IMC 2024 Proceedings

First Meteor Observations with SPADE

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Various technical parameters of the Solar Phase-Array Demonstrator located at the Humain Radio Astronomy Station of the Royal Observatory of Belgium have been adjusted to initiate its operation in radio frequency. The BRAMS radio beacon, located in Dourbes, Belgium, offers an opportunity to verify the instrument's performance by observing radio meteor echoes. This paper presents the preliminary results obtained with the instrument.

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1 Introduction

The development of the Small Phased-Array DEmonstrator (SPADE) by the Solar Influences Data analysis Center (SIDC) of the Royal Observatory of Belgium (ROB) is currently in the commissioning stage.

Located at the Humain Radio-Astronomy Station (HuRAS) in the south of Belgium, SPADE monitors solar radio activity from 20 to 80 MHz (Mouhaou et al., 2024). This operational range includes the frequency of the radio-beacon of the Belgian RAdio Meteor Stations (BRAMS) system located in Dourbes, Belgium, which continuously emits a pure sine signal of 130 W at $f =$ 49.97 MHz (Lamy et al., 2024).

When not tracking the Sun, SPADE can detect meteors using the *forward-scatter* principle, where a transmitter — located some distance from the receiver — emits a signal that illuminates a large area of the sky. When this electromagnetic wave encounters a meteor trail, it reflects part of power of the signal which can then be received (see, e.g., McKinley, 1964). Figure 1 illustrates this scenario for the BRAMS–SPADE radio meteor echo hop.

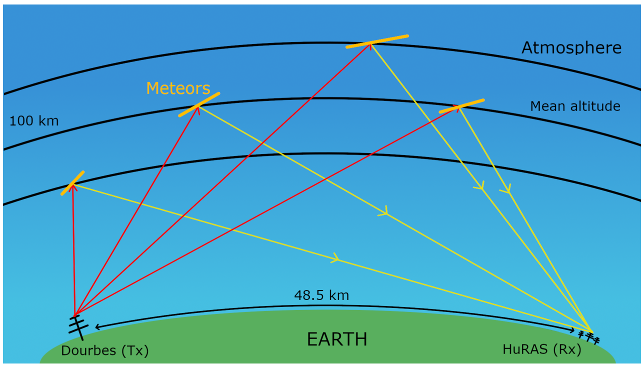

Figure 1 – Meteor forward-scattering principle illustrated for BRAMS at HuRAS.

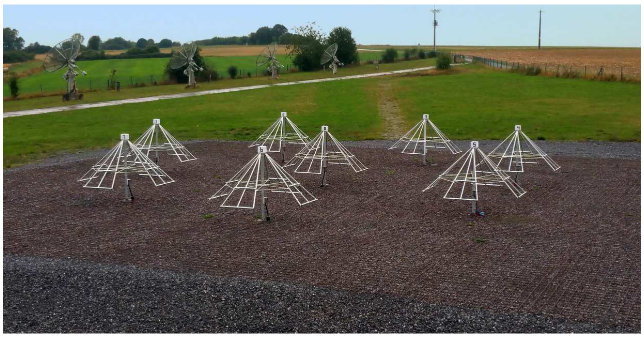

Figure 2 – View of the SPADE array antenna field.

2 Description of SPADE

SPADE, consisting of eight Long Wavelength Array antennas (Hicks et al., 2012), is a radio-telescope that employs beamforming techniques to direct its primary detection lobe toward an observational target, originally the Sun.

The antennas are connected to two *Ettus USRP X300* receivers, each equipped with two *TwinRX* daughterboards. This configuration provides four channels per receiver, each capable of sampling incoming signals at a rate of 200 MS/s with a 14-bit resolution and 80 MHz bandwidth.

The digitized signals are transmitted to a main processing computer, where Software-Defined Radio (SDR) technology is used to combine the eight incoming signals via software. Achieving an accurate array pattern requires precise synchronization of the phases of all received signals.

Therefore, maintaining coherence between the channels, which necessitates exact phase synchronization, is essential. This is typically accomplished by using an internal local oscillator to generate a Phase-Locked Loop signal from one channel, which is then distributed to the remaining seven channels of the receivers.

Once sampling synchronization is achieved, each input signal from the antennas must be precisely aligned in phase. Physical alignment of these phases is challeng-

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ing; however, SDR technology allows for phase adjustements via software by computing and applying the necessary phase shifts to each channel. Additionally, the electrical length of the connecting cables from each antenna to the receivers must also be considered (Mouhaou et al., 2024).

All these corrections are incorporated into the operational SDR script, leaving a final stage of individual phase manipulation to orient the beam of the radiotelescope.

The software, developed using the *GNU Radio*[a] platform, provides an interface that displays real-time spectrograms for both individual antenna signals and combined signals, along with interactive controls to adjust the direction of the main beam (Figure 3). The captured data can optionally be recorded in separate files for further post-processing.

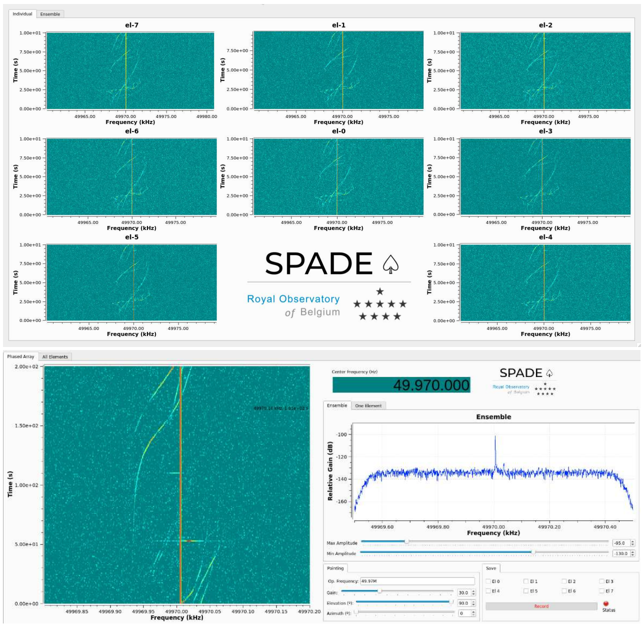

Figure 3 – Graphical User Interface to control SPADE operation in real-time when observing meteors.

3 Meteor observations with SPADE

The first light of SPADE occurred early August already providing high resolution observations of fine structures and *striae* (see, e.g., Jebaraj et al., 2023) during a Type III solar radio burst. However, it was during the night of 11–12 August 2024 that its first attempt to detect meteors took place. Unfortunately, an unknown source of radio frequency interference significantly disrupted the observations, leaving little usable scientific data.

After making minor adjustments to the receivers phase synchronization, specifically for the BRAMS frequency, a campaign was conducted on 13–16 September during local night-time at HuRAS, resulting in a total of 24 hours of observations.

[a]`https://www.gnuradio.org`

For these observations, the main beam of SPADE was oriented toward the zenith. Numerical simulations show that the 3 dB beamwidth of the array ensemble at the BRAMS frequency is $\approx 20°$ (see Figure 4).

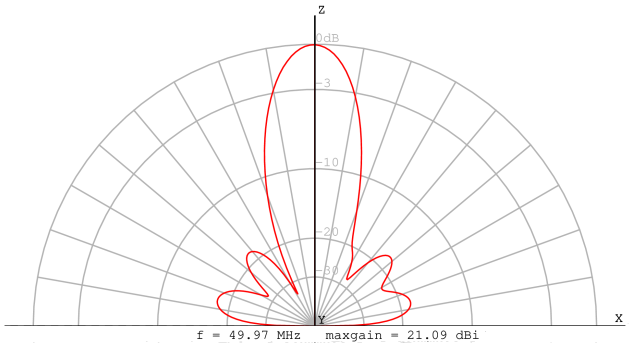

Figure 4 – Vertical radiation pattern for SPADE pointing its beam to the zenith at $f = 49.97$ MHz.

4 Results and Discussion

A total of 694 radio meteor echoes were visually identified on screen using the spectrograms produced for each observed hour. This results in an average hourly rate of ≈ 29 meteors per hour recorded during the first meteor observing campaign of SPADE, a notable value, especially considering the narrow beamwidth of the array in this configuration. It is important to note that the observing period did not include the maximum of any catalogued meteor shower, so it is reasonable to conclude that most of the detected radio meteor echoes can be classified as sporadic.

Figure 5 shows a series of spectrograms[b] for selected periods during the observation campaign.

Currently, the volume of data generated during solar observations, when the instrument operates at full capacity, makes it virtually impossible to conduct meteor observations simultaneously. This restricts radio meteor observations to periods when SPADE is not engaged in solar observations (i.e., local night-time). Implementing a more efficient data pipeline and compression techniques could enable simultaneous observations.

In the future, it will be necessary to conduct a series of tests using different azimuth and elevation angles of the main beam of SPADE to identify the optimal scattering area in the sky that maximizes the meteor echo detection rate.

SPADE demonstrates good capability during its first-light meteor echo observation. Its sensitivity to detect faint, underdense meteors is promising, especially given the possibility of orienting the main beam as needed. Upcoming tests will include different hardware settings, the implementation of an appropriate data pipeline, the development of more efficient SDR scripts, and the application of signal processing techniques to the raw data, all aimed at fine-tuning and optimizing data collection.

[b]For a quick review, see, e.g., `http://www.radiometeorzoo.eu`

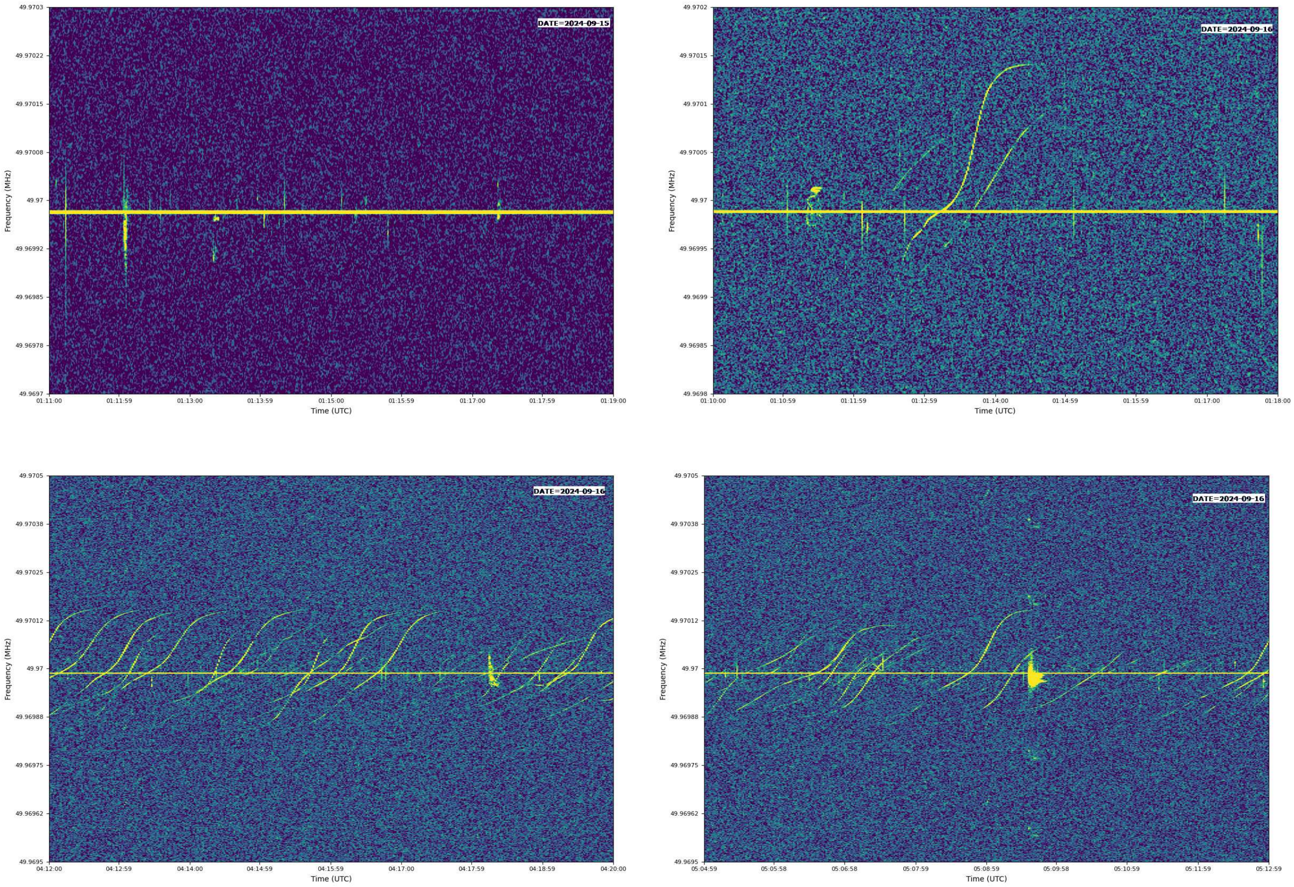

Figure 5 – Spectrograms of the signal captured by SPADE during its first-light meteor observation campaign on September 2024 (*Top-left*: Several underdense meteor echos and a potential head-echo; *top-right*: An *epsilon*-overdense meteor among a series of underdense meteor echos; *bottom-left*: Several airplanes tracks, underdense and overdense meteor echoes; *bottom-right*: Strong overdense meteor echo).

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