Millimetron Space Mission: status and technology

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and members of the Millimetron Science Working Groups

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Groningen/online, 4 Jan, 2022

Millimetron Mission Summary

A 10 m, cooled FIR/Submm/Mm Space Telescope for Cosmology and Astronomy

Approved and supported mission, by Russian Space Agency (ROSCOSMOS)

- Deployable and adjustable in orbit (diff. limit at 80 μm)
- Antenna and Instruments actively cooled (< 10K);
- Lifetime > 10 yrs; with active cooling > 3 yrs.
- Orbit around L2 Lagrange Point and possibly Elliptical for VLBI
- Dual Operation Modes (single dish and space-earth VLBI)
  - ✓ Space-Earth VLBI for 0.3 – 10 mm (EHT bands +),
    - ✓ with a VLBI receiver (4X) package.
    - ✓ 10-20% of observing time
  - ✓ Single dish for 70 μm – 3 mm; 3 imagers and spectro-polarimeters
    - ✓ with sensitivities: 0.5 μJy for camera and 10^{-22} W/m^2 for spectroscopy, including heterodyne receivers.
    - ✓ 80-90% of observing time
- **Antenna in Phase-B**
- **Spacecraft bus and instruments in Phase-A**
- **Lead by PI, S. Likhachev at ASC LPI, after N. Kardashev**
- **Launcher Angara 5M. Launch date: 2029-30.**
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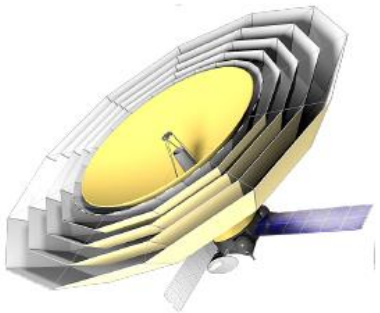


Millimetron mission initiated by Nicolay Kardashev

Roscosmos will pay all expenses for:

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

More information: http://millimetron.ru/

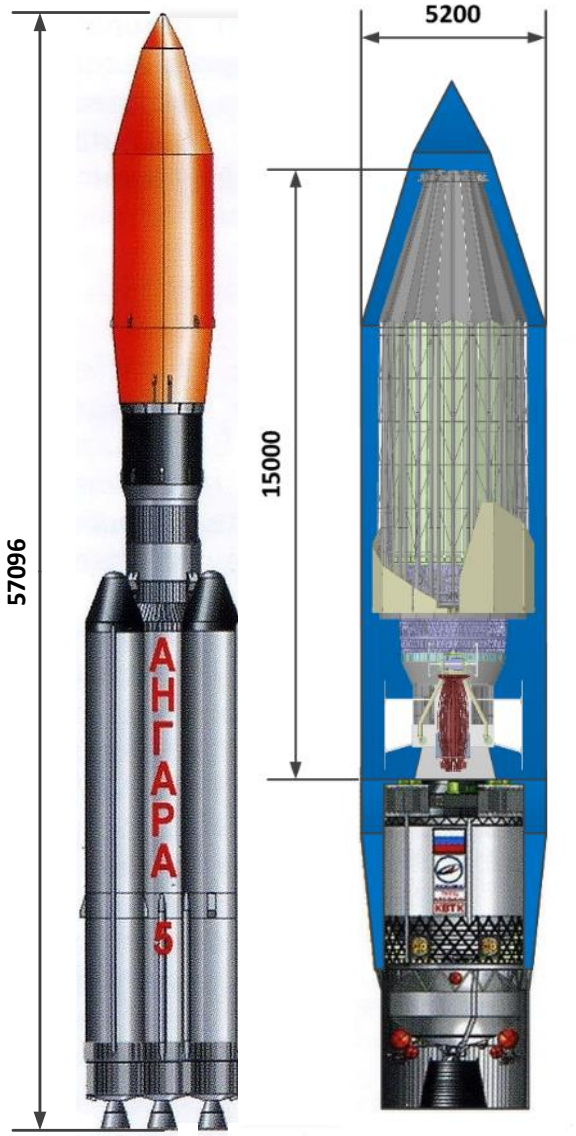
Millimetron Mission Approach

- Millimetron will be an international space mission, as was Radioastron

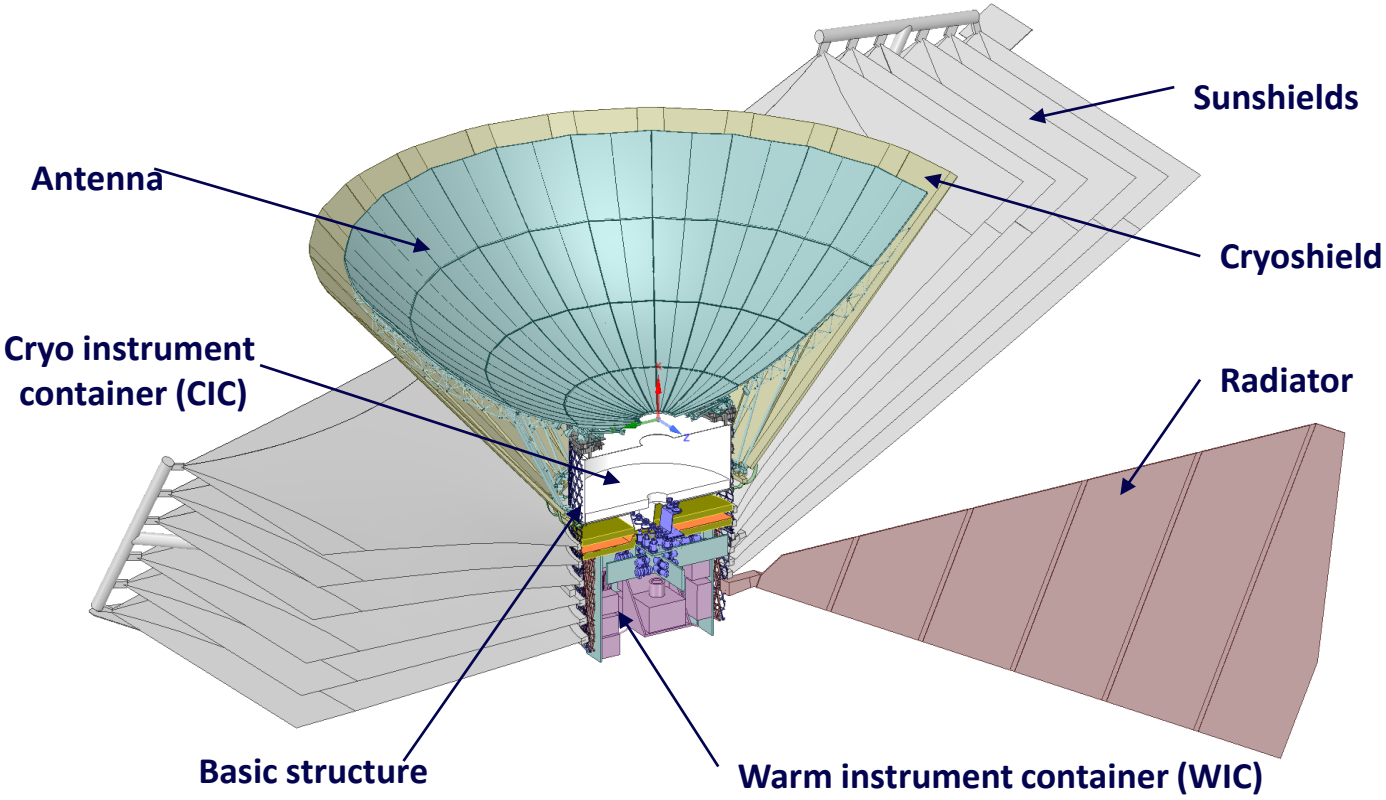
  Note: Radioastron holds an extensive experience heritage for Millimetron but it was in another wavelength range: different science, different earth stations

- Millimetron's Science Management Plan (MSMP) is ready and is similar to Herschel's SMP
- ASC is seeking international cooperation on Millimetron
- **ESA M7 Millimetron Proposal as a mission of opportunity in preparation**
  - **ESA -> Cryogenic container, cry cooler package, testing, instrumentation coordination (with ASC)**
  - **Involvement of US/NASA partners is welcome ant all levels**
  - **Coordination: Andrey Baryshev andrey@astro.rug.nl**

Millimetron Main Elements



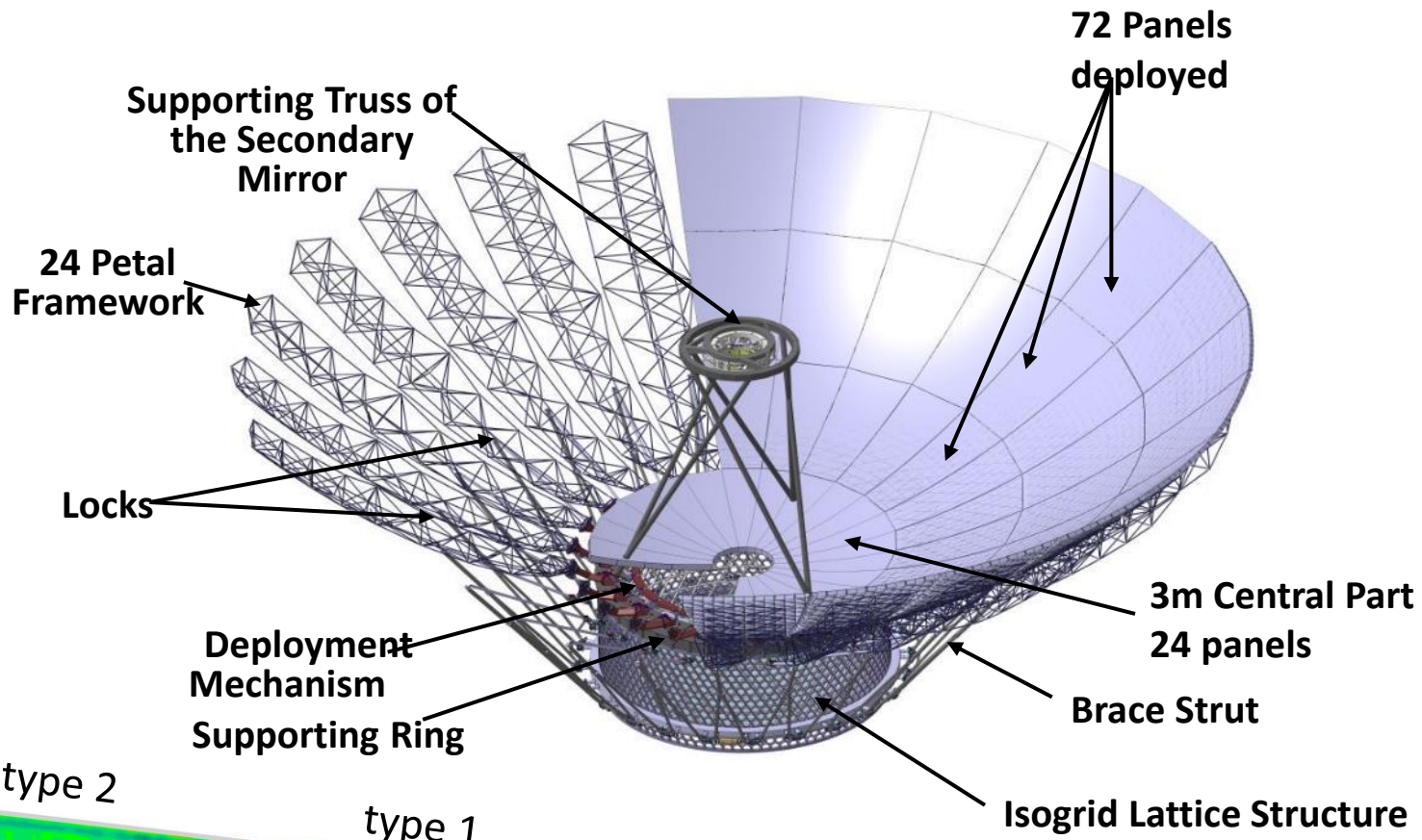
QM of Primary Mirror backplane assembly, 2021

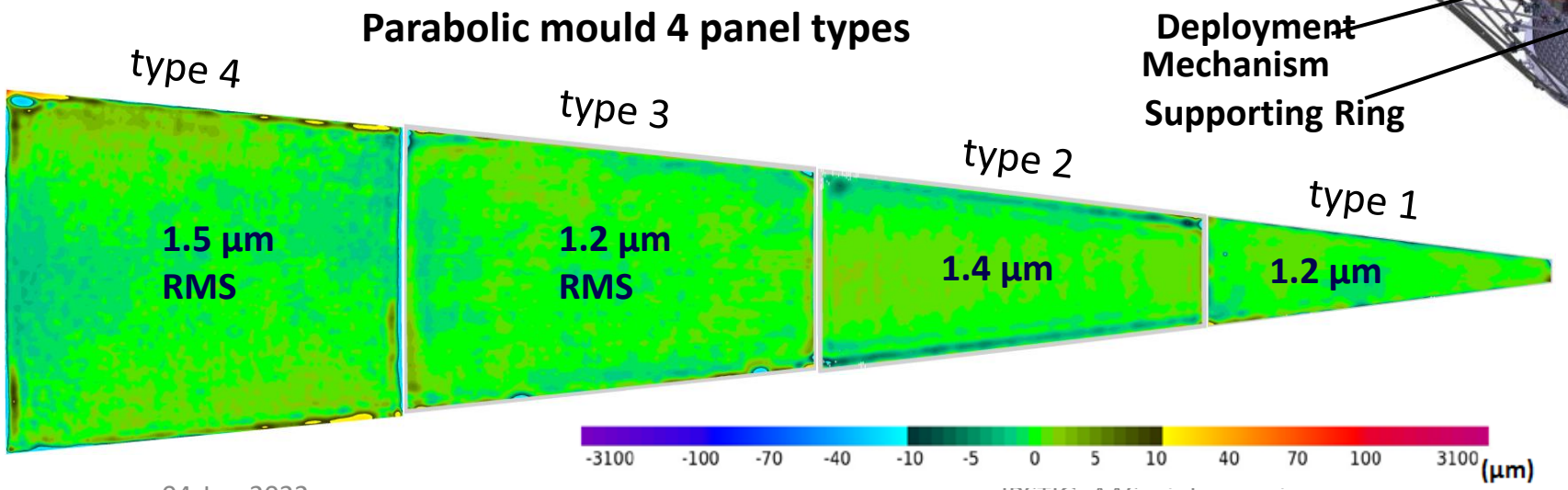


Structure diagram of Millimetron payload

Antenna panels specifications

- Operational temperature below 10 K
- Surface accuracy (RMS) at the operational conditions (requirement):
  panel 1..4 ≤ 3..8 µm
- Roughness: *Ra* ≤ 0.3 µm
- Reflection coefficient: *R* ≥ 0.98

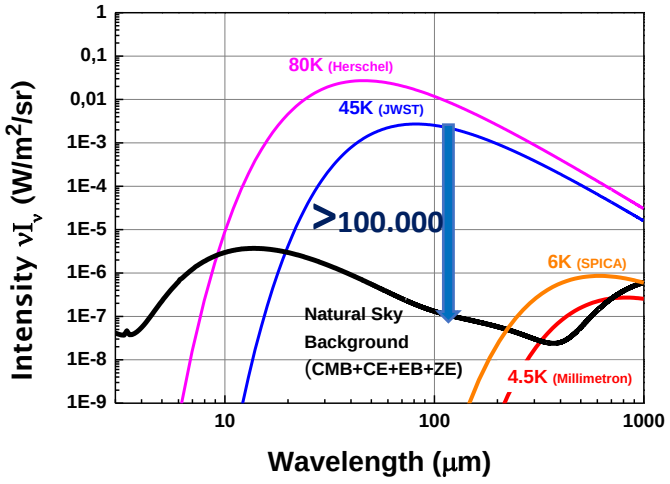




Millimetron, a **10 m cooled antenna** as single dish:

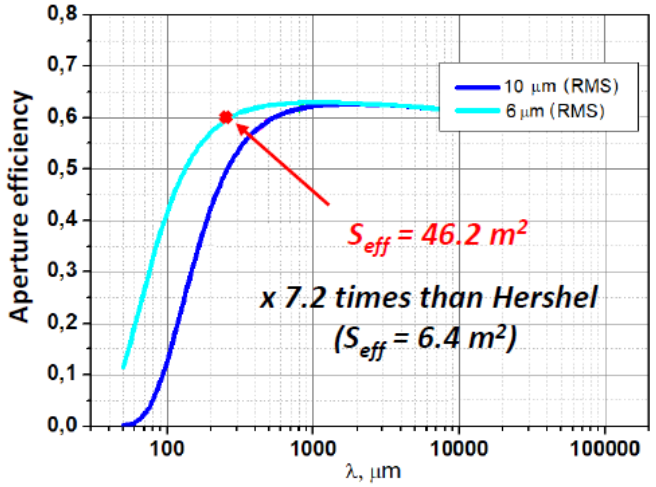
A) >100 times more sensitivity.

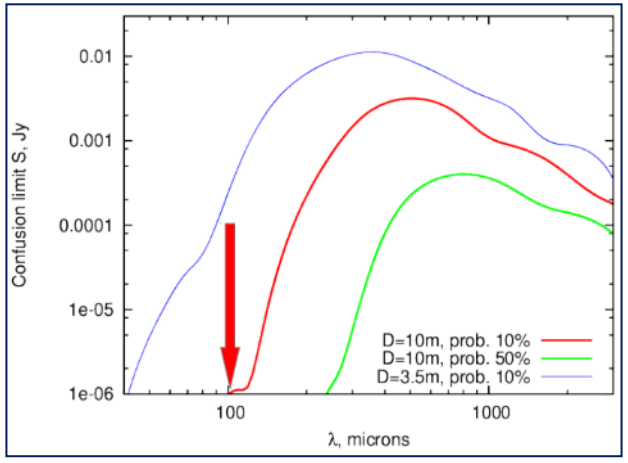
Thermal self-emission and natural sky background
if the telescope is cooled to temperatures < 10K.
Background limited < 300 µm if $T_{tel} \approx 4.5$ K

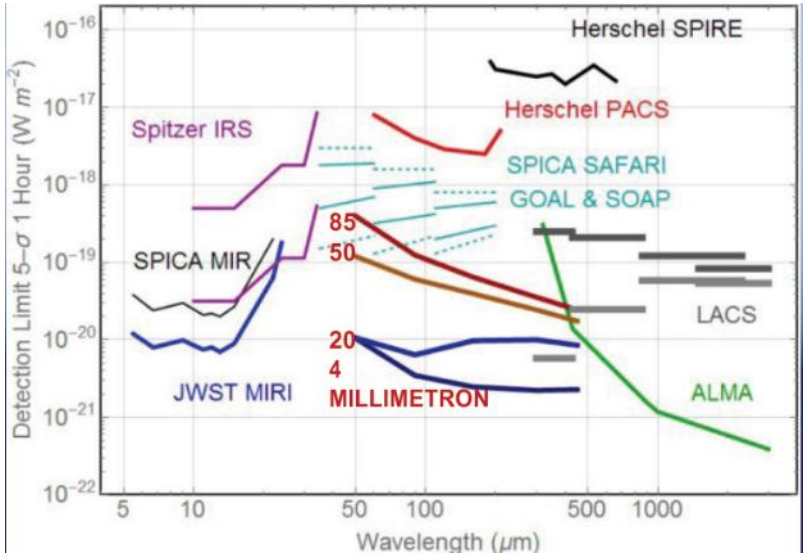


B) beats the Confusion Limit in FIR

Confusion Limit (CL) calculations following model
by Bethermin et al. 2011, for 10m and 3.5m mirror

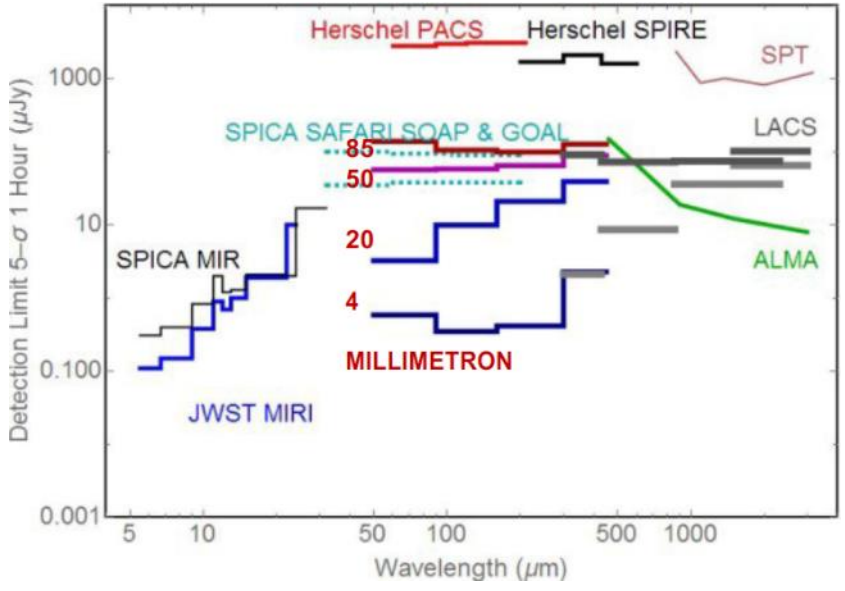






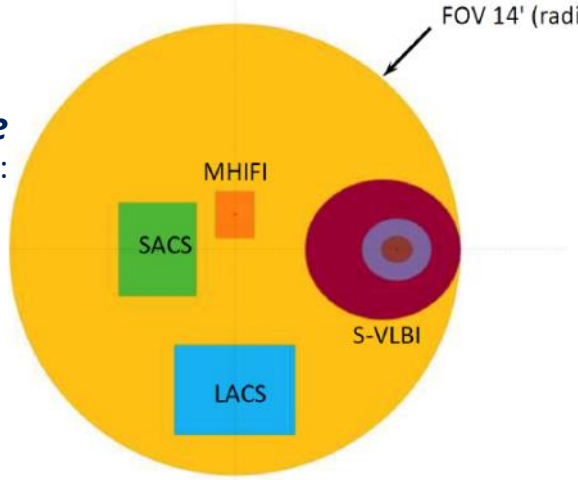
Photometry comparison
direct detection mode;
Camera R=3

Spectroscopy comparison
direct detection mode;
R=1000



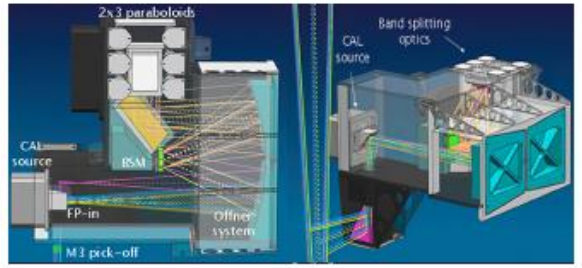
Planning Millimetron Instruments

instrument focal plane footprint:

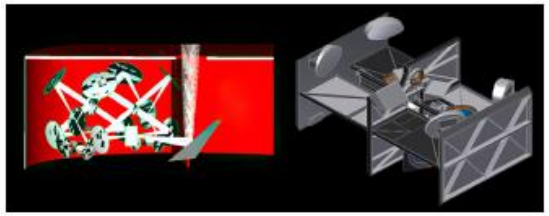


1) **S**pace-**VLBI** receivers (**S-VLBI**)**:** (2x lin. polarization)
   0.65 - 10 mm; 4 or 5 bands; more later
2) **M**mtron **H**eterodyne **I**nstrument for the **F**ar-**I**nfrared (**MHIFI**)**:**
   Selected ranges, 60 - 600 µm; 2x lin. Pol.; small arrays (3,7)
3) **S**hort-wave **A**rray **C**amera **S**pectro-Polarimeter **(SACS):**
   - **Camera**: 4 bands: **70, 125, 230, 375 µm**
   - **Studying a modified SPICA B-BOP,**

   with spectroscopy section added: **45 - 350 µm**
4) **L**ong wave-**A**rray **C**amera **S**pectro-Polarimeter **(LACS):**
   - **Camera**: 4 bands: **0.4, 0.7, 1.2, 2.3 mm**
   - **Spectro- polarimeter**: the FTS: **0.3 - 3 mm**



Preliminary design with ray-tracing (3D model), produced by SRON

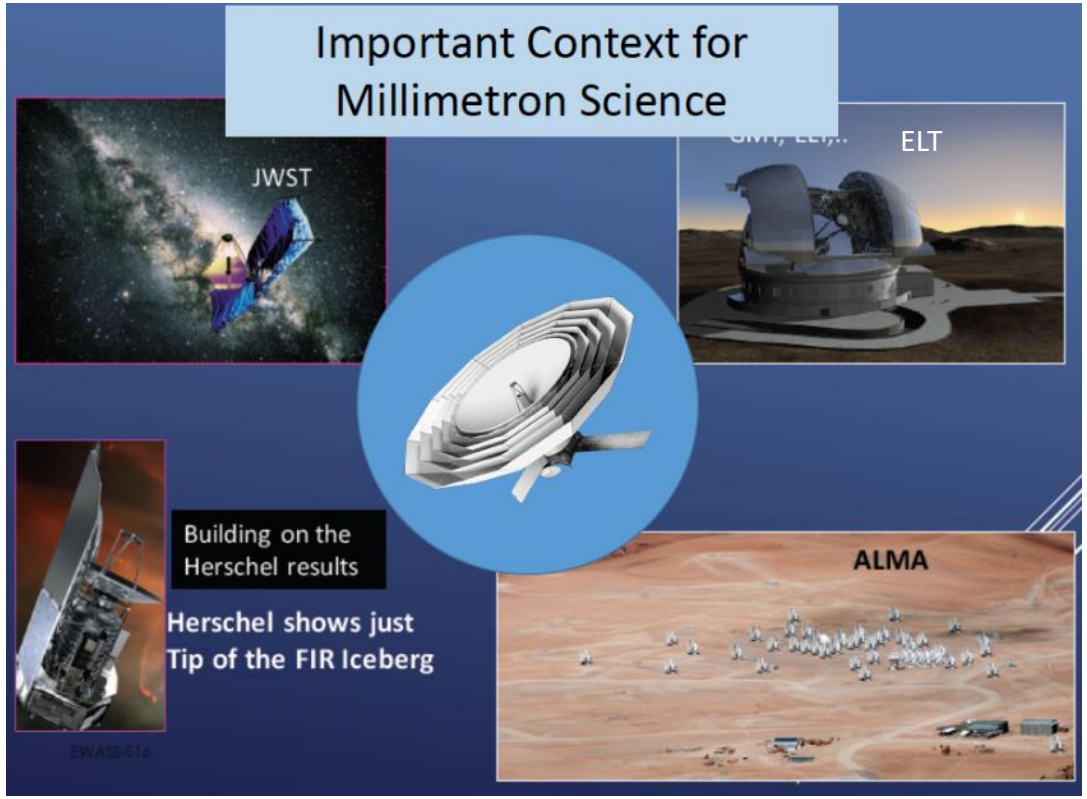


Preliminary design with ray-tracing (3D model), proposed by Paolo de Bernardis from Sapianza Univ.,Rome

Millimetron Science Program Re-assessment

- ***Millimetron has several unique, important characteristics:***
  - ***Largest cooled antenna in space for the next 2-3 decades***
  - ***Mission with two operating modes: Space Earth VLBI and Single dish***
  - ***Millmetron will have heterodyne receivers***

- **International Millimetron Science Working Groups are re-defining key program (75 people involved)**
  General Coordination/Contact: Thijs de Graauw (ESO, ASC-LPI, tdegraau@alma.cl
- **Millimetron mission science priorities will focus on:**
  - Few, very important well-defined **key science cases,**
  - Followed by other highly ranked science cases
- **Selection of science and related instrument concepts** are constrained and based on Results from Herschel, Spitzer, ALMA (incl. EHT) and from near-future projects JWST and ELT, etc.. Feasibility in budget and programmatics
- **A late change of science priorities might well occur**



MILLIMETRON

List of preliminary identified Key Science cases

1. Space-Earth VLBI (S-EHT)
2. S-Z surveys and other Spectral Shape Distortions
3. High-redshift obscured: Galaxy nuclei, QSOs, SMBHs
4. Water in circumstellar disks: “the water trail”
5. Role of magnetic fields: from molecular filaments to proto-stellar collapse
6. Role of Water in formation and evolution of the Solar System

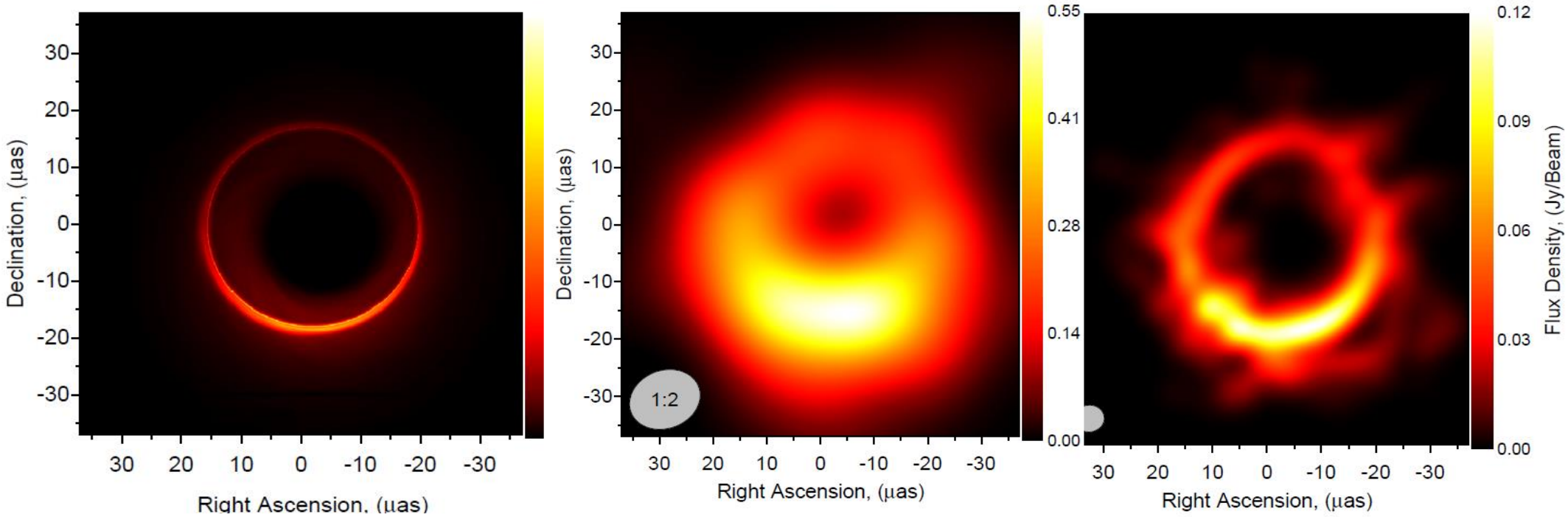
SWG-1. Relativistic Astrophysics and S-E VLBI with topics:

- Study of the nature of compact supermassive objects **with EHT-Millimetron imaging**
- A polarimetric S-EVLBI program of MSO – ALMA to measure the magnetic field strength, its spatial variation and topology
- Possibly wormholes, manifesting itself as supermassive gravitating bodies in galactic centers (cquantify improvement in microas)

M87 model

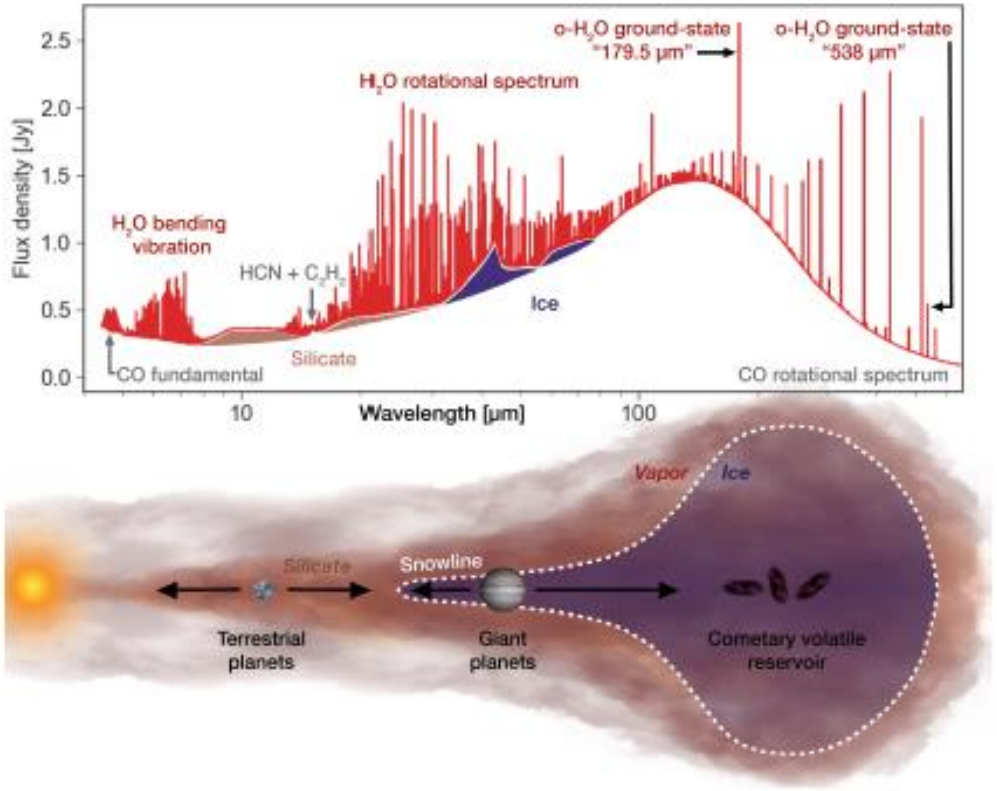
M87 EHT CLEAN model map

M87 EHT+Millimetron CLEAN model map



SWG-4. Water in circumstellar disks: “the water trail”

(from interstellar ices to oceans)



“A model of a typical disk around a solar-mass star at a distance of 125 pc, with line strengths from strong emission from water fitted to Spitzer and Herschel spectra”
By Klaus M. Pontoppidan

- Water is a key **diagnostic** for understanding planet formation
- Solid water (ice) plays a critical role in this process

We will observe gaseous and solid water as well as deuterated water at all temperatures during the evolution of protoplanetary system.

Other topics addressed in this SWG are:

- *Hydrides with HD as the best proxy for gas mass in protoplanetary disks*
- *Atomic oxygen, ionized carbon and nitrogen to study cooling and mass loss in protoplanetary systems*
- *General Astrochemistry*
- *Primodial molecules*

Summary

- Millimetron Space Observatory mission with a cooled and deployable **10m** antenna is under development in Russia. **It is presently the only (heterodyne) FIR/Submm space observatory that is approved and under development and it will have unique instrumentation**.
- A science program re-assessment is being carried out by international Science Working Groups
- The main key science cases address the important themes from exo-planet formation to early universe formation and evolution of Galaxies, SMBH, Quasars …
- Significant advances are being made in the development of antenna technology and VLBI applications
- **Preparation of ESA M7 Call is under way. Discussions and support are welcome from US community**

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