VLB ARRAY MEMO No. 106

Dirty Beam Maps of Various Array Configurations

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I. INTRODUCTION

Dirty beam maps were calculated for ten familiar arrays at eight declinations. The rms of the sidelobe levels was calculated in eight angular sectors each 22.5° wide, in an ellipical annulus immediately surrounding the main beam and over the entire map plane (excluding the main beam). The rms^{-1} of the entire dirty beam map is roughly proportional to the dynamic ranges previously calculated for arrays D2 and CIT-13. Dirty beam maps and rms levels may be calculated in 10 to 20 minutes real time on the VAX 11/780 computer.

II. ANALYSIS PROCEDURE

Dirty beam maps were constructed using the Cal Tech programs FAKE and INVERT, and evaluated by two additional programs BEAMER and MAPPLOT. FAKE was used with no modifications. The run time for INVERT is dominated by the uniform weighting algorithm. For uv data sets of 5000 to 6000 samples INVERT requires several minutes to weight the data. To speed things up a bit, a weighting grid having the same dimensions as the uv grid was added to INVERT. The weight thus assigned to a uv sample is the number of uv points falling within the same cell. The weighting grid scheme is rather fast and speeds up the execution of INVERT dramatically. INVERT was allowed to set the map cell size (XYINT) by requiring the oversampling factor to equal 2.0. All beam maps unless otherwise stated were tapered to 0.3 at the maximum uv distance. All of the beam maps calculated in this study are 64 by 128 elements on a side.

The BEAMER program fits a gaussian profile to the main beam. Using the fit values, BEAMER estimates the location of the 5% level of the main beam, and thus defined, the main beam is excluded from all subsequent map plane analysis. The mean and rms of the sidelobes were measured in a beam-shaped ellipical annulus. The inner boundry is the 5% level of the main beam, and the outer boundry is 2.5 times the radial distance to the inner boundry. The mean and rms were also measured in

the map region beyound the annulus. One half of the dirty beam plane was divided into eight angular sectors each 22.5° wide. The first sector is centered on p.a. = 0°, the eighth sector is centered on p.a. = −180°. The mean and rms levels were measured in each sector. Finally, a single mean and rms were calculated over the entire dirty beam map. In all of the above measurements the mean sidelobe levels were essentially equal to zero.

BEAMER also returns the amplitude and location of the maximum and minimun map cells.

III. Results

The ten array configurations analized for this report are listed in Table I. The arrays designated I-7, II-6, III-1, III-3 and III-4 are those arrays in the figures of the same name in Walker's VLBA Memo No. 97.

Figures 1 and 2 show the dynamic ranges for arrays D2 and CIT-13 as taken from the NRAO and Cal Tech Design Studies. The dashed lines are plots of 4.032/rms, where the rms is that of the entire dirty beam maps at each declination. The constant factor is set such that 4.032/rms = 252 at 64° for D2. The simple inverse rms relation roughly mimics the declination dependence of the dynamic range numbers. Various combinations of angular sector rms' , inner and outer annulii rms' , sidelobe max - min, and so-forth, were tried in attempt to make a dynamic range like number from the BEAMER analysis. Perhaps not suprisingly, the inverse rms of the entire map scales best with dynamic range, especially for array D2. In the remainder of this report, the values of 4.032/rms are called array figures-of-merit (F.M.).

Table II shows the effects of uv tapering, and the grid weighting scheme versus the usual INVERT weighting algorithm. Columns 2, 3 and 4 are the F.M.'s for D2 with UVTAPER=0.3 and 1.0 and the two weighting algorithms; columns 5, 6, and 7 are the beam dimensions. Differences in the F.M.'s calculated through the two weighting schemes are less than 10 %. The faster but cruder grid weighting is acceptable for array studies.

The array figures-of-merit are listed in Table III. Column 2 contains the F.M.'s for D2, the following columns are the respective arrays' F.M.'s scaled by that of the D2 array at the same declination. A number greater than one indicates a better array (lower rms levels) than D2. Table IV lists beam dimensions in milli-arcseconds.

The dirty beam maps are plotted. On each plot we list the total map rms, the rms in the elliptical annulus around the main beam divided by the rms in the rest of the beam map, and the ratio of the maximum rms per angular sector to the minimum rms per angular sector.

IV. SUMMARY

The array figures-of-merit derived here scale roughly proportionally with array dynamic range. These F.M.'s are probably most useful in comparing large numbers of array configurations. The FAKE-INVERT-BEAMER-MAPPLOT sequence requires about 15 minutes real time on the VAX 11/780 for eight declinations. The rms-based F.M.'s may be a safer standard for array comparison than the calculated dynamic ranges. The D.R.'s are affected to some degree by the structure of the model source and the noise level in the test data. The F.M.'s don't reflect the unequal distribution of the sidelobe levels with position angle. This is an obviously important effect in the declination range from $-18°$ to $+18°$.

The array figure-of-merit as defined here will be most useful in evaluating array configurations when it is used along with other tests : beam sizes, inspecting uv plots and dirty beam maps, and the Mutel-Gaume and Schwab algorithms for evaluating uv coverage.

Table I : Array Configurations

Array	Stations	Comments
D2	HAWAII, ANCH, OVRO, SOCORRO, LASL, BLDR, BRVL2, CRFK2, NRAO, HSTK	Optimized array from the NRAO VLBA Design Study.
CIT-13	HAWAII, ANCH, OVRO, SALEM, DSS14, BLDR, BOIS, LRDO, IOWA, HSTK	Optimized array from the Cal Tech VLBA Design Study.
I-7	HAWAII, OVRO, SOCORRO, LASL, BLDR, BRVL2, CRFK2, NRAO, HSTK, ARECIBO	Array D2 with Arecibo replacing Anchorage.
II-6	HAWAII, SPKN, TUSC, VLASW, BLDR, FDVSNEW, BRVL2, IOWA, BANGOR, ARECIBO	A strongly centrally condensed array.
III-1	HCRK, OVRO, VLA, FDVS, NRAO, HSTK, BONN	The array in common use today.
III-3	HAWAII, HCRK, OVRO, VLA, FDVS, IOWA, NRAO, NRL, HSTK, ARECIBO	Eight existing observatories plus Arecibo and HAwaii.
III-4	HAWAII, OVRO, VLA, NRAO, NRL, HSTK, ARECIBO	The current array that is useful at 22 GHz.
N-5	HAWAII, ANCH, OVRO, VLA, COSPR, LARA, LDRO, HSTK, MIAMI, ARECIBO	Best U.S. territory array from VLBA Memo No. 84 (Mutel and Carme).
SQ-2	HAWAII, OVRO, SALEM, TUSC, VLA, BRVL, BISMARCK, QUITO, HSTK, ARECIBO	Includes Quito, Equador.
SEG-1	HAWAII, OVRO, TUSC, VLA, BRVL, EASTER, BISMARCK, GALAPA, HSTK, ARECIBO	Includes a site in the Galapagos Islands and at Easter Island.

Table II : Comparison of Weighting and Tapering on Array D2

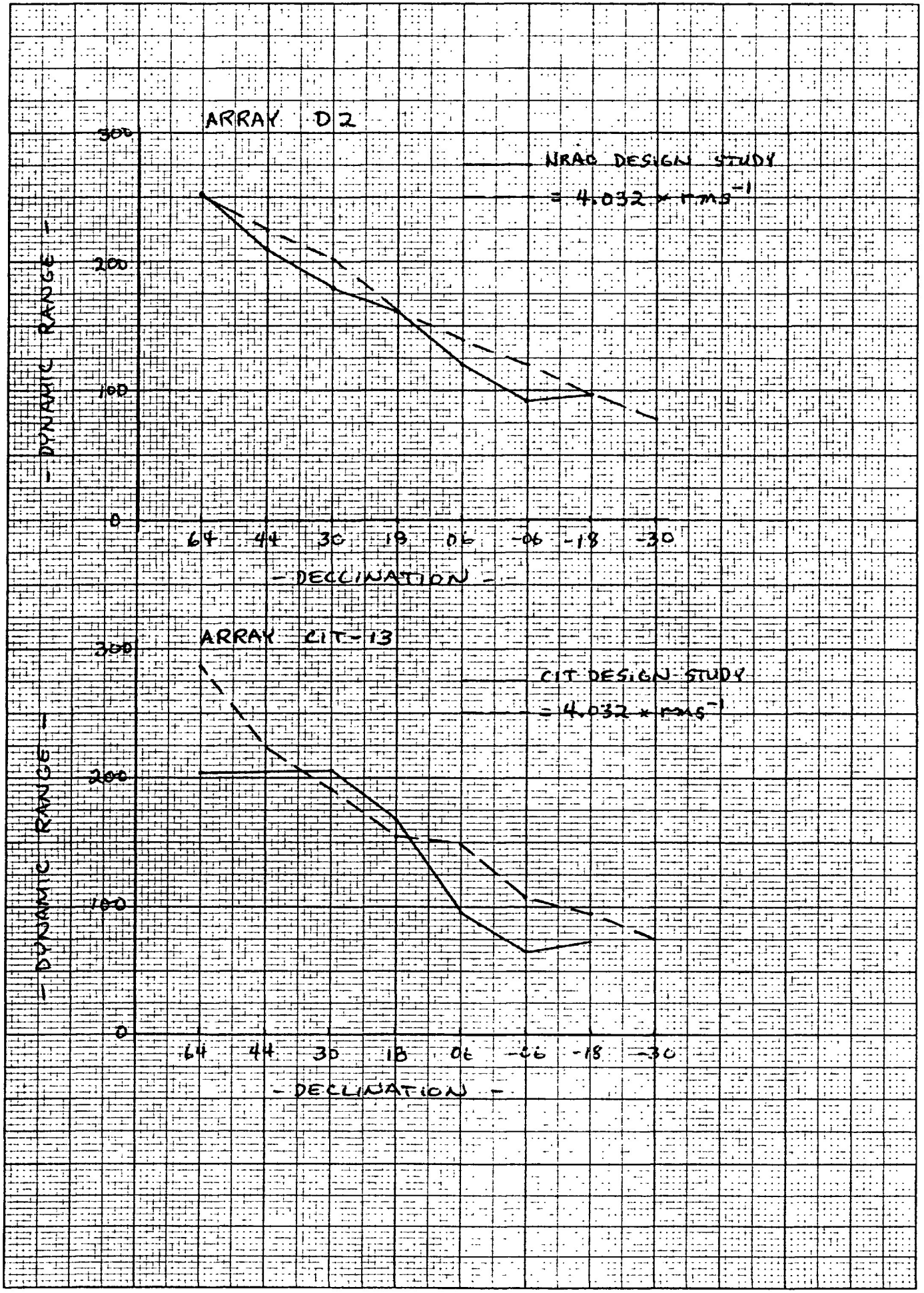
taper = weight=	0.3 grid	1.0 grid	0.3 INVERT	0.3 grid	1.0 grid	0.3 INVERT
64	252	252	269	0.81	0.71	0.67
				0.78	0.69	0.66
				- 87	- 82	- 34
44	224	224	252	0.76	0.65	0.79
				0.73	0.65	0.78
				- 51	- 45	- 44
30	202	202	212	0.95	0.90	0.87
				0.91	0.79	0.78
				- 39	- 34	- 34
18	161	155	175	1.07	1.05	1.00
				0.81	0.69	0.74
				- 16	- 18	- 17
06	139	134	144	1.25	1.20	1.13
				0.83	0.70	0.75
				- 11	- 11	- 11
-06	119	115	122	1.57	1.51	1.36
				0.79	0.66	0.72
				- 10	- 11	- 9
-18	98	96	98	2.09	2.07	1.86
				0.75	0.62	0.69
				- 12	- 13	- 12
-30	77	79	86	3.00	2.88	2.68
				0.74	0.61	0.64
				- 13	- 14	- 13

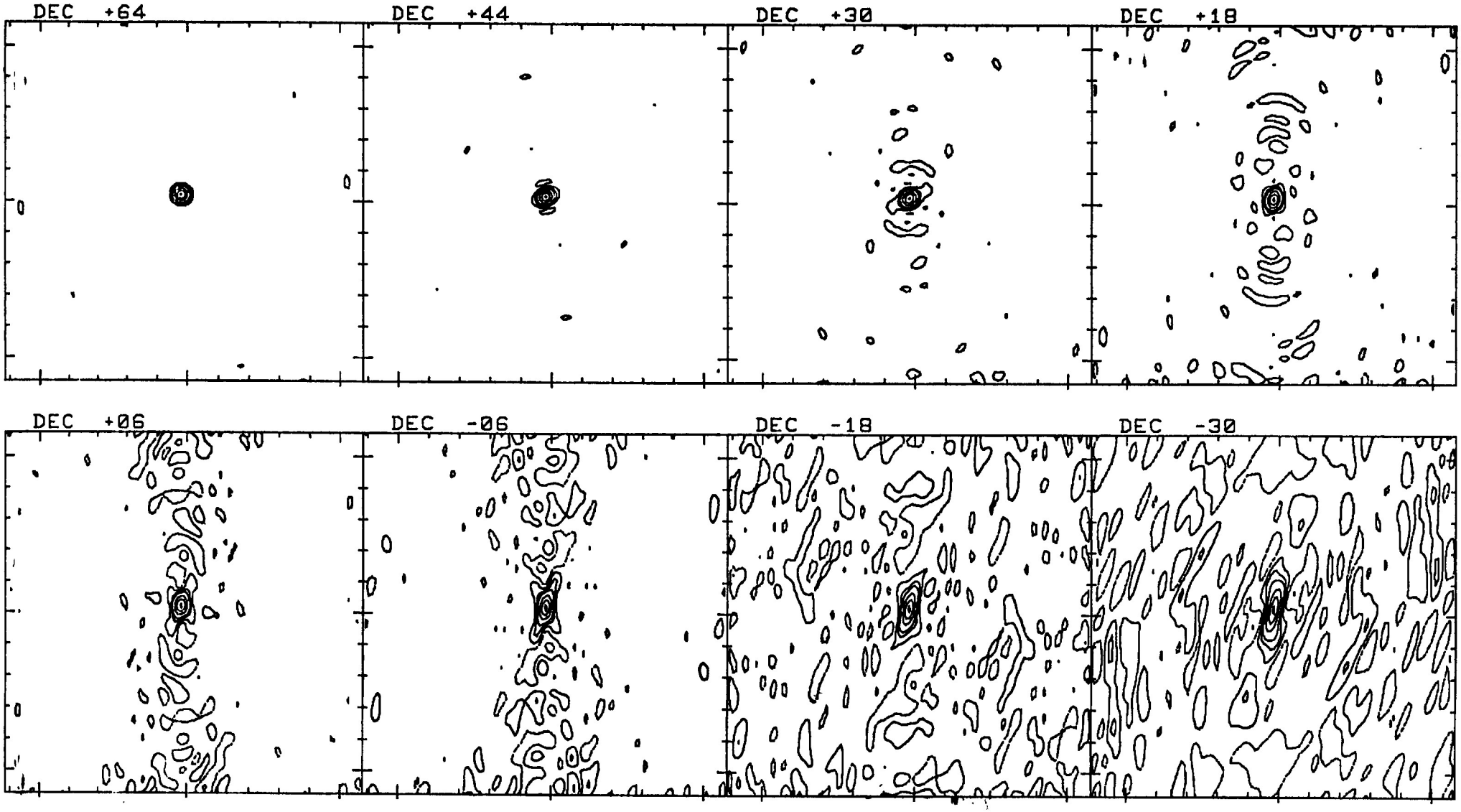
Table III : Array Figures of Merit

Dec	D2	CIT-13	I-7	II-6	II-6C	III-1	III-3	III-4	N-5	SQ-2	SEC-1
[redacted]4	252	1.14	0.89	0.94	0.59	0.62	0.84	0.62	0.94	1.00	0.94
44	224	1.00	0.86	0.86	0.53	0.56	0.82	0.54	0.95	0.90	0.81
[redacted]0	202	0.95	0.83	0.77	0.51	0.51	0.77	0.50	0.91	0.89	0.80
18	161	0.96	0.96	0.86	0.57	0.60	0.81	0.50	1.05	0.93	0.83
[redacted]6	139	1.07	0.91	0.86	0.69	0.63	0.86	0.55	1.00	0.94	0.86
[redacted]06	119	0.92	0.97	0.89	0.68	0.53	0.82	0.54	0.97	1.03	0.97
[redacted]8	93	0.98	1.11	0.96	0.65	0.52	0.90	0.61	0.94	1.05	1.11
[redacted]0	77	1.00	1.14	1.12	0.73	0.69	1.09	0.74	1.06	1.25	1.31

Table IV : Array Beam Dimensions

Dec	D2	CIT-13	I-7	II-6	II-6C	III-1	III-3	III-4	N-5	SQ-2	SEC-1
[redacted]	0.81	0.85	0.80	0.79	1.58	0.71	0.78	0.75	0.72	0.74	0.74
	0.78	0.80	0.77	0.77	1.57	0.60	0.69	0.68	0.69	0.68	0.71
	- 87	- 86	-148	-143	-136	-165	-163	-156	-177	-118	-121
[redacted]	0.76	0.84	0.91	0.87	1.56	0.94	0.91	0.89	0.75	0.79	0.75
	0.73	0.78	0.76	0.76	1.55	0.68	0.68	0.63	0.72	0.78	0.75
	- 51	- 59	- 16	- 10	-138	- 21	- 5	- 10	- 4	-137	- 44
[redacted]	0.95	0.97	1.00	1.01	1.60	1.41	1.03	1.03	0.83	0.81	0.71
	0.91	0.93	0.79	0.77	1.56	0.64	0.68	0.63	0.73	0.75	0.70
	- 39	- 39	- 21	- 10	-152	- 14	- 9	- 14	-165	-152	- 50
[redacted]	1.07	1.08	1.13	1.14	1.59	2.14	1.18	1.22	0.95	0.89	0.73
	0.81	0.87	0.77	0.79	1.54	0.68	0.71	0.62	0.73	0.77	0.72
	- 16	- 20	- 13	- 9	-178	- 13	- 9	- 10	-163	-157	- 55
06	1.25	1.28	1.28	1.03	1.68	3.16	1.34	1.39	1.19	0.95	0.77
[redacted]	0.83	0.86	0.78	0.83	1.53	0.72	0.72	0.63	0.73	0.78	0.74
	- 11	- 11	- 10	- 9	- 5	- 9	- 7	- 11	-170	-157	- 64
-06	1.57	1.54	1.47	1.48	1.94	4.09	1.60	1.55	1.40	1.05	0.79
	0.79	0.81	0.77	0.78	1.51	0.74	0.68	0.60	0.70	1.05	0.78
[redacted]	- 10	- 11	- 5	- 5	-169	- 7	- 9	- 7	-176	-164	- 43
-18	2.09	2.03	1.68	1.68	2.48	3.65	1.71	1.65	1.66	1.16	0.79
	0.75	0.74	0.70	0.73	1.51	0.75	0.64	0.57	0.66	0.67	0.69
[redacted]	- 12	- 12	- 2	- 1	-171	- 5	- 5	- 5	-178	-165	- 7
-30	3.00	2.84	1.89	1.85	3.05	3.87	1.78	1.76	1.93	1.22	0.86
	0.74	0.75	0.64	0.64	1.51	0.94	0.60	0.61	0.62	0.63	0.64
	- 13	- 12	- 2	- 3	-175	- 3	- 2	- 3	-178	-166	- 3

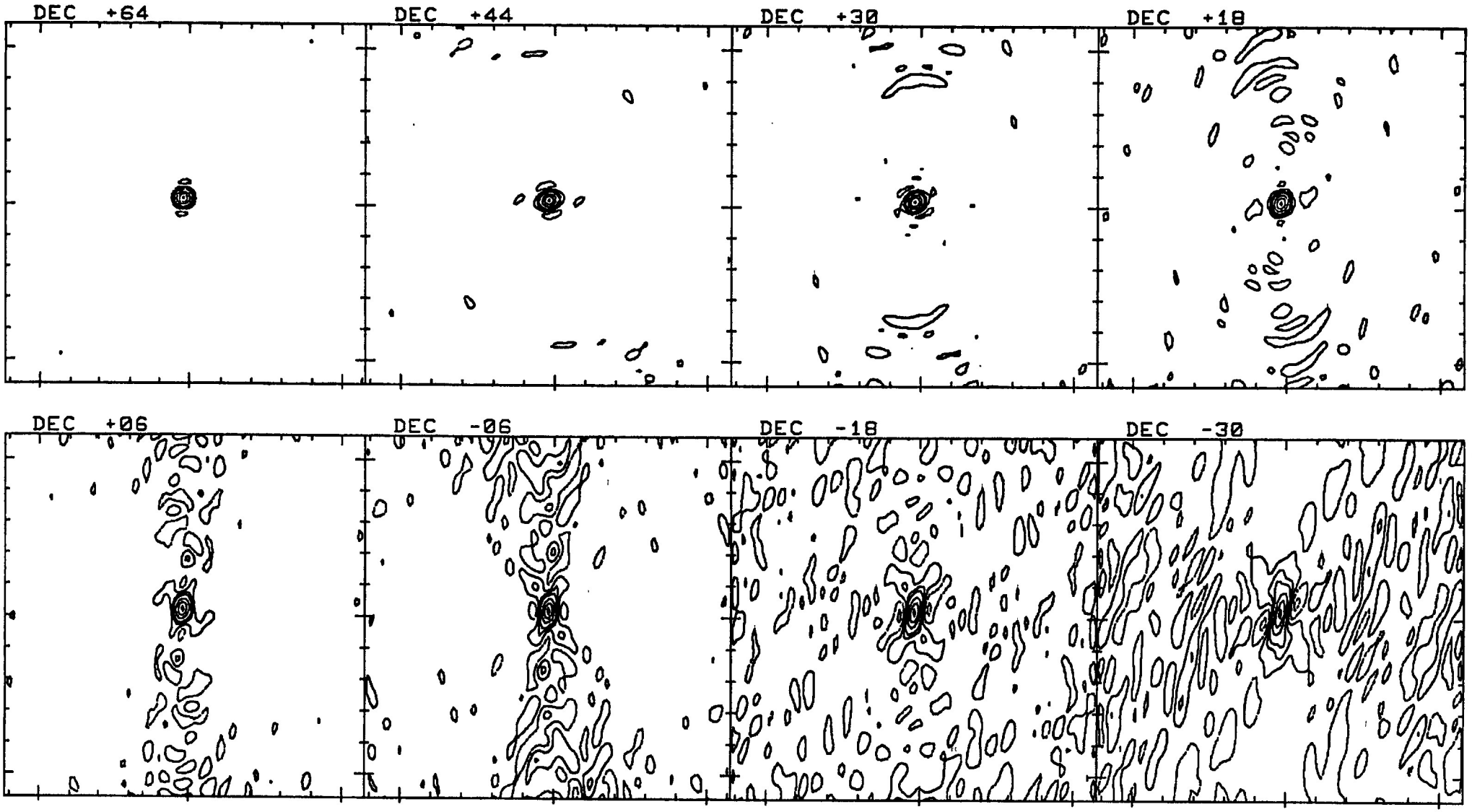




HAWAII ANCH OVRO SOCORRO LASL BLDR GRFK2 NRAO HSTK BRVL2

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 23.9 by 23.9

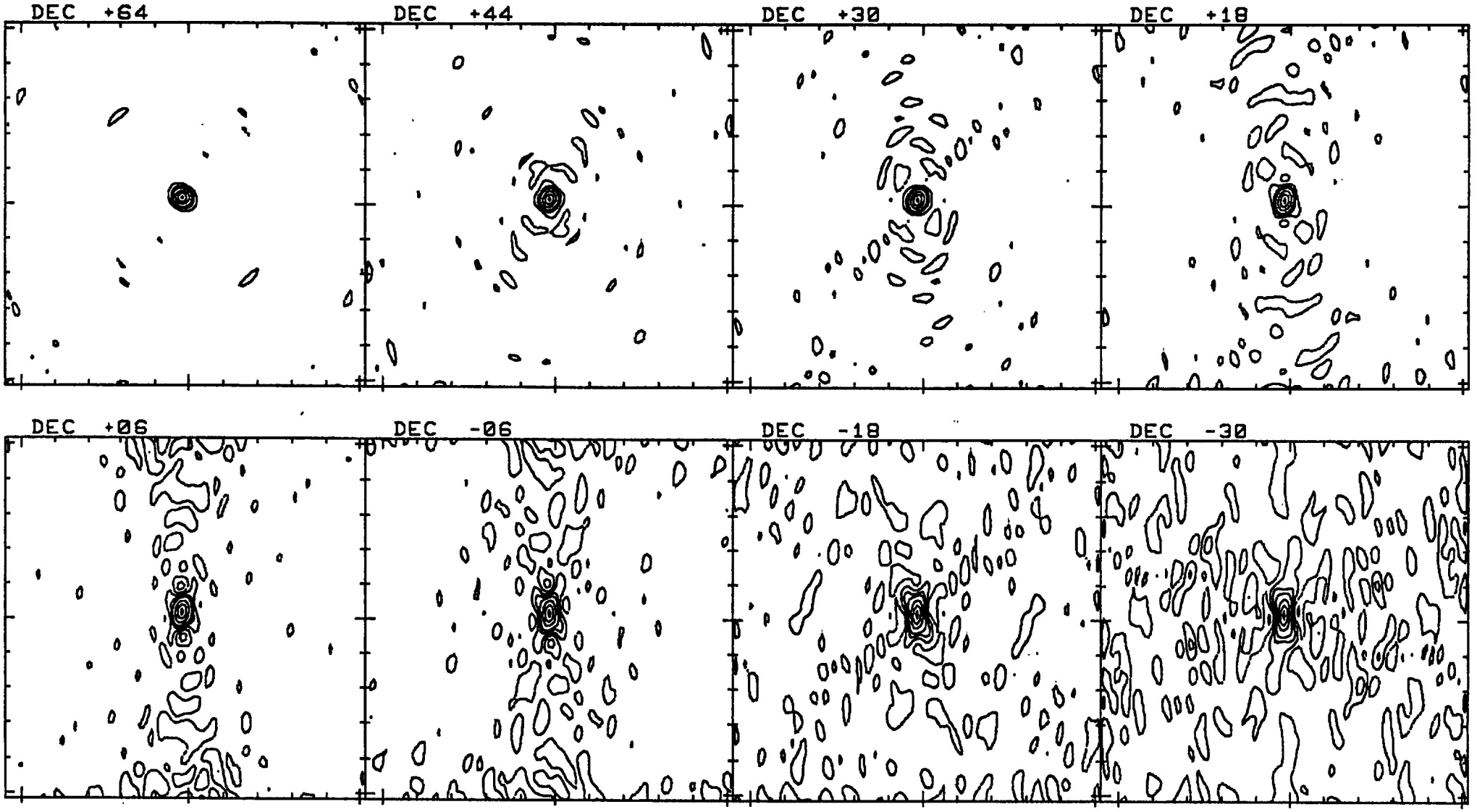
Array : D2 :	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.016	0.018	0.020	0.025	0.029	0.034	0.041	0.052
inner rms / outer rms :	1.07	1.78	2.06	1.42	1.94	2.25	1.27	1.44
max rms / min rms (angular) :	1.18	1.19	1.65	2.26	2.86	2.96	1.57	1.50



HAWAII ANCH OVRO SALEM BOIS BLDR DSS14 IOWA HSTK LRDO

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 23.9 by 23.9

Array : CIT-13 :	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.014	0.018	0.021	0.026	0.027	0.037	0.042	0.052
inner rms / outer rms :	1.63	1.94	1.34	1.18	1.63	1.83	1.70	1.45
max rms / min rms (angular) :	1.31	1.38	2.06	2.23	2.70	3.06	1.31	1.49

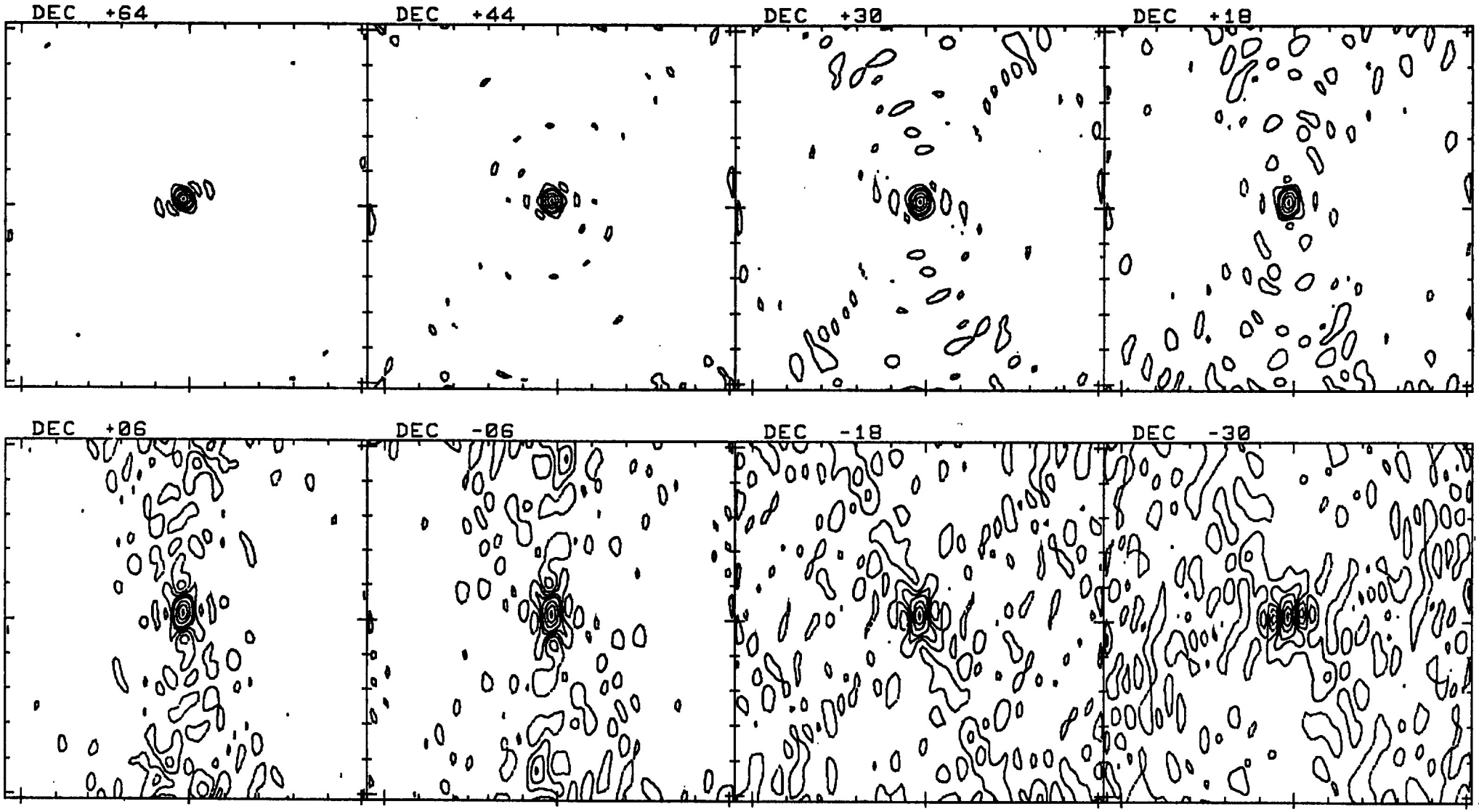


HAWAII ARECIBO OVRO SOCORRO LASL BLDR GRFK2 NRAO HSTK BRVL2

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0

Plot size (mas) : 21.3 by 21.3

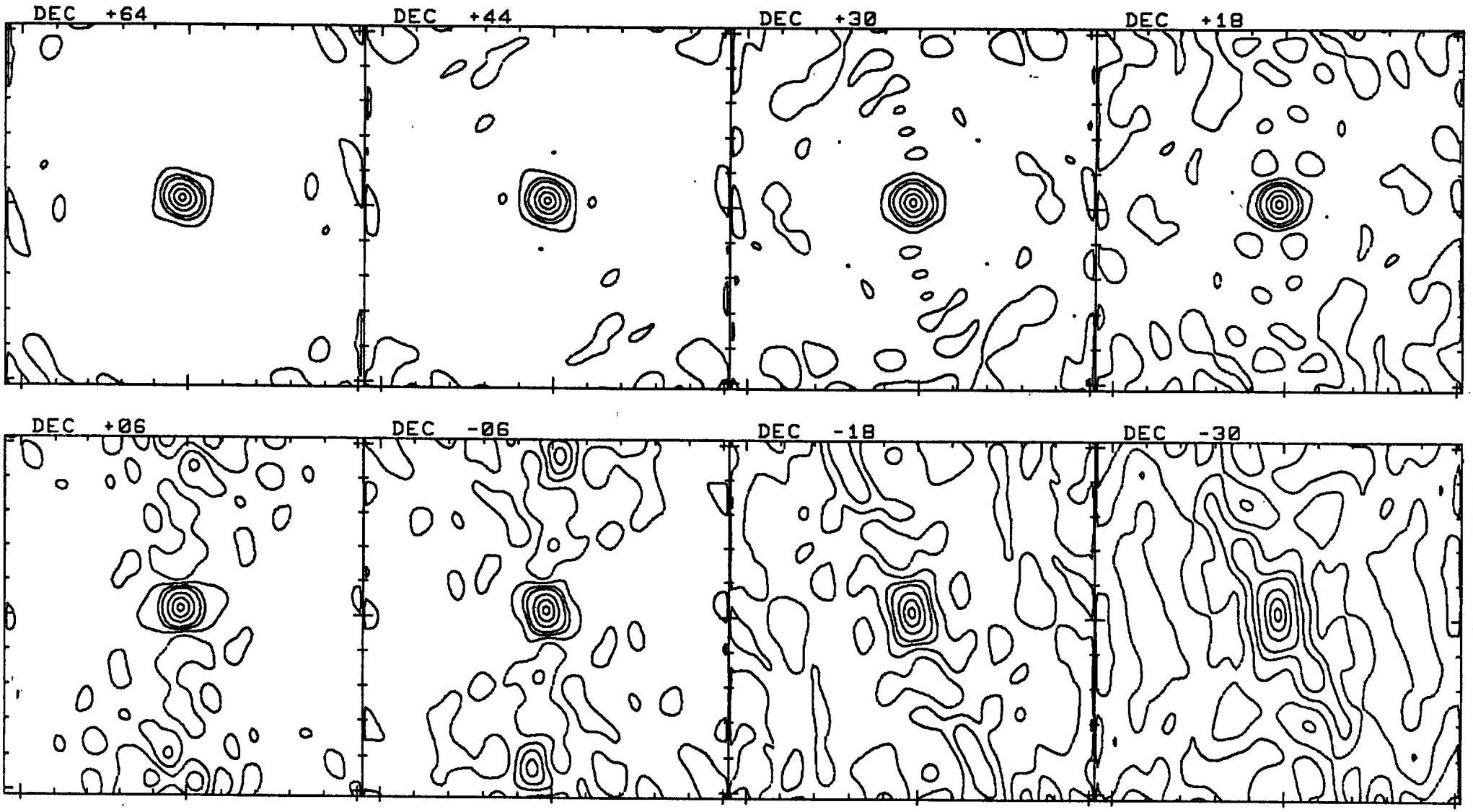
Array : I-7 :	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.018	0.021	0.024	0.026	0.032	0.035	0.037	0.046
inner rms / outer rms :	1.26	1.94	1.92	1.60	1.74	1.79	1.52	1.63
max rms / min rms (angular) :	1.41	1.25	1.67	2.68	2.98	2.53	1.32	1.47



HAWAII ARECIBO SPKN BANGOR BRVL2 VLASW IOWA TUSCNE FDVSNEW BLDR

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

Array : II-6	:	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam)	:	0.017	0.021	0.026	0.029	0.034	0.038	0.043	0.047
inner rms / outer rms	:	1.92	1.32	1.20	1.07	1.78	1.90	1.43	1.78
max rms / min rms (angular)	:	1.34	1.40	1.51	1.68	3.02	2.83	1.80	1.65

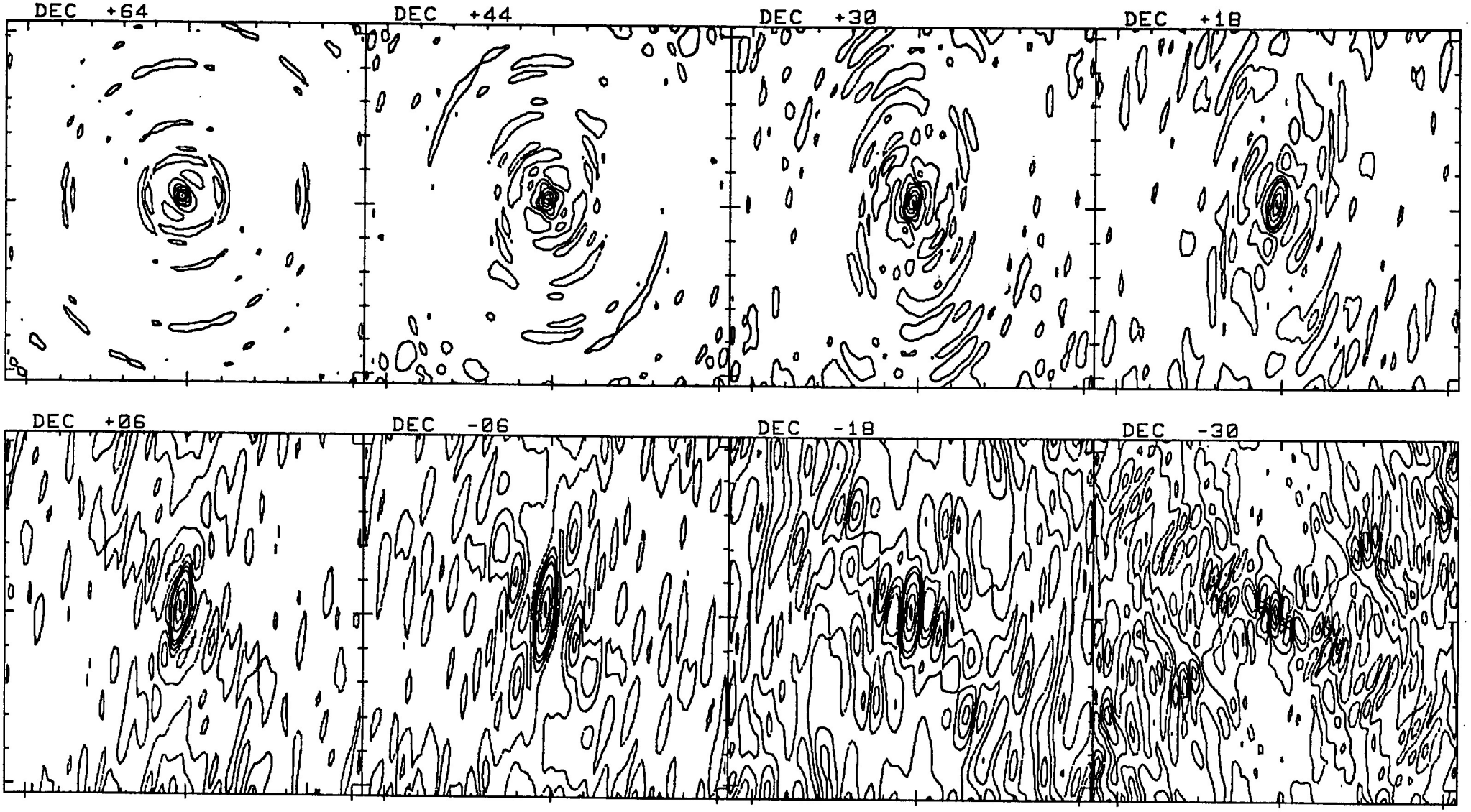


HAWAII ARECIBO SPKN BANGOR BRVL2 VLASW IOWA TUSCNE FDVSNEW BLDR

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

Array : II-6 uv taper = 0.3 at 2500 km.

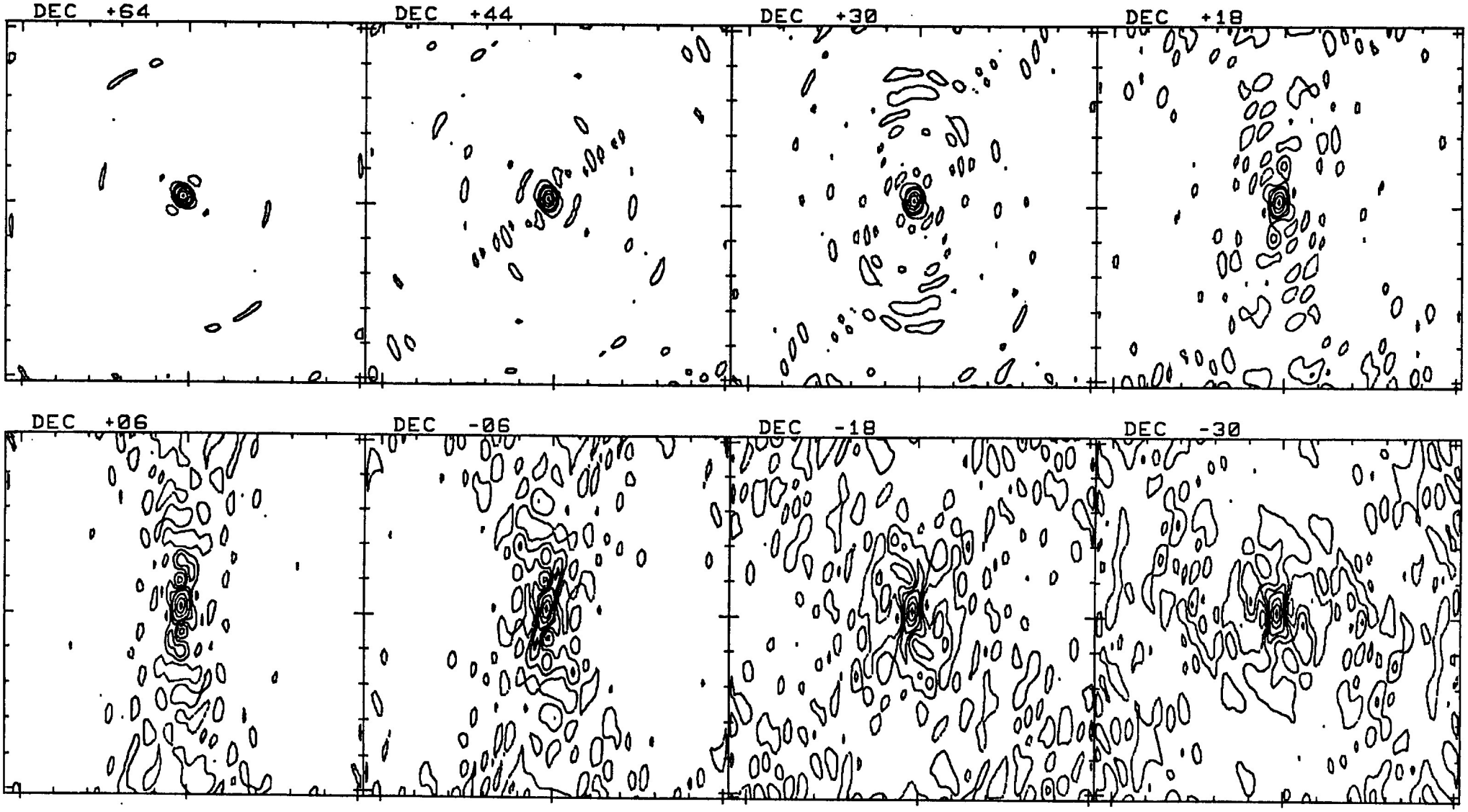
	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.027	0.034	0.039	0.044	0.042	0.050	0.063	0.072
inner rms / outer rms :	0.85	0.80	0.72	0.84	1.37	1.24	0.98	1.17
max rms / min rms (angular) :	1.83	1.87	1.78	1.66	3.41	3.53	1.84	1.99



HCRK OVRO VLA FDVS NRAO HSTK BONN

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 44.6 by 44.6

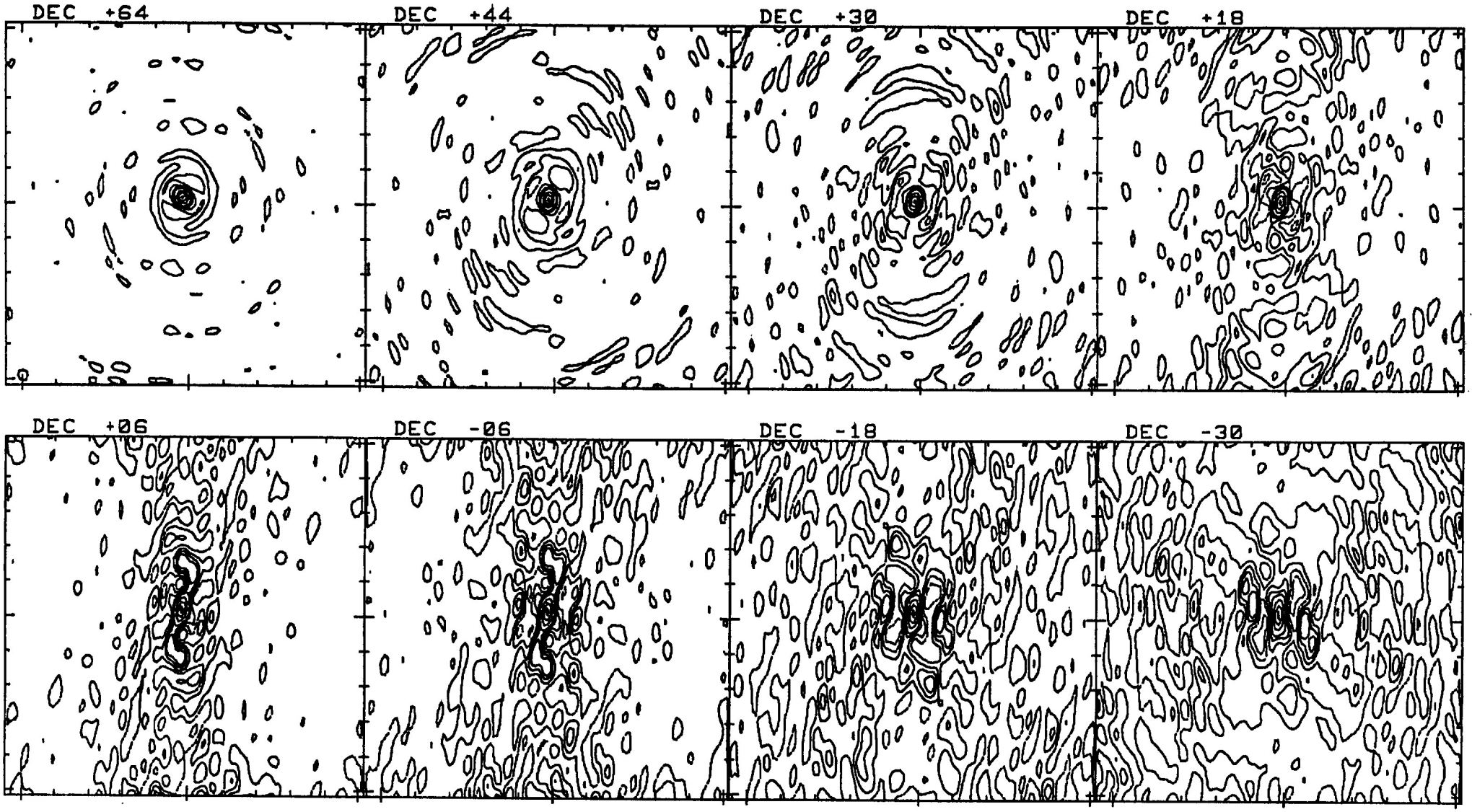
Array : III-1	:	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam)	:	0.026	0.032	0.039	0.042	0.046	0.064	0.079	0.076
inner rms / outer rms	:	2.35	2.06	1.59	1.54	1.74	1.56	1.27	1.61
max rms / min rms (angular)	:	1.19	1.71	2.06	2.40	2.82	2.46	1.51	2.20



HCRK OVRO VLA FDVS NRAO HSTK HAWAII ARECIBO IOWA NRL

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

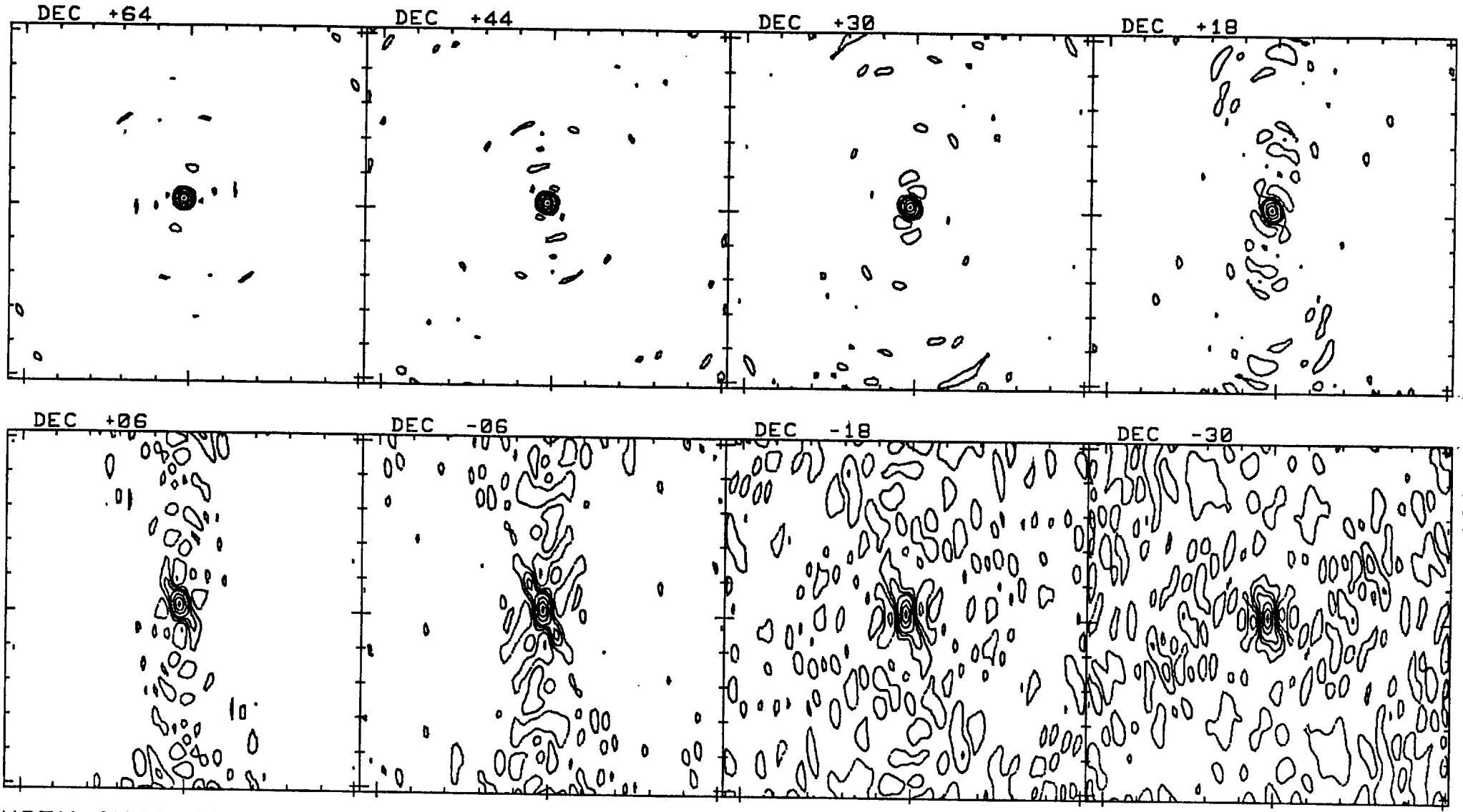
Array : III-3 :	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.019	0.022	0.026	0.031	0.034	0.041	0.046	0.048
inner rms / outer rms :	1.66	1.77	1.47	1.88	2.74	2.68	1.93	1.80
max rms / min rms (angular) :	1.26	1.44	1.70	2.32	3.30	3.06	1.49	1.41



OVRO VLA NRAO HSTK HAWAII ARECIBO NRL

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

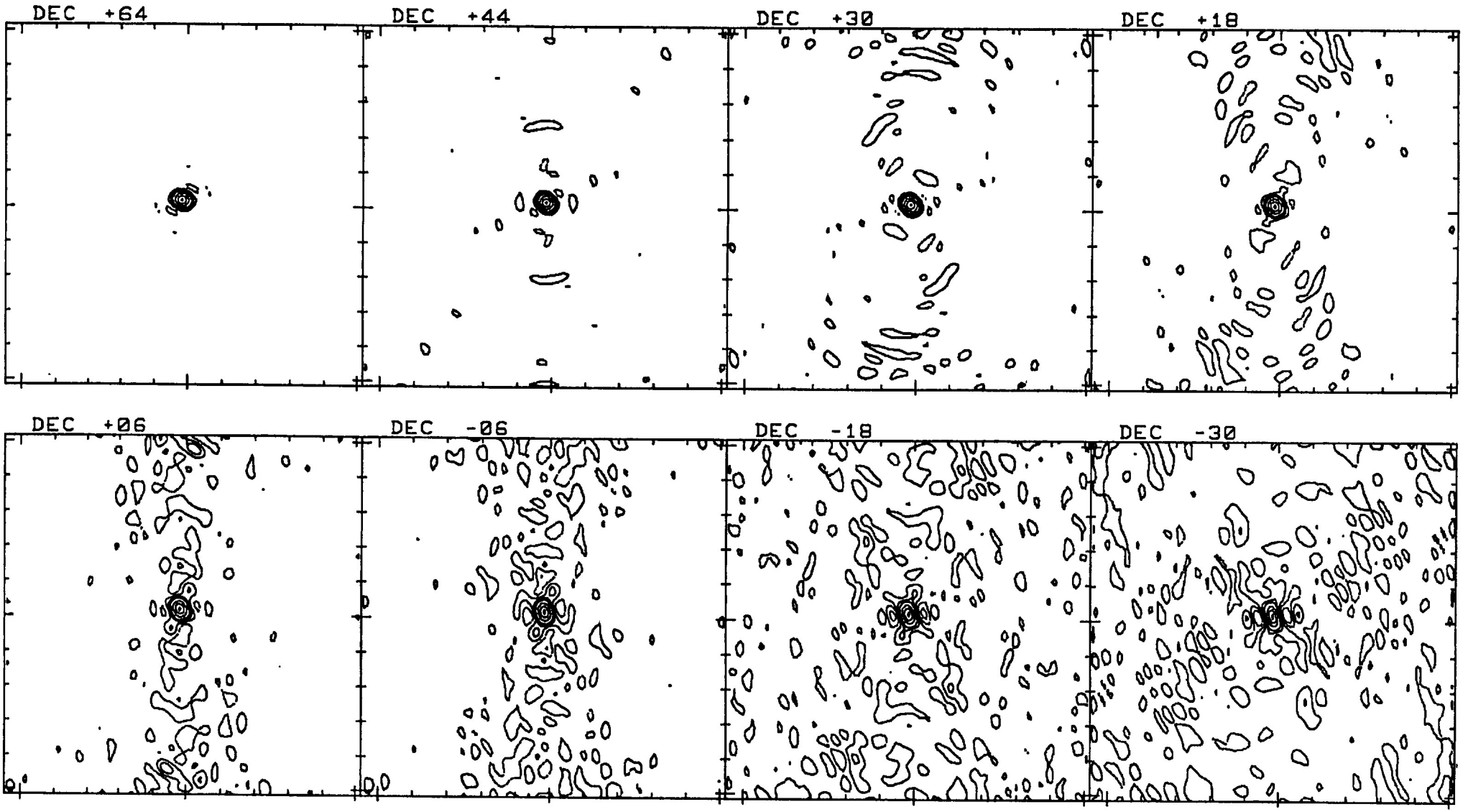
Array : III-4	:	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam)	:	0.026	0.033	0.040	0.050	0.053	0.063	0.067	0.071
inner rms / outer rms	:	2.57	2.05	1.63	1.70	3.50	3.23	1.96	1.81
max rms / min rms (angular)	:	1.31	1.54	1.70	2.54	3.85	3.05	1.63	1.24



HSTK OVRO ANCH HAWAII VLA COSPR LARA ARECIBO LRDO MIAMI

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

Array : N-5	:	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam)	:	0.017	0.019	0.022	0.024	0.029	0.035	0.044	0.049
inner rms / outer rms	:	1.55	1.48	2.14	1.90	2.52	2.90	1.83	1.40
max rms / min rms (angular)	:	1.26	1.44	1.83	2.26	3.01	2.73	1.51	1.58

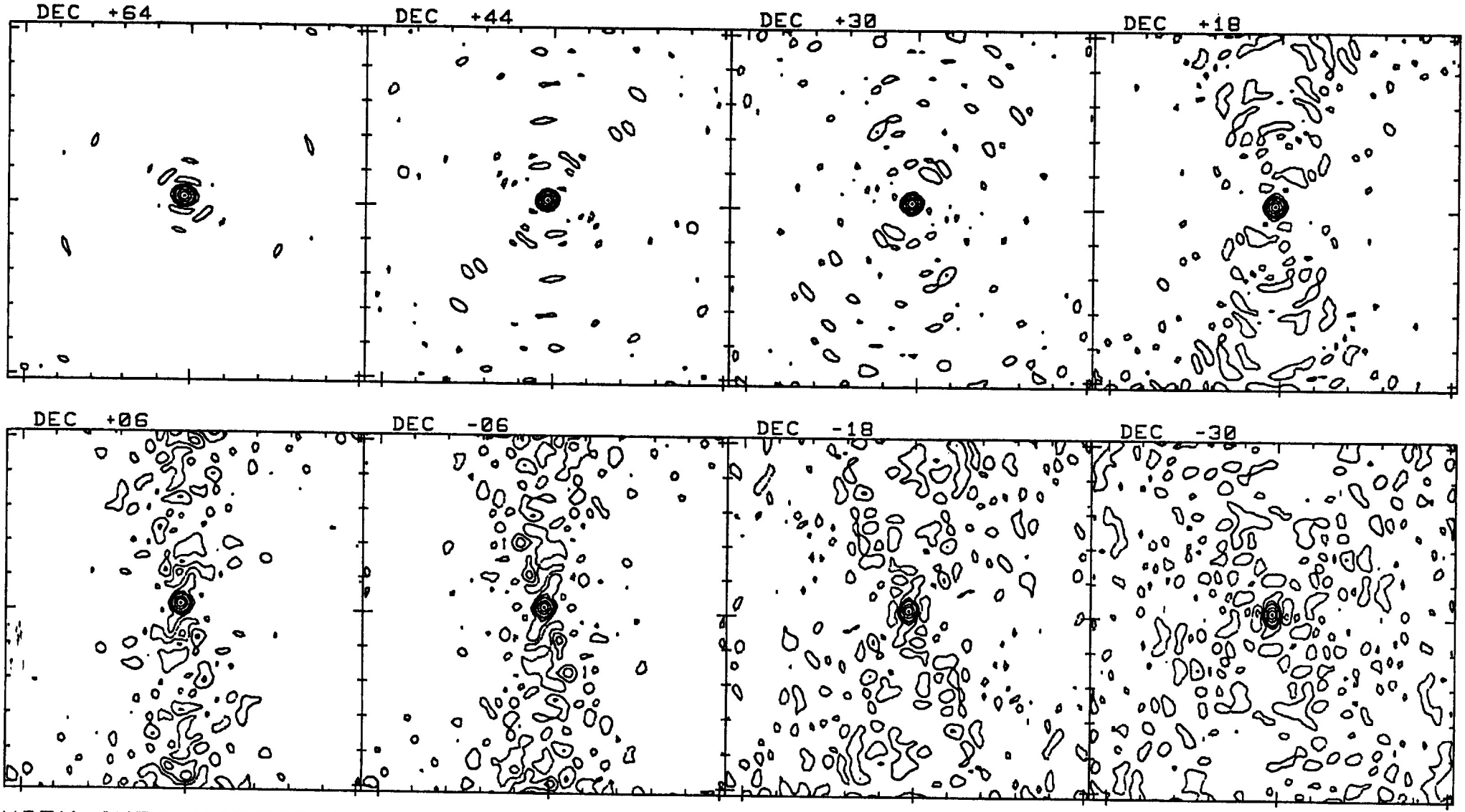


HSTK OVRO SALEM HAWAII VLA TUSC BRVL ARECIBO QUITO BISMARCK

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

Array : SQ-2

	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.016	0.020	0.025	0.027	0.031	0.033	0.039	0.042
inner rms / outer rms :	2.08	1.73	1.40	1.41	1.83	2.25	1.70	2.00
max rms / min rms (angular) :	1.29	1.42	1.74	2.45	3.01	2.74	1.82	1.26

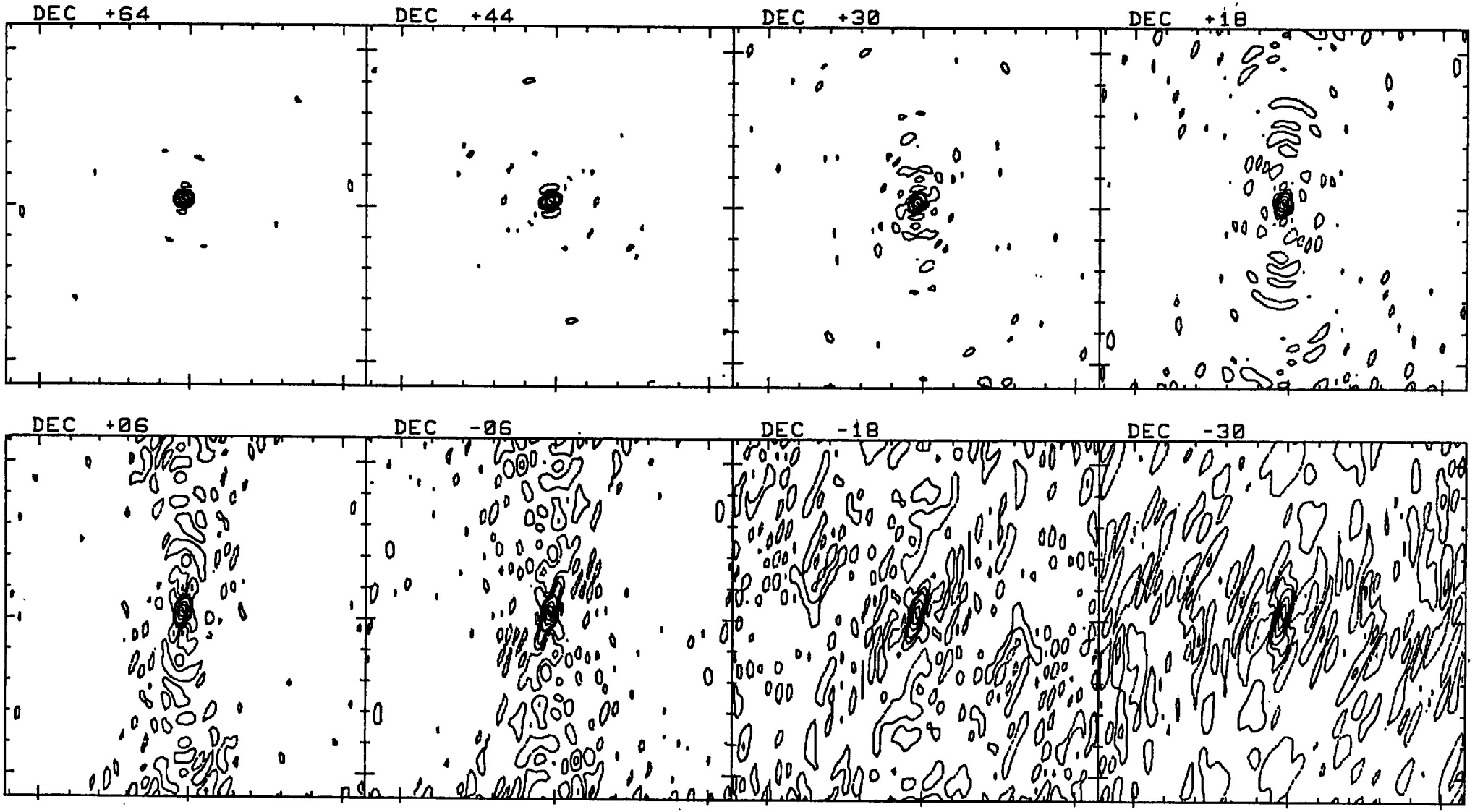


HSTK OVRO EASTER HAWAII VLA TUSC BRVL ARECIBO GALAPA BISMARCK

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 21.3 by 21.3

Array : SEC-1

	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.17	0.022	0.025	0.030	0.034	0.035	0.037	0.040
inner rms / outer rms :	2.31	1.20	1.00	1.10	1.62	1.81	1.51	1.76
max rms / min rms (angular) :	1.37	1.33	1.45	2.60	3.18	2.98	2.02	1.28

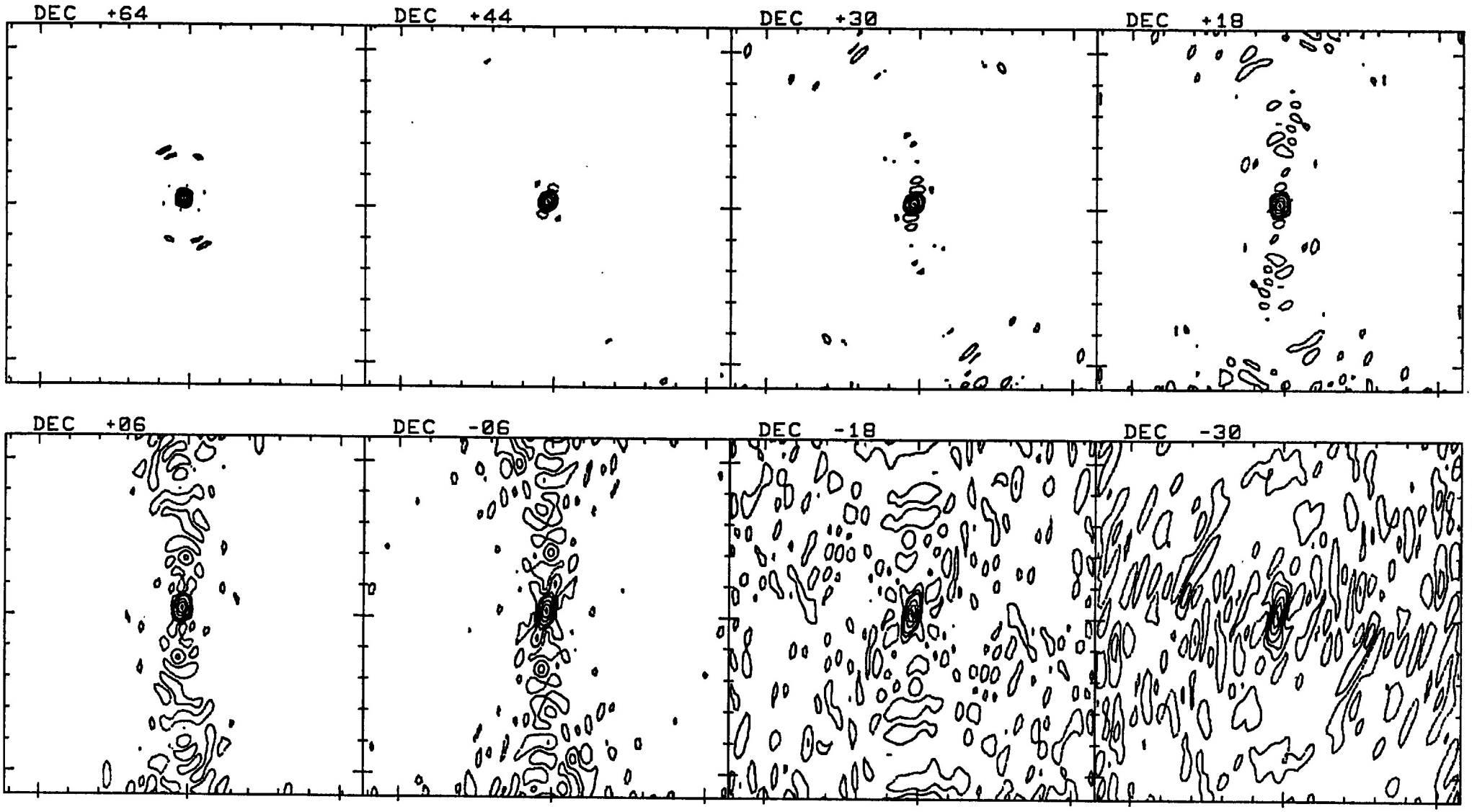


HAWAII ANCH OVRO SOCORRO LASL BLDR GRFK2 NRAO HSTK BRVL2

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0

Plot size (mas) : 23.9 by 23.9

Array : D2 - no uv taper	:	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam)	:	0.016	0.018	0.020	0.026	0.030	0.035	0.042	0.051
inner rms / outer rms	:	1.42	2.21	2.13	1.53	2.14	2.36	1.26	1.58
max rms / min rms (angular)	:	1.25	1.33	1.58	2.07	2.78	2.59	1.36	1.56



HAWAII ANCH OVRO SOCORRO LASL BLDR GRFK2 NRAO HSTK BRVL2

Contours : -15.0 -5.0 5.0 15.0 25.0 50.0 75.0 95.0
Plot size (mas) : 23.9 by 23.9

Array : D2 - INVERT weighting :	64	44	30	18	06	-06	-18	-30
total map rms (excluding beam) :	0.015	0.016	0.019	0.023	0.028	0.033	0.041	0.047
inner rms / outer rms :	1.52	1.65	1.82	1.39	1.64	1.97	1.12	1.20
max rms / min rms (angular) :	1.16	1.39	1.77	2.29	3.45	3.10	1.51	1.79