

Millisecond solar radio bursts in the metric wavelength range

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Abstract. A study and classification of super-short structures (SSSs) recorded during metric type IV bursts is presented. The most important property of SSSs is their duration, at half power ranging from 4-50 ms, what is up to 10 times shorter than spikes at corresponding frequencies. The solar origin of the SSSs is confirmed by one-to-one correspondence between spectral recordings of Artemis-IV¹ and high time resolution single frequency measurements of the TSRS².

We have divided the SSSs in the following categories:

1. Broad-Band SSSs: They were partitioned in two subcategories, the *SSS-Pulses* and *Drifting SSSs*;
2. Narrow-band: They appear either as *Spike-Like SSSs* or as *Patch-Like SSSs*;
3. Complex SSS: They consist of the absorption-emission segments and were morphologically subdivided into *Rain-drop Bursts* (narrow-band emission *head* and a broad-band absorption *tail*) and *Blinkers*.

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THE SHORTEST, AS YET, OBSERVED SOLAR RADIO EMISSIONS

The decimetric spikes (cf. [1] for a review, also [6]) have been long considered as the solar radio bursts with the shortest duration recorded; this has only been occasionally challenged ([3], [9], [4]). We present observational evidence and characteristics of a variety of solar radio bursts with durations shorter than spikes up to an order of magnitude. These are, hence, named *Super Short Structures*, or *SSS*. Our observations consist of radio data with 1-10 ms time resolution, which enable the detection of, as yet unobserved, fine structure embedded in the type IV continuum; they comprise in particular :

- Single frequency measurements at 237, 327, 408 610, 1420 and 2695 MHz, recorded with time resolution of 1 ms by the solar multichannel radiopolarimetric system of the INAF-Trieste Astronomical Observatory (TSRS-Trieste Solar Radio System).

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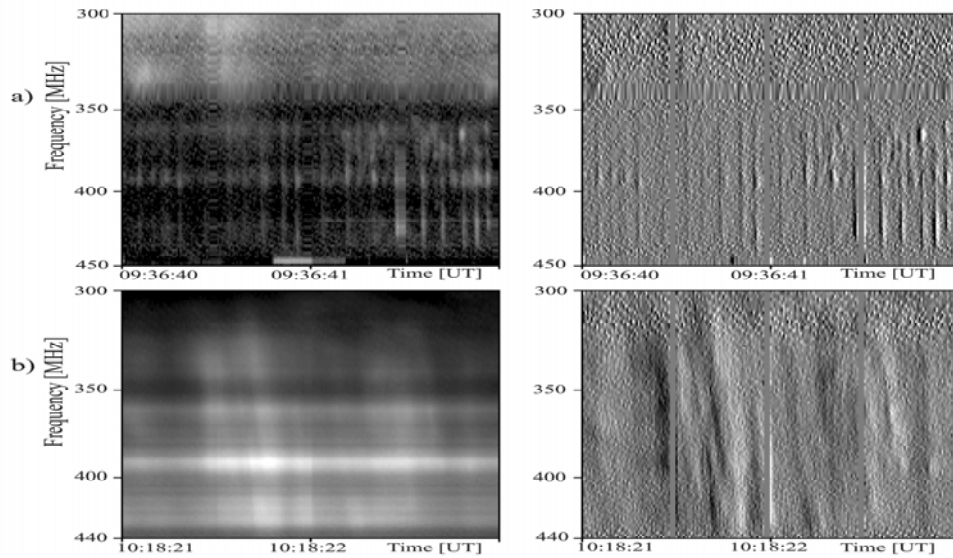


FIGURE 1. ARTEMIS-IV Dynamic Spectra (Intensity on the left and differential on the right) of broadband SSS: (a) SSS pulses, (b) Drifting SSSs.

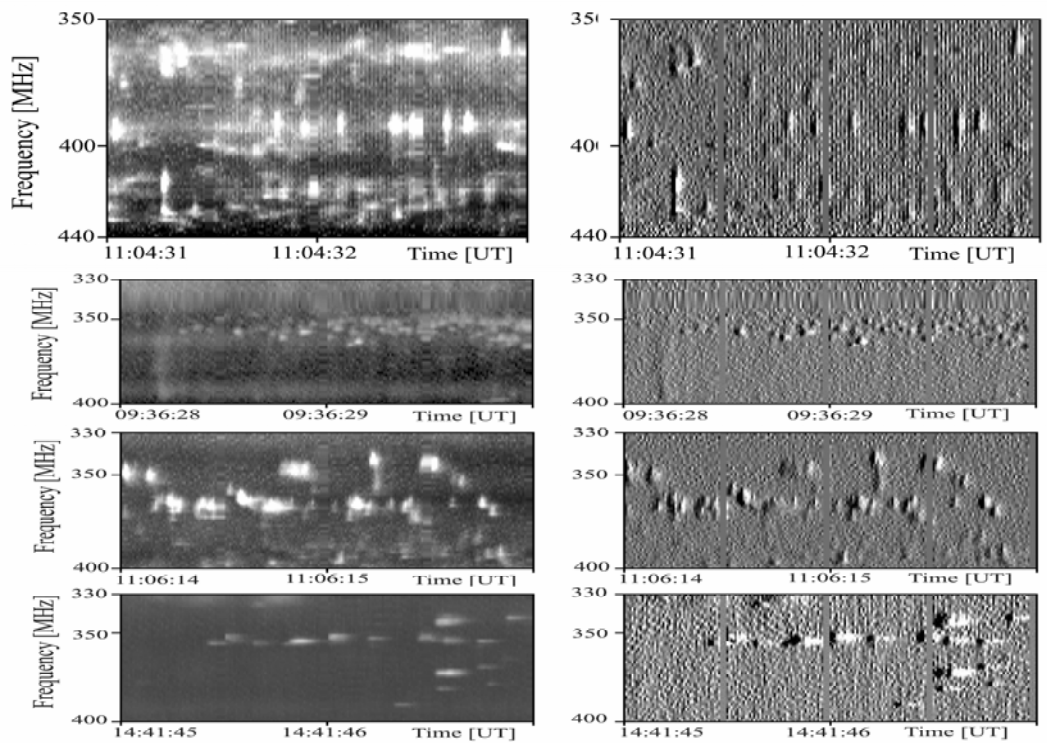


FIGURE 2. ARTEMIS-IV Dynamic Spectra of narrow band SSS. Top to Bottom: Spike-like SSSs, dot-like, sail-like, flag-like. Intensity spectra are on the left and differential on the right.

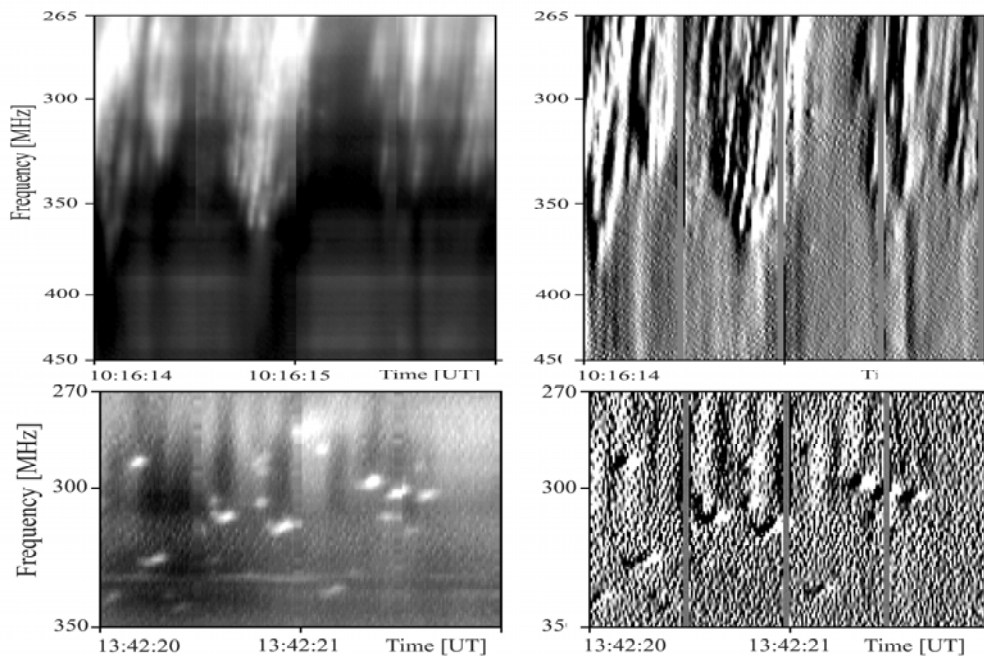


FIGURE 3. ARTEMIS-IV Dynamic Spectrum of Blinker (Upper Panel) and Raindrop-like SSS (Lower Panel). Intensity spectra are on the left and differential on the right.

- ARTEMIS-IV, cf. [2], dynamic spectra were obtained by the high sensitivity multi-channel acoustooptical analyser (SAO) which covers the 265-450 MHz range, with time resolution of 10 ms.

The credibility of the SSSs was confirmed by one-to-one identification of individual SSS bursts in the single frequency recordings and in the corresponding ARTEMIS-IV spectra. We have classified the SSSs in the following morphological categories:

- *Simple broad-band SSSs*; characterized by a broad frequency bandwidth $\Delta f \geq 100$ MHz (Figure 1). They can be subdivided in two subcategories:
 - *SSS-pulses* have duration in the range 10-20 ms, and frequency bandwidth ≈ 100 MHz. They appear in groups and, occasionally, exhibit quasi-periodic behaviour. Due to morphological similarity with pulsations of the type IV fine structure, they may be considered as an extension of pulsating structures towards higher time scales.
 - *Drifting SSSs* have duration in the range 30-70 ms. Their bandwidth in general exceeds the 100 MHz, and frequency drift rates ($|\Delta f / \Delta t| \approx 400-1000$ MHz/sec) are similar to the drift rates of the metric type III bursts. ([8], [7]).
- *Simple narrow-band SSSs* are distinguished by their narrow frequency bandwidth $\Delta f \leq 20$ MHz. They are, also, subdivided into two subcategories:
 - *Spike-like SSSs* are the shortest SSSs with a duration in the 4-30 ms range (Figure 2 top panel). Their frequency bandwidth is mostly $\Delta f \leq 20$ MHz. If

measurable, frequency drifts are $|\Delta f/\Delta t| \geq 800$ MHz/sec. On dynamic spectra they very much resemble spikes, ([1]) as their name implies.

- *Patch-like SSSs* exhibit, due to their morphological diversity, a rather broad range of duration which varies between 4 and 50 ms (Figure 2, three lower panels). The frequency bandwidth is $\Delta f \leq 15$ MHz, and it can be as low as a few MHz. This qualifies *patch-like SSS* as the SSSs of the narrowest bandwidth. Their spectral appearance varies; they can resemble dots, sails or flags and were further subdivided accordingly to: *dot-like SSS*, *sail-like SSS* and *flag-like SSS*. *Dot-Like* structures in the 1000-2000 MHz range, recorded by the Brazilian Solar Spectroscope with 50 ms resolution, have been reported by [10].
- *Complex Super Short Structures* are characterised by an emission and an absorption element. Two subcategories could be distinguished:
 - *Rain-drop bursts* (Figure 3, lower panel) consist of a narrow-band emission *HEAD* ($\Delta f \approx 5$ MHz) and a broad-band absorption *TAIL* ($\Delta f \approx 40$ MHz). The durations are approximately 50 ms for the *HEAD* and 30 ms for the *TAIL*. Both the *HEAD* and the *TAIL* exhibit frequency drift which is $|\Delta f/\Delta t| \approx 60 \pm 10$ MHz/sec and $|\Delta f/\Delta t| \approx 1000 \pm 400$ MHz/sec, respectively. Morphologically these SSSs resemble, somehow, to the tadpole bursts ([11]).
 - *Blinkers* (Figure 3, upper panel) are drifting bursts ($|\Delta f/\Delta t| \approx 650$ MHz/sec) consisting of absorption element that is switching abruptly to emission element. Opposite cases have also been found (emission in the high-frequency part, and absorption in low-frequency part of the burst). The duration $d_{1/2} = 30-40$ ms, is approximately the same along the whole burst. They are the SSSs with the largest frequency bandwidth $\Delta f > 150$ MHz.

DISCUSSION & CONCLUSIONS

The analysis of high time resolution spectral recordings (ARTEMIS-IV) and single frequency measurements (TSRS-data) reveals a number of different classes of *Super Short Structures*. The basic characteristics of the described SSS classes are summarized in Table 1.

It is stressed that all of the presented features have duration considerably shorter than spikes which in the frequency range 250-450 MHz have duration to 100-50 ms. This does not necessarily establishes SSSs as the shortest in existence, but only as the shortest recorded until now. It is to be expected that the improvement of instrumental resolution may reveal the existence of even shorter radio bursts.

The duration of the SSSs varies with frequency, and from event to event. Therefore, at present it is not possible to establish a systematical dependence of the SSSs duration on the observation frequency; this would be in favour of plasma radiation mechanisms which cannot be yet confirmed. For more specific results a detailed case study is under way.

Lastly, although some morphological similarities with already known burst types (pulsations, type IIIs, tadpoles) exist, there is no as yet conclusive evidence of a common

TABLE 1. Classification and Basic Characteristics of Super Short Structures (SSS)

Class	Subclass	Characteristics	Morphologically Similar Bursts
Simple Broad Band SSS	SSS	$\Delta f \approx 100\text{MHz}$, Duration=10-20 ms	Pulsations
	Pulses	Some Groups Exhibit Quasi Periodicity	
	Drifting SSS	$ \Delta f/\Delta t \approx 400\text{-}1000\text{ MHz/sec}$ Duration=30-70 ms, $\Delta f \geq 100\text{MHz}$	Type III like Bursts [8]
Simple Narrow Band SSS	Spike-like SSS	$\Delta f \leq 20\text{ MHz}$, $ \Delta f/\Delta t \geq 800\text{ MHz/sec}$ Duration=4-30 ms	Spikes [1]
	Patch-like SSS	$\Delta f \leq 15\text{ MHz}$, Duration=4-50 ms Further Subdivision: Dot-like SSS Sail-like SSS and Flag-like SSS	Dot like Structures [10] -
Complex SSS with emission and absorption element	Blinkers	$ \Delta f/\Delta t \approx 650\text{ MHz/sec}$ $\Delta f > 150\text{ MHz}$, Duration=30-40 ms Absorption switches to emission	-
	Raindrop bursts	Emission <i>HEAD</i> , Duration $\approx 50\text{ ms}$ $\Delta f \approx 5\text{MHz}$, $ \Delta f/\Delta t \approx 60 \pm 10\text{ MHz/sec}$ Absorption <i>TAIL</i> , Duration $\approx 30\text{ ms}$ $\Delta f \approx 40\text{MHz}$, $ \Delta f/\Delta t \approx 1000 \pm 400\text{ MHz/sec}$	Tadpole Bursts [11]

radiation mechanism.

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