Next steps in radio astronomy INAF technologies

Giornate INAF - Capodimonte 2-5 Maggio
Sessione: New challenges and future perspectives
Speaker: Jader Monari

Istituto di Radioastronomia

Framework

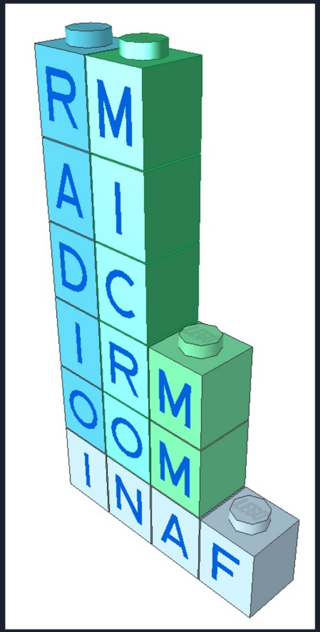
- We cover from **few MHz to hundred GHz** a really tiny fraction of EM spectrum but a **very big difference in technology and methods**
- **INAF** has collected **long tradition and experience** in developing **RF/Microwave and mm-wave technology**, instruments, and experiments
- Through national facilities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

2023 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

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

- Italian Radio Facilities
  - **S**ardinia **R**adio **T**elescope (PON-PNRR)
  - **NOTO** radio telescope (PON-PNRR)
  - **MEDICINA** radio telescopes Northern Cross and 32m Dish (PNRR-SST-FRB-PON)
- **SKA** (SKAlow/Mid, Meerkat+)
- **LOFAR2** (station @ Medicina)
- **ALMA**
- Others mm projects (SOLARIS, LSPE-STRIP, LiteBIRD, TMS)



INAF Labs and Institutions
"Radio" Design&Verification capabilities

Design for high and low frequency antennas elements

ELM simulations of dense/sparse arrays

Analogue conversions and conditioning systems

Radio over Fibers analogues systems

High performances multi ADC and high speed processing systems

Digital beamformers, spectrometers, polarimeters

ELM DESIGN Antenne	Mechanic, electromechanics
Analogue Systems Receivers	FW & SW
Backends	Test and Verification

SYSTEM ENGINEERING & MANAGEMENT

Cryogenics dewards

High precision steerable systems for antennas, minor and major servo systems

Mirrors and active surfaces to improve high frequency capabilities

Tools for radioastronomical observations

FPGA programming

Processing and data archiving

High accurate test benches for RX characterization

Development and testing of innovative techniques (i.e. UAV)

Material studies or subsystems development (i.e. cold load)

IRA Bologna
OACt Catania
OAA Arcetri
IRA Medicina
OAC Cagliari
OAS Bologna

RFoF – common «link» between projects (and years)

2007

32 RF downlink for BEST SKADS demonstrator

1GHz, Tekmar/Andrew

2013

4 IF downlinks for Medicina VLBI dish

2GHz, Protech

2015

16 IF downlinks for SRT K-band multifeed

2GHz, Optel

2017-2021

100 RF downlinks for SST and 10 RF/IF downlinks for Noto

2GHz (shared design for both projects), Protech

2022

38 RF/IF downlinks for SRT prime/gregorian focus

4GHz, SELT

2016-?

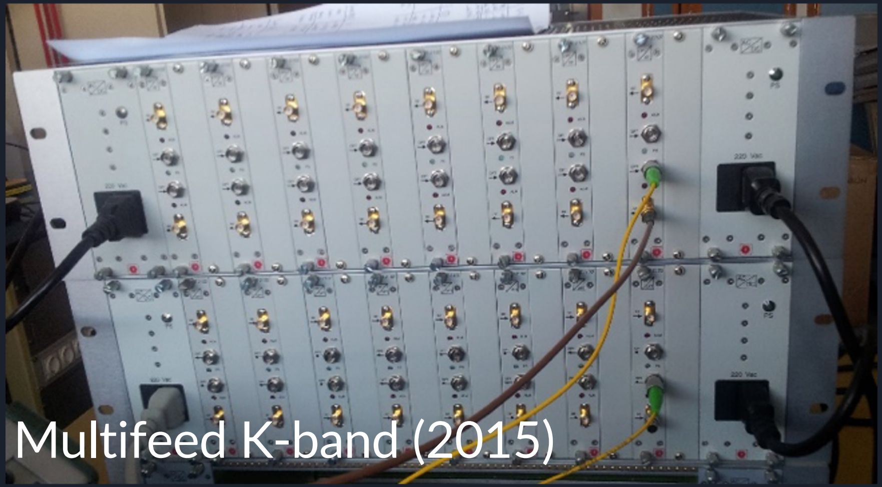
512 RF downlinks for SKAlow demonstrators,

650/350MHz, Optel/Protech

2022-?

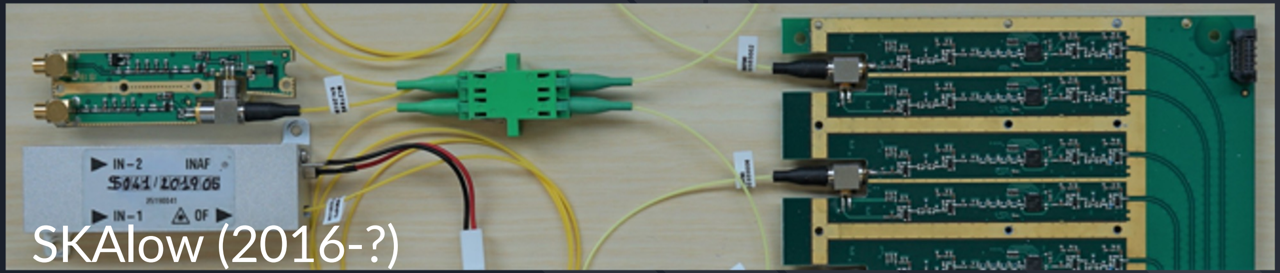
38 IF downlinks for SRT Q&W multifeed

18GHz, SELT



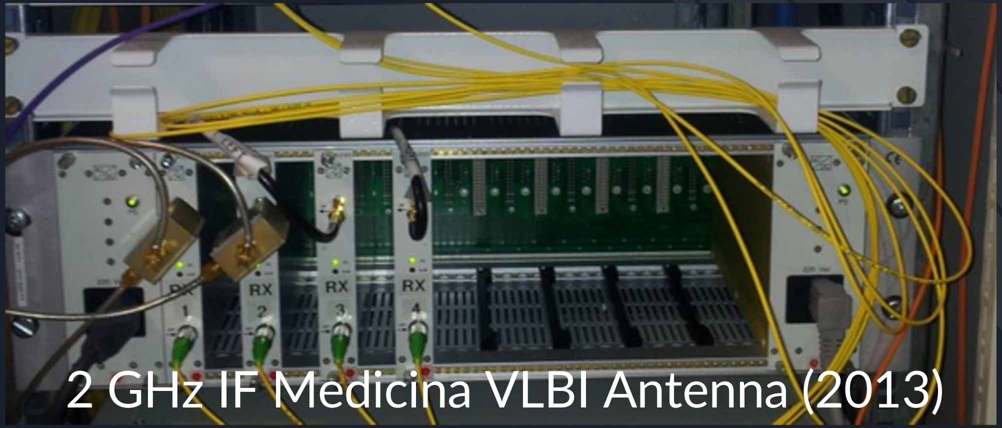
Multifeed K-band (2015)

500MHz Northern Cross (2013)



SKAlow (2016-?)

4GHz SRT (2022)



2 GHz IF Medicina VLBI Antenna (2013)

Italian radiotelescopes dishes

SRT 64m					
RX	RF Band [GHz]	Out Band [GHz]	Pixel per polarizzazione	polarizzazione	Stato
LP coassiale	0.305-0.410	0.305-0.410	1 x 2	H/V o L/R	Operativo
	1.3-1.8	1.3-1.8	1 x 2	H/V o L/R	Operativo
C_{high}	5.7-7.7	0.1-2.1	1 x 2	L/R	Operativo
K	18-26.5	0.1-2.1	7 x 2	L/R	Operativo
X-ASI	8.2-8.6		1 x 1		Operativo
S	3-4.5	0.3-1.8	7 x 2	H/V	In costruzione
C_{low}	4.2-5.6	0.1-1.5	1 x 2	L/R	In costruzione
Q	33-50	2-18	19 x 2	L/R	PON
W	75-116	4-12	16 x 2	H/V	PON
3-band	18-26	2-18	1 x 2	L/R	PON
	34-50	2-18	1 x 2	L/R	
	80-116	2-18	1 x 2	L/R	
W bolometro	80-115	/	400	/	PON

RICEVITORI AL SARDINIA RADIO TELESCOPE

MEDICINA 32m					
RX	RF Band [GHz]	Out Band [GHz]	Pixel per pol.	Pol.	Stato
L	1.58-1.71	0.29-0.43	1 x 2	L/R	Operativo
	1.35-1.45	0.29-0.43	1 x 2	L/R	Operativo
SX coassiale	2.2-2.36	0.1-0.5	1 x 2	L/R	Operativo
	8.1-8.9	0.1-0.9	1 x 2	L/R	Operativo
C_{low}	4.3-5.8	0.1-0.9	1 x 2	L/R	Operativo
C_{high}	5.9-7.1	0.1-0.9	1 x 2	L/R	Operativo
K	18-26.5	0.1-2.1	2 x 2	L/R	Operativo
Ku	13.5-18	0.1-2.1	2 x 2	L/R	In costruzione
3-band	18-26	2-18	1 x 2	L/R	PON
	34-50	2-18	1 x 2	L/R	
	80-116	2-18	1 x 2	L/R	

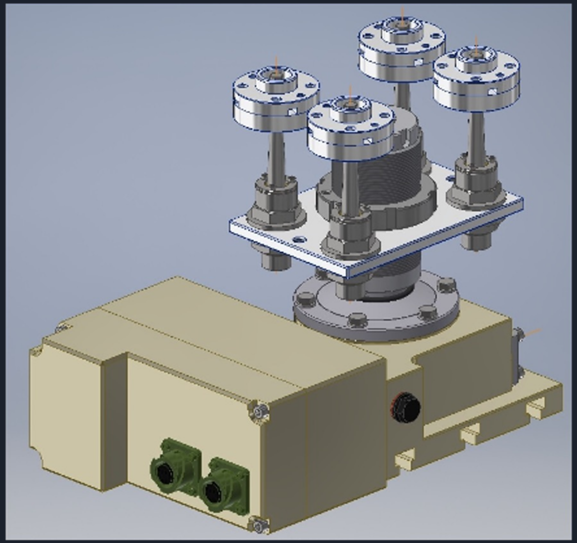
RICEVITORI AL MEDICINA RADIO TELESCOPE

NOTO 32m					
RX	RF Band [GHz]	Out Band [GHz]	Pixel per pol.	Pol.	Stato
L	1.58-1.71	1.58-1.71	1 x 2	L/R	Operativo
	1.35-1.45	1.35-1.45	1 x 2	L/R	Operativo
SX coassiale	2.2-2.36	2.2-2.36	1 x 2	L/R	Operativo
	8.1-8.9	0.1-0.9	1 x 2	L/R	Operativo
C_{low}	4.6-5.0	0.1-0.5	1 x 2	L/R	Operativo
C_{high}	5.1-7.2	0.1-0.5	1 x 2	L/R	Operativo
K	21.5-23	0.1-0.6	1 x 2	L/R	Operativo
3-band	18-26	2-18	1 x 2	L/R	PON
	34-50	2-18	1 x 2	L/R	
	80-116	2-18	1 x 2	L/R	

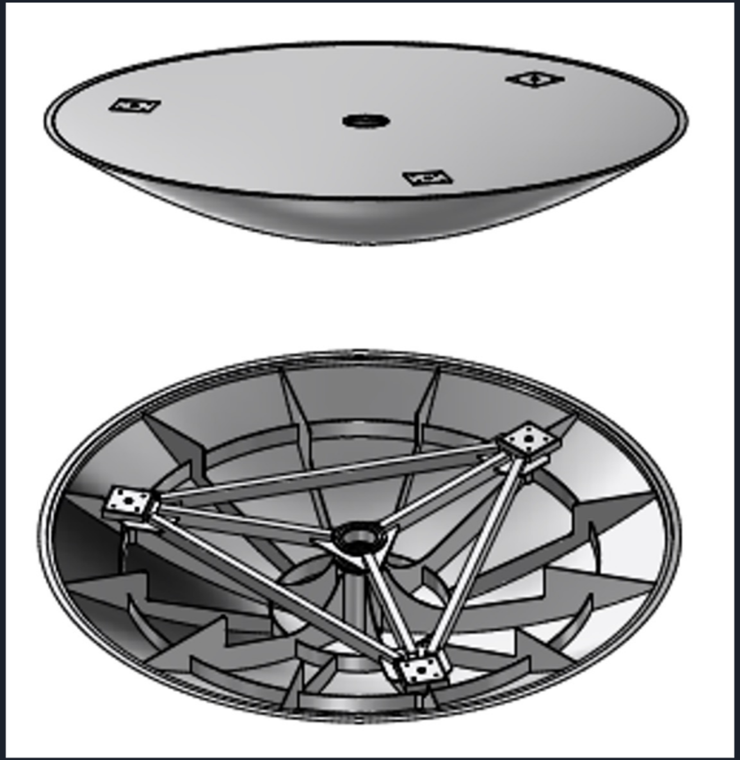
RICEVITORI AL NOTO RADIO TELESCOPE

New active surface

New 244 Aluminum panels forming the primary mirror of the 32m Medicina radio telescope.
Manufacturing rms accuracy: ≤ 65 micron
Delivered.



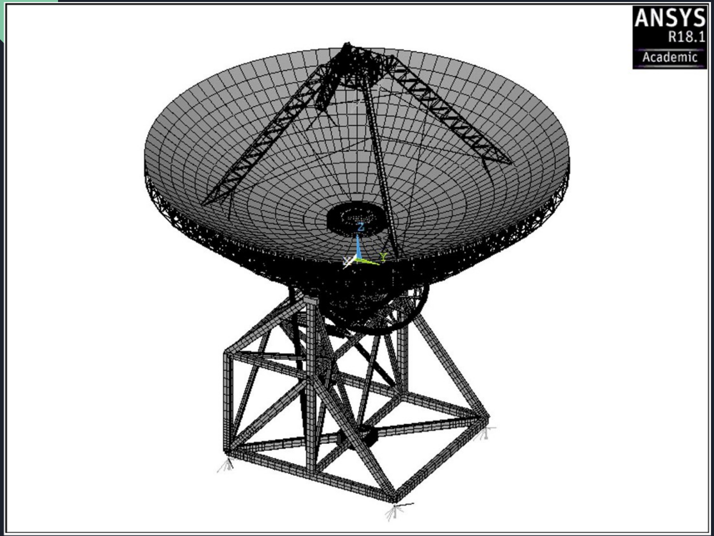
244 electromechanical actuators to be mounted underneath the primary mirror panels of the 32m Medicina radio telescope.
Parts delivered. To be assembled.



New 3.2m secondary mirror for the 32m Medicina radio telescope.
Manufacturing rms accuracy: ≤ 50 micron
Under construction.
One more will be done for Noto radio telescope.

By the active surface, the telescope, with a max observing frequency of 26GHz, will get the capability to observe up to 116GHz, showing an antenna efficieny such to join the Global Millimeter VLBI Network.

FEM – Finite Element Model



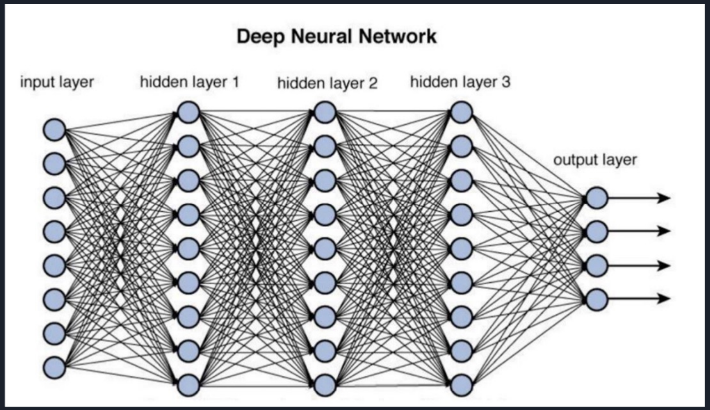
Modeling of the environmental loads effects :

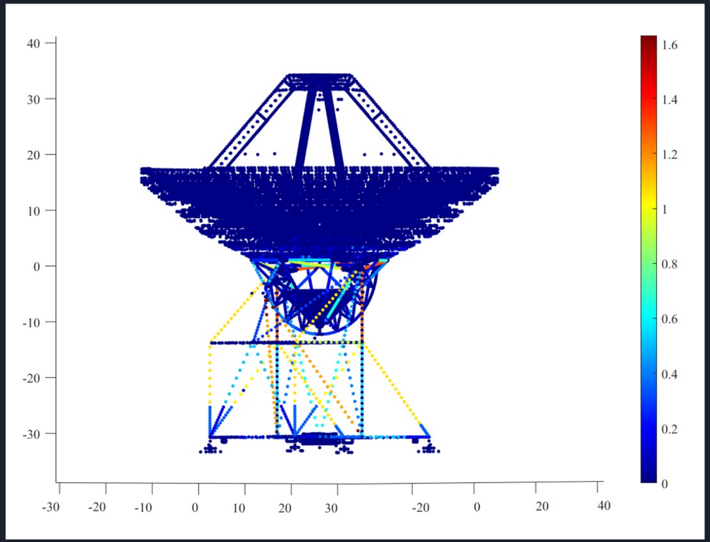
- **Gravitational load**
- **Thermal Loads**
- **Wind**

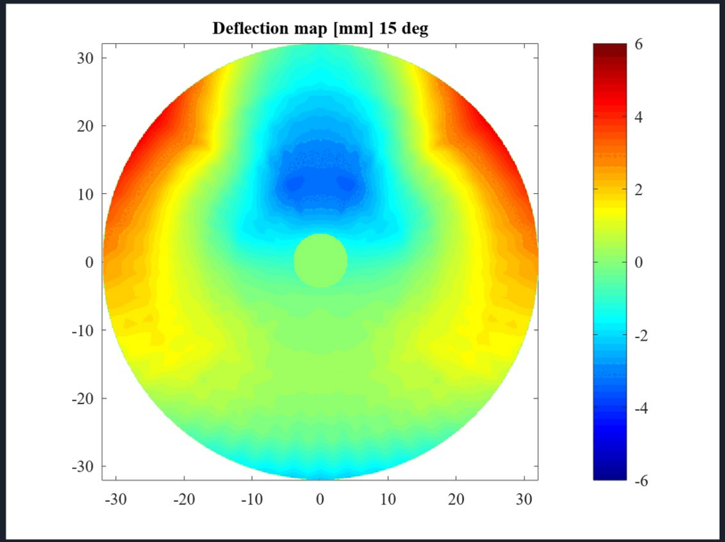
FOCUS: Characterization of

- Pointing Errors
- Large scale deformations on M1 surface

Use of environmental data for simulation of real load scenarios.







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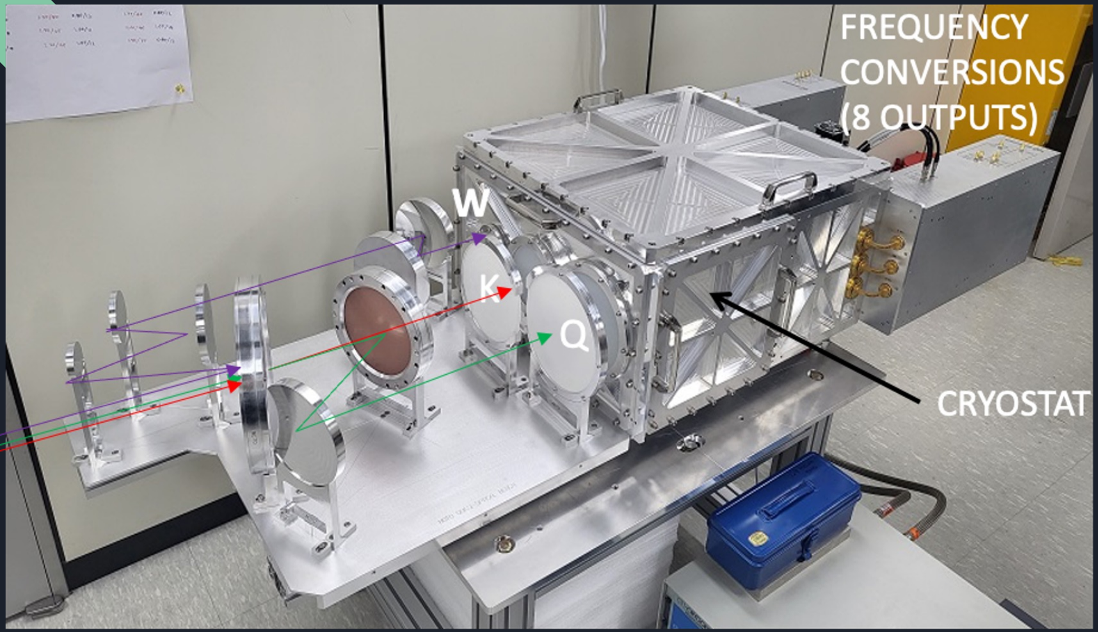
High frequency multi feed/frequency receivers



- SIMULTANEOUS TRI-BAND: 18-26GHz/34-50GHz/80-116GHz
- KASI (Korea Astronomy and Space Science Institute) work with INAF collaboration
- 8 IF outputs in the band 2-18GHz for a total of 128GHz to be processed
- Destination: Medicina, Noto and SRT radio telescopes

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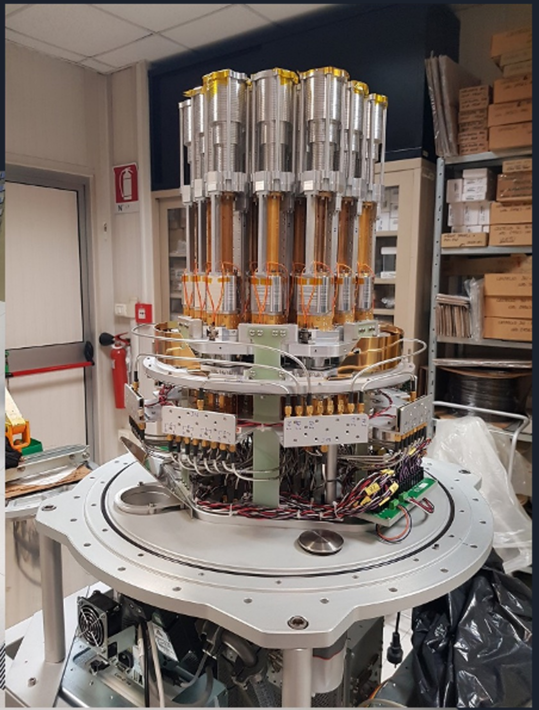
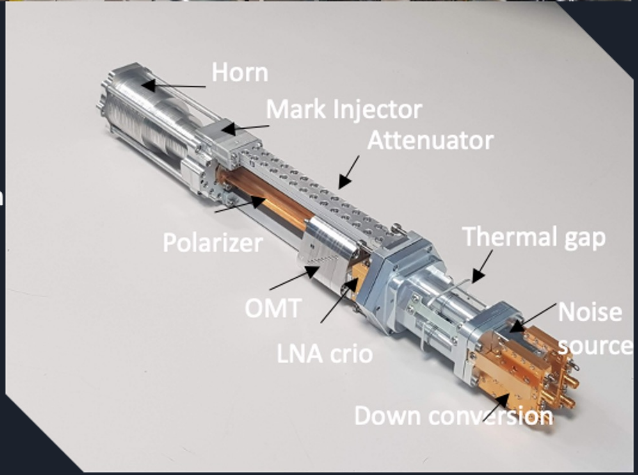
19 pixel chains



Complete receiver

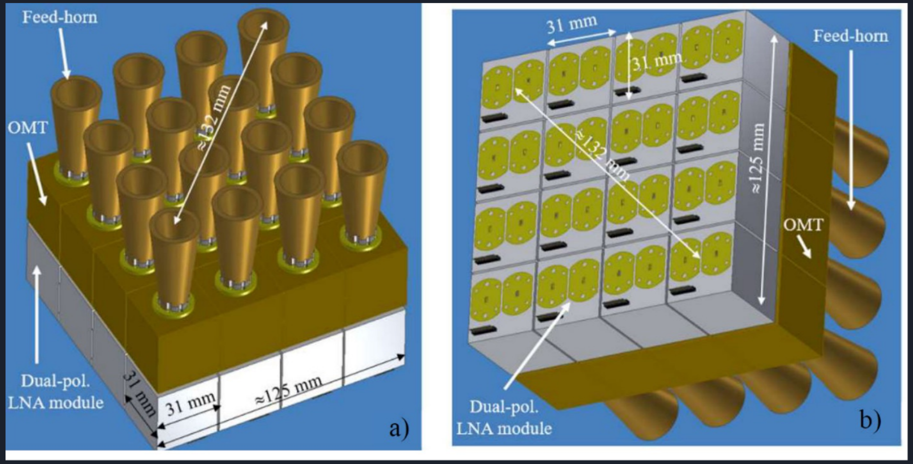
Pixel chain

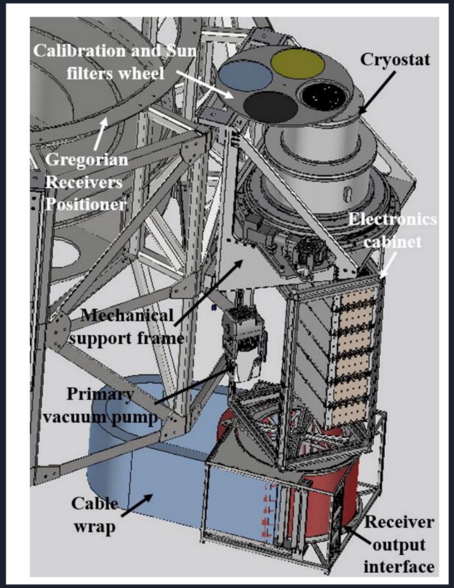


- 19 pixel MULTIFEED 33-50GHz
- INAF design and construction (IRA and OAA) + IEIIT-CNR (mark injector), Manchester Univ. (polarizer)
- 38 IF outputs in the band 1-18GHz for a total of 646GHz to be processed
- Destination: SRT radio telescope

CARUSO (W Band receiver)

- Tender for the supply of a W-band multibeam heterodyne receiver for the Sardinia Radio Telescope awarded to **UK Research and Innovation** (UKRI).
- Array configuration: 4x4 (square lattice). Dual-linear polarization with RF band: 70-116 GHz.
- Angular resolution HPBW 12 arcsec at 93 GHz / angular separation between contiguous feeds: 43 arcsec
- Custom W-band MMIC amplifiers and sub-harmonic image rejection mixers cryogenically cooled at ≈20 K
- Dual-sideband separation (2SB) with two sidebands, LSB and USB, both available at the IF output
- Expected Single Side Band receiver noise temperature <60 K;
- Mechanical derotator to track the parallactic angle
- Science goal: Surveys and spectro-polarimetric studies of galactic and extragalactic sources across W-band





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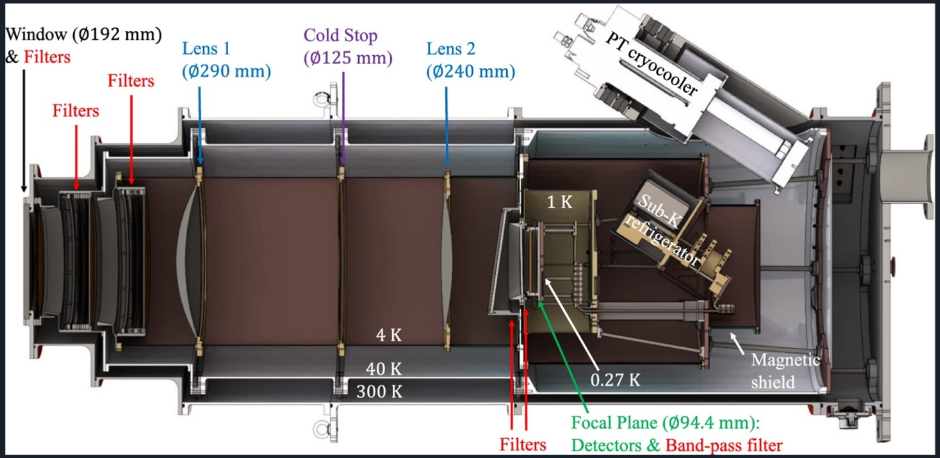
Millimiter Camera (MISTRAL)

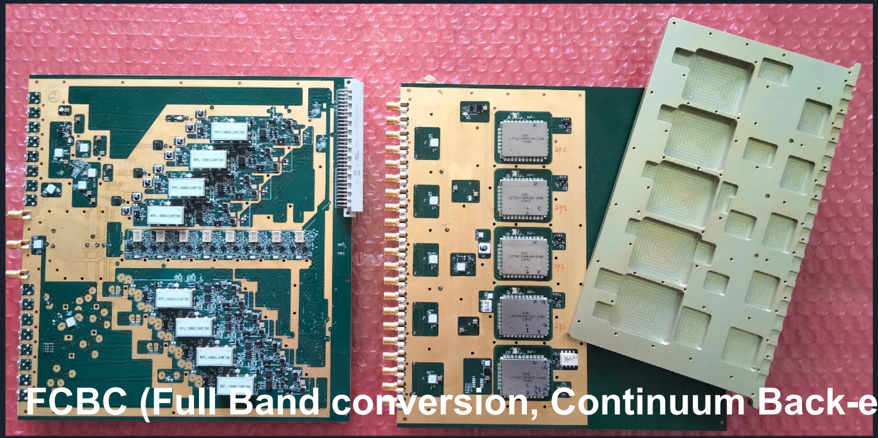


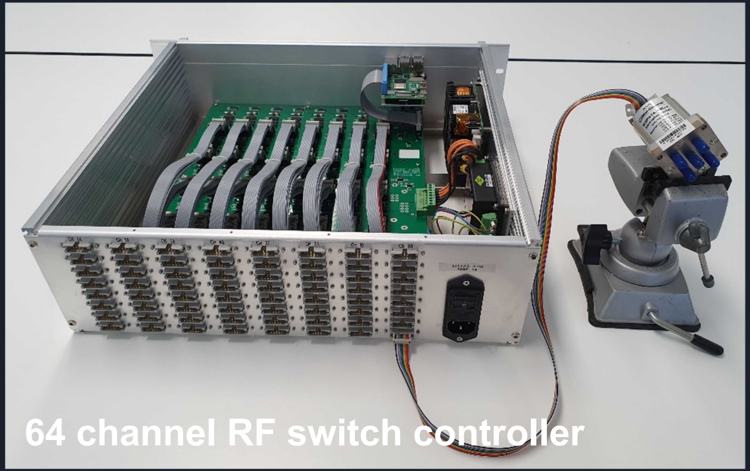
- Tender for the supply of a Millimetric Sardinia radio Telescope Receiver based on Array of Lumped elements MKIDs awarded to Università di Roma La Sapienza.

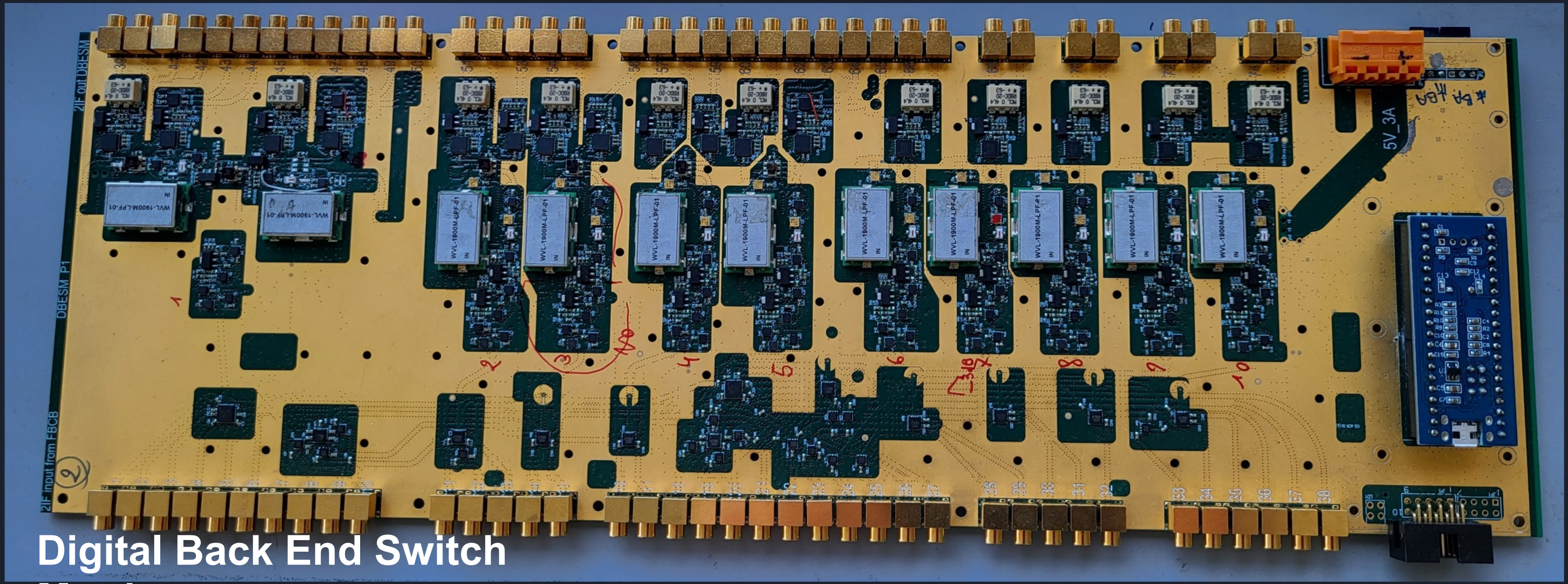
- Detector Layout: 408 pixels, bandwidth: 30 GHz centered at 90 GHz; Field of View = 4 arcmin, resolution 12 arcsec

- Main science cases: Measure of Sunyaev-Zeldovich (SZ) effect in galaxy clusters and filaments, Spectral Energy Distribution of external galaxies, surveys of star forming regions.

Distribution systems

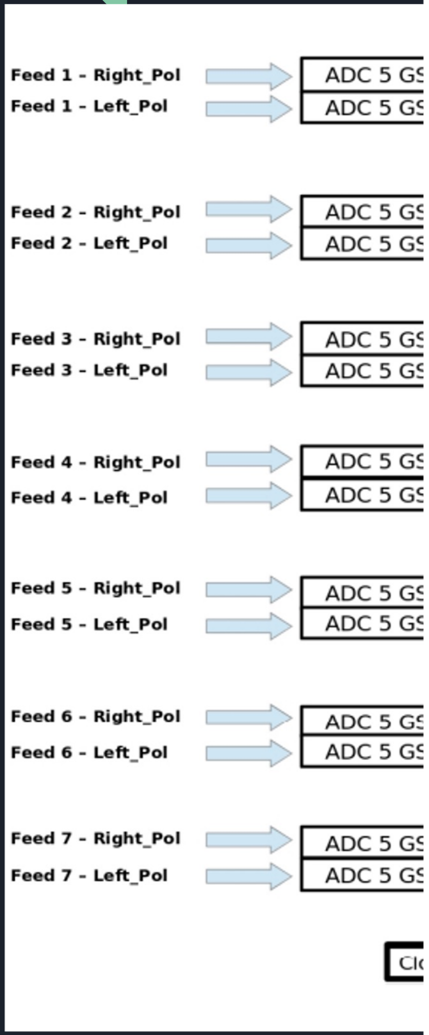

FCBC (Full Band conversion, Continuum Back-end)

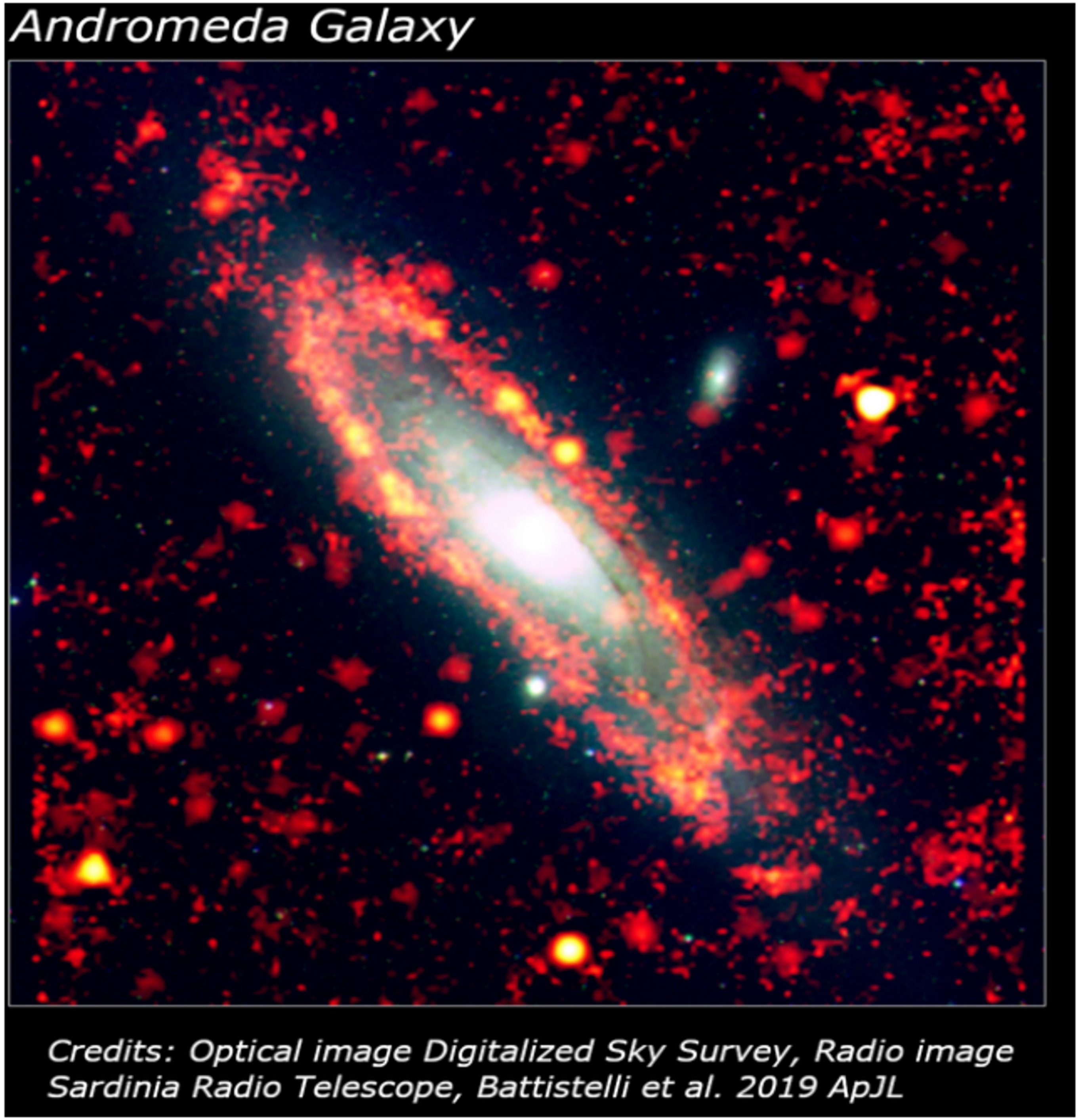

64 channel RF switch controller



Digital Back End Switch
Matrix

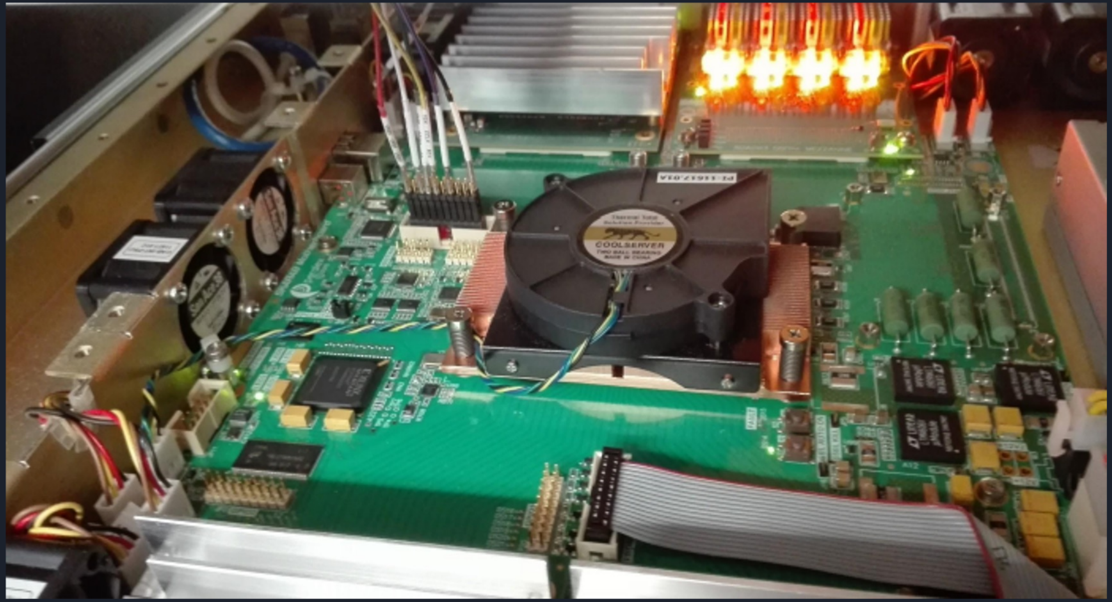
SArd ecture
for R

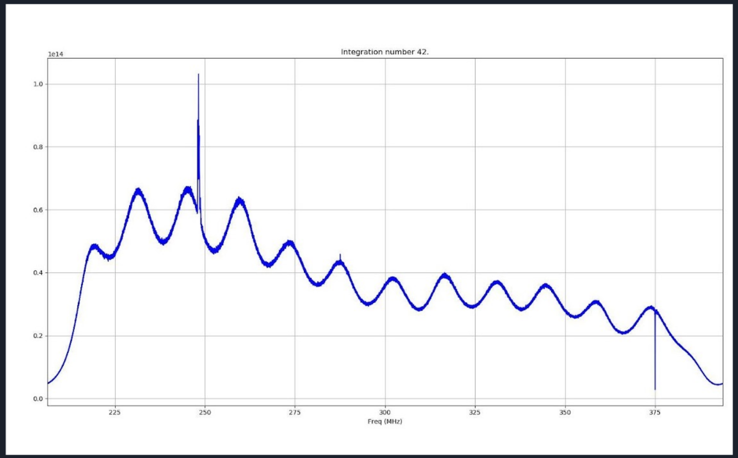




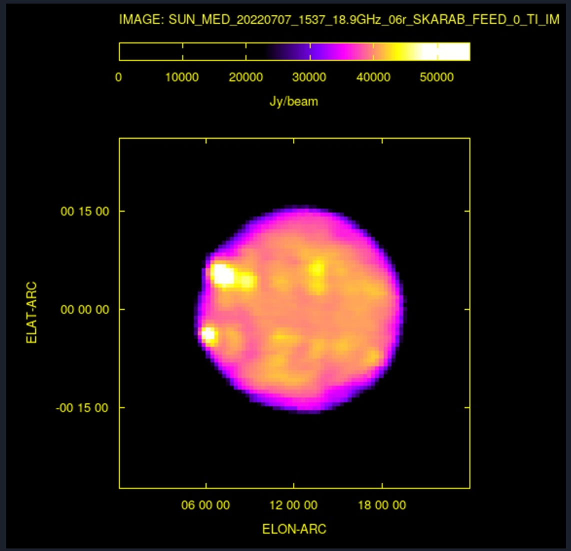
New generation of digital backends

Square Kilometre Array Reconfigurable Application Board (SKARAB)

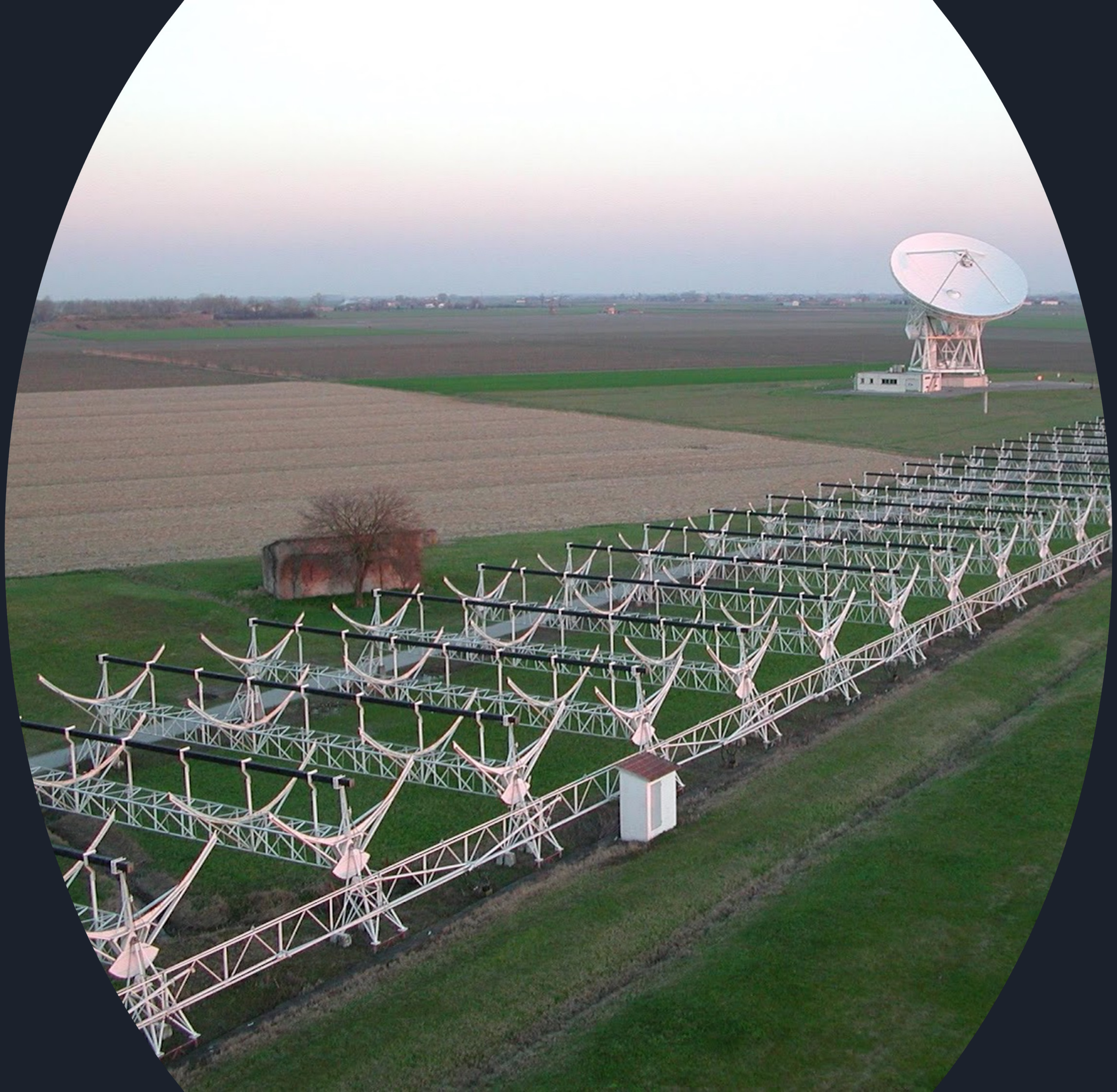


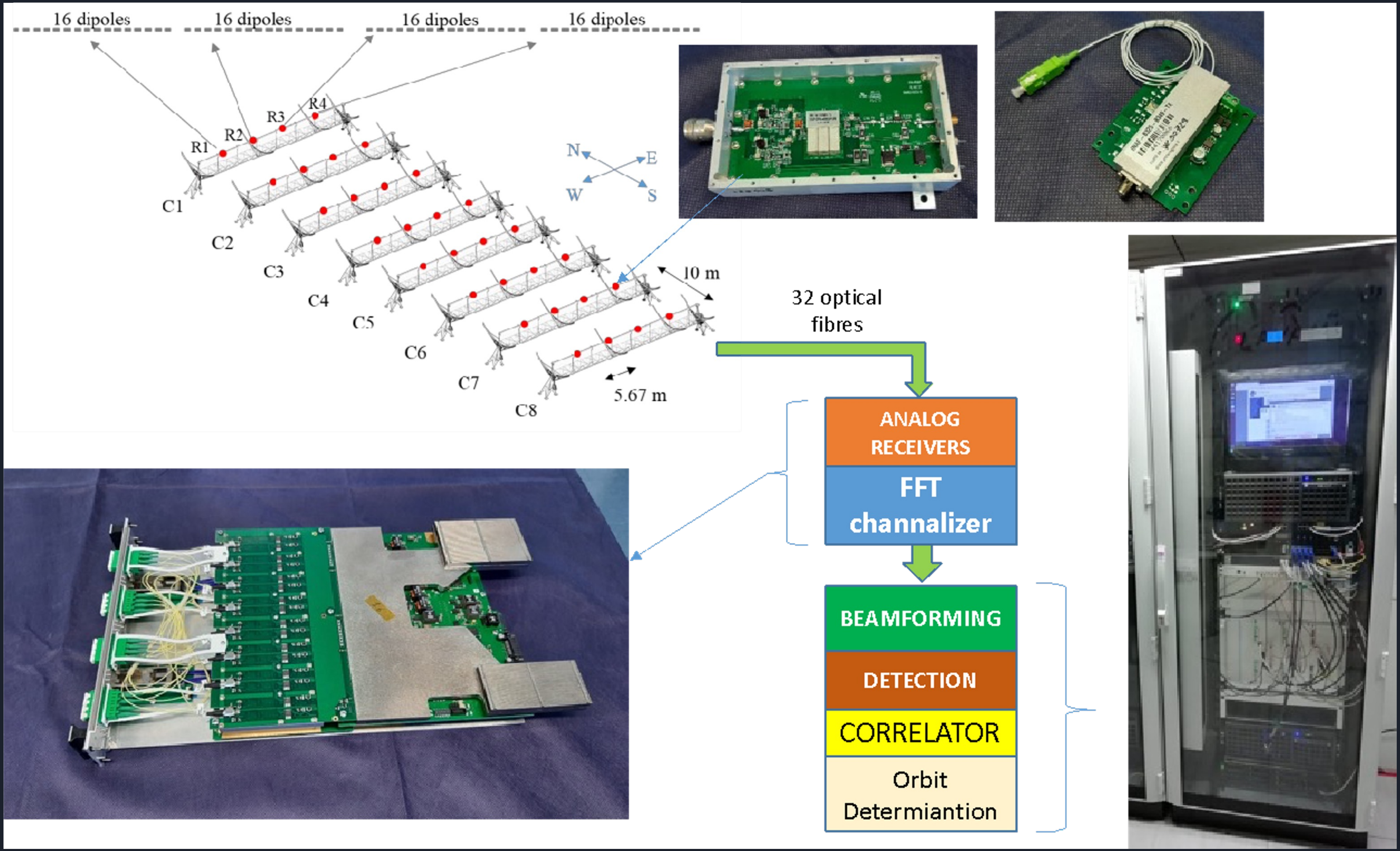


Water MASER in the region of W3OH observed in K-band at Medicina Radio Telescope

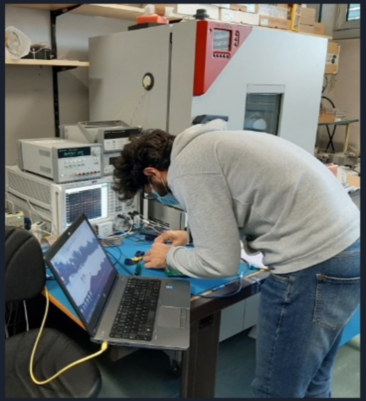


Sun observed in K-band at Medicina Radio Telescope (credit S. Mulas)

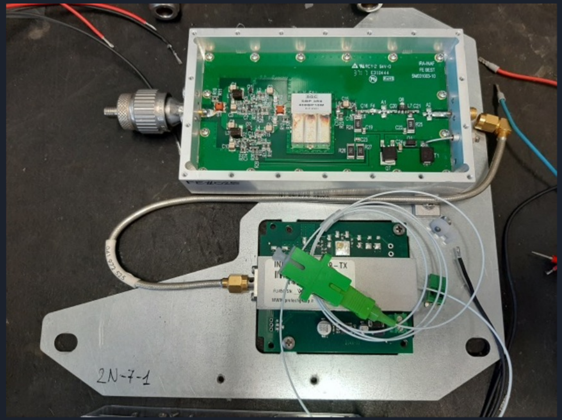



16 dipoles
16 dipoles
16 dipoles
16 dipoles
R1
R2
R3
R4
C1
C2
C3
C4
C5
C6
C7
C8
N
E
W
S
10 m
5.67 m
32 optical fibres
ANALOG RECEIVERS
FFT channalizer
BEAMFORMING
DETECTION
CORRELATOR
Orbit Determiantion

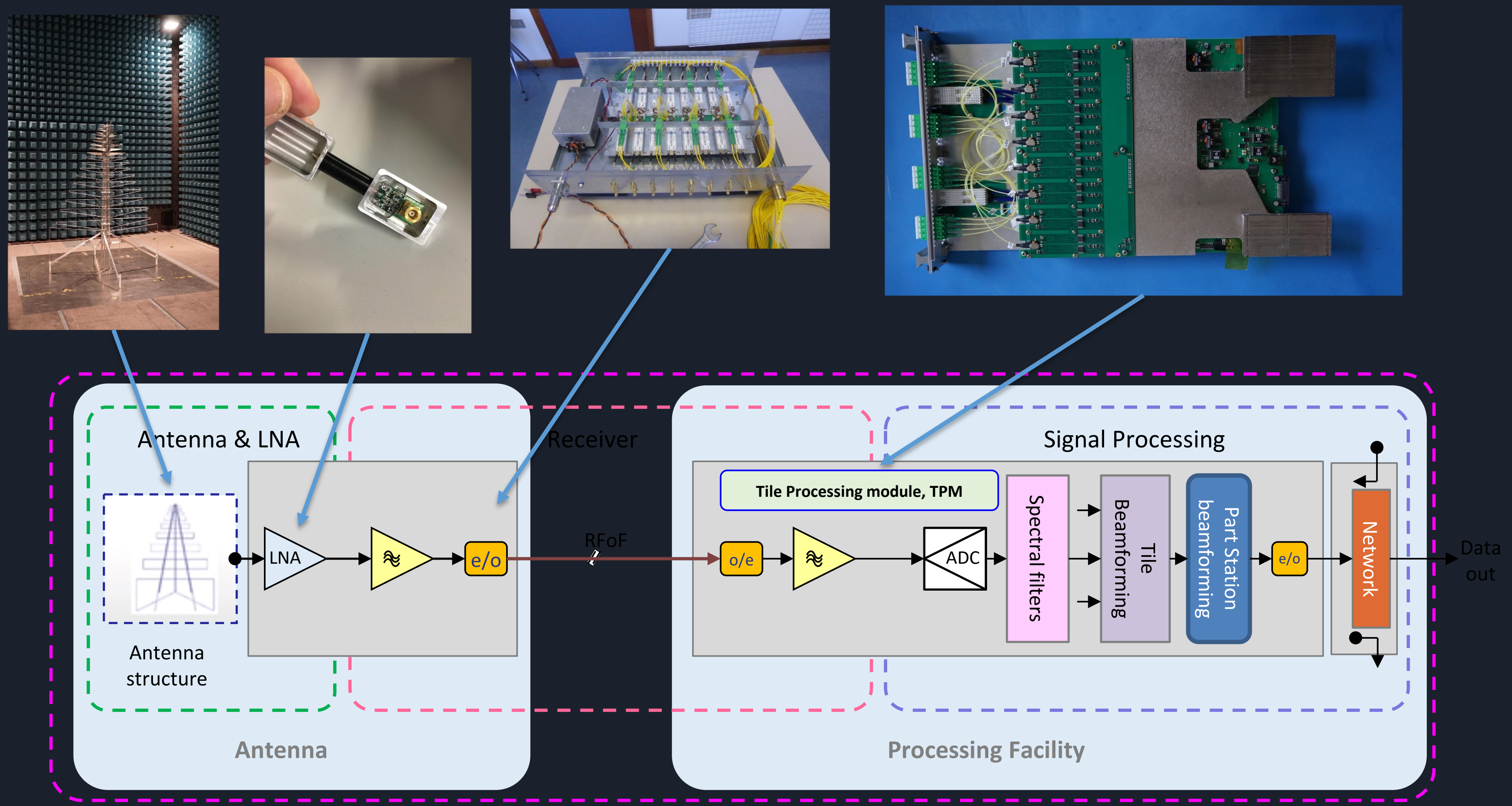
Design, development, test and installation of new receivers for NC

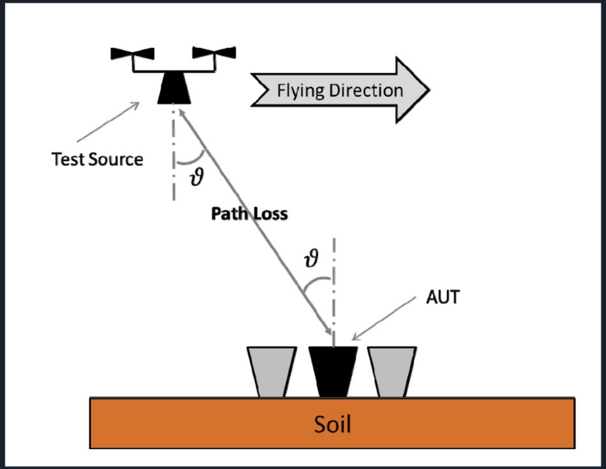


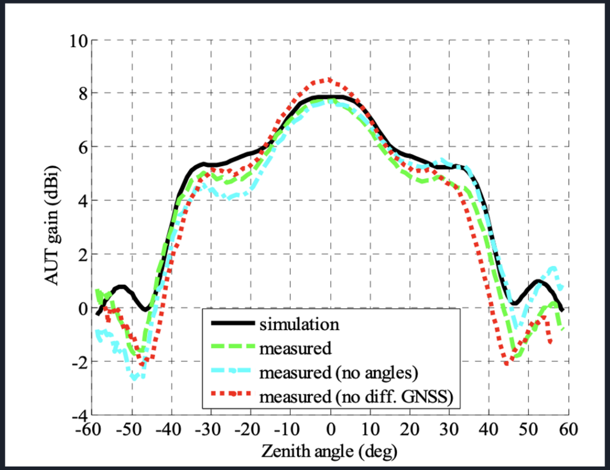



Receiver chain: technology made in Italy



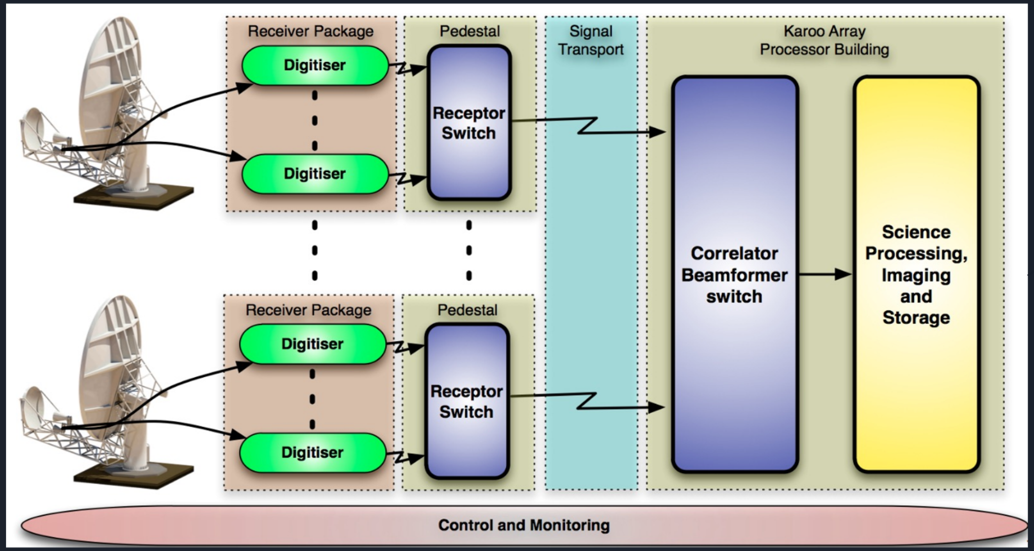
UAV measurement for Low frequency Aperture Arrays





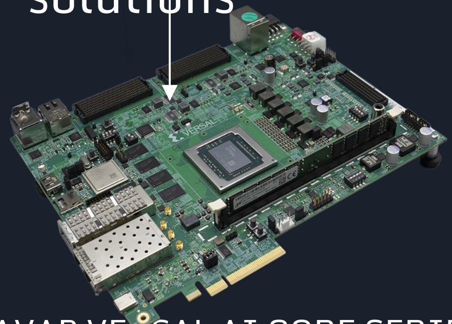
Participation to MeerKat+

Design of correlator



several solutions

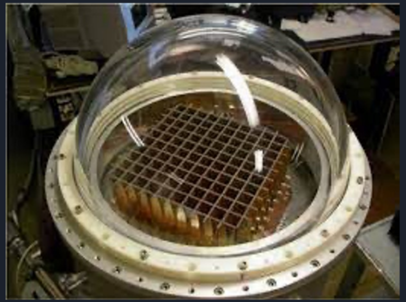
Square Kilometer Array Reconfigurable Application Board (SKARAB)

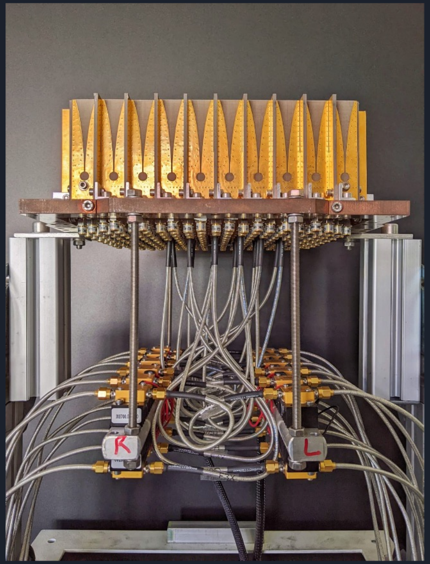


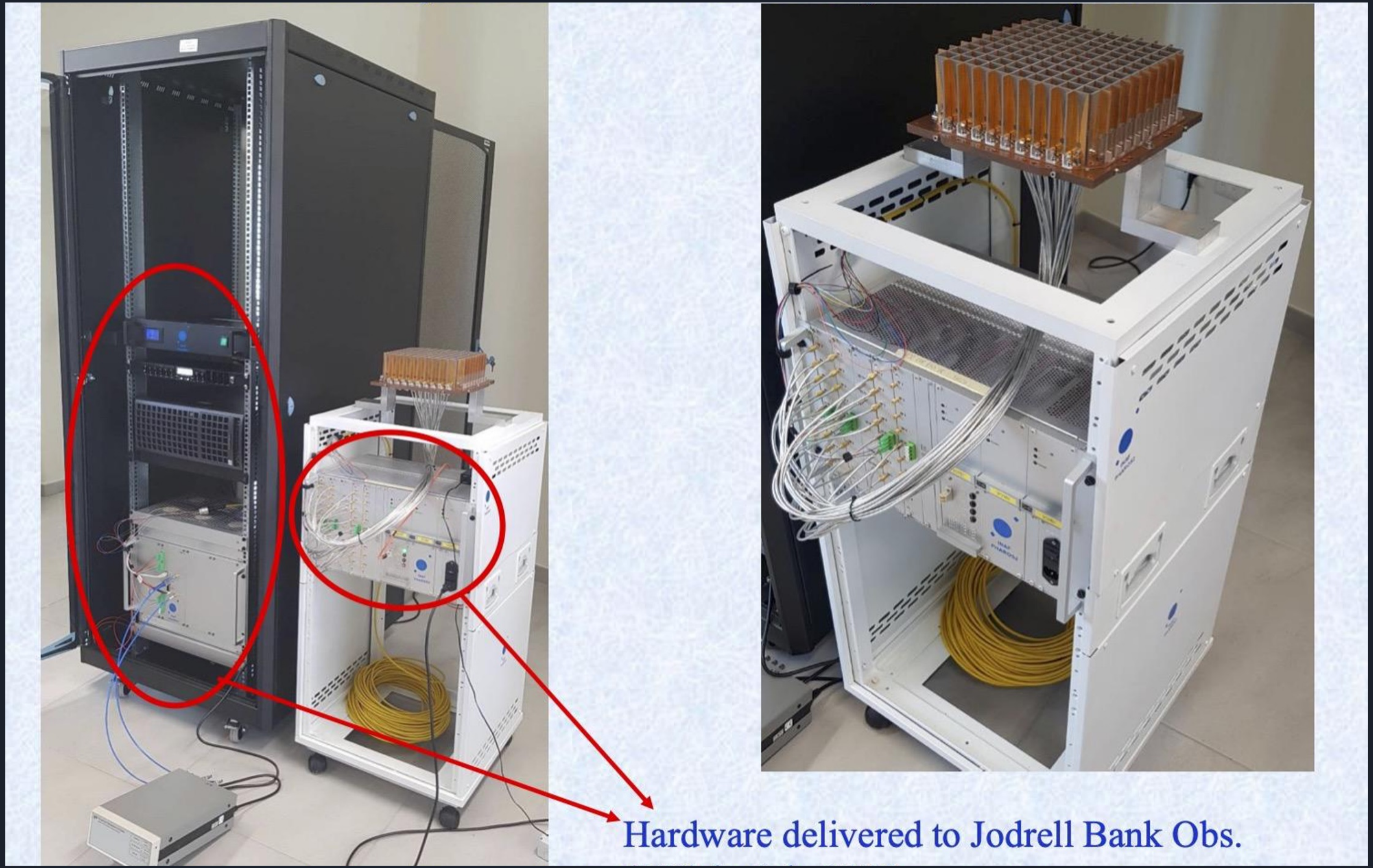
AVAP VERSAL AI CORE SERIES VCK190 - VCK5000

GPU ONLY -Supermicro A+4124-GS-TNR

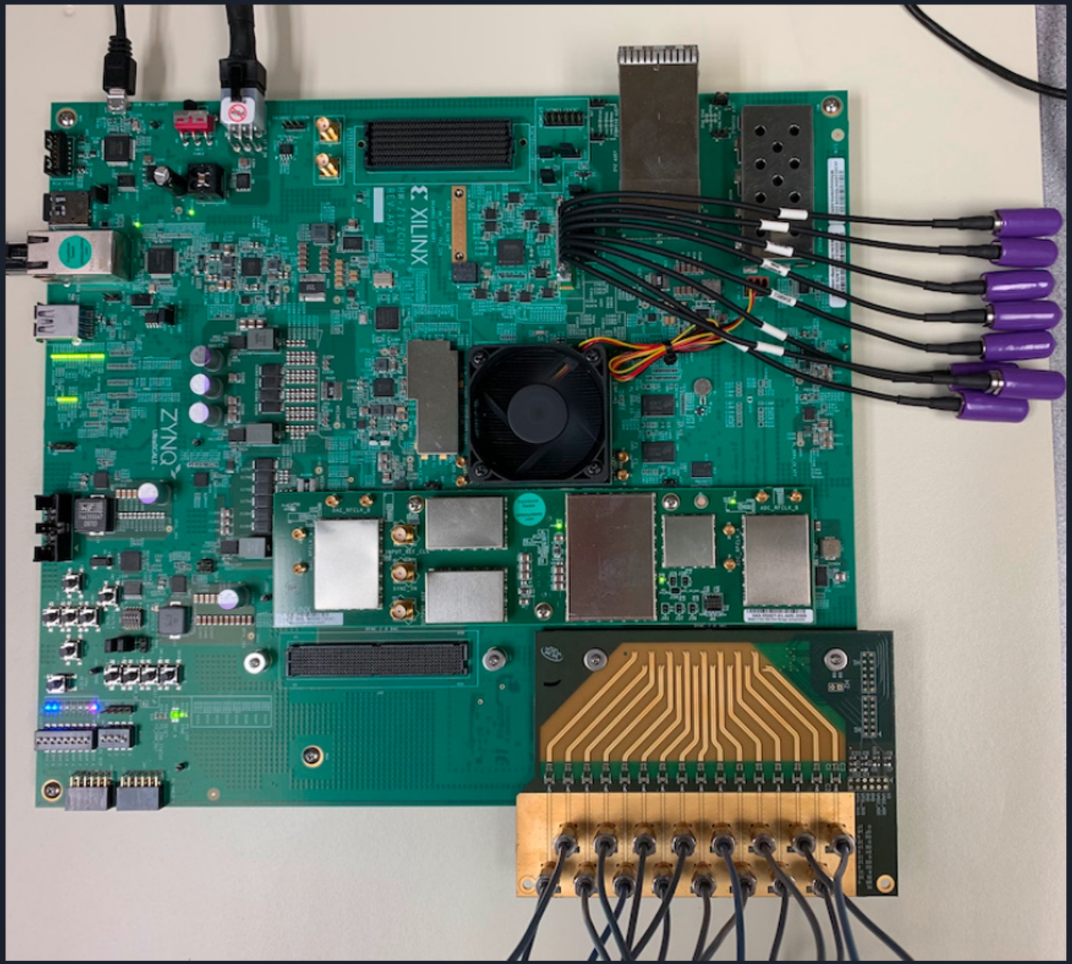
Pharos2: Phased Array Feed (PAF) C Band



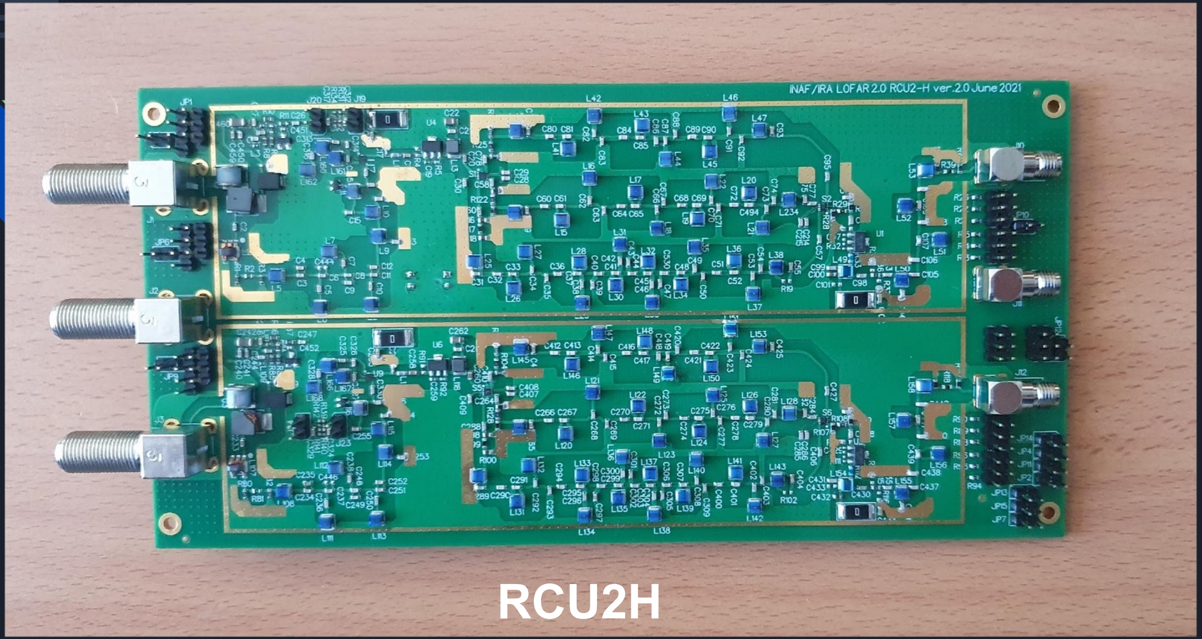


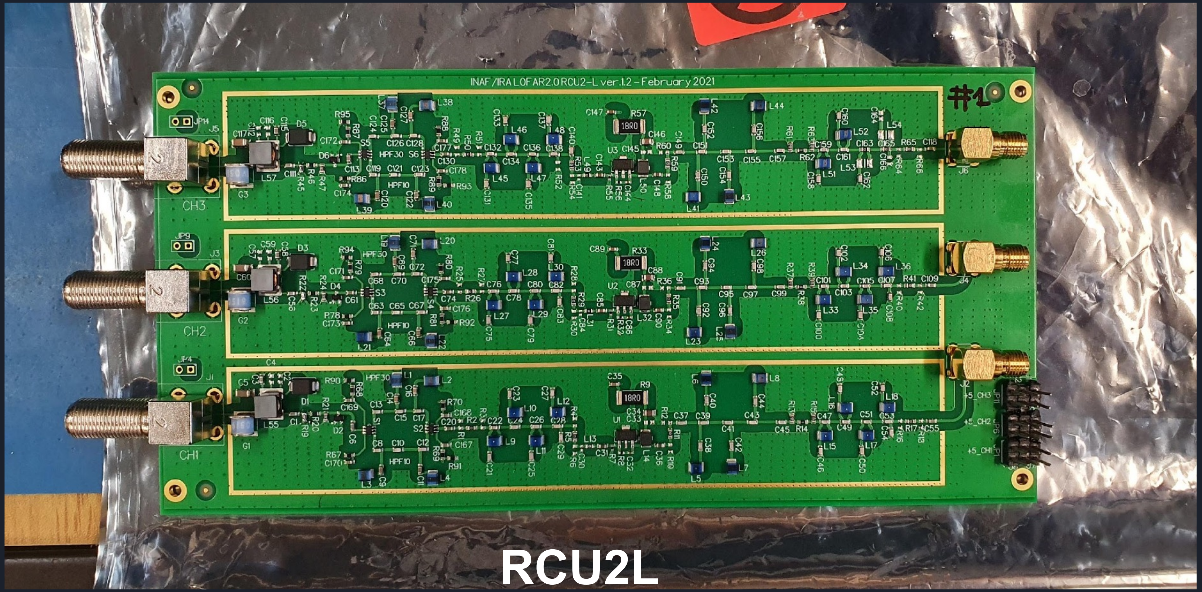


Xilinx Zynq UltraScale+ RFSoC board



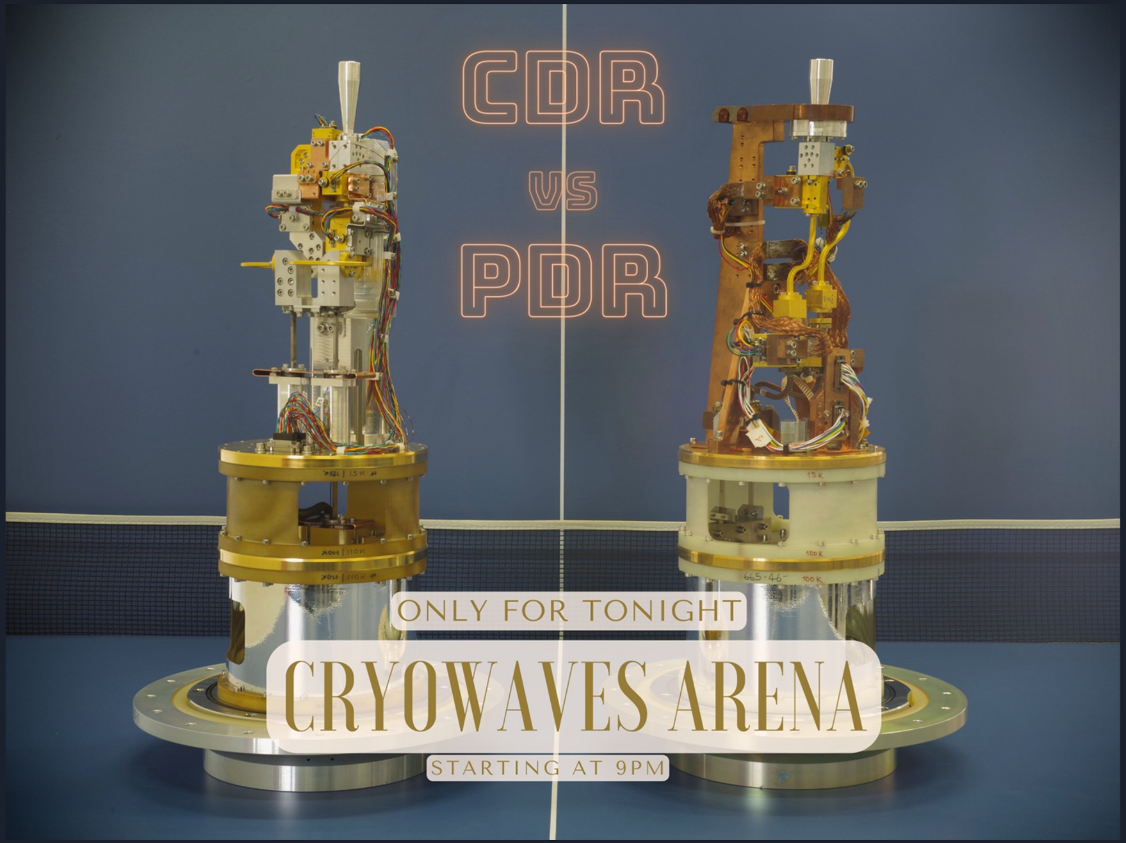
Xilinx Evaluation kit ZCU216:
- 16 inputs, 1.25 GHz BW;
- Each sample coded with 14 bit;
- Max input frequency: 6 GHz;
- I/O capacity: 4x25 Gbps.


INAF/IRA LOFAR 2.0 RCU2-H ver.2.0 June 2021
RCU2H


INAF/IRA LOFAR2.0 RCU2-L ver.1.2 - February 2021
RCU2L

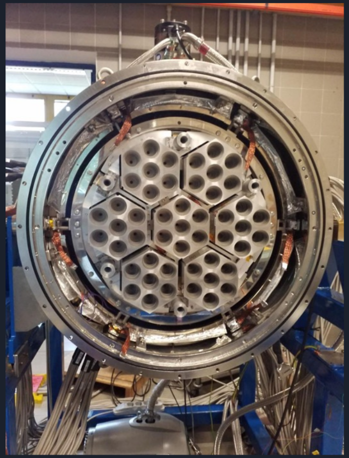
Ultra-wide bandwidth technologies in the mm-wave range

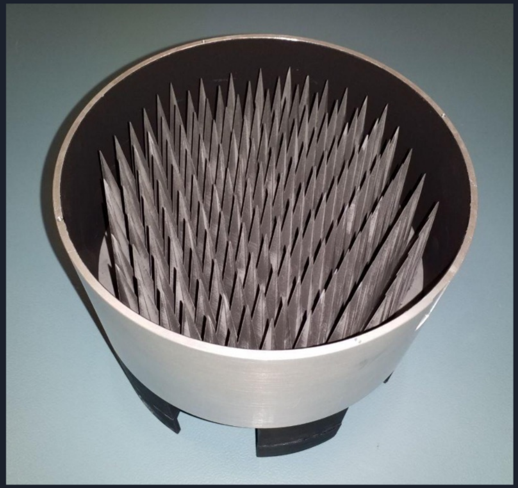
- **ALMA band 2** (+3) developments at **INAF-OAS** and **INAF-OAA** demonstrated the feasibility to develop **ultra wide band receivers** (RF BW > 50%, 2-20 GHz IF output)
    - consolidation of the role of INAF in ALMA developments
    - **production of Band 2 Receiver's cartridges for ALMA**
        - permitted the starting of development studies for ultra-wide-band receivers in other ALMA bands
        - permitted the availability of 'commercial' components in extended W-band (67-116 GHz)
- **Application of technologies for SOLARIS**
    - 67-116 GHz receiver development for Solar observation from Arctic and Antarctica (related to SUNDISH project, MUR and PNRA proposals submitted)
    - upgrade of mm-wave telescopes in Antarctica
- **Future upgrades for ALMA receivers (ALMA 2030 roadmap)**



CMB related developments: Multi-feed focal planes, calibrators and system level activities

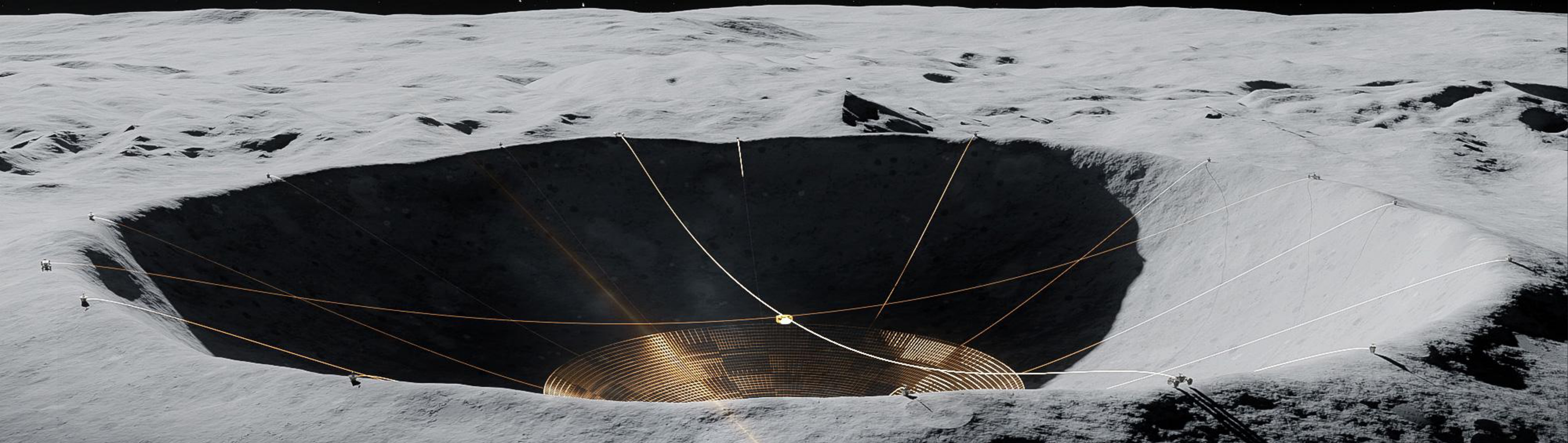
- Internationally recognized expertise in **AIV activities** (management and lab activities) and **System Engineering activities**
  - **LSPE (large Scale Polarization Experiment) / STRIP** telescope to be installed in Tenerife
    - AIV of the 49 Q-band and 6 W-band focal plane cryogenic instrument
    - System engineering of the 1.5 Meter telescope
- Sub system level **technology developments**
  - Development of the cryogenic cold load for **TMS (Tenerife Microwave Spectrometer)**
    - High performance blackbody for precise CMB spectral distortion measurements in the range 10 - 20 GHz .
  - Material characterization (RF and Cryo) for **LiteBIRD** JAXA mission for ultimate CMB polarization measurements
- **Fundamental research in mm-wave technologies**
  - material studies at cryogenics and mm-wavelength
  - study of new calibration facilities and calibration methods





Conclusions

The experience and capabilities exploited by INAF researchers in the field of radio technologies is today recognized internationally thanks to the promotion and efforts and development of the last 20 years in various national and international projects. This allows our young technological researchers to be able to enter even more challenging and ambitious projects with a layer of state-of-the-art knowledge.



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Jader Monari: jader.monari@inaf.it