ASKAP-30 configuration study (v3. 31 Aug 2015)

Our Brief

The currently funded 30 ASKAP antennas equipped with MkII PAFs is significantly different to the 36 originally proposed so there is a need to decide on a 30 element configuration that balances the impact on the key SSPs (EMU and WALLABY) while maximising the science that can be delivered. CSIRO has established a small working group with representation from both key projects to address the various issues, identify the key criteria and recommend a baseline 30-antenna configuration to present to all the SST's, and to the broader community, for comment.

Background

The HI galaxy survey (WALLABY) and the continuum survey (EMU) have very different configuration requirements. WALLABY is brightness sensitivity limited and processing limitations restrict it to spacings < 2km. EMU is sensitivity limited and requires the longer spacings to avoid classical confusion and to obtain sufficient positional accuracy for identifications. The full ASKAP-36 array is a hybrid of two configurations optimised for each survey: i) with 30 antennas in a high brightness sensitivity 2km core array and ii) with 6 antennas in an outer Reuleaux triangle to provide a higher angular resolution 6km array. The 36 element ASKAP configuration has been highly optimised for these two proposals so the reduction in the total number of antennas equipped with MkII PAFs will have a disproportionately large impact.

Study

The two key Survey Science Projects (EMU and WALLABY) have conflicting requirements so we explored the science impacts of the configuration trade-offs. We were not trying to compare the very different science cases but looking for a metric or methodology to compare the impact of the reduced number of MkII PAF equipped antennas on each project.

The comparison could not be based on a simple metric because the impact of reduced array elements is not symmetric. For WALLABY, loss of core antennas can be almost directly translated into a loss of sensitivity and hence a need for longer observing time, but the question is whether a scientifically viable project can still be done in the maximum time that can reasonably be made available. For EMU the loss of angular resolution would compromise the science in a way that could not be recovered by increased observing time.

Two documents provided to our working group by Tobias and Lister quantify the impact of the sensitivity loss for WALLABY. Figure 1 shows the expected number of galaxies detected in HI. The dashed red line is the original objective, which could be achieved with 8hrs per field (blue) and all 30 core antennas. But with only 24 cores antennas and T_{sys}/η =

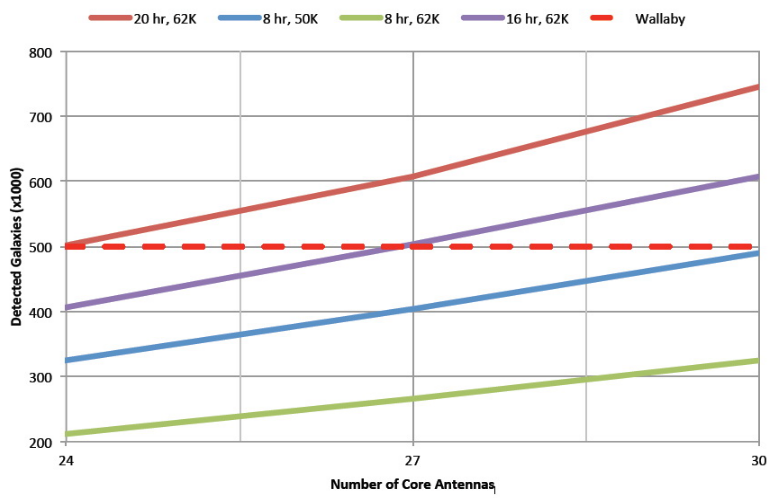

Figure 1

62K it's less than half this.For EMU the angular resolution is needed to avoid confusion and to measure radio source positions with adequate accuracy to make identifications with faint galaxies. It is impossible to achieve this higher resolution without re-weighting the visibilities so it's no longer possible to make a simple estimate of the reduced sensitivity. Ian Heywood's ASKAP Commissioning & Early Science memoranda #6 solves this rather complex problem by assuming that a 10" beam is required for a viable survey. He then modifies the weights (using the robustness parameter) for different numbers of outer antennas to find the most sensitive solution with a 10" beam in each case. Note that the 10" beam assumption requires at least two MkII PAFs in the outer array to get one 6km baseline. Josh Marvil continued these simulations using parameters which could be directly compared with the WALLABY simulations by Tobias Westmeier. These simulations only looked at sensitivity and not at beam quality which is a complex issue because it involves loss of beam circularity, higher sidelobes, actual observing time (eg 8 or 12 hours), and is declination dependant. Realistic continuum simulations using multi-frequency synthesis take about a day per case so thorough exploration of this space is impractical. Higher sidelobes will also introduce a sidelobe confusion term but this has not been analysed.

The assumption of an absolute requirement for 10" resolution in the continuum is key to this analysis so also needs to be examined. Jim Condon's 2008 ASKAP Science Case Memoranda #15 provides an excellent analysis of the effect of classical confusion for ASKAP continuum surveys and recommends 10" resolution as a compromise between the confusion limit and survey incompleteness due to the resolution of extended sources. Note that confusion is not a Gaussian distributed error so can't be simply added quadratically to the rms noise. The probability of a 5 sigma confusion error greatly exceeds the probability of a 5 sigma noise error.

The effect of resolution on the rms confusion level can be examined in more detail by taking Condon's equation 3, assuming all sources >5σ have been subtracted (q = 5), and using the Condon (2007) faint source counts. This is plotted in Figure 2. The 10" rms confusion of 5 μJy / beam is half the expected rms noise for EMU and this is already uncomfortably high. At 14" resolution the survey would be dominated by classical confusion. We looked at the effect of only having 12" resolution but the small increase in sensitivity did not offset the effects of the higher confusion level.

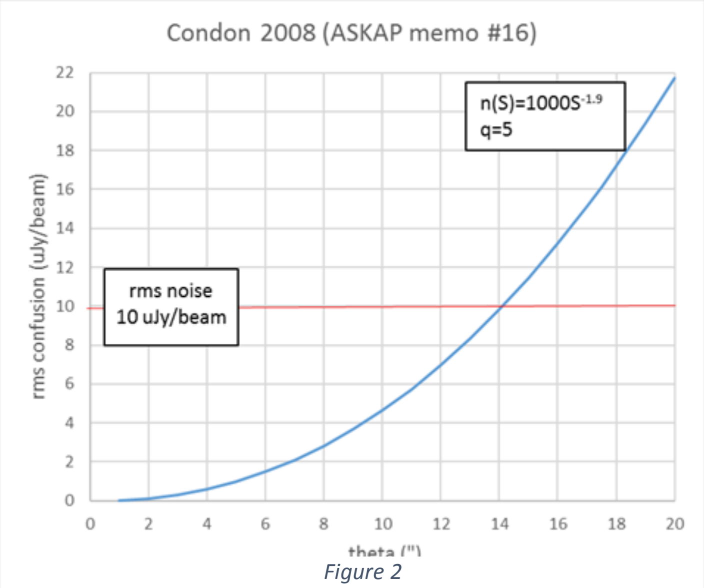

Figure 2

Simulations

Both Josh Marvil & Tobias Westmeier have been simulating the impact of varying the number of antennas in the outer array. For a 30 element array this can be varied from 0 to 6. The following table summarises these simulations. For comparison both surveys have the same (8h) observation time and HA coverage per observation. The EMU times are simulated assuming a 10" beam is required using the optimal robust weighting as outlined in the Heywood memo. WALLABY time estimates assume a 2km natural weighted core array and that the outer antennas do not contribute.

The times given are relative to the full 36-element array assuming the same values for T_{sys}/η for both EMU and WALLABY. For WALLABY the sensitivity with n=0 is the same as for the full ASKAP-36 but for EMU all elements are always used but with varying weights. Note that the currently measured T_{sys}/η values are significantly worse that those assumed in the original proposals so total times may be even longer but this has been excluded from this analysis since it has the same impact on both projects.

Sensitivity and beam quality simulations are complex with dependencies on declination, HA coverage, weighting, FoV, sample dump time, software limitations etc. The Table includes the amplitude of the first negative sidelobe in a high-resolution image (from the Heywood memo) which is a proxy for the sidelobe level. Obviously missing antennas due to downtime or maintenance will impact these results.

Relative Observing Time v number of elements in the outer array

Number of outer antennas with PAFs	Time factor WALLABY Natural weighting	Time factor EMU 10" resolution	Peak sidelobe (%)
6	1.56	1.25	7
5	1.44	1.35	8
4	1.33	1.48	10
3	1.23	≈1.7	12
2	1.15	≈3.0	14
1	1.07	∞	
0	1.00	∞	

We then used the DINGO input (June 2015 memo), which provides simulations of 3 possible 2-km core solutions. Although their preferred "optimised" solution had the best brightness sensitivity at 20" it did not include antenna #1 and so removes half of the antennas which have spacings < 64m. This will seriously impact our ability to combine Parkes and ASKAP data as well as losing information about large-scale structures. Both are especially critical for GASKAP and it has been agreed by all parties that this is unacceptable. However all parties have agreed that the "compromise" solution which omits antennas # 07, 11, 21, 29, 31, 35 is acceptable. This "compromise" solution also has a well-behaved PSF (as measured by the uv-gap parameter), still includes all the ASKAP-12 antennas, and has little affect the continuum optimisation.

Other factors

In reaching the "baseline configuration solution" described above a number of other critical factors emerged.

- Eventual completion the full 36 element ASKAP should remain the goal
- It will be possible to move the PAFs between antennas in future providing the frequency of such moves is not excessive. This option make it possible to further optimise configurations

for different experiments, and it avoids being locked into this baseline configuration as we gain experience with the array and are able to explore more detailed simulations.

- In some cases with a reconfigurable configuration pure commensality may not optimise science or even minimize the total observing time although we would still expect commensality to remain the norm.
- We do not yet have a definitive measurement of on dish T_{sys}/η for the MkII PAFs but we know that while the high frequency performance is greatly improved the average value of T_{sys}/η is now expected to be significantly worse than that initially used in the science cases. Since this has more impact on ASKAP science than the configuration compromises being discussed it is essential that R&D be continued to further optimise the PAF performance.
- We note that the outer 6 antennas will have high weight in any high angular resolution image so any improvement in T_{sys}/η for just these PAFs would result in a disproportionally large improvement in sensitivity. This suggests that any PAFs of a later design with superior performance needs to be compatible with the MkII PAFs in the rest of the array.
- These considerations are very sensitive to antenna down time and maintenance assumptions, which are not well understood at this time. The idea of equipping the array with "hot spares" is attractive.
- We assume that BETA antennas can be used since short spacings are essential and there will be no combined BETA and MkII modes.
- The currently imposed 2km spectral line processing limit should be revisited

Recommendations

The Table indicates comparable sensitivity loss with between 4 and 5 antennas in the outer array equipped with MkII PAFs. Given the greater flexibility of EMU to fine tune weighting and ultimate resolution, and the slightly better T_{sys}/η in the continuum band, we recommend that only 4 outer antennas (#32,33,34,36) be equipped with MkII PAFs. The choice of outer antennas is not flexible.

The choice of which 4 antennas to omit in the inner 2 km array is less critical. We recommend the DINGO and WALLABY "compromise" solution (June 2015 memo), which omits antennas 7, 11, 21, 29. This keeps all very short spacings, and also optimises brightness sensitivity for the 20" resolution preferred by DINGO without significantly compromising the other projects and it preserves the current ASKAP-12 configuration.

In summary the recommended ASKAP-30 configuration is all antennas except: #7, 11. 21, 29, 31, 35.

Community consultation

A presentation on the ASKAP 30 baseline **c**onfiguration recommendation was made to all the SSP leaders at the ASKAP Early Science Forum meeting in Sydney on 21 April 2015. Since then we have iterated through three options for the inner array until agreement was reached with representatives from all projects.

The following additional topics were discussed:

- A comparison of ASKAP30 HI survey speed with MeerKAT
- Consider the science impact of reduced survey area rather than increased survey time.
- Investigate the effect of poorer image quality on the survey science.
- ASKAPSoft has built in weighing restrictions that may have to be considered.
- Including sufficient very short spacings to combine Parkes and ASKAP data

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