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THE DAILY 110 MHZ RADIO WAVE SKY SURVEY: STATISTICAL ANALYSIS OF IMPULSE PHENOMENA FROM OBSERVATION IN 2012-2013

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ABSTRACT. On the Pushchino Radio Astronomy Observatory of Lebedev Physical Institute by radio telescope BSA (Big Scanning Antenna) in 2012 started daily multi-beam observations at the frequency range 109-112 MHz. The number of frequency bands range from 6 to 32, while the time constants range from 0.1 to 0.0125 sec. This data is an enormous opportunity for both short and long-term monitoring of various classes of radio sources (including radio transients), the Earth's ionosphere, interplanetary and interstellar plasma monitoring, search and monitoring for different classes of radio sources, etc. A specialized database was constructed to facilitate the large amount of observational data (http://astro.prao.ru/ cgi/out_img.cgi). We discuss in this paper method of allocation from the database for impulse data of various types. By using the database allocated 83096 individual impulses in declination from +3 to +42 degrees for July 2012 – October 2013 from pulsars, scintillation sources and so one. In result we constructed homogeneous sample suitable for statistical analyzes.

Keywords: radio survey, radio transients, monitoring, database

1. Observations

In 2012 the multi-beam feed array has become operational on the BSA FIAN radio telescope (Oreshko et al., 2012). As of July 2015 it is capable of 24-hour observation using 96 beams in declination of -8 to +42 degrees in the 109–111.5 MHz frequency band.

Radio Observatory of Lebedev Physical Institute in Pushchino has one of the most sensitive radio telescope at 110 MHz BSA (Big Scanning Antenna). Radio telescope originally worked in a range of 101–104 MHz, but in 1996 was rebuilt to a range of 109–112 MHz. In this range BSA telescope is the most sensitive in the world (and one of the most sensitive in the world in the meter wavelength range as a whole). Systemic equivalent flux density (SEFD) radio telescope is 34 Jy (Oreshko V.V. et al., 2012) at the zenith at a minimum temperature of the background, while a radio telescope LOFAR SEFD at a frequency of 120 MHz is about 2000 Jy (Van Haarlem et al., 2013). We need note that now the long-wave radio astronomy (in the range of 10 to 300 MHz) is experiencing a new wave of interest. There is a wide class of scientific problems for this range (see., eg, Konovalenko et al., 2016). Existing radio telescopes (the most famous of them UTR-2 – Braude et al., 1978) are experiencing a rebirth, as the construction of new radio telescopes – except LOFAR (Van Haarlem M. P. et al., 2013) should be called GURT (Konovalenko et al., 2016) and LWA (Taylor et al., 2012).

Since 2012 BSA started multi-beams observations using 96 beams in declination from -8 up to +42 degrees in 6 and 32 frequency bands at 109-112 MHz and time sampling 0.1 s and 0.0125 s. The data stream in 32 bands and time sampling of 0.0125 s is producing 87.5 gigabytes per day. It was accumulated more than 70 TB (i.e. 3.5 TB with 100 ms time resolution from 2012 and 67 TB with 12.5 ms resolution from 2014).

The main technical parameters of the radio telescope BSA are:

operating frequency band 109 – 112 MHz;

the effective area of the antenna (maximum) – 47 000 square meters;

the system noise temperature (minimum) – 560 K;

antenna polarization – linear (horizontal, along the east-west direction);

the number of beams today in registration – 96;

the width of beam diagrams in the E-plane – 54 arcmin;

the width of beam diagrams in the H-plane – 24 arcmin (zenith).

The sensitivity of the survey is 0.07 Jy at 100 ms time resolution and 0.2 Jy at 12.5 ms resolution.

Since July 2012 it was observed daily about 2 steradians, and starting April 2013 it is monitoring about 5 steradians for 50 degrees in declination. This is unique survey of North Hemisphere. Based on accumulated data and newly recording data we suggest to monitor and to search different types of astronomical phenomena. There are two main classes of the phenomenon which can be investigated using BSA data: long term monitoring (from daily up to yearly variations) and short transient detection (from ms to seconds). In this work we are testing short transient phenomena.

2. The selection methodic of pulse signals from data

We may found that for the case of source entering into the area of the main lobe of a ray diagram for example with S/N≥10 detection criterion for sporadic (transient)

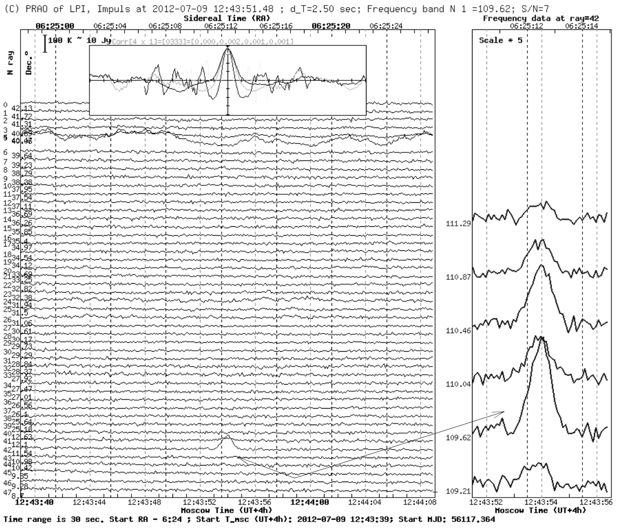

Figure 1: An example of one of the found pulse events: response from the passage of a satellite of the Earth (the International Space Station, showing the reflection area of about 400 m^2) through the beam glissade aircraft radio beacon from one of the near airports. These beacons operate at frequencies around 110 MHz (BSA frequency range). The arrows indicate the selected pulse (width of about 1.5 sec): on the left, mainly boxing picture – temporary scan by BSA beams, in the right box – scan a beam over 6 frequencies. The upper figure shows the result of boxing Pearson correlation results for the 3th time scales: they have the correlation is maximum at zero time scale for data from different observation frequency. At the top of the figure, on the 6th beam from above – an example of the scintillation point radio source. Such strong (single) order of magnitude as the scintillation of a second is usually also allocated as independent impulse events.

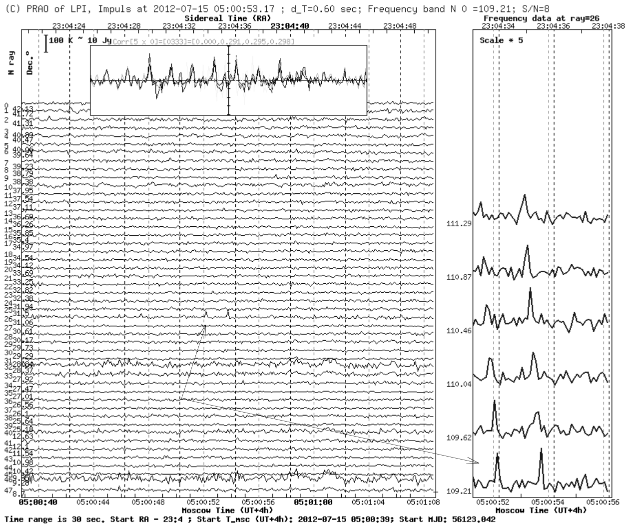

Figure 2: An example of one of the found pulse events: a response from one of the pulses (in the center of the figure) of the pulsar PSR2305+3000. The arrows indicate the selected impulse: to the left, mainly boxing picture – temporary scan beams on BSA, in the right box – scan a beam with impulse over 6 frequencies. In the right box clearly visible time drift along the frequency (here DM = 49,6 pc/cm^3). The upper figure shows the correlation boxing search result Pearson for the 3th time scales: they all showed a clear shift of the lower frequency data about the high-frequency band. This pulsar is bright enough (~ 5 Jy) and noticeable series of pulses following each other with a period of P = 1,58 sec. In total for PSR2305 + 3000 on the time interval 6.07.2012 – 10.20.2013 years allocated 334 pulse events.

signal it have the following estimates. The unit reliably detectable pulse emission data on a band 415 kHz (Δt = 100 ms) will ≥1,6 Jy, for the band 78 kHz (Δt = 12,5 ms that very goog for FRB searching work) – ≥10,6 Jy.

Note that for a recent LOFAR pulsar pilot survey (Coenen, 2014), the authors have made a similar estimate with the same criterion of S/N = 10 to find fast radio bursts (FRB – see Lorimer et al, 2007), and it was ≥107 Jy for Δt = 0,66 ms (for our time scale Δt = 12,5 ms it will move to ≥25 Jy). So in result 32-frequency data from BSA with Δt = 12,5 ms have good potential even in comparison with LOFAR, but in addition such survey we producing daily.

In this paper we worked until with 6-frequency data (Δt = 100 ms). We we chose also more soft detection criterions: S/N≥5 for at least three of the six frequency bands. In our case signal $S=S_{max} - S_{median}$ for any 5 second data segment and N is dispersion of S on this data segment at some frequency band. In result we found usually all events on time scale from 0.1 to nearly 1 seconds. After we allow only events that found not more than in 1-3 ray. So interference signal eliminated that reflected usually on tens rays. We are deleted also region $\delta \leq +3.5°$ so as we have big interference unclear nature.

3. The results of searching and sorting

In this work we discuss first results for short transient found from our database (Samodurov et al., 2015) in July 2012 – October 2013. We found 83096 events in diapason $+3.5° \leq \delta \leq +42.5°$ which could be associated with pulsars, scintillation sources and fast radio transients. These found events are a homogenous sample suitable for statistical analysis. We found such classes of transient sources:

A) False signal so as interference, apparatuses and like unrealistic phenomena – 21962 events from 83096 or 26,43 %. They are:

– the impulses generated by far lobe diagram response on flush/deviation in strong radio sources (usually Sun): 5,87 % ;

– the impulses generated by apparatuses: 13.28 % ;

– the impulses generated by interference (man-made, thunderstorms): 3.94 % ;

– the impulses generated by different man-made reasons (for example overflights) and other: 3.34 % ;

B) Scintillation single signal produced by interstellar medium or ionosphere – 29283 events from 83096 or 35,23 %. They are:

– the scintillations with $\Delta t \leq 1$ second (in base generated by interstellar medium): 27,38 % ;

– the scintillations with $1 \leq \Delta t \leq 5$ second: 6,78 % ;

– the scintillations with $\Delta t \geq 5$ second (in base generated by ionosphere): 0,60 % ;

– other (satellites – fig. 1 and not clear reason): 0,40 %

C) The single impulses with some dispersion time delay along frequencies bands, that are generated by pulsar (fig. 2) – 31851 events from 83096 or 38,33 %.

The most interesting results of the selection pulse last type. About 340 pulsars from ATNF pulsar catalog (Hobbs et al) falling within a declination band $+3.5° \leq \delta \leq +42.5°$ and have periods of more than 0.3 seconds. We found in our sample pulses for 41 of them (even 2 pulsar found of having period 0.2-0.3 seconds). Pulse events number that found for these pulsars ranges from 1 (one) to thousands for the above observation time (an average of about one year).

The account of pulsars (for found sample from ATNF catalogue) with the different dispersion delay is varied:

– DM<16 pc/cm^3 : 9 units from 20;

– DM<50 pc/cm^3 : 37 units from 112;

– 50 pc/cm^3 <DM<100 pc/cm^3 : 4 units from 91;

– DM>100 pc/cm^3 : 0 units from 187.

This variation is clear so as good corresponding with distance to pulsars and its resulting brightness.

In end to end we found also of some pulses from candidates in new pulsars. We hope that after adding checking and analysis any from them really are unknown before pulsars.

4. The future plans of data processing

Noticeably influence scattering pulsar pulse broadening on the effectiveness of the pulse discharge from the database. So ways of improving the search technique of pulse phenomena is now nearly clear: increase in analysis time (to appear from 5 sec to 15 sec) and the transition to data with Δt=12.5 ms and 32 frequency bands.

The database will updated by data for 2013-2016 for the subsequent stages of the work on the allocation of pulse phenomena. The database also will be expanded to the "fast" data (32 bands with a sampling time of 12.5 ms), which will dramatically expand the class to solve scientific problems: to investigate the fine structure of the giant pulses of pulsars, fine temporal structure of solar flares, to organize search FRB.

Indeed, the search for the FRB we need:

– Millisecond scale recording observations. The sampling of 12.5 ms at a frequency of 110 MHz for the BSA telescope essentially meets the necessary criteria;

– Large search area and the long-term observations. Some yars continuous observations of the 40% sky now provide good base for statistics, and the accumulation of observations is continuing;

– The total bandwidth is 2.5 MHz, the difference between adjacent bandwidth of 78 KHz, while passing through the diagram BSA for about 5 minutes. These characteristics correspond to the available catch even short bursts of very high dispersion delays. Thus, it is easy to find that DM=1000 time delay in the region of 110 MHz with a difference frequency of 2 MHz is about 12 seconds, and for DM = 10,000 – about 120 seconds, which is also less than the width of beam of BSA telescope. Thus, the BSA is suitable telescope for observation and search for FRB.

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