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Metric radio bursts and fine structures observed on 17 January, 2005

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Abstract

A complex radio event was observed on January 17, 2005 with the radio-spectrograph ARTEMIS-IV, operating at Thermopylae, Greece; it was associated with an X3.8 SXR flare and two fast Halo CMEs in close succession. We present dynamic spectra of this event; the high time resolution (1/100 s) of the data in the 450–270 MHz range, makes possible the detection and analysis of the fine structure which this major radio event exhibits. The fine structure was found to match, almost, the comprehensive Ondrejov Catalogue which it refers to the spectral range 0.8–2 GHz, yet seems to produce similar fine structure with the metric range.

Keywords: Sun; Solar flares; Sun radio emission; Sun fine structure

1. Introduction

Radio emission at metric and longer waves trace disturbances, mainly electron beams and shock waves, formed in the process of energy release and magnetic restructuring of the corona and propagating from the low corona to interplanetary space. The fine structures, on the other hand, including drifting pulsation structures, may be used as powerful diagnostics of the loop evolution of solar flares.

The period 14–20 January, 2005 was one of intense activity originating in active regions 720 and 718; while in the visible hemisphere of the sun, they produced 5 X-class and 17 M-class flares, an overview is presented in Bouratzis et al. (2006).

January the 17th is characterized by an X3.8 SXR flare from 06:59 UT to 10:07 UT (maximum at 09:52 UT) and two fast Halo CMEs within a 40 min interval. The corresponding radio event included an extended broadband continuum with rich fine structure; this fine structure is examined in this report.

2. Observations

2.1. Instrumentation

The ARTEMIS-IV[1] solar radio-spectrograph operating at Thermopylae since 1996 (Caroubalos et al., 2001b; Kontogeorgos et al., 2006a) consists of a 7-m parabolic antenna covering the metric range, to which a dipole antenna was added recently in order to cover the decametric range. Two receivers operate in parallel, a sweep frequency analyzer (ASG) covering the 650–20 MHz range in 630 data channels with a cadence of 10 samples/s and a high sensitivity multi-channel acousto-optical analyzer (SAO), which covers the 270–450 MHz range in 128 channels with a high time resolution of 100 samples/s.

Events observed with ARTEMIS-IV have been described, by Caroubalos et al. (2004, 2001a), Kontogeorgos et al. (2006b, 2008), Bouratzis et al. (2006), Petoussis et al. (2006), cf. also Caroubalos et al. (2006) for a brief review.

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[1] Appareil de Routine pour le Traitement et l' Enregistrement Magnetique de l' Information Spectral.

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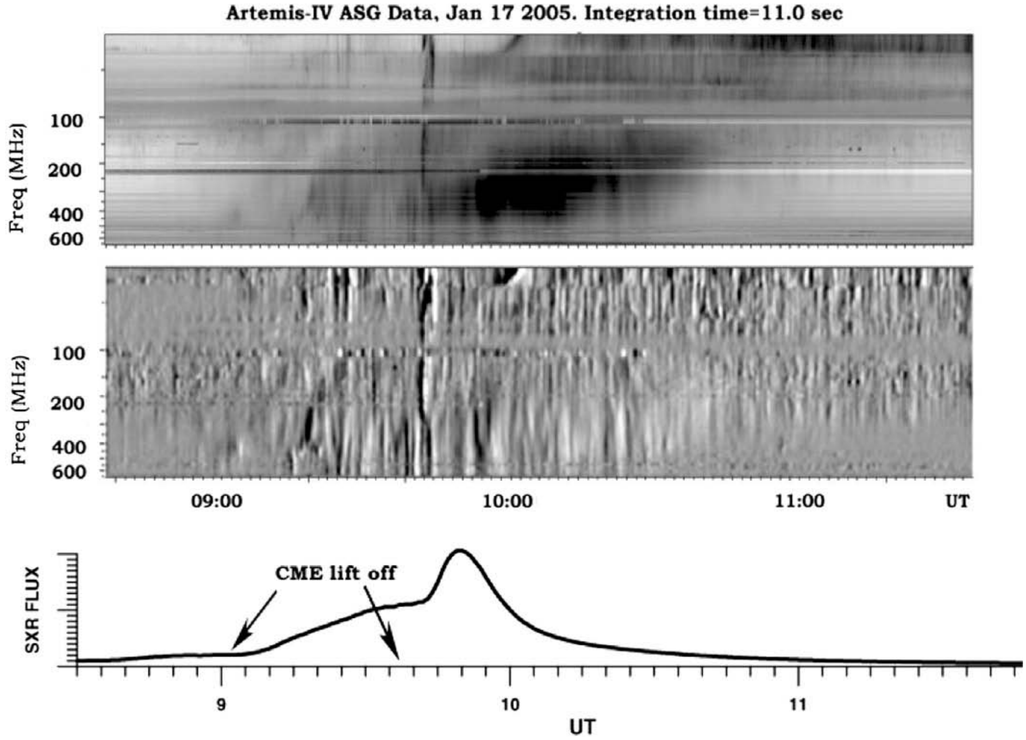

Fig. 1. ARTEMIS-IV dynamic spectrum (08:40–11:30 UT). Upper panel: ASG spectrum, middle panel: ASG differential spectrum, lower panel: GOES SXR flux (arbitrary units); the two CME lift-offs are marked on the time axis.

The broadband, medium time resolution recordings of the ASG are used for the detection and analysis of radio emission from the base of the corona to two R_{SUN}, while the narrowband, high time resolution SAO recordings are mostly used in the analysis of the fine temporal and spectral structures.

2.2. The event of January 17, 2005 – overview

Two groups of type III bursts and a very extensive type IV continuum with rich fine structure characterize the ARTEMIS-IV dynamic spectrum. The high frequency type IV emission starts at 08:53 UT, covers the entire 650–20 MHz spectral range (Fig. 1, upper and middle panels) and continues well after 15:00; it was associated with an SXR flare and two fast Halo CMEs (CME_1 and CME_2 henceforward) in close succession.

The GOES records[2] report an X3.8 SXR flare from 06:59 UT to 10:07 UT, with maximum at 09:52 UT; this is well associated with the brightening of sheared S-shaped loops from the EIT images. The SXR light curve (Fig. 1, lower panel) exhibits an, initially, slow rising phase which changes into a much faster rising a little before the peak flux is reached; it thus appears on the time–SXR flux diagram as a two stage process. The CME data from the LASCO lists on line[3] Yashiro et al. (2004) indicate that each of the stages coincides with the, estimated, lift-off time of CME_1 and CME_2, respectively; its also well associated with the high frequency onset of the two type III groups mentioned in the beginning of this subsection. The *Halo* CME_1 was first recorded by LASCO at 09:30:05 UT. Backward extrapolation indicates that it was launched around 09:00:47 UT. CME_2 was first recorded by LASCO at 09:54 UT; it was launched around 09:38:25 UT and was found to overtake CME_1 at about 12:45 UT at a height of approximately 37 solar radii.

2.3. Fine structure

The high sensitivity and time resolution of the SAO facilitated an examination on fine structure embedded in the type-IV continua within the studied period. In our analysis, the continuum background is removed by the use of high-pass filtering on the dynamic spectra (differential spectra in this case).

As fine structure is characterized by a large variety in period, bandwidth, amplitude, temporal and spatial signatures, a morphological taxonomy scheme based on Ondrejov radio-spectrograph recordings in the 0.8–2.0 GHz range was introduced (Jiřička et al. (2001, 2002) also Mészárosová et al. (2005)); the established classification criteria are used throughout this report.

We present certain examples of fine structures recorded by the ARTEMIS-IV/SAO in the 450–270 MHz frequency range; this range corresponds to ambient plasma densities which are typical of the base of the corona ($\approx 10^9\ cm^{-3}$

[2] http://www.sel.noaa.gov/ftpmenu/indices.
[3] http://cdaw.gsfc.nasa.gov/CMElist.

(cf. for example Mann et al., 1999). The fine structures of our data set, are divided according to the Ondrejov classification scheme and described in the following paragraphs (cf. also Figs. 2–5).

2.3.1. *Broadband pulsations and fibers*

The broadband pulsations appear for the duration of the type IV continuum; they are, for same period, associated with fibers; these structures intensify within the rise phase of the SXR, which in turn, coincides with the extrapolated lift-off of CME_1 and CME_2. Follows a closer examination:

- Radio pulsations are series of pulses with bandwidth >200 MHz and total duration >10 s; on the ARTEMIS-IV recordings they persisted for the duration of the type IV continuum. Some, with a slow global frequency drift, were of the *Drifting Pulsation Structures* (DPS) subcategory. The pulsations bandwidth exceeded the SAO frequency range, however from the ASG dynamic spectrum we observe a drift of the pulsating continuum towards the lower frequencies, following the rise of CME_2. Three physical mechanisms were proposed as regards the source of this type of structure (cf. Nindos et al. (2007) for a review):
  – Modulation of radio emission by MHD oscillations in a coronal loop.
  – Non-linear oscillating systems (wave–wave or wave particle interactions) where the pulsating structure corresponds to their limit cycle.
  – Quasi-periodic injection of electron populations from acceleration episodes within large scale current sheets.

  Combined radio-spectrograph, radio and SXR imaging and HXR observations (Kliem et al., 2000; Khan et al., 2002; Karlický et al., 2002) favor the last mechanism; furthermore they identify the sources of Drifting Pulsation Structures with plasmon ejections.
- Isolated broadband pulses: Pulsating structures but with duration ≈10 s, cf. Fig. 7.
- Fast drifting bursts: Short-lasting and fast drifting bursts with frequency drift >100 MHz/s; similar to the isolated broadband pulses, except for the frequency drift, cf. Fig. 6.

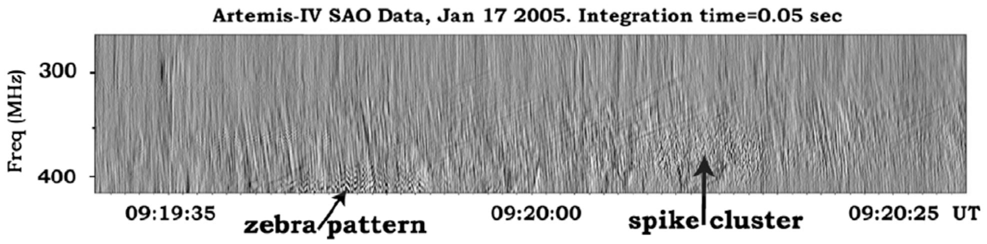

Fig. 2. ARTEMIS-IV SAO differential spectrum: zebra pattern (09:19:40–09:19:52 UT) and a spike cluster (09:20:08–09:20:15) on a background of fiber bursts and pulsations (09:19:30–09:20:30 UT); the pulsations with the fibers cover the observation period but they appear more pronounced in the 09:350–09:55 UT interval.

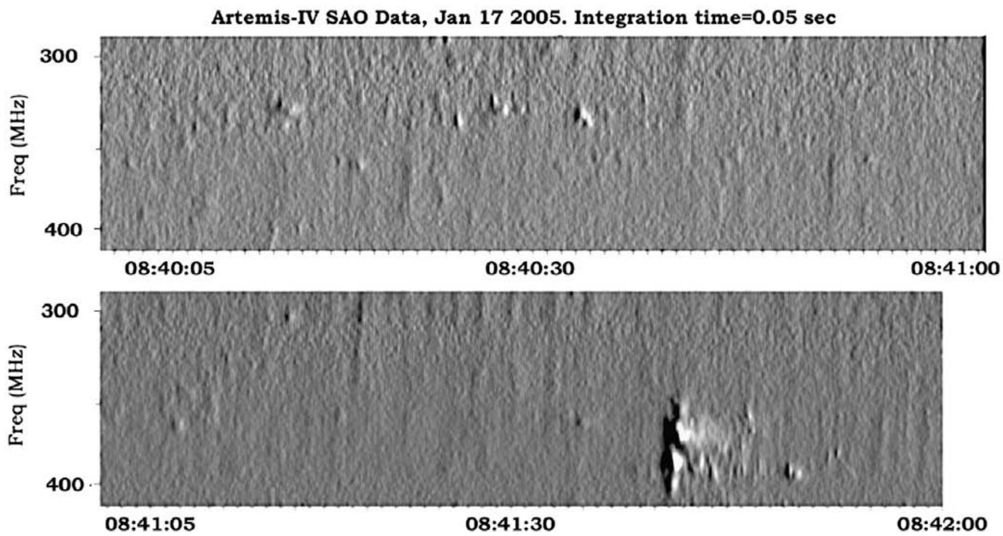

Fig. 3. ARTEMIS-IV differential spectra of fine structures embedded in the type IV continuum. Upper panel: spikes, lower panel: narrowband type III(U) bursts.

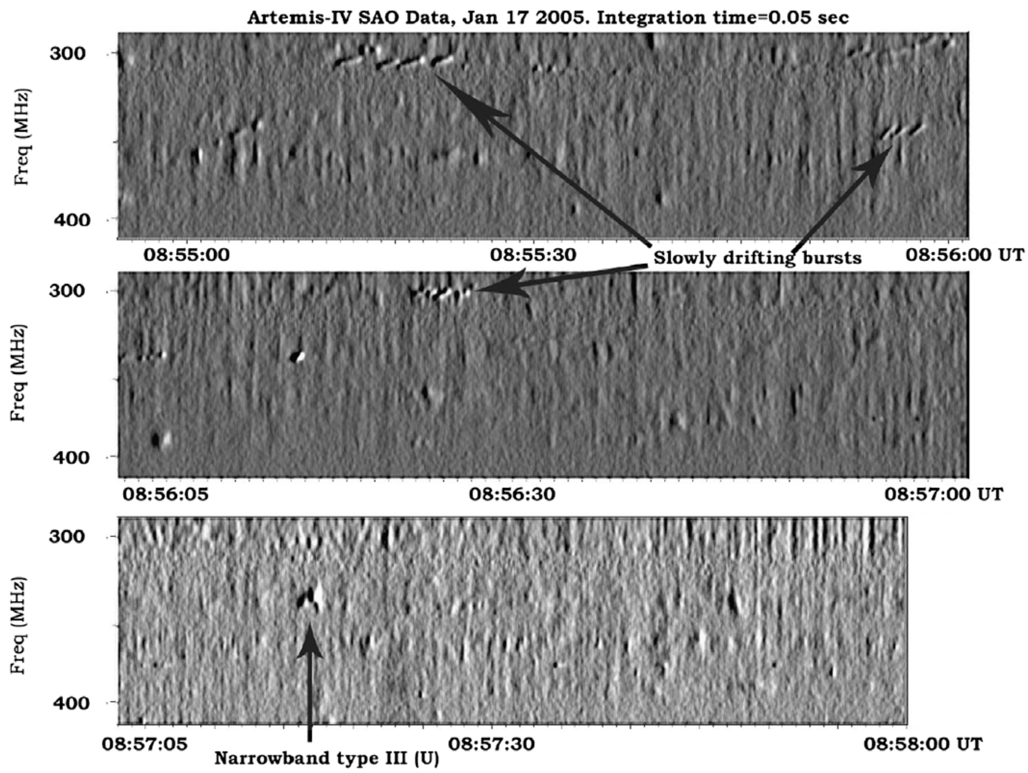

Fig. 4. ARTEMIS-IV differential spectra of fine structures embedded in the type IV continuum. First two panels: narrowband slowly drifting bursts, lower panel: narrowband type III(U).

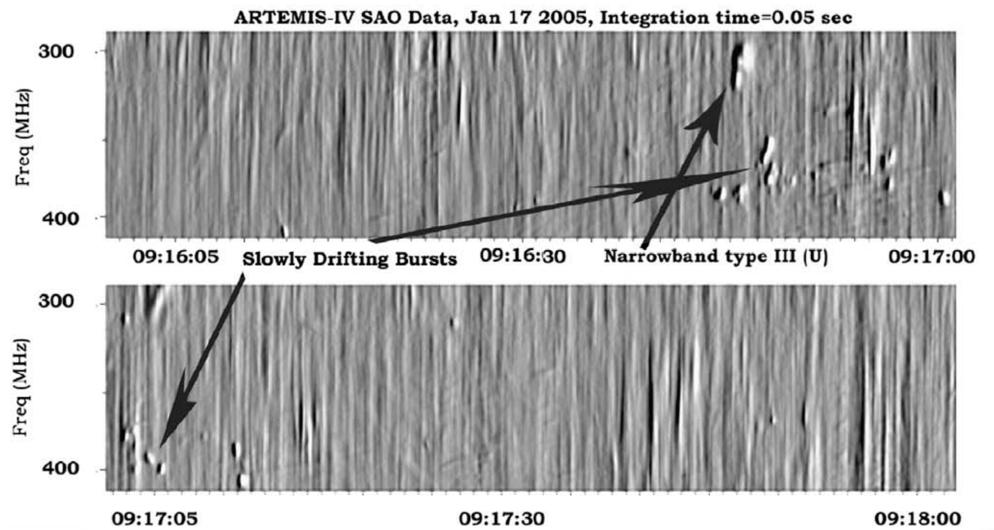

Fig. 5. ARTEMIS-IV differential spectra of fine structures embedded in the type IV continuum; narrowband bursts within groups fiber bursts and pulsating structures: upper panel: narrowband type III(U), narrowband slowly drifting bursts and spikes, lower panel: narrowband slowly drifting burst and spikes.

- Fibers or intermediate drift bursts: Fine structure bursts with the frequency drift ≈100 MHz/s; they often exhibit nearly regular repetition. On our recordings they coincide with broadband pulsations and they also cover the duration of the type IV continuum. They are usually interpreted as the radio signature of whistler waves coalescence with Langmuir waves in magnetic loops; the exciter is thought to be an unstable distribution of non-thermal electrons (cf. Nindos et al. (2007), and references within).

2.3.2. Zebra patterns

The zebra structures are characterized by several emission lines, which maintain nearly regular distance to their

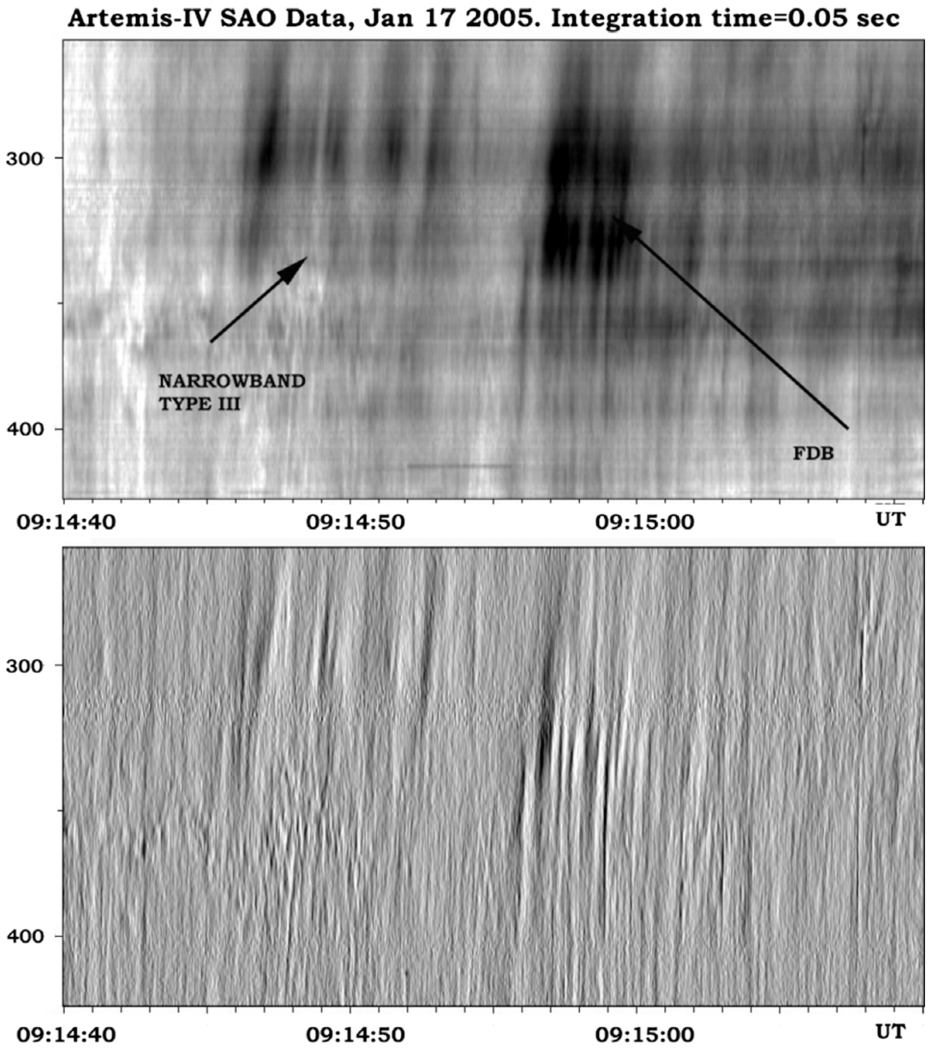

Fig. 6. ARTEMIS-IV spectra of fast drift bursts (FDB), 09:14:55–09:15:00 UT, preceded by narrowband type III bursts. Upper panel: intensity spectrum, lower panel: differential spectrum.

neighbors (Fig. 2). The zebras from our data set are associated with pulsations and fibers and cover almost the same period with them. They appear, however, more pronounced in the 09:35–09:55 UT interval; this interval includes the CME_2 estimated launch and the rise phase of the SXR flare. Zebra patterns were explained as the result of electrostatic upper-hybrid waves at conditions of the double plasma resonance where the local upper-hybrid frequency equals a multiple of the local gyrofrequency ($\omega_{UH} = \sqrt{\omega_e^2 + \omega_{Be}^2} = s \cdot \omega_{Be}$) (cf. for example Chernov et al. (2006), Nindos et al. (2007), and references therein). The upper-hybrid waves are excited by electron beams with loss-cone distribution (Kuznetsov and Tsap, 2007).

2.3.3. Narrowband structures

The narrowband activity (Figs. 3–5), including spikes, narrowband type III and III(U) bursts as well as slowly drifting structures, is rather intermittent. A large group of spikes appears at about 09:20 UT; this coincides, in time, with the rising of the first stage of the SXR and the start of the first type III group. Three types of narrowband structures were recorded:

- Narrowband spikes are very short (≈0.1 s) narrowband (≈50 MHz) bursts which usually appear in dense clusters. An example of such a cluster appears in Fig. 2. The models proposed for the spike interpretation are based either on the loss-cone instability of trapped electrons producing electron cyclotron maser emission or on upper-hybrid and Bernstein modes. An open question remains whether or not spikes are signatures of particle accelerations episodes at a highly fragmented energy release flare site.
- Narrowband type III bursts: Short (≈1 s) narrowband (<200 MHz) fast drifting (>100 MHz/s) bursts. A number of this type of bursts, on the SAO high resolution dynamic spectra, exhibit a frequency drift turn over; as they drift towards lower frequencies and after reaching a minimum frequency (*turn over frequency*) they reverse

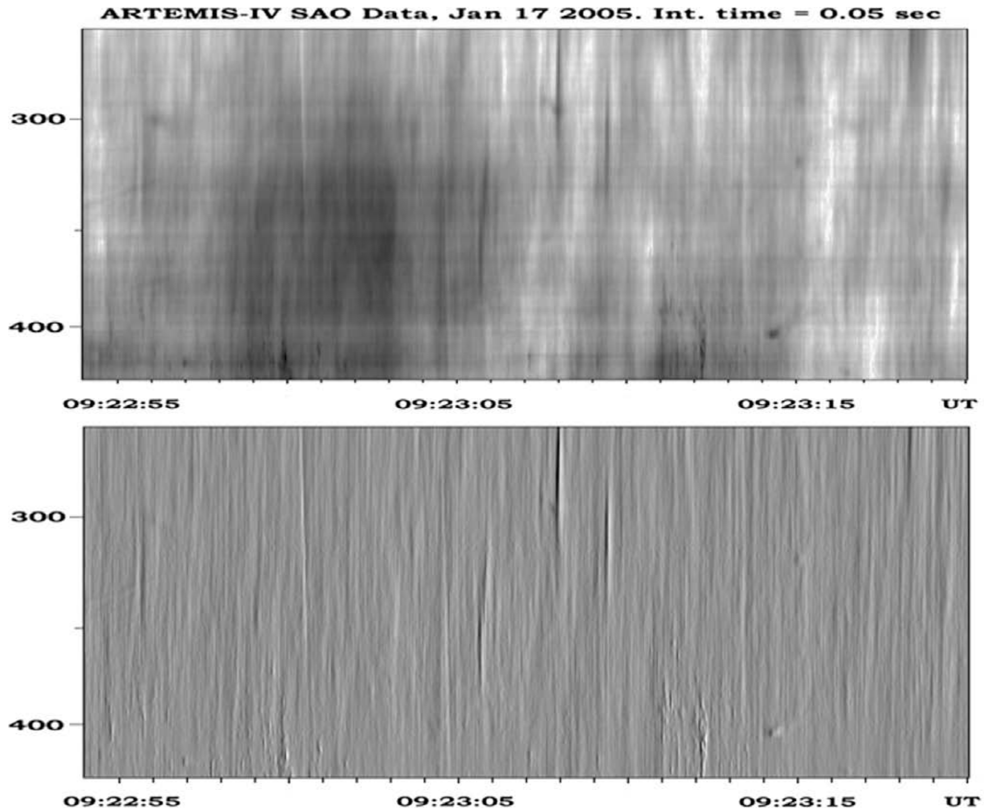

Fig. 7. ARTEMIS-IV spectra of isolated pulsating structures (IPS), 09:22:55–09:23:05 UT. Upper panel: intensity spectrum, lower panel: differential spectrum.

direction towards higher frequencies appearing as inverted U on the dynamic spectra. These we have marked as narrowband type III(U) in Figs. 3–5. Similar spectra (III(U), III(N)) were obtained in the microwave range by Fu et al. (2004).

- Narrowband slowly drifting bursts: They are similar to narrowband type III bursts but with a drift rate <100 MHz/s.

3. Summary and discussion

The ARTEMIS-IV radio-spectrograph, operating in the range of 650–20 MHz, observed a number of complex events during the super-active period of period 14–20 January, 2005; the event on January the 17th was characterized by an extended, broadband type IV continuum with rich fine structure.

We have examined the morphological characteristics of fine structure elements embedded in the continuum; it, almost, matches the comprehensive Ondrejov Catalogue (Jiřička et al., 2001, 2002). The latter, although it refers to the spectral range 0.8–2 GHz, seems to produce similar fine structure with the metric range.

The high resolution (100 samples/s) SAO recordings facilitated the spectral study of the fine structures and permitted the recognition and classification of the type III(U) and III(J) subcategory of the narrowband type III bursts in the metric frequency range; similar structures have been reported in the microwaves (Fu et al., 2004).

The pulsating structures and fibers, although they cover the full observation interval, appear enhanced during the SXR rise phase and the two CME lift-off where the major magnetic restructuring takes place. The narrowband structures, on the other hand, are evenly distributed for the throughout the observation period; this indicates that small electron populations are accelerated even after the flare impulsive phase.

Two types of fine structures from the Ondrejov Catalogue were not detected in our recordings:

- Continua: As the long duration pulsations accompanied by fibers were prevalent in the SAO spectra, any possible appearance of Continua was, probably, suppressed within the pulsating background.
- Lace pattern: It is new type of fine structure first reported by Jiřička et al. (2001); it is characterized by rapid frequency variations, both positive and negative. It is a very rare structure with only nine reported in the Ondrejov Catalog out of a total of 989 structures.

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