

# Simulating the Sky as Seen by the Square Kilometer Array using the MIT Array Performance Simulator (MAPS)

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## I. Background

The Square Kilometer Array (SKA) is a next-generation radio telescope array being planned by the international astronomy community. The SKA will operate over a wide range of frequencies (~0.1 to 30 GHz) and once fully operational, will be 50-100 times more sensitive than existing radio arrays. At 1.4 GHz, this translates to a limiting flux density of ~10 nJy (1 $\sigma$ ) from a 100-hour integration. Construction (in Australia or South Africa) is expected to begin some time around 2012 and full operation is expected by 2020.

SKA's leap in sensitivity implies that observations, particularly at lower frequencies, will be confusion limited. Moreover, currently favored SKA designs comprising large numbers of small-diameter dishes ("large-N, small-D arrays") will naturally have large fields-of-view. Consequently, not only will the confusion problem be enhanced, but instrumental and atmospheric effects will vary significantly across the field. If not handled properly, these effects will dramatically limit the achievable dynamic range of the array. New hardware developments (e.g., correlator FOV shaping; Lonsdale et al. 2004) and new software (e.g., Cornwell 2007) will be required to overcome these limitations. Testing and optimizing these tools, as well as optimizing the overall design of the SKA, demands the ability to realistically model the sky background and its impact on routine SKA observations.

MIT Haystack is currently working to develop a streamlined pathway for performing realistic simulations of large radio arrays under a variety of observing conditions. This poster describes tools in existence and under development for meeting these goals.

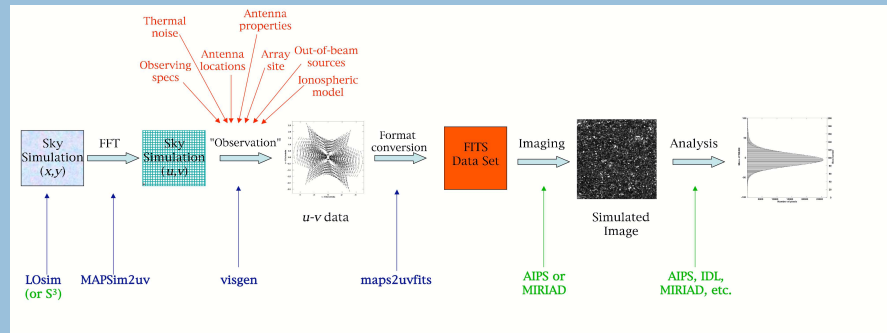


Figure 1: Steps for Computing a Simulated Radio Observation using MAPS

Fig. 1 shows a schematic depicting the process of performing a realistic, simulated radio observation using the MAPS package. Text in blue refers to MAPS modules used to perform various steps. Green labels/arrows refer to external packages that may be used for generating the initial input sky model and for performing imaging or other analysis of the simulated data. Red text and arrows depict user-specified inputs that may be included in the simulation.

## II. An Overview of MAPS

Development of the MIT Array Performance Simulator (MAPS) began at MIT Haystack Observatory in 2001 with the goal of providing a flexible tool for the generation of simulated low frequency radio array observations and for testing new radio calibration and processing algorithms (Lonsdale 2001; Doleman 2001a, 2001b, Cappallo 2002). Recently, a number of enhancements to MAPS have been introduced by Randall Wayth and collaborators (Wayth et al., in prep.).

MAPS was designed to accommodate detailed descriptions of heterogeneous interferometric arrays and a variety of other highly flexible user inputs. Features include:

- ability to input an arbitrary sky brightness distribution
- option to include out-of-beam sources
- user-specified array geometries (including placement and orientation of individual receptors)
- station-based beam forming
- variable station beams
- observing specifications through an input template (RA and DEC; field-of-view; time and frequency resolution; bandwidth; channel width; correlator integration times; observation start and stop times)
- option to include thermal noise
- time- and location-dependent ionospheric effects; modeling of large- and small-scale ionospheric structure
- fully polarized instrument response
- ability to do all-sky simulations
- ability to export simulated data into FITS format

A schematic illustrating how MAPS could be used for an arbitrary simulation is shown in Fig. 1. MAPS has a command line-driven interface, with user inputs specified via command line switches and text files.

MAPS remains under active development. The current version is maintained by R. Wayth, and persons interested in using the program may contact: r.wayth@curtin.edu.au. However, plans are to make the code publicly available in the near future. Additional information on MAPS can also be found at <http://www.haystack.mit.edu/ast/arrays/maps>.

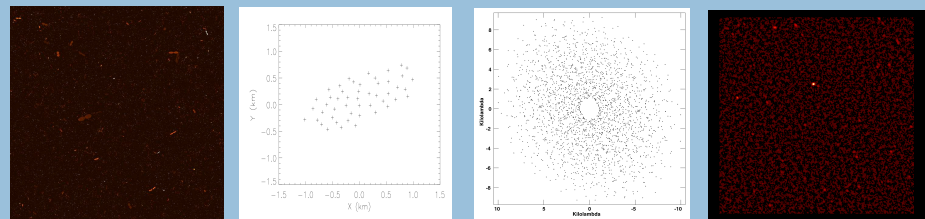


Figure 2: Components of a Sample Simulation

Fig. 2a (far left) shows an example of a 1 $^{\circ}$   $\times$  1 $^{\circ}$  18 GHz simulated sky image derived using S<sup>3</sup>. The intensity scale is logarithmic. No noise is included in the simulation; all features correspond to "real" sources. No beam convolution has been applied, so point sources appear as bright specks.

Fig. 2b (second panel) shows the antenna locations for the core of an array, containing forty-nine 2-m parabolic antennas.

Fig. 2c (third panel) depicts the monochromatic u-v coverage of this array during a 60-second observation.

Fig. 2d (far right) shows the results of a simulated 60-second observation with the array in Fig. 2b in a single 1 kHz channel (as imaged with AIPS). The low surface brightness, extended sources are not recovered in this short snapshot. No thermal noise was added to the simulation; the visible background noise in the image results from limitations of an unrestricted CLEAN for deconvolving a wide-field image filled with background sources whose locations are not known a priori.

## III. Methods for Producing Simulated Skies

The LOSim module of MAPS allows the production of simple sky models for use in MAPS simulations (e.g., Doleman 2001b). The user supplies an input list of bi-axial Gaussian sources (specifying sizes, positions, and flux densities), and a FITS image of the desired field-of-view and pixel scale is generated. However, more sophisticated and realistic sky simulations over large fields-of-view will become increasingly important for future SKA development efforts.

The SKADS Design Study (SKADS) initiative at the University of Oxford has recently produced a semi-empirical simulation of the extragalactic radio sky at five frequencies: 151 MHz, 610 MHz, 1.4 GHz, 4.86 GHz, and 18 GHz (Wilman et al. 2008). This simulation (known as SKADS-SEK or S<sup>3</sup>) covers an area 20 $\times$ 20 deg<sup>2</sup> down to a limiting flux density of 10 nJy. The simulated sources are drawn from observed luminosity functions, extrapolated to the necessary brightness limits, which are in turn populated onto an underlying dark matter density distribution. Galaxy clustering is also included. In total, the simulations contain ~320 million radio continuum sources. These highly flexible simulations allow the user to "post-process" the data to test the effects of, e.g., changing the limiting flux densities or altering the adopted luminosity functions for various classes of sources. Results can then be outputted in FITS format. These features make the S<sup>3</sup> simulations valuable for generating mock sky images for input into MAPS. Our group has therefore been incorporating S<sup>3</sup> simulations as part of the development of a streamlined pathway for performing virtual observations of the radio sky (Fig. 2).

### References

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### Acknowledgments

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