Life in the Universe and the Drake Equation

- What is life, anyway?
- The chemistry of life
- How can our universe be so agreeable to the existence of Life, and what does that say about Cosmology?
- The Drake Equation and refinements
- How might we contact ET?
- Puzzles regarding ET contacting us
- “Rare Earth” and implications

What criteria must something have before you would call it "alive"?

There's another issue which we won't get too deep into in this PDF; the psychology of asking the very question!

If our real goal is not to feel alone, then likely we are really asking "What is life <u>as we know it and love it</u>?"

Here's some that biologists pretty much agree on…

- Must be able to reproduce itself – this is probably the most defining characteristic
- Must take in nutrients and energy from environment to accomplish its goals
- Must fight for an ecological niche by out-competing other life wanting to use those resources
- Must be capable of evolving to keep its competitive edge

These actions are complicated

- They require a large number of “degrees of freedom” in the entity doing them, in the jargon of Information Theory
- In plain English – ***Life is Complex***
- There are 92 chemical elements allowed by the laws of physics in this Universe.
- **There is only one which is capable of forming the basis of complex molecules – carbon**
- We see no way that any conceivable life in our universe could originate from any other chemistry than carbon-based. It doesn’t look like a limitation in our imagination, it seems dictated by our laws of physics. Life in our Universe, it seems, at least starts out as Carbon-based.
- Finding life as we know it, elsewhere in our universe means finding environments where carbon can assemble complex molecules – organic molecules

Evolving simplicity into complexity requires a special environment

- Environment must be not too cold (frozen: no complex actions possible) or hot (high heat destroys all molecules, hence reduced to simple atoms or ions, no complexity possible).
- Parts of the Universe must collapse on smaller scales to form planets, stars…
- But yet expand on large scales so that it can be long-lived
- Because….

To assemble complexity requires TIME

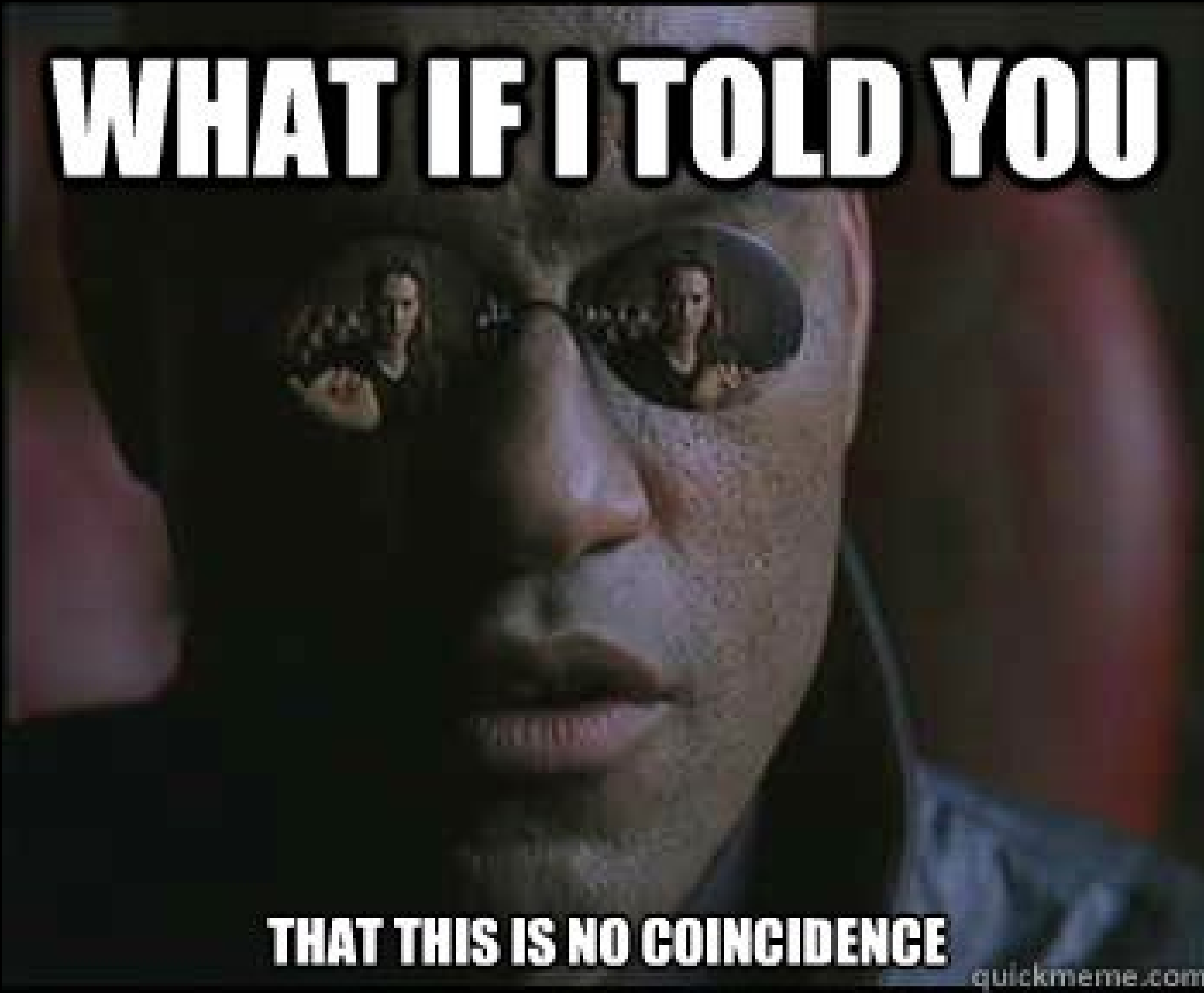
- **Evolution proceeds by errors in the self-replication of DNA.** But such errors need to be small and “rare”, else death. So intergenerational changes are small and incremental. Successful evolution takes time
- Therefore, the Laws of Physics must permit stable environments for LONG times.

- But there's endless ways the 19 (or 26 Or 32 depending on how you count and view them) different independent(?) parameters which define the **Standard Model of particle physics** (which is very well verified experimentally) can be specified and yet which make for a universe in which complexity cannot evolve at all – no life!

- Example: Our Law of Gravity – an inverse square law - permits stable two-body orbits. Most conceivable gravity laws will not do that, making planets and stable climate impossible.

Were we just very lucky?

Not likely…


WHAT IF I TOLD YOU
THAT THIS IS NO COINCIDENCE
quickmeme.com

Pretty Improbable…

- …that the one and only Universe that ever has or will exist, happened to have a rare set of laws of physics which would allow life, or…
- **(1) A God created it**? - but then, where did HE/SHE/IT come from?
- If God can be Eternal, why not the Universe? So the “first cause” argument for God falls flat.
- Also, any Being capable of creating the Universe with all its complexity, would need to be even more complex – says straightforward information theory. You don’t solve the origin of complexity by postulating a first cause even more complex.
- This is not to mention the insoluble moral arguments against the existence of the Biblical God with his observed vs postulated characteristics.
- And, we don’t need to, as it turns out.

Postulating a God leads to circular reasoning and doesn’t solve the problem of the origin of complexity from simplicity

- The orthodox religions’ versions of God have deep moral and internal logic flaws too numerous to go into here. (see here for some **Online Talks** with thoughtful discussions)
- Instead, physical laws **show** how complexity which constitutes life, evolves naturally and unconsciously from simplicity, once inheritance is part of the picture.
- Similarly, we’ll see we’re self-selected if the simplest models of Inflation continue to explain observations. **It’s a cleaner, more evidence-based solution.**

Not only does Inflation have solid observational evidence to support it…

- …It is very difficult to find <u>any</u> mechanism generating Inflation which would not also produce a near-infinite number of Universes through ongoing Inflationary moments. “Eternal Inflation”

An ~Infinite Number of Universes! – The MultiVerse

- “Universe” now means a particular instance in this “multi-verse” with its own framework. Space, time, dimensions, and force laws, which tumble out of symmetry-breaking in a random way, subject only to the Quantum Uncertainty Principle and laws of Quantum Mechanics, which we believe is more deeply fundamental than the physical constants and force laws, and is likely common to ALL universes)
- Said another way, we can understand how a multi-verse of universes all obeying the same fundamental laws of quantum mechanics, can yet have a wide variety of physical constants and force interaction laws, and this is the simplest (and most quantitatively explorable) model.
- Could it instead be “deuces wild” on EVERYthing? I suppose that’s hard to disprove, but it’s not necessary, and therefore not so interesting.
- Inflation describes how universes in which Total Energy=0 could be created out of the Vacuum. **“Eternal inflation”**

Testing these ideas against reality…not so easy

- String theory versions, and others speculated upon, require such incredibly high energy particle physics experiments that it is hopeless to expect humans will ever be able to design such powerful particle accelerators. They'd require cyclotrons the diameter of the Earth's orbit (!)
- We perhaps can only hope that Nature has done such high energy experiments for us and is leaving, or has left, clues for us to see.

…If true, the Multi-verse (or "landscape"; its version in String Theory), is a natural solution to the puzzle of our Living Universe

- How? **Easy!** No need to wonder why we're in such a wonderfully inhabitable universe: We're "self selected" to be in just such a universe.
- Most universes would likely come out of the "Cosmic Oven" botched – laws of physics may freeze out of the inflationary creation event differently and most are incompatible with the formation of stable environments suitable for the evolution of complexity in any form, thus excluding Life.

And therefore - there's no living things in those sterile universes to complain about how unlivable their Universe is!

- We, obviously, could have **ONLY** evolved in a universe in which its randomly set laws and cosmic parameters happened to allow life to form and evolve –
- **No need to feel lucky or divinely inspired or created. We're "self-selected".**

Directly testable or not - It’s the most logically compelling and observationally well-motivated idea we have

- Quantum processes within a larger framework create Universes, which, through Inflation, can create and populate their own space, time, laws, all of which may be unique to that particular Universe
- Analog; the laws of fluids are the same everywhere, but yet every snowflake is different. Symmetry-breaking includes randomness.
- We, OF COURSE, find ourselves in one of the rare, wonderfully incredible universes with physics which is friendly to the evolution of life.
- Tons of other Universes are likely to be out there which are totally MESSED UP! In this regard. But, no one lives in them to complain about it!

Let's look at just one key parameter – the Cosmological Constant Λ

- Remember our video **"Runaway Universe"?** This is the parameter that describes the accelerating expansion of the Universe.
- Its value is labelled **Λ**, the Greek letter lambda, by convention
- The most "natural" expected value is about **10^{120}** times BIGGER than the one we actually have. This is a vastly huge number in which no structure, no complexity, let alone life, could possibly develop
- **Λ** must be vastly smaller to be compatible with a universe that can gravitate structure and permit long lived environments for life (given other physics parameters as they actually are)
- A new paper, though, shows surprisingly that it cannot be the other temptingly "natural" value we had originally expected, namely exactly **Λ = 0** (no accelerating universe)…

Piran *et al.* 2015 show…

- …that a small but non-zero **Λ** is required, else too many galaxies and stars form too close together and too many nearby fatal **Gamma Ray Bursts** go off during life's evolution, sterilizing life-giving planets too often.
- The following graph shows our actual universe has a value of **Λ** which is just about what the probabilities would expect, given all the factors determining a life-suitable Universe such as we live in.

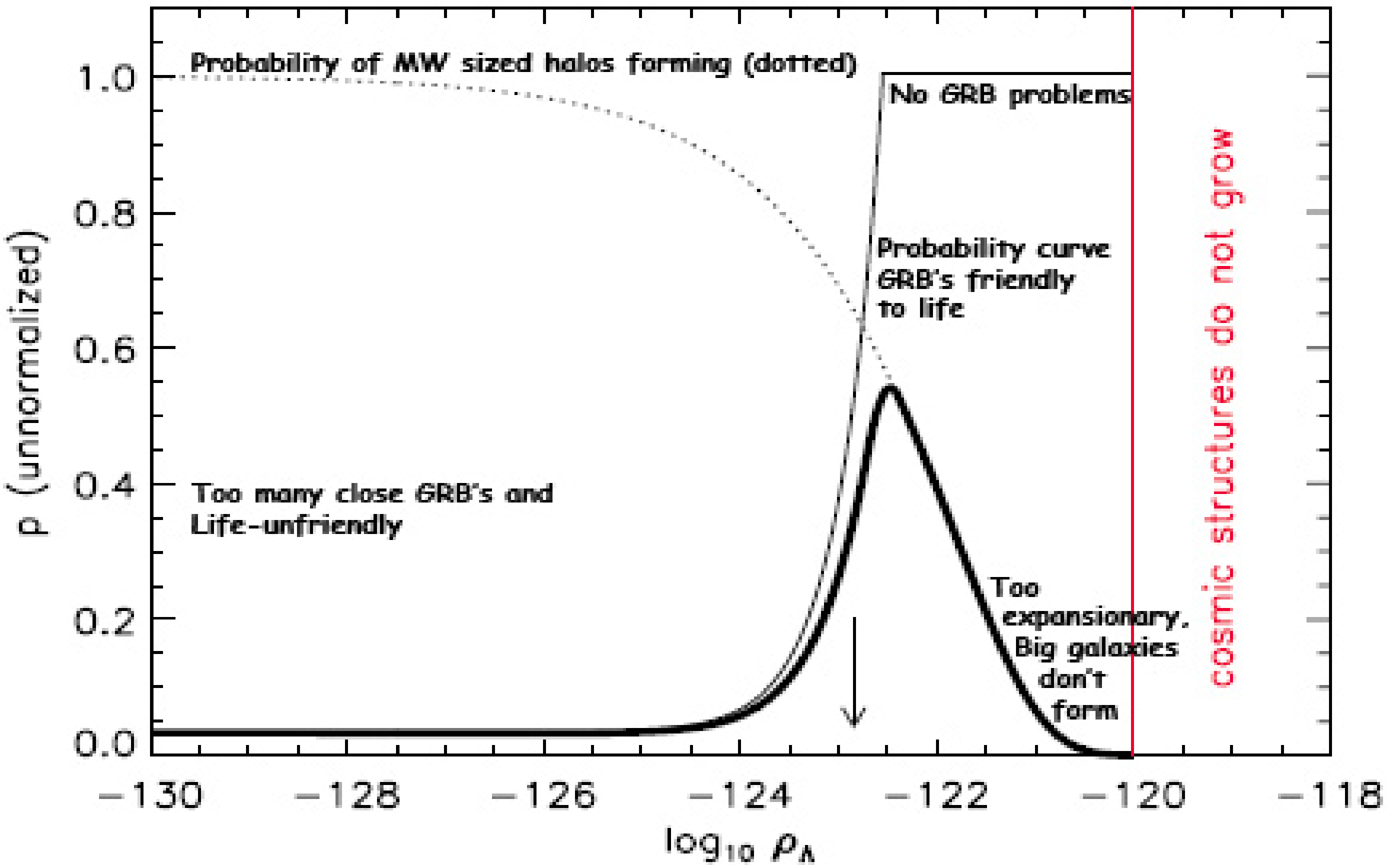


FIG. 2. The probability distribution function for ρ_Λ. The thin solid line is the result of this work ($I(\Lambda)$ from Eq. 1 and Fig. 1). The dotted line is $F(\Lambda)$ from [21], for Milky-Way mass halos. The thick solid line is the combined result. The upper bound is the requirement of [1] that large galaxies can form. The arrow shows the value of ρ_Λ for the concordance ΛCDM model.

Is the Multi-Verse paradigm true?

- We don’t know.
- Some versions of this paradigm include expanding universes within a larger space. If, by unlikely chance, these universes overlap and if the laws of physics within these differ, then you’d see the physics of the night sky might not be isotropic – it would show a circular patch with different properties
- Existing data don’t show this, but if the changes in the laws are subtle (unlikely), maybe looking closer could tell?
- Otherwise, we have no tests we have yet thought of.
- But, the Inflationary Multi-verse paradigm is appealing…
- **---1.** It is a natural outcome of most cosmologies that produce Inflation; the Inflationary moments are not unique, but happen “all the time”.
- --- **2.** The observed properties of large scale structure are perfectly in agreement with the predictions of Inflation, and no other idea.
- --- **3.** The Multi-Verse paradigm answers questions which otherwise don’t have apparent solutions.

We will say more about the conditions required by life

- …but only after being properly motivated by observational facts
- For now, lets turn to another question – if life evolved elsewhere and reached the capability of communicating across the stars, what would be the most efficient way to begin such a reaching out?
- **“ET Phone Home!” How?**

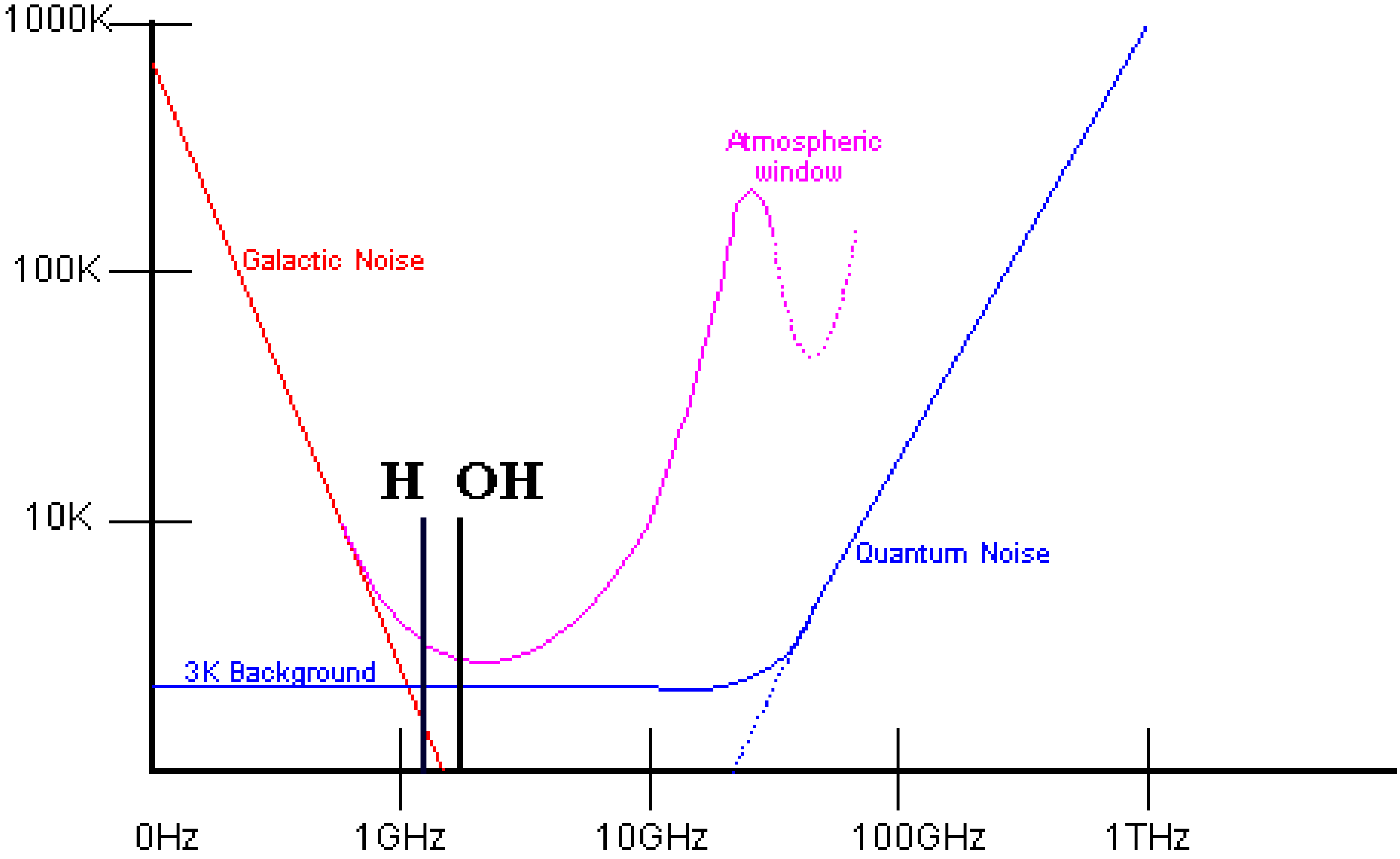
How would we contact them (or them, us)?

- EM radiation is fastest and by far the cheapest way.
- Gamma rays? X-rays? UV?
- Visible?
- IR?
- Microwave?
- Radio?

- **Gamma Rays, X-rays, UV** are all too high energy – they'd ionize every atom they hit and thereby scramble any information encoded on those waves.
- **Visible light** – no problem with broad band absorption, ***except*** you'd have a lot of trouble picking out that visible light signal against the glare of the parent star!
- **Infrared** – also a lot of hot interference. However, very short nano-pulses of IR could in that instant, outshine, and encode information. We're pondering this.
- **Microwaves** – cosmic microwave background radiation is 99% of all photons; that's a lot of noise to overcome.
- **Radio** – It's dark in this band! Easiest and perhaps most likely

Where in the radio band would you look?

- At the short wavelength end, the Cosmic Microwave Background competes and provides background noise in all directions
- At the long wavelength end, radiation from electrons spiraling in the magnetic field of the galaxy would add noise
- In the middle, around 1420 Mhz, it's quietest, and also this is near where hydrogen H and hydroxl OH have their key absorption features.
- H + OH = H_2O = water: **The water hole!** Galactic civilizations would perhaps congregate (and sing Kumbaya?) around the Water Hole in the electromagnetic spectrum. At least, it's a Santa Cruzy thought.
- This is where SETI is concentrating their searches



1000K
100K
10K
Galactic Noise
Atmospheric
window
H
OH
Quantum Noise
3K Background
0Hz
1GHz
10GHz
100GHz
1THz

What About Contact Using InfraRed Light?

- If they don't concentrate their power into incredibly short and powerful bursts, it suffers from the same problem as Visible light – being overwhelmed by light from the parent star.
- But it is technologically possible to concentrate IR into very short, very intense beams which could get around that problem.
- **We now have the technology**, as of 2015, to begin searching in IR in this way.
- Unlike Radio, IR beams would have to be aimed at us. This is good! They'd know we're here (that part's easy to determine for Them). Maybe the bad part is that if they DON'T want to let us know about them, they can avoid aiming their beams at us. Surprise attack!

“ET Phone Home… ET Phone Home” – Life Elsewhere in Our Galaxy

- How many civilizations are in the Galaxy which are able and willing to communicate with us?
- Frank Drake (at UCSC) took on this seemingly impossible question, and in ~1960 broke it into a series of more focused questions we could hope to make progress on - ***The Drake Equation***…
- It’s really just freshman probability theory applied to an interesting question
- **Here’s the original Drake Equation….**

$N = R^{*} f_p n_p f_L f_l f_c L$

- N = the number of interstellar-communicating civilizations in the Galaxy today
- R^{*} = rate of formation of suitable stars
- f_p = fraction of these with solar systems
- n_p = number of life-suitable planets per solar system
- f_L = fraction of these planets with life
- f_l = fraction of living planets with intelligent life
- f_c = fraction of intelligent living planets which choose to communicate across the stars
- L = average lifetime of a communicating civilization

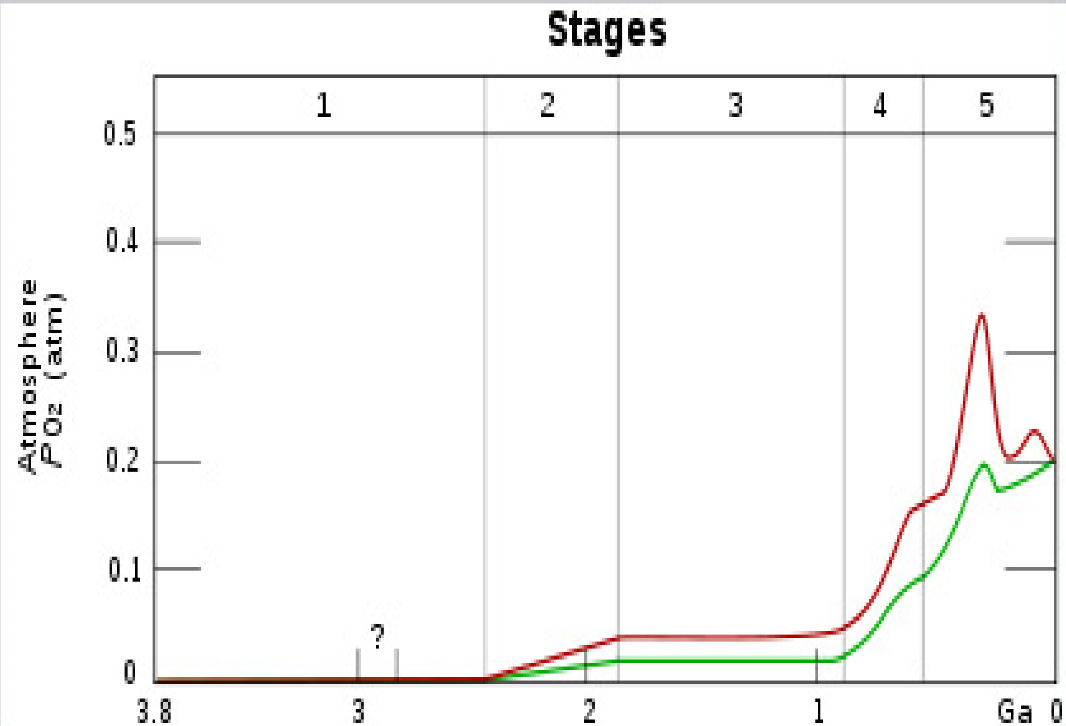
Let's put some numbers to these terms…

- **R* = rate of formation of suitable stars**

- We need temperatures suitable for complex carbon molecules and a liquid environment for chemistry to happen. Not too hot (breaks them apart), not too cold (hard to reproduce if you're frozen solid). Stars are too hot, we need planets orbiting stars!
- Life capable of interstellar communication took 4.6 billion years to evolve on our planet. If that's typical, it means we need stars who are stable for at least that long.
- Why do long, and is this necessary?

We May Need Most or All of that 4.6 Billion Years…

- Oceans, and solid crust on our planet got started quickly, within a few hundred million years.
- And life got going about 3.5 billion years ago, as primitive single-celled oceanic organisms for which oxygen was toxic.
- But complex and **energy-active life** requires oxygen for power
- And, oxygen in the atmosphere is also required in order to build an ozone layer high up, to block out the sun's dangerous UV light
- And it took till only ½ billion years ago for enough oxygen to build up to create an ozone layer that could shield us from deadly solar UV light, and therefore give life the chance to evolve rapidly away from mere ocean microbes into large land plants and animals in all their complexity and capacity.



O_2 build-up in the Earth's atmosphere. Red and green lines represent the range of the estimates while time is measured in billions of years ago (Ga).

Stage 1 (3.85–2.45 Ga): Practically no O_2 in the atmosphere.

Stage 2 (2.45–1.85 Ga): O_2 produced, but absorbed in oceans and seabed rock.

Stage 3 (1.85–0.85 Ga): O_2 starts to gas out of the oceans, but is absorbed by land surfaces and formation of ozone layer.

Stages 4 and 5 (0.85 Ga–present): O_2 sinks filled, the gas accumulates.[1]

Atmospheric O2 didn't build to high enough levels to allow UV safe inhabiting of the land, and the evolution of oxygen-using life until ½ billion years ago; ~4 billion years after the birth of the solar system

Is this Time Scale Typical?

- We don’t know if this is due to perhaps another rate-limiting biochemical step (molybdenum availability??), or other factors which may be unusual and unique to Earth
- If so, perhaps oxygen-using complex life capable of intelligence could have evolved in not 4.6 billion years, but perhaps in only ~2 billion years? Highly speculative.

A Useful Clock to Remember

- If the entire period since the birth of the Earth were thought of as a single 24 hr day, that’s saying that until just **3 hrs before midnight (midnight being right now)**, life was non-existent or very simple single-celled organisms and incapable of being intelligent or interstellar-communicating, and existed almost entirely in the oceans.

If that's Typical of Other Solar Systems…

- …then we need stars who's main sequence stable lifetimes are at least 4.6 billion years - so we need G & K main sequence stars. Rate of formation of these is about **1 per year** in our Galaxy.
- If instead, only 2 billion yrs may be needed, then late F stars could work, that won't change our number below significantly; it's still about 1 per year
- **R* = 1**

f_p = Fraction of these stars which have solar systems

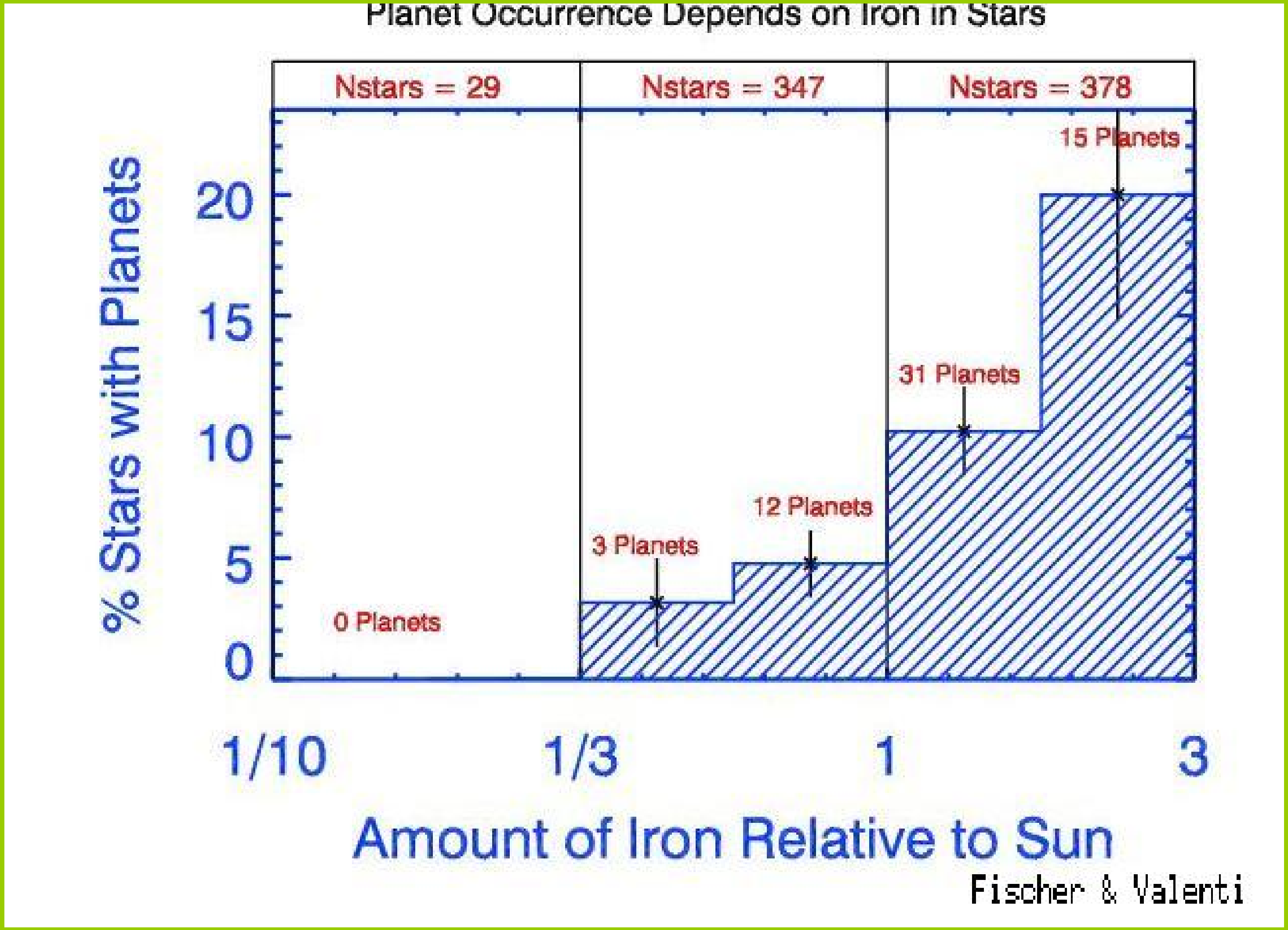
- Till recently, we had no confident idea of how common solar systems were. **Now, we do**.
- Kepler Mission data and Doppler method data show that **nearly all stars have planets; 90-95%.**
- **But age is relevant, and metallicity too, and these two aspects are related…**

Supernovae go off about once per century per galaxy, seeing the interstellar medium and future star formation regions with their heavy elements ("metals"). So the "metallicity" of later born stars is gradually going up.

We want G, K Main Sequence stars which have been around for a few billion years already

- But the probability of having a solar system is strongly correlated with having significant heavy elements in your spectrum.
- And the “metallicity” of stars being born is going up with time. So stars born billions of years ago the odds will be a bit less than those born today

Solar Systems don't form for low metallicity stars (Fischer and Valenti 2005). This suggests we should drop the "~90%" to, say, ~70% for stars old enough to have advanced life. f_p=0.7



n_P = Number of life-suitable planets per solar system

- This is a far more intricate question than Drake's time could deal with, and will require more thinking later in the presentation… but for now let's be naive and optimistic:
- In our solar system, we have ~2 planets in the "habitable zone", where temperatures are just right. Earth is alive, of course, but we're "self-selected" so we can be misleading to include in this calculation.
- But Mars was suitable, and maybe Venus for a while. Just bad luck their fortunes went south?

We have data on $f_p n_p$ as of 2020.

- About 50% of G, K main sequence stars have ~small planets relatively close to the parent star (Bryson *et al.* 2020) in the habitable zone. This does not mean “life suitable” though, that’s a stricter statement. But we’re being naïve and optimistic at this early stage, so in the spirit of the original Drake equation, we’ll say planets in the Habitable Zone are life-suitable
- **So the product of f_p = .7 and n_p should result in 0.5 to be consistent. This gives…**
- **n_p = .5/.7 = .7**

f_L = Fraction of these planets with life

- Life seems pretty tenacious, and bacteria appeared on Earth very soon after the Early Bombardment period.
- We find life even buried inside rocks miles beneath the surface.
- If life's possible, it seems to happen. And quickly.
- **In other words, If Life Can Happen, It WILL Happen**
- life-suitable planets WILL have life, at least most of the time, so…
- **f_L =1**

f_I = fraction of living planets with Intelligent Life

- Let’s kick this one around a bit, in class
- Should we expect life to always evolve towards higher intelligence?
- What is the survival value of intelligence?
- Here, we’re considering “intelligent” means it is capable of creating technology to communicate across the stars, as we are doing

- Myself, I think that sooner or later, life ***will*** get around to evolving intelligence as a survival tactic. So many millions of species, so many ways to carve out a niche. Intelligence certainly does have survival value (at least until it kills its environment).
- I know what you're thinking…! But Hey, we don't need to ask yet how LONG an intelligent civilization will last (that's the last term in Drake Equation); here we only care whether interstellar-communication-capable intelligent life will arise at all

It might be optimistic, but it's not unrealistic to set…..

- **f_I=1**

f_c = fraction of intelligent living planets which choose to develop and use the technology to communicate across the stars

- This one needs some kicking around the class too…

My thoughts…

- I can’t imagine a mature intelligence, an intelligence capable of interstellar communication, which does not also feel curiosity.
- Curiosity is our in-built motivation to ***use*** intelligence
- (Doesn’t mean Nature has to oblige my inability to imagine such lack of curiosity, of course). Nature could in principle evolve other motivations besides curiosity to engage intelligence

Are We Too Pathetic and Ridiculous to be Curious About? (I hear this one a lot from students**)**

- Hey wait – our species has produced more than just Donald Trump's. It's also produced Einstein, Rembrandt, Michelangelo, da Vinci, Rachmaninoff…. Yes, we've got plenty of pathetic individuals, many of them in prominent places, but we're not a pathetic ***species***.
- And even if we were, look at how many intelligent and curious scientists are fascinated with bloodworts and slime molds and doggy fleas! Wouldn't aliens therefore likely want to study US?
- For me, it's hard to imagine that they would NOT want to talk to us (if for no other reason, than to find out where we went so wrong).
- $\mathbf{f_c=1}$

L = The average lifetime of a communicating civilization

- So our Drake equation has a rate of formation, and then a bunch of probabilities which pare down the suitable stars and get to real civilizations we can talk to.
- To get a dimensionless pure number of civilizations, we need a term in the equation with units of time.
- This is L = **the lifetime of the civilization**
- This is the toughest one of all, since we have **NO** data on the answer… let's kick it around some

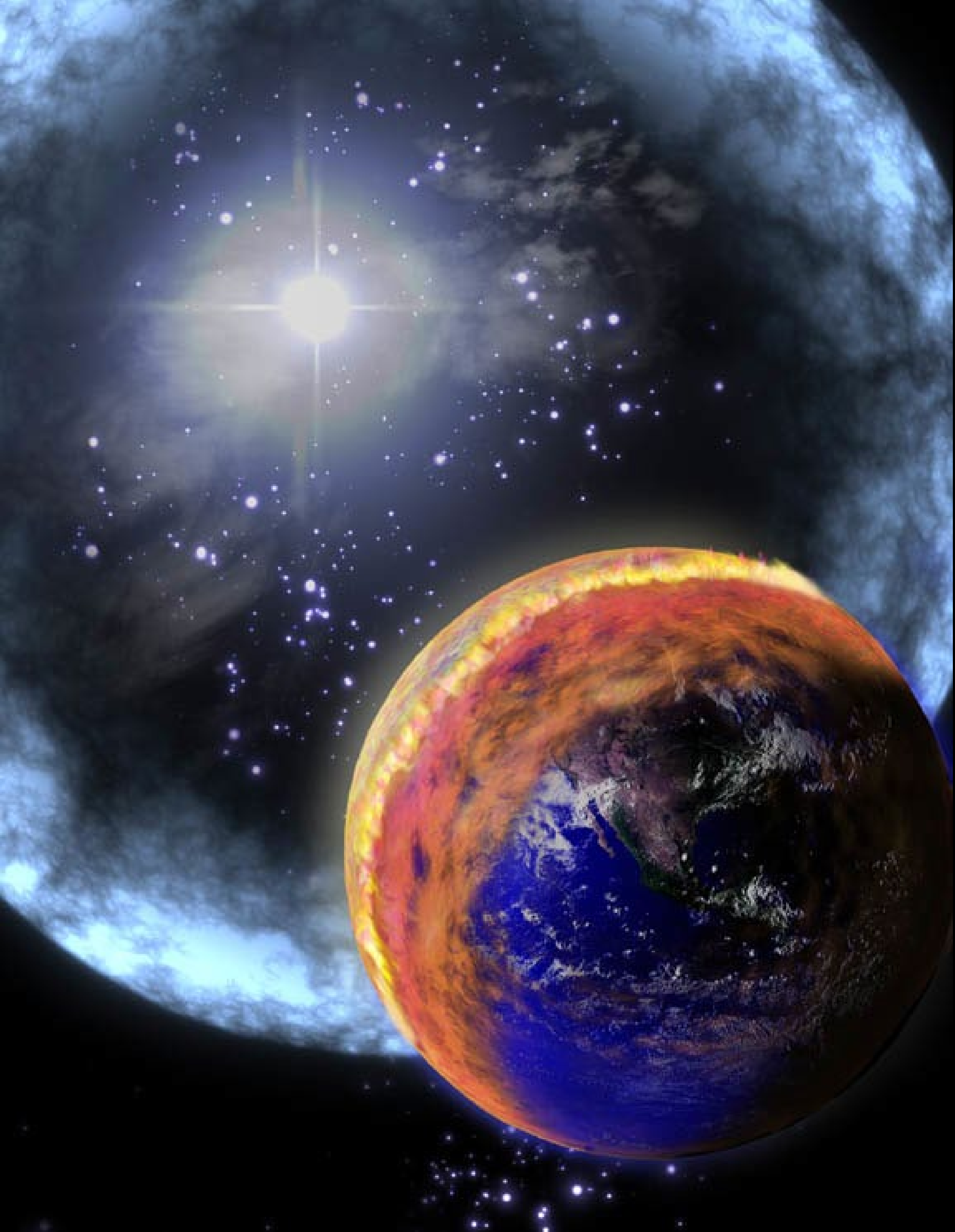
Earth is in Crisis. Now. Today's Population is 8 billion.

- *"Estimates of the long-term carrying capacity of Earth with relatively optimistic assumptions about consumption, technologies, and equity, are in the vicinity of **1 billion people**. Today's population cannot be sustained on the 'interest' generated by natural ecosystems, but is consuming its vast supply of natural capital -- especially deep, rich agricultural soils, 'fossil' groundwater, and biodiversity -- accumulated over centuries to eons. In some places **soils, which are generated on a time scale of centimeters per century are disappearing at rates of centimeters per year**. Some **aquifers are being depleted at dozens of times their recharge rates**, and we have embarked on the **greatest extinction episode in 65 million years**."* -- Paul Ehrlich (Sept. 25, 1998)
- **Half or more of all species of life on Earth are predicted to go extinct – thanks to Humans – by the end of the 21st Century.**

Nolthenius' First Law "***People Learn the Hard Way***".

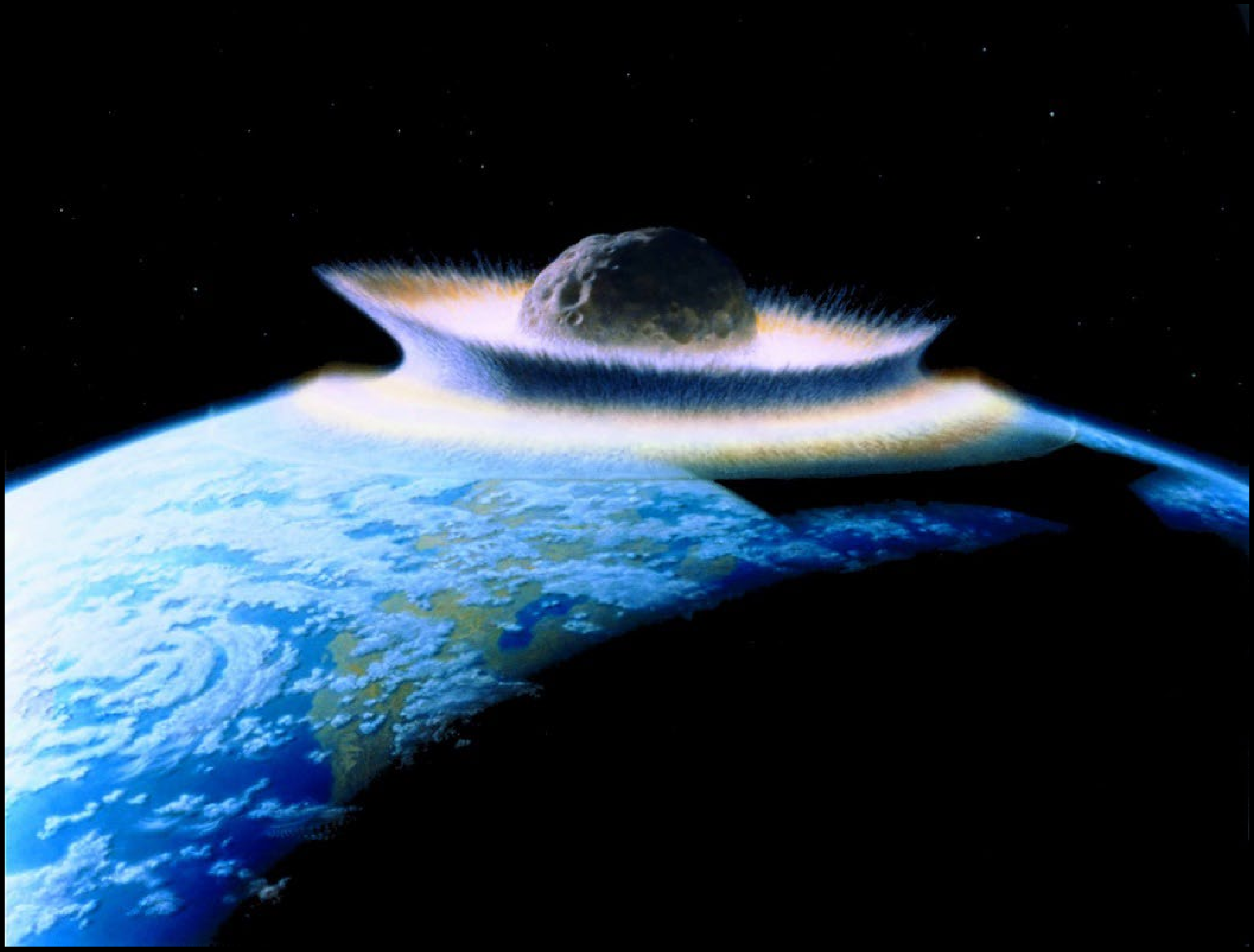
- Earth's population will very likely decline to ~2 billion, or less. It's very likely that this will happen the hard way, because people tend to only get out of their "comfort zones" in emergencies. Vastly unfortunate because…
- Climate change time scales mean "cause" and then "effect" are decades to centuries apart, so humans who complacently wait for "effect") respond far too late to prevent disaster
- Even with 1-child-per-family worldwide, starting today, population will continue to grow for decades, and only fall to 4 billion by 2100; **FAR** too late.
- We likely cannot support that many people for another century, and that's assuming the political will to enforce it. Even China has backed away from their 1-child policy. **Grim….**
- But, If we somehow survive ourselves… **what other Planet-killers do we face?**

A Supernova within 35 light years would also fry the ozone layer for centuries, killing most life on land. Several hundred million years+ between these



Even thousands of light years away – a Gamma Ray Burst aimed our way would fry the ozone layer. About One per Billion Years. May Have Caused the Ordovician Extinction 444 mya

What about Killer Asteroids and Comets?

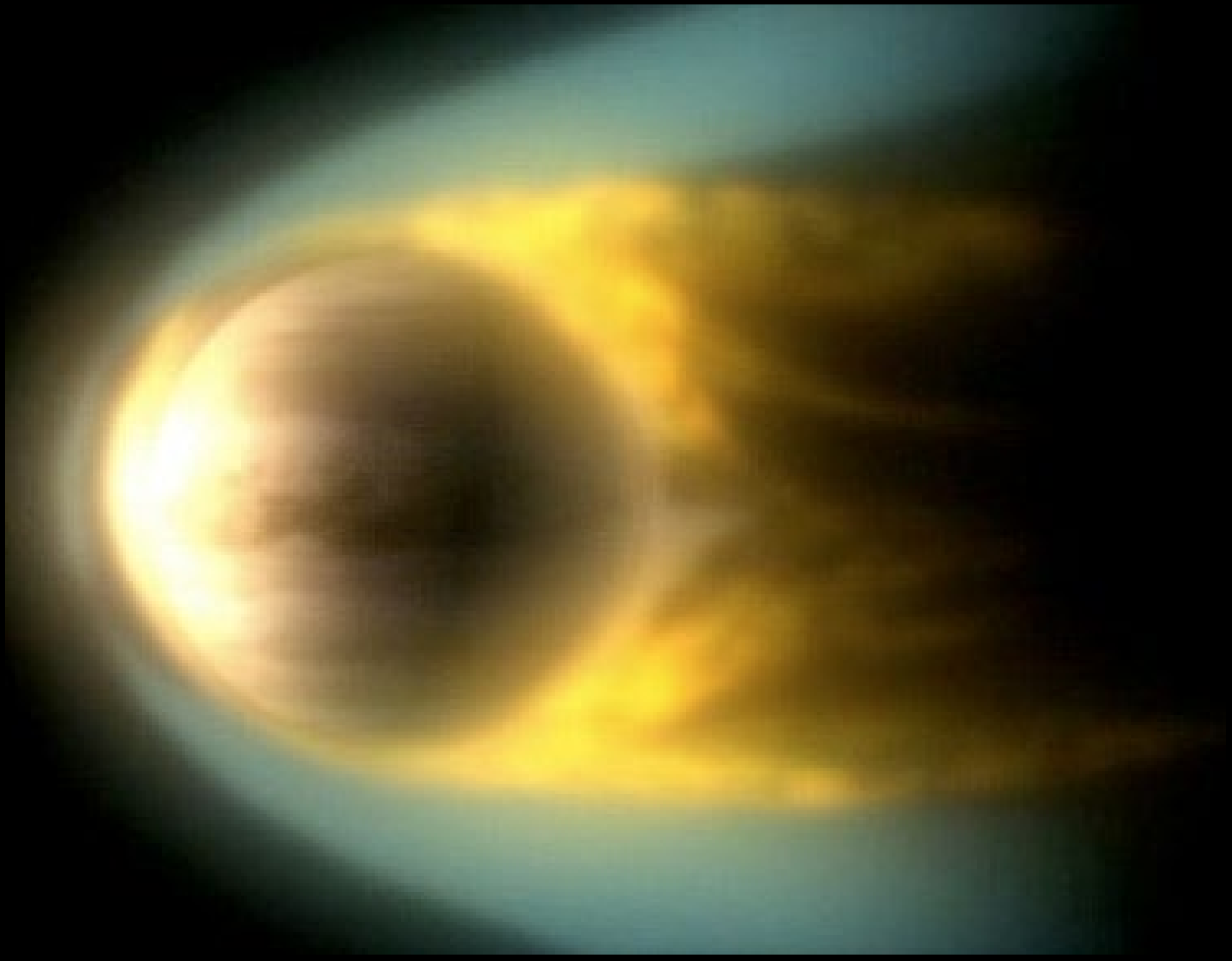


Will We Be Prepared?

Actually, I think We Will

- We've already discovered 90% of all asteroids on orbits which could intersect ours and are large enough to cause significant loss of human life
- A rare comet coming straight in from the Oort Cloud would require a fast mission to blow it up, but we could be ready for even that, in a decade or so with a bit of work.
- ***No Problemo!***

Solar evolution will eventually bake Earth to a Runaway Greenhouse death…but not for a few hundred million years



Truth is, We really don't know How Long A Civilization Typically Lasts

- For us, I think the 21st century will be very bad, but the human race will not go extinct.
- We'll muddle through, and learn to live on the planet we crippled
- So let's use The **Principle of Mediocrity**; This says - we're roughly at the midpoint (a mediocre point) of our ultimate lifetime.

If We Survive Ourselves…

- The human species is very roughly 1 million years old (lets not split hairs over sub species).
- Figure we make it through the tough part of our evolution, and if we can survive our adolescence – today - that we'll survive with our knowledge for another 1 million years; so that we're at the mid point of our time since our ancestor's beginnings.
- Consider it a compromise between our iffy odds of making it through w/o nuclear or climate annihilation, and the long period between astronomical generated extinctions
- **So: L = 10^6 yrs = 1 million years**
- We can now plug this into the Drake Equation and calculate our guesstimate of how many civilizations are out there for us to talk to…

$N = 1/yr \times 0.7 \times .7 \times 1 \times 1 \times 1 \times 10^6$ yrs

- **= 500,000 civilizations in the Milky Way Galaxy right now!**
- Wow. That's a LOT.
- Too many, actually, to really be believable, as we'll see…
- But first…

…A more Interesting question is – How far away is the Nearest Galactic Civilization?

- One night I decided to take a stab at this…
- We need Pop I stars, with rocky material; Galactic exponential scale length is 5 kpc, scale height is 200 pc, and we're 8 kpc from the center of our Galaxy
- Throw some calculus at the problem, plug and chug, and we arrive at what we'll call – the **Nolthenius Equation**
- **$D_{nearest}$ = 77,000 lyr / Sqrt(N)**
- **= 109 light years assuming N=500,000 civilizations**
- **We'll see that's probably WAY too optimistic**

Von Neumann Machines, Monoliths, or Berserkers?

- Technology advances so rapidly, we would expect an intelligent species to be able to make "**von Neumann machines**" within a thousand years or so after becoming technological (like we did, about a century ago).
- **Von Neumann machine**: capable of reproducing itself from native materials on a planet it lands on, launching copies to other planets to further explore and send back information..
- Futurist Ray Kurzweil thinks we'll have 3D printers capable of 3D printing every component of their own machinery as early as 2020. It's now 2023 and we have nothing of the sort – but Ray is often wrong in this way. But suppose some day we succeed:
- would they self-evolve to become "**berserker machines**"?
- Well, either way…

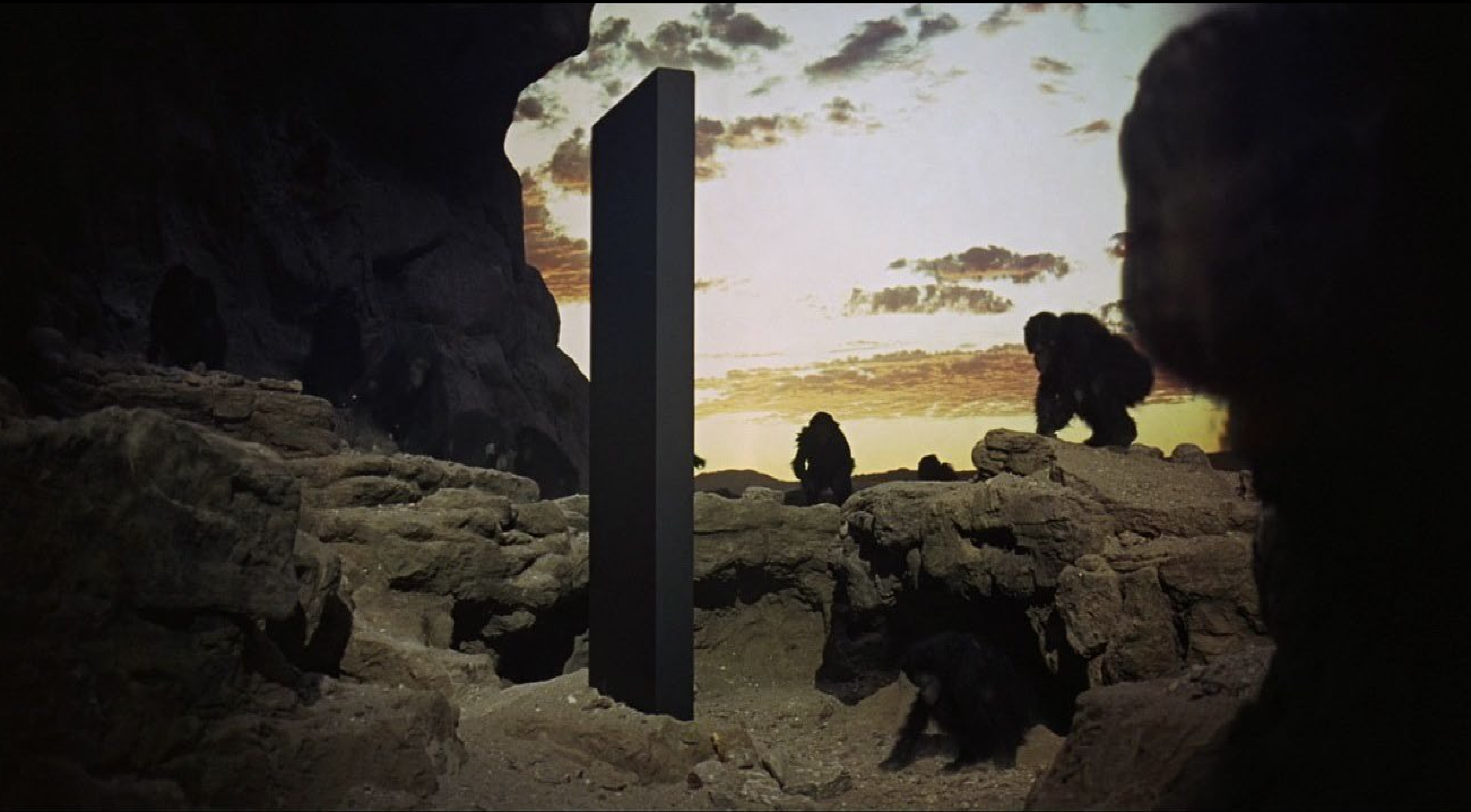
What I'm Coming to Think…

- … is that **They** are just not out there.
- Intelligence and language enable growth through teaching.
- Learning and technology increase at a fantastic rate *vs.* the glacial pace of biological evolution.
- Moore's Law of computers is that computer capabilities double every 18 months. Been true since the 1950's.

Colonize by von Neumann machines?

- As machines, they can handle large accelerations and could colonize the Galaxy in less than 100 million years – short compared to the age of the Galaxy. Exploration grows geometrically fast, characterized by a doubling time!
- **Earth is a rare, desirable planet.** It would be vastly easy for **Them** to have recognized us right away (atmospheric O_2 and CH_4 together are the giveaway for a living planet, in the spectrum)
- ***Yet - we see no evidence of visitation having happened.***
- ***It is tempting to conclude – we are alone.***

…We See No Monoliths Left from Visits by the Aliens (well, except maybe for Oumuamua!)



Why?

- Why?
- When …. an apparently reasonable calculation shows that hundreds of thousands of civilizations should exist out there, and Earth is easy to recognize as a planet covered with abundant life, and that living planets are a tiny minority of all planets so we'd be seen as a special jewel.

Are You Thinking They Just Haven't Had Time to Evolve Yet?

- Our solar system didn't get started till just 4.5 billion years ago, *vs* the 13 billion year age of our Galaxy. So there was plenty of earlier time for civilizations to mature and evolve around earlier stars.
- It's hard to get around… It seems obvious they'd already BE here, or show evidence of having been here and set up a monolith or similar. They haven't: this is called **Fermi's Paradox. So, maybe…**

…Hard to Identify Alien-Human Hybrids Amongst Us ??

More seriously, many more things have to go <u>right</u>, to give birth to an Interstellar Communicating Civilization

- First, most of our Galaxy may be tough for life. In closer to the center, the rate of nearby supernovae is much higher. Too far away, not enough metals to make suitable planets. We live in the Galaxy's own "habitable zone", so the 1 star/year should be reduced some.
- But the Galactic "habitable zone", at first glance anyway, is wide and this argument will only knock down N by factors of a few - it won't solve **Fermi's Paradox**…

Where Could we Have Gone Wrong in our Original Drake Equation Numbers?

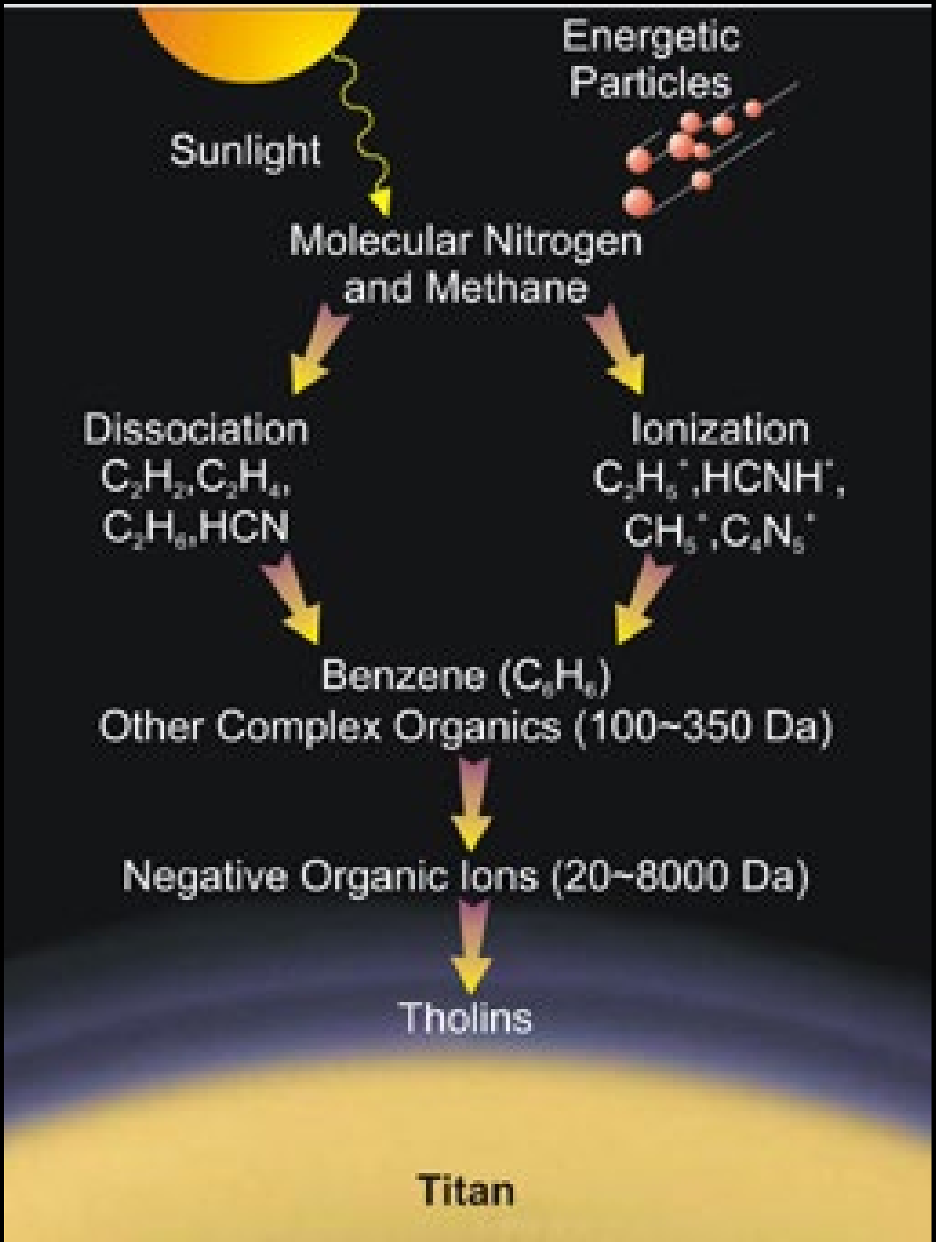
- The basic raw materials of life – organic molecules, truly are common.
- We see them in meteorites (carbonaceous chondrites) and in the spectra of comets.

And We see Organic Molecules in Interstellar Clouds

We See Organic Molecules in Proto-planetary Disks

- HR 4796, home to a protoplanetary disk with Tholins – organic molecules

Tholins are Large, Complex Molecules Required by Life – and are Also Found Now in the Atmosphere of Titan



But It’s a BIG step from Organic Molecules, to Life

- Did that require an incredibly rare circumstance?
- DNA codes nearly all life on our planet.
- The problem with DNA is that it requires significant chemical catalysts to form – catalysts which are coded for… by DNA!
- Chicken-and-Egg problem!

So Do we Need Supernaturalism - a Miracle - to Get it Started?

- **Well, no.**
- Turns out that Ribozymes, relatives of RNA, a single strand relative of DNA, are capable of acting both as a catalyst and as a messenger for genetic information. These have been synthesized in the lab, although not yet found in outer space
- We now suspect that the first life was RNA-based, not DNA-based. And DNA came along later.
- RNA can do catalysis just like proteins coded by DNA, but very slow and inefficient. Once DNA happened, DNA-based life would out-compete RNA-based life in any niche they shared.
- Interesting link for you on this.

Now Let's Go Back and Re-ponder New Factors we Have Learned in Recent Decades

- There are quite a few special things about our Earth and solar system that the discovery of other solar systems by Kepler Mission and ground-based Doppler Method have helped us understand.
- So, we should multiply our original number of civilizations $\mathbf{N_{p0}}$ by the following additional probabilities
- $\mathbf{N_p = N_{p0}\, f_{nv}\, f_{ss}\, f_{co}\, f_{lm}\, f_{cj}\, f_{w}\, f_{mf}\, f_{pt}\, f_{o}\, f_{gh}\, f_{nr} f_{hz}}$
- So, let's start that process… first, to re-cap:
- N_{p0} = Our first, naïve, optimistic original N_{p0} **= 500,000 Galactic Civilizations**

An Important Principle to Remember…

- **What limits the ability of a planet to support life, is CLIMATE.**
- **STABLE CLIMATE is all-important. Major climate change - is BAAD. I can't stress this enough!**
- Complex oxygen-using life requires temperatures in a very narrow range to succeed. Biological processes go at a rate which is proportional to absolute temperature to a very high power, hence narrow range, which requires an external climate which can permit such constant internal body temperatures to exist
- Most of the factors we've already looked at, and all of the remaining ones we'll now look at, relate to the probabilities of a **STABLE CLIMATE**

f_{nv} = fraction with non-variable star

- The parent star can't be variable to any more than about 7% or this will cause climate to be too variable to adapt to.
- Most stars are more variable than the sun
- Most sun-like stars are more variable than the sun, although the sun could be MORE variable by a factor of a few and still permit life here. So… figure that….
- **f_{nv} ~ 0.8, this is high; so it doesn't knock down our # civilizations much**

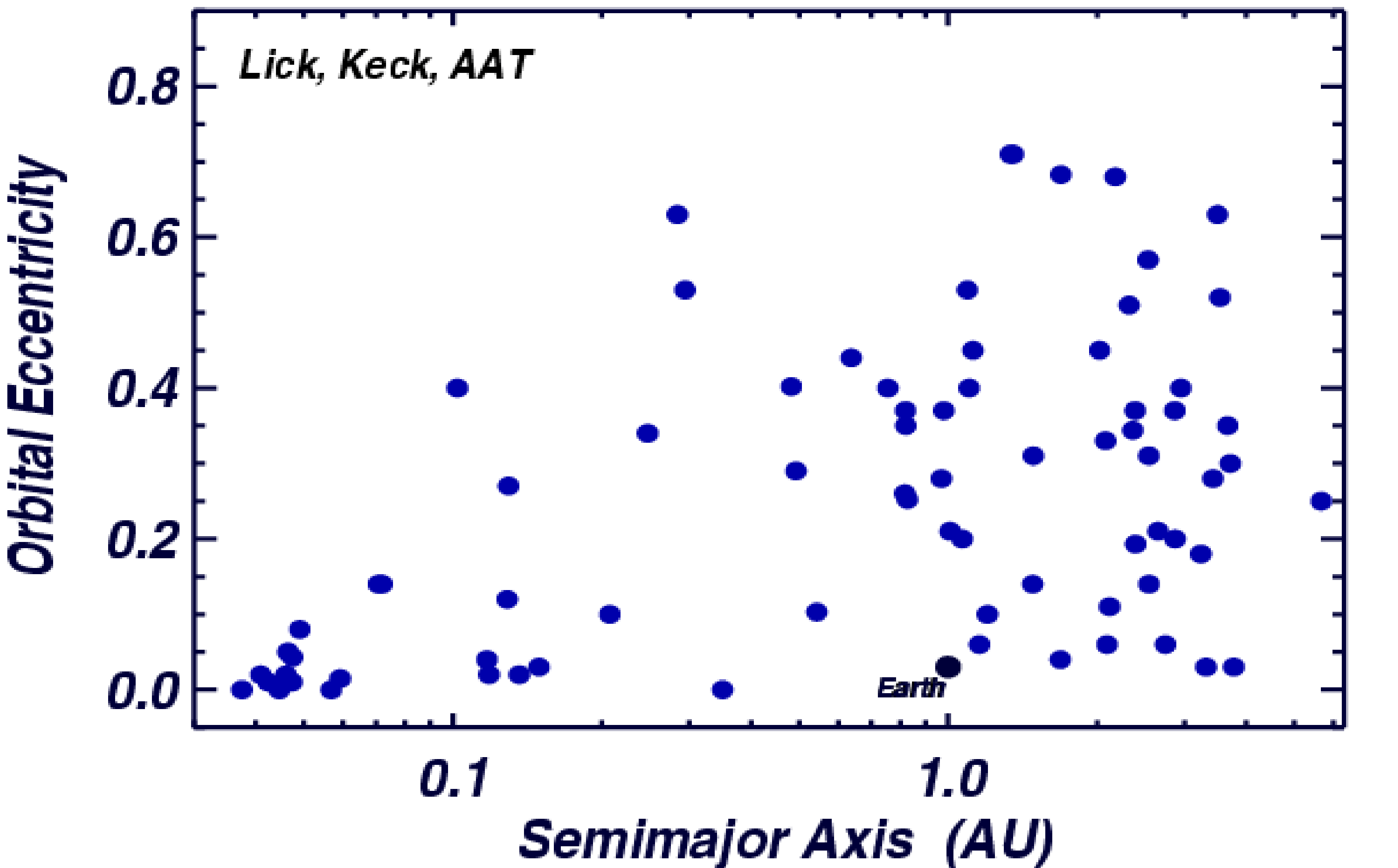
f_{ss} = fraction of suitable stars which are single, or wide enough binaries that stable orbits exist where it's nicely warm

- Binary stars are trouble, as this will cause both orbital instability and variable heating problems. Most binaries are close binaries – exactly what you do NOT want for a living planet.
- Among wide binaries, about half could harbor an Earth in a stable orbit close to one star (Lada *et al.*). But by far most binaries are close binaries
- Most red dwarfs are single, but they're M type stars are subject to flares and their deep convection zones makes those flares strong and fatal. Medium and higher mass stars - more than half are in binaries
- Roughly, $\mathbf{f_{ss} = 0.5}$

f_{co} = fraction of habitable zone planets with ~circular orbits

- Significantly elliptical orbits cause large changes in climate. Planets would freeze and boil alternately unless the orbit was of low eccentricity.
- From Kepler data, appears roughly 70% of planets have orbits too elliptical for comfort. See next slide.
- **f_{co} = 0.3**

We see… lots of planets have very eccentric orbits, unlike the circular orbits of our own Solar System. Dynamics indicates this is caused by migration



f_{lm} = fraction with a large moon to stabilize the spin axis

- A wandering spin axis makes for extreme climate, freezing or boiling away large amounts of our water, or both (just ask Mars).
- We have no data on exoplanet moons to judge this, but only the Earth has a large moon among our inner planets, and it likely was the product of a unique collision with just the right impact parameter so the resulting collision debris doesn’t all fall back to the planet and some stays in orbit. And it also spins up the Earth so we get a rapid day/night cycle, equalizing temperatures. Maybe only 15% odds of this good luck.
- **f_{lm} ~ 0.15**

f_{cj} = fraction without “Jupiters” in significantly elliptical orbits

- Planets outside the “frost line” should often be gas giants like Jupiter. Kepler data suggests these planets are common.
- But a “Jupiter” in a strongly elliptical orbit will strongly disturb the orbits of most planets, including those inside its orbit in the Habitable Zone. Lucky for us that our Jupiter (and Saturn too) are in nice circular orbits
- Kepler data shows, unfortunately, most exoplanets **are** in much more elliptical orbits than our planets.
- **f_{cj} = ~0.3**
- On the plus side, new studies show that the old argument that you need Jupiter to knock away dangerously numerous comets in the inner solar system, seems to not make any real difference, so neglect that factor.

f_w = Fraction with significant water, but not "water worlds"

- Think of how perfect Earth is, in having an ocean covering an ideal 70% of our surface. Not too little, not too much
- The high thermal capacitance of all that water makes for very narrow temperature range for the planet, and so a good stable climate for Earth, permitting liquid water in most places
- But yet, it does have 30% land for non-fishy intelligent beings with opposable thumbs to live on. Hard to figure how interstellar-communicating civilizations could happen on a Water World…. How do you cast metal, build electronics, etc. under salt water? And with fins? Dolphins may talk, but they don't build machines or do space communication or space travel.

- Jupiter’s Europa, Ganymede, and Callisto are all very thick ocean “water worlds”, but frozen solid
- Titan has a vast ocean under its frozen ice surface too
- Mars looks like it had continents and oceans early on. But no liquid at all, now.
- Also need some sort of active geology in order to continuously build mountains, otherwise they wash away and you’re back to a water world

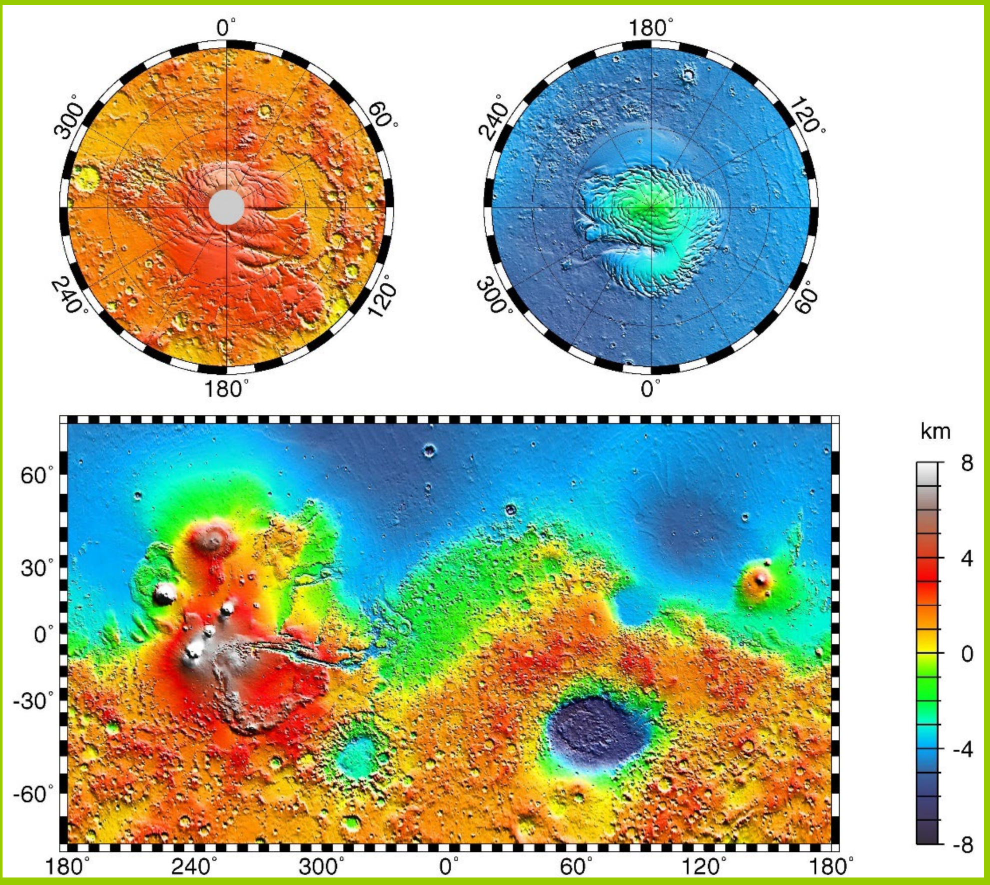
- Need also to have not too little water, or climate is again extreme. Land has little thermal capacitance.
- A few lakes might not be enough to prevent that water from not boiling away and leaving to outer space on billion year time scale.
- **We need water: not too much, and not too little**, let's estimate 4 times out of 5 it'll be not right, so…
- $\mathbf{f_{w} = 0.2}$

f_{mf} = Fraction with significant magnetic field

- A magnetic field strong enough to deflect the stellar wind is essential to maintain your atmosphere from getting sand-blasted away.
- Look at poor Mars!
- Need rapid rotation and iron core for magnetic field
- Earth is the only rocky planet with a significant magnetic field, so odds low?
- But if you have a large moon, you may have had the collision which made things right, so this may not have to be an “independent” variable. So these joint probabilities raise the odds to roughly…
- **$f_{mf} = 0.6$**

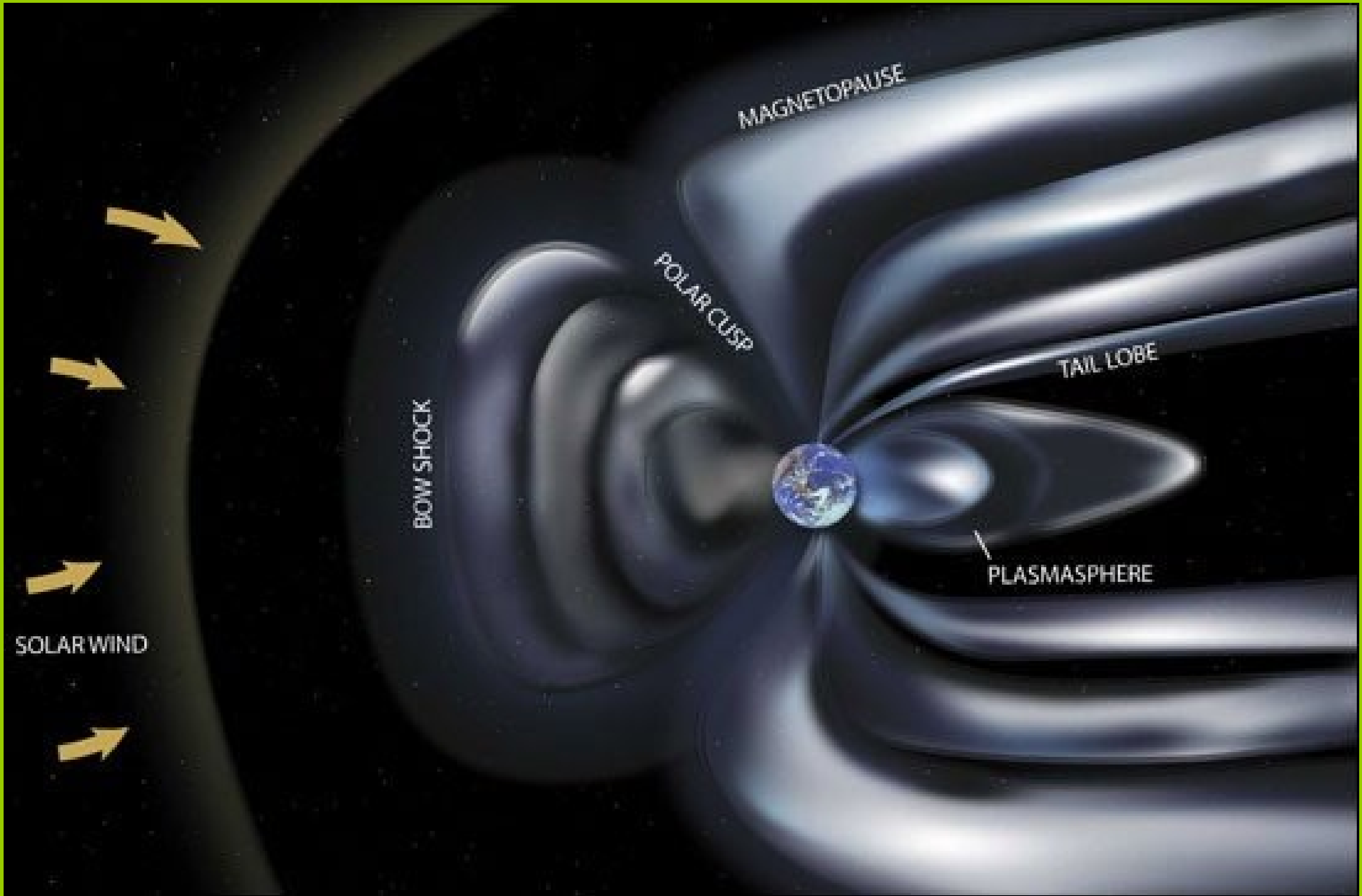
Ancient Mars – strong evidence for a major ocean, needing thicker atmosphere to confine a liquid water with higher pressure. Where did that thicker atmosphere go?

Deep low topography at north pole – impact size from large planetesimal or major asteroid collision?



- Yet this is hypothesized to also have shut OFF Mars' magnetic field, by scrambling its liquid to solid core, where we believe Earth's magnetic field comes from.

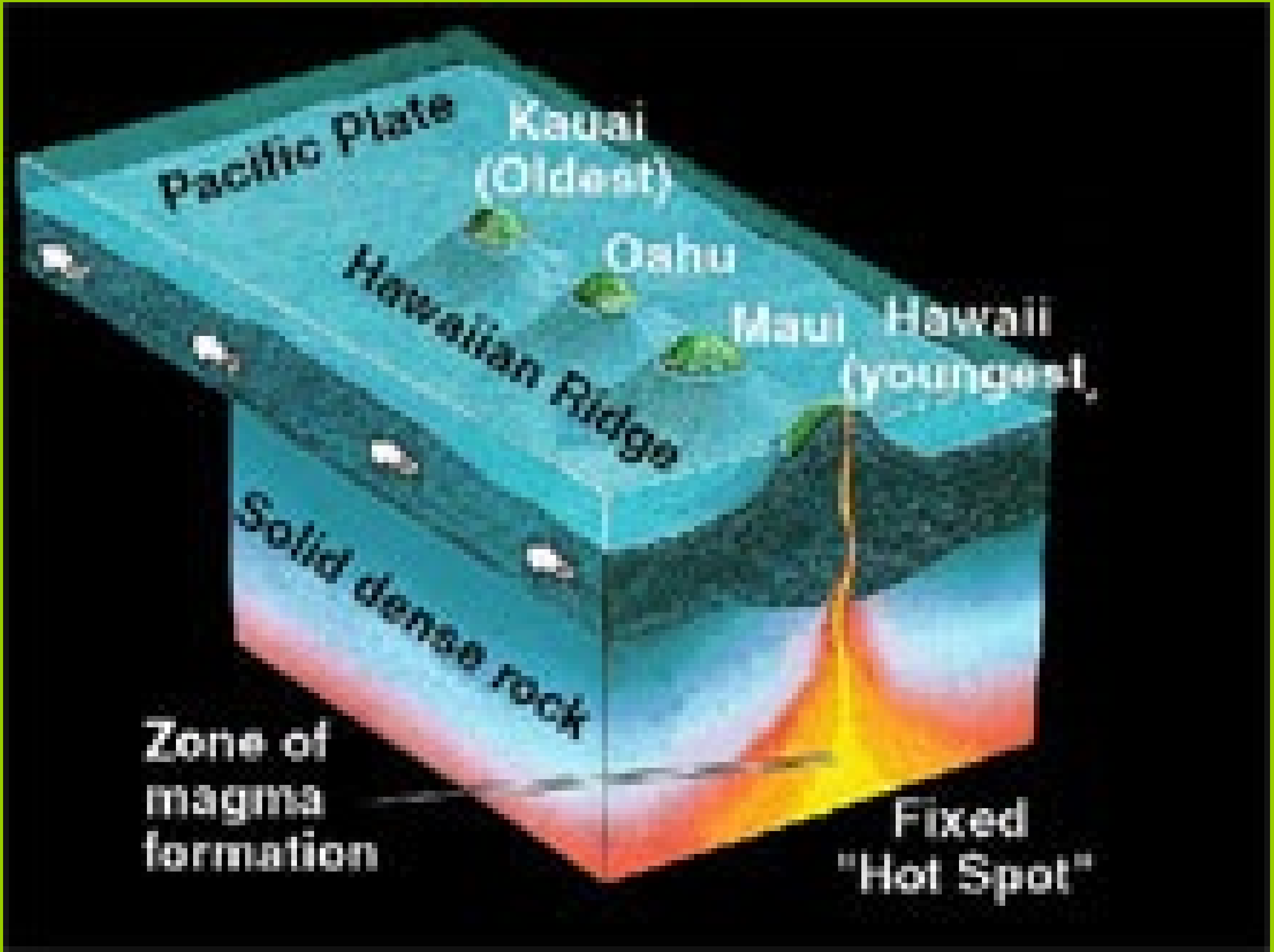
Magnetic fields will shunt the high speed solar wind out and around your planet, protecting your planet from having its atmosphere sand-blasted away

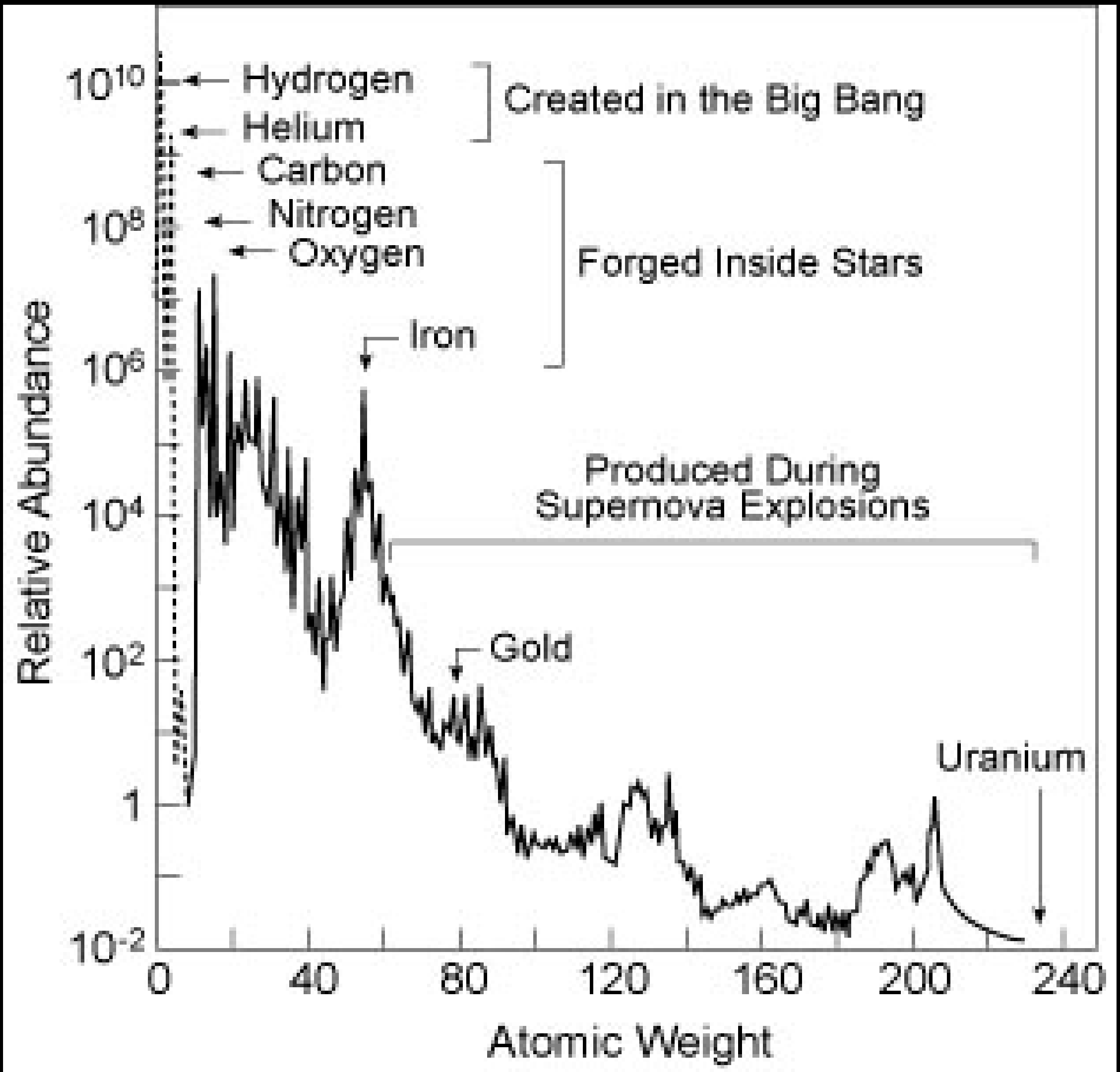


f_{pt} = Fraction with Plate Tectonics

- Plate tectonics is necessary to recycle the key chemicals for life: hydrogen, nitrogen, phosphorus, sulfur, and carbon
- Also tectonics produces mountains and rebuilds continents so that they can poke above the oceans and give a platform for land life.
- It also provides a mechanism for removing CO2 and progressive greenhouse cooling to counter the generic warming of all stars during their life, as we’ll now see…

Molten deep heavy material recycled to the surface





Note how common iron is, because SN II's blow a lot of iron out into the galaxy. But we still need some essential very heavy elements for life as we know it, like Molybdenum

Life got going, at the hot vents of the Mid-Atlantic Ridge, created by plate tectonics

- Tectonics also recycles heavy elements to the surface, and buries carbon over time, to pull CO2 out of the atmosphere, to compensate for the gradual increasing luminosity of your star

Plate Tectonics May be <u>Essential</u> for Another Reason

- Carbonate cycling via subduction allows removal of greenhouse gas (mostly CO_2) and prevent the **Venus Syndrome** as the sun's luminosity increases over billion year time scales, as do ALL stars.
- Stellar luminosity increase during its Main Sequence phase is not unique to our Sun – <u>ALL stars do this</u>; it's a real problem for a planet to keep a climate as stable as ours has been, under rising parent star luminosity, for billions of years.
- **In our Solar System, only Earth clearly has plate tectonics.**
- But given earlier factors (rapid rotation, large), and plate tectonics is not completely independent of these… so if we've gotten this far, having some sort of plate tectonics is not that unlikely
- **$f_{pt} = 0.5$**

f_o = Fraction with significant free oxygen, but not too much

- We had oxygen at 1% for billions of years, but no complex life, just microbes.
- It took development of a significant oxygen atmosphere to permit the kind of high-energy metabolism which gives animal life its ability to cope, evolve quickly, and solve problems as quickly as necessary. In other words – be smart!
- Oxygen is VERY reactive, and we only know of one way to get it to stay in the atmosphere; massive plant life and ongoing strong photosynthesis. Presumably animal life will develop to the extent permitted by the oxygen-production of plants. Then too, animals produce CO2 which the plants need.

Could sulfur-based life have the energy to compete? Not clear. Besides, We Need O2 Also to Develop an Ozone Layer to Protect against UV from the Star

- Too much oxygen and lightning fires will burn out of control, this is a stabilizer to help keep O2 at right level.
- Our 21% is about perfect, but has been as high as ~35% during Carboniferous Period.

- **f_o = .3?**

f_{gh} = fraction whose greenhouse heating changes closely balanced the rising stellar luminosity over billions of years

- ALL low mass stars have rising luminosities during their billions of years of main sequence evolution. **K stars even more so than G-type Sun.**
- Somehow the planet must develop life, and then keep increasing the ability to cool itself while the parent star gets more luminous.
- For Earth, this was apparently done by our atmosphere of CO_2, NH_3 and CH_4 being progressively removed as the sun warmed.
- CO2 is removed from atmosphere by chemical weathering and sea life performing carbonate rock formation, but if climate gets too hot, this is hindered, and this only makes things worse by keeping the CO2 in the atmosphere and its greenhouse heating.
- While sun's luminosity was low, more greenhouse gases needed to keep Earth warm enough for liquid oceans.
- However…. It's more interesting than this -

A Mechanism Keeping Earth Oceans Relatively Ice-free

- Ditlevsen (2005 in J. Astrobiology) shows that "Snowball Earth" episodes cannot last.
- Dry cold frozen Earth has no silicate weathering and ice-covered ocean cannot absorb CO2
- So, no way to pull CO2 out of the atmosphere. Volcanoes are unaffected, and continue to belch CO2, until greenhouse heating melts the frozen Earth and ocean, letting atmospheric CO2 once again dissolve into the oceans.
- High CO2 levels are necessary to break this albedo-driven cold, and result in overshoot and a hothouse Earth until silicate weathering can reduce greenhouse CO2 once again.
- Paleo data show **"Snowball Earth"** episodes are indeed very few and short, and indeed followed by "hot house" conditions.
- So, within a fairly wide range (from Ice Age to jungle-heat) Earth seems destined to have liquid oceans, until solar luminosity grows so large that oceans are no longer possible and boil away.

GHG Cooling Must Match Stellar Luminosity Heating Rate

- For any planet with tectonic plates and silicate weathering, this mechanism will make it easier to adjust habitable global climate to compensate for increasing stellar luminosity.
- Since we've already included factors for tectonics at least going in the right direction, if not the perfect rate, then $\mathbf{f_{gh}}$ is likely not far below 1.
- $\mathbf{f_{gh} = 0.8}$ as a guesstimate

f_{nr} = Fraction with no low-order resonances with other planets, so a long-lived stable orbit

- This is closely related to the circular orbit need, but not the same
- You can still have a circular orbit but in a resonance which will cause planetary orbit migration.
- Our inner solar system shows stable non-migrating orbits and no resonances, but it's easier to get resonances than not.
- **f_{nr} = 0.2, and would be less except some of this improbability is taken up elsewhere above.**

f_{hz} = Fractional reduction of planetary habitable zone by CO2, CO for complex life

- Schwieterman *et al* 2019 have refined the habitable zone with new understanding of the necessary CO2 and possible CO in the atmospheres necessary to keep planets warm in the outer regions of the conventional habitable zone.

High CO_2 Levels – Not Good

- The levels of CO_2 necessary to warm the planet by the greenhouse effect at the cold distances of the outer conventional “habitable zone” are toxic to complex life, even if not necessarily to simple life
- And high CO_2 levels lead to increased CO levels by photo-dissociation, which is far more highly toxic than CO_2.
- **They find $f_{hz} = 0.3$**

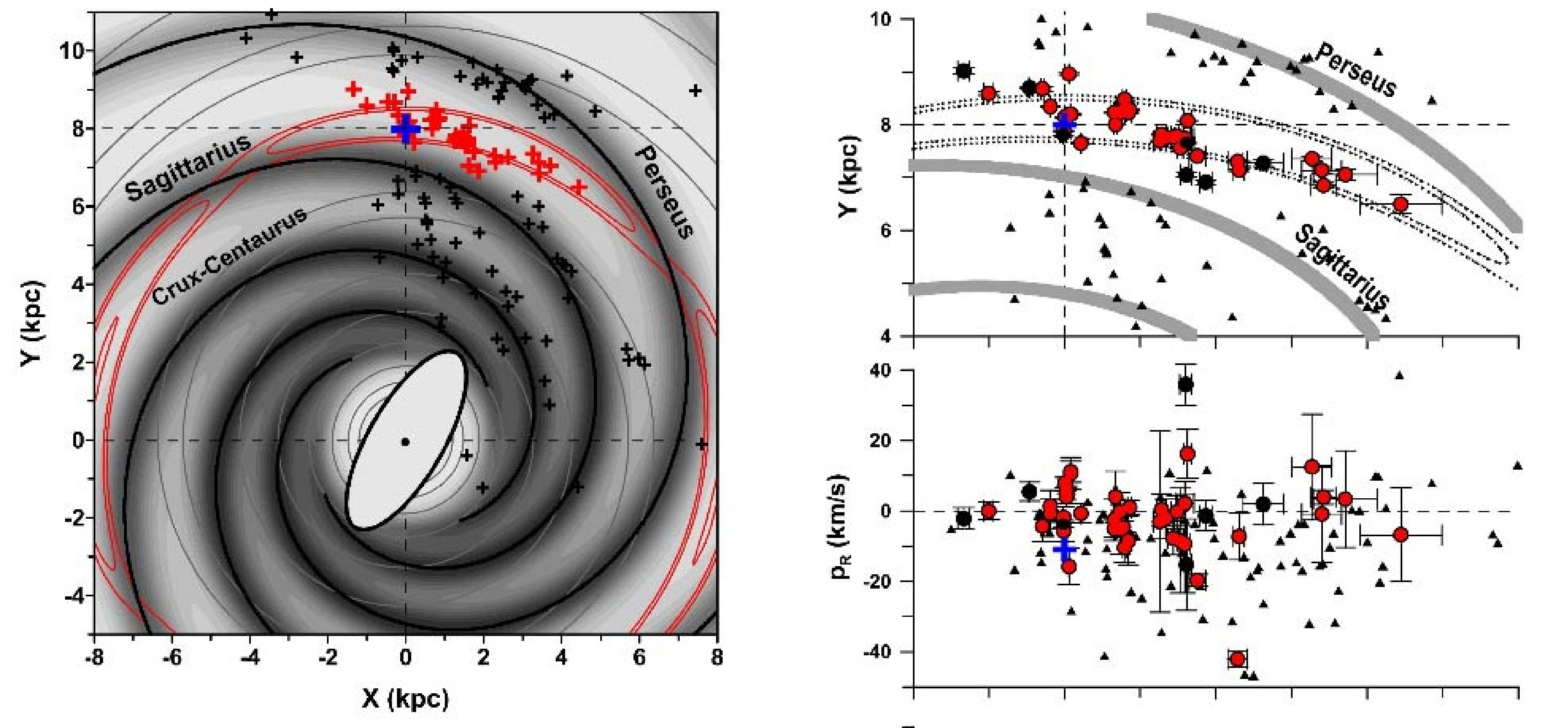
A Fascinating New Study of the "Habitable Zone" for the Galaxy

- If the sun passes through spiral arms in our Galaxy, the odds increase for nearby stellar passages disrupting Oort Cloud comets and resulting comet impacts. Also the odds of fatally close type II supernovae go up.
- While it's not clear exactly how high these odds are, the calculated odds of disaster are comparable to observationally constrained estimates (*e.g*. **Filipovic *et al.* 2013**)
- It's quite possible that passage through spiral arms is a mass-extinction-inducing event

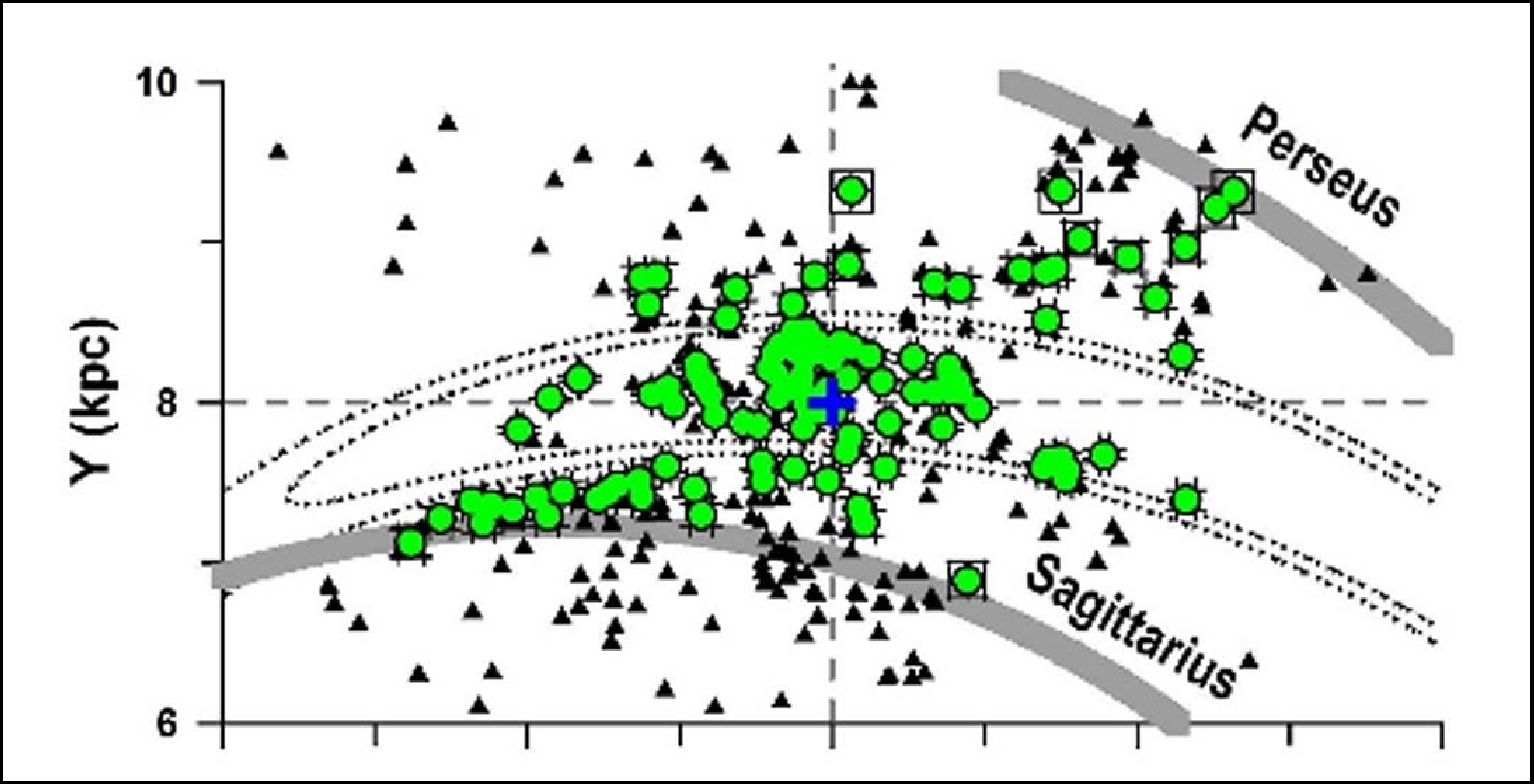
How Has the Earth Survived This, Given We Have Made 20 Orbits of the Galaxy?

- Lepine *et al.* 2017 show that the sun is in a small region between two spiral arms near the "co-rotation" resonance radius of the galaxy
- This is such that the sun's orbit is confined to regions which KEEP us from ever entering a spiral arm.

The sun (blue cross) is between the Sagittarius and Perseus spiral arms, in a banana-shaped region (red) where co-rotation insures stability against spiral arm crossing. Permanent safety! We were SO lucky!



The "Orion Spur", is our (blue +) local star-formation region (green tracers), also in the stability region



This means we can't apply the "1 G,K star formed per year" for suitable stars

- That number – "1 per year" - began our whole Drake's Equation discussion, and it's now clearly too optimistic
- This implies that not only is the narrow region roughly near the sun's radius is the **"Galactic Habitable Zone"**, but also that only a smaller subset of certain orbits between our two major local spiral arms (Sagittarius and Perseus) permit local star formation rates and stellar densities suitable for billion-year long lived living planets.
- Call this new reduction factor $\mathbf{f_{GHZ} = 0.15}$

Now multiply all these f's together…

- **$N_p = N_{p0}\ f_{nv}\ f_{ss}\ f_{co}\ f_{lm}\ f_{cj}\ f_{w}\ f_{mf}\ f_{pt}\ f_{o}\ f_{gh}\ f_{nr}\ f_{hz}\ f_{GHZ}$**
- **= 0.35 Intelligent Civilizations in the Galaxy**
- **0.35 ! Round it up to 1. <u>So, That's Us!</u> – One** civilization in the Galaxy!
- This agrees with our observations and would resolve Fermi's Paradox, but admittedly very dependent on these uncertain guesstimates
- **If this calculation is wrong, and intelligent life is indeed far more common, let's ponder other solutions…**

New in 2020, Confirming Calculations from Columbia University

- Prof. David Kipping of Columbia University, has done a Bayesian statistical new look at the Drake Equation and also finds essentially the same result as mine – that the odds of another intelligent civilization in the Galaxy today, is only about 66%
- Here's an **interview with Dr. Kipping** and **his YouTube channel main presentation**.
- Unfortunately, studies which indicate we are alone are not popular and you have to dig a little harder to find them.

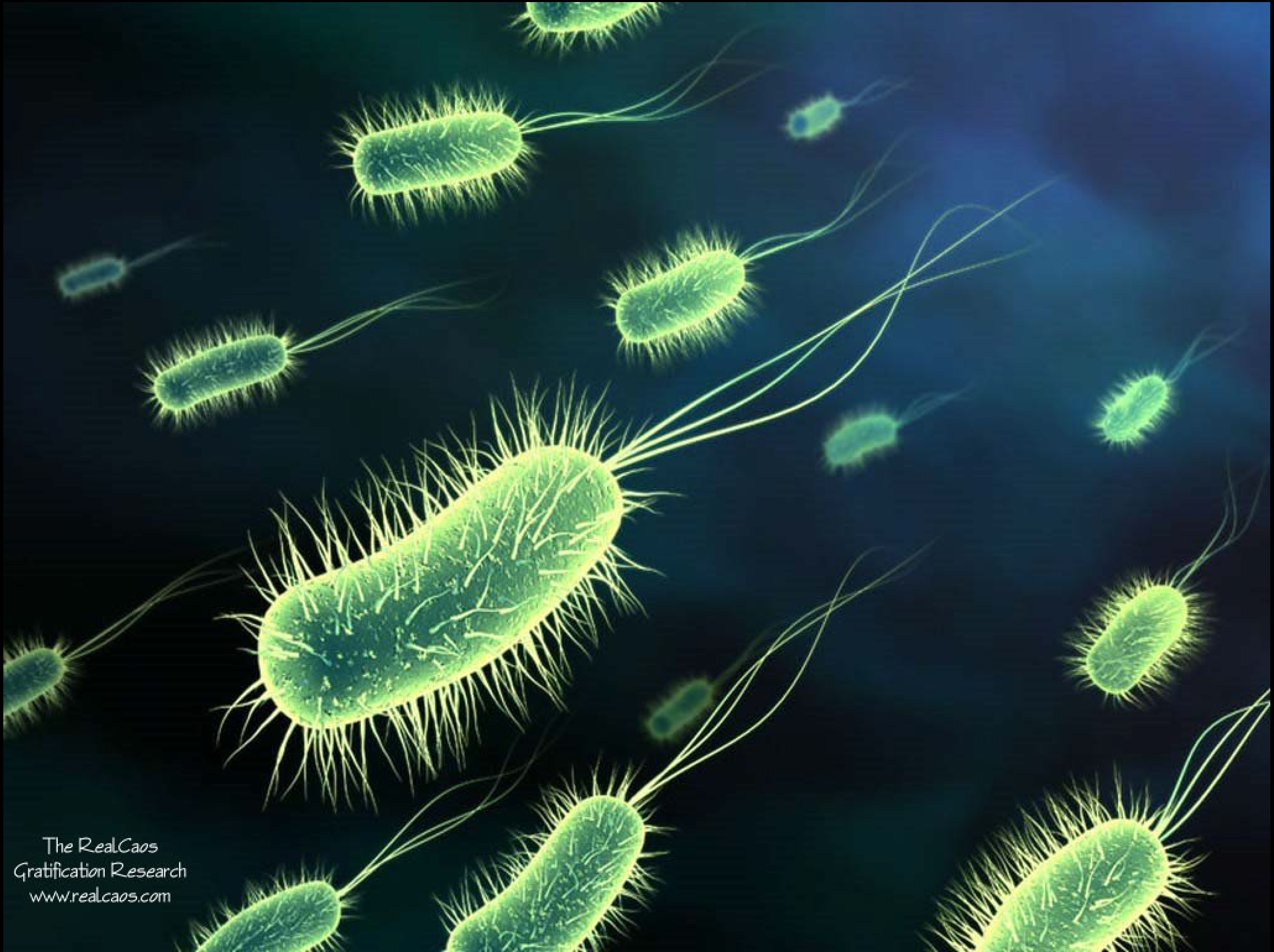
Fermi's Paradox: So, where are They?

- If civilizations last ~1 million years, the typical Galactic interstellar-communicating capable civilization has been around vastly longer than our paltry 80 years, and so any other civilization would be very likely far advanced of us.
- Technology advances at a blistering pace… an *accelerating* blistering pace (until societal collapse?).
- We should be able to travel with our robots to the stars in maybe a 1000 years, tops. We can listen to civilizations even at our infant stage, for thousands of nearby stars already
- **So… where are they? <u>This is Fermi's Paradox</u>**
- **(after Enrico Fermi; Nobel Prize winning 20th Century nuclear physicist)**

Fermi's Paradox is a Puzzle If you Think Galactic Civilizations are Common

- The Area 51 nonsense has been debunked.
- Do you really believe ET is going to kidnap Farmer John and his wife in the way Farmer John reports to the press?
- We see no monoliths on the moon or anywhere else (but Oumuamua as an alien craft has at least some support)
- SETI is listening to radio waves from the stars… and hears only silence. And we're now able to scan 1 billion quantum frequencies simultaneously with the current SETI correlator hardware and software
- And the more important point is – **if they WANTED to talk to us, they certainly would've made it easy for us to find them by now**

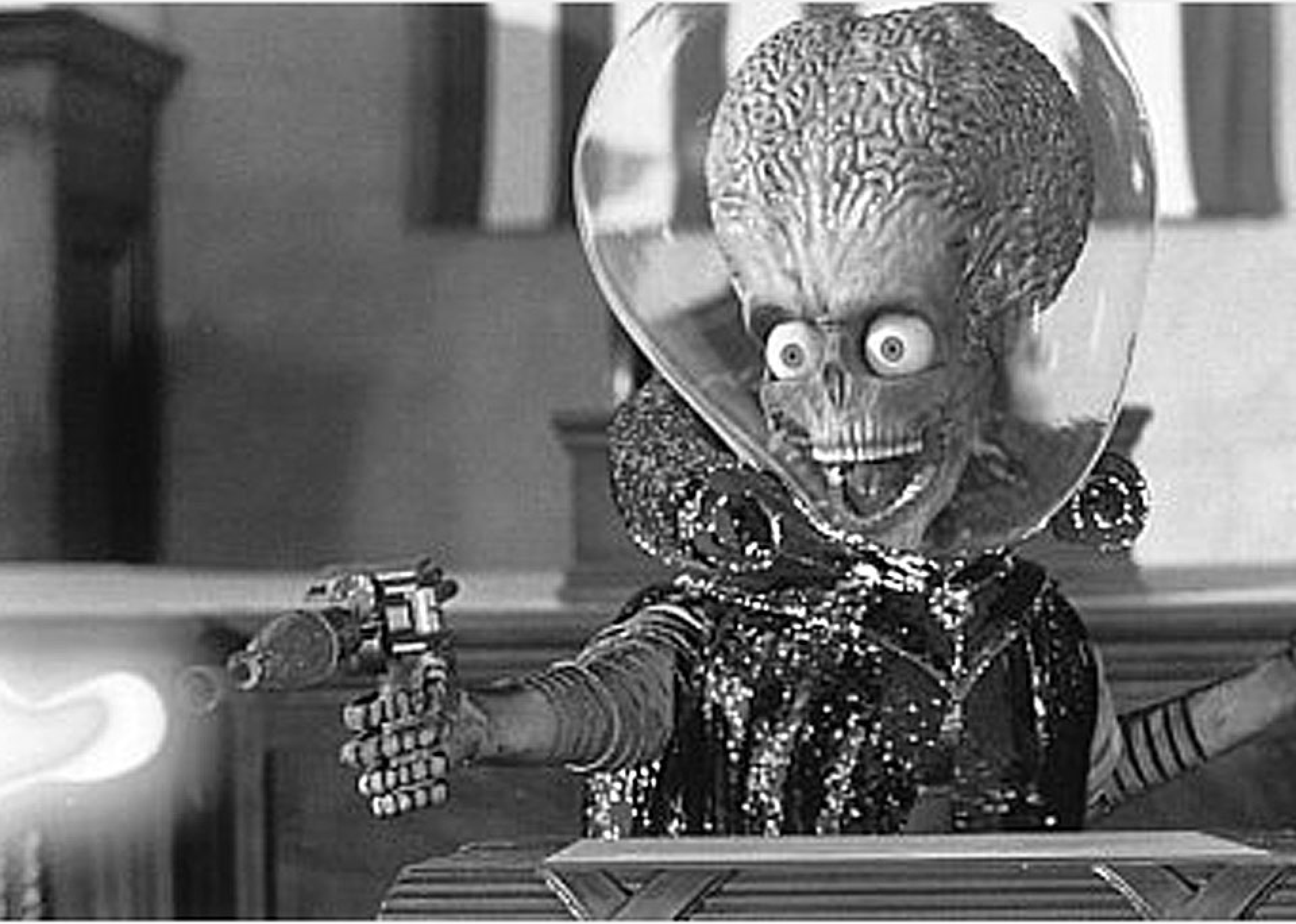
It's those *f* factors AFTER the original Drake Equation that may be the answer. So, microbe life may be common, but intelligent life may be so rare that we are perhaps unique



But then again, Maybe they ARE out there, and are all members of the Galactic Federation… Obeying the Star Trek "Prime Directive" – ***Don't Disturb the Natives***

- Maybe. But every civilization? Hundreds or Thousands of them? And not one has enough curiosity or compassion (or greed? Earth is a rare, juicy prize, trashed by a race seemingly bent on its destruction) to break the "Prime Directive" to save, or exploit, the Earth?
- I think that's unlikely

Maybe they’re watching. Waiting. Plotting. Silently. And will soon arrive and ***take over*** our planet for themselves!



Will Country Music Be All that Saves Us?
(see “Mars Attacks”)

…. But Not Likely

- As life's problems are solved and survival isn't seen as such a challenge, Earth's example shows humans become less violent, less threatening.
- Modern civilization has its horrors, but not like the Dark Ages, or the Old Testament (yet)

Other Civilizations Are Likely Far Advanced of us

- We've argued that interstellar communicating civilizations will likely last of the order of millions of years. Yet we have only achieved this technological level in the past 100 years.
- So the odds are, among such civilizations, we're very likely the most primitive
- So THEY'LL likely also be far advanced in terms of benevolence and good will…
- …Right?

But Before We Lay Out the "Welcome" Mats…

- The late physicist Gerard O'Neill observed that in every case, when Western civilization encountered a primitive culture, that other culture has suffered greatly, if not gone extinct.
- This is true even when we take the greatest care in preserving that culture
- In any encounter between the Aliens and Us, **WE are the primitive culture, based simply on the math presented.**
- **Does this suggest that "they" know this, and out of benevolence for our culture, are deliberately keeping a low profile? "They" – the entire Galactic Federation?**
- **It's not such an unreasonable answer to the Fermi Paradox**

But if Amazing Planets Like Earth Truly Are Very Rare…

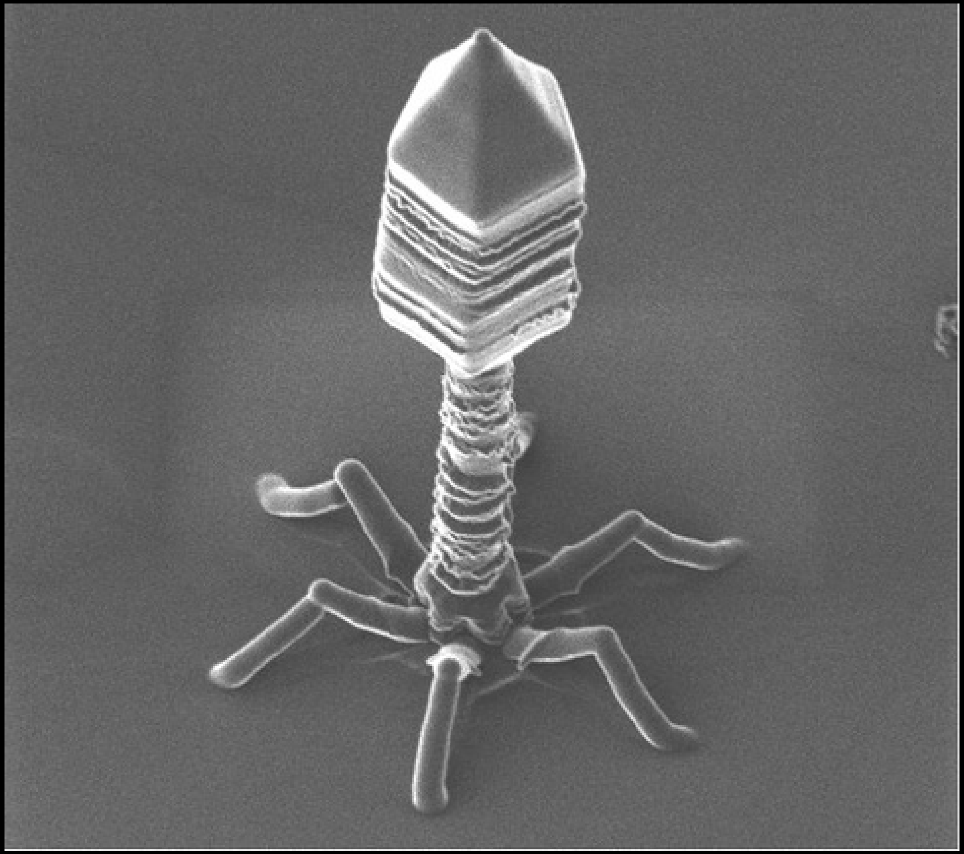
- After all, it's **easy for aliens** to tell Earth is **covered** with life; methane and oxygen together in our atmosphere make that an easy give-away – our planet must be *chock-a-block* with Life!
- For other civilizations only a few years more advanced in technology than we are, it's easy to tell we're a living planet around a stable star in a perfect solar system….
- ***Then why are they letting Humans wreck this incredibly rare and precious planet and not doing anything about it?***

Why Aren't They Already Here, to Terminate Humans, So Earth Can Live?

Dissolving Us With Their <u>Deadly Nano-bots?</u>

Or At Least, Shocking Us With their Outrageous Attire?

Recently, However, We Discovered These Suspicious Looking sub-microscopic Things... Microbes? We know *we* didn't build them... are they instead... Nano-DeathBots??? (OK -they're probably just viruses)



More to Read…

- Paleontologist Peter Ward's: "Rare Earth" (but makes the possible mistake of assuming all life is perhaps too closely like Earth life?)
- And, "Here be Dragons"

If They Come…Will They Like Us? It Depends on Who they Meet, I Expect.

- A disturbingly unvarnished look at how Mankind relates to his fellow species on his own planet… and how that “welcome mat” may look.
- **SteveCuttsCartoonVideo** (3 min)

Key Points: The Drake Equation

- Plants and animals happened on Earth only ½ a billion years out of the 4.6 billion since formation.
- All life, however, is far more complex than most non-life
- We guess that other civilizations wanting to talk to us would use radio frequencies near those of hydrogen and hydroxl (OH)
- Life was impossible on land until enough ozone formed to block solar UV, roughly 4 billion years after life first evolved.
- The Miller-Urey experiment; aminos acids form naturally out of the raw materials of early Earth, no miracles required
- Fermi's Paradox: if civilizations endure, why aren't they talking or visiting us?
- Do civilizations "commit suicide" soon after their adolescence, as many are worried we're doing?
- The most recent mass extinction – **Happening Now**! Half of all species will be gone in a few decades; a geological instant, thanks to humans.
- A more informed Drake Equation calculation – Earth may be almost unique in the Galaxy in nurturing evolving life for billions of years, up to the point of interstellar communication ability