

Using Fast-Switching Data to Characterize Atmospheric Phase Fluctuations at the Submillimeter Array

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Abstract For the submillimeter band observations, we have been routinely adopting the calibration cycle time of 20–30 minutes, which is the same as any typical centimeter and millimeter band observations. This cycle time, largely corrects only the instrumental phase fluctuations and there exists residual phase fluctuations, which are attributed to temporal and spatial atmospheric phase fluctuations. Hence, the classical calibration cycle needs closer attention for any future submillimeter band observations. We have therefore obtained fast-switching test data, cycling between three nearby calibrators, using the submillimeter array (SMA) with a cycle time of ~ 90 sec, in order to understand and optimize the calibration cycle suitably, thereby to achieve the projected sensitivity, angular resolution and dynamic range for the SMA. Here, we present the preliminary results from this study.

Keywords atmospheric effects · instrumentation: interferometers · submillimeter · techniques: dynamic range · techniques: sensitivity

1 Introduction

The Submillimeter Array (SMA, Ho et al. 2004) is the world's first dedicated submillimeter band interferometer, located at the Mauna Kea, Hawaii, ~ 4100 m altitude, and consists of eight 6 m antennas. It covers the

frequency range of 180–900 GHz with a 2 GHz bandwidth in both upper and lower side-bands.

The water vapor in our atmosphere is spatially inhomogeneous and highly time-variable, resulting in atmospheric electrical path fluctuations that alter the phase of propagating electromagnetic radiations (Battat et al. 2004). At submillimeter bands, the effect of atmosphere fluctuations is particularly severe, and limits the resolution, and the coherence of interferometric arrays.

2 Our Goal

Fast switching entails switching between the target source and a bright calibrator on timescales shorter than the baseline crossing time of the water vapor clumps by the wind. At this moment, we are adopting the calibration cycle time of 20–30 minutes, which is the same as the millimeter observations. However, we are not sure if this is the right way for the submillimeter observations. The phase fluctuation is larger for the submillimeter wave than the millimeter wave; therefore, the classical calibration cycle may be too long for the submillimeter observations. To determine the optimized calibration cycle, we need to understand the characteristics of the atmosphere (*e.g.*, structure function). This characteristic information would also allow us to determine, whether we need to do fast switching, what is the optimized integration time for each data point (it currently being 30–60 sec), etc. This information, in future, will allow us to obtain data of highest possible quality.

3 Proposed Experiments

We therefore conducted following two experiments as test observations using the SMA in the standard spec-

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Table 1 Log of SMA test observations. For each of the two experiments, weather, available antennas, observing bands, the calibrator quasars observed, and the range of baseline lengths available are listed.

	Experiment I	Experiment II
Observe date	05 Sep 2004	02 Sep 2004
Weather	$\tau_{225 \text{ GHz}} = 0.10\text{--}0.14$	$\tau_{225 \text{ GHz}} = 0.08\text{--}0.13$
Antennas	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3, 4, 7, 8
Receiving Bands	230 GHz	345 GHz
Loop between quasars	3C279, 1244–255, 1334–127	3C454.3, 2230+114, 2145+067
Calibration quasar	3C279	2230+114
Flux densities	3C279 : ~ 8 Jy 1244–255 : ~ 1 Jy 1334–127 : ~ 4 Jy	2230+114 : ~ 5 Jy 3C454.3 : ~ 4 Jy 2145+067 : ~ 2 Jy
Relative separations between quasars	$\sim 12\text{--}20$ deg	$\sim 06\text{--}18$ deg
Baseline lengths, shortest/longest	$\sim 20/170$ k λ	$\sim 30/260$ k λ

tral line mode. We chose three calibrators which are close-by (relative separation between them being $\sim 6\text{--}20$ deg) and made a loop cycle of ~ 90 sec with an integration time of ~ 15 sec for each source. Table 1 gives the details of the observations. The continuum data from the full data set were extracted for our analysis below. For both experiments, we adopted similar observing strategy and the data was analysed using Classic ‘AIPS’. Since, the relative flux density would suffice our requirements, we did not set the flux density scales for the observed sources. We performed our analysis of the fast switching technique in the image-plane, and the imaging was performed using AIPS task IMAGR and the ‘uniform’ weighting function was used.

3.1 Experiment I

As a first exercise, we observed sources 3C279, 1244–255 and 1334–127 at 230 GHz. Typical separation between any two sources is $\sim 12\text{--}20$ deg. We chose 3C279, the brightest source, as the calibration quasar and used it to map 1244–255 and 1334–127 at the fastest switching cycle.

The data set suffered from severe atmospheric phase errors and had extremely bad phase stability (see Fig. 1). In spite of having a fastest switching cycle, namely 90 sec cycle, the two target sources, 1244–255 and 1334–127 were barely detected at 3.5 and 2.5 sigma levels, respectively. On the other hand, on self-calibrating (phase only) the visibility data with its own map and mapping the same, we could extract most of the flux density (Fig. 2).

To conclude, in this severe weather condition, fast switching cycle of ~ 90 sec does not work. Instead, the observations possibly require further shorter switching cycle. Furthermore, since, this fastest switching cycle

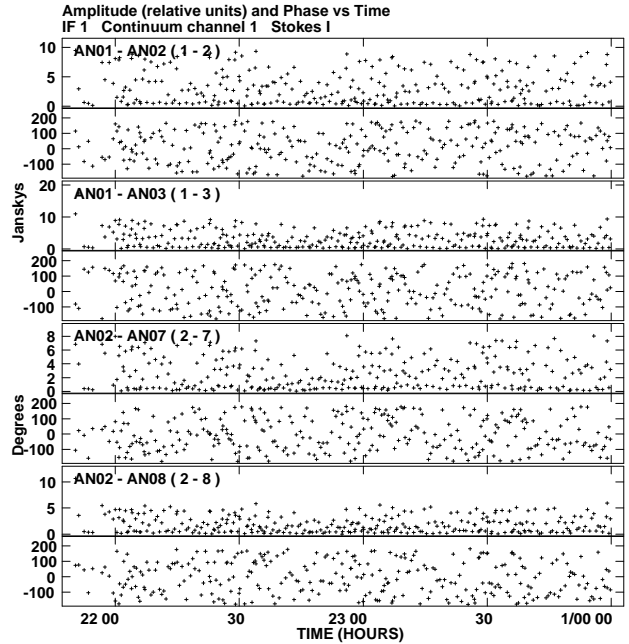


Fig. 1 Figure showing the stability of phase (in degrees) and amplitude (in Jy) for 1244–255 and 1334–127 sources at 230 GHz for the duration of observation (Experiment I).

did not provide fruitful results and the phase stability being bad, we did not attempt to increase the switching cycle time.

3.2 Experiment II

Here, we observed sources 3C454.3, 2230+114 and 2145+067 at 345 GHz. Typical separation between any two sources is $\sim 06\text{--}18$ deg. Once again, here, all three observed sources are of different flux densities, we chose 2230+114, the strongest source as the calibration quasar and used

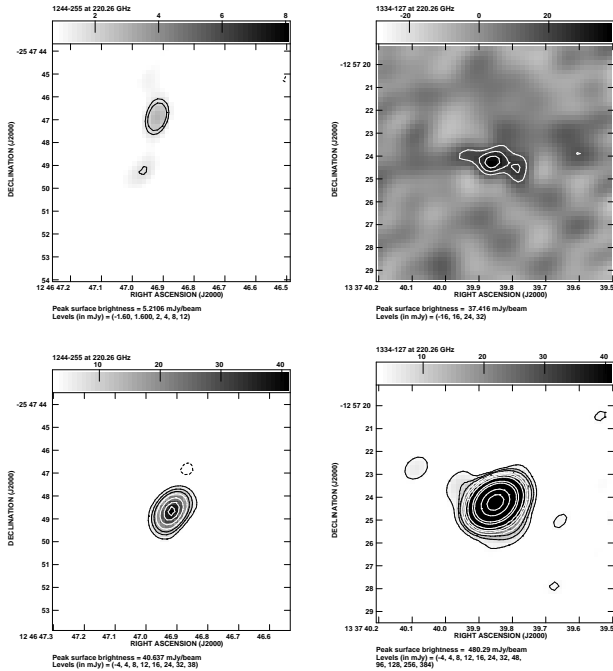


Fig. 2 Figure showing images of 1244–255 (left panels) and 1334–127 (right panels) at 230 GHz (Experiment I). The upper images were reduced under the fastest switching cycle of 90 sec and CLEANed; whereas the lower images are the CLEAN images from the phase-only self-calibrated visibility data. The barely detected 1244–255 (upper left panel) source is amplified in the phase-only self-calibrated image (lower left panel), implying that by using the methodology of self-calibration, we could extract most of the flux density.

it to map 3C454.3 and 2145+067 at the fastest switching cycle. In order to increase the switching cycle time, the interleaved observations of calibrator source 2230+114 were FLAGged, thereby we obtained switching cycle in multiples of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 times ~ 90 sec.

As compared to the earlier 230 GHz data, this data set did not suffer from severe atmospheric phase errors (see Fig. 3). Instead, it had a better phase stability. It made very little difference having a fastest switching cycle or the default switching cycle, and in either case the two target sources were detected at more than 10 times the noise levels. Furthermore, on self-calibrating (phase only) the visibility data with its own map and mapping the same, we could extract most of the flux density and the achieved dynamic range was more than 20 in the two maps (Fig. 4).

To conclude, in this good weather condition, fast switching cycle of ~ 90 sec and ~ 22 min does not have significant difference, but the self-calibration (phase-only) improves significantly. Therefore, to meet the signal-to-noise levels of maps obtained *via.*, self-calibration, a

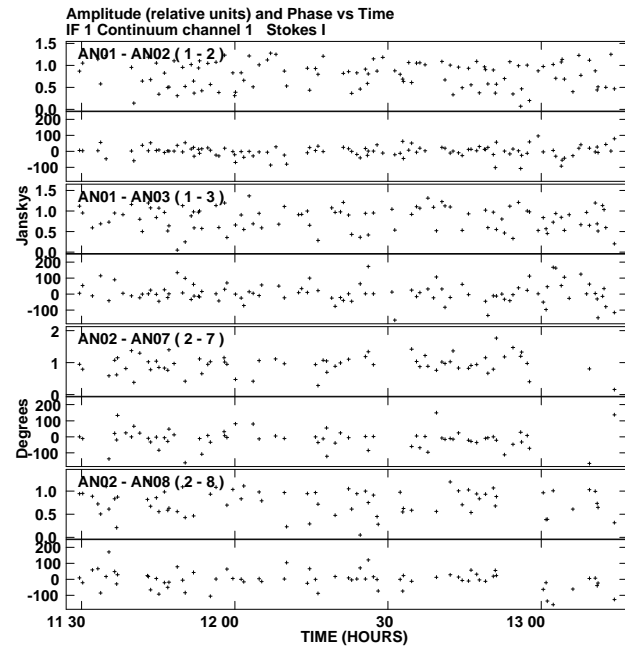


Fig. 3 Figure showing the stability of phase (in degrees) and amplitude (in Jy) for 3C454.3 and 2145+067 sources at 345 GHz for the duration of observation (Experiment II). This weather condition is good for science observations.

much shorter switching cycle is needed, and hence to improve the map quality.

4 Discussion

Phase variations at the SMA, *i.e.* at observing frequencies ≤ 400 GHz, are larger than centimeter and millimeter band observation, and are caused predominantly by temporal changes in the water vapor content. The implied changes in index of refraction are non-dispersive, in particular at millimeter bands (*e.g.* Sutton & Hueckstaedt 1996, Pardo et al. 2001), and hence phase variations increase linearly with frequency.

One of the methods to compensate these phase fluctuations is the fast switching method. The technique of phase calibration by fast switching has been successfully demonstrated with the Very Large Array (VLA) at 22 GHz with the minimum cycle time being 80 sec in the standard VLA mode (Holdaway et al. 1995) and subsequently improved to 40 sec at 22 and 43 GHz (Carilli et al. 1996). Therefore, the phase calibration through fast switching is important, in particular, when the dynamic range limitation is set by the phase errors and/or to obtain images of faint sources with diffraction limited resolution on arbitrarily long baselines.

However, the fast switching technique in our two experiments did not work as planned. One possible reason

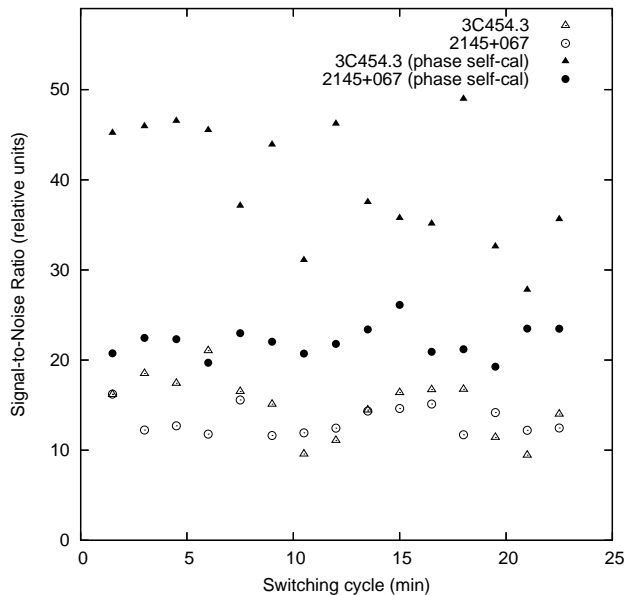


Fig. 4 Signal-to-noise ratio based on series of images of 3C454.3 and 2145+067 sources at 345 GHz as a function of switching cycle (Experiment II). The left-most data point has “1 times ~ 90 sec” as the switching cycle, subsequently increasing in multiples of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15. The lower two sets of symbols (open circles and open triangles) are from the CLEAN images, whereas the upper two sets of symbols (filled circles and filled triangles) are from the phase-only self-calibrated CLEAN images.

could be that the baseline lengths used in the two experiments are small (in the two experiments conducted, the longest baselines were ~ 170 k λ at 230 GHz and ~ 260 k λ at 345 GHz) and hence, the effect of atmosphere is not completely checked. Or in other words, it seems that the diffraction limited images of the quasars are even more smaller and instead, the obtained spatial resolution is limited by tropospheric ‘seeing’ (Morita et al. 2000, Carilli & Holdaway, 1999, 1997, Carilli et al. 1996, Holdaway et al. 1995). It is also possible that during observations either too bad or too good weather conditions is unlikely to provide any improved results.

In addition, in these and future observations, we should also consider the effect of natural weighting during imaging for the fast switching technique. Since the weather condition during the experiment II was good and/or the phase stability being good, hence the improvement in the image-plane will not be as dramatic as it may be in the case of experiment I.

5 Conclusions

The data presented above attempts to provide a measure of the atmospheric phase fluctuations between antennas and can help recover suitable results depending on intrinsic atmospheric phase fluctuations.

- Based on these two experiments, both, very bad weather conditions and good weather conditions, we have demonstrated that there is no difference between ~ 90 sec and ~ 22 min calibration switching cycle. However, self-calibration works better in both cases, suggesting that a further shorter calibration switching cycle is needed in both weather conditions.

We conclude that the self-calibration can often be performed (typically with a 40 sec averaging time on sources stronger than 100 mJy at 43 GHz (Carilli et al. 1996) and ~ 5 sec averaging time on sources observed here). Furthermore, there is definitely a need to undertake an additional experiment in order to bridge the gap between these two extreme experiments.

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