DOI: http://dx.doi.org/10.18524/1810-4215.2016.29.85210

PARAMETERS OF THE TRANSIENT SIGNALS DETECTED IN THE DECAMETER SURVEY OF THE NORTHERN SKY

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ABSTRACT. Decameter all-sky Survey has been running at UTR-2 radio telescope over the past few years, about 70% of observational data are processed. The Survey is aimed at searching for pulsars and transient sources. Present work shows results of processing aforementioned part of data in order to find transient sources. The processing allowed detecting more than 500 signals. Distributions of the signals' parameters (dispersion measures, galactic latitudes, "signal-to-noise-ratios" etc.) are obtained, which give reason to consider the vast majority of these pulses the signals from cosmic sources.

Keywords: astronomical data bases: surveys – Galaxy: solar neighborhood – methods: data analysis

1. Introduction

Decameter survey of the Northern sky aimed at searching for pulsars and sources of transient radio emission (Vasylieva, 2014), which is held at the world's largest UTR-2 radio telescope, is the first survey of its kind in such a low-frequency range. The main risk of the automatic search (Vasylieva, 2013) for individual pulses (transient events) and their identification (determining the dispersion measure (DM), signal arrival directions, etc.) is a high probability of incorrect classification of the signals by their nature: signals from cosmic radio sources or interference of terrestrial origin.

That's why the routine for analysis and visualization of all data processing steps was developed at the next stage of "candidates" data processing and analysis (Zakharenko, 2015). Also, the possibility of Radio Frequency Interference (RFI) mitigation parameters tuning, filtering of low- and high-frequency interference, changing DM with a 0.002 pc/cc (parsec per cubic centimeter) step and some other are added to this routine. Despite the fact that each individual pulse cannot be unambiguously classified as interference or, vice versa, space radiation source, a large number of them allows to build a distribution on different parameters, such as DM, galactic latitude etc. Latter can be compared to the same characteristics of nearby pulsars, rotating radio transients (RRATs) or other types of neutron stars, which can indirectly indicate that "candidates" belong either to cosmic radio sources or interference of terrestrial origin.

In order to estimate the possibility of detecting a significant number of pulsed sources of radio emission, the decameter census of known pulsars was held (Zakharenko, 2013). A very important result of this study was the confirmation of pulsar's pulse broadening towards lower frequencies. Earlier (due to the small number of detected pulsars) this phenomenon was not well substantiated in the decameter range. Figure 1 (bottom panel) shows the pulsar pulses broadening when the central frequency of observations changes from 100 MHz to 25 MHz. The amount of the broadening (top panel of the figure shows the extension of the radiation cone of pulsars for decameter waves compared to the meter ones) is 3.5 times at its maximum, and 1.6-1.8 times on average. This implies that we can expect detection of normal, giant or an anomalously intense pulses of pulsars (Ulyanov, 2006; Ulyanov, 2007), pulses of RRATs and other neutron stars which are oriented such that they cannot be detected at higher frequencies.

That is, considering the fact that neutron stars generate pulsed and transient radio emission, the number of transient signals can be much higher than that at high frequencies, even at 100 MHz (LOFAR).

The results of processing of approximately 70% of the Survey data and verification of nearly 1,000 "candidates" – individual pulses with the DMs which differ from the DMs of pulsars detected at the first stage – are presented in the present work. Thanks to the refining the dispersion measure, "signal-to-noise-ratio" (SNR) and pulse durations were refined. Section 2 describes the routine for processing the "candidates" data and the typical results of its work. Section 3 shows the distributions of various parameters of the "candidates". The final section provides the discussion of the results obtained after processing about 70% of the Survey data and suggests the direction of improving the processing routines and the further stages of data analysis.

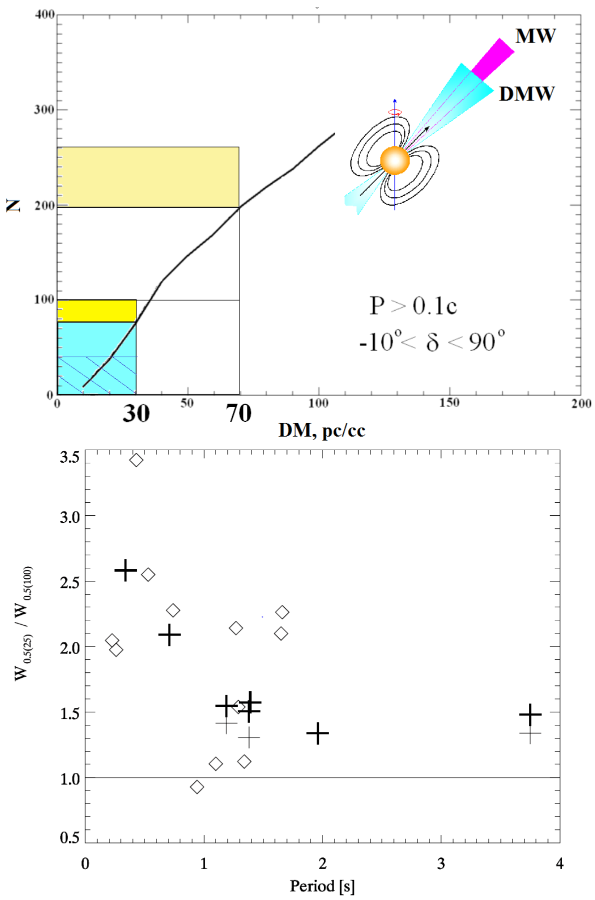

Figure 1: Top panel shows the extension of radiation cone at decameter waves compared to meter waves. The thick curve shows the number of known pulsars in the range of dispersion measures with 10 pc/cc step (Manchester, 2005).We consider that the extension will provide an opportunity to detect the pulsars, which aren't visible at higher frequencies (yellow rectangles). Bottom panel shows increasing of the «beaming fraction» (fraction of the period occupied by pulse or "opening" of the radiation cone) by 1.5-3 times (Relative expansion of the FWHM profile between frequencies 25 and 100 MHz as a function of period (Zakharenko, 2013, Fig. 11)).

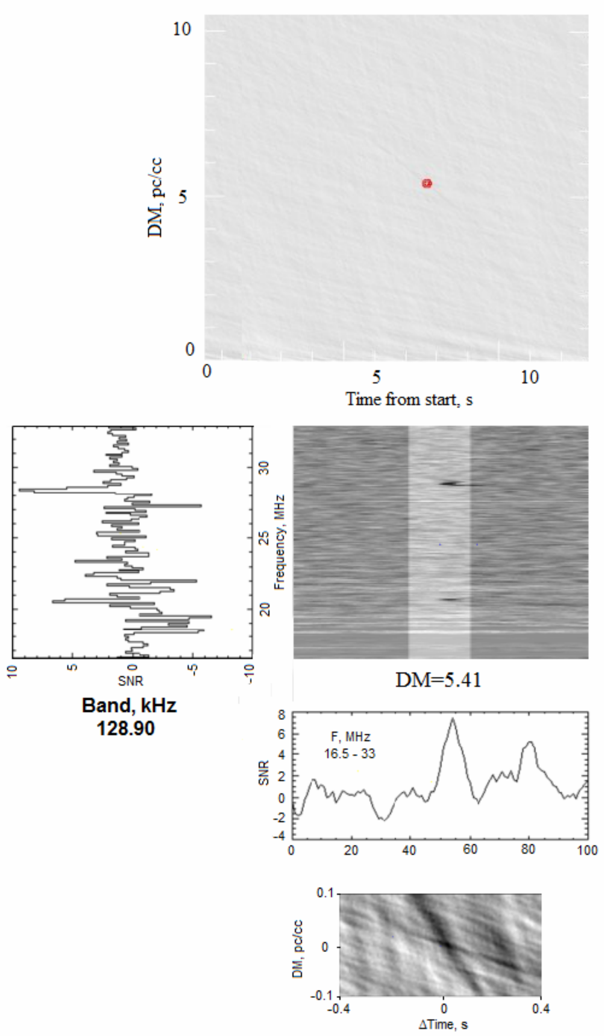

Figure 2: RFI which is identified by means of our developed verification routine and using the criteria set (see text).

2. Data Processing

The developed routine for transient signals analysis (Zakharenko, 2015) allowed to carry out the processing of each "candidate" out of about 1000. During the verification, the part of observational data which contains the supposed event is reprocessed by varying parameters of RFI mitigation, DM values etc. in order to obtain the maximum SNR of the transient signal. All these steps are visualized (displayed as a 2-dimensional spectrogram or integrated versus frequency and time). In addition the signal should satisfy the following criteria:

– to have a wide band (a few MHz);

– to be sufficiently homogeneous (without explicit narrowband or short spikes);

– to be present mostly in RFI-free frequency channels (in case of a significant number of polluted areas on the spectrogram, usually in a frequency range below 24 MHz).

Moreover, some RFI are repetitive. Individual pulses may appear relatively broadband. Such RFI must be analyzed using a toolkit for periodic signal analysis that is a part of the "candidates" analysis routine. If a sequence of pulses is found, usually the pulsar pulses can be distinguished from repetitive interference exactly by the broad band of their emission.

Such criteria cannot be programmed for automatic processing; therefore visual inspection with checking all the re-processing stages is used for "candidates" selection.

Examples of the obvious interference signals have been shown in earlier works (Vasylieva, 2014; Zakharenko, 2015).

Example of RFI which has been identified using the above-mentioned criteria are presented in Fig. 2.

3. Results

Currently, almost all observation sessions of the Survey have been carried out (Fig. 3). Fig. 4 shows the current status of the data processing (detected and verified signals are mapped there).

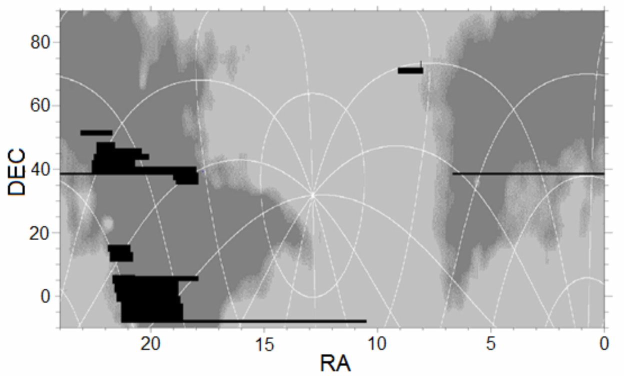

Figure 3: Current status of observations.

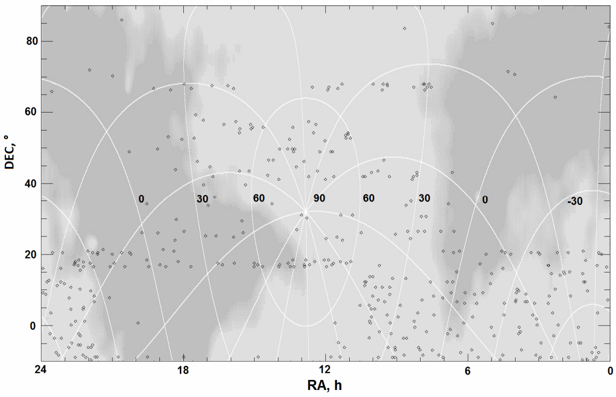

Figure 4: Transient signals at the sky map (about 70% of data are processed), verified by the developed routine.

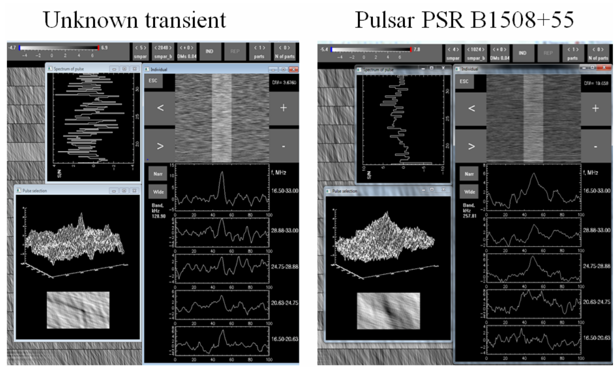

Figure 5: Presumably transient signal with DM = 3.676 pc/cc (left panel) and individual pulse of PSR B1508+55 (right panel) with DM = 19.6 pc/cc.

An example of "candidate" which with high probability is a pulse from the source of cosmic transient radio emission is shown in Fig. 5 in comparison with a pulse of a powerful well-known pulsar B1508+55. More broadband peaks (left panel, "highlighted" part of the spectrogram) are typical of the signals with a lower DM (Ulyanov, 2006).

Although it is impossible to claim doubtless classification of "candidates" (RFI / cosmic signal), we, nevertheless, can analyze distributions of certain properties of the detected signals. In the paper (Zakharenko, 2015) we presented distributions of DMs and galactic latitudes (b) of some number of processed "candidates". Now, having more candidates, we can add distributions of other properties.

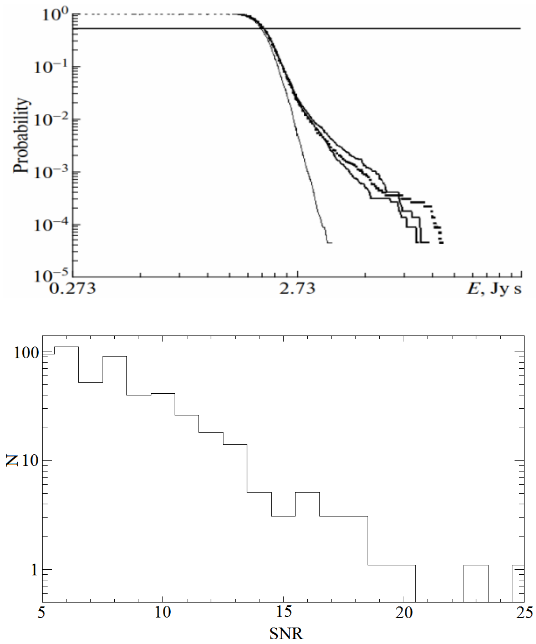

Figure 6: Distribution of detected pulses by SNR (bottom panel) and the distribution law of anomalously intense pulses of PSR B0809+74 by the energy (top panel, thin line – at the longitude of pulsar's average profile, where the radiation is absent, the other (bold) curves – at different longitudes around the maximum of the average profile).

The distribution of "signal-to-noise" ratio (SNR). We obtain this parameter after tuning (by means of the aforementioned analysis routine), mainly of the DM parameter with a 0.002 pc/cc step for each of the detected events. This is necessary, because the step 0.01 pc/cc (which is used during the primary pipeline processing) is quite rough. Fig. 6 (bottom panel) shows the distribution of pulses by the SNR parameter. The top panel of the figure shows the integral distribution law of energies of anomalously intense pulses of the pulsar B0809+74 (Ulyanov, 2012) at different longitudes of average pulse profile. The similarity of the most intense ejections (bold curves) on the top panel and distributions of SNRs of the detected transients, which both obey the power law, is obvious.

The distribution of the frequency of transient occurrence by the local time (LT). The observations of the survey are carried out mostly from 18:00 LT to 6:00 LT with a half-hour additional overlap. Fig. 7 shows the distribution of the number of detected "candidates" depending on the local time (bottom panel). To observe one full sky "strip" in right ascension (24 hours), two observation sessions of the same declination are required, with a six months shift. The maximum similarity in terms of the RFI environment is thus for observations carried out near the days of spring and autumn equinoxes. In the ideal case of no RFI influence on the number of detected signals, it would be natural to assume the equiprobable appearance of transients independently of the observation time. But by analyzing (Fig. 7, top panel) the start and finish time of the corresponding observation "strips", it proves that coincidentally the beginning and the end of most strips of

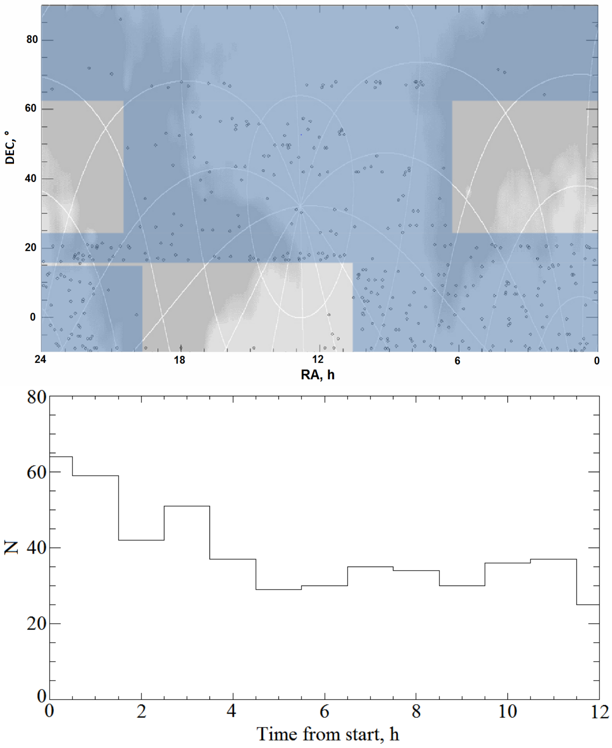

Figure 7: Bottom panel: the number of detected individual pulses depending on the observation time. Observation sessions began at 18:00 LT. Some sessions started in the range from 15:00 to 21:00 LT.
Top panel: current status of data processing, blue regions of the map indicate processed parts of the sky recordings.

fully or partly processed data (blue part) correspond to low galactic latitudes, where a maximum number of neutrons stars should be observed. So the maximum for the first two hours of observation and a slight increase of the number of "candidates" to the end of the 12-hour sessions can be caused both by the effect of unidentified RFI (which is more numerous in the daytime than at night), and the real distribution of cosmic sources of transient radio emission.

Two other distributions (of candidates' dispersion measures and galactic latitudes) have already been given based on a more limited dataset (about 30% of the Survey) in the paper (Zakharenko, 2015). In this paper we cleaned the set of "candidates" used previously from a few obvious interference and added the next part of the processed data (for now it is about 70% of the Survey).

Distribution of candidates' DMs is presented in the bottom panel of Fig. 8. The top panel shows the simulated distribution of pulsars by DM that can be discovered using the radio telescope under construction – SKA (Keane, 2015) based on the population synthesis and characteristic parameters of known pulsars (clear bars: strip 350-14000 MHz, gray ones: 50-350 MHz). At low DMs, the distance from the observer, the corresponding space volume, and the number of sources in it increase. Then due to scattering and weakening of the signal from more distant sources, the number of detectable sources starts to decrease. The same is true for our Survey (bottom panel of Fig. 8).

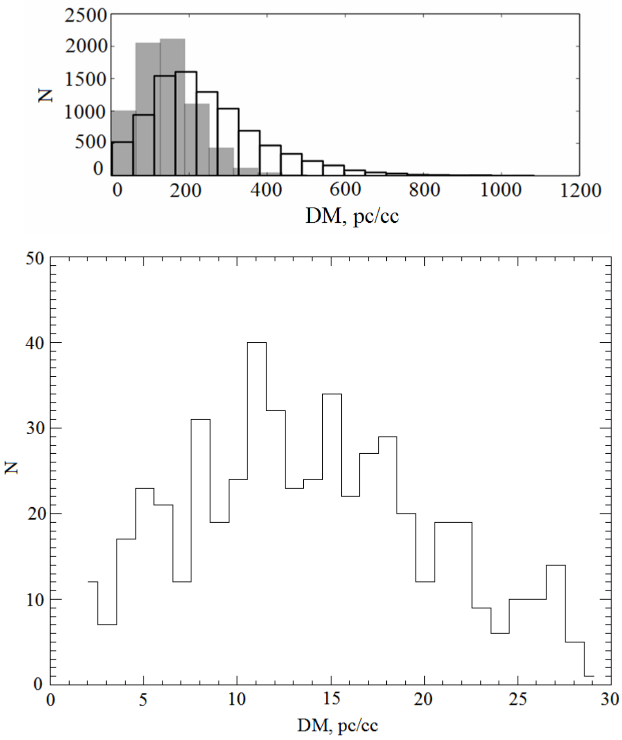

Figure 8: Simulated histograms of DM of pulsars, expected to be observed with SKA Phase 1, for SKA1-LOW (gray bars) and SKA1-MID (clear bars) (top panel) and DM distribution of the detected transients (bottom panel).

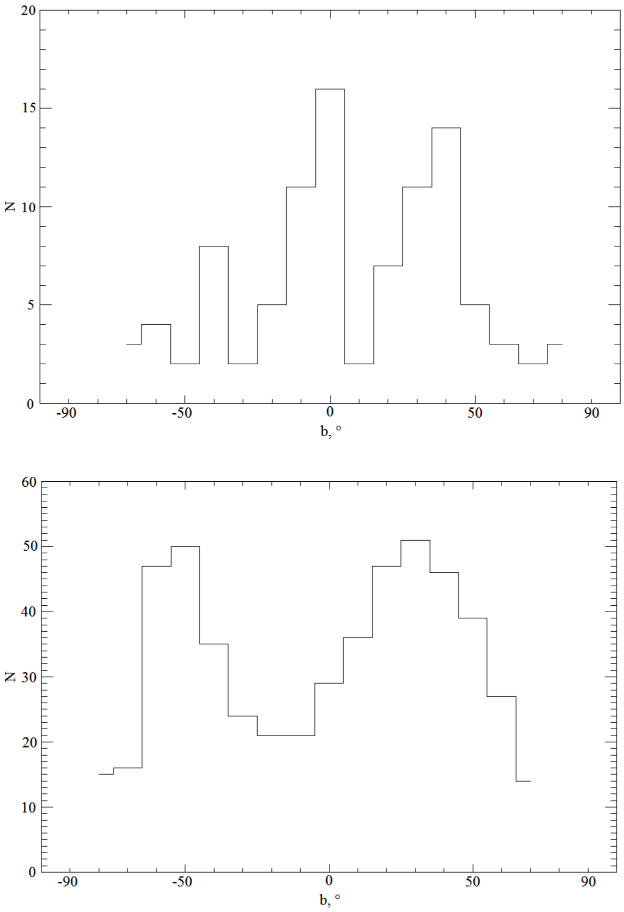

Figure 9: Galactic latitude distributions of known pulsars (top panel) (Manchester, 2005) and of detected transient signals (bottom panel).

Distribution of candidates' galactic latitudes (Fig. 9) also has characteristic features, which can be expected of close neutron stars' distributions. The lower panel shows the distribution of "candidates" in our Survey, the upper panel – distribution of nearby pulsars with DM under 30 pc/cc and period more than 0.1 seconds. Both distributions have a maximum close to zero galactic latitude.

Remarkably, both distributions have intrinsic maxima around minus and plus 50 degrees. The data cleaning using the developed routines and processing of the next part of data caused the noticeable changes of this distribution compared with (Zakharenko, 2015, Fig. 3a). The maximum at -50º latitude decreased by 40% and became smaller than the broad maximum between 0 and 60 degrees. This feature of the distribution of the closest neutron stars has to be explored in future.

4. Conclusions and Prospects

Thus, it becomes clear that pulsars/transients decameter survey of the Northern sky has some unique features and during its conducting we succeeded to detect a sufficiently large number of individual pulses.

Such a result is influenced by the peculiarities of the low-frequency range, which have both negative and positive aspects:

– wide beam of the telescope does not allow to define the coordinates with high accuracy, however the large field of view can captures a large number of simultaneous events;

– large dispersion delay complicates data processing, but allows to distinguish accurately the interference and space signals with different dispersion measures;

– scattering in the propagation medium (along with the radiation cone broadening, which is characteristic of different types of NS) also increase probability of individual pulse detection.

All these features allowed detecting a relatively large number of sources, than it would be possible at high frequencies.

Currently, we are improving methods for identifying weaker and weaker interference and continue processing the remaining 30% of the data.

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