CARMA Memorandum Series #41

# Optimal Track Lengths for CARMA


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## ABSTRACT

Using relevant parameters for CARMA, I revisit the analysis of Regan & Rand (1996) who recommended optimum track lengths for BIMA based on source declination, observing frequency and site characteristics, with an upper limit of 8 hrs. Using CARMA site characteristics, I compute percentage of maximum achievable SNR as a function of track length over a wide declination range. For CARMA, I recommend that the fiducial track length be the length at which 90% of the achievable SNR is reached with an upper limit of 12 hours.[1].


[1] As of Feb. 2008, the CARMA Science Steering Committee has adopted 90% SNR and an 8 hour maximum

## 1. Introduction

There is currently no well-articulated policy at CARMA for how long any given track should run. An existing policy establishes purely declination-dependent elevation cutoffs in 3 broad declination ranges. The standalone scheduling program `mksched` uses these declination cutoffs to generate a multi-day schedule; the project database has hour angle limits for each source which typically correspond to the policy limits; the Sensitivity Calculator uses the Regan & Rand (1996) recommended track lengths with an eight hour maximum [2] ; and observers tend to schedule on-the-fly without paying much attention to starting or ending hour angle (e.g. observing the highest priority project returned by the SAC command `projectsWithinRange`.) This can lead to some tracks being cut off while they might productively add to signal-to-noise ratio (SNR) or UV coverage, while others are continued past the point of any effective gain in SNR or UV coverage. A rationalization of the scheduling policy is needed based on some measure of optimal track length.

Fortunately, Regan & Rand (1996) in BIMA Memo #47 (hereafter RR96) addressed the idea of optimal track lengths to solve the same problem for the BIMA array. They examined the SNR and UV coverage as a function of track length, source declination and observing frequency using the Hat Creek site characteristics. A similar analysis can be undertaken for the CARMA site. Again fortune shines upon us: The shell script that Mel Wright wrote for CARMA Memo #24 (Wright 2004) requires only small modifications to accomplish this analysis.

## 2. SNR and UV Coverage As a Function of Time

As noted by RR96, the optimal elevation cutoff for a given track depends on the atmospheric opacity $\tau$ at the observing frequency. Since atmospheric opacity is a principal contributor to system temperature, continuing to observing at lower and lower airmasses does not improve the image fidelity because visibilities with higher system temperatures are usually downweighted during the transform to the image plane. The contributors to atmospheric opacity are water, dry air, and, for frequencies near 115 GHz, the telluric oxygen line. Assuming a typical precipitable water vapor column of 5 mm, zenith opacity values for Cedar Flat are $\tau_{zenith} \sim 0.1$ at $\nu \sim 100$ GHz, and $\tau_{zenith} \sim 0.3$ at both $\nu \sim 115$ GHz and $\nu \sim 230$ GHz (see MIRIAD task `obstau`). Using these opacities, I computed the achieved SNR and sidelobe level over a range of track lengths and declinations.

Figures 1 and 2 show the achieved SNR in the CARMA C array expressed relative to the maximum achievable SNR observing horizon to horizon (where horizon is defined to be elevation of 10 degrees). The dotted line corresponds to 90% of the achievable SNR. (Shadowed visibilities are flagged). Using plots such as these, one can determine the optimum length a track at any given declination should run to reach a given percentage of the achievable SNR for any array configuration (see Tables 1 – 3).

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[2]For reference, in 2008A, most proposers seeking single-track observations requested and were granted the length used by the Sensitivity Calculator.

One can also examine the sidelobe level at a given SNR level compared with a full horizon track (again already a nice feature of Mel's script).

## 3. Proposal for Scheduling Observations

The results indicate that a target 90% SNR level is a good choice to balance SNR, image fidelity, and efficient use of array time, in agreement with the conclusions of RR96. Beyond 12 hours, there is no addition gain in UV coverage, so I suggest no regular science track be allowed to observe longer than this.

The 90% SNR level requirement can be encapsulated in code (via lookup tables) such that `mksched` would use it when creating schedules and the project database would use to set the hour angle limit fields for a given source (since they are in the same code tree, it would in fact be the identical subroutine). The Sensitivity Calculator would be modified similarly. The observers would then run the `schedule()` python wrapper to generate a schedule for the next few days, and run the array according to that. (Note the `schedule()` wrapper runs `mksched` using the project database information as input, so any hour angle overrides by the AD or FOT are always included.) This gives observers the benefit of the schedule packing optimization built in to `mksched`, which should result in higher efficiency use of the array. We could even implement a crontab that runs once a day to generate separate 3 mm and 1 mm schedules as well as a master script for each. The observers would just then run the master script appropriate to the weather.

By comparison with 2008A tracks, a 90% limit gives slightly longer tracks for $\delta \lesssim -15$, about the same length for $-15 \lesssim \delta \lesssim 20$, and longer tracks for $\delta > 20$. At high declinations, tracks can be hours longer since the maximum length is raised from 8 hours to 12 hours.

The updated version of Mel Wright's hetero.csh for use in generating the data in this memo is available in the MIRIAD distribution as `$MIR/demo/carma/hetero.csh`.

## REFERENCES

Regan, M.W. & Rand, R.J. 1996, BIMA Memo #47: *Optimizing the Length of Observing Tracks with BIMA*

Wright, M.C.H.W. 2004, CARMA Memo #24: *Antenna Configuration Evaluation*

Table 1: Track lengths to reach 100% SNR threshold for A,B,C arrays

| | $\nu < 115$ GHz | | | | | $\nu > 115$ GHz | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Declination (degrees) | Length (hours) | Elev. Limit (degrees) | Sidelobe (%) Rms | Max | Min | Length (hours) | Elev. Limit (degrees) | Sidelobe (%) Rms | Max | Min |
| –30 | 6.22 | 10 | 1.5 | 7.6 | –7.1 | 6.22 | 10 | 1.7 | 8.1 | –7.3 |
| –25 | 7.17 | 10 | 1.5 | 8.8 | –7.2 | 7.17 | 10 | 1.6 | 9.8 | –7.3 |
| –20 | 7.95 | 10 | 1.5 | 11.1 | –7.5 | 7.95 | 10 | 1.6 | 12.2 | –7.7 |
| –15 | 8.63 | 10 | 1.5 | 11.9 | –7.6 | 8.63 | 10 | 1.7 | 13.9 | –7.7 |
| –10 | 9.24 | 10 | 1.6 | 11.8 | –8.4 | 9.24 | 10 | 1.7 | 14.0 | –8.5 |
| –5 | 9.80 | 10 | 1.7 | 15.9 | –8.6 | 9.80 | 10 | 1.9 | 18.3 | –8.7 |
| 0 | 10.33 | 10 | 2.0 | 47.7 | –10.7 | 10.33 | 10 | 2.2 | 48.4 | –11.1 |
| 5 | 10.84 | 10 | 1.7 | 15.4 | –8.1 | 10.84 | 10 | 1.9 | 16.6 | –8.3 |
| 10 | 11.33 | 10 | 1.6 | 13.0 | –7.9 | 11.33 | 10 | 1.7 | 14.7 | –7.9 |
| 15 | 11.83 | 10 | 1.5 | 9.4 | –7.2 | 11.83 | 10 | 1.6 | 10.1 | –7.8 |
| 20 | 12.33 | 10 | 1.4 | 8.7 | –7.1 | 12.33 | 10 | 1.5 | 8.6 | –7.6 |
| 25 | 12.86 | 10 | 1.3 | 8.0 | –7.1 | 12.86 | 10 | 1.5 | 7.6 | –7.5 |
| 30 | 13.42 | 10 | 1.3 | 6.9 | –6.8 | 13.42 | 10 | 1.4 | 6.8 | –7.4 |
| 35 | 14.03 | 10 | 1.2 | 6.1 | –6.6 | 14.03 | 10 | 1.3 | 6.7 | –7.2 |
| 40 | 14.73 | 10 | 1.2 | 5.8 | –6.4 | 14.73 | 10 | 1.3 | 6.5 | –7.0 |
| 45 | 15.54 | 10 | 1.1 | 5.8 | –6.0 | 15.54 | 10 | 1.2 | 6.4 | –6.7 |
| 50 | 16.55 | 10 | 1.1 | 5.5 | –5.6 | 16.55 | 10 | 1.1 | 6.2 | –6.3 |
| 55 | 17.90 | 10 | 1.0 | 5.3 | –5.4 | 17.90 | 10 | 1.1 | 6.0 | –5.8 |
| 60 | 20.00 | 10 | 0.9 | 5.0 | –4.8 | 20.00 | 10 | 1.0 | 5.7 | –5.3 |

Table 2: Track lengths to reach 90% SNR threshold for A,B,C arrays

| | $\nu < 115$ GHz | | | | | $\nu > 115$ GHz | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Declination | Length | Elev. Limit | Sidelobe (%) | | | Length | Elev. Limit | Sidelobe (%) | | |
| (degrees) | (hours) | (degrees) | Rms | Max | Min | (hours) | (degrees) | Rms | Max | Min |
| –30 | 4.30 | 16.48 | 1.8 | 9.3 | –7.9 | 3.70 | 18.11 | 2.0 | 11.7 | –8.5 |
| –25 | 4.70 | 19.66 | 1.8 | 10.4 | –7.9 | 4.00 | 21.85 | 2.0 | 12.1 | –8.6 |
| –20 | 5.27 | 21.93 | 1.8 | 13.0 | –8.1 | 4.50 | 24.70 | 1.9 | 14.7 | –8.3 |
| –15 | 5.50 | 25.09 | 1.8 | 16.1 | –8.1 | 5.00 | 27.13 | 1.9 | 17.4 | –8.5 |
| –10 | 6.00 | 26.84 | 1.8 | 15.6 | –8.6 | 5.00 | 31.28 | 2.0 | 19.2 | –8.7 |
| –5 | 6.50 | 28.16 | 2.0 | 19.4 | –8.8 | 5.50 | 33.06 | 2.2 | 19.5 | –8.7 |
| 0 | 6.50 | 31.77 | 2.3 | 48.9 | –11.5 | 5.80 | 35.39 | 2.5 | 49.3 | –11.8 |
| 5 | 7.00 | 32.46 | 2.0 | 18.0 | –8.6 | 6.00 | 37.94 | 2.2 | 18.6 | –8.8 |
| 10 | 7.50 | 32.78 | 1.8 | 16.1 | –8.5 | 6.30 | 39.66 | 2.0 | 17.5 | –8.5 |
| 15 | 7.50 | 35.75 | 1.8 | 10.6 | –8.5 | 6.50 | 41.63 | 1.9 | 12.6 | –8.5 |
| 20 | 8.01 | 35.53 | 1.7 | 9.4 | –8.6 | 7.00 | 41.50 | 1.8 | 10.1 | –8.7 |
| 25 | 8.50 | 35.06 | 1.6 | 7.9 | –8.4 | 7.00 | 44.02 | 1.7 | 9.3 | –8.7 |
| 30 | 8.50 | 37.36 | 1.5 | 7.0 | –8.2 | 7.50 | 43.25 | 1.6 | 8.3 | –8.6 |
| 35 | 9.00 | 36.56 | 1.4 | 6.5 | –7.8 | 7.50 | 45.13 | 1.6 | 8.2 | –8.4 |
| 40 | 9.50 | 35.71 | 1.4 | 6.4 | –7.5 | 8.00 | 43.85 | 1.5 | 7.6 | –8.0 |
| 45 | 10.0 | 34.88 | 1.3 | 6.2 | –7.1 | 8.50 | 42.49 | 1.4 | 7.1 | –7.6 |
| 50 | 10.5 | 34.15 | 1.2 | 6.1 | –6.8 | 9.00 | 41.12 | 1.3 | 7.1 | –7.2 |
| 55 | 11.5 | 31.54 | 1.1 | 5.9 | –6.2 | 9.50 | 39.82 | 1.2 | 7.1 | –7.0 |
| 60 | 12.5 | 29.69 | 1.0 | 5.6 | –5.8 | 10.0 | 38.66 | 1.2 | 6.8 | –6.6 |

Table 3: Track lengths to reach 80% SNR threshold for A,B,C arrays

| | $\nu < 115$ GHz | | | | | $\nu > 115$ GHz | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Declination | Length | Elev. Limit | Sidelobe (%) | | | Length | Elev. Limit | Sidelobe (%) | | |
| (degrees) | (hours) | (degrees) | Rms | Max | Min | (hours) | (degrees) | Rms | Max | Min |
| –30 | 3.20 | 19.31 | 2.1 | 12.9 | –8.6 | 2.70 | 20.34 | 2.3 | 14.9 | -8.8 |
| –25 | 3.50 | 23.24 | 2.1 | 12.7 | –8.7 | 3.00 | 24.46 | 2.3 | 14.2 | -8.8 |
| –20 | 4.00 | 26.35 | 2.0 | 15.4 | –8.5 | 3.30 | 28.39 | 2.2 | 17.4 | -8.6 |
| –15 | 4.20 | 30.12 | 2.0 | 18.5 | –8.7 | 3.50 | 32.40 | 2.2 | 19.6 | -8.8 |
| –10 | 4.50 | 33.31 | 2.1 | 20.6 | –8.7 | 3.70 | 36.25 | 2.3 | 21.3 | -8.8 |
| –5 | 4.80 | 36.23 | 2.3 | 21.6 | –8.8 | 4.00 | 39.52 | 2.5 | 25.2 | -8.9 |
| 0 | 5.00 | 39.30 | 2.6 | 49.5 | –12.0 | 4.30 | 42.47 | 2.8 | 49.7 | -12.2 |
| 5 | 5.20 | 42.11 | 2.3 | 19.9 | –8.9 | 4.50 | 45.55 | 2.5 | 22.6 | -8.9 |
| 10 | 5.50 | 44.08 | 2.1 | 19.2 | –8.5 | 4.50 | 49.32 | 2.4 | 19.8 | -8.8 |
| 15 | 5.80 | 45.66 | 2.0 | 13.5 | –8.5 | 4.70 | 51.78 | 2.2 | 16.0 | -8.7 |
| 20 | 6.00 | 47.43 | 1.9 | 10.8 | –8.7 | 5.00 | 53.24 | 2.1 | 13.3 | -8.8 |
| 25 | 6.00 | 50.01 | 1.8 | 10.2 | –8.8 | 5.00 | 55.95 | 2.0 | 13.0 | -8.9 |
| 30 | 6.50 | 49.20 | 1.7 | 9.2 | –8.8 | 5.50 | 55.18 | 1.9 | 11.3 | -8.9 |
| 35 | 6.50 | 50.95 | 1.7 | 7.9 | –8.7 | 5.50 | 56.83 | 1.8 | 10.4 | -8.9 |
| 40 | 7.00 | 49.41 | 1.6 | 7.4 | –8.4 | 5.80 | 56.17 | 1.7 | 8.2 | -8.8 |
| 45 | 7.50 | 47.68 | 1.5 | 7.1 | –7.8 | 6.00 | 55.58 | 1.7 | 8.2 | -8.7 |
| 50 | 7.50 | 48.28 | 1.4 | 6.6 | –7.6 | 6.20 | 54.54 | 1.6 | 8.0 | -8.5 |
| 55 | 8.00 | 46.24 | 1.3 | 6.4 | –7.2 | 6.50 | 52.67 | 1.5 | 7.8 | -8.1 |
| 60 | 9.00 | 42.39 | 1.2 | 6.5 | –6.9 | 7.00 | 49.86 | 1.4 | 7.0 | -7.6 |

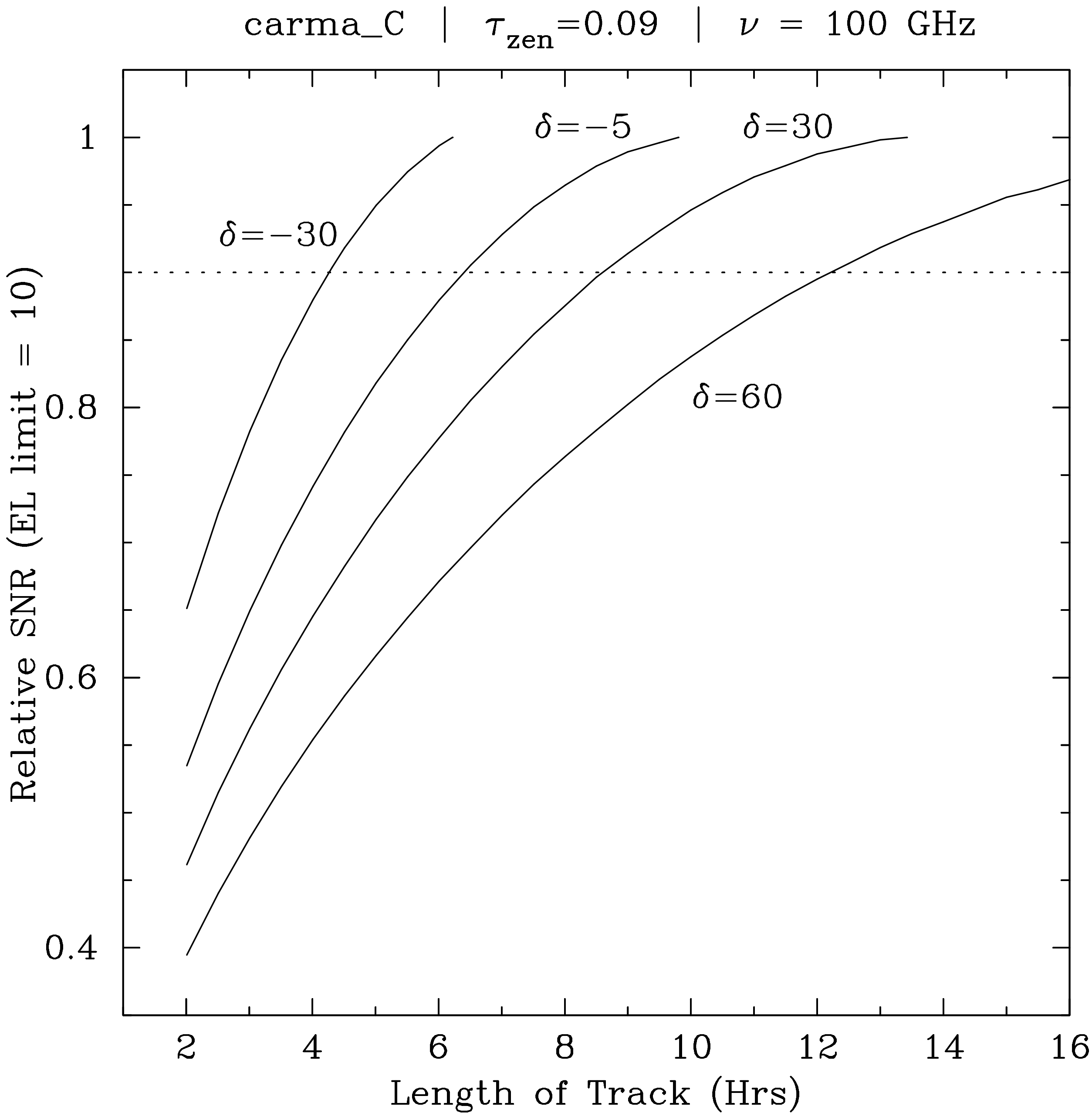


Fig. 1.— The signal-to-noise of tracks as a function of track length expressed relative to the maximum achievable SNR in a full horizon-to-horizon track. Data were computed using the CARMA C array configuration and a zenith opacity of $\tau = 0.09$, appropriate for $\lambda = 3$ mm non-CO observations. Dotted line indicates 90% of achievable SNR.

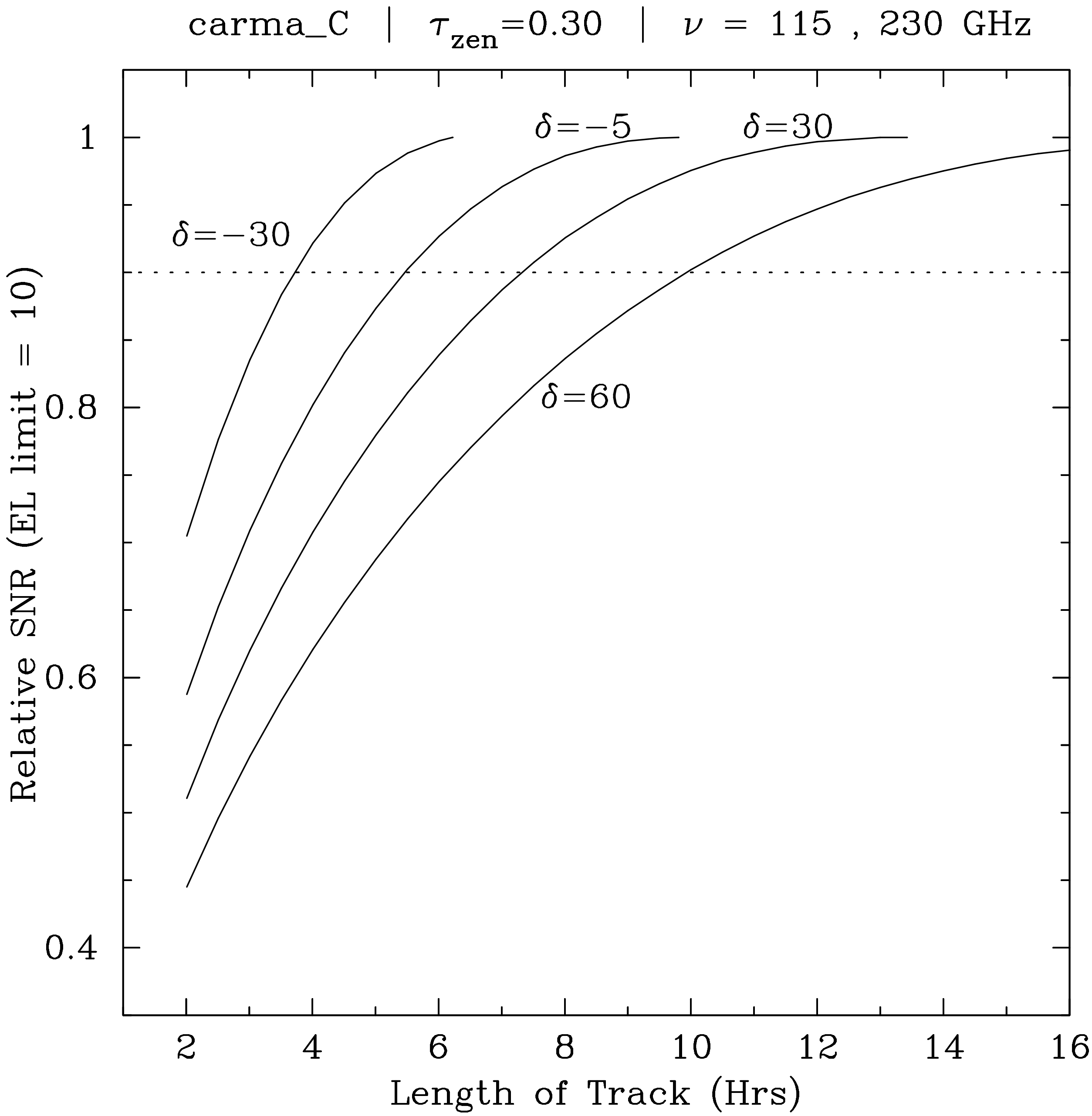


Fig. 2.— The signal-to-noise of tracks as a function of track length expressed relative to the maximum achievable SNR in a full horizon-to-horizon track. Data were computed using the CARMA C array configuration and a zenith opacity of $\tau = 0.30$, appropriate for CO(1-0) observations or $\lambda = 1$ mm observations. Dotted line indicates 90% of achievable SNR.

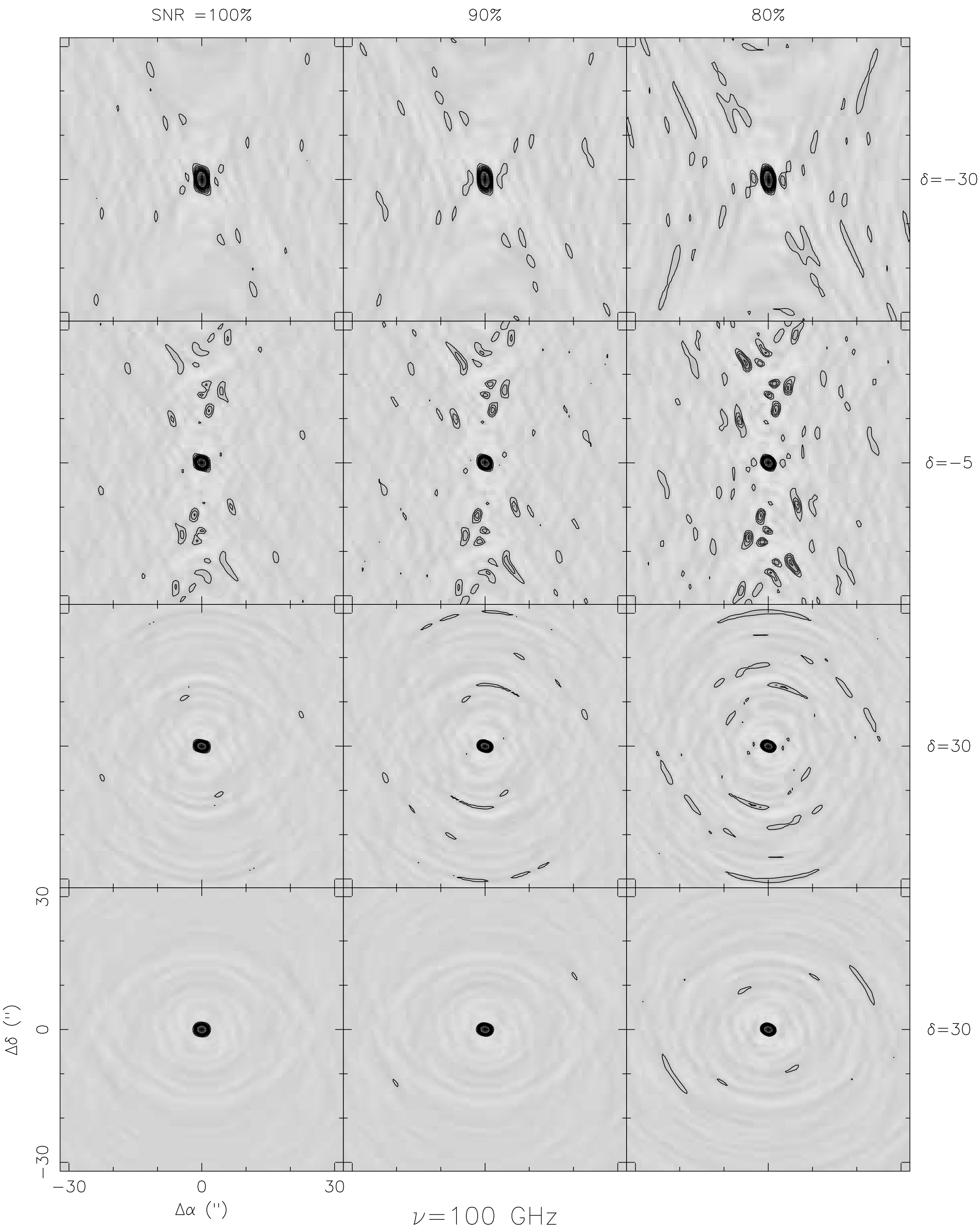


Fig. 3.— Synthesized beam patterns as a function of SNR level relative to maximum achievable SNR and declination. Contour levels are 5%. Beams were computed using the CARMA C array configuration and a zenith opacity of $\tau = 0.09$, appropriate for $\lambda = 3$ mm non-CO observations.

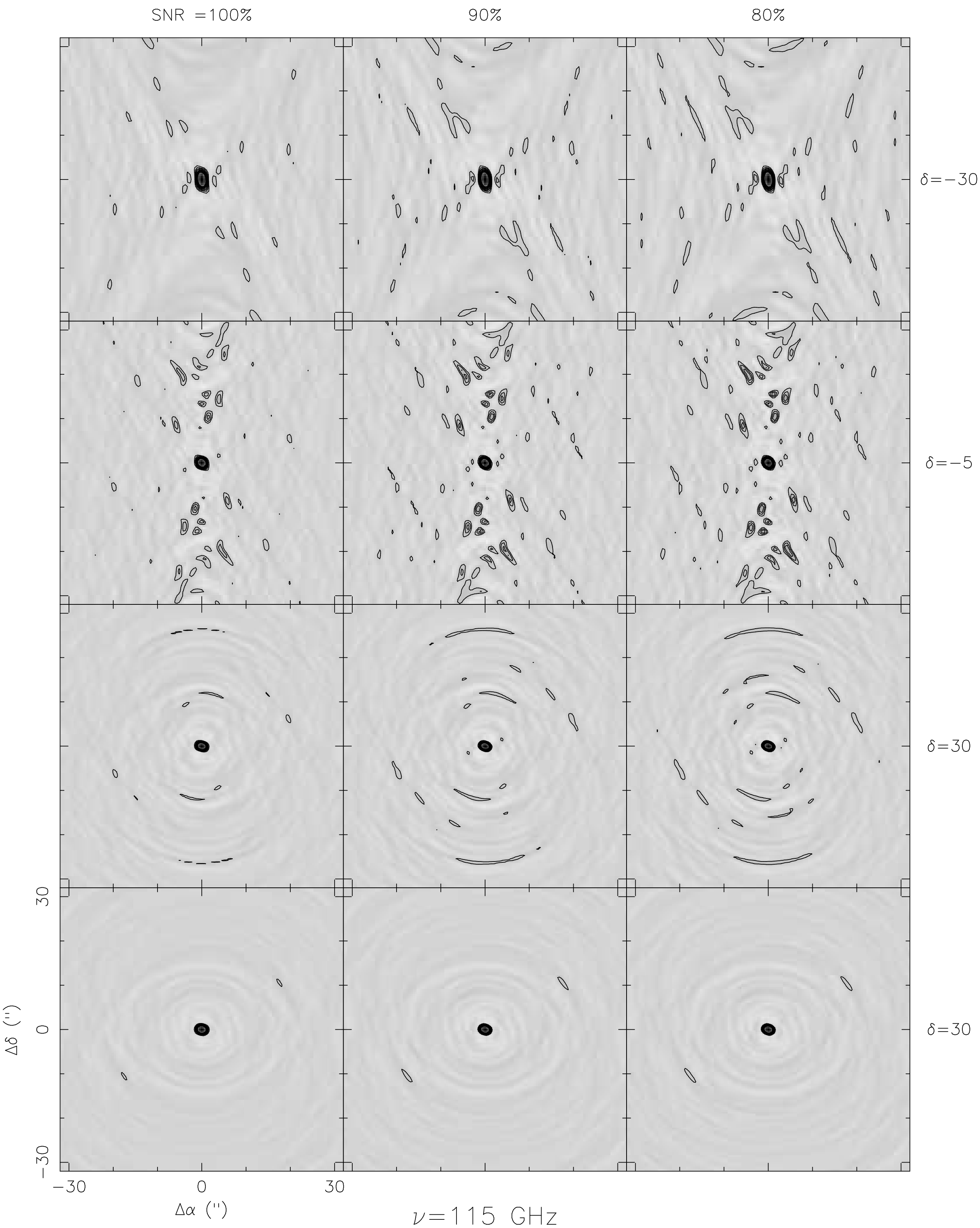


Fig. 4.— Synthesized beam patterns as a function of SNR level relative to maximum achievable SNR and declination. Contour levels are 5%. Beams were computed using the CARMA C array configuration and a zenith opacity of $\tau = 0.30$, appropriate for CO(1-0) observations or $\lambda = 1$ mm observations.