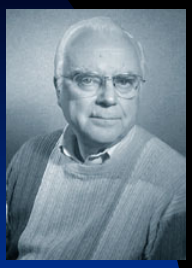
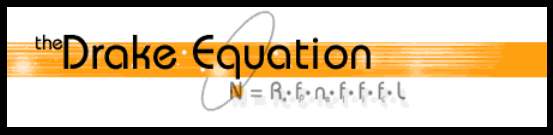
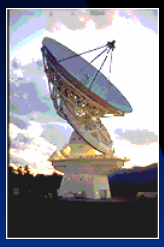
Life in the Universe





An exercise in applied logic that cuts across every field of human knowledge…

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



the number of civilization in the Galaxy that can communicate across stellar distances

Human Knowledge Required…

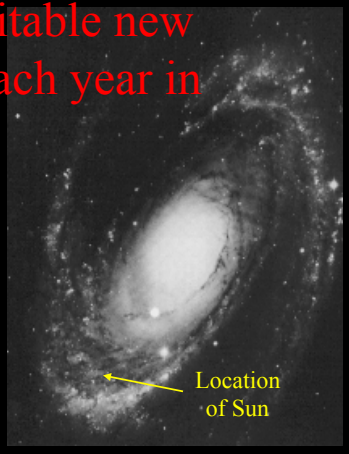
Astronomy Astrophysics Physics Chemistry Climatology Oceanography Geophysics Biology Evolution Paleontology Archeology Anthropology Sociology Psychology Politics Culture Economics Ethics Theology…

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

the ***rate*** at which suitable new ***stars are forming*** each year in the Galaxy

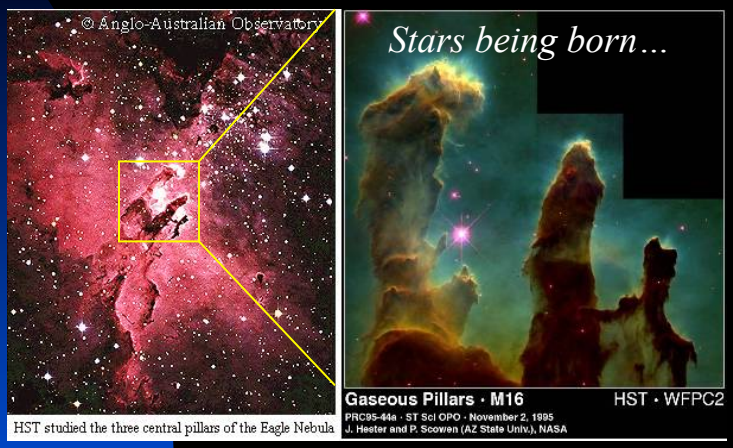
The Galaxy has ***~400,000,000,000*** stars, which are forming, living, and dying in billion year cycles-

Stars are the fundamental platforms and energy sources for life…



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

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



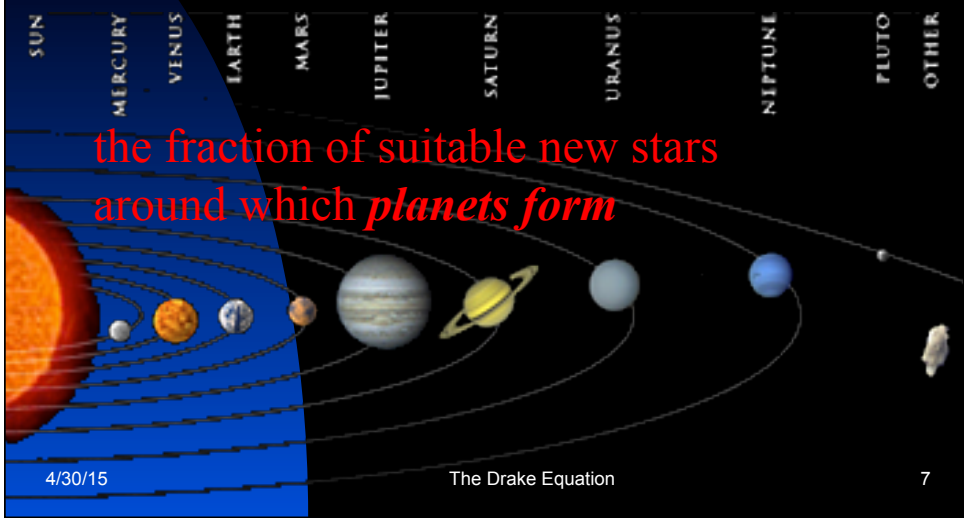
HST studied the three central pillars of the Eagle Nebula

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

R_* is pretty well known because astronomical technology is up to the task of measuring it…

$R_* \sim 10$ stars per year

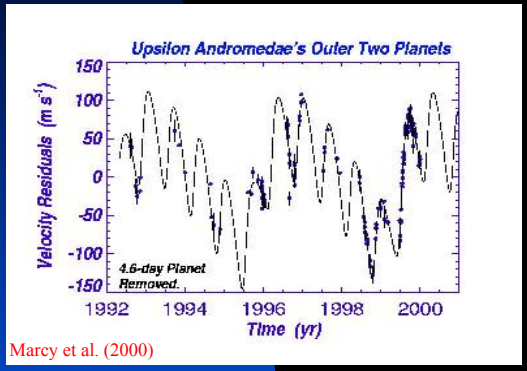
$N = R_* f_p n_e f_l f_i f_c L$



the fraction of suitable new stars around which ***planets form***

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

Planet Detections: The Doppler Velocity Method

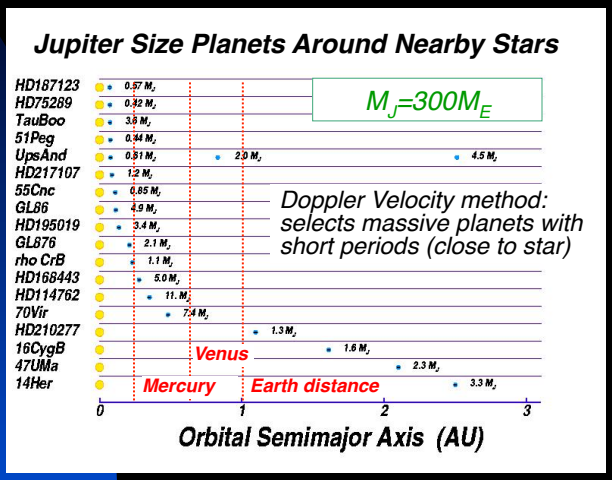


Marcy et al. (2000)

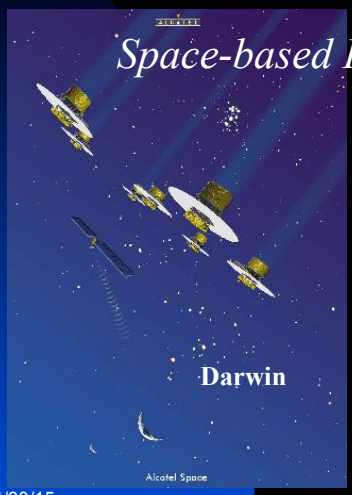
As planets orbit, they pull the star around the center of gravity.

The stellar velocity oscillates, increasing and decreasing with time.

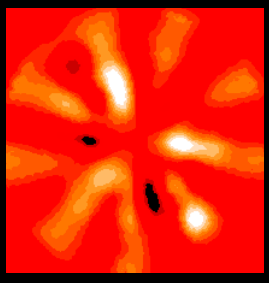
$N = R_* f_p n_e f_l f_i f_c L$



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



Space-based Infrared Interferometery



Venus and Earth detection
from 30 light years away!

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

f_p is becoming better known as we speak… long term Doppler programs and future space mission like TPF and Darwin will increase our knowledge.

$f_p \sim 0.5$

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

the number of planets residing in an ***ecosphere***, the shell of life

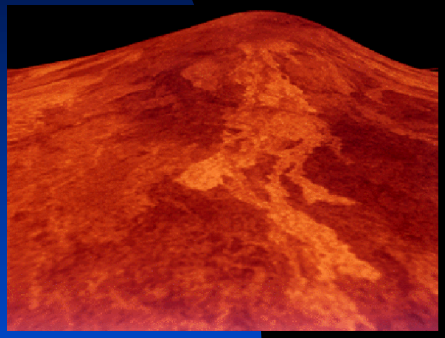
Direct energy: light from star
- Proximity to star (too close, too far, just right)
- Atmosphere of planet (climatic evolution)

Indirect energy: localized
- Solar wind + local magnetosphere
- Geothermal (radioactive decay)
- Central Planet (tidal forces on moons)

Requires stability and flexibility for billions of years

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

Rare Earth? ***Venus***

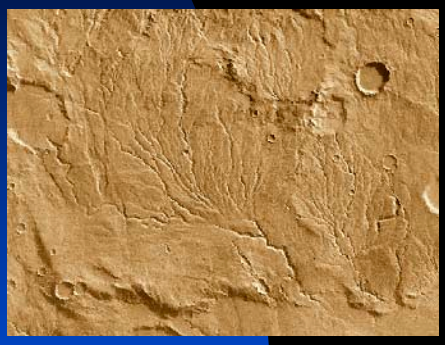


Too close to the Sun

Venus suffers from a runaway Greenhouse effect, in which light energy from the star is trapped as heat by the atmosphere.

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

Rare Earth? ***Mars***



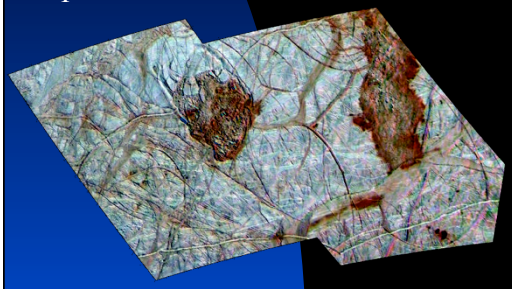
Too far from the Sun

Mars suffers from a runaway Ice Catastrophe, in which light energy from the star is reflected back into space.

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

Rare Earth? *Europa*

Jupiter's moon…



Heated by Jupiter's tidal forces and/or radioactive elements in its core?

Europa is geologically active with glacier-like ice sheets of Frozen Water. Changing cracks indicate underground oceans!

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

Europa's magnetic field suggests a metallic core and its average density indicates a rocky interior.

An ice mantle or sub-ocean?
A stable site conducive to life?

Boldly Go…

A JPL proposal for a Europan ocean explorer

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

Serious unknowns:

- what are conditions under which life can arise?
- i.e., what is a "primordial" ecosphere?
- how does early life modify "primordial" ecosphere?
- how do planetary atmospheres and oceans evolve and how do they respond to astrophysical pressures?

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

n_e probably is zero in some planetary systems and is a few to several in others (ours?). We need to know what n_e is on average, its typical value.

n_e uncertain (~ 2?)

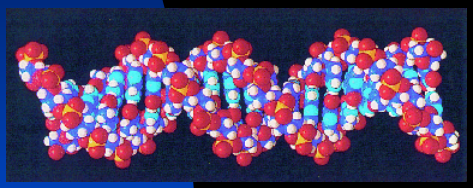
$N = R_* f_p n_e f_l f_i f_c L$

the fraction of ecosphere planets on which ***life arises***

Key Question: how readily does life arise?

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

- All life (as we know it) is made of carbon based molecular chains
- Only 30 complex molecules comprised of only five (5) basic elements



DNA molecule

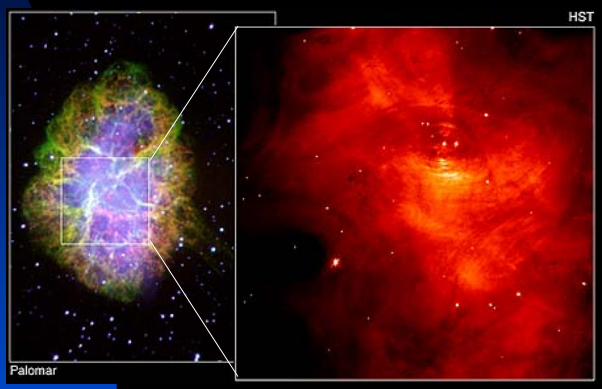
C = carbon
H = hydrogen
N = nitrogen
O = oxygen
P = phosphorous

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

- C, H, N, and O are among the five most abundant elements is the universe; (helium is 2nd to hydrogen)
- The five elements of life are created in stars and supernovae explosions distributed them throughout the interstellar medium
- Organic molecules, such as amino acids, are commonly found in interstellar, molecular gas clouds, and in comets and meteorites

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

Supernovae create elements and distribute them into the galaxy



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

Comets, such as Halley, contain water ice and organic molecules, which are evaporated into interplanetary space

- Building blocks of planets during planet formation epoch
- Deposit water and organic molecules on planets
- Can alter course of evolution if impacting life bearing planet

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

Just how robust is life?

• Life persists in a wide range of terrestrial environments- from the high desert to frozen ice tundra, from the tropics to the black depths of the oceans…

Are there alternatives to photosynthesis?

• Life in the ocean depths exploits geothermal energy and survives ***not*** on sunlight, but on bacteria that metabolizes sulfuric acid outgasing from thermal vents

Life can arise in a range of environments and can survive on a variety of primary energy sources. (?)

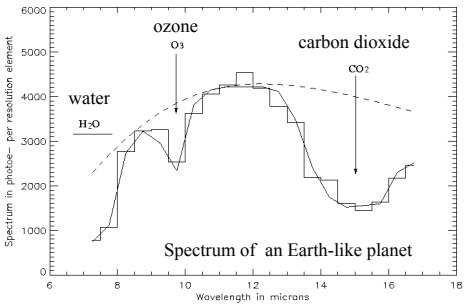
$N = R_* f_p n_e f_l f_i f_c L$

How will we detect signs of life on extrasolar planets?

Terrestrial Planet Finder will take spectra of earth sized planets up to 30 light years away!

Ozone, water, and carbon dioxide absorption features are indirect indicators of life processes (photosynthetic)

Terrestrial Planet Finder



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

f_l , presently, can be guesstimated only by carefully studying our solar system, and in particular, Earth.

That life is a "language" with a 30 molecule "alphabet" and is comprised of the five most abundant elements is encouraging

$f_l \sim 0.1\text{-}1$ (?)

NOTE: f_l is likely *not* vanishingly small, say 10^{-8} or so

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

the fraction of life bearing planets upon which ***intelligence arises***

- How to define intelligence?
- Humans and dinosaurs?
- Special events required?

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

Defining intelligence…

Encephalization Quotient

Encephalization (E) is the ratio of brain mass to body "surface mass"

$$E = \frac{\text{Brain Mass}}{(\text{Body Mass})^{2/3}}$$

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

Encephalization Quotient

Encephalization Quotient (EQ) measures how "intelligent" a species is relative to other *comparable* life forms

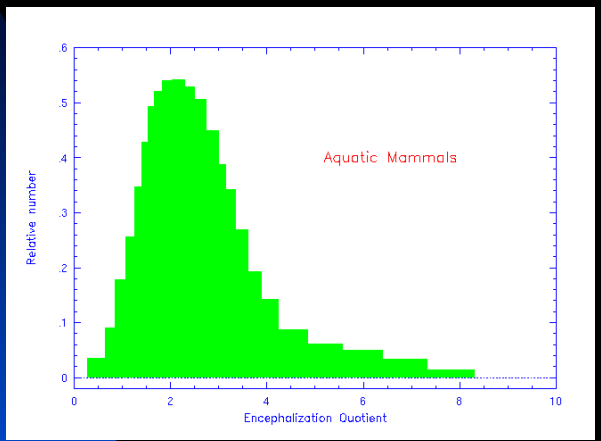
ex. Dolphins compared to similar mass aquatic mammals

$$EQ = \frac{E(actual)}{E(average)}$$

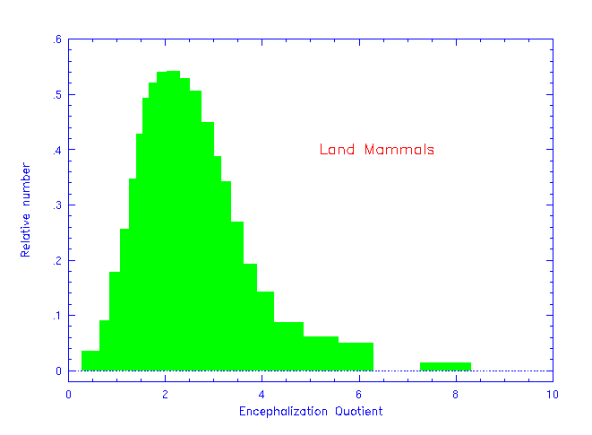
land mammals

EQ(cows) = 0.2
EQ(dogs) = 1
EQ(chimps) = 4
EQ(humans) = 8

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



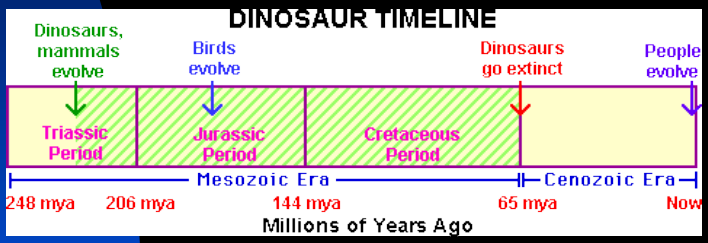
$N = R_* f_p n_e f_l f_i f_c L$



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

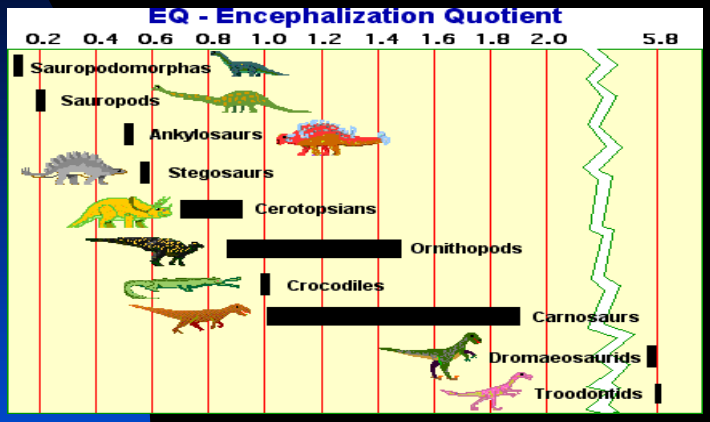
Were some dinosaurs smart?

They evolved over 160 million years, whereas humans have been around only 200 thousands years… what was different?



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

In fact, some dinosaurs were "intelligent", with EQ ~ 6 !



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

Troödon

- Binocular Vision
- Stereoscopic Hearing
- Dexterous "Hands"
- Largest EQ of dinosaurs

All this… and still not as smart as a chimp…

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

f_i can only be studied via the history of intelligence on Earth

- intelligence has always steadily increased with time, even with the repeated mass extinctions
- no "freak" circumstances of events have ever intervened in history to *increase* the chances of intelligence

$f_i \sim 0.1\text{-}1$ (?)

NOTE: f_i is likely ***not*** vanishingly small, say 10^{-8} or so

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

the fraction of planets hosting intelligent life where a *technological civilization* arises at least once

Must be able to communicative across stellar distances

Must be fast : Must be economical

→ *electromagnetic radiation*

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

Technology. In the form of electromagnetic transmitters…

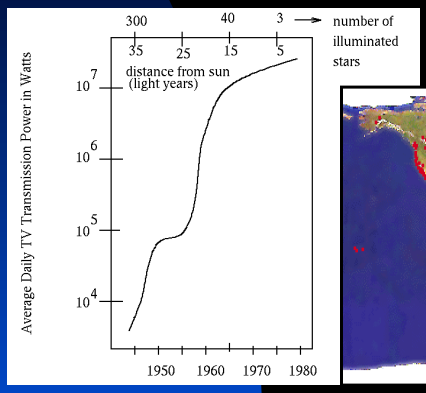
The physics is the same everywhere and is easily understood/developed

This simple technology was conceived and built only 5000 yrs after the pyramids and 10,000 yrs after writing appeared

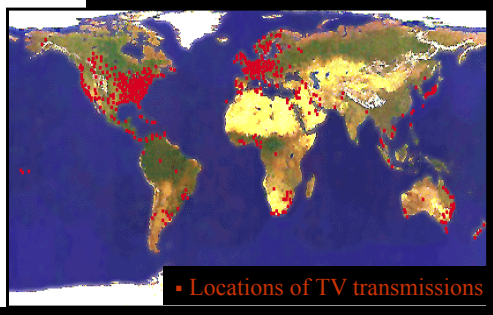
The Very Large Array

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

By 1980, Earth was detectable at distance of 35 light years; ~300 stars

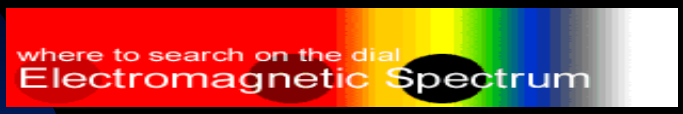


By 2000, the sphere has a 55 light year radius and has illuminated ~1200 stars!



▪ Locations of TV transmissions

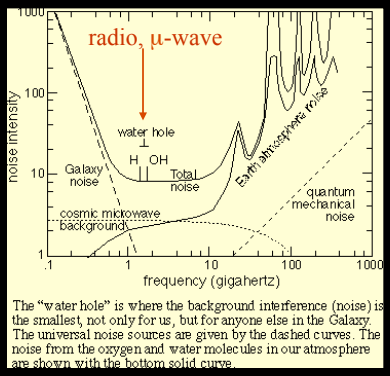
$N = R_* f_p n_e f_l f_i f_c L$



Where the universe is quiet, of course!

The water hole…

where cosmic noise is minimal at ~3 gigahertz; *we exploit this window for our TV and satellite transmissions.*



The "water hole" is where the background interference (noise) is the smallest, not only for us, but for anyone else in the Galaxy. The universal noise sources are given by the dashed curves. The noise from the oxygen and water molecules in our atmosphere are shown with the bottom solid curve.

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

The road to technology…

1. Ecological competitiveness and aggressive domination of habitat; frees species from "survive or die" centered consciousness
2. Living and working in groups; leads species to higher socialization stratification and communication skills
3. Control of fire (a technology)
4. Settlements and migrations; a ceasing of previous nomadic lifestyles
5. Development of agriculture and food storage

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

Why not dinosaurs?

Dinosaurs dominated Earth for 165 million years… why did they not develop radios and TVs?

No single type of dinosaur ever had complete dominion over its habitat in the way that modern humans have for some 30,000 years now.

Dinosaurs never surpassed a "survive or die" centered consciousness level, even though some were quite intelligent.

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

f_c can only be understood in terms of the human experience of technological development

- once humans dominated their habitat, the development of technology took only ~10,000 years, or 500 generations
- many dogmas and ideals have mitigated the progress of free expression, and therefore technological growth, yet… here we are

$f_c \sim 0.1\text{-}1$ (?)

NOTE: f_c is likely *not* vanishingly small, say 10^{-8} or so

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

the average ***life time*** (in years), that technological civilizations remain in a *communicative* or *detectable* state

Do civilizations quickly destroy themselves, or after a brief time become quiet (i.e., dismantle or baffle their technology), or remain detectable for millions of years?

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

Since there is likely a distribution of lifetimes, we estimate the mean, $\bar{L}$

The mean is the sum of possible lifetimes, L_i, weighted by their relative probabilities, p_i

$$\bar{L} = \Sigma\, p_i L_i$$

L_i = lifetime of civilization i

p_i = probability of L_i $(0<p_i<1)$

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

Estimating L (in years)…

$L_1 = 10$	$p_1 = .50$	$p_1 L_1 =$	5
$L_2 = 10^3$	$p_2 = .25$	$p_2 L_2 =$	250
$L_3 = 10^7$	$p_3 = .25$	$p_3 L_3 =$	2,500,000
$L_4 = 10^{10}$	$p_4 = 10^{-6}$	$p_4 L_4 =$	10,000
		$\overline{L} =$	2,510,255

L is dominated by technological longevity and is very probably greater than 10,000 years

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

Evaluating N…

R_* =	5-10
f_p =	0.5
n_e =	2
f_l =	0.1-1
f_i =	0.1-1
f_c =	0.1-1

Maximum	N = 10 L
Moderate	N = L
Minimum	N = 0.005 L

$N \sim L$

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

Sending…

In 1974, Drake et al. sent a message into space from the huge Arecibo telescope…

The transmission contained "0"s and "1"s that could be arranged into the picture at right…

- How to count (1-10)
- C, H, N, O, P
- DNA molecular structure
- DNA physical structure
- Sender population, form, size
- Sender planet and system
- Radio telescope and size