SKA-VLBI capacity and technique

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SQUARE KILOMETRE ARRAY
Exploring the Universe with the world’s largest radio telescope
SKA-VLBI: broadest angular resolution

![Graph showing angular resolution at 1.5 GHz for various telescopes with SKA-VLBI.]

- In development
- Commissioning / Early science
- Operational

Physical scale at $z = 1$ (kpc)

Angular resolution at 1.5 GHz (arcsec)

Global VLBI
VLBA
LBA
EVN
eMERLIN-EVN
eMERLIN

VLA
A
B
C
D
ASKAP
MeerKAT

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SKA-VLBI:
brodest angular resolution

Angular resolution at 1.5 GHz (arcsec)

Physical scale at $z = 1$ (kpc)

- In development
- Commissioning / Early science
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Global VLBI
VLBA
LBA
EVN
eMERLIN-EVN
eMERLIN

VLA
A
B
C
D

ASKAP
MeerKAT
SKA1-MID
SKA2-MID

+ Global VLBI
+ Global VLBI

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SKA-VLBI: broadest angular resolution
SKA-VLBI

SKA provides …

• INDEPENDENT MULTI-BEAM CAPABILITY
• ACCESS to SOUTHERN SKIES and GALACTIC CENTER
• BOOST in SENSITIVITY to µJy regime
• SUPERIOR AMPLITUDE and POLARISATION CALIBRATION
SKA provides …

- INDEPENDENT MULTI-BEAM CAPABILITY
- ACCESS to SOUTHERN SKIES and GALACTIC CENTER
- BOOST in SENSITIVITY to µJy regime
- SUPERIOR AMPLITUDE and POLARISATION CALIBRATION

VLBI provides …

- IMAGES of SKY at BROAD RANGE of ANGULAR SCALES RESOLUTIONS
- HIGH RESOLUTION for SKA HPSOs
- INDEPENDENT COMMISIONING TOOL and EARLY PUBLIC RELATIONS OPPORTUNITIES
- AN ENTHUSIASTIC USER COMMUNITY
SKA-VLBI Science
SKA-VLBI Science

- JUMPING JIVE 2nd deliverable: Portfolio of Science Cases
- SKA VLBI Science Working group support
- Outcomes inform the SKA-VLBI operational model and KSPs
VLBI with SKA1-MID:

6 science cases updated (from SKA1 scientific use cases doc.)

**SKA continuum surveys**

- Adding high angular resolution to SKA surveys:
  - Giroletti et al.

**Transients**

- Resolving (ultra)-relativistic outflows with SKA-VLBI:
  - Paragi et al.

**Our Galaxy, Astrometry and CoL**

- Galactic structure using maser parallax measurements:
  - Ellingsen et al.

**Pulsars, Astrometry**

- Dynamics of the Galactic Bulge using OH masers:
  - Imai et al.

- Parallax measurements of SH pulsars:
  - Deller et al.
VLBI with SKA1-MID:

16 new science cases!

**AGNs (6)**
- Polarimetric survey of a big AGN sample: Agudo et al.
- Intermediate mass black holes: Mezcua et al.
- Chasing merged and merging SMBH: Anton et al.
- HI absorption in high-z radio AGN: Morganti et al.
- Extremely high-z AGNs: Perger et al.
- Strong gravitational lensing: McKean et al.

**Transients (4)**
- FRBs and their hosts: Paragi et al.
- ULXs in the local Universe: Middleton et al.
- Superflares on low-mass stars: Villadsen et al.
- Inhomogeneous SNe at low freqs: Chandra et al.

**Astrometry (4)**
- Continuum sources in star forming regions: Dzib et al.
- Ultra-precise astrometry to the MCs: Rioja et al.
- Gaia counterparts: Charlot et al.
- Radio and Gaia tie with radio stars: Zhang et al.

**Stars, planets and ISM (2)**
- Pulsar scintillometry with SKA1-MID: Kirsten et al.
- Radio emission from massive exoplanets: Gawronski et al.
VLBI with SKA1-LOW:
7 new science cases!

**Galaxies and AGN**
AGN physics at very low freqs: Morabito et al.
HI absorption at high z: Gupta et al.

**Transients**
Jets from low mass YSO at very low frequencies: Ainsworth et al.

**Pulsars and ISM**
Pulsar scintillometry at very low freqs: Kirsten et al.

**Stars, Planets, Astrometry**
Precise astrometry of low frequency pulsars: Dodson et al.
Precise astrometry for exoplanets detection: Guirado et al.
VLBI with SKA1-LOW and SKA1-MID: 1 new science case

Multi-view astrometry with SKA-VLBI: Rioja et al.

ΔΘ ~ few deg

ΔΘ_{eff} ~ 0

Target Source

Ionosphere

Ionosphere

~1000's km

Multi-Beam capability

Widely applicable

1 microarcsec relative astrometric precision!
VLBI with SKA:

key operational concepts

Multiple VLBI beams produced from a subarray of antennas/stations
typically the core
VLBI with SKA:

key operational concepts

Multiple VLBI beams produced from a subarray of antennas/stations
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Independent subarrays:
different purposes, up to 16
VLBI with SKA:
key operational concepts

Multiple VLBI beams produced from a subarray of antennas/stations
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Simultaneous/commensal observing modes:
Imaging (continuum, spectral line and fast imaging for slow transients)
Non-Imaging (PSS, PST, transient buffer and VLBI)
VLBI with SKA:

key operational concepts

Multiple VLBI beams produced from a subarray of antennas/stations
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Simultaneous/commensal observing modes:
Imaging (continuum, spectral line and fast imaging for slow transients)
Non-Imaging (PSS, PST, transient buffer and VLBI)

Independent multi-beam capability
within each subarray (in scan boundaries)
SKA1 VLBI technical implementation
SKA1 VLBI technical implementation

SKA-VLBI high angular resolution images
SKA1 VLBI technical implementation

SKA-VLBI high angular resolution images

SKA image cubes (continuum and spectral line, from same subarray)
SKA1 VLBI technical implementation

- **JUMPING JIVE 1st deliverable:** “Details on VLBI Interfaces to SKA Consortia”
- **Revision of Level 1 VLBI requirements** (CDR outcomes, CSP assumptions, VLBI SWG inputs).
SKA1 VLBI technical implementation

- **CPF facility**
  - CSP MID
  - ICD: SADT to CSP Mid SADT_CSP_005
  - 80x100GE shared lines for Visibilities, VLBI beams (VDIF packets), transient data, etc.

- **SPC facility**
  - SDP Ingress Ethernet switch
  - SaDT SPC Core routers
  - SPC External router
  - SKAO Requirements for SPC
  - External Correlator

**VLBI Terminal**
- VLBI Terminal
- VLBI server (LMC/Tango Framework)
- VLBI recorder jiveSab
- VLBI recorder jiveSab

- **ICD**
  - ICD: SADT to VLBISDP_VLB1.001
  - 4x100GE dedicated lines for VLBI beams
  - ICD: SADT to VLBISADT_VLB1.001
  - 2x10GE (or 100GE) dedicated lines for NSDN
  - SKAO Requirements for SPC

**SKA-MID RSA Karoo site**
- ICD: CSP Mid to VLBI CSP_VLB1.001
- ICD: TM to VLBI TM_VLB1.001

**Exploring the Universe with the world’s largest radio telescope**
SKA-VLBI with SKA1-MID
VLBI with SKA1-MID:
All observing modes simultaneously within a subarray with bandwidth sacrifice

Correlation:
- Normal visibilities, zoom (100-3 MHz, 6 kHz - 190 Hz)
- VLBI coarse visibilities: 200 kHz

Tied-array beams:
- 4 VLBI beams but up to 52 beams max per subarray (200 MHz b/w), from any subarray size
- Each VLBI beam: dual-pol real channels (1-128 & 200 MHz, 2-16 bits, Nyquist)
- RFI flagging/excision and polarisation correction
- 1500 for Pulsar Search PSS
- 16 for Pulsar Timing PST

SKA1-MID Antenna
Antenna Beam

Subarray #1
Subarray #2

Exploring the Universe with the world’s largest radio telescope
VLBI with SKA1-MID: configurations

VLBI beams FoV:
4km: 25.5-0.6"
20km: 5-0.12"
full: 1.3-0.03"

Remote telescope 100m class
best: 10th Tgal, PWV=5mm
60sec integration, 1 sigma

Full array (100%)
VLBI with SKA1-MID: configurations

VLBI beams FoV:
- 4km: 25.5-0.6"
- 20km: 5-0.12"
- full: 1.3-0.03"

SEFD - SKA1-MID subarray radius (best vs. worst conditions)
- best: 10th Tgal, PWV=5mm
- worst: 90th Tgal, PWV=20mm

SKA1-MID VLBI baseline sensitivity
- Subarray radius and b/w
- Sensitivity subarray radius 4Km, 256 MHz b/w
- Sensitivity subarray radius 4Km, 1024 MHz b/w
- Sensitivity subarray radius 4Km, 2048 MHz b/w
- Sensitivity full array, 2048 MHz b/w

Remote telescope 100m class
- best: 10th Tgal, PWV=5mm
- 60 sec integration, 1 sigma

tens of μJy!!
Simultaneous Observing with **SKA1-MID**: limited by processing resources (26+1 FSP=Frequency Slice Processor)

<table>
<thead>
<tr>
<th>Band</th>
<th>VLBI + coarse Vis</th>
<th>Imaging</th>
<th>PSS</th>
<th>PST</th>
<th>Zoom</th>
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<tbody>
<tr>
<td><strong>Band 1</strong> (0.35-1.05GHz)</td>
<td><strong>4 beams full (700MHz)</strong> (8 FSP)</td>
<td>Full (4 FSP)</td>
<td>1500b 300MHz (8 FSP)</td>
<td>16b full (4 FSP)</td>
<td>2 (2 FSP)</td>
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<td>4b 600MHz (6 FSP)</td>
<td>Full (4 FSP)</td>
<td>1500b 300MHz (8 FSP)</td>
<td>16b full (4 FSP)</td>
<td>4 (4 FSP)</td>
</tr>
<tr>
<td><strong>Band 2</strong> (0.95-1.76GHz)</td>
<td><strong>4 beams full (810MHz)</strong> (10 FSP)</td>
<td>Full (5 FSP)</td>
<td>1500b 300MHz (8 FSP)</td>
<td>16b 600 MHz (3 FSP)</td>
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<td>2 beams 5GHz (26 FSP)</td>
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<td>4 beams 600MHz (6 FSP)</td>
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Simultaneous Observing with
SKA1-MID: limited by processing resources
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SKA-VLBI with SKA1-LOW
VLBI with SKA1-LOW: 50-350 MHz

All observing modes simultaneously:
for each subarray, for each station beam

**SKA1-LOW Antenna/Receptor**
Antenna Beam

**SKA1-LOW “Station”**
Station Beam 300 MHz b/w

**SKA1-LOW “subarray”**
Correlation: normal and zoom (14.4 kHz - 5.4kHz - 226 Hz)

- Tied-array beams from 20 Km diameter subarray:
  - 4 **VLBI beams** (in total)
  - 500 for **Pulsar Search PSS**
  - 16 for **Pulsar Timing PST**
VLBI with SKA1-LOW: configurations

VLBI beams FoV:
4km: 178-25.5"
10km: 71-10"

Remote telescope 100m class
60sec integration, 1 sigma

SKA1-LOW VLBI baseline sensitivity
Subarray radius and b/w

SEFD - SKA1-LOW subarray radius
VLBI with SKA1-LOW: configurations

VLBI beams FoV:
4km: 178-25.5”
10km: 71-10”

Remote telescope 100m class
60sec integration, 1 sigma

hundreds of µJy!!
65 scientists from 18 countries

Workshops sessions: AGN, transients, pulsars and FRBs, high precision stellar astrometry and prospects for SKA-VLBI including African telescopes

SKA-VLBI data challenges

Four working groups to discuss SKA-VLBI Key Science Projects

“Women in action” from the astrometry working group
SKA-VLBI Conclusions
SKA-VLBI Conclusions

- VLBI is an observing mode of the SKA Observatory
- CSP design compatible with VLBI standards & networks
- SKA-VLBI System level solution ready, it can be applied to SKA precursors
- The SKA-VLBI community supports enthusiastically
- Let’s start cutting-edge VLBI science with SKA precursors: MeerKAT-VLBI, (MK+)-VLBI, ASKAP-VLBI…
VLBI with SKA: Global VLBI network
**Table 2: Common visible time in hours for the SKA sites with other array elements**

### South African SKA

<table>
<thead>
<tr>
<th>Dec</th>
<th>W. Aus</th>
<th>JP</th>
<th>CN</th>
<th>NZ</th>
<th>CL</th>
<th>USA-HI</th>
<th>USA-NM</th>
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### Western Australian SKA

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*Key:* W. Aus: Western Australia; ZA: South Africa; JP: Japan; CN: Eastern China; NZ: New Zealand; CL: Chile (latitude of former TIGO site); USA-HI: Hawaii; USA-NM: New Mexico; USA-PR: Puerto Rico; Europe: Id.

**uGMRT (130MHz-1500MHz)**

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**SKA1-MID**

**SKA1-LOW**