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Statistical Characteristics of Radio Source Scintillations at Decameter Wavelengths

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Abstract.

This article shows the results of determination of some statistical characteristics (break frequency and exponent of power spectrum and cross - correlation coefficient between signals at two frequencies) of the interplanetary and ionospheric radio stars scintillations in the frequency range 20 to 30 MHz. These statistical characteristics have been obtained by processing synchronous scintillation data from two radio telescopes UTR-2 and URAN-2 belonging to Ukrainian low frequency system URAN (operating frequency range of the radio telescopes is 8 to 32 MHz, decameter wavelengths). The data processing with record statistics for decameter wavelengths has shown that mentioned above statistical characteristics are essentially different for interplanetary and ionospheric scintillations. The results obtained in the article can be used at decameter wavelengths for: improving techniques used for obtaining the interplanetary and ionospheric plasma parameters, separation of the interplanetary and ionospheric scintillations, estimation of their effects on low frequency radio astronomical observations.

Introduction

When conducting low frequency radio astronomical observations from Earth's surface, the main source of errors and an important interfering factor is the influence of irregularities in the interplanetary and ionospheric plasma. To estimate these effects, it is necessary to know scintillation characteristics on the specified media with sufficient statistics. Also, the better we know scintillation characteristics the more sophisticated technique can be created and used for data processing and obtaining the parameters of the interplanetary and ionospheric plasmas. The statistical characteristics of the interplanetary scintillations are well known at high frequencies (higher or about 100 MHz) [see e.g. *Cohen et al.*, 1966; *Salpete*r, 1966; *Shishov and Shishova*, 1979; *Fallows et al.*, 2008 and others] at least in the weak scattering case. This cannot be said about the decameter range of radio waves. There is a small set of works made in the last century based on episodic observations [Bovkoon and Zhock, 1981a, Bovkoon and Zhock, 1981b]. Among other things, this is due to the relative complexity of scintillation observations in the discussed frequency range when the operating frequencies are close to the critical frequency of Earth's ionosphere and when there exist a relatively large level of human made interference. The ionospheric scintillation characteristics are better known [see e.g. *Crane*, 1972, *Rashkovsky*, 2004] although there are some debatable issues here too [*Fallows e*t *al.*, 2016]. The purpose of this work was to estimate break frequency and exponent of power spectrum as well as cross - correlation coefficient between signals at two frequencies for the interplanetary and ionospheric scintillations in the operating frequency range 20 to 30 MHz with record statistics for decameter range.

Observations

Since 2001, we have regularly carried out scintillation observations [*Kalinichenko*, 2009; *Kalinichenko et al.* 2019; *Kalinichenko et al.*, 2021] with URAN radio telescope system containing 5 radio telescopes including the largest in the world decameter radio telescope UTR-2 [Konovalenko et al., 2016] (Fig. 1). Ukrainian low frequency radio telescopes are situated throughout the Ukraine (UTR-2 – Grakove, URAN-1 – Zmiiv, URAN-2 – Poltava, URAN-3 – Lviv, URAN-4 – Odesa). The operating frequency range of the radio telescopes is 8 to 32 MHz (decameter range).

a)

b)

c)

d)

e)

Fig.1. Outward appearances of Ukrainian decameter radio telescopes: a) - UTR-2, b) - URAN-1, c) - URAN-2, d) - URAN-3, e) - URAN-4).

Fig. 2 shows an example of the registration of scintillations by using radio telescopes UTR-2 and URAN-2. These are so-called dynamic spectra (intensity on plane time vs frequency).

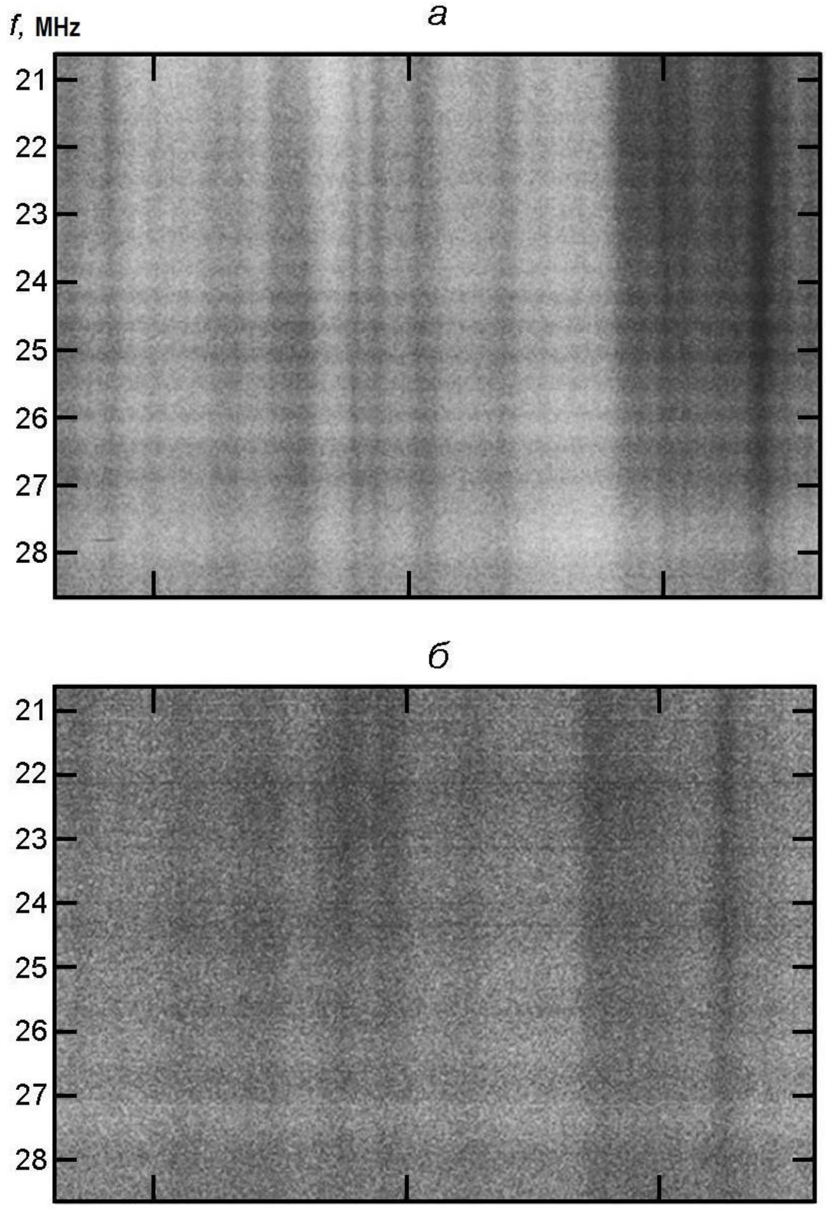


Fig.2. Dynamic spectra of scintillations registered by using the radio telescopes UTR-2 (a) and URAN-2 (b).

Data processing

To achieve our goal, we have analyzed scintillation data from the radio telescope UTR-2 and the radio telescope URAN-2 obtained synchronously since 2015, for 5 years, in the same month, in November. The observations session lasted as usually for 7 days. We have analyzed scintillations among many others of three sources. One of them is the radio galaxy Virgo A and two others are the supernova remnants Cassiopeia A and Crab Nebula. These are the most powerful radio sources at decameter wavelengths in the sky. Cassiopeia A and Virgo A scintillate only on the irregularities of Earth's ionosphere while Crab Nebula shows the interplanetary scintillations too. So we could obtain statistical characteristics both of the interplanetary and ionospheric scintillations.

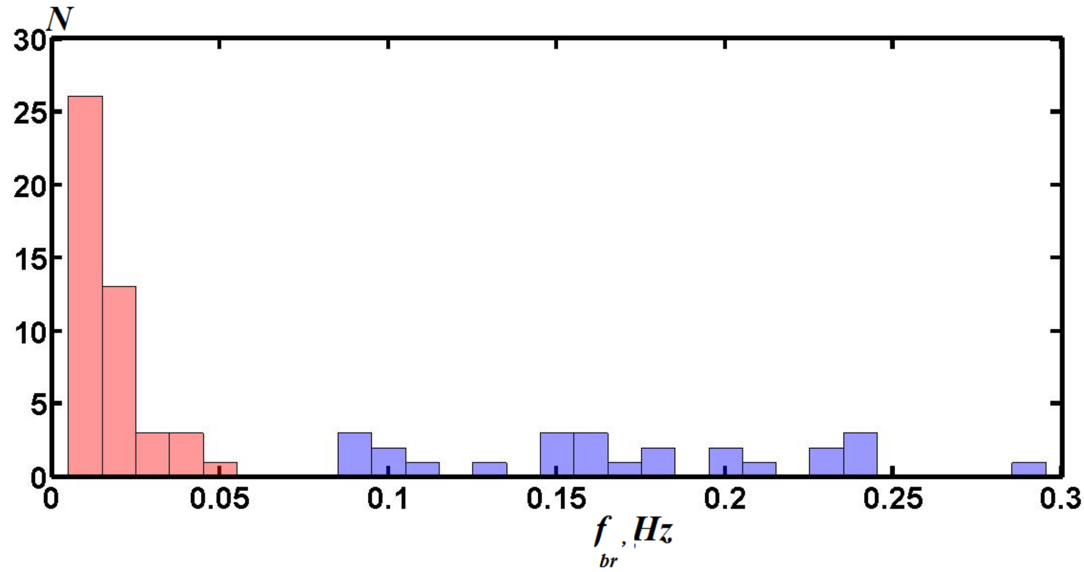
Data processing consists in estimation of power spectrum $P(\nu)$ (1) and the cross-correlation coefficient between signals at two frequencies selected at the edges of the range 20 to 30 MHz (2):

$$P(\nu) = |F(\nu)|^2 / T, \tag{1}$$

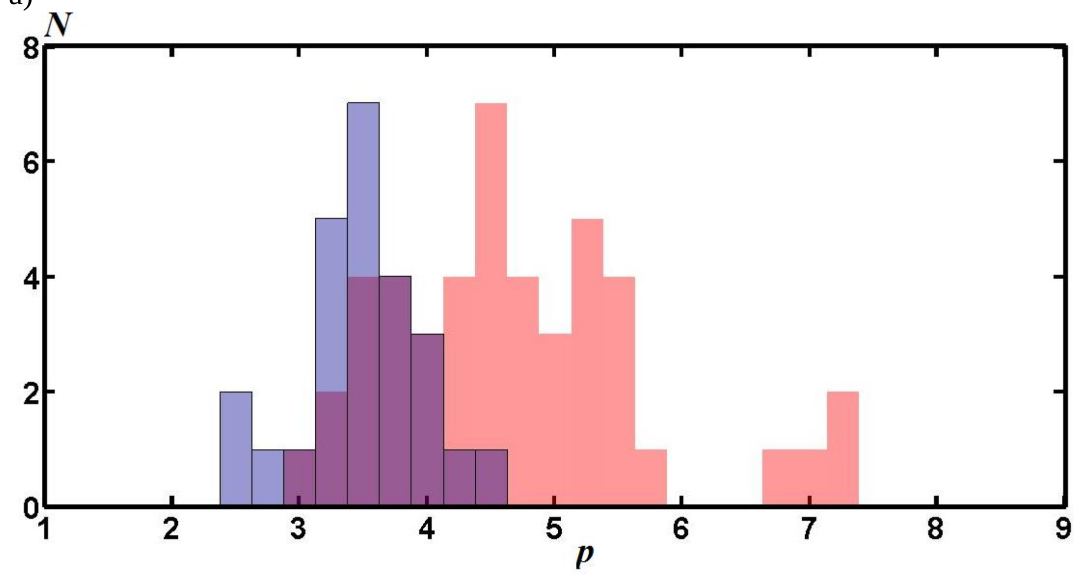
where $F(\nu)$ is Fourier transform of $I(t)$ process, ν is the fluctuation frequency, T is the duration of time series.

$$R(\tau) = \int_{-T}^{T} I_1(t) I_2(t+\tau) dt \tag{2}$$

Fig. 3 shows daily averaged values for two important parameters of scintillations spectrum: break frequency (Fig. 3a) and exponent of spectrum (spectral index) (Fig. 3b). The red histograms correspond to the ionospheric scintillations and blue histograms are the interplanetary scintillations.



a)



b)

Fig.3. The break frequency (a) and exponent of power spectrum (b) for interplanetary (blue) and ionospheric (red) scintillations .

It is well seen that the mean values of break frequency are essentially different for the interplanetary and ionospheric scintillations (0.16 and 0.01 Hz correspondingly). There is an appreciable difference in exponent of power spectrum (3,5 and more than 4) for the interplanetary and ionospheric scintillations. These results are consistent with those obtained earlier at decameter wavelengths in the articles [Bovkoon and Zhock, 1981a] and [Bovkoon and Zhock, 1981b] based on episodic observations with low statistics. Our results also demonstrate all possible values for break frequency and exponent of power spectrum. The difference between power spectra of the interplanetary and ionospheric scintillations is used for spectral separation of these types of scintillations. And in general, the different fluctuation frequencies are frequently the most obvious criterion for existence of one or the other type of scintillations in low frequency radio astronomical data.

Fig. 4 shows cross - correlation coefficient between signals at two frequencies (which were selected at the edges of the range 20 to 30 MHz). The frequency spacing is 8 MHz. The red histogram corresponds to the ionospheric scintillations while the blue histogram is the interplanetary scintillations. It is well seen that the interplanetary scintillations are well correlated for mentioned above frequency spacing while ionospheric ones not. These results are also consistent with those obtained in earlier work at higher frequencies [*Fallows et al.*, 2014, *McKay-Bukovski et al*., 2015].

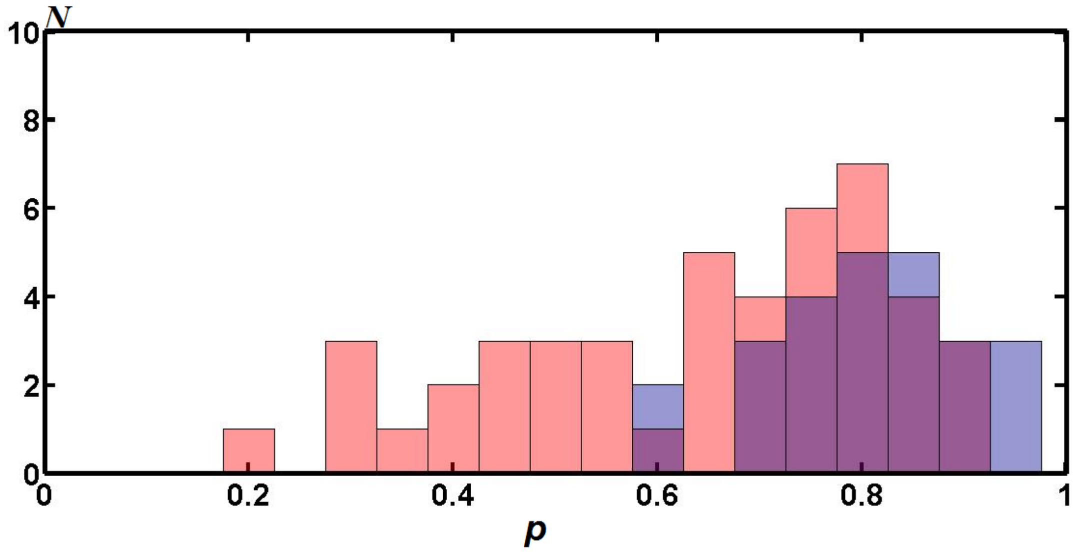


Fig.4. The cross - correlation coefficient between signals at two frequencies selected at the edges of the range 20 to 30 MHz. The red histogram corresponds to the interplanetary scintillations and the blue histogram is the interplanetary ones.

Conclusions

Obtained results can be used for: improving techniques used for estimation of the interplanetary and ionospheric plasma parameters, separation the interplanetary and ionospheric scintillations, estimation of the interfering influence of the interplanetary and ionospheric plasma on radio astronomy experiments of a wide range of targets, analysis of the interplanetary scintillations at other frequencies.

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