

Calibration System for Spectral Data of the New Solar UV–NIR Spectrometer (SUNS)

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Abstract. The study of solar flares, in particular White-Light Flares (WLFs), remains a challenge in solar physics due to the rarity of wide-band spectral observations with adequate resolution. To address this gap, the Mackenzie Center for Radio Astronomy and Astrophysics (CRAAM), in partnership with the Steiner Institute, developed the Solar UV-NIR Spectrometer (SUNS). SUNS operates in the spectral range 200–1100 nm and aims to diagnose the solar chromosphere by investigating rare Balmer series in solar flares. This work focuses on developing a calibration technique for SUNS spectral data, accounting for losses introduced by the instrument’s optical elements, to produce reliable absolute flux measurements. The instrument began commissioning in June 2025 and has already registered its first solar spectra.

Resumo. O estudo de explosões solares (flares), em particular White-Light Flares (WLFs), permanece desafio na física solar devido à raridade de observações espectrais de banda larga com resolução adequada. Para abordar esta lacuna, o Centro de Rádio Astronomia e Astrofísica Mackenzie (CRAAM), em parceria com o Instituto Steiner, desenvolveu o Solar UV-NIR Spectrometer (SUNS). O SUNS opera na faixa espectral de 200–1100 nm e tem como objetivo diagnosticar a cromosfera solar investigando raras séries de Balmer em flares. Este trabalho concentra-se no desenvolvimento de técnica de calibração dos dados espectrais do SUNS, considerando perdas introduzidas pelos elementos ópticos do instrumento, visando produzir medições de fluxo absoluto confiáveis. O instrumento iniciou sua fase de comissionamento em junho de 2025 e já obteve registro de seus primeiros espectros solares.

Keywords. spectroscopy – telescopes – flares

1. Introduction

The study of the Sun is essential for understanding astrophysical phenomena that remain unresolved. In particular, the investigation of solar flares and, specifically, White-Light Flares (WLFs). Since the first observation of a solar flare by Carrington and Hodgson in 1859 (Carrington 1859), determining the origin of the excess visible continuum emission in these events has been a key challenge. Broadband spectral observations covering the entire visible range with resolution are rare but crucial for uncovering the physics underlying WLFs (Hudson et al. 2010; Kerr & Fletcher 2014).

Motivated by this lack of observational data, the Mackenzie Radio Astronomy and Astrophysics Center (CRAAM), in partnership with the Steiner Institute, developed the Solar UV-NIR Spectrometer (SUNS), supported by FAPESP (2013/24155-3 and 2022/15700-7) and MackPesquisa (231017). The new instrument was designed to expand the capabilities of the Mackenzie Solar Observatory (OSM) for solar physics, operating in parallel with the imaging modules already in place at the observatory.

The main scientific goal of SUNS is to carry out spectral observations of flares in active regions of the Sun. The instrument will specifically enable the investigation of rare Balmer series occurrences in solar flares, which are extremely important for diagnosing the solar chromosphere and for understanding the physics of these events (Hiei 1982; Neidig 1983; Kudaka et al. 2015).

However, to transform the raw data into spectra of scientific quality, a calibration process is essential. The light collected by the instrument is inevitably affected by signal losses, both due to instrumental factors and atmospheric influence. The purpose of this work is therefore to develop and detail robust procedures for

calibrating SUNS spectral data, ensuring the fidelity and scientific validity of the data and future observations.

2. About SUNS

SUNS was designed to operate nominally in the 200–1100 nm spectral range, covering the ultraviolet (UV), visible, and near-infrared (NIR). It operates in parallel with the existing infrared imaging (MI) and $H\alpha$ (MH) modules, enriching the observatory’s data collection capabilities. After completing the Conceptual, Preliminary, and Critical phases, the instrument began its commissioning phase in June 2025. SUNS has already obtained its first solar spectra, marking its “first light.”

3. Objective

The main goal of this work is to establish robust calibration procedures through algorithms implemented in software. This step is critical for adjusting and compensating the raw spectral data, ensuring they are transformed into spectra of the highest scientific quality for detailed analysis and dissemination.

Spectral data calibration will be performed in software developed in Python. The methodology is structured to correct signal losses progressively, from the reference source to atmospheric attenuation. First, a reference lamp will be used to adjust the intensity scale and wavelength calibration of the system. Then, the software will correct signal losses introduced by each of the instrument’s main optical components. These components include the Polka Dot beamsplitter, the achromatic objective, the neutral density (ND) filters, and the microscope beamsplitter. Finally, MODTRAN, an atmospheric simulation software, will

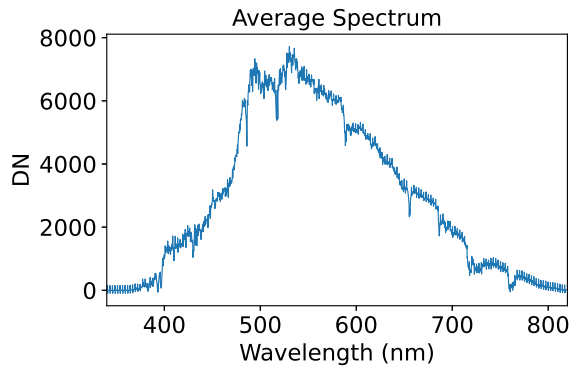


FIGURE 1. Solar spectrum recorded by SUNS during its first light.

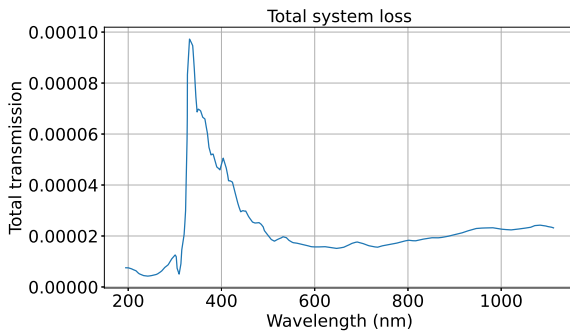


FIGURE 2. Total transmission loss of SUNS, obtained from the product of the loss curves of each optical component.

be applied to compensate for signal attenuation caused by Earth’s atmosphere, ensuring the high quality of the final data. The definition and implementation of these procedures will ensure that SUNS data can be delivered with the accuracy and reliability required by the scientific community.

4. Methodology

The calibration follows a sequence of linked steps. First, the solar spectrum recorded by SUNS is read in counts. These values will be converted into physical units of spectral irradiance ($\text{W}/\text{m}^2/\text{nm}$) using commercial intensity-calibration lamps already acquired, enabling comparison with models and physical analysis. In parallel, wavelength calibration is performed to ensure the correct identification of solar and telluric lines. Fig. 1 shows the solar spectrum obtained during the instrument’s first operation, serving as an example of the raw data.

The calibration software must calculate and correct the losses introduced by the SUNS optical elements, including beamsplitters, the objective lens, and filters. Instrument curves provided by the manufacturers (reflectance and transmittance) are used in this process. Fig. 2 shows the combined and interpolated transmission curves of each component and their product, which represents the total system loss across the spectrum.

Atmospheric losses and the identification of telluric lines will be treated using atmospheric transmission models generated by MODTRAN, due to the complexity of radiative transfer calculations.

After generating the transmission curves and computing the total loss, the original solar spectrum was compared with the

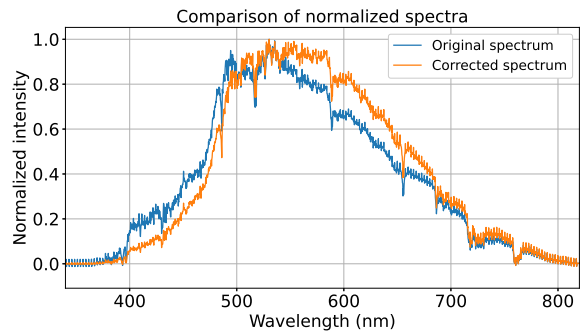


FIGURE 3. Comparison between the original spectrum and the spectrum corrected for instrumental losses, both normalized to their maximum value for easier visualization.

corrected spectrum, with both normalized. Fig. 3 shows the result, highlighting the difference between the raw and corrected spectra.

5. Expected Results

The main expected result of this work is the implementation and validation of a fully Python-based calibration software designed to ensure the systematic and robust conversion of the raw spectral data obtained by SUNS into spectra of the highest scientific quality. The software will automatically correct instrumental losses, compensating for the light-intensity reductions caused by the various optical elements of the instrument, including beamsplitters, the objective lens, and filters. Additionally, regular comparisons with calibration sources will be performed to monitor and verify variations in the detector’s sensitivity over time. The atmospheric model will be applied to compensate for signal attenuation caused by Earth’s atmosphere, which is essential for ensuring high-quality data.

The final product of this calibration procedure will be spectra ready for analysis, with values converted from counts to physical units of $\text{W}/\text{m}^2/\text{nm}$, allowing immediate use in rigorous physical analyses and direct comparison with models. Achieving these validated, high-precision spectra is crucial for advancing the investigation of solar phenomena such as the Balmer series and WLFs, and will enable reliable dissemination of data to the international scientific community.

References

- Carrington, R. C. 1859, MNRAS, 20, 13
- Hiei, E. 1982, Sol. Phys., 80, 113
- Hudson, H. S., Fletcher, L. & Schmahl, E. J. 2010, Mem. SAIt, 81, 637
- Kerr, G. S. & Fletcher, L. 2014, ApJ, 783, 98
- Kudaka, A. et al. 2015, Sol. Phys., 290, 2603
- Neidig, D. F. 1983, Sol. Phys., 85, 285