The outer six antennas and the WALLABY and EMU survey times for a 30 PAF ASKAP array

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Summary

Working on the assumption that ASKAP will consist of 30 antennas equipped with Mk2 PAFs, some discussion is now underway as to which of the 36 antennas should form the array. The effects of visibility weighting *must* be taken into account in order to perform an assessment of a configuration as EMU is wholly dependent on this being efficient. I present a method for assessing the effects of weighting for any given configuration, the outputs of which are an estimation of the increase in survey time for EMU and WALLABY over that of the ASKAP-36 case.

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1. Introduction

I present here some calculations related to the execution times for the EMU and WALLABY surveys under the assumption that they will be carried out with 30 ASKAP antennas equipped with Mk2 Phased Array Feeds and not the 36 antenna array for which the surveys were designed. The core-dominated layout of the array means that EMU relies on significant weighting of the visibilities in order to overcome the classical confusion limit. Achieving the angular resolution required to do this comes at the cost of reduced sensitivity, and this trade off is coupled somewhat strongly to the density of points in the *uv* plane via the array layout. Reducing baselines in the outer part of the *uv* plane requires a more aggressive tapering scheme to achieve a given resolution, reducing the sensitivity contribution from the core baselines and translating to an increase in observing time. WALLABY has somewhat orthogonal requirements: it is assumed that baselines longer than 2 km cannot be processed by the real time system, and natural weighting may be employed. Increasing the number of baselines that satisfy this requirement provides a corresponding linear decrease in the time it takes to execute WALLABY, and there is no penalty due to imaging weights.

2. Method

The calculations that follow are based on Equation 6.62. from *Interferometry & Synthesis in Radio Astronomy* (2nd Ed., Thompson, Moran & Swenson, 2004):

$$S_{rms} = \frac{2k_B T_{sys}}{A\eta_Q\sqrt{n_a(n_a-1)}\Delta\nu T}\frac{w_{rms}}{w_{mean}} \tag{1}$$

where S_{rms} is the rms noise level, k_B is Boltzmann's constant, T_{sys} is the system temperature, A is the effective area of one of the receptors, η_Q is the correlator quantisation efficiency, n_a is the number of antennas in the array, $\Delta\nu$ is the bandwidth and T is the total observing time. The w_{rms} and w_{mean} are respectively the rms and mean of the weights w_i determined for each visibility point, defined as:

$$w_{mean} = \frac{1}{n_d}\sum w_i \tag{2}$$

and

$$w_{rms}^2 = \frac{1}{n_d}\sum w_i^2 \tag{3}$$

where n_d is the number of visibility measurements.

Recasting this in terms of a fractional increase in survey time between ASKAP-30 (subscript 1) and ASKAP-36 (subscript 2) where both observations reach equal depth means that no assumptions have to be made about most of the parameters in the equation above:

$$\frac{T_1}{T_2} = \frac{W_1^2}{W_2^2}\frac{N_2}{N_1} \tag{4}$$

The parameter N is the number of baselines, expressed in Equation 1 as $n_a(n_a-1)$. For WALLABY the ratio of N_2/N_1 in Equation 4 is the ratio of the number of baselines <2 km in length for ASKAP-36 to the corresponding number for the array under consideration. For EMU the value of N_2/N_1 is always (36*35)/(30*29) = 1.4047. W is defined as w_{rms} / w_{mean} and is equal to 1 for calculations involving WALLABY due to the assumed use of natural weighting of the visibilities.

The key assumption for EMU is that it becomes viable when the synthesised point spread function of the array achieves an effective angular size of 10". Naturally weighting the visibilities results in images that never meet this criterion, so for an array configuration under consideration the weighting scheme is adjusted from natural until the resulting PSF is viable, and then adjusted no further in order to achieve the maximum sensitivity[1]. At this point the minimum value of W is determined and the corresponding increase in survey time over the ASKAP-36 case can be calculated via Equation 4.

[1]The weighting scheme also has significant effects on the PSF side lobe levels, which have consequences for imaging quality (e.g. reliable deconvolution, side lobe confusion levels), and are worthy of investigation. This article focuses solely on the survey time metric.

The simplest way to measure the minimum-W value for a given configuration is to simulate a Measurement Set, apply a range of robust weighting parameters and then compute w_{rms} and w_{mean} from the list of image weights determined by the imager. This can then be compared to the resulting PSF size. A subtlety here is that unlike natural weighting there is no characteristic resolution for a tapered data set. The assigned weights depend on the size of the grid cells in the uv plane which most imagers typically set via an inversion of the extent of the image[2]. The simplest way to ensure the effects of weighting are captured in a realistic way is simply to make an ASKAP-sized image, thus for a given configuration under test I have used `CASA` to create simulated Measurement Sets of eight hours duration, containing 304 $\times$ 1 MHz channels from 1100 to 1404 MHz. These visibility sets are gridded using multifrequency synthesis and inverted into single 4096 $\times$ 4096 pixel images at 2" per pixel. Robust parameters of -2 to 2 in ten intervals are used, with 2 being equivalent to natural weighting[3].

The N_2/N_1 ratio for the case of WALLABY is also determined from the simulated Measurement Sets by determining the number of projected baselines that are less than 2 km in length for both the ASKAP-36 case and the case of the test configuration. I do not know whether the real time spectral line calibration pipeline will impose cut in uv distance or select data based on the exclusion of outer antennas, but the the results for WALLABY change by a few percent depending on which of these cases is assumed true, with the formed case (employed here) being more favourable.

3. Results

After generating an ASKAP-36 simulation as a reference point, I perform six other simulations, starting with the "3-BETA" configuration[4]. This has all six of the outermost antennas in place, so from there I simulate cases where five of these six antennas are brought into the core one by one. The antennas used are as follows:

$N_o = 6$: 1 2 3 4 5 6 7 10 12 13 14 16 17 19 20 21 22 23 24 25 26 27 28 30 31 32 33 34 35 36
$N_o = 5$: 1 2 3 4 5 6 7 10 12 13 14 16 17 18 19 20 21 22 23 24 25 26 27 28 30 31 32 33 34 36
$N_o = 4$: 1 2 3 4 5 6 7 10 12 13 14 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 32 33 34 36
$N_o = 3$: 1 2 3 4 5 6 7 10 11 12 13 14 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 32 34 36
$N_o = 2$: 1 2 3 4 5 6 7 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 32 36
$N_o = 1$: 1 2 3 4 5 6 7 8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 36

For each of these configurations I determine the minimum W that meets the resolution requirement for EMU and the number of baselines <2 km in order to adjust the WALLABY survey time, and evaluate Equation 4 in order to determine the increase in observing time. Figure 1 shows the result of this process. The estimated survey time increases are provided on each panel, with further details in the caption. Note that in the case of $N_o = 1$ the increase in observing time for EMU is not applicable as it corresponds to that derived from the minimum robust parameter. In practice, without the long baseline afforded by a minimum of two outer antennas the angular resolution requirements of EMU are never met. The test case presented here is for a source at Dec = -30°.

[2] `lwimager` and the `CASA imtoolkit` do have parameters to control this manually however in the case of the latter it is not exposed to the user via the `clean` task.

[3] Note that in recent versions of `CASA` the `IMAGING_WEIGHT` column of the Measurement Set is not retained after imaging, likely motivated by data volume considerations. The `clean` task could probably be modified to undo this change, but if you want to run these scripts it's simpler to just use an older version of `CASA`. `casapy-30.1.11097-001-64b` fits the bill.

[4] From M. Whiting's presentation here: `https://pm.atnf.csiro.au/askap/projects/sup/wiki/Wiki_sup_forum_meet_1`

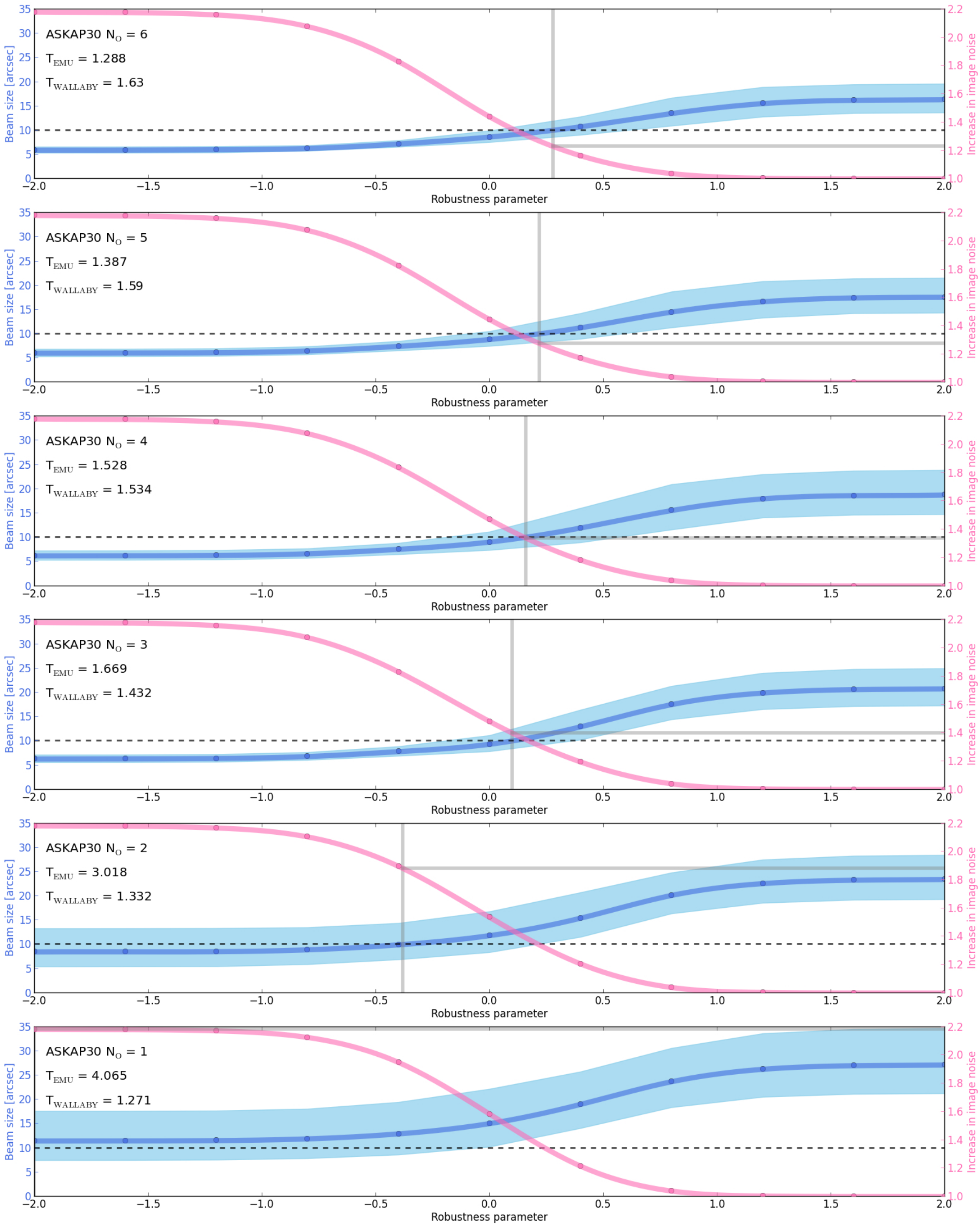

Figure 1: Results of the simulation for a Dec -30° observation using the configurations listed in Section 3. The blue region follows an envelope defined by the major and minor axes of the fitted PSF as a function of weighting, expressed as the robustness parameter. The dark blue line shows the extent of a circular restoring beam of equivalent area. The dashed horizontal line shows represents 10". As the weighting taper increases (right to left) the angular resolution increases, however the sensitivity drops (as W increases, Equations 1 and 4) as shown by the pink curve and the second y-axis. EMU becomes viable when the solid blue line crosses the dashed line, as marked by the vertical grey line. At this point the minimum-W value is reached and the effect on survey time can be calculated. The fractional increase over the ASKAP-36 survey time is provided on the plot for both EMU and WALLABY, as per Section 2.

A. Some point spread function metrics

A natural by-product of this work are images of the point spread function (PSF, a.k.a. the synthesised or dirty beam) as a function of robust parameter for the array layouts under consideration. Figure 2 in this appendix contains some metrics derived from these images, specifically the absolute value of the minimum of the PSF (a proxy for peak side lobe level) and the RMS of the PSF excluding the main lobe (relevant for side lobe confusion noise calculations). I include these here in the hope that they may prove useful pending a full analysis. The points on Figure 2 show the values measured from the PSF images and the solid lines are univariate spline curve fits to these measurements. The vertical lines correspond to the robustness parameter where the resolution requirements of EMU are met for a given array configuration.

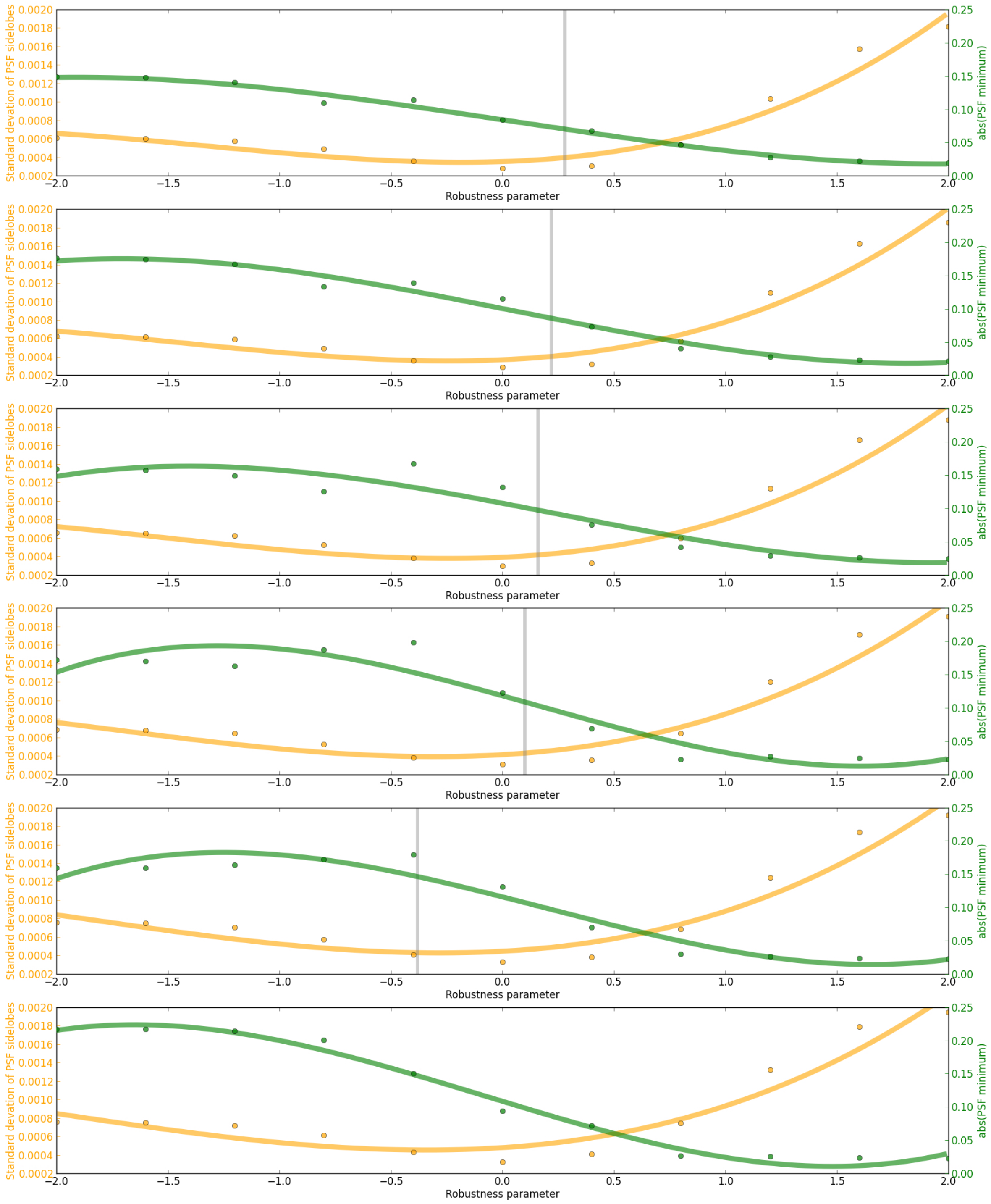

Figure 2: The absolute value of the minimum of the PSF image (green) and the RMS of the PSF image excluding the main lobe (yellow) as a function of robustness parameter for each of the array configurations considered in this document. The peak of the PSF is normalised to 1.