Millimetron Space Mission
Current Status and Future Prospects

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On behalf Millimetron mission team

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Russian Academy of Sciences (ASC LPI RAS)

East Asian VLBI Workshop, Pyeongchang, 2018

ROSCOSMOS ASC LPI

*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

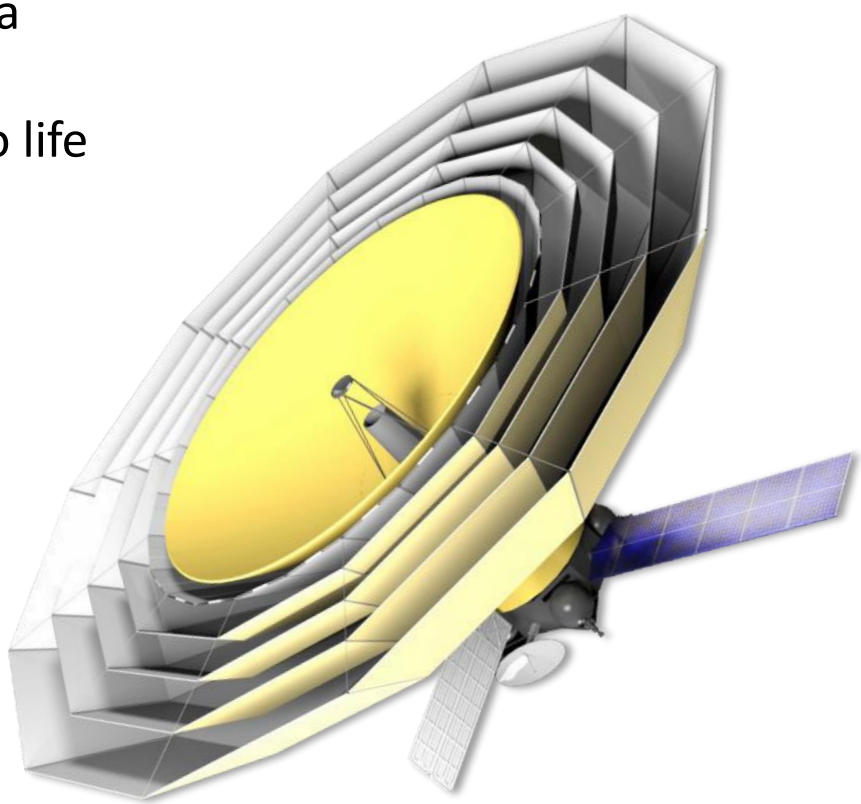
- FIR, sub-mm and mm range
- In orbit deployable and adjustable antenna
- Cosmology and astrophysics studies
- Mechanically cooled (<10K) with post-cryo life
- Orbit around L2 Lagrange point
- Lifetime: 10 years; at cryo >3 years

Two operation modes:

Space-VLBI at 1 – 17 mm

Single dish at 0.05 – 3 mm

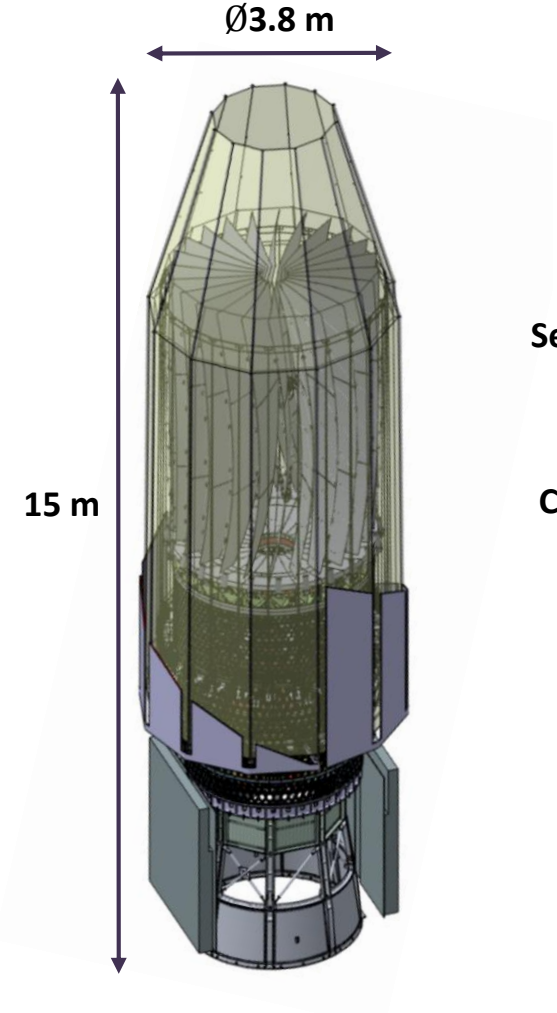
Study of Early and Late Universe



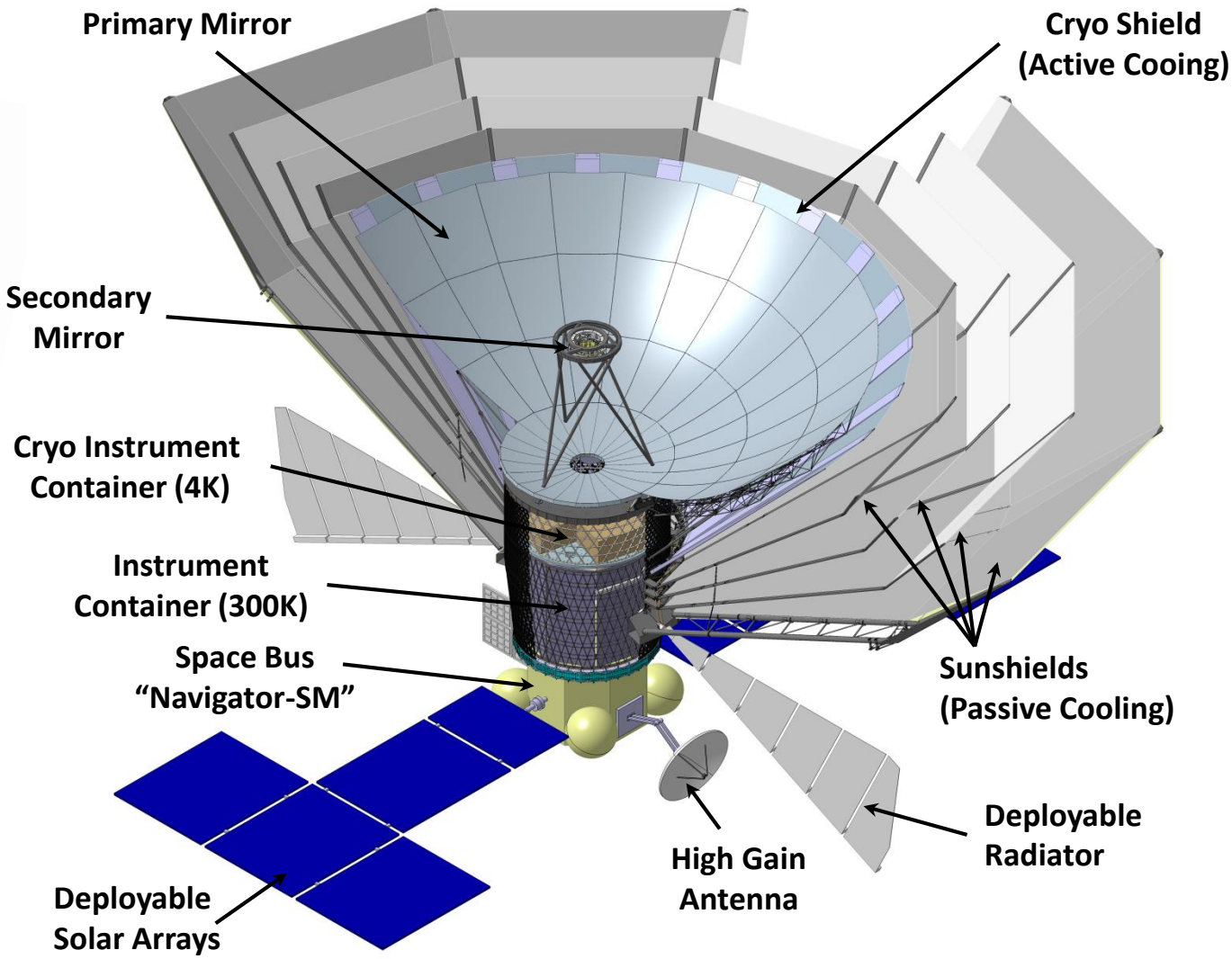
- **Spacecraft bus in Phase-B**
- **Scientific payload in Phase-A**
- **Launch date : after 2025**

More information: http://millimetron.ru/

Millimetron Mission

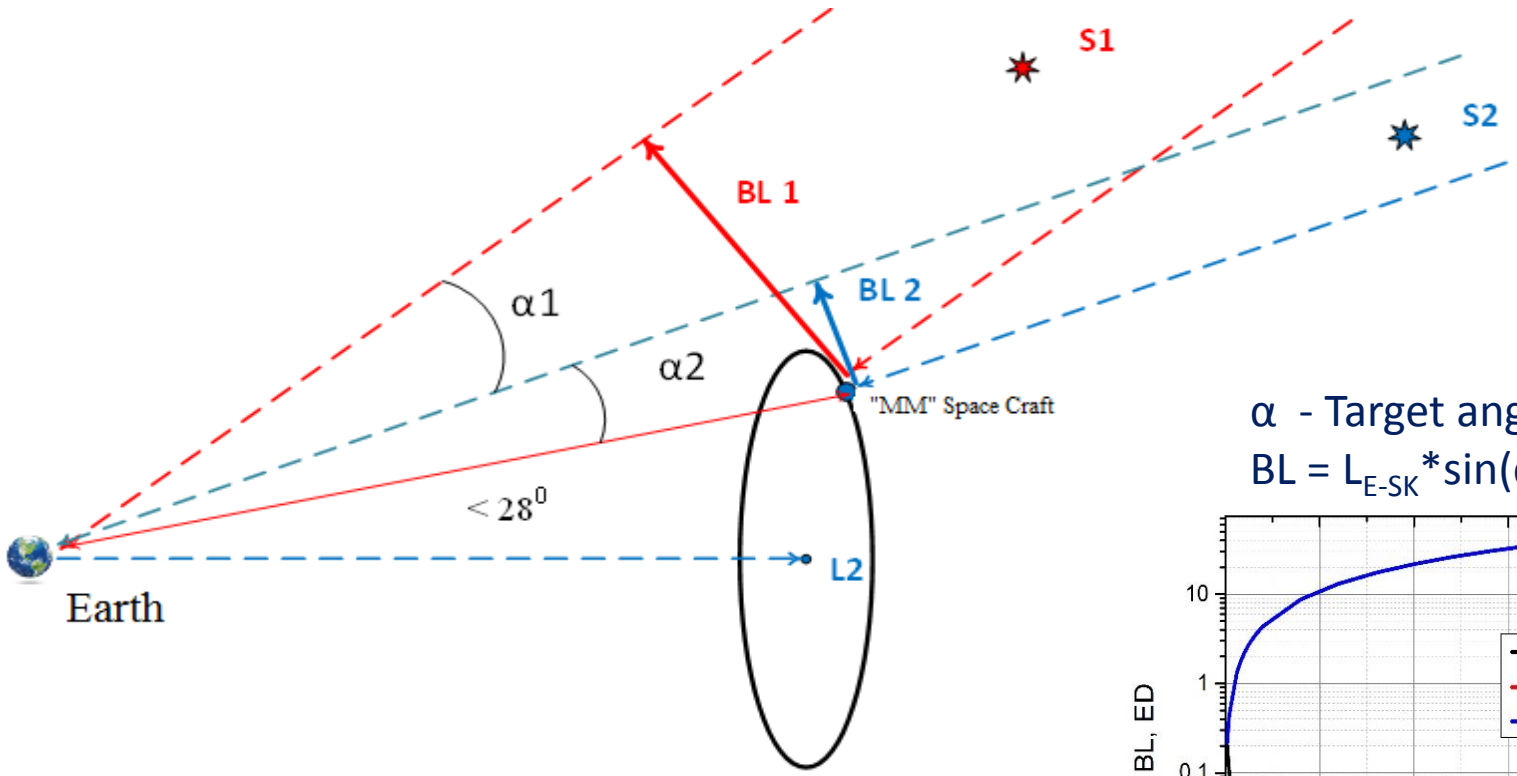


Launch configuration



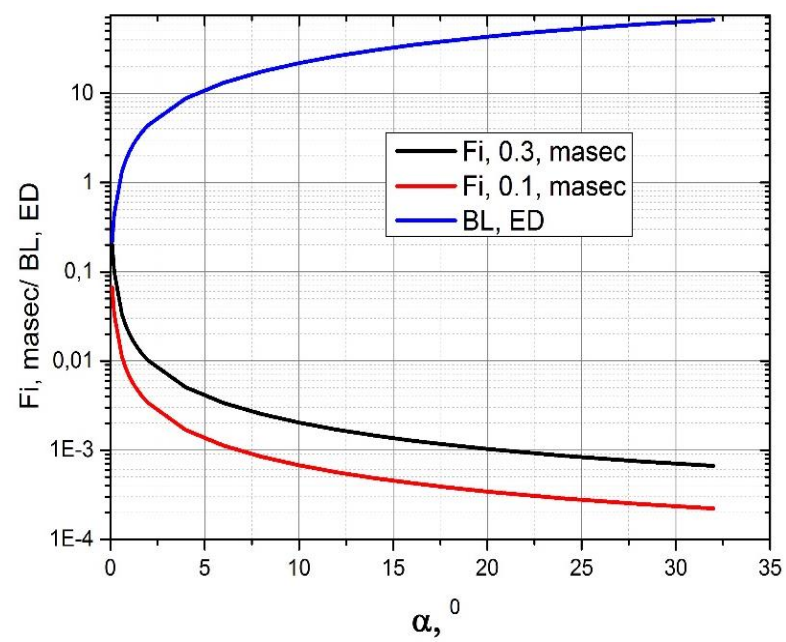
Millimetron Mission

Orbit Configuration



α - Target angle,

BL = $L_{E\text{-}SK}$*sin(α) Resolution/BL



- 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.

Scientific Payload for Millimetron

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

2) **Millimetron H**eterodyne **I**nstrument
for the **F**ar-**I**nfrared (**MHIFI**): **60 - 600 μm**

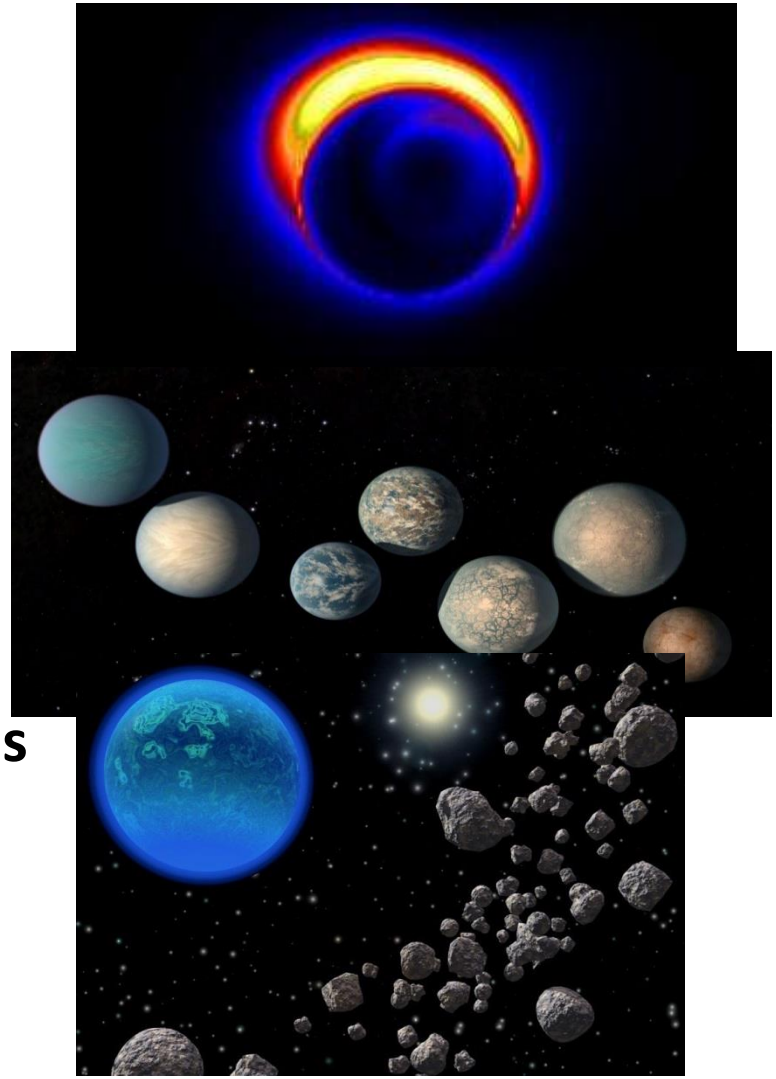
3) **S**hort-wave **A**rray **C**amera **S**pectrometer **(SACS):**
- **Camera**: 4 bands: **70, 125, 230, 375 μm**
- **Spectrometer**: long slit grating spectrometers: **50 - 450 μm**

4) **L**ong wave-**A**rray **C**amera **S**pectrometer **(LACS):**
- **Camera**: 4 bands: **0.4, 0.7, 1.2, 2.3 mm**
- **Spectrometer**: the FTS: **0.3 - 3 mm**

Millimetron Mission
Breakthrough Science

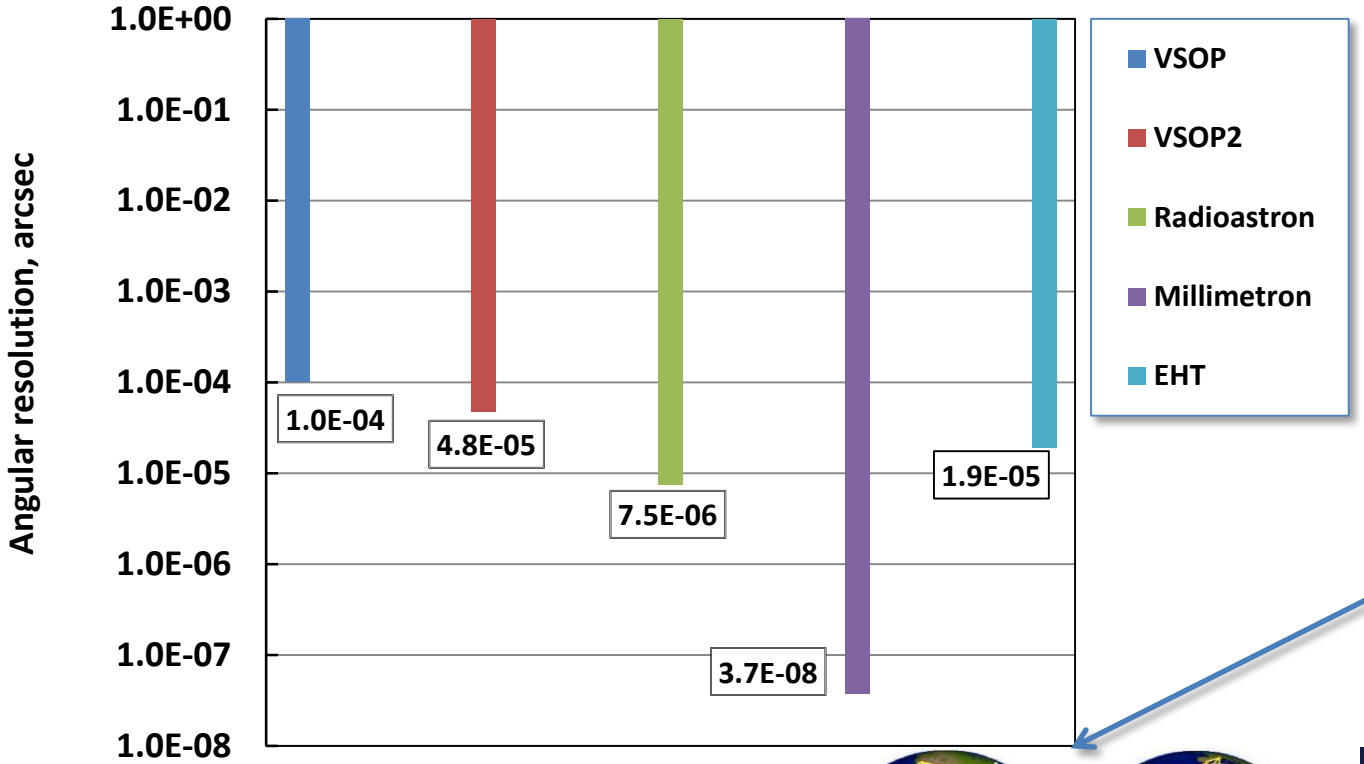
Nobel Laureate breaking trough scientific tasks.

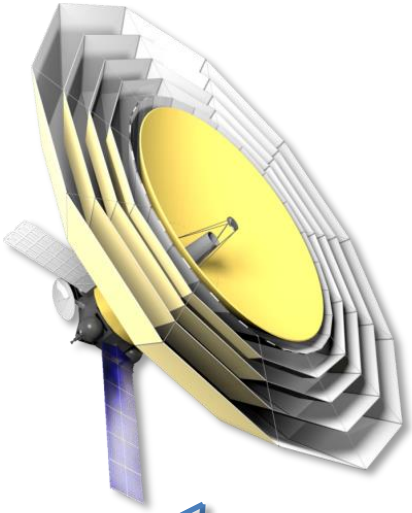
1. Looking inside of black hole
2. Search for wormholes
3. Distortions of CMB spectra
4. Interplanetary medium
5. Search for the complex molecules (prebiotics) and signs of life



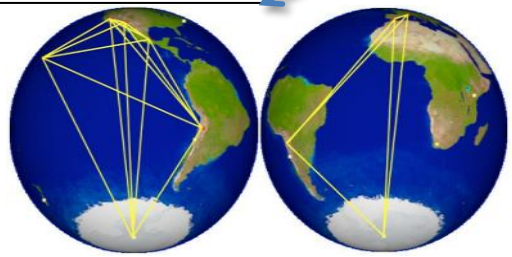
Millimetron Capabilities

Angular Resolution





The 10-m telescope located at the L2 Lagrange point and working in Space-VLBI mode can increase angular resolution ≈ 100 times (≈ 10^{-8} arcsec).

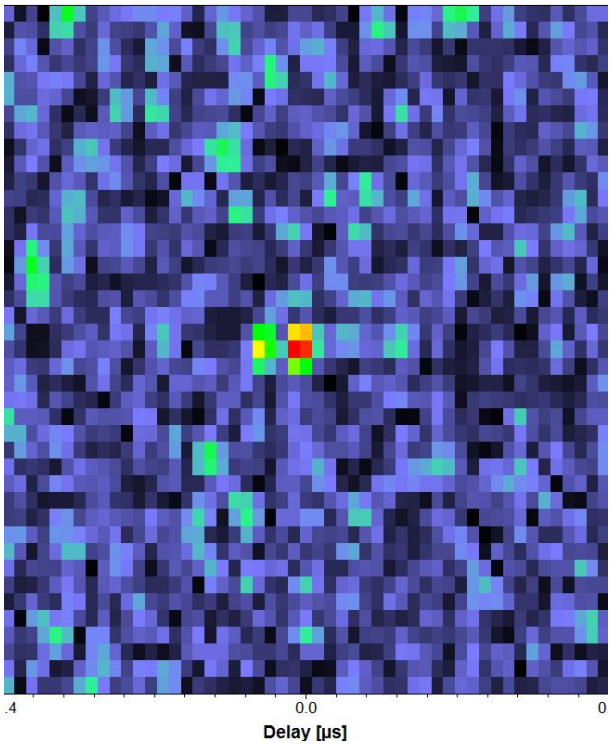


Global mm-VLBI

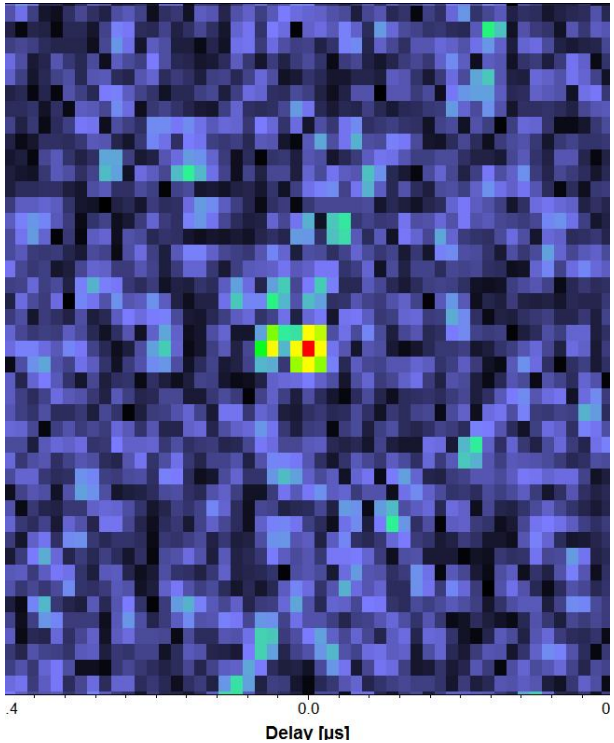
ALMA

Multi-frequency Synthesis

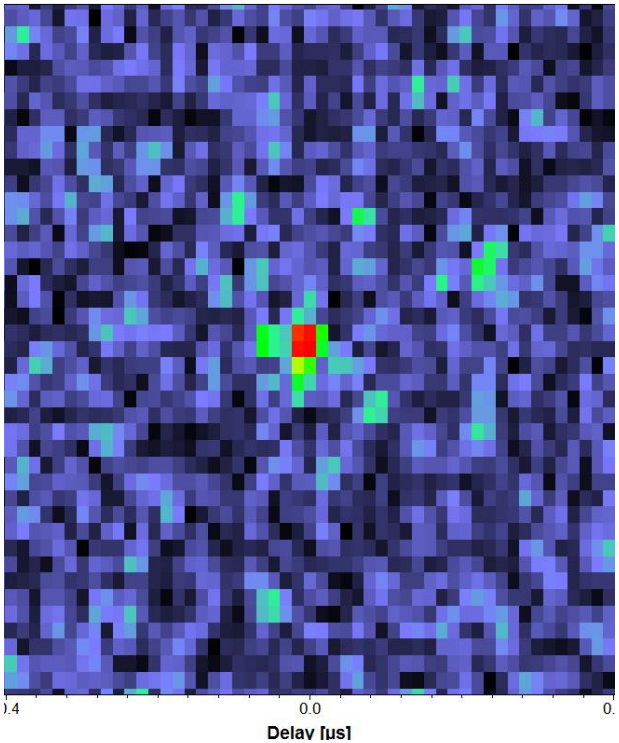
Radioastron Test Experiment (RATS01)



21GHz



22GHz



23GHz

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))

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

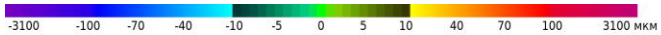
Secondary reflector (hyperbolic) - SiC

Diameter	542.13 mm
Surface errors	≤ 1µm RMS

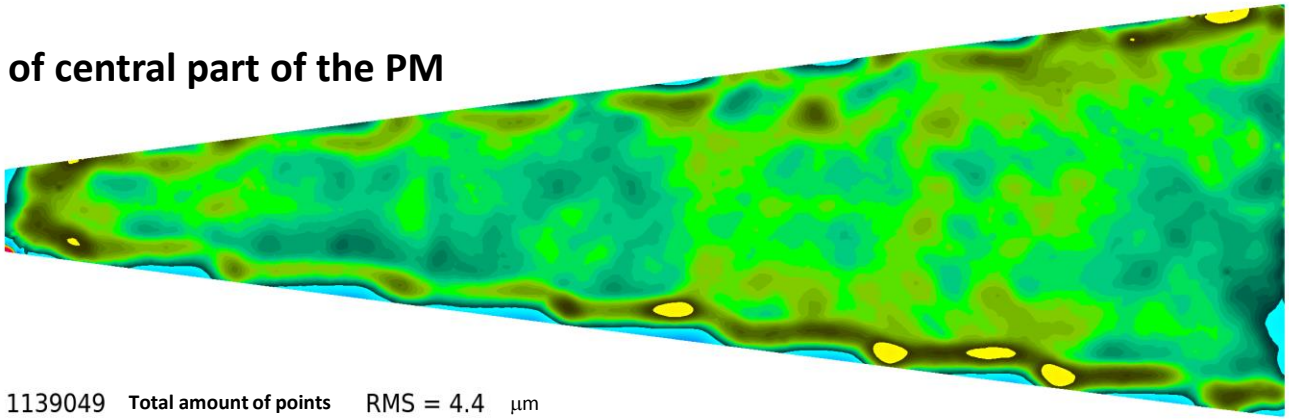
Parabolic mold

Parabolic panel of central part of the PM

Panels Surface Accuracy

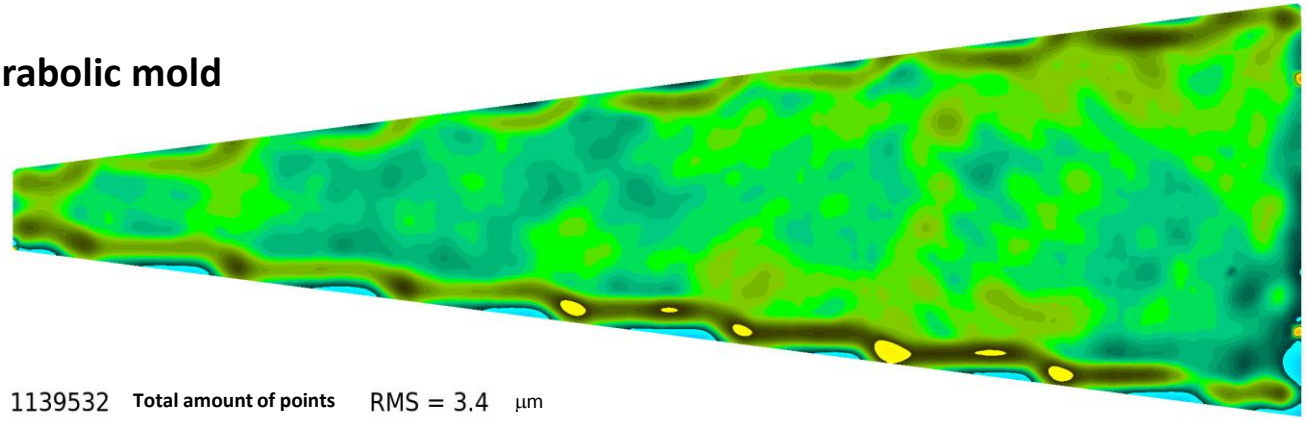


Parabolic panel of central part of the PM



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



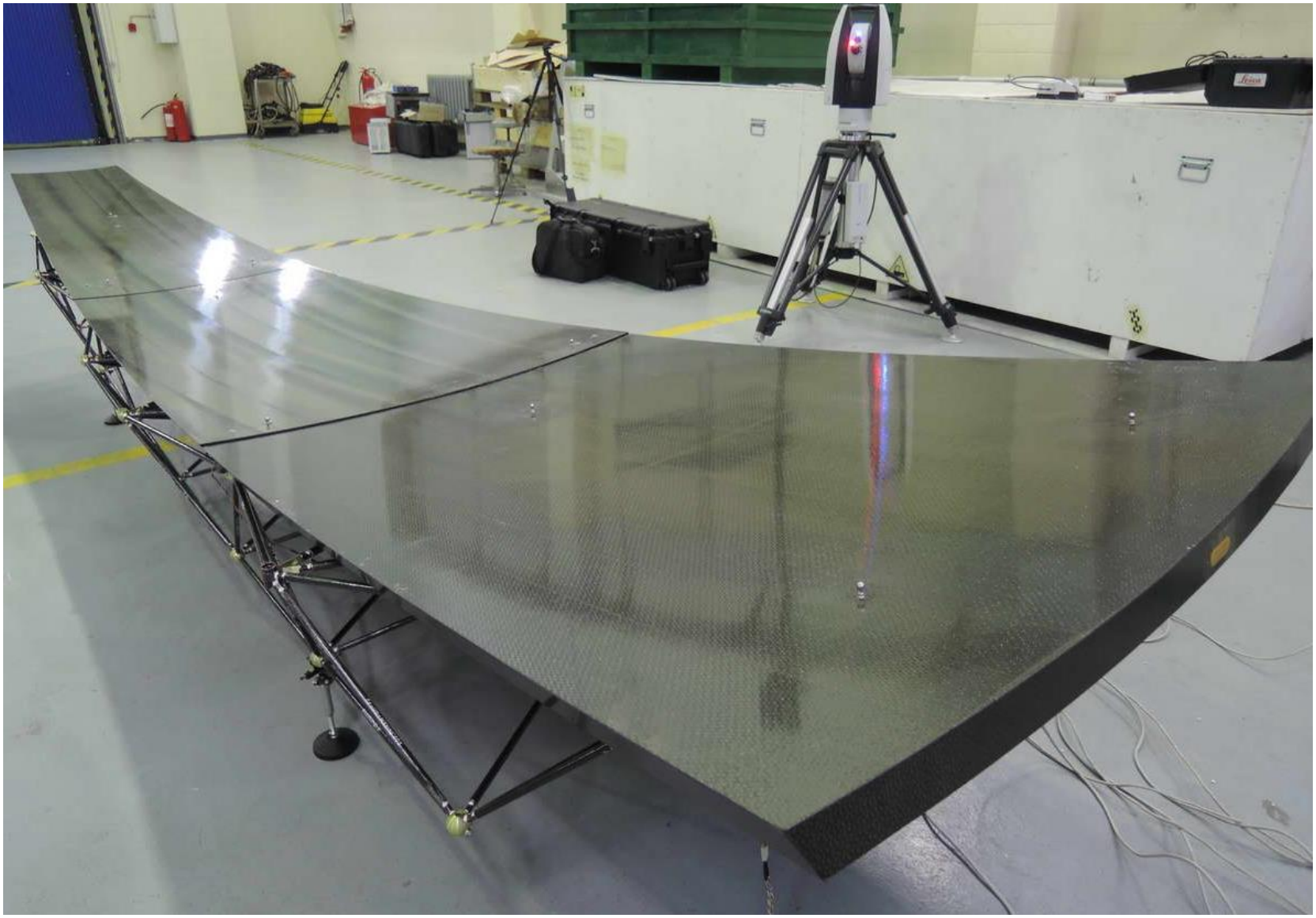
1139532	**Total amount of points**	RMS = 3.4	μm
1043948	**Total intern. points**	RMS = 2.8	μm
1037974	**Intern. points**	RMS = 2.8	μm

Millimetron Primary Mirror

Central Section

The full scale facility to assembly the solid dish of the primary mirror

Petal Assembly



Cryoshield

Full scale kinematic mockup (deployable) of the cryoshield

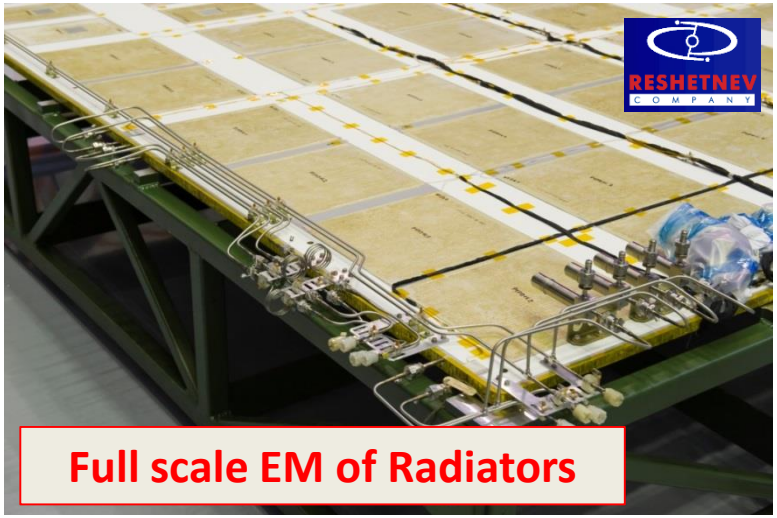
Sunshield

Full scale mockup of the first sunshield

Cryoshield, Radiators and System for Sunshields

Full scale mockup of deployment system of the cryoshield

Full scale mockup
of the systems for sunshields

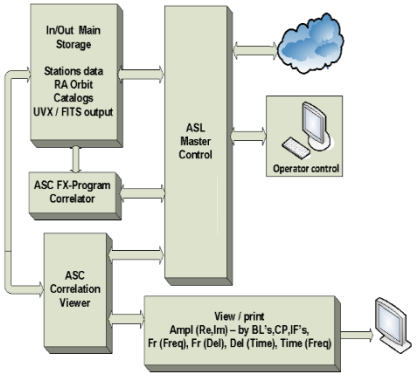


Full scale EM of Radiators

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!

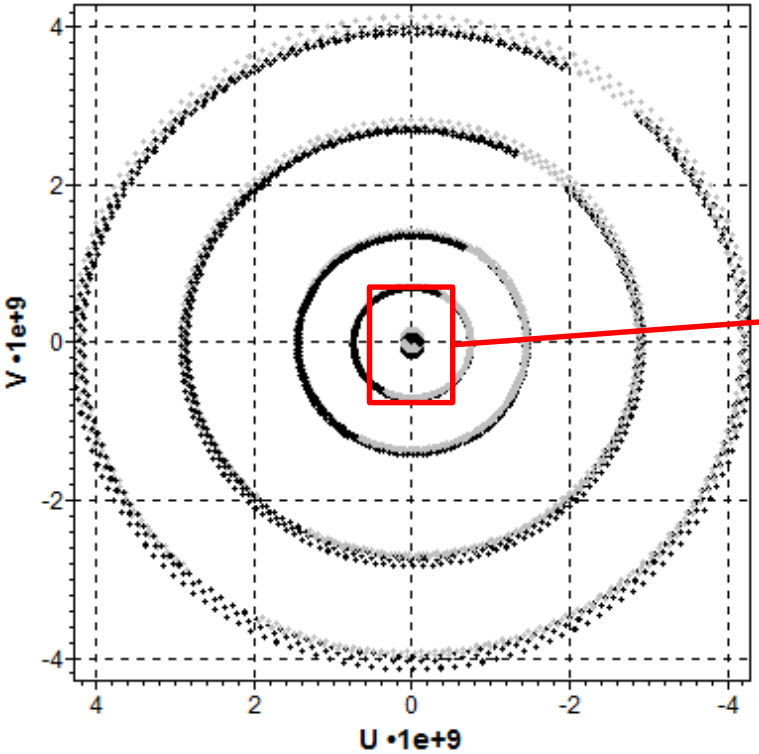
Suffa Radio Telescope

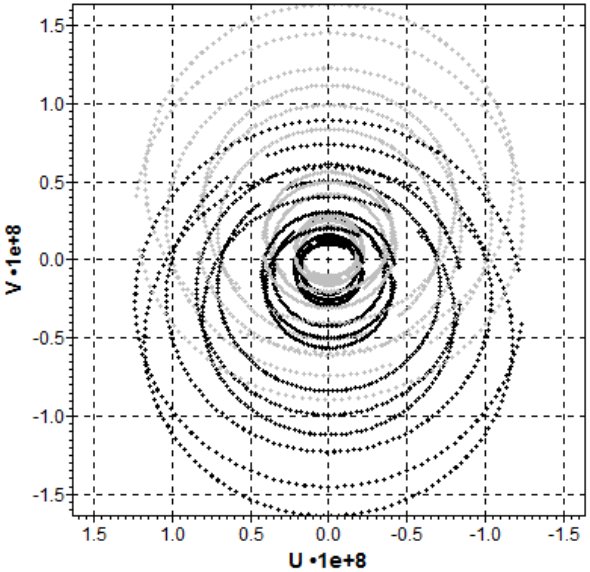
Antenna development on Suffa plateau in Uzbekistan:

- 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

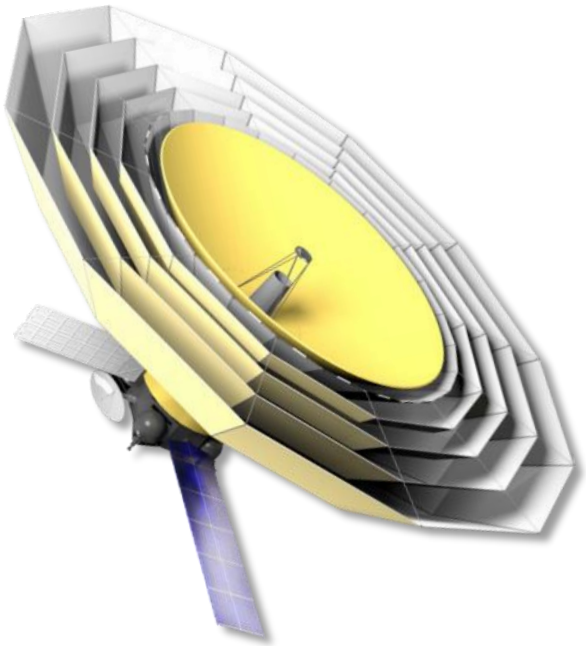




Example of VLBI observations simulation:

Source: 0716+714, MFS

Suffa + KVN antennas, 24 hour session



Thank you for your attention!

Millimetron project: http://millimetron.ru/

RESHETNEV COMPANY

ROSCOSMOS

ASC LPI