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Algorithm for instrumental noise treatment of the POEMAS Radio Telescope

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Abstract. The understanding of solar activity is essential for the study of space weather and its impacts on Earth. In this context, the POEMAS radio telescope (POlarization Emission of Millimeter Activity at the Sun) was developed to observe the Sun at frequencies of 45 and 90 GHz, with angular resolutions of 1.0° and 1.4°, respectively, and with right and left circular polarization. During its operational period, despite the success in detecting events, the light curves presented instrumental noise due to mechanical vibrations and misalignment of the telescope, with the noise treatment being carried out manually. In this work, we developed a Python program for the automated correction of POEMAS data, aiming at the systematic removal of instrumental noise and the identification of solar flares. The model validation was performed using 20 previously detected flares. As a final result, an open-source program was created to assist in the extraction and processing of POEMAS data, facilitating the detection of solar flares and future research on solar flares at millimeter wavelengths.

Resumo. A compreensão da atividade solar é essencial para o estudo do clima espacial e seus impactos na Terra. Nesse contexto, o radiotelescópio POEMAS (POlarização da Emissão Milimétrica da Atividade Solar) foi desenvolvido para observar o Sol em frequências de 45 e 90 GHz com resolução angular de 1,0° e 1,4°, respectivamente, e com polarização circular à direita e à esquerda. Durante seu período de funcionamento, apesar do sucesso na detecção de eventos, as curvas de luz apresentaram ruídos instrumentais decorrentes de vibrações mecânicas e desalinhamento do telescópio, sendo o tratamento desses ruídos realizado manualmente. Neste trabalho, desenvolvemos um programa em Python para correção automatizada dos dados do POEMAS, visando a remoção sistemática de ruídos instrumentais e a identificação de explosões solares. A validação do modelo foi feita utilizando 20 explosões já detectadas. Como resultado final foi criado um programa em código aberto que auxília na extração e tratamento dos dados do POEMAS, facilitando a detecção e futuras pesquisas sobre explosões solares em comprimentos de ondas milimétricas.

Keywords. Methods: data analysis – Instrumentation: detectors – Sun: radio radiation

1. Introduction

To understand space weather effects on the planets of the Solar System, it is essential to study the Sun Silva (2006), particularly its magnetic activity. Phenomena such as sunspots, faculae, flares, and coronal mass ejections (CMEs) are central to evaluating their potential impacts on Earth and its atmosphere. Flares and CMEs often occur together, and when a CME is directed toward Earth, the released energy can disturb the upper atmosphere and affect satellites, communication systems, and power transmission infrastructure.

To study this activity, the properties of solar flares are analyzed using radio telescopes at various frequencies. Some radio telescopes are dedicated exclusively to observing the Sun, such as the OVSA in California, USA, which operates from 1 to 18 GHz, the RTSN with stations around the world, operating from 0.25 to 15.4 GHz, and the Nobeyama Radio Polarimeters, which operate at various frequencies between 1 and 80 GHz. It is noticeable that most observatories operate at lower frequencies, in the range of 20 GHz or less (Valio et al. 2013b). At higher frequencies, there is the Submillimeter Solar Telescope (SST) in Argentina, which has been operating at 212 and 405 GHz since 1999. Thus, due to the lack of solar observation at intermediate frequencies, a circular polarization radiotelescope system, POEMAS, was designed, which stands for POlarization Emission of Millimeter Activity at the Sun, dedicated to observing the Sun exclusively at frequencies of 45 and 90 GHz (Valio 2013a).

In November 2011, POEMAS was installed at the El Leoncito Astronomical Complex (CASLEO), located in the Andes, Argentina, at an altitude of 2550 meters, due to its better sky conditions for observations at higher frequencies. During its 2 years of operation, from 2011 to 2013, it was possible to observe dozens of solar flares with this radio telescope (Hidalgo Ramirez et al. 2019; Lessa & Valio 2023). However, during this period, several instrumental issues were observed in the light curves detected by the polarimeter. This was due to mechanical misalignment caused by encoder problem that occurred at higher angles when observing the Sun, especially near local noon, between 15 UT and 19 UT Boscatti (2024).

Therefore, we developed a software to process the POEMAS' light curves. The goal is to mitigate these effects and extract reliable measurements of the flares that occurred during the observation period at the POEMAS frequencies.

2. Objective

This project aims to analyze the data from the POEMAS radio telescope and apply various data processing methods with the primary objective of obtaining flare information from the collected data, such as intensity and peak time, to enable a better analysis of solar activity signals.

3. Methodology

The strategy used to mitigate the oscillations in the POEMAS light curves was to subtract a reference curve ("background") obtained on a quiet day, typically the day before or after the event of interest. This procedure, however, was cumbersome and required manual intervention. Consequently, an automated calibration method was needed to streamline and standardize the process.

The development of the software for data analysis and processing was done using the Python programming language, as it

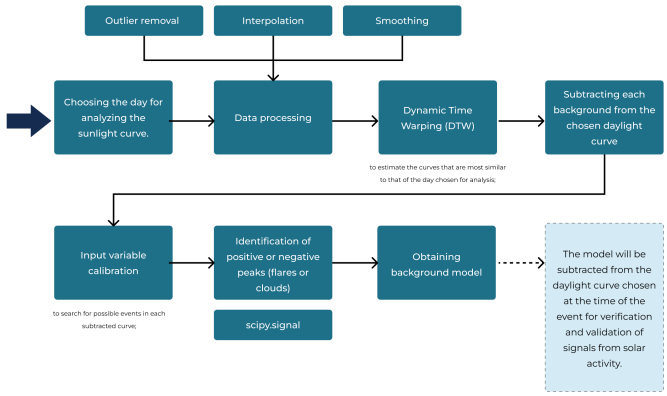

Figure 1. Flowchart representing the stages of the program developed in Python.

is a versatile language with various libraries specialized in areas such as data processing, statistical analysis, and Astronomy.

3.1. Developing the software

VERSOS (Validação e Extração de Ruídos de Sinais de Origem Solar) Visualizer is a software developed to visualize and assist in calibrating inputs for the processing of POEMAS light curves. The flow chart shown in Figure 1 highlights the complete execution flow of VERSOS.

3.2. Validation

The program was validated using light curves from days where flares had already been detected previously (Lessa & Valio 2023) to ensure that events are correctly identified by the program, as well as from light curves of days when we believe there were no events, to minimize the presence of false positives.

4. Results

As a result, the VERSOS Visualizer was developed, as shown in operation in Figure 2. This tool assists in calibrating the inputs for a future automated algorithm designed to detect flares and estimate their properties, such as occurrence time and intensity at each frequency and polarization, as illustrated in Figure 3. Currently, the program allows for the download of the light curve (intensity in time) extract of the flare data in CSV format. The VERSOS software is available in a public repository on GitHub[1].

5. Next Steps

In the future, an algorithm will be developed based on the optimized variables obtained through the VERSOS Visualizer for the automatic detection of events, with minimal or no need for manual assistance. The event detection method will also be refined so that events can be identified at the 90 GHz frequency in both right and left circular polarizations, as these data are more affected by instrumental noise.

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[1] https://github.com/Transit-Model-CRAAM/versos-visualizer

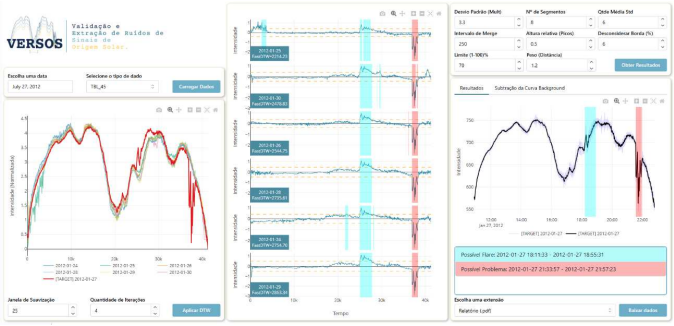

Figure 2. VERSOS Visualizer in operation, displaying the analysis of the signal recorded on January 27, 2012, at the frequency of 45 GHz with left-hand circular polarization.

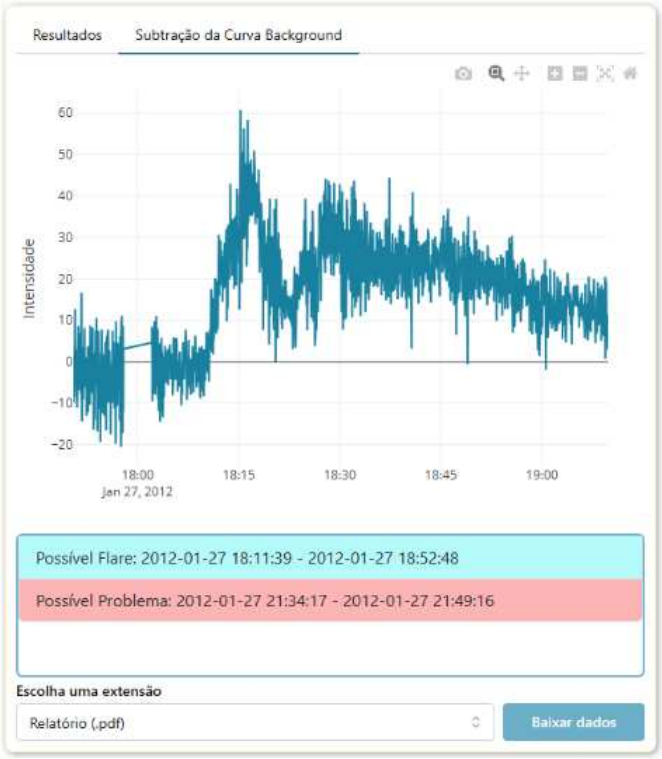

Figure 3. Resulting light curve of the flare after the subtraction of the background, generated for the event on January 27, 2012.

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