Communication

Communication

Much cheaper than travel

Energy needed for Mass (M) at speed (v)

$E = 1/2\ Mv^2$ if v much less than c

e.g., travel to nearest star (4 *l*y) in 40 yr

$\Rightarrow$ v = 0.1 c $\Rightarrow$ $E = 4.1 \times 10^{-9}$ ergs

for M = M (electron)

Photon $E = h\nu$ $h = 6.6 \times 10^{-27}$

ν = frequency

$= 6.6 \times 10^{-18}$ ergs if $\nu = 10^9$ Hz

Ratio ~ 10^9 (and photon gets there in 4 yrs)

100 M watt transmitter - 1 yr

\$ 40×10^6

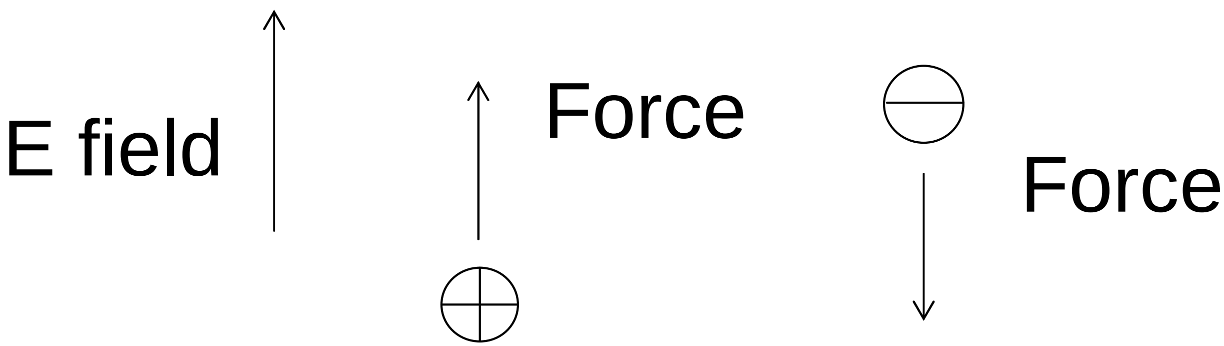
Spacecraft to nearest star

~ \$ 5×10^{16}

(some recent analysis questions this conclusion)

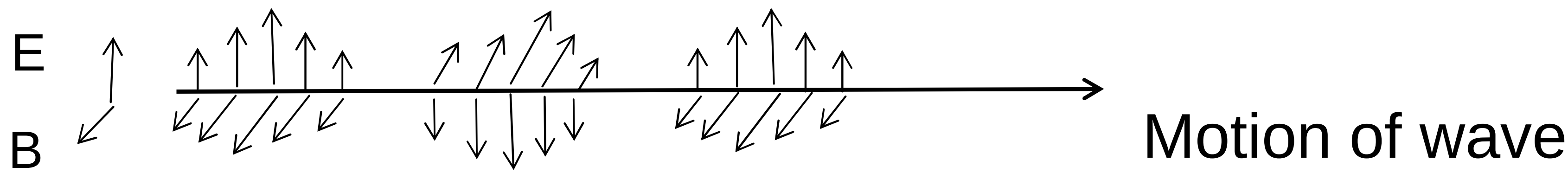
Light is an Electromagnetic Wave

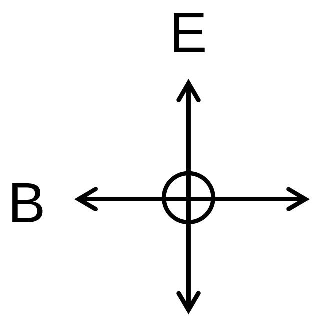
Electric Field: Indicates force on charged particle



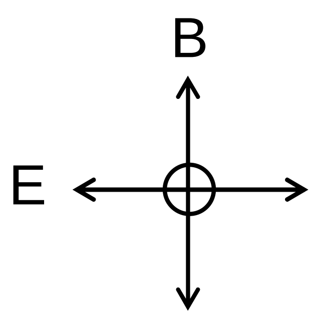
Magnetic field: created by changing electric field. At right angle to electric field.

Electromagnetic Wave

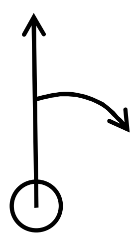




Vertically Polarized



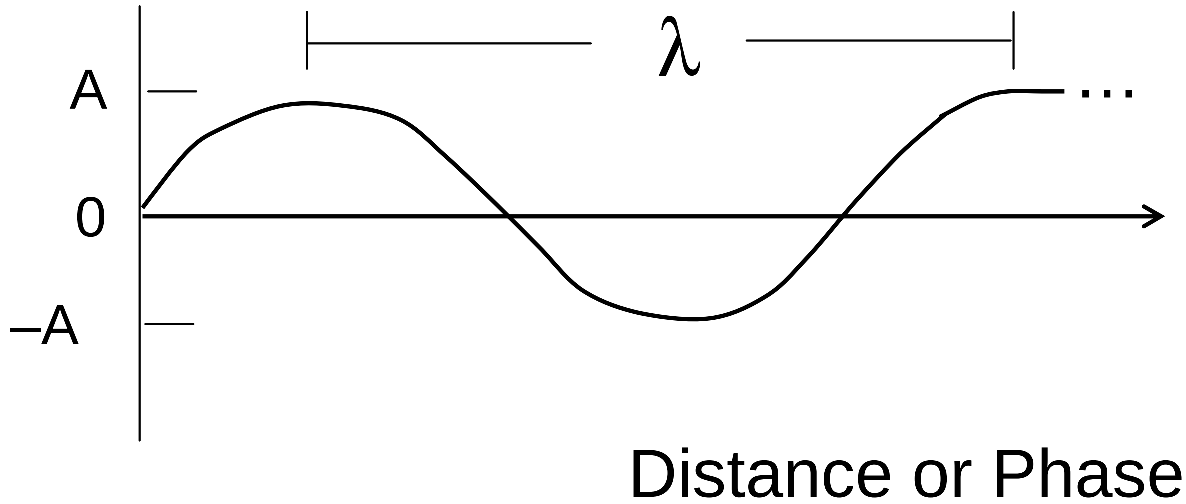
Horizontally Polarized



Circularly Polarized

Wave Properties

Snapshot

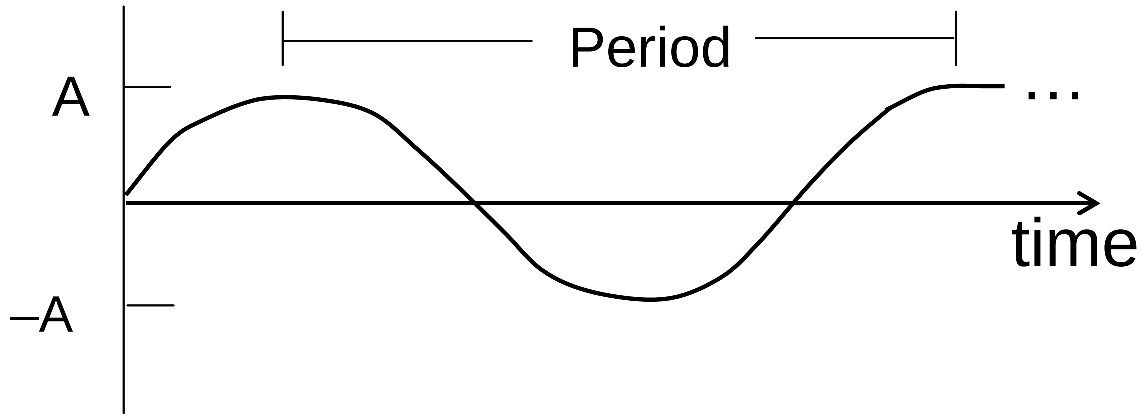


A = Amplitude

λ = Wavelength

Wave Properties

Look at one point along wave



ν = frequency = $\dfrac{1}{\text{period}}$

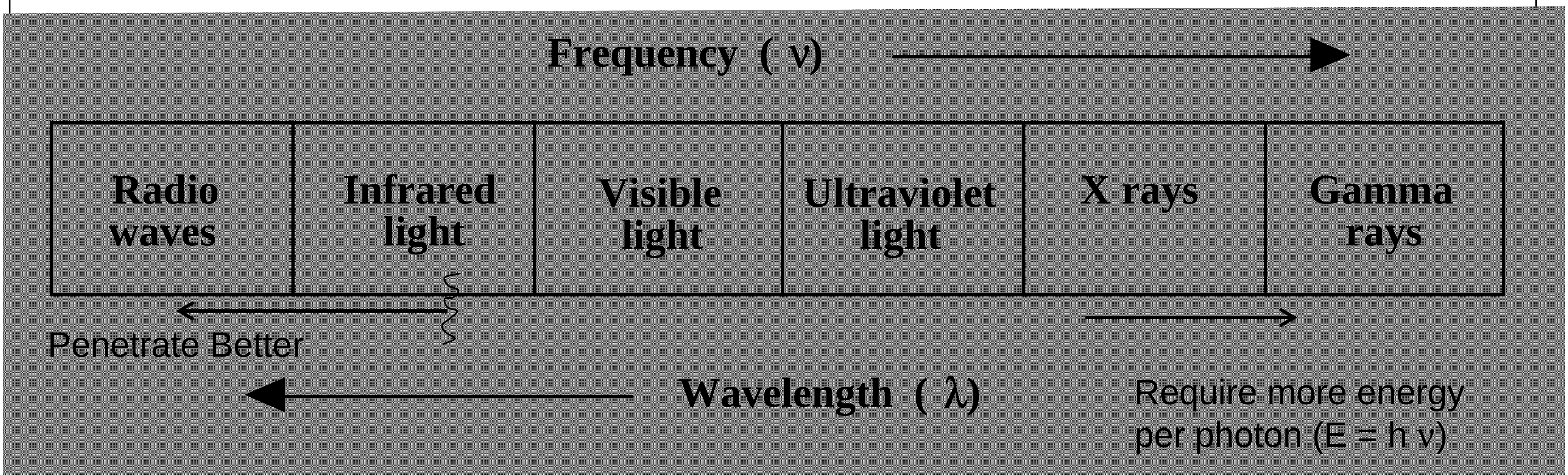
# of cycles per second (hertz, Hz)

1 kHz = 10^3 Hz 1 MHz = 10^6 Hz

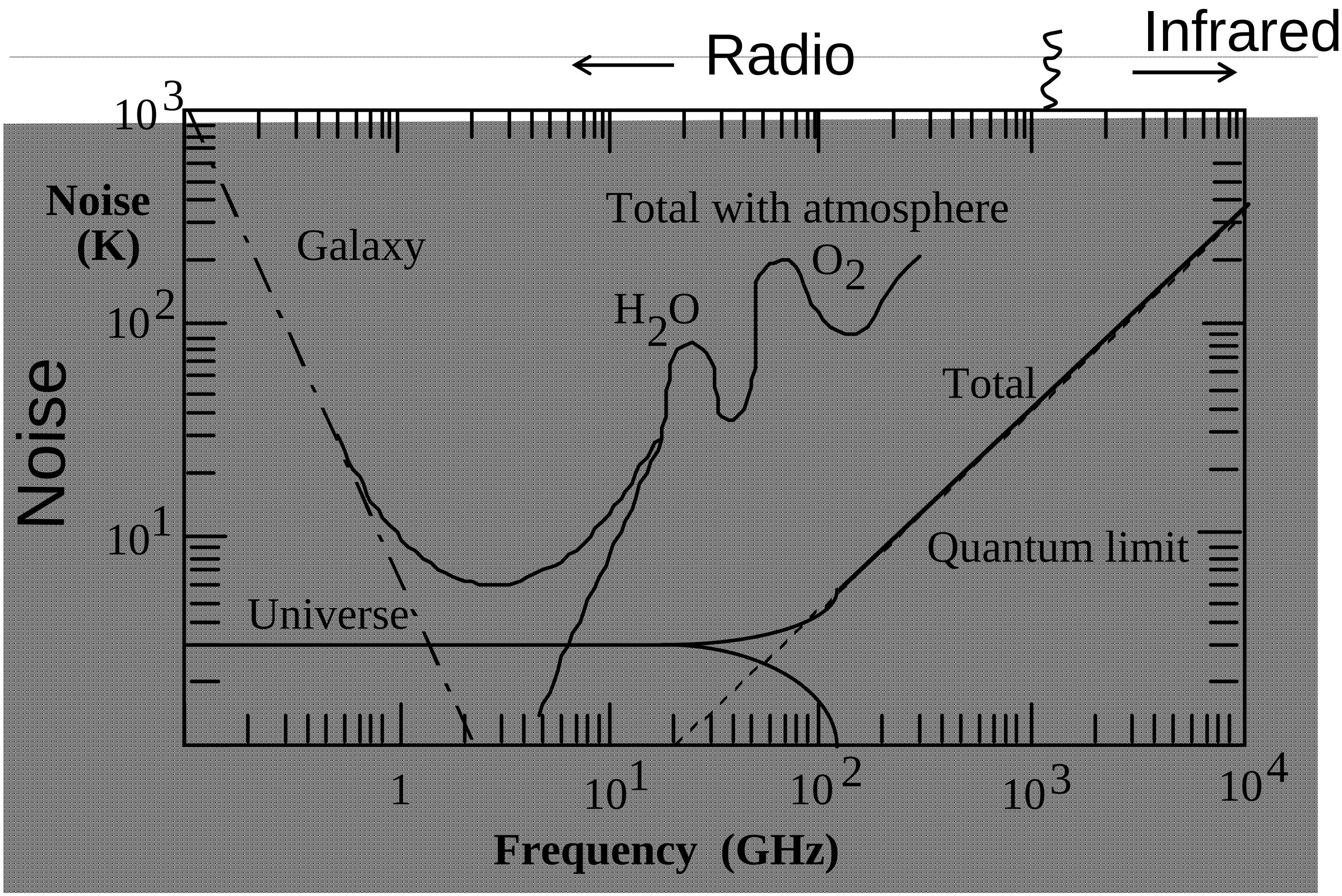
1 GHz = 10^9 Hz

Speed of light $c = \lambda\nu \Rightarrow \lambda = \dfrac{c}{\nu}$

Electromagnetic Spectrum (Light)



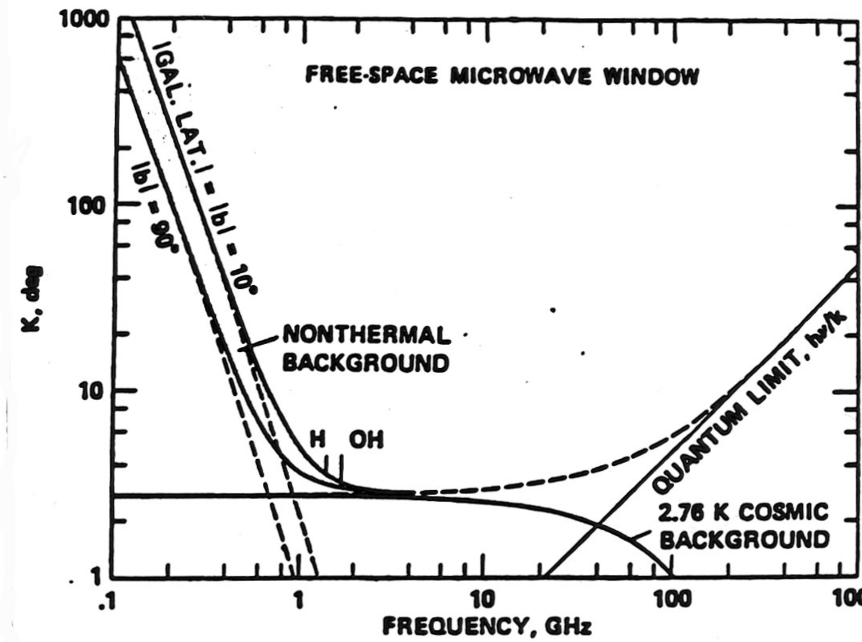
Noise: Any unwanted signal
Artificial, Natural



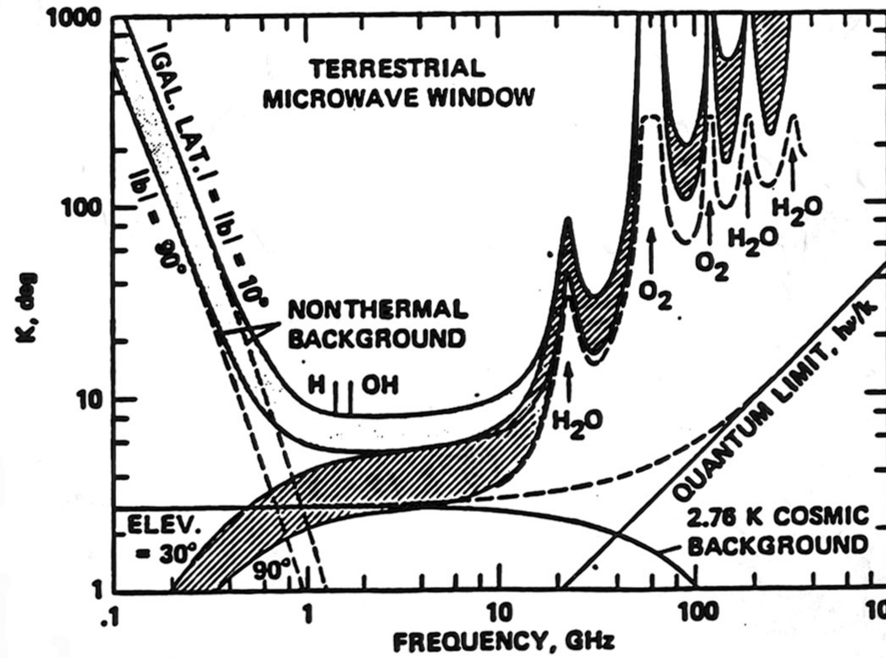
ν = (GHz)

10^9 Hz

Figure 6.8



Free-space microwave window, in which the basic noises that limit radio communication over interstellar distances are least disruptive.



Terrestrial microwave window. Atmospheric water vapor and oxygen degrade the upper end of the microwave window for receivers on Earth's surface and raise the temperature in the lower portion of the window.

Magic Frequencies

1. Morrison & Cocconi 1959

   ν = 1.42 GHz λ = 21 cm

   H atoms

2. Water "Hole"

   OH 1st molecule discovered at Radio λ

   ν = 1.6 GHz

   H + OH $\longrightarrow$ H_2O

   Low Noise "Hole"

   1.4 1.6 GHz

3. Kuiper - Morris

Use fundamental constants

$$\nu = \frac{c}{\text{length}}$$

all very high ν

Most plausible is electron "radius"

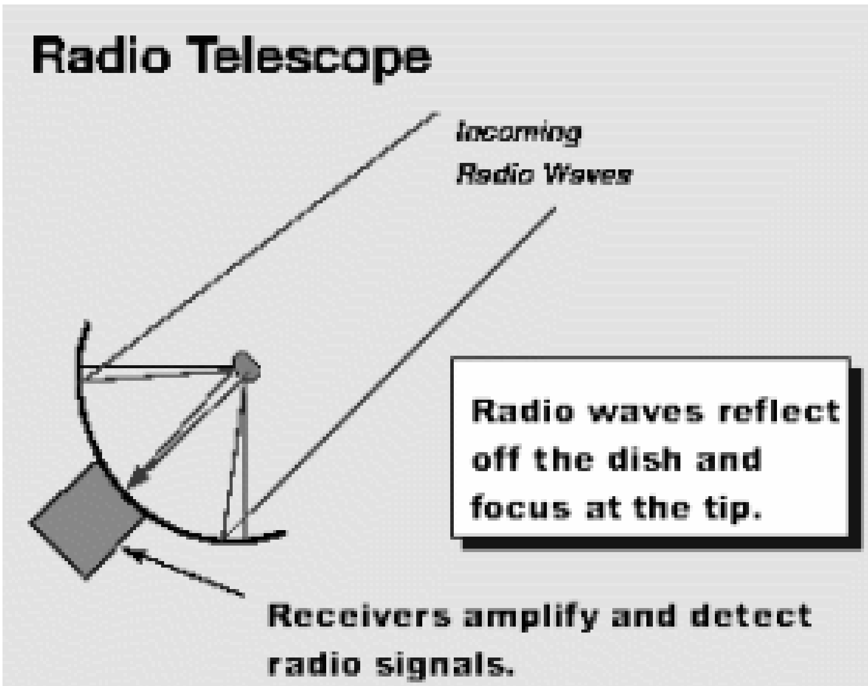
Scale by powers of "fine structure constant"

$$\sim \frac{1}{137}$$

(if multiply 5 times, get to radio)

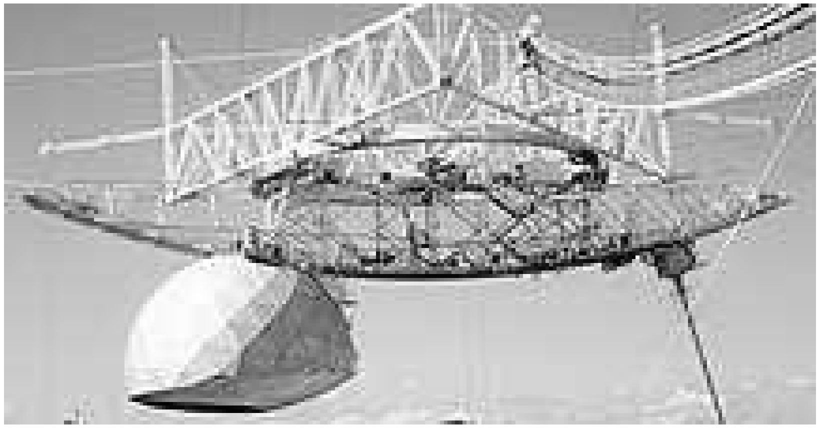
$\longrightarrow$ $\nu = 2.5568$ GHz

Radio Telescope Principle



Green Bank Telescope (GBT)

Arecibo Telescope

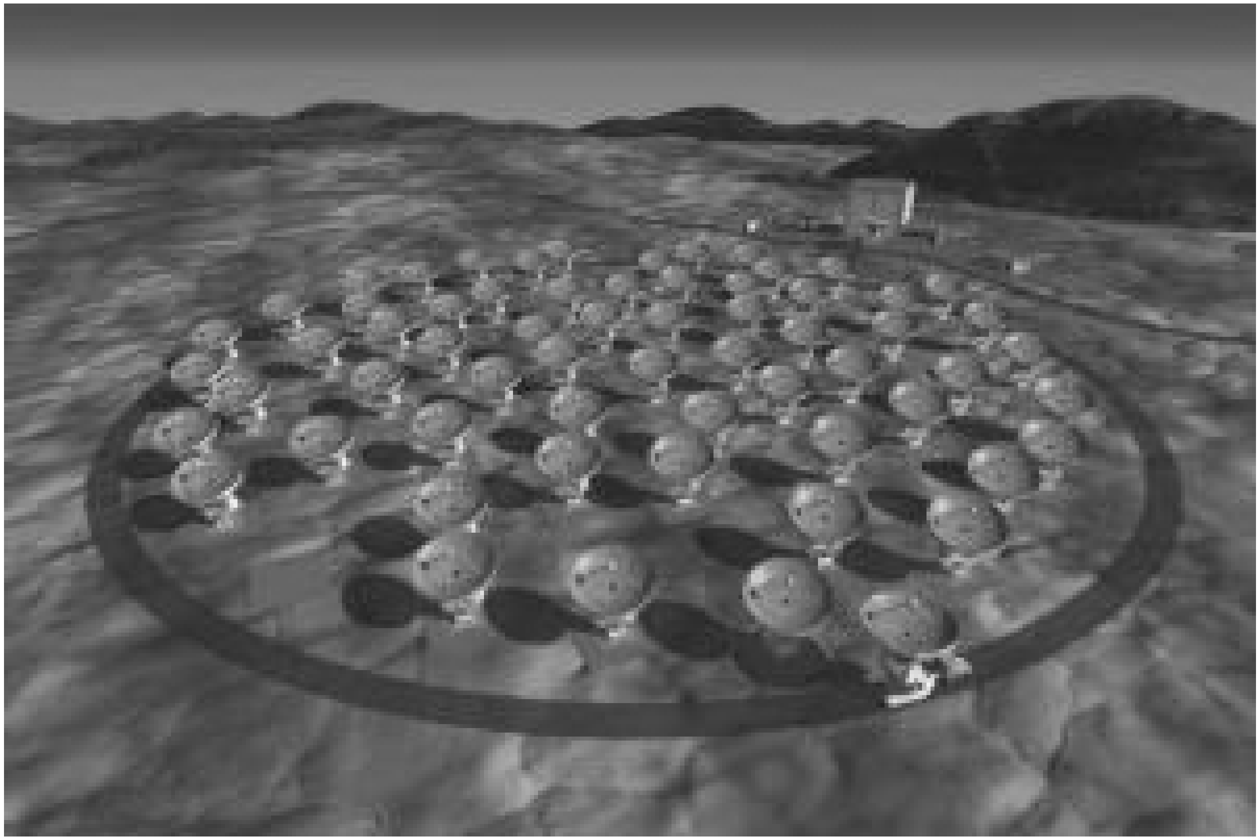


Very Large Array (VLA)

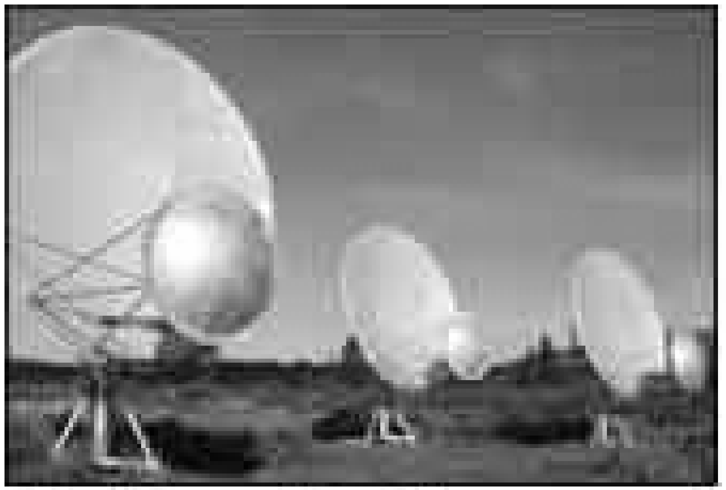
Very Long Baseline Array (VLBA)

Caltech Submillimeter Observatory (CSO)

Atacama Large Millimeter Array (ALMA)



Allen Telescope Array (ATA)



Prototype Test Array

Recognizing the Message

Distinguishing from natural "signals":

Expect: Variation with time, narrow band (small range of freq.)

Crucial $\longrightarrow$ Not random noise

If not random, it is artificial (ETI or Human)

Examples of natural signals that <u>might</u> have been ETI

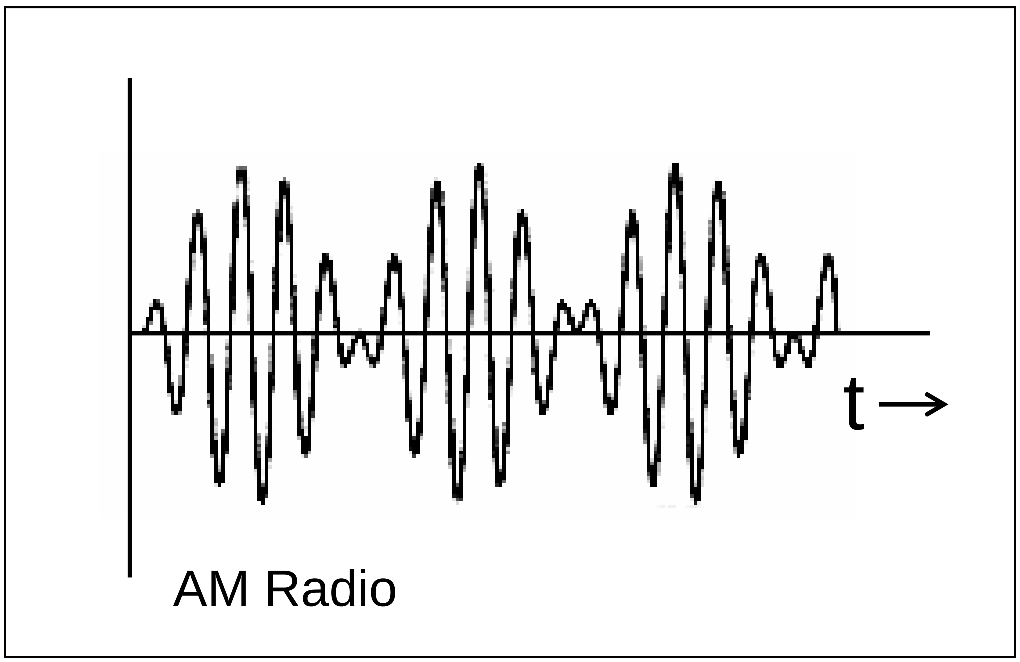
1. Pulsars (LGM)
2. OH Masers

Both are random noise (no coded information)

Coding the Message

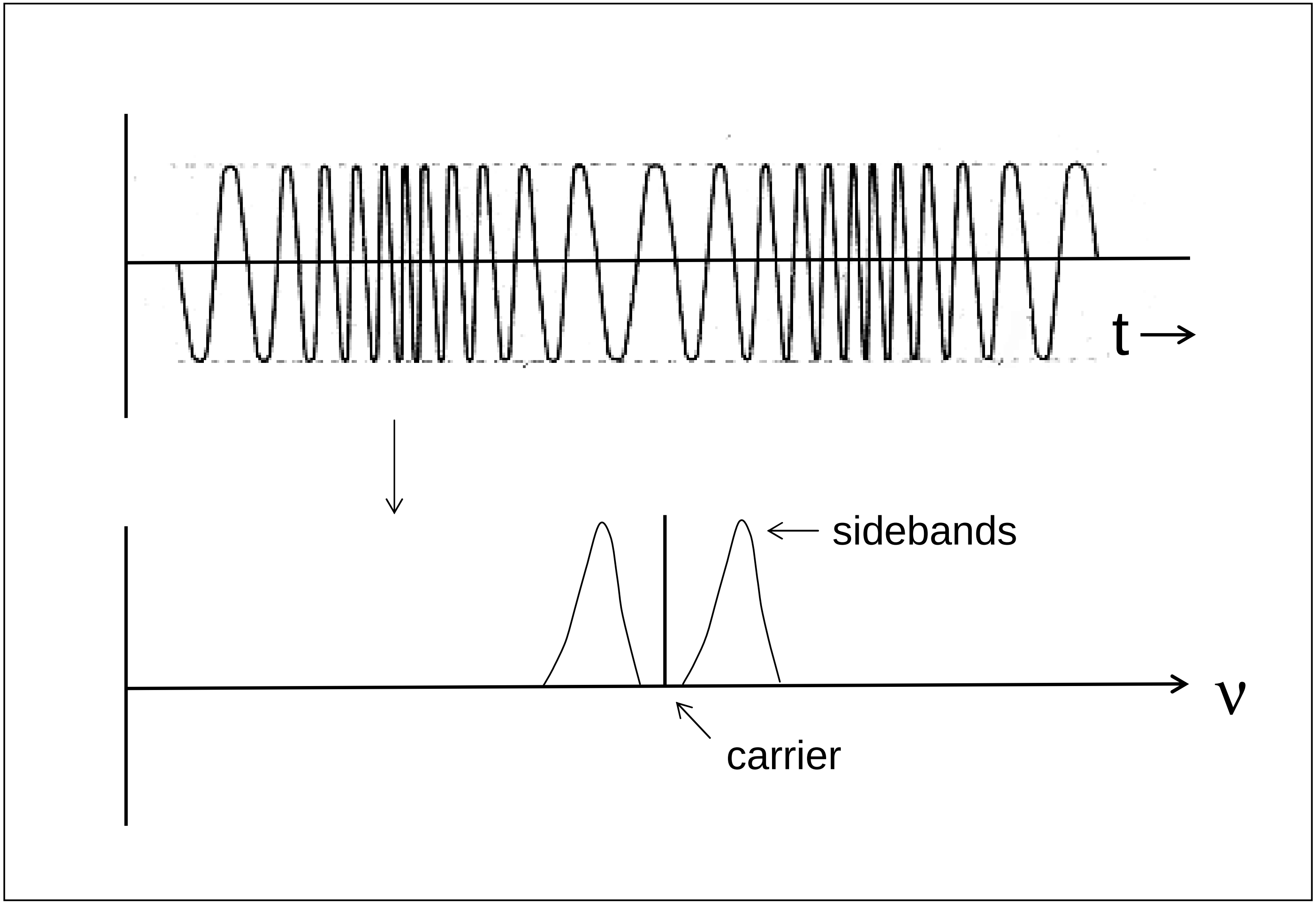
Change the signal with time

1. Amplitude modulation (AM)

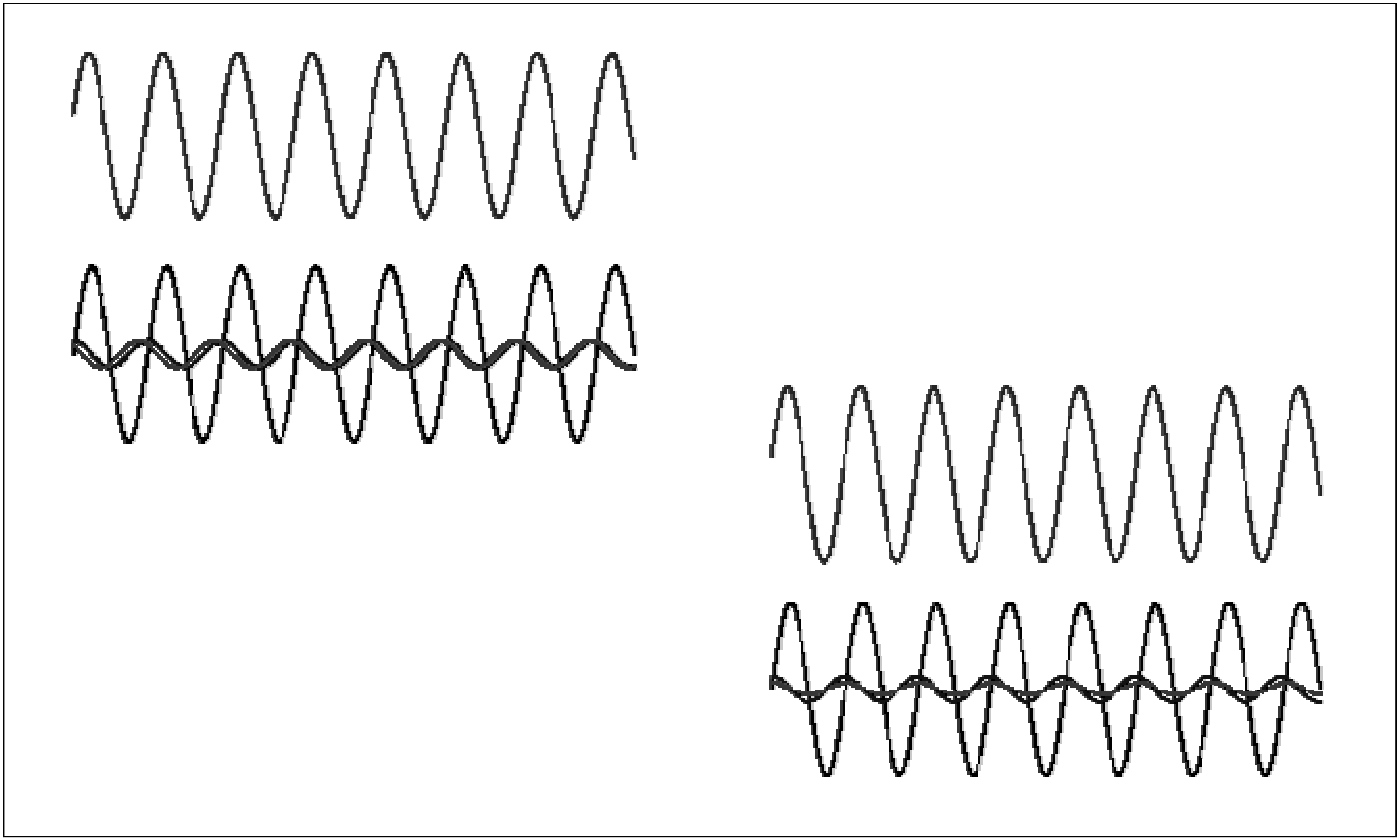


Coding the Message

2. Frequency Modulation (FM Radio)



Coding the Message



http://www.chem.tamu.edu/rgroup/north/FM.html

Analog vs. Digital

1. Analog - need accurate amplifiers, etc.
   to avoid distortion
   e.g. radios, tv, records, analog tapes

2. Digital → “digitize” signal
   Represent by Base 2 Number

Base 10	Base 2
0	0
1	1
2	10
3	11
4	100
⋮	⋮

Analog vs. Digital

Send one digit at a time so electronics just need to Distinguish 1 from 0

Can use 2 very different voltages

$\longrightarrow$ Need fast digital electronics

e.g. CD’s, DVDs, Computers, Digital Tapes, Digital TV, …

Decoding the Message

Assume Digital

Repeat to Establish Pattern

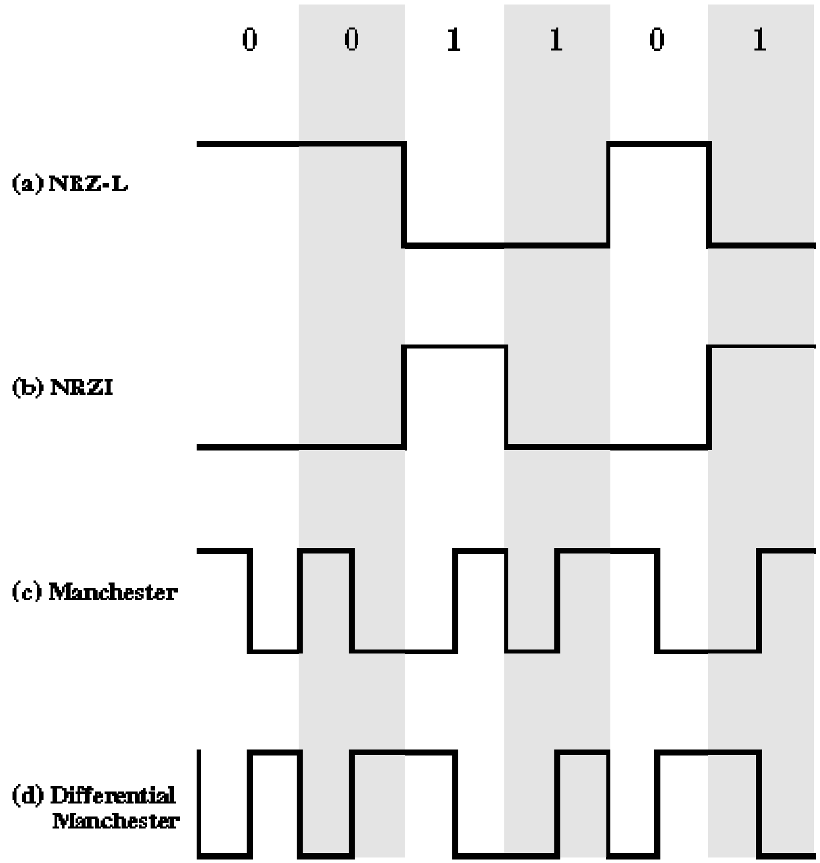


Figure 5.5 Examples of Digital Signal Encoding Schemes

Image? 1 dimension (string of bits)

↓

2 dimensions

Rows + columns

Make product of # rows + # of columns

each a prime number

e.g., $23 \times 73 = 1679$ so 23 rows, 73 columns

or vice versa

Semantics

Can we <u>understand</u> the message?

0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 1 0
0 0 0 0 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 1 0 0 1 0 1 0 1 0 1
0 1 0 1 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0
1 1 1 0 0 0 1 1 0 0 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 1 0
0 0 0 1 1 0 1 0 0 0 1 1 0 0 0 1 1 0 0 0 0 1 1 0 1 0 1 1 1 1 1 0 1 1 1 1 1
0 1 1 1 1 1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 0 0 0 0 1 1 0 0 0 0 1 1 1 0 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 0 1 0 0 0 0 1 1 0 1 0 0 0 0 1 1 0 0 0 1 1 1 0 0 1 1 0 1 0 1 1 1
1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0
0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1
0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0
1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 1 0 0 0 0 1 1 0 0 0 0 0
0 0 0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0
0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0
1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0
0 1 0 0 0 1 1 1 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
0 1 0 1 1 1 0 1 0 0 1 0 1 1 0 1 1 0 0 0 0 0 0 1 0 0 1 1 1 0 0 1 0 0 1 1 1
1 1 1 1 0 1 1 1 0 0 0 0 1 1 1 0 0 0 0 0 1 1 0 1 1 1 0 0 0 0 0 0 0 0 0 1 0
1 0 0 0 0 0 1 1 1 0 1 1 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 1 1 1 1 1 0 0
1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 1 0 0 0 0 0 1 1 0 1 1 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0
0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 1 0 1 0 0 0 1 0 1 0 1 0 1 0 1
0 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 1 1 1
0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 0 1 0
0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 1 1 0 0 1 1 0 0
0 0 1 0 0 0 1 0 1 0 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 1
0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 1 1
1 1 1 0 1 0 0 1 1 1 1 0 0 0

Figure 19.12 The message sent in 1974 from the Arecibo telescope in the direction of the globular cluster M13 consists of 1679 bits of information, either "on" or "off," shown here as 0's and 1's.

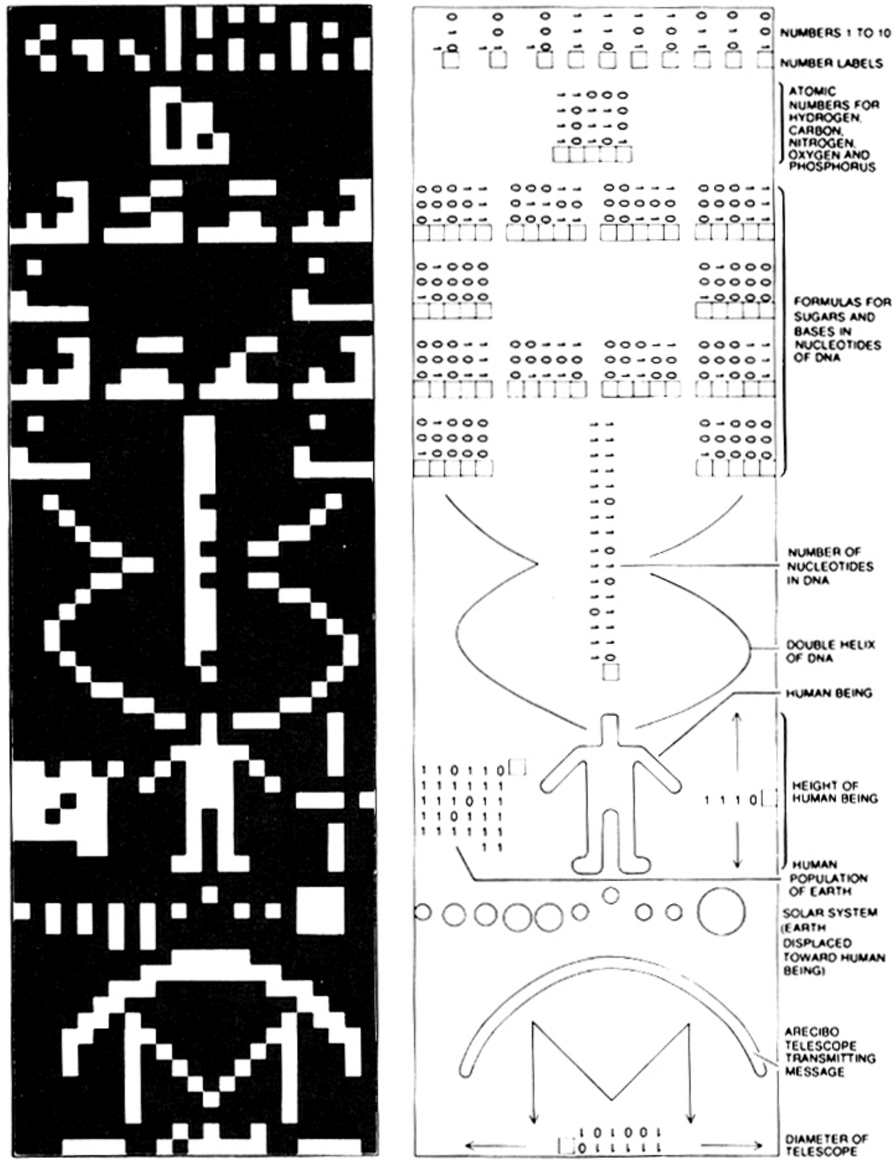


Figure 19.13 If the 1679 bits of the Arecibo message are arranged into 23 columns of 73 rows each, and if the on and off bits are given different colors, a picture emerges that is loaded with information—for those who can decipher it.

Leakage Radiation

- Various sources
  - TV, radio, …
    - Repeatable pattern due to Earth rotation
  - Defense radars
    - Most powerful, but won’t repeat

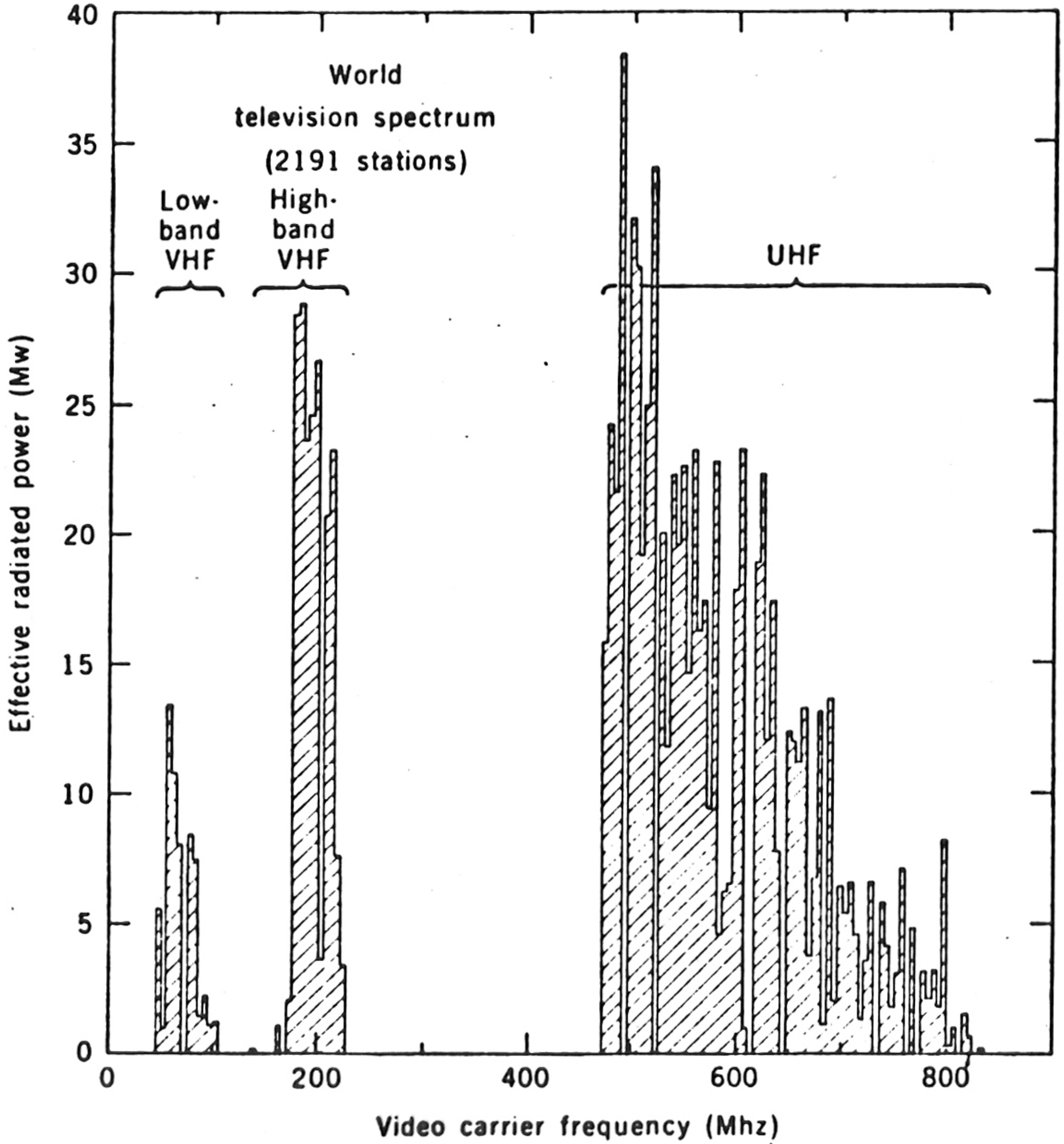
TABLE 20-1

ESTIMATED POWER OUTPUT OF VARIOUS RADIO-PHOTON SOURCES THAT OPERATE AT FREQUENCIES GREATER THAN 20 MHz

				Per Individual Transmitter		
Source	*Frequency Range (MHz)*	*Number of Transmitters*	*Fraction of Time that Transmitters Emit*	*Maximum Power Radiated (watts)*	*Effective Frequency Bandwidth (hertz)*	*Total Average Power Radiated (watts per hertz of bandwidth)*[a]
Citizen-band radios	27	10,000,000	1/100	5	2	200,000
Professional landmobile radios	20–500	100,000	1/10	20	1	200,000
Weather, marine, and air radars	1000–10,000	100,000	1/100	10,000 to 1,000,000	1,000,000	10 to 1000
Defense radars[b]	400	2	1/10	10,000,000,000	0.1	20,000,000,000
FM radio stations	88–108	10,000	1	4000	0.1	400,000,000
TV stations (for photons that carry picture, not sound)	40–850	2000	1	500,000	0.1	10,000,000,000

[a]The last column shows the power radiated *per hertz of bandwidth*. Systems that cover a wider bandwidth (most noticeably, weather, marine, and air radars) will radiate a greater total power over *all* frequencies than this column would suggest. This table, as well as Figures 20-7, 20-8, and 20-9 follow the results of a study made by W. Sullivan III, S. Brown, and C. Wetherill in *Science*, vol. 199, p. 377, 1978.

[b]We have considered only the most powerful defense radars; these dominate the total power output from all such radar systems.



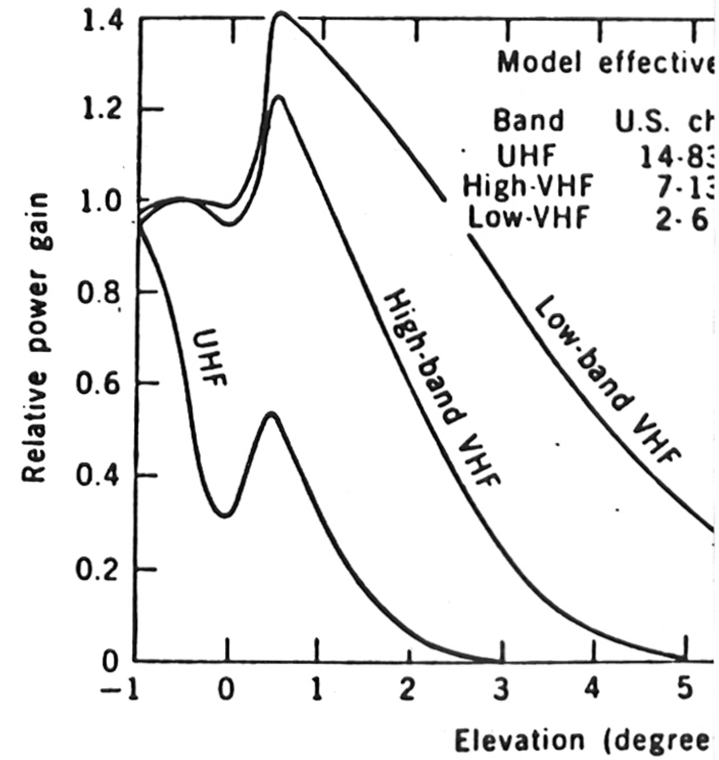
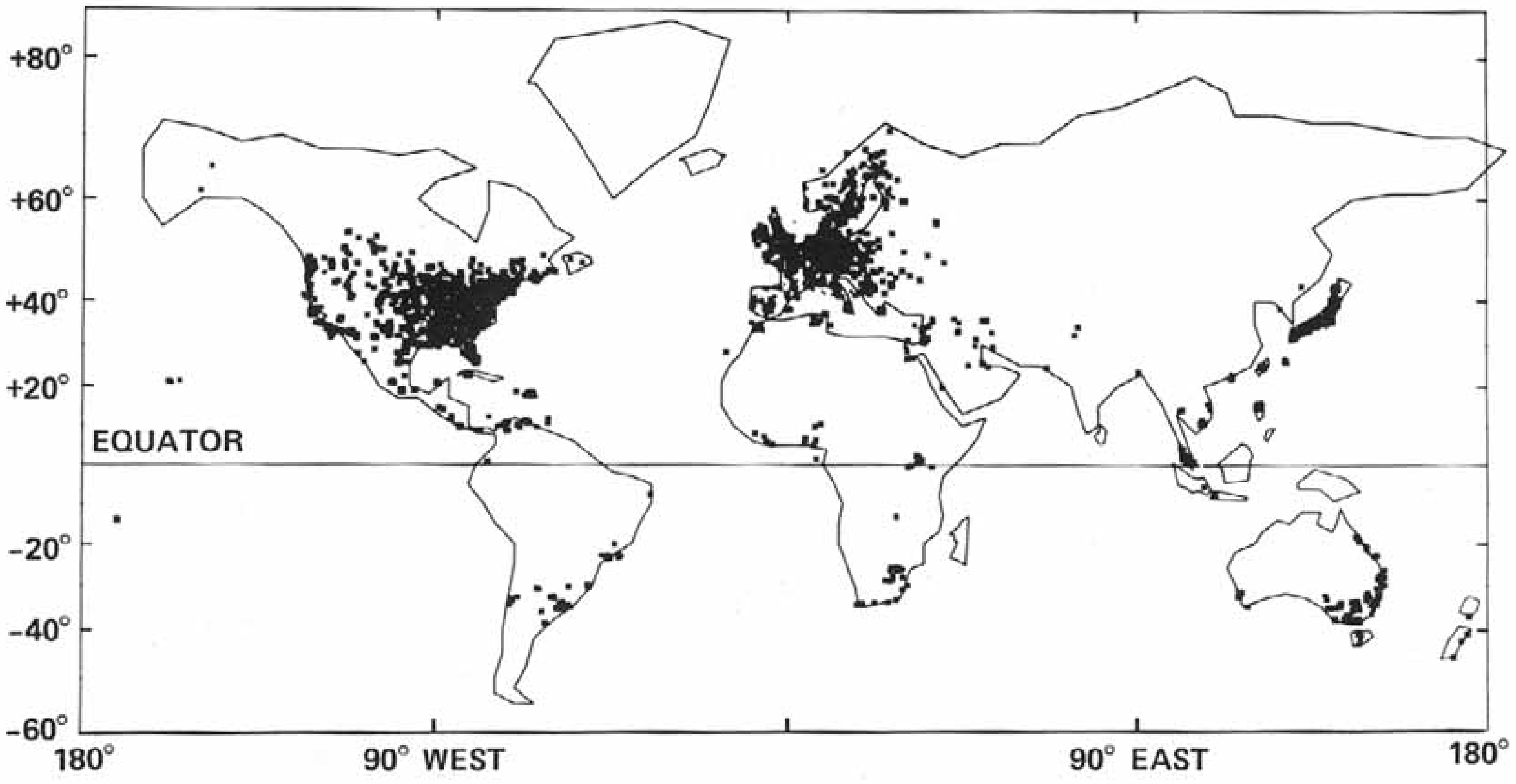
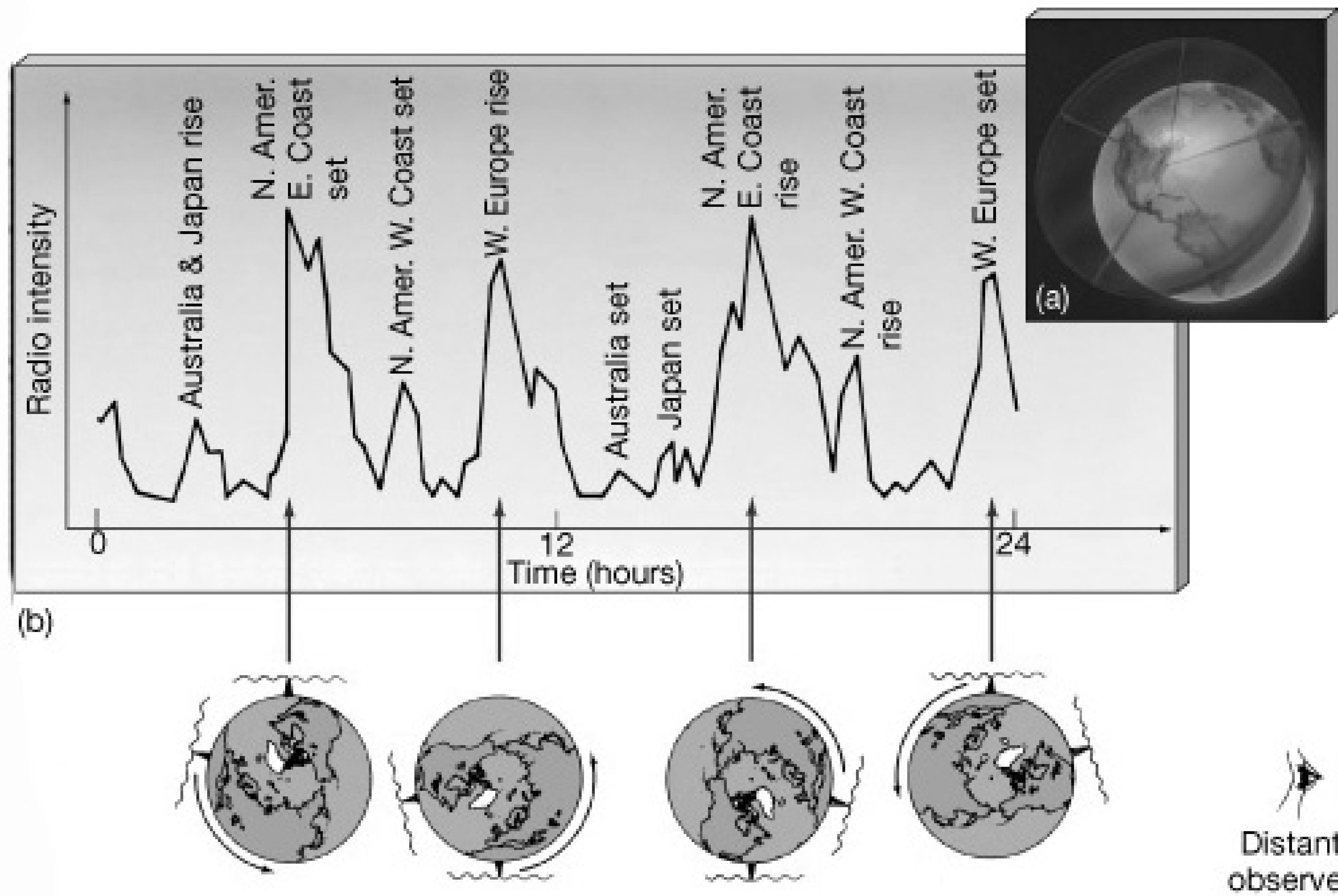


Fig. 3 (left). World television spectrum, show which the most power is radiated (5-Mhz-v primary bands (channels 2 to 6, 7 to 13, and States) are also indicated. A distant extrater a frequency resolution of 5 Mhz would at n spectrum roughly of this shape. Fig. 4 tenna power patterns adopted in the model television frequency bands. The radiation is s to the local horizon of each transmitter and directional in azimuth.

World Television Transmitters




(a)
(b)
Radio intensity
Australia & Japan rise
N. Amer. E. Coast set
N. Amer. W. Coast set
W. Europe rise
Australia set
Japan set
N. Amer. E. Coast rise
N. Amer. W. Coast rise
W. Europe set
0
12
24
Time (hours)
Distant observer

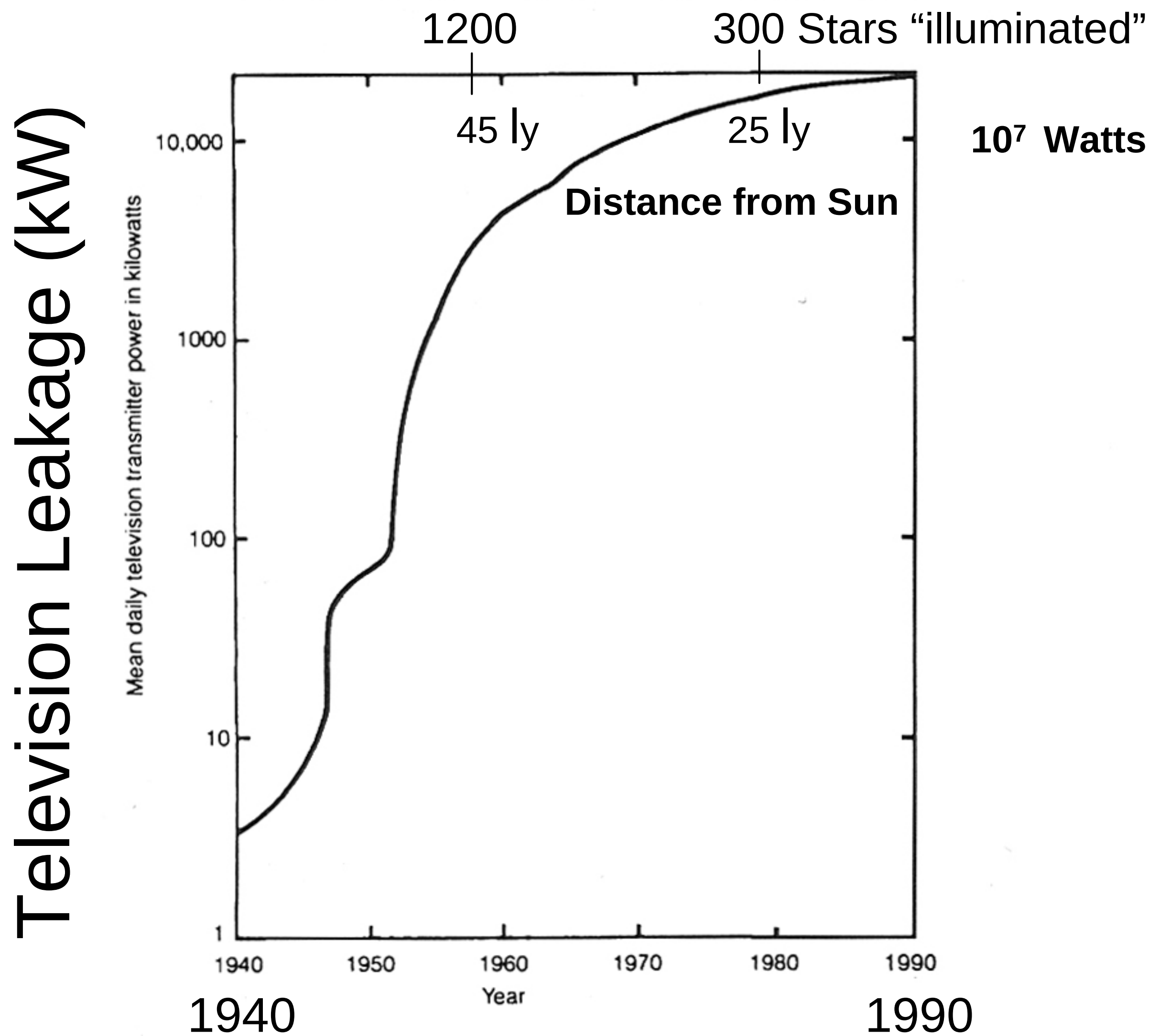


Figure 19.8 The Earth's power output in the radio region of the spectrum has increased many thousandfold since the start of the World War II in 1939.