Simulating the characteristics of extra-terrestrial civilizations that encounter Earth

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The Society for UAP Studies
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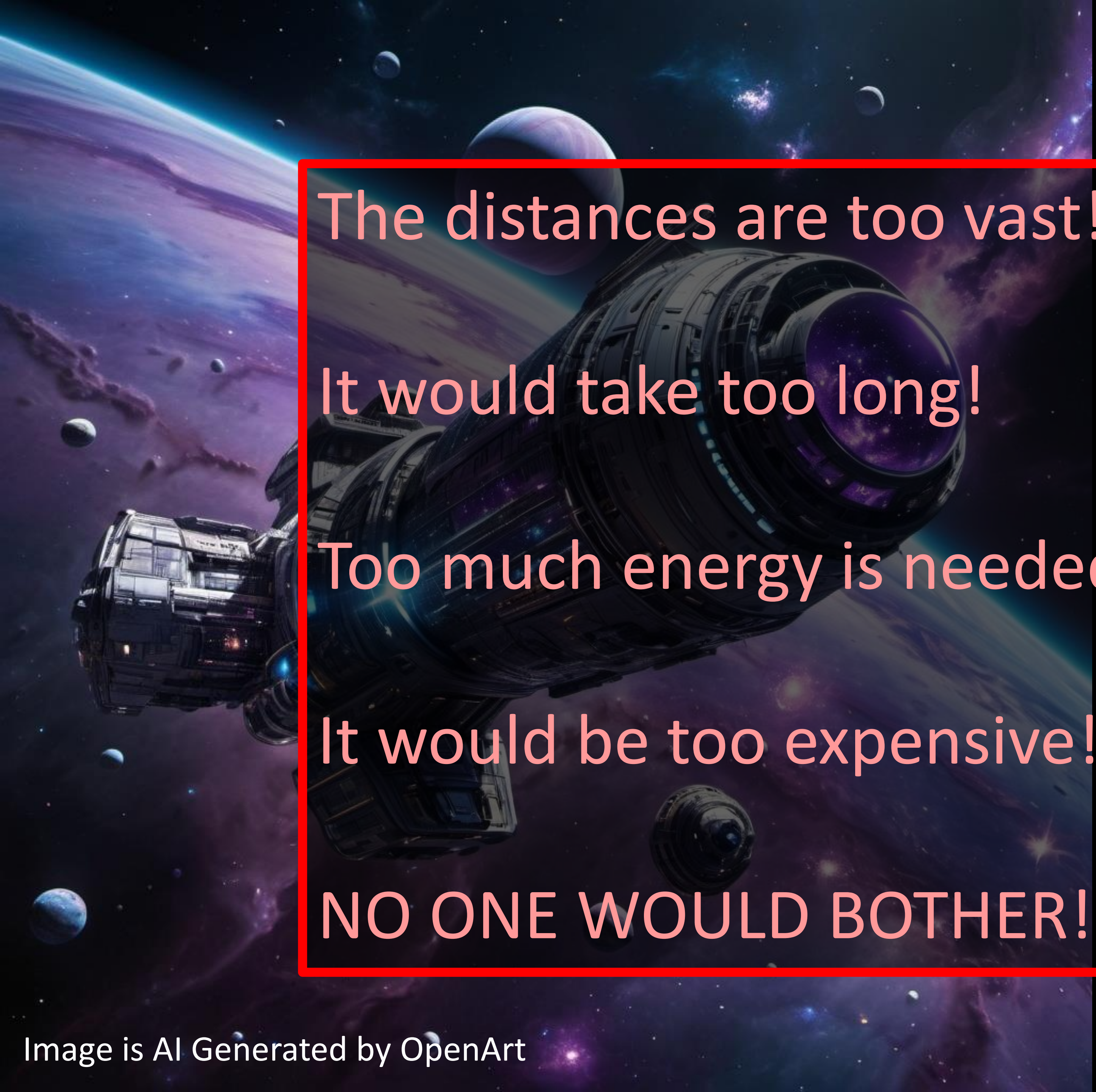
QUESTIONS


Image is AI Generated by OpenArt

Is Interstellar Travel possible?

Could anyone ever colonize other Star Systems?



The distances are too vast!

It would take too long!

Too much energy is needed!

It would be too expensive!

NO ONE WOULD BOTHER!

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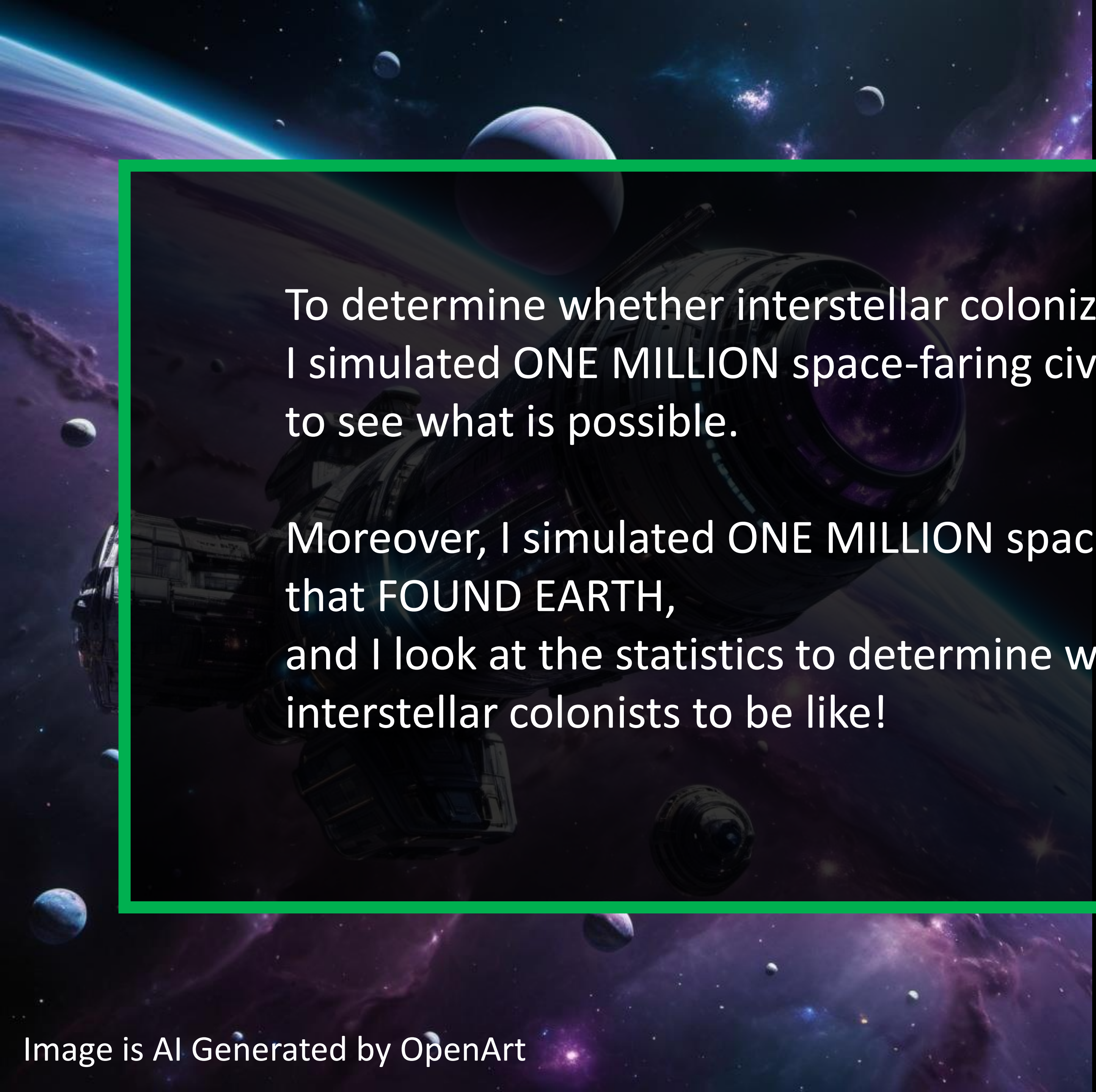


Is Interstellar Travel possible?

Could anyone ever colonize other Star Systems?

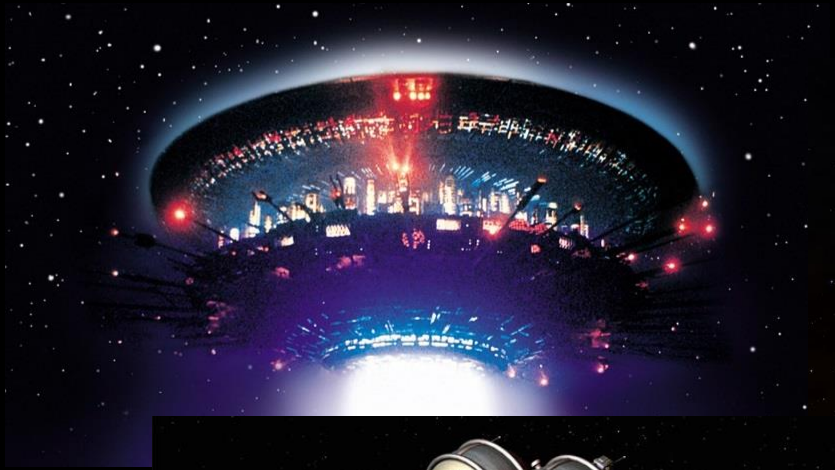
To determine whether interstellar colonization is feasible,
I simulated ONE MILLION space-faring civilizations
to see what is possible.

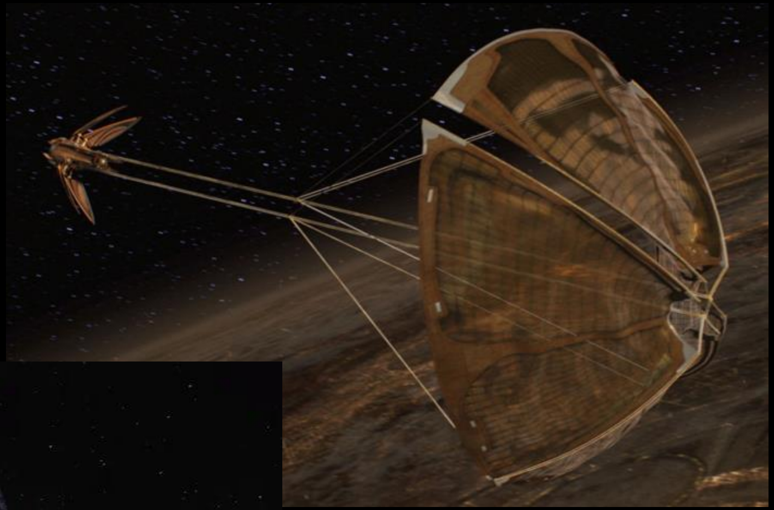
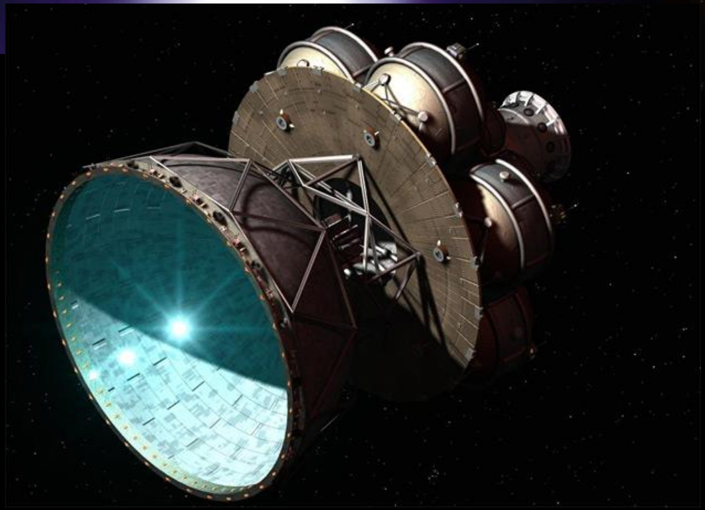
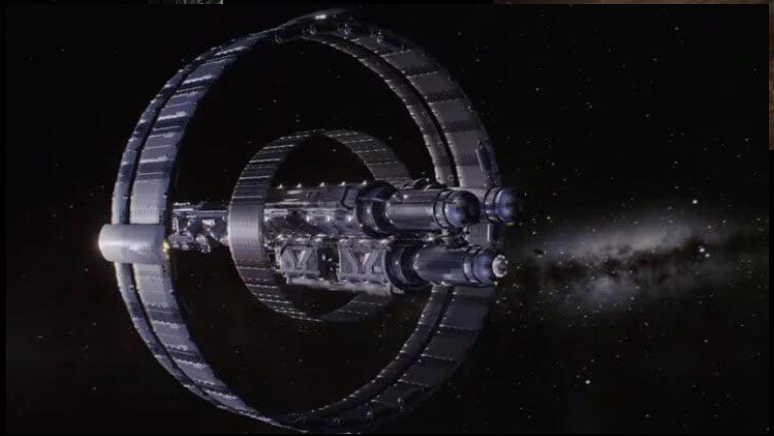
Moreover, I simulated ONE MILLION space-faring civilizations
that FOUND EARTH,
and I look at the statistics to determine what we might expect
interstellar colonists to be like!

Image is AI Generated by OpenArt

How to Model an Interstellar Civilization?

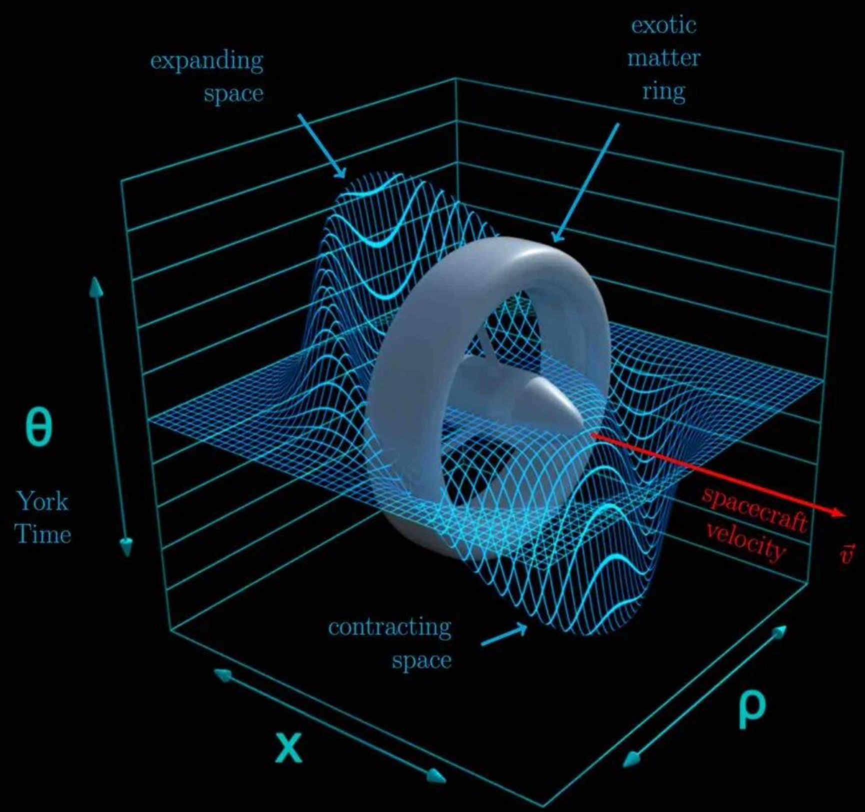
The potential diversity in both
biology and technology cannot be fathomed

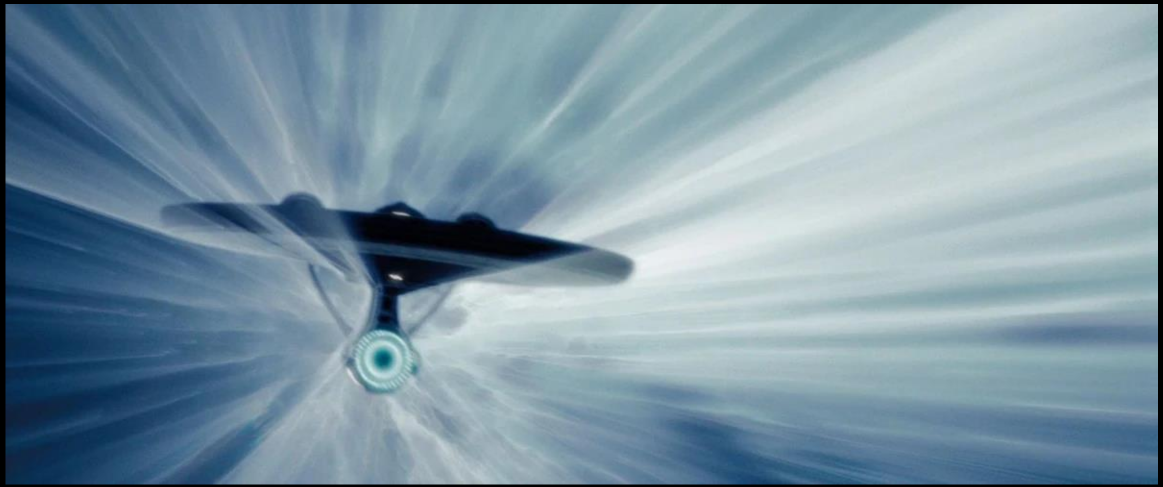



How to Model an Interstellar Civilization?

- CANNOT model physics we do not thoroughly understand





KISS: Keep it Simple, Stupid!

Civilization Parameters

Table 1. Civilization Parameters and their Prior Probabilities.

Model Parameters				
Symbol	**Parameter**	**Prior Range**	**Units**	**Prior Type**
x_o	galactic x-coordinate	within the GHZ	ly	Uniform
y_o	galactic y-coordinate	within the GHZ	ly	Uniform
z_o	galactic z-coordinate	$[-450, 450]$	ly	Uniform
$\mathscr{R}$	resilience	$[0, 1]$	unitless	Uniform
T	civilization lifetime	$[1, 10 \times 10^6]$	years	Jeffreys
t_{col}	colonization time	$[1, 5000]$	years	Uniform
$\tau_{\max}$	endurance	$[1, 1000]$	years	Jeffreys
$a_{\max}$	max. acceleration	$[1, 25000]$	g	Jeffreys
$v_{\max}$	max. velocity	$[0.001, 1)$	c	Jeffreys

Derived Parameters			
Symbol	**Parameter**	**Units**	**Constraints**
δ	interstellar reach	ly	$\delta > 7.37$ ly
R	characteristic domain radius	ly	
v_{dom}	domain expansion velocity	c	
d_e	distance to Earth	ly	
t_e	time of first contact	y	

Note: Jeffreys priors were handled by working with uniformly-distributed logarithms of the parameters.

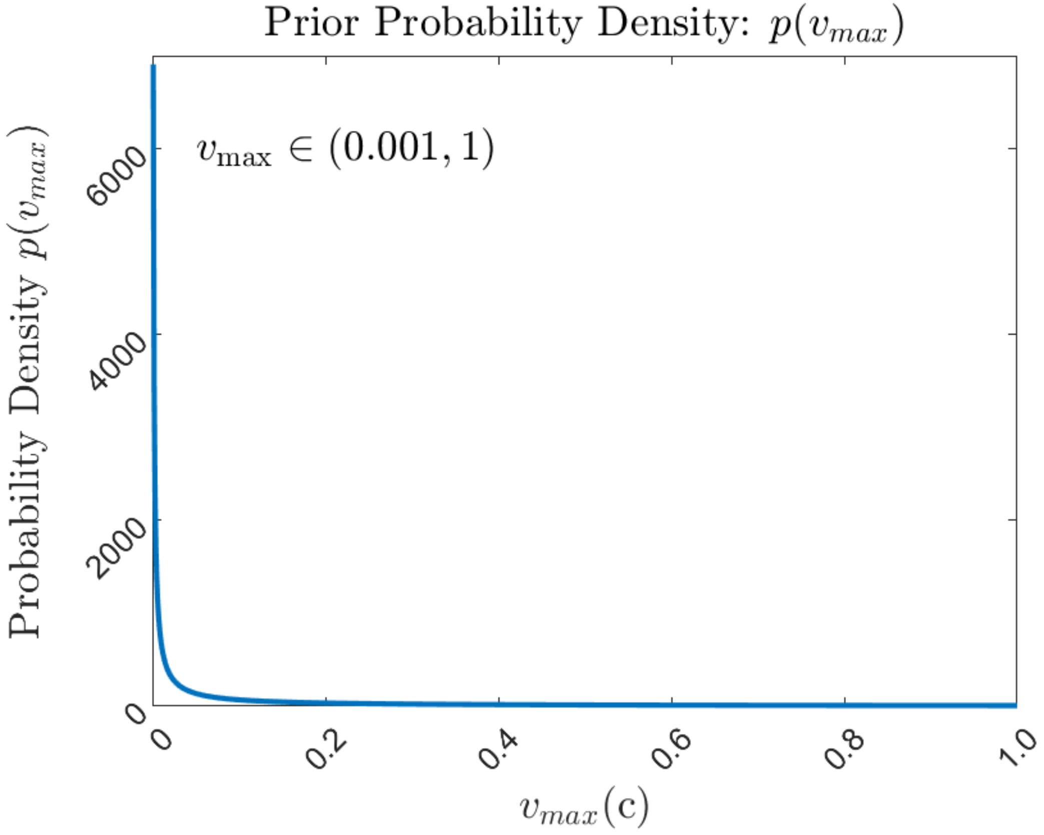
Jeffreys Priors

Jeffreys Priors are invariant with respect to change of units.

They favor smaller values.

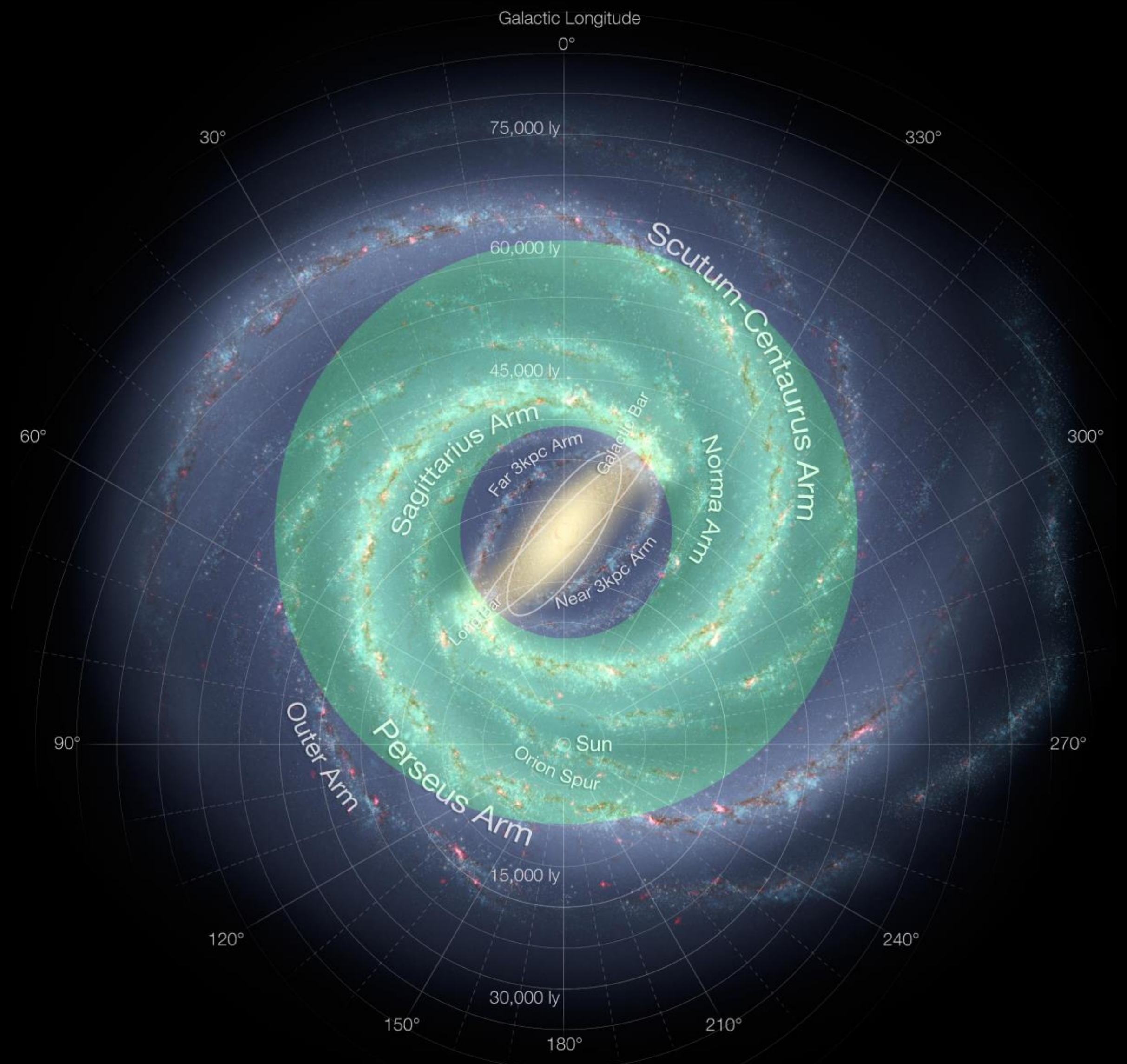
Parameters using Jeffreys Priors

- Civilization Lifetime: $T \in [1, 10 \times 10^6]$ years
- Endurance: $\tau_{max} = [1, 1000]$ years
- Max. Acceleration: $a_{max} = [1, 25000]$ g
- Max. Velocity: $v_{max} = [0.001, 1)$ c



These are best handled with uniform priors on the logarithm of the parameter.

Galactic Habitable Zone



Near the Galactic Center, the stellar metallicities are higher, which results in an excess of Jovian gas planets, and a deficit of small rocky worlds.

In addition, the stellar density is higher, which makes Supernovae sterilization events more likely. Moreover, relativistic travel is more hazardous.

At the outer edge of the galaxy, stellar metallicities are low resulting in a deficit of rocky worlds.

We expect that relativistic interstellar travelers would limit themselves to the Galactic Habitable Zone (GHZ).

REFS: CH Lineweaver, Y Fenner, BK Gibson - Science, 2004

Resilience

What worlds might a species or civilization prefer to occupy or colonize?

Instead of modeling details that we are clearly ignorant about we instead model this as a probability that a given star system will have a world that the civilization can inhabit.

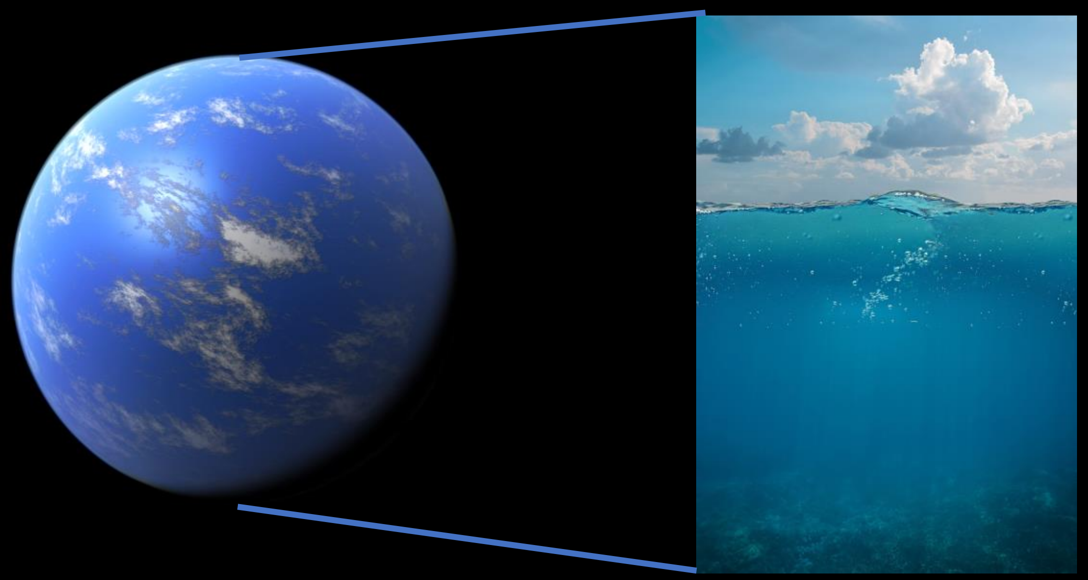
This probability is called the

Resilience - $\mathscr{R}$

For example, we know that 1 out of 5 stars possess a planet that falls within the region where water on the surface would be liquid.
If this was the only requirement for habitability, then the resilience would be about 0.2

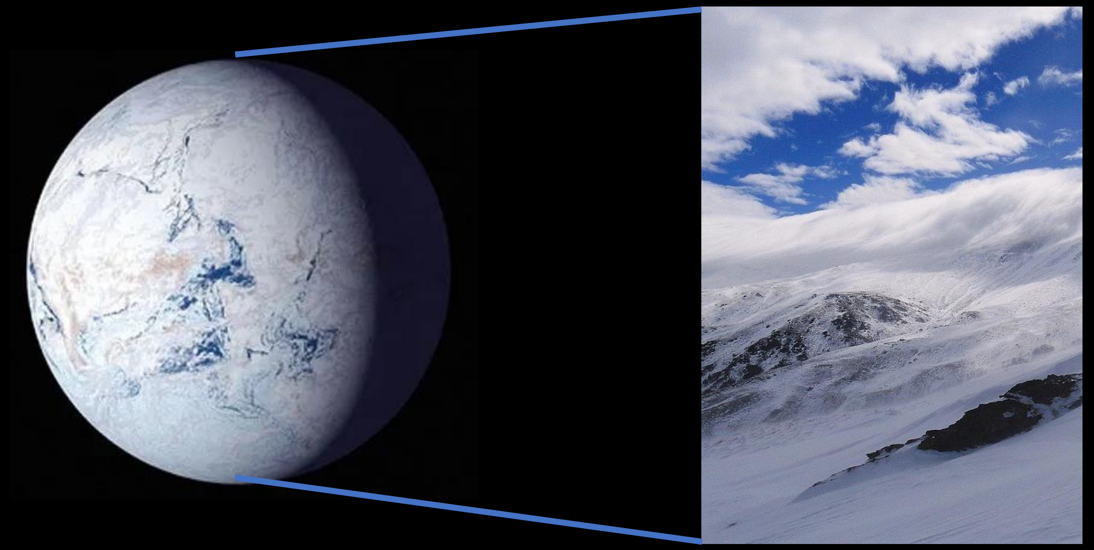
Resilience

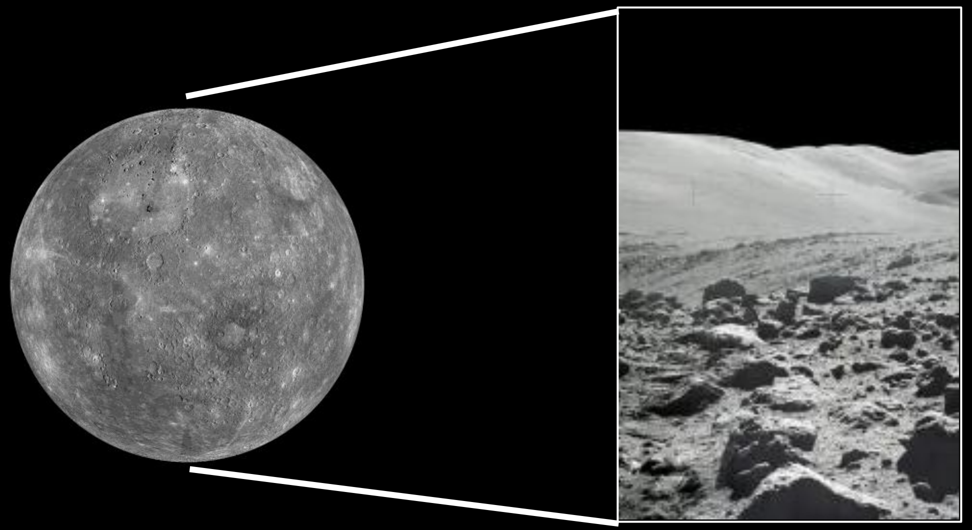
The Resilience is the probability that there will be a place to occupy in the Star System.



$$\mathscr{R} \in [\,0, 1]$$

Uniformly distributed





Civilization Lifetime

$$T \in [1, 10 \times 10^6] \text{ years}$$

Jeffreys distributed

The Civilization Lifetime describes how long the civilization was involved in galactic colonization.

Image from the *History Channel*

Endurance

$\tau_{max} \in [1, 1000]$ years

Jeffreys distributed

The endurance is how long they can spend in their spacecraft.

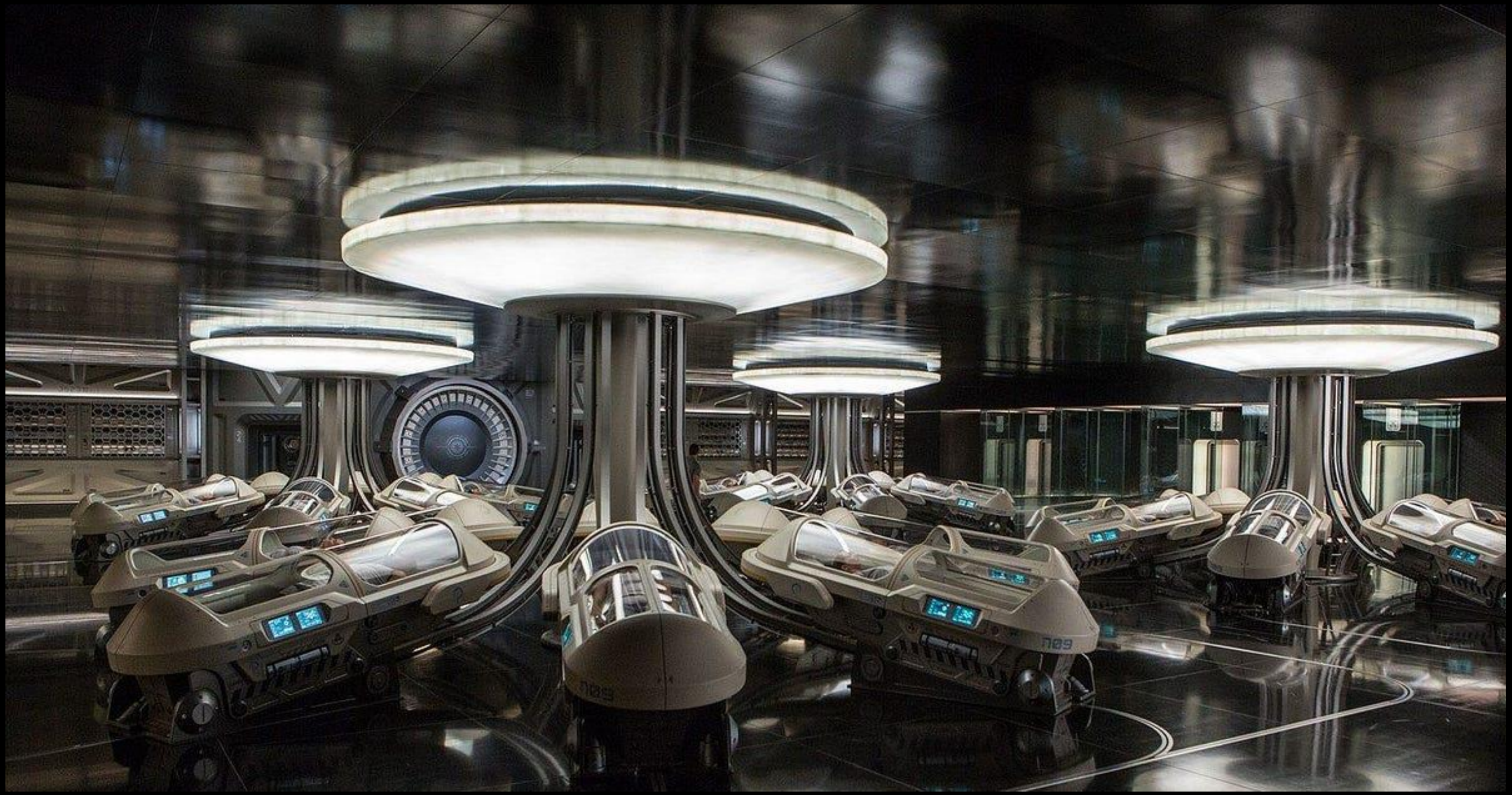


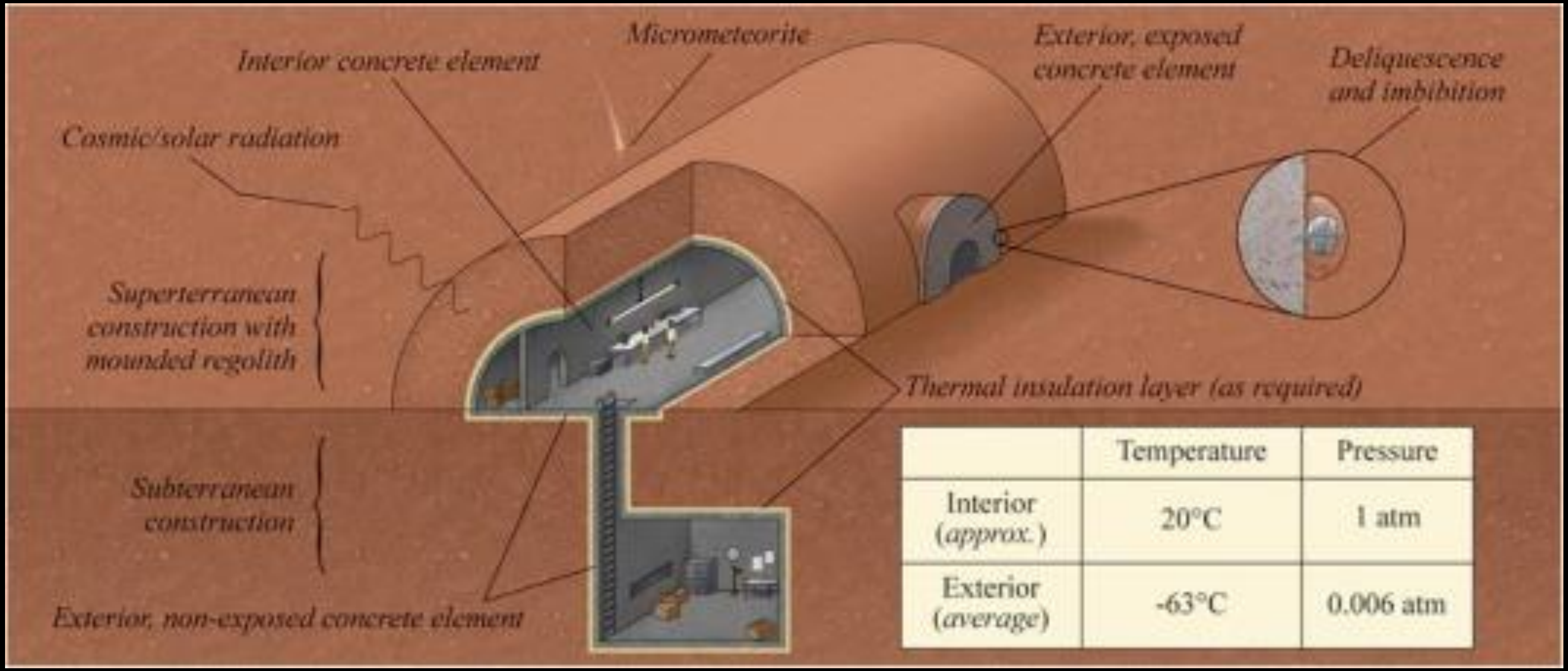
Image from the movie *Passengers*

Colonization Time

$$t_{col} \in [1, 5000] \text{ years}$$

Uniformly distributed

The Colonization Time describes how long it takes to establish a presence before moving on.



Y. Reches Cem. Concr. Compos., 104 (2019)

Maximum Acceleration and Velocity

$$a_{max} \in [1, 25000] \text{ gs}$$

Jeffreys distributed

$$v_{max} \in [0, 1) \text{ c}$$

Jeffreys distributed

NASA

Maximum speeds, less than the speed of light, are considered.

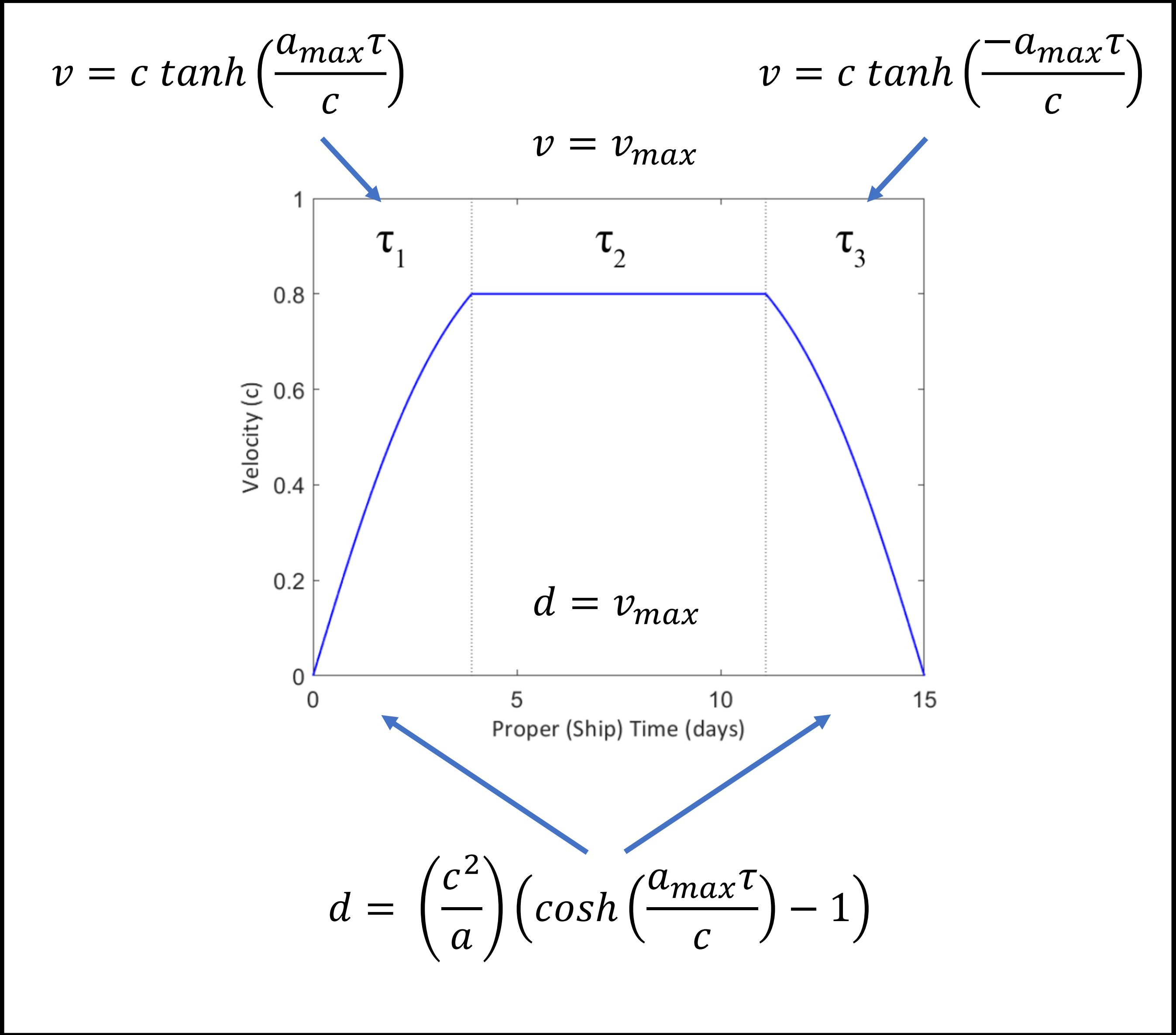
Maximum accelerations, up to 2.5 times the acceleration observed in the JAL 1628 case (Coumbe 2022), are considered.

Interstellar Reach

The *reach, δ,* of the society is the maximum distance that they can travel to another star system.

The reach depends on their maximum travel duration, τ_{max} their maximum acceleration, a_{max} and their maximum speed, v_{max}

It can limit their ability to perform interstellar colonization if their resilience is low, and there are no habitable systems within their reach.



The Kardashev Scale is focused on
the amount of energy a civilization controls.

This is not a practical measure for describing space travel

Space Traveler Classes	
Home World Bound	
Class 0	Unable or unwilling to reach orbital speeds
Class I	Can orbit Homeworld and visit accompanying Moons
System Bound	
Class IIa	Can traverse their Star System and visit its Worlds with speeds on the order of orbital velocities
Class IIb	Can traverse their Star System and visit its Worlds with speeds greater than orbital speeds but less than 0.01c
Near Interstellar	
Class IIIa	Reach nearby stars (within 5 LY) in 10s of years with speeds $0.01c < v < 0.1c$
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Relativistic Interstellar	
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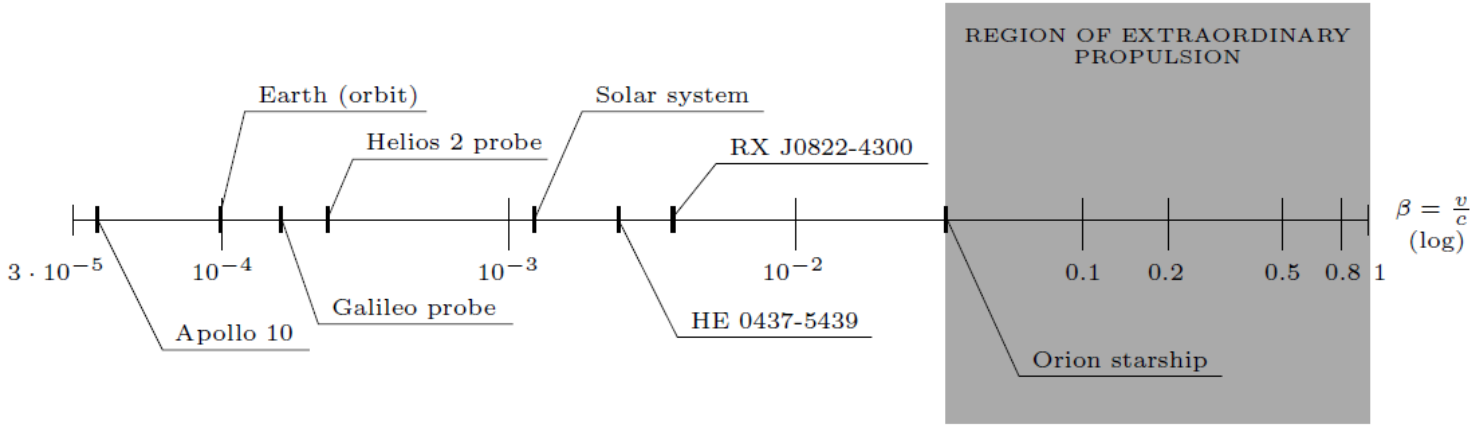
Cut-Off for the Garcia-Escartin & Chamorro-Posada Region of Extraordinary Propulsion



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Class IIIb	Can reach nearby stars with speeds $0.1c < v < 0.3c$ (*)(**)

(*) "Shielding … easy for ship's velocities below 0.3c; a titanium or aluminum hull of 1 to 2 cm in thickness can provide sufficient protection against the oncoming flow of nucleonic radiation."
(**) "deterioration of a frontal part of a hull or a frontal shield caused by intense micrometeorite bombardment with a rate exceeding 100 relativistic dust particles per square meter per second for $\beta > 0.3$"

Y. Semyonov, "Radiation hazard of relativistic interstellar flight", *Acta Astronautica* 64.5-6 (2009): 644-653.

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(**) Pion production from nucleon-nucleon collisions becomes an issue at 0.69c

U. Yurtsever and S. Wilkinson, “Limits and Signatures of Relativistic Spaceflight”, *Acta Astronautica* 142 (2018): 37-44.

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(***) "The situation worsens dramatically for ultra-relativistic velocities. For example for β = 0.995, all cosmic rays will come from the front and their kinetic energy will be near 10 GeV; the penetration depth of protons of this energy will be ~ 40 m in water and ~ 10 m in titanium. Obviously, such a frontal shield falls out of reasonable scale."

Y. Semyonov, "Radiation hazard of relativistic interstellar flight", *Acta Astronautica* 64.5-6 (2009): 644-653.

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Diffusion Model with Basic Parameters

Differential Equation Model

Diffusion Equation: Fick's Second Law

$$\frac{\partial}{\partial t}p(r,t) = D\nabla^2 p(r,t),$$

Gaussian Solution

Differential Equation Model

Diffusion Equation: Fick's Second Law

$$\frac{\partial}{\partial t}p(r,t) = D\nabla^2 p(r,t),$$

Gaussian Solution

Consider, instead, a source term to model growth

Logistic Equation

$$\frac{d}{dt}p(r,t) = \rho\left(\mathscr{R} - p(r,t)\right)p(r,t)$$

Logistic Solution

Differential Equation Model

Diffusion Equation: Fick's Second Law

$$\frac{\partial}{\partial t} p(r,t) = D\nabla^2 p(r,t),$$

Gaussian Solution

Consider, instead, a source term to model growth

Logistic Equation

$$\frac{d}{dt} p(r,t) = \rho \left(\mathscr{R} - p(r,t)\right) p(r,t)$$

Logistic Solution

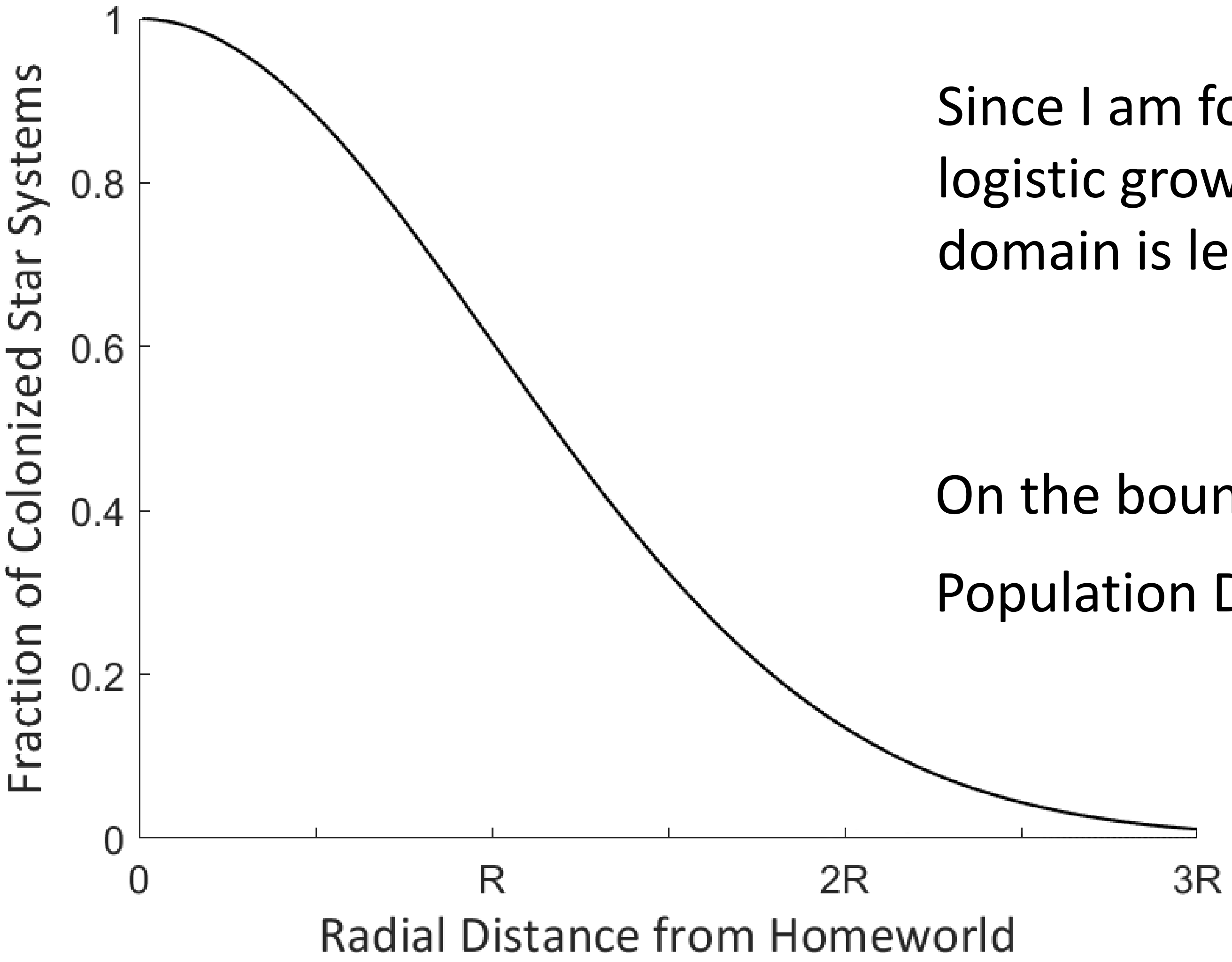
Together these give

Fisher's Equation = Kolmogorov-Petrovsky-Piskunov (KPP) Fisher (1937), Kolmogorov et al. (1937)

$$\frac{\partial}{\partial t} p(r,t) = D\nabla^2 p(r,t) + \rho \left(\mathscr{R} - p(r,t)\right) p(r,t)$$

No Analytic Solutions

Differential Equation Model



Gaussian Population Density
with and Expanding Domain Boundary

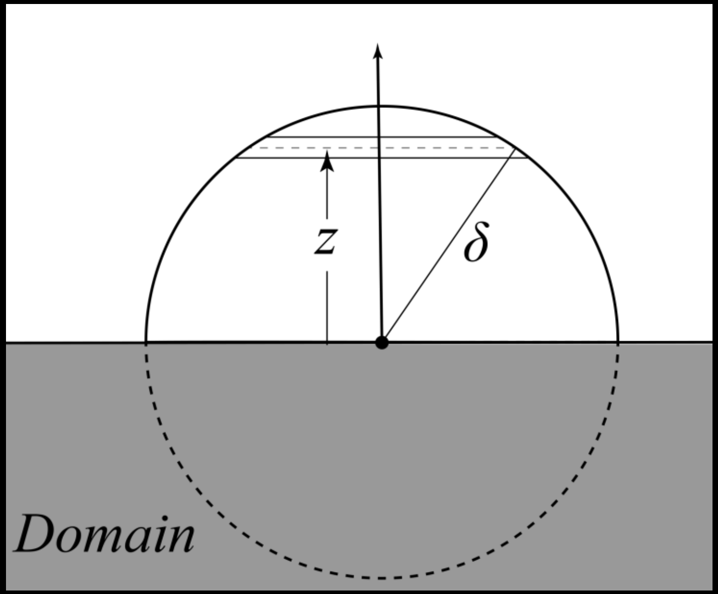
Since I am focused on finding Earth, the logistic growth-like component within the domain is less important.

On the boundaries:

Population Density $\propto \; \mathrm{Exp}\left(-\frac{(\mathbf{x}-\mathbf{x}_o)^2}{2\,R^2}\right)$

Carroll-Nellenback et al (2019) modeled the domain boundary as a logistic function.

Domain Expansion



$$v_{dom} \approx \frac{\langle z \rangle}{t + t_{col}}$$

$$\langle z \rangle = \frac{3}{8}\,\delta$$

Bennett and Shostak (2007)
Maccone (2012)
argued that domain expansion would zig-zag from system to system:

$$v_{dom} \approx \frac{k\langle z \rangle}{t + t_{col}}$$

Domain Expansion

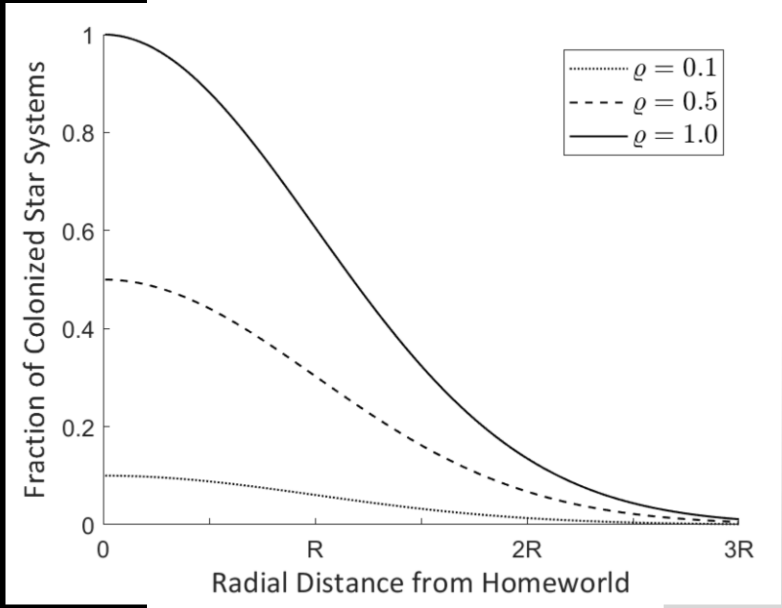
Using a Taylor series expansion of the population density at the domain boundary, we can estimate the expected value of $\langle z \rangle$.

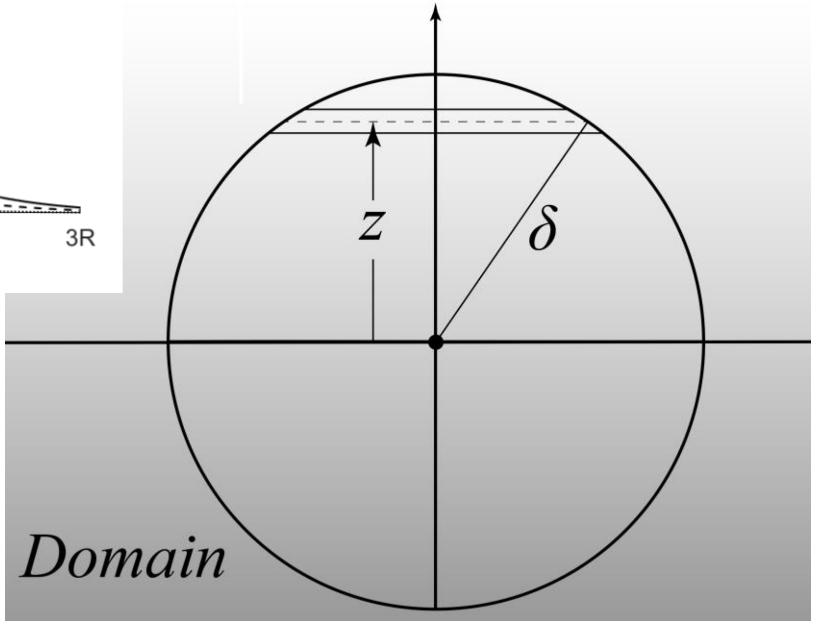
We see that the “constant” k

$$v_{dom} \approx \frac{k\langle z \rangle}{t + t_{col}}$$

is not constant, but is dependent on the size of the domain R, and the resilience of the civilization $\mathscr{R}$

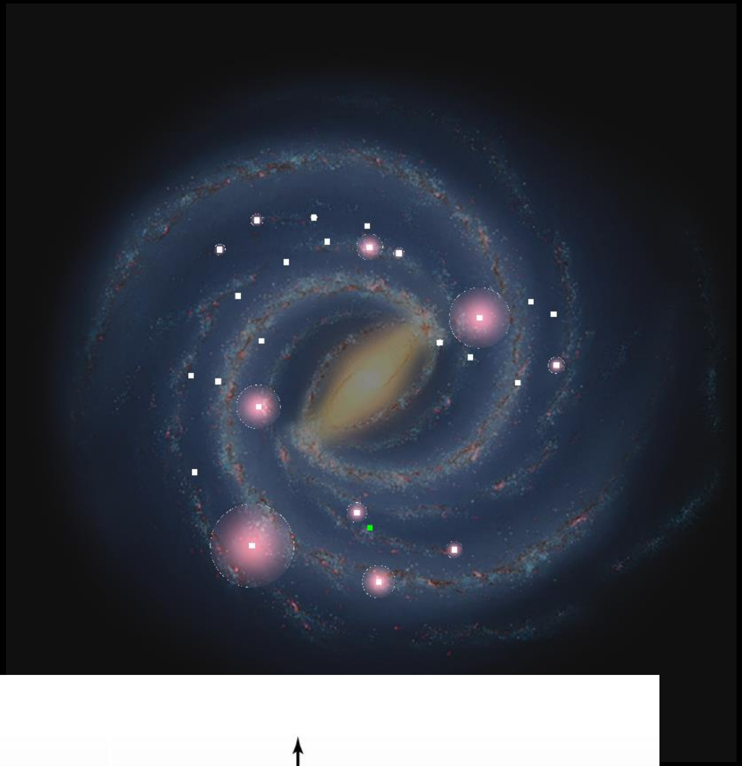
$$\langle z \rangle = \frac{1}{5} \frac{1}{(\mathscr{R}^{-1} e^{1/2} - 1)} \frac{\delta^2}{R}$$





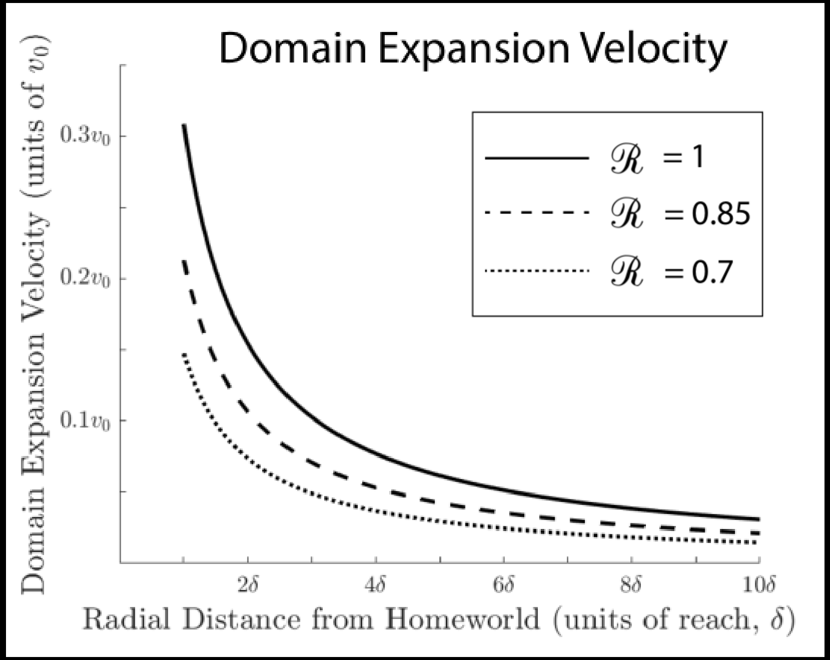
Domain Expansion

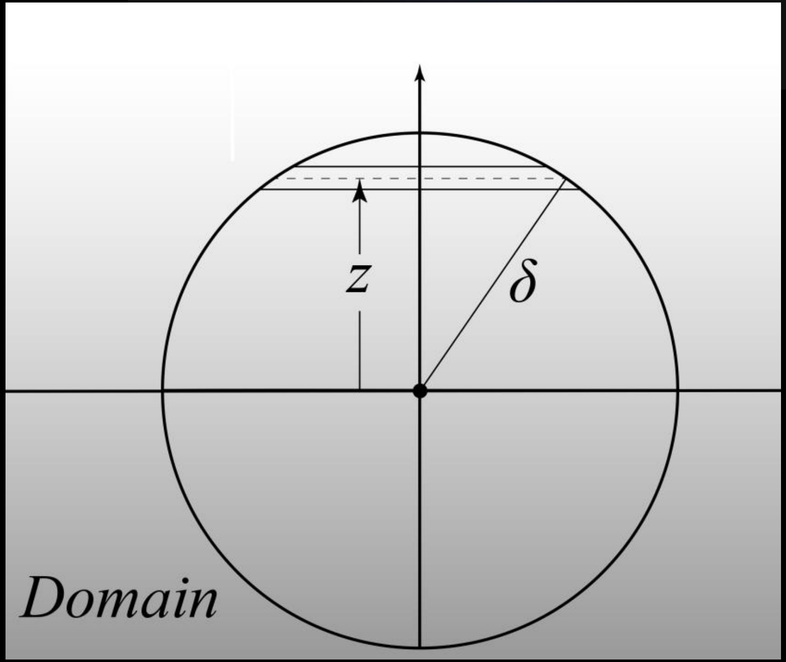
$$v_{dom} \approx \frac{\frac{1}{5}\,\frac{1}{(\mathscr{R}^{-1}\,e^{1/2}\,-1)}\,\frac{\delta^2}{R}}{t+\,t_{col}}$$



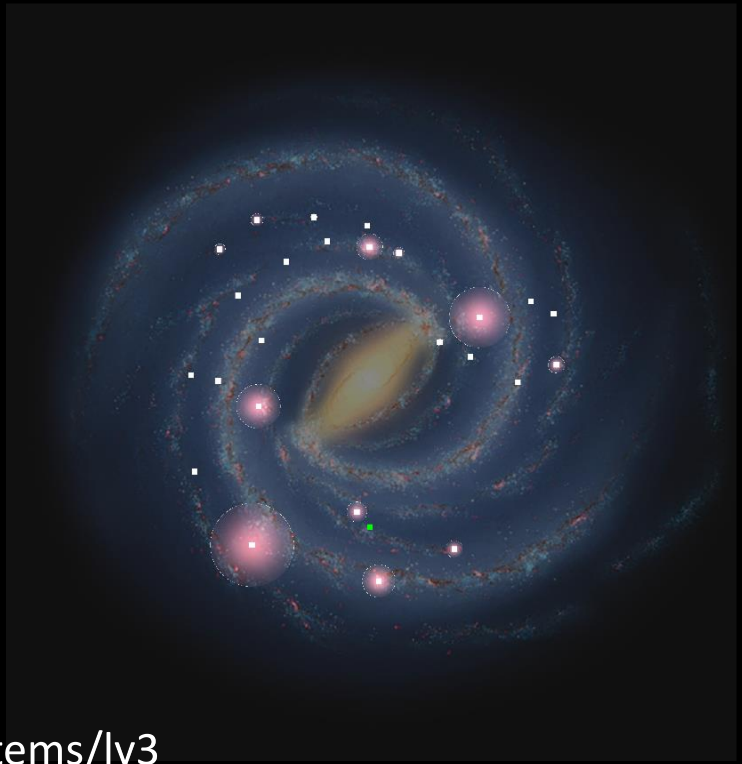
Initially, the domain expands rapidly as There are many places to colonize.

As the domain expands, the interior fills slowing down the expansion!





Bottlenecks



Carroll-Nellenback et al (2019) found that for spherical expansion, the normalized density of settleable systems, η, must be greater than a critical value

$$\eta = \quad \rho\, \delta^3 \; > \; \eta_c \sim \; 0.88$$

ρ = 0.0022 systems/ly3
is the stellar density

or else the domain fractures into tendrils.

This means that the reach

$$\delta > \sqrt[3]{\frac{0.88}{\mathscr{R}\rho}} \;\sim\; 7.37 \text{ light years}$$

Commencing Colonization

The probability a system is habitable is given by the resilience $\mathscr{R}$

The probability a system is NOT habitable is $q = 1 - \mathscr{R}$

The probability that the N_δ systems are NOT habitable is $q^{N_\delta} = (1 - \mathscr{R})^{N_\delta}$

We use this to check if the civilization can even get started.
If there are no habitable systems in reach, then they aren't going anywhere!

Basic Statistics

Out of 10 Million randomly generated civilizations:

7,780,208 civilizations could NOT leave their star system!

2,219,792 civilizations, or 22%, were capable of interstellar travel.

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ONLY 9 civilizations found Earth!

Out of the interstellar-capable civilizations, only

$$\frac{\mathbf{9}}{\mathbf{2\,219\,792}} \approx \mathbf{0.000405}\%$$ will encounter Earth!

Moreover, only 9 of the 10 million space-faring civilizations encountered Earth.

If we **ever learn that someone had visited Earth**,
these results serve as a sort of Drake equation to estimate that:

there are about 1.1 million spacefaring civilizations
and about
250 000 interstellar spacefaring civilizations in the galaxy.

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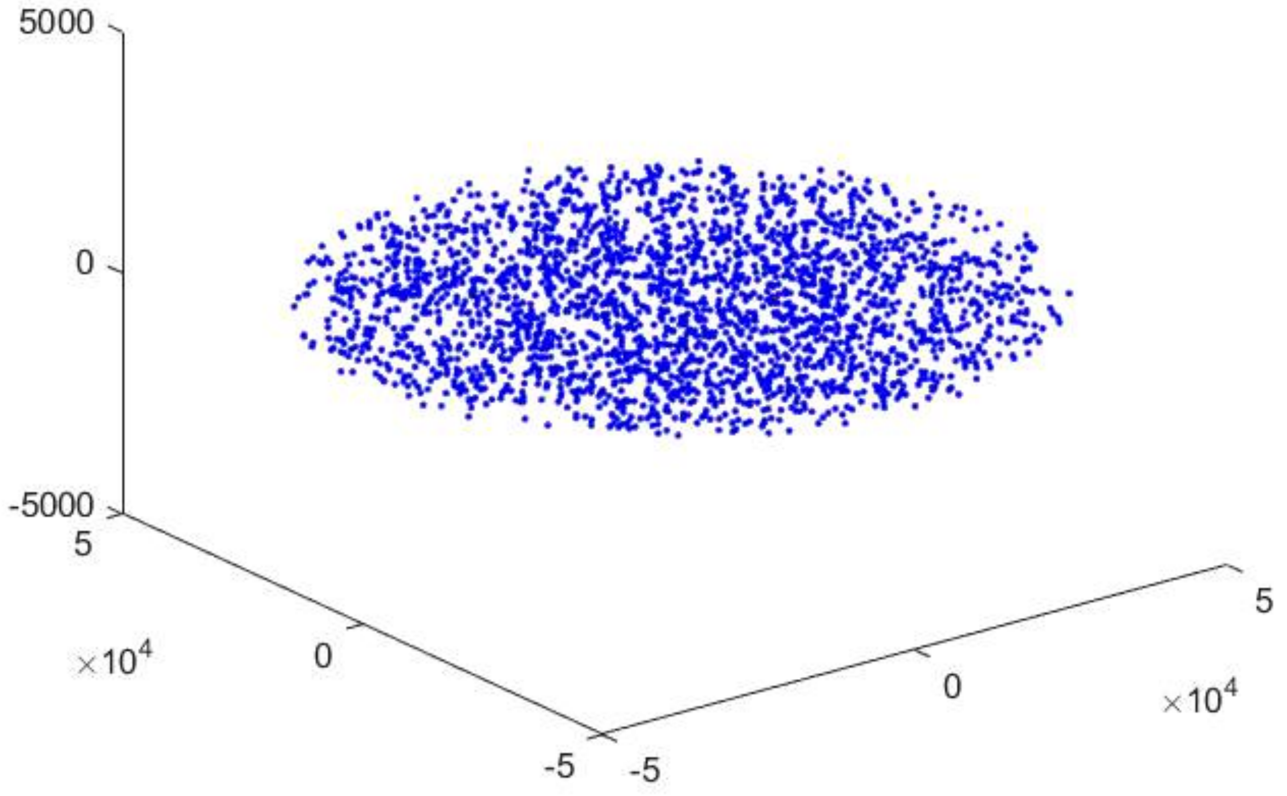
Inadequacies of the Model

A slowly expanding domain near the galactic interior is dragged around by the stellar motions into an annulus.

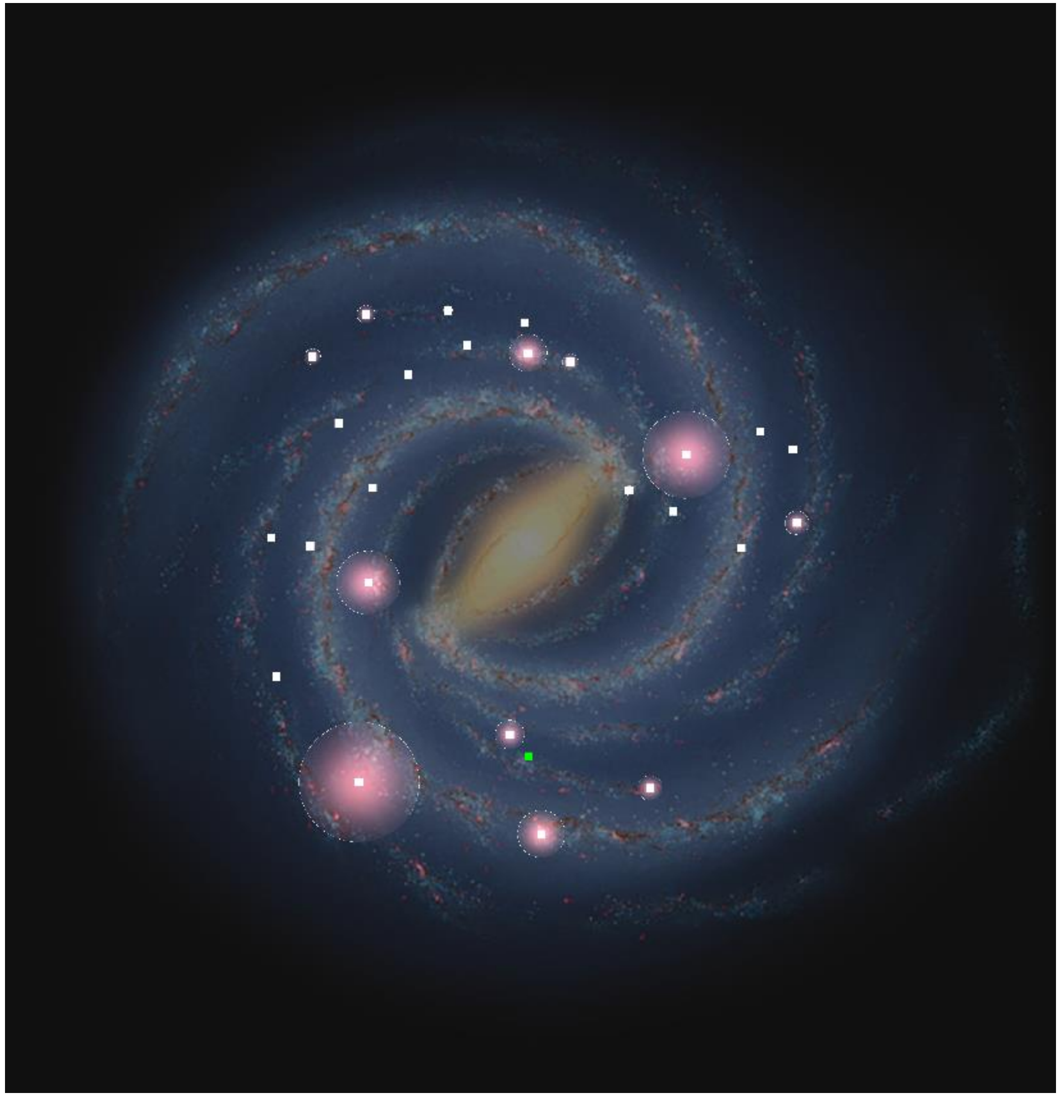
These time scales are on the order of 100 million years

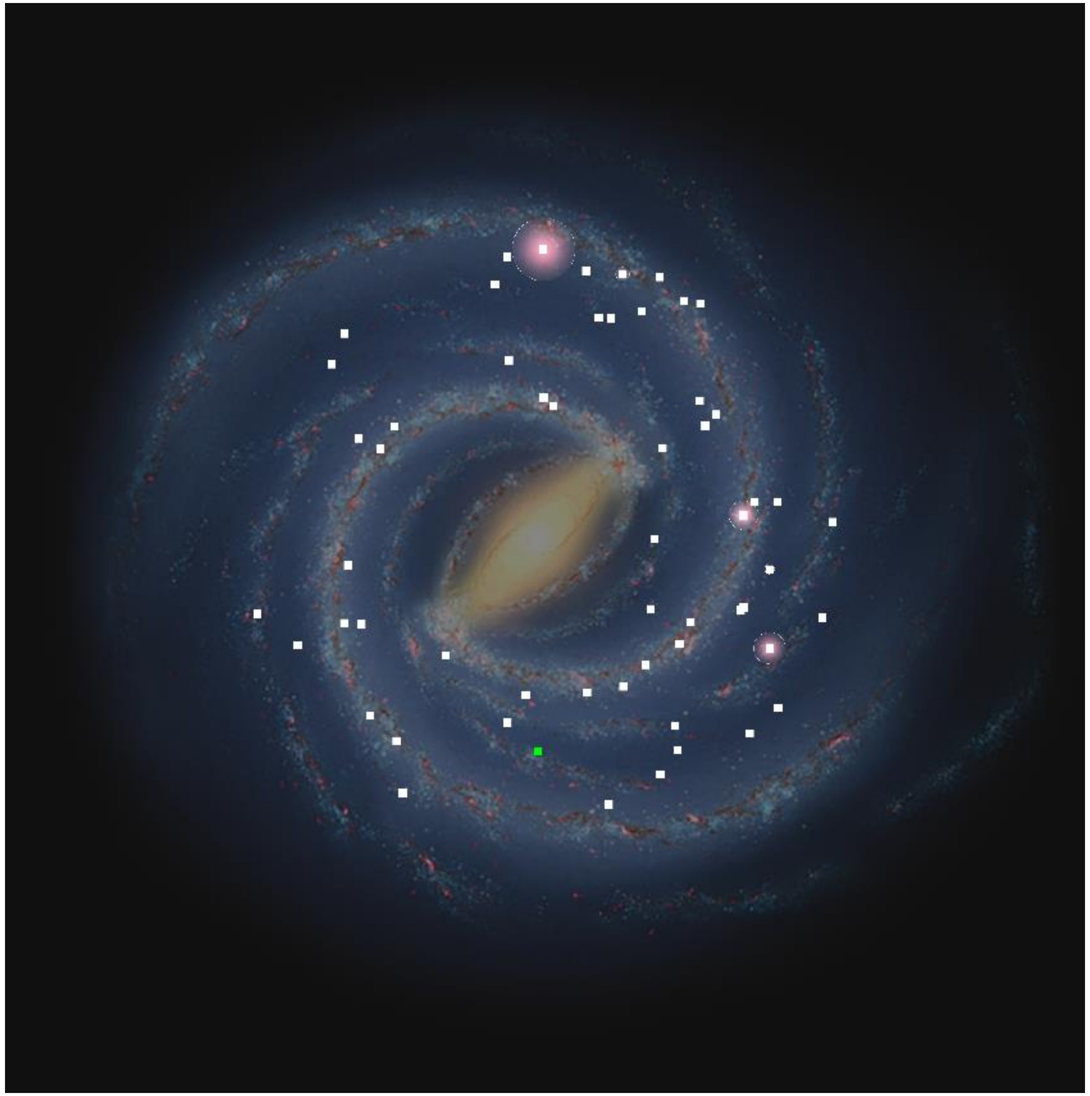
For a civilization closer to the galactic interior, the diffusion model should accommodate stellar motions.

The Great Annular Empire!



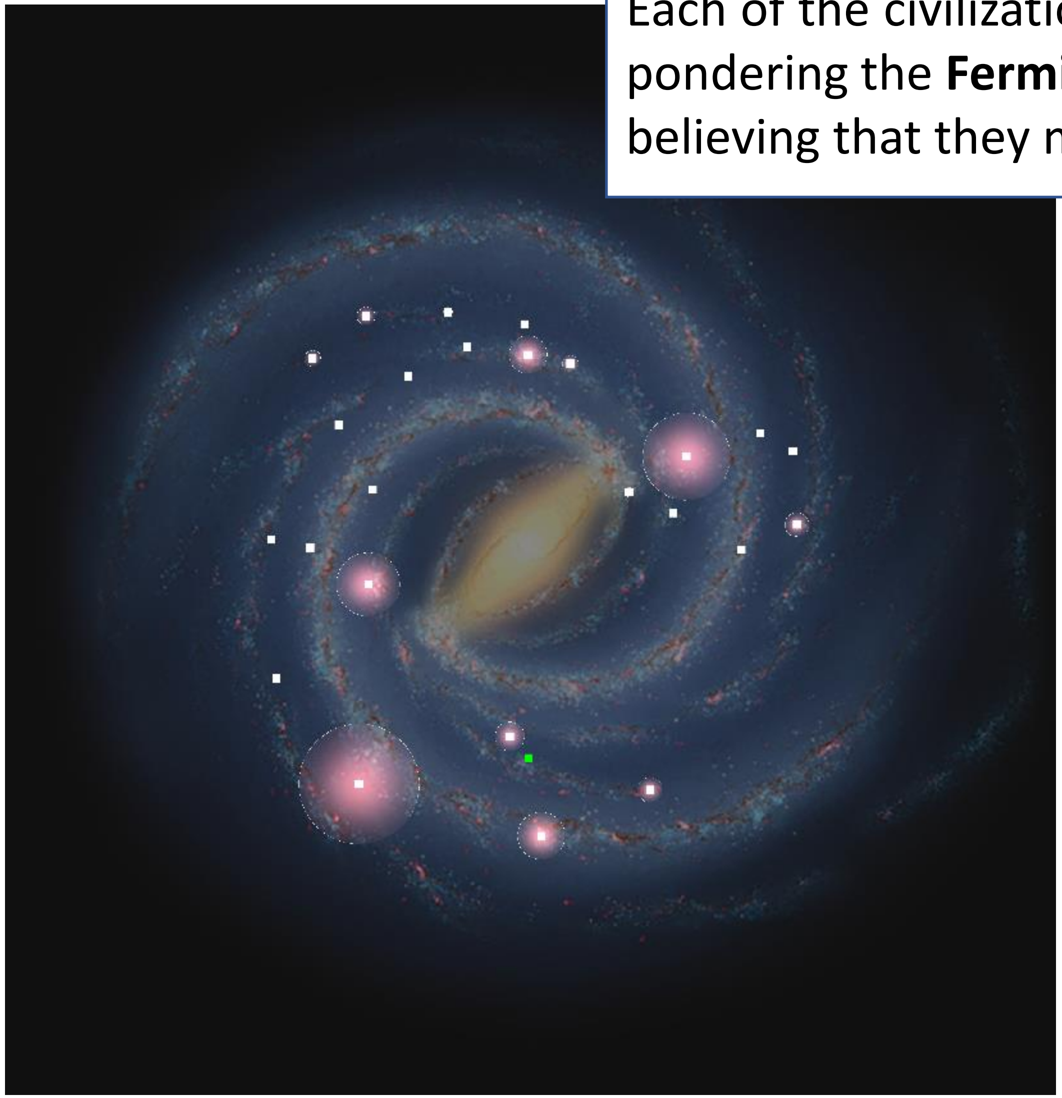
Examples of Lonely Space-Faring Civilizations





Examples of Lonely Space-Faring Civilizations

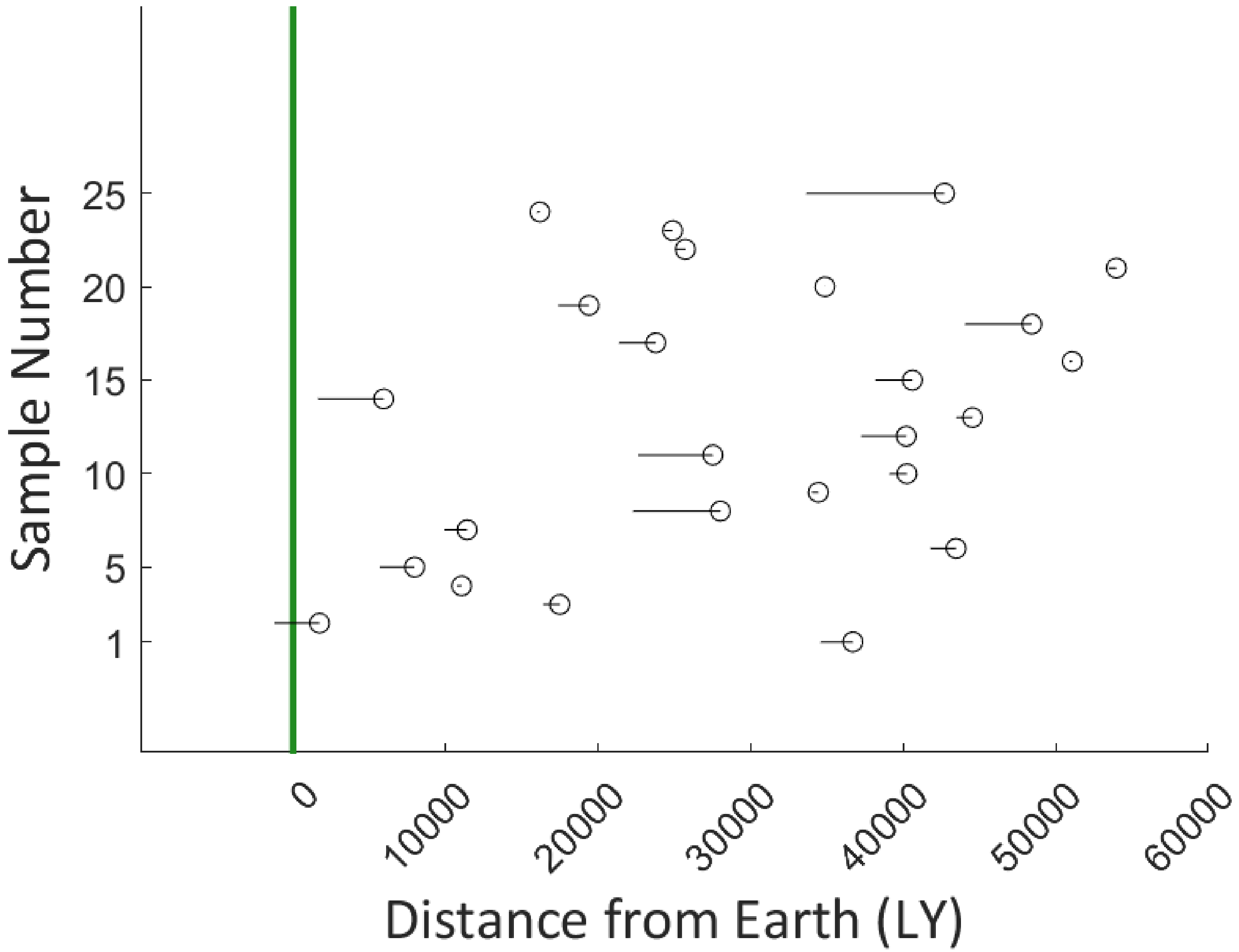
Each of the civilizations pictured here could be pondering the **Fermi Paradox** believing that they must be alone!



The fact that only 1 out of a million civilizations find Earth means that to generate 1 million civilizations that find Earth, I would need to generate 1 TRILLION civilizations!

I am going to have to be CLEVER!

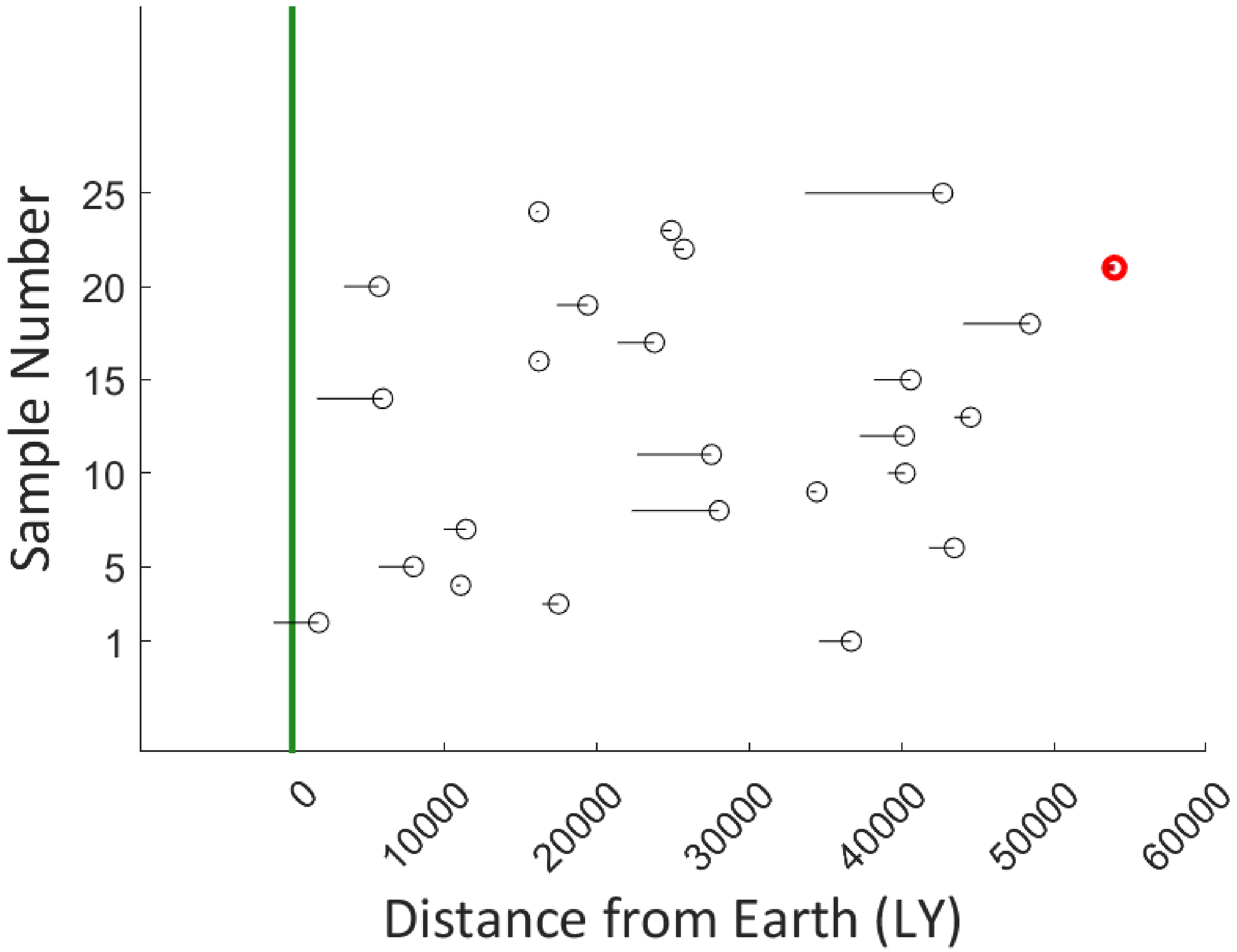
Nested Sampling for Exploring Small Areas of Parameter Space



$$\log L = -\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}$$

25 Samples from the prior

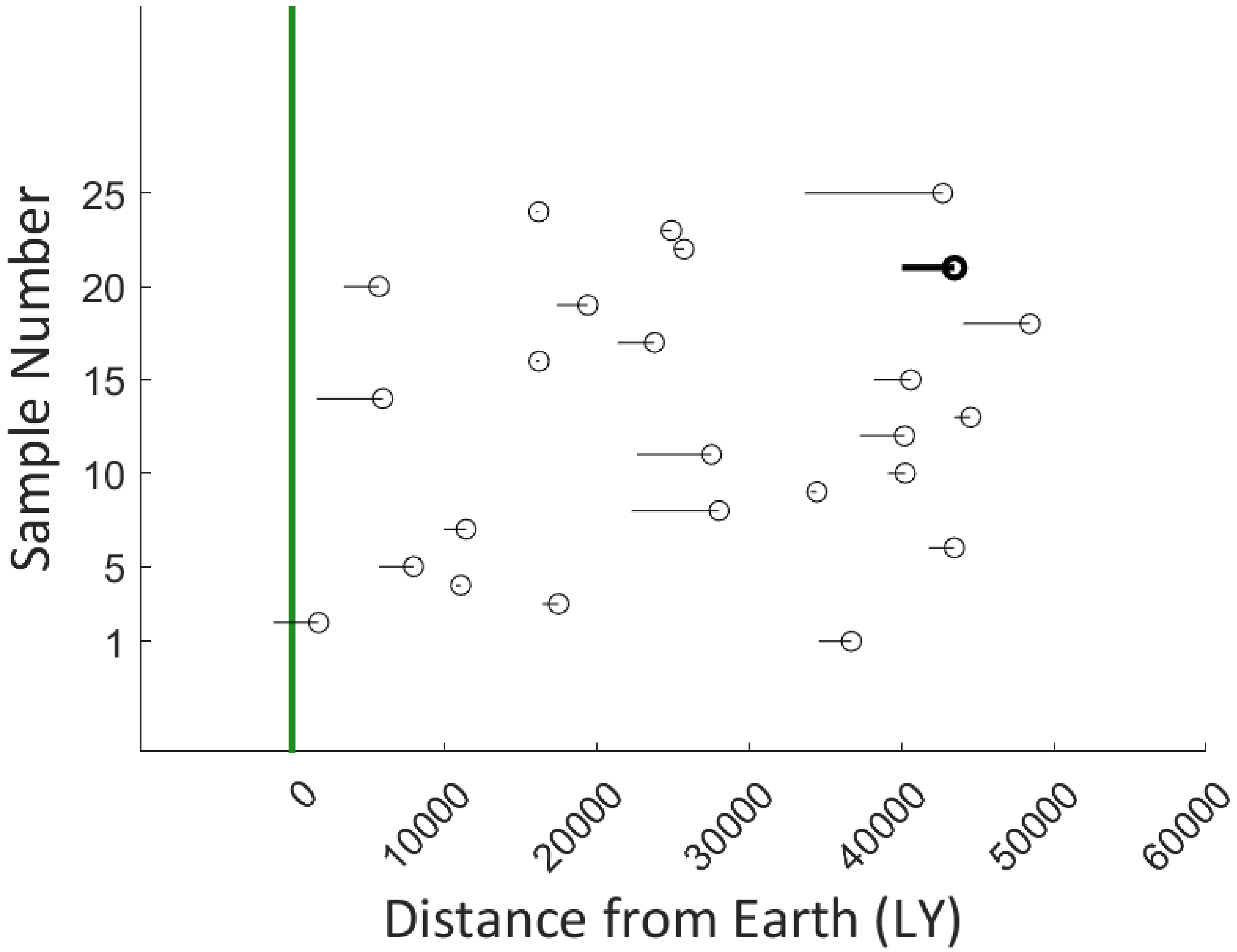
Nested Sampling for Exploring Small Areas of Parameter Space



$$\log L = -\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}$$

Next
Worst Sample

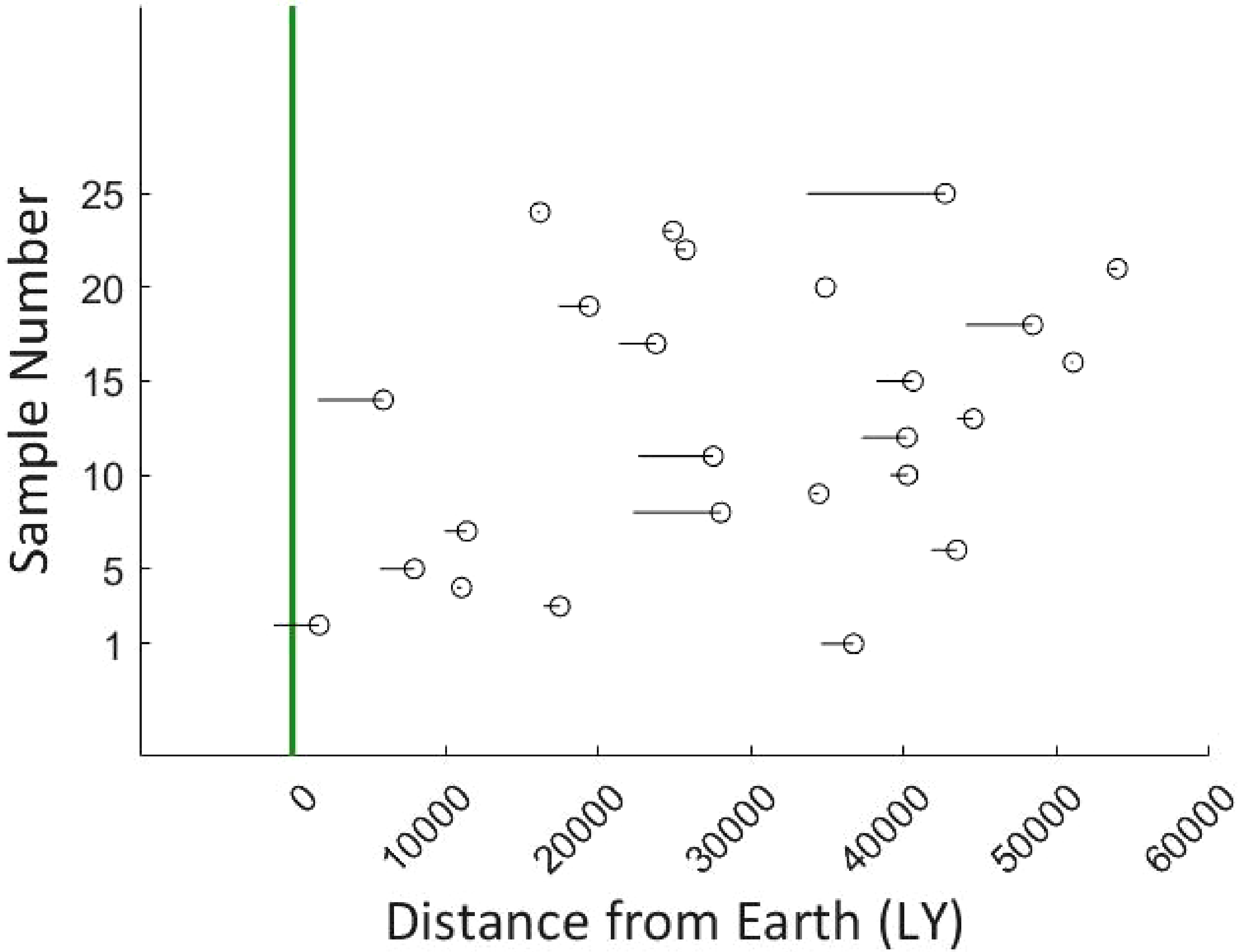
Nested Sampling for Exploring Small Areas of Parameter Space



$$\log L = -\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}$$

Worst Sample Evolved

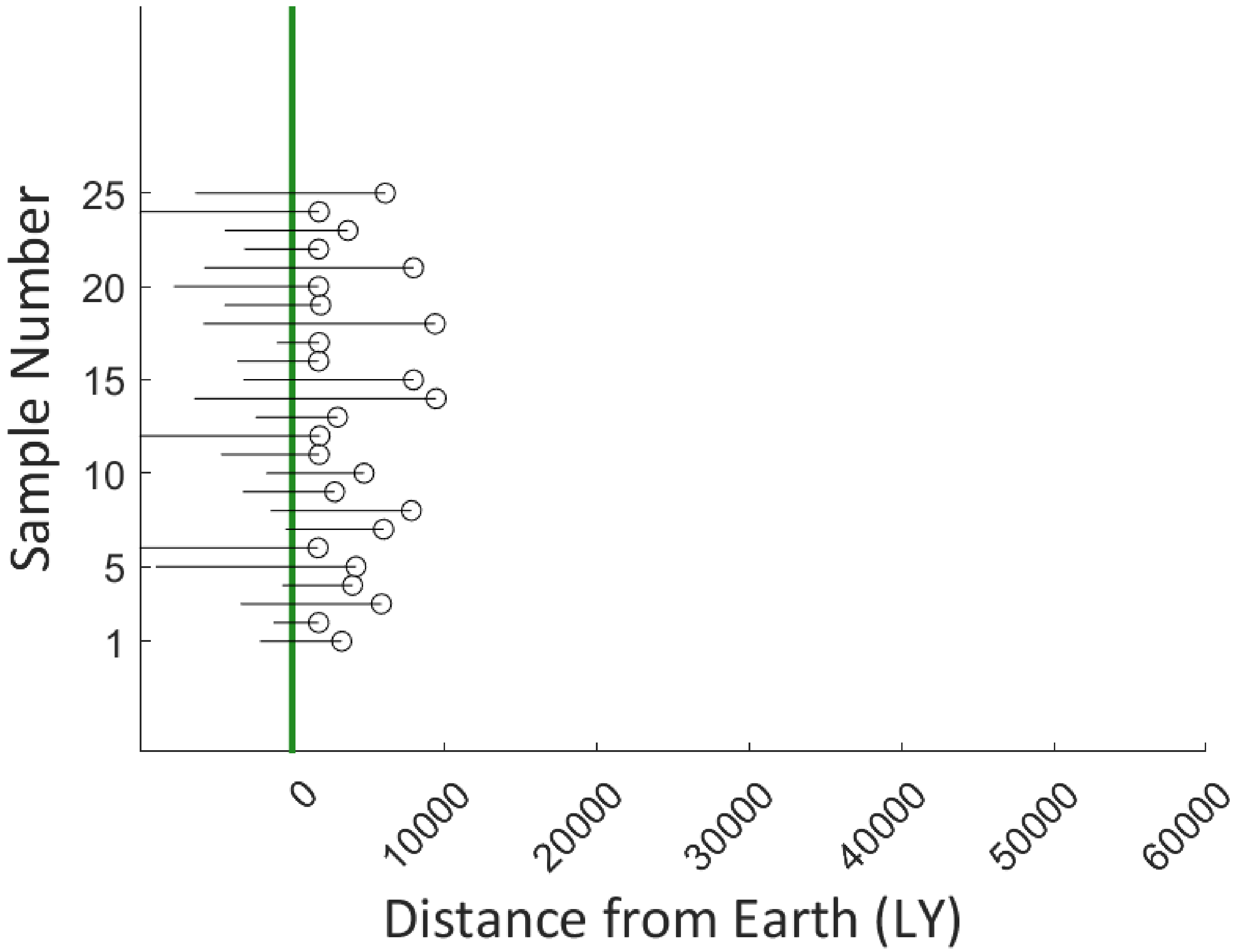
Nested Sampling for Exploring Small Areas of Parameter Space



$$\log L \;=\; -\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}$$

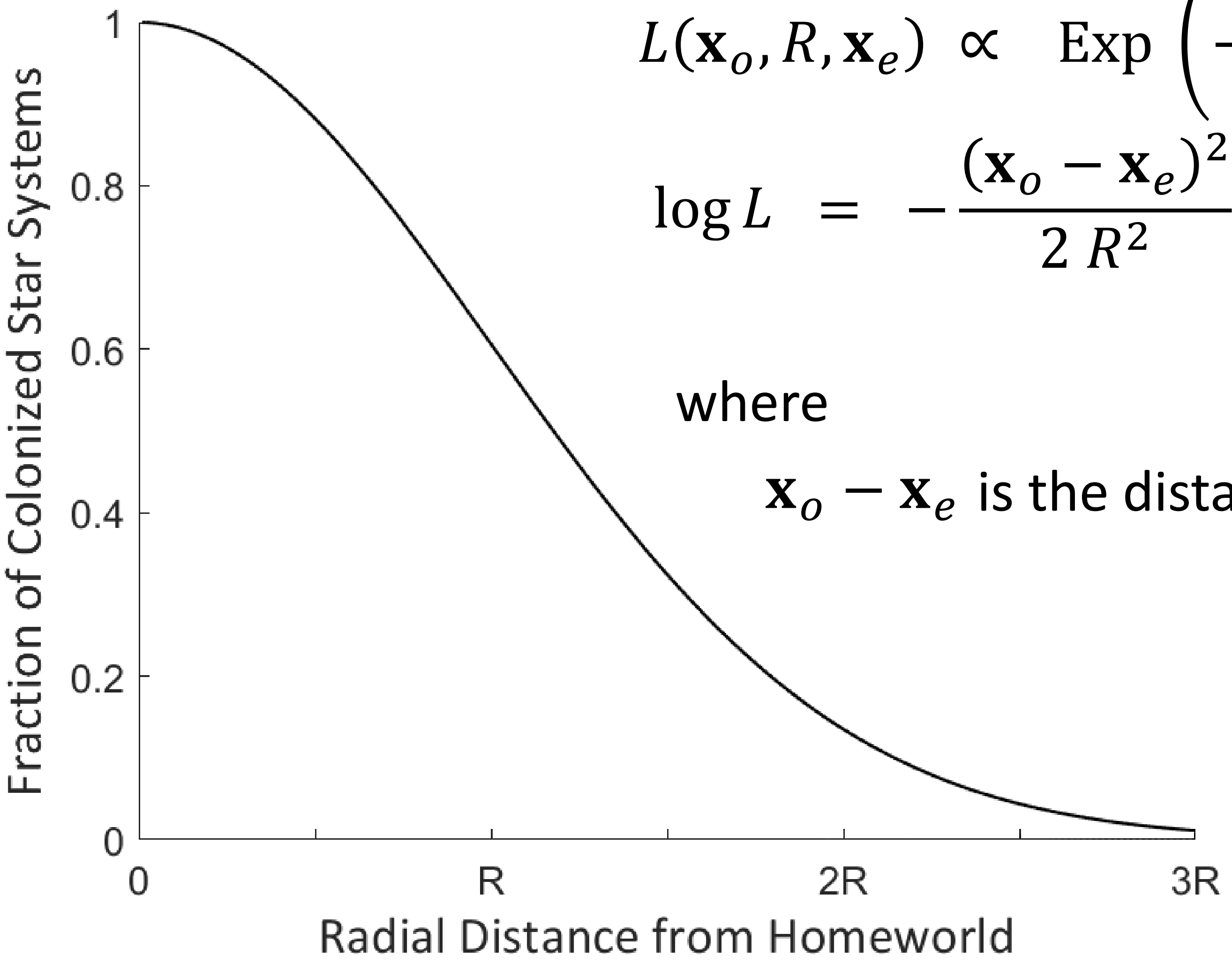
Nested Sampling for Exploring Small Areas of Parameter Space

$$\log L = -\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}$$



Uniformly
Distributed
Samples

Log L for Nested Sampling



$$L(\mathbf{x}_o, R, \mathbf{x}_e) \propto \text{Exp}\left(-\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}\right)$$

$$\log L = -\frac{(\mathbf{x}_o - \mathbf{x}_e)^2}{2\,R^2}$$

where

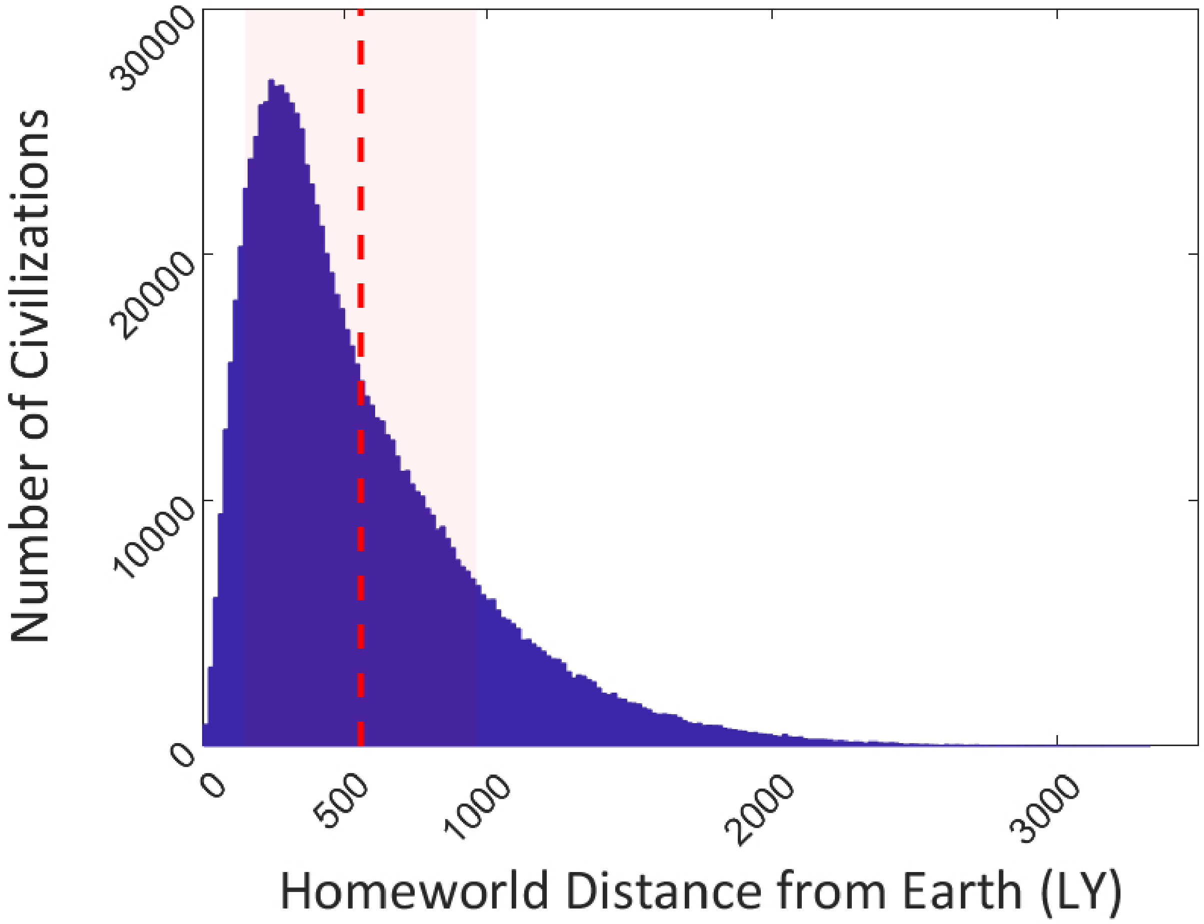
$\mathbf{x}_o - \mathbf{x}_e$ is the distance between the Homeworld and Earth

What Can Be Inferred About a Civilization That Discovers Earth?

RESULTS

Distance between their Homeworld and Earth

10^6 Civilizations



They are easily from within our galactic quadrant (within 16,000 LY).

The most probable distance is

$$\hat{d}_{earth} = 248\ LY$$

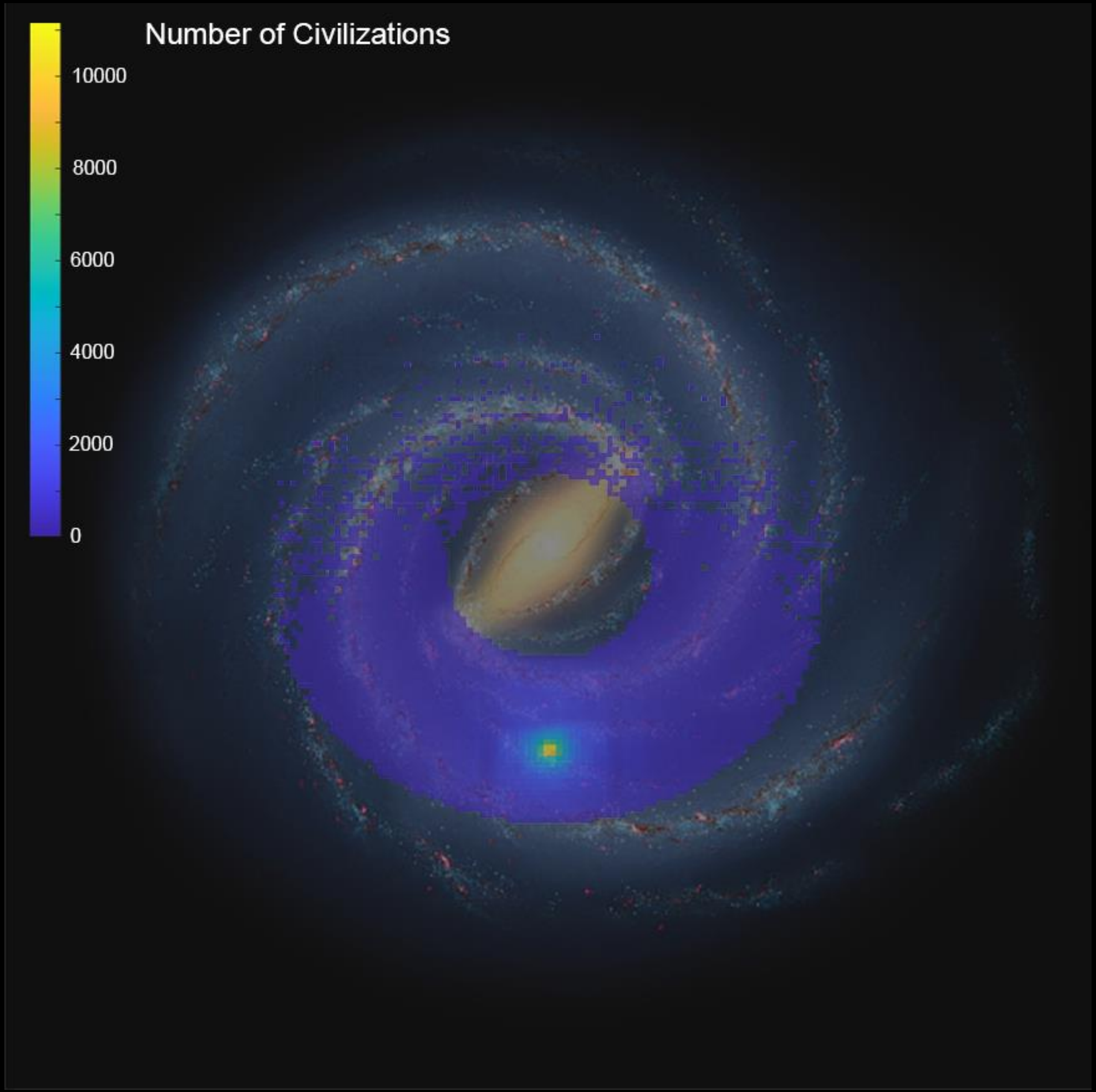
(there are about 250,000 stars within this radius)

The mean distance is

$$\langle d_{earth} \rangle = 560 \pm 410\ LY$$

Homeworld Location

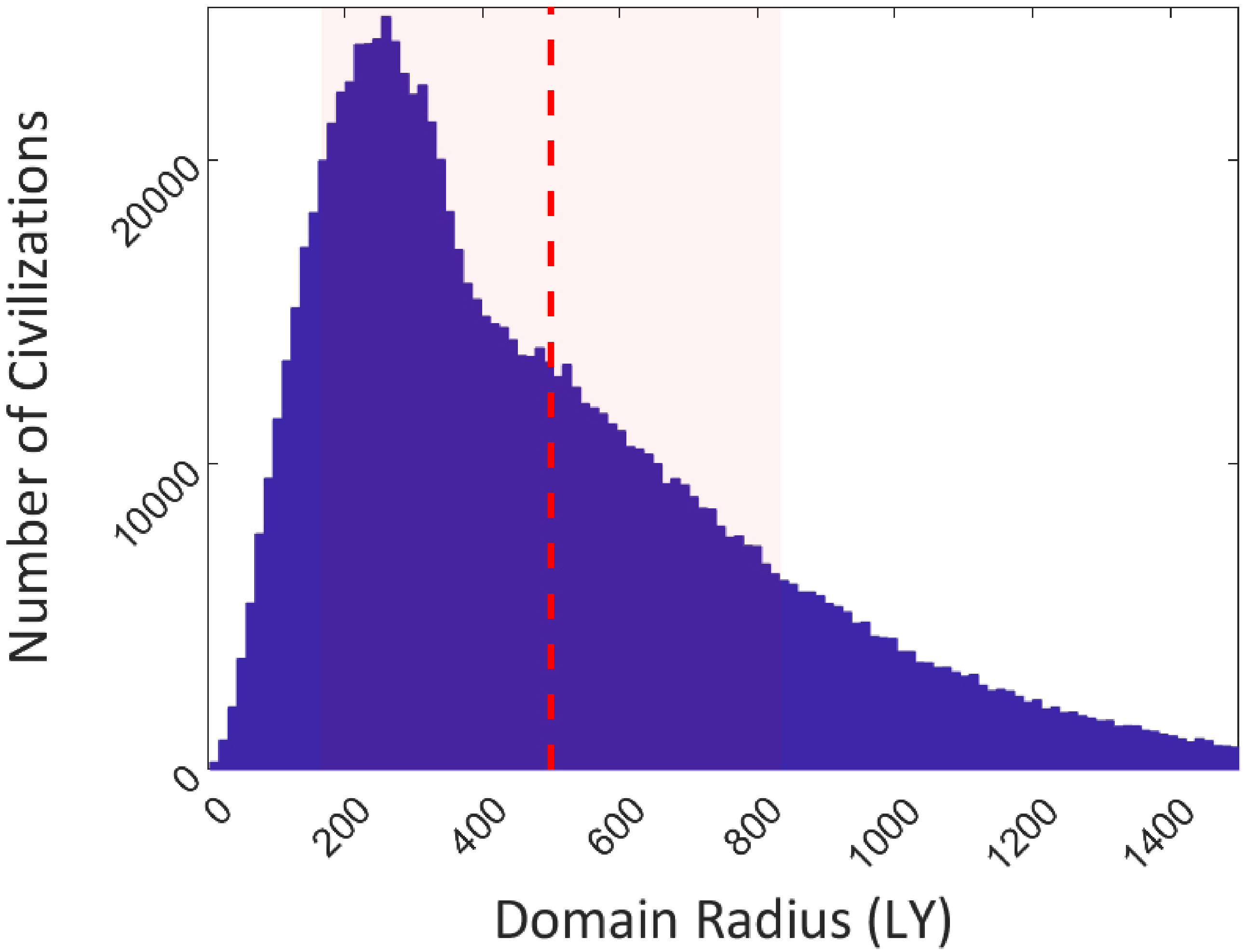
10^6 Civilizations



They are probably from within 560 LY

Domain Extent

10^6 Civilizations



Their domains can be quite large with some radii exceeding 1,000 LY.

The most probable domain radius is about 260 LY.

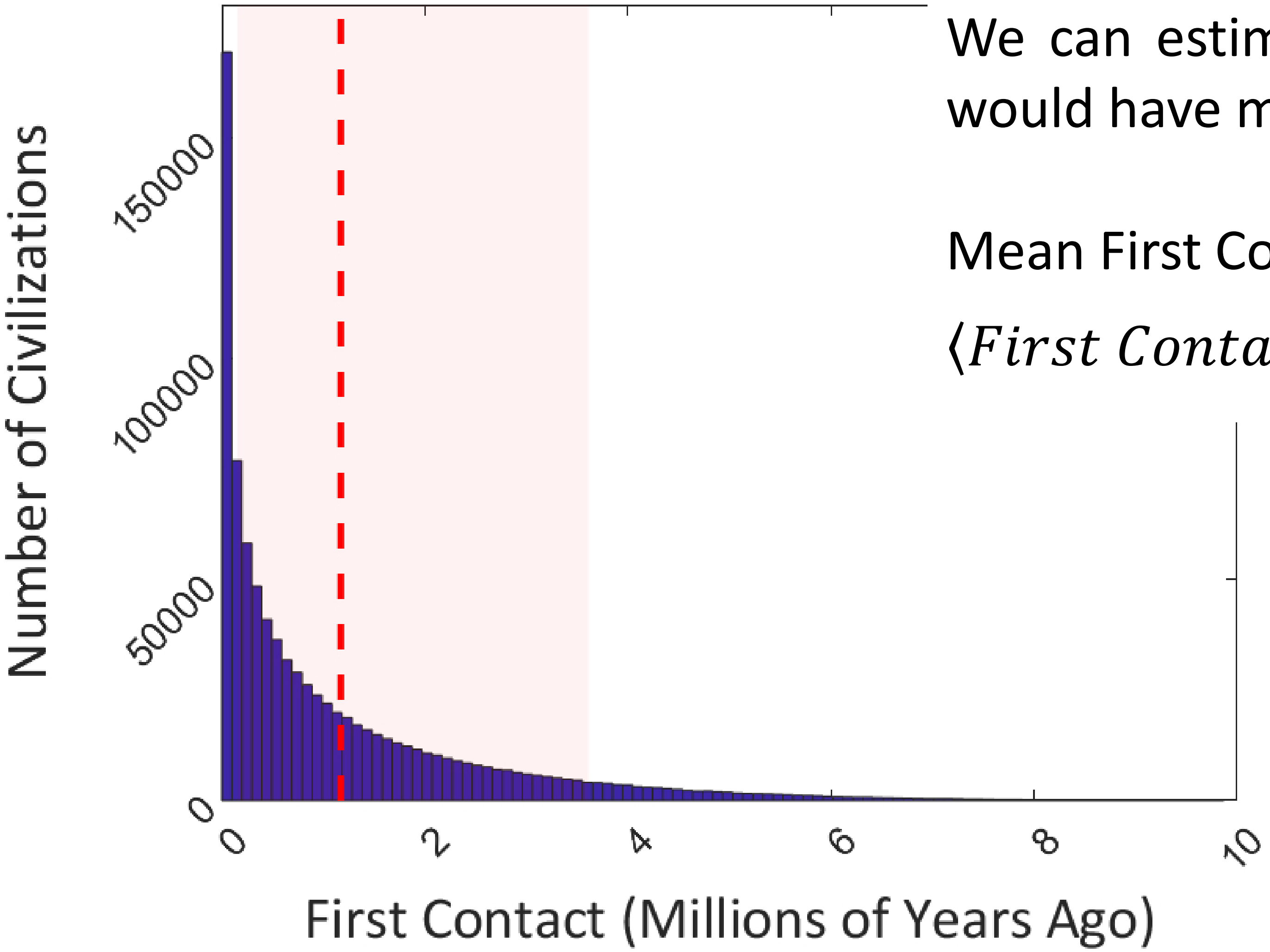
The mean radius is

$$\langle R \rangle = 500 \pm 330 \, LY$$

Given the distances between their Homeworlds and Earth, it would be reasonable to say that our solar system lies well within their domain.

First Contact with Earth

10^6 Civilizations



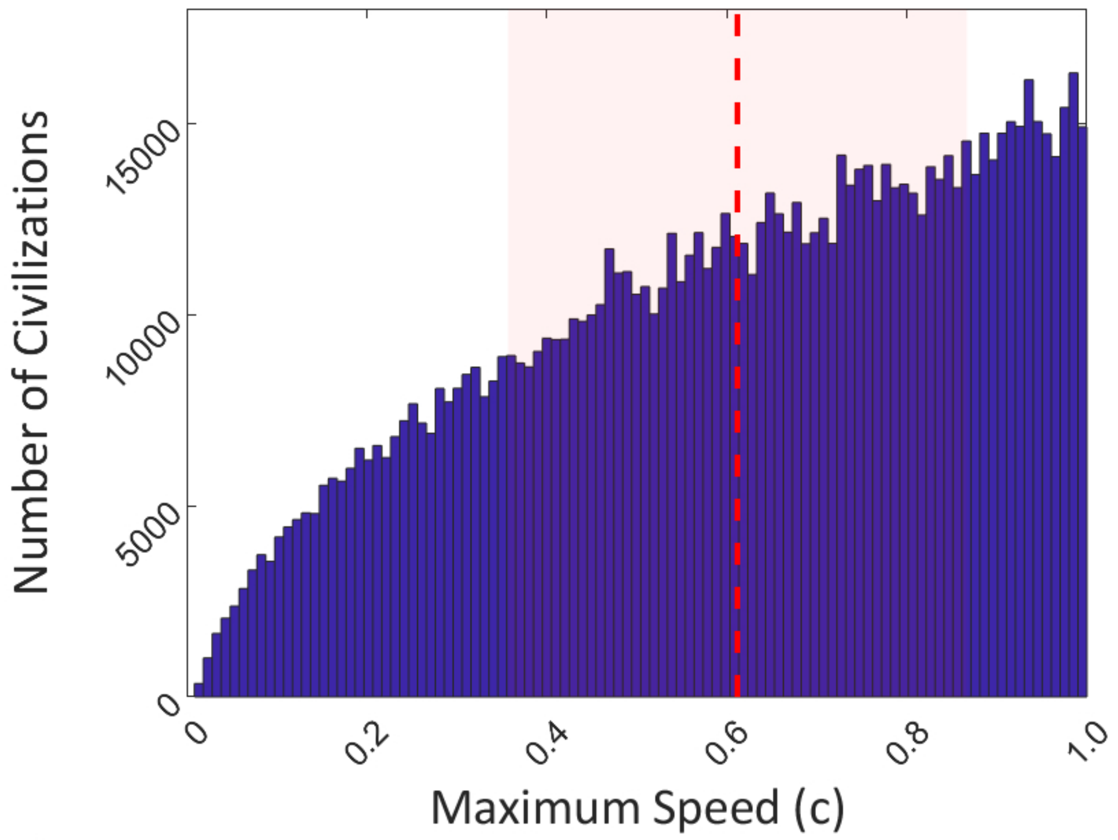
We can estimate when each of these civilizations would have made first contact with Earth.

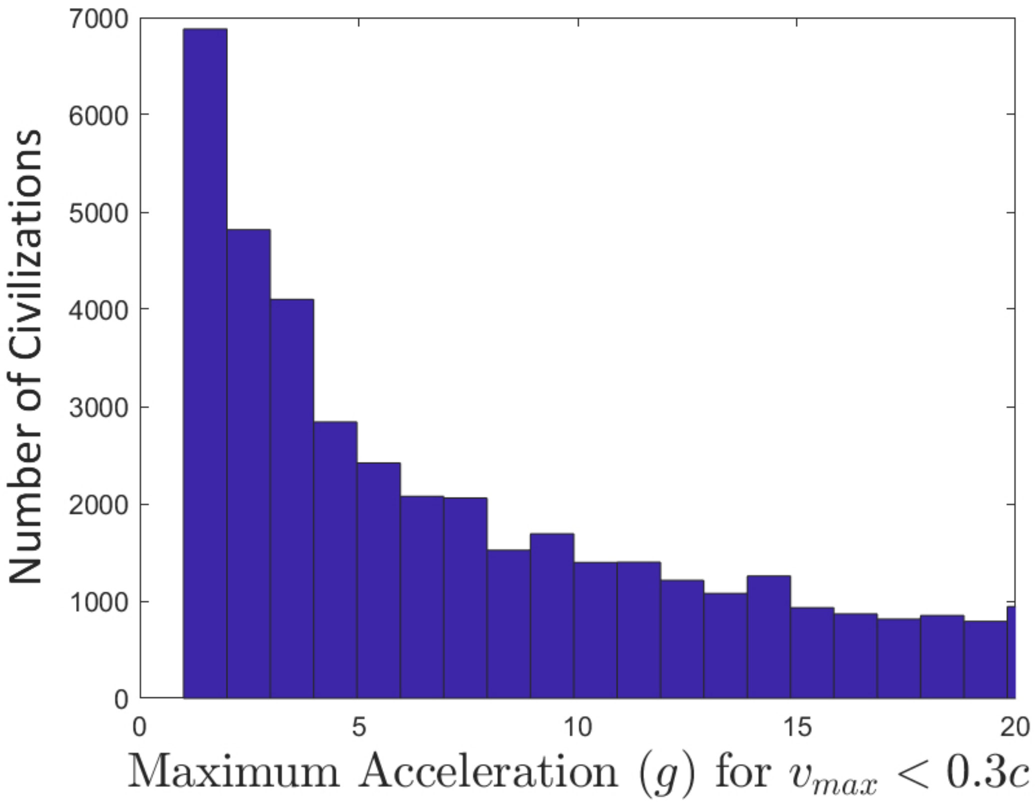
Mean First Contact occurred:

$$\langle First\ Contact \rangle = 1.17 \begin{matrix} +2.44 \\ -1.02 \end{matrix} \text{ Years Ago}$$

Maximum Speeds and Accelerations

10^6 Civilizations





$$\langle v_{max} \rangle = 0.61 \pm 0.25\, c$$

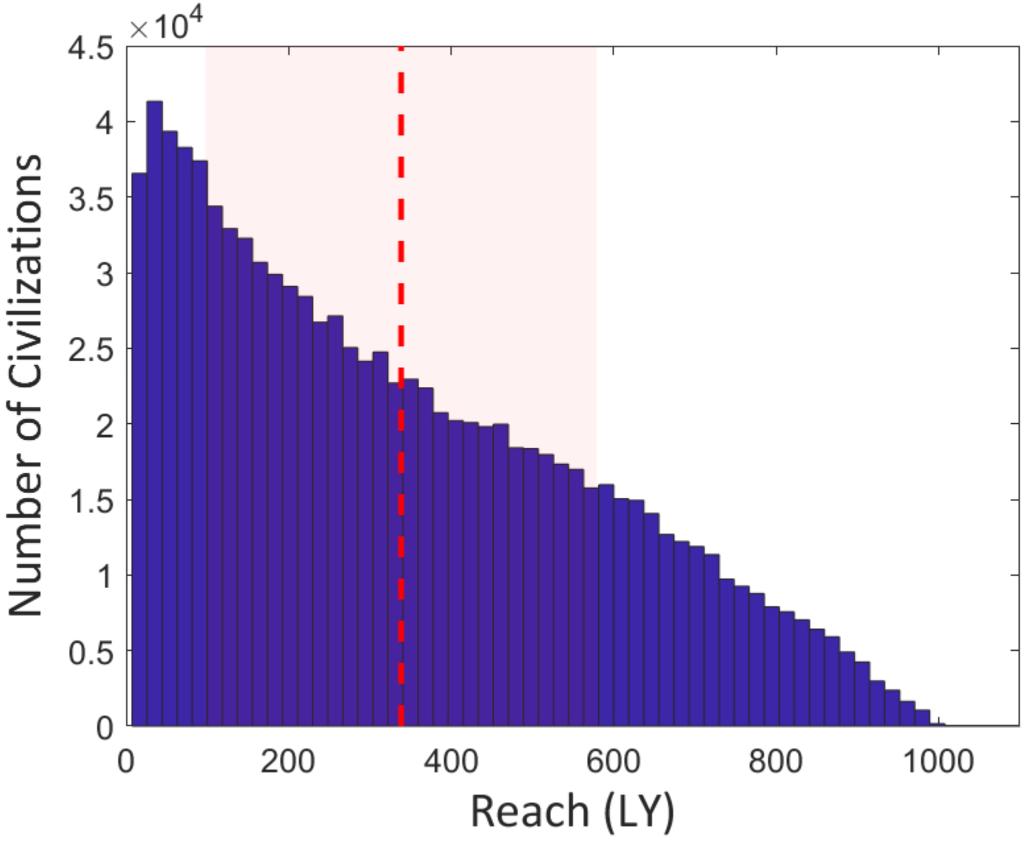
$$\langle a_{max} \rangle = 2060 \pm 4414\, g$$

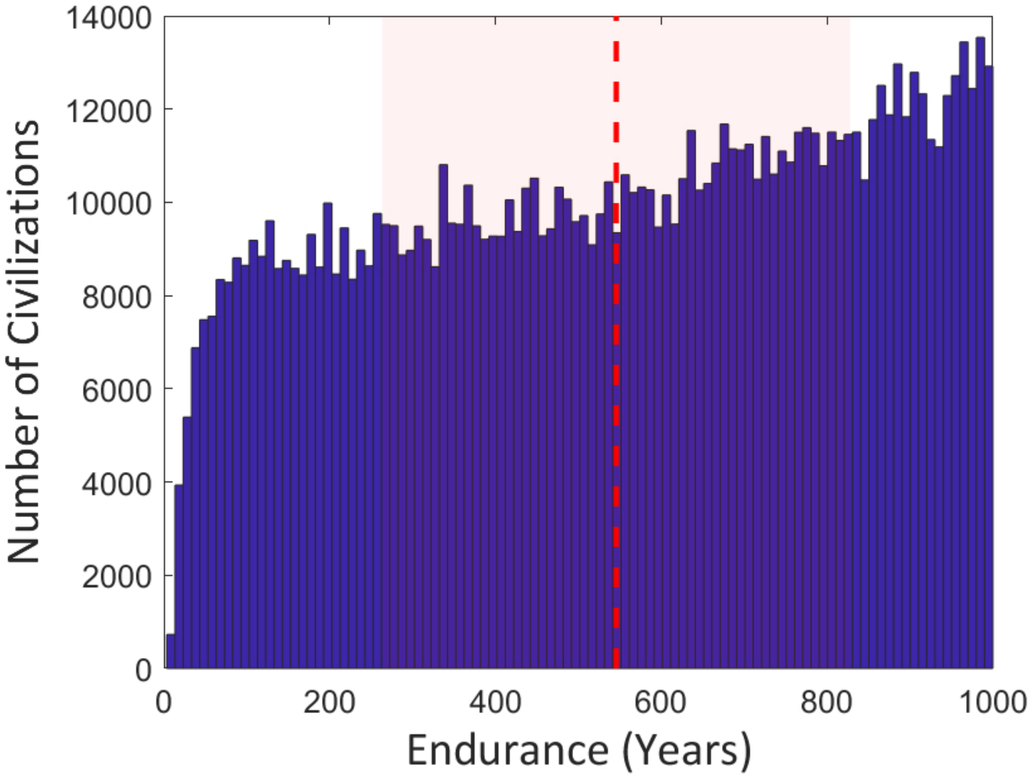
Over 21 600 civilizations (~2%) were able to find Earth by traveling at speeds less than 10% the speed of light

Accelerations of spacecraft with v_{max}<0.3 c reveal that accelerations between 1 to 2 g are in many cases sufficient.

Reach and Endurance

10^6 Civilizations





The most probable reach is about 26 to 44 LY.

The mean reach is

$$\langle reach \rangle = 340 \pm 240\ LY$$

The mean endurance (t_{max}) is:

$$\langle t_{max} \rangle = 545 \pm 282 \text{ Years}$$

Conclusions

1. Allowing for greater possible endurance (t_{max}) means that they do not need to take significant advantage of relativistic travel. Speed matters more than acceleration.

2. Anyone who finds Earth probably originates from no more than 500 - 1000 LY away and most probably about 250 LY away.

3. Earth was probably first encountered, on average, about 1 million years ago.
   If we discover them now, then they have probably been here throughout human history. (They took over Earth a LONG time ago!)

4. Our Solar System would exist well within their domain.
   They could very well believe that they OWN us.

5. The statistics allow us to form a sort of Drake equation, such that if we discover that anyone has found
   Earth, then there are about 1.1 million spacefaring civilizations in the galaxy
   and about
   250 000 interstellar spacefaring civilizations in the galaxy!

Perchance, coming generations will not abide the dissolution of the globe, but, availing themselves of future inventions in aerial locomotion, and the navigation of space, the entire race may migrate from the earth, to settle some vacant and more western planet…. It took but little art, a simple application of natural laws, a canoe, a paddle, and a sail of matting, to people the isles of the Pacific, and a little more will people the shining isles of space. Do we not see in the firmament the lights carried along the shore by night, as Columbus did? Let us not despair or mutiny.

— *Henry David Thoreau,* Paradise (to be) Regained*,*
1843.

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We are all tired of being stuck on this cosmical speck with its monotonous ocean, leaden sky, and single moon that is half useless. Its possibilities are exhausted, and just as Greece became too small for the civilization of the Greeks, so it seems to me that the future glory of the human race lies in the exploration of at least the solar system!

— *John Jacob Astor,* Journey in Other Worlds: A Romance of the Future*, 1894*

Life, for ever dying to be born afresh, for ever young and eager, will presently stand upon this earth as upon a footstool, and stretch out its realm amidst the stars.

— *H. G. Wells,* The Outline of History*, 1920*

We are beholden to give back to the Universe… .
If we make landfall on another star system, we become immortal.

— *Ray Bradbury, speech to the National School Board Association, 1995*.