A Potential Array Configuration for the LWA

Aaron Cohen[1]

aaron.cohen@nrl.navy.mil

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ABSTRACT

This memo presents a detailed description of a potential array configuration for the Long Wavelength Array (LWA). The station locations have been chosen to satisfy both astrophysical science requirements and practical considerations. The main astrophysical requirement is to have a distribution of baseline lengths capable of providing both high resolution and sensitivity to large angular-scale source features without leaving major gaps in the intermediate baselines. Practical considerations include pre-existing infrastructure such as roads and fiber as well as land ownership. While the station sites suggested here are a reasonable estimate for where stations might be built, most sites need to be fully investigated before they can be chosen definitively. Therefore, the main goal of this memo is to lay out the overall concept for both the final LWA array configuration and the progressive phases in its construction.

1. Background

The LWA is currently planned to have 52 stations. Some fraction of the 52 stations (about 15) will be grouped into a compact core to provide sensitivity to source structure with large angular sizes. The remaining stations (about 37) will be spread out into outlying station with a maximum baseline of 400 km in order to achieve high resolution.

The LWA will be built in stages, with each stage capable of significantly increased levels astrophysical output. This memo will first describe the complete array configuration. With this final vision in mind, intermediate phases of construction are also described in detail. These phases are described in terms of which set of the final 52 stations should be built at what time to produce the optimum astrophysical results and ionospheric calibration development at each phase.

[1]Naval Research Laboratory, Code 7213, Washington, DC 20375

2. The Complete Array Configuration (Phase IV)

2.1. Outlying stations

Table 1 lists 37 potential outlier station locations. One of these sites is the current LWDA (Phase I) location. Another 9 sites are the locations chosen for the future EVLA Phase II antennas, which have already been well researched by NRAO. The other 27 sites were chosen on sites that are (1) near a public road, (2) on either state land or BLM land and (3) near an existing fiber line (although whether these lines can be accessed will need to be investigated for each station). These locations were also chosen generally to fill in the *uv*-coverage relatively smoothly for baseline lengths between roughly 10-400 km. For this reason, there is a concentration of relatively closely spaced station locations near the likely location of the core. That will ensure a more even distribution of baseline lengths. For these 37 stations, the precise lengths of the shortest and longest baselines are 7.6 km and 401 km respectively.

2.2. The LWA Core

The purpose of the LWA core is to fill in the short baselines that are not provided by the outlying stations. Thus the length of the longest baseline within the core is roughly set by the smallest outlying station baseline, but a bit larger to provide some overlap and avoid any "holes" in the *uv*-coverage. The shortest baseline within the core is set by the scientific requirements for sensitivity to large angular scales.

With this in mind, a log-spiral design was chosen, as shown in Figure 1. This has a total of 15 stations (3 arms with 5 stations each). The advantage of a log-spiral design is that it can be made to be very centrally condensed, which is necessary to achieve sufficiently short baselines. Most other designs, including arrays that are optimized for low sidelobes, have much worse *uv*-coverage on the shortest spacings. The *uv*-coverage at various declinations is shown for this design in Figure 2.

The design shown in Figure 1 has 5 stations on each arm at the following radii from the center: 240 m, 960 m, 2,160 m, 3,840 m and 6,000 m. The arms are curved rather than straight to improve *uv*-coverage and avoid the 6-sided star pattern of high-sidelobes that the VLA has. The shortest and longest baselines are 415 m and 10.4 km respectively. Depending on the physical constraints at the core location, this design might have to be modified somewhat. However, it is a fairly flexible design. It can be also be rotated if needed. The outer stations can be moved around a bit without much impact, although the *uv*-coverage is impacted to a much greater degree by changes to the locations of the inner stations. Of course the effect of a rotation or movement of core stations on the *uv*-coverage will have to be evaluated in terms of its effect on the intermediate baselines to the inner outlying stations closes to the core.

At present it is unclear where to place the core, though a location near the VLA seems likely. One promising location is towards the west of the end of the north arm of the VLA, because of the large amount of available land there. However, before this site can be confirmed, a study of the radio frequency interference (RFI) environment in the area surrounding the VLA must be performed. RFI has the largest impact on closely spaced stations, and therefore it is a crucial issue for the core. Other sites that might be chosen are to the south-east of the VLA and the west of the west arm of the VLA. Because of the large number of closely space outlier stations in the vicinity of the VLA, any of these locations would be acceptable in terms of avoiding gaps in *uv*-coverage between the intra-core baselines and the longer baselines. For the purpose of this memo, it will be assumed that the core will be located at the first position mentioned – to the west of the north arm of the VLA.

2.3. The Complete LWA Configuration

The complete LWA configuration proposed here is shown in Figure 3. It consists of 52 stations, with 15 in the core and 37 spread throughout the southwest of New Mexico. The shortest baseline is 415 m and the longest is 401 km, giving a range of baseline lengths that is nearly 1000 to 1. For reference, this range is just under 50 to 1 for a single VLA configuration. The VLA produces a 1000-to-1 ratio only when all four configurations are combined. The LWA will achieve this in a single configuration.

The *uv*-coverage at several declinations is shown in Figure 4. As can be seen, the *uv*-plane is quite well covered at all declinations. The array was designed with a slight north-south extension so that the synthesized beam at the southern declinations is less elongated.

3. LWA Phase II

3.1. Overview

LWA Phase I will consist of a single station located at the VLA center, which is also called the Long Wavelength Development Array (LWDA). The purpose of the LWA Phase I is to develop the hardware and techniques to produce a fully operational LWA station.

The first LWA phase that will be capable of independent interferometric imaging (without the VLA 74 MHz system) will be Phase II. In the current plan, Phase II will consist of 9 stations, with medium to long baselines. The longest baseline should be between 100 km and 200 km. The purpose of this phase is to probe ionospheric effects on long baselines, and to conduct low-frequency imaging at unprecedented resolution. The lack of short baselines in a core at this stage will prevent the ability to detect structures with large angular scales. Also, the small number of baselines at this stage will most likely prevent full-field ionospheric calibration. However, using the VLSS survey (http://lwa.nrl.navy.mil/VLSS), we have determined that at least several hundred low-frequency radio sources are bright enough and isolated enough to be imaged with self-calibration alone.

Therefore, even at this early stage, we are certain to produce a large amount of new science.

The LWA Phase II will consist of 9 stations at locations chosen from the eventual 52 station locations described in Section 2. These 9 will be chosen to meet the astrophysical and testing goals of Phase II with the best possible *uv*-coverage. Another factor will be logistics. Certain sites might be cheaper or easier to obtain and develop than others. Therefore, the final decision on the Phase II configuration will likely have to be a compromise between science goals and logistics. Two possible options for Phase II are described in Section 3.2.

3.2. Options for the LWA Phase II

3.2.1. Option 1

The first option proposed for LWA Phase II consists of the 9 stations emphasized in Figure 5. These 9 stations have minimum and maximum baseline lengths of 17.2 km and 178 km respectively. With only 45 independent baselines, the snapshot *uv*-coverage is limited, yet the Earth-rotation synthesis *uv*-coverage is reasonably good at most declinations (Figure 6).

3.2.2. Option 2

A second option for the LWA Phase II is shown in Figure 7. The *uv*-coverage for this configuration is shown in Figure 8. This is a somewhat smaller configuration, with minimum and maximum baseline lengths of 10.1 km and 117 km respectively. Compared to "Option 1", this configuration will have lower resolution, but more sensitivity to large angular scales. It will be easier to calibrate, yet will not probe baselines which are as long as those in "Option 1". These considerations, along with logistical factors, will determine which of these options (or additional options) will be chosen.

4. LWA Phase III

4.1. Overview

The LWA Phase III will consist of adding 7 core stations to the LWA Phase II. This will fill in the short baselines that are not covered by the widely spaced Phase II array. Because the final core will have 15 stations, a set of 7 station locations in the core will be used for this phase. One such set is shown in Figure 9. This "partial" core will not have as comprehensive *uv*-coverage as the full core (see Figure 2), but will provide a reasonable sampling of the shorter baselines as shown in Figure 10. The addition of this "partial" core greatly enhances the *uv*-coverage of the LWA Phase II as shown in Figure 11. This will add to the existing Phase II array the capacity to detect large scale structure. The smallest baseline length in this core is 947 m, which is more than an order of magnitude smaller than the shortest baseline in the Phase II. However, this is a bit more than twice the length of the shortest baseline in the full core, which will have to wait until Phase IV.

It should be noted that the construction time-line of the full Phase III, is flexible. For example, it may be advantageous to build one or more stations in the core as soon as possible. Therefore, one or more core stations can be built in Phase II in place of an equal number of Phase II stations that will instead wait until Phase III. This will result in the same Phase III, with little change to the Phase II capabilities. Further, if a core location is not yet decided at the time of Phase II construction, one or more Phase II sites could be placed at possible core locations in order to gain familiarity with working at these sites. If one of these locations is chosen for the core, an additional outlier station can be built elsewhere to replace the intermediate baselines provided by that station.

4.2. Imaging Capability

The 16 stations in Phase III, will alone constitute a very powerful instrument. At 74 MHz, it will have roughly 10 times the collecting area as the VLA, and about 5 times the resolution. It's imaging capability has been simulated by projecting a high-resolution 1.4 GHz model of Cas A onto the 74 MHz synthesized *uv*-coverage of the LWA Phase III (using "Option 1" for Phase II). This image is shown in the top panel of Figure 12. For reference, an actual 74 MHz image of Cas A taken with the VLA in A-configuration is shown in the bottom panel of Figure 12. As can be seen, the LWA Phase III as proposed in this memo can produce images that are both high-resolution and also preserve the large scale structure with a high overall image fidelity. Future memos will examine the image fidelity of various configurations in a more quantitative way.

5. Overview of LWA Phases

This memo describes a complete 52-station LWA configuration. Also, it describes a 9-station LWA Phase II and a 16-station LWA Phase III, both of which are highly capable instruments. Figure 13 gives an overview of the range of baseline lengths for each phase. The LWA Phase II will be able to obtain high resolution images of bright sources. Phase III will greatly increase the number of short baselines, allowing large scale structure to be imaged. Phase IV improves by over a factor of 2 both the longest and shortest baselines, along with greatly improving the density of *uv*-coverage in the intermediate baselines. This along with a tripling of the overall collecting area will allow for a capability to achieve nearly all of the astrophysical goals of the LWA project.

6. Conclusion

This memo describes both a set of possible station locations and an overall concept of the phased LWA construction. This design will fulfill nearly all the astrophysical goals of the LWA project and is logistically reasonable given what we know now. Therefore, this configuration represents a starting point for future planning and discussions. Because a full investigation of the station locations still needs to be done, this design will likely be modified as additional facts become available.

Table 1: List of Potential Outlier LWA Station Sites.

Name	Code	Long.	Lat.	Notes
Akela	AK	$-107.42°$	$32.24°$	South of Akela, NM, on NM 549
Alegres Mountain	AM	$-108.11°$	$34.18°$	12 km south of Pie Town, on rt. A56
Canoncito	CA	$-106.97°$	$35.09°$	1 km up Rt. 7070 from intersection with US 40
Cuchillo	CU	$-107.38°$	$33.23°$	Cuchillo EVLA site
Datil	DA	$-107.84°$	$34.14°$	just west of Datil on Rt. 12
Dusty	DU	$-107.61°$	$33.68°$	Dusty EVLA site
East Arm	EA	$-107.56°$	$34.11°$	On US60 just east of NM 52 intersection
Elk	EL	$-105.16°$	$32.89°$	Elk EVLA site
Engle	EN	$-107.02°$	$33.17°$	South of Engle, on A013
Edgewood	EW	$-106.19°$	$35.08°$	North of Edgewood, NM, on NM 344
Greens Gap	GG	$-108.12°$	$34.10°$	about 10 miles on dirt road off NM12
Grants	GR	$-107.82°$	$35.12°$	SE of Grants, NM, off US 40
Hermanas	HE	$-107.93°$	$31.84°$	East of Hermanas, NM, on NM 9 and rt. C4
Horse Mountain	HM	$-108.06°$	$33.97°$	Due East of Horse Mountain on NM12
Horse Springs	HS	$-108.29°$	$33.93°$	Probable Phase I station
Magdalena	MA	$-107.27°$	$34.14°$	few km north of Magdalena on NM169
Mangas Valley	MV	$-108.45°$	$32.73°$	Mangas Valley EVLA site
NM 113	NM	$-108.57°$	$32.07°$	NM 113 EVLA site
Pie Town	PT	$-108.12°$	$34.30°$	Pie Town EVLA/VLBA site
Quemado	QM	$-108.42°$	$34.33°$	East of Quemado, NM, on US60
Rincon	RN	$-107.02°$	$32.68°$	East of Rincon, off E71
Rock Springs	RS	$-107.71°$	$33.81°$	At intersection of NM52 and NM163
San Antonio	SA	$-106.86°$	$33.89°$	South of San Antonio, NM, on NM 1
Sugarloaf Mountain	SL	$-107.94°$	$34.08°$	8 miles South of Datil on Rt. 12
Spurgeon Mesa	SM	$-108.93°$	$33.48°$	Spurgeon Mesa EVLA site
Santa Teresa	ST	$-106.80°$	$31.81°$	15 km west of Santa Teresa, NM, on rt. A3
Sevilleta	SV	$-106.88°$	$34.35°$	In Sevilleta NWR at the UNM Field Station
Tres Montosas	TM	$-107.45°$	$34.09°$	Off east arm of VLA on rt. 549 & US60
Torrance	TO	$-105.51°$	$34.33°$	Torrance EVLA site
Twin Peaks	TP	$-107.72°$	$34.12°$	10 km east of Datil on US60
Tularosa	TU	$-106.04°$	$33.13°$	North of Tularosa, NM, on US 70
VLA South	VS	$-107.63°$	$33.99°$	8km south of VLA center on NM52
VLA	VL	$-107.63°$	$34.07°$	Near VLA center (LWDA site)
West Arm	WA	$-107.79°$	$34.00°$	Near End of VLA West Arm
Water Canyon	WC	$-107.04°$	$34.05°$	On Rt 60 between Socorro and Magdalena
Winston	WN	$-107.59°$	$33.38°$	5km NE of Winston on NM52
West US60	WU	$-108.78°$	$34.26°$	West US60 EVLA site

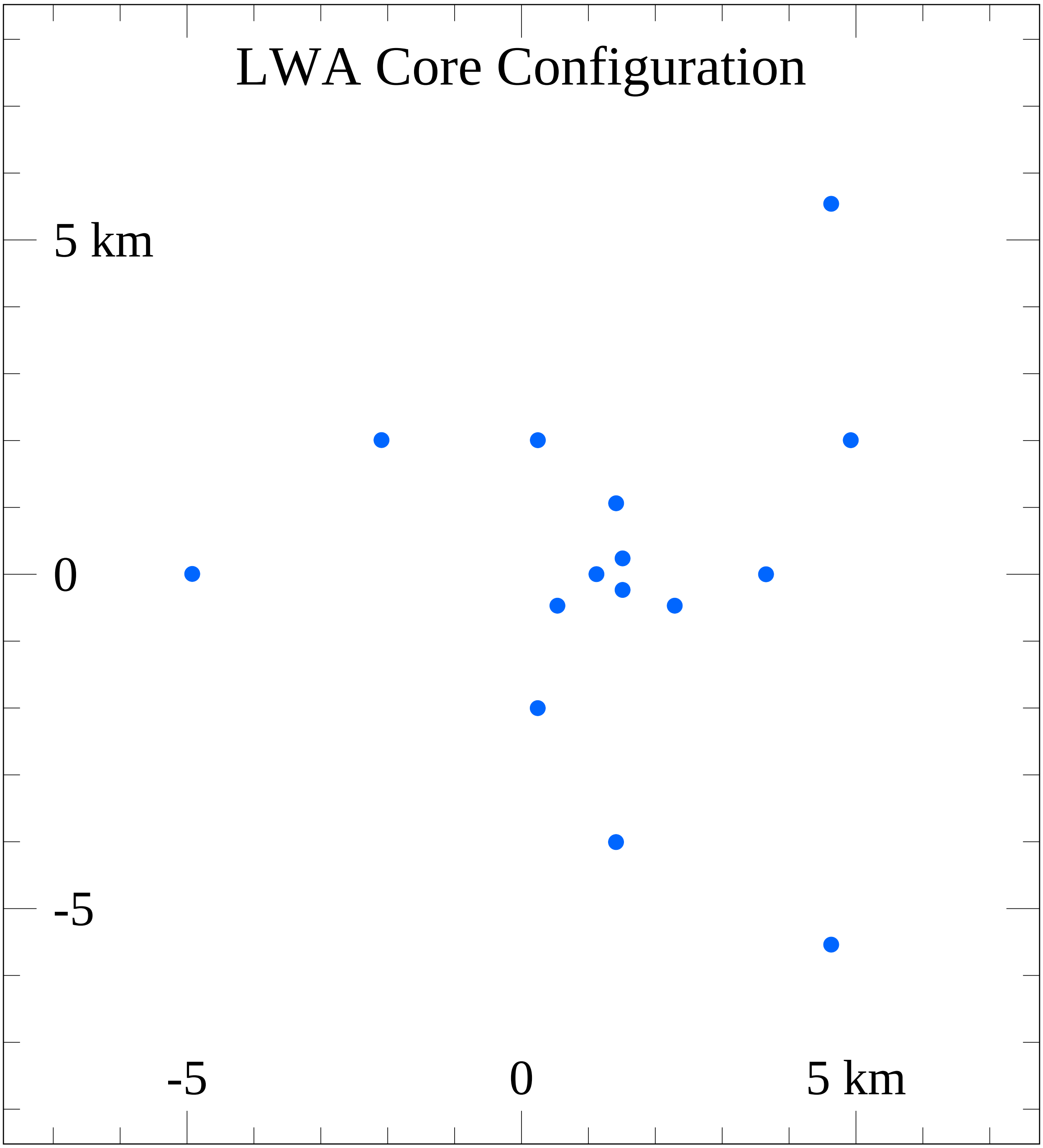

Fig. 1.— Station locations in the LWA core.

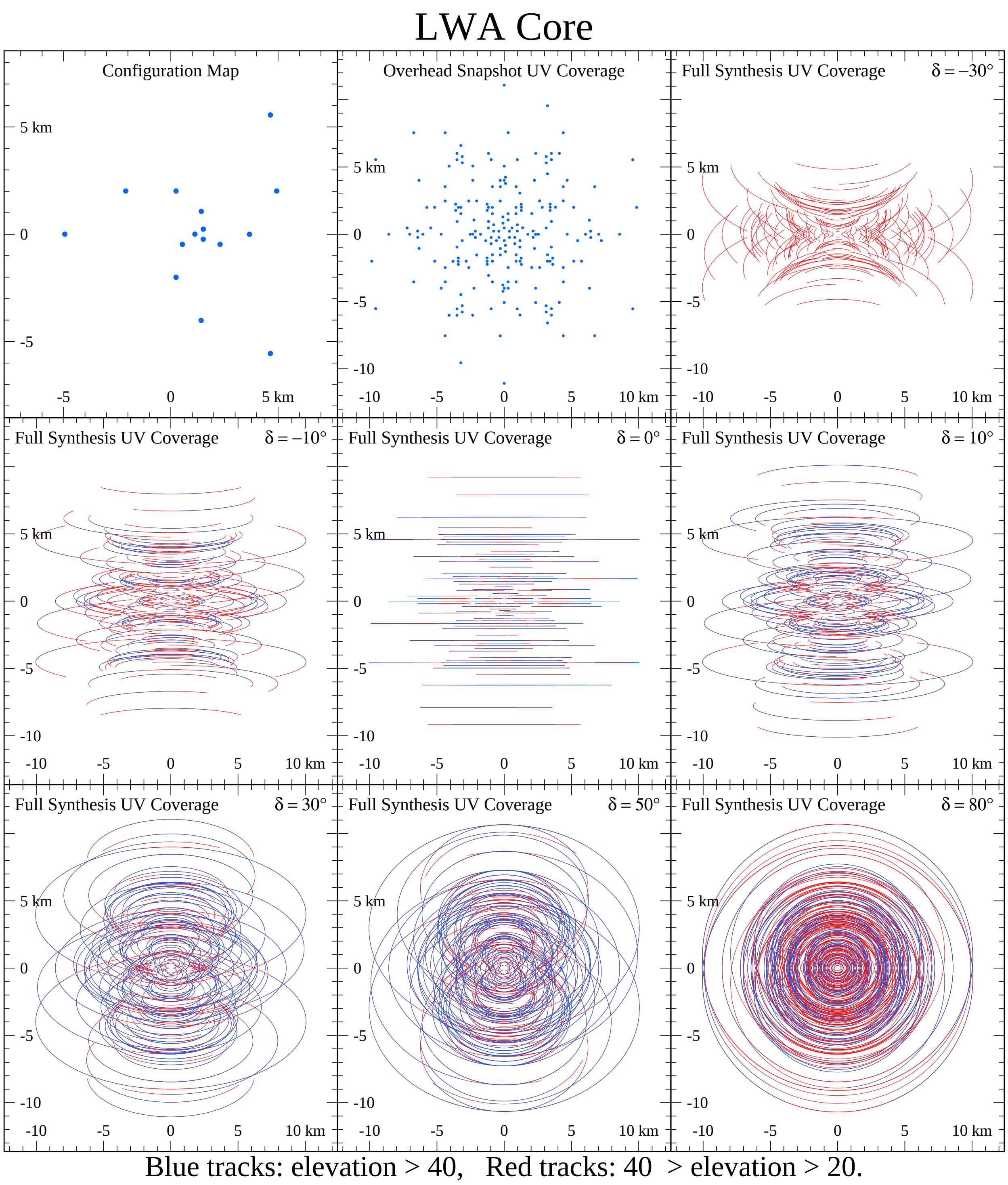

Fig. 2.— LWA core uv-coverage at various declinations.

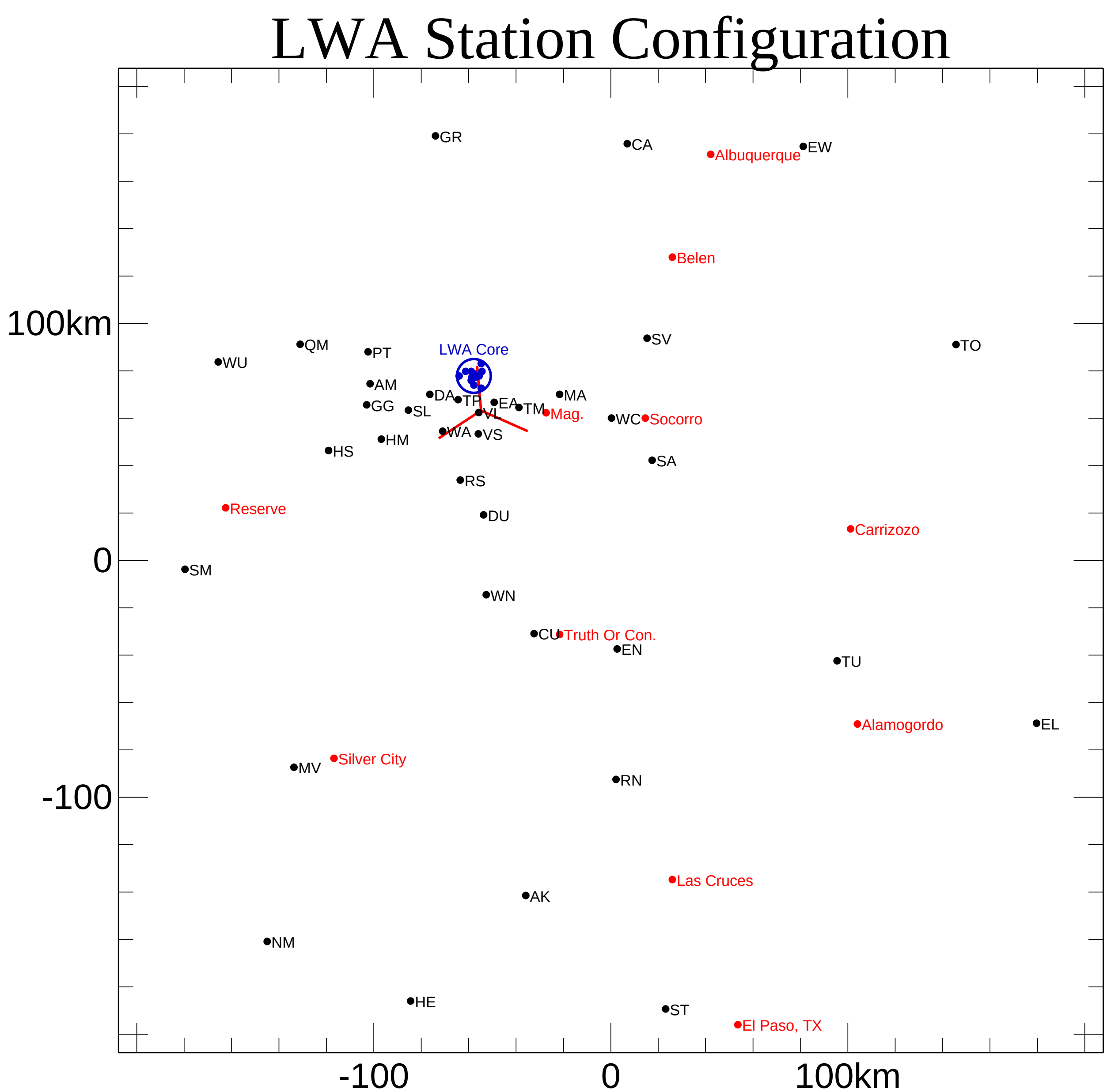

Fig. 3.— Station locations for the complete LWA. The core stations locations are shown with blue dots with the entire core circled. The outlying stations are the black dots, each labeled with that station's two-letter code (see Table 1). Various cities are shown in red for a spatial reference.

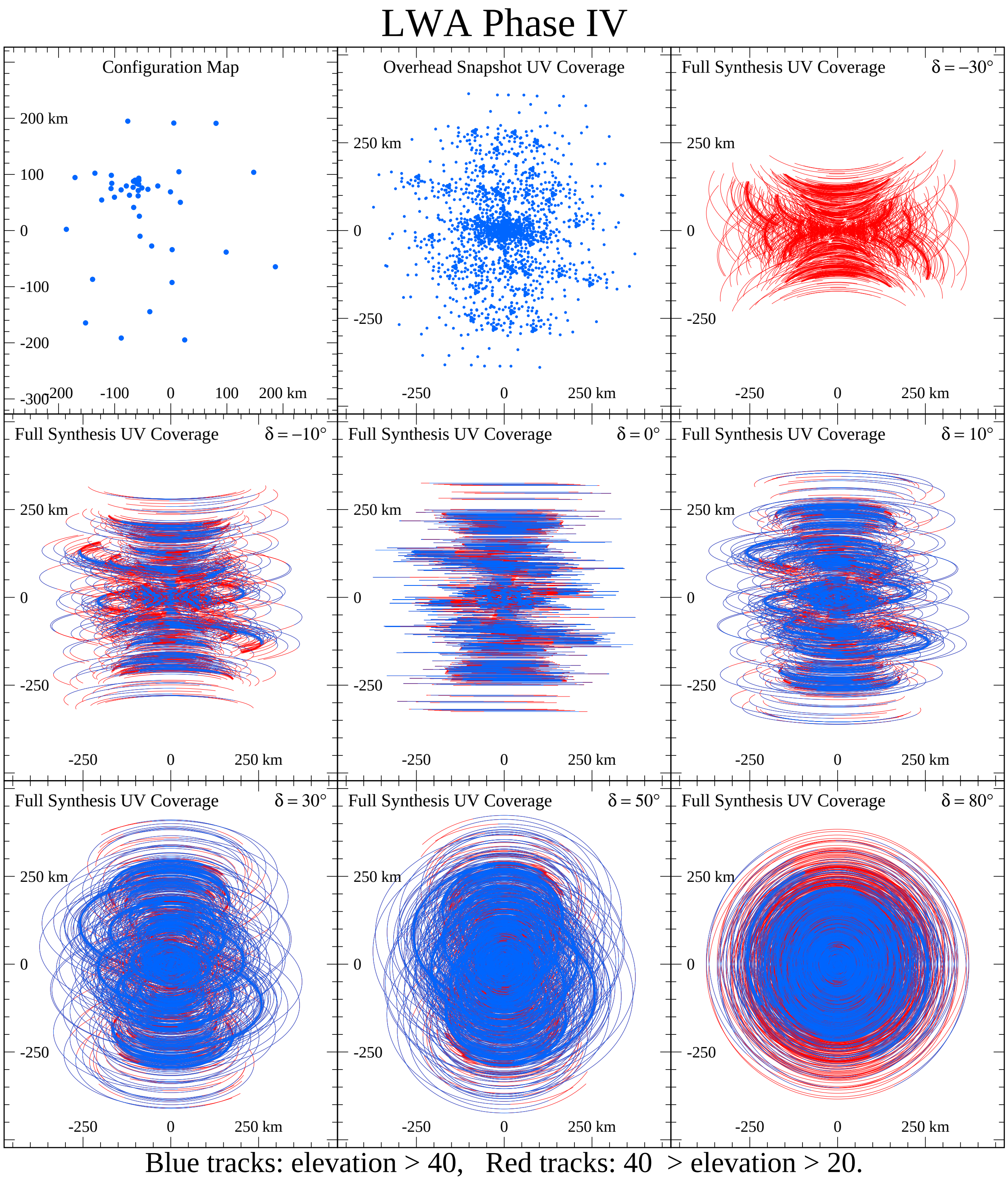

Fig. 4.— Complete LWA uv-coverage at various declinations.

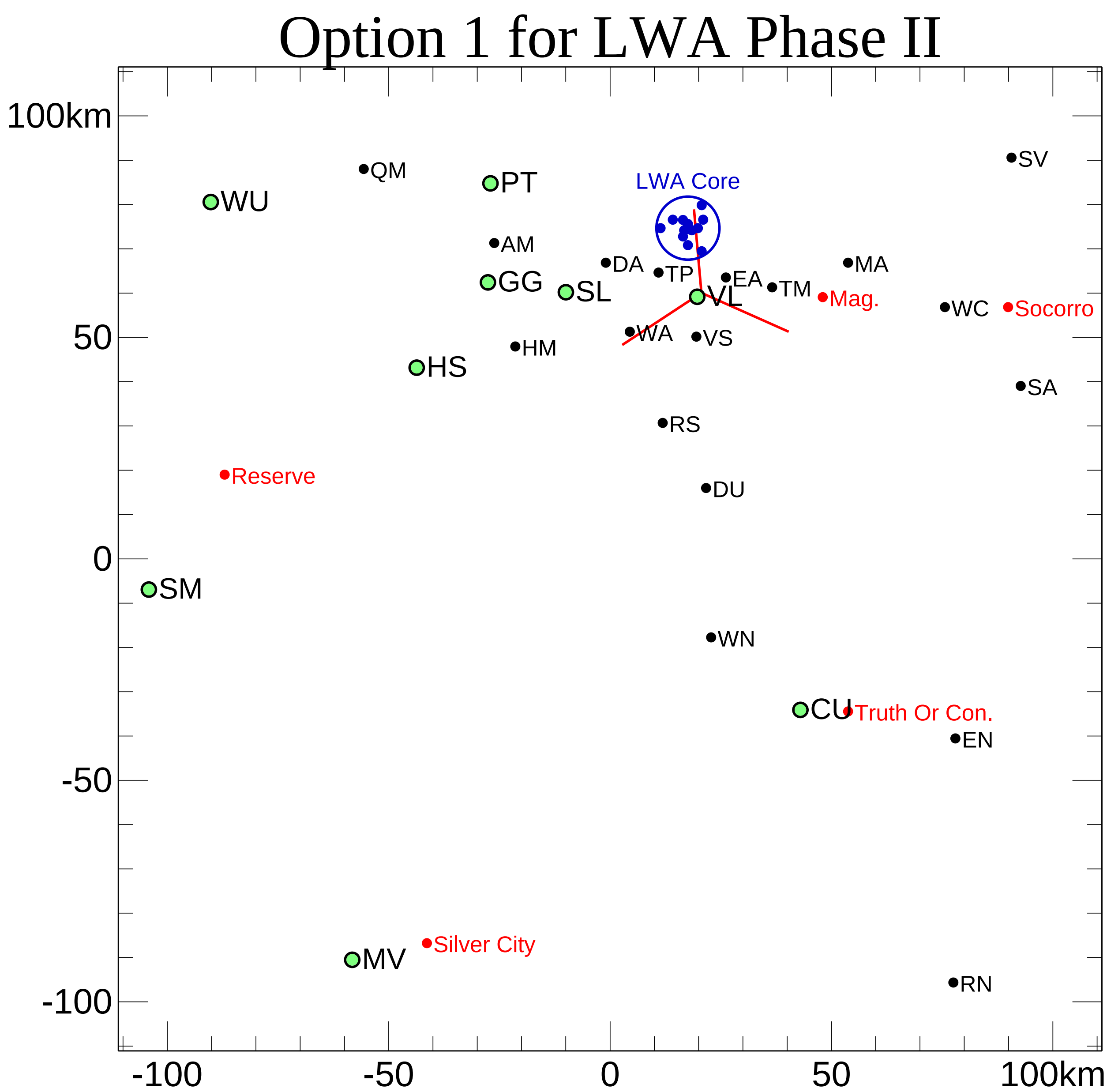

Fig. 5.— Station locations for "Option 1" for the LWA Phase II. The 9 stations locations chosen for Phase II are shown as the large green- filled circles, while the other stations are shown as the smaller black dots and the core is shown in blue.

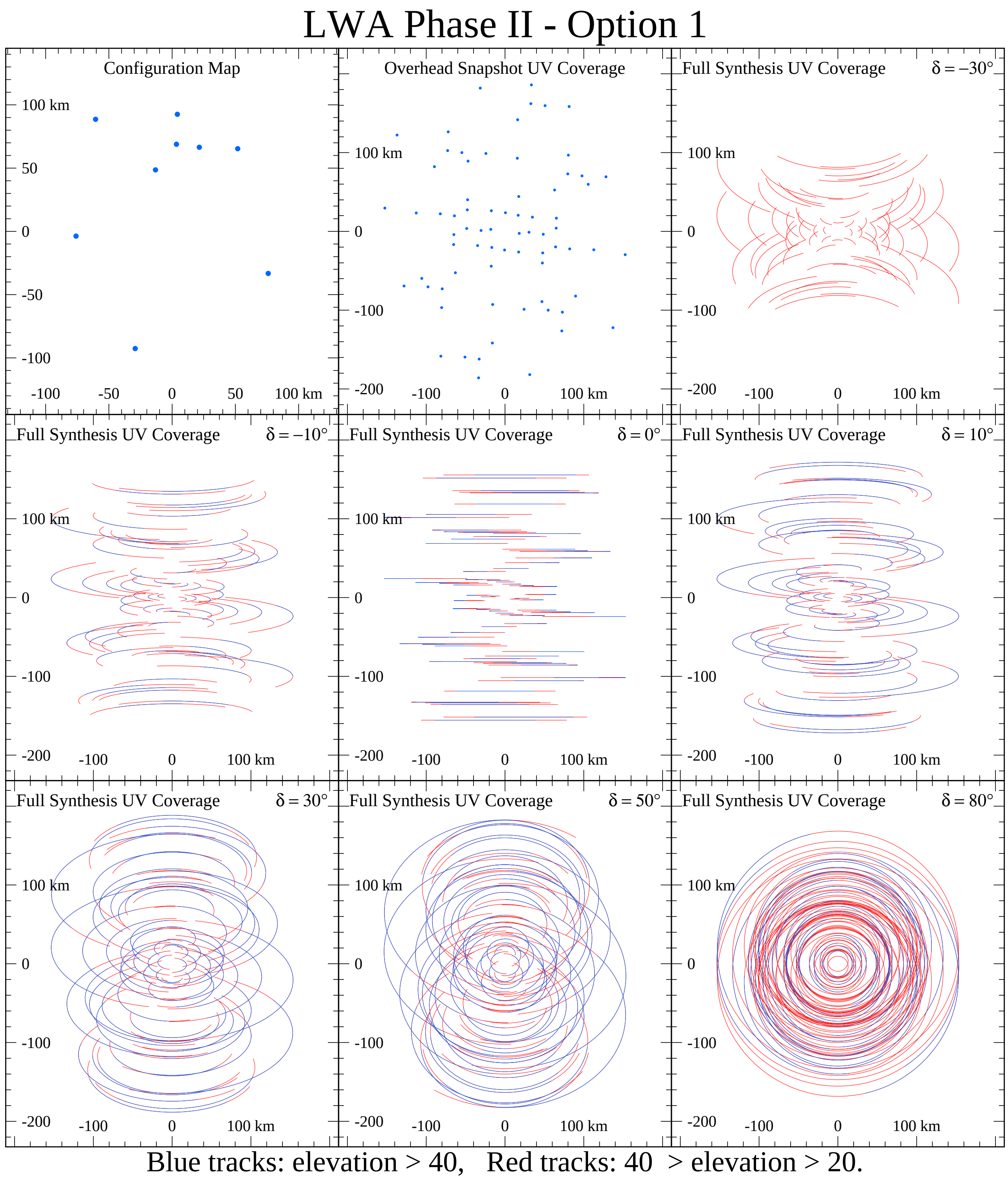

Fig. 6.— The *uv*-coverage for "Option 1" for the LWA Phase II.

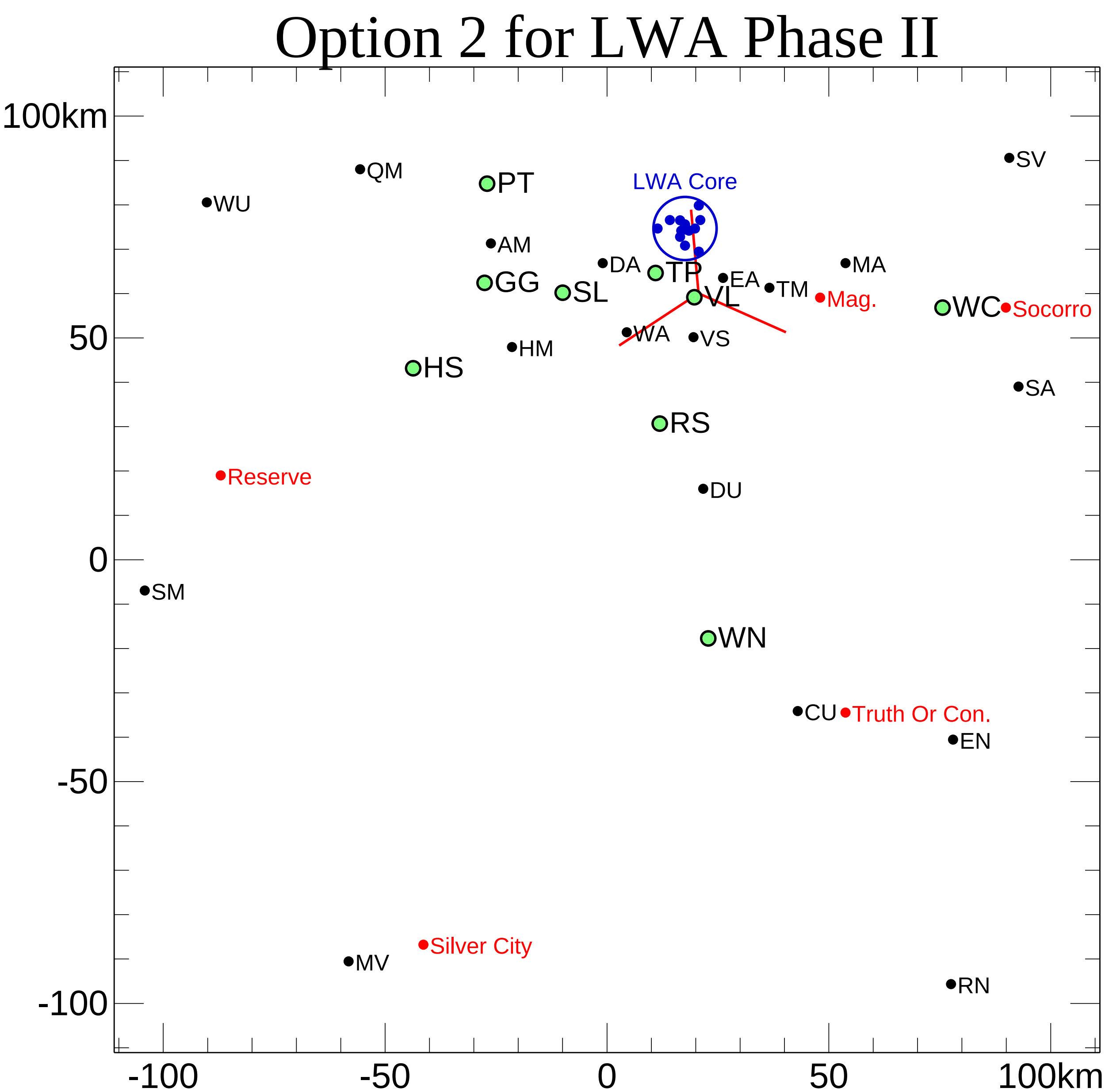

Fig. 7.— Station locations for "Option 2" for the LWA Phase II. The 9 stations locations chosen for Phase II are shown as the large green- filled circles, while the other stations are shown as the smaller black dots and the core is shown in blue.

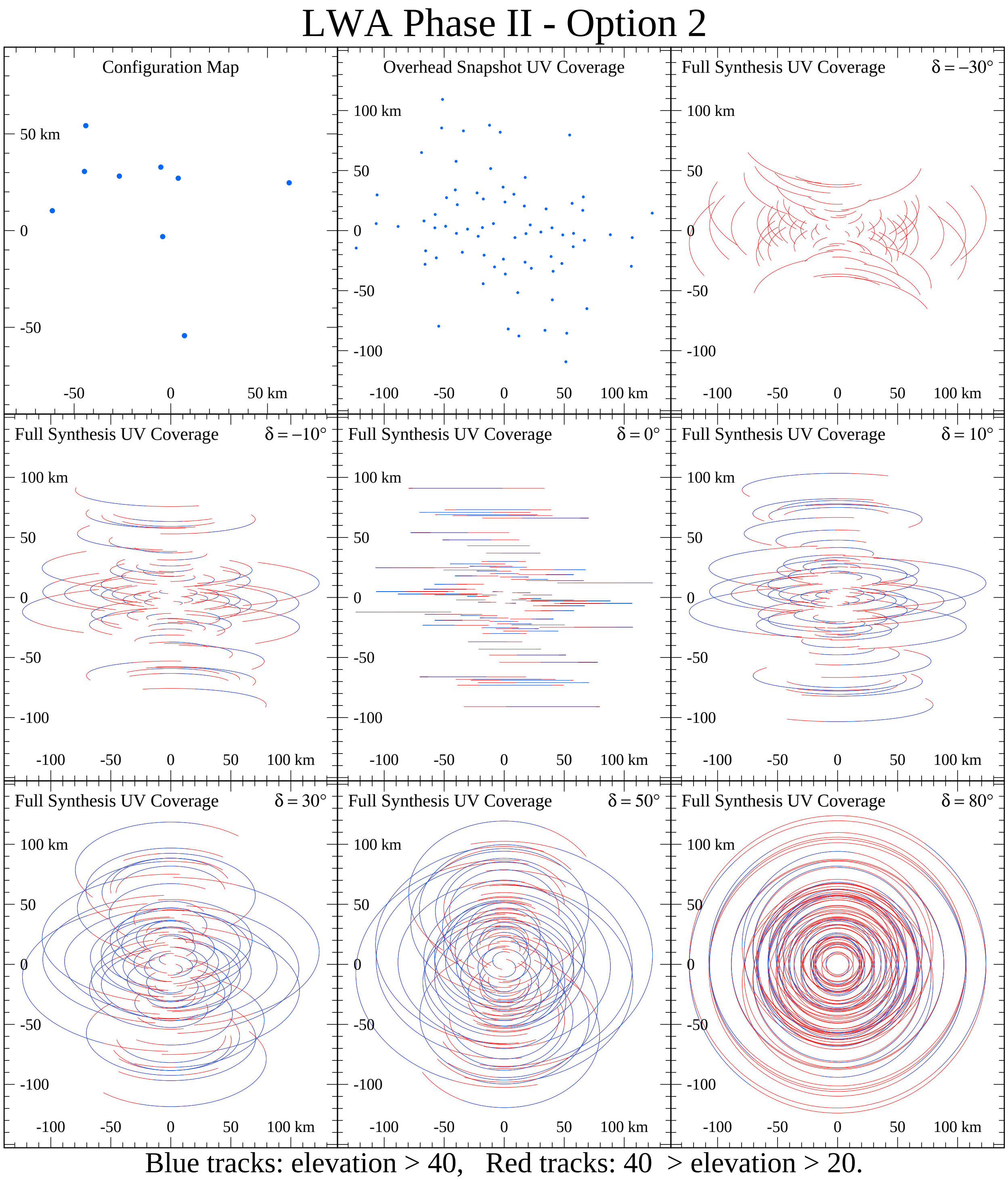

Fig. 8.— The *uv*-coverage for "Option 2" for the LWA Phase II.

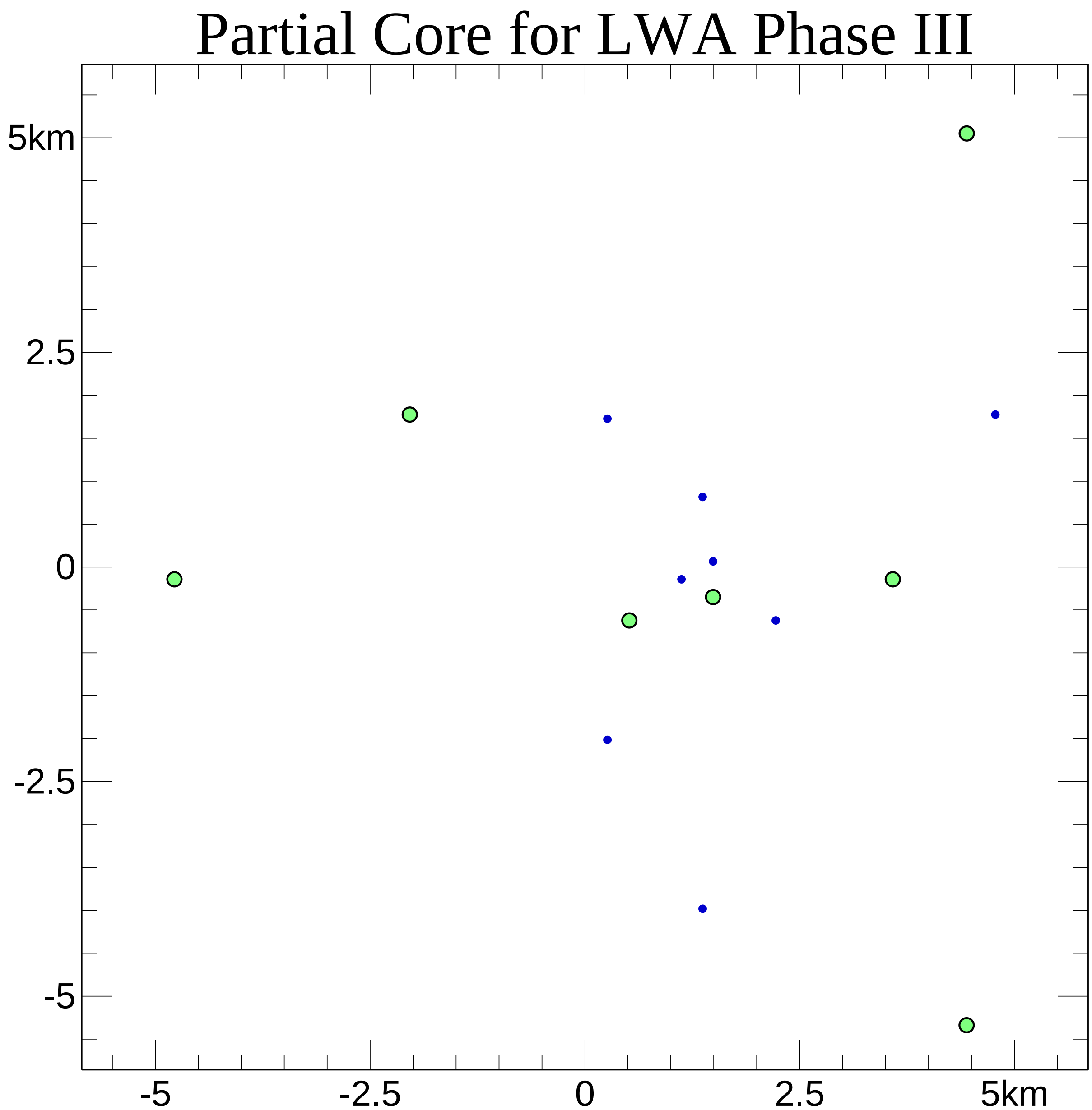

Fig. 9.— A possible set of 7 station locations in the core that may be used for the LWA Phase III. These 7 stations locations are shown as the large green- filled circles, while the other future stations locations are shown as the smaller blue dots.

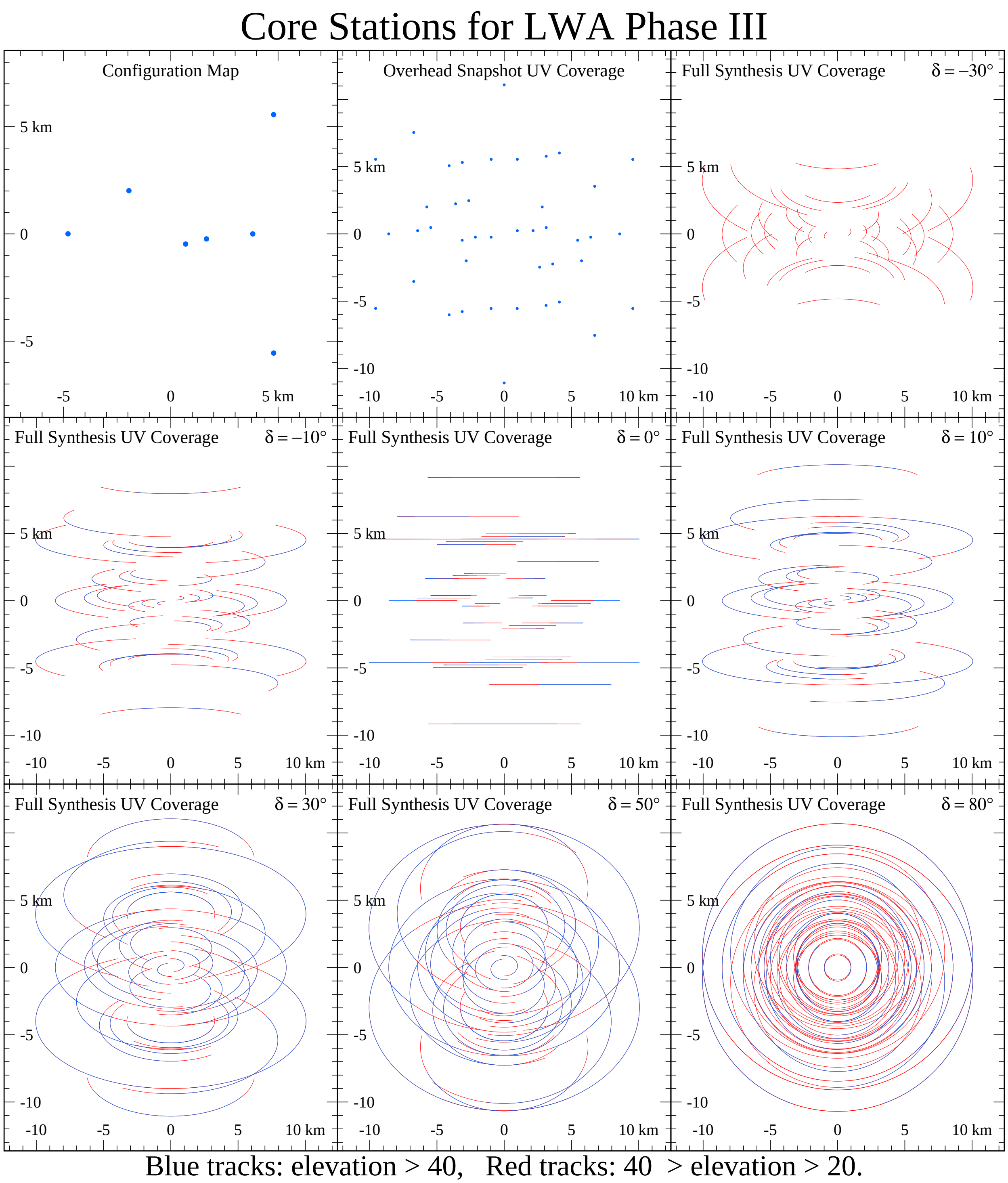

Fig. 10.— LWA Phase III core station uv-coverage. These 7 stations do not have the uv-covererage of the full core, yet give a reasonable sampling of the shorter baselines.

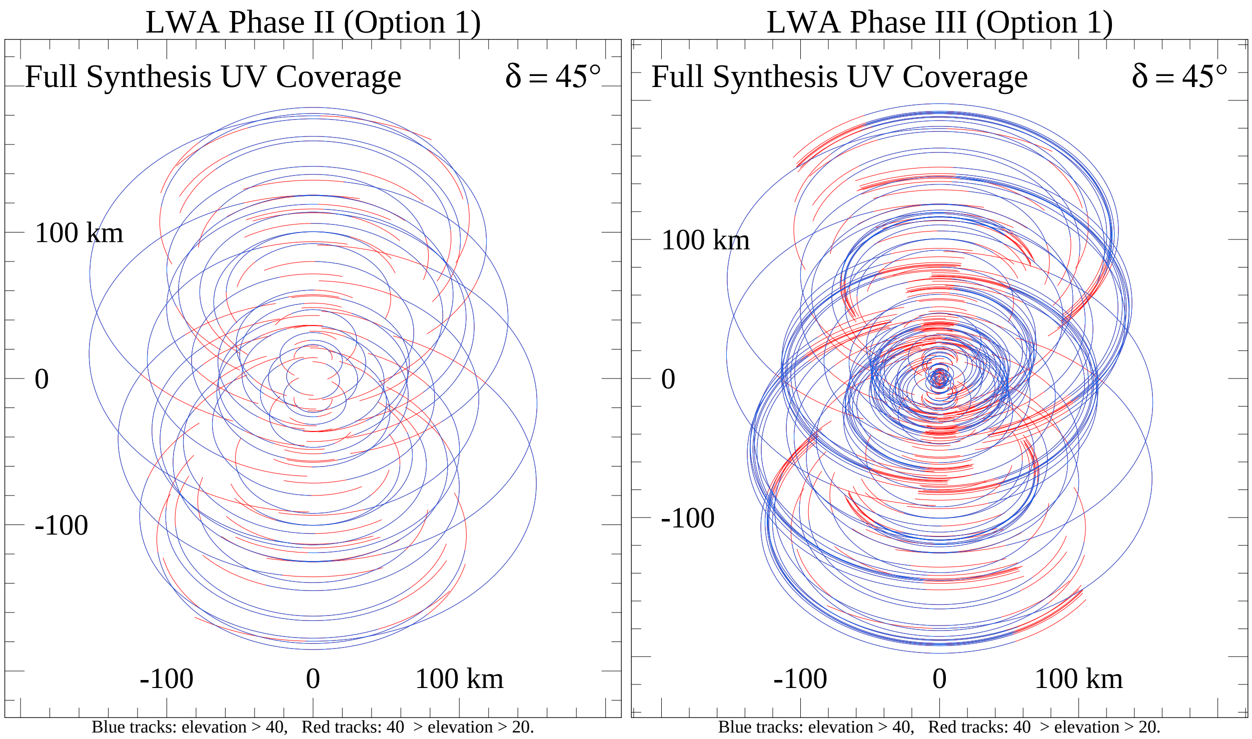

Fig. 11.— Comparison of the uv-coverage of the LWA Phases II and III for the "Option 1" design. The addition of 7 core stations fills in the short baselines and also adds to the intermediate baseline coverage.

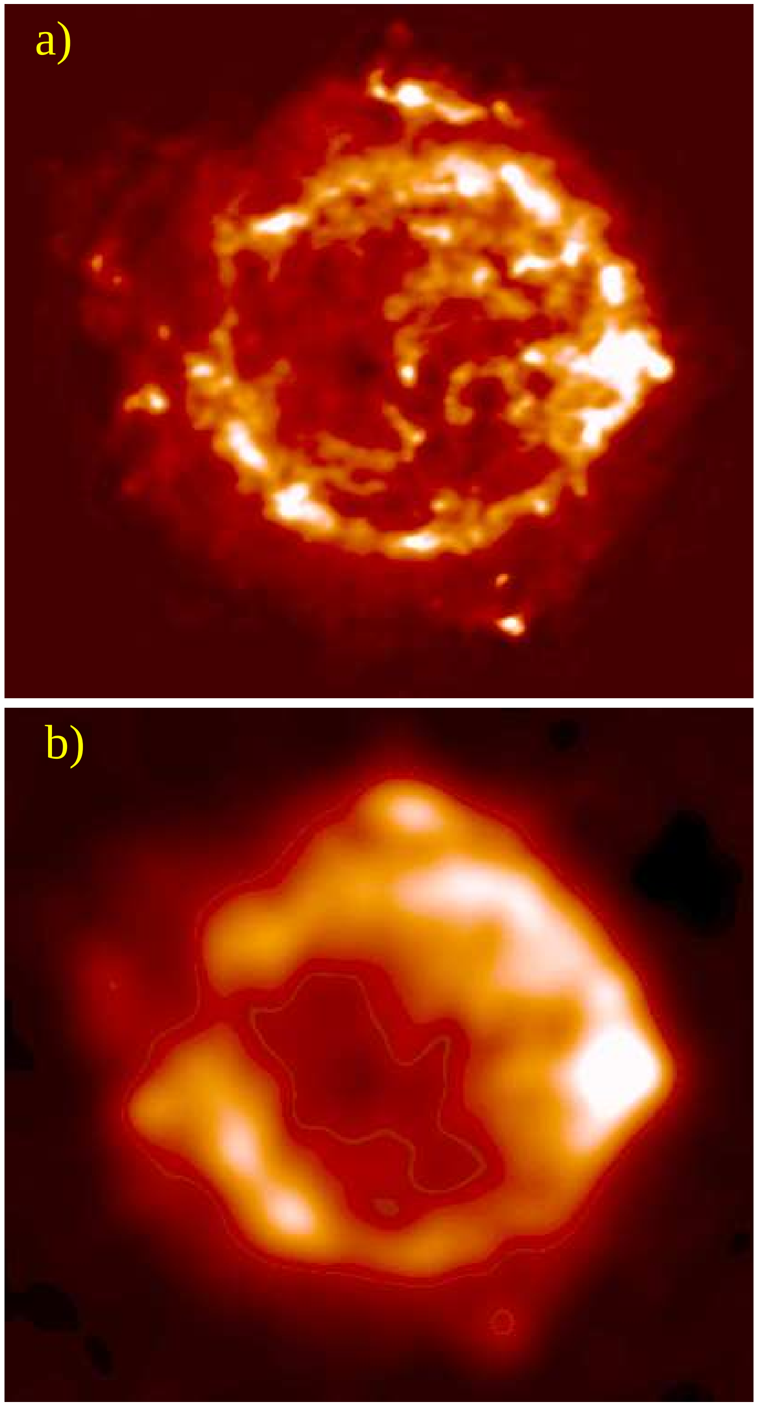

Fig. 12.— a) Simulated image of Cas A at 74 MHz using the LWA Phase III (with "Option 1" of Phase II) based on a high-resolution model at 1.4 GHz. b) Actual image of Cas A at 74 MHz using the VLA in A-configuration.

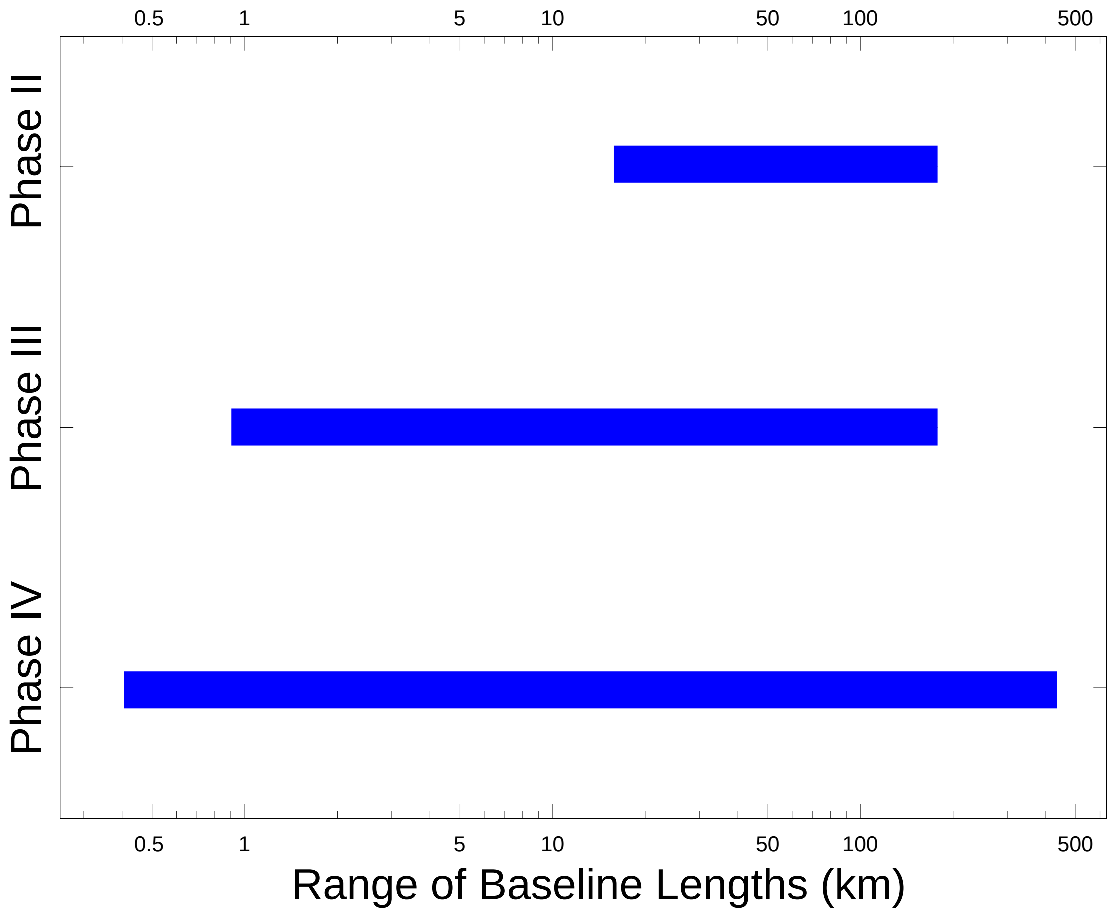

Fig. 13.— Range of baseline lengths for each of the LWA phases capable of independent imaging. Phase III greatly increases the number of short baselines. Phase IV improves by over a factor of 2 both the longest and shortest baseline, along with greatly improving the density of uv-coverage in the intermediate baselines, and of course nearly tripling the overall collecting area.