RATAN-600 Radio Telescope: Observing Programs and Outlook

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Abstract. RATAN-600 is the largest radio telescope in the world with a variable profile ring antenna 600 m in diameter. Due to its wide free-aberration zone it is possible to get instantaneous radio spectra of cosmic objects in the frequency range 1-22 GHz during 2-3 min. Almost all telescope time is spent on the astrophysical tasks solution. The observational time is provided on a competitive basis by the Russian Telescope Time Allocation Committee. The current status of RATAN-600 observing programs and some important research and resources are discussed.

Keywords: techniques: radar astronomy; methods: observational

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1 Introduction

RATAN-600 is the radio telescope with the variable profile ring antenna 600 m in diameter (Esepkina et al. 1973). It means that the focus and the form of the main mirror are changed during the observations. Such antenna was created for achieving a large geometric area and a high angular resolution. Due to its wide free-aberration zone it is possible to get instantaneous radio spectra of objects in the frequency range 1-22 GHz during 2-3 min without significant losses of a signal with the transverse removal of a primary feeds. Disadvantage of this design is an unmoving diagram and limited observing modes.

RATAN was built 45 years ago and first light was seen in 1974. Initially the radio telescope was designed as an instrument with a manual control. It was possible to observe 10-20 sources daily. In the 90's the telescope was automated and observations up to 100 radio sources at each antenna sectors are conducted. The telescope observes continuously except the scheduled maintenance stops which happen once a week for several hours and twice a year for the adjustment and technical support. Annual radio telescope loading is about 8,000 hours.

In average 50-60% out of them is given to external users both Russian and international ones.

The telescope has a status of open public instrument and RATAN is registered in the scientific and technological infrastructure of the Russian Federation[1]. The observational time is provided free of charge on a competitive basis only. The scientific expertise of users proposals is made by the Russian Telescope Time Allocation Committee[2] (RTTAC). The Committee defines key programs with a highest priority and upholds the standard principles: scientific importance and relevance of a research, support of cooperative and multi-wave programs, efficiency of a program including publications, implementation and development of the newest methods, young scientist support.

2 Parameters and Methods

Due to the geometric features RATAN is used as four independent antennas (sectors) and several observing programs can be carried out simultaneously. The main regimes are unmoving and fixed focuses, azimuths. RATAN is a multi-elements antenna. The elements are moving synchronously during an observation forming the knife antenna beam shape (for separate sector). As a result the declination angular resolution (Dec) is three to five times worse than the right ascension one (RA). The main parameters of the telescope are following:

Independent Sectors 4
Diameter of the main mirror 576 m
Number of elements 895
Size of an element 11.4 x 2 m
Geometric area 15000 m^2
Effective area (cm) of the ring 3500 m^2
Wavelength range 1-25 cm
Frequency range 1-30 GHz
Maximum angular resolution 5 arcsec (North sector)
Coordinate accuracy 1-10 arcsec
Flux density limit 5 mJy (4.7 GHz)
Brightness temperature limit 0.05 mK
Radiometers 100 channels
Tracking time (South+Flat) 1-3 hours.

At present the following equipment and methods are used:

[1] https://www.ckp-rf.ru/
[2] https://www.sao.ru/hq/Komitet/

(i) The continuum radiometers at 1.25, 2.25, 4.7, 8.2, 11.2 and 22.3 GHz with bandwidths from 4% (at dm wavelengths) up to 10-12% (cm) relative to the central frequency. Method: the spectral flux density measurement at the frequency range of 1.25-22.3 GHz.

(ii) The continuum radiometers complex ERIDAN at 2.25, 4.7, 11.2 and 22.3 GHz with bandwidths from 4% (at dm wavelengths) up to 10-12% (at cm) relative to the central frequency. Method: the spectral flux density measurement at the frequency range of 2.25-22.3 GHz.

(iii) Multibeam radiometric complex at 4.7 GHz for the fast radio bursts (FRB) searching. Method: the spectral flux density measurement at the frequency range 4.4-5.0 GHz with a high temporal resolution (up to 62.5 μs).

(iv) Solar spectral-polarization complex at 3-18 GHz. Method: the radio emission intensity and polarization measurement of the discrete radio sources and the Sun in a dynamic range up to 60 dB at the frequencies 3-18 GHz.

3 Scientific Programs

Cooperative and multiwave observing programs are considered as a top priority. Among them for last years: Bright Sources Monitoring during Planck Mission in 2009-2012 (Planck WG 6); AGNs study using the RATAN-600 and the RadioAstron ground-space interferometer in 2014-2018 (ASP), Sunspot chromosphere and the transition area joint studies with the ALMA interferometer and RATAN-600 radio telescope in 2019-2020 (SAO RAS, NJIT USA). In these cooperative projects RATAN provided a ground-based support of AGN and Sun studies and presented 1-22 GHz frequency range measurements (Planck Collaboration et al. 2011; Giommi et al. 2012; Planck Collaboration et al. 2016; Bogod et al. 2020). All observations were carried out quasi-simultaneously to provide the full picture of non-thermal variable radiation from MHz up to hundreds GHz frequencies.

Nowadays alert observations as well as multichannel astronomy research become more relevant and they are must be implemented intensely and promptly, out of the competition. Alert events or target opportunity events are the most interesting ones in the sky, most often they are related with the flaring or burst activity in the cosmic objects. The cooperative program "Radio observations of a newly-discovered blazar Fermi J1544-0649" (Shanghai Astronomical Observatory, SAO)" was initiated to study a transient source Fermi J1544-0649 from radio to γ-rays after one year after its awakening (Tam et al. 2020). A multichannel astronomy research is carried out when study in different channels are necessary (an electromagnetic radiation, gravitational waves and elementary particles). This is up-to-date area of astrophysical research for today. For example, a program in 2020 “IceCube trigger: monthly monitoring of the new high-energy neutrino candidates” (Institute for Nuclear Research RAS) aimed to research high energy neutrinos origin in AGNs has been conducting within the multimessenger astronomy framework.

3.1 High-Energy Neutrino Candidates

RATAN observations of TXS 0506+056 are the part of multichannel research of candidates in high-energy astrophysical neutrinos which can be produced in central parsec-scale nuclei of radio-bright active galaxies (Kovalev et al. 2020). The blazar TXS 0506+056 is a possible PeV-energy neutrino-associated source has been studying intensely after the high energy neutrinos detection in its direction by the IceCube observatory (IceCube Collaboration et al. 2018). Multifrequency RATAN measurements for bright AGNs (active galactic nuclei) analized at 10 years time scale allowed to establish a connection between the ultra-high energy cosmic neutrinos and quasars flare activity (Plavin et al. 2020). It was found that the epochs of a radio emission increasing at frequencies above 10 GHz coincide with neutrino arrival times for VLBI-selected AGN in IceCube error regions. The intensity of quasar observations with RATAN-600 have increased, as the radio emission state could be a key to the neutrino nature.

3.2 Peaked Spectrum and High-Redshift Sources

The long-term research of the peaked-spectrum sources (PS) in the radio continuum has been ongoing with the RATAN on the time scale more than 20 years. The classical PS type sources are associated with compact young AGNs and they are interesting as an early stage of galaxies evolution. As a result of RATAN monitoring the several PS sources catalogues at the frequencies 1-22 GHz were released (Mingaliev et al. 2012b, 2013b; Sotnikova et al. 2019b) and the small part, about 2-3% among the total bright AGNs, was determined as genuine GPS (gigahertz-peaked spectrum) sources only (Torniainen et al. 2007, 2008; Sokolovsky et al. 2009; Tornikoski et al. 2009; Mingaliev et al. 2011, 2012a, 2013a; Sotnikova et al. 2019a). A reliable spectral classification based on quasi-simultaneous measurements and variability parameters allowed to reveal increasing of PS objects proportion in the high-redshifts samples (Verkhodanov et al. 2018). So, for four most distant blazars the PS spectra were revealed for three of them (Mufakharov et al., 2020 submitted). The fourth most known distant blazar PSO 0309+27 at z=6.1 can be a compact steep-spectrum (CSS) or a megahertz peaked-spectrum (MPS) source with a maximum at the frequencies 1 GHz or less in the rest frame (Fig. 1).

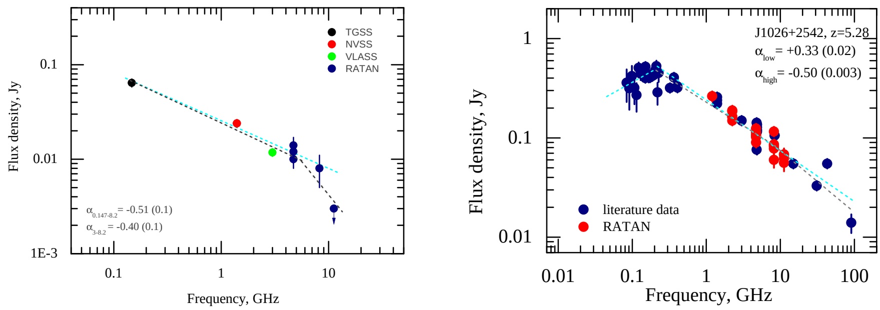


Fig. 1. Left: a summarized radio continuum spectrum of only known at z>6 distant blazar PSO J0309+2717 (RATAN, 2020, blue points) with a flat part ($\alpha_{0.147-8.2GHz} = -0.53 \pm 0.02$) and possible ultra-steep one at the higher frequencies ($\alpha = -1.4 \pm 0.05$). Right: the radio continuum spectrum for blazar J1026+2542 at z=5.28 constructed using the RATAN (red points, 2017-2019) and literature data (blue); a peaked spectrum is confirmed by more than 40 years time scale measurements.

3.3 Microquasars

RATAN-600 long-term daily monitoring of bright microquasars (GRS1915+105, SS433, Cyg X-1, Cyg X-3, LSI+61^{o}303) has been carrying out at 2.3, 4.7, 8.2, 11.2 and 22 GHz for almost 10 years and as a result an unprecedented spectral and long-term set of radio data have been obtained. RATAN multifrequency data turned out to be a good indicator of the microquasars jet activity and could be used for comparison with the optical, X-ray and γ-ray measurements. A search for the correlations or associations of processes in the accretion disks and jets is the key task in the building of the physical picture for microquasars (Trushkin et al. 2017a,b; Koljonen et al. 2018).

3.4 The Solar Radio Emission Monitoring

A solar activity monitoring is carried out in multi-azimuth measurements regularly. Multifrequency, high sensitivity and angular resolution allow to study both bright and low contrast variable structures in the Sun's corona. A standard solar measurements at 3-18 GHz in 84 channels (intensity and polarization) is presented on the Fig 2. Long-term measurements are also presented in the Radio astronomy Center for Solar activity forecast[3]. The database contains the RATAN's measurements starting with 1997 and allows to analyze them including quick online processing. In online form one can calculate fluxes, build radio

[3] http://91.151.190.98/prognoz/db.html

spectra, superimpose a RATAN scan on a two-dimensional image, find polarization inversions for selected time period.

Results of the Sun daily observations are available on the SAO RAS home page together with the radio-astronomical flare activity forecast (Bogod et al. 2018). The forecast is based on the modified Tanaka-Enome criteria (1975). According to this criterion for the flare raising the flux of radio emission must be sufficiently high at short wavelengths and should increase compared to the general intensity. If this criterion is fulfilled the probability of a flare over the next 3 days is at the level of 75-80%.

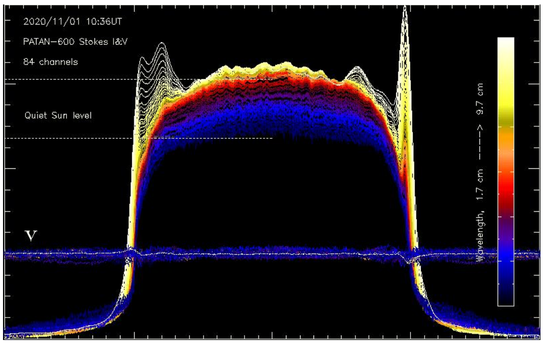


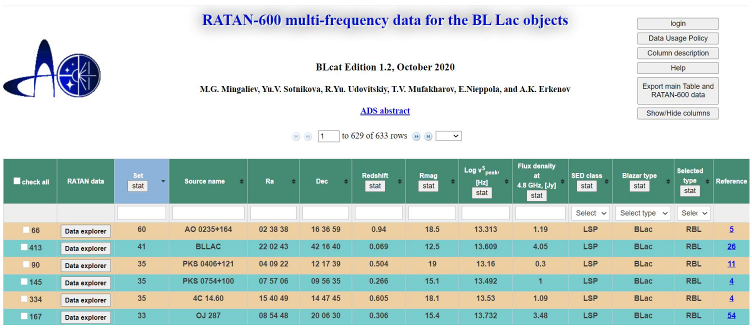
Fig. 2. The Sun daily monitoring with RATAN-600: the distribution of intensity I and circular polarization V across the solar disk. The color scale on the right corresponds to 80 wavelengths in the range 1.65–10 cm. Polarized emission V characterizes the magnetic-field strength in solar active regions. The large deviations in the graph indicate the presence of regions with strong local magnetic fields, which are seen as sunspots in the visual range. The dashed lines indicate the range of intensity I levels of the quiet-Sun emission at different wavelengths.

3.5 Blazar Monitoring. BLcat

The mass monitoring of the blazars is being carried out in continuum during many years. This long-term program aims to research the AGN radio properties and features their variability. RATAN measurements of the BL Lac blazars type are summarized as the online BLcat[4] catalogue “RATAN-600 multi-frequency data for the BL Lac objects” (Mingaliev et al. 2014). The AGN classification

[4] https://www.sao.ru/blcat/

are taken from the Massaro blazar catalogue Roma-BZCAT[5] (Massaro et al. 2009). The current version includes more than 600 objects. The general part of the catalogue is a collection of the multifrequency radio band measurements obtained quasi simultaneously at six frequencies over the 15 years. The data is presented online in a convenient form (Fig. 3) with interactive features. Everyone can have a look quickly at the behavior of a certain BL Lac object from the list at the radio band, which includes examining spectra evolution or light curves; some basic objects characteristics are also presented as a main table in the catalogue.



check all	RATAN data	Set stat	Source name	Ra	Dec	Redshift stat	Rmag stat	Log ν^{S}_{peak} [Hz] stat	Flux density at 4.8 GHz, [Jy] stat	SED class stat	Blazar type stat	Selected type stat	Reference
										Select	Select type	Selec	
66	Data explorer	60	AO 0235+164	02 38 38	16 36 59	0.94	18.5	13.313	1.19	LSP	BLac	RBL	5
413	Data explorer	41	BLLAC	22 02 43	42 16 40	0.069	12.5	13.609	4.05	LSP	BLac	RBL	26
90	Data explorer	35	PKS 0406+121	04 09 22	12 17 39	0.504	19	13.16	0.3	LSP	BLac	RBL	11
145	Data explorer	35	PKS 0754+100	07 57 06	09 56 35	0.266	15.1	13.492	1	LSP	BLac	RBL	4
334	Data explorer	35	4C 14.60	15 40 49	14 47 45	0.605	18.1	13.53	1.09	LSP	BLac	RBL	4
167	Data explorer	33	OJ 287	08 54 48	20 06 30	0.306	15.4	13.732	3.48	LSP	BLac	RBL	54

Fig. 3. BLcat main page screenshot

4 CATS

CATS[6] Database is an Astrophysical CATalogs support System was created in 1995 (Verkhodanov et al. 1997). Initially CATS was designed as a system for the RATAN-600 observations support and due to rapid growth the number of new radio sources. The statistics shows that 2500-3000 CATS requests per month are processed. Currently, the CATS is a set of astrophysical catalogs, their descriptions and programs for working with them. The including of the existence catalogues to CATS is based on the following principles: the radio catalogs are based on sky surveys; the large (more than 1000 objects) non-star catalogs from other frequency ranges; catalogs at other wave bands in which radio data is used. Basically they are the radio catalogs. Now the CATS includes over 630 catalogs.

[5] https://www.asdc.asi.it/bzcat/
[6] https://www.sao.ru/cats/

The CATS is being expanded and updated continuously and nowadays it is one of the effective resources for radio data working.

5 Summary

RATAN-600 radio telescope is the large multifrequency instrument with possibility of instantaneous radio spectrum obtaining at the frequencies of 1-22 GHz. This main telescope advantage allows to solve a wide range of astrophysical tasks, space weather forecasting and multichannel astronomy ones.

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