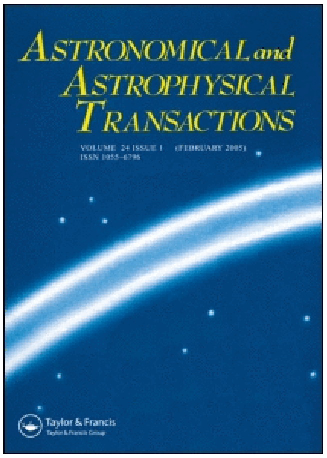

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Pulsar diffractive scintillation at 1.4 and 4.8 GHz

V. Malofeev [a]; O. Malov [ab]; W. Sieber; A. Jessner [b]; S. Tyul'bashev [ab]; B. Klein [b]; R. Wielebinski [b]
[a] Pushchino Radioastronomy Observatory of Lebedev Physical Institute, Pushchino, Russia
[b] Max-Planck-Institut fur Radioastronomie, Bonn, Germany

Online Publication Date: 01 December 2007
To cite this Article: Malofeev, V., Malov, O., Sieber, W., Jessner, A., Tyul'bashev, S., Klein, B. and Wielebinski, R. (2007) 'Pulsar diffractive scintillation at 1.4 and 4.8 GHz', Astronomical & Astrophysical Transactions, 26:6, 549 - 556
To link to this article: DOI: 10.1080/10556790701614755
URL: http://dx.doi.org/10.1080/10556790701614755

Astronomical and Astrophysical Transactions
Vol. 26, No. 6, December 2007, 549–556

Pulsar diffractive scintillation at 1.4 and 4.8 GHz

V. MALOFEEV*†, O. MALOV†‡, W. SIEBER§, A. JESSNER‡, S. TYUL'BASHEV†‡, B. KLEIN‡ and R. WIELEBINSKI‡

†Pushchino Radioastronomy Observatory of Lebedev Physical Institute, 142290, Pushchino, Russia
‡Max-Planck-Institut fur Radioastronomie, Auf dem Huegel 69, 53121 Bonn, Germany
§Hochschule Niederrhein, Reinarzstr. 49, 47805 Krefeld, Germany

(Received 19 July 2007)

The diffractive interstellar scintillation of 11 pulsars at 1410 MHz and of five pulsars at 4800 MHz was analysed to estimate the spectrum of the electron density fluctuations as well as the ACF, CCF and the structure function. We present dynamic spectra for a few pulsars at high frequencies in the strong and weak regime and show that a lensing effect probably exists for pulsar PSR B2020+28 at 1410 MHz. The mean value of the indexes of the power law spectra for an ensemble of pulsars is in good agreement with a Kolmogorov spectrum.

Keywords: Stars; Pulsars; General-scattering-interstellar medium; Structure-turbulence

1. Introduction

After 40 years of investigation we know that scattering as well as diffractive and refractive interstellar scintillation effects are caused by electron density fluctuations in the interstellar medium (ISM) [1–4]. The character of the investigation of these phenomena has changed however, in recent years. Latest observations indicate that typical parameters like decorrelation time and bandwidth are probably simultaneously influenced by diffractive as well as refractive scintillation, resulting in time dependent and so far unpredictable variations from observation to observation (see e.g. [5, 6]) and different line-of-sights to pulsars (see e.g. [7]).

A most important characteristic of the turbulent interstellar medium is the three-dimensional spatial spectrum of the electron density fluctuations. This spectrum is often described either by a Gaussian or a power law. Most popular is the so-called "Kolmogorov" spectrum characterized by an exponent $n = 11/3$ [4, 8]:

$$\Phi_{\mathrm{Ne}}(q) = C_{\mathrm{Ne}}^2 |\mathbf{q}|^{-n}, \quad n = 11/3 \tag{1}$$

where Φ_{Ne} denotes the squared Fourier spectrum of the electron density fluctuations, C_{Ne}^2 characterizes the level of plasma turbulence and $\mathbf{q}$ is the space frequency. It is important

*Corresponding author. Email: V.Malofeev.malofeev@prao.ru

Astronomical and Astrophysical Transactions
ISSN 1055-6796 print/ISSN 1476-3540 online © 2007 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/10556790701614755

to note that the shape of the spectrum was determined in the past e.g. by observations of the scintillation characteristics of an ensemble of pulsars, relying on the assumption that the interstellar medium is more or less homogeneous and isotropic on large scales. There are good indications that these assumptions have to be modified. Smirnova *et al.* [7] showed very convincingly by investigating the statistical dependence of the refractive scintillation index $m_{\rm ref}$ on the dispersion measure DM that at least two types of turbulence spectra exist in the ISM. Their measurements of 21 pulsars at 610 MHz show two groups of points. Group I corresponds to a medium with a piecewise power law spectrum with an exponent of $n \cong 11/3$ and an inner scale length $\mathrm{l} \cong 3 \cdot 10^{10}$cm and an exponent $n_1 > 4$ at higher space frequencies ($q > 1/\mathrm{l}$). Group II corresponds to line-of-sights with a pure power law spectrum with $n \cong 11/3$. The observations show that the shape of the spectrum can obviously be different for different regions in the sky and that spectra composed from measurements of different objects, i.e. different line-of-sights, may be misleading. Investigations of the turbulence spectrum must, therefore, treat different line of sights separately. This requires new sets of multi-frequency scattering and scintillation observations for selected pulsars covering a wide frequency range from centimetre to metre wavelengths. The Bonn 100 m telescope is a good instrument to cover especially the high-frequency observations.

So far, few observations have been made at high frequencies above 1300 MHz [6, 9–14]. Reliable data of scintillation spectra were obtained only for PSR B0355+54 [11], PSR B0809+74 [6, 15], PSR B0329+54 [13] and PSR B1642-03 [14], where one spectrum (B0809+74) is of the pure Kolmogorov type, the others are either steeper or flatter. Malofeev *et al.* [11] determined scintillation indexes and temporal scales of scintillation for a number of pulsars at 4.7 and 10.5 GHz in the weak scintillation regime.

Our new measurements, presented in this paper, were complemented by scintillation observations and dynamic spectra at 1.4 (11 pulsars) and at 4.7 GHz (five pulsars), including distant pulsars sensing the diffuse turbulent plasma between the spiral arms of the Galaxy. A meaningful estimate of the power spectrum is certainly only possible if the measurements extend over at least 20–30 times the decorrelation time, which results in a significant demand of observing time (1–10 hours). Another peculiarity of the new observations is the attempt to measure the decorrelation bandwidth at the high frequency of 4800 MHz for the first time. The intention of the following investigation is to find out if the exponent of the power law spectrum is indeed exactly equal to the "Kolmogorov" value or not.

2. Observations

Our observations were carried out in September 2003 at 1410 and 4800 MHz using the 100-metre radio telescope in Effelsberg. Dynamic spectra can be observed when the decorrelation bandwidth is much narrower than the total bandwidth of the receiver. The decorrelation bandwidth depends critically on the observing frequency and on the dispersion measure DM, which means, once the observing frequency is selected, only a certain range of DMs can be observed. At 1.4 GHz we used the PSE (Pulsarsignalentzerrer), which offers a total bandwidth of 40 MHz split into two groups of 30 channels of 1.33 MHz each for two polarizations. At 4.8 GHz we used the 8×60 MHz filter bank (for two polarizations), taking full advantage of the broad 500 MHz bandwidth and low noise temperature of this system ($\sim$60 K). The factor 100 in bandwidth between the two observing frequencies is extremely useful due to the steep dependence of the decorrelation bandwidth on frequency and as a compensation for the decline in pulse intensity. We based our source list on the following criteria: the pulsars should clearly show scintillation, they should be strong enough for a good signal-to-noise ratio and the total receiver bandwidth should, if possible, be (much) broader; the one-channel bandwidth on the other hand must be narrower than the calculated scintillation decorrelation bandwidth. Some interesting sources with broader scintillation bandwidth were also included. Total intensity was recorded for all pulsars, adding just the two circular polarizations. The sampling interval was equal to $1/1024$ of the observing period and the individual pulses were integrated in the data logger for over 30 sec (block of data) to obtain a better signal-to-noise ratio.

3. Analysis

Measurements of 13 pulsars at 1410 MHz and 4800 MHz were used for our analysis. The procedure included: fitting of a baseline, application of calibration factors to obtain total intensity from the sum of the two circular polarized channels and adjustment of the pulse window phase for the calculation of the flux density for every block. The noise contribution was estimated from "off-pulse" samples. We present examples of temporal sequences of flux measurements and dynamic spectra for 30 channels at 1410 MHz (figures 1, 2 and 4) and for 8 channels at 4800 MHz (figures 5 and 6).

A second step of data reduction included the calculation of the mean autocorrelation function (ACF) of the temporal sequences of flux for every channel, and the cross-correlation function (CCF) of the temporal sequences of the first channel with the other channels, the mean structure function and the mean power spectrum. Examples of all four functions for two pulsars are presented in figures 3 and 7. Formulas for the calculation of the ACF, the structure function and the power spectrum have been taken from [11].

We present in a new paper examples of temporal sequences of flux for three regimes of diffractive interstellar scintillation (see e.g. [16]), i.e. the regime where the observing frequency is higher than the critical frequency—weak scintillation (figures 1, 5)—and the regime where the observing frequency is smaller than the critical frequency—the strong scintillation regime (figures 2a, 4 and 6). As third regime may be considered the case when the observations are made near the critical frequency and when one can expect to see a lensing or focal spot effect (see e.g. [17]).

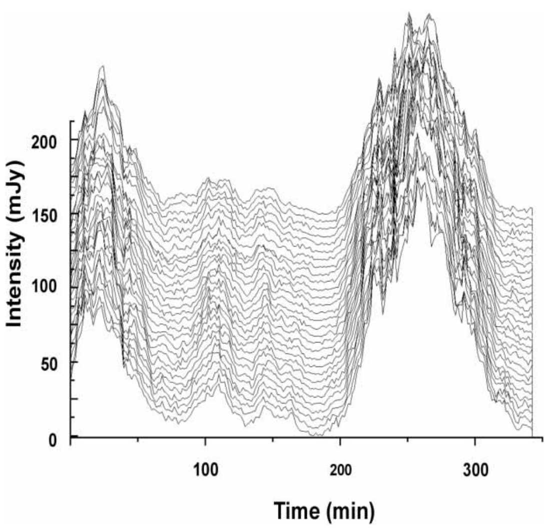

Figure 1. Example of the dynamic spectrum of PSR B1929+10 at 1410 MHz (7.09.03).

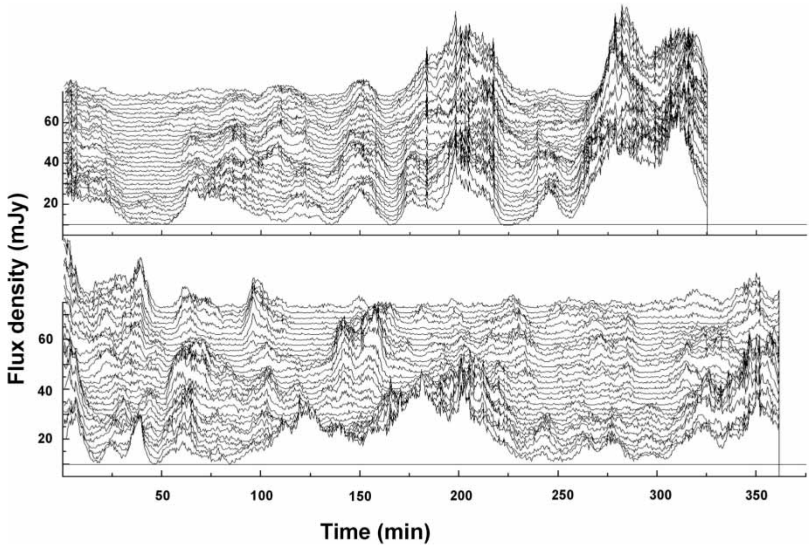

Figure 2. Example of the dynamic spectrum of PSR B2020+28 at 1410 MHz: a) 3.09.03; bottom b) 10.09.03 upper.

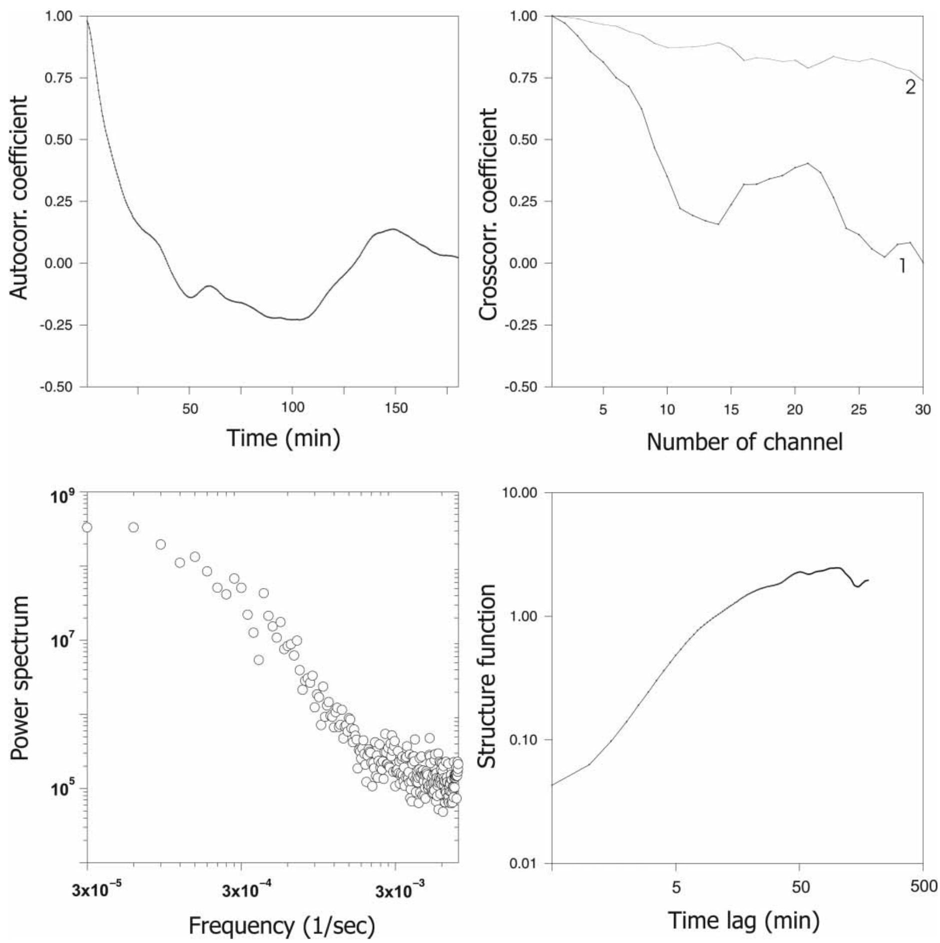

Figure 3. Scintillation data: ACF, CCF (curve 1 − 3.09.03 and curve 2 − 10.09.03), power spectrum and structure function for PSR B2020+28 at 1410 MHz (3.09.03).

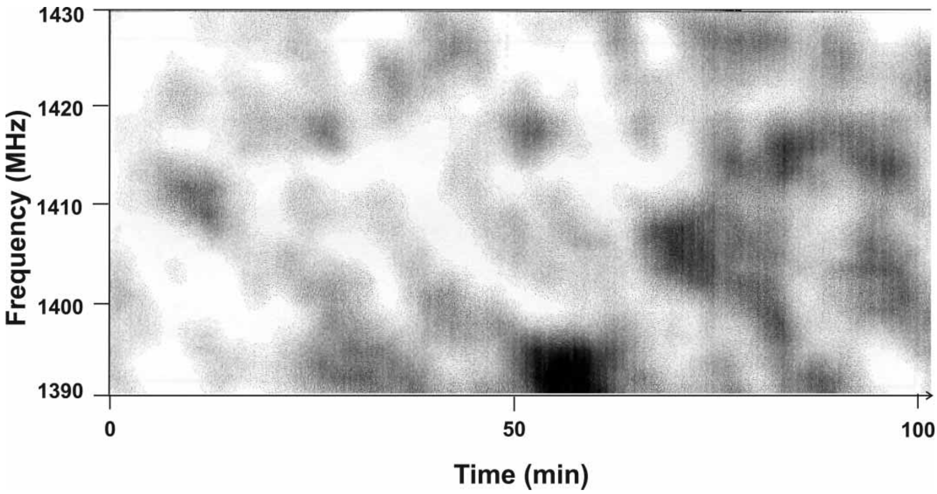

Figure 4. Example of the dynamic spectrum of PSR B0329+54 at 1410 MHz (18.09.03).

The presented temporal flux density variations and decorrelation times estimated from the ACF are typical for the different regimes. Strong variations of the flux density in the frequency domain are evident only in the strong scintillation regime (figures 2a, 4 and 6), where the scintillation index is close to 1.0; the CCF reflects the width of the decorrelation bandwidth (figures 3 and 7). The scintillation index is less than 1.0 and the decorrelation bandwidth is much wider than the total bandwidth of the receiver in the weak regime (figures 1 and 5). The intermediate case is shown in figure 2b for PSR B2020+28. Here we can see strong temporal and weak frequency variations of the flux density, as indicated by the CCF (curve 2) in figure 3. The comparison of all four functions for the two days of observations (3rd and 10th September 2003) shows that large differences appear only in the CCF (figure 3). Just two pulsars—PSR B2020+28 (figure 2) and B2021+51—demonstrate a visible difference in the character of the diffractive interstellar scintillation over our period of observations of seven days. These changes suggest possibly that we see the presence of a lensing effect, may

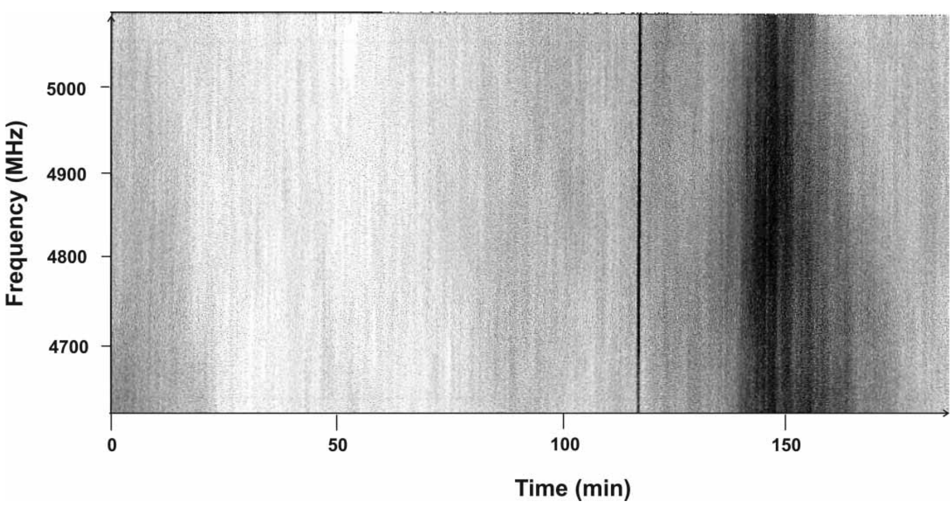

Figure 5. Example of the dynamic spectrum of PSR B1642-03 at 4850 MHz (6.09.03).

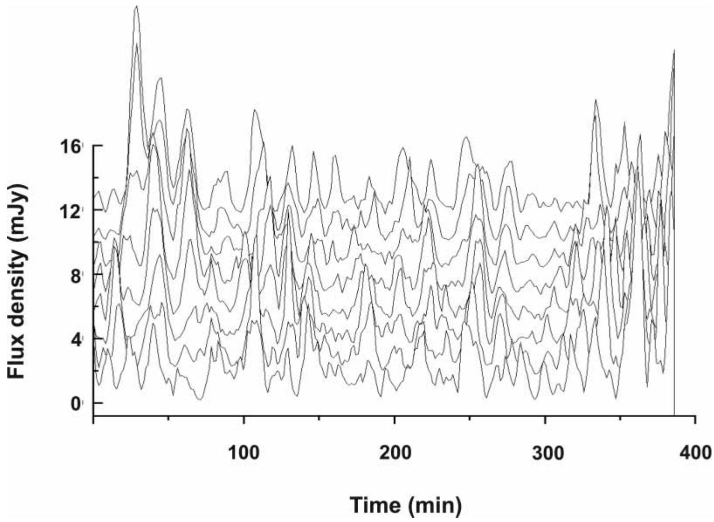

Figure 6. Example of the dynamic spectrum of PSR B0355+54 at 4850 MHz (5.09.03).

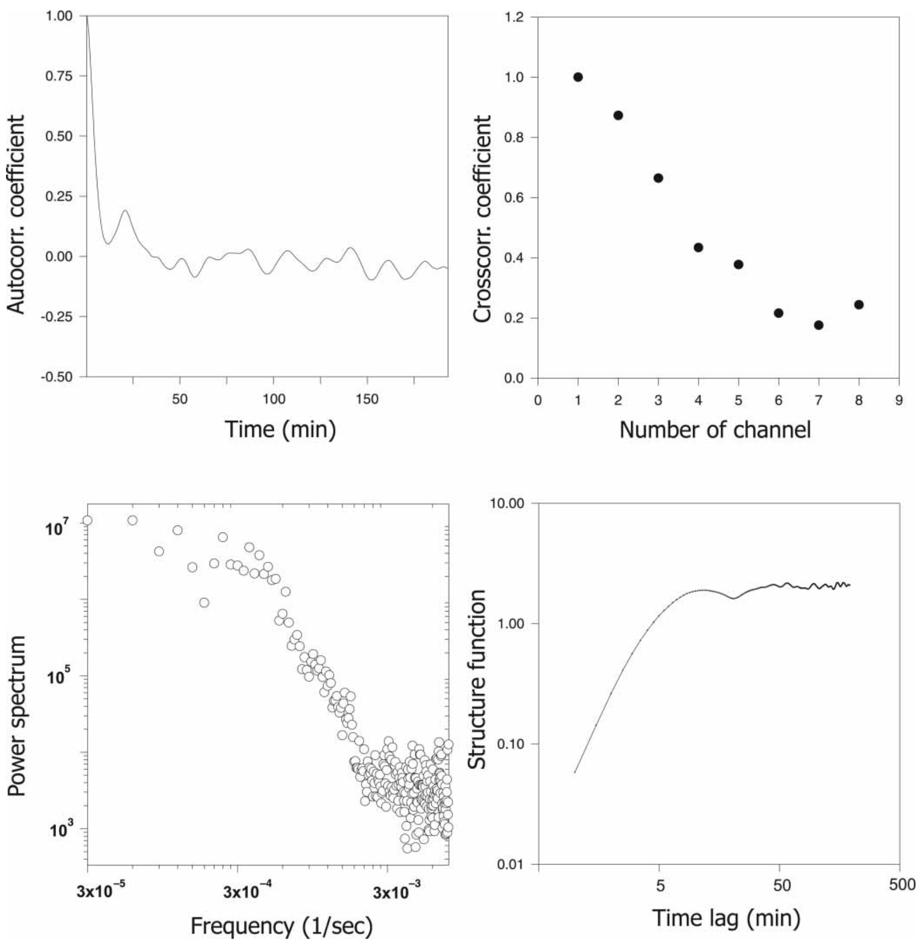

Figure 7. Scintillation data: ACF, CCF, power spectrum and structure function for PSR B0355+54 at 4850 MHz (5.09.03).

Table 1. Mean value of both indexes n1 and n2.

Frequency	n_1	n_2
1.4 GHz	2.7 ± 0.4	1.5 ± 0.3
4.8 GHz	2.8 ± 0.4	1.2 ± 0.4

be for the first time in interstellar scintillation. An estimate of the critical frequencies gives $\nu_{\rm cr} \geq 1.0$ GHz and $\nu_{\rm cr} \sim 2.7$ GHz for PSR B2020+28 and B2021+51 correspondingly [11], very close to our observing frequency 1.4 GHz.

In a third step of analysis power laws were fitted to some frequency and time lag intervals of the computed structure functions and power spectra. For example, we used the interval $3 \cdot 10^{-4}$–$3 \cdot 10^{-3}$ Hz and the time lag interval 2–5 min to compute the spectral index $n_1 = 2.6 \pm 0.4$ and the structure function index $n_2 = 1.4 \pm 0.3$ in the cases presented in figure 3 for PSR B2020+28 (3 September 2003). We have measured both indexes for 11 pulsars at 1.4 GHz and five pulsars at 4.8 GHz. The mean values of both indexes are presented in table 1.

The index of the power law function of the three-dimensional spatial spectrum of the electron density fluctuations is connected to the index of the scintillation spectrum and the structure function as $n = n_1 + 1$ and $n = n_2 + 2$. All four indexes (table 1) are for our observations in good agreement with a Kolmogorov spectrum ($n = 3.67$).

We presented here only part of the scintillation data hoping to give a detailed analysis of all parameters in a forthcoming paper. We would like to prove then that the shape of the spectrum can be different for different regions in the sky and that spectra composed from measurements of different objects, i.e. different line of sights, may be misleading.

4. Conclusions

An analysis of diffractive interstellar scintillation of 13 pulsars at 1410 and 4800 MHz has been made. The dynamic spectra for a few pulsars at high frequencies showed the presence of strong and weak scintillation regimes and possibly a lensing effect for PSR B2020+28 at 1410 MHz. We computed the ACF, CCF, the power spectrum and the structure function and found that the mean values of the index of the power law spectra for an ensemble of pulsars are in a good agreement with a Kolmogorov spectrum.

Acknowledgements

The authors thank V. Shishov and T. Smirnova for useful discussions. We thank the staff of the Effelsberg radio telescope for support with the observations and L. Potapova for technical assistance. This work was supported by the Russian Foundation for Basic Research, grants 06-02-16888 and 06-02-16522.

References

[1] P.A.G. Scheuer. Nature **218** 920 (1968).
[2] B.J.Rickett. Nature **221** 158 (1969).
[3] W. Sieber. J. Astrophys. Astron. **113** 311 (1982).
[4] J.W. Armstrong, B.J. Rickett, S.R. Spangler. Astrophys. J. **443** 209 (1995).
[5] N.D. Bhat, A.P. Rao, Y. Gupta. ApJS. **121** 483 (1999).
[6] B.J. Rickett, W.A. Coles, J. Markkanen. Astrophys. J. **533** 304 (2000).
[7] T.V. Smirnova, V.I. Shishov, D. Stinebring. Astron. Reports **42** 766 (1998).

[8] V.I. Shishov, T.V. Smirnova. Astron. Reports **46** 731 (2002).
[9] D.C. Backer. J. Astrophys. Astron. **43** 395 (1975).
[10] J.M. Cordes. Astrophys. J. **311** 183 (1986).
[11] V.M. Malofeev, V.I. Shishov, W. Sieber, A. Jessner, M. Kramer, R. Wielebinski. J. Astrophys. Astron. **308** 180 (1996).
[12] M. Kramer, K. Xiloris, B.J. Rickett. J. Astrophys. Astron. **321** 513 (1997).
[13] V.I.Shishov, T.V. Smirnova, W. Sieber, V.M. Malofeev, V.A. Potapov, D. Stinebring, M. Kramer, A. Jessner, R. Wielebinski. J. Astrophys. Astron., **404** 557 (2003).
[14] T.V. Smirnova, V.I. Shishov, W. Sieber, D. Stinebring, V.M. Malofeev, V.A. Potapov, S.A. Tyul'bashev, A. Jessner, R. Wielebinski. J. Astrophys. Astron. **455** 195 (2006).
[15] T.V. Smirnova. Astron. Astrophys. Trans. **26** (2007).
[16] B.J. Rickett. J. Astrophys. Astron. (2007).
[17] A.S. Gurevich, M.A. Kallistratova, F.E. Marvel. Radiofizika **20** 1020 (1977).