Upcoming Astronomy-themed Talks and Events

Thursday, 2/27, 3:45-5:00pm Astronomy Colloquium – Phys-Astr A102 – Jessie Christiansen (CalTech) – “Ten Thousand Pieces of Blue Sky: Building towards the complete picture of exoplanet demographic”.

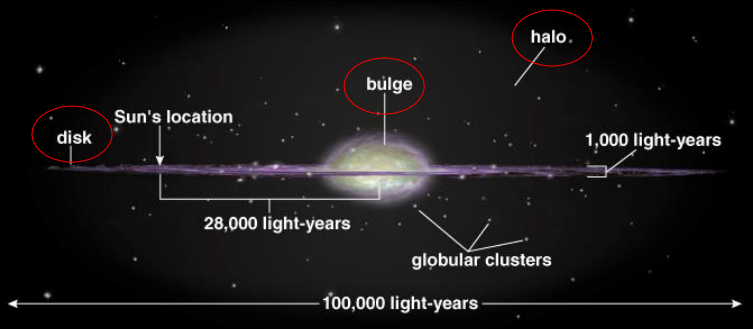
A Modern Map of the Milky Way

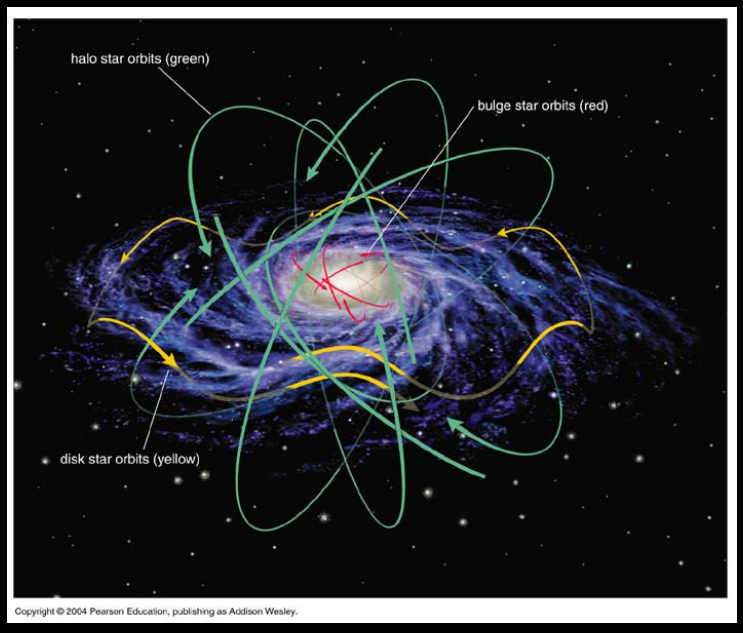
diameter of disk ~ 100,000 l.y. (30,000 pc)

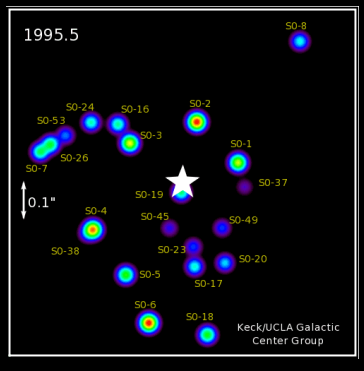
radius of disk ~ 50,000 l.y. (15,000 pc)

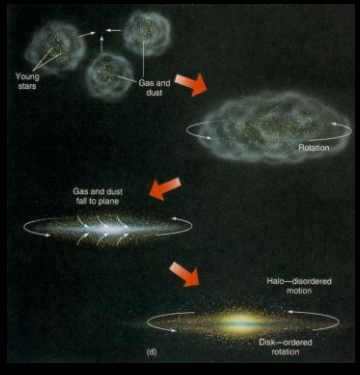
thickness of disk ~ 1,000 l.y. (300 pc)

number of stars ~ 200 billion





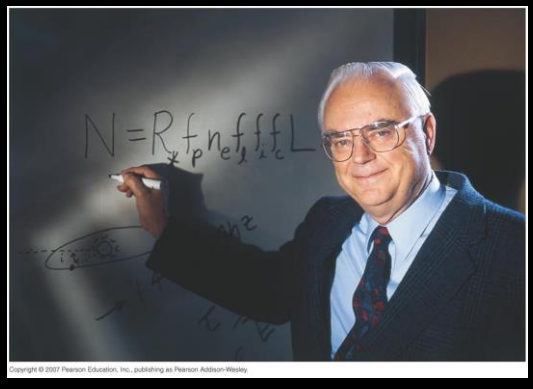




While we don't yet fully understand everything about our Galactic home – the details of its formation, or how that supermassive black hole in its center was made – we do know *much* more about the true shape and content of our Galaxy than ever before – and with much, much higher precision than ever before.

We can now, for instance, say with great certainty that there are *at least* 200 billion main sequence stars in our galaxy – and that's a lot of stars no matter how you slice it.

With so many "Suns" out there, it's natural to wonder how many stars in our galaxy might support some kind of intelligent life?



Drake, with a version of his famous equation on the whiteboard. The terms in the equation are basically the probabilities of various factors relevant to the existence of intelligent life.

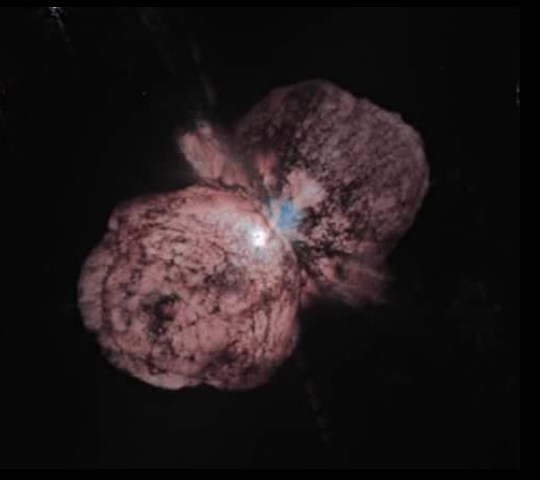
Addressing these questions invokes the ***Drake Equation***, a mathematical formalism developed in the late 1960's by Frank Drake.

It attempts to estimate the number of alien species in our galaxy that are capable of communicating with us here on the Earth.

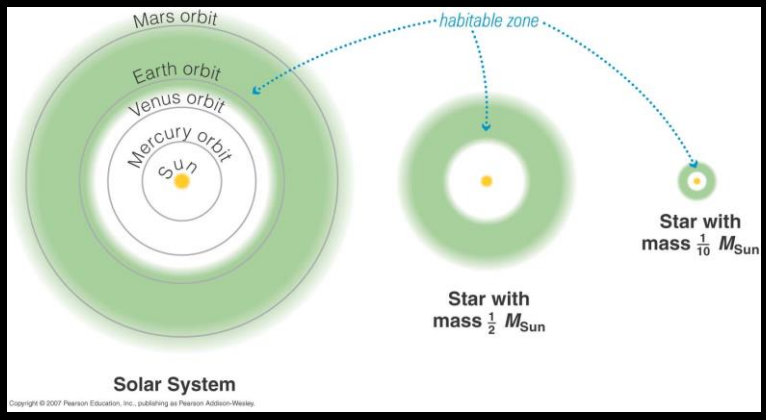
Although Drake's Equation doesn't really produce an exact *answer*, it's useful as a means of thinking about the number of "interstellar species" out there – a way of breaking that very hard question down into simpler, perhaps more answerable questions (a classic move in science!):

1. How many habitable planets are there in our galaxy?
2. What fraction of those planets ever had life?
3. What fraction of those habitable planets ever had intelligent life, capable of communicating with us?
4. What fraction of those civilizations currently exists?

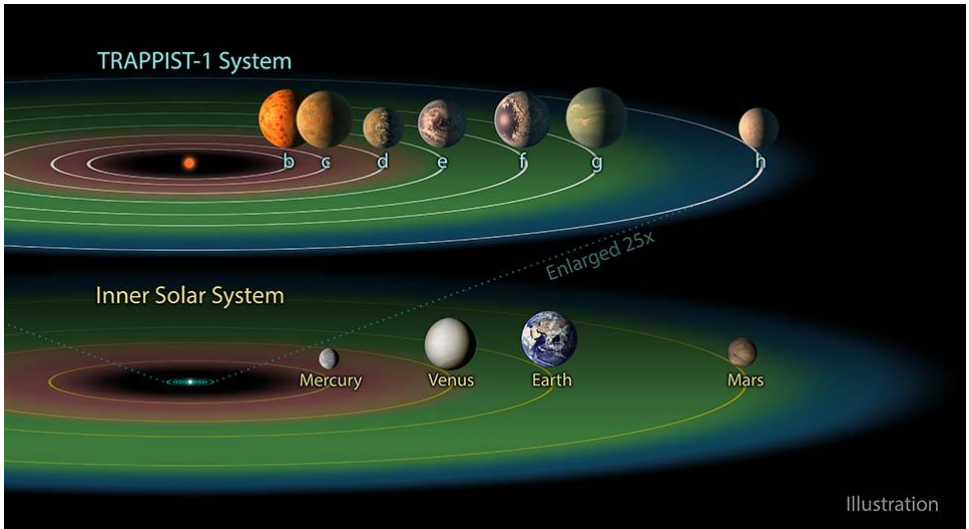
For Question 1, we know that there are well over 200 billion stars in our galaxy – though not all are equally viable for life. Stars much more massive than the Sun lead short and violent lives, and only those stars at around the Sun's mass or lower can stay stable for the billions of years (apparently!) needed for intelligent life to evolve.



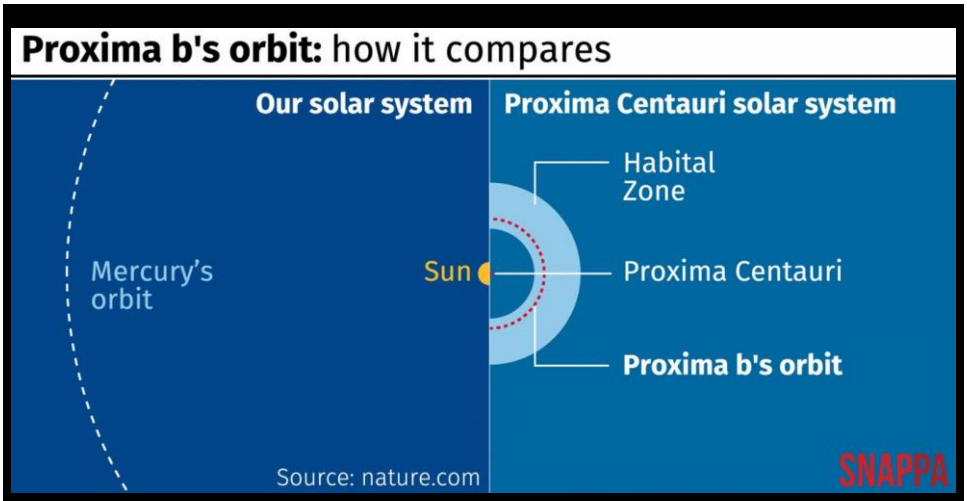
Eta Carinae, a very massive star in the process of dying – after only a few million years of existence.



But that leaves most stars available, since most stars are lower in mass than the Sun. Those K and M dwarfs have their own issues, though – a planet with life on it must be close enough to its star for water to remain liquid. For a low mass star, that places the "***habitable zone***" uncomfortably close to the star itself!

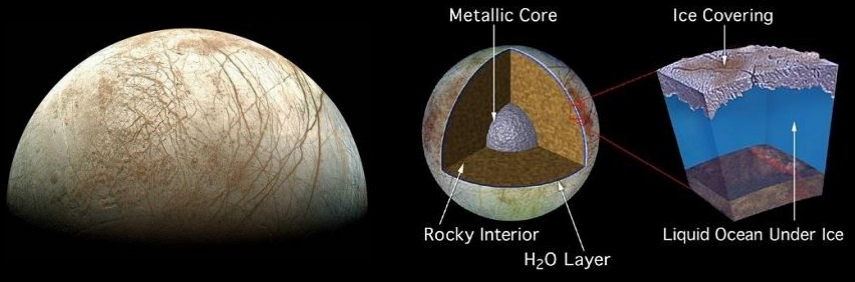


Of the 7 planets of the Trappist-1 system, 3 lie in the star's habitable zone – but note how small those orbits are!

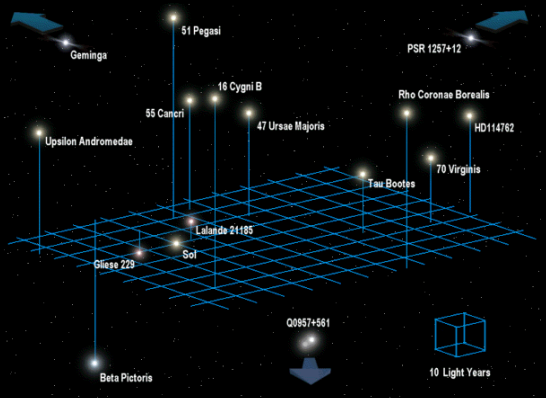


The nearest star to us, Proxima Centauri is an M dwarf with a planet in its "habitable zone" – but can it truly be habitable that close to its star? The answer to that remains highly uncertain.

On the other hand, evidence from the moons of Jupiter and Saturn suggest that liquid water – and by extension life – might exist in quite cold regions, far from the traditional "habitable zone" – so we may need to consider even more worlds as "habitable".



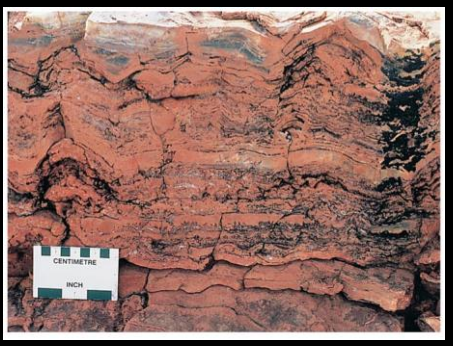
We have also seen that at least 50% of the low-mass stars in our vicinity have planets around them, and that fraction may be much higher – 90% or even more. Combining all of these factors together, we find that there may be over ***ten billion*** 'habitable' planets in our Galaxy!



A map of the nearest stars with planets – and this one is a little out of date and doesn't include Proxima Centauri, the nearest star to Earth other than the Sun!

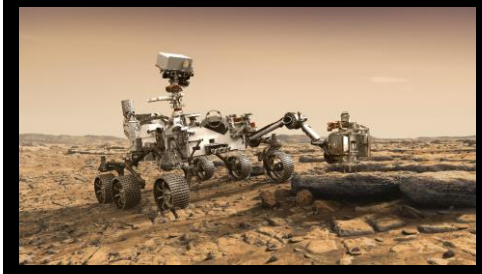
That's a relatively precise estimate, and a very large number. But what about Question 2 – how many of those planets have life?

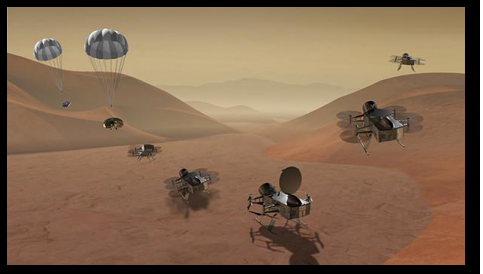
Well, the Earth is the only place in the Universe that we ***know*** to have life, and we have *never* found any robust evidence of it ever developing anywhere else. From that, one could reasonably conclude that life might be a 1-in-10 billion phenomenon.



But the record cast in the rocks of the Earth clearly shows that ***simple*** life (such as the bacterial mats shown above) arose very quickly following the cooling of Earth's surface – less than a billion years after the planet's fiery and violent formation.

Further, we've recently discovered that life is far more adaptable to "hostile" conditions than once believed. Deep in the ocean, and in the very rocks of the Earth's crust, microbial life has been discovered that survives at extremely high temperatures, and without direct sunlight! All of this taken together suggests that simple life might arise in a much wider range of environments than we might have once suspected.



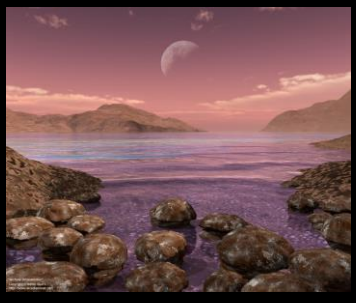


And let me note that this basic and profound question – how likely is that simple life starts once the basic ingredients are in place – will largely be answered in your lifetimes!
By scientists and students just like yourselves, exploring our very own Solar System! Get in on the fun!!

What will it mean if we find signs of life on disparate worlds like Mars, Europa, or Titan?

Or on none of them?

What would such findings tell us about the distribution of life outside of our Solar System, or on planets orbiting other stars in our galaxy?

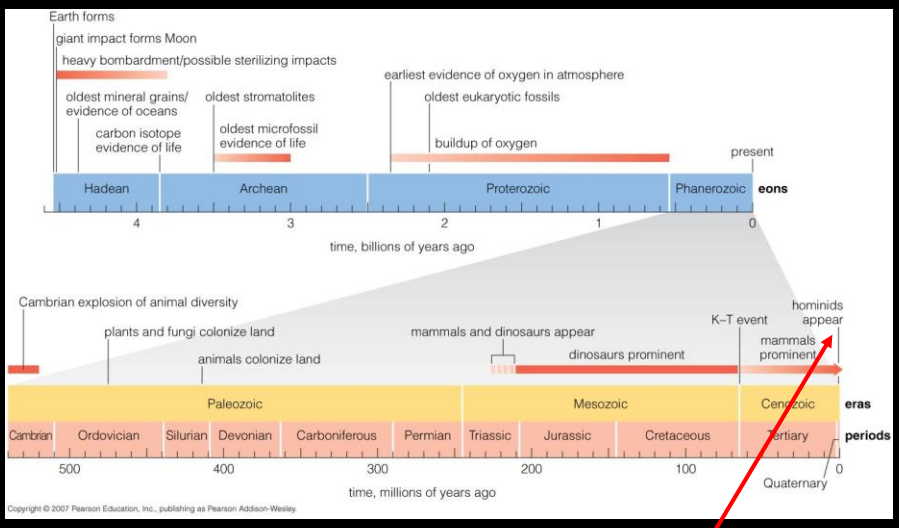


Typical life in the Archaen (top) and Proterozoic Eras – more than 3 billion years of Earth's history.

But as complicated as this is so far, we've still only addressed ***simple*** life – what about Question 3, the number of planets with ***intelligent*** life in our galaxy?

Well, history is not so kind here – for ***most*** of the time that life has been on Earth, there have been no species capable of chatting with aliens!

(though there was that advanced dinosaur civilization that developed just before the asteroid hit…)



Kidding of course – but seriously, what we would call ***intelligent*** life has been on Earth for less than 0.0001% of its history!

This strongly suggests that life might arise on many worlds without *any* species ever evolving into a form capable of space travel or interstellar communication.

The immediate biological payoff of such an ability is certainly not readily apparent – species are capable of considerable success (and smarts!) without ever developing astronomy!

Still, if we assume a relatively low number – say 0.01% – for the number of life-bearing worlds that *eventually* developed some form of intelligent life, then we still have ***millions*** of space-savvy civilizations that should have arisen over the entire history of the Milky Way so far – and that's a lot of potential aliens to chat with.

But that brings us to factor number 4 – how many civilizations, of all those that have ever existed, exist ***now***? This is really asking how long the typical intelligent civilization lasts; if they survive only a short time – say a few thousand years – then very few of those that have ever existed are still here. If they last for billions of years, then almost every one that has ever arisen may still be here!

Are civilizations more like fireflies? Or lanterns?

This by far the most slippery of the factors to quantify, as it deals with how long a planetary civilization can “keep it together” before destroying itself or being destroyed…

…which is kinda fun to watch movies about, but arguably impossible to measure in any meaningful way – beyond knowing that we can at least exist for a few thousand years!

(and this isn’t counting the stories where aliens themselves are the ones who kill us!)

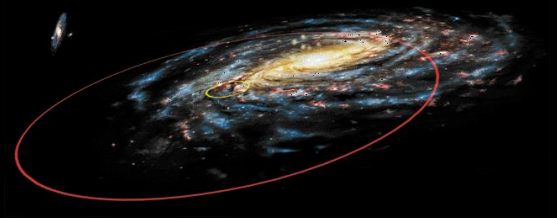
All of this now brings us to a famous conundrum posed in the so-called “Fermi’s Paradox”:

If there are have been *millions* of extraterrestrial, space-faring civilizations throughout Galactic History, then under all but the most apocalyptic assumptions, ***many*** of them still exist ***right now*** in the Galaxy. Further, some of these civilizations should be <u>at least</u> hundreds of thousands of years older than our own.

So where are they? Where is the evidence of these “Galactic Civilizations”? Why have we never found them, or seen any direct evidence of their presence?

It’s not as though we haven’t been looking. Programs like SETI, for example, have been searching for signs of large, interstellar civilizations for decades.

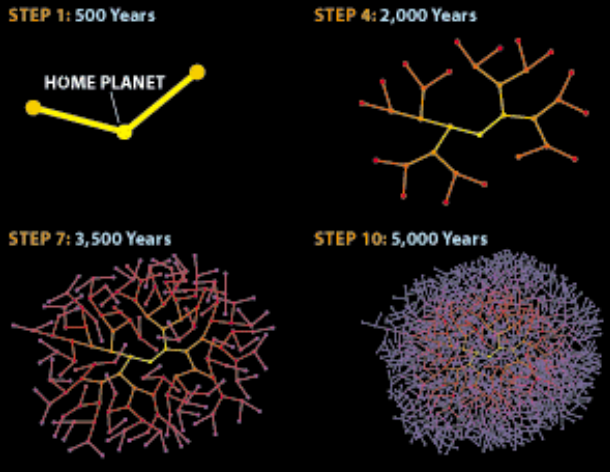
And while it’s certainly not clear that they’re looking in the right ways, by some of their own benchmarks, much of the galaxy has already been searched!



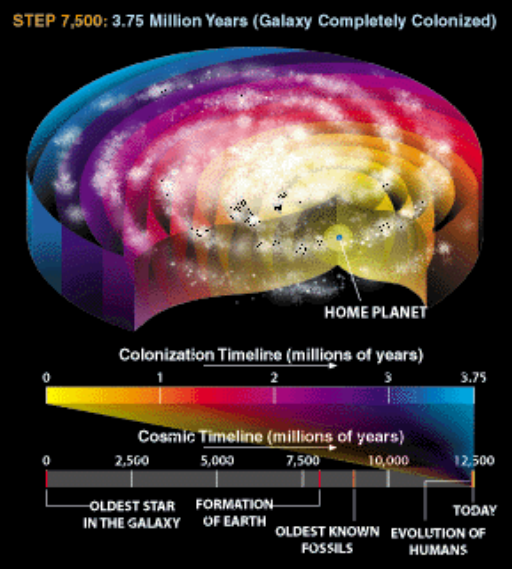
And there is ***certainly*** no clear evidence that we have ever been visited or contacted by any such interstellar civilizations.

(aside from some funny agri-business)

Though seriously, if there are civilizations capable of extensive space travel, some of them *millions* of years older than our own, then they really **<u>should</u>** be here already! Let's see why this is…



With a relatively brute force, low technology approach, sending self-replicating colonies (or machines) to nearby planets…

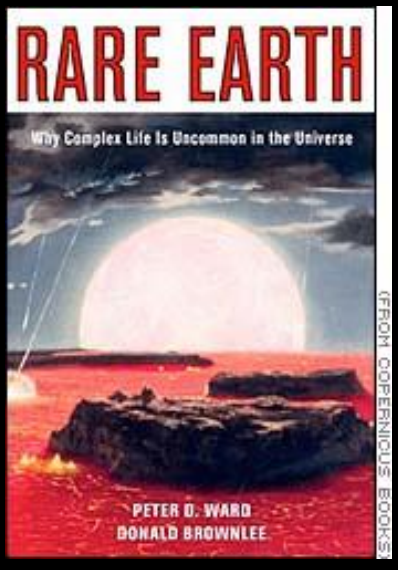


…a determined civilization could implant some physical signature of itself on every available planet in the Milky Way within just several million years!

And if they start early enough, they'll find most of the planets are unoccupied by any sort of meaningful 'competition'! Bonus!

So where are these conquering – or just exploring! – aliens? How do we resolve "Fermi's Paradox"?

One possibility we saw from the Drake Equation is that there may be ***no intelligent*** alien life out there. Perhaps life, or at least intelligent life capable of space travel, is so exceedingly rare that we are literally the only example in the entire Galaxy.



Necessary for intelligent life on Earth?

There are many compelling arguments suggesting this may be the case – the role of our Moon in providing a long-term steady climate, or the Jovian planets in channeling enough asteroids to bring water to the Earth, but not so many that they keep killing off budding higher life forms… How critical are these historical contingencies?

And we've already noted the lack of an obvious evolutionary advantage to exploring the stars – after all, sharks have managed quite well for over 400 million years without needing astronomy!

But with that all said, the idea that there are absolutely ***no*** other intelligent civilizations in the Galaxy strikes many as unlikely – the sheer number of planets, the billions of years available, and the apparent robustness of at least ***simple*** life suggest that ***intelligent*** life should not be unique to the Earth.

So what possible solutions are there to Fermi's Paradox **with** advanced alien life? I'll break it into three broad options:

1. There are alien space-faring civilizations aware of us, but they choose not to contact us for their own reasons (this is often called the *Prime Directive* solution).

Live long and prosper…

Well… maybe. *Maybe* aliens advanced enough for space travel do usually develop such benevolent ethics – but remember we're considering many alien civilizations – with perhaps millions of such cultures arising throughout galactic history.

Have none of these *millions* of interstellar species been colonizing conquerors? ***None*** of them? Recall that a single determined galactic civilization could do this in less than 10 million years – so arguably the first expansive and 'conquering' civilization that gets going wins the prize – a pretty strong incentive indeed!

...or not!

And even if ***none*** of these alien civilizations are ruthless conquerors – or just naturally curious and expansive! – they ***must*** eventually at least try to leave their home worlds as their original planetary systems evolve and die along with their parent stars. Staying at home is simply not a viable long-term option!

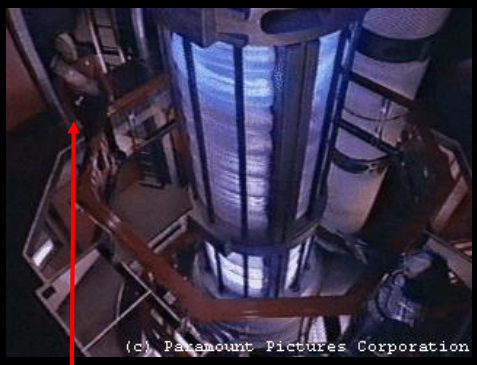
Which brings us to the next potential solution…

2. There are alien civilizations, but they are unable to traverse interstellar space – so there are aliens, and they may know of us, but there is no star-hopping fun to be had with them.

Fastest-ever launch of the ***New Horizons*** probe in 2006, at just over 16 km/s.

This is very likely a big part of the answer. After all, the distances involved in interstellar travel – and the associated ***travel times*** they imply – are truly staggering. At the speeds of the Apollo spacecraft, for example, it would take over 170,000 years just to reach the nearest star! And even at 1% of the speed of light – over a million times faster than any spacecraft we've ever launched – it would still take almost 400 years. Clearly we must go much faster!

But the energy required to get a spaceship the size of the Enterprise to 50% of the speed of light would be the equivalent of over 10 billion trillion watts of power – over a million times greater than the energy output of all human civilization throughout its entire history! And that's just to do it once – you've got to do it again to slow down!



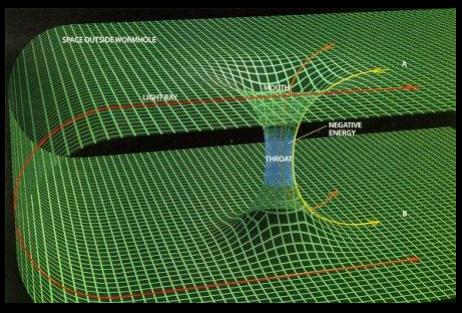
The Enterprise's Engine "Core"

(I would not stand so close to such a device.)

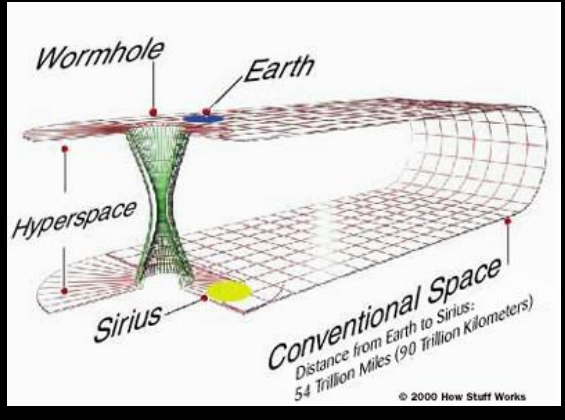
What about **Warp Drive**?

Is it even theoretically *possible* to 'travel' through the galaxy at speeds faster than the speed of light?

Well, some potential faster-than-light travel methods do appear to exist, such as so-called "wormholes" in spacetime.



However, the "natural" wormholes predicted by physics – if they exist in nature at all – are extremely small and short-lived, and therefore not so effective at moving spaceships around!



It ***may*** be possible to create larger wormholes, but the ends of such space-time portals must be physically close to each other when formed. You would then have to drag one of the two holes to where you wanted the 'exit' to be – so you have to fix the long-distance travel part ***before*** you use the wormhole! No shortcuts here!

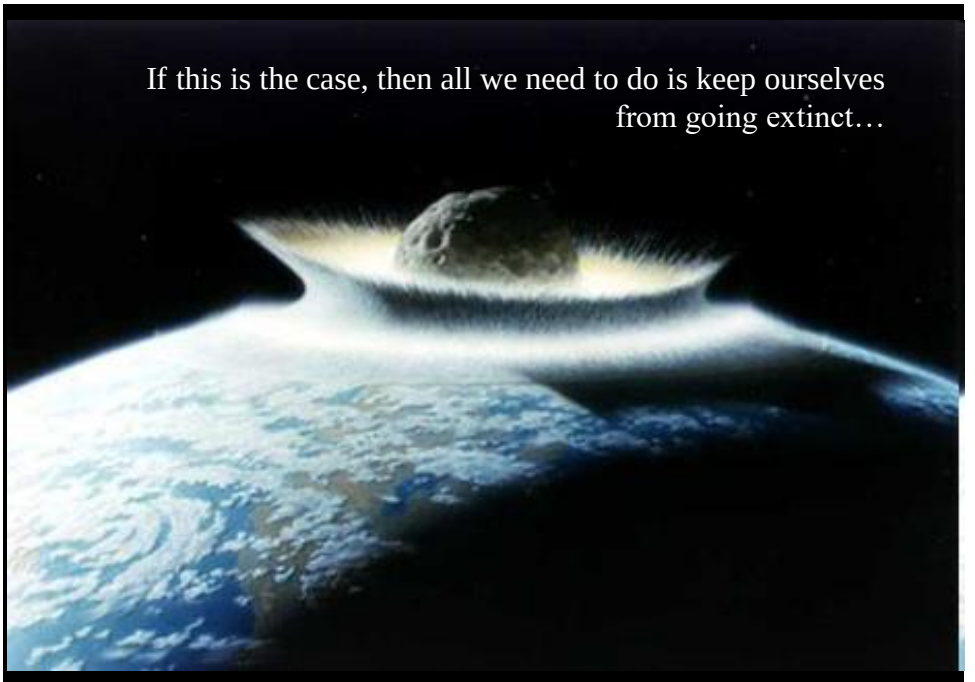
(Unless, of course, you find one already laid here by some other aliens… Let me know if you find one!)

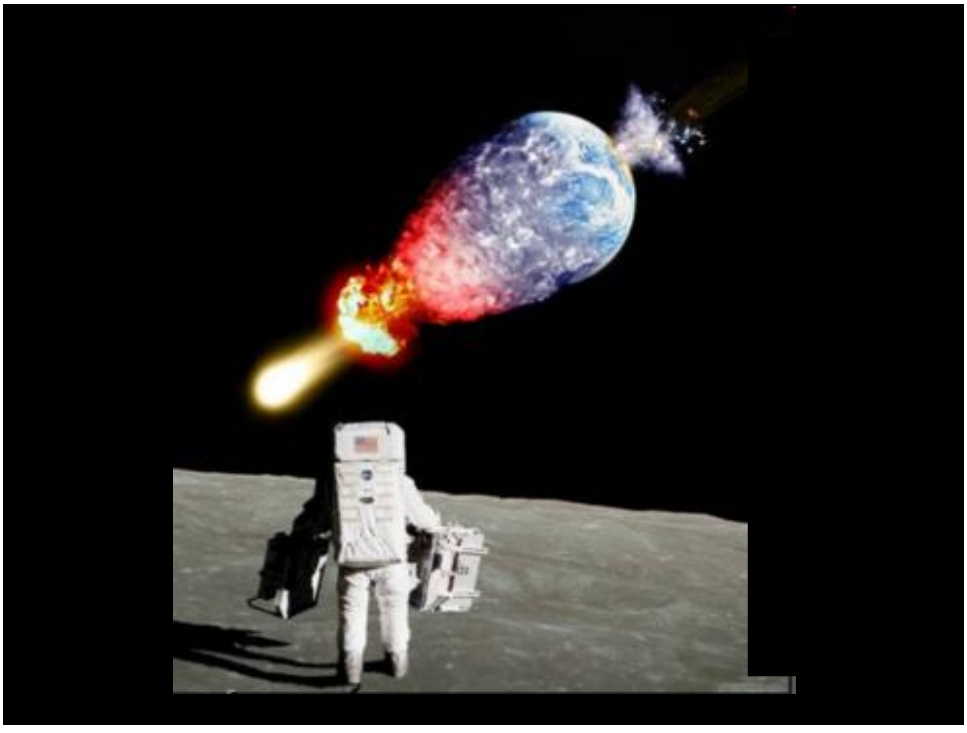
All of which brings me to the last – and both most optimistic *and* pessimistic – potential "with-aliens" solution…

3. Life is common, but intelligent life is much more rare – so there are aliens, but very few in the galaxy at any one time capable of even pondering space travel…

   Space travel itself is possible, but craaaaaaazy difficult – so hard that no other civilization has avoided their own apocalypse long enough to figure out how to do it…yet!!

If this is the case, then all we need to do is keep ourselves from going extinct…





…while pursuing the technological innovations necessary to traverse the stars! Remember, it's only been just over 100 years since our first *flight* – and less than 70 since our first rocket launch!

Heavier-than-air flying machines are impossible.

- Lord Kelvin (1824-1907), British mathematician and physicist; ca. 1895.

...no possible combination of known substances, known forms of machinery, and known forms of force, can be united in a practical machine by which man shall fly long distances through the air...

- Simon Newcomb (1835-1909), astronomer, head of the U. S. Naval Observatory, ca 1901.

To place a man in a multi-stage rocket and project him into the controlling gravitational field of the moon where the passengers can make scientific observations, perhaps land alive, and then return to earth – all that constitutes a wild dream worthy of Jules Verne. I am bold enough to say that such a man-made voyage will never occur regardless of all future advances.

- Lee deForest (1873-1961) (American radio pioneer and inventor of the vacuum tube.) Feb 25, 1957.

If the optimistic part of this is case is close to true, then it's up to us – the fine students of this class, and the humans you will go on to inspire – to keep the world together and reaching for the stars!

(My son and a friend – clearly they're prepared!)

So seriously – go conquer the galaxy!

Or at least your next class!!!