Communication, 2.

Recognizing the Message

Distinguishing from natural "signals":

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

Crucial → Not random noise

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

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

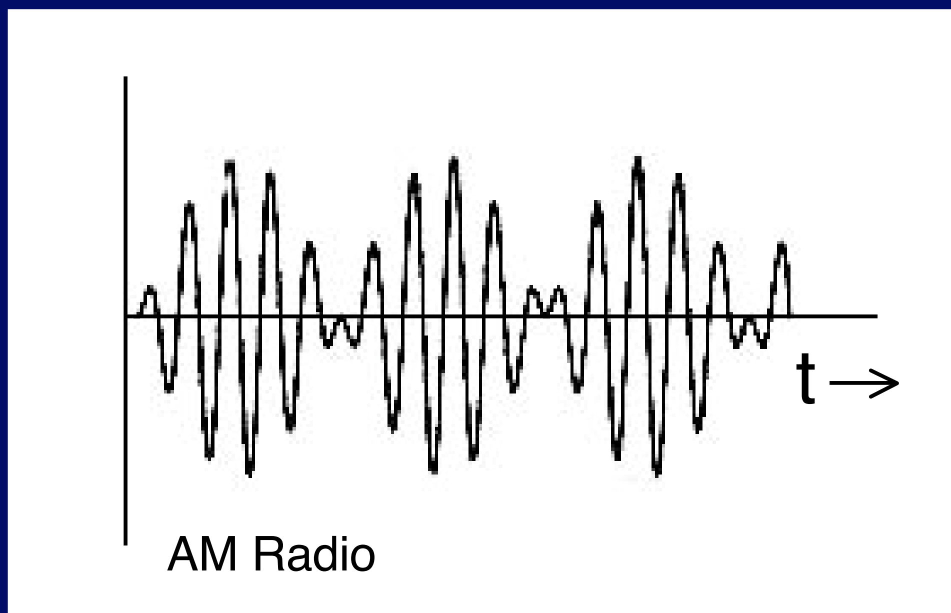
1. Pulsars (LGM)
2. OH Masers

Both are random noise (no coded information)

Coding the Message

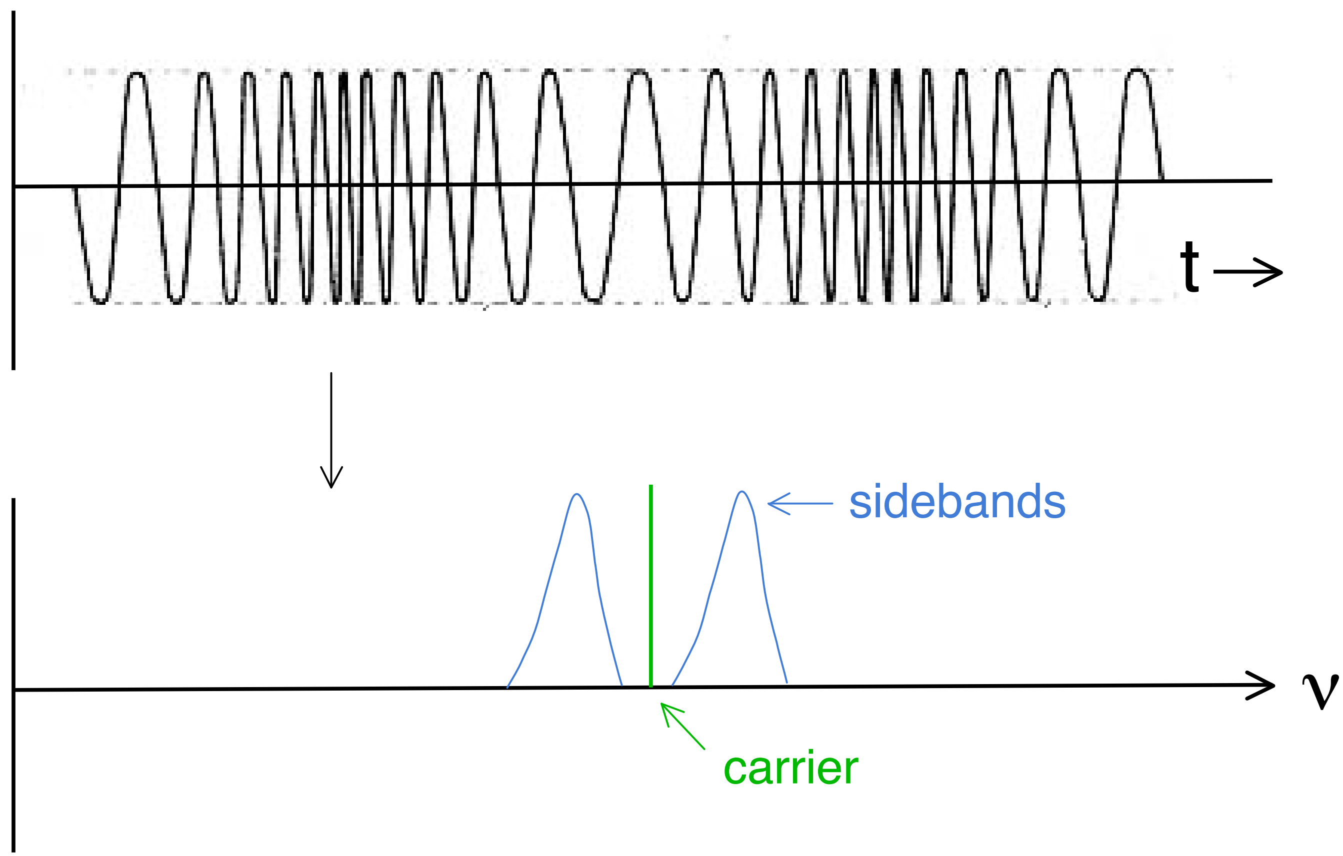
Change the signal with time

1. Amplitude modulation (AM)

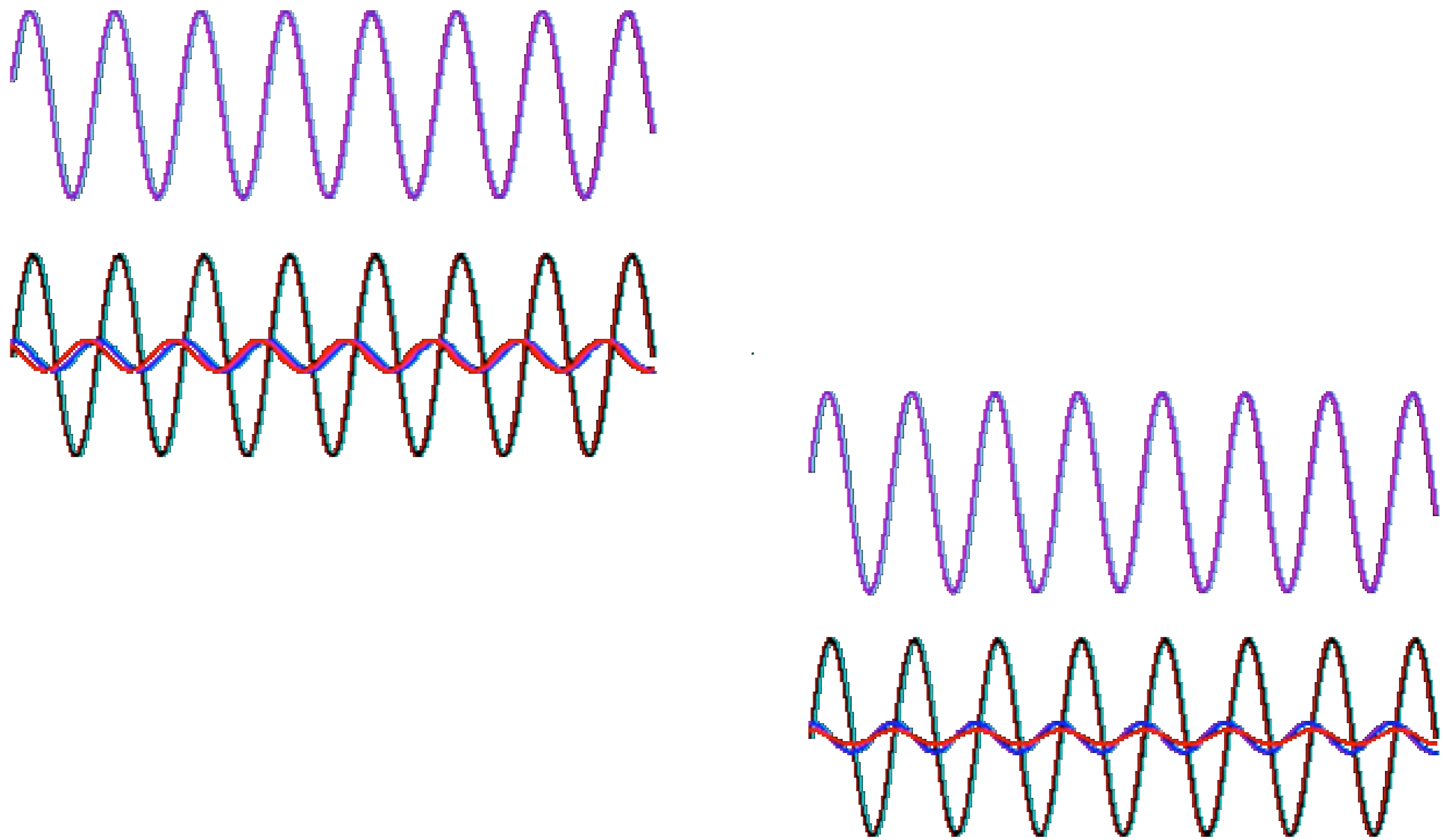


Coding the Message

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

⟶ Need fast digital electronics

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

Decoding the Message

<u>Assume Digital</u>

Repeat to Establish Pattern

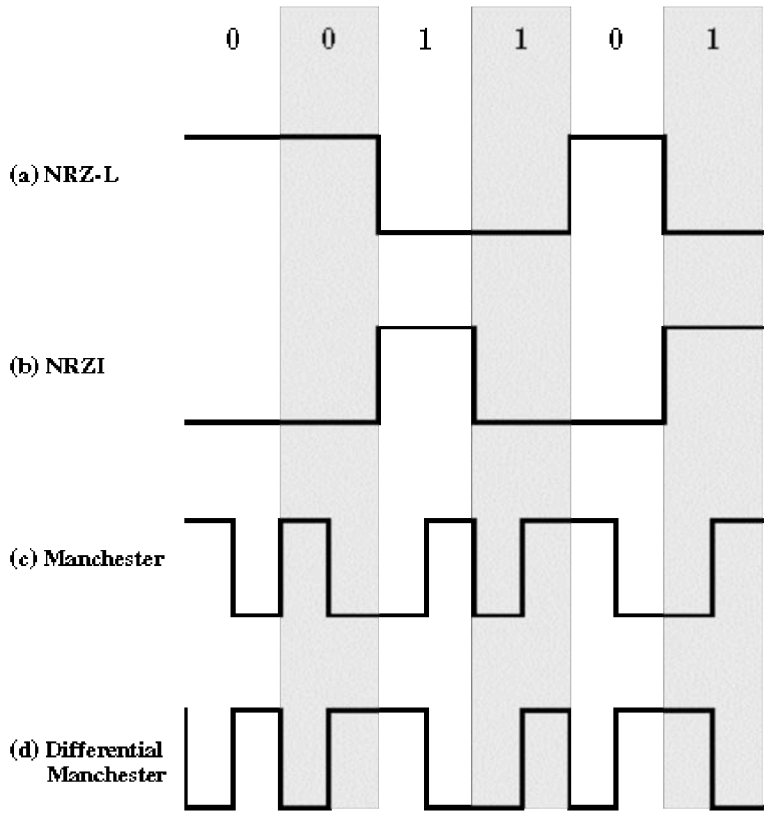


Figure 5.5 Examples of Digital Signal Encoding Schemes

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 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 1 1 0 1 0 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.

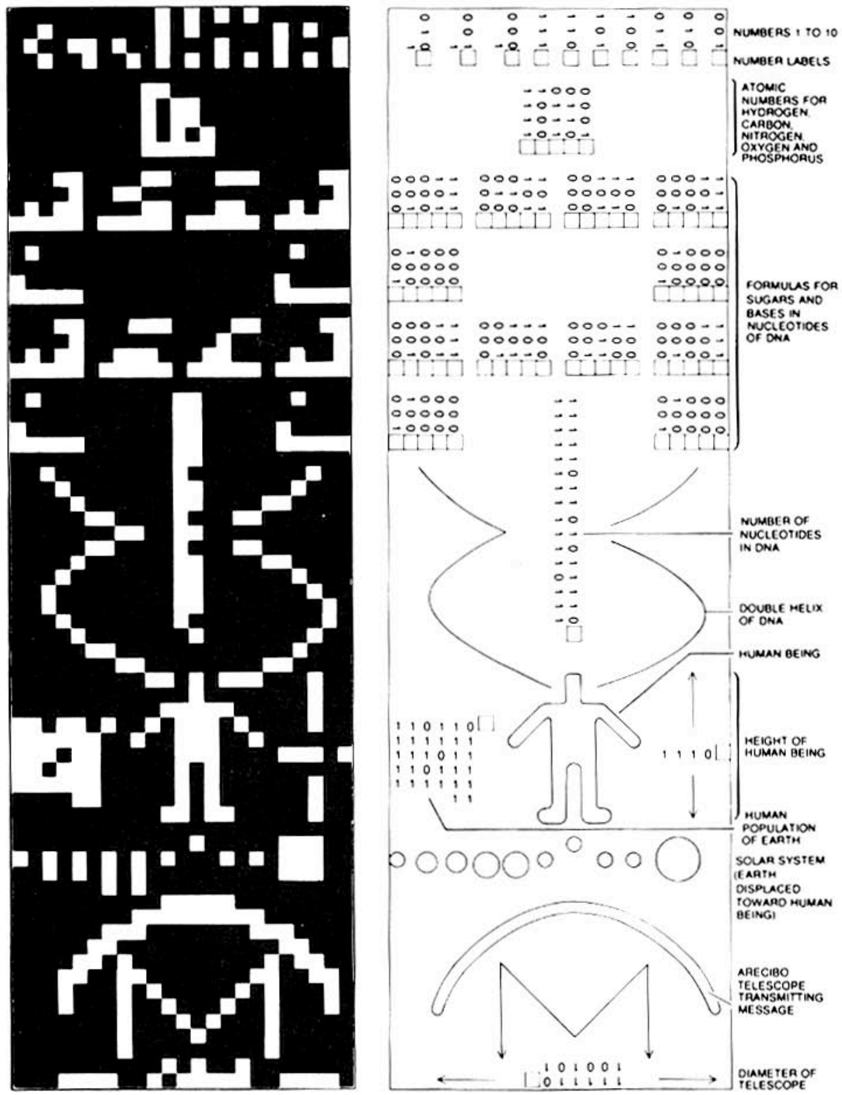


Figure 19.13 If the 1679 bits of the Arecibo message are arranged into 23 columns of 73 rows each, and if the on and off bits are given different colors, a picture emerges that is loaded with information—for those who can decipher it.

Search Strategies

- Basic Problem: where to look?
- Possible Scenarios
  - Powerful, omnidirectional beacons
    - Implies very advanced civilization
    - Seeking to attract attention of new civilizations
  - Nearby, not so advanced, broadcasting to us
    - Unlikely
  - Detect leakage radiation

Leakage Radiation

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

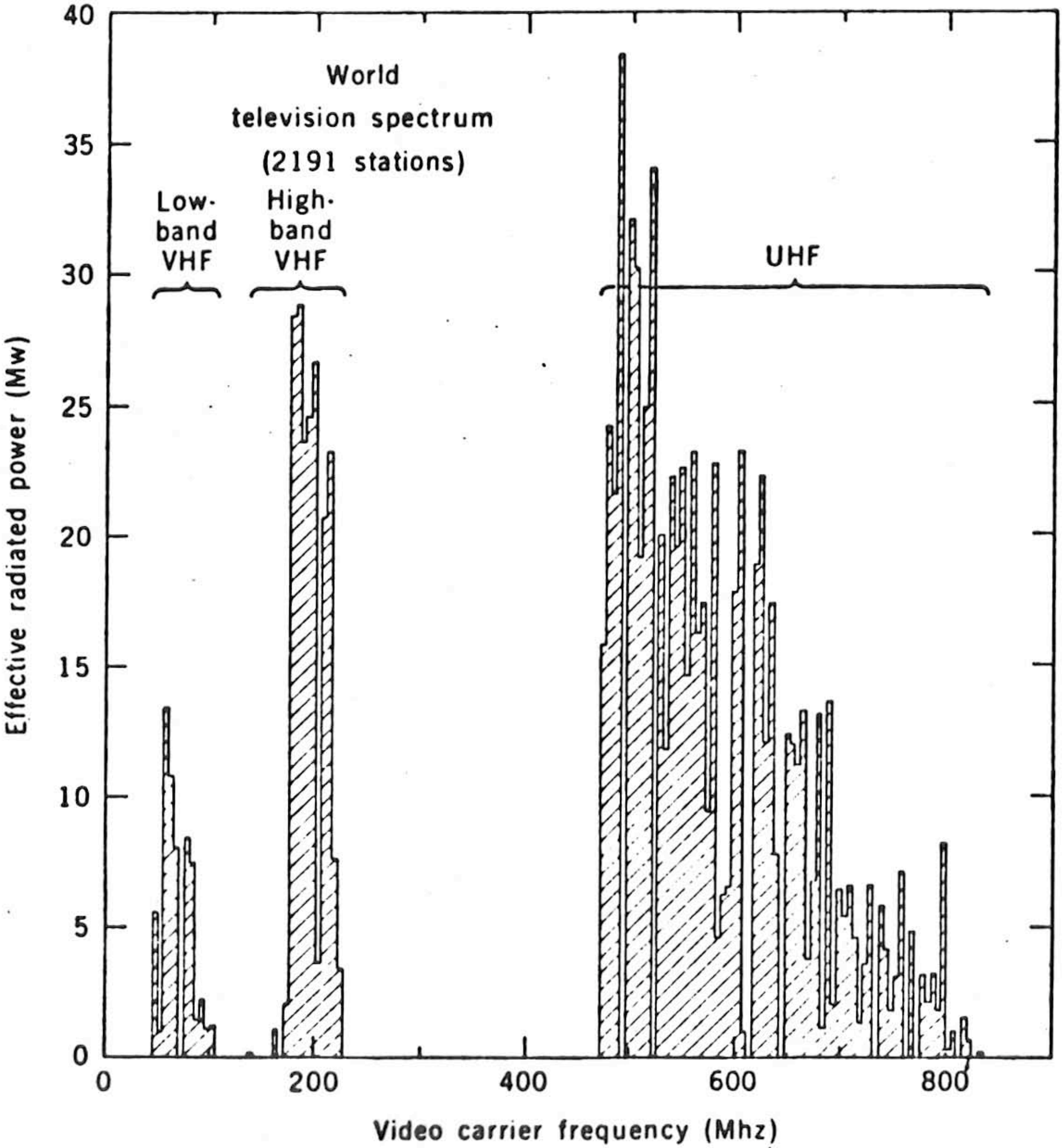
TABLE 20-1

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.



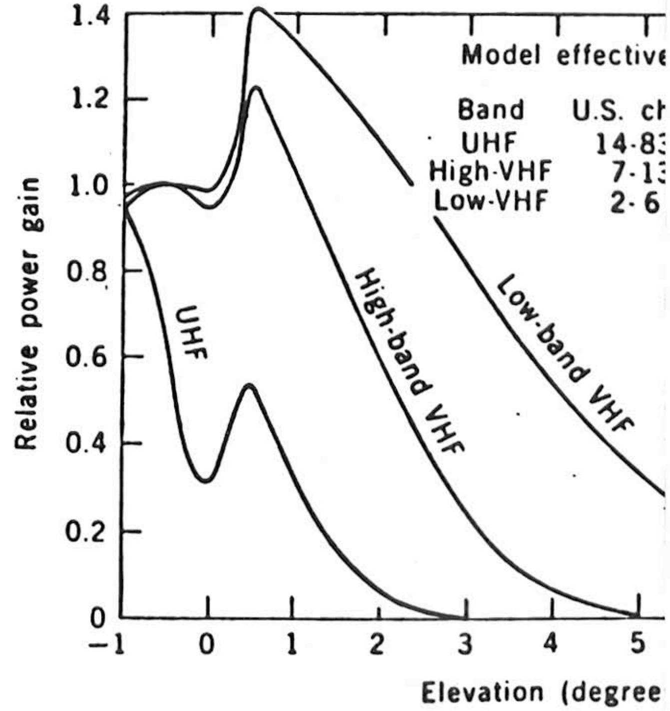
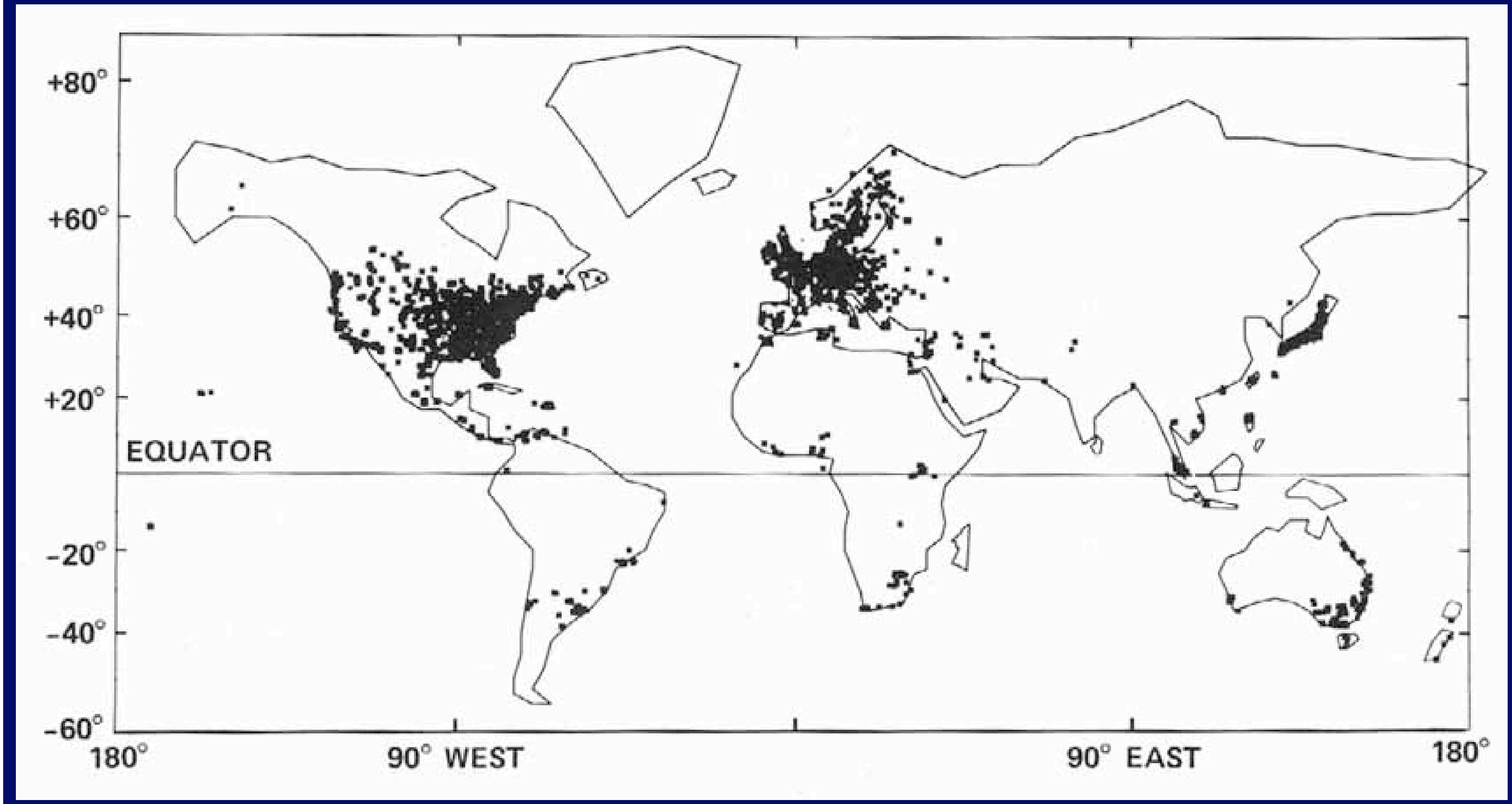
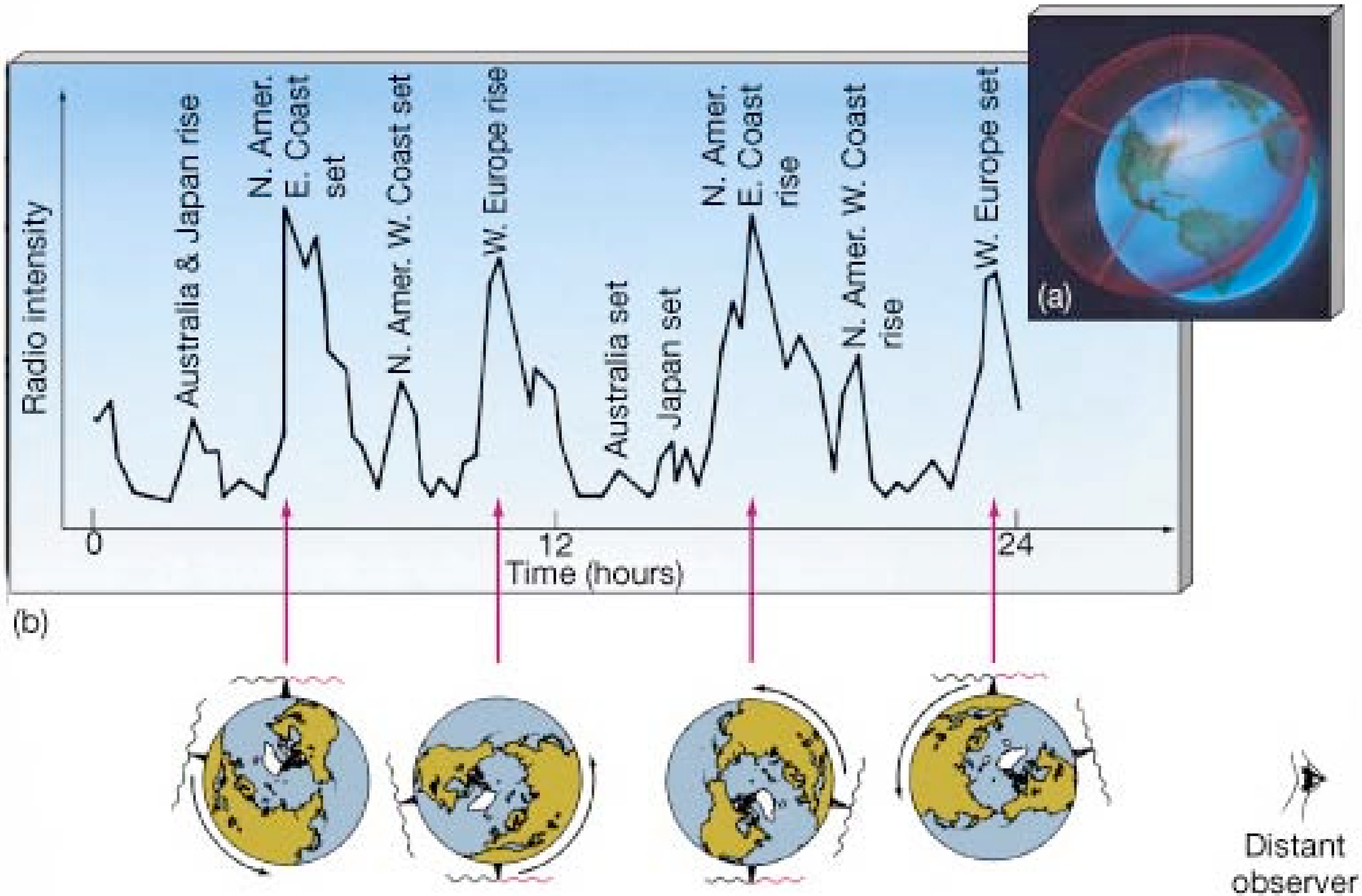


Fig. 3 (left). World television spectrum, show which the most power is radiated (5-Mhz-w primary bands (channels 2 to 6, 7 to 13, and States) are also indicated. A distant extrater a frequency resolution of 5 Mhz would at n spectrum roughly of this shape. Fig. 4 tenna power patterns adopted in the model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

World Television Transmitters





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)
(a)
(b)
Distant observer

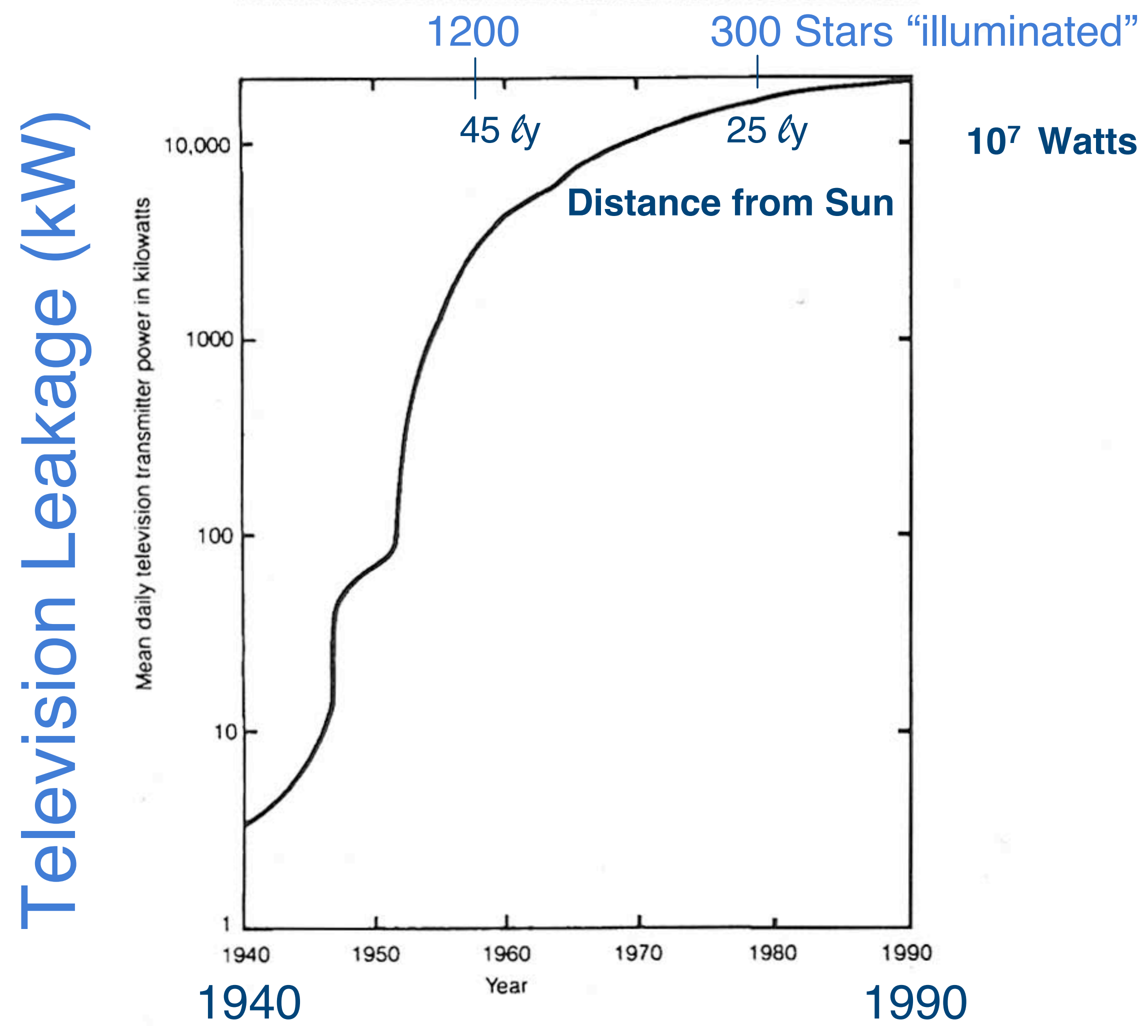


Figure 19.8 The Earth's power output in the radio region of the spectrum has increased many thousandfold since the start of the World War II in 1939.

The Cosmic Haystack

Frequency

Large frequency range

But narrow channels

$\Downarrow$

Lots of channels

Direction

Large number of directions

Small beam $\Leftarrow$

Conflict

Sensitivity

$S \propto D^{-2}\, t^{-1/2}$

want small S

Large telescope

Long time per direction

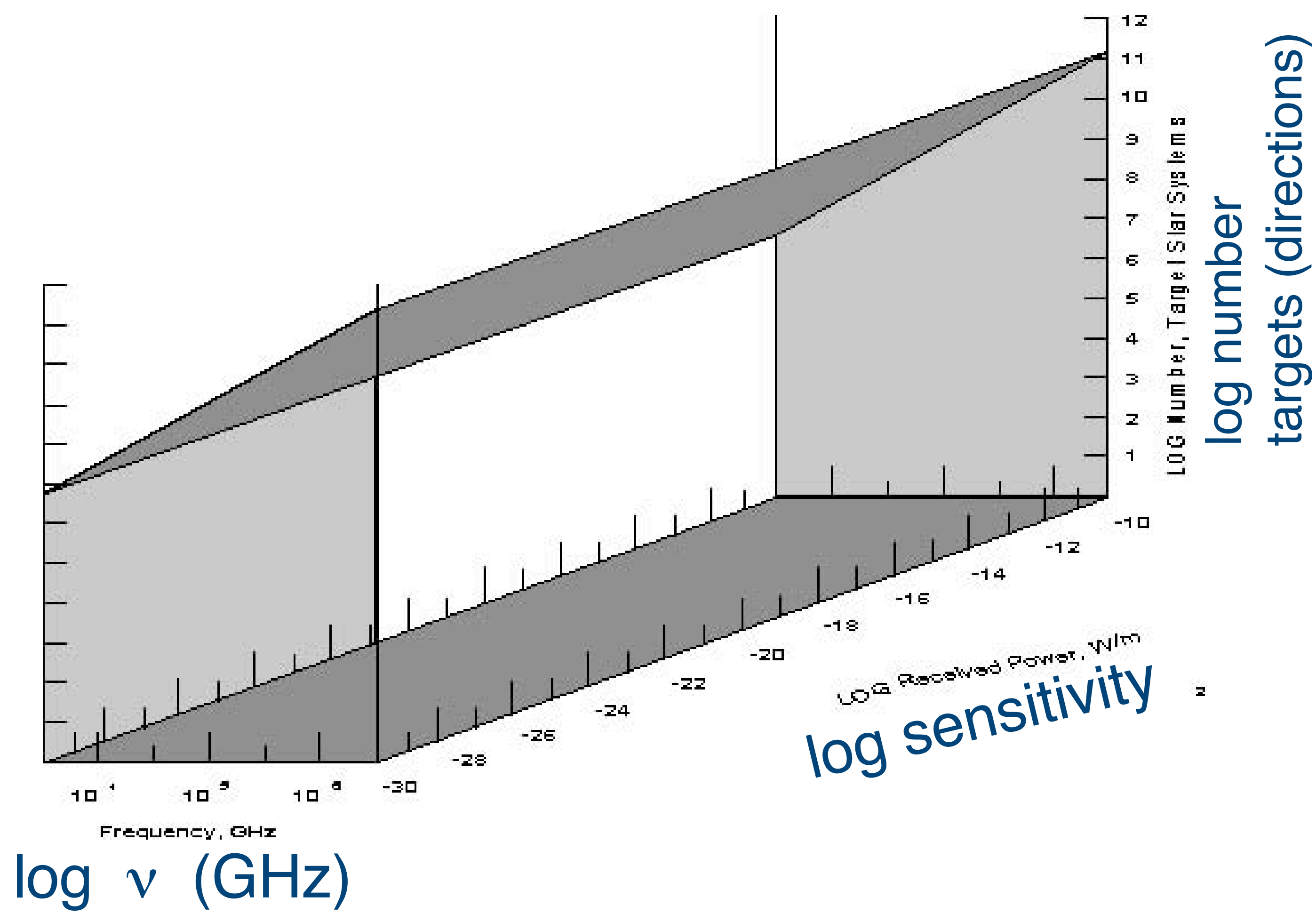
Strong signals, unknown origin

$\Rightarrow$ Small telescope, short t , cover sky

Weak signals, nearby stars

$\Rightarrow$ Large telescope, longer t , only stars

Cosmic Haystack



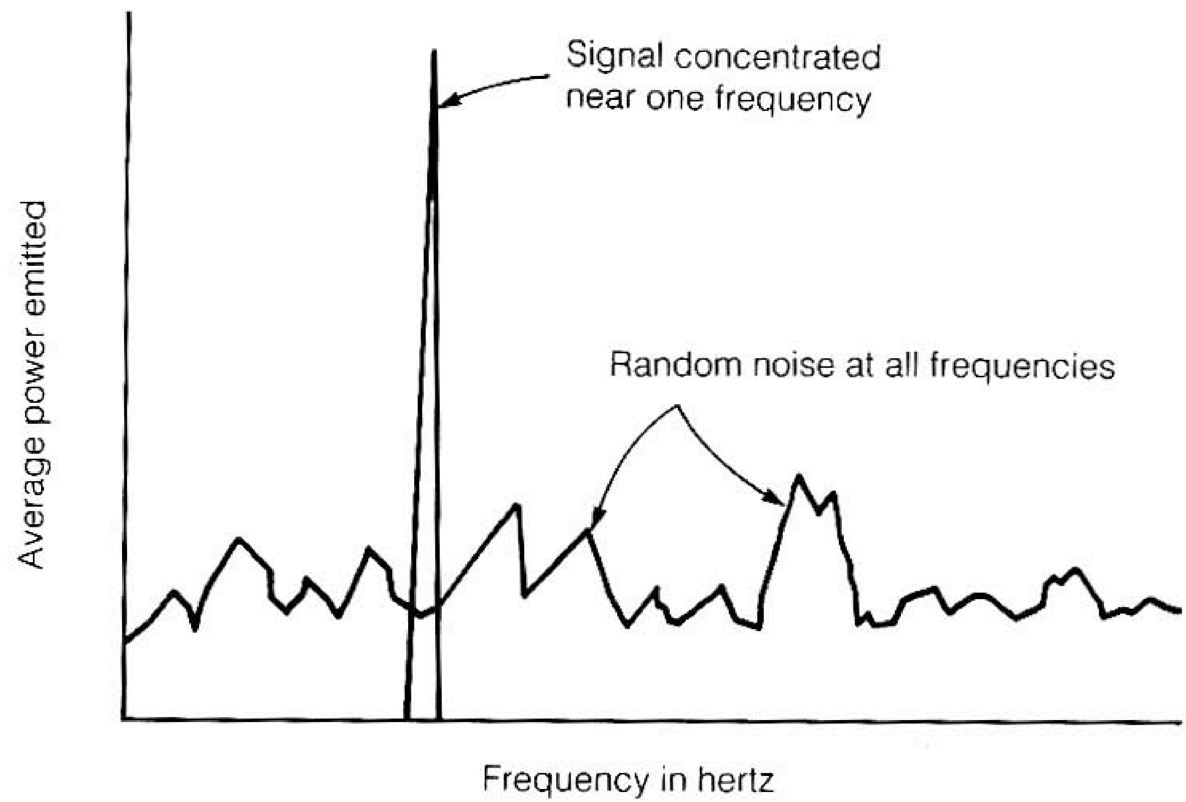
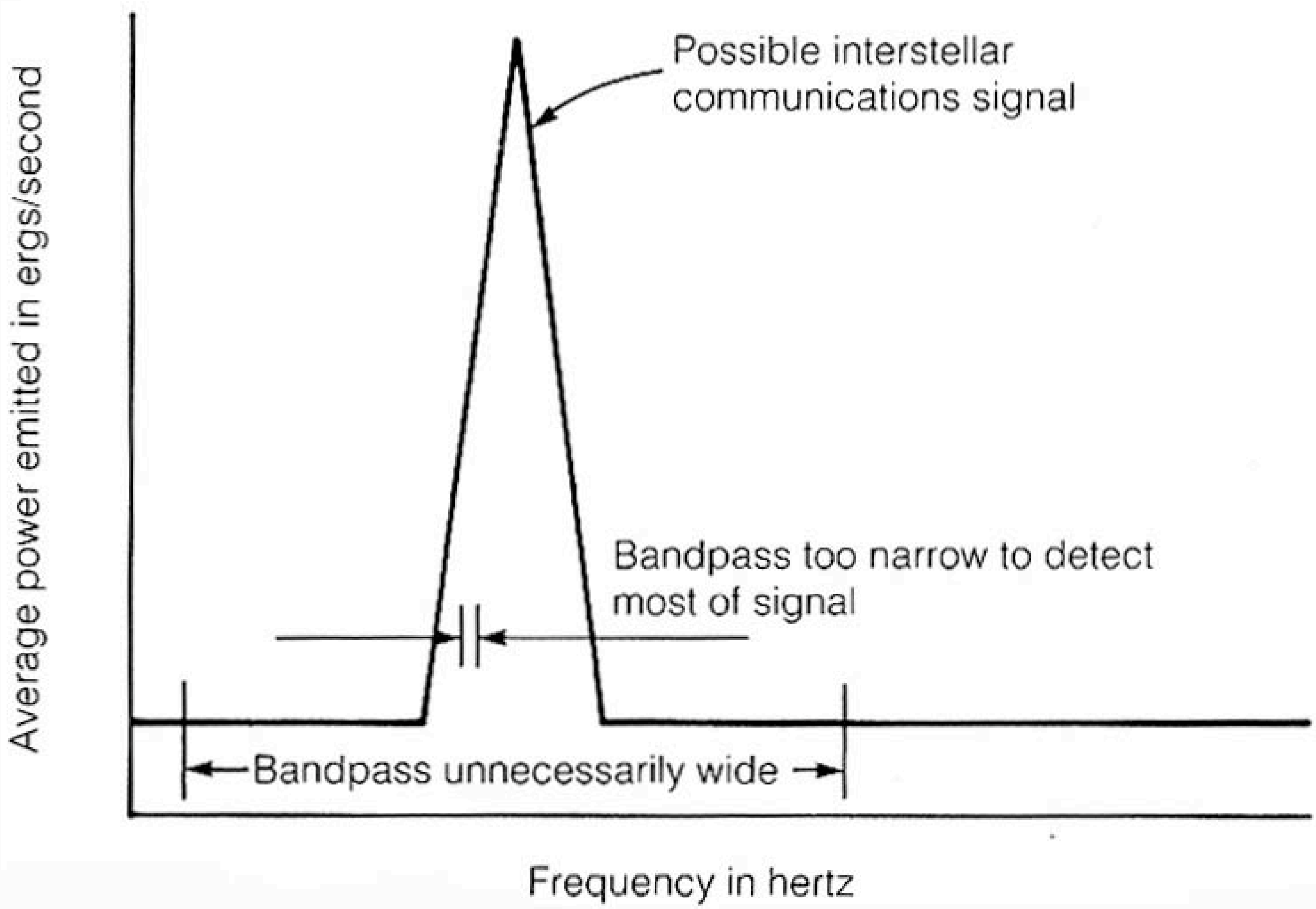
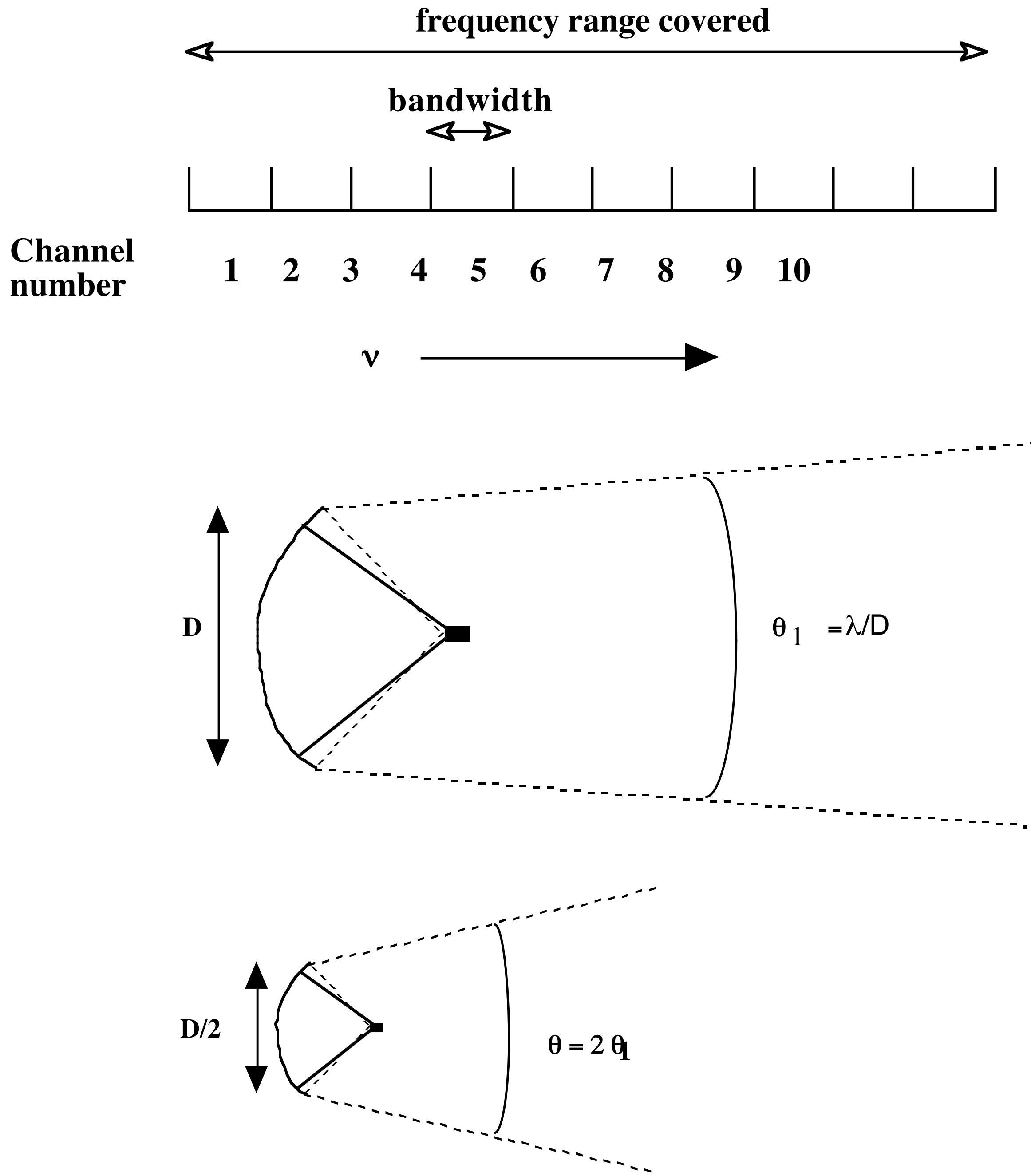


Figure 19.5 Concentrating a signal into a narrower bandpass makes it much easier for the signal to stand out against the background noise that exists at all frequencies.



Possible interstellar communications signal
Bandpass too narrow to detect most of signal
Bandpass unnecessarily wide
Average power emitted in ergs/second
Frequency in hertz


frequency range covered
bandwidth
Channel number
1 2 3 4 5 6 7 8 9 10
ν
D
θ 1 =λ/D
D/2
θ = 2 θ1

The Cosmic Haystack

Frequency

Large frequency range

But narrow channels

⇓

Lots of channels

Direction

Large number of directions

Small beam

Conflict

Sensitivity

$S \propto D^{-2}\, t^{-1/2}$

want small S

Large telescope

Long time per direction

Strong signals, unknown origin

⇒ Small telescope, short t , cover sky

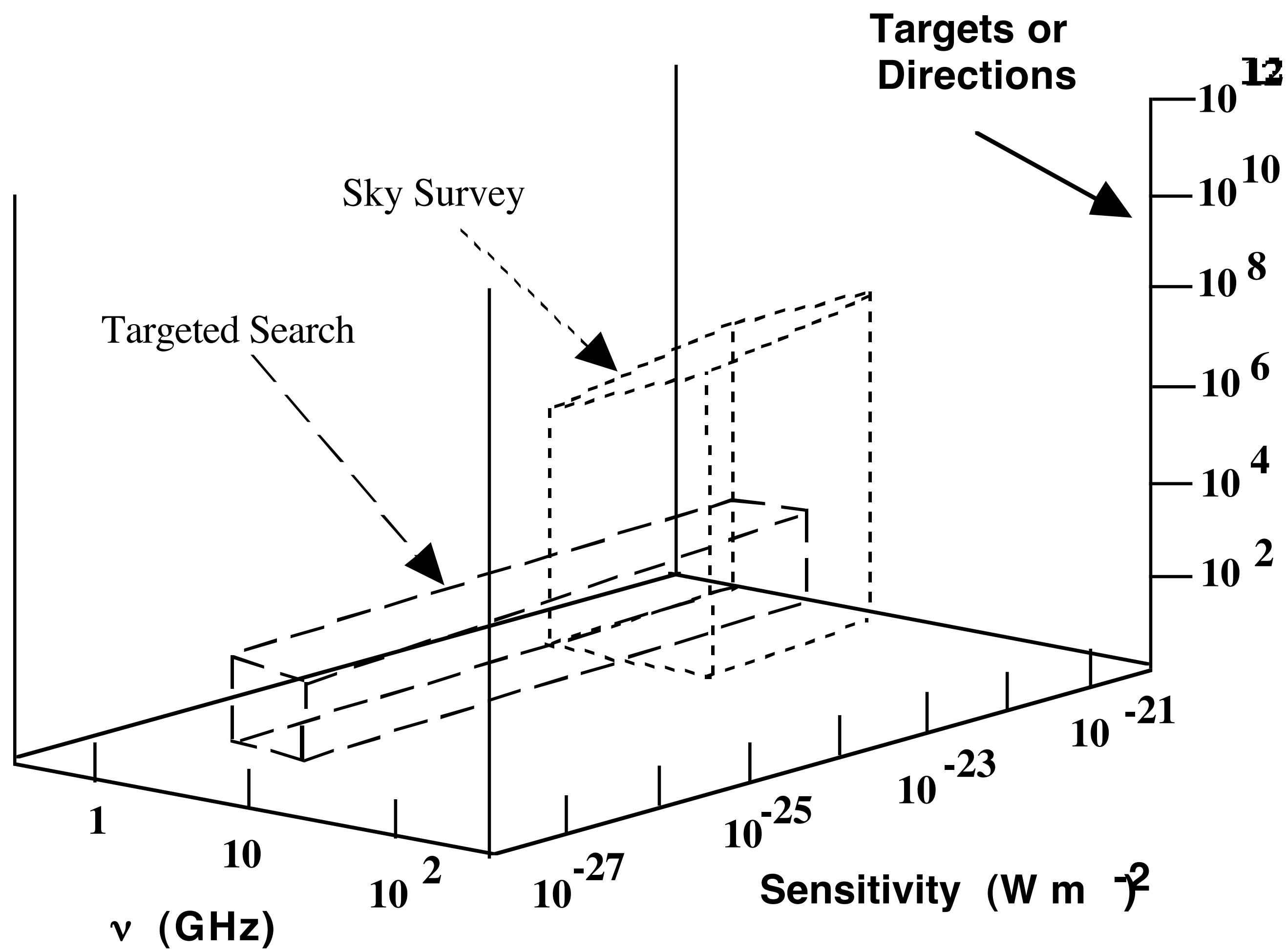
Sky Survey

Weak signals, nearby stars

⇒ Large telescope, longer t , only stars

Targeted Search

Targeted Search vs Sky Survey



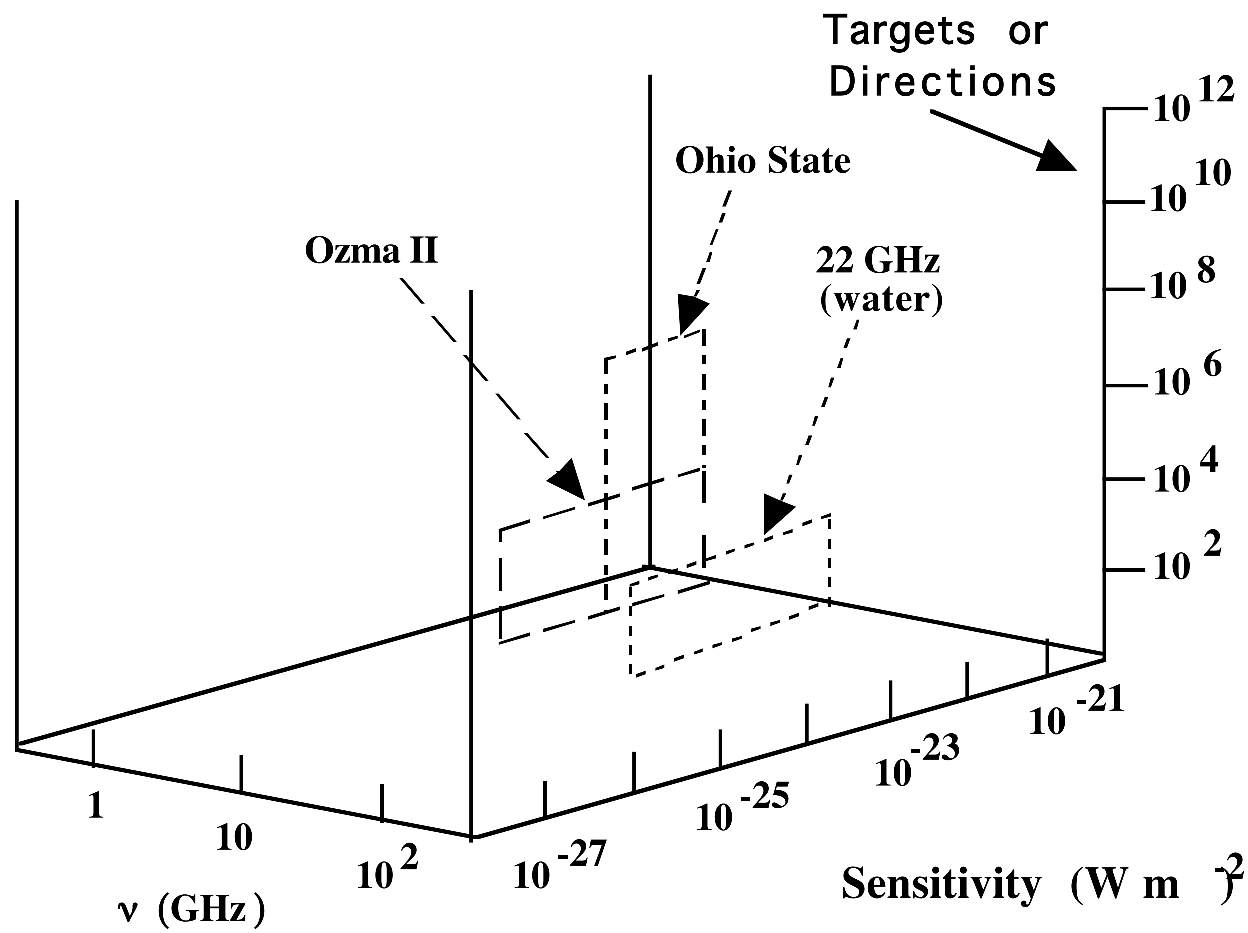
Some Searches for ETI

Year	Names	Frequency (MHz)	Telescope size (m)	# of stars
1960	Ozma (Frank Drake)	1420	26	2
1972	Ozma II (Zuckerman & Palmer)	1420	91	602
1985	Meta (Horowitz; Planetary Soc.; Spielberg) [8 million channels]	1420	26	All sky
1992(?) ↑ Oct. 12, 1992	NASA search Discrete source made	1200-3000 + selected ν Up to 25 GHz	300 → 34	244 800
	All sky Survey	1000 - 10,000 + selected ν	34	All Sky

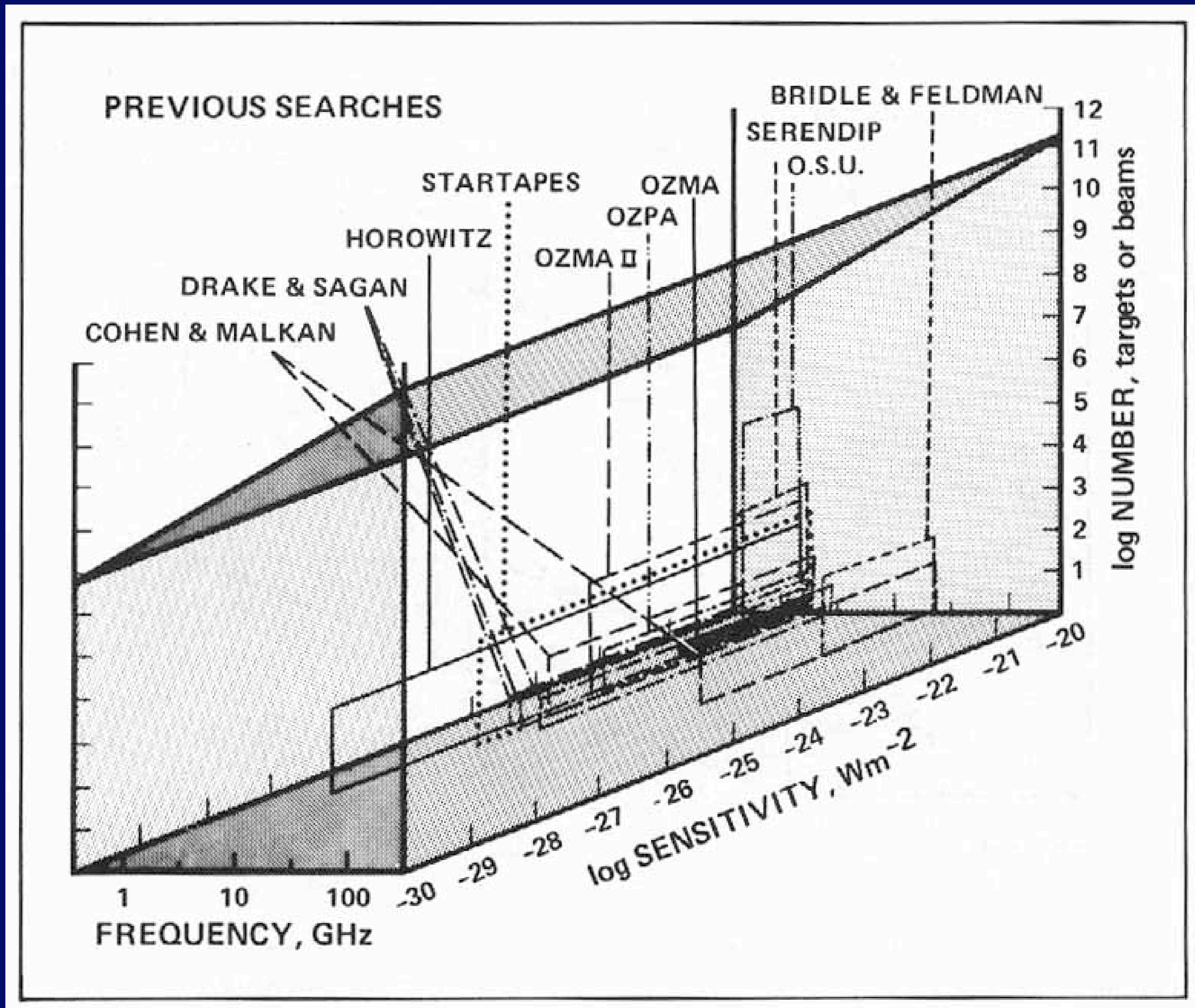
[10 million channels +?]

2 million in 1992 ; ~ 16 million in 1996

Some Searches



Previous Searches



SERENDIP - SETI@home

- Latest version:
  SERENDIP IV
  Uses ARECIBO telescope
  while regular obs.
  going on

ν = 1420 MHz

5×10^{-25} W m^{-2}
very sensitive

Data analyzed by screen savers
on millions of PC's SETI@HOME

Report on Project META
Megachannel Extra Terrestrial Assay

Horowitz & Sagan, 1993, *Astrophysical Journal*, **415**, 218.

5 years of searching at 1.420 GHz

8×10^6 channels   channel width: 0.05 Hz

coverage: 400 kHz

Covered sky 3 times 1.7×10^{-23} W m^{-2}

37 candidate events: narrow-band, apparently not interference

But none repeated

8 signals truly hard to explain as noise

Probably electronic "glitches"

But some tendency to lie in plane of galaxy $\Rightarrow$ extraterrestrial ?

Nothing convincing yet.

FIG. 5a

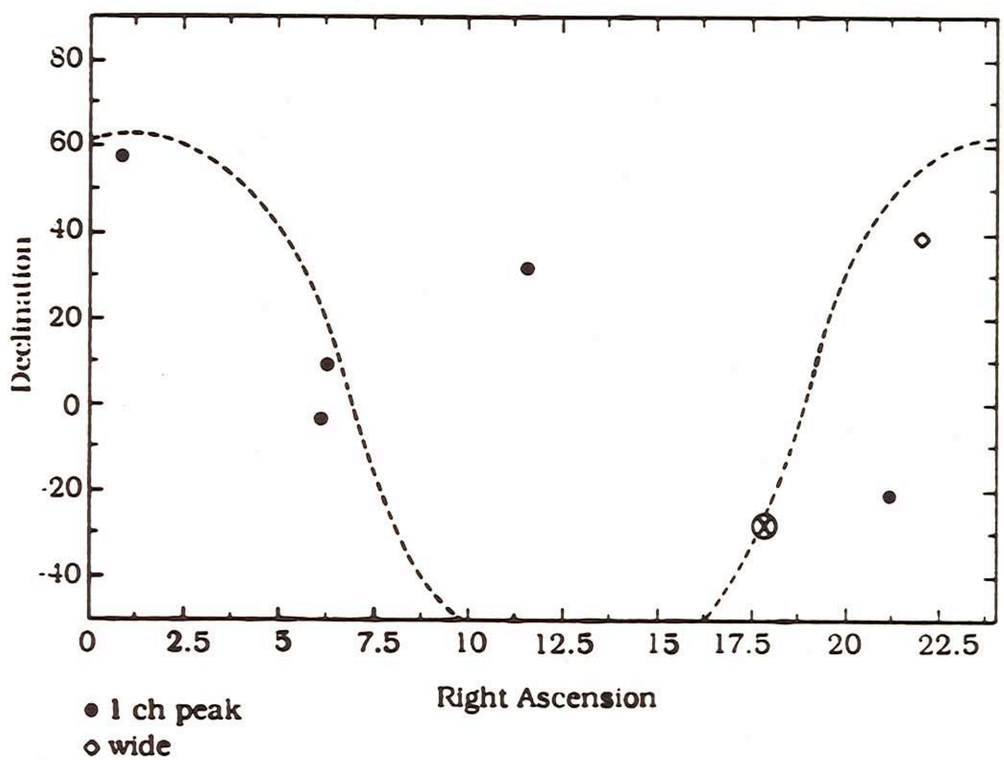


FIG. 5b

5.—Coordinates of strong spectral features for run A (1420 MHz). Thresholds are (*a*) $22P_0$ and (*b*) $28P_0$. The dashed line is the Galactic pla
center.

BETA

Successor to META

2.5×10^8 channels

0.5 Hz channel width

Covers 1.4 - 1.7 GHz in 8 steps

Sensitivity: 2×10^{-22} W m-2

Started 1995, suspended in Spring 1999

(antenna blew off mount!)

repairs underway

NASA Search

~~To begin~~ ~~began~~ ~~ended~~ → revived?

To begin Oct. 12, 1992

Microwave Observing Program (MOP)

Main improvement: frequency coverage

2 parts:

1. All sky survey - JPL - run

   Telescopes of modest 34-m diameter

   California, Australia, …

   Cover 1 - 10 GHz

   2×10^6 channels 16×10^6 channels (~ 1996)

   Channel width: 20 Hz

Coverage: 40 MHz , 320 MHz

right and left circular polarization

Sensitivity: only spend a few sec. per direction

⇒ strong signal

(Arecibo Planetary Radar)

out to 25 ℓy

Timespan: 6 years to cover sky once

2. Targeted search - Ames - run

(~ 800 Nearest (< 75 ly) stars like Sun)

Largest telescopes available:

Arecibo 300 m (244 stars)

+ Australia, France, …

Cover: 1 - 3 GHz

16×10^6 channels

Channel width: 1 Hz

Coverage: 10 MHz

right and left circular polarization

Sensitivity: ~ 10^3 sec. per star

$\Rightarrow 10^{-27}$ W m^{-2}

$P_{trans} = 10^{-27}$ W $m^{-2} \cdot 4\pi\, d^2(m)$

$d(m) \simeq 10^{16}\, d(\ell y)$

$P_{trans} \simeq 10^6\, d^2(\ell y)$ = 1 M Watt at 1 ℓy

e.g. 100 Mega Watts at d = 10 ℓy

Defense radars to ~ 1000 ℓy

HR 5158

EXCERPTS REGARDING SETI

101st Congress of the United States, 2nd Session

From Senate Report 101-474, to accompany H.R. 5158, from the Departments of Veterans Affairs, HUD and Independent Agencies Appropriation Bill, 1991, dated September 16, 1990 (Senator Barbara Mikuski--chair):

Regarding the NASA budget:

> "...For life sciences, the Committee recommends the following:
>
> -$25,000,000 from the $168,000,000 requested for life sciences, to be taken as a general reduction, subject to the normal reprogramming guidelines. None of this reduction is to be taken from the request for the search for extraterrestrial intelligence (SETI) program.
>
> "In recommending the full budget request of $12,100,000 for the SETI program, the Committee reaffirms its support of the basic scientific merit of this experiment to monitor portions of the radio spectrum as an efficient means of exploring the possibility of the existence of intelligent extraterrestrial life. While this speculative venture stimulates widespread interest and imagination, the Committee's recommendation is based on its assessment of the technical and engineering advances associated with the development of the monitoring devices needed for the project and on the broad educational component of the program. The fundamental character of the SETI program provides unique opportunities to explain principles of such scientific disciplines as biology, astronomy, physics, and chemistry, in addition to exposing students to the development and application of microelectronic technology.
>
> "The Committee has included the full request of $2,000,000 for the Lifesat project..."

1990

$14.5 MILLION FY92

From the Joint House-Senate Conference Report for Veterans Affairs, HUD and Independent Agencies (approved on October 17, 1990):

$0 FY94 !

Regarding the NASA budget:

> "...- $25,000 from Life Sciences
>
> "The Conferees agree that within the balance of funds available in this action, $12,100,000 shall be allocated to the Search for Extraterrestrial Intelligence and $2,000,000 for Lifesat..."

SETI Office/10-90

SEARCH IS DESCRIBED IN CHAP. 9

Congress may hang up on research of E.T.s

■ Extraterrestrials won't be able to phone home if there's nobody on earth to take the call

By Keay Davidson
New York Times News Service

SAN FRANCISCO — Who killed E.T.?

An effort by the National Aeronautics and Space Administration effort to detect signals from extraterrestrials has been axed by Congress.

Experts blame everything from its "giggle factor" to poor salesmanship to Congress' unwillingness to cut politically stronger programs.

Hollywood has made big money from fictional extraterrestrials, and they clutter TV shows and grocery-store tabloids.

But NASA's $104 million attempt to find real aliens — the Mountain View, Calif., High Resolution Microwave Survey — was too costly for a joint congressional committee. It agreed to end the program just one year into its planned 10-year search. The program is popularly known by its previous name, Search for Extraterrestrial Intelligence, or SETI.

"I'm pretty depressed," said Pe-

Critics accuse Congress of making SETI a sacrificial lamb after failing to kill two programs — the oft-maligned space station and the $3 billion Advanced Solid Rocket Motor, which *Reader's Digest* last year called "the unstoppable pork booster." It's based in Yellow Creek, Miss., home to Democratic Rep. Jamie Whitten, who until last year chaired the House Appropriations Committee.

Project staff members took pride in the program's size. "Each space shuttle launch has been estimated to cost as much as $1 billion. That's a century worth of SETI research," said Seth Shostak of the quasi-private SETI Institute in Mountain View.

But politically, "the SETI people made a fundamental mistake — stupid, stupid, stupid! — in the way they've been lobbying for their programs," said John Pike, a policy expert with the Federation of American Scientists in Washington. "SETI is one of the things that is most readily understood and widely appreciated by the public.

Ralph De Gennaro, a senior budget analyst for Friends of the Earth in Washington, D.C., shed no tears for SETI.

"I'm sick and tired of being told that we can't afford to save this planet but we do have enough money to listen to aliens on other

Project Phoenix

Underway Feb. 2, 1995

SETI Institute (- minus NASA $$)

Private Funding (Packard of HP)

\+ …

Relocate to Australia 64 - m telescope

1.2 - 3.0 GHz , 28×10^6 channels

1 Hz channel width

Targeted search sensitivity ~ 1×10^{-26} W m^{-2}

~ 200 stars like Sun, no binaries, $t \geq 3 \times 10^9$ yr

Within 150 ℓy observe each for 5 min

(eventually 1000 stars)

Can detect 1 Mega Watt if beamed to us by similar size telescope

Immediate followup by second telescope

No ETI found in first run (sp 95)

Webpage: http://www.seti-inst.edu

Used various other telescopes, including Arecibo

No civilizations found yet.

Amateur Projects

BAMBI (Bob and Mike's Big Investment)

3.7 - 4.2 GHz Sky survey

SETI League project ARGUS

Use Satellite TV Dishes (~ 100) as of 2001

1.4 - 1.7 GHz Channel width: 1 Hz

Sens. ~ 1×10^{-21} W m^{-2}

Goal is 5000 sites

Aim for continuous sky coverage

Allen Telescope Array (ATA)

Under construction SETI Institute, UC Berkeley

Major telescope dedicated to SETI

Cost ~ 26 M $ ~ 1/2 provided by Paul Allen,
Nathan Myrrvold (Microsoft)

Hat Creek, California

350 × 6 m antennas

1 - 10 GHz

Can examine 10^5 stars 3 times over a decade

Will extend targeted search much farther.

Expanding the Search Radius

Comparison of the Allen Telescope Array and Project Phoenix

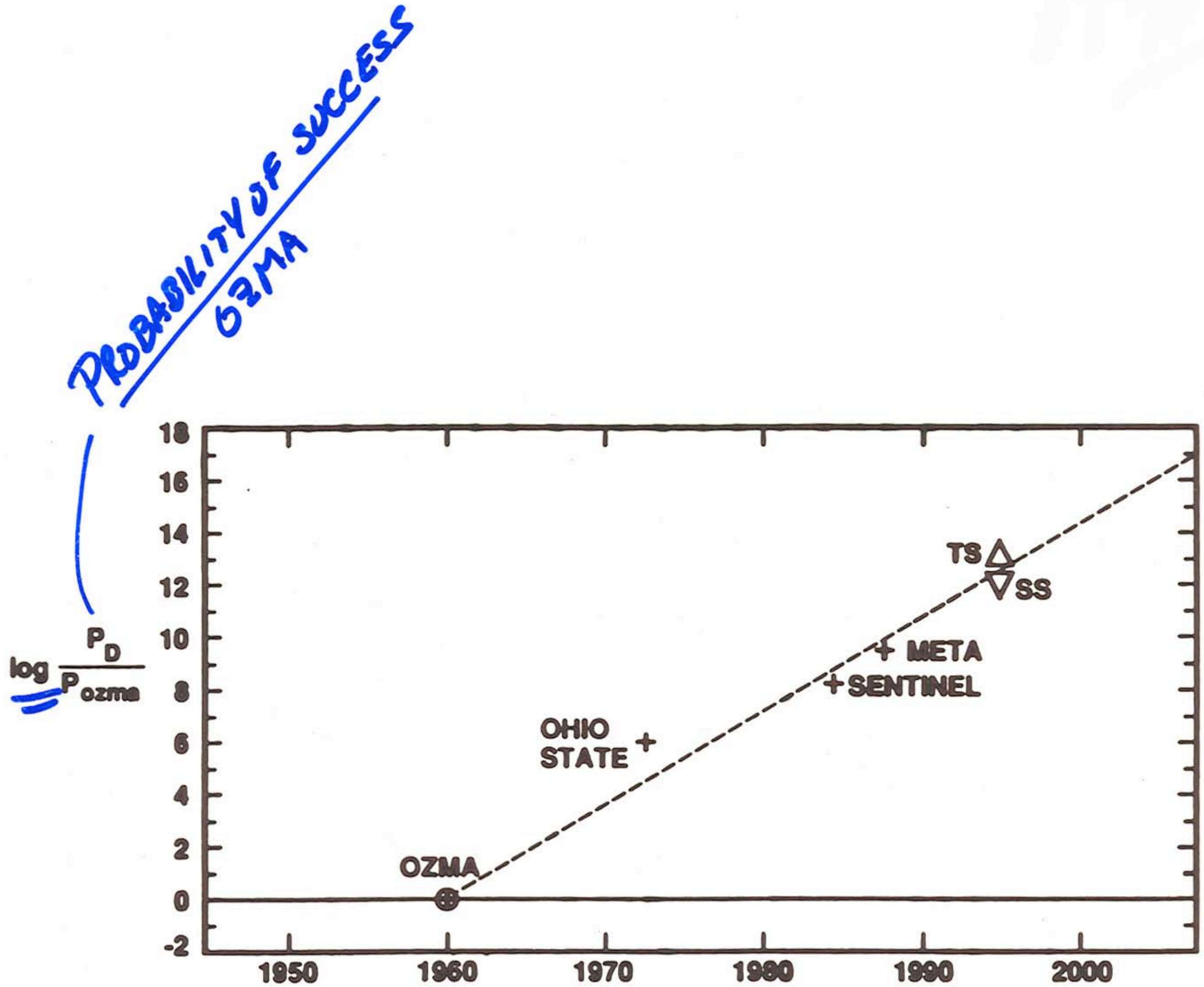


Figure 2. A representation of the increase in relative detection probability of SETI searches with date. The positive slope of these data is correlated with the technological enhancements that have benefited SETI search systems from one decade to the next.

Websites for SETI

http://www.seti-inst.edu/ Many Links

http://www.mc.harvard.edu/seti/ Project BETA

Update on Searches

Article by Jim Tarter, 2001

Annual reviews of Astronomy & Astrophysics, **39**, 511

Appendix Available on WWW

99 SETI projects   > 14 ongoing in 2001

Some Optical, most radio

Update on Searches

Notable Ones:

Serendip	⟶	SETI@home
META	⟶	BETA
NASA	⟶	Phoenix
BAMBI, ARGUS		(Amateurs)
Allen Telescope Array		(Future)

Beyond MOP

VLA Expansion ⟶ "ARGUS"

Cyclops

1000 telescopes, each 100-m diameter

Detect 1000 MW transmitter at 1000 ℓy

or monitor 1000 stars simultaneously

or detect leakage radiation at 100 ℓy

Square Kilometer Array (SKA)