Detection of New Pulsars at 111 MHz

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Abstract—The first results of a search for pulsars using the Large Phased Array of the Lebedev Physical Institute at 111 MHz for right ascensions 0°–24° and declinations 21°–42° are reported. Data with a time resolution of 100 ms in six frequency channels within a 2.5-MHz frequency band have been processed. Thirty-four pulsars have been detected, of which seventeen were observed on this telescope earlier; ten known pulsars had not been observed earlier. Seven new pulsars have been discovered.

DOI: 10.1134/S1063772916020128

1. INTRODUCTION

Since the time of discovery of pulsars in 1967 [1], searches for new pulsars have been regularly carried out in both the northern and the southern hemispheres. As a rule, searches for pulsars have been carried out using directed “lanterns”: in the Galactic plane, globular clusters, and supernova remnants. Only a few surveys have covered areas of at least one steradian. The first surveys covering a considerable part of the sky include those carried out at Molonglo [2, 3], Jodrell Bank [4, 5], and Green Bank [6]. Ongoing surveys include the AO327 survey on the 300-m Arecibo radio telescope [7], GBNCC survey on the 100-m radio telescope in Green Bank [8], NHTRU survey on the 100-m Effelsberg telescope [9], HTRU survey on the 64-m Parkes radio telescope [10], and LOTAS survey on the LOFAR aperture synthesis system [11]. To cover a considerable part of a celestial hemisphere, these surveys require years of observations. As a rule, the total observation time is reduced at the expense of limiting the integration time in a given direction. It is usual not to repeat observations of a given area. At the same time, it is known that pulsars display strong variability due to both external (interstellar scintillations, see e.g., the survey [13]) and internal (flaring pulsars, e.g., J0946+0951 [14]) effects. Therefore, regular observations of the entire celestial sphere could reveal powerful new pulsars in previously studied areas.

A daily survey of the sky covering a full day in right ascension and 50° in declination is being carried out in a test mode on the Large Phased Array (LPA) of the Lebedev Physical Institute. Brief reports of the detection of seven new pulsars have been published in [16, 17]. Here, we present details of this search for new pulsars.

2. OBSERVATIONS AND DATA PROCESSING

The LPA radio telescope is a phased antenna array. It was upgraded in 2012. During its modernization, the first-stage low-noise amplifiers and Butler phasing matrices were replaced, and new cable systems were laid. As a result of this work, two independent beam-forming systems, LPA1 and LPA2, have appeared on the radio telescope. The first phasing system is based on the old beam-forming system; this forms 16 beams, which can be shifted by a half beamwidth, so that it is possible to cover the sky with the LPA beams at a power level of 0.8 over two days of observations. This system of 16 beams covers about 8° in declination and can be switched to provide observations at declinations from −27° to +88°. Observations of pulsars with specialized pulsar receivers are carried out on the LPA1. The maximum effective area of this system is 20 000 ± 2000 m². The second antenna beam was built in a special manner. This second system creates 128 untoggled beams, which overlap at the 0.4 power level. This system of beams enables observations of sources with declinations from −8° to +60°. The effective area of the LPA2 reduced to the zenith value is 47 000 ± 2500 m². Both the LPA1 and LPA2 have total frequency bandwidths of 2.5 MHz. A multichannel digital receiver...
Table 1. Expected zenith sensitivity of the LPA pulsar search

| Sensitivity   | $S_{\text{best}}$ (mJy) | $S_{\text{worst}}$ (mJy) | $S_{\text{typical}}$ (mJy) |
|--------------|--------------------------|--------------------------|-----------------------------|
| In the Galactic plane | 9.9                      | 24.5                     | 15–20                       |
| Outside the Galactic plane | 4.4                      | 10.8                     | 6–8                         |

has been manufactured for the LPA2, which has enabled the recording of the signals from 96 of the LPA beams covering declinations from $-8^\circ$ to $+42^\circ$.

For the calibration of the power of the incoming signals, a dedicated system has been designed to measure the main parameters of the radio telescope—the system noise temperature and effective antenna area—and carry out a functional check of the distributed amplification system and its separate units. The low-noise-amplifier frontend is toggled between the antenna and a calibration noise generator. The noise generator forms two levels of calibration signal corresponding to the noise temperatures of a matched load and the enabled generator. The noise temperature of the matched load is equal to the ambient temperature. The temperature of the noise signal of the calibration generator is 2400 K, and depends only weakly on the ambient temperature. The measured changes in the step magnitude do not exceed $\pm 3\%$ as the ambient temperature changes from $-15^\circ$C to $+43^\circ$C.

The multichannel digital radiometer consists of two recorders, which are industrial computers with multichannel receiving and recording modules capable of recording the signals for the 96 beams of the radio telescope. Each recorder includes six 8-channel digital signal processing modules with four paired TI ADS62P29 analog-to-digital converters at the input of each module. The digital processing is realized using EP3SL780C3 (Stratix III, Altera) programmable logic integrated circuits. Direct digitization of the signal, digital filtration systems, translation of frequencies, and spectrum analysis are used. The digitization rate is 230 MHz, an the bandwidth of the recorded signal in each channel is 2.5 MHz with a central frequency of 110.25 MHz. The programmable logic integrated circuits enable the implementation of eight independent video converters, filtration of high- and low-frequency signals, spectral analysis, and processing of eight independent data streams on a single microchip. The possibility of recording the signal power on a hard disk in 32 or six spectral channels with a frequency resolution of 78 or 415 kHz is realized in the recording module. The time resolution of the signal is 12.5 ms or 100 ms.

Since July 2014, simultaneous data recording with a time constant of 100 ms in six frequency channels ("short data") or a time constant of 12.5 ms in 32 frequency channels ("long data") has been implemented. Monitoring of the time service is carried out at the beginning of each hour of the observations. The digitization of the first point has an accuracy no worse than 5 ms. The accuracy of the sampling of the channel signals within an hour is determined by the precision of the quartz frequency oscillators of the digital receiver. The estimated maximum possible time discrepancy over one hour is $\pm 25$ ms ($\pm$ two points of the raw "long data") and $\pm 100$ ms ($\pm$ one point of the raw "short data").

Q1/C++ code distributed under the GPL V3.0 license\(^1\) and consisting of two blocks was written for the pulsar search. The first block carries out direct addition of the periods and an exhaustive search over the possible dispersion measures. All detected periodic signals with signal-to-noise ratio $\text{SNR} \geq 4$ are written to the a basic catalog. The analysis of the detected signals is performed in the second block. The program can be used to compare the catalogs for all processed days for a number of parameters, and to carry out additional digital filtration. For example, we can trace the recurrence of periodic signals on consecutive days, check for the approximate coincidence of the maxima of the accumulated pulses while also searching for pulsars with the double period, isolate candidate pulsars with $\text{SNR}$ values greater than a specified value, eliminate known pulsars from the candidate lists, and construct dynamical spectra. The program also includes other digital filters.

The time for the transit of a point-like source across the LPA beam is $425 \, \text{s} / \cos \delta$ ($\delta$ is the source declination). The maximum sensitivity in a given direction is achieved at the moment of the meridian transit. When processing the observations, we usually used data from an interval of $\pm (1.5–2)$ min about the meridian transit. Therefore, to obtain the maximum sensitivity during the search, three-minute intervals with a 1.5-min shift were processed. This shift enabled us to ensure that the processed records include the transit of the pulsar across the peak of the antenna beam, where the maximum sensitivity is achieved.

3. DETECTION OF PULSARS

The sensitivity for the detection of pulsars with extremely weak flux densities is given by the well-known formula

$$S_{\text{min}} = \frac{\text{SNR}_{\text{min}} T_{\text{sys}}}{G \sqrt{\nu \Delta f \Delta f_{\text{MHz}}}} \sqrt{\frac{W_e}{P - W_e}} \text{ (mJy)},$$

\(^1\)https://github.com/vtyulb/BSA-analytics
Table 2. Comparison of current pulsar surveys

| Telescope (size)       | $\nu$ (MHz) | $\Delta \nu$ (MHz) | $\Delta t$ (s) | $S_{\text{min}}$ (mJy) | $S_{111}$ (mJy) | References |
|------------------------|-------------|--------------------|----------------|------------------------|----------------|------------|
| Effelsberg (100 m)     | 1360        | 240                | 90/1500        | 0.17/0.05              | 28.7/8.4       | [9]        |
| Parkes (64 m)          | 1352        | 340                | 270/4300       | 0.61/0.2               | 101.8/33.4     | [10]       |
| Green Bank (100 m)     | 350         | 50                 | 140            | 0.6/3.9 (1.34)         | 7.3/47 (16.6)  | [8]        |
| Arecibo (300 m)        | 327         | 57                 | 60             | 0.3/??                | 2.6/??         | [7]        |
| Pushchino (200 × 400 m)| 111         | 2.5                | 180            | 7/18                   |                | This work  |

1 According to [9], the sensitivity of the Effelsberg and Parkes surveys is the same, but the estimated sensitivities taken from the original papers differ by almost a factor of four. Our estimates of the expected sensitivity in the Parkes pulsar search virtually coincide with those for the pulsar search at the 100-m Effelsberg telescope. The estimated sensitivity of the Green Bank antenna for observations in the Galactic plane is given for an assumed temperature of 300 K [8]. This may be an extreme case. The sensitivity in parentheses was obtained assuming a temperature in the Galactic plane of 90 K, which is a factor of three higher than the temperature outside the Galactic plane. In the Arecibo observations, the Galactic plane was eliminated (Galactic latitudes $|b| > 5^\circ$ were observed). The Arecibo sensitivity is taken from [7, Fig. 2] ("Mock").

where the expected sensitivity $S_{\text{min}}$ in a pulsar search using fully steerable antennas is determined by a specified minimum signal-to-noise ratio ($SNR_{\text{min}}$) (in practice $SNR_{\text{min}} = 6$--8), the system temperature ($T_{\text{sys}} = T_b + T_r$, where $T_b$ is the temperature of the background and $T_r$ the temperature of the receiver), the parameter $G$, which is related to the effective antenna area by a normalizing factor, the total integration time $\Delta t$, the frequency bandwidth $\Delta \nu$, the number of observed linear polarizations $n_p$, and the ratio of the pulse width $W_e$ to the period $P$ of the pulsar.

When antenna arrays (such as the LPA) are used, several additional factors affecting the sensitivity must be taken into account. (a) The sensitivity of the antenna decreases with zenith distance. (b) The total time of the observations is restricted by the time for the source transit across the meridian. The maximum sensitivity at the peak of the LPA beam is achieved during 3 min. (c) The position of the beams is fixed in declination, so that the sensitivity decreases if the source coordinates do not coincide with the coordinates of the beam center.

Let us estimate the sensitivity of the LPA in its pulsar search. This depends first and foremost on the temperature of the Galactic background and on how far from the LPA beam center the pulsar crosses the celestial meridian. Adopting a temperature of 1500 K in the Galactic plane and 500 K outside the plane (see the 178 MHz radio maps [15]), estimating the temperature and recalculating to 111 MHz assuming a spectral index $\alpha = 2.55$ ($S \sim \nu^{-\alpha}$), and assuming a pulsar transit exactly across the beam center in between two beams, we can estimate the best ($S_{\text{best}}$) and worst ($S_{\text{worst}}$) expected sensitivity using the above formula for the case when the time constant is less than the pulsar pulse duration. In our estimates, we adopted the parameters $SNR = 6$, $G = 17$ K Jy, $n_p = 1$, $\Delta \nu = 2.5$ MHz, $\Delta t = 180$ s, $W_e = 0.1 P$, and $T_r = 300$ K. Table 1 lists the resulting estimates of the LPA sensitivity for the best, worst, and expected typical case.

Recent and current pulsar searches (see the Introduction) have been carried out at observing frequencies from 111 MHz to 1400 MHz. Therefore, to compare with different surveys, the estimated sensitivities from the original studies must be translated to 111 MHz taking into account the expected spectral index of the pulsar radiation. Other things being equal, the sensitivity of pulsar searches in the Galactic plane is a factor of two to three lower than searches outside the plane, due to the difference in the background temperatures in and outside the Galactic plane. On the other hand, the overwhelming majority of known pulsars lie precisely in the Galactic plane. Therefore, in some of the surveys quoted in the Introduction, longer integration times were used for observations in than outside the Galactic plane; consequently, the sensitivities in these surveys are the opposite: high in the Galactic plane and lower outside the Galactic plane.

Table 2 collects information on all large-scale surveys currently conducted. The columns present (1) the radio telescope on which the pulsar search is carried out; (2)–(3) the survey frequency and total frequency bandwidth; (4) the integration time; (5) estimates of the expected best sensitivity in the survey outside the Galactic plane/in the Galactic plane; (6) the sensitivities recalculated to 111 MHz assuming a spectral index of 2; and (7) references to the pulsar surveys from which the sensitivities listed in column (5) were taken, or the numbers on which our sensitivity estimates were based.
Table 3. Known pulsars detected during the blind search

| Name                          | $P_{\text{ATNF}}$ (s) | $P_{\text{survey}}$ (s) | $S_{102}$ (mJy) | $S_{400}$ (mJy) | $S_{111}$ (mJy) | $W_{50}$ (ms) | $N$ |
|-------------------------------|------------------------|--------------------------|-----------------|----------------|----------------|--------------|-----|
| PSR J0048+3412 (B0045+33)    | 1.21709                | 1.2171                   | 88              | 2.3            | 75             | 21.7         | 17  |
| PSR J0323+3944 (B0320+39)    | 3.03207                | 3.0326                   | 230             | 10.8           | 196            | 42.7         | 23  |
| PSR J0528+2200 (B0525+21)    | 3.74554                | 3.7443                   | 100             | 57             | 85             | 185.5        | 21  |
| PSR J0611+3016*              | 1.4209                 | 1.4120                   | 1.4             | 18.9           |                |              |     |
| PSR J0613+3731               | 0.61920                | 0.6190                   | 1               | 21             | 11             | 18           |
| PSR J0754+3231 (B0751+32)    | 1.44235                | 1.4422                   | 49              | 8              | 42             | 12.2         | 7   |
| PSR J0826+2637 (B0823+26)    | 0.53066                | 0.5306                   | 620             | 73             | 529            | 5.8          | 18  |
| PSR J0943+4109               | 2.22949                | 2.2302                   | 8.6             | 112            |                |              |     |
| PSR J1238+2152               | 1.11859                | 1.1181                   | 60              | 2              | 51             |              |     |
| PSR J1239+2453 (B1237+25)    | 1.38245                | 1.3822                   | 260             | 110            | 222            | 51.1         | 23  |
| PSR J1532+2745 (B1530+27)    | 1.12484                | 1.1246                   | 94              | 13             | 80             | 25.7         | 19  |
| PSR J1741+2758               | 1.36074                | 1.3608                   | 30              | 3              | 26             | 7            | 7   |
| PSR J1758+3030               | 0.94726                | 0.9472                   | 60              | 8.9            | 51             | 27           | 23  |
| PSR J1813+4013 (B1811+40)    | 0.93109                | 0.9311                   | 8               | 104            | 12.2           | 22           |
| PSR J1821+4145*              | 1.26179                | 1.2620                   | 2.6             | 35             |                |              |     |
| PSR J1907+4002 (B1905+39)    | 1.23576                | 1.2355                   | 23              | 299            | 58.5           | 24           |
| PSR J1921+2153 (B1919+21)    | 1.33730                | 1.3371                   | 1900            | 57             | 1620           | 30.9         | 24  |
| PSR J2018+2839* (B2016+28)   | 0.55795                | 0.5580                   | 260             | 314            | 222            | 14.9         | 24  |
| PSR J2055+2209 (B2053+21)    | 0.81518                | 0.8152                   | 9               | 117            | 16.9           | 16           |
| PSR J2113+2754 (B2110+27)    | 1.20285                | 1.2030                   | 130             | 18             | 111            | 13           | 24  |
| PSR J2139+2242               | 1.08351                | 1.0835                   | 30              | 26             | 91             | 22           |
| PSR J2157+4017 (B2154+40)    | 1.52527                | 1.5250                   | 200             | 105            | 171            | 38.6         | 21  |
| PSR J2207+40                 | 0.63699                | 0.6370                   | 3.8             | 49             |                |              |     |
| PSR J2227+3036               | 0.84241                | 0.8423                   | 2.4             | 31             |                |              |     |
| PSR J2234+2114               | 1.35875                | 1.3587                   | 35              | 2.6            | 30             | 43           | 17  |
| PSR J2305+3100 (B2303+30)    | 1.57589                | 1.5758                   | 24              | 312            | 17.4           | 23           |
| PSR J2317+2149 (B2315+21)    | 1.44465                | 1.4445                   | 100             | 15             | 86             | 20.2         | 24  |

PSR J0611+3016* was observed at 430 MHz in the Arecibo survey [18]. PSR J1821+4145* was observed at 350 MHz in the Green Bank survey [19]. The estimated 111-MHz flux density of PSR J2018+2839 is formal, because its spectrum between 102.5 and 400 MHz is inverted.

Note that the Parkes and Eifelberg surveys used different integration times for high, mean, and low Galactic latitudes. The integration times for high ($|b| > 15^\circ$)/low ($|b| < 3.5^\circ$) Galactic latitudes are given in Table 2. The sensitivity estimates in column (5) are those indicated in the original studies. If the estimated sensitivity was not stated, we calculated the sensitivity using information given in the original study or taken from the corresponding figures. In the original studies, sensitivity estimates were given for various $SNR_{\text{min}}$ and various ratios of the pulse duration to the period. To compare the survey sensitivities, these estimates were first recalculated for $SNR_{\text{min}}=6$, $W_e=0.1P$, and then recalculated to a frequency of 111 MHz.

Table 2 shows that the expected sensitivity of the LPA is inferior to that of the 300-m Arecibo telescope for observations outside the Galactic plane. It is also
lower than the sensitivity of the 100-m Effelsberg telescope and, probably, the 64-m Parkes telescope, for observations in the Galactic plane ($|b| < 3.5^\circ$). In all the remaining cases, the expected sensitivity of the LPA pulsar search should be comparable to or better than those of the other searches considered.

We chose an area with declinations $21^\circ 23' - 42^\circ 08'$ for a test pulsar search. In all, 24 days of observations were processed. Approximately 400,000 periodic signals were found in this area each day, of which several hundred were selected for manual processing using the digital filters. A direct addition of periods with an exhaustive search from 0.5 to 15 s and an exhaustive search of dispersion measures in the range 0–200 pc/cm$^3$ were carried out. We used the “short data” for the search. A pulsar was taken to be detected if it was found on no fewer than three days, at least once with $SNR > 6$.

According to the ATNF database$^2$, 77 pulsars with periods longer than 500 ms and dispersion measures up to 200 pc/cm$^3$ fall into the survey area. A blind search program detected 27 known pulsars, for which data are given in Table 3, whose columns contain (1) the J2000 name of the source with its B1950 name in parentheses, if used for the given pulsar; (2)–(3) the estimated periods from the ATNF catalog and obtained by us; (4)–(5) the estimated flux densities at 102.5 MHz[12] and 400 MHz (the ATNF catalog); (6) a crude estimate of the expected flux density of the pulsar at 111 MHz; (7) the halfwidth of the pulsar pulse from the ATNF catalog; and (8) how many times the pulsar was detected during the 24 processed days. The estimates in column (6) were based on the flux density at 102.5 MHz if available, and the flux density at 400 MHz otherwise, assuming a spectral index $\alpha = 2$. An asterisk after the pulsar name refers to a comment for this source at the end of Table 3.

Table 3 shows that the accuracies of the periods for most of the detected pulsars are better than 0.001 s. This corresponds to the expected accuracy for the record length of 180 s used in the search. It is difficult to assess the actual sensitivity obtained in the processing of the pulsar monitoring data using Table 3. Let us consider column (6) of Table 3. The weak detected pulsars outside the Galactic plane have expected flux densities of 20–30 mJy, while weak pulsars in the Galactic plane have expected flux densities of 80–100 mJy. Both estimates are a factor of three higher than the expected survey sensitivity threshold. Thus, the actual sensitivity is appreciably lower than expected.

In addition to the known pulsars, we detected seven new pulsars that are not present in the ATNF catalog. A new pulsar was taken to be discovered if (a) the SNR was greater than six on at least one of the processed days; (b) a mean profile with approximately the same height is visible in the record for the double period; (c) the pulsar is detected in records on no fewer than three of the 24 days processed; (d) the observed SNR as a function of the dispersion measure (SNR vs. DM diagram) has a pronounced maximum. Table 4 lists the parameters of these new pulsars. The columns give (1) the J2000 source name; (2)–(3) the pulsar coordinates; (4)–(6) the pulsar period, dispersion measure, and mean profile half-width; and (7) how many time the pulsar was detected during the 24 processed days. The accuracies of the coordinates of J0146+3104, J0928+3037, J1242+3938, J1721+3524 are $\pm 40''$ in right ascension and $\pm 10''$ in declination. The corresponding accuracies for J0220+3622, J0303+2248, and J0421+3240 are $\pm 60''$ and $\pm 15''$.

The data presented in Table 4 are preliminary. Observations intended to refine the parameters (dispersion measure and period) of the detected pulsars on a facility designed specifically for pulsar studies are now carried out. The pulsars J0146+3104, J0220+3622, J0421+3240, J1242+3938, and J1721+3524 have

| Name          | $\alpha_{2000}$ | $\delta_{2000}$ | $P$ (s) | DM (pc/cm$^3$) | $W_{0.5}$ (ms) | $N$ |
|---------------|----------------|----------------|--------|----------------|---------------|-----|
| J0146+3104    | $01^h46^m15^s$ | $31^\circ04'$  | 0.9381 | 24–26          | 20            | 7   |
| J0220+3622    | $02^h20^m50^a$ | $36^\circ22'$  | 1.0297 | 30–50          | 220           | 8   |
| J0303+2248    | $03^h03^m00^a$ | $22^\circ48'$  | 1.207  | 15–25          | 50            | 4   |
| J0421+3240    | $04^h21^m30^a$ | $32^\circ40'$  | 0.9005 | 60–90          | 400           | 4   |
| J0928+3037    | $09^h28^m43^s$ | $30^\circ37'$  | 2.0919 | 20–24          | 50            | 16  |
| J1242+3938    | $12^h42^m34^a$ | $39^\circ38'$  | 1.3100 | 25–27          | 35            | 14  |
| J1721+3524    | $17^h21^m57^a$ | $35^\circ24'$  | 0.8219 | 19–25          | 60            | 18  |

Table 4. Parameters of new pulsars

$^2$http://www.atnf.csiro.au/people/pulsar/psrcat/
already been confirmed using LPA1 observations. Their periods have been refined to the seventh decimal place (Malofeev et al., in preparation).

Special attention should be paid to the pulsars J0220+3622 and J0421+3240, which have broad mean profiles that can cover about half the period.

Figures 1–7 present for the dynamical spectra and mean profiles of the new pulsars, as well as the dependence of the SNR on the dispersion measure for an observational day. The “long data” were used to plot these diagrams. The graphs of the dynamical spectra and mean profiles are plotted with the double period. The dynamical spectra were constructed using the “long data.” Since these new pulsars are weak, we have averaged the dynamical spectra over frequencies and/or time (see comments in the figure captions). The lowest frequencies in the observing band correspond to the upper part of the dynamical spectra, and the highest frequencies to the lower part of the dynamical spectra.

4. DISCUSSION AND CONCLUSIONS

Table 1 lists the theoretically estimated expected sensitivity of the LPA pulsar-search survey. Our
reduction of the actual survey data demonstrates that this sensitivity is appreciably lower than the expected value. There are a number of factors that can be taken into account in order to help us approach the theoretical sensitivity.

First, the maximum sensitivity in the pulsar search will be achieved if the pulse duration is equal to the time constant. If the time constant in the raw data is less than the expected pulse duration, it is possible to perform additional averaging within the presumed pulsar period in order to obtain the maximum SNR. Table 3 shows that approximately 80% of all the detected, previously known pulsars have a mean pulse profile halfwidths of less than 30 ms. Therefore, since our time constant is 100 ms, the losses in the SNR during the processing of these data were a factor of 1.5 or more. These SNR losses will have a substantial effect on the detection of the weakest pulsars. These losses can be avoided by processing the “long data.” The time constant of 12.5 ms is sufficient to obtain the maximum SNR in the search for the overwhelming majority of known second-period pulsars, and will most likely also sufficient for the search for new pulsars.

Second, scintillations of radio sources on the interplanetary plasma and in the Earth’s ionosphere are observed at meter wavelengths. According to the earlier studies [20], the mean confusion of scintillating...
radio sources at 102 MHz is 0.14 Jy, which is close to the fluctuation sensitivity of the LPA2. Scintillations of compact radio sources are continuously observed in the actual raw recordings. Early studies on the LPA showed that the density of detected compact (scintillating) radio sources on the sky is approximately one source per square degree [21], which is comparable to the size of the LPA beam. Since scintillation is a stochastic process, it increases the width of the noise track, thus deteriorating the sensitivity of the pulsar search survey. Note also that the scintillation timescale at meter wavelengths is approximately 0.5 s. This raises problems in subtracting the background signal from the records. The zone of scintillation detections is broad. Monitoring of scintillating radio sources carried out at the LPA demonstrates that, with the current sensitivity of the LPA2, the zone of enhanced scintillations can extend over 12–18 hours, depending on the season [22]. If we can eliminate magnetic storms, ionospheric scintillations occupy approximately one hour in the morning and in the evening. The timescale of the ionospheric scintillations begins from several seconds [23]; like interplanetary scintillations, this can result in problems with subtracting the background from the records. Hence, to achieve the maximum sensitivity in the
pulsar search, it makes sense to select only five to six night-time hours from the records.

Third, during the search, only about a third of the known pulsars ($P > 0.5$ s) located in the studied area were detected. Another third that were not detected during the search are probably too weak to be detected with the LPA. The expected flux densities of these pulsars extrapolated from the ATNF estimated flux densities may be less than 20–30 mJy at 111 MHz; this is the case for J0540+3207, J0546+2441, J0555+3948, J0947+2742*, J1503+2111, J1720+2150, J1746+2245, J1746+2540, J1900+3053, J1903+2225, J1911+2525, J1913+3732, J1929+2121, J1931+3035, J1937+2950, J1939+2449, J1946+2224, J1949+2306, J1953+2732, J2007+3120, J2010+2845, J2015+2524, J2036+2835, J2151+2315*, J2155+2813*. Apart from those labeled with a *, these pulsars are located in the Galactic plane, where the sensitivity of the pulsar search survey is lowest. Some pulsars are X-ray pulsars or RRATs, such as J1308+2127, J1605+3249, and J2225+3530. Nevertheless, approximately 20–25 of the known pulsars apparently should have been detected during the search, but were not. This includes some pulsars that were observed earlier on the LPA at 102.5 MHz:}

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**Fig. 4.** Observational data for J0421+3240. The dynamical spectrum has been averaged over both time and frequency.
J0417+3545 ($S_{102} = 46$ mJy), J0927+2347* ($S_{102} = 30$ mJy), J0943+2556* ($S_{102} = 77$ mJy), J1649+2533 ($S_{102} = 60$ mJy), J1652+2651 ($S_{102} = 40$ mJy), J1920+2650 ($S_{102} = 30$ mJy), J1948+3540 ($S_{102} = 60$ mJy), J2002+3217 ($S_{102} = 80$ mJy), J2002+4050 ($S_{102} = 170$ mJy), J2008+2513 ($S_{102} = 60$ mJy), J2030+2228 ($S_{102} = 22$ mJy), J2037+3621 ($S_{102} = 34$ mJy), J2212+2933* ($S_{102} = 50$ mJy), and J2307+2225* ($S_{102} = 30$ mJy) [12]. Approximately a half of the pulsars enumerated in the present paragraph have been found either at SNR $< 6$ or less than three times or with higher harmonics, therefore they were eliminated from the search for new pulsars.

Methodical works on improving the search program are now carried out.

A number of other factors should be noted. (1) Strong interference is observed at low declinations, whose sources are located to the south and are industrial objects. (2) Many records are lost in Spring and the beginning of Summer many records, due to thunderstorms. (3) The 111 MHz frequency range is not protected at the primary and secondary level; this means that additional interference is regularly observed, probably associated with mobile services. All these factors result in the inability of processing approximately 20–25% of all records.
The main advantages of the LPA are its large effective area and associated high sensitivity, the possibility of simultaneous observations in many beams, and the possibility of daily monitoring. In other current pulsar search programs (see Table 2), high sensitivity is achieved at the expense of observing with a broad frequency band, and the decrease in the system temperature ($T_{\text{sys}}$) with increasing frequency. The possibility of daily monitoring of the entire sky is ruled out in these surveys.

Searches for pulsars through daily monitoring data with the LPA is especially advantageous for detecting rare objects: flaring pulsars, in which long intervals of relative quiescence can be replaced by a considerable increase in the observed flux density, RRAT-type pulsars, Geminga-type pulsars, pulsars with nullings, and pulsars with giant pulses. We separately note also nearby pulsars, which can considerably change their observed flux densities from day to day due to interstellar scintillations, and pulsars with very steep spectra ($\alpha > 2.5$).

To conclude, processing half of the area accessible in declination using the “short data” has yielded the discovery of seven new pulsars. In view of the obvious reduction in the search sensitivity for these observations compared to the expected sensitivity, whose
nature is not entirely clear, and the fact that we plan to analyze the “long data” in the future, we expect the future detection of no fewer than several dozen new pulsars using the LPA monitoring data.

ACKNOWLEDGMENTS

The authors thank V.M. Malofeev for reading the manuscript and for comments that helped to improve the text, and to L.B. Potapova and G.E. Tyul'basheva for help with the manuscript and figures.

This work was supported by the program of the Division of Physical Sciences of the Russian Academy of Sciences “Transient and explosive processes in astrophysics.”

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Translated by G. Rudnitskii