Introduction to Millimetron ("Spektr-M")

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On behalf of "Millimetron" project team

Paris, 9-11 September, 2019

Acknowledgements

Many elements of this presentation are based on existing presentations prepared by other members of the “Millimetron” project.

All along this presentation you will see results from work conducted by a large number of Millimetron contractors.

Contents of the presentation

- What is “Millimetron”?
- General description of the “Millimetron” mission
- Astro Space Centre and its role in “Millimetron”
- Place of ”Millimetron” in the Russian Federal Space Program
- “Millimetron” modes
- International cooperation

What is “Millimetron”?

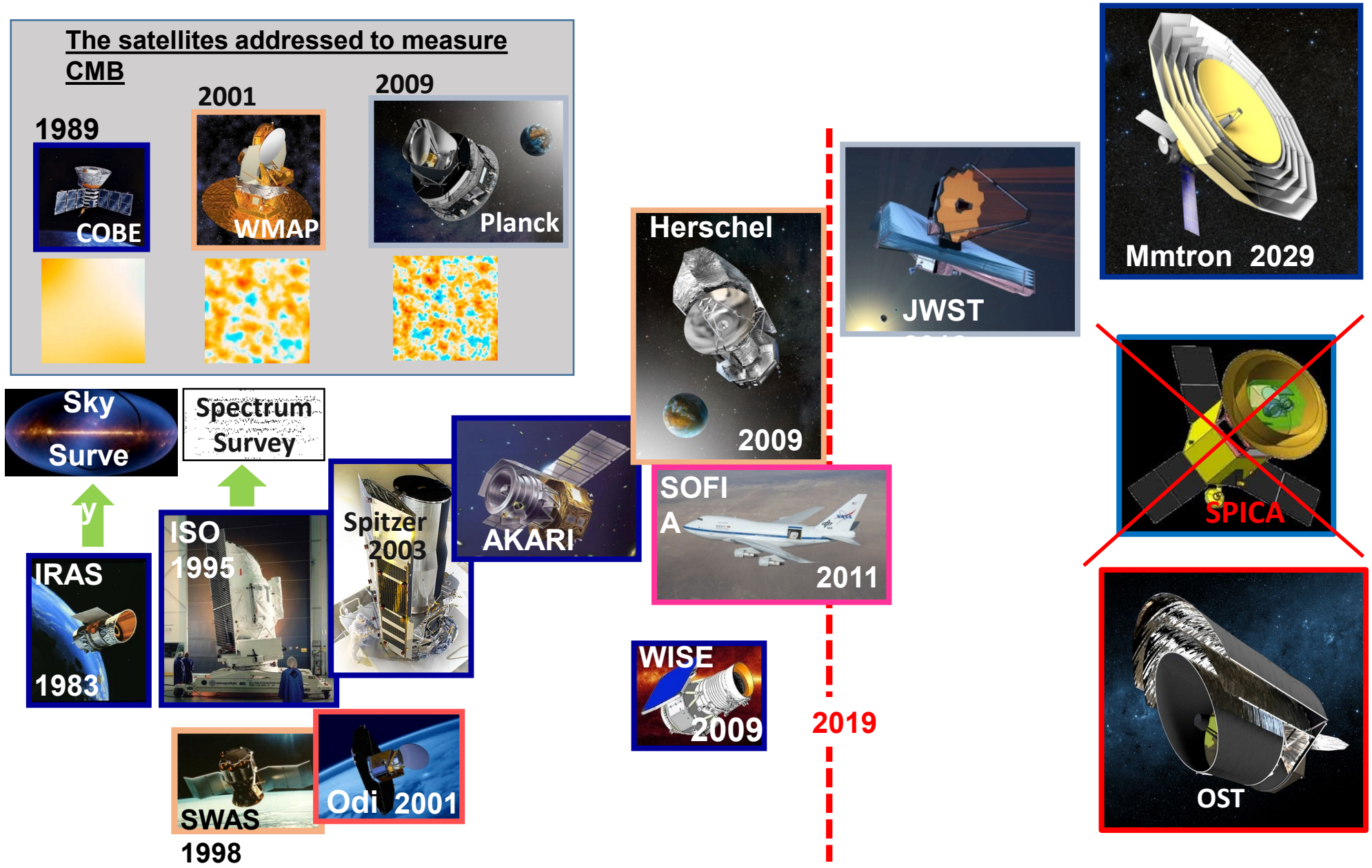
The idea of the “Millimetron” mission was expressed by **Nikolay S. Kardashev** in the mid 80s of the last century.

What is “Millimetron”?

- The “Millimetron” also called “Spektr-M”, is a large, space-based observatory, optimized for millimeter and infrared wavelengths from 0.05 to 7 mm. which will complement and extend the discoveries of the “Radioastron” mission.

- It will cover shorter wavelengths of light than “Radioastron” and will have **greatly improved angular resolution** (as a part of ground-space VLBI) and **sensitivity** (as a single telescope).

Evolution of the FIR/Submm/Mm Instruments for Space Science



The “Millimetron” Mission in one slide …

The first 10-m deployable and cooled space
sub-mm and FIR telescope.

The mission is approved and supported by Russian Space Agency

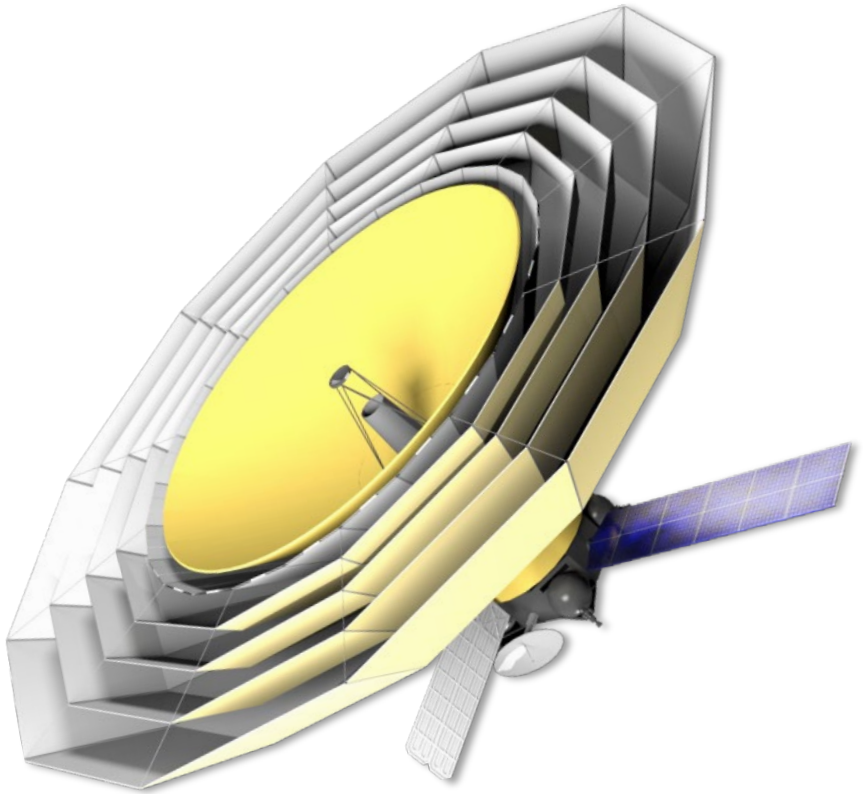
- FIR, sub-mm and mm range
- In orbit deployable and adjustable antenna
- Mechanically cooled (<10K) with post-cryo life
- Orbit around L2 Lagrange point
- Lifetime: 10 years; at cryo >3 years

Two operation modes:

Space-VLBI at 0.3 – 7 mm

Single dish at 0.08 – 3 mm

- Step forward with respect to earlier missions
- Sensitivity: 10^{-22} W/m^2 for spectroscopy and 0.5 μJy
- for photometry (single dish)



- **Spacecraft bus in Phase-A**
- **Scientific payload in Phase-B**
- **Launch date : 2029**

More information: http://millimetron.ru/

Energetic characteristics of “Angara-A5” LV family for departure orbit to L2 Langrangian point

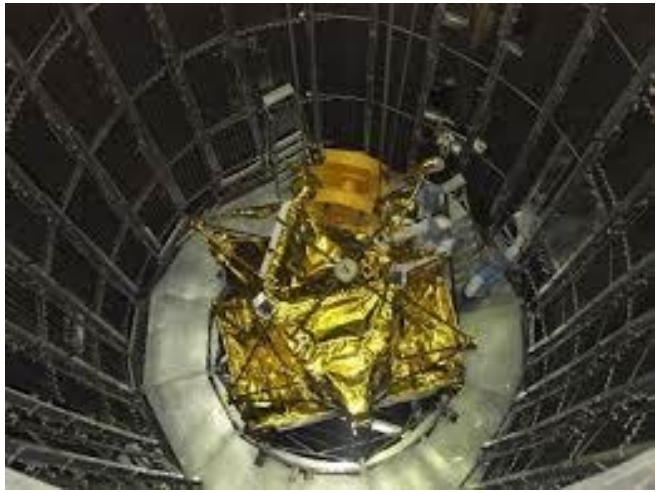
LV	Booster	Payload mass to L2, [tones]	Fairing diameter [m]	Year of flight tests start from “Vostochny” spacedrome
«Angara-A5»	DM-03 1 phase	6,55	4.35	2023
«Angara-A5»	DM-03 2 phase	7,2	4.35	
«Angara-A5M»	DM-03 1 phase	7,5	5.2	2024
«Angara-A5M»	DM-03 2 phase	8,1	5.2	
«Angara-A5M»	KVTK	9,35	5.2	2026
«Angara-A5B»	KVTK	14,4	5.2	2026-2027


Image © Ministry of defense, Russia

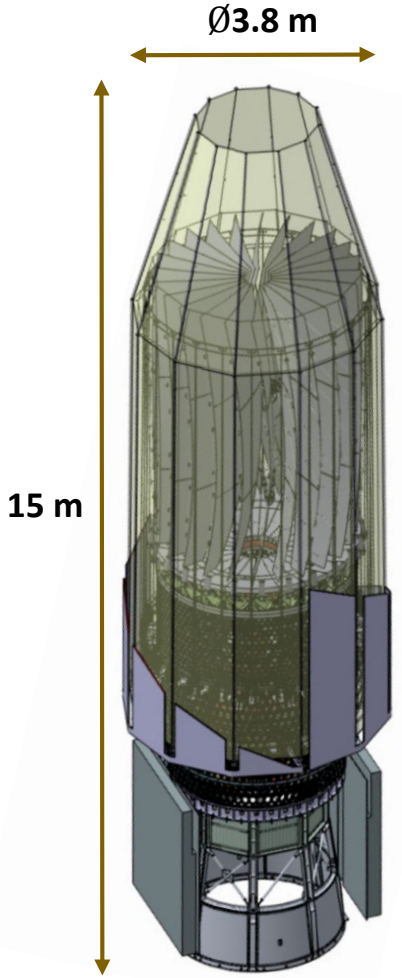
KVTK – new Russian heavy class booster that uses hydrogen and oxygen as fuel components

“Millimetron” Spacecraft “Navigator-M”

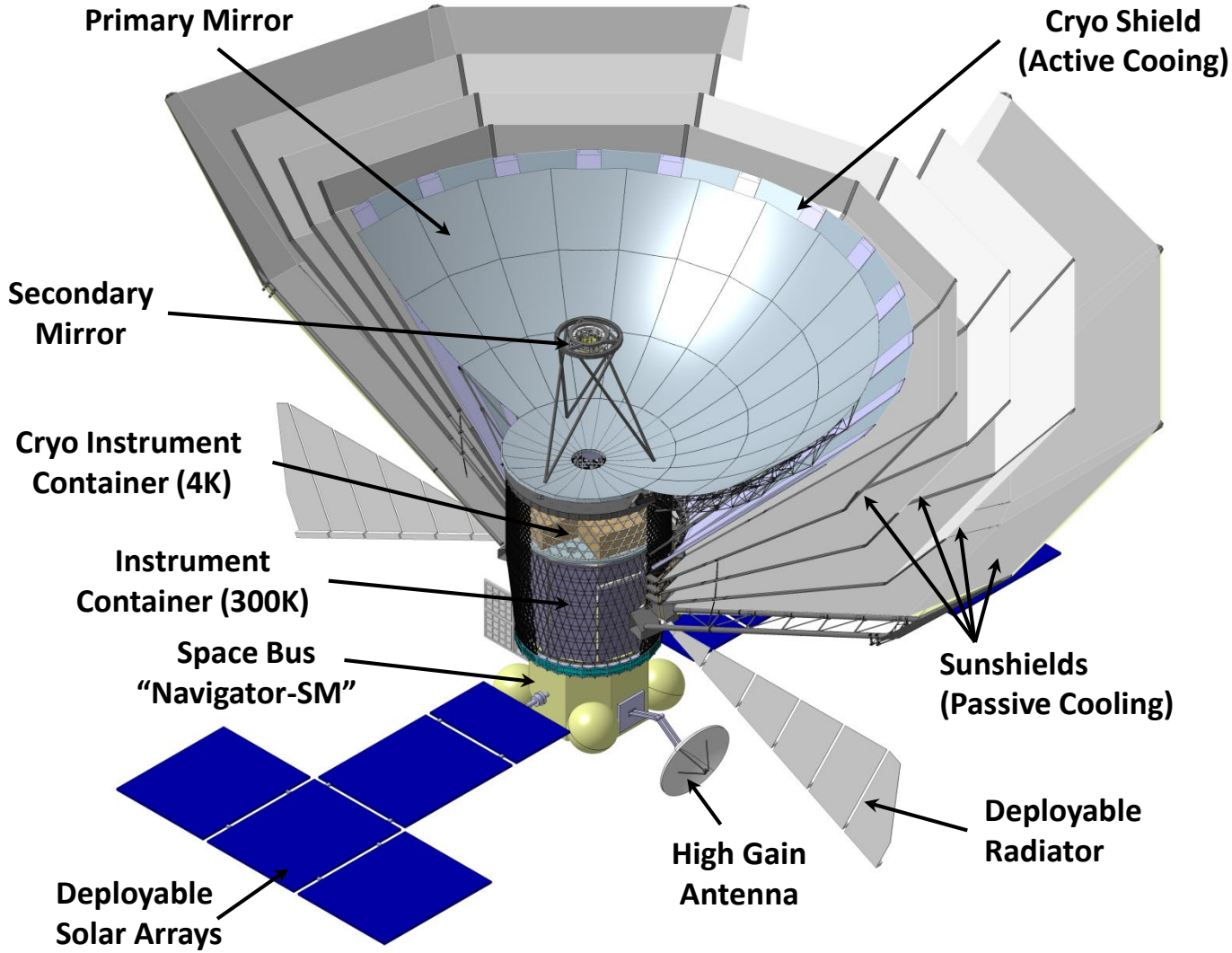
- The space platform is based on the “Navigator” spacecraft, which was used by Spektr-R (Radioastron) and Spektr-RG (SRG) with the modernization of basic systems (guidance systems, systems, stabilization, power supply systems, radio links).
- The modified space platform will be called “Navigator-M”.
- The beginning of the development – 2023. Lavochkin Association, Moscow.



“Millimetron” Mission Concept



Launch configuration



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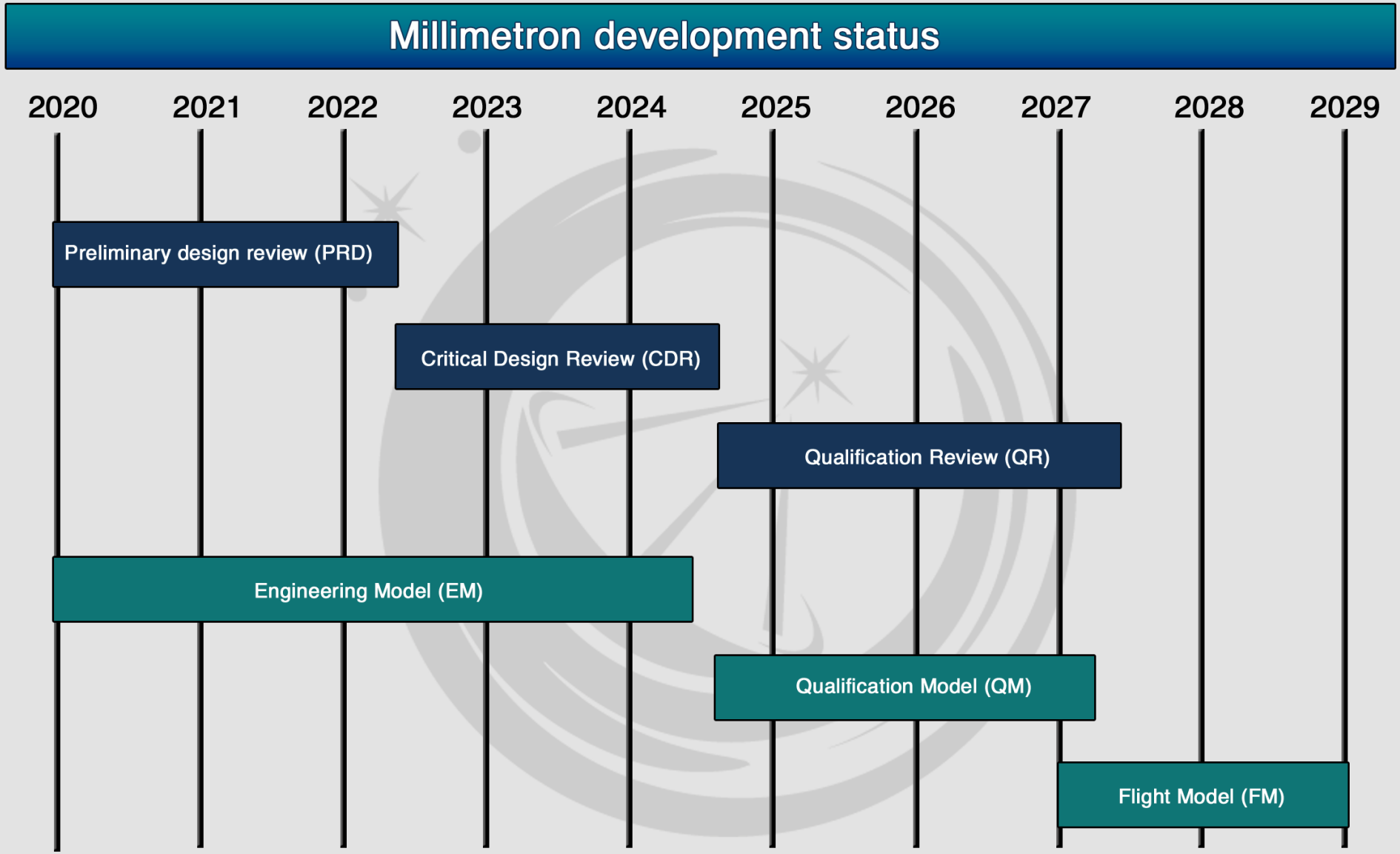
Mission Timeline



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“Millimetron” PI Institute

ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ УЧРЕЖДЕНИЕ НАУКИ
Физический институт имени П.Н.Лебедева РОССИЙСКОЙ АКАДЕМИИ НАУК
Ф И А Н

- The **Astro Space Centre** is a part of the oldest physical institute of Russian Federation – **P. N. Lebedev Physical Institute (LPI).**

- The **Astro Space Center (ASC)** *of P. N. Lebedev Physical of Russian Academy of Sciences* was **founded in 1990** for fundamental researches in astrophysics

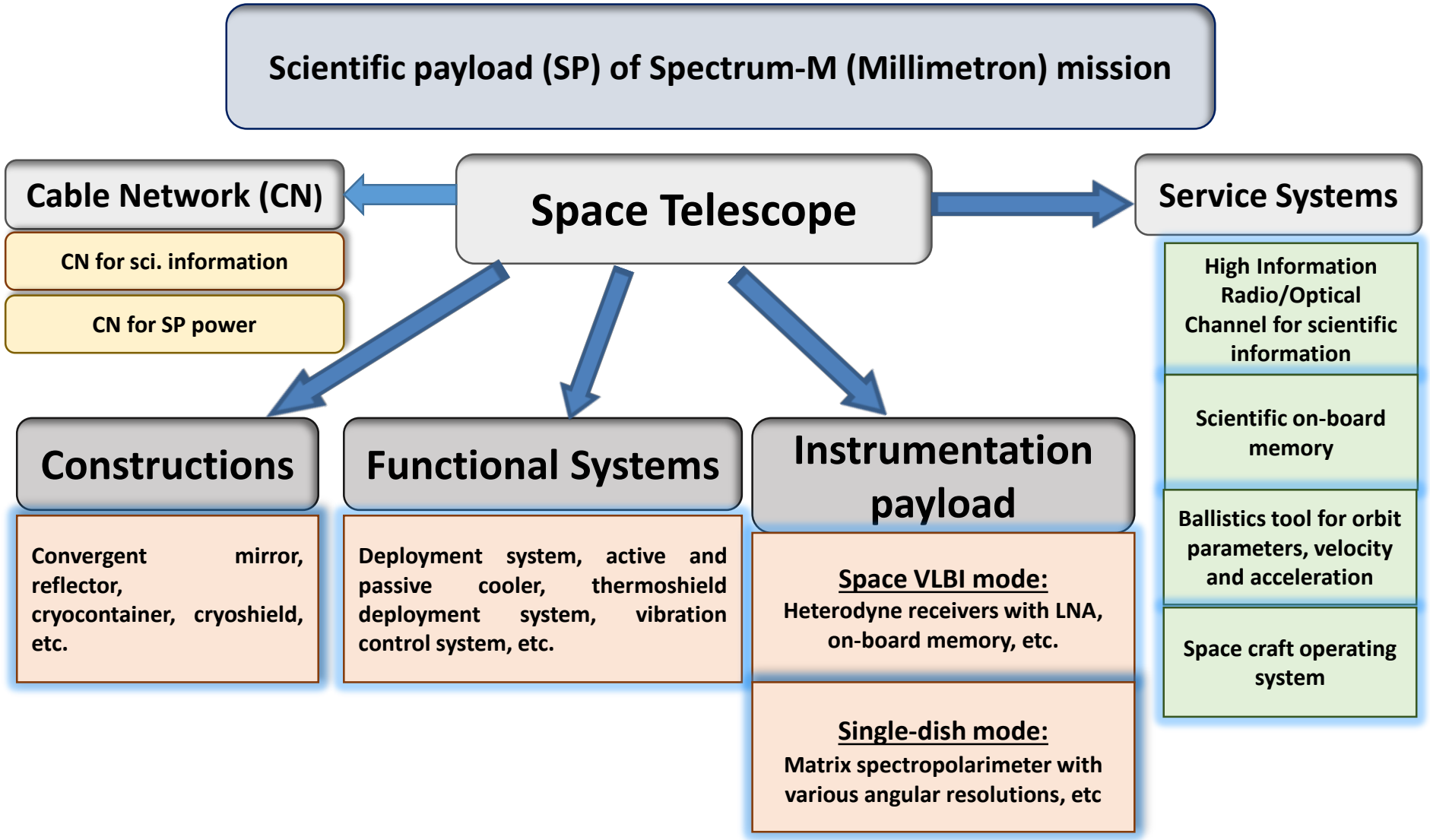
- Our primary goal is the space telescopes projects: **“Radioastron” (the mission was over in June 2019) and “Millimetron”.**

ASC and Millimetron Mission

Astro Space Centre of P. N. Lebedev Physical Institute of RAS is responsible for:

- Formulate and produce requirements specifications for co-executors.
- Execution phase control.
- Integrates on-board scientific units incoming from co-executors into the space scientific payload.

Work Breakdown Structure of Millimetron Mission



Place of Millimetron in the Russian Space Federal Program

- Roscosmos (Russian: Роскосмос), is a state corporation responsible for the wide range and types of space flights and cosmonautics programs for the Russian Federation.

- The **Federal Space Program (FSP)** of Russia developed by Roscosmos is approved by Russian Government and is **a state law of Russian Federation.**

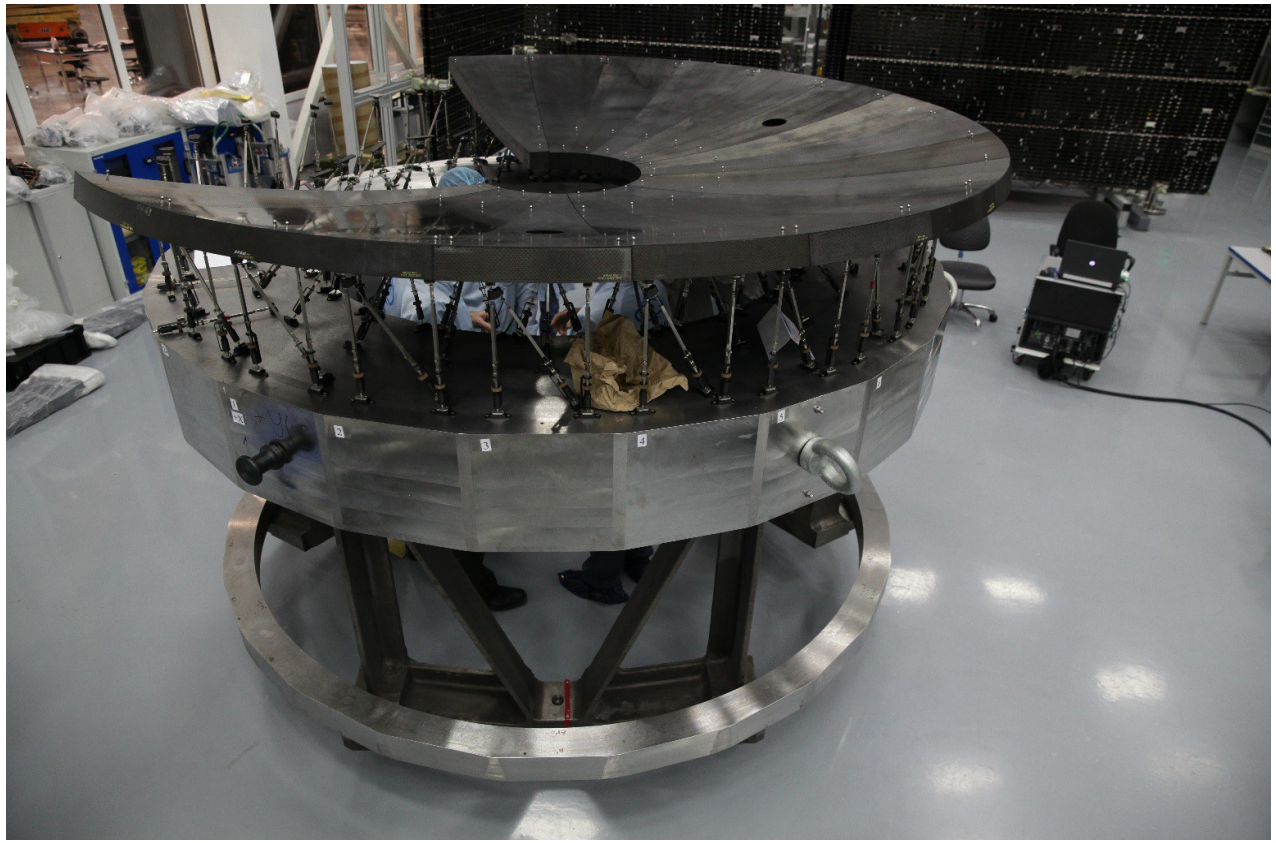
- “Millimetron” was included in FSP 2016-2025 and expected to be continued in FSP 2026-2035.

Place of “Millimetron” in the Russian Space Federal Program

According to FSP the state contract between Roscosmos and ASC was signed in 2016, and Roscosmos will pays all expenses for:

- **Antenna**
- **Cryo-container**
- **Space bus (Navigator-M)**
- **VLBI instruments**
- **Rocket/launch (Angara-5)**
- **Ground support and mission control**
- **Data center**

Antenna Mock-Up (ISS-Reshetnev, Russia)



Preliminary Science Payload of “Millimetron”

1) **S**pace-**VLBI** receivers (**S-VLBI**): **0.3 - 7 mm**

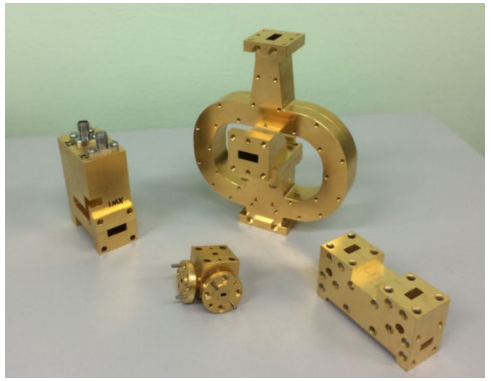
2) **M**mtron **H**eterodyne **I**nstrument
for the **F**ar-**I**nfrared (**MHIFI): 60 - 600 µm**

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**



Modes of the “Millimetron” mission

- **VLBI mode** – investigation of late Universe (10…20% of total observational time). L2 and near-Earth high elliptical orbit (TBC)
- **Single –dish mode** -- investigation of early Universe (80—90% of total observational time).

Millimetron Science Program

- **Millimetron has some unique characteristics**
  - **Largest cooled antenna in space for the next 2-3 decades**
  - **Mission with two operating modes: Space-Earth VLBI and Single dish**
  - **Millimetron will have heterodyne receivers; This is unique capability!**
    Not in any other FIR mission under study, particular important for galactic ISM and CSM studies

- **Millimetron mission science program will focus on**
  - Few, very important well-defined **key (breakthrough) science cases**
    that drive **the instrument concept** selection
  - However, proposals with highly ranked science are accepted as in an open observatory
  - Organized science working groups are preparing key science cases

- **Selection of science programs** and associated instrument concepts are constrained and based on…:
  - Science heavily influenced by results from Herschel, Spitzer, ALMA (incl. EHT) and JWST, now and to come, eventually by SPICA (not OST), SPACEx and ELT/GMT/TMT, etc..
  - Feasibility in budget and programmatics

More information: http://millimetron.ru/

Millimetron Science Working Groups

Millimetron will have six main scientific directions with ***breakthrough scientific tasks of Nobel prize level***. Science working groups were organized in 2019 to prepare corresponding scientific cases for both observational modes of the observatory:

1. **Relativistic Astrophysics and S-E VLBI**
2. **Cosmology**
3. **Compact Heavily Obscured Galaxy Nuclei**
4. **The Water Trail**
5. **Filaments and magnetic fields on various scales**
6. **Solar System**

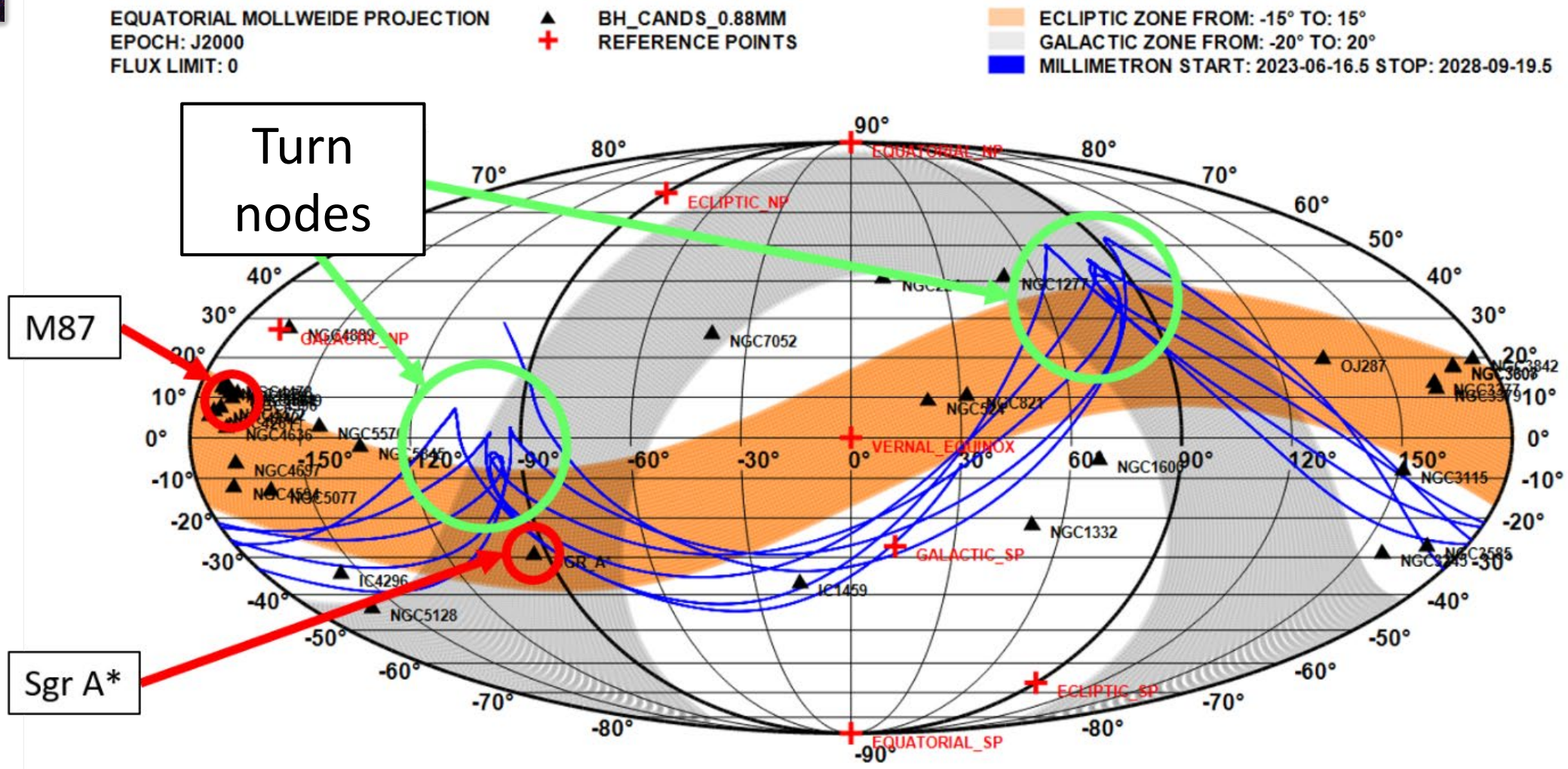
More information: http://millimetron.ru/

VLBI Mode
(Late Universe Investigations)

1. Search for wormholes in the centers of galaxies (properties of the magnetic field, outflow of matter, observation through wormholes). The goal is to confirm the theory of the multiverse

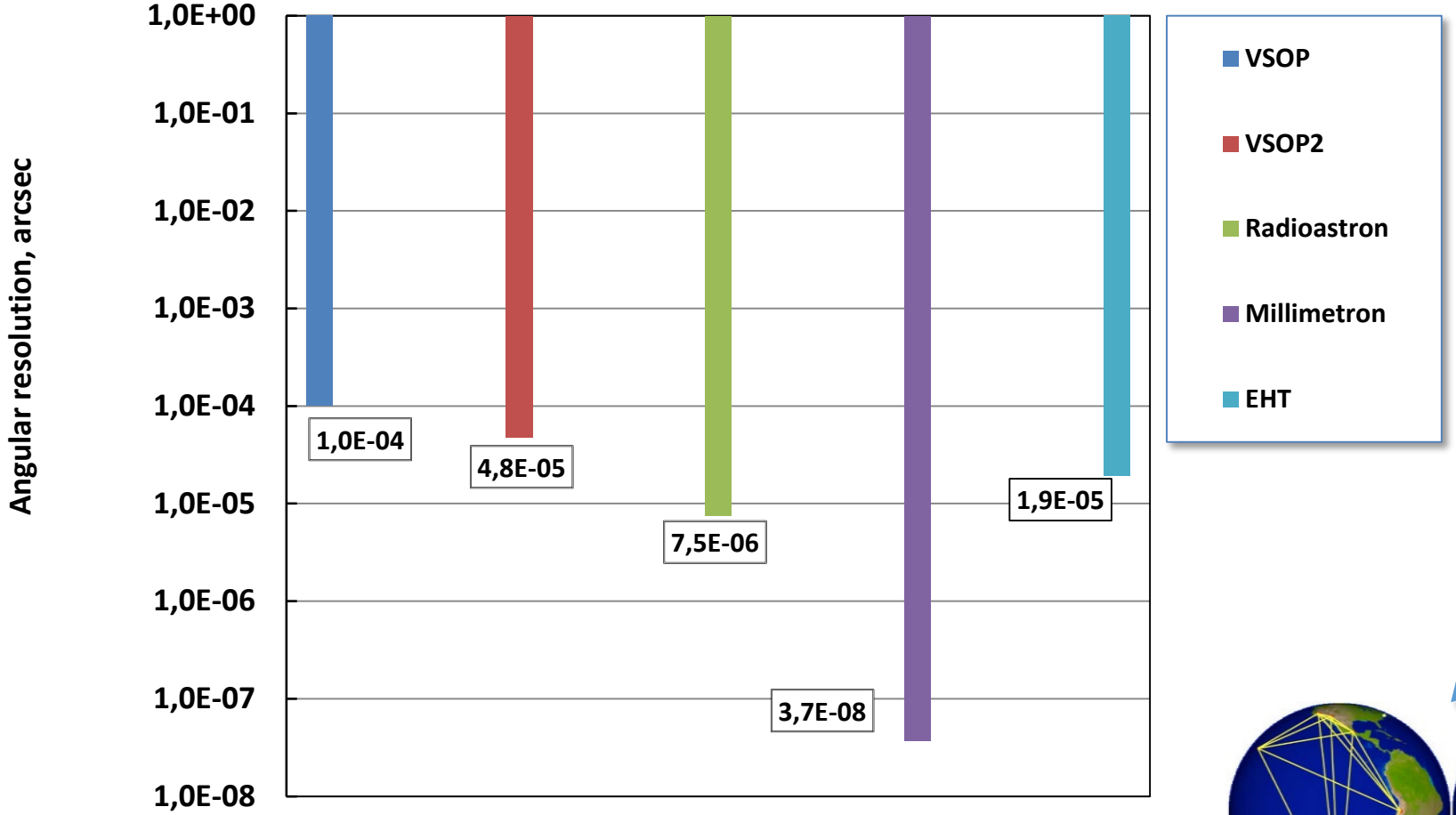
2. Determination of the structure of space and time in the vicinity of supermassive black holes in the centers of galaxies. The goal is reliable direct observation of black holes, determination of their parameters and obtaining images of shadows, verification of the general theory of relativity.

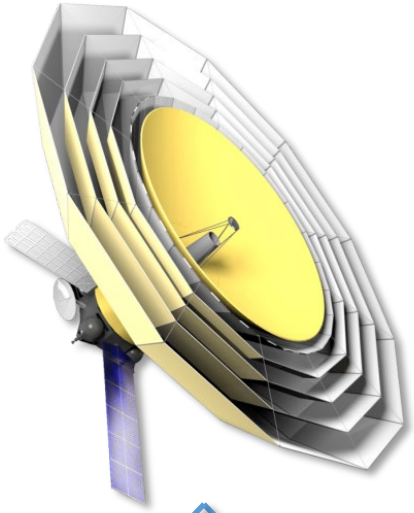
Millimetron VLBI Science



The geocentric equatorial Molweide projection and the track of Millimetron observatory for 5 years. The blue curve is the Millimetron track. The orange bar is an ecliptic region of ± 15 °. The gray bar is the ± 20 ° region at the Galactic equator. Black triangles correspond to the sources. Turn nodes - the moment of the passage of Millimetron of the upper (north) pole of the halo orbit when the speed along the Z axis changes its sign.

Angular Resolution



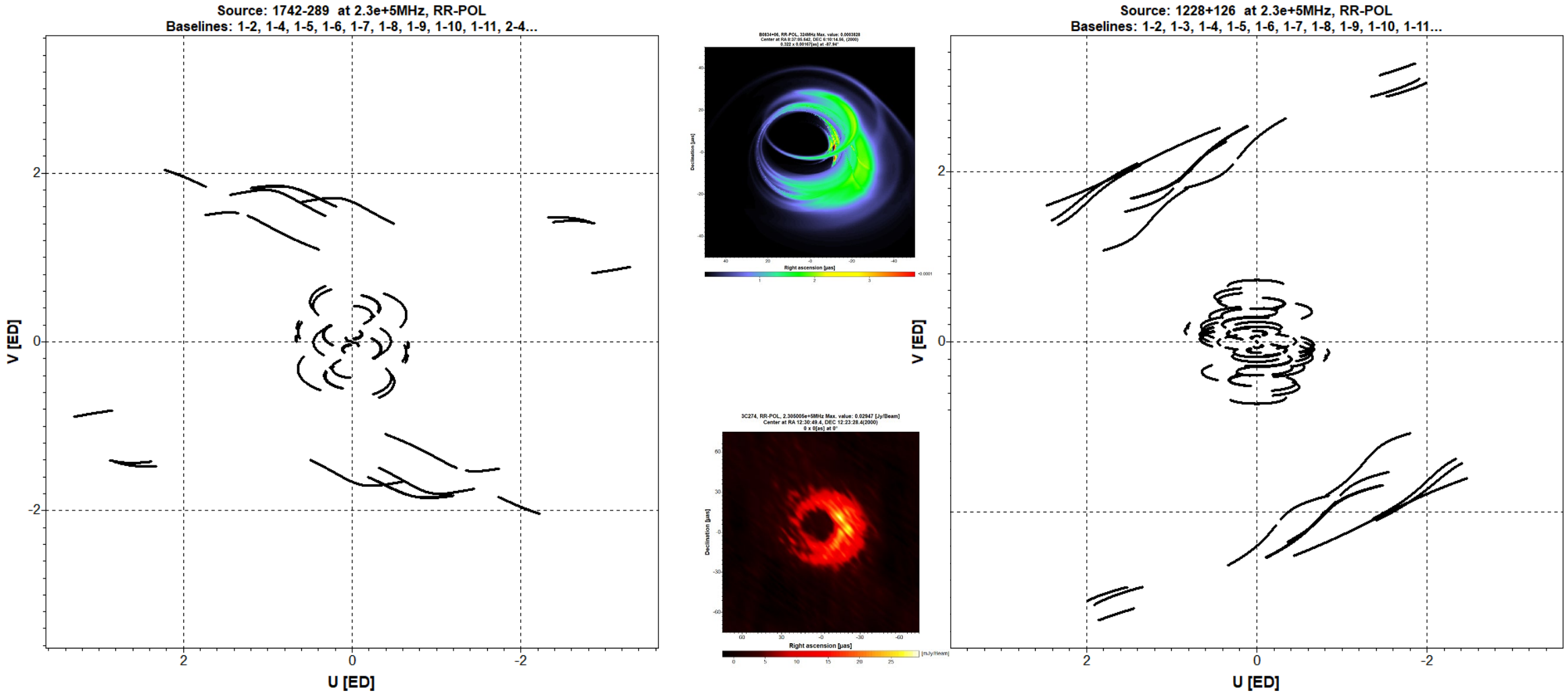


Global mm-VLBI

ALMA

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).

VLBI Simulations (MM+EHT)
L2 Orbit: (u,v) coverage



(u,v) coverage for Sgr A* (left) and M87 (right)

VLBI Ground Support:

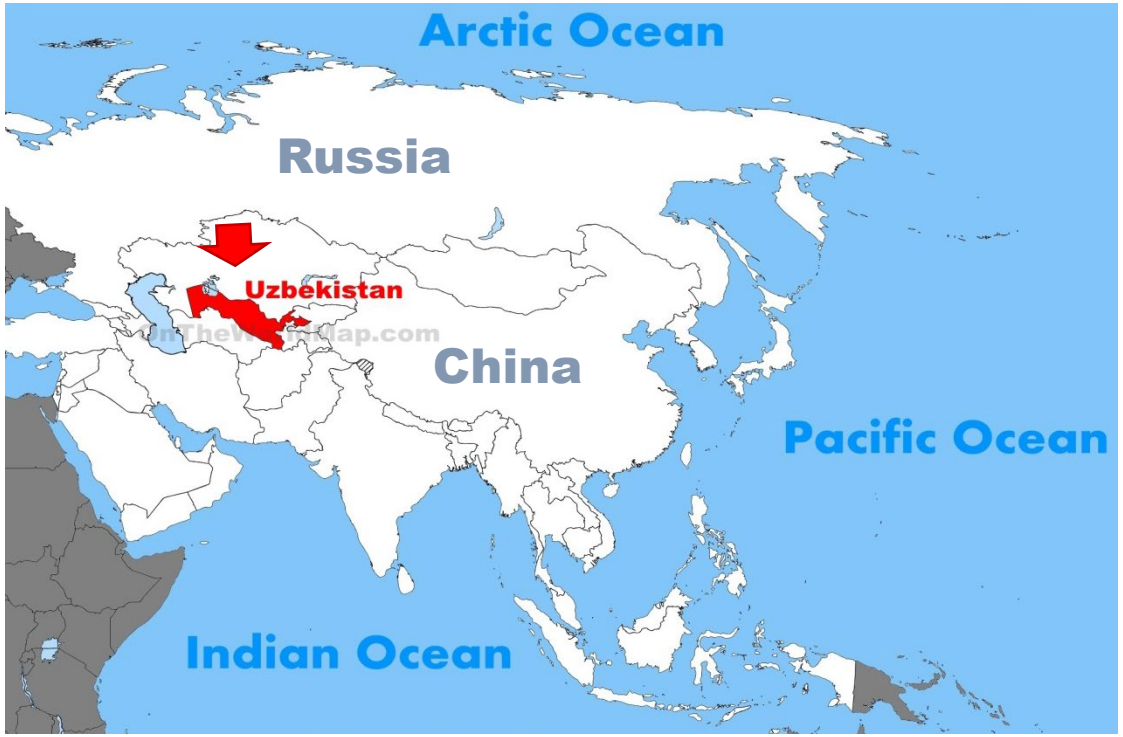
Suffa Radio Telescope

Antenna development on Suffa plateau in Uzbekistan:

- 70-meter antenna operating at wavelengths down to 0.8 mm

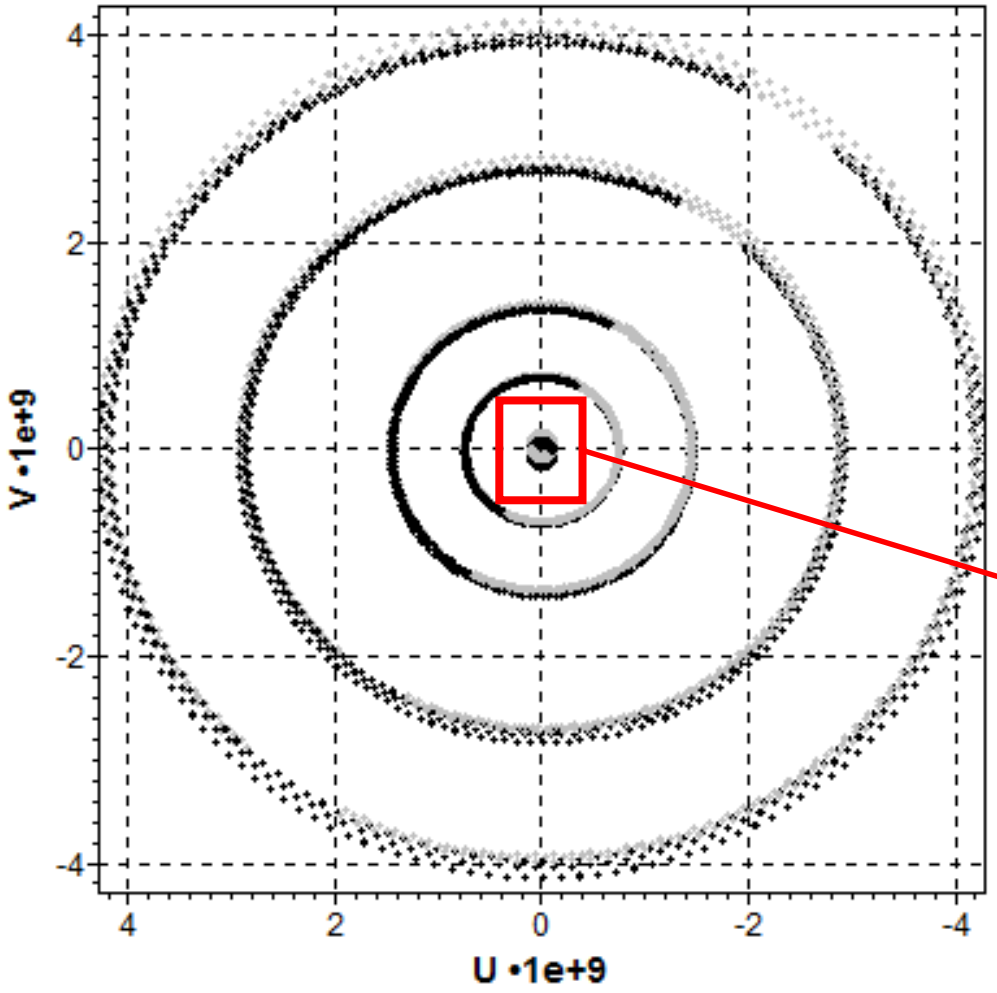
But before:

- A 12-20 meter 0.8 mm antenna with receivers and equipment for bands ALMA 2-3, 6, 7 and equipment for VLBI observations capable of multi-frequency observations



VLBI Ground Support:

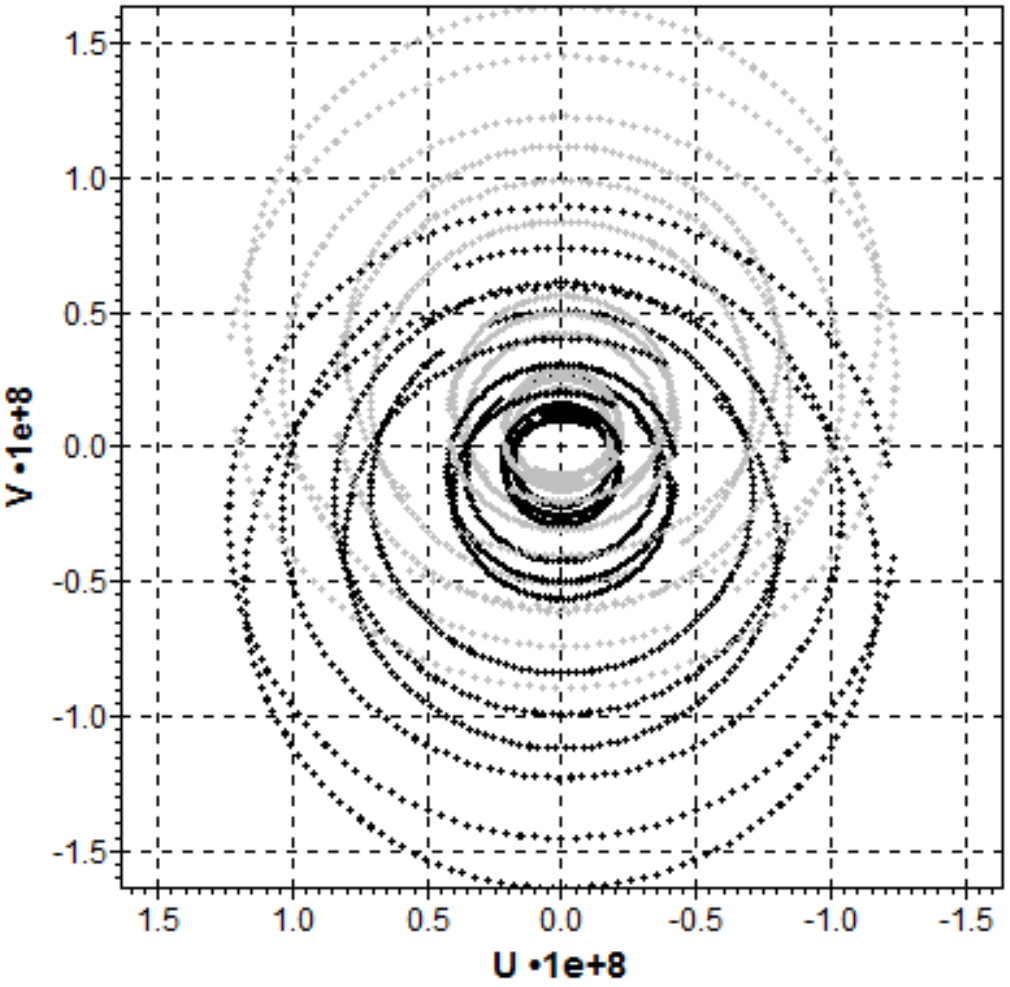
Suffa Radio Telescope



Example of VLBI observations simulation:

Source: 0716+714, MFS

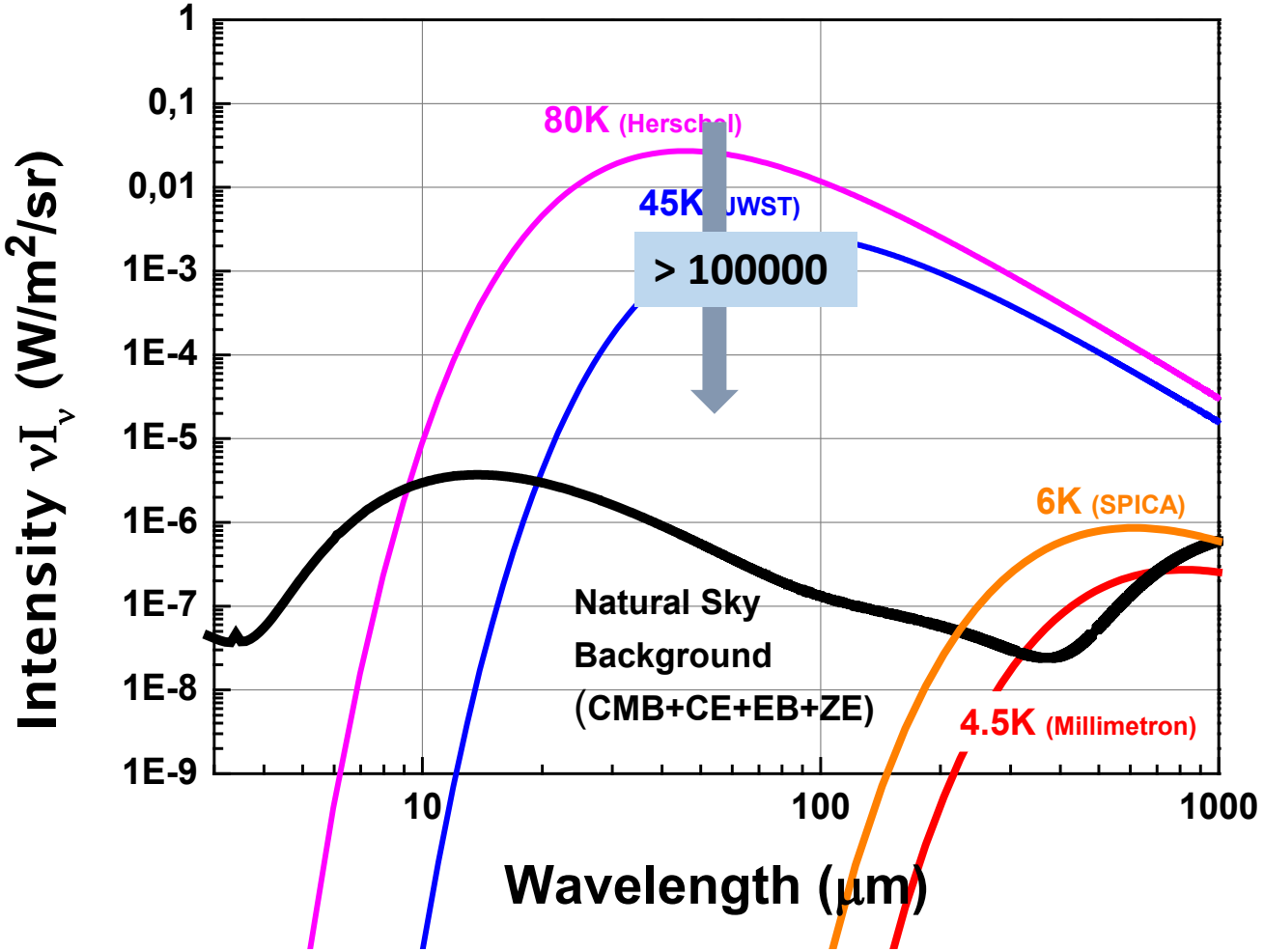
Suffa + KVN antennas, 24 hour session



Single Dish Mode
(Early Universe Investigation)

I. The origin of life
II. Limitations on modern cosmological scenarios
III. Other directions
    A. Studying the structures of galactic clusters
    B. Search for hidden matter in intergalactic space
    C. Star and planet formation processes
    D. Evolution of the stars

A cooled antenna can provide 100 times more sensitivity



The intensity of the thermal self-emitted radiation falls below the limit provided by the natural sky background if the telescope is cooled to temperature < 10K

Background limited < 300 μm if $T_{tel} \approx 4.5$ K

Importance of International Cooperation

- Ambitious and exciting scientific objectives “Millimetron” mission needs the best on-board scientific payload in the world.
- Complexity of “Millimetron” mission. Astro Space Centre won’t be able to provide whole volume of the necessary scientific payload.
- Timely development and testing of onboard scientific equipment will ensure the reliability of the space mission and avoid a shift in the launch date of the mission.
- Therefore, international collaboration is necessary for the space mission of such scale. Interferometry requires collaboration with other stations as well.

International Cooperation

International agreements so far:

Millimetron is included into Russia-China Program on Cooperation in Space 2018-2022

Inter-agency agreement with Italian Space Agency (ASI) on LACS

In preparation: Inter-agency agreements with South Korea (KASI), China (CNSA), France (CNES)

On instrumentation development:

MoU with Onsala observatory (Sweden, Chalmers University)

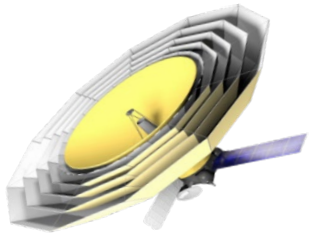
MoU with Observatoire de Paris (LERMA, France)

MoU with Purple Mountain Observatory (PMO, KLRA, China)

MoU with KASI (South Korea)

The uniqueness of scientific tasks dictates the uniqueness of devices!

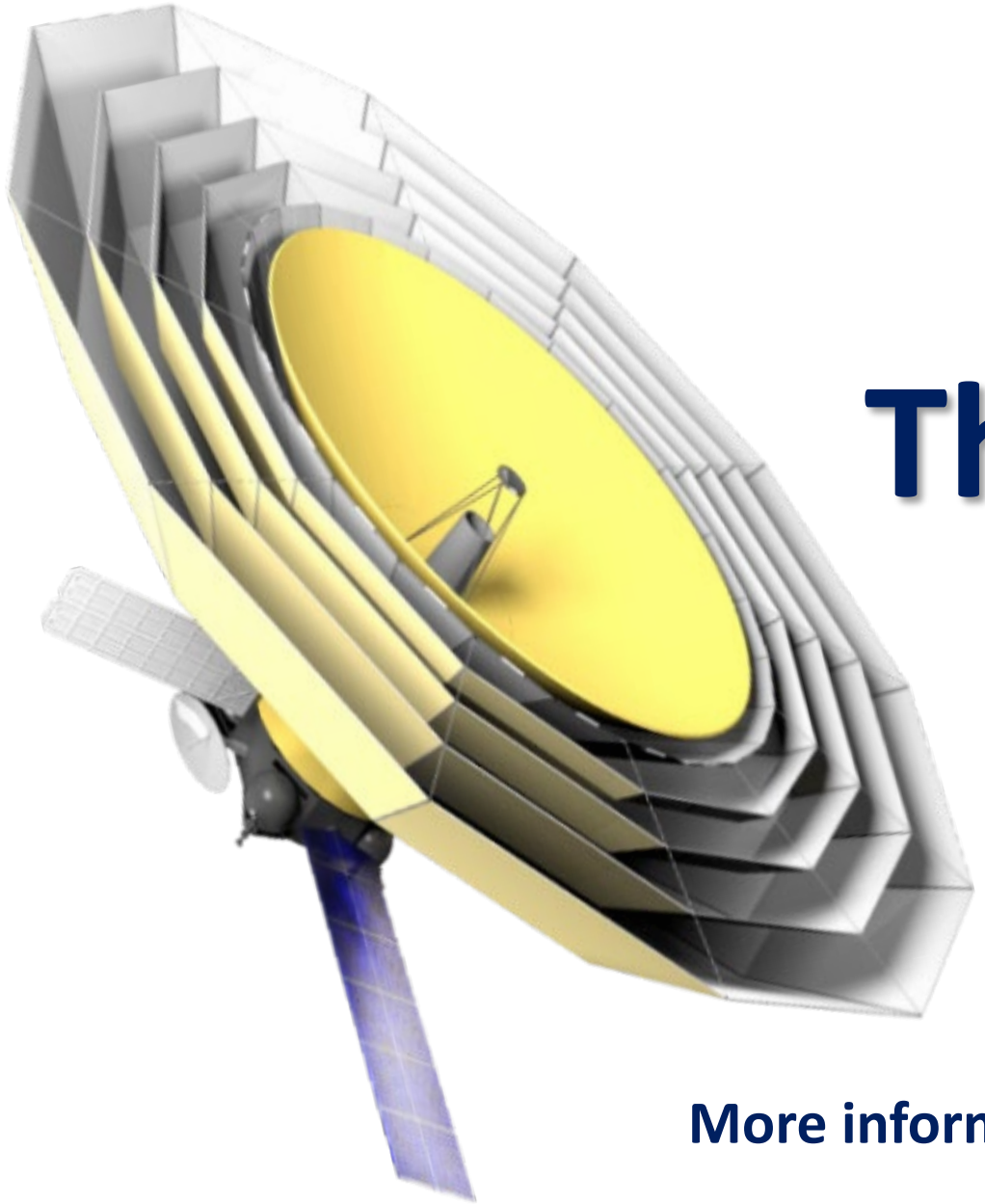
Summary



- **“Millimetron”** is the next step of space based astronomy. As a single dish and space-ground VLBI observatory in mm, sub-mm and FIR it will provide ***unprecedented sensitivity*** and the ***highest*** angular resolution.

- The project is ***fully supported*** by Russian Space Agency and included in Russian Federal Space Program.

- The capabilities of **“Millimetron”** mission will bring the astrophysical research to a new level and perform the revolutionary discoveries in the study of the Universe.



Thank you!

More information: http://millimetron.ru/

ROSCOSMOS ASC LPI