograph software.

2. 3. FIBRE OPTICS

The optical connection between the 1.4m telescope and spectrograph is a FOB. There are several firm reasons to use FOB but the most important one in our case is that we found difficult to install the heavy (22kg) and big spectrograph directly on the de-rotator.

AOB procured several different types of FOBs from Acton Research Corporation (ARC) but only two types were used in our instrument setup. Both types include 200 μm diameter fibres but they differ in their number and arrangement. Left panel of the Figure 2 shows the 4-leg FOB (model QFB-455-3) with 3 fibres per leg. Right panel of the figure shows the 1-leg FOB (model code is LG-455-020) with 19 fibres in the leg. The illumination and slit ends of the two FOBs are shown in the small inserted images in the figure. As can be seen, fibres at the illumination end (or telescope end) have circular arrangement, whereas at slit end they have slit arrangement for both FOBs.

Four groups containing three fibres in the 4-legs FOB are separated at the slit end, so the FOB can be used to detect spectra from 4 different sources (even simultaneously if their brightness are similar). In our setup, we use this feature to detect spectra

Figure 2: Two FOBs that were used with spectrograph: 4-legs FOB (left) and 1-leg FOB (right).

from 1) a target, 2) HgAr lamp, 3) continuum lamp, and 4) pencil laser (laser is used for spectrograph calibration only). In general case, if adapter is carefully designed, it can be used to detect four different sources on the sky simultaneously (Multi-Object Spectrograph). This is the main advantage of the 4-leg FOB over the 1-leg one but there are numerous disadvantages as well. For example, due to telescope tracking errors, it is easier to keep the 1-leg FOB with 19 fibres on the target (200 μm diameter fibre scale about 4 arcsec of the sky at the focal plane of the telescope). Also, the flatfielding in classical way is meaningless because the spectrum of the tungsten lamp cover different pixels than spectrum from a target (or HgAr lamp).

We made spectral observations with both FOBs. However, we note that the 1-leg FOB must be setup manually during the night to acquire spectra from different sources (target and calibration lamps), so it is more difficult to use. More importantly, we don't know how these manual intervention influence the FOB characteristics. Theoretically, both, the throughput and the focal ratio degradation (see bellow) depends on FOB curvature.

It is important to note that the telescope beam is f/8 and the spectrograph acceptance cone is f/9.7. Due to this difference, there would be flux losses even if the spectrograph would be directly attached to the telescope (without fibre bundles). Relative to that, FOB increase light losses at least in two ways:

1) Focal ratio degradation (FRD) which "speeds up" the input focal ratio. In our case, f/8 telescope beam enters the FOB but only a portion of the incoming flux will leave the fibre bundle at f/8 due to FDR. Theoretically, the 100 % of the flux should be inside the numerical aperture of the fibre which is in our case of silica fibres and cladding 0.22 (that is f/2.22). More details on FRD can be found in Brodie et al. (1988).

2) Fresnel reflection occurs at the air-fibre interface at input and output ends of the FOB (about 4% per interface).

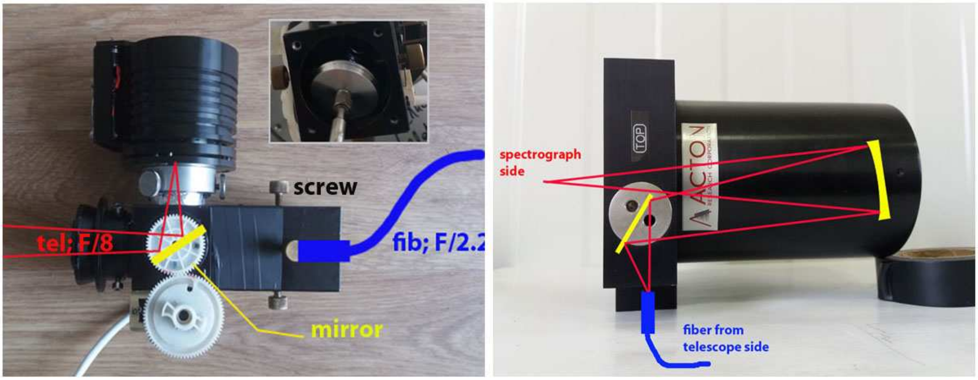

Figure 3: Instrument selector (left) and fibre coupler (right).

Flux losses due to FRD is usually mitigated by setting an adequate optical lens between FOB and spectograph. Vince & Lalović (2005) proposed a method to decrease light losses due to FRD in this manner. We didn't apply any correction for this effect but we have estimated the FOB output focal ratio to be about f/7 (the method will be described elsewhere) which means that we may expect photon losses due this effect.

2. 4. INSTRUMENT SELECTOR

At the telescope end, the FOB is connected to the telescope by instrument selector (IS) which is shown in the left panel of the Figure 3. IS is a home-made device with a flipping mirror which has two extreme positions - in one position, the mirror allows the light beam to hit the FOB and in the second position, the mirror redirects the light beam toward the CCD camera. The distance between the mirror and CCD chip is equal to the distance between the mirror and FOB, so the CCD has an essential role in focusing the stellar image on the FOB.

The second very important role of the IS is to enable precise pointing of the FOB to a star on the sky. The calibration of the IS for precise pointing is done by help of star image and consist of two steps: (1) the star image is centered on the CCD field of view and (2) the FOB is moved in the plane perpendicular to light beam until the largest flux is detected in the spectrograph (in zero order for example). Shifting a FOB is enabled by a disc which holds the bundle (show in the inserted image on the left panel of the Figure 3) which is grooved on the edge and can be moved in the plane by 4 screws on the ID.

Originally, the IS was an old OPTEC polarimeter and the fliping mirror was movable manually. For needs of the spectrograph, the mirror was motorized and can be controlled via serial port of the PC. Automatization of the IS was an essential part of the spectrograph setup.

2. 5. FIBRE COUPLER

At the spectrograph end, the FOB is connected to spectrograph by fibre coupler (FC) which was procured from ARC company (right panel of the Figure 3.). The

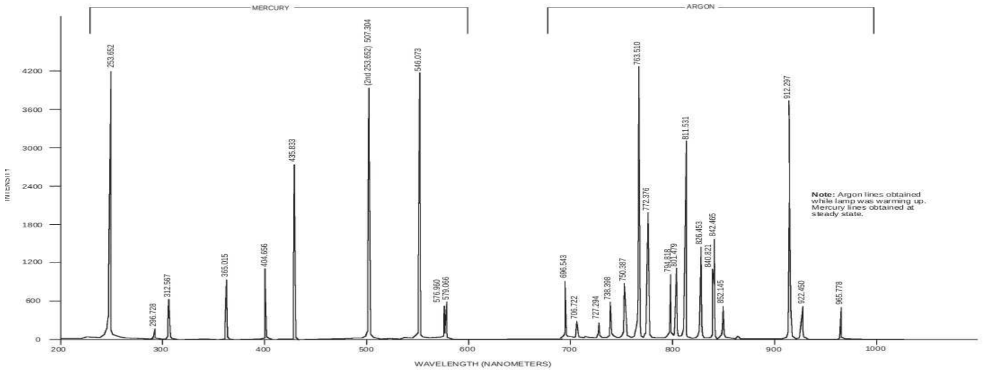

Figure 4: Emission line spectrum of the HgAr calibration lamp.

device eliminates chromatic aberrations and the aspheric mirror cancels astigmatism allowing precise imaging of fibers at slit.

2. 6. CALIBRATION LAMPS

We use two lamps for calibration of spectral images: (1) HgAr emission line lamp, which was purchased from Oriel Instruments Corporation, for wavelength calibration and (2) Tungsten continuum lamp for flatfielding. HgAr lamp has a drawback that spectrum is poorly populated with emission lines for λ¡700nm (see Figure 4.). This deficiency is especially noticeable when we work with 1200 groowes/mm grating where the spectral range is the lowest.

2. 7. NOTEBOOK

Unfortunately, the 64bit computer inside the fork of telescope couldn't run the WinSpec32 software, so we use a Dell Noteook to control the spectrograph and CCD. We communicate with the Notebook via WiFi internet connection.

3. RESULTS AND CONCLUSIONS

In this section, we show the first spectra made with our spectrograph on the 1.4m telescope. Results on measurements of some spectral parameters, as well as more spectral analysis, will be presented elsewhere.

Stellar spectra were acquired on several occasions in period from May to August 2017. We chose relatively bright targets (from 0 to 8 magnitudes in V band). We included in the sample photometric standard stars with the aim to measure spectrograph throughput and to compare our results with the catalog values.

For reduction purposes we acquired the following calibration images:

- Bias images for zero level correction.

- Dark images with the same exposure time as the target for dark current calibration.

- Flat images. Tungsten lamp was used as a light source for these images

- Emission line lamp images for wavelength calibration.

- Twilight sky images for illumination correction.

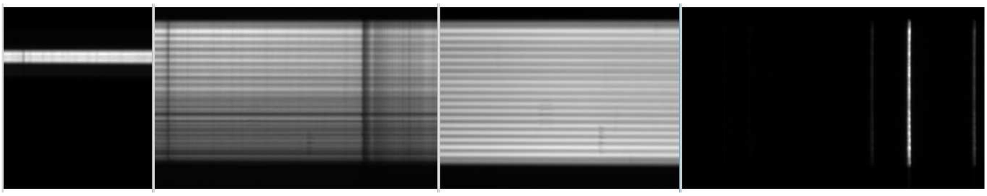

Figure 5: Raw calibration spectra. From left to right: target, twilight sky, flatfield lamp and emission line lamp images are presented

- Sky images. They were taken near the target with the aim to subtract sky background.
- Target images.

Due to ability of the CCD to cool down the sensor to -70 ^{o}C, dark images turned out unnecessary. Also, the night sky images, which were taken close background subtraction, were at the level of bias images even for the longest exposure time we applied (10 min), so they were also not used in the reduction process. Reduction and calibration of spectra were done in IRAF package.

Figure 5 shows raw spectra of the a target, twilight sky, tungsten lamp and emission line lamp from left to right. Spectra were made by 4-leg FOB. As can be seen, spectra from individual fibres in the FOB are clearly noticeable in the flatfield spectrum for example. Individual fibres sample about 4 arcsec of the sky, so this feature can be used for Integral Field Spectroscopy of extended sources.

From the target spectrum, we may see that the target is sampled by (only) two fibres in the FOB and the rest of the fibres sample the nearby sky. This feature can be used for background sky subtraction if needed (e.g. very bright sources may have extended scattered light under certain atmospheric conditions).

Figure 6. shows the spectrum of the HD192281 photometric standard star. The spectrum was first calibrated for bias and flatfield images. It was then extracted to one dimensional spectrum and wavelength calibrated. Lastly, relative intensities are converted to flux units to be able to compare to catalog values (star-like points). As can be seen, our spectrum agree well with the catalog values which indicates that the calibration was performed in a good way.

We note several important drawbacks of the spectrograph that observer should be aware of when using our spectrograph:

- At this point, we haven't guiding system on the telescope and the longest exposure time is limited to about 5 minutes. Consequently, one can't be sure if the FOB is pointing the target after 5 minutes due to tracking errors. This time period is based on experience and it depends on many factors (pointing model, wind and so on).

- As we have already mentioned, HgAr lamp is not the best one for calibration of 1200 g/mm grating spectra in the red part of the spectrum due to lack of strong (reliable) emission lines in the lamp spectrum. Telluric absorption lines may be used for calibration in some cases.

- There are certainly flux losses on different telescope/spectrograph elements but the most dominant one is the mismatch of instruments focal ratio. Still, with 5 min exposure, one may detect 8 magnitude star with relatively good signal to noise ratio

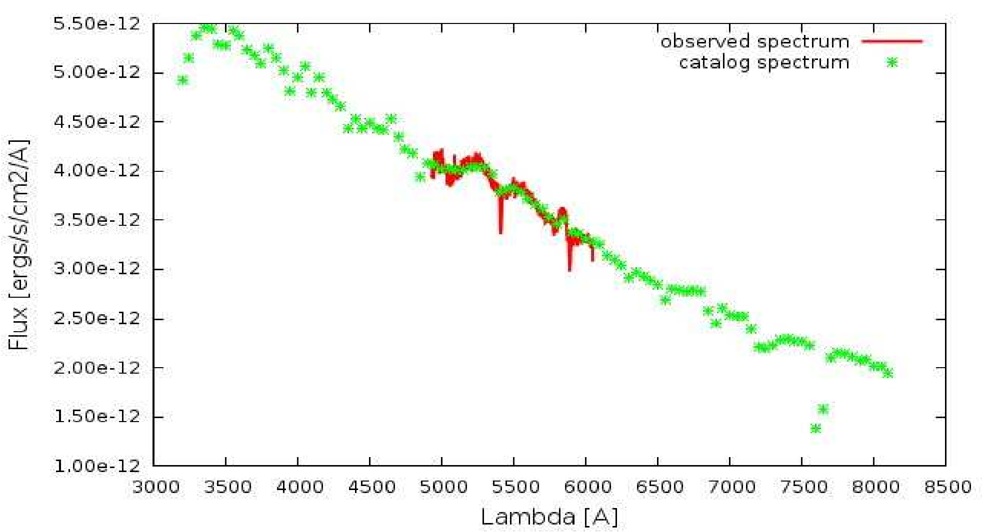

Figure 6: Flux calibrated spectrum of the HD192281 photometric standard star compared with catalog values

(SNR). If the spectrograph is well calibrated, the SNR mainly depends on seeing and it can be improved by fanning the primary mirror and airconditioning the pavilion before observations.

It is important to note that all the mentioned elements that badly influence our observations can be mitigated. Guiding system for example is out of function because the roll-roof of the pavilion can't be opened/closed when it is installed. Likewise, photon losses can be cured by adequate optics (see above).

Acknowledgment

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through projects No. 176021, "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations", No. 176004 "Stellar Physics", and No. 176011 "Dynamics and Kinematics of Celestial Bodies and Systems". We thank the Ministry of Education, Science and Technological Development of the Republic of Serbia for the continued support related to the construction works at the Astronomical Station Vidojevica. We acknowledge the financial support by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract No. 256772). We thank our collaborators Pančić L. and Naumović N. for automatization of the Instrument selector.

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