Imaging the radio sky

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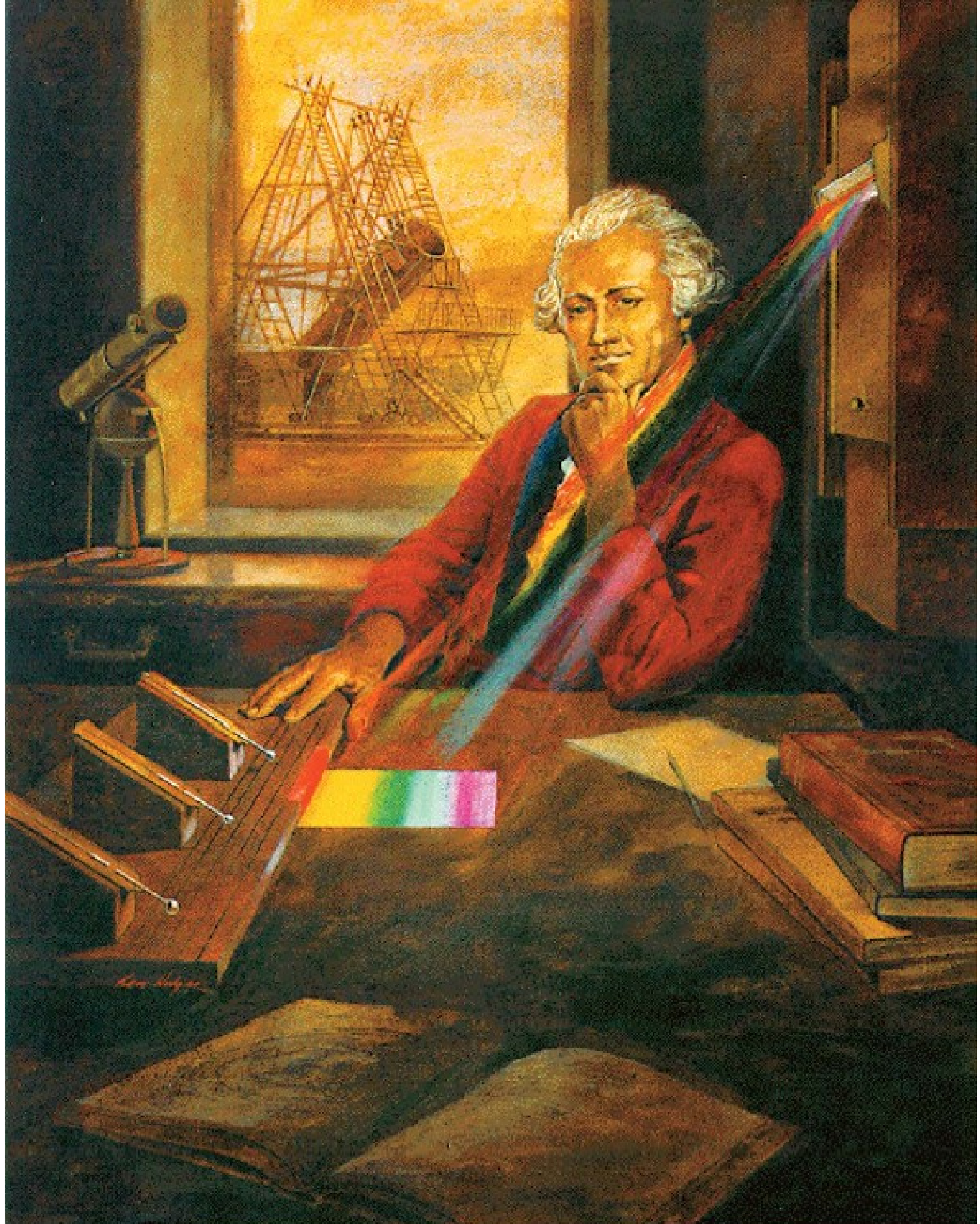
High-performance Signal and Data Processing, 28 January 2014

Content :

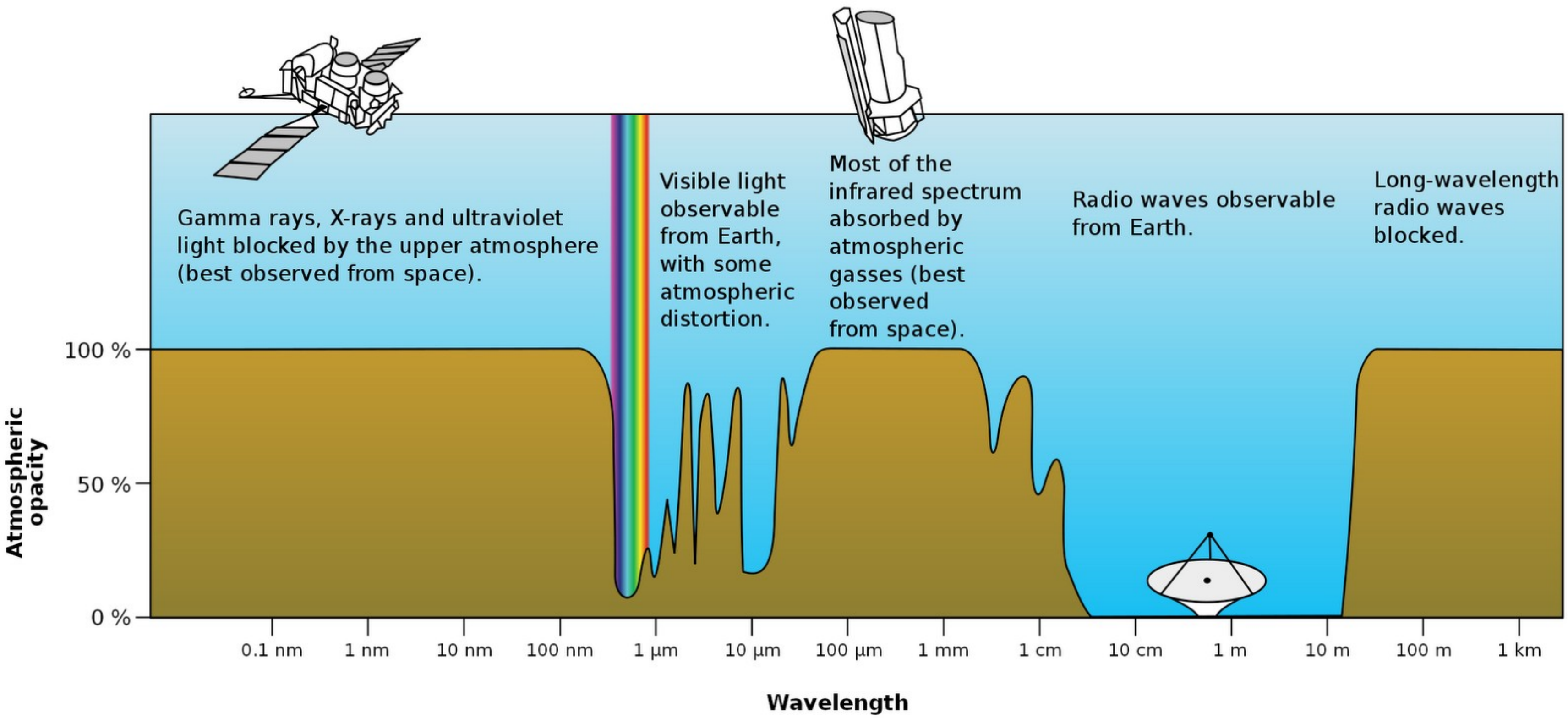
- Electromagnetic spectrum
- Dipole
- Antenna
- Single aperture telescopes
- Two element interferometer
- Aperture synthesis

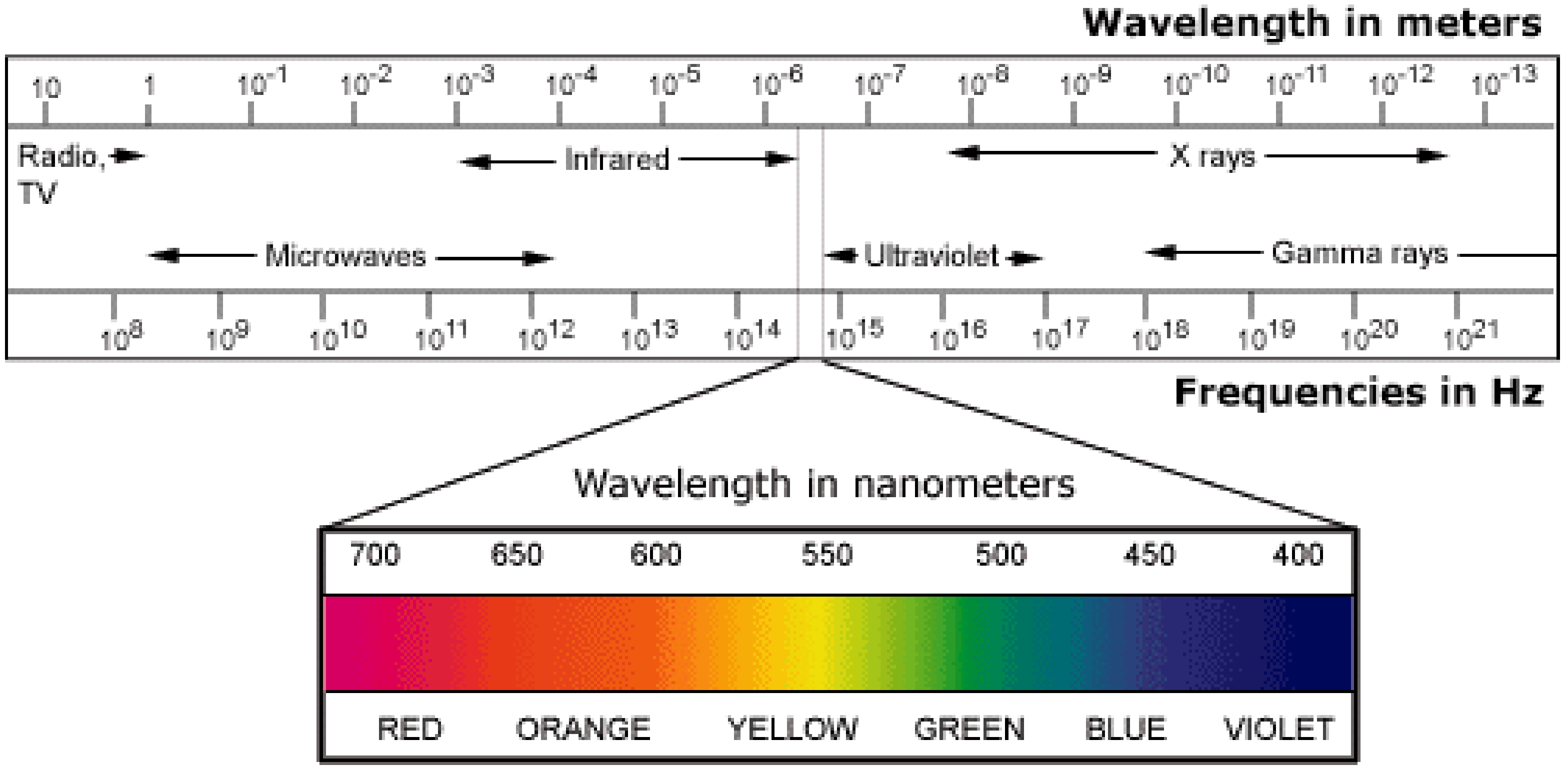
Electromagnetic spectrum

1800
William Hershel discovers the electromagnetic spectrum



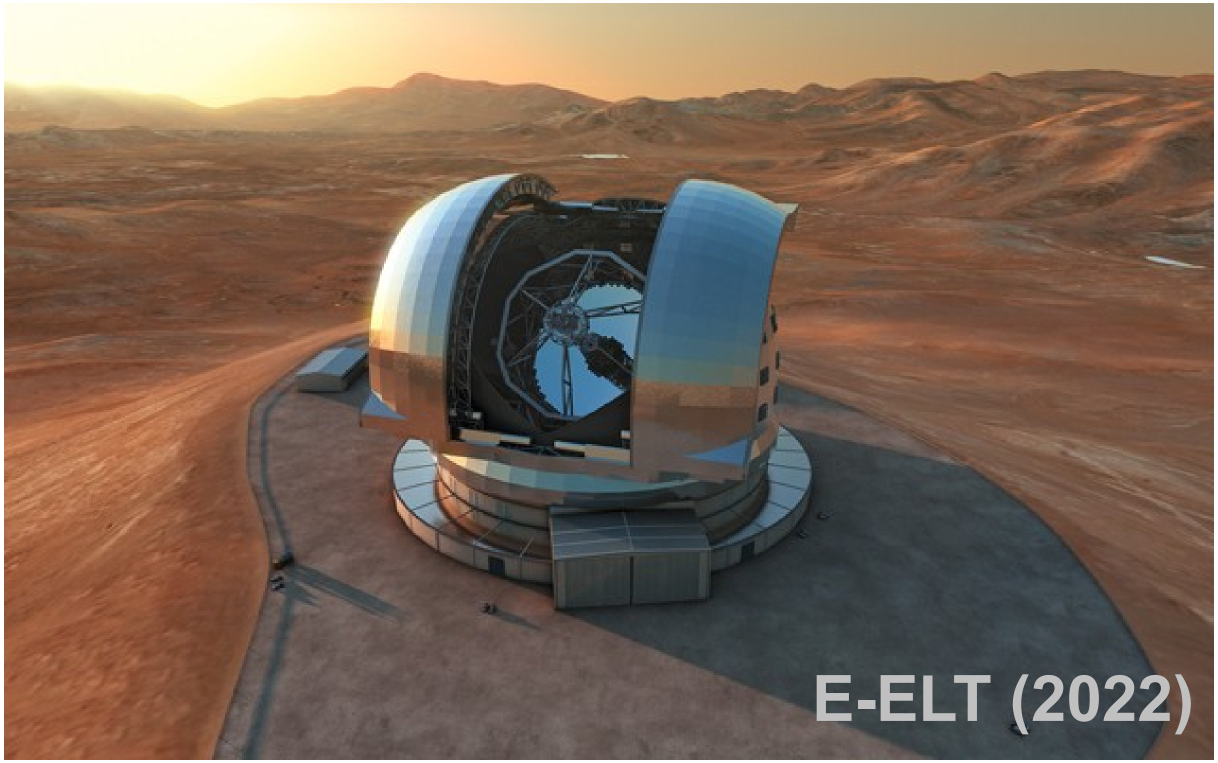
Only optical and radio waves penetrate the atmosphere



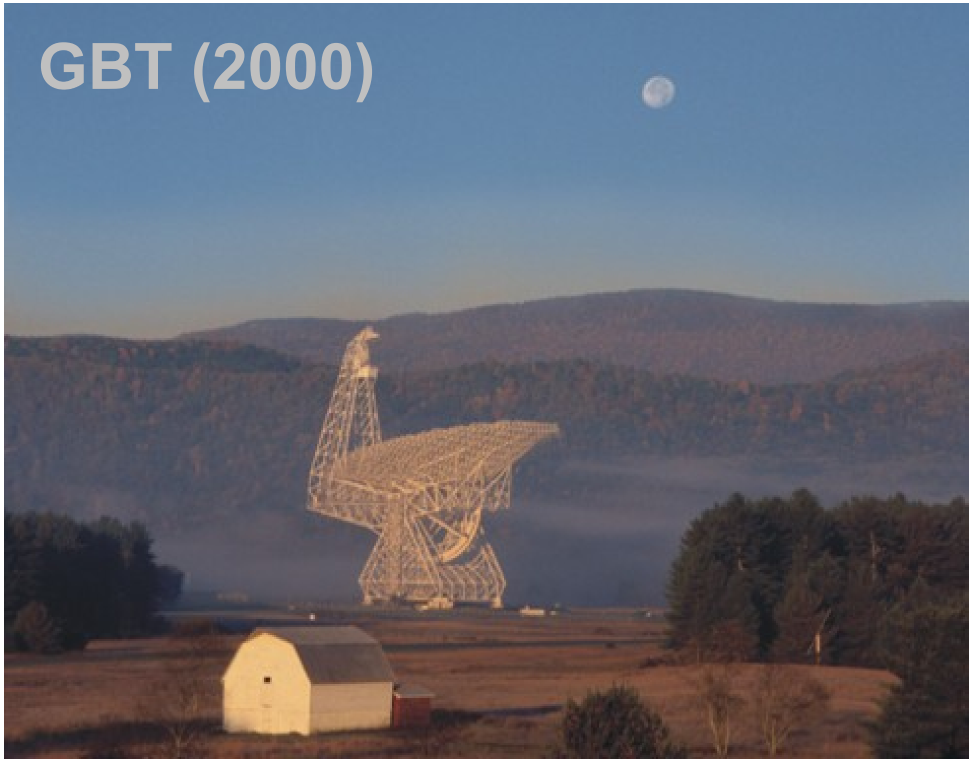


optical : $\lambda = 550 \times 10^{-9}$ m $\qquad \nu = 5 \times 10^{15}$ Hz

radio : $\lambda = 1$ m $\qquad \nu = 10^{8}$ Hz



D = 100 m

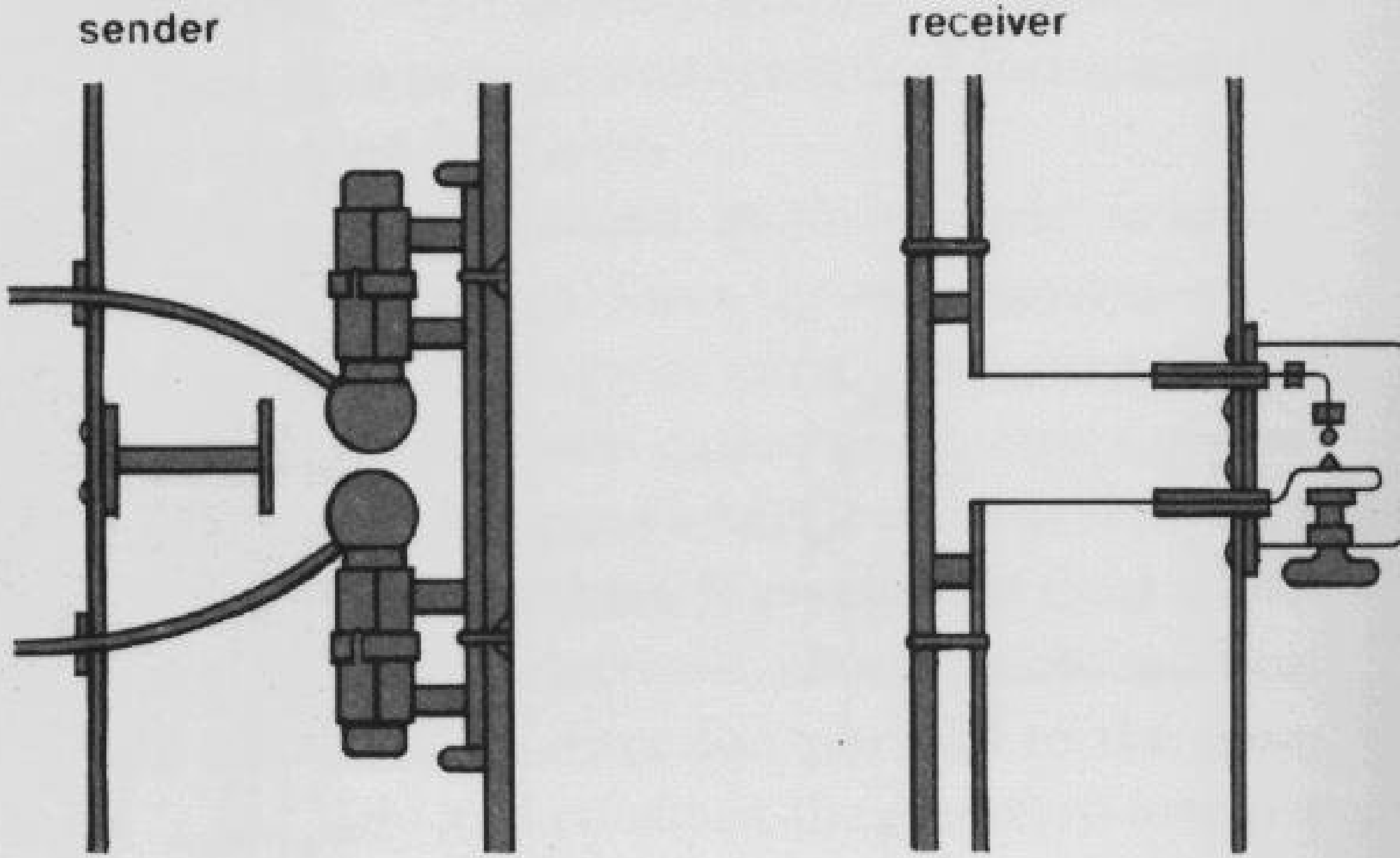


D = 40 m

Dipole

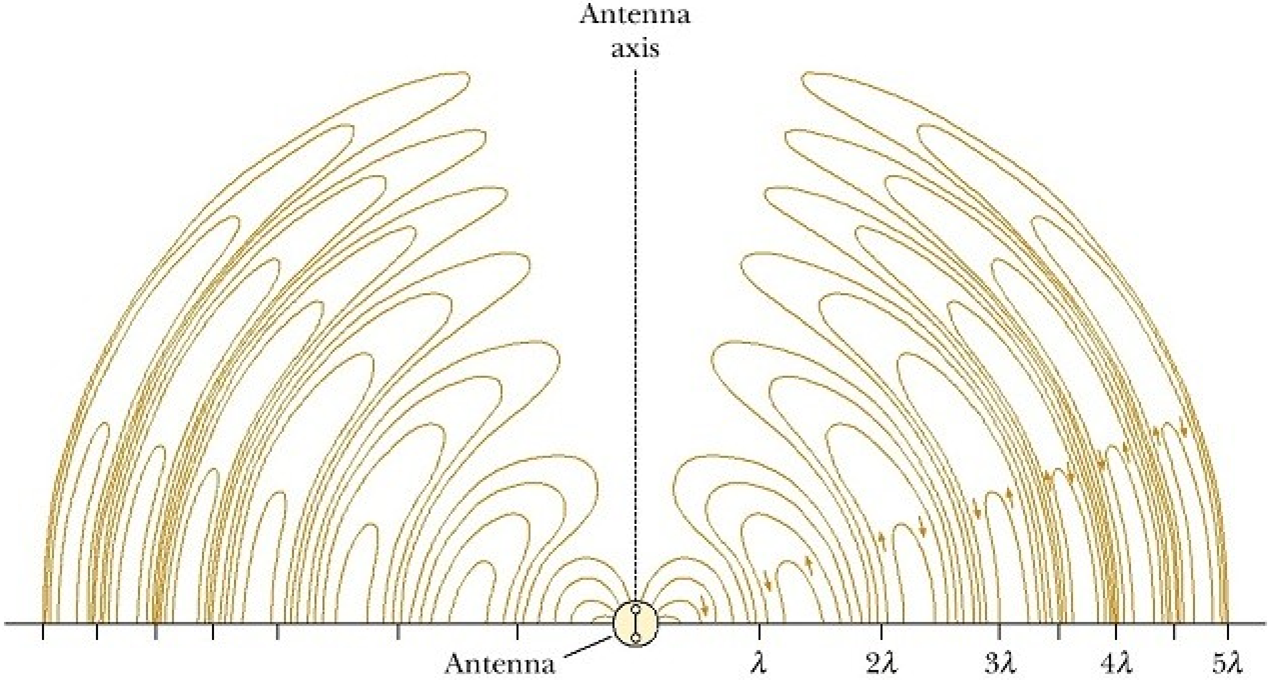
1865 **James Clerk Maxwell** proposes that light is an electromagnetic wave

1886 **Heinrich Hertz** develops devices to transmit and receive electromagnetic waves



Once it was shown that the quantity that oscillates in a light wave is the electric field or the magnetic field, Heinrich Hertz artificially produced waves of different wave-length from those of visible light. Above are his oscillator, or sender, and his resonator, or receiver.

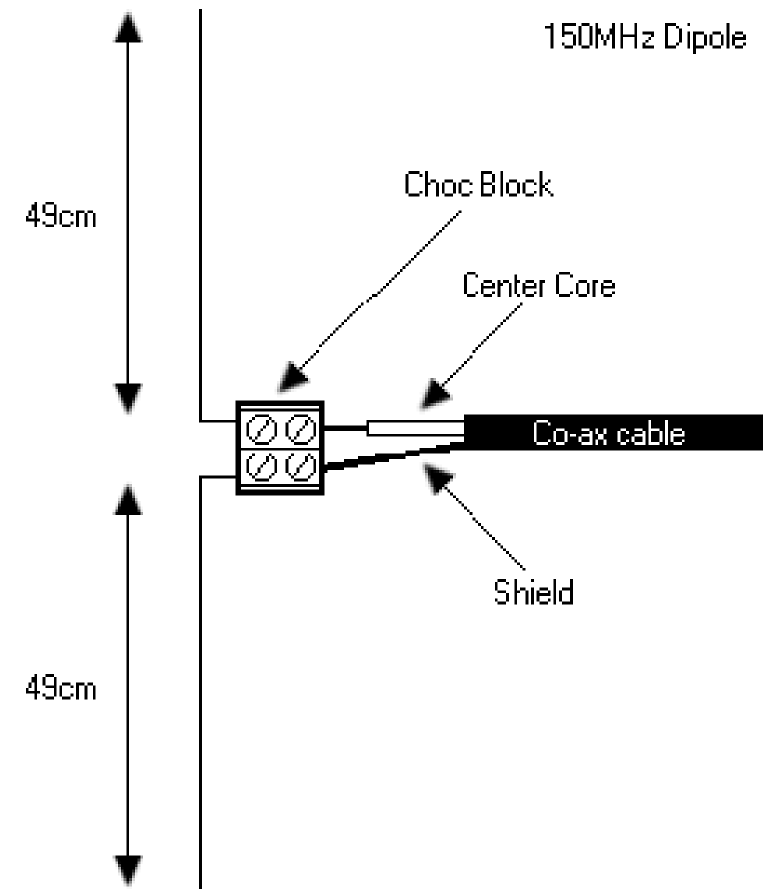
Electric filed of a dipole antenna



- can be considered isotropic at large distances
- energy is transported by the elm. waves

Antenna

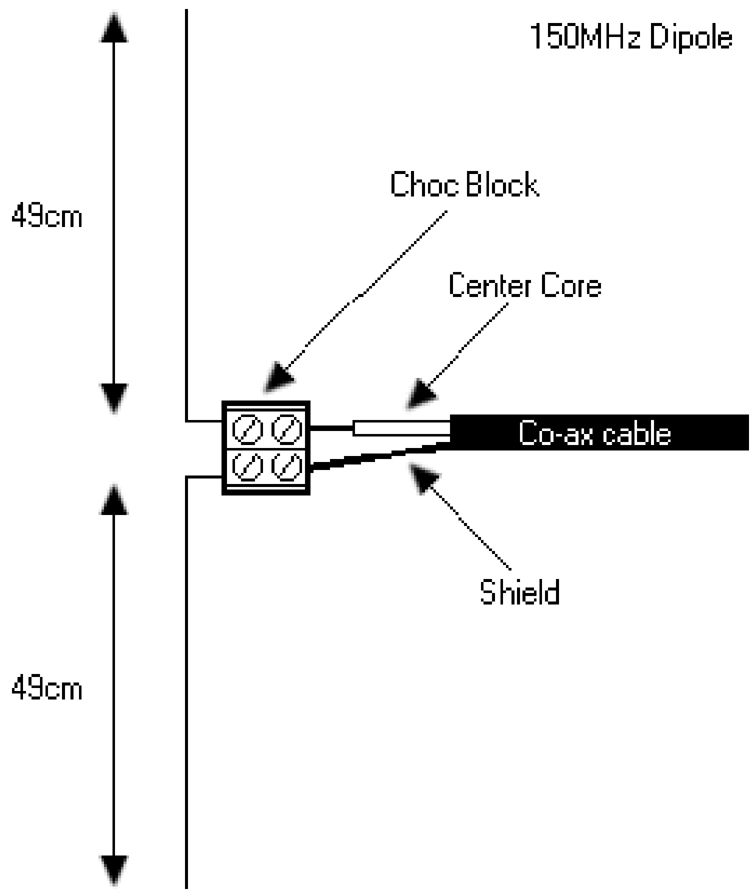
Dipole antenna



If the antenna is exposed to an electromagnetic wave

- an oscillating voltage can be measured at the terminals of the antenna
- the square of the voltage is proportional to the intercepted power of the elm wave

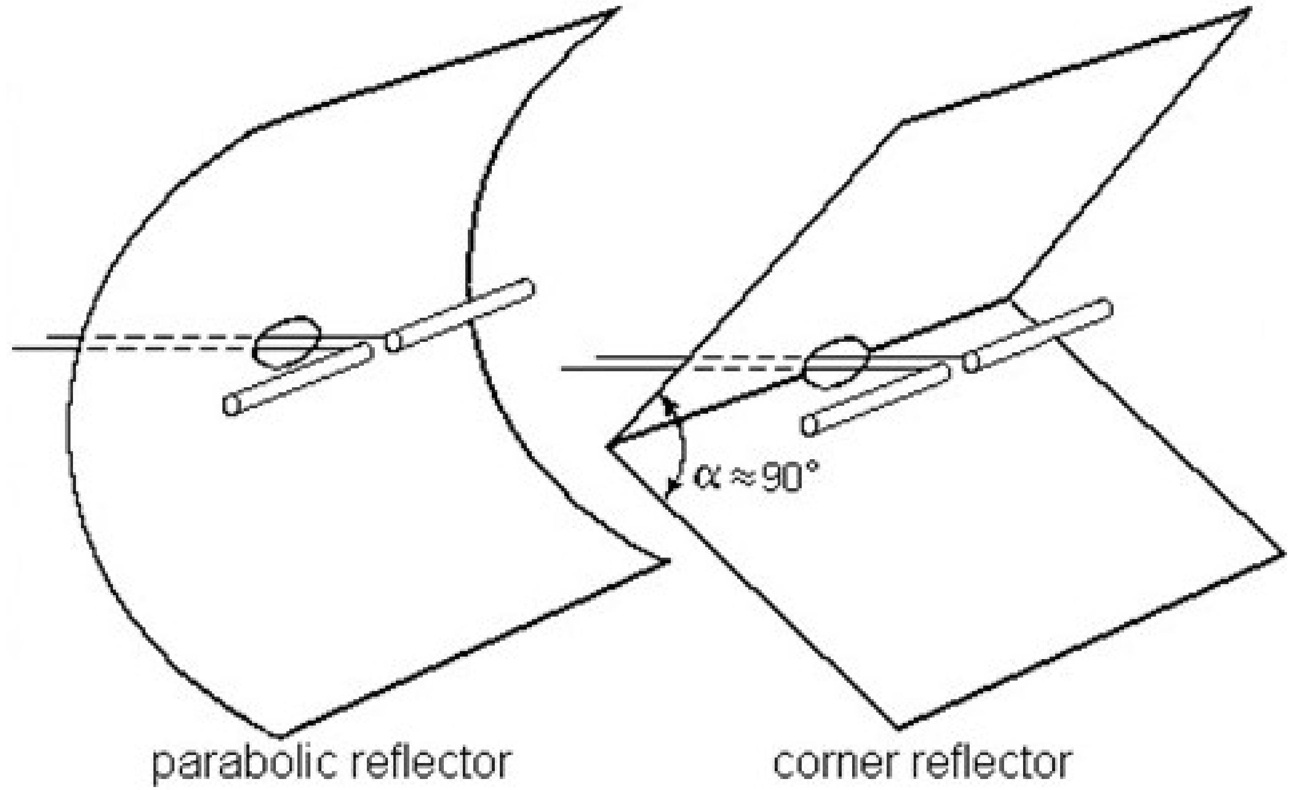
Noise



An antenna can be modelled as an ideal receiving device and a resistor

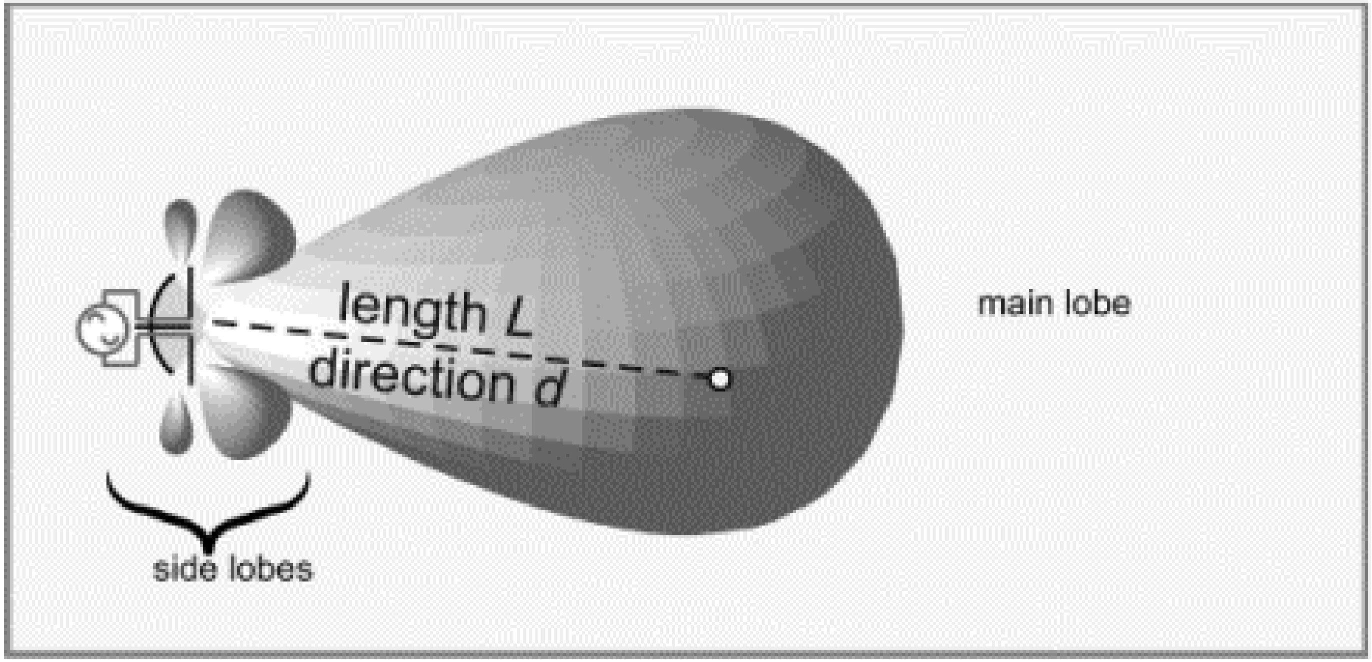
- voltage is generated if the antenna is exposed to a elm wave
- due to random motions of the electrons the resistor generates additional voltage
  Nyquist theorem

Introducing reflectors to point the *beam*



Reciprocity theorem : The parameters of an antenna when used to receive or transmit radiation are the same.

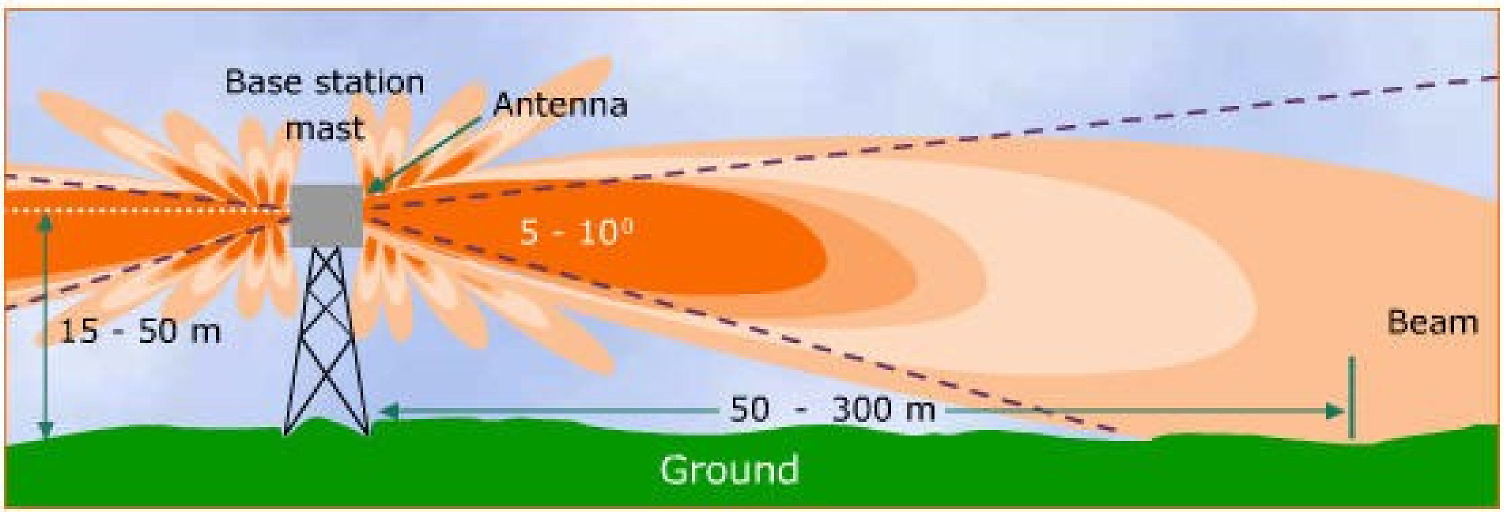
Side lobes



Gain or Directivity :

$$G(\vartheta, \varphi) = \frac{4\pi P(\vartheta, \varphi)}{\int\int P(\vartheta, \varphi)\, \mathrm{d}\Omega}$$

Side lobes



…. fairly common in everyday life

Single aperture telescopes

~ 1940 **Grote Reber**

produces the fist maps of the radio sky at 160 MHz

using a dish with an aperture of 9m

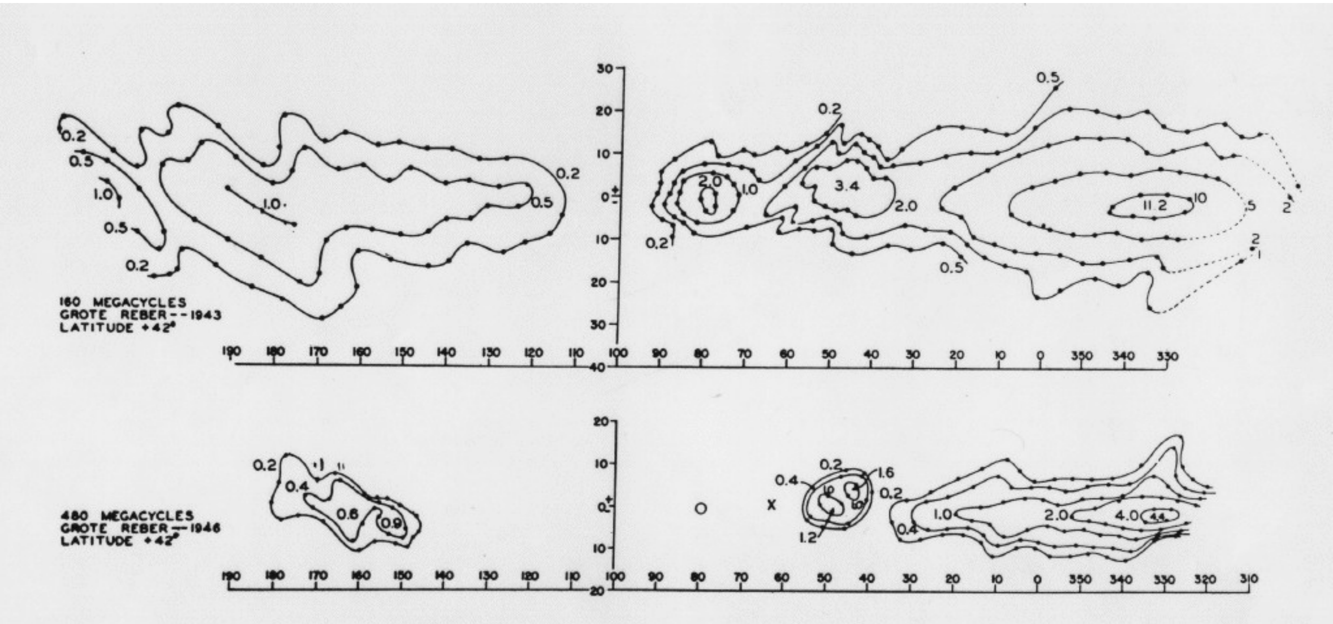
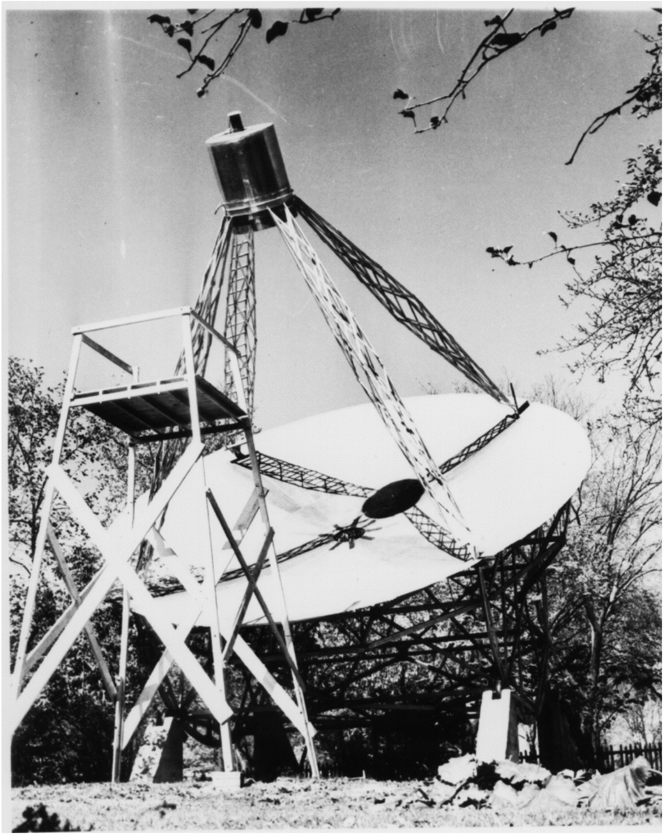
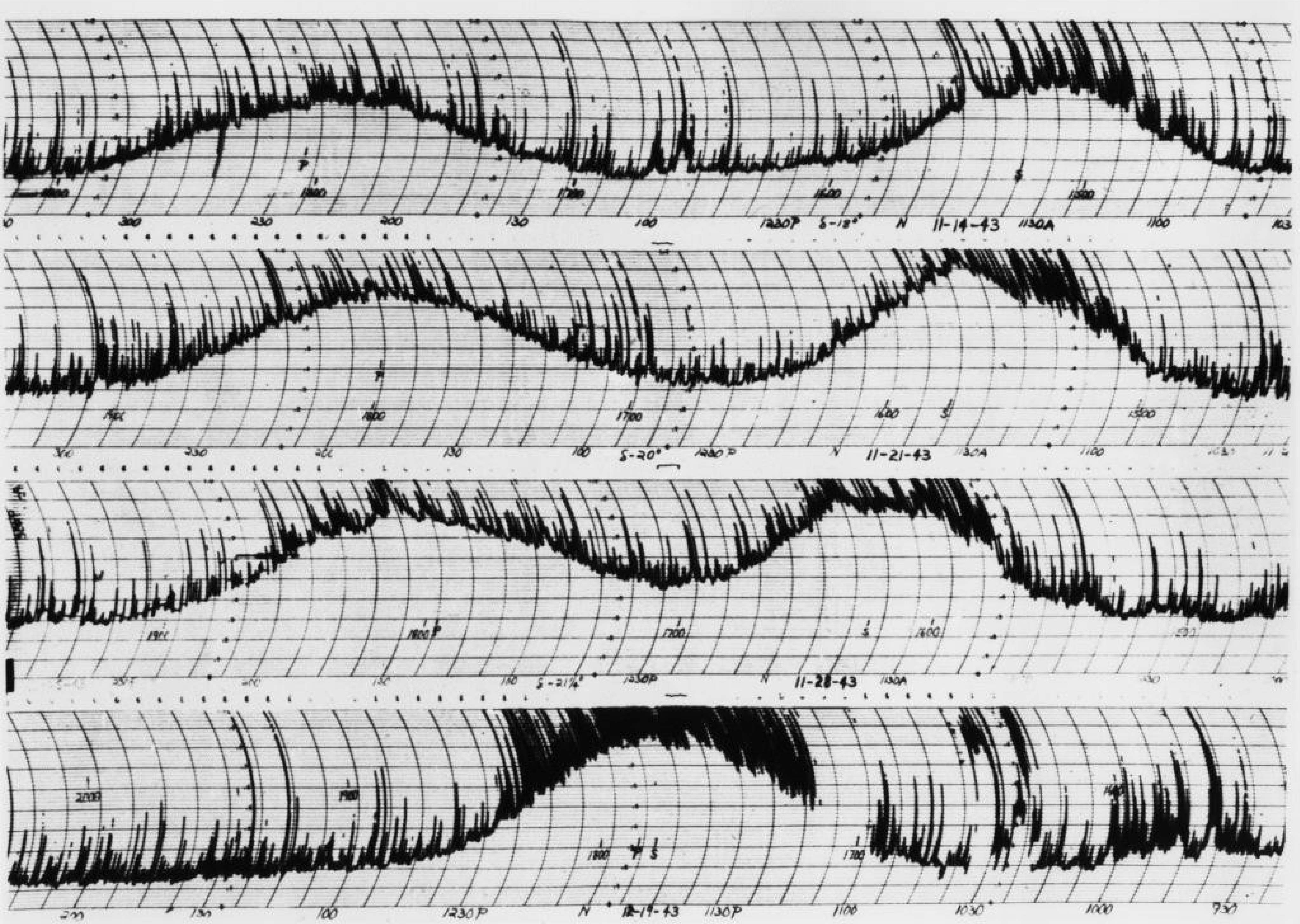


FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

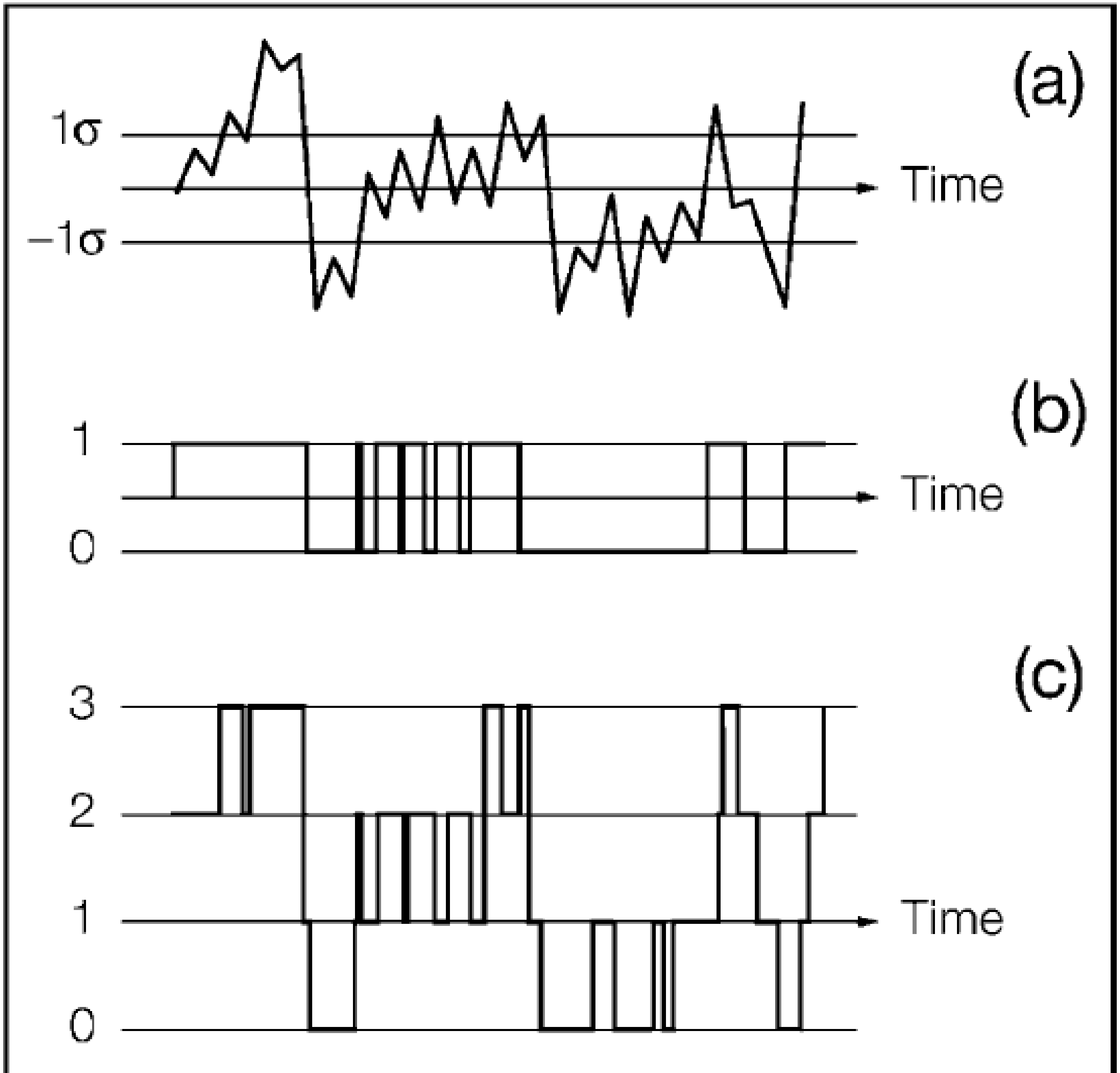


Reber's telescope, like all other single aperture radio telescopes, is a **single pixel device**. Mapping of the sky is achieved by drift scans

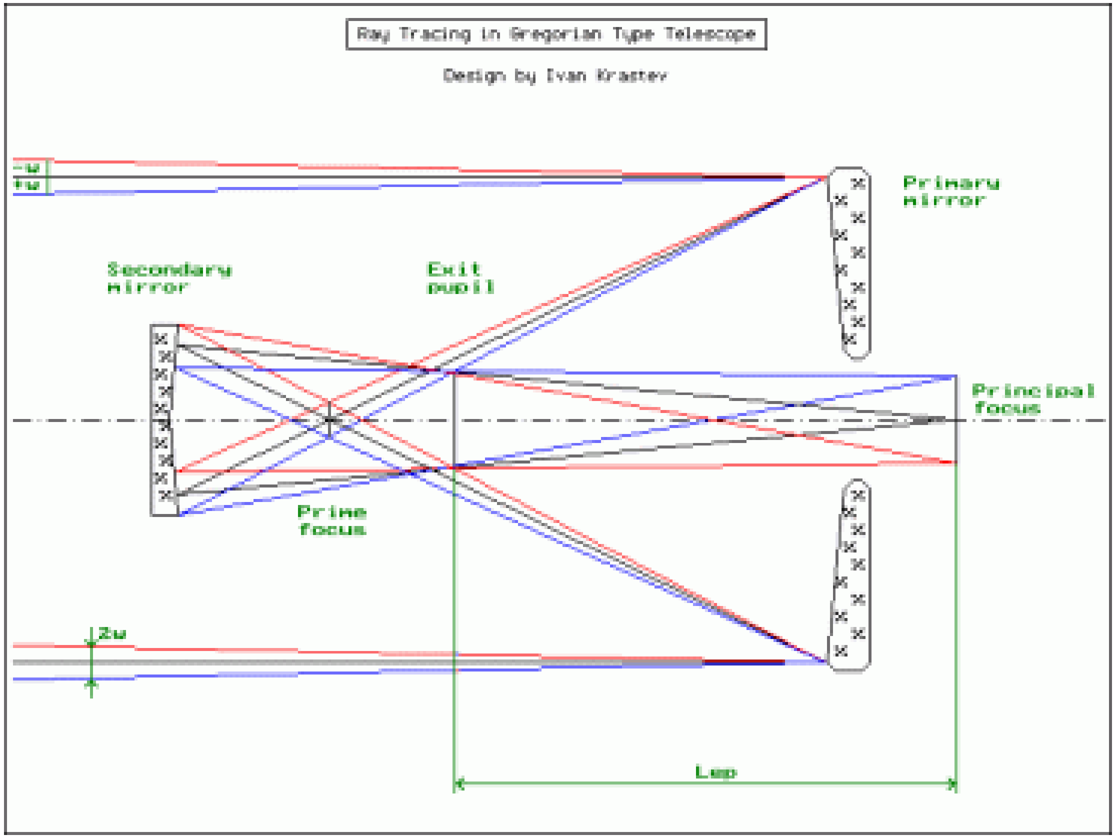


1900
1800
1700
1600
1500
300
230
200
130
100
1230P
S-18°
N
11-14-43
1130A
1100
1800
1700
1600
1500
230
200
130
100
S-20°
1230P
N
11-21-43
1130A
1100
1800 P
1700
1600
100
S-21¼°
1230P
N
11-28-43
1130A
2000
1900
1800
1700
200
130
100
1230P
N
12-19-43
1130P
1100
1030
1000
930

Digitized signal



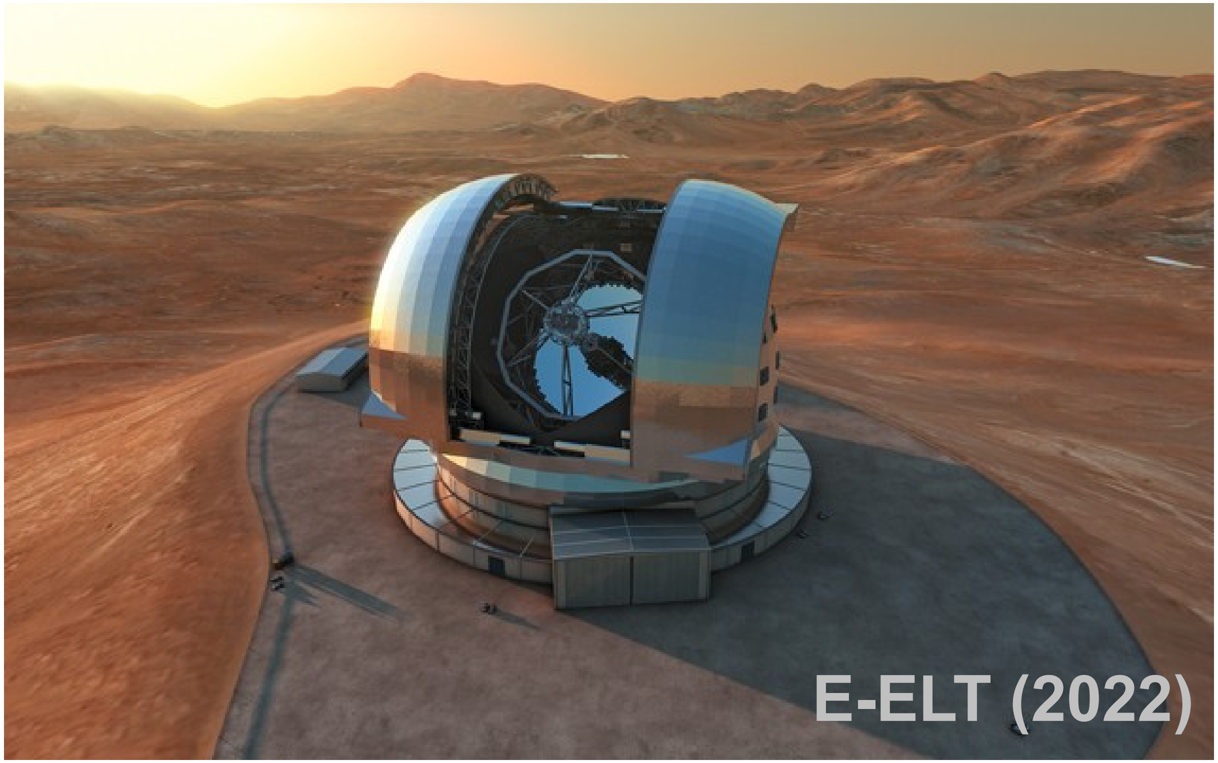
Optical telescope



~ 1000 X 1000 pixels illuminated at a time

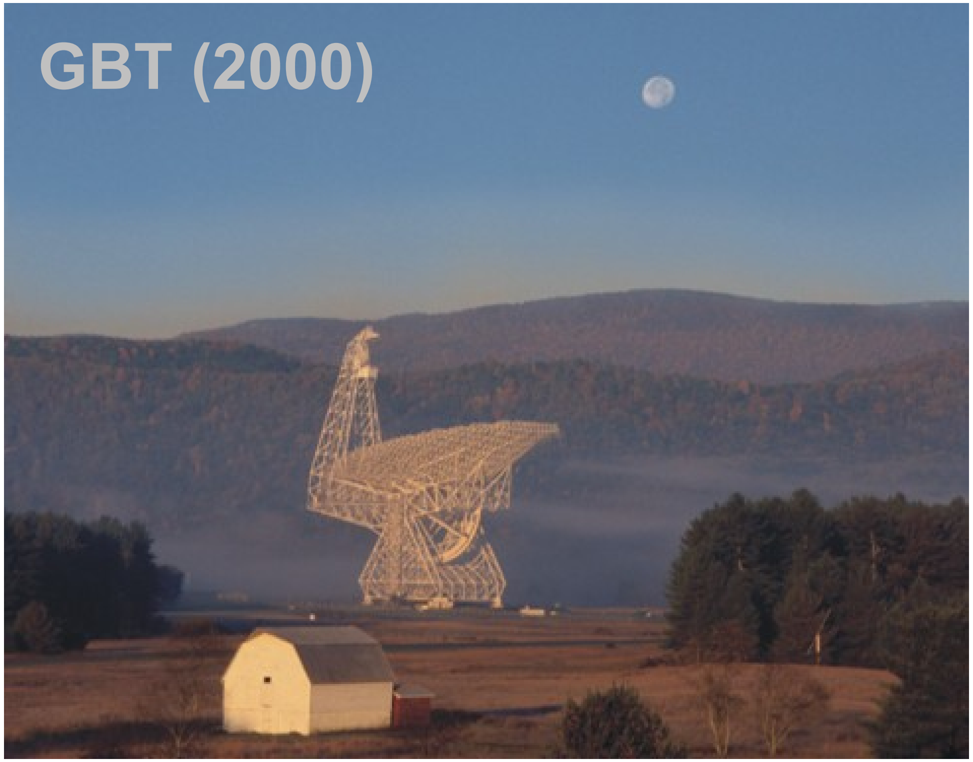
Resolution : $\theta = \lambda / D$

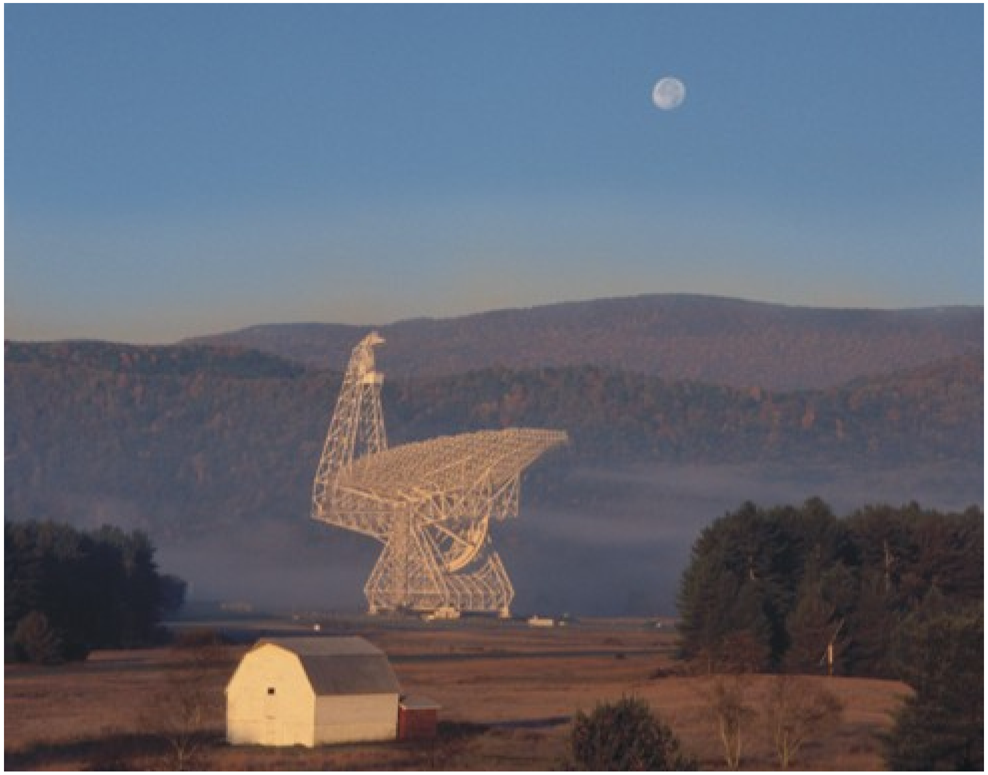
Diffraction limit



θ = 3'

θ = 0.003''





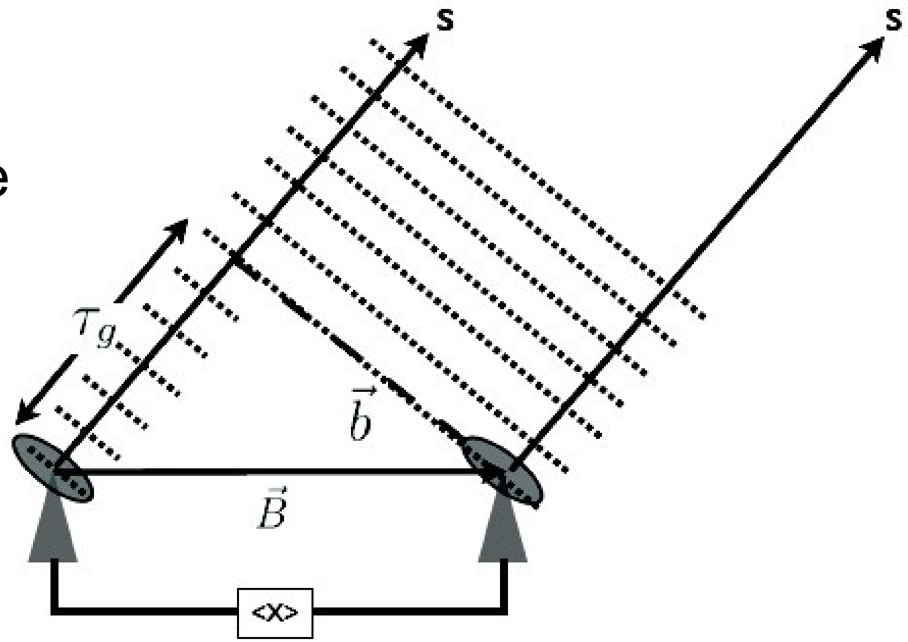
a radio telescope is a single pixel machine with poor resolution

Two element radio interferometer

Cross correlation, resolution $\theta = \lambda / B_{max}$

Input source voltage signals induced by incoming elm wave electric field oscillations:

$$V_1 \text{ and } V_2$$



are combined together and time-averaged in the correlator. The voltages at each telescope (1 and 2) are composed of the source signal, V_s, and the receiver noise,

$$V_1 = V_s + V_{R1}$$

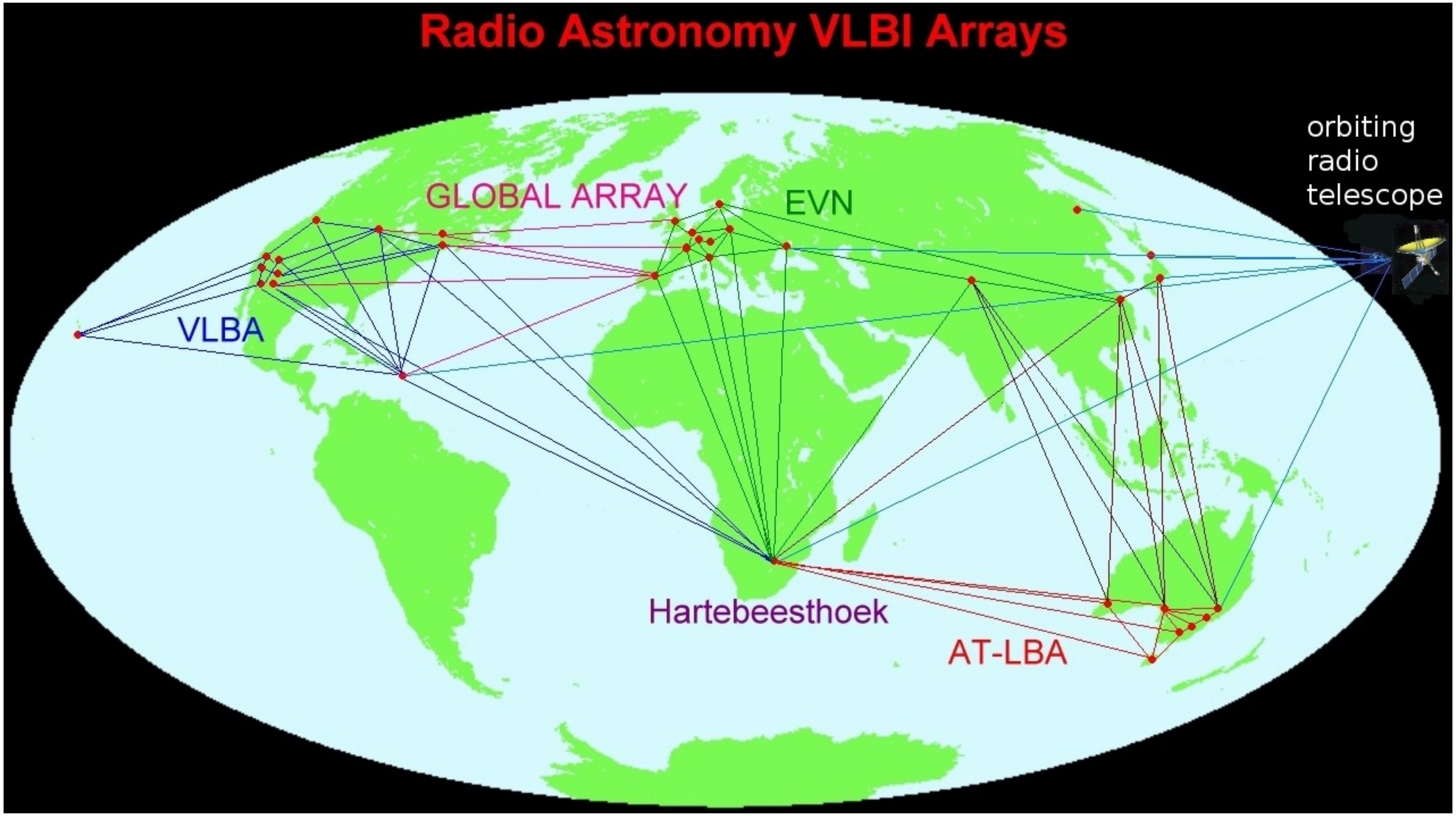
and

$$V_2 = V_s + V_{R2}$$

The signals from the two telescopes are **multiplied** together:

$$\langle (V_1 V_2) \rangle = \langle (V_{R1}V_S + V_{R1}V_{R2} + V_S V_{R2} + V_S^2) \rangle = \langle V_S^2 \rangle$$

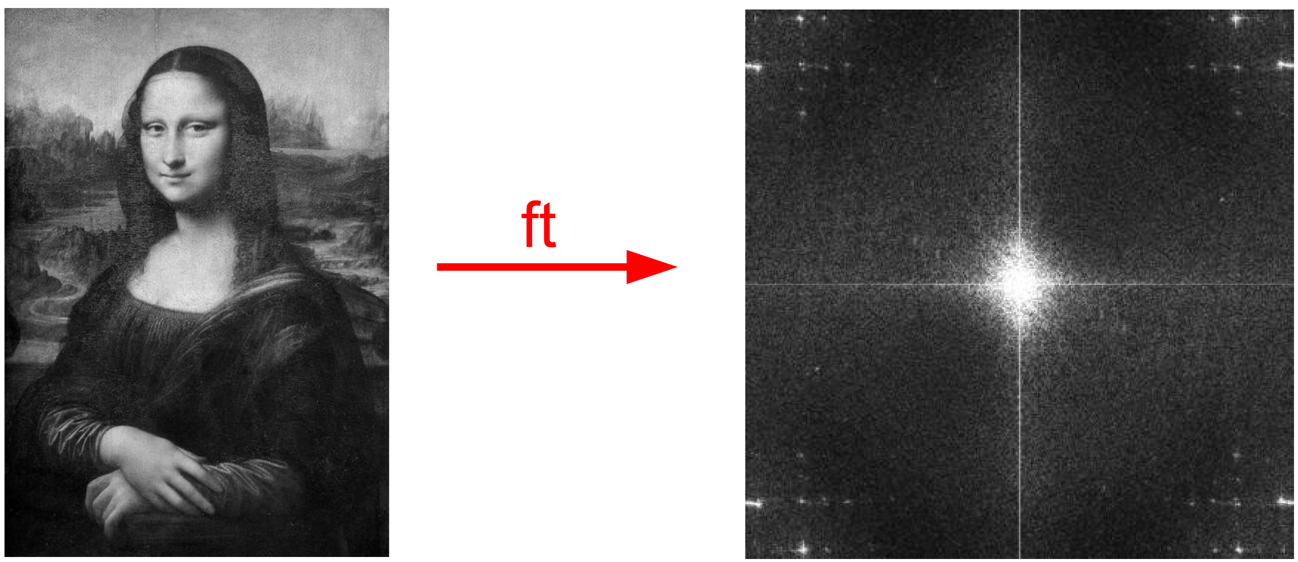
Radio interferometry can provide very accurate positions.
The Very Long Baseline Interferometry (VLBI) technique provides the most accurate positions (and proper motions) in all of astronomy.
Absolute positions can be measured to better than 1 milliarcsecons.
In particular, VLBI defines the ICRS (the international celestial reference system) which is the fundamental frame in which all celestial bodies are measured.



Aperture synthesis

Fourier transform

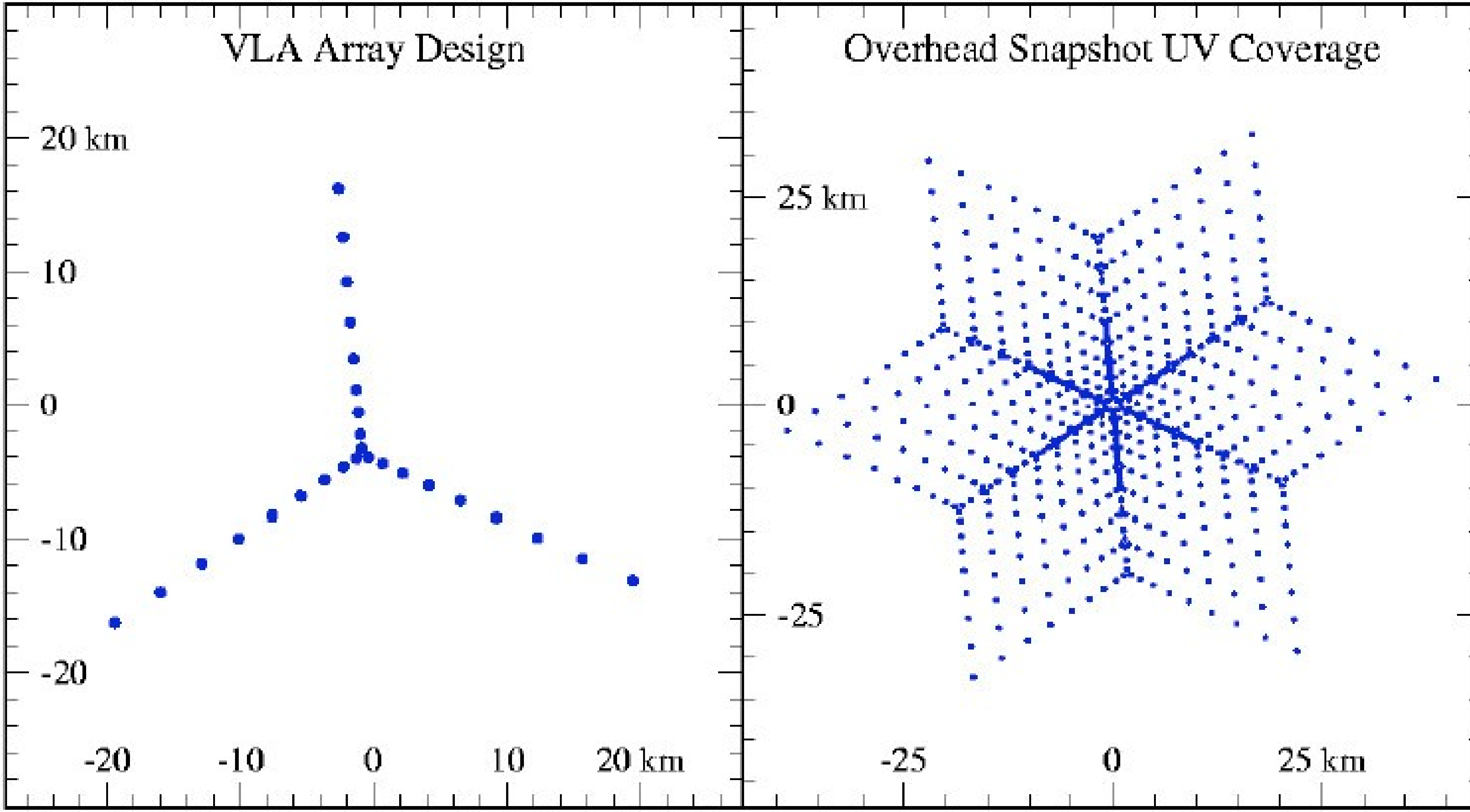
In the late 40s Pawsey, McCready and Payne-Scott recognized that the interferometer's response to an extended source amounted to determining a particular value of the Fourier transform of the source brightness distribution,



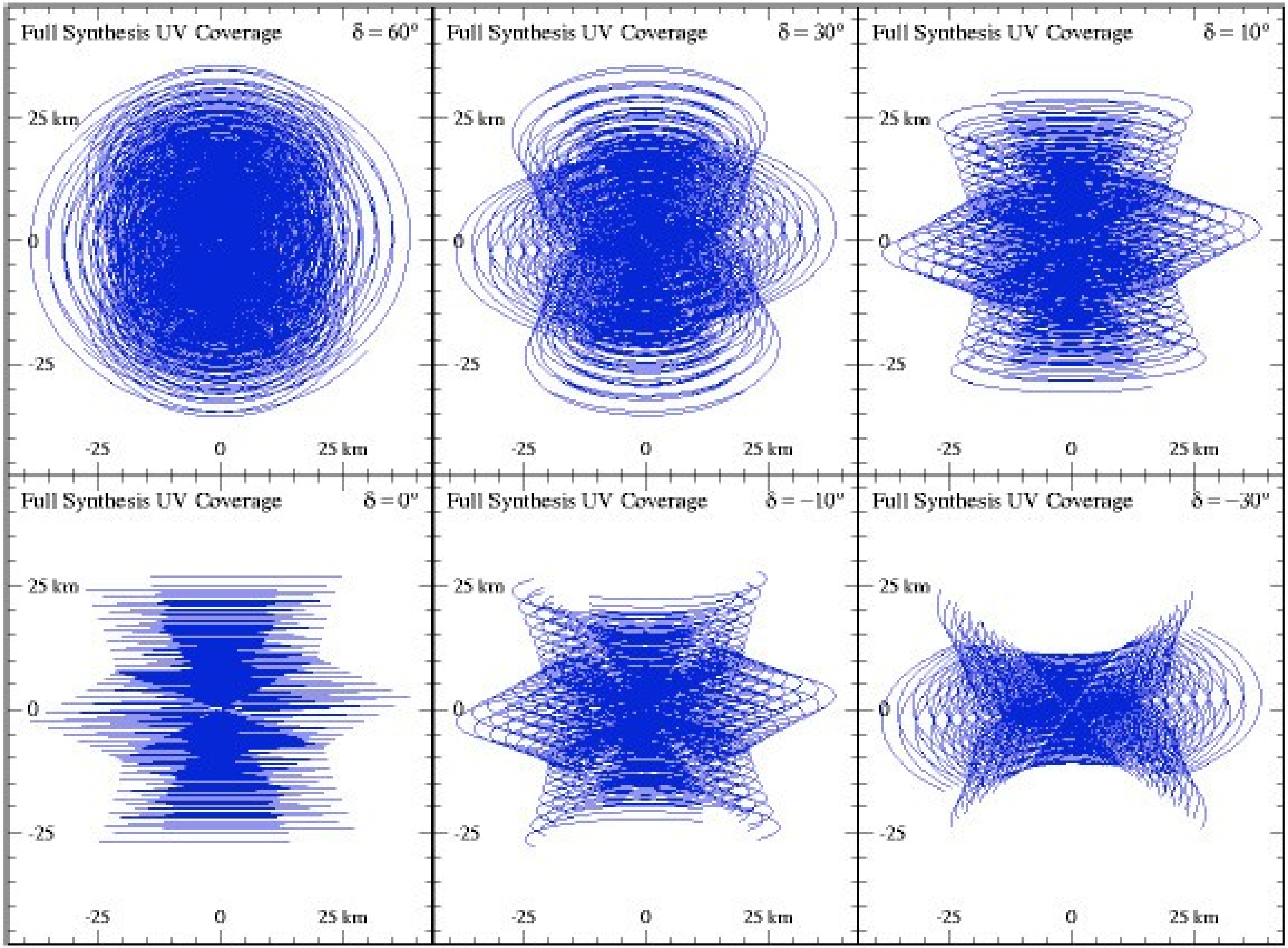
A point in the Fourier space plane with a distance $1/\lambda$ from the origin corresponds to a plane wave with a wavelength of λ and normal vector parallel to the connecting line between origin and that point. A point at the origin corresponds to λ = infinity.


VLA: 27 dishes of 25 m diameter

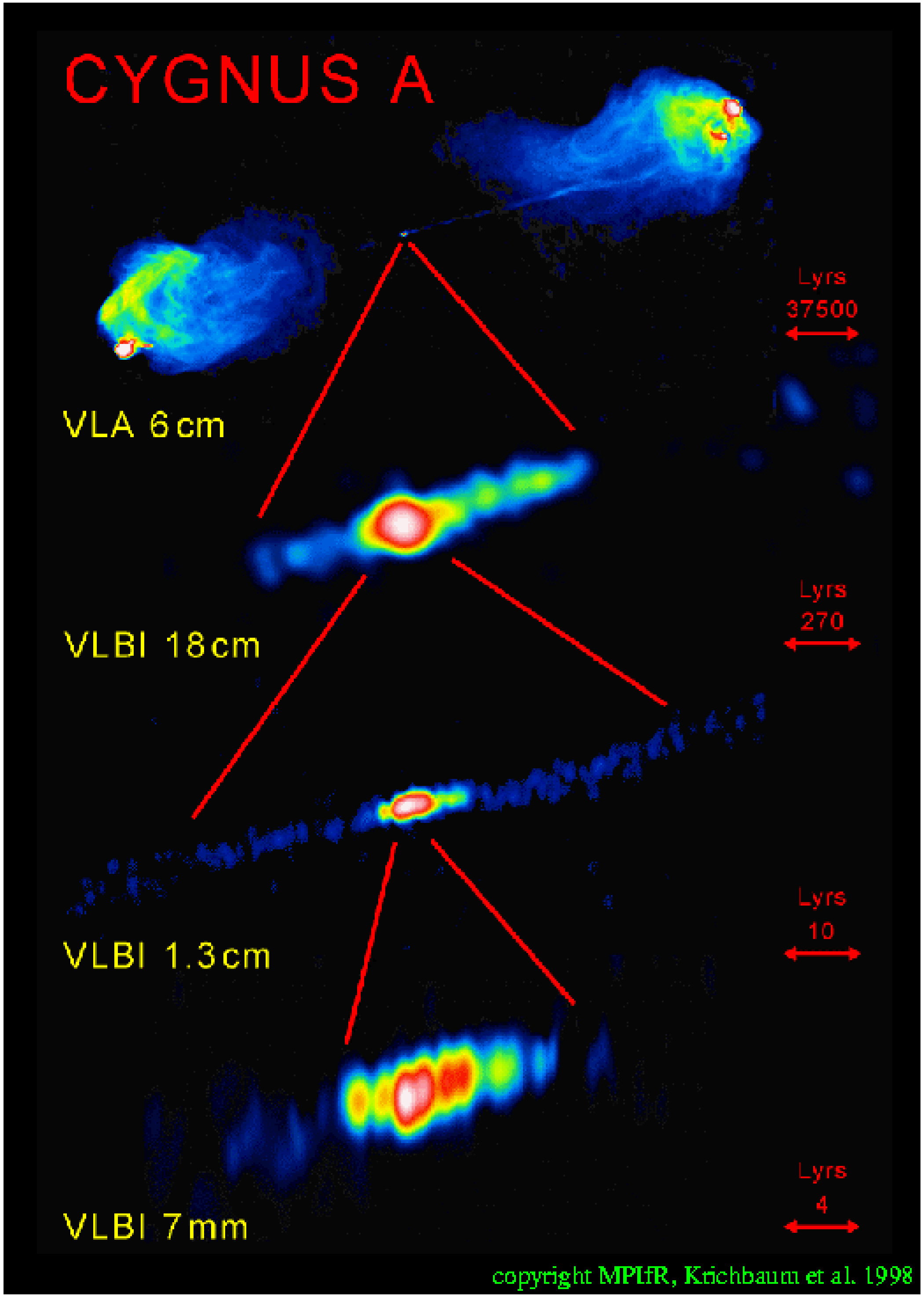
UV plane (similar to Fourier space plane)



UV coverage, taking rotation of the earth into account



Tracks: elevation > 10 degrees



arcmin

arcsec

milliarcsec

A radio telescope is a single pixel machine

High resolution radio imaging requires:

- **multi aperture (Fourier) approach**
- **large computational capacity**