MEERKAT: PROGRESS AND PLANS

Fernando Camilo

SWISS SKA DAYS 2017 (MAY 22, LAUSANNE)
MeerKAT in the Karoo: SKA precursor under construction

64 x 13.5-metre highly efficient offset Gregorian dishes spread over 8 km (~75% 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).
Extremely good L-band performance
The SKA South Africa Karoo site: ever improving radio telescopes
KAT-7 (engineering testbed) L-band image in 2012
4-dish MeerKAT in May 2016 (commissioning)
16-dish MeerKAT in June 2016 (Array Release 1)

1% of First Light image
Best image of this patch of sky before MeerKAT
The MeerKAT sky

10% of First Light image

www.ska.ac.za
MeerKAT First Light

FR1 radio galaxy

FR2 radio galaxy

Star forming galaxy

?
**MeerKAT science program**

- **2010**: Open invitation by SKA SA to propose MeerKAT “Key Project Science” resulted in 10 approved “Large Survey Projects” (LSPs; each >1000 hours of telescope time over 5 years)

- **2016**: Scientific context has evolved; also, particularly at L-band, MeerKAT has improved sensitivity (but with shorter baselines, & lower frequencies)

- Therefore, in mid 2016 we requested revised LSP proposals (review underway)

- Plan to allocate ~70% of telescope time over 5 years to LSPs, ~30% to “Open Time” (to be allocated via periodic calls, open to researchers worldwide)

- Expect to have 64 antennas operational by April 2018 (+ continued development)

- Eventually MeerKAT will be integrated into the SKA Phase 1 MID-frequency array
## MeerKAT science: LSPs approved in 2010

<table>
<thead>
<tr>
<th>Radio Pulsar Timing</th>
<th>Bailes (AU)</th>
<th>7860 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Einstein's theory of gravity and gravitational radiation - Investigating the physics of enigmatic neutron stars through observations of pulsars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LADUMA</th>
<th>Blyth, Holwerda, Baker (SA,NL,US)</th>
<th>5000 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>An ultra-deep survey of neutral hydrogen gas in the early universe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MESMER</th>
<th>Heywood (UK)</th>
<th>6500 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Searching for CO at high red-shift (z&gt;7) to investigate the role of molecular hydrogen in the early universe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MeerKAT Absorption Line Survey</th>
<th>Gupta, Srianand (NL, IN)</th>
<th>4000 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey for H and OH lines in absorption against distant continuum sources; OH line ratios may give clues about changes in the fundamental constants</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MHONGOOSE</th>
<th>de Blok (NL,SA)</th>
<th>6000 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigations of different types of galaxies; dark matter and the cosmic web</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MeerKAT HI Survey of Fornax</th>
<th>Serra (NL)</th>
<th>2450 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxy formation and evolution in the cluster environment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MeerGAL</th>
<th>Thompson, Goedhart (UK,SA)</th>
<th>3300 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galactic structure and dynamics, distribution of ionised gas, recombination lines, interstellar molecular gas and masers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIGHTEE</th>
<th>Jarvis, van der Heyden (UK,SA)</th>
<th>1950 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep continuum observations of the earliest radio galaxies</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRAPUM</th>
<th>Stappers, Kramer (UK, DE)</th>
<th>3080 h + commensal (timing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Searching for, and investigating new and exotic pulsars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ThunderKAT</th>
<th>Woudt, Fender (SA,UK)</th>
<th>3000 h + commensal (imaging)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study of explosive radio transients with MeerKAT; accretion-induced outflow from compact stellar remnants, e.g. relativistic jets and (super)novae</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Array configuration
(April 2017, 32 antennas to choose from)
Commissioning in April 2017, up to 32 antennas

(but only 32 inputs into ROACH2 correlator)
HI emission in M83

(famous spiral galaxy discovered in Cape Town in 1752 by Nicolas Louis de La Caille)

- 9 hour track, 2017-04-05
- 32K (26 kHz) channels (140 imaged)
- 16 core antennas, dual polarisation
- Mosaic: 7 pointings
- ~50 minutes per pointing
- Min baseline (projected) 16 m
- Max baseline 711 m
- Beam 90x70 arcsec
- Measured rms 2.8 mJy (emission-free channel) vs 2.3 mJy theoretical
M83
G330.89-0.36 star forming region (continuum, 32k mode)
A newly identified Giant Radio Galaxy

- Hint of extended source in SUMSS
- 7-point MeerKAT mosaic in 4K mode
- Radio source (blue) angular size = 0.8 deg; elliptical galaxy (red/IR) at $z = 0.02$; linear size = 1.2 Mpc: GRG
MeerKAT Data Rates

- **Digitiser**
  - x 64 antennas
  - 10 bit SPEAD data
  - 2.2 Tbps

- **Correlator**
  - 32+32 bit integer data
  - 200 Gbps

- **SDP Ingest**
  - 32+32 bit float data

- **Spectral Imager**
  - 7k x 7k x 32k cubes

- **Cal**
  - 32+32 bit float data
  - Cal tables into tstate B,G,K etc..
  - Self-cal from continuum imager

- **Visibility data @ 2 Hz**
  - Time x Freq x Baseline 32k Freq Channels

- **Visibility data @ 0.5 Hz**
  - + Flags and precision
  - 11 Gbps avg.
  - Typical 8 hour obs gives 20-40 TByte Vis Data

- **Typical obs gives**
  - 12 TByte Image Cube
MeerKAT SDP Hardware Landscape

1.6 PFLOPs (GPU)  
23 PBytes (Disk - CEPH)  
40 PBytes (Tape)
Data Flows and Hardware Location

Coloured blocks and lines are data. Grouping blocks are physical nodes. Internal blocks are processes. Dashed lines is transport via SPEAD. Solid lines is transport via librados.

**WF Ingest Node 1 of 4**
- Spectral Vis + weights (Numpy array)
- SPEAD Streamer (Vis)

**Cal Node 1 of 4**
- Spectral Vis + weights (Numpy array)
- SPEAD Streamer (Flags)

**Telescope State Node**
- Telescope State (Redis)
- Telescope State Serializer

**Imaging Node 1 of 22**
- Image Object
- Image Object
- Image Object

**Site Storage Node**
- RADOS Gateway
- Block, NFS, Object

**Site Storage (KAPB)**
- 380 GB in 3 Pods
- Site storage
- USE / CAM etc...
- 3:1 replication

**Data Store Node(s)**
- Vis Object Writer
- Flag Writer

**SDP Data Store (CHPC)**
- 10.6 PB in 55 Storage Pods
- 2:1 Replication
- Y1:
  - 8.5 PB Vis Data (11 Mo)
  - 1.5 PB Image Data (12 Mo)

**Vis Buffer Node**
- Vis Object Writer
- Flag Writer

**SDP Vis Buffer (KAPB)**
- 380 GB in 2 Pods
- Short term protection for link outage
- ~ 10 days
- 2:1 replication

**CHPC Rosebank**
- Visibility Object
- Image Object
- Telstate Object
- Flag Object

**KAPB Karoo**
- Visibility Object
- Image Object
- Telstate Object
- Flag Object
- Image Object Writer (FIFO)
Pipelines expressed as graphs of operations (nodes) and data transfer (edges). Execution Framework (based on Apache MESOS) deploys and manages graph at scale. Container approach allows easy deployment of new algorithmic ideas within the pipeline infrastructure.
Dealing with the Data - Quality Metrics

- Ingest
  - Spectral
    - astrometry
    - photometry
    - spectrometry
    - polarimetry
  - Continuum
    - self-cal solutions
  - Cal
    - 8-bit flag per vis (2D)
    - cal tabs (B,G,K,Kcross)
    - calibration report
  - FileWriter
  - Workflow Manager
    - observation report
      (range of data and plots including operator obs)
CEPH Cluster – Custom Hardware

High Speed Pod: 40 Gbps to disk / 40 TiB
Bulk Pod: 25+Gbps to disk / 360 TiB
23 PB CEPH Cluster ~ $1.2 million all in
Custom Tape Robotics

3k – 50k slot LTO tape library at 10x cheaper
Scaling to SKA-1 MID

**Data Path**
- **200 Gbps**
  - Ingest (8k channels)
  - Buffer 1 PB
  - Image 7k grid 1.6 PFiop
- **4 Tbps**
  - Ingest (3k channels)
  - Buffer 1 EB
  - Image 20k grid 150 PFiop

**Logical Nodes**
- 4 Nodes
- 1000 Drives
- 130 Compute Nodes
- 3k Spindles
- Archive 10 PB per year
- Archive 40 PB per year

**物理节点**
- Physical Graph ~10k nodes
- Physical Graph ~1m nodes
- Telescope State 500 MB per obs 10k keys
- Telescope State 10+ GB per obs 1m keys
- Object Store 1B objects
- Object Store 10B objects

**MeerKAT**

**SKA-1 MID**
SKA South Africa, a Business Unit of the National Research Foundation, is supervising South Africa’s involvement in the SKA on behalf of the Department of Science & Technology.

Thank you