Interferometric Observations of the CMB from the South Pole with DASI

Clem Pryke

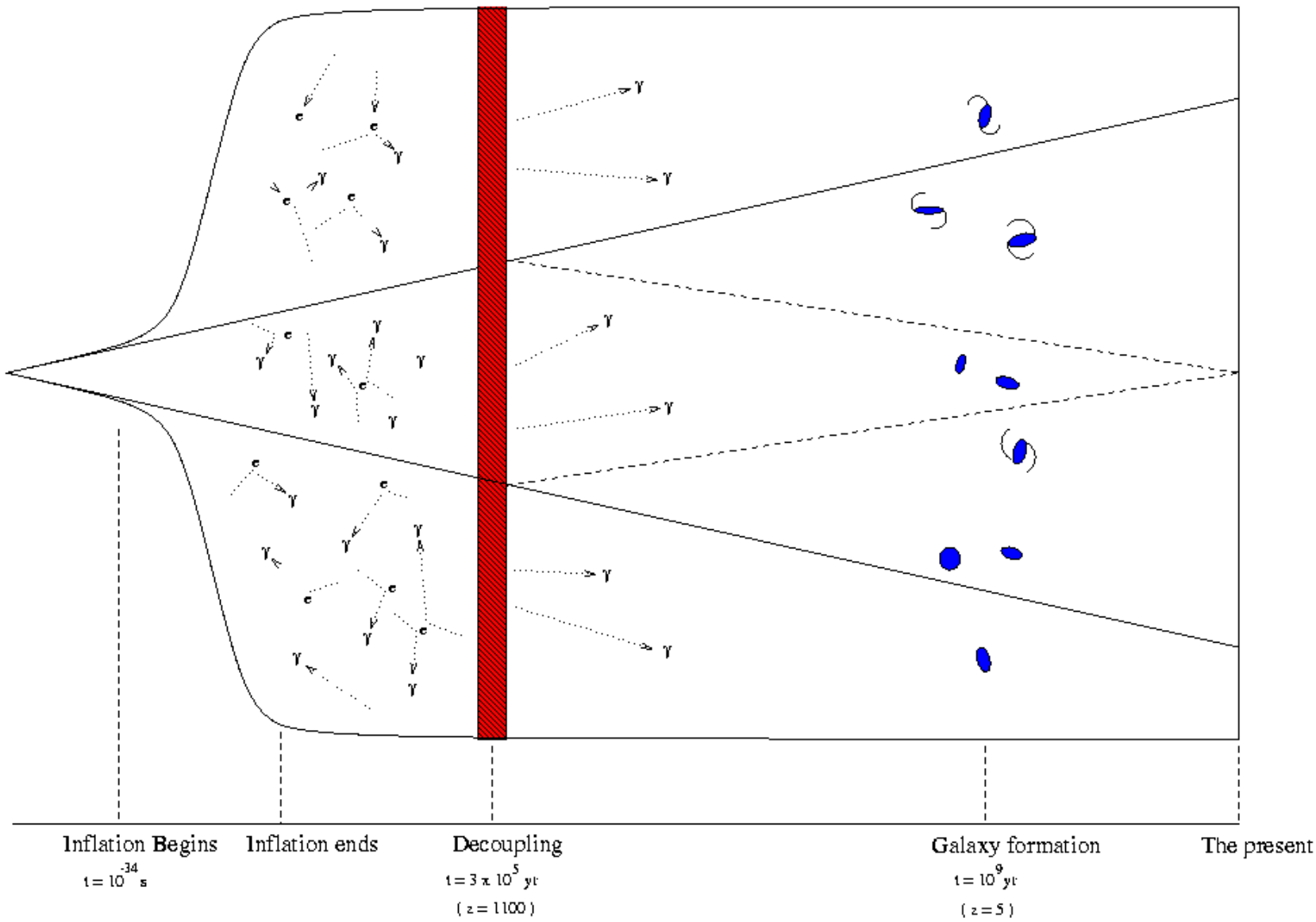
Madison Astrophysics Seminar

October 26 2000

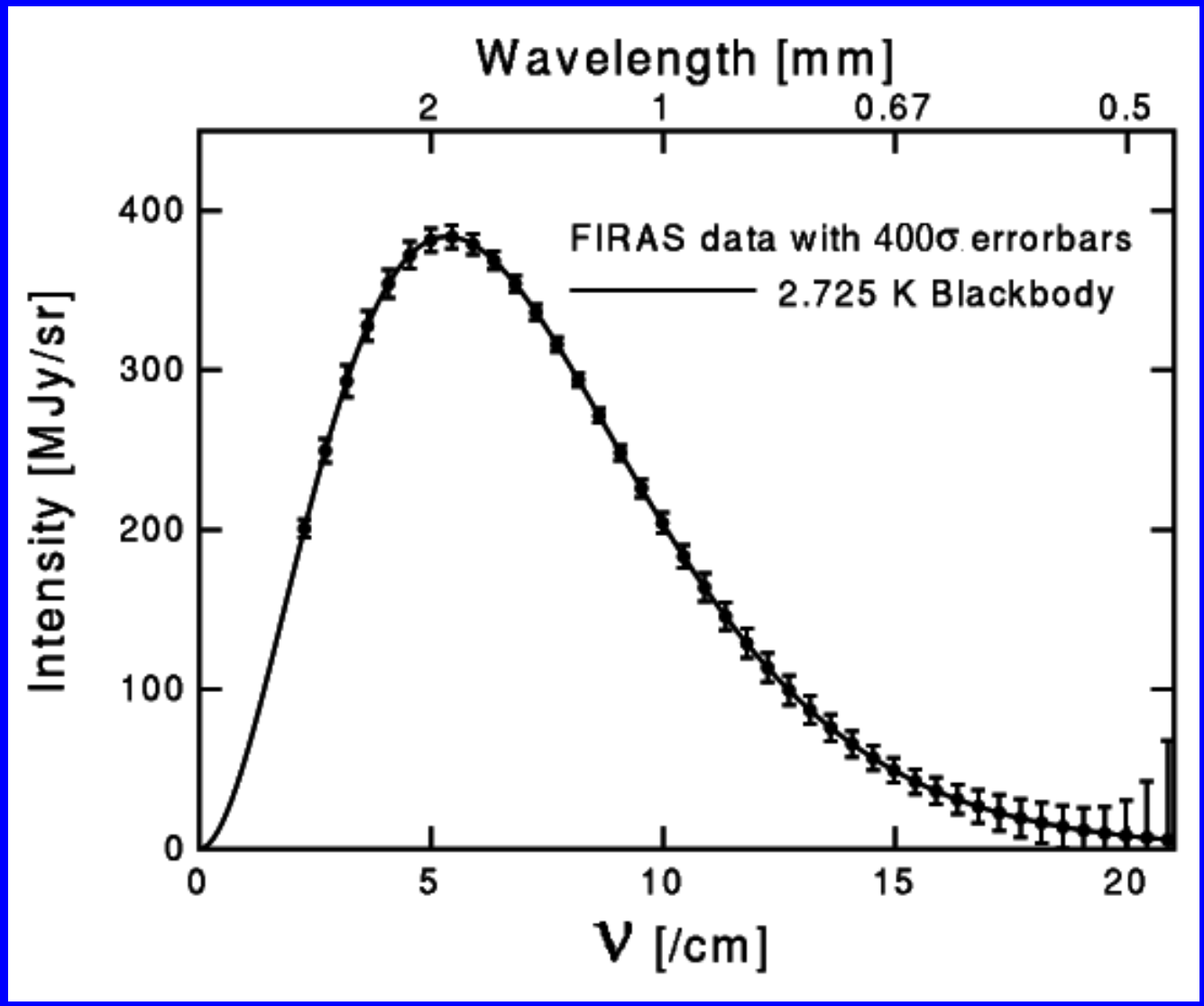
Outline

- CMB, multipoles, and current anisotropy data
- How DASI works in principle
- Design and implementation
- Deployment
- Analysis overview
- Conclusions

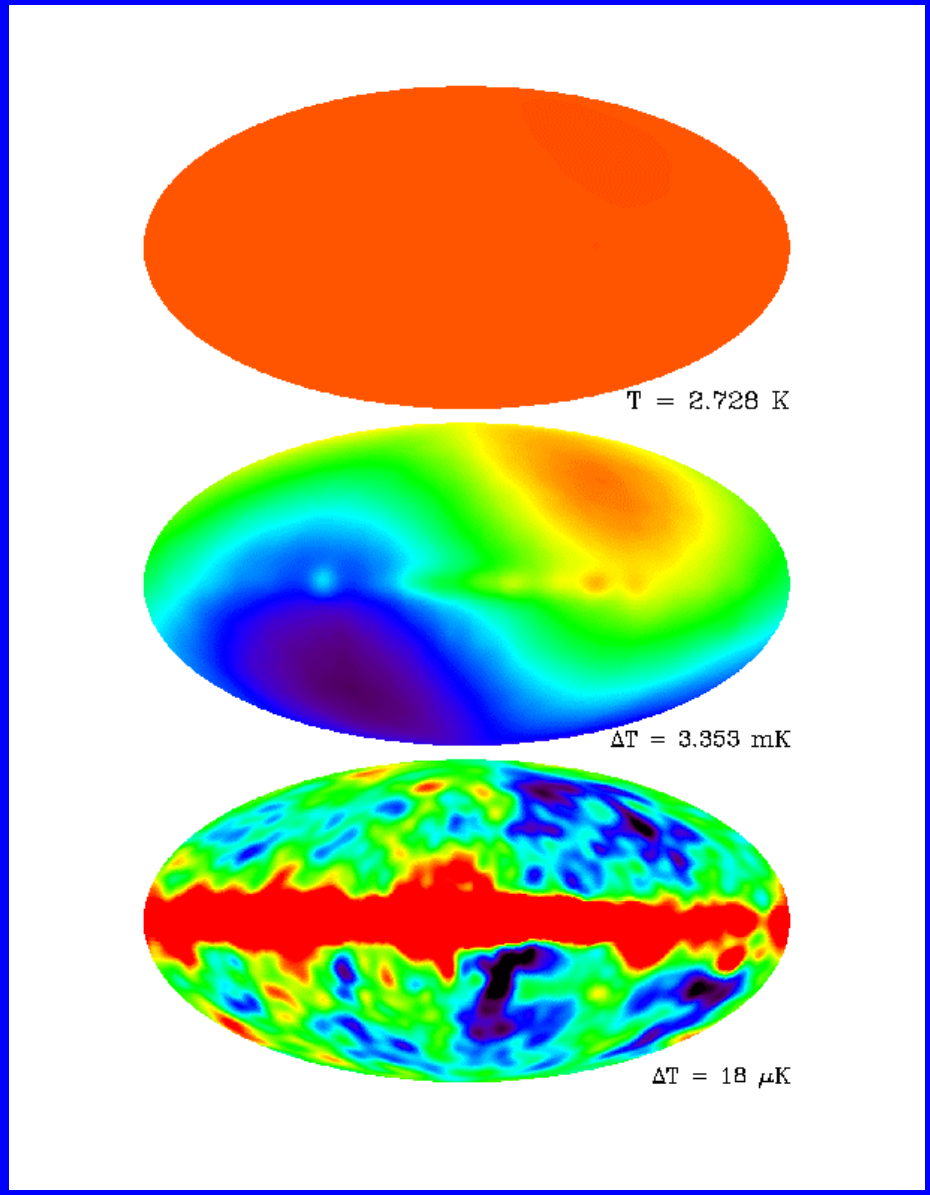
A Cartoon History of the Universe



CMB is Blackbody Radiation

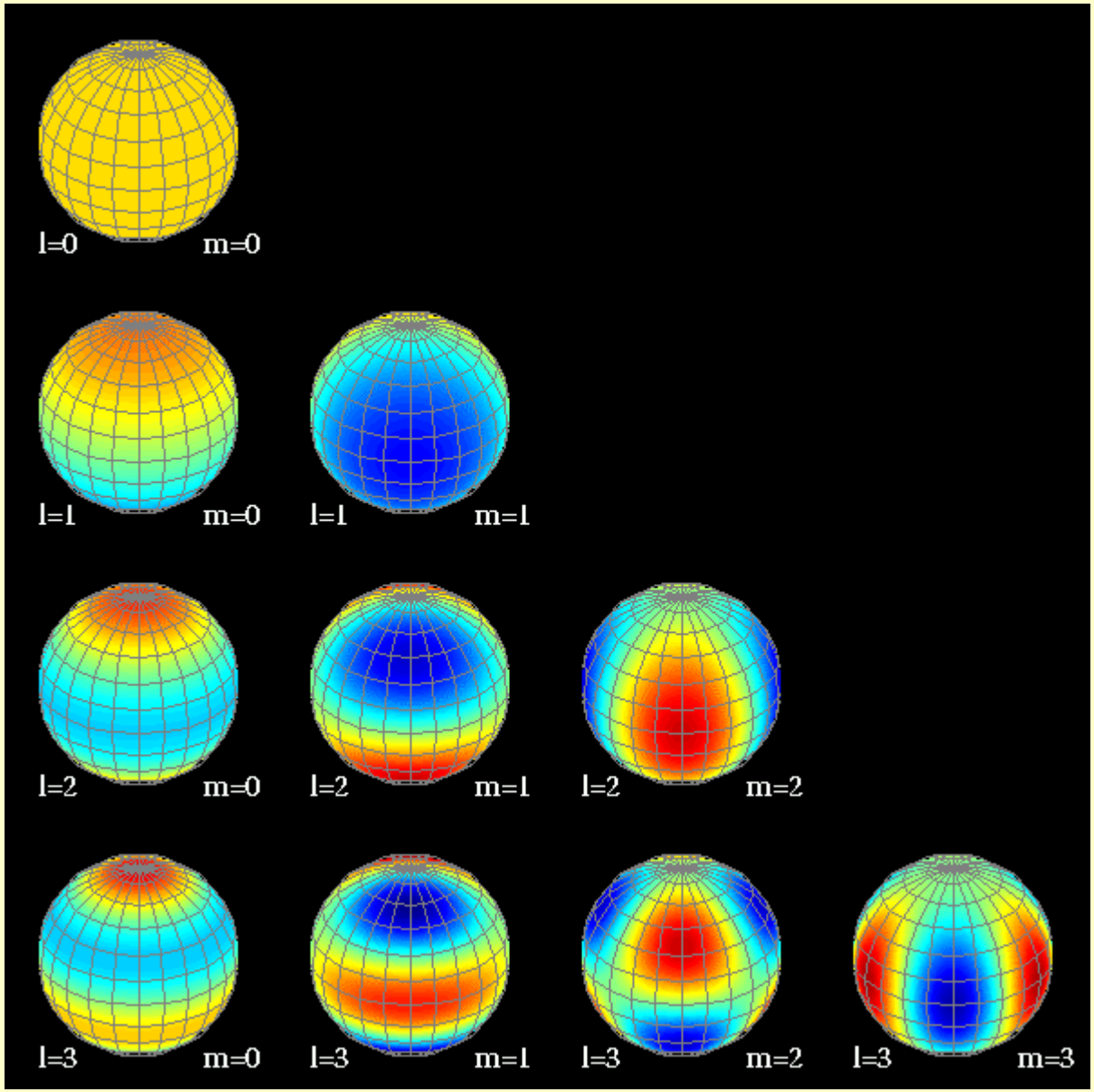


CMB is nearly Isotropic

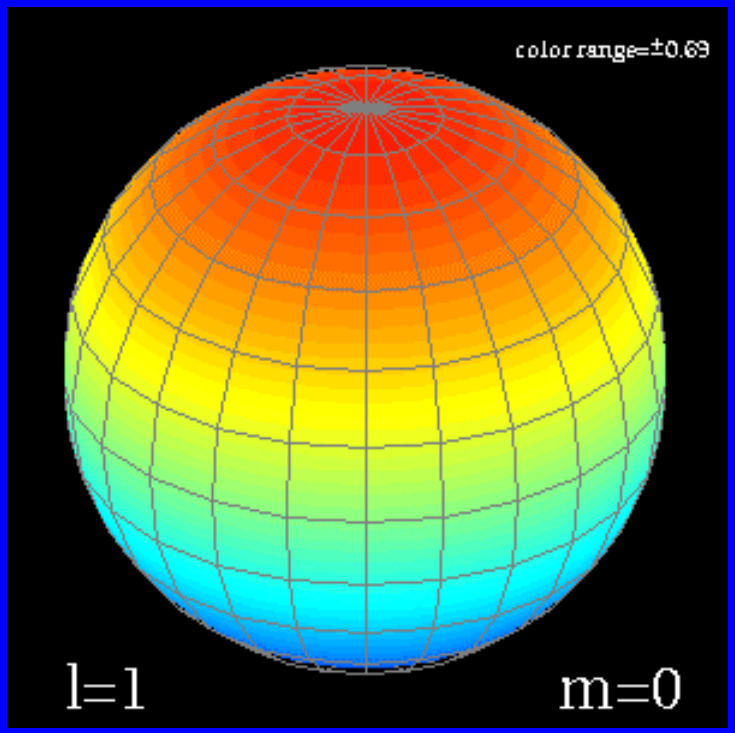


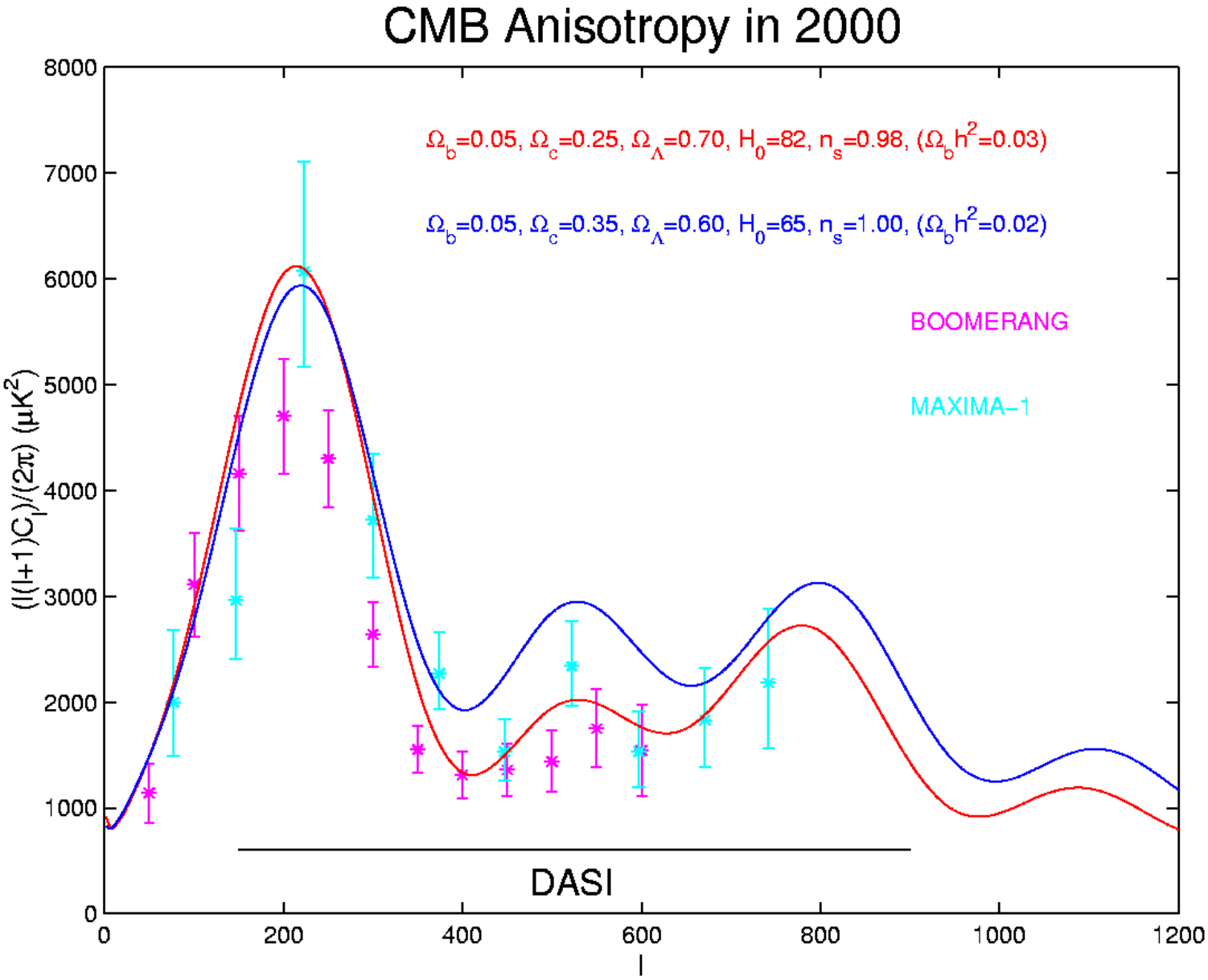
$$T(\theta,\phi) = \sum_{l=0}^{\infty} \sum_{m=-l}^{+l} t_{l,m} Y_{l,m}(\theta,\phi)$$

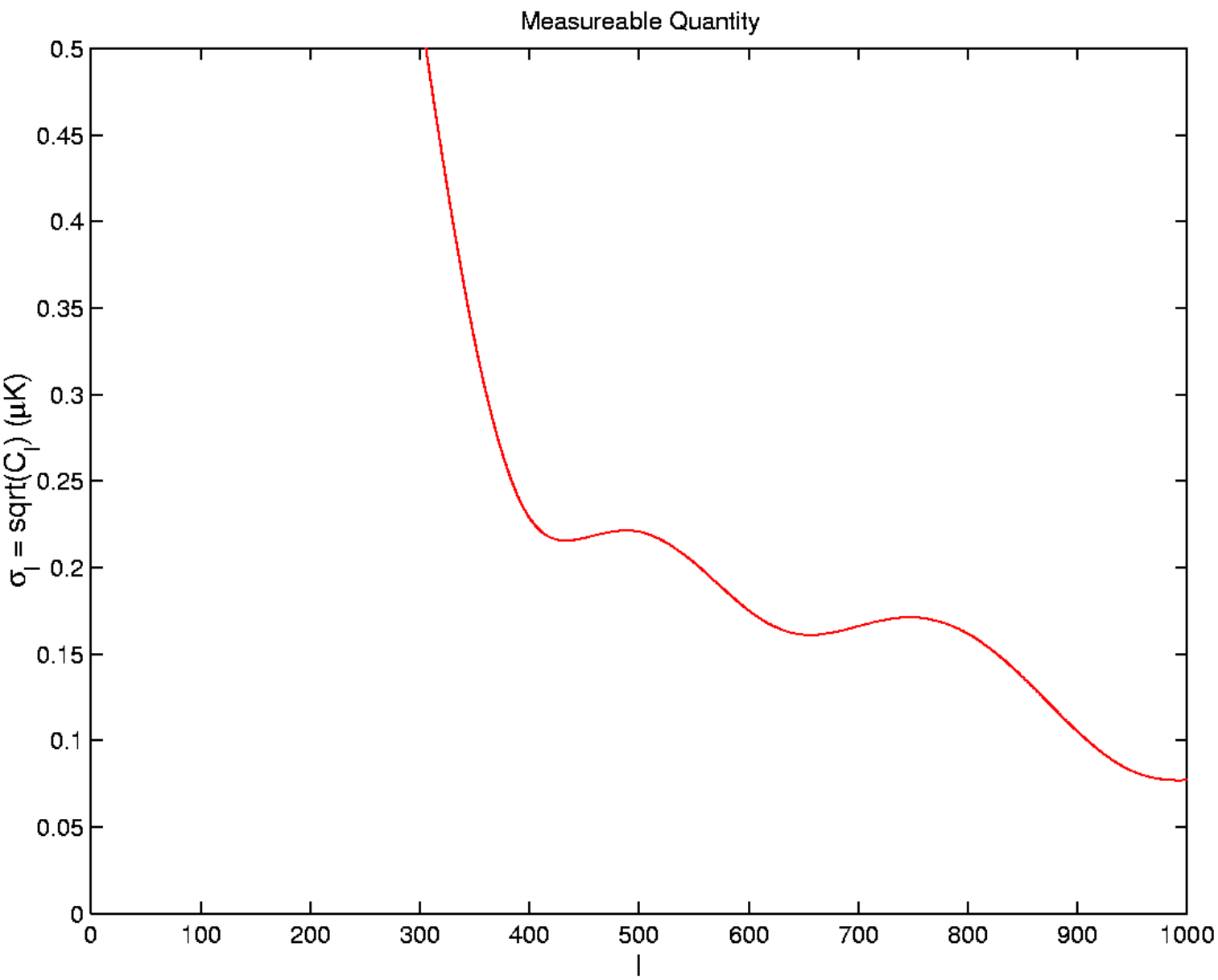
$$t_{l,-m} = t^*_{l,+m}$$



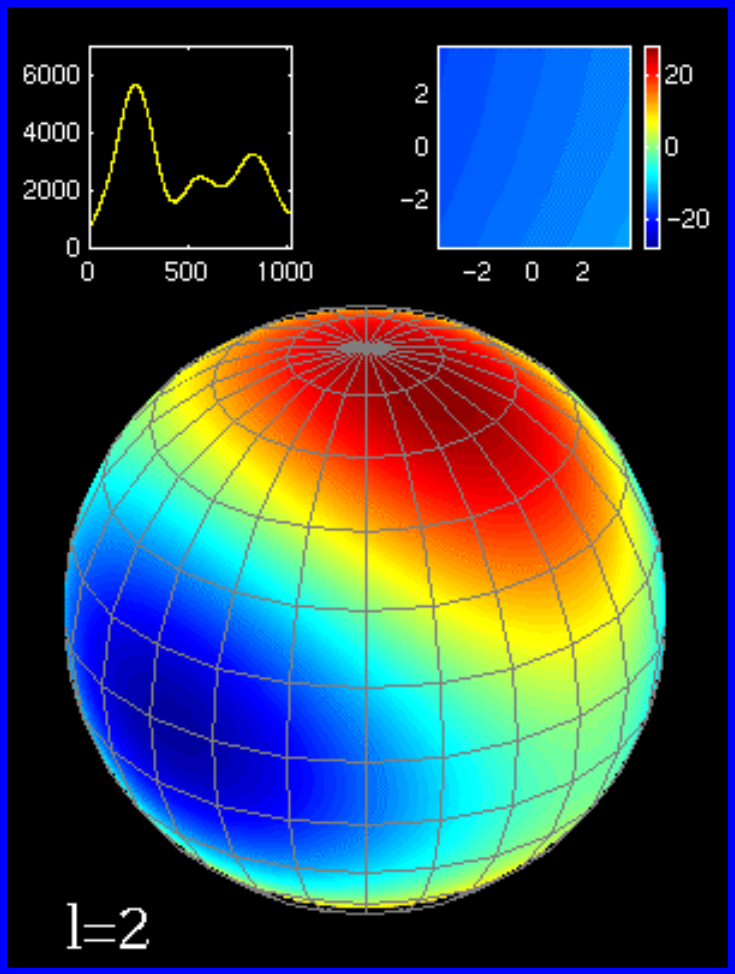
Multipole Components



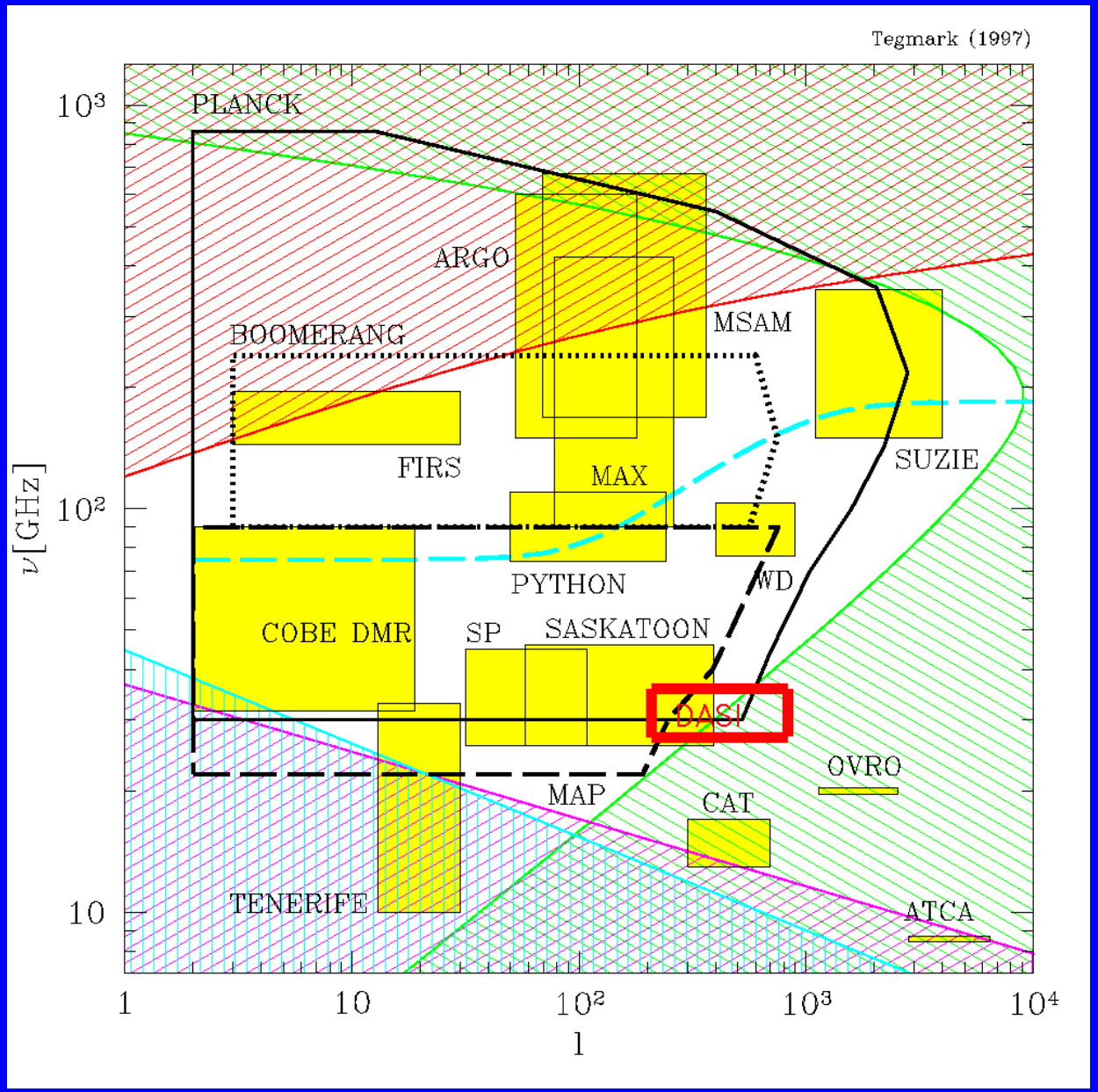

CMB Anisotropy in 2000
Ω_b=0.05, Ω_c=0.25, Ω_Λ=0.70, H_0=82, n_s=0.98, ($\Omega_b h^2$=0.03)
Ω_b=0.05, Ω_c=0.35, Ω_Λ=0.60, H_0=65, n_s=1.00, ($\Omega_b h^2$=0.02)
BOOMERANG
MAXIMA–1
DASI
$(l(l+1)C_l)/(2\pi)$ (μK^2)
l
0
1000
2000
3000
4000
5000
6000
7000
8000
0
200
400
600
800
1000
1200


Measureable Quantity
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
σl = sqrt(Cl) (μK)
0
100
200
300
400
500
600
700
800
900
1000
l

CMB Sky Simulation



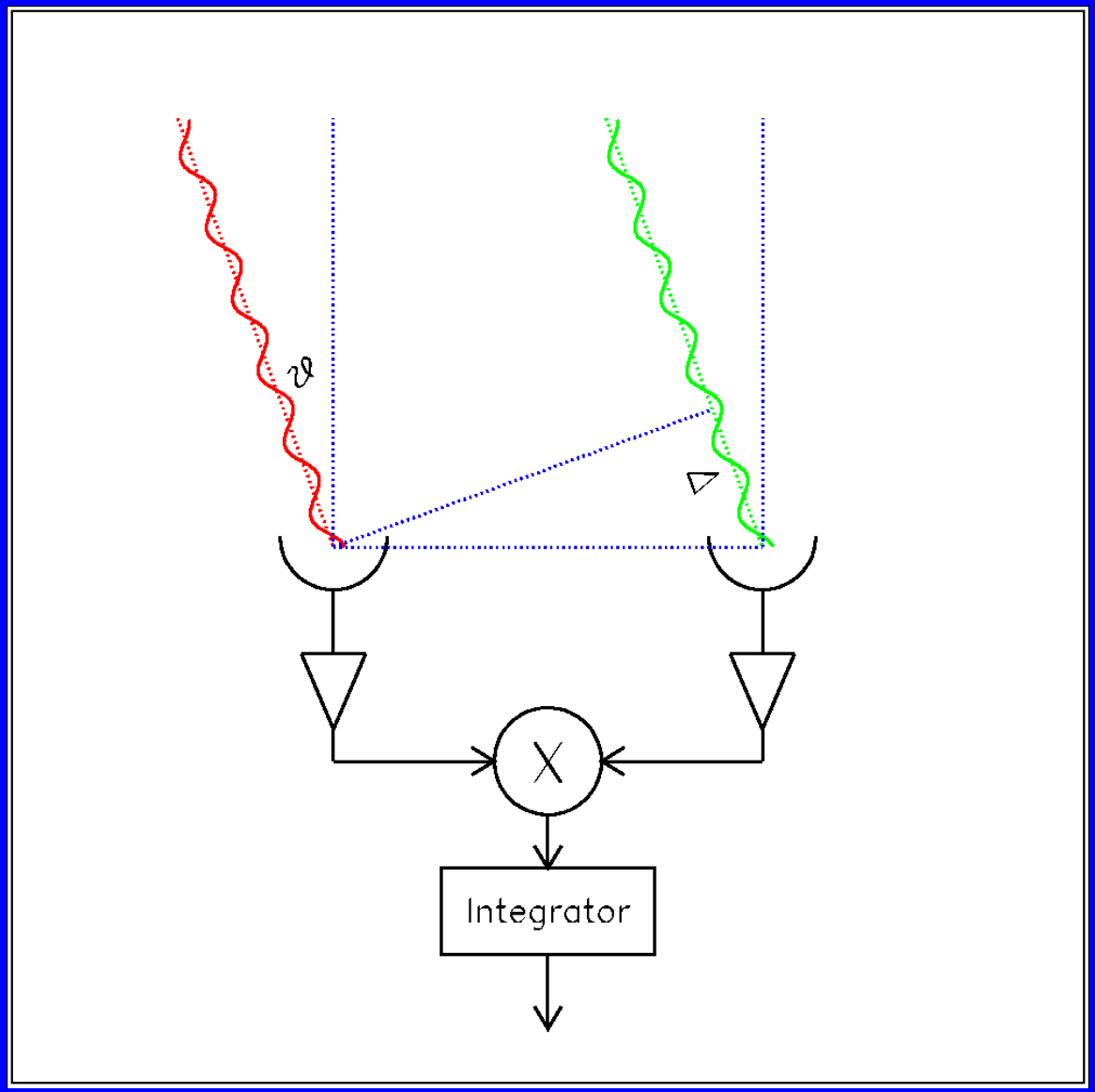
Foregrounds

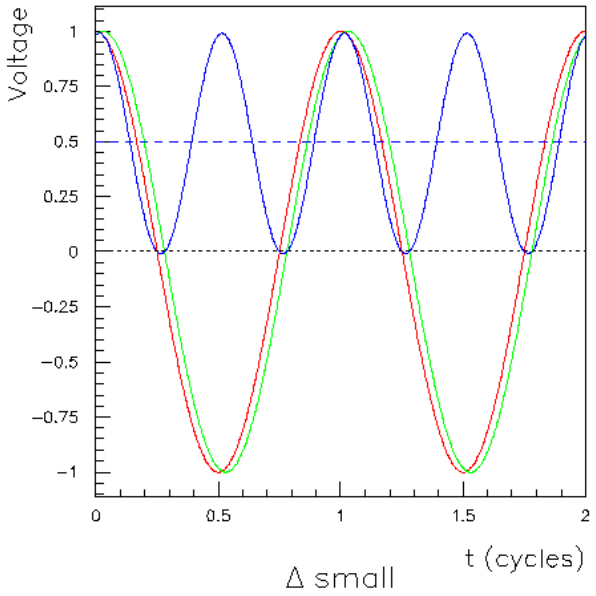


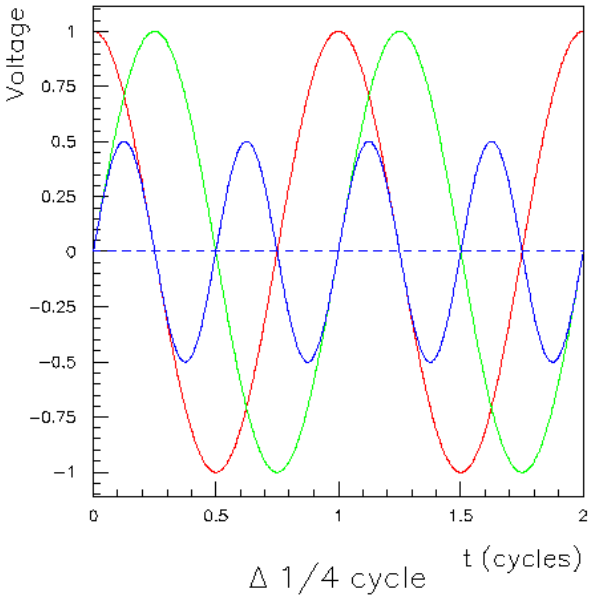
Why an Interferometer?

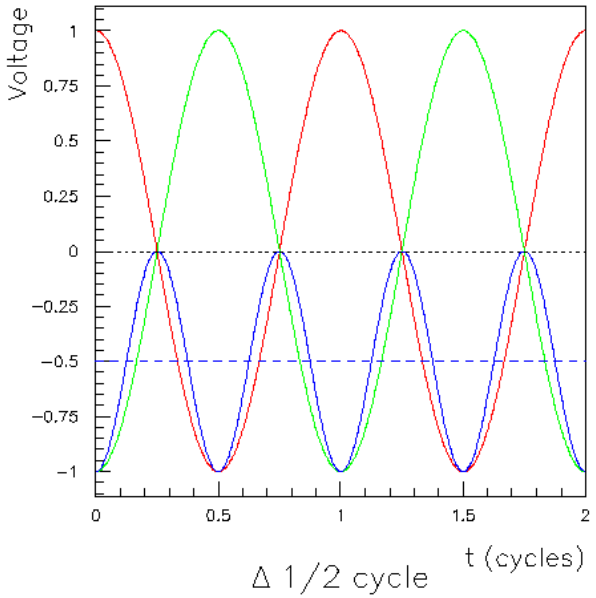
- Directly measures power spectrum of the sky.
- Intrinsically stable – only correlated signals are detected.
- Designer can control angular range covered.

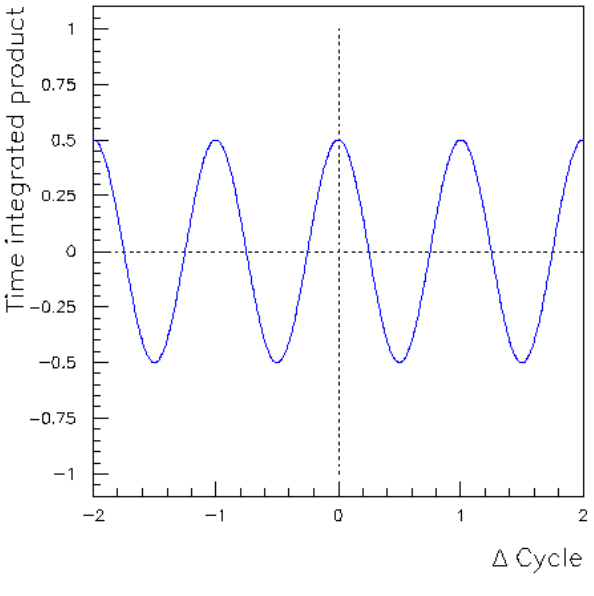
Radio Interferometry

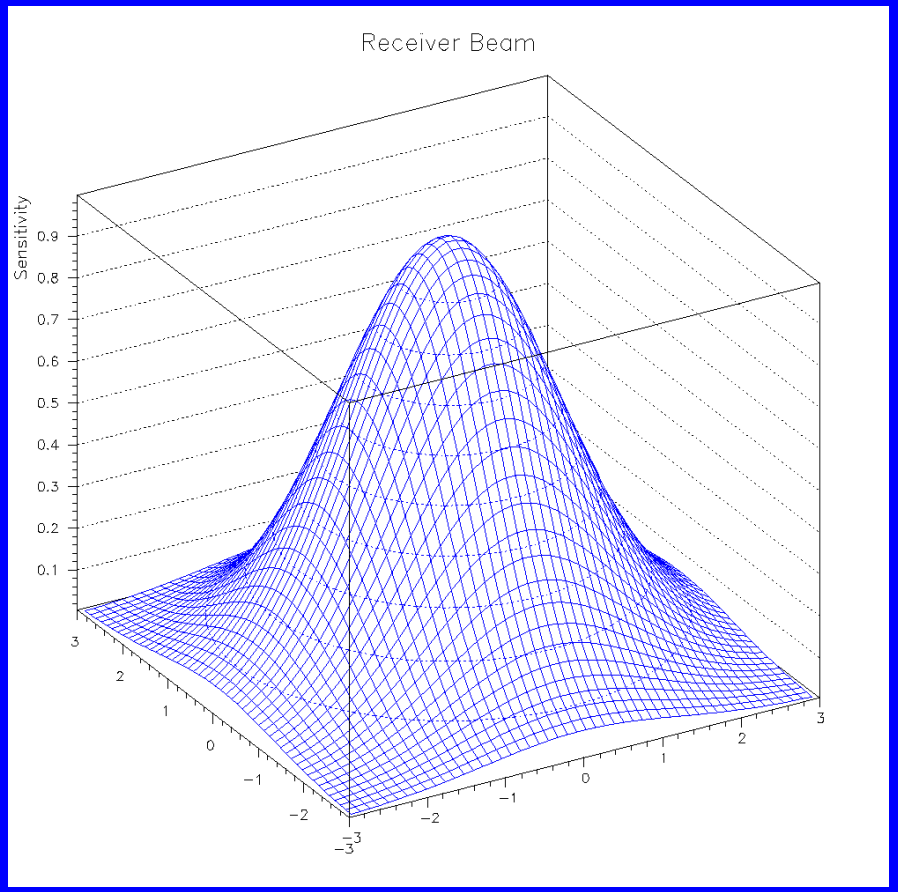


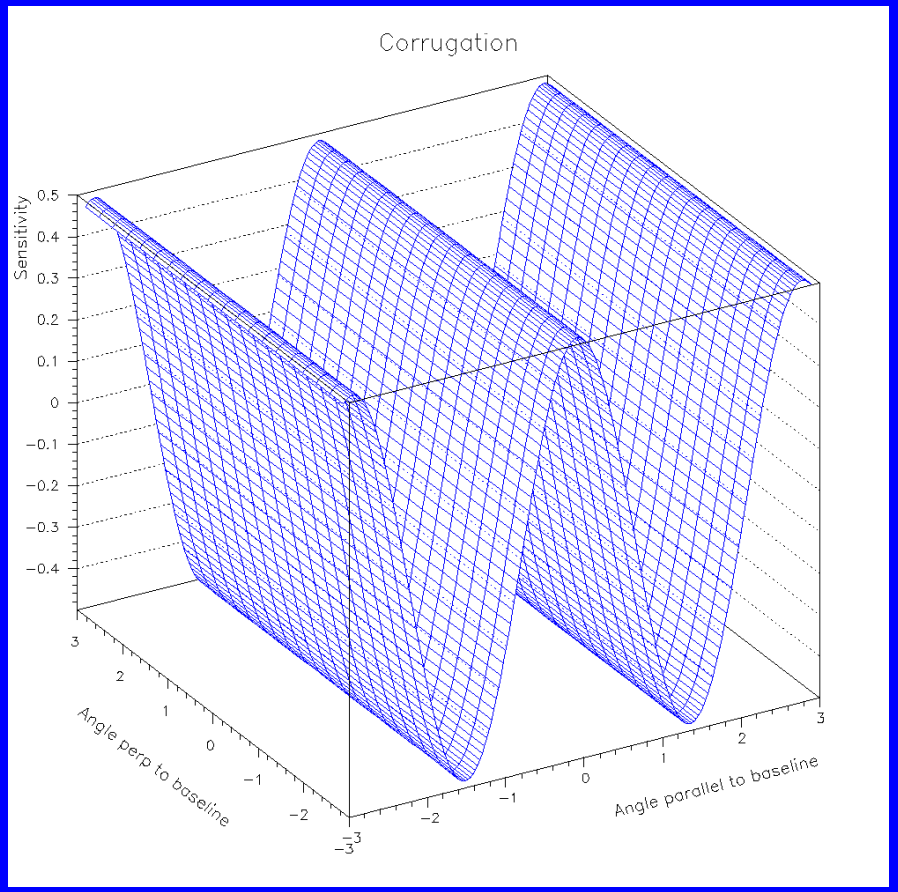

Voltage
1
0.75
0.5
0.25
0
−0.25
−0.5
−0.75
−1
0
0.5
1
1.5
2
t (cycles)
Δ small

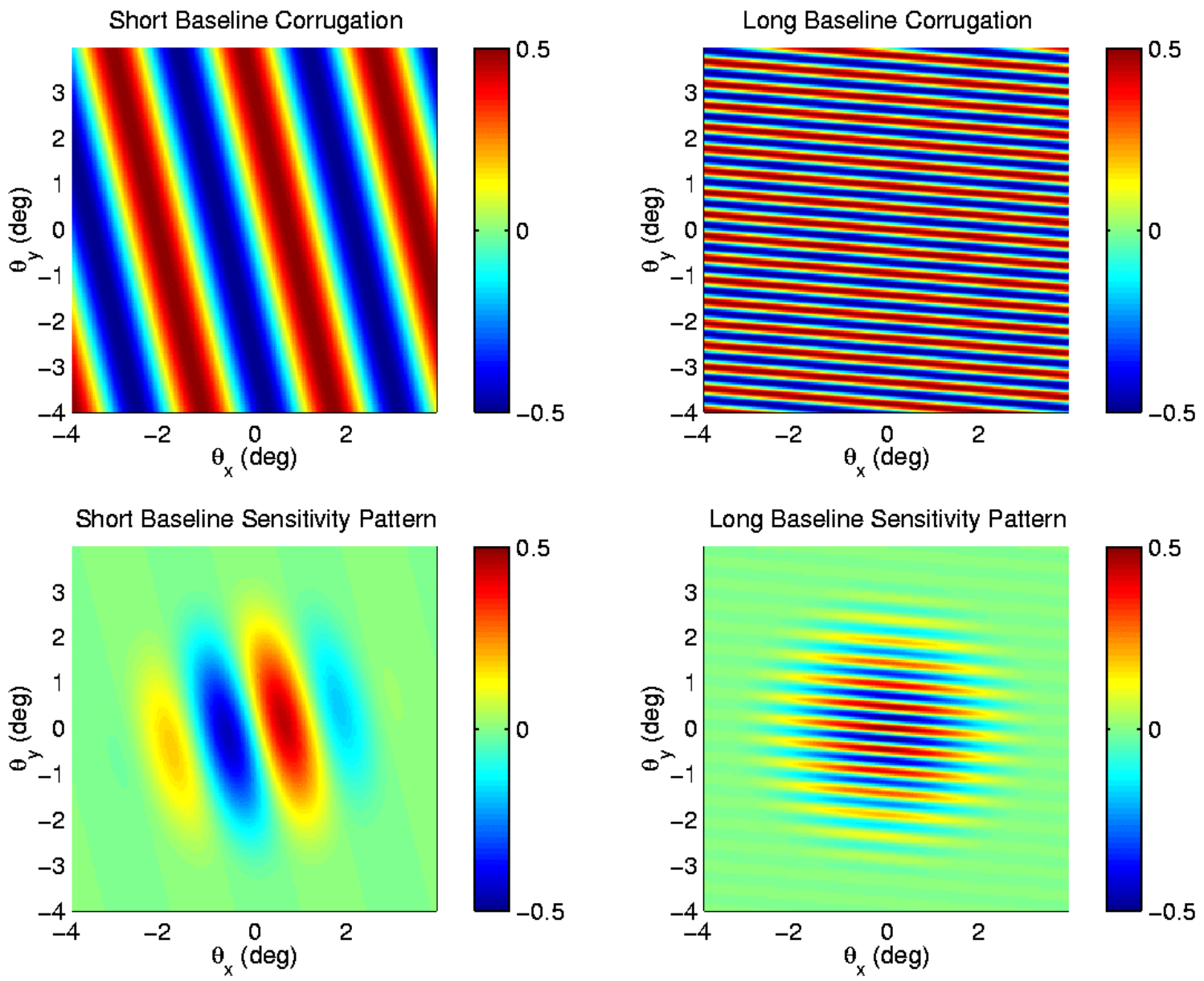

Voltage
1
0.75
0.5
0.25
0
−0.25
−0.5
−0.75
−1
0
0.5
1
1.5
2
t (cycles)
Δ 1/4 cycle

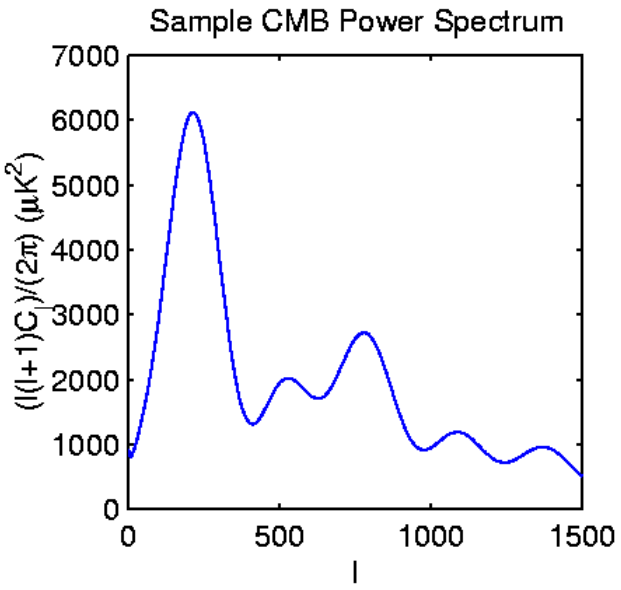

Voltage
1
0.75
0.5
0.25
0
−0.25
−0.5
−0.75
−1
0
0.5
1
1.5
2
t (cycles)
Δ 1/2 cycle

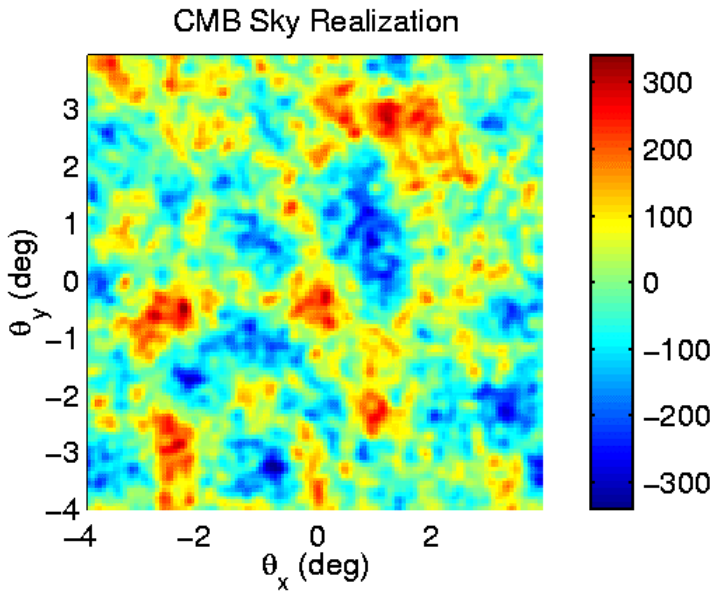

Time integrated product
1
0.75
0.5
0.25
0
−0.25
−0.5
−0.75
−1
−2
−1
0
1
2
Δ Cycle

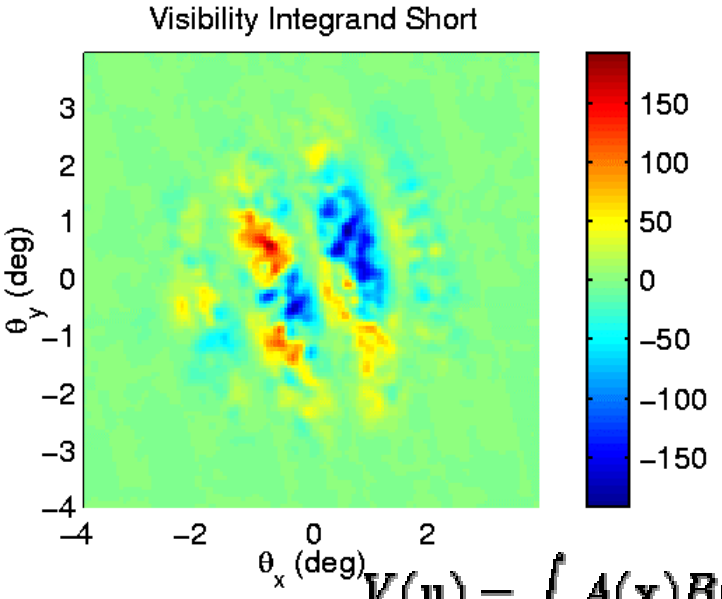

Receiver Beam
Sensitivity
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
3
2
1
0
−1
−2
−3

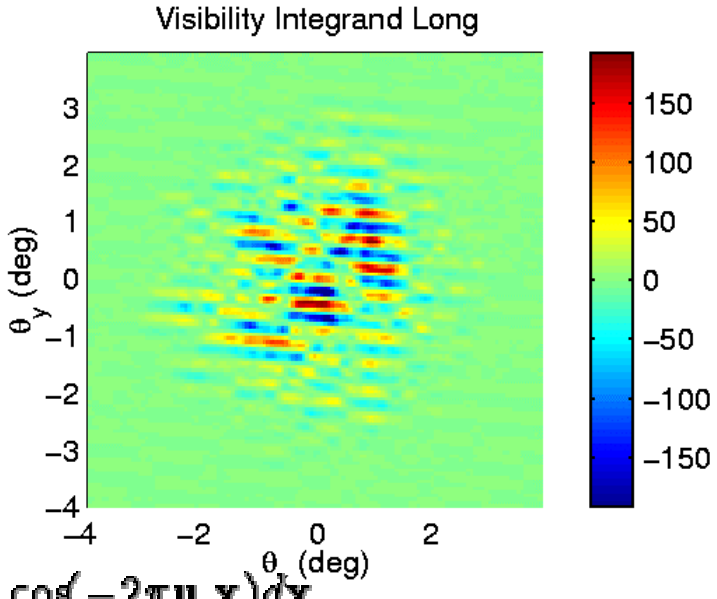

Corrugation
Sensitivity
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
Angle perp to baseline
Angle parallel to baseline
3
2
1
0
−1
−2
−3


Short Baseline Corrugation
Long Baseline Corrugation
Short Baseline Sensitivity Pattern
Long Baseline Sensitivity Pattern
θy (deg)
θx (deg)
3
2
1
0
−1
−2
−3
−4
−4
−2
0
2
0.5
0
−0.5

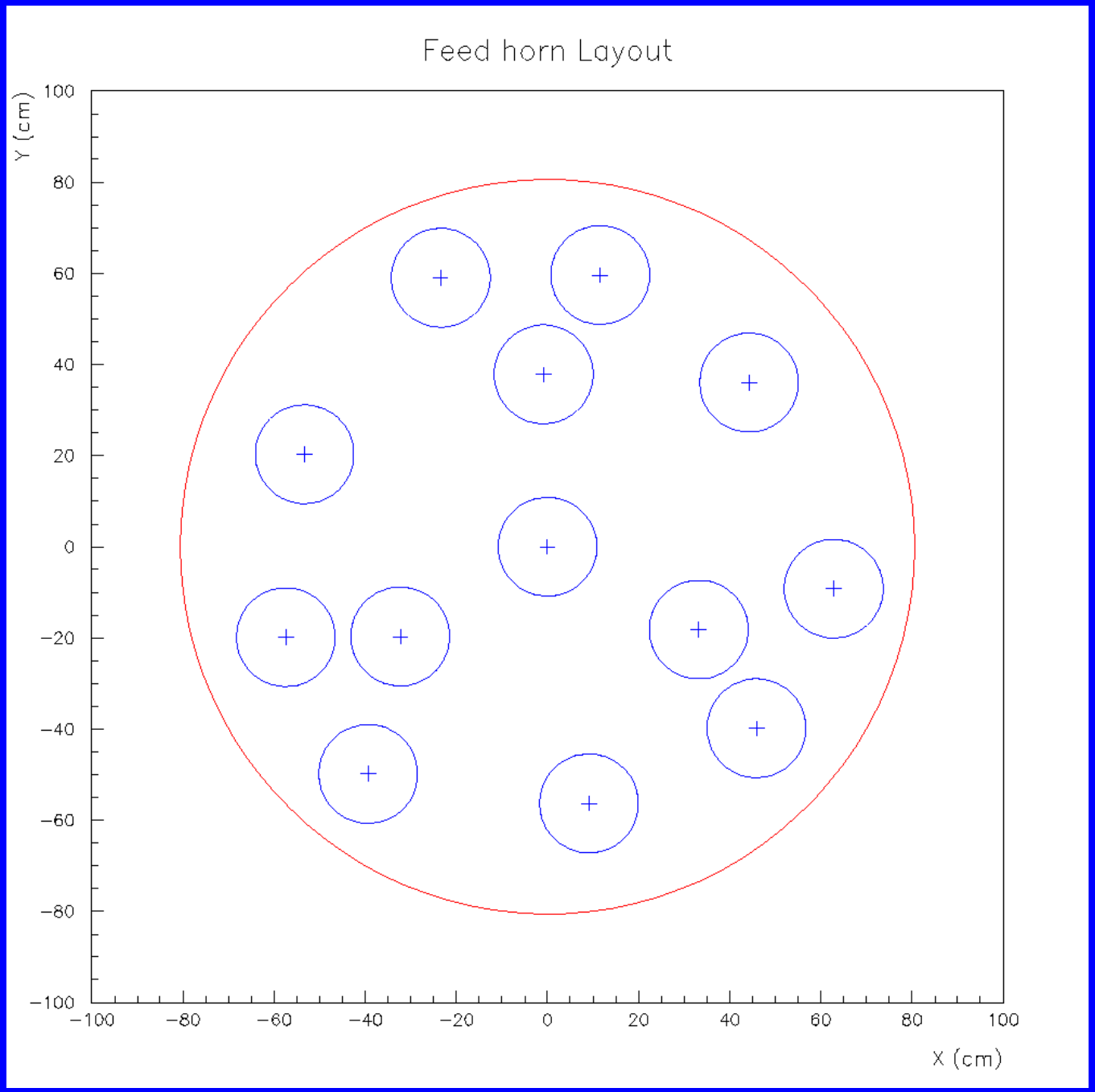


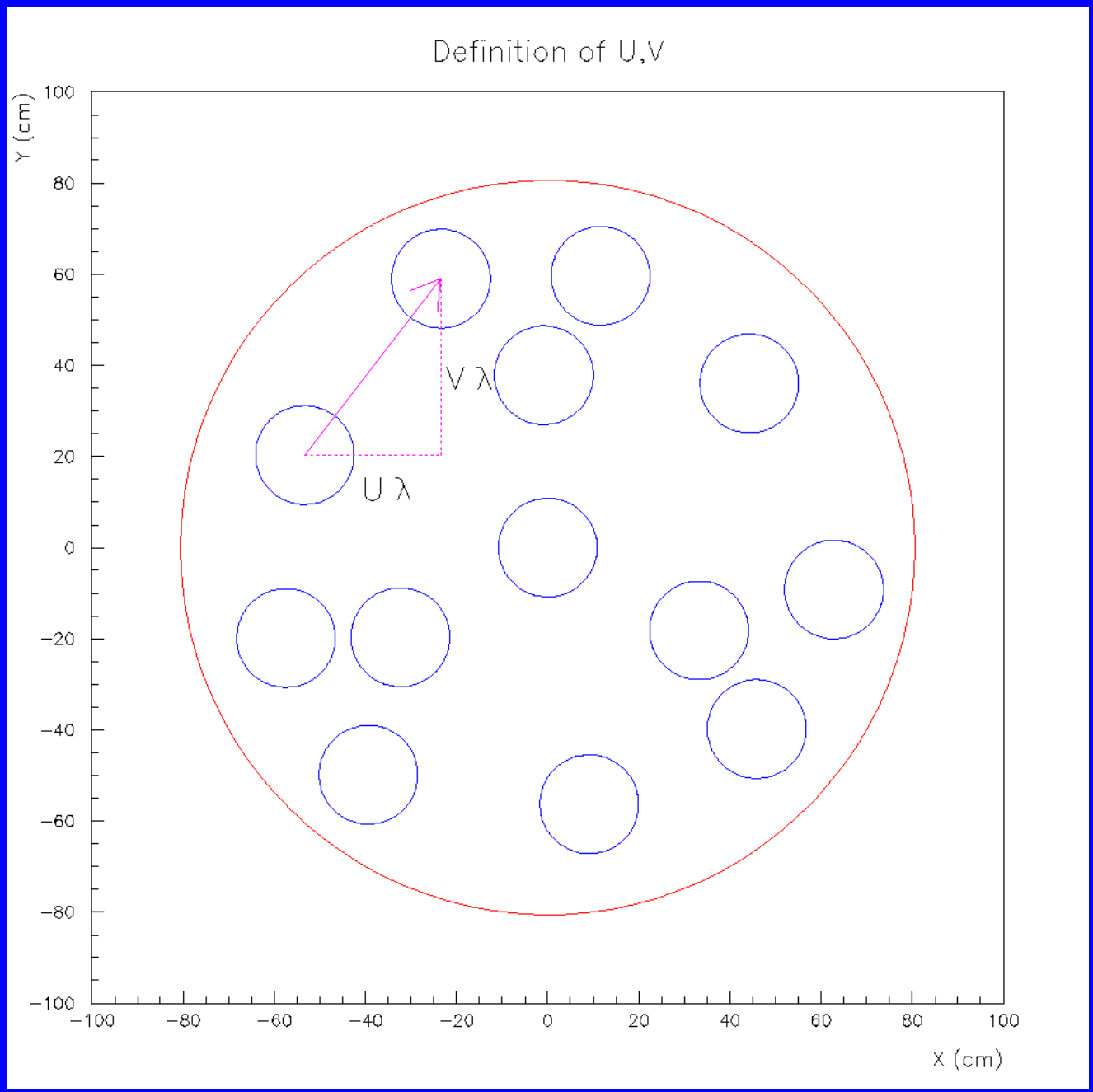


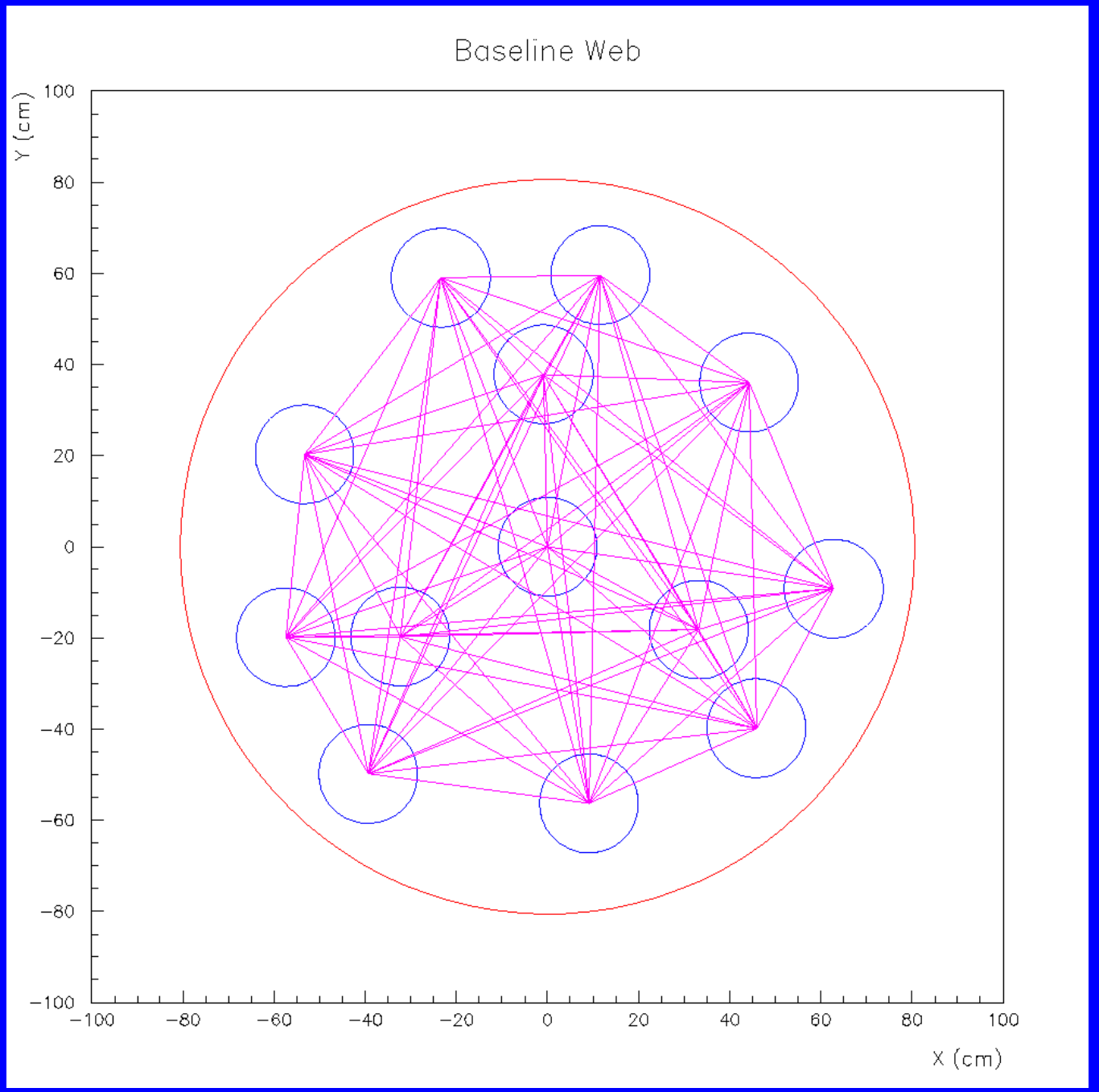


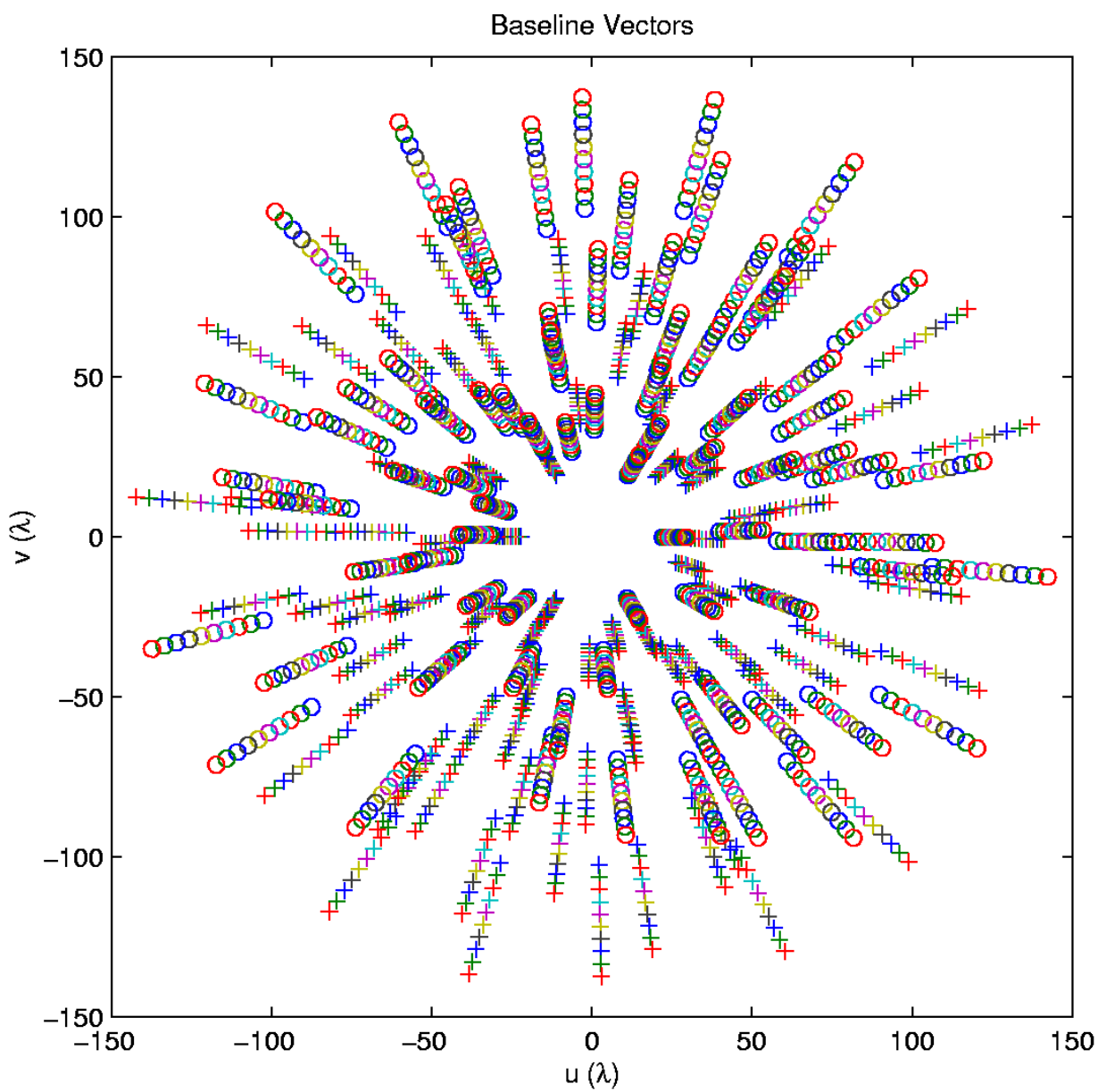


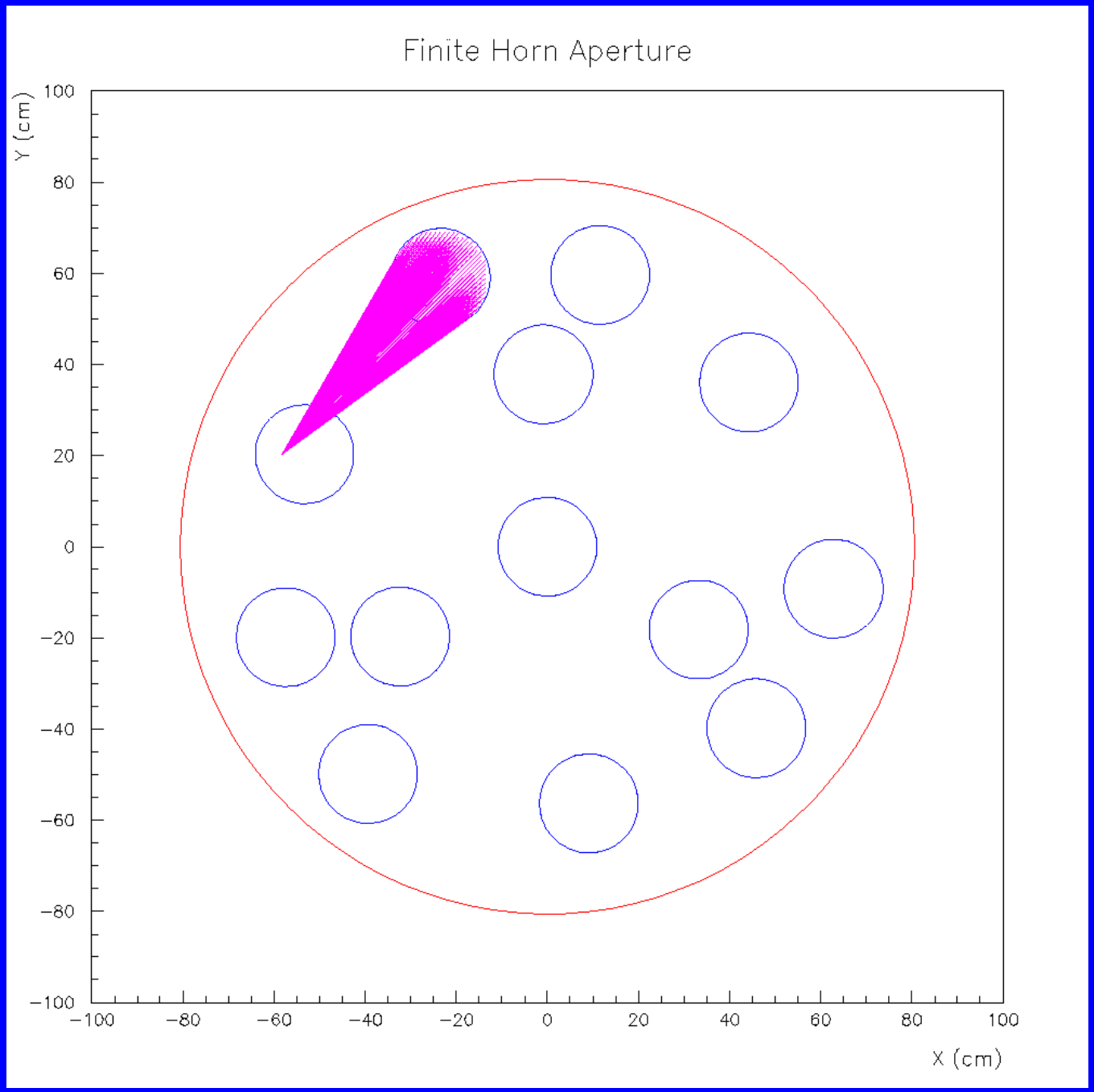
$$V(\mathbf{u}) = \int A(\mathbf{x}) B(\mathbf{x}) \cos(-2\pi \mathbf{u}.\mathbf{x}) d\mathbf{x}$$

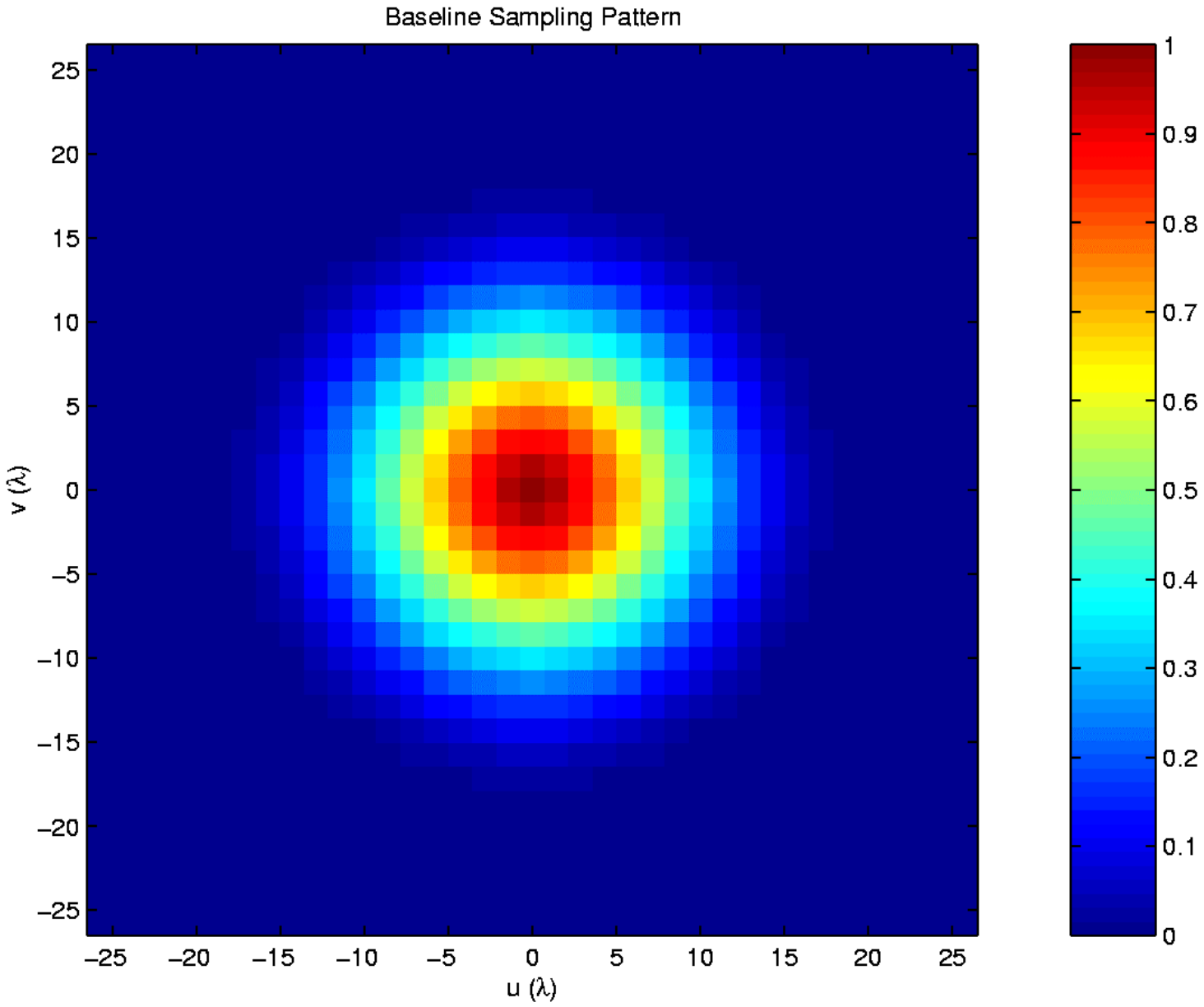

Feed horn Layout
Y (cm)
X (cm)
100
80
60
40
20
0
−20
−40
−60
−80
−100
−100
−80
−60
−40
−20
0
20
40
60
80
100

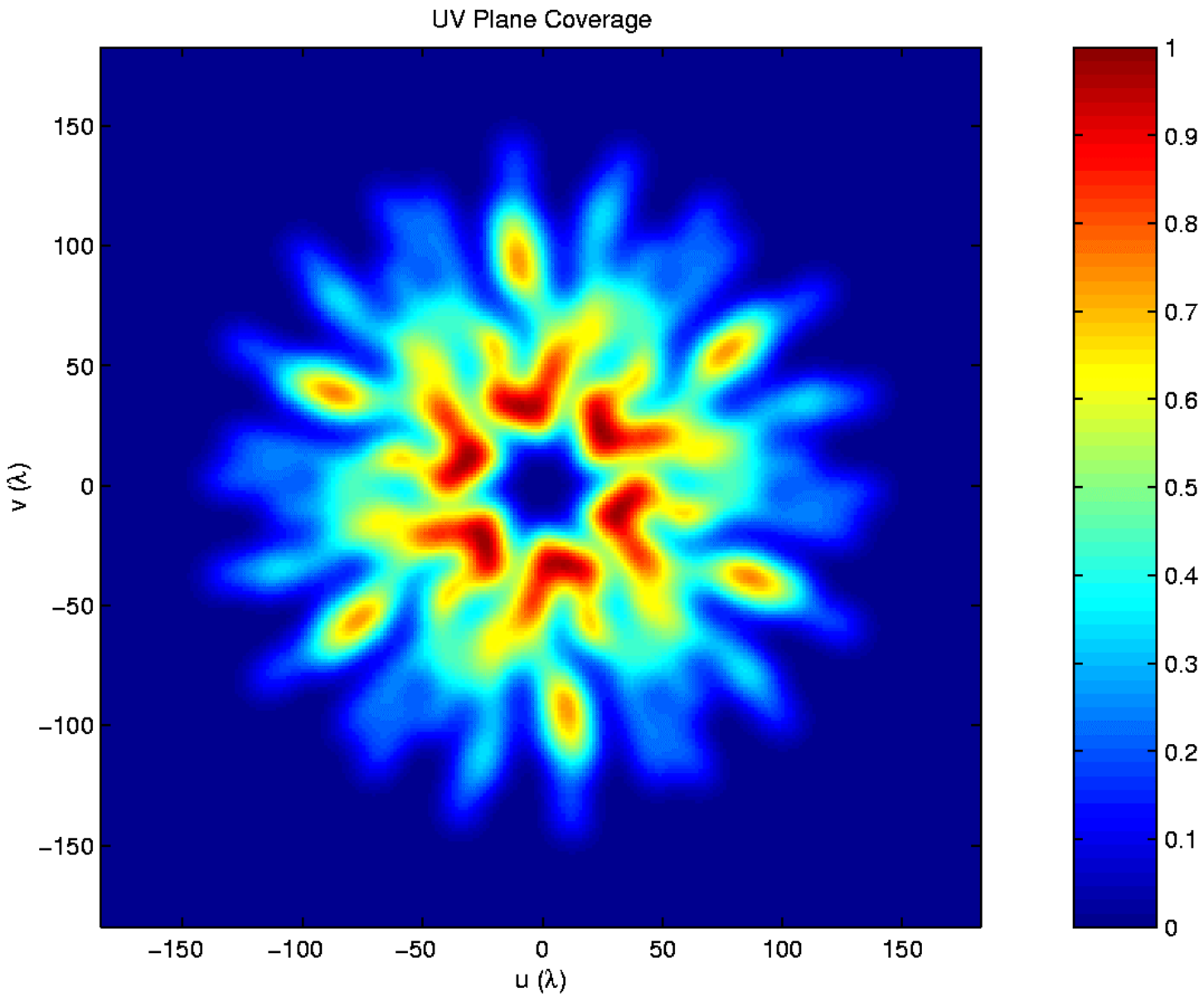

Definition of U,V
Y (cm)
X (cm)
V λ
U λ
100
80
60
40
20
0
−20
−40
−60
−80
−100
−100
−80
−60
−40
−20
0
20
40
60
80
100

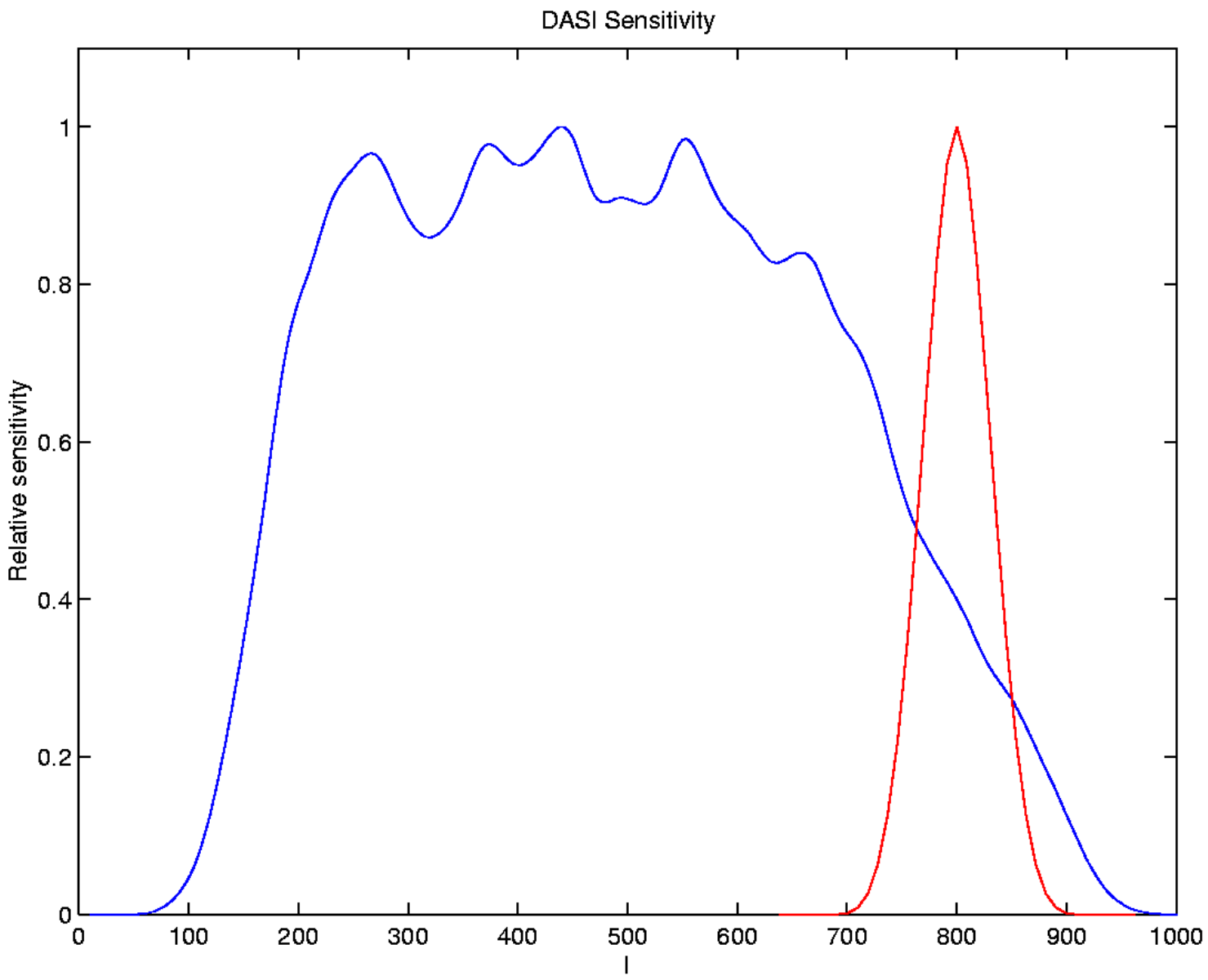

Baseline Web
Y (cm)
X (cm)
100
80
60
40
20
0
−20
−40
−60
−80
−100
−100
−80
−60
−40
−20
0
20
40
60
80
100


Baseline Vectors
150
100
50
0
−50
−100
−150
v (λ)
−150
−100
−50
0
50
100
150
u (λ)


Finite Horn Aperture
Y (cm)
X (cm)
100
80
60
40
20
0
−20
−40
−60
−80
−100
−100
−80
−60
−40
−20
0
20
40
60
80
100

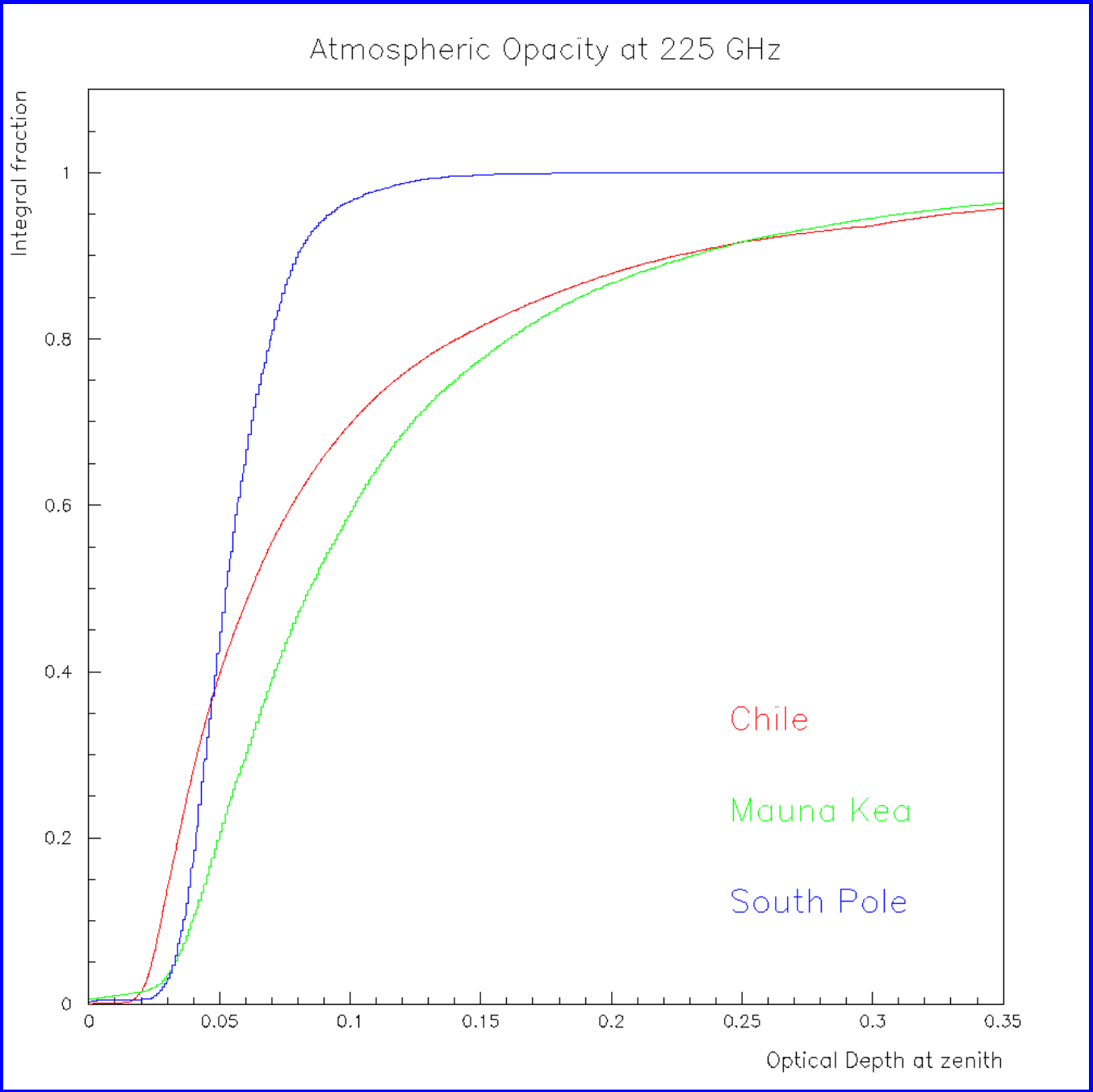

Baseline Sampling Pattern
v (λ)
u (λ)
25
20
15
10
5
0
−5
−10
−15
−20
−25
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

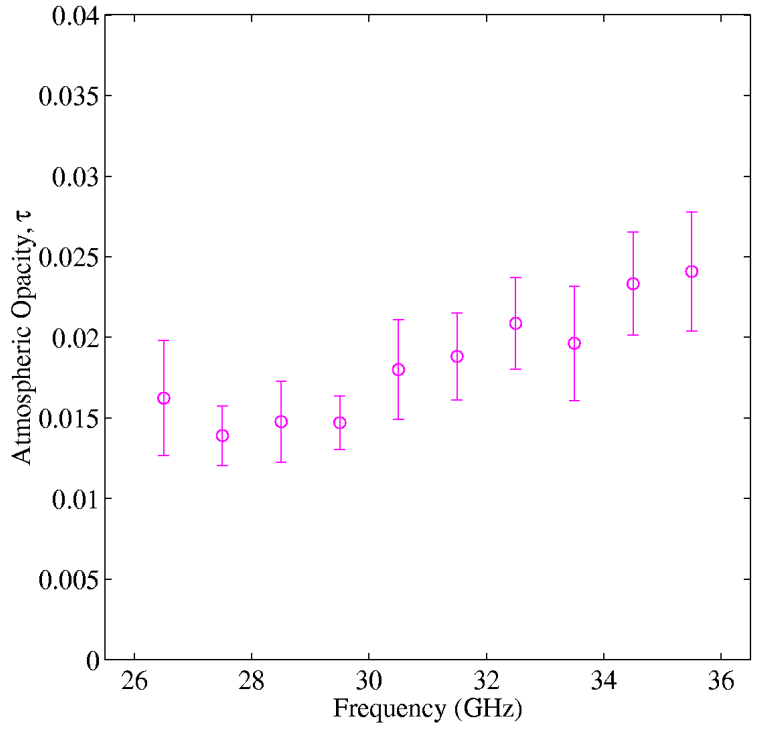

UV Plane Coverage
150
100
50
0
−50
−100
−150
v (λ)
−150
−100
−50
0
50
100
150
u (λ)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

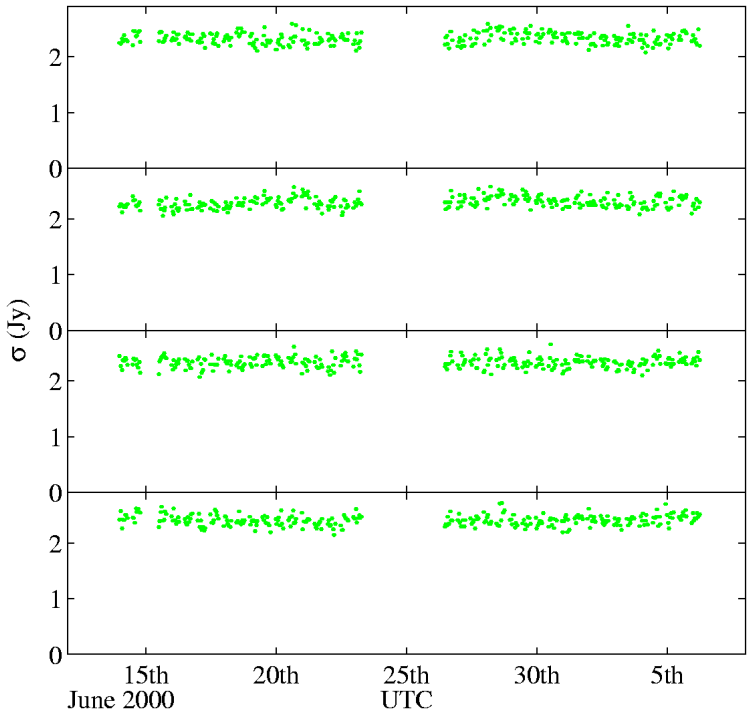

DASI Sensitivity
Relative sensitivity
l
0
0.2
0.4
0.6
0.8
1
0
100
200
300
400
500
600
700
800
900
1000

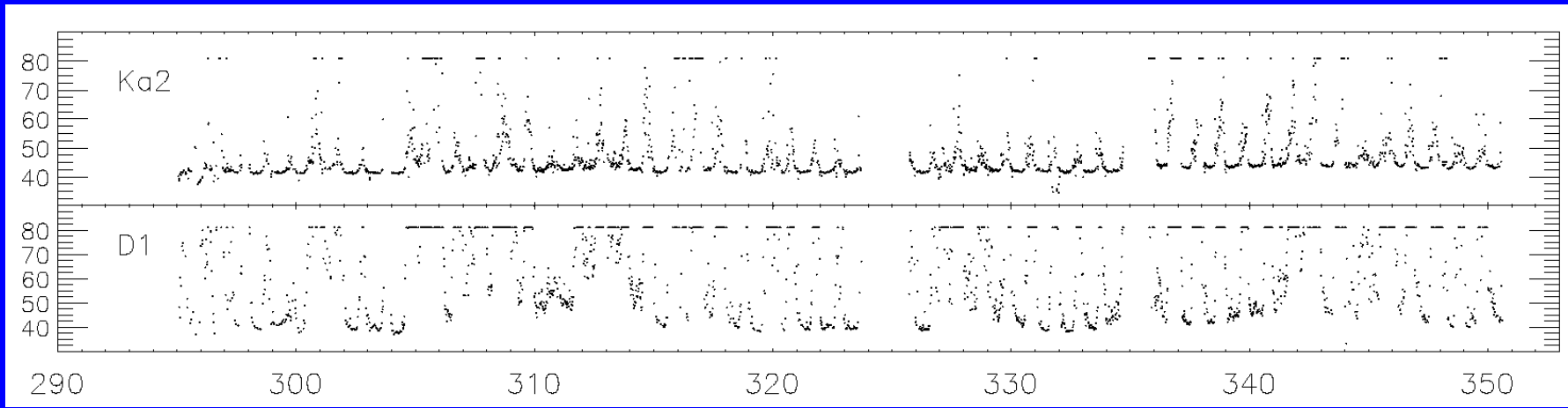
Why at the South Pole?

- Low atmospheric moisture
- Atmosphere highly stable
- No Sun for 6 months of the year
- Fields remain at constant elevation angle
- Existing infrastructure and logistics


Atmospheric Opacity at 225 GHz
Integral fraction
0
0.2
0.4
0.6
0.8
1
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Optical Depth at zenith
Chile
Mauna Kea
South Pole


Atmospheric Opacity, τ
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
26
28
30
32
34
36
Frequency (GHz)


σ (Jy)
2
1
0
15th
20th
25th
30th
5th
June 2000
UTC


Ka2
D1
80
70
60
50
40
290
300
310
320
330
340
350

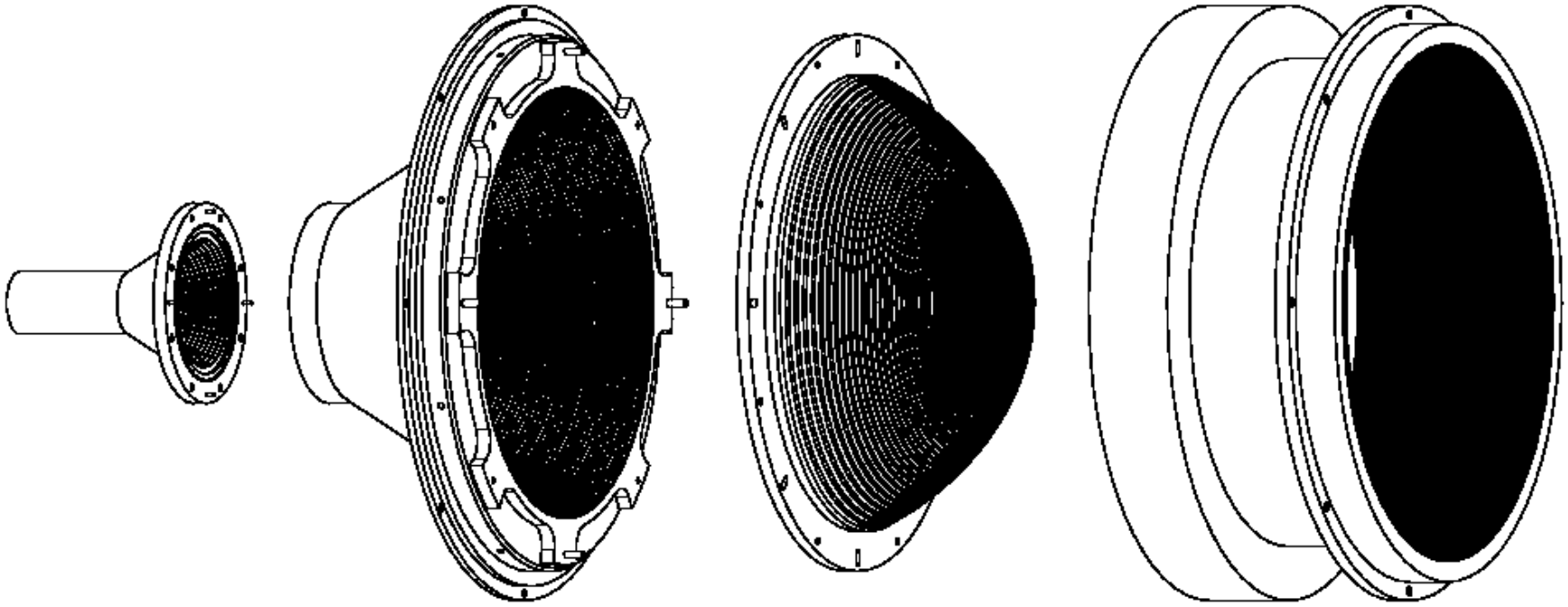
DASI/CBI Collaboration

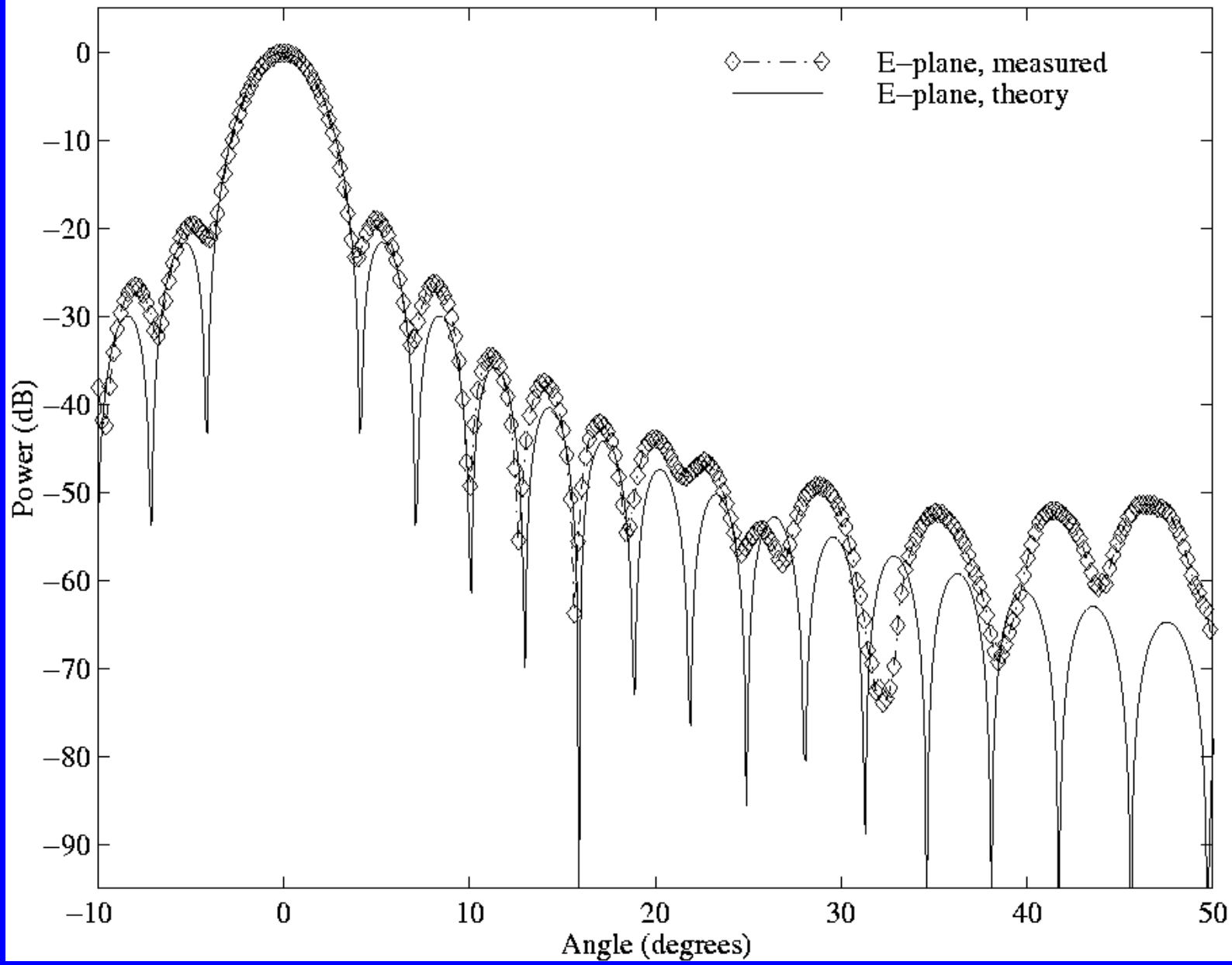
- CBI at CalTech / Chile
- Steve Padin / Tony Readhead
- Tim Pearson, Martin Shepherd
- John Cartwright
- DASI UofC / South Pole (CARA)
- John Carlstrom / Mark Dragovan
- Bill Holzapfel, Erik Leitch, Clem Pryke
- Nils Halverson, John Kovac
- Ethan Schartman
- John Yamasaki / Gene Davidson

DASI Design

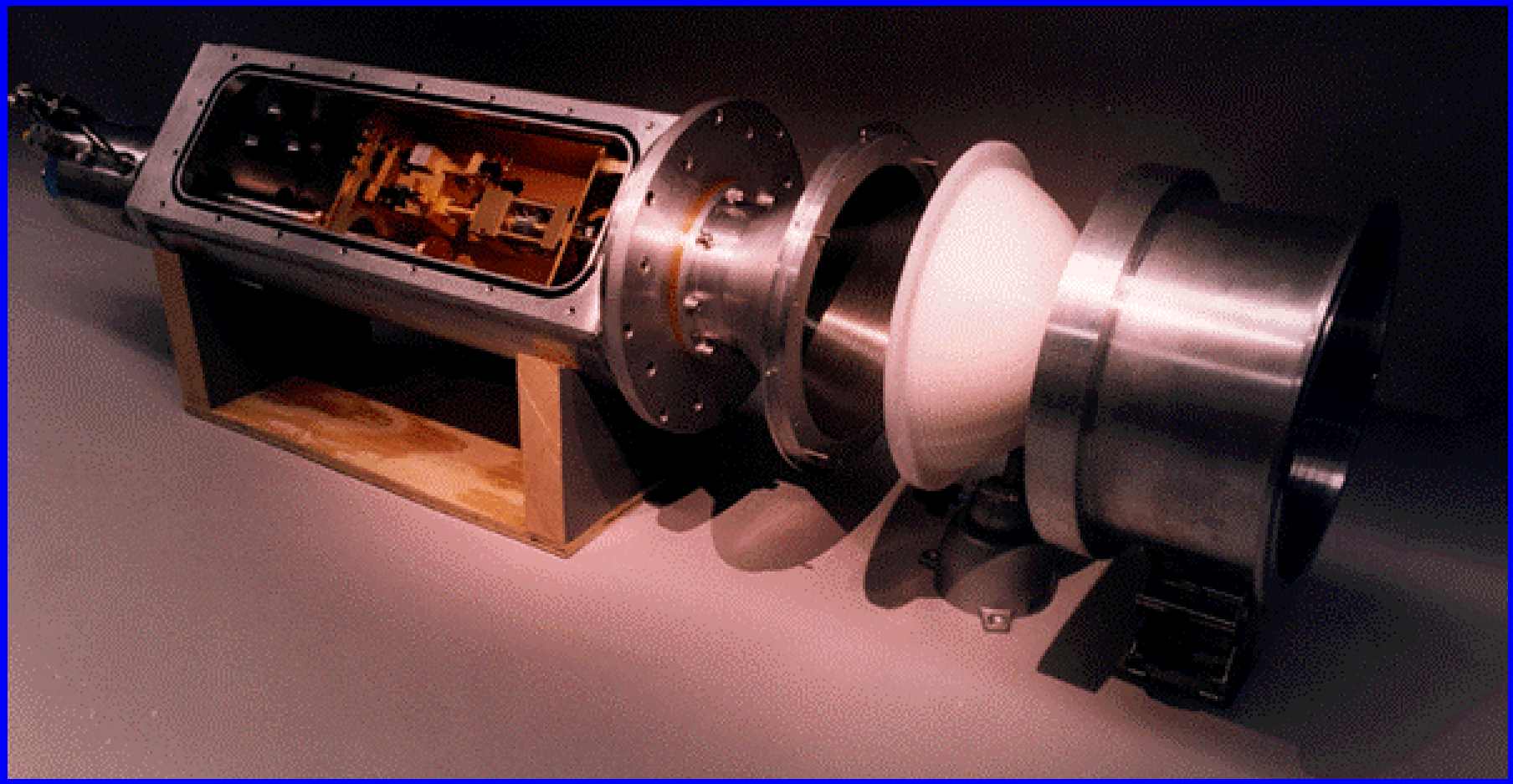
- Corrugated microwave feedhorns
- 26-36 GHz HEMT amplifiers cooled to 20K, downconvert to 2-12 GHz
- Passive filter splits into 10 x 1GHz bands
- Each band correlated to form 156 visibilities

Feedhorns

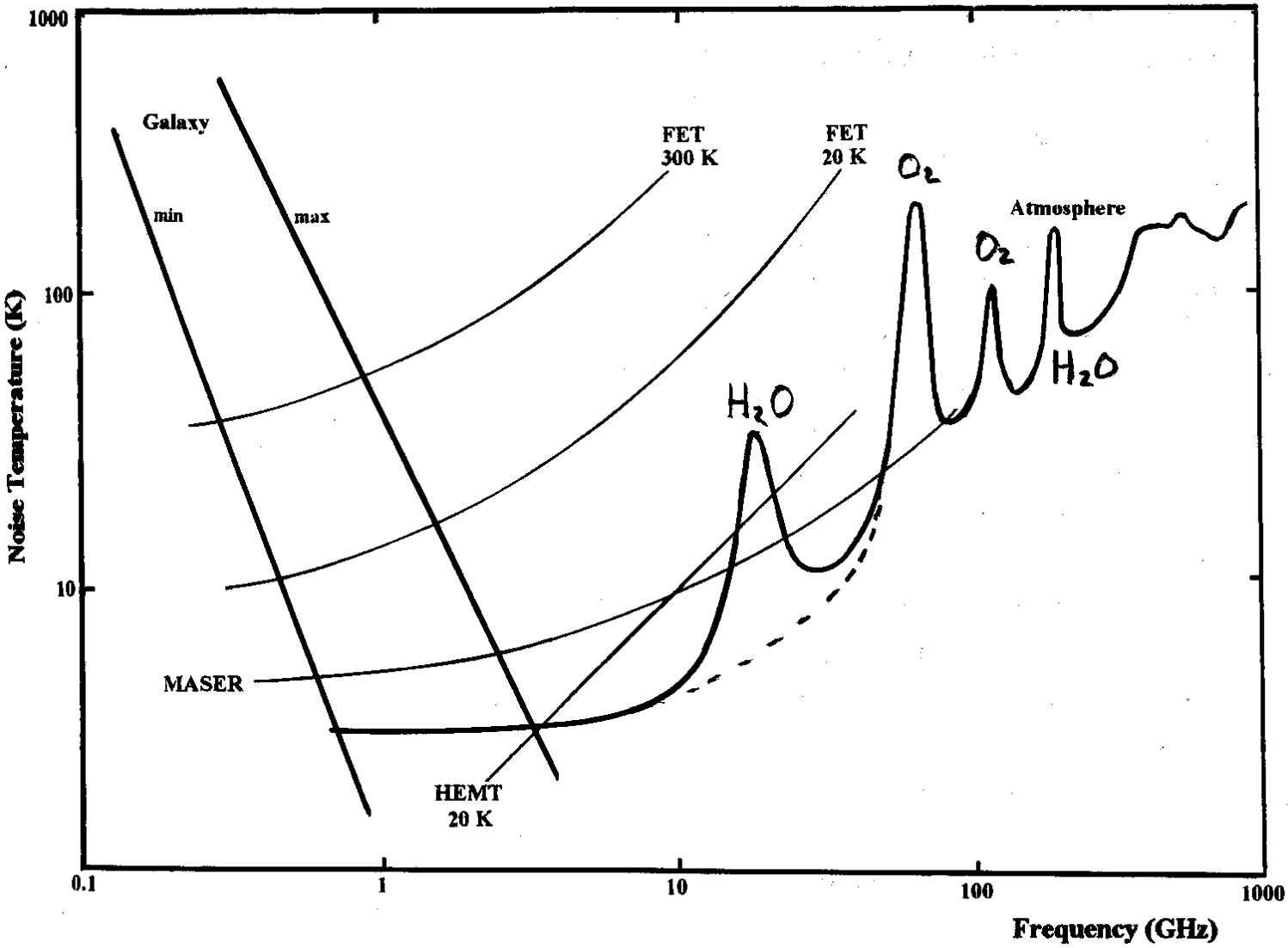



E–plane, measured
E–plane, theory
Power (dB)
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−10
0
10
20
30
40
50
Angle (degrees)

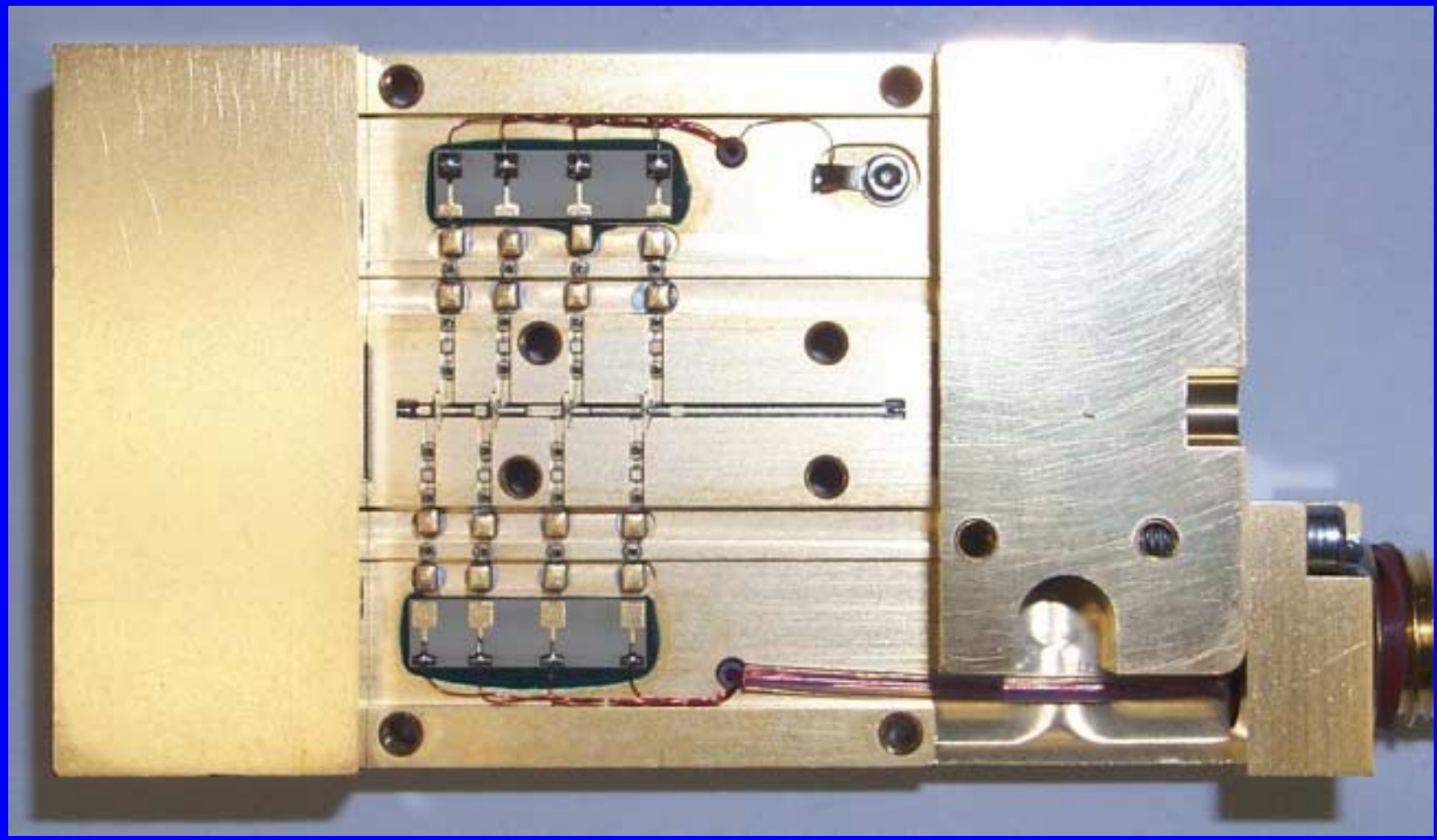
Receivers



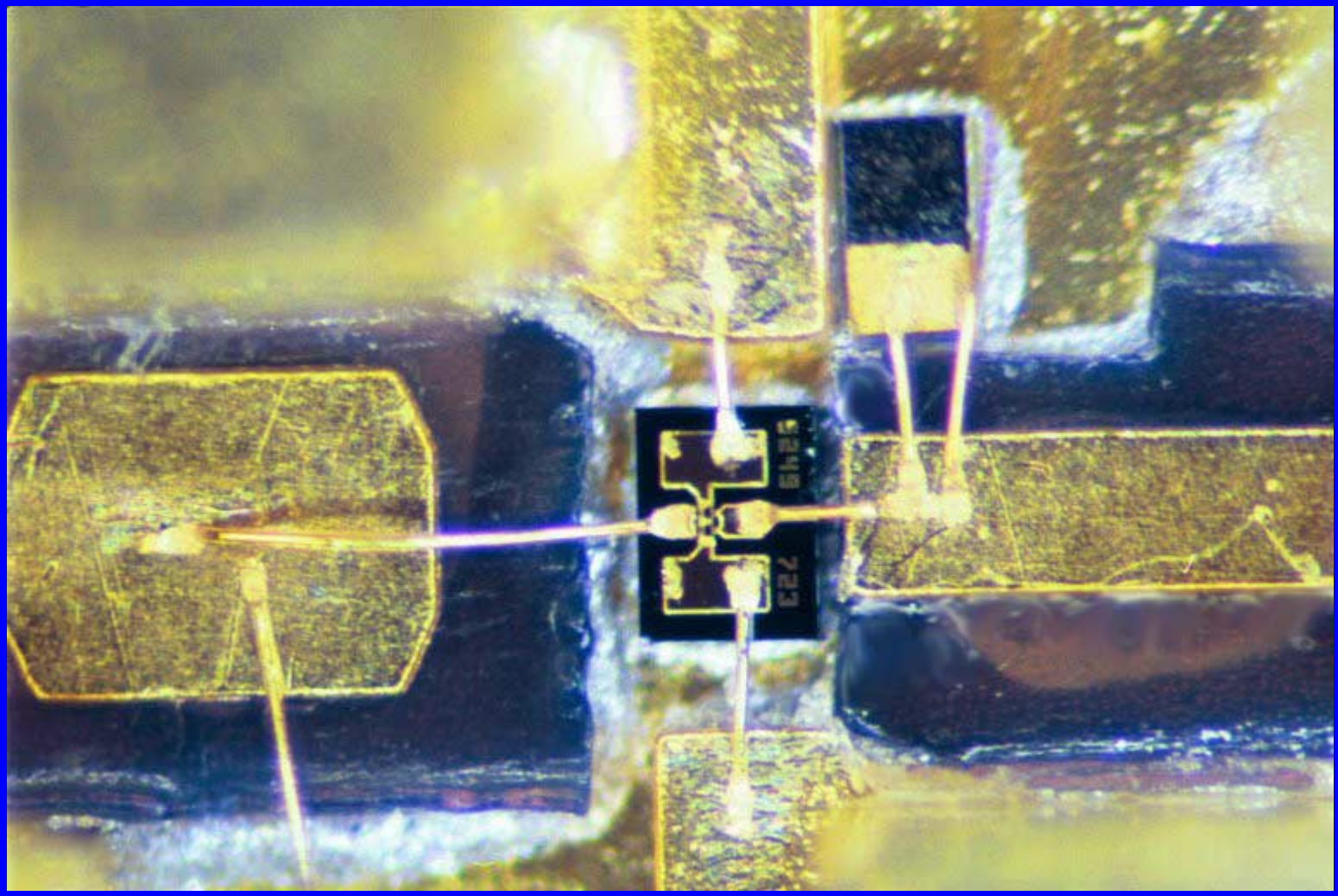
Atmospheric Emission



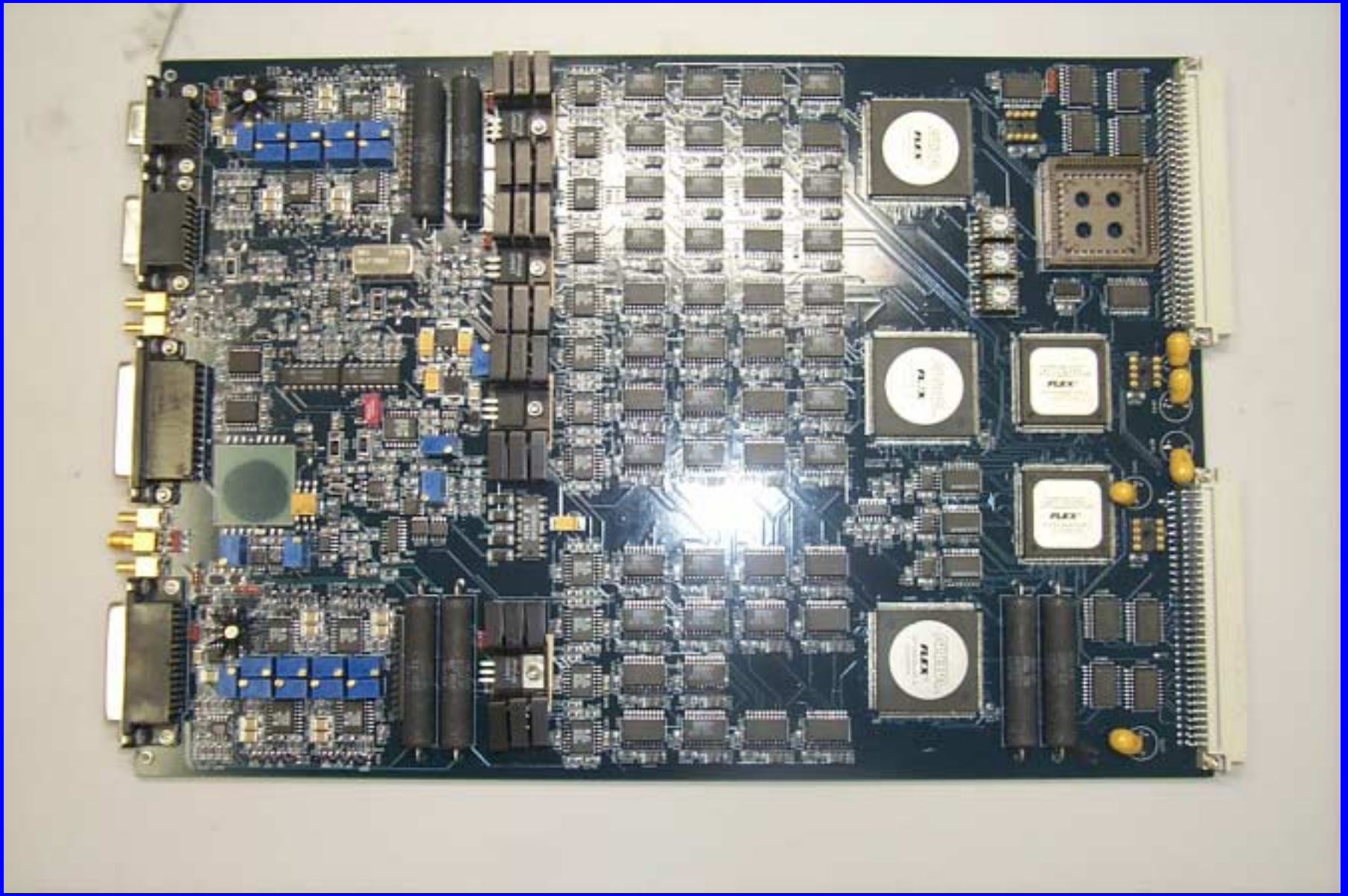
HEMT Amplifiers



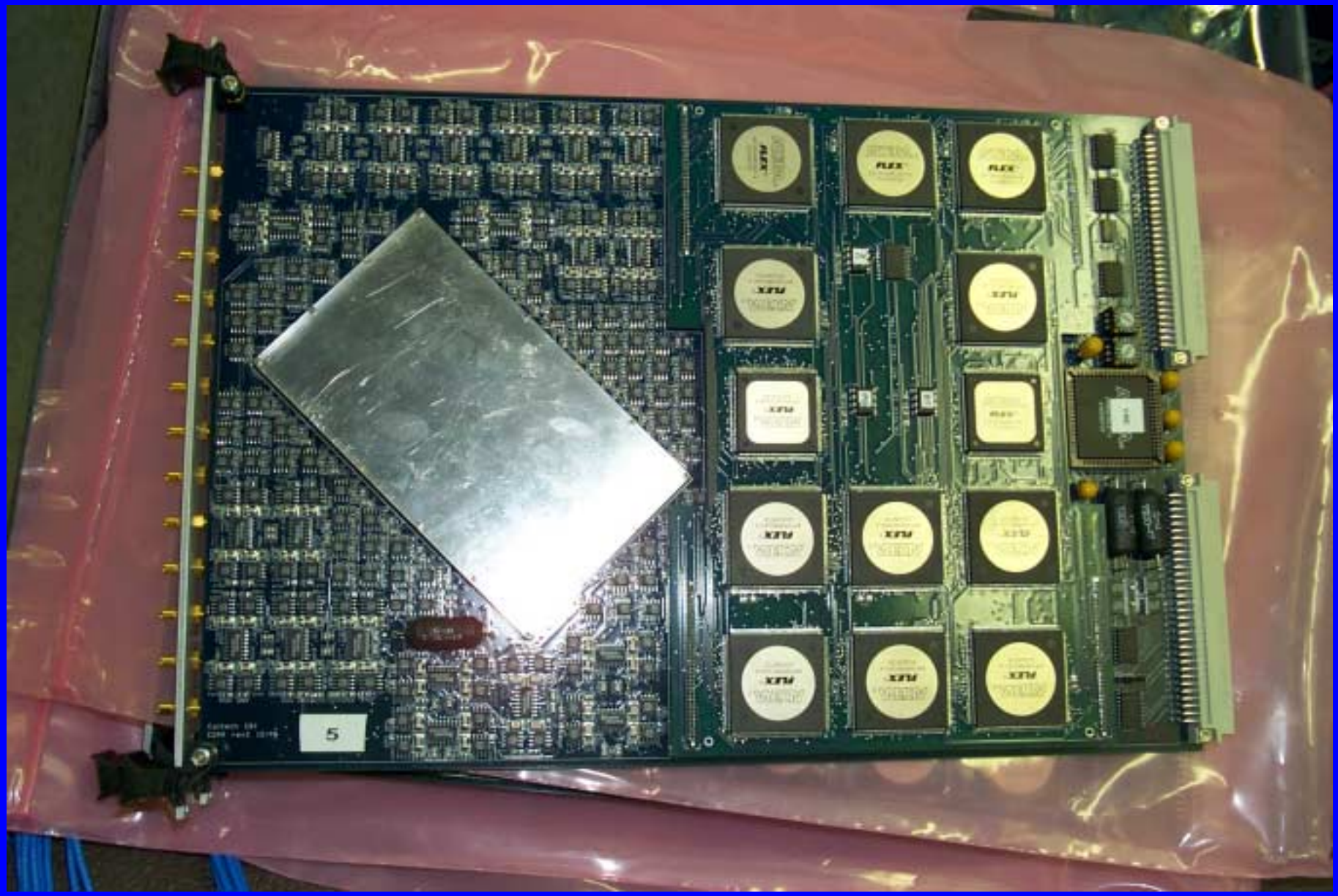
First stage FET



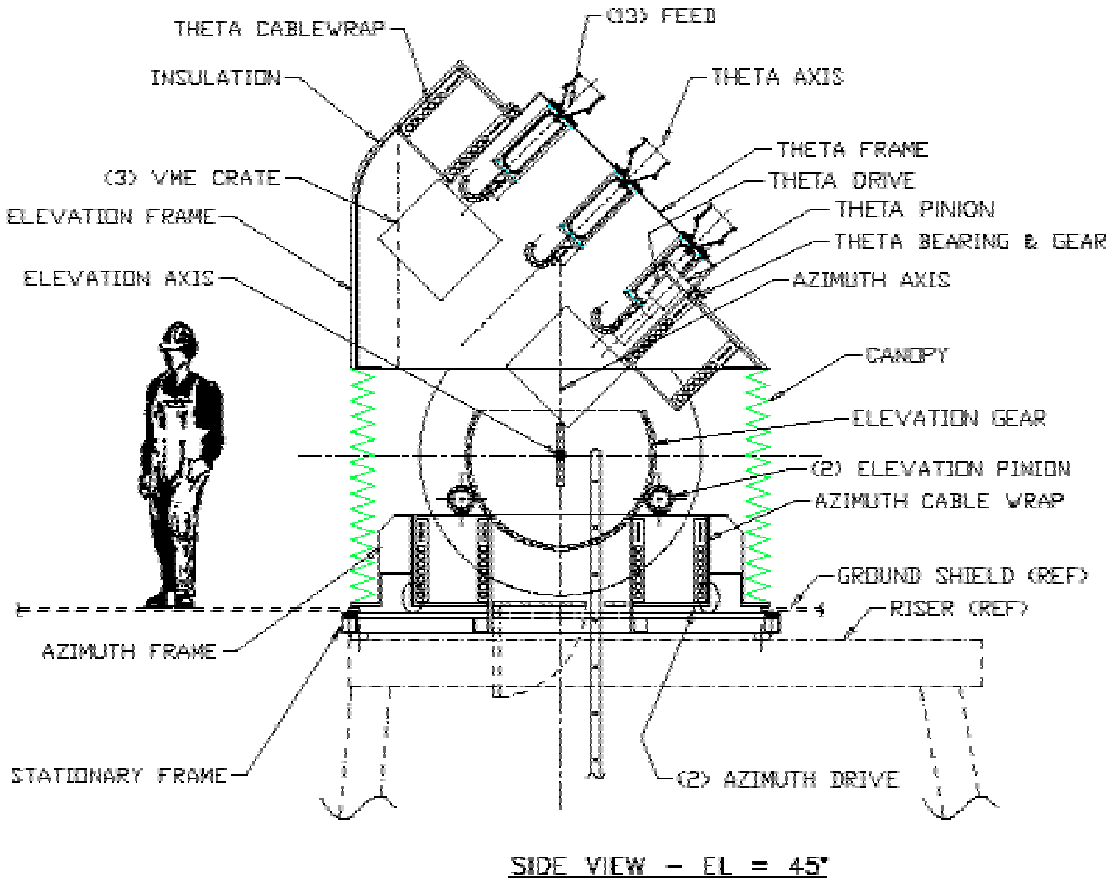
Receiver Control Card



Correlator Card



DASI Mount



SIDE VIEW - EL = 45°

DASI Deployment

- Mount completed April 99 by Vertex Inc.
- Initial assembly and integration in EFI high bay.
- Moved out to parking lot July 99
- Disassembled for shipping August 99
- Arrived in Antarctica October 99
- Arrived at South Pole November 99
- Fully operational by station closing February 00
- Data taken from sunset to sunrise

DASI at Vertex

DASI Leaves High Bay

Summer Testing

Arrival in Antarctica

Arrival at South Pole

Re-assembly

Lifting to Tower

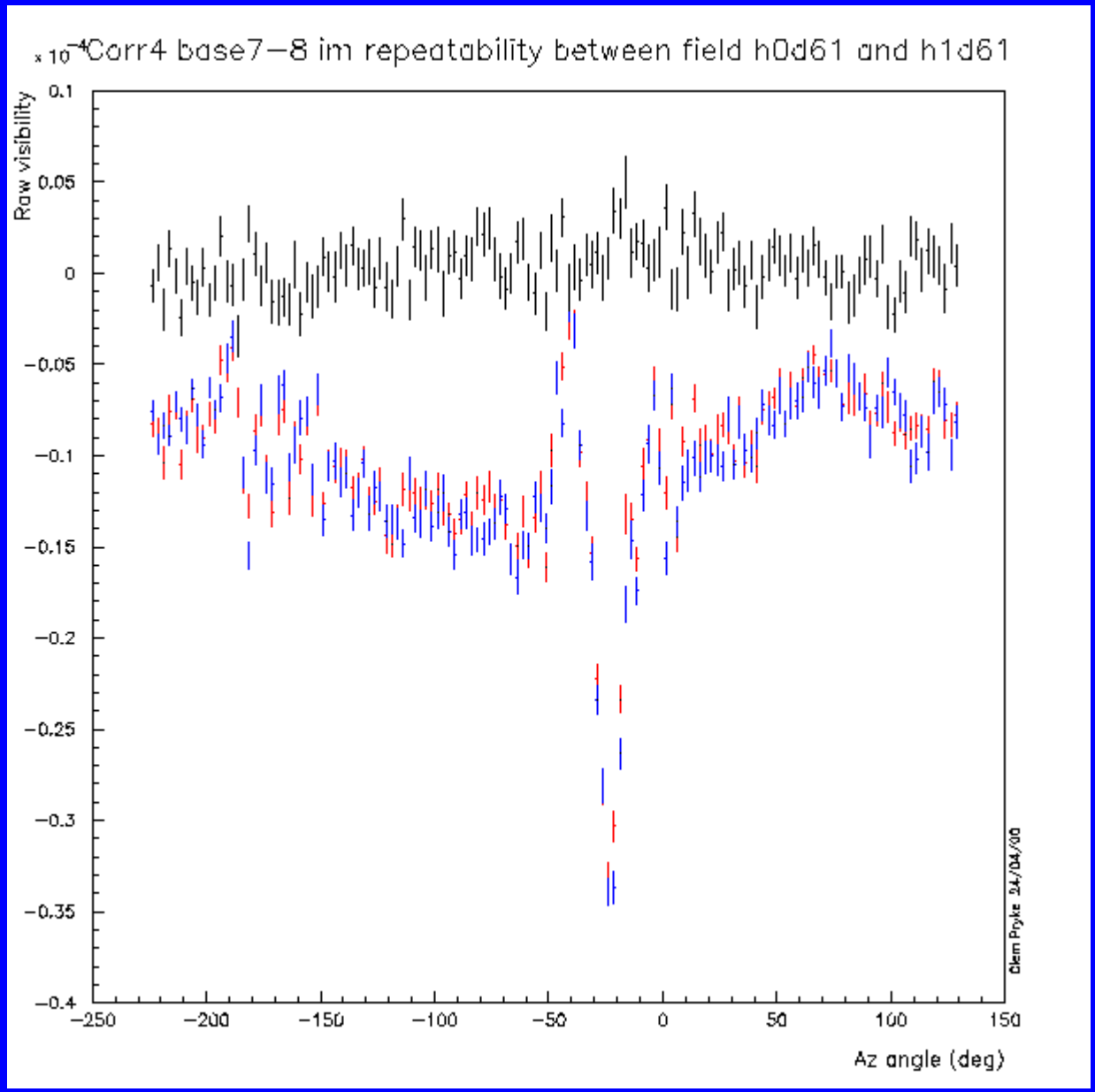
Cover for Working

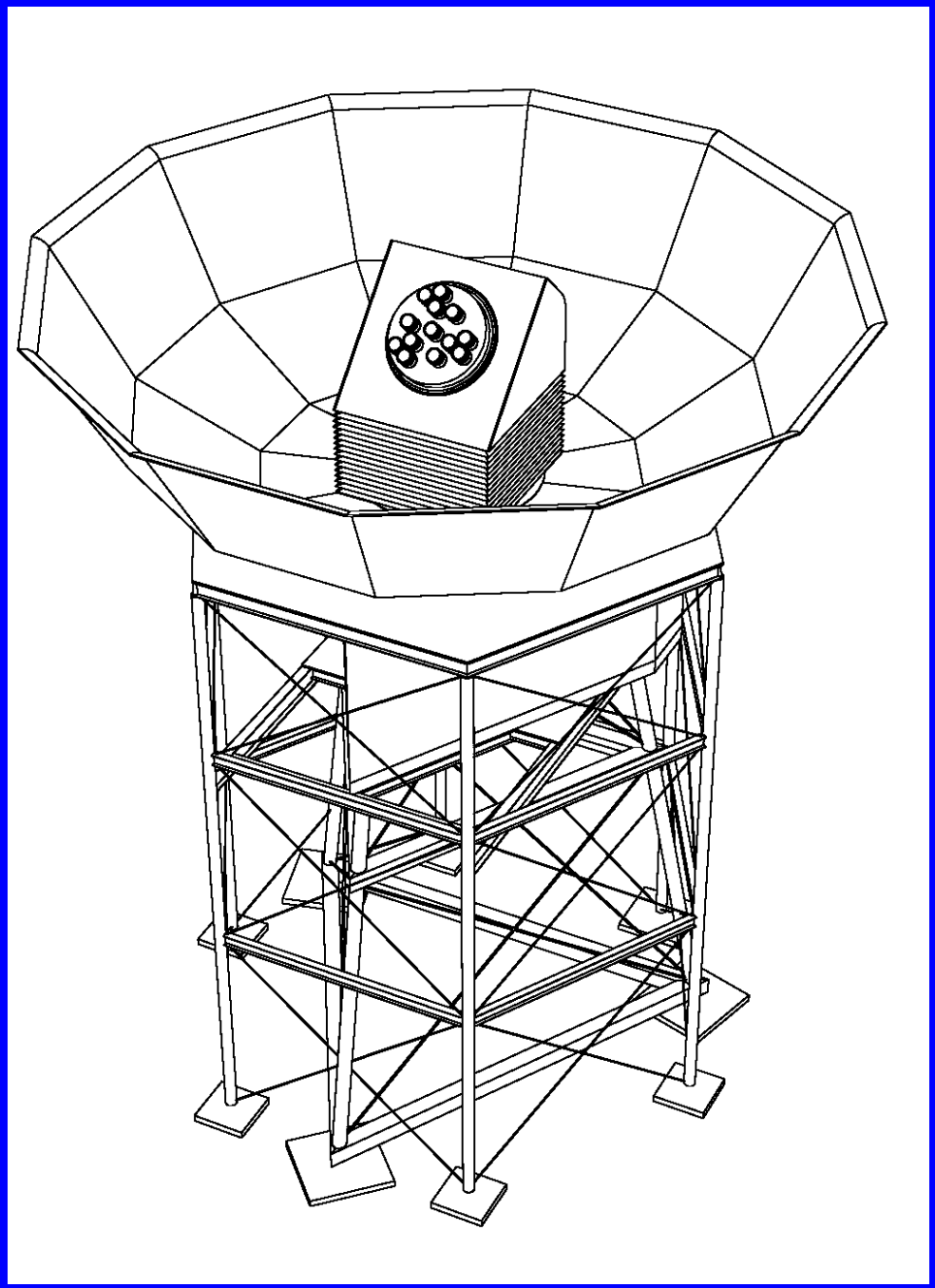
DASI at Sunset

First Impressions

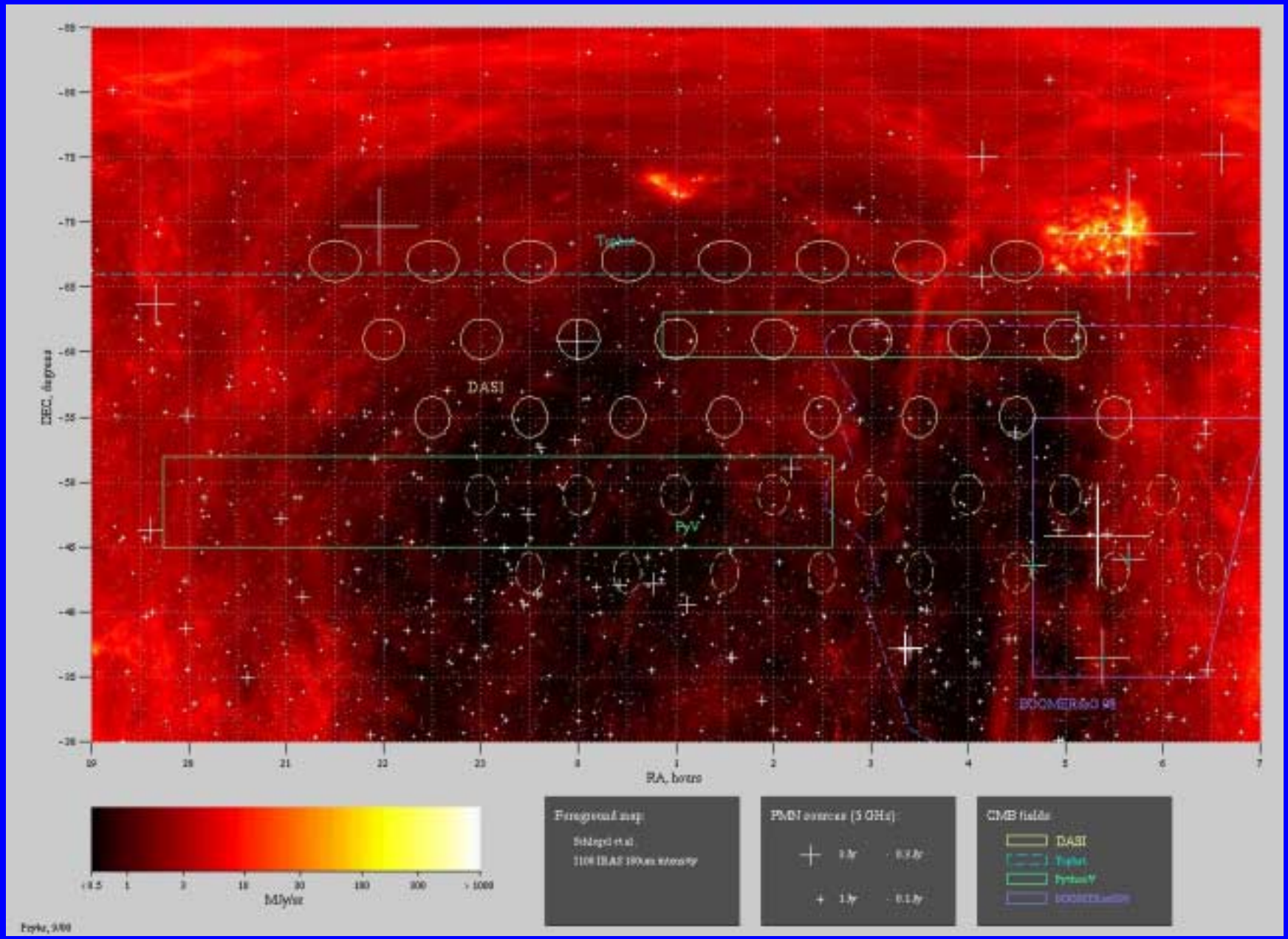
- System works well and is very stable
- Imaged astronomical object quickly
- Initially ground pickup seemed to be a problem…

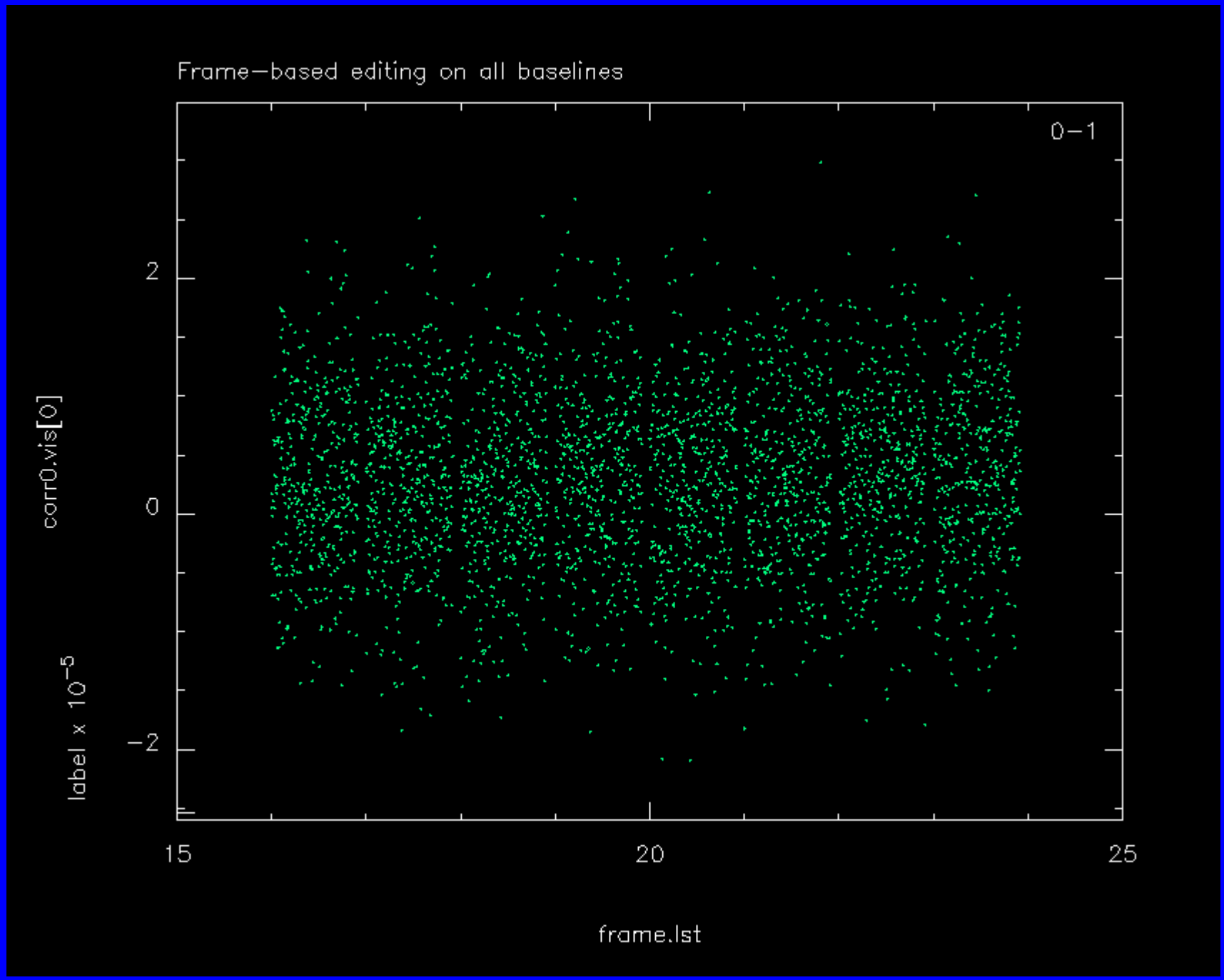
Ground signal is stable



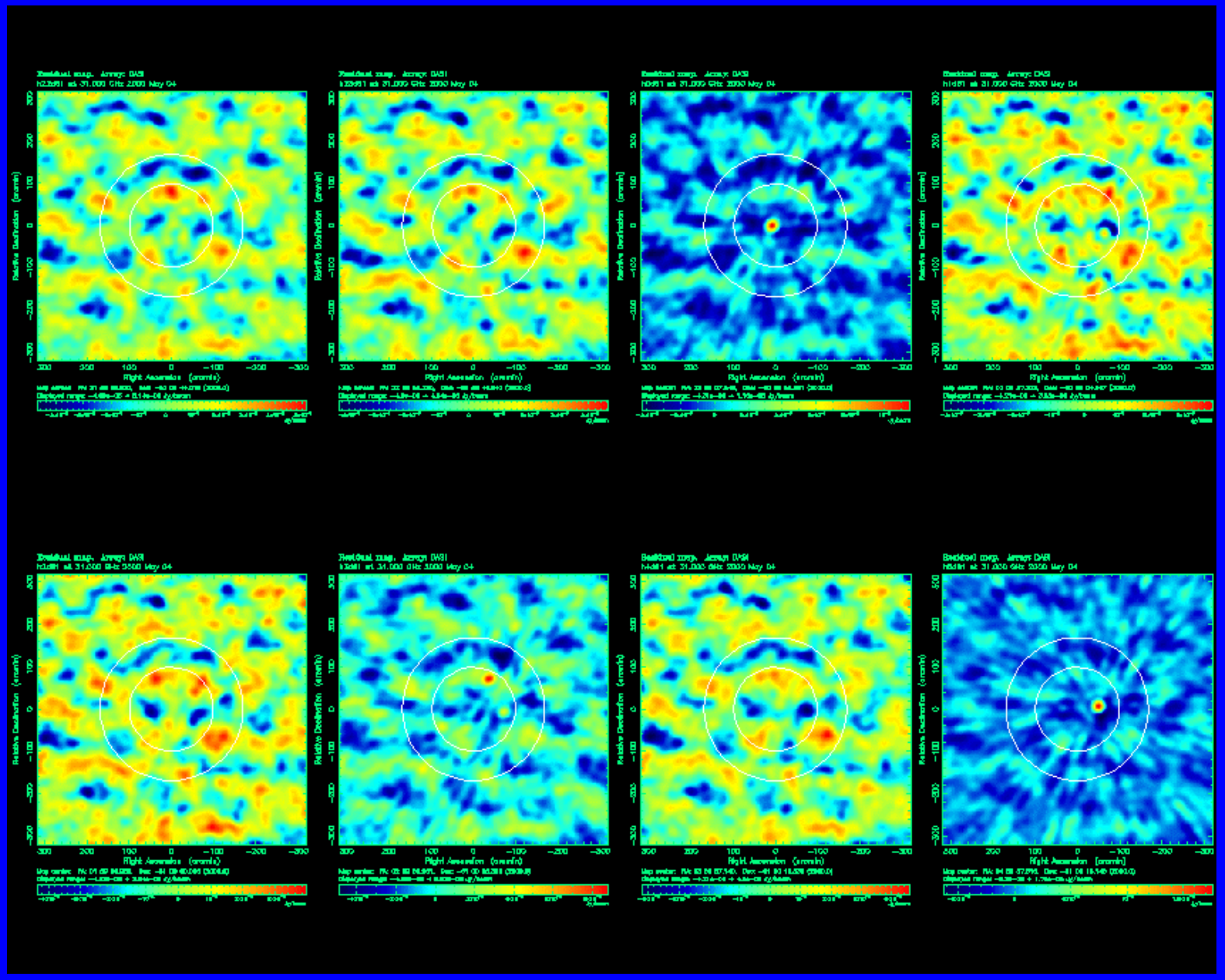


Southern Dust Skymap and DASI Fields

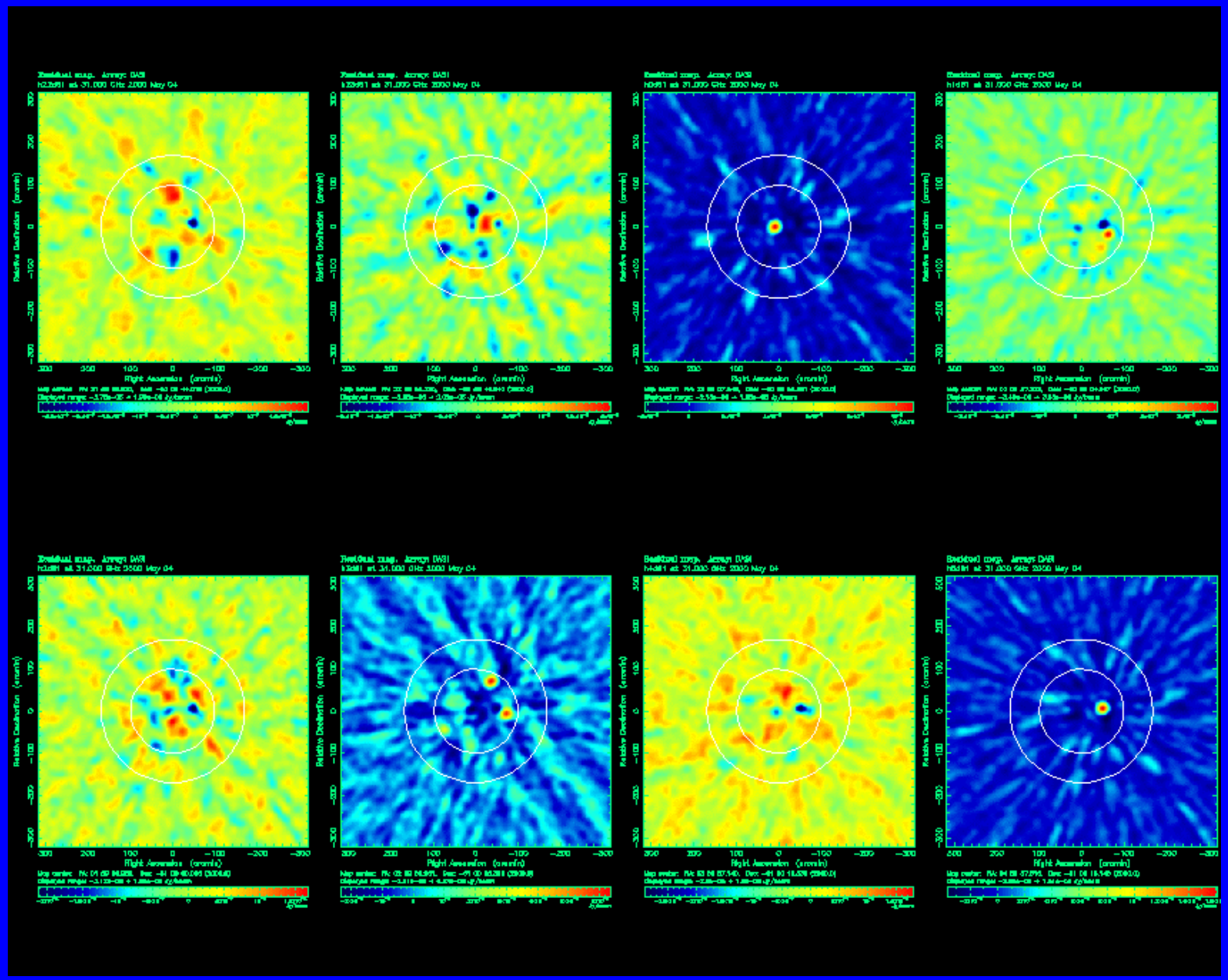



Frame-based editing on all baselines
0-1
2
0
-2
corr0.vis[0]
label x 10^-5
15
20
25
frame.lst

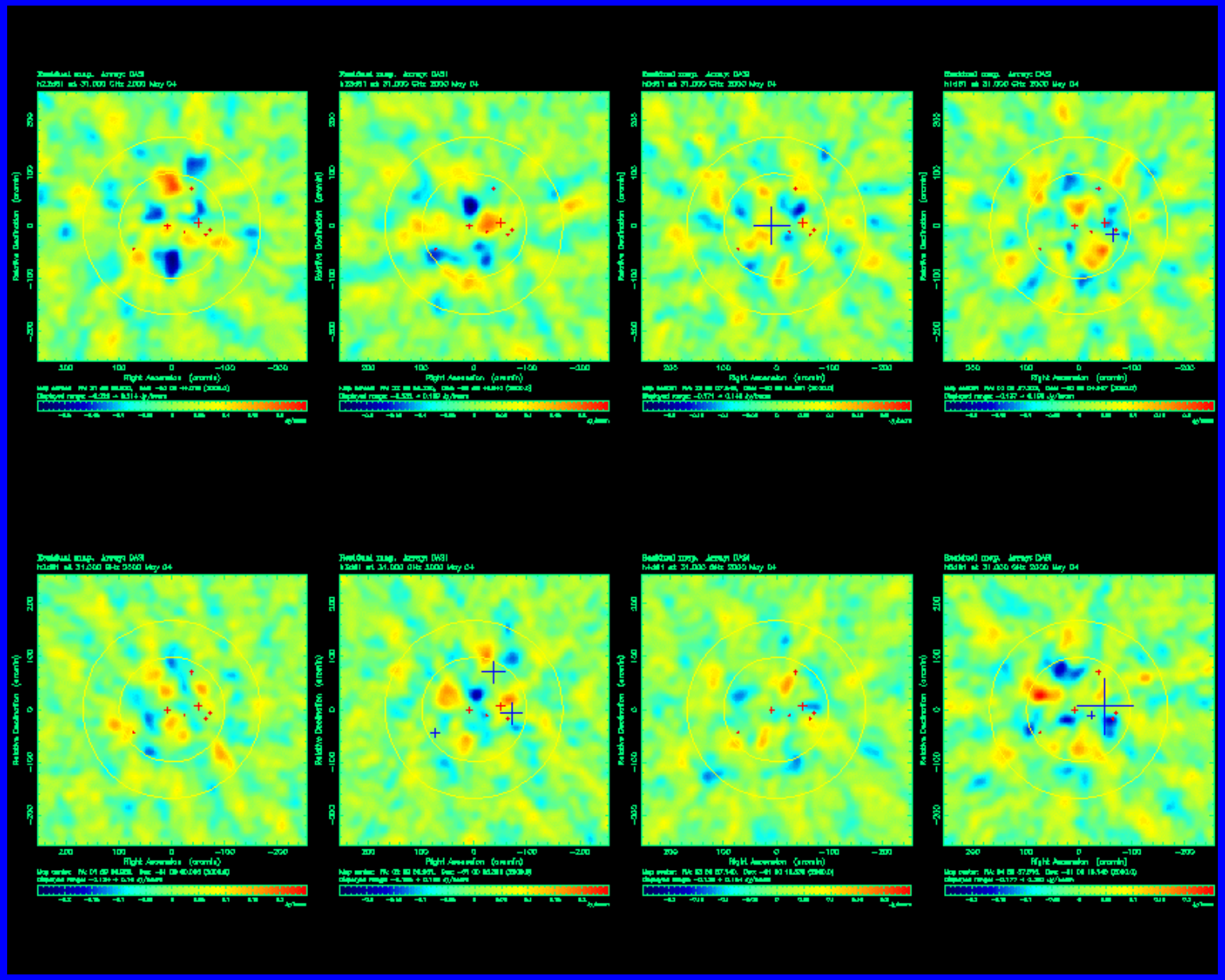
Raw Images



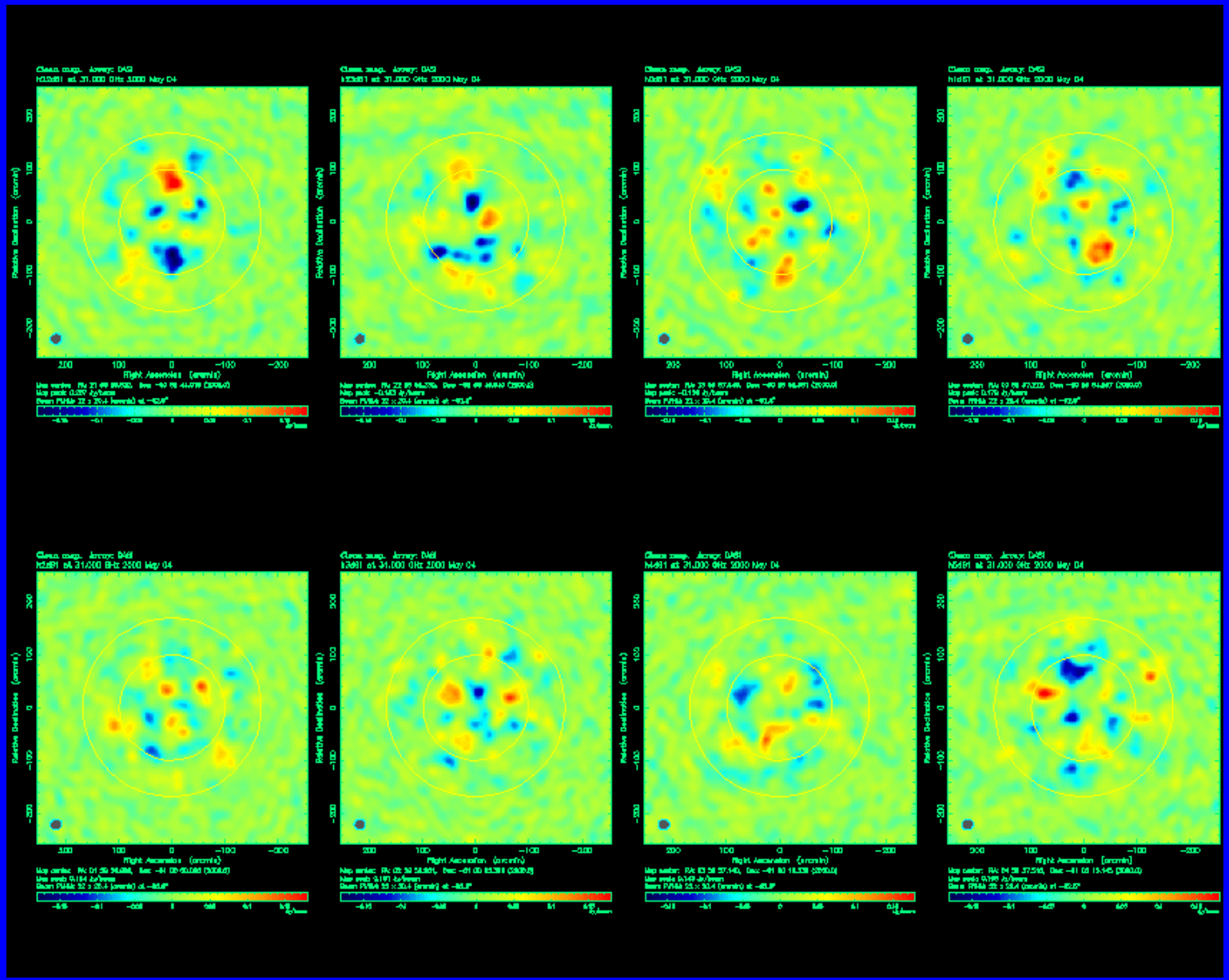
Ground Subtracted



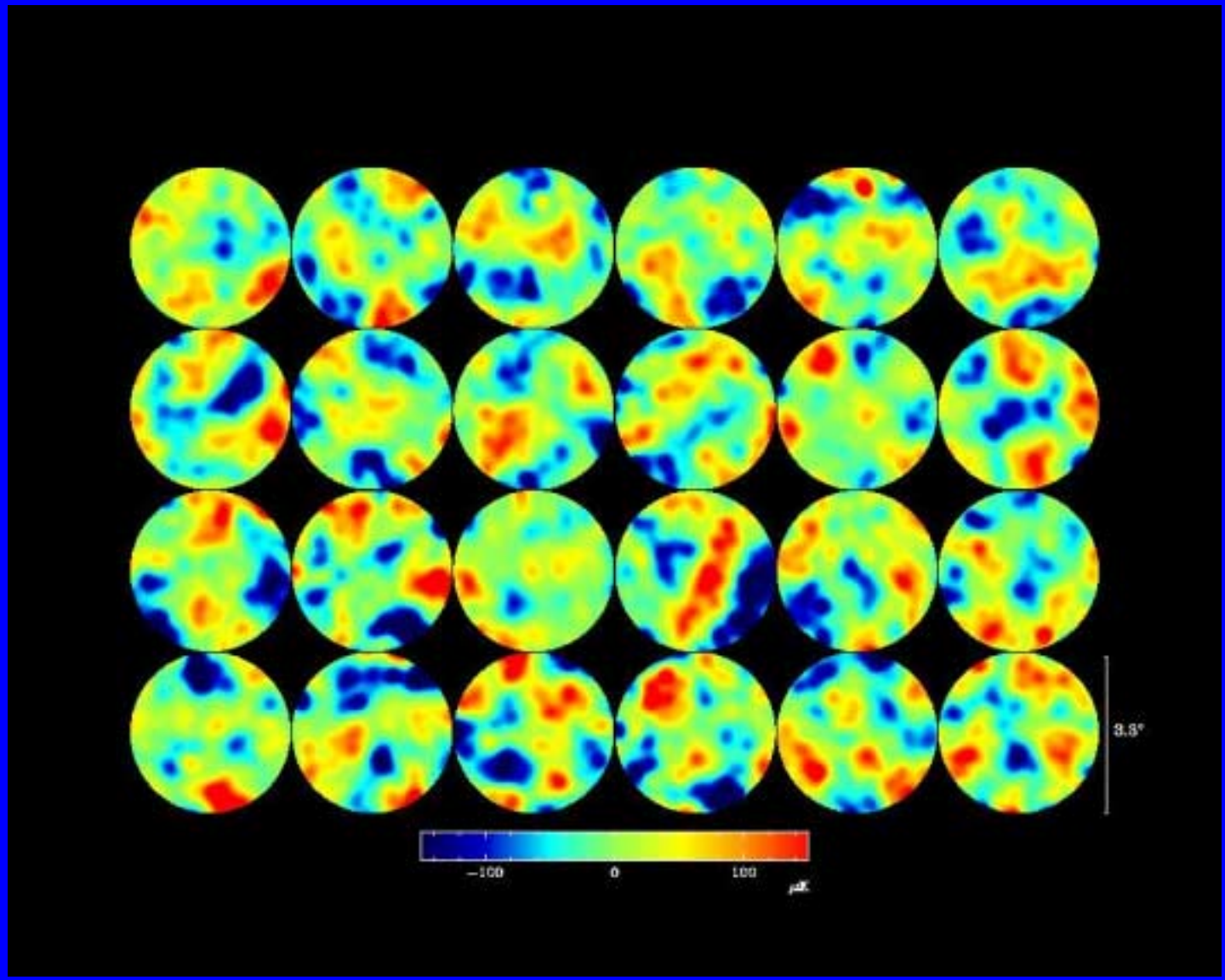
Ground and Point Sources Subtracted



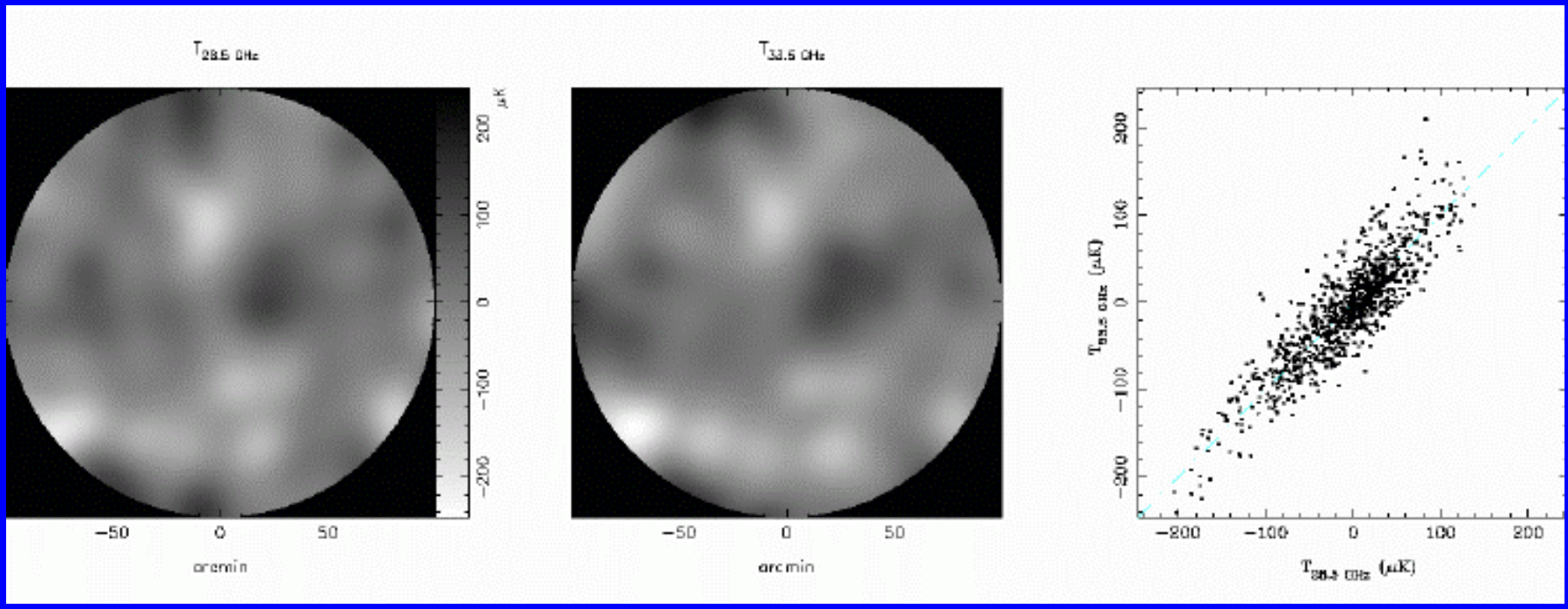
…Plus Cleaning

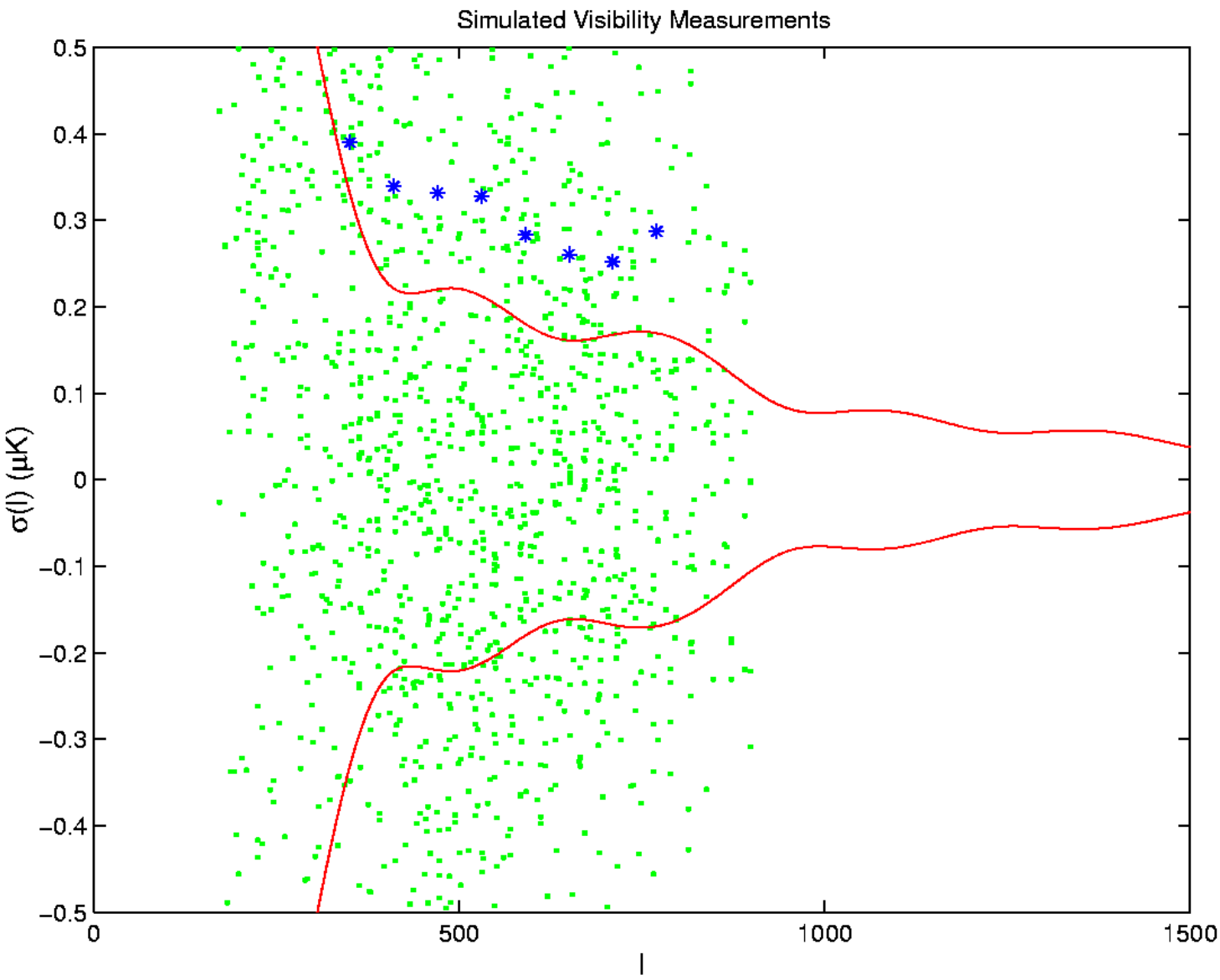


Primary Beam Adjusted

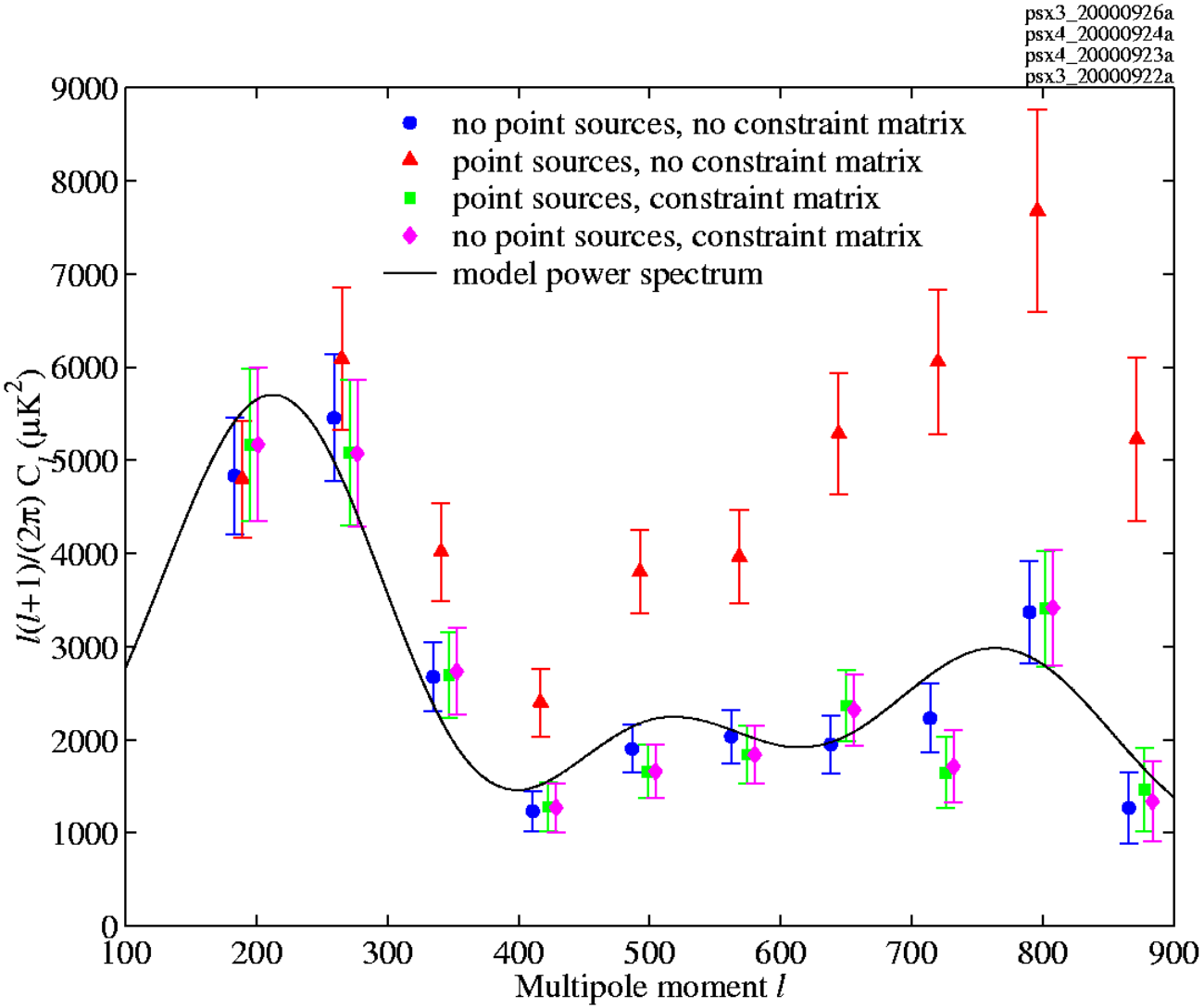


Images have expected spectrum




Simulated Visibility Measurements
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
σ(l) (μK)
0
500
1000
1500
l

Simulations!



Conclusions

- DASI has run excellently in it's first season.
- 1000 (good) hours of CMB field integration have been collected.
- Ground subtraction is necessary, but seems to work fine.
- Point source subtraction is also required.
- Construction of analysis "machinery" is almost complete.
- Look forward to a power spectrum soon.