URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Technical Achievements and Scientific Results of RadioAstron Mission 2011-2018

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Abstract

A review of the unique technical parameters of the RadioAstron ground-to-space interferometer measured in flight is presented. The main scientific results obtained in seven years are also discussed.

1. Introduction

The RadioAstron Mission is led by the Astro Space Center (ASC) of the Lebedev Physical Institute of the Russian Academy of Sciences and the Lavochkin Association under a contract with the State Space Corporation ROSCOSMOS, in collaboration with partner organizations in Russia and other countries.
On July 18, 2011, the 10-m space radio telescope (SRT) was successfully launched by the rocket Zenit3F with the upper stage Fregat–SB from the Baikonur Cosmodrome. SRT rotating round the Earth at elliptical orbit with maximum height of about 350000 km forms space-ground interferometer (SGI) in conjunction with network of ground radio telescopes, providing high angular resolution of about 10 microseconds. SGI RadioAstron is successfully operating during more than 7 years bringing unique scientific results. A number of original technical solutions laid the foundation for this project: high surface accuracy 10-m antenna, low noise space qualified radio astronomical receivers, on-board H-maser frequency standard, high data rate (144 Mb/s) communication radio link (HDRC), original design multifrequency feed system.

2. Technical parameters

In order to achieve a high surface accuracy, the SRT consists of a solid central mirror of 3-m in diameter surrounded by 27 solid petals made of carbon fiber. The maximum deviation for the surface from a paraboloid must not exceed 2 mm.
SRT operates at four frequency ranges P, L,C and K, corresponding to wavelengths of 92, 18, 6.2 ,and 1.19-1.63 cm. Multifrequency feed system is installed at a prime focus of radio telescope. The feeds for 92, 18 and 6.2 cm wavelengths are ring resonators, while the 1.19-1.63 cm feed is a conical horn. The concentric design provides the possibility of observing at two different frequencies, or, alternatively, at two circular polarizations simultaneously. Radio astronomical receivers at each frequency range have two independent channels to accept signals with right-hand and left-hand circular polarization (RCP and LCP) from the feed system. . The low noise amplifiers (LNA) utilize high electron mobility transistors (HEMTs). The L-, C-, and K-band LNAs are located on a “cold plate" with a passive cooling system, which maintains a temperature of about 130 K. The LNA for the P-band receiver operates at a physical temperature of about 300 K [1-3].
The RadioAstron satellite is moving in a moon-perturbed orbit, where the orbital elements have been chosen to maximize their evolution caused by gravitational perturbations from the Moon and the Sun. Such evolution is desirable in order to provide maximum variety of UV-coverages for imaging of radio sources. Accurate orbit determination of the RadioAstron spacecraft is a challenging task because of significant impact of non-gravitational perturbations on its motion. Orbit measurements are being performed by a complex of techniques: radio measurements of range and range rates,, laser, optics, VLBI. Achieved accuracy of orbit reconstruction is at a level of <300m for 3D position and <0.01m/s for 3D velocity [4].
There are two commanding stations at Ussuriisk (70-m dish), and in Bear Lake (64-m dish), and there are two telemetry stations in Pushchino (22-m) and in Green Bank (45-m). At the telemetry stations science data transmitted from the SRT at a carrier frequency of 15 GHz are being recorded by the dedicated recording system (RDR) designed and manufactured at the ASC. Data correlation is conducted at the ASC Software correlator as well as in Bonn and in JIVE.

3. Main scientific results

There are three major areas of studies made with RadioAstron: active galactic nuclei (AGN), maser sources, and pulsars. During 7 years of operations many new and unique scientific results were obtained with RadioAstron:
1) Interferometric fringes were detected for over 150 quasars in the continuous spectrum up to a record resolution of 10 μas. Their nuclei turned out to be at least 10 times brighter than the predictions of the theory, and the measured brightness exceeds significantly the previously

obtained results. Formally, the inverse Compton limit turned out to be violated. Possible explanations are: underestimated Doppler factor, magnetic reconnection in nuclei, synchrotron-emitting relativistic protons [5,6].
2) An increase in the degree of linear polarization with a resolution was found in the BL Lac and 3C273 quasars. This indicates the presence of ultra-compact regions with a uniform magnetic field in the quasar nuclei. According to the results of polarization mapping of quasars, it turned out that the magnetic fields at the base of the jets have a toroidal structure [7,8].
3) Many of the jets of quasars as a result of mapping could be resolved across. Plasma instabilities in relativistic jets were detected. There is a brightening of radiation towards the edges of the jets — this is the result of the stratification of the flow of a relativistic plasma. For the first time, there were indications of the operation of the Blandford-Payne mechanism during the formation of a jet in the core of the 3C84 galaxy - that is, an accretion disk was shown to be involved [9].
4) A sub-relativistic shell around jets, previously predicted indirectly from the Faraday rotation, was discovered [10].
5) As a result of the analysis of the probing interstellar plasma by radio pulses of pulsars, a new scattering effect was discovered - a substructure of the scattering disk. The effect of the substructure should be taken into account when analyzing the data of interferometric observations with extreme angular resolution [11].
6) By analyzing the structural and correlation functions of the scattered radio emission of pulsars, layers of interstellar plasma close to the solar system were detected for the first time, which can cause rapid variability of compact extragalactic radio sources [12-14].
7) As a result of comparing the angular dimensions of the scattering disks of the radio emission of pulsars with a characteristic pulse scattering time, the distances to the effective scattering screens were determined. An analysis of these measurements indicates a possible layered structure of the interstellar plasma in our Galaxy [15-17].
8) Compact high-brightness details in the disk of the megamaser of water vapor of the galaxy NGC 4258 are found up to a resolution of 10 µas. The disk turned out to be extremely thin - valuable information for modeling.
9) The galactic maser of water vapor Cep A in our Galaxy has two parts the size of the Sun. The results are explained by the model of a turbulent vortex, highlighted by ejection from the disk. The dissipation scale is about 0.1 astronomical units [18].
10) The equivalence principle of GR is verified to an accuracy of about 0.01%, comparing to the Gravity Probe A experiment, as measured by Radioastron's one orbit based on the use of the onboard hydrogen frequency standard.. An improvement in accuracy by an order of magnitude is expected in result of processing all the data [19].

4. Acknowledgements

The RadioAstron project is led by the Astro Space Center of the Lebedev Physical Institute of the Russian Academy of Sciences and the Lavochkin Scientific and Production Association under a contract with the State Space Corporation ROSCOSMOS, in collaboration with partner organizations in Russia and other countries.

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