



Giornate INAF del Raggruppamento Scientifico Nazionale 4
Astrofisica relativistica e particelle



The SKA project

Tiziana Venturi
INAF, Istituto di Radioastronomia

Napoli, 24 Novembre 2022



The SKA project

The SKA project

- SKA-MID e SKA-LOW
- Status & timeline

MeerKAT & MeerKAT+

- The radio interferometers
- PNRR and Band 5 for MeerKAT









PNRR investments for radio astronomy in RSN4



SKA in a nutshell



- *Huge* science project: global collaboration of 16 countries – Italy and 7 others are full members
- *Biggest* radio interferometer ever: km-square collecting area, thousands km extension
- Construction phase: 07/2021 – 07/2029
- Sites: Karoo and Murchison *remote* deserts (radio-quiet/good atmospheric conditions)

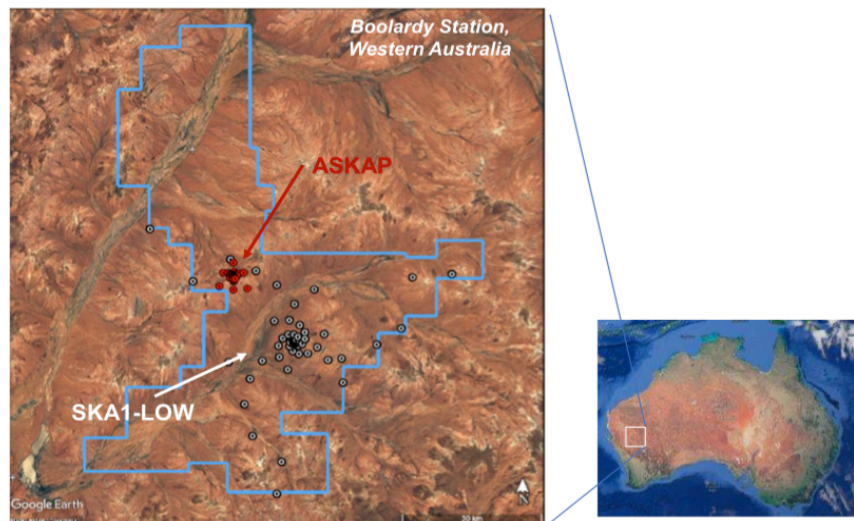
SKA1-mid the SKA's mid-frequency instrument	SKA1-low the SKA's low-frequency instrument
 Location: South Africa	 Location: Australia
 Frequency range: 350 MHz to 15.3 GHz with a goal of 24 GHz	 Frequency range: 50 MHz to 350 MHz
 197 dishes (including 64 MeerKAT dishes)	 ~131,000 antennas spread between 512 stations
 Maximum baseline: 150km	 Maximum baseline: ~65km

- **Unprecedented performances:**

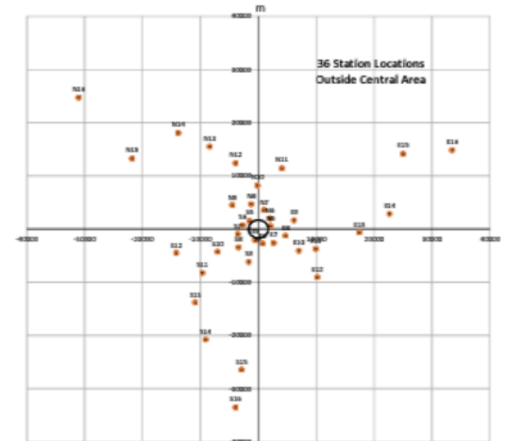
SKA1 LOW x1.2 <small>LOFAR NL</small>	SKA1 LOW x135 <small>LOFAR NL</small>	SKA1 LOW x8 <small>LOFAR NL</small>
SKA1 MID x4 <small>JVA</small>	SKA1 MID x60 <small>JVA</small>	SKA1 MID x5 <small>JVA</small>
RESOLUTION	SURVEY SPEED	SENSITIVITY

SKA in a nutshell – SKA-LOW

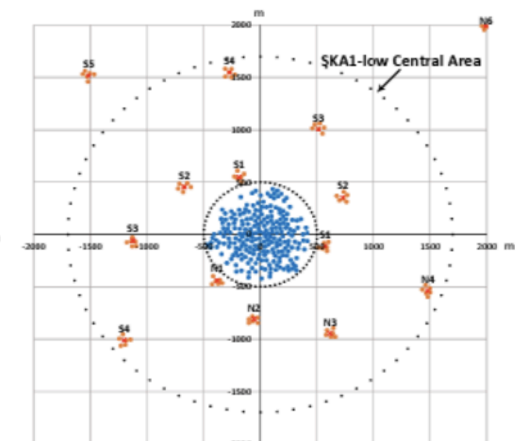
- Frequency range: 50-350 MHz
- Aperture phased array: no moving parts - digital beamforming
- 256 elements x 512 stations -> **~131000 wide bandwidth identical antenna**
- total collecting area of **~ 0.4 square Km**
- **close-packed** pseudo-random configuration



3 spiral arms, out to a radius of ~65 km



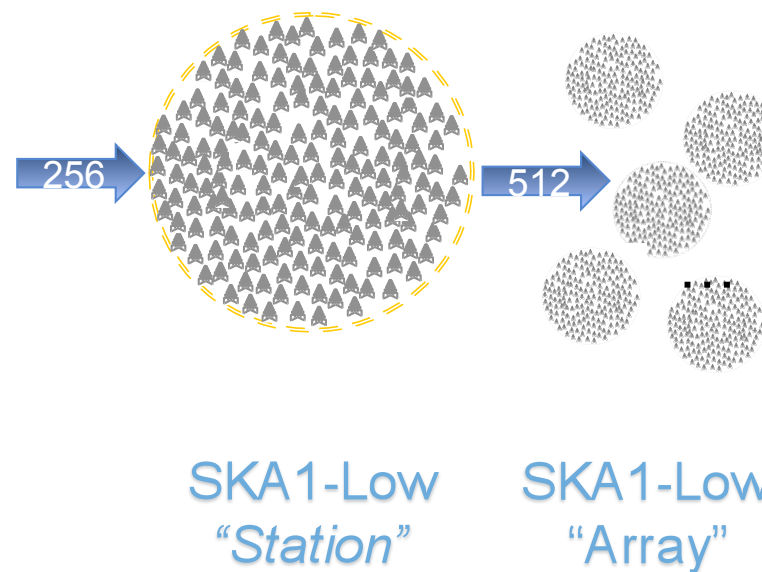
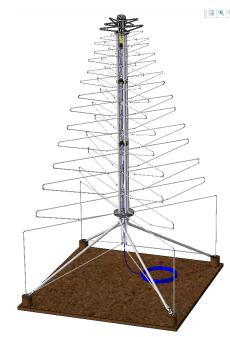
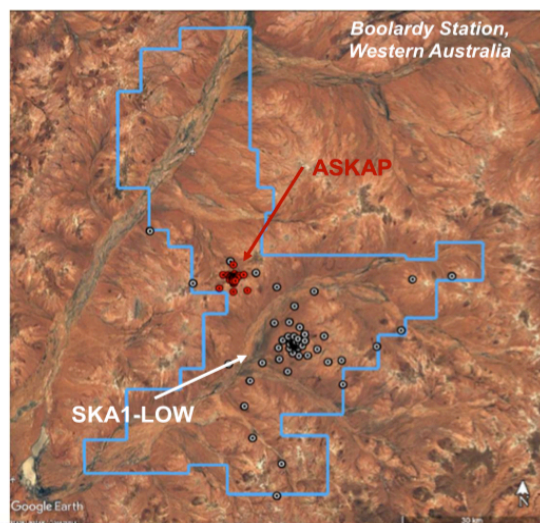
core , 75% of the antennas within 2km



Labate et a. 2017

SKA in a nutshell – SKA-LOW

- Frequency range: 50-350 MHz
- Aperture phased array: no moving parts - digital beamforming
- 256 elements x 512 stations -> **~131000 wide bandwidth identical antenna**
- total collecting area of **~ 0.4 square Km**
- **close-packed** pseudo-random configuration

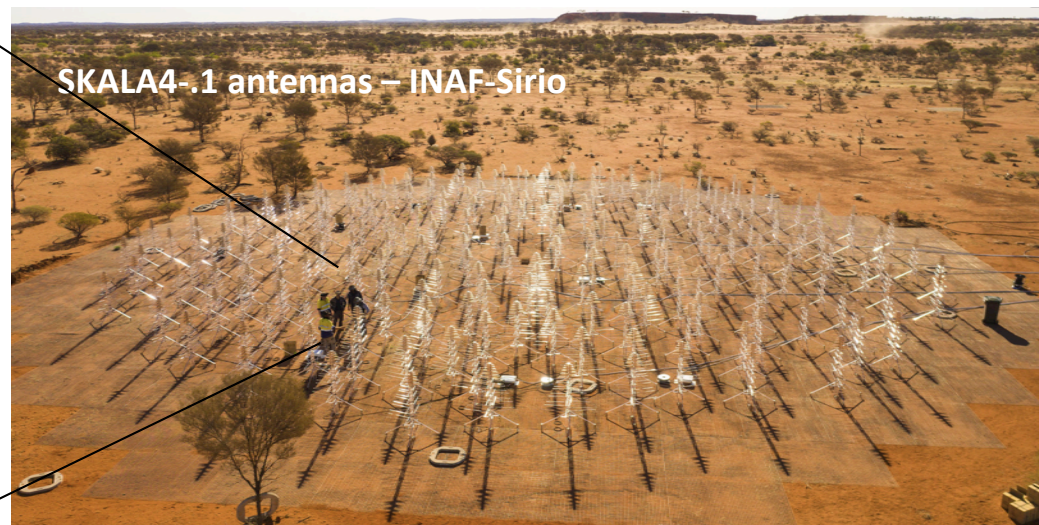
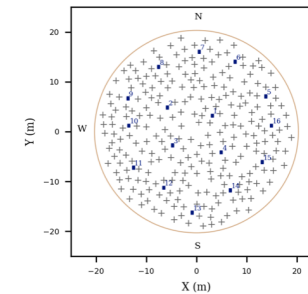




SKA in a nutshell – SKA-LOW



- *Frequency range: 50-350 MHz*
- *Aperture phased array: no moving parts - digital beamforming*
- *256 elements x 512 stations -> ~131000 wide bandwidth identical antenna*
- *total collecting area of ~ 0.4 square Km*
- *close-packed pseudo-random configuration*





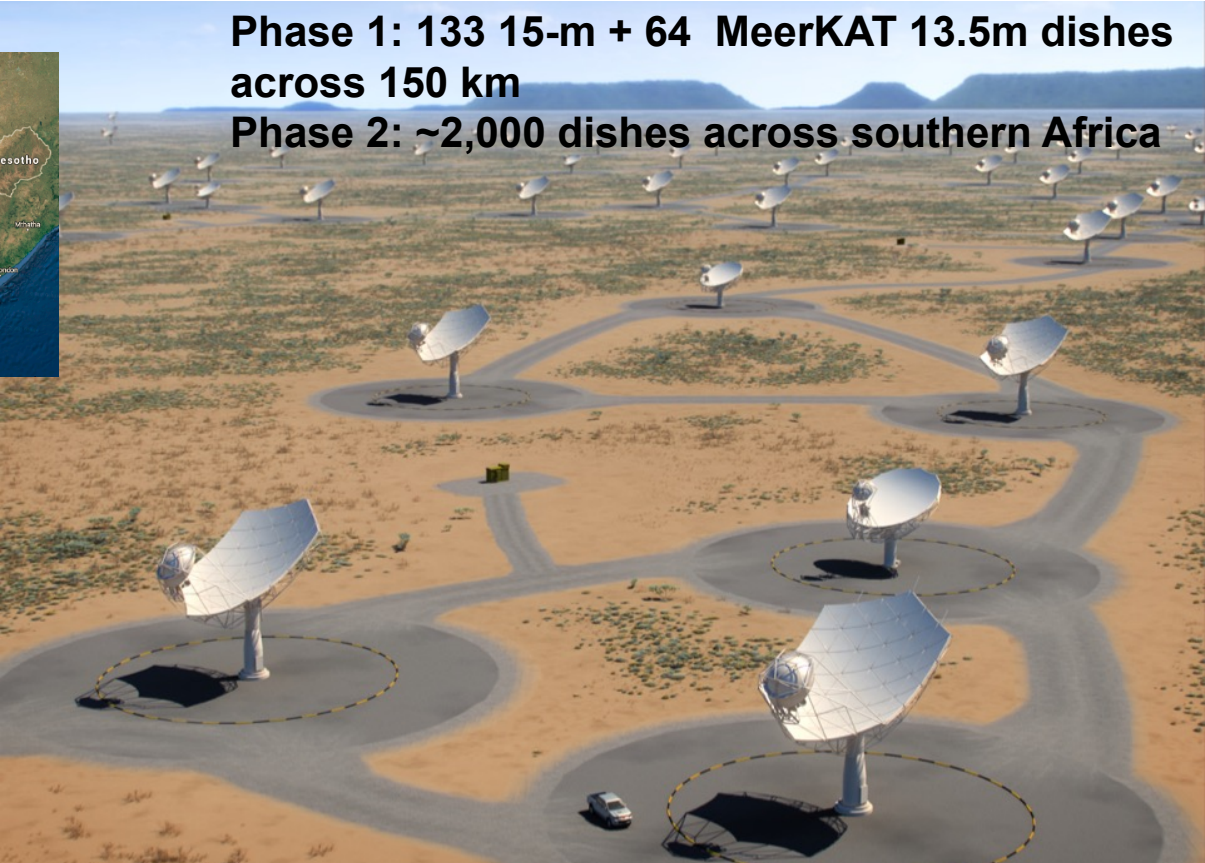
Status and future steps of SKA-LOW



- SKALA4.1 INAF-Sirio antenna validated as SKA-LOW prototype – Sirio will build at least 300 stations
- First prototype station deployed in Murchison by the Italian team
- A second prototype station (AVS3) will be delivered in Murchison in 2023 (at a distance of 300 m) for observational and correlator tests
- Know-how being transferred to SKAO to move to the construction phase
- Electronics for the first SKA antenna in place in Fall 2023
- Agreements with the local people under arrangement to access the land to start preparing the infrastructure
- First SKA station at the SKA site expected to be in place at the end of 2023, just after AVS3 is installed
- Four to six SKA antennas in place in Spring 2024, as per timeline



SKA in a nutshell – SKA-MID



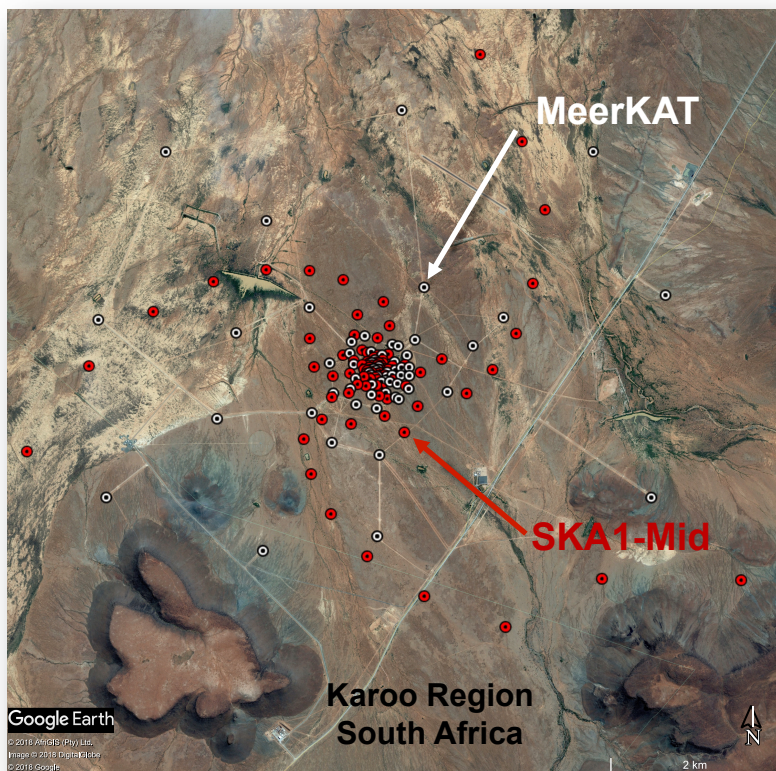
Phase 1: 133 15-m + 64 MeerKAT 13.5m dishes across 150 km

Phase 2: ~2,000 dishes across southern Africa

**SKA1-MID: Africa
350 MHz – 15 GHz**



SKA in a nutshell – SKA-MID



MeerKAT:

Operated by SARAO
64, 13.5-m dishes over 8 km
580-3500 MHz
L-band (900-1670) & UHF
(500-900 MHz) open-time
proposals

SKA-MID:

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



**The 64 antennas of
MeerKAT are already
the core of the SKA**



SKA in a nutshell – Timeline



	SKA-Low	SKA-Mid
Start of construction (T0)	1ST JULY 2021	1ST JULY 2021
Earliest start of major contracts (C0)	AUGUST 2021	AUGUST 2021
Array Assembly 0.5 finish (AA0.5) SKA-Low = 6-station array SKA-Mid = 4-dish array	FEBRUARY 2024	MARCH 2024
Array Assembly 1 finish (AA1) SKA-Low = 18-station array SKA-Mid = 8-dish array	FEBRUARY 2025	FEBRUARY 2025
Array Assembly 2 finish (AA2) SKA-Low = 64-station array SKA-Mid = 64-dish array, baselines mostly <20km	FEBRUARY 2026	DECEMBER 2025
Array Assembly 3 finish (AA3) SKA-Low = 256-station array, including long baselines SKA-Mid = 133-dish array, including long baselines	JANUARY 2027	SEPTEMBER 2026
Array Assembly 4 finish (AA4) SKA-Low = full Low array SKA-Mid = full Mid array, including MeerKAT dishes	NOVEMBER 2027	JUNE 2027
Operations Readiness Review (ORR)	JANUARY 2028	DECEMBER 2027
End of construction	JULY 2029	JULY 2029

Napoli, 24 Novembre 2022



MeerKAT & MeerKAT+



- MeerKAT 64 antennas
- One of the possible 31 distributions of the additional 16 antennas leading to MeerKAT+

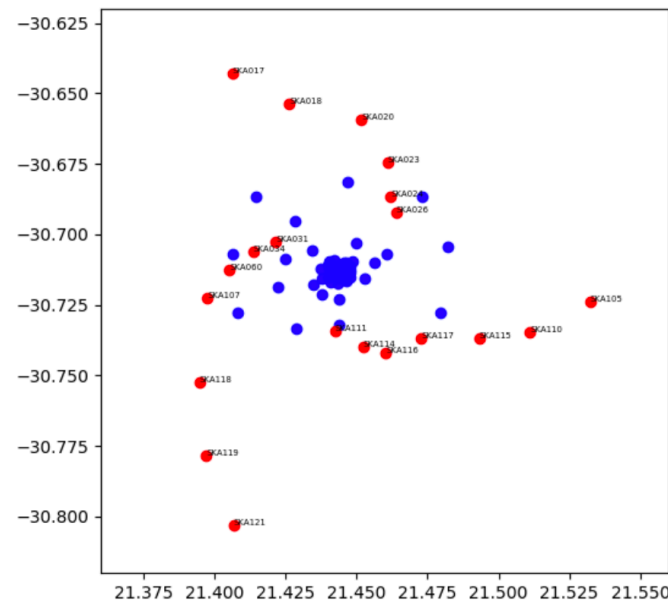
Shortest baseline 29 m
Longest baseline 16.8 km



Almost seamless coverage of the angular scales from tens of arcsec to 1-2 arcsec



Simultaneous A+B+C+D configurations of the VLA!



MeerKAT Extension (MeerKAT+)

- SARA0/MPIfR project started in 2019
- **INAF joined in 2020**
- Goal to develop novel capabilities in the transition between now and the SKA
- Enormous technological development compared to MeerKAT
- Addition of 13-16 antennas of SKA design doubling the longest baseline
- L-Band and S-Band receivers (0.9-1.67 GHz & 1.75- 3.5 GHz)
- Backend to process all 80 antennas simultaneously



MeerKAT & MeerKAT+



Now ~end 2024? ?

MK Current MeerKAT capabilities
Beam, Visibilities 4k, 32k, 32k Narrowband, Calibration, Phase-up,
Imaging, USE, Commensal

MK+
Phase 1 Capabilities on any 64 antennas
[with some limits]: Beam, Visibilities 4k, 32k, 32k
Narrowband, USE, Commensal

MK+
Phase 2 Capabilities on all 80 antennas
Single new 8k mode: Visibilities

Additional features



MeerKAT & PNRR



Strengthening the Italian Leadership in ELT and SKA - STILES

- A coordinated program that establishes an Italian leadership in the development of **radio and optical infrastructures**, aimed at **ELT & SKA**, and on their scientific exploitation.
- The goal is to develop a network between research infrastructures in the National Research Infrastructure Plan.
- **ELT, SKA, but also their "pathfinders/precursors**
- Requested 91 MEuro, financed 70 MEuro

BAND-5 on MeerKAT (about 11% of total request)

- Aim: to provide band 5 receivers for MeerKAT dishes (8.4-15 GHz) and end-to-end capabilities for band 5 on MeerKAT
- A project conducted in the framework of a broader collaboration between INAF, SARA0 and Oxford and Leeds Universities
- **INAF**: to procure all the hardware necessary for the assembly of the 64 band-5 receivers, including design and realization of new digitizers.



Some basic considerations



- ✓ The transformational capabilities of the SKA (LOW and MID) are the final stages of a long process of development whose starting results are already at hand now
- ✓ The impact of MeerKAT is already clear and the Italian community is one of the largest users of MeerKAT
- ✓ The science case for Band5 on the MeerKAT antennas includes several topics of RSN4 (galactic and extragalactic)
- ✓ A consistent fraction (~30%) of the expressions of interest received for the INAF MeerKAT+ Legacy Surveys are related to RSN4



PNRR investments for radio astronomy relevant to RSN4



STILES

Band 5 receivers on MeerKAT antennas

- All galactic and intergalactic science at high frequency (8.4-15 GHz) at subarcsecond angular resolution

CTA+

Partial funding of the broad band receiver BRAND (1.5-15 GHz) for Medicina and Noto

- Broadband receivers for Medicina and Noto for VLBI observations with increased sensitivity

Croce

P-band (300 MHz) receiver for Noto

- boost in the potential of the EVN in this band with the inclusion of uGMRT in the array

KM3

New subreflector in Noto

- Telescope Maintenance



Funding sources for the radio projects & infrastructures relevant to RSN4 beyond PNRR



SKA

- Funding from MUR – DM450 (SKA+CTA)

VLBI antennas

- Note that INAF is part of an ERIC, i.e. **JIV-ERIC**, and the antennas in Medicina, Noto and SRT are high priority infrastructures for MUR
- Funding from MUR
- PON-SRT

LOFAR

- INAF will be part of the **LOFAR-ERIC** (2023)
- LOFAR 2.0 station to be hosted in Medicina in 2024
- Funding from MUR – DM450

MeerKAT+

- Funding from MUR – DM450



Involvement of INAF in the large radio astronomical projects and observing facilities



SKA

SKA working group in UTG-II

- Process started almost 20 years ago under the EC program SKADS (FP4)
- Involvement of the scientific INAF community at large through three SKA national meetings
- Leadership of a number of SKA scientific working groups and large participation as core members and associate members (Chairs and co-chairs: Camera, Spinelli, Ingallinera, Mesinger, Raccanelli, Serra, Vacca)
- Italy full member of the SKA
- Leadership in the development of SKA-LOW – transfer of technological know-how from INAF to SKAO
- Involvement in the LMC for SKA-MID



Involvement of INAF in the large radio astronomical projects and observing facilities



VLBI antennas

VLBI Working group in UTG-II

- Participation in the EVN CBD, JIVE Council and related bodies with leading roles
- EVN/VLBI adopts open sky policy – PIs from all over the world, including several from INAF and Italian Universities
- Main scientific areas: stellar evolution (continuum & spectral line), nuclear regions of all flavours of AGNs, multi-messenger science, transients (FRBs, novae, GRBs, blazars...)
- International leadership in technological development, such as broadband receivers, digital backends and participation in the development of software correlators



Involvement of INAF in the large radio astronomical projects and observing facilities



LOFAR

LOFAR working group in UTG-II

- Broad impact of LOFAR in the Italian scientific community both within and outside INAF
- Italian GO & GTO LOFAR time
- Several papers (140+), many with Italian PIship, some of them on high impact journals (Nature, Science, Nature Astronomy, Science Advances...)
- HPC (8 nodes at IRA, 4 in Trieste, 3 in Catania, 2 in Torino)
- PLEIADI for the data analysis of LoLSS and LOFAR-VLBI
- PhD from PNRR-HPC (LOFAR-VLBI)



Involvement of INAF in the large radio astronomical projects and observing facilities



MeerKAT & MeerKAT+

SKA precursors at high frequency in UTG-II

- Several Italian scientists already involved with scientific exploitation of MeerKAT (a lot has happened during the PGR between Italy and South Africa, RADIOSKY2020) – High fraction of Italian proposals in all three MeerKAT AO so far
- Italian scientists involved in the development of the pipelines for the data analysis in continuum, spectral line and polarizations
- Considerable number of papers with Italian leadership (considering that full operations started only 3 years ago)
- Involvement of the community towards the MeerKAT+ Legacy Surveys (online half-day meeting in December 2021 & in presence meeting in Bologna in June 2022)
- White paper in progress collecting the Expressions of Interest for the MeerKAT+ LS
- Strong collaboration between INAF and SARA0 & other South African Universities (co-supervision of master and PhD students)
- Italian visiting professors at South African Universities