# BRAZILIAN SOLAR SPECTROSCOPE (BSS):
# 15 YEARS OF SOLAR FLARES INVESTIGATIONS IN DECIMETRIC RANGE

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## ABSTRACT

In 1990, the Astrophysics Division of the National Institute of Space Research (INPE), Brazil, initiated the development of one solar radio spectrograph, later on called "Brazilian Solar Spectroscope (BSS)", to carry out solar observations in the decimeter frequency range. Since the beginning of its development, BSS instrumentation and capabilities are in continuing improvement, especially the sensitivity and the temporal and spectral resolutions. During the 15 years of operation, more than 800 solar bursts have been recorded many of them for the first time observed in the decimeter frequency band and/or with so high resolutions by using the BSS, and their analysis and interpretation have contributed for a better understanding of several solar phenomena associated with solar flares. In this work, we summarized the main characteristics of the BSS instrumentation in the different phases of its development. Highlights of significant results from the analysis of solar bursts recorded using BSS in these 15 years are also presented and its potential to continue the investigations of fundamental problems in solar physics is discussed.

## INTRODUCTION

In the late 70's, the *Skylab* observations have shown evidences of the soft X-rays enhancement during the solar flares is originated from sources, where the electron densities are of the order of $10^9$-$10^{11}$ $cm^{-3}$, which correspond to the layers of solar atmosphere where the decimeter burst are generated by plasma emission mechanisms [1]. More recently, such evidences have been enforced by solar X-ray images obtained by *Yohkoh* satellite [2]. Those evidences indicate the importance of solar radio observations in the decimeter frequency range, and also multi-wavelength observations, as the main requirements for the investigation of the fundamental problems in the solar physics. Then, since the 80's, a new generation of radio spectrographs with better time and frequency resolutions and better sensitivity, have being developed. The Brazilian Solar Spectroscope (BSS), at INPE [3], belongs to this set of radio spectrographs. Table 1 presents the decimeter spectrographs in operation in the world for solar observations.

Table 1. Solar spectrographs in operation in decimeter frequency range

| Radio spectrograph | Place | Frequency range (MHz) | Time resolution (ms) | References |
|---|---|---|---|---|
| PHOENIX-2 | Switzerland | 100-4000 | 0.5*-1000** | [4] |
| Ondrejov | Czech Rep. | 800-2000<br>2000-4500 | 100<br>100 | [5] |
| Beijing | China | 1000-2000<br>2600-3800 | 8<br>100 | [6]<br>[7] |
| Ichon – ISR3 | Korea | 500-2500 | | [8] |
| Hiraiso | Japan | 500-2500 | 500 | [9] |
| Culgoora | Australia | 18-1800 | 3000 | [10] |
| **BSS** | **Brazil** | **1000-2500** | **10-1000** | **[3]** |

*(max) for 1 channel **(min) for 2000 channels

## THE BSS PROJET

The Brazilian Solar Spectroscope (BSS) started being developed in 1990, at INPE, in São José dos Campos, Brazil. BSS operates in conjunction with a 9-meter diameter polar mounted wired mesh antenna. In the first configuration it operates with a narrow band feeder (1.6 ± 100 MHz) and the observations were recorded on black and white 35 mm film by an analog data acquisition system. The time resolution was 100 milliseconds and the spectral resolution of 3 MHz. The digital data acquisition started in 1992, initially only in 8 frequency channels [11,12].

Between 1994 and 1996, the spectrograph was completely updated and it had been put in regular operation using a broadband log-periodic feeder. Since then, it operates in decimeter range (1000-2500 MHz) with high time and high frequency resolutions [13,14,3]. It allows select suitable observing frequency range, frequency and time resolutions. The recorded data can be digitized in 25, 50 or 100 frequency channels. The software for data acquisition, visualization end analysis has been developed in IDL environment [15]. BSS has capabilities of quasi-real time display of the ongoing dynamic spectrum that enables the observer to modify observational parameters and improve the quality of data acquisition. Minimum detectable flux density of the instrument is ~ 3 sfu, for spectral resolution of 3 MHz, and a combination of time resolution (10-100 ms) and frequency observing band (100-1000 MHz). Table 2 shows the main characteristics of the BSS instrument.

Table 2. Main characteristics of the BSS in actual configuration

| | |
|---|---|
| Antenna diameter | 9 meters |
| Mounting | polar |
| Feeder | Broad band cross log-periodic |
| Frequency range | 1000-2500 MHz |
| Time resolution | 10 , 20 , 50 , 100 , 500 or 1000 ms |
| Spectral resolution | 3 MHz |
| Absolute timing accuracy | 3 ms |
| Sensitivity | ~3 sfu |
| Number of channels | 25 or 50 or 100 |
| Dynamic spectrum display | Quasi-real time (1–5 min) |
| Observing time | 11:00-19:00 UT |

## HIGHLIGHTS OF SOLAR BURSTS OBSERVATIONS

During these 15 years of operation, more than 8000 hours of continuous monitoring of solar activity were carried out using the BSS, totalizing about 800 solar bursts (or group of bursts) recorded [16,17,18,19]. Many important observations, including new fine structures observations, are briefly summarized below and the Fig. 1 shows the dynamic spectra of them.

### Narrow-band split frequency decimeter bursts

On 15 June, 1991 (~13:38 UT) a narrow-band (1580-1630 MHz) patch-like radio emission exhibiting split in frequency was observed for the first time by BSS. The burst duration was about 15 seconds and the separation between two split components is 30 MHz. Based on the observed characteristics, a hypothesis of plasma waves conversion by combinational scattering on up going ion-sound waves in a magnetic loop was proposed [20].

### Type III bursts

First systematic study was reported based on the analysis of 44 moderately strong groups of decimeter (~1.6 MHz) type-III reverse slope bursts [21]. For 100 individual type-III bursts analyzed, the frequency drift rates estimated was 350-3000 MHz/s, the half-power duration ranges between 280 and 1500 ms. On September 13, 2001, decimeter type-III bursts (2000–2500 MHz) were recorded with time resolution of 20 ms, for the first time (Fig. 1a). They were harmonically related with type-III bursts recorded by the Ondrejov Observatory, in the frequency range of (800–1000) MHz. The total duration was of 100-400 ms, with maximum flux of ~300 sfu, and frequency band between 40 and 500 MHz, with low limit of frequency drift rate of ~ 2000 MHz/s [22].

### Decimeter dot-like structures and the chains of dot-like bursts

First time reported of statistical analysis of 165 isolated dot-like radio emissions and their chains observed from September 1999 to September 2000, by the BSS in the frequency range of 1000-2000 MHz (Fig. 1d). In 50% f the cases, isolated dots-like structures have instantaneous bandwidth of 5 MHz and flux of 20 sfu. Dots are observed in groups spread over the frequency-time plane, lasting several seconds. Chains of dots cover the frequency range of about 150 MHz, mostly associated with the rising part of impulsive flares, with drift rates of 180-1200 MHz/s [23].

### Decimeter fine structures associated with pre-impulsive phase of solar flares

Radio fine structures associated with the pre-impulsive phase of 13 solar flares was recorded BSS, in the frequency range of (1000-2500) MHz, in the period of March, 1999 to July, 2002 (Figs. 1f and 1g). The common characteristics of those fine structures are the narrow-band of about 5-10 MHz and short duration of about 50 milliseconds. The high frequency edge of the fine structure groups slowly drifts towards lower or higher frequency, with slow rates less than 50 MHz/s. These fine structures are observed over a time interval of a couple of minutes before the impulsive phase of the associated flare.

**“Lace” bursts**

Rare radio bursts with rapid frequency variations (lace bursts) lasting for many hours were recorded in the 1000-2500 GHz frequency range by BSS, on 17 August, 2000 (Fig. 1b), simultaneously by Ondrejov radio spectrograph. The frequency variations of these bursts were analyzed by the Fourier method, and the spectra showed the presence of frequency variability in the 0.01-3.00 Hz interval, indicating fast changes in the radio source plasma parameters [24].

**Harmonically related zebra patterns**

The unique case of decimeter zebra patterns in harmonic ratio 1:2 was observed by BSS (Fig. 1c) and Ondrejov radio spectrograph, respectively in the frequency ranges of 1200-1700 MHz and 2000-4500 MHz. They were associated with the long lasting June 6, 2000 solar flare (15:00-17:00 UT), which was unusually rich in the high-frequency radio zebra patterns above 1 GHz [25].

**Decimeter intermediate drift (IMD) bursts observed with high time resolution**

Ten groups of IMD bursts have been recorded in decimeter band (950-2650 MHz) by BSS during the period of June 1999 to October 2001, for the first time with high time resolution of 20 -50 ms (Fig. 1e). The main characteristics determined for each individual IMD bursts are [26]: (a) total duration of 200-2000 ms; (b) frequency bandwidth of 50-150 MHz; (c) instantaneous bandwidth of about 2-12 %; (d) negative frequency drift rate of 30-270 MHz/s.

**Radio and X-ray simultaneous solar flares investigations**

Since March 2002 to August 2003, a total of 13 solar flares have been recorded by the BSS simultaneously in X-rays by the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite (Fig. 1h). Multi-spectral investigations of them are in progress [27].

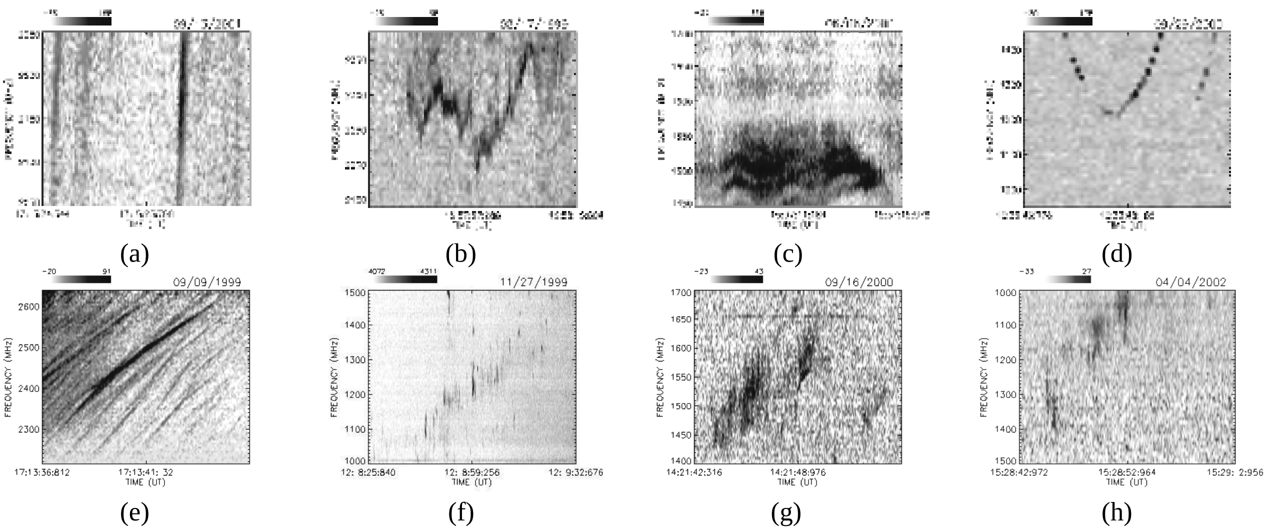


Fig. 1. Dynamic spectra of decimeter fine structures recorded by BSS: (a) type-III bursts; (b) lace bursts; (c) zebra patters; (d) chain of dot-like emissions; (e) intermediate drift bursts; (f) and (g) fine structures associated with pre-impulsive phase of flares; (h) group of fine structure simultaneously observed in hard X-ray by RHESSI satellite.

## CONCLUDING REMARKS

The BSS is the unique decimeter spectrograph dedicated to solar observations with high resolutions in the southwestern hemisphere. Besides the development of instrument, the BSS project provided a large sample of radio bursts observed in decimeter frequency range, during the last two solar cycles. Recently, a Brazilian funding agency (CNPq) has approved a financial support for a complete improvement and modernization of the BSS instrumentation, specially the data acquisition and storage systems. This update will allow improve significantly the performance of the instrument, in order to keep its great potential and scientific role in the solar radio astronomy field in the near future.

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