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THE LONG-TERM OBSERVATIONS OF THE POWER COSMIC RADIO SOURCES ON THE RADIO TELESCOPE URAN-4 AT THE DECAMETER WAVE RANGE

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ABSTRACT. The radio telescope (RT) URAN-4, located near the city of Odessa, started to work in 1987 as a component of the radio interferometric system URAN, which operates in the decameter range of radio waves and whose elements are placed in several points throughout Ukraine. The first successful VLBI observations of compact cosmic radio sources in the URAN system were carried out on the RT URAN-4–UTR-2 interferometer at the end of 1987. In the same period, a program was launched for regular observations of powerful cosmic radio sources 3C 144, 3C 274, 3C 405, 3C 461 at frequencies of 20 and 25 MHz in the radiometric mode. Later, several stages of modernization of radiometric equipment and systems for automation of observations took place. This made it possible by 2000 to switch to practically continuous radiometric monitoring of a group of these radio sources. Method of measuring and processing of the records of the radio sources passage through RT direction pattern, statistics of the observation records on time periods in dependence on the registration systems of the data obtained during more 35 years observations on the RT URAN-4 are considered in this paper. Some results are given which related to the study of the flux densities of the observing radio sources and ionospheric scintillation effect which is essential at the decameter wavelength range.

Keywords: radio astronomical observations; cosmic radio sources; decameter radio wave range.

АНОТАЦІЯ. Радіотелескоп (РТ) УРАН-4, який розміщений поблизу міста Одеса, був введений в стрій в 1987 році як складова частина радіоінтерофероетричної системи УРАН, що працює в декаметровому діапазоні радіохвиль та елементи якої розташовані в декількох пунктах на всій території України. Перші успішні РСДБ спостереження компактних космічних радіоджерел в системі УРАН були проведені на інтерферометрі РТ УРАН-4–УТР-2 в кінці 1987 року. В той же час була запущена програма регулярних спостережень потужних космічних радіоджерел 3С 144, 3С 274, 3С 405, 3С 461 на частотах 20 і 25 МГц в радіометричному режимі. Пізніше пройшло декілька етапів модернізації радіометричної апаратури і систем автоматизації спостережень. Це дозволило до 2000 року перейти до практично безперервного моніторингу групи названих радіоджерел. В роботі розглядаються методика вимірів і обробки записів проходження радіоджерел через діаграму спрямованості РТ, статистика записів спостережень по часовим інтервалам в залежності від системи реєстрації даних, що були отримані за більш ніж 35 років спостережень на РТ УРАН-4. Спостереження в декаметровому радіодіапазоні супроводжується великою кількістю радіоперешкод, які впливають на якість вимірювань. При обробці спостережень кожний запис отримує оцінки якості, що допомагає вибрати записи потрібної якості для конкретної дослідницької задачі. Наведено деякі результати, які стосуються досліджень щільності потоку спостережуваних джерел, зокрема показано, що середньомісячні значення цих величин варіюються протягом циклу сонячної активності. Ефект іоносферних мерехтінь є дуже суттєвим в декаметровому діапазоні радіохвиль. Всі спостережувані радіоджерела мерехтять на неоднорідностях електронної концентрації іоносферної плазми, тому це явище досліджувалось з початку спостережень на РТ. З допомогою розробленої методики обробки до теперішнього часу отримана велика кількість оцінок таких параметрів іоносферних мерехтінь як індекс, період і спектральний індекс. Це дозволило дослідити сезонно-добову залежність параметрів іоносферних мерехтінь, а також їх кутові залежності.

Ключові слова: радіоастрономічні спостереження; космічні радіоджерела; декаметровий діапазон радіохвиль

1. Introduction

The radio telescope (RT) URAN-4 is a component of the radio interferometric system URAN whose elements are placed in several points throughout Ukraine. The URAN system is intended for the investigations of cosmic objects with high resolution at the decameter range of radio waves. Particularities of this wave range are the essential influence of ionosphere, high level of the background cosmic radiation, presence of the large level of interferences which have different origin. Working range defines characteristics of the RT antenna and possibility to observe the different cosmic sources.

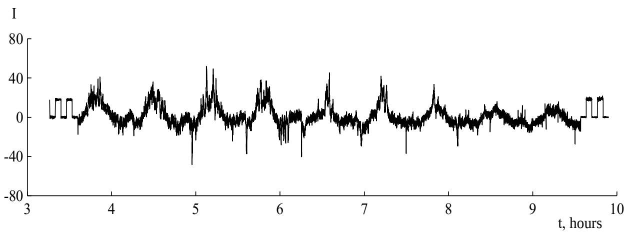

Figure 1: The example of the observation record of the radio source 3C 274 at the frequency 20 MHz during day

RT URAN-4 (Galanin et al., 1989) is located in the village Mayaky near Odessa and it is a multi-element antenna array with size 238×28 m. It includes antenna with phasing system, hardware complex, and precise time system and data registration. Direction pattern (DP) width at half power level, frequency 25 MHz, zenith position of the beam is $(2{,}7 \times 22)^{\circ}$. The observations on the RT are carried out at four channels: at two frequencies (20 and 25 MHz) and for two polarizations (A and B). To separate the cosmic radio source signal from background noise the modulation measurement mode is used – signals of two half of the antenna array are multiplied.

RT not used most of the time in the interferometric measurements. Therefore for greater efficiency of its work the monitoring program of the studying of relative density flux non-stationarity of the power cosmic source was adopted. Four radio sources were chosen for this two of which are the supernova remnants (3C 144, 3C 461) and others two are the radio galaxies (3C 274, 3C 405).

The purpose of the paper is an overview of the RT URAN-4 work over a period of more than 35 years.

2. Data of the observations and processing

2.1. Observations

The observations at the RT URAN-4 are carried out as records of several passages of each radio source through RT DP during day. For calibration of relative measurements of flux densities the calibration step of the noise generator which is recorded in the beginning and in the end of measurement session is used (Derevyagin et al., 2019). The example of the observation record of the radio source on the RT is showed in the Figure 1.

2.2. Processing

The processing of each source record is carried out by the fitting of calculating function of the RT DP to the observing record of cosmic radio source (Panishko & Lytvynenko, 2019). As a result of processing the different characteristics of record were measured, for example, such as record amplitude and also the ionosphere scintillation parameters – index, period and spectral index. Data is stored in the text files of computer memory. The example of processing of the radio source record which obtained on the RT is showed in the Figure 2. The ionosphere scintillation parameters which estimated from record are given.

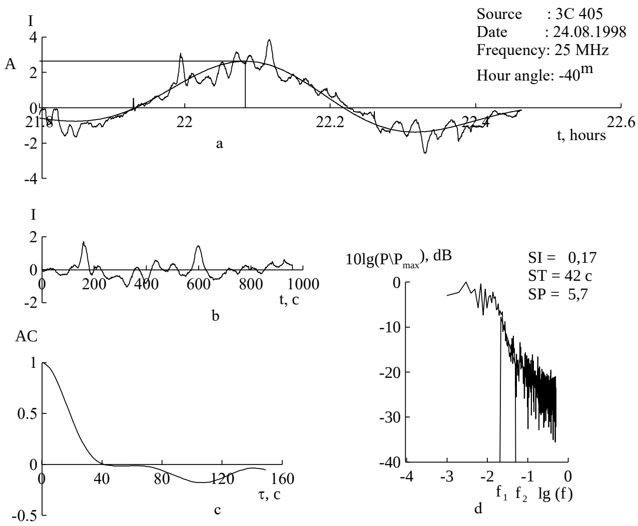

Figure 2: Example of the processing of the radio source record: a – row obtained from observations with fitting DP; b – high frequency part in the center of record (observation row without fitting direction pattern) that associated with ionospheric scintillations; c – autocorrelation function; d – power spectrum of the signal scintillations

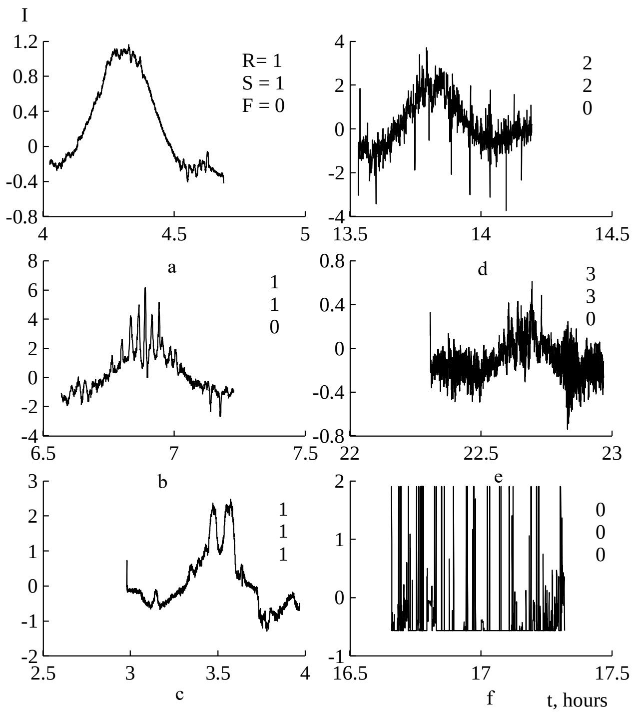

Figure 3: The examples of radio source records with different level of the interferences: a – record of good quality; b – record of good quality with scintillations; c – presence of the intensive fluctuations; d – record of satisfactory quality; e – the interferences strongly distort the record; f – the large interferences, record is not processed

2.3. Accounting of the radio interferences

Observations at the decameter radio wave range are accompanied by the presence of a large amount of interference of various origins. To account for them during processing, each record is evaluated as follows: 1) quality of the fitting of DP calculating function (R: 0..3); 2) presence of the interferences in a central part of record (S: 0..3); 3) presence of the intensive fluctuations which distort the overall form of the record (F: 0..1). The radio source records with different level of the interferences are showed in the Figure 3. When analyzing data, these ratings help select records of acceptable quality for a particular research problem.

3. Analysis of the observation data obtained at the RT URAN-4

3.1. Time intervals

There are some time intervals in the working of RT URAN-4 those characterized of several systems of data registration (Derevyagin et al., 2019):

1. From 1987-1990 regular observations of four radio sources carried out by sessions near 10 days during month. Measurements were written to paper tape of self-recorder. Processing was fulfilled manually with ruler.
2. In the 90s first automatical registration was developed that permitted to process of data using computer program but observations carried out very sporadically.
3. Regular measurements on RT began from 1998 and continued up to 2001. During this time new system of automatical measurements and digital registration with time interval 1 s was developed. From 2002 the registration system of observations was upgraded – automatical record of calibration step was appeared and time interval became 2 s. Measurements in such format continued up to April 2007. This data processed by computer program.
4. From 2007 up to 2010 regular observations on RT URAN-4 did not carried out due to technical occasions and were resumed in 2011. In this time next version of system of automatical measurements and digital registration was developed, time interval 1 s. This format uses in present time and new program of computer processing was created for it.

3.2. Statistics of the observation data

For the entire period of work of the RT URAN-4 the large amount of observation data was obtained. Statistics of the radio source records which observed at the RT is showed in the Table 1 for the above time intervals.

Distribution of the number of records depending on the record quality is showed in the Table 2 in percentages. When analyzing data, records with ratings 1 and 2 are usually used, this is about 40 percent of all recorded data, as follows from the table.

Table 1: Statistics of the radio source records which obtained at the RT URAN-4

Time interval, years	Number of the obtained records
1987-1990	8712
1998-2007	198340
2011-2023	446772
Sum	653824

Table 2: Distribution PR of the observation record number N in the dependence from a quality estimation R

R	N	PR, %
0	256993	40
1	51623	8
2	201774	31
3	134722	21

3.3. Influence of the solar activity cycle on the measurements of the flux densities of cosmic radio sources

Long-term observation data allows studying the behavior of the relative flux densities of cosmic radio sources including due to the impact of the solar activity. During solar cycle the concentration and temperature of the electron plasma particles in the higher atmosphere and, particularly, in the ionosphere are changed, that leads to a change in the nature of the interaction of radiation from the cosmic radio sources and the earth's ionosphere (Yakovlev, 1985). The behavior of the monthly mean values of the relative flux densities of the observing radio source during solar cycle at the frequency 25 MHz is showed in the Figure 4. You can notice a decrease in these values during maximum phase of solar cycle. The trend (sold line) is indicated by a polynomial of the fifth degree.

3.4. Ionospheric scintillations

The effect of the ionospheric scintillations is essential for observations at the decameter radio wave range (Crane, 1977). All observing radio sources are scintillated on the irregularities of the ionospheric plasma. The studying of this effect is carried out at the RT URAN-4 from the beginning of work that made it possible to obtain, in particularly, a seasonal-daily dependence (Lytvynenko & Panishko, 2015), which is well expressed for all ionospheric scintillation parameters (index, period and spectral index). Figure 5 shows the seasonal-daily dependence for a spectral index on the monthly mean values.

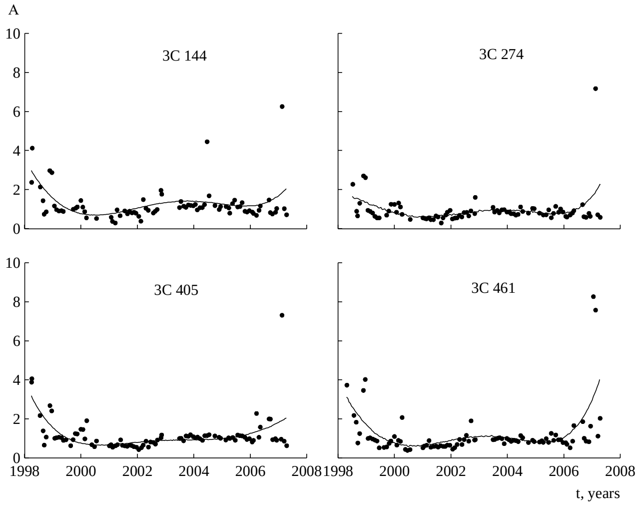

Figure 4: Absorption effect in the maximum of 23-th cycle of the solar activity on the monthly mean values of relative flux densities of the radio sources

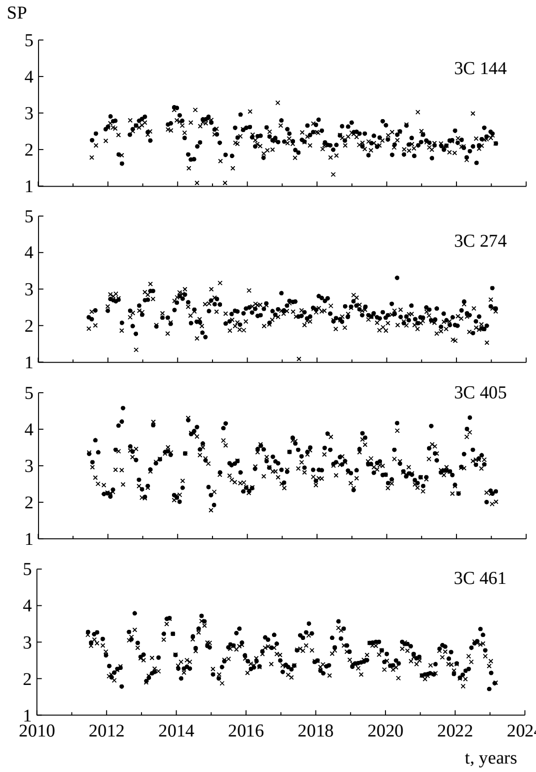

Figure 5: Seasonal-daily dependence of the ionospheric scintillation spectral index

Figure 6 shows the dependencies for the mean values of ionospheric scintillation parameters which calculated for each radio source (Panishko & Lytvynenko, 2019). Figure 6a (the inversely proportional dependence of an index on a period of ionospheric scintillations) and Figure 6b (the dependence of a scintillation period on an angle between direction on the radio source and a power line of the geomagnetic field) confirm that irregularities which caused ionospheric scintillations are stretched along geomagnetic field lines. At the same time, the magnitude of a spectral index depends on the height above horizon on which radio source are observed (Figure 6c). This connects with the reflective layer thickness (Lytvynenko et al., 2022) which changes with height.

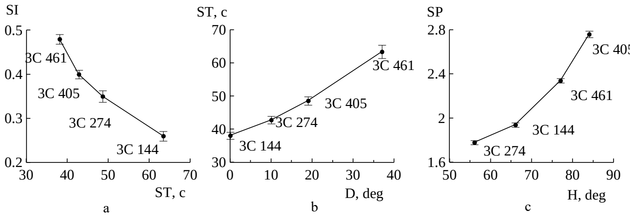

Figure 6: The angular dependencies of the ionospheric scintillation parameters: a – index–period; b – period–angle between the direction on the source and geomagnetic line; c – spectral index–height above the horizon

Conclusions

1. Using monitoring program long-term series of observations of power cosmic sources (3C 144, 3C 274, 3C 405, 3C 461) were obtained at the frequencies 20 and 25 MHz during 1987-2023.

2. Automatical digital registration from 1998 by means of the computer processing was allowed to get the values of relative fluxes and ionosphere scintillation parameters of the sources that observed. Keeping system of data with convenient access to original observations and processing results was designed.

3. Long-term measurements enabled the studying of regularity in the behavior of several values for several time intervals. In particular the effect of the absorption in the Earth's ionosphere of the radiation from cosmic radio sources in the maximum of the solar activity cycle was found. Also the seasonal-daily dependence of ionosphere scintillation index, period and spectral index and angular dependencies of the scintillation parameters were derived from observation data.

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