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AN ECHELLE SPECTROGRAPH FOR THE MILANKOVIĆ TELESCOPE

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Abstract. In this paper we report some general outlines on a construction of a high resolution échelle spectrograph, which we propose to build for our future 1.5-m class Milanković Telescope (**MIL**anković **E**chelle **S**pectrograph - MILES). MILES would be a mechanically stabilised and temperature controlled high-resolution ($R \sim 50000$) fibre-fed spectrograph for visible and near infrared wavelength region of electromagnetic radiation. Here, a white-pupil optical design of the spectrograph is described and the main optical and mechanical elements are discussed. The set of these elements includes: an optical fibre for a link between the telescope and the spectrograph entrance slit, an échelle grating, the collimator and camera optics, the cross-disperser prisms, a CCD detector and an optical table. Since we plan to build MILES from commercially available elements, it has been possible to estimate its price, which amounts to about 550 kEU.

1. INTRODUCTION

The motivation for planning a high-resolution spectrograph is based on achievements of the second work-package (WP2) of the Belissima project [1] financed by the European Commission under the FP7 REGPOT and operated at the Astronomical Observatory of Belgrade since 2010. The main goal of WP2 has been the acquisition of a 1.5-m class telescope. This project was seriously progressed in the last period and the telescope optical design was almost completely defined. The optical parameters of the telescope necessary for planning and designing any astronomical instruments to be attached to it are known. The atmospheric parameters relevant for astronomy, such as the seeing conditions, humidity, cloudiness, wind speed and direction are also known, owing to an automated whether station, a seeing monitor and a 60-cm telescope that have been regularly operated at the telescope site (Vidojevica mountain) for two years. Therefore, we have access to all necessary information required for designing an astronomical instrument for the Milanković telescope. In this paper we present an optical design for a high spectral resolution and mechanically and thermally controlled échelle spectrograph.

[1] `http://belissima.aob.rs/`

2. THE TELESCOPE CHARACTERISTICS

According to our Technical Description incorporated into the Bidding Documentation for purchasing a 1.5-m class research grade astronomical telescope for the Astronomical Station Vidojevica (ASV) the main telescope parameters that have the most crucial influence on its scientific capability are as follows:

- primary mirror effective aperture: $1.35 \text{ m} \leq d_{\text{eff}} \leq 1.40 \text{ m}$,
- two or more ("bent") Cassegrain focal stations, or a combination of Nasmyth and Cassegrain foci,
- effective optical system focal ratio: $7.0 \leq N \leq 9.0$,
- encircled energy (EE) value of 80%, or better, within a diameter of 0.5 arcsec for on-axis measurements, and EE value of 80%, or better, within 0.7 arcsec for off-axis measurements,
- tracking accuracy (without auto-guider correction) of ≤ 0.5 arcsec RMS over a time period of at least 600 seconds.

3. THE CHARACTERISTICS OF THE LOCATION

The new telescope will be installed at the Astronomical Station Vidojevica, located on the summit of the mountain Vidojevica, about 20 km from the town of Prokuplje, in southern part of Serbia. The main site characteristics are as follows:

- Astronomical Station Vidojevica coordinates:

  geographic latitude: $43^\circ\ 8'\ 28''$ N,
  geographic longitude: $21^\circ\ 33'\ 20''$ E,
  altitude: 1155 meters above sea level,
- Meteorological characteristics:

  common yearly temperature range: from -20 to $+35$ degrees Celsius, relative humidity range: from 30% up to 100%, mean 70%.
- Atmospheric seeing: 1.3 arcsec (median, at zenith).

4. RATIONALES

Since the 1.5-m class Milanković telescope will be operated by the Astronomical Observatory of Belgrade, it will guarantee a long and secured access for observers, which is ideal for dedicated monitoring programmes of variable phenomena.

Telescopes of $\sim$ 1.5-m objective diameter are ideal for high spectral resolution ($R \sim 50000$) observations of celestial objects with available large grating sizes ($\sim$ 50 cm) and seeing conditions ($\sim 1.5''$) at Astronomical Station Vidojevica (ASV). Therefore, we plan to use the telescope for collecting high-quality time series of high-resolution spectra. Based on our prior experience with various spectra taken for line profile analysis of solar like stars and radial velocity measurements of close binary stars, we propose for the Milanković telescope a high-resolution, fibre-fed, gravity-invariant, thermally-controlled échelle spectrograph (MILES) with a white pupil optical design, similar to some existing large astronomical spectrographs (Raskin et al. 2011).

5. GENERAL OPTICAL LAYOUT

A simplified diagram of a fibre-fed échelle spectrograph is shown in Figure 1. The optical fibre entrance is located in the focus of a telescope with the aperture diameter D and focal length F, so that the focal ratio of the input cone is $N = F/D$. For the sake of simplicity, the picture does not show the actual optical system which reduces the focal ratio to a value of about $N = 4$ suitable for the optical fibre. The fibre has a diameter s and transfers the light to the other end. We will neglect here the effect of the focal ratio degradation (FRD) in the optical fibre and assume that the light emerges at the same focal ratio N. In reality, this will only be slightly degraded, perhaps to about $N \approx 3.75$.

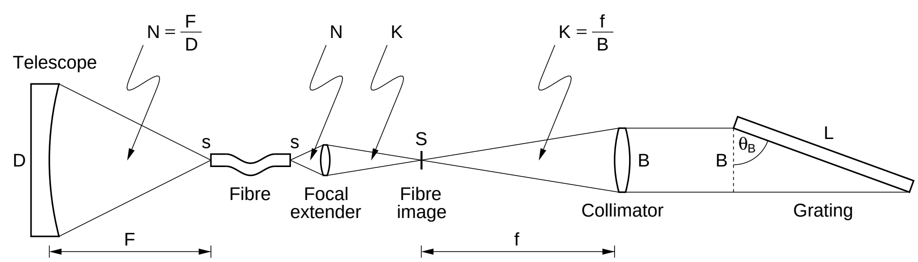

Figure 1: Main elements of a fibre-fed échelle spectrograph. Only the parts affecting the resolving power are included. The cross-disperser and the camera are not shown.

If the collimated beam illuminates an échelle grating at the blaze angle (Littrow configuration), the resolving power is:

$$R = \frac{2NB \tan \theta_{\rm B}}{s}.$$

It is obvious from this equation that the resolving power does not depend on any focal extension used at the fibre exit. It depends only on the fibre diameter s, original focal ratio N, collimated beam diameter B, and the blaze angle $\theta_{\rm B}$. By using a grating with a steep blaze angle of 76° ($\tan \theta_{\rm B} = 4$), and assuming that the focal ratio N is around 3.75 (including the degradation), we find that a relatively small diameter of the collimated beam of $B = 100$ mm can be sufficient for high resolving powers. In this case, the formula for R becomes $R = 3000000/s$, where s is in micrometres. With a 50-μm fibre, the resolving power is 60000. With a 75-μm fibre, we have $R = 40000$, which is still high enough for most spectroscopic applications in astronomy. The expression for R can also be rearranged as:

$$R = \frac{2L \sin \theta_{\rm B}}{\theta_{\rm s} D},$$

where $\theta_s = s/F$ is the angular size of the fibre entrance projected onto the sky, D is the diameter of the telescope, and L is the length of the grating. Since θ_s is determined by the atmospheric seeing, which at ASV, for zenith angles 0–45°, in average amounts to about 2–3 arcsec, it is obvious that in order to maintain a resolving power of about 50000 a telescope of 1.5-m aperture requires a 40-cm grating with a blaze angle of 75°.

6. Optical design

Our fibre-fed échelle spectrograph is based on a white-pupil design, which offers a significant reduction in the size (and cost) of all optical elements, while maintaining a high resolving power. This is achieved by redirecting the diffracted beams from the échelle grating back into one white pupil of the same diameter as the original collimated beam. A schematic diagram of a spectrograph based on a white-pupil design is shown in Figure 2. This particular design uses two parabolic mirrors as collimators. The input cone of diverging light from the optical fibre is sent to the first collimator (on the right). The collimated beam illuminates the échelle grating and is dispersed back into a fan of beams depending on the wavelength. The diffracted beams fall onto the collimator again (second pass) and are focused at the focal plane of the parabola. The light rays then pass trough the focal plane as a fan of diverging beams directed at the lower part of the second collimator (on the left) where they are reflected, collimated again, and directed towards the cross disperser (a pair of prisms). The re-collimated beams of different wavelengths, when they fall on the cross disperser, form a single white circle of light of the same diameter as the input collimated beam.

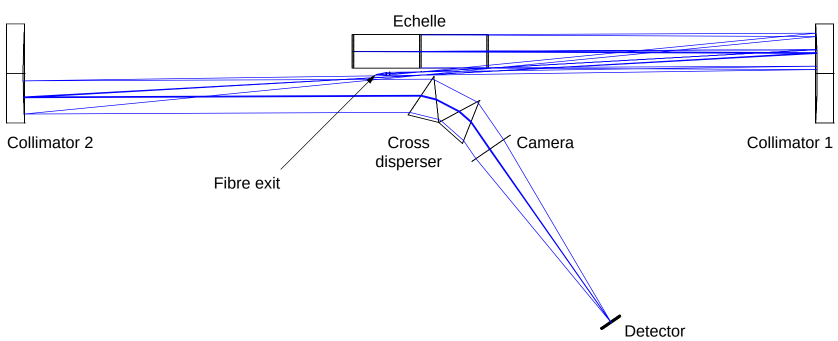

Figure 2: Proposed optical design of the MILES spectrograph.

We have used the Zemax optical design software to obtain the spot diagrams for our échelle spectrograph, using the input parameters very close to the parameters of commercially available optical elements.

The parameters used in the optical design are listed in Table 1. The results are shown in Figure 3, which contains the spot diagrams for five representative orders:

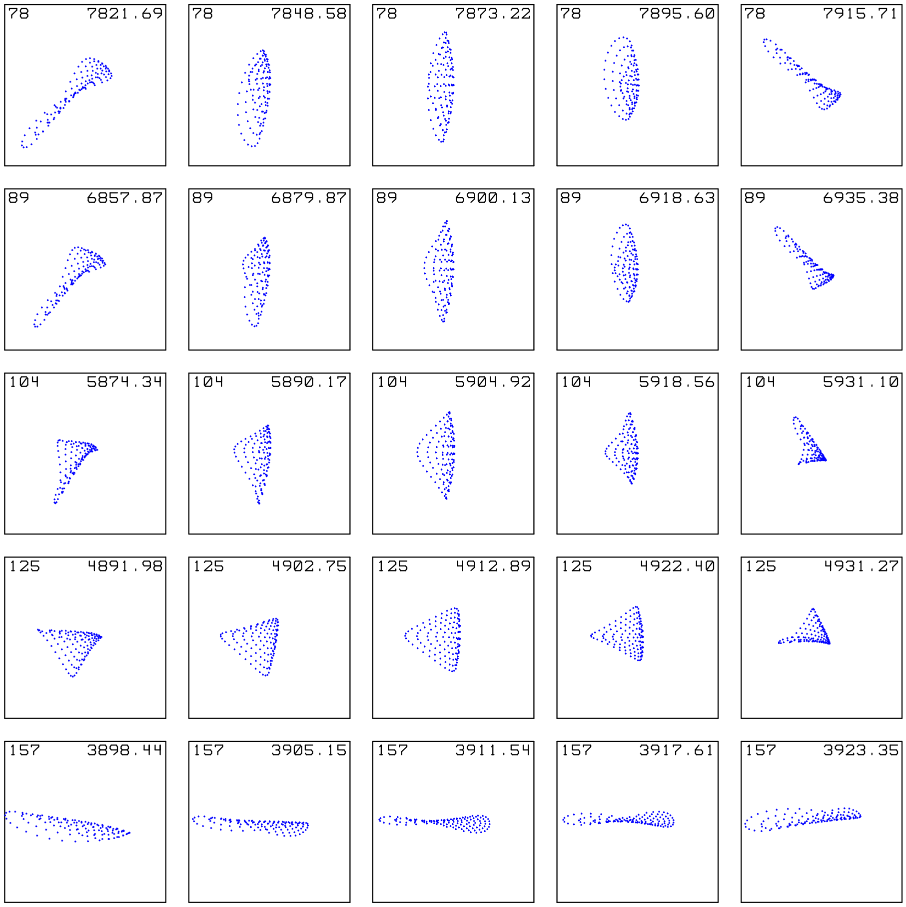

Figure 3: MILES spot diagrams.

78, 89, 104, 125 and 157, as indicated in the upper-left corner of each diagram, and for five different wavelengths (indicated in the upper-right corner, in Angstroms). The total spectral range is between about 390 nm and 790 nm. Each box represents 2×2 pixels (30 μm squared). A quick analysis of the spot diagrams shows that for each examined spectral order and wavelength the light rays at the camera focal plane stay mainly within one pixel. Therefore, the proposed optical design does not decrease the spectral resolution of the spectrograph.

From Table 1, the expected combined cost of the spectrograph's elements is 285 kEU. The total cost, including the spectrograph elements, transport, insurance, salaries of optical and mechanical engineers etc. is evaluated to about 550 kEU.

7. CONCLUSION

A high resolution spectrograph (MILES) for the Milanković telescope is described. A

Table 1: Parameters of optical elements.

Element	Properties	Commercial price (kEU)
Optical fibre	Core diameter: 50 μm Length: $\sim$ 20 m	5
Collimators	Parabolic mirrors (2 pieces) Diameter: 30 cm Focal length: 120 cm	5
Echelle grating	Grating Surface: ruled Groove Frequency: 31.6 per mm Blaze Angle: 76° ($\tan\theta_{\rm B} = 4$) Groove Length: 100 mm Ruled Width: 400 mm	60
Cross disperser	Two identical prisms Dimensions: 140 $\times$ 140 mm Apex angle: 40°	25
Camera	Diameter: 140 mm Focal length: 640 mm	10
CCD	Pixel size: 15 μm Chip dimensions: 4096 $\times$ 4096 pixels	160
Optical table	Thickness: 30 cm Width: 120 cm Length: 240 cm	10
Other optical and mechanical elements		10

white-pupil design is proposed, as it gives a relatively small pupil on the entrance to the cross-disperser and camera, resulting in a significant cost saving and complexity reduction.

When compared to other commercially available spectrographs of a similar design and comparable performance, the estimated price of the MILES spectrograph is by over 50% lower. This is a significant factor that needs to be taken into account when the instrument is acquired.

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References

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