Millimetron Space Mission
Current Status and Future Prospects

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*Rosette Nebula image captured by Herschel telescope*
Radioastron Mission

The largest in the world 10-m deployable space radio telescope.

Launched on the 18th of July, 2011

- Daily Space-VLBI observations
- Support from more than 40 ground radio telescopes around the world
- Orbit around the Earth up to 350 000 km
- More than 6 years of successful operation
- Capable of multi-frequency observations (18392 – 25112 MHz)

Studies on:
- AGN+QSO (imaging, surveys)
- Masers (imaging, surveys)
- Pulsars (ISM, scattering effects, etc.)

Frequency bands:
316 MHz, 1660 MHz, 4868 MHz, 22220 MHz

More information: http://radioastron.ru/
Radioastron Data Opened!

The correlated data of Radioastron observations conducted from 2011 to June 2015 in now available!

http://opendata.radioastron.ru/

AGN & quasar survey and imaging, pulsar, maser data.
Millimetron Mission
The first 10-m deployable and cooled space sub-mm and FIR telescope.

Mission has been approved and supported by Russian Space Agency

- FIR, sub-mm and mm range
- In orbit deployable and adjustable antenna
- Cosmology and astrophysics studies
- Mechanically cooled (<10K) with post-cryo life
- Orbit around L2 Lagrange point
- Lifetime: 10 years; at cryo >3 years

Two operation modes:
Space-VLBI at 1 – 17 mm
Single dish at 0.05 – 3 mm

Study of Early and Late Universe

- Spacecraft bus in Phase-B
- Scientific payload in Phase-A
- Launch date: after 2025

More information: http://millimetron.ru/
Millimetron Mission

Launch configuration

- Ø3.8 m
- 15 m

- Primary Mirror
- Secondary Mirror
- Cryo Instrument Container (4K)
- Cryo Shield (Active Cooling)
- Sunshields (Passive Cooling)
- Deployable Radiator
- Deployable Solar Arrays
- Space Bus “Navigator-SM”
- High Gain Antenna
- Deployable Solar Arrays

- Instrument Container (300K)
Millimetrion Mission
Orbit Configuration

- Orbit period – 365 days (L2).
- Baseline – 1 500 000 km, max.
- Time of oscillation around L2 is about half of a year.
- MM antenna view angle opening is ± 75° in ecliptic latitude and longitude.

\[ \alpha \text{ - Target angle, BL} = L_{E-SK} \times \sin(\alpha) \text{ Resolution/BL} \]
Scientific Payload for Millimetron

1) **Space-VLBI receivers (S-VLBI):** 1 - 17 mm

2) **Millimetron Heterodyne Instrument**
   for the Far-Infrared (**MHIFI):** 60 - 600 µm

3) **Short-wave Array Camera Spectrometer (SACS):**
   - **Camera:** 4 bands: 70, 125, 230, 375 µm
   - **Spectrometer:** long slit grating spectrometers: 50 - 450 µm

4) **Long wave-Array Camera Spectrometer (LACS):**
   - **Camera:** 4 bands: 0.4, 0.7, 1.2, 2.3 mm
   - **Spectrometer:** the FTS: 0.3 - 3 mm
Millimetron Mission
Breakthrough Science

Nobel Laureate breaking through scientific tasks.

1. Looking inside of black hole
2. Search for wormholes
3. Distortions of CMB spectra
4. Interplanetary medium
5. Search for the complex molecules (prebiotics) and signs of life
The 10-m telescope located at the L2 Lagrange point and working in Space-VLBI mode can increase angular resolution $\approx 100$ times ($\approx 10^{-8}$ arcsec).
Multi-frequency Synthesis
Radioastron Test Experiment (RATS01)

Date: 2017-01-14 03:10:00 - 2017-01-14 04:00:00
Ground telescopes: Medicina, KVN, Torun
Baseline projections: ~1xED
ASC Processing

Baseline Radioastron-KVN (KY)
**Millimetron Antenna Elements**

**Primary reflector (parabolic) - CFRP**
- Diameter: 10 m
- Surface errors: ≤ 10µm RMS (6µm (goal))

**Secondary reflector (hyperbolic) - SiC**
- Diameter: 542.13 mm
- Surface errors: ≤ 1µm RMS

**Material**: CFRP (M55j + cyanate ester resin)
- Lightweight
- Extremely low thermal expansion coefficient
- Very low moisture absorption
- Developed for high stability space structure

**Method**: replica technique

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Parabolic mold

Parabolic panel of central part of the PM
Panels Surface Accuracy

Parabolic panel of central part of the PM

- 1139049 Total amount of points RMS = 4.4 µm
- 1027219 Total intern. points RMS = 3.0 µm
- 1022144 Intern. points RMS = 3.0 µm

Parabolic mold

- 1139532 Total amount of points RMS = 3.4 µm
- 1043948 Total intern. points RMS = 2.8 µm
- 1037974 Intern. points RMS = 2.8 µm
Millimetron Primary Mirror
Central Section

The full scale facility to assemble the solid dish of the primary mirror
Petal Assembly
Cryoshield

Full scale kinematic mockup (deployable) of the cryoshield
Sunshield

Full scale mockup of the first sunshield
Cryoshield, Radiators and System for Sunshields

Full scale mockup of deployment system of the cryoshield

Full scale EM of Radiators

Full scale mockup of the systems for sunshields
Zero Gravity System for the Primary Mirror

Created an unique zero gravity system for the validation of the mechanical driver of the deployment of primary mirror
Millimetron Data Center

- Millimetron Data Processing Center (DPC) will be organized as a Data-Center.

- Main objectives of DPC are: collecting, processing and archiving of all the observation data and organizing information exchange among mission’s participants.

- Expected volume of data ~3300 PB/year or 33000 PB for 10 years of operation.

- It is necessary to connect the DPC with tracking stations and other ground telescopes with high speed channels.

Radioastron mission experience will be used in creation of Millimetron Data Center.
Space-VLBI Critical Points

- **Accuracy of the orbit determination.** Use of laser ranging and selective VLBI tracking of the spacecraft.
- **On-board accelerometer and clock.** According to the requirements for acceleration and velocity.
- **Choice of the baseline vector projection to avoid “gaps” on the (u,v)-plane.** Requires accurate scheduling of the mission. It’s possible that successive scientific targets will be rare enough.
- **Provide acceptable sensitivity.**
- **On-board maser stability for higher frequencies.**
- **Data downlink channel supply.**
Summary

- “Millimetron” is the next step of space based astronomy. Currently, the only one future space mission that as a single dish and space-ground VLBI observatory in mm, sub-mm and FIR it will provide unprecedented sensitivity and the highest (dozens of nas) angular resolution. The project is fully supported by Russian Space Agency and included in Russian Federal Space Program.

We welcome for scientific proposals and technical discussions!
Suffa Radio Telescope

Antenna development on Suffa plateau in Uzbekistan:
- 70-meter antenna operating at wavelengths down to 0.8 mm

**But before:**
- A 12-15 meter 0.8 mm antenna compatible with ALMA bands 2-3, 6, 7

Example of VLBI observations simulation:
**Source:** 0716+714, MFS
Suffa + KVN antennas, 24 hour session
Thank you for your attention!

Millimetron project: http://millimetron.ru/