Optimizing the Length of Observing Tracks with BIMA

Michael W. Regan & Richard J. Rand

May 29, 1996

1. Introduction

Presently the length of observing tracks are based on several different criteria: user requests, arbitrary cutoff elevations, or standard track lengths. All of these methods can lead to the continuation of tracks for only minimal gains in signal-to-noise ratio (SNR) or UV coverage. In addition, some tracks are cut short when they are still productively adding to their UV coverage and SNR. To obtain the maximum productivity for the array it is important to determine the optimum track length and the optimum array configuration for each declination. This document deals with the track length issue.

The current method of scheduling is to assign all tracks a length of eight hours. For reference, we note that an eight-hour track corresponds to a 30° elevation limit at Dec 11°, and a 20° elevation limit at Dec –3°. When determining the SNR and the beam for tracks it is important to weight the observations by the system temperature to correctly determine the value of added observations. For these calculations we use the approximation of

$$T_{sys} = ke^{\tau A} \tag{1}$$

where k is approximately the receiver temperature, τ is the optical depth of the atmosphere at 1 airmass, and A is the observing airmass. We use the approximation that $A = 1/sin(elevation)$. There are two different observing frequency ranges that have different values of τ. A source of optical depth at all frequencies is from water in the atmosphere and here we will assume good weather leading to a contribution to τ of 0.2. For observations near 115 Ghz the contribution of the telluric Oxygen line adds about 0.3 optical depths, so that $\tau = 0.5$. The assumption of good weather increases the lengths of tracks since in such weather T_{sys} deteriorates less rapidly with decreasing elevation than in bad weather.

2. The increase in the SNR with time

A method that can be used to investigate optimum track lengths is to look at the SNR of a track that observes from horizon to horizon and compare that to the SNR for subsets of that time.

Figure 1 shows the relative SNR as a function of the length of the track for various declinations when $\tau = 0.2$; while Figure 2 shows the relationship when $\tau = 0.5$. From these Figures it is possible to determine how long a track should be for a given declination to reach a certain percentage of the maximum SNR. Table 1 shows what values are obtained for various declinations and relative SNR thresholds.

3. The improvement of UV coverage with time

What are the consequences for the dirty beam shape of enforcing track-length limits such as have been used in the past at BIMA vs. limits based on the SNR thresholds above?

All the beams shown here have been produced by a version of the miriad program 'uvgen', modified so that the system temperature outputted follows the form of equation 1. This allows optimal beams and maps to be produced by weighting the uv sampling by T_{sys} upon running 'invert', which is standard practice. We consider both $\tau = 0.2$ and $\tau = 0.5$, but for tracks with a fixed time or elevation limit, beams are quite similar for these two values, regardless of declination.

First, Figure 3 shows dirty beams for tracks with lengths fixed by a time restriction: 8 hours in the standard C array for Dec 60°, 30° and –5°, and 7 hours in the hybrid (H) array for –28° (H array is used for low-dec sources because of shadowing in C array). This is, roughly speaking, how tracks are currently being scheduled. $\tau = 0.5$ is assumed. These beams serve as a reference for the following comparisons.

Now we consider beams for tracks limited by the three SNR thresholds of Table 1. Since the durations are very much dependent on τ we consider both values. Again, C array is used except for Dec –28°. Figures 4 and 5 show beams for $\tau = 0.2$ and $\tau = 0.5$, respectively.

Table 1 Track Lengths for Reaching Various SNR thresholds

	$\tau = 0.2$			$\tau = 0.5$		
Declination	80%	90%	95%	80%	90%	95%
60	11.0	15.0	17.64	8.32	11.30	13.64
30	7.10	9.60	11.0	6.0	8.0	9.4
–5	5.10	6.58	7.80	4.10	5.4	6.58
–28	3.2	4.32	5.16	2.4	3.32	4.16

Tables 2 and 3 show the worst sidelobe for all the cases shown in these figures. For all Decs except –5°, the sidelobe considered is the worst positive one that is separated from the main peak by negative sidelobes (these are higher than the worst negative sidelobe in every case). For Dec –5°, the beam quality is more limited by the strong positive sidelobes oriented north-south which are connected to the main peak (as occurs for all sources near Dec 0°); these are quoted in the table. Note that worst sidelobe is not the only measure of the quality of the dirty beam. Boxiness and elongation of the central peak and the size and shape of the sidelobes are in general important.

Table 2 Worst Dirty-Beam Sidelobes for the Current Scheduling Method. $\tau = 0.5$

Declination and Array	Time (hrs)	Elev. limit (degrees)	Worst sidelobe
60°(C)	8.0	49	9%
30°(C)	8.0	41	12%
–5°(C)	8.0	19	45%
–28°(H)	7.0	6	25%

Table 3 Worst Dirty-Beam Sidelobes for the Various SNR Thresholds. $\tau = 0.2$

Declination and Array	SNR Threshold	Time (hrs)	Elev. limit	Worst sidelobe
60°(C)	80%	11.0	38°	7%
60°	90%	15.0	25°	6%
60°	95%	17.6	18°	5%
30°(C)	80%	7.1	46°	13%
30°	90%	9.6	32°	9%
30°	95%	11.0	24°	9%
–5°(C)	80%	5.1	32°	45%
–5°	90%	6.6	26°	45%
–5°	95%	11.0	20°	45%
–28°(H)	80%	3.2	18°	35%
–28°	90%	4.3	15°	25%
–28°	95%	5.2	12°	25%

Table 4 Worst Dirty-Beam Sidelobes for the Various SNR Thresholds. $\tau = 0.5$

Declination and Array	SNR Threshold	Time (hrs)	Elev. limit	Worst sidelobe
60°(C)	80%	8.3	48°	11%
60°	90%	11.3	37°	7%
60°	95%	13.6	29°	6%
30°(C)	80%	6.0	52°	15%
30°	90%	8.0	41°	12%
30°	95%	9.4	33°	10%
–5°(C)	80%	4.1	36°	45%
–5°	90%	5.4	31°	45%
–5°	95%	6.6	26°	45%
–28°(H)	80%	2.4	19°	45%
–28°	90%	3.3	17°	35%
–28°	95%	4.2	15°	35%

4. The importance of centering on transit

In general, a schedule can be made shorter if tracks are not required to be centered on the transit LST of the source. What are the consequences for the SNR and beam quality? For this section, only the cases Dec=–28°, $\tau = 0.2$ and Dec=30°, $\tau = 0.5$ are considered, and tracks are taken to be 5 and 8 hours for these Decs, respectively. Both C and H array are considered for Dec 30°, and H array for Dec -28°. Track center times of up to 3 hours from the transit LST are considered. The beams for these cases are shown in Figures 6 (Dec 30°, C array), 7(Dec 30°, H array), and 8 (Dec –28°, H array). The worst sidelobes are listed in Table 5. Only cases where the track is centered at or before the transit LST are listed in the Table; the corresponding cases for centering after the transit LST give the same numbers.

Table 5 Effect of Not Centering Tracks on Transit LST on Worst Dirty-Beam Sidelobe. $\tau = 0.2$

Declination Array, τ	H.A. Range (hrs)	Start Elev	End Elev.	Worst sidelobe
30°(C,τ=0.5)	–4 to +4	41°	41°	12%
30°	–5 to +3	30°	52°	13%
30°	–6 to +2	19°	63°	13%
30°	–7 to +1	9°	74°	18%
30°(H,τ=0.5)	–4 to +4	41°	41°	35%
30°	–5 to +3	30°	52°	35%
30°	–6 to +2	19°	63°	40%
30°	–7 to +1	9°	74°	40%
–28°(H,τ=0.2)	–2.5 to +2.5	13°	13°	25%
–28°	–3.5 to +1.5	6°	18°	25%
–28°	–4.5 to +0.5	0°	21°	35%

5. Conclusions

As far as a criterion for track length is concerned, it seems reasonable to use a **minimum track length corresponding to 90% of the achievable SNR or eight hours, whichever is smaller**. Longer tracks only produce small improvements in both signal-to-noise and dirty beam quality at the expense of a less productive schedule. In the case of high-declination sources when τ is as low as 0.2 (lines other than CO), the eight hour track will result in only 70% to 80% of the achievable SNR but the beam is still good and if more signal is needed more tracks can be requested.

Tracks could be expanded beyond this length once a first cut at the schedule has been made and there are gaps in the schedule either before or after a track. It also seems reasonable that the **maximum length of a track would be the time to reach 95% of the achievable SNR**.

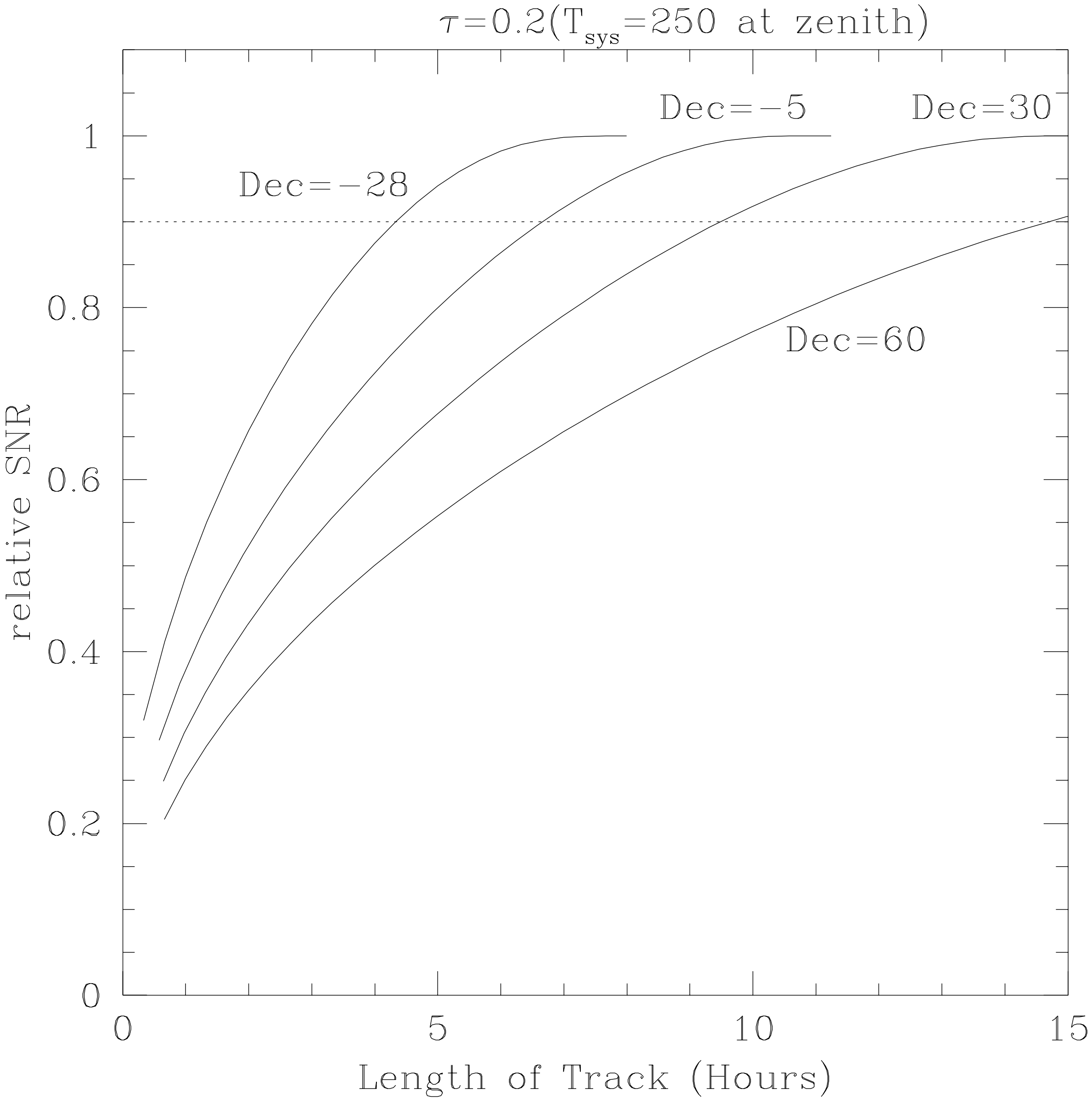

Fig. 1.— The relative signal to noise ratio of tracks as a function of length of track compared to the signal to noise ratio if the source was observed from horizon to horizon. This plot shows the results for the case where τ=0.2 which is appropriate for observing away from 115 Ghz in good weather. The dotted line shows is placed at the 90% level.

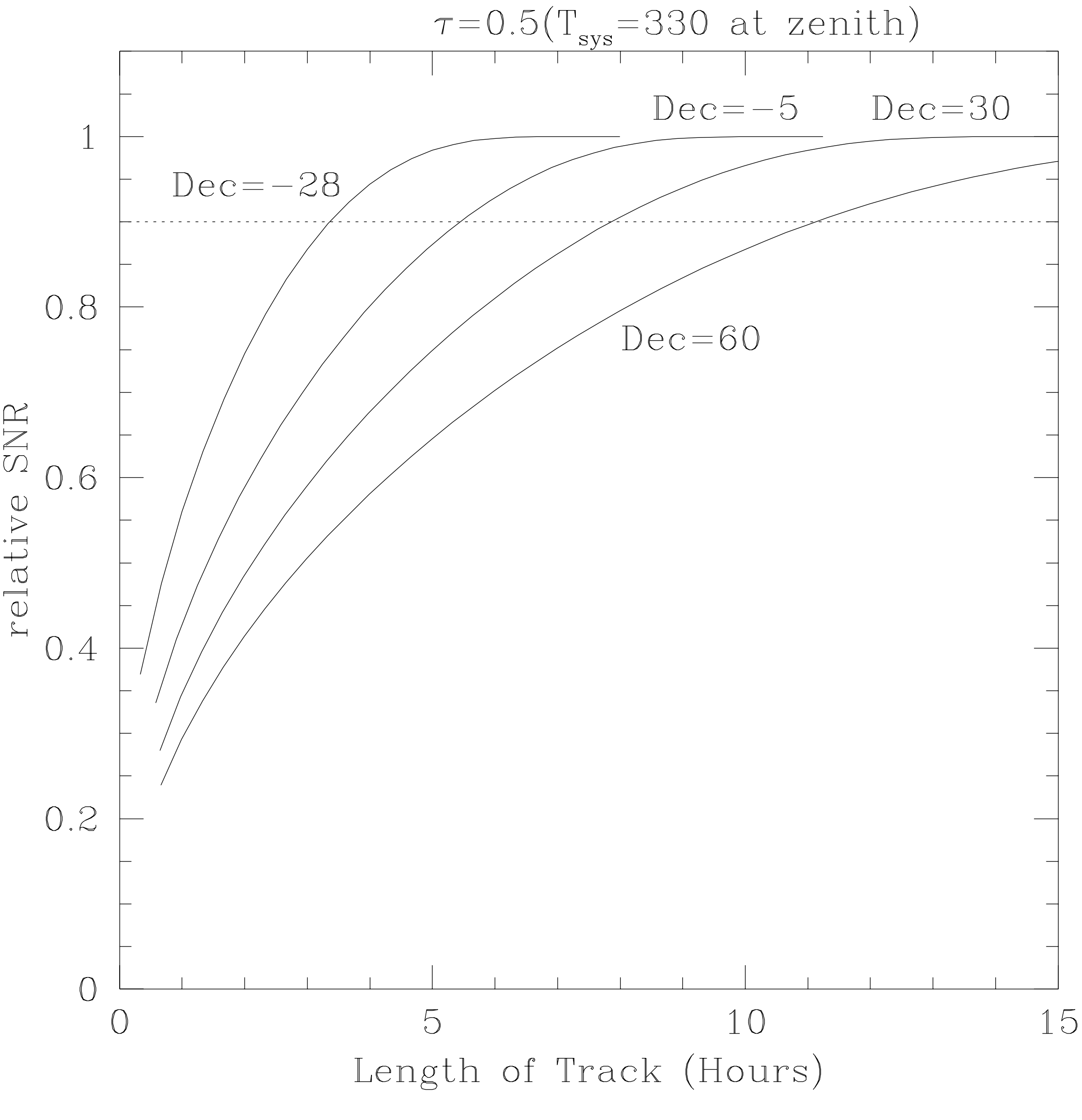

Fig. 2.— The relative signal to noise ratio of tracks as a function of length of track compared to the signal to noise ratio if the source was observed from horizon to horizon. This plot shows the results for the case where τ=0.5 which is appropriate for observing near 115 Ghz in good weather. This yields shorter tracks than the $\tau = 0.2$ since the system temperatures rise more quickly with airmass in the τ=0.5 case. The dotted line shows is placed at the 90% level.

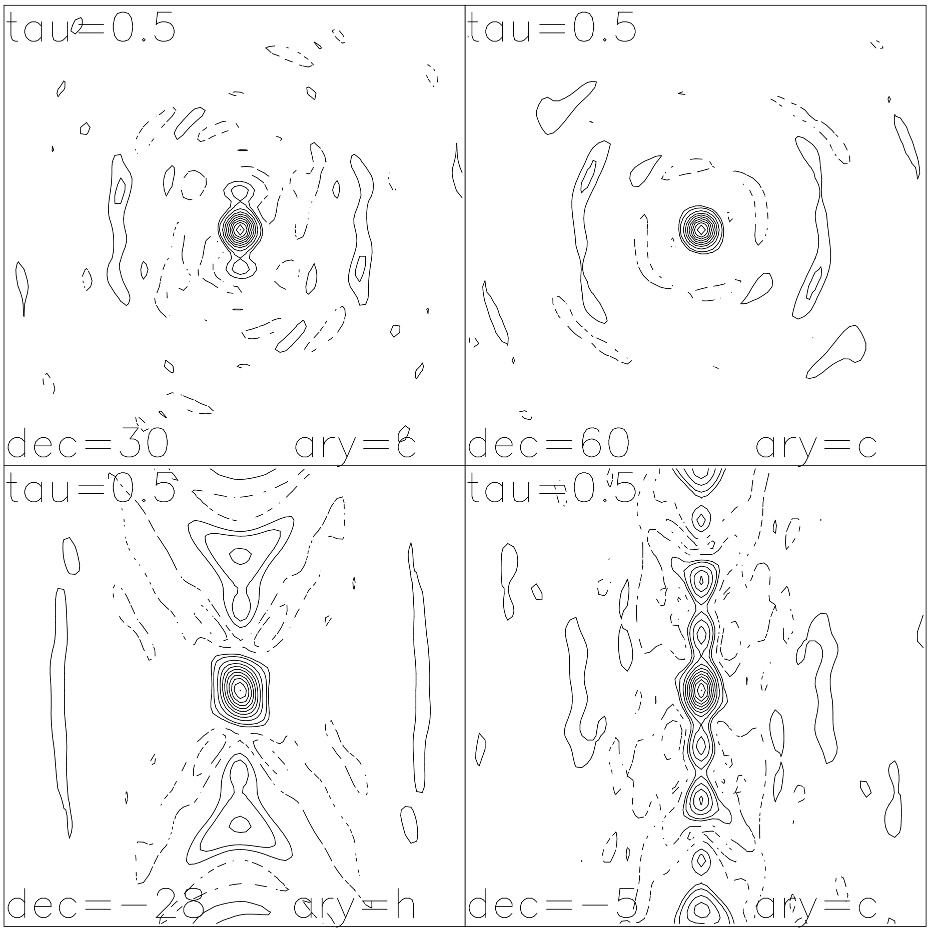

Fig. 3.— The beams for the current scheduling method of all tracks get 8 hours (dec -28 gets only 7 hours). The visibilities are weighted by the system temperature to correctly account for the noise at low elevations.

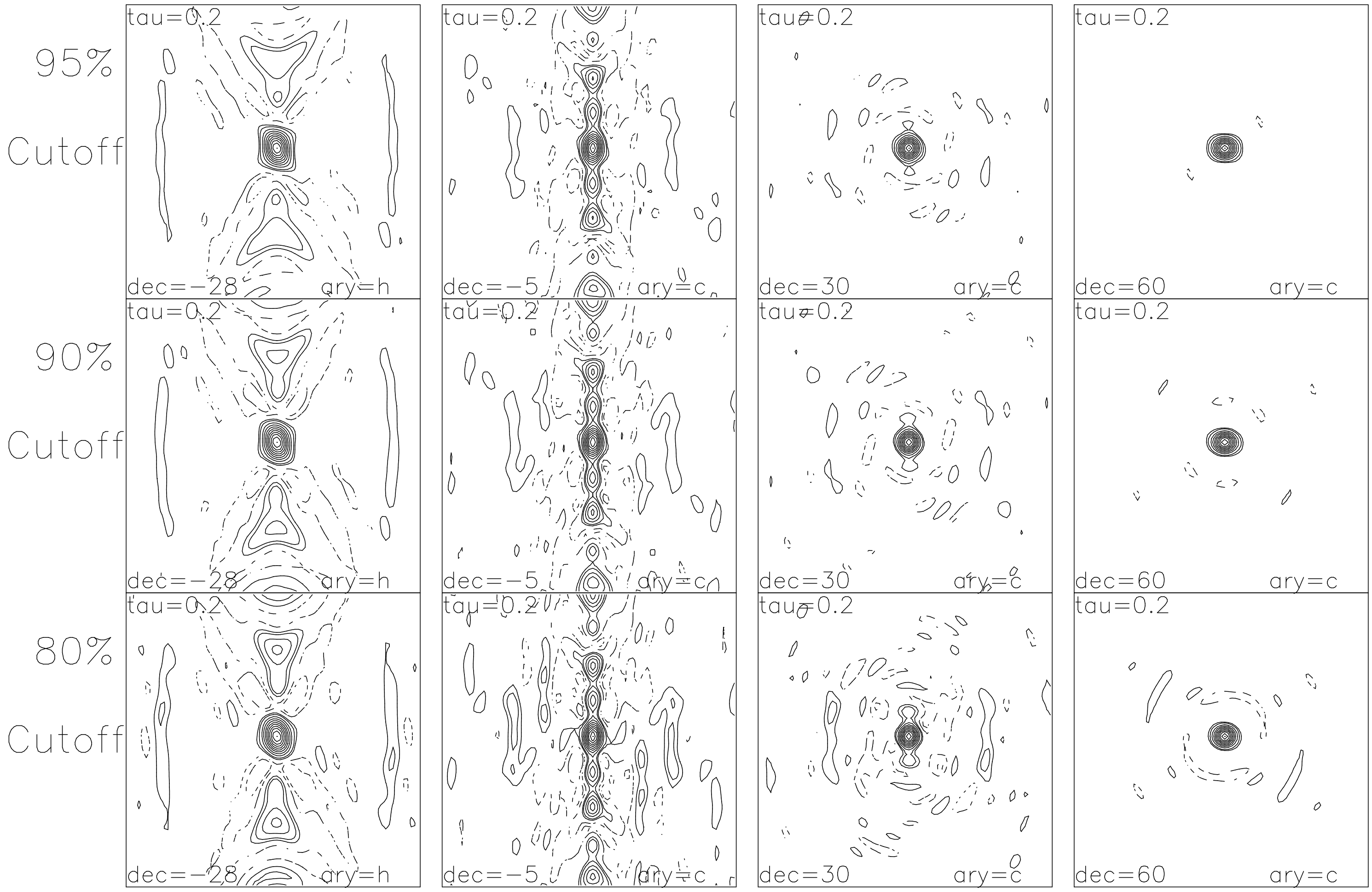

Fig. 4.— Beams for tracks of various SNR cutoffs. The cutoff is relative to the SNR of a track that observes from horizon to horizon. These beams are for $\tau = 0.2$ which is appropriate for observing away from 115 Ghz in good weather.

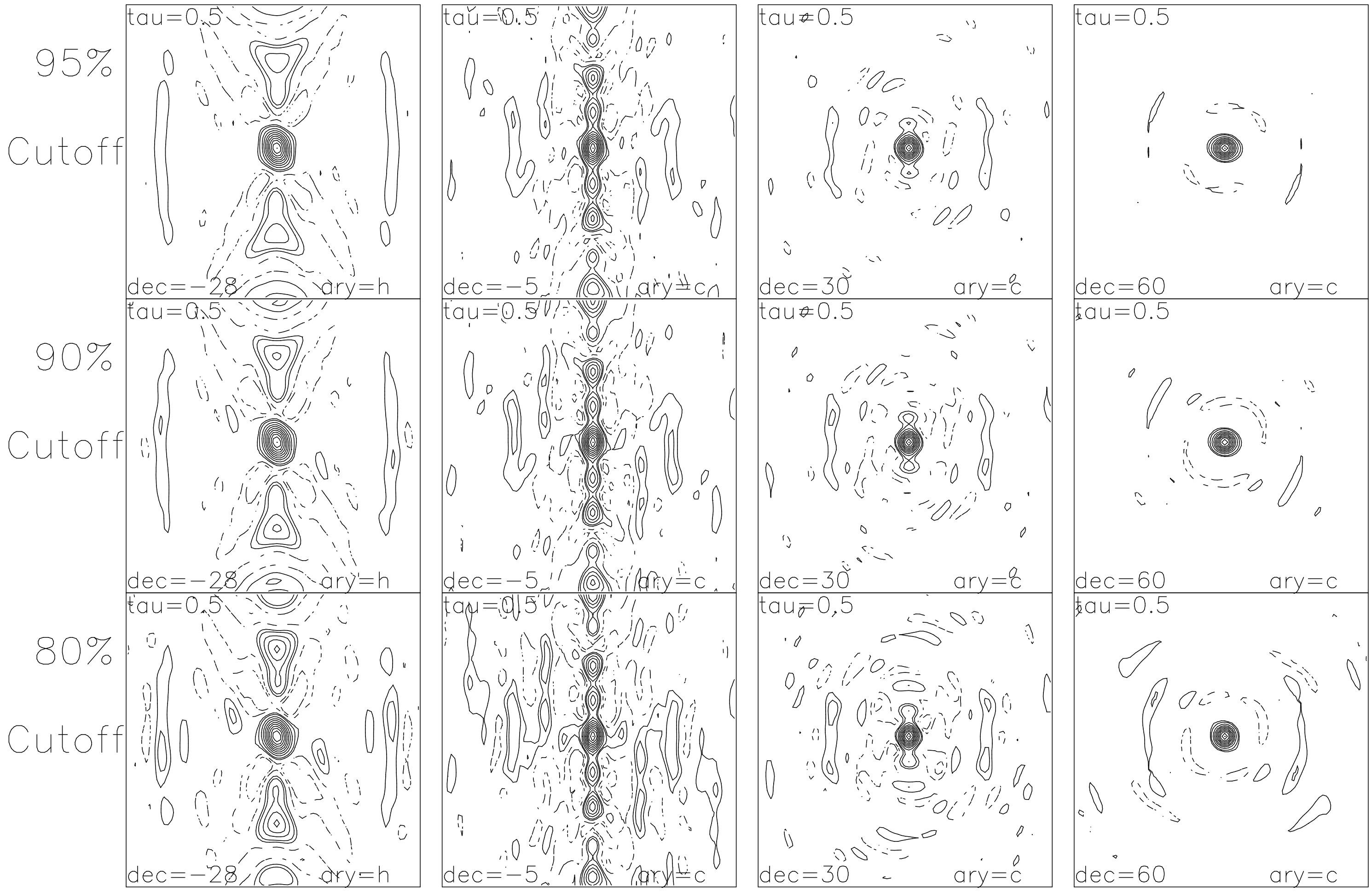

Fig. 5.— Beams for tracks of various SNR cutoffs. The cutoff is relative to the SNR of a track that observes from horizon to horizon. These beams are for $\tau = 0.5$ which is appropriate for observing near 115 Ghz in good weather.

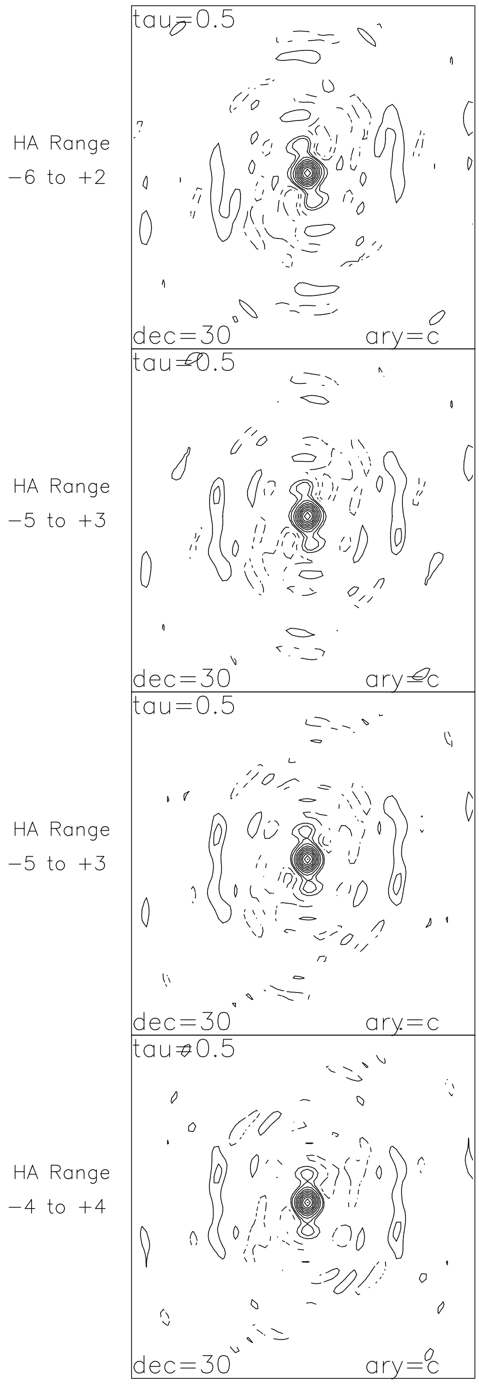

Fig. 6.— C-array beams for off center tracks and declination of 30°.

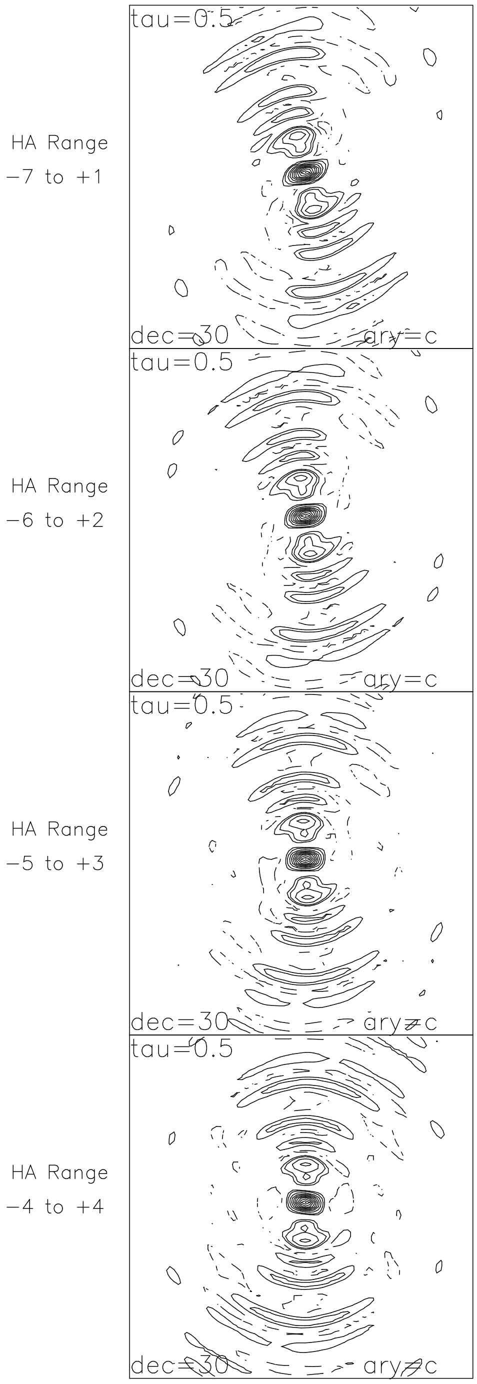

Fig. 7.— H-array beams for off center tracks and declination of 30°.

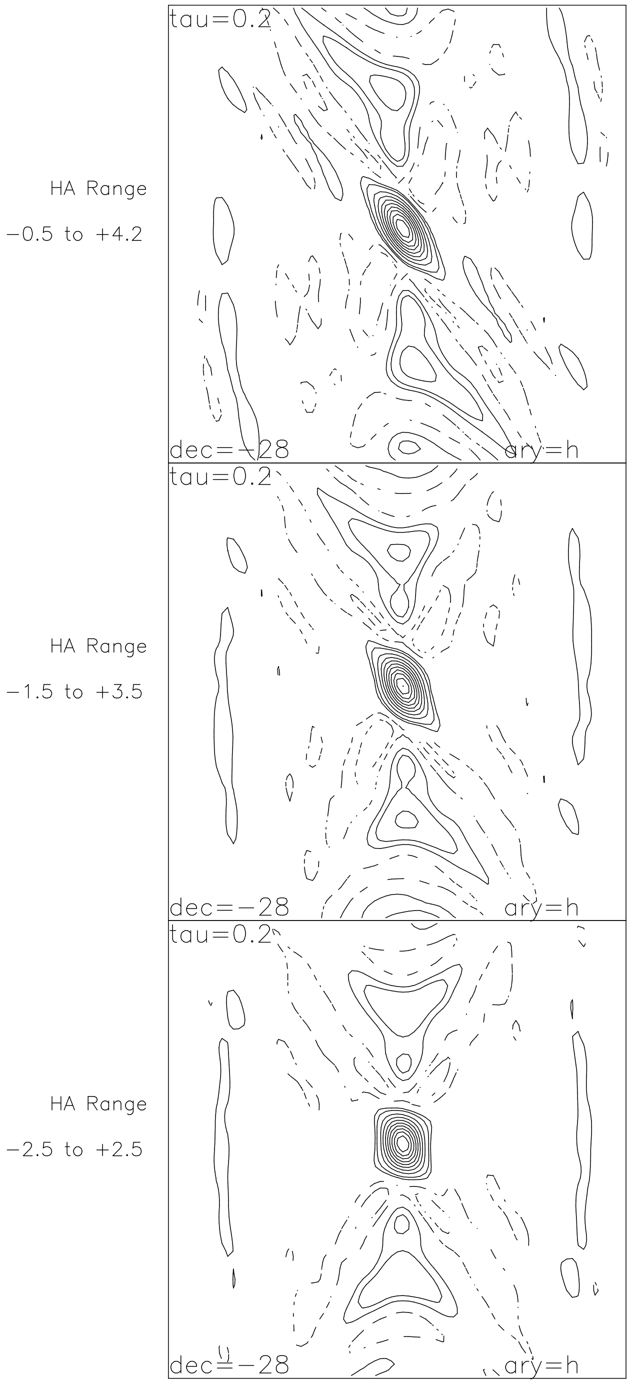

Fig. 8.— H-array beams for off center tracks and declination of −28°.