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Portable broadband astronomical spectrograph

Xiaolin Huang[1,2,3], Jiajia Wu[1,2], Yuan Liang[1,2,3], Liang Wang[1,2,3], Chuandong Chen[1,2,3], E Xiang[4], Zhengyang Li[1,2], Kai Zhang[1,2,3*]

[1]*Nanjing Institute of Astronomical Optics & Technology*, *Chinese Academy of Sciences*, *Nanjing* 210042, *China*

[2]*CAS Key Laboratory of Astronomical Optics & Technology*, *Nanjing Institute of Astronomical Optics & Technology*, *Nanjing* 210042, *China*

[3]*University of Chinese Academy of Sciences*, *Beijing* 100049, *China*

[4]*National Astronomical Observatories*, *Chinese Academic Sciences*, *Beijing* 100101, *China*

*Correspondence: kzhang@niaot.ac.cn

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Abstract: Astronomical spectroscopy is a critical tool in many advanced research topics such as cosmic origin, galaxy evolution, stellar formation, and exoplanet detection. Medium-to-large aperture optical telescopes equipped with various spectrographs are suitable for many large programs. However, many small-aperture (30–80 cm) telescopes have the potential to perform quick and flexible observations in the astronomical field. Using current technology, most portable astronomical spectrographs can capture broadband spectra by rotating or changing the gratings to scan the spectrum at multiple exposures. This paper presents a portable broadband astronomical spectrograph (called ESPEC-2) that features an echelle grating as the main disperser and a group of collimating and imaging lenses to simplify the optical system. For 30–80 cm aperture telescopes, the lightweight prototype (~3.5 kg) enables spectral observation with a spectral resolution of $R \geqslant 6200$ over a wavelength range of 400–900 nm with a single exposure. Moreover, it can be directly mounted on the telescope's focus or connected via optical fiber. Its portability and versatility make it suitable for use as a general-purpose spectrograph in other scientific experiments. The developed compact broadband spectrograph is expected to make significant contributions to scientific research, outreach, and education.

Keywords: Astronomical spectrograph; Broadband spectroscopy; Echelle grating

1. INTRODUCTION

In the fields of astronomy and astrophysics, spectroscopic observations play a critical role in advanced research areas such as cosmic origin, galaxy formation and evolution, black hole discovery, the chemical composition of unusual stars, and the search for exoplanets, driving the development and validation of theoretical models. Despite the continuous observations of hundreds of billions of celestial objects by a global network of 14 large-aperture optical telescopes in the 10-m class and over a hundred telescopes with apertures larger than 1 m, the scientific demands of the astronomical community remain unmet. Table 1 presents the relevant parameters of some low-to-medium resolution spectrographs installed on medium- and large-aperture astronomical telescopes[1–6]. To meet specific observational requirements, the spatial dimensions and technical specifications of these spectrographs vary, and each is custom-developed for a particular telescope, making them unsuitable for direct adaptation to other telescope systems. Meanwhile, universities and amateur astronomical groups possess a much larger number of 30–80 cm optical telescopes, which have already achieved numerous scientific discoveries through imaging observations. However, the majority of these telescopes lack spectroscopic capabilities. This highlights the significant potential for popularizing astronomical spectroscopy among both professional and amateur communities as well as the substantial latent demand for specialized, versatile, and integrated small-scale astronomical spectrographs.

Although the development of small astronomical spectrographs remains a niche field, several research teams and companies are advancing various types of spectrographs for scientific research, education, and public outreach. Baker et al. developed a compact astronomical spectrograph in a laboratory that can capture spectral images with a resolution of $R \geqslant 60000$ within the 500–1000 nm range[7]. This spectrograph is fed by a single-mode fiber

Table 1. Specifications of selected professional spectrographs

Instruments	Telescopes	Wavelength/nm	Resolution (Δλ/λ)	Dimensions (mm × mm × mm)
Long-slit Spectrograph (LSS)[1]	1.2 m Telescope Sun Yat-sen University (SYSU)	400–900 Multi-exposure	1000–3000	800 × 800 × 400
Beijing Faint Object Spectrograph and Camera (BFOSC)[2]	2.16 m Telescope National Astronomical Observatories, Chinese Academy of Sciences (NAOC)	330–1020 Multi-exposure	500–2000	1200 × 800 × 600
Yunnan Faint Object Spectrograph and Camera (YFOSC)[3]	2.4 m Telescope Yunnan Observatories, Chinese Academy of Sciences (YNAO)	340–980 Multi-exposure	545–10000	1500 × 800 × 700
Next Generation Palomar Spectrograph (NGPS)[4]	5 m Telescope Hale Palomar Observatory	310–1040 Single-exposure	1800–6000	3200 × 1700 × 700
X-shooter (VIS)[5]	8.2 m Telescope VLT European Southern Observatory (ESO)	550–1020 Single-exposure	5000–18000	2500 × 1500 × 1000
Faint Object Camera and Spectrograph (FOCAS)[6]	8.2 m Telescope Subaru, National Astronomical Observatory of Japan (NAOJ)	370–1000 Multi-exposure	250–2000	3000 × 1800 × 1800

with a core aperture only 10 μm in diameter to obtain a high spectral resolution. In astronomical observation, telescopes normally couple stellar light into a multi-mode fiber instead of a single-mode fiber. However, no observations were reported in this paper. Bagusat et al. designed a cross-dispersion spectrograph using reflective optical components, achieving a theoretical resolution of $R \geqslant 900$ in the range 330–1100 nm[8]. Shelyak Instruments released LISA, Lhires III, and other astronomical spectrograph products, enabling spectral observations at varying resolutions within the optical band[9]. Some of these devices have been adopted in astronomical applications in Chinese universities. Huang et al. designed a compact spectrograph using a scanning grating mechanism, achieving a resolution of $R \geqslant 800$ in the 800–1800 nm range[10]. Zhang et al. proposed an optical design for a small spectrograph that employs a prism as the disperser. It can theoretically achieve a resolution of $R \geqslant 80$ over the wavelength range 400–1750 nm[11].

The specifications of some portable spectrographs are listed in Table 2[6–16]. The spatial dimensions of these spectrographs are all less than 350 mm × 150 mm × 100 mm, which is much smaller than the professional astronomical spectrometers listed in Table 1. The existing portable astronomical spectrographs provide the basic ability to observe at a low-to-medium resolution over a broad range of wavelengths. However, the spectral resolution is limited by low illumination at the slit due to the small aperture of the telescope, limiting its light-gathering capability. This means that the portable spectrographs work well with small-aperture telescopes to observe bright objects and planets in the solar system for science popularization, astronomical education, and scientific research.

Fig. 1 shows some compact astronomical spectro-

Table 2. Comparison of several portable spectrographs

Team/Company	Wavelength range/ nm	Resolution/ (Δλ/λ)	Dimensions/ (mm × mm × mm)	Product or prototype
ESPEC-2	400–900 Single-exposure	⩾ 6200	355 × 215 × 100	Prototype
Tsinghua University[12]	300–860 Multi-exposure	2500	149 × 106 × 48	Prototype
Baker et al.[7]	500–1000 Single-exposure	⩾ 60000 (φ10 μm fiber)	300 × 140 × 90	Prototype
Bagusat et al.[8] (Not for astronomy)	330–1100 Multi-exposure	⩾ 900	110 ×110 ×30	Prototype
Huang et al.[10] (Not for astronomy)	800–1800 Multi-exposure	⩾ 800	90 × 70 × 70	Prototype
Zhang et al.[11] (Not for astronomy)	400–1750 Multi-exposure	⩾ 80	145 × 48 × 48	Prototype
Shelyak Instruments (LISA)[13]	300–700 Multi-exposure	1000	250 × 200 × 60 (No detector)	Product
Shelyak Instruments (Lhires III)[9]	400–750 Multi-exposure	18000@23 μm slit	250 × 200 × 83 (No detector)	Product
Shelyak Instruments (UVEX)[14]	350–1000 Multi-exposure	210–6738	150 × 150 × 130	Product
Ocean Optics (ST-VIS)[15] (Not for astronomy)	350–810 Multi-exposure	2.2 nm	42 × 40 × 27	Product
Ocean Optics (HR4)[16] (Not for astronomy)	220–1050 Multi-exposure	1 nm@25 μm slit	150 × 107 × 48	Product

graphs in Table 2 and demonstrates that technical groups tried to make progress on this kind of spectrograph in different ways. Most of the portable spectrographs listed in Table 2 have demonstrated their ability to perform astronomical spectral observation, but some of their characteristics could be improved. First, most of these spectrographs obtain the broadband spectrum through multiple exposures, which increases observation errors and wastes time. Second, most only allow an optical connection to the telescope. Third, only the LISA spectrograph by Shelyak Instruments is equipped with a guidance system, which is important to ensure the position of the stellar image at the slit remains stable. If some of these aspects of portable spectrographs could be improved, it would improve the performance of the instrument during actual observations.

With the popularization of astronomy, the application of miniaturized spectrographs in astronomical spectral observations has attracted increasing attention. Some scientific research teams are exploring their scientific application in the field of bright star observations. For example, a student team from the Department of Astronomy at Tsinghua University, China, successfully captured the spectra of Comet C/2023 A3 using an 80-mm telescope and a custom-built spectrograph at Lenghu Astronomical Base, China[12], see Fig. 2. This success demonstrated that the combination of a small telescope and portable spectrograph can contribute to scientific study and education in astronomy.

Most existing commercial astronomical spectrographs adopt a single-order dispersion scheme. The observation band for a single exposure is relatively short, and it is usually limited by the small size of the detector. To achieve a wider wavelength coverage, the grating must be rotated or replaced. To address this challenge, our team developed a portable broadband astronomical spectrograph called ESPEC-2. Its prototype is shown in Fig. 3. The goal is to achieve scientific-grade and broadband astronomical spectral observations under the constraints of miniaturization and low cost. A single exposure covers a wide range of 400–900 nm, yielding medium-resolution spectral images with a resolution of $R \geqslant 6000$, which is appropriate for optical telescopes with an aperture of 30–80 cm, as a higher resolution would reduce the spectrograph's ability to observe faint targets. Moreover, ESPEC-2 has two observation modes, direct connection to the telescope and optical fiber connection, and it is equipped with a guide-star unit and calibration unit, which can address the requirements of diverse observation tasks.

This paper describes the instrument design, prototype performance, and test performance of ESPEC-2. Its contributions are as follows: (1) A highly efficient, low-cost spectrograph design is proposed that meets functional and technical requirements; (2) The results of the prototype trial production and main performance tests of the spectrograph are reported; and (3) The trial observation results of the spectrograph and its application in a calibration task experiment are presented.

2. SPECTROGRAPH DEVELOPMENT

2.1. Overall Technical Specifications

The ESPEC-2 portable broadband astronomical spectro-

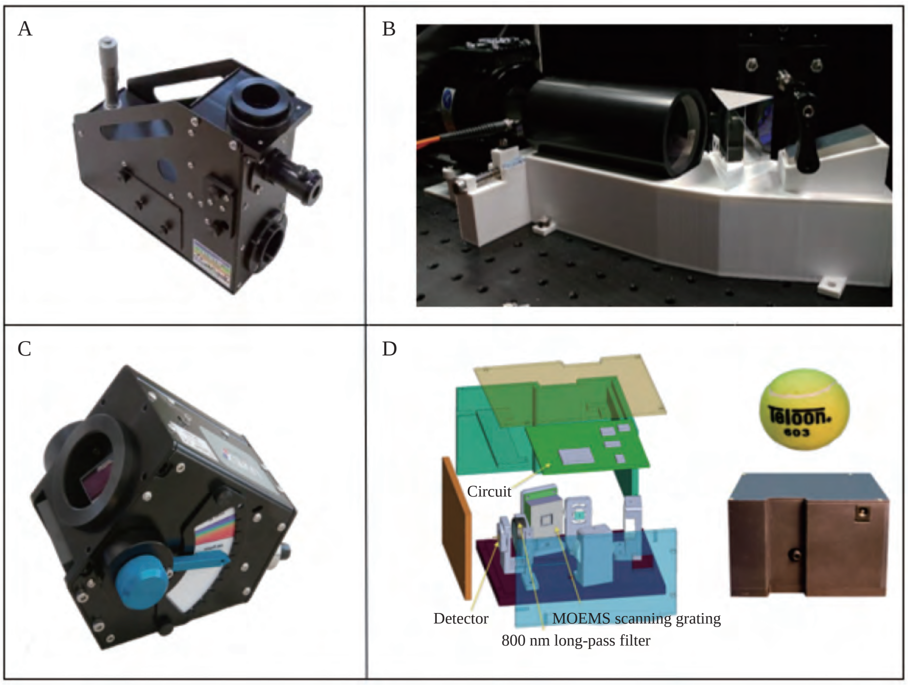

Fig. 1. Example compact astronomical spectrographs. (A) Lhires III commercial astronomical spectrograph[9]. (B) Prototype of a compact astronomical fiber spectrograph designed by Baker et al.[7]. (C) UVEX commercial astronomical spectrograph[14]. (D) Compact general-purpose fiber spectrograph designed by Zhang et al.[11].

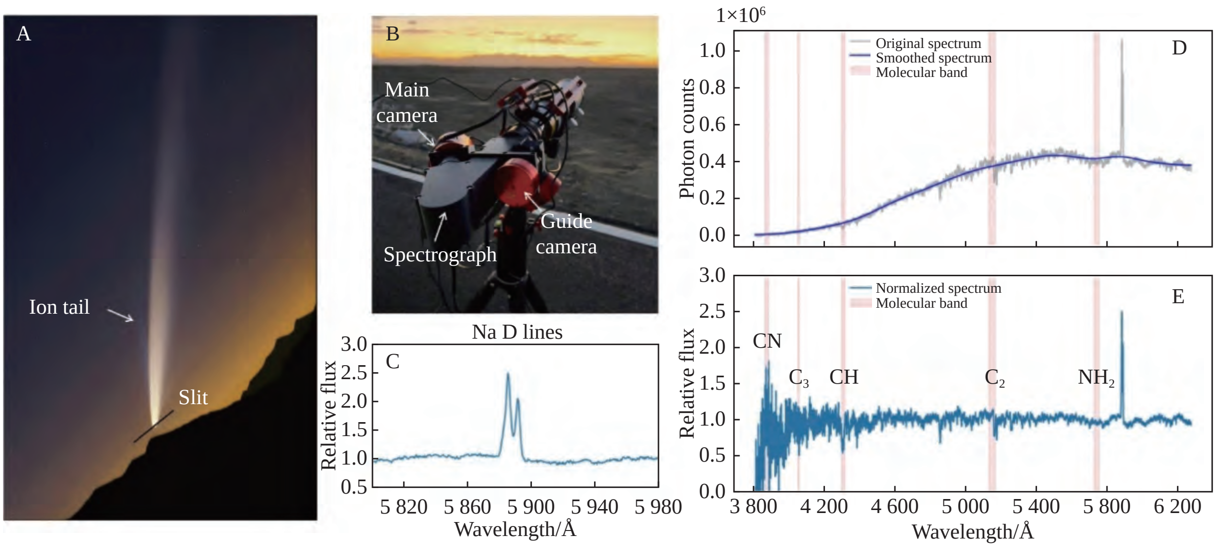

Fig. 2. Spectra of Comet C/2023 A3 obtained by a Tsinghua University student team using a compact spectrograph (reproduced from Tang et al.[12] with permission).

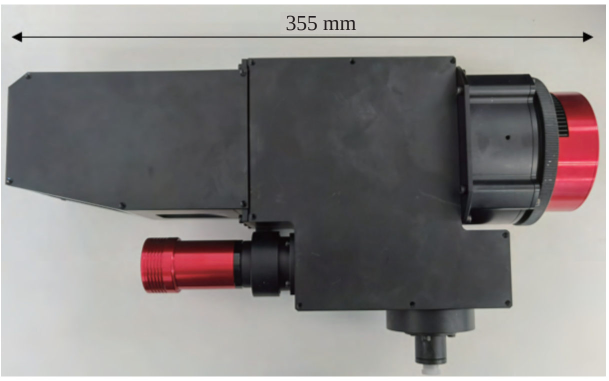

Fig. 3. Prototype of the ESPEC-2 portable broadband astronomical spectrograph.

graph is composed of an telescope adaptor interface, the spectrograph main module, a guidance module, and a calibration module, providing instrument versatility and multiple functions. The design includes two telescope adaptors. The spectrograph can be directly mounted on the Cassegrain focus of a telescope to perform observations. Alternatively, a fiber-coupling module can be mounted, and an optical fiber can then be used to transmit starlight from the telescope to the spectrograph. The spectrograph main module adopts a cross-dispersion scheme to obtain a two-dimensional broadband spectrum. A group of transmissive collimating and imaging lenses with secondary multiplexing are included in the design and perform the two functions of beam collimation and spectral imaging simultaneously, reducing the overall instrument size and cost. Its optical design, shown in Fig. 4, is analogous to a folded Gaussian system, which effectively compensates for optical aberrations and while reducing the system's overall length. The compact structure achieves the goals of miniaturization and cost saving, and the final overall dimensions are less than 360 mm × 220 mm × 100 mm, other key parameters are shown in Table 3. Because a modular structure is used, the guiding and calibration modules are placed in front of the entrance slit for spectral observation and wavelength calibration, making the device more efficient.

The spectral resolution is determined by multiple factors such as slit width, grating parameters, collimated aperture size, and detector type. To increase spectral resolution, the spectrograph requires a larger collimated aperture and grating, resulting in a corresponding increase in the size and weight, which is not conducive to the design goals mentioned above. Therefore, under the given band and spectral resolution specifications, the main parameters and device specifications of the instrument must be optimized through theoretical calculations.

The main disperser of the spectrograph is an echelle grating. When the input and diffracted light satisfy the quasi-Littrow condition, incident angle α is equal to diffraction angle β, and the relevant parameters can be calculated according to the following grating equation:

$$m\lambda = \sigma(\sin\alpha \pm \sin\beta) = 2\sigma\sin\beta\,, \tag{1}$$

where m is the diffraction order, λ is the wavelength of the incident light, σ is the grating constant (i.e., the distance between adjacent grating lines), and α and β represent the incident and diffractive angles of the light, respectively. After taking the derivative of both sides of the formula with respect to wavelength, we obtain the angular dispersion formula as follows:

$$\frac{\mathrm{d}\beta}{\mathrm{d}\lambda} = \frac{m}{\sigma\cos\beta} = \frac{2\tan\beta}{\lambda}\,. \tag{2}$$

If the focal lengths of the collimating and imaging lenses are f, the inverse linear dispersion coefficient can be calculated as follows:

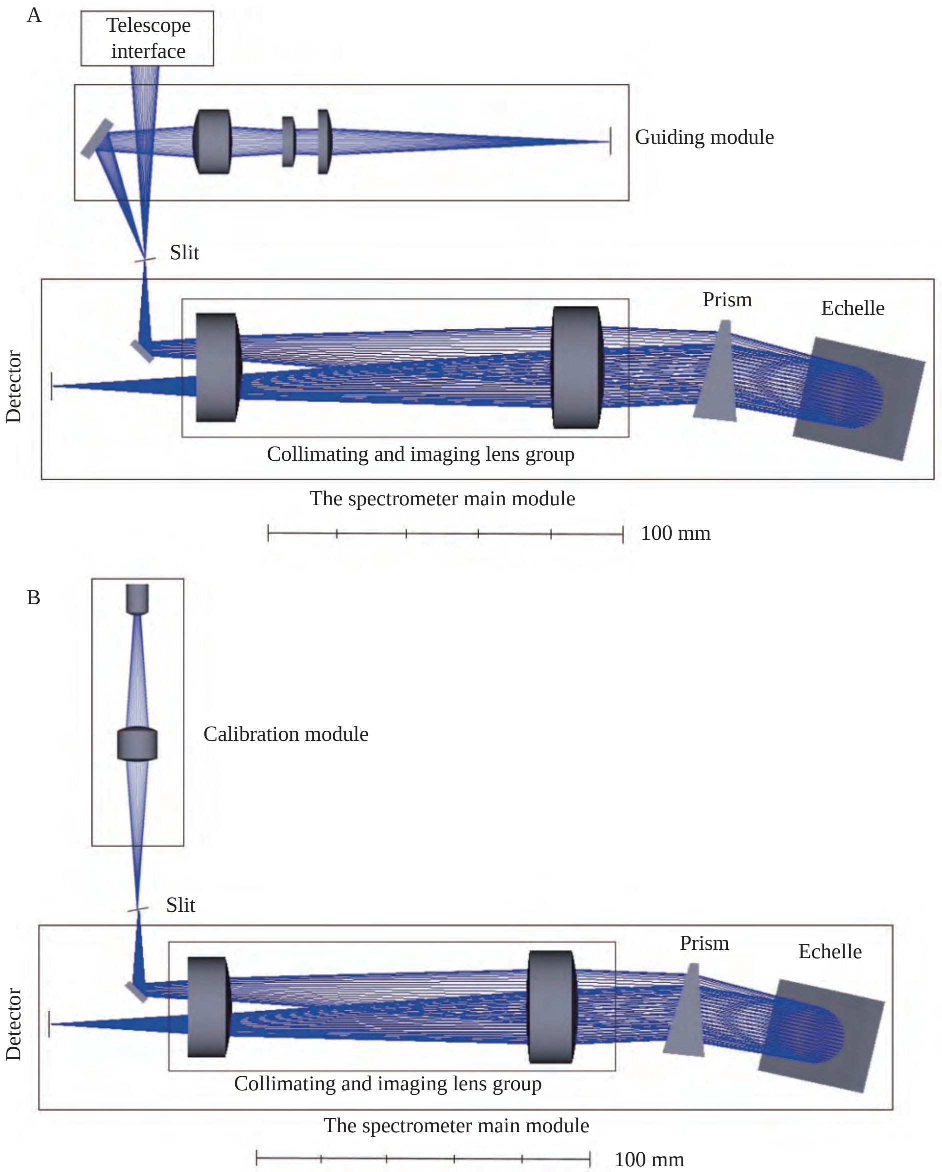

Fig. 4. Main optical path of the spectrograph. (A) Telescope observation mode. (B) Calibration and fiber optic observation mode.

Table 3. Specifications of the ESPEC-2 spectrograph

Parameter	Value
Resolution	$R \geqslant 6000$
Wavelength range/nm	400–900
Slit width/μm	50
Weight/kg	⩽ 5
Dimensions/ (mm × mm × mm)	⩽ 360 × 220 × 100
Adapted telescope aperture/mm	300–800
Appropriate telescope focal ratio	⩾ F/7

$$\frac{d\lambda}{dl} = \frac{1}{f\frac{d\beta}{d\lambda}}. \tag{3}$$

Since the collimating and imaging mirrors of the instrument share the same optical assembly, resulting in a magnification factor of one, the width of the slit on the focal plane corresponds to its actual physical width w. Combining this with Equation (3), the spectral purity can be calculated as follows:

$$\Delta\lambda = w\frac{d\lambda}{dl} = \frac{w\lambda}{2f\tan\beta}. \tag{4}$$

Let D_c represent the collimated aperture of the spectrograph and D_t represent the telescope aperture. When the focal ratios of the telescope and spectrometer are matched, θ denotes the angular width on the sky subtended by the slit and can be calculated as follows:

$$\theta = \frac{wD_c}{fD_t}. \tag{5}$$

Consequently, the theoretical spectral resolution of the central wavelengths at each order can be derived as follows:

$$R = \frac{\lambda}{\Delta\lambda} = \frac{2f\tan\beta}{w} = \frac{2D_c\tan\beta}{\theta D_t}. \tag{6}$$

The collimated aperture and grating parameters should be selected for telescopes with 50–80 cm apertures and typical seeing conditions of 1″ to 3″. To meet the requirements of spectrograph miniaturization and a moderate resolution, the instrument employs an echelle grating with a relatively small blaze angle of 46° as the main disperser. Using the quasi-Littrow condition, the angles of incidence and diffraction of the spectrograph were both determined to be 46°. To separate the input and diffractive beams, a small angle of 2° is added in the direction perpendicular to the dispersion. Consequently, the collimated pupil D_c is defined to be 23 mm, which corresponds to the focal lengths of the lenses of approximately 125 mm. An apex angle of 20° is adopted in the prism to provide adequate order separation, and the R1 echelle grating has an effective area of 30 mm × 40 mm to achieve the required power of dispersion when combined with the collimated pupil.

The selection of the slit size is primarily constrained by the atmospheric seeing conditions. The angular width on the sky subtended the slit must be larger than the seeing conditions at the observation site while preventing excessive ambient light from entering the instrument. Fig. 5 shows the angles on the sky for different slit widths when the focal ratio is 7. We selected a slit width of 50 μm to match telescopes with apertures ranging from 50 to 80 cm. In environments with lower sky background light, a 50-μm slit remains suitable for telescopes with apertures ranging from 30 to 50 cm.

2.2. Optomechanical Design

The spectrograph is equipped with a CMOS detector with a chip area of 1 920 pixels × 1 080 pixels for the guidance system, and another CMOS detector with a chip area of 3 000 pixels × 3 000 pixels for spectrum acquisition. Fig. 6 shows a simulated spectral format on the detector (m = 29–66), demonstrating that the spectra at each order do not overlap with each other. Fig. 7 shows a spot diagram of the central wavelength at each order in this design. The spot size is less than 20 μm, which

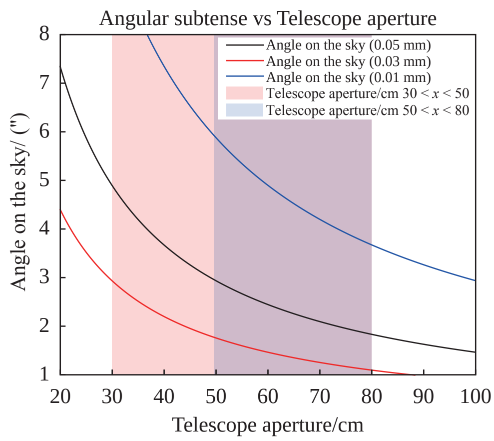

Fig. 5. Relationship between telescope aperture and angular width on the sky subtended by the slit.

approaches the diffraction limit, indicating excellent imaging quality.

This instrument was developed for various types of small-aperture telescopes, and its structure adopts a lightweight and modular design. According to the spatial arrangement of the optical system, the structure of the instrument is divided into modules for guidance, the slit, collimating and imaging lenses, the disperser (grating or prism), and the detector. Each module is mounted on the main body of the instrument using bolts and dowel pins, which improves the assembly and adjustment efficiency and ensures installation accuracy.

When making observations with a telescope, this spectrograph can be installed at the telescope's Cassegrain focus. Because the instrument's orientation changes with respect to the telescope movements and its operating temperature fluctuates significantly, its opto-mechanical structure is designed to prevent additional deformations or displacements caused by gravity and thermal variations. Fig. 8 illustrates the mechanical structure of the instrument's main module and submodules. All planar optical components (mirrors and gratings) are secured using silicone rubber adhesive, ensuring robust adaptability to vibra-

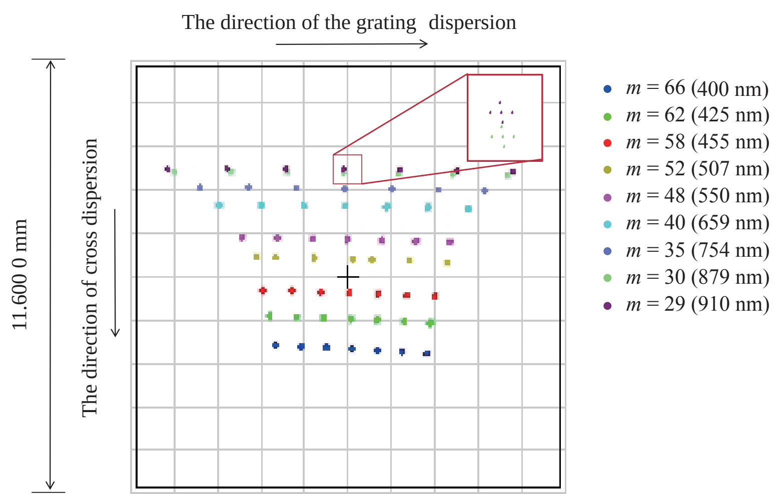

Fig. 6. Spectral format on the detector.

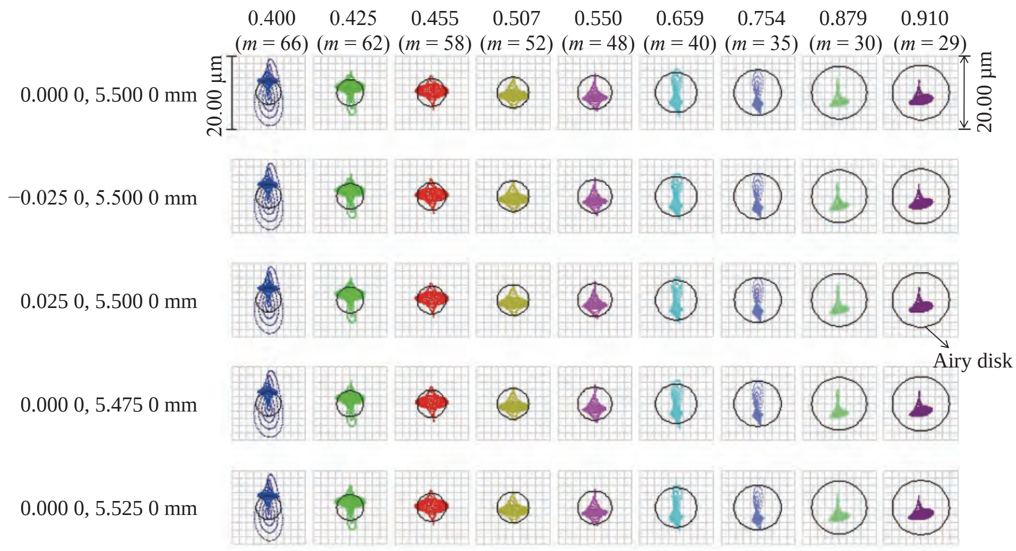

Fig. 7. Image quality analysis of the spectrograph (spot diagram).

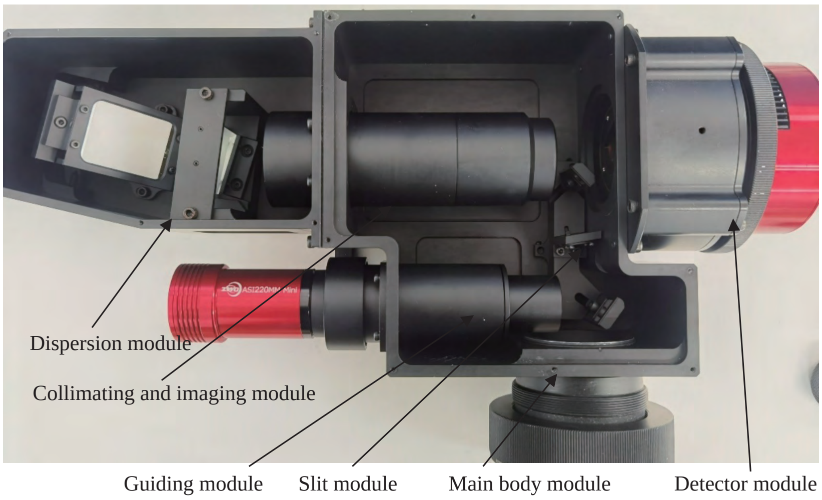

Fig. 8. Spectrograph modules.

tions and temperature changes. The lens cell maintains a unilateral clearance of ⩽ 0.02 mm and is combined with a precision compression-ring positioning mechanism to suppress lens eccentricity and tilt errors. The detector module employs an anti-backlash thread and spacer-nested mechanism to achieve axial focusing (travel range ±2 mm, resolution 10 μm) and field rotation compensation (360° free adjustment), ensuring conjugate alignment between the spectral imaging plane and detector surface. A multiple degrees-of-freedom constraint strategy was adopted in these designs, enabling the instrument to achieve exceptional environmental adaptability while remaining light in weight and ensuring long-term stability. The overall instrument was measured and found to be less than 355 mm × 215 mm × 100 mm in size and approximately 3.5 kg in weight.

Additionally, as shown in Fig. 9, the spectrograph is equipped with a telescope connector and fiber coupler, offering two interchangeable connection modes to accommodate different operational requirements. When the spectrograph is configured with the silver connecting ring shown in the diagram, it can be directly mounted on the telescope's Cassegrain focus. When the spectrograph is configured using the fiber coupler, lamp light can be integrated for wavelength calibration or the spectrograph can be

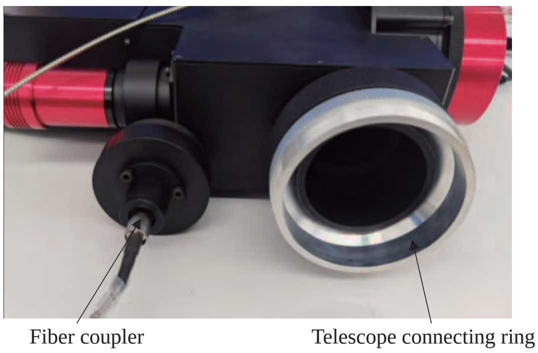

Fig. 9. Interchangeable connectors for different observation modes.

connected to the telescope's focal point for spectroscopic observations.

3. PERFORMANCE

In a laboratory setting, the instrument's performance was tested using calibration light and sunlight. The evaluations included experiments on slit size, spectral resolution, wavelength coverage, and order spacing.

3.1. Slit Size

The width and shape of the slit directly affect the actual spectral resolution and data-processing accuracy. Fig. 10A shows a slit image taken by a guiding camera when the calibration fiber injected light for illumination. Microscope-based tests reveal that the slit is a regular pinhole approximately 53 μm in diameter, and its deviation is within the allowable tolerance.

3.2. Spectral Resolution

A thorium-argon (ThAr) hollow cathode lamp has a rich set of emission spectral lines in the optical band and is commonly used as a wavelength calibration source for various medium- and high-resolution spectrographs. In this project, a ThAr hollow cathode lamp was used to test the spectral resolution of the proposed spectrograph. Fig. 11A shows the calibrated image taken by the spectral camera. Argon has some strong emission lines in the near IR band, resulting in a slight overexposure at the red end. Fig. 11B shows the measured resolution of the calibrated spectrum within the spectral coverage. The spectral resolution (R) in the full wavelength band is $R \geqslant 6200$, and the median value is $R = 6337.26$, meeting the technical specifications.

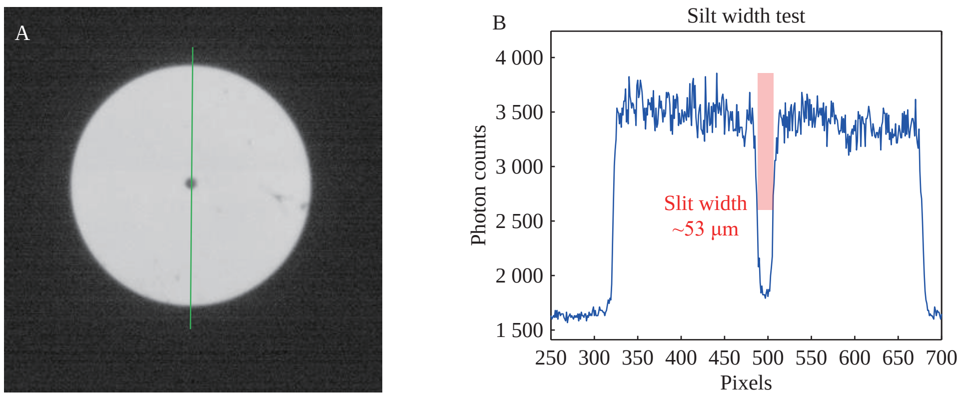

Fig. 10. Slit measurement. (A) Slit image illuminated by a calibration spot. (B) Slit size.

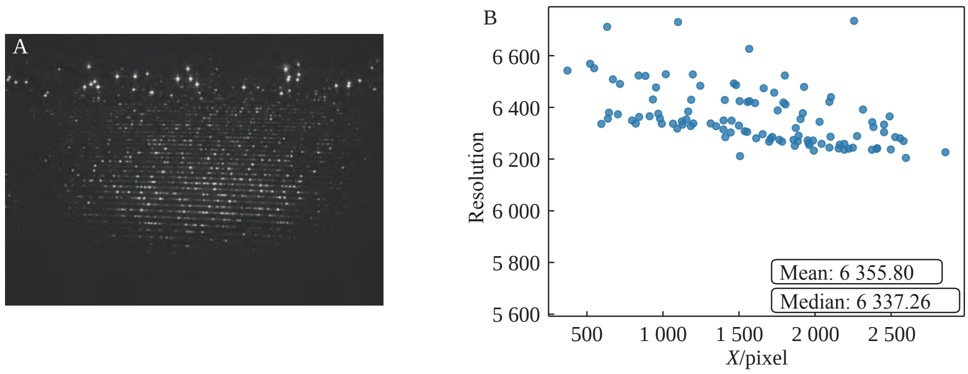

Fig. 11. Spectral image and spectral resolution. (A) Spectral image of ThAr. (B) Measurement of the spectral resolution (R).

3.3. Wavelength Coverage

Wavelength coverage can generally be determined using spectra with typical characteristics. In this project, two reference sources, a calibrated spectrum and the solar spectrum, were used for measurement. First, the spectrum of the ThAr lamp was used to determine the effective spectral range. As shown in Fig. 12A, the wavelength coverage meets the technical requirement of 400–900 nm, where the unit of the vertical axis is Analog-to-Digital Units (ADUs). The figure shows the absorption lines of a ThAr lamp measured by the spectrograph, and this can be used to establish the corresponding relationship between pixel positions and wavelengths. Similarly, the solar spectrum was captured in a laboratory setting, further verifying the wavelength coverage of the instrument. The normalized results are shown in Fig. 12B.

The solar spectrum can be used to determine the wavelength coverage of the instrument and evaluate the performance of the instrument by analyzing its characteristic spectral lines. Fig. 13A shows the solar spectrum obtained by the instrument. We extracted some representative characteristic spectral lines, as shown in Fig. 13B, Fig. 13C, and

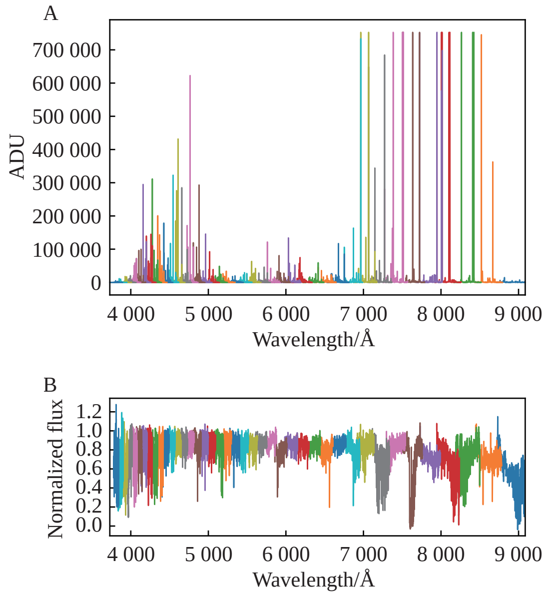

Fig. 12. ThAr lamp spectra and solar spectra captured by the spectrograph. (A) ThAr lamp spectrum captured by the spectrograph. (B) Spectrum of the Sun captured by the spectrograph.

Fig. 13D. The profiles of these characteristic spectral lines help confirm that the instrument performs well, and their wavelengths can be used to verify the wavelength solution (i.e., wavelength versus pixel position).

4. TRIAL OBSERVATION AND SCIENTIFIC APPLICATION

4.1. Trial Observation

To further evaluate the spectrograph's performance, a trial observation was conducted with a 50-cm telescope, as shown in Fig. 14.

Sirius was among the first celestial bodies to have its motion measured through spectral analysis. Its data are often employed for performance evaluation because of its abundant available data. In this trial observation, the spectrum of Sirius was used to verify the spectrograph's performance by comparing the observed results with existing spectral data for Sirius from publicly available sources. Fig. 15 compares the two spectra obtained by different spectrographs, the ESPEC-2 on a 50-cm telescope and Potsdam Echelle Polarimetric and Spectroscopic Instrument (PEPSI) on the Large Binary Telescope. The spectrum obtained by PEPSI has a high resolution of R~220000. The medium-resolution spectrum obtained by the ESPEC-2 shows the general line profiles of Mg I and Fe I, which are located at the same position as the ones resolved by PEPSI. This result indicates that the ESPEC-2 performs astronomical observations well.

4.2. Experimental Application in Calibration Tasks

In the field of broadband wavelength calibration, the phenomenon of significant flux change with wavelength is serious and can affect the consistency of the spectral signal-to-noise ratio over a wide wavelength range. Spectral flattening technology can render the spectral flux smoother over the entire band. Given its miniaturization and multi-function advantages, the spectrograph was used in the spectral flattening technology experiment to verify its potential for other applications, as shown in Fig. 16. Through the fiber optic input, the spectrograph collected equally spaced, flattened modulated light, effectively verifying the working principle of spectral flattening technology. The test results are currently being prepared for publication. This experimental demonstration indicates that the

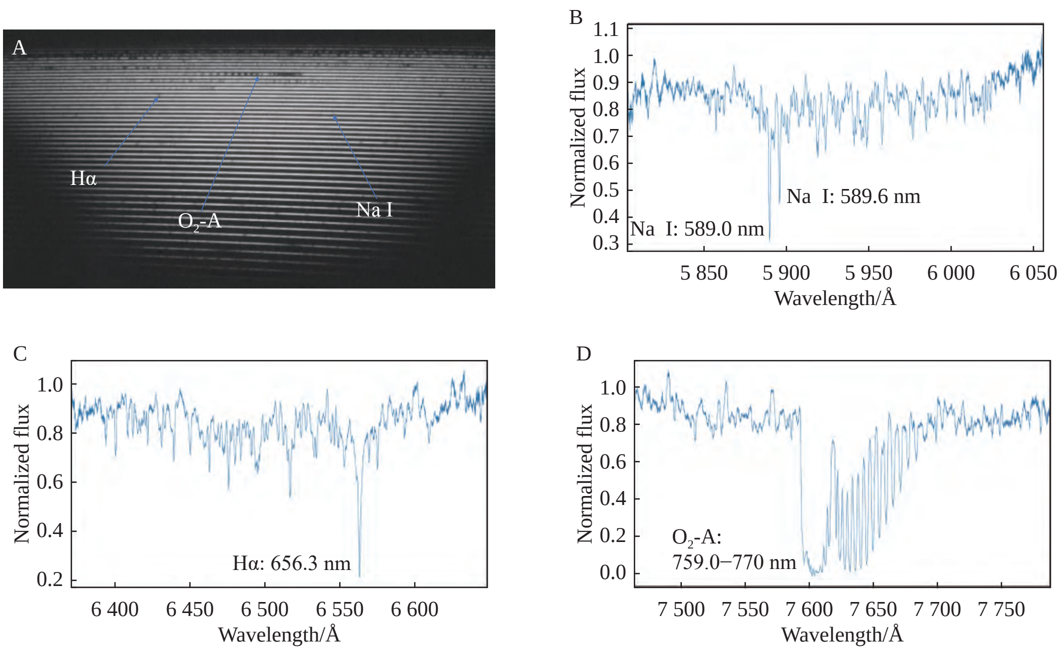

Fig. 13. Solar spectroscopy test results. (A) Solar spectrum. (B) Na I lines. (C) Hα line. (D) Telluric O_2-A bands.

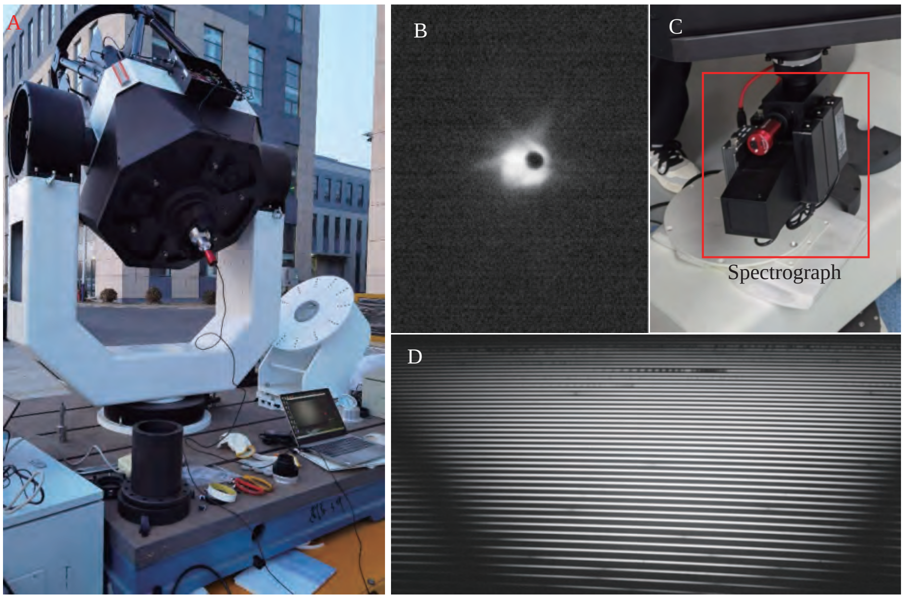

Fig. 14. Trail observation of the spectrograph. (A) Telescope set. (B) Guiding image. (C) Spectrograph mounted on the telescope. (D) Spectrum.

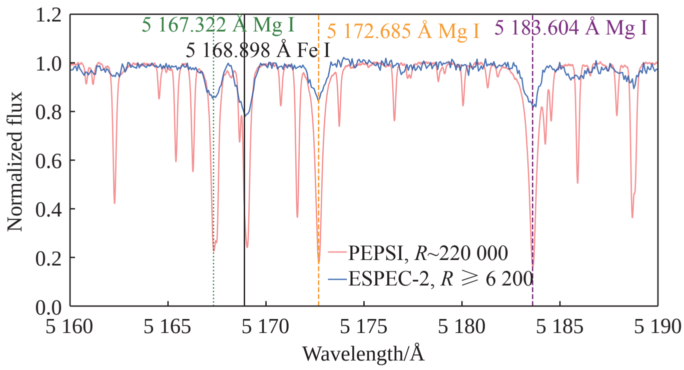

Fig. 15. Spectra of the trail observation.

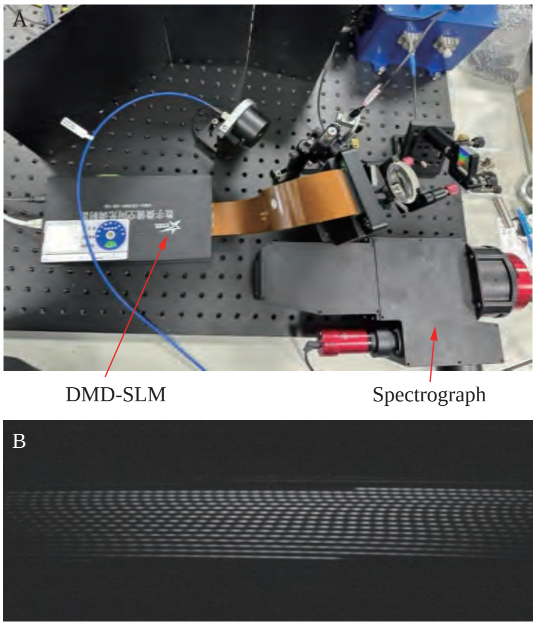

Fig. 16. Laboratory application of the spectrograph. (A) Experimental application of the spectrograph. (B) Spectrum of modulated light captured by the spectrograph.

developed portable broadband astronomical spectrograph has the potential for application in other fields of scientific research.

5. CONCLUSION

The ESPEC-2 portable broadband astronomical spectrograph is compatible with optical telescopes with apertures of 30–80 cm. It supports two connection modes, direct connection at the Cassegrain focus and fiber optic coupling, and it can perform spectral observations at a resolution of $R \geqslant 6200$ in the wavelength range of 400–900 nm. Its design, which combines an echelle grating with a prism, meets the requirements of both spectral resolution and wavelength coverage. The reuse of the collimating and imaging lens group reduces the system complexity and development cost. Tests showed that, for many existing small-aperture telescopes, this spectrograph will enable the spectral observation of bright stars and support related scientific research. It is also a promising solution for other applications in scientific research experiments, astronomical education, and the field of popular science.

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AI DISCLOSURE STATEMENT

Deepseek was employed for language and grammar checks within the article. The authors carefully reviewed, edited, and revised the Deepseek-generated texts to their own preferences, assuming ultimate responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Kai Zhang took charge of instrument project and optical design. Xiaolin Huang was responsible of mechanical design, instrument integration and commissioning observation. Jiajia Wu made electronic controller and calibration unit. Yuan Liang did stray light analysis and joined the instrument integration and commissioning observation. Liang Wang provided data reduction software and verified instrument performance by spectral data. Chuandong Chen made contribution on optical manufacture and test. Zhengyang Li and E Xiang provided the telescope platform for commissioning observation. Kai Zhang, Xiaolin Huang and Yuan Liang wrote the manuscript. All authors read and approved the final manuscript.

DECLARATION OF INTERESTS

Zhengyang Li is an executive editor-in-chief for Astronomical Techniques and Instruments. Kai Zhang is an editorial board member for Astronomical Techniques and Instruments. They were not involved in the editorial review or the decision to publish this article. The authors declare no competing interests.

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