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A broadband low-resolution spectrograph: SpectrumMate LR

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Abstract:

This article presents the development and application of SpectrumMate LR, a broadband, low-resolution spectrograph specifically tailored for use with small telescopes. SpectrumMate LR is designed to offer affordable and accessible spectroscopic capabilities for amateur astronomers, students, and educators, responding to the growing demand for versatile instrumentation in non-professional and educational settings. Employing a 300-grooves-per-millimetre diffraction grating together with 80 mm focal-length collimator and objective lenses, the system is optimised to analyse light across the entire visible spectrum. These optical parameters allow users to classify stars by spectral type, estimate stellar effective temperatures, and verify the transmission characteristics of astronomical filters. Laboratory and on-sky tests demonstrate SpectrumMate LR's ability to record accurate, well-calibrated spectral data, validating its efficacy when observing a variety of both celestial and terrestrial light sources. Because all components are commercially available and assembly procedures are straightforward, the instrument fills an important niche for cost-effective spectroscopy, empowering a broader community to engage in detailed observational astronomy. By lowering financial and technical barriers, SpectrumMate LR promotes hands-on learning, encourages citizen-science contributions, and provides a practical pathway for schools, small observatories, and enthusiast clubs to expand their research and outreach activities. As a result, SpectrumMate LR stands out as an exemplary tool for introductory spectroscopy courses worldwide today.

Keywords: **amateur spectroscopy, filter testing, spectral analysis, SpectrumMate LR, star classification.**

Classification numbers: **2.1, 2.3**

1. Introduction

Spectroscopy is a crucial tool for understanding the physical and chemical properties of stars and other celestial bodies. By analysing the spectrum of a light source, we can deduce essential characteristics such as temperature, chemical composition, and age, along with motion, distance, and more subtle features like magnetic fields and atmospheric conditions. For centuries, spectroscopic techniques have deepened our knowledge of the universe, revealing not only the life cycles of stars but also the conditions in distant galaxies, the composition of exoplanetary atmospheres, and the large-scale structure of the cosmos.

In recent years, advancements in spectroscopic technology have enhanced our ability to capture and analyse celestial spectra; however, the high costs and complexity of traditional equipment often place it out of reach for amateur astronomers and small observatories. These barriers have limited broader engagement in astronomical spectroscopy, despite the immense value that even lower-resolution data can provide in educational settings and citizen science projects.

In Vietnam, the Nha Trang Observatory is equipped with a medium-resolution eShel II spectrograph (R=10000), while Quy Nhon Observatory (QNO) hosts the low-resolution SpectrumMate spectrograph (R=2666). Although these instruments are effective for high-precision spectral observations, neither can capture the entire visible spectrum in a single image due to limited spectral coverage per exposure.

This limitation poses challenges for applications such as chemical composition analysis and spectral classification,

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which often require broader spectral coverage. To address this gap, we have developed the broadband spectrograph presented in this article, named SpectrumMate LR.

SpectrumMate LR is a broadband, low-resolution spectrograph specifically optimised for small telescopes. Designed with accessibility and affordability in mind, SpectrumMate LR brings spectroscopic capabilities to smaller observatories, amateur astronomers, and educational institutions. Its user-friendly setup and compatibility with standard telescope mounts make it an ideal tool for individuals and organisations eager to participate in spectroscopic observations and data collection. With the ability to observe a wide range of wavelengths at a low resolution, SpectrumMate LR allows users to perform meaningful analyses of stellar spectra, tracking changes over time and comparing characteristics across various types of stars and other celestial objects.

SpectrumMate LR's design emphasises both usability and data quality. Its broadband sensitivity spans the visible spectrum, making it suitable for observations of many different kinds of objects, from bright stars to nebulae. The low-resolution capability allows for a quick and reliable assessment of spectral features such as absorption and emission lines, which are essential for identifying key elements within a star or nebula. Although the instrument is limited in its ability to resolve very fine spectral details, its broadband, low-resolution approach provides a sufficient level of information for a wide variety of analyses, enabling users to identify prominent spectral features and obtain general characteristics of the observed objects.

By making spectroscopic analysis more accessible, SpectrumMate LR opens new pathways for amateur astronomers and educators to contribute to scientific research. This tool offers a hands-on way to engage with the same fundamental techniques used by professional astronomers, facilitating a broader understanding of the universe and inspiring new generations to explore astrophysics through direct observation. SpectrumMate LR aims to democratise spectroscopic data collection, empowering users worldwide to participate in astronomy at a deeper level.

2. SpectrumMate LR design

2.1. Requirements

In contrast to the original SpectrumMate, which has a spectral coverage of 368 Å in one image, SpectrumMate LR is engineered to capture a broader range of wavelengths, from 3400 Å to 7000 Å. This enhanced wavelength range enables the observation of a wide spectrum of celestial features, from the hydrogen and helium lines typical in stellar spectra to more complex molecular signatures found in nebulae and other diffuse objects. The increased bandwidth and optimised resolution make SpectrumMate LR suitable for capturing both broad spectral features and essential details of emission and absorption lines.

The design requirements for SpectrumMate LR prioritise accessibility, user-friendliness, and compatibility with small telescopes, addressing the need for affordable and efficient spectroscopic tools in amateur astronomy and educational settings. Several key requirements have been established for SpectrumMate LR to ensure that it can provide high-quality, broadband spectroscopic analysis accessible to a wider audience, enabling educational institutions and amateur astronomers to explore the universe in greater depth.

Firstly, broad spectral coverage is essential. Covering the visible spectrum allows for versatile analysis across different types of celestial bodies. This range captures visible light and near-infrared or near-ultraviolet spectra, depending on the user's observational goals, making the device suitable for a wide range of astronomical applications.

Secondly, moderate spectral resolution is required. With a resolving power of R=990 at 5500 Å, the middle of the visible wavelength range, SpectrumMate LR achieves a balance between detail and accessibility. While it does not reach the high resolutions needed for detailed spectral line measurements in professional research, this level of resolution is ideal for detecting major spectral lines, such as hydrogen alpha (Hα) and beta (Hβ) lines, sodium, magnesium, and other elements, providing valuable data for amateur and educational use.

Thirdly, high light sensitivity is crucial. The device's sensitivity must be optimised to perform well with small-aperture telescopes, typically 5 to 10 inches in diameter and with focal ratios from about f/5 to f/10, which are common in amateur astronomy. This ensures that SpectrumMate LR can capture sufficient light from fainter objects, such as stars of magnitude 10 or 12, without prohibitively long exposure times, while maintaining a manageable field of view for the spectrograph's setup.

Next, ease of installation and calibration is important. Designed for compatibility with standard mounts and small telescopes, SpectrumMate LR should allow for straightforward setup and calibration procedures. Features such as an integrated calibration lamp or easy access to external calibration sources are essential to ensure that users of all skill levels can quickly calibrate and maintain accuracy in their observations.

Finally, high portability and durability are necessary. Given its intended use in amateur astronomy and educational outreach, the device should not weigh more than 2 kg and must be durable, allowing for transport to various observation sites. This portability expands the tool's utility, enabling users to bring it to remote locations with minimal setup, maximising the flexibility of observation opportunities.

2.2. Theoretical optical designs

The theoretical background provided in the work of C. Buil (2003, 2024) [1, 2] offers a basis for the optical system of SpectrumMate LR (Fig. 1), determining optimal spectral range, resolution, and other design parameters to enhance performance for small-telescope compatibility. The two mentioned works also cover telescope aperture compatibility and the sensitivity of a spectrograph, which are not addressed in this article.

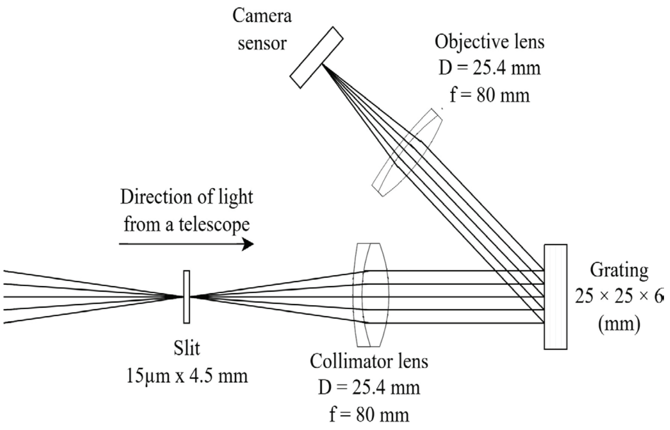

Fig. 1. SpectrumMate LR optical system. Compared to SpectrumMate, the lenses and the grating are the main differences.

Figure 1 shows the optical system of SpectrumMate LR. The collimator lens (OP0176) and objective lenses (OP0182) utilised in this spectrometer are both achromatic doublets, specifically designed to minimise chromatic aberration, thereby significantly reducing colour distortion across the entire visible wavelength range. The objective lens is also optimised for high transmission in this range.

Following the theoretical framework established, we calculated the parameters for SpectrumMate LR to meet the specific requirements for broadband, low-resolution spectroscopic applications. The parameters marked with an asterisk in Table 1 are not components of the spectrograph and may vary depending on the instrument used.

Table 1. Parameters used for calculation. The calculated parameters for SpectrumMate LR provide details on the achievable wavelength range, spectral resolution, and light sensitivity.

Parameters	SpectrumMate LR
Collimator lens: focal length f_1 and diameter D_1	80 mm; 25.4 mm
$F_C = f_1/D_1$	1.97
Objective lens: focal length f_2 and diameter D_2	80 mm; 25.4 mm
$F_O = f_2/D_2$	1.97
The total angle between the incident ray and the diffracted ray G	34°
Distance from the slit to the collimator lens	80 mm
Distance from the objective lens to the camera	80 mm
Grating groove density m	300 grooves/mm
Grating size	25×25×6 mm
Slit width w	15 μm
Telescope's principal mirror diameter D and focal length f	610 mm; 3962 mm
Sensor dimensions	5496×3672 pixel
Pixel size p	2.4×2.4 μm

2.2.1. Vignetting check at the collimator

The aperture ratio $F_\#$ of the telescope will be:

$$F_\# = \frac{f}{D} = \frac{3962}{610} = 6.5 \tag{1}$$

The collimator lens will be large enough to pass all the light from the telescope if $F_C < F_\#$. Since $F_C = 1.97 < 6.5$, this condition is satisfied.

2.2.2. Beam diameter

We denote the diameter of the beam exiting the collimator as d_1. In this case, we find assuring the correct dimension of the collimator lens diameter.

$$d_1 = D\,\frac{f_1}{f} = 610 \times \frac{80}{3962} = 12.32\ mm \tag{2}$$

2.2.3. Angles of incidence and diffraction

The spacing between the grooves in the grating determines the angle at which the different wavelengths of light are diffracted. The grating equation, given by

$$k\lambda = d(\sin\alpha + \sin\beta) \tag{3}$$

relates the wavelength of the light λ, the distance between the grooves d, the angle of incidence α, the angle of diffraction β (both in the unit of degrees), and the order of the diffraction k. It is sometimes convenient to write the equation as

$$mk\lambda = \sin\alpha + \sin\beta \tag{4}$$

where $m = 1/d$ is the groove density (groove per millimetre).

The equations presented are applicable only when the incident and diffracted rays are situated in a plane that is perpendicular to the grooves at the centre of the grating, as shown in Fig. 2. This condition, called classical or in-plane diffraction, encompasses most grating systems [3].

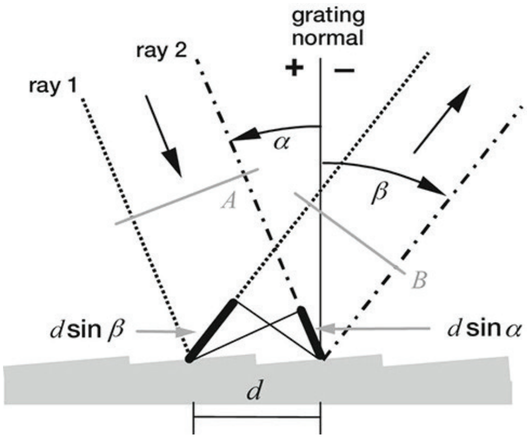

Fig. 2. Grating geometry by C. Palmer (2020) [3].

For the design of SpectrumMate LR, the light of wavelength λ=5500 Å is aimed at the centre of the imaging sensor. We have chosen the centre of the visible spectrum (green) as the reference wavelength.

We let $G=\alpha-\beta$ and replace β with $G-\alpha$ so that the grating equation can be written as:

$$\sin\alpha + \sin(\alpha - G) = mk\lambda \tag{5}$$

For maximum signal-to-noise (S/N) performance, it is generally recommended to work with the first order $k=\pm1$ (high light intensity) spectrum. Here, we only work on the first order k=1. Solving for α, the above equation becomes:

$$\alpha = \arcsin\frac{mk\lambda}{2\cos(G/2)} + \frac{G}{2} \tag{6}$$

$$= \arcsin\frac{1 \times 300 \times 5500 \times 10^{-7}}{2\cos\left(\frac{34}{2}\right)} + \frac{34}{2} = 21.95$$

From this, we find:

$$\beta = \alpha - G = 21.95 - 34 = -12.05 \tag{7}$$

Note that angles of opposite signs mean the incident ray and the diffracted ray lie on opposite sides of the normal to the grating.

2.2.4. Minimum grating dimension

For the required minimum grating dimension (L), we have

$$L = \frac{d_1}{\cos\alpha} = \frac{12.32}{\cos 21.95°} = 13.28\,mm \tag{8}$$

Since L<25 mm, the chosen holographic diffraction grating is large enough for no light loss to occur.

2.2.5. Spectral dispersion on sensor

Let ρ be the degree of dispersion in units of Å/pixel on the camera sensor. To optimise data storage, we use 2×2 binning, which groups four neighbouring pixels into one superpixel that has a size double that of the original pixel. Therefore, in dispersion calculations, the effective pixel size p is doubled.

The dispersion is given by

$$\rho = 10^7 \times \frac{p \times \cos\beta}{m \times f_2} \tag{9}$$

which yields

$$\rho = 10^7 \times \frac{2.4 \times 10^{-3} \times 2 \times \cos(-12.5°)}{300 \times 80} = 1.96\frac{Å}{pixel} \tag{10}$$

2.2.6. Diameter d_2 of the diffracted rays

The beam diameter d_2 of diffracted rays reflected off the grating is given by:

$$d_2 = \frac{\cos(\beta)}{\cos(\alpha)} \times \frac{f_1}{F_\#} + \frac{X \times p \times N}{f_2} \tag{11}$$

where X is the distance from the grating to the objective lens and N is the number of pixels across the sensor in the dispersion direction. Due to mechanical constraints, X is set to 80 mm. For the chosen sensor (Sony IMX183CLK-J), N=5496 pixels.

Although 2×2 binning is used for data collection, we utilise the pixel size p=2.4 µm and the pixel count N=5496 in this calculation. This is because the beam diameter d_2 depends on the actual physical parameters of the sensor, rather than on the effective value after binning. Binning does not alter the physical dimensions of the sensor, which directly affects the beam spread.

Substituting values, we find

$$d_2 = \frac{\cos(-12.05°)}{\cos(21.95°)} \times \frac{80}{6.5} + \frac{80 \times 2.4 \times 10^{-3} \times 5496}{80} = 26.16\,mm \tag{12}$$

To ensure the total absence of vignetting of the sensor, the condition $F_0 < f_2/d_2$ must be fulfilled. For our setup, we calculate 1.97<3.06, thus satisfying the required condition.

2.2.7. Spectral range coverage

The extreme wavelength limits from one side of the sensor to the other are given by the relation:

$$\lambda_{1,2} = \lambda \mp \frac{N\,\rho}{2} = 5500 \mp \frac{\frac{5496}{2} \times 1.96}{2} \tag{13}$$

Here, *N* represents the full number of pixels (5496) across the sensor's width. Although we employ 2×2 binning to save data, which reduces the effective spatial resolution, the physical width of the sensor remains unchanged. Therefore, we use the original pixel count (5496) to calculate the spectral range. Binning only affects the sampling resolution and not the physical span of the sensor, which determines the wavelength range coverage.

Substituting values, we find

$$\mathring{A} \text{ and } \lambda_2 = 8193.04\ \text{Å} \tag{14}$$

Thus, SpectrumMate LR in this configuration covers a spectral range of 5386.08 Å with a spectral dispersion of 1.96 Å/pixel.

2.2.8. Spectral resolution and resolving power

The spectral resolving power *R* is defined as

$$R = \frac{\lambda}{\Delta\lambda}, \tag{15}$$

where $\Delta\lambda$ is the full-width half maximum (FWHM) of the spectral peak being investigated. The higher the value of *R*, the higher the spectral resolution. SpectrumMate LR is of low resolution with a value of *R*=524, which tells us that SpectrumMate LR allows one to see details of 5500/524=10.50 Å in the range near 5500 Å.

2.3. Mechanical design

Before initiating the 3D printing process, a comprehensive mechanical design was developed using Catia V5[1]. We adopted a modular design approach to facilitate ease of assembly, maintenance, and potential future upgrades. The design process involved detailed simulations to verify component tolerances, ensure proper optical alignment, and minimise light leakage. Specific design solutions were implemented to guarantee robust interfaces between critical components, such as maintaining an optimal distance between the collimator lens and the slit, and ensuring precise alignment of the objective tube with the camera system.

After completing these design and validation steps, the finalised 3D models were converted into STL files for printing on an Ender 3 printer. Due to its ease of use, rapid prototyping capability, and cost-effectiveness, PLA filament was chosen as the primary material for SpectrumMate LR's enclosure and parts, rather than traditional aluminium milled components. Although aluminium offers superior mechanical stability and thermal resistance, the use of PLA was deemed sufficient for our application under typical operating conditions. Moreover, we carefully evaluated the potential for PLA deformation under varying telescope positions and ambient temperatures. Our tests, including thermal and alignment verifications, indicated that any deformation of the PLA parts is minimal and does not adversely affect the optical alignment or overall performance of the system. Routine calibration and maintenance procedures are also in place to mitigate any minor misalignment that could arise over time.

Images of the components can be seen in Fig. 3.

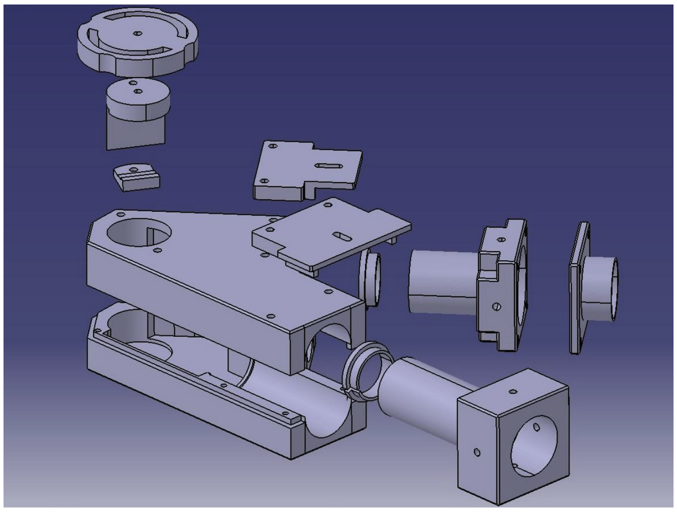

Fig. 3. 3D model of SpectrumMate LR.

For the collimator lens and its interface, when the lens and slit were installed, the distance between them was maintained at approximately 50 mm, ensuring a robust setup. The objective tube was tested with the ASI183 Pro camera and a focuser, directed at a distant object to simulate parallel rays, successfully achieving focus at infinity. These validations confirm that SpectrumMate LR functions as intended.

Basic tools such as pliers, screwdrivers, M3/M4 Allen keys, and various M3/M4 screws, nuts, threads, and washers were used to assemble the printed parts. Once assembled, ensuring that light entered and passed through the system without obstruction or leakage was the highest priority.

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[1] Dassault Systèmes (2024), "Catia V5", https://www.3ds.com/products/catia/catia-v5, accessed 10 September 2024.

A laser test confirmed proper alignment and revealed no unintended light blocking within the optical path. When the slit was blocked, no stray light was detected in the camera image, thereby affirming that SpectrumMate LR effectively prevents light leakage.

Figure 4 shows an image of SpectrumMate LR with several accessories attached. The image caption provides a short description of the components.

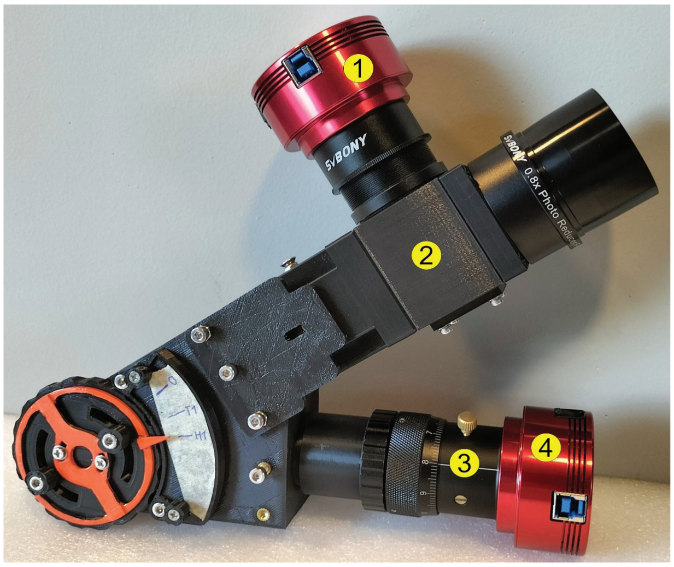

Fig. 4. SpectrumMate LR equipped with accessories. (1) is a guiding camera that allows the user to see what the slit is pointing to by looking at the guider (2). (3) is a helical focuser used for precisely adjusting the focus of the main camera (4), which captures the spectra.

Figure 5 below illustrates the field of view (FOV) of the spectrograph as observed through the guider system, clearly depicting the central slit (indicated by the black line) that selectively admits light from the target object.

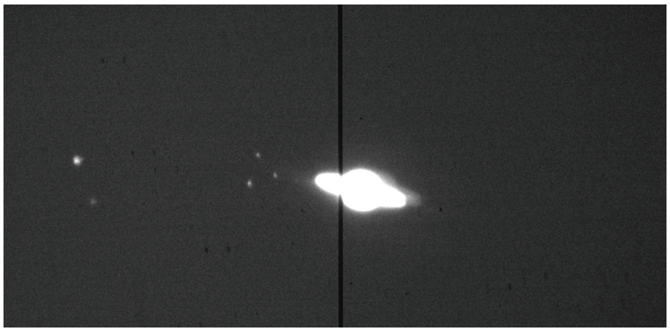

Fig. 5. Field of view (FOV) of the spectrograph through the guider. The black line in the middle represents the slit. The light from the object that the slit is pointing to will enter the spectrograph; in this case, it is light from the ring of Saturn.

3. Observations

This section describes the observational capabilities and tests conducted with SpectrumMate LR to evaluate its performance. These observations aimed to classify stars by spectral type, measure the temperatures of different light sources, and validate the spectral transmission properties of various optical filters. Through these tests, we verified the resolution, accuracy, and reliability of SpectrumMate LR for amateur and educational spectroscopy.

3.1. Raw spectra obtained by SpectrumMate LR

Figure 6 shows the raw spectrum of Vega, captured by SpectrumMate LR.

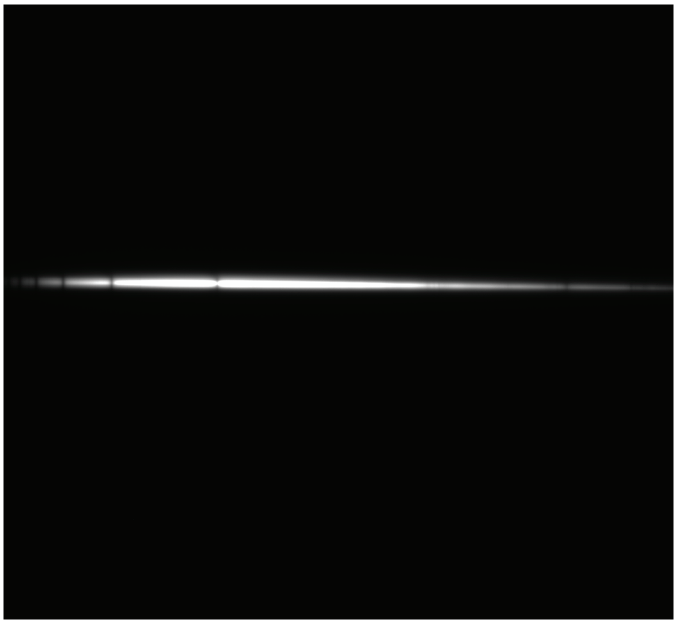

Fig. 6. Raw spectrum of Vega. Absorption lines can be seen.

To enhance the quality of the spectrum, we performed the necessary calibration on the image (bias/dark subtraction, flat fielding, and stacking). For spectral calibration and normalisation, we used the calibration module from Shelyak[2]. This module includes a reference spectrum, and the wavelengths of emission lines (Fig. 7) can be automatically recognised when using Demetra[3] software. Demetra also assists users in calibrating the images, significantly reducing the workload.

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[2] Shelyak Instruments (2024) "Module d'étalonnage", https://www.shelyak.com/produit/pf0037-module-detalonnage-alpy/, accessed 10 September 2024.

[3] Shelyak Instruments (2024), "Demetra software", https://www.shelyak.com/software/demetra/?lang=en, accessed 10 September 2024.

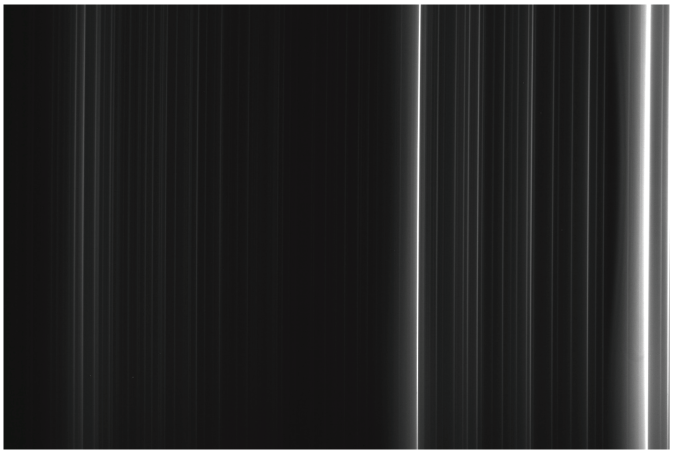

Fig. 7. Calibration spectrum. This spectrum was also used to measure the spectral resolution of SpectrumMate.

3.2. Star classification based on spectral type

To test the capabilities of SpectrumMate LR, we observed and classified stars across various spectral classes, including O, B, A, F, G, K, M, and Wolf-Rayet types. These classifications are based on spectral features characteristic of each class, such as specific absorption lines, which correlate with stellar temperature and composition.

We obtained the spectra using the CDK600 telescope at QNO. The mount's accurate tracking system allowed us to capture spectra of even low-brightness objects. This telescope supported the first detection of exoplanet transit in Vietnam by T.V. Nguyen, et al. (2023) [4] and was the main instrument used in the SAGI Summer School 2023, as detailed in the study by Q.N. Luong, et al. (2023) [5].

A set of representative stars from each spectral class was selected and observed to capture their spectra. In the present work, we focus on the relative shape and features of each star's spectrum rather than its absolute flux scale. Since the final spectra are normalised, the plotted y-axis units are arbitrary but comparable from star to star.

Figures 8 and 9 are examples of stars in each spectral class captured with SpectrumMate LR, demonstrating the

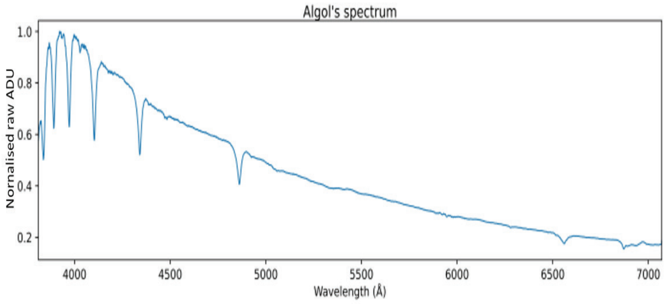

Fig. 8. Algol (HD 19356) - B8V.

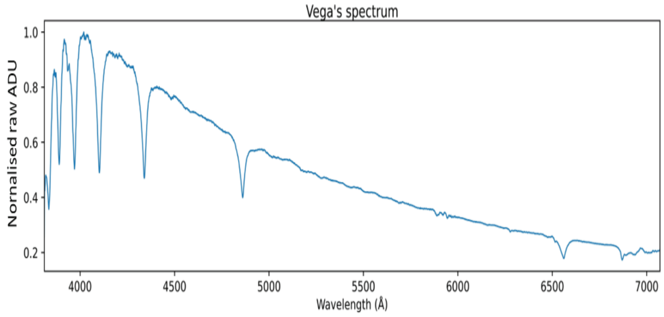

Fig. 9. Vega (HD 172167) - A0V.

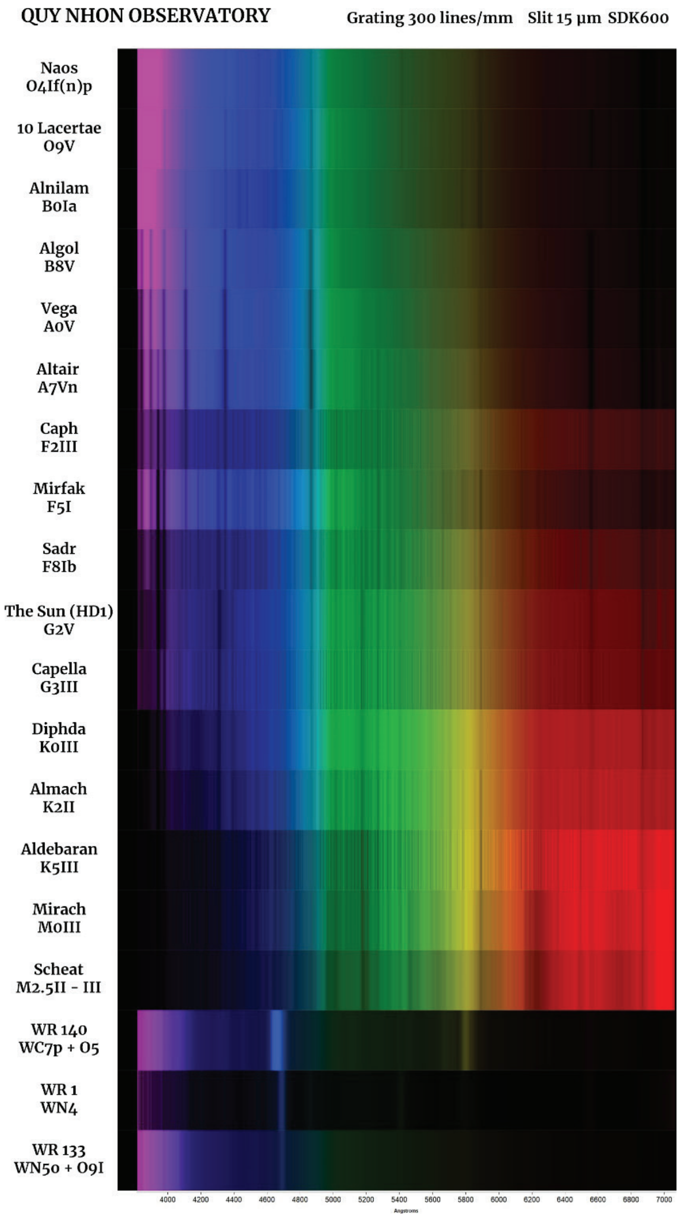

Fig. 10. Star classification based on spectral types. The hotter the star, the shorter the peak wavelength at which it emits light. For the high-resolution version, visit the data of N.N. Duc (2024b) [7].

instrument's ability to resolve and distinguish these spectral features. For a complete set of spectra, please refer to the supplementary materials available at the data collected by N.N. Duc (2024a) [6].

Demetra also generated colour spectra for each star, facilitating analysis and categorisation based on the visualised spectral lines. In Fig. 10, we arranged the spectra in order of descending star temperature, with the exception of the last three.

Based on the calibrated spectrum, the spectral dispersion and spectral range coverage of SpectrumMate LR were measured using Demetra. As shown in Table 3, the spectral range coverage and resolving power are lower than theoretical calculations. Real-world performance often falls short of theoretical predictions due to minor mechanical misalignments, imperfect focus, manufacturing variations in optics and gratings, and small calibration errors. Even slight deviations in component angles, lens coatings, or sensor alignment can shift the actual spectral range on the detector and reduce resolution. Thus, small cumulative discrepancies between design assumptions and physical realities lead to lower-than-expected coverage and resolving power.

Table 2. Parameters of SpectrumMate LR.

	Theory	Reality
Spectral dispersion ρ (Å/pixel)	1.96	1.18
Spectral range coverage (Å)	5368.08	3260.15
Spectral resolution (Å)	10.50	13.64
Resolving power R (at 5500 Å)	524	403

3.3. Temperature measurement of light sources

Based on Wien's law, we measured the temperatures of two incandescent light bulbs with 12 V operating voltage and power ratings of 3 W and 50 W, respectively. Wien's law relates the peak emission wavelength λ_{max} to the temperature T of the object as in:

$$\lambda_{max} = \frac{2.898 \times 10^{-3}}{T} \tag{16}$$

where λ_{max} is in meters and T is in Kelvin.

Figure 11 shows the spectra of the light bulbs, illustrating how peak wavelength shifts as temperature changes.

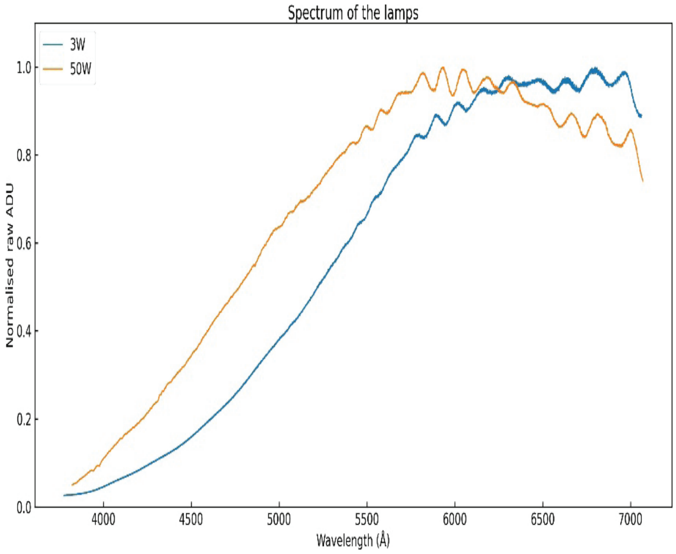

Fig. 11. Spectra of 3 W and 50 W incandescent lamps, showing the peak wavelength shift due to temperature differences.

Using equation (16), we measured the temperature of the two light bulbs. The results indicate a significant discrepancy between the temperature measured using the peak wavelength and the temperature reported by the manufacturer. This difference can be explained by several factors. Firstly, the peak emission wavelengths observed in the visible range do not correspond to the true blackbody peak for these incandescent light bulbs; the actual emission peaks for the stated temperatures (2500 and 3350 K) lie in the infrared. Since the spectrograph primarily captures the visible tail of the spectrum, applying Wien's law to this portion results in an overestimation of the temperature. Secondly, the calculation assumes the source behaves as an ideal blackbody (with emissivity equal to 1), but real materials, such as tungsten filaments, exhibit wavelength-dependent emissivity that can alter the spectral shape and shift the apparent peak. Finally, instrumental factors, such as calibration inaccuracies in the spectrograph's wavelength scale and sensitivity, further contribute to the discrepancy.

Table 3. Parameters of SpectrumMate LR.

Power	Peak wavelength (Å)	Temperature measured (K)	Temperature by the manufacturer (K)
3 W	6800	4261.76	2500
50 W	5938.46	4883.42	3350

3.4. Filter transmission testing

We conducted tests with the SpectrumMate LR spectrograph to validate the spectral transmission characteristics of the Antlia SLOAN/SDSS (g’r’i’z’) Photometric Imaging Filter Set[4], which contains four filters with technical specifications provided by the manufacturer, as shown in Table 4, and a transmission profile provided by the manufacturer, as shown in Fig. 12.

Table 4. Parameters of SpectrumMate LR.

	g’	r’	i’	z’
Bandpass (nm)	401-550	562-695	695-844	>820
Peak transmission (%)	95	98	98	98

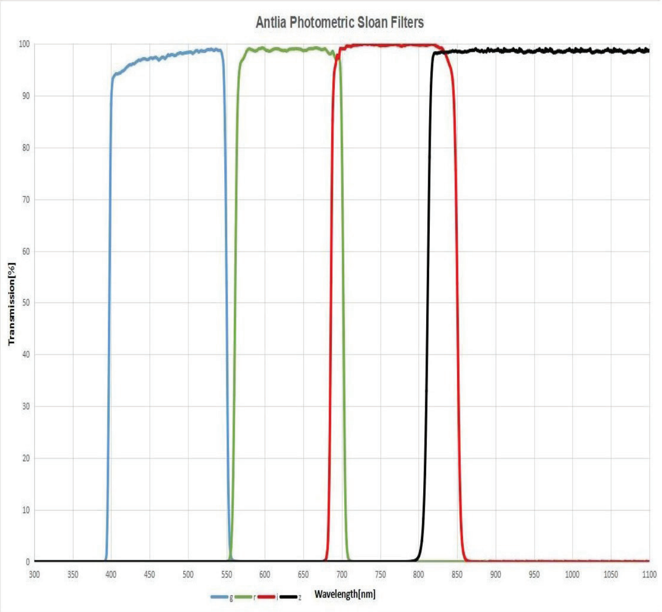

Fig. 12. Transmission profile of the filters by the manufacturer. The vertical axis is for transmission (%), and the horizontal axis is for wavelength (nm).

The transmission tests involved comparing the spectra of a light source in both filtered and unfiltered configurations. A combination of scattered sunlight and incandescent lamps was used as the light source. This hybrid setup was chosen because incandescent lamps lack ultraviolet (UV) radiation, necessitating the inclusion of sunlight to ensure adequate UV coverage. The transmission ratio, defined as the ratio of the filtered spectrum to the unfiltered spectrum, was calculated to accurately quantify the spectral range of each filter. To extend the observed spectral range beyond the standard coverage of the SpectrumMate LR, the diffraction grating was slightly tilted to capture wavelengths at both the UV and near-infrared (NIR) ends of the spectrum. This approach ensured a comprehensive analysis of the filters’ transmission properties across a broad wavelength range.

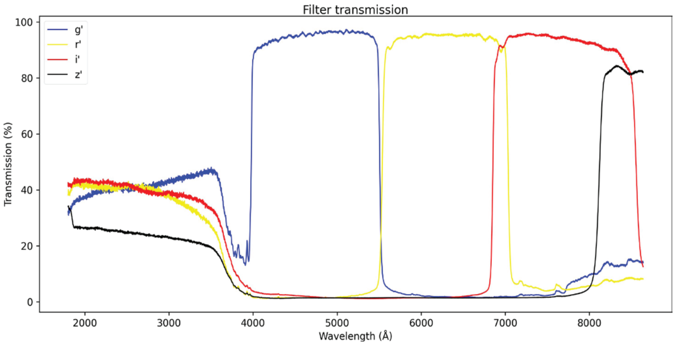

Fig. 13. Transmission spectra of the filters measured using SpectrumMate LR.

As shown in Fig. 13, in the visible range, the filters exhibited a high transmission percentage (more than 90%) across each band, with a well-defined cutoff, while its performance decreased significantly in the UV range (below 50%). This decrease can be attributed primarily to the glass material of the lenses used in SpectrumMate LR, which absorbs most UV radiation due to the intrinsic absorption properties of standard optical glass (e.g., borosilicate or crown glass). Additionally, shorter UV wavelengths tend to scatter more due to Rayleigh scattering, further reducing the system’s signal-to-noise ratio (SNR). Another contributing factor may be the detector’s reduced sensitivity in the UV range, as many CCD or CMOS sensors exhibit a natural drop in quantum efficiency at shorter wavelengths unless specifically designed for UV detection. These combined factors lead to a noticeable decline in performance in the UV spectrum. The data used to create the transmission profile can be found at the study by N.N. Duc (2024c) [8].

4. Conclusions

SpectrumMate LR has proven to be a powerful and accessible tool for amateur and educational spectroscopy. It successfully captures detailed spectra for stellar classification, allows for temperature measurement of light sources using Wien’s law, and enables precise verification of filter transmission properties. These capabilities demonstrate that SpectrumMate LR is not only functional but also reliable, providing low-resolution spectral data that can support a range of observational and educational applications. Its performance suggests potential for further

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[4] Agena Astro Products! (2024), “Antlia Sloan/SDSS (griz’) photometric imaging filter set of four filters - 50 mm round unmounted”, https://agenaastro.com/antlia-sloan-sdss-griz-photometric-imaging-filter-set-50mm-round.html?srsltid=AfmBOorLiYmKJ8hMPEmfjryqhooJlT1qK1t82eyp_IUovZ33WQkkLdjv, accessed 10 September 2024.

use in amateur astronomy and basic research, making it a valuable addition for those interested in spectroscopy.

CRediT author statement

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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