On the Scientific Benefits of Cross Correlating the 12m Array and the ACA

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ABSTRACT

The scientific benefits of taking cross correlation between the ACA antennas and the 12m antennas (the *Combined Array* hereafter) are summarized. We provide two of our main arguments to recommend the implementation of the Combined Array in the following.

The *Combined Array* will provide; (1) 15-20% improvement in the sensitivity of the 12m array which will significantly impact ALMA science that targets deep and small fields, and (2) a factor of six improvement in point source sensitivity of the ACA which will allow us to meet the stringent calibration requirements of ALMA in a much shorter time (by x 4–9), providing considerably more on-source integration time which is highly important for maximum science output. We found that the relative array location between the ACA and the 12m array in compact configuration will produce a beam that is well behaved in almost all parts of the sky for both a snapshot and a longer track. We also show that the difference in the slew acceleration between the ACA and the 12m antennas does not degrade the sensitivity of the *Combined Array*. We are aware of the importance of developing new software (or modifications of existing software) to properly calibrate the data obtained using the heterogeneous array, but the two pioneering heterogeneous millimeter instruments (the Nobeyama Rainbow Array and CARMA) will provide the needed expertise in time for efficient and proper software development.

We note here that although the *Combined Array* will provide the scientific advantages outlined in this text, the primary role of the ACA is to provide the short-spacing *uv* data that is not physically attainable by using the 12 meter array alone. While imaging simulations of a few specific cases have shown that the routine use of the *Combined Array* is feasible (Takakuwa et al.), the parameter space is still largely unexplored, and the *Combined Array* may not provide significant advantages in all science cases. Thus we advocate that the *Combined Array* should be kept as an observing mode option for the user to chose from.

1. Terminology

- **12m Array:** The array of 12-m antennas implemented by the NA/EU baseline project. We assume in this document a 48 element 12-m array.
- **ACA:** Atacama Compact Array is composed of twelve 7m antennas and four 12m antennas. The term, ACA, is used in general to express the whole system.
- **7m Array:** The array of 12 7m antennas in ACA mainly operated as an interferometer.
- **TP Array:** The four 12m ACA antennas, mainly operated as single dish telescopes
- **ACA full array:** array composed of 7m + TP arrays, operated as an interferometer for mainly taking calibration data.
- **Coordinated Observations:** observations performed on common observing programs using both the 12m array and the ACA that are executed separately. This is the primary observing mode of the ACA, and cross correlation between the 12m array and the ACA is not obtained.

- ***Combined Array* (or Heterogeneous array):** an array composed of the 12m array + the 7m array (+ TP array), operated as an interferometer (TP array might also be combined for calibration purposes etc.). Cross correlation between the 12m array and the ACA is obtained. This term is italicized in this document to emphasize its proposed use.

2. Introduction

The Atacama Compact Array (ACA) will deliver 12 7 meter and 4 12 meter dishes to the ALMA project, providing short spatial frequencies in the *uv* domain that are not observable with the 12 meter array. The dominant constituent of the cold universe is extended gas and cold dust emission, and thus the addition of the ACA will significantly improve the image quality of many astronomical sources targeted by ALMA. According to the current plan, the complete 64 element 12 meter array will not be delivered in the initial stages of the commissioning of ALMA, and thus finding an efficient way to improve the sensitivity and image quality with minimum cost impact to the project is highly desired. In addition, it has been becoming apparent that some of the current ACA calibration specs are extremely difficult to achieve in a reasonable amount of observing time using the ACA alone. Thus we propose here that the implementation of the *Combined Array* as one such way to help the ACA meet the stringent calibration specs required for some ACA projects, and to deliver high quality, high fidelity images required by the 12m array science. See a Memo by M. Wright [ALMA memo 450] for studies of the heterogeneous ACA full array (cross-correlating the 7m and 12m ACA antennas).

3. Improvements in Sensitivity

Table 1 summarizes the theoretical point source sensitivities (see Appendix A for the definition) calculated using various ALMA observing modes. It is obvious from the table that the ACA sensitivity is a factor 5 – 6 worse than that using the 12m array alone. The sensitivity, however, improves significantly by adopting Coordinated Observations, and further improves by $\sim$ 15% when the *Combined Array* is used. Further improvement in sensitivity is expected at submm wavelengths; i.e. the 7m aperture efficiency is expected to be higher than the 12m antennas in submm wavelengths which in turn yields a 17% improvement in the sensitivity of the 12m array. The aperture efficiency of $\sim$ 40% for the 7m antenna with 20 micron surface accuracy and $\sim$ 25% for the 12m antenna with 25 micron surface accuracy at 850 GHz will yield $\eta_{7m}/\eta_{12m} \sim 1.3$.

These improvements in sensitivity brought by the *Combined Array* can provide significant impact to both **the 12m science** and **the calibration accuracy of the ACA**, and we provide a detailed account of the proposed improvements in the following subsections.

3.1. Impact to the 12m array science

From the inclusion of all of the 7m-12m (+ TP) correlations, the *Combined Array* will improve the sensitivity of the 12m array by 15 – 20%. This is equivalent to adding about eight 12m antennas to the 12m array. The 15 – 20% improvement in sensitivity (which amounts to $\sim$ 30% less observing time) can provide significant impact to deep observations that require multiple tracks of small fields. There are at least two

Level 1 ALMA science projects that meet these criteria, such as (1) "Detecting the Milkyway at z=3" and (2) "Protoplanetary Disks". Initial statistics from the DRSP shows that about $\sim 60\%$ of the total ALMA time requests the use of the 12m array alone (Table 2). Of the 60% , about 20% of the time is requested for observing sources similar to ones mentioned above. **Thus about 10% of all ALMA science projects will benefit from the 15-20% improvement in the sensitivity, or in other words the required sensitivity will be achieved in about 30% shorter observing time.** The latter is quite significant for higher frequency bands where the time window for observation may be short due to time constraints given by variable weather conditions.

3.2. Improvements in the ACA Calibration

3.2.1. Improved Antenna-based Calibration using the Combined Array

The point source sensitivity of the ACA is a factor of $5 - 6$ worse than the 12m array, and thus preliminary estimates show that it will take $2 - 3$ hours in order to obtain bandpass calibration data with spectral dynamic range of $> 100 : 1$. Obtaining accurate gain calibration faces a similar problem – ACA will need to observe a calibrator twice as distant in order to achieve a calibration accuracy that is comparable to the 12m array [Kawabe, ALMA-90.00.00.00-013]. To increase the ACA sensitivity toward gain calibrators, the ACA full array will be used when observing bandpass and gain calibrators. The added signal provided by this method, however, still is not enough to match the sensitivity of the 12m array, and it is proposed here that many of the calibration steps could be expedited by implementing the *Combined Array*, such as;

- Baseline calibration
- Interferometric pointing calibration
- Instrumental delay calibration
- Bandpass calibration
- Sideband gain calibration for DSB receivers
- Complex gain (Amplitude and Phase) calibration during observations
- Absolute flux calibration and bootstrapping from primary to secondary
- Cross calibration (here defined as adjusting amplitude scales between visibilities taken by 7m-7m and 12m-12m baselines, and TP array; this does not mean only adjusting amplitude scales locally at overlapped UV ranges)

Our current basic plan is to use the ACA full array (7m + TP) to perform each calibration step down to the required accuracy. Extremely high and challenging accuracy is required for some calibration items (e.g., a spectral dynamic range higher than 1000:1). It has been becoming apparent that the high accuracy of these calibration items is very difficult and time consuming to achieve using the ACA alone, and the *Combined Array* will provide us the valuable sensitivity needed to calibrate antenna-based, e.g., bandpass gain can be obtained more accurately and much faster assuming that the calibration accuracy is s/n limited. By using the *Combined Array*, we expect a $\sim 2 - 3$ improvement in the antenna based calibration sensitivity which is equivalent to $4 - 9$ time less observing time. From initial statistics of the DRSP (Table 2), **we estimate**

that about 20% of all ACA projects will benefit from the implementation of the *Combined Array*.

3.2.2. Improved Cross-calibration between the ACA and the 12m array in Coordinated Observations

The key element of the ACA system is to provide short spatial frequency data (with TP) to the 12m array such that extremely high image fidelity is achieved [Tsutsumi et al. ALMA Memo 488]. However, properly adjusting the visibility amplitude scales taken at two independent arrays could be a major issue, possibly deteriorating the overall image quality and dynamic range. For Coordinated Observations, the same target is not necessarily observed concurrently with the ACA and the 12m arrays, and a common calibrator should be observed at some point during the observation in order to adjust the amplitude scales of the target visibilities. Even if a common calibrator is properly observed using both arrays, the difference in observing conditions and time variability of the calibrator (which can be calibrated to some accuracy) may introduce errors to the final image when two data are added in the *uv* domain. On the other hand, the scaling errors will be minimal when the calibration is performed using the Combined Array[1]. Extremely accurate cross calibration data will be obtained because the same calibrator is observed under the same observing conditions using both arrays simultaneously.

4. Possible Issues

Since the *Combined Array* was not considered initially as part of the ALMA design, possible technical and scientific issues need to be studied carefully.

4.1. *uv* Sensitivity and Beam characteristics

The array location of the ACA relative to the 12m array, which is $\sim 150m$ apart, may not be optimized for the *Combined Array* (Figure 1). However, the additional baselines given by cross-correlating the 7m and the 12m antennas will provide improvements in the *uv* sampling function as seen in Figure 2. The effect of adding these additional correlations is seen particularly in the intermediate spatial frequencies for the adopted pad locations (i.e. the most compact configuration for the 12m array). If a more sparse array configuration for the 12m array is used, the improvements in the *uv* sampling will be seen in a much broader range of spatial frequencies than that shown in Figure 2.

We have also studied the beam characteristics and its impact to scientific imaging using the relative array locations shown in Figure 1. The synthesized beams and *uv* coverage from a 18 minute snapshot (and a full track) observation is shown in Figure 3 (and 4). Table 3 summarizes the results of simulations for sources at various declinations across the sky using the *Combined Array*, and its comparison to the beams obtained from the 12m array alone. Here we note that each *uv* data is weighted by the diameter of the dish when the the synthesized beam is produced. In general, the elongation of the beams is insignificant except for observations at low elevation, and sidelobes are significant at the 0.1% level for a snapshot observation.

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[1] In this case we assume a observing mode in which the calibrators are observed using the *Combined Array* mode, but the target source is observed using the Coordinated Observation mode. See §5.

Comparing the beam characteristics for the *Combined Array* with a snapshot observation taken with the 12m array alone shows that the axial ratio, angular resolution, and the sidelobe levels do not change significantly between the two observing modes. A full track with the *Combined Array* provides a synthesized beam that is fairly round with significantly lower sidelobes. We note that the synthesized beams created here will most likely improve when a more extended configuration for the 12m array is adopted. Hence the values given here are probably the worst case scenario.

These preliminary studies show that the degradation in the images by adopting the *Combined Array* is minimal. The beam is well behaved for sources at different declinations, both for a snapshot and a full track. Thus the *Combined Array* will provide high fidelity images for short tracks as well as for tracks that need long integrations for improving the sensitivity.

4.2. Antenna characteristics

One of the possible concerns is in the difference in the slew acceleration (Table 4) between the ACA and the 12m array antennas (See Memo by Takakuwa for a complete discussion). Here we estimate how the reduced acceleration of the ACA antennas degrades the sensitivity of fast-switching observations in the *Combined Array*. Figure 5 schematically shows one fast-switching cycle and the potential loss in sensitivity due to the difference in antenna acceleration. Since it is required to observe a calibrator simultaneously, the faster 12m antennas must wait for the ACA antennas to completely settle on a calibrator, whereas observations of the target source does not need to be performed simultaneously.

We calculate the sensitivity of the *Combined Array* relative to a hypothetical array in which the acceleration is uniform for all antennas (i.e. 18 deg/s^2 for AZ and 9 deg/s^2 for EL). In Figure 6, we show the relative sensitivities as a function of calibrator distance with ACA 12-m (dashed curve) and 7-m antennas (solid curve) at the 10-sec (blue), 20-sec (green), and 30-sec (red) sequence time. The sensitivity decrease as the separation increases, while it increases as the sequence time increases. Our simulations of the *Combined Array* suggest that the difference in antenna slew acceleration typically results in ≤ 1 percent loss in signal-to-noise ratio using a 30-second sequence, and we conclude that the **impact is negligible in real observations**.

4.3. Technical Issues

In terms of developing new hardware, the most important aspect is to install patch panels to correctly propagate the data signal obtained from the ACA antennas to the 12m array correlator. A common LO system is also needed. Cross correlation will be performed using the 12m array correlator, but the ACA data obtained from the ACA correlator will also be used for cross-checking the results. Additional effort is necessary to develop software that properly handles data from the heterogeneous array, and to properly correct for the difference in the FOV in the final image construction. The pioneering millimeter experience gained from the heterogeneous Nobeyama Rainbow Array and CARMA will provide the needed expertise in time for efficient and proper software development.

If higher imaging quality is required for the *Combined Array*, re-optimization of both array configurations should be considered in a way such that better *uv* sampling is achieved. Alternatively, it is possible to re-optimize the ACA configuration alone (7m & TP array). However, these changes might sacrifice the existing roles of the ACA system and will have a big impact on both the baseline and Japanese projects.

Implementing the *Combined Array* will introduce added complexity to the dynamical scheduling. A sophisticated scheduler will be necessary in order to properly and efficiently organize science projects that each require different array settings. Although a complete set of observing modes needs to be developed before the commissioning of ALMA, a few major modes will be given as examples in the following sections.

5. Proposed Observing Modes

5.1. Case 1: When Maximum Sensitivity on Target is Required

This will be the simplest case for the use of the *Combined Array* and it is shown in Figure 7 ($left$). In essence, all of the data from both arrays will be cross-correlated using the baseline correlator regardless of the observing target (i.e. for bandpass, gain, and target source). A slight deviation from this is shown in Figure 7 (*right*). In this case, the total power array will conduct its own (i.e. OTF) observation toward the same target. We estimate that about 10% of all ALMA projects will adopt one of these modes (see §3).

5.2. Case 2: When High ACA Spectral Dynamic Range is Required

Let us consider the case in which the calibration alone is performed using the *Combined Array* mode. Here, we assume that the science project requires a wide-field mosaic that involves multiple pointing centers. Since performing mosaic observations using an inhomogeneous array faces significant technical issues such as poor beam characteristics (see §4.1), Coordinated Observation is adopted instead for the target source.

In the first example (Figure 8 ($left$)), all necessary initial calibration data (i.e. bandpass, flux) is taken using the *Combined Array* at the beginning of the science track. The gain calibrator is also observed using the *Combined Array.* During the target mosaic observation, the two arrays perform each of their own mosaic schemes independently. Detailed coordinates of the pointing centers should be carefully planned before the science observation such that the final image sensitivity is uniform across the observed region. When it is time to perform fast switching gain calibration (a cycle of 20-100 seconds for the *Combined Array*), the *Combined Array* mode is executed again. TP data should be taken either during the *Combined Array* observations by using a sub-array, or after/before the *Combined Array* observation is conducted.

For mosaic observations of extended sources, it is found that the ACA requires 2.5 times more observing time per source in order to match the *uv*-sensitivity (per unit area) of the 12m array [Morita & Holdaway, ALMA Memo 538]. This proposed observation scheme still suffers from a factor of 1.6 sensitivity difference between the ACA and the 12m array. One possible solution to compensate for the sensitivity is to conduct additional (1.5 times more) observations with the ACA alone (i.e. not in the *Combined Array* mode) as shown in Figure 8 ($left$). In this case, the calibration accuracy will be less than the *Combined Array*, inevitably. To efficiently maximize the science output while the ACA is performing these additional observations, the 12m array can execute the next observing program in queue which does not need the ACA.

In the second example (Figure 8 (*right*)), two arrays are tuned to the frequency specified by the ACA science, and then cross-correlated for ACA bandpass calibration. The 12m array re-tunes to a different frequency for a different project. Normal observation scheme is performed when the ACA and the 12m array observe different target sources. At the end of the track, the ACA is tuned to the frequency adopted for the

12m array in order to perform bandpass observation to meet the science goals of the 12m array.

6. Summary

We have considered in this document the scientific benefits of implementing the *Combined Array*. Our studies suggest that;

- $\sim$ 10% of all ALMA science will benefit from the 15-20% improvement in the 12m sensitivity
- ACA science that require stringent spectral dynamic range (i.e. $> 100:1$) will benefit from the (factor of 4–9) reduction of calibration time, which in turn will yield more on source observing time. This amounts to about 20% of all of the proposed ACA science.

By studying the beam characteristics, we found that the relative array location between the ACA and the 12m array in compact configuration is not a significant issue. We also show that the difference in the antenna acceleration will not degrade the sensitivity of the *Combined Array*. We are aware of the importance of developing new software (or modifications of existing software) to properly calibrate the data obtained using the heterogeneous array, but the pioneering millimeter experience gained from the heterogeneous Nobeyama Rainbow Array and CARMA should provide the needed expertise in time for efficient and proper software development.

We note here that although the *Combined Array* will provide the scientific advantages outlined in this text, the primary role of the ACA is to provide the short-spacing *uv* data that is not physically attainable by using the 12 meter array alone. While imaging simulations of a few specific cases have shown that the routine use of the *Combined Array* is feasible (Takakuwa et al.), the parameter space is still largely unexplored, and the *Combined Array* may not provide significant advantages in all science cases. Thus we advocate that the *Combined Array* should be kept as an observing mode option for the user to chose from.

A. Sensitivity Calculation

The sensitivity ($\equiv S/N$; signal to noise ratio) is proportional to

$$S/N \propto \sqrt{N_{12m-12m} \times t_{12m} + N_{12m-ACA} \times t_{ACA} \times (\frac{\eta_{ACA}}{\eta_{12m}})(\frac{A_{ACA}}{A_{12m}}) + N_{ACA-ACA} \times t_{ACA} \times (\frac{\eta_{ACA} A_{ACA}}{\eta_{12m} A_{12m}})^2}, \tag{A1}$$

where A is an aperture area of the dish ($A_{7m} = 38.5$ m^2, $A_{12m} = 113.1$ m^2), and η is an aperture efficiency, and we adopt $\eta_{7m} = 0.70$ and $\eta_{12m} = 0.75$. These values correspond to those at $\sim$ 230 GHz. At higher frequencies than $\sim$ 300 GHz, η_{7m} becomes higher than η_{12m}. N is the number of baselines, that is, $N_{12m-12m}$ = 1326 (=52 $\times$ 51 / 2), $N_{12m-ACA}$ = 624 (= 12 $\times$ 52), and $N_{ACA-ACA}$ = 66 (= 12 $\times$ 11 / 2) in the case of the inclusion of the ACA 7-m antennas in the combined array, and $N_{12m-12m}$ = 1770 (=60 $\times$ 59 / 2), $N_{12m-ACA}$ = 240 (= 4 $\times$ 60), and $N_{ACA-ACA}$ = 6 (= 4 $\times$ 3 / 2) in the case of the inclusion of the ACA 12-m antennas in the combined array.

Table 1. Various ALMA Sensitivities Normalized to the Sensitivity[a] of the 12m Array

η_{7m}/η_{12m}[b]	ACA (7+12m) only	Coordinated Obs.	*Combined Array*
1.0	5.939	0.996	0.854
1.3	5.173	0.993	0.836

[a]Sensitivity shown here is the single-field point source sensitivity obtained in 1-second (see appendix), and they are normalized to the sensitivity of the 12m array (i.e. 5.939 means that the sensitivity of the ACA is 5.939 times worse than that obtained using the 12m array alone)

[b]Aperture efficiency ratio of the 7m and 12m antennas calculated using the Ruze Formulae. If we assume that each 7m and 12m antenna has a surface accuracy of 20 micron and 25 micron in rms respectively, the aperture efficiency ratio is about 1.3 at 850 GHz. This ratio is close to 1 at the mm bands.

Table 2. Fraction of DRSP that will benefit from the *Combined Array*

	Fraction of Time
12m Science[a] that requires deep and small fields	$\sim$ 20% of the total 12m time
ACA Science that needs bandpass accuracy of 100:1 or better	$\sim$ 20% of the total ACA time
ACA Science that needs bandpass accuracy of 1000:1 or better	$2-3$% of the total ACA time

[a]ALMA Science that requires the 12m array only is estimated to be $\sim$ 60% of the total ALMA time

Table 3. Beam Characteristics

	Full Track (CA)[a]			Snapshot (CA)			Snapshot (12m)		
Dec (El)	Beam$_{230GHz}$ ($''$)	Axial Ratio	1st Sidelobe (% of peak)	Beam$_{230GHz}$ ($''$)	Axial Ratio	1st Sidelobe (% of peak)	Beam$_{230GHz}$ ($''$)	Axial Ratio	1st Sidelobe (% of peak)
-89 (23)	2.7×2.4	1.12	< 0.1	3.9×1.9	2.04	~ 0.1	4.1×1.7	2.41	~ 0.1
-69 (44)	2.4×2.0	1.18	< 0.1	2.3×1.9	1.21	~ 0.1	2.4×1.7	1.35	~ 0.1
-46 (67)	2.4×1.7	1.39	< 0.1	1.9×1.7	1.15	~ 0.1	1.8×1.7	1.04	~ 0.1
-23 (90)	2.4×1.6	1.46	~ 0.1	1.9×1.6	1.22	~ 0.1	1.7×1.6	1.08	~ 0.1
0 (67)	2.3×1.7	1.34	~ 0.1	1.9×1.7	1.15	~ 0.1	1.8×1.7	1.04	~ 0.1
23 (44)	2.3×2.1	1.09	< 0.1	2.3×1.9	1.21	~ 0.1	2.4×1.7	1.35	~ 0.1
46 (21)	4.3×1.9	2.25	~ 0.1	4.4×1.9	2.32	~ 0.1	4.7×1.7	2.75	~ 0.1

[a]CA: *Combined Array*, 12m: the 48 element 12m array

Note. — A full track is defined as a track with an hour angle range from -5h to 5h, while a snapshot is -0.15h to 0.15h.

Table 4. Antenna Velocity and Acceleration

	Azimuth		Elevation	
	Accel (deg/s^2)	Max Vel (deg/s)	Accel (deg/s^2)	Max Vel (deg/s)
12 array	18	6	9	3
ACA 12m	10	6	5	3
ACA 7m	9	6	4.5	3

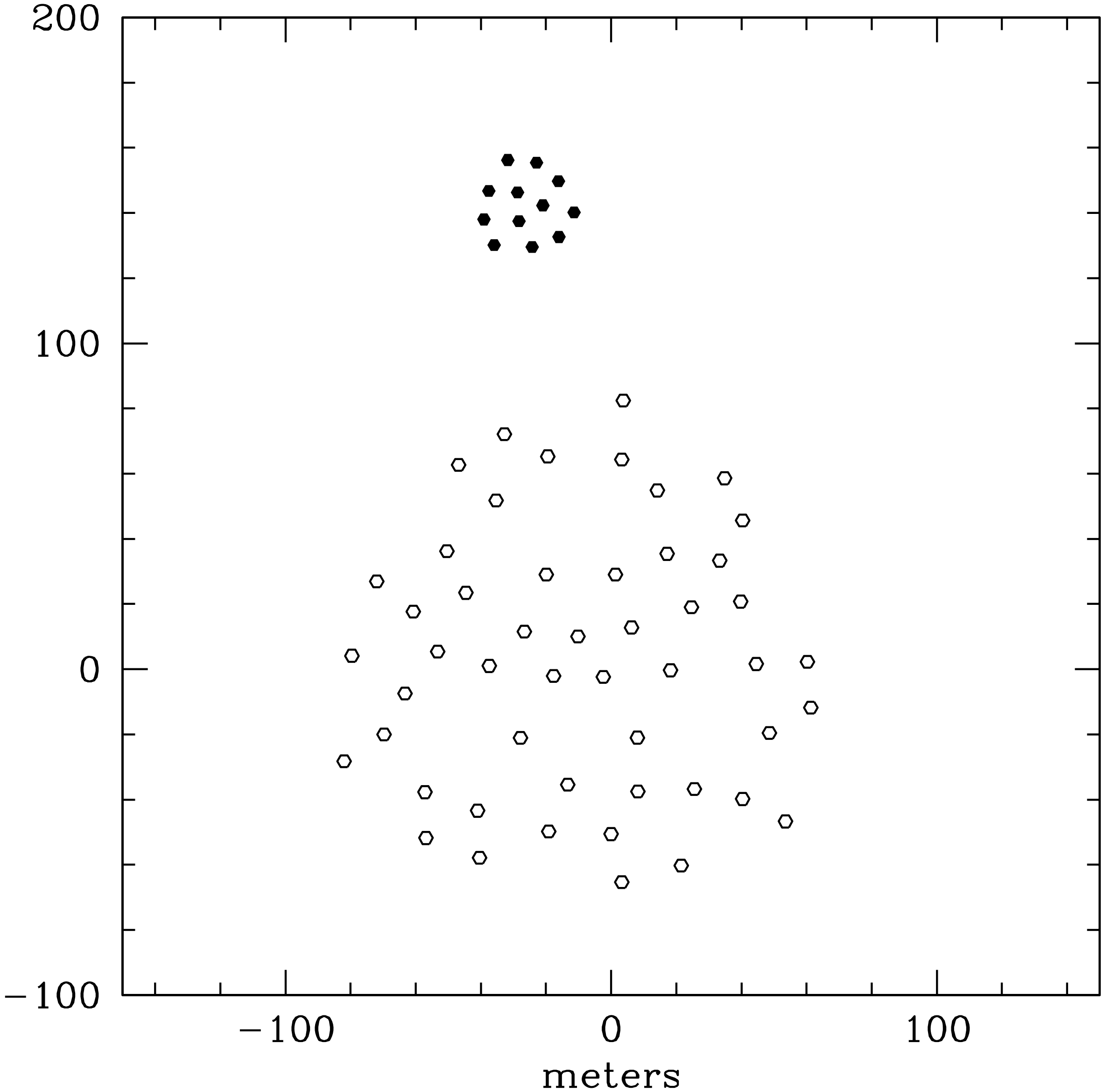

Fig. 1.— Relative array locations between the ACA and the 12m array in compact configuration. The filled circles represent the ACA pad locations while the open circles represent the 12m array pad locations. The units are in meters.

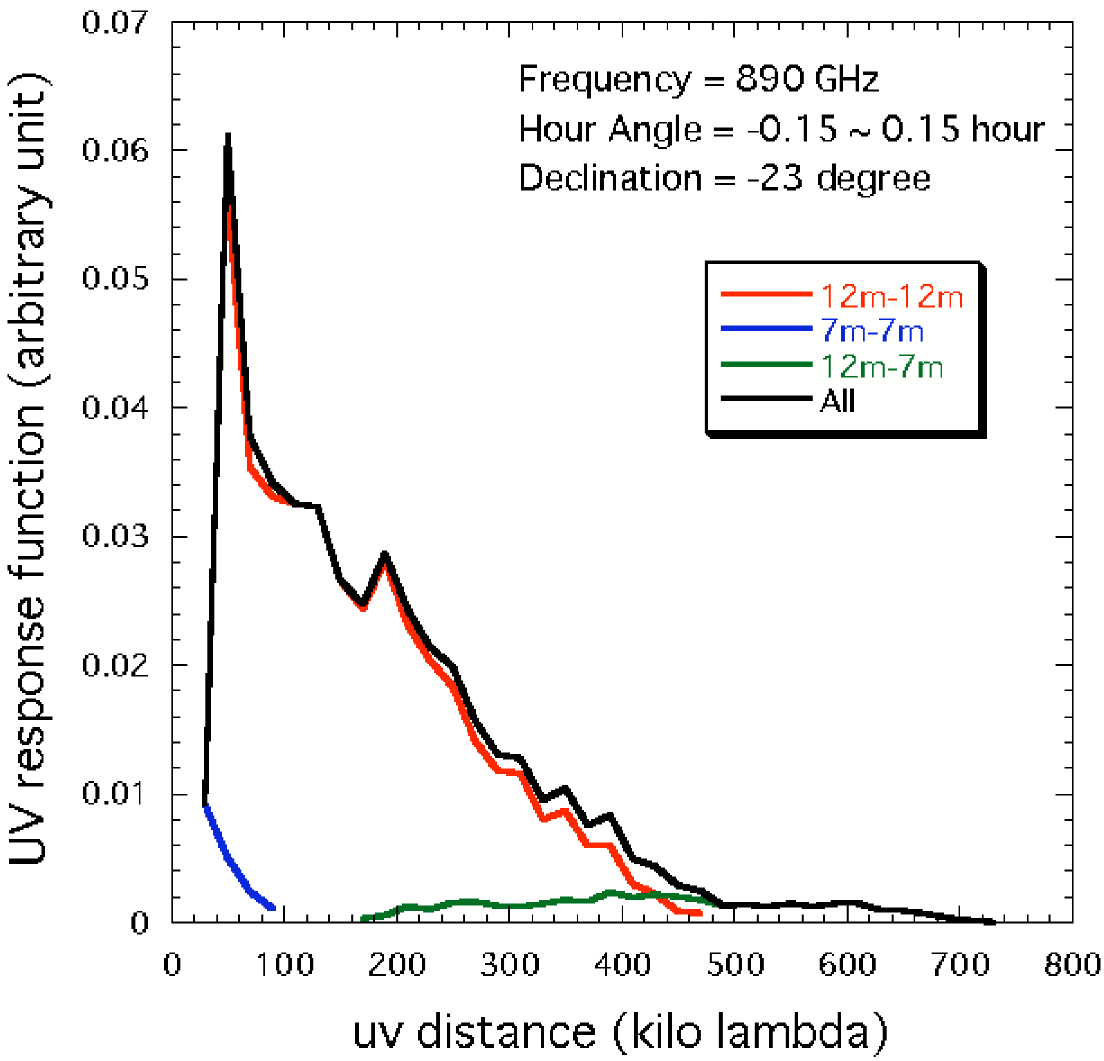

Fig. 2.— The *uv*-response as a function of *uv* distance for a single field using the same integration time for all antennas. In essence, the *uv* response is the number of *uv* points per unit *uv* area scaled by the antenna diameter (see Morita & Holdaway [ALMA memo 538] for detailed discussion). The blue and red lines show the *uv* response for the ACA 7m array and the 12m array, respectively. The green line shows the *uv* response of the *Combined Array*, and the dark line represents the entire ALMA array. The added *uv* response given by the *Combined Array* is evident in the spatial frequencies drawn in dashed line.

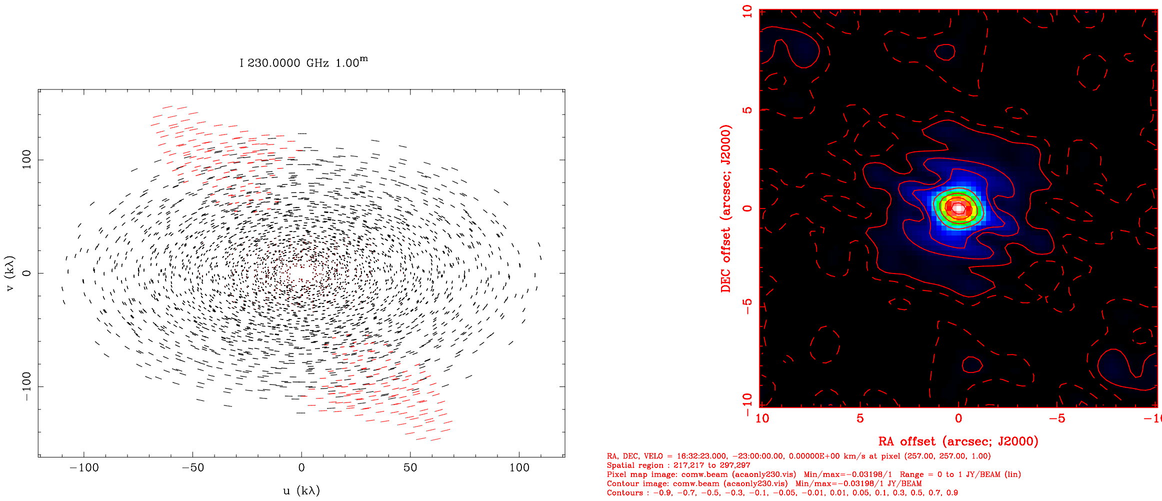

Fig. 3.— (*left*) The *uv* coverage and (*right*) the synthesized beam at 230 GHz for a snapshot track observation of a source at $\delta = -23$. The outer *uv* data shown in red are the extra correlations obtained by the *Combined Array* (The inner *uv* data also shown in red are the data from the ACA). The contour levels are 1, 5, 10, 30, 50, 70, 90% of the peak.

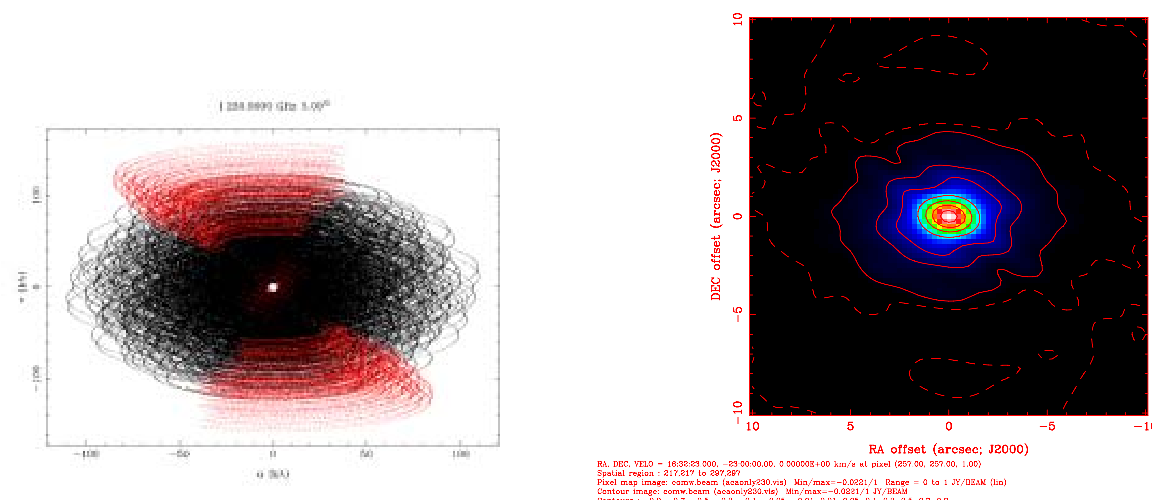

Fig. 4.— The (*left*) *uv* coverage and the (*right*) synthesized beam at 230 GHz for a full track observation of a source at $\delta = -23$. The contour levels are 1, 5, 10, 30, 50, 70, 90% of the peak.

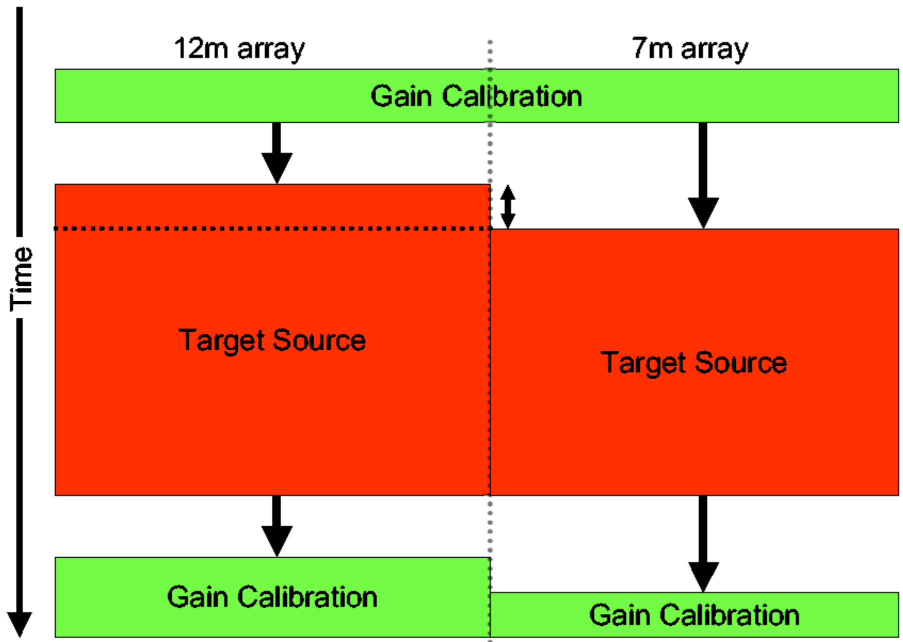

Fig. 5.— The fast switching sequence for both arrays. The 12m array arrives at the target faster, and needs to wait for the ACA antennas to arrive.

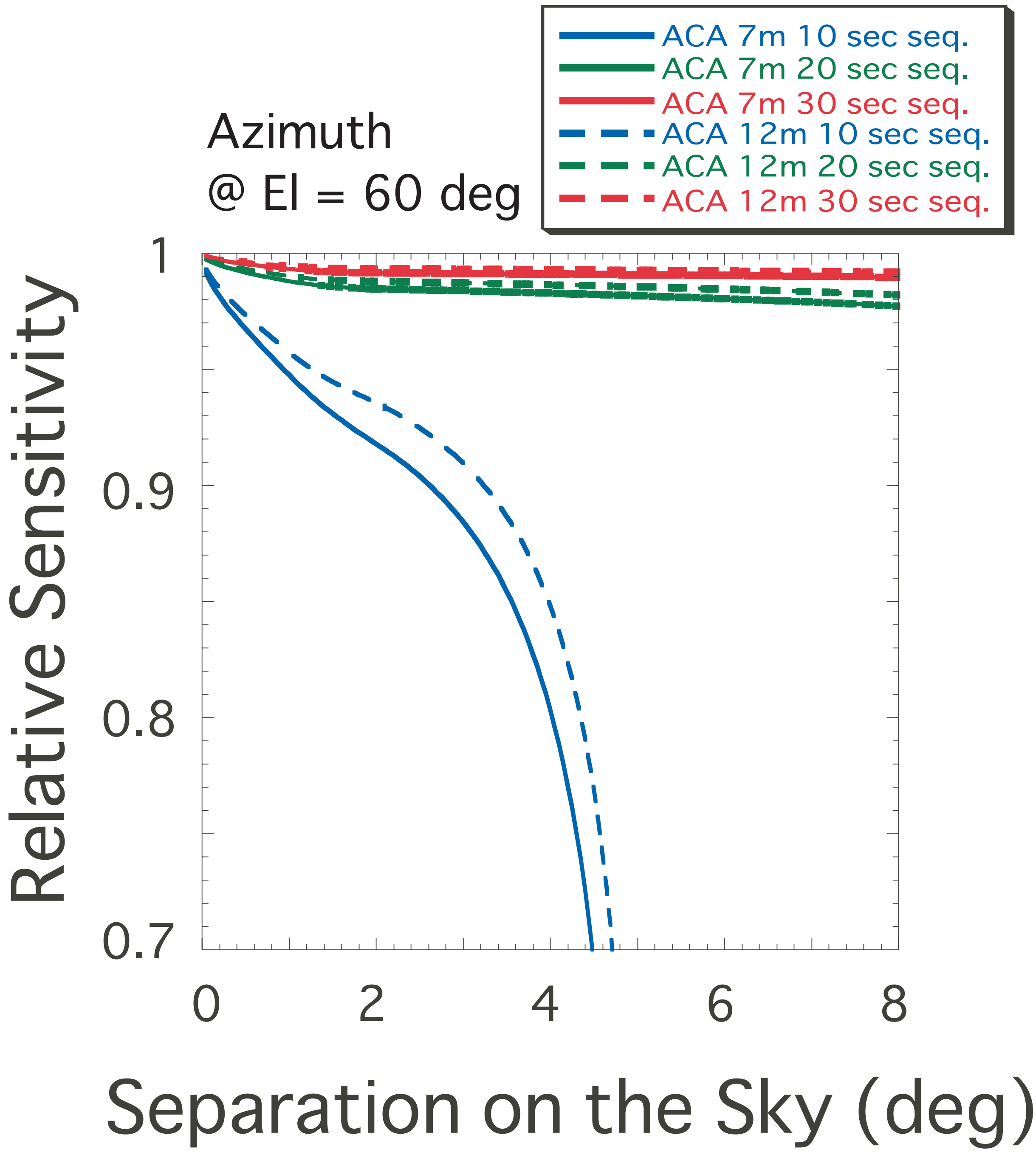

Fig. 6.— Relative Sensitivities as a function of the separation between the calibrator and the target source in the *Combined Array*. Dashed curves represent the results of the combined array with the ACA 12-m antennas, while solid curves the results of the combined array with the ACA 7-m antennas. Blue, green, and red curves indicate 10-sec, 20-sec, and 30-sec sequence time, respectively.

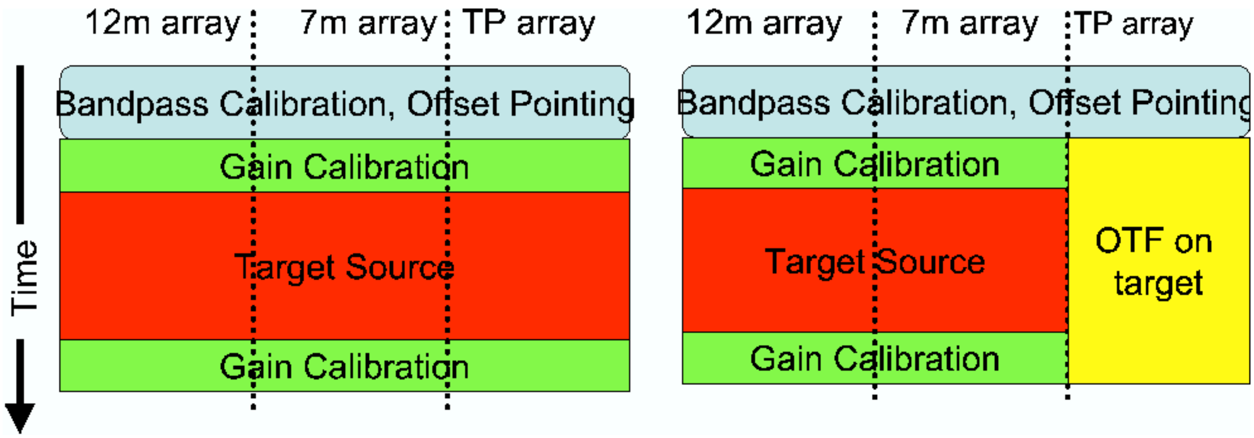

Fig. 7.— Proposed observation mode of the *Combined Array* when maximum sensitivity on target is needed. (*left*) The simplest case where all the antennas are cross-correlated all of the time. (*right*) A slight deviation from *left* where the TP array performs its own (e.g. OTF) observation while the 12m and the 7m arrays are cross-correlated.

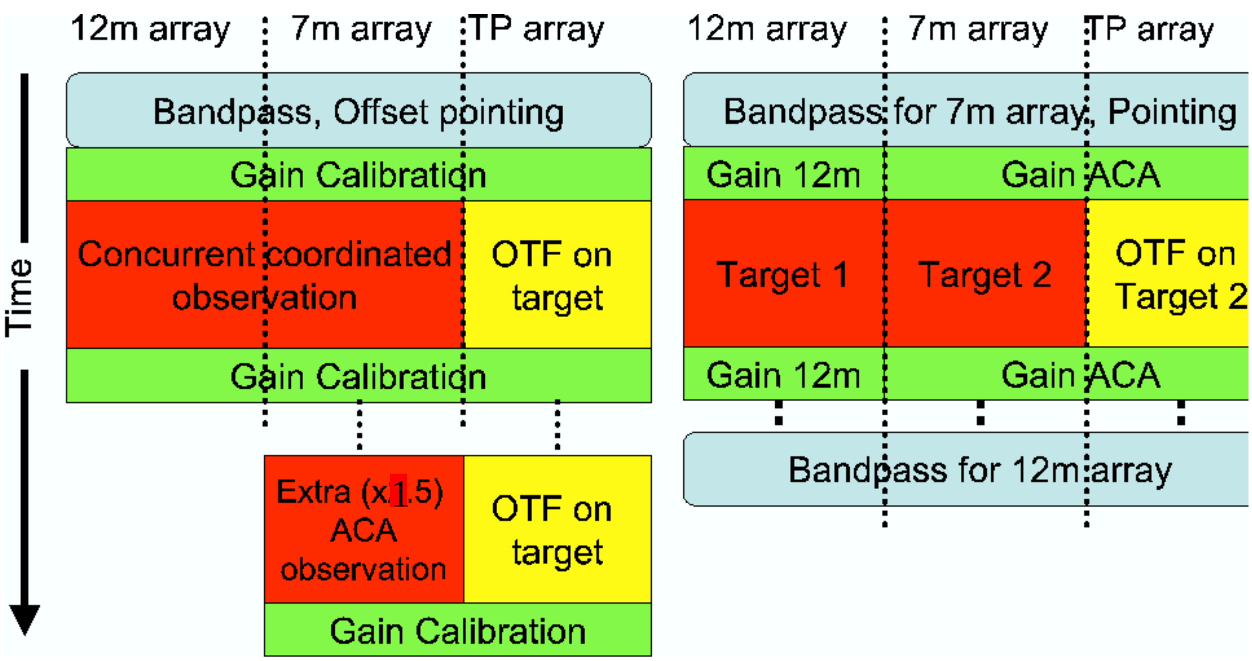

Fig. 8.— Proposed observation mode of the *Combined Array* when high ACA spectral dynamic range is needed. (*left*) All of the antennas are cross-correlated during bandpass calibration and gain calibration, but coordinated observation is adopted for a common target source. Extra observation toward the target source is obtained at the end in order to match the *uv* sensitivity between the ACA and the 12m array. (*right*) A slightly more complicated version of *left*. In this case ACA bandpass calibration is done at the beginning using the *Combined Array*. The 12m array tunes to a different frequency for a different science project, while the ACA remains at the same tuning. At the end of the observation, we obtain bandpass data for the 12m array.