2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

On the observational properties of the decameter striae

M. V. Shevchuk*(1), V. N. Melnik(1), S. Poedts(2), V. V. Dorovskyy(1), J. Magdalenic(3), and A. A. Konovalenko(1)
(1) Institute of Radio Astronomy, Mystetstv, 4, Kharkov, Ukraine, 61002, http://rian.kharkov.ua
(2) Catholic University of Leuven, Leuven, Belgium
(3) Royal Observatory of Belgium, Brussels, Belgium

Abstract

In the paper we present the preliminary results of analysis of the solar Type IIIb bursts properties observed on June 14, 2012. Namely the parameters of their fine structure known as striae are studied in the continuous frequency band 8 - 32 MHz. It is shown that durations and instantaneous frequency bandwidths depend on the observing frequency. Notably, bandwidth increases and duration decreases with the frequency. The comparative analysis of the decameter spikes and striae is also performed.

1 Introduction

For the first time Type IIIb bursts were described in details by de la Noe et al. [1]. They identified them as chains of short ($\approx$ 1 second), narrow-band (15 - 100 kHz) striae bursts drifting similarly to the usual Type III bursts. It is currently well known that Type IIIb bursts are observed in the wide frequency range from 10 MHz up to 200 MHz [1–7, 9–12]. The occurrence rate of the elementary striae increases toward the lower frequencies [2]. Individual Type IIIb burst may consist of more than 30 striae for the frequency extension of 10 MHz [10]. The frequency separation between individual striae varies from few kHz up to 100 kHz [8]. The frequency drift rates of the Type IIIb bursts are negative and approximately equal - 2 - 7 MHz s^{-1} [1, 10]. The individual striae in most cases have no frequency drift. The polarization of the elementary striae is circular and can reach 80 - 100 % [1, 12, 13].

Type IIIb bursts are observed either as isolated bursts or accompanied by Type III bursts forming well known IIIb-III pairs. Up to now the relation between components of the IIIb-III pairs is not fully understood. Some authors inclined that Type IIIb bursts are precursors for the Type III bursts [1, 6] and another suppose that IIIb–III pairs are harmonically related where Type IIIb bursts are the first harmonic, and Type III bursts the second one [3, 5, 6, 12].

The similarity and association of the Type IIIb bursts and Type III bursts lead to the assumption that Type IIIb bursts are generated by the plasma emission mechanism. According to Takakura et al. [6] fast electrons propagate through the plasma irregularities that leads to the generation of the Type IIIb bursts. This idea was developed and numerically calculated by Kontar [14]. He showed that if the fast electron beams propagated in the solar corona with density fluctuations then the Langmuir turbulence of high level would be excited in the sequence of regions, which gives chains of striae.

In the present paper the analysis of the Type IIIb bursts, namely, their fine structure striae, in the frequency band 8 - 32 MHz observed simultaneously with the Type III bursts storm and spikes on June 14, 2012 is given. The aim of this study is to determine the main parameters of the decameter striae and their dependencies on the observing frequency. Comparison of the obtained parameter and dependencies with those obtained for the decameter spikes observed this day.

2 Instrumentation

On June 14, 2012 only four sections of the radio telescope UTR-2 with the effective area of about 50,000 m^2 were used. During this campaign the signal registration was performed with the new digital spectra polarimeter of Z-modification (DSP-Z) [15, 16]. The observations were carried out in the frequency band 8 - 32 MHz with the high temporal and frequency resolution 100 ms and 4 kHz, respectively. The observations lasted about six hours near local noon.

3 Analysis of the observations

For the analysis we chose Type IIIb bursts observed simultaneously with spikes on June 14, 2012. On this day a large variety of different types of bursts such as spikes, drift pairs, Type III bursts, Type IV burst, etc. were observed [18]. But only several well-identifiable Type IIIb bursts in the frequency range 10 - 32 MHz were recorded (see Figure 1). The main parameters of the observed Type IIIb bursts and forming them striae, viz. drift rate, number of the striae in an individual Type IIIb burst, duration, bandwidth and flux were measured.

Type IIIb bursts observed this day have negative drift rates, i.e. they drift from high to low frequencies. The measured drift rates of the Type IIIb bursts are in interval 3 - 5 MHz s^{-1}.

The number of striae which form an individual Type IIIb burst is not regular from burst to burst. The mean number of striae forming Type IIIb burst in the frequency range 10

- 32 MHz is about 95 striae. The number of striae in 1 MHz frequency band is approximately 5 - 6 bursts. The spacing between the neighboring striae varies in the wide range from about 100 kHz up to 1 MHz.

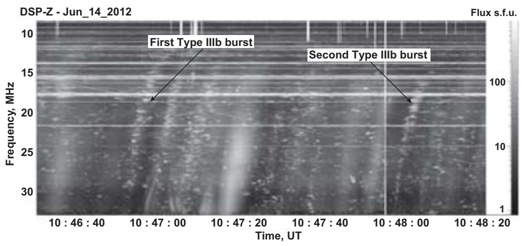
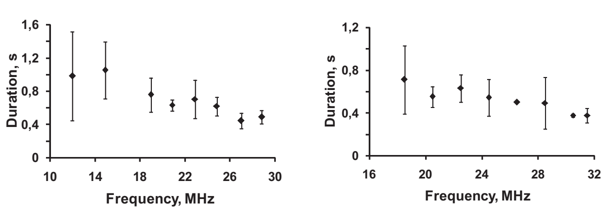


Figure 1. Type IIIb bursts observed simultaneously with spikes and Type III bursts in the frequency range from 10 to 32 MHz.

The Type IIIb burst flux is determined by the flux of striae. The striae flux changes from one stria to another in a single Type IIIb burst. For all analyzed striae the flux do not exceed 300 s.f.u. and vary from 20 s.f.u. up to 280 s.f.u. Comparable values of the flux were observed for the decameter spikes. In most cases the flux of the spikes did not exceed 500 s.f.u. and was in the range from 20 s.f.u. to 100 s.f.u. [17, 18]. No specific flux dependence on the frequency was found in both cases.
Due to difficulty of separation of one individual stria from another in the majority of the observed Type IIIb bursts the durations and bandwidths of the striae were measured only for two of all observed Type IIIb bursts indicated in Figure 1. The obtained durations and bandwidths of the striae and their dependences on the frequency are presented below.

3.1 Striae duration

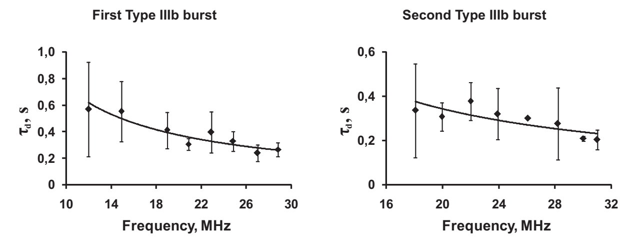
The duration (d), rise (τ_r) and decay (τ_d) times of the stria at half the peak power emission intensity were measured. In this study we focused only on the dependences of the duration and decay time on the frequency to compare them with those obtained for the spikes [18]. The obtained dependences of the striae duration on the frequency are shown in Figure 2. From these figures it is clearly visible that striae



a) b)

Figure 2. The striae duration dependences on the frequency for the first (a) and second (b) analyzed Type IIIb bursts.

duration is decreasing from approximately 1 to 0.46 seconds with the frequency increase. Consequently the decay time of the striae decreases with the frequency as well (Figure 3). The dependencies of the decay times on the fre-



a) b)

Figure 3. The striae decay time (τ_d) dependences on the frequency for the first (a) and second (b) analyzed Type IIIb bursts.

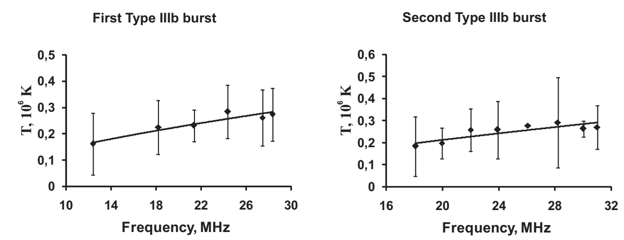
quency were approximated by the power law dependence $\tau_d = af^p$ using the least square method. The power index p for the first and second Type IIIb bursts equals -0.97 and -0.9, respectively. These values are close to -1, thus to simplify further calculations the obtained dependences we approximated with the dependence in the form of $\tau_d = af^{-1}$. The coefficient a approximately equals 7.6 and 7 in the case of the first and second Type IIIb bursts, respectively.
If we assume that striae decay time τ_d, similarly to the spikes decay time, is determined by the particles collision time in the plasma τ_{coll}, that in turn depend on plasma temperature $\tau_{coll} \sim T^{3/2}$ [18], then we can trace the variation of the temperature along the path of the electron beam, responsible for the generation of Type IIIb burst:

$$T = 8 \times 10^3 f^{4/3} \tau_d^{2/3} \quad (1)$$

Observations show that $\tau_d \sim f^{-1}$, thus we can rewrite Equation 1 as following:

$$T(f) \approx 4 \times 10^4 f^{2/3} \quad (2)$$

According to our analysis of the first Type IIIb burst the plasma temperature varied from 0.16 MK up to 0.27 MK (Figure 4a) and the temperature estimated using the second Type IIIb burst varied from 0.18 MK up to 0.27 MK (Figure 4b) at the heights 3.3 - 1.6 solar radii in assumption of Newkirk coronal model.
It is important to note that the obtained dependences for



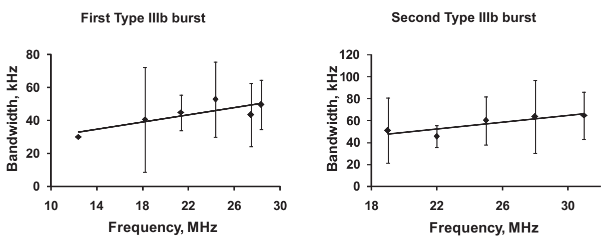
a) b)

Figure 4. Temperature variation with the frequency obtained using the first (a) and second (b) Type IIIb bursts.

the striae decay time, the coefficients a and the estimated temperatures are in good agreement with those obtained for the spikes which were observed during the same temporal interval. So, spikes decay time depends on the frequency in the same manner $\tau_d = bf^p$ with the power coefficient -1.01. The coefficient of proportionality b in the case when $\tau_d = bf^{-1}$ equals 7.6. And the coronal temperatures calculated using spikes τ_d varied from $\approx$ 0.2 to 0.43 MK at the same heights [18]. Thus, we got very good match of the obtained parameters. If our assumptions are correct this result indicates that the electron beams responsible for the spikes and striae generation propagate through the plasma with comparable temperature.

3.2 Striae bandwidth

According to our analysis the frequency bandwidth of striae increases with the frequency. The obtained dependences for the both Type IIIb bursts are shown in Figure 5. As it can be seen from the figure the striae bandwidth for the first Type IIIb burst increases from 30 kHz at frequency 13 MHz up to 50 kHz at frequency 29 MHz. For the second Type IIIb burst the striae bandwidth rises from 50 kHz up to 65 kHz at frequencies 19 MHz and 31 MHz, correspondingly. These dependences were approximated with the linear function in the form $\Delta f = Af$. The coefficient A equals 1.2×10^{-3} and 1.4×10^{-3} for the first and second Type IIIb bursts, respectively. The coefficient A obtained after spikes analysis during the same time interval equals 1.1×10^{-3} [18]. And again there is rather good match of the analysed parameter Δf.



a) b)

Figure 5. The striae bandwidth dependences on the frequency for the first (a) and second (b) Type IIIb bursts.

We suppose that decameter striae similarly to the decameter spikes are generated by the fast electron beams which propagate through the coronal plasma within some solid angle θ and generate Langmuir waves l at the upper hybrid frequency [18]. These Langmuir waves l are transformed into electromagnetic waves t in the processes $l + i = t + i$. The frequency of electromagnetic waves is approximately equal to local plasma frequency ω_{pe} and their frequency bandwidth is defined as following:

$$\Delta\omega = \omega_{uh}(\theta) - \omega_{uh}(0) \approx \frac{\omega_{Be}^2}{2\omega_{pe}^2} \sin^2\theta \qquad (3)$$

in the case when $\omega_{Be} \ll \omega_{pe}$, where $\omega_{pe} = \sqrt{4\pi e^2 n/m}$ denotes the plasma frequency, $\omega_{Be} = eB/mc$ corresponds to the electron cyclotron frequency, e and m denote the electron charge and mass, c is the speed of light and B is the magnetic field. Thus the relative frequency bandwidth can be written as:

$$\frac{\Delta f}{f} = \frac{\omega_{Be}^2}{2\omega_{pe}^2} \sin^2\theta \qquad (4)$$

Then using the coefficient $A = \Delta f / f$ obtained from observations we can write equation for the estimation of the magnetic field:

$$B = \frac{\sqrt{2A} mc\omega_{pe}}{e \sin\theta} \qquad (5)$$

Assuming that the fast electrons are confined within angle $\theta = 20^\circ$ [19] we found that magnetic field in the place of striae generation equals 1.2 - 1.4 G in the case of the first and second Type IIIb bursts, respectively.
The obtained value of the magnetic field agrees well with the magnetic field estimations made using spikes observed simultaneously with the analyzed Type IIIb bursts [18] and with the estimation made using decameter S-bursts [20].

4 Conclusion

The important result of the present study is the dependence of the striae duration and bandwidth on the observing frequency. The obtained dependencies exactly replicated the same dependencies obtained for the spikes observed on the same day during the same temporal interval up to coefficients. Thus it is reasonable to assume that the decameter striae and spikes parameters (duration and bandwidth) are determined by the same parameters of the coronal plasma in the place of the bursts generation, i.e. by the temperature and magnetic field. Based on the assumptions made for the spikes [18] these parameters in the place of striae generation were estimated. According to our analysis the temperature varied from 0.16 to 0.27 MK at the heights 3.3 - 1.6 solar radii and the magnetic field was 1.2 - 1.4 G. These values of the temperature and magnetic field are close to the one obtained in spikes analysis. We can assume that the electrons responsible for the striae and spikes generation propagate through the same regions of coronal plasma with approximately the same parameters.
Comparing the parameters of the decameter spikes and striae such as duration, bandwidth, flux and their dependence on the frequency we come to another one important result of our study - decameter spikes and striae are most likely the same type of the solar radio bursts. However, the question about the spikes and striae location on the dynamic spectrum, i.e. chaotic position of the spikes on the dynamic spectrum and grouping of striae in drifting on frequency chains (Type IIIb bursts), still remains open and needs further study.

5 Acknowledgements

The work was partially fulfilled in the framework of FP7 project SOLSPANET(FP7–PEOPLE-2010-IRSES-269299) and by project DBOF-12-0261 of the KU Leuven.

References

[1] J. de La Noe, and A. Boischot, "The Type III B Burst", *Astron. Astrophys.*, **20**, August 1972, pp. 55–62.

[2] G. R. A. Ellis, and P. M. McCulloch, "Frequency splitting of solar radio bursts", *Australian Journal of Physics*, **20**, October 1967, p. 583, doi:10.1071/PH670583.

[3] E. P. Abranin, L. L. Baselian, N. Iu. Goncharov, V. A. Zinichev, V. O. Rapoport, Ia. G. Tsybko, "Harmonic structure of type IIIb and III bursts", *Solar Phys.*, **62**, May 1979, pp. 145–151, doi: 10.1007/BF00150141.

[4] B. Moller-Pedersen, "Solar noise storms in the decametric wavelength range", *Astron. Astrophys.*, **37**, December 1974, pp. 163–168.

[5] R. T. Stewart, "An example of a fundamental type IIIb radio burst", *Solar Phys.*, **40**, February 1975, pp. 417–419.

[6] T. Takakura, and S. Yousef, "Type IIIb radio bursts - 80 MHz source position and theoretical model", *Solar Phys.*, **40**, February 1975, pp. 421–438.

[7] H. S. Sawant, R. V. Bhonsle, and S. K. Alurkar, "Microscopic spectral features in solar decametric bursts and coronal irregularities", *Solar Phys.*, **50**, December 1976, pp. 481–490.

[8] R. A. Smith, and J. de La Noe, "Theory of type IIIb solar radio bursts", *Astrophys. J.*, **207**, July 1976, pp. 605–629.

[9] V. Krishan, K. R. Subramanian, and C. V. Sastry, "Observations and interpretation of solar decameter type IIIb radio bursts", *Solar Phys.*, **66**, June 1980, pp. 347–355.

[10] V. N. Melnik, H. O. Rucker, A. A. Konovalenko, N. V. Shevchuk, E. P. Abranin, V. V. Dorovskyy, A. Lecacheux, "Type IIIb bursts and their fine structure in frequency band 18–30 MHz", *AIP Conference Proceedings*, **1206**, January 2010, pp. 442–449, doi:10.1063/1.3292552.

[11] A. I. Brazhenko, V. N. Melnik, A. A. Konovalenko, V. V. Dorovskiy, R. V. Vashchishin, A. V. Frantsuzenko, G. Rucker, "The Comparative Characteristic of Components in the IIIb-III Pairs According to the Observation Data Obtained by Radio Telescope URAN-2", *Odessa Astronomical Publications*, **24**, 2011, p. 153.

[12] V. N. Melnik, A. I. Brazhenko, A. V. Frantsuzenko, V. V. Dorovskyy, H. O. Rucker, "Properties of Decameter IIIb-III Pairs", *Solar Phys.*, accepted.

[13] M. G. Aubier, Y. Leblanc, and B. Moller-Pedersen, "Type I and Type III Storm Radiation", *Astron. Astrophys.*, **70**, November 1978, p. 685.

[14] E. P. Kontar, "Dynamics of electron beams in the solar corona plasma with density fluctuations", *Astron. Astrophys.*, **375**, August 2001, pp. 629–637.

[15] V. B. Ryabov, D. M. Vavriv, P. Zarka, B. P. Ryabov, R. Kozhin, V. V. Vinogradov, and L. Denis, "A low-noise, high-dynamic range, digital receiver for radio astronomy applications: an efficient solution for observing radio-bursts from Jupiter, the Sun, pulsars, and other astrophysical plasmas below 30 MHz", *Astron. Astrophys.*, **510**, January 2010, A16, doi:10.1051/0004-6361/200913335.

[16] V. Zakharenko, A. Konovalenko, P. Zarka et al., "Digital Receivers for Low-Frequency Radio Telescopes UTR-2, URAN, GURT", *Journal of Astronomical Instrumentation*, **5**, March 2016, p. 738 , doi:10.1142/S2251171716410105.

[17] V. N. Melnik, N. V. Shevchuk, A. A. Konovalenko, H. O. Rucker, V. V. Dorovskyy, S. Poedts, A. Lecacheux, "Solar decameter spikes", *Solar Phys.*, **289**, May 2014, pp. 1701–1714, doi:10.1007/s11207-013-0434-1.

[18] N. V. Shevchuk, V. N. Melnik, S. Poedts, V. V. Dorovskyy, J. Magdalenic, A. A. Konovalenko, A. I. Brazhenko, C. Briand, A. V. Frantsuzenko, H. O. Rucker, and P. Zarka, "The Storm of Decameter Spikes During the Event of 14 June 2012", *Solar Phys.*, **291**, January 2016, pp. 211–228, doi:10.1007/s11207-015-0799-4.

[19] V. V. Zaitsev, "Quasi-one-dimensionality of plasma wave spectrum in type III radio burst sources", *Soviet Astron.*, **18**, February 1975, pp. 475–481.

[20] V. N. Melnik, A. A. Konovalenko, H. O. Rucker, V. V. Dorovskyy, E. P. Abranin, A. Lecacheux, and A. S. Lonskaya, "Solar S-bursts at frequencies of 10–30 MHz", *Solar Phys.*, **264**, June 2010, pp. 103–117, doi:10.1007/s11207-010-9571-y.