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# Changes in the spectral index of the interplanetary plasma turbulence in the period of low solar activity from observations of strongly scintillating source 3C 298

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We present the results of the analysis of temporal power spectra of interplanetary scintillation for the strong radio source 3C 298 observed at 111 MHz with radio telescope BSA LPI in the period near the solar activity minimum. The velocity of the solar wind plasma irregularities and the power exponent of the turbulence spatial spectrum are estimated from the measured temporal scintillation spectra. It is shown that some high frequency flattening of the temporal scintillation power spectra due to the noise influence can bias the estimates of the source angular size and the spectral index of plasma turbulence. The comparison between the turbulence parameters for the sources 3C 48 and 3C 298 have been carried out. The decrease in the turbulence spectral exponent by transit from the high latitude fast solar wind to the low latitude slow solar wind is found from the 3C 298 data that confirms similar dependence found recently for the 3C 48 data.

**Key words:** solar wind, interplanetary scintillation

## INTRODUCTION

The interplanetary scintillation (IPS) was discovered in 1964 by Hewish et al. [7]. This scintillation effect is caused by the diffraction of radio waves propagating from a distant compact radio source on the density irregularities of the interplanetary plasma (IPP) with the scales of about Fresnel scale (several hundred kilometres for the meter wave length). Therefore, IPS is widely used to investigate properties of the IPP and parameters of scintillating radio sources. Compact ($< 1''$) radio sources, such as active galactic nuclei (AGN), are usually used in IPS observations.

There are several methods of IPP and scintillating sources investigation using IPS measurements. One of them is based on the analysis of IPS temporal power spectra. This method was developed by Shishov [11, 12]. The possibility to estimate the solar wind speed using IPS temporal spectra were demonstrated in [3, 8].

The method of simultaneous estimates of the spectral power exponent of small-scale plasma turbulence, the source angular sizes and the solar wind speed from temporal scintillation spectra was developed in [4, 9]. The evidences of the dependence of the turbulence spectral index on heliolatitude connected with solar wind bimodal structure during the minimum of solar activity were obtained. In order to confirm the results of [4], the IPS observations data for the quasar 3C 298 in the period of solar activity minimum are analysed in this paper.

## OBSERVATIONS

The scintillation observations were carried out in monitoring mode by the radio telescope BSA (Big Scanning Array) of Lebedev Physical Institute from 2007 to 2011. The radio telescope allows to observe scintillating sources simultaneously in 16 beams. BSA LPI beam system covers about eight degrees in declination. The frequency of observations was 111.5 MHz, bandwidth was 600 kHz, the sampling rate was 10 Hz. The radio telescope effective area toward the zenith was 20000–25000 $\mathrm{m}^2$. The sizes of individual beam are approximately $1^\circ \times 0.5^\circ$ (along the east-west and north-south directions).

Since the solar declination varies from $-23^\circ$ (in winter) to $23^\circ$ (in summer) the optimal elongations (the angular distance between the line of sight and the direction to the Sun, $\varepsilon$) for observations of scintillating sources are reached in different regions of the sky. Therefore two declination bands with coordinates of $3.5^\circ - 12.5^\circ$ from October to March and $28.5^\circ - 35^\circ$ from March to October were selected for monitoring. Radio sources 3C 298 (right ascension $14^h17^m$, declination $6^\circ41'$) and 3C 48 (right ascension $1^h35^m$, declination $32^\circ53''$) are the strongest scintillating sources in the lower and upper bands, respectively. These sources are the strongest in our observations.

The results and details of techniques for the radio

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source 3C 48 observed in April–May 2007–2009 are described in [2, 4]. In this paper we analyse the IPS observations for the source 3C 298 during the long quiet period November 2007–2009.

During the observation series for 3C 48 and 3C 298 elongations were within the limits $\varepsilon = 20^\circ - 40^\circ$, when IPS reaches its maximum value. The state of the interplanetary plasma was relatively quiet[1]. The examples of initial records of the sources 3C 48 and 3C 298 are presented in Fig. 1 which shows that the source 3C 48 is much stronger than the source 3C 298. In our previous paper [4] 157 IPS power spectra were used for analysis with signal-to-noise ratio greater than 30. In this paper we analyse only 52 IPS spectra selected from the criteria that signal-to-noise ratio is above 15.

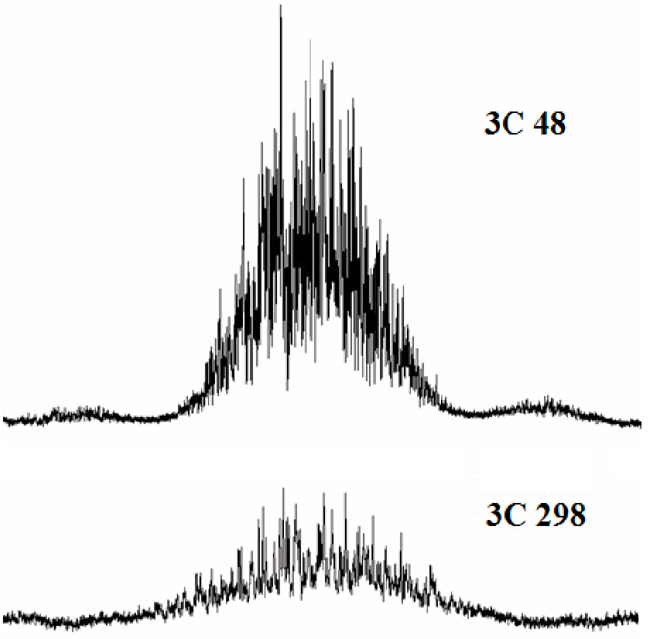

Fig. 1: The examples of typical IPS records for the sources 3C 48 and 3C 298.

## INFLUENCE OF NOISE ON THE TURBULENCE INDEX AND THE SOURCE ANGULAR SIZES ESTIMATES

The ideal IPS temporal power spectrum shown in Fig. 2 has typical shape with approximately constant level at low frequencies and exponential decrease to higher frequencies (3D spectral index is about $n \approx 3.6$)

In real observations the received signal has a finite duration and a power spectrum is distorted by noise. Noises are revealed in the power spectra as a flat part at highest frequencies. The noise influence on the shape of power spectrum is shown in Fig. 2. At the highest frequencies power spectrum flattens. So the source angular size and the turbulence spectral index can be distorted by the noise. Qualitatively it is clear that the weaker is the source (the lower signal-to-noise ratio), the greater is the contribution of noise. However, quantitative estimates of the noise contribution to the change in the estimates of the source angular size and the turbulence spectral index are not known. Fig. 3 shows the real power spectrum of the source 3C 298 in comparison with schematic representation.

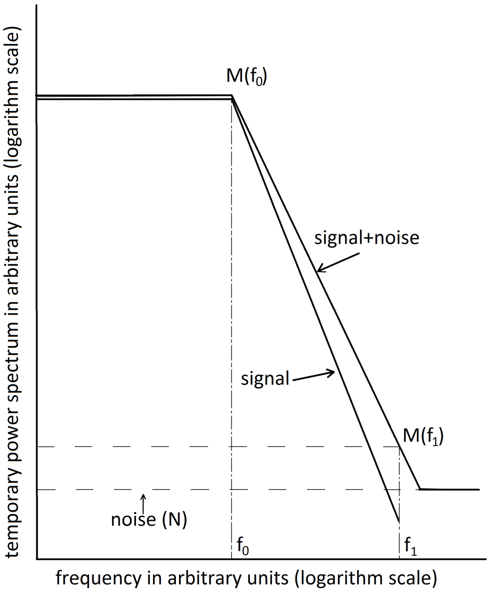

Fig. 2: Schematic representation of the power spectrum in the absence of noise (ideal case) and in the case when noises are included.

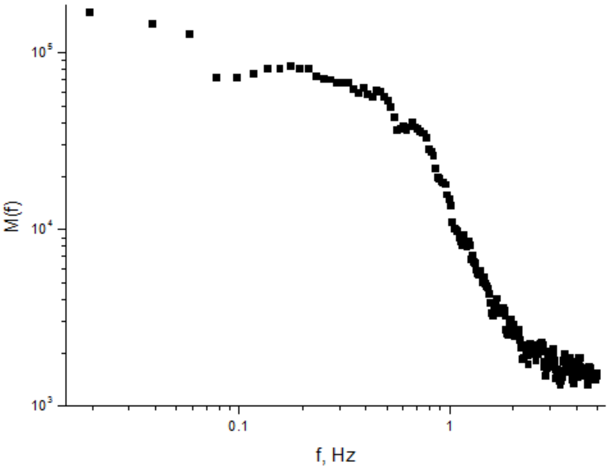

Fig. 3: The example of the power spectrum of the source 3C 298.

In Fig. 2: $f_0$ is the frequency of the power spec-

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[1] http://www.lmsal.com/solarsoft/last_events/

trum break, $N$ is the average noise level, $f_1$ is the last point where the power spectrum is above the noise level (up to this point we compare the experimental spectrum with a set of theoretical power spectra). The details of the reduction are presented in [4].

In the absence of noise (ideal case) the IPS power spectrum is power law, $M_0(f) = Af^{-\alpha}$. The spectral index of IPS temporal power spectrum $\alpha$ is connected with the turbulence 3D spectral index $n$ by the simple relation $n = \alpha + 1$. In the case with noise the power spectrum becomes more flat, $M_s(f) = Af^{-\alpha} + N = Bf^{-\beta}$, where $\beta < \alpha$.

In the case without noise we have:

$$M_0(f_0) = Af_0^{-\alpha}, \quad M_0(f_1) = Af_1^{-\alpha}. \tag{1}$$

From (1) one can obtain the temporal IPS spectral index:

$$\alpha = \frac{lg\left(\dfrac{M_0(f_0)}{M_0(f_1)}\right)}{lg\left(\dfrac{f_1}{f_0}\right)}. \tag{2}$$

If the noise is included the spectral index is shifted to lower values:

$$M_{s0}(f_0) = Af_0^{-\alpha} + N = f_0^{-\beta},$$
$$M_{s1}(f_1) = Af_1^{-\alpha} + N = f_1^{-\beta}, \tag{3}$$

where $\beta$ is the temporal IPS spectral index in the presence of noise. Taking into account relations (1)-(3) one can found:

$$\beta = \frac{lg\left(\dfrac{M_{s0}}{M_{s1}}\right)}{lg\left(\dfrac{f_1}{f_0}\right)} = \frac{lg\left(\dfrac{Af_0^{-\alpha}+N}{Af_1^{-\alpha}+N}\right)}{lg\left(\dfrac{f_1}{f_0}\right)} =$$
$$= \alpha - \frac{lg\left(1+\dfrac{Nf_1^{\alpha}}{A}\right)}{lg\left(\dfrac{f_1}{f_0}\right)} = \left\{M(f_1) = Af_1^{-\alpha}\right\} =$$
$$= \alpha - \frac{lg\left(1+\dfrac{N}{M(f_1)}\right)}{lg\left(\dfrac{f_1}{f_0}\right)} = \alpha - \Delta\alpha, \tag{4}$$

$$\Delta\alpha = \frac{lg\left(1+\dfrac{N}{M(f_1)}\right)}{lg\left(\dfrac{f_1}{f_0}\right)}. \tag{5}$$

Equation (5) describes the dependence of the spectral exponent shift $\Delta\alpha$ on the signal-to-noise ratio and can be used for systematical correction of the power exponent if this ratio is measured. When the signal-to-noise ratio $q \gg 1$, then $\Delta\alpha = 0$. In case $q \ll 1$ equation (4) does not make sense.

Information on the source angular size is needed to obtain the correct estimates of turbulence spectral index. Accuracy of the estimates of the source angular size from IPS data is not better than $0.1''$ at 100 MHz [1]. In addition the interstellar medium scatters the signal, and the degree of scattering varies with the direction in the Galaxy that gives its own limits on the angular size of the observed sources. We have taken the source angular size from original papers in order to separate the contributions to temporal scintillation spectra from the source angular size and from the turbulence spectral index. Radio source 3C 298 is a bright quasar. A lot of interferometric observations of this source are available. The observations of the source at frequencies of 327 MHz, 608 MHz, 1.7 GHz, 5 GHz are given in [5, 6, 10]. These observations suggest that the source at low frequencies is a three-component, the components are aligned along the straight line. The flux density of the middle component is a few times less than from the outer components. The total distance between the outermost components is about $1.5''$, and the angular sizes of each of the three components are approximately equal to $0.25'' \times 0.1''$.

## RESULTS

We analysed the calculated IPS power spectra in order to define the model which describes adequately the IPP turbulence. Fig. 4 shows the dependencies of the spectral index of the turbulence on the elongation without (A) and with correction $\Delta n$ (B). We assumed the angular size of the source to be equal to $0.25''$ in our model. We can see that the turbulence index decreases with increasing the elongation angle.

The source 3C 298 has several components, they are aligned and the distance between the components is such that it is difficult to describe the source by a simple model. We can put additional parameters on the applied model [4]: the elongation of the details, the distance between the components, the angular size of each component, taking into account the relative details position of the source relative to the direction of the solar wind. However, using such model one cannot obtain a unique solution. We supposed that the obtained values of the turbulence spectral index which are lower than those of the source 3C 48 are connected with a complex angular structure of the source 3C 298.

The dependence of the plasma turbulence spectral index on the observed speed of the solar wind is presented in Fig. 5. We see that the turbulence spectral index decreases with transit from fast high latitude to slow low latitude solar wind. Fitting the line $n = n_0 + kv$ by least-squares method to the resulting dependence gives the following results: $n_0 = 2.6$,

$k = 0.002$.

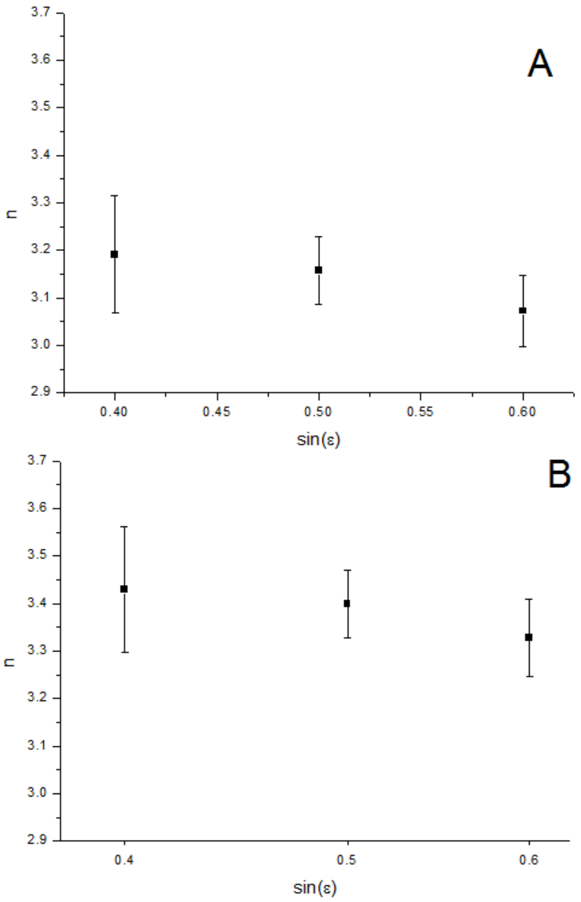

Fig. 4: Dependence of the turbulence spectral index on elongation. On the x-axis in logarithmic scale: initial results (A); results corrected for the noise influence (B).

The tendency of the turbulence spectral index increase with increasing of the solar wind speed is the same as previously found from IPS observations of the source 3C 48 [4]. The results can be explained by bimodal structure of the solar wind, that is typical for the period of solar activity minimum.

## CONCLUSIONS

1. The values of the solar wind plasma turbulence spectral index estimated from IPS data should be corrected for the noise influence if the signal-to-noise ratio is not very high.

2. The dependence of the turbulence spectral index on the speed of the solar wind during the period of solar activity minimum is confirmed by the IPS data for the source 3C 298.

3. The last conclusion can be useful for developing of new models of the solar wind turbulence.

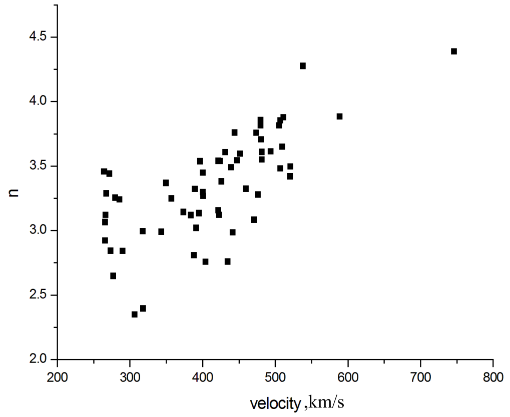

Fig. 5: The dependence of the plasma turbulence spectral index on the speed of the solar wind for the source 3C 298.

## REFERENCES

[1] Artyukh V. S. & Smirnova T. V. 1989, Soviet Astronomy Letters, 15, 344

[2] Glubokova S. K., Chashei I. V. & Tyul'bashev S. A. 2012, Advances in Astronomy and Space Physics, 2, 164

[3] Glubokova S. K., Glyantsev A. V., Tyul'Bashev S. A., Chashei I. V. & Shishov V. I. 2011, Geomagnetism and Aeronomy, 51, 1

[4] Glubokova S. K., Tyul'bashev S. A., Chashei I. V. & Shishov V. I. 2013, Astron. Rep., 57, 586

[5] Dallacasa D., Zhengdong C., Schilizzi R. T. et al. 1994, in *Proc. of the NRAO workshop*, eds.: Zensus J. A. & Kellermann K. I., Green Bank, WV: NRAO, 23

[6] Fanti C., Fanti R., Dallacasa D. et al. 2002, A&A, 396, 801

[7] Hewish A., Scott P. F. & Wills D. 1964, Nature, 203, 1214

[8] Manoharan P. K. & Ananthakrishnan S. 1990, MNRAS, 244, 691

[9] Manoharan P. K., Kojima M. & Misawa H. 1994, J. Geophys. Res., 99, 23411

[10] Nan R., Schilizzi R. T., Fanti C. & Fanti R. 1991, A&A, 252, 513

[11] Shishov V. I. & Shishova T. D. 1978, Soviet Astronomy, 22, 235

[12] Shishov V. I. & Shishova T. D. 1979, Soviet Astronomy, 23, 345