# "Millimetron" Project

# Space-VLBI Capabilities Overview


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## Main mission parameters

- **Approved mission** of Russian Space Agency
- **Led by** Astro Space Center, P.I.: N. Kardashev (Radioastron)
- **Launch date:** ~2025
- **Life time:** 10 years (3 years of active cooling)
- **Orbit** – Lagrange L2 point, ~185 days period, inclination ±23.5°
- **Antenna:**
  - Ø10m deployable, adjustable surface, λ > 50 µm
  - Ø3m solid central part
- **Cooling: Passive cooling and Active cooling** (Mechanical coolers, with 20K, 4K, 2K)
- **In Russia development:**
  - Launcher: Proton-M / Angara
  - Satellite bus: Navigator-M
- **Two observing modes:** ***Space-VLBI element*** and ***Single-dish***
- **Instruments** to be contributed by international consortia
  - Heterodyne arrays HIFI (500GHz—6 THz)
  - Imaging grating polari-spectrometer (50 -350 µm)
  - Imaging FTS polari-spectrometer (0. 3 – 3mm)
  - S-VLBI channels (22, 40, 90, 250, 340 GHz)

## Key science cases in SVLBI mode

**1. Space structure and physics near the black holes horizon, cosmic ray accelerators.**

Black holes silhouettes
Radioactively-inefficient (weak) accretion flows
Jets physics
Binary systems with stellar mass black holes and micro-quasars

**2. Rapid events:**
**(The structure and physics of powerful explosions and their orientation, pulsars with flat spectra)**

Determination of the asymmetry of supernova bursts
Search for afterglows of gamma -ray bursts and determination of their energy
Observation of the pulsar light cylinder

**3. The formation and evolution of galaxies, stars and planetary systems.**

Structure of millimeter masers

## Millimetron Sensitivity (SVLBI Mode)

### Millimetron-ALMA

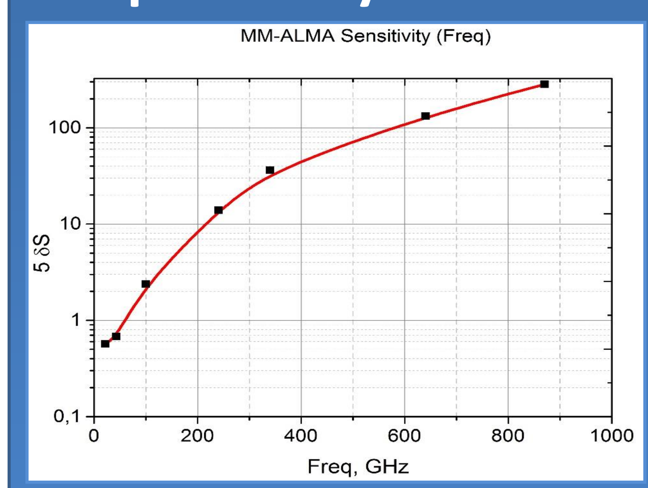
| Freq, [GHz] | SEFD ALMA, [Jy] | SEFD MM, [Jy] | SEFD MM-ALMA, [Jy] | τ, [sec] | 5δS, [mJy] |
|---|---|---|---|---|---|
| 43 | 16 | 1190 | 137,99 | 250 | 0,683 |
| 100 | 49 | 2290 | 334,98 | 120 | 2,393 |
| 240 | 73 | 6490 | 688,31 | 15 | 13,909 |
| 340 | 164 | 12990 | 1459,58 | 10 | 36,123 |
| 640 | 810 | 17570 | 3772,49 | 5 | 132,037 |
| 870 | 1640 | 23740 | 6239,68 | 3 | 281,939 |

* Estimated sensitivities for MM-ALMA at frequencies from 340 up to 870 GHz are presented as prospective values. During estimation ALMA water vapor receivers information taken into account.

### Millimetron-GBT, 22 GHz, Band 18-27.5 GHz

| Freq, [GHz] | SEFD GBT, [Jy] | SEFD MM, [Jy] | SEFD MM-GBT, [Jy] | τ, [sec] | 5δS, [mJy] |
|---|---|---|---|---|---|
| 22 | 15 | 1050 | 125 | 300 | 0.55 |

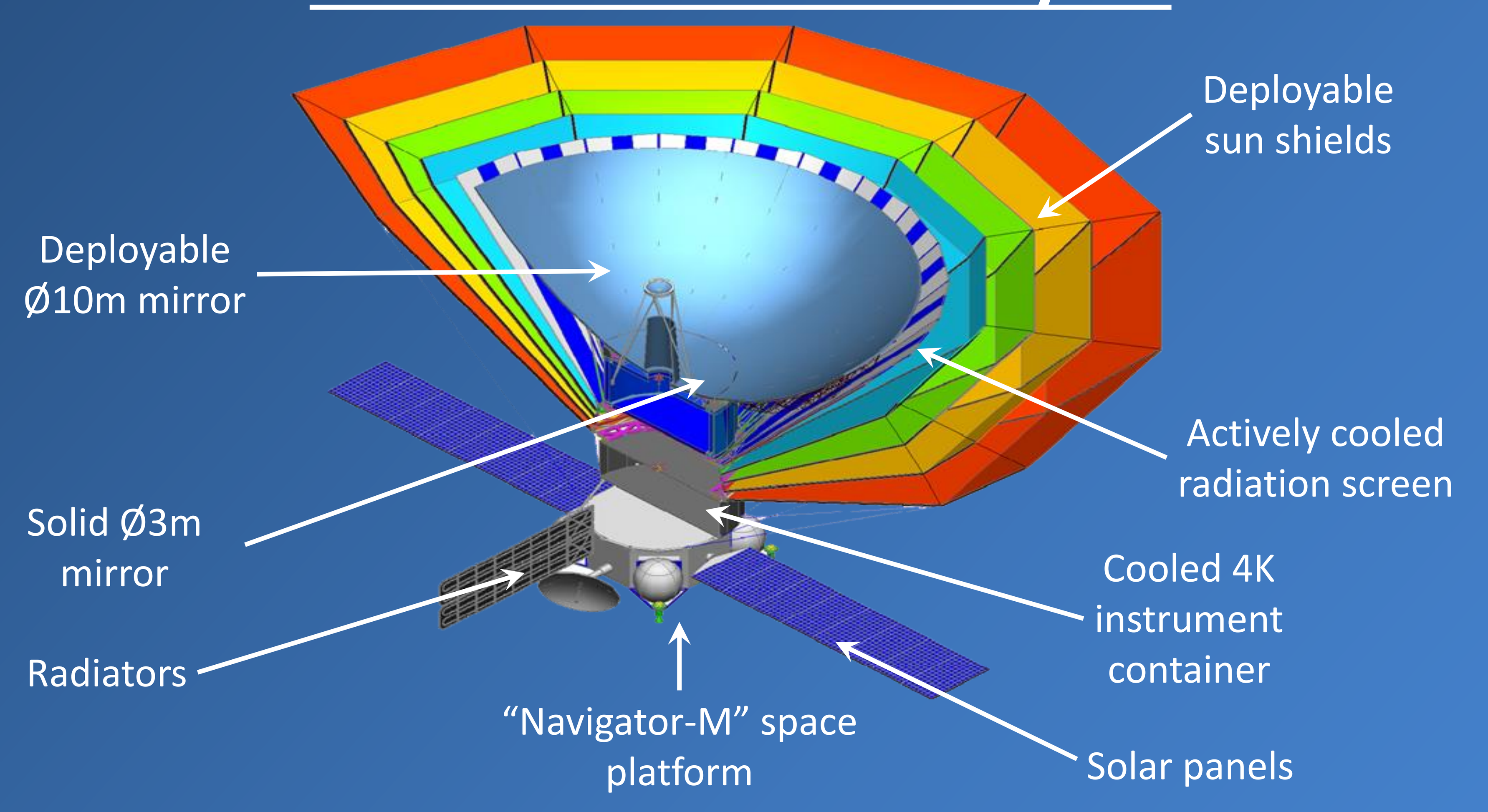
### Dependency of sensitivity from frequency for Millimetron-ALMA




$SNR = S_{source} / 5\delta S$
**5δS** – minimal detectable flux at a given frequency

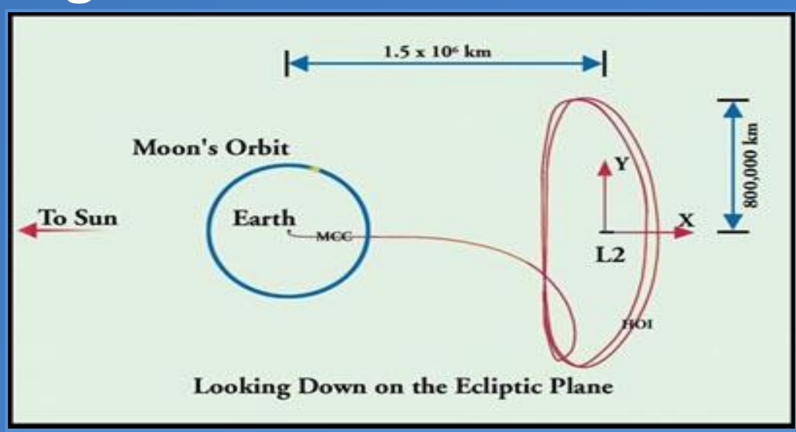
Orbit configuration together with high sensitivity will provide an unprecedented high angular resolution in the SVLBI mode. Up to **$10^{-8}$ arc seconds** operating together with ALMA or EHT.

## Millimetron satellite layout



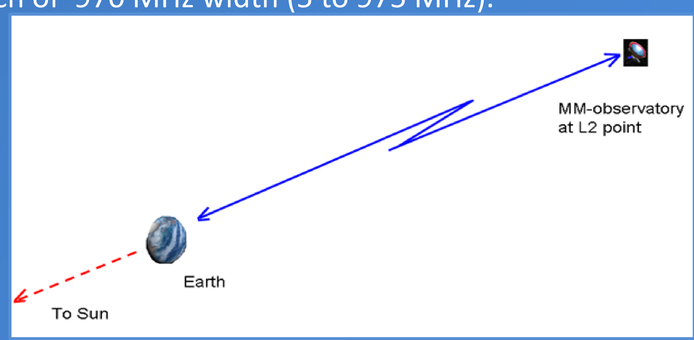

### Millimetron orbit configuration

- Space Telescope will be located at L2 Lagrange Point.
- **Orbit period** – ~185 days.
- **Baseline** – 1 500 000 km, max.
- Millimetron antenna view angle opening is +/- 75 deg. in ecliptic latitude and longitude.




### Signal Communication Channel

- In *receive* mode there are four bands: USB , LSB in LHC and RHC polarizations, each of 970 MHz width (5 to 975 MHz).
- Sampling frequencies - not less than 2 GHz.
- The signals are quantized in amplitude by 1 or 2-bit coding method (corresponds to 2 or 4 levels).
- On-board memory data write rate - 16 Gbit/sec (for 2-bit quantization).
- On-board memory size of 10 TB (write duration amounts to about 1 hour 23 minutes of observing time).
- RF data channel 15GHz communication band carrier.

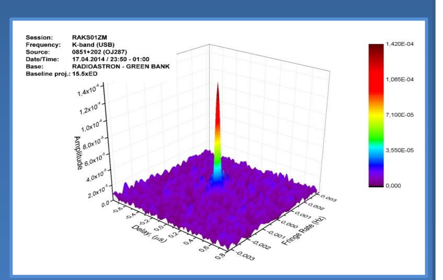



- In "Millimetron" project it is proposed to use the well-known technology of orthogonal frequency multiplex mode (OFDM-**O**rthogonal **F**requency **D**ivide **M**ultiply)
- Data rate **1.2 Gbit/s** (standard mode) and **2.25 Gbit/s** (high speed OFDM): 18 hours to download 10TB without OFDM, 9-10 hours to download 10TB using high speed OFDM.

## Millimetron SVLBI Frequency Bands

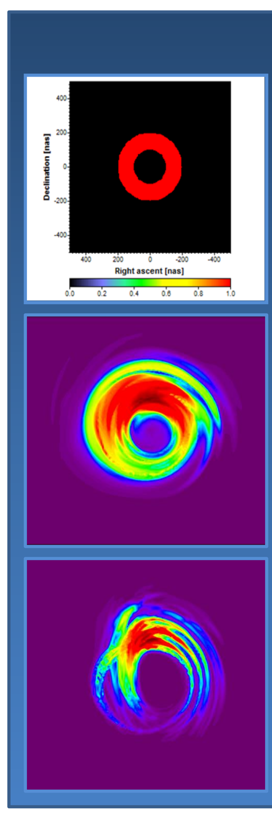
| Band | Frequency, [GHz] | Instantaneous bandwidth, [GHz] | Polarization | $T_{noise}$ [K] | Comments |
|---|---|---|---|---|---|
| 1 | 18 – 26 | 4 (max) | H V | < 10 | Post cryo capable |
| 2 | 33 – 50 ALMA Band 1 | 4 (max) | H V | < 17 | Post cryo capable |
| 3 | 84 – 116 ALMA Band 3 | 4 (max) | H V | < 37 | Post cryo capable |
| 4 | 211 – 275 ALMA Band 6 | 4 (max) | H V | < 90 | Dedicated SIS receiver |

- SVLBI mode will be designed to be compatible with modern ground VLBI facilities such as ALMA and EHT.
- Three frequency bands are capable of observing in post cryo mode.
- Capability of multi-frequency observations
- Lowest frequency band (22 GHz) is compatible with all global VLBI ground facilities.
- According to the results, obtained by Radioastron mission at 22 GHz, it is expected to have guaranteed result at 22 GHz with Millimetron VLBI.
- Simultaneous observations at 22 GHz together with higher frequencies will provide additional capability of orbit determination accuracy improvement.

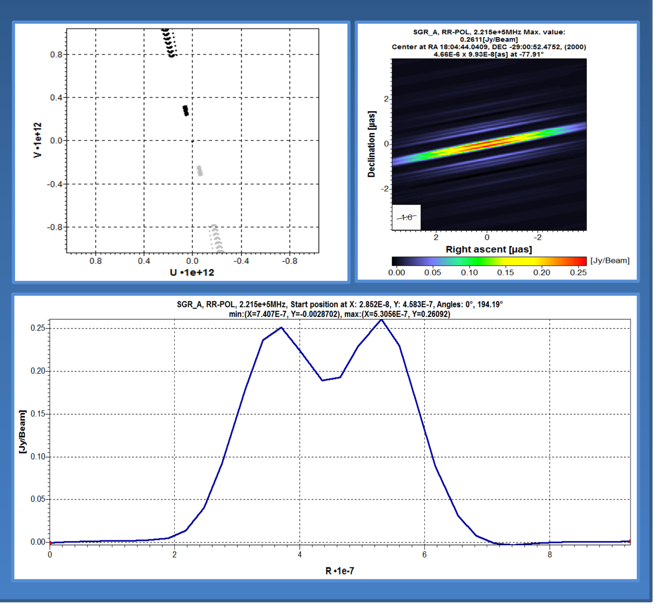


Detected fringe, baseline Radioastron-GBT, 22 Ghz. Record baseline projection - 15.5 Earth diameters. (Source: 0851+202)

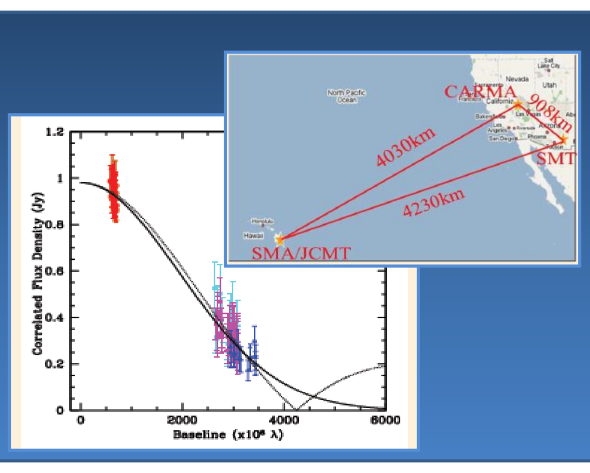
## Multi-frequency Observations with Millimetron



- Millimetron will be able to observe at several frequencies simultaneously.
- Multi-frequency observations (MFS) can improve UV-coverage within one observing session.
- Simulations of MFS VLBI observations were done for simple model of SMBH visibility distribution. (Showed the possibility to obtain instant 2D profiles of SMBH).
- New simulations to be done for better SMBH visibility distribution model provided by (Jason Dexter et al.).



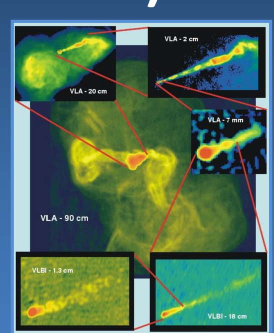
## Millimetron comparison with 1.3 mm (230 GHz) EHT results of SMBH in M87



Results of **"S. Doeleman et al., EHTP (Event Horizon Telescope Project) group, February, 2013. SMBH in M87 at 1.3 mm"** shows that
At 230 GHz (1.3 mm) $R_{sch} \rightarrow$ 7.3 µas, M = $3 \cdot 10^9 \cdot M_{\odot}$

**Expected Values:**
**$4.5 \cdot R_{sch}$ = 17 µas**, max spin mode
**$7.4 \cdot R_{sch}$ = 27 µas**, max Lansing mode, 0 spin

Visibility spectrum of 2-component model gives **0.05** to **0.20** Jy correlation amplitude at baselines $6 \cdot 10^9$ to $8 \cdot 10^9$ D/λ



M87 Radio Montage Image courtesy of AO/AUI and F. Owen, J. Biretta & J. Eilek

Consequently for **"Millimetron– ALMA"** and with 4 GHz bandwidth at baseline projection of approximately 9000 km (~1 Earth diameter) it gives:
**0.05** Jy to **0.20** Jy as $25 \cdot \delta S_{corr}$ to $100 \cdot \delta S_{corr}$

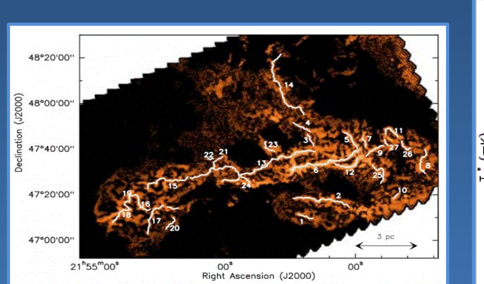
| F (GHz) | Tau (sec) | $S_{corr} / \delta S_{corr}$ |
|---|---|---|
| 230 | 70 | 25-100 |
| 230 | 10 | 10-38 |

**This is an exciting and promising source for Earth-Space MM VLBI!**

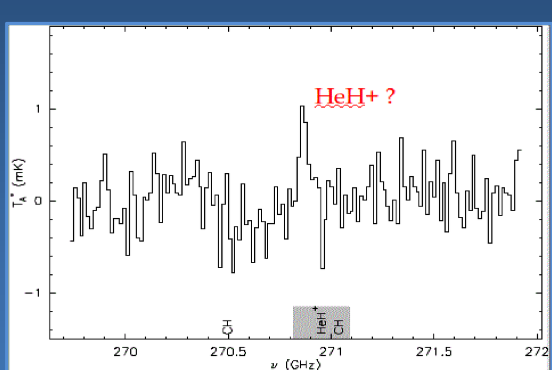
## Millimetron Single-dish Mode

Millimetron space observatory will also operate in single dish mode. Operational high sensitivities and spectral resolution provide capabilities for the following key science cases for single-dish mode:

- **The formation and evolution of galaxies, stars and planetary systems.**
  (Hidden hydrogen, filaments, photometry and spectroscopic observations, search for water, etc.)
- **Physics and evolution of solid objects in the Solar system, our own and other galaxies, the manifestations of life and mind.**
  (Dust in nearby galaxies and in star-forming regions, sub-mm observations of asteroids and comets, etc.)
- **The formation and evolution of supermassive black holes, dark matter and dark energy.**
  (Sunyaev-Zeldovich effect, small-scale anisotropy of CMB, sub-mm AGN, jets, lensing, etc.)
- **The first objects in the Universe, the first stars and galaxies, primordial black holes, wormholes and Multiverse.**
  (Spectroscopy of the most distant galaxies, GRB afterglows and their energy, etc.)



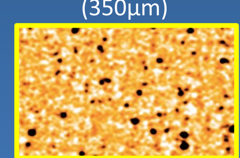
27 filaments in which the star formation currently occurs in the IC 5146 cloud, based on the images taken by Herschel space observatory. Source: D. Arzoumanian et al., A&A 529, L6 (2011)



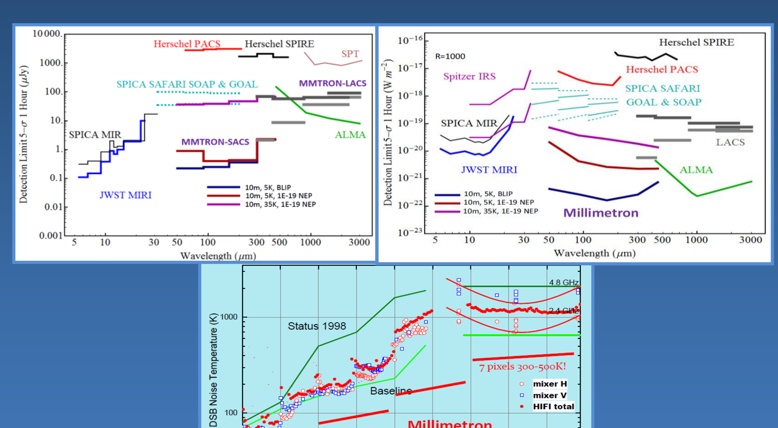

Possible detection of the HeH+ ion emission line in the spectrum of a distant quasar with redshift z=6.42. Source: I. Zinchenko, V. Dubrovich, C. Henkel "A search for $HeH^+$ and CH in a high-redshift QSO", MNRAS 415, L78-L80 (2011).

Herschel (350µm)

Millimetron (350µm)



Millimetron 10- meter antenna beats confusion limit.




Photometry, spectroscopy capabilities comparison calculated for the direct detection mode (top figures) and expected performance (bottom).

For more details and information, please visit: [http://millimetron.ru/](http://millimetron.ru/)