HOW COMMON IS LIFE IN THE UNIVERSE?

Joseph Silk

Gresham College

2 March 2016

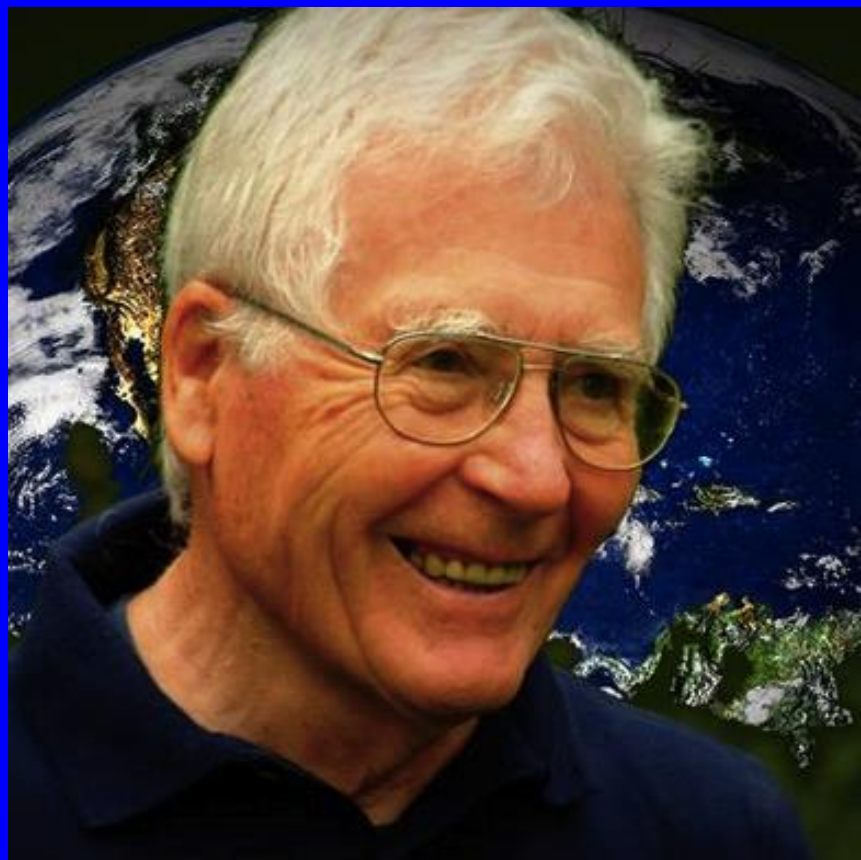
It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present. But if (and oh! what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, &c., present, that a protein compound was chemically formed ready to undergo still more complex changes...

Charles Darwin, 1871

The Earth is a very special place

Almost everything about its composition seems to violate the laws of chemistry... The air we breathe... can only be an artifact maintained in a steady state far from chemical equilibrium by biological properties.

James Lovelock 1988



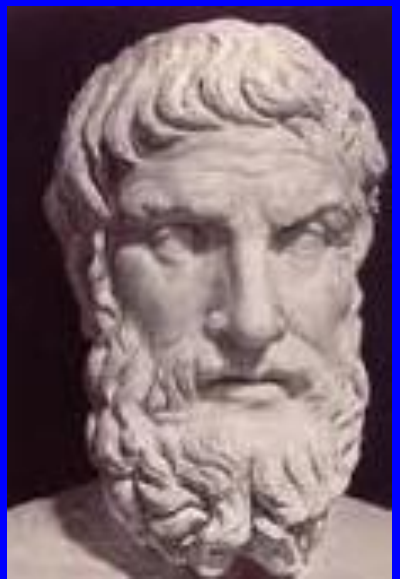
There are no limits

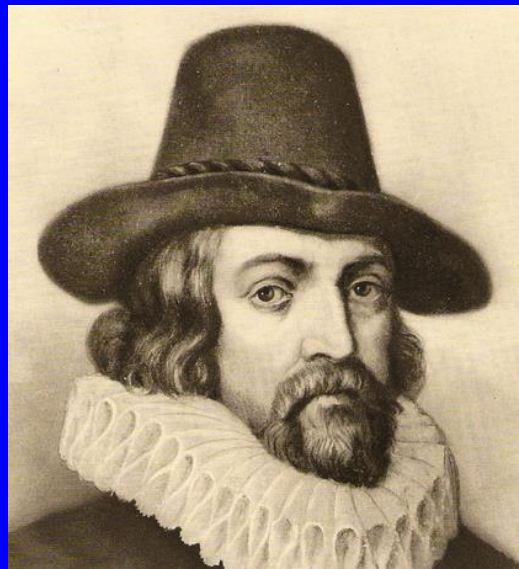
The end of our foundation is the knowledge of causes, and secret motions of things; and the enlarging of the bounds of human empire, to the effecting of all things possible.

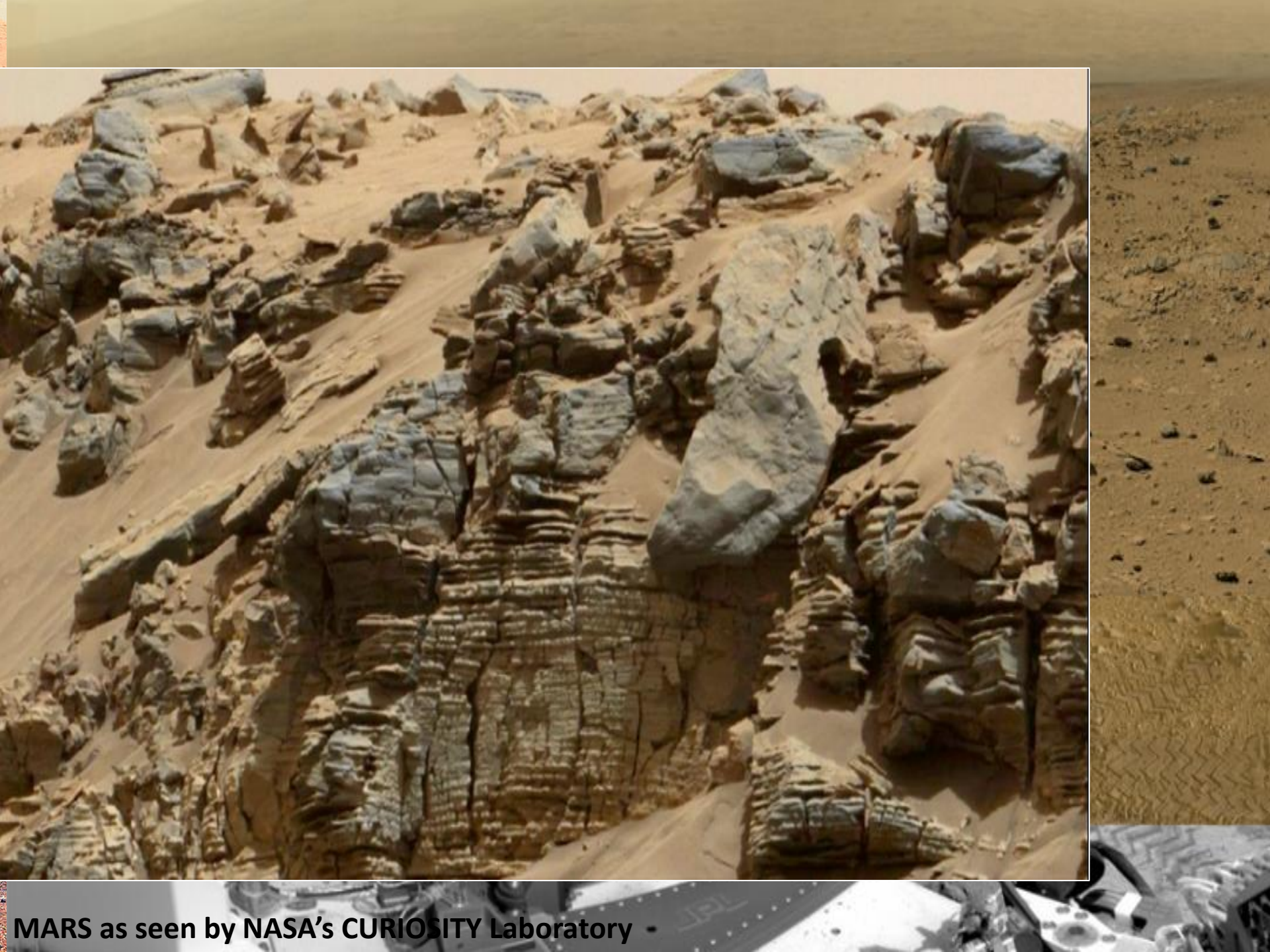
Francis Bacon, 1626

It is in the highest degree unlikely that this earth and sky is the only one to have been created…Nothing in the Universe is the only one of its kind.

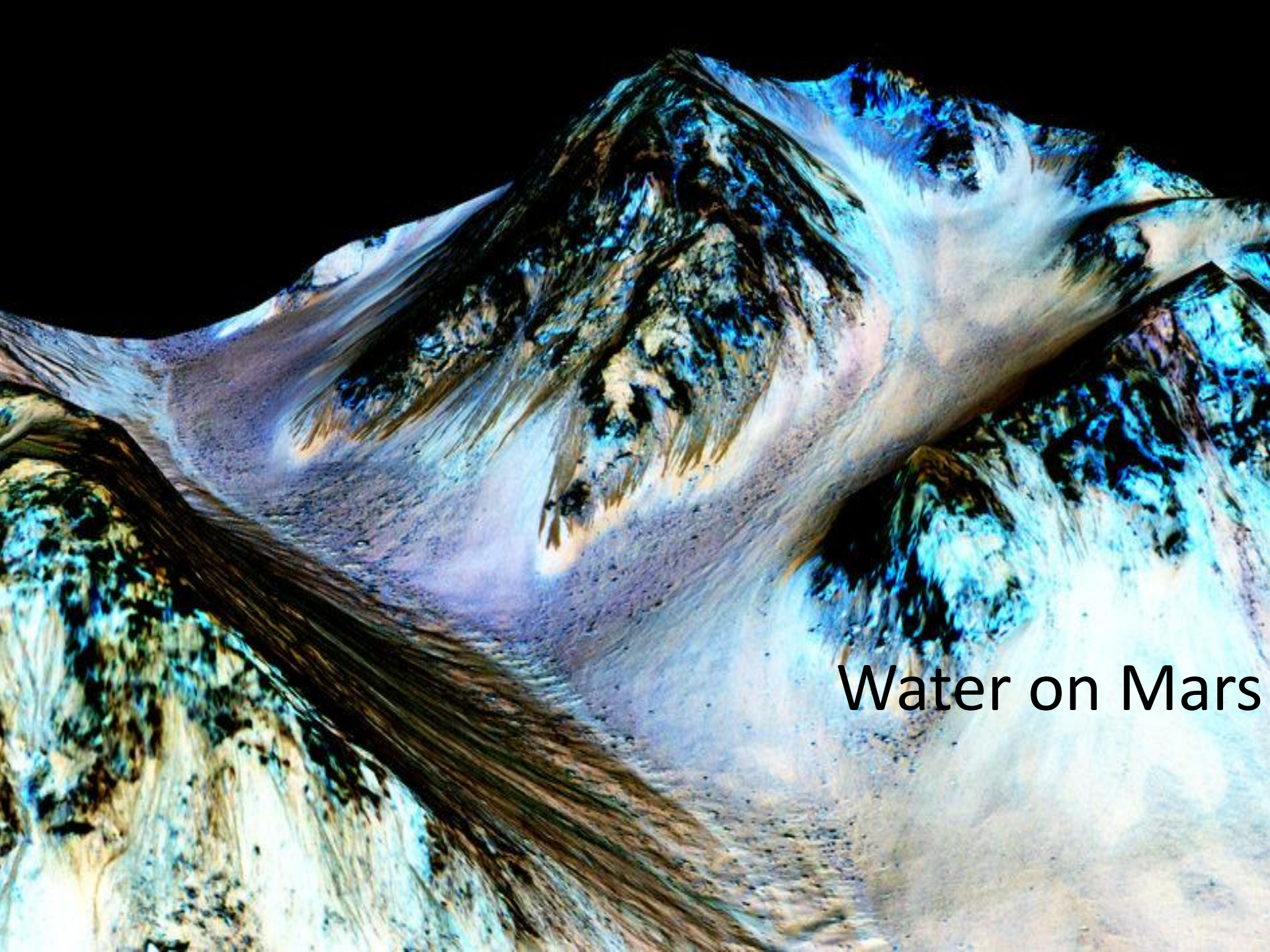
Lucretius, c. 50 BC.







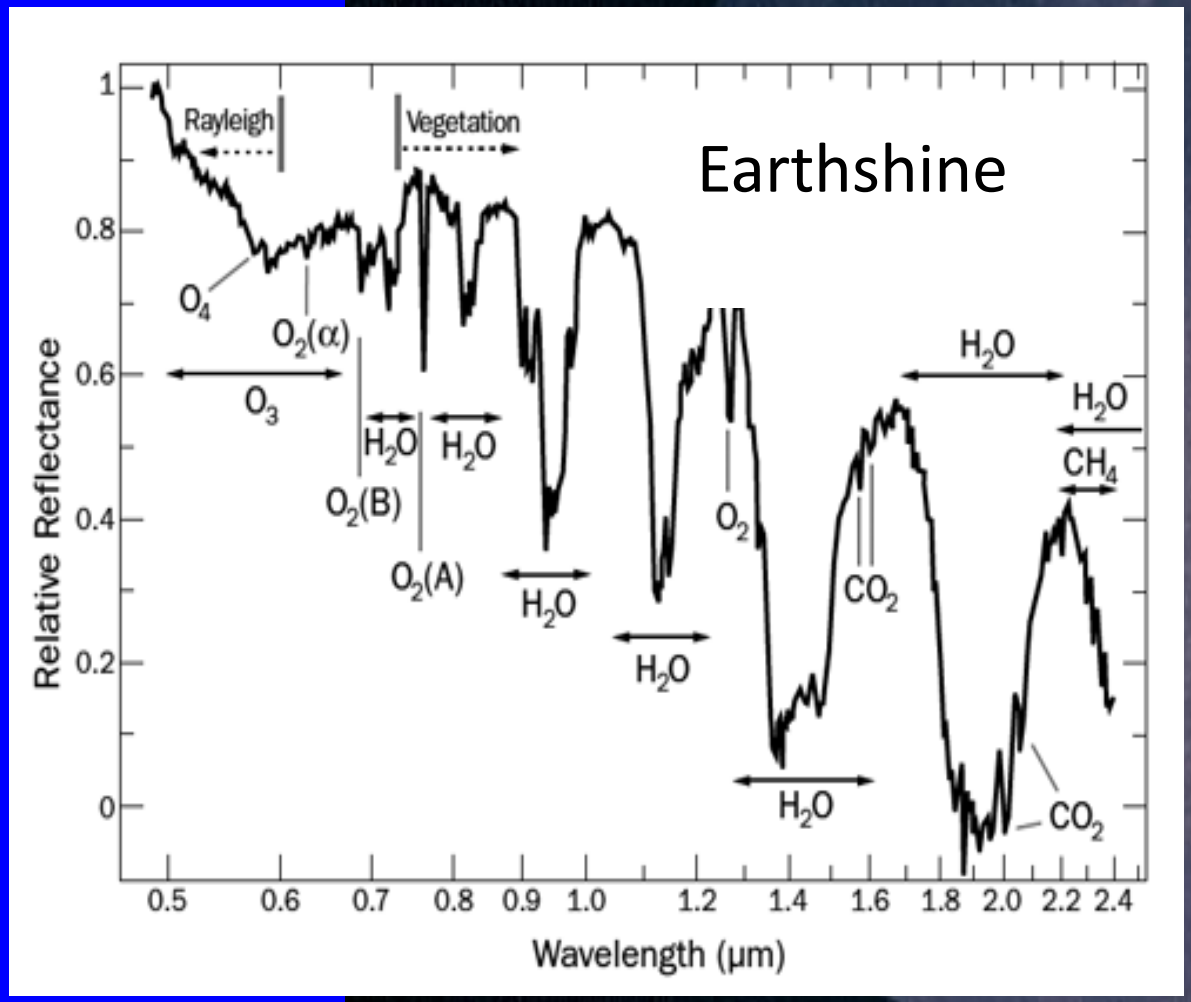
MARS as seen by NASA's CURIOSITY Laboratory -


Water on Mars

The oldest biological evidence on Earth, 3.45 billion years ago

Stromatolites in Yalgorup National Park, Australia

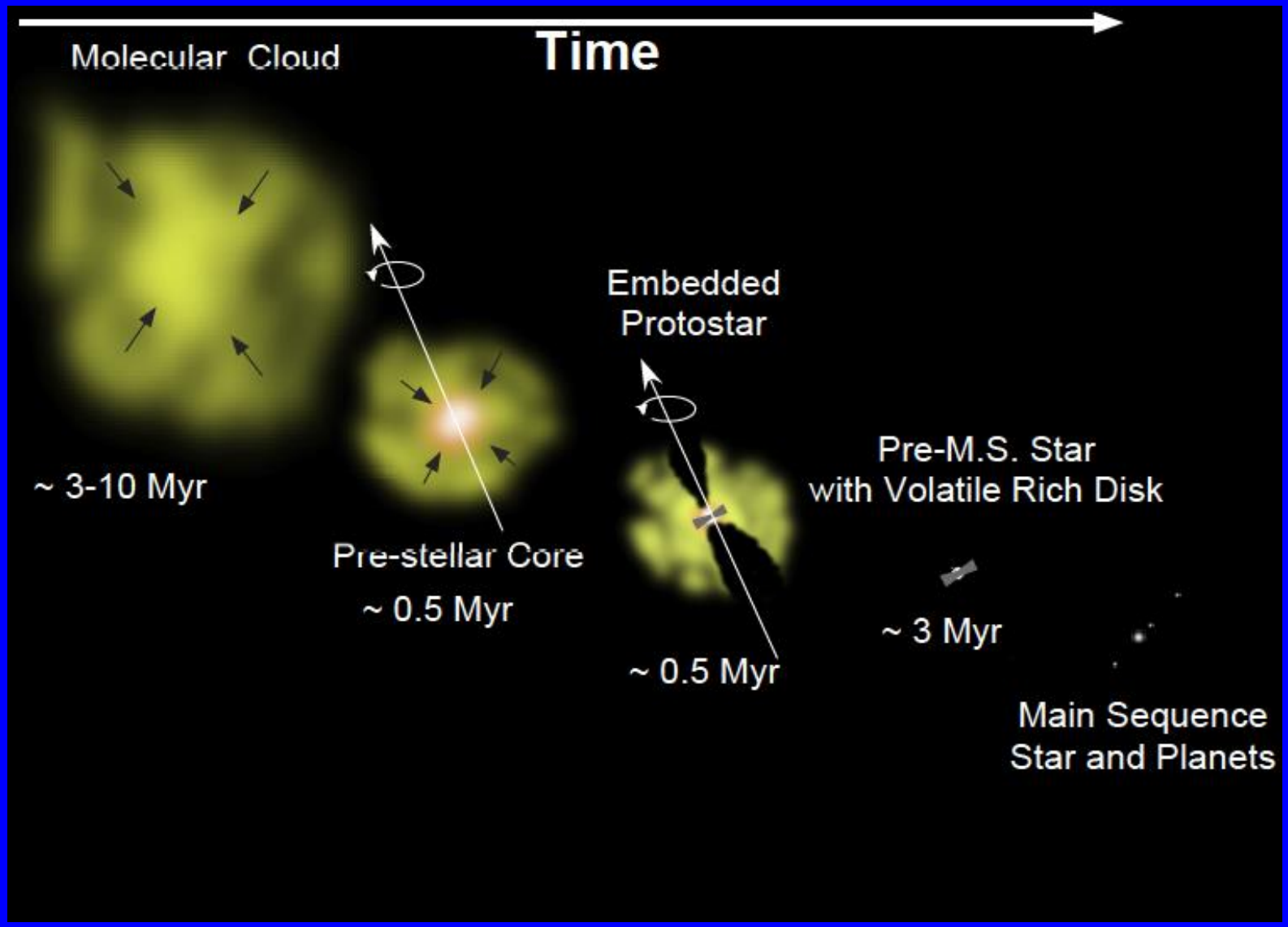
Biosignatures: earthshine

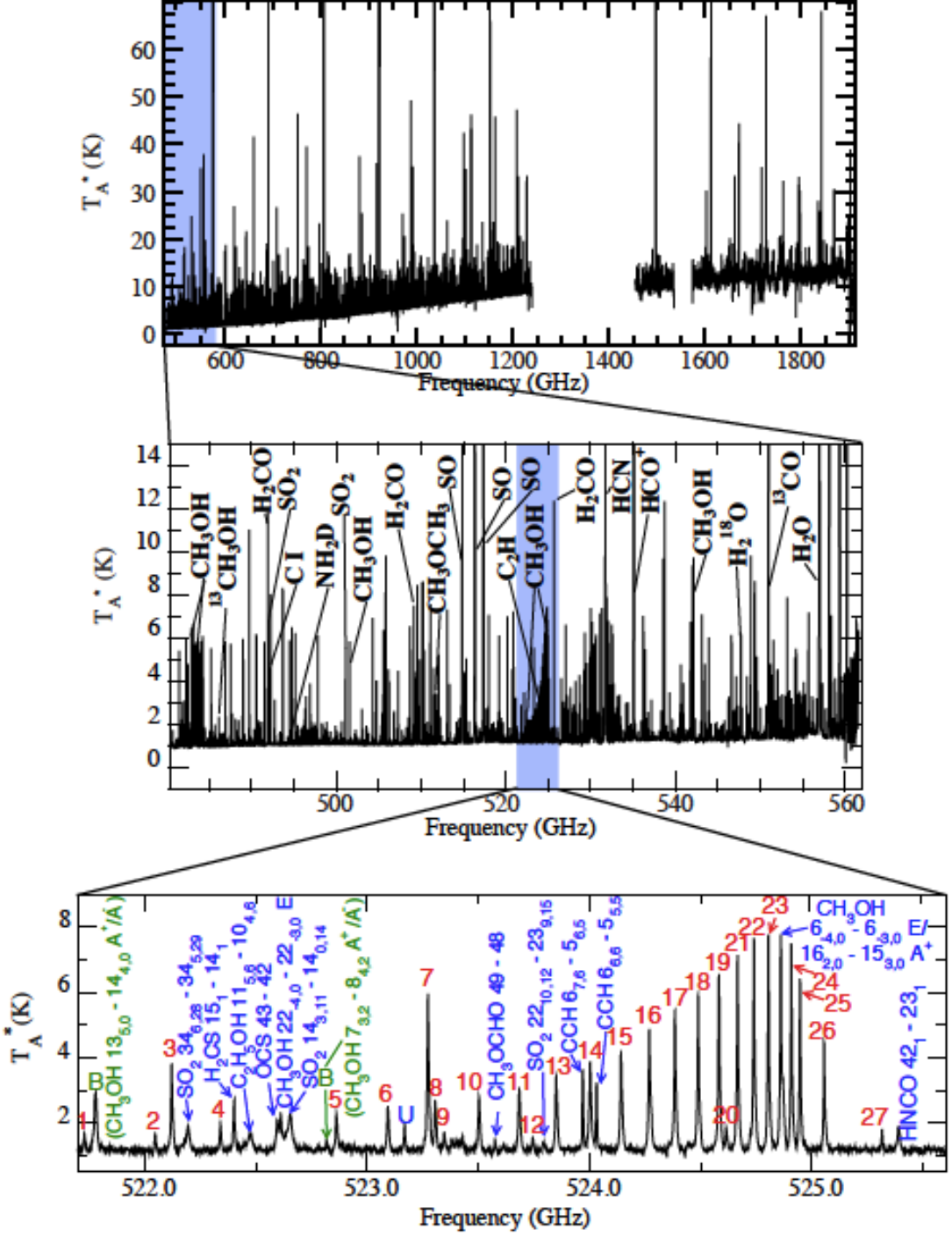


Courtesy J. Tarter, SETI

ASTROBIOLOGY is the study of life as a planetary phenomenon

aims to understand the fundamental nature of life on Earth and the possibility of life elsewhere.


Time
Molecular Cloud
~ 3-10 Myr
Pre-stellar Core
~ 0.5 Myr
Embedded
Protostar
~ 0.5 Myr
Pre-M.S. Star
with Volatile Rich Disk
~ 3 Myr
Main Sequence
Star and Planets



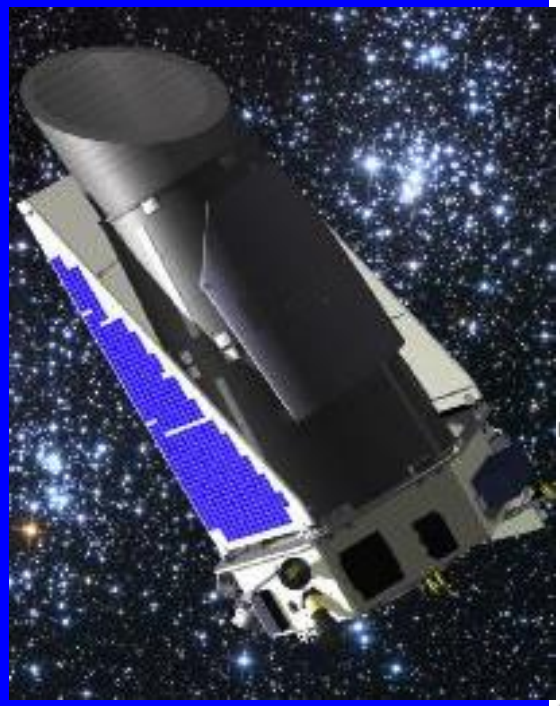
An amazing revolution in astronomy

75 years ago all we had was atomic hydrogen

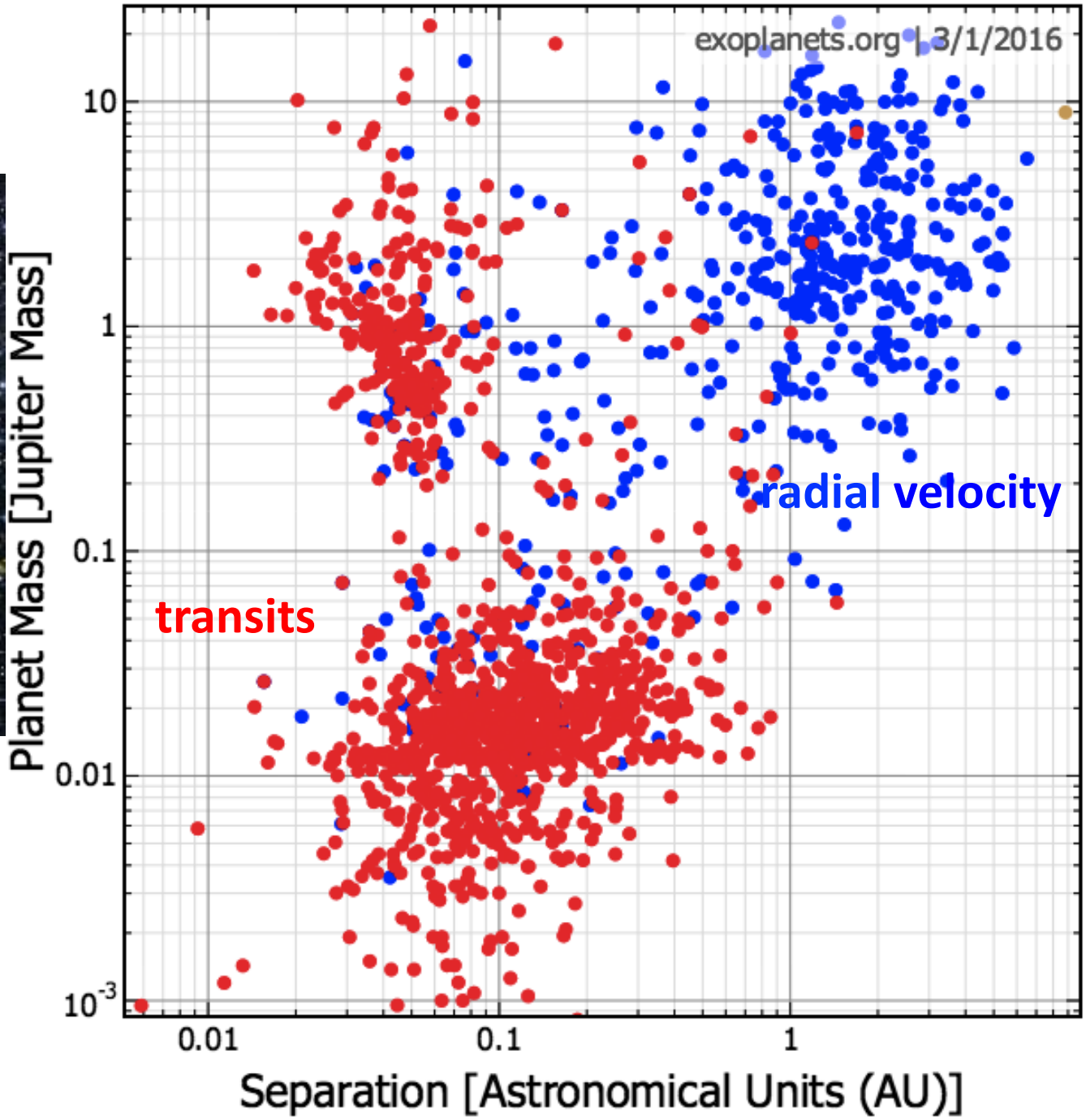
Now, molecules galore!

How common are planetary systems like ours?

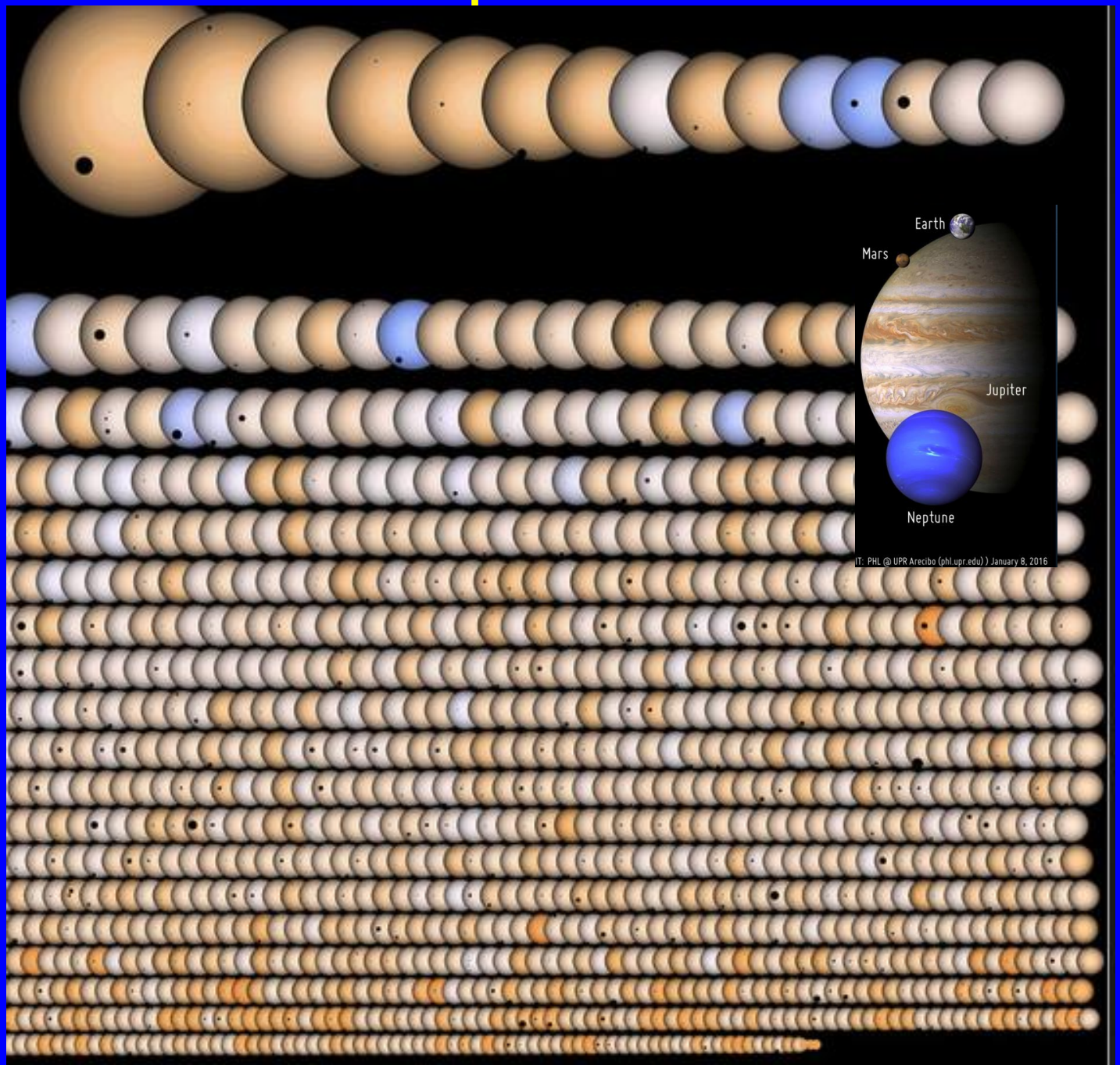
Kepler telescope launched in 2009

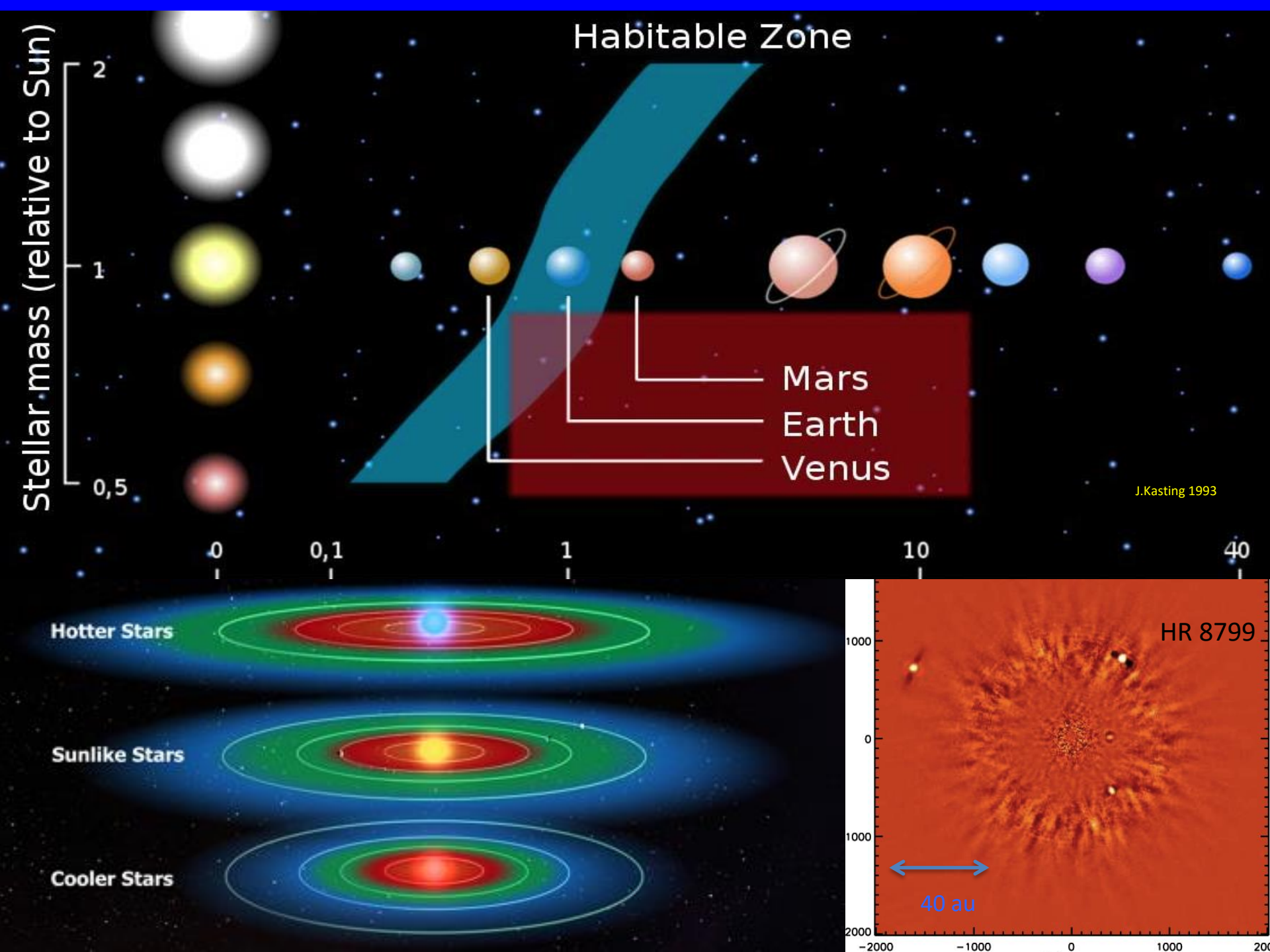


More than 5000 exoplanets so far!

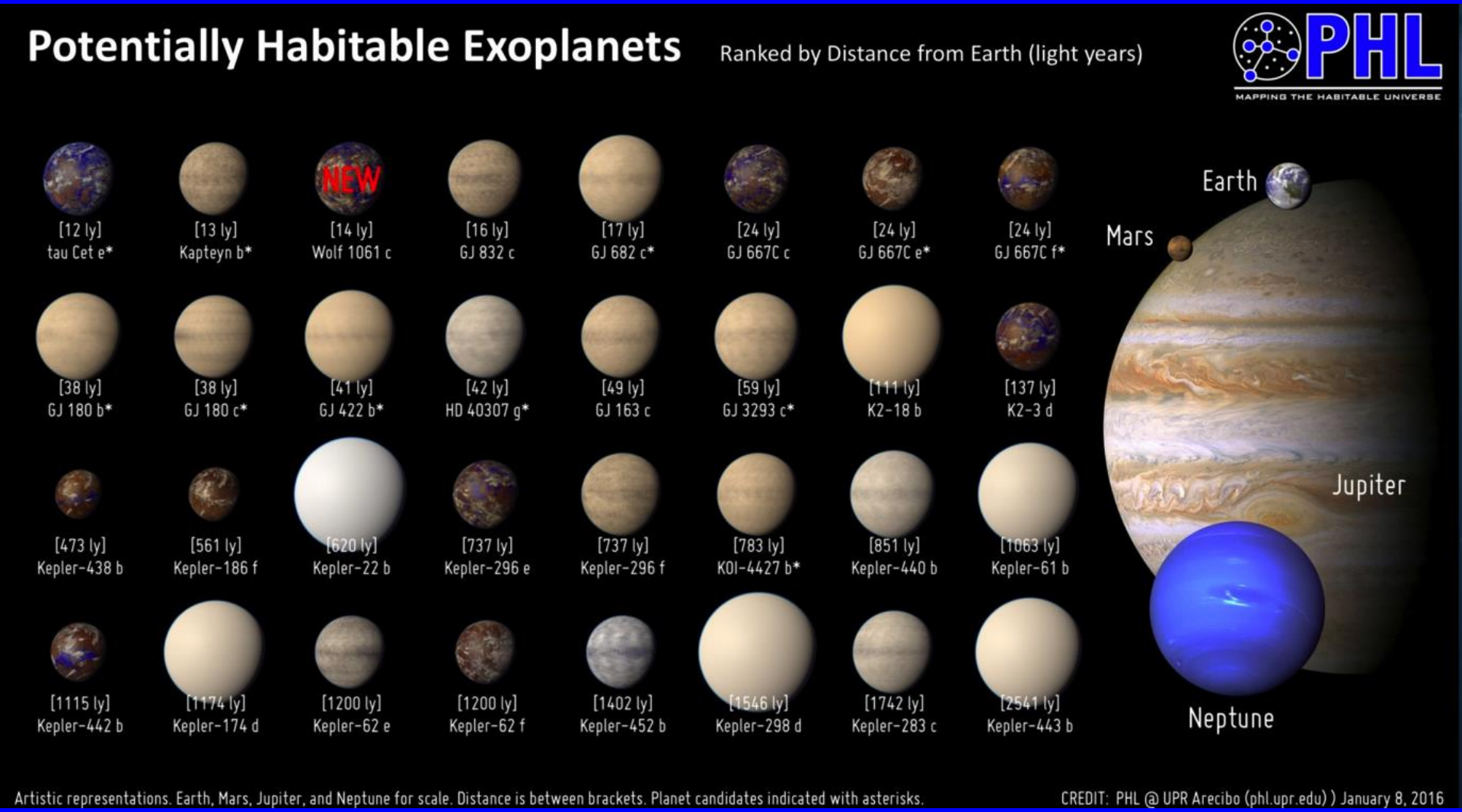


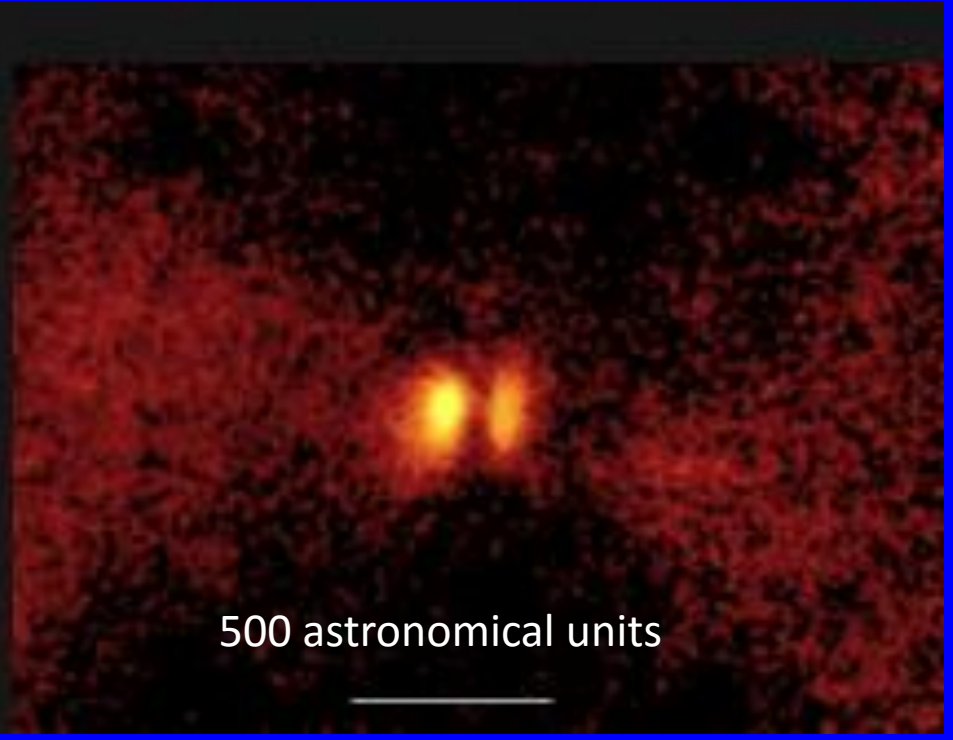
Exoplanet sizes




Habitable Zone
Stellar mass (relative to Sun)
2
1
0,5
Mars
Earth
Venus
J.Kasting 1993
0
0,1
1
10
40
Hotter Stars
Sunlike Stars
Cooler Stars
HR 8799
1000
0
1000
2000
40 au
−2000
−1000
0
1000

Kepler's discoveries



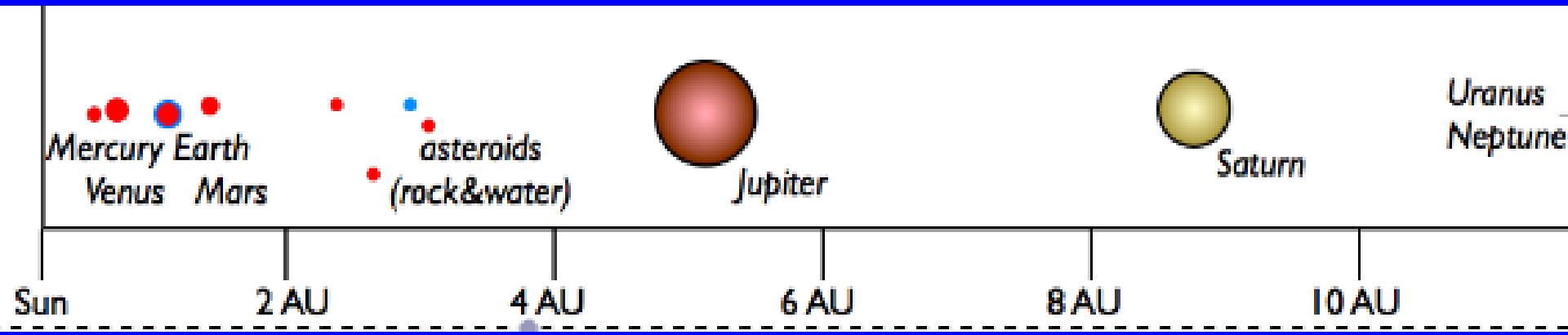


Cold molecular cloud core
Water, ice and simple organic materials formed

Protostar and forming planetary disk
Warm conditions promote formation of more complex organic material

A scenario for the solar system

Condensation from a spinning cold cloud of dust and gas and rocks to….



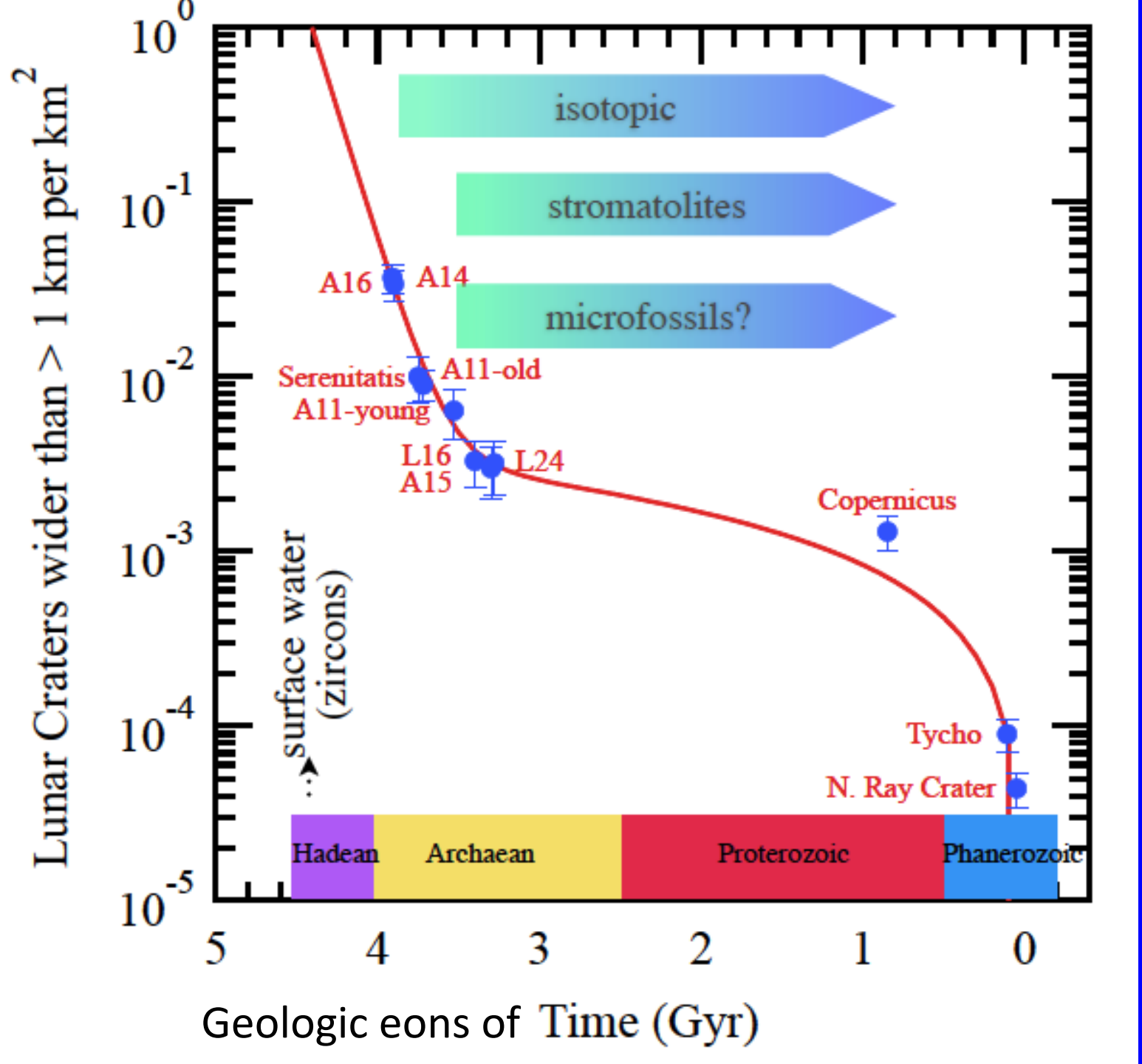
Walsh, Morbidelli et al. (2013).

Meteorite impact 50000 years ago in Arizona

Backside of the moon

Saturn's Dione

Meteorite impacts were common in early solar system

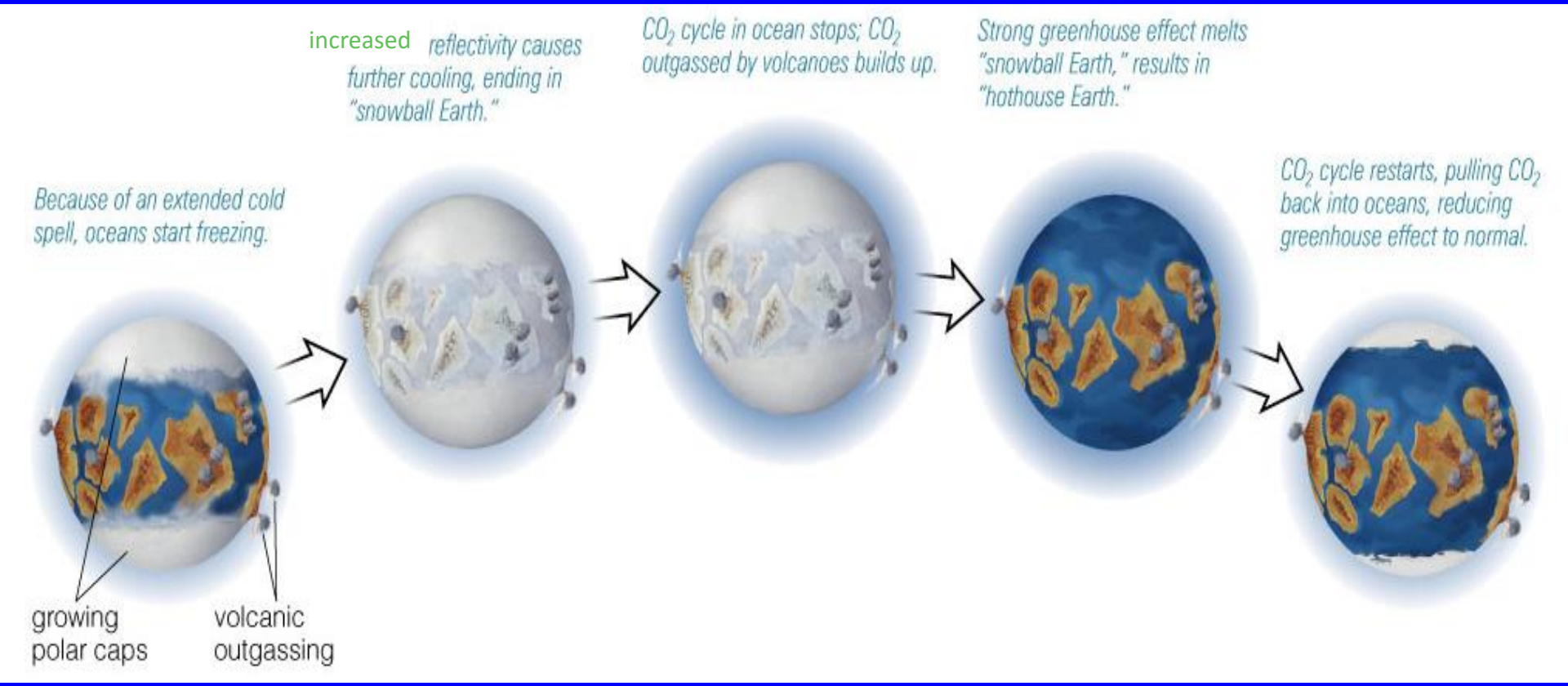


Cratering impacts once were common

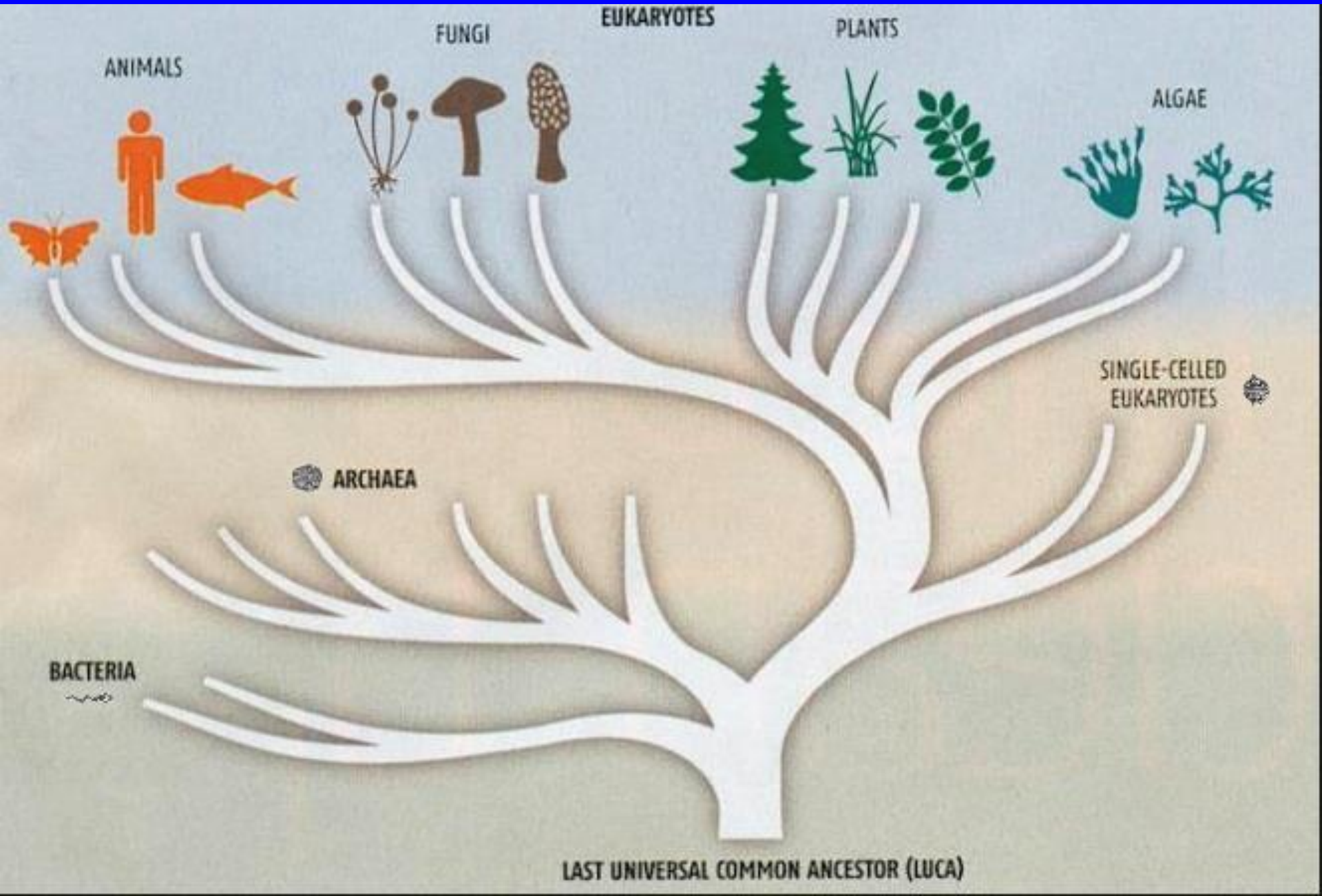
Cratering impacts: potentially fatal for evolution?

Or beneficial in stimulating evolution?

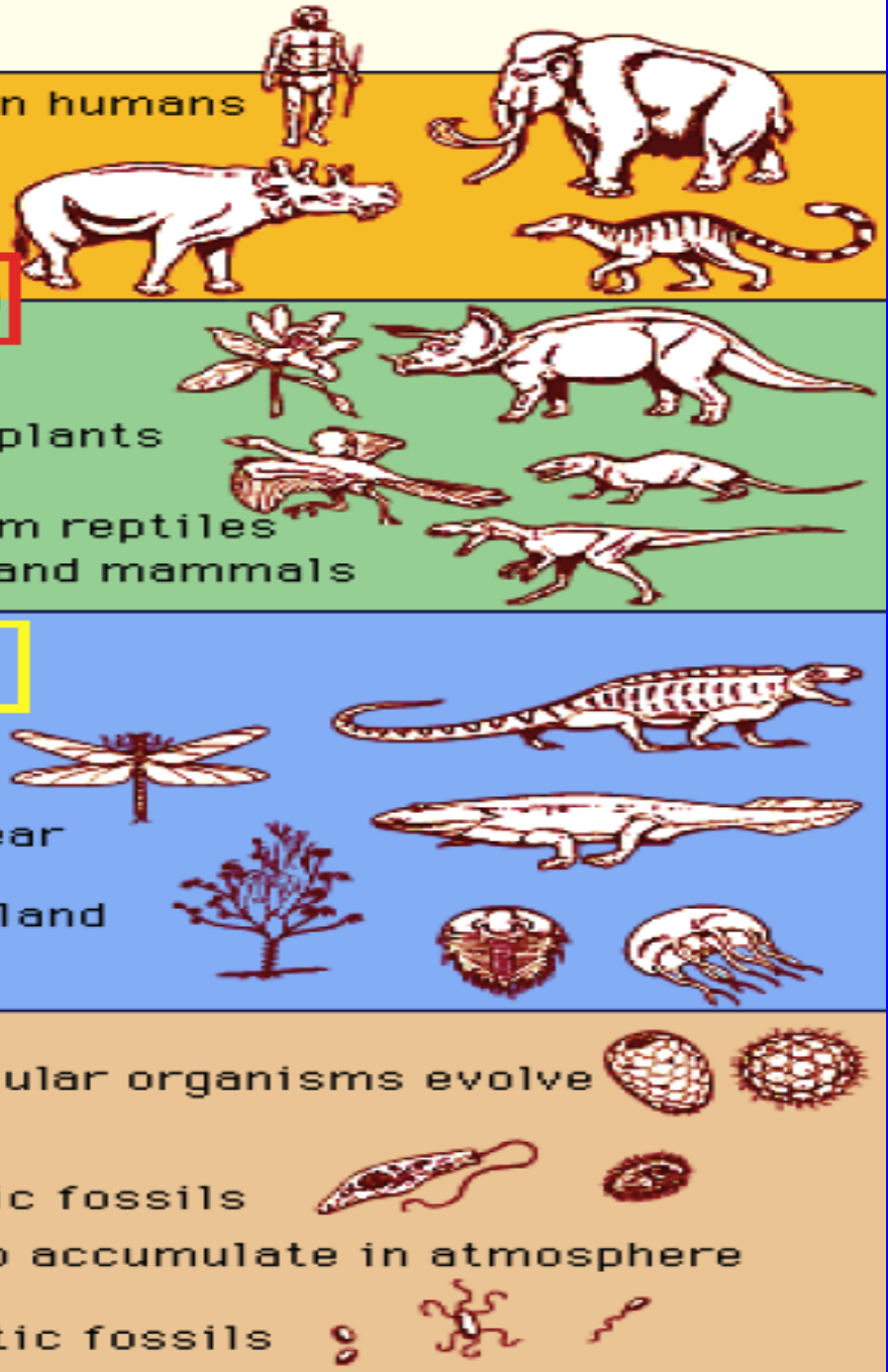
What makes a planet habitable?



The Tree of Life



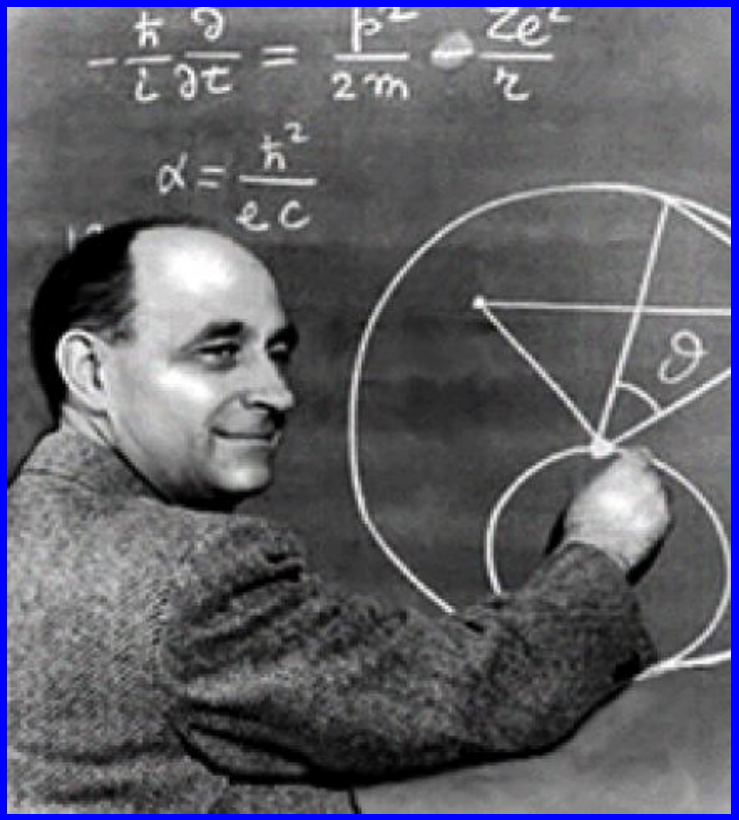
era	time (millions of years ago)	important events
Cenozoic	0.0	present time
	less than 0.1	advent of modern humans
	2.4	ice age
	66.4	mass extinction
Mesozoic	141	first flowering plants
	195	birds evolve from reptiles
	230	first dinosaurs and mammals
	245	
Paleozoic	280	mass extinction
	340	reptiles appear
	360	first insects
	370	amphibians appear
	420	plants colonize land
	540	
Precambrian	700	simple multicellular organisms evolve
	2,100	oldest eukaryotic fossils
	2,500	oxygen begins to accumulate in atmosphere
	3,500	oldest prokaryotic fossils



Where are they?

At a luncheon ……. Fermi said, virtually apropos of nothing: “Don’t you ever wonder where everybody is?” ….we all knew he meant extra-terrestrials. He then followed up with a series of calculations on the probability of earthlike planets, the probability of life given an earth, the probability of humans given life, the likely rise and duration of high technology… He concluded on the basis of such calculations that we ought to have been visited long ago and many times over.

Los Alamos, 1951, in letter by Herbert York, 1984 (to Eric Jones)

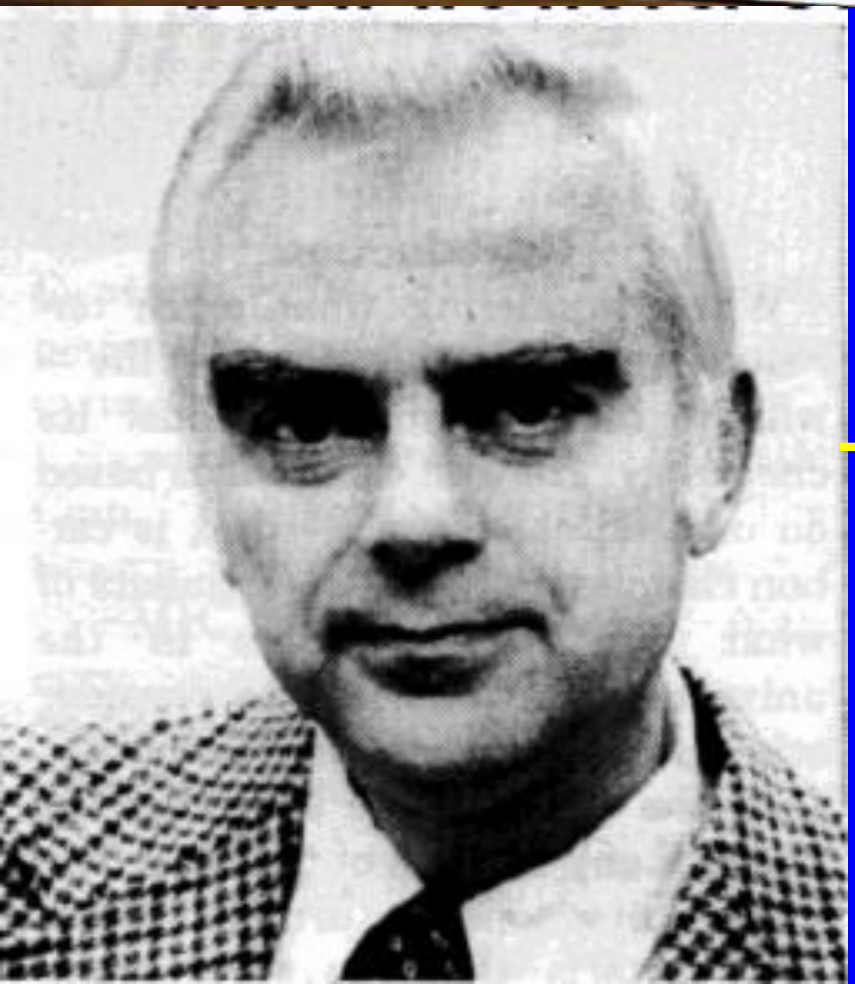


But not all astronomers agree

- There are few other civilizations, probably none
- Research for extraterrestrial signals is a waste of time and money

Michael Hart 1975

$$N = R_* f_p n_e f_l f_i f_c L$$



How many are there ?

THE DRAKE EQUATION

Frank Drake, radio astronomer

NUMBER OF INTELLIGENT CIVILIZATIONS $= R_{ASTRO}\, f_{BIOTEC}\, L$

There are three huge uncertainties

$R_{ASTRO} = R_* f_p n_e$ — ***Astronomical factor:*** **creation rate of habitable planets**

$f_{BIOTEC} = f_l f_i f_t$ — ***Biotechnological factor:*** **fraction of planets with technology**

L — ***Lifetime*** **in the corresponding technological phase**

Prantzos 2014

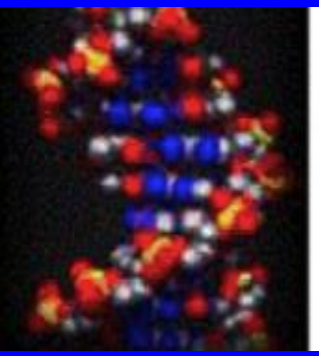
R* is the rate of formation of stars in the galaxy

fs is the fraction of stars that are suitable suns for planetary systems

fp is the fraction of those stars with planets (thought to be around 1/2)

Astro OK!

ne is the number of "earths" per planetary system -- planets suitable for liquid water



fl is the fraction of those planets where life develops

Biotech ???

fi is the fraction of planets with life where intelligence develops

fc is the fraction of those planets that achieve technology which releases detectable signals into space

L is the lifetime of such communicative civilizations

We don’t know any of these factors!

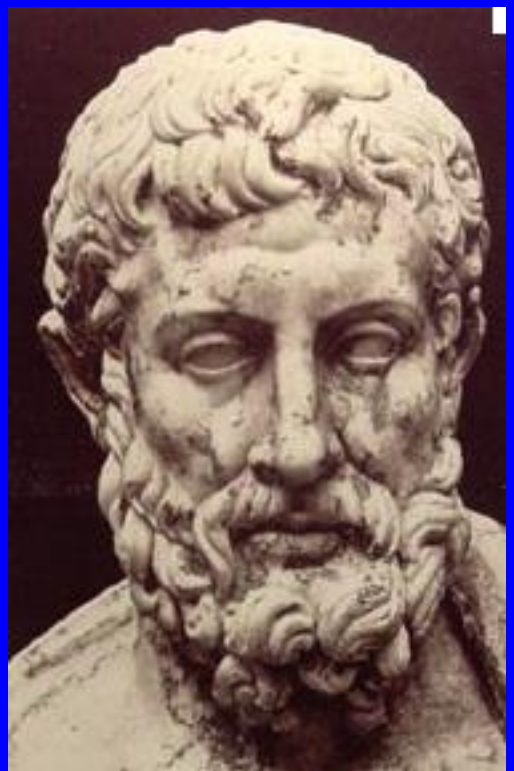
Few will deny the profound importance, practical and philosophical, which the detection of interstellar communications would have. We therefore feel that a discriminating search for signals deserves a considerable effort. The probability of success is difficult to estimate; but if we never search, the chance of success is zero.

:

- Giuseppe Cocconi and Philip Morrison, Nature, 1959

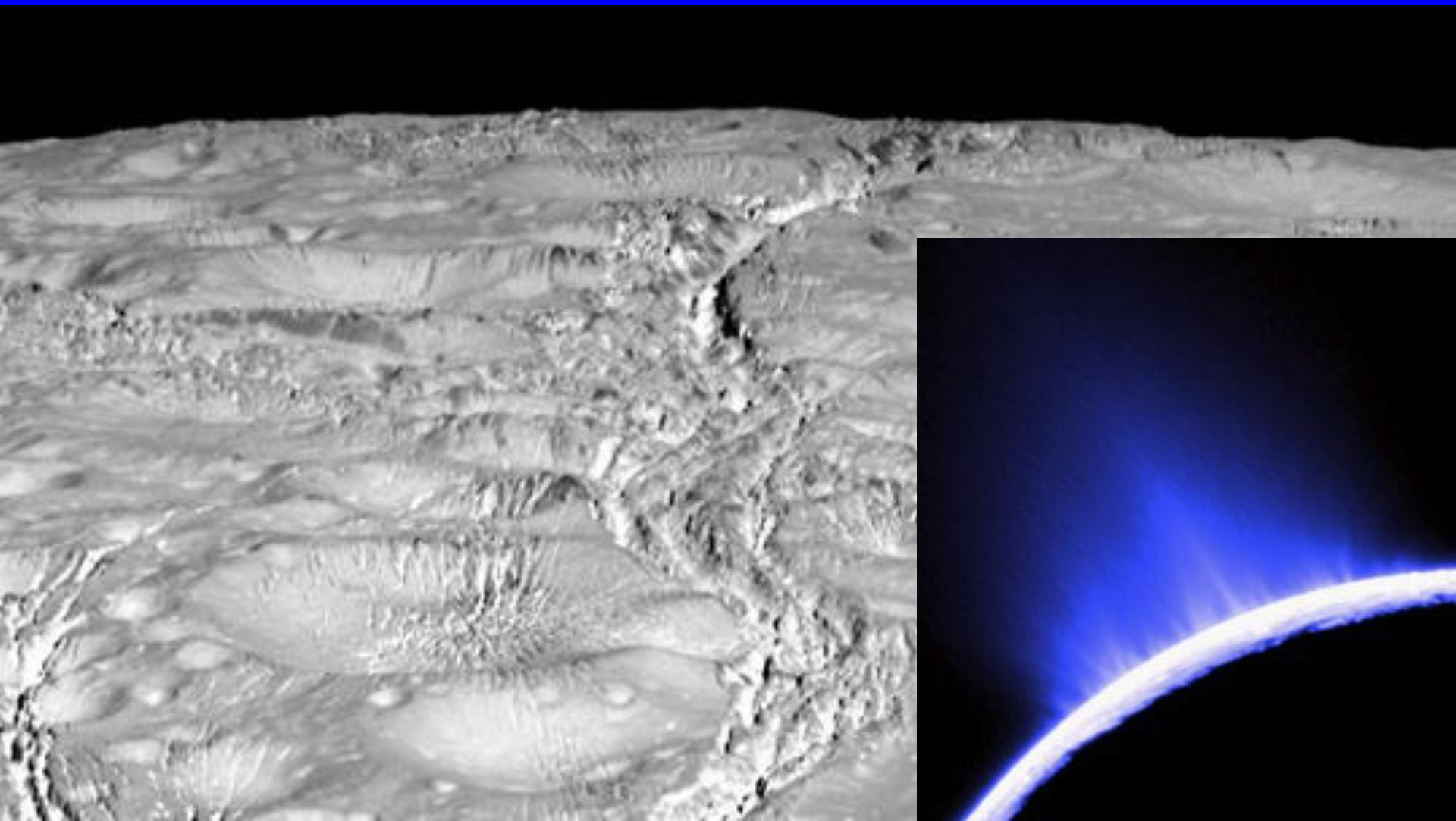
To consider the Earth as the only populated world in infinite space is as absurd as to assert that in an entire field sown with millet only one grain will grow.

Metrodorus of Chios, 4th century BC

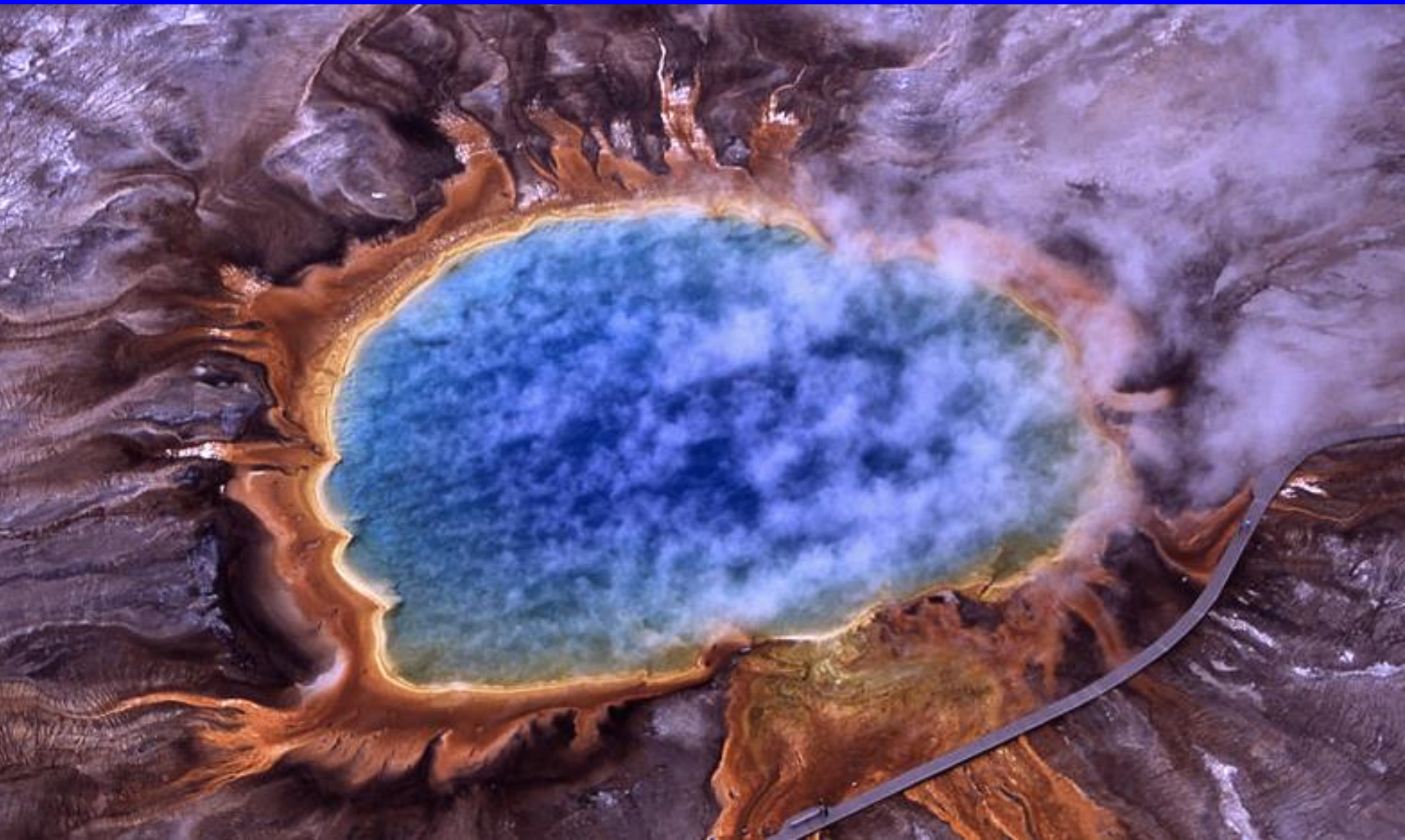


Life in unlikely places?

Ice geysers on Enceladus:
oceans of water under the ice



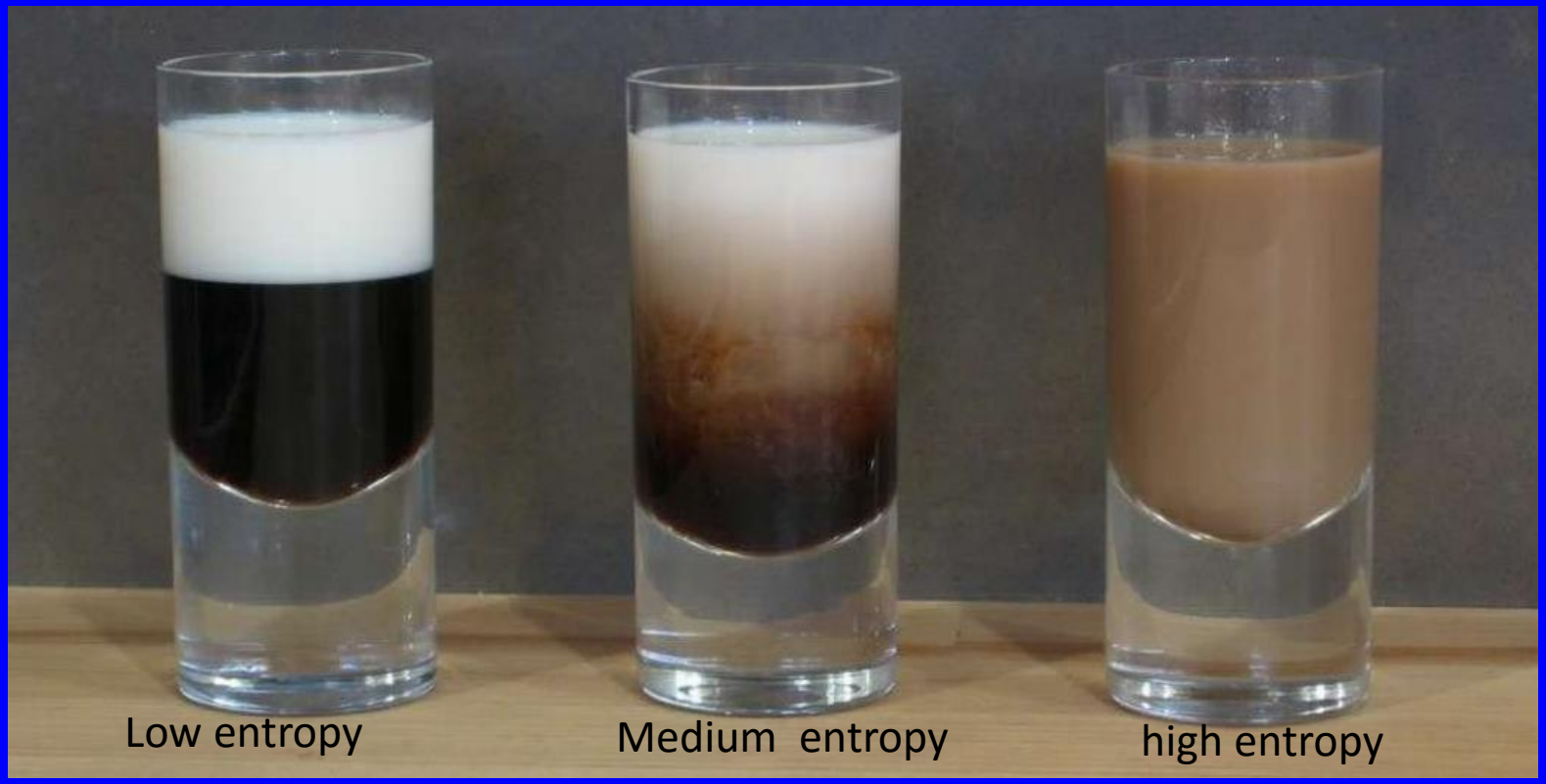
Life in hot places



The future of life in the universe?

Entropy = information content = can never decrease

In the beginning Now In the far future

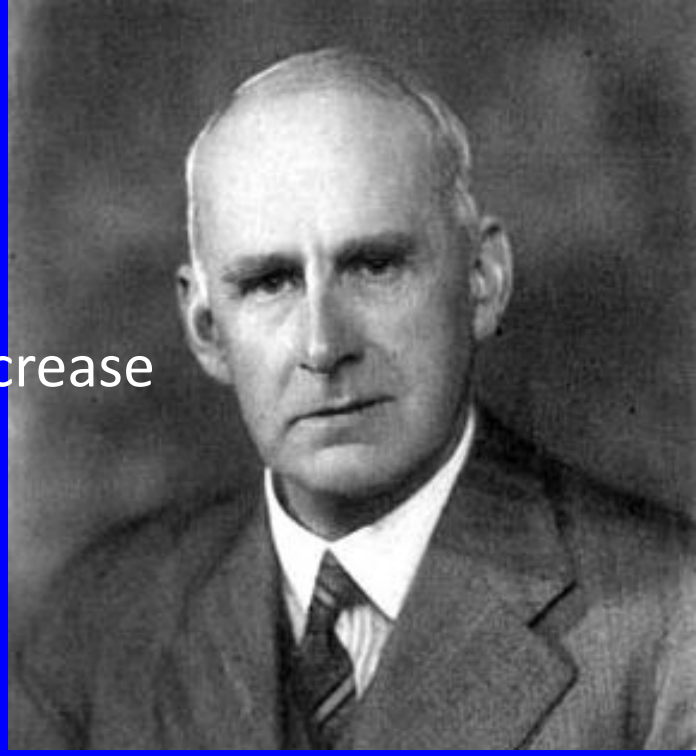


Life may be simpler in the future…..

S. Caroll (2011):

Physics is optimistic

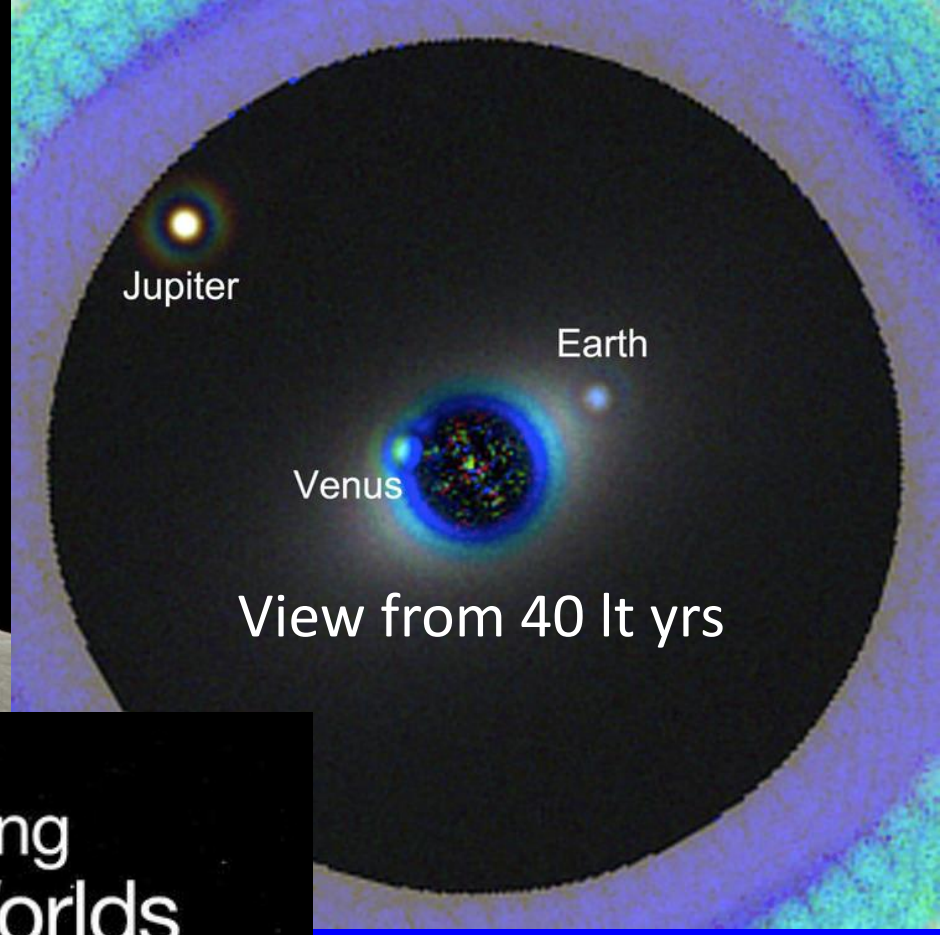
Information content aka entropy can never decrease



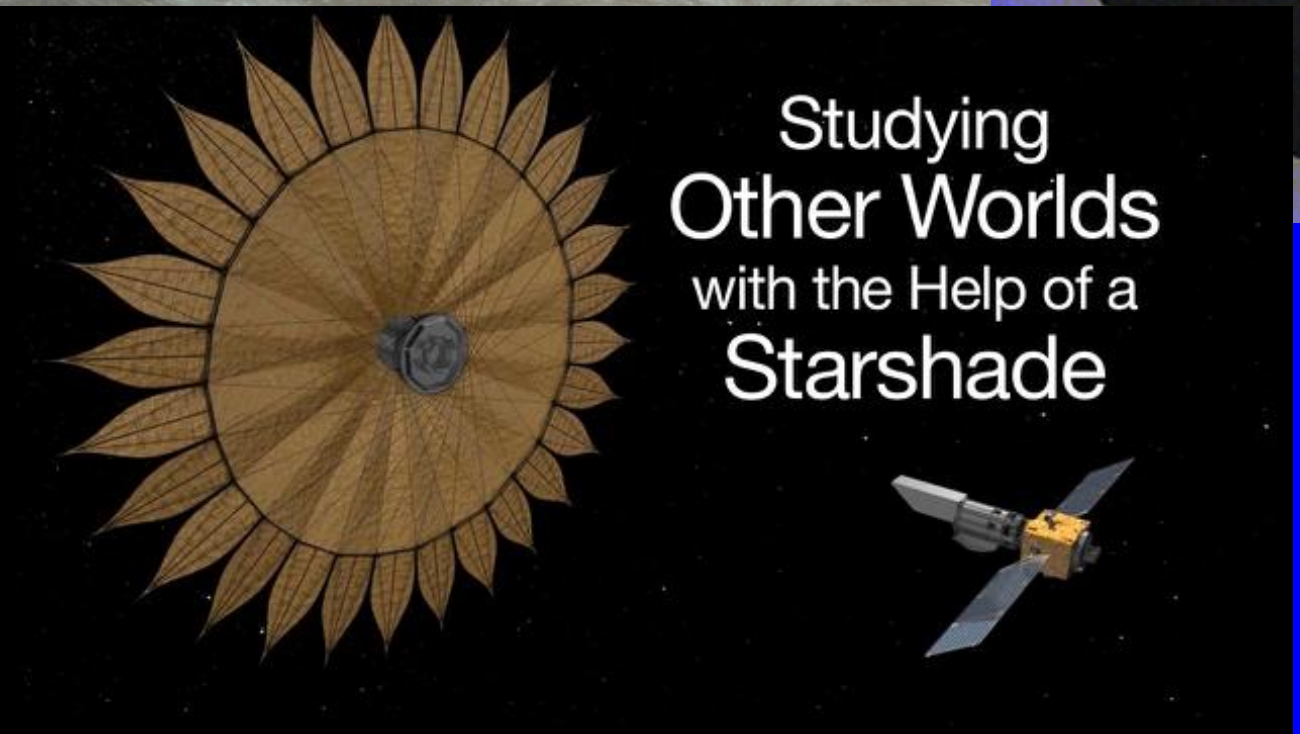
If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations—then so much the worse for Maxwell's equations. If it is found to be contradicted by observation—well these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics, I can give you no hope; there is nothing for it but to collapse in deepest humiliation.

Arthur Eddington 1927

View of Earth from Moon



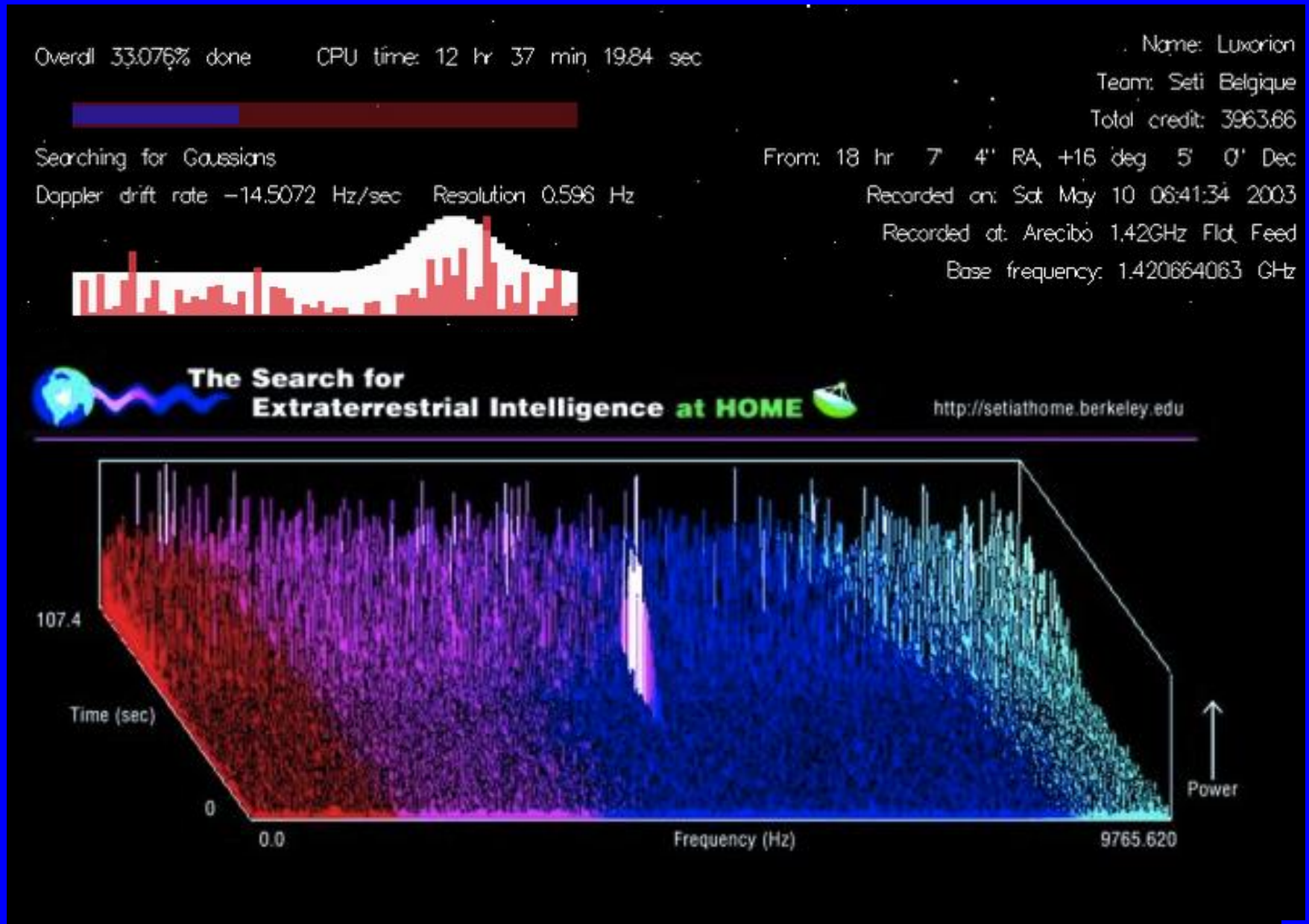
View from 40 lt yrs



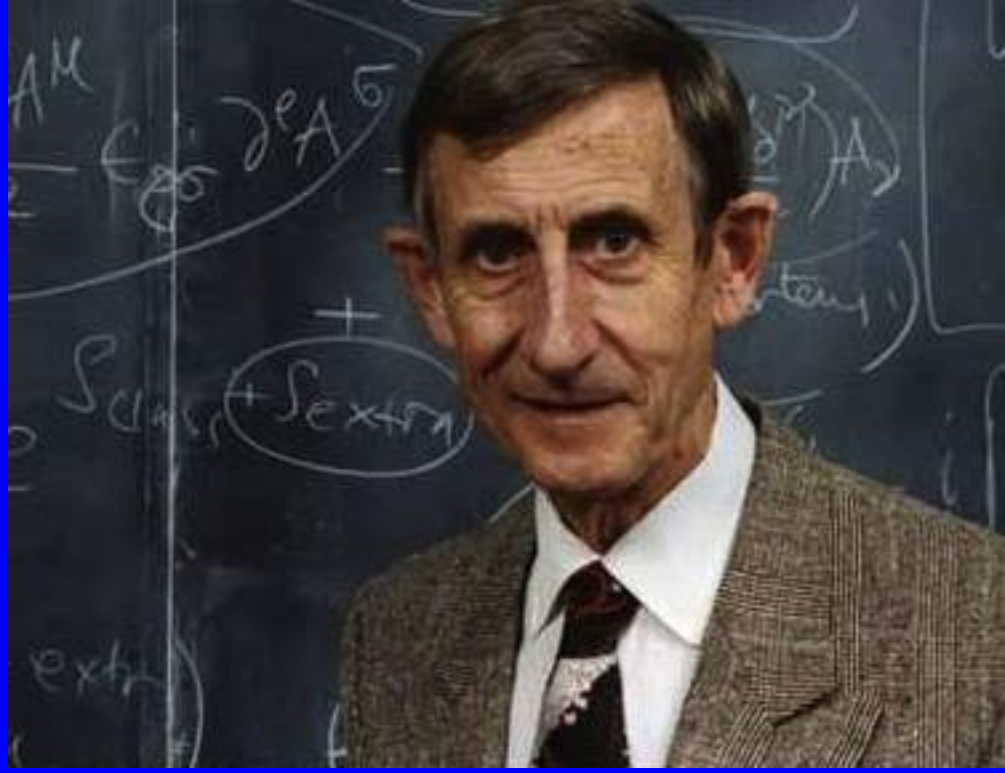
2.4m optical/UV
WFIRST telescope
+ 16m starshade
~2025

RADIO SIGNALS

PROJECT SETI search for extraterrestrial intelligence



Dyson spheres: artefacts of a future civilization. They must use lots of energy!



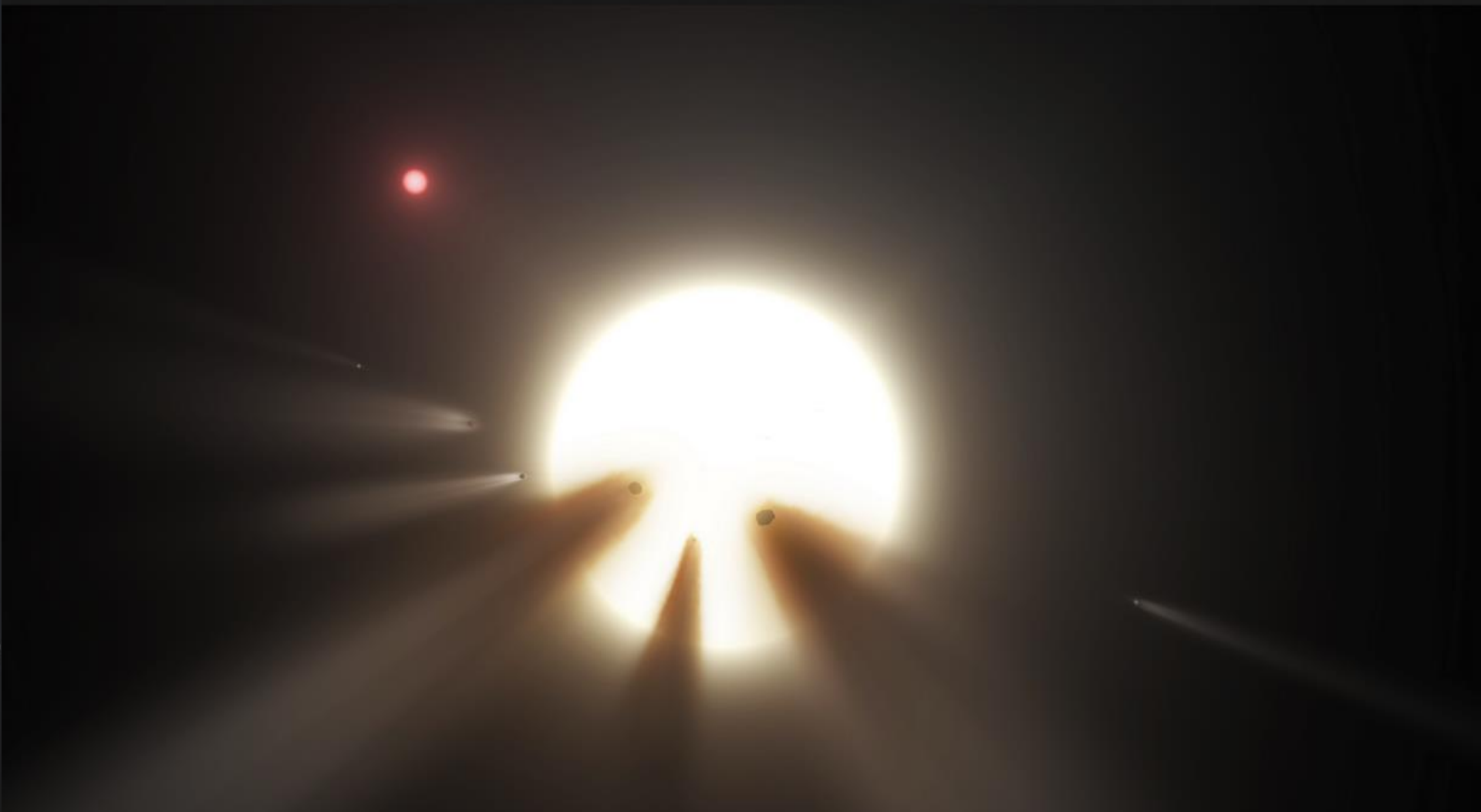
Search for Artificial Sources of Infrared Radiation

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.

Freeman Dyson, Science, 1960

A more likely explanation

a cloud of comets



GALACTIC HABITABLE ZONE

TRANSMISSION OF INFORMATION BY EXTRATERRESTRIAL CIVILIZATIONS

N. S. Kardashev

P. K. Shternberg Astronomical Institute

Translated from Astronomicheskii Zhurnal, Vol. 41, pp. 282-287, March-April, 1964

The protracted duration of signal propagation is a determining factor in the one-way transmission of information through space. Reliable reception, or any reception at all, of signals by unknown subscribers necessarily requires an isotropic emission. The optimum signal spectrum for transmitting the maximum amount of information in the presence of quantum noise and the background of cosmic radio-frequency emission has been calculated. It is shown that a civilization located at any distance in the universe and in possession of power on the order of $L_{\odot} \approx 4 \times 10^{33}$ erg/sec or more, which it is capable of transmitting in a coded isotropic radio-frequency signal, may be detected by conventional radio astronomical techniques. The expected distinguishing properties of artificial sources of cosmic radio-frequency emission are enumerated. It is speculated that even some sources known to us today (notably CTA-21 and CTA-102) may be artificial radio sources.

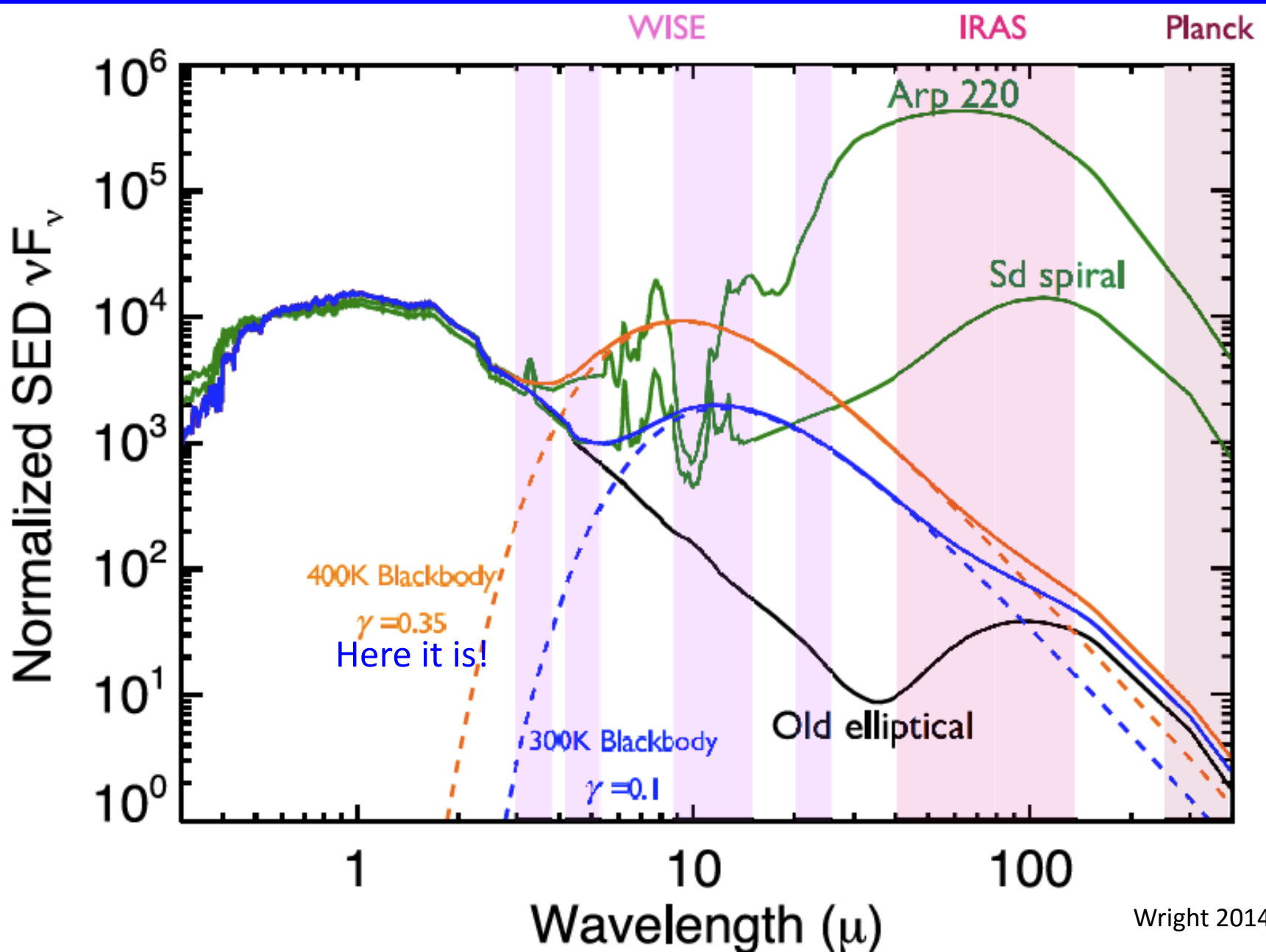
1. SO YOU WANT TO BE A ROCK 'N' ROLL STAR
-J. McGuinn - C. Hillman-
2. HAVE YOU SEEN HER FACE -C. Hillman
3. C.T.A. - 102 -J. McGuinn - R.J. Hippard
4. RENAISSANCE FAIR

CLASSIFYING EXTRATERRESTRIAL ADVANCED CIVILIZATIONS BY POWER GENERATION

Nikolai KARDASHEV (1964)

- TYPE 1 : PLANETARY 100 TeraWatts (actual usage)
  10^5 TW (using all incident sunlight)
- TYPE 2: STELLAR 10^{14} TW
- TYPE 3: GALACTIC 10^{24} TW

Prediction of a Type 3 Civilization

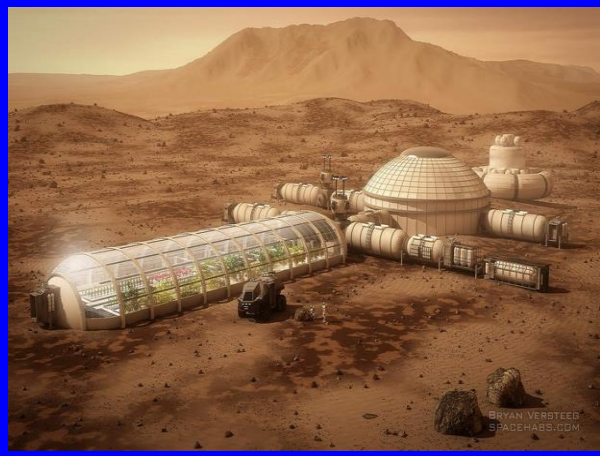


Wright 2014

Going There

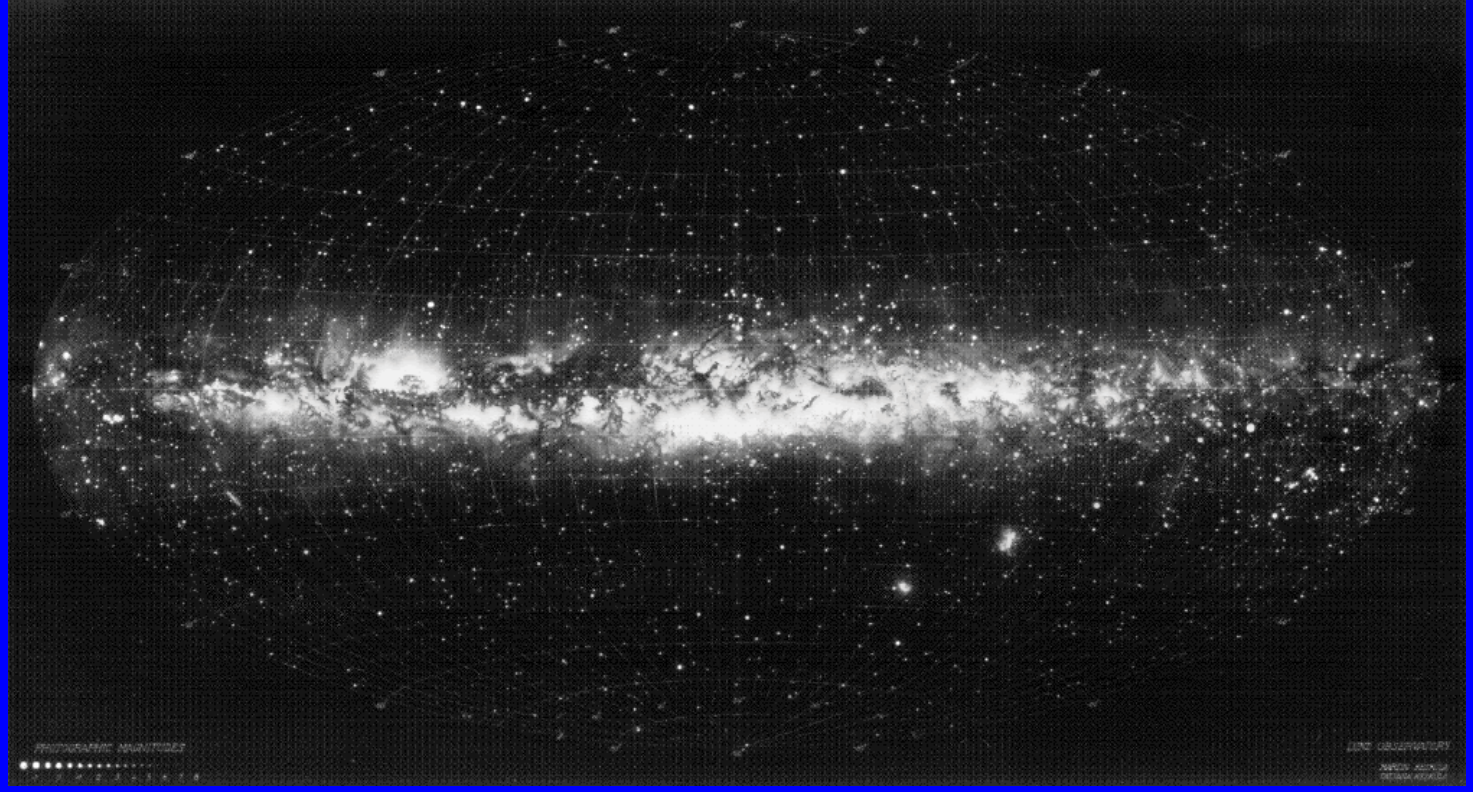
Tourism

Orbital Habitats



Settlements

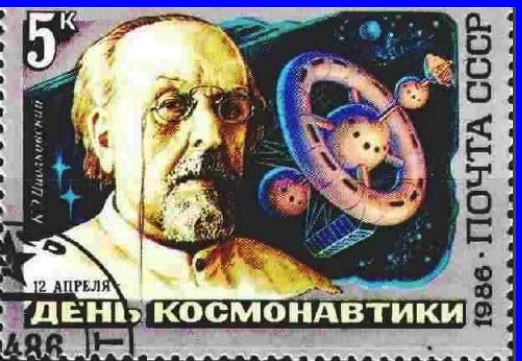
Courtesy J. Tarter, SETI



There are billions of habitable planets in our Milky Way galaxy

The big question:

do any have life…or intelligent life?



The Earth is the cradle of the mind but we cannot live forever in a cradle

Konstantin Tsiolkovsky 1911

THANK YOU!