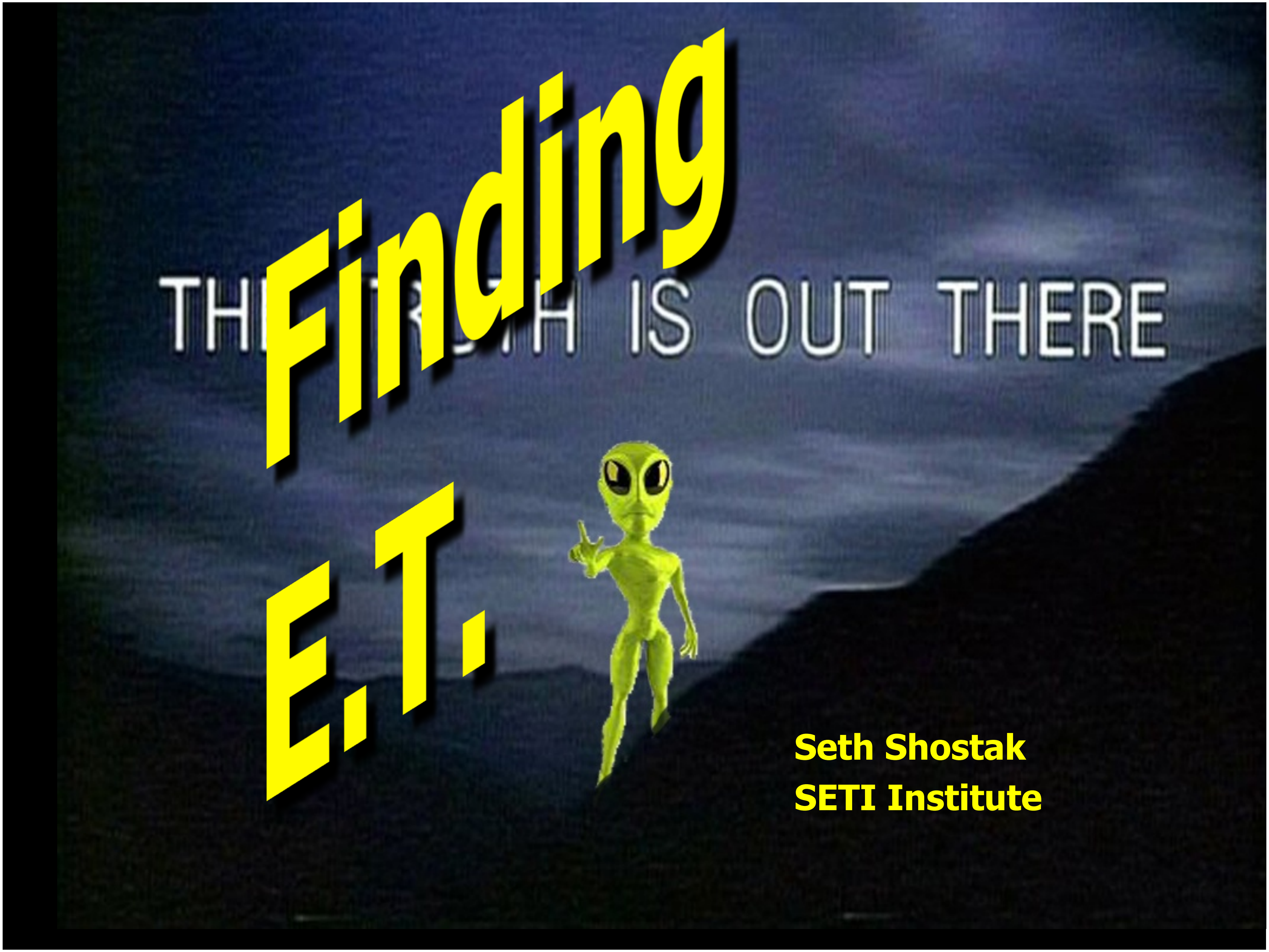
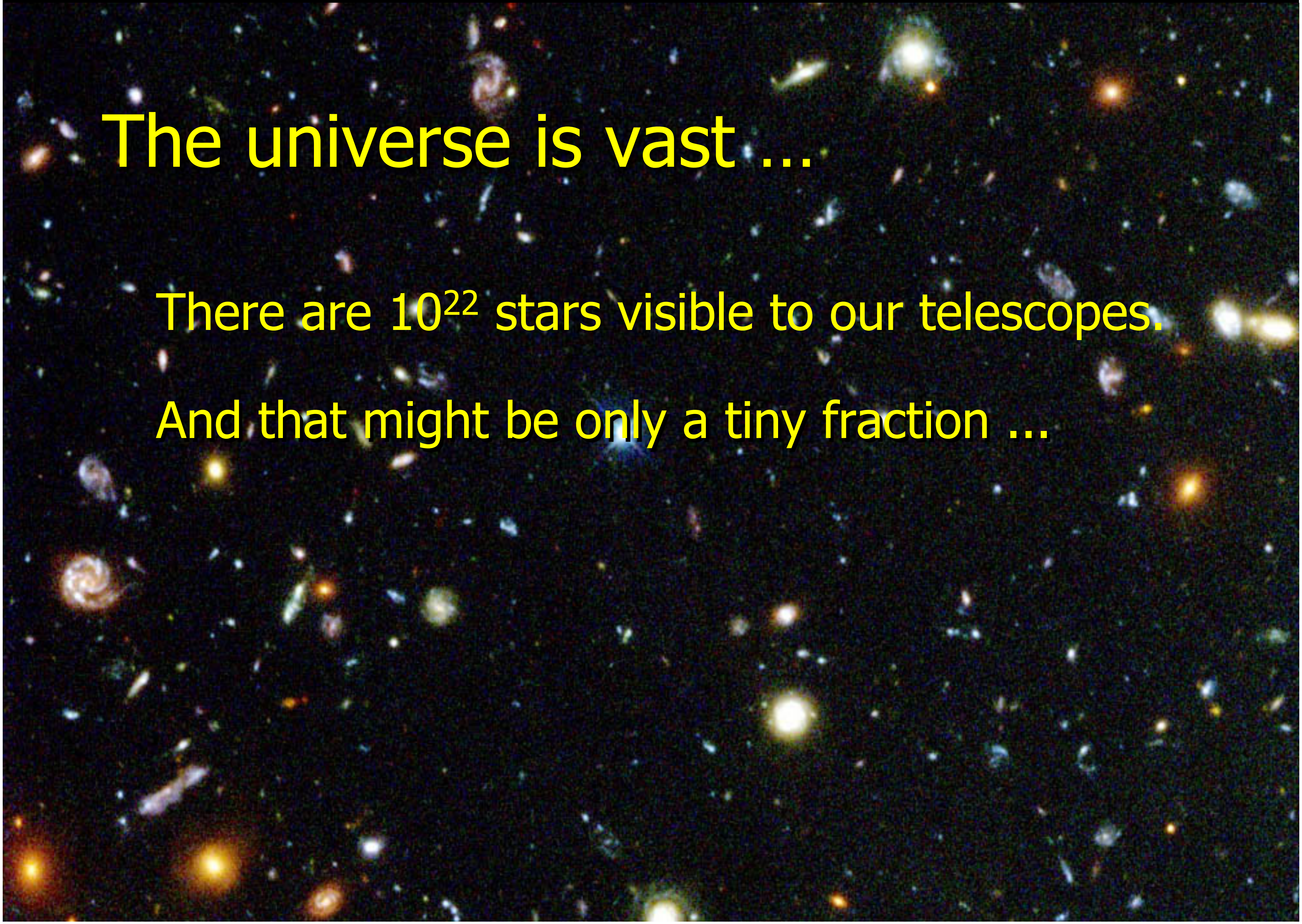

Finding
E.T.
IS OUT THERE
Seth Shostak
SETI Institute

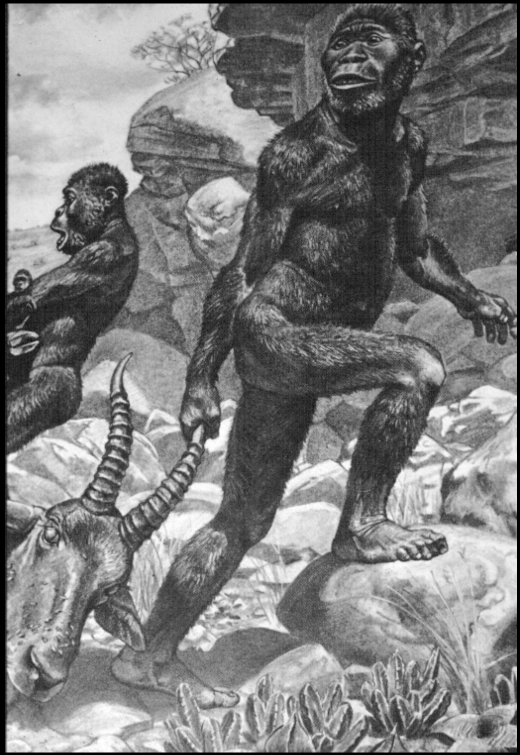


# The universe is vast …

There are $10^{22}$ stars visible to our telescopes.

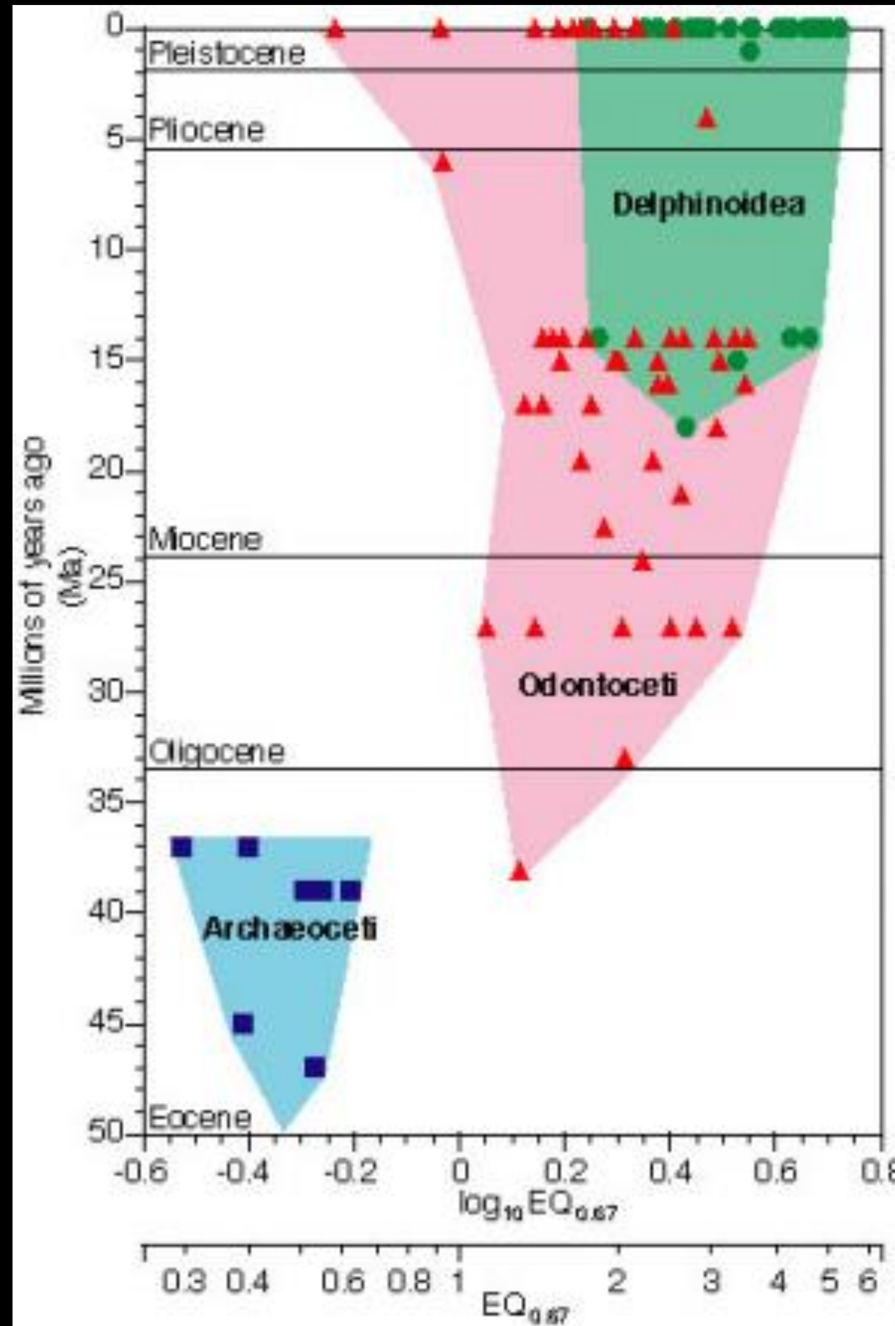
And that might be only a tiny fraction ...

# Is intelligence likely?



Possible mechanisms:

- Predatory-prey and social behavior can ratchet up intelligence
- Evidence for increased encephalization in primates, cetaceans,…
- “Signal for fitness” may encourage IQ

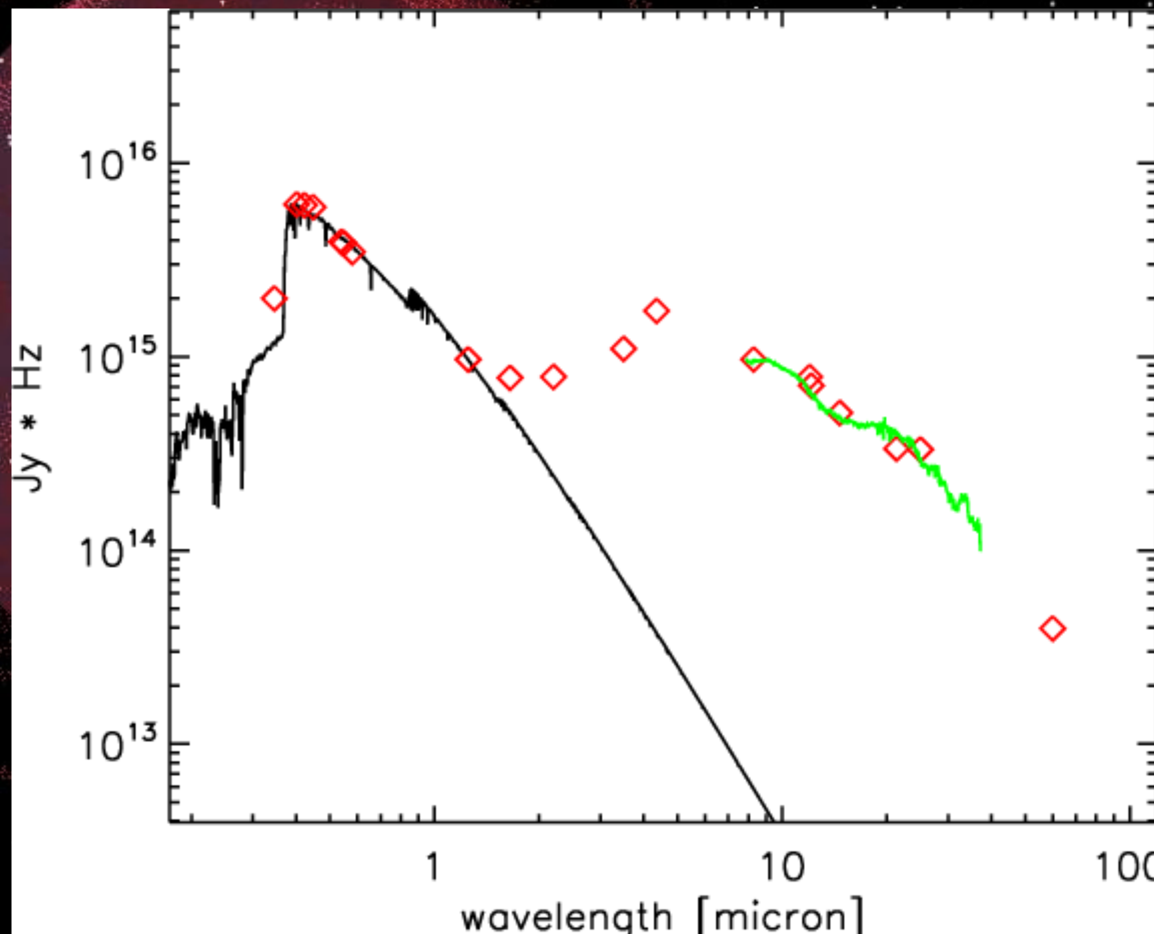


Pleistocene
Pliocene
Delphinoidea
Miocene
Odontoceti
Oligocene
Archaeoceti
Eocene
Millions of years ago (Ma)
0
5
10
15
20
25
30
35
40
45
50
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
log10 EQ0.67
0.3 0.4 0.6 0.8 1 2 3 4 5 6
EQ0.67


Lori Marino


Finding evidence of intelligence …

# Look for artifacts ...




Look for flashing lights …

G-type star: 4 $10^{26}$ watts

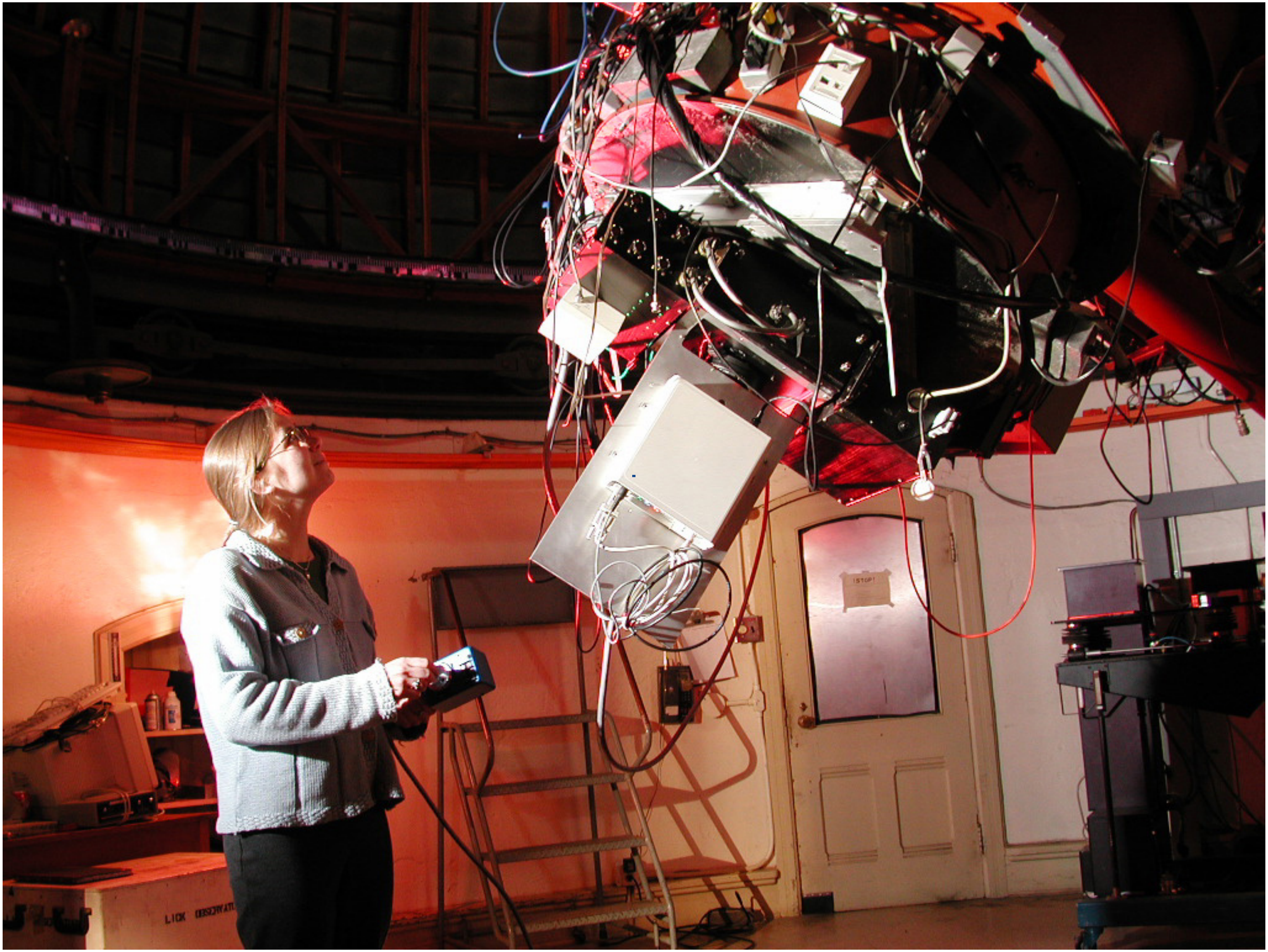
= $10^{45}$ photons/sec

At 100 light-years, that's $10^{8}$ photons/sec in a 1 $m^{2}$ mirror

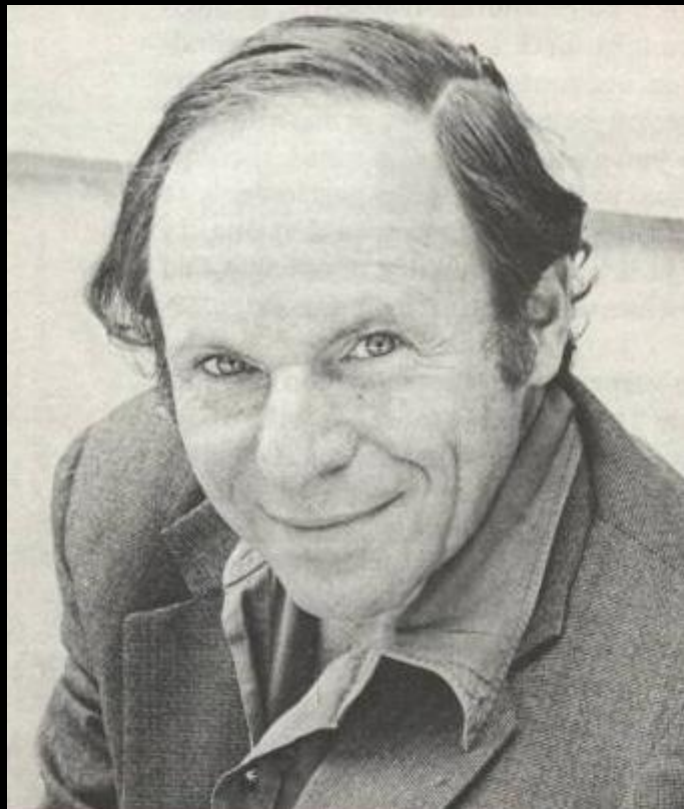
In a nanosecond, that's 0.1 photons

A laser could pump in 100 – 1000 photons in that same nanosecond!


Lick Observatory


LICK

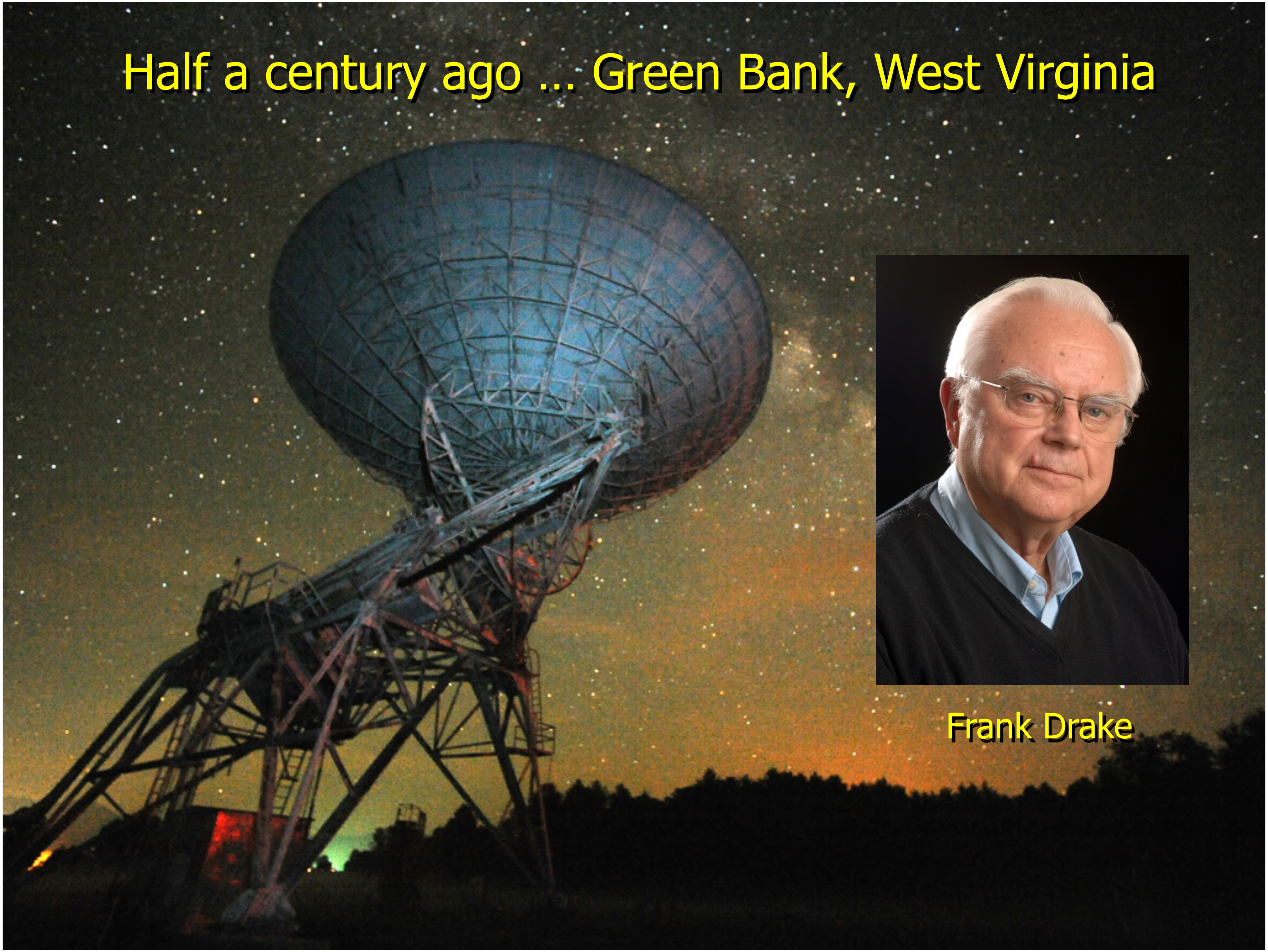
Listen for ET on the radio …



Philip Morrison

Giuseppe Cocconi

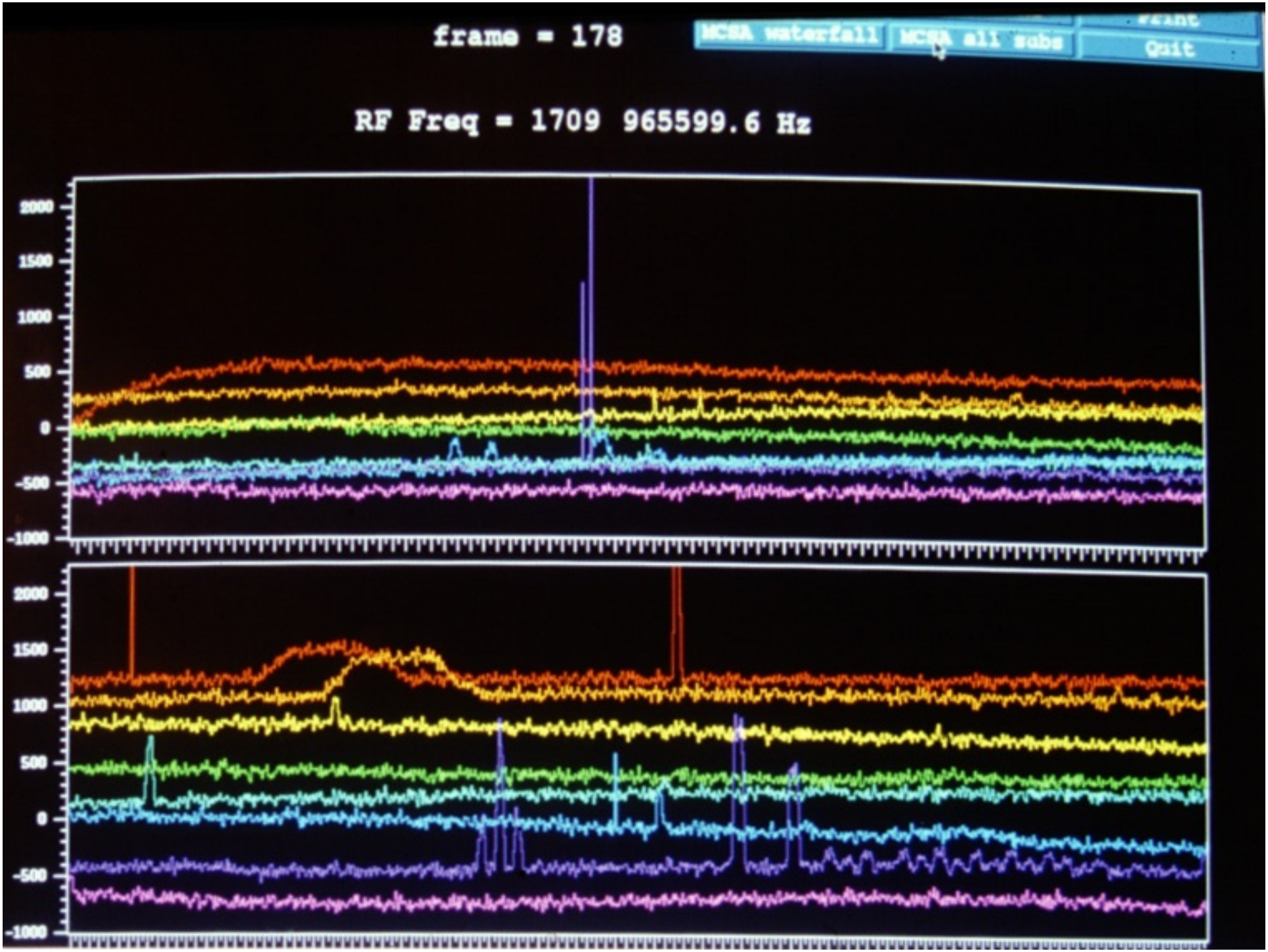
*Nature* article, 1959

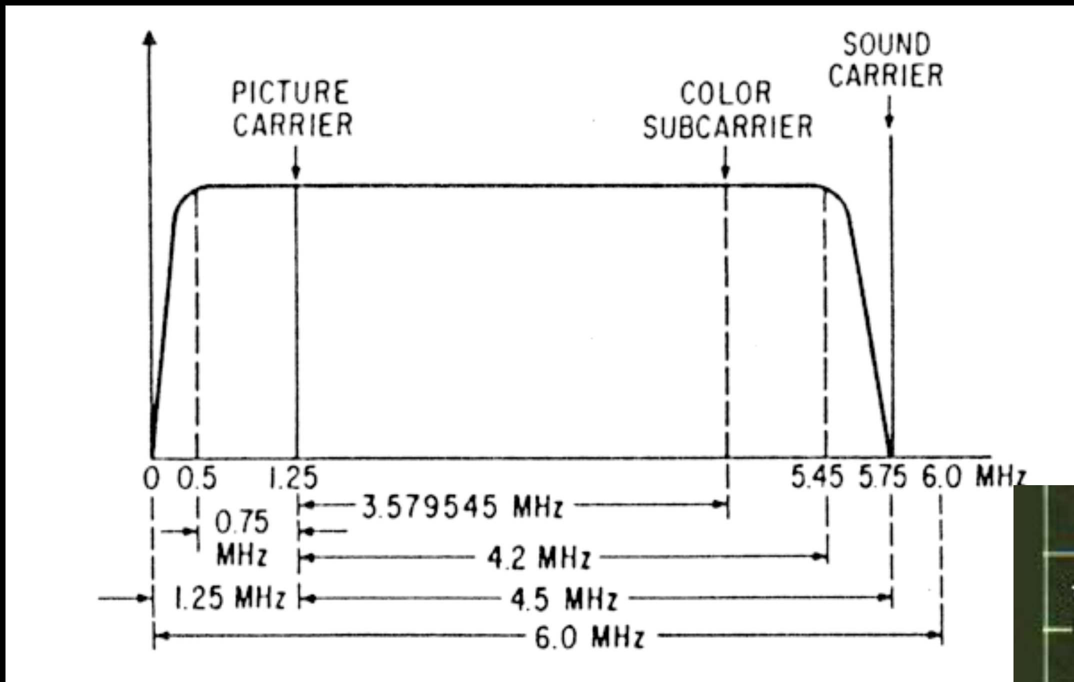

Half a century ago … Green Bank, West Virginia
Frank Drake

# Two Strategies:

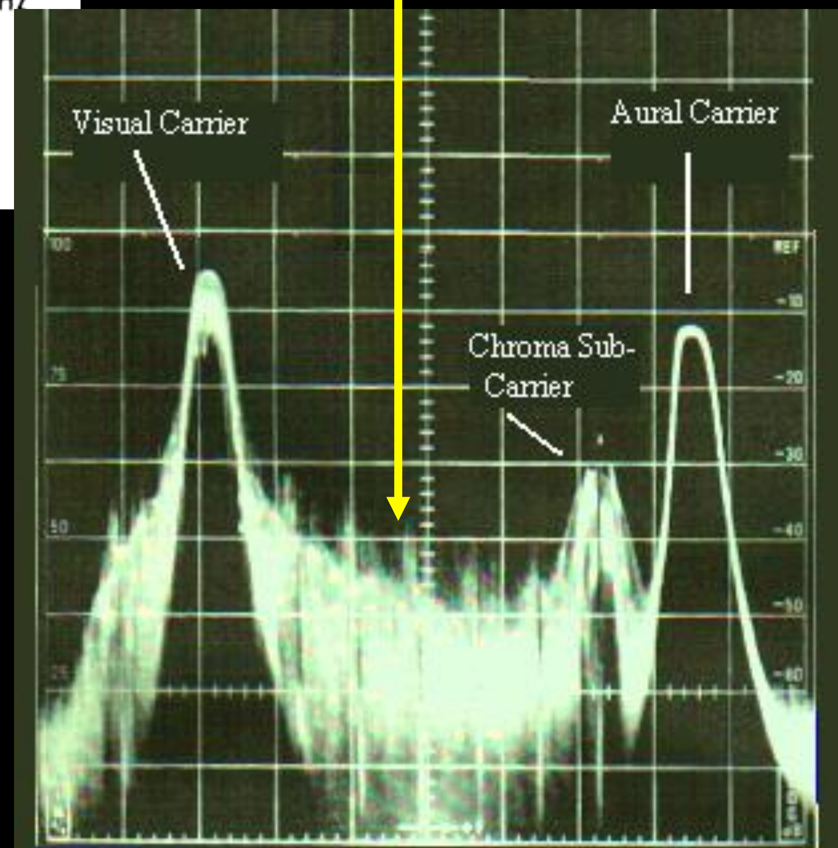
1. Sky Surveys
2. Targeted Searches


Project Phoenix
Targeted Search
1 – 3 GHz
1 Hz channels
Parkes, Green Bank 140-ft,
Arecibo
1995 - 2000


frame = 178
MCSA waterfall
MCSA all subs
Quit
RF Freq = 1709 965599.6 Hz
2000
1500
1000
500
0
-500
-1000

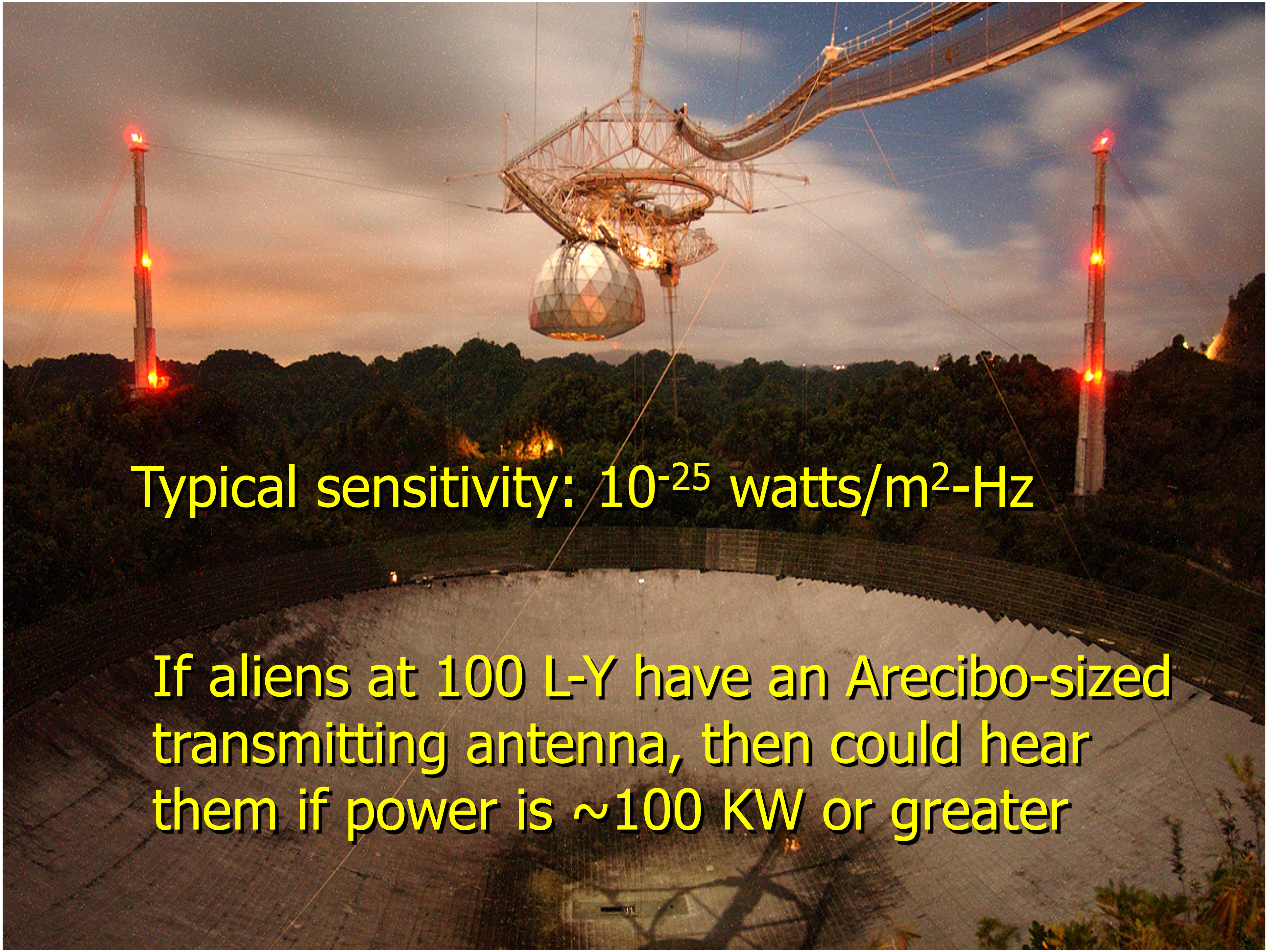

PICTURE CARRIER
COLOR SUBCARRIER
SOUND CARRIER
0 0.5 1.25 5.45 5.75 6.0 MHz
3.579545 MHz
0.75 MHz
4.2 MHz
1.25 MHz
4.5 MHz
6.0 MHz

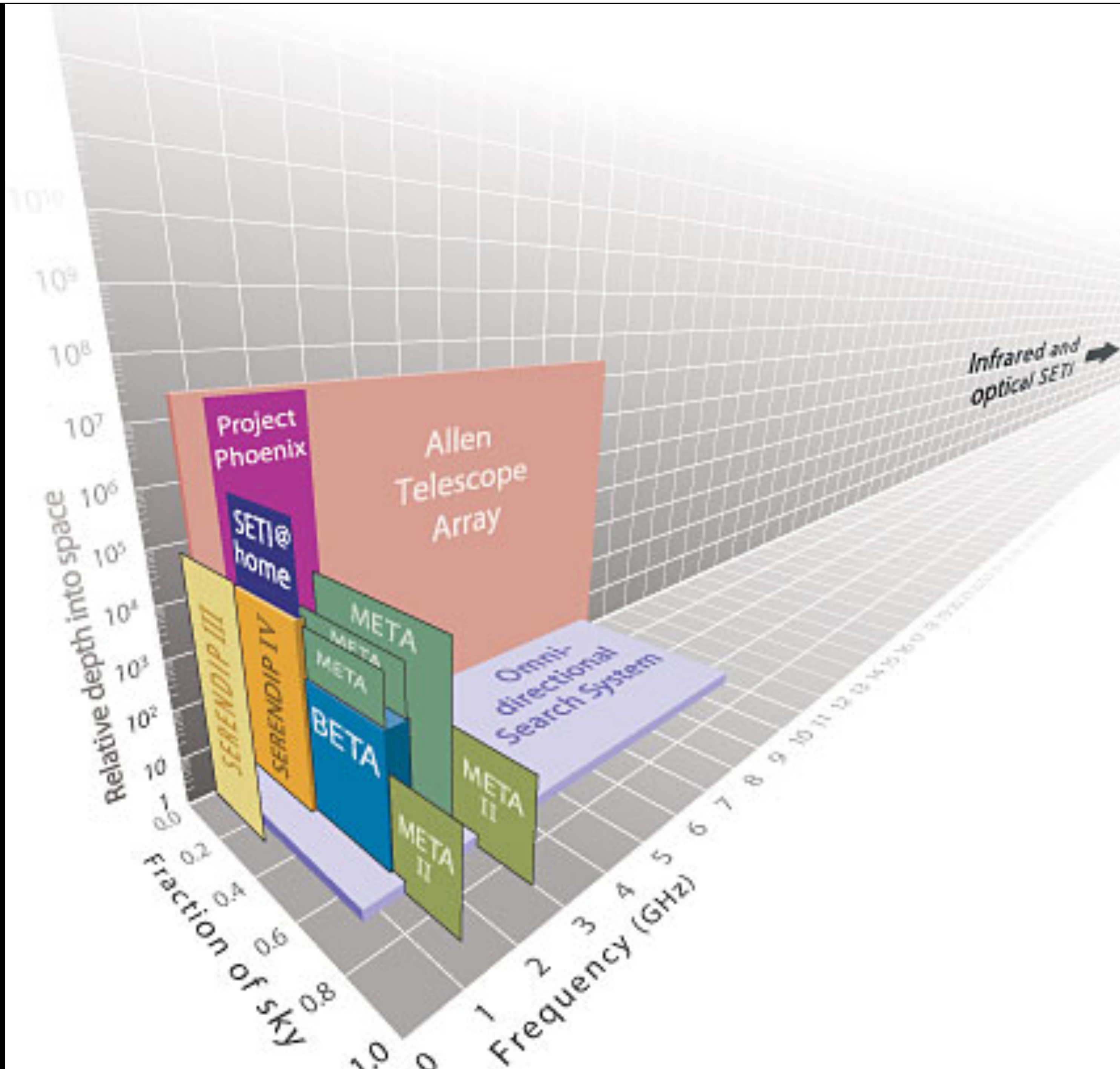
# Jon Stewart


Visual Carrier
Aural Carrier
Chroma Sub-Carrier


So far … no dice
Only ~1000 star systems carefully observed.
Problem is: low duty cycle.

# Two weeks a year …


Typical sensitivity: $10^{-25}$ watts/$m^2$-Hz
If aliens at 100 L-Y have an Arecibo-sized transmitting antenna, then could hear them if power is ~100 KW or greater

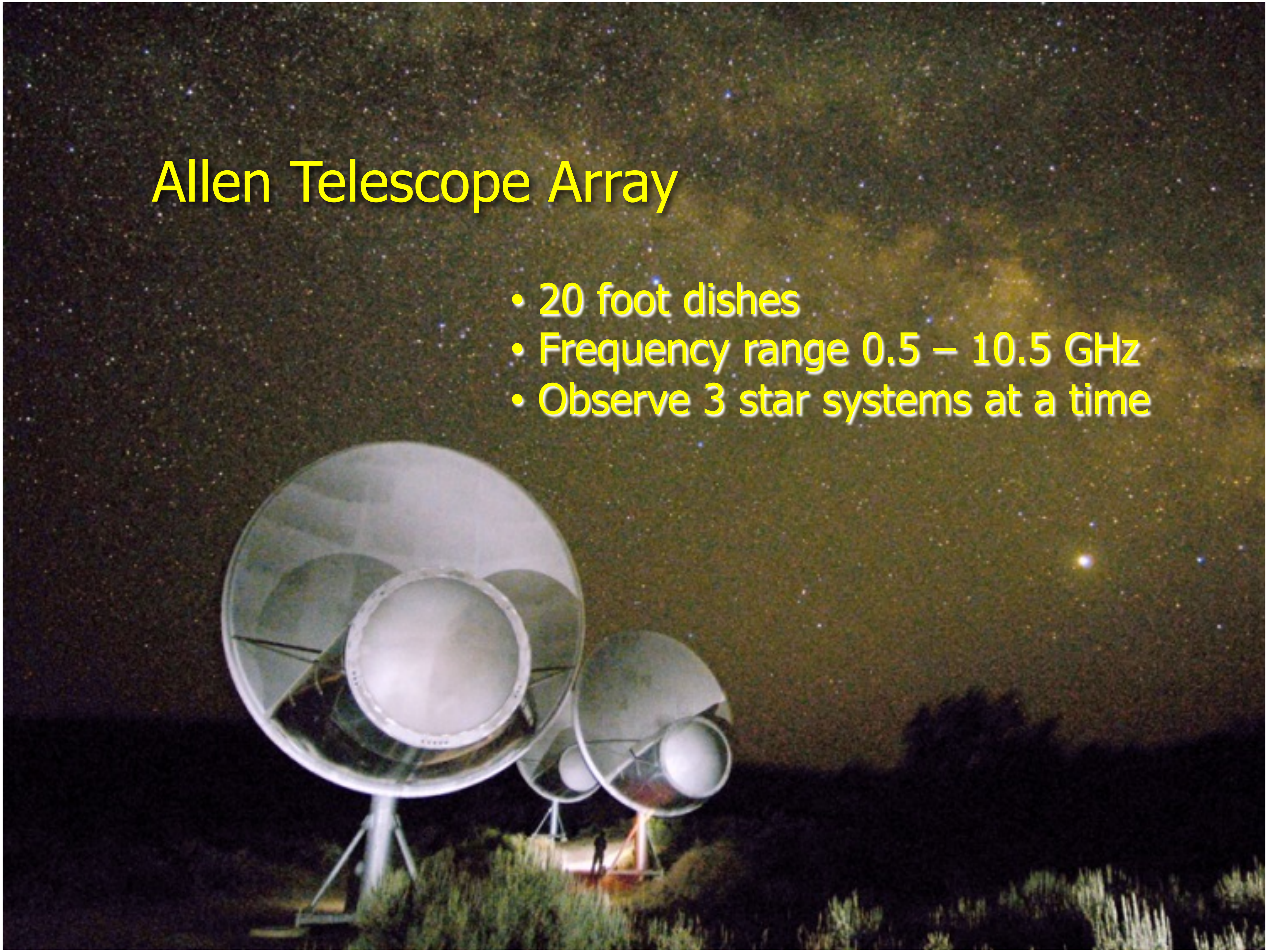


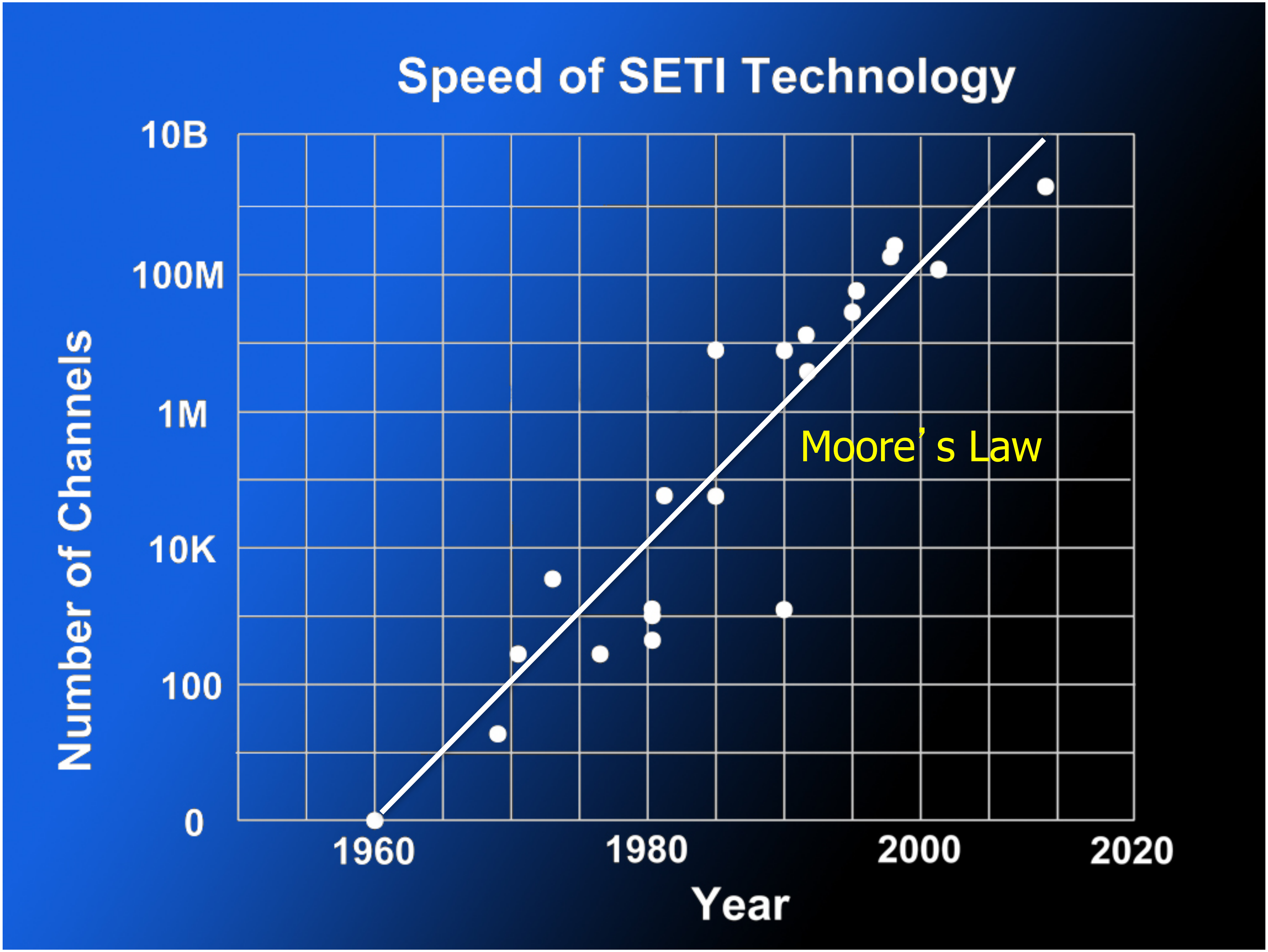
Relative depth into space
1
10
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
Fraction of sky
0.0
0.2
0.4
0.6
0.8
1.0
Frequency (GHz)
0
1
2
3
4
5
6
7
8
9
10
Project Phoenix
SETI@home
Allen Telescope Array
SERENDIP III
SERENDIP IV
META
META
META
BETA
META II
META II
Omni-directional Search System
Infrared and optical SETI


So when do we find them?

# Allen Telescope Array

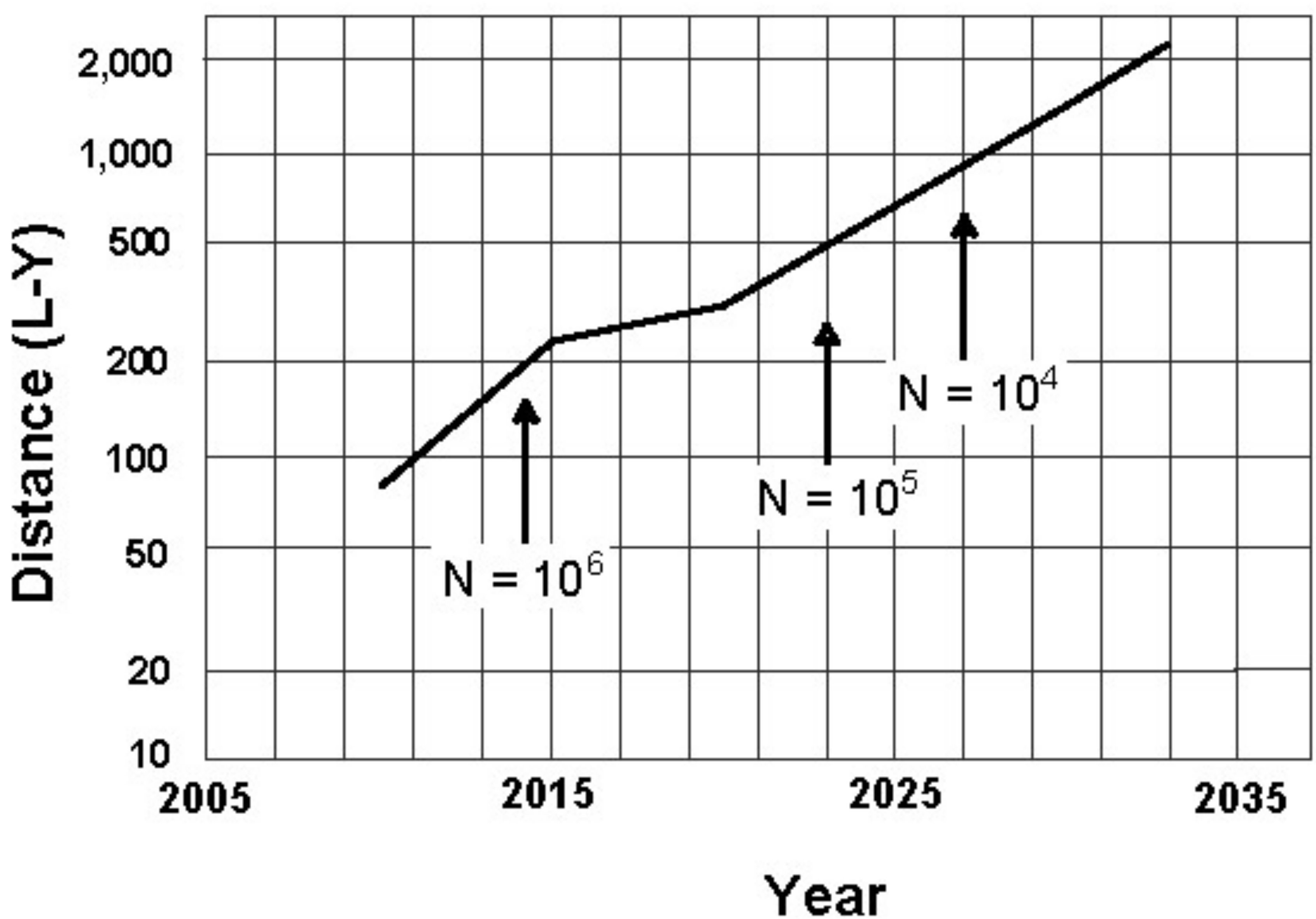
- 20 foot dishes
- Frequency range 0.5 – 10.5 GHz
- Observe 3 star systems at a time





Speed of SETI Technology
Number of Channels
10B
100M
1M
10K
100
0
1960
1980
2000
2020
Year
Moore’ s Law

**Figure 3. Distance Within Which All Suitable Targets Observe**

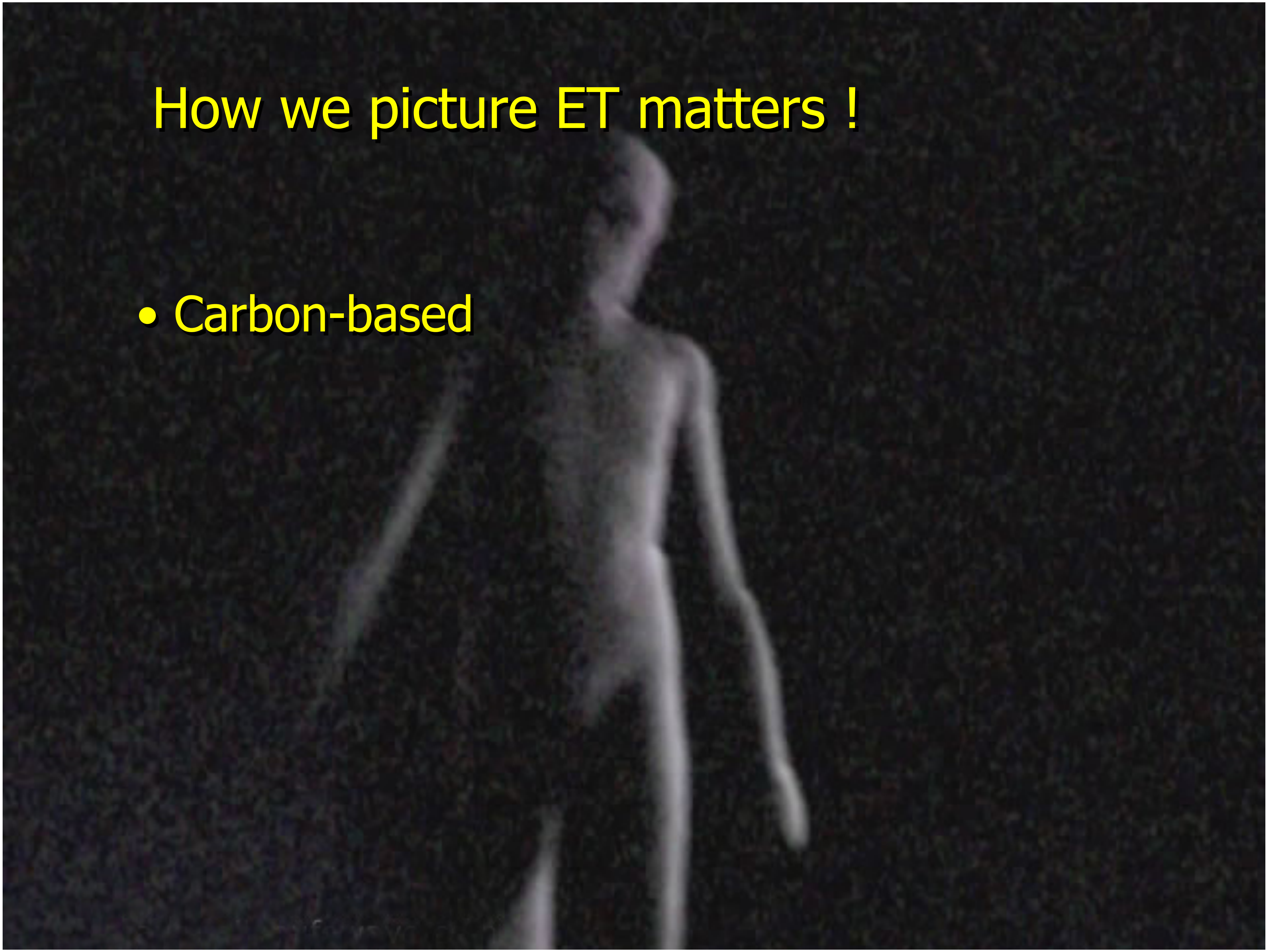


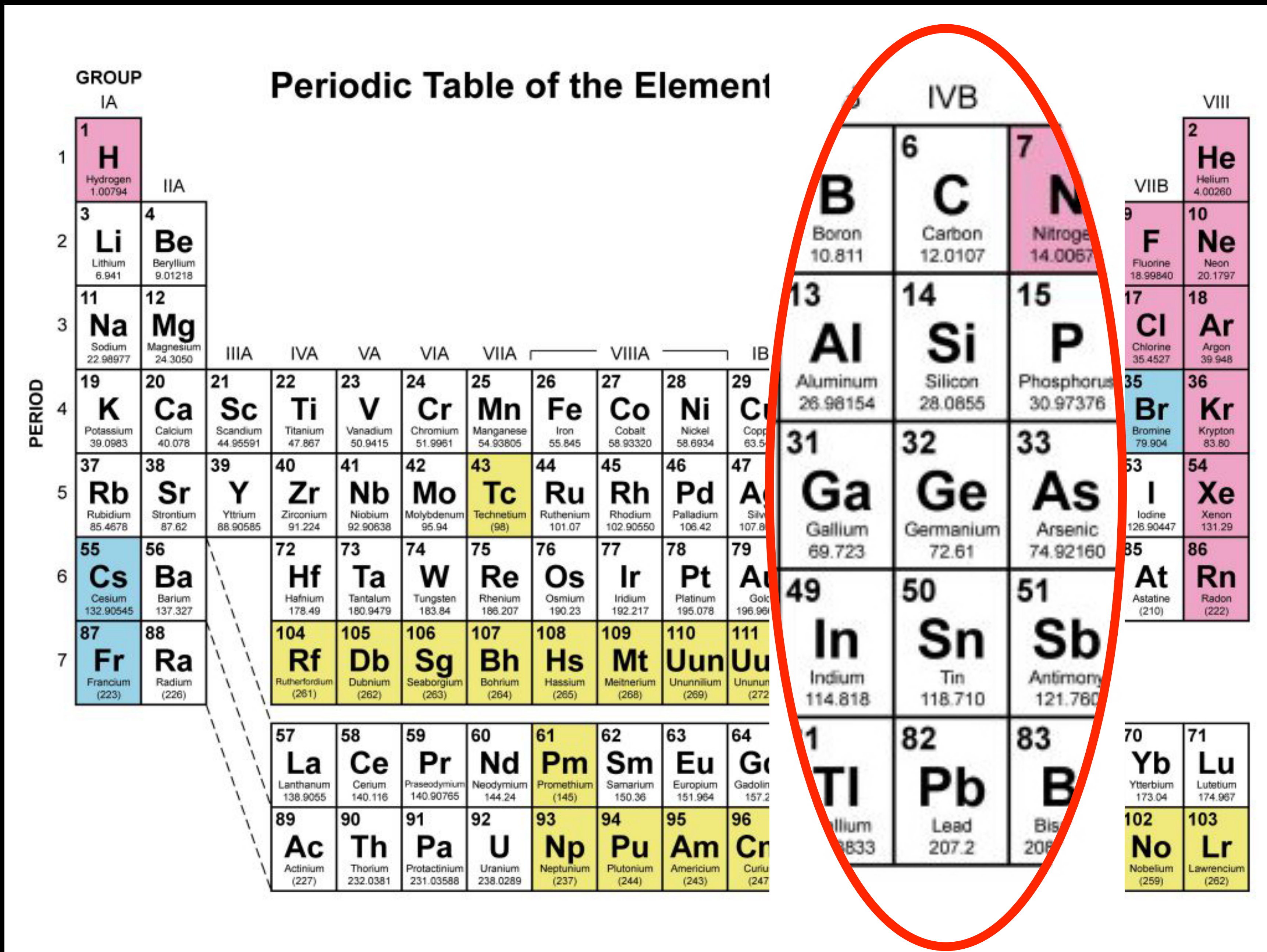

We will find ET within two dozen years …
2B

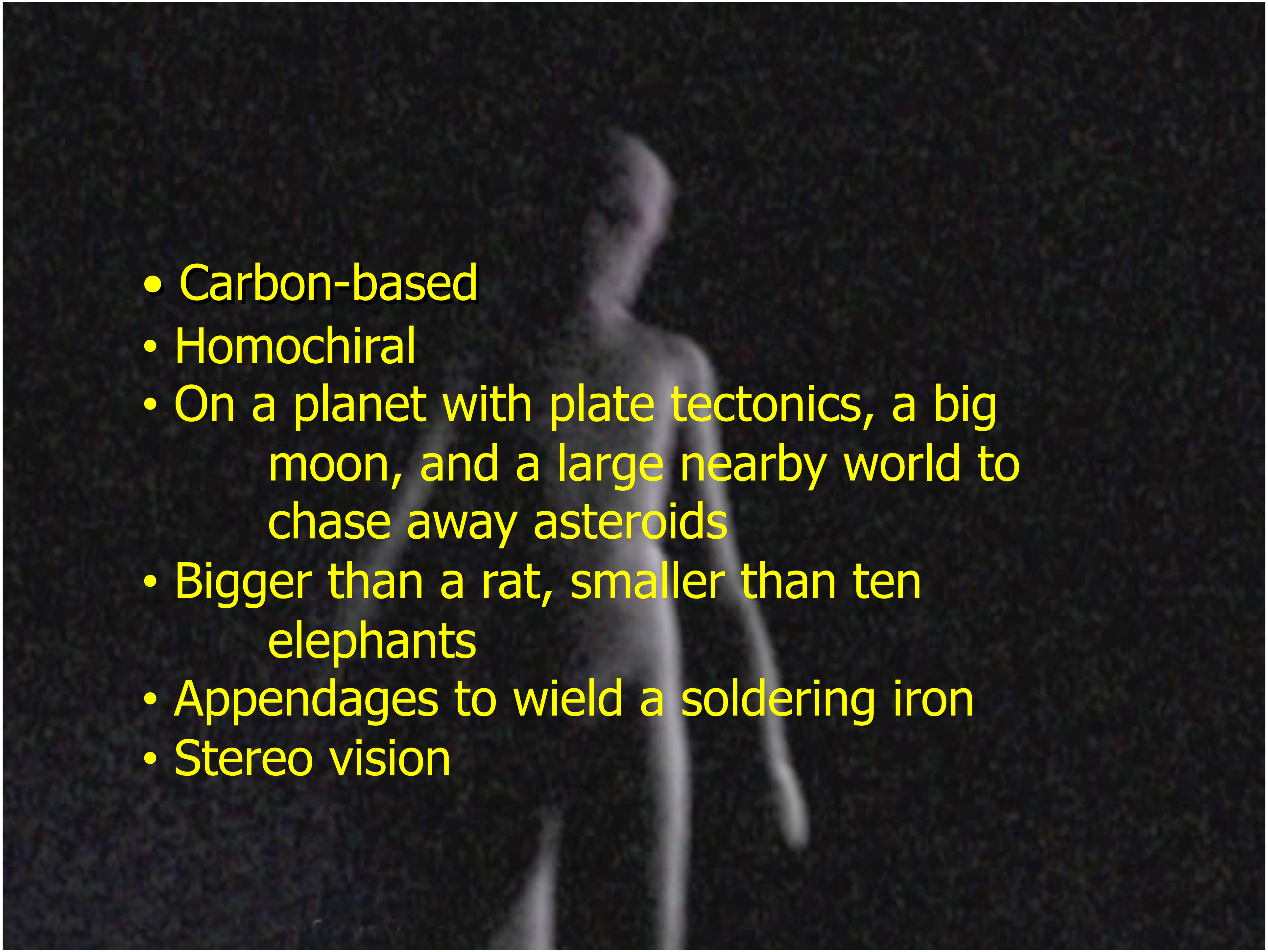
or

# How we picture ET matters !

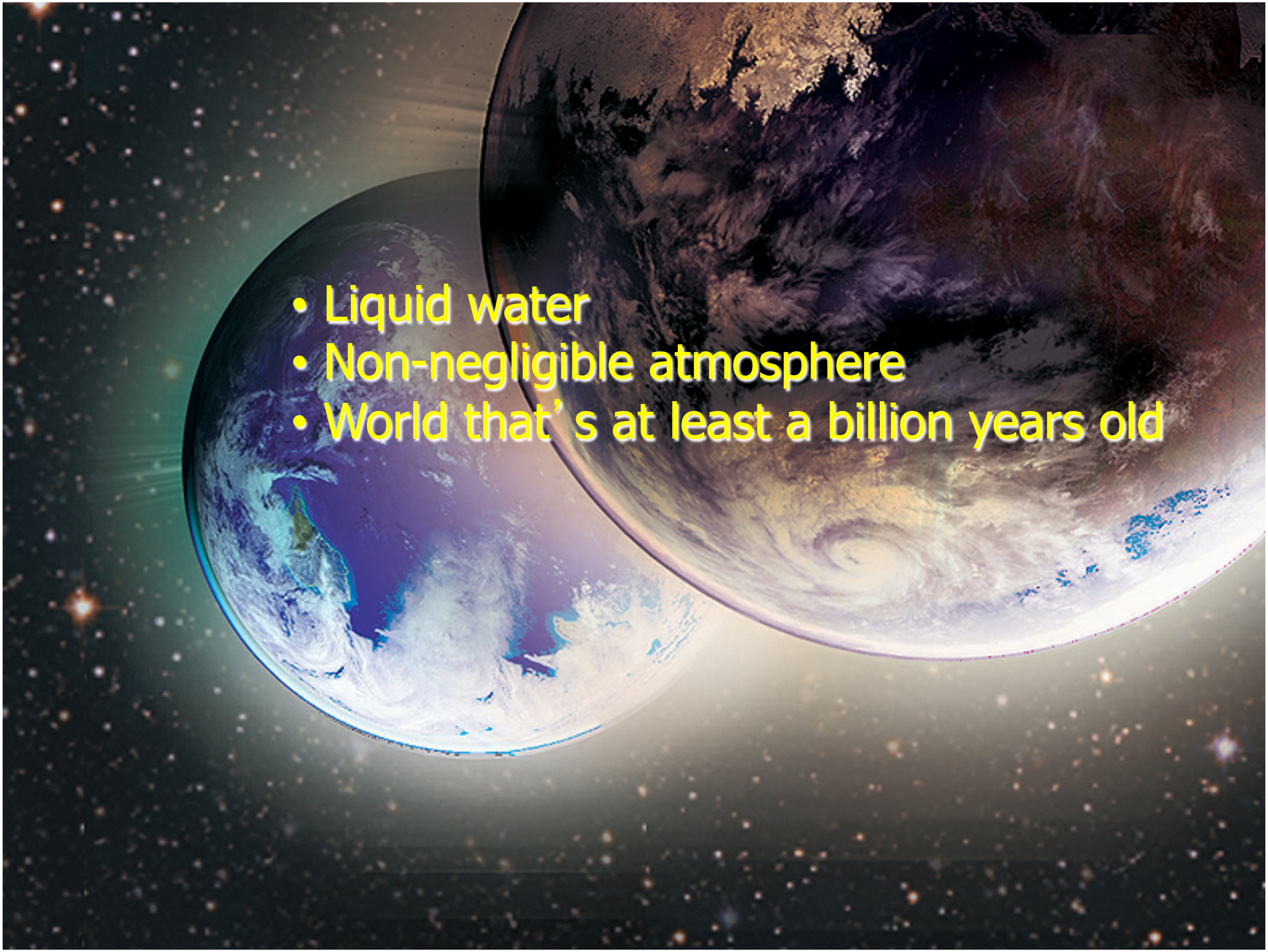
- Carbon-based

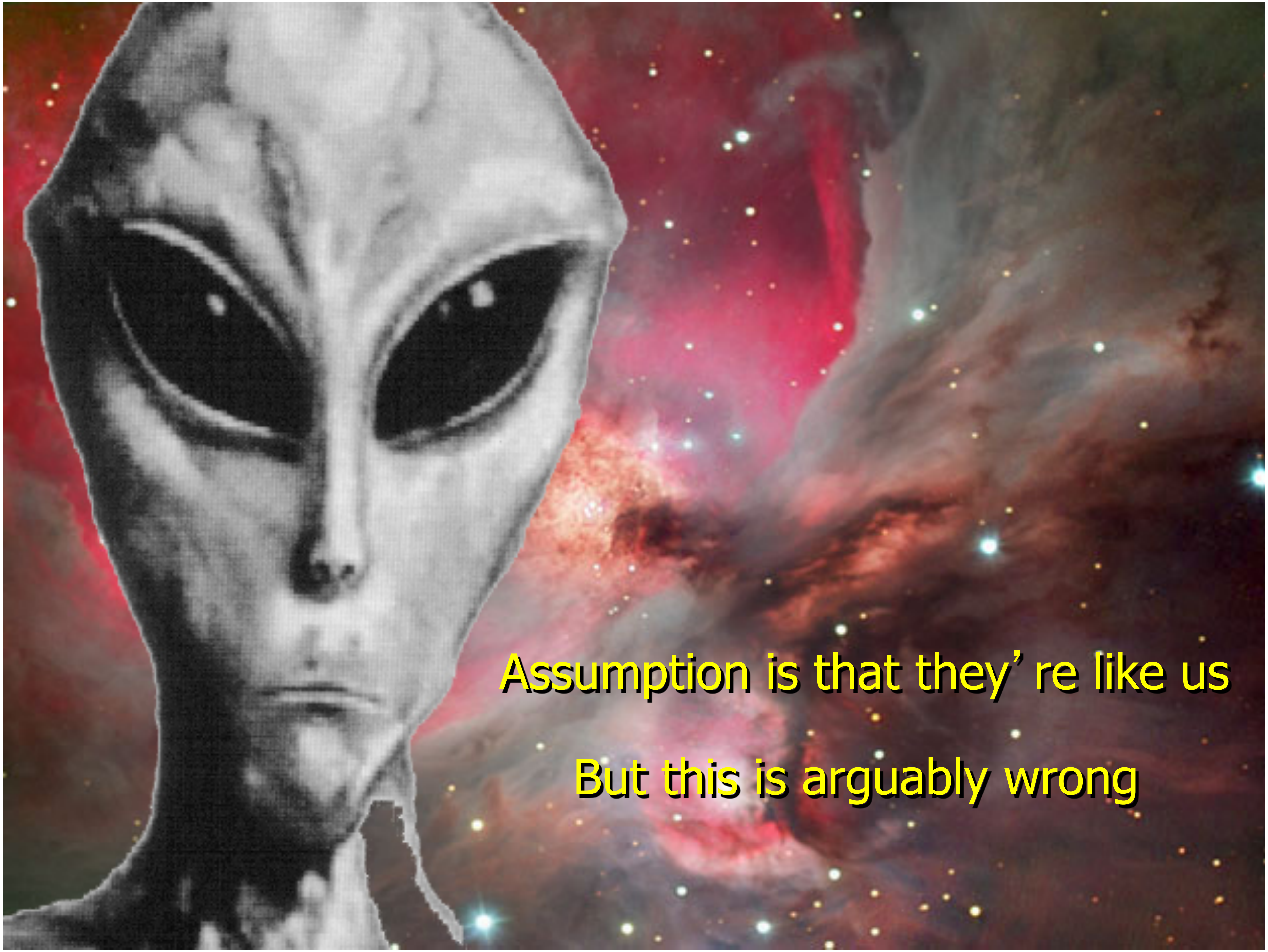


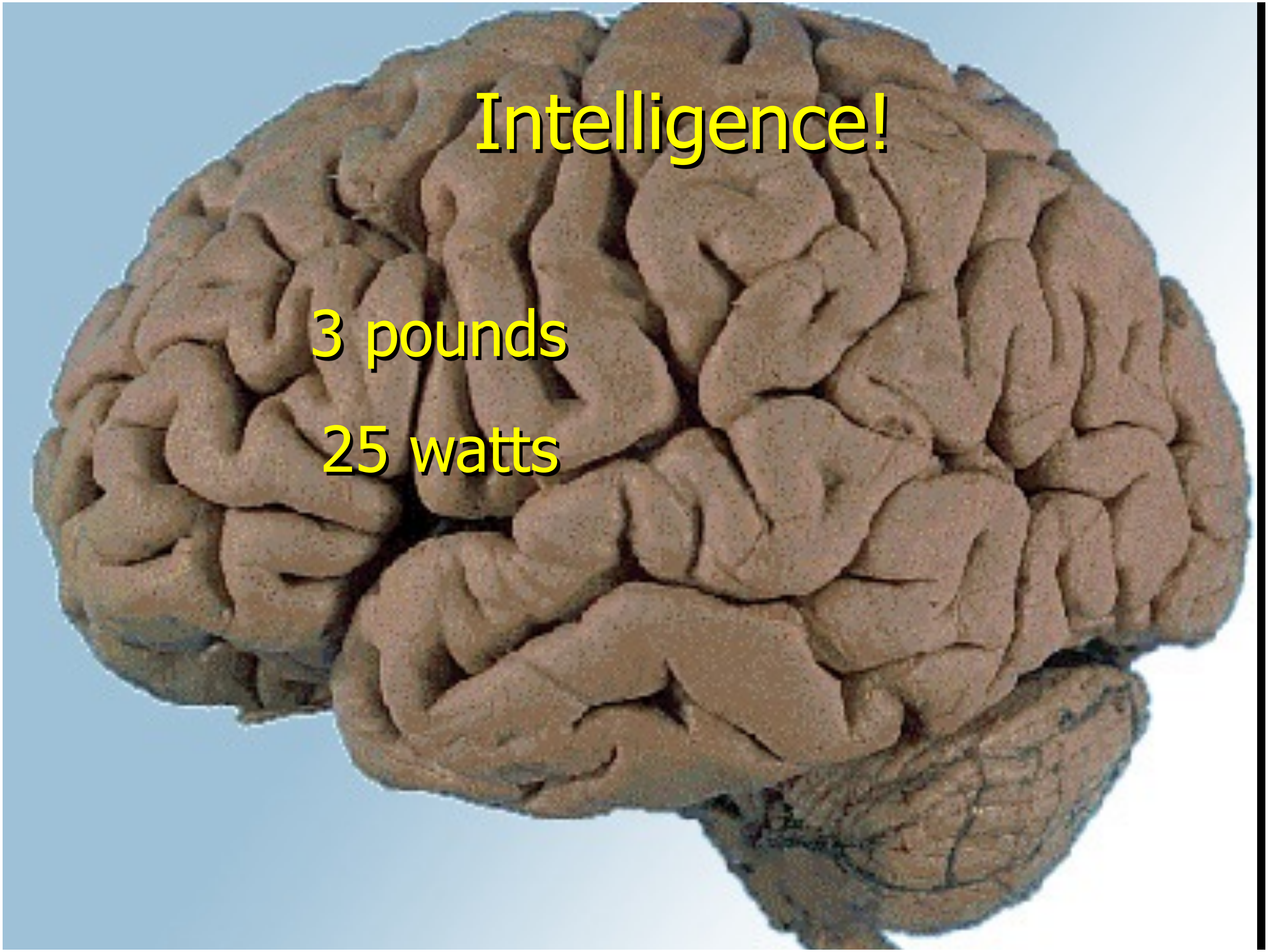

Periodic Table of the Element
GROUP
IA
IIA
IIIA
IVA
VA
VIA
VIIA
VIIIA
IB
IVB
VIIB
VIII
PERIOD
1
2
3
4
5
6
7
1 H Hydrogen 1.00794
2 He Helium 4.00260
3 Li Lithium 6.941
4 Be Beryllium 9.01218
B Boron 10.811
6 C Carbon 12.0107
7 N Nitroge 14.0067
9 F Fluorine 18.99840
10 Ne Neon 20.1797
11 Na Sodium 22.98977
12 Mg Magnesium 24.3050
13 Al Aluminum 26.98154
14 Si Silicon 28.0855
15 P Phosphorus 30.97376
17 Cl Chlorine 35.4527
18 Ar Argon 39.948
19 K Potassium 39.0983
20 Ca Calcium 40.078
21 Sc Scandium 44.95591
22 Ti Titanium 47.867
23 V Vanadium 50.9415
24 Cr Chromium 51.9961
25 Mn Manganese 54.93805
26 Fe Iron 55.845
27 Co Cobalt 58.93320
28 Ni Nickel 58.6934
29 Cu Copp 63.5
31 Ga Gallium 69.723
32 Ge Germanium 72.61
33 As Arsenic 74.92160
35 Br Bromine 79.904
36 Kr Krypton 83.80
37 Rb Rubidium 85.4678
38 Sr Strontium 87.62
39 Y Yttrium 88.90585
40 Zr Zirconium 91.224
41 Nb Niobium 92.90638
42 Mo Molybdenum 95.94
43 Tc Technetium (98)
44 Ru Ruthenium 101.07
45 Rh Rhodium 102.90550
46 Pd Palladium 106.42
47 Ag Silv 107.8
49 In Indium 114.818
50 Sn Tin 118.710
51 Sb Antimony 121.760
53 I Iodine 126.90447
54 Xe Xenon 131.29
55 Cs Cesium 132.90545
56 Ba Barium 137.327
72 Hf Hafnium 178.49
73 Ta Tantalum 180.9479
74 W Tungsten 183.84
75 Re Rhenium 186.207
76 Os Osmium 190.23
77 Ir Iridium 192.217
78 Pt Platinum 195.078
79 Au Gold 196.96
Tl llium
82 Pb Lead 207.2
83 Bi Bis 208
85 At Astatine (210)
86 Rn Radon (222)
87 Fr Francium (223)
88 Ra Radium (226)
104 Rf Rutherfordium (261)
105 Db Dubnium (262)
106 Sg Seaborgium (263)
107 Bh Bohrium (264)
108 Hs Hassium (265)
109 Mt Meitnerium (268)
110 Uun Ununnilium (269)
111 Uu Ununun (272)
57 La Lanthanum 138.9055
58 Ce Cerium 140.116
59 Pr Praseodymium 140.90765
60 Nd Neodymium 144.24
61 Pm Promethium (145)
62 Sm Samarium 150.36
63 Eu Europium 151.964
64 Gd Gadolin 157.2
70 Yb Ytterbium 173.04
71 Lu Lutetium 174.967
89 Ac Actinium (227)
90 Th Thorium 232.0381
91 Pa Protactinium 231.03588
92 U Uranium 238.0289
93 Np Neptunium (237)
94 Pu Plutonium (244)
95 Am Americium (243)
96 Cm Curiu (247)
102 No Nobelium (259)
103 Lr Lawrencium (262)

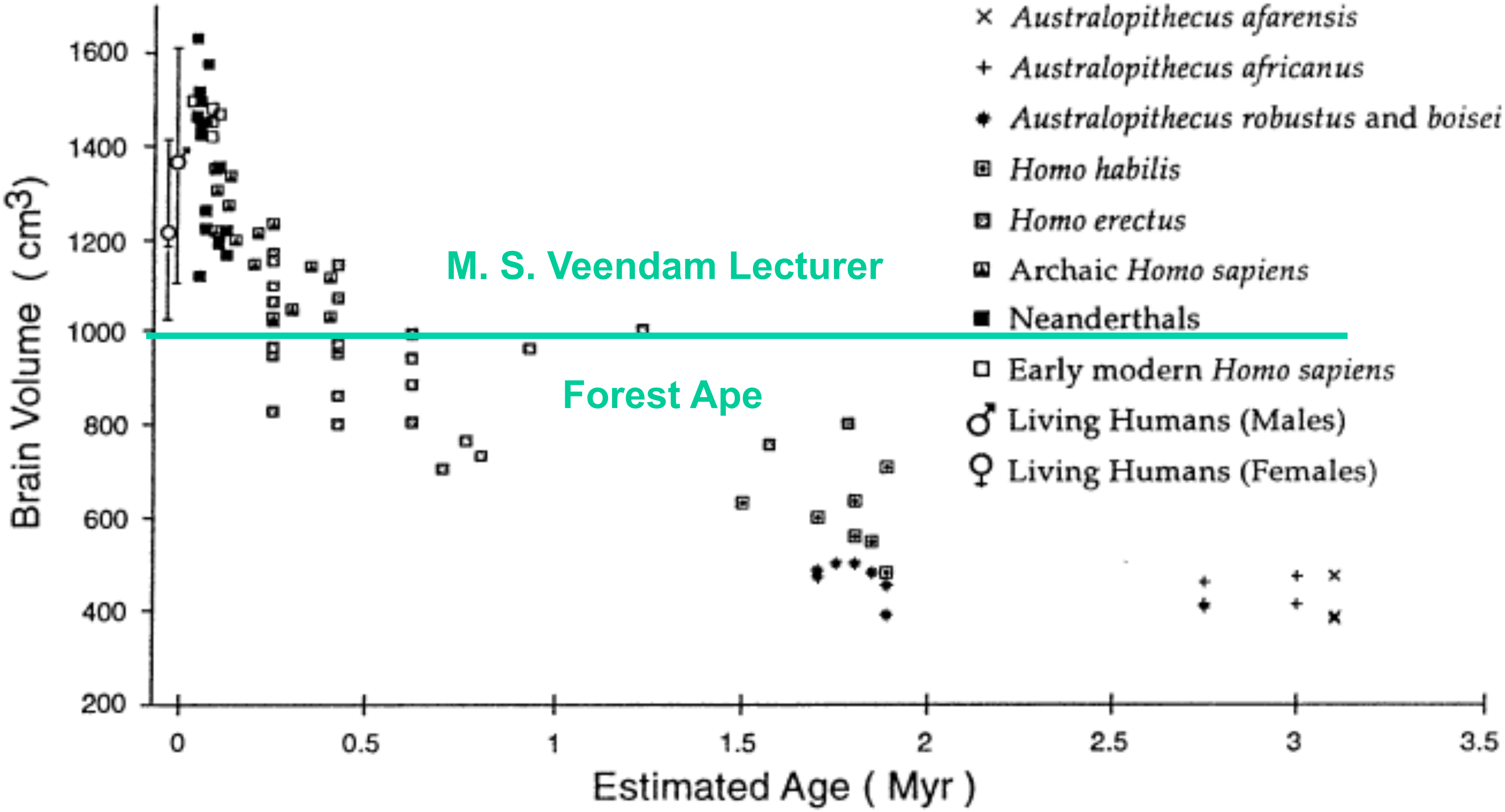


- Carbon-based
- Homochiral
- On a planet with plate tectonics, a big moon, and a large nearby world to chase away asteroids
- Bigger than a rat, smaller than ten elephants
- Appendages to wield a soldering iron
- Stereo vision

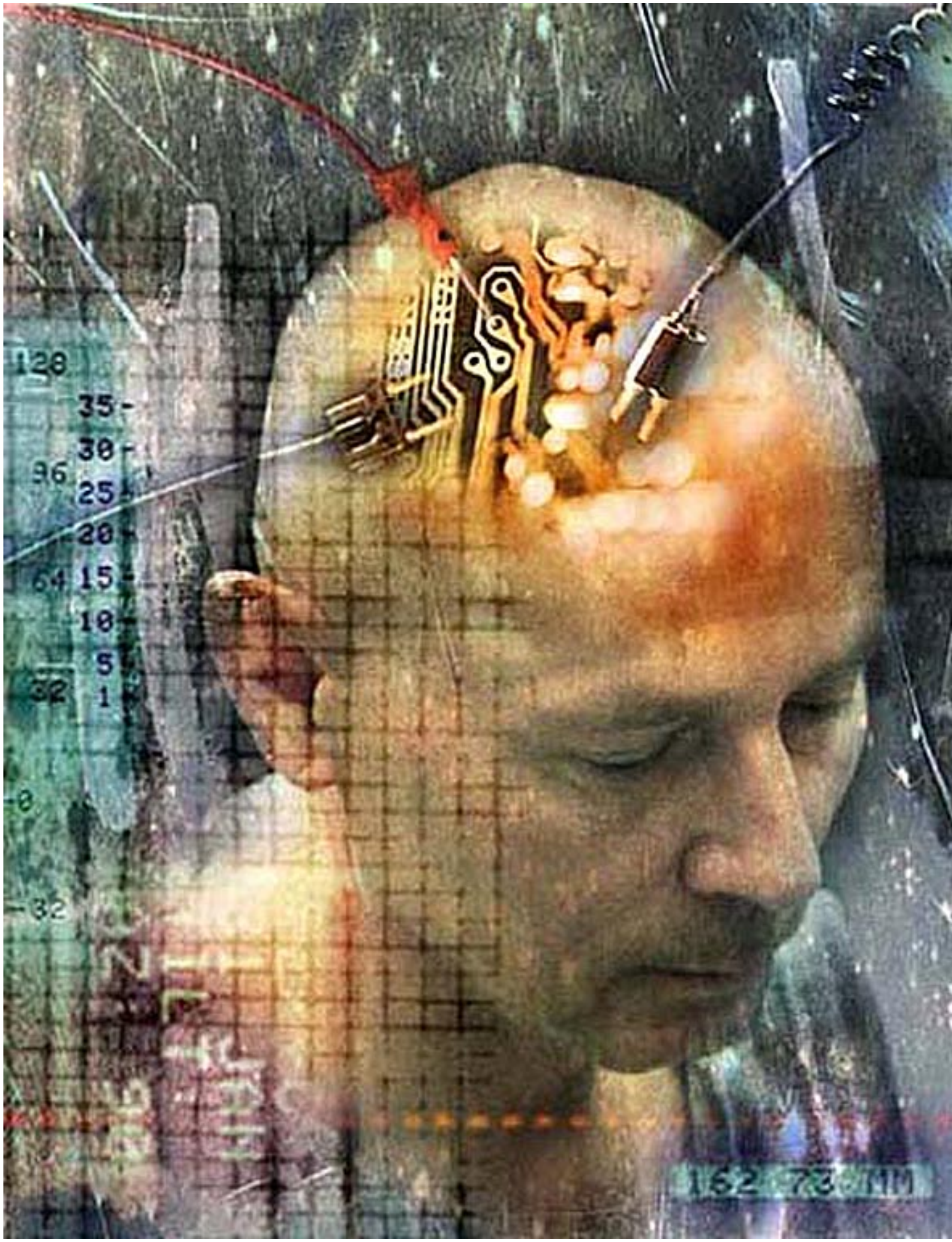

• Liquid water
• Non-negligible atmosphere
• World that's at least a billion years old


Assumption is that they’re like us
But this is arguably wrong

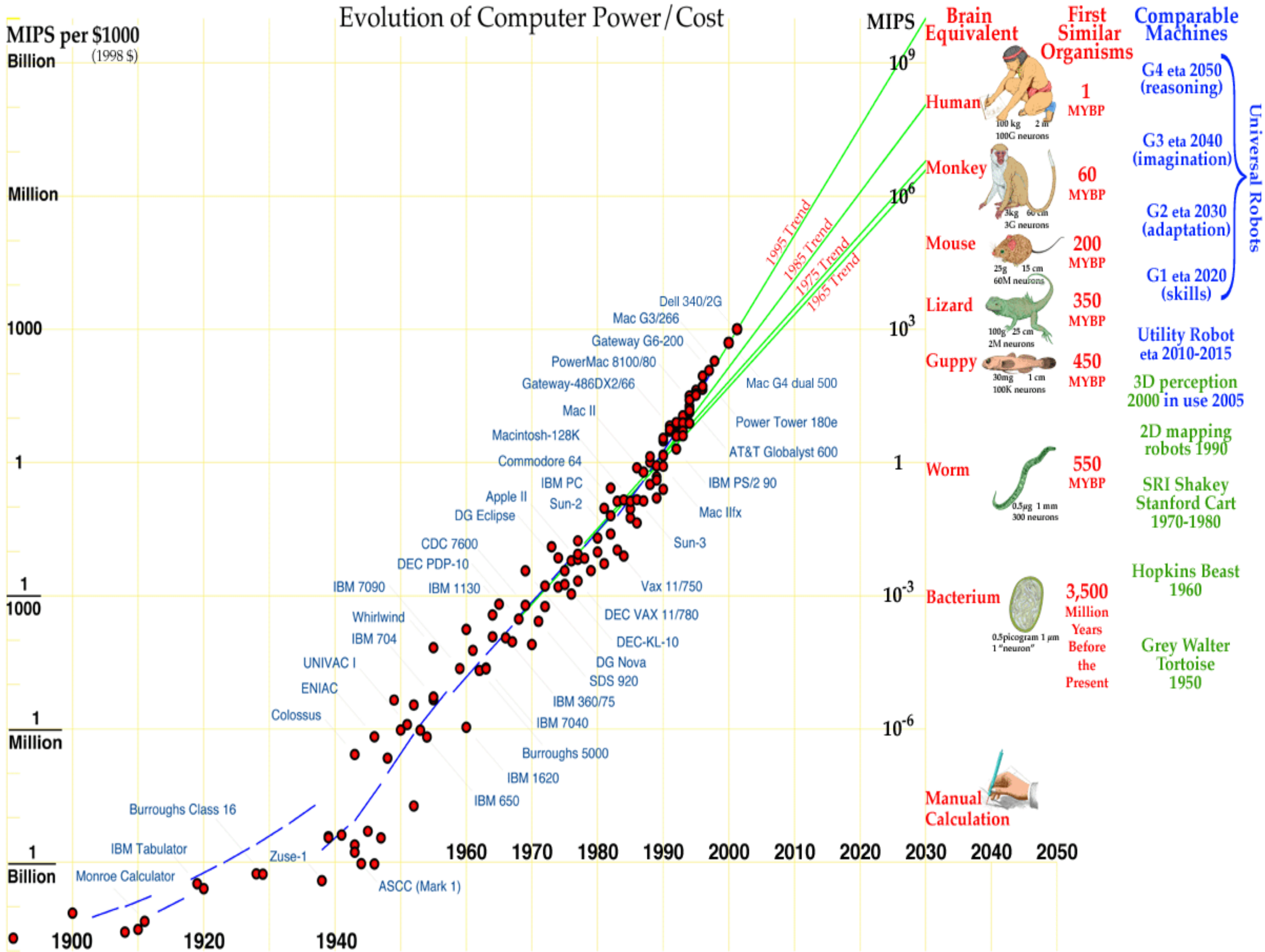

Intelligence!
3 pounds
25 watts



Brain Volume (cm³)
1600
1400
1200
1000
800
600
400
200
0
0.5
1
1.5
2
2.5
3
3.5
Estimated Age ( Myr )
M. S. Veendam Lecturer
Forest Ape
Australopithecus afarensis
Australopithecus africanus
Australopithecus robustus and boisei
Homo habilis
Homo erectus
Archaic Homo sapiens
Neanderthals
Early modern Homo sapiens
Living Humans (Males)
Living Humans (Females)

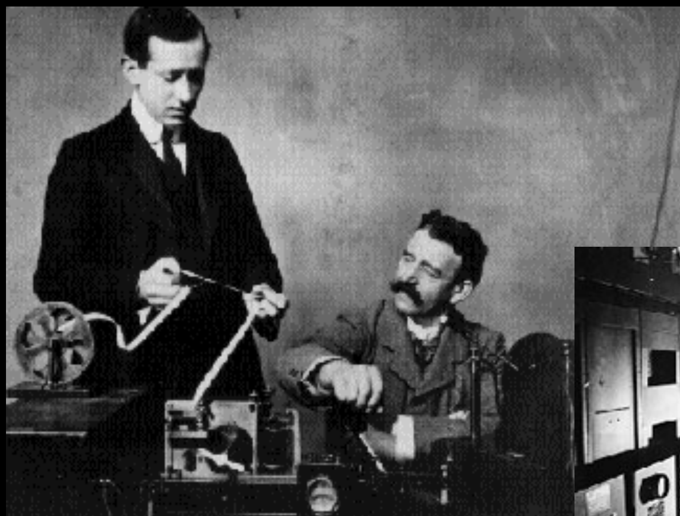


Maybe they’ve got cybernetic enhancements …



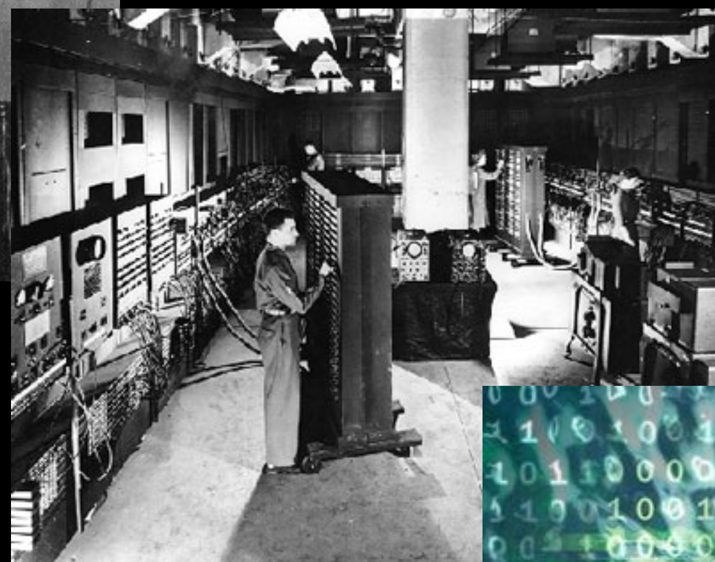
Evolution of Computer Power/Cost
MIPS per $1000
(1998 $)
Billion
Million
1000
1
1/1000
1/Million
1/Billion
1900
1920
1940
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
MIPS
10^9
10^6
10^3
1
10^-3
10^-6
1995 Trend
1985 Trend
1975 Trend
1965 Trend
Dell 340/2G
Mac G3/266
Gateway G6-200
PowerMac 8100/80
Gateway-486DX2/66
Mac II
Macintosh-128K
Commodore 64
IBM PC
Apple II
Sun-2
DG Eclipse
CDC 7600
DEC PDP-10
IBM 7090
IBM 1130
Whirlwind
IBM 704
UNIVAC I
ENIAC
Colossus
Burroughs Class 16
IBM Tabulator
Zuse-1
Monroe Calculator
ASCC (Mark 1)
IBM 650
IBM 1620
Burroughs 5000
IBM 7040
IBM 360/75
SDS 920
DG Nova
DEC-KL-10
DEC VAX 11/780
Vax 11/750
Sun-3
Mac IIfx
IBM PS/2 90
AT&T Globalyst 600
Power Tower 180e
Mac G4 dual 500
Brain Equivalent
First Similar Organisms
Comparable Machines
Human
100 kg 2 m
100G neurons
1 MYBP
Monkey
3kg 60 cm
3G neurons
60 MYBP
Mouse
25g 15 cm
60M neurons
200 MYBP
Lizard
100g 25 cm
2M neurons
350 MYBP
Guppy
30mg 1 cm
100K neurons
450 MYBP
Worm
0.5μg 1 mm
300 neurons
550 MYBP
Bacterium
0.5picogram 1 μm
1 "neuron"
3,500 Million Years Before the Present
Manual Calculation
G4 eta 2050 (reasoning)
G3 eta 2040 (imagination)
G2 eta 2030 (adaptation)
G1 eta 2020 (skills)
Universal Robots
Utility Robot eta 2010-2015
3D perception 2000 in use 2005
2D mapping robots 1990
SRI Shakey Stanford Cart 1970-1980
Hopkins Beast 1960
Grey Walter Tortoise 1950

# Time Scale Argument

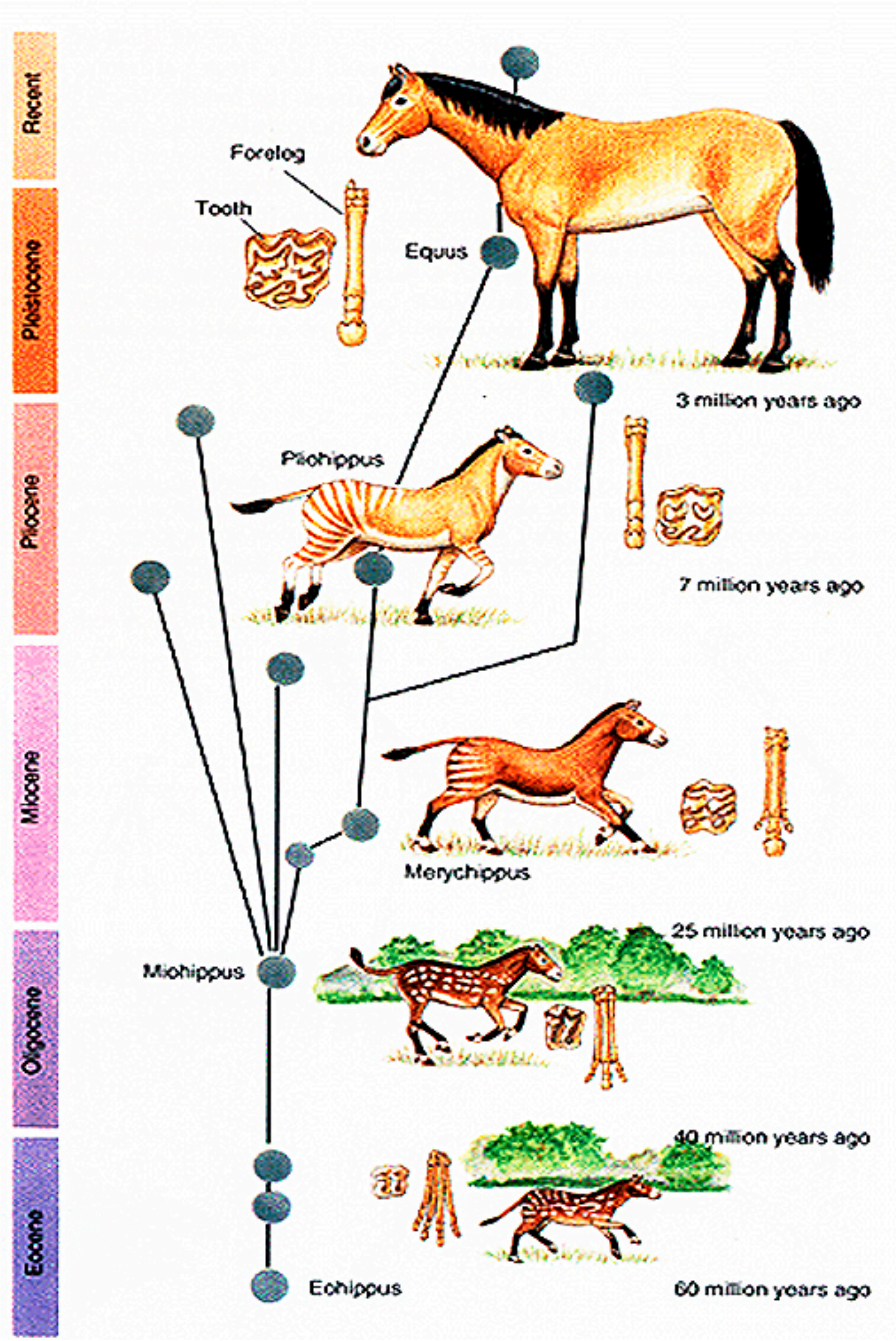


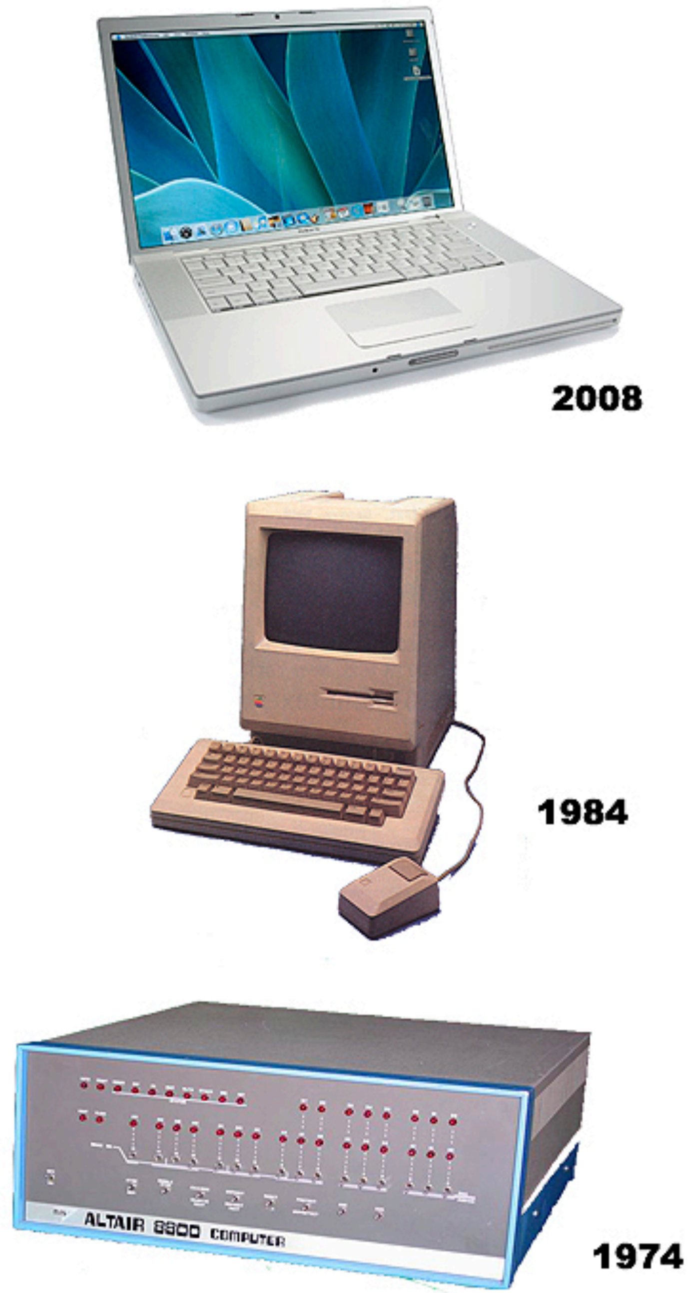
1900: Radio

1945: Computer



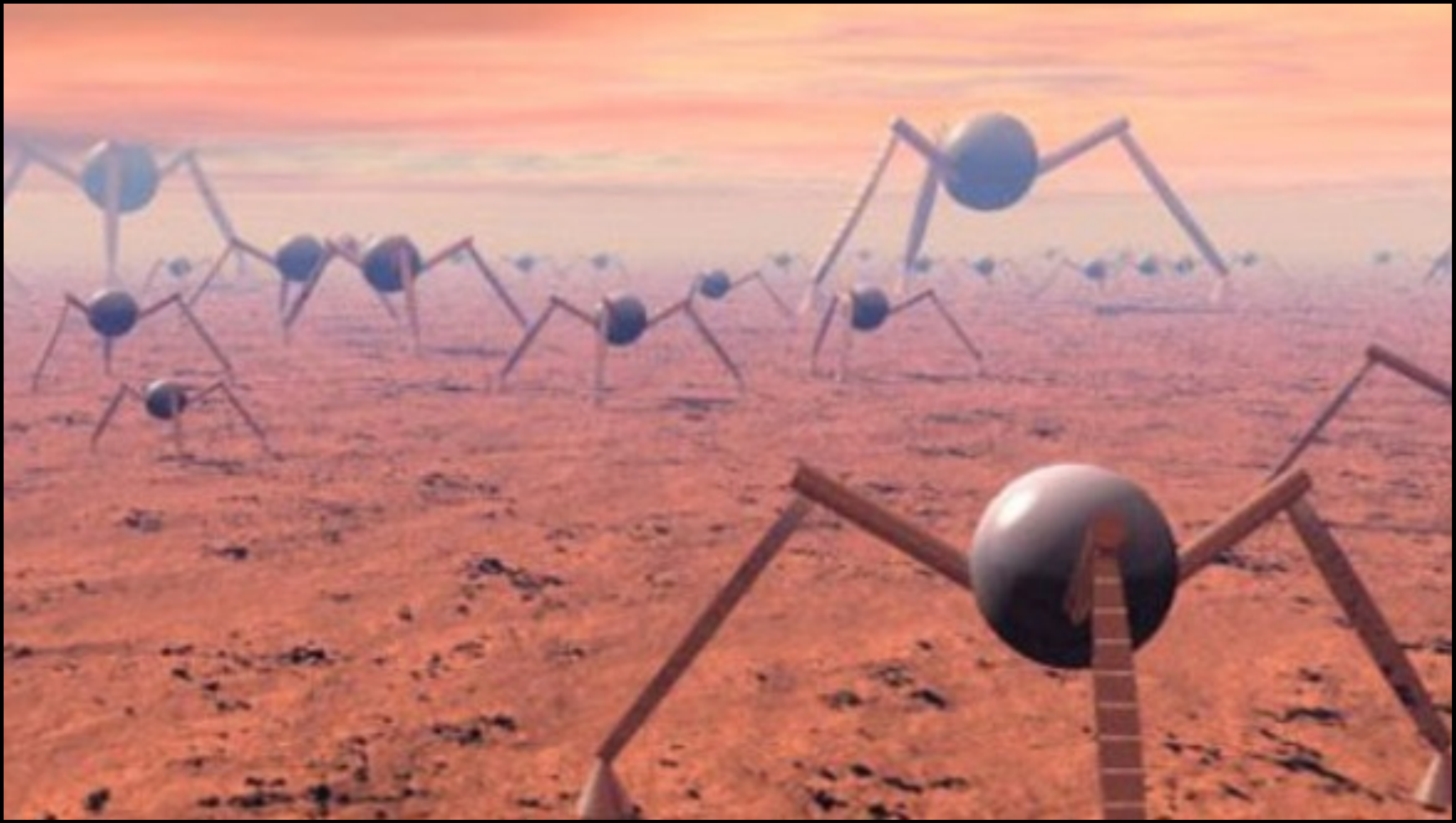
2050?  Strong AI


Recent
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Foreleg
Tooth
Equus
3 million years ago
Pliohippus
7 million years ago
Merychippus
25 million years ago
Miohippus
40 million years ago
Eohippus
60 million years ago


2008
1984
ALTAIR 8800 COMPUTER
1974


It' s not going to be these guys!

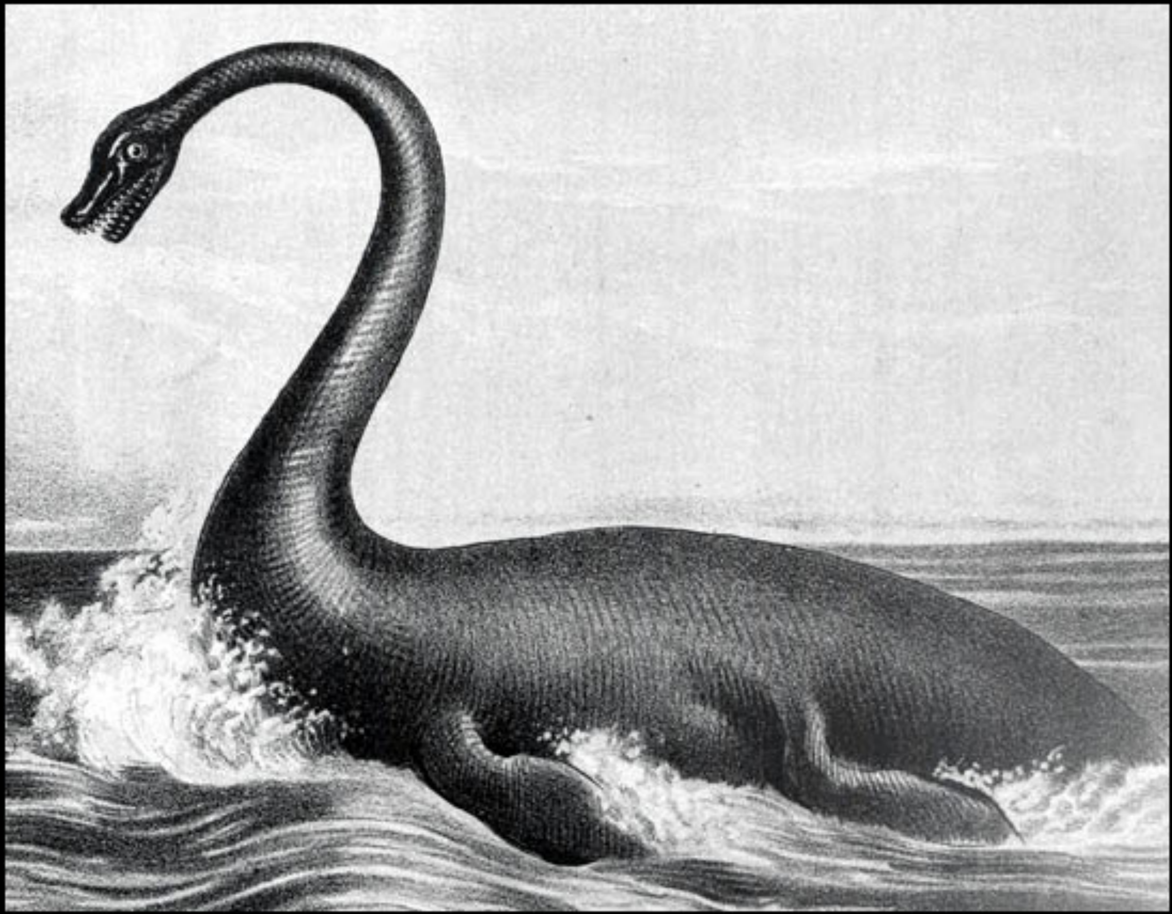
# Machines Design the Next Generation



The last invention we need to make ...


AI doesn’t require a “habitable” world

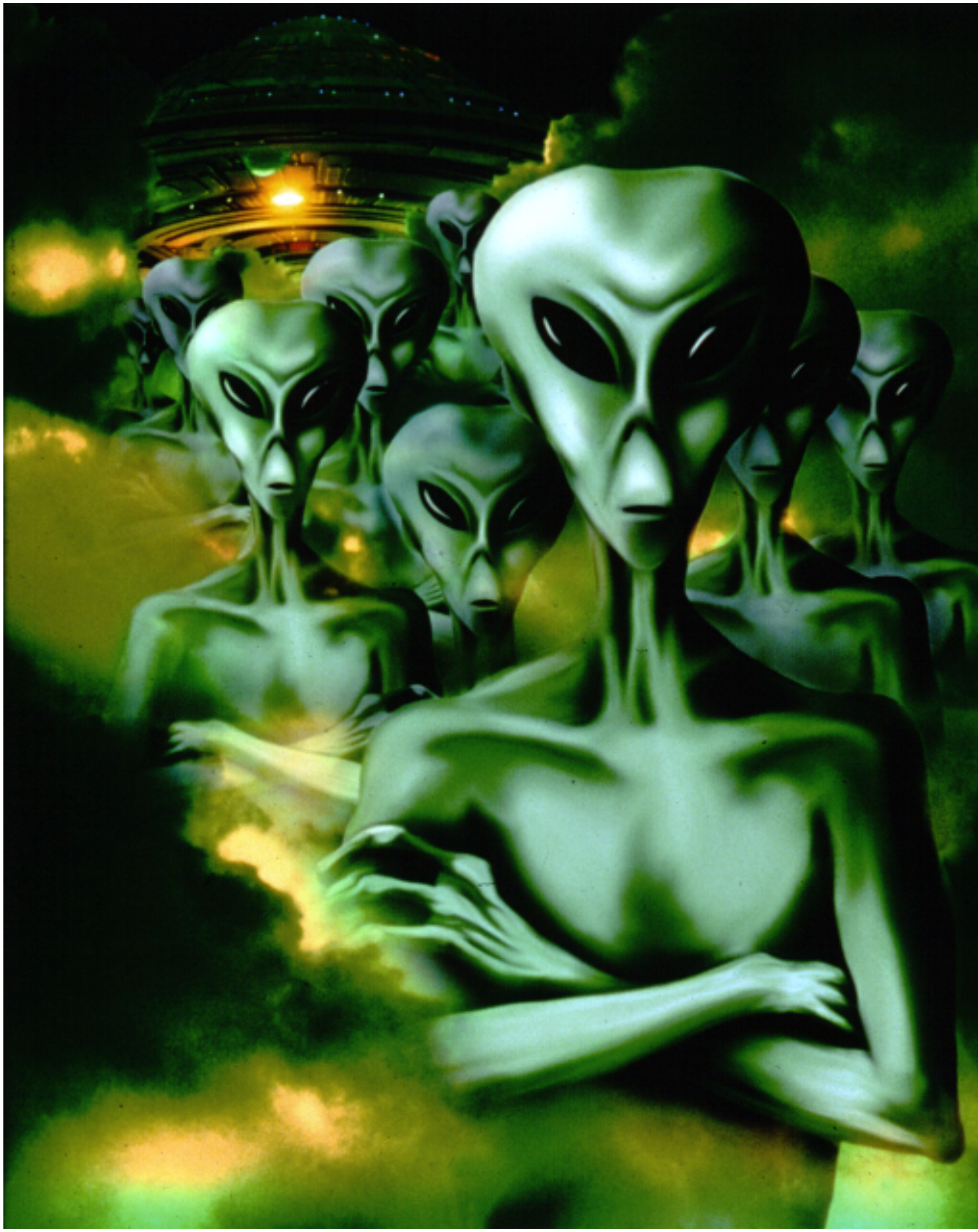
# Not a species with a finite lifetime



Bottom Line:

AI dominates intelligence in the cosmos


Wrong approach ...



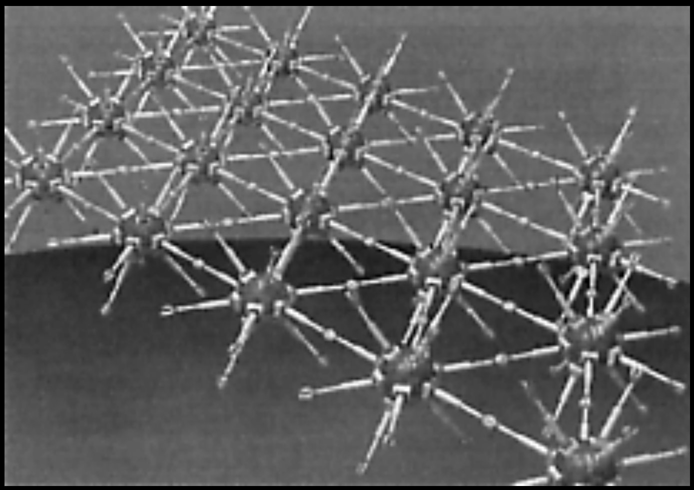
Forget these guys …

# What can we say about cosmic AI?

1. Our species has been engineered “bottom up”
2. AI will be engineered “top down” – highly functional
3. Nonetheless, one predictable property is LONG-TERM SURVIVAL (otherwise, they’re not around)
4. (Only alternative to #3 would be if they grossly altered the universe)

# Two Strategies for Long-Term Survival

1. Finite lifetime, but lots of offspring and adaptation
2. Indefinite lifetime with self-repair



Cosmic AI might choose for indefinite lifetime and self-repair, to better preserve knowledge and capability

1. Swarms of nanobots


2. Centralized IQ

# Where Should We Look?

Need (1) Energy and (2) Matter

| Spect Type | Luminosity | Main Sequence Lifetime | Total Emitted Energy |
|---|---|---|---|
| | *(solar units)* | *(years)* | *(joules)* |
| O | $10^6$ | $5\ 10^5$ | $6.0\ 10^{45}$ |
| B | $10^3$ | $5\ 10^7$ | $6.0\ 10^{44}$ |
| A | 20 | $1\ 10^9$ | $2.4\ 10^{44}$ |
| F | 7 | $2\ 10^9$ | $1.7\ 10^{44}$ |
| G | 1 | $1\ 10^{10}$ | $1.2\ 10^{44}$ |
| K | 0.3 | $2\ 10^{10}$ | $7.3\ 10^{43}$ |
| M | 0.003 | $6\ 10^{11}$ | $2.2\ 10^{43}$ |

O stars … wer
and (2) …

But …
shor … next
refu …

Bett …

O-B association in Scorpio

Another possibility: Bok globules with embedded, hot stars …

$e = 1 - T_{sink}/T_{source}$

Typically 10 times cooler than ISM (~10K)

## Why Would AI Communicate, and How?

(1) Sending a backup data stream to a distant storage unit (or another AI) as a hedge against catastrophe
(2) Data transmitted to maintain social systems ("clubs") of AI's
(3) Data to/from satellite observers – probes of other parts of the galaxy

But all of the these could best be accomplished with point-to-point (laser) links … and therefore would be undetectable via SETI.

A fourth possibility:

Locating *new* intelligence
(competition, new info, etc.)

That type of signal would be a marker – not an information-rich signal !

Why? Because, given the long time scales of the universe, and the rapid evolution of AI capability, any message would inevitably be at the wrong level for the recipient !

A response would indicate the correct level !

And they can afford to wait.

Types of Markers:

(1) Blatantly non-natural signal characteristic (e.g., as for traditional SETI, either narrow-band ($\leq$1 Hz) radio emission or short ($\leq 10^{-9}$ sec) optical flashes)
(2) Signals of high intensity or in an uncrowded field, e.g. anomalous emission in deep, natural stellar absorption lines.  Another approach: look for second-order correlations in light sources, a scheme used by Hanbury Brown and Twiss to measure stellar diameters

# Conclusion:

Although most targeted SETI searches will continue to examine habitable worlds, we should expend at least some effort in searching for intelligence that is not simply a *mirror of ourselves*.