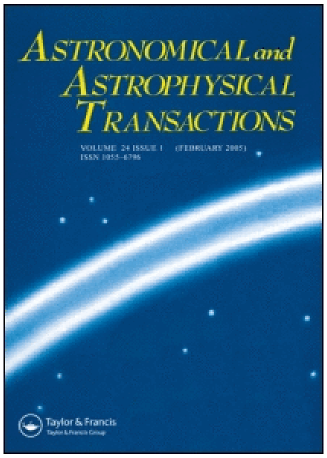

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Monitoring of interplanetary and ionosphere scintillations at frequency 110 MHz

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Large Phased Array of the P.N. Lebedev Physical Institute is the most sensitive in the world at the metre waveband. It allows simultaneous observation of two independent diagrams each consisting of 16 beams. We are planning to introduce a program of monitoring interplanetary and ionospheric scintillation using observations of radio sources by one multi-beam diagram. The methods of observations and data reduction are discussed. We present the first results of seven day test observations for a strip of the sky in a region with declinations between 28° and 32° by using an eight-beam diagram.

Keywords: Solar wind; Interplanetary scintillation; Ionospheric scintillation

1. Introduction

The method of radioastronomical mapping of interplanetary plasma based on observations of interplanetary scintillation of several hundreds of sources was proposed in 1976 [1]. This method made it possible to explore the global structure and non-stationary phenomena in the solar wind [2–5]. The grid densities in these measurements were about one source per 30 square degrees. Angular resolution was not sufficient for detailed exploration of the interplanetary shock structure for any individual event [5]. It was proposed in [6] to observe simultaneously a large number of weak scintillating sources in 16 beams of Large Phased Array antenna (LPA) of the P.N. Lebedev institute. It allows the observation of hundreds of sources in the sky strip with a size of $8^\circ \times 24^{\mathrm{h}}$.

Below we present the results of 24 observations of interplanetary and ionospheric scintillations during one week in April 2006.

2. Observations

We carried out 24 observations of interplanetary and ionosphere scintillations during 4–10 April 2006. Observations were performed with eight beams of Large Phased Array antenna

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(LPA) of P.N. Lebedev institute at the Pushchino Radio Astronomy Observatory, at a frequency of 111 MHz using 600 KHz bandwidth and time constant of 0.1 s. All the beams neighbours are equally separated by 0.5° in declination. The half power beam width (HPBW) is approximately equal to $0.5° \times 1°$. In addition LPA is the meridian instrument. Therefore, sources can be observed only when they pass the reception pattern. Eight beams registered all sources in the declination range from $+28° \div 31°$.

3. Reduction of observational data

Initial data of our observations are the fluxes for each beam as functions of the time $I_1(t)$. We calculate a structure function of flux fluctuation for some known scintillating sources:

$$D_{\mathrm{I}}(\tau, t) = \langle [I(t+\tau) - I(t)]^2 \rangle. \tag{1}$$

The angle brackets correspond to time averaging over 1-min time intervals. The structure function of flux fluctuations usually has a two-component shape. A component with characteristic temporal scale 1 s is determined by the interplanetary scintillation. The second component with the characteristic scale of 10 s is determined by ionospheric scintillation. We also calculated the asymmetry function [7]:

$$\begin{aligned} \gamma_{2,1}(\tau, t) &= -\frac{2\langle [\Delta_2(\tau, t)]^3 \rangle}{\{[4D_{\mathrm{I}}(\tau, t) - D_{\mathrm{I}}(2\tau, t)][D_{\mathrm{I}}(2\tau, t)]^{1/2}\}} \\ \Delta_2(\tau) &= I(t+\tau) - 2I(t) + I(t-\tau) \end{aligned} \tag{2}$$

As shown in [7], the asymmetry function is related to the structure function $D_{\mathrm{I}}(\tau, t)$ by the formula

$$\gamma_{2,1}(\tau, t) = \frac{A[D_I(\tau, t)]^{1/2}}{\langle I_{\mathrm{c}} \rangle} \tag{3}$$

where I_{c} is the flux of the compact scintillating component of the source and A is a weak function on τ.

For mass-measurement we used the values of the structure function of flux for time delays 1 s and 10 s for each beam $D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ and $D_{\mathrm{I},1}(\tau = 10\,\mathrm{s}, t)$. Time averaging combines time series over 1-min time intervals. The time required for a source to pass the antenna beam is approximately equal to 6 min. Therefore $D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ and $D_{\mathrm{I},1}(\tau = 10\,\mathrm{s}, t)$ were measured for 1 min, making it possible to obtain several significant points per LPA pattern. These parameters are equal

$$\begin{aligned} D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t) &= (2\sigma^2{}_{\mathrm{IPP}} + 2\sigma^2{}_{\mathrm{noise}}) \\ D_{\mathrm{I},1}(\tau = 10\,\mathrm{s}, t) &= (2\sigma^2{}_{\mathrm{ion}} + 2\sigma^2{}_{\mathrm{IPP}} + 2\sigma^2{}_{\mathrm{noise}}) \end{aligned} \tag{4}$$

Here $\sigma^2{}_{\mathrm{ion}}$ and $\sigma^2{}_{\mathrm{IPP}}$ are variances of flux fluctuations due to ionosphere and interplanetary scintillations and $\sigma^2{}_{\mathrm{noise}}$ is a noise variance. The time dependence of parameter $\lg D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ during the 24 interval for each beam is shown in figure 1. The value of $\lg D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ was averaged over all days of observation. The Sun position corresponds to time 4.5 hours. A minimal value of $\lg D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ corresponds to $\sigma_{\mathrm{noise}} \cong 0.35$ Jy. We can in fact measure sources with scintillation fluxes of the order of $\sigma_{\mathrm{IPP}} \geq 0.2$ Jy.

The scintillation index of a point source m_0 is determined only by the value of turbulent fluctuations of electron density. The scintillation index of real source m also depends on the

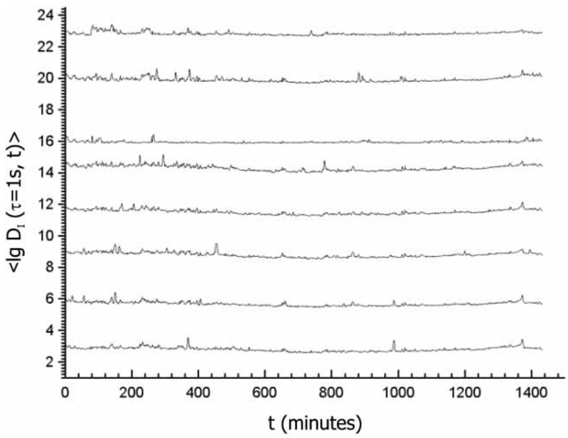

Figure 1. The time dependence $\lg D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ during the day and night intervals. The value $\lg D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$ was averaged over all days of observation. The Sun position corresponds to the time 4.5 hours.

source structure. We must preliminarily investigate the structure of each source and determine the factors that reduce the variance to the scintillation index

$$m_{0,\mathrm{IPP}}{}^2 = \frac{(\delta_c \delta_\varphi m_{\mathrm{IPP}} \sigma_{\mathrm{IPP}})^2}{\langle I \rangle^2} \tag{5}$$

where δ_c is fraction of flux of the compact scintillating component relative to total flux and δ_φ is the reduction factor determined by an angle size of the compact scintillating component of a source.

A variance of ionosphere scintillation is determined by a difference between $D_{\mathrm{I},1}(\tau = 10\,\mathrm{s}, t)$ and $D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t)$

$$2\sigma^2{}_{\mathrm{Ion},1} = D_{\mathrm{I},1}(\tau = 10\,\mathrm{s}, t) - D_{\mathrm{I},1}(\tau = 1\,\mathrm{s}, t) \tag{6}$$

Additionally we measured the values of the asymmetry function for time delays 1 s and 10 s. Neglecting a noise contribution we obtain [7]:

$$\gamma_{2,1}(\tau = 1\,\mathrm{s}, t) = 2^{1/2} 3\, \delta_\varphi\, m_{0,\mathrm{IPP}} \tag{7}$$

If ionosphere scintillation dominates we obtain the similar relation for $\gamma_{2,1}(\tau = 10\,\mathrm{s}, t)$.

4. The averaged observational data

To avoid measurement of the reduction factors for individual sources we use the measurements of the scintillation parameter averaged on a source ensemble. If the number of sources in the ensemble is sufficiently large we can suppose that the statistical properties of ensembles don't depend on the position in the sky. Therefore the effective reduction coefficients are the same for different ensembles. For averaging, we used $\lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t)$ instead of $D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t)$. It allows an increase of the weight of weak sources and an increase of the effective number of sources in the ensemble. Then we passed this value through the diagram filter

$$\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t) = \left(\frac{1}{2}\right)[\lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t - 3\,\mathrm{MNH}) - 2 lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t) + \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t + 3\,\mathrm{MNH})], \tag{8}$$

where 3 min is half of the time required for a source to pass the antenna beam.

The diagram filter decreases the contribution of noise to the averaged value of $\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t)$.

To investigate the time dependence of the interplanetary scintillation parameter during 24 hours we averaged the parameter $|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t)|$ over a 1 hour time interval. Then these values were averaged over all beams and over all days of observation. The dependence $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{sec}, t)|\rangle$ on time is shown in figure 2. Similar averaged values were calculated for ionospheric scintillations.

The dependence $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 10\,\mathrm{sec}, t)|\rangle$ on time is shown in figure 2. Additionally we calculated values $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle$ and $\langle\gamma_{2,1}(\tau = 10\,\mathrm{s}, t)\rangle$ averaged over a 1 hour time interval, over all beams and over all days of observations. These data are also shown in figure 2. In this figure the initial time of observations was fixed on stellar time. The Sun is passing through the meridian approximately at the time of 4.5 hours. Midnight corresponds to the time of 16.5 hour. The dependences for the values $|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{s}, t)|$ and $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle$ are similar and correspond to the dependences of interplanetary scintillation parameters on elongation. The minimal value of the elongation is equal to $\varepsilon_{\min} \cong 30°$. During the day time the averaged value $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle \cong 0.3$, which corresponds to an effective value of the scintillation index $\langle m_{\mathrm{c}}\rangle \cong 0.1$. At night-time the averaged value $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle \cong 0.1$, which corresponds to an effective value of the scintillation index $\langle m_{\mathrm{c}}\rangle \cong 0.03$. The interplanetary scintillation dominates ionosphere scintillation during the daytime. At night-time the ionosphere scintillation index is comparable to the interplanetary scintillation index.

To estimate day to day variations of the scintillation parameters we determined the parameters $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{s}, t)|\rangle_{\mathrm{t,1}}$ and $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle_{\mathrm{t,1}}$ averaged over all beams and over eight hour time intervals for daytime and night-time. These data are shown in figure 3. We see that variations $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{s}, t)|\rangle_{\mathrm{t,1}}$ and $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle_{\mathrm{t,1}}$, are proportional. Day to

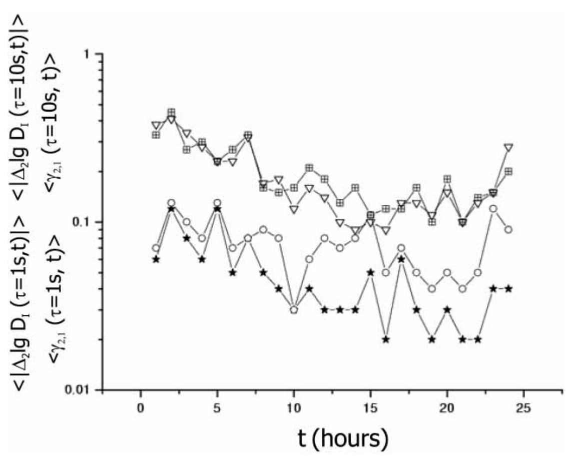

Figure 2. Averaged time dependence of scintillation parameters during the day and night intervals. $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{s}, t)|\rangle$ is denoted by ($\star$), $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle$ – (∇), $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 10\,\mathrm{s}, t)|\rangle$ – (+), $\langle\gamma_{2,1}(\tau = 10\,\mathrm{s}, t)\rangle$ – ($\bigcirc$). These values were averaged over 1 hour time intervals, over all beams and over all days of observations. The Sun position corresponds to the time 4.5 hours.

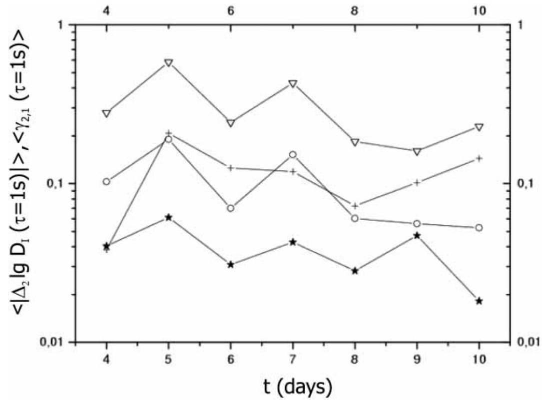

Figure 3. Day to day variations of the interplanetary scintillation parameters. These values were averaged over 8 hour daytime interval and over 8 hour night-time interval and also over all beams. The daytime value of $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{s}, t)|\rangle$ is denoted by ($\circ$), the night-time value of $\langle|\Delta_2 \lg D_{\mathrm{I,i}}(\tau = 1\,\mathrm{s}, t)|\rangle$ – (+), the daytime value of $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle$ – (∇), and the night-time value of $\langle\gamma_{2,1}(\tau = 1\,\mathrm{s}, t)\rangle$ – ($\star$).

day variations of the night-time ionosphere scintillations are weak. During the period of the observations the interplanetary plasma and the ionosphere were in quiet conditions.

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