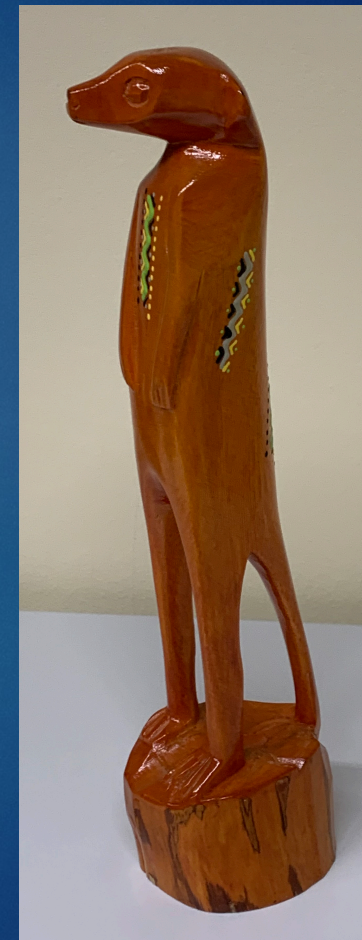




Mid-frequency SKA precursors/pathfinders: Italian Involvement and opportunities



G. Umana



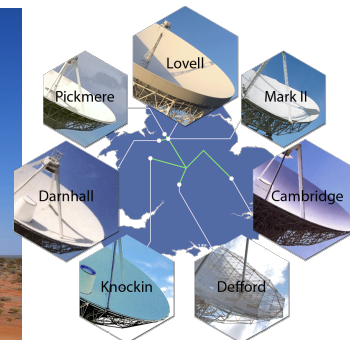
Activities within UTG-II (F. Govoni)/WG4

The WG “High frequency SKA precursors and pathfinders” was established (2019) within the organization of INAF UTG-II

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

Facilities (new or refurbishment of operating facility) to explore the science and technical challenges in the way to SKA

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



SKA Pathfinders: JVL

Specifications

27 antennas (25m)

Max baseline= 37 km

Frequency coverage: 1-50 GHz

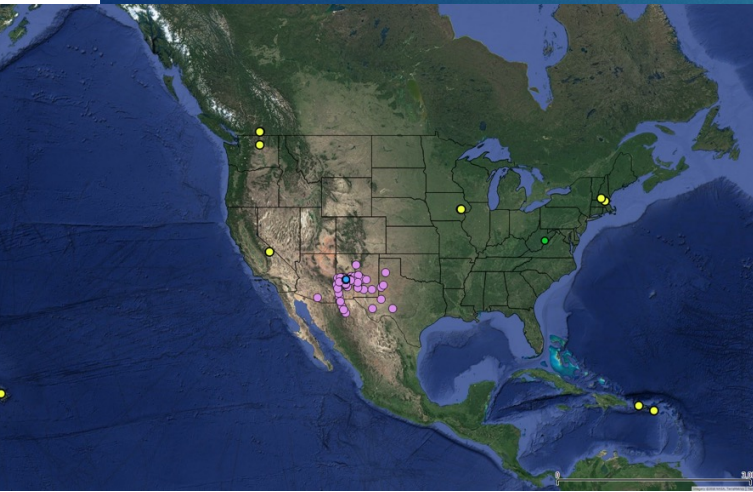
Bandpass: 1000 MHz

Sensitivity: 20 μ Jy/hr @ 1.4 GHz

Open Sky: 2 call/yr, ToO, DDT

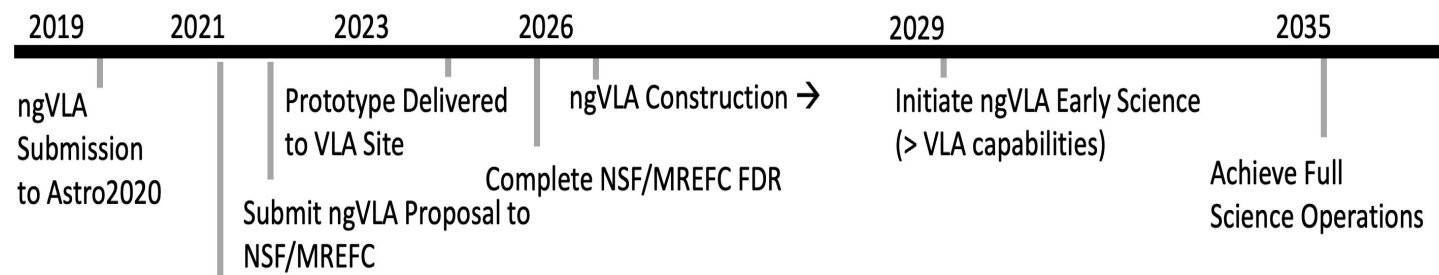


ngVLA



- **1.2 - 116 GHz** Frequency Coverage (bridging SKA-ALMA)
- **Main Array:** 214 x 18m offset Gregorian Antennas.
 - Fixed antenna locations across NM, TX, AZ, MX.
- **Short Baseline Array:** 19 x 6m Antennas
 - to fill in $[\nu, \nu]$ hole.
- **Long Baseline Array:** 30 x 18m antennas located across continent for baselines up to ~ 8860 km.

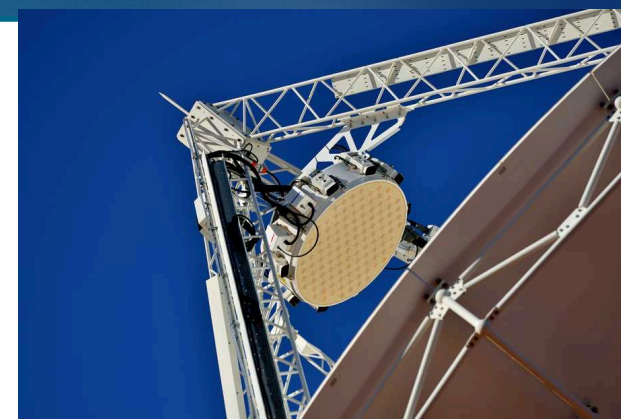
Sensitivity/Resolution Goal: ***10x sensitivity & resolution of JVLA/ALMA***



SKA Precursors: **ASKAP**

Specifications

36 antennas (12 m)
Max baseline: 6 km
Frequency coverage: 0.7- 1.8 GHz
Bandpass: 300 MHz
Sensitivity: 25 μ Jy/hr @ 1.4 GHz
Angular resolution= 10 arcs
FOV (PAF)= 30 deg²
Survey Speed= 220 deg²/hr (0.1 mJy)
Large surveys, ToO, DDT

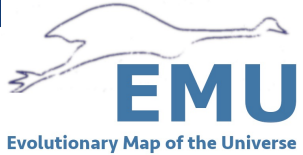


5

Unique capability:
The Phased Array Feed
Innovative technology, allows a FOV
of 30 deg²



ASKAP- LSPs



2 selected as highest priority:

EMU: Evolutionary Map of the Universe

Continuum survey of the sky

PI: (R. Norris), A. Hopkins

Wallaby: Wide-field ASKAP L-band Legacy

All-sky Blind survey

Neutral Hydrogen survey of the sky

PI Bärbel Koribalski & Lister Staveley-Smith

Data will be public as soon as the surveys
completed and validated

ASKAP-FLASH: The First Large
Absorption Survey in H I

VAST: An ASKAP Survey for
Variables and Slow Transients

GASKAP: The Galactic ASKAP
Spectral Line Survey

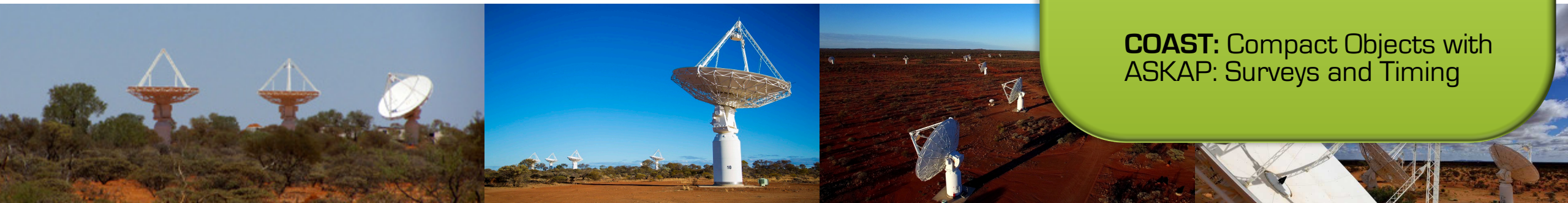
POSSUM: Polarization Sky
Survey of the Universe's
Magnetism

CRAFT: Commensal Real-time
ASKAP Fast Transients survey

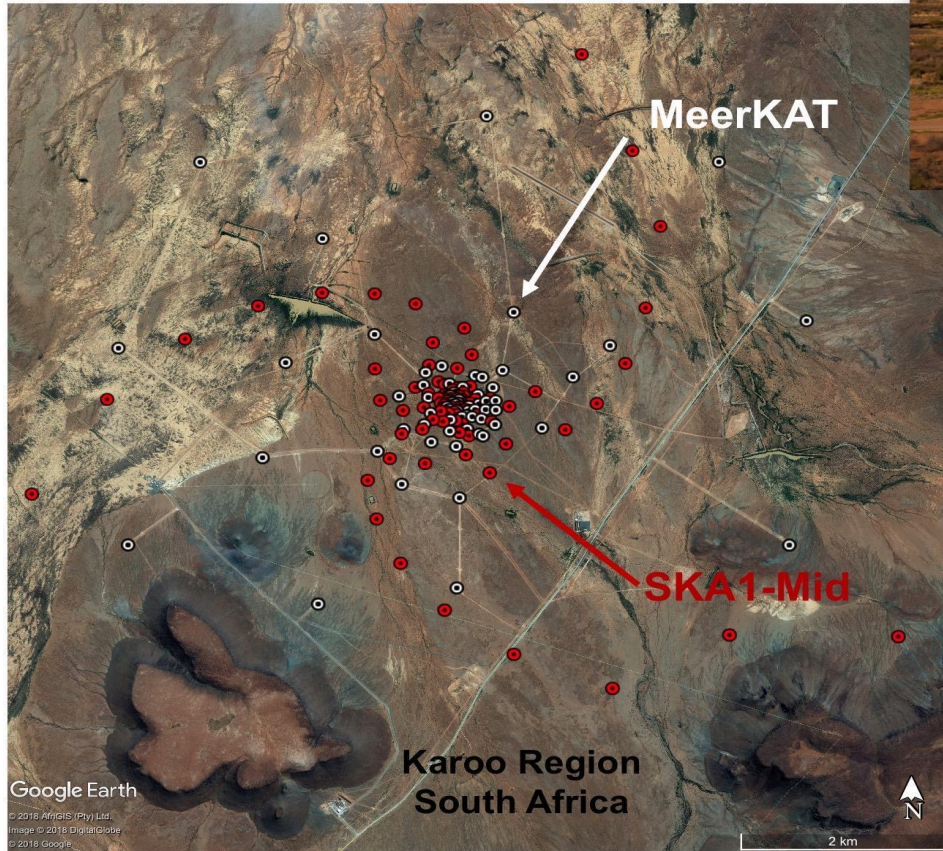
DINGO: Deep Investigations of
Neutral Gas Origins

VLBI

COAST: Compact Objects with
ASKAP: Surveys and Timing



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

Specifications	
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

From SKA Italy Roadmap, *outcome* of the "National Conference of Science and technology of SKA" (Bologna 3-5 December 2018):

The SKA precursors represent a unique opportunity to strengthen the technical/scientific skills of Italian researchers. As already done for LOFAR, forms of formal involvement in the precursors ASKAP and MeerKAT need to be explored.

We focus
our activity on:

A wider participation in *the Legacy Surveys* and a greater involvement in the scientific exploitation of MeerKAT

A full involvement in the technological development and sophisticated pipelines for data analysis of MeerKAT

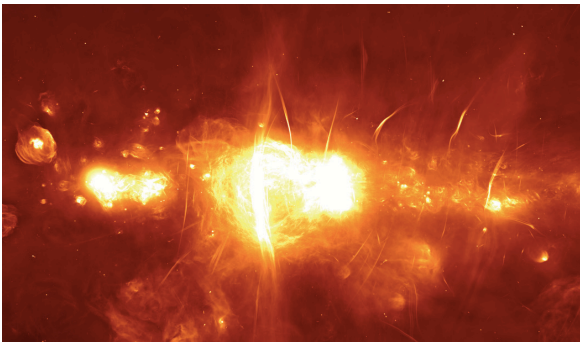
Providing a continuous training for young researchers and technologists in the pre-SKA era, preparing a new generation of scientists ready to face the challenges of SKA.

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

- **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:

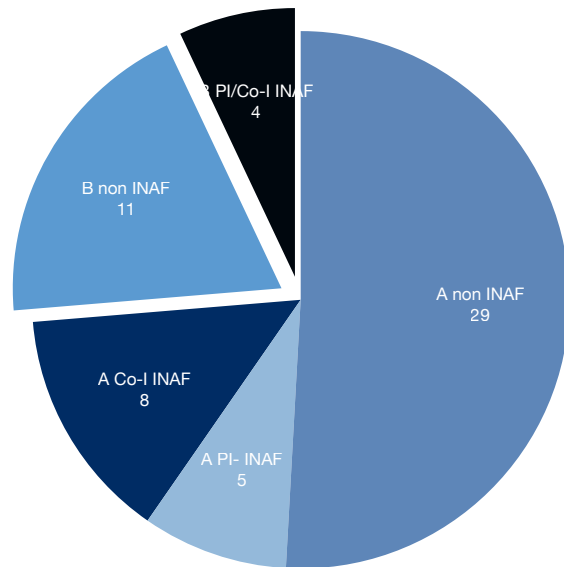
SARAO MeerKAT Galaxy Cluster Legacy Survey (IRA)

SARAO MeerKAT Galactic Plane Legacy Survey (OACT)

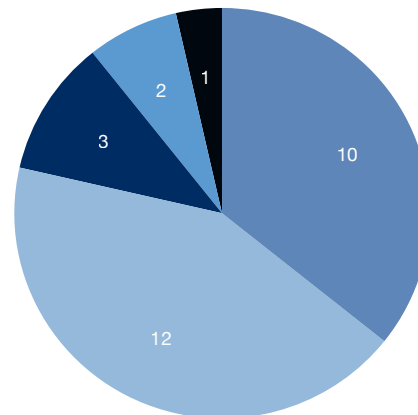
INAF activities in MeerKAT

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

Total approved projects: 57/113
A & B represent different priorities

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 plus: The project in a nutshell

INAF's participation in the MK+ project appears to be a concrete and efficient response by the Institution to the requests of the community.

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)

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)

INAF has a technological involvement in some specific sectors on the basis of consolidated and already started activities (prior 2020)

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

MeerKAT

MeerKAT:

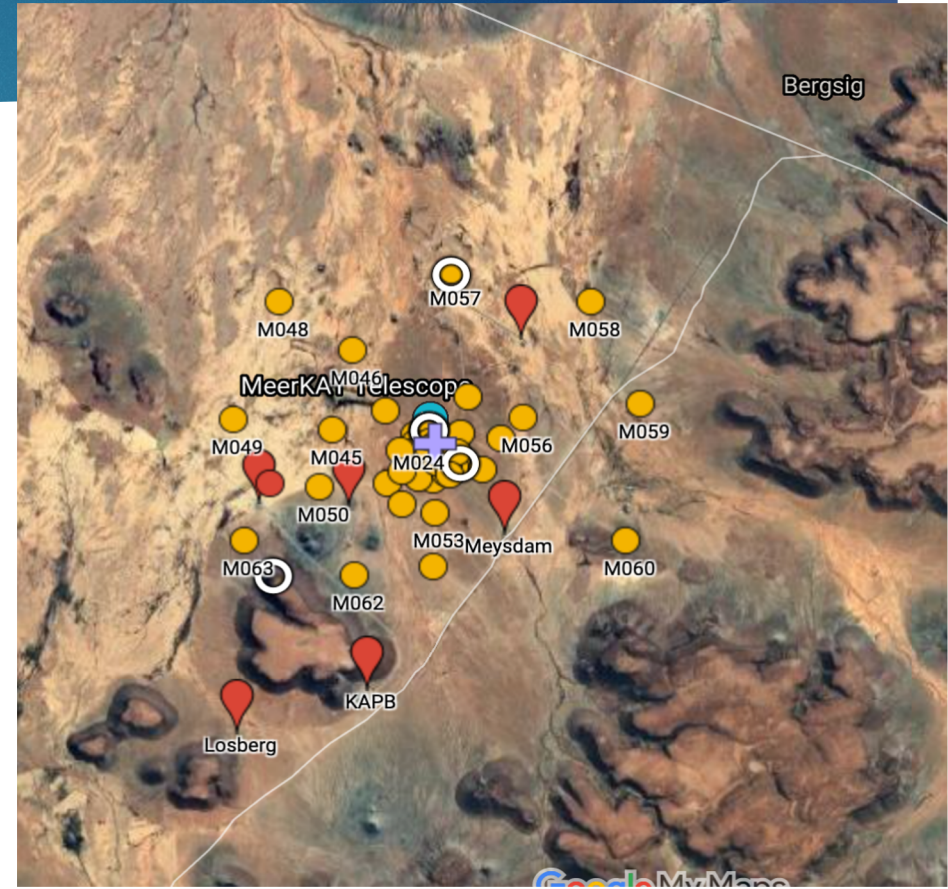
Operated by SARAO

64, 13.5-m dishes over 7.7 km

580-3500 MHz

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

Angular resolution: 8"



MeerKAT → MeerKAT+

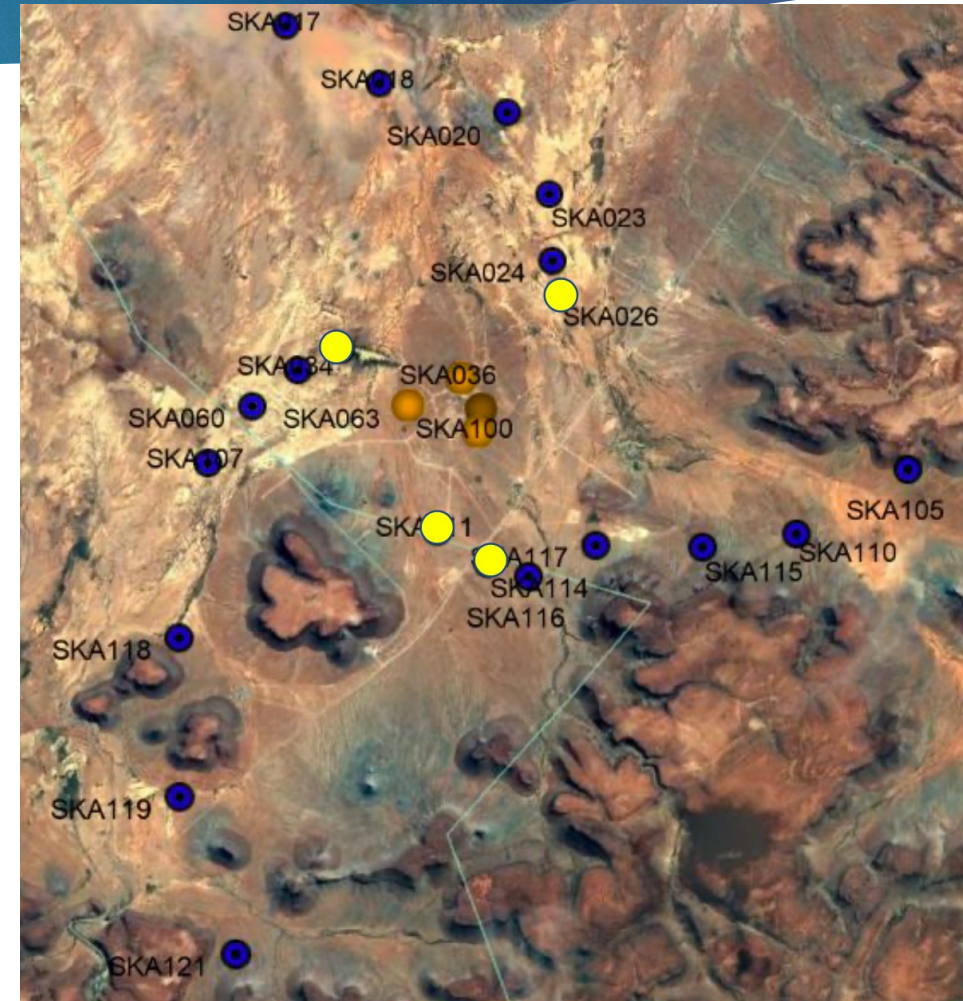
MeerKAT plus represents:

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

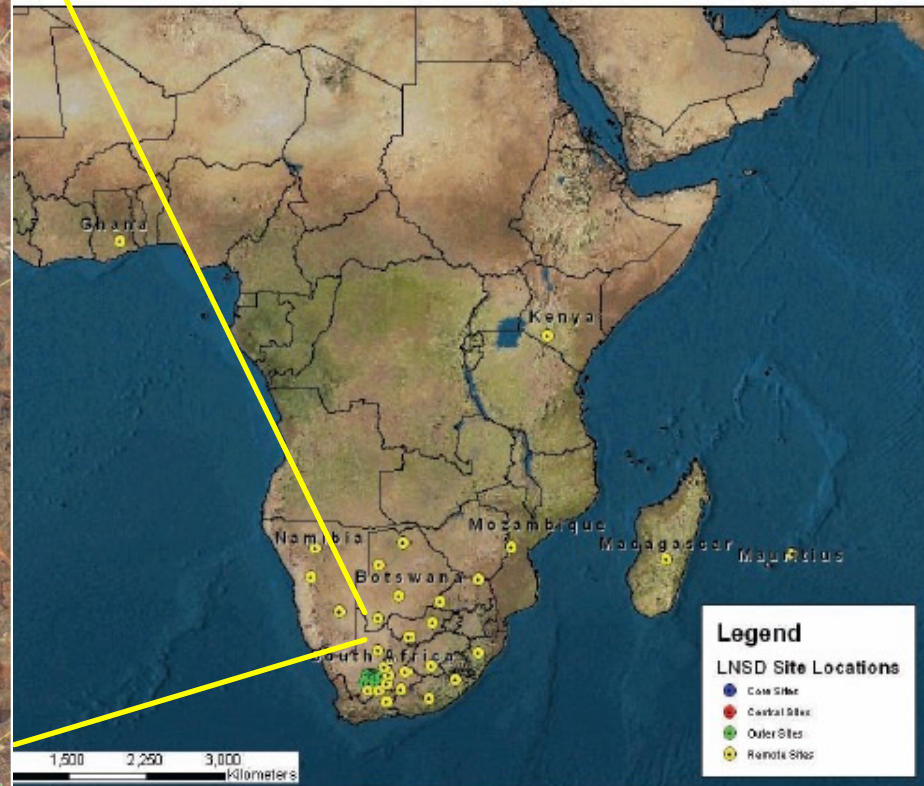
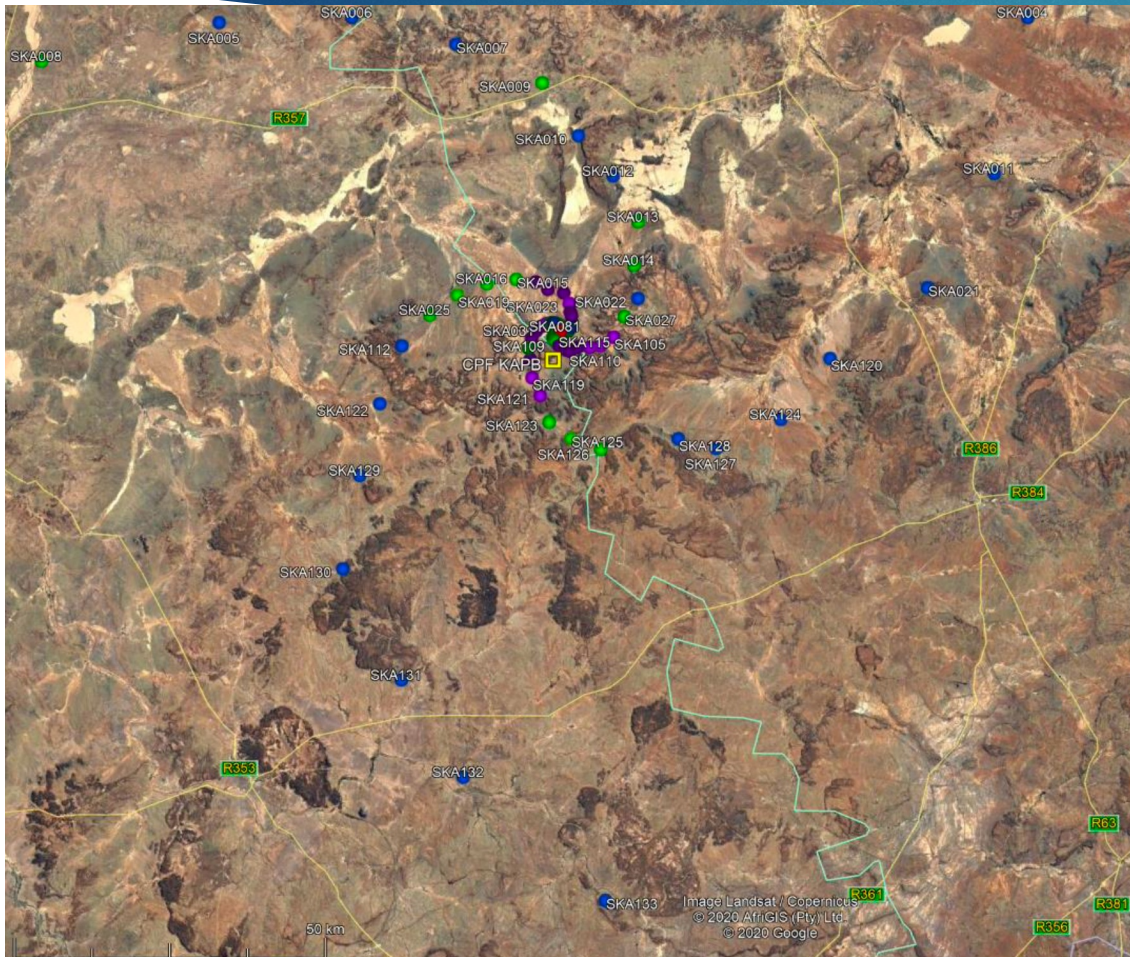
Area +30% (16 antennas)

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

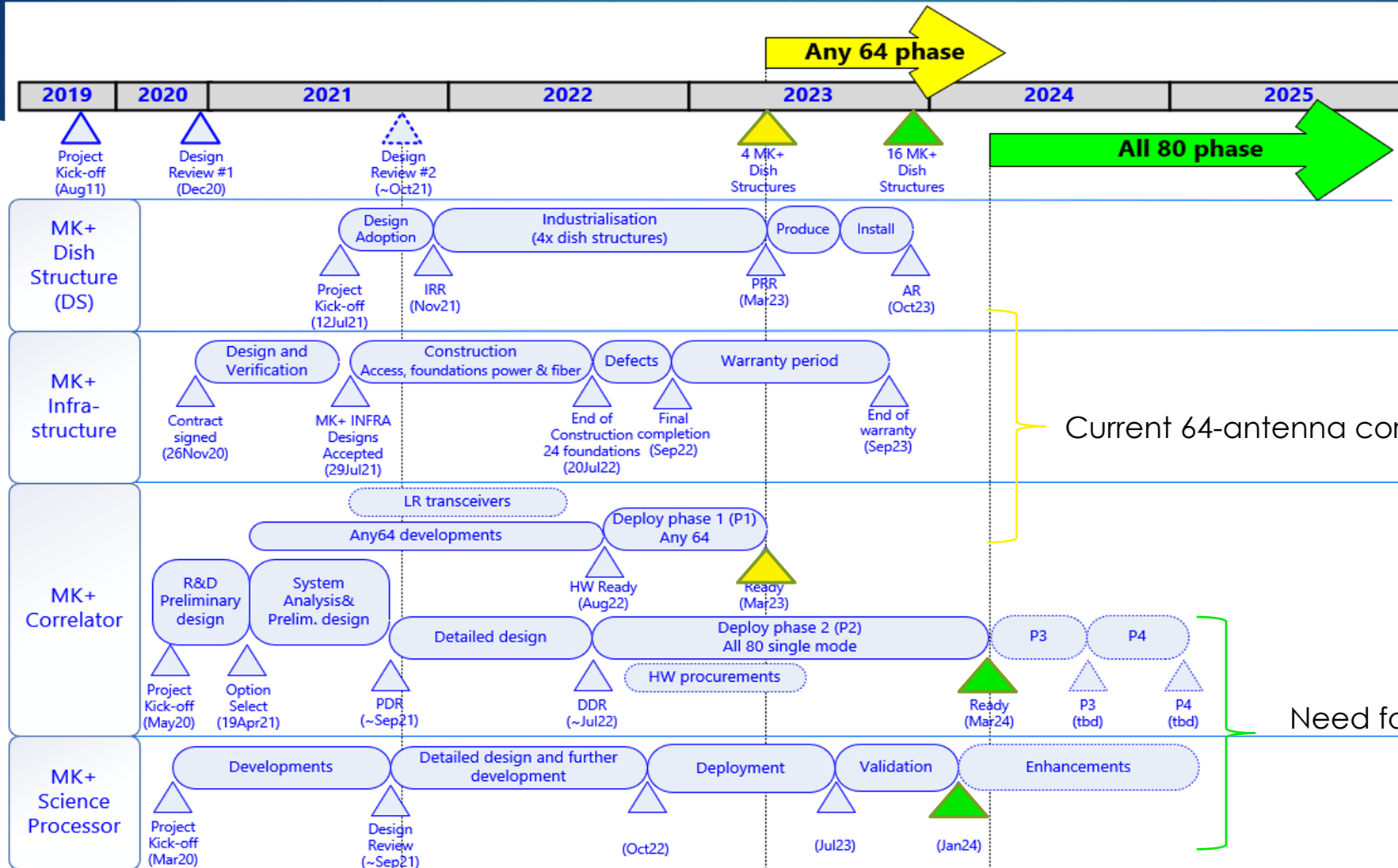
Angular resolution: $8'' \rightarrow 3.4''$



MeerKAT → MeerKAT+ → SKA1-Mid



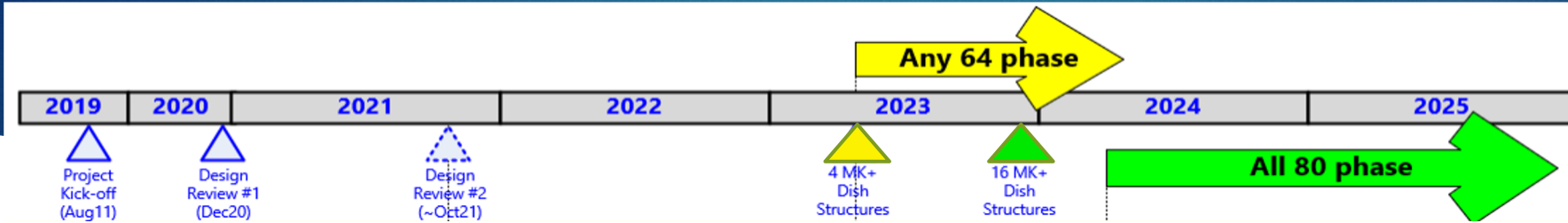
MeerKAT -> MeerKAT+



Current 64-antenna correlator

Need for new correlator

MeerKAT -> MeerKAT+: system capability & phasing



MK Current MeerKAT capabilities

MK+
Phase 1

Capabilities **on any 64 antennas** (Q1 2023)
with some limits
Q2 2023- to be used for testing and commissioning
Q4 2023 could be available (64+16) for some science (?)

MK+
Phase 2

Capabilities on **all 80 antennas** (Q1 2024)
single new 8K mode
Q1 2024 planned to be available for commissioning
Science to start when suitable capabilities demonstrated

Italian Participation to MK+ (technology)

Italy (INAF) participates in MK+

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



SKA DSH LMC: an Italian project

From 2017 DSH.LMC is lead by INAF. Two Italian companies join 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.

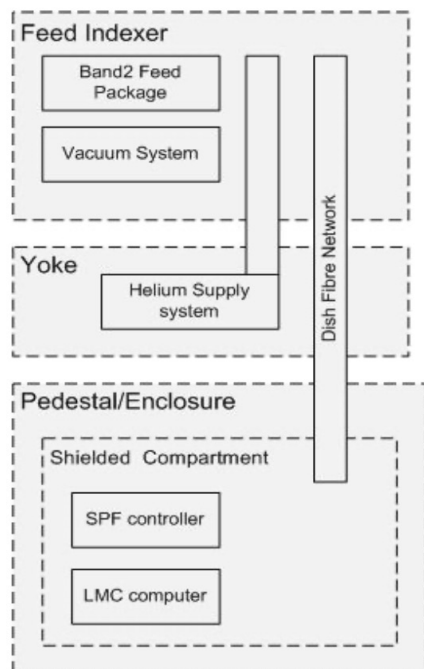
In 2020 **SARAO invited us** to joint the MK+
project for Dish.LMC.



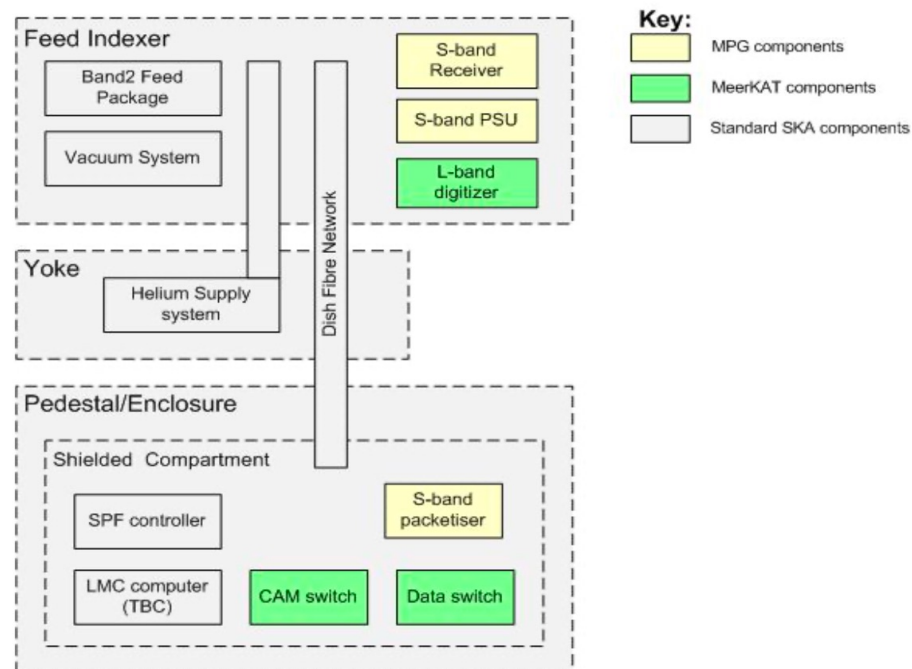
CDR for DSH.LMC in 2018. Italian LMC team with panel, SKADC and SKAO.

DSH LMC: SKA vs MK+

“SKA Compliant” Dish



MeerKAT Extension Dish



Design and tests performed with “SKA compliant dish”.

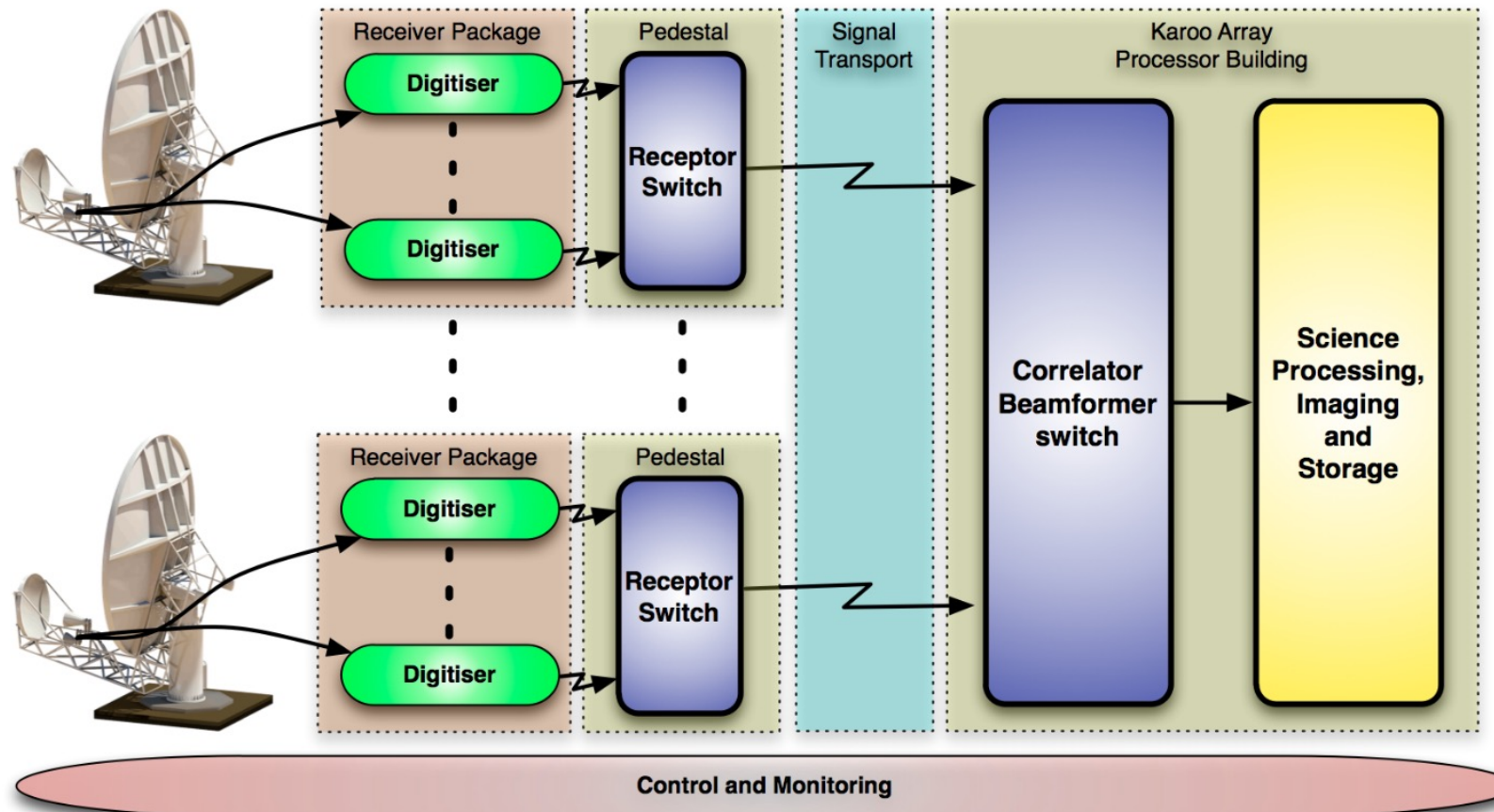
Differences with the MK+ dish are outlined.

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 SARA0. Roles TBD

INAF-SARAO collaboration for designing a new digital correlator

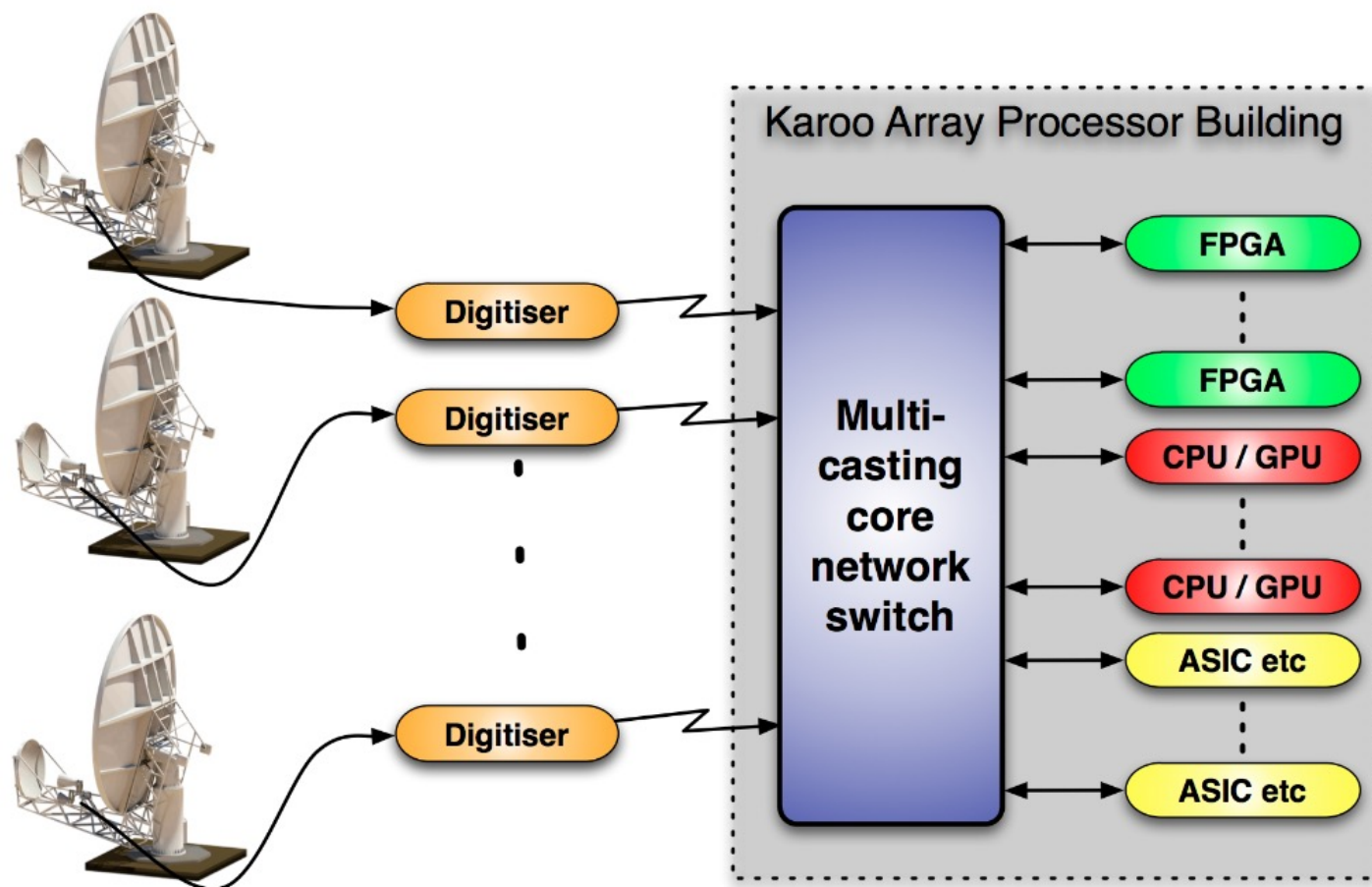


Current SKARAB FPGA-based digital correlator for MeerKAT (64 antennas)



Square Kilometer Array Reconfigurable Application Board (SKARAB)

What technology for the new correlator?



Need for a new correlator (SKARAB only 64) both for the current needs of MK+, and from a SKA perspective;

Goal: to develop a completely scalable correlator (does not depend on the number of antennas)

INAF team involved to find the best solution in terms of performance, cost, power consumption and scalability.

Heterogeneous devices appear to be the best choice
Currently under testing

LMC & Correlator INAF teams

LMC

C. Trigilio (leader) OA Catania
A. Ingallinera OA Catania
S. Riggi OA Catania
F. Schillirò OA Catania

Correlator

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

Close collaboration with the team of the MOSAICO (Metodologie Open Source per la Automazione Industriale e delle Procedure di CalcOlo in Astrofisica)



Towards a joint science program

Science use of enhanced MeerKAT by MK+ partnership

- MK+: joint project by SARA0, MPIfR, INAF to enhance MeerKAT's capabilities
- Intent of joint collaboration is to select observing project(s) for reserved share that produce legacy science products remaining relevant into SKA era
- Reserved share of telescope time dedicated to joint selected projects
 - Reserved share is ~10% of overall time awarded for competed science observations
For planning purposes this is ~500 hours/year, until integration into SKA (~2026?)
 - ~90% to be awarded through standard SARA0 processes (LSP, OT, DDT) to wider community

Science use of enhanced MeerKAT

- Current White Paper (WP), released on May 2021, presents ideas for 3 legacy science projects.
INAF did not participate/contribute to the discussion that led to the drafting.

While broad in their science goals, these three surveys can be summarised as:

- (1) a medium-shallow HI galaxy evolution survey;
- (2) a full-Stokes S-band southern sky survey ($\delta < -40^\circ$)
- (3) a cosmological HI survey at L-band, including the intensity-mapping technique to probe large-scale structure

All three are aligned with SKA-MID key science programmes and contribute to SKA Key Science Projects survey design in the future.

Potential ideas

Two at L band (900-1670 MHz), one at **S band** (1750-3500 MHz);
each would require more telescope time than may be available, but are scalable to different degrees

Projects outlined in WP are **starting point** for further development/eventual downselection of collaborative science program;

other projects could be considered/developed by community

	Low HI galaxy survey	S-Band Polarimetry	HI Intensity mapping
Sky coverage [deg ²]	1000	7368	5000
rms [μ Jy/beam]	550 line/ 10cont	15	5
hours	2000	3000	2000
band	L-band	S-band	L-band
Total BW [MHz]	875	856	875
Spectral resolution	26 kHz	209 kHz	104 kHz
Survey strategy	continuous area	continuous area	continuous area
Data rate required	380/760 MB/s	115 MB/s	266 MBs
Archive storage req.	5.4 PB	1.3 PB	2 PB
req. angular res [asec]	3/10	1-2	10-1800
Precursor to a SKA1-MID KSP	Y	N	Y

Framework for selecting collaborative LSPs

dates will depend on status of relevant milestones

- At a suitable time (Q2 2022?) a call for proposals seeking to utilize reserved share will be issued. Projects will be evaluated based on scientific and technical merit by advisory review panel
- Selected project(s) will be different from typical PI-led projects, (data to be 'owned' by partners, not PIs)
- After review and selection of project(s), late 2022/early 2023, further discussions to engage with relevant research communities in South Africa, Germany, Italy, to *establish and implement end-to-end requirements* for broad science exploitation of expected datasets
- Substantial novel capabilities of MeerKAT *assumed* for Q1 2024 (start commissioning of phase 2) ***Planning for science projects should be resilient against possible uncertainties on specific capabilities***

Next steps towards the legacy science program

1. The relevant science communities should engage amongst themselves and as relevant with SARA0 staff developing backend (ongoing process, just started for INAF- July 2021)
2. Planning (proposed) for Italian community
 - step 1 Collect all the information for the 3 proposed ideas (ongoing) and inform the community
(help from CSN)
 - step 2 Internal call for Eol either
 - to collaborate to one of the proposed LSP
 - to propose new projects
 - step 3 – Focused internal workshop(s) to finalise the Italian contribution
 - step 4 Workshop together with MK+ partner institutions, to constitute project (s) team(s), to focus on optimizing readiness for analysis of future datasets and further developing plans for wider exploitation.