Configurations on Badger Flat

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This report summarizes a study of possible configurations for a 16-element star array on Badger Flat. The objective is to determine antenna locations which provide the best A-array beams and uv coverages within the topographic and Forest Service constraints on the site. It is assumed that the standard star array (see earlier memos) is being utilized for the D, C, and B configurations. The issues addressed here are:

(1) the placement of the center of the star on Badger Flats,

(2) the placement of outrigger antennas for the A-array, and

(3) the possible benefit of placing antennas on Peak.

Three scenarios are covered in this memo. First, a star configuration placed near the center of Badger Flat is presented. This is the easiest option to design but the center of the Badger Flat is reported by Mark Hodges to be poorly suited for the construction of the array center – a considerable amount of terrain flattening and road work would be required. Second, a scenario with the star configuration on a flat region to the southeast of the center is presented. The site was selected by Mark Hodges as being flat enough to allow easy construction of the central array. Third, A-array configurations with antennas near Mazourka Peak are considered.

Assumptions and Evaluation Criteria:

The following assumptions were made in placement for the star array and outrigger pads:

- It is desirable to locate pads along lines of equal elevation as much as possible.
- It is desirable to locate pads in areas without trees.
- The target maximum baselines are approximately 2 km.
- The A array observations can be complemented by the B array as needed so good coverage of the inner uv plane is not important.

The figures of merit for configurations were: (1) the peak sidelobe levels, (2) the near-in ($\leq$2.5" from the beam center) sidelobe level, (3) the *rms* level in the beam outside of a central 1.3" square area, and (4) the beam size. The objective was to minimize all four with a target resolution of 0.4" at ν=100 GHz. The antenna placement was done manually so the configurations are only roughly optimized.

In optimizing the arrays, I calculated *u,v* coverages for complete tracks on sources at declinations of -20 -5, 18, and 55 degrees. Complete tracks are defined as tracks covering from -5^h to +5^h hour angle, or as long as the source is above 17 degrees elevation. The peak sidelobe levels, near-in sidelobe levels, and beam *rms* were usually well correlated so they could be optimized simultaneously. The peak and near-in sidelobe levels were usually most sensitive to the detail of antenna placement.

The *u,v* coverage in ± 1.5 hours tracks (rather than ± 5 hour tracks) provided the determining criteria in scenario 3, in which antennas were placed on Mazourka Peak. The same figures of merit were used.

Scenario 1: A-Array with a Central Star Configuration

Figure 1 shows the star and pad layout for the central star configuration. Because the star is near the center of the usable "flat" area, the outriggers are roughly extensions of the arms of the star to the north, northwest, southwest and south. The areas to the east and southeast of the proposed pads are in the Forest Service wilderness area; the east-most antenna is right at that boundary, as is the antenna at the end of the eastern star-arm. There is 40-60 meters of height variation between the pads shown. The locations of the antennas are given in Table 1.

Figures 2 and 3 show the beams and *u,v* coverages for 10-hour and 3-hour tracks centered around transit. Each figure has a left column displaying the synthesized beam and a right column with the corresponding uv coverage. The four panels in each column correspond to four source declinations as noted in each panel.

The beams are generally clean for 10-hour tracks; the near-in sidelobes peak at the 5% to 10% level, depending on source declination. The *u,v* sampling is concentrated in the 80 to 400 kλ region. The north-south elongation of the array and the limited ground available for east-west baselines makes the beam significantly elongated east-west for high declination sources and result in the diagonal elongation for southern sources. The levels of the near-in sidelobes increase dramatically in 3-hour tracks for source declinations from -5 to + 20 degrees.

Table 2 reports the beam sizes, sidelobe levels and *rms* level for each of the beams presented. The beam size is the Gaussian fitted FWHM. The sidelobe levels are in percentages of the main beam with the first number corresponding to the largest negative sidelobe and the second the largest positive sidelobe.

Compared to the previous study of Upper Harkless Flat, the beam sizes in Table 2 are about 15% smaller in the current configuration; the peak beam sidelobe levels are nearly the same.

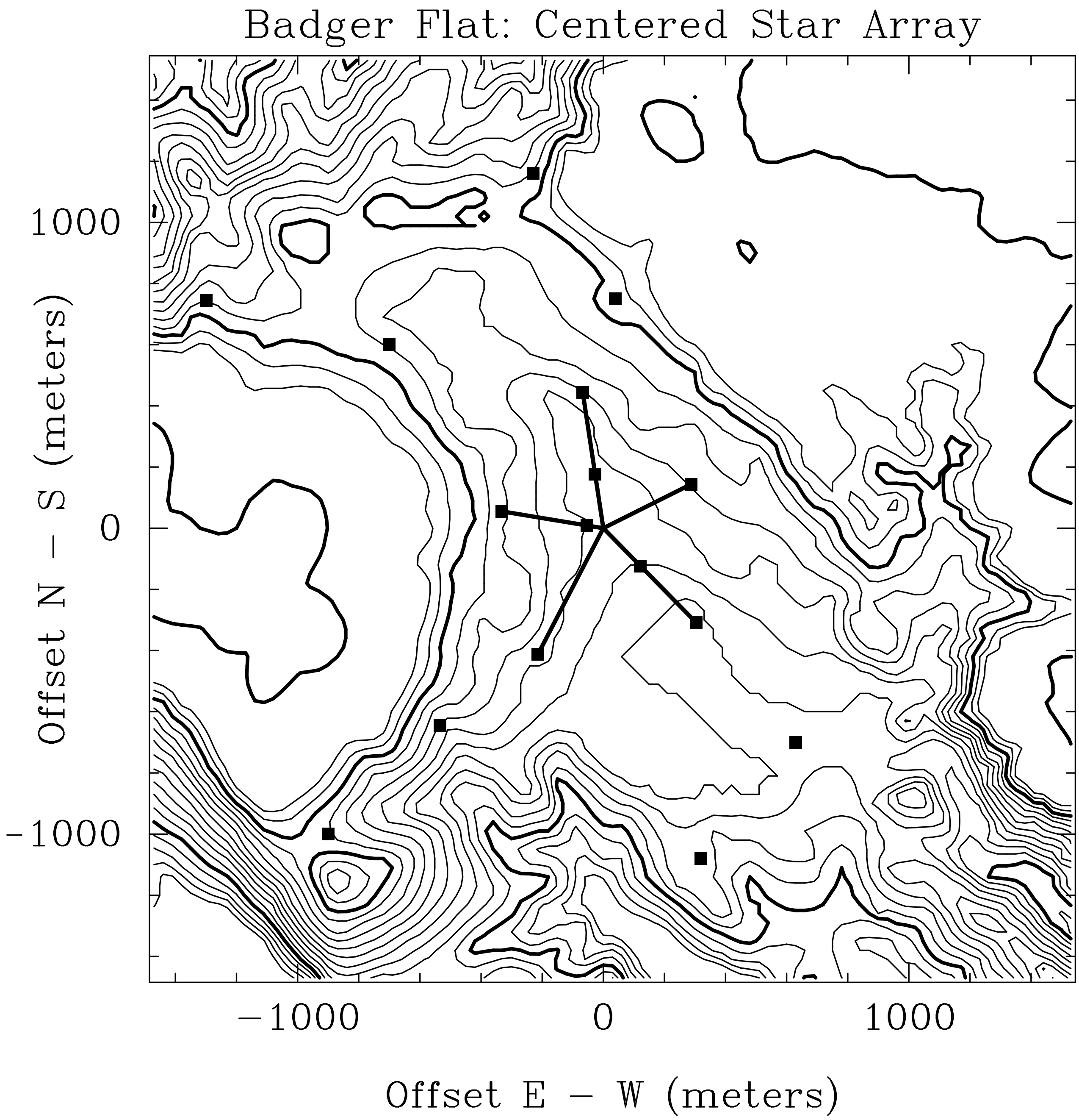

Fig. 1.— Antenna locations for Centered Star Configuration overlaid on a contour plot of elevation. The thin contours run from 2560 to 2690 meters in steps of 10 meters. The thick contours are at levels of 2600 and 2700 meters. The center of the star is at an elevation of approximately 2660 meters. The filled squares mark the locations of antennas. The stick-figure star represents the star layout for the D, C, and B configurations.

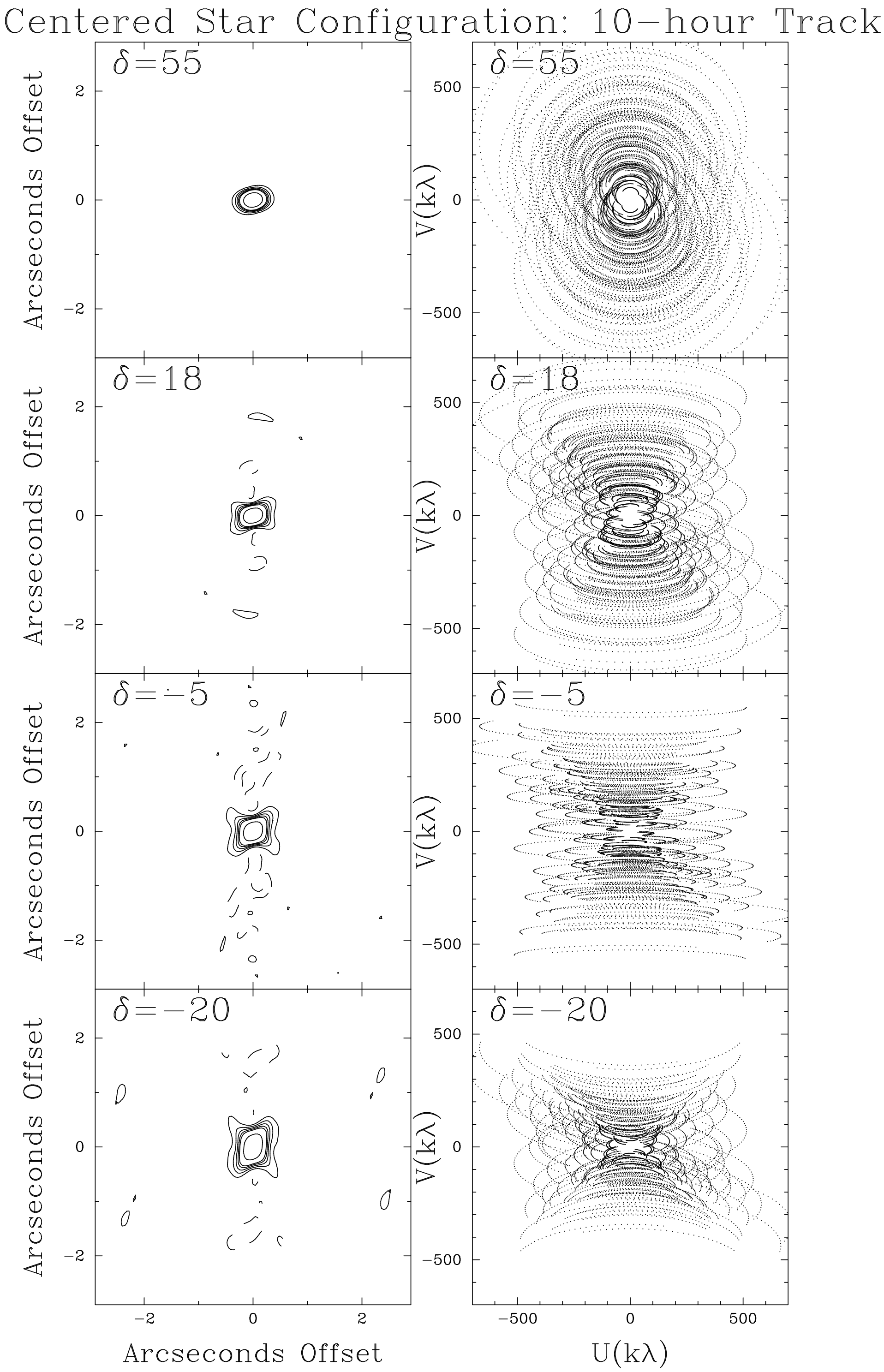

Fig. 2.— Plots of the beams and uv coverages for the centered star configuration for a track covering ±5 hours from transit. The contour levels in the beam panels are -20, -15, -10, -5, 5, 10, 15, 20, 30, and 50 percent of the peak. The source declinations for each panel is given in the upper-left corner.

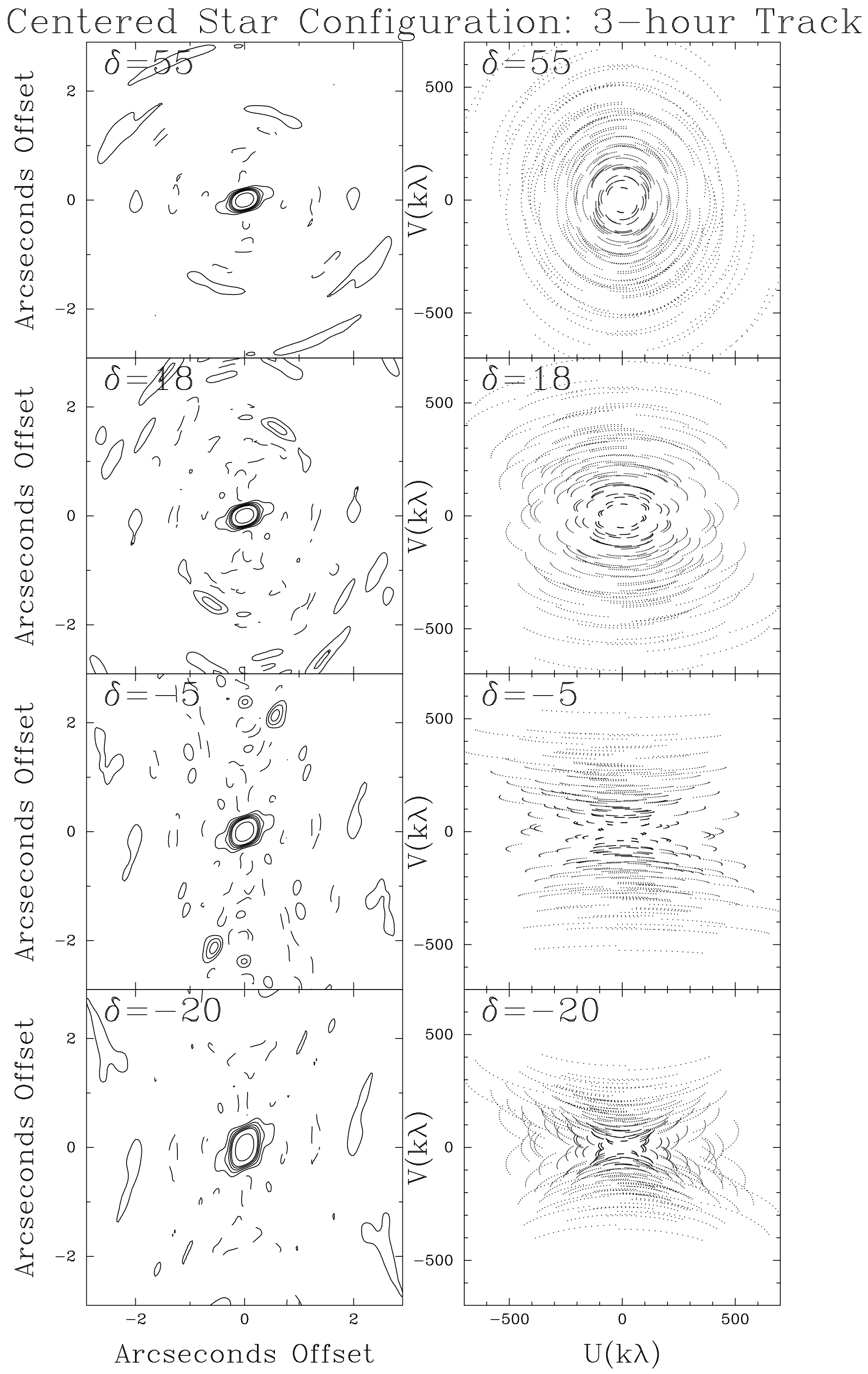

Fig. 3.— Plots of the beams and uv coverages for the centered star configuration for a track covering ±1.5 hours from transit. The contour levels in the beam panels are -20, -15, -10, -5, 5, 10, 15, 20, 30, and 50 percent of the peak. The source declinations for each panel is given in the upper-left corner.

East (meters)	North (meters)	Designation
-26.8	177.5	N5
-67.1	443.8	N7
286.7	143.6	E7
121.6	-123.3	SE5
303.9	-308.2	SE7
-213.8	-412.5	SW7
-53.1	8.8	W3
-332.1	55.0	W7
40.0	750.0	N8
-230.0	1160.0	N9
-700.0	600.0	NW1
-1300.0	745.0	NW2
-535.0	-645.0	SW1
-900.0	-1000.0	SW2
630.0	-700.0	SE1
320.0	-1080.0	SE2

Table 1: A-Array with Central Star

Scenario 2: A-array with the Star to the Southeast

Figure 4 shows the A-array configuration with the star center now located to the southeast: 242 meters east and 493 meters south of the previous star center. The star has been rotated by 180 degrees (the normal north arm now points south) to fit the star up against the Forest Service wilderness boundary to the east. The wilderness boundary actually has a notch which reaches in between the east and northeast arms. Many of the outrigger pads in this configuration are placed in positions similar to the previous configuration.

The key feature of this configuration is the displacement of several antennas to the northern part of the star, and off the star, in order to create an overall array which is more nearly centered on the center of the Flat. If this is NOT done, there are a large number of diagonal southeast to northwest baselines which degrade the beam. The pad locations are given in Table 3.

The beams and uv coverages are shown in Figures 5 and 6. Table 4 reports the main beam sizes, sidelobe levels, and *rms* levels for each of the beams. The beam are generally smaller; the sidelobes and *rms* values are a little larger than for the centered-star configuration. This difference could be lessened through more careful placement of the

Decl.	HA=± 5 hours			HA=± 1.5 hours		
	syn beam	sidelobes	rms	syn beam	sidelobes	rms
-20	0.53 x 0.36	-6,7	0.012	0.52 x 0.33	-6,10	0.017
-5	0.44 x 0.33	-6,11	0.012	0.41 x 0.30	-7,24	0.019
18	0.39 x 0.28	-6,7	0.010	0.37 x 0.24	-6,15	0.017
55	0.36 x 0.26	-5,5	0.009	0.37 x 0.24	-7,11	0.016

Table 2: A-Array with Central Star

antennas and perhaps taking another antenna off of the star. If one does not worry about the costs of extra pads (in the trade-off between extra construction costs of centering the star in the Flats or building extra off-star pads), this scenario could yield nearly identical beams to the Scenario 1.

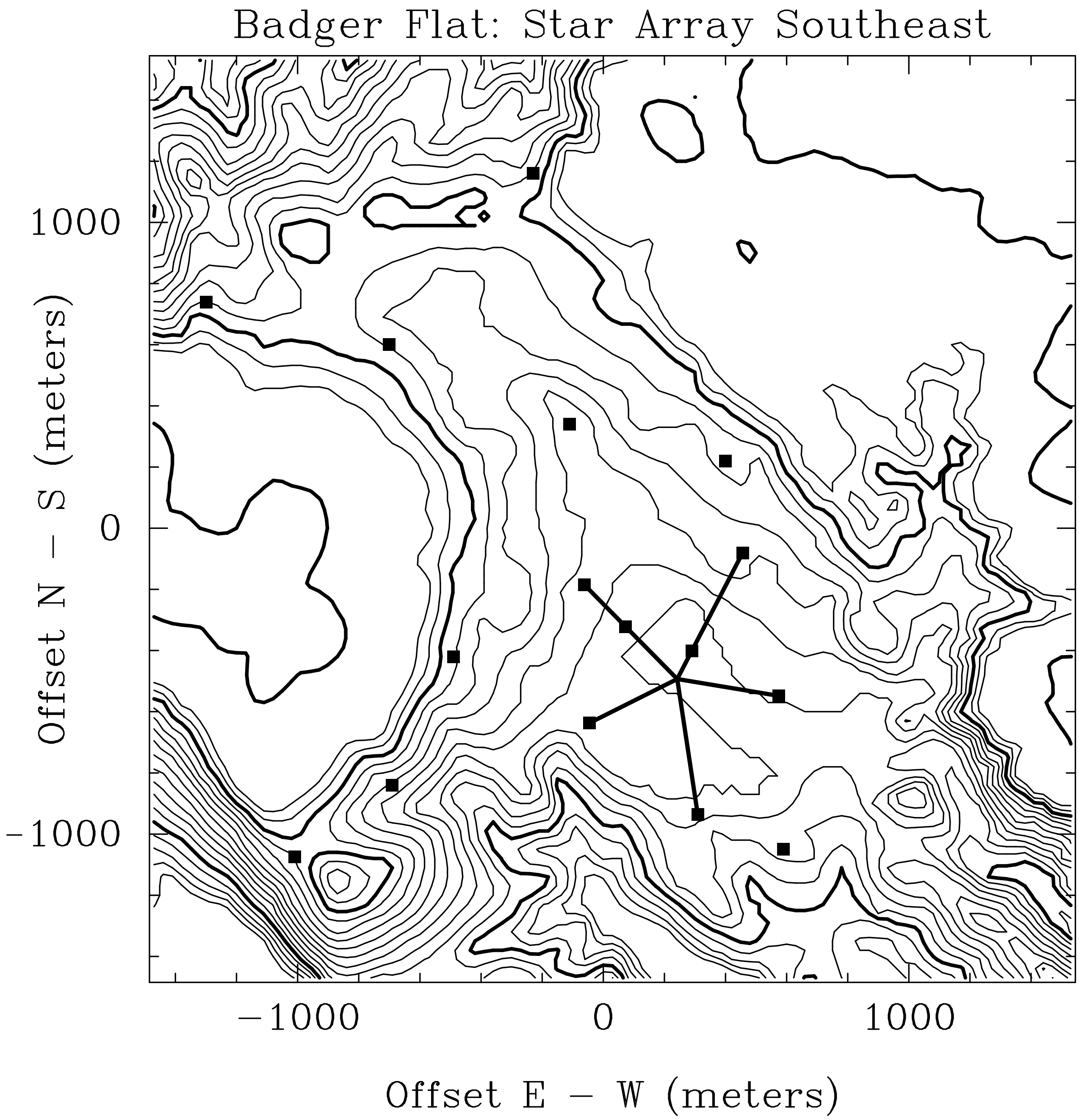

Fig. 4.— Antenna locations for Southeastern Star Configuration overlaid on a contour plot of site elevations. The thin contours run from 2560 to 2690 meters in steps of 10 meters. The thick contours are at levels of 2600 and 2700 meters. The center of the star is at an elevation of approximately 2660 meters. The filled squares mark the locations of antennas. The stick-figure star represents the primary star layout for the D, C, and B configurations.

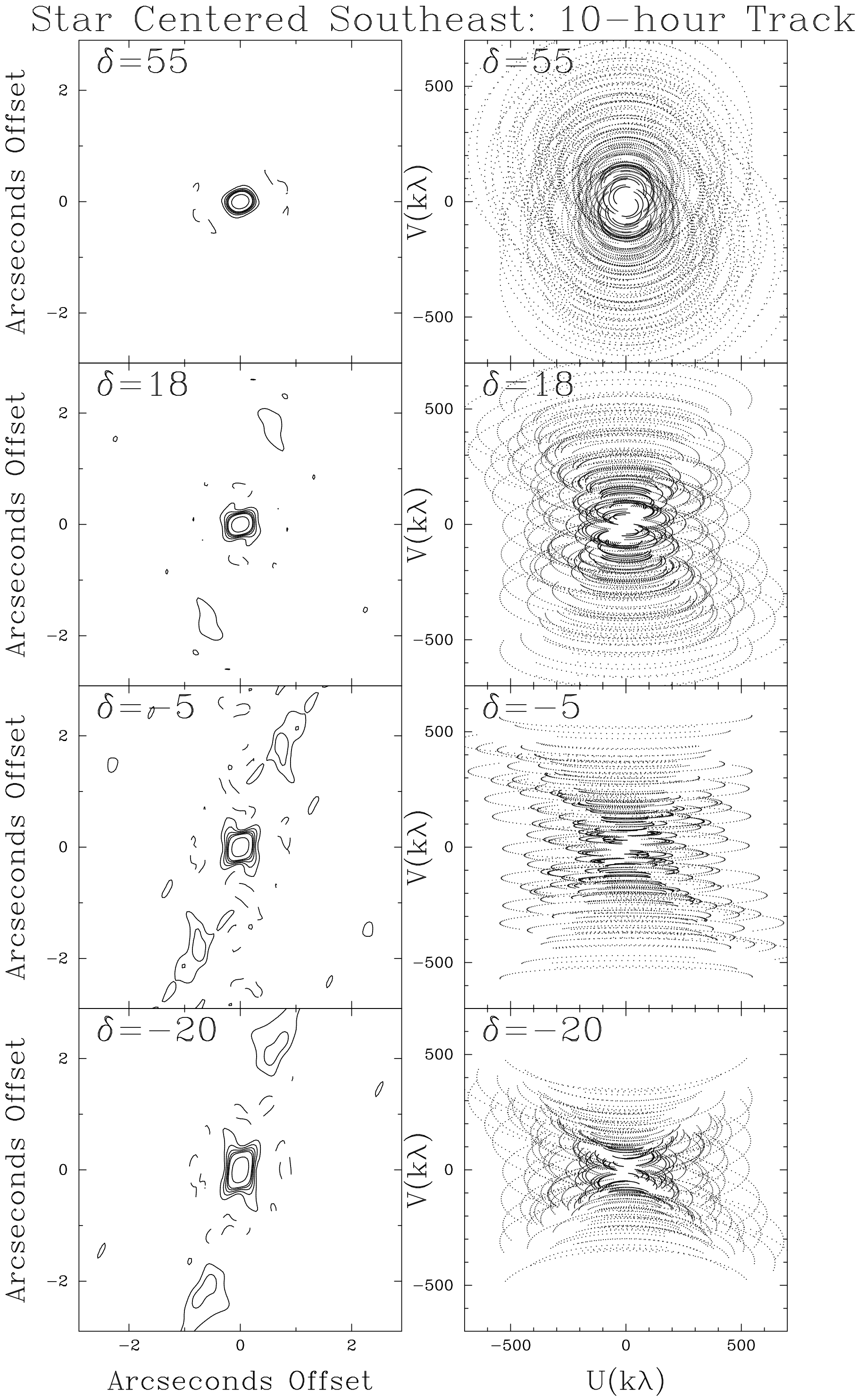

Fig. 5.— Plots of the beams and uv coverages for the southeastern star configuration for a track covering ±5 hours from transit. The contour levels in the beam panels are -20, -15, -10, -5, 5, 10, 15, 20, 30, and 50 percent of the peak. The source declinations for each panel is given in the upper-left corner.

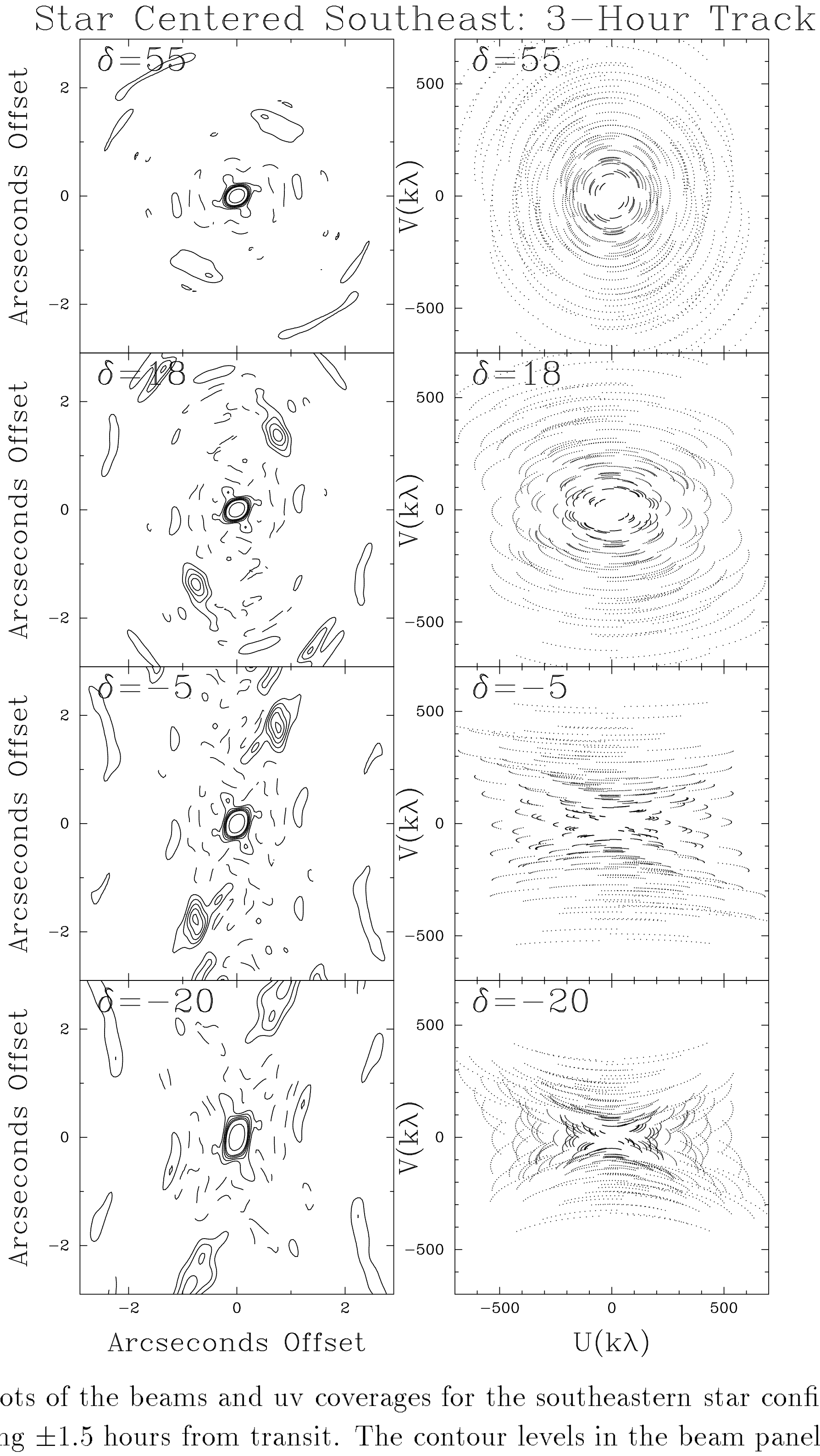

Fig. 6.— Plots of the beams and uv coverages for the southeastern star configuration for a track covering ±1.5 hours from transit. The contour levels in the beam panels are -20, -15, -10, -5, 5, 10, 15, 20, 30, and 50 percent of the peak. The source declinations for each panel is given in the upper-left corner.

East (meters)	North (meters)	Designation
309.0	-936.5	S7
573.9	-548.0	E7
289.5	-401.4	NE3
455.8	-80.5	NE7
-44.5	-636.4	SW7
73.3	-321.9	NW5
-61.7	-185.0	NW7
-490.0	-420.0	W8
-690.0	-840.0	SW8
-1010.0	-1075.0	SW9
400.0	220.0	NE9
-110.0	340.0	N8
-230.0	1160.0	N9
-700.0	600.0	NW8
-1300.0	740.0	NW9
590.0	-1050.0	S8

Table 3: A-Array with Star to the Southeast

A-Array with Mazourka Peak

In Scenarios 1 and 2, the beams for 3-hour tracks are significantly degraded relative to those for 10-hours tracks. Can these beams be improved? Examination of the u,v plots (Figures 3 and 6) reveals that a major weakness in both configurations is the scarcity of true east-west baselines. This scarcity is directly tied to the topology of Badger Flat. The placement of antennas on Mazourka Peak will provide additional long east-west baselines and improved instantaneous coverage in the u,v plane. The question is: how much can the coverage be improved if two antennas are placed on the peak? The following tables and figures present a first cut at an A-configuration.

Figure 7 shows the configuration with two antennas on the flat southern portion of Mazourka Peak. Table 5 lists the antenna position relative to the zero point near the center of Badger Flats. This is the same coordinate system as for scenarios 1 and 2 with the center of the star array located at (242m, -493m). The Mazourka Peak antennas increase the number of east-west baselines and increase the maximum east-west baselines to roughly 1.8 km. The maximum north-south baselines in the configuration shown are about 2.1 km. In order to move the centroid of the configuration closer to the geometric center of the outer stations, an additional antenna was moved off the star array relative to scenario 2. This is

Decl.	HA=± 5 hours			HA=± 1.5 hours		
	syn beam	sidelobes	rms	syn beam	sidelobes	rms
-20	0.51 x 0.31	-6,12	0.013	0.50 x 0.28	-7,17	0.017
-5	0.39 x 0.32	-7,14	0.012	0.37 x 0.27	-7,26	0.020
18	0.34 x 0.27	-6,9	0.010	0.32 x 0.24	-6,24	0.017
55	0.36 x 0.26	-5,5	0.009	0.31 x 0.23	-7,10	0.016

Table 4: A-Array with Star centered to the Southeast

a penalty for having the main star placed along the southeast boundary of Badger Flat: the array is sparcely populated to make the u,v coverage more uniform and symmetric, resulting in a cleaner synthesized beam.

East (meters)	North (meters)	Designation
309.0	-936.5	S7
-44.5	-636.4	SW7
-61.7	-185.0	NW7
289.5	-401.4	NE3
455.8	-80.5	NE7
573.9	-548.0	E7
-103.0	-384.0	W8
-376.0	-381.0	W9
-1191.0	-175.0	W10
-953.0	-346.0	W11
-509.0	-757.0	SW8
-941.0	-1045.0	SW9
383.0	225.0	NE8
-118.0	341.0	N8
-322.0	1022.0	N9
-855.0	633.0	NW8

Table 5: A-Array with Antennas in Peak

Figures 8 and 9 show u,v coverages and beams for the configuration in Figure 7. Table 6 lists the beam characteristics. We are successful at making modest improvements in the $\pm$1.5 hour peak sidelobe levels by including two antennas located on the Peak. The peak sidelobe levels have decreased for source declinations of -5 and 18 degrees (24% for star-centered and 26% for star-southeast versus 20% for the current configuration at δ=-5, 15% and 24% versus 11% for δ=18). Likewise, the peak near-in sidelobes have decreased for these declinations: 18% for star-centered and 26% for star-southeast versus 15% for the current configuration at δ=-5, 12% and 23% versus 9% for δ=18. The beam *rms* levels show a little improvement with the antennas on the peak.

The increased east-west coverage in this configuration makes the beams narrower east-west than in the previous scenarios. The resulting peak are overall narrower and more symmetric for northern sources (the beam is circular for source declination of 18 degrees).

The peak stations do NOT have a significant impact on the *u,v* coverages or beams for the ±5 hour tracks.

Decl.	HA=± 5 hours			HA=± 1.5 hours		
	syn beam	sidelobes	rms	syn beam	sidelobes	rms
-20	0.56 x 0.30	-6,7	0.012	0.56 x 0.27	-6,10	0.017
-5	0.42 x 0.32	-6,11	0.012	0.40 x 0.27	-7,20	0.019
18	0.33 x 0.32	-5,7	0.010	0.31 x 0.27	-6,11	0.017
55	0.31 x 0.28	-5,5	0.009	0.29 x 0.27	-7,9	0.016

Table 6: A-Array with Southeast Star and Pads on Peak

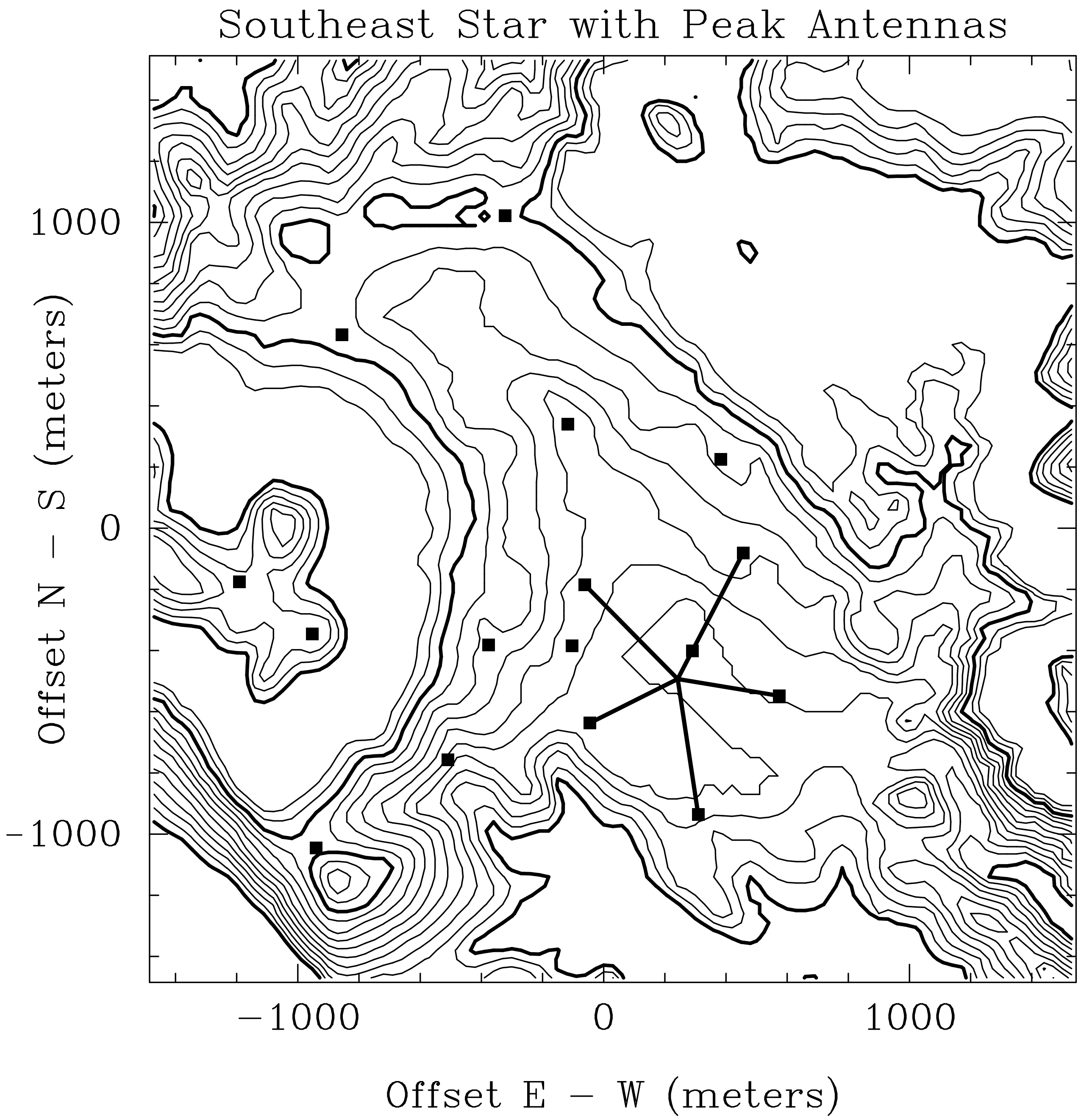

Fig. 7.— Antenna locations for Southeastern Star Configuration with antennas on Mazourka Peak overlaid on a contour plot of site elevations. The thin contours run from 2560 to 2690 meters in steps of 10 meters. The thick contours are at levels of 2600 and 2700 meters. The center of the star is at an elevation of approximately 2660 meters. The filled squares mark the locations of antennas. The stick-figure star represents the primary star layout for the D, C, and B configurations.

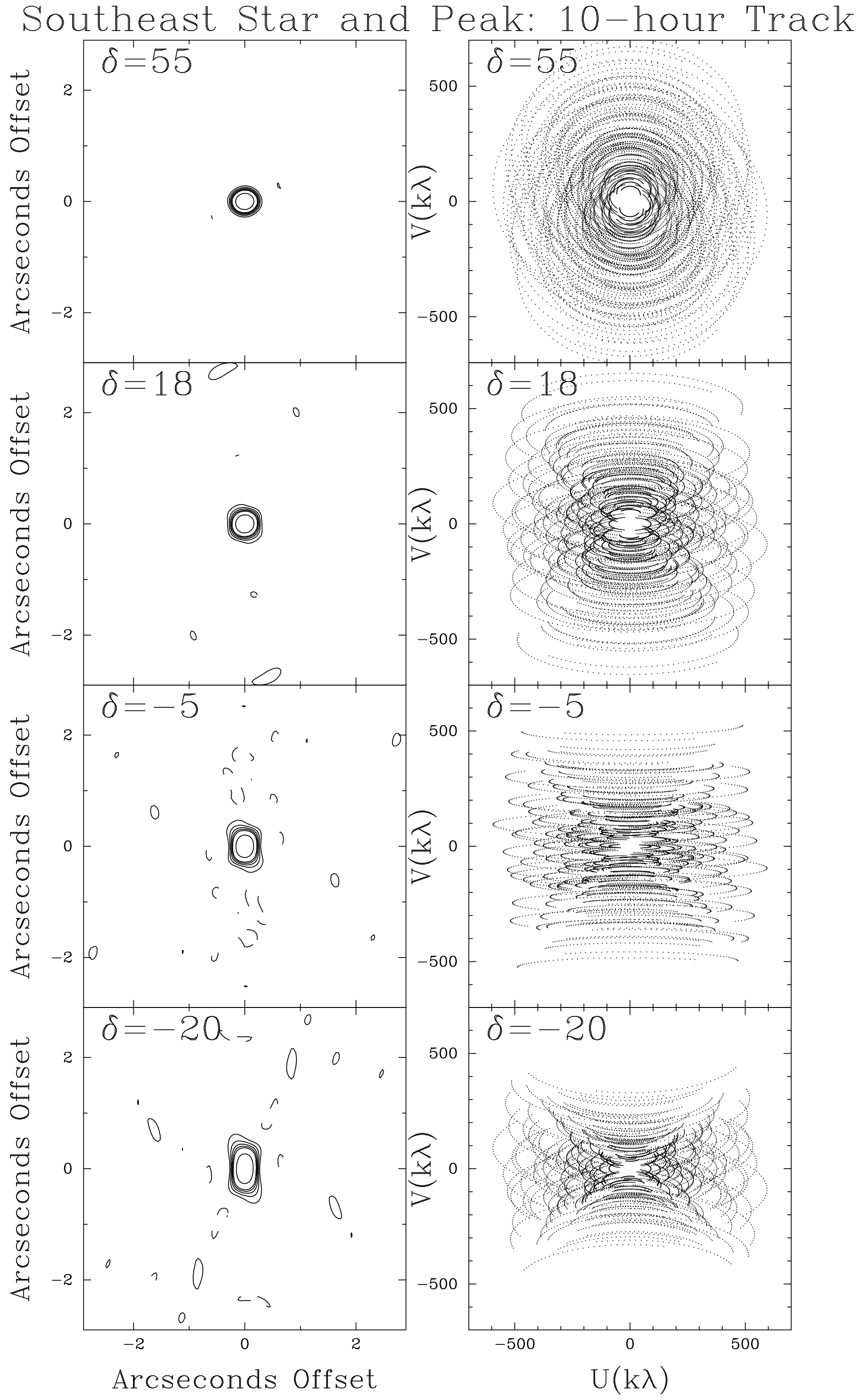

Fig. 8.— Plots of the beams and uv coverages for the southeastern star configuration with antennas on Mazourka Peak for a track covering ±5 hours from transit. The contour levels in the beam panels are -20, -15, -10, -5, 5, 10, 15, 20, 30, and 50 percent of the peak. The source declinations for each panel is given in the upper-left corner.

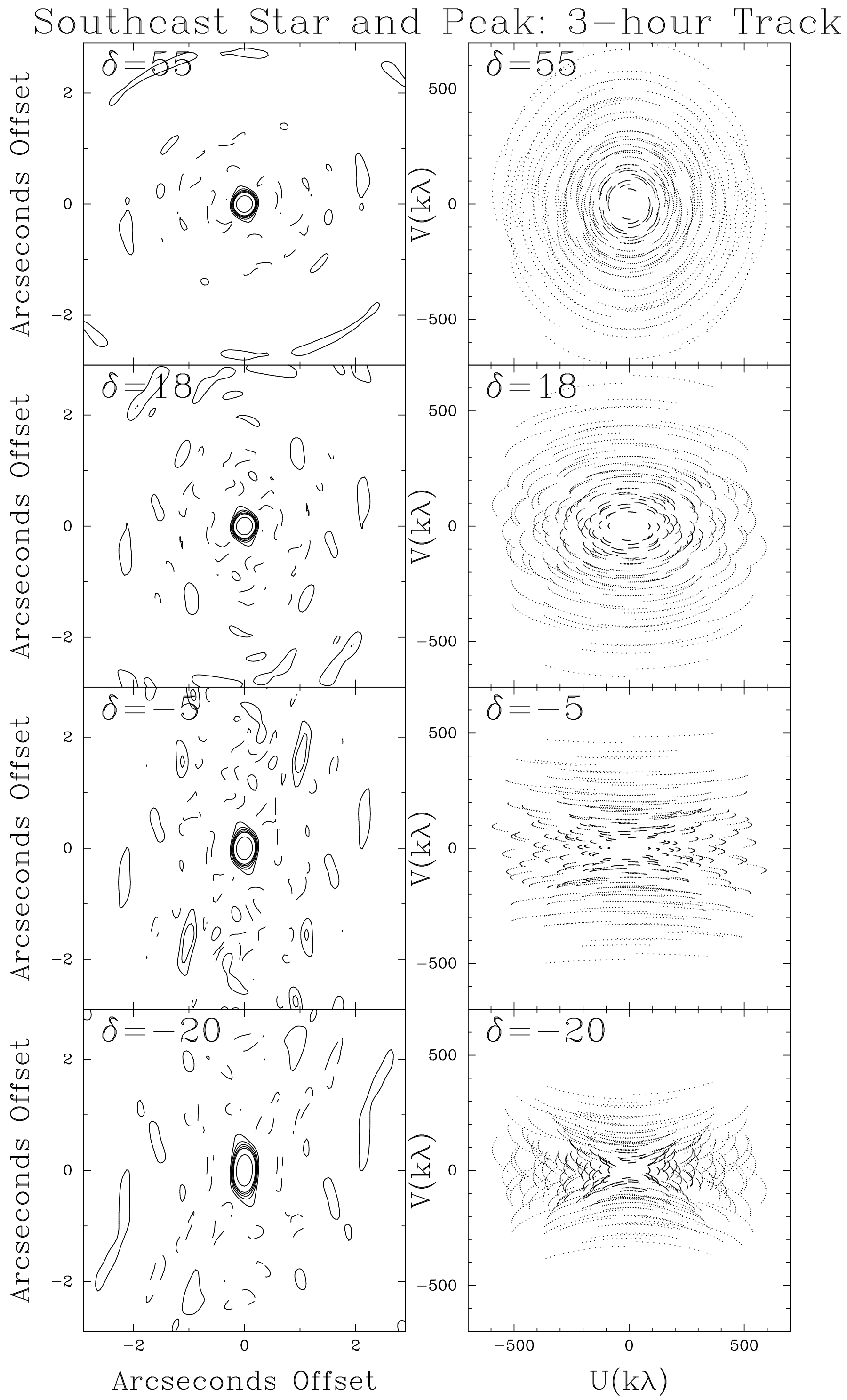

Fig. 9.— Plots of the beams and uv coverages for the southeastern star configuration with antennas on Mazourka Peak for a track covering ±1.5 hours from transit. The contour levels in the beam panels are -20, -15, -10, -5, 5, 10, 15, 20, 30, and 50 percent of the peak. The source declinations for each panel is given in the upper-left corner.

Summary and Recommendations

1. Badger Flats is capable of supporting A-array configurations with beam sizes comparable to or smaller than those constructed for Upper Harkless Flat. In the examples presented here the beams are ∼15% smaller due to the slightly longer baselines at Badger Flat. The sidelobe levels for the full tracks are nearly the same for Upper Harkless Flat and the central star configuration presented here.

2. Placement of the central star array near the center of Badger Flat results in the best *u,v* coverages and beams. It is also the simplest to design and optimize. Acceptable configurations can be designed with the star located in the southeast area of Badger Flat but the A-array antenna layout is more difficult. We have not completely optimized this scenario but it is clear that additional A-array pads "off-the-star" are need to compensate for the off-center placement of the star. The southeast star configuration presented here has significantly higher sidelobes for some declinations.

3. Reasonable A-arrays on Badger Flat require that a number of antennas be placed close to the wilderness boundary. In arrays with the star displaced to the southeast, the center of the star is very near the wilderness boundary. Addition of a buffer-zone along the wilderness boundary (if required by the Forest Service) will cut down the available east-west baseline and compromise further the instantaneous *u,v* coverage.

4. The placement of antennas on Mazourka Peak improves the instantaneous *u,v* coverage and the coverage in short tracks. Quantitatively, the peak sidelobe levels for sources at -5 degrees declination are reduced by 20-30%; the peak levels for sources at 18 degrees declination are reduced by 40 - 100%. Placing antennas on Mazourka Peak does NOT significantly improve the *u,v* coverages and beams for observations made with full tracks (±5 hours).

5. The configurations presented here have not undergone extensive optimization. A second round of optimization will be useful once we know more about the geo-political constraints and have thought more about the cost-benefit exchange regarding terrain. In particular,

(I) Can we realistically sprinkle many antennas along the wilderness boundary?,

(II) Is use of the peak realistic in cost and logistics?

(III) Is the southeast centered array necessary or significantly less costly?

(IV) Are all of the pad locations in the Flats presented here realistic in terms of cost and logistics?

It would be particularly useful to quantify crudely the cost of placing the star in the center of Badger Flat compared to the cost of 4 additional stations and ∼1 kilometer of extra roadway. After answering these questions, further field measurements are needed to determine precise pad locations in the neighborhood of the proposed positions. In general, moving a pad location by 5-10 meters does not have a significant effect on the beam; moving even 1 antenna by 50-100 meters can have a clear effect on the sidelobe levels for source with declinations around zero.

Important caveats:

A. The current calculations do NOT take into account the differing altitudes of the antennas. This should be done for the next level of optimization and could change some pad locations by 10's of meters.

B. Antenna placements presented here do NOT take into account visual impact. For example some may be visible from the valley or from distance away on the road.