Outline of a MeerKAT configuration

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MeerKAT will consist of 80 dishes of 12 m diameter. Each antenna will be equipped with a dual-polarisation single-pixel receiver with a desired $T_{sys} = 30$ K.

In general, an array configuration can be chosen in two possible ways. The first option is to choose a desired resolution, and then optimize the antenna distribution for that resolution. This will result in an optimum sensitivity for the chosen resolution, and if the array has a Gaussian distribution, the need for deconvolution is minimised. The fixed resolution can however limit the types of science that can be done with the instrument.

The second option is to optimize the array for a range of resolutions. This will greatly increase the scientific breadth of the telescope. The disadvantage is that data processing is not “simple” anymore: some kind of weighting, tapering and deconvolution may have to be used to provide useable data. The sensitivity of the array at a certain resolution will also be less than that of an array fully optimized for that resolution.

In this document we explore the second option: the “straw-man” design of MeerKAT that has been used for the past few years, has always included a compact core, containing the majority of the dishes, combined with a smaller number of long baselines out to about 8 km. The core provides the short baselines and better column density sensitivity required for neutral hydrogen (HI) studies, pulsars and transients. The longer baselines give the resolution required for continuum studies and in-depth HI studies.

Here we make a first attempt at identifying an array configuration that can provide the range of resolutions required, at sensitivities close to that of an array optimised for any single resolution. The work shown here is based on more extensive evaluations performed by Masters student Bradly Frank at UCT. A full presentation of these results is beyond the scope of this short document. Note that this discussion does not take into account the possibility of creating longer baselines by placing telescopes along the road between the MeerKAT site and the Klerefontein support base. Addition of these telescopes would allow the possibility of very high resolution continuum studies, but will likely not affect the HI or pulsar science.

Our main goal here is to find an array design that has a good performance from resolutions of $\sim 6''$ (as determined by the maximum 8 km baseline) down to $\sim 100''$. This does not preclude observing at even lower resolutions, however, given that the Arecibo HI beam measures $\sim 210''$ we decided not to optimize for resolutions lower than $\sim$ 100”. Arecibo will always be superior in its resolution niche due to the large collecting area.

A multi-resolution array as proposed here has no “clean” intrinsic beam, and some kind of tapering or weighting of the *uv* data has to be used to “tune” the resolution of the array. We use the AntConfigServer program developed by Mattieu de Villiers to evaluate the effect of the tapering/weighting on sensitivity as a function of resolution. We aim to identify an array design that has a constant point source sensitivity over the desired resolution range. After much experimentation, it was found that the following configuration provided a good starting point:

(i) a central core, containing 70% of the antennas, distributed as a two-dimensional Gaussian with a dispersion between 300 and 400m. The effective maximum baseline of this component is ~ 1 km;

(ii) an extended outer component, also distributed as a Gaussian, with a dispersion of 2.5 km. The effective maximum baseline of this component is ~ 8 km.

The performance of this array is relatively sensitive to the ratio of the number of antennas in each component: a 50/50 or a 60/40 distribution gives substantially different results. The 70/30 configuration was found to give the best starting point for our goal of a constant point source sensitivity as a function of resolution. This particular ratio of Gaussian dispersions and number of antennas in each component gives a smooth transition between the high and low resolution regimes, and minimises the effect of the array having two "optimum" resolutions (as defined by the two components), with inferior sensitivity at intermediate resolutions.

Evaluation of this array showed that the performance for the shortest baselines could be improved somewhat by "pinching" the array slightly: for each antenna we worked out the distance d to the center of the array, and scaled that distance by $(d/d_{max})^{\gamma}$, where γ has a value of 0.2 and d_{max} is the distance of the outermost antenna to the center of the array. This has the effect of moving all antennas inwards by a small amount, with the inner antennas moving further inward than the outer ones. Finally, we moved 6 antennas by hand in order to create a number of very short baselines which tend to be somewhat under-represented in the Gaussian array components. This further enhanced the sensitivity to low column densities.

Figure 1 shows the layout of the resulting array. Note that this merely shows a sketch of the individual antenna placements. Further studies taking into account geographical features and cable paths will still need to be made.

Figure 2 shows the integrated baseline distribution for an 8 hour observation towards a declination of −70 degrees. This choice of declination may not be optimal, and work is underway to characterize the properties of this particular array for other declinations and observing times, but experience from evaluation other, similar arrays suggests that results will not change significantly, though this obviously needs to be quantified.

Figure 3 shows the resulting 1σ point source sensitivity ΔS of such an array, derived assuming an 8 hour observation (from -4^h to 4^h hour angle) at 21-cm, using a 5 km/s (23 kHz) channel width. Note that these are all theoretical sensitivities, derived from antenna equations etc., they do not take into account things like antenna efficiencies, correlator efficiencies, continuum subtraction, calibration errors etc.

The horizontal axis shows the resolution on a logarithmic scale. This is the resolution towards which the multi-resolution array data is being weighted/tapered. The vertical axis shows the resulting noise per channel in mJy per beam. The AntConfigServer program was used to evaluate the sensitivies with respect to the natural sensitivity of a fully optimized single resolution array. The latter is shown as a horizontal dotted line. Note that this dotted line should not be interpreted as a line, but a series of points: once we have chosen a fixed resolution, we can only build one optimized fixed resolution array involving all 80 dishes. The vertical dashed line shows the maximum resolution theoretically possible with an 8km baseline.

The full and dashed thick black curves show the performance of two MeerKAT designs. The full curve corresponds to the one shown in Fig. 1 with a 300m dispersion inner core, the dashed one shows results for a similar array but with a 400m dispersion core. (For completeness, note that both of these arrays have been pinched and that 5-7 antennas were moved by hand to enhance short baseline sensitivity). These curves show that if we observe for 8h with the proposed design at 5 km/s and weight the data towards a resolution of e.g. $60''$, we expect to find a noise of ~ 0.35 mJy. Similarly, we can weight the same data set to a resolution of $8''$ and find a noise of ~ 0.4 mJy. Scaling to other other observing times and channelwidths goes as $\Delta S \propto 1/\sqrt{\Delta t\, \Delta\nu}$. Shown as the gray stars are the sensitivities of the individual VLA arrays at their intrinsic resolutions, again assuming an 8 hour observation and 5 km/s velocity resolution. The gray filled squares show the same for the various ATCA configurations. The VLA configurations have reasonable sensitivities over a wider range than just their intrinsic resolutions, this has however not been shown to avoid cluttering the plot.

Figure 4 shows a similar evaluation, but concentrating on the HI column density sensitivity. As column density sensitivity $\Delta\sigma$ changes as $\Delta\sigma \propto \Delta S \Delta\nu$, the values in Fig 4 can be scaled to other times/channel widths as $\propto \sqrt{\Delta\nu}/\sqrt{\Delta t}$.

These results show that an array configurations with a constant point source sensitivity over a large range in resolutions is achievable, with only a mild cost in sensitivity. It is hoped this configuration document can help the decision making process towards a final configuration.

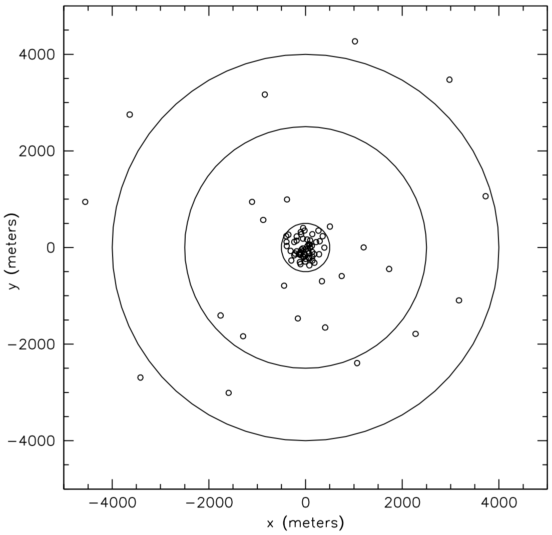

Fig. 1.— Array layout. Circles are 1 km, 5km and 8 km in diameter.

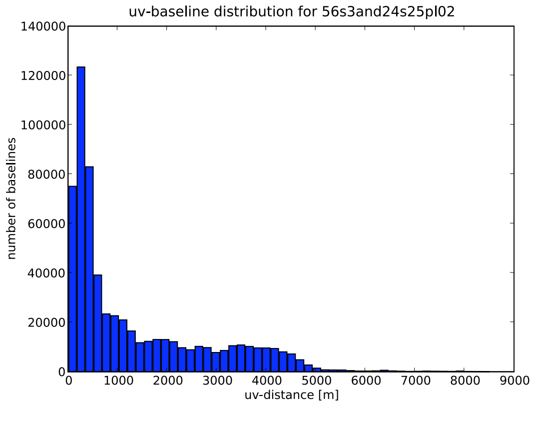

Fig. 2.— Cumulative baseline distribution for an 8hr observation towards −70 degrees declination.

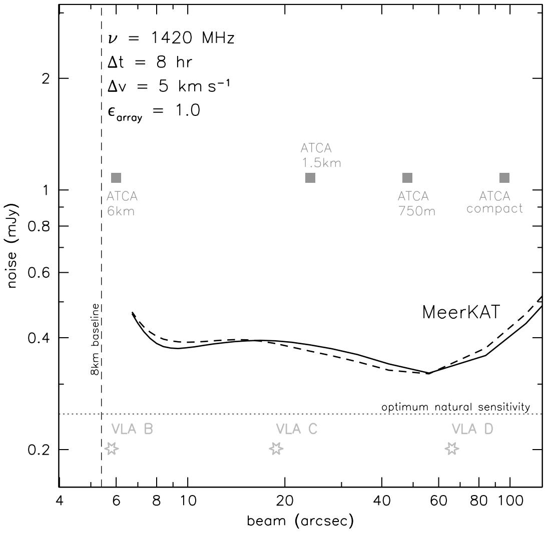

Fig. 3.— Point source sensitivity. For explanation see text.

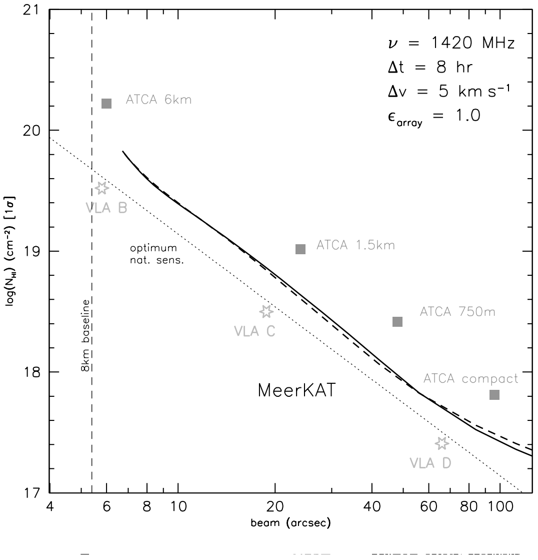

Fig. 4.— HI column density sensitivity. For explanation see text.