Next Generation Very Large Array Memo #121

Subarray Study for the Envelope Observing Program

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Abstract

In this study we made simulations for 60 science cases from the Envelope Observing Program, assigning the Main (or Main+Long) subarray to each observation. In many cases, observing with all the antennas is not efficient because some fraction of the baselines will be either unneeded or unused. Therefore, we developed heuristics based on the science requirements to identify a more efficient or a better performing ngVLA subarray for each science case, for which the new subarray could still satisfy the science requirements as well as the whole array while using fewer antennas. Our results indicate that subarrays show a clear advantage for the majority of projects studied in the EOP. Specifically, some 'low resolution' projects can be observed with a subarray, e.g., Core, in about the same total time than Main. Additionally, some 'high resolution' projects that also need a good PSF can be observed with a subarray, e.g., dropping half of the Core (Mid–Spiral–Outer50Core), in about the same total time than Main. Additionally, we found that more projects in the EOP have a smaller antenna hour metric when using a subarray instead of Main.

1 Introduction

The ngVLA is being designed to accommodate a variety of science goals in an non-reconfigurable array by delivering high sensitivity over a wide range of resolutions. The ngVLA is comprised of three fundamental components: 244 18-m antennas that are part of the Main (214) and Long (30) baseline arrays and 19 6-m antennas known as the short baseline array (SBA). Additionally, four antennas from Main will be equipped to measure total power (TP). In this study we only consider the 18-m antennas for our simulations and analysis. The ngVLA has a centrally condensed antenna distribution with its Core component accounting for more than half the collecting area of the Main array. Therefore, the ngVLA has a large ratio of short to long baselines which allows it to accommodate a wide range of resolutions within an acceptable decrease in sensitivity (see taperability section 5.1). However, this results in a naturally-weighted beam that features a broad skirt characteristic of a non-Gaussian point spread function (PSF).

Depending on the science requirements, the ngVLA can in principle operate with combinations of different groups of antennas or subarrays. The Envelope Observing Program (EOP)

[6] aims to quantify the science and technical needs of the key science goals (KSGs), making sure that the ngVLA array configuration can meet their requirements. Furthermore, the ngVLA reference design is primarily driven by the requirements of these science goals. From the EOP we consider 60 unique use cases that were submitted by the scientific community and identified by the Science Advisory Council as driving or supporting the KSGs. Each use case provides a detailed set of requirements, for which the frequency, largest angular scale (LAS) and angular resolution the more relevant requirements for this study. Additionally, the use cases in the EOP have been carefully vetted to include all the information needed for reasonable time estimates including per target sensitivity, number of targets/passes, etc.

In order to understand the best strategy to observe the EOP we consider two options:

1. Giving the entire array to each use case
2. Choosing an appropriate subarray for each use case

The first option is the most sensible one since the Main (and/or Main+Long) component is a compatible subarray for the majority of the science cases. Additionally, this option will always provide the maximum point source sensitivity because it provides the largest collecting area (i.e. the greatest number of 18m baselines). On the other hand, the second option opens up the possibility of observing multiple science cases simultaneously. In this Memo, we simulate both of the above scenarios and compare the results, to ultimately achieve the main purpose of this study which is to ***learn about the potential advantages of using subarrays.***

2 Making the Case for Using Subarrays

Figure 1 shows a visualization of the range of scales for an extended list of science use cases (~ 170), including the ones from the EOP which are analyzed in this memo. The use case requirements such as the LAS and angular resolution are expressed as minimum and maximum baseline lengths in meters (see ngVLA memo #55 [1] equation 3). Additionally, the plot shows the cases coded by frequency from band 1 to band 6 of the ngVLA (see Table 1 for the central frequencies at each band) sorted by the shortest baselines. The use cases are grouped by science categories as follows:

- TDCP: Time-Domain, Cosmology, Fundamental Physics
- HiZ: Galaxy Assembly
- NGA: Galaxy Ecosystems
- SETI: Cradle of Life related to extraterrestrial intelligence tracers
- SPI: Cradle of Life related to extrasolar space weather
- SS: Cradle of Life related to planetary objects
- SF: Cradle of Life related to stellar formation

- ExoP: Cradle of Life related to exoplanets
- DD: Cradle of Life related to debris disks
- AC: Cradle of Life related to astrochemistry
- PF: Cradle of Life related to protoplanetary systems

The gray dashed vertical lines represent the minimum and maximum baselines of a few representative components of the ngVLA i.e., the SBA, Core, Spiral and Mid subarrays. Each horizontal line represents the range of scales needed for each use case. Horizontal lines that have smaller values than the minimum baseline of the SBA (i.e., going all the way to the left) indicate that the project requires TP in order to meet the LAS requirements. As we can see in the figure, this is the case for several use cases within the TDCP, NGA, SPI and SS science goals. Horizontal lines that surpasses the maximum baseline of the Mid subarray (i.e., going all the way to the right) indicate that the project requires the baselines from Long in order to meet the angular resolution requirements, which is the case for a handful of use cases within TDCP, NGA and PF. Perhaps most importantly, we can see from Figure 1 that the majority of horizontal lines do not extend all the way from left to right which means that ***most projects do not need both the shortest and longest baselines of the ngVLA at the same time–this indicates that subarrays should be a good option to consider.***

Scheduling algorithms might decide that each of these projects can be observed using the complete array if one only takes into consideration meeting the requirements of LAS and angular resolution. However, this may not be the most efficient way to carry out the entire suite of observations because some fractions of the Main+Long baselines will be either unneeded or unused, as we will show in the following sections. In this memo we develop an alternative to using all the antennas for each project, by way of a heuristic that assigns either a more efficient or a better performance subarray.

2.1 Considered Subarrays

For this study we present a list of 17 nominal subarrays in Table 1 that is based on a mutual compatibility matrix of subarray combinations that could be used concurrently. The columns in Table 1 are as follow: column 1 lists the subarray names and column 2 and 3 are the maximum and minimum baselines in units of km and m, respectively. Column 4 lists the number of antennas per subarray. Columns 5 and 6 show the resulting naturally-weighted resolution (θ_{Nat}) and a rough estimate of the largest angular scale[1] (LAS) of the subarrays from simulations at 30 GHz. Figure 2 shows the histograms of baseline lengths for a representative set of subarrays from Table 1.

[1]This is based on the minimum baseline resolution divided by two, the same approach used for estimating the LAS of the VLA. Detailed simulations are needed to find more accurate results for the ngVLA.

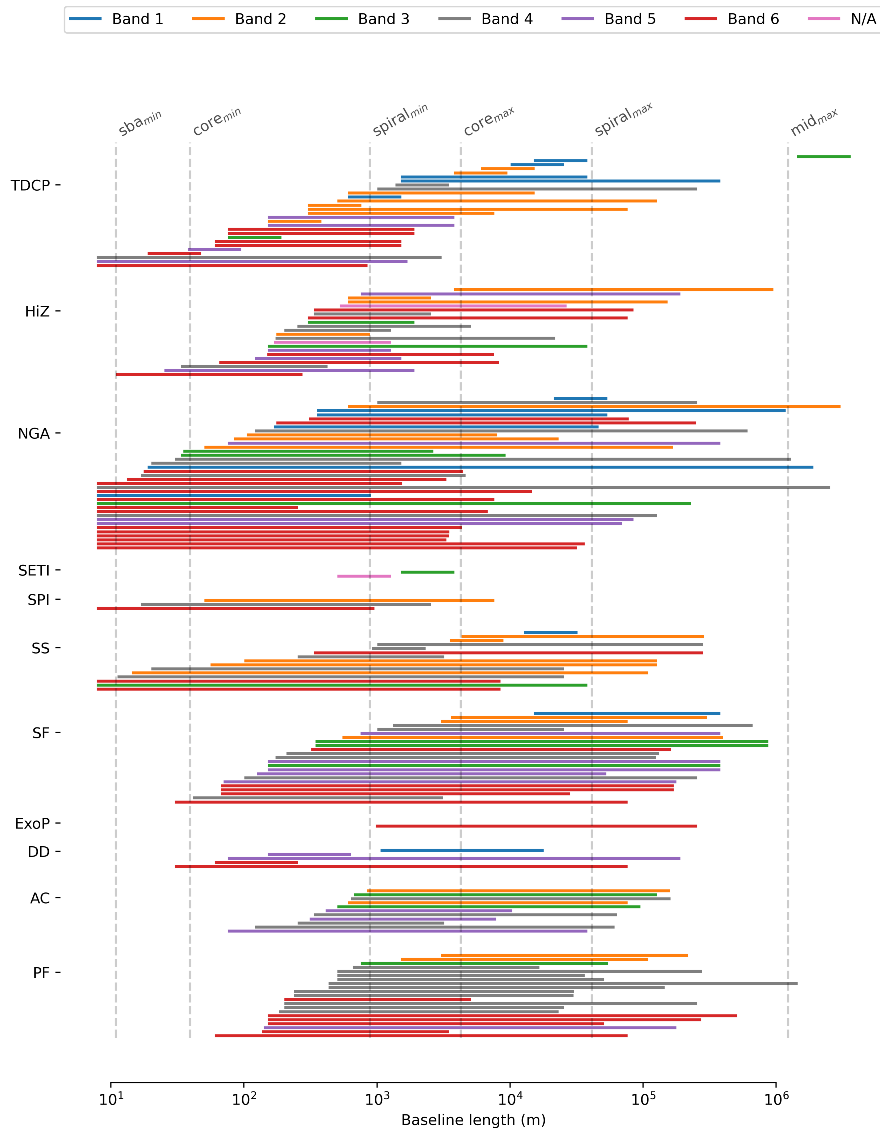


Figure 1: Visualization of the range of scales in meters (horizontal axis) of an extended list of ngVLA science use cases (vertical axis), coded by ngVLA frequency bands and sorted by the shortest baselines. The gray dashed vertical lines represent the minimum and maximum baselines of a few representative components of the ngVLA i.e., the SBA, Core, Spiral and Mid subarrays. The horizontal lines represent the range of scales needed to satisfy the angular resolution and LAS requested by each use case. Since most of the horizontal lines do not extend all the way from left to right, we conclude that most projects do not need both the shortest and longest baselines of the ngVLA at the same time.

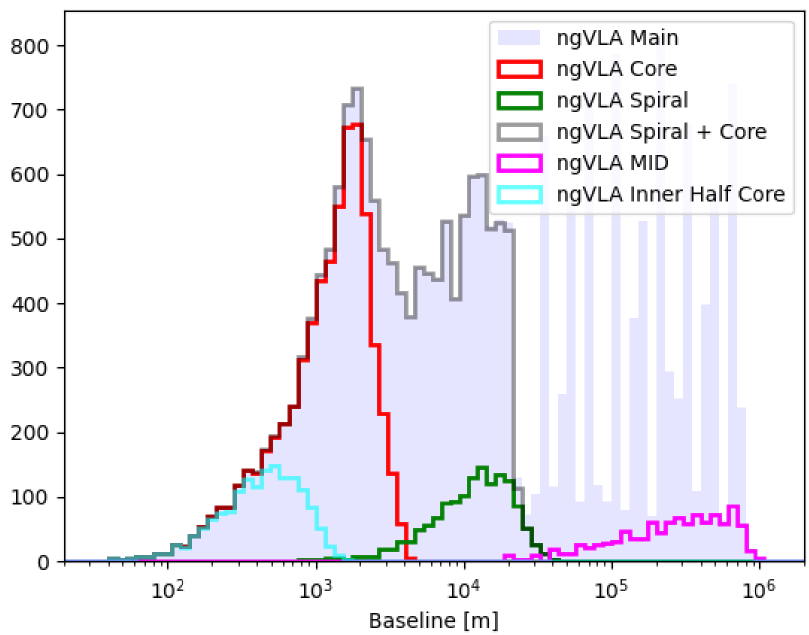


Figure 2: Histograms of the baseline lengths in meters for a representative set of subarrays considered in this memo and listed in Table 1.

Table 1: Considered ngVLA subset/subarrays, their natural resolution and LAS at 30 GHz.

Subarray	# antennas	B_{max} [km]	B_{min} [m]	θ_{Nat}@30 GHz [mas]	LAS@30 GHz [arcsec]
Long+Mid	76	8685.6	18951.9	0.54	0.055
Main	214	1227.6	39.4	6.77	26.255
Spiral+Mid+5Core	105	1227.6	403.6	4.64	2.560
Long+Mid+Spiral+5Core	135	8685.6	403.6	0.74	2.560
Long+Main	244	8685.6	39.4	1.01	26.255
Mid	46	1227.6	18951.9	2.92	0.055
Spiral+Core	168	39.3	39.4	147.67	26.255
Long+Mid+Spiral	130	8685.6	811.0	1.13	1.274
Spiral+Mid	100	1227.6	811.0	4.52	1.274
Mid+Spiral+outer50Core	157	1227.6	179.0	5.75	5.773
Core	114	4.3	39.4	718.78	26.255
Spiral	54	39.3	811.0	76.16	1.274
Long	30	8685.6	131630.9	0.33	0.008
Spiral+5Core	59	39.3	403.6	80.34	2.560
CoreInner	57	1.6	39.4	2034.55	26.255
Long+Mid+Spiral+outer50Core	187	8685.6	179.0	0.88	5.773
Spiral+outer50Core	111	39.3	179.0	116.99	5.773

Note: B_{max} and B_{min} are the physical (*unprojected*) maximum and minimum baseline lengths, respectively. θ_{Nat} is the resulting natural resolution from simulations at 30 GHz. LAS is calculated as per footnote 1 in the text. To scale θ_{Nat} and LAS to a central frequency ν multiply by $\frac{30}{\nu\,[\mathrm{GHz}]}$. B_{min} and LAS for the Long subarray are based on the shortest station to station baseline. The minimum physical baseline length (unprojected) for Long within stations is 36.4 m, but this is expected to be used only for calibration and not for imaging. In this study we are using the ngVLA Rev E configuration (except for Long (Rev. D), for which the Rev. E configuration was still under development at the time of this study began).

2.2 Assigning Subarrays to the Science Cases

We define a compatible subarray as one that meet the LAS and angular resolution requirements for each science case. Since Main is always a compatible subarray and will *always* give the maximum sensitivity because is has the most antennas, we analyzed all science cases using Main (or Main+Long when needed by the resolution requirement). Moreover, we developed a heuristic to identify *all* compatible subarrays within the list of considered subarrays (presented in Table 1) for each science case of the EOP as follows:

- perform simulations for each of the 17 subarrays from Table 1 with imaging using Natural weighting
- tabulate the maximum baseline from the actual resolution (the PSF fit from simulations) vs the diffraction limited resolution of the longest baseline (predicted; see columns 3 and 4 in Table 7 in the Appendix section)

- estimate a factor to calculate the effective maximum baseline[2] (see last column in Table 7 in the Appendix section)
- compare requested B_{min} and B_{max} from the science use cases to the effective baselines of each subarray in the list
- produce list of compatible subarrays per science case

Once we have the list of compatible subarrays we proceed to rank them using the two metrics that we developed for this study: efficient and performance (see below). Each science use case will therefore have 3 compatible subarrays for us to compare:

- Main (or Main+Long) subarray
- the most efficient subarray
- the better performance subarray

2.3 Subarray Metrics

2.3.1 Efficient

The most efficient subarray has the largest ***fraction*** of baselines between the minimum and maximum science use case requirement (i.e., subarray baselines between B_{min} and B_{max} / total number of baselines in that subarray). Therefore, the efficient metric considers which baselines are either not needed or will not be used by a specific science case. For example, for a low resolution project the longer baselines of Main would need to be highly tapered to meet the requested resolution, giving them effectively zero weight. In contrast, an efficient subarray for the same low resolution project would exclude the most outlying antennas, therefore removing these longer baselines entirely.

2.3.2 Performance

The most performant subarray has the largest ***total number*** of baselines between the minimum and maximum science use case requirement (i.e., subarray baselines between B_{min} and B_{max}). This tries to minimize the observation time, which is inversely proportional to the number of utilized baselines. Since we know that the full array (Main, or Main+Long) will always give the shortest observation time, the performance metric ranks the compatible subarrays by observation time to provide the next best alternative to Main in point source sensitivity while also providing an incremental improvement in efficiency.

[2]Note: when using the physical maximum baseline, the predicted resolution is too high compared with the values from the simulations, resulting in the assignment of subarrays without long enough baselines. Thus the simulations would fail to achieve the target resolution if assignments used a heuristic based only on the physical maximum baseline.

3 Simulations

For the simulations, we generated visibilities with the CASA `sm` toolkit using a 4 hr synthesis centered on the transit of a single field at +24 declination. The simulations have a center frequency given by the requirements of each use case and are composed of a single channel and an integration time of 60 seconds[3]. No source visibilities were predicted, i.e., each simulation is of a blank field. An arbitrary amount of thermal noise was added to the visibilities using the `sm.setnoise` function of the CASA simulation toolkit.[4]. The noise value is arbitrary because we are only interested in the ***ratio*** of image noise resulting from different imaging parameters;

From the EOP there were 63 science use cases from which we identified a total of 60 unique cases[5] that we used for our analysis. We made simulations for all the use cases for which the observations are to be recorded in either continuum or line mode. Additionally, for the purpose of comparison we made simulations for the three compatible subarrays based on our metrics (Main or Main+Long, efficient and performance); this resulted in a total of 180 simulations for 60 use cases.

4 Imaging

The imaging was done using CASA's `tclean` (version 5.6.2–2.el7) and the heuristic used in this study for the construction of the images was previously developed and presented in ngVLA memo #76 [4] (see memo for details). *In total, for the 60 use cases considered at each of the three assigned subarrays, this resulted in a total of more than 50,000 images.* A summary of the procedure is described below.

4.1 Determination of Imaging Parameters to achieve the Desired Resolution

In order to determine the combination of image parameters that will produce the desired resolution for each use science case we produced a grid of PSFs over a range of Briggs robust weighting and uv-tapers, composed of *275 images per use case per considered subarray (∼49500 images)*: 11 values of robust from uniform ($R = -2$) to natural ($R = 2$) in steps of 0.4 and 25 linearly spaced values of uv-taper from zero to twice the target resolution.
Figure 3 shows an example of the resulting grid for a specific use case, where the color scale represents the achieved resolutions of the resulting PSFs from the robust - taper grid. One figure was produced for each of the 60 use cases and for each of the three assigned subarrays. Interpolation is used to determine pairs of Briggs robust and uv-taper values that result in

[3]We choose this integration time in order to keep the measurement set files small. Time smearing is not an issue for simulated observations, but this value would need to be reconsidered before scheduling actual observations.

[4]For more on generating measurement sets (MSs) using the `sm` toolkit, estimating the expected rms noise in an untapered, naturally-weighted Stokes I image and adding thermal noise to a MS see https://casaguides.nrao.edu/index.php/Simulating_ngVLA_Data-CASA5.4.1

[5]The three use cases excluded (i.e., HiZ7 7.9 GHz, HiZ7 16.4 GHz, TDCP16 80GHz) were duplicates for the purpose of the simulations, meaning the duplicate had the same frequency, resolution and LAS.

the target resolution, as represented by the white solid line; the white dashed lines indicate the combination of parameters that yields $\pm 20\%$ of the target resolution.

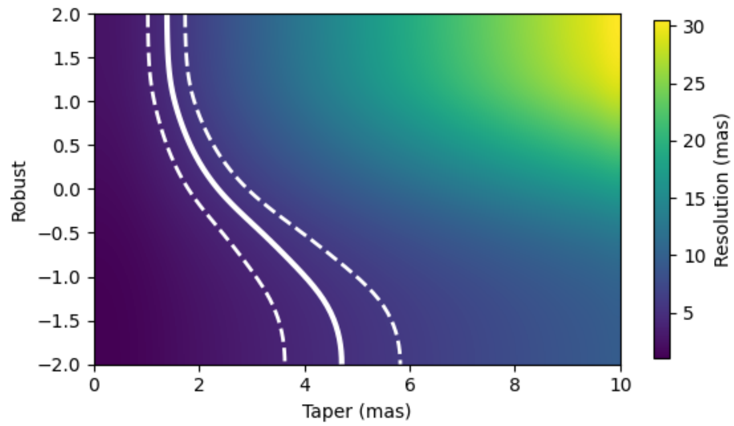


Figure 3: Resolution as a function of the robust and uv-taper values. The color scale shows the size of the clean beam as fit with the CASA `tclean` task. The solid white line is the combination of robust and uv-taper values that will result in the target resolution, and the dashed lines delimit the combination of parameters that yield $\pm 20\%$ of the target resolution. This example is from the simulations of the use case PF3(KSG1) at 80 GHz for the Main subarray.

4.2 Images at the Desired Resolution

We created new simulated images using only the combinations of Briggs weighting and uv-taper from the PSF grid that produce the target resolution. Therefore, we varied the robust value from uniform ($R = -2$) to natural ($R = 2$) in steps of 0.2 to have a suite of 21 equally spaced values. Then, we paired each robust value with a uv-taper based on interpolation of the PSF grid (i.e., the combinations from the interpolated values as represented by the white solid line as in Figure 3). *This resulted in 21 images per use case per considered subarray (∼3700 images in total).*

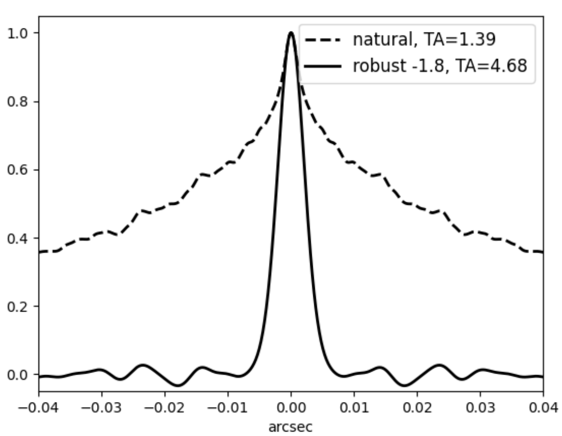
5 Simulation Analysis

In our analysis we use the *taperability* and *sculptability* concepts which have been extensively studied in previous ngVLA memos (e.g., #55 [1], #65 [2], #76 [4] and #106 [5]), which we summarize below.

5.1 Taperability

Taperability, the change of sensitivity with resolution, is used as a metric to compare arrays and to understand how well an array can perform at both high and low resolutions (e.g., ngVLA memo #55 [1]). Taperability curves (see ngVLA memo #106 [5]) show the change in sensitivity versus resolution as parameterized by an inefficiency factor, η_{weight}, which accounts for the change in sensitivity due to the use of image weights. The factor η_{weight} is defined by $\sigma_{rms} = \eta_{weight}\sigma_{NA}$ to be the increase in image rms (σ_{rms}) compared with the naturally weighted, untapered image σ_{NA}.

The ngVLA (Main+Long) has a very high degree of taperability which means that it can be used over a large range of resolutions without a great loss of sensitivity ($\eta_{weight} \leqslant 2$; e.g., ngVLA memo #55[1]). Such a feature is highly desirable since it can allow a non-reconfigurable array to accommodate a wide range of science cases. Good taperability results from a centrally condensed array configurations like the ngVLA which have a large ratio of short to long baselines. However, this comes with the caveat of having a naturally weighted PSF that is inherently non-Gaussian. *Therefore, in principle taperability allows us to achieve the desired target resolution but it does not account for all aspects of beam sculpting that many science cases are likely to require.* It is important, for that reason, to also understand the quality of the synthesized beam needed for each specific use science case and assess the additional sensitivity penalty that such sculpting would incur.



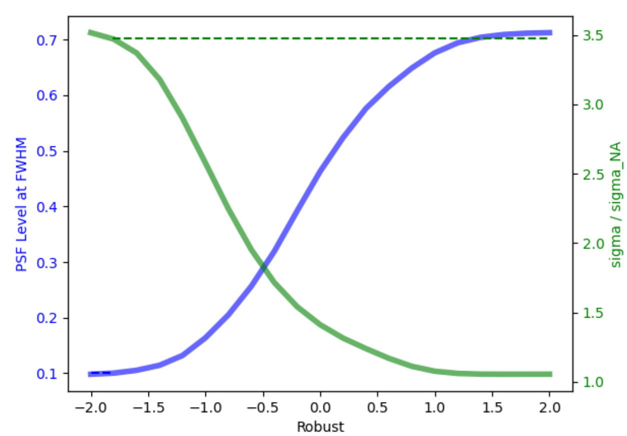


Figure 4: This example is for the simulations of the use case PF3(KSG1) at 80 GHz for the Main subarray (see the results summarized in Table 2). **left**: East-West cuts through the natural plus taper PSF (dashed black line) and the robust plus taper PSF closest to the combination that reaches a PSF skirt level of 10%. As we can see the quality of the beams are very different despite both having the same official clean beam resolution i.e., 5 mas. **right**: PSF skirt level (solid blue line) and inefficiency factor (solid green line) versus the Briggs robust parameter. A target PSF skirt level of 10% (dashed blue line close to the bottom left corner) and corresponding inefficiency factor for the robust-taper combination that yields this target level (dashed green line) are also shown.

5.2 Sculptability

Scientific cases may need to adjust the uv-weighting and other image parameters to sculpt a more Gaussian synthesized beam in order to meet specific science requirements, e.g., image fidelity. To quantify the additional penalty in sensitivity that should be accounted for, we produced a scultability curve for each of the science cases presented in this memo based on analysis of the 21 constant resolution images (per science case) described in section 4.2. Figure 4 (right panel) is an example of a scultability curve. These curves show the level of the PSF skirt versus the Briggs robust parameter and also show the inefficiency factor (η_{weight}; solid green line) which is the factor by which the sensitivity increases over natural weight and no uv-taper. A target PSF skirt level of 10%[6] (dashed blue line) and corresponding inefficiency factor for the robust-taper combination that yields this target level (dashed green line) are also shown. Figure 4 (left panel) shows the resulting PSF for two of the 21 constant resolution images for case PF3(KSG1) at 80 GHz using the Main subarray (see the results summarized in Table 2). As we can see the quality of the beams are very different despite both having the same resolution i.e., 5 mas. The results from the scultability curves are summarized in Tables 2, 4 and 5 (robust columns) for the assigned subarrays per case.

6 Simulation Results

Each simulation provides the resulting parameters of taper, resolution, inefficiency factor and PSF skirt level for both natural and robust weighting. These results are presented in Tables 2, 4 and 5 for the assigned subarrays of Main, Efficient and Performance, respectively. The formatting of the tables for the efficient and the performance subarrays is as follows: column 1 is the name of the science use case, columns 2 and 3 are the frequency in units of GHz and the angular resolution in units of mas, respectively. Columns 4 and 5 are the name of the assigned subarray and the number of antennas in that subarray. The results of the taperability analysis (i.e., using natural weighting or $R = +2$) are shown in column 6, 7, 8 and 9 where we present the taper in mas, the achieved resolution in mas, the PSF skirt level and the inefficiency factor, respectively. The results of the sculptability analysis are shown in columns 10, 11, 12 and 13 where we present the taper in mas, the robust value, the level of the PSF skirt and the inefficiency factor, respectively. Using robust values allow us to achieve the target resolution in most of the cases unless indicated in the Notes in column 14. A similar format is used for the results presented in Table 2 except that columns 4 and 5 (i.e., the name of the assigned subarray and the number of antennas) is omitted to avoid redundancy.

6.1 Main Subarray

Figure 5 summarizes the results when each of the 60 science use cases are assigned the Main subarray. The top panel shows that more than 50% of use cases achieve the target resolution with a natural plus taper weighted PSF (blue bins in the histogram) and inefficiencies $\leqslant 2$. Several use cases appear to have a greater loss in sensitivity ($\eta_{weight} \geqslant 2$; i.e., the

[6] We are assuming that a skirt which raises the PSF to a level of 10% at a radius of one FWHM may be acceptably low (for comparison, a Gaussian beam is ~6% at a radius of one FWHM. However, this depends on the scientific requirements of each use case.

tail of the histogram) and the explanation is related to Main having a native resolution[7] that is higher than the target resolution at the specific frequency requested. Therefore, for Main to achieve the target resolution a large taper is needed (see for example cases HiZ1(KSG3.3.1)@40.5GHz and HiZ2@38.4GHz). However, as discussed previously we need to keep in mind that additional beam sculpting might be needed depending on the individual requirements of each science case.

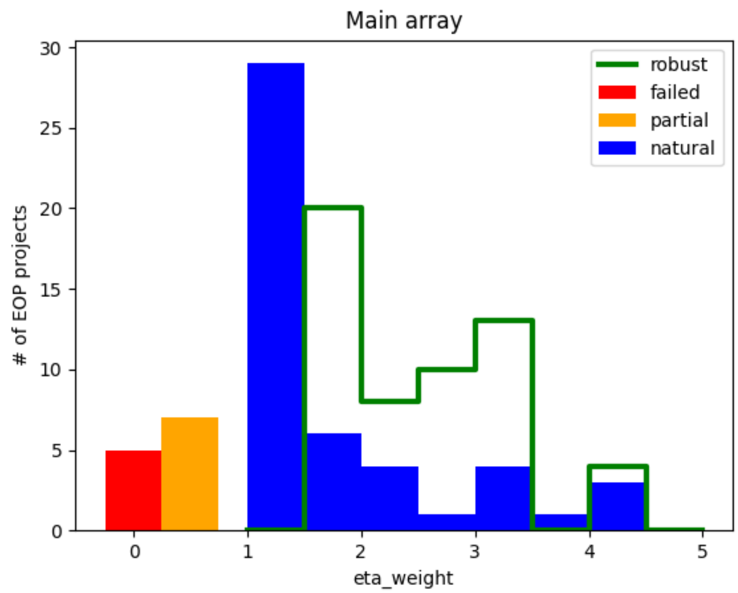
When sculpting of the beam is included (green solid line in the histogram) the distribution of inefficiency values (η_{weight}) appears to be wider with more cases having values $\geqslant 2$, which is an indication that the imaging parameters are resulting in more significant down-weighting of certain baselines. This invites the possibility that an alternative subarray could be a better, more efficient choice for those cases.

Figure 5 (top panel) shows that seven cases are labeled as 'partial' meaning that for the Main subarray they were unable to achieve the requested resolution with natural weighting, but were able to for some value of robust. Figure 6 shows one of these cases, specifically use case NGC6 at 27.25 GHz, where we see that the simulation can meet the resolution requirement using robust-taper combinations only for robust values $\leqq 0.5$. The native resolution of the Main subarray is lower than the desired one at the requested frequency (i.e., 7.5 mas vs 6 mas, respectively), and Figure 6 shows how this subarray does not have long enough baselines to achieve the desired resolution with natural weighting. Note that the sculptability plot in Figure 7 (right) also shows that there were no robust-taper combinations which could yield a PSF skirt of $\leqslant$10%; the smallest PSF level that can be achieved for this case is $\sim$ 16% at uniform weighting but with a large penalty in sensitivity (η_{weight} =2.79). All these 'partial' use cases are highlighted by the orange cells in Table 2 column 5. Additionally, in Table 2 column 10 we show that a total of 13 use cases can not achieve a PSF level of 10% even at uniform weighting. As we will see in the sections below several of those use cases do not actually require the shortest baselines from the Main subarray that are contributing to this large skirt.

6.1.1 Main+Long Subarray

Figure 5 (lower panel) shows that seven cases were given Main+Long because they needed the longer baselines to achieve the desired angular resolution. These use cases are highlighted by the red cells in Table 2 column 8. The results of the simulations performed for those use cases using the Main+Long subarray are presented in Table 3. However, five of these cases still failed (red values in the histogram Figure 5 (top panel); see the column Notes in Table 3 for the list of cases) to achieve the requested resolution, even with Main+Long and uniform weighting (see notes column in Table 3). Furthermore, for three of those cases Long alone achieves the target resolution, and for the remaining two cases, Long alone came close (about 1.5x lower) but was unable to achieve the requested resolution even with uniform weighting (see results in Table 4).

[7] We define native resolution as the resolution of an array at natural weighting and no taper.



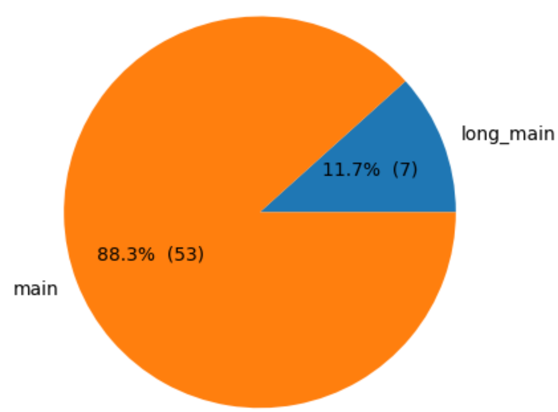


Figure 5: Summary of the simulations for the Main (or Main+Long) subarray **top**: histogram of the results presented in Table 2. **lower**: pie chart showing the occurrence of assigned subarrays.

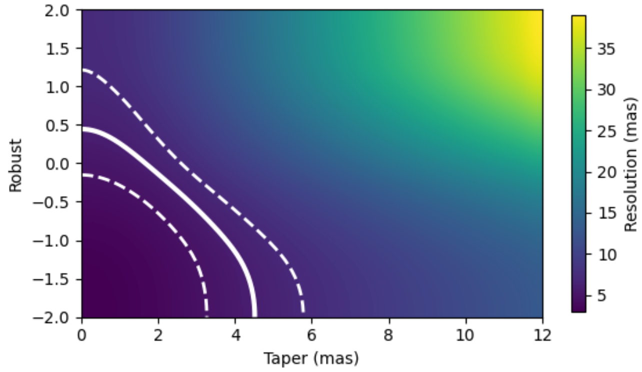


Figure 6: Similar graphic as shown in 3 but for use case NGC6 at 27.25 GHz for the Main subarray. The simulation can meet the resolution requirement using robust-taper combinations only for robust values $\leqq 0.5$. The native resolution of the Main subarray is lower than the desired one at the requested frequency (i.e., 7.5 mas vs 6 mas, respectively), and this subarray does not have long enough baselines to achieve the desire resolution with natural weighting.

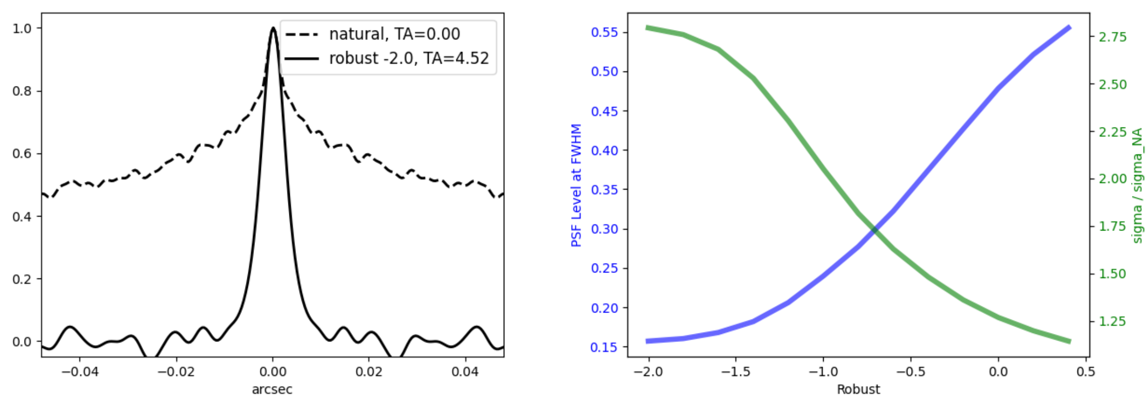


Figure 7: Similar graphic as shown in Figure 4 but for use case NGC6 at 27.25 GHz for the Main subarray. This use case is an example of the 'partial' results from Main. **left**: The dashed line shows the PSF cut for natural (dashed line) weighting with a resulting resolution of 7.48 mas and a PSF level of 70%, showing that for this specific use case the Main subarray can not achieve the target resolution of 6 mas at natural weighting. The solid line shows the PSF for uniform weighting plus taper which achieves the target resolution of 6 mas but with a 16% PSF level. **right**: The sculptability curve shows that there were no robust-taper combinations which could yield a PSF skirt of $\leqslant$10%; the smallest PSF level that can be achieved for this case is $\sim$ 16% at uniform weighting but with a large penalty in sensitivity (η_{weight} =2.79).

Table 2: Main Subarray

			Main – Natural				Main – Robust				
Name	Freq [GHz]	Res [mas]	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
PF3(KSG1)	80	5	1.39	5.00	0.71	1.05	4.68	-1.81	0.10	3.47	
PF3(KSG1)	27.25	5	0	7.47	0.72	1.00	3.48	-2.00	0.17	2.64	
PF1	80	15	4.64	15.00	0.67	1.15	14.50	-0.95	0.10	2.87	
PF1	27.25	15	4.18	15.00	0.71	1.06	14.06	-1.75	0.10	3.47	
PF5	80	5	1.39	5.00	0.71	1.05	4.68	-1.81	0.10	3.48	
PF5	27.25	5	0	7.46	0.72	1.00	3.48	-2.00	0.17	2.64	
AC5(KSG2)	40.5	100	36.62	100.03	0.50	1.29	89.91	0.04	0.10	1.72	
AC5(KSG2)	27.25	100	33.24	100.01	0.53	1.23	68.70	0.06	0.10	1.69	
AC5(KSG2)	16.4	100	31.56	99.99	0.63	1.18	90.40	-0.66	0.10	2.27	
AC1	24	400	199.11	400.09	0.37	1.50	359.41	0.38	0.10	1.70	
AC2	37	200	95.13	199.98	0.43	1.42	187.21	0.23	0.10	1.75	
AC3	45	35	11.01	35.00	0.64	1.18	32.24	-0.72	0.10	2.39	
AC4	70	200	108.13	200.12	0.25	1.63	159.20	0.71	0.10	1.69	
AC6	24	1000	710.11	998.05	0.16	1.95	838.82	1.09	0.10	1.96	
SS06	16.4	20	5.2	20.00	0.71	1.04	18.27	-2.00	0.11	3.39	
SF9	16.4	8	0	12.34	0.73	1.00	5.49	-2.00	0.17	2.62	
SF9	27.25	1.5	0	7.46	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
HiZ1(KSG3.3.1)	40.5	2000	1981.62	2,004.41	0.12	4.10	2,377.35	-2.00	0.12	4.10	
HiZ1(KSG3.3.1)	27.25	2000	1836.46	2,046.89	0.16	3.13	2,132.92	0.87	0.10	3.08	
HiZ1(KSG3.3.1)	16.4	2000	1650.09	2,000.13	0.17	2.29	1,958.57	0.97	0.10	2.28	
HiZ5(KSG3.3.2)	72	100	47.26	100.01	0.44	1.42	92.03	0.23	0.10	1.72	
HiZ5(KSG3.3.2)	36	100	35.2	100.01	0.51	1.27	85.47	0.03	0.10	1.72	
HiZ5(KSG3.3.2)	28	100	33.37	100.01	0.53	1.24	69.96	0.06	0.10	1.68	

(Continued Main Subarray Results)

			Main – Natural				Main – Robust				
Name	Freq [GHz]	Res [mas]	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
HiZ2	38.4	2000	1958.21	2,003.85	0.13	3.93	2,371.67	-1.44	0.10	4.01	
HiZ3	29	2000	1836.84	1,950.61	0.16	3.25	2,110.09	0.91	0.10	3.16	
HiZ6	36	1500	1364.05	1,524.84	0.16	3.09	1,559.78	0.93	0.10	3.02	
HiZ7	16.4	190	64.61	190.01	0.52	1.25	144.31	0.06	0.10	1.69	
HiZ7	7.9	150	46.39	150.03	0.68	1.15	145.22	-0.95	0.10	2.89	
HiZ7	16.4	190	...	...	...	...	...	...	...	...	2
HiZ7	7.9	150	...	...	...	...	...	...	...	...	3
HiZ8	38	50	15.97	50.00	0.60	1.20	39.39	-0.36	0.10	1.94	
HiZ10	7.9	100	30.43	100.01	0.70	1.12	92.66	-1.03	0.10	2.99	
NGA8(KSG3.3.3)	115	100	51.42	99.94	0.32	1.56	85.28	0.52	0.10	1.68	
NGA2 (KSG3.3.4)	1.42	2000	668.97	2,000.22	0.53	1.24	1,405.34	0.07	0.10	1.68	
NGA2(KSG3.3.5)	1.42	60000	0	142.77	-1.00	-1.00	-1.00	-2.00	-1.00	-1.00	4
NGA3	40.5	1000	878.6	1,008.09	0.17	2.61	1,040.18	0.88	0.10	2.55	
NGA3	27.25	1000	769.27	999.70	0.16	2.07	903.19	1.05	0.10	2.08	
NGA3	16.4	1000	572.43	998.35	0.21	1.71	769.94	0.88	0.10	1.74	
NGA3	7.9	1000	482.43	1,000.20	0.42	1.44	917.85	0.27	0.10	1.73	
NGA3	2.35	1000	326.08	1,000.04	0.56	1.22	678.27	-0.04	0.10	1.73	
NGA6	40.5	6	1.18	6.00	0.70	1.01	5.15	-2.00	0.14	3.15	
NGA6	27.25	6	0	7.48	0.70	1.00	4.52	-2.00	0.16	2.79	
NGA6	16.4	6	0	12.34	0.76	1.00	3.04	-2.00	0.20	2.44	
NGA7	23	2500	2333.99	2,599.03	0.16	3.26	2,617.46	0.92	0.10	3.14	
NGA9	115	200	138.79	199.97	0.16	1.92	165.10	1.08	0.10	1.93	
NGA10	88	1000	986.91	982.55	0.14	4.19	1,182.77	-2.00	1.48	4.34	4
NGA15	16.4	100	31.56	99.99	0.63	1.18	90.39	-0.66	0.10	2.28	

(Continued Main Subarray Results)

			Main – Natural				Main – Robust				
Name	Freq [GHz]	Res [mas]	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
NGA16	86	0.15	0	2.37	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
NGA17	40.5	1	0	4.98	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
TDCP1 (KSG4)	16.4	20	5.2	20.00	0.71	1.04	18.27	-2.00	0.11	3.39	
TDCP2 (KSG5)	2.4	1000	326.88	1,000.03	0.55	1.22	675.74	-0.02	0.10	1.72	
TDCP8	16.4	0.6	0	12.33	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
TDCP5	27.25	1000	770.72	1,003.45	0.16	2.07	903.23	1.05	0.10	2.08	
Prepare	7.9	1000	482.44	1,000.23	0.42	1.44	917.84	0.27	0.10	1.74	
TDCP17	16.4	10	0	12.34	0.70	1.00	7.57	-2.00	0.16	2.81	
TDCP17	16.4	1	0	12.33	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
TDCP17	40.5	0.17	0	4.98	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
NGA12	115	50	21.79	49.99	0.47	1.35	46.84	0.13	0.10	1.76	
TDCP7 (KSG3.5.5)	2.35	100	17.97	99.99	0.69	1.01	84.96	-2.00	0.14	3.11	
TDCP16	80	0.1	0	2.55	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	1
TDCP16	80	0.1	...	...	...	...	...	...	...	...	5
TDCP16	27.25	1000	766.23	999.27	0.16	2.07	903.47	1.05	0.10	2.08	
TDCP18	7.9	15	0	25.68	0.74	1.00	9.61	-2.00	0.19	2.54	

[1] Simulation did not work; need to run with a subarray with longer baselines. See Table 3
[2] Same simulation as other HiZ7_16.4; difference related to observational parameters that are not relevant for the simulations
[3] Same simulation as other HiZ7_7.9; difference related to observational parameters that are not relevant for the simulations
[4] Image size did not well sample PSF skirt
[5] Same simulation as other TDCP16_80; difference related to observational parameters that are not relevant for the simulations

Table 3: Main+Long (or Long) Subarray

			Main+Long – Natural				Main+Long – Robust				
Name	Freq [GHz]	Res [mas]	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
PF3(KSG1)	80	5	...	...	...	...	...	...	...	...	
PF3(KSG1)	27.25	5	...	...	...	...	...	...	...	...	
PF1	80	15	...	...	...	...	...	...	...	...	
PF1	27.25	15	...	...	...	...	...	...	...	...	
PF5	80	5	...	...	...	...	...	...	...	...	
PF5	27.25	5	...	...	...	...	...	...	...	...	
AC5(KSG2)	40.5	100	...	...	...	...	...	...	...	...	
AC5(KSG2)	27.25	100	...	...	...	...	...	...	...	...	
AC5(KSG2)	16.4	100	...	...	...	...	...	...	...	...	
AC1	24	400	...	...	...	...	...	...	...	...	
AC2	37	200	...	...	...	...	...	...	...	...	
AC3	45	35	...	...	...	...	...	...	...	...	
AC4	70	200	...	...	...	...	...	...	...	...	
AC6	24	1000	...	...	...	...	...	...	...	...	
SS06	16.4	20	...	...	...	...	...	...	...	...	
SF9	16.4	8	...	...	...	...	...	...	...	...	
SF9	27.25	1.5	0.34	1.50	0.73	1.02	0.82	-2.00	0.28	3.42	
HiZ1(KSG3.3.1)	40.5	2000	...	...	...	...	...	...	...	...	
HiZ1(KSG3.3.1)	27.25	2000	...	...	...	...	...	...	...	...	
HiZ1(KSG3.3.1)	16.4	2000	...	...	...	...	...	...	...	...	
HiZ5(KSG3.3.2)	72	100	...	...	...	...	...	...	...	...	
HiZ5(KSG3.3.2)	36	100	...	...	...	...	...	...	...	...	
HiZ5(KSG3.3.2)	28	100	...	...	...	...	...	...	...	...	

(Continued Main+Long (or Long) Subarray Results)

			Main+Long – Natural				Main+Long – Robust				
Name	Freq [GHz]	Res [mas]	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
HiZ2	38.4	2000	...	...	...	...	...	...	...	...	
HiZ3	29	2000	...	...	...	...	...	...	...	...	
HiZ6	36	1500	...	...	...	...	...	...	...	...	
HiZ7	16.4	190	...	...	...	...	...	...	...	...	
HiZ7	7.9	150	...	...	...	...	...	...	...	...	
HiZ7	16.4	190	...	...	...	...	...	...	...	...	
HiZ7	7.9	150	...	...	...	...	...	...	...	...	
HiZ8	38	50	...	...	...	...	...	...	...	...	
HiZ10	7.9	100	...	...	...	...	...	...	...	...	
NGA8(KSG3.3.3)	115	100	...	...	...	...	...	...	...	...	
NGA2 (KSG3.3.4)	1.42	2000	...	...	...	...	...	...	...	...	
NGA2(KSG3.3.5)	1.42	60000	...	...	...	...	...	...	...	...	
NGA3	40.5	1000	...	...	...	...	...	...	...	...	
NGA3	27.25	1000	...	...	...	...	...	...	...	...	
NGA3	16.4	1000	...	...	...	...	...	...	...	...	
NGA3	7.9	1000	...	...	...	...	...	...	...	...	
NGA3	2.35	1000	...	...	...	...	...	...	...	...	
NGA6	40.5	6	...	...	...	...	...	...	...	...	
NGA6	27.25	6	...	...	...	...	...	...	...	...	
NGA6	16.4	6	...	...	...	...	...	...	...	...	
NGA7	23	2500	...	...	...	...	...	...	...	...	
NGA9	115	200	...	...	...	...	...	...	...	...	
NGA10	88	1000	...	...	...	...	...	...	...	...	
NGA15	16.4	100	...	...	...	...	...	...	...	...	

(Continued Main+Long (or Long) Subarray Results)

			Main+Long – Natural				Main+Long – Robust				
Name	Freq [GHz]	Res [mas]	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
NGA16	86	0.15	...	...	...	...	...	...	...	...	1
NGA17	40.5	1	0.23	1.00	0.73	1.02	0.54	-2.00	0.29	3.40	
TDCP1 (KSG4)	16.4	20	...	...	...	...	...	...	...	...	
TDCP2 (KSG5)	2.4	1000	...	...	...	...	...	...	...	...	
TDCP8	16.4	0.6	...	...	...	...	...	...	...	...	1
TDCP5	27.25	1000	...	...	...	...	...	...	...	...	
Prepare	7.9	1000	...	...	...	...	...	...	...	...	
TDCP17	16.4	10	...	...	...	...	...	...	...	...	
TDCP17	16.4	1	...	...	...	...	...	...	...	...	1
TDCP17	40.5	0.17	...	...	...	...	...	...	...	...	2
NGA12	115	50	...	...	...	...	...	...	...	...	
TDCP7 (KSG3.5.5)	2.35	100	...	...	...	...	...	...	...	...	
TDCP16	80	0.1	...	...	...	...	...	...	...	...	2
TDCP16	80	0.1	...	...	...	...	...	...	...	...	
TDCP16	27.25	1000	...	...	...	...	...	...	...	...	
TDCP18	7.9	15	...	...	...	...	...	...	...	...	

[1] Unable to achieve target resolution. Long alone works; see results in Table 4
[2] Unable to achieve target resolution. Long does not work but close; see results in Table 4

6.2 Efficient Subarray

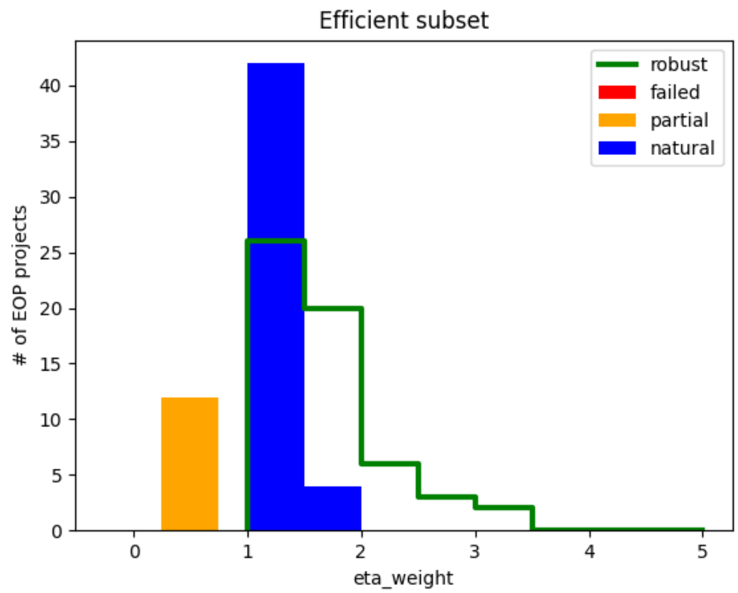
Figure 8 summarizes the results when each of the 60 science use cases were assigned the most Efficient subarray (see Section 2.3.1). The top panel shows that all use cases achieve the target resolution[8] with a natural plus taper weighted PSF (blue bins in the histogram) and inefficiencies $\leqslant 2$. However, as discussed previously the quality of the beams should be studied in detail for each case when using natural plus taper weighting, and beam sculpting may be needed depending of the science requirements.

There is a significant improvement in the inefficiency factors at both natural plus taper (blue bins in the histogram) and robust (green solid in the histogram), as expected from using a more 'efficient' subarray. But of course these subarrays have fewer antennas than Main, so we also need to consider the effect on observation time (see section 10).

Figure 8 (top panel) shows that eleven cases are shown as 'partial' meaning that for the Efficient subarray they were unable to achieve the requested resolution with natural plus taper weighting (although they were typically close enough: <2x lower resolution), but were able to for some value of robust. All these 'partial' use cases are highlighted by the orange cells in Table 4 column 7.

Figure 8 (lower panel) shows that a wide variety of subarrays were chosen by the Efficient metric. Only two cases were assigned Main due to their requirements for both high angular resolution and large LAS. Additionally, in Table 4 column 12 we show that a total of 13 use cases can not achieve a PSF level of 10% even at uniform weighting, although in the majority of the cases the level is very close ($\leqslant 12\%$).

[8] None of the simulations failed to reach the requested resolution, i.e. Long worked for cases where Main+Long did not (see section 6.1.1).



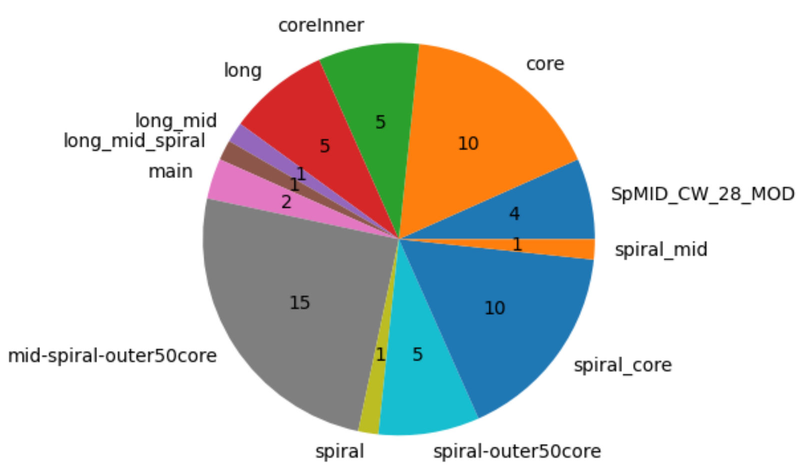


Figure 8: Summary of the simulations for the Efficient subarray **top**: histogram of the results presented in Table 4. **lower**: pie chart showing the occurrence of assigned subarrays.

Table 4: Efficient Subarray

					Efficient – Natural				Efficient – Robust				
Name	Freq [GHz]	Res [mas]	name–sub	#ant	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
PF3(KSG1)	80	5	mid-spiral-outer50core	157	1.71	5.00	0.63	1.09	4.67	-1.24	0.10	2.58	
PF3(KSG1)	27.25	5	mid-spiral-outer50core	157	0.00	6.35	0.63	1.00	3.48	-2.00	0.17	1.98	
PF1	80	15	mid-spiral-outer50core	157	5.69	15.00	0.57	1.24	14.60	-0.42	0.10	2.24	
PF1	27.25	15	mid-spiral-outer50core	157	5.17	15.00	0.63	1.10	14.02	-1.18	0.10	2.58	
PF5	80	5	main	214	1.39	5.00	0.71	1.05	4.68	-1.80	0.10	3.48	
PF5	27.25	5	mid-spiral-outer50core	157	0.00	6.35	0.63	1.00	3.48	-2.00	0.17	1.98	
AC5(KSG2)	40.5	100	spiral_core	168	0.00	108.70	0.47	1.00	80.86	-2.00	0.11	1.51	
AC5(KSG2)	27.25	100	spiral-outer50core	111	0.00	128.47	0.36	1.00	19.64	-2.00	0.11	1.17	
AC5(KSG2)	16.4	100	mid-spiral-outer50core	157	39.19	100.01	0.51	1.29	90.39	-0.13	0.10	1.88	
AC1	24	400	spiral-outer50core	111	270.89	400.00	0.16	1.36	319.91	0.83	0.10	1.39	
AC2	37	200	spiral_core	168	88.80	199.99	0.42	1.09	181.93	-0.05	0.10	1.54	
AC3	45	35	mid-spiral-outer50core	157	13.65	35.00	0.51	1.28	32.86	-0.21	0.10	1.95	
AC4	70	200	spiral_core	168	106.48	200.00	0.25	1.25	159.60	0.55	0.10	1.35	
AC6	24	1000	core	114	453.92	1,000.31	0.12	1.02	525.96	1.04	0.10	1.02	
SS06	16.4	20	mid-spiral-outer50core	157	6.56	20.00	0.64	1.07	18.34	-2.00	0.11	2.53	
SF9	16.4	8	Mid	46	4.88	8.00	0.21	1.12	6.13	-2.00	0.11	1.22	
SF9	27.25	1.5	long_mid_spiral	110	0.27	1.50	0.65	1.01	1.04	-2.00	0.18	2.38	
HiZ1(KSG3.3.1)	40.5	2000	coreInner	57	1,370.00	1,999.97	0.08	1.10	1,598.24	-2.00	0.03	1.15	
HiZ1(KSG3.3.1)	27.25	2000	core	114	1,751.81	2,000.00	0.15	1.63	1,915.76	0.86	0.10	1.66	
HiZ1(KSG3.3.1)	16.4	2000	core	114	1,516.96	1,999.99	0.16	1.18	1,728.56	0.70	0.10	1.23	
HiZ5(KSG3.3.2)	72	100	spiral_core	168	43.92	100.00	0.43	1.08	90.54	-0.06	0.10	1.54	
HiZ5(KSG3.3.2)	36	100	spiral_core	168	0.00	122.33	0.49	1.00	0.00	1.54	0.10	1.46	
HiZ5(KSG3.3.2)	28	100	spiral-outer50core	111	0.00	124.06	0.35	1.00	35.53	-2.00	0.11	1.18	

(Continued Efficient Subarray Results)

					Efficient – Natural				Efficient – Robust				
Name	Freq [GHz]	Res [mas]	name–sub	#ant	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
HiZ2	38.4	2000	coreInner	57	1,259.56	1,999.87	0.08	1.07	1,495.58	-2.00	0.04	1.12	
HiZ3	29	2000	coreInner	57	0.00	2,104.94	0.12	1.00	0.00	1.17	0.10	0.99	
HiZ6	36	1500	core	114	1,312.51	1,500.00	0.15	1.62	1,443.19	0.83	0.10	1.66	
HiZ7	16.4	190	spiral-outer50core	111	0.00	212.15	0.32	1.00	0.00	1.84	0.10	1.58	
HiZ7	7.9	150	mid-spiral-outer50core	157	56.88	149.99	0.57	1.24	146.13	-0.42	0.10	2.25	
HiZ7	16.4	190	...	...	...	...	...	...	...	...	...	...	1
HiZ7	7.9	150	...	...	...	...	...	...	...	...	...	...	2
HiZ8	38	50	mid-spiral-outer50core	157	19.95	50.00	0.47	1.31	39.51	0.14	0.10	1.71	
HiZ10	7.9	100	mid-spiral-outer50core	157	36.87	100.00	0.61	1.18	93.40	-0.50	0.10	2.31	
NGA8(KSG3.3.3)	115	100	spiral_core	168	50.18	100.00	0.32	1.19	86.53	0.31	0.10	1.40	
NGA2 (KSG3.3.4)	1.42	2000	spiral-outer50core	111	0.00	2,467.53	0.35	1.00	695.31	-2.00	0.12	1.17	
NGA2(KSG3.3.5)	1.42	60000	coreInner	57	43,801.63	59,999.36	0.08	1.13	50,596.22	-2.00	0.02	1.19	
NGA3	40.5	1000	core	114	831.53	999.98	0.17	1.35	933.98	0.69	0.10	1.40	
NGA3	27.25	1000	core	114	623.36	999.36	0.13	1.07	718.47	0.85	0.10	1.09	
NGA3	16.4	1000	spiral_core	168	567.51	1,000.02	0.21	1.30	747.47	0.76	0.10	1.34	
NGA3	7.9	1000	spiral_core	168	455.24	999.99	0.41	1.10	912.57	-0.01	0.10	1.52	
NGA3	2.35	1000	mid-spiral-outer50core	157	412.81	1,000.08	0.41	1.35	700.54	0.42	0.10	1.61	
NGA6	40.5	6	main	214	1.18	6.00	0.70	1.01	5.15	-2.00	0.14	3.15	
NGA6	27.25	6	mid-spiral-outer50core	157	0.00	6.35	0.61	1.00	4.53	-2.00	0.16	2.09	
NGA6	16.4	6	mid-spiral-outer50core	157	0.00	10.49	0.69	1.00	3.03	-2.00	0.20	1.84	
NGA7	23	2500	core	114	2,203.60	2,500.00	0.15	1.69	2,380.70	0.90	0.10	1.71	
NGA9	115	200	core	114	72.41	199.95	0.12	1.01	87.87	1.06	0.10	1.01	
NGA10	88	1000	coreInner	57	755.49	999.99	0.07	1.15	867.93	-2.00	0.02	1.21	
NGA15	16.4	100	mid-spiral-outer50core	157	39.19	100.01	0.51	1.29	90.38	-0.13	0.10	1.88	

(Continued Efficient Subarray Results)

					Efficient – Natural				Efficient – Robust				
Name	Freq [GHz]	Res [mas]	name–sub	#ant	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
NGA16	86	0.15	long	30	0.07	0.15	0.18	1.14	0.09	0.04	0.10	1.08	
NGA17	40.5	1	long_mid	76	0.57	1.00	0.41	1.33	0.69	-2.00	0.19	1.84	
TDCP1 (KSG4)	16.4	20	spiral_mid	100	9.11	20.00	0.49	1.17	18.25	-2.00	0.11	1.82	
TDCP2 (KSG5)	2.4	1000	spiral	54	336.65	999.99	0.08	1.00	489.17	-2.00	0.04	1.04	
TDCP8	16.4	0.6	long	30	0.00	0.61	0.17	1.00	0.20	-2.00	0.10	1.09	
TDCP5	27.25	1000	core	114	623.49	999.36	0.13	1.07	718.53	0.85	0.10	1.09	
Prepare	7.9	1000	spiral_core	168	455.24	999.99	0.41	1.10	912.69	-0.01	0.10	1.52	
TDCP17	16.4	10	Mid	46	6.91	10.00	0.20	1.24	8.38	0.39	0.10	1.33	
TDCP17	16.4	1	long	30	0.63	1.00	0.23	1.38	0.79	-2.00	0.11	1.44	
TDCP17	40.5	0.17	long	...	...	...	...	...	...	...	...	...	3
NGA12	115	50	spiral_core	168	18.50	50.00	0.45	1.03	44.78	-0.29	0.10	1.57	
TDCP7 (KSG3.5.5)	2.35	100	Mid	46	78.16	100.00	0.16	1.49	87.25	0.82	0.10	1.51	
TDCP16	80	0.1	long	...	...	...	...	...	...	...	...	...	4
TDCP16	80	0.1	...	...	...	...	...	...	...	...	...	...	5
TDCP16	27.25	1000	core	114	623.39	999.36	0.13	1.07	718.41	0.85	0.10	1.09	
TDCP18	7.9	15	Mid	46	8.32	15.00	0.22	1.08	10.70	-2.00	0.12	1.17	

Notes: Orange colored cell indicates that Natural weighting + Taper is unable to achieve target resolution, but it is otherwise achieved using robust values

[1]Same simulation as other HiZ7_16.4; difference related to observational parameters that are not relevant for the simulations
[2]Same simulation as other HiZ7_7.9; difference related to observational parameters that are not relevant for the simulations
[3]Simulation did not work, but close. Resolution ∼0.23 at uniform instead of 0.17 requested
[4]Simulation did not work, but close. Resolution ∼0.12 at uniform instead of 0.1 requested
[5]Same simulation as other TDCP16_80; difference related to observational parameters that are not relevant for the simulations

6.3 Performance Subarray

Figure 9 summarizes the results when each of the 60 science use cases are assigned the most Performance subarray (see section 2.3.2). The top panel shows that all use cases achieve the target resolution[9] with a natural plus taper weighted PSF (blue bins in the histogram)[10].

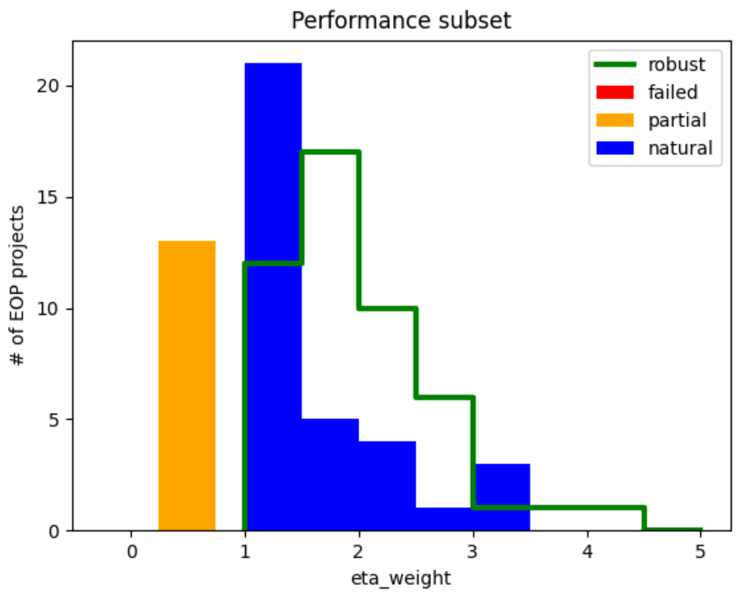
The histogram of inefficiency factors is an improvement over Main (for both natural plus taper and robust weighting), but not as good as the Efficient metric. That makes sense because the subarrays chosen by Performance are trying to be an incremental improvement in efficiency over Main, not the most efficient. However, it is interesting to note that in 31 of the 60 use cases, the subarray assigned by the Efficient and Performance metrics were the same.

Figure 9 (top panel) shows that thirteen cases are shown as 'partial' meaning that for the Performance subarray they were unable to achieve the requested resolution with natural plus taper weighting (although they were typically close, within <2x lower resolution), but were able to for some value of robust. All these 'partial' use cases are highlighted by the orange cells in Table 5 column 7.

We see in Figure 9 (bottom panel) that two subarrays (i.e., Spiral+Core and Mid+Spiral+ Outer50Core) were highly favored by the Performance metric. This makes sense because we know the metric is trying to preserve baselines for the purposes of sensitivity while also making an incremental improvement in efficiency over Main by removing baselines. So the algorithm really only has two reasonable choices based on the 17 potential subarrays it considered: to drop the smallest allowable inner part of the array (CoreInner), or drop the smallest allowable outer part (Mid).

[9] None of the simulations failed to reach the requested resolution.

[10] As discussed previously the quality of the beams should be studied in detail, case by case, when using natural weighting. Beam sculpting may be needed depending of the science requirements.



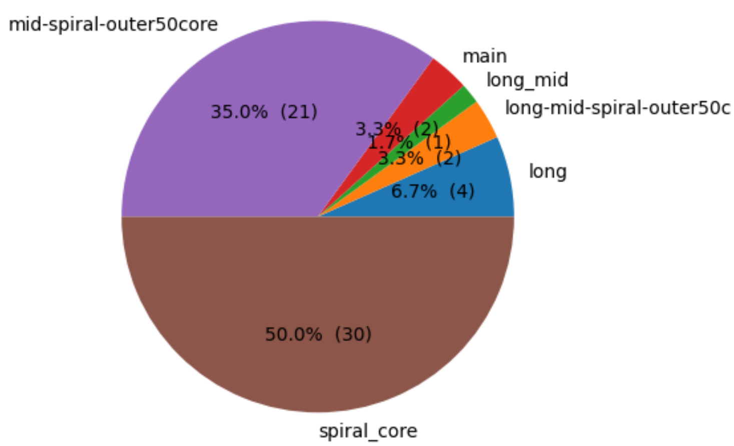


Figure 9: Summary of the simulations for the Performance subarray **top**: histogram of the results presented in Table 5. **lower**: pie chart showing the occurrence of assigned subarrays.

Table 5: Performance Subarray

					Performance – Natural				Performance – Robust				
Name	Freq [GHz]	Res [mas]	name–sub	#ant	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
PF3(KSG1)	80	5	Efficient	157	1.71	5.00	0.63	1.09	4.67	-1.24	0.10	2.58	
PF3(KSG1)	27.25	5	Efficient	157	0	6.35	0.63	1.00	3.48	-2.00	0.17	1.98	
PF1	80	15	Efficient	157	5.69	15.00	0.57	1.24	14.60	-0.42	0.10	2.24	
PF1	27.25	15	Efficient	157	5.17	15.00	0.63	1.10	14.02	-1.18	0.10	2.57	
PF5	80	5	Efficient	-1	...	...	...	...	...	...	...	...	1
PF5	27.25	5	Efficient	157	0	6.35	0.63	1.00	3.48	-2.00	0.17	1.99	
AC5(KSG2)	40.5	100	Efficient	168	0	108.70	0.47	1.00	80.86	-2.00	0.11	1.52	
AC5(KSG2)	27.25	100	spiral_core	168	0	162.26	0.54	1.00	10.80	-0.26	0.10	1.42	
AC5(KSG2)	16.4	100	Efficient	-1	...	...	...	...	...	...	...	...	2
AC1	24	400	spiral_core	168	192.32	400.01	0.37	1.15	355.43	0.16	0.10	1.46	
AC2	37	200	Efficient	168	88.8	199.99	0.42	1.09	181.98	-0.05	0.10	1.54	
AC3	45	35	Efficient	157	13.65	35.00	0.51	1.28	32.86	-0.21	0.10	1.96	
AC4	70	200	Efficient	168	106.47	200.00	0.25	1.25	159.59	0.55	0.10	1.35	
AC6	24	1000	spiral_core	168	706.32	1,000.00	0.16	1.48	822.10	1.00	0.10	1.49	
SS06	16.4	20	Efficient	157	6.56	20.00	0.64	1.07	18.33	-2.00	0.11	2.54	
SF9	16.4	8	mid-spiral-outer50core	157	0	10.49	0.64	1.00	5.49	-2.00	0.17	1.97	
SF9	27.25	1.5	long-mid-spiral-outer50core	187	0.44	1.50	0.68	1.04	0.82	-2.00	0.28	2.68	
HiZ1(KSG3.3.1)	40.5	2000	spiral_core	168	1849.61	2,000.12	0.10	3.11	1,855.50	1.81	0.10	3.11	
HiZ1(KSG3.3.1)	27.25	2000	spiral_core	168	1787.93	1,999.99	0.15	2.40	2,004.74	0.99	0.10	2.42	
HiZ1(KSG3.3.1)	16.4	2000	spiral_core	168	1648.04	1,999.98	0.17	1.75	1,917.91	0.91	0.10	1.77	
HiZ5(KSG3.3.2)	72	100	Efficient	168	43.91	100.00	0.43	1.08	90.51	-0.06	0.10	1.54	
HiZ5(KSG3.3.2)	36	100	Efficient	168	0	122.32	0.49	1.00	0.00	1.54	0.10	1.47	
HiZ5(KSG3.3.2)	28	100	spiral_core	168	0	156.11	0.53	1.00	31.98	-0.24	0.10	1.41	

(Continued Performance Subarray Results)

					Performance – Natural				Performance – Robust				
Name	Freq [GHz]	Res [mas]	name–sub	#ant	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
HiZ2	38.4	2000	spiral_core	168	1838.73	1,999.99	0.11	3.00	1,886.88	1.45	0.10	2.99	
HiZ3	29	2000	spiral_core	168	1796.04	2,000.03	0.15	2.50	1,987.34	1.03	0.10	2.50	
HiZ6	36	1500	spiral_core	168	1340.03	1,499.98	0.15	2.39	1,507.16	0.98	0.10	2.41	
HiZ7	16.4	190	spiral_core	168	0	267.10	0.51	1.00	113.33	-0.67	0.10	1.44	
HiZ7	7.9	150	Efficient	157	56.88	149.99	0.57	1.24	146.15	-0.42	0.10	2.25	
HiZ7	16.4	190	...	...	...	...	...	...	...	...	...	...	3
HiZ7	7.9	150	...	...	...	...	...	...	...	...	...	...	4
HiZ8	38	50	Efficient	-1	...	...	...	...	...	...	...	...	2
HiZ10	7.9	100	Efficient	157	36.88	100.00	0.61	1.18	93.39	-0.50	0.10	2.31	
NGA8(KSG3.3.3)	115	100	Efficient	168	50.18	100.00	0.32	1.19	86.53	0.31	0.10	1.40	
NGA2 (KSG3.3.4)	1.42	2000	spiral_core	168	0	3,113.05	0.53	1.00	722.72	-0.41	0.10	1.42	
NGA2(KSG3.3.5)	1.42	60000	spiral_core	168	55835.28	59,997.77	0.09	3.22	68,445.77	-2.00	0.05	3.86	
NGA3	40.5	1000	spiral_core	168	866.73	999.99	0.17	1.99	990.94	0.91	0.10	2.01	
NGA3	27.25	1000	spiral_core	168	760.5	1,000.00	0.16	1.57	876.57	0.98	0.10	1.59	
NGA3	16.4	1000	Efficient	168	567.48	1,000.02	0.21	1.30	747.51	0.76	0.10	1.34	
NGA3	7.9	1000	Efficient	168	455.25	999.99	0.41	1.10	912.75	-0.01	0.10	1.52	
NGA3	2.35	1000	Efficient	-1	...	...	...	...	...	...	...	...	2
NGA6	40.5	6	Efficient	-1	...	...	...	...	...	...	...	...	1
NGA6	27.25	6	Efficient	157	0	6.35	0.61	1.00	4.53	-2.00	0.15	2.09	
NGA6	16.4	6	Efficient	157	0	10.49	0.69	1.00	3.03	-2.00	0.20	1.84	
NGA7	23	2500	spiral_core	168	2243.66	2,500.05	0.15	2.48	2,486.20	1.03	0.10	2.49	
NGA9	115	200	spiral_core	168	137.52	200.00	0.16	1.45	161.79	0.99	0.10	1.47	
NGA10	88	1000	spiral_core	168	934.73	999.96	0.09	3.29	1,140.01	-2.00	0.05	4.15	
NGA15	16.4	100	Efficient	-1	...	...	...	...	...	...	...	...	2

(Continued Performance Subarray Results)

					Performance – Natural				Performance – Robust				
Name	Freq [GHz]	Res [mas]	name–sub	#ant	TA [mas]	Res [mas]	level	η	TA [mas]	robust	level	η	Notes
NGA16	86	0.15	Efficient	-1	...	...	...	...	...	...	...	...	2
NGA17	40.5	1	long-mid-spiral-outer50core	187	0.29	1.00	0.68	1.04	0.55	-2.00	0.28	2.67	
TDCP1 (KSG4)	16.4	20	mid-spiral-outer50core	157	6.56	20.00	0.64	1.07	18.34	-2.00	0.11	2.54	
TDCP2 (KSG5)	2.4	1000	mid-spiral-outer50core	157	414.51	1,000.04	0.40	1.35	691.45	0.44	0.10	1.61	
TDCP8	16.4	0.6	Efficient	-1	...	...	...	...	...	...	...	...	2
TDCP5	27.25	1000	spiral_core	168	760.49	999.99	0.16	1.57	876.57	0.98	0.10	1.59	
Prepare	7.9	1000	Efficient	168	455.24	999.99	0.41	1.10	912.69	-0.01	0.10	1.52	
TDCP17	16.4	10	mid-spiral-outer50core	157	0	10.49	0.61	1.00	7.59	-2.00	0.15	2.11	
TDCP17	16.4	1	long_mid	76	0.12	1.00	0.36	1.00	0.27	-2.00	0.29	1.23	
TDCP17	40.5	0.17	Efficient	...	...	...	...	...	...	...	...	...	5
NGA12	115	50	Efficient	168	18.5	50.00	0.45	1.03	44.78	-0.29	0.10	1.57	
TDCP7 (KSG3.5.5)	2.35	100	mid-spiral-outer50core	157	27.54	99.99	0.63	1.03	85.29	-2.00	0.13	2.33	
TDCP16	80	0.1	Efficient	...	...	...	...	...	...	...	...	...	5
TDCP16	80	0.1	...	...	...	...	...	...	...	...	...	...	6
TDCP16	27.25	1000	spiral_core	168	760.5	1,000.00	0.16	1.57	876.55	0.98	0.10	1.59	
TDCP18	7.9	15	mid-spiral-outer50core	157	0	21.83	0.66	1.00	9.60	-2.00	0.18	1.91	

Notes: Orange colored cell indicates that Natural weighting + Taper is unable to achieve target resolution, but it is otherwise achieved using robust values

[1] Main only option
[2] Assigned array same as Efficient
[3] same simulation as other HiZ7_16.4; difference related to observational parameters that are not relevant for the simulations
[4] same simulation as other HiZ7_7.9; difference related to observational parameters that are not relevant for the simulations
[5] Long does not work
[6] same simulation as other TDCP16_80; difference related to observational parameters that are not relevant for the simulations

7 Relative Target Times when Compared to Main

In section 2.3 we showed how using an alternative subarray can yield an efficiency improvement over Main. But we also know that these efficient subarrays have fewer antennas than Main. Therefore, an important point to consider is how choosing to use such a subarray will increase the observation time.

In equation 1 we define a 'relative T_{target} metric' which accounts for the improvement in efficiency together with the reduction of antennas.

$$T_{target,rel} = \left(\frac{T_{Efficient}}{T_{Main}}\right) = \left(\frac{\eta_{Efficient}}{\eta_{Main}}\right)^2 \times \left(\frac{N_{Main}}{N_{Efficient}}\right)^2 \tag{1}$$

This is derived from the radiometer equation with the large N approximation for the number of baselines. In this equation, η is the inefficiency factor of the indexed subarray and N is the number of antennas in that subarray. Equation 1 is showing an example for the case where we consider the time factor of the Efficient subarray compared with Main. This shows that, at least in principle, that you could achieve the same observation time by choosing Efficient instead of Main if your efficiency (or 'inefficiency' factor) improves enough to offset the loss of antennas.

Additionally, in the presentation of our results we organize the EOP cases by 'relative resolution', i.e. the requested resolution scaled to a constant frequency, so we can refer to the science cases as either 'low' ($\gtrsim 10^2$ mas) or 'high' ($\lesssim 10^2$ mas) resolution, respectively.

$$Resolution_{relative} = Resolution_{EOP} \times \left(\frac{\nu_{EOP}}{30\,\mathrm{GHz}}\right) \tag{2}$$

7.1 Relative Target Times: Efficient, Natural

Figure 10 shows the $T_{target,rel}$ results for the efficient metric, using natural plus taper weighting (i.e. the inefficiency factor comes only from taperability). The y-axis shows the square root of $T_{target,rel}$ to help compress the outliers. Thus, a value of 4 here on the Y-axis is actually 16x more observing time. The large outliers are mostly for subarrays having a lot less antennas than Main, for example Mid-only represented by the blue dots. For these cases it seems like using such a small subarray is probably undesirable compared with using the full array. Mid was chosen as the most efficient compatible subarray for these cases since they do not request a large LAS, but getting rid of all the Core and Spiral antennas appears is greatly reducing the sensitivity.

But besides these outliers we see many results within a factor of 2x Main observing time, and even *a whole group of results that appear to have nearly the same observing time as Main*. This result is extremely positive and shows the importance of using subarrays for certain science cases. The results near 1 are all low resolution ($\gtrsim 10^2$ mas) cases for which the efficient metric has selected a subarray that drops the outer antennas (specifically, using subarrays like Spiral+Core, or just Core, or just CoreInner). If these projects were assigned Main instead of the Efficient subarray, they would have to use a very extreme UV-taper to

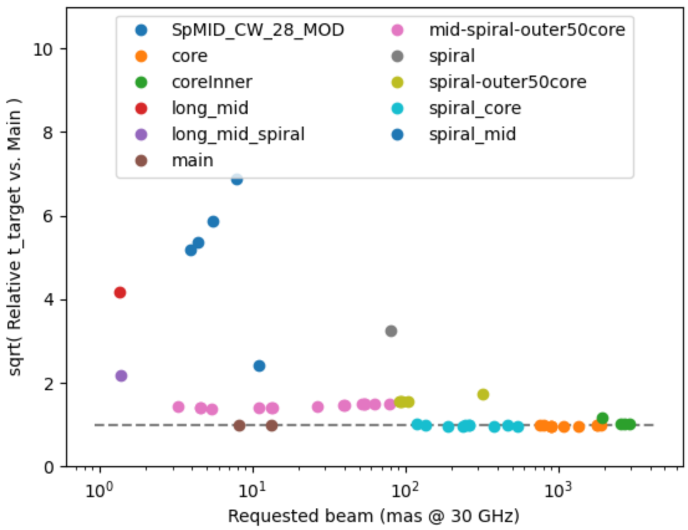


Figure 10: Relative requested beam as a function of the square-root of the $T_{target,rel}$ for the **Efficient metric** compared with Main using **natural** weighting.

remove a lot of long baselines.

In order to better understand these results, in Figure 11 we show the histograms of the baselines of Main, Spiral+Core and Mid. When comparing the baselines from Main with Spiral+Core they are the same up to $\sim$ 20000m. Thus, adding Mid to Spiral+Core does not add any short baselines like the ones a low resolution project would want to use. Moreover, adding Mid only adds long baselines that would fall under the UV-taper. So our relative target time result in Figure 10 is showing that the observational time is the same whether we include Mid with a large UV-taper versus just not using Mid at all.

7.2 Relative Target Times: Efficient, Robust

Figure 12 shows the square root of the $T_{target,rel}$ results for the efficient metric, using robust weighting. These simulations are trying to use beam sculpting (taper + robust) to achieve a high quality PSF (defined as a level of 0.1). We see that the results for the low resolution ($\gtrsim 10^2$ mas) cases have not changed much, which is expected since they usually have a pretty good PSF at natural and do not need much beam sculpting. But for the higher resolution ($\lesssim 10^2$ mas) projects, which can have a very poor natural PSF, we see that some of the efficient subarrays like mid-spiral-outer50core can achieve about the same target time as Main.

An explanation for these results can be found in the studies presented in ngVLA memos #72 [3] and #76 [4]. That is, an alternative method to reduce the level of the PSF skirt is to select a subarray where the number of short baselines is not as large when compared with

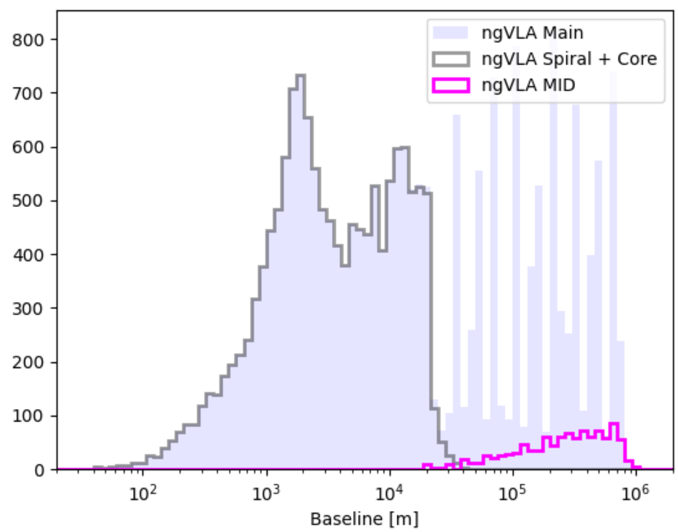


Figure 11: Histograms of the baselines of Main, Spiral+Core and Mid. When comparing the baselines from Main with Spiral+Core they are the same up to $\sim$ 20000m. Thus, adding Mid to Spiral+Core does not add any short baselines like the ones a low resolution project would want to use.

the amount of longer baselines. Furthermore, subarrays that 'naturally' produce a more Gaussian PSF will require less extreme imaging weights and therefore will incur a less severe sensitivity penalty. An example of this is shown in ngVLA memo #72 [3] Figure 16, where it shows that by removing antennas from the Core we can reduce the skirt of the naturally weighted PSF. Therefore, for the higher resolution projects $\lesssim 10^2$ mas) in the EOP, we see several cases where the Efficient subarray is choosing to remove CoreInner and therefore getting a better natural PSF, so beam sculpting to reach a skirt level of 0.1 can be done with less of a sensitivity penalty.

The takeaway of this part of the study is that at *low resolution* the Efficiency metric (i.e., Efficient subarray) seems to be the preferred subarray since it is using fewer antennas but the observation time is nearly the same than when using the Main subarray. This is true for both natural plus taper and robust cases.

7.3 Relative Target Times: Performance, Natural

Figure 13 shows the square root of the $T_{target,rel}$ results for the performance metric, using natural plus taper weighting (i.e. the inefficiency factor comes only from taperability). As we saw before, this metric is trying to maximize the number of baselines over the range that the science case has requested, but is also trying to improve the efficiency over Main

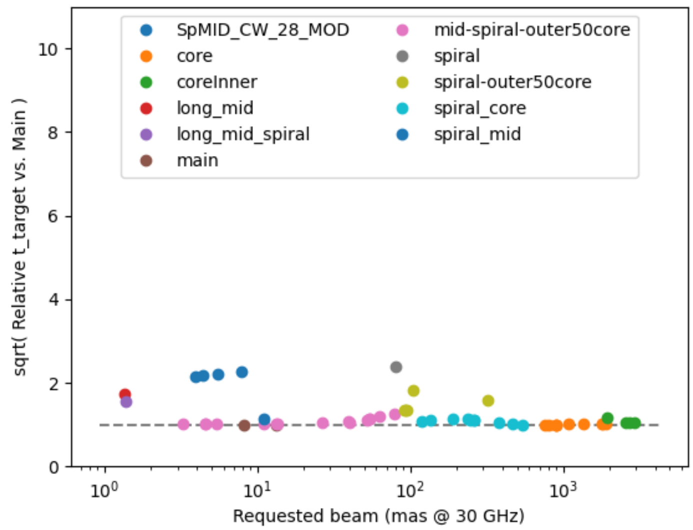


Figure 12: Relative requested beam as a function of the square-root of the $T_{target,rel}$ for the **Efficient metric** compared with Main using **robust** weighting.

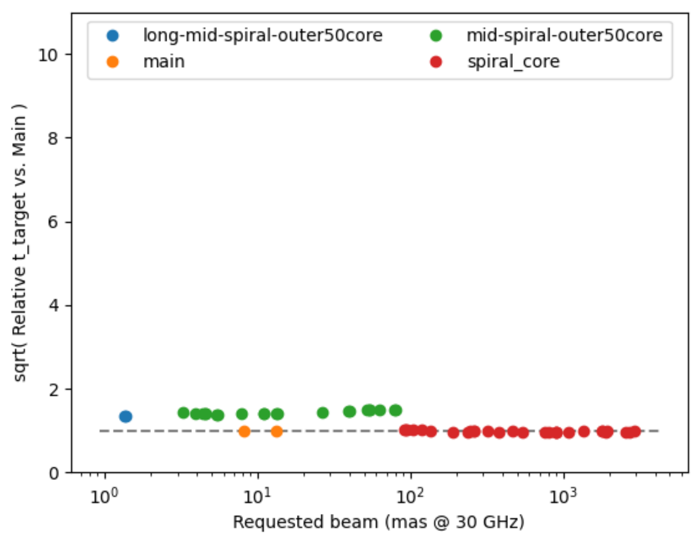


Figure 13: Relative requested beam as a function of the square-root of the $T_{target,rel}$ for the **Performance metric** compared with Main using **natural** weighting.

by dropping a small number of antennas (usually by dropping either Mid or CoreInner). There are two cases where Main has to be used because of the angular resolution plus LAS requirements.

Basically these results are very consistent with the Efficient metric except without the efficient outliers, because we are avoiding very small subarrays (i.e., small number of antennas) like Mid-only.

For the *higher resolution* projects (e.g. green dots) there is a clear sensitivity (and therefore observing time) penalty from dropping Core antennas. This is because the Core provides a lot of medium-length baselines between Core antennas and the outer parts of the array. ***For high-resolution science cases that do not require a good PSF it seems preferable to use the full array instead of a subarray.***

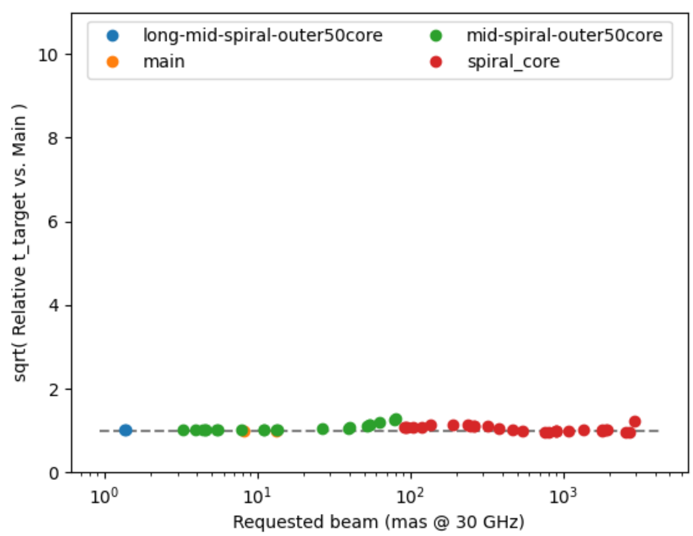
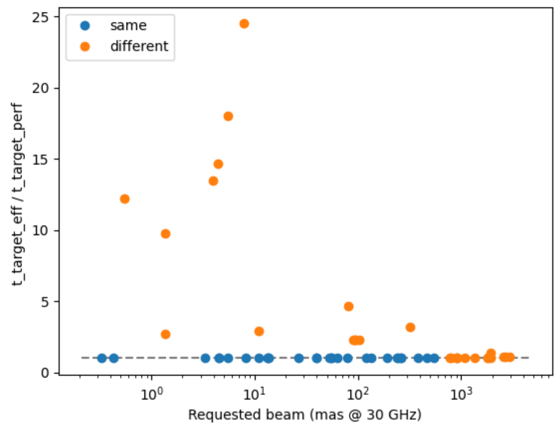


Figure 14: Relative requested beam as a function of the square-root of the $T_{target,rel}$ for the **Performance metric** compared with Main using **robust** weighting.

7.4 Relative Target Times: Performance, Robust

Figure 14 shows the square root of the $T_{target,rel}$ results for the performance metric, using robust weighting. These simulations are trying to use beam sculpting (taper + robust) to achieve a high quality PSF (defined as a level of 0.1). Specifically, we see that for high resolution ($\lesssim 10^2$ mas) projects that need a good PSF, dropping CoreInner may be preferable than more extreme beam sculpting. In general, it will be important to collect use case requirements about quality of the beam in order to decide the most appropriate strategy to meet the science requirements and create an efficient observing program.



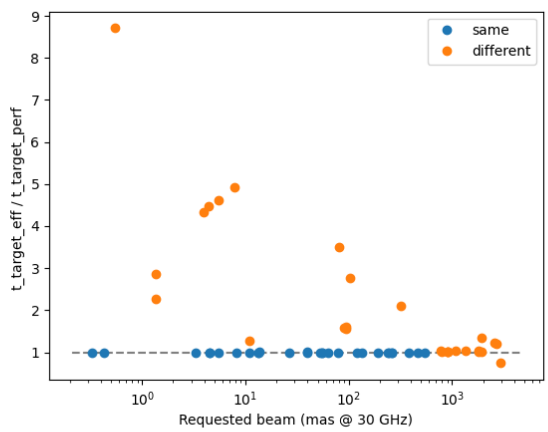


Figure 15: Relative requested beam as a function of the $T_{target,rel}$ for the Efficient metric compared with the Performance metric using **(top)** natural plus taper and **(bottom)** robust weighting. Note the y-axis in these plots are not the square-root of the relative times as in the other versions in the previous section.

8 Relative Target Times when Comparing Both Metrics

Figure 15 shows the relative requested resolution as a function of the $T_{target,rel}$ for the Efficient metric compared with the Performance metric using natural plus taper (top) and robust (bottom) weighting. The two colors of dots represent the use cases for which the Efficient and Performance metrics have assigned the same (blue) and different (orange) subarrays.

From Figure 15, for the low resolution part (i.e., where the Performance metric assigns

Spiral+Core; see Figures 13 and 14), we can see that for the 'highest resolution' of that region ($\sim$100 – 600 mas in Figure 15) the same subarray is selected. Then, for the lowest resolution the results suggest that for all the cases where the relative time of Efficient/Performance is close enough to 1 we should select the subarray having fewer antennas (i.e., Efficient metric). **Therefore, for everything in the low resolution region it is recommended to select the results from the Efficient metric.**

For the high resolution part ($\sim$0.3 – 100 mas), with the exception of some outliers, we see that both Efficient and Performance algorithms have made the same assignment, which is the Mid+Spiral+outer50Core subarray (see Figures 10, 12 13 and 14). For these cases, the choice of Mid+Spiral+outer50Core or Main would depend on if a good PSF is needed. For the outliers, where Efficient has chosen a much smaller subarray than Performance, it appears that the Performance subarray is the preferred choice over Efficient. So in general, for all the high resolution cases, the preferred subarray appears to be either Performance or Main, depending on if a good PSF is needed.

9 Relative Antenna Hours

Similar to $T_{target,rel}$, we can also analyze the EOP results using the metric of relative antenna hours. For an observation that uses N_{ant} antennas for a duration T_{target} we define the absolute quantity of antenna hours, AH, as

$$AH = N_{ant} \times \frac{T_{target}}{1\,\mathrm{hour}} \tag{3}$$

and the antenna hours for a subarray relative to Main, AH_{rel}, as

$$AH_{rel} = \frac{AH_{subarray}}{AH_{Main}} = \frac{N_{ant,subarray}}{N_{ant,Main}} \times T_{target,rel} \tag{4}$$

In Figure 16 we show the resulting AH_{rel} for all projects in the EOP if they were to be observed with the most efficient subarray (blue), the better performance subarray (red), and cases where the efficient and performance algorithms both select the same subarray (green), and for each of two weighting scenarios: taperability (top plot; for which only UV-taper weights are used) and sculptability (bottom plot; for which UV-taper and robust weights are used). If no imaging weights were considered then AH_{rel} would depend only on the number of antennas in the subarray and the results would follow the theoretical curve (black dashed line). Our results show that many projects have AH_{rel} below the theoretical curve and a significant number actually lie below the AH_{rel}=1 line, meaning that these cases could be observed in less antenna hours using the assigned subarray than by using Main. Our explanation for these results is that in the calculation of AH_{rel}, the improvement in the subarray's efficiency (by way of improving $T_{target,rel}$) more than offsets the reduction in the number of antennas. We consider this to be an important result that demonstrates the importance of including the effects of weighting on planning an efficient, high-throughput observing program. We also display these same AH_{rel} results in Figure 17 plotted against the 'relative resolution' axis. This allows the data to spread out more instead of being concentrated at specific numbers of subarray antennas, and provides a more direct comparison to previous figures (i.e., the results of $\mathrm{T}_{target,rel}$).

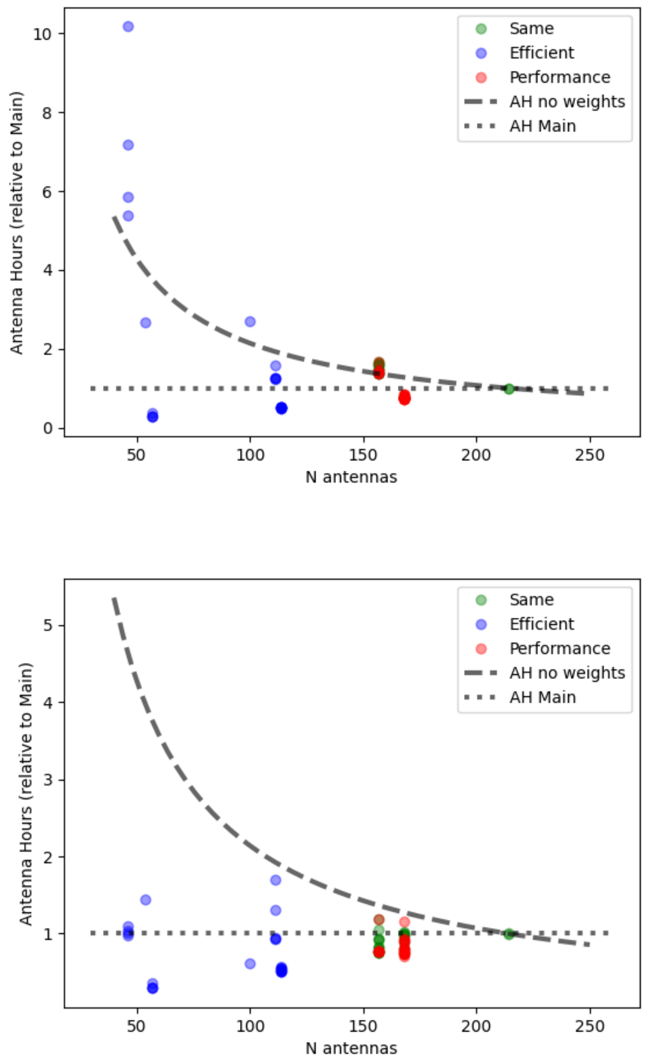
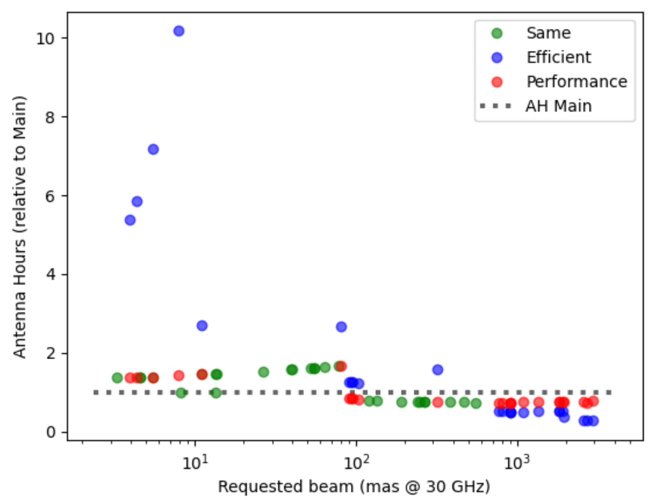


Figure 16: Number of antennas as a function of the relative antenna hours using **(top)** natural plus taper and **(bottom)** robust weighting. Note the y-axis range in these plots are different to accommodate the outliers. The dashed curve represents the theoretical change in AH based only on changing N without including any weights. The dotted line is drawn at AH_{rel}=1 for reference.



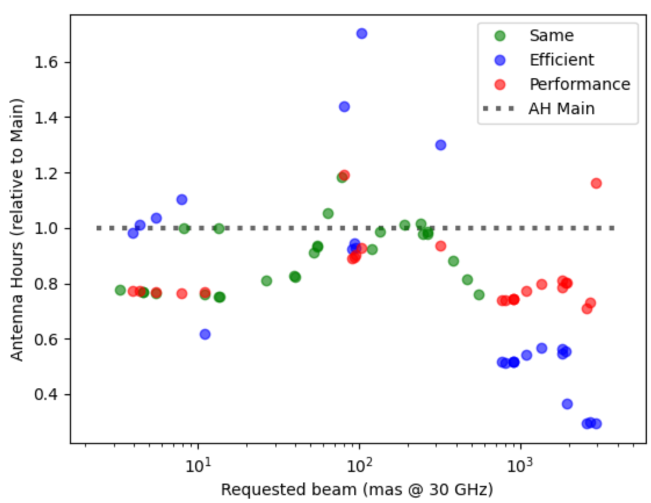


Figure 17: Relative requested beam as a function of the relative antenna hours using **(top)** natural plus taper and **(bottom)** robust weighting. Note the y-axis range in these plots are different to accommodate the outliers.

10 Example of the Advantage of using Subarrays

Analyzing absolute target times could help us understand the effects of a total EOP observing time, since using subarrays will then allow for parallel observations. However, we will defer a thorough estimate of absolute times to a later memo.

In this section we present a toy example demonstrating the advantage of using subarrays. Consider an extreme case where we have two projects in an observing program, for which:

- Project 1: The efficient algorithm assigns only the Core subarray
- Project 2: The efficient algorithm assigns a subarray that excludes the Core (i.e., Spiral+Mid)

Table 6: Comparison of Proposed Scenarios

	Project 1	Project 2
Science Case	HiZ1 @ 16.4 GHz	TDCP1 @ 16 GHz
Subarray	Core	Spiral+Mid
η_{Main}	2.28	3.39
η_{Eff}	1.23	1.82
N_{Eff} [antennas]	114	100
$T_{target,rel}$	1.025	1.32
Efficient T_{target} [hrs]	102.5	132
Antenna hours (Eff)	11,685	13,200
Antenna hours (Main)	21,400	21,400
Baseline hours (Eff)	660,202	653,400
Baseline hours (Main)	2,279,100	2,279,100

Furthermore, let us assume that both cases require a good PSF (i.e., need beam sculpting) for a skirt level of 0.1, so for this example we will use the results from robust weighting. From our results in Table 4 we identified use cases HiZ1 at 16.4 GHz and TDCP1 at 16.4 GHz as matching the description of Projects 1 and 2 above, respectively.

We also adopt a nominal target sensitivity for this example such that it will take 100 hours with Main to reach the target sensitivity for each project. We then explore two scenarios:

- Scenario A – observing in series: We complete project 1 and then project 2 using the Main subarray, thus both projects will be observed in a total of 200 hrs
- Scenario B – observing in parallel: We complete projects 1 and 2 using the assigned subarrays from the Efficient metric, observed concurrently.

The results of this analysis are summarized in Table 6. For scenario A, we know that both projects 1 and 2 will be observed in a total time of 200 hrs to achieve the nominal target sensitivity. For scenario B, Table 6 row 7 shows that the observing time for each individual project is less than 200 hrs. Since the projects are running concurrently in this scenario, they will both be completed within the longer of the two individual observing times, which in this case is only 132 hours. This example provides a demonstration of how observing with multiple subarrays can improve the throughput of a ngVLA observational program.

11 Conclusions

The results of this study show that subarrays offer a lot of potential for ngVLA. Some of the most important results are as follows:

- For 'Low resolution' projects the $T_{target,rel}$ are about the same for both metrics (i.e., Efficient and Performance), even in the cases when they recommend different subarrays
- For 'Low resolution' projects the Efficient subarray seems to be giving the better solution since it is using fewer antennas and the $T_{target,rel}$ is approximately the same than when using Main. Therefore, these projects can be observed without the outer parts of the full array without significant penalties. This is true for both natural plus taper and robust cases
- For 'High resolution' projects, with the exception of some outlier cases, both the efficient and performance metrics converge to the same suggested subarray which is Mid+Spiral+outer50Core. However, the decision to use Mid+Spiral+outer50Core instead of Main needs to consider the requested quality of the beam:
  - Cases OK with natural plus taper weighting (i.e., a large PSF skirt) should use the Main array
  - Cases that need a higher quality PSF should use a subarray which drops at least CoreInner, in order to provide a more efficient alternative to very extreme (approaching uniform) robust weighting
- For a significant number of use cases, especially when using robust weighting, the use case can be observed with a more efficient subarray in less antenna hours than if it was observed with Main. This demonstrates the importance of including the effects of weighting when planning an efficient, high-throughput observing program. More specifically, the weight should be considered together with other factors like the pressure of various subarrays.

Acknowledgments

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Table 7: Appendix –Factor to estimate the effective B_{max} used in the heuristic to assign subarrays

Subarray	B_{min} [m]	B_{max} [m]	B_{maxNat} [m]	$factor_{Nat}$
mid	18951.898	1227573.498	707019.218	1.736
long-mid-spiral-outer50core	179.004	8685633.125	2350915.909	3.694
long	515172.474	8685633.125	6237110.809	1.392
coreInner	39.358	1630.532	1015.784	1.605
spiralPlus5core	403.584	39269.926	25725.146	1.526
long+mid+spiral+5core	403.584	8685633.125	2798654.840	3.103
spiral	811.050	39269.9265	27135.616	1.447
spiral+mid	811.050	1227573.498	457349.571	2.684
long+mid	18951.898	8685633.125	3838747.825	2.263
spiral+mid+5core	403.584	1227573.498	445420.538	2.756
main	39.358	1227573.498	305143.489	4.023
spiral-outer50core	179.004	39269.926	17665.648	2.223
long+main	39.358	8685633.125	2045516.031	4.246
long+mid+spiral	811.050	8685633.125	1830706.859	4.744
spiral+core	39.358	39269.926	13995.544	2.806
core	39.358	4268.96	2875.223	1.485
mid-spiral-outer50core	179.004	1227573.498	359113.638	3.418

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