MeerKAT in the Karoo: SKA precursor

64 x 13.5-meter highly efficient offset Gregorian dishes spread over 8 km (70% within 1 km diameter); superb L-band receivers (0.9–1.67 GHz); also UHF (0.58–1.0 GHz) and S-band (1.75–3.5 GHz – by MPIfR)
Radio image made with MeerKAT of the center of our Milky Way galaxy

Clearest such image ever made – unveiled at MeerKAT inauguration, July 2018
A brief history of MeerKAT:

- **2003**: SKA South Africa Project Office established
- **2005**: XDM groundbreaking (eXperimental Development Model)
- **2007**: PED First Light (Phased Experimental Demonstrator)
- **2010**: MeerKAT Concept Design Review
- **2012 May**: SKA Site announcement
- **2012 Oct**: KAT-7 (7-dish Karoo Array Telescope) inaugurated
- **2014**: 1st MeerKAT dish
- **2015**: MeerKAT receiver production line inaugurated

- **2016**: MeerKAT First Light with 16 dishes
- **2017**: Last MeerKAT dish erected
- **2018 Apr**: 1st MeerKAT observation with 64 dishes
- **2018 Jul**: MeerKAT inaugurated
- **2009**: 1st Call for MeerKAT science projects
Neuchâtel technology: key role in timing science – Karoo Telescope Timescale (KTT)

- Atomic clock ensemble: used to time events over 10+ years to ns level, and give pure sinewave to digitisers
- T4Science maser clocks: low vibration temperature controlled units – predictable drift, lowest phase noise clocks in the world?
EPFL President Vetterli
SERI StS Dell’Ambrogio
EPFL Prof Kneib
Ambassador to Budliger Artieda
MeerKAT science program

- **2010**: Call for scientific proposals by SKA South Africa resulted in 10 approved *Large Survey Projects* (LSPs, >1000 hours of MeerKAT observing time over 5 years)

- **2016**: MeerKAT is a different telescope than planned in 2009, and science has evolved

- SKA SA requested 8 LSPs to submit revised project plans; reviewed in 2017

- 64 dishes operational since **2018** (plus continued development of capabilities)

- 2/3 of telescope time to be used by LSPs; 5% for DDT; rest awarded through periodic Calls:
  - **2019**: 1\textsuperscript{st} *Open Time* Call resulted in 38 projects, led by South African-based PIs
  - **2020–21**: 2\textsuperscript{nd} Call for ~1000 hours; 113 proposals from 18 countries requested 3400 hours; 57 projects awarded some time; 1/3 of submitted and accepted proposals have SA-based PIs

- Eventually, MeerKAT will be integrated into the SKA1-MID telescope
Approved MeerKAT LSP program

- Pulsar timing
- Deep HI studies in 30 isolated nearby galaxies; and in Fornax cluster
- Ultra-deep HI survey
- Pulsar searches
- Explosive / accreting transient studies
- Deep continuum survey in 4 fields
- Absorption line survey
Inflation of 430–parsec bipolar radio bubbles in the Galactic Centre by an energetic event

MeerKAT DEEP2

The most sensitive radio image to star-forming galaxies
($\sigma = 550 \text{ nJy beam}^{-1}$)

(Mauch et al. 2020)
(Matthews et al. 2021a,b)
X-shaped galaxies: mystery solved
Hydrodynamical backflow in giant radio galaxy PKS 2014-55
(Cotton et al. 2020)

New mystery
Collimated synchrotron threads
(Ramatsoku et al. 2020)
Threads, ribbons, and rings in the radio galaxy IC 4296

“New results like this from MeerKAT are set to overhaul our understanding of extragalactic radio sources”

(Condon et al. 2021)
The missing hydrogen in Fornax A: found
(Serra et al. 2019)

- 40 dishes, 8 hr
- 4k channels (209 kHz / 44 km s$^{-1}$)
- $\sim$14x more hydrogen detected than previously known
First MeerKAT 32k paper
(de Blok et al. 2020)

- 59 dishes, 5 hr
- 32k channels (26 kHz / 5 km s$^{-1}$)
- “Exquisite [HI] imaging data… over a large range in angular resolution”
ThunderKAT

Discovery of 1\textsuperscript{st} transient with MeerKAT

(Driessen et al. 2020)
Ultra high precision pulsar timing (MeerTime)

PSR J2241-5236

~4 ns timing in 1 hour – world record
Three SARAO legacy surveys

Galaxy clusters
• $250^\circ < l < 60^\circ$, $|b| < 1.5^\circ$
• 9-point mosaic observing
• $\sim 1$ hr on source per position
• Stitched in 3x3 deg$^2$ images (sqrt scaling)
MOST SNR (MSC)
Threads all over the place
What is this?
Magellanic Clouds

**SMC**: ASKAP RACS, and MeerKAT
MeerKAT status, coming developments

- All 8 LSPs underway
- ~50% of the time used for science (mostly at L-band)
- Imaging in 4k, 32k, Narrowband (32k across 107 MHz)
- Pulsar timing (1k) / searching (4k); >1000 pulsars observed
- Commensal users (MeerTRAP, MeerLICHT)
- UHF: observations have started
- S-band: being commissioned
- Further developments: SETI backend; some VLBI capability
- *And lots still to learn about a hugely complex instrument!*

- MeerKAT is now operationally oversubscribed
- *Many datasets are no longer proprietary, and (mainly visibilities) are available through the archive interface: https://apps.sarao.ac.za/katpaws/archive-search*

- 76 refereed publications with MeerKAT data (72 since Aug 2019): MeerKAT ADS Library
- Beyond MeerKAT, there’s *MeerKAT extension* (16 SKA1-MID dishes on baselines up to 17 km, with new correlator and science processor), and SKA
The future today: SKA1-MID (prototype) / MPG dish in the Karoo
Thank you

Merci

Danke

Grazie

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Engraziel fegt