Exoplanets, SETI, and Technosignatures

A short course for the KISS workshop

Sofia Sheikh, Penn State University
Andrew Howard, Caltech

(for Jason Wright)
May 20, 2019

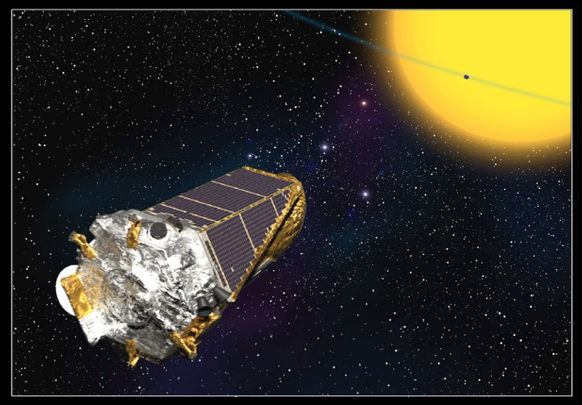
Exoplanets are Ubiquitous

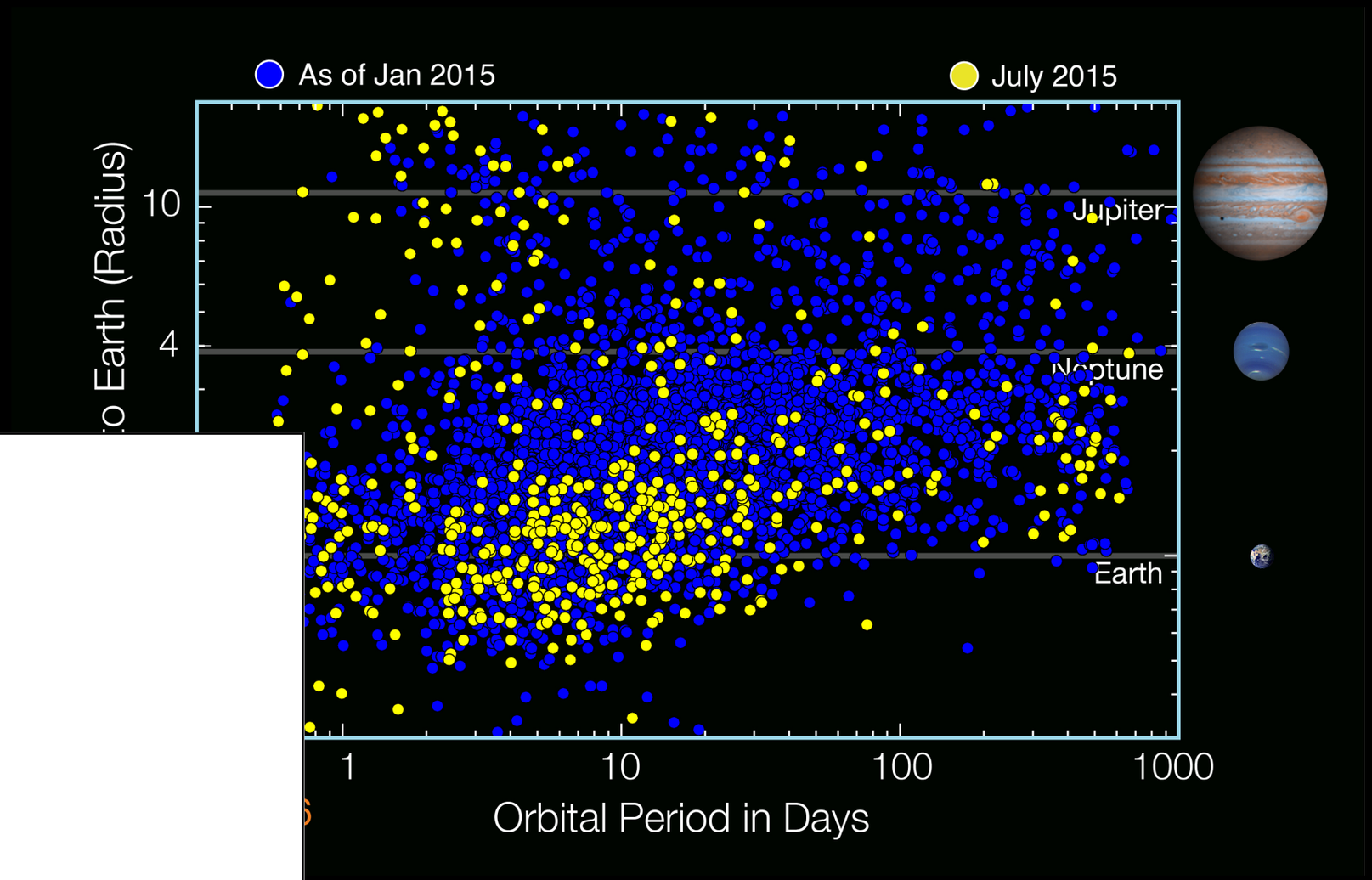
Number of planets per star: ~1 (bigger than Earth, inside 1 AU)

Fraction of Sun-like stars with Earth-size planet in Habitable Zone: 20% (*)

* many caveats

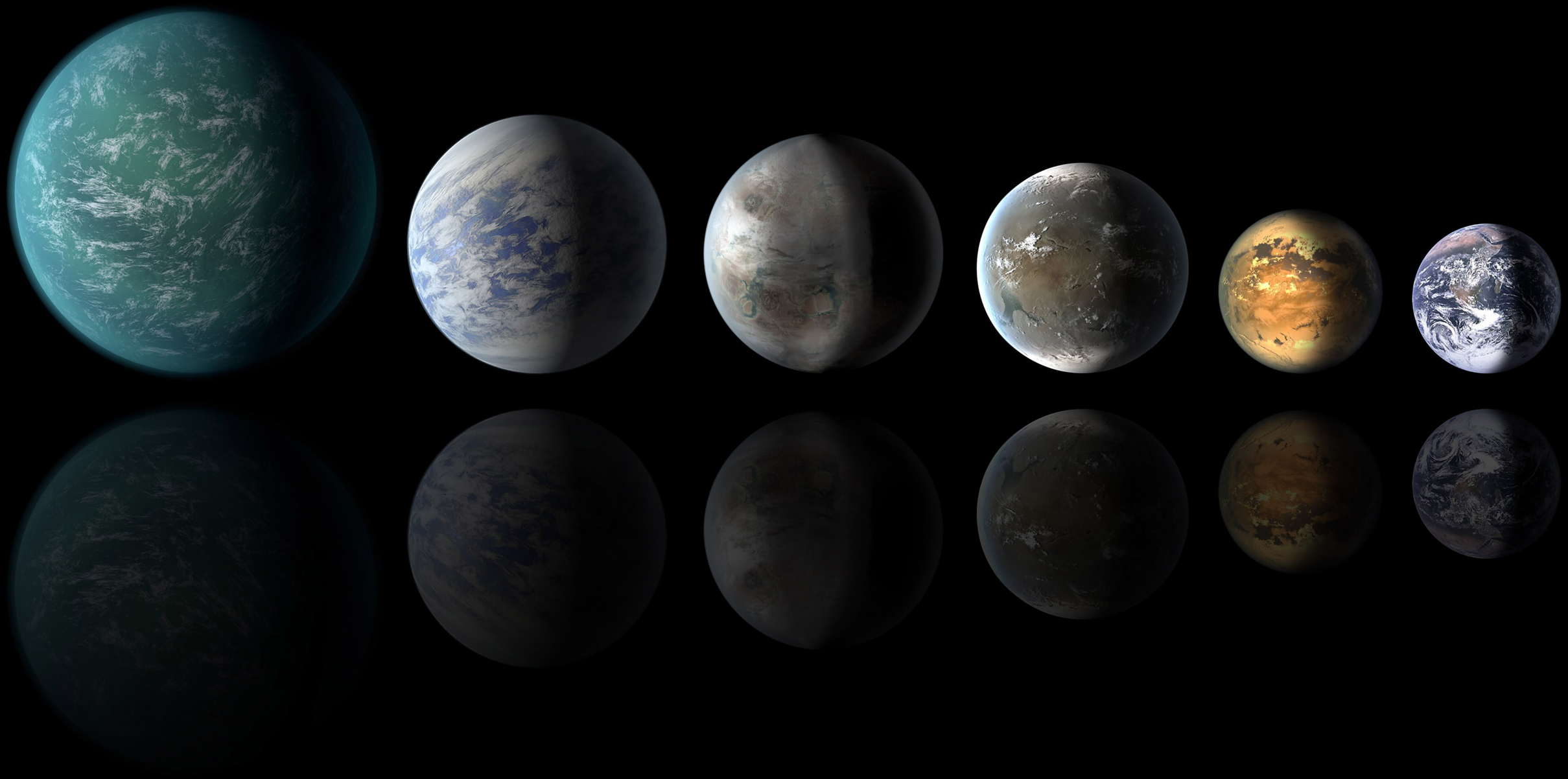
Kepler Space Telescope



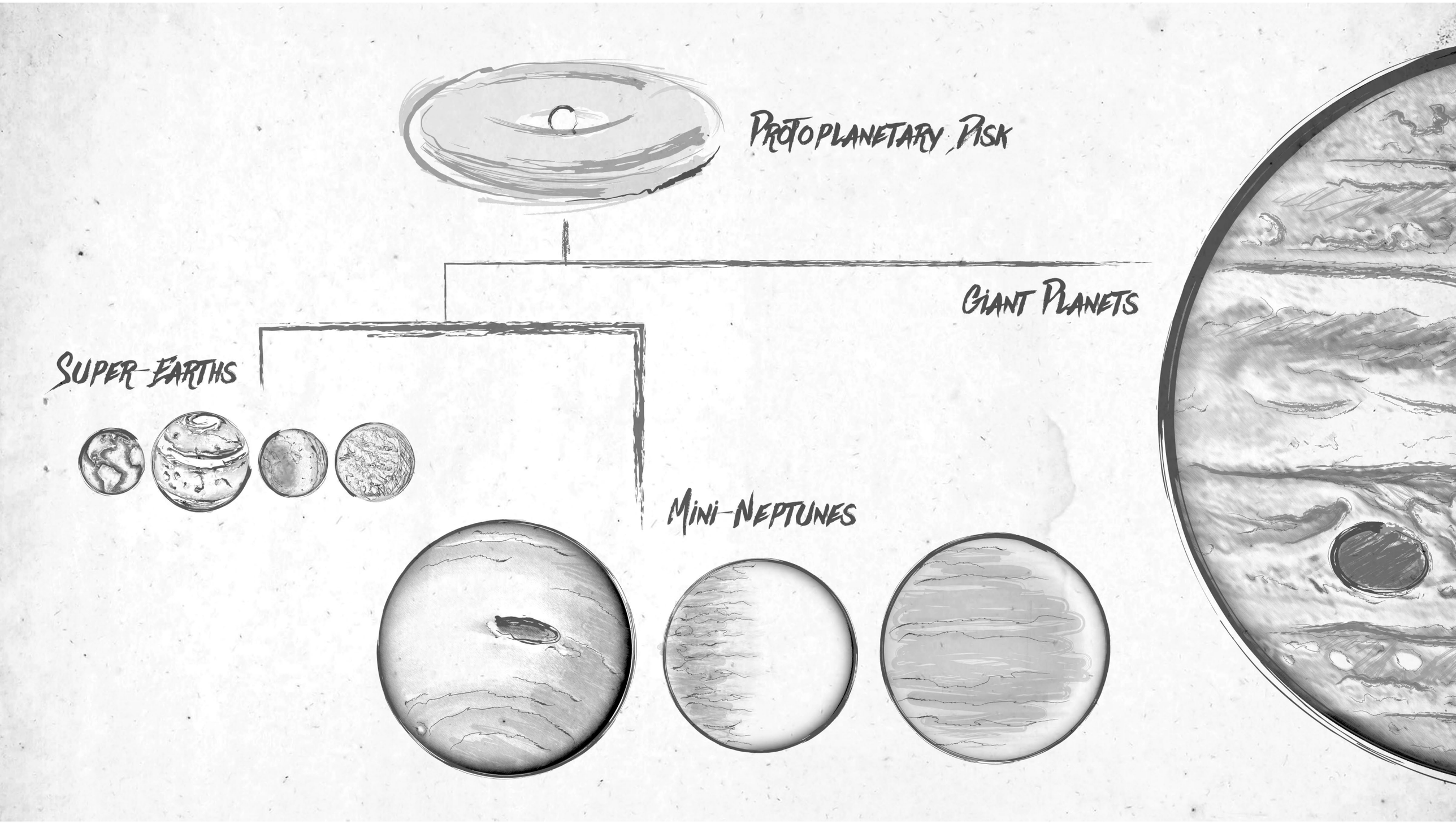


Images: NASA

Exoplanets are Diverse



Some Order in the Diversity



Solar System not a Universal Template

What makes a planet ‘Earth-like’?

Size

Mass

Density

Composition

Atmosphere

Water

Simple Life

Complex Life

Coffee, Sushi, …

Image: NASA

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Image: NASA

SETI

“Search for Extraterrestrial Intelligence”

Jargon

- See ad hoc committee on SETI nomenclature report (Wright, Sheikh, Almár, Denning, Dick, Tarter, 2018)
- Also:
  - Almár (2008, Acta Astronautica, 68, 351)
  - Denning (2008, NASA-SP-2009-4802 Ch. 3 pp.63–124)
  - Wright (2018, arXiv:1803.06972)

“SETI”

Originally a radio program at NASA

Now the name of the field generally

CETI: “Communication…”
SETT: “…technology”
SETEE: “…electrical engineers”

Let’s not quibble.

“Technosignatures”

Apparently coined by Jill Tarter in 2006

Makes analogy to biosignatures explicit

Inclusive of all signs of technology: radio, laser, waste heat, whatever.

“Produces fewer antibodies” at NASA (per Michael New)

Search for technosignatures = SETI

Loaded terms

“Civilization”
“Colonization”
“Alien”
“Alien race”

If you use these, be aware that they have meanings you may not intend

Mean what you write and write what you mean.

Searches for Alien Life in Astrobiology

Biosignatures

Exoplanets:
Atmospheric gases
Surface reflection spectra

Solar System:
Microfossils
Molecular Biomarkers

Technosignatures (SETI)

Communication

NIROSETI:
pulsed lasers
continuous lasers

Radio:
carrier wave
broadband

Other carriers
(X rays, ν's,
GW's, etc.)

Artifact

Waste heat:
Dyson spheres
Type III galaxies

Radio:
radar
propulsion

Solar System:
Probes
Structures

Exoplanets:
Pollution
Waste heat

Transits:
Arnold
megastructures

"Nature-plus"

Disappearing
stars

"Tickling"
Cepheids

Ĝ red spirals

Przybylski's Star

Organized pulsar
arrays

METI

Strong radio
trasmission

Embedded
messages in leaked
emission

Voyager records
Pioneer plaques

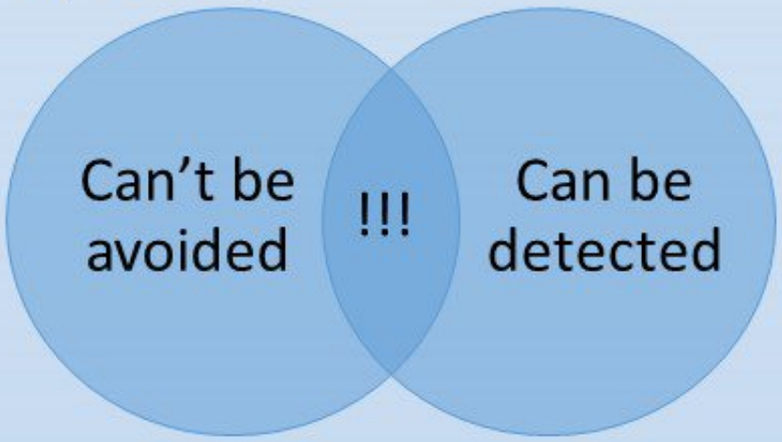
Technosignature Axes of Merit

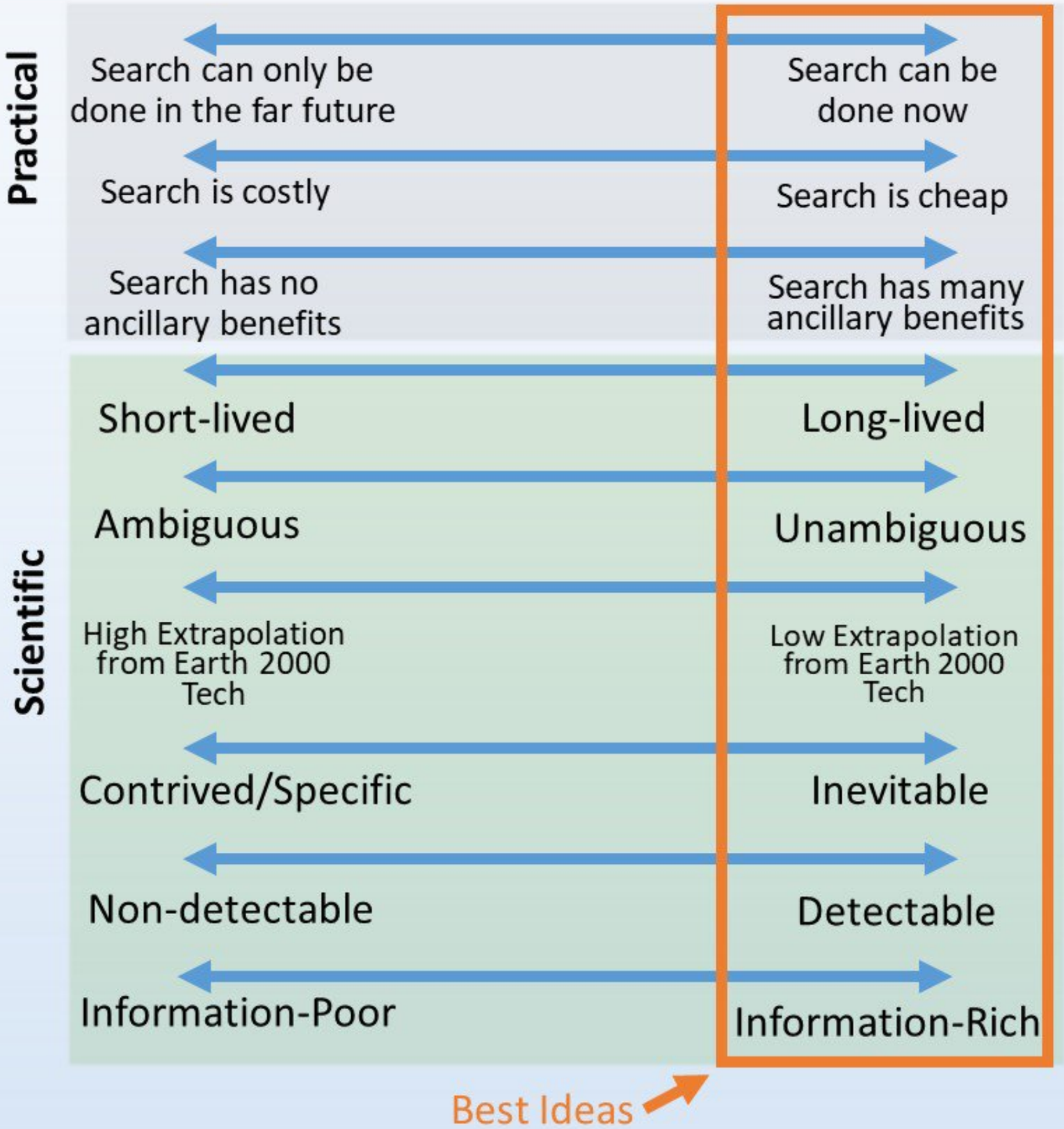
With so many potential technosignatures to look for, how do we compare them?

OR

Given finite resources, what do we prioritize?

Inspired by…





S. Sheikh, with input by D. Kipping, A. Frank, S. Walker

Dyson's First Law of SETI Investigations

"Every search for alien civilizations should be planned to give interesting results even when no aliens are discovered."

Communication SETI

The birth of Radio SETI

1960 — Cocconi & Morrison suggest interstellar communication via radio waves

SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCONI* and PHILIP MORRISON†
Cornell University, Ithaca, New York

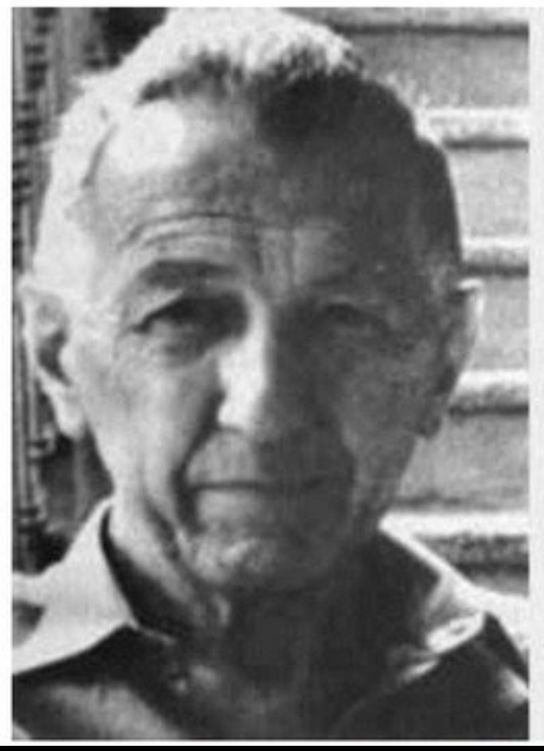
NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation ; (2) origin of life ; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known ; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

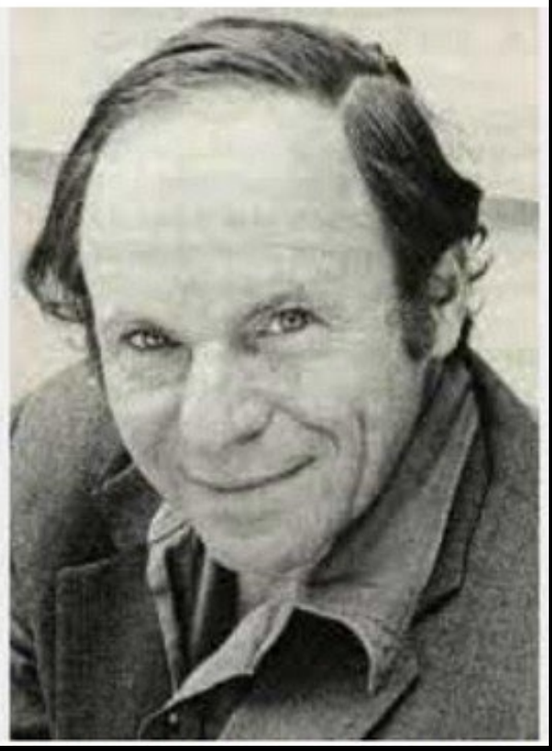
To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We
they established a channe
would one day become kn
look forward patiently to t
the Sun which would make
society has entered the c
What sort of a channel wou

The Optimu

Interstellar communicat
plasma without dispersion i
is practical, so far as we
magnetic waves.

Since the object of thes
is to find a newly evolved
that the channel used w
minimum burden of freque





* Now on leave at CERN, Geneva.

† Now on leave at the Imperial College of Science and Technology, London, S.W.7.

Frank Drake, Project OZMA

BREAKTHROUGH LISTEN

Not just narrowband carrier waves

- Radar
- Pulsed emission
- Spillover from point-to-point communications
- Byproducts of propulsion / high energy work
- Huge range of necessarily non-natural waveforms can be searched for “agnostically”

Communication SETI

The birth of Laser SETI

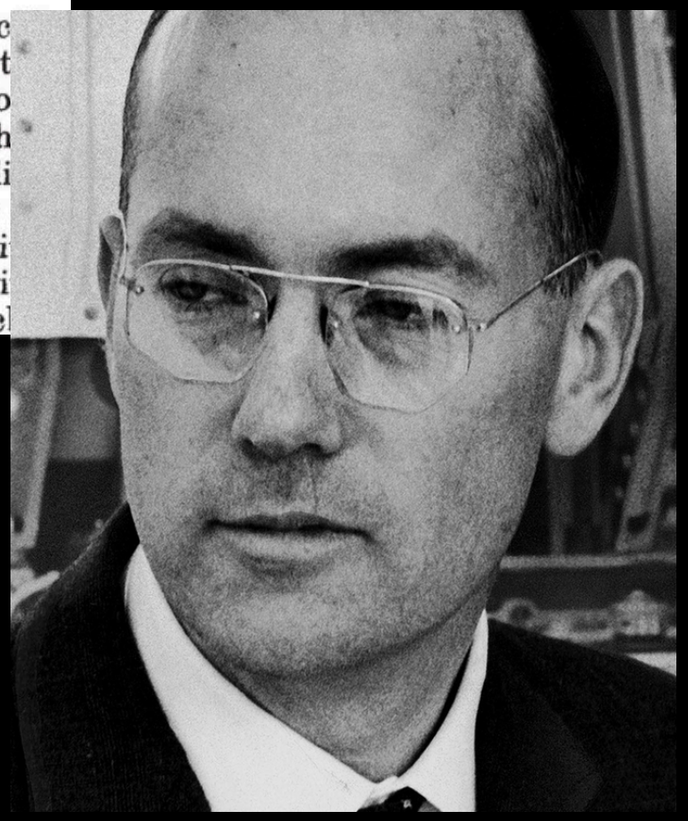
1961 — Schwartz & Townes point out lasers work well, too

INTERSTELLAR AND INTERPLANETARY COMMUNICATION
BY OPTICAL MASERS

By Dr. R. N. SCHWARTZ and Prof. C. H. TOWNES*
Institute for Defense Analyses, Washington, D.C.

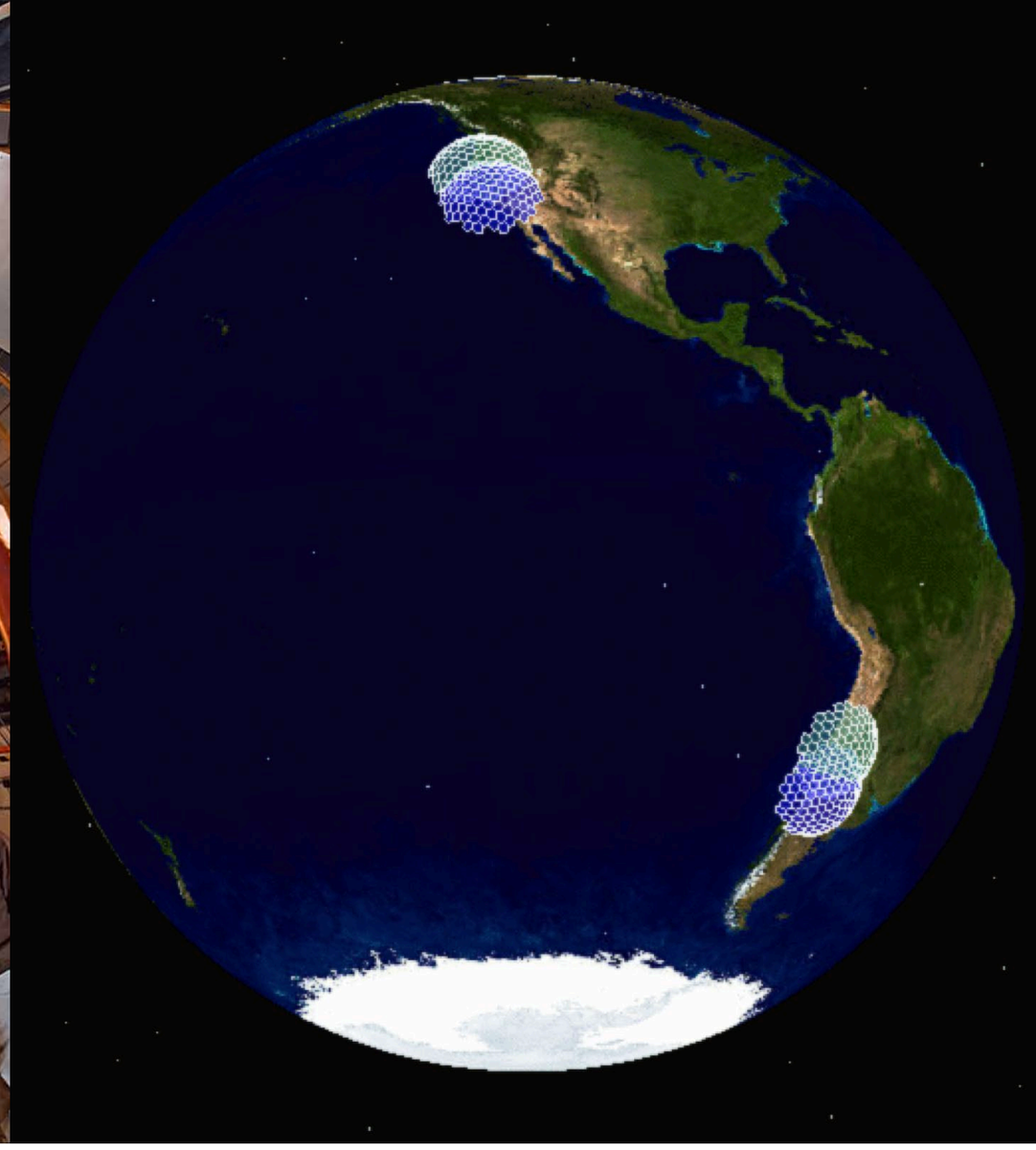
LONG-RANGE communication by radio-waves is already well known, and the possibility of interstellar communication by radio-waves in the microwave region has been suggested in several interesting proposals[1-3] to search for signals from intelligent beings on planets associated with nearby stars. The supposition is that curiosity such as our own would motivate advanced civilizations associated with stars other than our Sun to make determined efforts to

frequency-interval of about 10 kilocycles per sec
The latter case is much closer to theoretical expect
tions[4] for an ideal maser in so far as coherence is co
cerned. There seems to be no general reason, oth
than the necessary dissipation of power, why soli
state optical masers cannot operate continuously
high power and with a short-term monochromatici
close to theoretical expectations, or hence wi
frequency-widths very much less than 1 megacycl

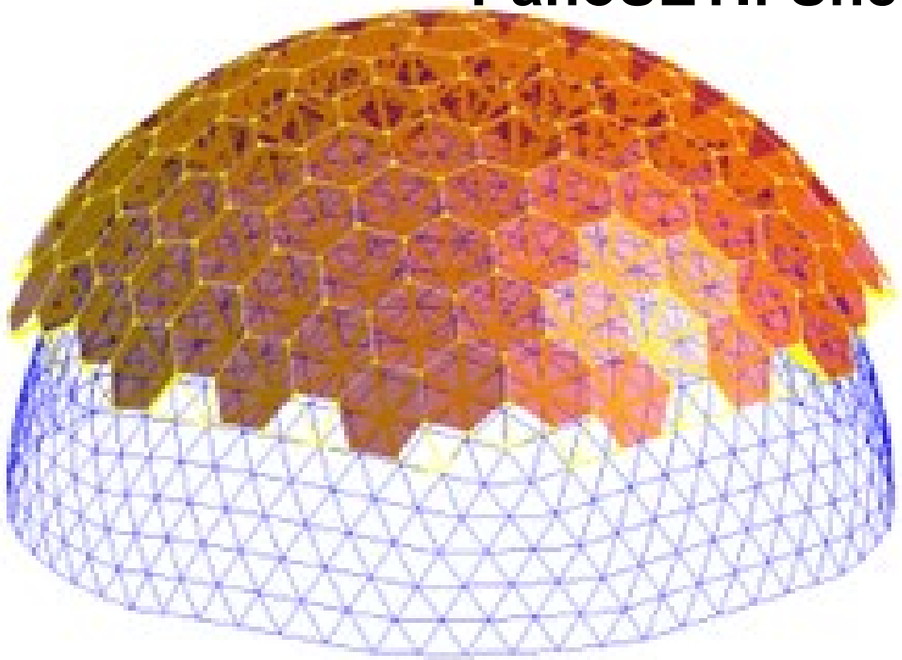


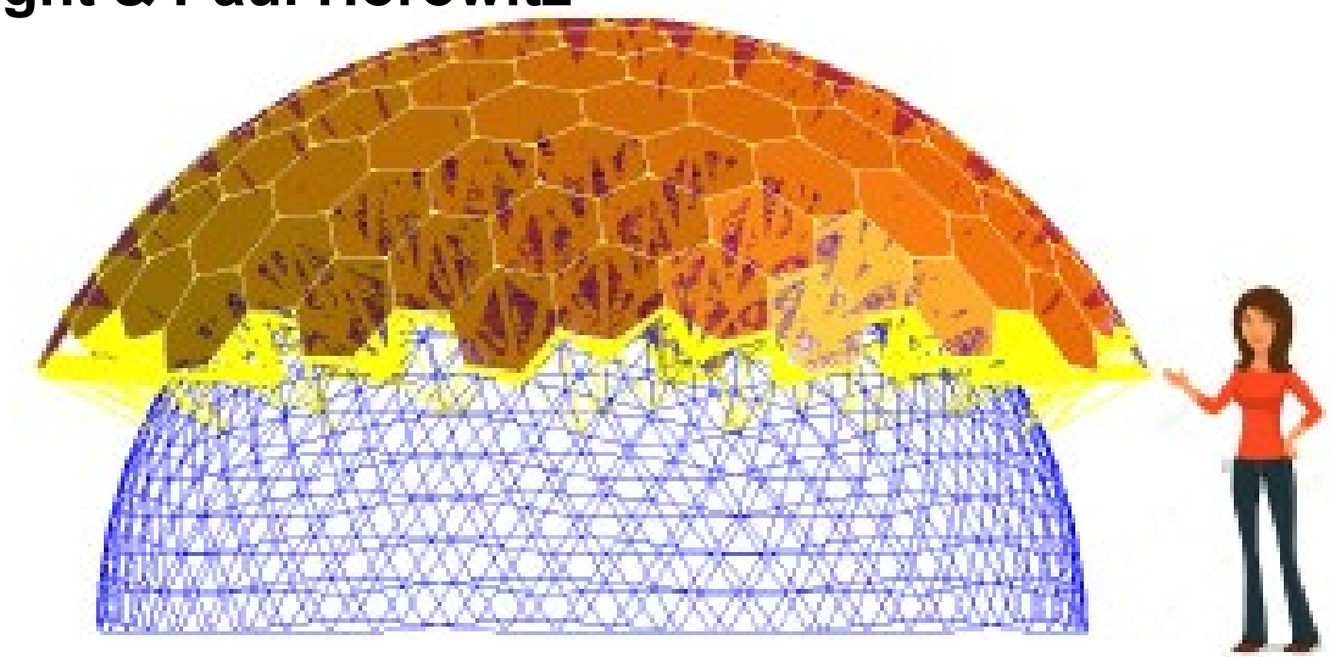
Laser advantages

- Pulsed lasers provide very high bandwidth
- Optical transmissions can have very high gains
- IR lasers have great dust penetration
- Can be concentrated in time or frequency domains

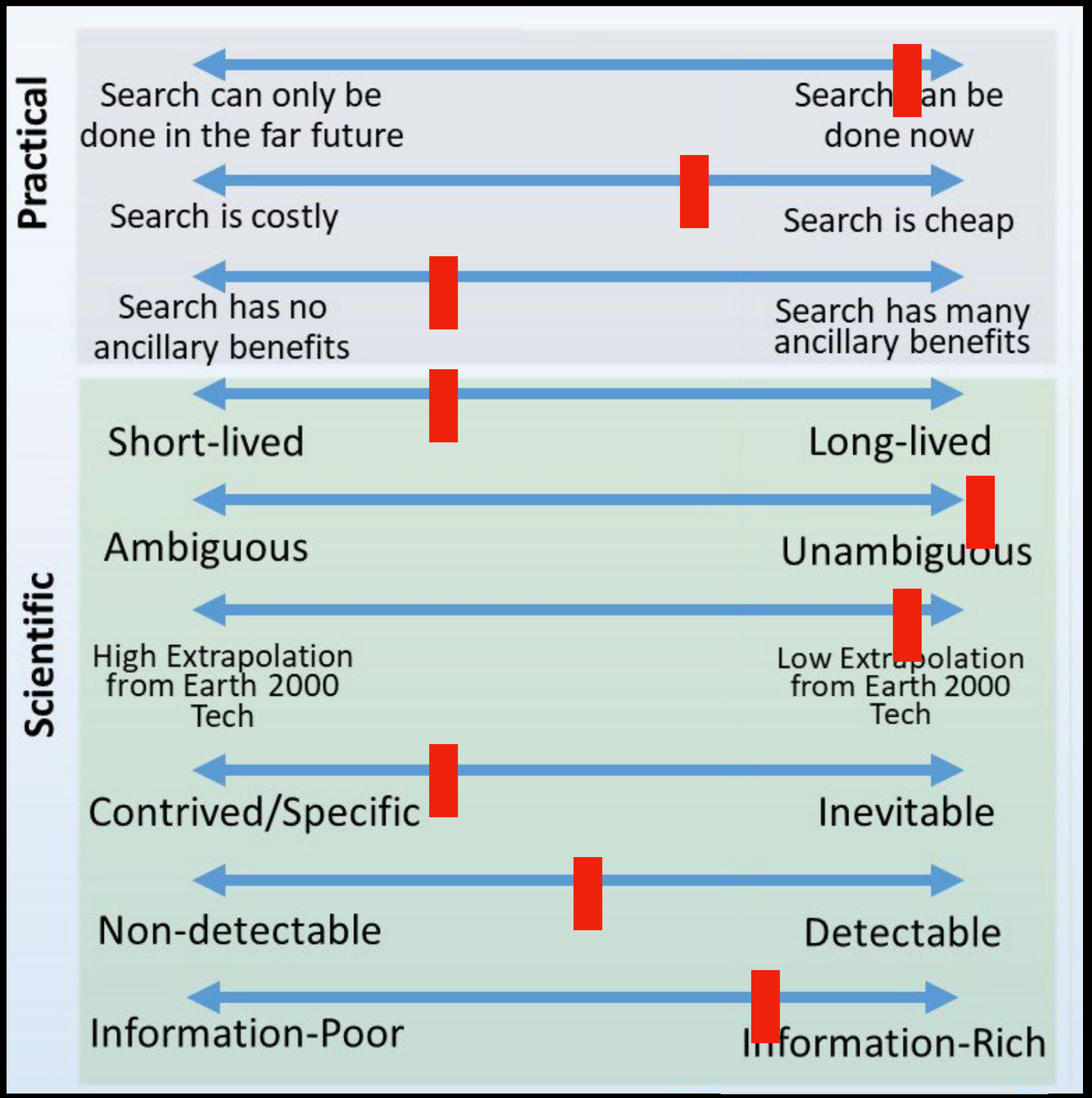


PanoSETI: Shelley Wright & Paul Horowitz





Radio/Laser SETI



Artifact SETI

Dyson (1960)

here” really just any orbital m
collects or generates energy

Search for Artificial Stellar Sources of Infrared Radiation

Abstract. If extraterrestrial intelligent beings exist and have reached a high level of technical development, one by-product of their energy metabolism is likely to be the large-scale conversion of starlight into far-infrared radiation. It is proposed that a search for sources of infrared radiation should accompany the recently initiated search for interstellar radio communications.

Cocconi and Morrison (*1*) have called attention to the importance and feasibility of listening for radio signals trans-

Emission of low-entropy “waste” heat in IR is required by thermodynamics

Sensitive to *almost all* technological energy use in the system

Primary confounder is dust which has similar MIR properties

IRAS All-Sky map (1983)

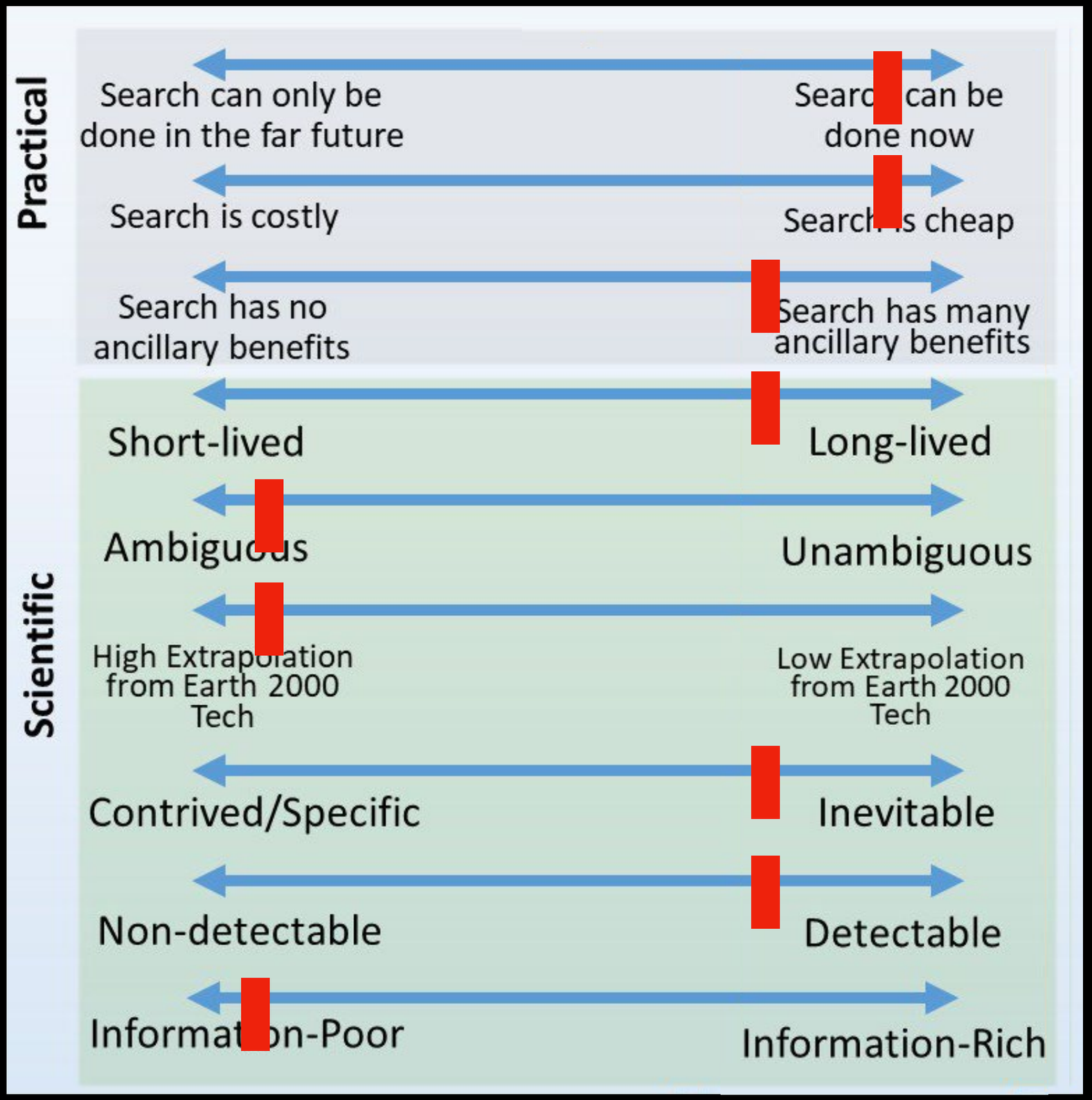
The discovery of infrared cirrus complicated Dyson sphere searches.

Credit: NASA GSFC, LAMBDA

Some work

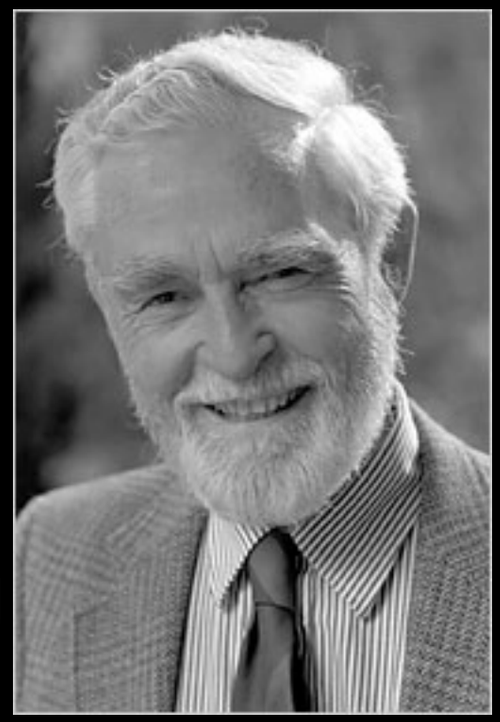
- Jugaku & Nishimura (2004): Nearby stars with *IRAS*
- Carrigan (2009): All-sky *IRAS* non-detection
- Annis (1999): Pan-galactic Dyson spheres via low optical surface brightness (Kardashev type III)
- Griffith et al (2015): Ĝ extragalactic search upper limits with *WISE*
- Arnold (2005): *Kepler* as megastructure hunter (see also Boyajian's Star)

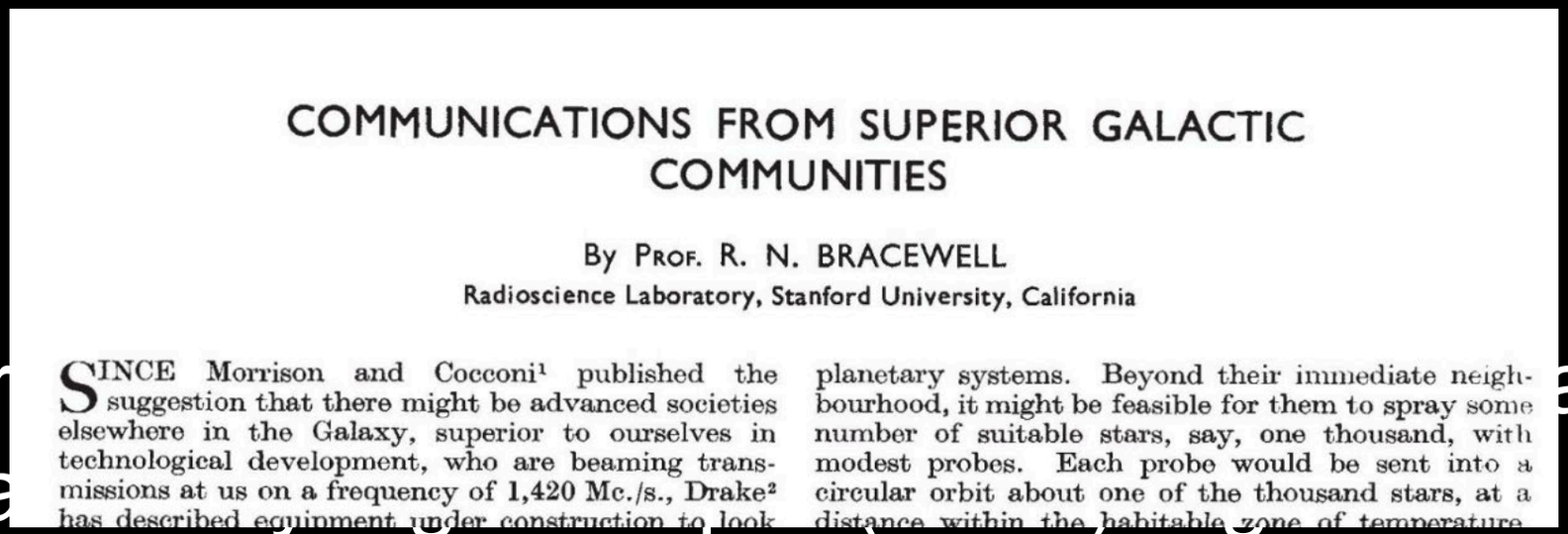
Waste Heat / Transit SETI



Solar System SETI

Bracewell (1960)





COMMUNICATIONS FROM SUPERIOR GALACTIC COMMUNITIES

By Prof. R. N. BRACEWELL

Radioscience Laboratory, Stanford University, California

SINCE Morrison and Cocconi[1] published the suggestion that there might be advanced societies elsewhere in the Galaxy, superior to ourselves in technological development, who are beaming transmissions at us on a frequency of 1,420 Mc./s., Drake[2] has described equipment under construction to look

planetary systems. Beyond their immediate neighbourhood, it might be feasible for them to spray some number of suitable stars, say, one thousand, with modest probes. Each probe would be sent into a circular orbit about one of the thousand stars, at a distance within the habitable zone of temperature

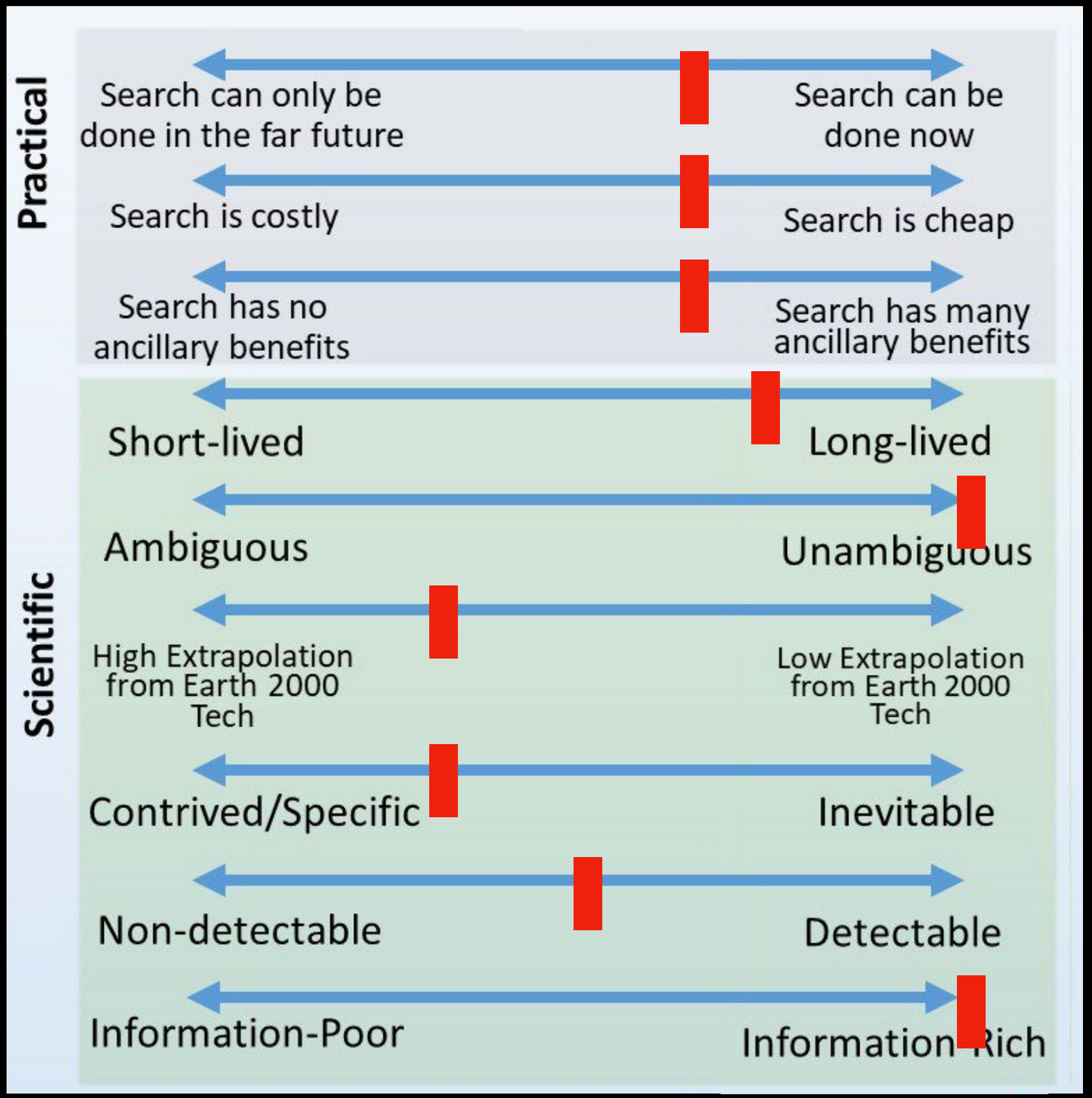
Pr ating
ha (

Probes might be sent for many purposes (contact, exploration) and might “pass through” or “lurk” indefinitely

Solar System SETI

- Intelligent Martians were once legitimate scientific hypothesis
- Mariner showed no cities: now idea that technology *ever* existed there is taboo
- Claim that there are proveably zero probes in the Solar System *now* has been used to argue ETIs must not exist
- In reality, completeness is very low (Haqq-Misra & Kopparapu 2012)
- Moon has best high-resolution imaging for searches (Davies & Wagner 2013)
- Free-floating artifacts (Freitas 1980, 1983)
- ‘Oumuamua (Bialy & Loeb 2018)

Solar System SETI



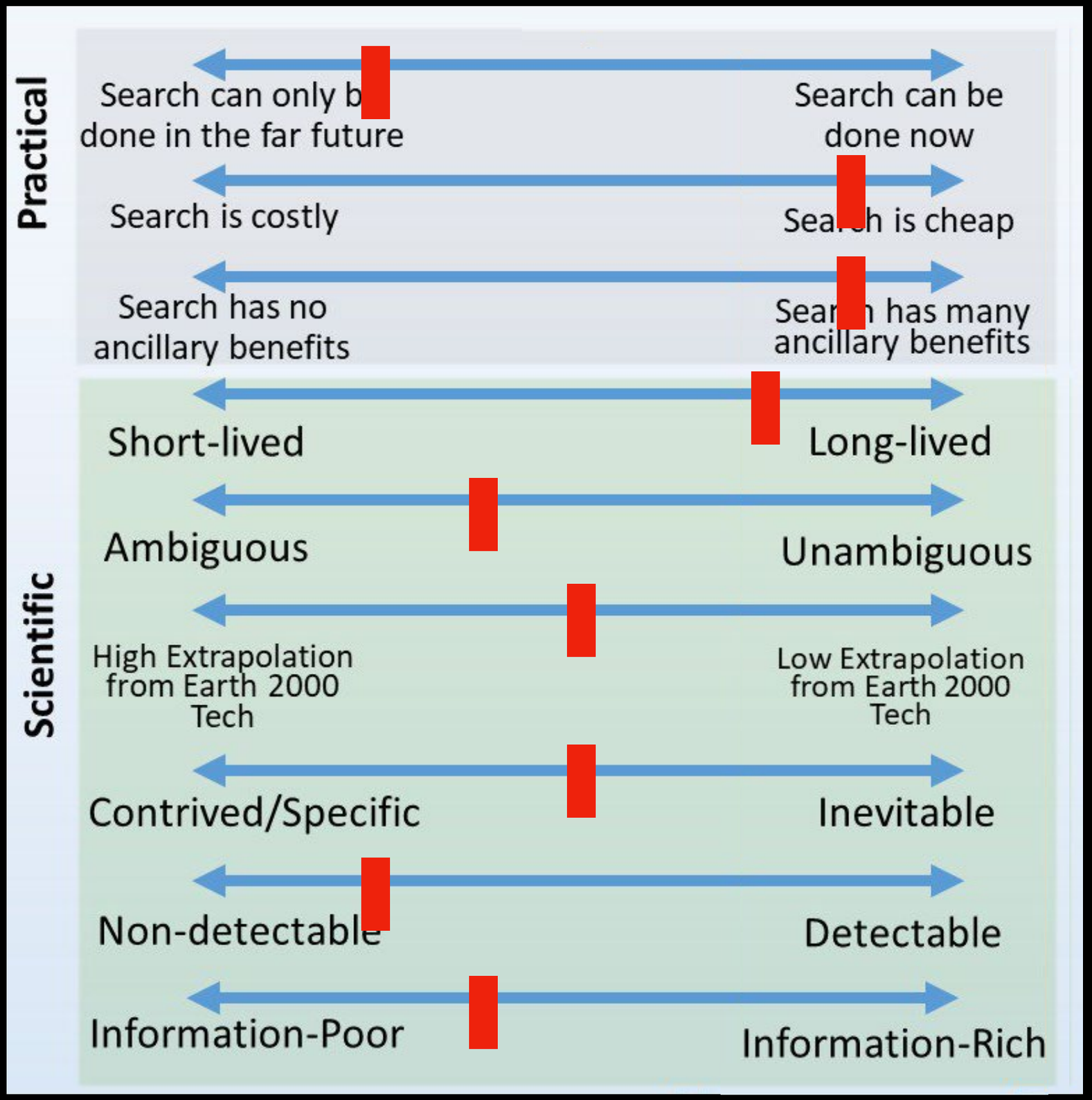
Exoplanet atmospheric pollution

Very little work on this so far

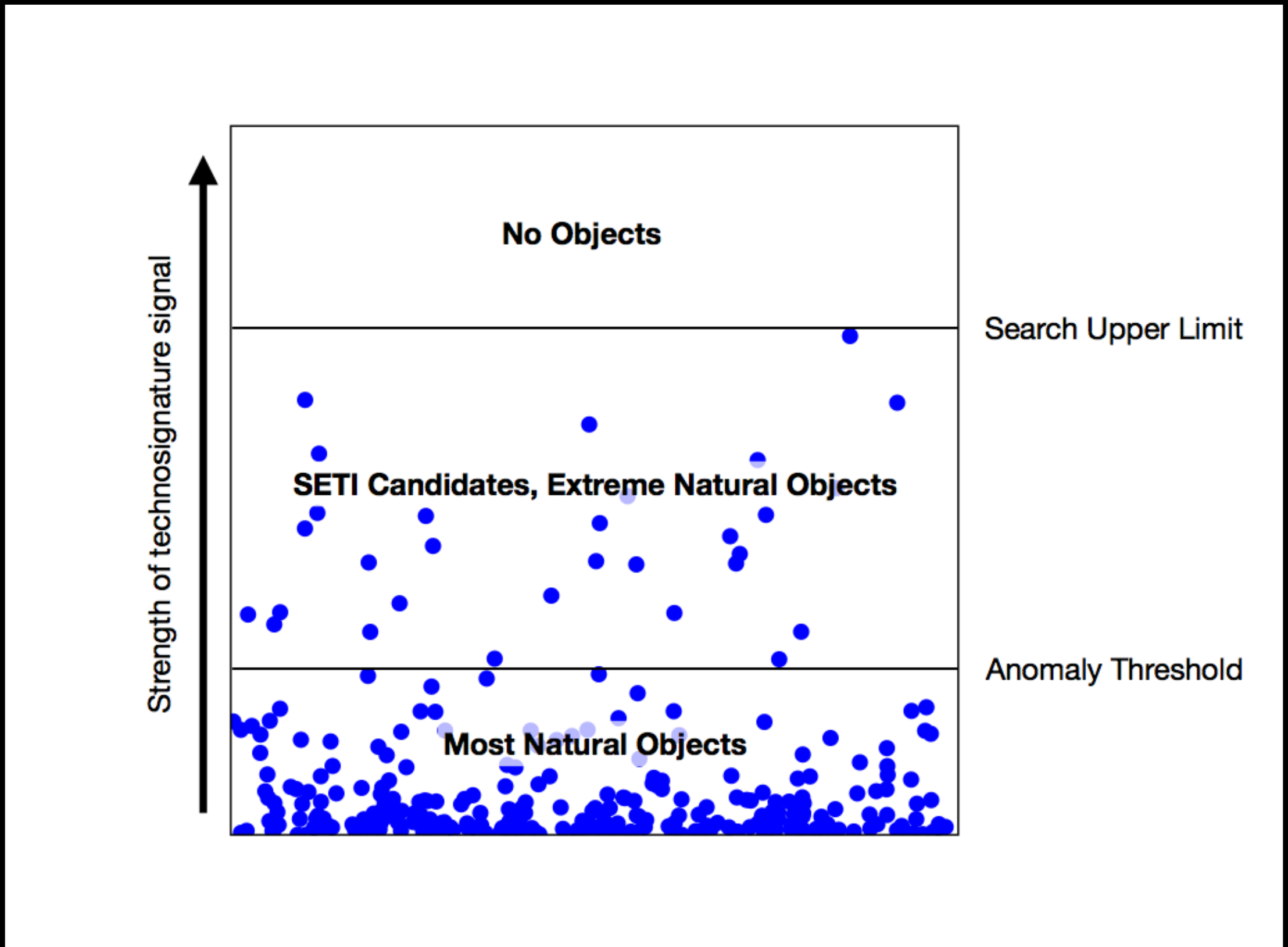
Natural synergy with hunts for biosignatures

- Lin, Gonzalez Abad, & Loeb (2014)
- Lingam & Loeb (2017)

Exoplanet Pollution SETI



Upper limits in SETI



History of Database Mining for Technosignatures

Database	Searching for?	Authors	Methods	Explicitly SETI?
IRAS	Dyson Spheres	Jugaku & Nishimura, Carrigan	Least-squares fitting to expected data	Yes
WISE	Dyson Spheres	Griffith/Wright et al.	Least-squares fitting to expected data	Yes
Kepler	Dyson Spheres	Giles & Walkowicz	Machine Learning (clustering)	No
SDSS	Kardashev Type III	Baron & Poznanski	Unsupervised Random Forest	No
[n/a]	Shape Agnostic Artificial Radio Signals	Zhang et al.	Self-supervised Deep Learning	Yes

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