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Extended ATA telescope with outrigger stations

Melvyn Wright, Rick Forster, Jack Welch, & Don Backer

Radio Astronomy laboratory, University of California, Berkeley, CA, 94720

ABSTRACT

The ATA 42 with outrigger antennas provides a unprecedented opportunity to develop essential technology for SSA and for SKA. The ATA 42 can image, and form multiple beams within a wide FOV; cross correlation with outrigger antennas produces a pencil beam over the full FOV of the 6m antennas.

Adding outrigger stations to the ATA provides some long baselines and higher angular resolution. With only a few long baselines, the high resolution data has low weight resulting in a composite synthesized beam of high resolution sitting on top of a lower resolution plateau from the ATA-42 station beam.

A high resolution beam without the low resolution plateau can be obtained by downweighting the ATA-42 stations using uniform weighting at the cost of reduced sensitivity. Good HA coverage is required to obtain these beams. With only 2 HA coverage the synthesized beams have higher sidelobes, and confusion in complex fields of view. The fitted beam size, flux and brightness sensitivity, and sidelobe levels are tabulated.

For position determination of high brightness targets, the synthesized beam sidelobe levels are less important. To realize the full potential as a Phased Array Passive Radar Tracking System some key technical developments need to be completed.

1. INTRODUCTION

The current ATA-42 antenna array has a maximum antenna separation of 323 m giving an angular resolution $\sim 220 \times 110''$ at 1430 MHz with equal (natural) weighting of the uv data. The angular resolution can be enhanced by uniform weighting the uv data giving an angular resolution $\sim 130 \times 80''$ at the cost of reduced sensitivity.

Adding existing BIMA-A stations to the ATA-42 provides a maximum antenna separation of 1872 m giving much higher angular resolution. With only a few long baselines, the high resolution data has low overall weight resulting in a composite synthesized beam with a high resolution sitting on top of a lower resolution plateau from the ATA-42 station beam.

The greatly enhaced angular resolution is attractive for locating high brightness targets and subtracting strong compact sources to reduce confusion in complex fields of view. In this memo we analyze the beam size, flux and brightness sensitivity, and sidelobe levels.

2. Results

ATA observations were simulated with the MIRIAD using a standard imaging scripts

(**$MIR/demo/ata/mfs.csh)** which generates uv data for an antenna configuration and images a point source. The beam size, flux and brightness sensitivity, and sidelobe levels are tabulated. Figure 1 shows the ATA 42 antenna array configuration.

Seven stations from the BIMA A-configuration were added to the ATA-42 antenna array. The antenna positions and station names are listed in Table 1, below. Figure 2 shows the ATA 42 antenna array configuration + 7 BIMA A-configuration stations.

With only a few long baselines, the high resolution data has low weight resulting in a composite synthesized beam of high resolution sitting on top of a lower resolution plateau from the ATA-42 station beam.

A high resolution beam without the low resolution plateau can be obtained by down-weighting the ATA-42 stations using uniform weighting of the uv data, at the cost of reduced sensitivity.

Good HA coverage is required to obtain these beams. With only 2 HA coverage the synthesized beams have higher sidelobes, which will result in confusion in complex fields of view.

The results are tabulated in Table 2 below for natural, robust and uniform weighting of the uv data.

For position determination of high brightness targets, the synthesized beam sidelobe levels are less important.

TABLE 1.

```
# Miriad style antennas file
# Note: file must contain x y z followed by antenna name.
# NOTE: x y z are N, E and Ht in meters (rotated 1deg - refant 4L)
# first baseline soln with fx8x8 08aug07 data
# Bima A-array stns in ATA coord system (relative to M) - jrf 26may09
#
#     N           E          H     stn    ant   date   ref
   -74.7322    65.9487    0.5470   1a      1   103008/1gx
   -91.5262   100.1497    0.3190   1b      2   103008/1gx
  -155.3822    92.5007    2.1540   1c      3   103008/1gx
  -151.5852    68.8337    0.5400   1d      4   103008/1gx
  -140.7712    54.5077    0.2180   1e      5   103008/1gx
  -141.7412    25.1097    0.5300   1f      6   103008/1gy
  -121.3972    24.5387    0.3880   1g      7   072608/2bx
  -106.4032    -0.3663    0.5060   1h      8   102708/1gx
   -61.6332   -10.7393    0.5820   1j      9   103008/1gx
   -74.5942    41.6047    0.5040   1k     10   041109/2ax
     4.9998    92.3617    0.5220   2a     11   103008/1gx
    -5.4882   115.2937    0.5140   2b     12   103008/1gx
   -33.0312   110.7317    0.4010   2c     13   103008/1gx
   -54.3992   150.1317    0.4420   2d     14   103008/1gy
   -51.6112   167.4497    0.4280   2e     15   103008/1gx
   -37.8892    24.0867    0.4060   2f     16   041109/2ax
   -39.8012    -4.9783    0.4870   2g     17   103008/1gx
   -27.5362     2.3737    0.4190   2h     18   103008/1gx
   -12.5082    14.5057    0.4750   2j     19   041109/2ax
    -6.7622    24.0937    0.5290   2k     20   103008/1gx
    -6.1312    49.0357    0.4100   2l     21   103008/1gx
    -7.8652    80.6387    0.2470   2m     22   103008/1gy
    37.4718   164.8887    0.3300   3c     23   103008/1gx
    59.8968   118.5897    0.2910   3d     24   103008/1gx
    48.8948    92.0717    0.2350   3e     25   012109/2ax
    36.6258    76.2487    0.3430   3f     26   103008/1gy
    34.1948    66.7167    0.3470   3g     27   103008/1gx
    43.6418    69.4807    1.1180   3h     28   103008/1gx
    81.9548   124.0407    0.2570   3j     29   041109/2ax
   101.7978    95.1997    0.1540   3l     30   041109/2ax
    66.8678   191.1037    0.3120   4e     31   080508/2by
```

85.9978	145.2877	0.2240	4f	32	011709/2ay
105.5658	117.5337	0.2210	4g	33	103008/1gx
108.7028	104.3997	0.1750	4h	34	103008/1gy
128.8198	146.0937	0.3160	4j	35	103008/1gx
102.8358	158.8117	0.1570	4k	36	041109/2ax
102.6038	169.6517	0.0040	4l	37	103008/1gx
94.0628	246.1947	0.3060	5b	38	102708/1gx
76.9358	252.5867	0.3320	5c	39	103008/1gy
68.6718	263.2077	0.5060	5e	40	103008/1gy
63.2778	236.3717	0.3350	5g	41	012109/2ax
76.3388	239.1747	0.3150	5h	42	012109/2ax
-68.5882	-17.3662	0.0000	740W		
-94.4728	664.9709	0.0000	1500E		
461.2059	303.2300	0.0000	1740N		
-148.8638	886.2124	0.0000	2220E		
755.4718	138.2629	0.0000	2700N		
927.9476	137.9554	0.0000	3270N		
942.6535	-634.2028	0.0000	4320N		
# N	E	H	stn	ant	date ref

TABLE 2.

```
  ---  ATA Single Field MFS Imaging    ---
 config    =  ata-42+
 dec       =  30
 harange   =  -1,1,.1  hours
 nchan     =  1
 select    =  -shadow(6.1)
 freq      =  1.42
 imsize    =  256
 systemp   =  40
 jyperk    =  150
 bandwidth =  100 MHz
```

Config	DEC	HA	Rms	Beam	Tb_rms	Sidelobe[%]			uvrange		weighting
	deg.	hrs.	[mJy]	[arcsec]	[mK]	Rms,Max,Min			[m]		
ata-42	30	-1,1,.1	0.12	220 x 110	3.0	1.0	8.7	-5.5	9.6	323	sup=0
ata-42	30	-1,1,.1	0.13	191 x 94	4.4	0.7	7.7	-12.5	9.6	323	robust=0.5
ata-42	30	-1,1,.1	0.16	168 x 79	7.2	0.8	10.4	-22.0	9.6	323	uniform
ata-42	30	-4,4,.1	0.06	213 x 124	1.4	0.5	4.5	-5.4	6.6	323	sup=0
ata-42	30	-4,4,.1	0.06	175 x 102	2.0	0.4	3.4	-12.3	6.6	323	robust=0.5
ata-42	30	-4,4,.1	0.10	131 x 80	5.7	0.5	10.0	-24.5	6.6	323	uniform
ata-42+	30	-1,1,.1	0.10	92 x 71	9.2	1.6	20.4	-10.6	9.6	1872	sup=0
ata-42+	30	-1,1,.1	0.11	65 x 52	19.4	1.6	33.9	-17.3	9.6	1872	robust=0.5
ata-42+	30	-1,1,.1	0.26	32 x 20	241.4	2.4	67.0	-42.1	9.6	1872	uniform
ata-42+	30	-4,4,.1	0.05	91 x 75	4.4	1.0	22.5	-5.8	6.6	1872	sup=0
ata-42+	30	-4,4,.1	0.06	65 x 55	10.0	1.1	34.4	-11.8	6.6	1872	robust=0.5
ata-42+	30	-4,4,.1	0.15	30 x 18	158.2	0.9	12.4	-19.2	6.6	1872	uniform

3. Discussion

Figure 3 shows the uv coverage for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -1,1 hours. Large gaps in the uv coverage result in high sidelobes in the synthesized beam.

Figure 4 shows the synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -1,1 hours and robust weighting of the uv data. The synthesized beam shows the high resolution beam resulting from the long baselines to the outrigger stations, sitting on the lower resolution beam from the ATA 42 antenna array. With limited HA coverage, the high sidelobe level results in a complex synthesized beam pattern with several peaks.

Figure 5 shows the synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -1,1 hours and uniform weighting of the uv data. Uniform weighting of the uvdata down weights the ATA 42-antenna data, and attenuates the lower resolution beam from the ATA 42 antenna array. With limited HA coverage, the high sidelobe level still results in a complex synthesized beam pattern with several peaks.

Extending the observations over 8 hours fills in much more of the uv plane and reduces the sidelobe level. Figure 6 shows the uv coverage for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -4,4 hours.

Figure 7 shows the synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -4,4 hours and robust weighting of the uv data. The synthesized beam shows the high resolution beam resulting from the long baselines to the outrigger stations, sitting on the lower resolution beam from the ATA 42 antenna array. With good HA coverage, the sidelobe level is reduced and the synthesized beam pattern has a single well defined peak.

Figure 8 shows the synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -4,4 hours and uniform weighting of the uv data. Uniform weighting of the uvdata down weights the ATA 42-antenna data, and attenuates the lower resolution beam from the ATA 42 antenna array, leaving a high resolution beam with $\sim$ 12% sidelobes.

3.1. Station beamforming

The ATA-42 antenna data could be combined in a beamformer and the data from the resulting station beam cross correlated with the seven outrigger antennas. This is similar to the SKA station beam approach for arrays with large numbers of antennas, and has the advantage of greatly reducing the number of cross correlations and the data rate from the correlator.

Cross correlating a phased array station beam (ATA-42, SKA stations etc) with individual antennas on longer baselines provides an anti-aliasing feature by attenuating signals outside the phased array voltage pattern. There is still confusion from the phased array beam sidelobes, of course, but with on-line control of the weighting in the phased array, or with full fast dump correlation, there are lots of things we can do to suppress, and deconvolve unwanted aliased responses to reduce confusion. We can develop these techniques on the ATA telescope.

There are several advantages if all the cross correlations of individual antennas can be preserved. (i) The field of view is then the full primary beam of the individual antennas. (ii) The primary beam of the individual antennas is well defined, whereas the primary beam for the station beam depends on the direction of the source, and the weighting of the antennas contributing to the station beam. (iii) The uv coverage with all cross correlations is much better. Each of the outrigger antennas paints a broad swath across the uv plance with the diameter of the ATA-42 antenna configuration.

3.2. Phased Array Passive Radar Tracking System

The ATA 42 with outrigger antennas provides a unprecedented opportunity to develop essential technology for SSA and for SKA. The ATA 42 can image, and form multiple beams within a wide FOV; cross correlation with outrigger antennas produces a pencil beam over the full FOV of the 6m antennas.

1. Outrigger antennas on the ATA-42 provide antenna separations up to 1800 m and much higher resolution for tracking satellites.

2. The beamformer can have multiple phased array targets at multiple frequencies.

3. A fast dump correlator with multiple phase centers provides much better uvcoverage and hence reduction of confusion in a cluttered FOV – better for SKA imaging and for SSA.

4. Passive radar, using some antennas pointing on the target sources and some pointed at powerful satellites to provide reference phase screens for the ATA-42 phased array.

5. The phased ATA-42 array voltage pattern can be weighted to produce nulls. Cross correlation with the outrigger antennas preserves these nulls.

Some key technical developments needed, and partially in place :

- 10 GbE digital output from phased array.
- station beamforming by feeding the digital output from phased array into the correlator.
- long delays and fast fringe rate tracking for low orbit targets.
- cross correlation at multiple phase centers.
- real time DSP and imaging.
- system integration.

3.3. Software correlation

With access to digital voltage data in software, at appropriately narrow bandwidth, one can likely see all GPS signals simultaneously albeit with confused phasing in sidelobes that one would need to learn about before any use could be made of such a sensor. We are doing hemispheric imaging with the Epoch of Re-ionization telescope (PAPER), but there we have simple hemispheric, single-lobe beam pattern. We can see the entire ORBCOM constellation of satellites at 137 MHz.

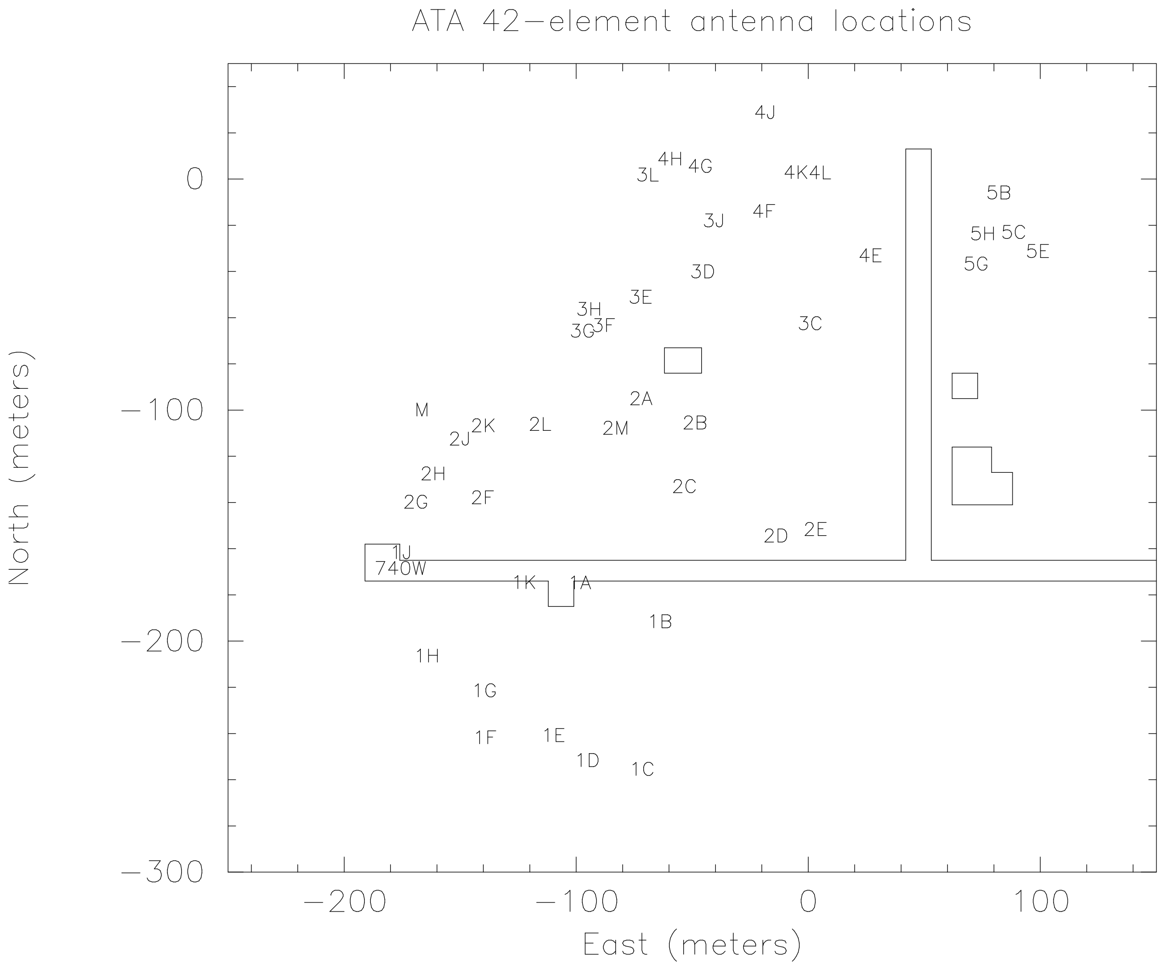

Fig. 1.— ATA 42 antenna array configuration.

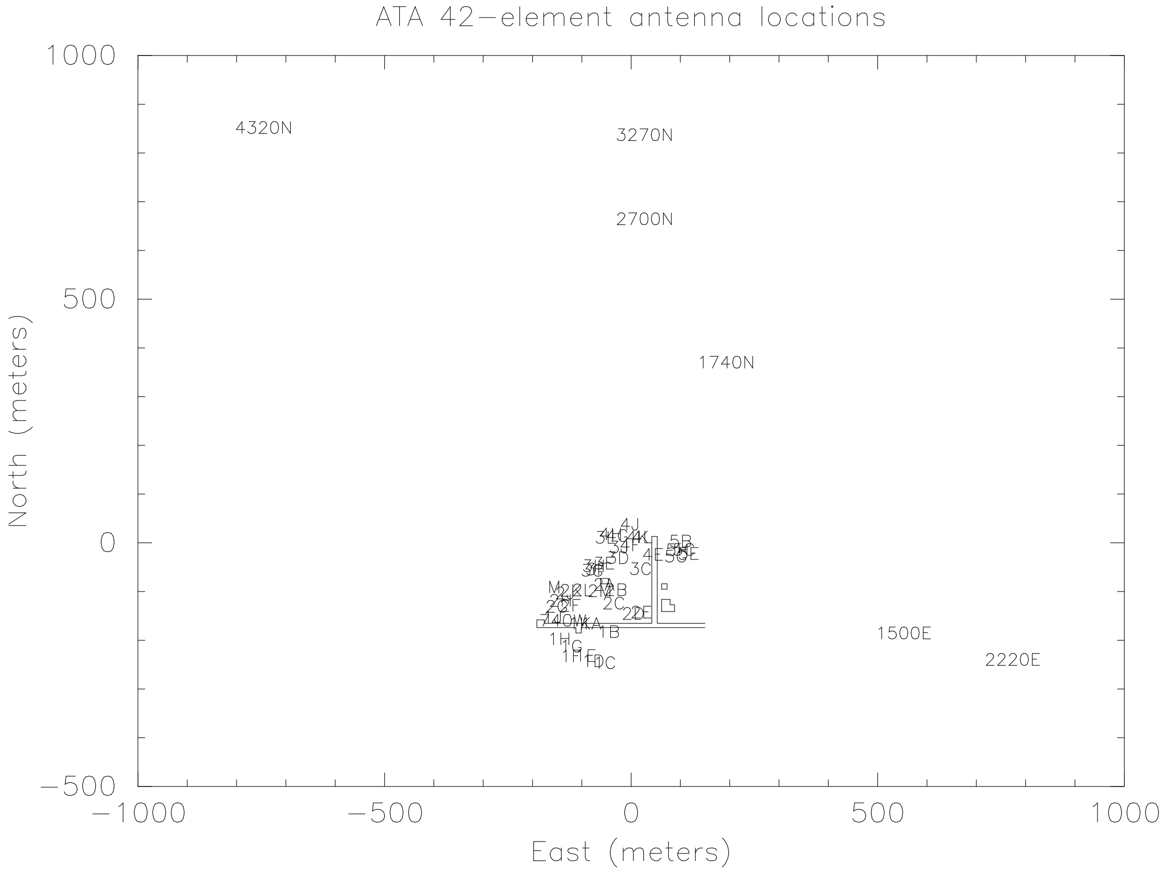

Fig. 2.— ATA 42 antenna array configuration + 7 BIMA A-configuration stations.

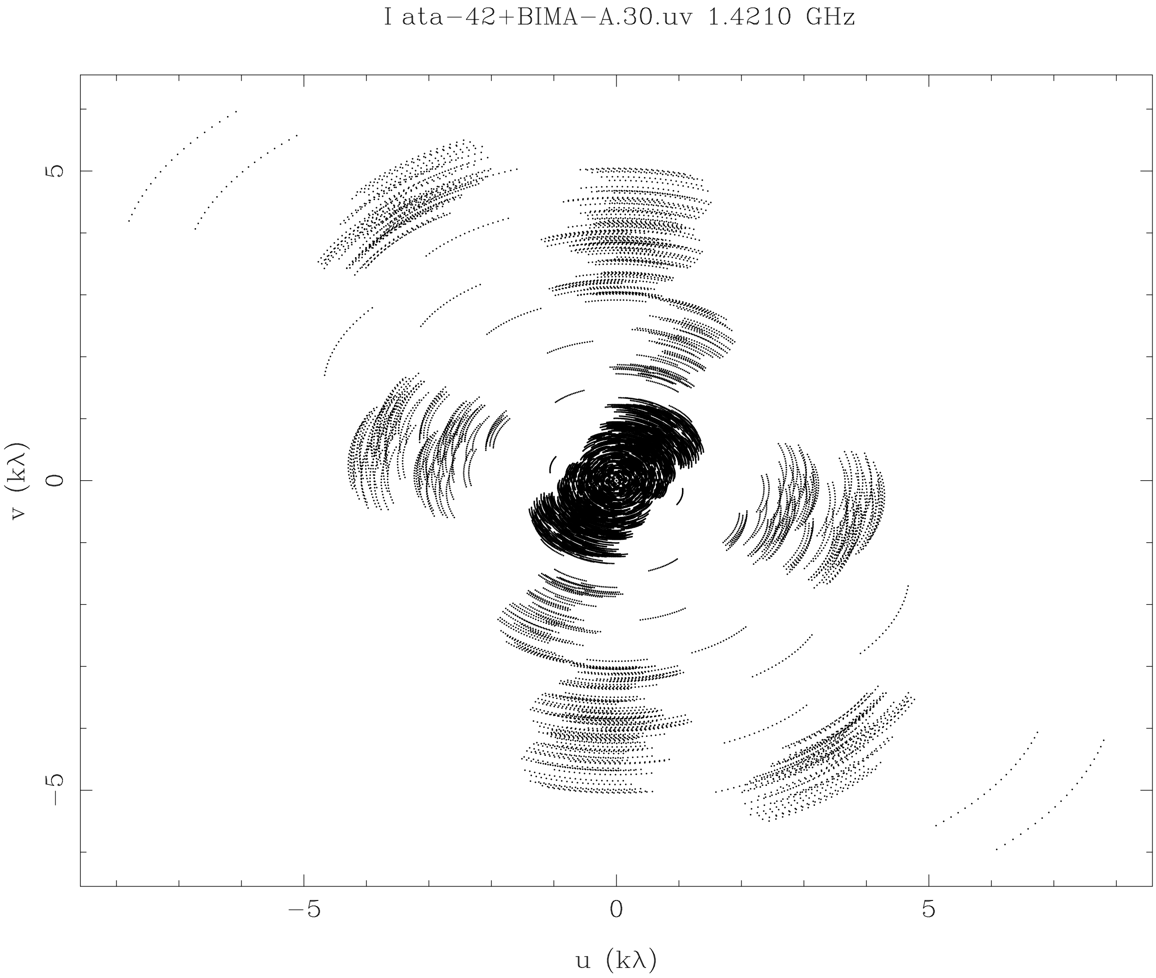

Fig. 3.— uv coverage for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -1,1 hours. Large gaps in the uv coverage result in high sidelobes in the synthesized beam.

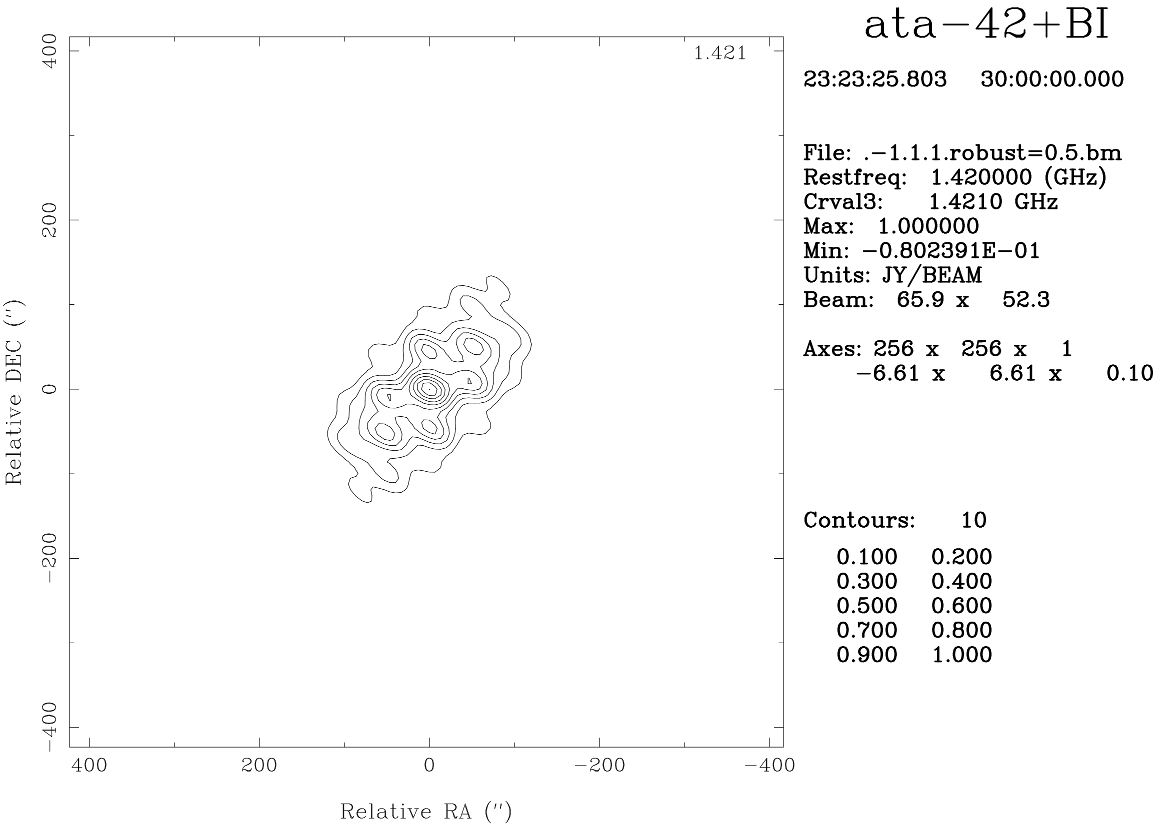

Fig. 4.— Synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -1,1 hours and robust weighting of the uv data. The synthesized beam shows the high resolution beam resulting from the long baselines to the outrigger stations, sitting on the lower resolution beam from the ATA 42 antenna array. With limited HA coverage, the high sidelobe level results in a complex synthesized beam pattern with several peaks.

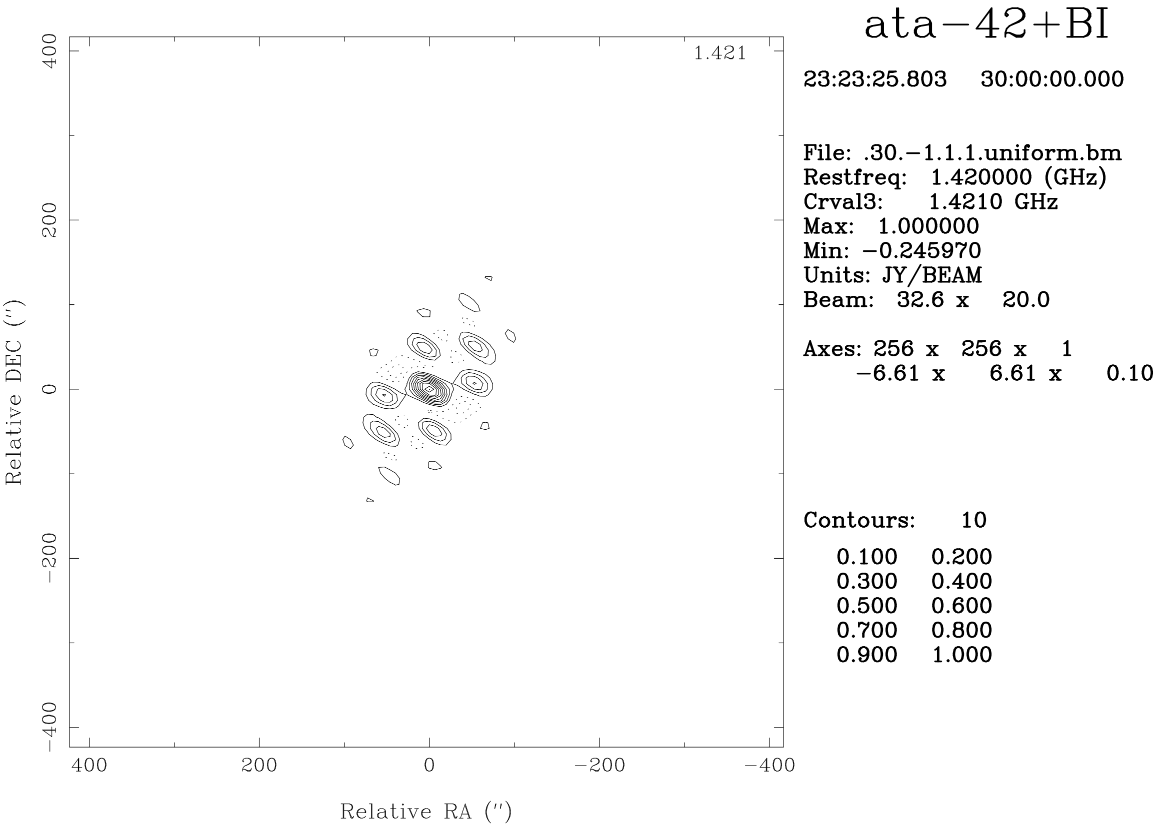

Fig. 5.— Synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -1,1 hours and uniform weighting of the uv data. Uniform weighting of the uvdata down weights the ATA 42-antenna data, and attenuates the lower resolution beam from the ATA 42 antenna array. With limited HA coverage, the high sidelobe level still results in a complex synthesized beam pattern with several peaks.

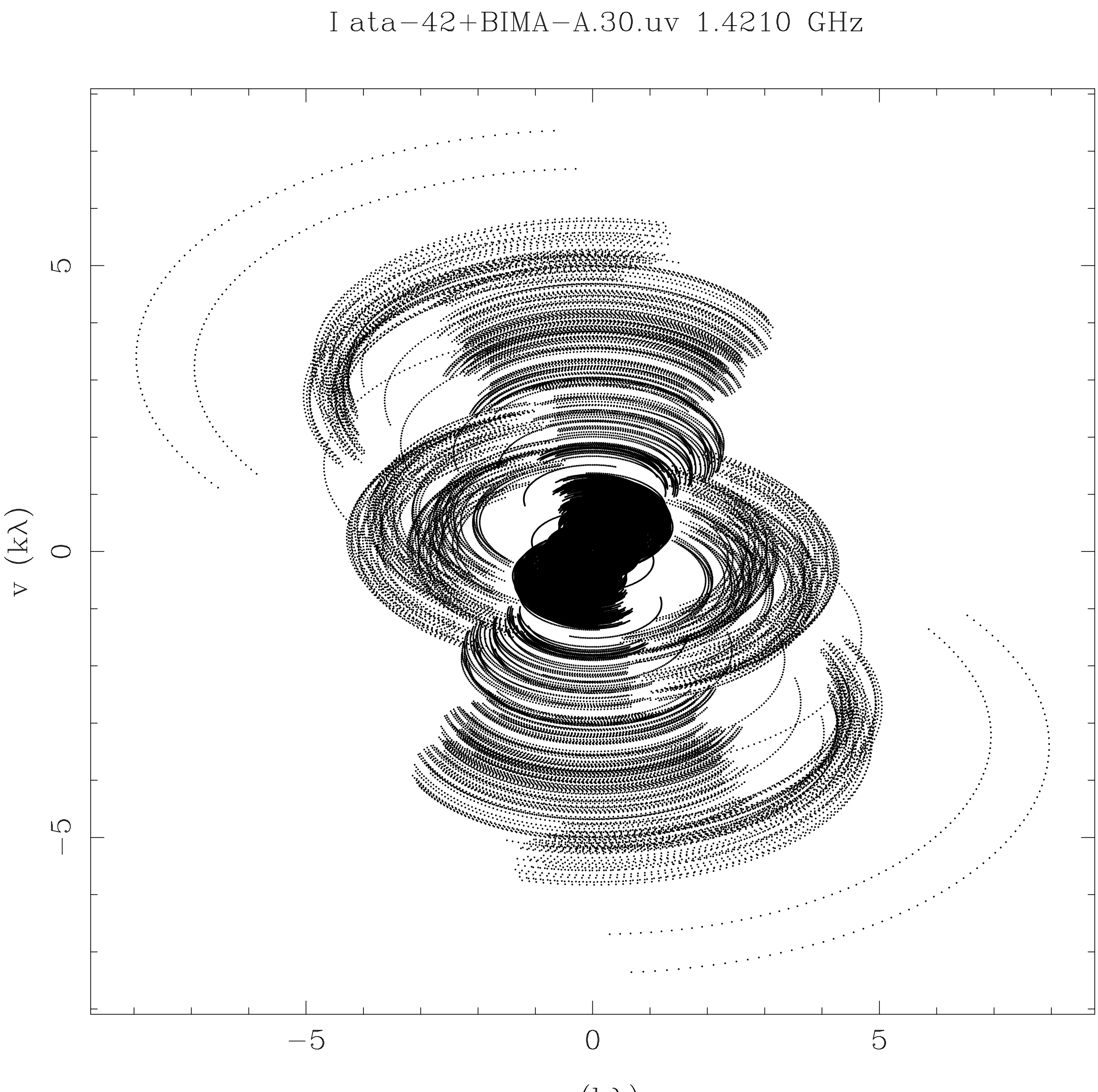

Fig. 6.— uv coverage for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -4,4 hours. Extending the observations over 8 hours fills in much more of the uv plane.

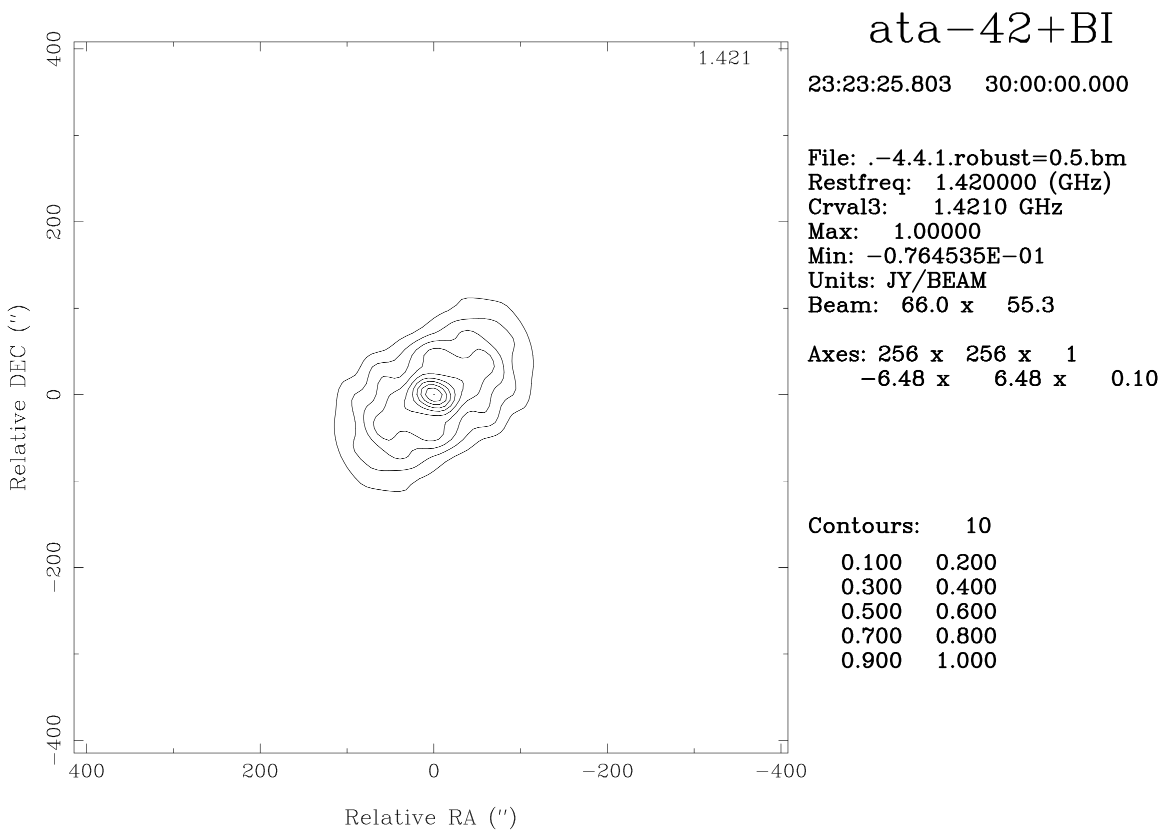

Fig. 7.— Synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -4,4 hours and robust weighting of the uv data. The synthesized beam shows the high resolution beam resulting from the long baselines to the outrigger stations, sitting on the lower resolution beam from the ATA 42 antenna array. With good HA coverage, the sidelobe level is reduced and the synthesized beam pattern has a single well defined peak.

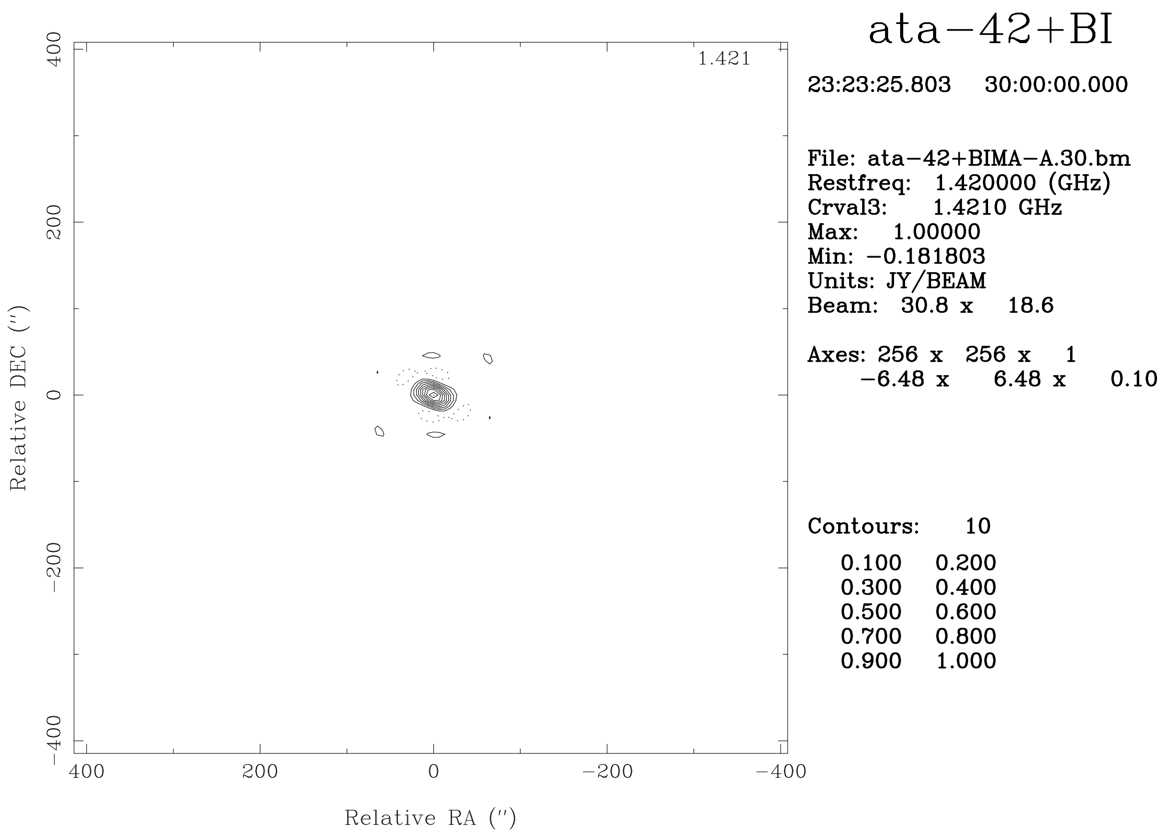

Fig. 8.— Synthesized beam for ATA 42 configuration + 7 BIMA A-configuration stations with HA range -4,4 hours and uniform weighting of the uv data. Uniform weighting of the uvdata down weights the ATA 42-antenna data, and attenuates the lower resolution beam from the ATA 42 antenna array, leaving a high resolution beam with $\sim$ 12% sidelobes.