Pre-selection of the Candidate Fields for Deep Imaging of the Epoch of Reionization with SKA1-Low

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(Received; Revised; Accepted)
Submitted to ApJ

ABSTRACT

The Square Kilometre Array (SKA) will be the first low-frequency instrument with the capability to directly image the structures of the Epoch of Reionization (EoR). This will be possible due to its unprecedentedly high sensitivity and angular resolution within its low-frequency observing band, even with the Phase I of the SKA (SKA1-low). Indeed, deep imaging of the EoR over 5 targeted fields of 20 square degrees each has been selected as the highest priority science objective for SKA1, probably the most exciting scientific outcome to be expected for the SKA1-Low. Aiming at preparing for this highly challenging observation, we perform an extensive pre-selection of the ‘quietest’ and ‘cleanest’ candidate fields in the southern sky to be suited for deep imaging of the EoR using existing catalogs and observations over a broad band. The candidate fields should meet a number of strict criteria to avoid contamination from foreground structures and sources such as the Galactic plane, Large and Small Magellanic Clouds, clusters of galaxies and bright radio sources. The candidate fields should also exhibit both the lowest average surface brightness and smallest variance to ensure uniformity and high quality deep imaging over the fields. We use two sets of field of view in our selection: the exactly same size of 20 square degrees as defined in current SKA1 documentation and 40 square degrees - an area of twice big as the EoR imaging fields. The choice of a larger area allows us to maximally reduce the environmental effect from radio structures/sources in the vicinity of the candidate field. Our selection yields a sample of 29 (9) ‘ideal fields of 20 (40) square degrees in the southern sky that could be targeted for deep imaging of the EoR. We have launched a campaign to observe these candidate fields with some of the SKA pathfinders (e.g. MWA) to set further constraints on these candidates. Meanwhile, simulations should be carried out to study the sidelobes of far field bright sources for each of the candidate fields using the beam pattern in terms of current design of SKA1-low station. These pre-selected candidate fields can provide a valuable guidance for eventual selection of the five targeted fields for imaging the EoR structures with the future SKA1-low.

Keywords: cosmology: observations – dark ages, reionization, first stars – instrumentation: interferometric – methods: observational

1. INTRODUCTION

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Exploration of the dark ages, cosmic dawn (CD) and epoch of reionization (EoR) constitutes the last frontier of observational cosmology for the next decades, which will unveil the mysteries of how and when the universe underwent a transient from a dark to bright phase, how the underlying large-scale structures grew from linear to nonlinear stage, and how baryonic matter became prominent for formation of cosmic structures. It has also been recognized that a direct probe of the 21 cm radiation associated with the neutral hydrogen beyond redshifts $z > 6$ would make this observational campaign possible, as the neutral hydrogen, amounting to 75% of the baryonic mass of the universe, can be considered as a good tracer of the properties of formation and evolution of the universe in its early stage (for reviews see Furlanetto et al. 2006; Pritchard & Loeb 2012; Zaroubi 2013; Ferrara & Pandolfi 2014). Essentially, there are three observational approaches to directly measuring the CD/EoR: (1) the spatially averaged global signature at each frequency, (2) the spatial fluctuations via statistical properties revealed by power spectra, and (3) tomographic imaging of the ionized structures. While many dedicated low-frequency radio facilities have been built or planned around the globe to search for either the mean brightness over all directions in the frequency range of 50-200 MHz [e.g. EDGES (Bowman & Rogers 2010; Bowman et al. 2008) with recent detection of an absorption signature at about redshift 17 (Bowman et al. 2018), BIGHORNs (Sokolowski et al. 2015), SCI-HI (Voytek et al. 2014), LEDA (Bernardi et al. 2015), SARAS (Patra et al. 2013), etc. or the statistical measurement of fluctuations in the redshifted 21 cm backgrounds [e.g. 21CMA (Zheng et al. 2016), LOFAR (van Haarlem et al. 2013), LWA (Taylor et al. 2012), MITEoR (Zheng et al. 2014), MWA (Bowman et al. 2013; Tingay et al. 2013), PAPER (Jacobs et al. 2011), GMRT (Paciga et al. 2013), HERA (DeBoer et al. 2017), etc.], the SKA-Low will be the first low-frequency instrument with the capability of directly imaging the structures of CD/EoR - probably the most exciting scientific outcome of the SKA-Low.

Imaging of CD/EoR was ranked first among the thirteen highest priority science objective selected by the Science Review Panel of SKA1 in December 2014 (Koopmans et al. 2015). In terms of current design and observational strategy, deep observations of 5000 hours integration time in total over 5 targeted-area of 20 square degrees each will be performed with SKA1-Low (Mellema et al. 2015; Koopmans et al. 2015). This will provide technical hurdles, which may hopefully allow one to reach the desired detection sensitivity (\(\sim 10 \mu K\) noise level with somewhat poor angular resolutions (\(\sim 10\)'), therefore the statistical measurements of the power spectrum will be the only way to probe the structures of CD and early EoR stages beyond redshift \(\sim 13\). With much larger collecting area, better angular resolution and wider frequency coverage, SKA2 will eventually enable us to reach our ultimate goals. Another key parameter for imaging the EoR is the adequate field-of-view (FoV), which should be at least a few degrees, in order to image the largest ionized structures during the later EoR stages. With the design of current SKA1-Low baselines, the primary beam of the 35 m station varies from 6° at 100 MHz to 3° at 200 MHz, which marginally meets the purpose.

The deep 1000-hr integrations for each of the 5 separated EoR fields with SKA1-Low are only the minimum requirement to reach the sensitivity of imaging the ionized structures. A considerably large number of radio quiet nights, adding up to 3-5 years, may be needed if the SKA1-low operates in drift-scan mode. The tomographic imaging reconstruction for SKA1-Low as an interferometer at low frequencies suffers from various systematic errors, including radio frequency interference, incomplete sampling, limited angular resolution, ionospheric distortion, inaccurate calibration, instrumental artifacts, poor sky modeling, confusion limit, etc. A small error from incomplete corrections to any of these factors may destroy the imaging recovery of the EoR structures which are deeply buried under both astronomical foregrounds (\(\sim 5\) orders of magnitude stronger than the EoR signal) and instrumental noises. Many state-of-the-art techniques and algorithms have been thus developed in past decades aiming to overcome these observational and technical hurdles, which may hopefully allow one to reach the desired detection sensitivity (\(\sim 1 \mu K\)) for the future 1000 hours integrated observations of the EoR field with SKA1-Low.

Aiming at preparing for the deep imaging of the EoR ionized structures with SKA1-Low which will be fully operated in 2027, it is timely to select the five (or more) candidate fields of 20 square degrees each in the southern sky to be suited for this purpose. Pre-observations and preliminary searches with existing radio facilities such as MWA, ASKAP, and even the Karl G. Jansky VLA and FAST (if the fields are observable in the northern hemisphere) over a wide waveband should be made in order to understand the ‘quietness’ and ‘cleanliness’ of the candidate fields and their environmental effects. This will help to answer the questions of how foreground bright cosmic sources, especially the extended and diffuse ones, are distributed and clustered in the fields, to what extent the sky models can...
be constructed and foreground sources removed, how sidelobe leakages of off-field bright sources affect the imaging quality and sensitivity, and what kinds of noise remain to be the major source of errors in imaging reconstruction and what kinds of technologies should be needed and further developed to beat down the noise(s) to an acceptable level. After all these exercises we will hopefully be able to determine whether the candidate fields are suited and eventually selected for the first EoR imaging observations before the first light of the SKA1-Low. With such motivation in mind, we attempt to fulfill the task in the present work by making a pre-selection of the candidate EoR fields, based mainly on the existing radio catalogs and observations.

2. TARGET SELECTION

2.1. Locations and Sizes of the Candidate Fields

SKA1-Low will be deployed at the remote site close to the Murchison Radio astronomy Observatory (MRO) in Western Australia. The telescope receptors of SKA1-Low will consist of about 130,000 log-periodic dual-polarized antennas grouped into 512 stations of 35 m in diameter, which operates at frequencies ranging from 50 MHz to 350 MHz. While SKA1-Low is designed to survey a significant fraction of the sky up to 10000 square degrees, its unprecedentedly high sensitivity allows us to detect extremely faint objects and study their structures. Within a long integration of 1000 hours, it is expected that SKA1-Low can reach \( \sim 1 \text{ mK} \) noise level under 0.1 MHz spectral resolution at frequencies of \( \nu > 100 \text{ MHz} \). SKA1-low will have a sky coverage similar to that of MWA, which can observe the entire sky south of Dec. \( +30^\circ \) (Hurley-Walker et al. 2017). Therefore, the first criterion for selecting the EoR candidate fields is to restrict the fields to the sky south of Dec. \( +30^\circ \). In reality, priority will be given to the fields with smaller zenith angles (typically \( < 50^\circ \)) to avoid the non-uniform beam pattern.

The candidate fields should also be large enough to capture the largest ionized structures during the very late stage of EoR near 200 MHz or \( z = 6 \). A comoving scale of \( 100 h^{-1} \text{ Mpc} \) at \( z = 6 \) corresponds approximately to an angular scale of roughly \( 1^\circ \). So, current design of SKA1-low with a primary beam of \( 3^\circ \) at 200 MHz should enable us to observe the entire ionized structures even near the end of the EoR, if other observational constraints such as sensitivity, resolution and foreground subtraction are left aside. The primary beam of SKA1-low would reach \( 6^\circ \) at 100 MHz, probably the lowest frequency at which we can capture the EoR imaging with SKA1-low due to rapidly decreasing sensitivity with decreasing frequency. So, our second criterion for selecting the EoR candidate fields is to choose an adequate FoV that should be larger than \( 3^\circ \) in radius. Here we adopt a more relaxed condition of \( 3^\circ \) in radius (corresponding to 40 square degrees of FoV) to further suppress sidelobe contamination or possible environmental effects.

2.2. Galactic Emission

The low-frequency radio sky is dominated by diffuse synchrotron emission from our Galaxy, which is on average 4-5 orders of magnitudes brighter than the EoR surface brightness at frequencies 50–200 MHz. Unfortunately, below 200 MHz little is known about the spatial and spectral properties of diffuse Galactic emission despite that many investigations have been made thus far (see, e.g. de Oliveira-Costa et al. 2008; Zheng et al. 2017). Like many previous studies of modeling of the low-frequency emission of the Milky Way, our selection of the EoR candidate fields begins with the 408 MHz Haslam map, which allows us to identify the ‘cooler’ regions in the southern sky. In principle, by extrapolating the 408 MHz Haslam map with a proper assumption of the spectral index, one can build the global sky model at the EoR window, 50–200 MHz (de Oliveira-Costa et al. 2008; Zheng et al. 2017). We further use the recent 80 MHz LWA map (Dowell et al. 2017), which covers the sky north of a declination of \(-40^\circ\), to cross-check these ‘cooler’ or radio-quiet regions. Figure 1 shows the 80 MHz LWA map and the 408 MHz All-Sky Map, respectively. The selected cooler regions, marked by A, B, C, D and E, will be the targeted fields for the selection of the EoR candidate fields.

2.3. The Magellanic Clouds

Besides the Galactic plane, the Large and Small Magellanic Clouds (LMC/SMC) are the most prominent extended celestial sources in the southern sky (Figure 2). In order to avoid both the possible obscuration/occultation of observations of the cosmic EoR structures and the difficulty of subtracting complex foregrounds, our candidate fields should be chosen far away from the Magellanic Clouds.

2.4. Bright Radio Sources
Point sources at low frequencies spread over the whole sky, and constitute one of the biggest challenges in detection of the EoR signal in addition to the contamination of the Galactic emission.

Therefore there are primarily three factors that we should follow in selecting the candidate EoR fields: (1), the EoR fields of 20 square degrees (2.52 degrees in radius) should not contain any bright radio sources; (2), the EoR fields...
should look somewhat ‘isolated’, i.e., there should be as few bright radio sources as possible even in the vicinity of the fields or the sidelobes of the SKA1-low stations. We will therefore survey an area of twice big as the EoR imaging fields, namely 40 square degrees or 3\(^\circ\).57 in radius; (3), since the EoR fields inevitably contain foreground faint radio sources, we need to select the fields over which the faint radio sources distribute as uniformly as possible. The last point is to ensure that the EoR imaging would have a uniform noise level across the entire field after the CLEAN process and subtraction of foreground sources. Clustering of the radio sources in the fields may add difficulty to these works.

The bright radio sources may refer to those with flux densities above a few Jy. Using a broken power-law for the differential radio source counts (Hales, Baldwin & Warner 1988; Cohen 2007; Moore et al. 2013) and assuming a mean spectral index of \(-0.8\), we can estimate how many foreground radio sources would be encountered at different fluxes over a field of up to 40 square degrees. It turns out that at a frequency of 150 MHz, the surface number density of radio sources reaches roughly \(\sim 0.05\) and \(\sim 0.1\) per square degree at 5 and 3 Jy, respectively. Therefore, on average a field of 40 square degrees contains roughly \(\sim 2\) (\(\sim 4\)) radio sources with fluxes brighter than 5 (3) Jy. It is possible to find the EoR candidate fields of 40 square degrees without containing any bright point sources with flux of greater than a few Jy at 150 MHz. If we restrict the EoR field to exactly 20 square degrees, we could even choose a lower flux threshold of \(\sim 1\) Jy. Yet, in either case, we also need to find efficient algorithms to remove all the faint sources below the flux threshold.

The GaLactic and Extragalactic All-sky MWA (GLEAM) survey (Wayth et al. 2015) provides the best sample of radio sources to date for our purpose. It covers half of the sky up to 24,831 square degrees over declinations south of +30\(^\circ\) and Galactic latitudes outside 10\(^\circ\) of the Galactic plane, almost the same region of sky that SKA-low will observe. Differential source counts from the GLEAM extragalactic catalogue (Hurley-Walker et al. 2017) yield a similar source surface number density as the above estimate.

Defining each of the EoR candidate fields as an circular area of 40 square degrees, we perform a survey of the radio ‘quiet’ fields over the GLEAM sky which contain no any bright radio sources of \(S \geq 1, 2, 3, 4, 5, 6\) Jy at 150 MHz. The image with the GLEAM sources was gridded using the angular resolution of 0.1 degree. We searched each single pixel to change the field centers and checked if the fields with certain radius contain any sources shouldn’t be included. This yields a total of 0/1/30/99/191/281 circular fields for \(S \geq 1/2/3/4/5/6\) Jy over the GLEAM sky. These numbers increase to 1/24/372/498/729/1083 if we adopt a small circular area of 20 square degrees.

Note that not all the selected fields are actually radio ‘quiet’ and suited for deep imaging of EoR structures. Some of them may contain too many faint sources, which as a whole look rather bright, and/or the faint sources may exhibit clumpy or clustering which would add extra work or difficulties for CLEAN or subtraction process. To this end, we calculate the mean flux and variance of each selected field and plot the results in Figure 3. While the mean fluxes for all the fields are smaller than \(\sim 0.05\) Jy, a few of the selected fields demonstrate rather large flux variance in the case of a smaller field of 20 square degrees. As a comparison, the average sky flux and variance are 0.52 \(\pm\) 0.13 Jy and 1.51 \(\pm\) 1.09 Jy, respectively. Our selected fields are typically one order of magnitude fainter in flux and smoother in
spatial distribution than the average. We will come back to this point later when we sort out the final list of candidate fields by applying and combining all the criteria.

![Figure 3](image_url)

**Figure 3.** The mean flux against flux variance for the candidate fields selected from the GLEAM survey. Six flux thresholds (1 Jy, 2 Jy, 3 Jy, 4 Jy, 5 Jy and 6 Jy) and two size limits (20 and 40 square degrees) are adopted.

2.5. **Diffuse Sources and Galaxy Clusters**

Foreground diffuse and extended radio sources in this low-frequency range could mimic the EoR structures and constitute one of the biggest problems for recovery of the true EoR signals from deep imaging observations. Though these diffuse sources may be subtracted based on their smooth spectral features, a tiny error from the imperfect modeling of the extended sources may invalidate our efforts. Therefore, we will apply another constraint to the EoR candidate fields: They should not contain any resolved radio diffuse sources in addition to the very extended, bright sources of the Milky Way and LMC/SMC.

We have therefore compiled a catalog of 6986 clusters, based on multi-wavelength observational data available in literature, which include 5249 optical Abell clusters (Abell et al. 1989), 1058 X-ray clusters (Piffaretti et al. 2011),
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679 Planck SZ clusters (Ade et al. 2014) and 225 clusters detected with diffuse emission using GLEAM at very low-frequencies (Johnston-Hollitt et al. in prep.). Yet, many of the X-ray/SZ/GELAM selected clusters have already been included in the Abell cluster catalog. Figure 4 shows the distribution of all these clusters over the Haslam 408 MHz All-Sky Map. The EoR candidate fields to be selected should contain as few clusters as feasible.

Figure 4. The distribution of the 6986 galaxy clusters on the Haslam 408 MHz All-Sky Map, which includes 5249 Abell clusters (Abell), 1058 X-Ray clusters (MCXC), 679 Planck SZ clusters (PSZ) and 226 galaxy clusters detected with diffuse emission using GLEAM (Diffuse). Note that many of the X-ray/SZ selected clusters and GLEAM clusters with diffuse emission are actually Abell clusters.

3. RESULTS

We now summarize the criteria for selecting the candidate fields for deep imaging of EoR with the future SKA1-low:

1. located within the five regions marked with A, B, C, D and E in Figure 1, the radio quiet zones in the low-frequency southern sky;
2. far away from the LMC, SMC and other bright, extended structures;
3. containing no other bright radio sources;
4. containing no bright clusters of galaxies;
5. having low mean surface brightness and exhibiting low surface brightness variance;
6. selecting only one field when the overlapping area of two adjacent candidate fields exceeds 20%.

Although our priority choice of field of view (FoV) is 40 square degrees or $3^\circ.57$ in radius, twice as large as the EoR imaging fields to be planned with SKA1-low, we also provide the candidates for a smaller value of 20 square degrees or $2^\circ.52$ in radius for both comparison and optional choices. The latter matches exactly the actual size that SKA1-low will adopt for the deep imaging of EoR in terms of current observational strategy. The key difference between the large (40 square degrees) and small (20 square degrees) fields is the flux threshold $S_{\text{lim}}$ that is used to define the so-called bright radio sources (see section 2.4). Using a higher cut of $S_{\text{lim}}$ would ensure a sufficiently large number of candidate fields (e.g. $\geq 5$) to be selected for deep imaging.

Keeping two choices of field sizes (20 and 40 square degrees), we now apply the above selection criteria to the southern sky by varying the flux threshold of bright sources $S_{\text{lim}}$. Figure 5 displays the total number of candidate fields, their average fluxes and their variance for different values of $S_{\text{lim}}$. It appears that for a larger field size of 40
square degrees, we may find five candidate fields with a bright sources limit of $S_{\text{lim}} \geq 5$ Jy at 150 MHz. 9 candidates can be reached if we raise the flux limit to $S_{\text{lim}} \geq 6$ Jy at the same frequency. For a choice of smaller field of 20 square degrees, three candidate fields may be found at $S_{\text{lim}} \geq 2$ Jy at 150 MHz, and this number becomes 29 if we adopt a larger value of $S_{\text{lim}} \geq 3$ Jy. No candidate fields can be found if flux threshold is taken to be lower than 2 Jy and 1 Jy for the 40 and 20 square degrees cases, respectively. These possible candidate for the fields of 20 and 40 square degrees are shown in Table 1 and Table 2, respectively. Meanwhile, we demonstrate in Figures 6 the locations of the selected 9 candidate fields of 40 square degrees on the 80 MHz LWA map and the Haslam 408 MHz All-Sky Map, respectively. Also, Figure 7 displays the locations of the selected 29 candidate fields of 20 square degrees on the 80 MHz LWA map and Haslam 408 MHz All-Sky Map listed in Table 2.

![Figure 5](image)

**Figure 5.** The average flux against flux variance for each of the candidate fields selected in terms of different flux thresholds for bright radio sources. Two choices of field of view, 40 and 20 square degrees, are used.

Moreover, we searched literature and collected images of all these candidate fields observed in other wavelengths, e.g. The PLANCK full mission bandpass leakage corrected single frequency map in 30 Ghz and 857 GHz (Figure 8) (Aghanim et al. 2018; Akrami et al. 2018), the WISE data in infrared bands of 3.4 \(\mu\)m and 4.6 \(\mu\)m (Figure 9) (Lang 2014), etc. The images of the five 40 square degrees fields under the flux threshold of 5 Jy at different wavebands are shown in Figure 8. Figure 9 presents the WISE observations of the five candidate fields. These figures provide an intuitive feeling of how these extremely radio-quit areas look like on the sky.
Table 1. Positions of the candidate fields of 40 square degrees with three choices of flux threshold of 4 Jy, 5 Jy and 6 Jy.

| field number | R.A.(J2000), Dec.(J2000) (4 Jy) | R.A.(J2000), Dec.(J2000) (5 Jy) | R.A.(J2000), Dec.(J2000) (6 Jy) |
|--------------|---------------------------------|---------------------------------|---------------------------------|
| 1            | -                               | (5:27:36, −17:30:00)            | (5:27:36, −17:30:00)            |
| 2            | (7:56:00, +6:24:00)             | (7:56:00, +6:24:00)             | (7:56:00, +6:24:00)             |
| 3            | (8:22:48, −12:24:00)           | (8:22:48, −12:24:00)           | (8:22:48, −12:24:00)           |
| 4            | (8:29:12, −2:00:00)            | (8:29:12, −2:00:00)            | (8:29:12, −2:00:00)            |
| 5            | (9:09:36, +25:42:00)           | (9:09:36, +25:42:00)           | (9:09:36, +25:42:00)           |
| 6            | -                               | -                              | (4:57:36, −14:00:00)           |
| 7            | -                               | -                              | (5:42:48, −53:00:00)           |
| 8            | -                               | -                              | (10:28:24, −1:18:00)           |
| 9            | -                               | -                              | (10:32:00, +24:36:00)           |

Table 2. Positions of the candidate fields of 20 square degrees with two choices of flux threshold of 2 Jy and 3 Jy.

| field number | R.A.(J2000), Dec.(J2000) (2 Jy) | R.A.(J2000), Dec.(J2000) (3 Jy) |
|--------------|---------------------------------|---------------------------------|
| 1            | (8:44:48, +21:48:00)            | (8:44:48, +21:48:00)            |
| 2            | (9:10:24, +28:00:00)            | (9:10:24, +28:00:00)            |
| 3            | -                               | (1:54:24, −52:06:00)           |
| 4            | -                               | (3:40:48, −16:00:00)           |
| 5            | -                               | (3:49:36, −0:42:00)            |
| 6            | -                               | (4:24:48, −14:30:00)           |
| 7            | -                               | (4:38:48, −6:12:00)            |
| 8            | -                               | (4:44:24, −13:18:00)           |
| 9            | -                               | (5:41:36, −56:06:00)           |
| 10           | -                               | (5:58:48, −25:24:00)           |
| 11           | -                               | (6:08:48, −53:48:00)           |
| 12           | -                               | (6:23:12, −49:54:00)           |
| 13           | -                               | (6:58:00, −53:06:00)           |
| 14           | -                               | (8:07:12, +7:24:00)            |
| 15           | -                               | (8:13:12, +25:48:00)           |
| 16           | -                               | (8:22:24, −1:18:00)            |
| 17           | -                               | (8:35:36, +3:24:00)            |
| 18           | -                               | (8:41:36, −4:00:00)            |
| 19           | -                               | (8:57:12, −16:54:00)           |
| 20           | -                               | (9:03:36, −23:24:00)           |
| 21           | -                               | (9:08:48, +13:36:00)           |
| 22           | -                               | (9:23:12, +24:48:00)           |
| 23           | -                               | (9:51:36, +11:48:00)           |
| 24           | -                               | (10:36:24, +8:06:00)           |
| 25           | -                               | (10:40:24, −14:06:00)          |
| 26           | -                               | (10:42:48, +25:06:00)          |
| 27           | -                               | (10:54:00, −6:12:00)           |
| 28           | -                               | (11:00:24, +28:54:00)          |
| 29           | -                               | (22:20:48, −21:42:00)          |

4. DISCUSSION AND CONCLUSIONS
Figure 6. Positions of the selected 9 candidate fields of 40 square degrees for a bright source threshold of 6 Jy, respectively. Overlaid are the Haslam 408 MHz map (top) and 80 MHz LWA map (bottom).

Using existing catalogs and surveys rather than only a wide frequency band especially in low frequencies, we have selected 9 (29) candidates fields of 40 (20) square degrees in the southern sky, which contain no prominent foreground features (e.g. the Galactic plane, LMC/SMC), no bright diffuse sources (e.g. within clusters), no bright point sources,
and also exhibit the smallest variance of surface brightness. This work could be regarded as the first step towards preparation of deep imaging of the EoR - the top priority science goal with the forthcoming SKA1-low.
Further investigation will be needed to explore at least two effects before these candidate fields can be eventually selected as the target fields of EoR imaging with SKA1-low: (1) the sidelobe effect from off-field bright sources especially the so-called ‘A-team’ sources (e.g. Cygnus A and Centaurus A), and (2) the extended sources such as radio galaxies within the fields.
The existence of sidelobes from sources can introduce difficulties in the deconvolution process. These sidelobes become more problematic with incomplete $u$–$v$ sampling and source complexity, and increase in strength with the brightness of the source. However, these can be reduced with precisely modeled bright foreground sources, and this will be a requirement to lower the image noise level.

We are considering combining the beam pattern from the current design of the SKA1-low station (e.g. SKA-TEL-SKO-0000941) with the low-frequency sky revealed by the Haslam 408 MHZ All-Sky Map, MWA GLEAM survey and LWA to demonstrate the contamination of sidelobes of the far field bright sources at 100-200 MHz for each of the selected candidate fields. A number of the currently selected candidate fields may be disqualified if the sidelobes from sources...
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bright sources dominate, e.g. from the ‘A-team’ sources, which will be resolved at SKA1-low resolutions and will be difficult to remove completely.

Additionally, whether we can achieve the desired sensitivity (∼1 mK) to detect the EoR structures in the candidate fields also depends on how precisely the sky model can be built and if all the foreground sources can be subtracted to an acceptable level, among which the extended and diffuse radio sources tend to be the most difficult targets to deal with. There have been no efficient or unique algorithm so far to model the extended sources, despite that many efforts have been made in recent years (e.g. Braun 2013; McKinley et al. 2015; Trott & Wayth 2017). If some of the candidate fields still contain faint, diffuse and complex radio sources that have not been seen by existing low-frequency surveys, we may meet problems in modeling and removal of these sources, which may in turn increase the noise level of deep imaging. Pre-observations of each of these candidate fields are therefore necessary with some of the SKA pathfinders to further reject the 'bad' fields. Recall that not only should the morphology of the extended sources be properly described, but also the spectral index of each component of the extended sources should be known a priori or can be fitted out in the modeling.

We have recently launched a campaign to observe, at least, each of the five selected candidate fields of 40 degrees for 100 hours with the MWA. Test observations of two radio-quiet areas with 7.5 degree radii (177 square degrees each) in the southern sky were carried out in 2017, however, data reduction and analysis are ongoing. We will make an extensive observational study of these candidate fields in a broad frequency range, towards a deep understanding of the properties of radio sources such as morphologies, spectral indices, structures, clustering, etc. in both the fields and their vicinities. Different imaging algorithms and techniques (weighting, wide-field imaging, sky model construction, CLEAN, etc.) will be applied and further developed to beat down the noises arising from various parameters and environments (thermal noise, confusion noise, deconvolution noise, sidelobe noise, calibration noise, etc.). This also allows us to estimate the computing capabilities for achieving high dynamical range and optimize the design and reduce the cost of high performance computing for SKA1-low.

This work is supported by the National Key R&D Program of China under grant No. 2018YFA0404601, the Key Projects of Frontier Science of Chinese Academy of Sciences under grant No. QYZDY-SSW-SLH022, and the Strategic Priority Research Program of Chinese Academy of Sciences under grant No. XDB23000000. SWD acknowledges an Australian Government Research Training Programme scholarship administered through Curtin University.

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