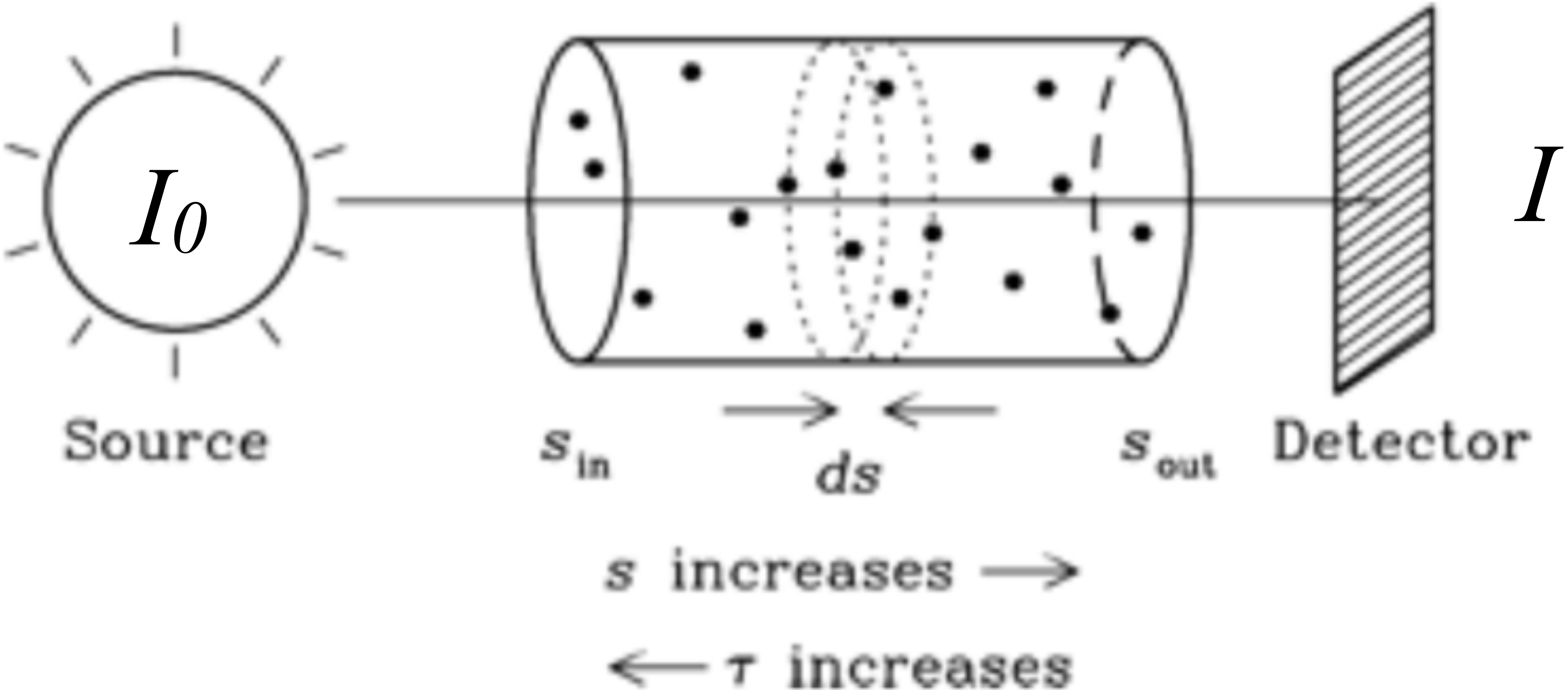
A Stroll Through Radio Astronomy

Things it took me the longest time to comprehend…

Jay Lockman August 2019

- The importance of the Planck Law
- Using the ideas of radiative transfer
- Reciprocity and antenna design
- Thinking about interferometers
- Nyquist sampling and convolution
- Noise and the propagation of errors

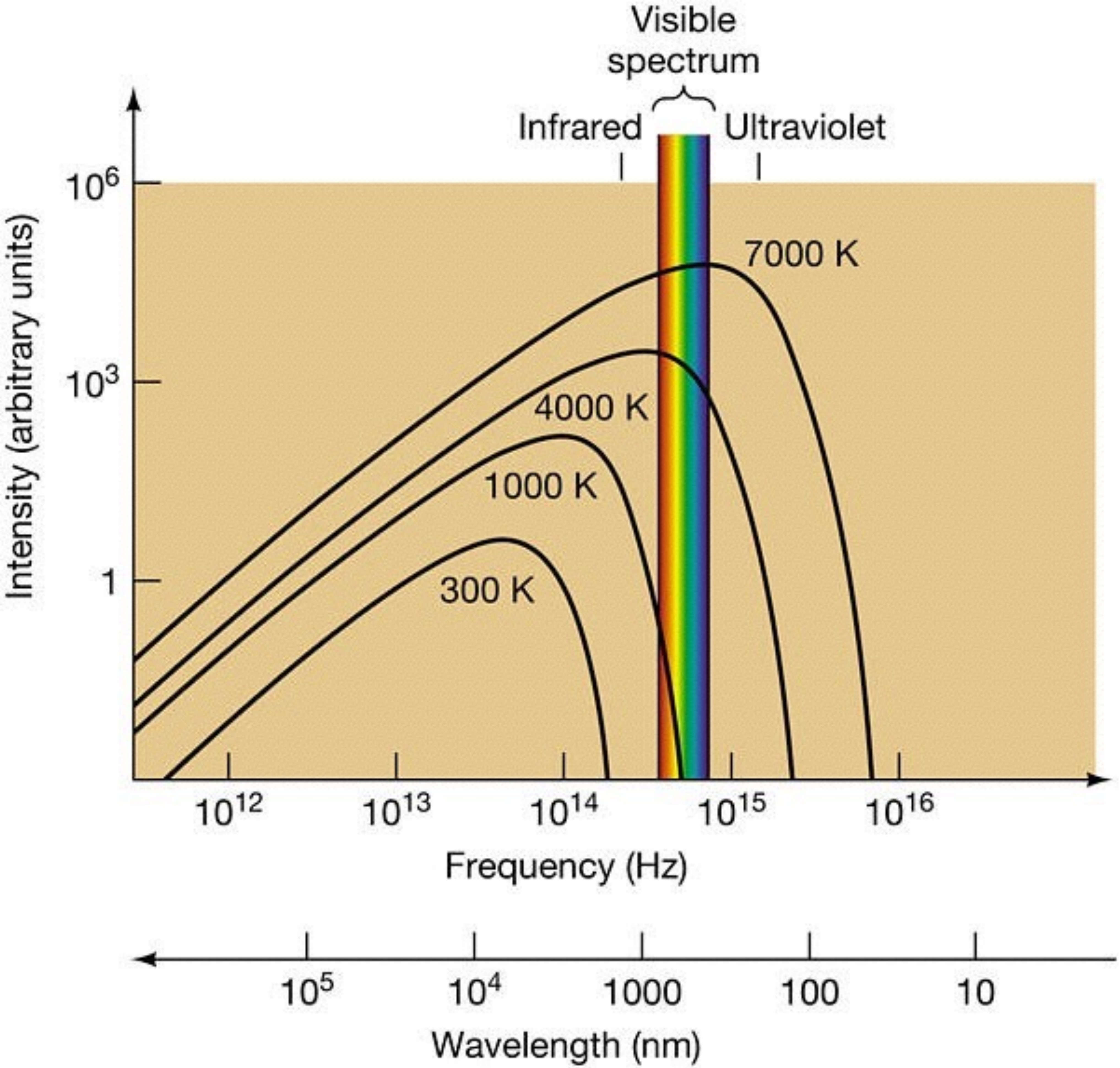


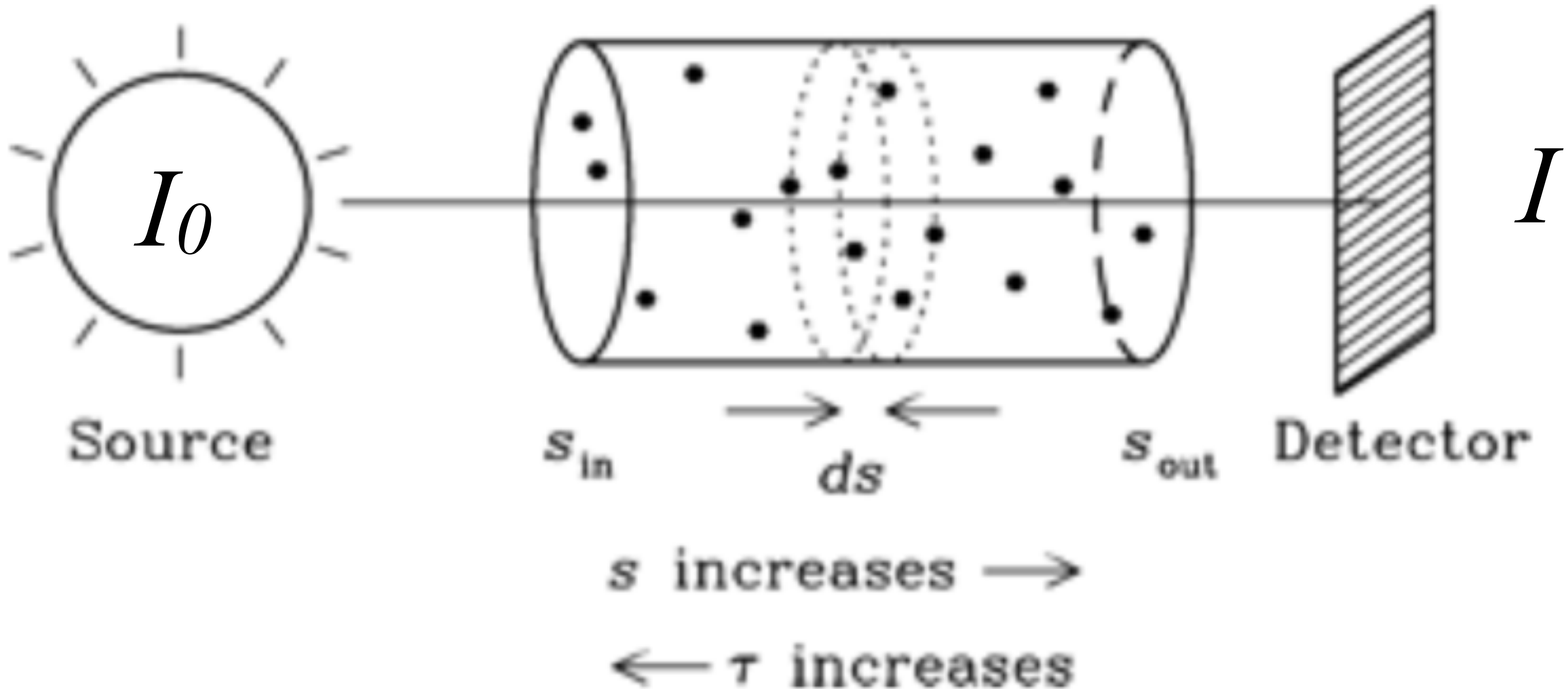
$$I = I_0 \, e^{-\tau} + I_s(1 - e^{-\tau})$$

$$\mathrm{W\ m^{-2}\ Hz^{-1}\ sr^{-1}}$$

The Planck Law for Blackbody radiation

$$\boxed{B_\nu\left(\nu,T\right)=\frac{2h\nu^3}{c^2}\frac{1}{\exp\left(\frac{h\nu}{kT}\right)-1}.}$$

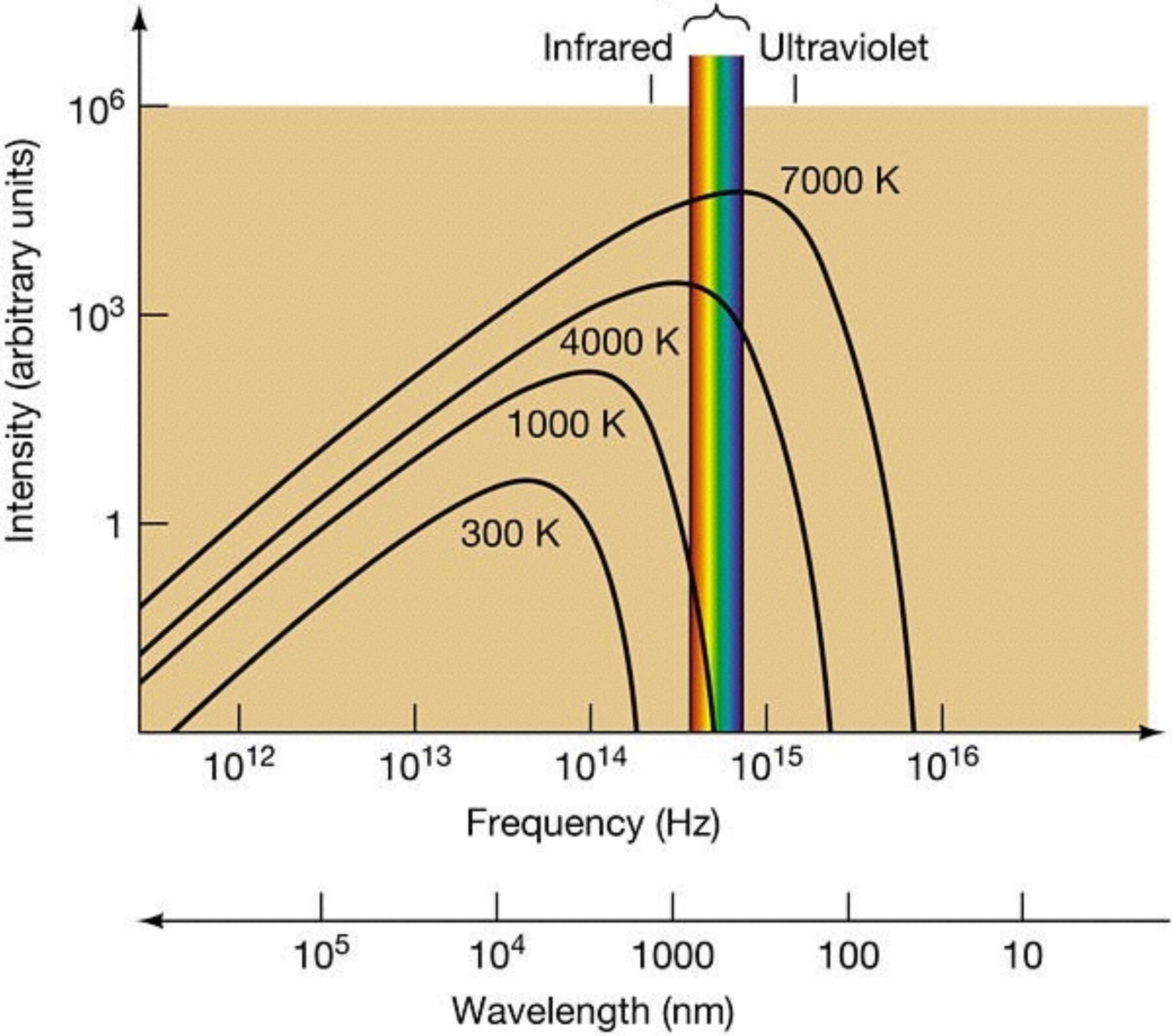

Visible spectrum
Infrared
Ultraviolet
10^6
10^3
1
Intensity (arbitrary units)
7000 K
4000 K
1000 K
300 K
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
Frequency (Hz)
10^5
10^4
1000
100
10
Wavelength (nm)



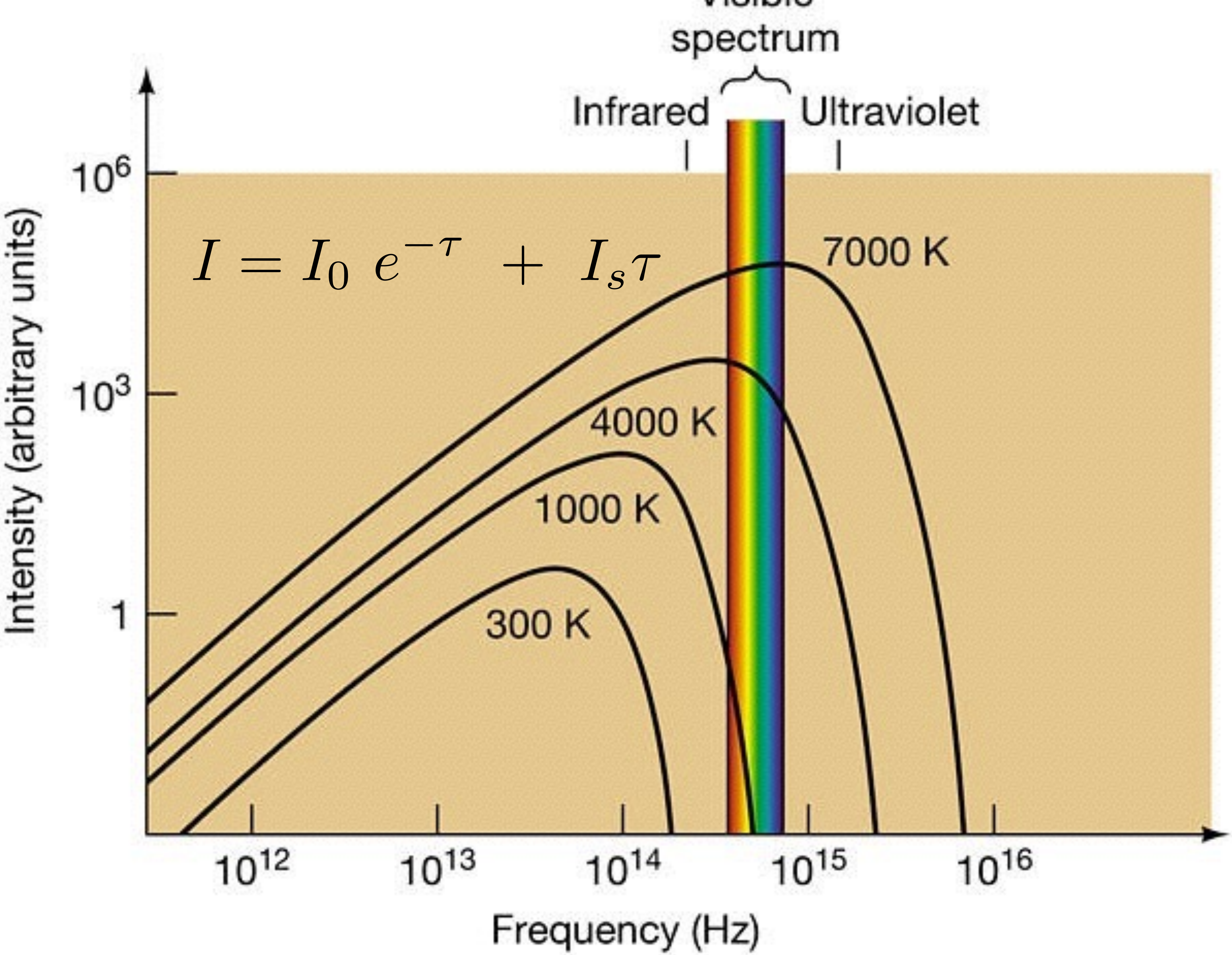
$$I = I_0\, e^{-\tau} + I_s(1 - e^{-\tau})$$

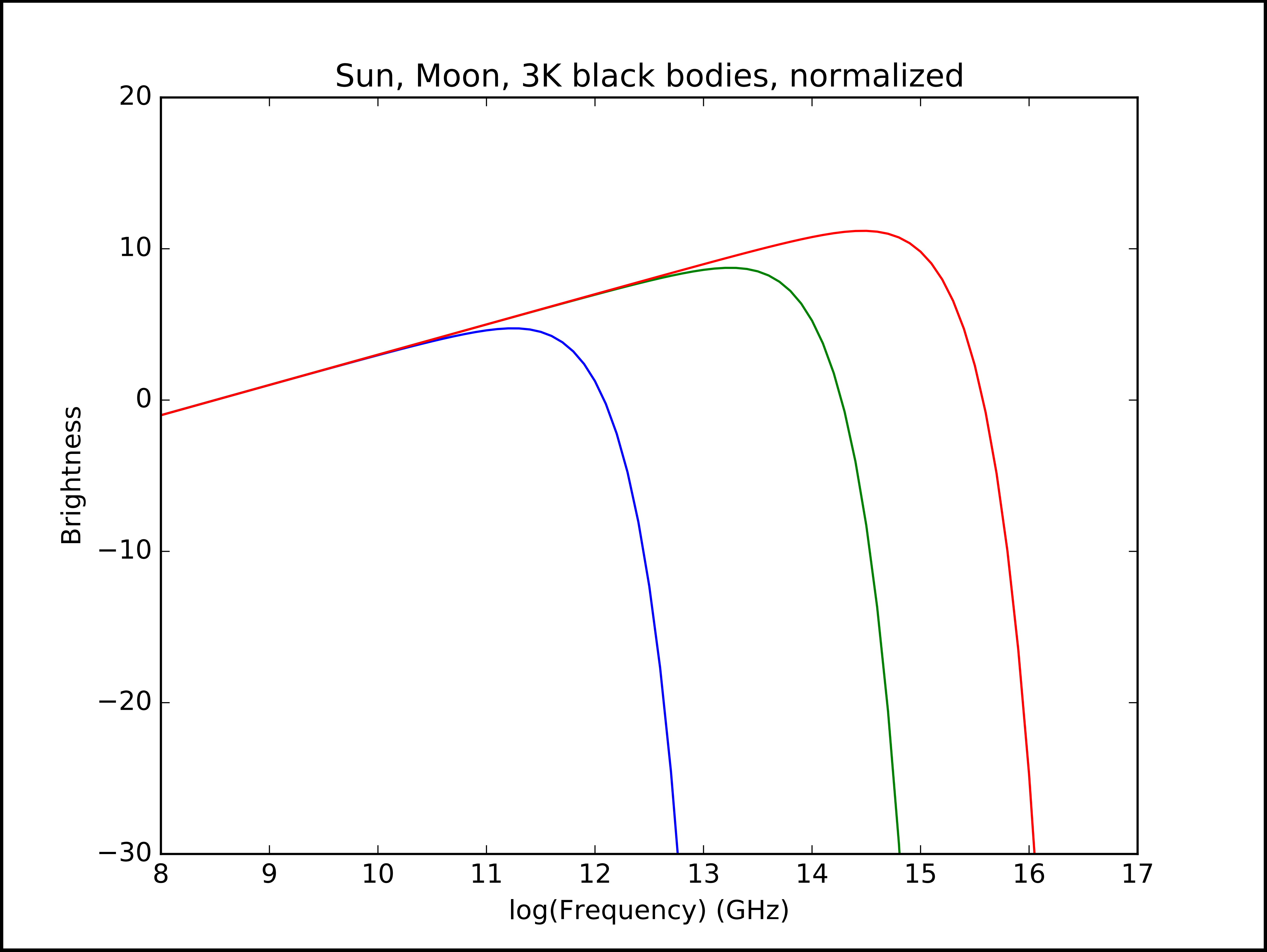
For Blackbody $\boldsymbol{\tau} = \infty$

$$I = I_0\, e^{-\tau} + I_s(1 - e^{-\tau})$$

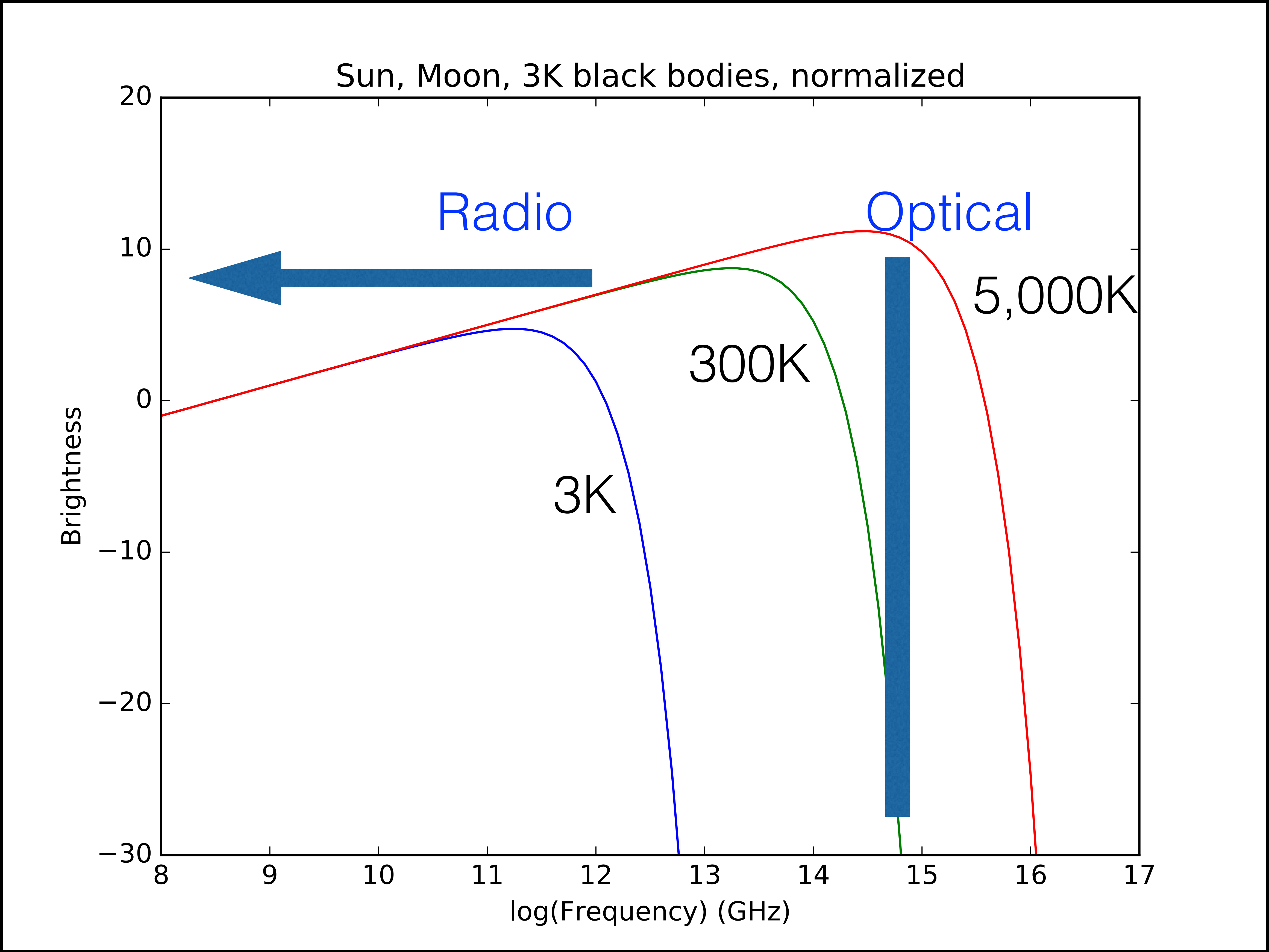


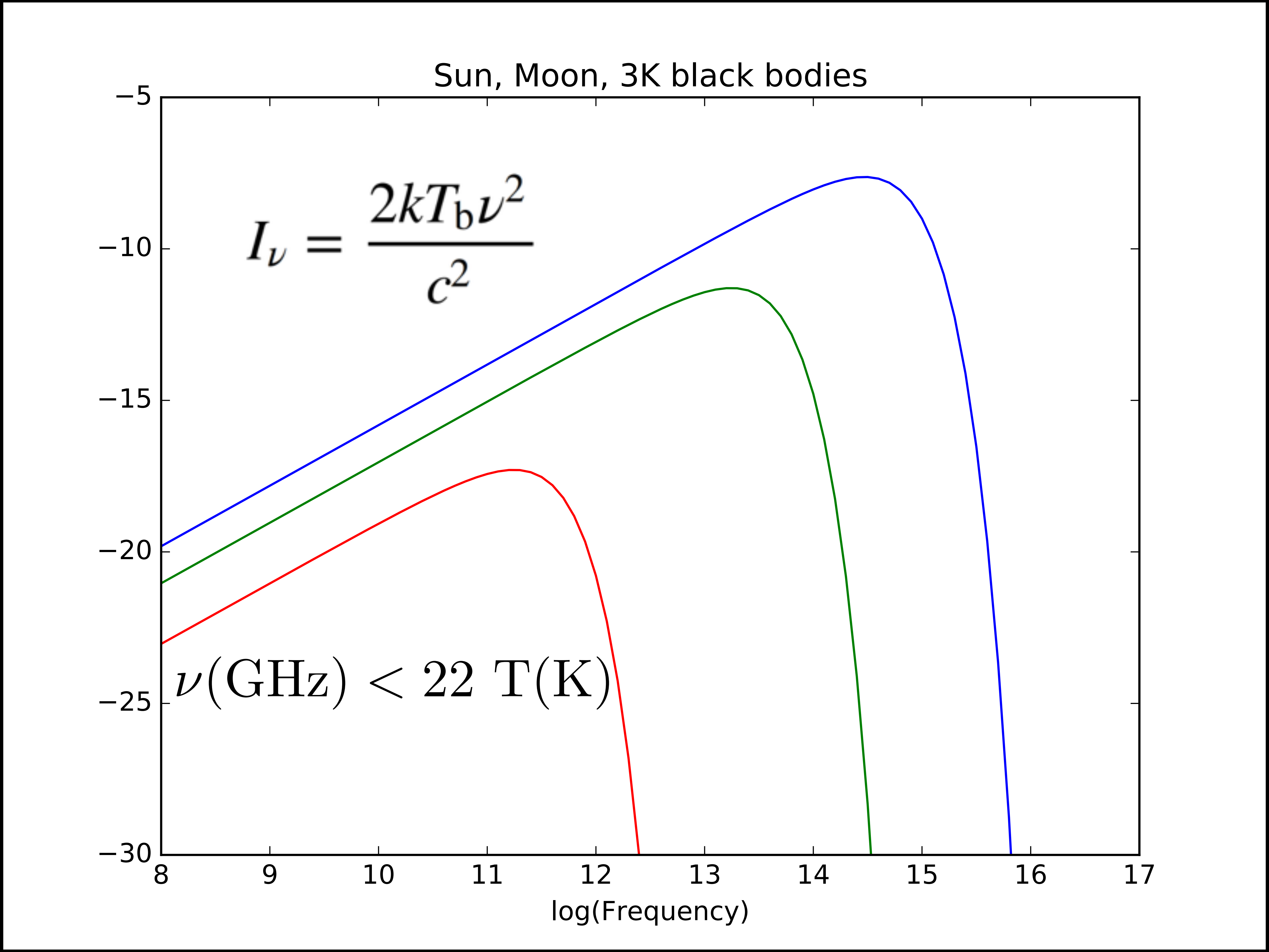
$$I = I_0\, e^{-\tau} + I_s \tau$$



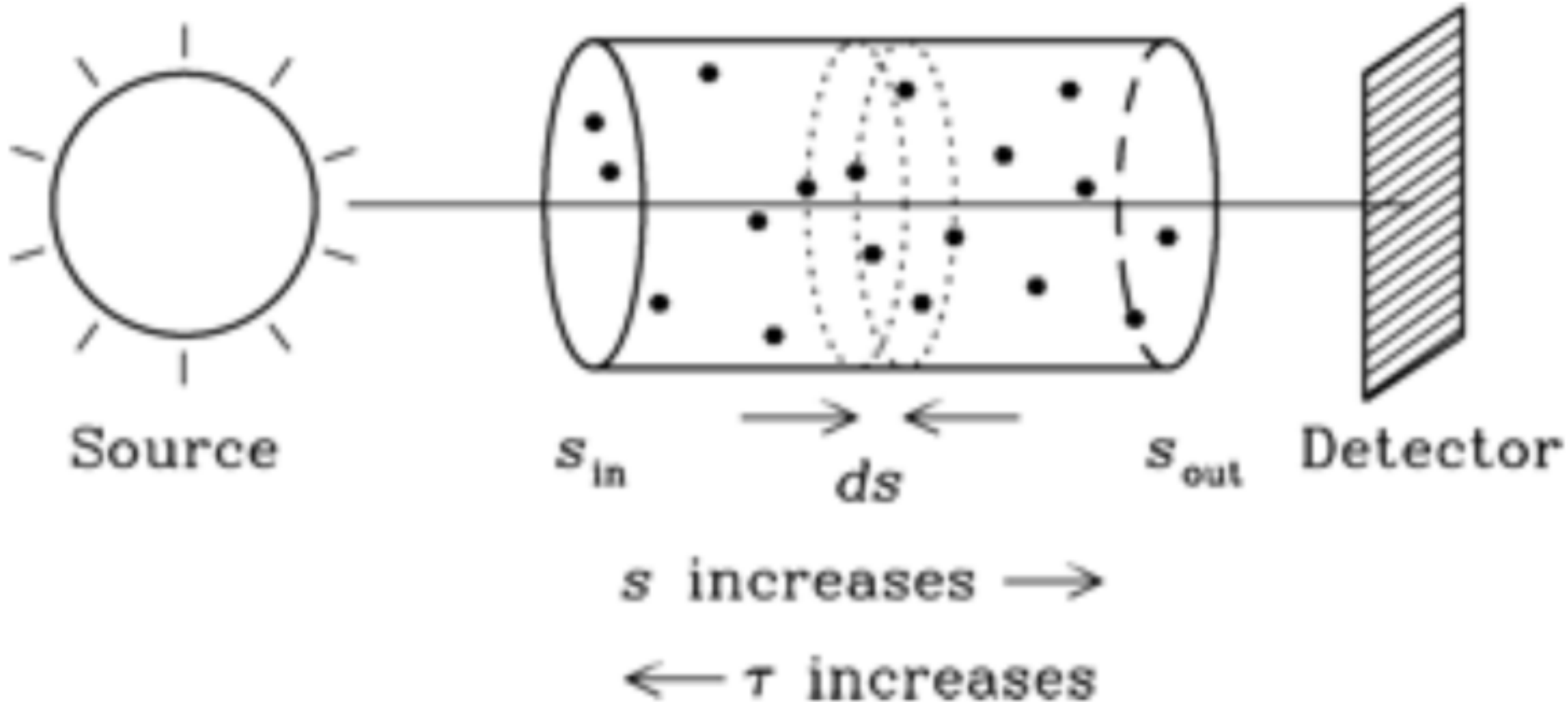


Sun, Moon, 3K black bodies, normalized
20
10
0
−10
−20
−30
Brightness
8
9
10
11
12
13
14
15
16
17
log(Frequency) (GHz)

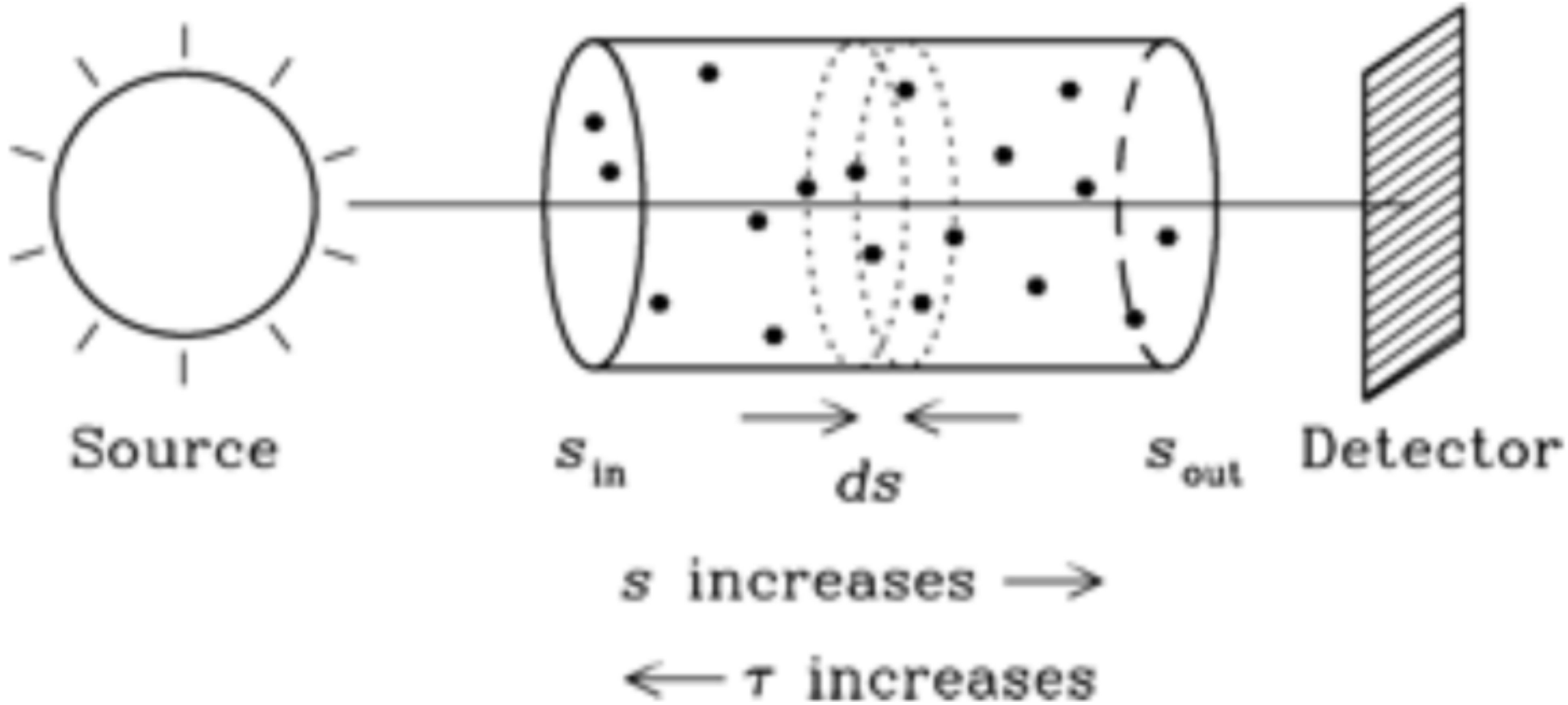

Sun, Moon, 3K black bodies, normalized
Radio
Optical
5,000K
300K
3K
Brightness
log(Frequency) (GHz)
20
10
0
−10
−20
−30
8
9
10
11
12
13
14
15
16
17



Sun, Moon, 3K black bodies
$$I_\nu = \frac{2kT_\mathrm{b}\nu^2}{c^2}$$
$\nu(\mathrm{GHz}) < 22\ \mathrm{T(K)}$
−5
−10
−15
−20
−25
−30
8
9
10
11
12
13
14
15
16
17
log(Frequency)

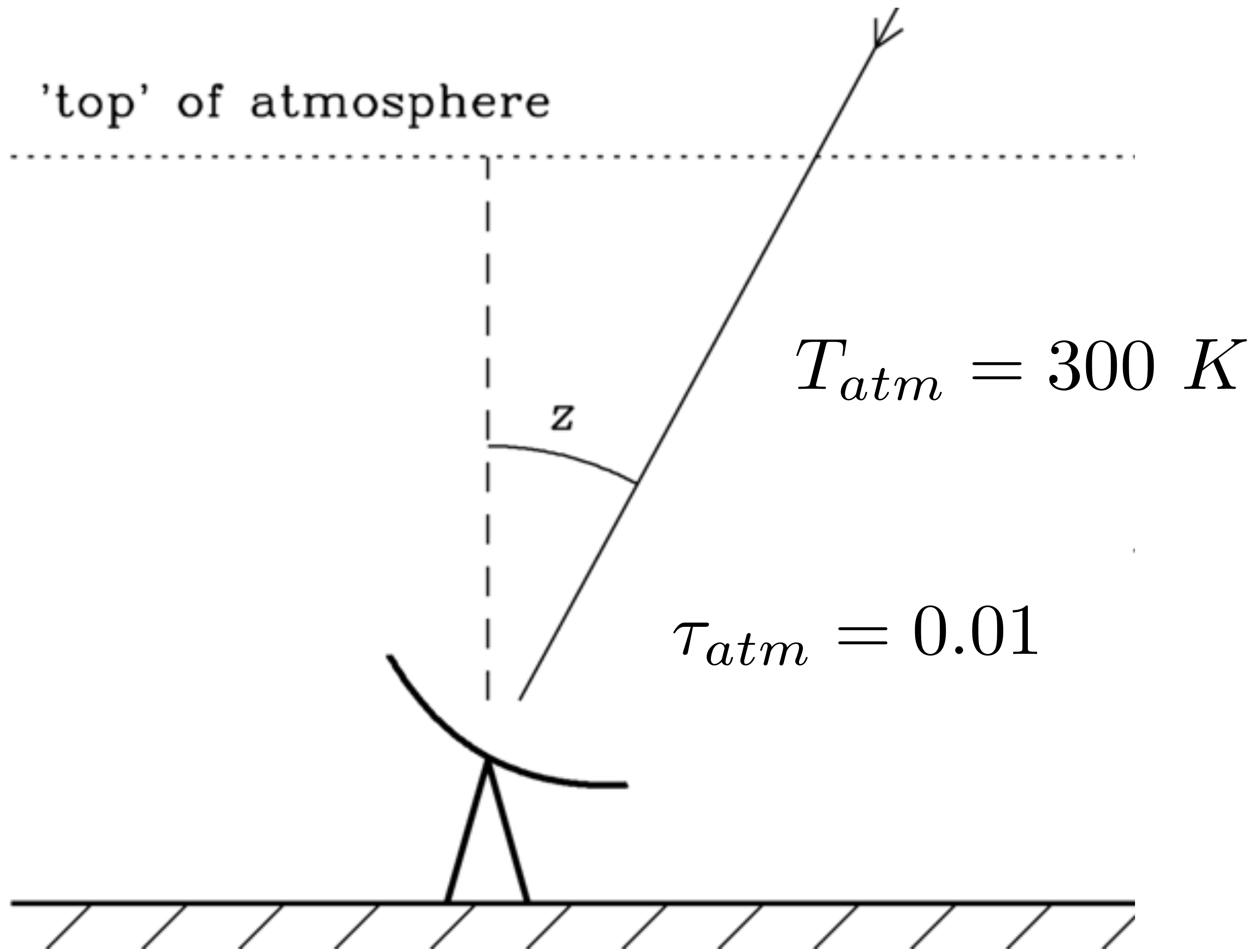


$$T_b = T_0\, e^{-\tau} + T_s(1 - e^{-\tau}) \quad \mathrm{K}$$



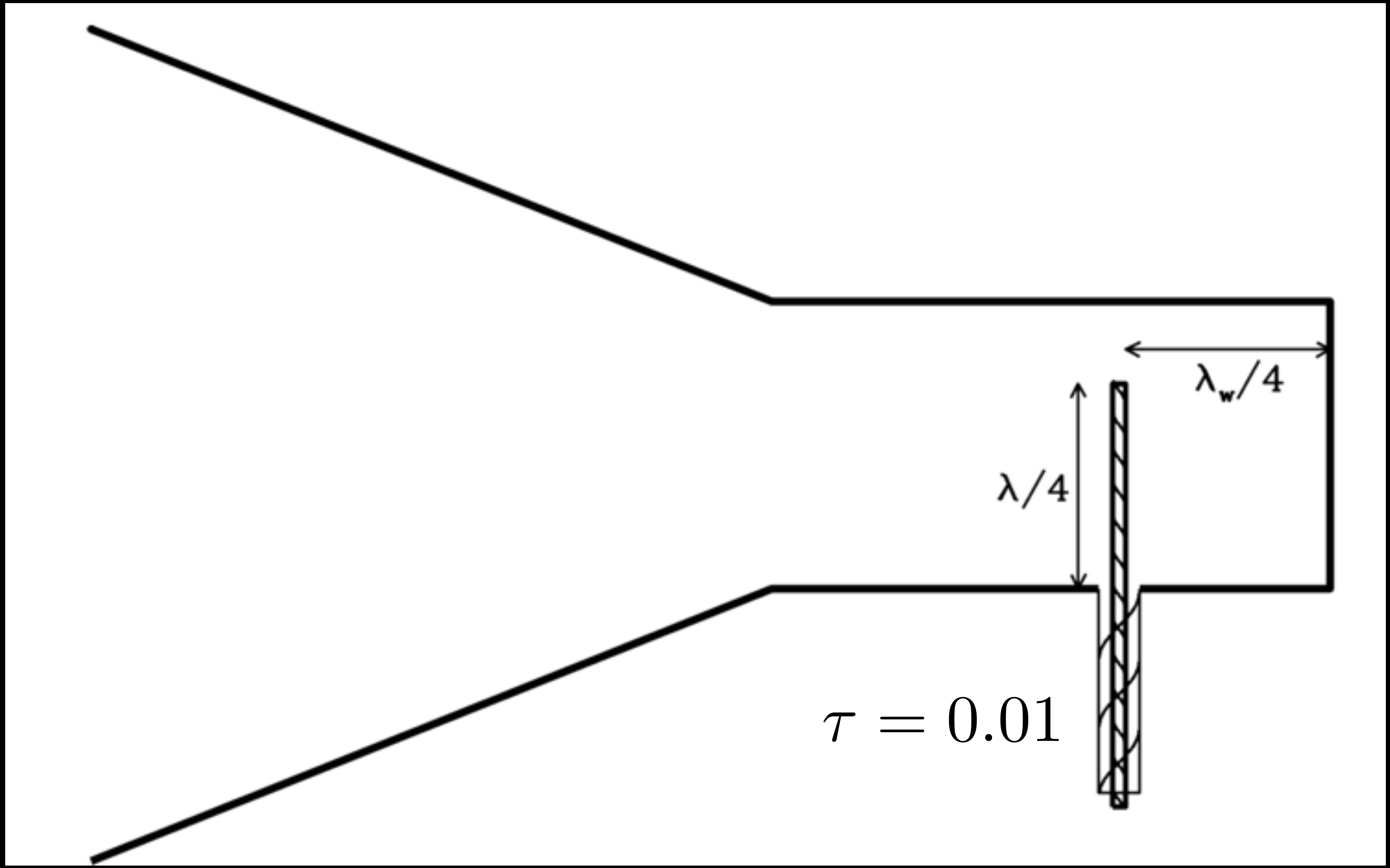
$$T_b = T_0\, e^{-\tau} + T_s(1 - e^{-\tau}) \quad \mathrm{K}$$

$$T_b \approx T_0\, e^{-\tau} + T_s\, \tau \quad (\tau << 1)$$



$$T_b \approx T_0\, e^{-\tau} + T_s\, \tau \quad (\tau << 1)$$

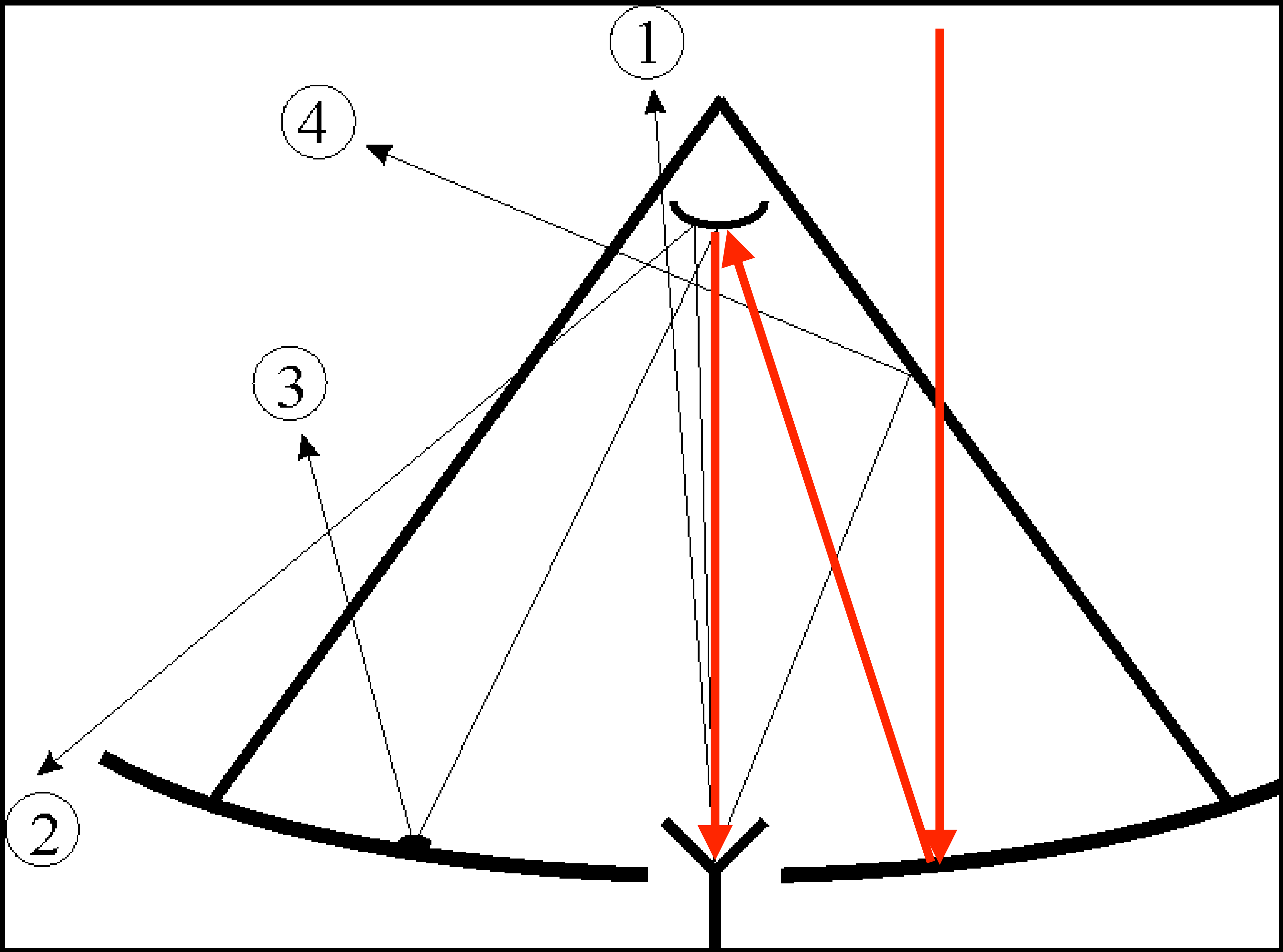
$$T_b = 0.99\ T_0 + 3 \ \ (K)$$

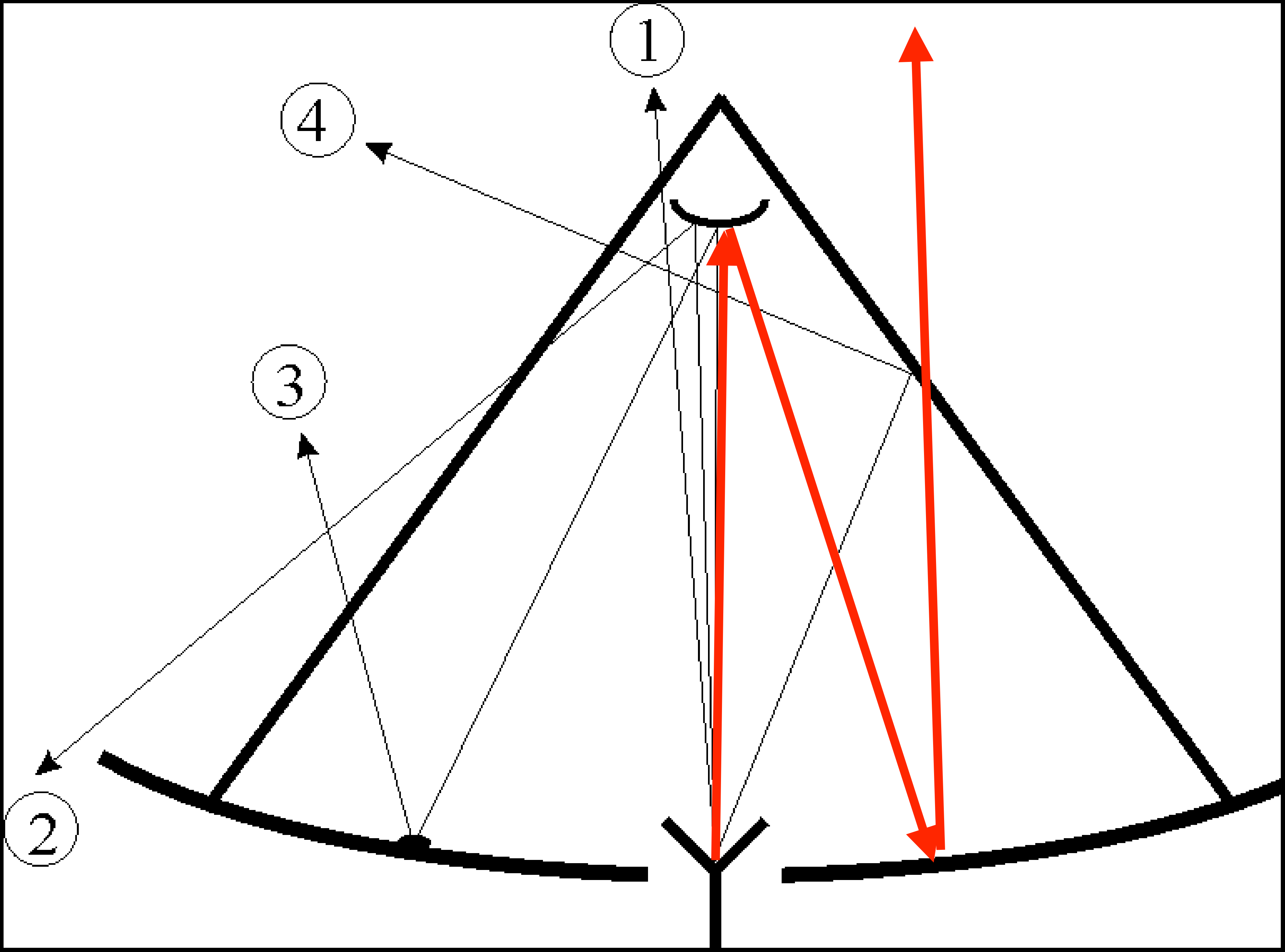


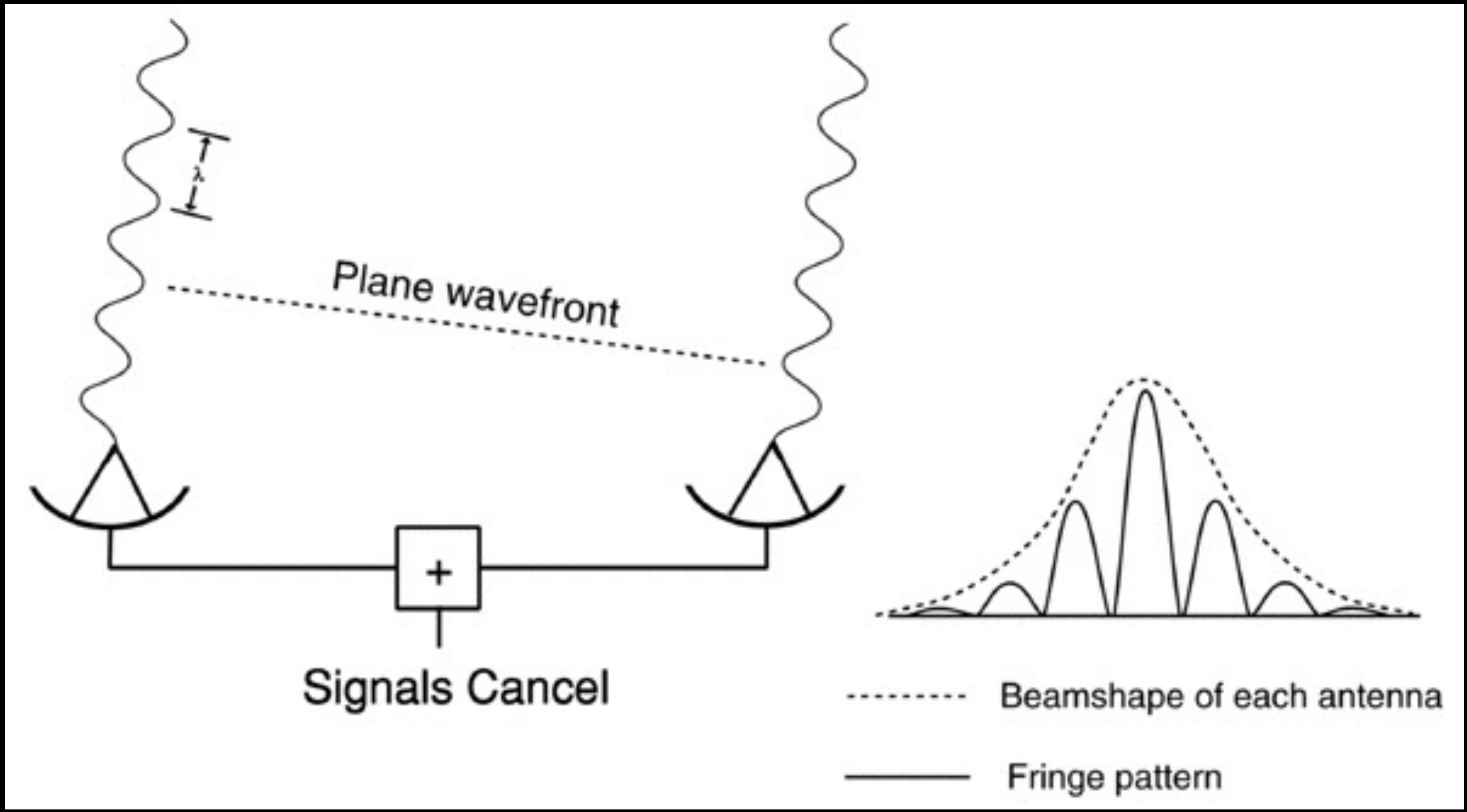
$$T_b = T_0 e^{-\tau} + T_s \tau$$

Reciprocity

$$f(t) = f(-t)$$

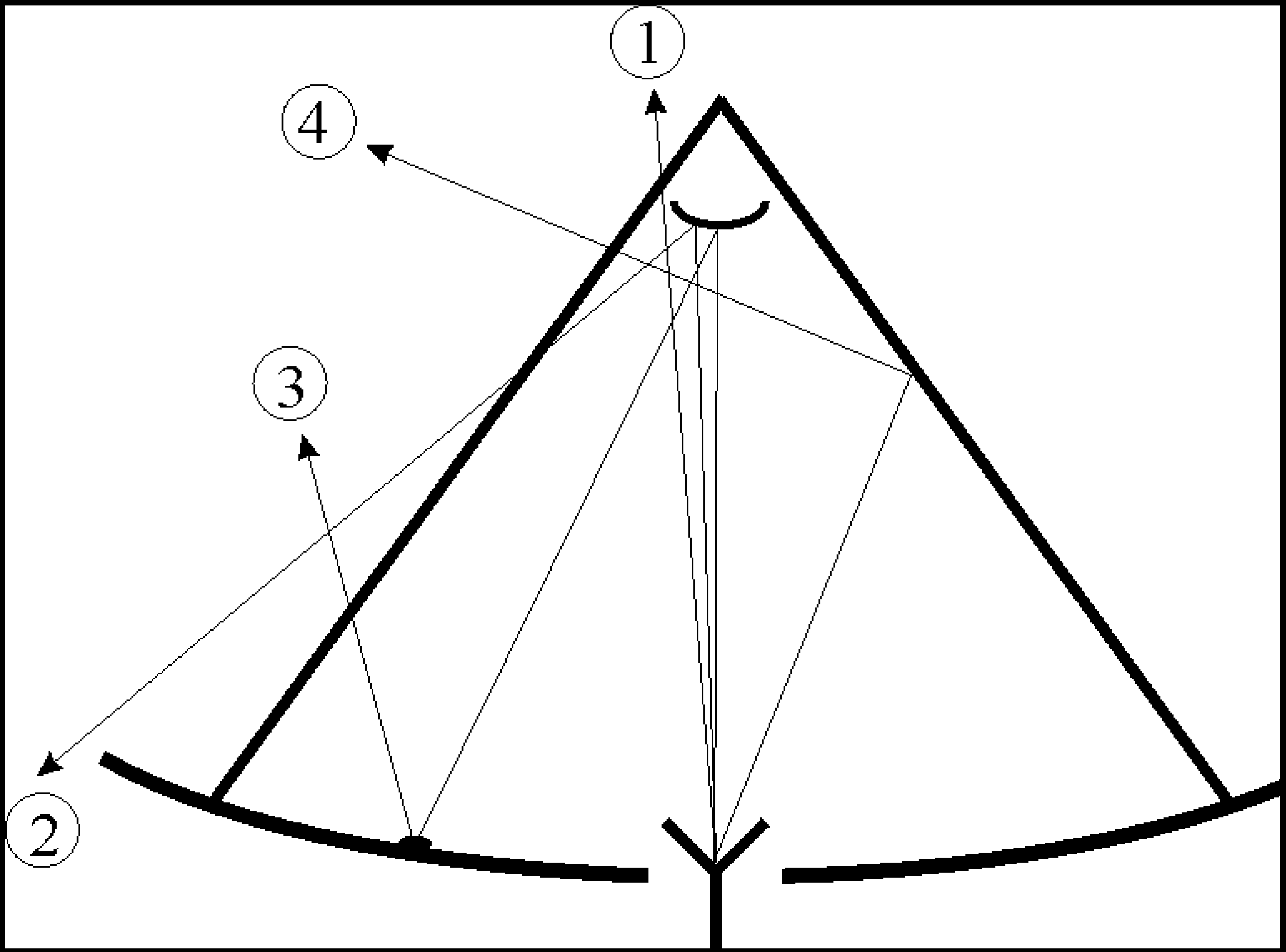

1
4
3
2


1
4
3
2



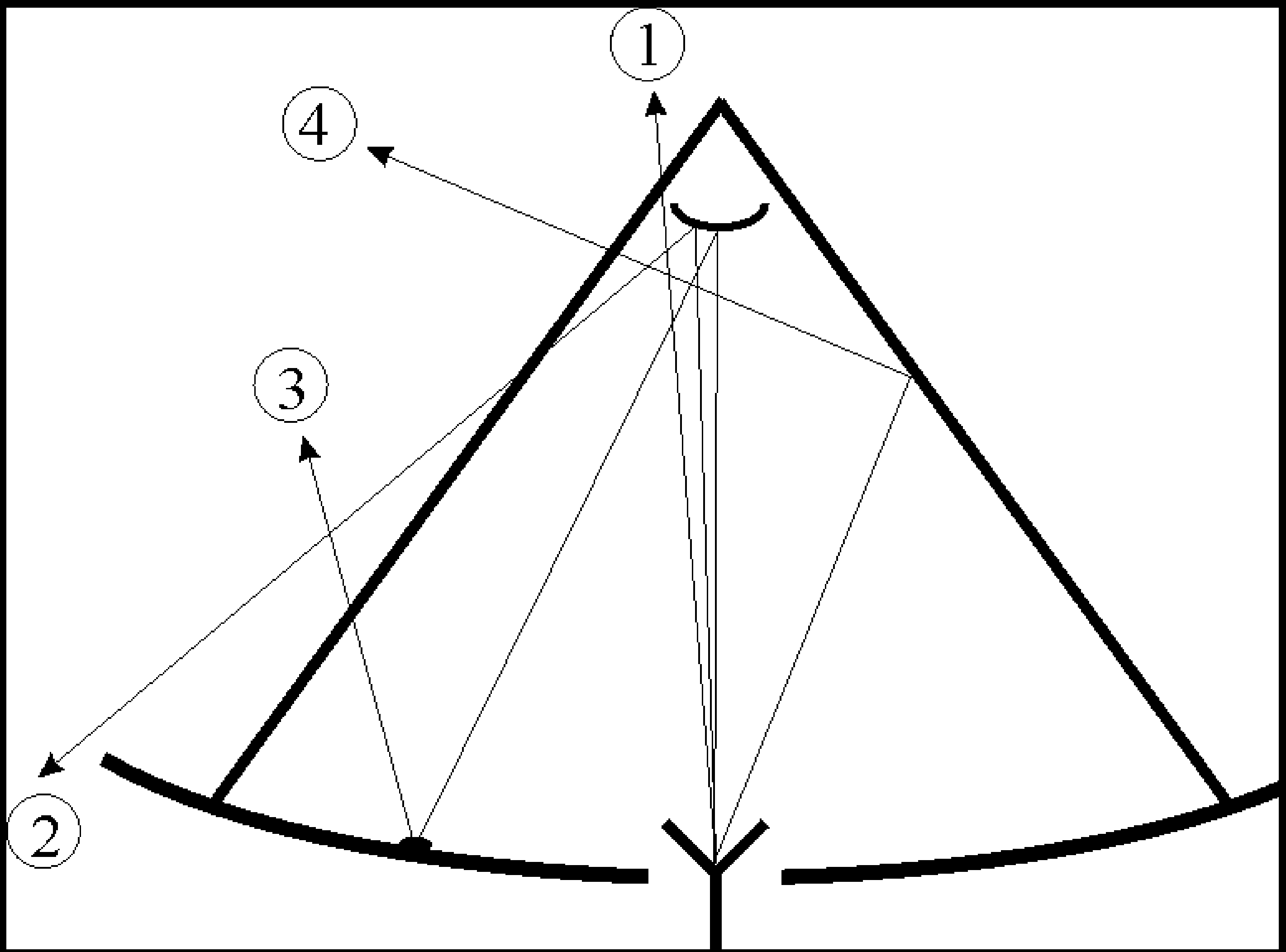
λ
Plane wavefront
+
Signals Cancel
Beamshape of each antenna
Fringe pattern

Reciprocity



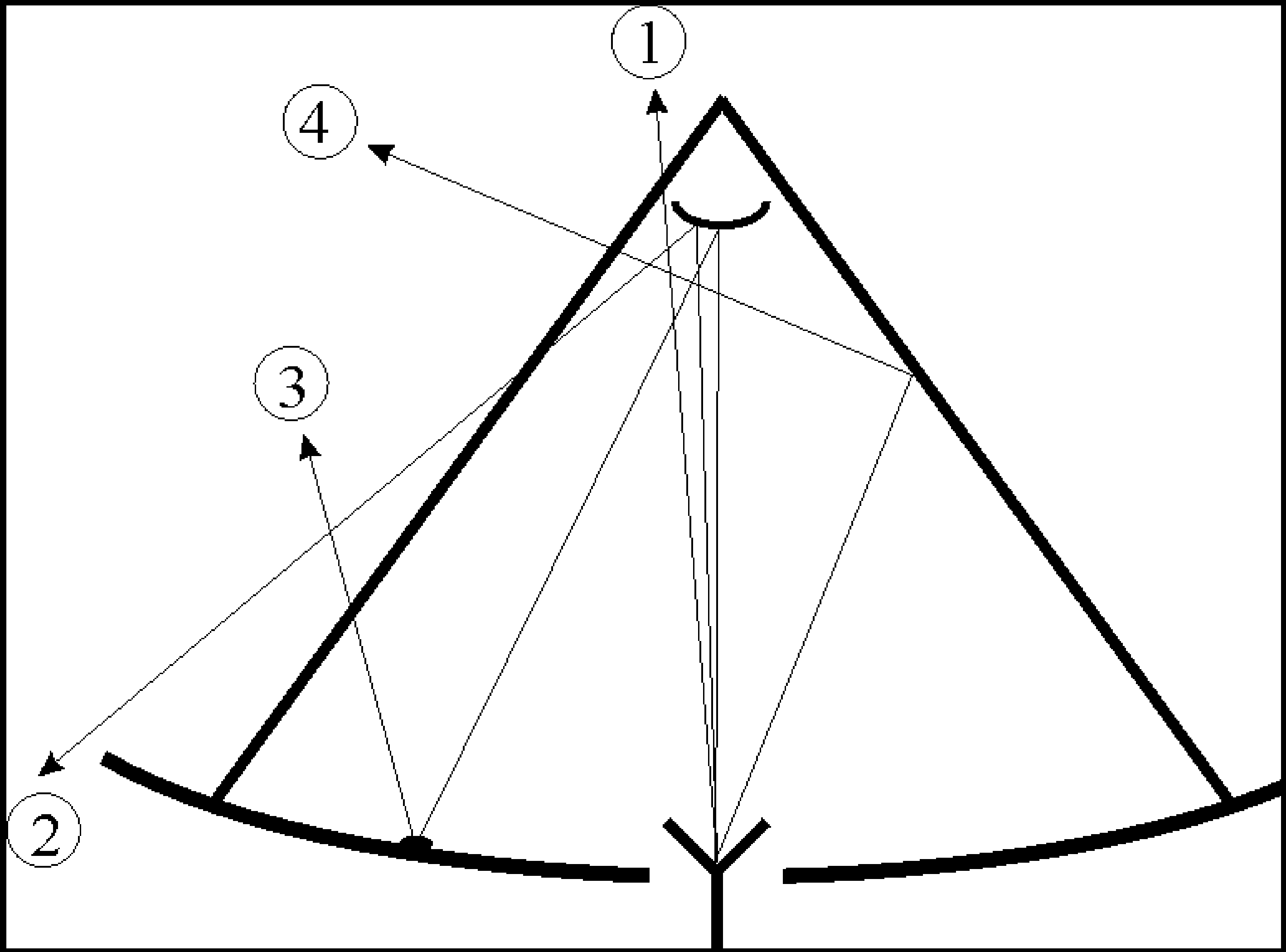
1, 2 Spillover

Reciprocity



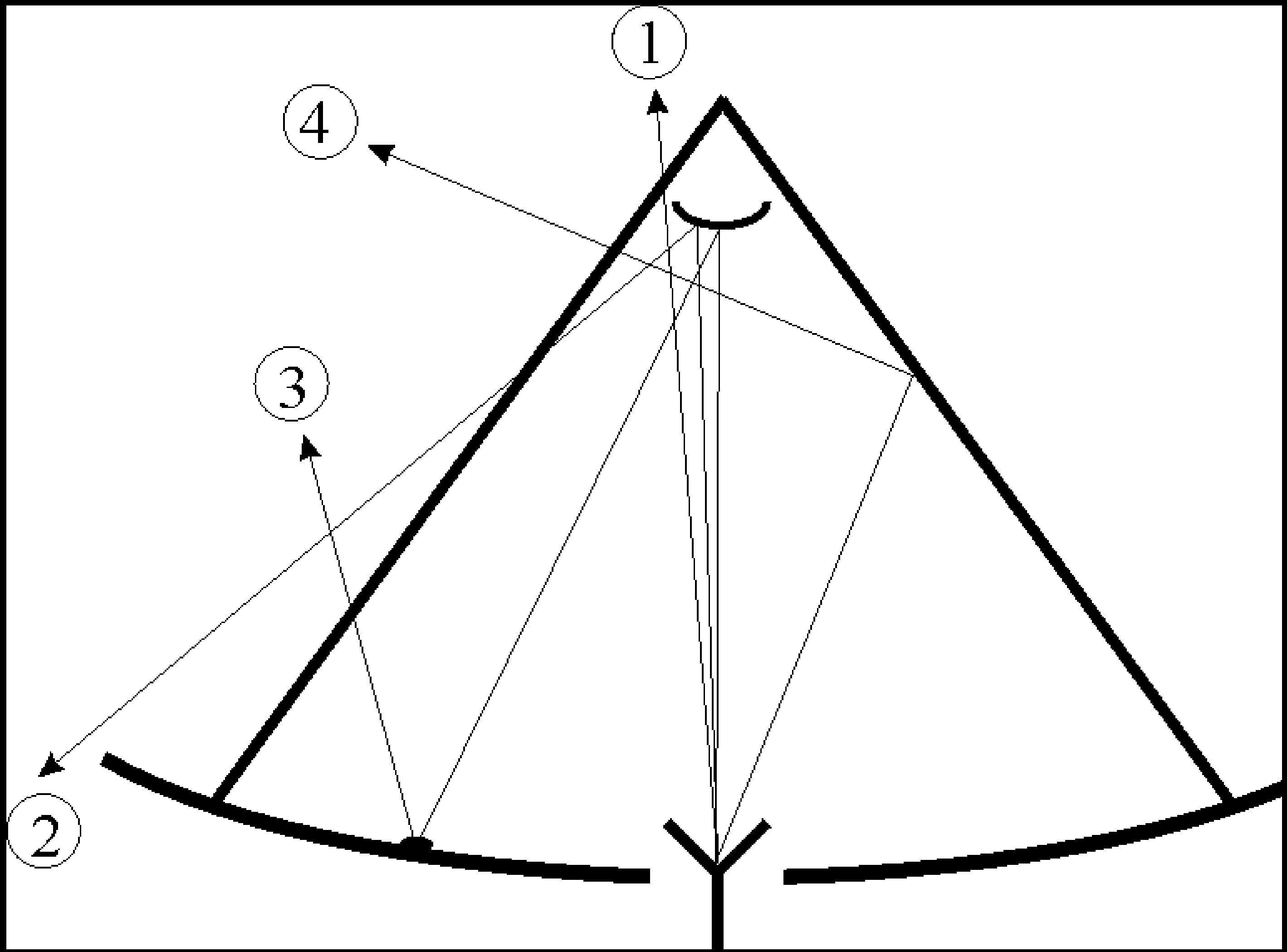
4. What are the effects of blockage?

Reciprocity

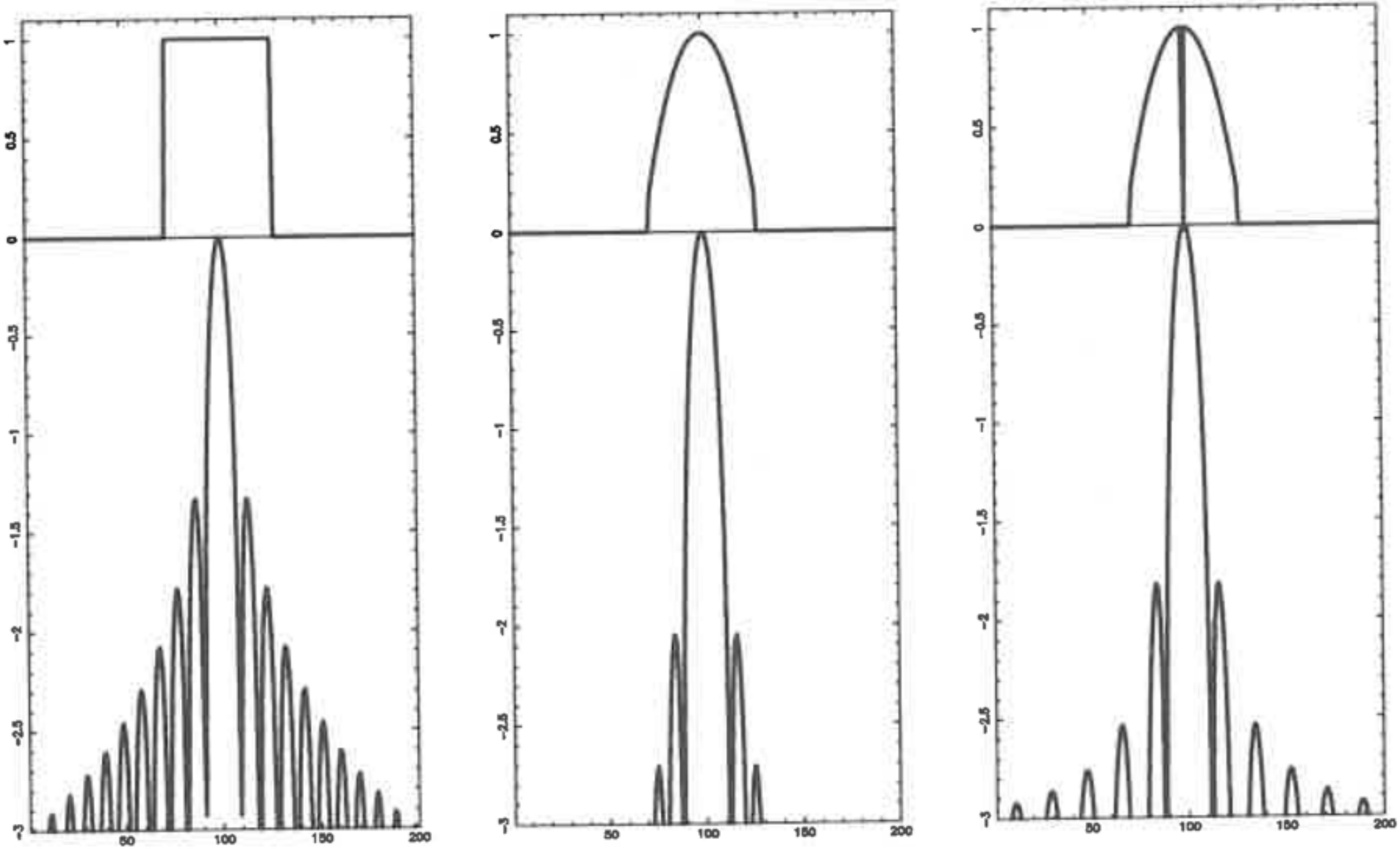


4. What are the effects of blockage?
3. What does it mean that the surface looses efficiency?

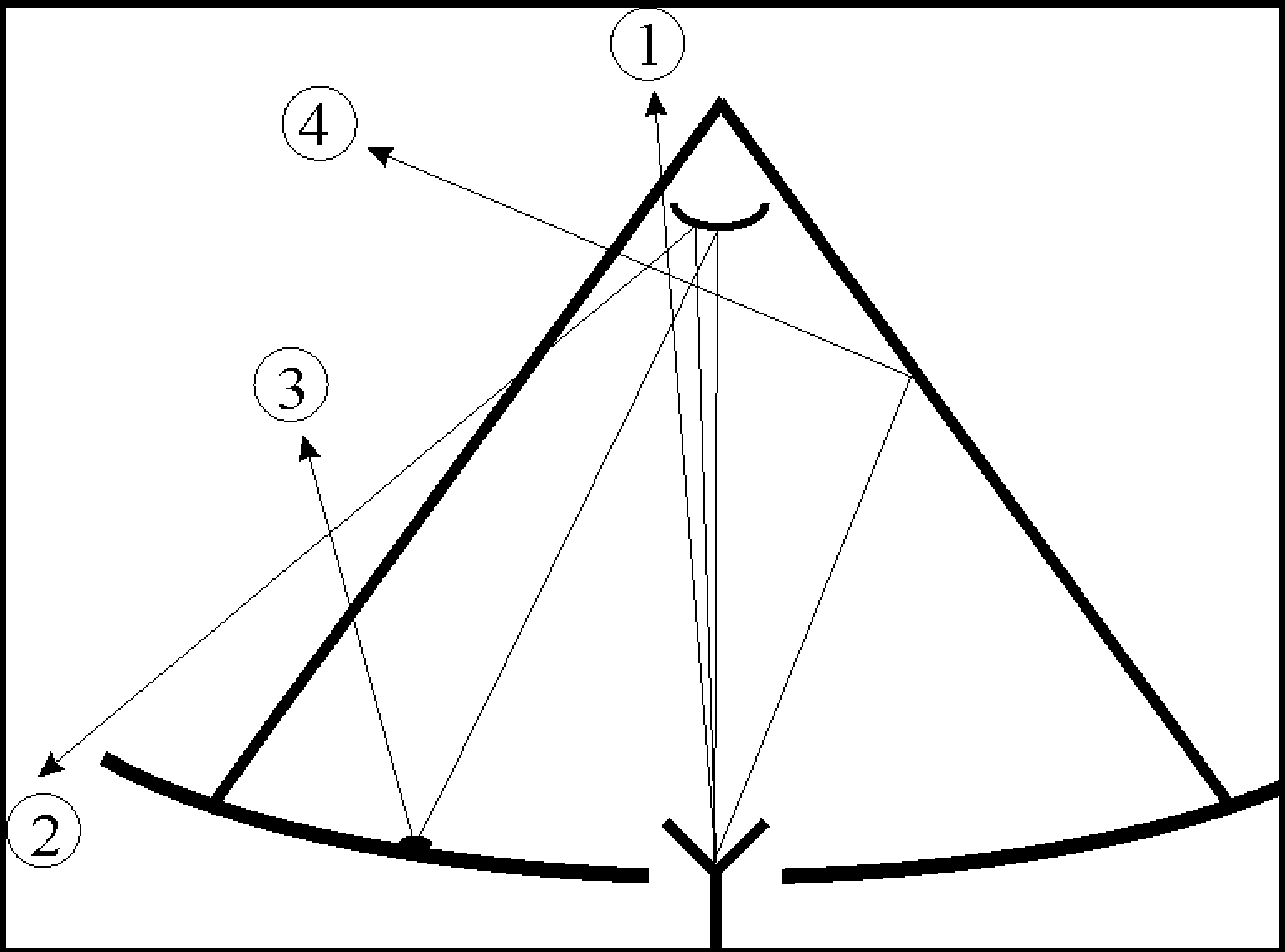
Reciprocity



4. What are the effects of blockage?
3. What does it mean that the surface looses efficiency?
What is the effect of a hole in the dish?

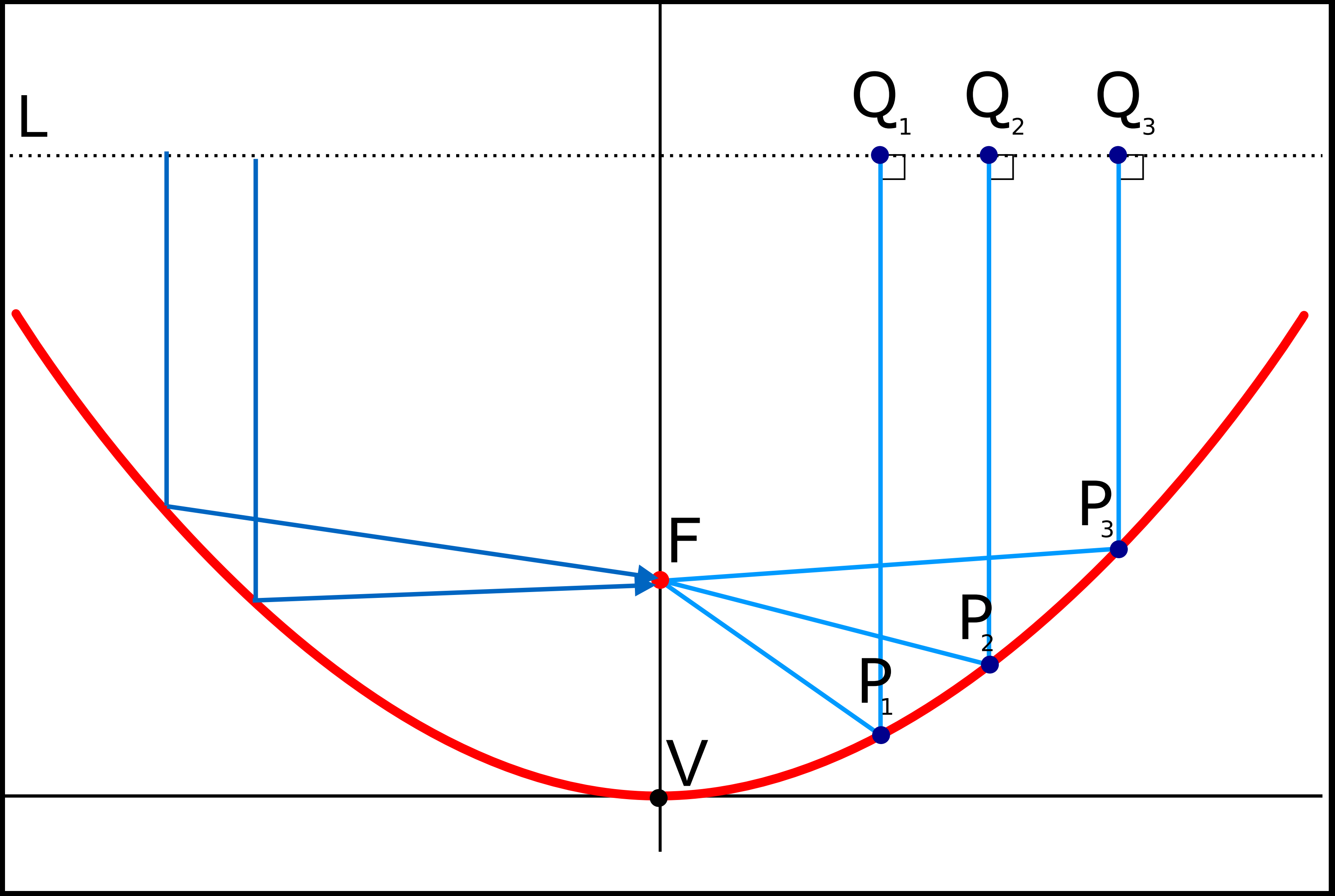

1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
50
100
150
200

Reciprocity

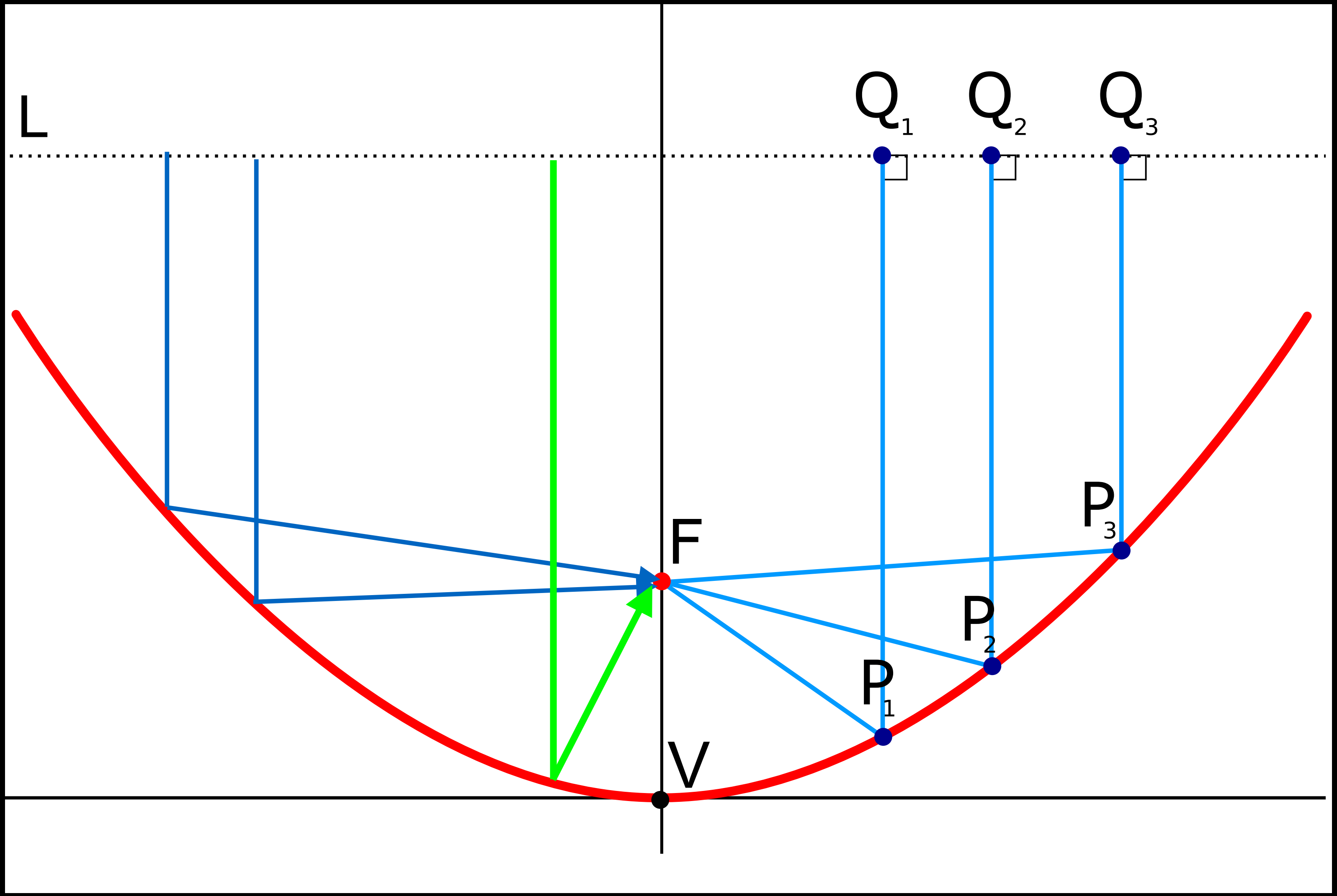


4. What are the effects of blockage?
3. What does it mean that the surface looses efficiency?
What is the effect of a hole in the dish?
Can you reduce sidelobes by wrapping legs in absorber?

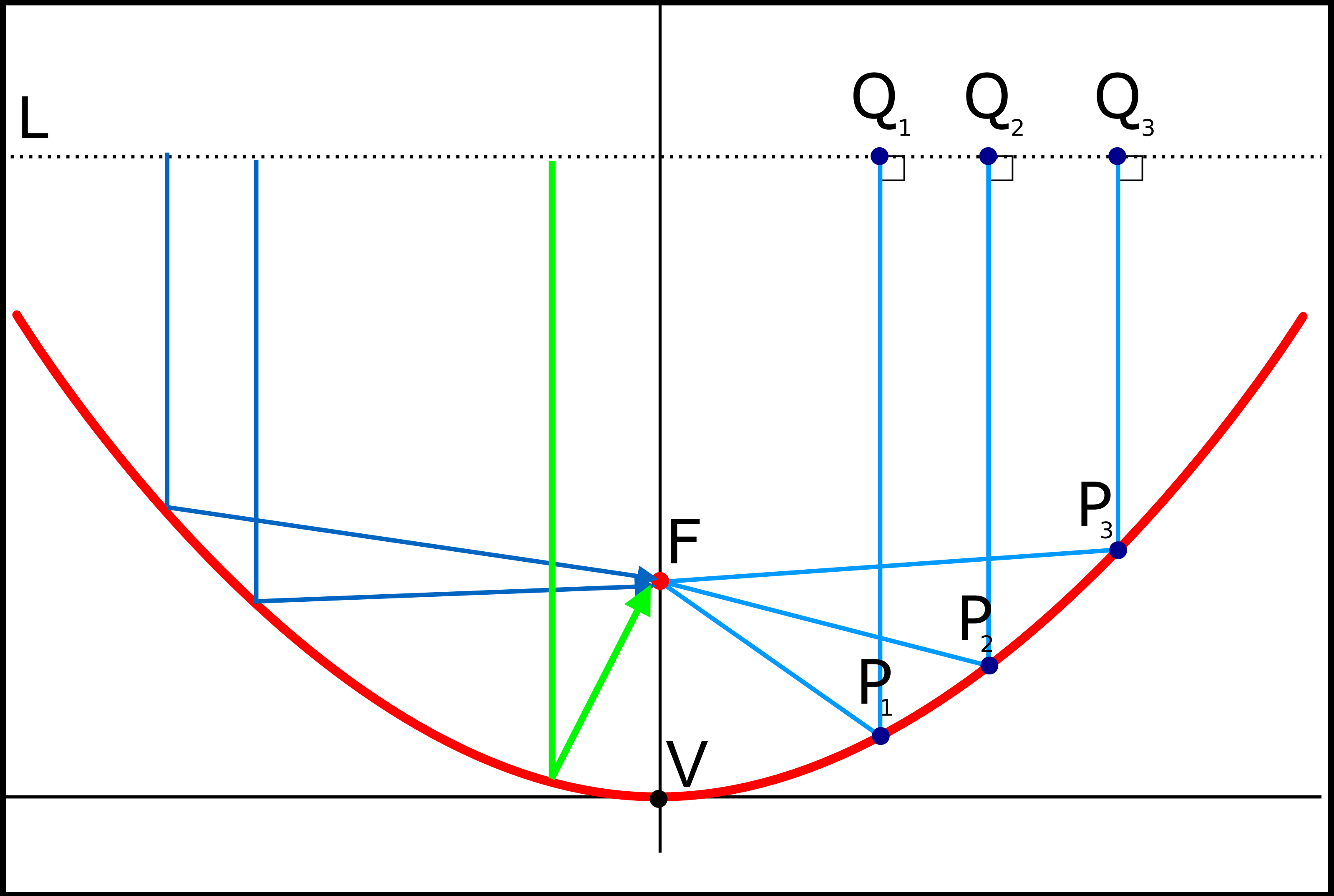
The Parabolic Reflector



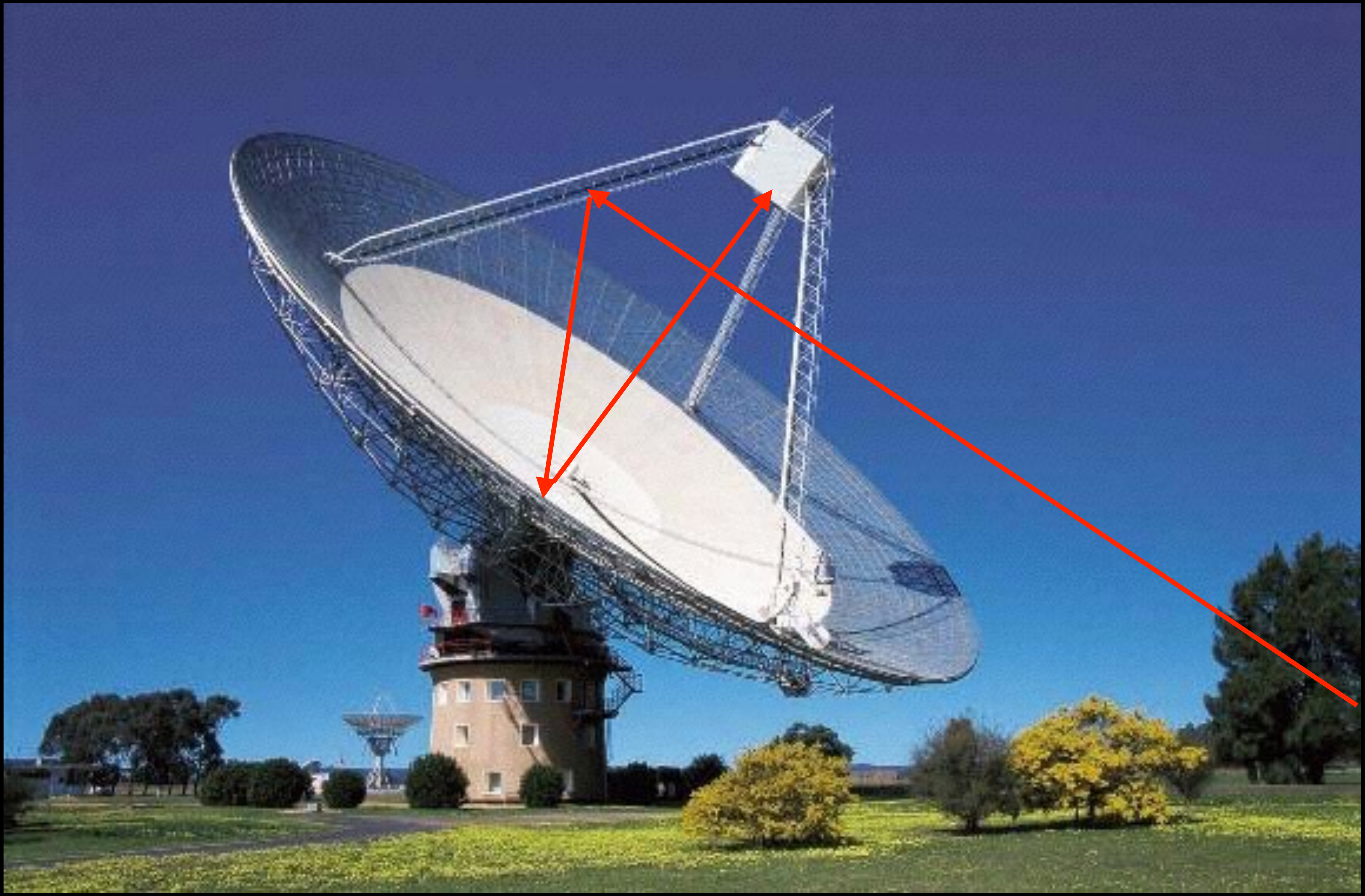
L
Q1
Q2
Q3
F
P3
P2
P1
V

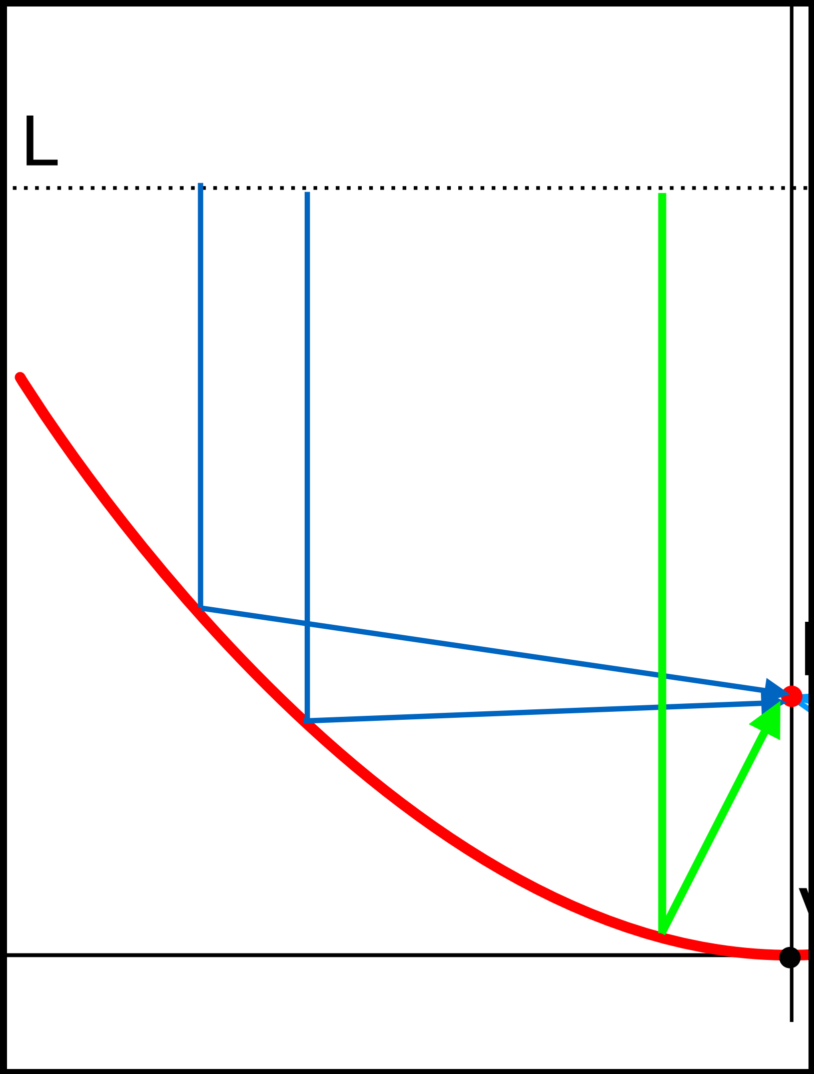


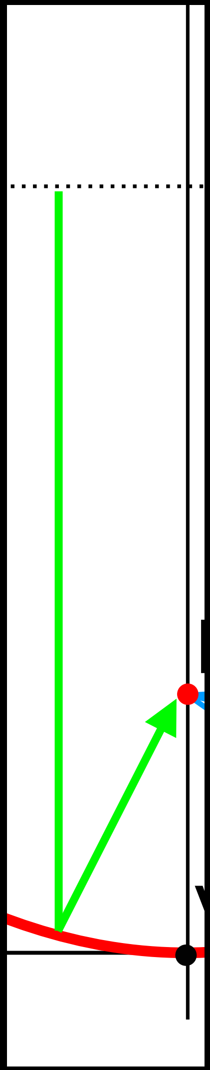
L
Q1
Q2
Q3
F
P3
P2
P1
V

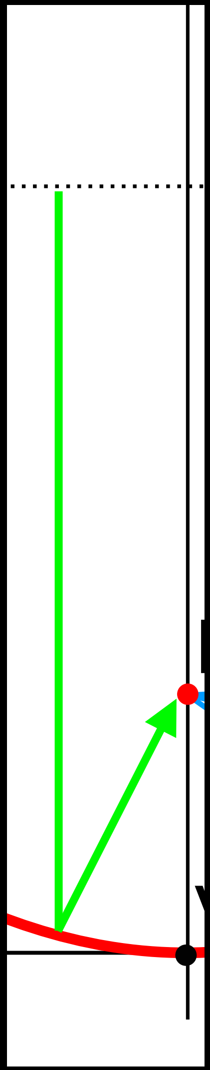


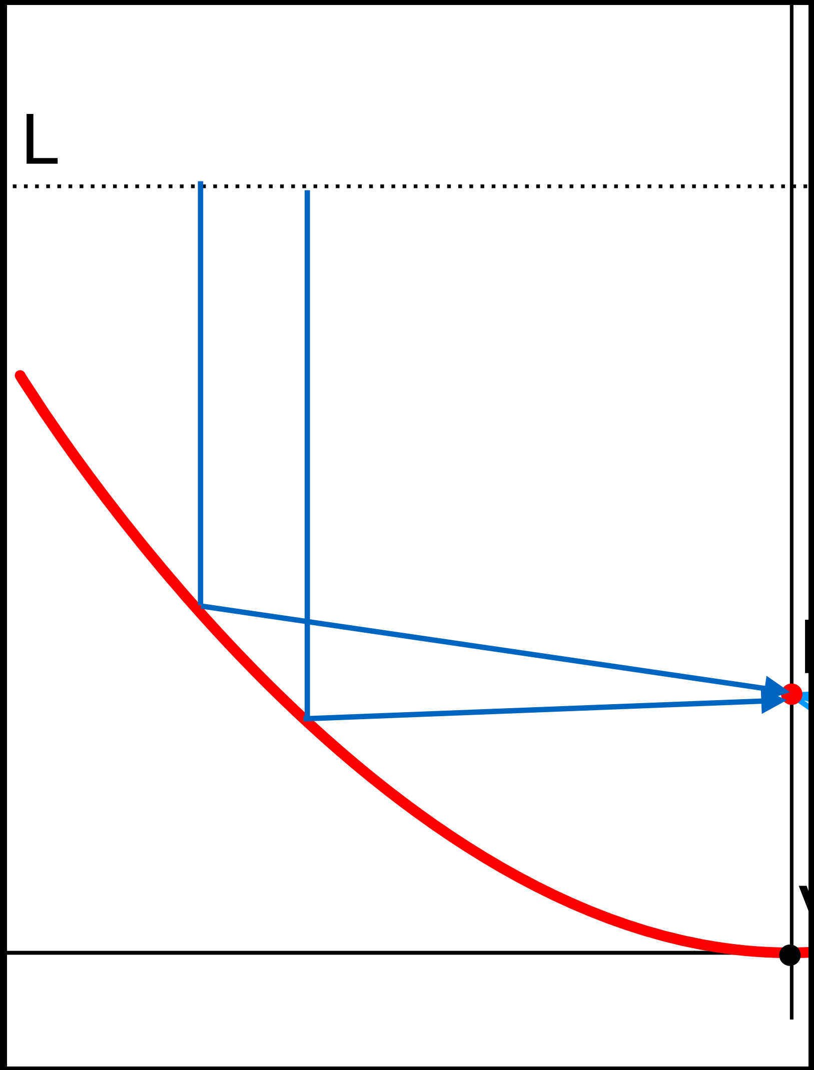
Blockage

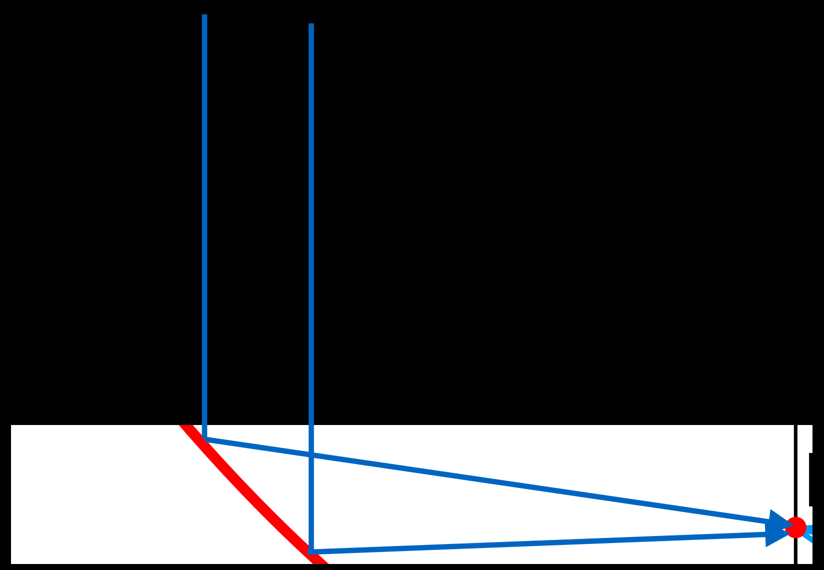


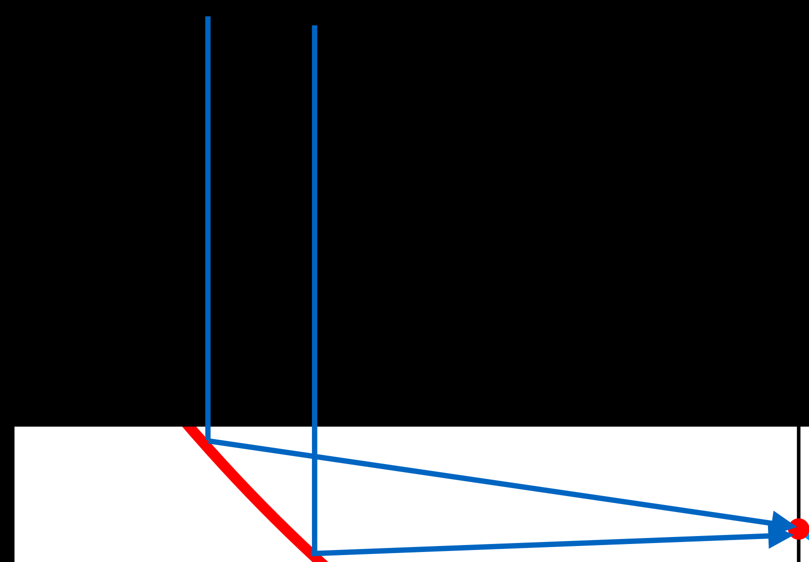

L






L





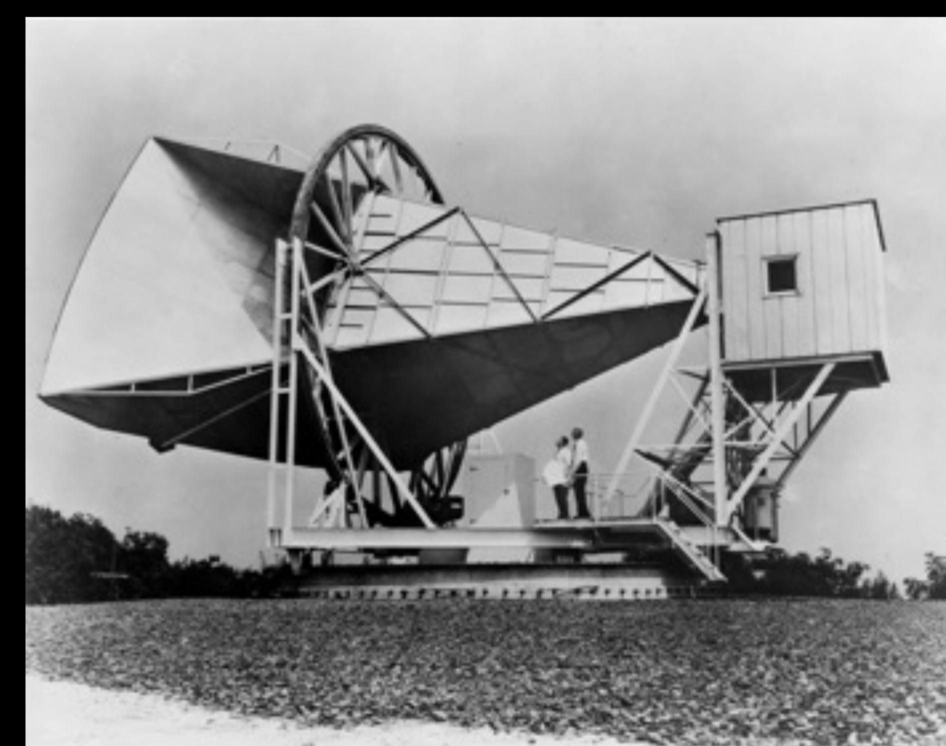


FIG. 7

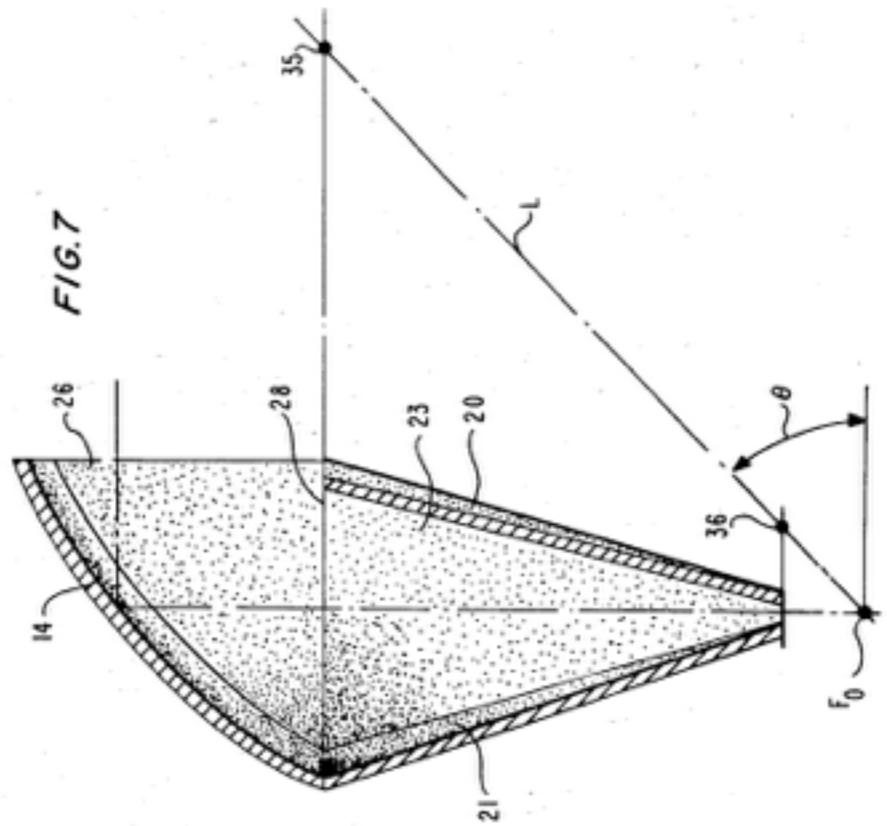


FIG. 6

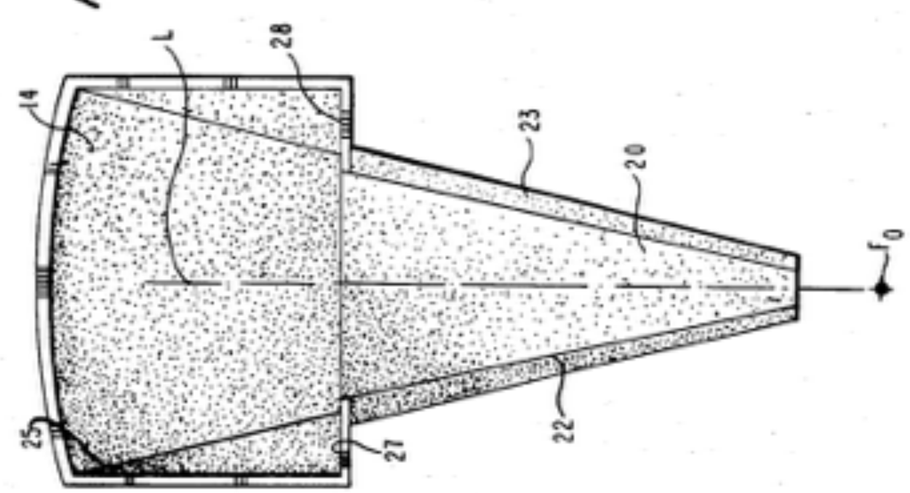


FIG. 7

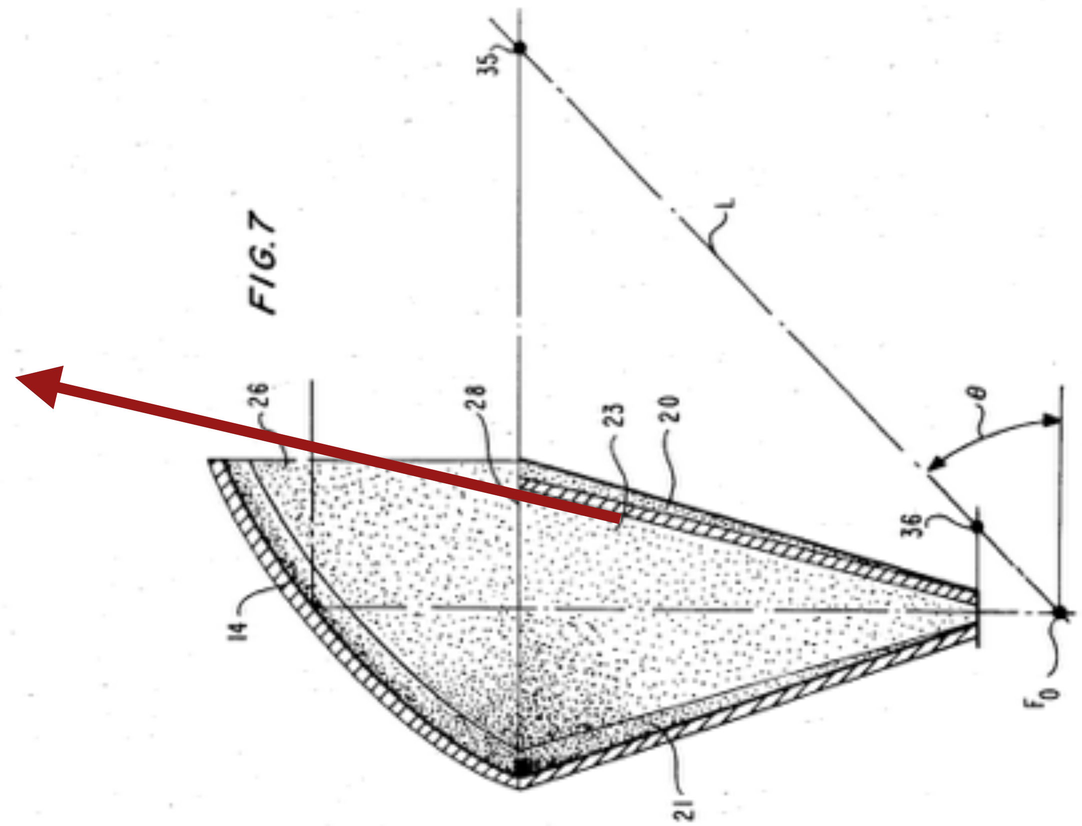
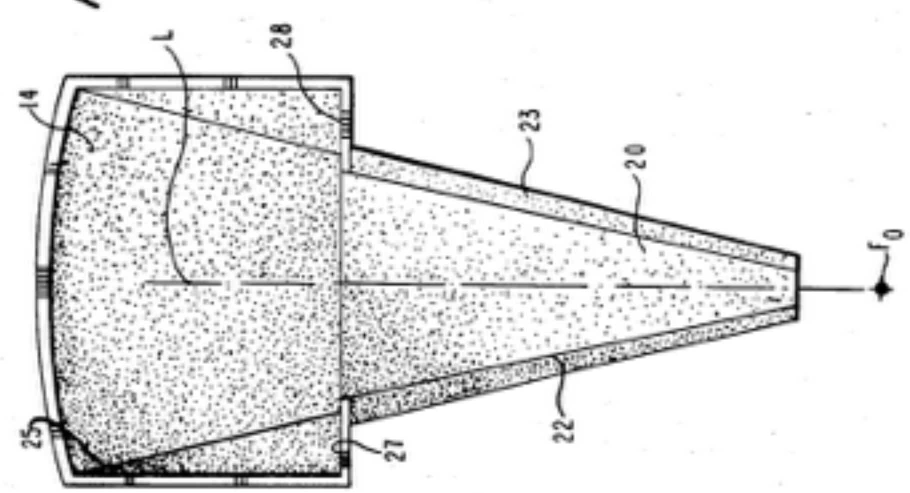
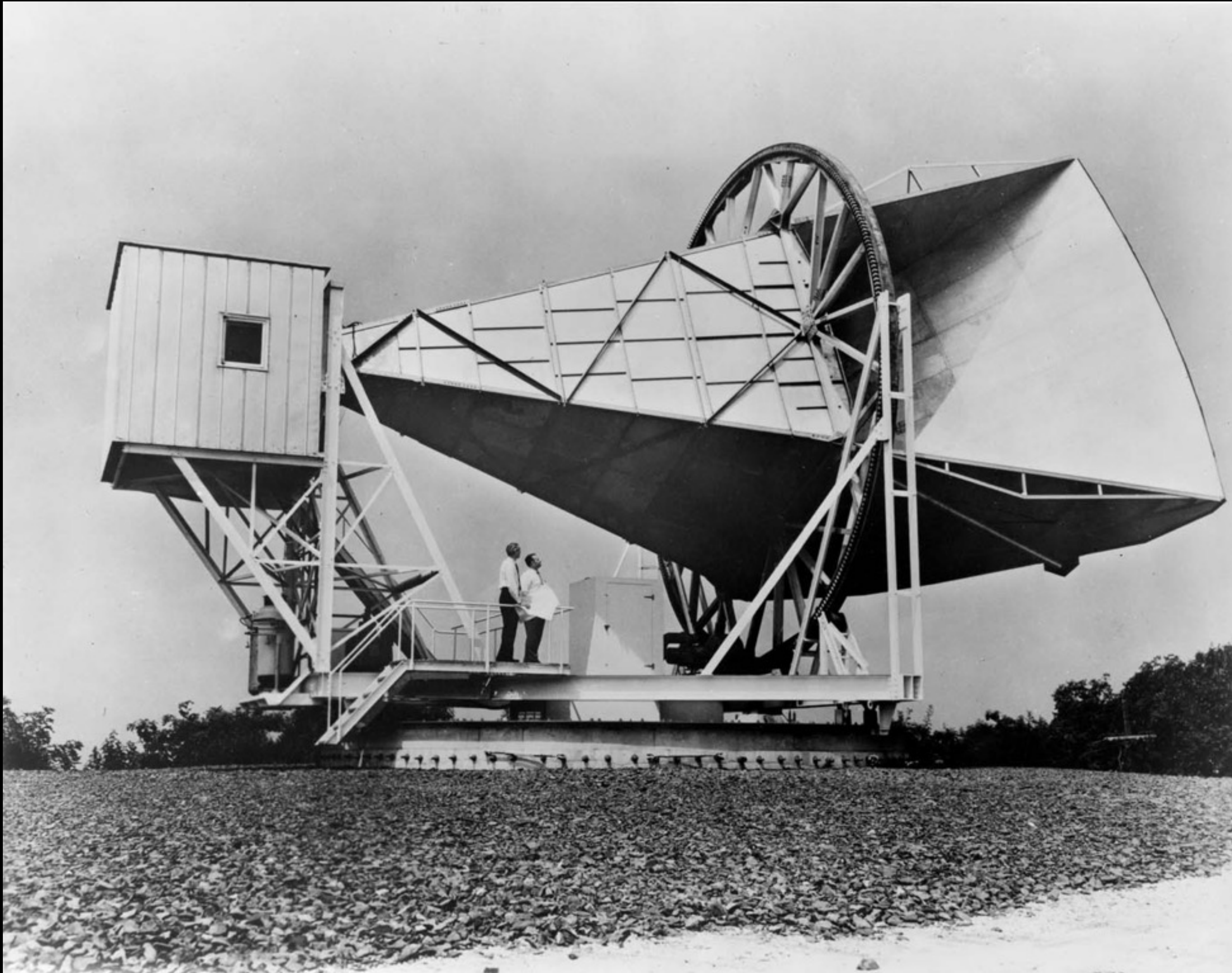


FIG. 6

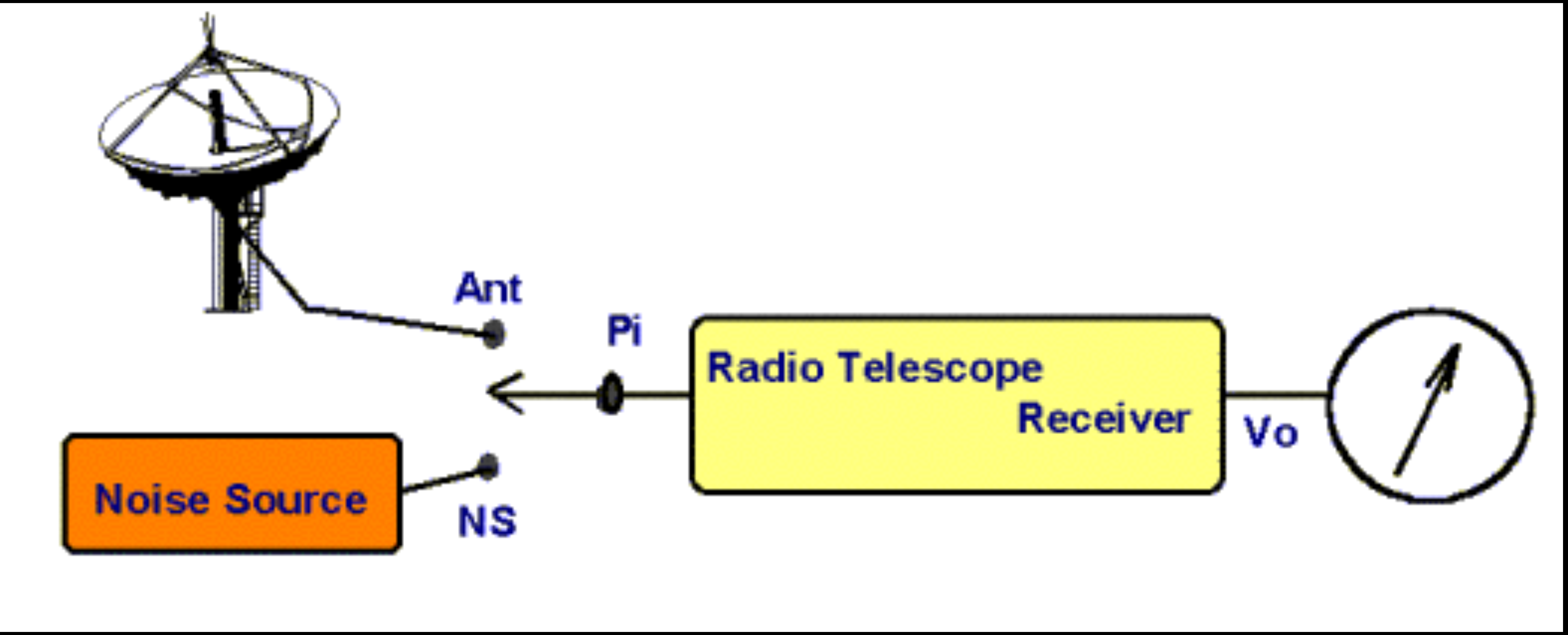



N.A.S.A.


COMMUNICATIONS FOR PEACE
ECHO I
U·S·POSTAGE
4¢



Load switch



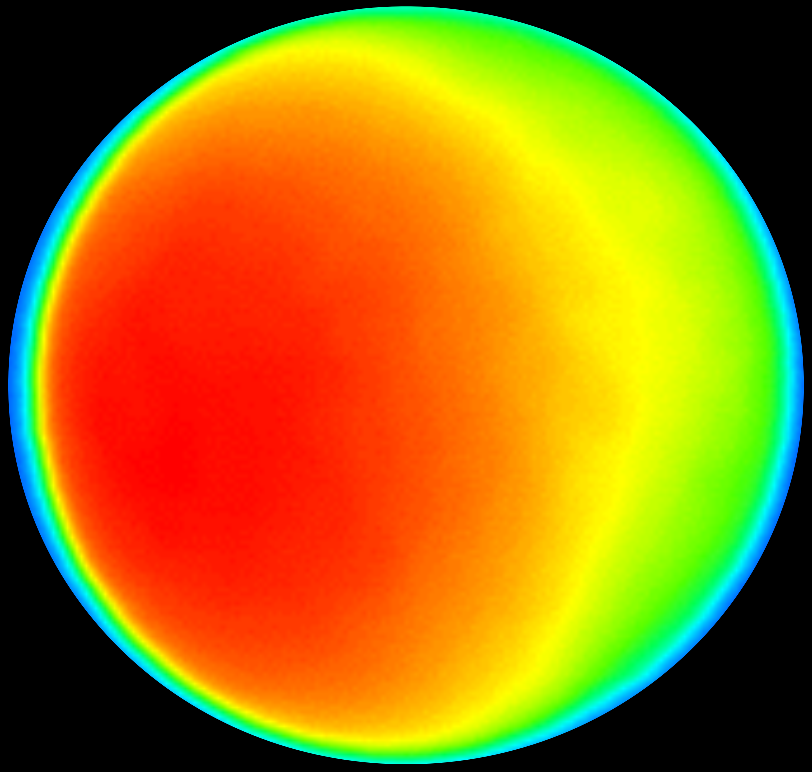
A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

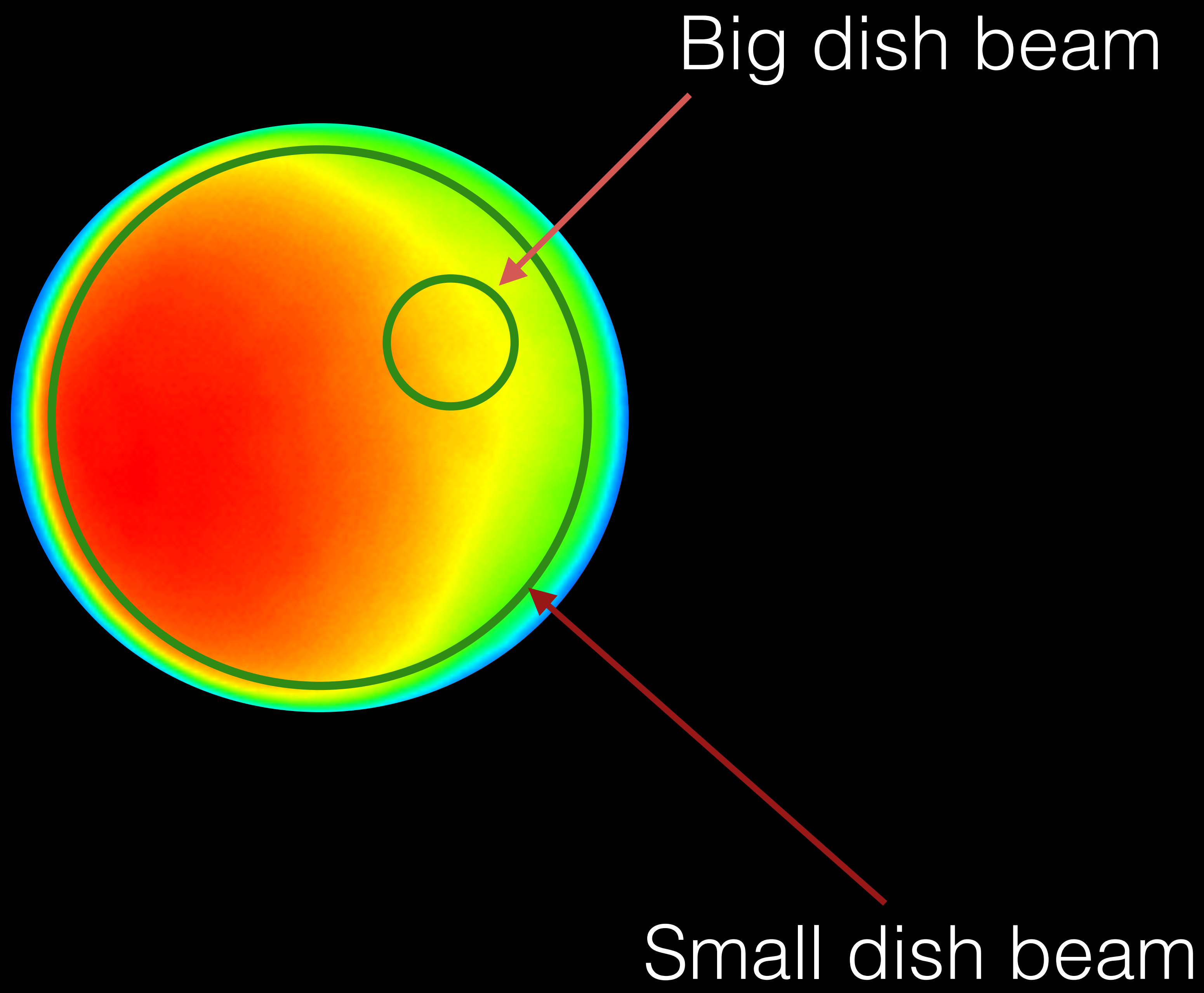
Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and free from seasonal variations (July, 1964–April, 1965). A possible explanation for the observed excess noise temperature is the one given by Dicke, Peebles, Roll, and Wilkinson (1965) in a companion letter in this issue.

The Big Bang!

Thinking about interferometers

Radio image of the Moon




Big dish beam
Small dish beam

angular resolution = λ/Diam

angular resolution = λ/Diam

$$Power = S\ A_e \quad (w\ Hz^{-1})$$

$$S = \int T_b\ d\Omega = \langle T_b \rangle\ \Omega$$

Flux Density

$$Power = S\ A_e \quad (w\ Hz^{-1})$$

$$S = \int T_b\ d\Omega = \langle T_b \rangle\ \Omega$$

$$\Omega = \frac{\lambda^2}{Diam^2}$$

Solid Angle

$$Power = S\ A_e \quad (w\ Hz^{-1})$$

$$S = \int T_b\ d\Omega = \langle T_b \rangle\ \Omega$$

$$\Omega = \frac{\lambda^2}{Diam^2}$$

Effective Area $A_e \propto n_{ant}\ D_{ant}^2$

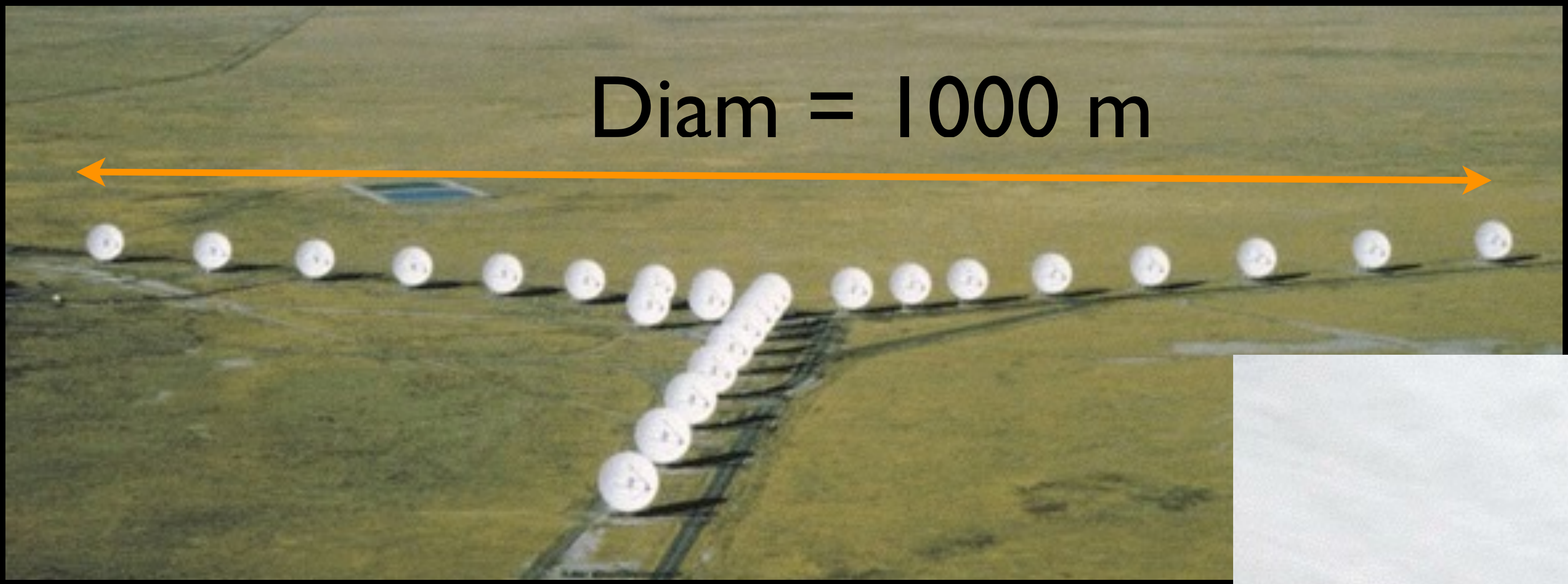
$$Power = S\ A_e \quad (w\ Hz^{-1})$$

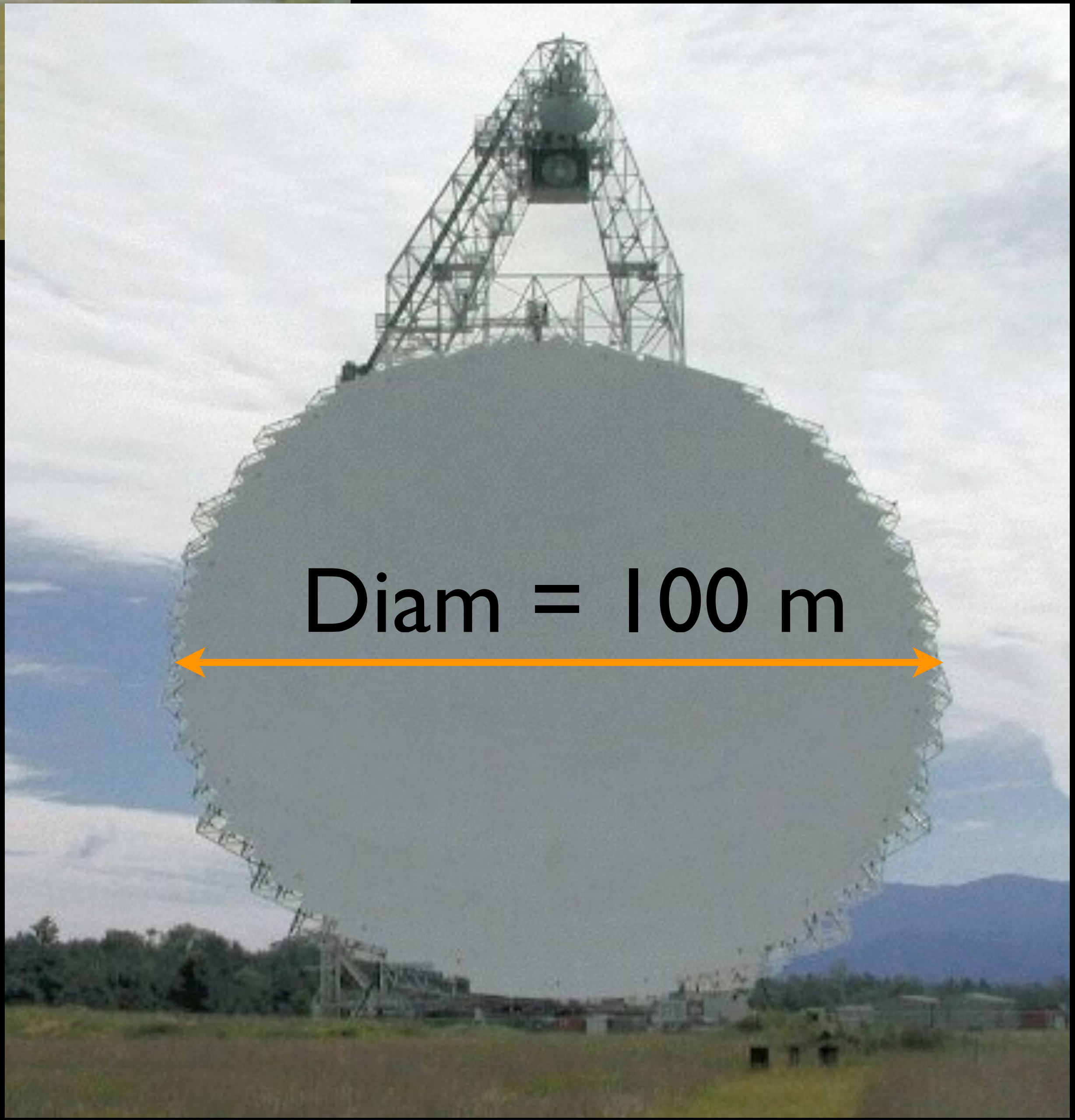
$$S = \int T_b\ d\Omega = \langle T_b \rangle\ \Omega$$

$$\Omega = \frac{\lambda^2}{Diam^2}$$

$$A_e \propto n_{ant}\ D_{ant}^2$$

$$Power \propto \langle T_b \rangle\ n_{ant}\ (\frac{D_{ant}}{Diam})^2$$


Diam = 1000 m


Diam = 100 m

angular resolution = λ/Diam

$$Power = S\ A_e \quad (w\ Hz^{-1})$$

$$S = \int T_b\ d\Omega = \langle T_b \rangle\ \Omega$$

$$\Omega = \frac{\lambda^2}{Diam^2}$$

$$A_e \propto n_{ant}\ D_{ant}^2$$

$$Power \propto \langle T_b \rangle\ n_{ant}\ (\frac{D_{ant}}{Diam})^2$$

point source

$$t \propto \frac{1}{A_e^2}$$

extended source

$$t \propto f^2 \propto \frac{Diam^4}{A_e^2}$$

A digression on the sensitivity of radio telescopes

Instrument	f^2	21cm HPBW
GBT	1	9.1’
Arecibo	1	3.2’
VLA-D	$\sim 10^4$	46”
VLA-C	$\sim 10^6$	14”
VLA-B	$\sim 10^8$	4.3”
ASKAP	$\sim 10^6$	

$$t \propto f^2 \propto \frac{Diam^4}{A_e^2}$$

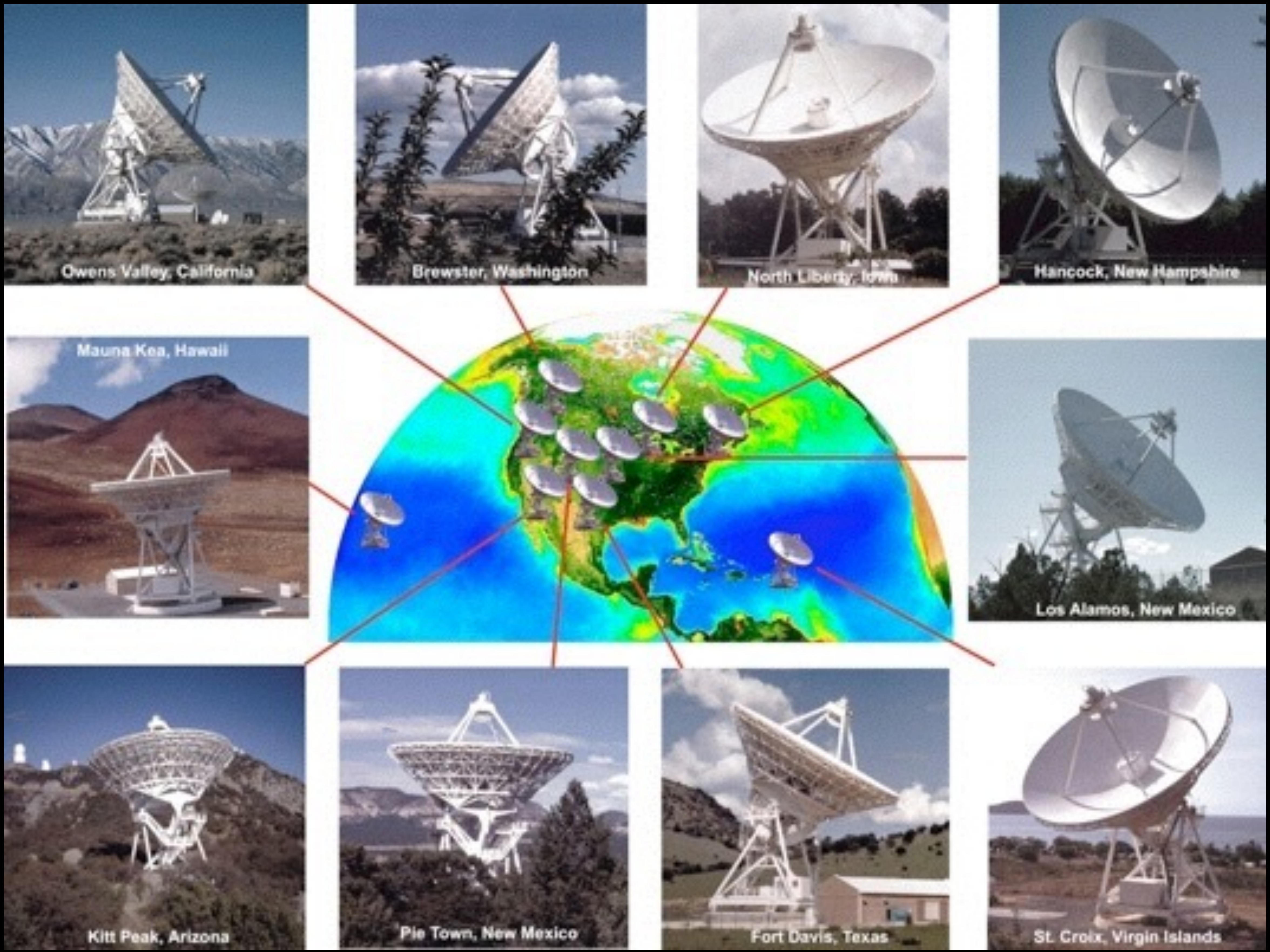
A digression on the sensitivity of radio telescopes

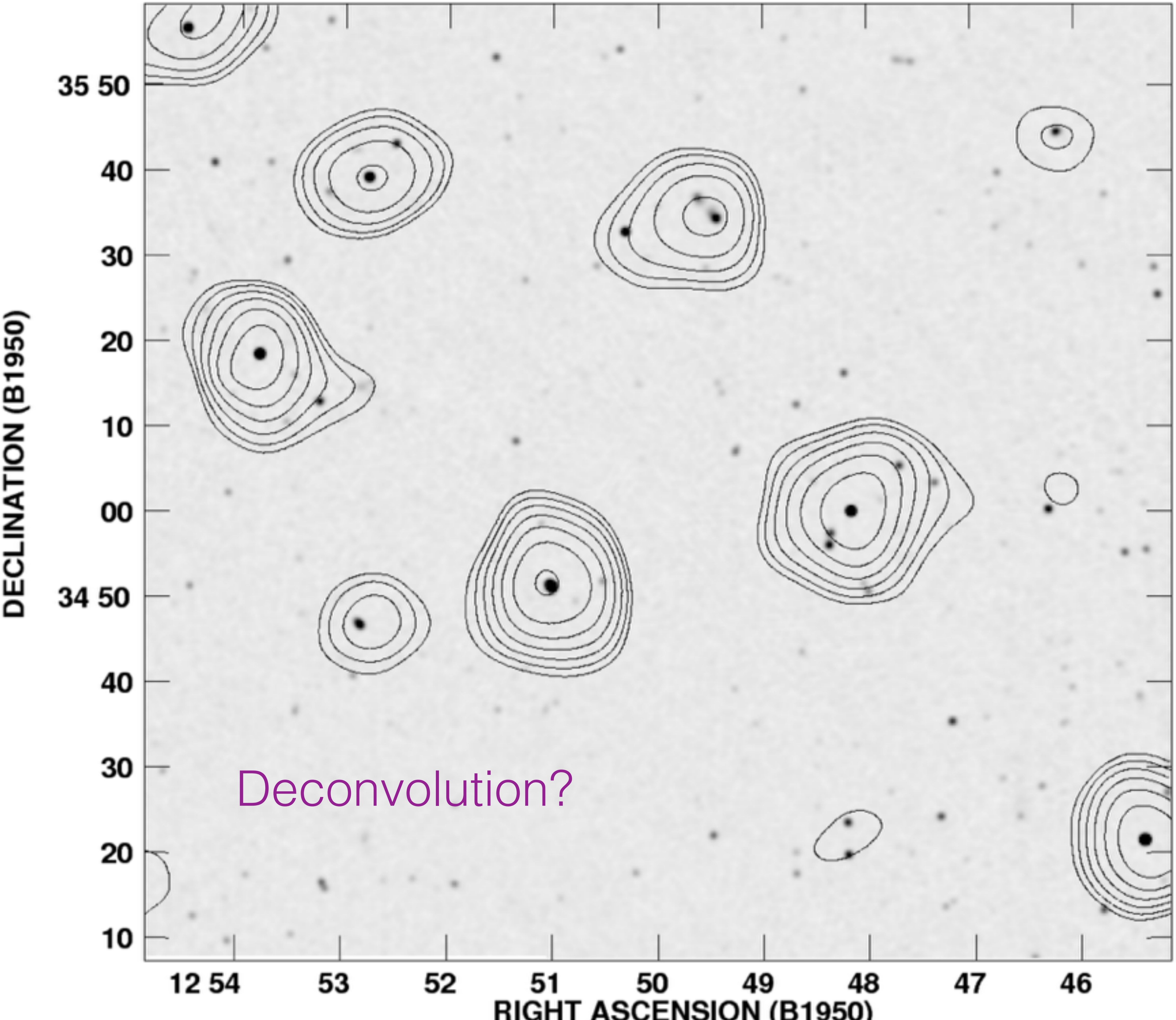
Instrument	f^2	21cm HPBW
GBT	1	9.1'
Arecibo	1	3.2'
VLA-D	$\sim 10^4$	46"

For a given angular resolution, the brightness sensitivity is always greatest for a filled aperture

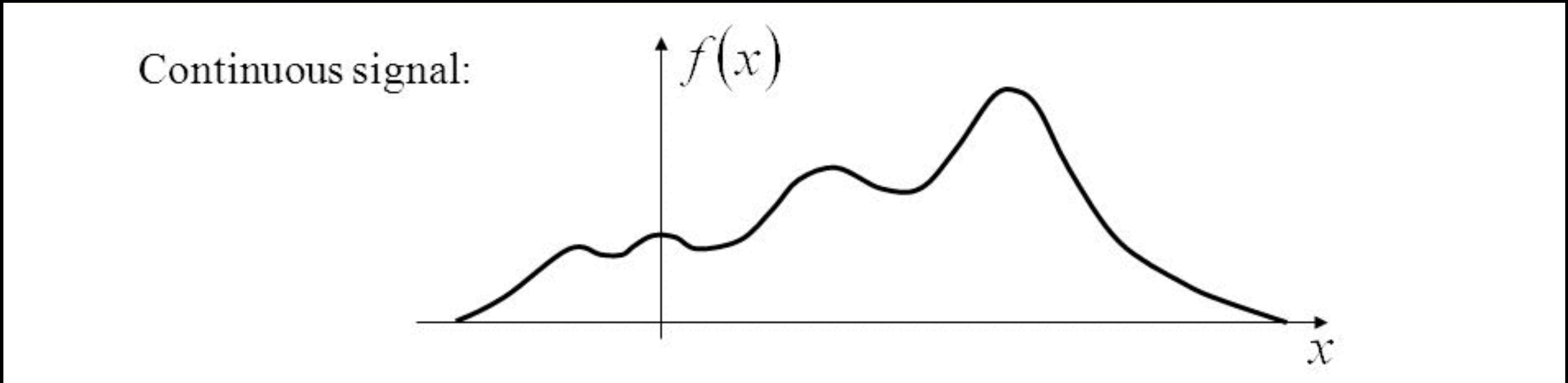
This is not related to the issue of missing short spacings

VLBA Limited to $T_b > 10^5$ K

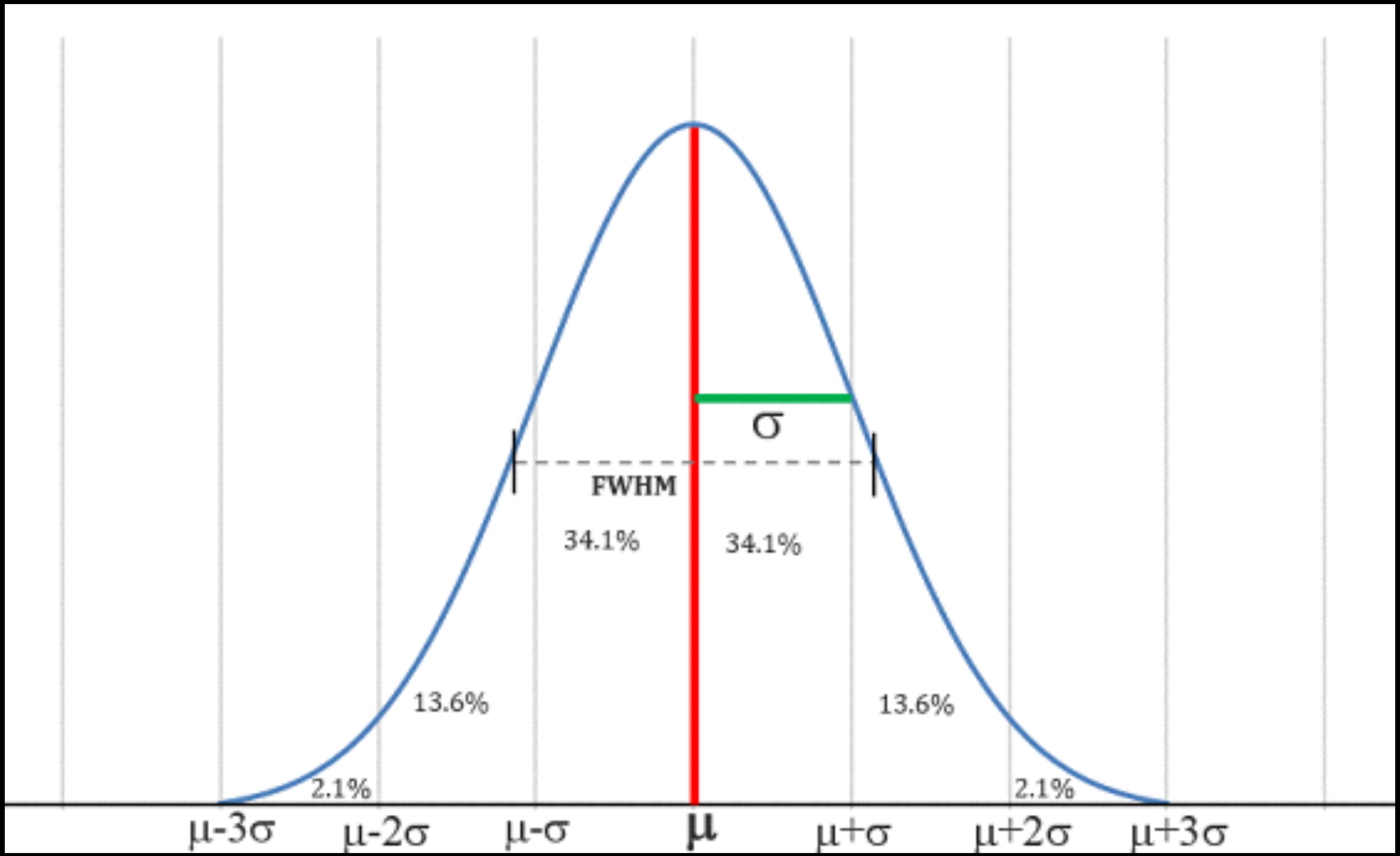




35 50
40
30
20
10
00
34 50
40
30
20
10
DECLINATION (B1950)
12 54
53
52
51
50
49
48
47
46
RIGHT ASCENSION (B1950)
Deconvolution?



If we know the beam, why can’t we deconvolve?


σ
FWHM
34.1%
34.1%
13.6%
13.6%
2.1%
2.1%
μ-3σ
μ-2σ
μ-σ
μ
μ+σ
μ+2σ
μ+3σ

Convolution of two Gaussians

$$\mathrm{FWHM(obs)}^2 \approx \mathrm{FWHM(source)}^2 + \mathrm{FWHM(beam)}^2$$

$$\mathrm{FWHM(beam)}=9'$$

$$\mathrm{FWHM(obs)} = 10'$$

$$\mathrm{FWHM(source)} = (100-81)^{1/2} = 4.36$$

$$\mathrm{FWHM(obs)}^2 \approx \mathrm{FWHM(source)}^2 + \mathrm{FWHM(beam)}^2$$

$$\mathrm{FWHM(beam)} = 9'$$

$$\mathrm{FWHM(obs)} = 10'(\pm 0.5)$$

$$\mathrm{FWHM(source)} = 4.36^{+1.04}_{-1.22}$$

$$\mathrm{FWHM(obs)}^2 \approx \mathrm{FWHM(source)}^2 + \mathrm{FWHM(beam)}^2$$

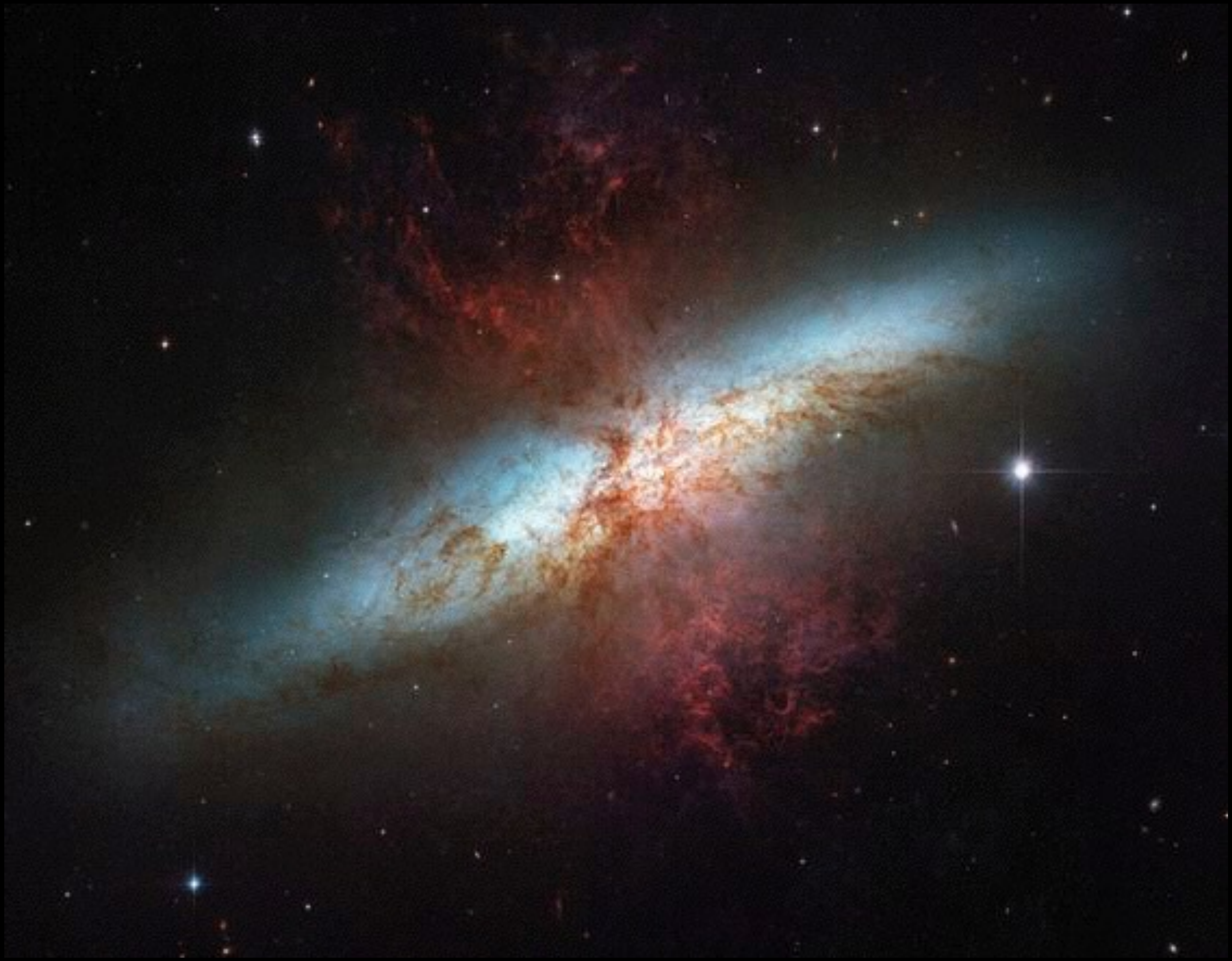
$$\mathrm{FWHM(beam)} = 9'$$

$$\mathrm{FWHM(obs)} = 10'(\pm 1')$$

$$\mathrm{FWHM(source)} = 4.36^{+1.96}_{-4.36}$$

Deconvolution is not robust!

Nuclear winds are common in galaxies

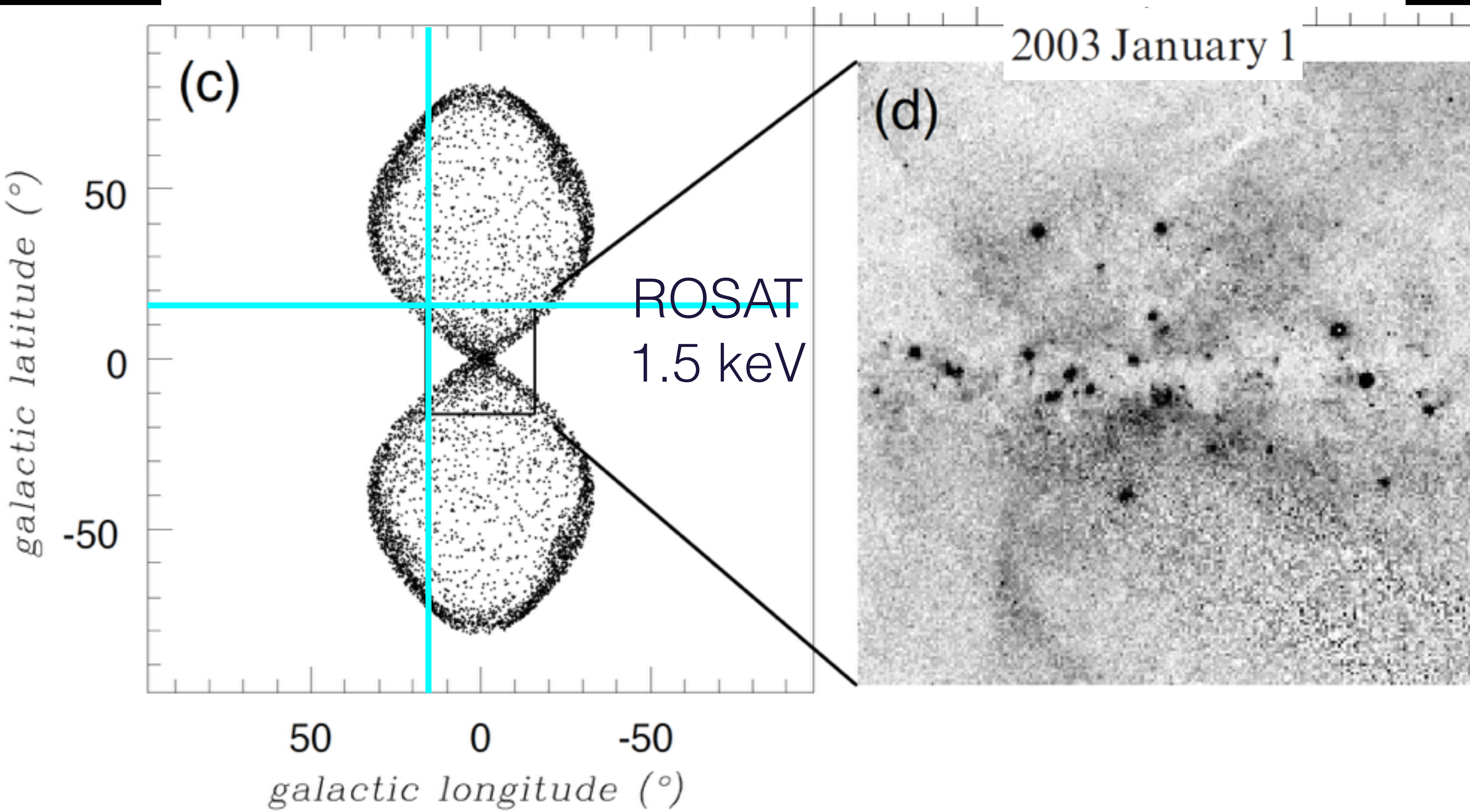


THE LARGE-SCALE BIPOLAR WIND IN THE GALACTIC CENTER

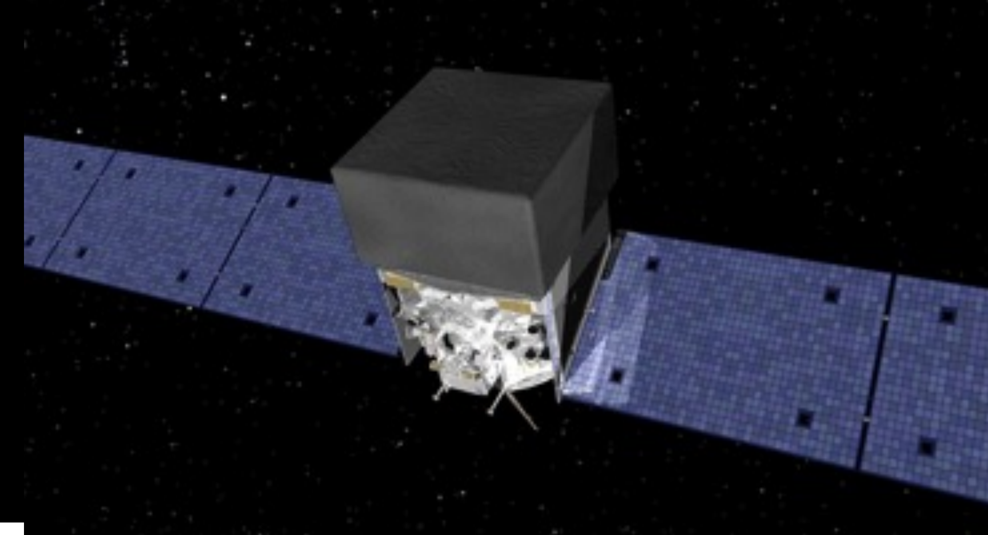
JOSS BLAND-HAWTHORN
Anglo-Australian Observatory, P.O. Box 296, Epping NSW, Australia

AND

MARTIN COHEN
Radio Astronomy Laboratory, 601 Campbell Hall, University of California, Berkeley, CA 94720
Received 2002 July 2; accepted 2002 September 4



γ-ray Data From Fermi



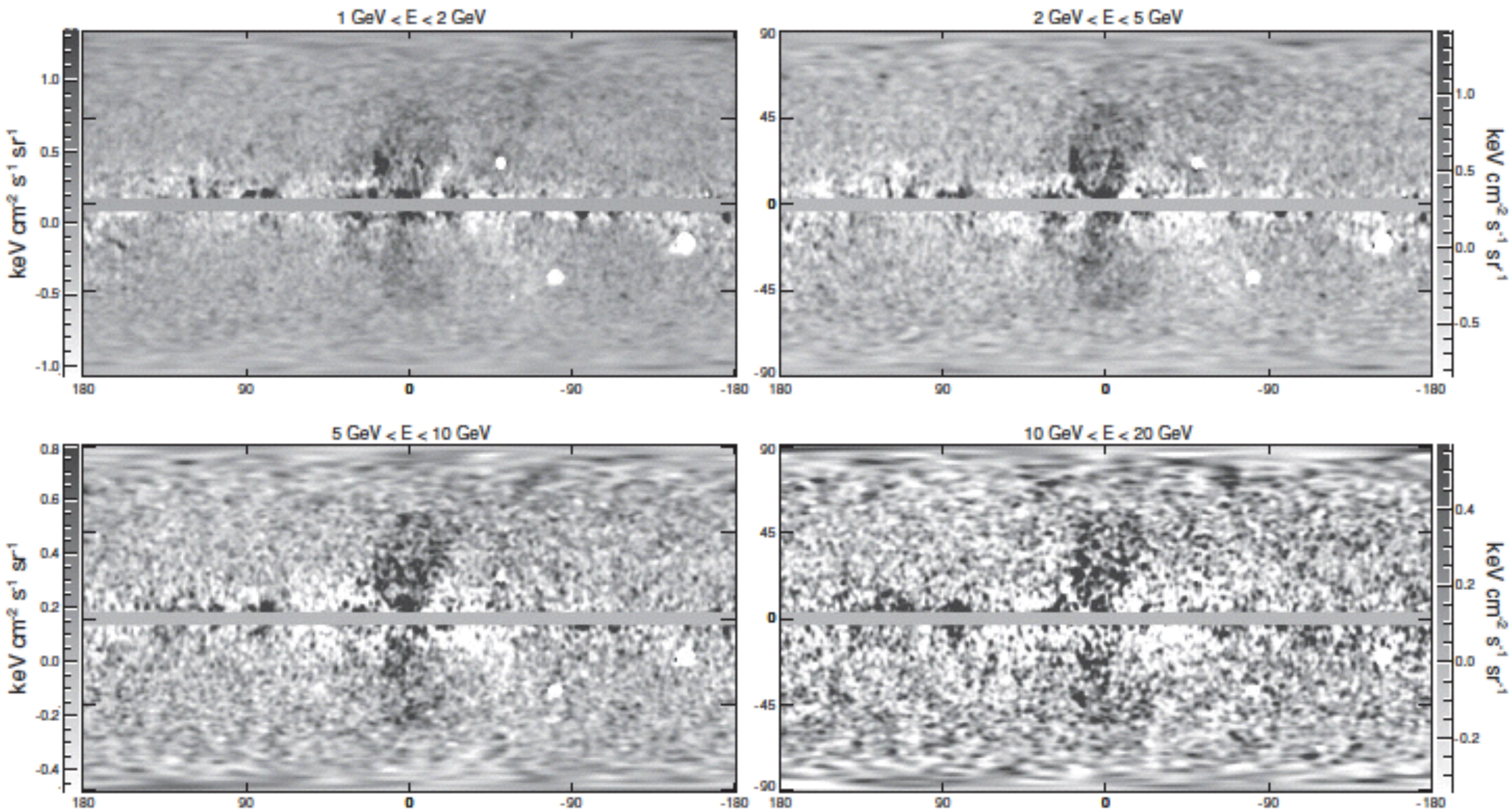
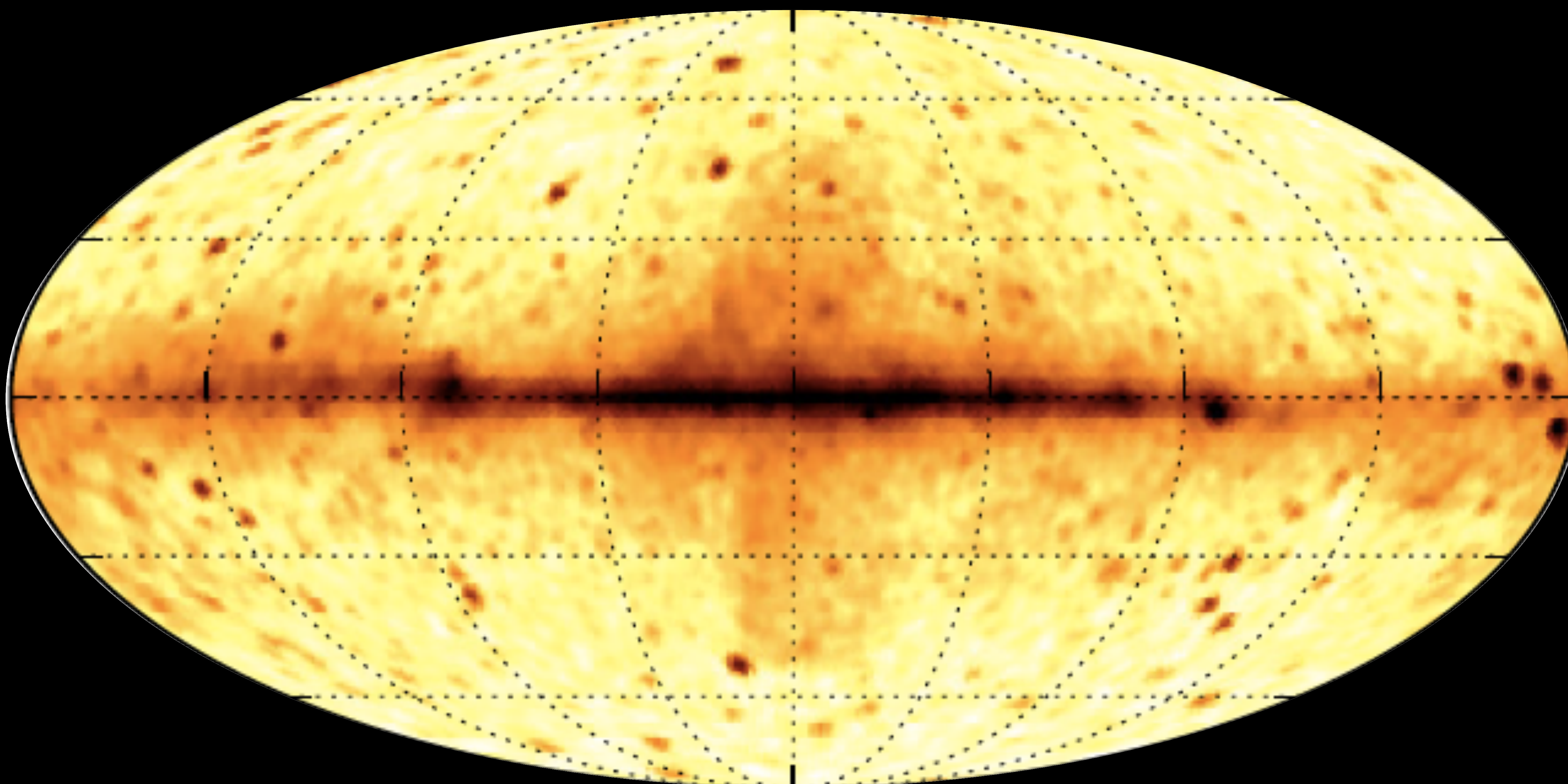
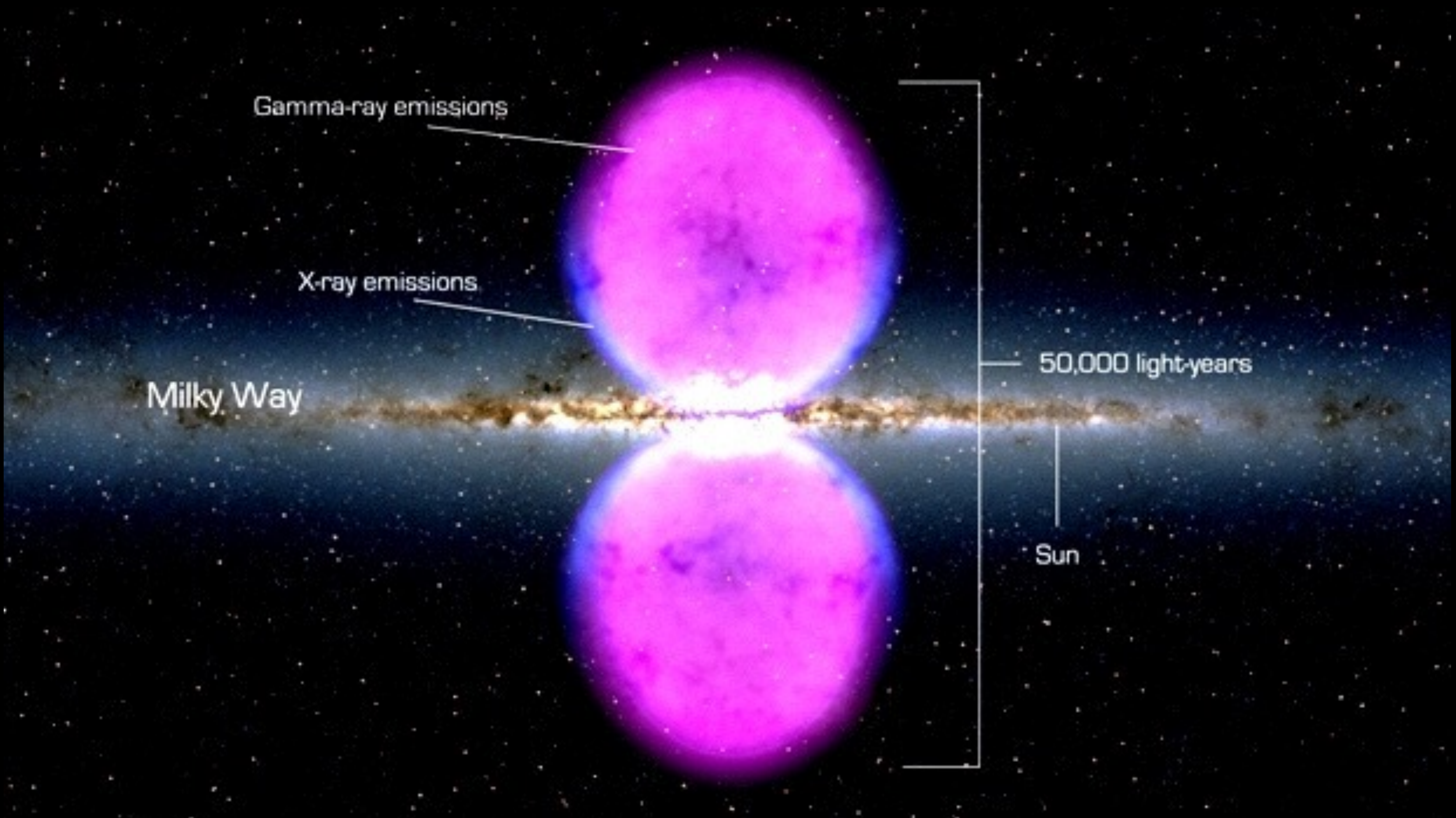


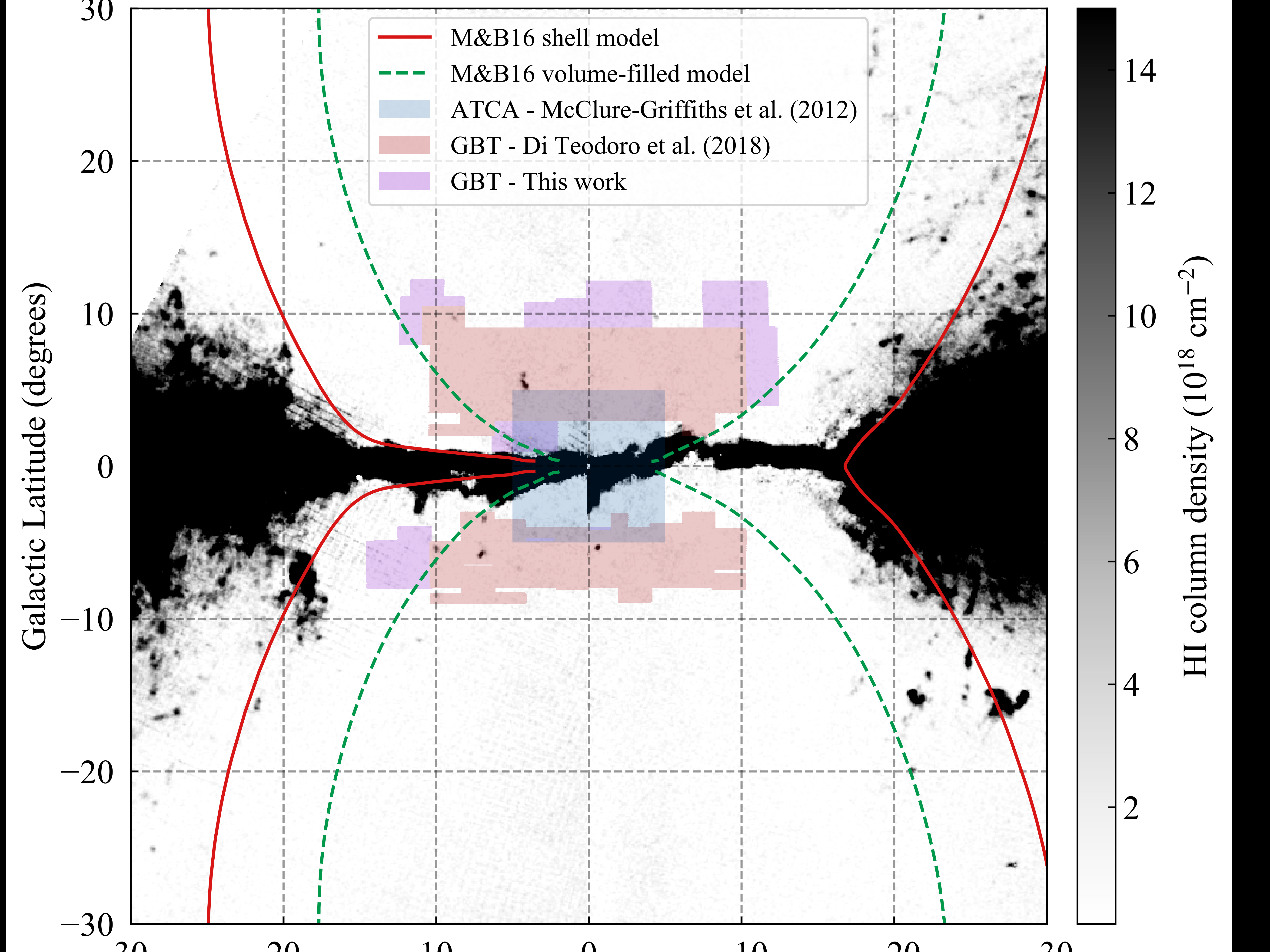
Figure 2. All-sky residual maps after subtracting the *Fermi* diffuse Galactic model from the LAT 1.6 year maps in four energy bins (see Section 3.1.1). Two bubble structures extending to $b \pm 50°$ appear above and below the GC, symmetric about the Galactic plane.

γ-ray Data From Fermi



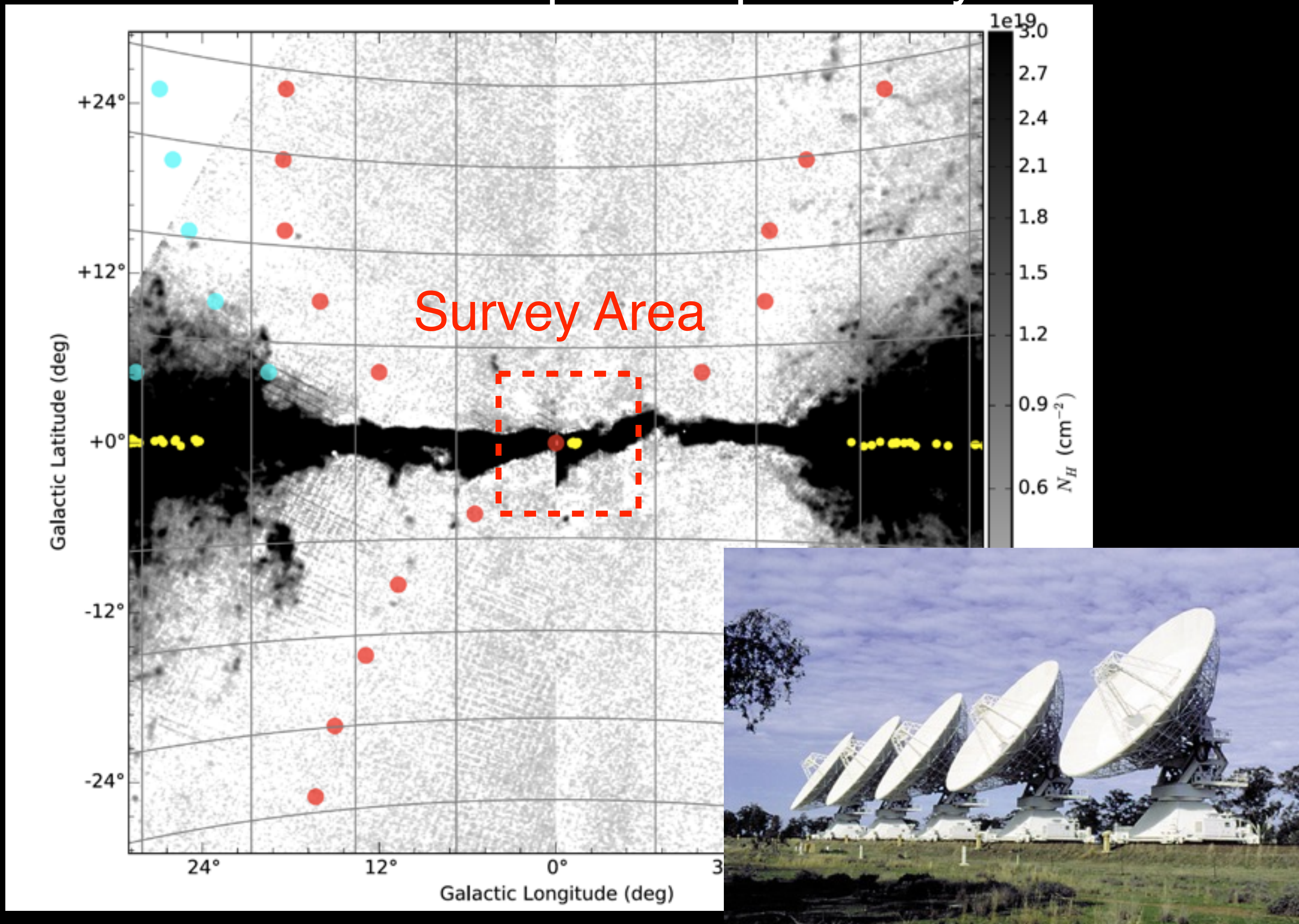
Fermi Bubbles Artist's Conception



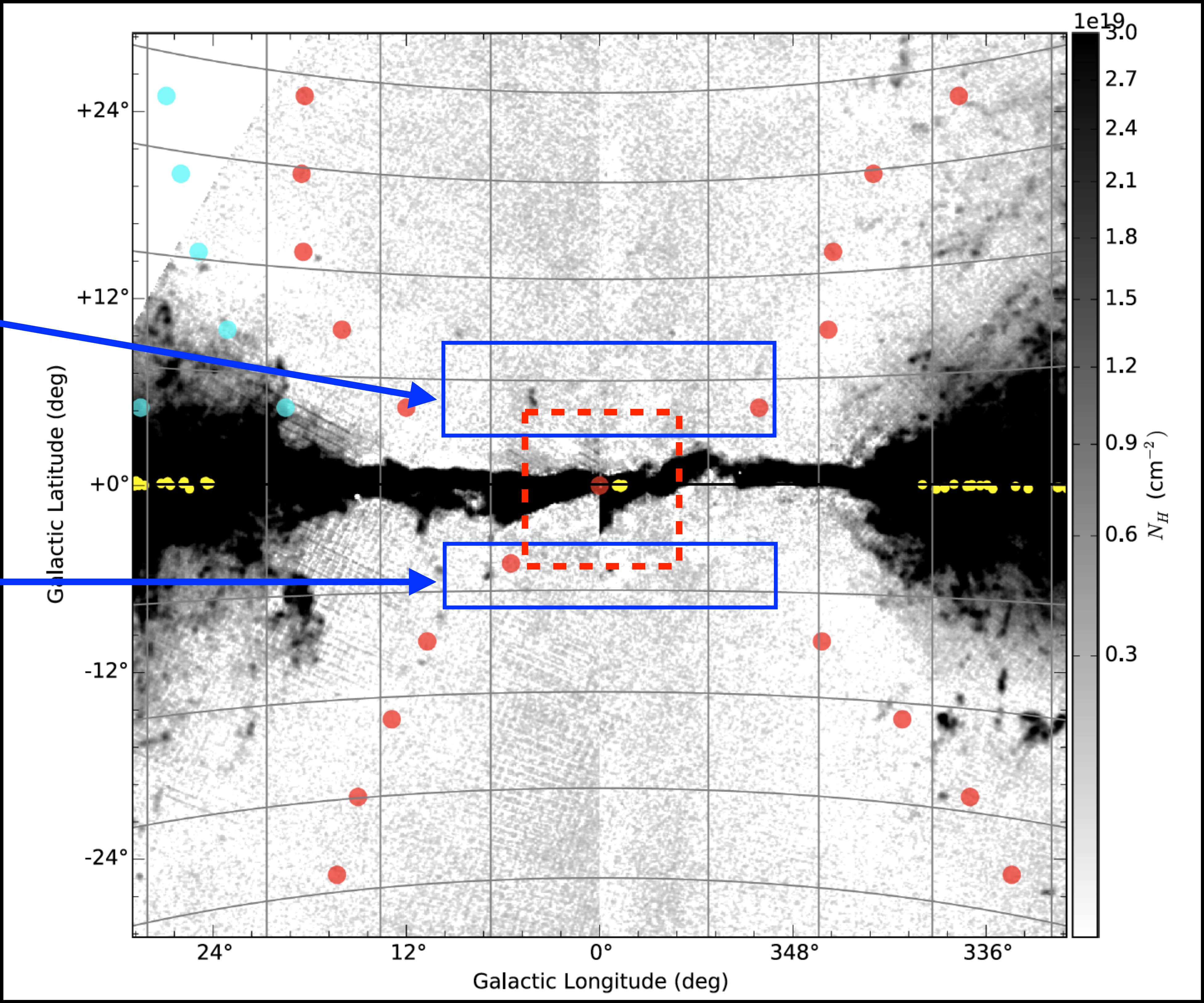


M&B16 shell model
M&B16 volume-filled model
ATCA - McClure-Griffiths et al. (2012)
GBT - Di Teodoro et al. (2018)
GBT - This work
Galactic Latitude (degrees)
HI column density (10^{18} cm^{-2})
30
20
10
0
−10
−20
−30
14
12
10
8
6
4
2

McClure-Griffiths et al. 2013
Australia Telescope Compact Array

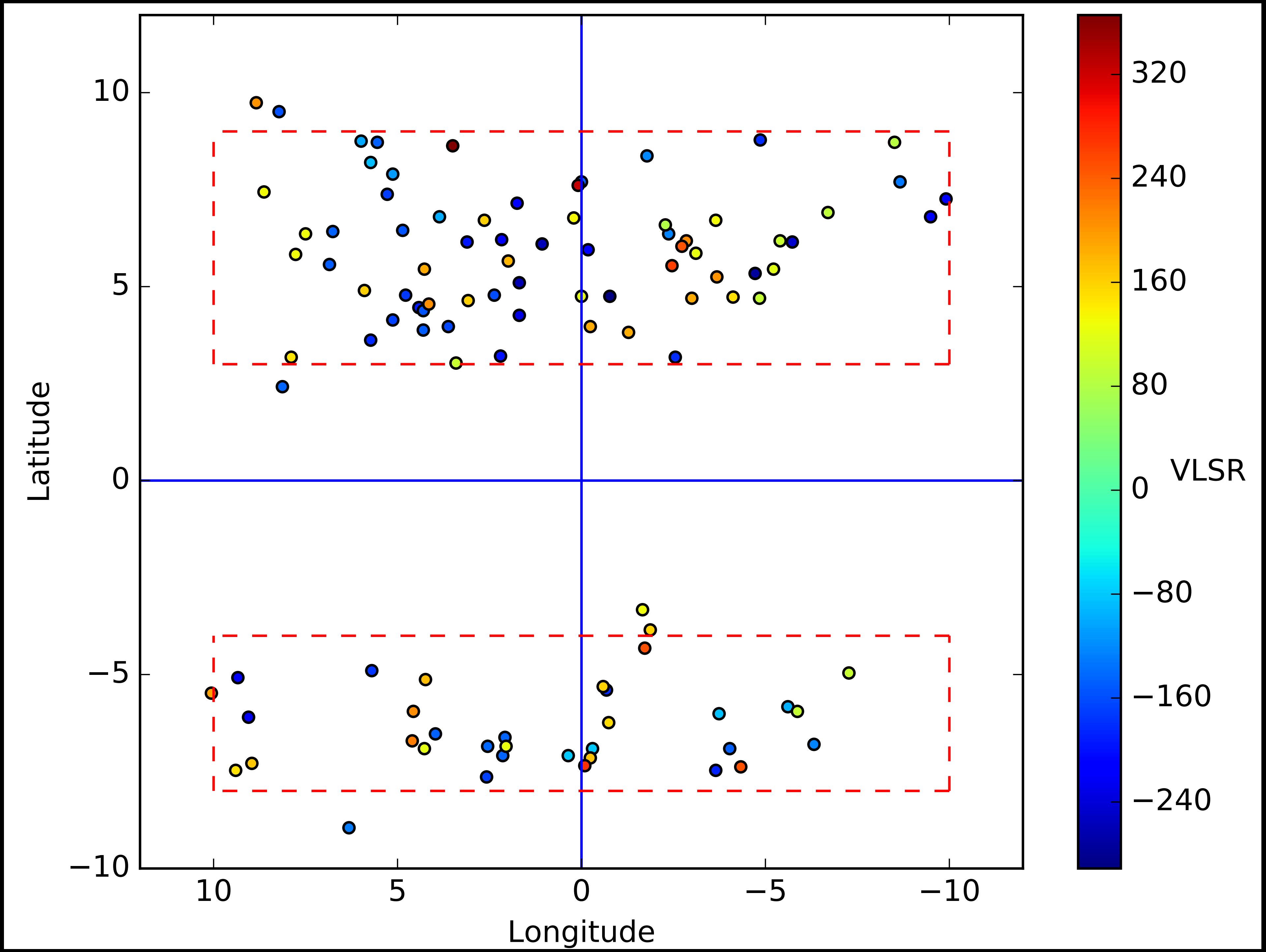


Green Bank Telescope

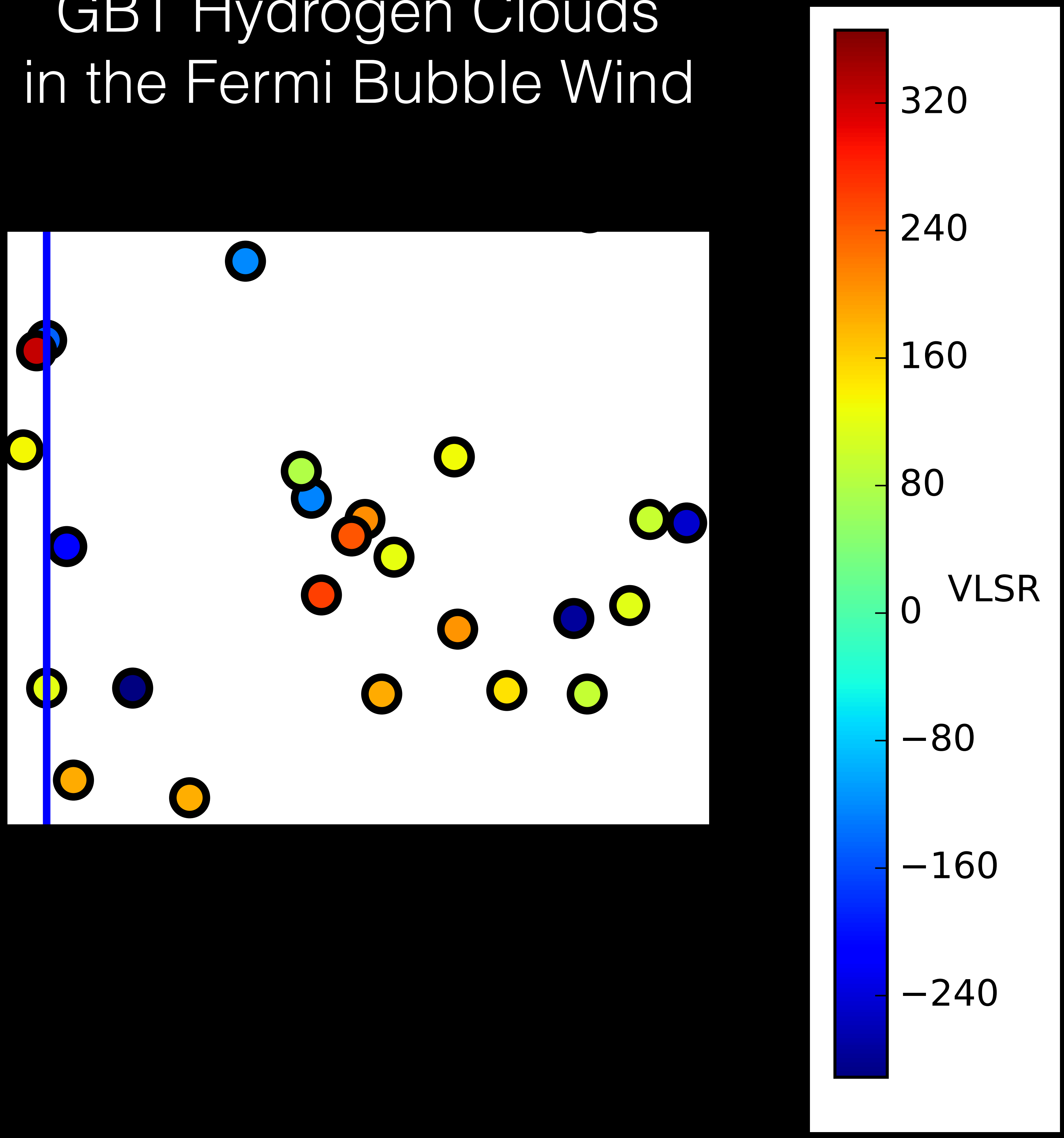


*More Area *More Sensitive *Further out in Fermi Bubble

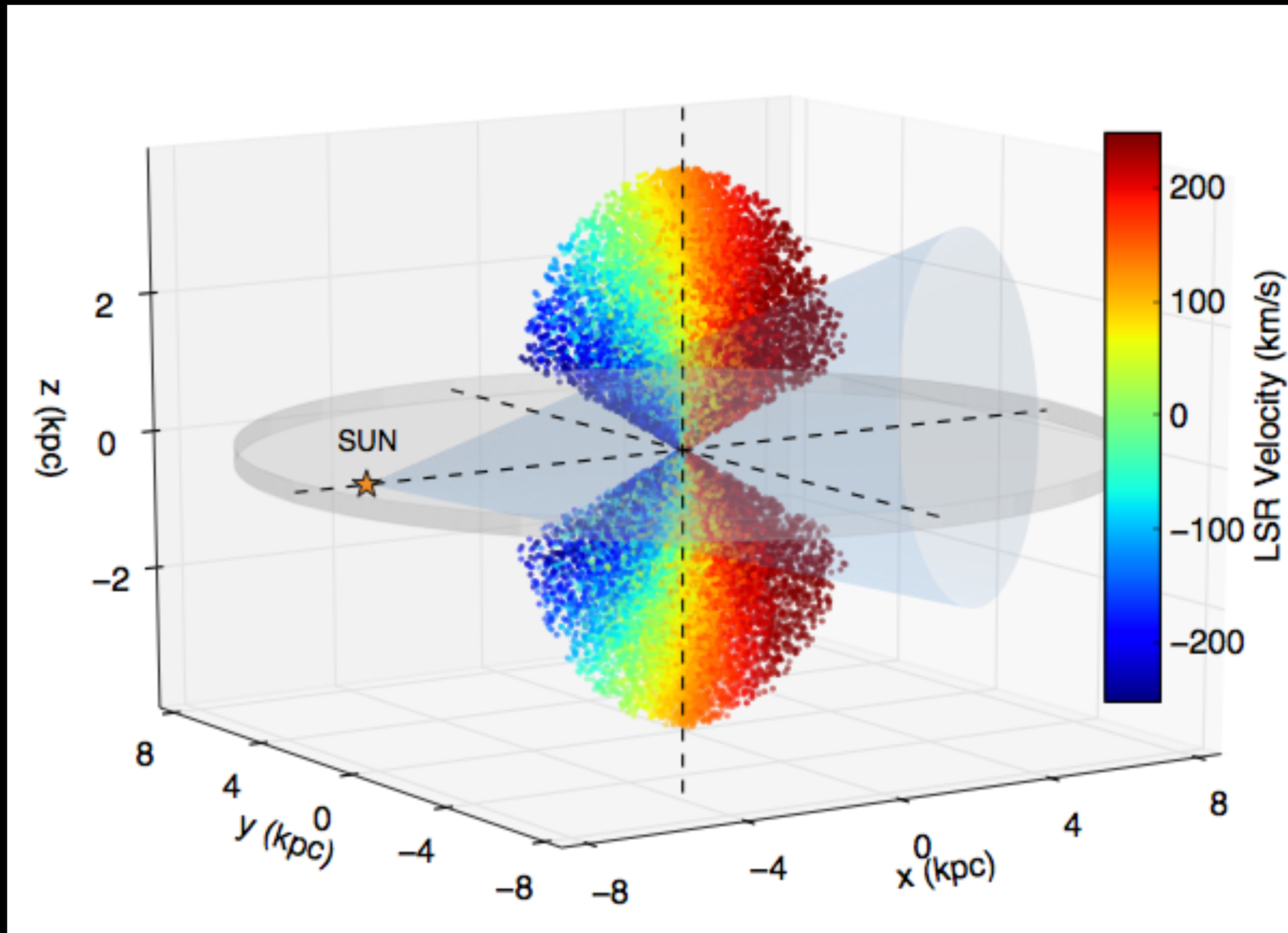
GBT Hydrogen Clouds in the Fermi Bubble Wind



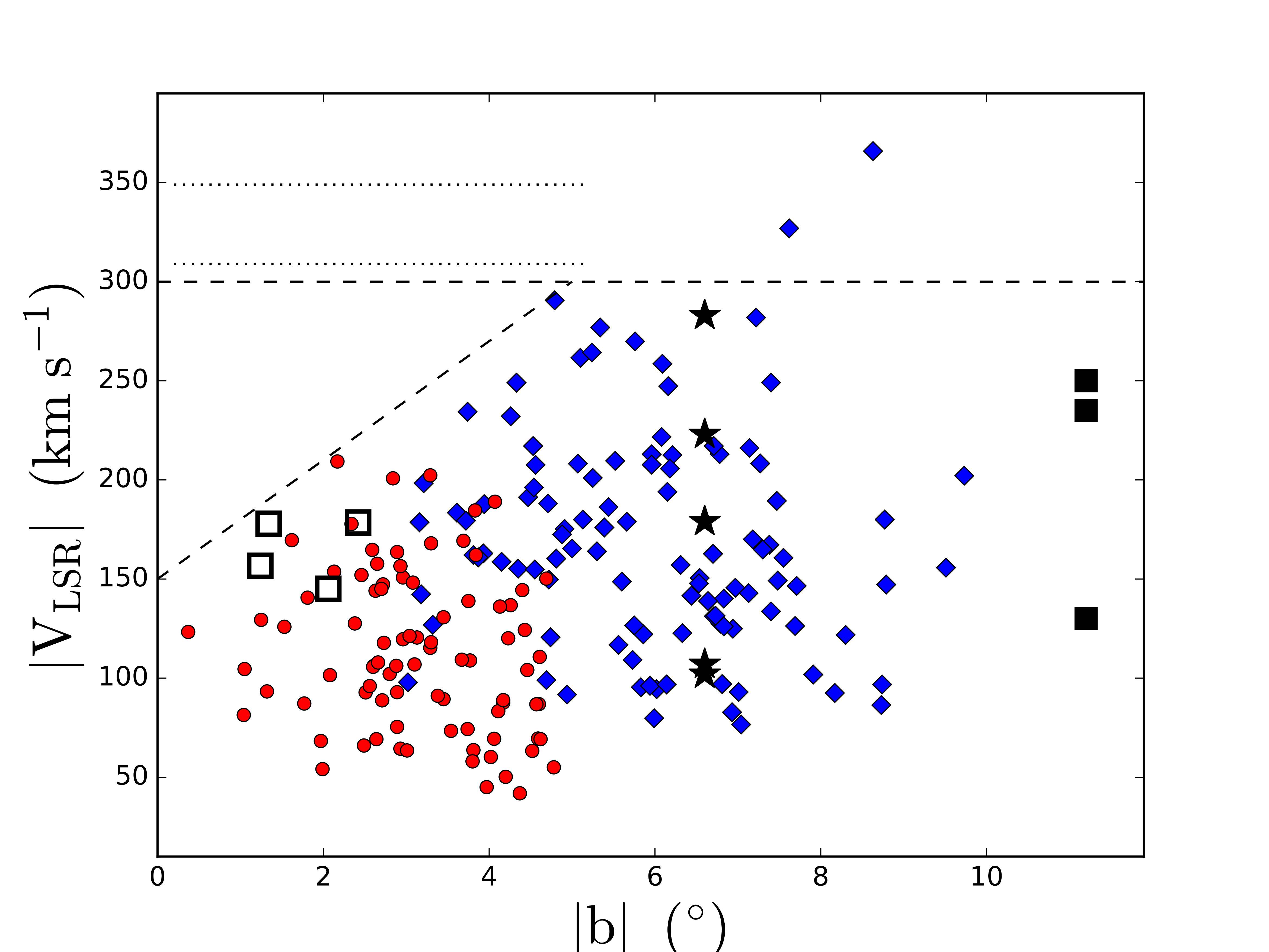
GBT Hydrogen Clouds in the Fermi Bubble Wind



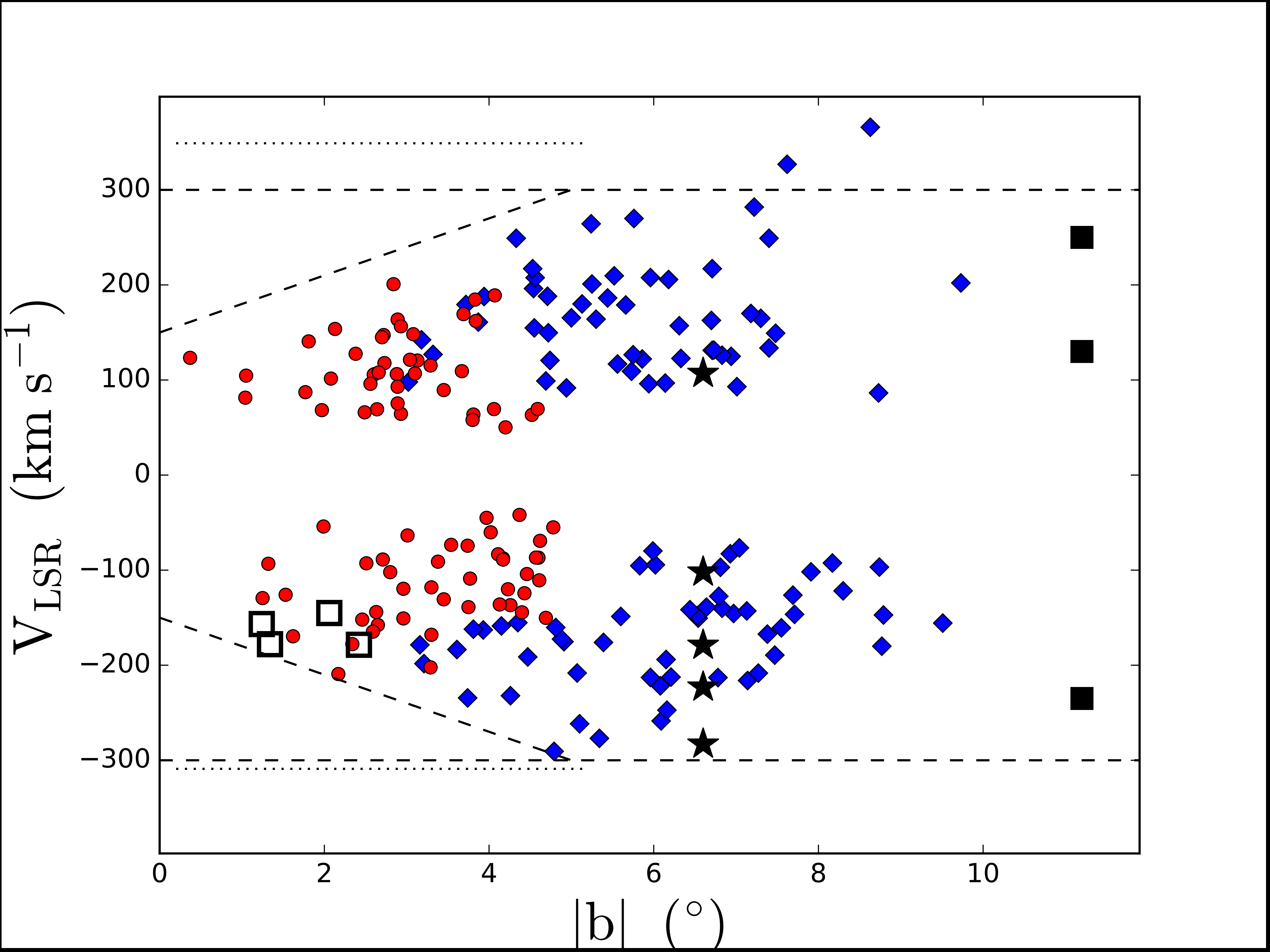
Model of the Hydrogen Clouds being Ejected from the Galactic Center

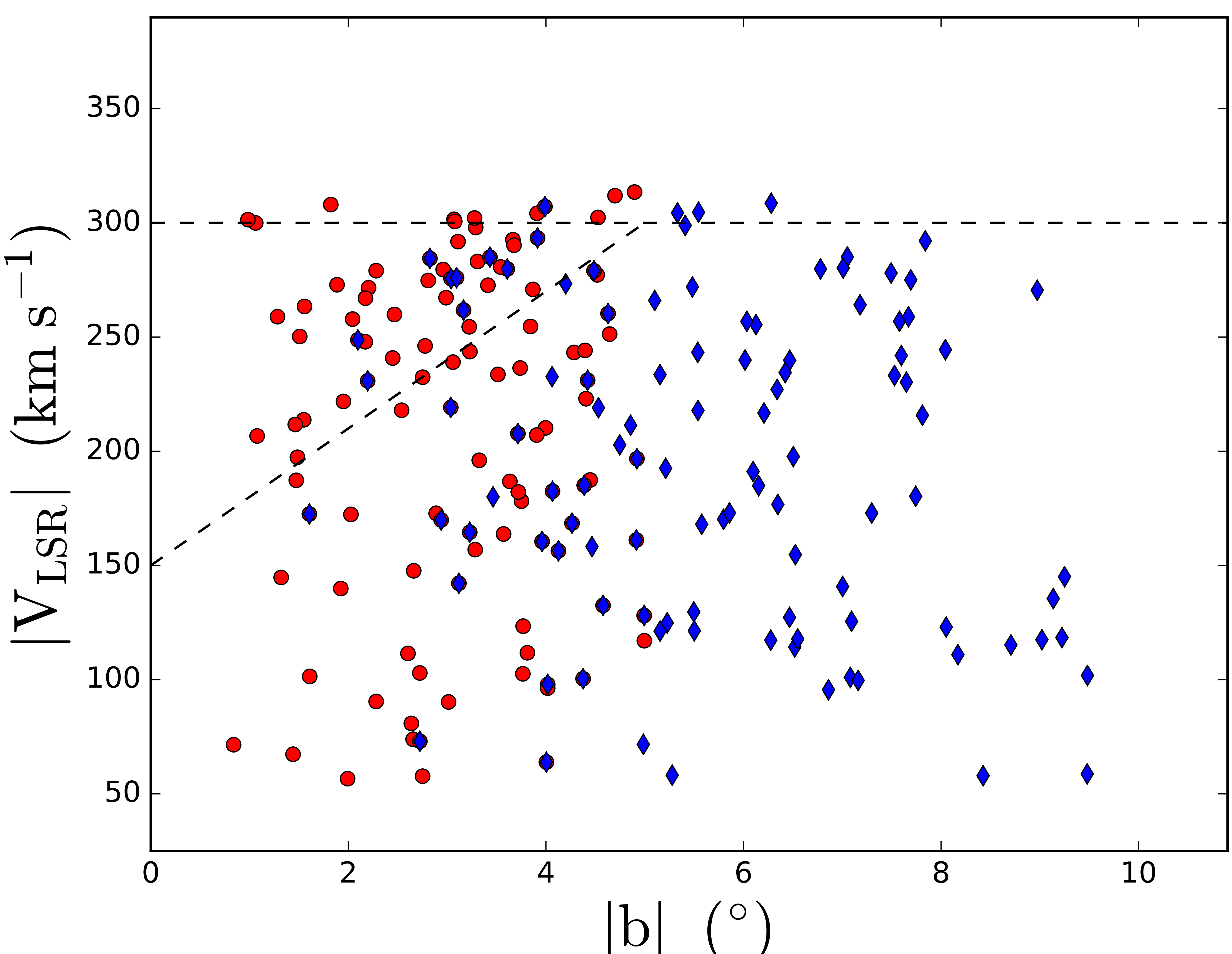


Vexp = 330 km/s

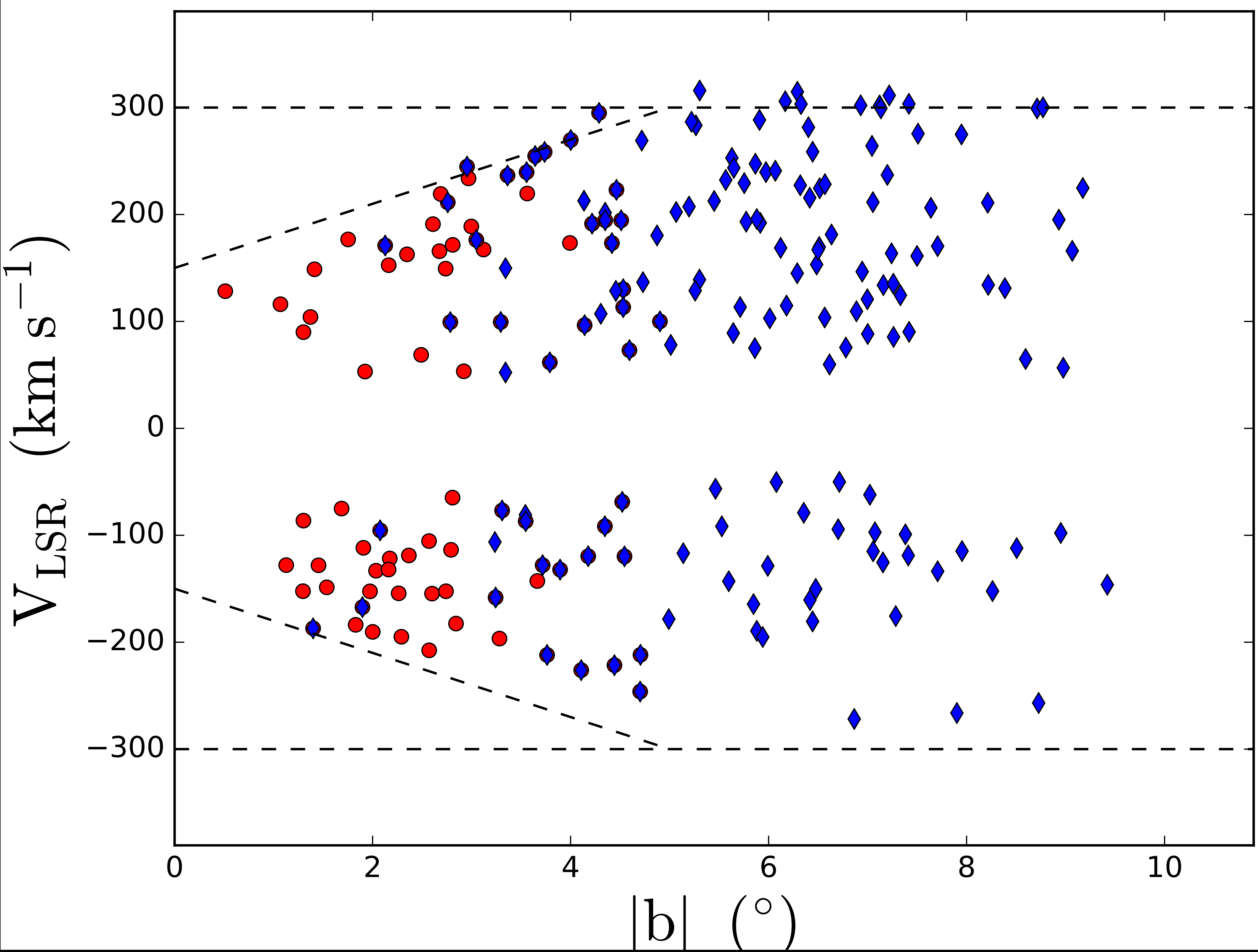


$|V_{LSR}|$ (km s^{-1})
$|b|$ ($^\circ$)
350
300
250
200
150
100
50
0
2
4
6
8
10


300
200
100
0
−100
−200
−300
V_{LSR} (km s^{-1})
0
2
4
6
8
10
|b| (°)



$|V_{LSR}|$ (km s^{-1})
350
300
250
200
150
100
50
0
2
4
6
8
10
$|b|$ ($^\circ$)



300
200
100
0
−100
−200
−300
$V_{\rm LSR}$ $(\rm km\ s^{-1})$
0
2
4
6
8
10
$|\rm b|$ $(^\circ)$