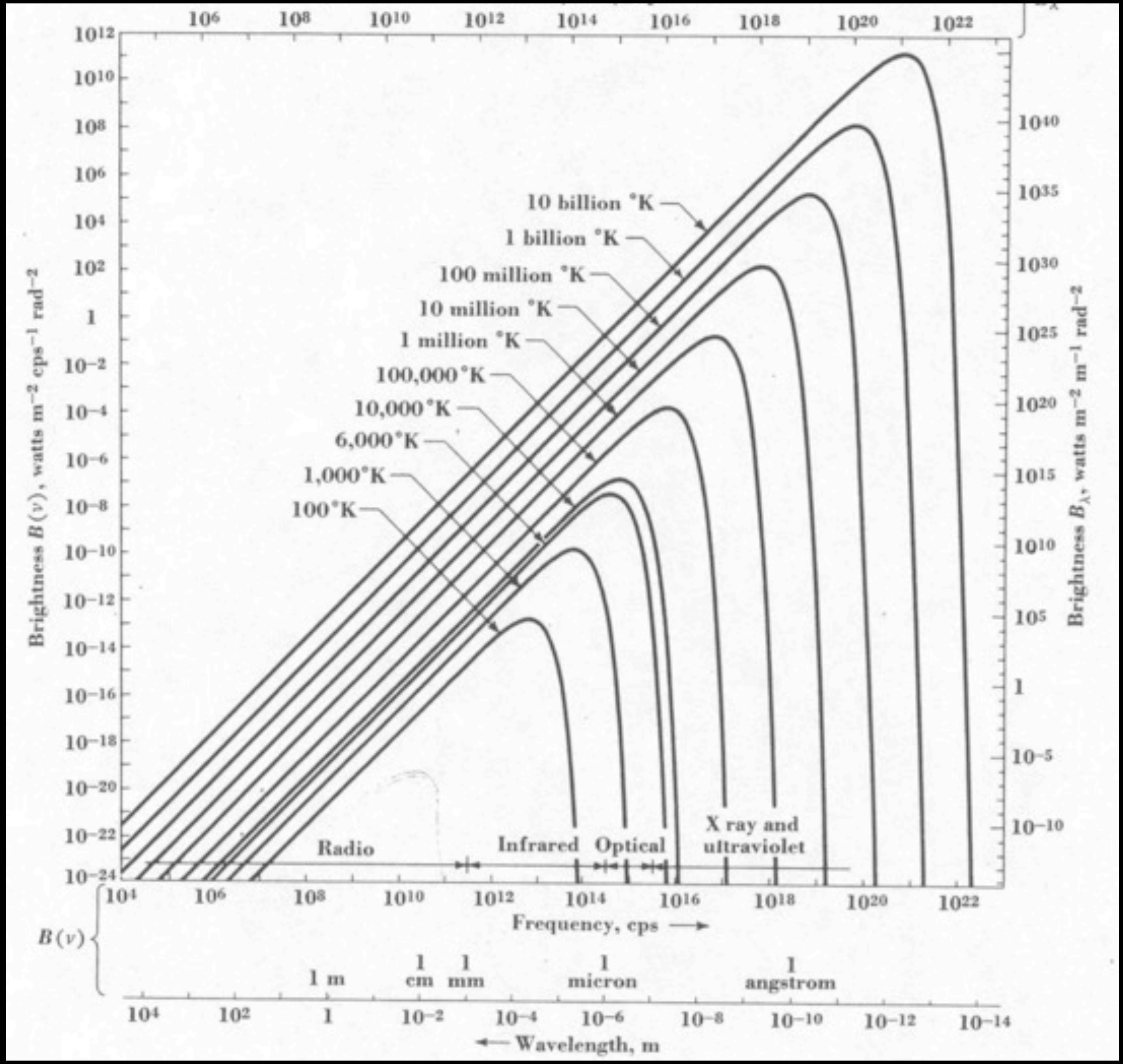
Observing Extended Sources

or

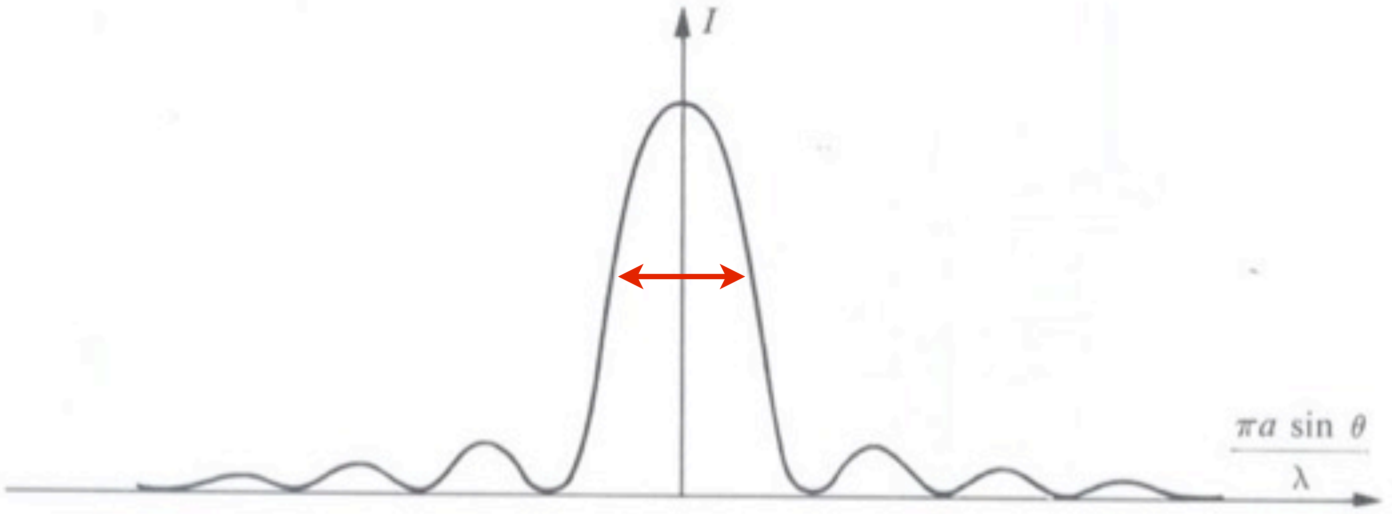
Issues in the dynamic range of radio telescopes

Felix "Jay" Lockman
NRAO, Green Bank WV
July 8, 2015

Why Radio astronomy is different
Number 3

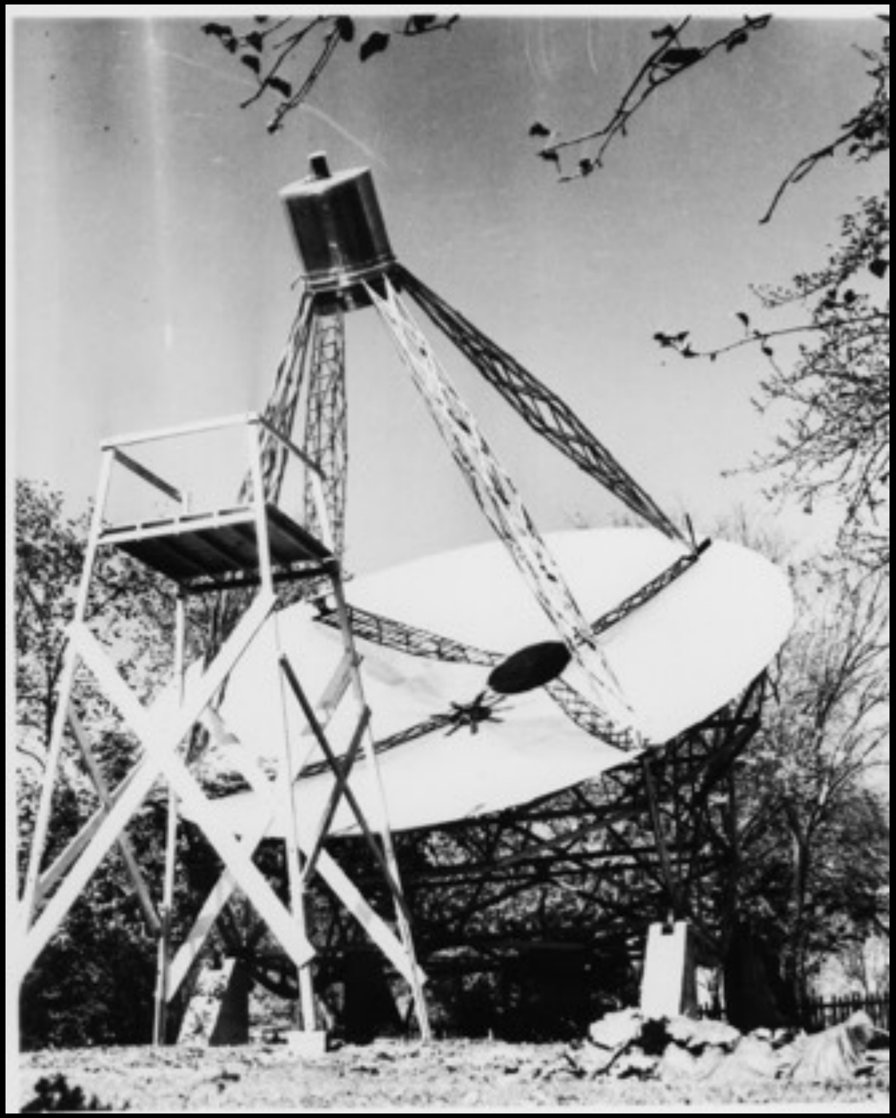


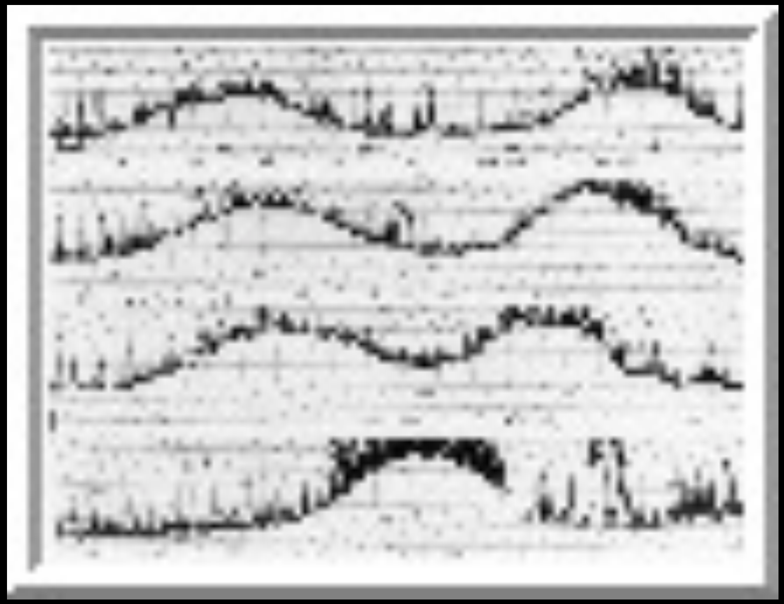
(a)



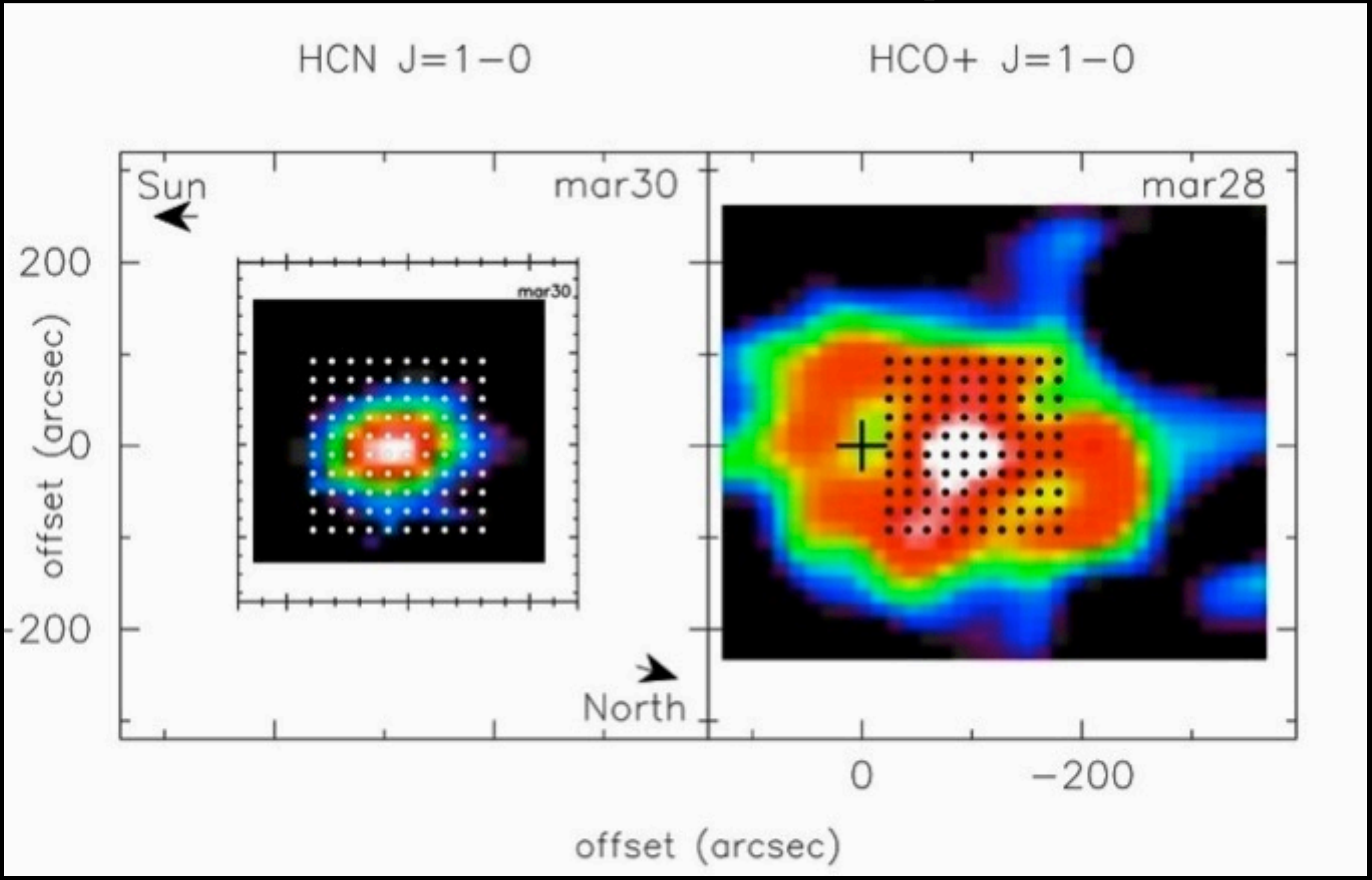
(b)

Grote Reber
Wheaton, Illinois 1937

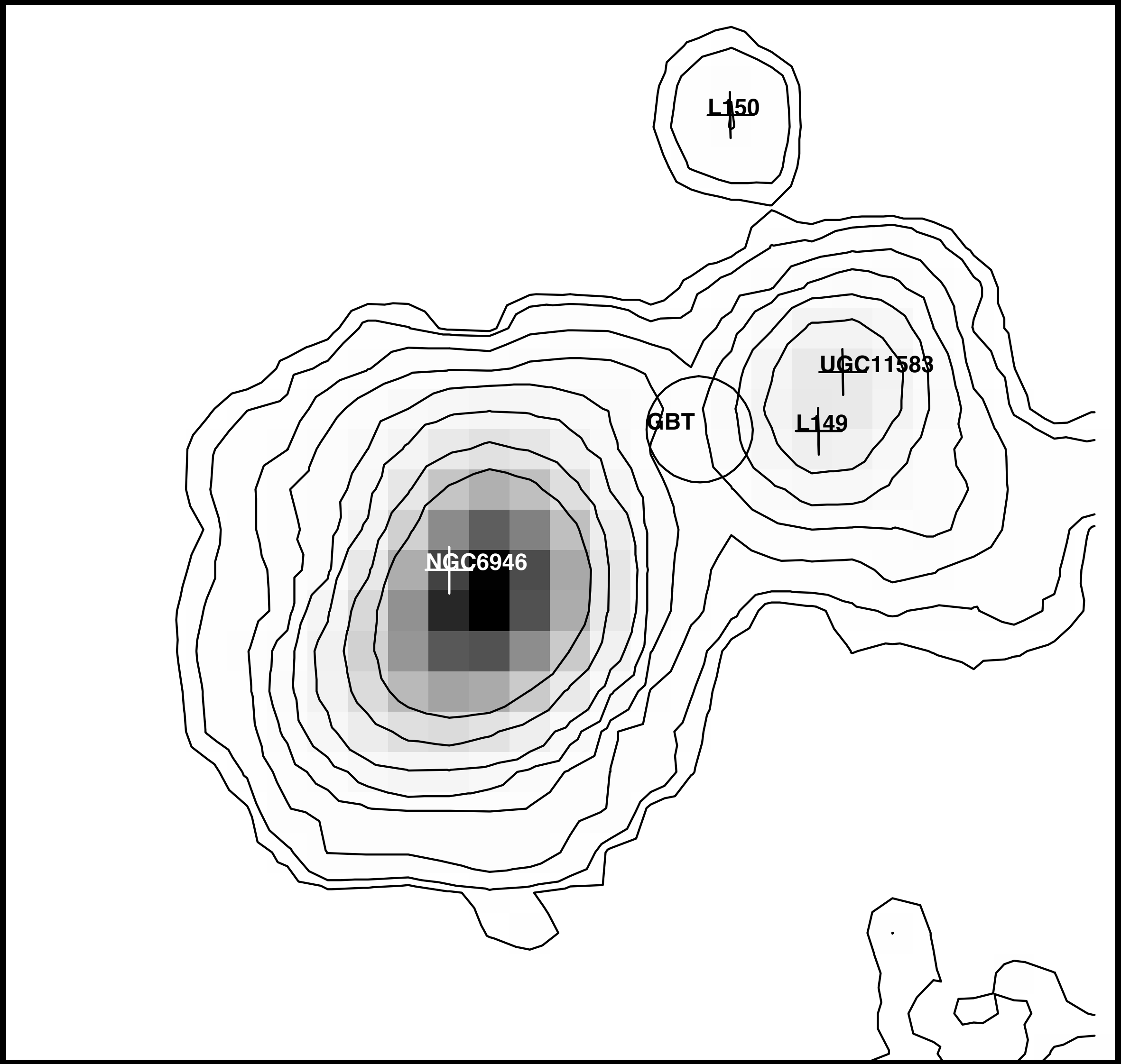




Comet Hale-Bopp with footprint of proposed GBT 3mm array

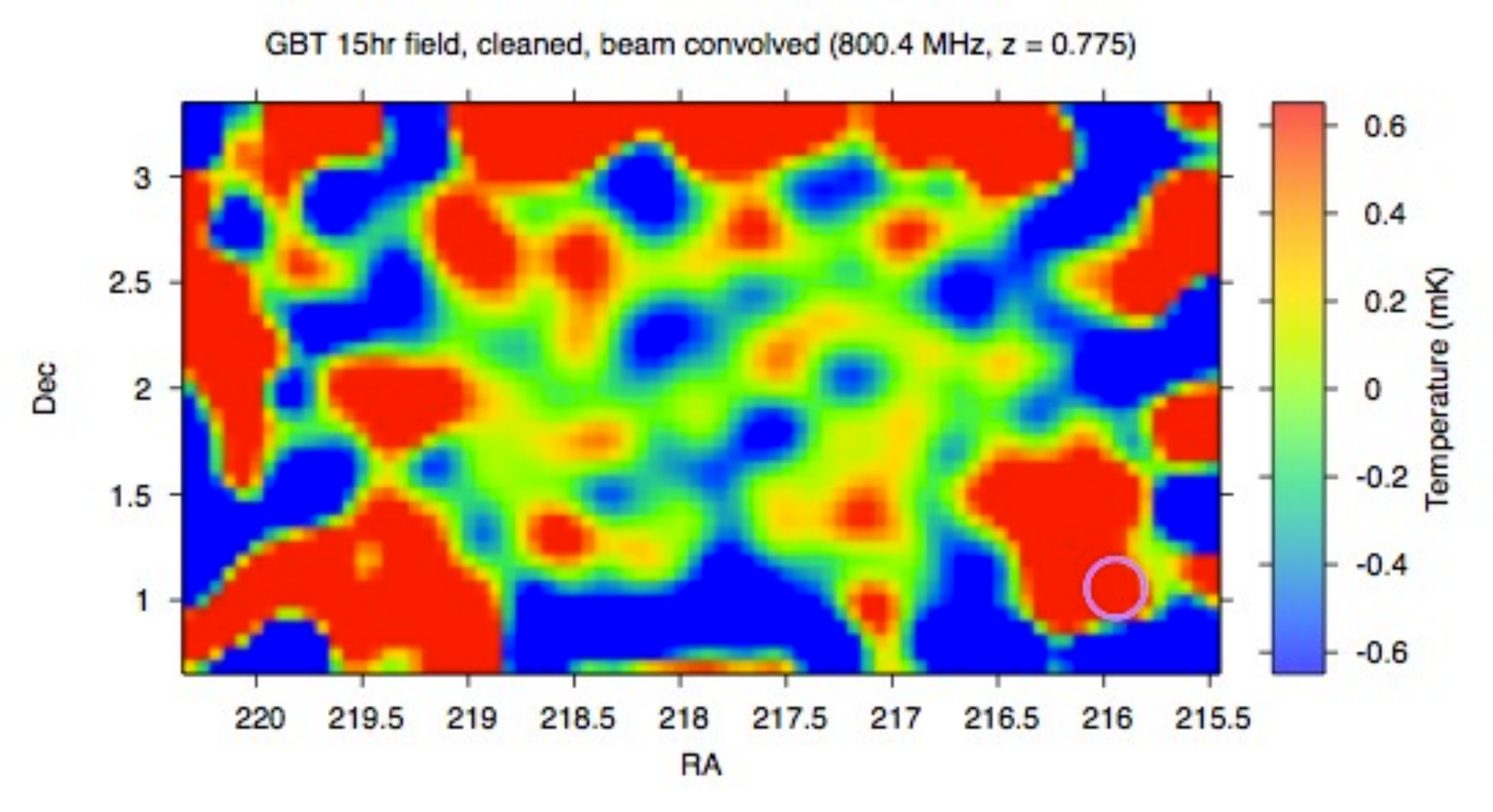


GBT HI Map of Two Galaxies



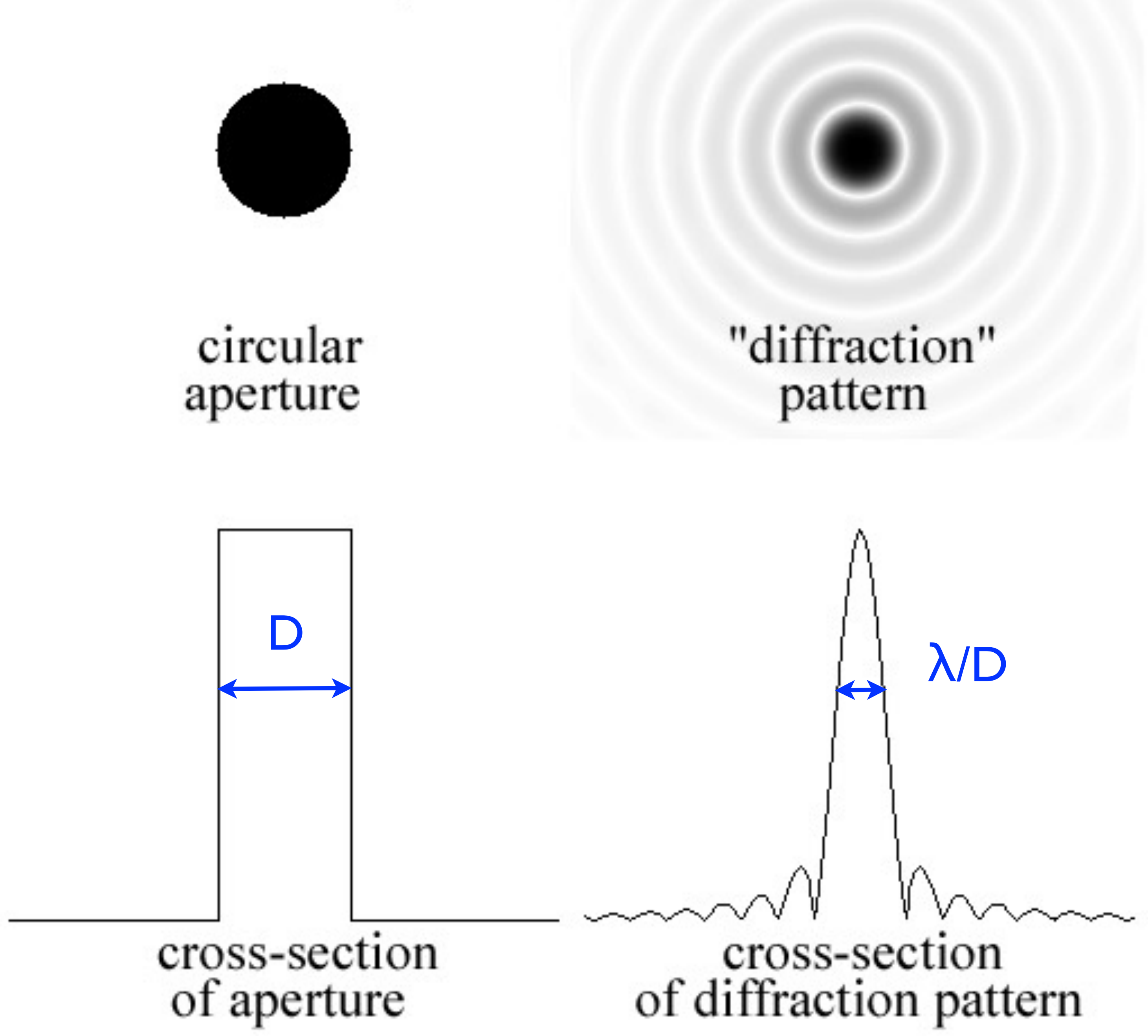
Pisano (2013)

Schnee et al. (2013)



Masui et al. (2013)

Fourier Transform relationship of aperture and beam



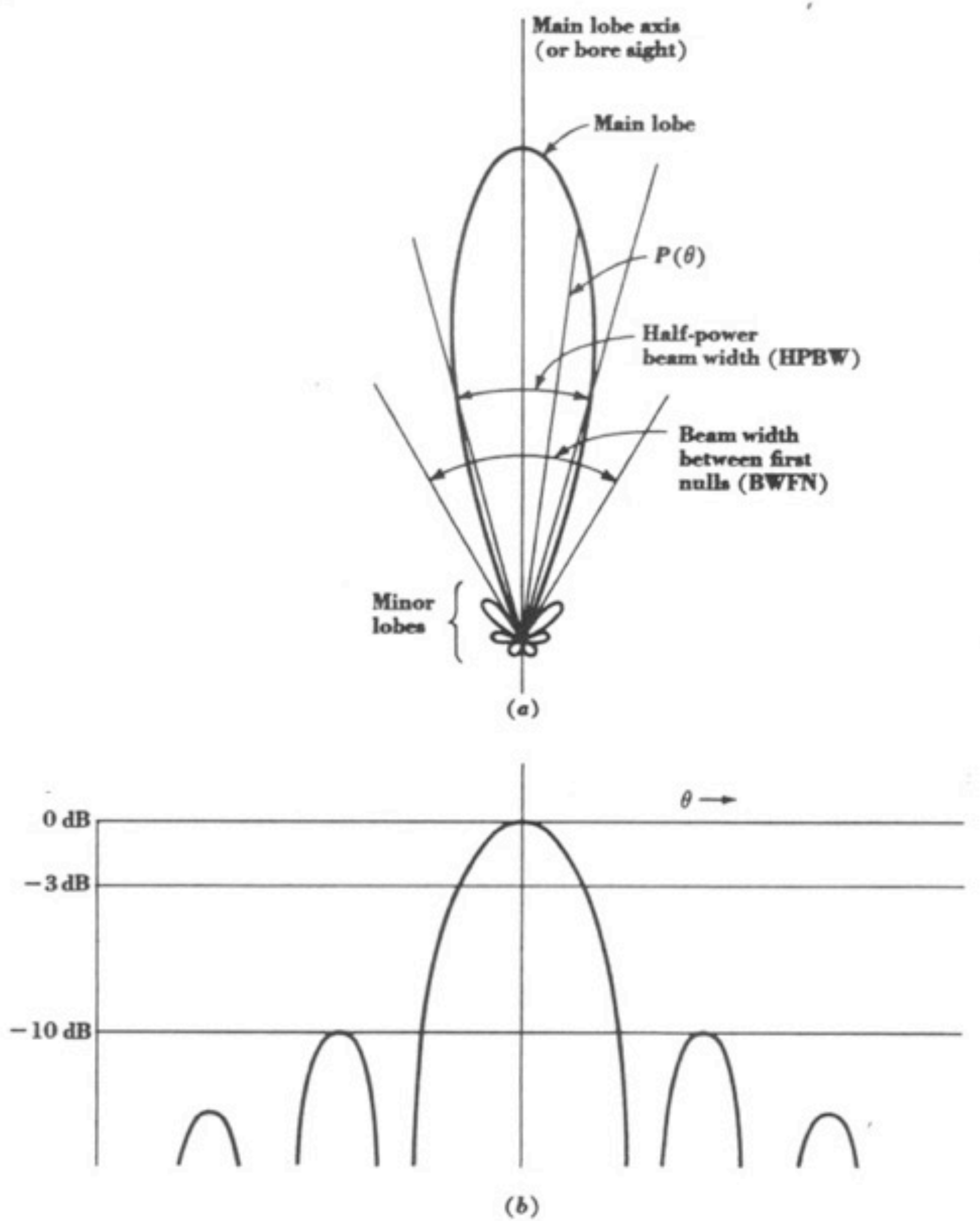
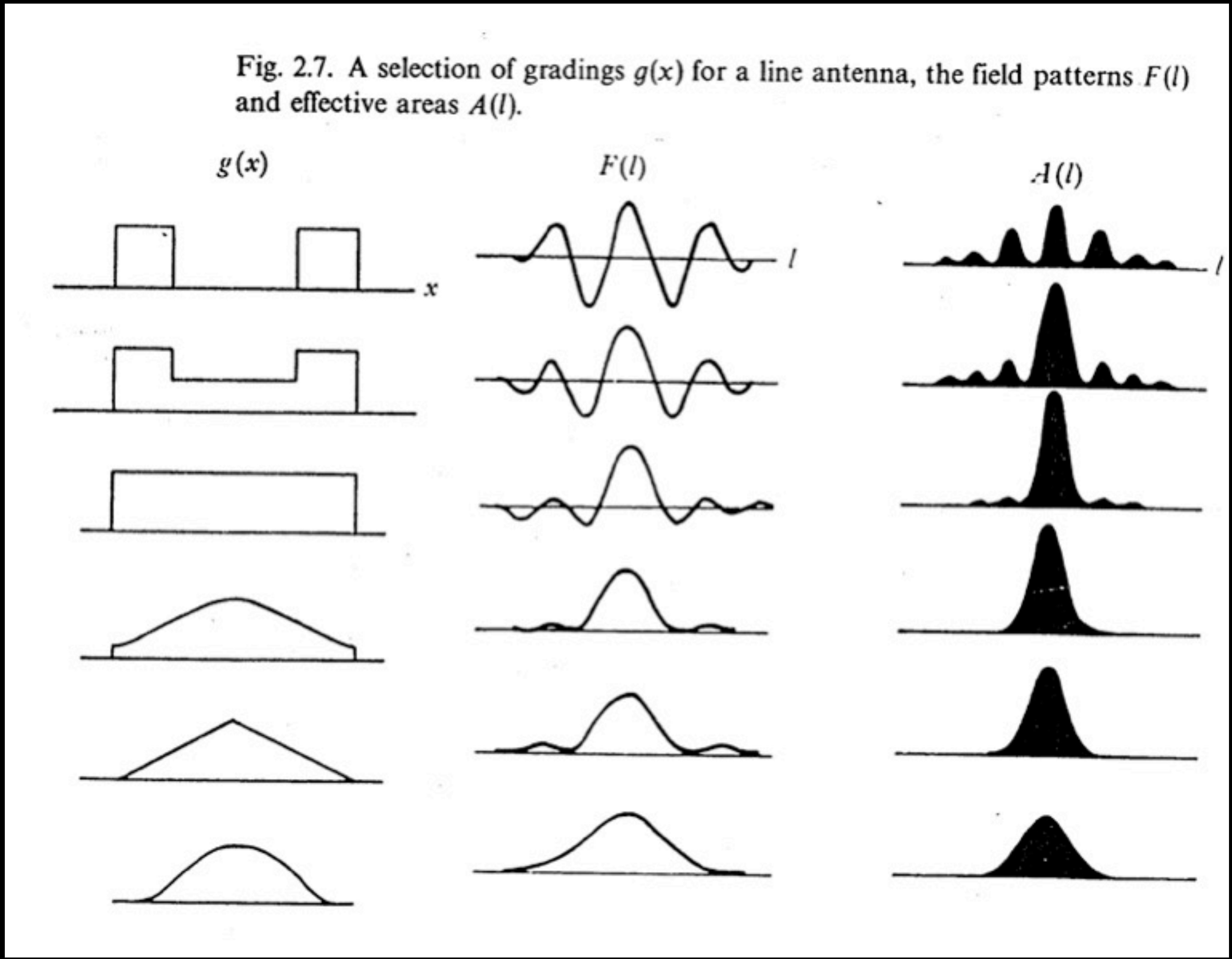


Fig. 6-1. (*a*) Antenna pattern in polar coordinates and linear power scale; (*b*) antenna pattern in rectangular coordinates and decibel power scale.

Radio telescopes have response in all directions: main "lobe" and "sidelobes"

Kraus (1966)



Christiansen & Hogbom (1985)

The Response of a Radio Telescope

tel

$$T_a = \eta_r \int_{4\pi} T_b(\theta, \phi) P(\theta, \phi) \; e^{-\tau_{at}} \; d\Omega$$

(all a function of frequency)

$$\int_{4\pi} P(\theta, \phi) \; d\Omega = 1$$

$$P = P_{mb} + P_{near} + P_{far}$$

sidelobes *what we want*

$$T_a \eta_r^{-1} = \int_{\Omega \neq \Omega_{mb}} T_b [P_{near} + P_{far}] d\Omega + \int_{\Omega mb} T_b P_{mb} \, d\Omega$$

$\eta_r \approx 0.99$

$$\eta_{mb} \equiv \frac{\int_{\Omega mb} P \, d\Omega}{\int_{4\pi} P \, d\Omega}$$

$\eta_{mb} \approx 0.85$

$$\int_{\Omega mb} T_b P_{mb} \, d\Omega = \langle T_b \rangle_{mb} \, \eta_{mb}$$

NRAO

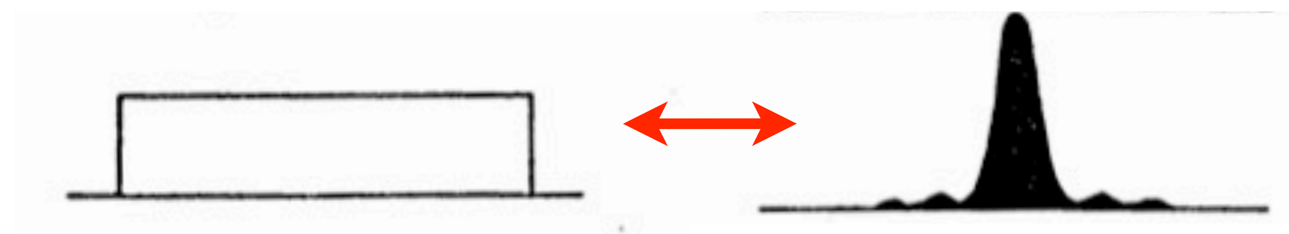
Aperture Efficiency vs. Main Beam Efficiency

$$\eta_a = \frac{A_e}{A_g}$$

effective area

physical (geometric) area

$\eta_a \approx 1.00$



illumination

Power pattern

$$\eta_{mb} \equiv \frac{\int_{\Omega mb} P \, d\Omega}{\int_{4\pi} P \, d\Omega}$$

$\eta_{mb} \approx 1.00$

Aperture Efficiency vs. Main Beam Efficiency

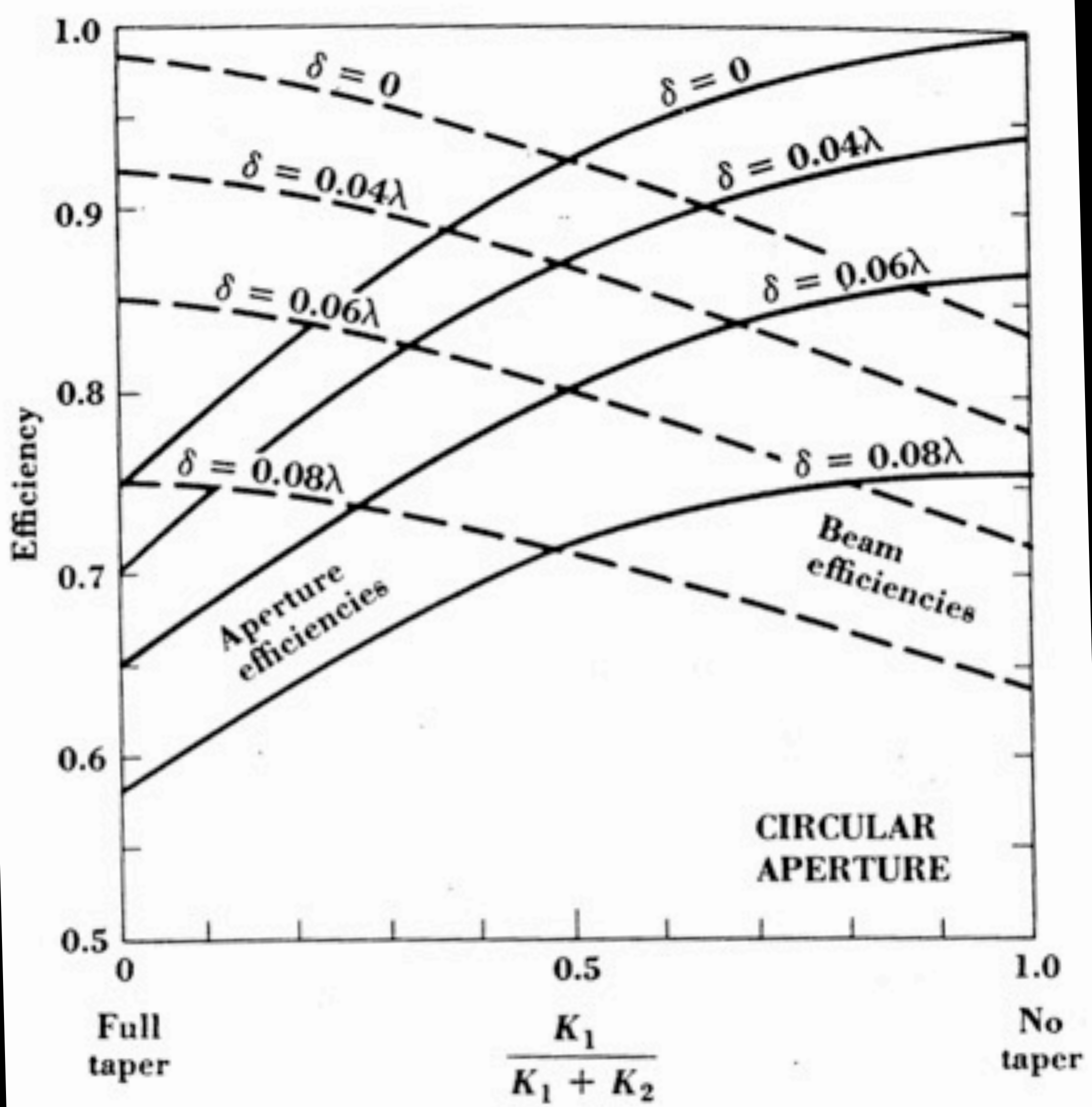
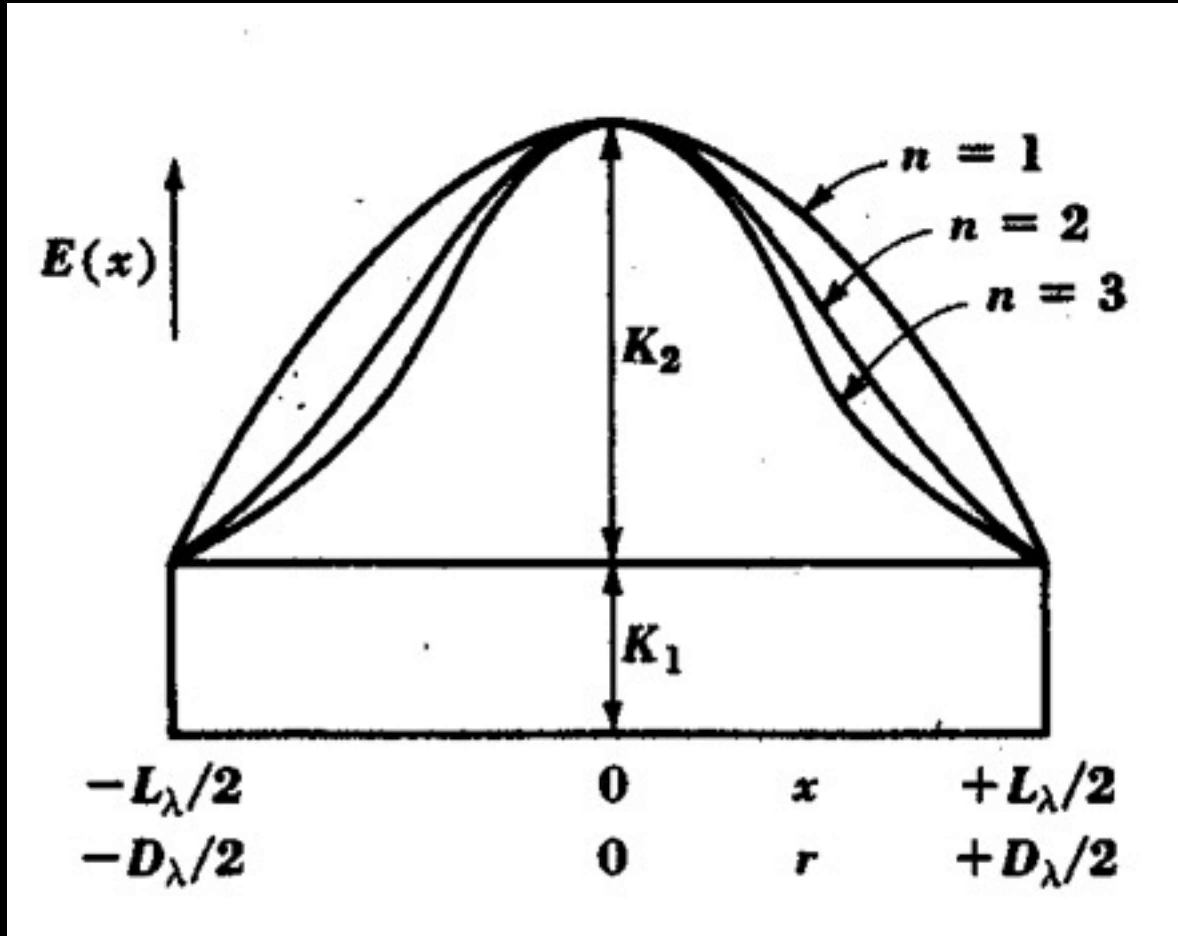
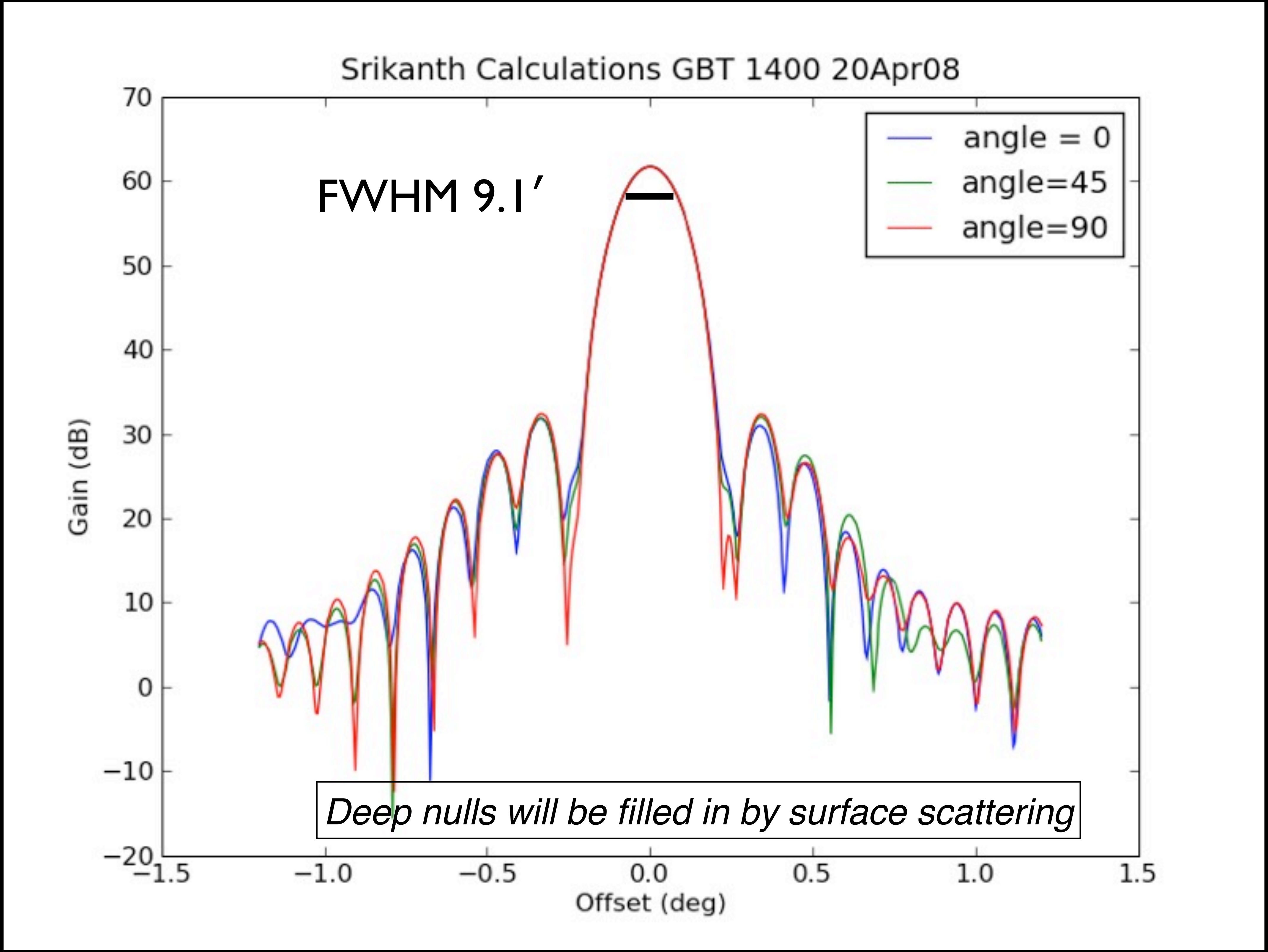


Fig. 6–106 Aperture efficiency (solid) and beam efficiency (dashed) of a circular aperture as a function of taper and phase error. (*After Nash*, 1964.)

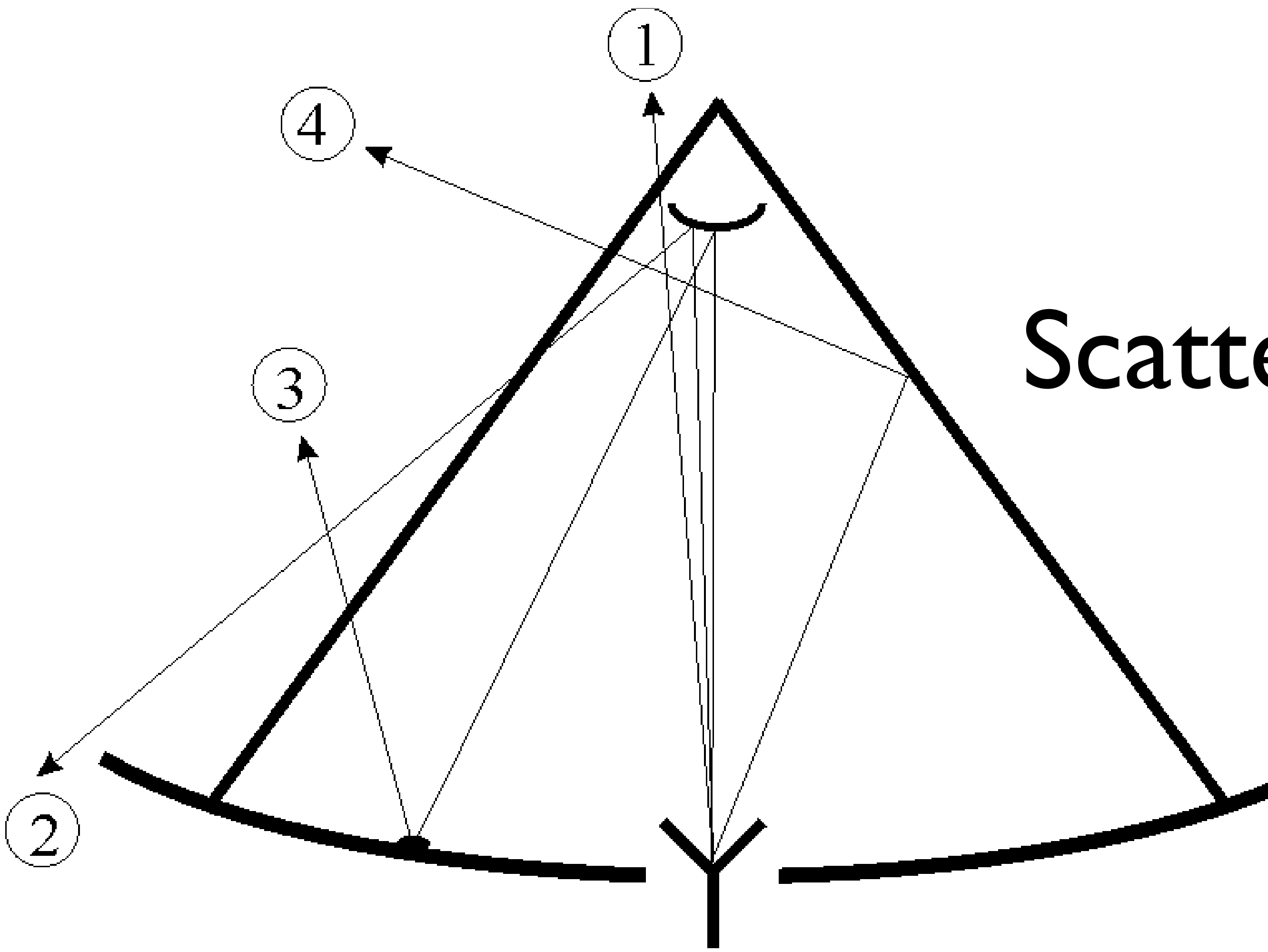


Kraus (1966)



Srikanth Calculations GBT 1400 20Apr08
FWHM 9.1′
angle = 0
angle=45
angle=90
Gain (dB)
Offset (deg)
70
60
50
40
30
20
10
0
−10
−20
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Deep nulls will be filled in by surface scattering

Surface Errors



Scatter power out of main beam

Create a sidelobe

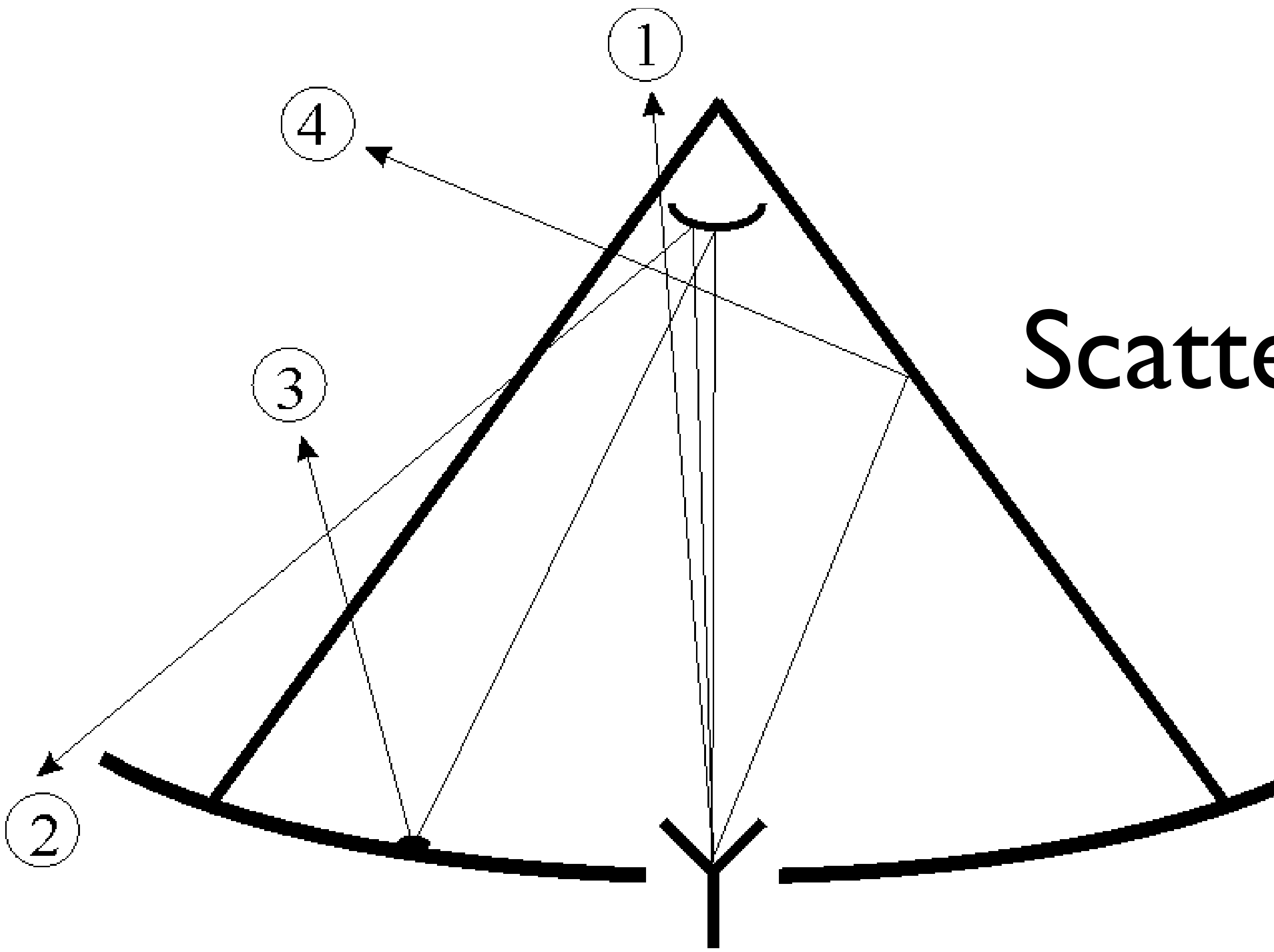
Reduce A_e

Ruze equation for rms error σ

$$\epsilon = e^{-(4\pi\sigma/\lambda)^2}$$

A_e reduced by factor of 2 for $\sigma=\lambda/16$

Surface Errors



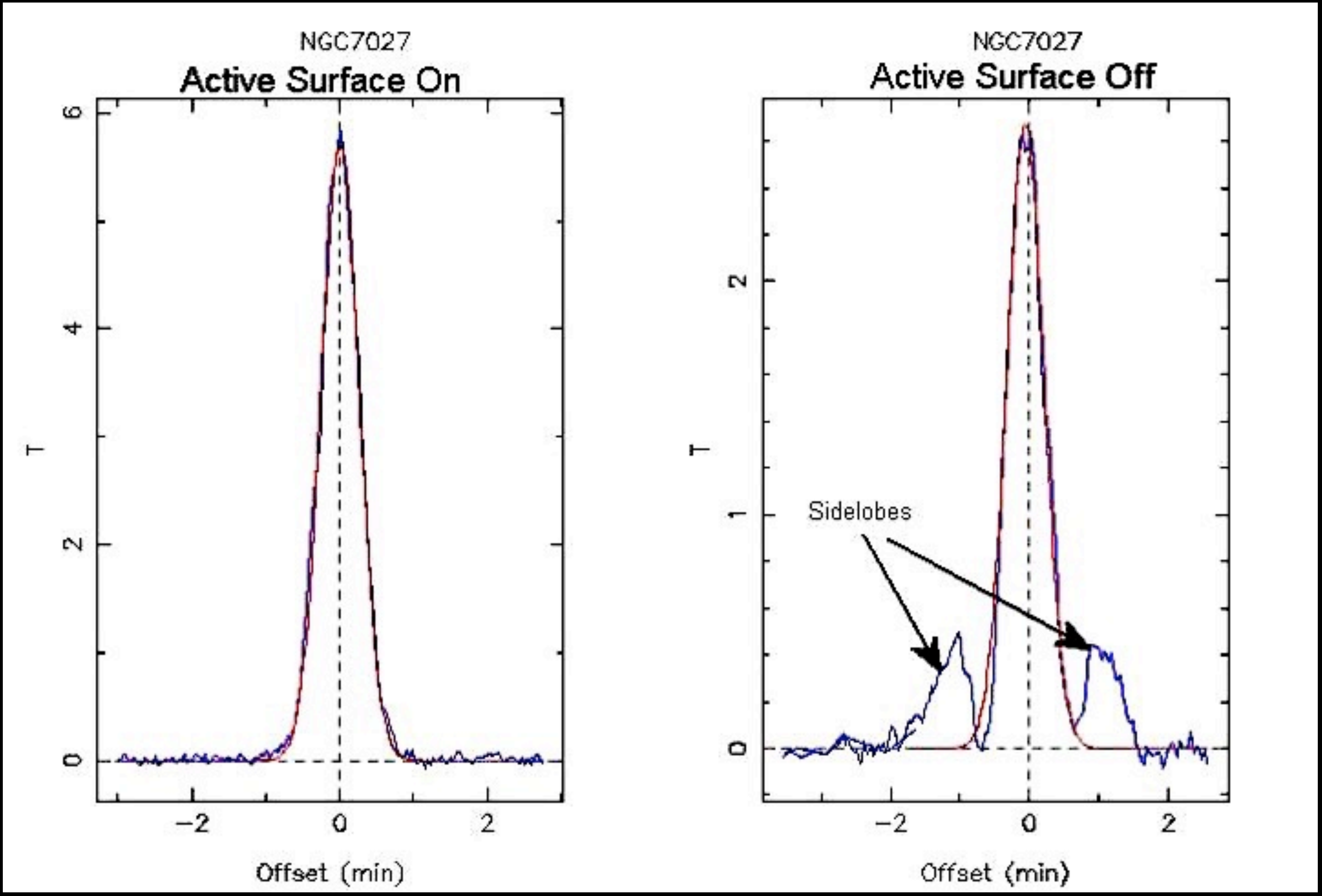
Scatter power out of main beam
Create a sidelobe
Reduce A_e

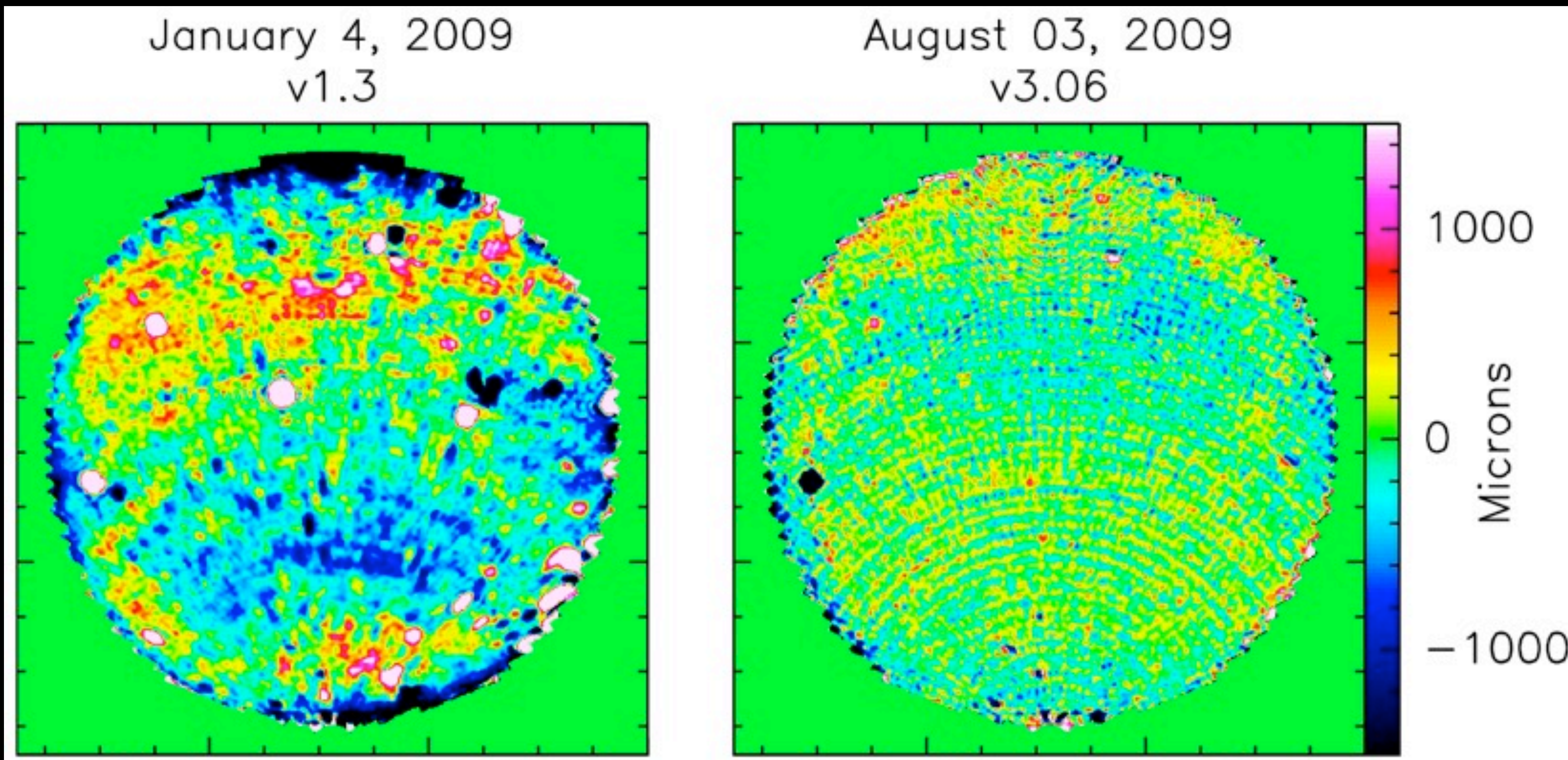
Ruze equation for rms error σ

$$\epsilon = e^{-(4\pi\sigma/\lambda)^2}$$

A_e reduced by factor of 2 for $\sigma=\lambda/16$

Where does it go?


NGC7027
Active Surface On
T
Offset (min)
NGC7027
Active Surface Off
T
Sidelobes
Offset (min)



January 4, 2009
v1.3
August 03, 2009
v3.06
1000
0
−1000
Microns

NRAO 36-Foot Telescope Machined, Solid Aluminum Surface

NRAO 36-Foot Telescope Machined, Solid Aluminum Surface

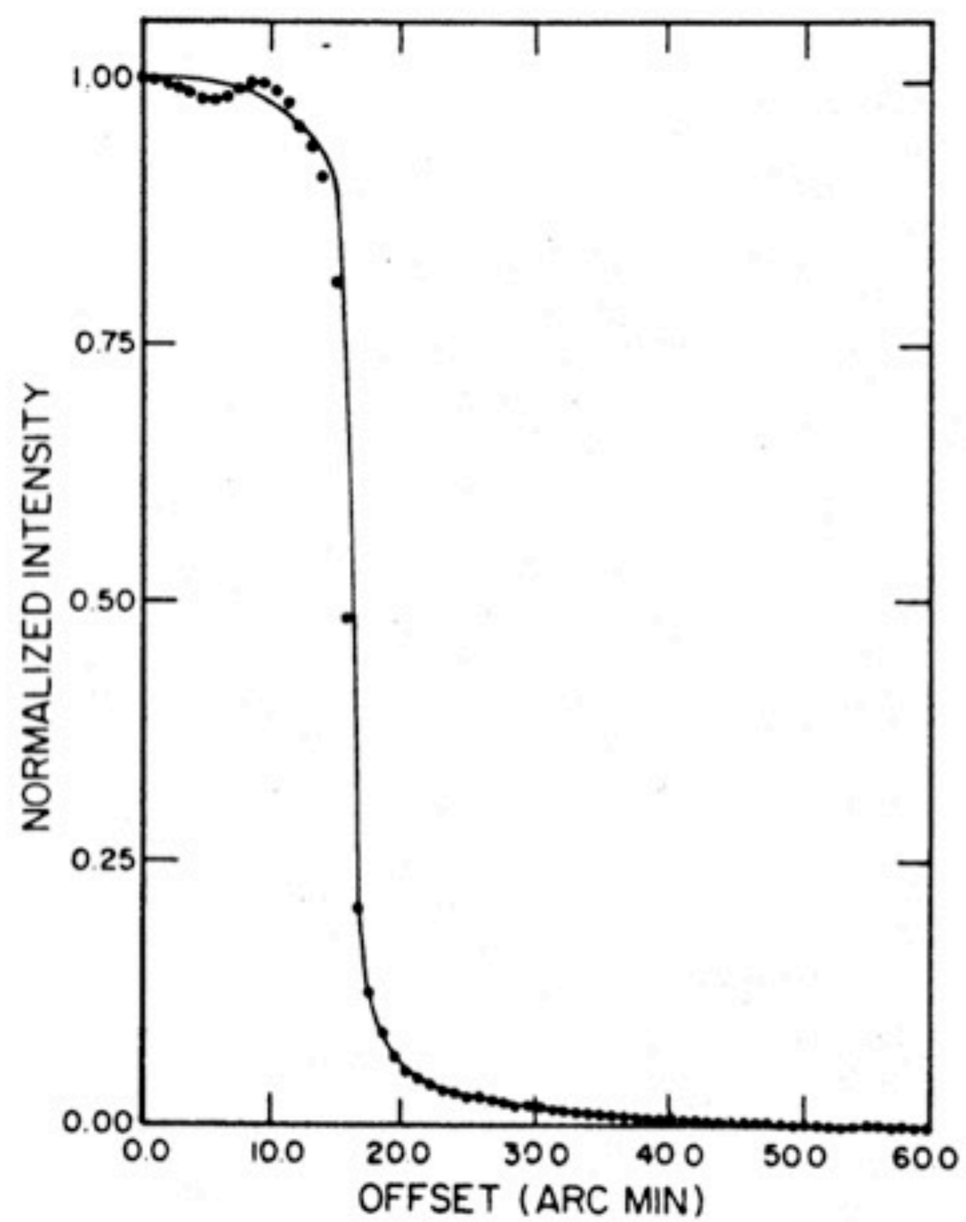


FIG. 2*a*

FIG. 2.—(*a*) Normalized intensity in sun drift scan vs. offset from center of Sun.
d the smooth curve is the result of the convolution of the three-Gaussian model

NRAO 36-Foot Telescope Machined, Solid Aluminum Surface

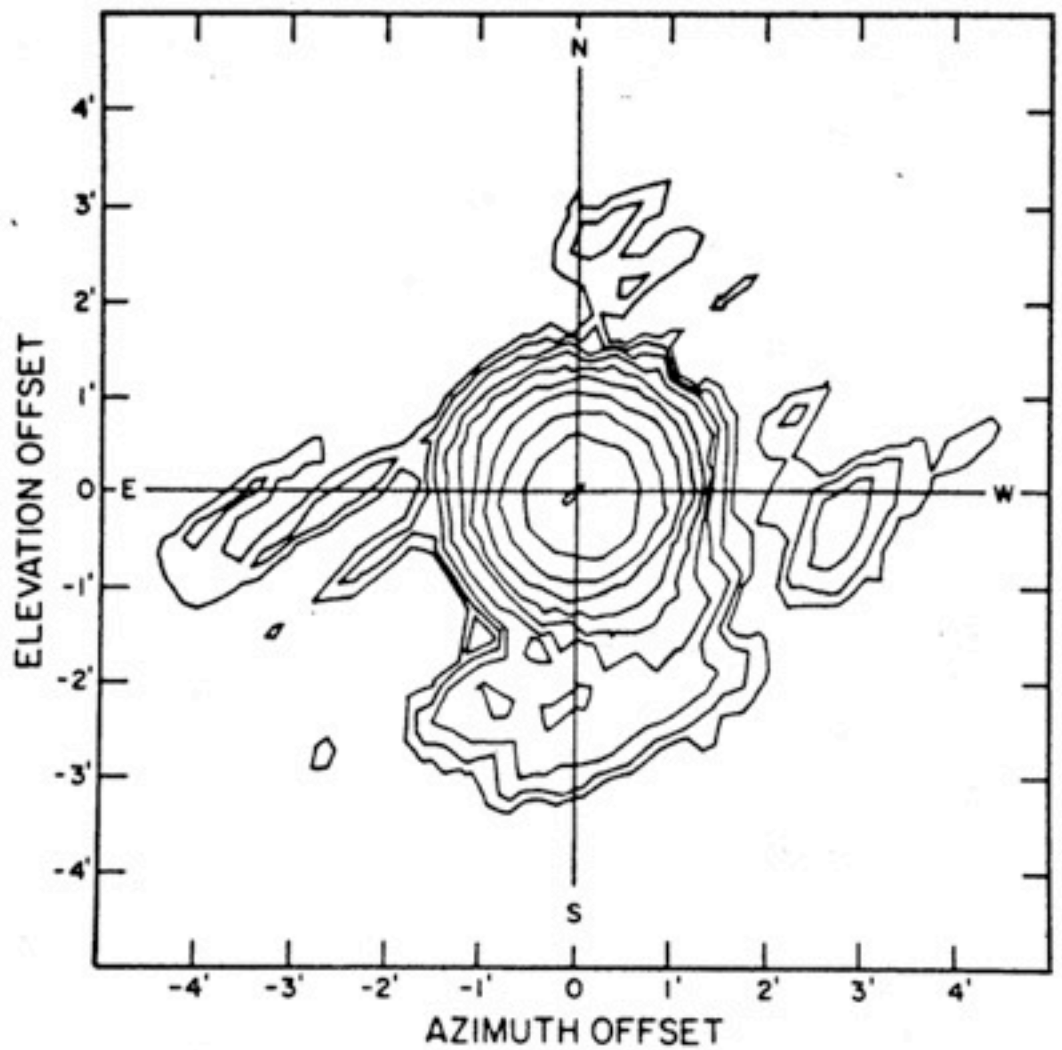
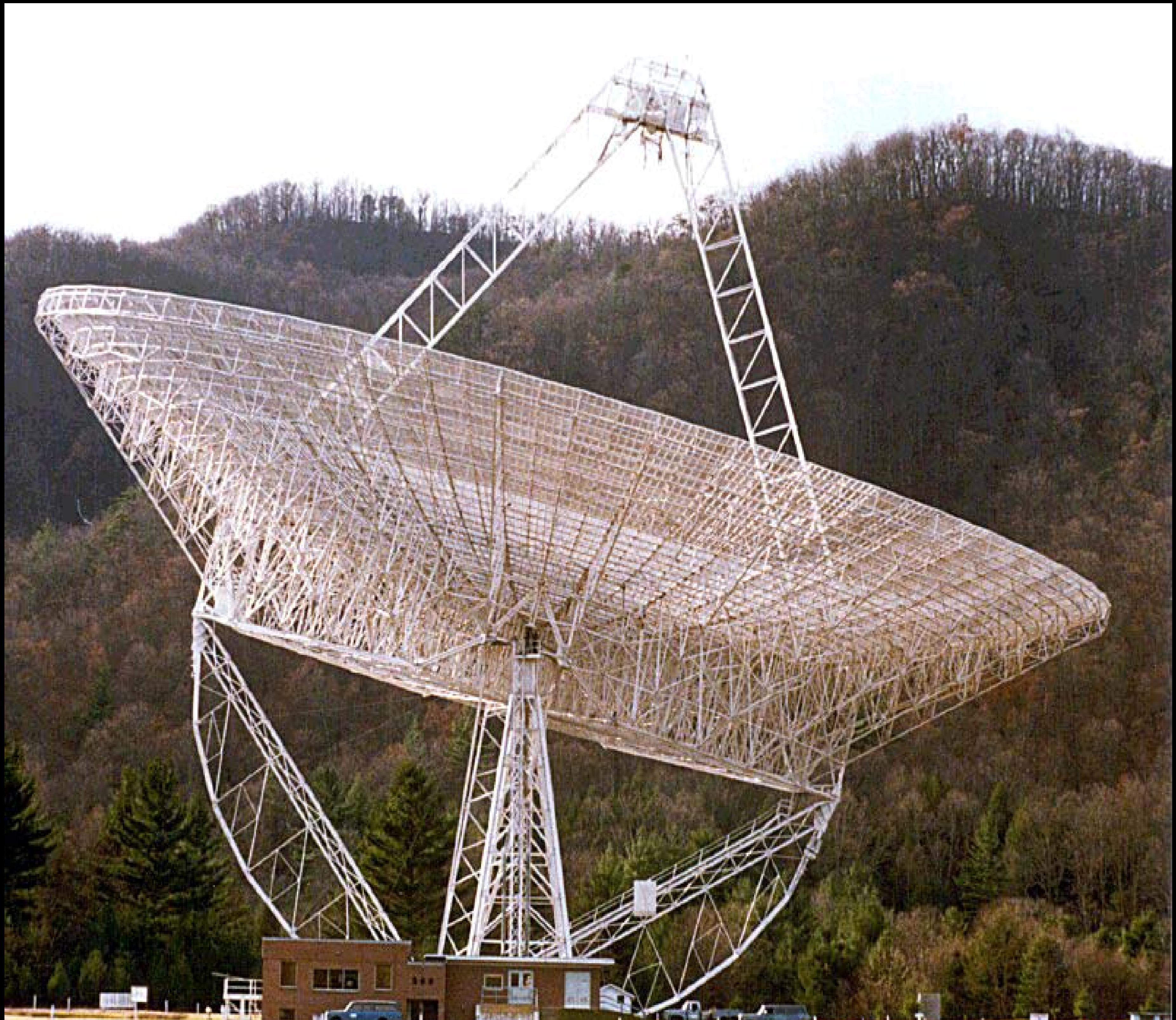


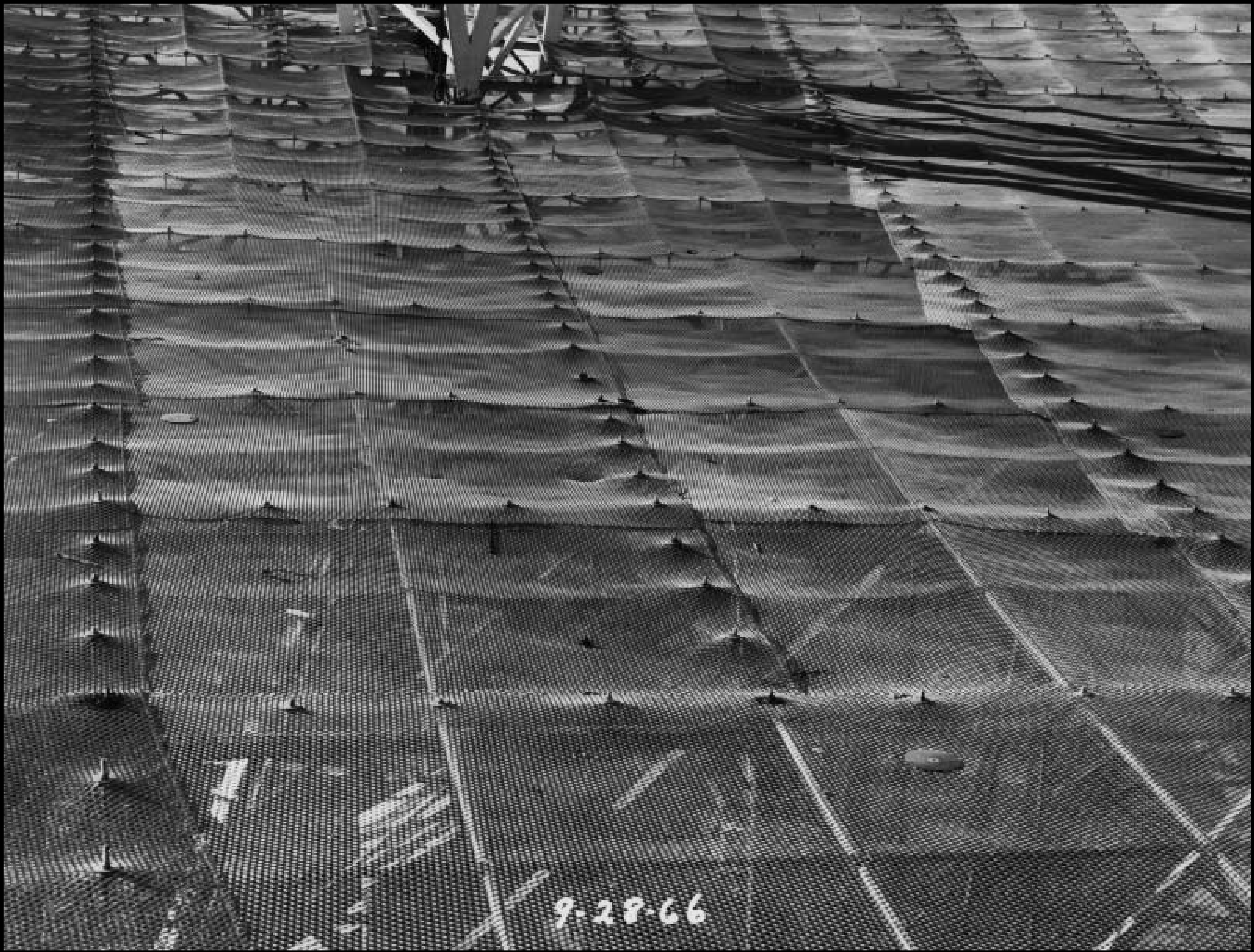
FIG. 1.—Map of the inner 10′ of the beam. The map was made in R.A. and declination offset, but the tilted axes give the orientation of azimuth and elevation. The LO was at 90.0 GHz. Contours are in 2 dB steps with the lowest contour 18 dB below the peak.

300 Foot Radio Telescope



300 Foot Radio Telescope

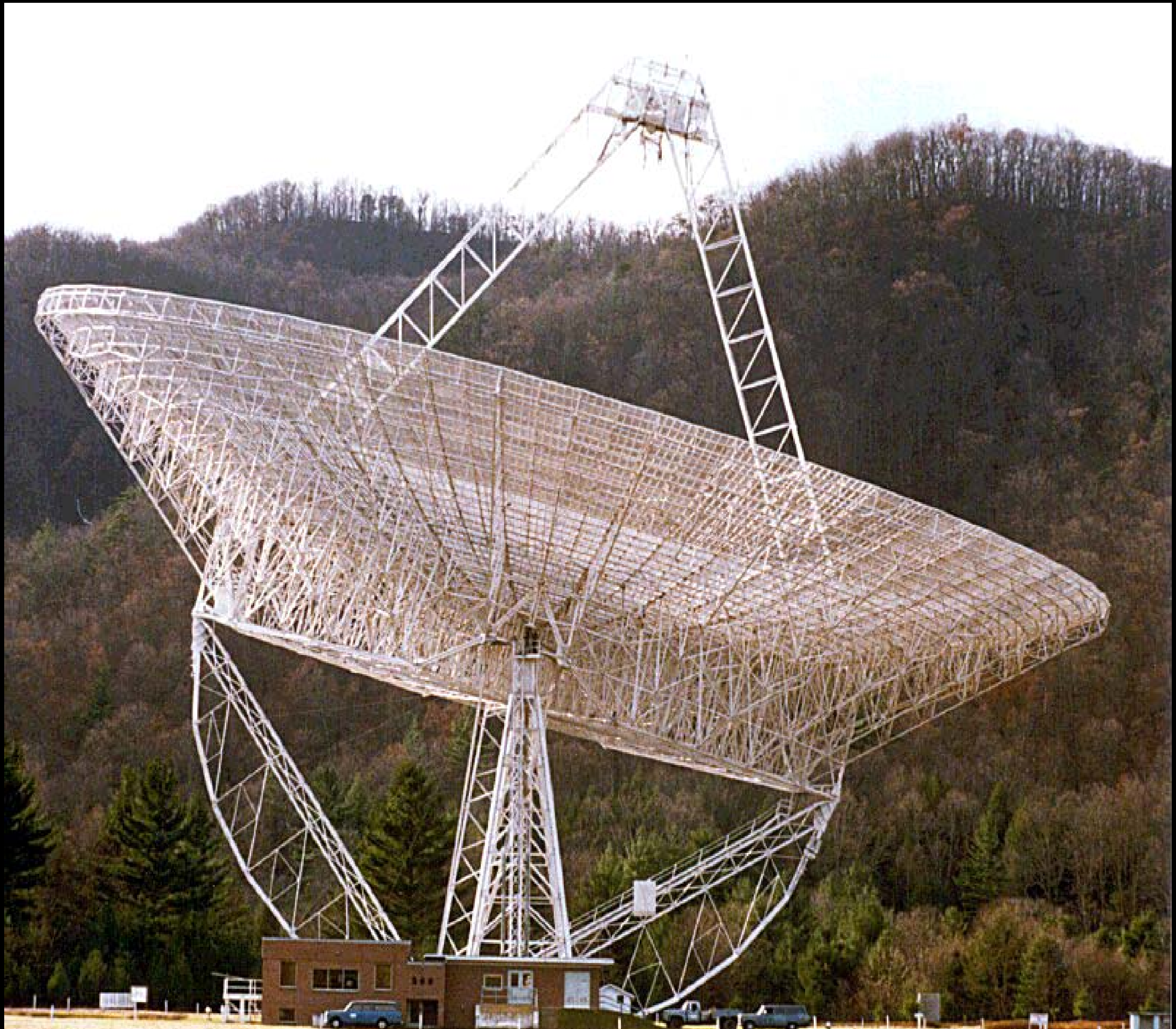
300 Foot Radio Telescope



300 Foot Radio Telescope

300 Foot Radio Telescope

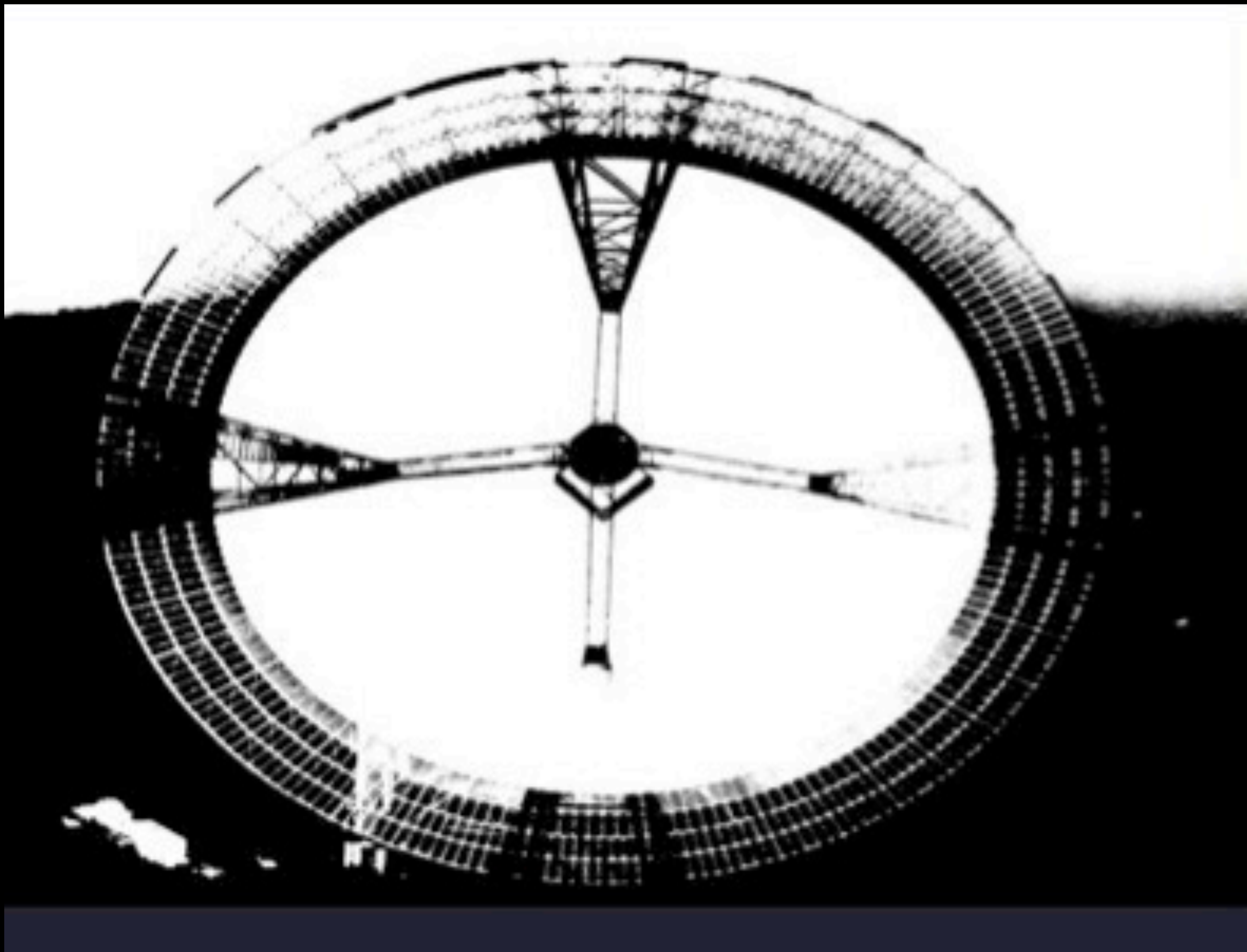
300 Foot Radio Telescope
November 15, 1988



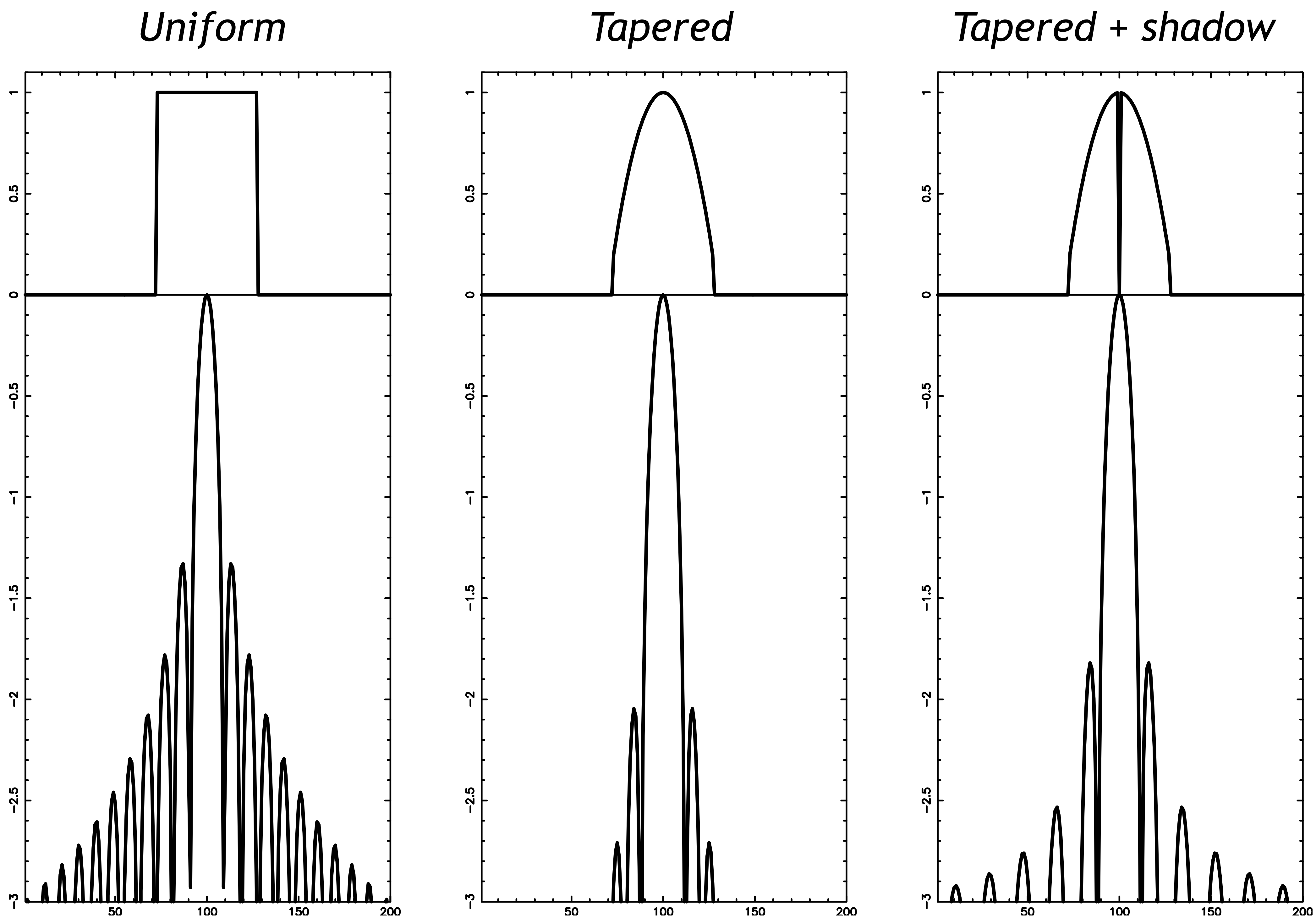
300 Foot Radio Telescope
November 16, 1988

300 Foot Radio Telescope
November 16, 1988

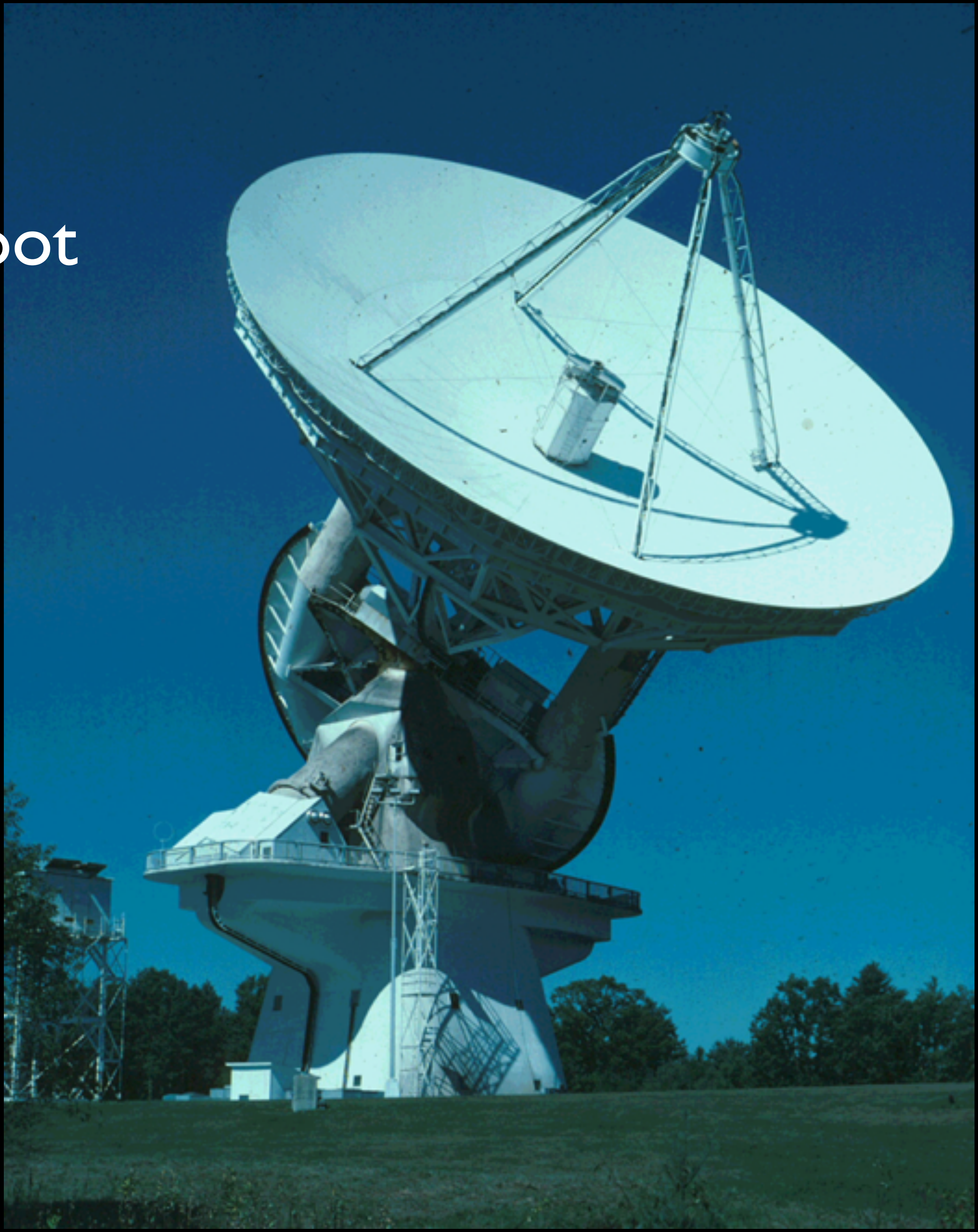
Blockage



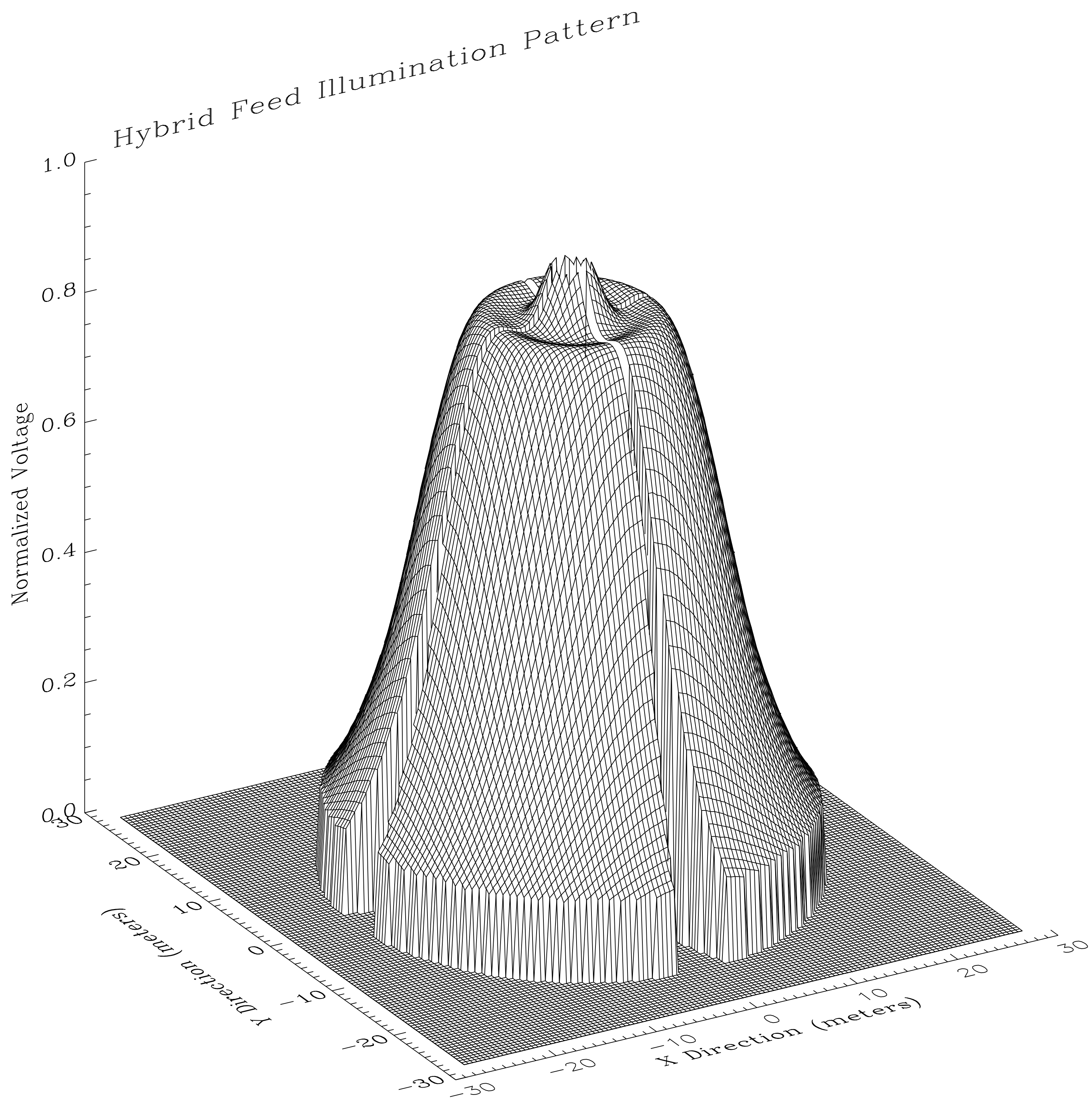
The Effects of Blockage (a 1-d example)



NRAO 140 Foot Telescope

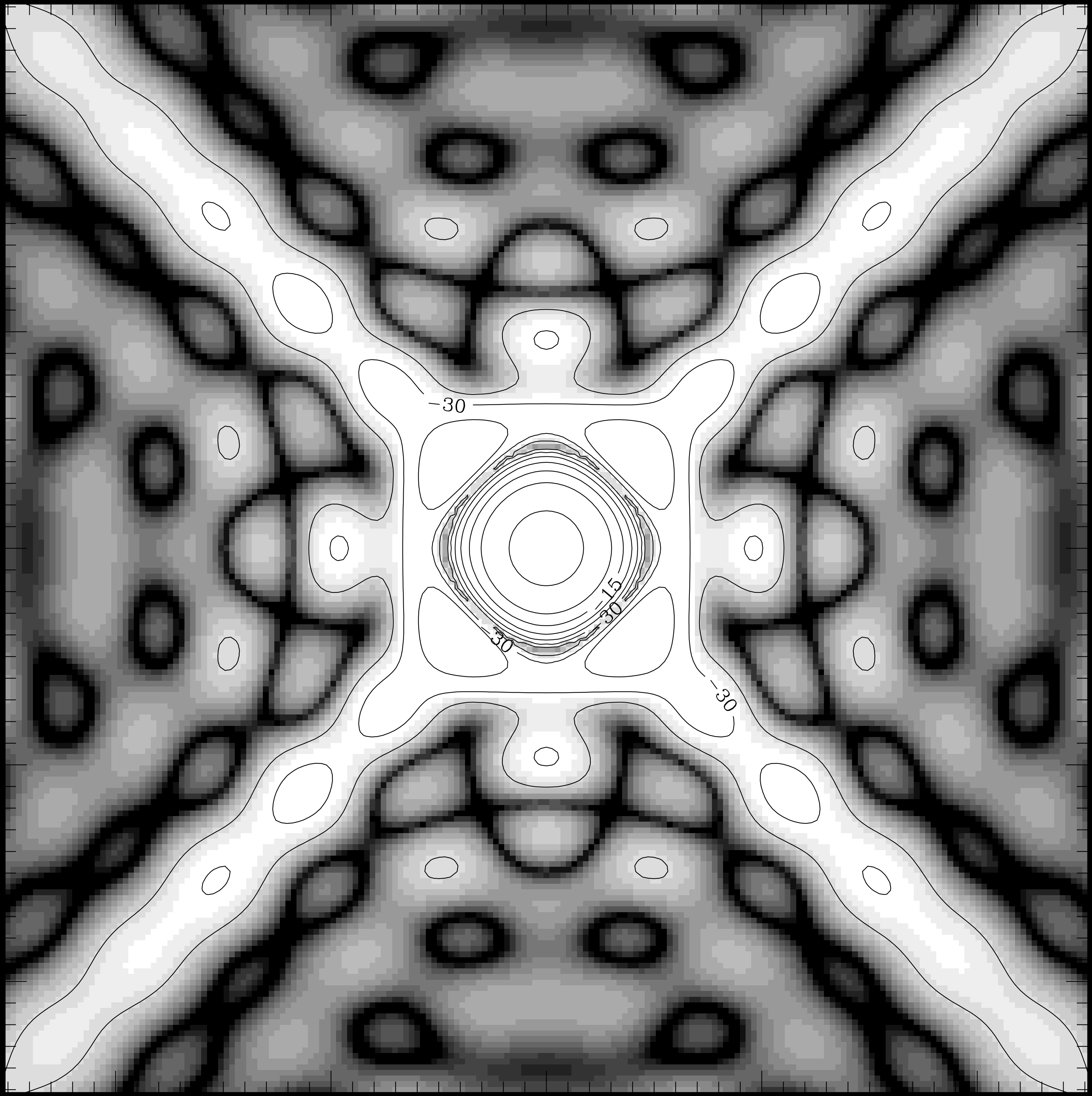


The Effects of Blockage -- 140 Foot Illumination Pattern



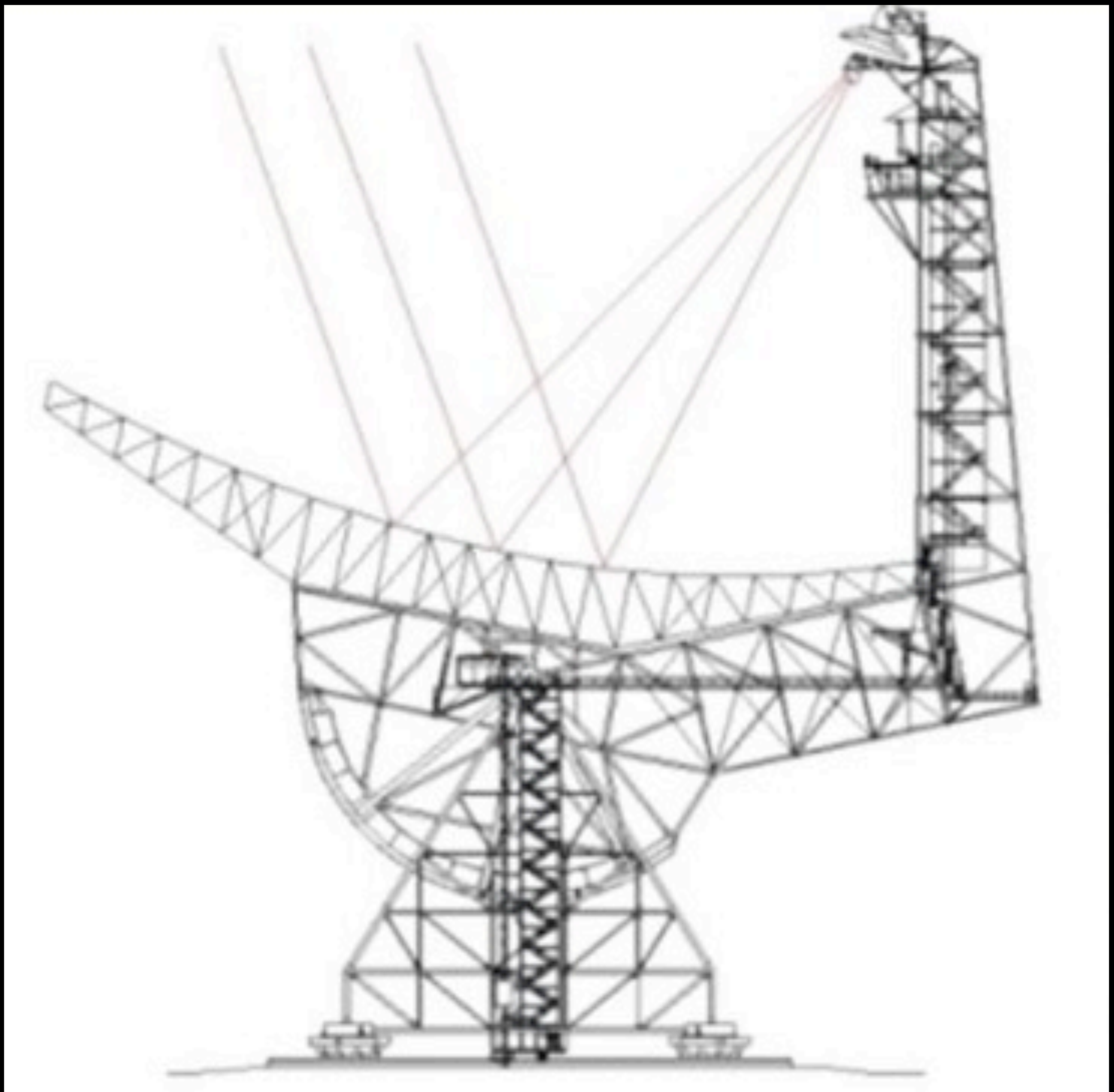
(Murphy 1993)

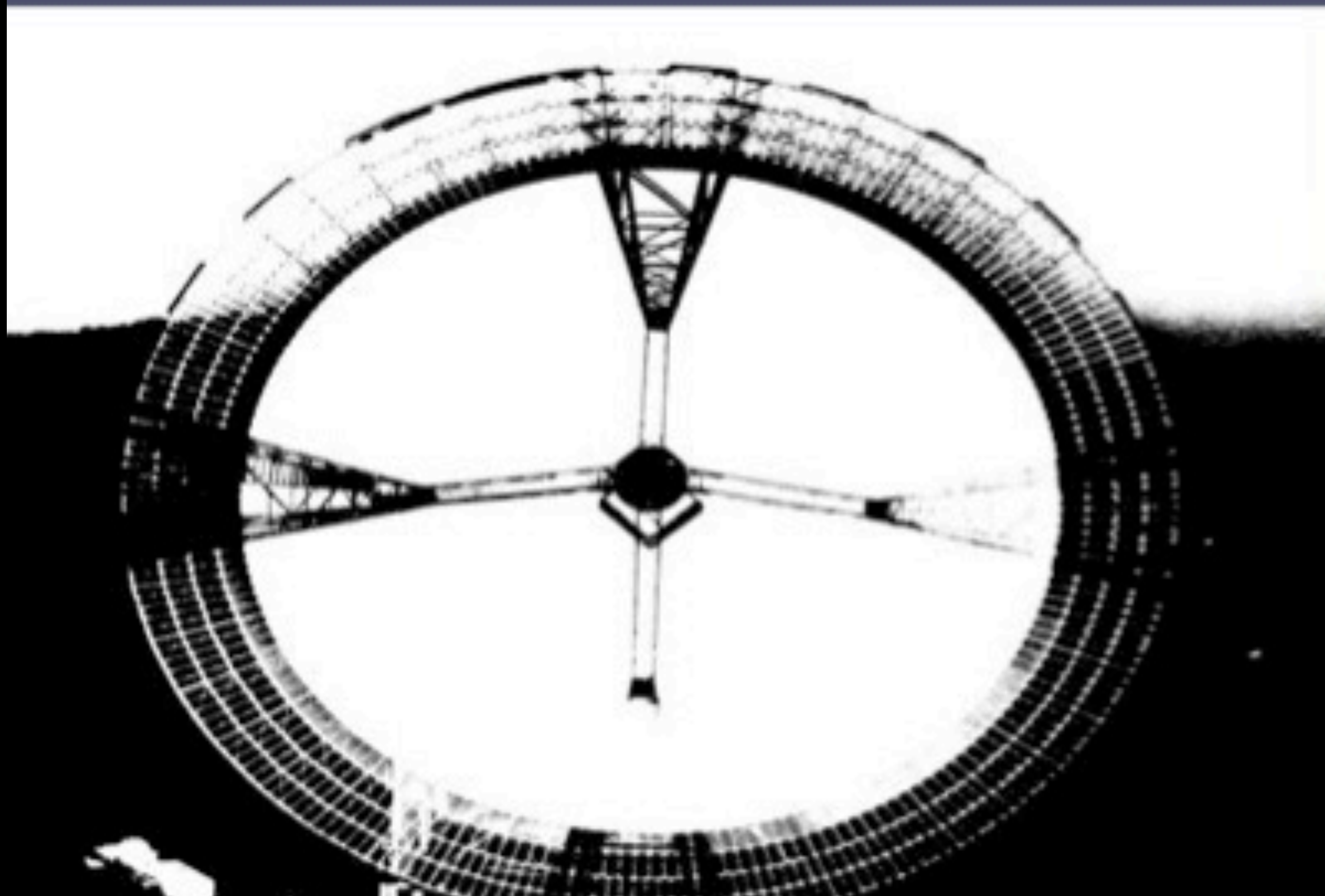
NRAO 140 Foot Telescope calculated

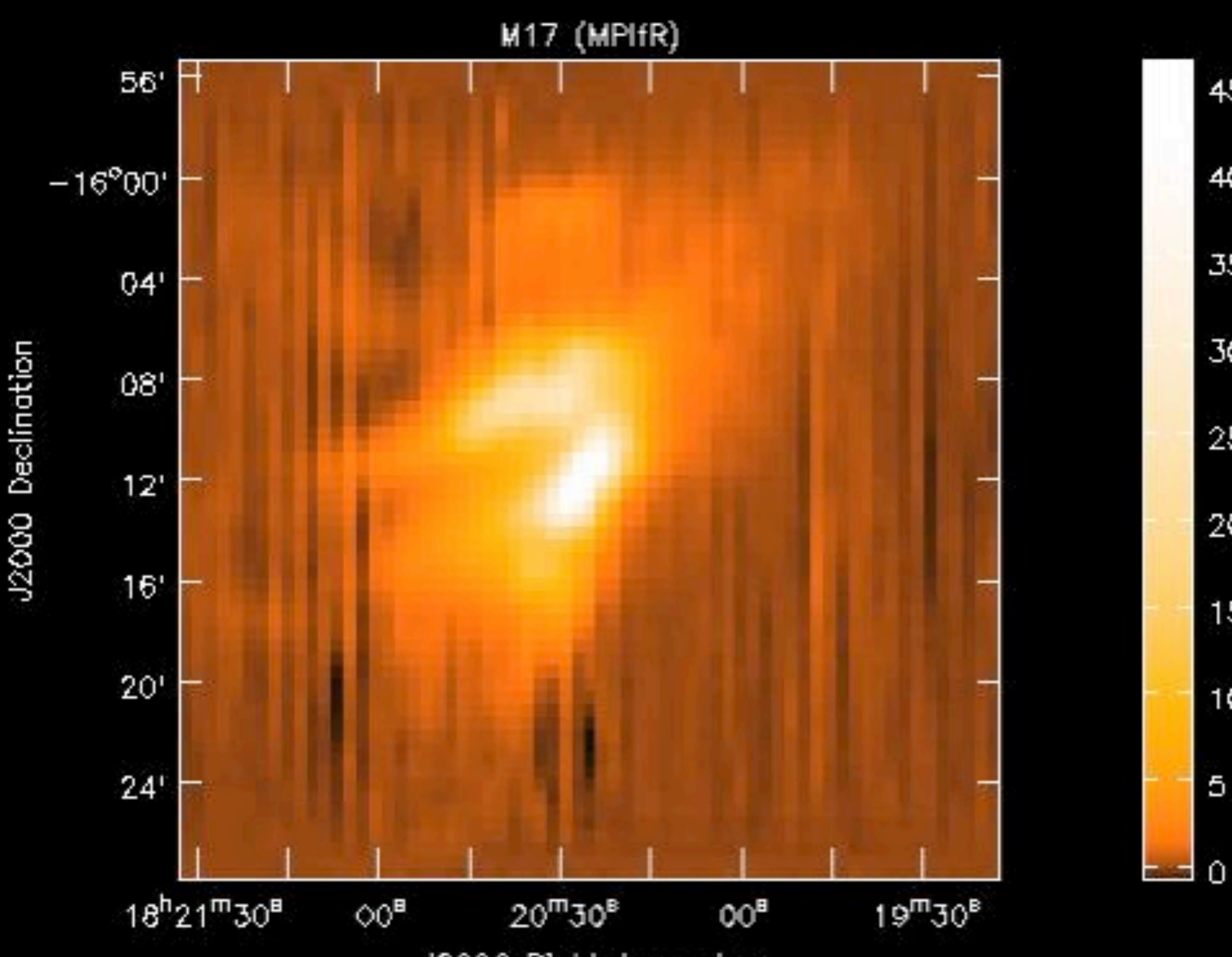


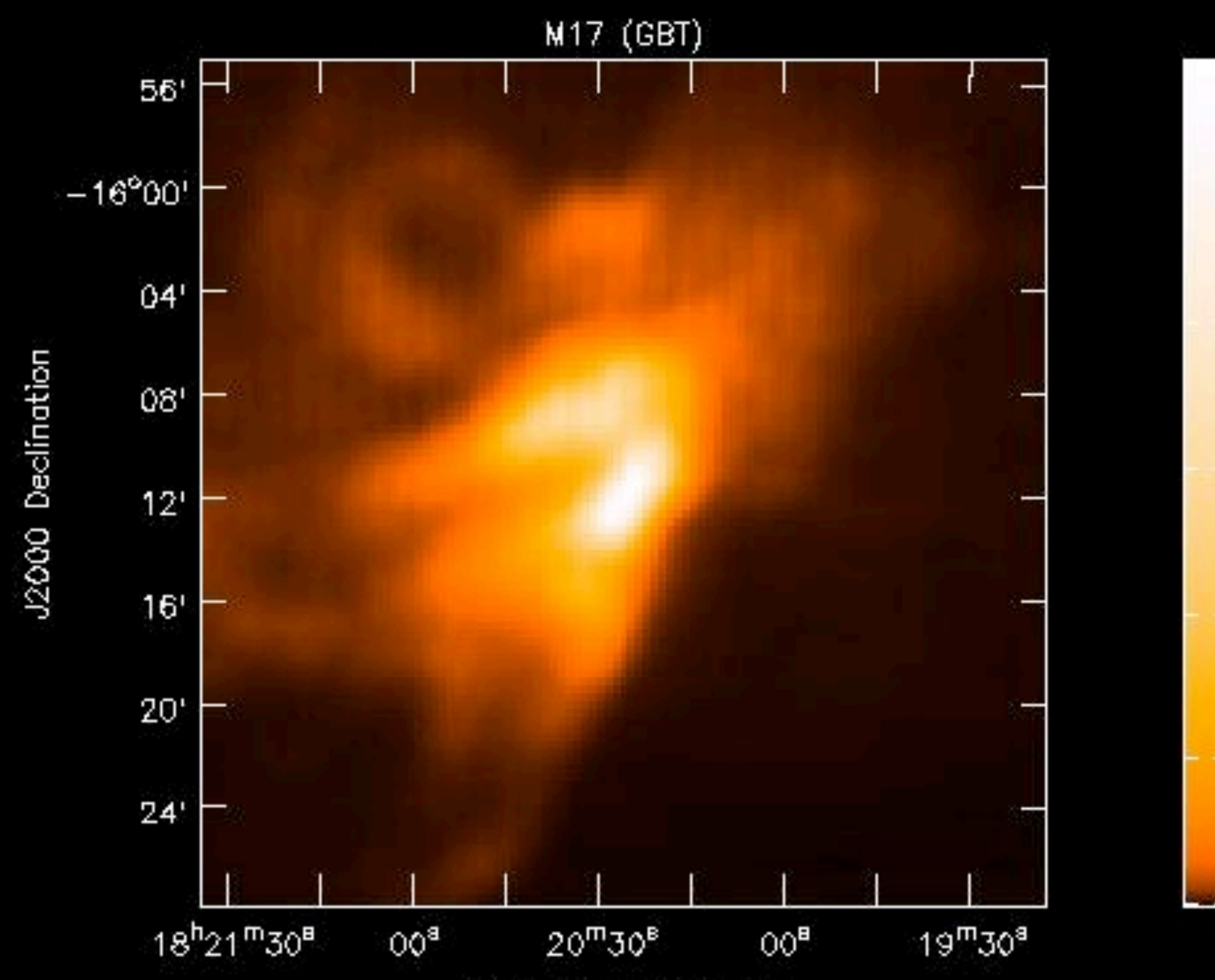
(Murphy 1993)

The Green Bank Telescope (GBT)

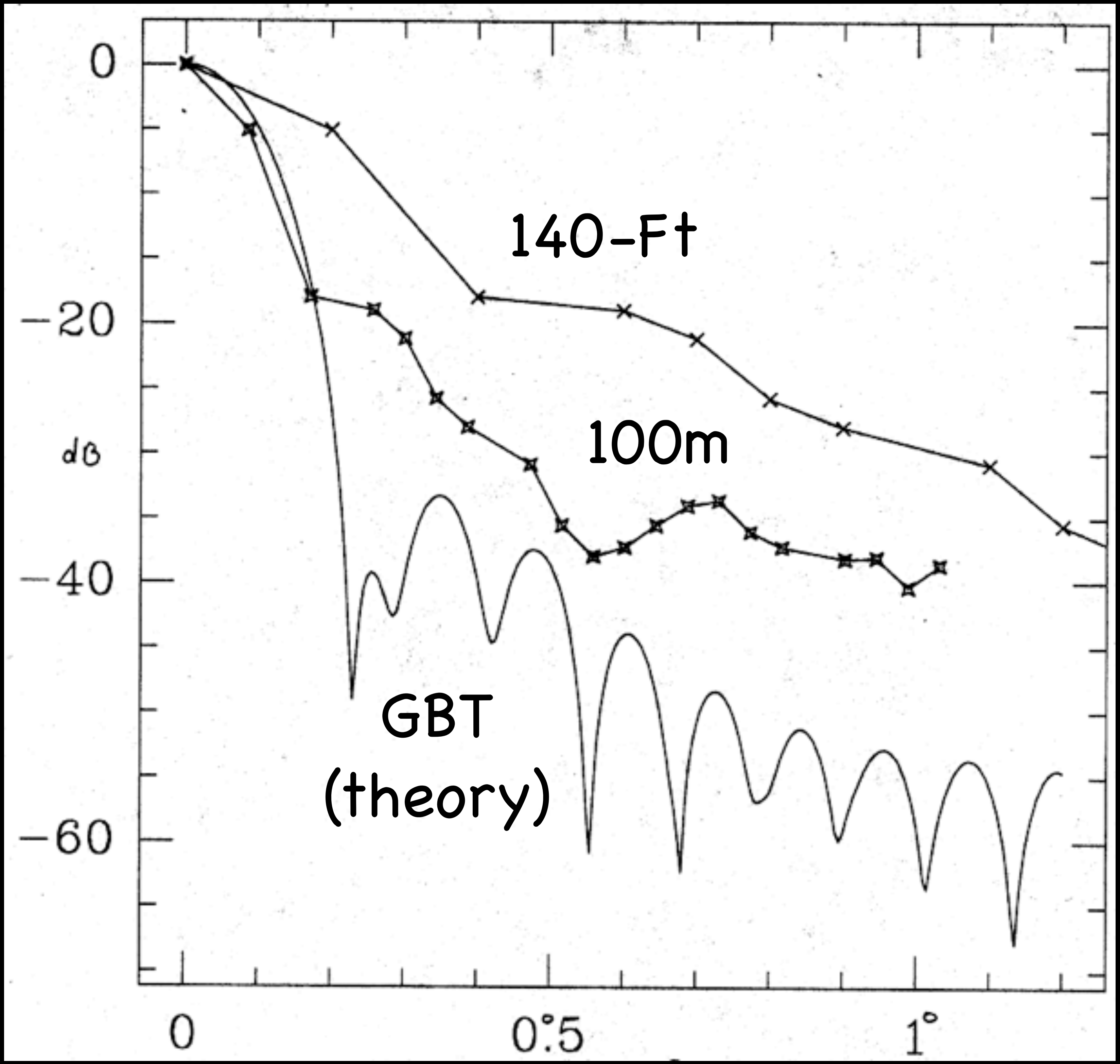





M17 (MPIfR)
56'
−16°00'
04'
08'
12'
16'
20'
24'
J2000 Declination
18h21m30s
00s
20m30s
00s
19m30s
J2000 Right Ascension
0
5


M17 (GBT)
56'
−16°00'
04'
08'
12'
16'
20'
24'
J2000 Declination
18h21m30s
00s
20m30s
00s
19m30s
J2000 Right Ascension

The Effects of Blockage on Near Sidelobes



Far Sidelobes

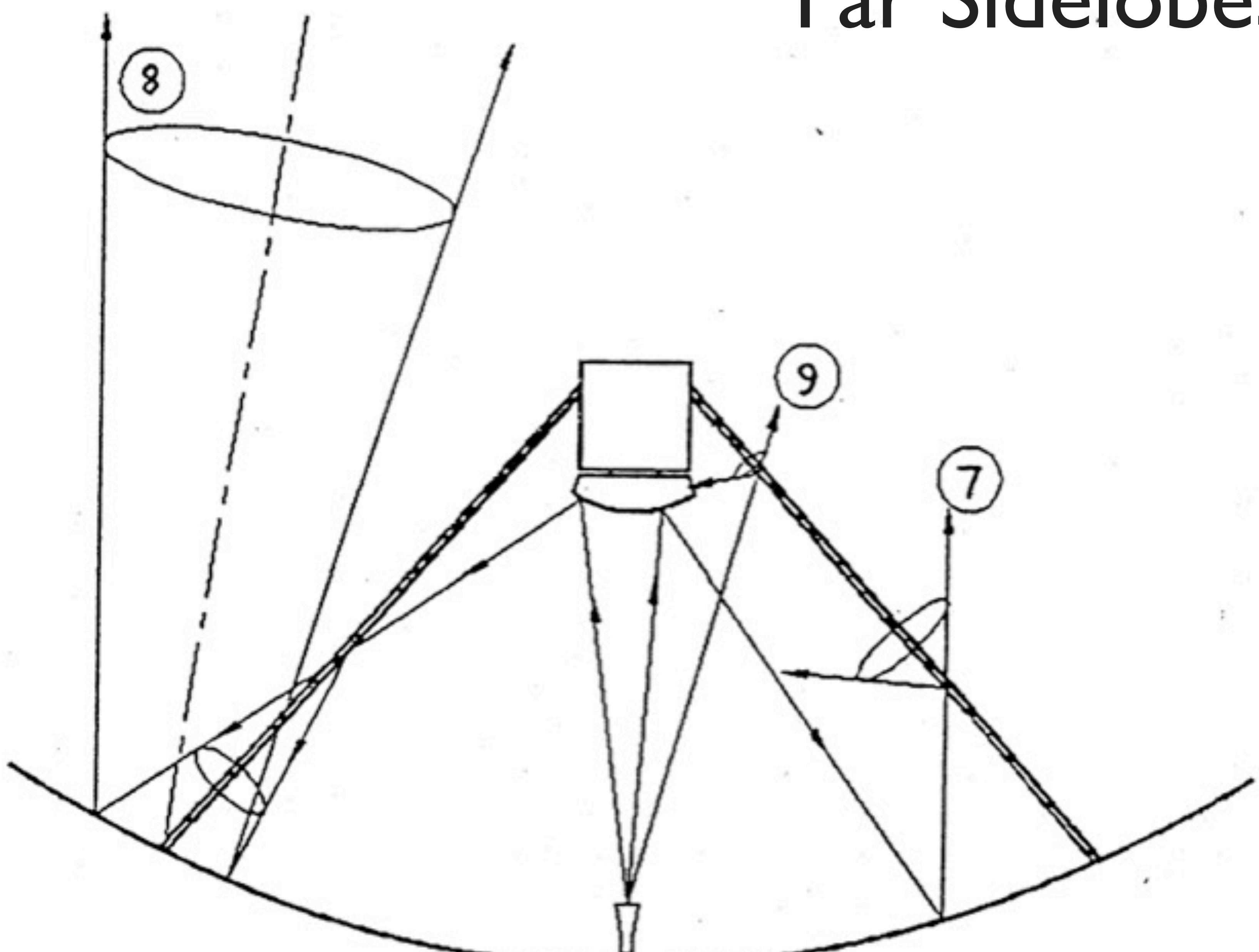
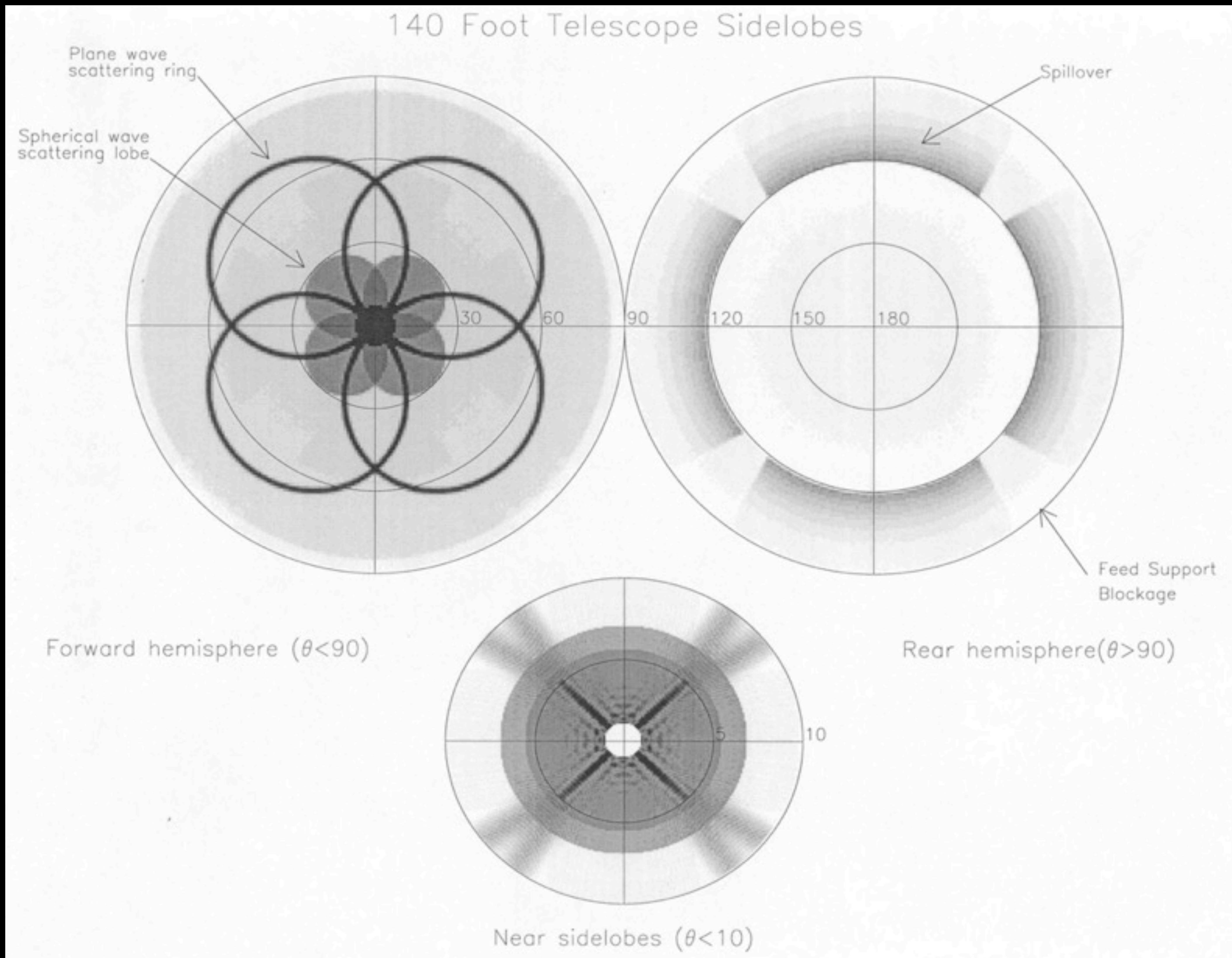


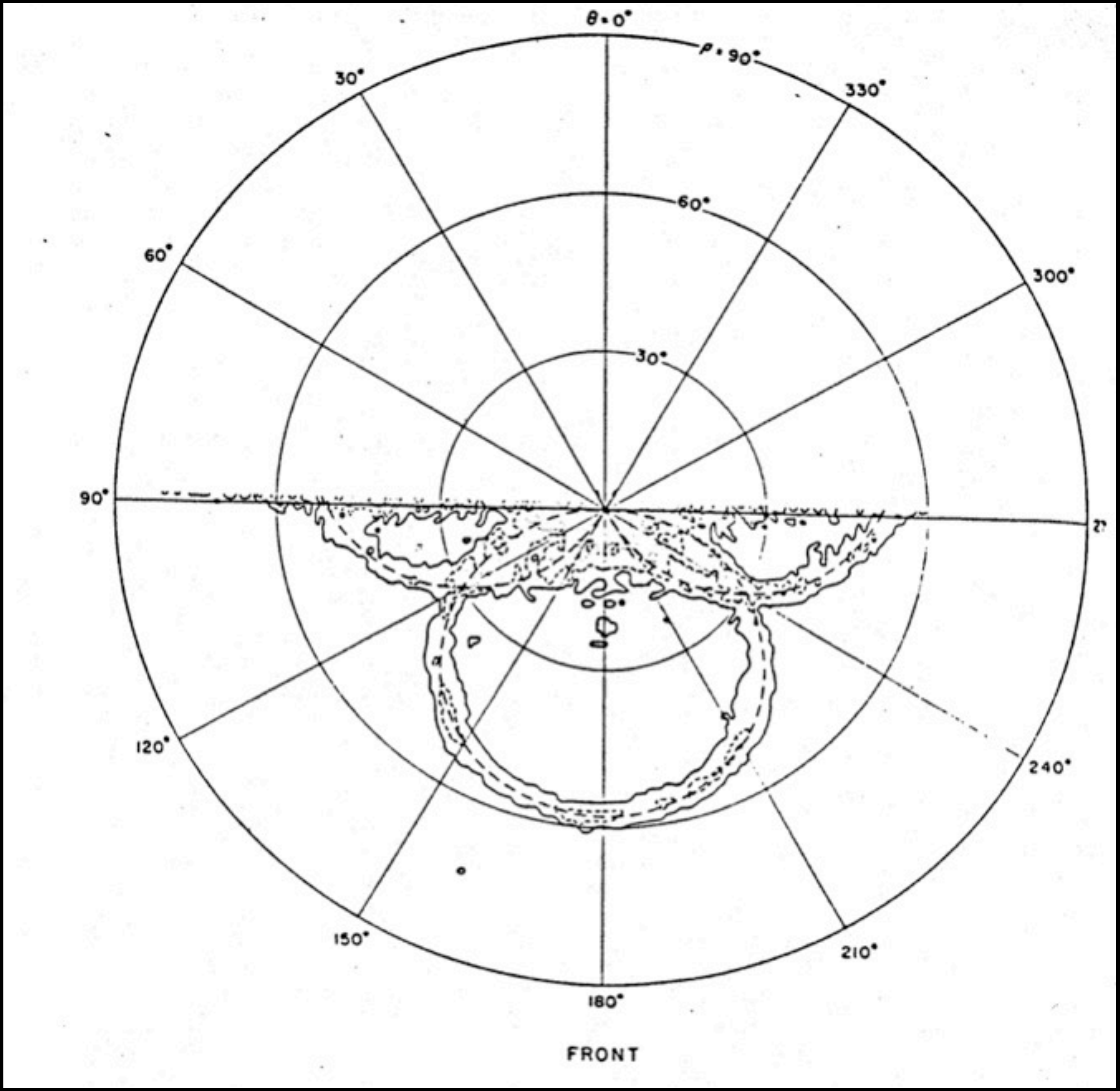
Figure 3 Some mechanisms resulting in sidelobes: (1)Near-in sidelobes, main beam, (2)spillover, (3)sec. diffraction, (4)prim. diffraction, (5)gap scattering, (6)gap trans,(7)plane wave scatt., (8)spher. wave scattering, (9)scattering of spillover power.



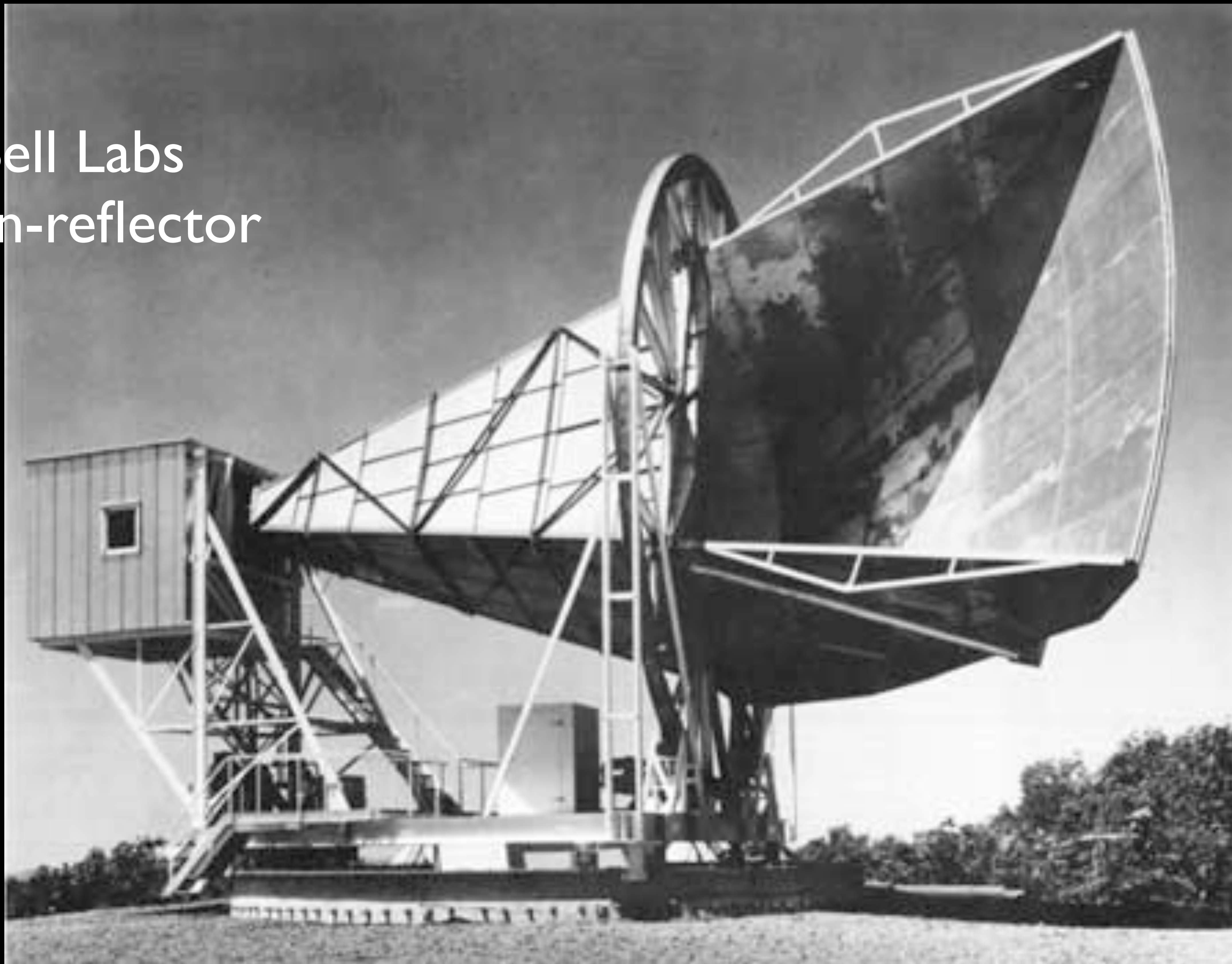
140 Foot Telescope Sidelobes
Plane wave scattering ring
Spherical wave scattering lobe
30
60
90
120
150
180
Spillover
Feed Support Blockage
Forward hemisphere (θ<90)
Rear hemisphere(θ>90)
5
10
Near sidelobes (θ<10)

Murphy (1993)

Dwingeloo 25m Telescope



Bell Labs
Horn-reflector



Spillover

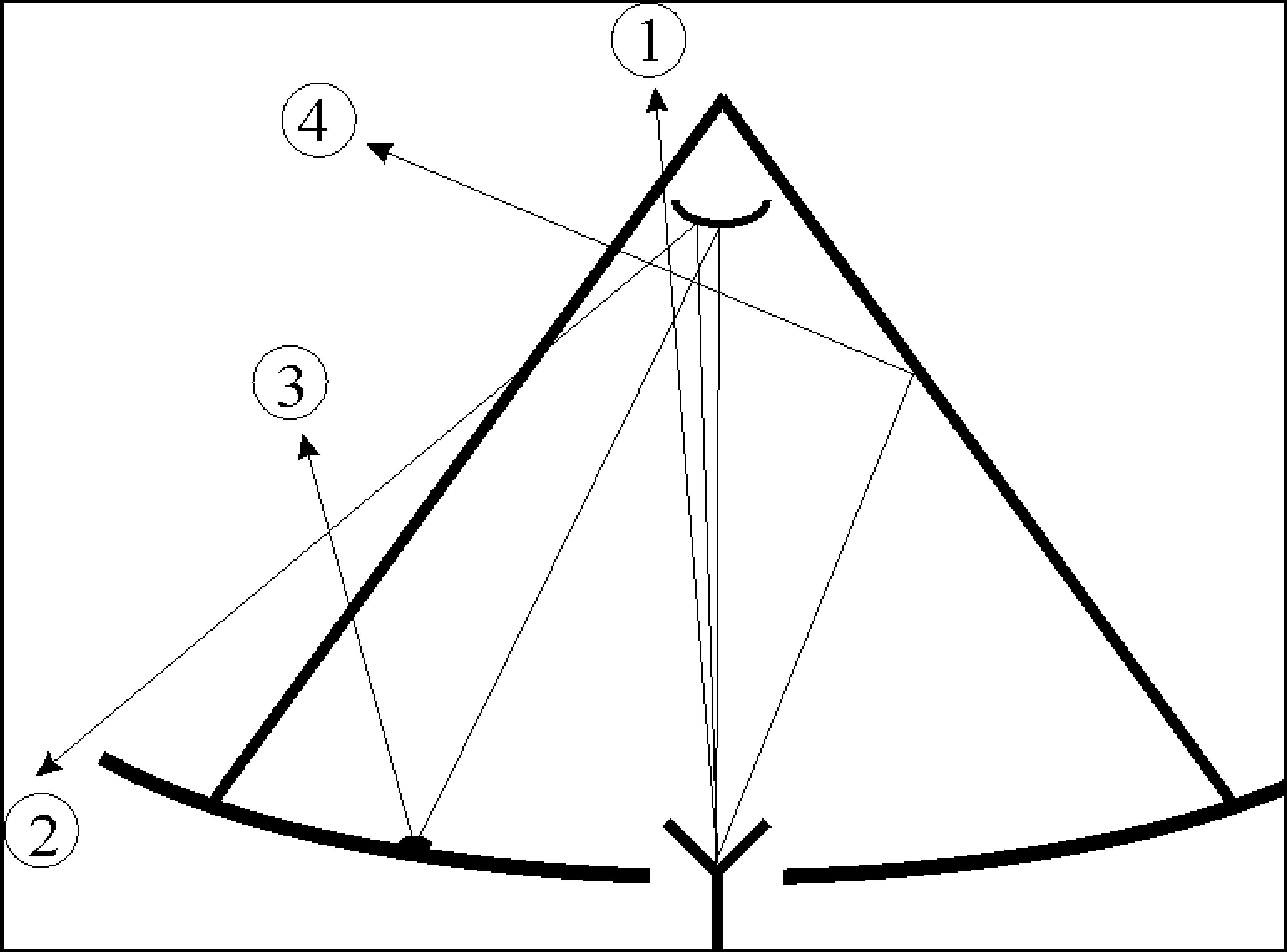
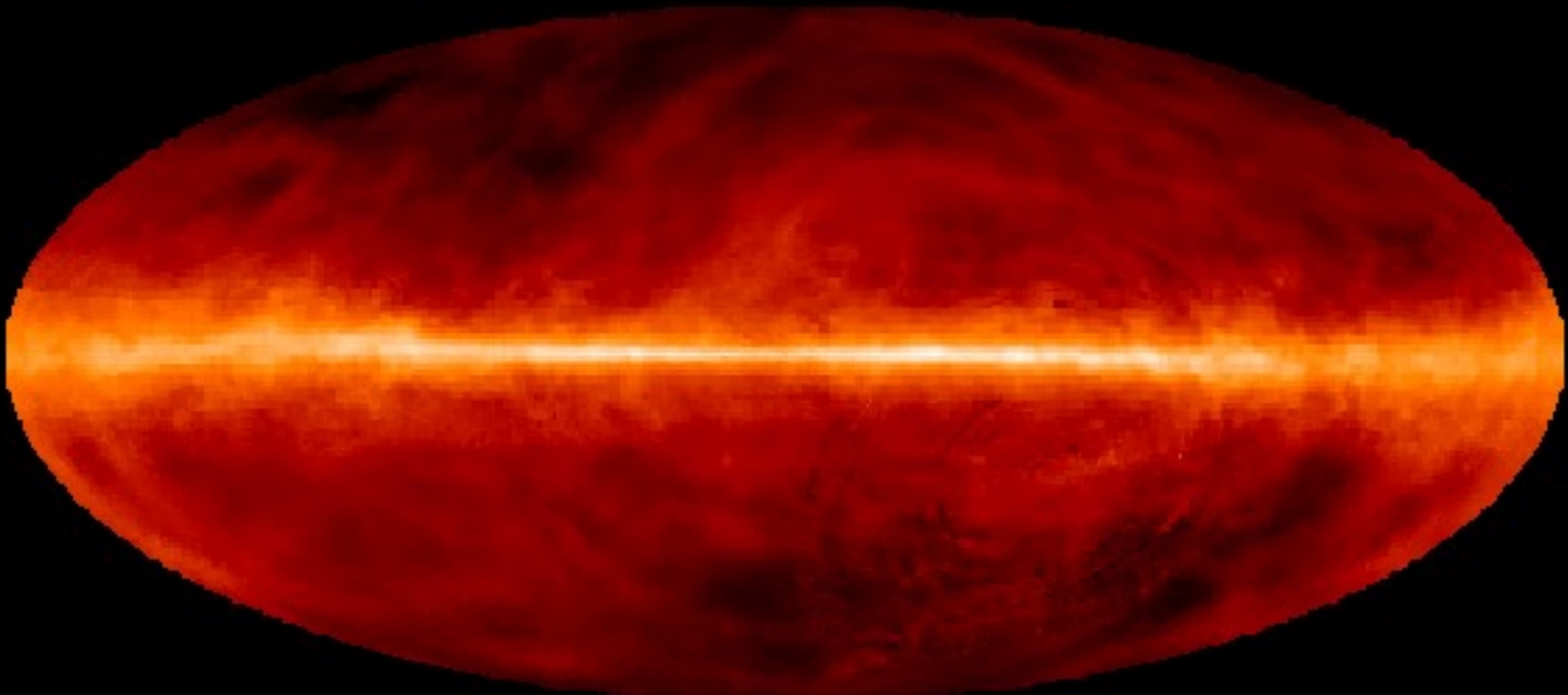


Table 2. Effects of Feed Taper for the GBT at 5 GHz

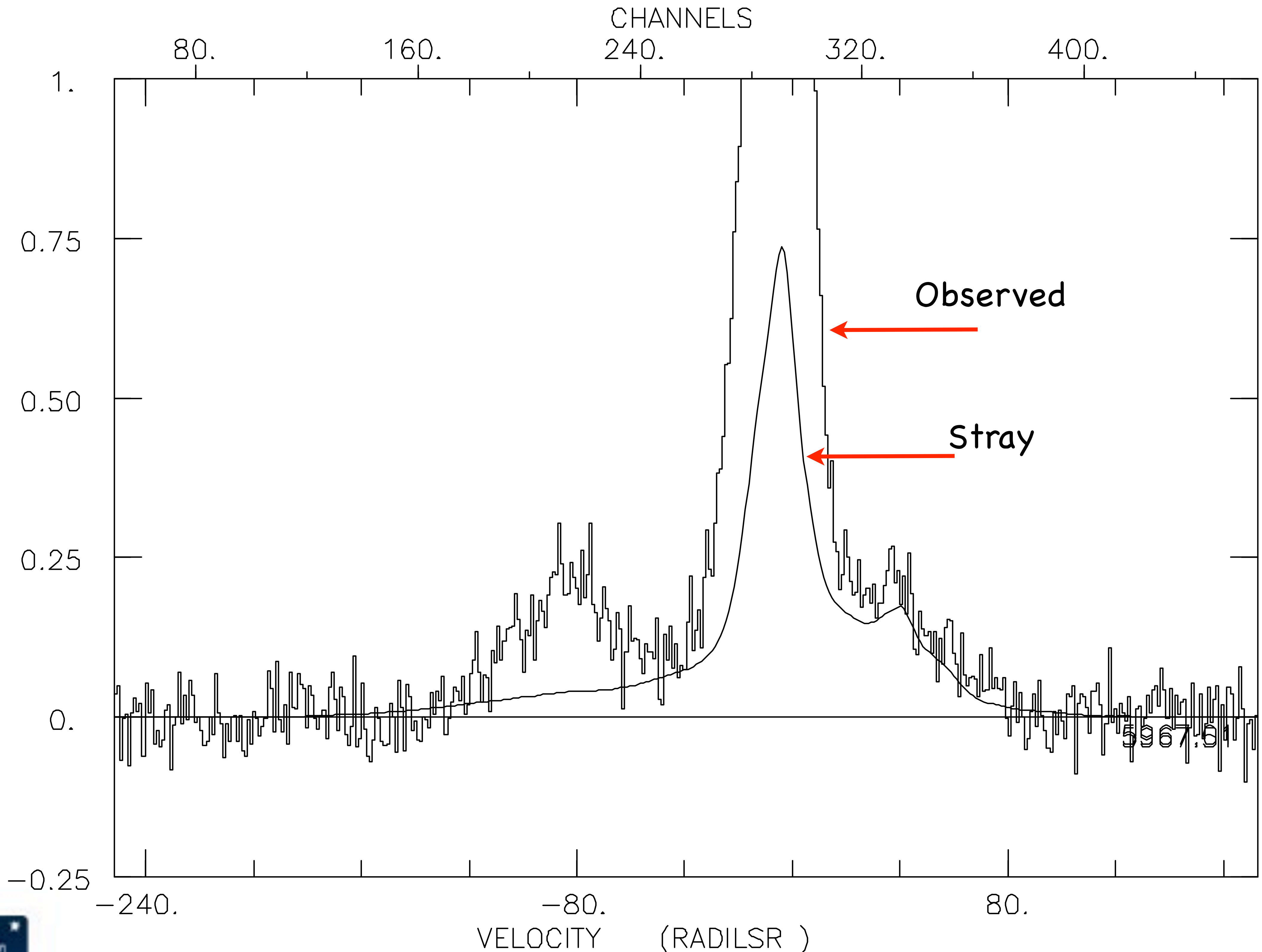
Edge Taper (dB)	Aperture Efficiency %	T_{spill} forward K	rear K
−12	70.0	0.4	2.6
−13	69.9	0.4	2.2
−14	69.3	0.4	1.9
−15	68.4	0.3	1.6
−16	67.3	0.2	1.4
−17	66.1	0.2	1.2

Hydrogen

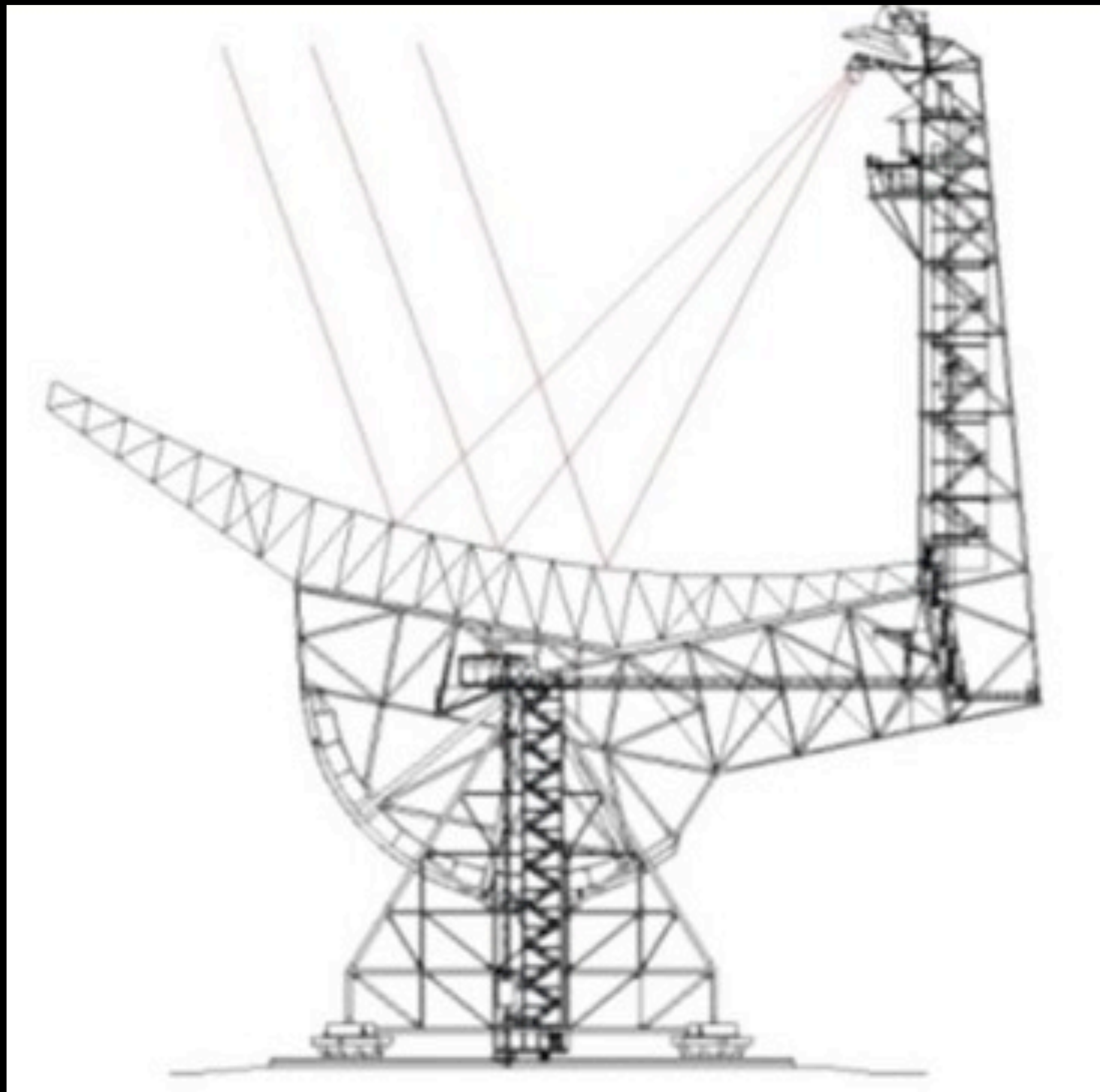


(Dickey & Lockman 1990)

“Stray” radiation on the 140 Foot Telescope

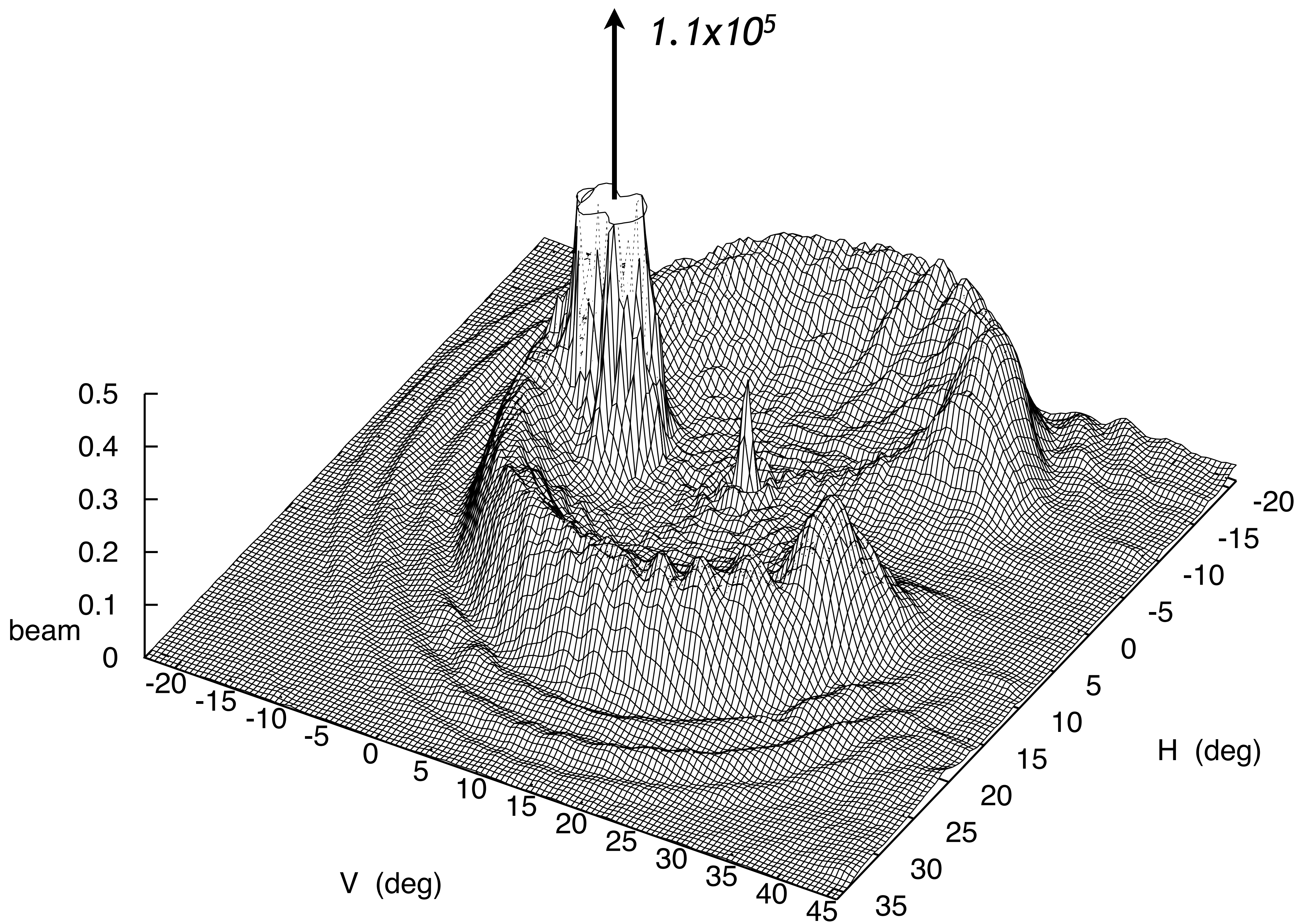


The Green Bank Telescope (GBT)

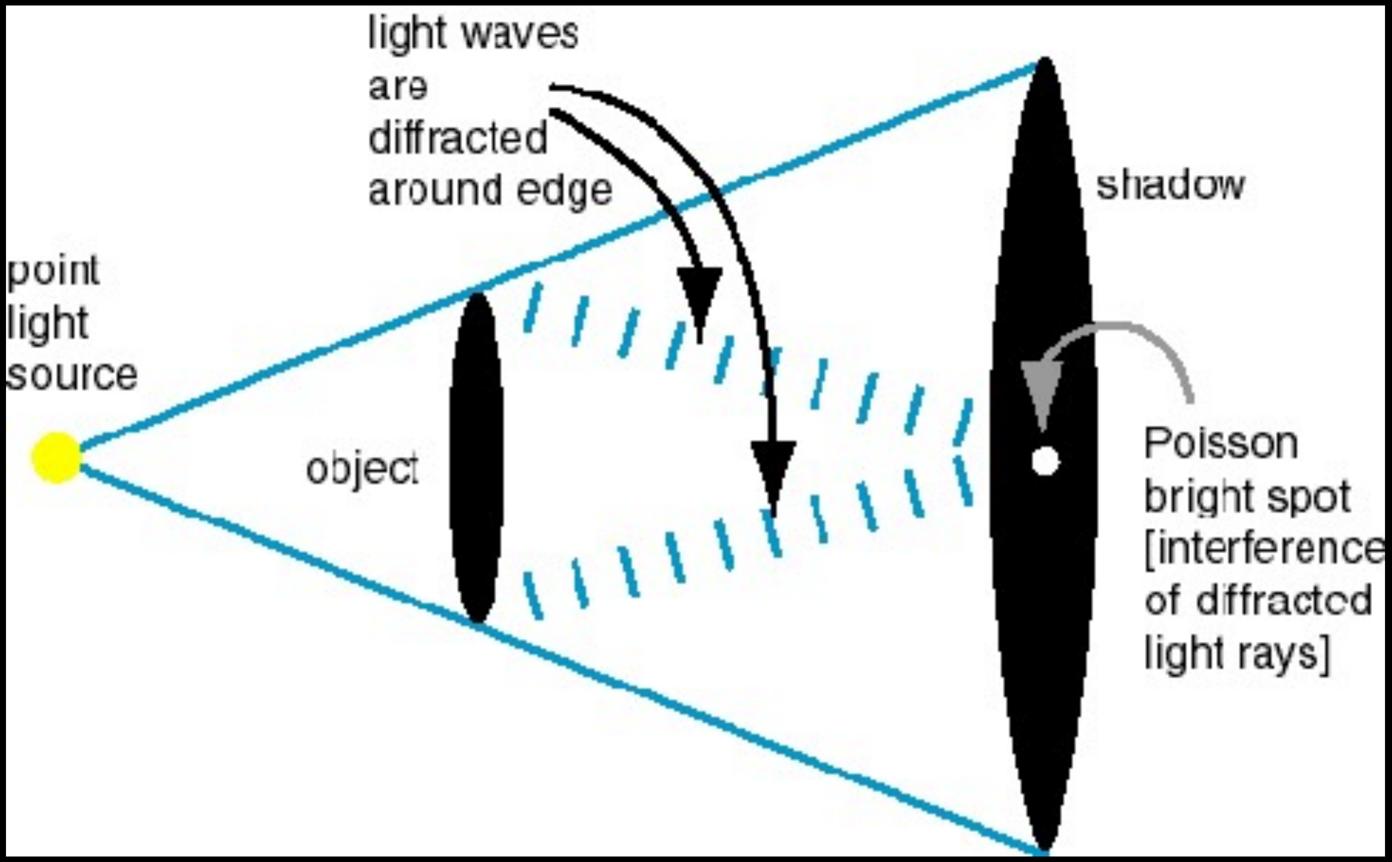


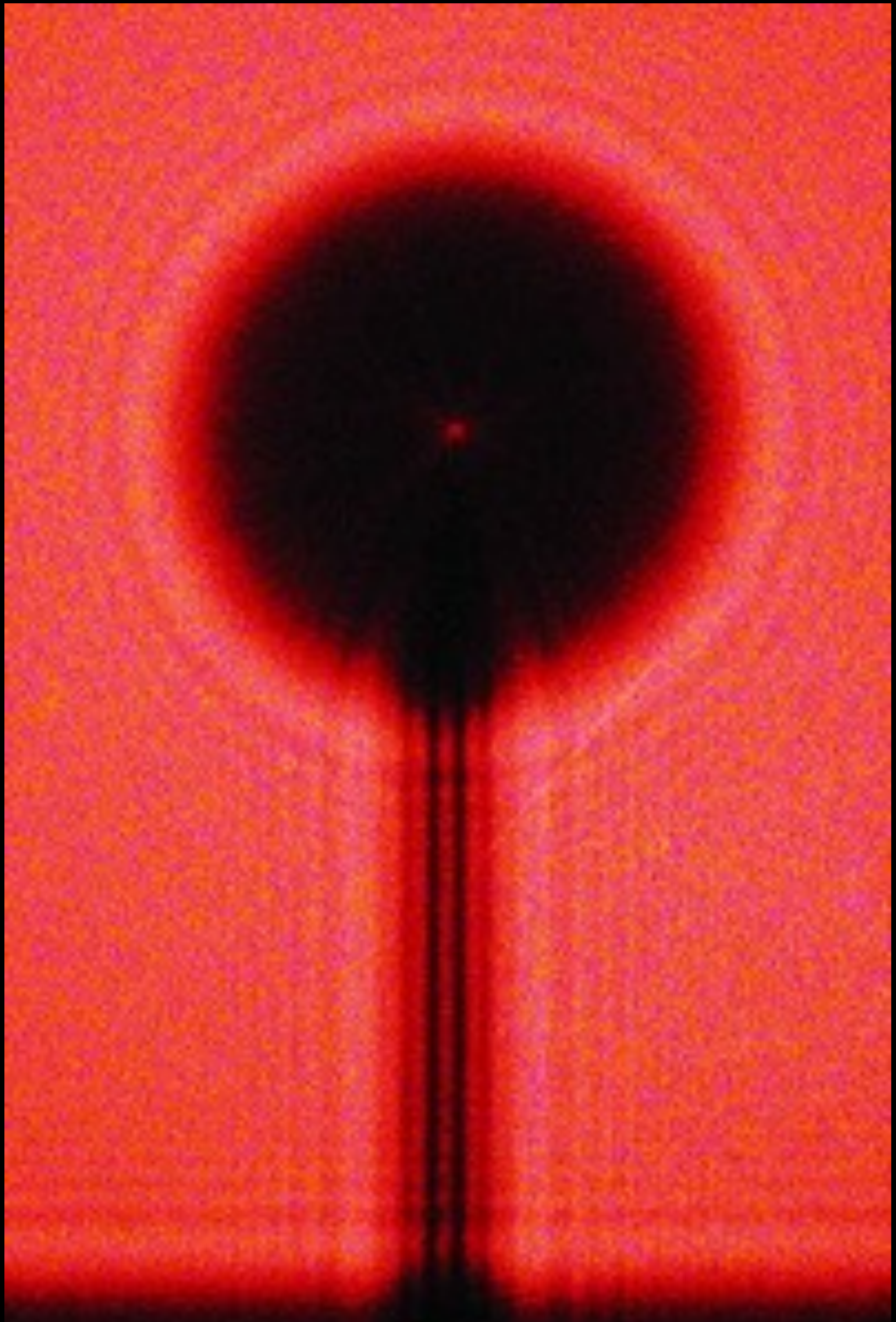
GBT Measured

(Boothroyd et al 2011)



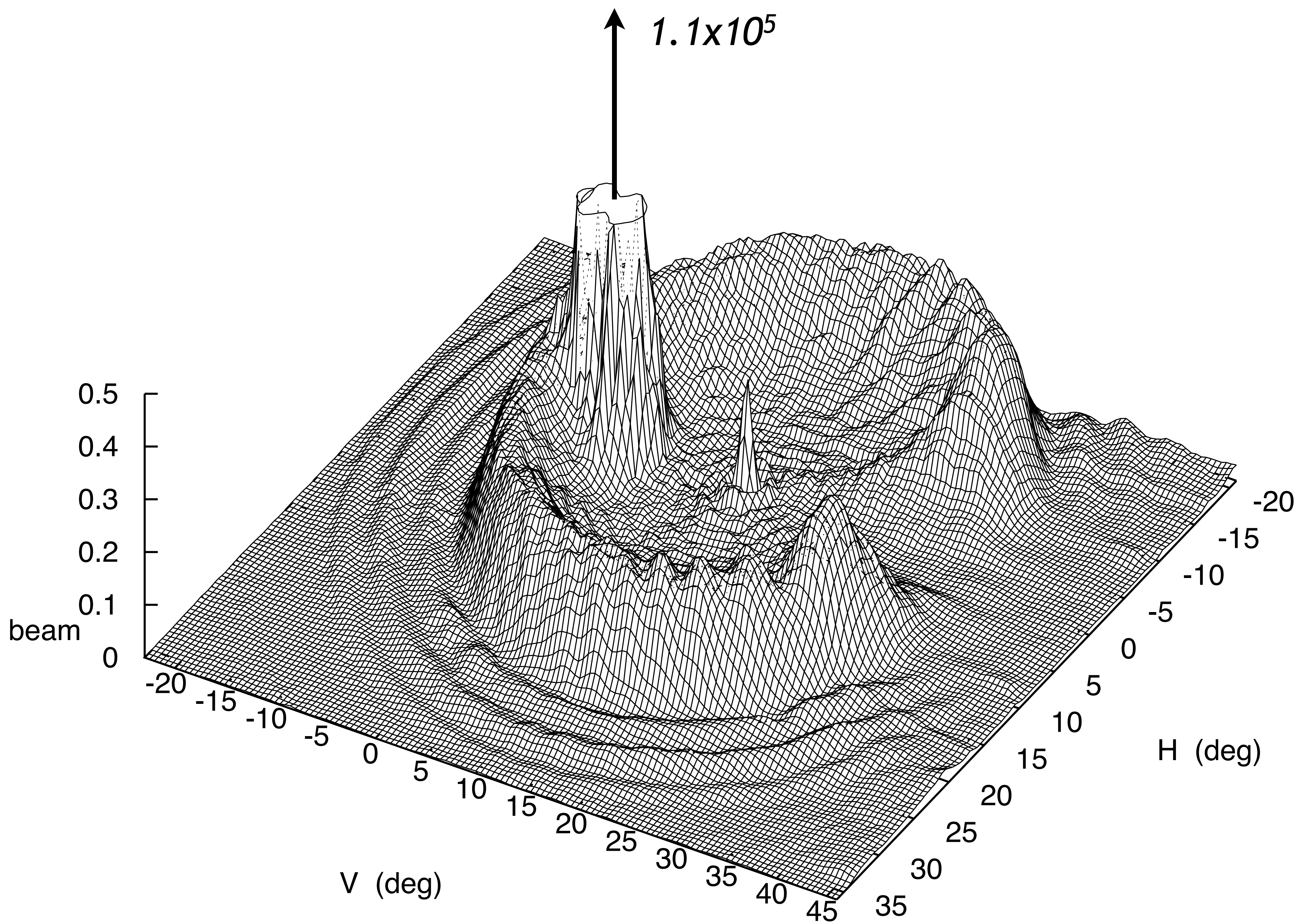
Poisson/Arago Spot



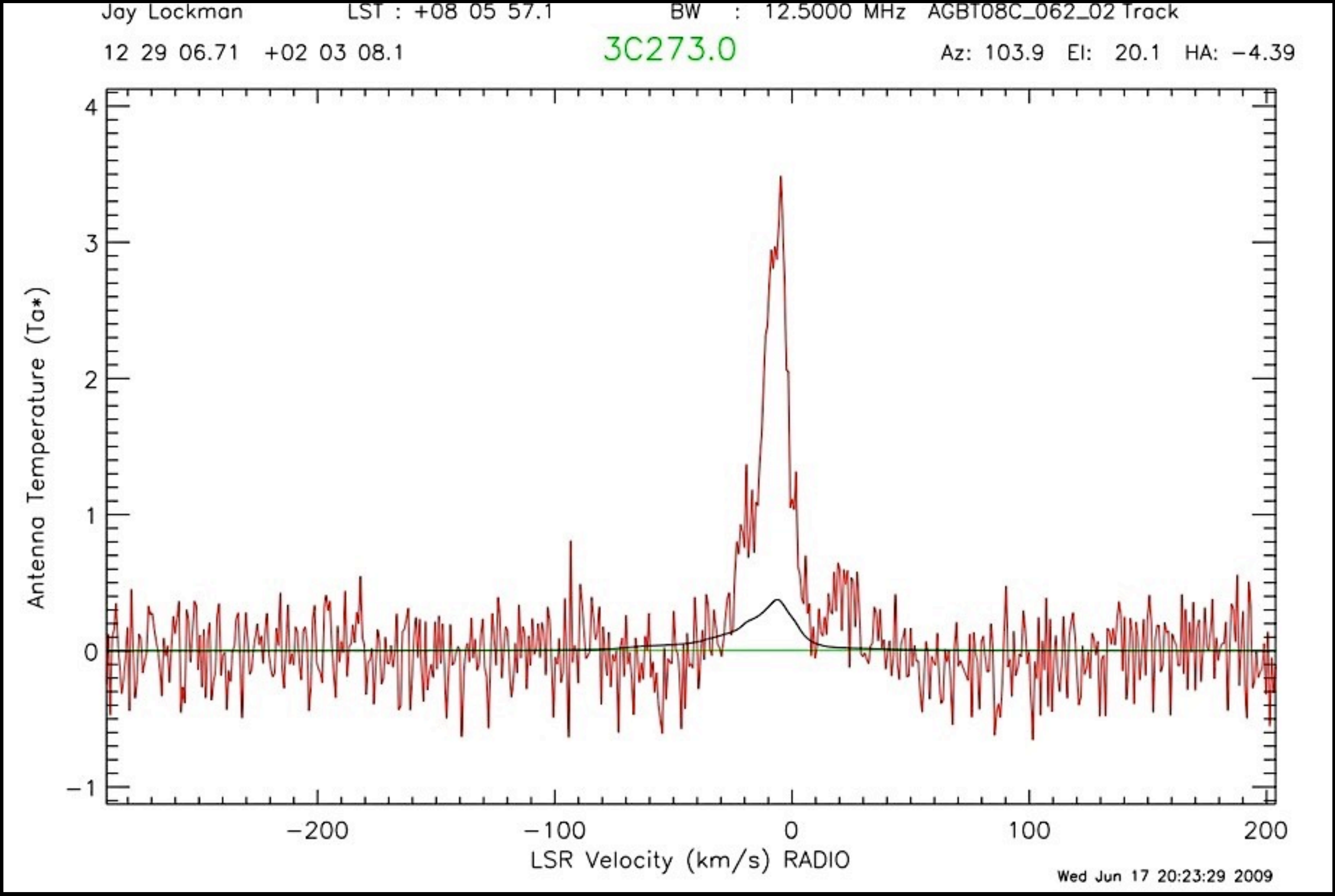


GBT Measured

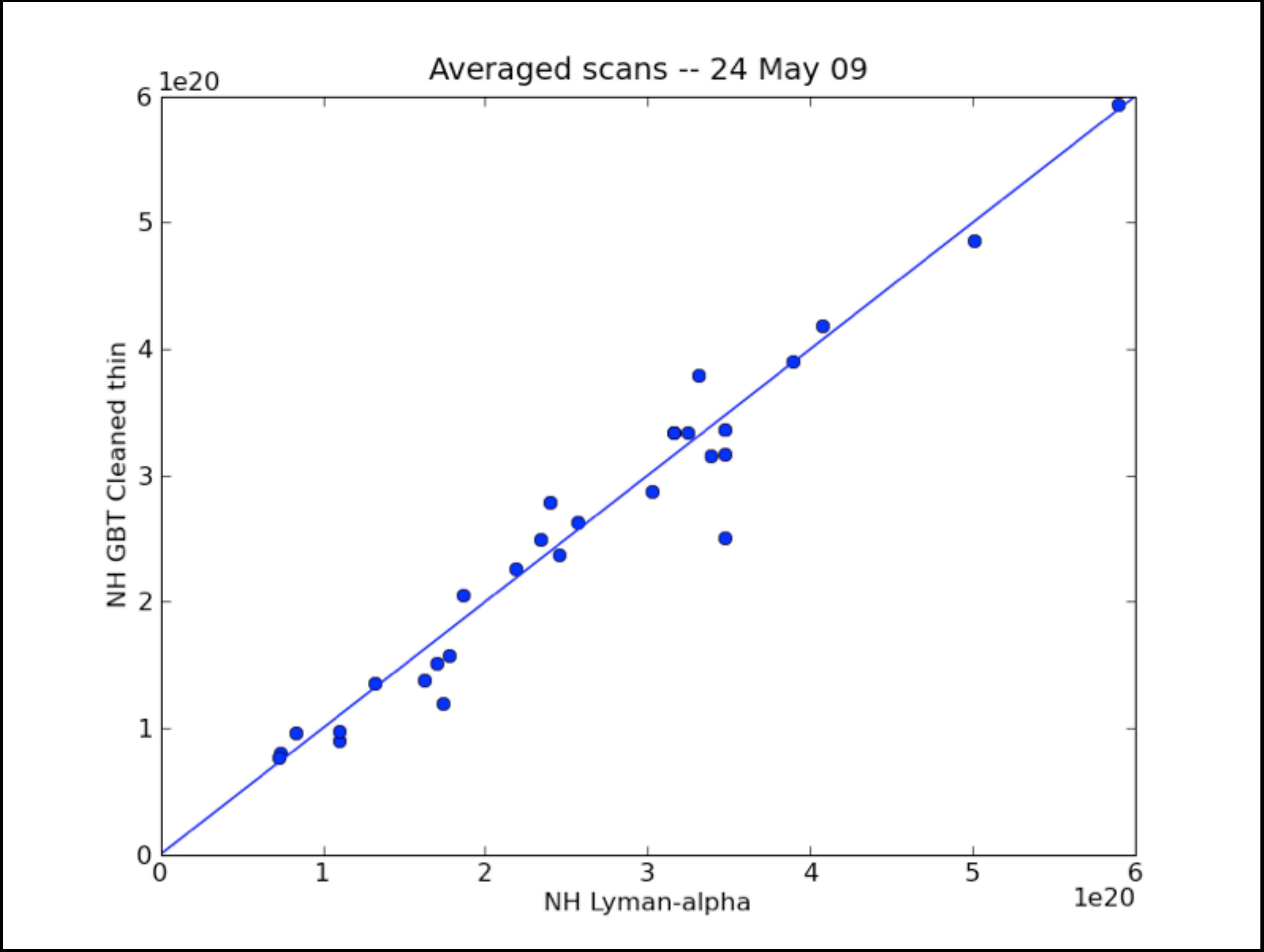
(Boothroyd et al 2011)



“Stray” radiation on the GBT

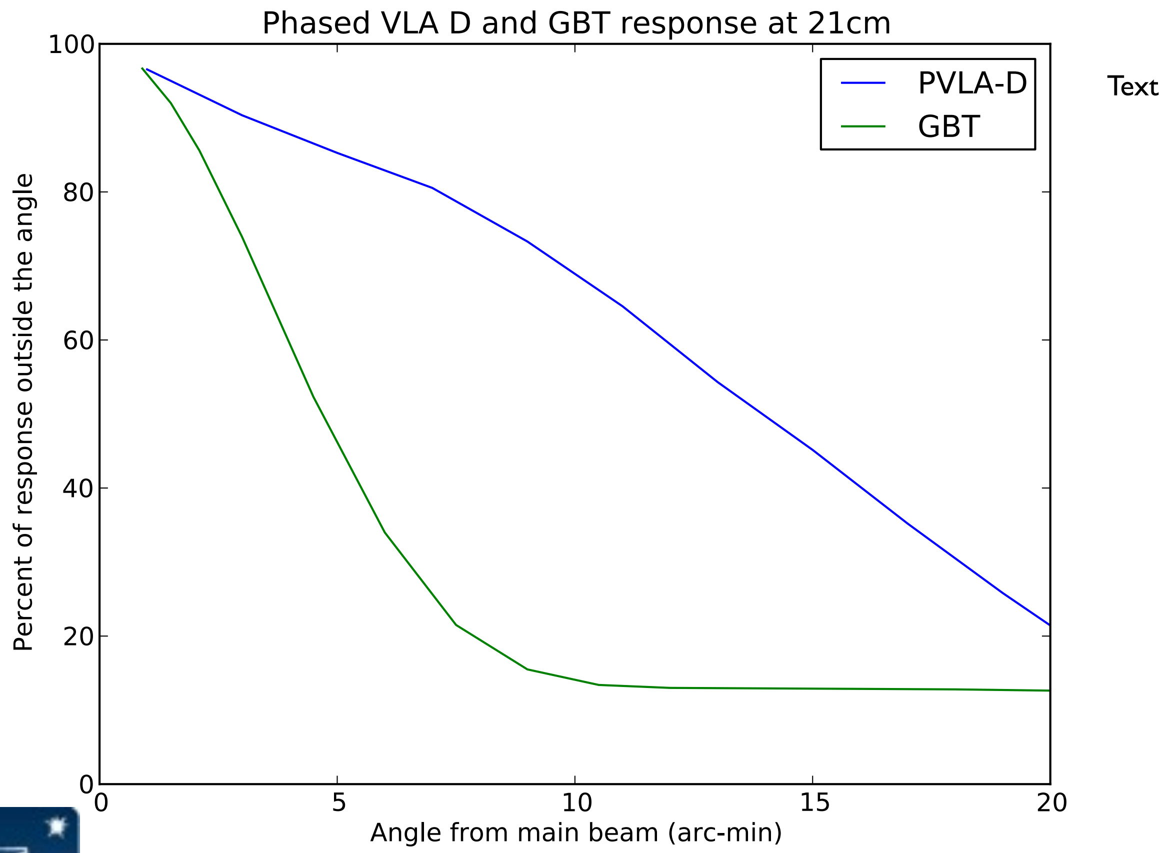


GBT vs. HST HI

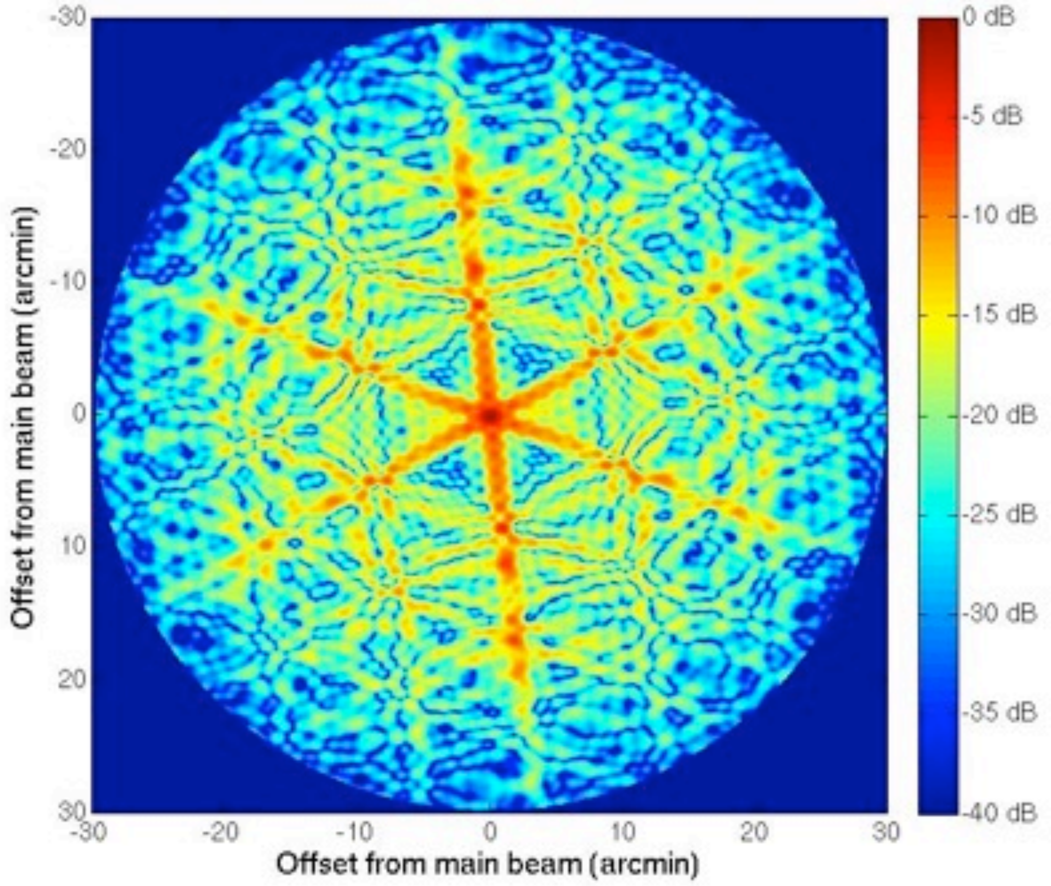


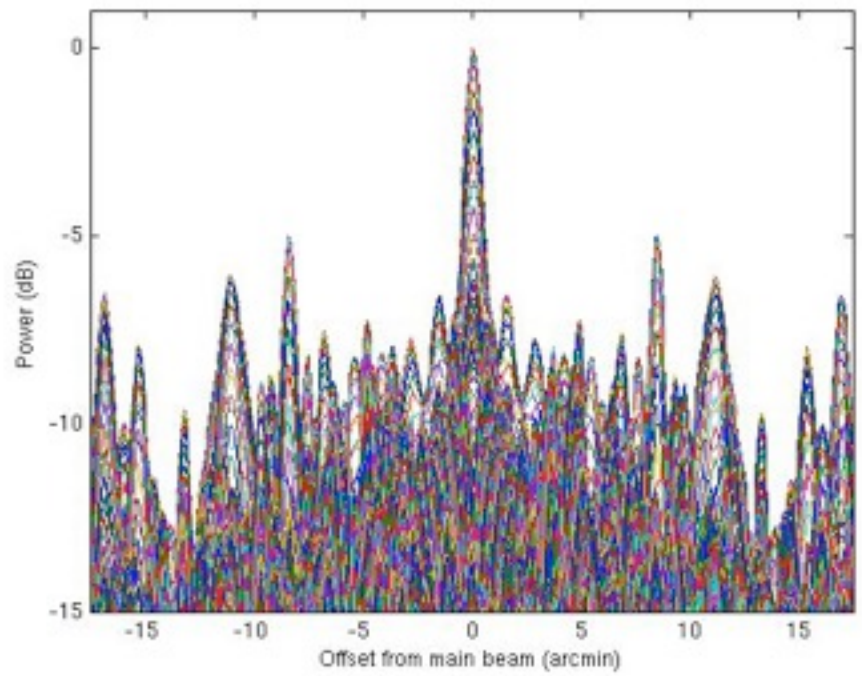
(Wakker, Lockman & Brown 2011)

The VLA as a "phased" array



Point Spread Function





NRAO

Observing Extended Sources

Be aware of antenna response

The topic is increasingly relevant as we observe with increasing angular resolution