Fitting a 12 km Configuration on the Chajnantor Site

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Abstract

We present a modified version of Keto's (1992) array optimization program which finds antenna locations which most nearly produce a uniform Fourier plane coverage, subject to constraints on where the antennas can and cannot be placed. Rather than solving the abstract problem of determining a good shape for the array and then trying to fit the array shape onto a geometrically non-optimal site, we can instead seek the array shape which gives optimal Fourier plane coverage considering the details of the site. As an example, we show how a 12 km array fits onto the geometrically limiting Chajnantor site.

Antenna plane constraints, such as are present for a 12 km array on the Chajnantor site, require long (u, v) tracks, rather than a single "snapshot", in order to obtain good Fourier plane coverage. The array configurations we obtain from optimizing the (u, v) coverage over 4 hour tracks, for either an unconstrained antenna geometry or the constrained Chajnantor site (which has a 4 km gap which does not permit antennas), are more closely related to circles than to Reuleaux triangles. The constrained array's Fourier plane coverage is essentially as good as either the unconstrained snapshot-optimized or unconstrained 4 hour track optimized Fourier plane coverages.

1 Introduction

Many factors determine the element locations in an interferometric array. The scientific goals of the instrument determine the desired maximum baseline, Fourier plane coverage, and the need for multiple configurations. Ideally, these would be the only constraints on the array design. The optimum antenna configuration under these ideal conditions has been studied (Cornwell, 1984; Keto, 1992; Foster, 1996, in preparation). Practical considerations, however, such as ease of construction, maintainance, and reconfiguration will also impact the configuration design. Among these considerations is the terrain on which the array is to be built.

In addition to being a dry, high elevation site, the VLA site was chosen because it is a large flat plain which would accomadate almost any antenna configuration imaginable, out to the desired maximum baseline. A millimeter wavelength array, however, requires a site which is even higher and drier than the VLA site. The search for such a site for the MMA led to sites such as the Magdelena Mountains near Socorro, NM, Millimeter Valley and the east slope of Mauna Kea, and most recently to Chajnantor in northern Chile. Each of these sites has some relatively flat areas which would allow an ideal antenna layout for some of the smaller MMA configurations. Mauna Kea and Chajnantor even have enough flat space for the 3 km configuration. However, for larger configurations, especially for the recently proposed 10-12 km configuration in Chile, the site terrain significantly limits the possible antenna configurations.

We present a modification of Keto's (1992) array optimization algorithm with the improvements implemented by Foster (1996, in preparation). This new approach considers the site terrain in the array design process, transforming an algorithm for abstract array design into a practical design tool for the MMA. As an example of this approach, we present an arrangement of 24 antennas (the algorithm is cpu intensive, and the 24 antenna case runs in a reasonable amount of time on our Sparc 2.) in a 12 km configuration on the Chajnantor site. In addition to demonstrating the modifications to Keto's algorithm, this configuration also demonstrates that excellent Fourier plane coverage can be achieved on the Chajnantor site with a 12 km array even with its geometrical constraints. This algorithm will find more use, even in the 3 km array, as our knowledge of the geometrical constraints become more detailed through obtaining a high resolution digital elevation model of the site.

2 Algorithm Modifications

Keto's algorithm, which utilizes a neural network code to find antenna locations which are optimal subject to some criteria such as "most uniform Fourier plane coverage over some region in the Fourier plane", is heuristically fairly simple. No objective function is optimized. Rather, positions in the Fourier plane are picked randomly, and the (u, v) sample closest to that position is dragged towards that position. In doing so, the antenna coordinates have to be adjusted to be consistent with where the (u, v) sample has just moved. As this procedure is repeated thousands of times, the algorithm siffens the (u, v) samples, making them more resistant to radical change, and the distance between any random position in the Fourier plane and its closest (u, v) sample is minimized.

Our modification is quite simple. We must incorporate the geometrical constraints into the steps in the algorithm which move the antennas, namely, antenna position initialization and the iterative pulling of antennas. The geometrical constraints are presented to the program in the form of an image of ones and zeros representing the probability of placing an antenna in that location. A further modification could add fractional probabilities to treat antenna locations which may be nonoptimal but not absolutely forbidden. The antenna position initialization is random, so we just keep picking random locations until we have the antenna within the allowed region. When the antenna is pulled into a forbidden position, we simply adopt its former, acceptable position. Forbidden regions with very complicated geometries may require partial moves, right up to the boundary with the forbidden region. Such a case would require more iterations, or a slower stiffening of the nueral network.

3 The 12 km Arrays on Chajnantor

From a topographical map of the Chajnantor site, we found regions in which it would not be possible to place an antenna due to steep terrain or water. We have encoded this information on a 1 km grid of 0's and 1's, but the antenna positions may be anywhere in any grid cell numbered with a 1. Figure 1 shows the antenna positions produced by the Keto algorithm optimizing for a snapshot over 12 km worth of the Fourier plane with 24 unconstrained antennas. The array is similar to the Reuleaux triangle solutions which Keto has obtained in the past. Figure 2 shows the Fourier plane coverage of this array for a $\delta = -30$ degree source over -2 to +2 hours with respect to transit. (Such an hour angle coverage is quite reasonable as the surface brightness sensitivity of the 12 km array will often require such long integrations to detect its targets.) Figure 3 shows the antenna positions optimized over -2 to +2 hour tracks for a $\delta = -30$ degree source. The array configuration is a somewhat squashed circle. Figure 4 shows the associated Fourier plane coverage over -2 to +2 hours. Figure 5 shows the antenna positions optimized over -2 to +2 hour tracks for a $\delta = -30$ degree source subject to the 1 km grid of geometrical constraints on the Chajnantor site. The array configuration is very similar to the unconstrained configuration optimized over the -2 to +2 hour tracks, but it is missing a 4 km section of the "circle" where antennas are not allowed due to the site geometry. Figure 6 shows the associated Fourier plane coverage over -2 to +2 hours. The Fourier plane coverage of the constrained array does have regions of slight underdensity due to the 4 km gap, but it basically looks pretty good.

Since we are looking at several different cases, it is beneficial to have a relative measure of the quality of the Fourier plane coverages. One consequence of this heuristic-based method is that the algorithm does not generate a measure of how good the (u, v) coverage really is. Hence, we look at the distribution of the distance between each cell in the Fourier plane and the nearest filled cell. For this analysis, we ignore the large hole in the center of the Fourier plane. [1] Statistics of the distances to the nearest filled cell for the different +/- 2 hour track Fourier plane coverage are shown in Table 1. The statistics of the holes in the Fourier plane coverages of our three cases are essentially indistinguishable. From this result we can make several preliminary conclusions:

[1] This overly large hole is a shortcoming of Keto's algorithm, which places more importance on making the size of the holes in the outer Fourier plane uniform than on filling the central hole properly. For our 24 antenna case, the central hole is about 3 times larger than the VLA's intentional central hole, relative to the longest baseline. We can correct for this deficiency by forcing the algorithm to pay more attention to the inner Fourier plane, which results in placing antennas is a very small ring in one of the corners (Foster, 1996). For the present work, we completely ignore such complications. Since the central hole is only a small fraction of the sampled portion of the Fourier plane, properly sampling it will have a small impact on the rest of the Fourier plane coverage.

	Unconstrained, Snapshot Optimized	Unconstrained, +/- 2 Hour Track Optimized	Constrained, +/- 2 Hour Track Optimized
25%	50 m	50 m	50 m
50%	90 m	100 m	100 m
75%	158 m	160 m	160 m
90%	230 m	246 m	230 m
95%	275 m	285 m	270 m
99%	353 m	360 m	350 m
max	480 m	491 m	482 m

Table 1: Quartiles and 90th, 95th, and 99th percientiles of the distances to the nearest filled cell to any given cell in the Fourier plane for +/- 2 hour track Fourier plane coverage at -30 degrees declination, for the three array configurations which we present in the Figures. The statistics of the holes in the Fourier plane are very similar.

- the peculiar Reuleaux triangle array is not significantly better than a circular array.
- optimizing the array shape for its long track Fourier plane coverage is not significantly better than optimizing the array shape for its snapshot Fourier plane coverage.
- The 4 km stretch of mountainous land on the eastern part of the Chajnantor site does not hurt the Fourier plane coverage very much.

References

Keto, 1992, SMA Memo.
Foster, Scott M., 1996, MMA Memo ???, "Array Optimization Considering Full Fourier Plane Tracks", *in preparation.*
Holdaway, M.A., 1996, MMA Memo ??? "What Fourier Plane Distribution is Right for the MMA?", *in preparation.*

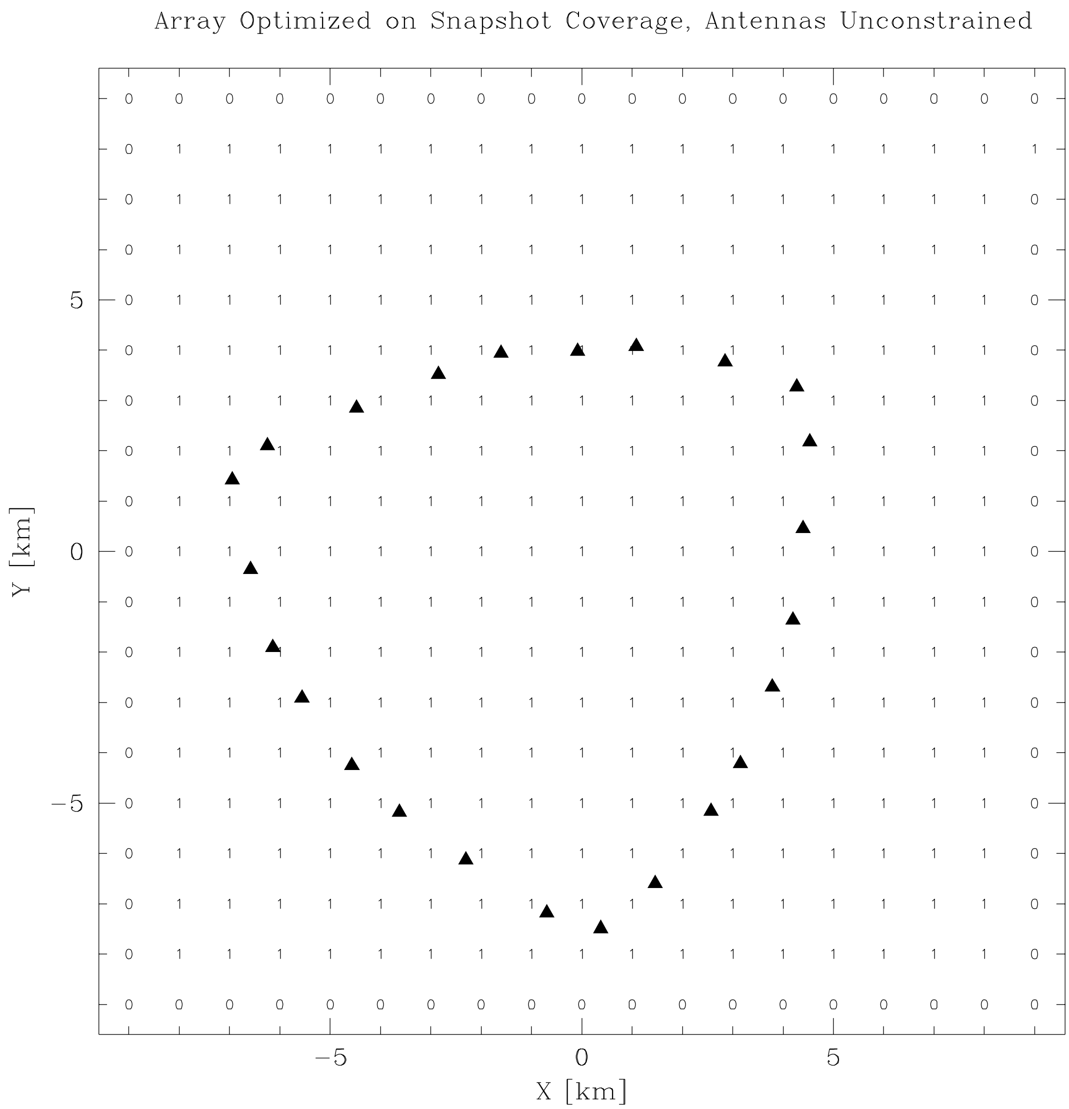

Figure 1: Antenna distribution for an unconstrained antenna plane geometry, yielding optimal (u, v) coverage for a snapshot at zenith.

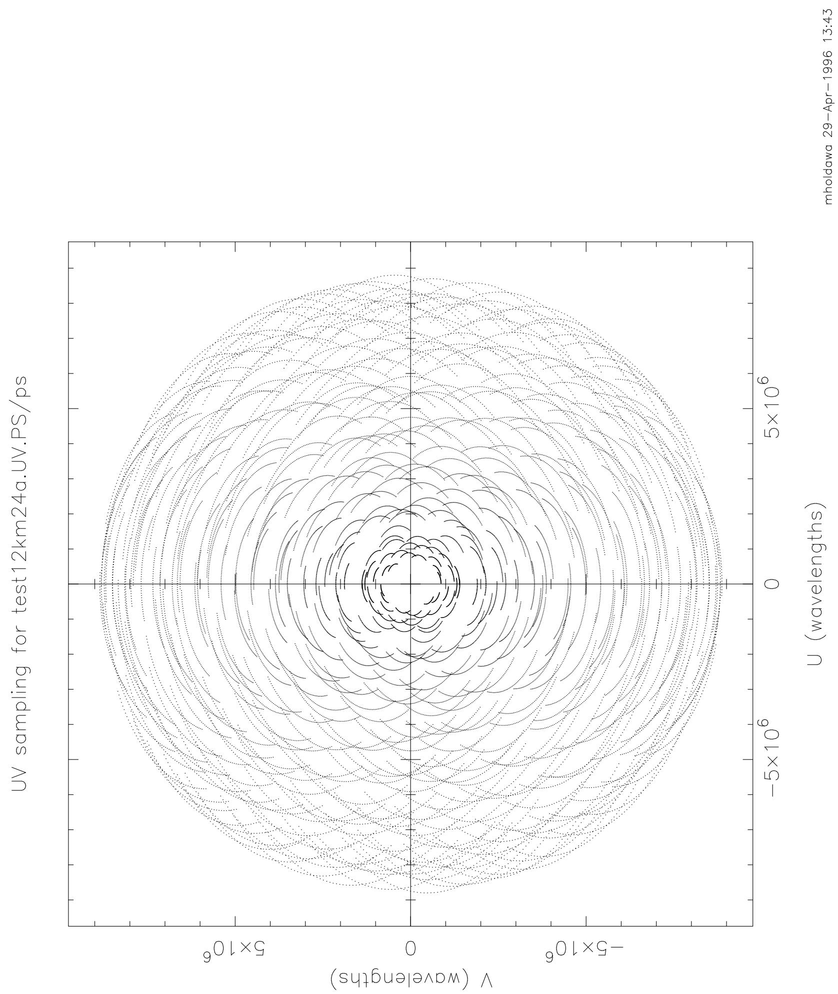

Figure 2: Fourier plane coverage (+/- 2 hour tracks at -30 degrees declination) for the unconstrained snapshot optimization.

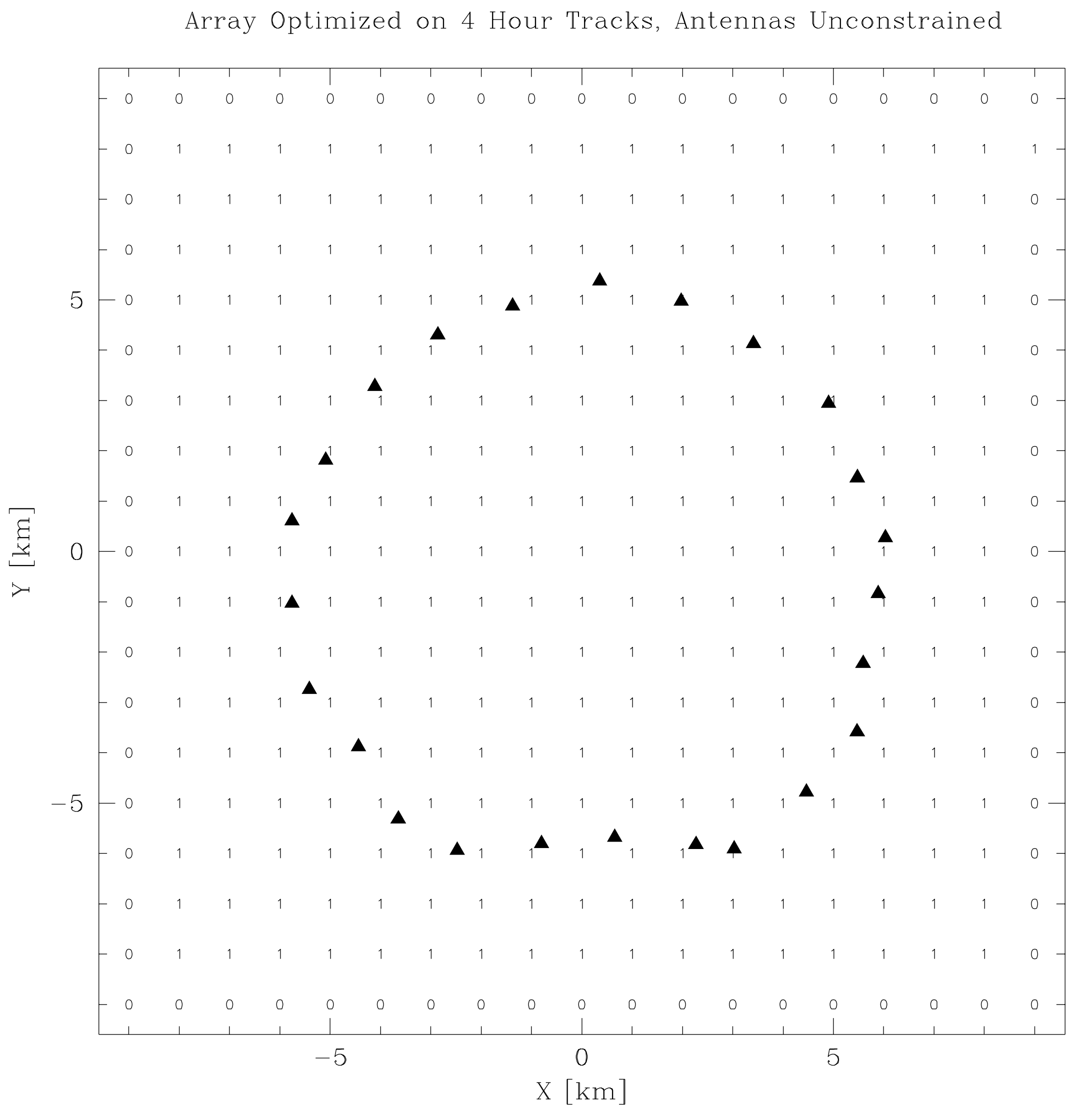

Figure 3: Antenna distribution for an unconstrained antenna plane geometry, yielding optimal (u, v) coverage for +/- 2 hour tracks at -30 degrees declination.

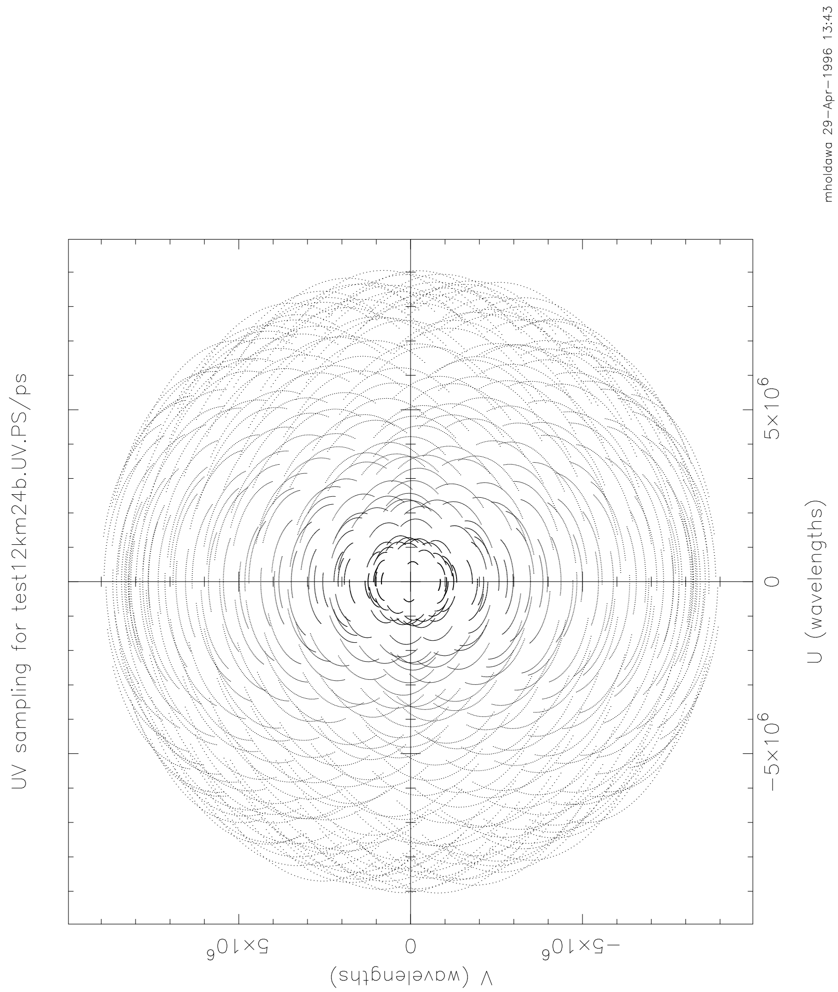

Figure 4: Fourier plane coverage (+/- 2 hour tracks at -30 degrees declination) for the unconstrained +/- 2 hour tracks optimization.

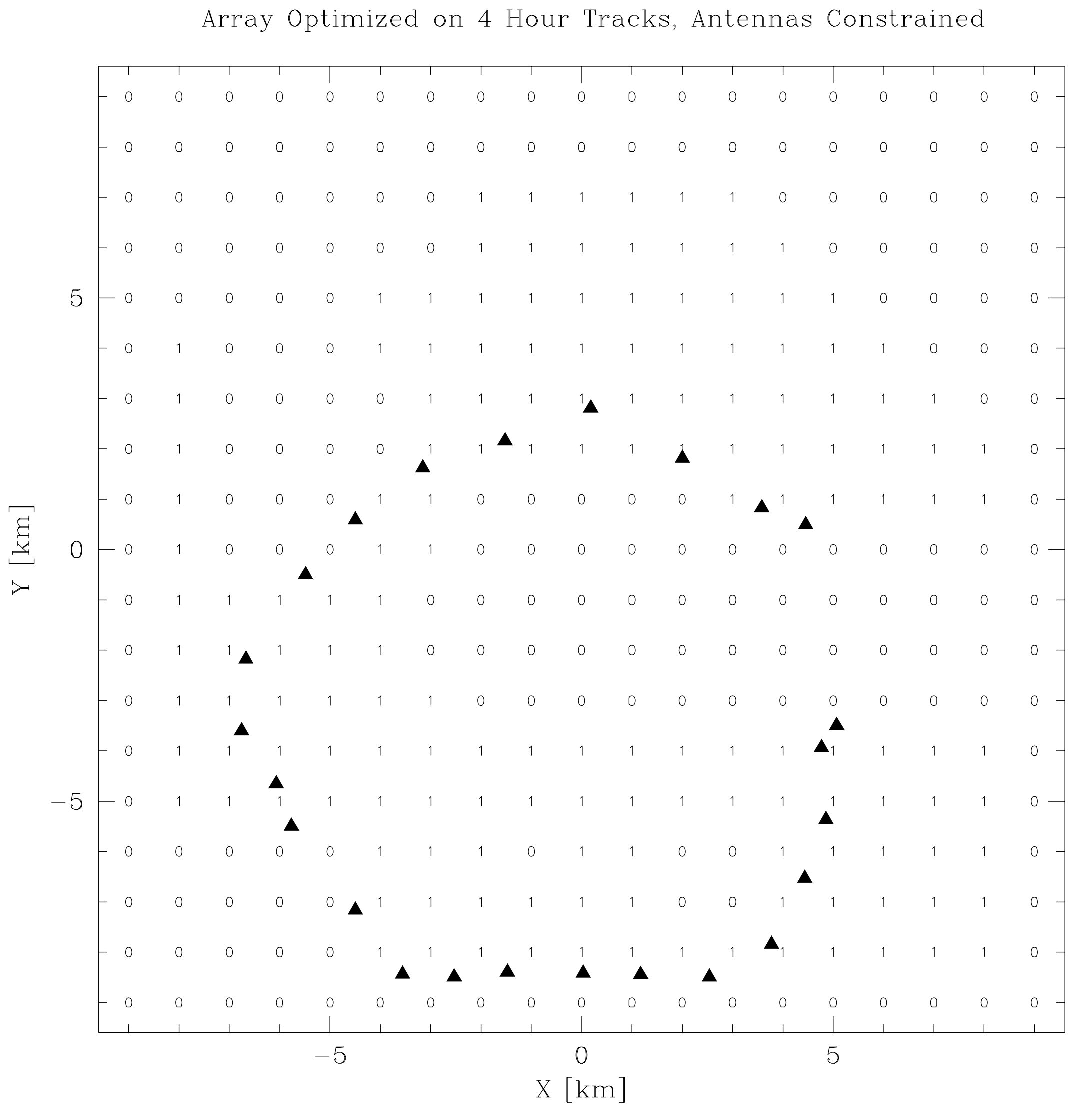

Figure 5: Antenna distribution for an antenna plane geometry which is constrained by the actual Chajnantor geometry, yielding optimal (u, v) coverage for +/- 2 hour tracks at -30 degrees declination. Locations marked with "0" do not permit antennas, but locations marked with "1" are acceptable.

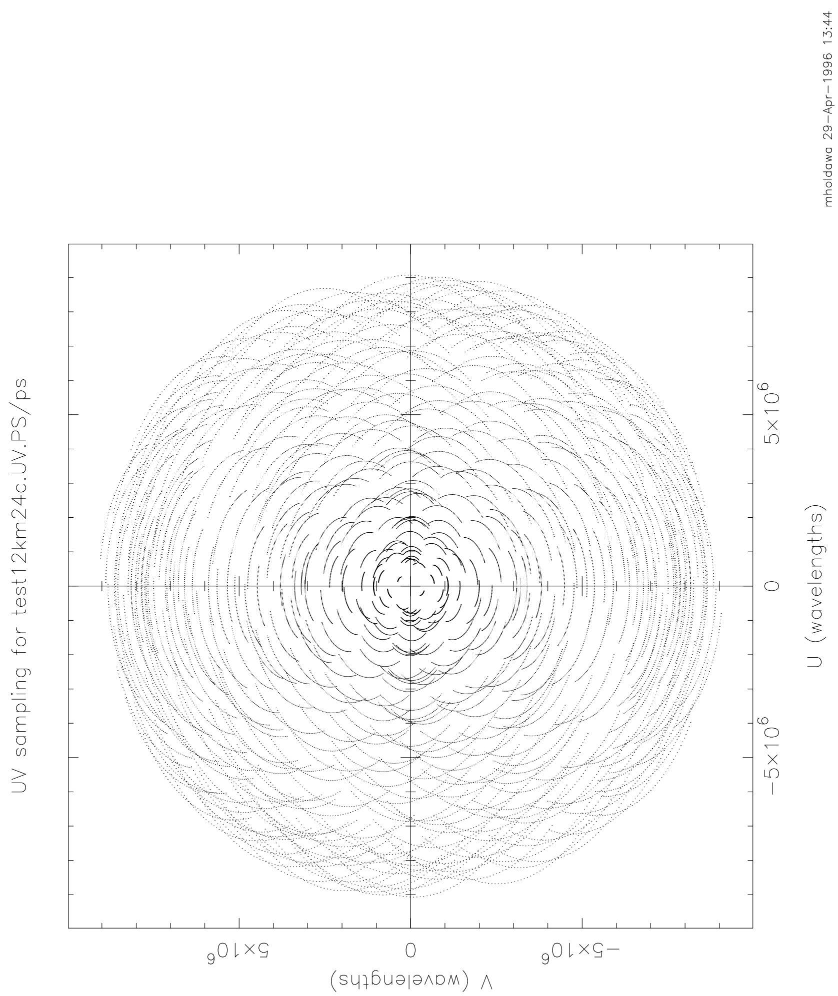

Figure 6: Fourier plane coverage (+/- 2 hour tracks at -30 degrees declination) for the constrained +/- 2 hour tracks optimization.