WALLABY simulations of ASKAP–30 configurations

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Configurations considered

The following simulations were carried out to test the performance of the two most extreme possible ASKAP–30 configurations for 21-cm H I observations:

- **No BETA**: a configuration with all 6 outer antennas and none of the BETA antennas.
- **No 6 km**: a configuration with all BETA antennas and none of the 6 outer antennas.

In addition we looked at several configurations with varying number of **core antennas** to study the effect of shifting receivers from the core to the six outer positions. A key to all configurations can be found in Table 4 at the end of this document.

Simulations

All simulations were done in *Miriad* (using the task uvgen) assuming a declination of **−30°**, an integration time of **8 h** (hour angle coverage of ± 4 h), a frequency of **1420.4 MHz** and a bandwidth of **18.5 kHz**. All simulations assume the nominal $\boldsymbol{T_{\mathrm{sys}} / \eta = 62.5}$ **K**, i.e. for the purpose of this memo the effect of the array configuration on sensitivity and imaging performance is studied in isolation from the effects of lower receiver sensitivity or equipment downtime. **All sensitivities quoted should therefore only be compared relative to each other and not on an absolute scale.**

For each of the configurations studied we imposed a projected ***uv* cutoff** radius of 2 km and created images with five different **robustness** parameters:

- ±2, ±0.5 and 0

and with two different Gaussian **tapers**:

- no tapering and tapering to 30″ angular resolution.

Parameters

For each case we determined the **beam** size (b_{maj}, b_{min}, $b_{\mathrm{eff}} \equiv [b_{\mathrm{maj}} \times b_{\mathrm{min}}]^{1/2}$, b_{pa}), the maximum **sidelobe** levels (SL_{min}, SL_{max}, $SL_{\mathrm{ampl}} \equiv \max[|SL_{\mathrm{min}}|, SL_{\mathrm{max}}]$), the RMS **noise** level in mJy and K, the 5σ H I **column density** sensitivity across 20 km/s, and the relative **integration time** and **noise level** factor under the assumption that the same point source sensitivity is to be achieved as for a naturally weighted, untapered ASKAP–36 array at $T_{\mathrm{sys}} / \eta = 62.5$ K (applying the 2 km cutoff), irrespective of beam size. In the latter case we distinguish three different scenarios:

- $T_{\mathrm{sys}} / \eta = 62.5$ K
- $T_{\mathrm{sys}} / \eta = 90.0$ K
- $T_{\mathrm{sys}} / \eta = 90.0$ K + 10% antenna downtime (maintenance / equipment failure)

The results of all simulations are summarised in Table 1. In addition, Fig. 1–5 show graphical representations of some of the results, and Tables 2–3 display the beam image for some of the configurations.

Main conclusions

- An ASKAP–30 array with all 6 outer antennas utilised would result in an increase in integration time for WALLABY by a factor of **5–7** (assuming $T_{\mathrm{sys}} / \eta = 90$ K and 10% downtime) compared to an untapered, naturally weighted ASKAP–36 array (still applying the 2 km cutoff though) at the nominal $T_{sys}/\eta = 62.5$ K if the same point source sensitivity were to be achieved in both cases.

- These factors would decrease to somewhere in the range of **3–4** for an ASKAP–30 array without any of the outer antennas (i.e. all antennas in the 2-km core).
- A slightly positive robustness parameter of $\boldsymbol{R \approx 0.5}$ with additional Gaussian tapering to **30″** resolution appears to provide a good balance between high sensitivity and low sidelobe levels.
- Doubling of the integration time to **16 h** would compensate for the effects of reduction in the number of core antennas and expected downtime due to maintenance or equipment failure. This would still leave the increased T_{sys}/η to be dealt with, either by reducing the 3π sr **survey area** at WALLABY's nominal sensitivity or by accepting a reduced **sensitivity** across the full survey area. A detailed analysis of the impact of these two options on the science outcomes will be required before a decision can be made.

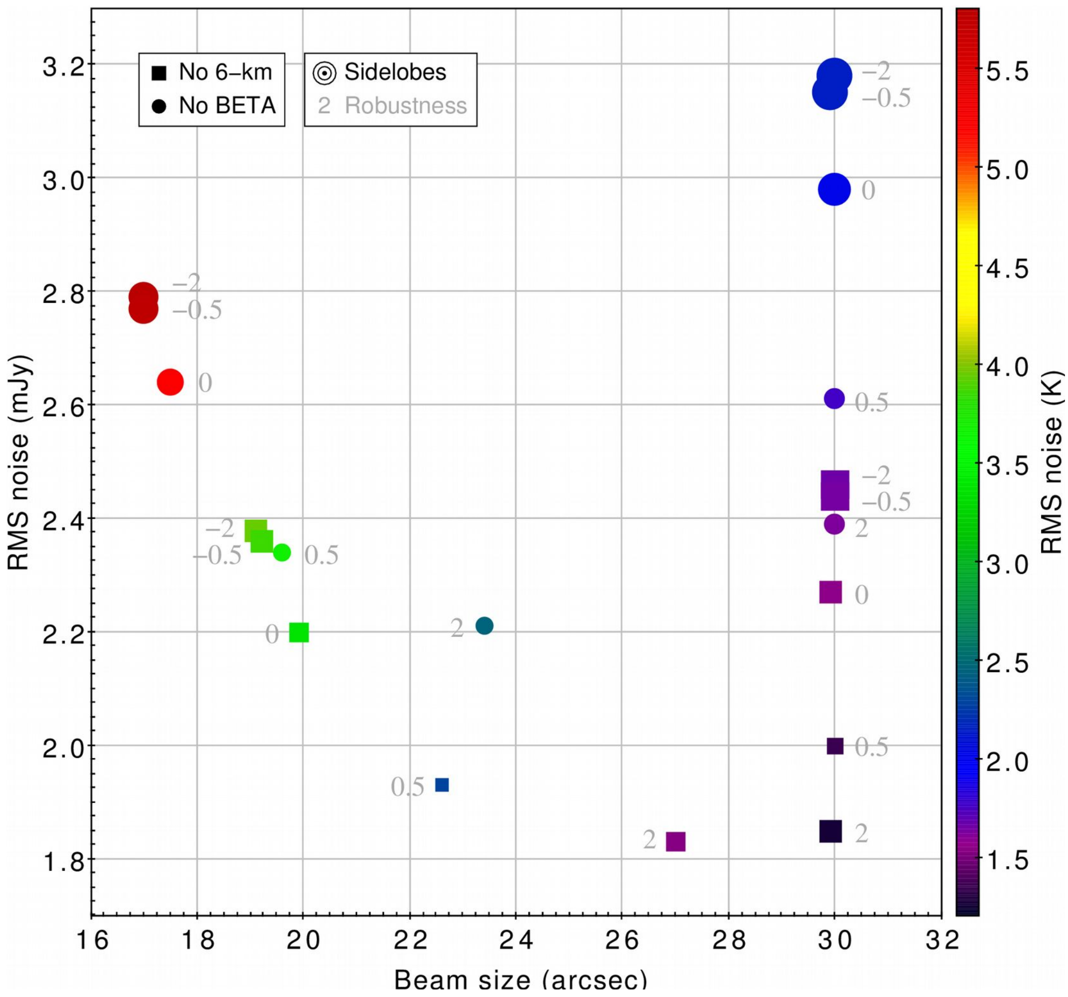


Figure 1: Plot of RMS noise level in mJy versus effective beam size, $(b_{max} \times b_{min})^{1/2}$, in arcsec for the two extreme ASKAP–30 simulations listed in Table 1 under the assumption of $T_{sys}/\eta = 62.5$ K. Untapered simulations are found across the lower-left half of the plot, while the data points near the right edge of the plot have been tapered to approximately 30″ resolution. Squares and circles indicate the "No 6 km" and "No BETA" configurations, respectively. The colour of the data points indicates surface brightness sensitivity in K, while the size of the markers correlates with maximum beam sidelobe amplitude. The grey numbers indicate the robustness parameter used in each case.

Table 1: Results of simulations of two ASKAP−30 simulations without BETA antennas ("No BETA") and without any outer antennas ("No 6 km") under the assumption of $T_{sys}/\eta = 62.5$ K. For each configuration we applied five different robustness parameters (−2, −0.5, 0, 0.5 and 2) and two different Gaussian tapers (untapered and tapered to 30″ resolution). A naturally weighted, untapered ASKAP−36 configuration ("ASKAP") is included as well and used as the reference in all flux and integration time comparisons. Lastly, we include five different ASKAP−30 configurations with increasing number of outer antennas. A key to all configurations can be found in Table 4 at the end of this document. All simulations assume only a single beam on the sky. H I column densities, N_{HI}. are 5σ values across $\Delta v = 20$ km/s. Relative integration times, Δt_{int}, were calculated for three cases: $T_{sys}/\eta = 62.5$ K, 90 K and 90 K + 10% antenna downtime. The same is true for relative rms noise factors, Δrms, with assumed integration times of 8 and 16 h. The colouration in the sidelobe, integration time and noise factor columns indicates low (blue), intermediate (green) and high (red and black) values.

Config.	Core ant.	δ_{J2000} (°)	Taper (")	Robustn.	b_{maj} (")	b_{min} (")	b_{eff} (")	b_{pa} (°)	SL_{min} (%)	SL_{max} (%)	SL_{ampl} (%)	rms (mJy)	rms (K)	N_{HI} (10^{20} cm^{-2}) 5σ 20 km/s	Δt_{int} T_{sys}/η 62.5	Δt_{int} T_{sys}/η 90	Δt_{int} T_{sys}/η 90 -10%	Δrms T_{sys}/η 62.5 8 h	Δrms T_{sys}/η 90 8 h	Δrms T_{sys}/η 90 -10%, 8 h	Δrms T_{sys}/η 90 -10%, 16 h
No BETA	24	-30	30.5	-2.0	31.7	28.4	30.0	11.0	-11.4	4.5	11.4	3.18	2.14	1.72	3.28	6.80	8.39	1.81	2.61	2.90	2.05
No BETA	24	-30	30.3	-0.5	31.6	28.4	29.9	11.3	-11.3	4.5	11.3	3.15	2.13	1.71	3.22	6.67	8.23	1.79	2.58	2.87	2.03
No BETA	24	-30	29.5	0.0	31.4	28.7	30.0	13.5	-10.4	4.5	10.4	2.98	2.01	1.62	2.90	6.00	7.41	1.70	2.45	2.72	1.93
No BETA	24	-30	25.5	0.5	30.6	29.4	30.0	35.0	-6.8	5.0	6.8	2.61	1.76	1.42	2.22	4.60	5.68	1.49	2.15	2.38	1.69
No BETA	24	-30	17.9	2.0	31.2	28.9	30.0	74.1	-3.4	6.8	6.8	2.39	1.61	1.29	1.85	3.85	4.75	1.36	1.96	2.18	1.54
No BETA	24	-30	0.0	-2.0	17.8	16.2	17.0	17.6	-9.2	3.9	9.2	2.79	5.85	4.72	2.52	5.23	6.46	1.59	2.29	2.54	1.80
No BETA	24	-30	0.0	-0.5	17.9	16.3	17.0	18.1	-9.1	3.9	9.1	2.77	5.77	4.65	2.49	5.16	6.37	1.58	2.27	2.52	1.78
No BETA	24	-30	0.0	0.0	18.2	16.9	17.5	22.7	-8.1	3.9	8.1	2.64	5.20	4.19	2.26	4.68	5.78	1.50	2.16	2.40	1.70
No BETA	24	-30	0.0	0.5	20.1	19.1	19.6	53.4	-5.5	4.3	5.5	2.34	3.68	2.97	1.78	3.68	4.55	1.33	1.92	2.13	1.51
No BETA	24	-30	0.0	2.0	24.5	22.3	23.4	75.7	-3.0	6.1	6.1	2.21	2.45	1.97	1.58	3.29	4.06	1.26	1.81	2.01	1.42
No 6 km	30	-30	28.7	-2.0	30.4	29.7	30.0	-11.6	-8.4	4.2	8.4	2.46	1.65	1.33	1.97	4.09	5.05	1.41	2.02	2.25	1.59
No 6 km	30	-30	28.5	-0.5	30.3	29.7	30.0	-13.3	-8.2	4.2	8.2	2.44	1.64	1.32	1.93	4.00	4.94	1.39	2.00	2.22	1.57
No 6 km	30	-30	27.0	0.0	30.0	29.7	29.9	-64.5	-7.1	4.3	7.1	2.27	1.54	1.24	1.67	3.47	4.29	1.29	1.86	2.07	1.46
No 6 km	30	-30	22.0	0.5	31.0	29.0	30.0	-88.1	-4.1	4.8	4.8	2.00	1.34	1.08	1.29	2.68	3.31	1.14	1.64	1.82	1.29
No 6 km	30	-30	12.0	2.0	31.8	28.1	29.9	-88.8	-2.5	6.4	6.4	1.85	1.25	1.01	1.12	2.31	2.86	1.06	1.52	1.69	1.20
No 6 km	30	-30	0.0	-2.0	19.8	18.5	19.1	-87.0	-6.3	2.9	6.3	2.38	3.94	3.18	1.85	3.83	4.73	1.36	1.96	2.17	1.54
No 6 km	30	-30	0.0	-0.5	20.0	18.5	19.2	-87.1	-6.2	2.9	6.2	2.36	3.86	3.11	1.81	3.75	4.63	1.34	1.94	2.15	1.52
No 6 km	30	-30	0.0	0.0	20.8	19.1	19.9	-87.6	-5.5	3.0	5.5	2.20	3.36	2.71	1.58	3.27	4.04	1.26	1.81	2.01	1.42
No 6 km	30	-30	0.0	0.5	24.0	21.3	22.6	-88.2	-3.4	3.8	3.8	1.93	2.29	1.84	1.21	2.50	3.09	1.10	1.58	1.76	1.24
No 6 km	30	-30	0.0	2.0	29.0	25.1	27.0	-88.5	-2.4	5.8	5.8	1.83	1.52	1.22	1.08	2.25	2.77	1.04	1.50	1.67	1.18
ASKAP	30	-30	0.0	2.0	27.6	24.6	26.0	-87.6	-2.3	5.4	5.4	1.75	1.57	1.26	1.00	2.07	2.56	1.00	1.44	1.60	1.13
3innOut	27	-30	22.5	0.5	31.0	28.9	29.9	73.3	-4.3	4.7	4.7	2.19	1.48	1.20	1.56	3.24	4.01	1.25	1.80	2.00	1.42
3outOut	27	-30	22.0	0.5	31.4	28.8	30.1	76.1	-4.2	4.7	4.7	2.21	1.48	1.20	1.59	3.30	4.08	1.26	1.82	2.02	1.43
4outer	26	-30	21.8	0.5	31.8	28.3	30.0	58.4	-4.1	4.9	4.9	2.27	1.52	1.23	1.67	3.46	4.27	1.29	1.86	2.07	1.46
5outer	25	-30	22.8	0.5	31.3	28.7	30.0	64.9	-4.6	5.2	5.2	2.37	1.60	1.29	1.83	3.79	4.67	1.35	1.95	2.16	1.53
Matt	24	-30	23.6	0.5	31.6	28.3	29.9	63.0	-5.4	5.9	5.9	2.53	1.71	1.38	2.08	4.30	5.31	1.44	2.07	2.31	1.63

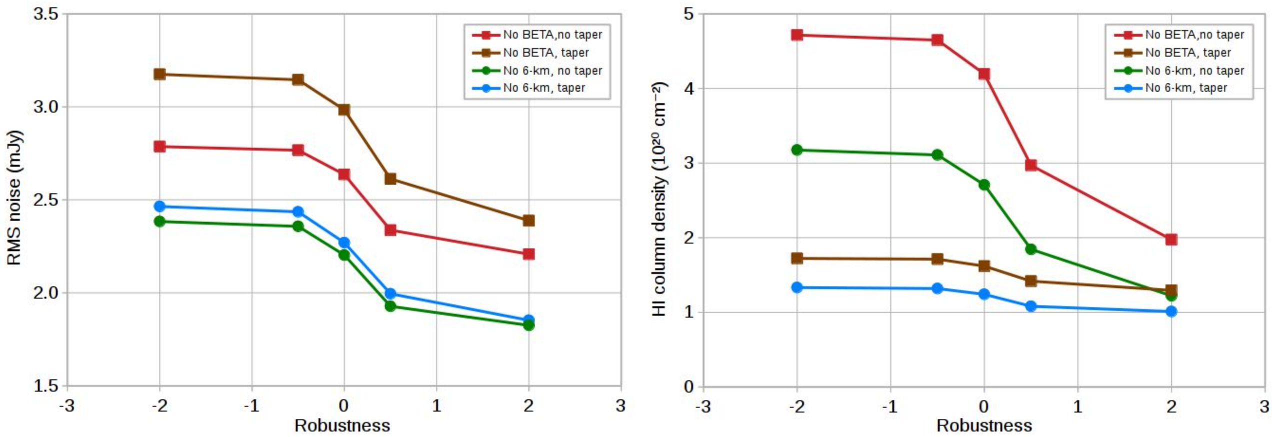


Figure 2: RMS noise level (left) and 5σ H I column density sensitivity across 20 km/s (right) as a function of robustness for the two extreme ASKAP−30 simulations listed in Table 1, assuming $T_{\rm sys}\,/\,\eta$ = **62.5 K** (hence looking at the effect of configuration only).

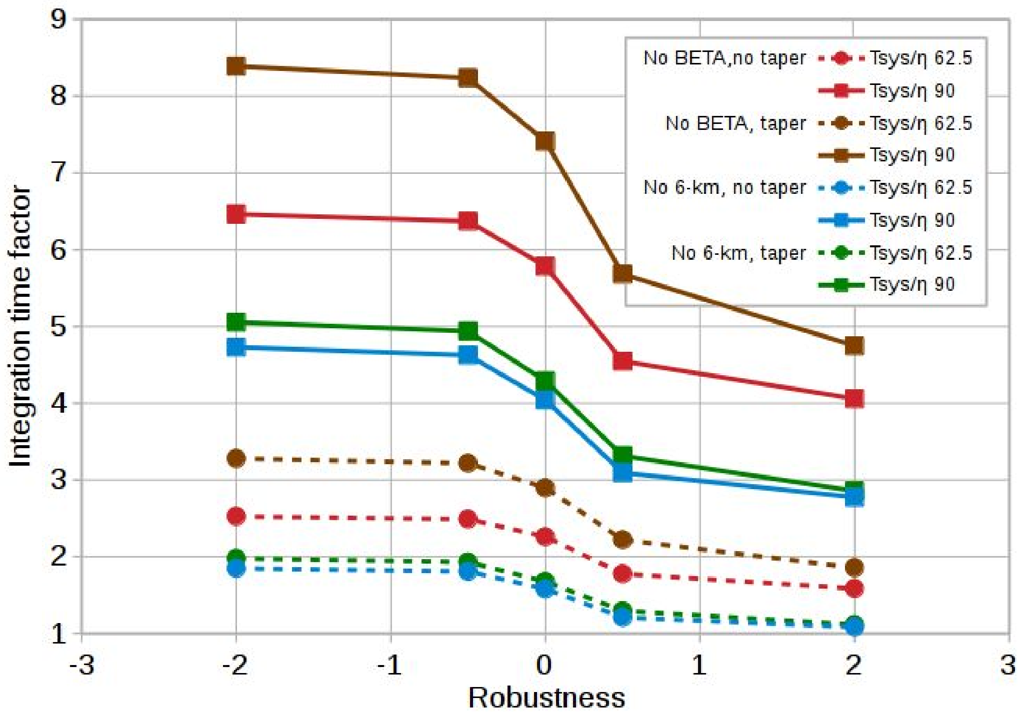


Figure 3: Increase in integration time for the two extreme ASKAP−30 configurations listed in Table 1 relative to a naturally weighted, untapered image with the full ASKAP array at $T_{\rm sys}\,/\,\eta$ = 62.5 K. Two extreme cases were assumed for each configuration regarding system temperature and availability of antennas: circles / dashed lines indicate $T_{\rm sys}/\eta$ = 62.5 K and no antenna downtime, while squares / solid lines indicate $T_{\rm sys}/\eta$ = 90 K and 10% of antennas unavailable. The calculated increase in integration time assumes that the same point source sensitivity is to be achieved irrespective of beam size.

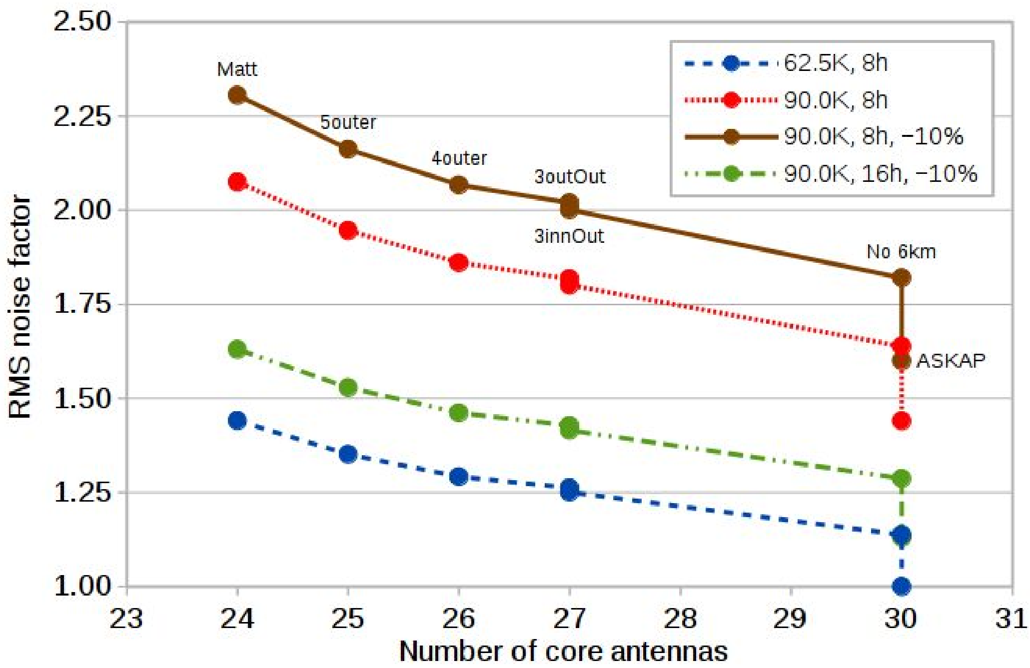


Figure 4: Increase in RMS noise level (relative to an 8 h integration with a full ASKAP at T_{sys}/η = 62.5 K) for several configurations with a varying number of core antennas from Table 1 (labelled in the uppermost curve). The different colours and lines correspond to different values of T_{sys}/η, integration times and percentage of antennas affected by maintenance or equipment failure as detailed in the legend. All simulations assume a robustness of 0.5 with additional Gaussian tapering to 30″ resolution (except for ASKAP where natural weighting without tapering is used).

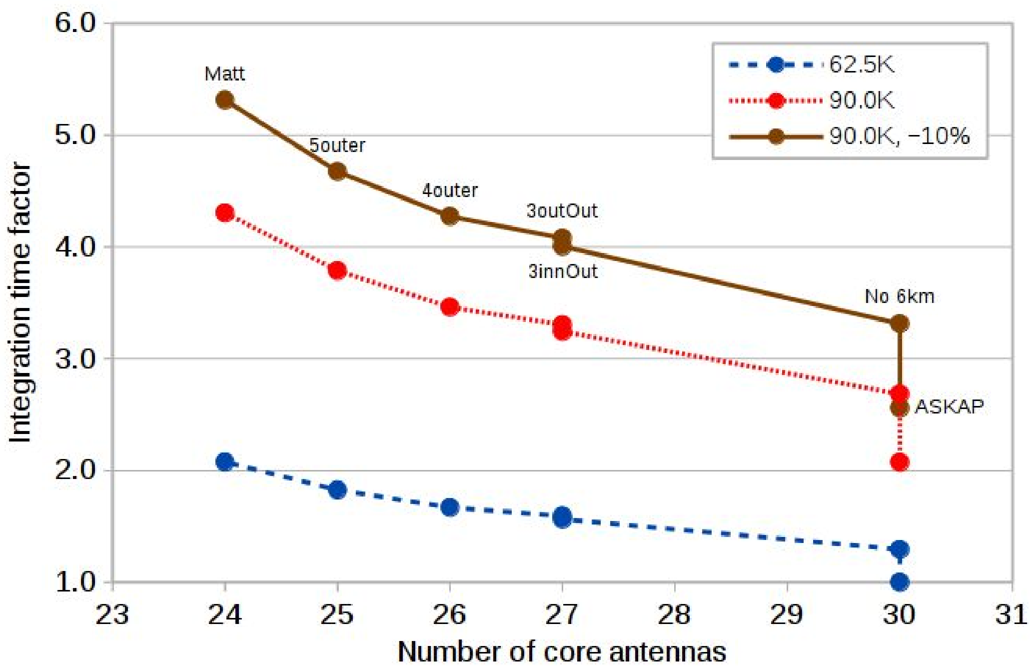
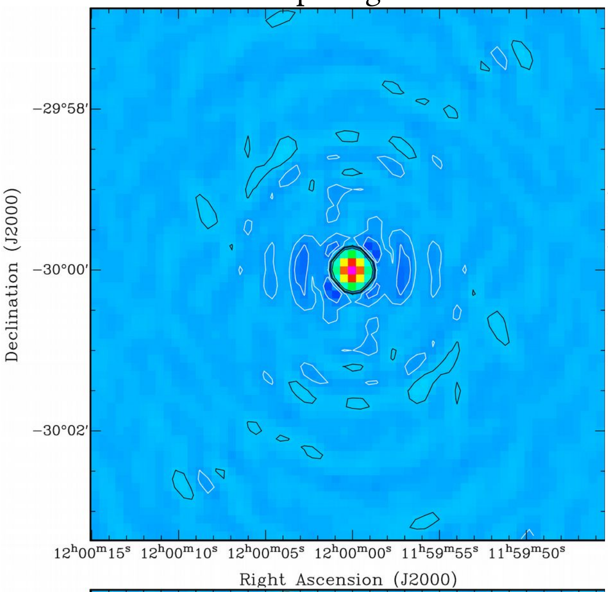
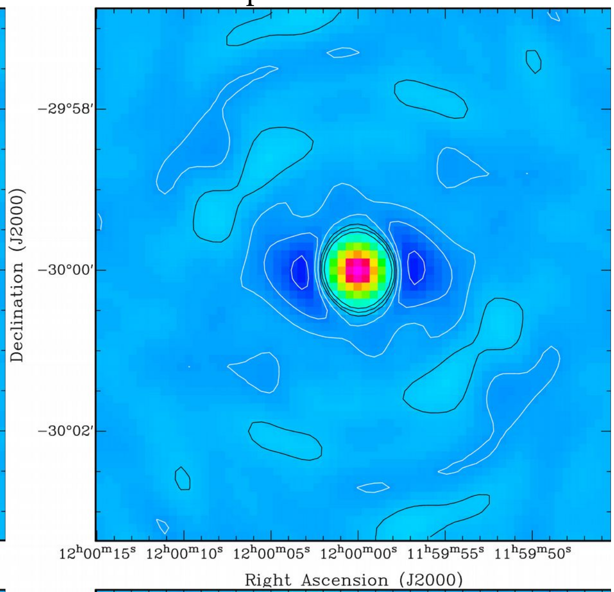
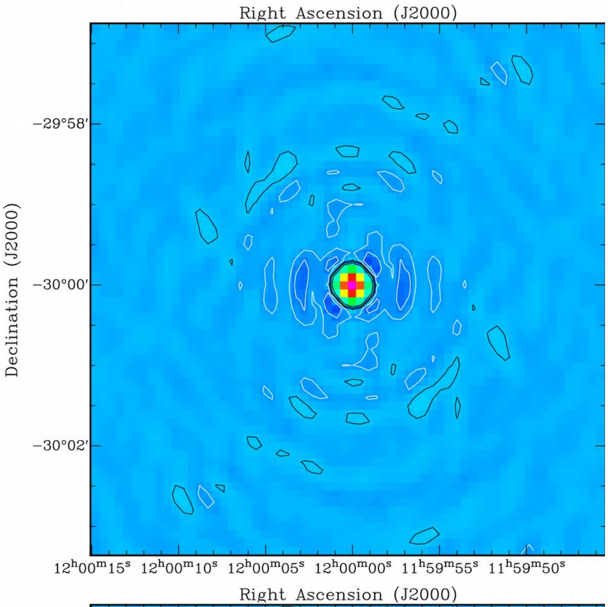
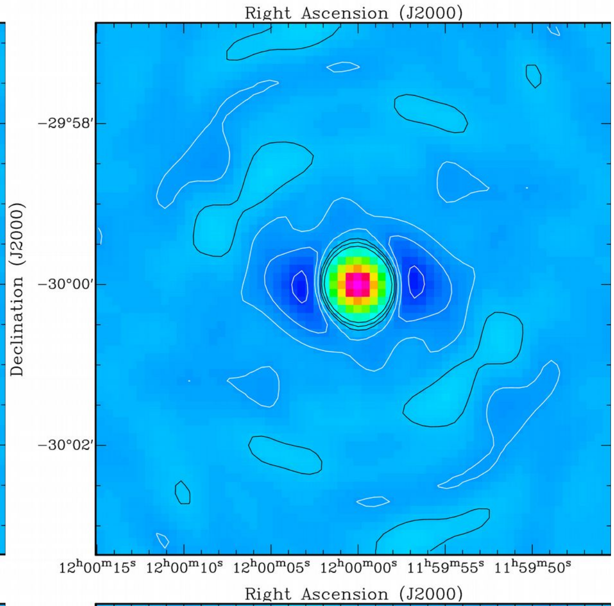
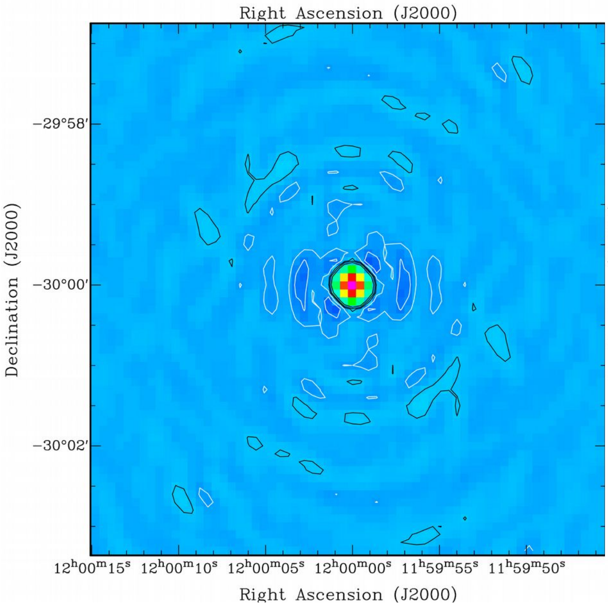
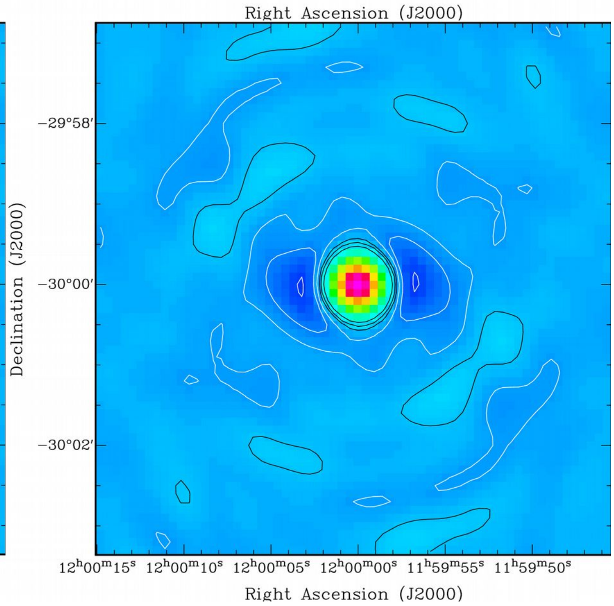


Figure 5: Increase in required integration time (relative to a full ASKAP at T_{sys}/η = 62.5 K) for several configurations with a varying number of core antennas from Table 1 (labelled in the uppermost curve). The different colours and lines correspond to different values of T_{sys}/η and percentage of antennas affected by maintenance or equipment failure as detailed in the legend. All simulations assume a robustness of 0.5 with additional Gaussian tapering to 30″ resolution (except for ASKAP where natural weighting without tapering is used).

Table 2: Beam images for the "No BETA" configuration using different tapering and robustness. Contour levels are −10%, −5%, −2% (white) and +2%, +5%, +10% (black).

	No tapering	Tapered to 30″
$R = -2$		
$R = -0.5$		
$R = 0$		

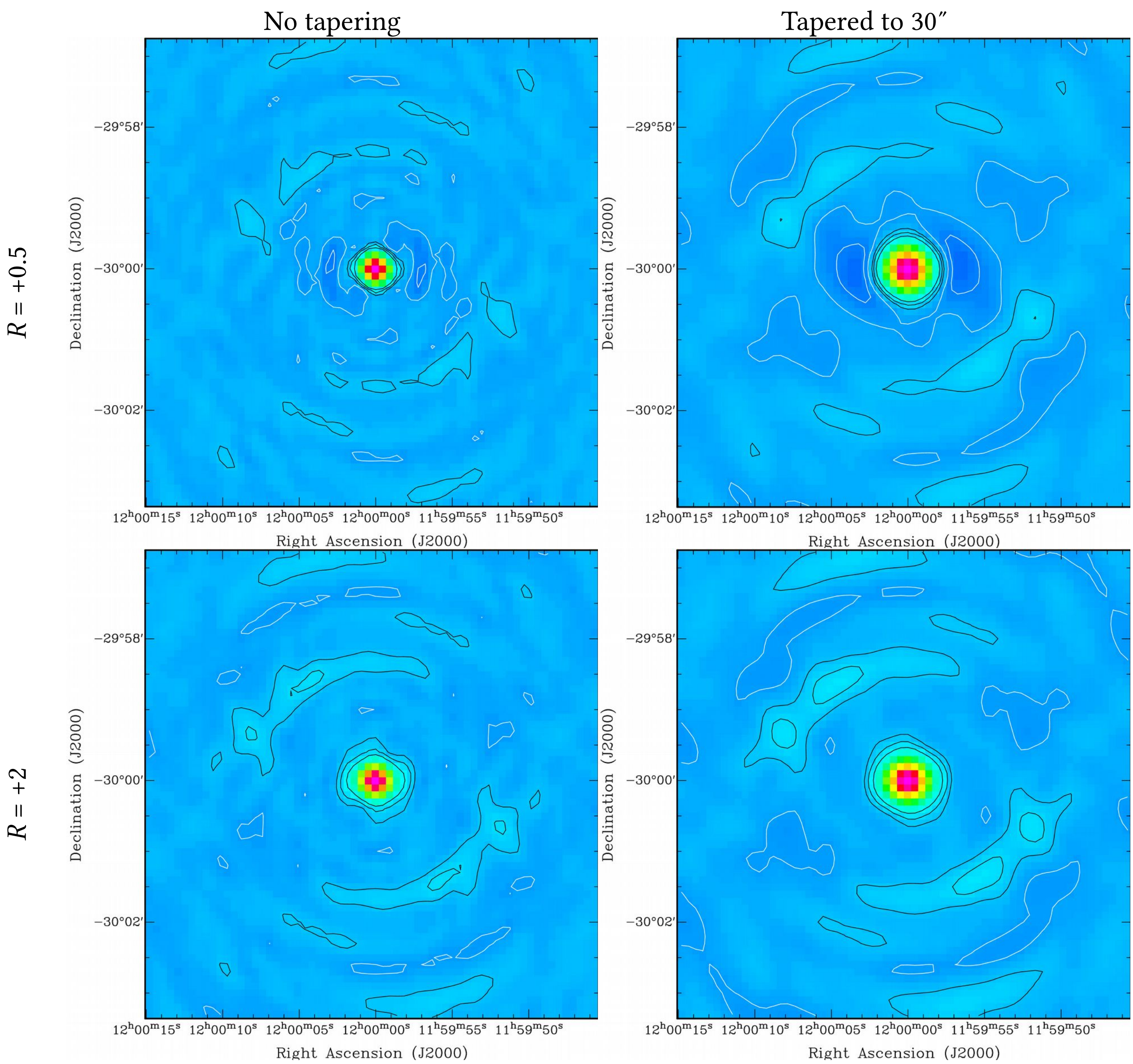
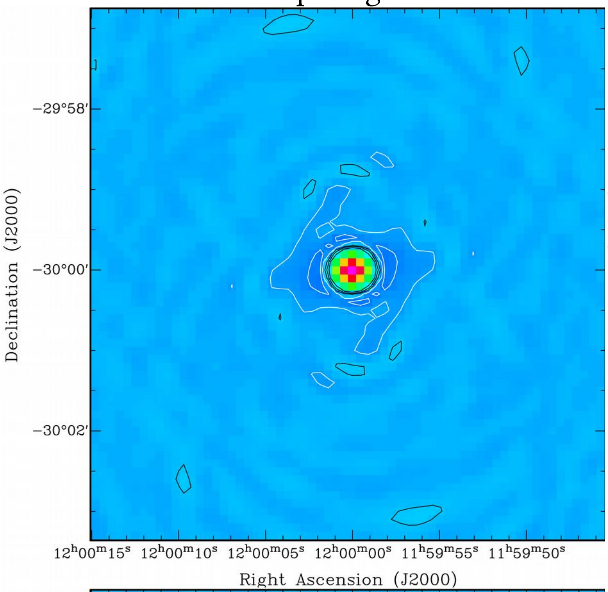
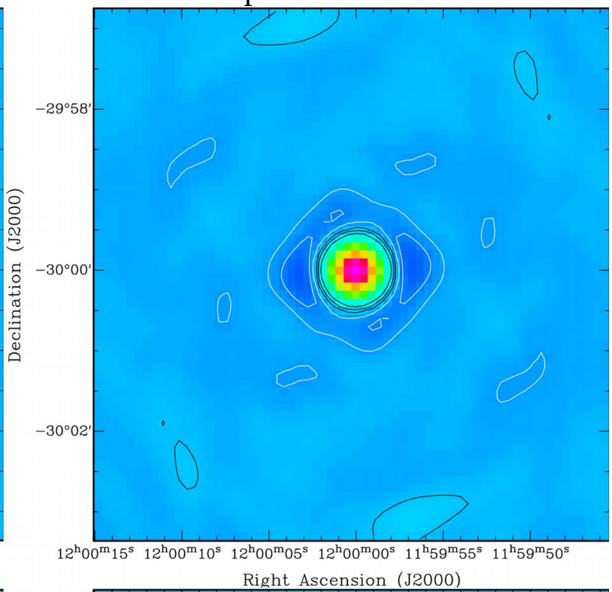
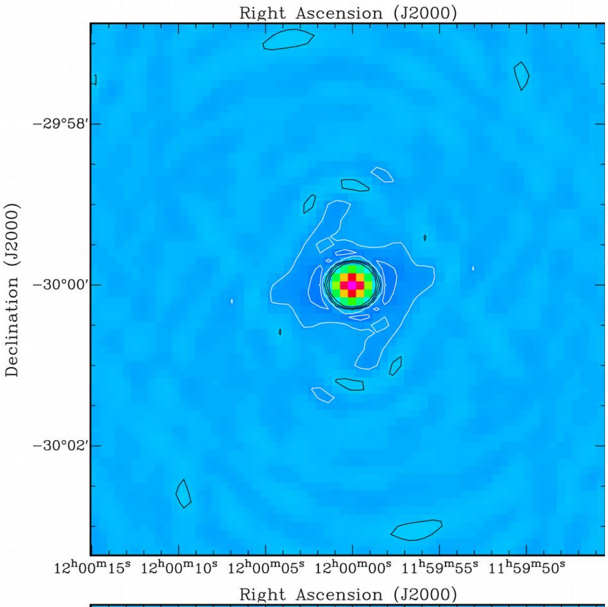
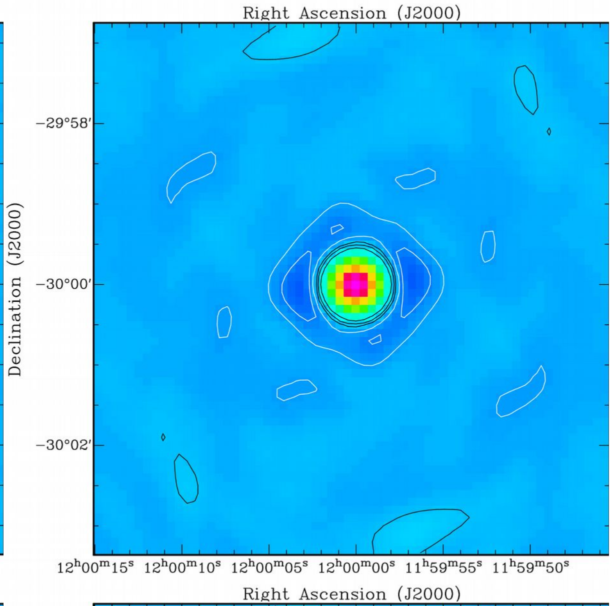
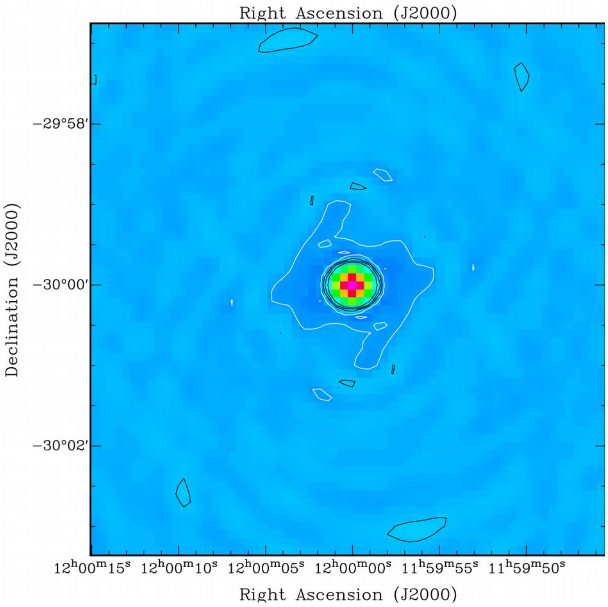
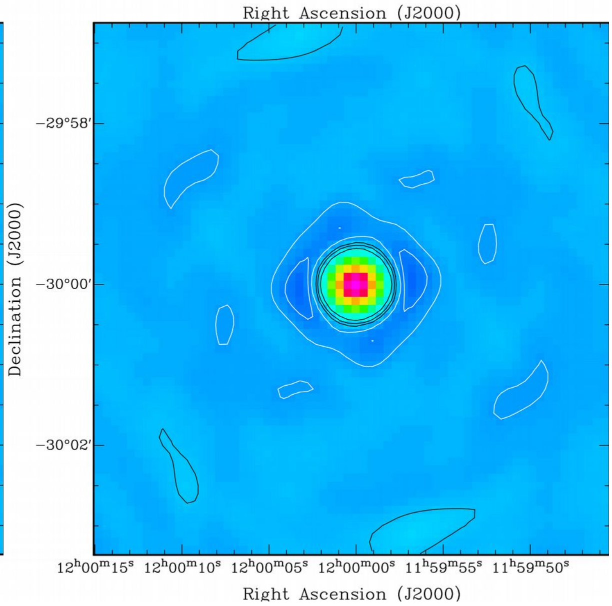

No tapering
Tapered to 30″
R = +0.5
R = +2
Declination (J2000)
−29°58′
−30°00′
−30°02′
12h00m15s 12h00m10s 12h00m05s 12h00m00s 11h59m55s 11h59m50s
Right Ascension (J2000)

Table 3: Beam images for the "No 6 km" configuration using different tapering and robustness. Contour levels are −10%, −5%, −2% (white) and +2%, +5%, +10% (black).

	No tapering	Tapered to 30″
$R = -2$		
$R = -0.5$		
$R = 0$		

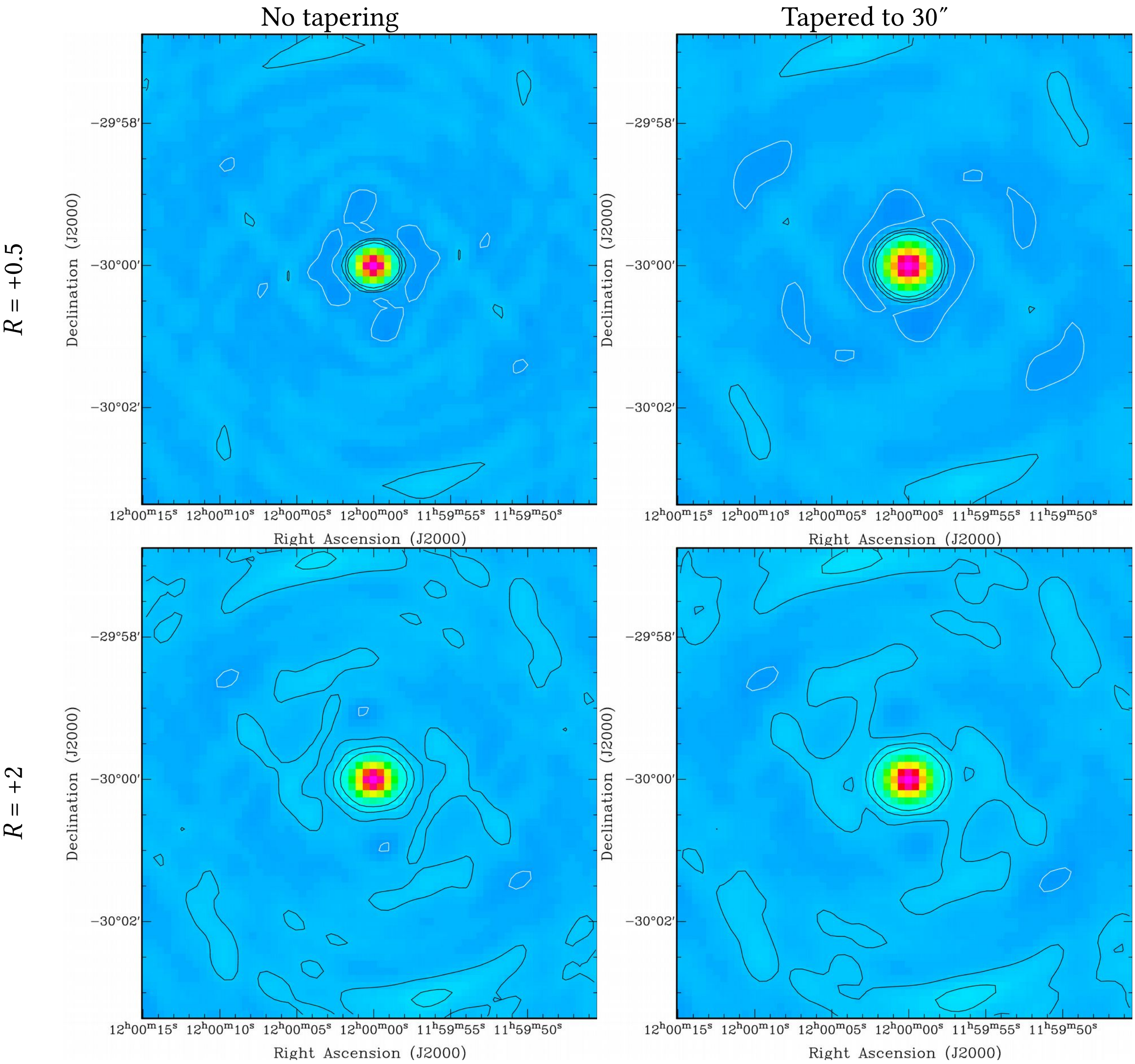


Table 4: Key to all configurations considered in this memo. Missing antennas are highlighted in red colour.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
No BETA	■		■			■		■	■						■																					
No 6 km																															■	■	■	■	■	■
3innOut								■	■						■																	■		■		■
3outOut								■	■						■																■		■		■	
4outer								■	■						■														■			■		■		
5outer								■	■						■			■											■			■				
Matt								■	■		■				■			■											■							
ASKAP																																				