



MeerKAT plus

THE LARGEST RADIOTELESCOPE IN THE WORLD BEFORE SKA



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Grazia Umana



MeerKAT plus: The project in a nutshell

A joint project between:

- South African Radio Observatory (SARAO)
- Max-Planck Gesellschaft (MPG) organisation in Germany
- INAF, Italy (formally member of the project since December 2020)

CETC54 in China is a secondary contributor to this project for dish structures.

Objective:

- to extend the MeerKAT instrument by adding 16 SKA-format dishes to the current 64 element array.
A significant improvement of the MeerKAT capabilities in terms of sensitivity and angular resolution.

The project has been approved by the various funding and governing authorities in South Africa, Germany and Italy and is endorsed and supported by the SKA observatory.

MeerKAT plus: Italian contribution

INAF signed a formal agreement on December 2020 to become an official partner of the project

- ▶ INAF will support MK+ with a financial contribution in order to take part in the scientific exploitation of the MK+ instrument
- ▶ INAF will have the opportunity to help define and take part in the legacy project(s) undertaken with the reserved share of observing time on MK+
- ▶ INAF will get a chair as Scientific Member of the MK+ board (DS)

We present only the technological aspect of the project, based on consolidated and already started activities. This is also reflected on the staff commitment, in terms of FTE.

Participation in the definition of scientific cases will take place downstream of a consultation of the scientific community, part of which already actively engaged in the scientific exploitation of MeerKAT data

The path to MeerKAT plus

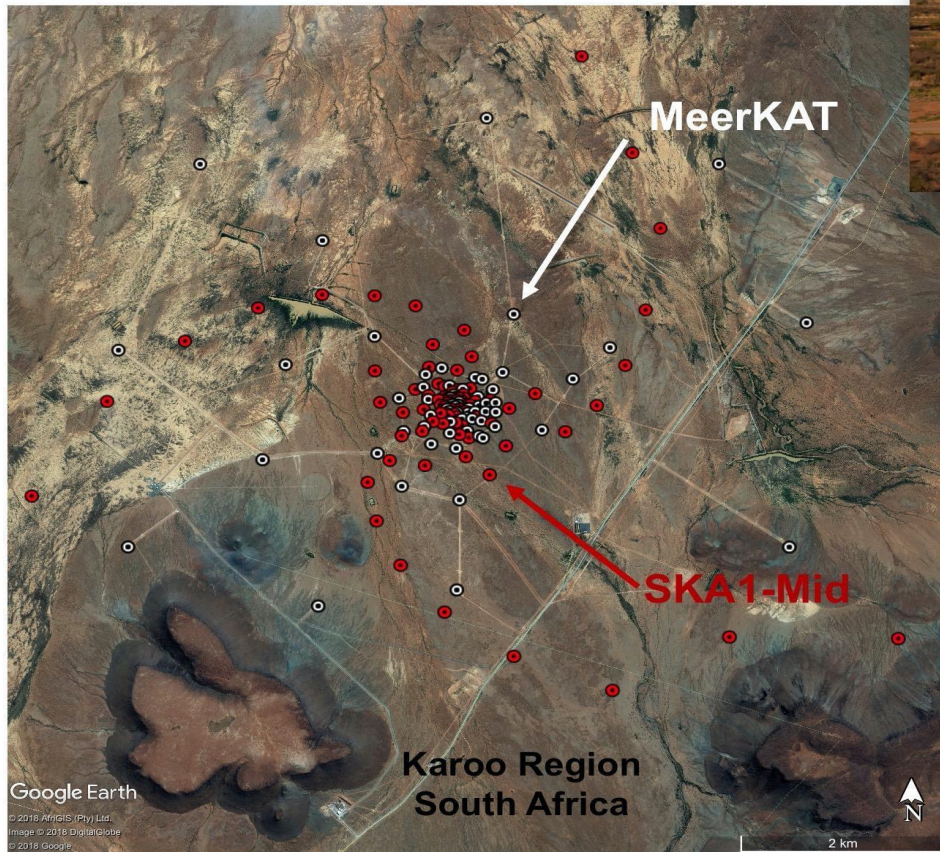
Activities within UTG-II (F. Govoni)/WG4

WG aimed at identifying actions to maximize **INAF** scientific return in the use of **SKA** high frequency precursors/pathfinders

- ▶ Grazia Umata (chair)
- ▶ Andrea Melis
- ▶ Andrea Possenti
- ▶ Isabella Prandoni
- ▶ Paolo Serra
- ▶ Corrado Trigilio
- ▶ Tiziana Venturi



MeerKAT as SKA-mid precursor



MeerKAT:

Operated by SARAO
64, 13.5-m dishes over 7.7 km
580-3500 MHz

SKA1_Mid:

133 SKA 15m dishes
64 MeerKAT 13.5m dishes
Maximum baseline 150 km
3 logarithmic spiral arms
~ 50% within ~2 km randomly distributed

L Band	900-1670 MHz
UHF	580-1015 MHz
<i>S Band</i>	1750-3500 MHz

L-Band sensitivity

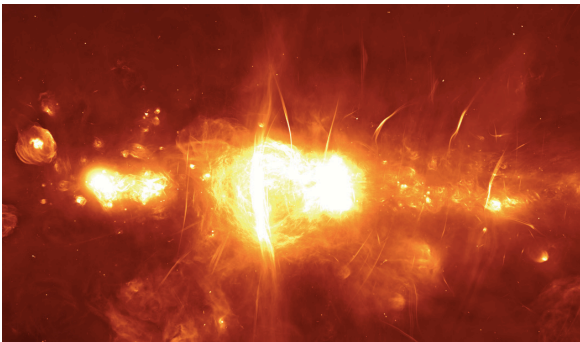
Continuum	12 μ Jy (1 hr)
Line	184 μ Jy (1 hr, 209 kHz channel)

The path to MeerKAT plus: INAF MeerKAT document

Le antenne MeerKAT nel deserto sudafricano del Karoo. Credits: SARAO



Partecipazione Italiana al MeerKAT Telescope



Il centro Galattico visto da MeerKAT (Banda L). Credits: SARAO

Document prepared by WG4 -contributions also by U. Becciani and F. Schillirò

- **Presentation of INAF activities related to the MeerKAT telescope and possible technological contribution to the MeerKAT+ project**
 - Some activities are initiatives undertaken by individual researchers, in major international collaborations as experts in the field.
 - Some activities resulted from the coordination work done to date by WG4.
- **Presentation of the collaborations between Italy and South Africa**

The document has been updated to February 2021 and is included in the UTG-II. Repository http://www.inaf.it/it/sedi/sede-centrale-nuova/direzione-scientifica/cartella-documenti-utg-ii-radioastronomia/MeerKAT_INAF_2021.pdf

The path to MeerKAT plus: INAF activities in MeerKAT

Italian interests cover a **wide range of scientific issues**, including: cosmology, galaxies and AGN and their evolution, galaxy clusters, pulsars for fundamental physics applications and the discovery of new pulsars, in particular in globular clusters, Magellanic clouds and some external galaxies, HI and magnetism in the near and distant Universe, transients, diffuse emission and radio sources present in our Galaxy.

Legacy Surveys

Italian researchers are currently involved in 5 of MeerKAT's 8 Legacy Surveys (OACa, IRA, OACT, OA-Brera, OANa, OAPd, UniBO, UniTs, UniPd; Leadership in **MeerKAT Fornax** Survey (P. Serra, OACa)

Early Science projects (IRA, UniBO);

Data from scientific commissioning:

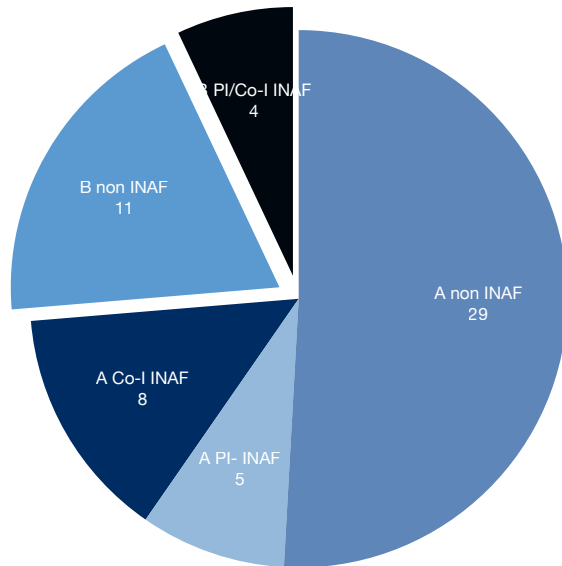
SARAO MeerKAT Galaxy Cluster Legacy Survey (IRA)

SARAO MeerKAT Galactic Plane Legacy Survey (OACT)

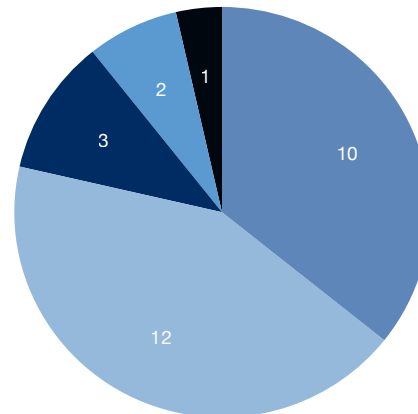
INAF activities in MeerKAT

Cycle AO-1 (no time-domain projects)

● A non INAF ● A PI- INAF ● A Co-I INAF ● B non INAF ● B PI/Co-I INAF



● Ammassi di Galassie ● Galassie ● Cosmologia ● Esopianeti ● Via Lattea



30% of approved proposals (tot 57) have an Italian contribution, 5 with INAF PI or INAF associate

6 proposals with PI INAF or ASSOCIATED INAF and 5 with INAF personnel or INAF associates, not approved in this call, indicate a wide interest in the reference community.

If time-domain mode had been activated there would have been greater participation of the Italian community.

Distribution of the themes of the proposed projects

INAF activities in MeerKAT

The path to MeerKAT plus: technologies for BIG DATA

Since 2018, INAF has started several **collaborations with South African** research groups that are **analysing MeerKAT's data**.

The interests of researchers have found **common areas of work** and professional experience to put at a common factor in the **development of innovative information technologies for Big Data** Analysis.

This activity, which is now formalised at different levels, is an important element of **collaboration in the exploitation of MeerKAT data and the future SKA**. It includes:

IDaVIE. Visual Analytic technologies in Virtual Reality (OACT, OACa, IRA)

SA-EU A Federated Cloud Demonstrator (OACT, OATs, IRA, OACa)

Big Data Analysis and Machine Learning Techniques for MeerKAT (OACT, IRA)

Radio interferometry pipeline (OACa)

MeerKAT

MeerKAT:

Operated by SARAO

64, 13.5-m dishes over 7.7 km

580-3500 MHz

Sensitivity (1 hr): $12\mu\text{Jy/b}$

Angular resolution: $8''$



MeerKAT → MeerKAT+

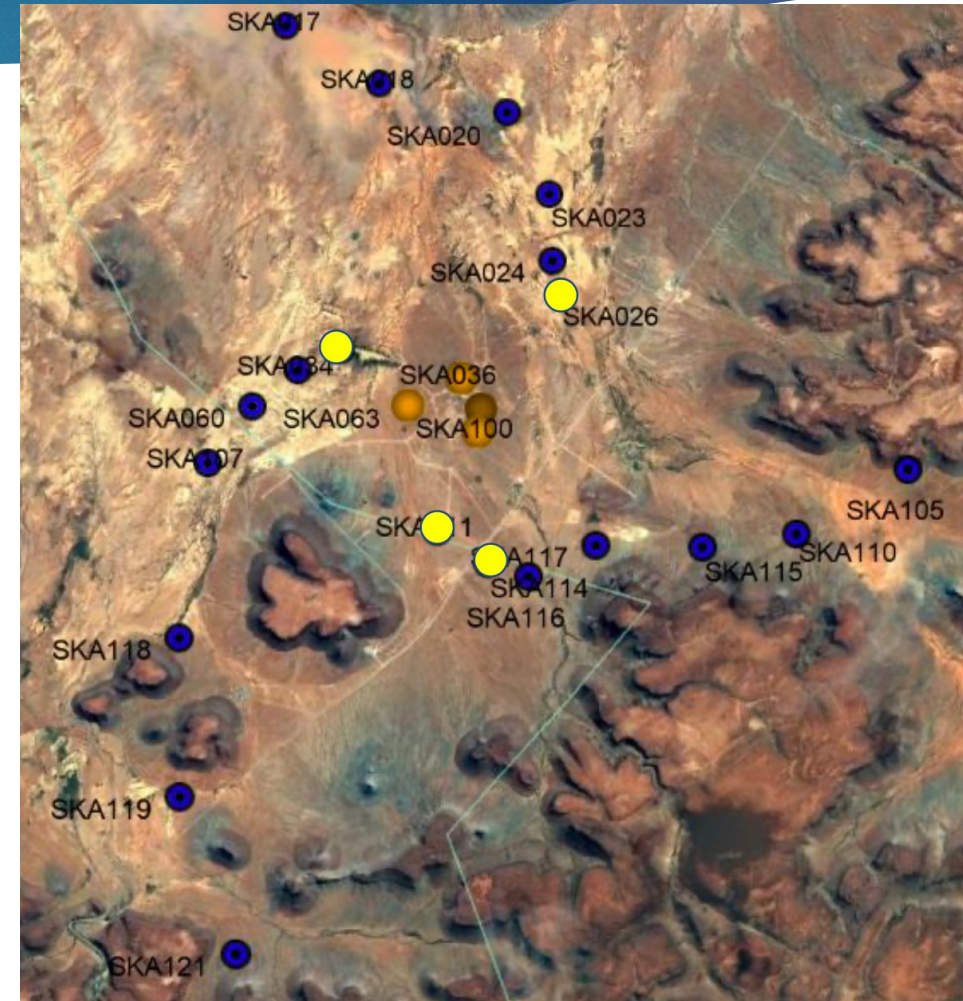
MeerKAT plus represents:

- a substantial increase in the scientific capability of MeerKAT, and
- a significant step forward for the construction of the SKA-MID array.

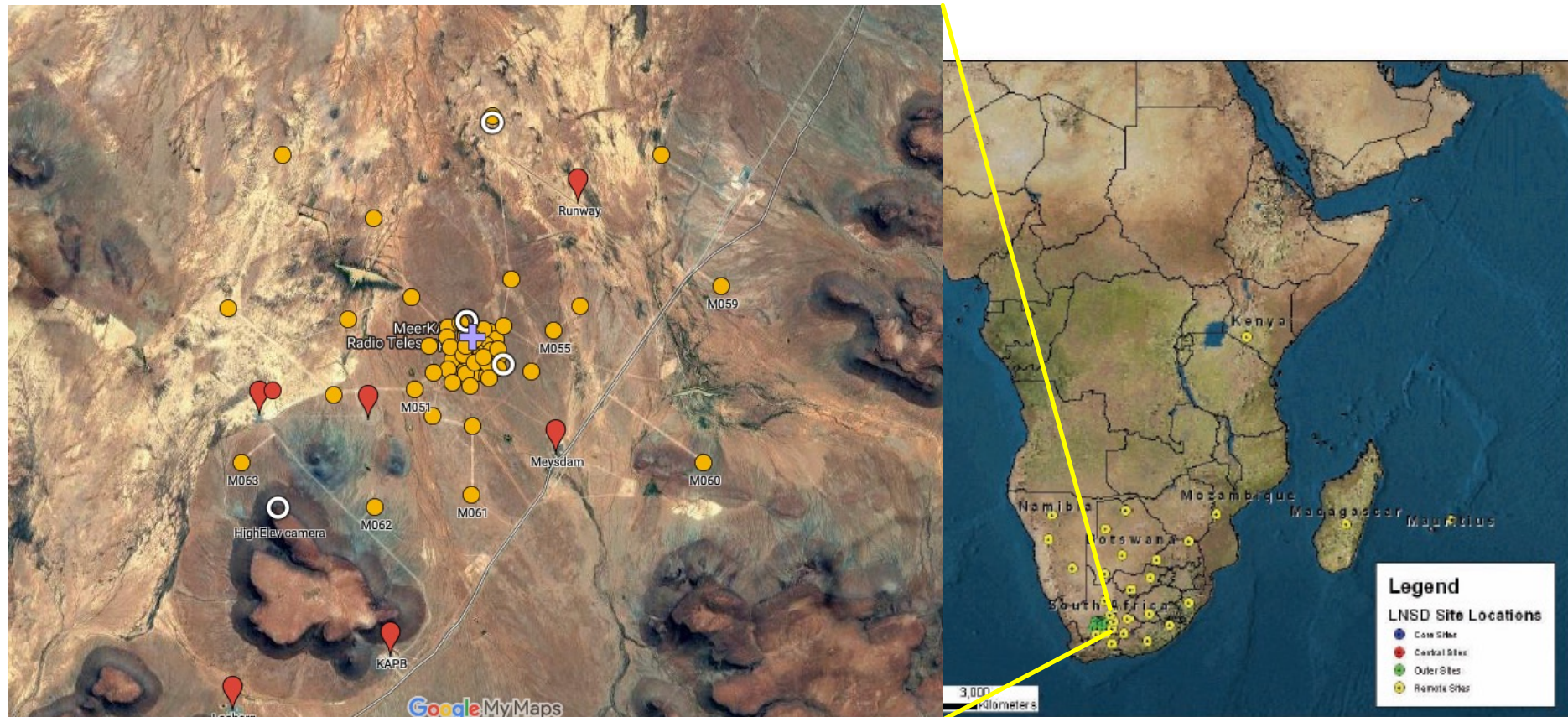
Area +30% [+38%]

Sensitivity (1 hr): $12\mu\text{Jy/b} \rightarrow 9\mu\text{Jy/b}$

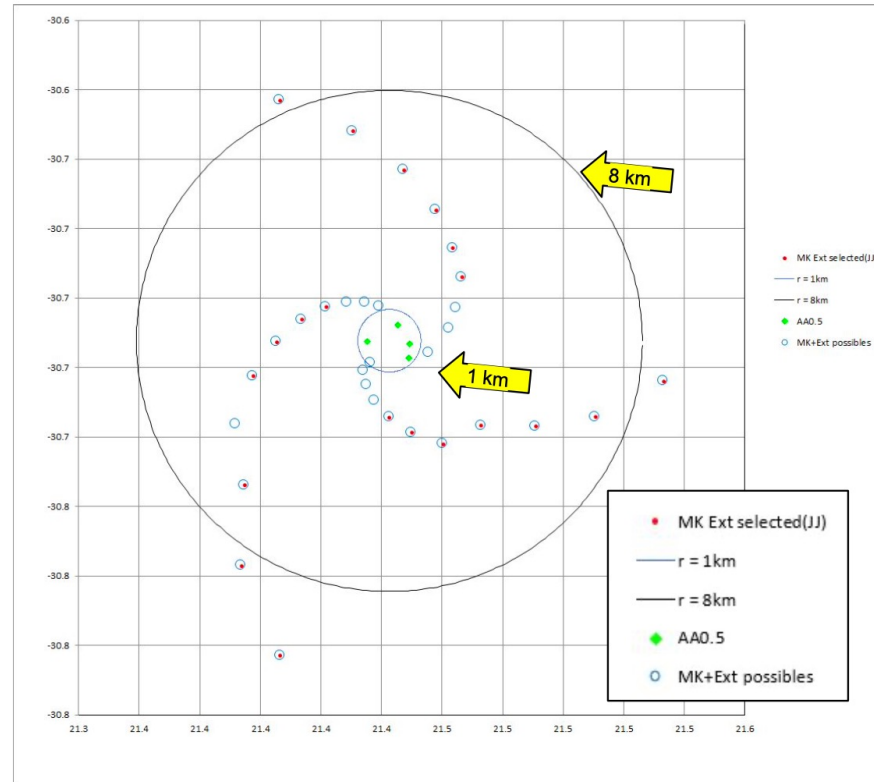
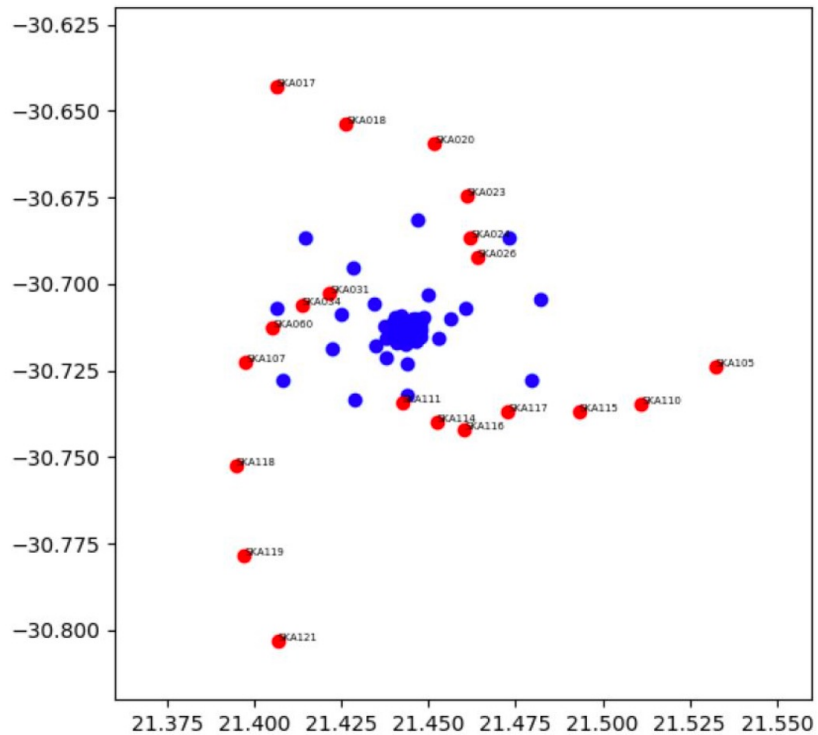
Angular resolution: $8'' \rightarrow 3.4''$



MeerKAT → MeerKAT+ → SKA1-Mid



MeerKAT vs MeerKAT+ array



MeerKAT

Baseline range: 20 m – 7.7 km

core ~ 1 km, 70% of dishes

Outer ~ 8 km, 30% of dishes

MeerKAT plus

Baseline range: 20 m - 16 km

Integration of MK+ into SKA1-Mid

MK+ will be operative for science from 2022 to 2027 (with possible delay).

Meantime: construction of SKA dishes.

MK+ will be integrated into SKA1-Mid at the end of the process of construction.

Table 1: Size of each Array Assembly.

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Total Number of Dishes	-	4	8	64	121 ⁽¹⁾	197
Number of integrated MeerKAT Dishes	-	0	0	0 ⁽²⁾	8	84 ⁽³⁾

⁽¹⁾ 113 SKA1-MID Dishes (since 20 SKA1-MID Dishes are incorporated into MeerKAT Extension) plus 8 MeerKAT Precursor Dishes.

⁽²⁾ The first MeerKAT Dish is handed-over to SKAO at the beginning of AA2 (see Section 10), but will only be fully integrated into SKA1-MID as part of AA3.

⁽³⁾ 64 MeerKAT Precursor Dishes plus 20 MK+ Dishes.

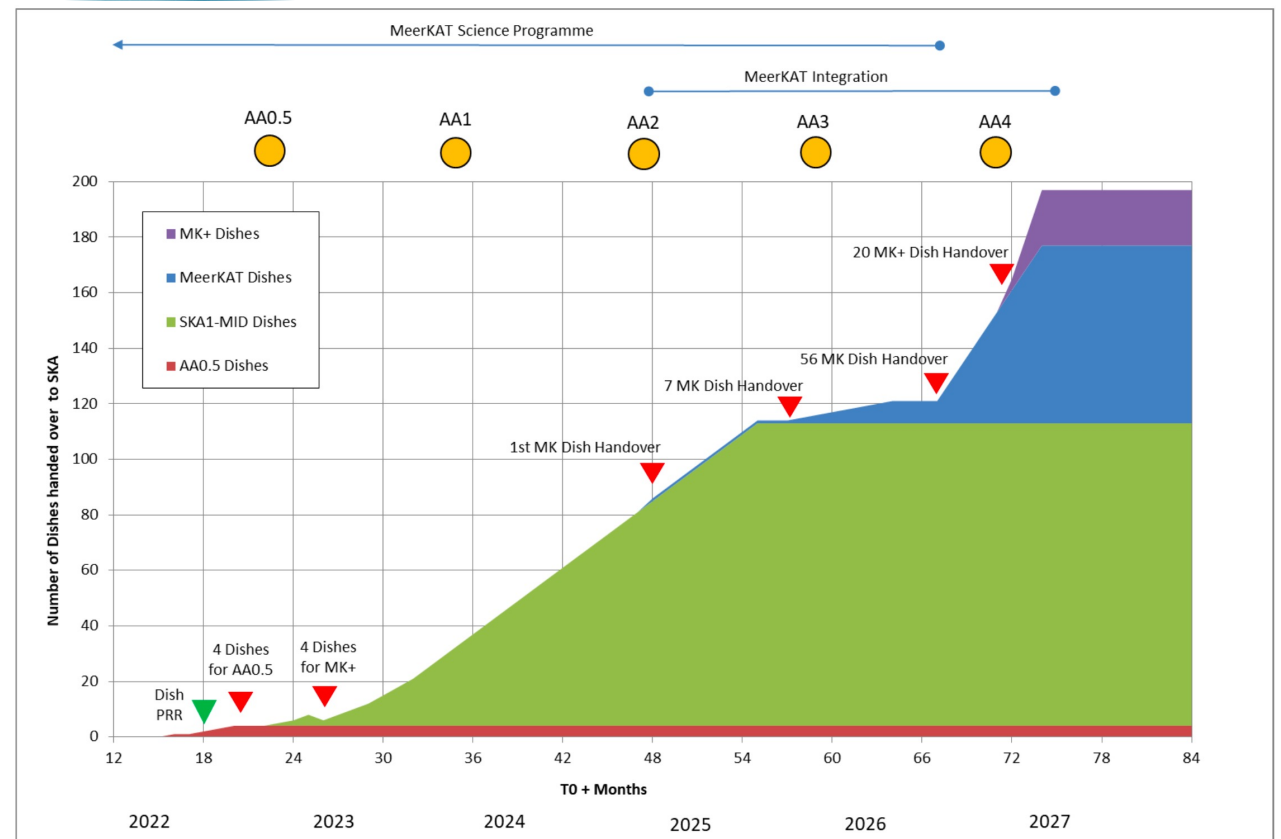


Figure 8: Overview of SKA1-MID Dish Roll-Out with MeerKAT integration.

Italian Participation to MK+

Italy (INAF) participates in MK+

- 1) software for the control and monitoring of the dishes
- 2) design of correlator



DSH: SKA vs MK+

SKA Dish:

Diameter 15m

Inside:

Dish Structure and ACU

Indexer (feed positioner)

Single Pixel Feeds

Receivers (digitalizers)

Local Monitor & Control

M&C managed by central
Telescope Manager

Tango based

LMC unique interface for M&C
TM < > Dish

Diameter 13m

Inside:

Dish Structure and ACU

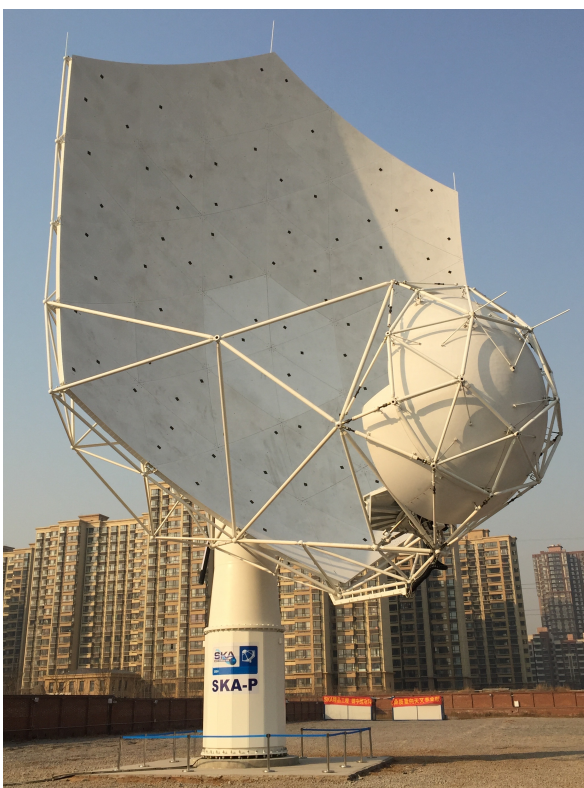
Indexer (feed positioner)

Single Pixel Feeds

M&C directly from
central KATCP, Karoo
Array Telescope Control
TCP/IP based

Digitalizers managed by
KATCP

MeerKAT Dish:



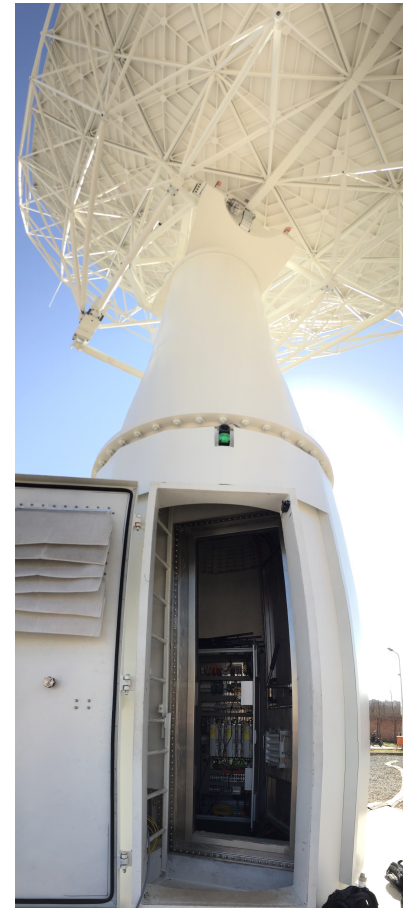
SKA DSH LMC: pre-construction phase

DSH LMC consists of:

- 1. software system** for C&M of the DISH equipment to TM;
 - 2. hardware computer** hosting it.
- The LMC PC is in the pedestal, in a 19" shielded rack inside a shielded compartment
 - SPF, SPFRx, DS controllers and network switch (SaDT) are hosted in the same rack

DSH Phase 2013-2018 – SKADC: SKA Dish Consortium

INAF joins the DSH.LMC project lead initially by China CET54 (JLRAT).
Our team: System Engineering and Software development.
Chinese team: management and hardware procurement.



SKA DSH LMC: an Italian project

From 2017 DSH.LMC is lead by INAF. Two Italian companies joint the project (SAM, EIE).

INAF Team:

C. Trigilio (lead)

S. Riggi, A. Ingallinera, F.
Schillirò, A. Marassi

In 2020 INAF Team works with SARAO for
integration test with Dish prototype in Karoo.

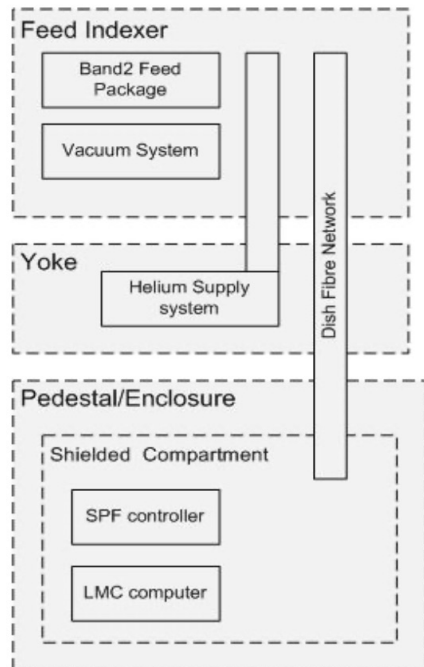
In 2020 **SARAO invited us** to joint the MK+
project for Dish.LMC.



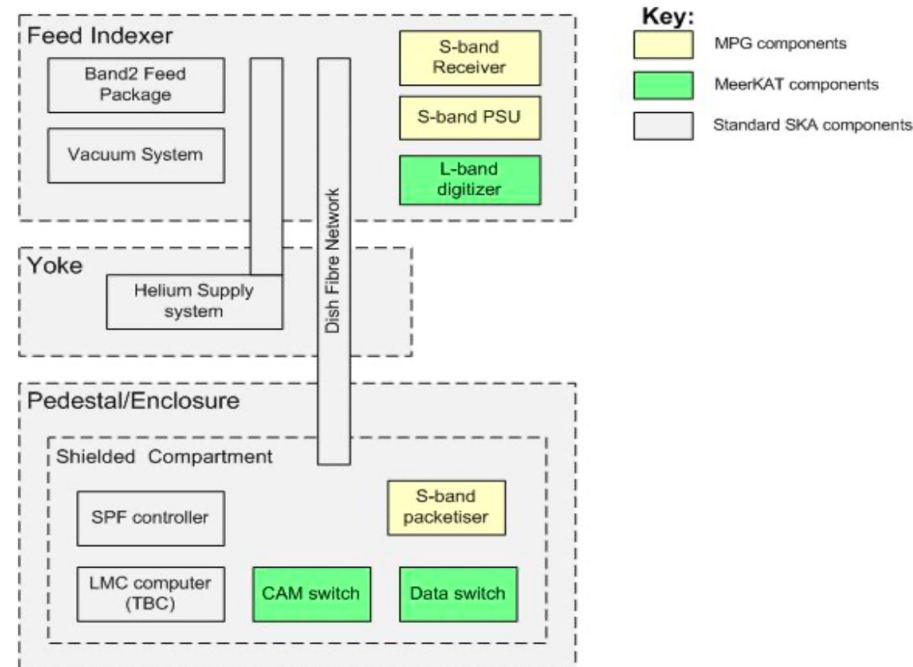
CDR for DSH.LMC in 2018. Italian LMC team with panel, SKADC and SKAO.

DSH LMC: SKA vs MK+

“SKA Compliant” Dish



MeerKAT Extension Dish



Design and tests performed with “SKA compliant dish”.

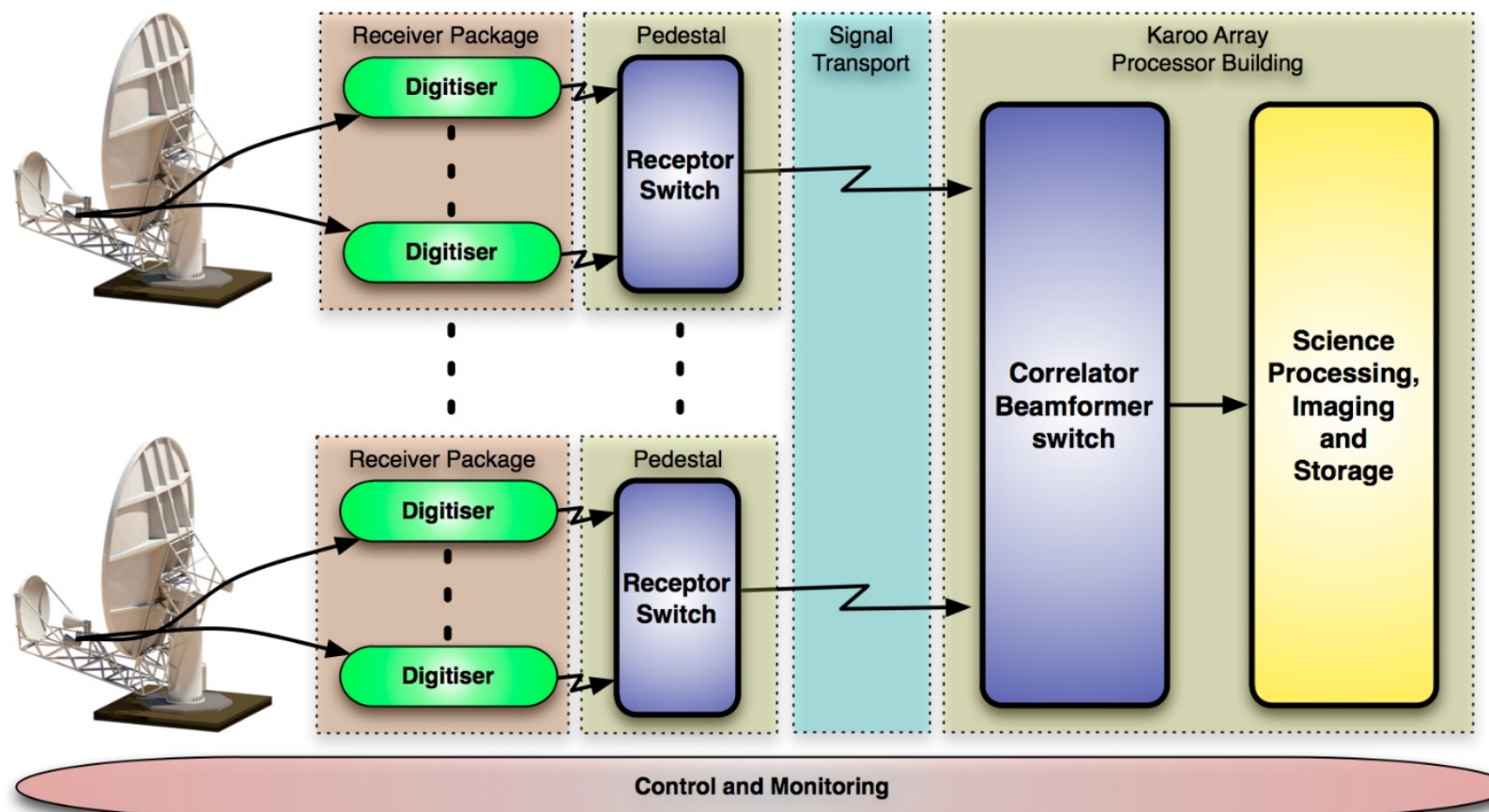
Differences with the MK+ dish are outlined.

Just started!

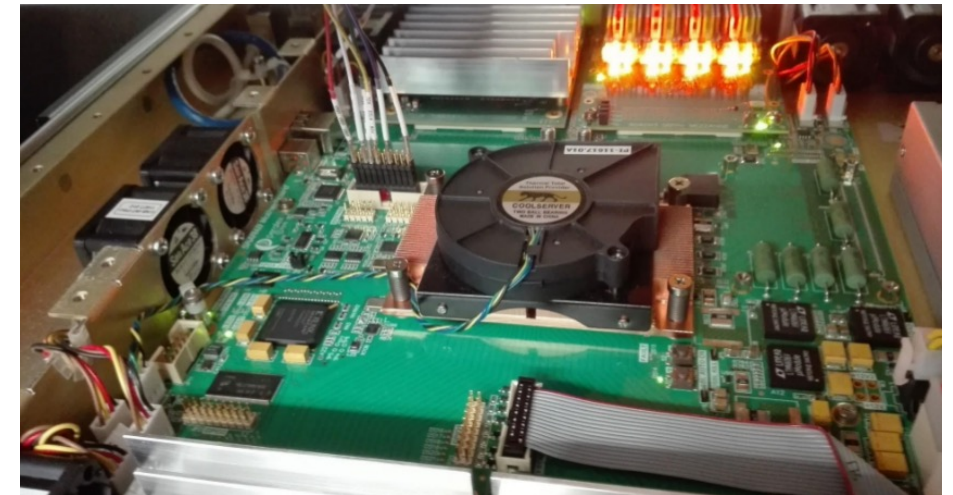
At the present, working at new interfaces, changes in the ACU...

INAF Team participates to the Observation Management and Control Software Development (**SKA_OMC**) with SARAO. Roles TBD

INAF-SARAO collaboration for designing a new digital correlator

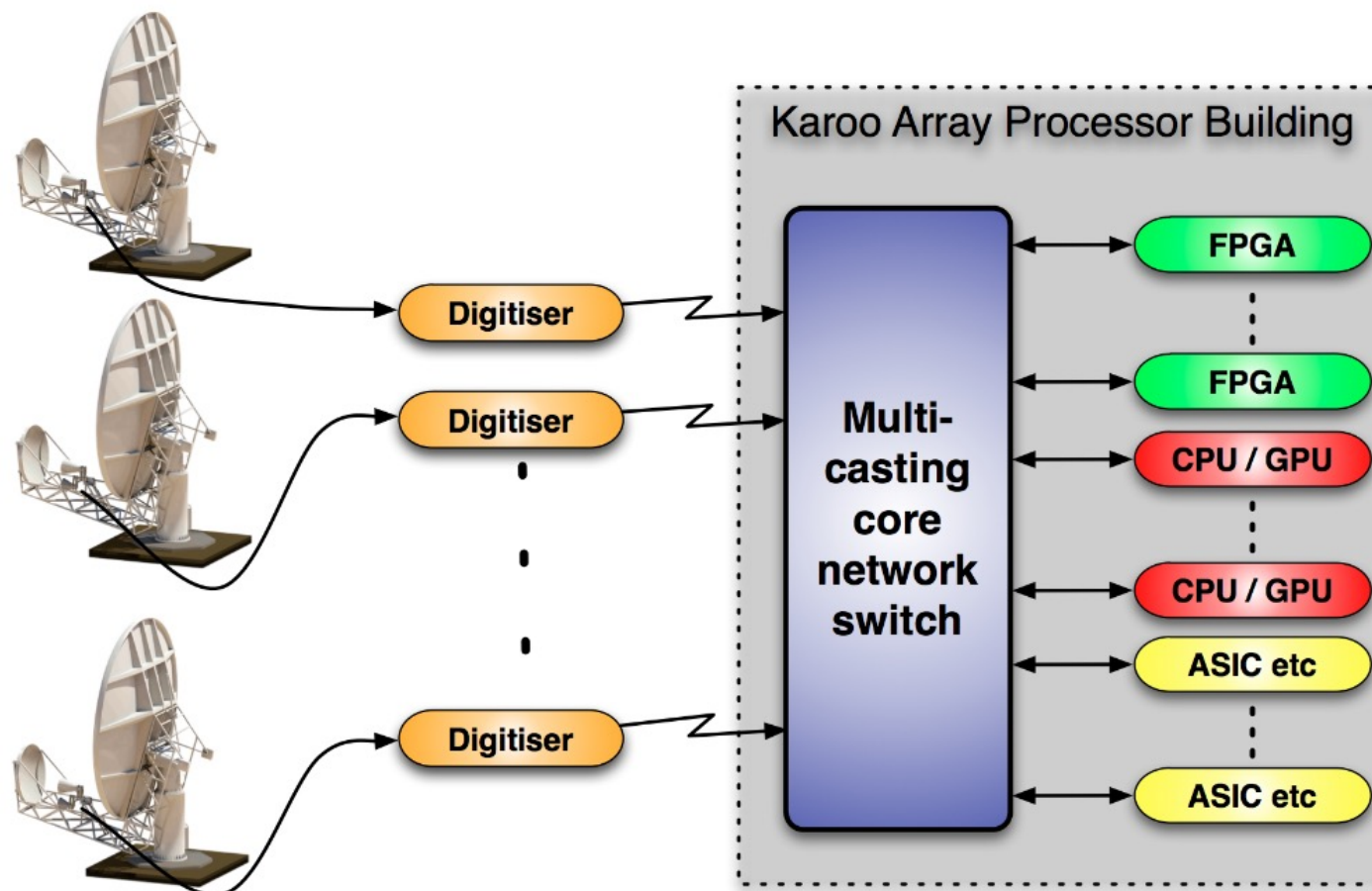


Current SKARAB FPGA-based digital correlator for MeerKAT (64 antennas)



Square Kilometer Array Reconfigurable Application Board (SKARAB)

What technology for the new correlator?



FPGA vs GPU. COTS solutions anyway



Candidate for the F-Engine
(INAF involved in this task)

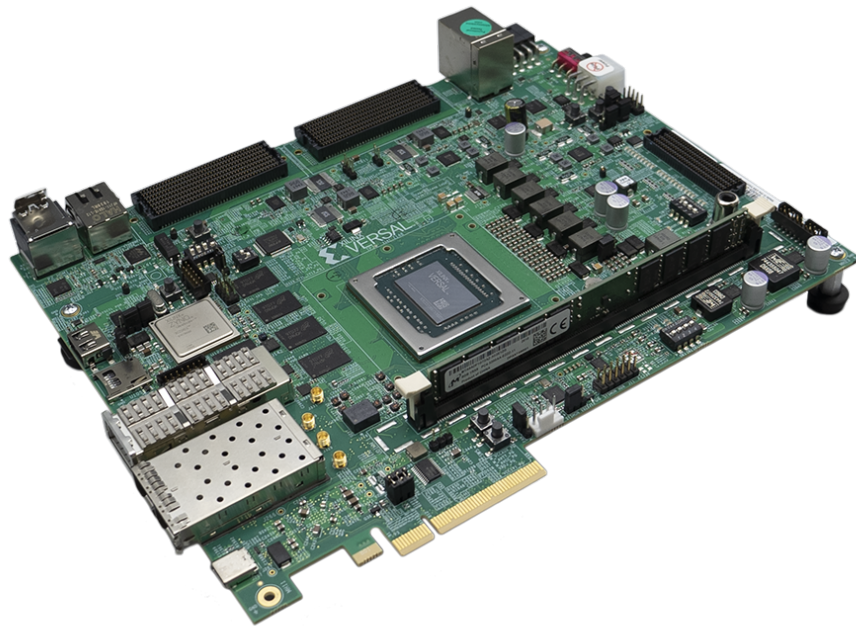


Candidate for all of the three major DSP
blocks:

F-Engine, X-Engine, B-Engine

Versal ACAP (Adaptive Compute Acceleration Platform): a look towards SKA

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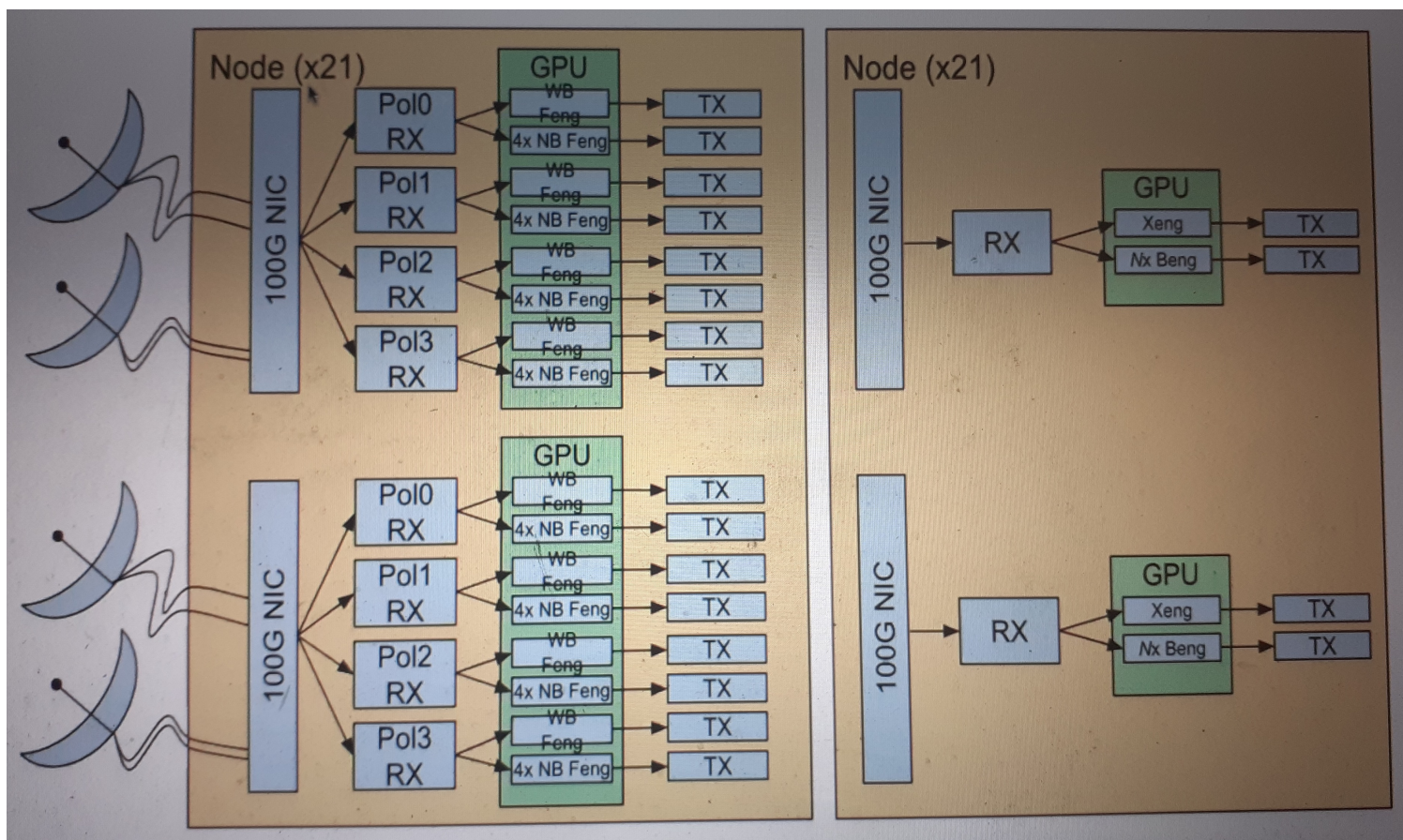


Versal AI Core Series VCK 190
Evaluation Kit



VCK5000 Versal Development Card for
AI Inference

GPU-only solution



Supermicro A+4124-GS-TNR



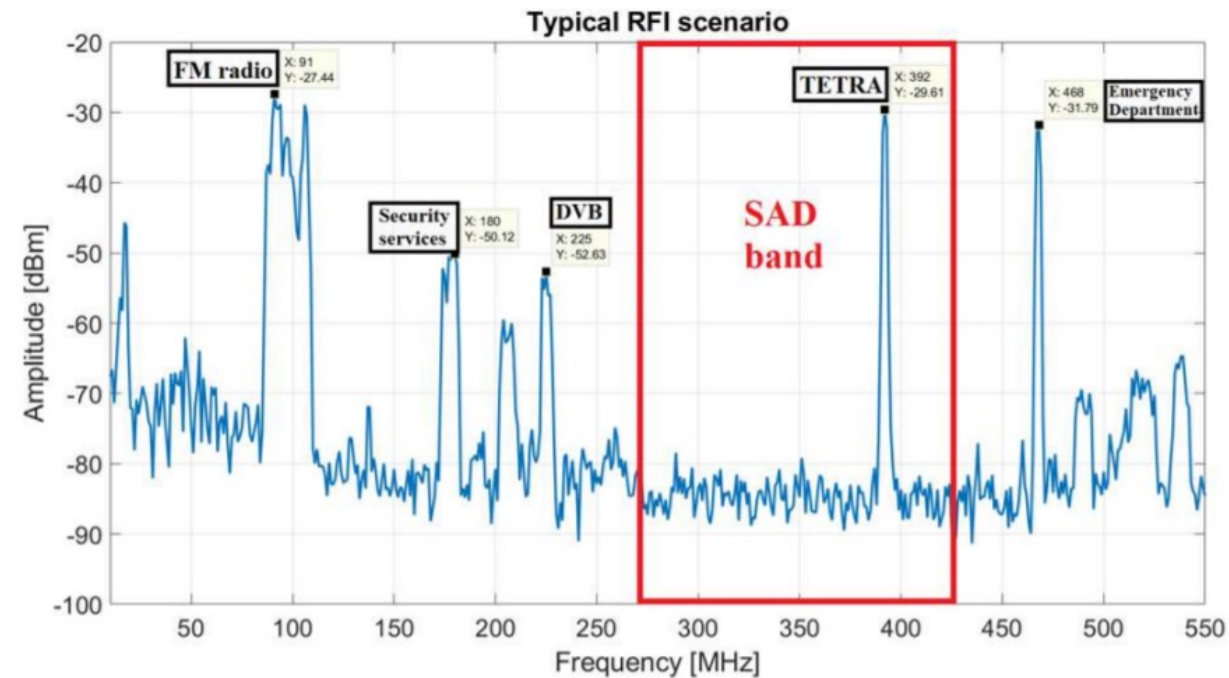
WP INAF for GPUs: water cooling solutions



Collaboration with the Italian company "Ybris Cooling", specialized in this field.

Sardinia Aperture Array Demonstrator (SAD) as test bench

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Correlator: INAF team

INAF Team:

<i>A. Melis (leader)</i>	OA Cagliari
<i>R. Concu</i>	OA Cagliari
<i>A. Poddighe</i>	OA Cagliari
<i>G. Naldi</i>	IRA Medicina
<i>F. Schillirò</i>	OA Catania

Close collaboration with the team of the MOSAICO (Metodologie Open Source per la Automazione Industriale e delle Procedure di Calcolo in Astrofisica) project, which is “daughter” of MeerKAT+.

Team and FTE ... at the moment

Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 12

Struttura	Nfte	N0	TI 21	TI 22	TI 23	TD 21	TD 22	TD 23	Nex	Extra
O.A. CATANIA	6	0	0.80	0.80	0.80	0.10	0.10	0.10	0	0.00
O.A. CAGLIARI	3	0	0.30	0.30	0.30	0.10	0.10	0.10	0	0.00
IRA BOLOGNA	0	1	0.00	0.00	0.00	0	0	0	0	0.00
DIREZIONE SCIENTIFICA	0	2	0.00	0.00	0.00	0	0	0	0	0.00
Totali	9	3	1.10	1.10	1.10	0.20	0.20	0.20	0	0.00

9 staff TI (incl 1 CTER)
3 TD (incl 1 CTER)

Plus a TD to be hired

0.5 1.00 1.00

TOTAL in 3 years:

6.4

Budget

From the international MK+ agreement, Italy participates to the construction of the MK+ with cash (5 M€) and in-kind (at least 1 M€) contributions.

The activities for the development of the DSH.LMC prototype in the pre-construction phase started in 2013, with various function objectives. The financial envelope for LMC was about €1M.

For the development, engineering, automatic testing of LMC for MK+ Dish and correlator development, a total of 1 M€ has been allocated through DM450. Contracts with Italian companies are included.

Criticalities

Dish LMC

- Pandemic has been as been a problem for the whole project. However, tests on the SKA-MPI dish prototype performed remotely with success.
- International collaboration: often changes in responsibilities and WBS, in particular for Dish Structure
- Need of expert Software Engineer: difficult to find! Not competitive salary?

Correlator

- The project begun a few weeks before the Italian lockdown.
- Nvidia GPUs 3080 basically unobtainable.
- The DSP leader at SARA0 is leaving the project for personal reasons