Optics, receivers and back end electronics for radio and microwaves instrumentations

INAF days 2019
Building the future

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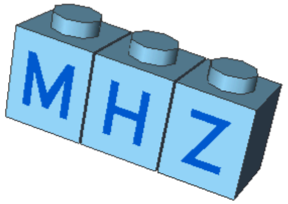
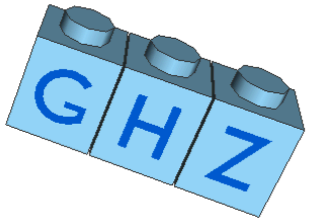
Presented by Fabrizio Villa
On behalf of INAF MA5 and INAF Institutes and Observatories

Too long with high risk to miss someone to list all the national and international Organizations, institutions, Universities, industrial partners and persons contributing in the work presented here. **Thanks to all of them!**

Framework





- We cover from **few MHz to hundred GHz** a really tiny fraction of EM spectrum but a **very big difference in technology and methods**
- **INAF** has collected **long tradition and experience** in developing **RF/Microwave and mm-wave technology**, instruments, and experiments
- Through national facilities (Medicina, Noto, SRT) and involvement on World-wide state-of-the-art projects, **INAF personnel continuously improve their expertise**

2019 and beyond

- **Requirements**
  - Large filed of view
  - High sensitivity
  - High time resolution
  - High spectral resolution
- **Possible Solutions**
  - Aperture **arrays**
  - Phased **arrays**
  - Cryogenic focal plane **arrays**

- **Cutting edge technologies**
  - Antenna's systems
  - Beam forming techniques
  - Multi-beam and –frequency systems
  - RF and Power analog signals transportation over optical fibers
  - Acquisition electronics
  - Signal processing back-end
  - cryogenics

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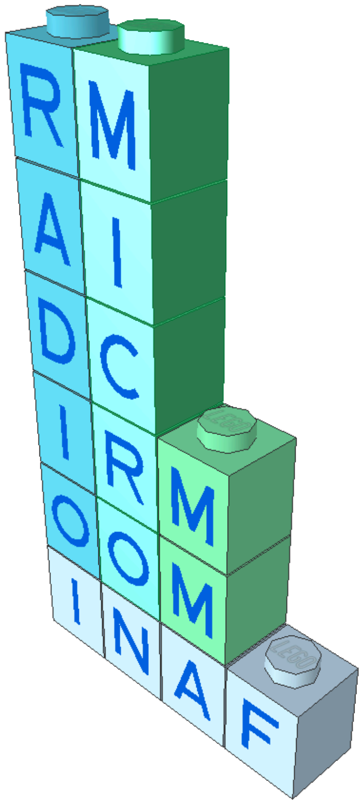
Lead Projects and facilities for Radio-/micro-/mm- wave

- Square Kilometer Array (**SKA**)
- **LOFAR** (station @ Medicina)
- **LSPE / STRIP** (CMB experiment based on Planck Heritage)
- **ALMA BAND 2+3** (prototype developments)
- **ALMA B2 CCA** Production (negotiation ended, to be approved)
- **PON** upgrades for SRT (funded right now)
- Italian Radio Facilities
  - **S**ardinia **R**adio **T**elescope
  - **NOTO** radio telescope
  - **MEDICINA** radio telescope



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SKA ACTIVITIES

SKA Consortia

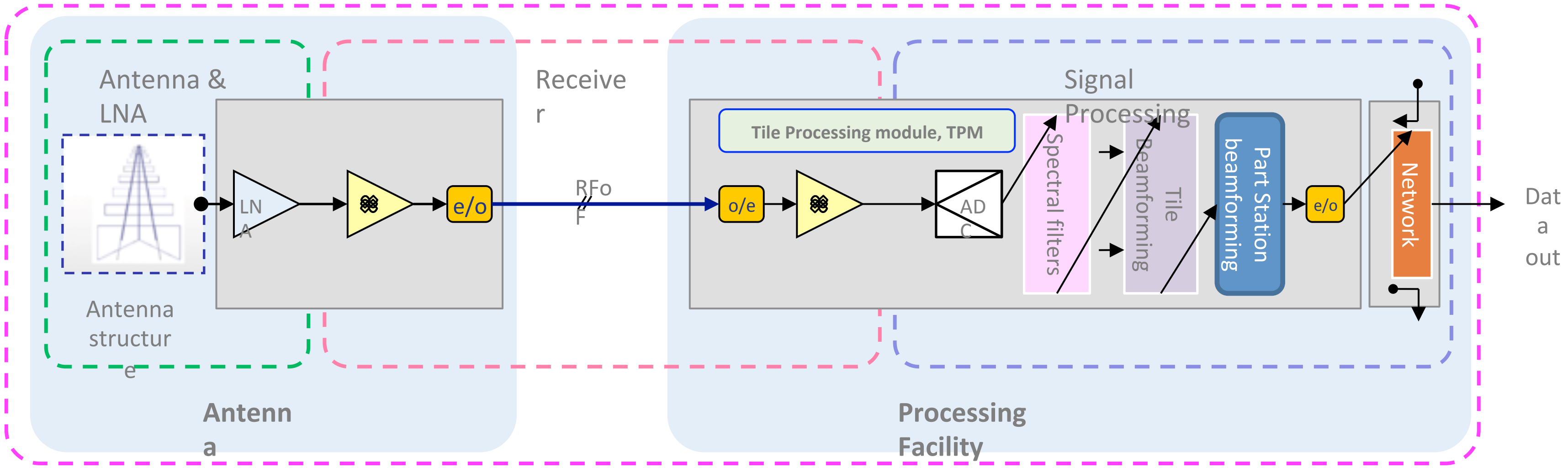
- Extensive involvement of INAF in SKA project
- **INAF** has a **key role** in SKA tech. dev. And construction (and science) being partner of several SKA consortia
- Partner of the **A**dvanced **I**nstrumentation **P**rogramme

SKA activities

- **Member of Aperture Array Design and Construction (AADC)**
  - Low Frequency Aperture Array (LFAA)
    - Design and Development of the analog receivers system,
    - Signal processing system for pre-treatment of data
    - Design, calibration and characterization of antennas and array:
      - BEST (Basic Element for SKA Training)/FP6-SKADS**: first “SKA oriented” European technological demonstrator** for Aperture Array based on **RFoF** technology
      - MAD (Medicina Array Demonstrator): **first demonstration of array measurements** and calibration through **UAV**
      - AAVS1.5: **100% INAF technology** from the antennas (**SKALA4.1-AL**) to the digital back end (**iTPM**) to be installed in Australia
  - Management and system engineering

LFAA receiver

- INAF is developing the analog receiver but in process to extend the development to cover the Antenna/LNA and the signal processing part



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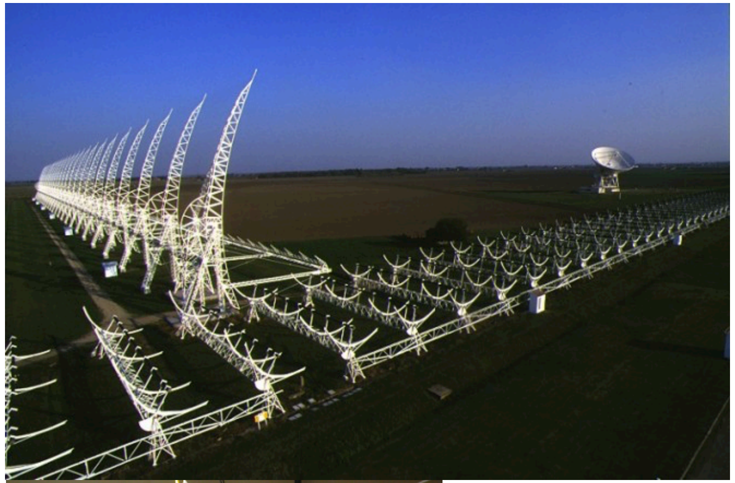
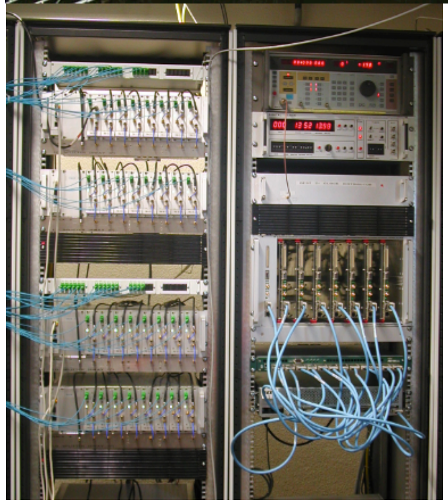
RFoF and SKA architecture

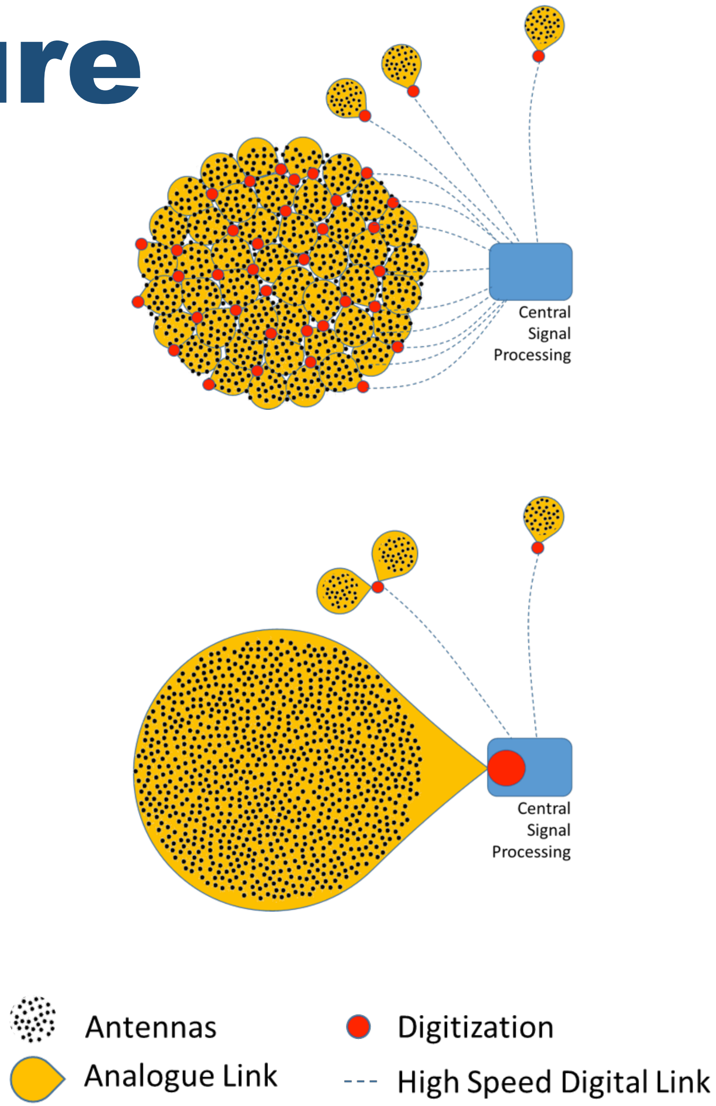




BEST (2004)

First ‘SKA oriented’ European technological demonstrator of an Aperture Array based on RFoF technology

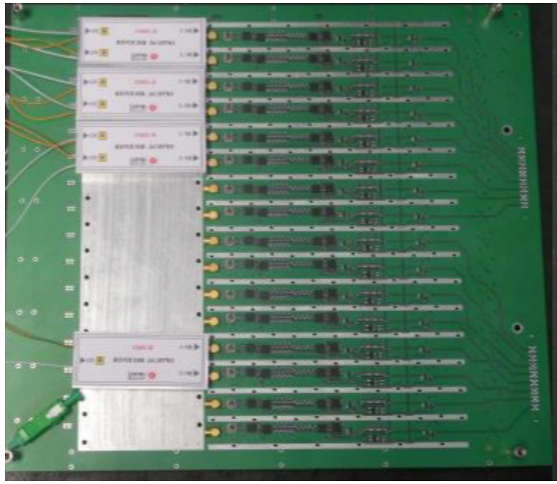
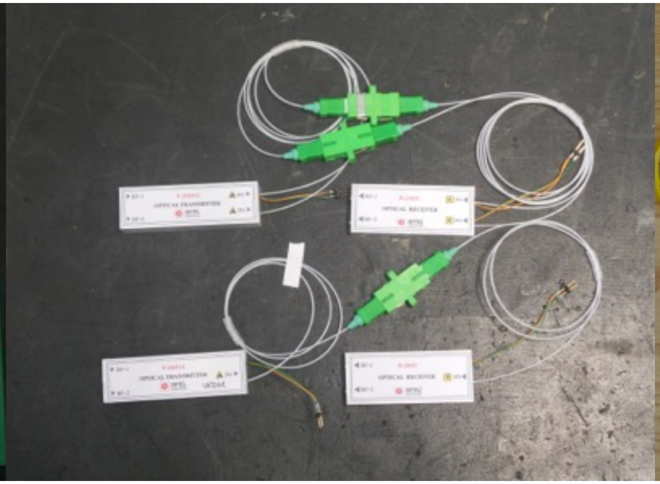
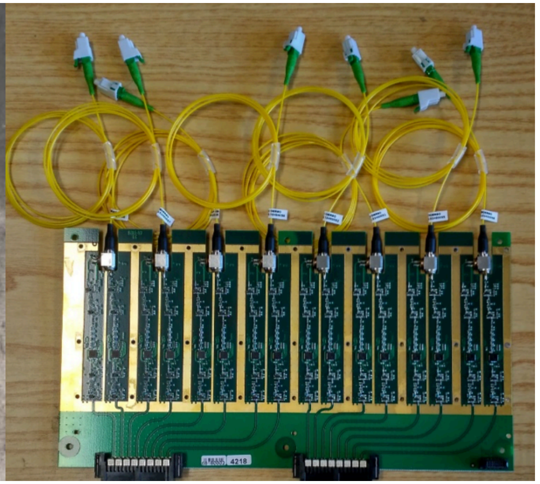
Cheaper
Lighter
Smaller
than copper



preADU1.0 (2014) Vs preADU3.0 (2018)

- First RF-over-Fiber RX prototype
- Demonstration of integration of 16RF chains (RF isolation)
- Designed to meet RF PDR specifications

- Reduced dimensions
- RF circuit simplification and optimization
- Step towards a full integration into ADU board

SKALA4.X Antenna solution for LFAA

- The SKALA4.0-AL antenna is one of the possible implementations of the SKALA4 conceptual design.
- The SKALA4.1-AL version is a new antenna currently under design to improve EM performance and mechanical aspects.
- For the low-bridging phase of SKA1-LOW, 128 SKALA4.1-AL antennas will be fabricated in 2019 to be installed on the Australian site
- UAV beam measurements and calibration

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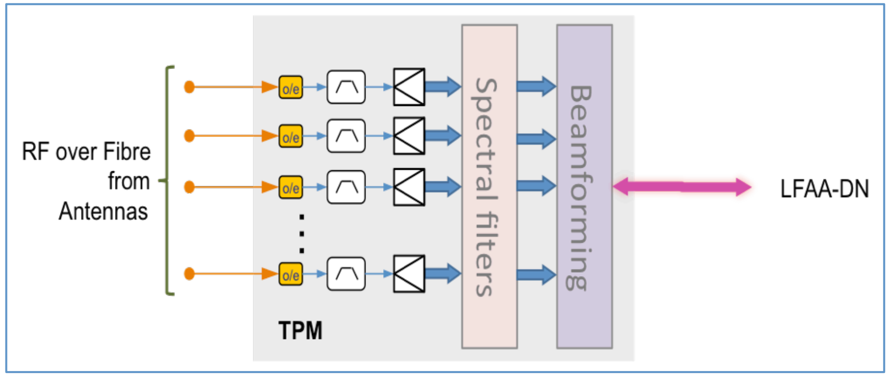
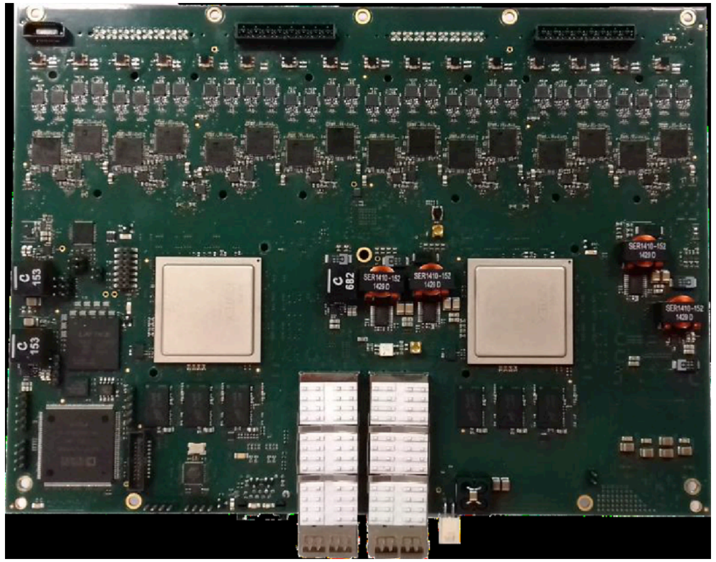
Italian Tile Processor Module (iTPM)

- 3 versions designed, produced and qualified (ver. 1.0, 1.1, 1.2)
- Version 1.2 produced and engineered for AAVS1
- 35 ITPM ver.1.2 produced (Italy, Nederland) and now installed for AAVS1
- Version 2.0 in production
- iTPM Adapted for PAF, a new version is in feasibility study.





ANTENNA SYSTEMS AND BEAM FORMING TECHNOLOGIES

Antenna systems and beam-forming technologies

- Front end under development for Italian facilities (PON)
- Application of state-of-the-art Technologies developed for projects (SKA, ALMA)
- Phased arrays

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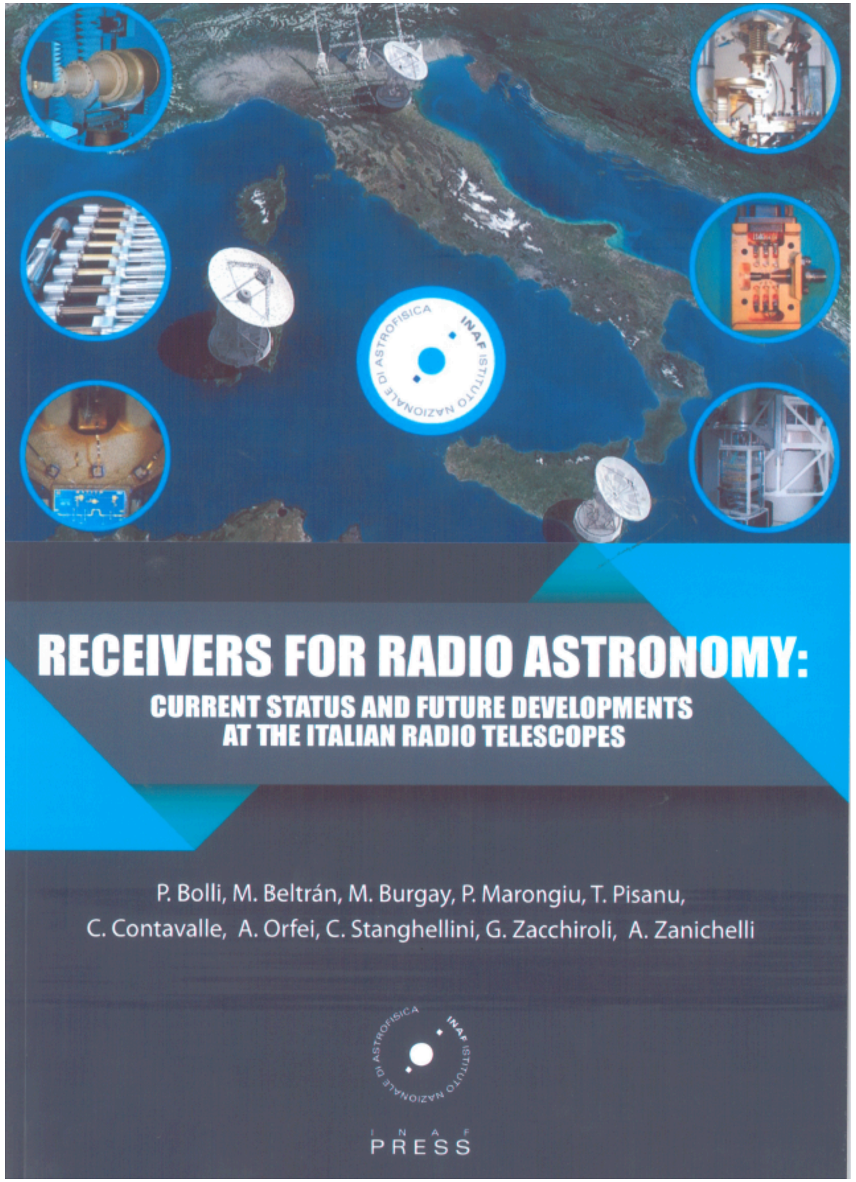
Future Developments

- Radio Receiver review: an example of virtuous and efficient work
- http://rx2017.inaf.it/RX2017/review.html



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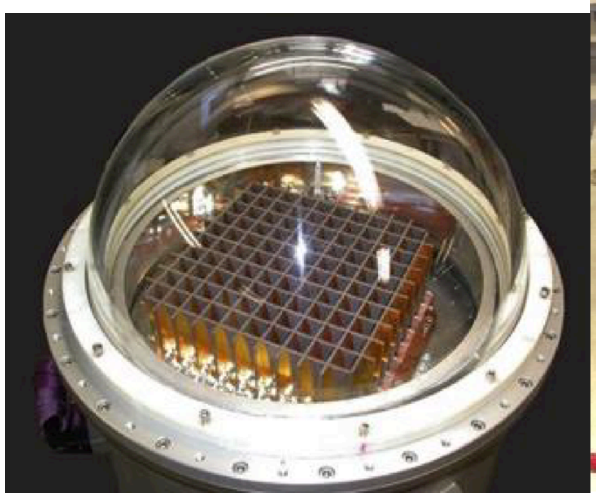
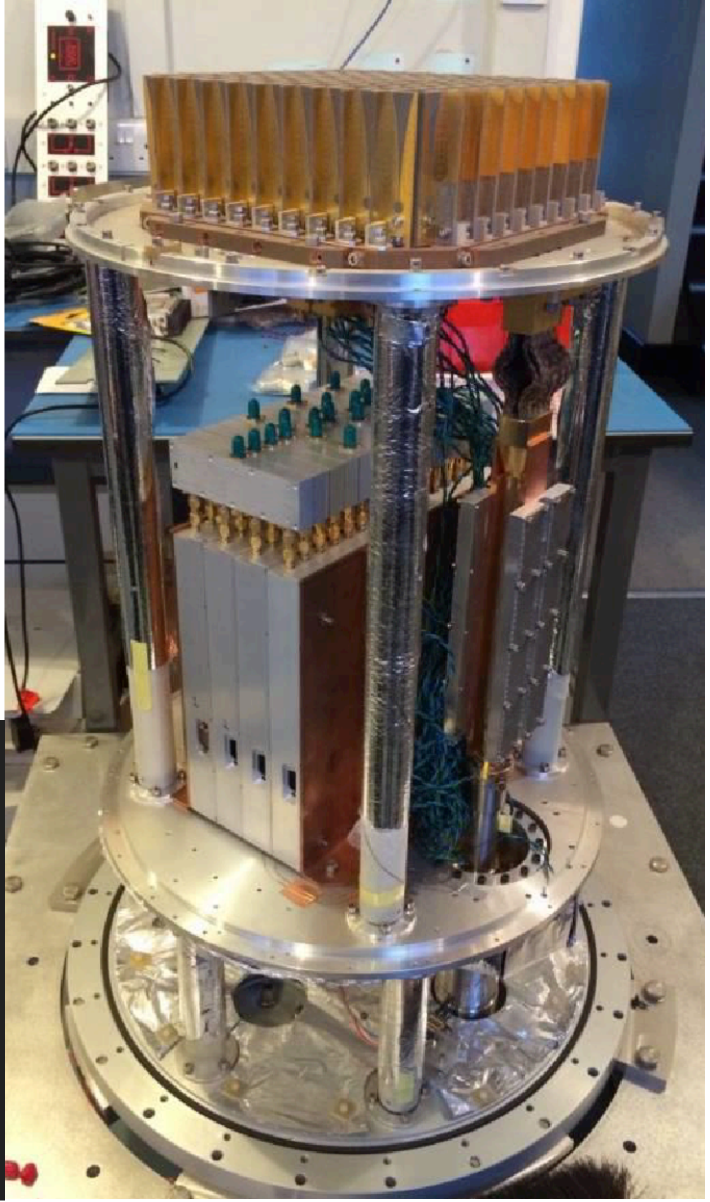
Phased Array Feeds

- Possibility to achieve complete coverage of the available radio telescope Field of View (FoV)
- multiple simultaneous beams, thus increasing the survey speed if compared to a single-pixel feed
- Improve antenna efficiency over very wide freq. band and Correct for off-axis aberrations
- Compensate for large-scale distortion of dish surface errors
- Radio Frequency Interference (RFI) mitigation;
- Reconfigure the properties of the beams in real time;
- Elaborate observations in post-processing using a post-correlation beam former

PHAROS2
C-Band Cryogenic PAF

- SKA Advanced Instrumentation Program (AIP): PAF Consortium
- INAF is part of the SKA AIP on PAF
- Currently funded by in-kind contributions of the member institutes that are focused on their own PAF R&D programs – with no real focus on SKA PAFs yet





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iTPM for Pharos 2

- Accepts 32 analog inputs
- Digitization at 700MS/s, the 375-650 MHz IF band is sampled in second Nyquist zone
- 2 x 40Gbps Ethernet interfaces (QSFP), one for each FPGA;
- High speed internal bus to connect the 2 FPGAs, 25 Gbps + 25 Gbps bidirectional;
- Power consumption ≈150 W (iTPM v1.2);

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Acquisition electronics and signal processing back-end

- High frequency (100 GHz and above), large amount of detectors, control system / data production integration require dedicated back-ends in terms of performance calculation , low-power, high programmability, possibly located in the proximity of the front-end.

- Digital electronics design and hardware production (FPGA, ASICS, boarding, housing and cooling)
- Firmware design and engineering in particular for PGA-based systems
- Software Development and engineering

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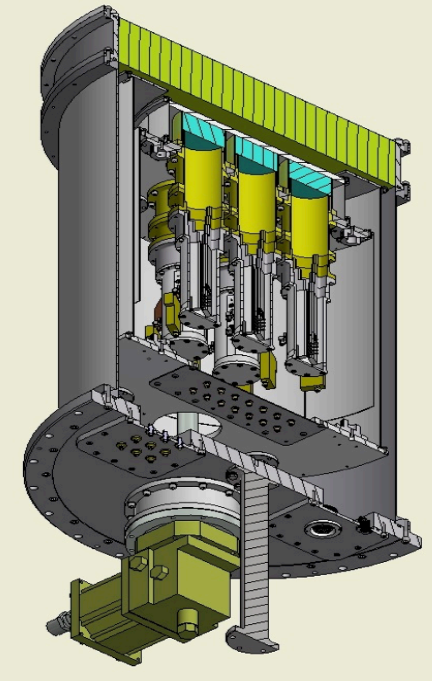
MULTI-BEAMS AND MULTI-FREQUENCY SYSTEMS

Cluster of Detectors

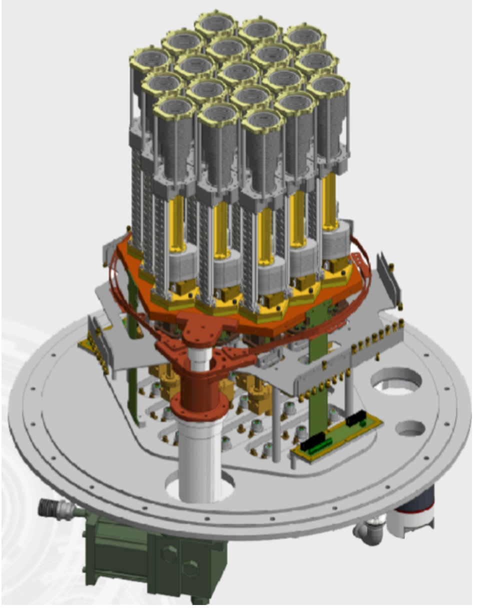
- **future for CMB instrumentation (extremely high sensitivity)**
- **Future for Radio-Astronomy survey and imaging (wide field coverage)**
- **Common areas of development**
  - End-to-end studies and characterization of antenna response with multi-detectors
  - Compact and wideband passive components (corrugated feed, OMTs, polarizers, filters, waveguides)
  - Cryogenic calibrators
  - AIV techniques for complex multi-feed arrays

receivers for SRT under development

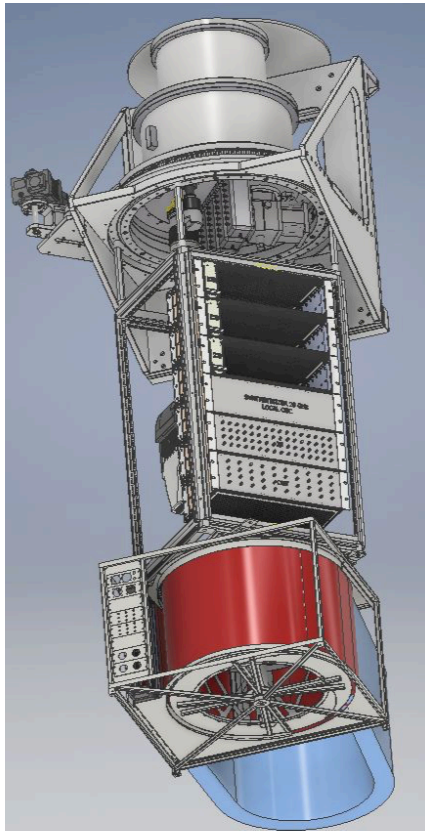
S-Band (3.0-4.5 GHz) 7-beam receiver for primary focus



Q-Band (33-50 GHz) 19-beam receiver for Gregorian focus



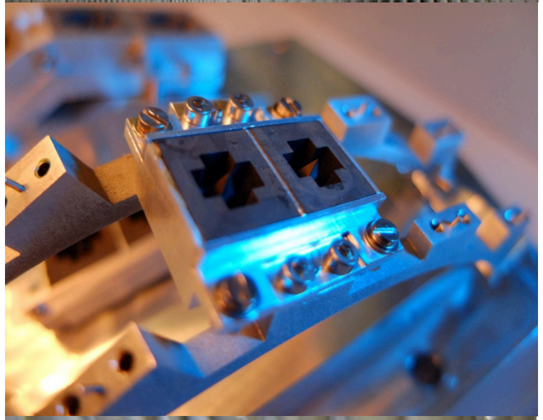
W-Band (75-116 GHz) multibeam receiver for Gregorian focus

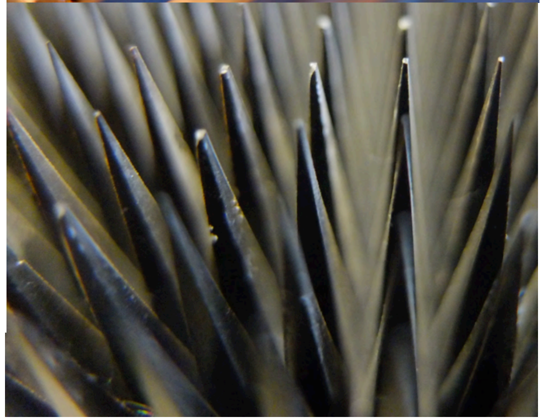


Planck Heritage applied to Cryowaves

- Full range (30GHz – 1THz) almost perfect cryogenics black-body Calibrators
- LNAs bias optimization
- AIV of cryogenic Front-Ends
- Performance verification, calibration and test
- Antenna Design, simulations and verifications (GRASP), RF design

Cryowaves
è Bologna





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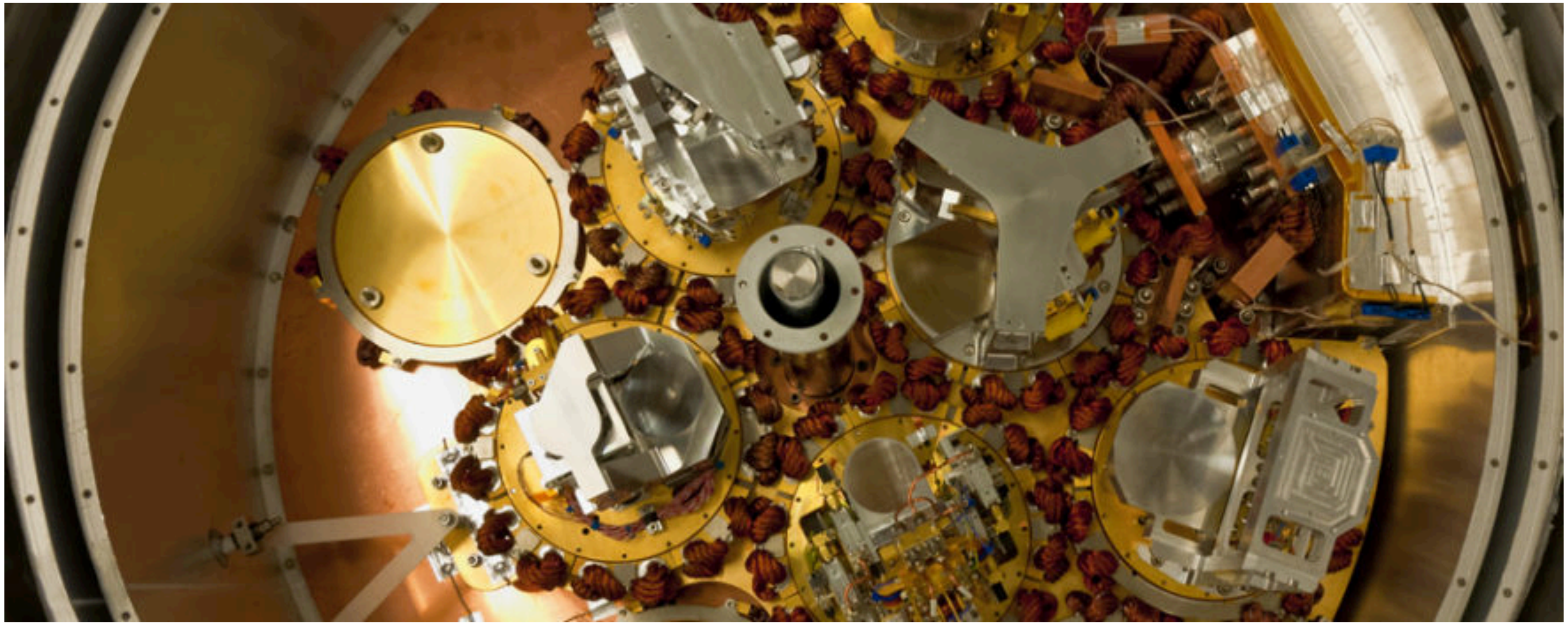
ALMA ACTIVITIES

Band 2: The last remaining cartridge



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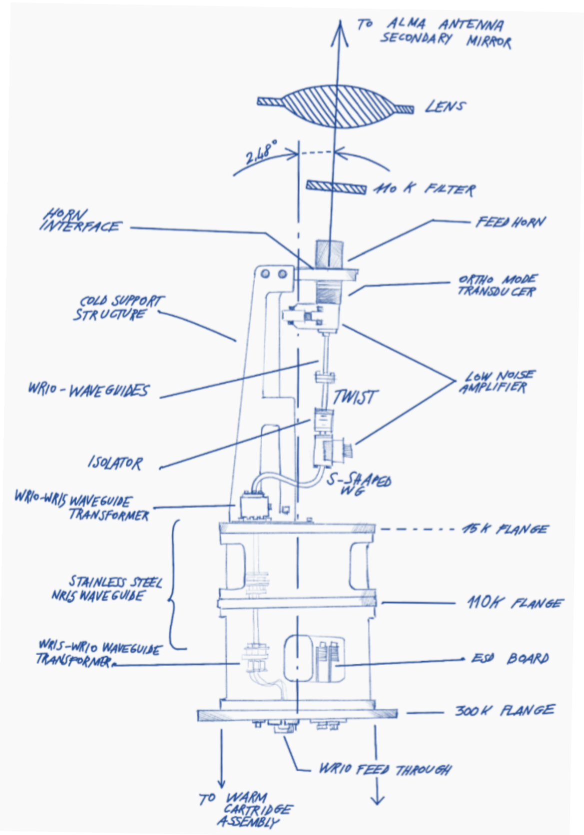
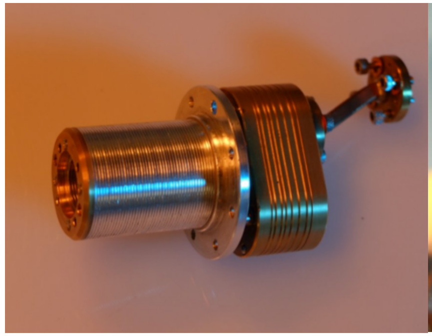
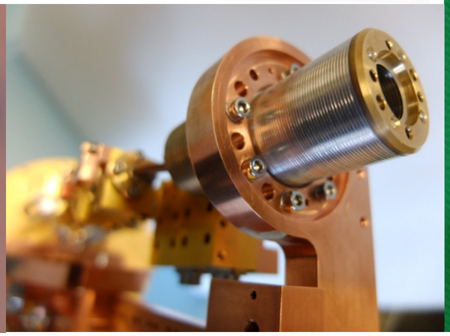
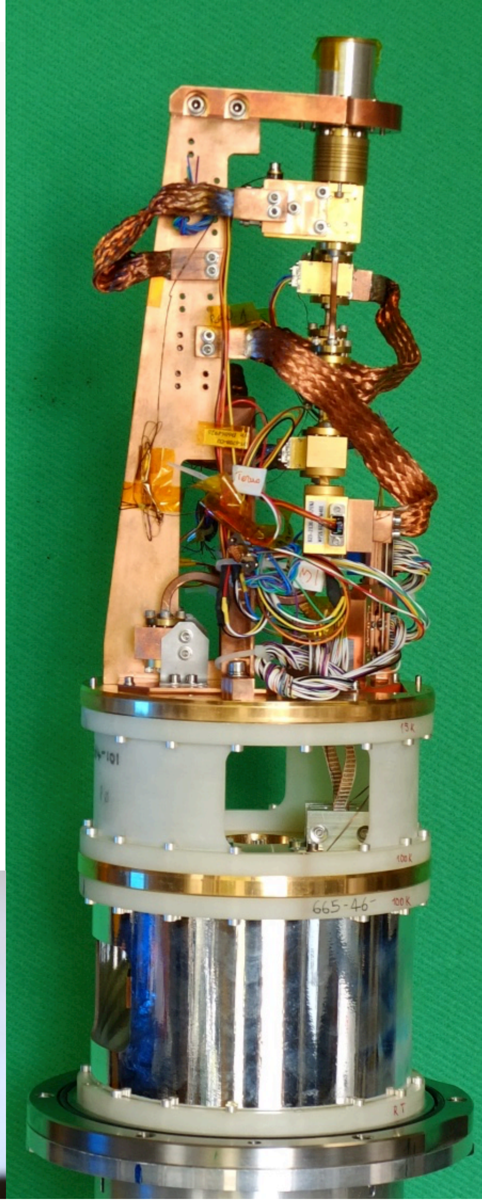
ALMA Band 2 (2+3)

- Development of **ultra-wideband** passive **components** and LNAs
- **Precursor** for wideband (50%) studies and feasibility in micro- and mm-wave technology
- Best Receiver with **world record performances** at (extended) W-band (67-116 GHz) at INAF laboratory
- Ready for **CDR** activities and **production**









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ALMA Band 2 (2+3) Status

European Organisation for Astronomical Research in the Southern Hemisphere

Garching, 15 June 2018
Ref. 11409/LET/CP/ATR

CONFIDENTIAL

Subject: **Call for proposals ref. CFP/ESO/18/88584/ATR for the production of 73 Cold Cartridge Assemblies for ALMA Band 2**

Dear Sir, Dear Madam,

ESO invites you to participate to the subject Call for proposals for the production of 73 Cold Cartridge Assemblies for ALMA Band 2, in accordance with the conditions defined hereafter and in the referred documents. You are kindly requested to confirm receipt of this Call for proposals and appended documents and your intention to bid. ESO will award the agreement for the production of 73 Cold Cartridge Assemblies for ALMA Band 2 to the bidder that provides the offer providing the most scientific advantage for ESO in relation to the cost.

The Panel would like to **congratulate the INAF team** on a very successful study, which has made a **major contribution to the Band 2+3 prototyping** effort and which leads naturally into the new effort

The panel were **impressed by the extensive work done by the Band 2+3 team** in preparation for this review and the excellent results reported

ESO Development Study: Band 2+3 Prototype Components

Final review meeting minutes

July 12 2017

Atacama Large Millimeter / submillimeter Array

ALMA

European Band 2+3 Preliminary Design Review

Report

FEND-40.02.02.00-0058-A-REP

Released

2018-02-02

Future in CMB experiments

- Major US funding agencies and Institution recognize the important scientific priority of CMB studies and related technologies
- CMB studies require technology development at the edge of the current capabilities
- Several basic technical questions are still open
- World-wide recognized experience on ESA Planck satellite hardware development and recent ALMA upgrades studies (Band 2+3)

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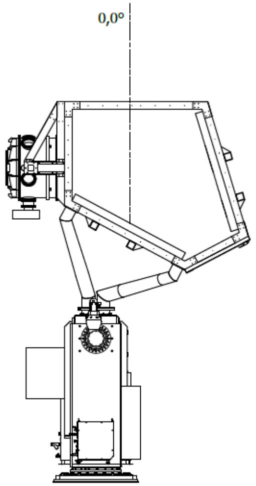
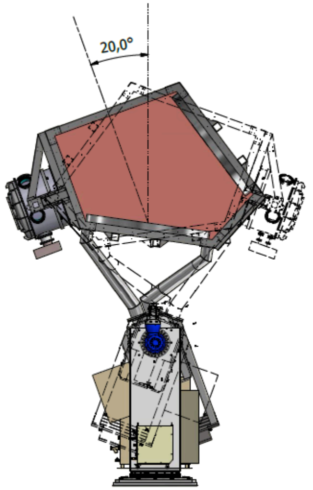
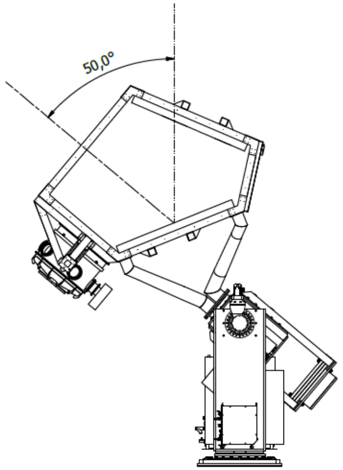
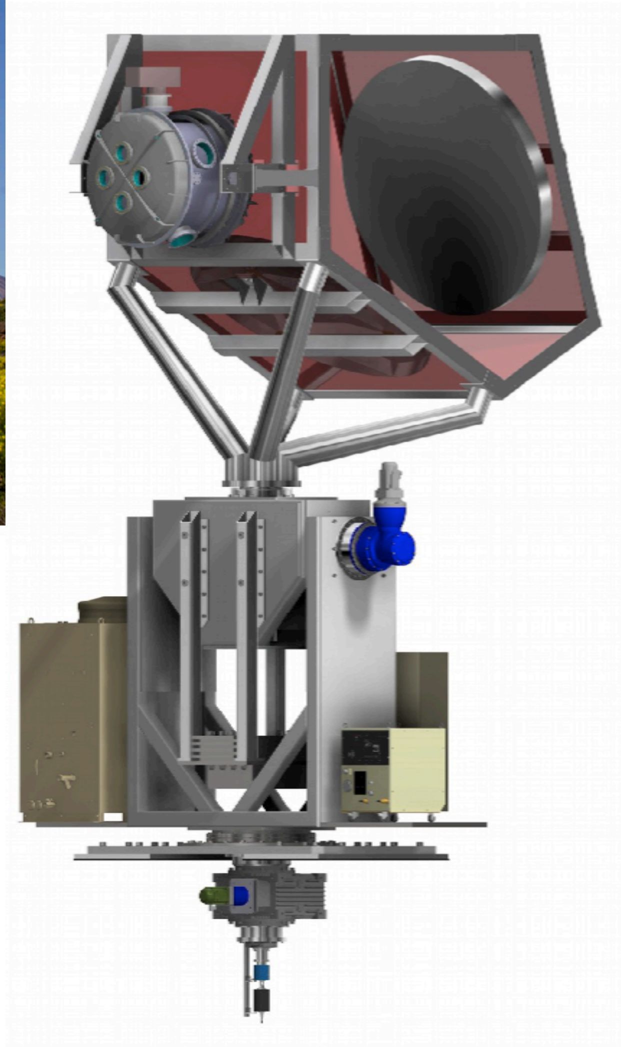
LSPE/ STRIP polarimeter, Tenerife









- 1.5 meter aperture
- Focal plane cooled at 20K
- Alt-Az mount
- 2 years nominal obs.
- To be installed in 2020

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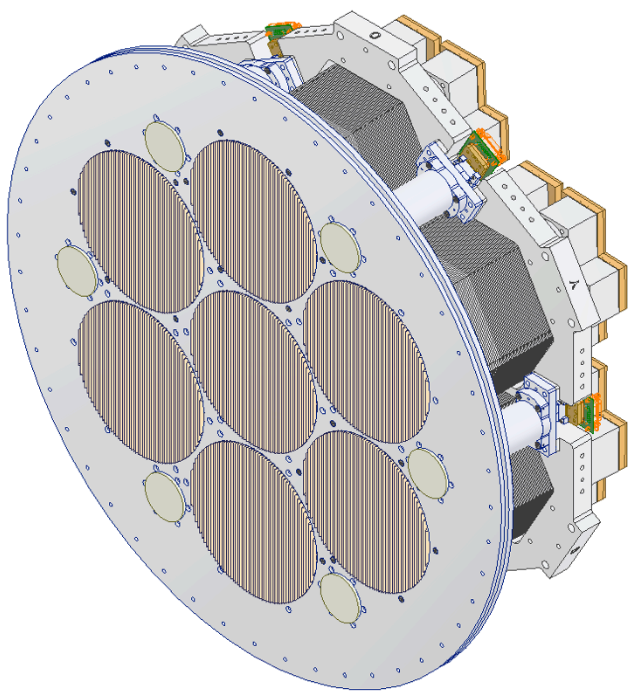
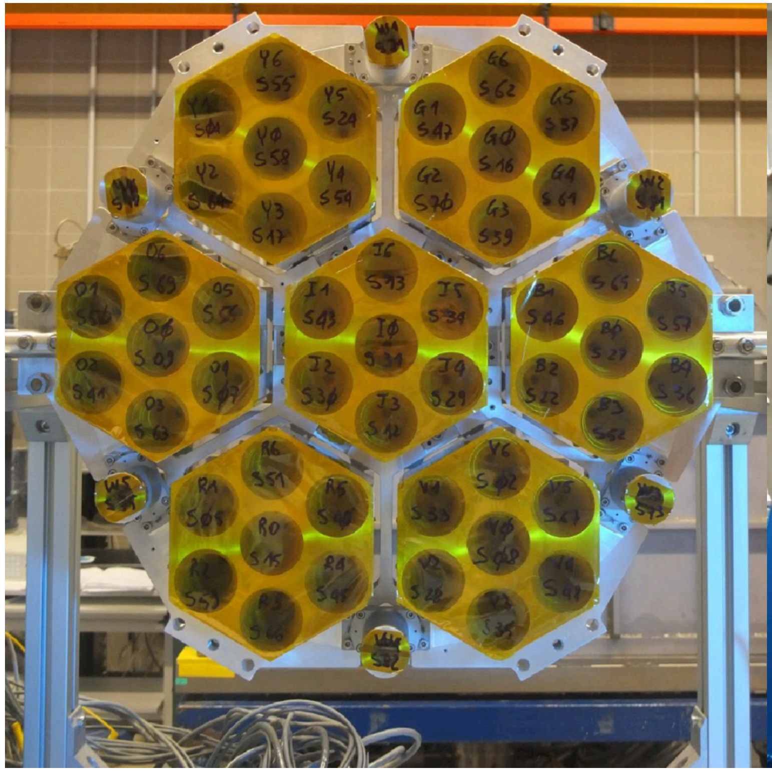
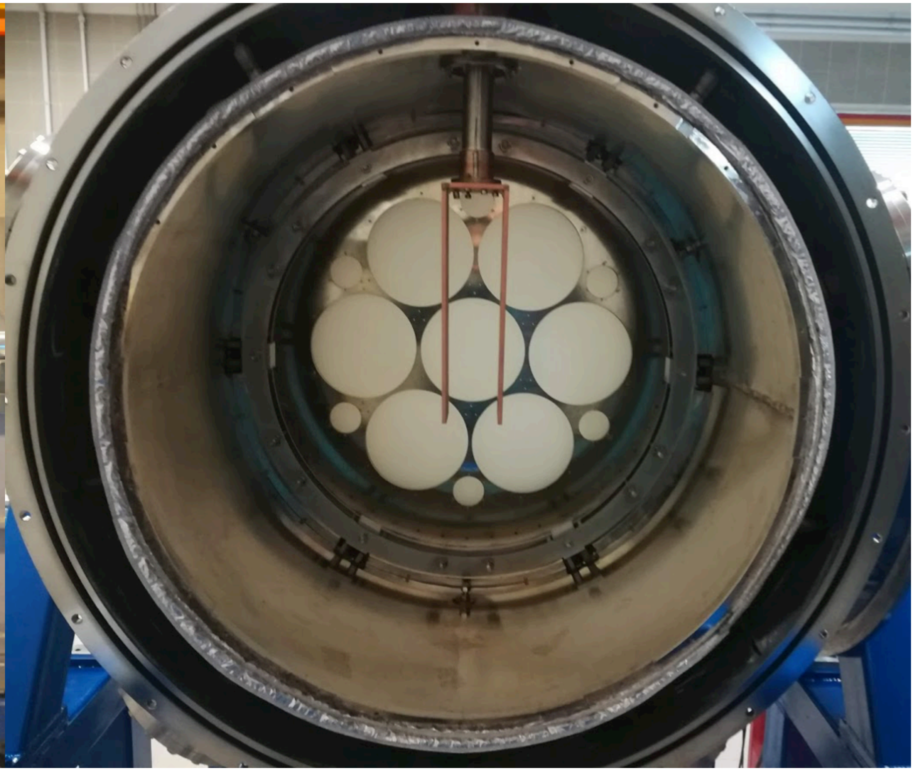
LSPE/STRIP Focal plane Array

- 49 Q-band channels, 6 W-band channels, full polarimeters



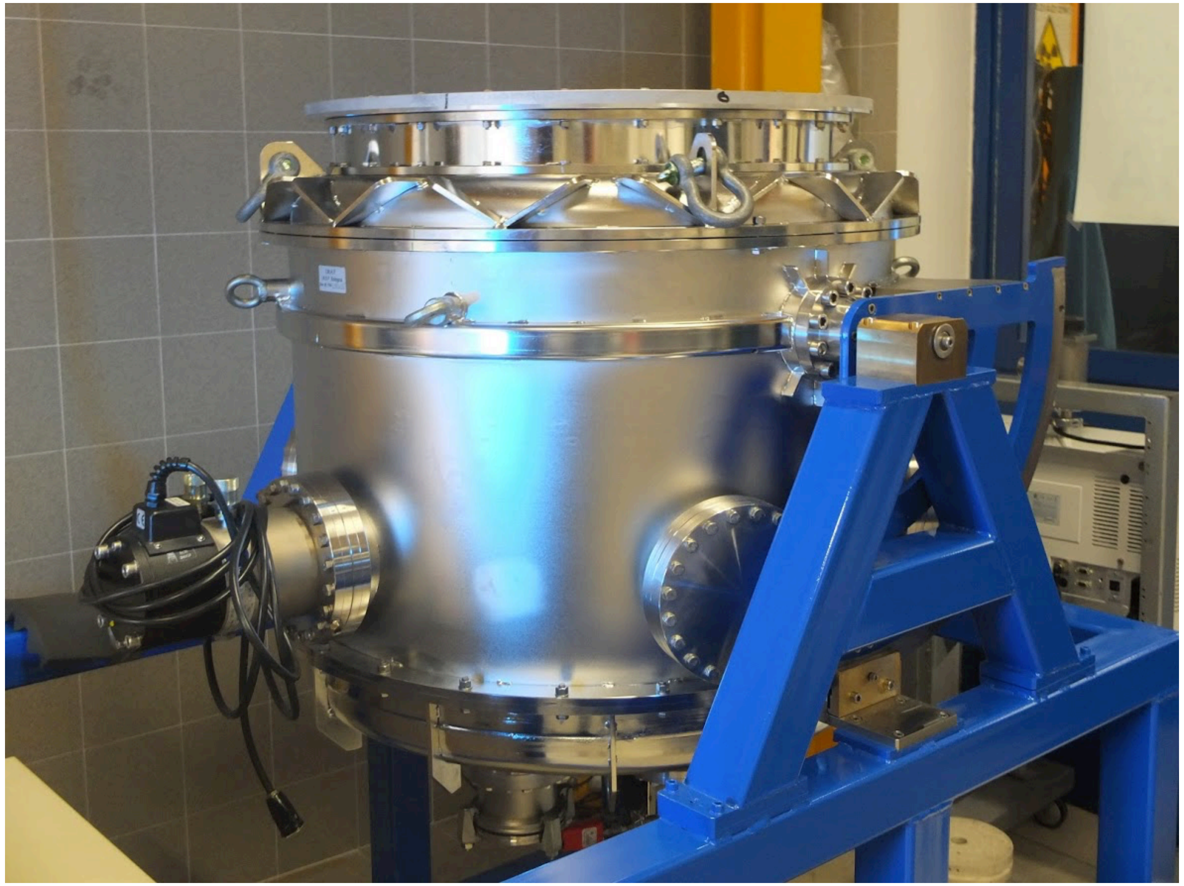




SYSTEM ACTIVITIES

Cryogenics and thermal engineering

- **Cooling and thermal control is mandatory to reach and exploit the performances at the best**
  - the instrumentation (amplifiers, antennas, filters, etc.
- **Cryogenics is required in technologies form radio-waves to gamma-ray**
- **Thanks to Planck heritage (at the moment the most advanced cryogenic satellite ever) INAF has a unique expertise in Italy to manage complex cryogenic systems in spaces and on-ground**



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System engineering and AIV

- Best practices of SE are fundamental to efficiently and successfully develop complex systems
- No way to develop instruments and experiments without SE approach
- ECSS standards are reference for technical management and big consortia
- INAF is the only Institute in Italy in which SE and AIV best practices are fully applied for the development of CMB experiments.

European Cooperation for Space Standardization

VERIFICATION VALIDATION & TESTING

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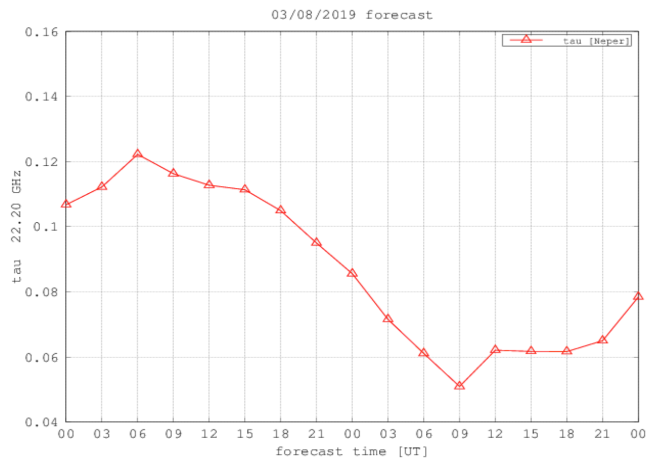
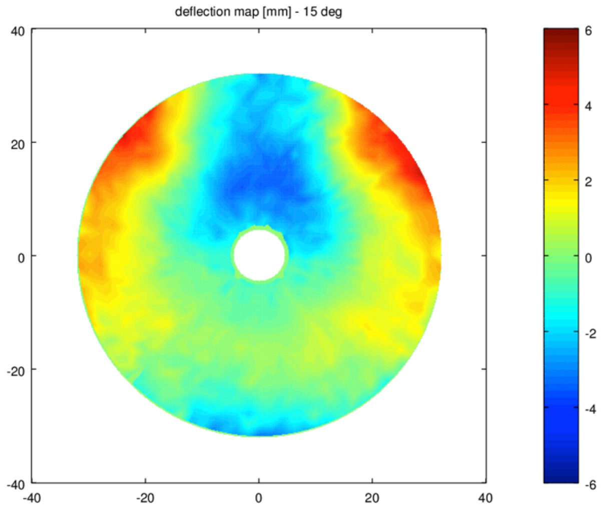
Site Testing, Metrology and RFI

- **Site testing**
  - Monitoring and forecast
  - Microwave radiometer
- **Gravitational and thermal deformations**
  - Photogrammetry
  - Holography
- **RFI monitoring**
  - Mobile station
  - Fixed station





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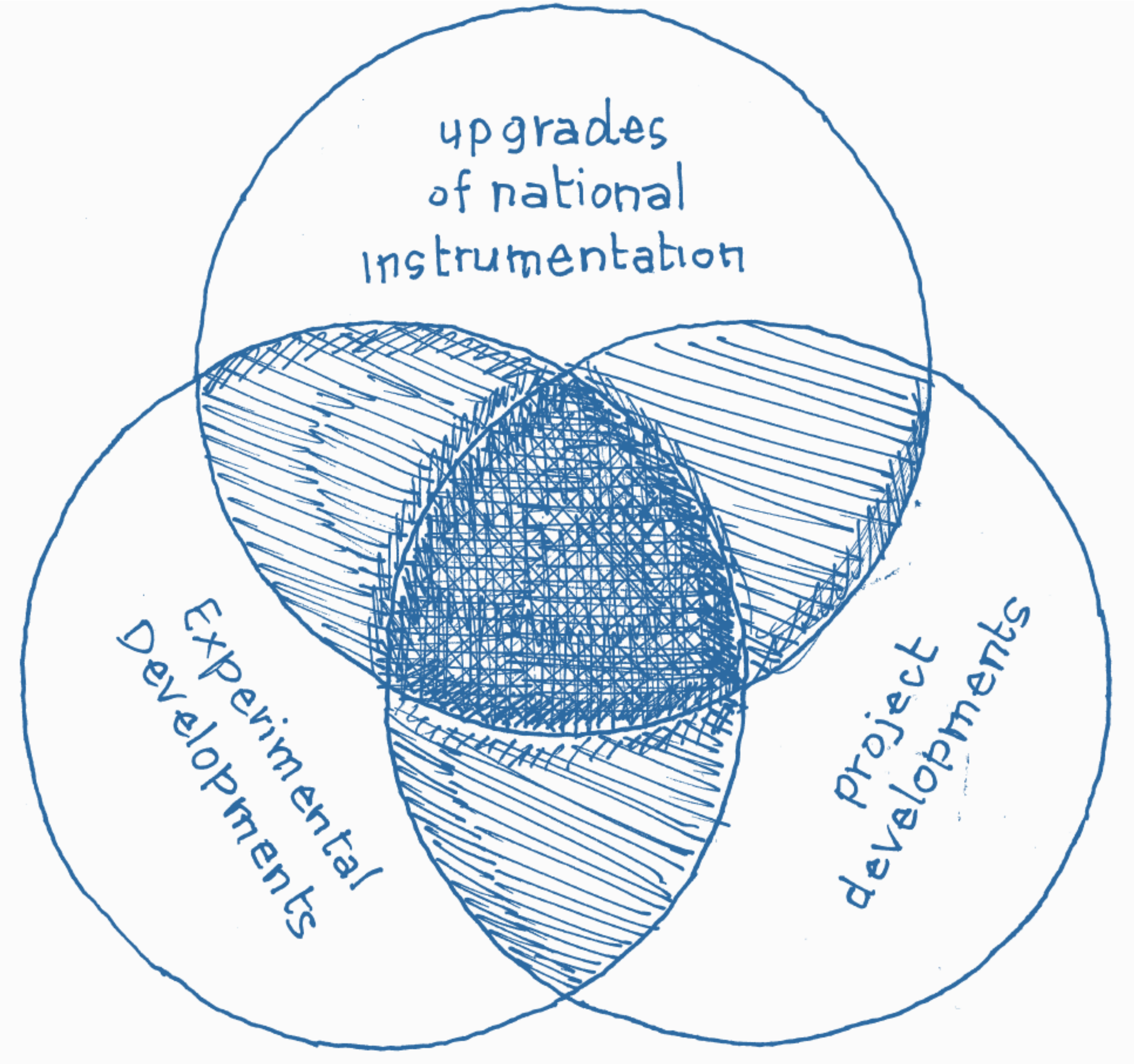
Involved INAF Labs and Institutions

- **OAS Bologna - Cryowaves**
  - Assembly integration and test, advanced cryogenics
- **OAC Cagliari**
  - RF tests, cryogenics, support to SRT
- **OAA Arcetri**
  - RF tests on passive components and antennas
- **IRA Bologna, Medicina**
  - RF tests, electronics, support to SKA and Medicina telescope
- **OACt Catania**
  - Electronics

Sharing of technologies is the way for INAF to jump towards the future



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Conclusions

- Technology activities and experimental developments are well developed and managed by INAF thanks also to a close collaboration with industrial partners
- Involvement on big projects with hardware development is fundamental
- **In this field INAF is able to conduct, manage and cover (technical) most of the experimental developments in this field**
- Reinforce the ability to develop prototype instrumentation, reinforce laboratory facilities since this will open doors to future projects. Experimental and Technology involvement in projects will reflect on involvement also in Science projects.

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