DOI: 10.31401/WS.2021.proc.04

Simultaneous Observations of Solar Radio Bursts with Ukrainian Radiotelescopes and by Parker Solar Probe During Its Encounter

Bubnov I.N.[1,2], *Stanislavsky L.A.*[1] *and Yerin S.N.*[1,2]

[1] Institute of Radio Astronomy NASU, Kharkiv, Ukraine
[2] V.N. Karazin Kharkiv National University, Ukraine

E-mail: bubnov.igor.n@gmail.com

Abstract.

The analysis of solar radio bursts observed by the Parker Solar Probe (PSP) and their interpretation are of great interest. In the encounter phase the space-based instrument has the time resolution about 7 sec in the frequency range of 10 kHz – 19 MHz However, this is not enough to recognize a fine structure of solar bursts, especially in high frequencies. It is useful for understanding intrinsic properties of emission mechanism in the solar corona. The problem can be overcome (partially or completely) by simultaneous ground-based observations using more advanced antennas and receivers. In this context the Ukrainian radiotelescopes are very useful, because they record solar radio emission at extremely low frequencies, near the ionospheric cutoff. We detect directly the radio events, observed by the PSP, having the frequency range that intersects with the frequency band of our instruments. This allows ones to discover solar phenomena in the corona reliably and confidently.

Introduction

Solar radio bursts are currently observed below 8 MHz by spacecraft devices above the terrestrial ionosphere [see, for example, *Bougeret et al.*, 2008; *Gopalswamy*, 2016 and references therein]. The success of such measurements is due to a number of reasons. Often the solar bursts of II, III and IV types are very intensive and sufficiently long in time. However, many ground-based observations manifest that the diversity of solar radio bursts at low frequencies is much more, and they varies in flux and frequency-time features [*Alissandrakis*, 2020], demonstrate a fine structure. Unfortunately, the spacecraft capabilities do not give such high resolution in time and frequency as ground-based instruments. Besides, the sensitivity of low-frequency spacecraft antennas is not high yet because of their simple design [*Stanislavsky et al.*, 2009]. Therefore, coordinated observations of solar bursts with ground- and space-based instruments are so preferable for better understanding the generation mechanisms leading to the variety of solar bursts, during different solar activity events. New missions open extended possibilities for space-based observations together with ground-based instruments. One of them is the Parker Space Probe (PSP).

The aim of this work is to consider a specific limiting feature of the PSP in radio observations of solar bursts and the role of ground-based radio telescopes with high time-frequency resolution in overcoming them. It should be pointed out that the Ukrainian radio telescopes (such as UTR-2, GURT, URAN) have been participated in the ground-based support of many space missions (STEREO, Wind/WAVES, Cassini, Juno) [*Konovalenko et al.*, 2016]. Their contribution was successful and informative. The PSP mission possesses new interesting advantages allowing us to improve this collaboration and our experience in the study of solar radio emission at low frequencies.

Observations and facilities

a) PSP spacecraft and its radio instruments

The PSP spacecraft are going to make 26 orbits around the Sun. Using repeated gravity assists at Venus, the probe will incrementally decrease its orbital perihelion to achieve a final altitude (above the surface) of approximately 8.5 solar radii. On June 7, 2020 it was in perihelion 5. Direct radio measurements on PSP are performed with the FIELDS instrument [*Bale et al.*, 2016]. As sensors of radio emission, it uses four whip antennas (called V1-V4) mounted near the edge of the PSP heat shield, and each of them is 2 meters long. Radio observations are processed by the dual-channel receiver. Low Frequency Receiver (or briefly LFR) covers the bandwidth of 10.5 kHz – 1.7 MHz, and another (High Frequency Receiver or HFR) is designed for the bandwidth of 1.3 MHz – 19.2 MHz [*Pulupa et al.*, 2017]. If the spacecraft flies closer to the Sun than 0.25 au, all its instruments operate continuously at a high-rate recording mode. This case is an encounter phase. There is also a cruise phase, when the distance of PSP from the Sun is larger than 0.25 au, and the data-recording rate becomes low. During the encounter phase, LFR and HFR record raw data at a cadence of one spectrum per ~7 seconds, whereas in another phase the data-recording cadence is noticeably less, one spectrum per ~56 seconds.

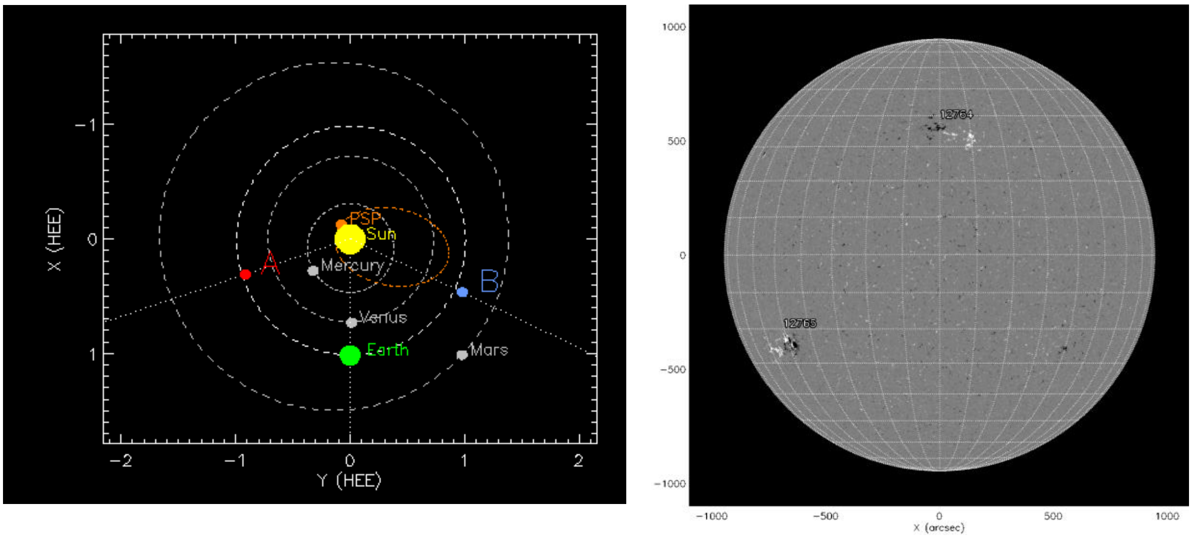

Fig.1. Positions of planets, spacecrafts STEREO A and B, as well as the PSP orbit (orange dotted line) and its position on June 5, 2020 (left picture). The right picture represents the solar SDO HMI magnetogram with active regions in that day.

b) Ground-based radio telescopes

The Giant Ukrainian Radio Telescope (GURT) is a new instrument designed to empower the UTR-2 in terms of spatial dimensions and frequency range and located nearby the latter [*Konovalenko et al.*, 2016]. One array section of the GURT consists of 25 cross-dipoles, five in each column and row. It just was used for the observations on June 5, 2020. The distance between the crossed dipole antenna elements is 3.75 m, and the suspension height is 1.6 m. The subarray design provides a wide frequency coverage from 8 to 80 MHz, high sensitivity (the galactic background level exceeds their self-noise by more than 7 dB), and high radio-frequency interference immunity due to high dynamic range of the dipole amplifier (input IP3 is 30 dBm). The effective area at the central frequency, confirmed by computer simulations and direct measurements, is about 350 m^2. The apparent advantages of the GURT over the UTR-2 are the ability to measure full polarization characteristics of the received radio waves and to track the source down to the altitude of a few arc degrees above the horizon. The GURT subarray is inferior to each UTR-2 section in sensitivity in the same frequency range, but the former has more than two times wider frequency band for observations. The spectrum records of solar radio emission were obtained by using the receiver ADR (short abbreviation for advanced digital receiver) which is a standard device of the radio telescope GURT [*Konovalenko et al.*, 2016]. Based on the technique, the frequency and time resolutions were about 4.8 kHz and 100 ms, respectively, in each channel.

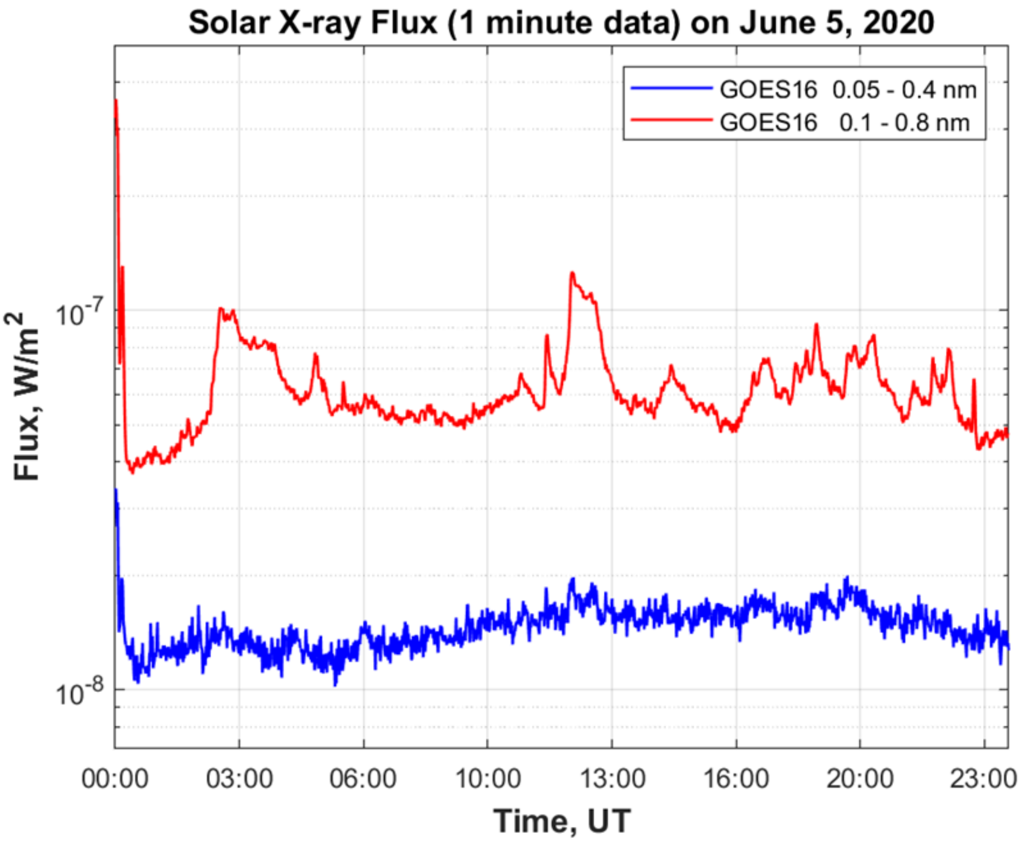

Fig.2. Solar X-ray data from GOES-16 covering 0.05-0.4 nm and 0.1-0.8 nm integrated passbands on June 5, 2020. Solar activity was weak.

c) Solar events and their observations

In the summer of 2020 the Sun was in a deep minimum. After the flare of the M class on May 29, 2020 the solar radio bursts were detected in early June 2020. This was the first noticeable manifestation of solar activity, starting from October 2017, when several X-class flares of September 2017 were observed. The activity was connected with a new active area, named NOAA AR12765, appeared on the limb from the eastern side of the Sun on June 3, 2020. The evolution of the active region started with a single spot, which became a small bipolar region on June 5, 2020 (Fig. 1). In the following days the region remained bipolar, but decaying, after 10 June it became unipolar until it vanished completely, moving to the far side of the Sun. The AR 12764 was only unipolar and non-active. Fig. 2 demonstrates the solar X-ray data from the satellite GOES-16. Often bipolar magnetic fields on the Sun are responsible for the type U solar radio bursts [*Reid and Ratcliffe*, 2014]. Such a radio burst was recorded with the GURT on June 5, 2020 [*Stanislavsky et al.*, 2021]. Solar observations on June 5, 2020 were also available with space-based observatories: Wind/WAVES, STEREO-A and PSP. They together observed the Sun and its activity from different points of view (Fig.1). On June 5, 2020, the PSP was near perihelion, at the distance of ~0.15 au from the Sun. This case just corresponds to the encounter phase. For the PSP spacecraft the AR 12765 was behind the solar limb with respect to the central meridian of the Sun. The STEREO-A, Wind/WAVES and ground-based observers can "see" directly the active region on the solar photosphere. The spectrogram from the PSP observations is shown in Fig. 3, whereas Fig. 4 shows the GURT U-type burst record.

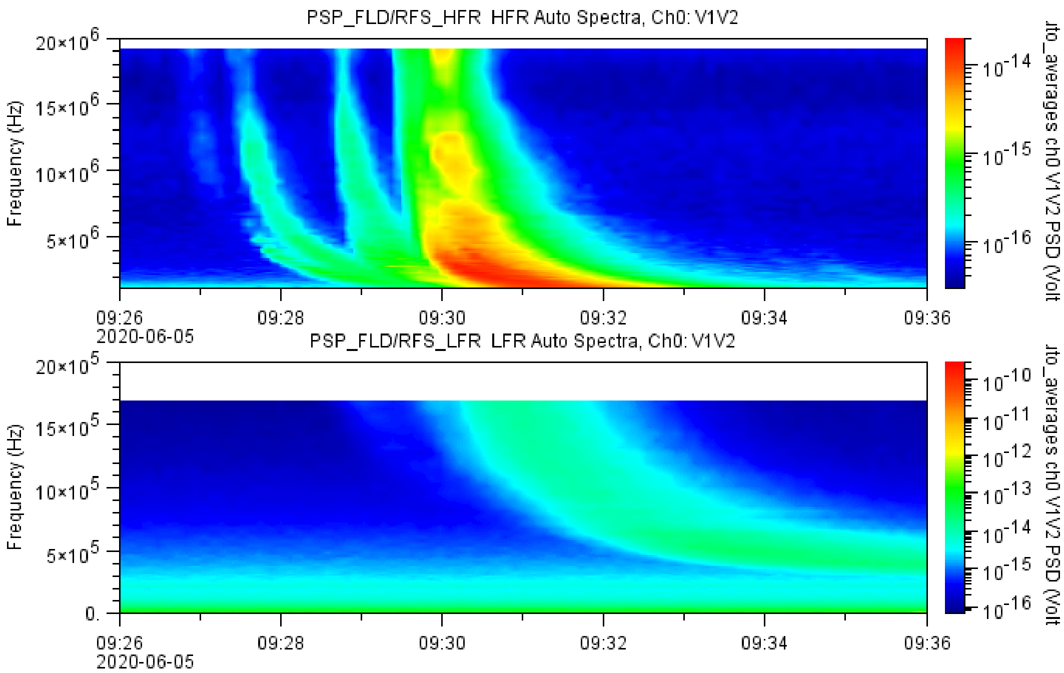

Fig.3. PSP radio spectra on June 5, 2020: the top picture was obtained with HFR, whereas the bottom picture manifests the LFR spectrum.

Data analysis and results

The most numerous among the solar bursts are bursts of type III [*Reid and Ratcliffe*, 2014], observed during both high and low solar activity and caused by high velocity electron beams. The electron beams move through open magnetic field lines, generating plasma waves which are scattered on ions, transforming into radio emission. That is why their frequency drift rate is so high. Typically, the type III bursts manifest a monotonic shape in dynamic spectra, going from high to low frequencies, showing the motion of beams to Earth. Nevertheless, the closed magnetic fields on the Sun can change this motion direction of beams, exhibiting the effect in dynamic spectra. Their overall spectral signature resembles the letters J and U, and the bursts are therefore called the type J and the type U, respectively [*Reid and Kontar*, 2017].

On June 5, 2020 we observed the U-type burst associated with type III solar radio bursts. This event was detected by many ground- and space-based radio instruments. These include such as the Nançay Decametric Array (NDA) in France, e-Callisto network stations, STEREO

A, Wind/WAVES and our radio telescopes [see *Stanislavsky et al*., 2021]. This means that the

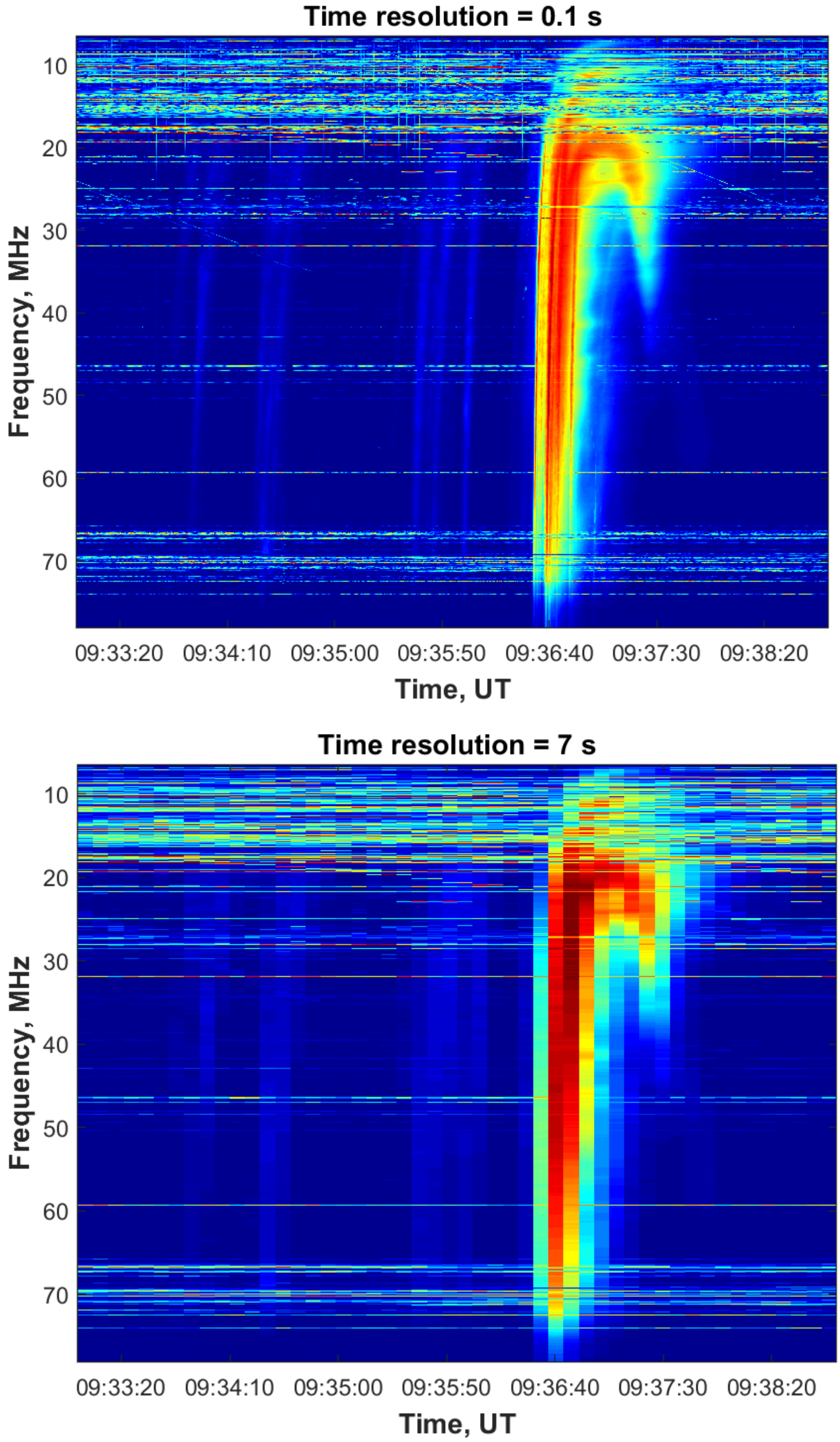

Fig.4. GURT spectra on June 5, 2020 with two different time resolutions: the top picture has original resolution (100 ms), whereas the bottom picture shows what the spectrum would look like with a resolution of 7 seconds typical for PSP radio measurements in the encounter phase.

observed U+III bursts had the solar origin and cannot be caused by ionospheric disturbances and/or equipment malfunctions. According to the radio observations by the PSP (Fig. 3), the event contains four bursts following each other. The most power burst was last. It is just related to the U-type solar burst mentioned above. Notice, the PSP received signals of solar bursts about 7 minutes earlier than the ground-based radio telescopes as the former was located about 6.7 times closer to the Sun. If we compare them with records obtained with the GURT (Fig. 4), the first, second and third bursts, shown in Fig. 3, are nothing but groups of type III solar bursts rather than separate bursts, as it may seem. This effect is explained by the PSP time resolution in ~ 7 sec. Therefore, very close bursts merge into one. As an example, Fig. 4 demonstrates two GURT spectra, the first of which has the original resolution, whereas another is rougher.

Conclusions

Based on this study we can notice following points:

1. The radio measurements with the PSP in the frequency range 8 – 19.2 MHz have so low temporal resolution that they cannot compete with observations of the ground-based radio telescopes such as the UTR-2 or the GURT.
2. Nevertheless, the PSP records manifest that the type III solar bursts were interplanetary.
3. Analyzing the solar bursts with the PSP measurements, the ground-based radio telescope records with high frequency-time resolution will come in handy.

Acknowledgment

The authors acknowledge a support of Grant 0120U101334 from the National Academy of Sciences of Ukraine and the GOES, STEREO and SDO teams for developing and operating the instrument as well as for their open data policy. The FIELDS experiment on the Parker Solar Probe spacecraft was designed and developed under NASA contract NNN06AA01C.

References

Alissandrakis, C.E. (2020). Structure of the solar atmosphere: a radio perspective, Front. Astron. Space Sci., 7, id.74, 10.3389/fspas.2020.574460, 2020.

Bale, S.D., Goetz, K., et al. (2016). The FIELDS instrument suite for solar probe plus–Measuring the coronal plasma and magnetic field, plasma waves and turbulence, and radio signatures of solar transients, Space Sci. Rev., 204, 49-82, 10.1007/s11214-016-0244-5, 2016.

Bougeret, J.L., Goetz, K., et al.: (2008). S/WAVES: The radio and plasma wave investigation on the STEREO mission, Space Sci. Rev., 136, 487-528, 10.1007/s11214-007-9298-8, 2008.

Gopalswamy, N. (2016). Low-frequency radio bursts and space weather, URSI Asia-Pacific Radio Science Conference, 471-474, 10.1109/URSIAP-RASC.2016.7601368, 2016.

Konovalenko, A., Sodin, L., et al. (2016). The modern radio astronomy network in Ukraine: UTR-2, URAN and GURT, Exp. Astron., 42, 11-48, 10.1007/s10686-016-9498-x, 2016.

Pulupa, M., Bale, S., et al. (2017). The Solar Probe Plus Radio Frequency Spectrometer: Measurement requirements, analog design, and digital signal processing, J. Geophys. Res., 122, 2836-2854, 10.1002/2016JA023345, 2017.

Reid, H.A.S., Kontar, E.P. (2017). Imaging spectroscopy of type U and J solar radio bursts with LOFAR, Astron. Astrophys., 606, A141, 10.1051/0004-6361/201730701, 2017.

Reid, H.A.S., Ratcliffe, H. (2014). A review of solar type III radio bursts, Res. Astron. Astrophys., 14, 773, 10.1088/1674-4527/14/7/003, 2014.

Stanislavsky, A.A., Konovalenko, A.A., et al. (2009). Antenna performance analysis for decameter solar radio observations, Astron. Nachr., 330, 691-697, 10.1002/asna.200911226, 2009.

Stanislavsky, L.A., Bubnov, I.N., et al. (2021). The first detection of the solar U+III association with an antenna prototype for the future lunar observatory, Res. Astron. Astrophys., 21, id. 187, 10.1088/1674-4527/21/8/187, 2021.