New Detectors for Radioastronomy

(on behalf of the RADIOINAF group)

Tonino Pisanu

INAF Radio people

Istituto INAF	FTE - RF and Electronic	FTE - Software and firmware	FTE - Mechanical/Electrical/Thermal	FTE - System Engineer	FTE - Total
IRA - Bologna	11	9	5	3	28
OAS - Bologna	2		2	1	5
OA-Cagliari	6	8	3	2	19
OA - Catania	1	2		1	4
OAA-Firenze	7	1		1	9
Total	27	20	10	8	65

CNR-IEIIT Torino
Sapienza Università di Roma
Università degli studi di Milano
Università degli studi di Milano Bicocca

INAF Labs and Institutions ”Radio” capabilities.

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

OAA – Arcetri
OAS - Bologna
IRA – Bologna
OAC – Cagliari
OACt Catania

ELECTROMAGNETIC DESIGN of ANTENNE and PASSIVE SYSTEMS	MECHANICS, ELECTROMECHANICS THERMAL
ELECTRONIC DESIGN OF ANALOGUE AND DIGITAL SYSTEMS	CONTROL SOFTWARE DEVELOPMENT
BACKENDS DESIGN AND FIRMWARE DEVELOPMENT	LABORATORY MEASUREMENT AND VERIFICATION

Design and simulation of antennas, phased arrays and passive components and system with ELM software

Mechanical design of receivers and dewars
High precision steerable systems, minor and principal servo systems Mirrors and active surface to improve high frequency capabilities,
Metrology

Analogue conversion and conditioning systems
Electronic design
microcontroller firmware
simulation RFoF analogue systems

Software Tools for radioastronomical observations, DISCOS
Processing and data archiving

High performance multi ADC and high speed processing systems
Digital beamformers, spectrometers, polarimeters, FPGA programming

High accurate test benches for RX characterization
Anechoic chamber measurements
Development an testing of innovative techniques (i.e UAV)
Material studies or subsystem development

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

- Italian Radio Facilities
  - **S**ardinia **R**adio **T**elescope (PON-PNRR-SST) and SAAD
  - **NOTO** radio telescope (PON-PNRR)
  - **MEDICINA** radio telescopes Northern Cross and 32m Dish (PNRR-SST-FRB-PON)
  - INAF **Laboratories** in Radio/Electronic/Mechanics/Cryogenic/Metrology
- **SKA** (SKAlow/Mid, MeerKAT, MeerKAT+)
- **LOFAR2 (station @ Medicina)**
- **ALMA**
- Other projects (SOLARIS, LSPE-STRIP, LiteBIRD, TMS, COSMOCAL)

INAF - radiotelescope receivers

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

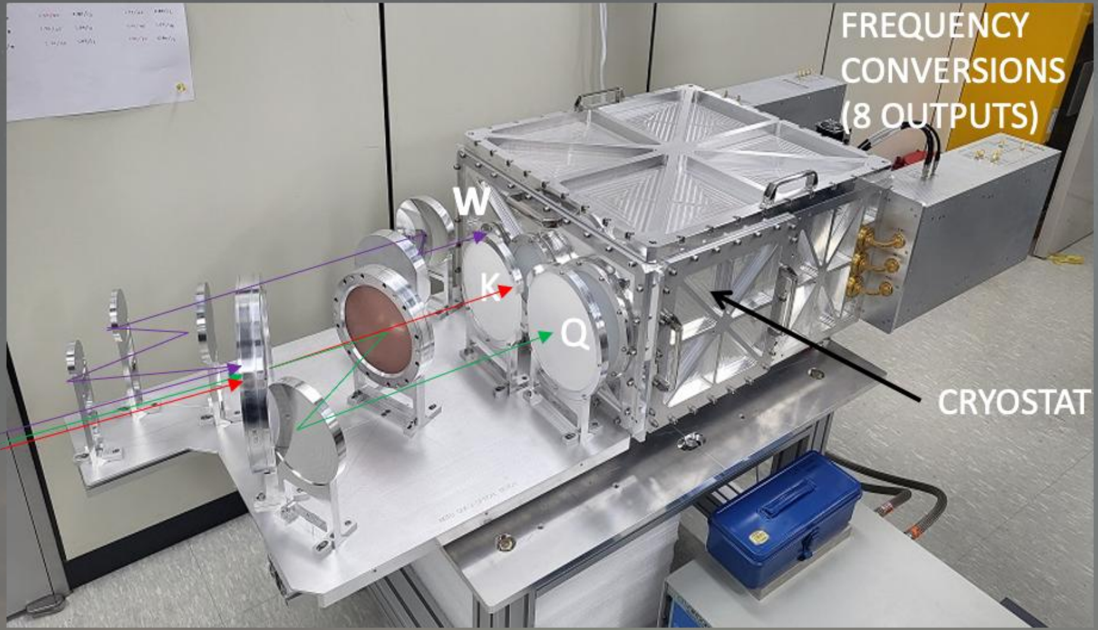
MEDICINA 32m					
RX	RF Band [GHz]	Out Band [GHz]	Pixel per pol.	Pol.	Stato
L	1.58-1.71	0.29-0.43	1 x 2	L/R	Operativo
	1.35-1.45	0.29-0.43	1 x 2	L/R	Operativo
SX coassiale	2.2-2.36	0.1-0.5	1 x 2	L/R	Operativo
	8.1-8.9	0.1-0.9	1 x 2	L/R	Operativo
C_{low}	4.3-5.8	0.1-0.9	1 x 2	L/R	Operativo
C_{high}	5.9-7.1	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

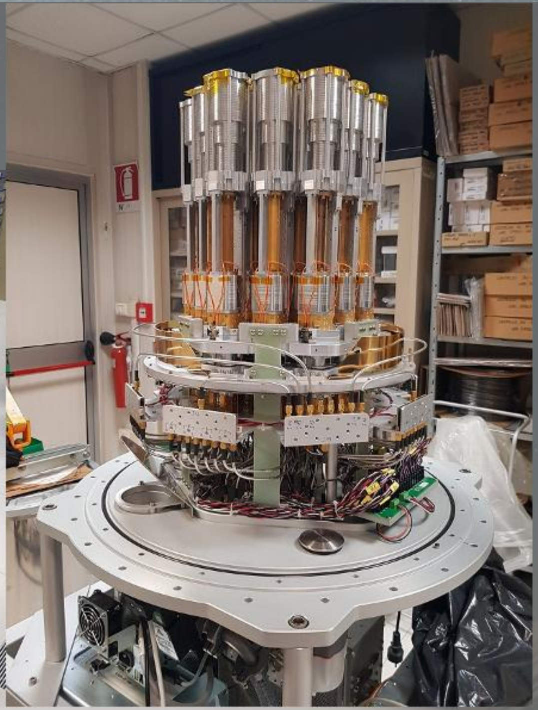
High frequency multi feed/frequency receivers



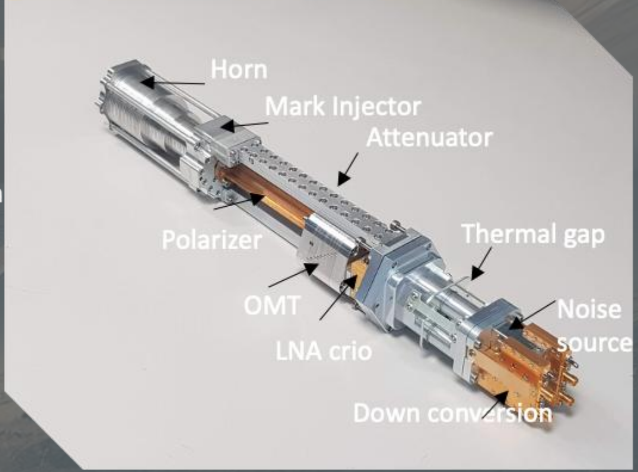
- SIMULTANEOUS TRI-BAND: 18-26GHz/34-50GHz/80-116GHz
- KASI (Korea Astronomy and Space Science Institute) work with INAF collaboration
- 8 IF outputs in the band 2-18GHz for a total of 128GHz to be processed
- Destination: Medicina, Noto and SRT radio telescopes

Complete receiver

19 pixel chains



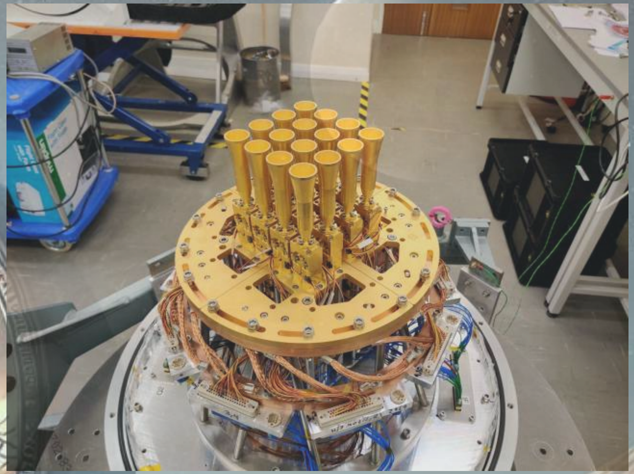
Pixel chain



- 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

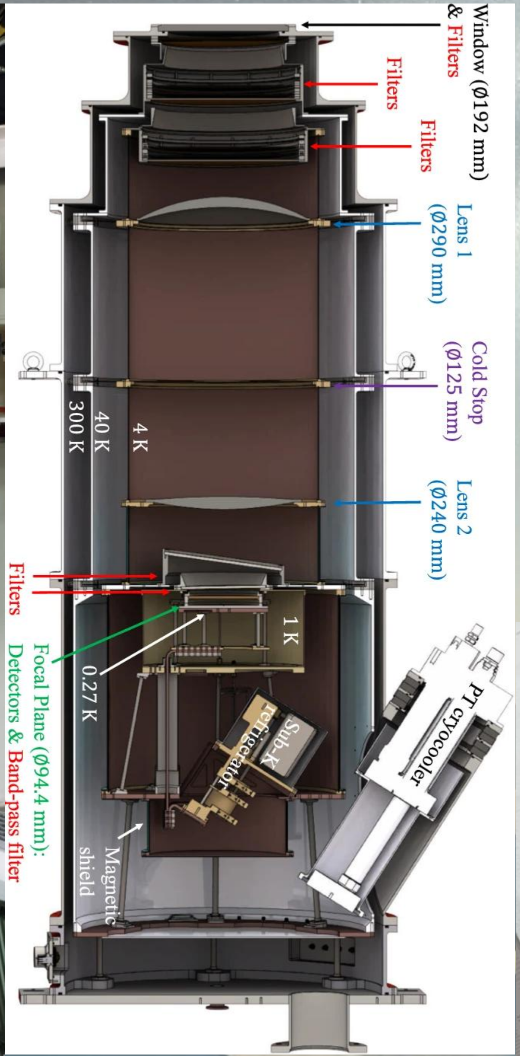
CARUSO (W Band receiver)

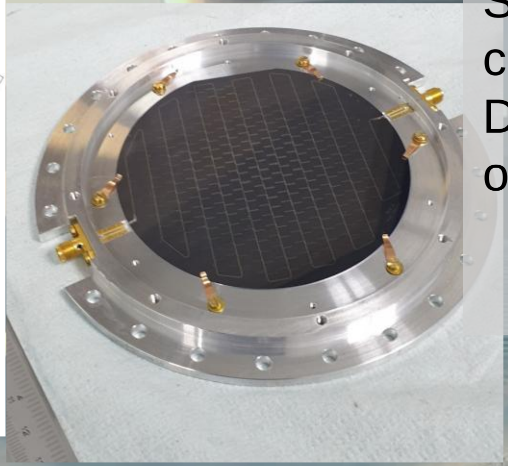
- W-band multibeam heterodyne receiver for the Sardinia Radio Telescope awarded to **UK Research and Innovation** (UKRI).
- Array configuration: 4x4 (square lattice). Dual-linear polarization with RF band: 70-116 GHz.
- Angular resolution HPBW 12 arcsec at 93 GHz / angular separation between contiguous feeds: 43 arcsec
- Custom W-band MMIC amplifiers and sub-harmonic image rejection mixers cryogenically cooled at ≈20 K
- 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



UNIONE EUROPEA
Fondo Sociale Europeo
Fondo Europeo di Sviluppo Regionale
Ministero dell'Istruzione, dell'Università e della Ricerca
PON RICERCA E INNOVAZIONE 2014 - 2020
INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Millimiter Camera (MISTRAL)





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

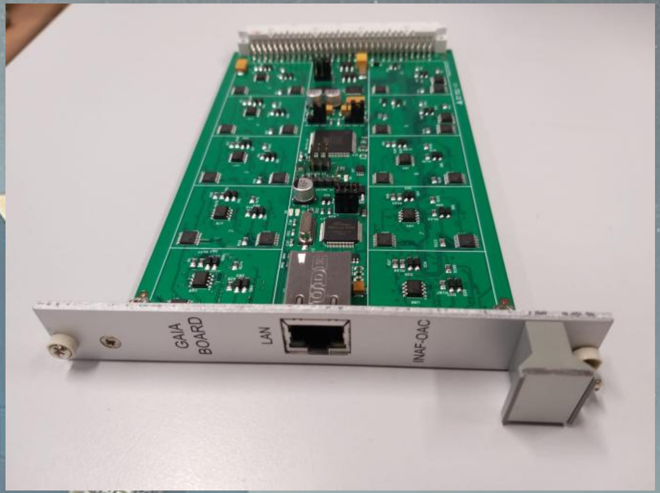
- Detector Layout: 408 pixels, bandwidth: 30 GHz centered at 90 GHz; Field of View = 4 arcmin, resolution 12 arcsec

- 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.

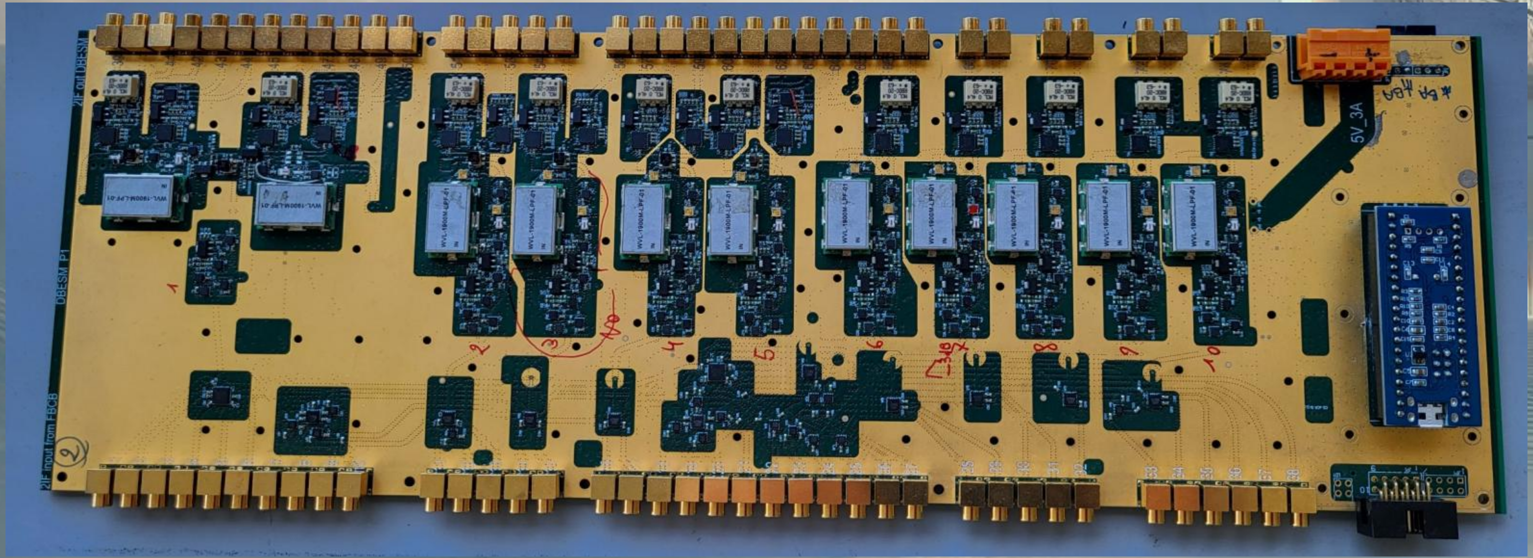
Power supply and Distribution systems

FCBC (Full Band conversion, Continuum Back-end)

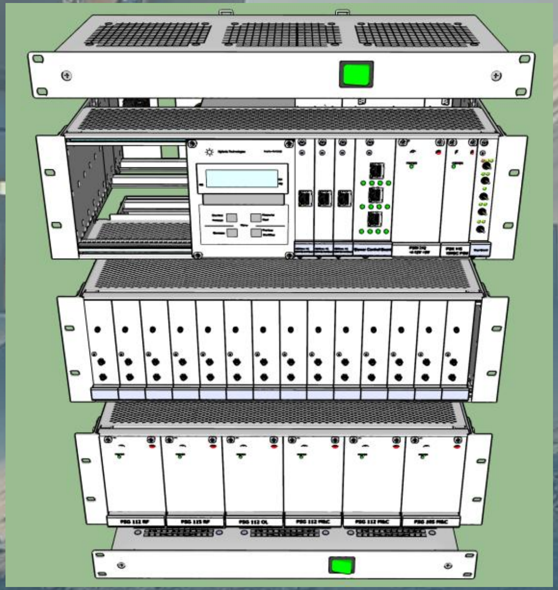
64 channel RF switch controller



GAIA board to power supply LNAs

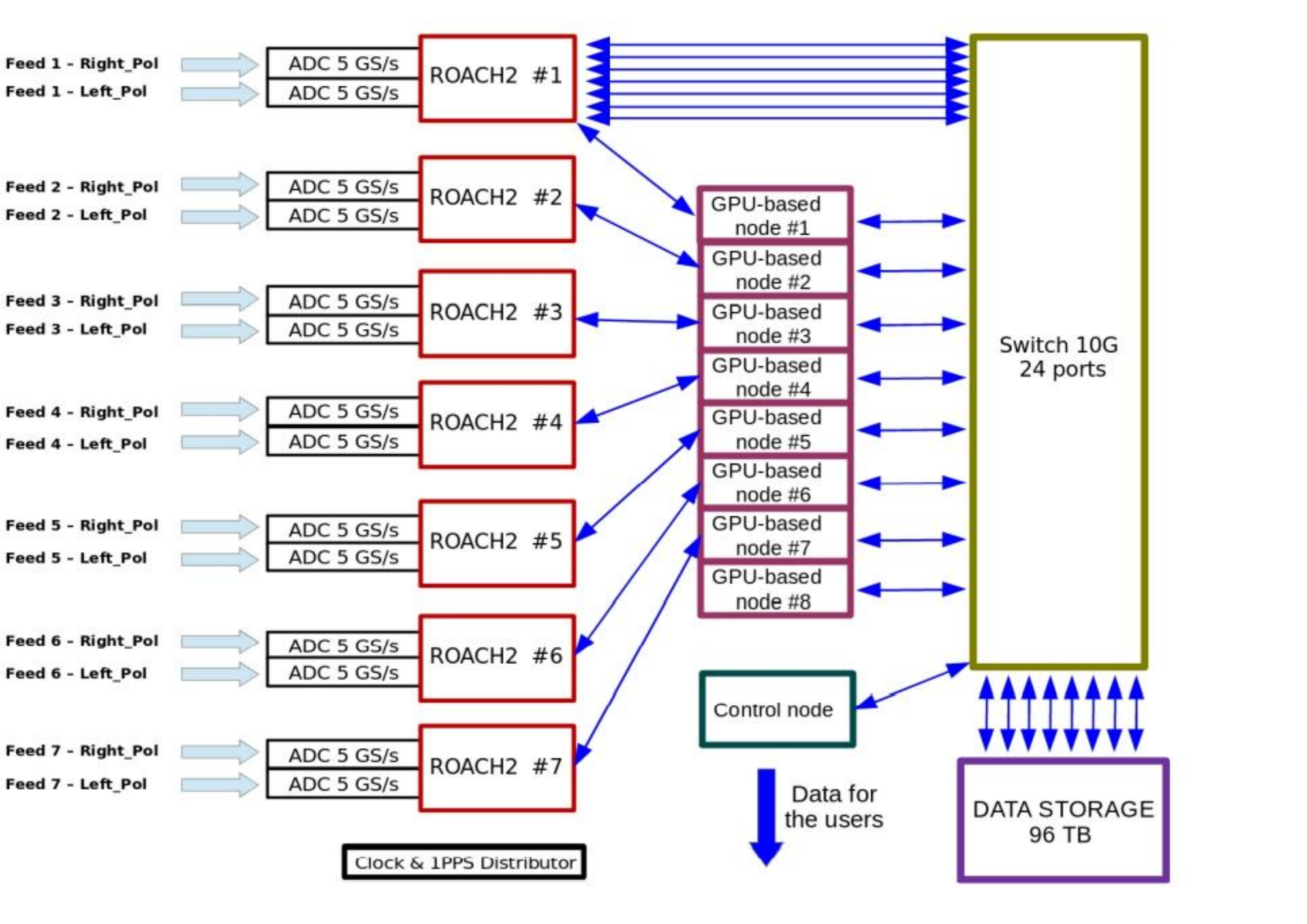


Digital Back End Switch Matrix



S-Band receiver rack

SArdinia Roach2-based Digital Architecture for Radio Astronomy (SARDARA)



MUlti-feed SKARAB-based backend for the Sardinia radio telescope (MUSKAS)

Mode	Bandwidth (MHz)	Number of channels	Full Stokes
Wideband imaging	1400; 1280; 1024	0.5k, 1k, 2k, 4k, 8k, 16k, 32k	Yes
Medium band imaging	750; 640; 512; 375; 320; 256	1k, 2k, 4k, 8k, 16k, 32k	Yes
Narrow band spectroscopy	187.5; 160; 128; 93.75; 80; 64; 46.875; 40; 32; 23.4375; 20; 16	4k, 8k, 16k, 32k	Yes
Narrow band spectroscopy	187.5; 160; 128; 93.75; 80; 64; 46.875; 40; 32; 23.4375; 20; 16	65k	No
Pulsar search	1280; 1024; 640; 512	2k, 4k, 8k, 16k	Yes
Pulsar timing	1280; 1024; 640; 512	2k, 4k, 8k, 16k	---
Pulsar timing	512; 256; 128; 64; 32; 16	---	---

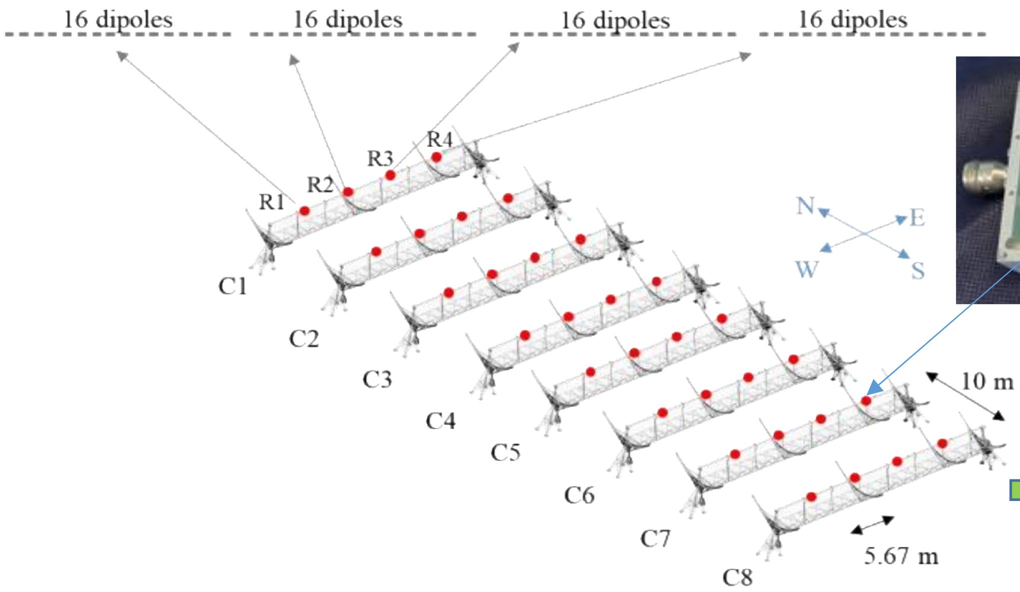
OAC Laboratories

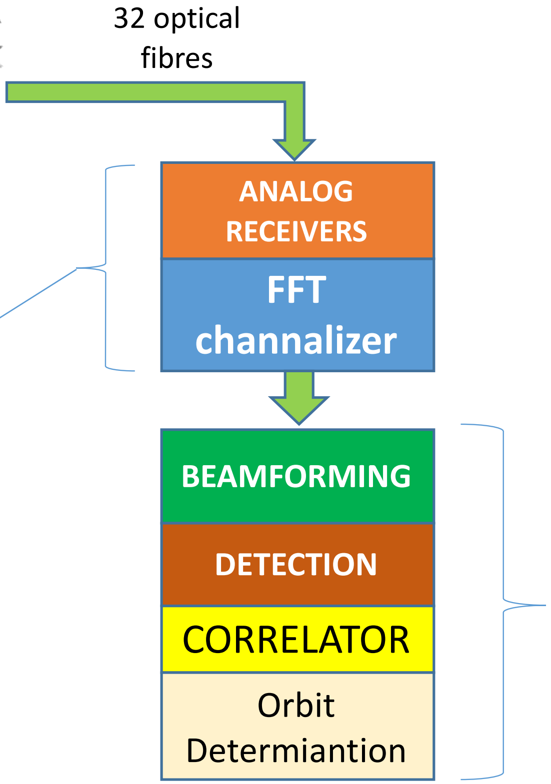
Microwave laboratory

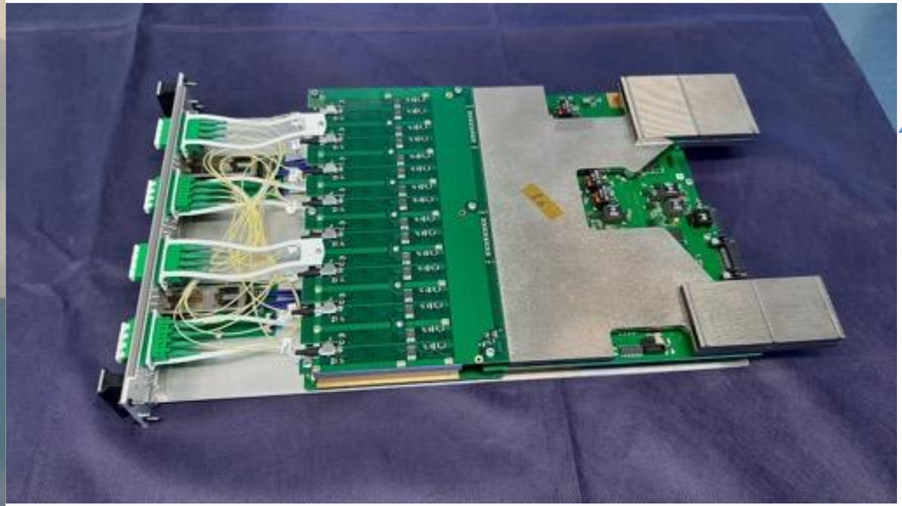
Electronic laboratory

Mechanical laboratory

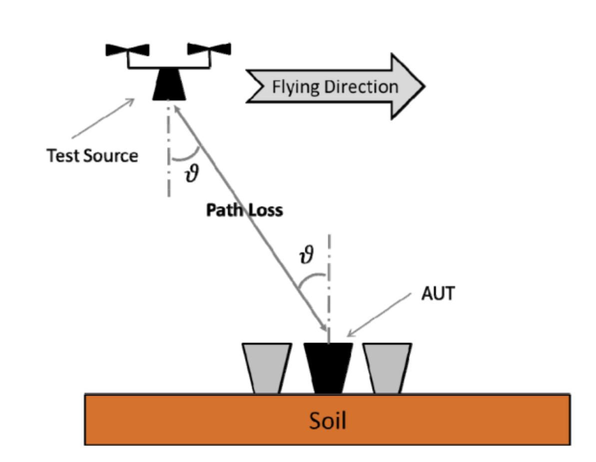
Northern Cross SST development

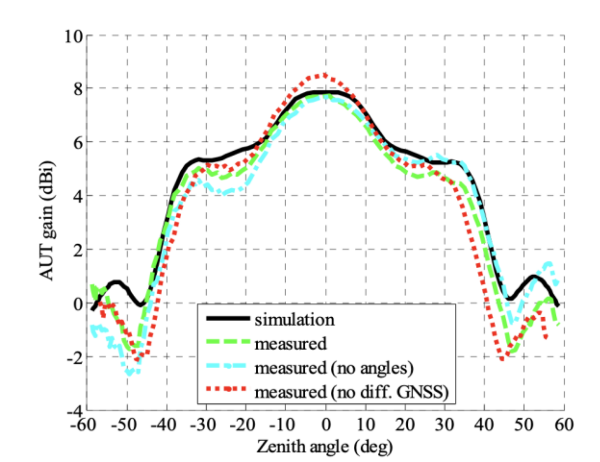




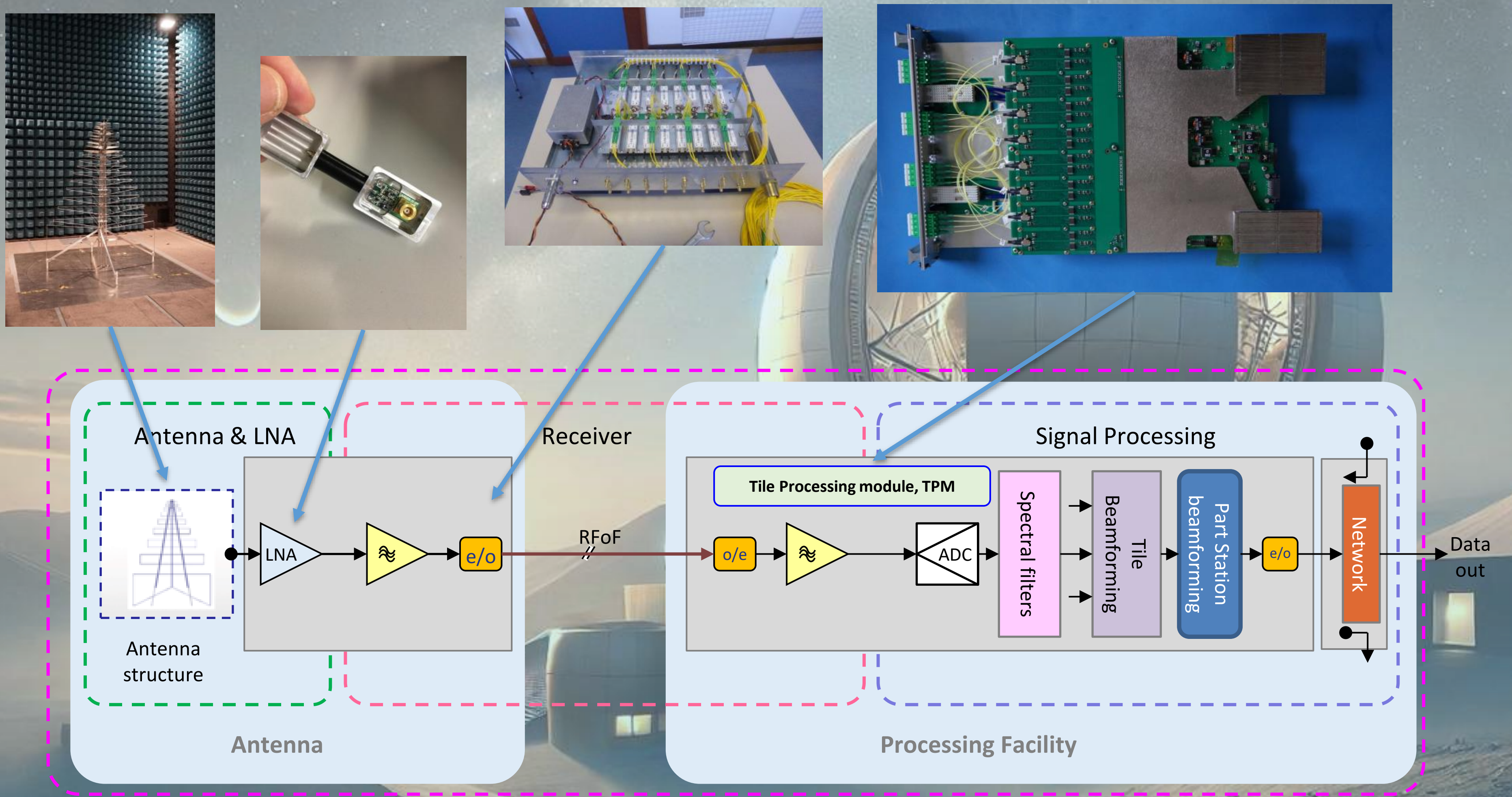


UAV measurement for Low frequency Aperture Arrays





Receiver chain: technology made in Italy



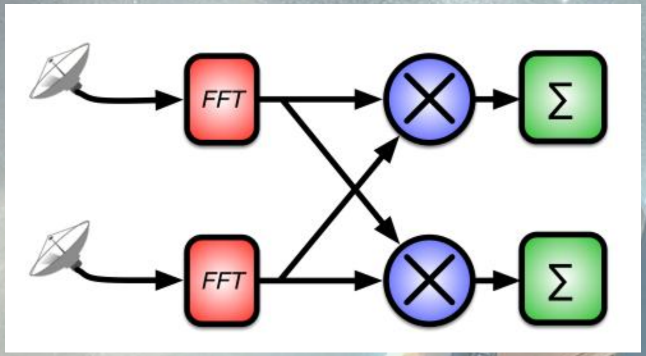
Participation to MeerKAT/MeerKAT+

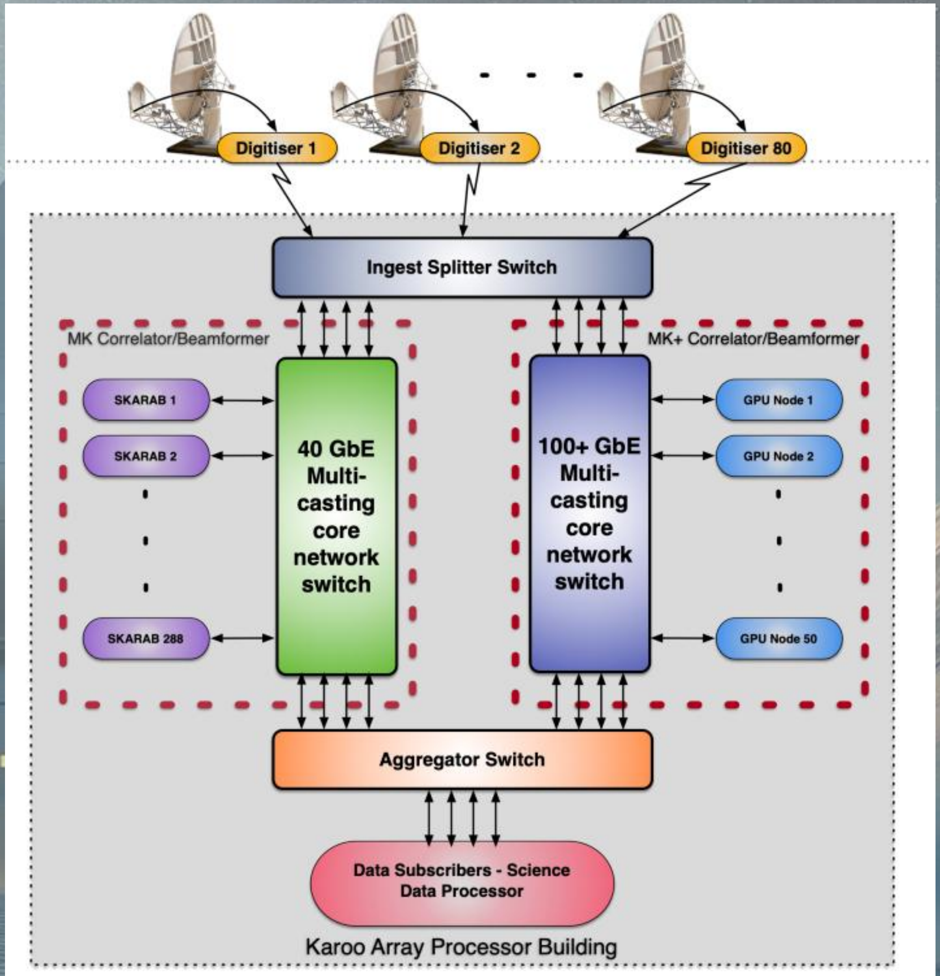
INAF-SARAO collaboration for designing a new digital correlator

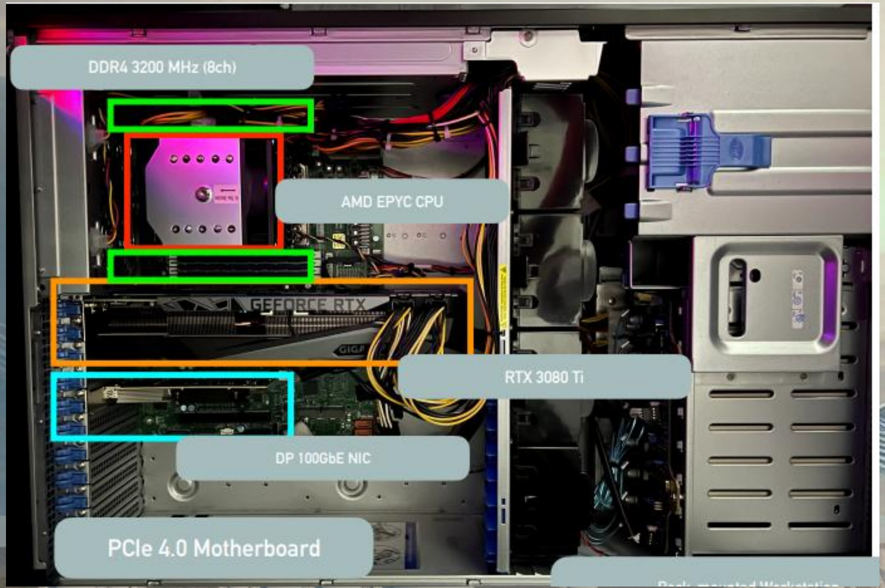
Alveos FPGA-based vs GPUs

Final decision: fully GPUs correlator

Commercial GPUs (RTX 3080 TI)

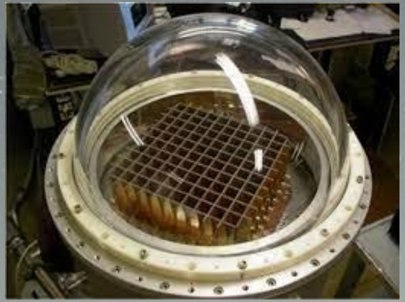


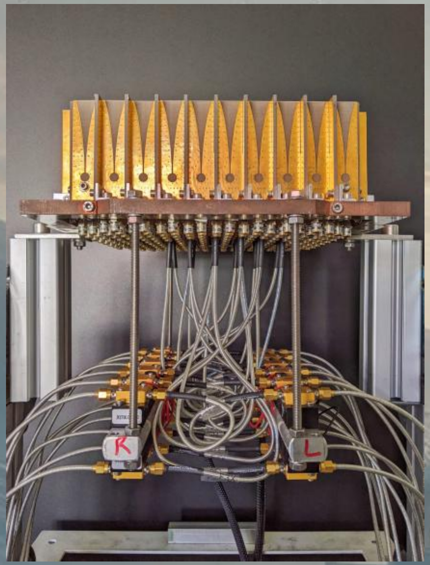


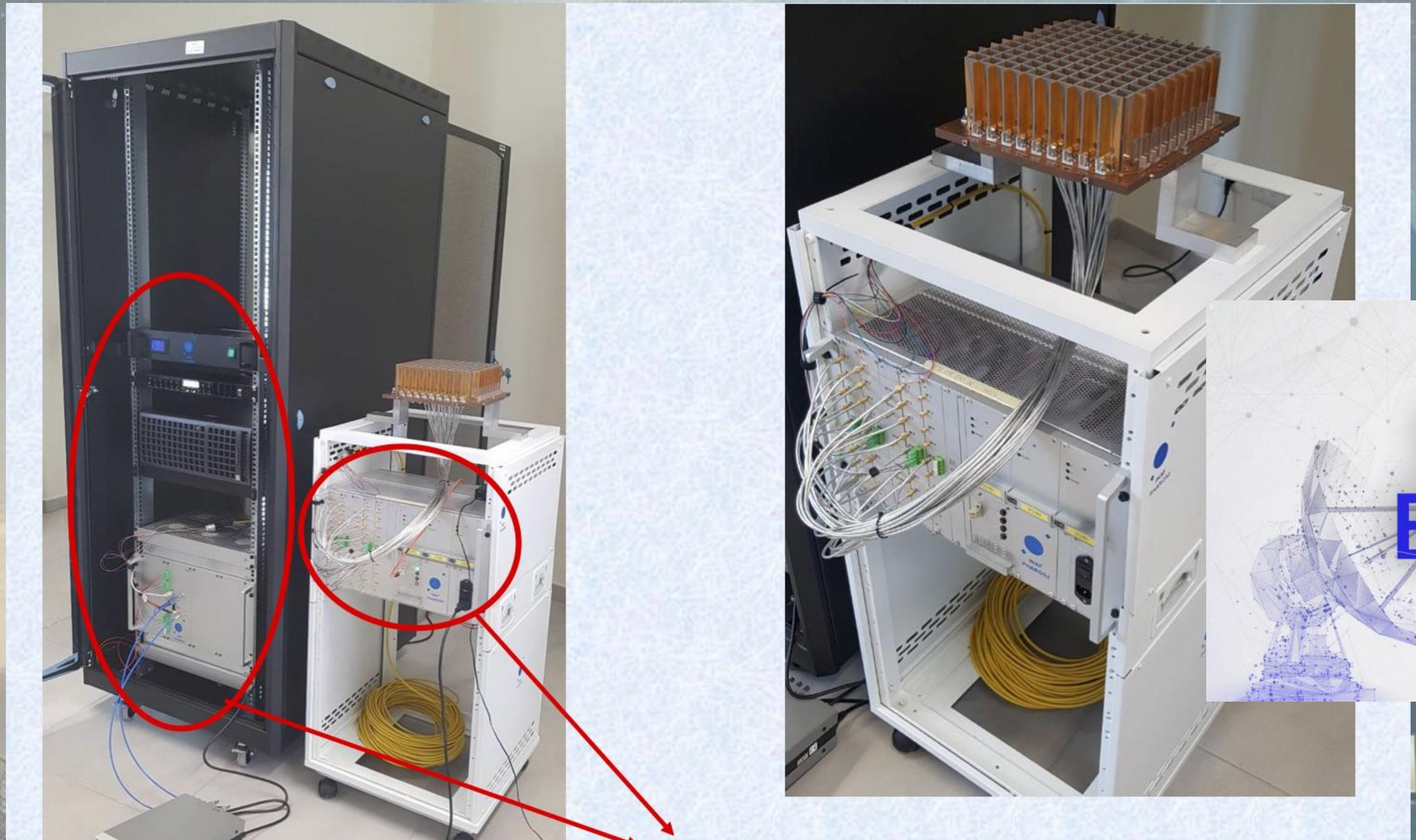


Band 5 receiver

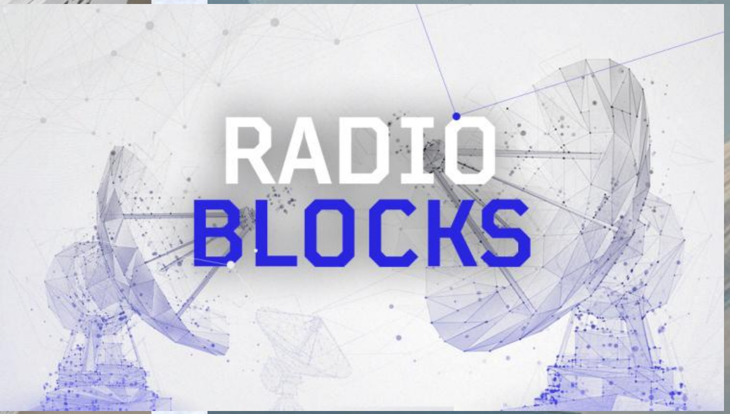
Phased Array Feed (PAF) C Band







Hardware delivered to Jodrell Bank Obs.



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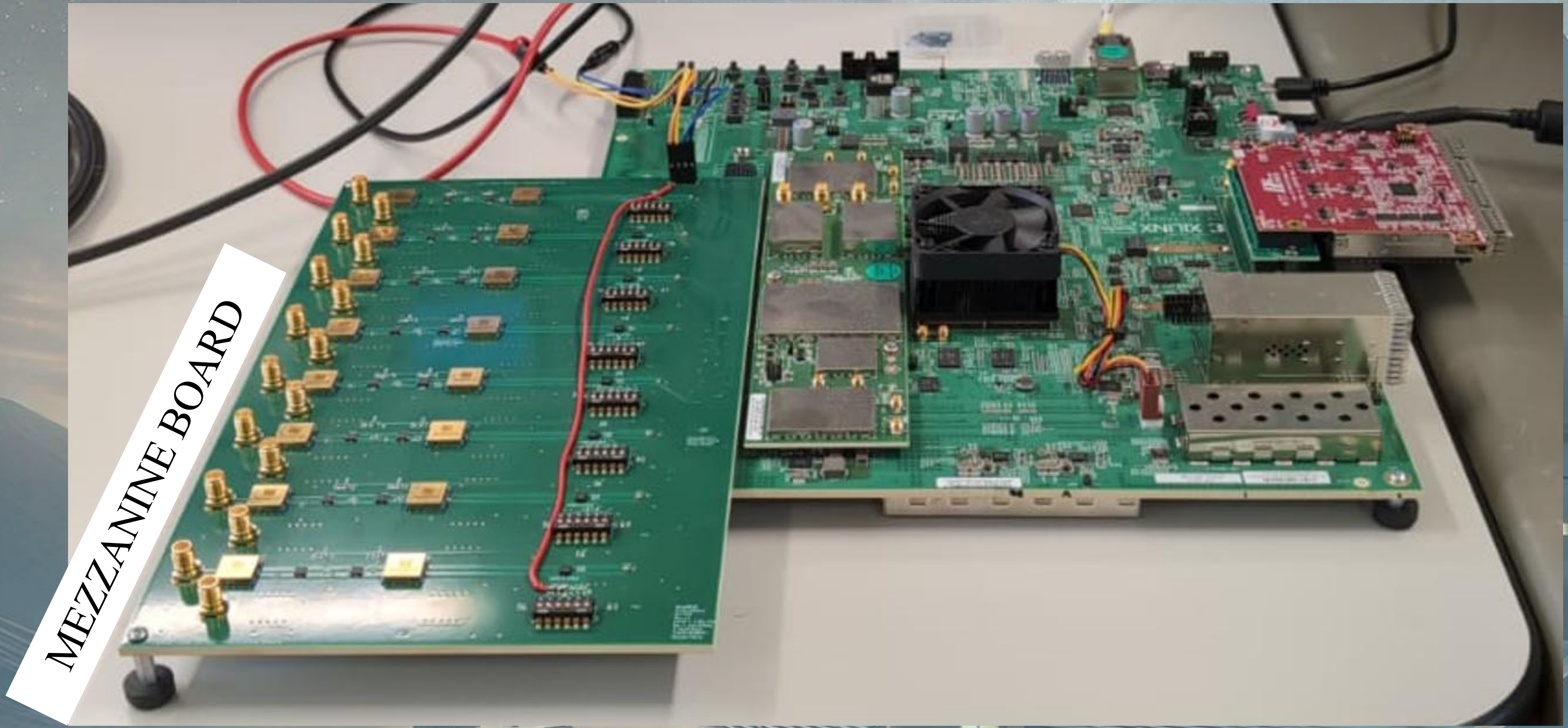
MANCHESTER 1824 The University of Manchester
L-Università ta' Malta
UNIVERSITY OF OXFORD
ONSALA RYMDOBSERVATORIUM CHALMERS TEKNISKA HÖGSKOLA
ASTRON

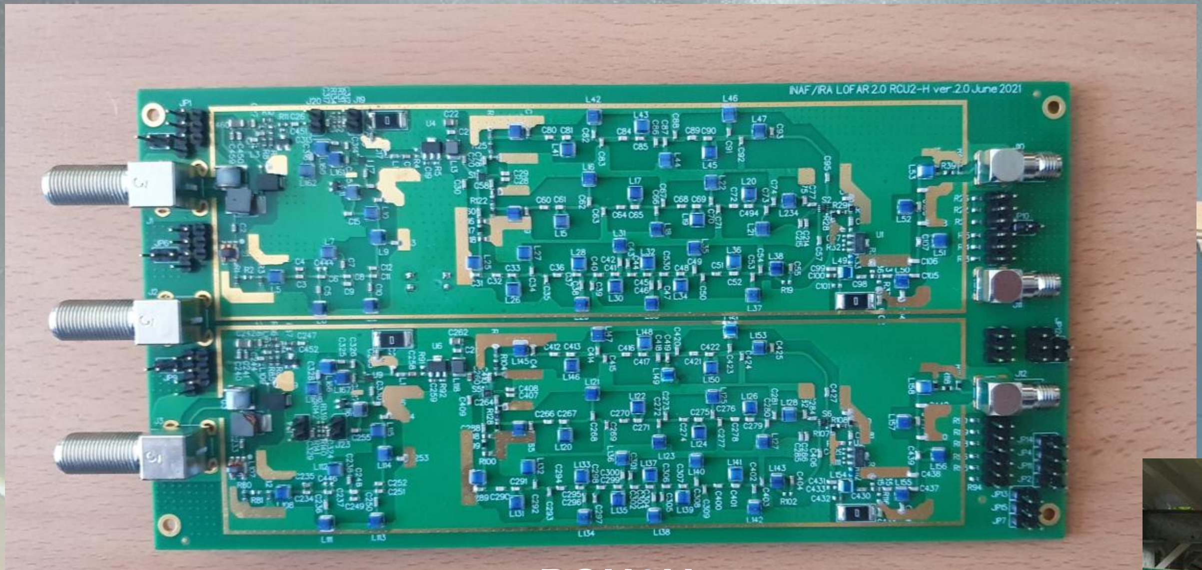
Xilinx Zynq UltraScale+ RFSoC board



CASPER

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.

LOFAR CONTRIBUTION



RCU2H

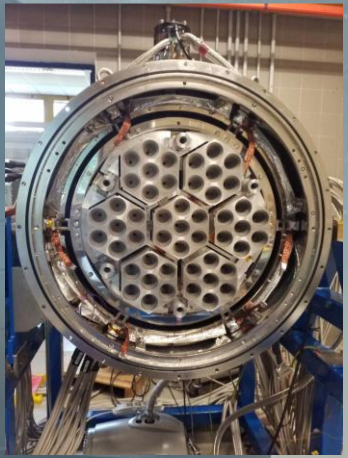
RCU2L

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



New technological trends in RADIOASTRONOMY

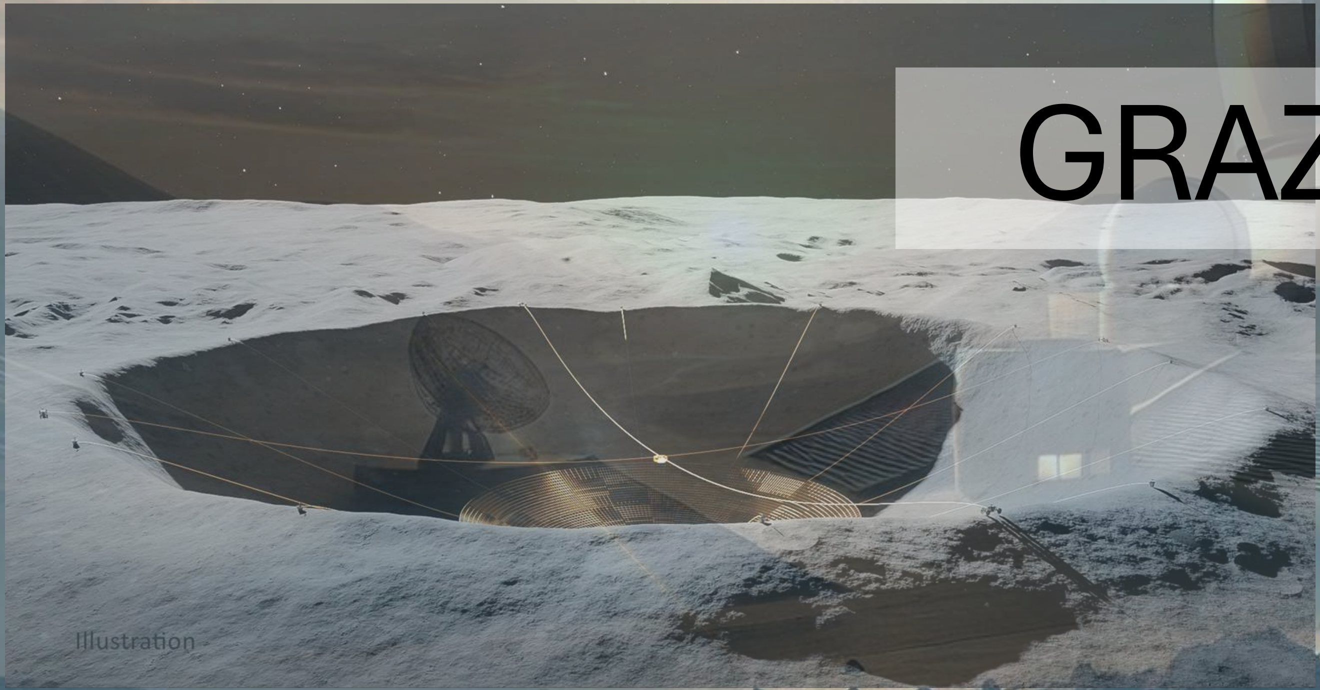
- Astronomical Requirements
  - Larger filed of view
  - Better sensitivity
  - Better time resolution
  - Better spectral resolution

- Possible Solutions
  - Aperture arrays
  - Phased arrays
  - Focal plane arrays
  - IA and data processing
  - New devices and components

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

Conclusions

The experience and expertise developed by INAF researchers in the field of radio technologies are now internationally recognized, thanks to the promotion, efforts and advancements of the past 20 years through various National and International projects. This enables our young technological researchers to engage in more challenging and ambitious future projects, backed by a strong foundation of cutting edge knowledge. We need a better coordination and specialization.



GRAZIE!