# Status and Main Parameters of Space VLBI Mission RadioAstron

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## Abstract

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The RadioAstron project is an international collaborative mission to launch a free-flying satellite carrying a 10-m space radio telescope (SRT) into an elliptical orbit around the Earth. The aim of the mission is to use the space telescope for radio astronomical observations using VLBI (Very Long Baseline Interferometry) techniques in conjunction with ground-based VLBI networks. In this presentation we will provide information on the present status of the misison, describe its parameters and scientific access to the mision.

## 1 Introduction

During the long period of project development, institutes from other countries have made notable contributions to the RadioAstron Project. The low-noise amplifier (LNA) for the 92-cm (P-band) receiver operating at 327 MHz has been built in India by NCRA. The 18-cm (L-band) receiver operating at 1665 MHz has been developed and manufactured in Australia by CSIRO. The initial 6.2-cm (C-band) receiver operating at 4830 MHz has been developed at ASTRON, NL on behalf of the European VLBI Consortium (EVN). Finally, the initial 1.35-cm (K-band) receiver operating at 22 GHz has been provided by the Helsinki University of Technology in Finland. Because of aging issues, the last two receivers (the C- and K-band) have been replaced by new models developed in Russia. The new K-band receiver contains an LNA provided by the NRAO, USA and can operate in frequency switching mode in the range of 18.392-25.112 GHz. Both initial receivers have been extensively used in system development tests, and particularly in the astronomical tests of the complete engineering complex of the SRT in Pushchino in 2004. In addition, the European Space Agency (ESA) conducted complicated tests of the SRT antenna petals in the vacuum chamber in Noordwijk. These test were essential for the final development of the RadioAstron project. ESA has also provided funding for the development of the on-board Rubidium frequency standard, which has been manufactured by the Neuchatel Astronomical Observatory in Switzerland.

## 2 Spacecraft design

The RadioAstron satellite consists of a parabolic reflector, a scientific payload located in two containers, the focal container and the instrumentation module, and a Navigator service module, which is a standard module used in several other scientific missions. An on-board Hydrogen frequency standard is installed separately. The space radio telescope (SRT) is a deployable parabolic reflector (10-m diameter) made of 27 carbon fiber panels. It has a focus to diameter ratio F/D = 0.43, and an overall RMS surface accuracy ±0.5 mm. The prime focus concentric feed arrangement provides the possibility of observing at two frequencies, or two circular polarizations simultaneously. Observing frequencies are: 0.327, 1.665, 4.830 and 18.392-25.112 GHz. The total satellite mass is 3660 kg, with 2500 kg belonging to the scientific payload including the SRT, and with 1160 kg for the service module Navigator. The satellite will be launched from Baikanur by the Zenit-2SB launcher manufactured by the Ukrainian KB-Yuzhnoe company. An elliptical orbit of the satellite with an apogee height of about 320000 km will be achieved by a Fregat-SB rocket upper stage.

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# 3 Scientific payload

The science payload consists of a space radio telescope, feed arms, a focal container, an instrumentation module, a high data rate communication system with a high-gain antenna, and two separate Hydrogen maser frequency standards located in open space.

## 3.1 Space Radio Telescope (antenna)

The Space Radio Telescope (SRT) with a diameter of 10 m and a focal distance of 4.22 m operates in four frequency ranges: 0.327(P band), 1.665(L band), 4.830(C band), and 18.392-25.112 GHz (K band). 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 ($34 \times 115 \times 372$ cm) made of carbon-fiber. The maximum deviation for the surface from a paraboloid must not exceed ±2 mm. The required high reflectivity of the SRT surface (0.98%) is provided by an aluminum coating of $100\mu m$ thick. To reduce thermal deformations of the SRT, the tubes of the petal framework are thermo-stabilized by special heating elements keeping the temperature within $\pm 50^{\circ}\ C$. At the rear, the petals also are shielded by multilayer thermal isolation. According to the functional constraints the Sun is never supposed to illuminate the SRT dish surface.

## 3.2 The Feeds

The feed system is located at the prime focus of the paraboloid and is attached to the bottom of the focal container. Fine-tuning of the position of the whole system is possible over a range of ±7 mm during its assembling before launch. 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.

## 3.3 The Receivers

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. All receivers are located in the focal container. The low noise amplifiers (LNA) utilize high electron mobility transistors (HEMTs). The LNAs for 1.665, 4.830 and 18.392-25.112 GHz are located on a ”cold plate” with a passive cooling system, which is expected to keep a temperature of about 130 ± 20 K. The LNA for a 92-cm receiver operates at a physical temperature of 303 ± 3 K.

# 4 RadioAstron orbit

RadioAstron will be in a moon-perturbed orbit, where the orbital elements have been chosen to maximize their evolution by weak gravitational perturbations from the Moon and the Sun.The orbit must have ballistic lifetime greater than 9 years, and the orbiting SC may not be in the Earth's shadow for longer than 2 hours.The initial orbital elements are: apogee height $H_a = 330,000$ km, perigee height $H_p = 400$ km, inclination of the orbit $i = 51.4^{\circ}$, and initial rotation period is about 8.5 days. During the evolution the perigee will vary from 400 to 65,000 km, the apogee will vary from 265,000 to 360,000 km, and the eccentricity of the orbit changes from 0.59 to 0.96. The characteristic period of these variations is about three years.

Table 1: The frequency set for the RadioAstron SRT

| LO2-frequency (MHz) | Designation | P-band | L-band | C-band | K-band |
|---|---|---|---|---|---|
| 500 | S1 | | 1652 | 4820 | 22220 |
| 508 | C2 | | 1660 | 4828 | 22228 |
| 516 | C3 | | 1668 | 4836 | 22236 |
| 524 | S4 | 324 | 1676 | 4844 | 22244 |

Table 2: The sensitivity of the RadioAstron mission

| | RadioAstron | | | |
|---|---|---|---|---|
| | P-band | L-band | C-band | K-band |
| Band (MHz) | 4 | $2 \times 16$ | $2 \times 16$ | $2 \times 16$ |
| $T_{sys}$(K) | 162 | 38 | 80 | 92 |
| $A_e(m^2)$ | 30 | 40 | 40 | 30 |
| SEFD (Jy) | 15400 | 2300 | 7300 | 13300 |
| | GBT | | | |
| $T_{sys}$(K) | 105 | 20 | 18 | 35 |
| $A_e(m^2)$ | 5500 | 5500 | 5500 | 4800 |
| SEFD (Jy) | 55 | 10 | 8 | 23 |
| | RadioAstron+GBT | | | |
| $S_{min}$(mJy) ($1\sigma, \tau = 1$ s) | 720 | 60 | 94 | 220 |
| $S_{min}$(mJy) ($1\sigma, \tau = 300$ s) | 42 | 4 | 5 | 13 |

## 5 The Frequency distribution

Four frequency ranges arre available for astronomical observations: 92-cm (P-band), 18-cm (L-band), 6.2-cm (C-band), and 1.19-163 cm (K-band). In each band two output channels that produce circular polarization (LCP and RCP) signals, which may be used simultaneously. Alternatively two different frequency bands may be used instead of two polarizations. In principle, any frequency combination is possible, except that the two frequency channels will have an opposite polarization.

## 6 System sensitivity

The parameters of the RadioAstron on-board receiver system have been measured in the laboratory at a physical temperature equivalent to the one expected during space operation, where passive cooling will give a physical temperature of $t_{LNA} = 130K$. The losses in the cable connections to the feeds were measured separately, as well as losses in the feeds themselves.

Table 2 shows estimates of the expected sensitivity of space-ground interferometry with SRT and using the NRAO GBT telescope as a example ground station. The system equivalent flux density (SEFD) has been calculated as $SEFD = 2kT_{sys}/A_e$. Estimates of the minimum detectable correlated flux density ($\sigma = \frac{1}{\eta_Q}\sqrt{\frac{SEFD_1 SEFD_2}{\Delta\nu\tau}}$) are made for one polarization channel with 4 or 16 MHz width for P-band and for the L-, C-, and K-bands, respectively, and with $\eta_Q = 0.637$ for one bit quantization. The sensitivity for L,C, and K-bands chanels is two times better when LSB/USB and LCP/RCP channels are combined.

## 7 Science access

The RadioAstron mission will begin with a *commissioning phase*, or In-Orbit-Checkout (IOC) period. The first part of the IOC includes an *engineering commissioning* with a spacecraft bus checkout, the unfolding of the SRT, receiver checks and tests of the radio astronomy antenna in single-dish mode (boresighting), and communication tests with the tracking stations (using the HDRC system). It is expected that this engineering commissioning period will occupy about five orbits (45 days). The second part of the IOC is a *scientific commissioning phase* that consists of tests of the SRT science payload in VLBI mode using large ground radio telescopes. For this process the largest ground-based radio telescopes are required, including those located in Russia.

The second phase of the IOC, although designed for engineering checkouts, will give the first scientific results of the mission. This IOC phase will be smoothly transitioned into a *scientific verification phase* for a agreed upon Early Science Program (ESP) with a duration of about 10 orbits (3 months) to be executed by Early Science Program Teams (ESPT). There will be no AO for the ESP period but the ESPT will need to submit proposals for peer review to individual international observatories for their use during the ESP. The ESPT will be chosen from individuals and organizations that have contributed to mission development. After the ESP period, there will be observations for the Key Science Programs (KSPs) with each KSP representing different important areas of the scientific research program for the mission. Scientists may participate in the KSPs by responding to an announcement of opportunity (AO) issued before the launch date. KSPs may continue during the whole mission as appropriate. After the commissioning phase, yearly series of AO's for individual investigators will be issued by the Mission for the observing period starting after the ESP phase (about half a year after the launch date).

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