Antennas

Greg Taylor

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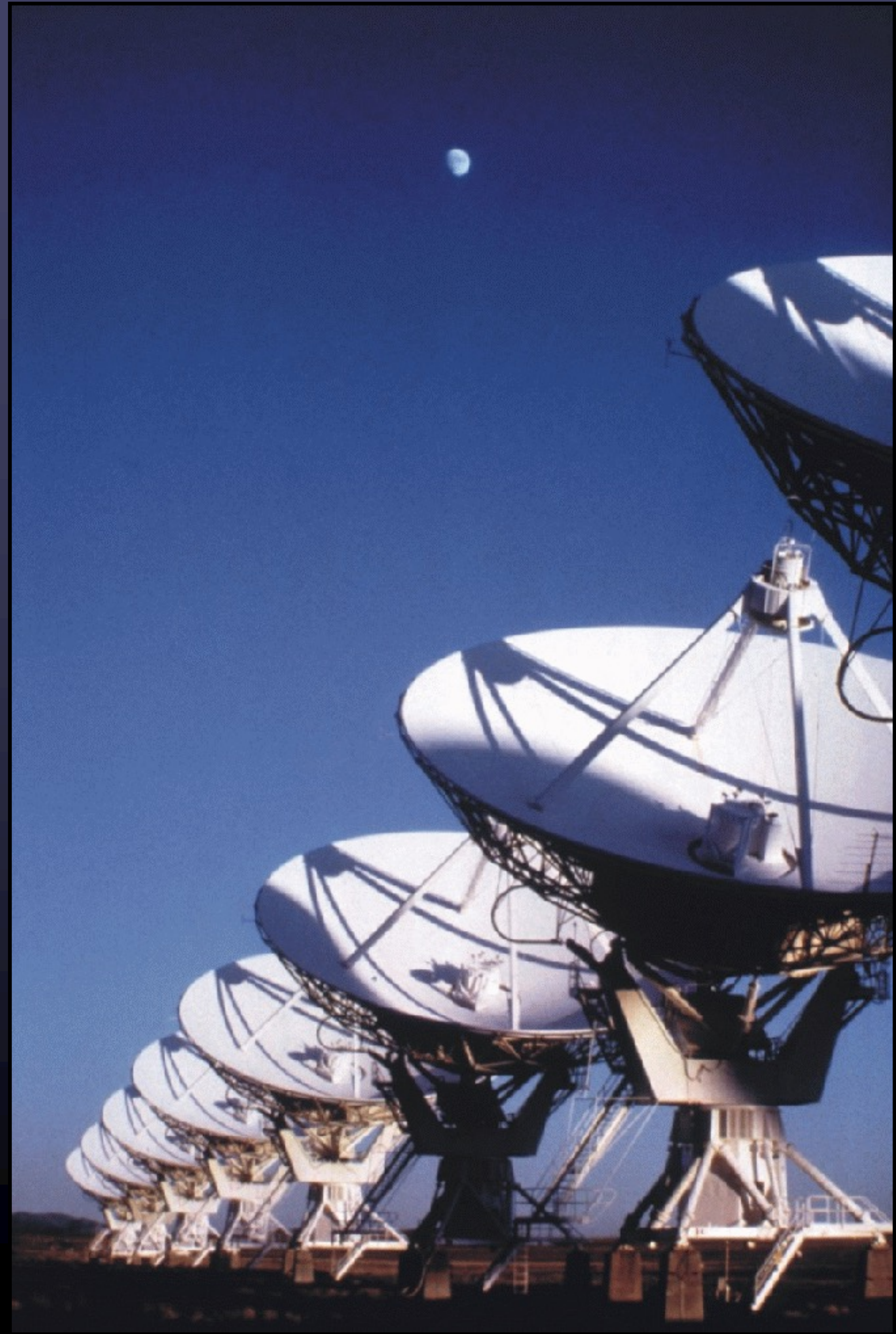


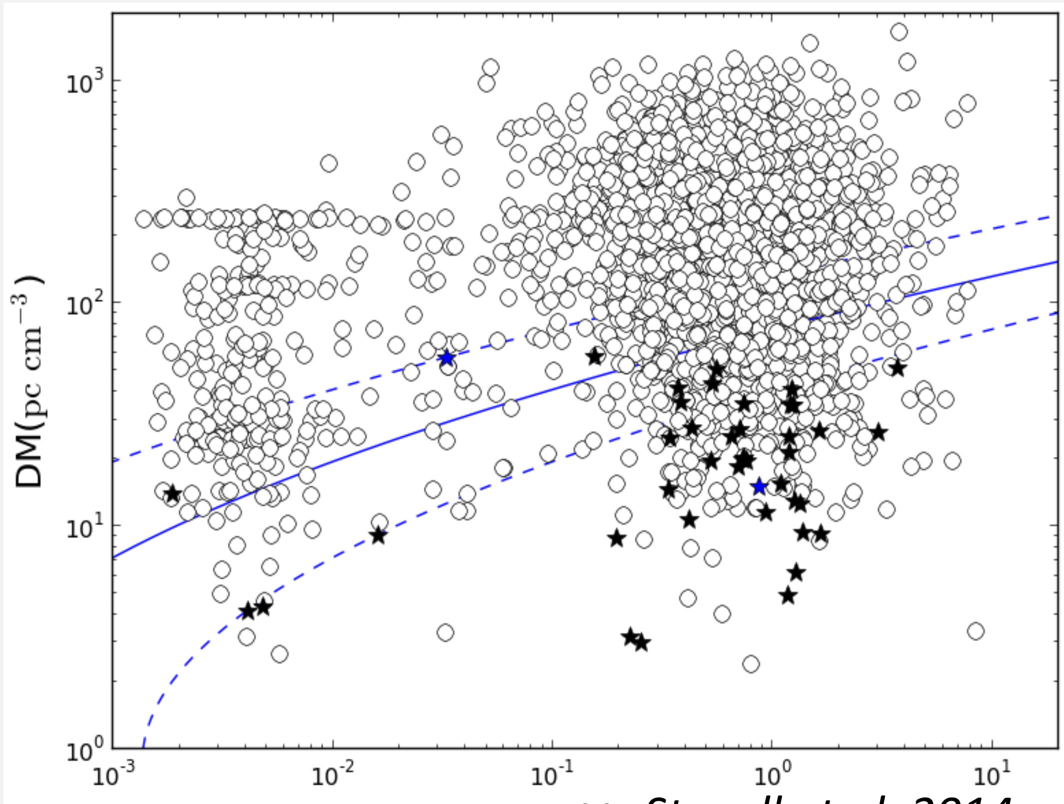
Astronomy 423 at UNM

Radio Astronomy

LWA1 Pulsar Detections

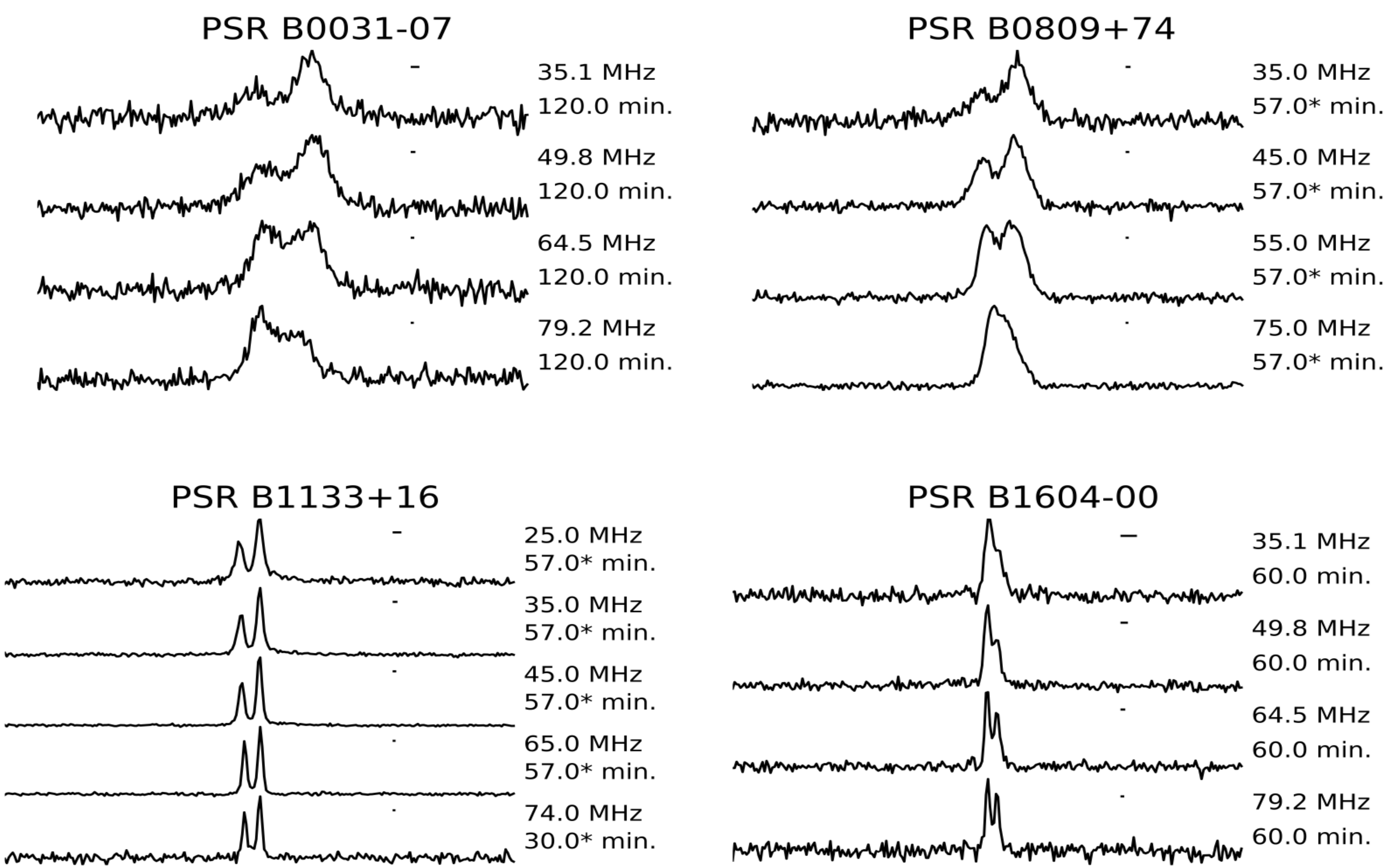
J0030+0451
B0031-07
J0034-0534
B0138+59
J0203+70
B0320+39
B0329+54
B0355+54
B0450+55
B0525+21
B0531+21*
B0628-28
B0655+64
B0809+74
B0818-13
B0823+26
B0834+06
B0919+06
B0943+10
B0950+08
B1112+50
B1133+16
B1237+25
J1327+34
B1508+55
B1540-06
B1541+09
B1604-00
B1612+07
B1642-03
B1706-16
B1749-28
B1822-09
B1839+56
B1842+14
B1919+21
B1929+10
B2020+28
B2110+27
J2145-0750
B2217+47
J2324-05

- >100 Pulsars detected (>94 through pulsations, 6 through single pulses)
- 6 MSPs detected
- Periods from 1.9ms to 4s

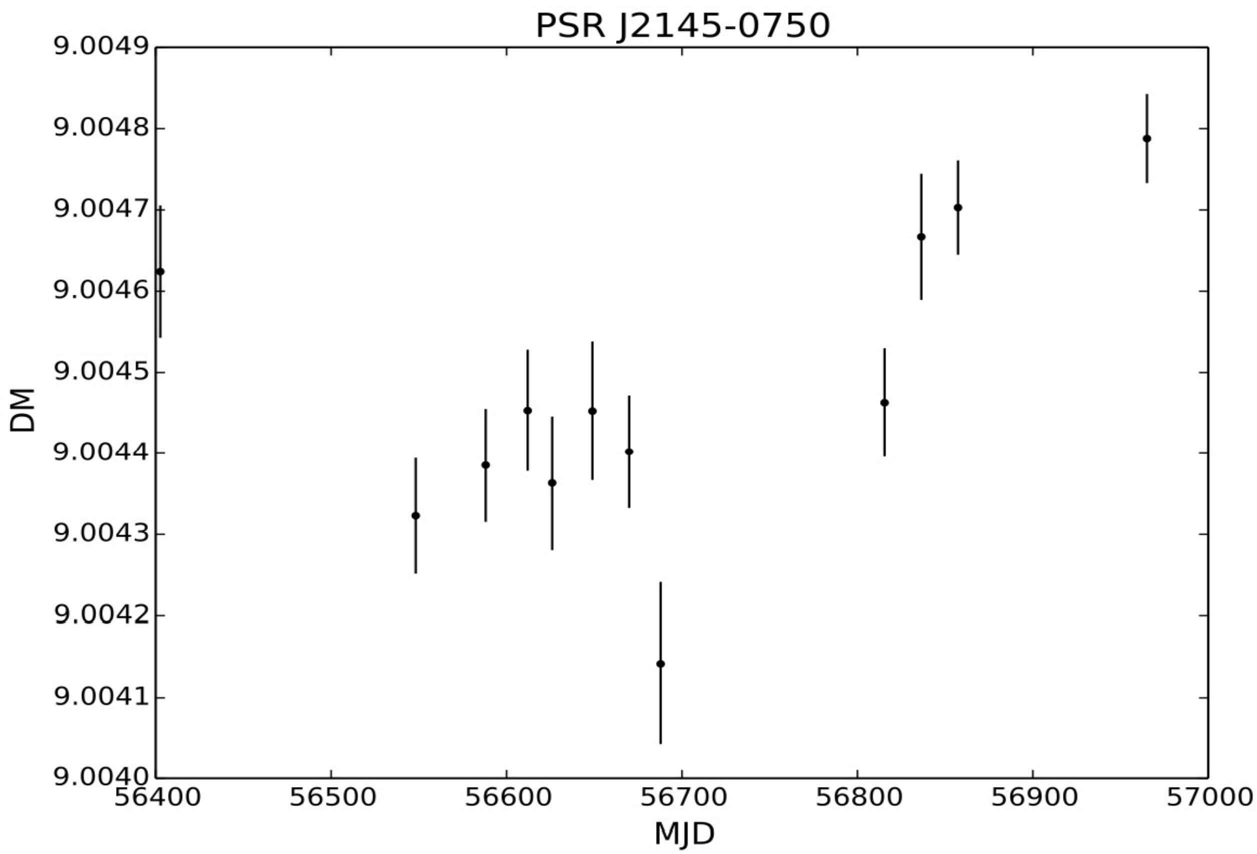


Stovall et al. 2014

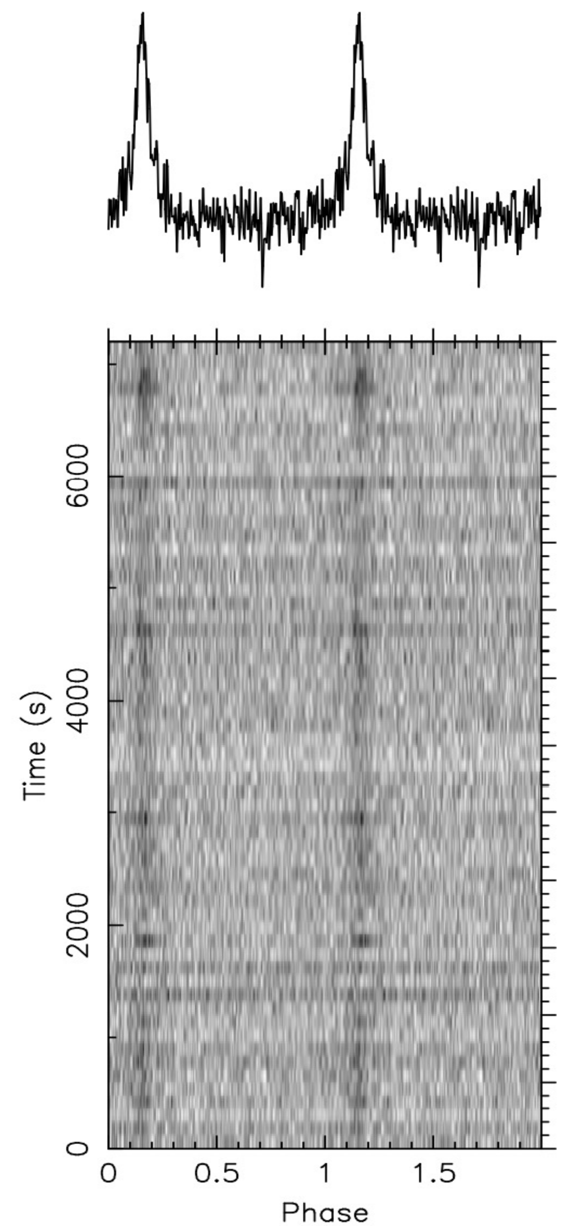
Frequency Evolution



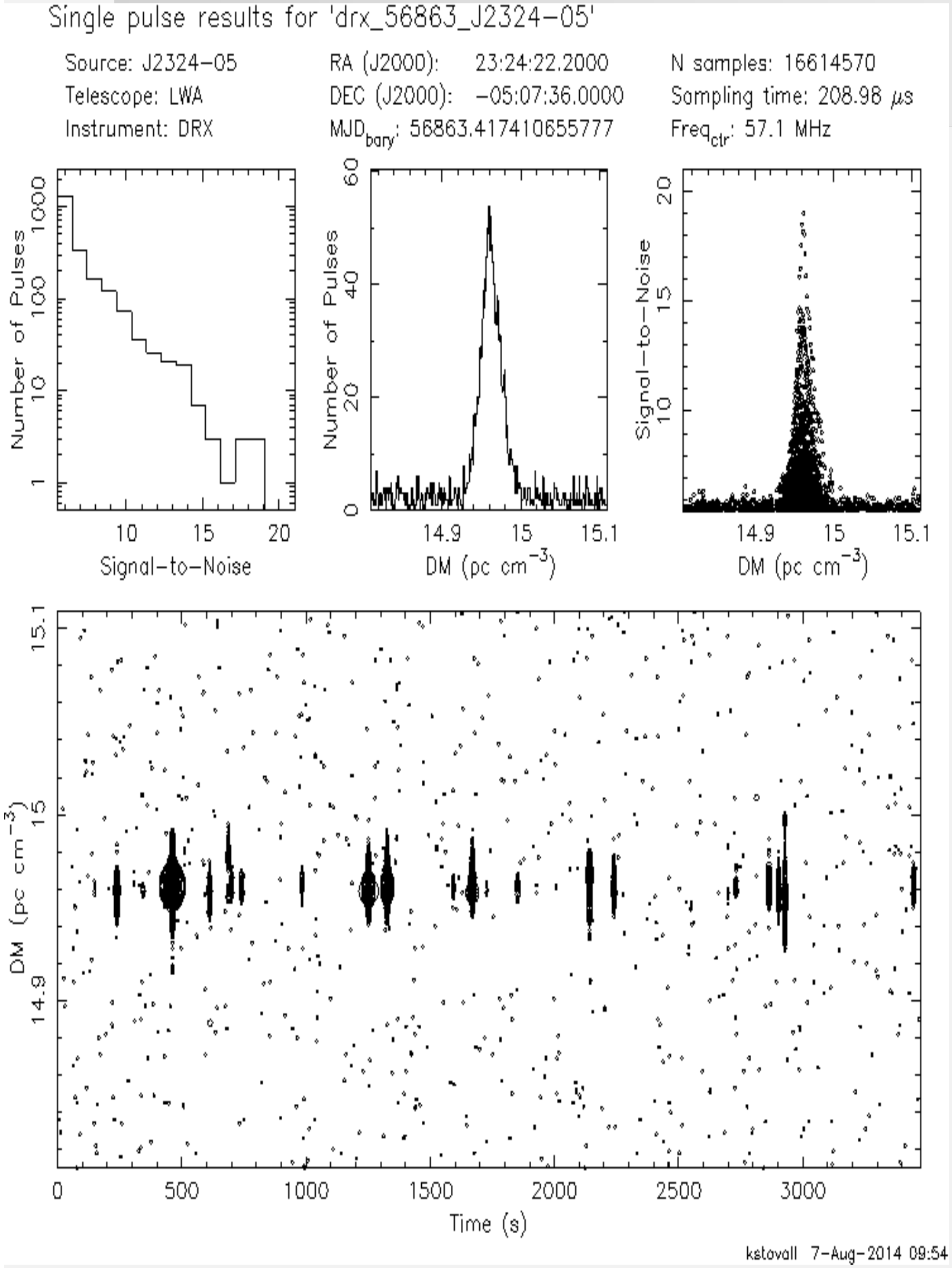
DM Monitoring



Pulsar	MJD	DM pc cm^{-3}	DM_{err} pc cm^{-3}
J0034−0534	56631	13.765017	0.000063
J0030+0451	56606	4.332741	0.000077
J2145−0750*	56588	9.004393	0.000059

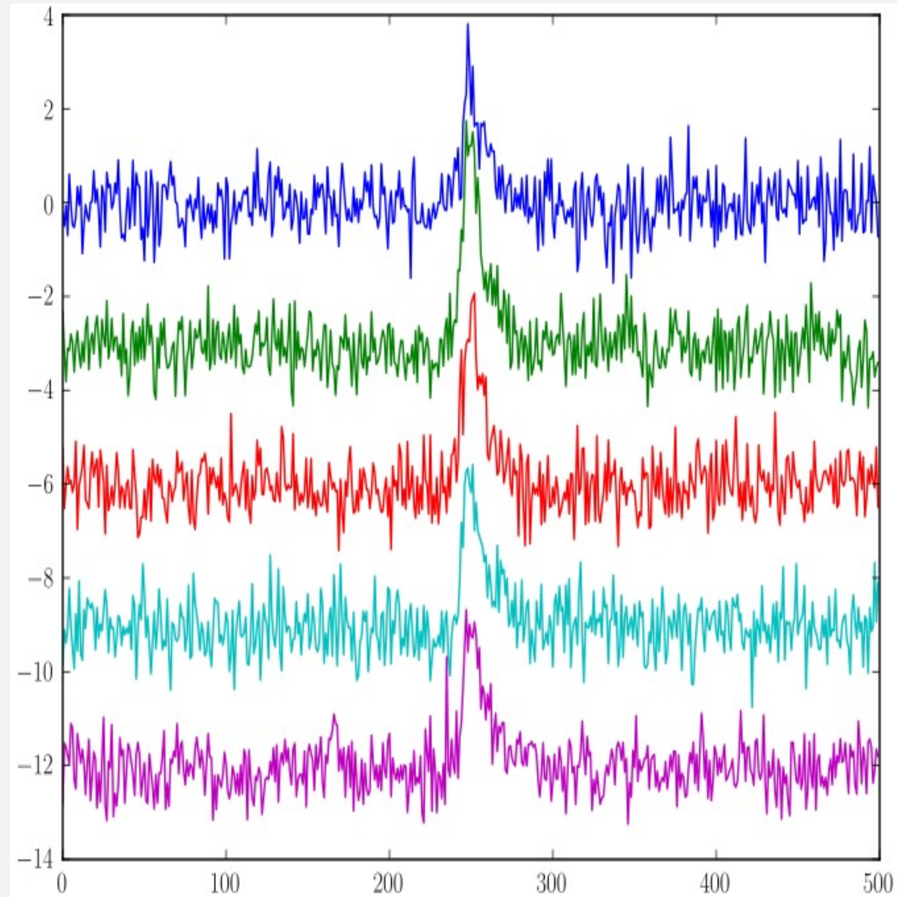


Rotating Radio Transients (RRATs)



Detection plot of J2324-05 with LWA

Profiles of pulses for LWA detection



LWA Dispersion Measure: 14.96 pc cm^{-3}

LWA Period: 870 ms

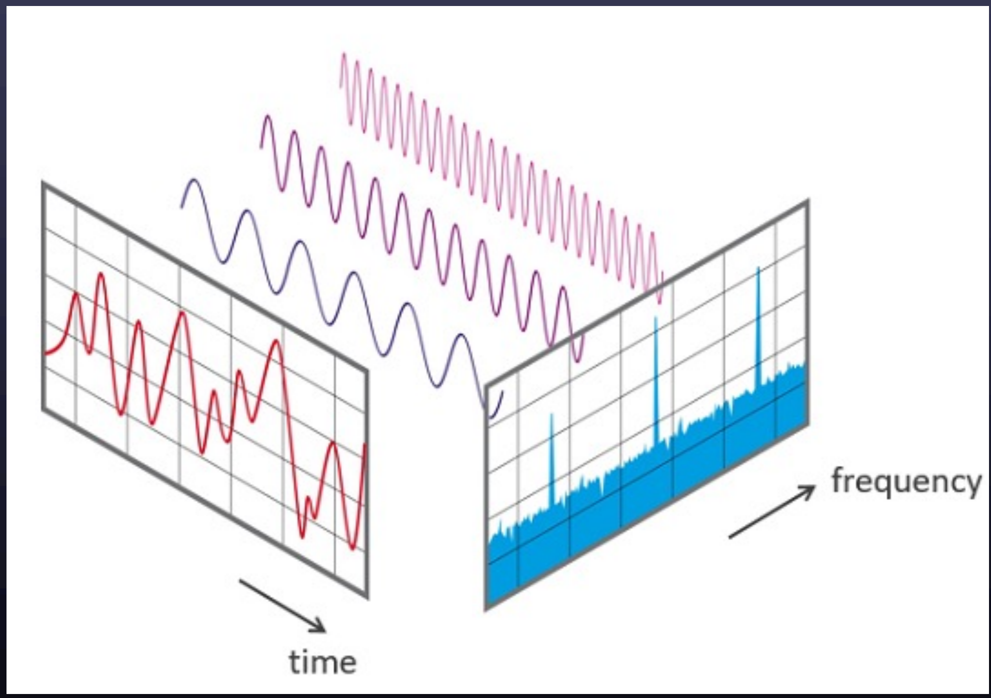
Outline

- Fourier Transforms
- Antenna fundamentals
- Types of antennas
- Antenna performance parameters

Fourier Transforms

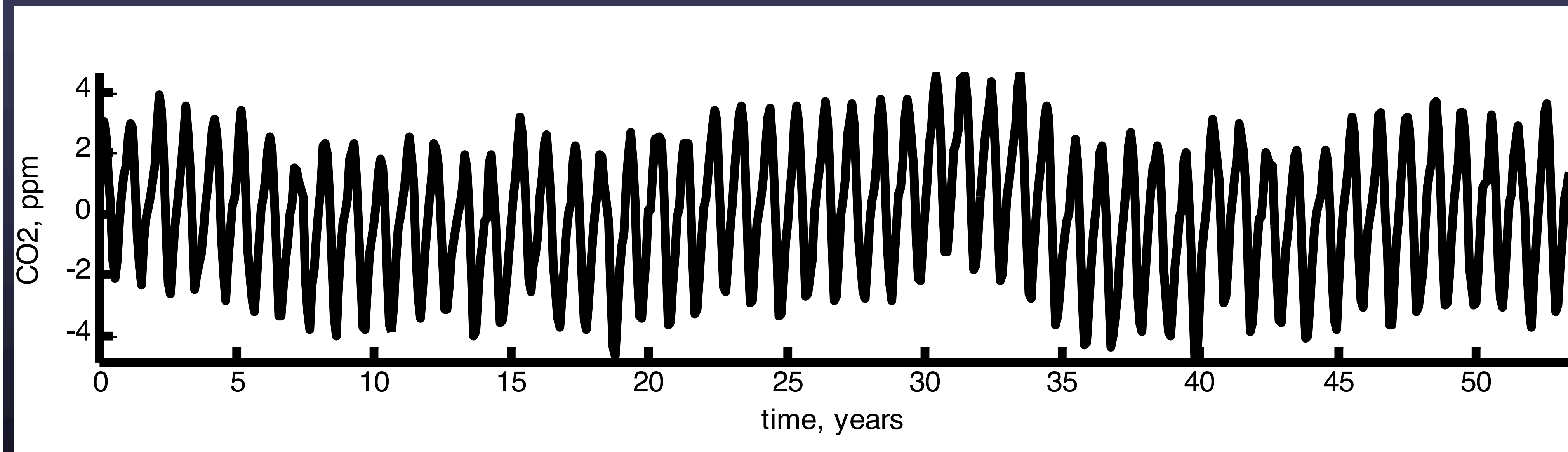
Fourier suggested that any function (continuous or discrete) could be represented as a series of sines and cosines or equivalently with complex exponentials

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi kn/N} \quad \overset{\text{FT}}{\longleftrightarrow} \quad x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k \cdot e^{i2\pi kn/N}$$



See also: https://betterexplained.com/articles/an-interactive-guide-to-the-fourier-transform/

Example: Atmospheric CO_2
(after removing anthropogenic trend)



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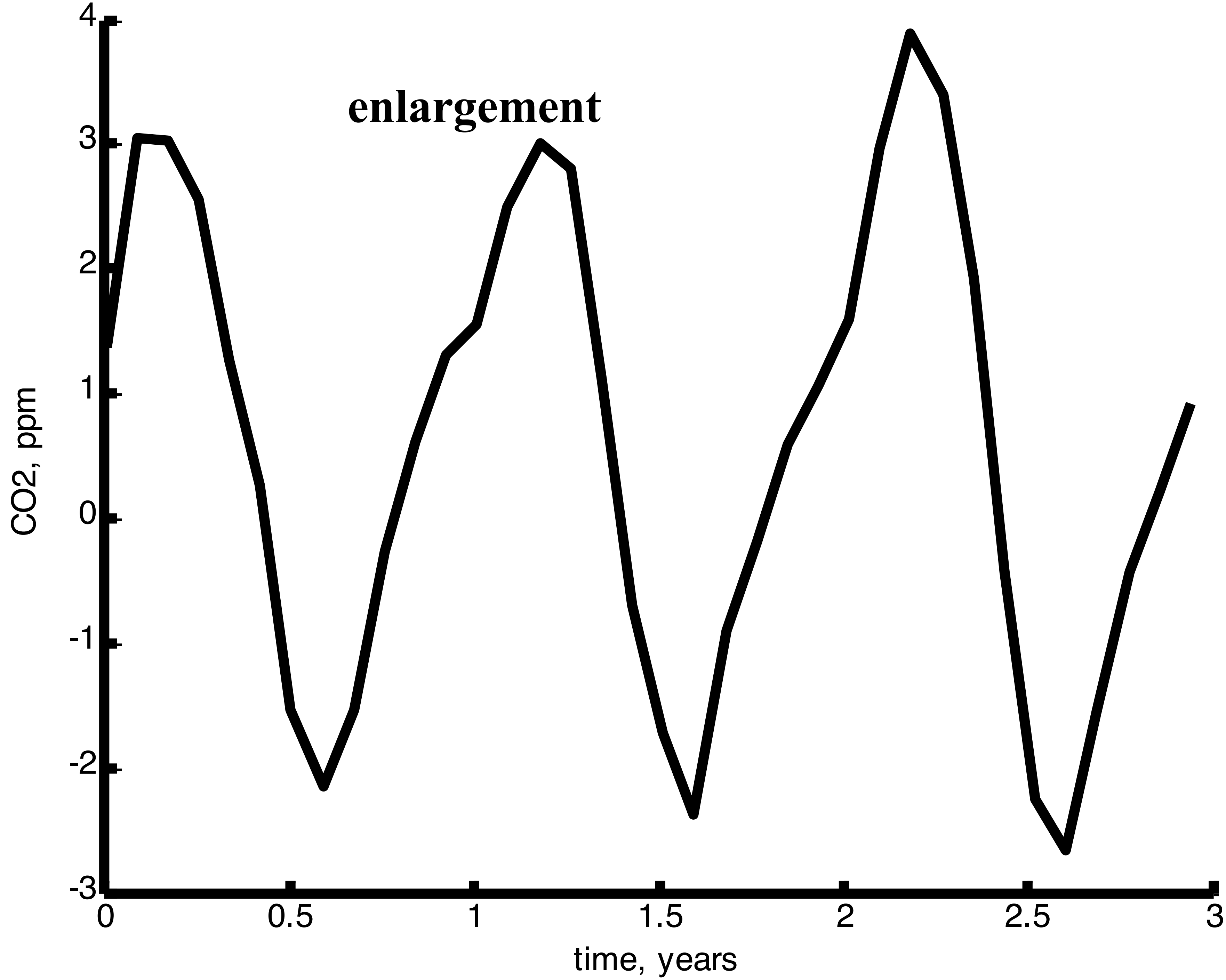
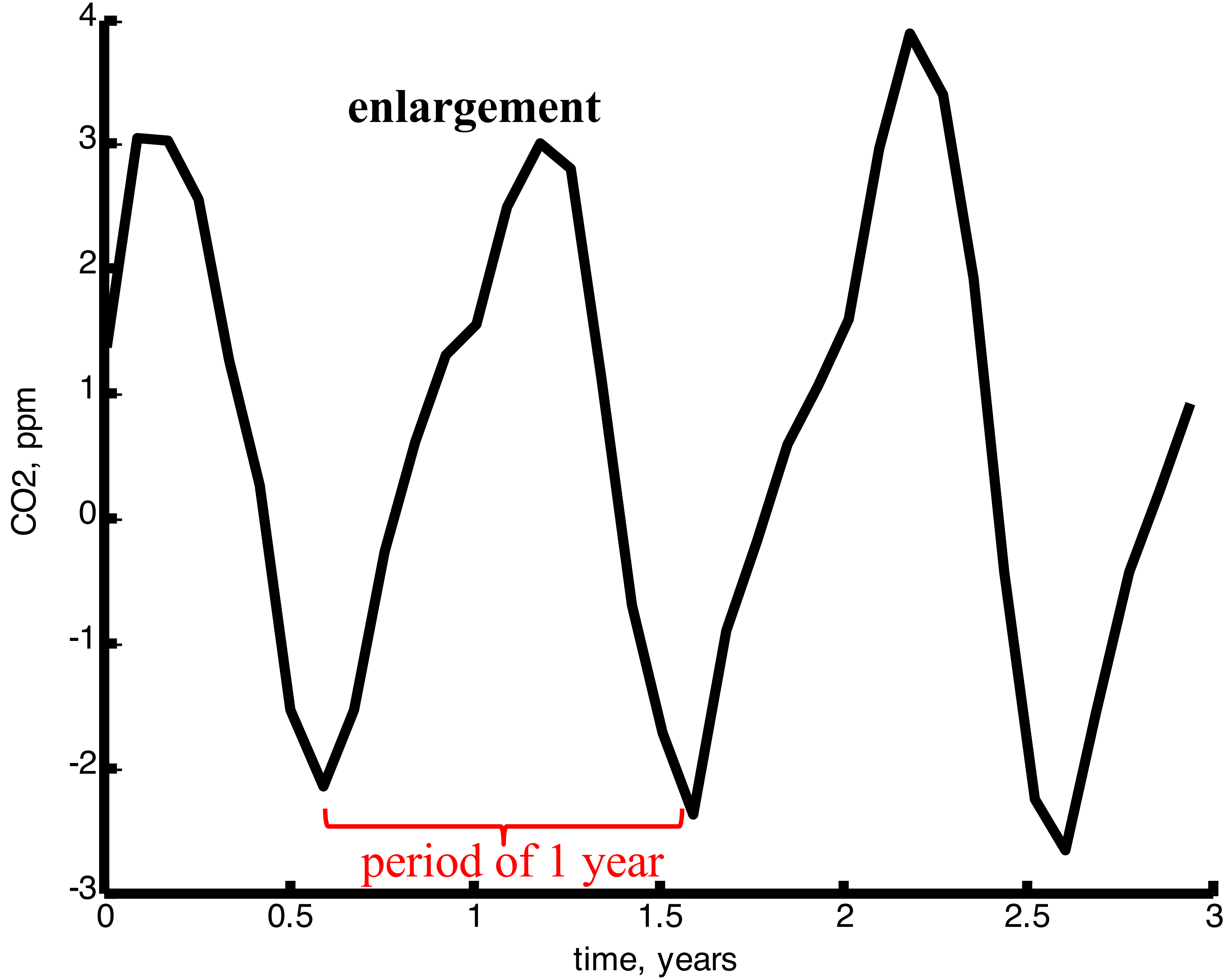
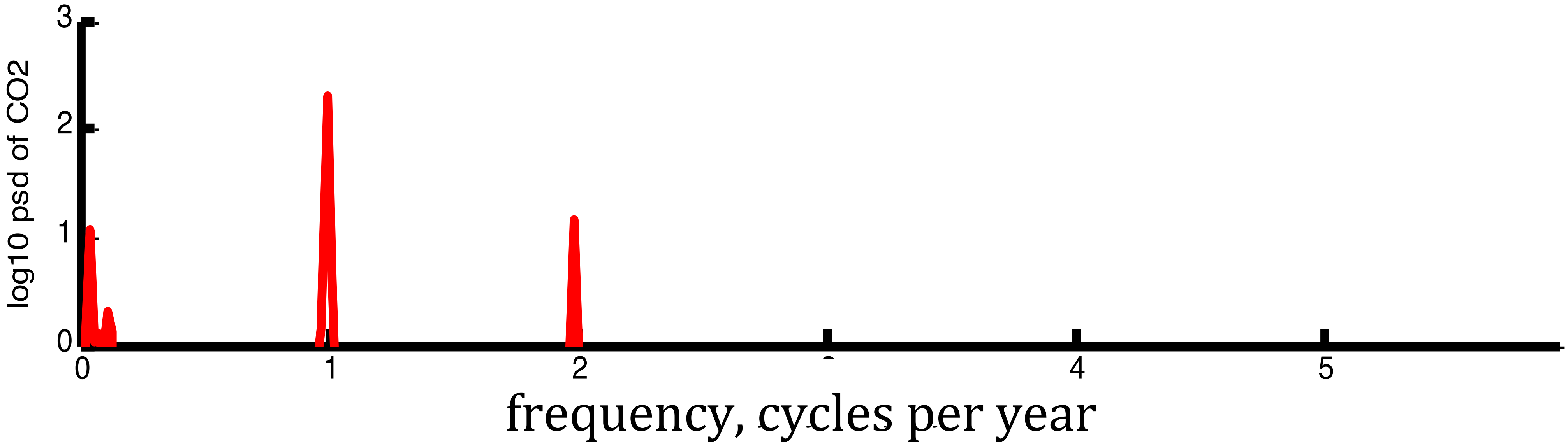

enlargement
CO2, ppm
4
3
2
1
0
-1
-2
-3
0
0.5
1
1.5
2
2.5
3
time, years

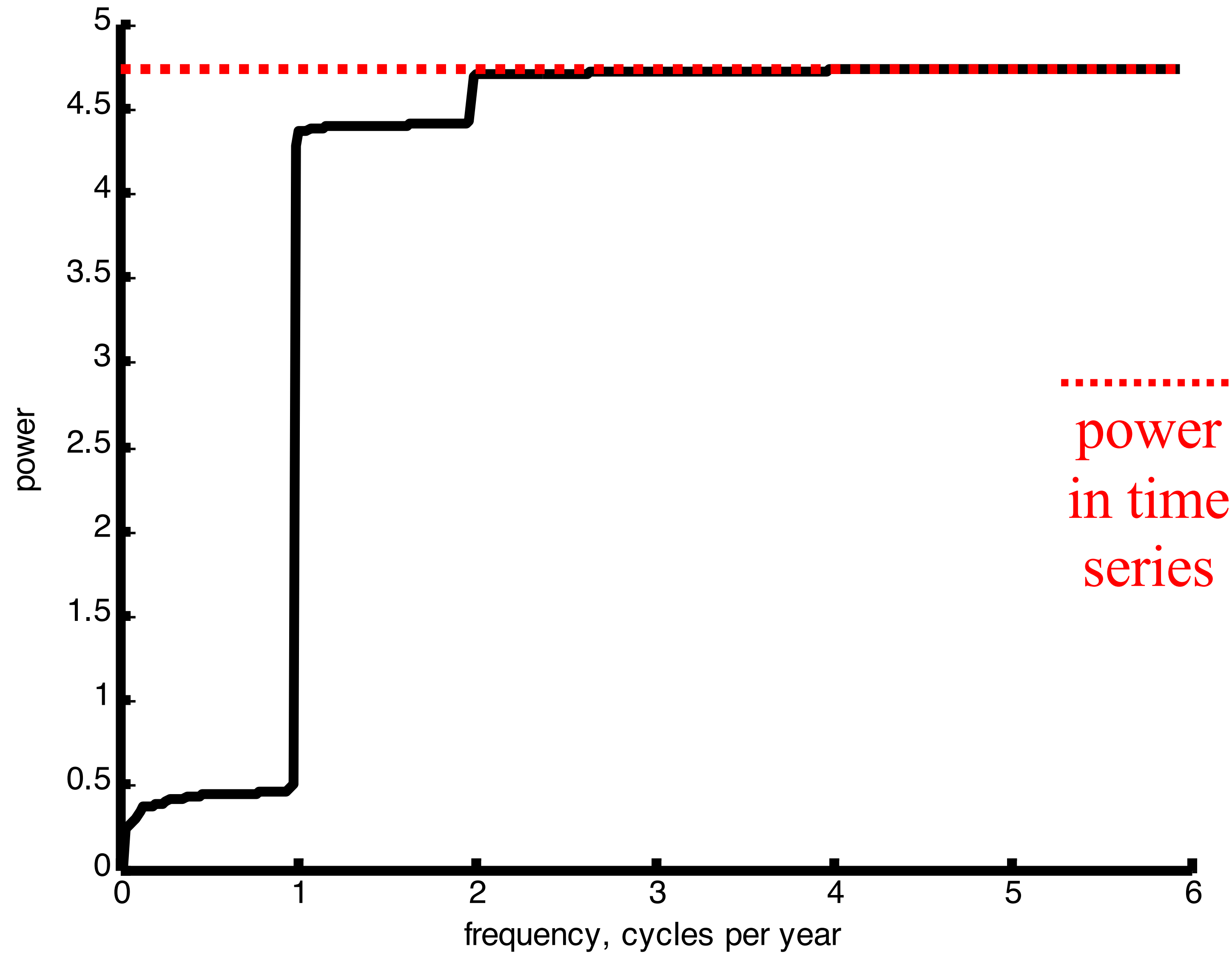


enlargement
period of 1 year
CO2, ppm
time, years
4
3
2
1
0
-1
-2
-3
0
0.5
1
1.5
2
2.5
3

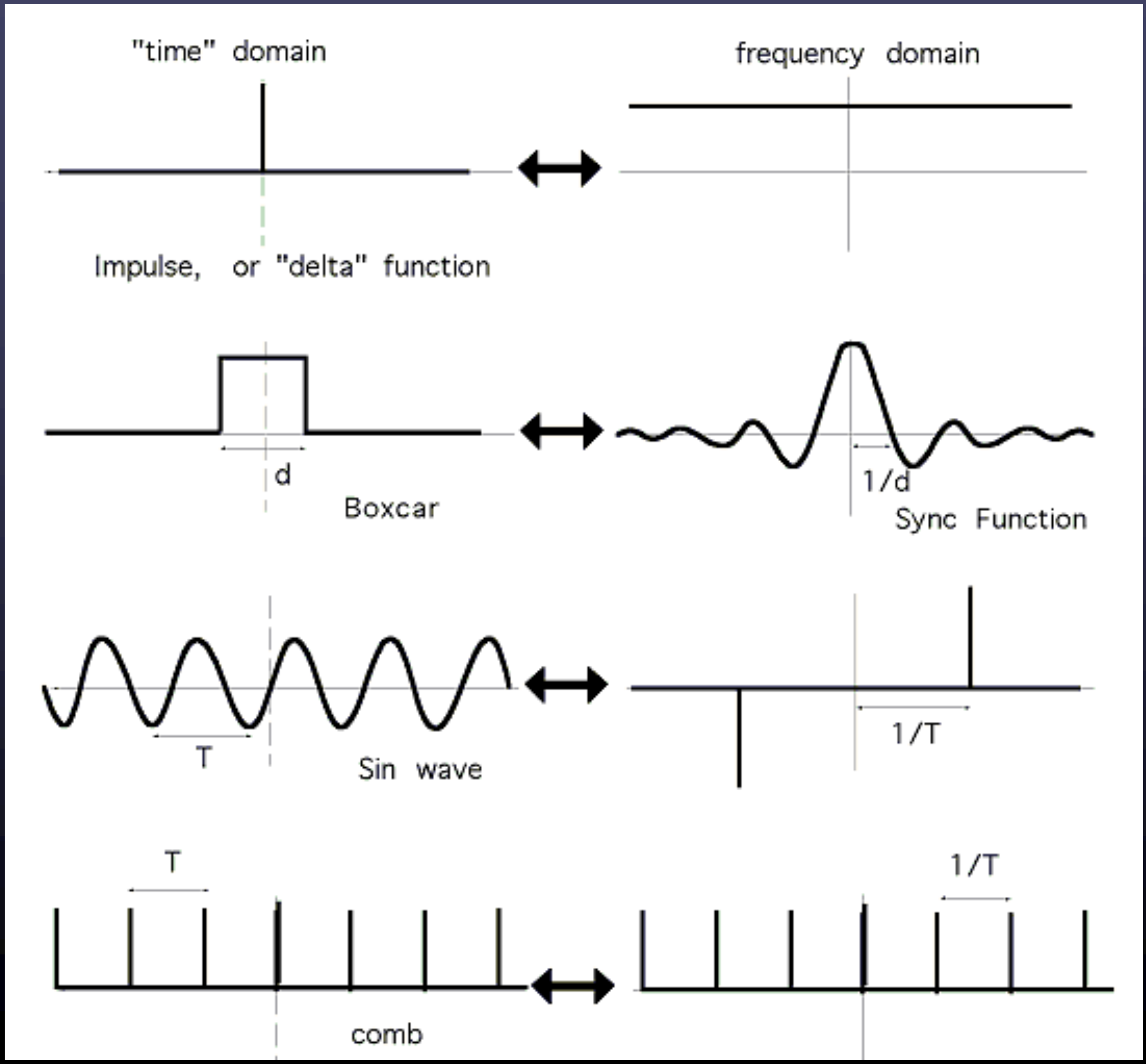
power spectral density



cumulative power



Example Fourier Transforms



Fourier Transform Rules

for any function $F(x)$ its FT is

$$f(\sigma) = \int_{-\infty}^{\infty} F(x)\, e^{2\pi i x \sigma}\, dx$$

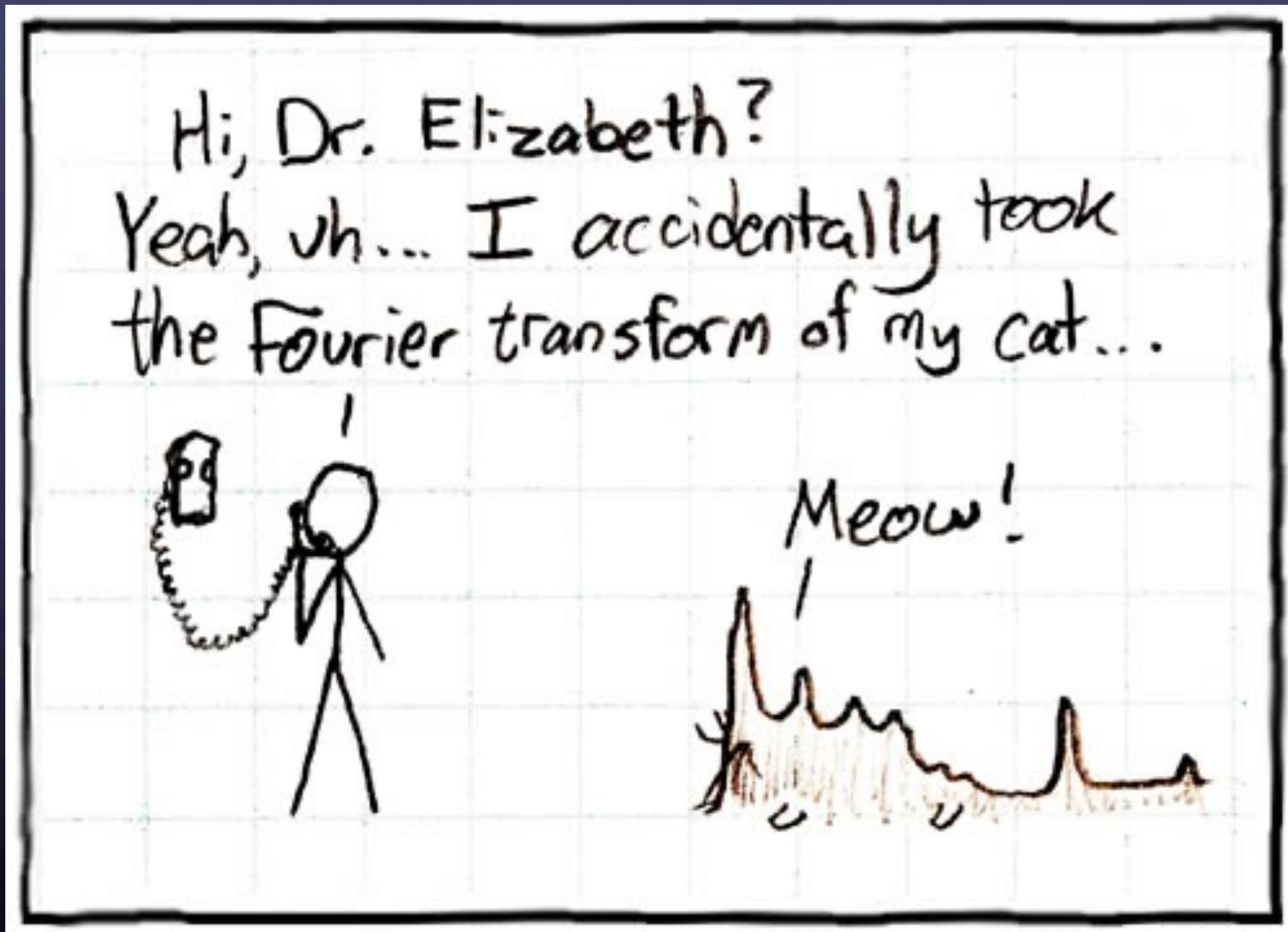
a "pair" in x, σ

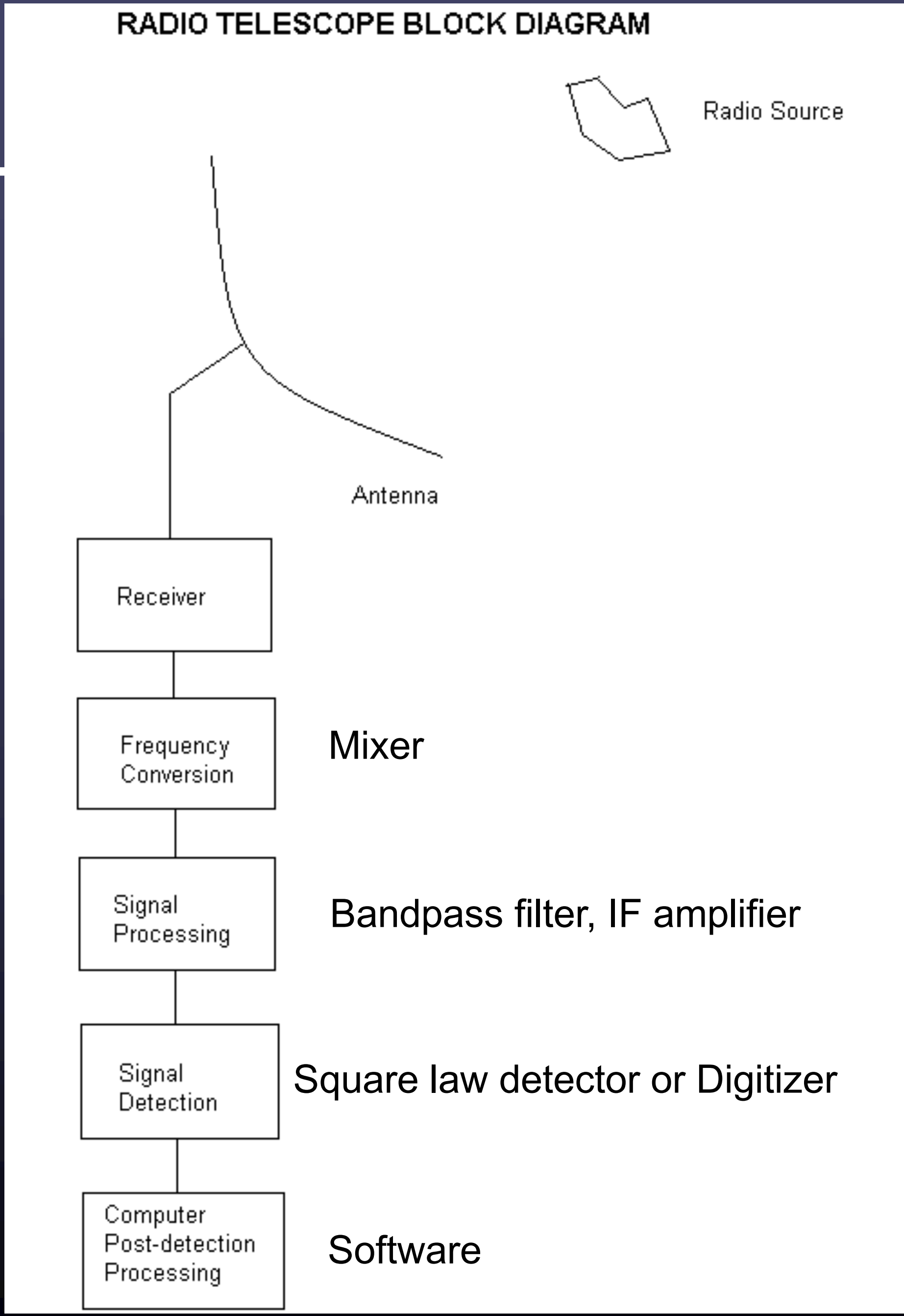
$$F(x) = \int_{-\infty}^{\infty} f(\sigma)\, e^{-2\pi i x \sigma}\, d\sigma$$

Theorems

	$f(\sigma)$	$F(x)$
similarity	$f(a\sigma)$	$\frac{1}{\lvert a \rvert} F\left(\frac{x}{a}\right)$
addition	$f(\sigma) + g(\sigma)$	$F(x) + G(x)$
shift	$f(\sigma - a)$	$e^{-i2\pi a x} F(x)$
Modulation	$f(\sigma) \cos \sigma$	$\frac{1}{2} F\left(x - \frac{\omega}{\pi}\right) + \frac{1}{2} F\left(s + \frac{\omega}{\pi}\right)$
Convolution	$f(\sigma) \otimes g(\sigma)$	$F(x)\, G(x)$
auto correl	$f(\sigma) \otimes f^{*}(\sigma)$	$\lvert F(x) \rvert^2$

Fourier Transforms





Mixer

Bandpass filter, IF amplifier

Square law detector or Digitizer

Software

E.g., pre-upgrade VLA observing at 4.8 GHz (C band)

Interferometer Block Diagram

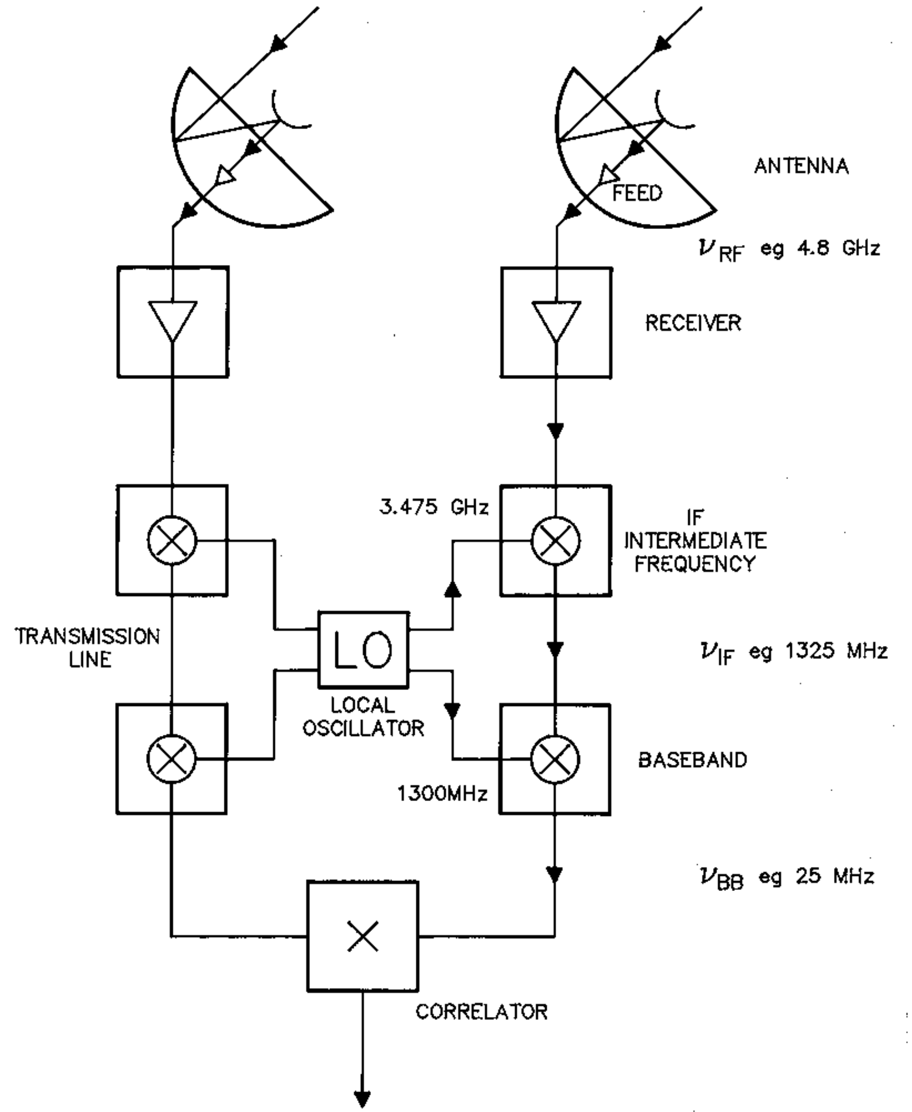
Antenna

Front End

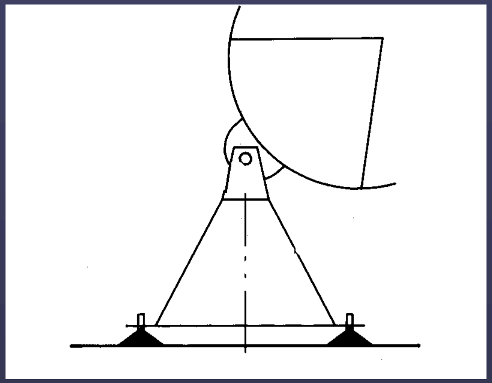
IF

Back End

Correlator



Importance of the Antenna Elements



- Antenna amplitude pattern causes amplitude to vary across the source.
- Antenna phase pattern causes phase to vary across the source.
- Polarization properties of the antenna modify the apparent polarization of the source.
- Antenna pointing errors can cause time varying amplitude and phase errors.
- Variation in noise pickup from the ground can cause time variable amplitude errors.
- Deformations of the antenna surface can cause amplitude and phase errors, especially at short wavelengths.

General Antenna Types

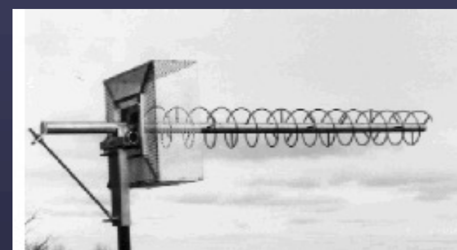
Wavelength > 1 m (approx)

Wire Antennas

Dipole

$A_e = G\lambda^2/4\pi$

Yagi

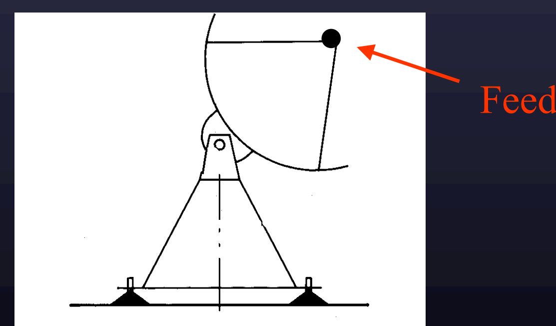


Helix

or arrays of these

Wavelength < 1 m (approx)

Reflector antennas



Wavelength = 1 m (approx) Hybrid antennas (wire reflectors or feeds)

Basic Antenna Formulas

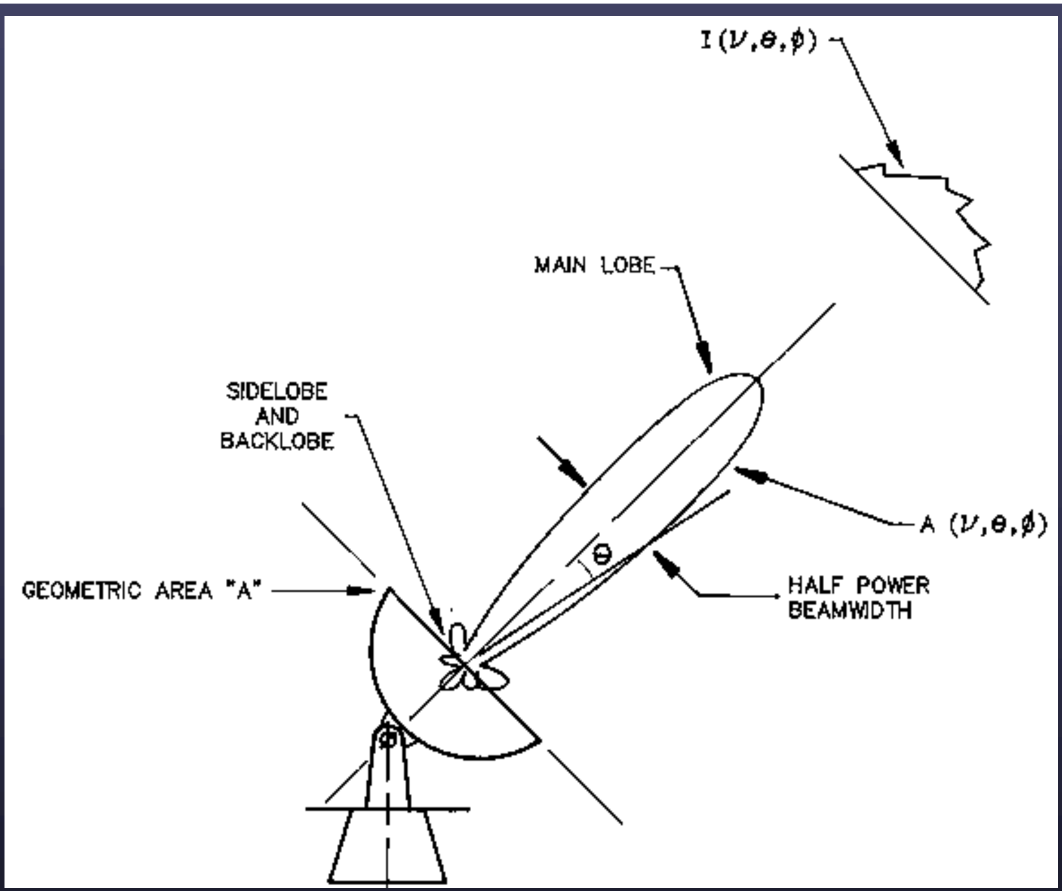
Effective collecting area $A(\nu,\theta,\phi)$ m^2

On-axis response $A_e = \eta A$

η = aperture efficiency

Normalized pattern (primary beam)

$\boldsymbol{A}(\nu,\theta,\phi) = A(\nu,\theta,\phi)/A_e$

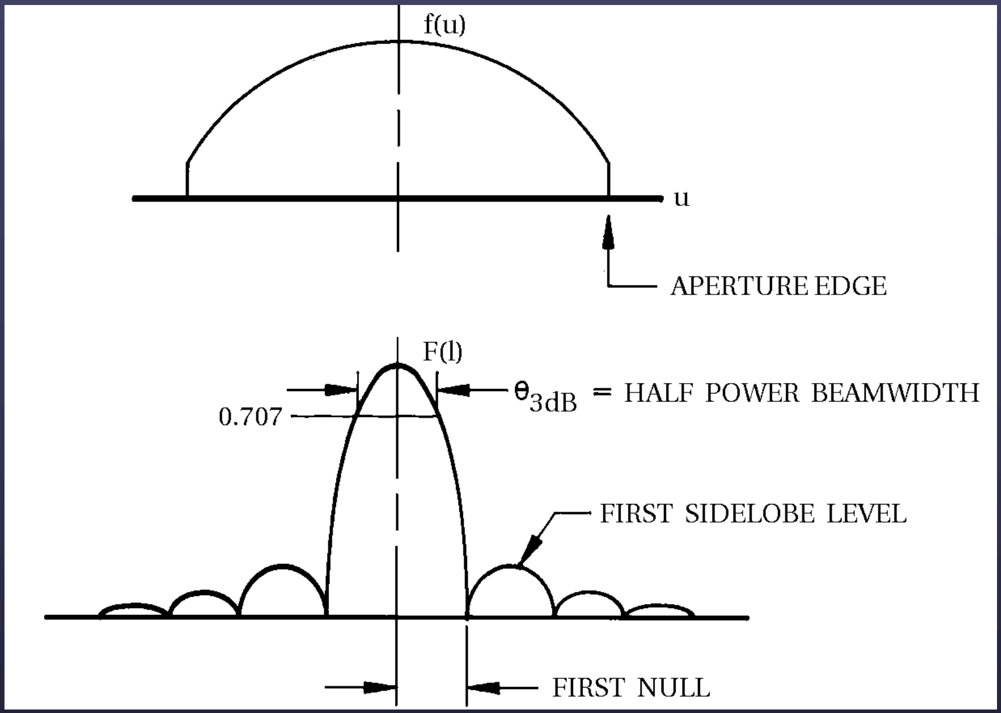


Beam solid angle $\Omega_A = \iint_{\text{all sky}} \boldsymbol{A}(\nu,\theta,\phi)\, d\Omega$

$A_e \, \Omega_A = \lambda^2$

Aperture-Beam Fourier Transform Relationship

$f(u,v)$ = complex aperture field distribution
u,v = aperture coordinates (wavelengths)

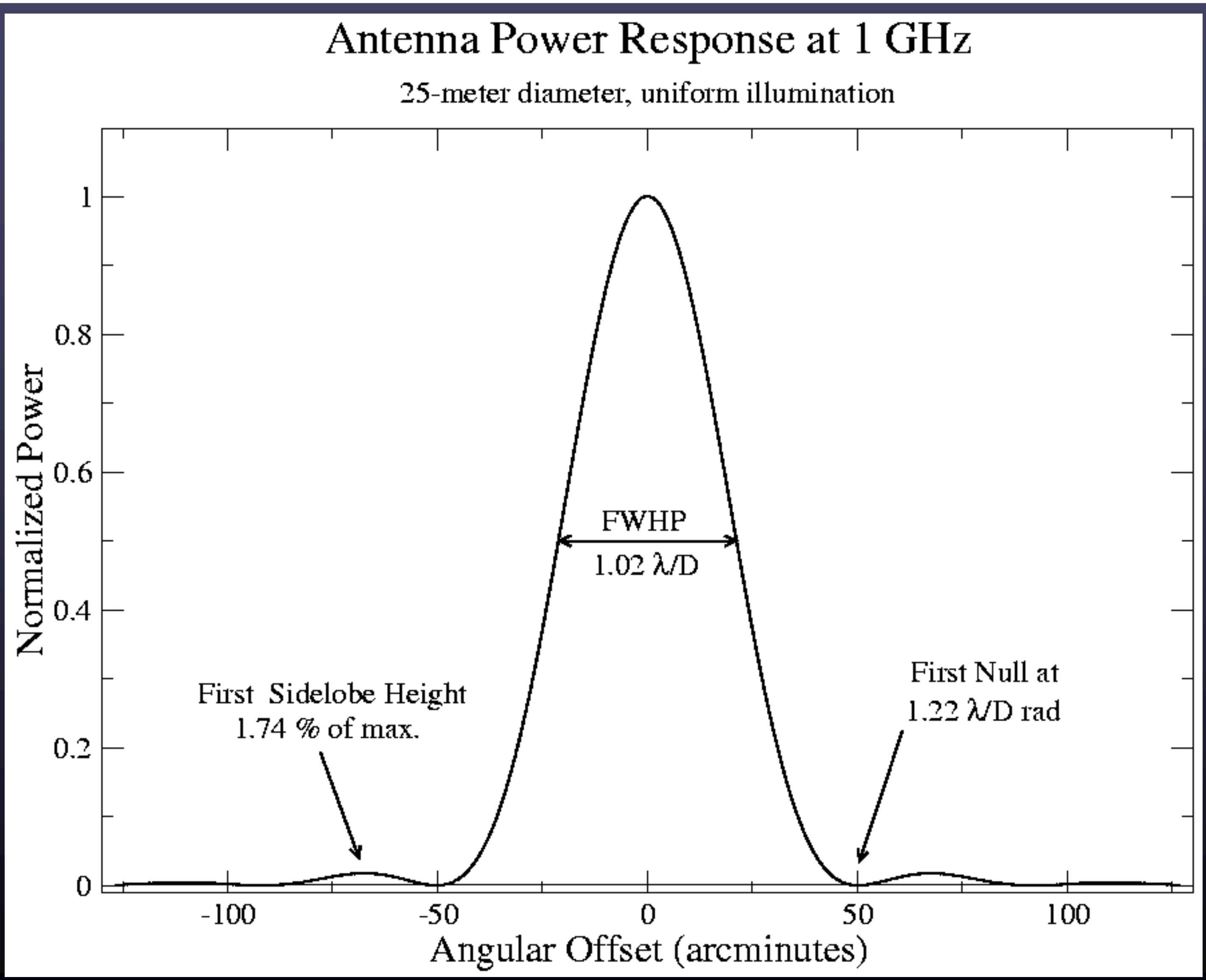


$F(l,m)$ = complex far-field voltage pattern
$l = \sin\theta\cos\phi$, $m = \sin\theta\sin\phi$

$F(l,m) = \iint_{aperture} f(u,v)\exp(2\pi i(ul+vm)dudv$
$f(u,v) = \iint_{hemisphere} F(l,m)\exp(-2\pi i(ul+vm)dldm$

For VLA: θ_{3dB} = 1.02/D, First null = 1.22/D,
D = reflector diameter in wavelengths

The Standard Parabolic Antenna Response

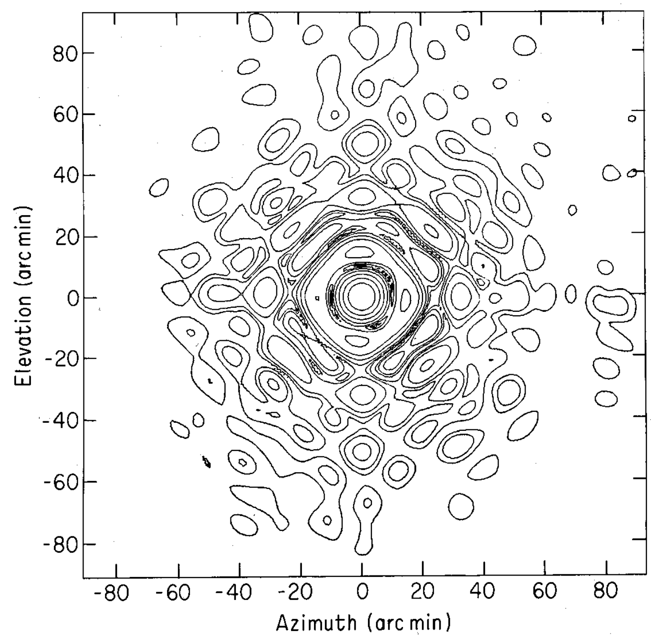


Antenna Holography

VLA 4.8 GHz

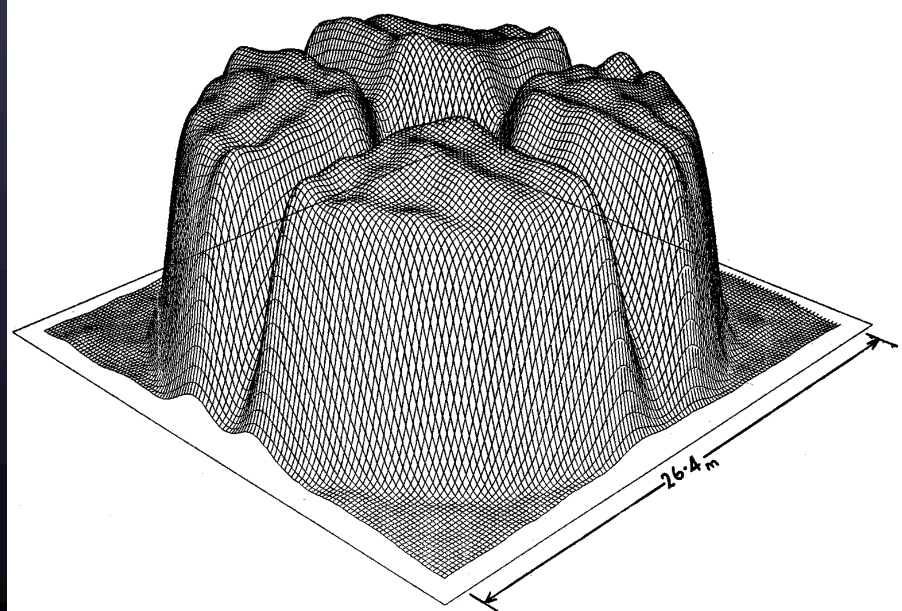
Far field pattern amplitude

Phase not shown

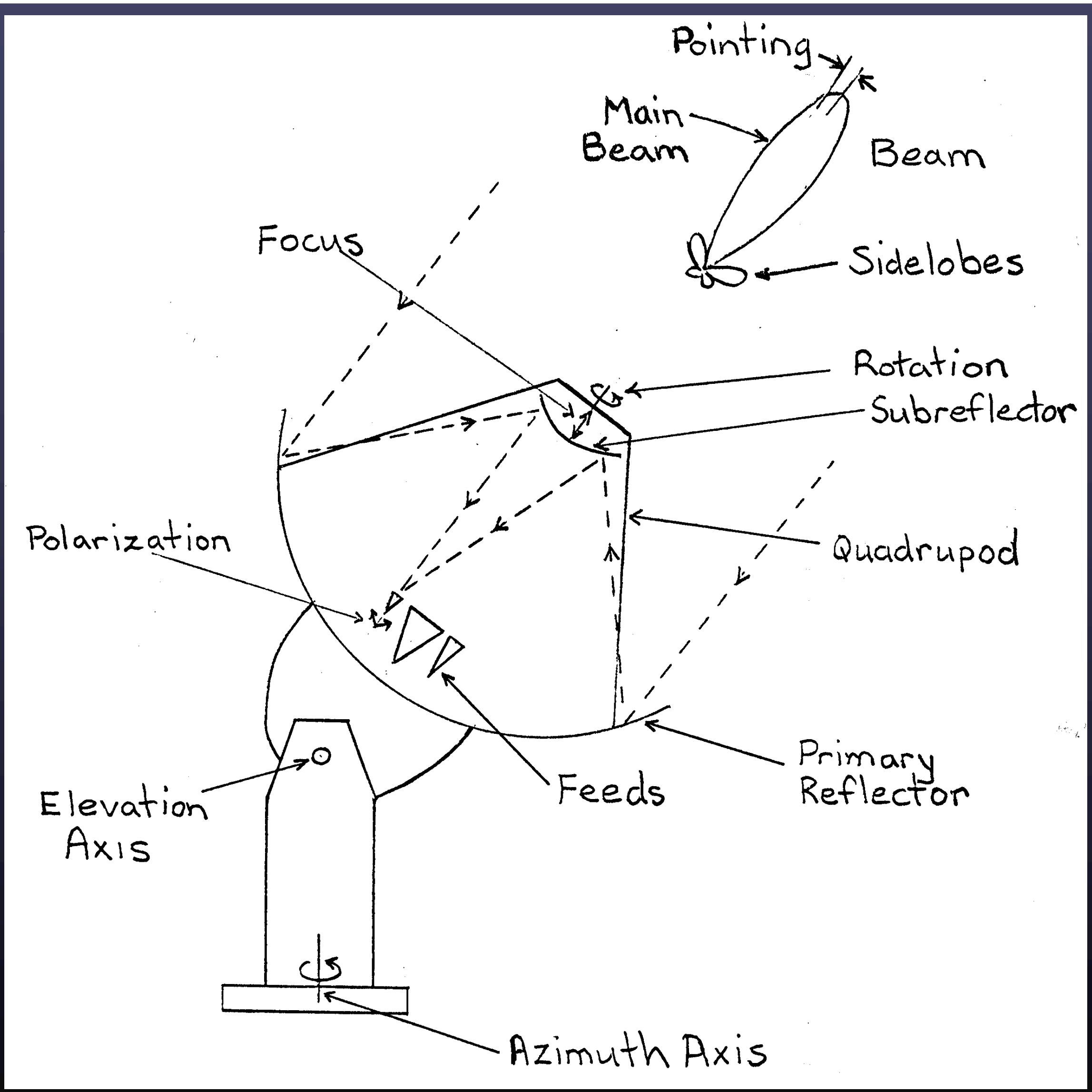


Aperture field distribution amplitude.

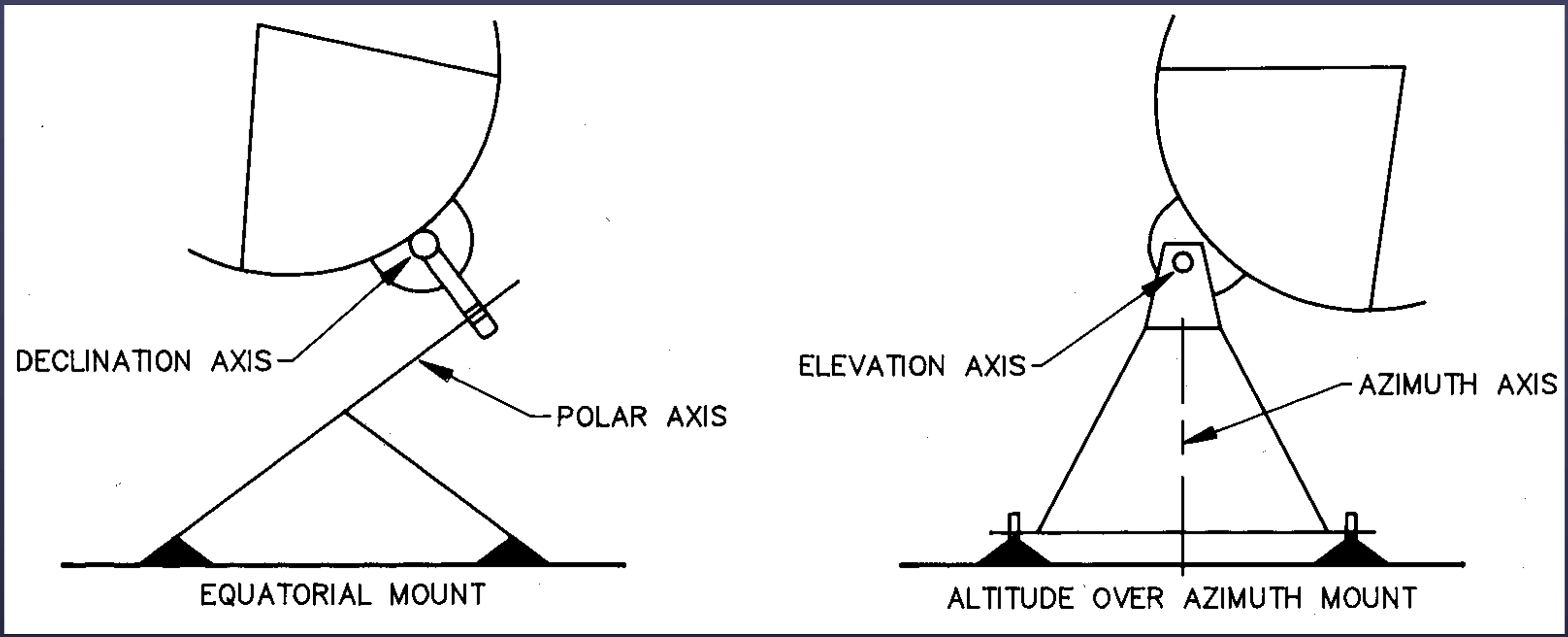
Phase not shown



Primary Antenna Key Features



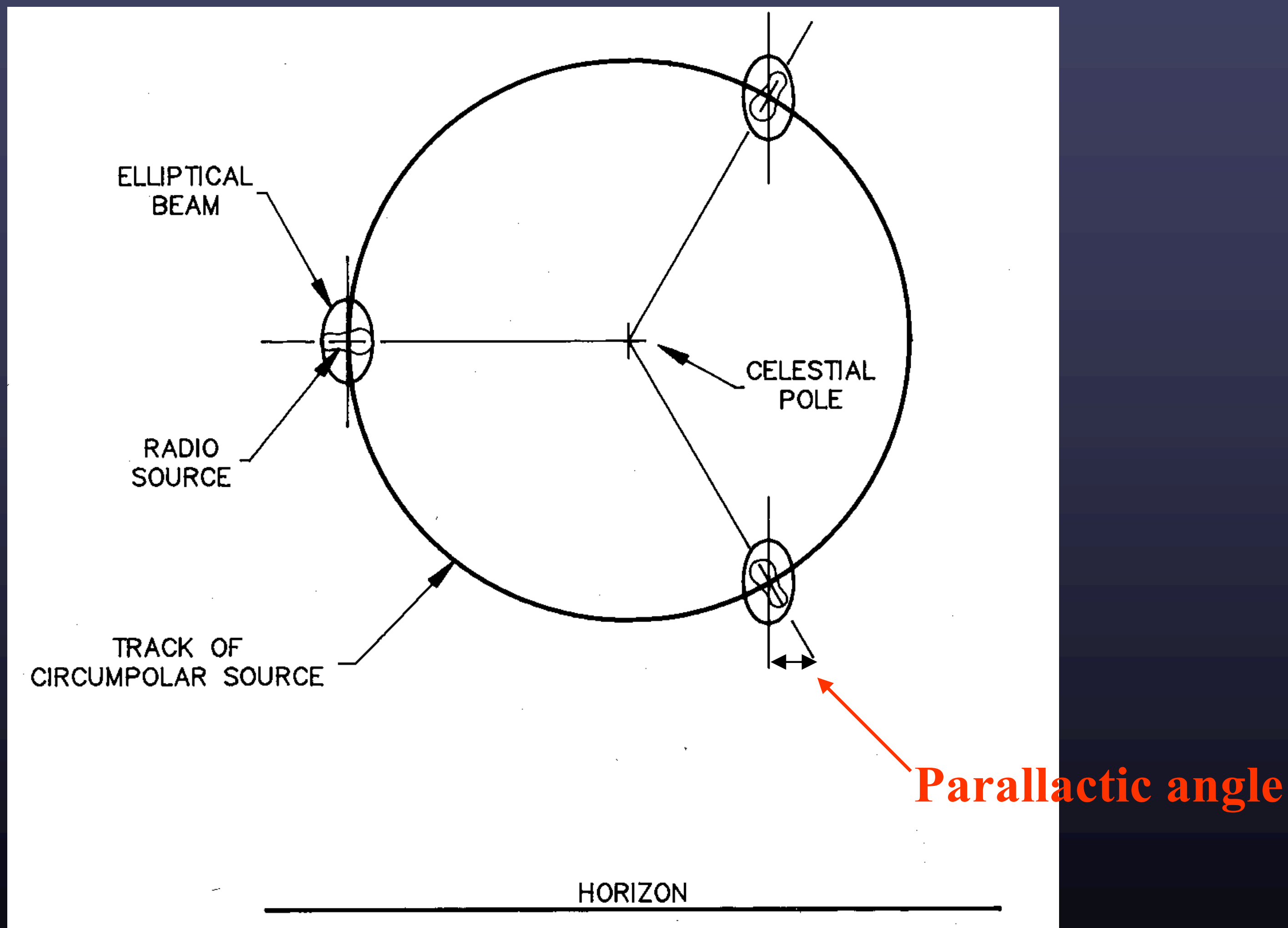
Types of Antenna Mount



+ Beam does not rotate
+ Better tracking accuracy
– Higher cost
– Poorer gravity performance
– Non-intersecting axis

+ Lower cost
+ Better gravity performance
– Beam rotates on the sky

Beam Rotation on the Sky



Reflector Types

Prime focus
(GMRT)

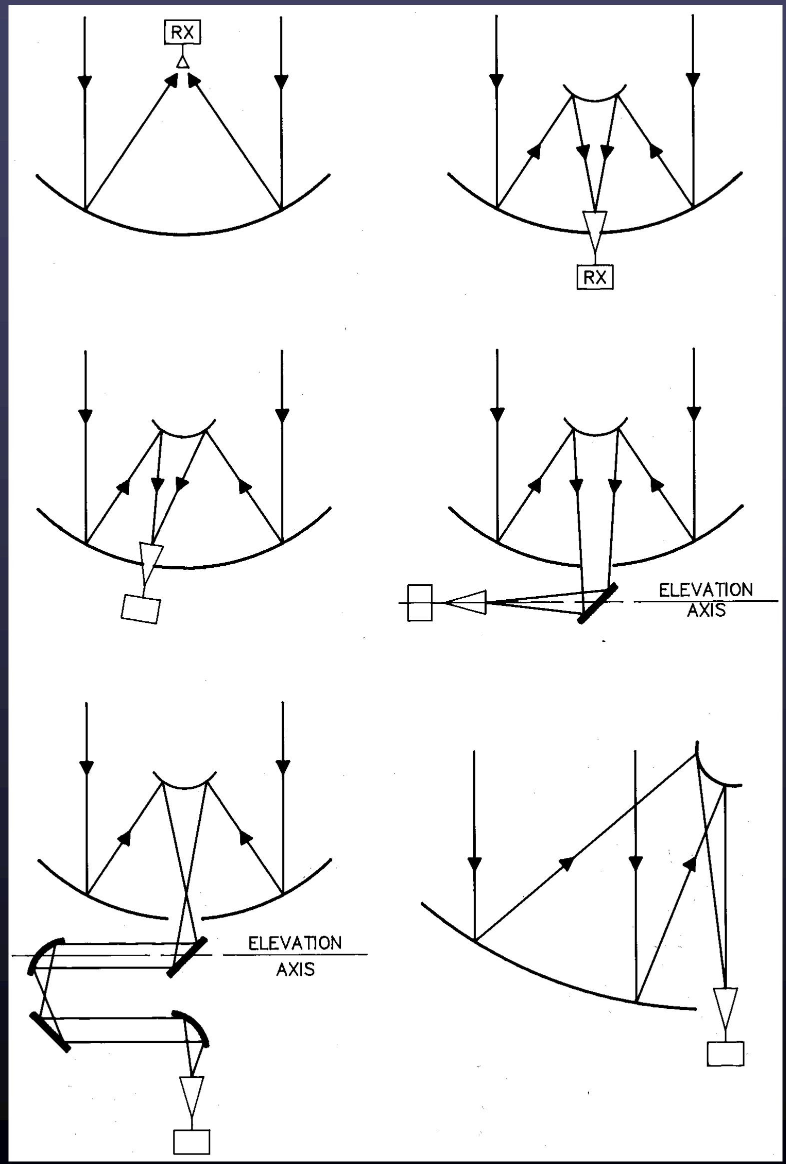
Cassegrain focus
(AT)

Offset Cassegrain
Naysmith
(VLA)

(OVRO)

Beam Waveguide
(NRO)
(ATA)

Dual Offset



Reflector Types

Prime focus
(GMRT)

Cassegrain focus
(AT)

Offset Cassegrain
(VLA)

Naysmith
(OVRO)

Beam Waveguide
(NRO)

Dual Offset
(ATA)

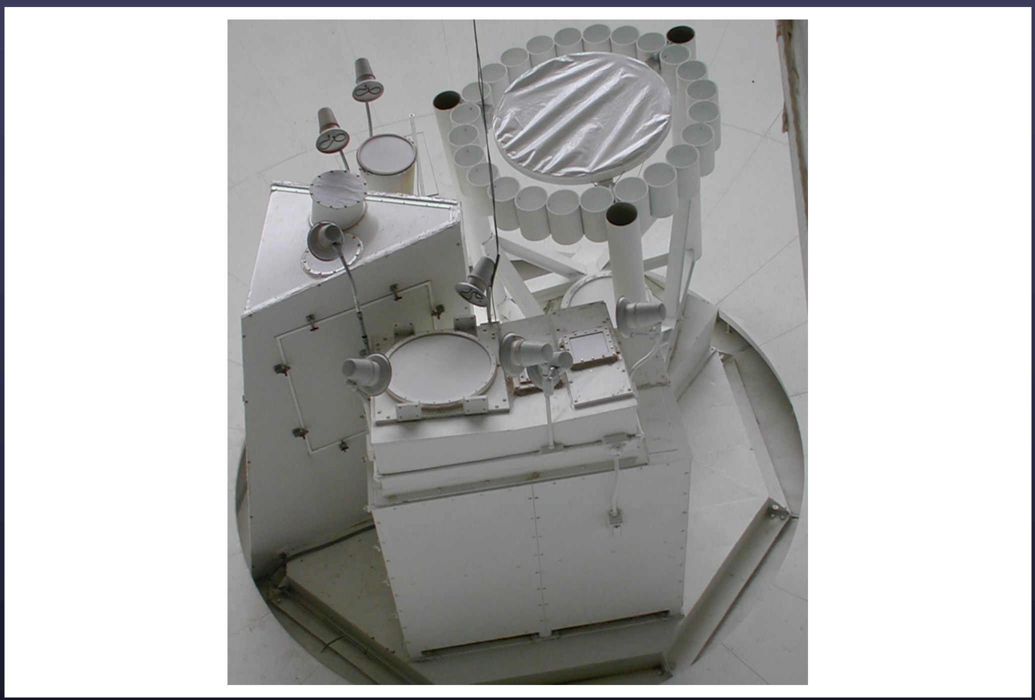
Effelsberg 100-m telescope near Bonn, Germany

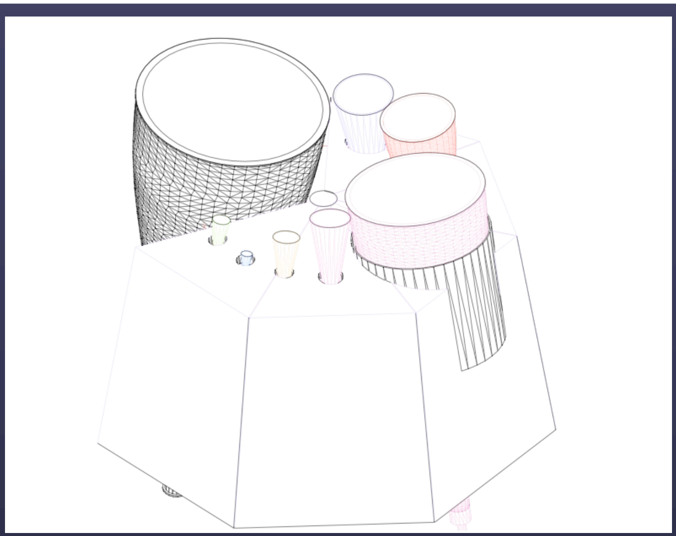
Reflector Types

Dual
Offset

Unblocked
Aperture
(GBT)

VLA and EVLA Feed System Design





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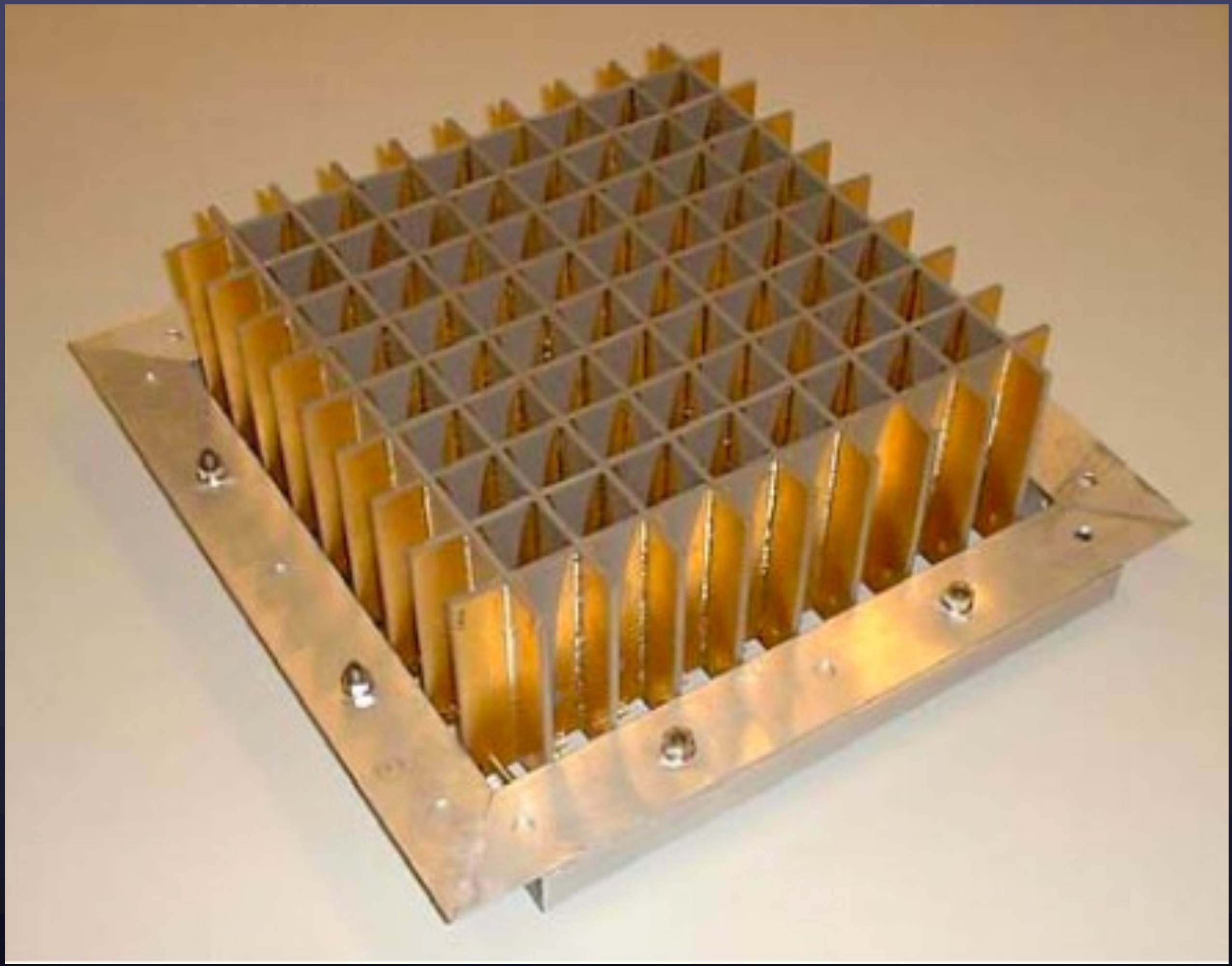
Example Feed Horn

Focal Plane Arrays

8 x 9
Array for
2-7 GHz

Ivashina
Et al.



Antenna Performance Parameters

Aperture Efficiency

$A_0 = \eta A,\ \eta = \eta_{sf} * \eta_{bl} * \eta_s * \eta_t * \eta_{misc}$

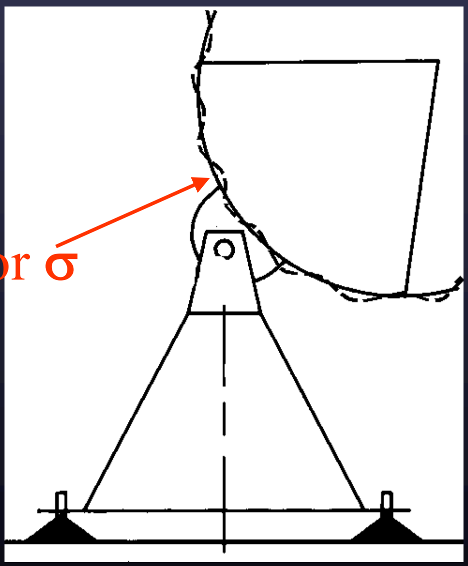
η_{sf} = reflector surface efficiency

η_{bl} = blockage efficiency

η_s = feed spillover efficiency

η_t = feed illumination efficiency

η_{misc}= diffraction, phase, match, loss



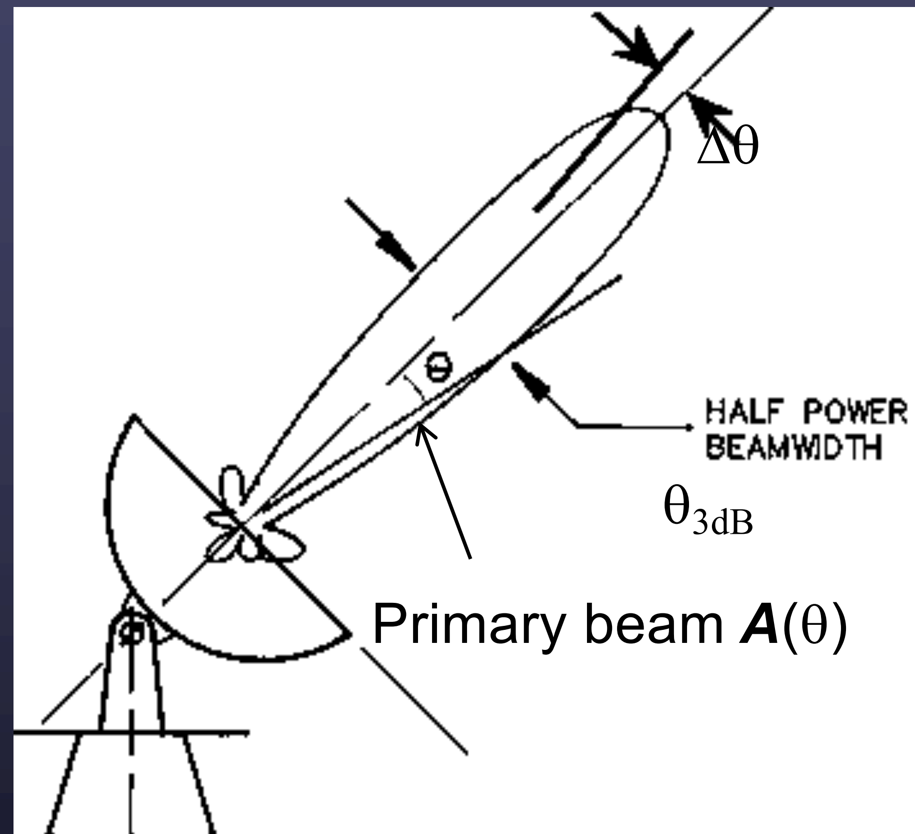
$\eta_{sf} = \exp(-(4\pi\sigma/\lambda)^2)$

e.g., $\sigma = \lambda/16$, $\eta_{sf} = 0.5$

Antenna Performance Parameters

Pointing Accuracy

$\Delta\theta$ = rms pointing error



Often $\Delta\theta < \theta_{3dB}$ /10 acceptable

Because $A(\theta_{3dB}/10) \sim 0.97$

BUT, at half power point in beam

$A(\theta_{3dB}/2 \pm \theta_{3dB}/10)/A(\theta_{3dB}/2) = \pm 0.3$

For best VLA pointing use Reference Pointing.

$\Delta\theta$ = 3 arcsec = θ_{3dB} /17 @ 50 GHz

Antenna Pointing Design

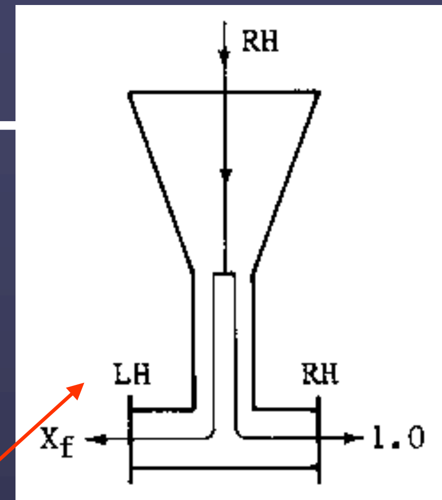
ALMA 12m Antenna

Surface: $\sigma = 25\ \mu m$

Pointing: $\Delta\theta = 0.6$ arcsec

Carbon fiber and invar reflector structure

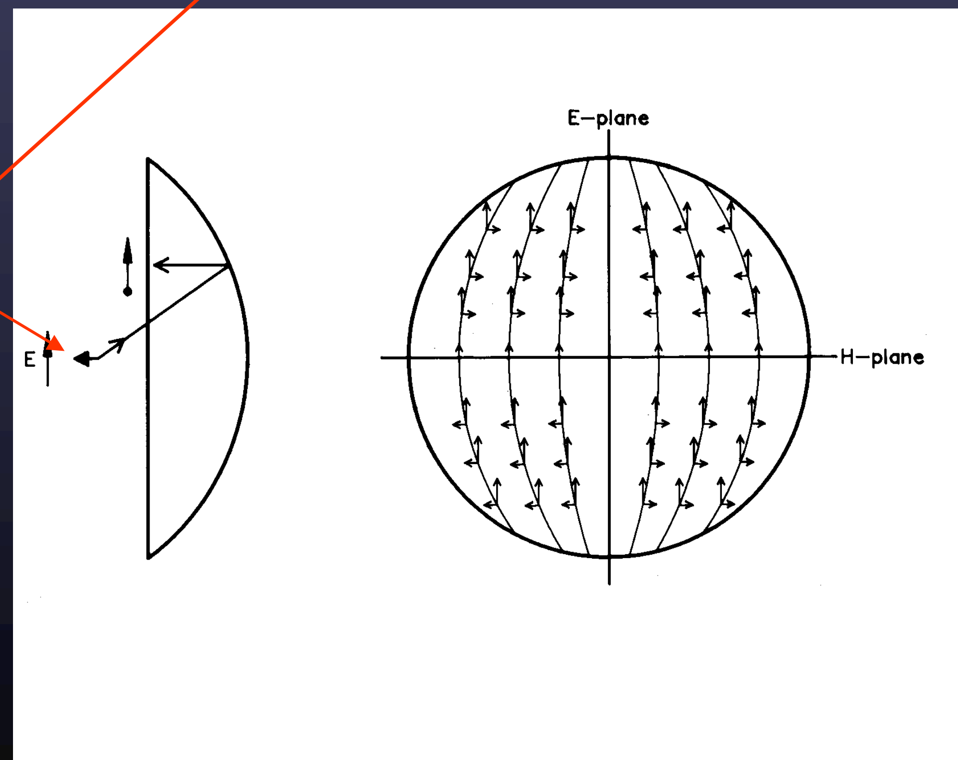
Antenna Performance Parameters



Polarization

Antenna can modify the apparent polarization properties of the source:

- Symmetry of the optics
- Quality of feed polarization splitter
- Circularity of feed radiation patterns
- Reflections in the optics
- Curvature of the reflectors



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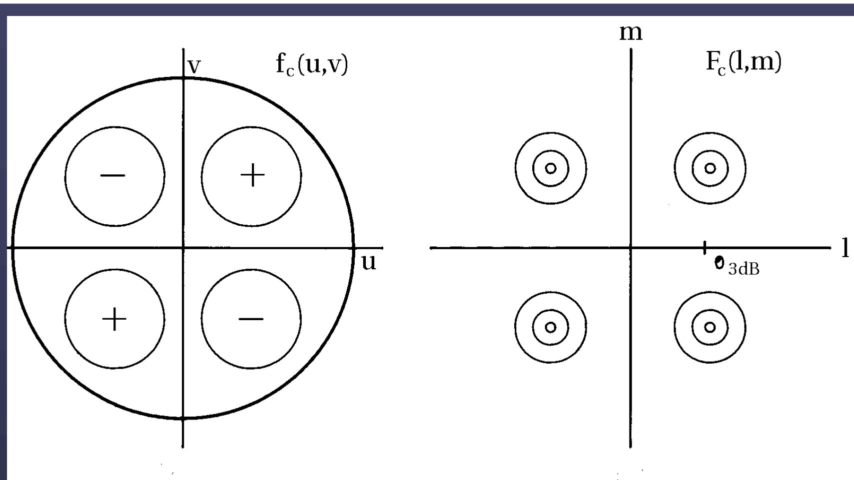
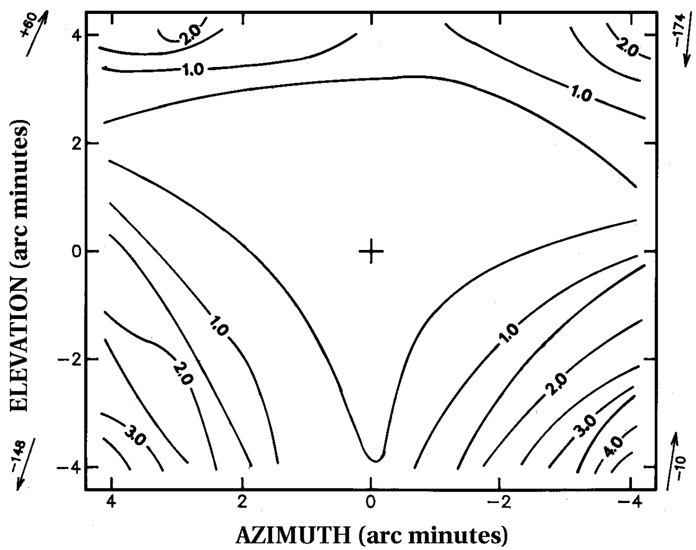
Off-Axis Cross Polarization

Cross polarized aperture distribution



Cross polarized primary beam

VLA 4.8 GHz cross polarized primary beam



Other Concerns

- Pointing errors, especially at high frequencies
- Gain curves
- Atmospheric opacity corrections
- Ionospheric effects: scintillation, isoplanatic patch size

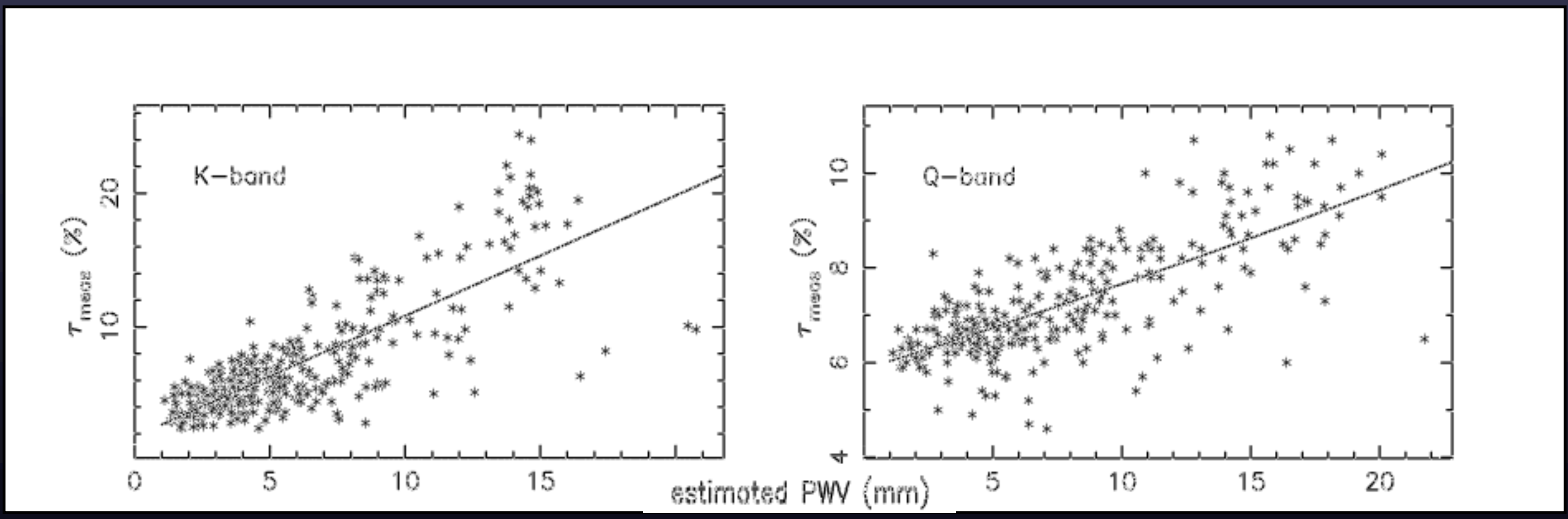
Practical concerns continued

- **Opacity corrections and tipping scans**
  - Can measure the total power detected as a function of elevation, which has contributions

$$T_{\mathbf{sys}} = T_{\mathbf{0}} + T_{\mathbf{atm}}(1 - e^{\tau_0 a}) + T_{\mathbf{spill}}(a)$$

and solve for τ_0.

  - Or, make use of the fact that there is a good correlation between the surface weather and τ_0 measured at the VLA (Butler 2002):



and apply this opacity correction using FILLM in AIPS

Further Reading

http://www.nrao.edu/whatisra/mechanisms.shtml
http://www.nrao.edu/whatisra/
www.nrao.edu

Synthesis Imaging in Radio Astronomy
ASP Vol 180, eds Taylor, Carilli & Perley