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Candidate Phase Calibrators at 93 GHz in the ngVLA Sky

J. M. Wrobel[1] and A. Y. Q. Ho[2]

[1]National Radio Astronomy Observatory, P.O. Box O, Socorro, NM 87801, USA
[2]Department of Astronomy, Cornell University, Ithaca, NY 14853, USA

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ABSTRACT

We update the fast-switching metrics advocated by Carilli (2015), given improvements to the ngVLA performance parameters at 93 GHz and to the accuracy and depth of published source counts at 95 GHz. We suggest that candidate phase calibrators be selected down to ∼10 mJy, leading to ∼1 deg^{-2}. We also suggest that these candidates be drawn from forthcoming CMB wide surveys below a declination of +35 deg.

Keywords: Interferometry (808)

1. METRIC UPDATES

The next-generation VLA (ngVLA) will be an interferometric array operating at frequencies between 1.2 and 116 GHz, with ten times the sensitivity and angular resolution of the VLA and ALMA (McKinnon et al. 2019). Its calibration strategies are being developed (Selina et al. 2022b).

At the highest-frequency band centered at 93 GHz, Carilli (2015) found that for ngVLA studies of faint targets using ∼200 18m antennas, fast-switching phase calibration should be viable with a switching angle of ∼2 deg and a switching time of 30 s, with 3 s on a calibrator of 25 mJy or more.

Below a declination of +40 deg, ALMA phase calibrators in its equivalent Band 3 have a typical flux density of ∼200 mJy (Bonato et al. 2018) and offer an average switching angle of ∼3 deg (Cortes et al. 2022). These ALMA phase calibrators will serve as a starting point for the ngVLA at 93 GHz, but the Carilli (2015) study points to needing weaker phase calibrators with a denser distribution on the sky.

Carilli (2015) adopted early estimates for the system temperature, efficiency and bandwidth of an 18m antenna, such that the phase noise due to the signal-to-noise on a calibrator as weak as 25 mJy was not a limiting factor for a 3 s integration. Those performance parameters have since improved (Selina et al. 2022b) and the associated RMS noise on a baseline between two antennas is now $8\,\mathrm{mJy} \times (65\,\mathrm{K}/80\,\mathrm{K}) \times (50\%/65\%) \times \sqrt{8\,\mathrm{GHz}/20\,\mathrm{GHz}} \sim 3\,\mathrm{mJy}$, so a 10 mJy calibrator is tolerable.

Carilli (2015) also adopted early estimates of source counts down to 25 mJy. These source-count estimates were billed as being uncertain by approximately a factor of two or so. Since then the accuracy and depth of published source counts at 95 GHz have improved, culminating in a survey over 2500 deg^2 at an angular resolution at FWHM of 1.7 arcmin with the South Pole Telescope, the SPT-SZ survey (Everett et al. 2020).

Figure 1 shows the SPT-SZ counts of the point-source population dominated by synchrotron emission from active galactic nuclei (AGN), that is, the population of candidate phase calibrators. Near ∼10 mJy the counts and their 1σ errors are $1.06 \pm 0.05\,\mathrm{deg}^{-2}$. The average switching angle is ∼1 deg. Being half the value inferred by Carilli (2015), this should help to improve fast-switching phase calibration at 93 GHz. We recommend that those improvements be explored and quantified in a separate document.

Near ∼10 mJy the counts of dust-dominated sources and their 1σ errors are $0.046^{+0.018}_{-0.013}\,\mathrm{deg}^{-2}$ (Everett et al. 2020). Thus the overall point-source population at 95 GHz is largely synchrotron-dominated and suffers only mild contamination by dust-dominated sources.

Corresponding author: J. M. Wrobel
jwrobel@nrao.edu

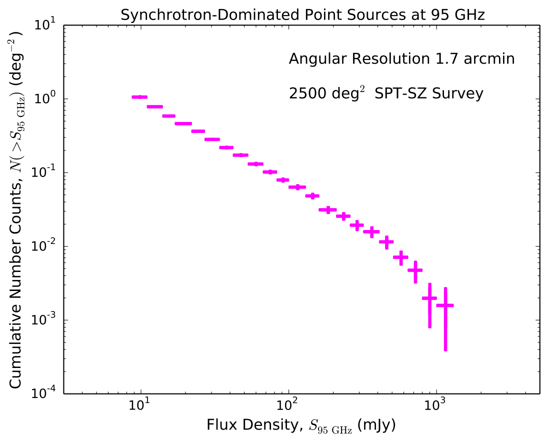

Figure 1. Cumulative number counts from the SPT-SZ survey at 95 GHz (Everett et al. 2020).

2. CANDIDATE PHASE CALIBRATORS

The ngVLA will access all right ascensions and all declinations above −40 deg (Figure 2; Selina et al. 2022a). We suggest that candidate phase calibrators for 93 GHz be drawn from three wide-area surveys conducted from northern Chile of the Cosmic Microwave Background (CMB). These surveys have angular resolutions near ∼2 arcmin and point-source depths of $\lesssim$10 mJy, and are either underway (Naess et al. 2020) or planned (Ade et al. 2019; Abazajian et al. 2019; Carlstrom et al. 2019). We discuss each wide survey below. We focus on frequencies near 93 GHz but tabulate the traits of these surveys at other frequencies for completeness.

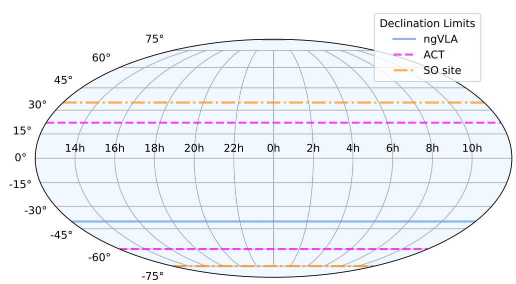

Figure 2. Declination limits are shown as solid lines for the ngVLA (Selina et al. 2022a), dashed lines for the current survey with the Atcacama Cosmology Telescope (ACT; Naess et al. 2020), and dash-dot lines for surveys planned from the Simons Observatory (SO) site in Chile (Stevens et al. 2018).

Paths to finding candidate phase calibrators at 93 GHz beyond the footprints of these three wide-area surveys will be explored in a separate document.

2.1. *ACT Wide Survey*

Table 1 gives the frequencies and angular resolutions at FWHM for the wide survey underway with the Atacama Cosmology Telescope (ACT) and spanning declinations from −60 deg to +22 deg (Figure 2; Naess et al. 2020, 2021).

The ACT wide survey is underway. In a preliminary ACT+Planck study covering ∼18,000 deg^2, Naess et al. (2020) report the results of applying a matched filter point-source finder. This yielded a not-yet-released catalog of 18,507 sources at 98 GHz detected above five times the local RMS noise. The corresponding detection thresholds are 3.5 mJy in deep regions and 15 mJy in shallow regions, regimes of interest for candidate phase calibrators. The ACT catalog could serve to identify candidates with declinations from −40 deg to +22 deg. To facilitate ngVLA Commissioning and Science Validation at 93 GHz, it would be desirable to have access to the ACT catalog soon after the start of ngVLA construction, notionally planned for 2026.

2.2. *SO Wide Survey*

Table 1 gives the frequencies and angular resolutions at FWHM for the wide survey to be conducted with one Large Area Telescope at the Simons Observatory (SO; Ade et al. 2019). The footprint of this SO survey is under discussion. Here we adopt the declination band from −75 deg to +35 deg that was shown to be feasible with an opportunistic survey strategy (Figure 2; Stevens et al. 2018).

Table 1. CMB Surveys from Chile

(1)	(2)	(3)	(4)	(5)	(6)	(7)
ACT Wide Survey						
Frequency (GHz)	...	...	98	150	225	...
Angular resolution (arcmin)	...	...	2.0	1.4	1.0	...
SO Wide Survey						
Frequency (GHz)	27	39	93	145	225	280
Angular resolution (arcmin)	7.4	5.1	2.2	1.4	1.0	0.9
CMB-S4 Wide Survey						
Frequency (GHz)	30	40	95	145	220	270
Angular resolution (arcmin)	7.4	5.1	2.2	1.4	1.0	0.9
Full depth RMS noise (mJy)	0.8	0.6	0.2	0.2	0.6	1.1
One week RMS noise (mJy)	15	11	3	4	11	21

The SO wide survey is planned to start in the 2020s and span 5 yr. At 93 GHz the full SO survey is projected to reach a 5σ detection threshold of 7 mJy. If an SO mid-survey catalog of point sources were made available, its detection threshold would be $\sqrt{2}\times 7$ mJy = 10 mJy, just the regime of interest for candidate phase calibrators. The SO mid-survey catalog could serve to identify candidates with declinations from +22 deg to +35 deg, plus assess the time variability of candidates identified years earlier in the ACT wide survey. To facilitate ngVLA Commissioning and Science Validation plus the planned start of ngVLA Early Science Operations at 93 GHz, it would be desirable to have access to the SO mid-survey catalog no later than 2029.

2.3. *CMB-S4 Wide Survey*

Table 1 gives the frequencies, angular resolutions at FWHM, and RMS noise values for the CMB-S4 wide survey to be conducted with three Large Area Telescopes at the SO site (Abazajian et al. 2019; Carlstrom et al. 2019). Although the survey's footprint is under discussion, we assign it the declination band from −75 deg to +35 deg that was shown to be feasible with an opportunistic survey strategy (Figure 2; Stevens et al. 2018).

The CMB-S4 wide survey is planned to start in the 2030s and span 7 yr. Weekly stacks will be released to enable investigations of the time-variable sky. At 95 GHz the weekly stacks are projected to reach an RMS noise of 3 mJy. A 5σ detection threshold in the weekly stacks could serve to monitor candidate phase calibrators at 95 GHz down to ∼15 mJy. Such monitoring would help to characterize the weekly, monthly and yearly variability of the candidates with declinations from −40 deg to +35 deg. It would be desirable to have some understanding of this time variability before ngVLA Full Science Operations begins at 93 GHz, notionally planned for 2035.

2.4. *Vetting Candidates*

Phase calibrator candidates would eventually need to be vetted for their compactness. They could be cross-matched with existing lists of VLBI sources, dominantly assembled at 8 GHz (e.g., http://astrogeo.org/). New vetting data at 93 GHz could also be acquired, analogous to the systematic approach taken for MERLIN (Patnaik et al. 1992) and the VLBA (Beasley et al. 2002).

A vast number of candidates are anticipated so they should be vetted strategically, as part of planning for each faint-target observation (Clark 2015) or based on astrophysical priors. Example priors are cross-matches with X-ray catalogs (Everett et al. 2020) or time variability among, say, the CMB-S4 weekly stacks at 95 GHz or the three epochs of the VLA Sky Survey at 3 GHz (Lacy et al. 2020).

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