

## **Giant Ukrainian Radio Telescope as an Instrument for Interplanetary Scintillation Observations**

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The potential of the radio telescope GURT in its present state for interplanetary scintillation (IPS) observations is discussed. We estimated the minimum detectable flux density in the case when two subsections of the radio telescope GURT are used. Corresponding test experiments have been also carried out. This work is interesting from point of view of expanding the global IPS network.

### **Introduction**

The beginning of the new millennium is marked by a sharp increase in interest in low-frequency radio astronomy. This is due, among other things, to the importance of the effects and cosmic objects that radio astronomy studies. So it is at low frequencies there are strong interaction of emission and space plasma; significant excess of non-thermal over thermal radio emission intensity, formation of many types of non-thermal radio emission with steep spectra. Some types of sporadic solar and planetary radio emission also have maximum at decameter - meter wavelengths. The increased interest is accompanied by the construction of a number of new unique radio telescopes such as Low Frequency Array (LOFAR), the Netherlands, 30 to 80 and 110 to 240 MHz [*van Haarlem et al.*, 2013], the Long Wavelength Array (LWA), USA, 10 to 88 MHz [*Taylor et al.*, 2012], the Murchison Wide-field Array (MWA), Australia, 80 to 300 MHz, new extension in Nançay Upgrading LOFAR (Nenu-FAR), France, 10 to 85MHz [*Zarka et al.*, 2012]. A similar radio telescope GURT is being created in Ukraine [*Konovalenko et al.*, 2016 a, b]. These instruments are already being used for investigations of the Sun, the Earth's ionosphere, and solar-terrestrial connections.

The aim of this paper is to estimate the perspectives of using the radio telescope GURT for interplanetary scintillation studies.

### **The radio telescope GURT**

GURT is being built at S. Y. Braude radio astronomical observatory in Kharkiv region, Ukraine (Fig.1). It is a phased array composed of identical subarrays consisting of 25 active antenna elements. Each antenna element is a crossed dipole (Fig.2a). The distance between antenna elements is 3.75 m, their height above the ground is 1.6 m. The subarray design provides a wide operational frequency range from 8 to 80 MHz, high sensitivity (the galactic background level exceeds their self-noise by more than 7 dB), and high interference immunity (achieved due to the high dynamic range of the dipole amplifier: input IP3 of 30 dBm). Subarrays are currently being added, with the finished array planned to incorporate 100 subarrays for a total of 2500 elements. As number of subarrays and effective area increase the number of astrophysical problems to be solved with GURT will increase significantly too. For receiving and post-processing signals each GURT subarray is equipped with a wideband digital receiver (Advanced Digital Receiver, Fig. 2b) [*Vasilyev et al.*, 2014]. The receiver parameters are well matched with the parameters of the GURT subarray and allow us to receive the cosmic signals in whole frequency band (from 8 to 80 MHz) with high time-frequency resolution and high dynamic range. Receivers have the high sensitivity and low level of intrinsic noise. The radio telescope GURT is planned to be equipped with additional facilities aimed at participation in

joint international observation campaigns using other large radio telescopes located worldwide. As at the end of 2020, there is no phasing system for subarrays yet, it is possible to use either one subarray or two subarrays with multiplying signals of one polarization.



*Fig.1. North arm of the radio telescope UTR-2 (foreground) and the radio telescope GURT behind it (white color). S. Y. Braude radio astronomical observatory*



a)



b)

*Fig.2. a) An antenna element of the radio telescope GURT, b) laboratory room with receiving equipment*

Possibilities of electronic scanning in wide sectors, high sensitivity in a wide frequency range and high interference immunity have allowed experiments to be carried out by using only one or two subarrays (observations of sporadic solar and planetary radio emission or observations of radio pulsars) [Konovalenko *et al.*, 2016 a, b]. The aim of this paper is to estimate the perspectives of using the radio telescope GURT for the study of the interplanetary scintillations.

**Interplanetary scintillations**

InterPlanetary Scintillations (IPS) is the random intensity fluctuations of the radio emission of cosmic radio sources (quasars, radio galaxies, pulsars) caused by diffraction of the wave front in the interplanetary plasma. A. Hewish was the first who observed the interplanetary scintillations [Hewish *et al.*, 1964]. Observations of the interplanetary scintillations allow us to measure the interplanetary turbulence parameters as well as to estimate the angular structure of radio sources [Kojima *et al.*, 1982, Manoharan *et al.*, 1990, Breen *et al.*, 1996, Fallows *et al.*, 2008]. IPS observation also is a powerful tool for studying interplanetary coronal mass ejections (ICME) and other solar wind disturbances connected with solar activity. At decameter wavelengths IPS observations are regularly carried out in Institute of Radio Astronomy of NAS of Ukraine by using UTR-2 - URAN radio telescopes [Konovalenko *et al.*, 2016 a] for the last 20 years [Kalinichenko, 2009; Falkovich *et al.*, 2010; Kalinichenko *et al.*, 2017; Kalinichenko *et al.*, 2019].

Now for IPS observations it is possible to use two subarrays of the radio telescope GURT with multiplying signals of one polarization. Let us estimate the minimum flux that a source should have in this case. It can be done in the following way.

The power spectra of the IPS signal and the noise are expressed by a power law:

$$P_{s,n}(f) = \frac{1}{1 + (f / F_{s,n})^{\alpha_{s,n}}},$$

where the indices “s” and “n” refer to the signal and the noise, respectively.  $\alpha_n$  is equal to 2 and  $F_n = 1/2\pi\tau$  ( $\tau$  is the time constant).  $\alpha_s$  varies from 2 to 4,  $F_s \approx 0.3$  Hz. The expression for the dynamic range of  $P_s(f)$  can be written as:

$$\frac{P_s(0)}{P_n(0)} = \gamma \frac{\sigma_s^2 F_n}{\sigma_n^2 F_s} = \frac{\gamma}{2\pi\tau} \frac{\sigma_s^2}{F_s \sigma_n^2},$$

where  $\sigma_s^2 = \frac{m^2 S^2 A_{ef}^2}{4k^2}$ ,  $\sigma_n^2 = \frac{T_{sys}^2}{\Delta f \tau}$ ,  $S$  is the flux density,  $A_{ef}$  is the effective area,  $T_{sys}$  is the system noise temperature (it is equal to the galactic background temperature),  $\Delta f$  is the observing bandwidth,  $k$  is Boltzmann’s constant ( $k = 1.38 \cdot 10^{-23}$  Дж/К). The coefficient  $\gamma$  ranges from 1 to 1.4 and takes into account the variations of  $\alpha_s$ . The variance of the periodogram estimate at any frequency is known to be equal to the square of its expectation value at that frequency (or the standard deviation is 100 percent of the value). The variance of the averaged estimate is smaller than the estimate itself by a factor of  $1/N$ , where  $N$  is the number of the averaged spectra. As we usually use  $N=10$ ,  $P_s(0)/P_n(0)$  has to be larger than 100 for interplanetary plasma parameters can be effectively estimated. The minimum detectable flux density  $S_{min}$  (in Jy) for  $P_s(0)/P_n(0)=100$  and  $\gamma = 1.2$  (mean value) can thus be estimated as:

$$S_{min} = 46 \frac{k T_{sys}}{m A_{eff}} \sqrt{\frac{F_s}{\Delta f}}.$$

$S_{min}$  is equal to about 800 Jy for the parameters:  $A_{eff} = 225 \cdot m^2$ ,  $m=0.2$ ,  $T_{sys} = 8 \cdot 10^3$  K (for the frequency of 45 MHz in the middle part of the GURT frequency band (10 to 80 MHz),  $\Delta f = 70$  MHz).

### Observations

Only one compact radio source has such a powerful flow. This is a compact radio source in Crab Nebula. Crab Nebula is the most famous and well studied supernova remnant formed from the star that exploded in the year 1054 AD. It is identified as a strong source of x-ray, optical and radio emission. At radio frequencies this supernova remnant is associated with the radio source 3C144. The compact radio source in Crab Nebula is known to be associated with the well-known pulsar PSR B0531 +21. The pulsar flux at decameter wavelengths is about 1000 Jy and the angular size of approximately 2 arcsec.

The observations of Crab Nebula was carried out at hour angles 1.5 hr near the upper culmination with scans lasting 20 min. Records were obtained by using Advanced Digital Receiver which allows us to carry out spectral analysis of a band up to 80 MHz wide (at a sampling frequency of 160 MHz) with high frequency and time resolutions. Fig. 3 shows examples of dynamic scintillation spectra (intensity in the time/frequency plane) obtained in the process of the observations. It can be seen that the Crab Nebula showed both ionospheric (long-period) and interplanetary (short-period) scintillations.

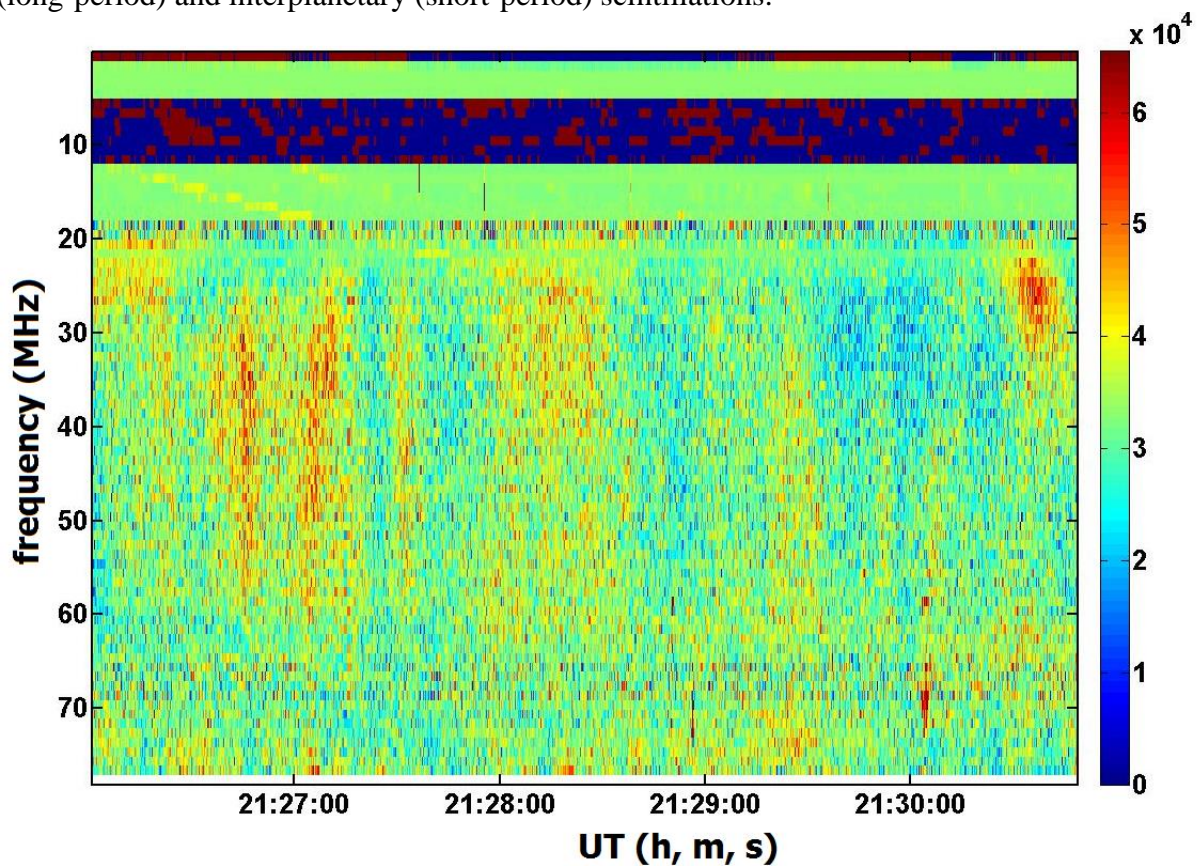


Fig.3. Dynamic scintillation spectrum of Crab Nebula

Let us estimate the scintillation spectrum by:

$$P(\nu) = |F(\nu)|^2 / T,$$

where  $F(\nu)$  is Fourier transform of scintillation process,  $\nu$  is the fluctuation frequency,  $T$  is the duration of time series (20 min).

Fig. 4 shows an example of daily averaged scintillation spectrum of Crab Nebula.

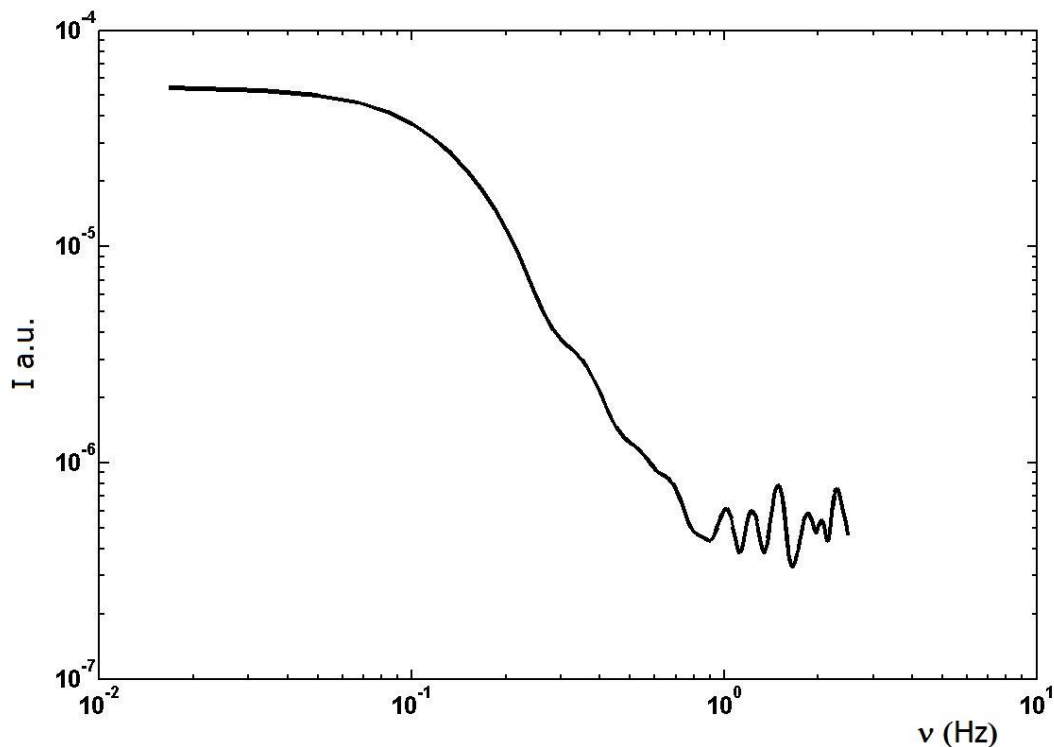


Fig.4. Scintillation spectrum of Crab Nebula

It can be seen that observed scintillation spectrum of Crab Nebula consists of low and high-frequency parts associated with Earth's ionosphere and interplanetary plasma correspondingly.

### Conclusions

The carried out investigations show the possibility to register interplanetary scintillations with only two subarrays of the radio telescope GURT. As the number of GURT subarrays increases, the sensitivity of IPS measurements will increase too. So joint observations of the same radio sources with GURT, UTR-2 - URAN and LOFAR radio telescopes will become possible. Such long - base observations can provide new information on the interplanetary plasma and physical processes in it.

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