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# On the origin of 140 GHz emission from the 4 July 2012 solar flare

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**Abstract**

The sub-THz event observed on the 4 July 2012 with the Bauman Moscow State Technical University Radio Telescope RT-7.5 at 93 and 140 GHz as well as Kislovodsk and Metsähovi radio telescopes, Radio Solar Telescope Network (RSTN), GOES, RHESSI, and SDO orbital stations is analyzed. The spectral flux between 93 and 140 GHz has been observed increasing with frequency. On the basis of the SDO/AIA data the differential emission measure has been calculated. It is shown that the thermal coronal plasma with the temperature above 0.5 MK cannot be responsible for the observed sub-THz flare emission. The non-thermal gyrosynchrotron mechanism can be responsible for the microwave emission near 10 GHz but the observed millimeter spectral characteristics are likely to be produced by the thermal bremsstrahlung emission from plasma with a temperature of about 0.1 MK.


*Keywords:* Sub-THz solar flares; Microwave and X-ray emissions; Electron propagation

## 1. Introduction

Despite the unprecedented opportunities of modern terrestrial and cosmic telescopes, the detailed mechanisms of the solar flare energy release remain unknown. Therefore observations in poorly explored wavelength ranges can be very fruitful and important. Specifically, sub-THz observations corresponding to the frequency range of $10^2$–$10^3$ GHz (3–0.3 mm) can give us valuable information about the acceleration of electrons with energy $E \gtrsim 1$ MeV as well as the flare coronal and chromospheric thermal plasma (Raulin et al., 1999; Lüthi et al., 2004; Giménez de Castro et al., 2009; Fleishman and Kontar, 2010; Trottet et al., 2011; Krucker et al., 2013).

Solar sub-THz observations became available only in XXI century with Solar Submillimeter Telescope (Kaufmann et al., 2001) and Köln Observatory for Submillimeter and Millimeter Astronomy (Lüthi et al., 2004) in the 200–400 GHz range. These first and subsequent observations of solar flares have shown that some events have a negative spectral slope, i.e., the spectral flux of radio emission decreases with frequency and can be considered as an extension of the gyrosynchrotron spectrum (Trottet et al., 2002; Raulin et al., 2004; Lüthi et al., 2004; Giménez de Castro et al., 2009). Surprisingly, other flares as a rule, long duration events, have revealed a positive spectral slope.

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This peculiarity can be observed during both the impulsive (Kaufmann et al., 2004; Silva et al., 2007; Kaufmann et al., 2009) and gradual (Trottet et al., 2002; Lüthi et al., 2004) flare phases. It should be emphasized that the observations mentioned above were obtained at frequency $> 200$ GHz and the frequency range of 100–200 GHz has remained unavailable until recently. Meanwhile, the observations in this frequency range are important to improve the spectral coverage of the radio emission. We can suggest that the sub-THz events with the positive spectral slope at lower frequencies occur more often (see also Akabane et al., 1973; Correia et al., 1994; Chertok et al., 1995) and appropriate events are characterized by simpler magnetic configuration than long duration ones.

This work focuses on the analysis and interpretation of the 4 July 2012 flare. Special attention is paid to the sub-THz emission component observed at 93 and 140 GHz with the solar radio telescope RT-7.5 operated by the Bauman Moscow State Technical University. Section 2 presents observations and instruments used in the study. Section 3 is dedicated to interpretations of obtained results. Section 4 presents discussion and main conclusions.

## 2. Instruments and observations

Sub-THz emission from GOES M5.3–class solar flare, which happened on 4 July 2012 in AR 1515 (S16W19), has been observed with the RT-7.5 solar radio telescope (Rozanov, 1981; Smirnova et al., 2013). This single-dish antenna of a Cassegrain-type with the diameter of 7.75 meters allows us to carry out simultaneous radio observations at two frequencies 93 and 140 GHz (3.2 and 2.2 mm). The half power beamwidths of the antenna are 1.5 and $2.5'$ at 140 and 93 GHz, respectively. Two superheterodyne receivers are included into the quasi-optical scheme, i.e., beams are overlaped to observe one chosen area on the solar disk. The time constant of 1 s provides the sensitivity of the receivers of about 0.3 K.

Antenna temperatures are measured during observations relatively to the quiet-sun level. Experiments have shown that the contribution of noise of the receivers in the desired signal is about 1–1.5%. The maximum error of the beam pointing is $10''$ (Rozanov, 1981). In order to estimate the atmospheric attenuation of the signal from an active region the signals from the center of the solar disk and the sky are recorded at the same zenith angle when the absorption coefficient of the Earth's atmosphere did not change significantly. We estimated the observed quiet-sun temperatures by subtracting the sky temperature level. Then we compared these temperatures with the quiet-sun ones obtained from observations of the new Moon. As a result, the quit-sun temperatures turned out to be equal to 6600 and 6400 K at 93 and 140 GHz, respectively.

To provide the calibration of the flare flux densities we need the quite sun and sky brightness temperatures preferably near the beginning of solar burst. The observed quiet-sun and sky temperatures on 04 July 2012 were obtained about 8:30 UT. The atmospheric opacities for 93 GHz and 140 GHz at that time were equal to 0.1 and 0.25 Np, respectively. The corresponding uncertainties in the determination of the flare maximum flux densities were about 10 and 15%. We note that the sky was clear during the flare observations on 4 July 2012 but only the second flare burst (09:54:30–09:56:00 UT) was detected (Fig. 1) because of the calibration map construction.

Microwave (centimeter) emission from the whole solar disk at 6.1 GHz frequency was obtained with the time constant of 1 s at Kislovodsk Mountain Astronomical Station. Observations carried out at a parabolic antenna with a diameter of 3 meters. Noise temperature of the antenna was about 1 K. Signal was detected by measuring of the antenna temperature. The conversion factors for solar fluxes units (sfu) derived from measurements of the moon temperature. Solar observations at 11.7 GHz (whole solar disk) were provided by the 1.8-m antenna located at Metsähovi Radio Observatory (Urpo, 1982). We also used measurements of total flux densities obtained by RSTN (San Vito) at 5.0, 8.8 and 15.4 GHz with the temporal resolution of about 1 s (Guidice et al., 1981).

Ultraviolet and X-ray diagnostics were done using SDO/AIA (Lemen et al., 2012), RHESSI (Lin et al., 2002), and GOES (White et al., 2005) instruments. These instruments are sensitive to the solar plasma in various temperature ranges: 0.5–20 MK (AIA), 4–40 MK (GOES), and above $\sim 10$ MK (RHESSI). RHESSI also allows observing hard X-ray emission in various energy bands. These spacecraft observations were complemented by $H_\alpha$ data from Kanzelhoehe Solar Observatory[1] with the imaging system providing 5 full-disk images per minute.

As shown in the panel [d] of Fig. 1, the flux density at 140 GHz exceeds that of at 93 GHz and its maximum (09:55:30 UT) coincides with the maximum GOES light curves at 1–8 and 0.5–4 Đ(panel [a]). The RHESSI light curves in ranges 25–50, 50–100, and 100–300 keV as well as microwave radio flux at 6.1, 8.8, and 11.7 GHz are presented in panels [b] and [c]. It is important to note that hard X-ray emission with photon energies $> 50$ keV is very weak and it has only one maximum as distinguished from the 25–50 keV time profile (panel [b] in Fig. 1).

As it follows from the upper panel in Fig. 2, the millimeter spectral index was, on average, equal to about 1.8 near the peak (09:55:24–09:55:36 UT) of emission. The error bars in our case indicate the error in measurements caused by the antenna and receiver noises, the beam pointing error as well as the atmospheric attenuation for millimeter emission. We note that the corresponding hard X-ray photon spectrum (Fig. 2, lower panel) is characterized by the very steep slope. According to the spectrum-fitting procedure, a thermal part of the observed hard X-ray is fitted by the

[1] http://www.kso.ac.at