All-sky signals from recombination to reionization
Advancing astrophysics with the SKA

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What is an all-sky signal (aka global signal)?

Monopole or global signal

Fluctuations

Single-dish or autocorrelation

Interferometric power-spec or imaging

21-cm is a line: possible to measure cosmic evolution (tomography)

( frequency = redshift )
The science case: Cosmic Dawn / EoR

1. Lyα onset and flux
2. X-ray heating onset and flux
3. EoR onset and duration
4. DM annihilation?

1. Are the fluctuations being seen in emission or absorption?
2. Which redshift range should power-spec, imaging focus on?
Where we currently stand

Reionization duration $\Delta z > 0.06$

Systematics at 1-2 orders of mag. above expected Cosmic Dawn signal

Remarkable! But not quite there yet!
Global signal: Why SKA at all?

Sensitivity to a global signal is independent of collecting area!
Single-day exposure with a single dipole: enough for measurement of CD/EoR global signal!

Why bother with the SKA at all?

1. A chromatic beam + ionosphere leads to mode-coupling of angular structure into frequency structure
2. Accurate bandpass calibration ($10^{-4}$ level) difficult in single-dish radiometers
3. "Spectrally Smooth" assumption insufficient for foreground subtraction: use angular structure for subtraction
4. Reflected RFI from man-made debris may impede detection with single dipoles

Use visibilities (cross-correlations) as a calibration set to mitigate effects (1) (2) and (3)
Use auto-correlation spectra as measurement set for global signal measurement
Design requirements - 1

At least 1 "isolated" special station with noise switching to calibrate out additive errors.

Borrow design strategies from current experiments like SARAS, EDGES, SCI-HI etc. (Balun design, optical isolators, reference noise loads)

Best config for bandpass calibration accuracy

5 deg resolution = better foreground subtraction

Mode-coupling high due to large antenna element
Design requirements - 2

At least 1 "isolated" special dipole with noise switching to calibrate out additive errors.

Borrow single dipole + receiver design from current experiments (EDGES, SARAS, SCI-HI etc)

Low mode coupling

Foreground subtraction challenging

It is feasible, inexpensive, and highly desirable to design for both configurations for SKA1-Low!
1. An interferometer can measure the Moon - global background brightness contrast.
2. No need for special receiver design (cross-correlations have no additive noise bias)
3. Early science: Lunar regolith characteristics up to 1 km depth (unprecedented)
4. Practical way to establish accurate flux scale at low freq?
Where we stand / Why SKA ?

1. Proof of concept stage (pilot experiment)
2. Demonstrated that reflected RFI is not a current limitation given long baselines (>100 λ)

1. Need filled uv-plane to mitigate sidelobe confusion
2. Need filling factor ~ 1 for detecting within reasonable integration times (days).

SKA1-Low is the only instrument that will have both a filled aperture and long baselines for global signal detection via lunar occultation.
The science case: Recombination

1. $10^{-7}$ level distortions in the CMB
2. Test of the standard model – precise predictions
3. SKA-mid is the optimal freq band (given SNR frac-bandwidth etc)
4. SKA-mid Band4: 2500 antenna-days for 1σ detection!
   (66 days with 190 antennas)
5. Prefer off-axis dishes to mitigate spectral ripple systematics due to reflections

SKA-mid is the only foreseeable instrument that can detect recombination lines from CMB era
Conclusions

Motivation
1. There exists a compelling science case to measure the global 21-cm signal from CD/EoR
2. Global signal measurements will establish the base-level on which fluctuations are measured
3. Global signal measurements are an important precursor to inform power-spec/imaging campaigns
4. Recombination lines from CMB era an excellent test of the standard model

What needs to be done
1. Measurement will require >1 specially (carefully) designed SKA1-low station / dipole
2. Design may be adapted from current single dipole experiments
3. No need for additional hardware design/modification for occultation based measurement

How SKA is unique
1. SKA1-low only foreseeable telescope for lunar-occultation based measurement
2. Exciting early/unprecedented science (Lunar regolith evolution with depth)
3. SKA1-mid only foreseeable telescope capable of detecting recombination lines from CMB era