Intensity Mapping with SKA

For a comparison of many IM experiment designs see Bull et al. 2015
Systematics of Single Dish Surveys

Lots of problems!

- Beam sidelobes
- Cross-polarisation
- Receiver gain stability (1/f noise)
- Bandpass calibration uncertainty
- Large-scale Foregrounds
- Atmospheric variations
- Standing waves
- And more…
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[Graph showing a bright RFI source with voltage and azimuth axes]
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![Graph showing voltage vs. azimuth with labeled peaks and a bright RFI source.](image-url)
Systematics of Single Dish Surveys

Lots of problems!

- Beam sidelobes
- **Cross-polarisation**
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*Red line is leakage of polarised Galactic emission*

(Alonso et al 2015)  
(~40dB leakage along LOS)
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**Red line is leakage of polarised Galactic emission**
(Alonso et al 2015)
(~40dB leakage along LOS)

**Black line is the HI intensity emission**

Systematics of Single Dish Surveys
First Attempts using the GBT

Several orders-of-magnitude difference!

Chang et al. 2010; Switzer et al. 2013; Masui et al. 2013; Wolz et al. 2015

Limited by mostly standing waves and cross-polarisation.
IM Simulation Pipeline

A General Overview

**Signal Generation**
- Cosmological signal

**Foregrounds**
- Galactic/Extra-Galactic
- Atmospheric/Sun/Moon

**Receiver**
- Add 1/f noise
- Uncertainties on bandpasses

**Component Separation**
- Residual foregrounds?
- Affect on signal?

**Parameter Estimation**

**Interaction of Beams**

**Interaction of Observing Strategy**
IM Simulation Pipeline

A General Overview

- Interaction of Beams
- Interaction of Observing Strategy
- Parameter Estimation
- Component Separation
- Residual foregrounds?
  - Affect on signal?
- Receiver
- Uncertainties on bandpasses
- Galactic/Extra-Galactic
- Atmospheric/Sun/Moon
- Cosmological signal

Work in progress!
IM Simulation Pipeline

A General Overview

Work in progress!

- Interaction of Beams
- Interaction of Observing Strategy
- Parameter Estimation
- Component Separation
- Residual foregrounds? Affect on signal?
- Residual bandpasses
IM Simulation Pipeline

A General Overview

Work in progress!

Interaction of Beams

Interaction of Observing Strategy

Parameter Estimation
SKA IM Simulation

Survey Tests

![Graph showing time series data with labels for 1Hz and 0.1Hz]
SKA IM Simulation

Survey Tests

Frequency of signal *increases* with scan speed

*Decreasing* knee frequency
SKA IM Simulation

Survey Tests

Frequency of signal *increases* with scan speed

*Decreasing* knee frequency

**Graph:**
- **Power** vs. **Frequency [Hz]**
- **1/f noise**
- **White-noise**
SKA IM Simulation

Survey Tests

Frequency of signal *increases* with scan speed

*Decreasing* knee frequency
SKA IM Simulation

Survey Parameters

- Survey Area: ~25000 sq. deg.
- Receivers: 180
- Observing time: 1 Month
- Slew length: 360°
- Slew speed: 0.5 - 3 deg. s\(^{-1}\)
- Bandwidth: 350 - 1050 MHz
- Channel Width: 15 MHz
- Cal. Uncertainty: 0 - 10%
- \(T_{\text{sys}}\): 60K
- Knee Frequency: 1 - 1000 mHz
- 100 realisations per observation mode
Scanning Strategy & 1/f Noise

Scan Speed vs. 1Hz 1/f

$T_{sys} = 60K$

1/f Noise Spectra

HI Emission
Scanning Strategy & 1/f Noise

$T_{\text{sys}} = 60K$

Scanning speed vs. 1Hz 1/f noise spectra:
- 0.5 deg/s
- 1 deg/s
- 3 deg/s
- White Noise
- $1/f$

1/f Noise Spectra

HI Emission
Scanning Strategy & 1/f Noise

Scan Speed vs. 1Hz 1/f

$T_{\text{sys}} = 60$K

1/f Noise Spectra

HI Emission
Scanning Strategy & 1/f Noise

Scan Speed vs. 1Hz 1/f

$T_{sys} = 60K$

$C_\ell \ell (\ell + 1) [mK^2]$

1/f Noise Spectra

HI Emission

3 deg/s
SKA IM Simulation

Results – Varying knee frequency

Preliminary

Harper et al., in prep.
SKA IM Simulation
Results – Variations in Frequency

Harper et al., in prep.
# SKA IM Simulation

## Results

<table>
<thead>
<tr>
<th>$\frac{\sigma(C_\ell)}{C_\ell}$ [per cent]</th>
<th>$\frac{\Delta(C_\ell)}{C_\ell}$ [per cent]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2 &lt; \ell &lt; 20$</td>
<td>$2 &lt; \ell &lt; 20$</td>
</tr>
<tr>
<td>$20 &lt; \ell &lt; 50$</td>
<td>$20 &lt; \ell &lt; 50$</td>
</tr>
<tr>
<td>$\ell &gt; 50$</td>
<td>$\ell &gt; 50$</td>
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<td>Knee [Hz]</td>
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</table>

Preliminary

Harper et al., in prep.
Conclusion

• Ground based single-dish instruments are very sensitive to systematics on large-scales.

• Modeling these systematics is non-linear and requires end-to-end simulations to quantify.

• Just the interaction of bandpass shape and 1/f noise can significantly limit measurements of scales at $l < 50$.

• Future simulations to include beam sidelobe interactions, cross-polarisation, standing-waves, etc…
SKA IM Simulation

Survey Tests

Effect of calibration on $T_{\text{sys}}$

Toy model for bandpass

Gain [dB]

-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4

Frequency [MHz]

300
700
1100

1/f spectral shape

bandpass shape