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Timber Ridge A Configuration Out on a Limb

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1 Can We Build on Timber Ridge?

The configuration studies of Ge (MMA 80, 1992a) explore a single option for the A configuration for the expansive, unconstrained Springerville site, and two options for the A configuration on the Magdalena (South Baldy) site with antennas confined to a system of ridges well above 9000 feet elevation. The Springerville A configuration has superior (u, v) coverage. The two Magdalena A configurations, known as the Timber Ridge and the North Ridge A arrays, have strange but acceptable (u, v) coverage.

The researchers performing the Environmental Impact Study (EIS) have suggested that the southern ~1 mile of the proposed use area on Timber Ridge may be too pristine and environmentally sensitive to disturb with the construction of a road and array operations. Indeed, the rugged outcroppings, steep fields of iris and aspen, old growth forest, and rolling meadows have aesthetic value which cannot be measured on the same scale as the cost of roads or the benefit of scientific discovery. The question then arises: can one build a viable array on Timber Ridge without the last 5 stations on its southern end (see Figure 1)?

2 Array Simulations

Is a truncated Timber Ridge A array viable? This question can be addressed using Ge's configuration design and array building toolkit (Ge, 1992b). Ge (1992a) used the visual appearance of the (u, v) coverage and the beamshape to evaluate his Magdalena A configurations. Since I am not generating a completely new configuration, I assume that the (u, v) coverage is satisfactory (or can be made to be satisfactory), and mainly use the beamshape for my analysis of the various arrays.

Most of the Timber Ridge configuration's long N-S baselines come from the antennas on Timber Ridge. When the southern 5 antennas are moved to other locations, the truncated array is longer in the E-W direction than the N-S direction, and there is a deficit of N-S spacings for high declination sources *unless* the source is tracked to hour angles beyond 2 hours of transit. This deficit becomes severe for southern sources.

To demonstrate the deficit of N-S spacings relative to the other candidate arrays, beam simulations were performed with the Full Timber Ridge array, the North Ridge array, and the

Truncated Timber Ridge array for full tracking (maximum air mass = 1.4 times the minimum air mass) and for snapshots at hour angles of -2, 0, and +2 hours. The resulting parameters of Gaussian fits to the synthesized beams formed using uniform weighting, along with the N-S resolution and the ratio of the beam major and minor axis, are shown in Tables 1 through 3. These irregular arrays have quite different behavior for snapshots at various hour angles, so we have included the beam parameters for snapshots at three different hour angles. Because of the oversubscription of the array and the dynamic allocation, an observer may not get observing time which is symmetric about the target source's transit, so it is important to look at the beam at a range of hour angles. Some configurations have poor beams at some hour angles (even at transit), but have reasonable beams at other hour angles. Sometimes it may be desirable to trade some opacity for more uniform (u, v) coverage by observing the source off-transit.

A few trends are obvious from the fit beam parameters:

- The Full Timber Ridge configuration has the highest resolution.
- At low declinations, the Full Timber Ridge configuration produces a highly elongated beam ($B_{maj}/B_{min} \sim 2 - 2.5$), except near hour angles of +2.
- While the North Ridge configuration does not have resolution as high as the Full Timber Ridge configuration, the beams are more uniform with $B_{maj}/B_{min} \sim 1 - 1.6$ even for low declination sources.
- The Truncated Timber Ridge configuration produces beams which are somewhat worse than the Full Timber Ridge configuration. For a snapshot of a source at $\delta = -30°$ at transit, $B_{maj}/B_{min} = 3.69$, resulting in north-south resolution which is comparable to what is obtained in the B configuration. Longer north-south spacings are found further away from transit. For full tracks on a source at $\delta = -30°$, $B_{maj}/B_{min} = 2.80$.

The Gaussian fits indicate the general nature of the problem with (u, v) coverage, but does not show the exact nature of that problem. Figure 2 shows the transit snapshot (u, v) coverage of a source at $\delta = 60°$ (where we expect the (u, v) coverage to be good) with the Truncated Timber Ridge configuration. The coverage is elongated in the east-west direction and there is a "notch" in the (u, v) coverage about 20° to the left of north. The (u, v) points are oriented as if we were looking up at the source.

In order to improve the N-S (u, v) coverage in the truncated Timber Ridge array, we can place antennas to the south on Hardy Ridge, or we can place antennas to the north on North Ridge. Heading south from the compact configuration site, Hardy Ridge drops 1000 feet in elevation in a bit more than a half mile before there are any acceptable antenna sites. This presents three problems: a road to Hardy Ridge will be expensive (about $6 million), the opacity and phase stability will be worse at 9000 feet than for the rest of the array, and a significant amount of deforestation on the thickly wooded ridge and the approach to the ridge will be inevitable. Hence, if the southern section of Timber Ridge is found to be inappropriate for development, the best option for the A array is to go out along the North Ridge to get the required N-S (u, v) coverage. While the North Ridge array does not have optimal coverage,

δ	B_{min}	B_{maj}	θ	B_{N-S}	B_{maj}/B_{min}
full tracking					
60.	0.0783	0.0759	38.0	0.0774	1.03
30.	0.0979	0.0765	-17.2	0.0953	1.28
0.	0.1125	0.0818	-3.4	0.1123	1.38
-30.	0.1988	0.0814	0.6	0.1987	2.44
snapshot HA = -2					
60.	0.1188	0.0868	-9.7	0.1174	1.37
30.	0.1368	0.1034	-55.3	0.1114	1.32
0.	0.0907	0.0767	-33.5	0.0857	1.18
-30.	0.1467	0.0791	-16.9	0.1336	1.85
snapshot HA = 0					
60.	0.0774	0.0750	-42.2	0.0763	1.03
30.	0.0736	0.0736	-44.9	0.0736	1.00
0.	0.0951	0.0848	-35.0	0.0913	1.12
-30.	0.2031	0.0799	1.7	0.2026	2.54
snapshot HA = +2					
60.	0.1325	0.0862	-70.0	0.0893	1.54
30.	0.1294	0.0823	-71.9	0.0848	1.57
0.	0.1114	0.1042	24.7	0.1100	1.07
-30.	0.1507	0.1149	28.3	0.1398	1.31

Table 1: Beam fit parameters for the Full Timber Ridge A configuration.

δ	B_{min}	B_{maj}	θ	B_{N-S}	B_{maj}/B_{min}
full tracking					
60.	0.1360	0.1002	87.4	0.1002	1.36
30.	0.1346	0.0930	85.7	0.0931	1.45
0.	0.1357	0.1121	78.8	0.1128	1.21
-30.	0.2095	0.1334	9.6	0.2054	1.57
snapshot HA = -2					
60.	0.1338	0.0986	-81.6	0.0991	1.36
30.	0.1386	0.0909	-75.8	0.0925	1.52
0.	0.1527	0.1207	-59.4	0.1270	1.27
-30.	0.1652	0.1213	-27.6	0.1519	1.36
snapshot HA = 0					
60.	0.1302	0.0970	87.4	0.0970	1.34
30.	0.1309	0.0898	85.2	0.0900	1.46
0.	0.1328	0.1106	75.8	0.1116	1.20
-30.	0.2144	0.1280	10.3	0.2085	1.67
snapshot HA = +2					
60.	0.1381	0.1012	75.7	0.1027	1.36
30.	0.1507	0.0993	67.7	0.1036	1.52
0.	0.1849	0.1347	54.7	0.1467	1.37
-30.	0.1333	0.1113	35.4	0.1245	1.20

Table 2: Beam fit parameters for the North Ridge A configuration.

δ	B_{min}	B_{maj}	θ	B_{N-S}	B_{maj}/B_{min}
full tracking					
60.	0.1032	0.0950	-31.3	0.1008	1.09
30.	0.1093	0.0892	-22.2	0.1056	1.23
0.	0.1406	0.0889	-12.0	0.1362	1.58
-30.	0.2602	0.0930	-4.7	0.2544	2.80
snapshot HA = -2					
60.	0.1285	0.0852	10.8	0.1257	1.51
30.	0.1243	0.0857	-9.9	0.1223	1.45
0.	0.1293	0.0832	-19.4	0.1203	1.55
-30.	0.1541	0.0797	-19.9	0.1343	1.93
snapshot HA = 0					
60.	0.1173	0.0793	-17.9	0.1112	1.48
30.	0.1094	0.0779	-19.4	0.1040	1.40
0.	0.1404	0.0819	-10.2	0.1363	1.71
-30.	0.3011	0.0816	-1.8	0.2992	3.69
snapshot HA = +2					
60.	0.1507	0.1196	-51.9	0.1290	1.26
30.	0.0918	0.0915	-44.6	0.0917	1.00
0.	0.1443	0.1054	0.3	0.1443	1.37
-30.	0.1808	0.0974	19.9	0.1596	1.86

Table 3: Beam fit parameters for the Truncated Timber Ridge A configuration.

numerical simulations (Holdaway, 1992) indicate that the (u, v) coverage will not limit the dynamic range to below 30,000:1 or the image fidelity (Holdaway, 1990) to below 120:1 for complicated source structures. (There are a host of other errors which often *will* limit the dynamic range and image fidelity to below these numbers.)

The North Ridge array is basically a $\vdash$ in shape, so the instantaneous (u, v) coverage will be the autocorrelation of the $\vdash$. This leads to a fairly uniform box in the (u, v) plane with some small regions of coverage to the north. Earth rotation leads to a more uniform coverage of the long baselines to the north. One of the disadvantages of the North Ridge array is that it does not have as high resolution as the Timber Ridge array. However, since Ge's work (1992a), it has become clear that a road and antenna stations may extend almost one half mile northward of Ge's northernmost antenna in the North Ridge configuration, and antennas may be located over half a mile east of the easternmost antennas along the existing Forest Service road. Hence, a new design for the North Ridge A array could produce higher resolution.

3 Suggestions for Future Configuration Design

So far, the work on the Magdalena configurations can be described as "guided trial and error". Clearly a more systematic approach is required. Cornwell (1986) has developed a simulated annealing approach to interferometer configurations which optimizes some characteristic of the (u, v) coverage, such as its uniformity. It should be simple to extend such an approach to deal with the current situation in which the antennas are constrained to lie on a system of ridges.

In finding an optimal array using simulated annealing, an "energy measure" is defined which, when minimized, results in an optimal array. Given an initial array configuration, the antenna locations are jiggled one at a time until the energy measure is minimized. After many iterations, the energy reaches a minimum. For complicated problems such as array design, there will be many false local minima. In a simulated annealing scheme, there is always a possibility that an antenna location will be accepted even if it does not locally minimize the energy; this prevents the array from getting stuck in a false minimum. The probability that a non-minimum energy configuration is accepted decreases with time so that the array will "freeze" into the global minimum. The most important aspect of such a scheme would be to define an appropriate energy measure. An energy measure may be composed of a number of appropriately weighted terms. We probably want to do something like minimize the size of the gaps in the (u, v) coverage, and also minimize the synthesized beam elongation.

Some thought must go into what sort of (u, v) coverage is to be optimized. Cornwell's work optimized only the snapshot coverage of a source at the zenith. We must expand this work to deal with both tracked observations and with observations at several declinations. Keto (1991) argues that an array which has been optimized for snapshot coverage and has autocorrelation points which are as widely spaced in the (u, v) plane as possible will also be optimized for tracking observations. This argument does not apply to the South Baldy A configurations. Since the antennas are constrained to lie on a network of ridges, the instantaneous beamshape may be quite bad. If the beam elongation is used in the energy measure for the array, then optimizing the array for snapshot coverage will be quite different from optimizing the array for a weighted combination of snapshot coverage and tracking coverage.

Keto (1991) continues to argue that an array which has been optimized for some midpoint declination will also be more or less optimized for a range of observable declinations if an appropriate stretching factor is included. However, given the weight that low declination sources such as the Galactic Center ($\delta = -27°$) and Orion ($\delta = -5°$) will have in the MMA's observing program, I feel that a more explicit optimization for a range of declinations weighted by their astronomical value is appropriate. The energy measure should consist of a weighted sum over several declinations. With such an energy measure, the algorithm would be able to look at the array's coverage at a range of declinations *all at once.*

Performing simulated annealing array optimization on an $N = 40$ element array will be computationally expensive. The computation time in Cornwell's method scales with N^4, and he used a maximum of 12 antennas, implying our arrays would require 100 times the CPU time. To reduce the CPU time, the locations of $\sim$ 20 antennas could be held fixed while the locations of the other antennas are optimized. Furthermore, in Cornwell's scheme, the antennas were not localized and could be jiggled across the entire array, increasing the convergence time. Some time may be saved by requiring the antennas to stay within some distance of their initial positions. Using information about several declinations and a range of hour angles will greatly increase the CPU time required for a simulated annealing array optimizer. While adding these two additional constraints to the problem, we will obviously miss the global minimum. However, with 40 antennas, the minimum will probably be fairly broad: there must be many arrays which produce very uniform (u, v) coverage and which have acceptable beamshapes.

References:

1. Cornwell, T.C., 1986, "Crystalline Antenna Arrays", MMA Memo 38.
2. Ge, Jing Ping, 1992a, "Further Simulations of (Possible) MMA Configurations", MMA Memo 80.
3. Ge, Jing Ping, 1992b, "Array Design Toolkit", *or something similar* MMA Memo *in preparation*
4. Holdaway, M.A., 1990, "Imaging Characteristics of a Homogeneous Millimeter Array", MMA Memo 61.
5. Holdaway, M.A., 1992, "Paired Antenna Phase Calibration", MMA Memo 88.
6. Keto, Eric, 1991, "Cybernetic Design for Cross-Correlation Interferometers", SMA Memo.

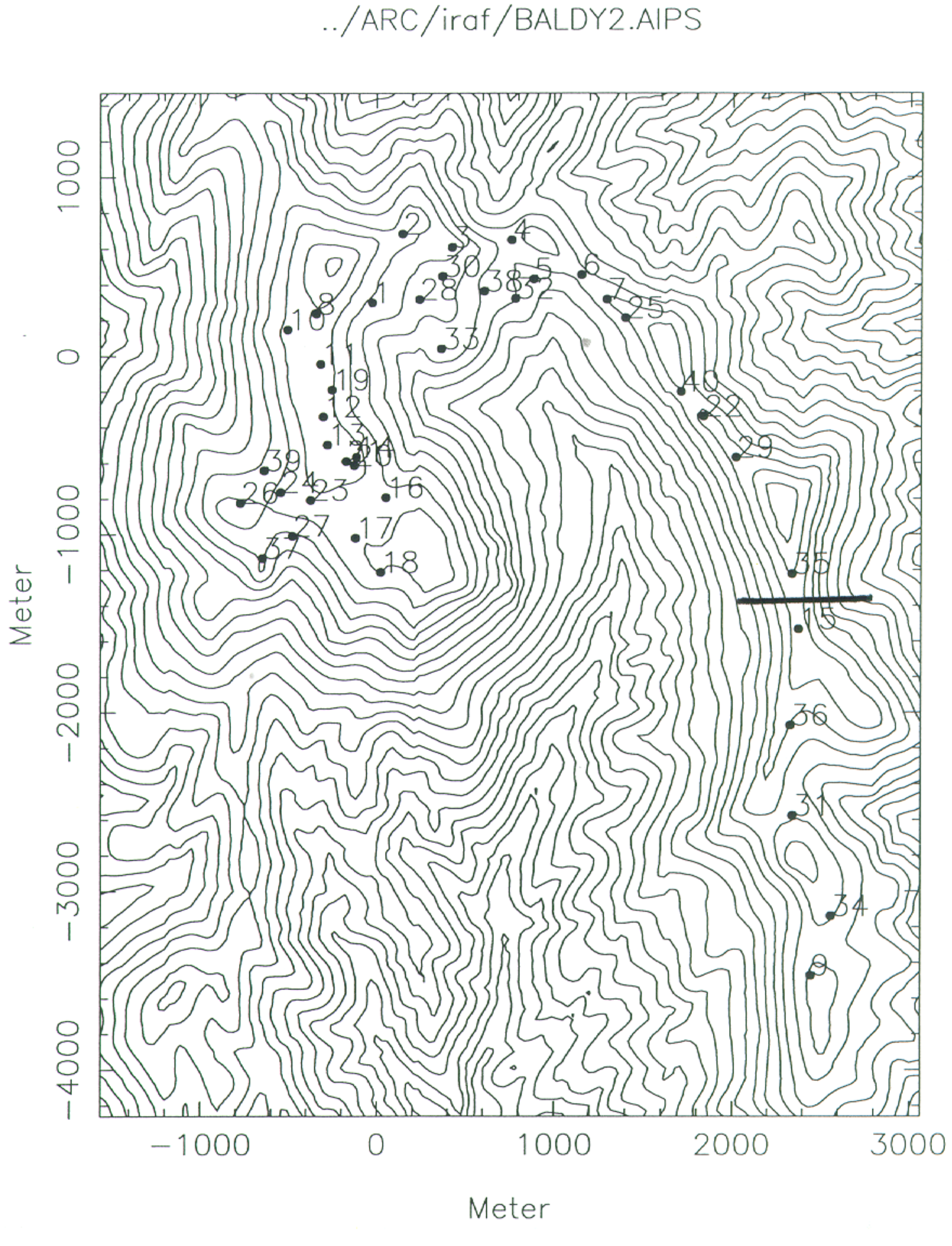

Figure 1: Ge's Timber Ridge A configuration. The stations south of the heavy line lie on a pristine, environmentally sensitive part of Timber Ridge.

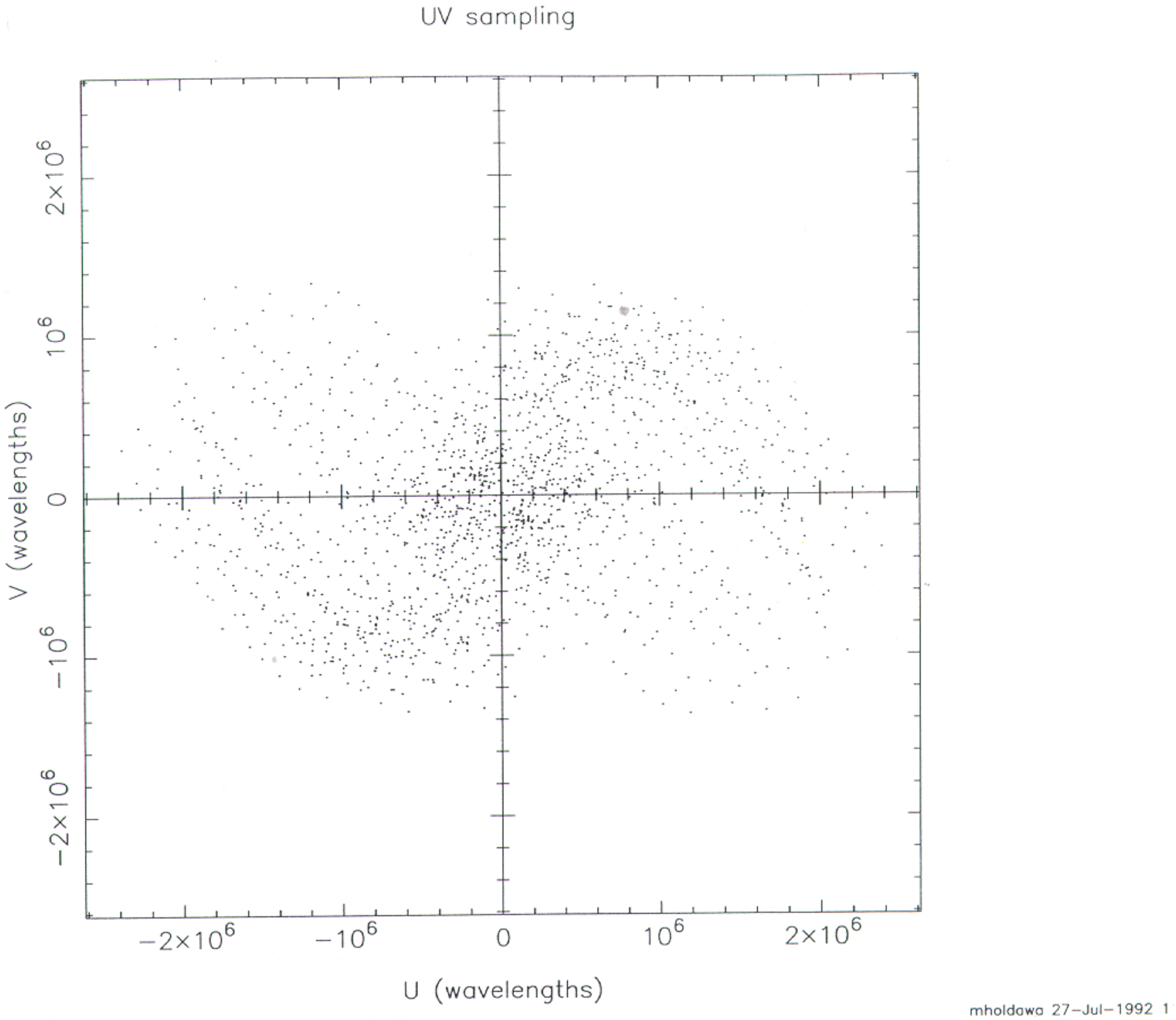

Figure 2: Snapshot Fourier plane coverage of a source at $\delta = 60°$ at transit with the Truncated Timber Ridge A configuration. Note the notch in the coverage at 20° left of north.