SKA-VLBI Key Science Programmes

Zsolt Paragi
JIVE
Why VLBI with the SKA?
Why is SKA-VLBI important?

- **Improved imaging capability**
  - GC region of high interest
  - Denser sampling of the “u-v” plane

- **Boost in sensitivity**
  - VLBI Survey of sub-mJy source population (fields of interest)
  - Individual sources in the $\mu$ Jy regime

- **Improved Calibration**
  - Make use of SKA superior amplitude and polarization calibration
  - Multiple beams for VLBI phase calibration over the target region

“Very Long Baseline Interferometry with the SKA”, Paragi et al. 2015, SKA Science book
SKA1 will change radio astronomy

- First publicly released MeerKAT image
- Part of SKA1-MID is already here!

https://www.ska.ac.za
SKA High Priority Science Objectives

- Science working groups are organized around the HPOs identified by the community

**VLBI WG**
- co-chair: Cormac Reynolds (CSIRO)
- co-chair: Zsolt Paragi (JIVE – till end 2017)
- co-chair: An Tao (ShAO – since end 2017)
- office contact: Evan Keane

- Very high resolution VLBI science is not a single topic, but it is related to several HPOs

https://astronomers.skatelescope.org/science-working-groups/
## Highest-ranked HPSOs and VLBI

<table>
<thead>
<tr>
<th>Science Goal</th>
<th>SWG</th>
<th>Objective</th>
<th>SWG Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CD/EoR</td>
<td>Physics of the early universe IGM - I. Imaging</td>
<td>1/3</td>
</tr>
<tr>
<td>2</td>
<td>CD/EoR</td>
<td>Physics of the early universe IGM - II. Power spectrum</td>
<td>2/3</td>
</tr>
<tr>
<td>4</td>
<td>Pulsars</td>
<td>Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection</td>
<td>1/3</td>
</tr>
<tr>
<td>5</td>
<td>Pulsars</td>
<td>High precision timing for testing gravity and GW detection</td>
<td>1/3</td>
</tr>
<tr>
<td>13</td>
<td>HI</td>
<td>Resolved HI kinematics and morphology of <del>10^10 M_sol mass galaxies out to z</del>0.8</td>
<td>1/5</td>
</tr>
<tr>
<td>14</td>
<td>HI</td>
<td>High spatial resolution studies of the ISM in the nearby Universe.</td>
<td>2/5</td>
</tr>
<tr>
<td>15</td>
<td>HI</td>
<td>Multi-resolution mapping studies of the ISM in our Galaxy</td>
<td>3/5</td>
</tr>
<tr>
<td>18</td>
<td>Transients</td>
<td>Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State</td>
<td>1/4</td>
</tr>
<tr>
<td>22</td>
<td>Cradle of Life</td>
<td>Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc</td>
<td>1/5</td>
</tr>
<tr>
<td>27</td>
<td>Magnetism</td>
<td>The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields</td>
<td>1/5</td>
</tr>
<tr>
<td>32</td>
<td>Cosmology</td>
<td>Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.</td>
<td>1/5</td>
</tr>
<tr>
<td>33</td>
<td>Cosmology</td>
<td>Angular correlation functions to probe non-Gaussianity and the matter dipole</td>
<td>2/5</td>
</tr>
<tr>
<td>37 + 38</td>
<td>Continuum</td>
<td>Star formation history of the Universe (SFHU) – I+II. Non-thermal &amp; Thermal processes</td>
<td>1+2/8</td>
</tr>
</tbody>
</table>

Also note: VLBI science = SKA2 science!
Highlight: Fast Radio Bursts

- A tool to study the cosmic web: the distribution of matter in the Universe
- Most of this matter within the galaxies is invisible otherwise

Bourke, Crain and Duffy

The distance must be known: localization!
FRBs: sub-arcsec localization is essential!

- <0.5" localizations are necessary for secure dwarf gx host identifications at \( z > 0.1 \)
- Progenitor environments (position within host gx) as well as high redshift localizations will require SKA1-MID and VLBI!
Nucelar activity in dwarf galaxies

Classic AGN/SF indicators do not (always) work in dwarfs/LLAGN...
- Requires multi-band approach
- Requires high frequencies (Band 5) and long baselines for SKA1-MID

NGC404: Nyland et al. (2017)
HI VLBI: pushing the limits

\[ N_{\text{HI}} = 1.8 \times 10^{18} \quad T_{\text{spin}} \quad \tau_{\text{peak}} \quad FWHM_{\text{line}} \]

\( (100 \text{ K}; 0.02-0.05; 100 \text{ km/s}) \quad \Rightarrow \quad \text{few } 10^{20} - 10^{21} \text{ cm}^{-2} \)

\[ N_{\text{HI}} \text{ detection limit using sensitivities of EVN and EVN+FAST or EVN+SKA1-MID} \]

- Need massive increase in collecting area to reach beyond \( N_{\text{HI}} \) limit of \( \sim 10^{20} \text{ cm}^{-2} \)
- Must improve \( \nu<1.2-1.3 \text{ GHz} \) coverage to reach beyond \( z \sim 0.1-0.2 \)
- Use e-MERLIN/MeerKAT/SKA1-MID short spacings to map extended outflows

Young radio source in an ULIRG, 4C12.50 at \( z=0.1217 \) Morganti et al., Science, 341, 1082, 2013
Piggybacking on SKA1-MID surveys?

- Besides HI, continuum surveys will reveal a new population of Jy sources
- What is the best strategy to very high resolution follow-up?

Radcliffe et al. (2018)
Key Science Projects with SKA1

- Projects that require 1000+ h over a few years
- What fraction of time will be available for VLBI?
- How many hours of support will come from other networks?
- Min. 240 h/yr EVN & LBA support should be possible, making it >1000 h for 5 yr duration (KSP domain, but not per science proposals)
- African VLBI Network (AVN) may support even more, but only a few telescopes will be there initially – commensal VLBI?

We need an operational model for SKA-VLBI

- KSPs, GOTs, TOO, “OOS” (not TOO, but time coordinated with other facilities for multi-band projects), triggered, and commensal observations
- Will be part of our KSPs absorbed by other groups of the relevant scientific interest?
- What are the outstanding science cases?
Is commensal VLBI possible?

<table>
<thead>
<tr>
<th>Band</th>
<th>VLBI + coarse Vis</th>
<th>Imaging</th>
<th>PSS</th>
<th>PST</th>
<th>Zoom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Band 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(0.35-1.05GHz)</td>
<td><strong>4b full</strong></td>
<td>Full (8 FSP)</td>
<td>1500b 300MHz (8 FSP)</td>
<td>16b (4 FSP)</td>
<td>2 (2 FSP)</td>
</tr>
<tr>
<td></td>
<td>4b 512MHz (6 FSP)</td>
<td>Full (4 FSP)</td>
<td>1500b 300MHz (8 FSP)</td>
<td>16b (4 FSP)</td>
<td>4 (4 FSP)</td>
</tr>
<tr>
<td><strong>Band 2</strong></td>
<td></td>
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<tr>
<td>(0.95-1.76GHz)</td>
<td><strong>4b full</strong></td>
<td>Full (10 FSP)</td>
<td>16b 600 MHz (3 FSP)</td>
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<tr>
<td></td>
<td>4b 512MHz (6 FSP)</td>
<td>Full (5 FSP)</td>
<td>1500b 300MHz (8 FSP)</td>
<td>16b (5 FSP)</td>
<td>2 (2 FSP)</td>
</tr>
<tr>
<td><strong>Band 5a/b</strong></td>
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<tr>
<td>(4.6-8.5 GHz &amp; 8.3-15.3 GHz)</td>
<td><strong>2b 5GHz</strong> (26 FSP)</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td><strong>4b 2.5GHz</strong> (26 FSP)</td>
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<td></td>
<td><strong>4b 512MHz</strong> (6 FSP)</td>
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</table>

*Note: FSP = Faint Source Processing.*
Time for brainstorming to start – community must self-organize
Note there are plans for an Early Production Array – must do VLBI!
SKA General Science Meeting and Key Science Workshop 2019

NEW SCIENCE
ENABLED BY
NEW TECHNIQUES
IN THE
SKA ERA

8-12 April 2019

SKA Global Headquarters, UK

#SKAscicon19
skatelescope.org/SKANewScience

2018 October 8-11
EVN Symposium
VLBI KSP and Operations meeting

- **Location:** SKA HQ, Jodrell Bank, fall 2019
- **JUMPING JIVE WP10 initiative**

**SOC**
- Antonio Chrysostomou, Zsolt Paragi (conveners)
- An Tao (ShAO, CN)
- ... (TBC)
- Francisco Colomer (JIVE, NL)
- John Conway (OSO, SE)
- ... (TBC)
- Roger Deane (Rhodes, SA)
- Preeti Kharb (NCRA, IN)
- Mar Mezcua (ICE, SP)
- Chris Phillips (CSIRO, AU)
- ... (TBC)
- Kazi Rygl (INAF, IT)
- ... (TBC)

**LOC**
- Cristina García-Miró
- ...
What will you do to make sure there is a bright future for (SKA-)VLBI in the coming 5-10+ years?

Spingola et al. (2018)