NGVLA Memo 105

Suggested Changes to ngVLA LONG

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ABSTRACT

Two changes to the NGVLA LONG configuration to improve UV coverage are suggested. They are to move the St Croix station to Florida and the Brewster station to northern Wyoming. They do not involve changing the number of stations or the number of antennas per station so should be straightforward.

The addition of a station at the LMT in Mexico is encouraged to improve the coverage on southern sources, to provide a high quality site in the south, and to facilitate calibration of joint observations with the large collecting area of the LMT at high frequencies. Such an addition requires either increasing the number of antennas or reducing the number of antennas at some other stations.

The number of antennas required for the highest quality astrometry is not yet decided. It is probably 3 or 4. The current plan is for 3. The implications are discussed for other choices. For 4 antennas per astrometric station, which might be required to measure gradients, new antennas are needed, the number of stations needs to decrease, or some stations need to have fewer antennas.

Introduction

The original configuration of the LONG segment of the ngVLA was basically the VLBA configuration with the addition of new stations close to the outer 4 VLBA sites to use as self-calibration partners. The segment was called the LBA, but that is the name of the existing Australian long baseline instrument so we are changing to LONG to avoid the conflict. Besides adding the 4 self-calibration partner antennas, the 4 VLBA stations closest to the VLA were subsumed into the MID segment of the ngVLA, so the total of 10 stations in the VLBA is the same as the total in ngVLA LONG. For enhanced sensitivity, each LONG station was, eventually, specified to have 3 antennas.

In ngVLA Memo 84, I made suggestions for how to improve LONG with the addition of new stations. I also suggested moving the calibration partner for the northeast site, Hancock, from Haystack to Green Bank. The calibration partners need to be separated by an amount such that the UV points provided by the baseline between them falls in a region of the UV plane that is well covered by baselines between other stations. That way, the self calibration is well tied to the rest of the array. The problem they addressed was most serious for the VLBA sites at Mauna Kea and St. Croix. Even the shortest baselines to each of those stations fell at or beyond the longest baselines between any other stations, leaving their calibration somewhat free to float. A common result was that the self-calibrated amplitudes on the long baselines were excessively high and the short baselines were low compared from what might be expect from the a priori calibrated data. The Hancock to Haystack baseline is only 54 km long. This is shorter than the otherwise shortest baselines of LONG. So the self-calibration constraints would be poor because that is a poorly sampled part of the UV plane unless MID is included. Hence the recommendation to adopt Green Bank instead of Haystack. This had the added benefit that, instead of basically duplicating the UV coverage of the baselines between Hancock and the other array stations, Green Bank filled in poorly covered parts of the UV plane. This change was adopted in Rev D.

In this memo, I suggest further improvements to LONG by moving the calibration partners for Penticton and Arecibo, which were Brewster and St. Croix in Rev D, to more distant locations that enhance the overall UV coverage while still providing baselines that are in the portions of the UV plane that are well covered between other stations. The new suggested sites are in Southern Florida instead of St. Croix and in northern Wyoming instead of Brewster. The partner separations increase from 239 and 130 km to 1616 and 1104 km respectively. The new separations are short enough to connect the self-calibrations of Arecibo and Penticton to the rest of the array. In both cases, the new station provides very useful contributions to the overall UV coverage. In addition, these changes allow escape from the high corrosion, marine environment of the St. Croix VLBA site and from the high RFI environment caused by the large satellite tracking facility overlooking the Brewster site. A site in Florida, like St. Croix, will still have poor atmospheric observing conditions, but that cannot be avoided on US territory in the region. An area for a possible site in the Bighorn Mountains of Wyoming has been identified with good road access (US 16) and elevations near 2800 m, making it potentially a very good site, although potentially a snowy one.

In addition to the above changes, that do not involve altering the number of LONG stations, the benefits of adding a station at the site of the Large Millimeter Telescope (LMT) in Mexico are described. It provides a tie to a large aperture at short wavelengths, helps calibrate that telescope when it is used for VLBI, provides good access to the southern sky, improving the UV coverage for southern sources, and provides an astrometric quality, high altitude site in the south. Adding such a station would require either adding to the total number of antennas or repurposing some antennas from other stations. For example, if 3 antennas continues to be preferred for astrometric stations, one might take one antenna from each of 3 less optimal astrometric sites use them to make an astrometric station at the LMT. That leaves those three sites with only two antennas each – enough to do paired antenna calibration but not as high quality astrometry as the rest of the array. For Arecibo and Florida, the atmosphere may prevent such high quality astrometry regardless.

The issue of the minimum number of antennas required for 1 microarcsecond astrometry is still being studied, but it is probably 3 or 4. If it is 3, plans don't need to change other than possibly adding antennas for the LMT. If it is 4, only a subset of stations can be full astrometric stations within the 30 antenna limit for LONG. Other stations will need to get by with two or even one antenna. This memo does not advocate one or the other choice, but presents the possibilies for the distribution of antennas among stations of the main options.

For a description of the tools I use for UV studies, see ngVLA Memos 49 and 102. For a discussion of enhancing the LONG portion of the array through additional stations, see ngVLA Memo 84. Note that the UV tracks shown here are for a single frequency. Plots that show the effect of wide bandwidths are possible with SCHED, but apply only to continuum sources and I've found them less useful for distinguishing configurations.

A note on terminology: a station is located at a site and includes anywhere from 1 to 4 antennas.

Two Station Location Alternatives

The original configuration of the LONG segment of ngVLA is basically the VLBA configuration with the 4 inner antennas transferred to MID and 4 new stations added close to the 4 outermost stations to provide short baselines to those outer stations to improve self calibration.   The resulting UV coverage has some weaknesses and does not really represent an improvement over the VLBA unless some MID antennas are included. When MID antennas are added, the UV coverage density improves dramatically, although the major limitations imposed by geography, such as poor north-south coverage for southern stations, does not change.

This memo explores what happens if the shortest baselines to the outer stations are allowed to be longer – long enough that the partner stations actually contribute to the UV coverage rather than just to the sensitivity and calibration. The main requirement for the self-calibration partners is that they ensure that there is at least one baseline to every station that falls within the range that is well covered between other stations. The Pacific Ocean guarantees that any Hawaii station will be isolated. But the island chain is long enough to obtain a good short baseline within the state and hence the choice of Mauna Kea and Kauai. For the VLBA, the nearest stations to St. Croix were Hancock and North Liberty, which were far enough away to make that station isolated. For Rev D and earlier configurations, that is addressed by adding a station at Arecibo. From a UV perspective, having a station in Florida would be a significant benefit even if the observing conditions are not significantly better than St. Croix. Meanwhile, the St. Croix site has been a maintenance headache. It is too close to the sea so there is extensive corrosion from the salt air. At the time of construction, it was thought that the site was far enough from the water, but that has not proven to be so. So here I propose to abandon St Croix, keep Arecibo, and add a station in southern Florida. The Florida to Arecibo baseline is about 1600 km, which is rather long compared to our original concept for self-calibration partners. But there are many other baselines in the array between other stations that are in that range so my intuition says it will work. Arecibo calibration will not be left free to float. For the plots in this memo, I am using the location of the old Richmond FL geodetic station (which ultimately collapsed), but that site is probably too urban. From a UV point of view, pretty much anywhere in the southern half of the state is probably ok.

The other self calibration partners considered here are Penticton and Brewster. One could be moved to another location to improve the UV coverage. In fact, the separation of Pentiction and Owens Valley is 1343 km which is less than the Arecibo-Florida separation and also well within the range covered by baselines between other stations. Brewster to Owens Valley is even shorter. So one of the pair could be moved to anywhere leaving Owens Valley as the self calibration partner for the remaining station. It doesn't really matter from a UV perspective which station is moved. Penticton is tied in with the Canadian contribution to the array and Brewster has local RFI issues from a large and active satellite station overlooking the site (it was one antennas and was projected to close at the time the VLBA site was chosen), so I am presuming that Penticton will be the one kept in place.

That leaves the question of where to put the other station. The array has two weaknesses that might be addressed with an additional station One is the coverage of north-south baselines. I considered addressing that issue, and the lack of southeastern astrometric sites, by putting the free station at the LMT.   The other issue is relatively poor coverage of the baselines, just outside those covered by MID,

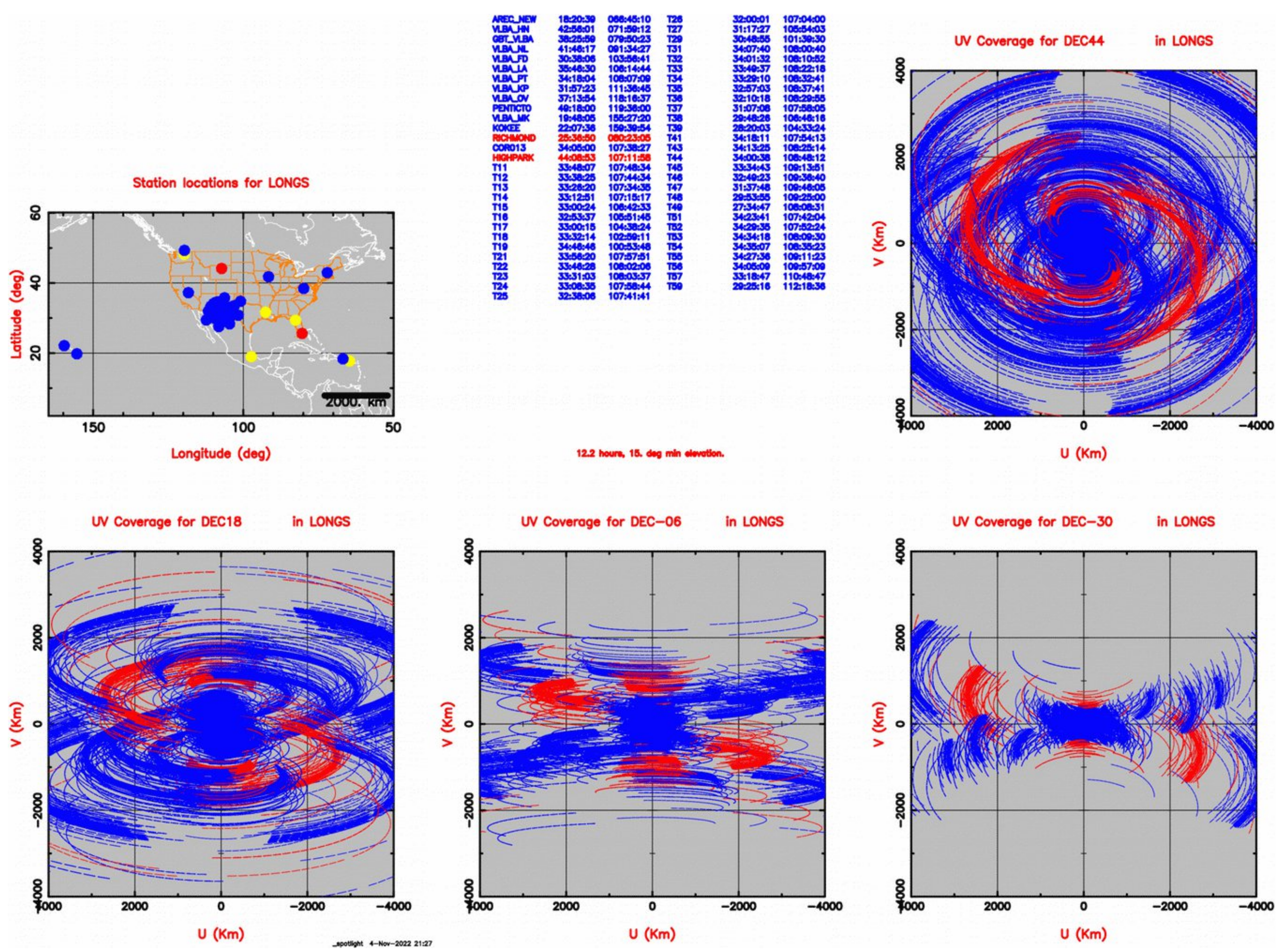

Figure 1: The inner 4000 km of the UV coverage of LONG plus MID. To demonstrate the benefits of moving St. Croix to Florida and Brewster to Wyoming, the baselines provided by those stations are shown in red. The baselines they provided in Rev D are not shown, but they would be almost indistinguishable from the baselines provided by Arecibo and Penticton, which are included here. Note in the map, yellow dots are for stations available for study, but not included in these UV plots.

that might be wanted by observations trying to extend the resolution of MID. For that, a station in northern Wyoming works well to fill a portion of the UV plane that has a gap in the dense swaths of baselines provided by MID when joint observations are made. Given the complications of going to Mexico, I suggest we move the Brewster station to northern Wyoming. The case for including the LMT as an additional antenna is made below.

The UV coverage of the inner 4000 km, the region most affected by the station moves, is shown in Figure 1. This plot includes the stations of both LONG and MID. The red baselines are ones to Florida and Wyoming that are not covered by Rev D. The baselines that were covered in Rev D by St. Croix and Brewster are so close to those provided by Arecibo and Penticton that they are almost indistinguishable at this scale, so they are not shown. It is clear that the new baselines fill in gaps in the dense coverage provided by the swaths of baselines between LONG and MID stations. The gap filled by the Wyoming station (the red baselines north and south of the center) is in the region of concern at baselines just a bit longer than those covered by the MID to MID baselines.

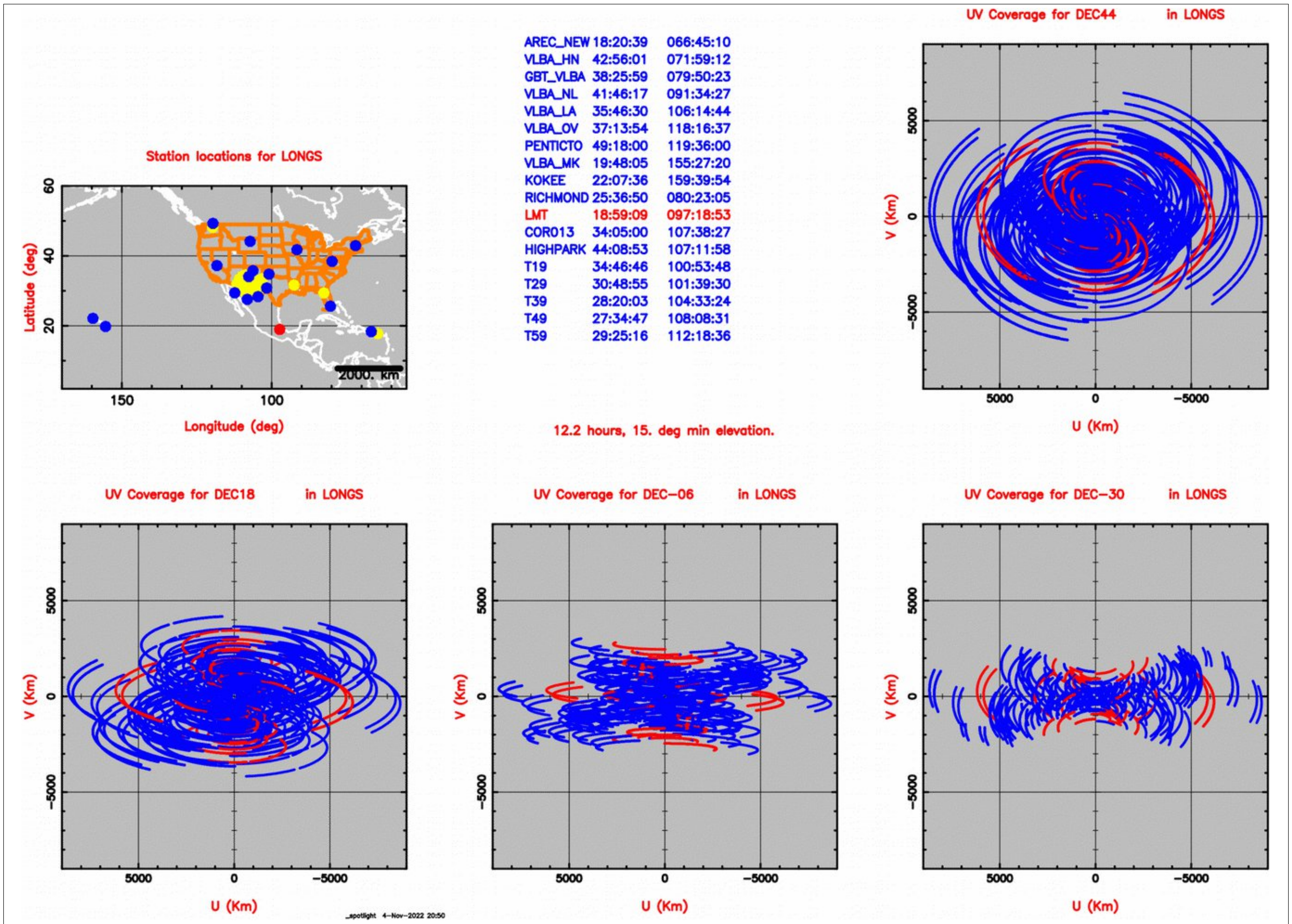

Figure 2: UV coverage of ngVLA LONG using northern Wyoming, southern Florida, and, in red, the LMT site in Mexico. Also 7 antennas of MID are included - the Los Alamos site, a central antenna in CORE, and the 5 outer tips of the arms of MID. The LONG portion of the array shown here is configuration CW_L2.

There is a lot of flexibility on where the Wyoming station could go. For the plots here, a specific site was chosen that is close to a small ski area (Meadowlark Ski Lodge) in the Bighorn Mountains at about 2800 m (over 9000 ft), so it is potentially a very good observing site. There is a considerable amount of land in the area at similar elevations, most in the Bighorn National Forest. It appears to be mainly open meadows and not very rugged. I am calling the site “High Park” after a nearby road and lookout tower. There is a major paved highway (US16) through the area and the ski area gives added motivation to keep it open in winter. The ski area does advertise an average annual snowfall of over 300 inches so that could be a bit of a problem for observing. I do not know what the environmental issues might be, but it is an attractive area so there may be some. The High Park site is 1104 km from Penticton and 1208 km from Owens Valley, so the self-calibration issue is well addressed. The site of the Wyoming Infrared Observatory (WIRO) in southern Wyoming was among other sites considered and it would have been good in many ways except that it is too close to the ngVLA center. Baselines to the center are of similar length to baselines from the center to the tips of the MID arms.

LMT

I explored many possibilities for where to put the Brewster antenna, including the Wyoming one advocated above. But I kept coming back to another that has significant advantages. That is the site of the Large Millimeter Telescope (LMT) in Mexico. It provides useful contributions to the UV coverage, especially in the south and on the longer baselines where adding MID antennas doesn't help much. This is shown in Figure 2 which shows the baselines contributed by the LMT in red. This figure also shows the large benefit of adding 7 antennas of MID – Los Alamos, one from CORE, and the 5 outer tips of the arms. Such an option should be available often when the MID science is focused on the shorter baselines. The LMT site also has other advantages. The LMT itself provides a large collecting area at the high frequencies that could be used with the ngVLA antennas providing improved calibration, much like what we intend to do with the GBT. It is at very high altitude (4593 m or just over 15000 ft) so calibration should be good, although a special heating/cooling system may be needed. The latitude is similar to Arecibo and Mauna Kea so access to the southern sky is better than most of the ngVLA. If it is deemed undesirable or infeasible to place the ngVLA antennas next to the LMT itself, there are is significant space in the vicinity at over 4000 m (13000 ft) including the site of HAWC Gamma-Ray Observatory. The LMT site is not on US territory, but Mexico is already a partner for the ngVLA and there are several MID stations already in Mexico, some of which could actually be on either side of the border if there are issues with the total number. The LMT was my first choice for the Brewster move, but the potential political issues, often mentioned, convinced me to request it as an addition and make a primary recommendations that should not be controversial. As for how we add a station in the presence of a 30 antenna limit, this is a problem and is included in the discussion below on the number of antennas per station. There is one issue with the UV coverage with the LMT – Penticton and LMT are almost at conjugate points for baselines to the ngVLA center so there is a lot of redundancy when using the whole array. One could use productively other sites farther east in Canada, even as far east as Algonquin. But then we lose the northwest corner of the array.

For the rest of this memo, I will refer to the configuration with St. Croix moved to southern Florida, Brewster moved to northern Wyoming, and LMT added as CW_L2.

Snapshot Coverage

Figure 1 (without LMT) and Figure 2 give a good idea of the UV coverage of CW_L2 for 12 hour observations with either all or some of MID included. Here the performance of CW_L2 for snapshot observations and no, or only a very few, antennas added is considered. Figure 3 shows a comparison of the snapshot coverage for a scan at transit at the ngVLA center of Rev D and CW_L2. The coverage plot for Rev D includes St. Croix and Brewster, the stations not included in CW_L2, in red to highlight what will be lost. Since they are very close to Penticton and Arecibo, they don't really add to the overall coverage except for a couple of very short baselines. The coverage plot for CW_L2 includes LMT and that station and its baselines are in red. Even without LMT, the coverage is rather better than Rev D and LMT contributes nicely.

The snapshot coverage plots for CW_L2 do show some weaknesses, especially in the NE-SW direction at around 2000 km. Adding one or more antennas from MID can help with this. Adding even just one of the more southerly MID antennas can help considerably as shown in the top plot of Figure 4. Adding 7 can have a large effect on the density of baselines. The large “Pacific Ocean” gap in the DEC-30 plots cannot be filled with a single transit snapshot. But, as can be seen in Figure 2, it can be

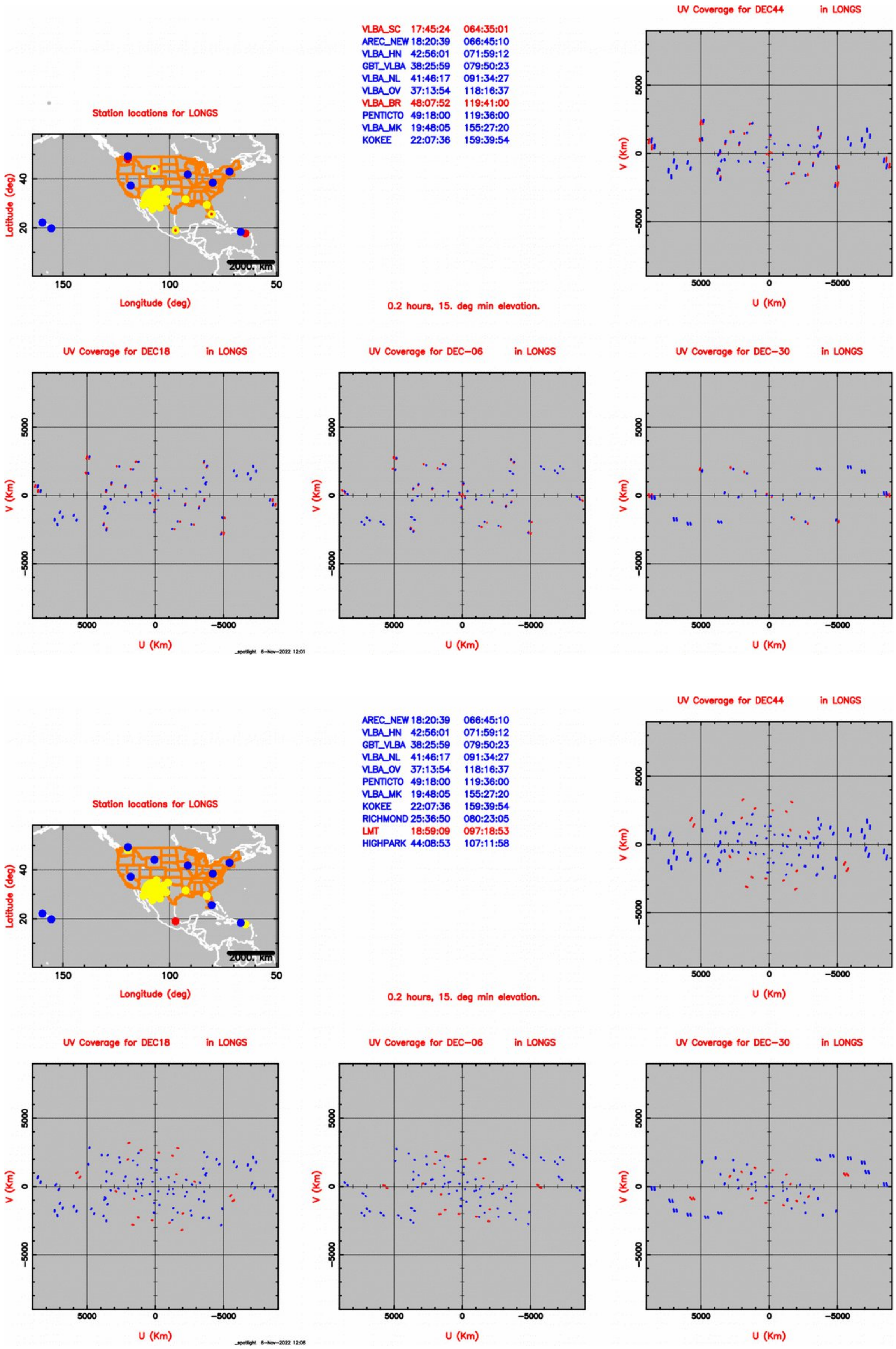

Figure 3: Comparison of snapshot UV coverage for Rev D (top) and CW_L2 (bottom). The red stations and baselines for Rev D are the contributions of St. Croix and Brewster. It is clear, while they aid calibration, they don't add much to the overall UV coverage. The red station and baselines on the CW_L2 plot are for the LMT site showing the contribution it would make if a station can be put there.

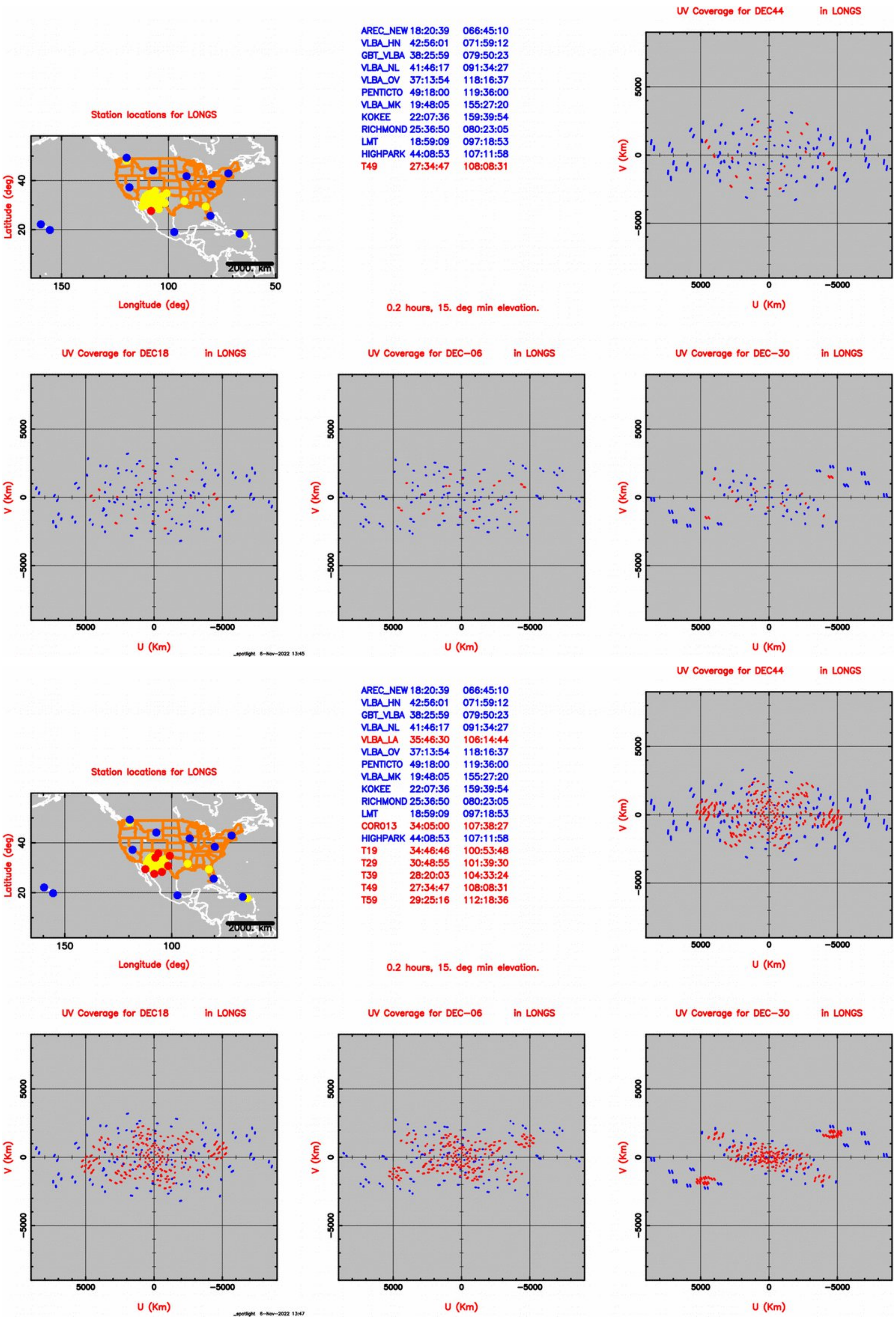

Figure 4: Snapshot UV coverage for CW_L2 with a single MID antenna (top) or 7 MID antennas (bottom) added. Even one of the southern MID antennas can deal with some of the NE-SW gap in the CW_L2 alone coverage. Adding 7 antennas makes the coverage much denser. The seven are Los Alamos, one antenna in CORE, and the outer tips of the arms.

filled utilizing projection effects with long tracks or, presumably, with multiple snapshots at times well away from transit. It is likely that using Los Alamos, a CORE antenna, and the outer tips of the MID arms with LONG , as shown in Figures 2 and 4, will be an available mode much of the time while MID is doing lower resolution science.

The UV plots in this memo show the large advantage of using some, even a very small number, of antennas from the inner parts of the ngVLA when imaging with LONG. While it has not been emphasized here, an additional issue is that LONG, by itself, is very thin on short baselines. Using antennas from the more compact parts of the ngVLA can fix that to any extent desired and allowed by the time allocation process. One problem with this is that the paired antenna calibration modes likely to be used on LONG cannot be supported on the rest of the array except in an ad-hoc manner in the CORE. In any case, the ngVLA project and planning should be prepared for most LONG projects, with the possible exception of astrometry projects, to request the addition of antennas from the more compact parts of the array.

Number of Antennas per Station

The current reference design for the ngVLA calls for 3 antennas per station in the LONG part of the array. The driver for having more than one was originally to provide additional sensitivity, but it can also have a major impact on calibration. There are two main reasons for considering changing this number for some or all sites. The first would be a determination that more, probably 4, antennas are needed for the best astrometric calibration. The other is to free some antennas to allow additional stations, such as LMT in CW_L2, to be added. Note that none of the more compact portions of the ngVLA, except very close to the center in CORE, have multiple antennas per station, so, when they are used with LONG, there will be a mixture of calibration styles and the tools need to be available to handle that.

Having multiple antennas close together at a station allows a potentially powerful calibration technique to be used, namely paired antenna calibration. If one antenna looks at a calibrator and the others look at a nearby target or other calibrators, the calibrator phases can be used to correct fluctuations in the phases on the other sources. It is equivalent to normal switched phase referencing but with very short switching times – times set by the scale of the atmospheric fluctuations and the wind speed, not the antenna slew and settling speeds. In addition, the most accurate astrometric calibration will likely require correction for atmospheric and model gradients over the antennas, which requires observation of at least 3 calibrators and is most effectively done with multiple antennas. A goal is to reach relative astrometric accuracies on the order of 1 microarcsecond, which is demanding but thought to be in reach. The calibration style, and hence the achievable accuracy, will depend on the number of antennas at each station. The options are:

1.) Single antenna per station. This requires either in-beam calibrators or fast switching and is the method used on the VLBA to achieve accuracies of about 10 microarcsecond with much narrower bandwidths. It is the planned method for the rest of the ngVLA, all of whose stations are on reasonably good sites. It is not clear that this method would work at the poor LONG sites like Florida and Arecibo at Band 6 (70-116 GHz).

2.) Two antennas per station. This allows paired antenna calibration, but any gradient determination would require three-way switching.

3.) Three antennas per station – the default. With this option, paired antenna calibration would be used and one could switch between target source scans and gradient measuring scans. Or one could alternate between the secondary gradient calibrators with one antenna while observing the primary calibrator and the target continuously with the other two. Regardless, all observations that need to determine gradients will need some form of switching.

4.) With four antennas, one could observe the primary calibrator, two secondary calibrators, and the target to get full time, nearly simultaneous (with offsets due to wind speed and antenna location offset) phase and phase gradient calibration. This would provide the best relative astrometric calibration although the target sensitivity would be reduced (only 1/4 of the antennas are on target) unless some switching is done.

For geodesy and absolute astrometry, multiple sources can be observed simultaneously with the multiple antenna cases with the possibility of obtaining continuous atmosphere and clock solutions.

For source frequency phase referencing, where calibrator and target are observed at at least 2 bands, some amount of switching is required in all but the 4 antenna case since it does not seem feasible to have multi-band receivers.

There is an ongoing project to look at these options for the number of antennas per site and try to determine their relative merit. Until that project is complete, I will not attempt to choose between the top options.

Superficially it looks like the 4 antennas per station would be best. But there is a nominal 30 antenna limit total for LONG for historical and political reasons related to the current status of the proposal. It is considered unlikely, but not impossible, that this number could be changed. Actually the number that is hardest to change is the total number of 18 m antennas in the ngVLA which is 244. Increasing the number in LONG would likely involve reducing the number in the inner array segments (CORE, SPIRAL, and MID). Given that most of the scientific interest in the ngVLA, as expressed by the community in use cases etc., is in those shorter baselines, such a change seems unlikely. One possible exception might be to use the single MID antenna at Los Alamos somewhere else, presumably a LONG site, since it does not fit on any of the spiral arms of the MID configurations being considered.

The implication of the 30 antenna limit for 4 antenna astrometric stations is that there is a maximum of 7 such stations. In that particular case, there would be a maximum of 2 additional, single-antenna, stations and only 9 stations total could be built. A new LONG configuration would be needed. For 10 stations and a desire to retain minimal paired antenna capability at all, one could only have 5 stations with 4 antennas with the other 5 having 2.

Note that, in all cases, an additional multi-antenna station can be assembled from antennas in the CORE segment temporarily assigned to work with LONG.

If LONG ends up with a mixture of stations in terms of number of antennas at each, it should be possible to combine the imaging capabilities of the full array with the position accuracy from the astrometric stations. A data reduction sequence might be to first do the best possible calibration, using phase referencing and calibrating for gradients where possible. The resulting phase referenced image of the target could then be self calibrated to achieve the best possible image using all stations. It is likely that a source strong enough to have its position measured to 1% or better of the beam width will be strong enough for some form of self-calibration. The self-calibration could be done with a constraint that the changes to the calibration phases of the astrometric stations are minimized while the

Astrometric Stations 3 antennas	Stations with 2 antennas	Single antenna stations	Total antennas	Total stations.	Implications
10 (Default)	---	---	30	10	No LMT
11	---	---	33 (3 new)	11	LMT best
8	3	---	30	11	LMT, no new
8	---	6	30	14	Improves UV
7	5	---	31 (incl LA)	12 (incl LA)	LA 2.
Astrometric stations 4 antennas					
7	---	3	31 (incl LA)	10	No LMT or LA
10	---	---	40 (10 new)	10	No LMT
11	---	---	44 (14 new)	11	LMT
6	2	2	30	10	No LMT
6	---	6	30	12	LMT + 1
5	5	---	30	10	No LMT
4	7	---	30	11	LMT

Table 1: Number of stations with 4, 3, 2, or 1 antennas per site for the most interesting, viable combinations. There are many more possible. Most are for configurations with 10 (LONG without LMT), 11 (LONG with LMT), or 12 stations (LONG with LMT and with more than one antenna at LA). Most have the 30 antennas currently assigned to LONG. Cases with 31 antennas include the one currently at LA, either moved, or one of two or more at LA. Larger cases include new antennas, either new to the ngVLA total or taken from other ngVLA segments. Note that, in all cases, an additional astrometric station of arbitrary size can be assembled when needed in the CORE. Single antenna stations will not be able to use paired antenna calibration and are avoided in most options. The LMT could be added to any "No LMT" option by removing some other station.

phases of the rest of the stations are allowed to float. Some scheme for accounting for phase ambiguities, possibly using the very wide bandwidth delays that will be available, will be needed. This is much like the use in the AIPS task CALIB of the parameter ANTUSE to let the amplitude scale be set by the antennas whose calibration is trusted by the user.

Table 1 shows the numerology for some of the more attractive combinations of number of stations with certain numbers of antennas each. Here the concept of "astrometric stations" has been used. Those are the stations with 3 or 4 antennas, depending on what is decided is needed. For any arrangements other than 10 stations total and 3 antennas per station, or the unlikely case that 2 antennas make an acceptable astrometric station, there will be some less capable stations with 1 or 2 antennas.

Some of the more attractive options, not in any particular order, are:

1.) The default of 10 stations of 3 antennas each. LMT is not covered in this case unless the Los

Alamos antenna is moved to put a single antenna there.

2.) Find the 3 extra antennas needed to add the LMT in the 3 antennas/station case or the 14 extra antennas to make all LONG stations plus LMT astrometric stations if in the 4 antennas/station case.

3.) Find 5 extra antennas to add LMT and make Los Alamos astrometric in the 3 antennas/station case. This gives full astrometric capability to one of the VLBA's high, dry sites, most of which have been allocated to MID as single antenna sites.

4.) Enable a three antenna astrometric station at the LMT by taking one antenna each from 3 stations (possibly Arecibo, Florida, and North Liberty or North Liberty, Penticton, and Los Alamos) leaving 8 astrometric stations (9 with CORE) with 3 antennas each and 3 paired antenna stations (or 2 paired antenna stations if Los Alamos is moved to LMT). For Arecibo and Florida, it is not clear how well gradient measurements would work regardless.

5.) Have 6 stations with 4 antennas each, two stations with two antennas (probably Florida and Arecibo because phase referencing at band 6 might depend on it) and two single antenna stations (maybe North Liberty and Penticton). Again the LMT is not covered unless Los Alamos is moved to put a single antenna there.

6.) Use the 31 antennas of LONG plus Los Alamos to make 7 three antenna stations (8 with one in CORE) and 5 two antenna stations for 12 total, one of which can be Los Alamos.

7.) Have 4 astrometric stations (plus one in CORE) with 4 antennas each plus 7 stations with 2 antennas for a total of 11 so LMT can be included. This is the option shown in Figure 5.

Clearly there are a lot of options! Without knowing the answer to the key questions below, it is hard to narrow down the choices much.

The impact of one specific choice of antenna numbers is shown in Figure 5. This shows the UV coverage, for a long track (12 hours), of choosing 4 stations with 4 antennas each and 7 stations with 2 antennas each. In addition, one 4 station site is assembled in the ngVLA CORE and Los Alamos is included in the plot as a single antenna station. The 5 astrometric stations, and the 10 baselines between astrometric stations, are shown in blue. The other 8 (with LA) stations, and 68 baselines with a non-astrometric station on one or both ends, are shown in red. The top plots are for a 12 hour track. The bottom plots show a snapshot.

Key Questions and Concerns

Before choosing which combination of sites and antennas per site to use, some questions need to be answered:

1.) How many antennas per astrometric station are required to meet the 1 microarcsecond goal? It will be significantly easier to contend with an answer of 3 than of 4.

2.) What is the minimum number of astrometric stations required to meet the astrometric goal?

3.) Is there any way to increase the total number of antennas assigned to LONG? If so, by how many?

4.) How valuable is a second antenna for paired antenna calibration even without a full astrometric set? Can it make poor sites like Arecibo and Florida significantly more useable than if they only have one antenna – such as allowing phase reference imaging at Band 6? Can better sites

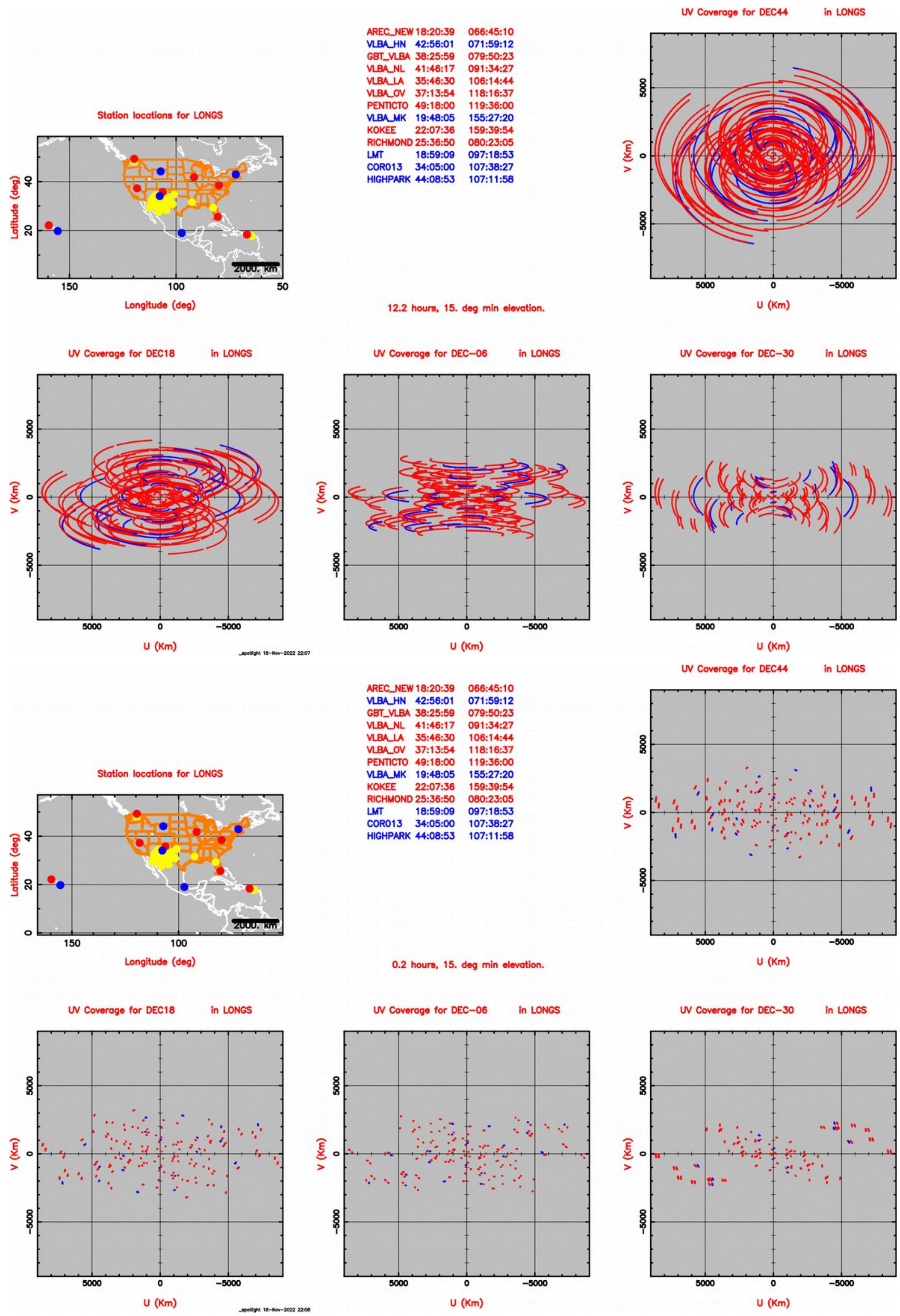

Figure 5: UV coverage of CW_L2 highlighting the effect of having 4 astrometric LONG stations plus one CORE station with 4 antennas each. The 5 lue stations have 4 antennas each. The 7 red LONG stations have 2 antennas each. Los Alamos, with 1 antenna, is also included. This is the somewhat extreme 4x4+7x2 option of the last line of Table 1. Only the blue baselines have full astrometric capability. Long tracks on top, snapshot on bottom.

like North Liberty and Penticton make do with one antenna?

5.) What is the minimum number of antennas per station needed to meet the source frequency phase referencing goals? How many stations need to have that many? How important is that capability if phase referencing can be done at Band 6?

6.) How harmful for imaging would it be to mix the number of antennas per station? Also, are single antenna stations useful for LONG?

Some concerns beyond the questions above are:

1.) Will Arecibo and Florida ever contribute to 1uas astrometry, even with 3 or 4 antennas?

2.) How well will Arecibo and Florida work for phase referencing with 2, 3, or 4 antennas?

3.) Can the ngVLA subarray concept handle LONG? A calibration sequence might have each antenna at a site observing a different source for a scan, then all looking at the same source the next scan and needing to all be correlated together maintaining phase. Geodetic observing might have multiple subarrays looking at different combinations of sources each scan with the subarray assignments changing every scan. Even more extreme is that the integration time on source for a scan may vary by station - an option has long been used in the geodetic world. Also, the calibrator and target might be continuum or line so one might need to switch bandwidth scan by scan without loosing phase and while switching subarray assignments.

4.) I don't like not having any of our high, dry southwestern VLBA stations among the astrometric stations. Those are KP, FD, PT, and LA. CORE will be good and OV pretty good, plus LMT, if used, would be very good and the new Wyoming site might be rather good. But we've lost all the rest to being absorbed into MID which has one antenna per site.

5.) Los Alamos is a good site and is an odd one out in MID since it is not naturally part of a spiral arm. Can it be considered mainly part of LONG? Can it be equipped as an astrometric station? Or could it's antenna be used to create or beef up a station farther out? Some of the options above do add antennas to LA so regaining that station for astrometry is possible.

6.) We should find out which VLBA stations the USNO cares most about maintaining continuity at. Can any of the MID stations, especially the ones from the VLBA, be equipped as astrometric stations with extra USNO funding?

Conclusions

The configuration of the LONG segment of the ngVLA has been reviewed. The following recommendations and conclusions are made:

1.) Move the St. Croix station to southern Florida.

2.) Move the Brewster station to northern Wyoming, perhaps along US 16 in the Bighorn mountains at high altitude.

3.) Add a station at the LMT in Mexico. This likely requires repurposing one or more antennas from elsewhere or adding new antennas to LONG.

4.) Recognize that most imaging observations with LONG will want one or more MID stations. Even 7 (Los Alamos, one in CORE, and the outer tips of the 5 arms) makes a very significant improvement to the UV coverage.

5.) Options for the distribution of antennas depending on the number of stations and the number of antennas per station were given.

6.) We need to answer the key questions outlined above to determine the arrangement of number of antennas per station over the array to provide good imaging and a possibility to reach one microarcsecond astrometry. Fortunately, I think these decisions can be independent of the configuration choice.

Appendix A:

Below is a .cfg file for LONG stations (one antenna per station) for the 11 stations of CW_L2. Only15 one antenna per station is shown. A final .cfg file should have however many antennas at each station we decide to use.

```
# observatory=NGVLA
#  Hand edited for LONG configuration CW_L2 Nov 7, 2022.
#  Most entries adapted from ../RevD/ngvla_revD.lba.cfg
#  Richmond, FL, High Park, WY, and LMT added with information from a SCHED .sum file.
#  Stripped to one antenna per station.
# coordsys=XYZ
-5469327.86714 -2494930.43893 2130520.58917 18.0 hi01
1446345.58057 -4447968.09007 4322309.08306 18.0 hn01
-5544010.48303 -2054622.51133 2387335.91967 18.0 ku01
881972.747247 -4925212.32671 3943404.32772 18.0 gb01
-130910.880405 -4762328.22326 4226866.75948 18.0 nl01
-2409161.00327 -4478575.081 3838627.78782 18.0 ov01
-2059737.4952 -3621582.6203 4813837.44062 18.0 pn01
2391064.7725 -5564466.47257 1994762.93309 18.0 pr01
961257.9541 -5674090.0386 2740533.8240  18.0 ri01
-768715.632 -5988507.072 2063354.852 18.0 lm01
-1356087.169 -4380960.196  4421860.934 18.0 hp
```