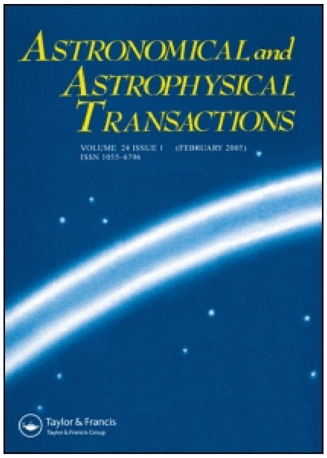

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Interstellar scintillation of radiosources as a probe for investigations of the local interstellar medium

N. G. Bochkarev [a]; M. I. Ryabov [b]
[a] Sternberg Astronomical Institute, Moskow, Russia
[b] Odessa Observatory URAN-4 of the Radioastronimical, Institute of the Academy Sciences of the Ukraine, Odessa, Ukraine

Online Publication Date: 01 July 1997
To cite this Article: Bochkarev, N. G. and Ryabov, M. I. (1997) 'Interstellar scintillation of radiosources as a probe for investigations of the local interstellar medium', Astronomical & Astrophysical Transactions, 13:4, 261 - 271
To link to this article: DOI: 10.1080/10556799708202968
URL: http://dx.doi.org/10.1080/10556799708202968

Astronomical and Astrophysical Transactions, 1997,
Vol. 13, pp. 261–271
Reprints available directly from the publisher
Photocopying permitted by license only

INTERSTELLAR SCINTILLATION OF RADIOSOURCES AS A PROBE FOR INVESTIGATIONS OF THE LOCAL INTERSTELLAR MEDIUM

N. G. BOCHKAREV[1] and M. I. RYABOV[2]

[1] *Sternberg Astronomical Institute, Moskow Russia*
[2] *Odessa Observatory URAN-4 of the Radioastronimical Institute of the Academy Sciences of the Ukraine, Odessa, Ukraine*

(Received February 7, 1996)

Based upon numerous observational data of variability in extragalactic radiosources of the Northern and Southern sky at low frequencies the possibility of obtaining information on ionized component structure in the local interstellar medium (LISM) is investigated. Isophot maps of scintillation index based upon these data were constructed in the galactic coordinate system on 80 MHz and 160 MHz for 1 month and 1 year time intervals of source variability. In the direction where scintillation indicates increase, regions of interaction of interstellar wind with large-scale structure of the LISM are located. Regions of decreased scintillation indices are observed towards the third galactic quadrant (near $l = 240°$), there is a gas-free tunnel.

Long-term observations of the sample from over 50 extragalactic radiosources using the radiotelescope DKR-1000 at a frequency of 102 MHz are used to justify the method of determing the distribution character of the LISM ionized component.

KEY WORDS Local interstellar matter, large scale structure of the LISM, variability of extragalactic radiosources, interstellar scintillation of extragalactic radiosources

1 STRUCTURE OF THE LOCAL INTERSTELLAR MEDIUM

An empiric at model of the local interstellar medium (LISM) has been developed (Bochkarev, 1987, 1990, 1992; Cox and Reynolds, 1987; Friesh, 1995). According to this model the Sun is on the brink of an envelope blown out with a stellar wind from the Scorpius–Centaurus association. This envelope radius is equal to 150 pc whereas the association centre coordinates are $l = 330°$, $b = 15°$. The supernova remnant known as the North Polar Spur originated inside an envelope formed with a stellar wind. Envelopes formed by a stellar wind occupy tens of percents of the interstellar medium volume being one of the characteristic large-scale formations in the Galaxy.

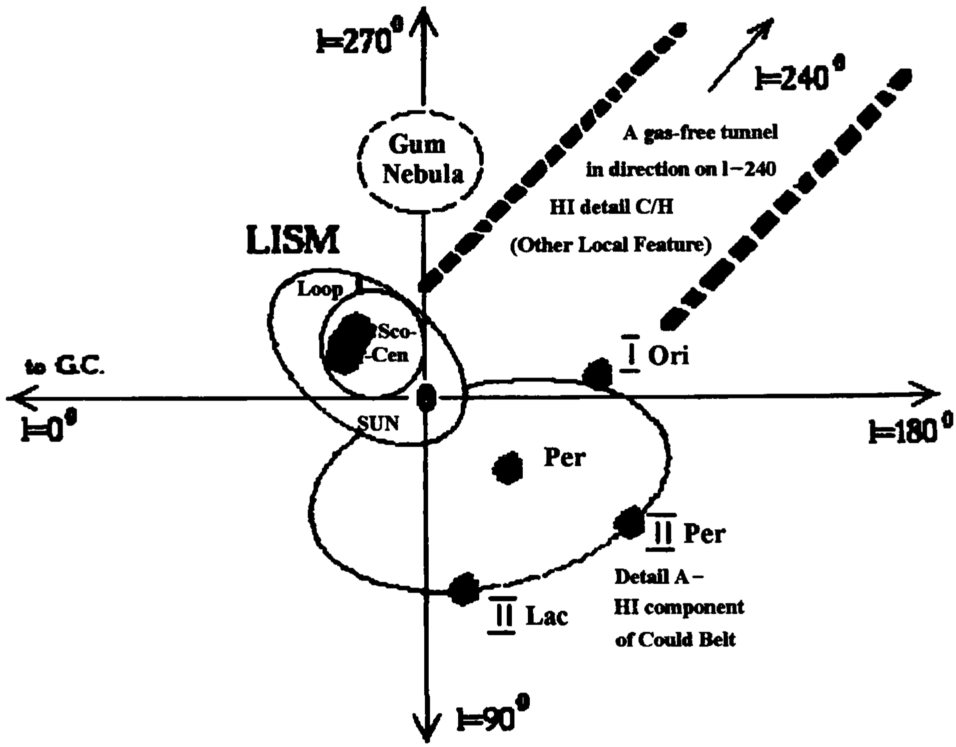

Figure 1 The galactic environment of the LISM (Bochkarev, 1992).

The structure of the ionized LISM component and the character of electron concentration inhomogeniety distribution are determined by physical conditions in the major LISM components (see Figure 1).

2 LOW-FREQUENCY VARIABILITY OF EXTRAGALACTIC RADIOSOURCES

Over the last 20 years a considerable amount of material on variability in extragalactic radiosources over a wide frequency range has been gathered.

Long-term and multifrequency observations have shown variability at comparatively low frequencies ranging from 0.4 to 14.5 GHz permitting us to investigate the major peculiarities of the variability (Padrielly, 1987). Thus, a group of sources has been found in which there is low-frequency (< 1500 MHz) variability but no marked high-frequency variability. These sources are known as LFV-sources. There are sources which show variability at high frequencies and do not show it at low frequencies: these are known as HFV sources. Finally, in sources of the third group the flux density variations at low and high frequencies markedly correlate with a corresponding time shift.

In separate periods even strongly variable sources can be stable or reveal only a very low level of flux density variation. So, at frequencies higher then 1000 MHz flux variability is thought to be caused by the activity of quasars or galaxy nuclei. At lower frequencies the flux variability of cosmic radiosources is due to scintillations at inhomogeneities of electron concentration in the interstellar medium.

3 INTERSTELLAR SCINTILLATION OF EXTRAGALACTIC RADIOSOURCES

The structure of the ionized galactic component is mainly investigated using data on dispersion of pulses and pulsar scintillations. However, the use of pulsars for studying large-scale ionized component distribution has a number of restrictions.

The first is conditioned by the fact that pulsars are galactic objects and are primarily distributed in the disc component of the Galaxy.

The second is due to characteristic times of pulsar interstellar scintillations within two intervals (Shishov, 1993). Short time-scale scintillations, of the order of minutes, result from radiowave diffraction on scales of 10^9–10^{11} cm, whereas long time-scale scintillations are caused by refraction and are associated with focussing effects on scales of 10^{13}–10^{15} cm.

The application of data on variability in extragalactic radio sources seems to be more useful for investigation purposes of large-scale galactic structure. Their distribution is more homogeneous in the galactic coordinate system and the data of flux variation character are obtained in over wide time and frequency ranges. Thus, the set of scale inhomogeneities covers wider ranges and remains quasi-continuous.

The largest scale of inhomogeneities is related to the spiral galactic structure, and here a characteristic time of flux variation constitutes 15 years. Other variability scales are connected with a disc and spherical components, large-scale regions of star formation.

4 MAPS OF INDICES OF RADIOSOURCE SCINTILLATION IN THE SOUTHERN SKY

During 1974–1980 Slee and Siegman (1988) looked for variability of about 2000 radiosources at frequencies of 80 and 160 MHz. Variability was found for more than 400 variable radio sources over a wide range of galactic coordinates. Figure 2 shows the location of variable sources at the frequencies of 80 MHz and 160 MHz in the galactic coordinate frame.

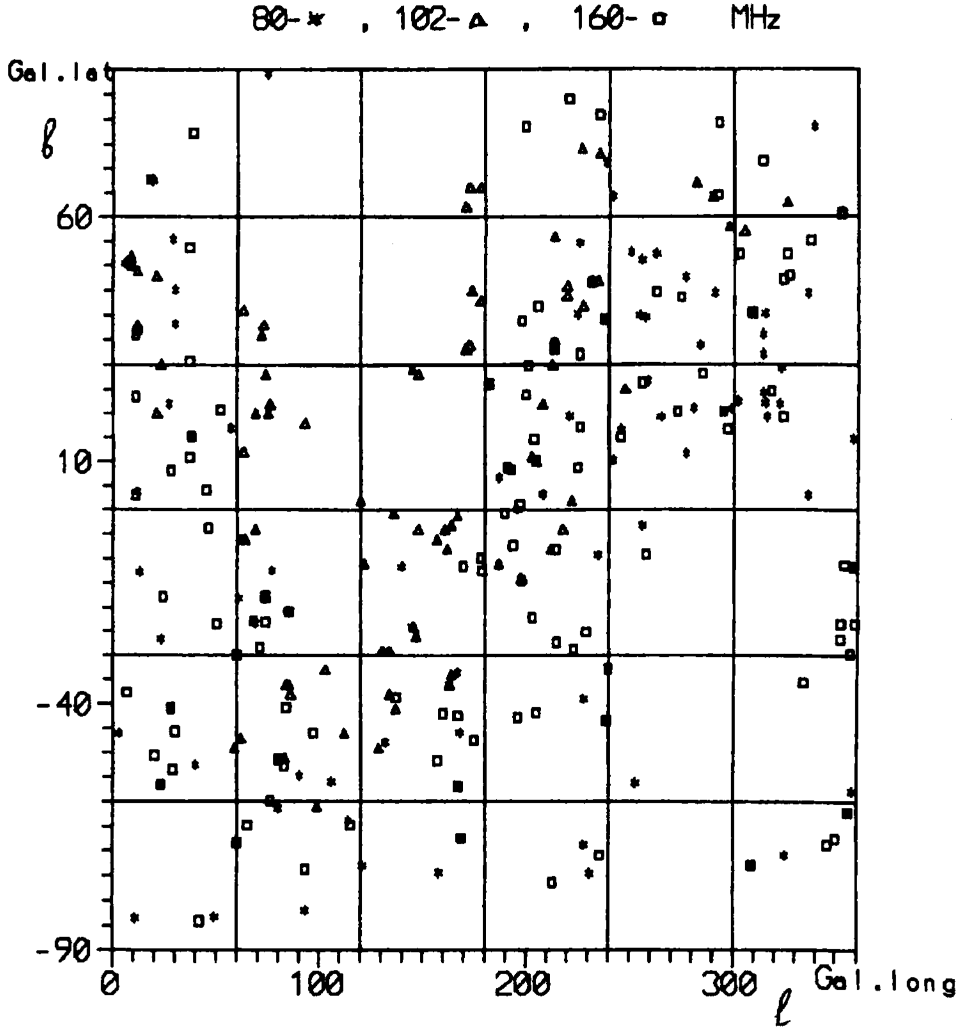

Figure 2 Location of variable sources at frequencies of 80 MHz and 160 MHz from the Slee and Siegman (1988) survey and from our observations at 102 MHz (see Section 5).

The authors computed two indexes of scintillation. On the basis of the data, one-monthly averages of flux density for each source calculation index was given by:

$$m_1 = \left[\frac{\sum(S_j - S_i)^2 - \sum E_j^2}{N_j}\right]^{1/2} / \bar{S}_i, \tag{1}$$

wheres S_j are the individual flux measurments, S_i is the average flux over all measurements, and E_j is the standard error in S_i.

For the year-to-year average of flux density calculated index:

$$m_{12} = \left[|S_L - S_M| - (E_L^2 + E_M^2)^{1/2}\right] / \bar{S}_i, \tag{2}$$

where S_L and S_M are the flux averages over different years, and E_L and E_M are the standard error in S_L ans S_M.

The variability with more than a year and less than a month time-scale was analysed. There are several difficulties in analysing the data of Slee and Siegman (1988). First, the samples of investigated sources at frequencies of 80 and 160 MHz are different. Besides, observations of sources at both the frequencies were not made simultaneously. The observations of only 24 of all the variable sources included in the surveys were performed at both the frequencies.

Isophot maps of scintilation index based these data were constructed in the galactic coordinate system (see Figure 3) separately for each frequency and for two time intervals of source variability. One feature of the method used to construct the isophot maps should be mentioned. It consists of separating sources with maximum scintillation index value: around every source with a large value of scintillation index, a region with a great number of isophots appears on the map.

Figure 3 shows that the scintillation index distributions for different frequencies and two variability time-scales have some differences. These differences may be connected with the peculiarity of the flickering process in the LISM. Slee and Siegman (1988) do not give enough data to determine the power spectrum of the scintillation.

The filling factor is low for fragments of the LISM with the turbulent state producing the scintillation. The process of scintillation may not be quasi-continuous but individual bursts of observed brightness.

Analysis of Figure 3 permits us to assume a correlation between the scintillation index distribution on the sky and the structure of the LISM.

Thus, it is possible to investigate characteristic structure formations of the LISM using data on scintillation of extragalactic radiosources at time-scales of about a year or less.

5 OBSERVATIONS AT A FREQUENCY OF 102 MHz

In order to reveal a set of variability time-scale for extragalactic source scintillation at inhomogeneities of the LISM regular observations are needed. Such observations at a frequency of 102 MHz were performed on the radio telescope DKR-1000 of the Radioastronomical Station of the Astro-Space Center of the P. N. Lebedev Physical Institute of the Russian Academy of Sciences.

In 1984–1985 and 1988–1995 a special programme was carried out to elaborate on the method of relative observations of variability in flux sources on DKR-1000 in order to as certain LISM structure. Over 50 sources were investigated in total; among these are compact and extended sources with different spectra, variable and ones of calibration.

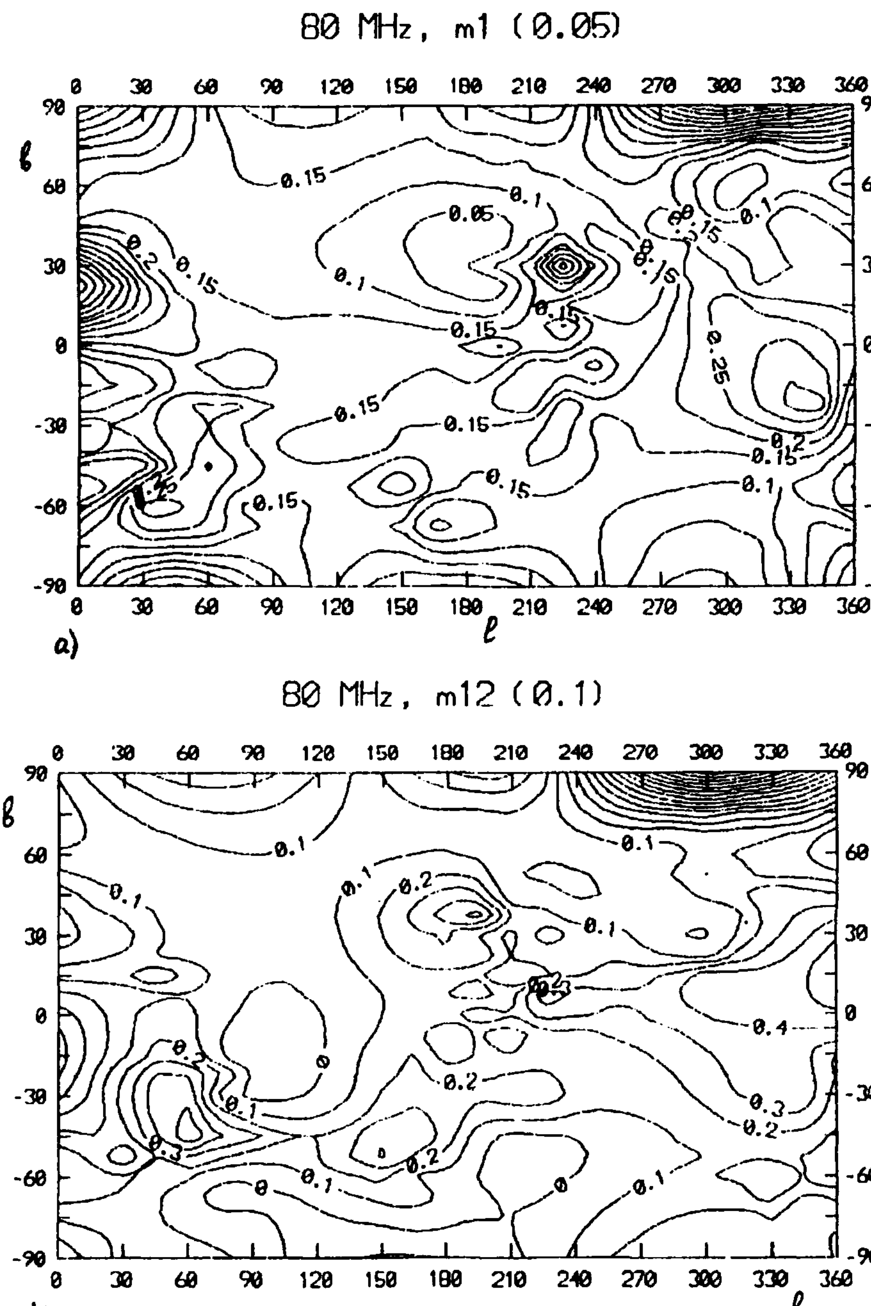

Figure 3 Isophot maps of interstellar scintillation index at frequencies of 80 MHz (a,b) and 160 MHz (c,d) on time-scales of less than a month (a,c) and more than a year (b,d) on the plane with galactic coordinates (l,b).

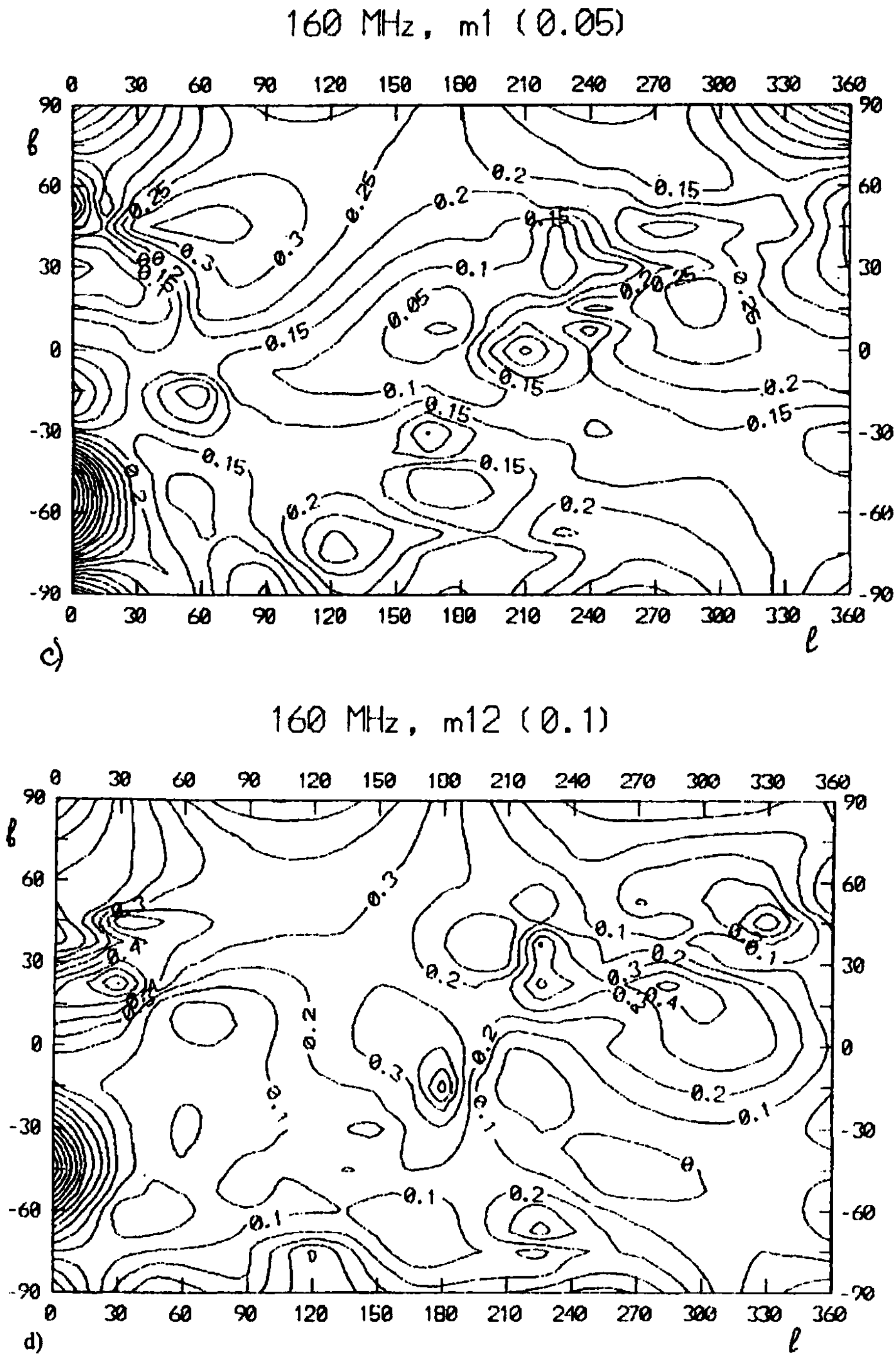

Figure 3 Continued.

The distribution in the galactic coordinate system completes the major selection of variable sources at frequences of 80 and 160 MHz (see Figure 2). During 1984–1985 nine cycles of observations from 9 to 20 days long were completed. Every day, during every observational setting from 6 to 18 hours long pass of some dozens of radiosources across the antenna beam was registered.

The consequent analysis was based upon correlation of the amplitudes of reaction of the radiosources obtained during individual sequances of observations. The main goal of the first stage was to perfect the observational method. Consequently, the list of radiosources observed was formed partly fortuitously and mainly of relatively powerful radiosources from the 3C and 3RC catalogues.

In total, 20 cycles for 1984–1985 and 1988–1992 were processed. During different cycles, the sources were observed on days and nights, in different seasons. The data obtained served for consideration of the day time variance and seasonal effects on the variation of the fluxes from the sources. Such effects may be due to the influence of the state of the ionosphere dependence season and the time of day. To reveal such effects, mean quantities were found for the estimated values of the fluxes from the sources for the cycles in which the sources were observed during the same 3 hours interval or in the same month. As the amplitudes of the modulation of the fluxes caused by the abovementioned effects may have a value of 25% it is clear enough that the interstellar scintillations can not be found if the effects are not taken into account.

Figure 4 shows the variations of the fluxes from the sources 3C196, 3C273, 3C279, 3C409, 3C410, 3C454.3. The sources reveal the variability of flux and ample interval of frequences. The dotted line shows the flux variability observed, the solid line demonstrates the result of discounting the day and seasonal effects of the variations of the state of the ionosphere.

It may seen that the flux changes more in the rank of month than in the rank of years. So, we come to the conclusion that the variations of the fluxes from extagalactic sources are due, in the first place, to structural heterogeniety of the interstellar medium.

6 DISCUSSION

From data (Fiedler *et al.*, 1987) of source flux investigations over seven years at frequencies of 2.7 GHz and 8.1 GHz the minima have been obtained in the light curves of variable sources as long as 1 year. The author suggest that the radiosource scintillations discovered are caused by the inhomogeneities of electron concentration in the LISM.

Here, characteristic sizes of inhomogeneities are equivalent to 10^{11}–10^{13} cm and are mainly generated as a result of the supernova explosion or by a stellar wind in young star associations. The LISM is the closest example of such formation. Times of variability in sources scintillating in inhomogeneities of the LISM are expected to several months. LISM structure is essentially anisotropic.

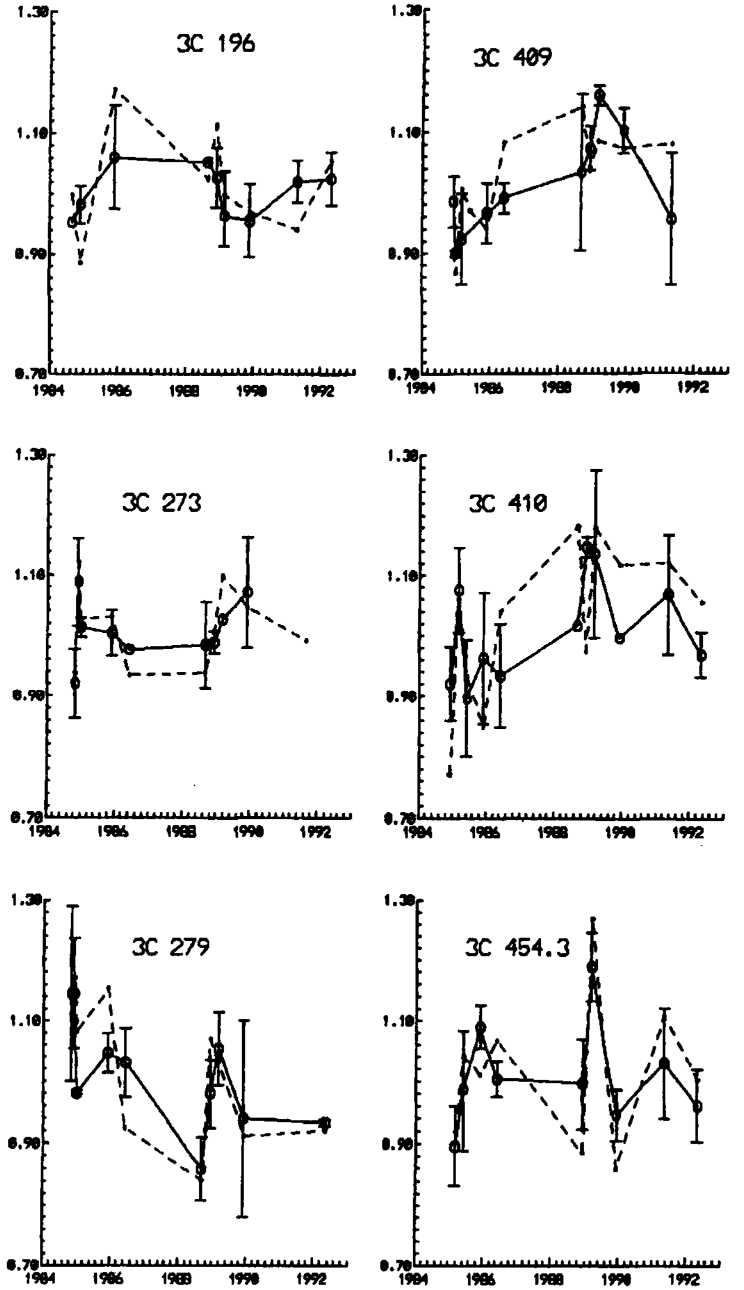

Figure 4 Variation of the flux from 3C196, 3C273, 3C279, 3C409, 3C410, 3C454.3 at 102 MHz observed at Pushchino with the radiotelescope DKR-1000 during 1984–1992. Dotted lines show the observed flux variability; solid lines demonstrate the results after removing the time-of-day and seasonal effects on the ionosphere condition variations. Ordinate axes are time in years; along abscess axis are fluxes in relative units.

Here, the interaction of stellar wind with the local medium surrounding the Sun, forms regions of enhanced turbulence and those free of interstellar medium. There are different scales of distribution for electron concentration inhomogeneities in the Galaxy which can be investigated using the extragalactic radiosource scintillation method. However, the choice of sources to be investigated is conditioned by the precence of compact components at low frequencies. In addition to this, because of the anisotropic LISM structure and, respectively, different turbulence medium degrees, characteristic scales of electon concentration inhomogeneity distribution and the degree of their filling LISM must be markedly different for different directions.

These peculiarities will be naturally revealed in a narrow time interval of compact source scintillations. This interval ranges from months to a year. Over large time intervals structure inhomogeneities will work in the entire Galaxy thickness providing an averaged turbulent state of the intergalactic medium.

7 CONCLUSIONS

Interpretation of the results of scintillations of Southern sky extragalactic sources at frequencies of 80 and 160 MHz and the preliminary results of more than 5 years of observations of source variability at a frequency of 102 MHz show that such observations may constitute a fruitful method of investigation of the LISM. On the map of scintillation indices (Figures 3 *a* and *c*) manifestations of the region of the Sco–Cen association can be assumed ($l = 4°$, $b = 18°$).

Beyond the local cloud, a region of reduced scintillation index for extragalactic sources may be noticed which may be associated with a corridor free of interstellar matter up to about 1–2 kpc (Bochkarev, 1990, 1992). Manifestations of star formation regions, for example, the Orion complex, may be suspected as well.

In the maps of source scintillation indices over a year (Figure 3*b*, *d*) the manifestation of regions of stellar complexes, gaseous fluxes, the local cloud and stellar wind region of the Sco–Cen association can be assumed as well.

To obtain more definite information about plasma turbulence in LISM which produces the observed radiosources scintillation it is necessary to have a special programme of low-frequency observations of the type used in programmes of investigation of shock wave propagation in the solar wind. The first stage of the programme has been started with the radiotelescope DKR-1000 in Pushchino (Moscow Region).

The present work was performed with in the frame of the State Scientific Technical Program Astronomy (project 3–287).

References

Bochkarev, N. G. (1987) *Astrophys. Space Sci.* **138**, 229.
Bochkarev, N. G. (1990) *Local Interstellar Matter* Moscow, Nauka.
Bochkarev, N. G. (1992) *Astron. Astrophys. Trans.* **3**, 3.
Cox, D. P. and Reynolds, R. J. (1987) *Ann. Rev. Astron. Astrophys.* **25**, 303.

Fiedler, R., Dennison, B., Jonston, K., and Hewish, A. (1987) *Nature*, **236**, 675.
Friesh, P. C. (1995) *Space Science Reviews* **72**, 499.
Padrielly, L., Aller, M. P., Aller, H. D., Fanti, C., Fanti, R., Ficarro, A., Gregoriny, L., Mantovany, P., and Nicolson, G. (1987) *Astron. Astrophys. Suppl.*, **67**, 63.
Slee, O. B. and Siegman, B. C. (1988) *Mon. Not. R. Astron. Soc.* **235**, 1313.
Shishov, V. I. (1993) *Astron. Zh.* **70**, 752 (in Russian); *Astron. Rept.* **37**, 378.