THE DAILY 110 MHZ SKY SURVEY (BSA FIAN): ON-LINE DATABASE, SCIENCE AIMS AND FIRST RESULTS OF DATA PROCESSING

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ABSTRACT. From 2012 on radio telescope BSA FIAN multi beams diagram was started. It capable at July 2014 daily observing by 96 beams in declination -8 .. 42 degrees in the frequency band 109-111.5 MHz. The number of frequency bands are from 6 to 32, the time constant are from 0.1 to 0.0125 sec. In receiving mode with 32 band (plus one common band) with a time constant of 12.5 ms (80 times per second) respectively produced 33x96x80 four byte real and so daily we produced 87.5 Gbt (yearly to 32 Tbt). These data are enormous opportunities for both short and long-term monitoring of various classes of radio sources (including radio transients) and for space weather and the Earth's ionosphere monitoring, for search for different classes of radio sources, etc. The base aims of our work are:

a) to obtain new scientific data on different classes of discrete radio sources, the construction of physical models and their evolution - obtained on the basis of the clock continuous digital sky radio monitoring at frequency 109-111.5 MHz and cross-analysis of data from third-party reviews on other frequencies;

c) launch the streaming data on various types of high-performance computing systems, including to create a public system of distributed computing for thousands of users on the basis of BOINC technology. The BOINC client for astronomical data from the monitoring survey of the big part of entire sky almost have not analogies.

We have some first science results (new pulsars, and some new type of radiosources).

Keywords: Stars: abundances – Galaxy: abundances – stars: late-type

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.

The number of frequency bands range from 6 (417 kHz per band as the "wide observational mode" or "light" mode) to 32 (78 kHz per band as the "narrow observational mode" or "heavy" mode) while the time constant ranges from 0.1 sec ("wide observational mode") to 12.5 ms ("narrow observational mode"). Such type of continu-

ous daily survey of the major observable part of the sky is not yet done by any observatories worldwide. Observations have already been carried out for more than 2.5 years, with a typical daily data production of 2.3 GB (gigabytes) in wide observational mode, equating to a total of 0.8 TB (terabyte) of data per year. Respectively, in narrow observational mode the data produced amounts to 87.5 GB daily, or 32 TB yearly.

It is now possible to record data in both modes at the same time. The narrow observational mode will be used in the near future for the purpose of searching for radio transients of different types (for example, pulsars). At the end of October 2015 we accumulated over 16 months of observations "heavy" mode (total volume of about 41.6 TB) and more than 3 years for "light" mode (total volume of about 3 TB).
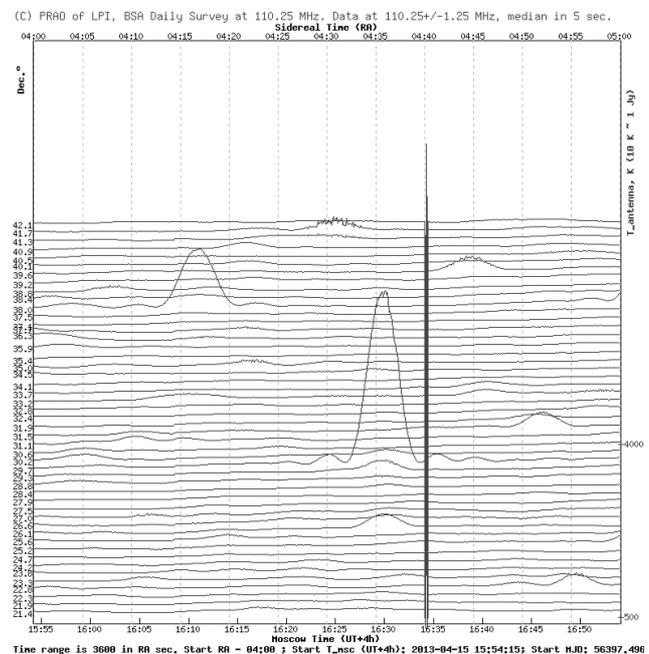

Figure 1: The sample of calibrated data from the multi beams diagram BSA at 15 April 2013. It showed the calibration signals (at RA = 4 h 40 m) of galaxy background with the some radio sources on it. The some sources (for example is upper sources) are showed phenomenon of flicker produced by interstellar medium scintillations from small sources with scales nearly fraction of arc second.

2. Database and data processing

A specialized database needs to be constructed to facilitate the large amount of observational data. In the period between 7 July 2012 and 20 October 2013 an experimental database collected more than 8 million calculated 5-second sample data from each beam for more than 27 parameters. The observational data parameters are maximal, minimal, median, average, dispersion etc. for 5-second periods of time in different frequency bands. Using this data close to one million images has been built. The figure 1 present example median data on hourly scale.

By the end of 2014 work will be completed on the on-line database, which will be publically available on http://astro.prao.ru/. This database will enable users, both local and remote, to use different ways to processing the observation data. The total size of the database is over than 200 GB.

We should highlight the fact that storing the compressed data in SQL database formats allows us to use the power of selection, sorting, matching, filtering and initial processing of data by using standard SQL commands. This will greatly simplify the interaction and the comparative analysis of the data for different sorts of data and their cross-temporal analysis, averaging etc. These data are enormous opportunities for both short and long-term monitoring of various classes of radio sources (including radio transients) and for space weather and the Earth's ionosphere monitoring, for search for different classes of radio sources, etc.

One of our goals is to launch data streaming processes on various types of high-performance computing systems, including creating a public system of distributed computing for thousands of users on the basis of BOINC technology. The BOINC client for astronomical data from the monitoring surveys of large parts of the entire sky almost has no analogies.

Preliminary estimates show that we may reach of data processing speeds practically bordering on "on-line" mode (with a time lag of no more than 2-3 hours following the observations). All data, including the original observations and the results of data processing for the purpose of various scientific objectives will be continuously displayed on the PRAO of LPI website. The data will be displayed in graphical form for external public users, while the project participants will also be able to access the data in its original digital form.

For mutual benefit it is possible to also facilitate for this database to include additional low-frequency (10-25 MHz) observation data from the Ukrainian UTR radio telescope.

3. The scientific goals

This monitoring system allows a potential to solve a tremendously wide range of classes of problems, not only fundamental scientific ones, but also challenges within applied sciences. The proposed project allows to continuously monitor celestial radio sources in most parts of the sky on time scales from milliseconds to years.

The following is a list of our primary goals:

1) Monitoring of the ionosphere state and its fluctuations (with a characteristic time scale of tens of seconds).

2) Analysis of meteor tracks in the higher layers of the Earth's atmosphere.

3) Monitoring of active phenomena on the Sun such as sporadic outbursts with the time scales from seconds to hours as well as the state of the near-solar plasma. This is a broad field of research on near-solar source flicker interplanetary plasma. This solar behavior will be monitored and its most common parameters will be displayed in graphical form on the PRAO of LPI website.

4) Radio monitoring of transient (flare) phenomena in the solar system such as ionospheric and storm phenomena of the giant planets, tracking of radio transient phenomena on the Moon and other radio phenomena in the solar system.

5) Monitoring of transient phenomena in our Galaxy. This covers a wide class of scientific problems, from studies of outbreaks of radio emission from cataclysmic variables to search for candidates in exoplanets around alien stars. Not all of them can be implemented on our radio telescope, however some of these events are available to us.

6) Monitoring of flux density of extragalactic radio sources. For this purpose we are able to perform daily monitoring of about 400-500 radio sources outside of 15-degree declination from the plane of our Galaxy.

7) Monitoring of extragalactic transient phenomena. The most interesting problem is searching for fast radio transient events in other galaxies (on the scale of a few milliseconds). According to several studies such radio transients have been discovered in the decimeter wavelength range in the last few years. Theorists associate these transient events with the possible merges of neutron stars. Phenomena of this magnitude emit great amounts of energy, the levels of which are high enough to be detected by our telescope even from galaxies as distant from us as hundreds of Mpc. This problem is currently a very popular topic for Astrophysics.

Ultimately, the multi-beam observations of the BSA of LPI telescope will take advantage of the wide-field survey capabilities to enable the discovery and investigation of variable and transient phenomena from the intra- to the extra- galactical, including flare stars, intermittent pulsars, X-ray binaries, magnetars, extreme scattering events, interstellar scintillation, radio supernovae and orphan afterglows of gamma-ray bursts. In addition, it will allow us to probe unexplored regions of parameter space where new classes of transient sources may be detected.

4. The first scientific results

We have today from base data processing of the some first science results. It is the first results for search of the new pulsars and search results of the other objects.

It is best test of our data is the pulsars search. The best solving of this problem on our data can be processing by a on supercomputers computing or a by BOINC distributed computing (look on http://boinc.berkeley.edu/).

The example of the last way is the Einstein@Home project in the decimeter band of radio wave for the data from Arecibo radio telescope (Cordes, J.M. et al: 2006) and from Parkes Observatory data (Knispel et al , 2013). The project found in the observatory data more than 50 new pulsars at a frequency of 1440 MHz.
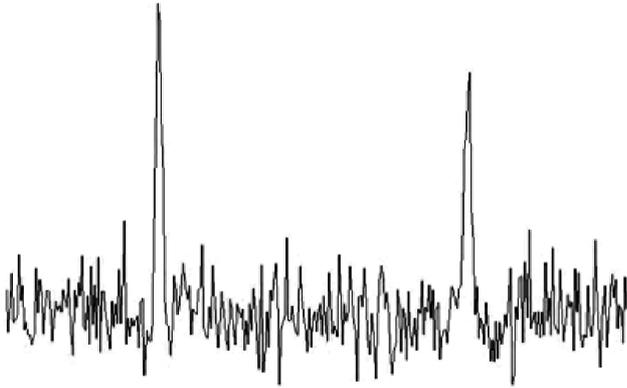
Figure 2: The result of search for new pulsar PSR $\alpha_{2000}=09^h28^m00^s\pm30^s$; $\delta_{2000}=+30°37'\pm20'$ with period P=2.0919s and DM=22-24 (from S.A.Tulbashev, V.S.Tulbashev, 2015). It is showed 2 pulsar periods.

BSA of LPI is one of the best in the world in antennas sensitivity parameter. Really, BSA effective area of approximately 30,000 square meters, which is about the same order as that in Arecibo and significantly more than Parkes radio telescopes. The pulsars is brighter by order on our frequency 110 MHz in additional. So although our frequency band is less (2.5 MHz against the tens of megahertz in Parkes and Arecibo), we may hope discover of some new pulsars in our data.

We began in April 2015 pulsars search in the standard regime by single personal computers as part of the work data testing. We have been using two searches methodic.

First method is classical folding – that is testing different periods and dispersion delay for pulsar candidate. Four new pulsar was already discovered by this work (S.A. Tulbashev, V.S. Tulbashev, 2015).

On the figure 2 is showed the result of searching for one from new pulsars that found by folding method (S.A. Tulbashev, V.S. Tulbashev: 2015).

The second method is search for new periodic objects by using spectral analysis. We dividing observation time in each beam scans on data segments that contain 2048 points (i.e., 2 in power 11, for to using of classical Fast Fourier Transform algorithms). So for the "small" mode of observation with a time constant of 0.1 seconds is provided time interval data equally 205 seconds. So we have near beam width BSA temporal scale (at the half power) that has about 5-6 minutes. Thus the range of 205 seconds is about twice less than the actual exposure time of sources. But this method allows summarizing the observations data from day to day. In result we will can find hundreds possible pre-candidates pulsar list with roughly defined periods $\pm0.0005^s$ by preprocessing FFT spectral analysis over all the sky. This big list of pre-candidates will be processing at next stage by BOINC computing. In result we hope found some very weak pulsar computing after preprocessing by FFT spectral analysis plus BOINC computing.

On the figure 3 is showed the result of checking data for this pulsar by FFT spectral analysis for sum all 3 year data (2012-2015) in observational "light" mode (with 0.1 sec time constant). We may look that both methods work very satisfactorily.
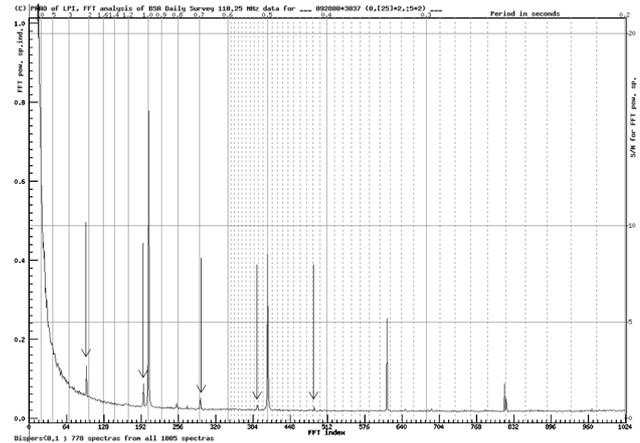

Figure 3: The result of testing for new pulsar PSR from figure 2 by FFT spectral analysis on 2012-2015 year data. The arrows marked 5 harmonics of the period P =2.0919 s. We may look also 4 harmonics of the period P=1.000 s that unfortunately produced by interferences from local GPS time receiver.

There are other scientific problems (sometimes quite unexpected nature) that can be solved with the help of your data. So, as an example of practical problems that proposed by one of the authors is search radar echoes from satellites that produce by ILS in airport near Moscow. An instrument landing system (ILS) is a ground-based instrument approach system that provides precision lateral and vertical guidance to an aircraft approaching and landing on a runway, using a combination of radio signals. ILS carrier frequencies range between 108.10 MHz and 111.95 MHz (with the 100 kHz first decimal digit always odd, so 108.10, 108.15, 108.30, etc., and are not used for any other purpose).

We not look (to our luck) direct radiation from ILS but we may look its echoes from Earth satellites. We really find reflections from the International Space Station in the target multi-beam diagram of BSA.

We did analysis of the 2 month statistics of detecting reflected radar signals indicated airfield complexes from the International Space Station. It is showed that in September-October 2013 there were 85 events across the track of the ISS (at a distance of 500-800 km away from the observer) target through diagram BSA. This 35-40 are reliably identified as short bursts of radio flux equally 10-20 Jy. Figure 4 shows one from these cases, where the ISS passing through BSA multi-beam diagram (which are directed along the South-North line). This work demonstrates that found radio transients in our survey data can be, unfortunately, also be produce manmade.

The figure 4 is showed that satellites track on the data is very symmetrical. But we also finding transient phenomena second timescale in non-symmetrical form and with traces of the influence of the dispersion delays. We will preparing in future some statistical work for this phenomena.
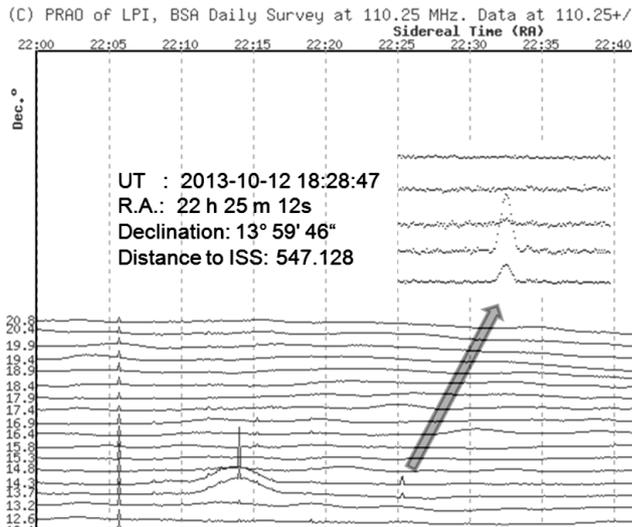
Figure 4: The result of ISS passing through BSA multi-beam diagram at 2013-10-12 in 18:28:47 UT. We may look that ISS at distance 547.1 km passing through diagram about 1.6 sec and has very symmetrical form.

5. Future prospects

This BSA monitoring system allows a potential to solve a tremendously wide range of classes of problems. The proposed project allows to continuously monitor of celestial radio sources in most parts of the sky on time scales from milliseconds to years. We hope produce thus regime of processing that all the work of patrol and processing possible transient phenomena, also as monitoring of known radio sources, searching for new sources and so on will be conducted in automatic mode.

The observational data will be automatically preprocessing and locating in total data base. At next stage we will find from this data base of some interesting goal for scheduled and will start processing on BOINC-server by method of distributed computing.

The part of the work will are produced from the known coordinates of some type of sources (for example the giant planets of the solar system, transients associated with cataclysmic variables, etc.).

Other part of sky targets will be produced by third-party information sources. It is in first different data base for example gamma-ray bursts data base and so on.

In our data reduction can be also included other long wave radio survey for cross testing. For example is the most low-frequency survey observations in word from the Ukrainian radio telescope UTR, also as Netherlands radio interferometric system LOFAR and so on.

References

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