SKA -low Continuum observations of the extragalactic Universe

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Surveys with SKA Phase 1
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The first phase of the Square Kilometre Array project will provide an ideal opportunity to conduct deep, sub-μJy, radio surveys over large sky areas. Here, predictions are presented for simple surveys which could be carried out with both the low and high frequency components of this instrument. They suggest that a maximum baseline length \( \geq 200 \) km is required: (1) to achieve the necessary resolution to carry out a weak lensing survey at 1.4 GHz; and (2) to avoid confusion limits \( > 10 \) μJy in surveys carried out at \( \leq 300 \) MHz.
Ingredients towards science requirements

- Astronomy landscape in 2020+
- Science case
- Confusion issues
- Next step after LOFAR
- Instrument needed
Astronomy landscape in 2020+

- JWST: sub-arcsec mid IR imaging + spectroscopy of $z>5$ galaxies
- ALMA: sub-arcsec near far imaging + spectroscopy $z>5$ galaxies
- Euclid: ‘all’ sky HST image in optical and near IR of ‘all’ $L^*$ galaxies up to $z=3$. 
# Euclid Legacy in numbers

<table>
<thead>
<tr>
<th>What</th>
<th>Euclid</th>
<th>Before Euclid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxies at 1&lt;z&lt;3 with good mass estimates</td>
<td>(\sim 2 \times 10^8)</td>
<td>(\sim 5 \times 10^6)</td>
</tr>
<tr>
<td>Massive galaxies (1&lt;z&lt;3) w/ spectra</td>
<td>(\sim \text{few } 10^3)</td>
<td>(\text{~few tens})</td>
</tr>
<tr>
<td>H(\alpha) emitters/metal abundance in z≈2-3</td>
<td>(\sim 4 \times 10^7/10^4)</td>
<td>(\sim 10^4/\sim 10^2)</td>
</tr>
<tr>
<td>Galaxies in massive clusters at (z&gt;1)</td>
<td>(\sim 2 \times 10^4)</td>
<td>(\sim 10^3)</td>
</tr>
<tr>
<td>Type 2 AGN (0.7&lt;z&lt;2)</td>
<td>(\sim 10^4)</td>
<td>(&lt;10^3)</td>
</tr>
<tr>
<td>Dwarf galaxies</td>
<td>(\sim 10^5)</td>
<td></td>
</tr>
<tr>
<td>(T_{\text{eff}} \sim 400\text{K Y dwarfs})</td>
<td>(\sim \text{few } 10^2)</td>
<td>(&lt;10)</td>
</tr>
<tr>
<td>Strongly lensed galaxy-scale lenses</td>
<td>(\sim 300,000)</td>
<td>(\sim 10-100)</td>
</tr>
<tr>
<td>(z &gt; 8) QSOs</td>
<td>(\sim 30)</td>
<td>None</td>
</tr>
</tbody>
</table>
Science: use unique diagnostic tools

- First black holes
  - When/how/properties?
  - extreme spectrum sources
- Clusters
  - halo’s/relics/accretion shocks/head tails
  - ultra steep spectrum emission/polarization
  - B?particle acceleration/gas heating/cluster formation
- Life cycle of AGN/accretion history
  - starting/giant/restarting phase
  - Peaked/steep spectrum/polarization
  - B?/Old electrons/Feedback mechanism? Start en end?
- Galaxies
  - warm neutral medium? spatially resolved absorption
  - out flow halos: feedback? spatially resolved steep spectrum emission/polarization
  - T=100-1000 K gas: recombination lines
The Hubble ACS image of the Spiderweb galaxy (z-2.2) overlaid with an 18 arcsec beam.
A2256
JVLA
Owen, Rudnick etal
Red: alpha<-2
old 50 km baseline LOFAR 60 MHz image van Weeren
Colliding clusters
toothbrush cluster 1 Mpc

cluster cores at z=1 ~ 10 arcsec
Modelled LF (Cassano et al.)
Radio galaxies with a ‘double-double’ morphology – III. The case of B 1834+620

Arno P. Schoenmakers,¹,²,³∗† A. G. de Bruyn,³,⁴ H. J. A. Röttgering² and H. van der Laan¹
30'' @610 MHz, 7'' @8.4 GHz, 1.5'' @1.4 GHz, 0.8'' @5 GHz
Figure 6: LOFAR interferometric RRL observations of extragalactic sources. (Left) M82. Shown is a stacked CRRL spectrum, which is the average of 9 lines around 60 MHz, for a 5 hr LBA observation. CRRL absorption is detected at the systemic velocity (250 km/s) for M82. (Right) Cygnus A. Shown is a stacked CRRL spectrum, which is the average of 45 lines around 45 MHz, for a 8 hr LBA observation. The absorption is consistent with foreground CNM and the best-fit model to the data indicates $T_e=110$ K, $n_e=0.06$ cm$^{-3}$ and $EM_C=0.001$ cm$^{-6}$ pc. This implies $[\text{C}/\text{H}]=1.8e-4$, for $N(\text{HI})=3e20$ cm$^{-2}$ (Carilli et al. 1998). Both M82 and Cyg A were imaged with a spatial resolution larger than the size of the source. However, the archived data will allow to us resolve both sources by re-imaging this data.
Figure 3: The predicted number of $\geq 3\sigma$ sources that would be detected in an area equivalent to 20 beams for four different maximum baselines for surveys at 100 MHz (top) and 50 MHz (bottom). The confusion limit of $1 > 3\sigma$ source per 20 beams is shown by the dotted line.
Figure 4: **Top:** the $1\sigma$ limiting flux density at which the confusion limit is reached for increasing maximum baseline length. **Bottom:** the integration time needed to reach the confusion limit for increasing maximum baseline length. A maximum baseline of $>100$ km is needed for surveys deeper than $10\mu$Jy.
Next step after LOFAR

19.5 MHz A2256 field

2 arcmin resolution
250 mJy/beam rms
van weeren et al. 2012
Niche for SKA low: 
<40 MHz

SKA low is essential for calibratability

Fig. 6. Measured sensitivity of the LOFAR low band antennas as a function of frequency.
Surveying the radio sky
15-45, 45-65, 120-180 MHz

1. The highest redshift radio sources - George Miley: \( \sim 100 \) at \( z > 6 \)
2. Starforming galaxies at moderate and high redshifts - Lehnert/Barthel: 100 protoclusters at \( z > 2 \)
3. Clusters and cluster halo sources - Brüggen/Brunetti: 100 @ \( z > 0.6 \); 60 nearby clusters
4. AGN at moderate redshifts - Philip Best
5. Gravitational lensing - Neal Jackson
6. Detailed studies of low-redshift AGN - Raffaella Morganti
7. Nearby galaxies - John Conway/Krzysztof Chyzi
8. Cosmological studies - Matt Jarvis/David Bacon
9. Galactic radio sources – Glenn White
Considerations

- Compatible with (non-)radio instruments
- Next step after LOFAR/open up new parameter space
- Good positions for follow-up
- Morphological information
- Maximise serendipity

Instrument needed

- 400 km baselines
- Observe down to 20 MHz (no one needs 300 MHz)
Conclusion

- longer baselines and lower frequencies