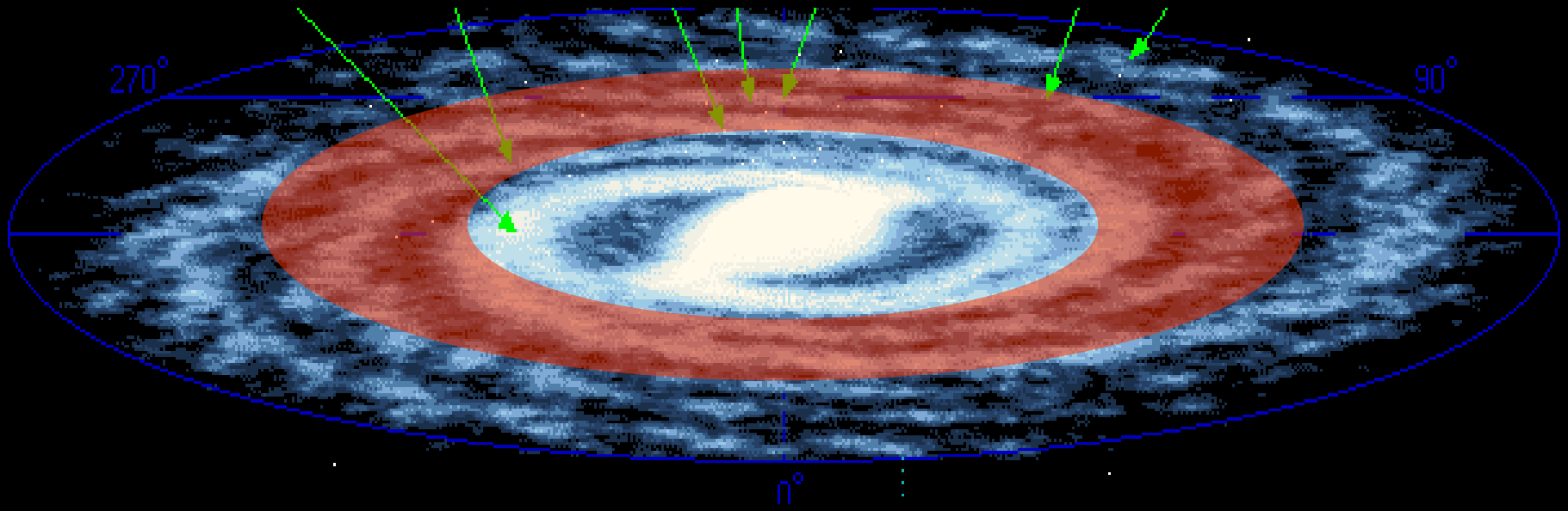
N. Prantzos
Institut d'Astrophysique de Paris

Part I: A Galactic Habitable Zone ?



Several properties of the Milky Way disk vary with radius… and with time

Which one of them *(if any)* are important `for "Galactic habitability"

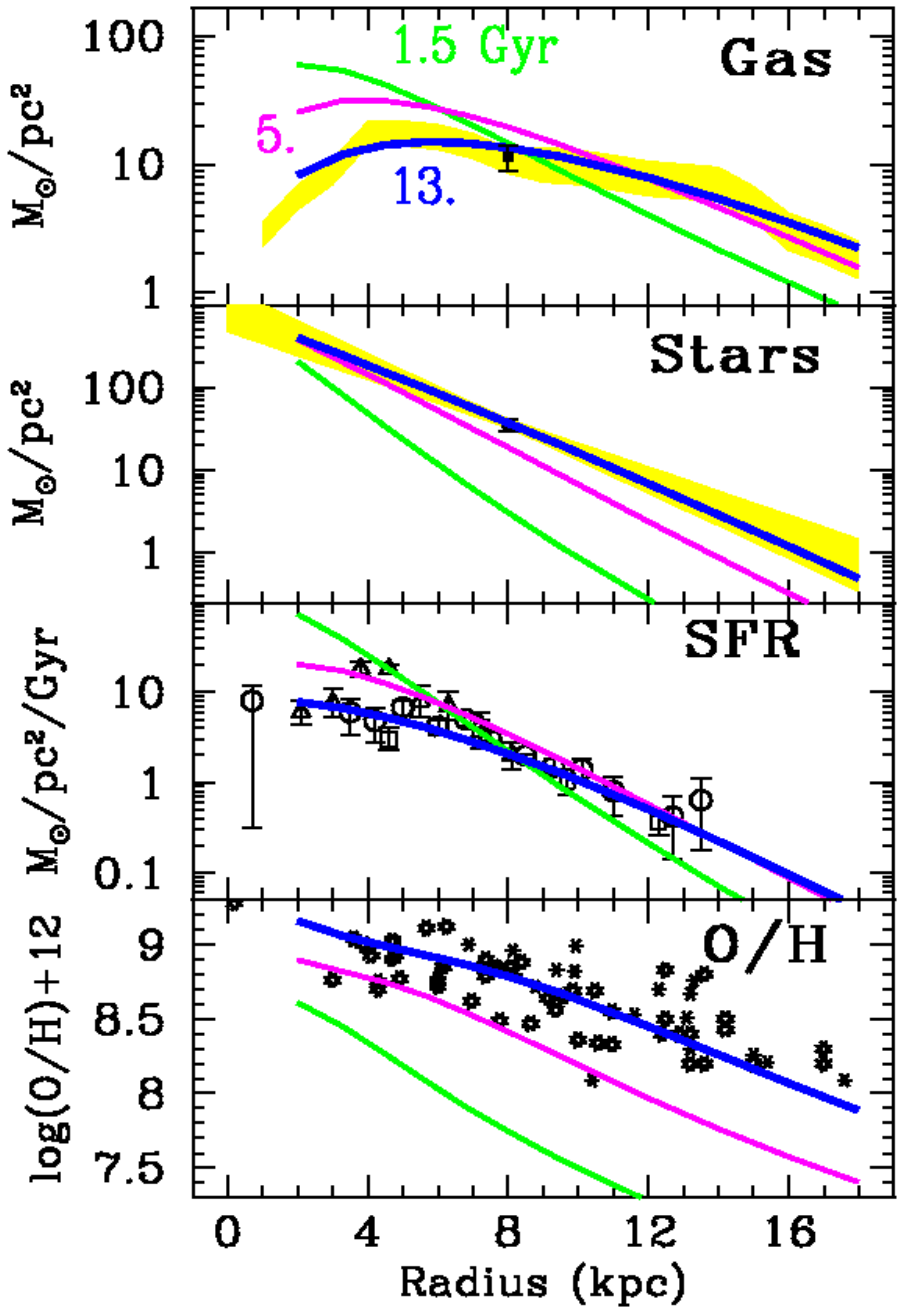
(=conditions favouring *formation of telluric planets and survival of life*)?

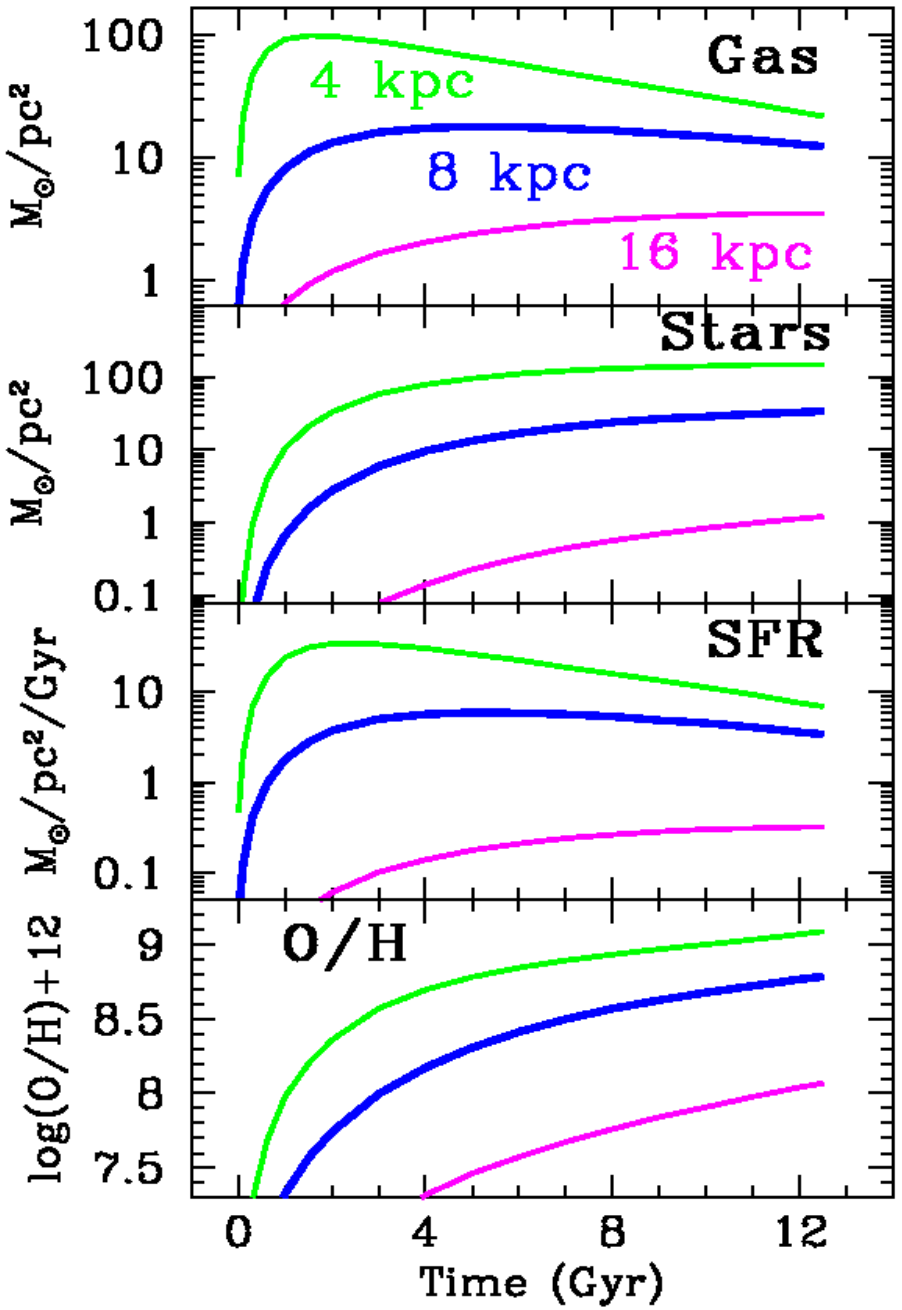
(Perhaps) *metallicity, density of stars, frequency of supernova explosions…*

They may define a "belt of life in the Galaxy" (Maroshnik and Mukhin 1986 ; Balazs 1988)

Or a GHZ (Gonzalez , Brownlee and Ward 2001, *Icarus, Scientific American* ; Lineweaver et al. 2004, *Science*)

THE EVOLUTION OF THE MILKY WAY DISK (*Boissier and NP 1999*)





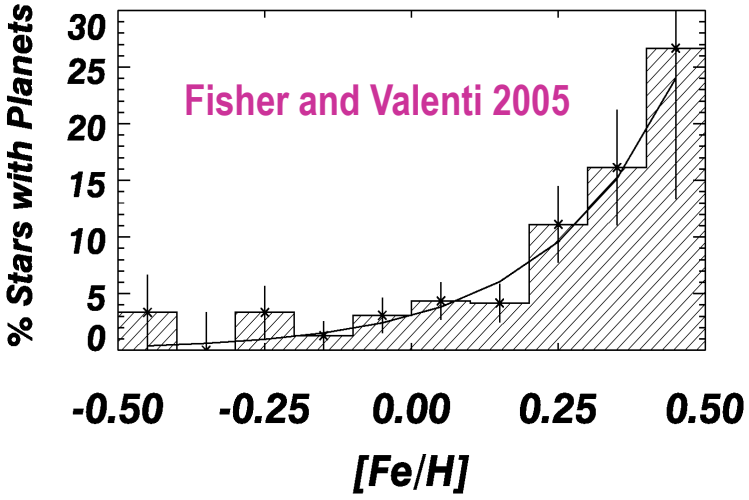
PROBABILITY OF FORMING HOT EXO-JUPITERS

Metallicity dependent:

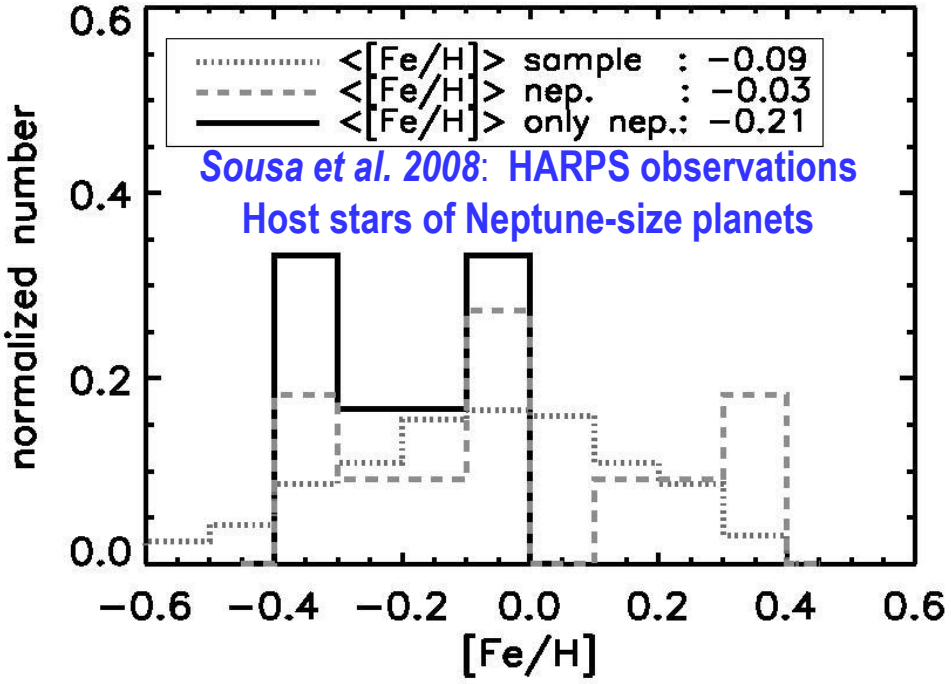
$f_{HJ} = 0.03\ (Fe/Fe_{\odot})^2$

(Fisher and Valenti 2005)

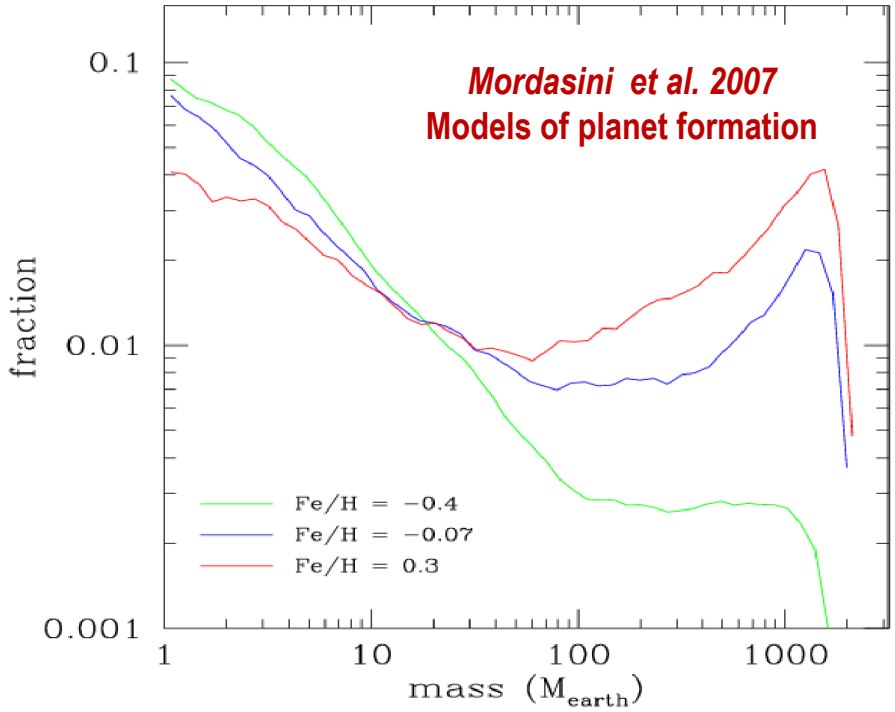
But hot Jupiters destroy Earths in their migration inwards…..



PROBABILITY OF FORMING EXO-EARTHS ?

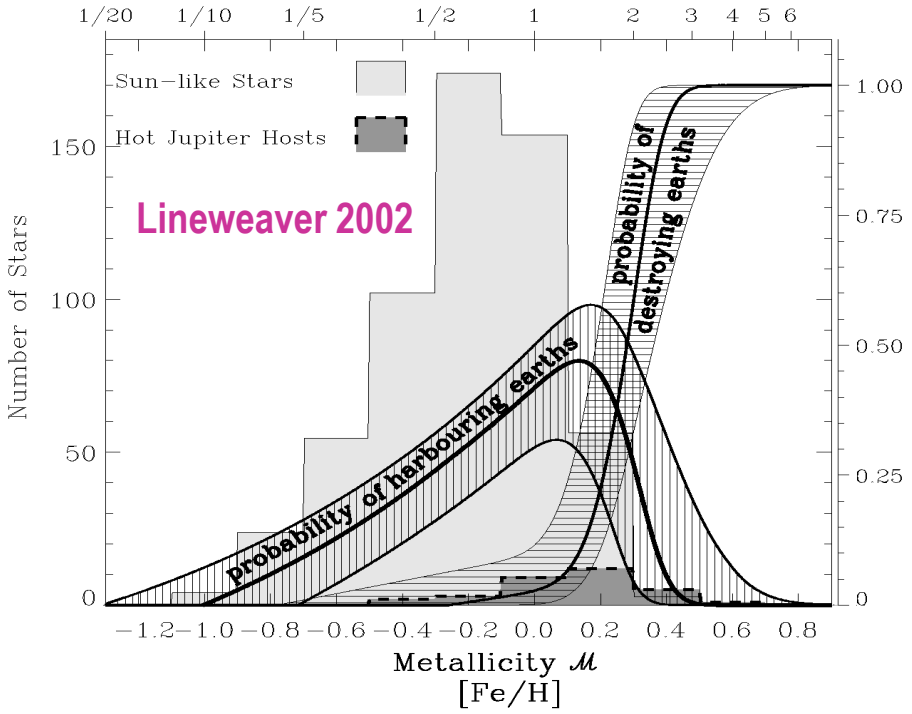


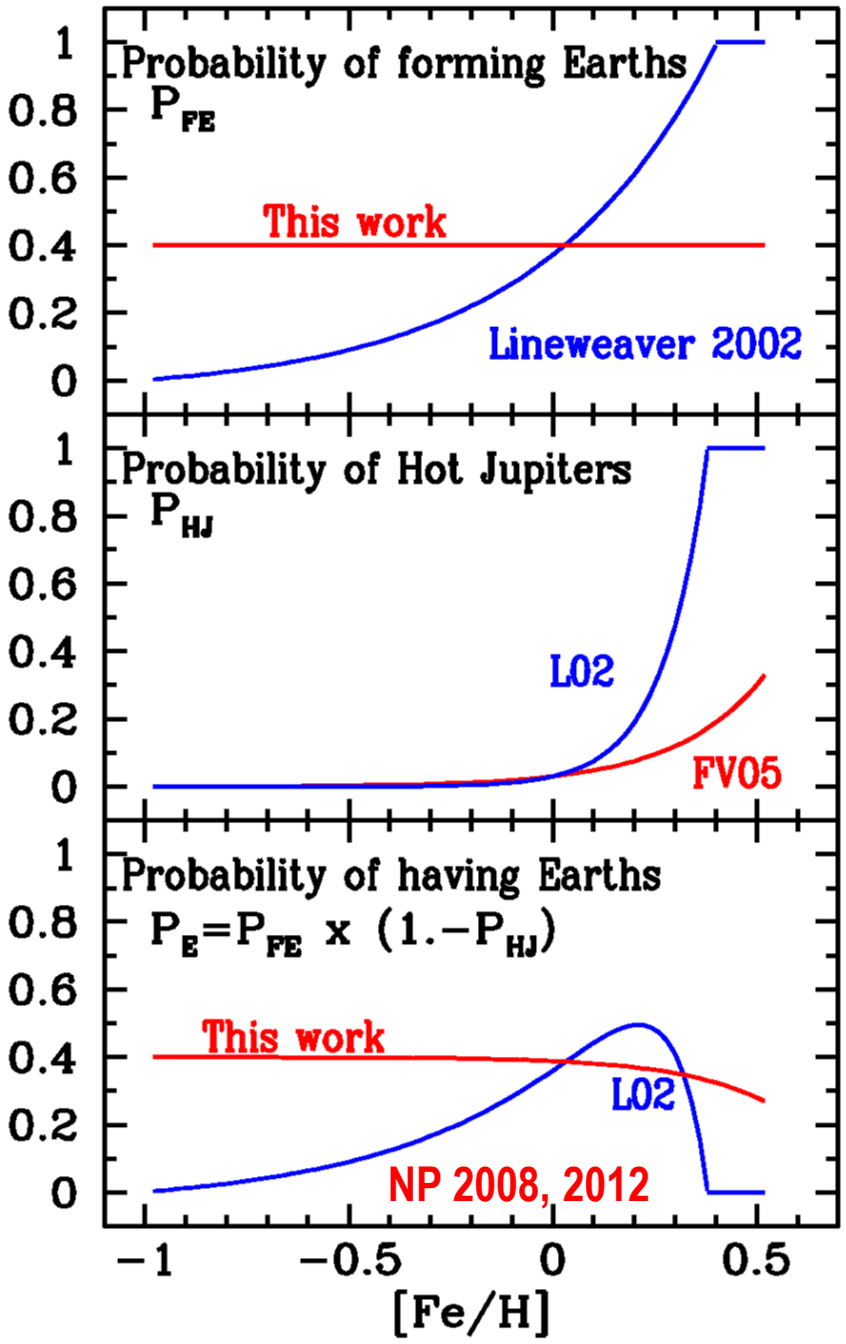
Probably less dependent on metallicity



Probability of having Earths not destroyed by Hot Jupiters

$$P_E = P_{FE} \times (1 - P_{HJ})$$






SUPERNOVAE
Energy released :
~10^47 ergs in UV (few minutes)
~ 10^48 ergs in X-γ (few months)
~10^50 ergs in Cosmic rays (few 10^4 yr)

Ionizing radiation
on
planetary atmospheres

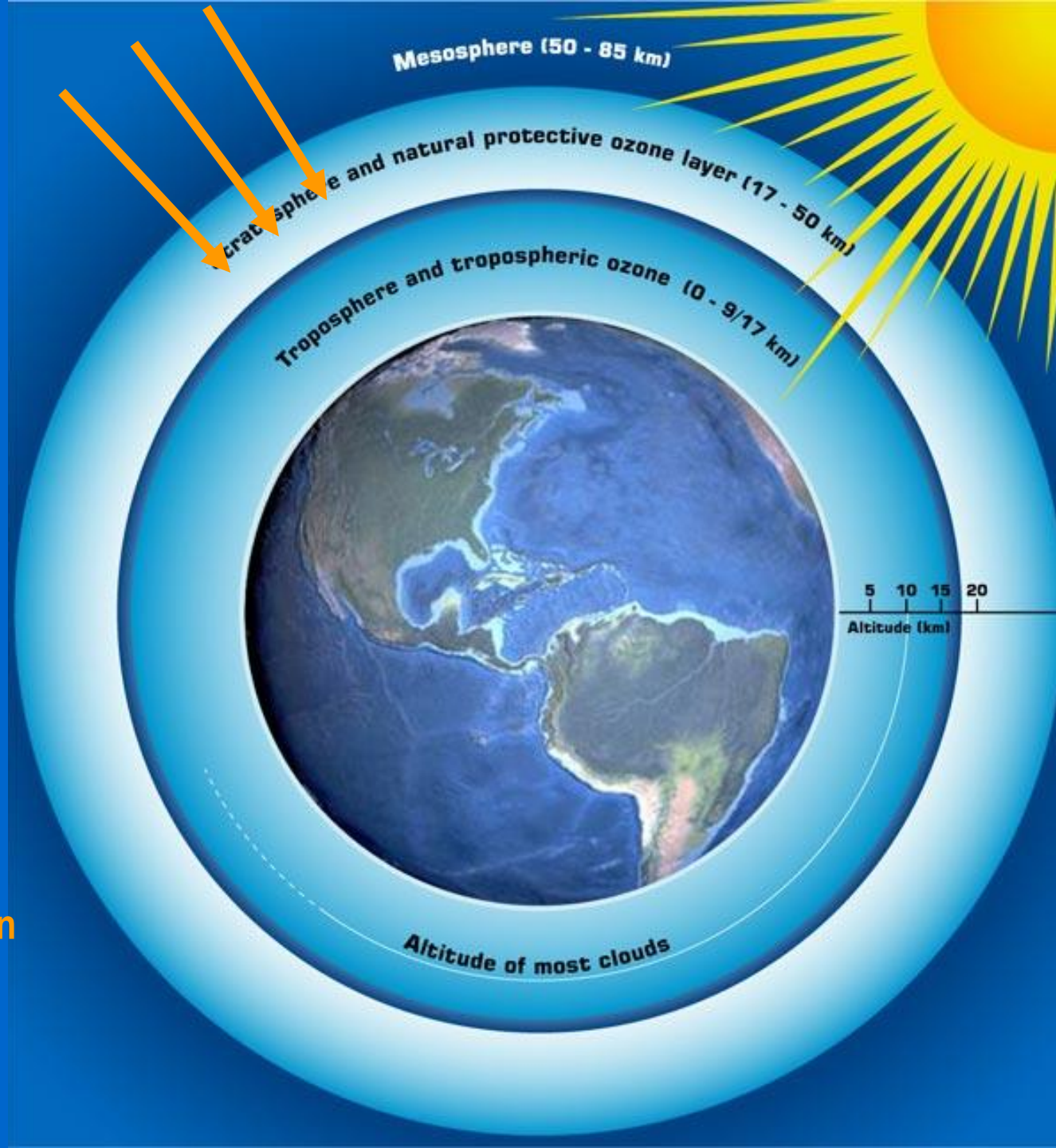
Induces chemical reactions producing NO_X which destroy the protective O_3 layer and increase the solar UV flux on surface

Produces secondary energetic particles and UV reaching the surface

But :

1) Mutations may accelerate and even induce evolution

2) Marine life appears rather immune to such events



SUPERNOVAE AS A THREAT FOR LIFE (?)

SNII (core collapse of massive stars) are more frequent and closer to the Galactic plane than SNIa (thermonuclear explosions of white dwarfs)
In Milky Way: f_{SN} = 2-3 per century

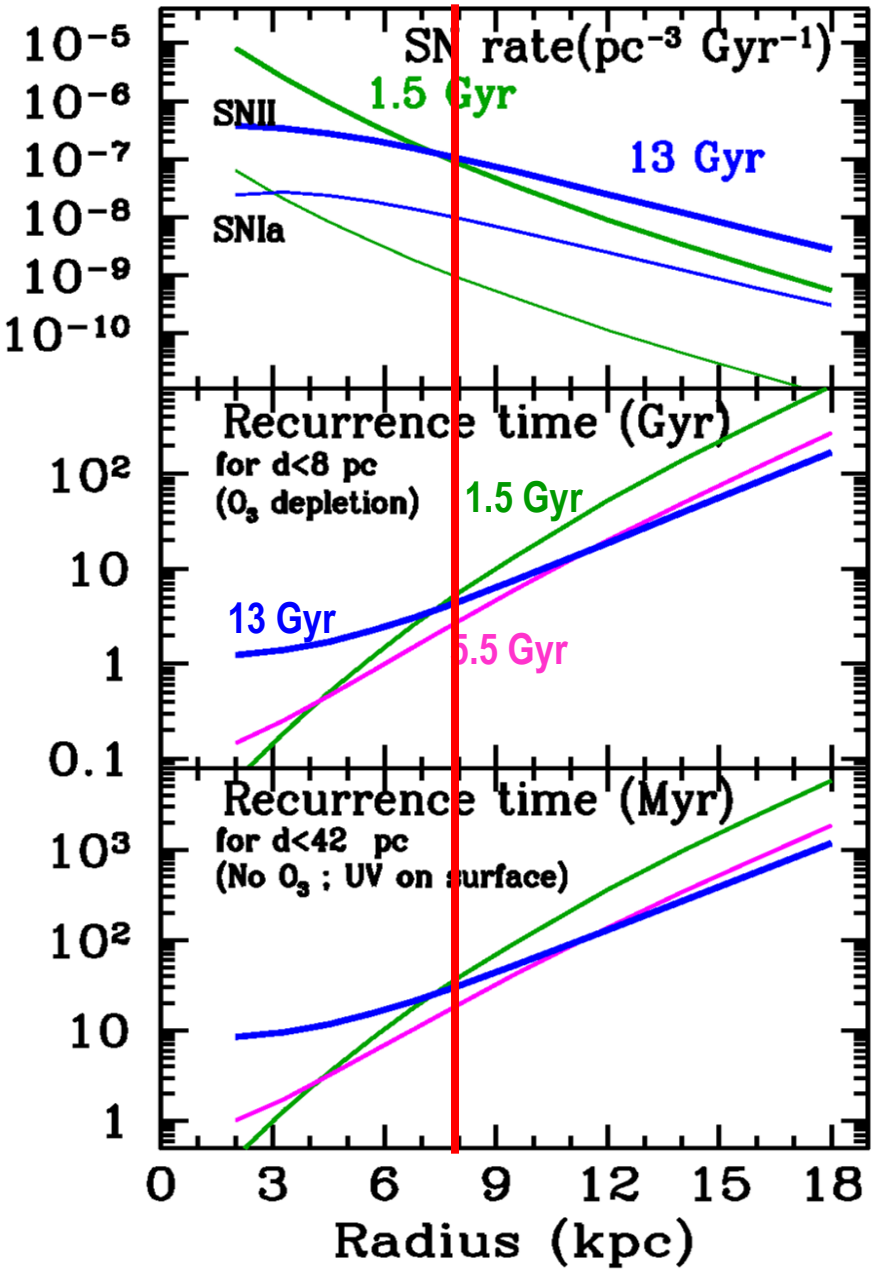
For depletion of O_3 layer by ~2
d_{SN} < 8 pc (Gehrels et al. 2003)

Local recurrence time: ~2. Gyr

For increase of UV on ground by ~2 in thick atmosphere with no O_3
d_{SN} < 42 pc (Scalo and Wheeler 2002)

Local recurrence time: ~several tens of Myr

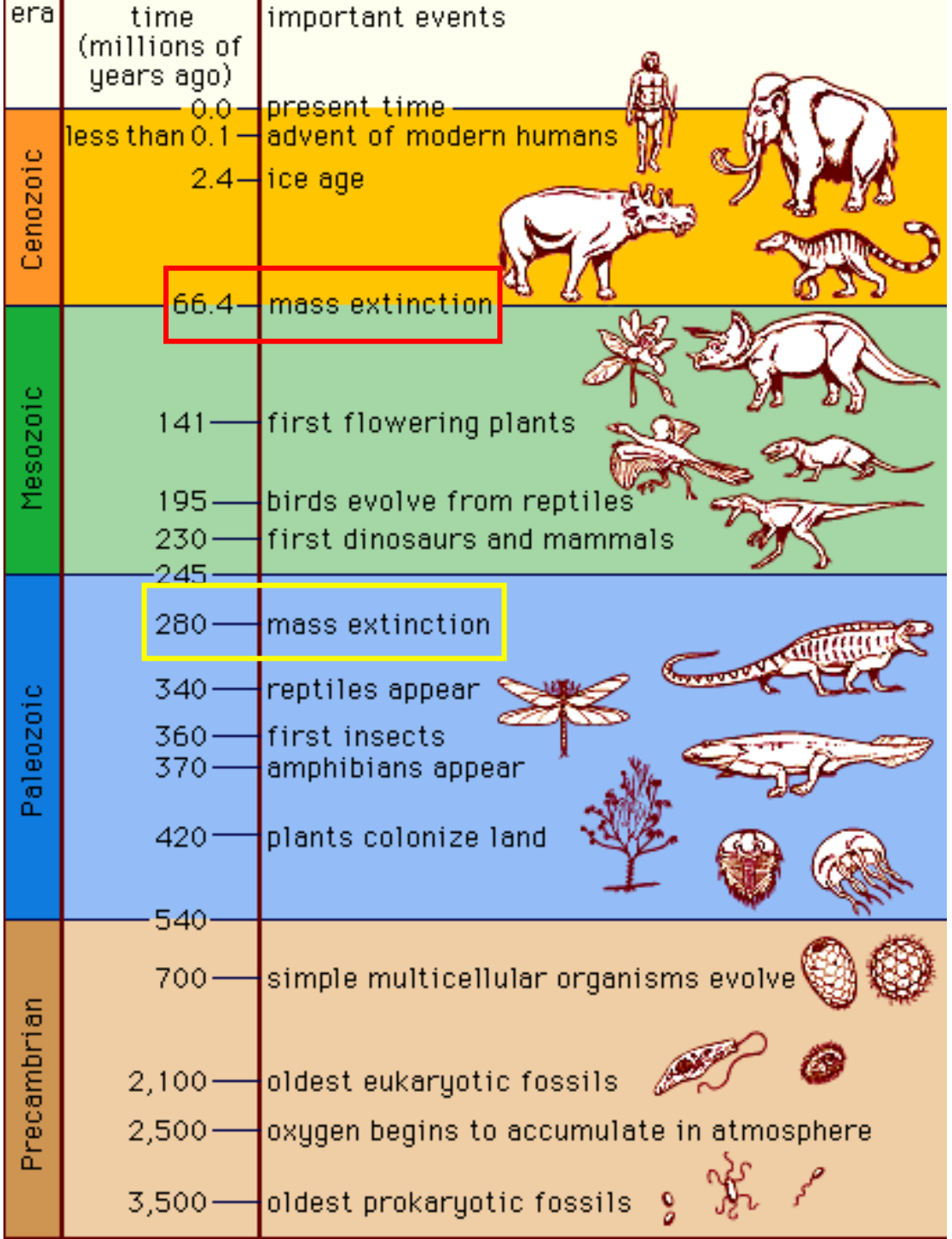
BUT: they concern complex life on land, none of these means definitive life extinction…



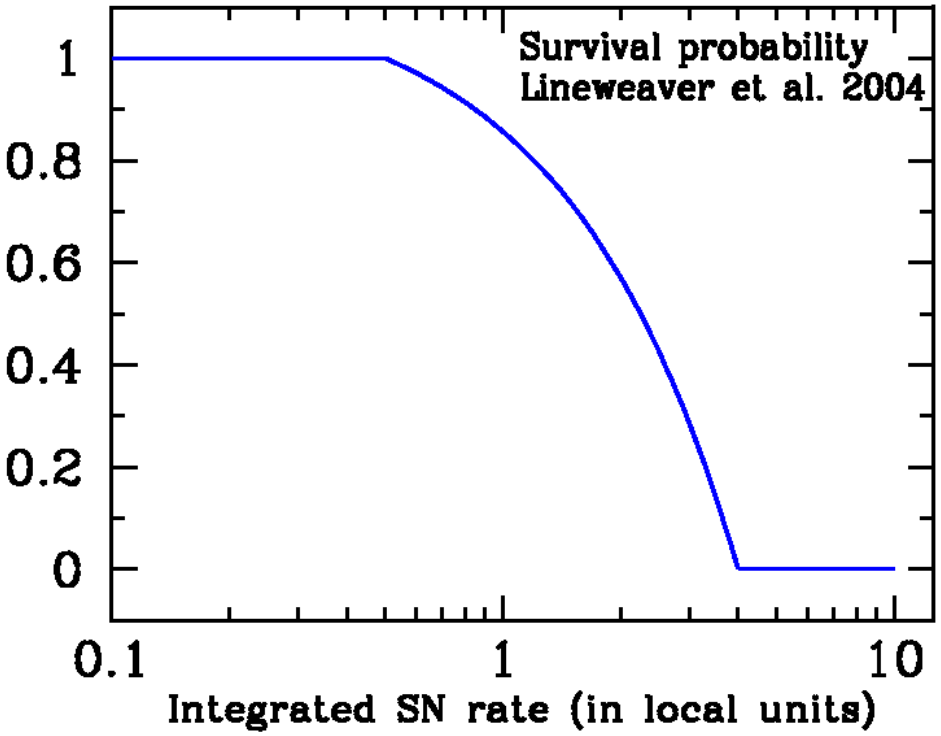
Several major catastrophes
occurred in the last
500 million years
of multi-cellular life
on Earth

But the planet
was not sterilized.

Life not only survived,
but evolved
to higher levels
of complexity



How to quantify the SN threat for life ?

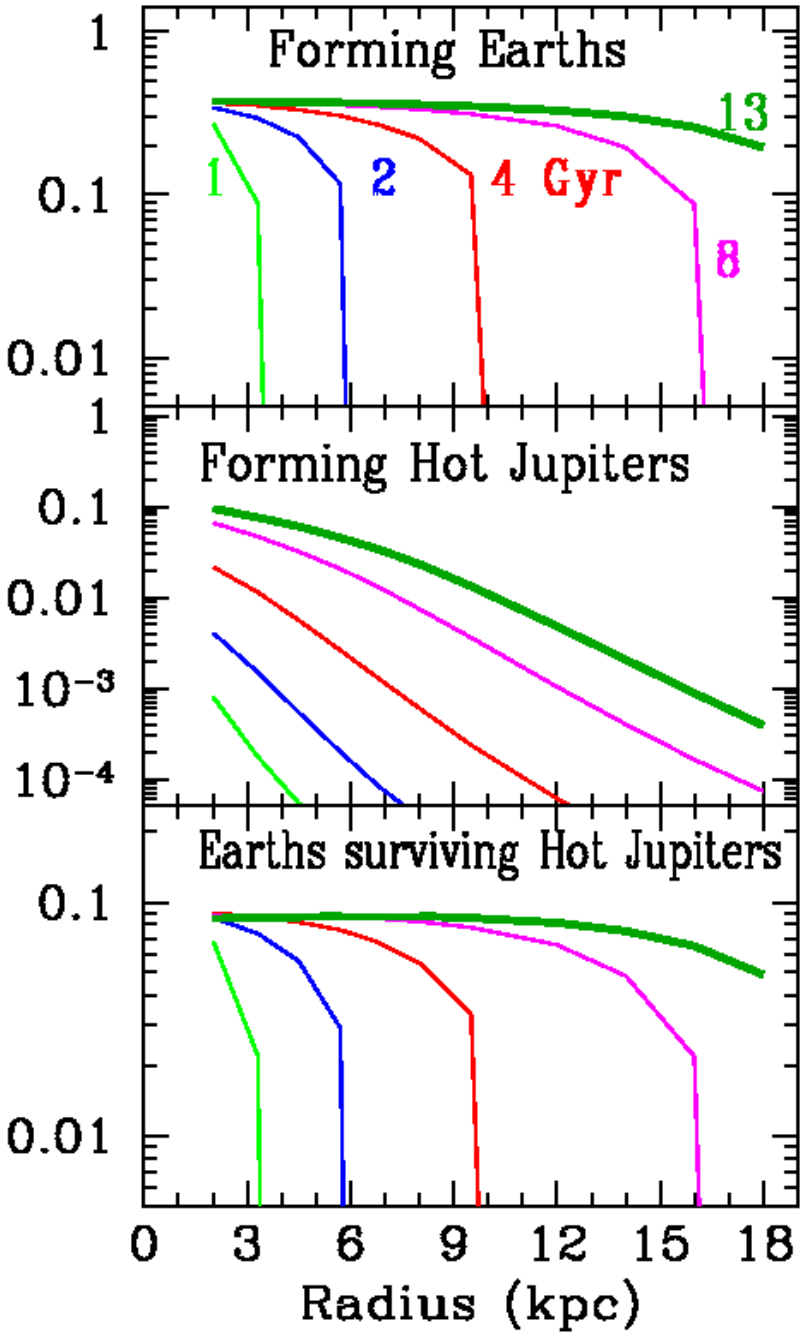


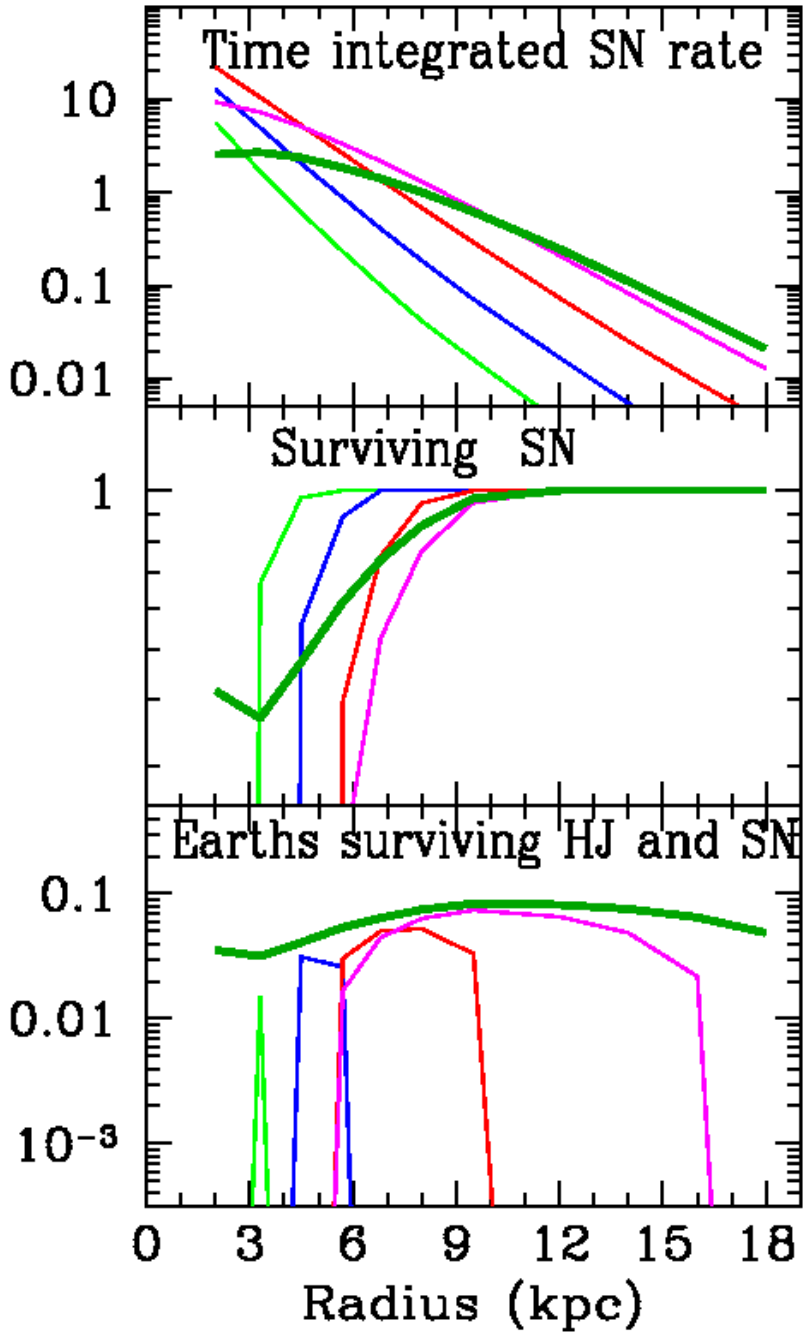
Local unit: $\int_{8\ \mathrm{Gyr}}^{12\ \mathrm{Gyr}} \mathrm{SNR}(t)\,dt = 1$ in Sun's position

Utterly arbitrary quantification

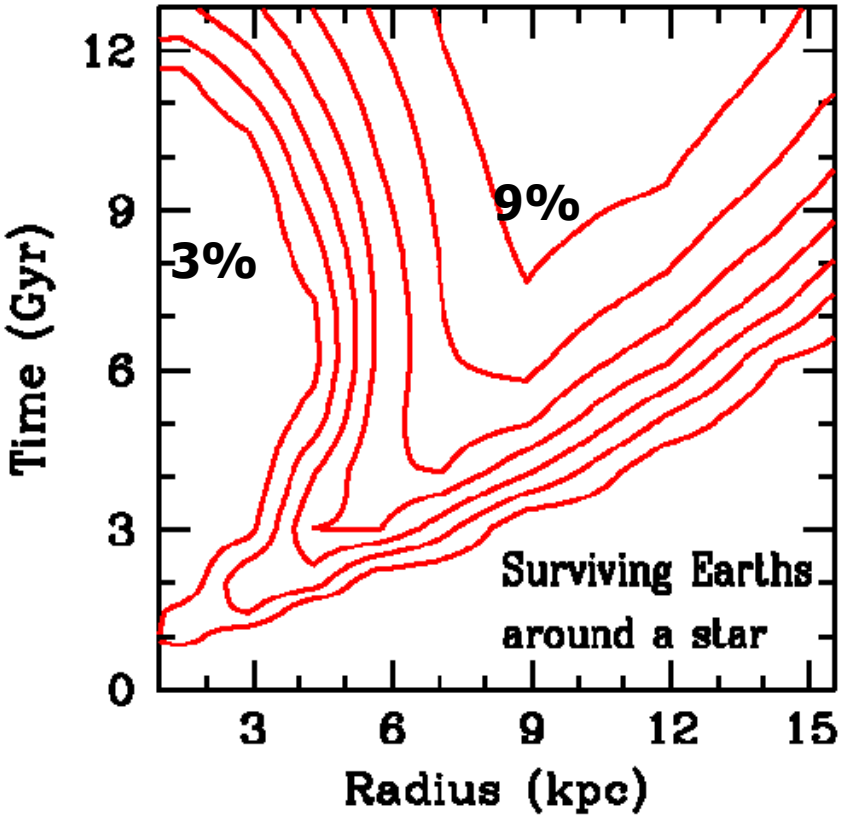
(and even qualification)…

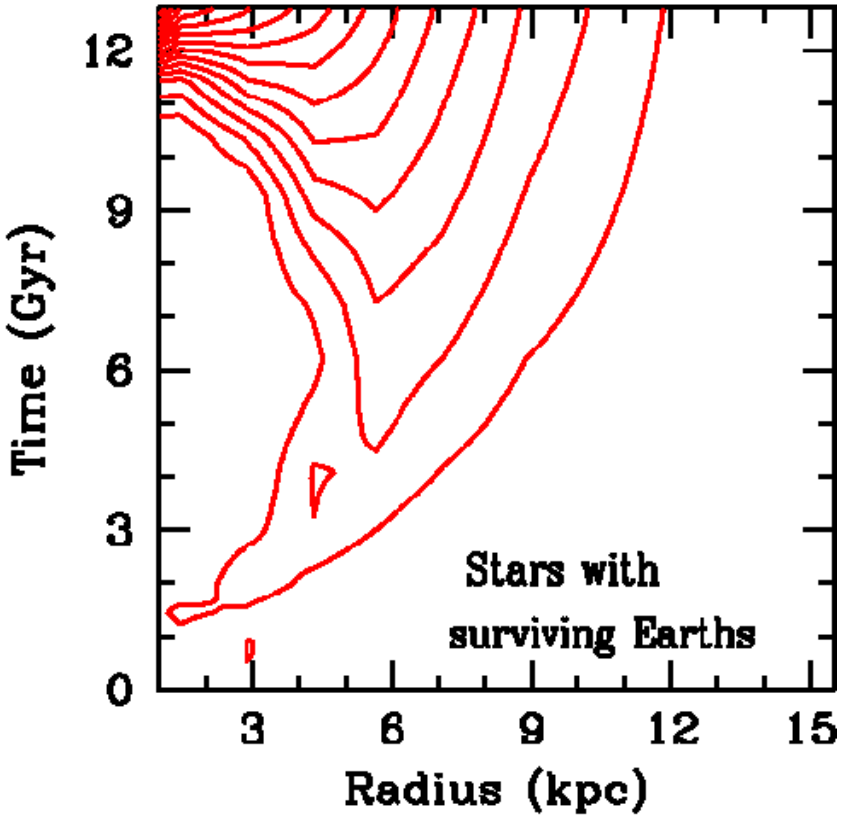
Propabilities…





Stars with Earths having survived threat from Supernovae

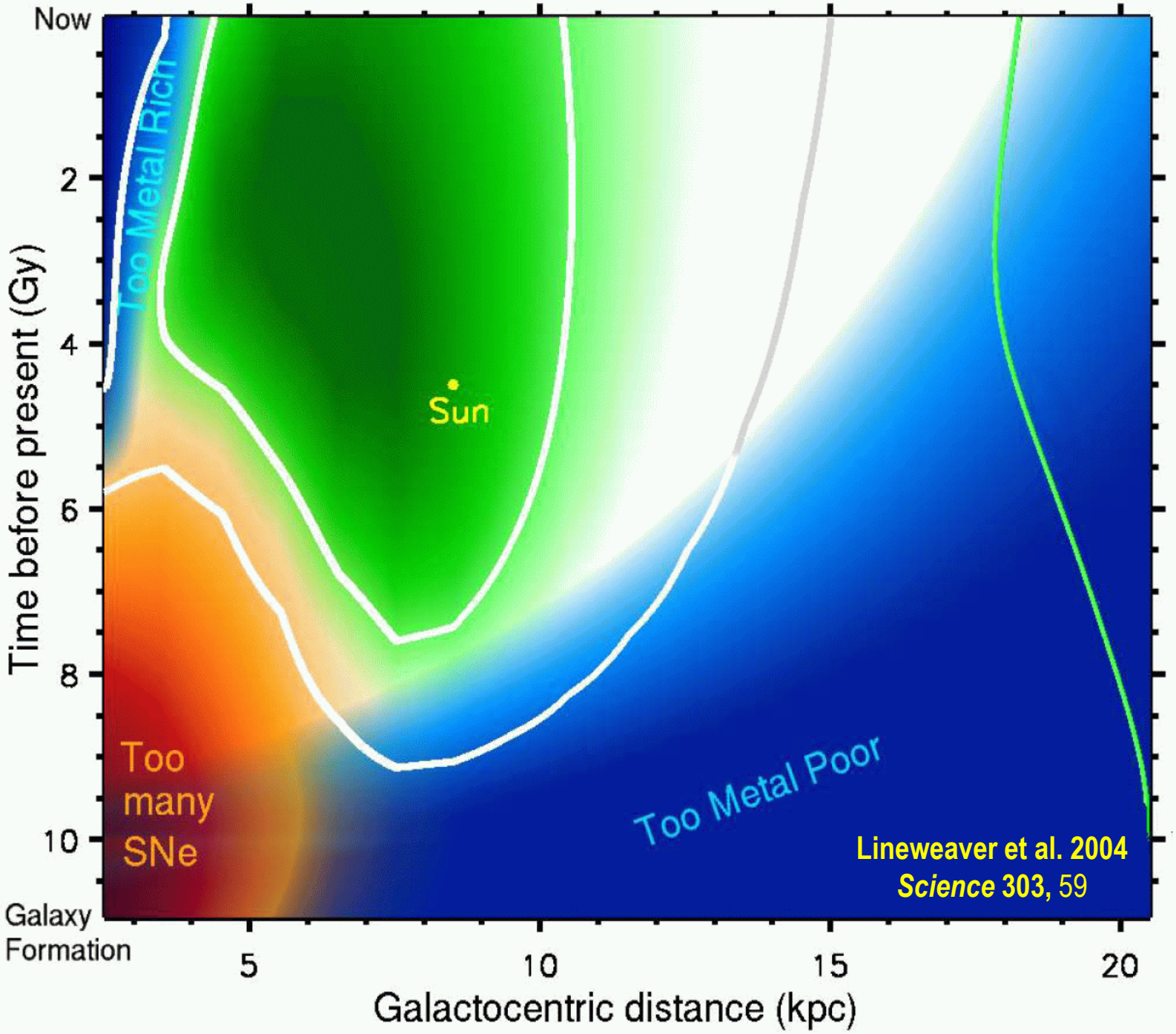




Relative probability to have life *around one star* at a given position,

Probability of having life hosting planets *per unit volume* (or surface density) in a given position

Because the density of stars is higher in the inner disk the probability of finding a star with Earth-like planets inside a given volume is higher in the inner Galaxy


Now
2
4
6
8
10
Galaxy Formation
Time before present (Gy)
Too Metal Rich
Sun
Too many SNe
Too Metal Poor
Lineweaver et al. 2004
Science 303, 59
5
10
15
20
Galactocentric distance (kpc)

SUMMARY : GALACTIC HABITABLE ZONE

GHZ: impossible to define either qualitatively
(probability of creating vs. destroying habitability by various
- time and position dependent - factors in the MW disk)
or quantitatively

The more so, since radial migration of stars mixes stellar populations across the MW disk

Simple and sea life forms appear to be robust (quasi-immune to cosmic catastrophes)

The concept of GHZ definitively has no predictive power at all
Is it a useless concept?

Perhaps not… it may allow us to structure our thoughts / educated guesses / knowledge about a very complex phenomenon

How philosophical preconceptions can affect physical “theories”.
A case in study : G. Gonzalez

We might say, then, that while the Earth is not the physical center of the universe, it seems, paradoxically, that it is the "center" in a more significant sense.

Gonzalez: Yes. If you consider the Earth in the "parameter space" of habitability, then we are very near the "center." Unfortunately, no one else has made this obvious observation. On the contrary, today scientists with anti-religious agendas continue to employ the historically revisionist and empirically discredited metaphysical Copernican Principle as a club to beat down anyone who publicly expresses religious ideas.

These scientists see the extraordinary nature of the Earth as a threat?

Gonzalez: Yes. And they have made public statements denouncing such views as "Pre-Copernican."

How does your work fit into all of this?

Gonzalez: My work, in part, deals with astrobiology from an astronomer's viewpoint. I simply follow the empirical evidence wherever it will lead me, and I try not to let philosophical preconceptions color my interpretations. Over the past decade, I have amassed a body of data that continues to reveal the Earth's uncommon qualities.

And what about our galaxy? Is it extraordinary as well?

Gonzalez: Our galaxy too is atypical. But again, most people are unaware of this, except for a few specialists in extra-galactic astronomy. For example, our galaxy is among the 1 percent most luminous galaxies in the nearby universe.

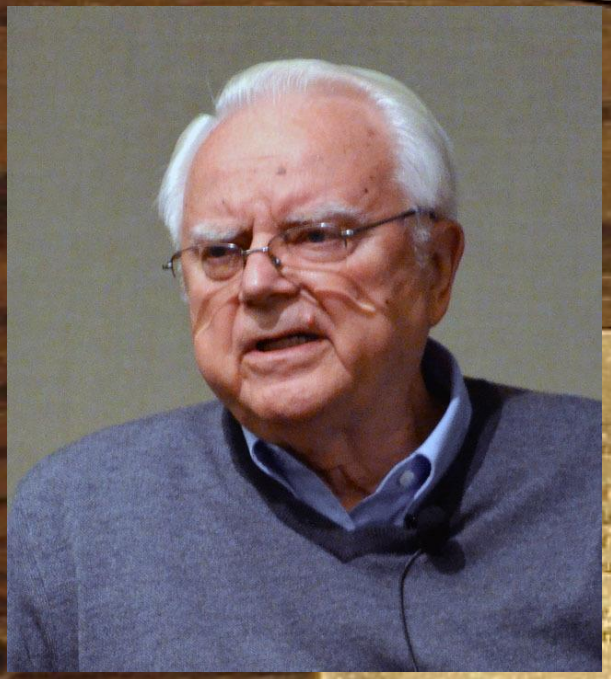
What effect does luminosity have on the Earth? Why is it important?

Gonzalez: The concentration of heavy elements correlates with the luminosity of a galaxy. More luminous galaxies have more heavy elements, and, thus, are more likely to have Earth-mass planets.

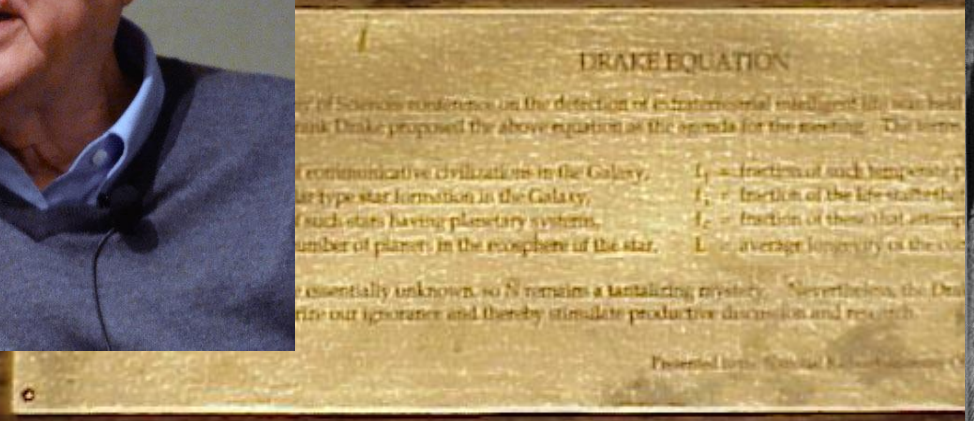
How are others in your field reacting to your arguments? I am assuming that you are challenging scientific orthodoxy, at least in astronomy?

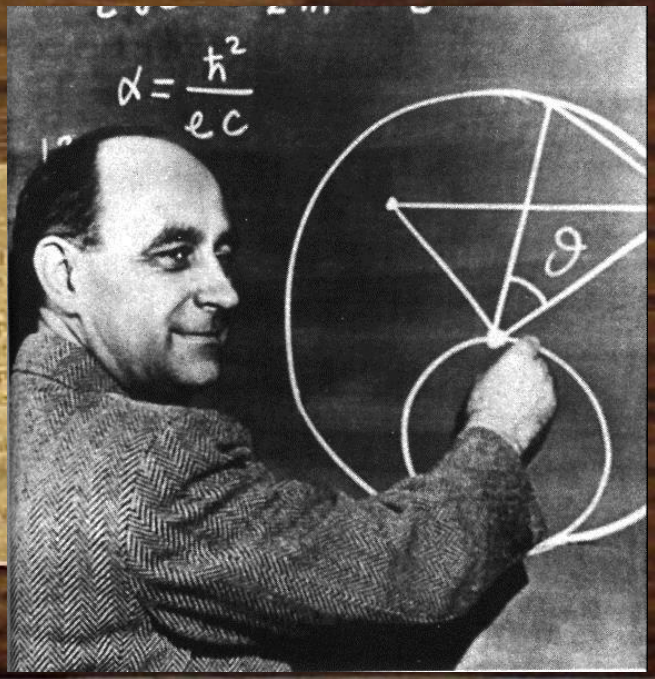
Gonzalez: They don't know what to make of these evidences. They don't deny the data, but they don't quite know how to fit it into their worldviews. A number of my colleagues have congratulated me for my work. Some astronomers who were originally skeptical have moved in my direction as the evidences have continued to accumulate.

$$N = R_* f_p n_e f_\ell f_i f_c L$$



Part II: The Drake Equation


DRAKE EQUATION



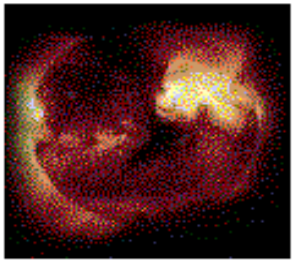
and the Fermi Paradox

NP (2013) International Journal of Astrobiology 12, 246

The Drake equation
(1960)
N = number of technological civilizations in the Milky Way

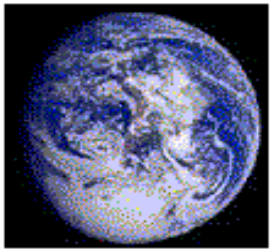
R* is the rate of formation of stars in the galaxy

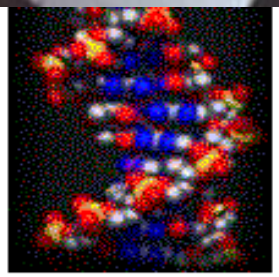
fs is the fraction of stars that are suitable suns for planetary systems



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

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





fl is the fraction of those planets where life develops

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

Radioactive decay : $\frac{dN}{dt} = -\frac{N}{T}$

Steady state : Production rate P = Destruction rate D

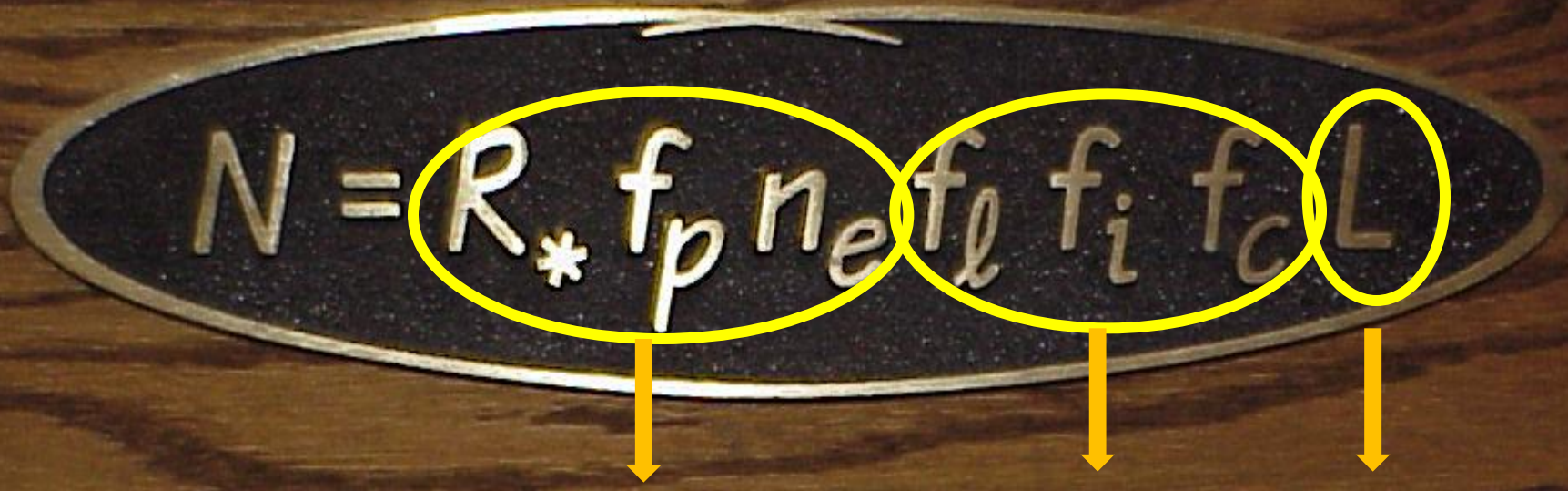
$$P = \frac{N}{T} \longrightarrow N = PT$$

Number of communicating civilisations

Creation rate of such civilisations

x Lifetime of such civilisations

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



$R_{ASTRO} = R_* f_p n_e$

Astronomical factor: **creation rate of habitable planets**

=0.1 per yr

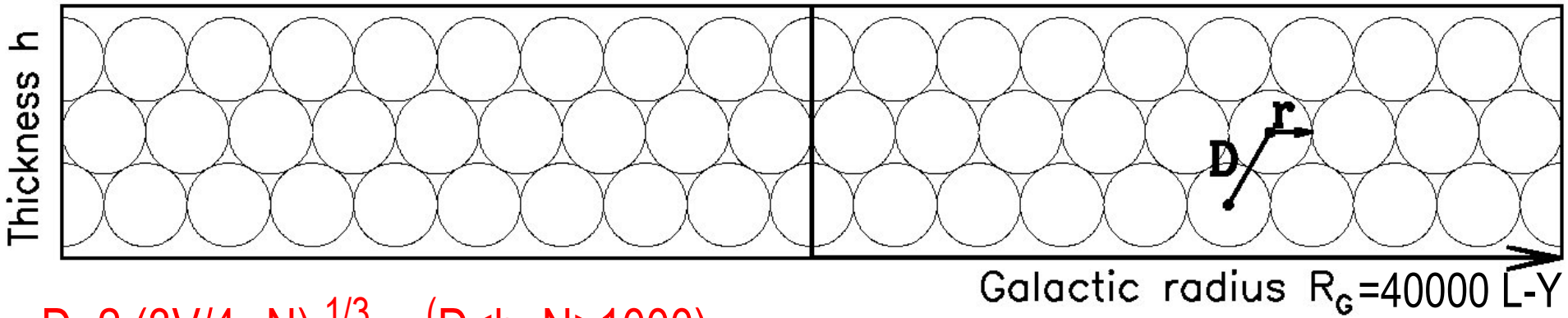
$f_{BIOTEC} = f_l f_i f_t$

Biotechnological factor: **fraction of planets with technology**

L

Lifetime **in the corresponding technological phase**

Galactic volume $V=h\pi R^2$ filled with N spheres of radius r and distance D=2r



$D=2\,(3V/4\pi N)^{1/3}$ (D<h, N>1000)

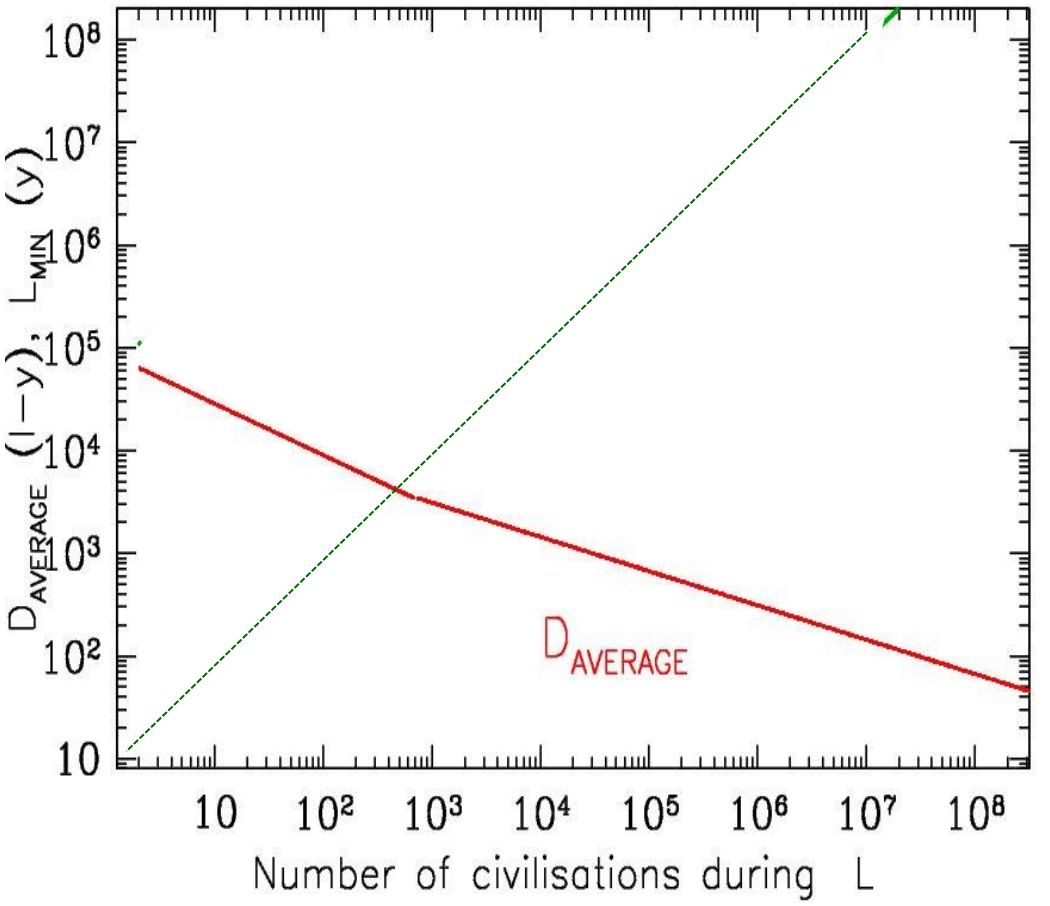
$D=2\,R/\sqrt{N}$ (D>h, N<1000)

$N = R_{ASTRO}\ f_{BIOTEC}\ L$

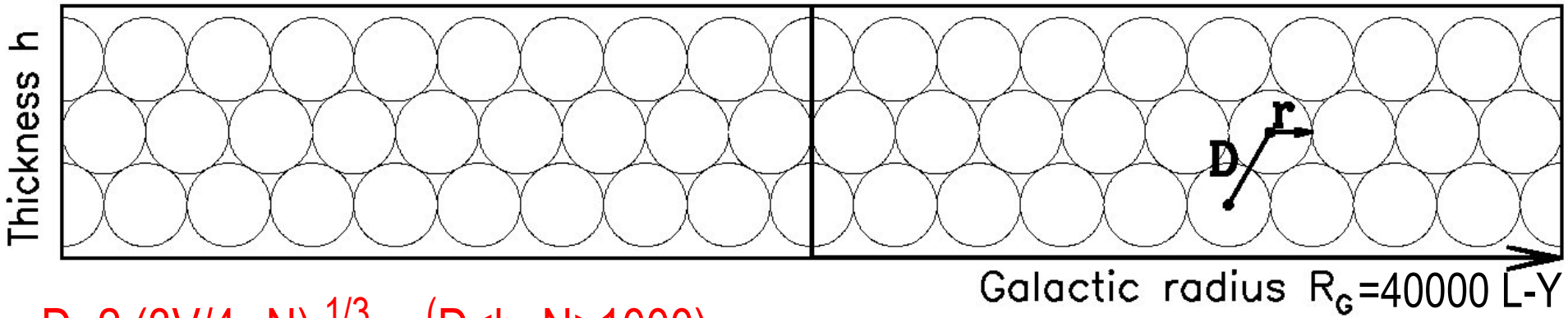
R_{ASTRO}=0.1 per yr $f_{BIOTEC,MAX}$=1

$N=0.1\ L_{MIN} \Rightarrow L_{MIN}=N/0.1$

Minimum L to have N civilisations



Galactic volume $V=h\pi R^2$ filled with N spheres of radius r and distance D=2r



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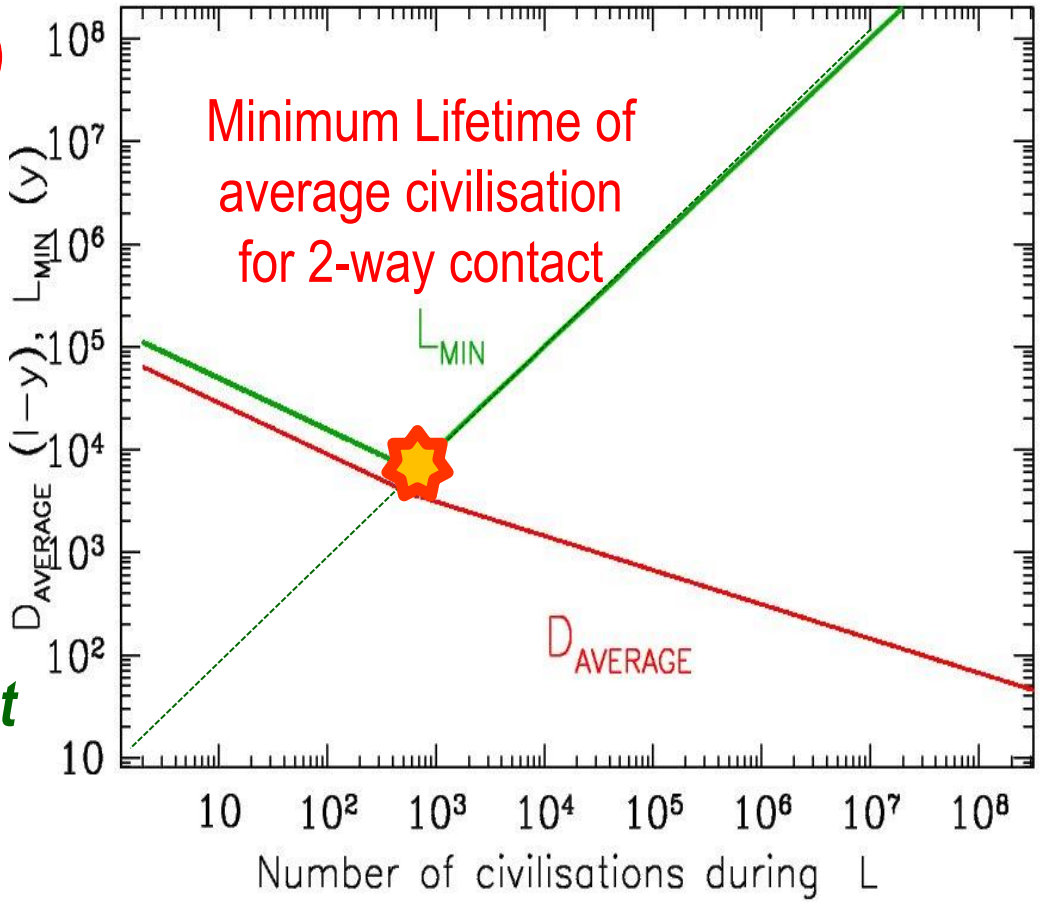
R_{ASTRO}=0.1 per yr $f_{BIOTEC,MAX}$=1

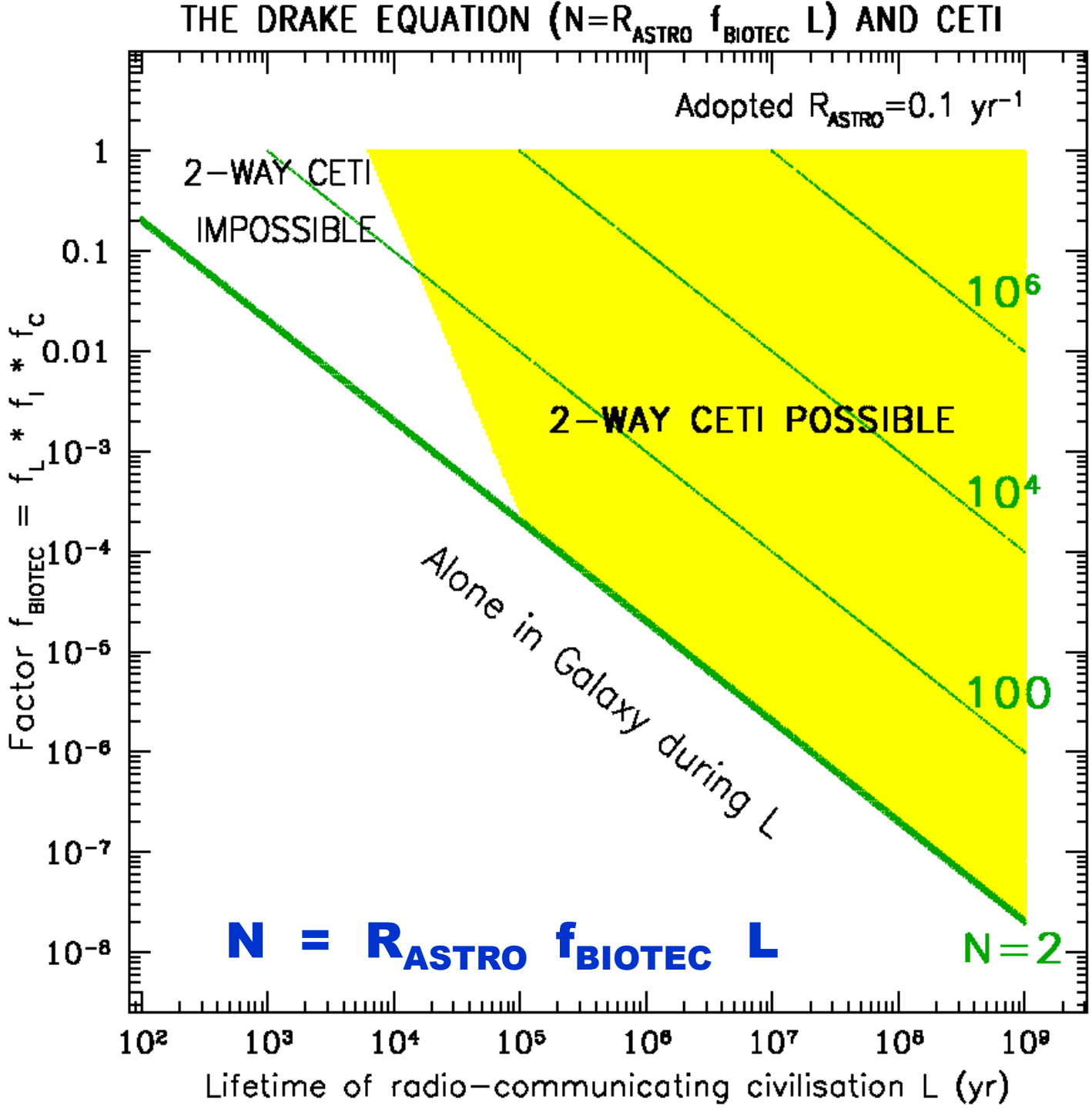
$N=0.1\ L_{MIN} \Rightarrow L_{MIN}=N/0.1$

Minimum L to have N civilisations

L_{MIN}= 2 D/c

Minimum L to have 2-way contact between close neighbours





IF civilisations are evenly spread in the Galactic disk then lifetimes $L > 10^4$ yr are required for 2-way contact

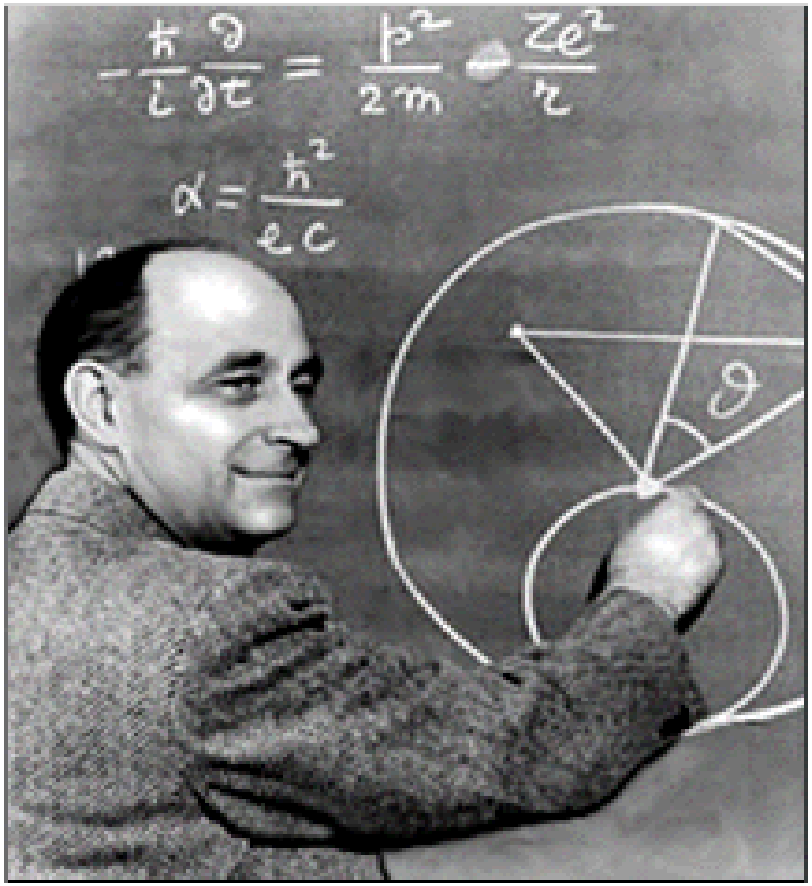
The Fermi paradox

Enrico Fermi

1950
Los Alamos Laboratory

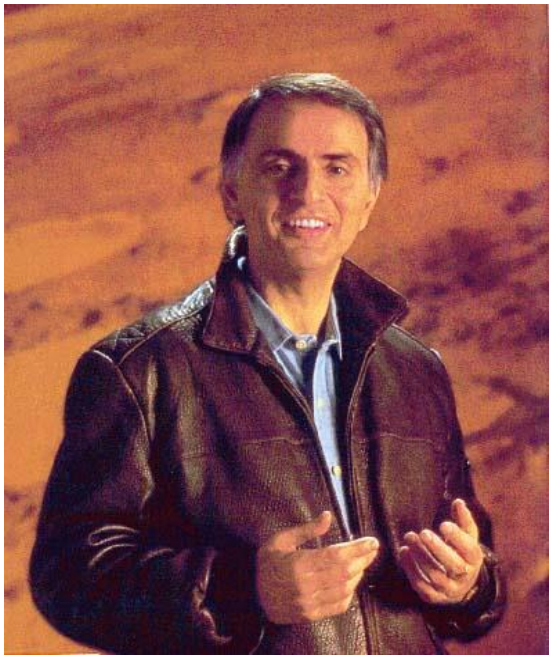
Lunch-time discussion
with Edward Teller and colleagues
on UFOs

No sign of extraterrestrials
(ships, artefacts, robots)
on Earth



Where are they ?

The phrase "**Where Are They ?**" appears for the first time
as a footnote in a paper by american astronomer
Carl Sagan in 1963
(Planetary and Space Science, 11, 485)



Then in the book ***Intelligent life in the Universe***
of C. Sagan and I. Shklovskii, published n 1965

in both cases without any comment…

Astronomer Michael Hart rediscovers independently Fermi's argument
and discusses its implications in 1975 in
"An explanation for the absence of Extraterrestrials on Earth"
(*Quartely Journal of the Royal Astronomical Society, 16, 128*)

His conclusions : 1) there are few other civilizations (probably none)
2) Recherche of extraterrestrial signals is a waste of time (and money)
3) Our descendants will coloniser the Galaxy (since the "others" are not interested)

After that paper , C. Sagan qualifies the whole issue as

The Fermi Paradox

SO, WHERE ARE THEY?

They are here

They – or their probes – came in the remote past
and observed – or even created/assisted – our ancestors ;
they probably left their probes on Earth or somewhere in the Solar system;
we should search better to find those probes (A. C. CLARKE, PAPAGIANNIS)

They are there

BUT: they do not wish to come (they have other interests)
or they are not able to come
(because their civilization is rapidly destroyed – FERMI
or Interstellar travel is impossible – HOYLE, DRAKE)

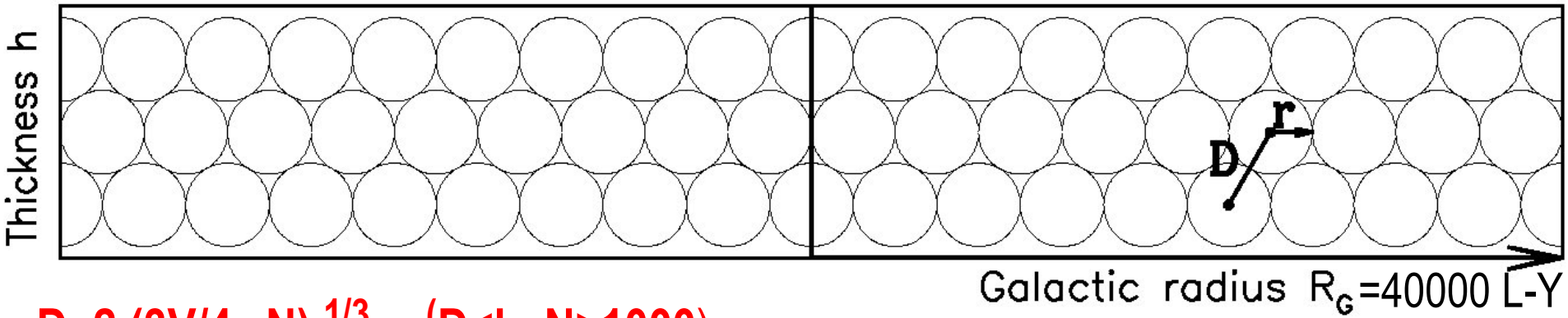
ALTERNATIVELY: they did come and are just observing us
without interfering, or they have put us in "cosmic quarantine"
or in a "cosmic zoo" (TSIOLKOVSKY, BALL)

They are nowhere

We are alone

(HART , TIPLER , BRACEWELL + SIMPSON, MAYR)

Galactic volume $V=h\pi R^2$ filled with N spheres of radius r and distance D=2r



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R_{ASTRO}=0.1 per yr f_{BIOTEC}=1

$N=0.1\ L_{MIN} \Rightarrow L_{MIN}=N/0.1$

Minimum L to have N civilisations

Drake

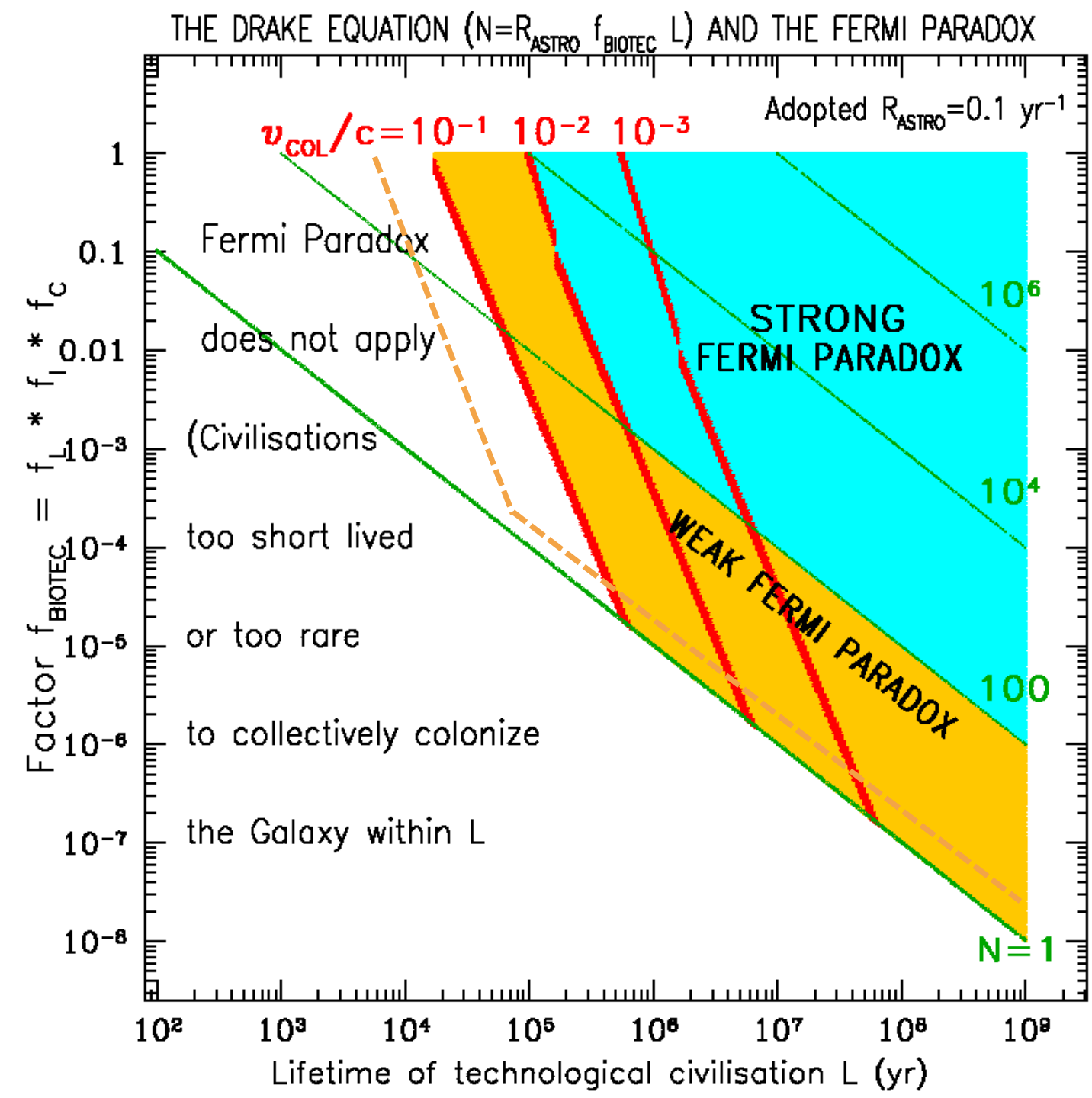
$L_{MIN}= 2\ D/c$

Minimum L to have 2-way contact between close neighbours within L

Fermi

$L_{MIN}= r\ /(\beta c)$

Minimum L to have the whole Galaxy covered by space-faring civilisations within L



Strong

Fermi paradox

(N>100,β=υ/c<0.01)

implies

L>10^5 – 10^6 yr

Conditions in

f_{BIOTEC} vs L plane

favouring

2-way radio-contact

and physical contact

are not very diffferent

(in log-log space!)

WHERE ARE THEY?

Assuming that

1) They exist

2) They desire to find other civilizations and to communicate with them

3) Their technological civilizations survive long enough

WHAT STRATEGY WOULD THEY ADOPT ?

Just a search of radio-signals ?
(inefficient, because there may be no answer, even after thousands or millions of years)

Or rather
undertake a program of interstellar travel and exploration ?
(guaranteeing a definitive answer WITHIN their lifetime IF $L>10^5$ yr))

SUMMARY

A joint analysis of the Drake equation AND the Fermi paradox

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IF civilisations are evenly spread

in the Galactic disk then

lifetimes $L > 10^4$ yr are required for 2-way contact

Conditions in f_{BIOTEC} vs L plane

favouring 2-way radio-contact and physical contact

are almost the same:

L a few times larger ($L>10^5$-10^6 yr) is required in latter case