EVLA MEMO 35

A NEW MEXICO ARRAY CONFIGURATION

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ABSTRACT

A possible NMA configuration is presented along with a discussion of the constraints and software used in its derivation. This configuration can be used as a viable option for use in estimating the cost of NMA site aquisition and logistics, including fiber access, and for showing the potential capabilities of the NMA. But it should be emphasized that this is very early in the NMA project and it is likely that both the actual configuration and the constraints on which it is based will be modified as the project progresses.

The configuration presented here was derived mainly by hand, looking at UV coverage, although a simple optimization scheme was used to help explore options. The possible antenna locations that were investigated were ones that seem appropriate given what we now know about land characteristics and ownership and about the locations where existing fiber optic cables can be accessed. The methods used were much like those used to find the VLBA configuration. The NMA and VLBA are similar in number of antennas and in the need to consider strong geographic and logistical constraints. The performance of this array and alternatives in terms of beam quality and imaging capabilities are being explored elsewhere.

1. Introduction

The major element of Phase II of the ELVA project is the New Mexico Array (NMA). The goal of building the NMA is to fill the UV gap between the VLA and the VLBA, with emphasis on obtaining good imaging performance when it is used to increase the resolution of the VLA by factors of up to 10. Keto (1998) and Cohen & Perley (2000) explored the capabilities of arrays of various numbers of antennas and resolutions. Both memos show the imaging capabilities of such arrays. Since that time, it has widely been assumed that the number of new antennas will be 8 and this has served as the basis of initial budget estimates. Any increase would require strong justification. Both of the above memos used arrays of ideal geometries, without consideration of the usability of the actual locations.

In an earlier memo, Holdaway & Perley (1996) developed an algorithm for finding NMA configurations. They did not consider arrays of more than 6 antennas and also did not consider realities on the ground. But the method might prove intresting for improving arrays such as the one presented in this memo.

Other recent configuration studies have focused on arrays of many more stations, such as ALMA, the ATA, and the VLA E configuration. For such arrays, optimization of the snapshot coverage at a single resolution is appropriate and there is great, although not complete, freedom in the siting of antennas.

The New Mexico Array (NMA) is somewhat different. The cost of developing an antenna location will be influenced significantly by the proximity to fiber optic cable, three phase power, and all-weather roads. Land availability is also a problem. There are many areas that cannot be used because they are too mountainous, in wilderness areas, on military reservations, in areas that are too populated, or in areas that are otherwise inappropriate. The configuration search comes close to being a process of identifying the good locations, then picking an appropriate subset of those locations to form an array with reasonable performance. When attempts are made to apply the optimization methods in use for large arrays to the NMA, the basic characteristics of the configuration end up being set while establishing the masks, before the optimization begins.

The NMA is also different in that a single configuration must serve for multiple resolutions without moving antennas. In simplest terms, the NMA covers the next two VLA configurations beyond the current A array. For this reason the size of tolerable holes in the UV plane scales with distance from the center. Many of the previously proposed NMA configurations have the weakness that they have holes near the center that are nearly as large as those farther out, which is not acceptable.

As I watched some of the efforts to find a usable NMA configuration using the techniques being applied to ALMA, I became concerned that the the results were being driven very hard by the initial conditions used for an optimization. I decided to use the relatively crude methods, which might be characterized as "hunt-and-peck", that I had used in the VLBA configuration search to at least determine a minimum array quality that could be obtained. These methods have the advantage that the array is ultimately chosen by a human who can juggle many, often conflicting, criteria. They have the corresponding disadvantage of not being truely quantitative. This memo gives the current results of that effort. The recommended configuration conforms to all of the constaints that we are aware of and could probably be built. It can be used for more detailed cost and feasibility estimation. It also serves as a standard for the minimum performance to be expected of any other suggested configurations. But the configuration search is by no means done and it is likely that a better configuration will eventually be found.

Meanwhile, Leonia Kogan, who had been trying the ALMA style optimization, also tried a simpler approach. He forced the antennas to be evenly spaced on half rings centered on the VLA. Even spacing implies that the angular separation between the antennas is $(180^\circ/N_{ring})$ where N_{ring} is the number of antennas on the ring. Such an approach guarantees that the beam will be circular and that the UV coverage will be even in the tangent direction for snapshot observations at the zenith. Each ring can be rotated to place antennas near existing fiber optics. He has not yet analyzed the distribution of the ring radii, although the inner ring is fixed by the VLA interaction and the outer ring is fixed by the desired maximum resolution. It is interesting to note that his initial specific configuration is almost identical to the configuration presented here. The inner and outer rings are effectively the same, sharing most sites. The middle ring has a slightly higher radius, which most likely gives improved high resolution and degraded low resolution coverage. Leonia is exploring options with a smaller middle ring.

2. Disclaimer

This document represents the work and ideas of the author on the subject of the NMA configuration as of this early date in the project. It is not a final specification nor does it necessarily represent the thinking of others in the project. Both the constraints and the specific configuration are subject to evolution as the project progresses. Future studies may well change the understanding of what constitutes good UV coverage for the NMA and thereby provoke changes in the configuration. Also many logistical factors are still very uncertain. Increased knowledge of the availability of land, fiber optics, power and other local factors may well change the locations that we consider viable.

3. Software

The UV coverage plotting program used in the VLBA configuration study is still available, but I had long had a desire, but not a good excuse, to make it much more interactive. This project provided the excuse. After considering various options, it became clear that the easiest way to obtain the desired functionality, and a lot more besides, was to enhance the UV plotting function of *SCHED*, the VLBI scheduling program. That had the advantages of putting these capabilities into an environment that is well maintained and that other people will be able to use. The main enhancements were to plot the UV coverage for different sources in different panels; to plot a map of station locations; to allow optional plotting of multiple scaled tracks to show the effect of multi-frequency synthesis; to allow interactive selection of antennas to plot by clicking on the map; to allow interactive moving of antennas by dragging them on the map; and to add a simple automated optimization. Using *SCHED* also made other capabilities immediately avaliable such as plotting beams, plotting elevations vs time and using arbitrary schedules. The figures included in this memo are all made by *SCHED*.

The optimization method is based on trying all combinations of N sites chosen from among M possible locations. The resulting arrays are ranked according to how well they fill cells in a UV grid. The grid is in polar coordinates and tends toward logarithmic at the longer spacings. The radial grid spacings are more even near the center to counter a tendency to select arrays that are too centrally condensed. The grid is slightly elongated north-south, and projected according to the maximum elevation reached by a source. All of the characteristics of the grid are adjustable with user inputs or simple number changes in the code. The best arrays are either those with simply the maximum number of sampled cells or those with the minimum rms scatter of the number of samples per cell. The optimum grid characteristics and quality measures are still under study. The code is reasonably fast. Using 4 sources at different declinations and 20 stations (including representative VLA antennas), several tens of configurations can be checked per second with a modern Linux PC. Eventually, I would like to use beam characteristics to select among those considered best by the UV characteristics, but that programming is not yet started.

The optimization scheme is by no means foolproof, so it was treated as a fast way of checking options and perhaps finding options that might not have otherwise been considered. Final configurations are picked by hand and tend to deviate somewhat from the ones *SCHED* selects. Hand searches also have the advantage that sites can be moved to locations that were not included in the options allowed in the optimization.

A possible future enhancement, other than the consideration of beams mentioned above, might be use of a scheme such as that used in Holdaway & Perley (1996) to fine tune station positions.

4. Constraints

As noted, the NMA configuration is strongly constrained. Here I list many of the constraints that were used in the search.

- The NMA is assumed to consist of a total of 8 new antennas plus the two inner VLBA antennas. Other options for the number of antennas were checked occasionally, but 8 was treated as a number that is no longer easily negotiable. Not surprisingly, additional antennas allow for better coverage with up to 3 more providing especially significant gains in terms of filling the UV plane with the swatches of VLA tracks.
- The full resolution should be close to 10 times that of the VLA in the A configuration. This was checked using the beam plotting capability in *SCHED*. Dense coverage with the NMA-VLA baselines for a bit over 200 km, with some longer individual baselines, provides such resolution.
- The UV coverage for a resolution of about 3 times that of the VLA should also be as good as possible.
- The UV coverage should be optimized for when the 10 NMA antennas are used with the VLA A configuration. The effect of this is that the optimization is mainly an effort to fill the UV plane with the wide swatches of tracks between each NMA antenna and the VLA. Fortunately the resulting configurations also tend to have good stand-alone coverage.
- The stand alone NMA UV coverage should degrade gracefully when the two VLBA antennas are not available.
- The Pie Town VLBA antenna is fixed, but the Los Alamos antenna may have to be moved, so options for it need to be considered.
- The antennas should be near optical fiber lines and, better yet, near points-of-presence (POPs) where it would be easy to get onto those lines. We have some information about where the lines and POPs are located and which companies might be most willing to be involved. We are still gathering information in this area. The companies don't always want such information to be public, so the text in this memo does not state all that we know. Staying near fiber is the strongest geographical constraint that was used.
- The antennas should be near 3 phase power lines, although it is possible that some single phase power lines could be used.
- The antennas should avoid major metropolitan areas because of the threat of RFI.

- The antennas should not be located in areas where there is likely to be significant local opposition. We should not poisen the atmosphere for future projects such as LOFAR and SKA.
- The antennas cannot be in rugged terrain or wilderness areas. This eliminates a large area southwest of the VLA that is symmetrically opposite Albuquerque from the VLA. This makes filling certain parts of the UV plane difficult.
- The sites should not be on military resvervations such as White Sands Missile Range. This also complicates matters because the region symmetrically opposite the WSMR from the VLA is a region where we are not comfortable with the land and fiber access.
- Sites should have characteristics, such as adequate available land and local acceptance, that would allow them to be used for LOFAR and/or SKA elements in the future.
- The UV coverage with the VLBA is of concern, although does not drive the configuration.

It quickly became clear that at least one site is going to involve a significant fiber and probably power installation. This is because a site is needed close, but not too close, to the VLA in the north-south direction for decent low declination UV coverage. There is very little installed infrastructure north or south of the VLA. But it should be possible to put all other sites close to appropriate infrastructure.

There is a choice to be made about the distribution of pure NMA baselines relative to the longest baselines to the VLA. The recommended configuration has one antenna, GLENWOOD, that is significantly west of the VLA. That provides a few NMA baselines to the easternmost stations that extend well beyond the longest VLA baselines. I have called these "dangling" baselines. They would act something like a taper when using the NMA and VLA together, and would increase the resolution of the NMA alone. They also improve coverage with the VLBA. Some good alternative configurations have 2 or 3 antennas west of the VLA, giving rather more dangling baselines. Alternatively, there are configurations with no antennas west of the VLA except Pie Town. These configurations have almost no dangling baselines, which gives a harder cutoff of the long spacing UV coverage. The benefits, or drawbacks, of dangling baselines are not obvious and is a topic that could be investigated with imaging tests. Note that all configurations sampled have dangling north-south baselines. Avoiding them entirely would leave two quadrants without any VLA baselines and so is not viable.

5. Sites

The sites of my current favorite configuration are listed below along with some discussion of their characteristics and some alternatives. The numbers are the latitude and west longitude used for plotting. The final location can be moved around by some distance that is larger for sites farther from the VLA. For each site, the amount of flexibility is described. Most of the sites have not yet been checked out locally, so there could be problems. It should not be too hard to adjust to changes. Roughly speaking, there are 3 sites close to the VLA, 3 sites at intermediate distances, and 4 sites in a rough outer ring.

1. VLBA_PT (34:18:04 108:07:09): This existing VLBA antenna is already connected to Western New Mexico Telephone Company (WNMTC) fiber for observations with the VLA.

2. DUSTYN (33:39:00 107:38:00): This site is a bit north of Dusty, south of the VLA. Road distance from the VLA control center is roughly 32 miles. There is no known fiber nearby and it is a significant distance to three phase power. The simplest option may well be to install both along the road from the VLA. Dusty is in the WNMTC service area so some cooperative arrangement for the fiber installation may be possible. The access to this site will be more expensive than some of the alternatives, but the more I look at it, the more I think this is the close-in N-S site we want for UV coverage reasons. Any close N-S site will have access problems. The UV coverage constrains the site to be within about 5 miles of the above location to the west, north, and east and about 1.5 miles to the south. The tight southern constraint is to avoid opening a significant gap to the VLA. An alternative site north of the VLA is:

   - FIELDN (34:36:00 107:23:00): This is north of Alamo. There is some degradation of low declination UV coverage compared to Dusty. It is better for the N-S antenna to be between two arms than off the end of one. The site is about 16 miles from Alamo by road, although it might be possible to go closer. I imagine it would need both power and fiber, both of which we believe are available at Alamo.

3. OLDHORSE (33:55:30 108:15:00): This is near Old Horse Springs on Highway 12 toward the western end of the Plains of San Agustin. The WNMTC fiber used for Pie Town joins the main WNMTC fiber nearby so access should be good. Power may be a problem. We did not see any three phase power within many miles during a recent visit. The UV coverage constrains to site to be within about 5 miles of the above position. Old Horse Springs is a small community, so it probably will be necessary to move a few miles away. More distant alternatives are:

   - RILEYS (34:22:30 107:12:00): This location is on the opposite side of the VLA from OLDHORSE. It is to the east of Riley, near the Sevilleta Wildlife Reserve. It is about 15 miles from Magdalena, where one could probably tap onto fiber and power and there is a road of unknown quality that goes directly to it from Magdalena.
   - MMTNBACK (34:06:00 107:01:00): This is another alternative to OLDHORSE. It is on or near NMT land on the back side of Socorro Peak (M Mountain). It provides poorer UV coverage than RILEYS or OLDHORSE, but has easier access to fiber and power than RILEYS. It is very close to the maintenance center in Socorro which would make it good for testing.

4. GLENWOOD (33:19:00 108:53:00): This is the first of 3 sites at intermediate distances from the VLA. It is near Glenwood Springs. The WNMTC fiber runs around the Gila Wilderness and through this area. The availability of appropriate sites that won't arouse local opposition needs to be investigated. The optimal place for this site is probably near the Willow Creek campgrounds in the Gila National Forest to the east of Glenwood, but that area has serious access problems. Sites along US180 to about half way to Reserve would be good and Reserve might be ok. The Gila National Forest access road south from Reserve should be checked

for possibilities. Farther south along US180 from Glenwood, the distance from the VLA gets uncomfortably large.

5. ENGLES (33:02:00 107:00:00): This site is along the rail line between Las Cruces and Socorro, some miles east of the Rio Grande. Several companies have fiber along the railroad. The site is south of Engle, not far from Truth or Consequences. Other sites along the rail line are also of interest for configuration studies. The UV coverage allows considerable flexibility for this site, especially to the west and somewhat north. TorC would be ok as would anything within something like 10 miles of the nominal site location.

6. BINGHAM (33:53:00 106:22:00): This site is along US Highway 380 east of San Antonio and north of the WSMR. There is a 3 phase power line along the highway and we have reason to believe that a fiber will be installed through the area on an appropriate time scale. The terrain looks reasonable in the vicinity. Sites within about 10 miles of the above location are ok for the UV coverage. It is better to go to the south, and sites along the edge of the Missile Range should be considered. Note that the Stallion site is a bit too close to the VLA.

7. VLBA_LA (35:46:30 106:14:44): This is the first of the outer ring sites. It is the existing VLBA site located in a Los Alamos National Laboratory technical area. Unlike Pie Town, we cannot treat this site as fixed because there is a significant chance that we will be forced to move to a different location. The potential for fiber access at the current site is unclear for various reasons. Some alternate sites, compatible with the favored configuration, are:

    - MILAGRO (35:57:00 106:43:00): Fenton Hill, site of Milagro, the LANL gamma ray observatory. It is located to the west side of the Valle Grande at rather high altitude. There are concerns about winter access and snow loads. The UV coverage is slightly better, if anything, than with the VLBA_LA site. These coordinates, like most others here, are just estimated from maps.
    - Lordsburg or Vicinity, in Southwest NM: At least 2 companies have fibers in this area and it is about symmetrically opposite the VLA from VLBA_LA so the UV coverage is similar. If this area is used, and the most northern site becomes Vaughn, VLBA users might want to use Vaughn plus a second antenna other than VLBA_PT that is not so close in latitude (of course they would like more than two).
    - Silver City. This is not as far south as Lordsburg, but the UV coverage from an antenna here fits nicely into some holes in the UV plane.
    - Along Interstate 25 east of Pecos: This isn't as good as the current site, but there is fiber in the area and probably good terrain shielding. Land availability is not known. Most of the land in the area is either private or in a National Forest.

8. VAUGHN (34:36:00 105:13:00): This area has plenty of space and all the required utilities. We don't know about local attitudes. There are a few small patches of BLM land in the area, but most is private. Eastern New Mexico Telephone Company (ENMTC) has fiber here. The UV coverage constrains this site to be within about 25 miles of the nominal location.

9. ELK (32:56:00 105:20:00): Elk is on a fiber line from Cloudcroft to Artesia, but access is still unknown. The availability of sites is also unclear. This area is a high priority for an

on-the-spot checkout. The UV coverage constrains this site to be within an oval bounded by Cloudcroft and the US82/NM24 junction in the east-west direction and by Piñon and Tinnie in the north-south direction.

10. LASCRUCS (32:09:00 107:08:00): This is along the railroad south and a bit west of Las Cruces. There is a lot of BLM land in the area and there is fiber along the railroad. This site helps with improved north-south coverage at low declinations, like the galactic center. Arrays without such a southern site get somewhat better coverage at the equator, at the cost of N-S resolution in the deep south. The UV coverage constrains this site to be roughly in an oval bounded by Deming and Las Cruces in the east-west direction extending about 15 miles north and south of the nominal position. Sites on the WNMTC fibers south of Silver City are also possible.

6. Fiber Miles

A major operating expense is expected to be the cost of leasing fibers to the sites. I have made a rough estimate of the total length of fibers required for the above configuration based on our current knowledge of where the fibers are located. That length is 860 miles. This assumes that more than one antenna can be brought back on a fiber. There would be 3 stations on the line going west from the VLA, 2 on the line south from San Antonio, and 3 on the line east from San Antonio. Plus Los Alamos will either come in from the north to Socorro or join the line going to Vaughn, making the number east of San Antonio 4. From San Antonio, or Socorro, there will be 6 stations routed to the VLA. The Dusty line will probably be owned by NRAO and will be separate from the others.

There are some ways in which the 860 km of fiber might change. Most of the links are fairly direct, so the changes won't be huge. The least direct line is to Elk. Roughly 100 km could be eliminated by a more direct line, which may be possible using Tularosa Basin Telephone Company lines. It is possible that some companies, especially along the Rio Grande corridor, will want to lease optical channels rather than whole fibers. In that case, the doubling of the lines south from San Antonio south would not work, adding about 65 miles. If Los Alamos has to be moved, there would be an impact on fiber miles and availability. Going to MILAGRO would increase the miles by roughly 20. Going east of Pecos would put us on ENMTC lines about 150 miles out from Vaughn so that would reduce the fiber miles by about 20. The largest savings would be if the Los Alamos antenna were moved to Silver City, about 64 miles from Glenwood on the WNMTC line, saving about 100 miles. Lordsburg is farther, making any fiber mile savings rather small. Of course, if we can't put several antennas on a single fiber, as is moderately likely, the miles go up by a lot — to about 1340.

7. VLBA

I looked briefly at the coverage for VLBA plus NMA on scales of a few thousands of kilometers. The details of the NMA configuration don't have a very significant effect on the coverage on larger scales. However configurations with antennas in both east and west directions from the VLA, as opposed to just to the east, are somewhat better. Since few thousand km spacings are the inner part of the VLBA UV coverage, there are still significant holes. A few additional antennas (2 to 4) in nearby states would prove very useful for filling the coverage to 1000 km and beyond. But that is not the NMA project.

8. UV Coverage

The following pages are UV plots for the suggested array and some varients. Each is discussed in the caption. Figure 1 shows the UV coverage of the recommended array plus the VLA on a scale of 350 km. Figure 2 shows the UV coverage with the VLA on a scale of 100 km to show the capability when attempting to about triple the VLA resolution. There are still some significant holes at the lower declinations. There probably will be holes of this sort somewhere for any 10 station NMA configuration that is attempting to increase the VLA resolution by a factor of 10. Figure 3 shows the snapshot UV coverage. The configuration was not optimized for this, but it came out rather good anyway. Figure 4 shows the UV coverage for the suggested NMA configuration without the VLA. Figure 5 shows the benefit of adding the VLBA stations at Fort Davis and Kitt Peak, which is not in the baseline plan. The scale is 550 km. I have a notebook of plots of this and other configurations that anyone who is really interested is welcome to browse.

REFERENCES

Cohen, A, & Perley, R. 2000, EVLA Memo 20.

Holdaway, M. A. & Perley, R. 1996, EVLA Memo 7.

Keto, E. 1998, EVLA Memo 9.

This preprint was prepared with the AAS LaTeX macros v5.0.

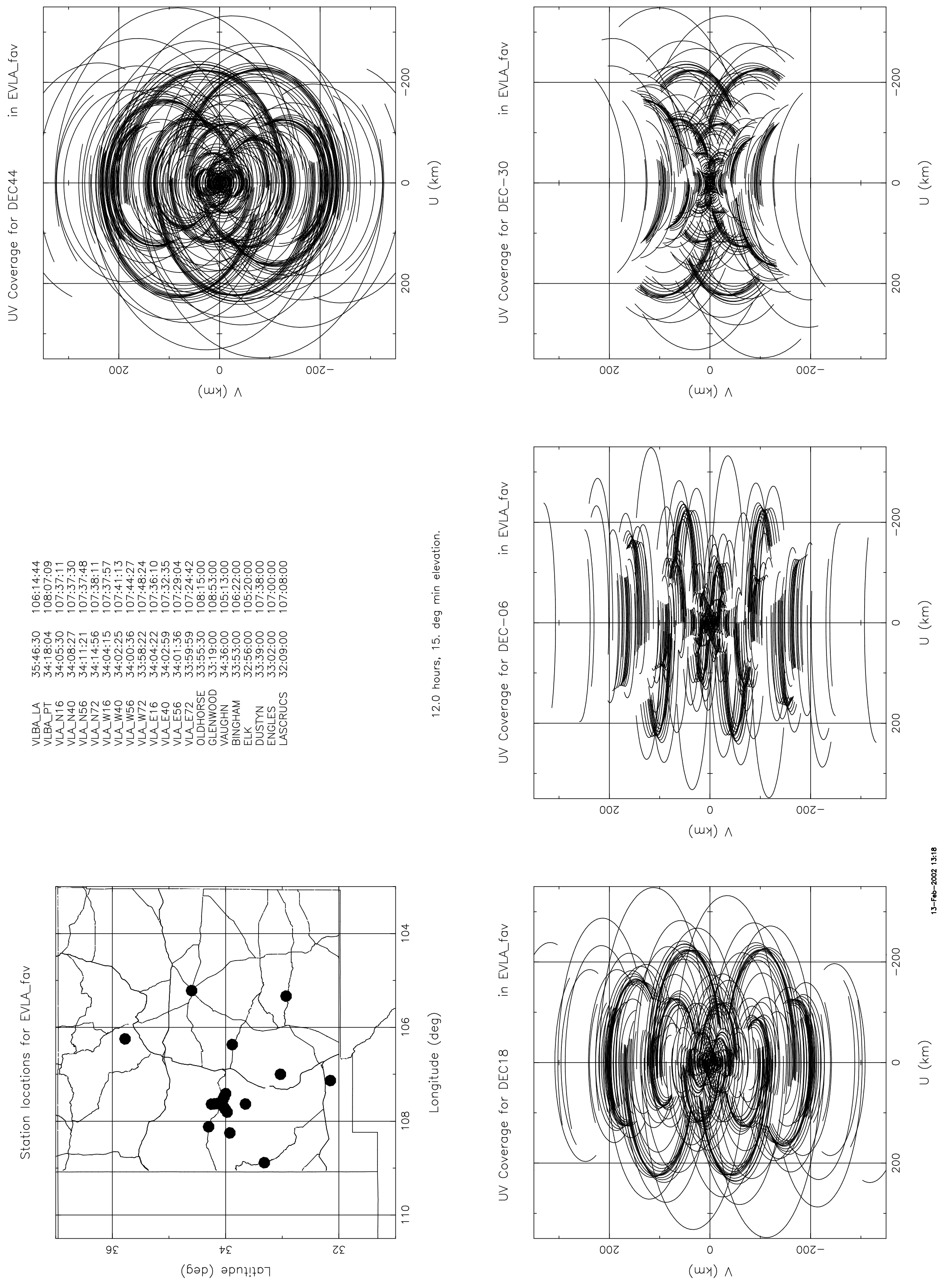

Fig. 1.— The UV coverage for the suggested array plus 12 VLA antennas. The map in the left panel shows the antenna locations relative to the state boundaries and major roads. The scale is in km and the plots cover baselines to 350 km. The declination of each fake source is obvious from the source name. The tracks are for 12 hours and elevations above 15 degrees. In practice, that means 12 hours for DEC44, a bit over 11 hours for DEC18, 9 hours for DEC-06, and 5.5 hours for DEC-30.

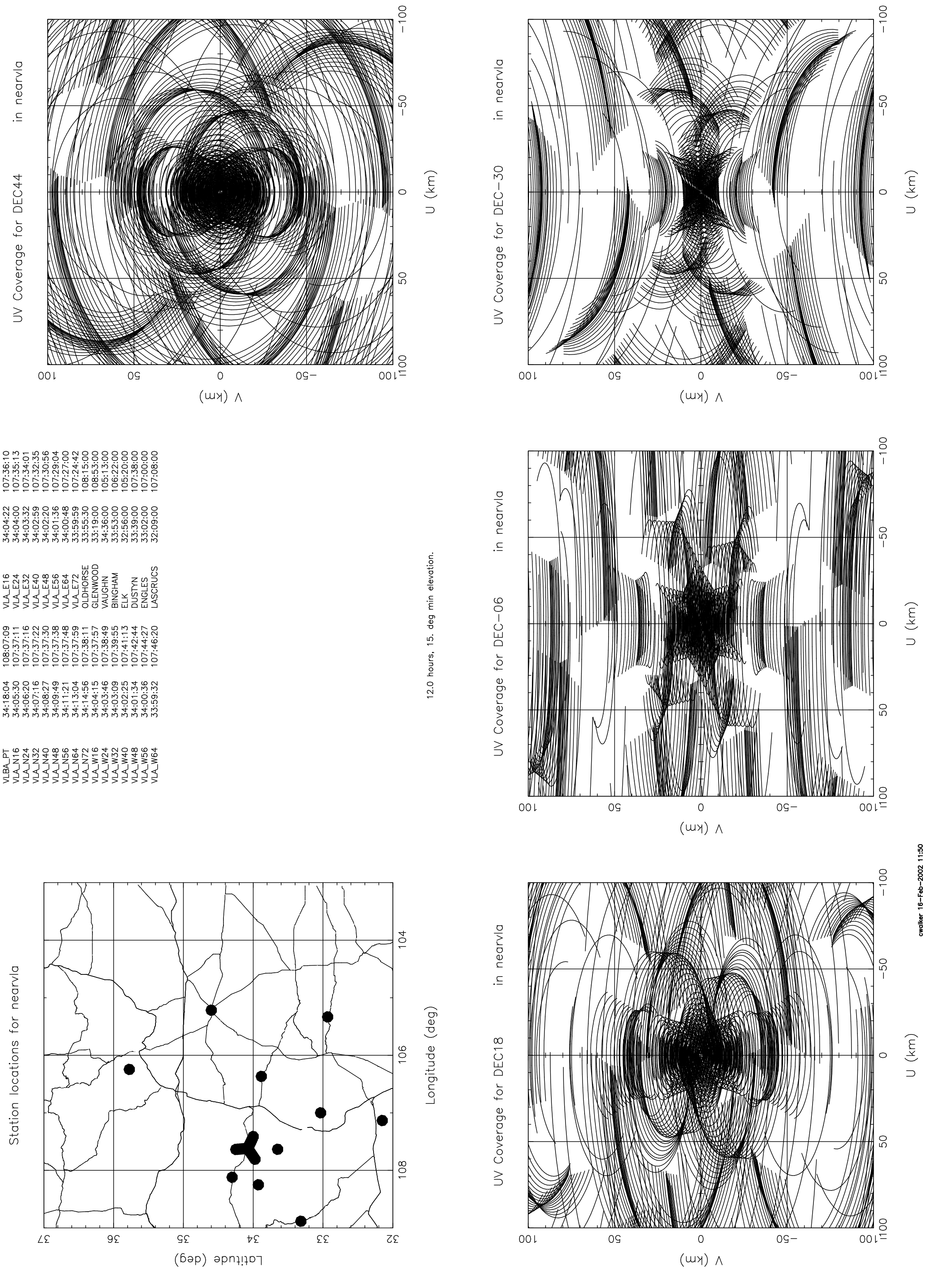

Fig. 2.— The UV coverage on a scale of 100 km to show the capability when the NMA is used to about triple the VLA resolution.

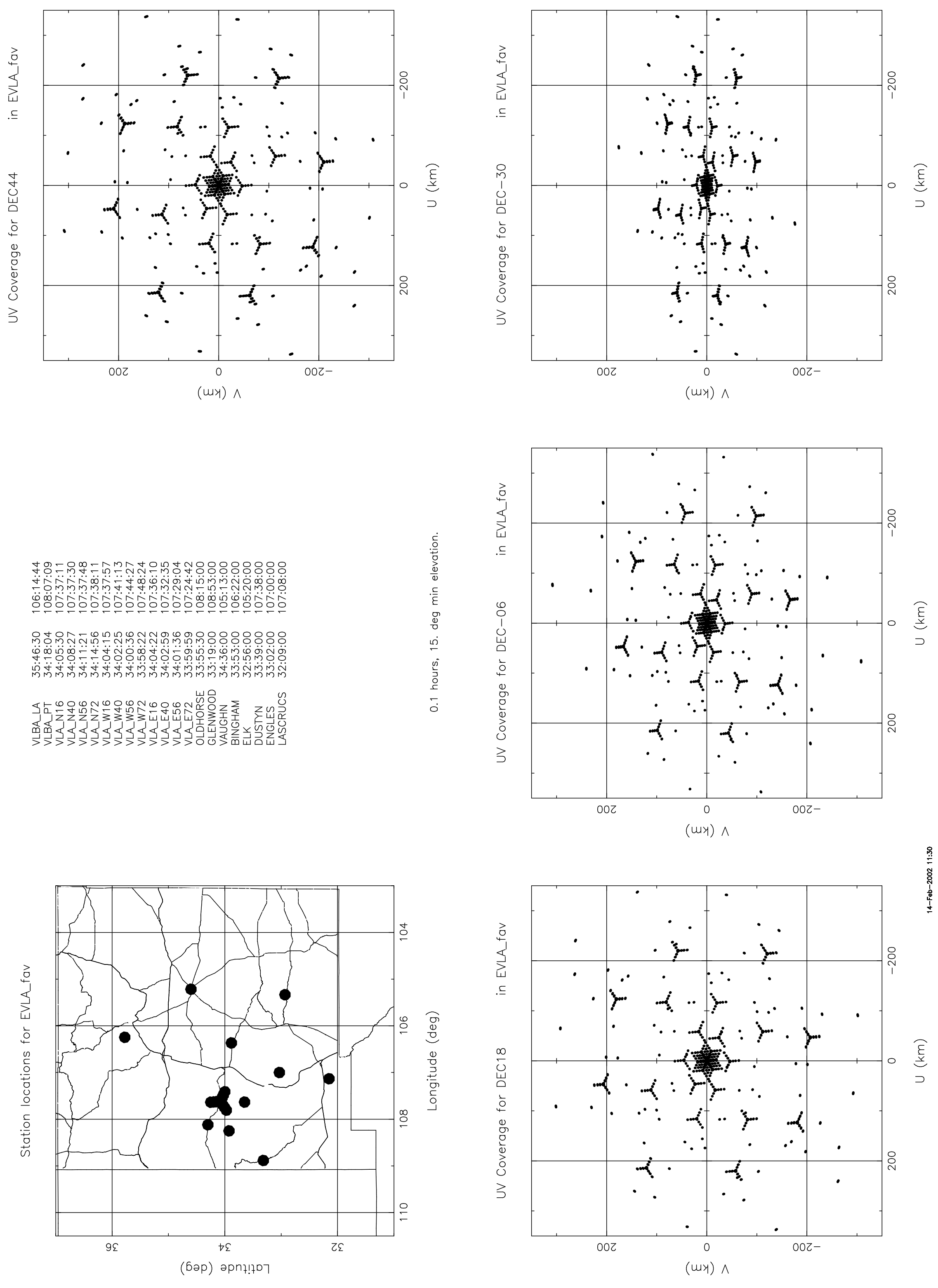

Fig. 3.— The snapshot UV coverage for the suggested array plus 12 VLA antennas. The sources are at transit.

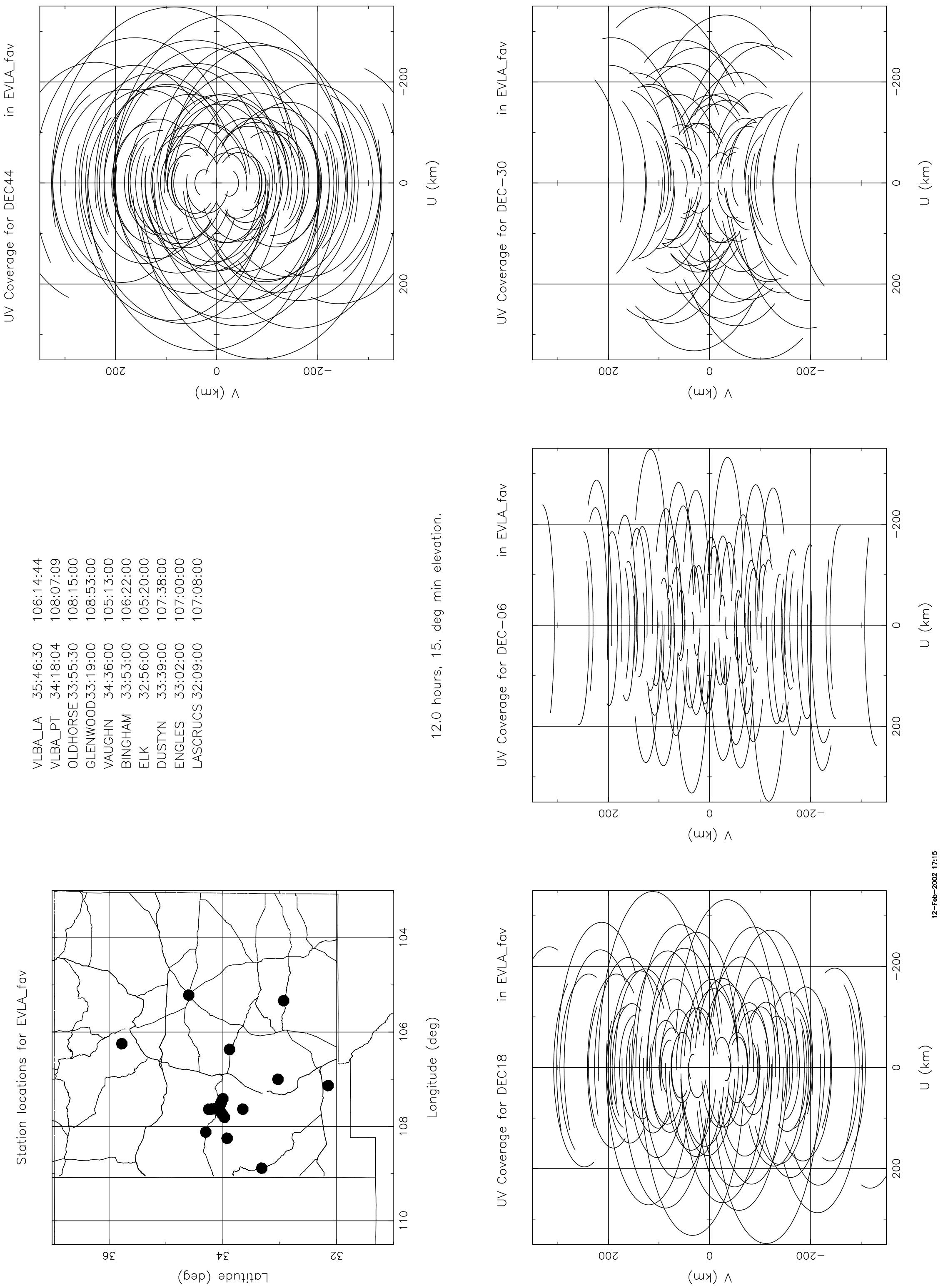

Fig. 4.— The UV coverage of the suggested array without the VLA. This coverage degrades reasonably gracefully (no big holes) when VLBA_LA and VLBA_PT are not available. The main problem is that the shortest baseline is lost, but that could be made up by adding a VLA antenna.

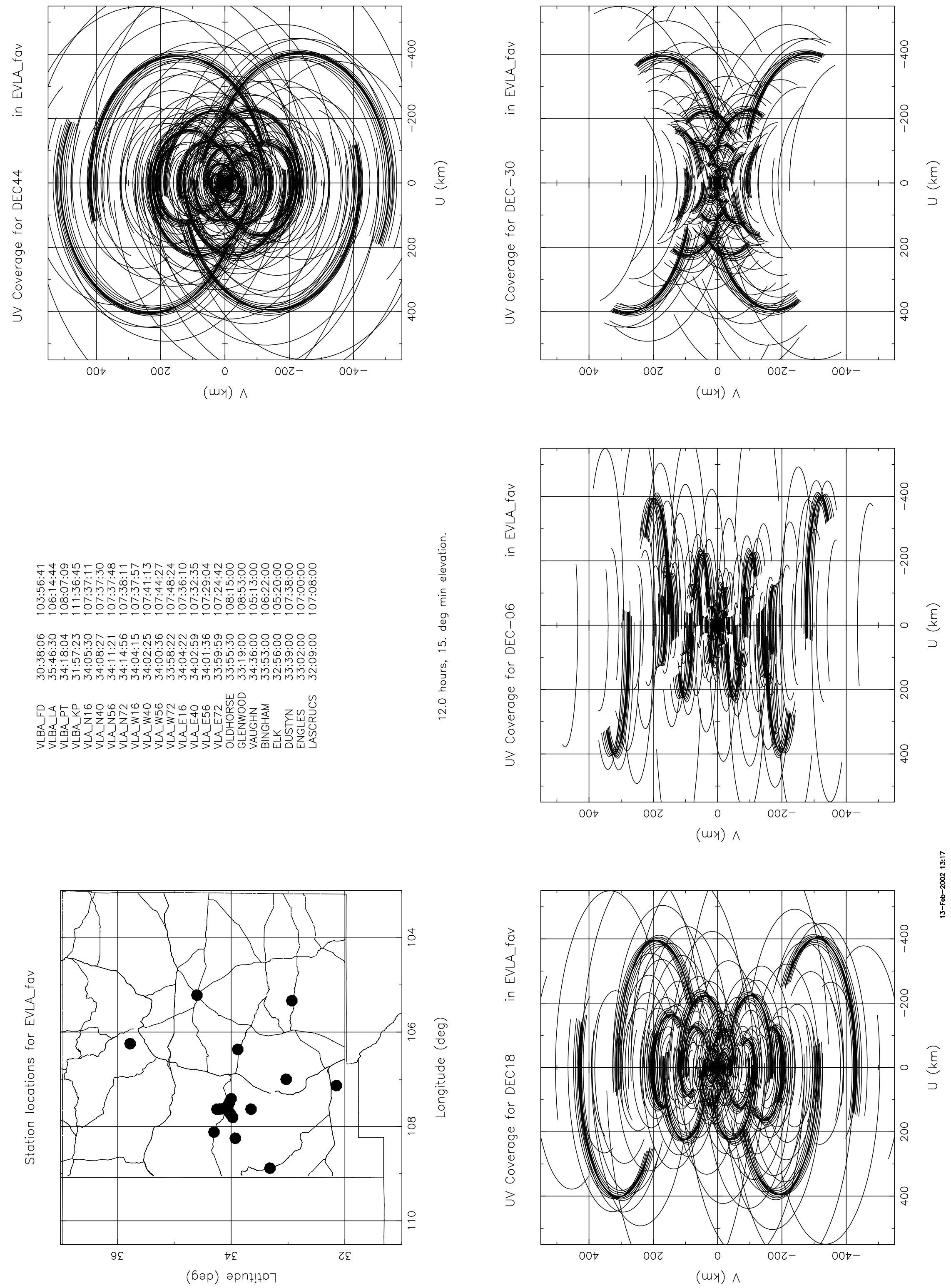

Fig. 5.— The UV coverage of the suggested array with the VLBA antennas at Kitt Peak and Fort Davis added. Notice the scale — the baselines to 550 km are shown. This shows that reasonably good UV coverage can be obtained for about 20 times the VLA resolution by integrating these two additional VLBA antennas.