



The Italian contribution to MeerKAT

G. Umana, Catania 27 Novembre 2023

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Ministry of Foreign Affairs
and International Cooperation



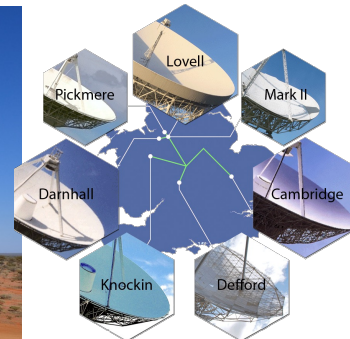
Activities within UTG-II (F. Govoni)/WG4

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 path to SKA

- ▶ 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, 13.5m dishes, over 7.7 km

L Band	900-1670 MHz
UHF	580-1015 MHz
S Band	1750-3500 MHz

L-Band sensitivity

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

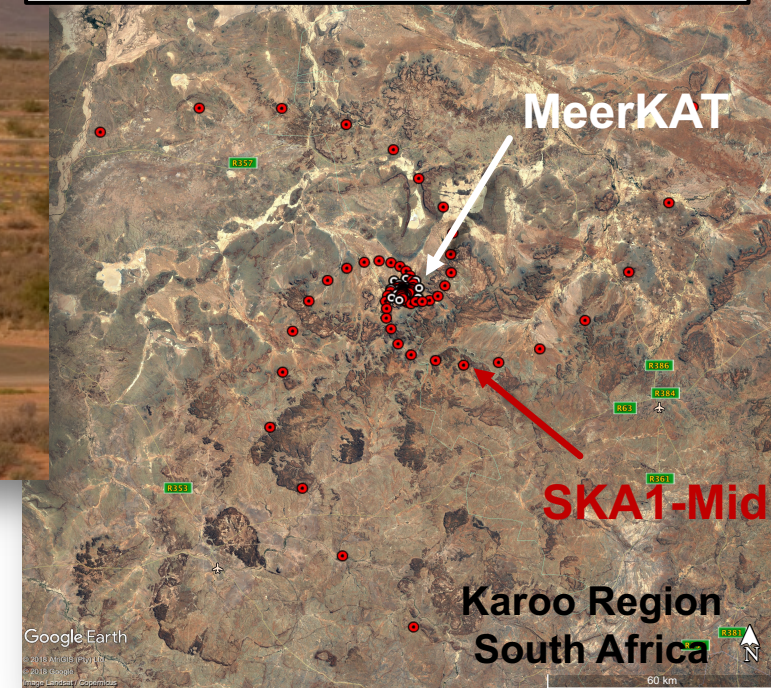
Array layout: 70% of the antennas in the 1 km core
+ an extended component up to 7.7 km
Excellent surface brightness sensitivity on angular scales 1'

SKA Mid:

Step 1: 133 SKA dishes (15m) +
64 MeerKAT dishes (13.5m)
350 MHz - 15 GHz

Maximum baseline 150 km, 3 spiral arms

Step 2: About 2000 SKA dishes
possible frequency extension
up to 24 GHz

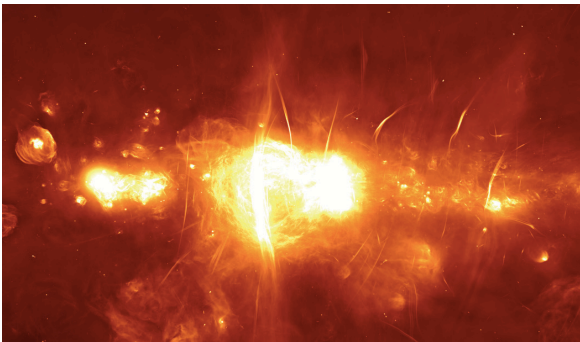


The path to MeerKAT plus: INAF MeerKAT document

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 science activities in MeerKAT

Italian interests cover a **wide range of scientific topics**, Galactic and Extragalactic

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)

Open time:

Great participation of the Italian community (INAF and INAF associate) to the open time calls
With a very high success rate.

The path to MeerKAT plus: INAF 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

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

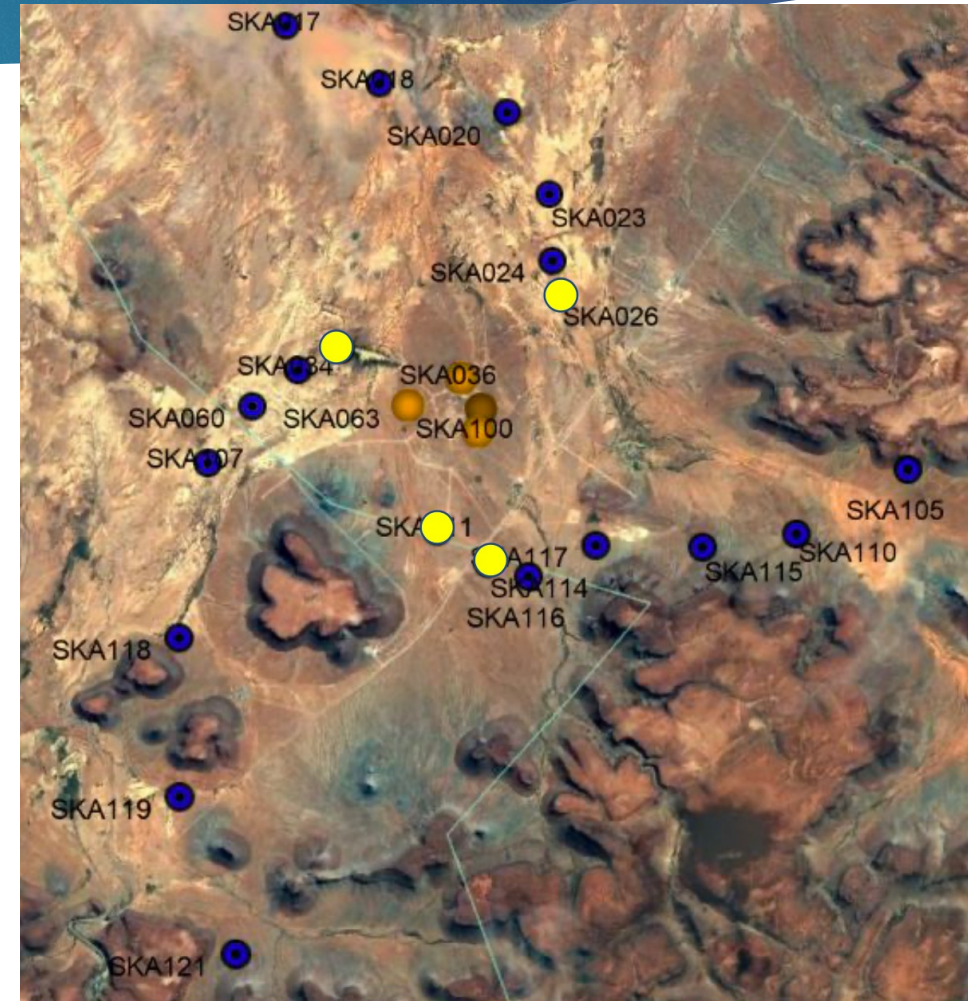
MeerKAT → MeerKAT+

MeerKAT plus represents a substantial increase in the scientific capability of MeerKAT

Area +30% (16 antennas)

L-Band

- Sensitivity (1 hr): 12mJy/b → 9mJy/b
- Angular resolution (max baseline from 7.7 to 16km): 8" → 3.4"
- Increase (56%) in number of baselines: improved calibration and image fidelity



Italian participation to MK+ (technology)

Italy (INAF) participates in MK+ (also from previous experiences in SKA-related projects)

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

Square Kilometer Array Reconfigurable
Application Board (SKARAB)- only for 64 dishes



LMC & Correlator INAF teams

LMC

<i>C. Trigilio (leader)</i>	OA Catania
<i>A. Ingallinera</i>	OA Catania
<i>S. Riggi</i>	OA Catania
<i>F. Schillirò</i>	OA Catania
<i>C. Bordiu</i>	OA Catania
<i>S. Costanzo</i>	OA Catania

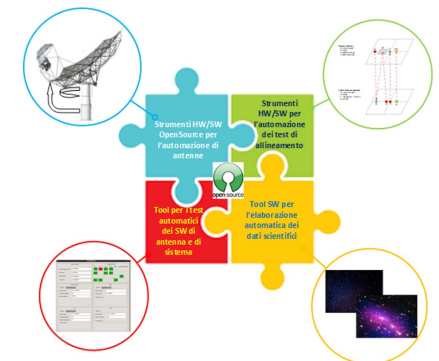
Correlator

<i>A. Melis (leader)</i>	OA Cagliari
<i>A. Poddighe</i>	OA Cagliari
<i>G. Naldi</i>	IRA Medicina
<i>F. Schillirò</i>	OA Catania
<i>S. Billotta</i>	OA Catania
<i>M. Belluso</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)

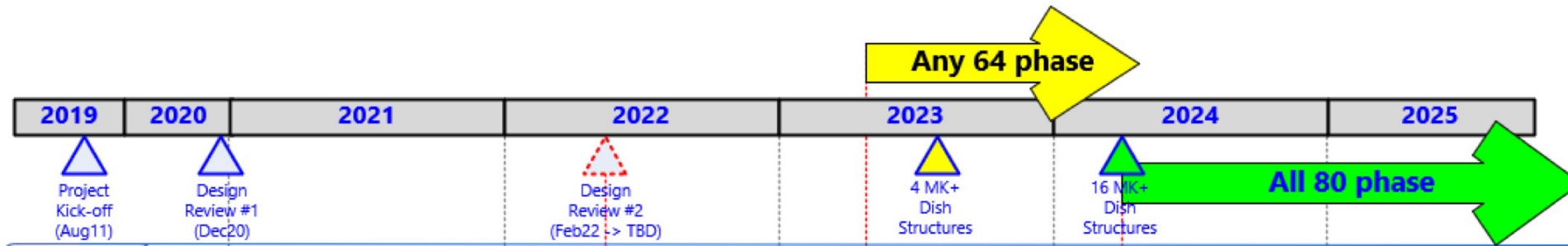
P.I. OACT, F. Schillirò

Financed by the Ministry of Economic Development through the call for proposals for "Smart Factory" Axis I Action 1.1.3. - co-financed with FESR Funds under the National Operational Programme "Imprese e Competitività" 2014-2020,



MeerKAT+ status: project baseline

12



A schedule slippage in the dish structures

- 4 MK+ dishes ready for commissioning → March 2024
- 14 MK+ dishes ready for operation → Oct 2024

The correlator upgrade (all 80 antennas) is underway and planned to be available when all the MK+ antennas are commissioned

Scientific commissioning of MK+ will began in late 2024

The operational phase of MeerKAT+, in which the observation programs will be carried out, **runs from 2024 to 2027 (expected delays)**

The integration phase of MK+ into SKA is planned over a period **of 2.5 years.**

As June 2022

As November 2023



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 $\sim 10\%$ of overall time awarded for competed science observations
For planning purposes this is ~ 500 hours/year, until integration into SKA ($\sim 2027?$)
 - $\sim 90\%$ 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 MeerKAT 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 *, one at **S band** (1.75-3.5 MHz);
each would require more telescope time than may be available, but are scalable to different degrees

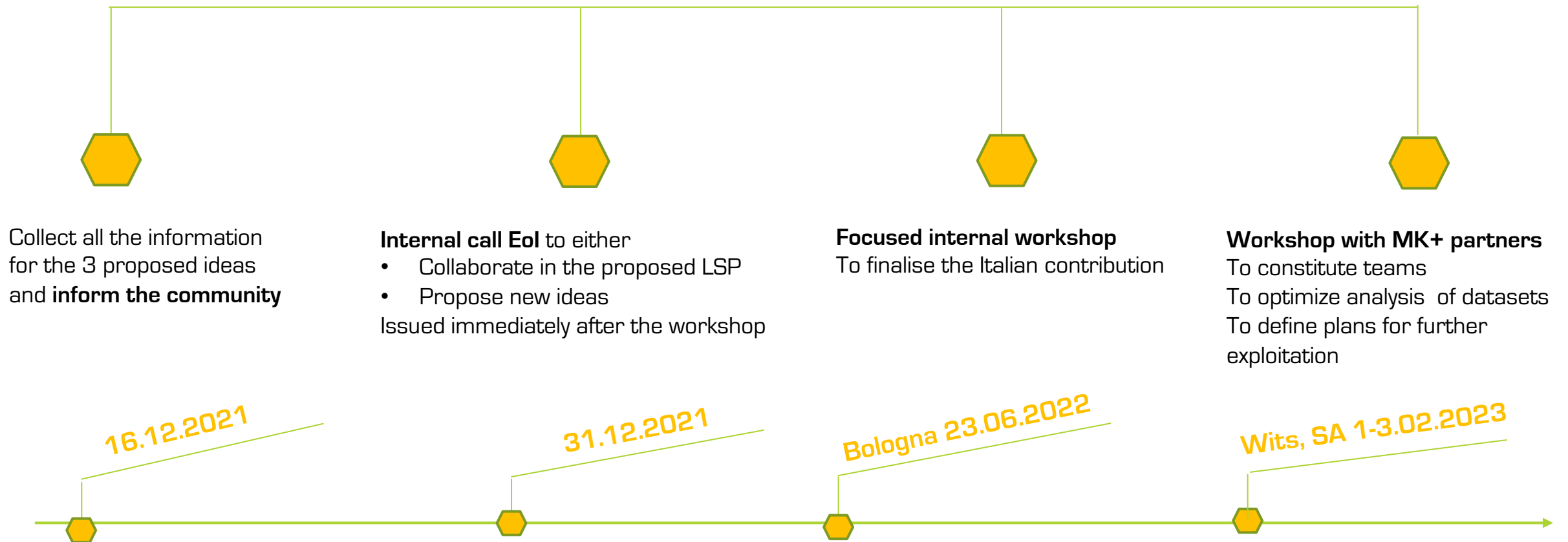
Projects outlined in WP are **starting point** for further development/eventual downselection of collaborative science program;

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

* The MK+ will be equipped with SKA Band-2 receivers (950-1760 MHz), MeerKAT L band (900-1670 MHz)

Path for the italian community



Steps towards the legacy science program: EoI

- In response to the call, a total of 24 EoIs were received, covering different topics of Galactic and extragalactic radioastronomy
- a total 136 unique authors including both INAF staff and INAF associates (about 30% of the total).
- There was also a good spread over the INAF Institutes and Observatories, with PIs from IRA, OACa, IAPS, OAA, OABrera, OAPd, OANa and OACt.
- There is a significant interest in S-Band observations (66% of the received EoIs), with about 25% of the EoIs requiring both L-band and S-Band observations.

Steps towards the legacy science program: Final Surveys

- A 3-day in person workshop in Wits, SA, to prepare for MeerKAT+ science and data processing needs:
 - To cover the science opportunities and technical capabilities of MeerKAT+,
 - to provide an opportunity for the project partners to plan for the MeerKAT+ Legacy Programme in more detail, following previous contributions to the MeerKAT+ Science White Paper.
- All the received Eols are under review and considered for the final version of the three themes.
- The final surveys will be evaluate by an external panel that will advise the MK+Board.

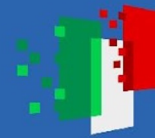
The process should be concluded by the Q1 2024.



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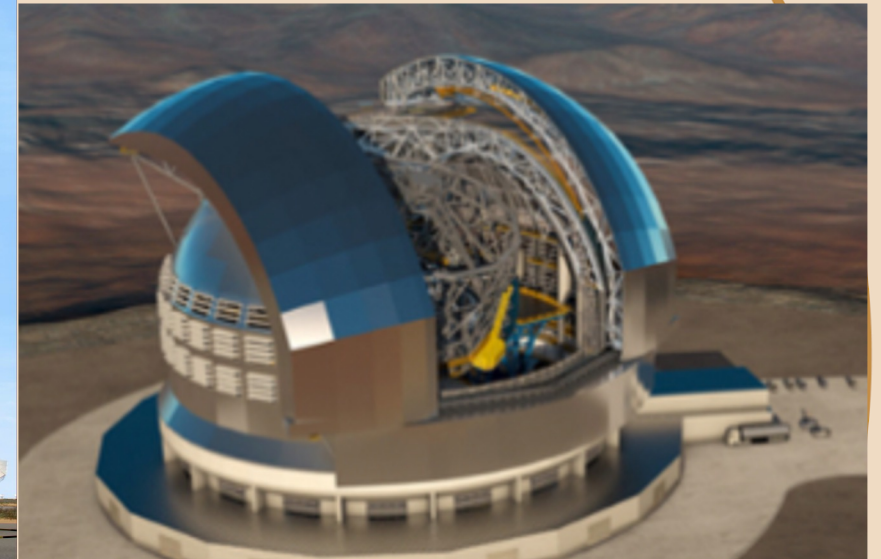


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PIANO NAZIONALE
DI RIPRESA E RESILIENZA

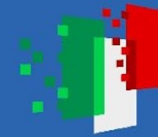


STILES

Strengthening the Italian Leadership in ELT and SKA



See Francesco's talk for more details



ENABLING HIGH-FREQUENCY CAPABILITY IN MEERKAT: THE CASE FOR BAND-5

MeerKAT is optimized for deep and high fidelity imaging of extended low-brightness emission, and, at the same time, for the detection of micro-Jansky compact radio sources.

Due to funding constraints, MeerKAT is not be able to access higher frequencies in the so-called SKA Band 5 region of the spectrum, which limits the range of science that can be conducted.

Moreover, although SKA-MID will be equipped at first light with SKA Band 5 receivers, the SKA Observatory has no plans to retrofit these receivers onto the 64 MeerKAT dishes.

The **central core of the SKA** will not be Band 5-capable for the foreseeable future, similarly, restricting the potential of the SKA.



We propose to provide this missing capability by retrofitting 64 Band 5b (8.3-15.4 GHz) receivers on MeerKAT dishes.

This enhanced capability will make MeerKAT until SKA-MID will be operative, the only sensitive centimetre-wave instrument in the Southern Hemisphere operating at high-frequency.

Italy has scientific leadership in a broad range of areas that would benefit from a high frequency capable MeerKAT, especially given the depth of Italian involvement with the SKA project and its pathfinders.

A fully capable MeerKAT has two main benefits for SKA

- The 64 extra receivers will significantly increase the sensitivity of SKA in Band 5.
- The additional short spacings provided by MeerKAT will substantially enhance the image fidelity of extended emission.





Three main activities within PNRR

Activity 1 RECEIVERS:

INAF will provide (>50, goal 64) band5b receivers, fully compliant with the MeerKAT antennas and infrastructure and with the SKA-MID, to be installed on MeerKAT.

Activity 2 CRYOGENICS:

INAF will purchase/upgrade new compressors for MeerKAT dish. INAF technologists will participate, together with the SRAO staff, in the identification phase of the type of compressors to be purchased to meet the needs of the receivers already operating and of the band-5.

Activity 3: DIGITIZERS:

INAF supplies the components for the realization of digitizers and collaborates with SRAO, who is leading the development of digitizers. INAF-SRAO technological collaborations are currently active as part of the "MeerKATplus" project.

12Meuro

Post-PNRR activities

Integration of the receivers including the cryogenic systems;
Technical and scientific **commissioning**

INAF Working Group

Grazia Umana (Leader of STILES WP2401)

All the three activities are coordinated by Corrado Trigilio (PM)

Francesco Schillirò, System Engineer

Ugo Di Giammateo, Deputy PM of STILES

WG-band5 will consist of the following main members:

Enrico Giro, Quality Assurance Engineer for procurement

Francesco Cavallaro, Commissioning and Qualification Scientist for the deployment of the instrument.

Pietro Bolli, coordinator of all activities related to “RECEIVERS” - Activity 1;

Tonino Pisanu, coordinator of all activities related to “CRYOGENICS” - Activity 2;

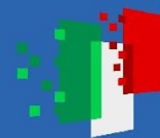
Andrea Melis, coordinator of all activities related to “DIGITIZERS” - Activity 3.



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**Target: build the SKA Baseline design (AA4)
197 MID dishes, 512 LOW stations**

Roll out the array in stages
(Array Assemblies)

Not all funding yet secured, therefore
following Staged Delivery Plan (AA*)

AA0.5- test array for interferometry

AA2- Start Science Verification. Observations
to ensure the system meets the needs of the
science users (test observing modes, verify
science requirements)

First data release to community after AA2

Milestone Event (earliest)		SKA-Mid (date)	SKA-Low (date)
AA0.5	4 dishes 6 stations	2025 Q1	2024 Q4
AA1	8 dishes 18 stations	2026 Q1	2025 Q4
AA2	64 dishes 64 stations	2027 Q1	2026 Q4
AA*	144 dishes 307 stations	2027 Q4	2028 Q1
Operations Readiness Review		2028 Q1	2028 Q2
End of Staged Delivery Programme		2028 Q3	2028 Q3
AA4	197 dishes 512 stations	TBD	TBD