

# Simulations of Array Configurations for the Square Kilometre Array (SKA)

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**Abstract** The Square Kilometre Array (SKA) is a new generation radio telescope for the next decades, working at metre to centimetre wavelengths. The SKA will be operational at the same time than other new optical, X-ray and Gamma-ray telescopes. It is of extreme importance that the SKA becomes competitive and complementary to those instruments. An extensive study of technologies and possible configurations involved is needed to ensure the SKA will reach the design specifications. To compare imaging capabilities between different SKA configurations or between the SKA and other instruments, we have implemented figures of merit based on several characteristics of these instruments. In this work we are presenting some results of numerical tests based on the Spatial Dynamic Range (SDR), which quantifies the range of spatial scales than can be reconstructed from interferometric data ([4]).

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## 1 Square Kilometre Array (SKA)

The Square Kilometre Array (SKA hereafter) is an instrument in design phase, called upon to revolutionise upcoming observations in a wide range of radio frequencies (between 100 MHz and 25 GHz). With a total collecting area of around a square kilometre, SKA is expected to improve the best sensitivity reached with present instruments in a factor of fifty, allowing astronomers to *see* weaker signals, from fainter or more distant sources. In order to build this huge collecting area and reach the requirements for the key science projects, different international teams are developing prototypes and new technologies that should converge in the final SKA configuration.

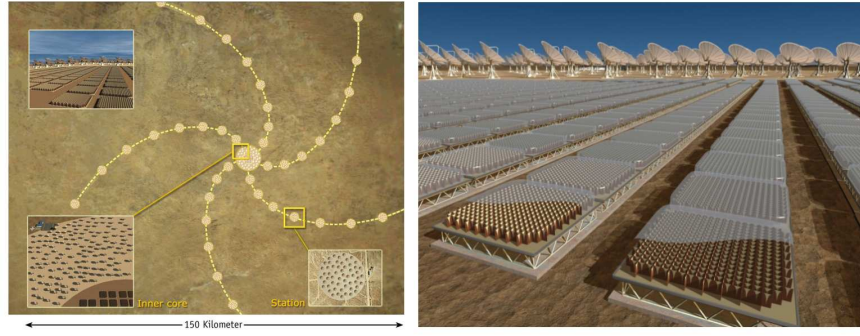
SKA construction is expected to start in 2012, with first science being produced in 2014. First phase (around 15 % to 20 % of total construction) will not be completed before 2016.

### 1.1 *Huge collecting area*

Increasing the collecting area of a telescope means to reach better sensitivity, but... how do we arrange a surface of one million square metres in order to optimise the performance? The SKA will be distributed in many stations (tens or a hundred), each of them having a diameter around one or two hundred metres. Using the aperture synthesis technique, a surface equivalent to a telescope of a few thousand kilometres of diameter is obtained. Approximately 50 % of the collecting area will be comprised in a central core of 5 kilometres, providing a great sensitivity for resolutions of one arc second. Around 25 % could be distributed in a diameter of 150 kilometres from the centre, and the rest be placed further, up to distances of thousands of kilometres. An scheme of the inner part of this distribution is shown in figure 1. Nevertheless, these figures are provisional, as they could be modified in the next years to provide better sensitivity (stronger core) or better resolution (longer maximum baselines).

### 1.2 *Location*

A very detailed study has been performed in order to decide the most suitable place for constructing this huge instrument. Besides an enormous available land surface, we need to find a place with low level of electromagnetic interferences in the SKA frequency range. It should be of great interest to count with good technological capabilities, accessibility, political stability and a strong astronomical community. In September, 2006, two different locations were short-listed among the candidates, and the SKA will be constructed either in Australia or in South Africa ([6]), decision that should be taken by the end of 2010.



**Fig. 1** The SKA will be distributed in many stations around an inner core, generating a huge equivalent surface using the aperture synthesis technique. Stations around the inner core (left) and detail of one of them (right) are shown in the figure [7].

### 1.3 Key Science Projects

In the previous sections, specifications and requirements for the construction of the SKA have been mentioned. Here we introduce the *key science projects* responsible for the design constraints:

- The origin and evolution of cosmic magnetism.
- Strong field tests of gravity using pulsars and BHs.
- The evolution of galaxies and large scale structures.
- Probing the dark ages.
- The cradle of life.

For further information, please consult [1].

### 1.4 SKADS

SKADS (Square Kilometre Array Design Studies) is a European Community funded international programme created for investigating and developing new technologies, components, architectures and algorithms for the SKA. SKADS is organised under eight main blocks, named Design Studies (DS), each of them divided in different Tasks ([5]). The work presented here has been developed for the DS2-T2, "Astrophysical Data Simulations".

### 1.5 Imaging with the SKA

The SKA is a new generation radio telescope for the next decades, working at metre to centimetre wavelengths. The SKA will be operational at the same time than other new optical, X-ray and Gamma-ray telescopes. It is of extreme importance that the SKA becomes competitive and complementary to those instruments. An extensive study of technologies and possible configurations involved is needed to ensure the SKA will reach the design specifications. To compare imaging capabilities between different instruments, we have implemented figures of merit (measurements of the performance of a given device) based on several characteristics offered by the instruments. Here we present our results of numerical tests based on the Spatial Dynamic Range (SDR); this magnitude accounts for the range of spatial scales than can be reconstructed from interferometric data ([4]). The SDR of an interferometer depends on the integration time of the correlator, the channel bandwidth and the coverage of the Fourier domain. For a real observation, the SDR will be limited by the most restrictive of the factors listed above. As the last one (Fourier domain coverage) is the most bound to the actual distribution of the telescopes in the SKA design, we can consider it as the limiting factor of the SDR ([2, 3]).

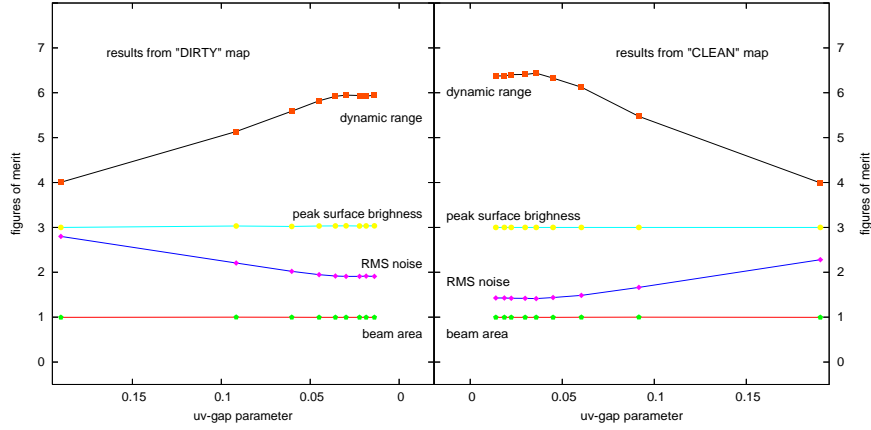
## 2 SDR: Simulations

As we stated before, we are considering the SDR only affected by the coverage of the Fourier domain, that is, the  $(u,v)$ -plane coverage. To understand the behaviour of the figures of merit as a function of this parameter, we perform some simulations ([3]) for different array distributions. For simplicity, we consider a single equiangular spiral arm pattern, with a constant value for the longest baseline length and with a variable number of stations populating it (from 50 to 640 stations). For each simulated data set, we generate clean and dirty maps (figure 2).

In the figure, we can see the dependence of some values of interest with the  $(u,v)$ -gap parameter ( $\Delta u/u$ , a measure of our coverage). It is worth to notice that the performance of our instrument is (almost) independent of the  $(u,v)$ -gap parameter for values smaller than 0.03. Therefore, we should demand our design to ensure a  $\Delta u/u \leq 0.03$  over the entire range of the Fourier domain, so that the selection of the number and position of individual elements is not the limiting factor for the Spatial Dynamic Range.

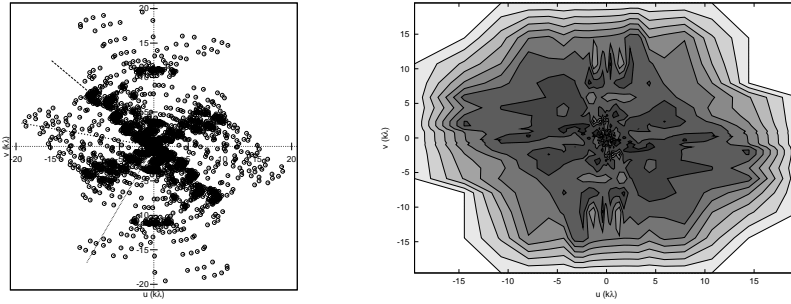
### 2.1 SDR determination

In this section, we show the results obtained for a given array distribution. In figure 3 (left), the  $(u,v)$ -plane coverage for this example is presented. Dashed lines

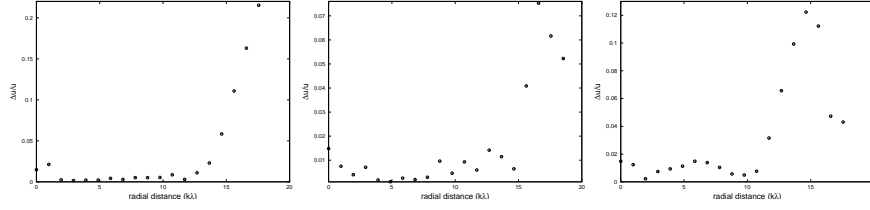


**Fig. 2** Figures of merit as a function of the  $(u,v)$ -gap parameter. Considering a single equiangular spiral arm pattern, with a constant value for the longest baseline length and with a variable number of stations, we obtain dirty (left) and clean (right) maps.

represent constant angle paths, where profile plots have been calculated (see figure 4). In figure 3 (right), we show the interpolated contour plot for  $\Delta u/u$ . For the outer region (where no information about visibilities is available) a value of one has been assigned. For the inner regions (between the core and the nearest visibilities) an interpolated value has been deduced. In those two figures, we find  $\Delta u/u$  values below our limiting 0.03, but, as we move away from the core (distances longer than 10 to 15  $k\lambda$ ), the coverage deteriorates. Further explanation of the procedure and in depth results can be found in [3].



**Fig. 3** *Left:*  $(u,v)$ -plane coverage used for our analysis. Dashed lines represent constant angle paths for profile calculations. *Right:* contour plot for the calculated  $(u,v)$ -gap parameter. For the outer region, a value of one has been assigned, whereas for the inner regions an interpolated value has been deduced. See text.



**Fig. 4**  $\Delta u/u$  profile plots for the angles shown on figure 3: 140 deg. (left), 170 deg. (middle) and 240 deg. (right). We find some values below 0.03, but the coverage deteriorates as we move away from the core.

### 3 Summary

We have developed a procedure for analysing any arbitrary array distribution in order to get the associated  $(u, v)$ -plane coverage behaviour. The result of our simulations is that the Fourier plane filling factor,  $\Delta u/u$  should be  $\leq 0.03$  over the entire range of  $(u, v)$ -plane coverage. This way, it will not be a limiting factor for the Spatial Dynamic Range obtained in the image plane by the SKA.

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### References

1. Carilli, S., Rawlings, S. (eds), *Science with the Square Kilometre Array*, New Astronomy Reviews, Vol 48, Elsevier (2004).
2. Jiménez-Monferrer, S., *Simulaciones de configuración del Square Kilometre Array (SKA)*. Tesis de Máster, Universidad de Valencia (2008).
3. Lal, D.V., Lobanov, A.P. and Jiménez-Monferrer, S., *Array configuration studies for the Square Kilometre Array - Implementation of figures of merit based on SDR*. SKA memo (in preparation).
4. Lobanov, A.P., *Imaging with the SKA: Comparison to other future major instruments*. SKA memo 38 (2003).
5. Perini, F., Bianchi, G., Monari, J., Montebugnoli, S. and Schiaffino, M., *SKADS*. PoS (MCCT-SKADS) 008 (2007).
6. *Australia and South Africa short-listed for giant radio telescope*, Jodrell Bank Observatory, The University of Manchester (2006).  
<http://www.jodrellbank.manchester.ac.uk/news/2006/skasite/>
7. *SKA - Square Kilometre Array*.  
<http://www.skatelescope.org>