Lecture Notes 4: Do Aliens Exist?

1 Where Are They???

Well, I hope I've been able to impress you so far about how interesting the Universe is. In the previous notes, I talked about all the crazy things that happen in a universe that is infinite — which all observations seem to indicate our Universe is. In an infinite universe, *anything* that is possible happens, even the most unlikely of things. In particular, in an infinite universe, there are infinitely many copies of our planet Earth, and infinitely many copies of you and me. (Of course, they're not *really* you or me; they're just clones of us.) Furthermore, in an infinite universe, there are obviously infinitely many aliens! This is simply a consequence of assuming that the Universe is infinite.

In *Lecture Notes 3*, I emphasized the importance of distinguishing between the *whole* Universe and the *observed* Universe. Because the Big Bang only happened a finite amount of time ago, there simply hasn't been enough time for light from all the galaxies in the Universe to reach us. So, unfortunately, it's impossible for us to observe the literal *infinitude* that is the Universe.

But what we *can* see is still unimaginably large. For starters, the observed Universe — which we will often simply call "our" universe in these notes — is about 80 billion light-years across, or about 500,000 billion billion miles (that's a 5 followed by 23 zeros!). To get from one end of it to the other is equivalent to making a trip across the equator of the Earth 60 billion billion times. Not quite infinite, sure, but still *big*.

Now, although most of our universe is empty space, much of it isn't. In fact, there are about 100 billion galaxies in the our universe. And, in each one of these galaxies, there are about 100 billion stars. This means there are about 10,000 billion billion stars in our universe. How many planets are there? Well, nobody knows for sure, but the best estimates people have calculated today say that about 30% of these stars or more have planets. This gives us about 3,000 billion billion planets in our universe.

A more interesting question is "how many planets are there in our universe that could potentially support life?" This question is harder to answer, but a reasonable guess is that about 1% of planets are habitable. (In our solar system, that number is at least 1/8 — all we know for sure is that Earth has life. But perhaps Mars has or had primitive life.) So, this gives us 30 billion billion habitable planets in our universe. Now, how many of these planets that can develop life *do*? Well, nobody really knows that either, but a reasonable estimate might be that 10% of them do. So this gives us 3 billion billion planets in the observed Universe with life.

An even more interesting (and important) question is "what fraction of these planets with life have *intelligent* life?" This question is even *harder* to answer, but just look at the sheer number of planets we've calculated so far. If the fraction of planets that have intelligent life is only 1%, this gives us 30 million billion planets with intelligent life in the observed Universe. Even if that fraction is 0.0000000001%, we'd still have 3 million planets with intelligent life in the observed Universe! And, even our estimates of some of those other probabilities were off by a lot, the sheer size of our universe would still result in a *lot* of planets harboring intelligent life.

So, with intelligent life so widespread in the our universe, shouldn't we obviously see signs of extraterrestrial intelligence all around us? They should be everywhere! So we might guess. However, if you actually *do* look around you, you'll notice that our universe is a rather quiet place. We don't seem to see these aliens. So the big question is:

Where are they?

This apparent contradiction between the seemingly obvious conclusion that we should see aliens and the observational fact that we *don't* is known as the Fermi paradox, named after the Italian physicist who first had this realization. It's actually a two-fold paradox: (1) the aliens don't seem to be *here* (on Earth), and (2) the aliens don't seem to be out *there* (in space).

In these notes, I won't try to give a definitive answer to the paradox — because, the truth is, nobody (sufficiently non-arrogant will say they) know the answer for sure — but I will tell you some of the most interesting and promising solutions that people have proposed. These solutions can generally be classified into three types.

The first type holds that that the aliens are here — no paradox! In fact, polls show that over 75% of Americans believe that our planet has been or is currently being visited by aliens. The second type of solution is that

intelligent aliens do exist, but they simply haven't had enough time to reach us or it's technologically infeasible to communicate with us (or something along those lines). After all, nothing can travel faster than light, and maybe it's just too difficult for them to reach us. Perhaps. The final kind of answer that people give is that we are *alone*, at least in our Galaxy and perhaps in the entire observed Universe.[1] It could be that, for some reason, we are alone; perhaps the probability of intelligent life developing on a planet is unbelievably small, or once intelligent civilizations form, they inevitably destroy themselves. I'll begin by discussing the first kind of explanation.

2 They're Here!

We've all heard stories of sightings of flying saucers that people have made over the years, along with the occasional abduction story. I won't spend a lot of time on this possibility because, unfortunately, these stories always have very skimpy evidence, and they're very often reproducible (and because most of the experts seem to agree on that).

It's a fact that a number of people report the sightings of UFOs throughout any given year. People see strange lights and shapes in the sky that are unfamiliar to them, so they call it a UFO; UFO simply stands for "unidentified flying object." However, it turns out that once these UFOs are analyzed more closely, far more often than not they turn out to be IFOs — "*identified* flying objects." For example, it might be that an unusual atmospheric condition causes a car headlight to be refracted in an odd sort of way, thereby causing a strange light. So, many UFOs simply result from faulty human perception.

A number of UFOs also turn out to be *hoaxes*, caused be people who deliberately want to cause mischief! For some years, for example, mysterious-looking "crop circles" have appeared throughout the world. These are geometric shapes that are, unsurprisingly, made out of crops (you may recall them from the movie *Signs*.) At first, these crop circles seemed rather puz-

[1] Most people agree that if the *whole* Universe is infinite, then intelligent life must exist elsewhere — infinitely other places, in fact! However, as I've emphasized, we unfortunately do not have contact with the unobserved Universe. So, while the existence of an extraterrestrial civilization a googol miles away is certainly metaphysically interesting, a more pragmatic thinker may not really care. (In other words, don't expect to impress everyone you encounter at a party with unobservable inferences based on an infinite cosmology.)

zling — perhaps they were extra-terrestrial in origin — but we now know that they're perfectly reproducible by man. In fact, several years ago a crop-circle maker even admitted to having making some of these crop circles (for which he was prosecuted).

Nevertheless, each year there are a handful of UFOs and otherwise strange effects that go unexplained. And this strikes many as unsettling. But should it be? Do we really need to explain *everything*? We're able to explain the vast majority of UFO cases, so it seems reasonable that if we spent the time and effort to explain these harder cases, then we'd be able to. But that's the thing — who has the time? Life is too short for us to be able to do everything. After all, police aren't able to solve all of their murder mysteries, yet we don't claim that any of those presumed murders were the result of alien intervention! Why should we be so demanding with explanations for UFOs?

3 They Exist But Haven't Communicated Yet

As I said before, the Fermi paradox stems from two observations: (1) the aliens don't seem to be *here*, and (2) they don't seem to be out *there* (in space). Let's focus on the first observation for now.

3.1 Why Aren't They Here?

An easy response is simply that they're so far away that it's impossible for them to make the trip. However, there doesn't seem to be anything in the laws of physics that forbid interstellar travel. For example, in principle, we could — even with today's technology — build a spacecraft that will eventually reach a distant star. The problem is that it might take hundreds of thousands of years, because we currently lack the technology to build (macroscopic) things that can move very fast. There is a speed limit to how fast things can travel — the speed of light — but the fastest rocketships of today's technology don't come anywhere *near* approaching the speed of light. (Our fastest manned spaceships can barely make it to half of a percent of a percent the speed of light!)

However, physicists today have certainly conceived of future technologies in which we can get spacecraft to travel much faster. Over the years, people have proposed antimatter fuel, nuclear fusion ramjets, laser sails, and other

methods based on *known* physics to get rockets moving much faster, eventually reaching significant fractions of the speed of light. People have also proposed methods based on more speculative physics — like using tachyons or wormholes or warp drives — but these methods are actually unnecessary in achieving high travel speeds (and we don't even know if they'd work).

So there doesn't seem to be a problem, at least in *principle*, with traveling from one star to the next. You may just have to wait a long time. So maybe *this* is the solution to Fermi's paradox: the reason we haven't seen any signs from aliens is that they simply haven't had time to reach us yet! But let's take a closer look at this argument.

Our species, *homo sapiens sapiens*, has been around for about a million years. When you consider the fact that the Universe is about 14 billion years old, our existence has been but the blink of an eye. And our Galaxy is almost just as old as the Universe, so our existence has been but a blink of an eye compared with the Galaxy as well.

Now, the Earth formed about 4.5 billion years ago, so it necessarily took evolution quite a while to go through the process of producing increasingly advanced species, finally to the point where intelligent life emerges. But there doesn't seem to be any particular reason why the Earth should have formed 4.5 years ago, as opposed to, say, 4.8 billion years ago, or 5.5 billion years ago. Surely, it takes some amount of time for planets to form, but it's very conceivable that Earth or another Earth-like planet could have formed before Earth actually did form. Therefore, it's very conceivable that intelligent life in the Galaxy could have formed before intelligent life on Earth formed.

So let's assume that (at least) one extraterrestrial species of intelligent life formed before our own a billion years ago in the Galaxy. It's conceivable that, eventually, such an extraterrestrial civilization would want to disperse throughout the Galaxy. After all, we've certainly seen that historically man tends to disperse geographically, so it seems reasonable that aliens might do the same. Of course, we have *no idea* how alien psychology might work, but the scenario is at least conceivable. Maybe they're simply curious like us, or maybe they eventually overpopulate themselves and *need* to spread out, or maybe eventually their own suns burn out and they need to disperse ...

We can then calculate how long it would take for the civilization to colonize the Galaxy. Let us suppose that the civilization sends ships to nearby stars to form colonies, and then those colonies send out ships to form more colonies, and then *those* colonies send out ships, and so on. And let's sup-

pose that the ships travel at 1% the speed of light. (With present-day *human* technology, we can barely get a ship to go a *percent* of a percent of the speed of light, but this number is surely expected to increase. Certainly a more advanced civilization will be able to do much better than us. How long would it take for a civilization to get significantly more advanced than us? Nobody knows, but even if it's a million years, that's still a very small amount of time in the grand scheme of things.)

Now, the Galaxy is about 100,000 light years across, so if we assume that the ships travel at 1% of the speed of light, and pause only for a short amount of time between the trips, then it would take about 10 million years to colonize the Galaxy. Well, you might say, maybe the travelers need to rest between voyages . . . maybe so. So let's say the amount of time they rest between each voyage is equal to the duration of a voyage. This doubles the colonization time to about 20 million years.

But wait, this civilization emerged a billion years ago — 20 million years is nothing compared to this! So, if the civilization emerged a billion years ago and took only 20 million years to colonize the Galaxy, they should certainly be here! Yet we don't seem to see them. So there seems to be something wrong with our assumptions.

One debatable assumption we've made is how long it takes to colonize each star system before sending out more ships — after all, colonization is hard work! So, if the colonization time is much longer than we've assumed, then there's an easy explanation of why they don't seem to be here: they simply haven't had enough time. It turns out, though, that even with very conservative assumptions, researchers have found that a civilization can still colonize the Galaxy in about 500 million years — significantly longer than 20 million years, but still rather small compared to 5 billion years.

Another possibility is that, for *some* reason, the aliens decide to stay home. Maybe they simply have no interest in visiting us, and maybe they don't need to (*e.g.*, their sun hasn't run out of nuclear fuel yet or, if it did, they know how to fix it). Or perhaps it's too expensive to perform a large-scale galactic colonization. It's really anybody's guess. But note that, for this stay-at-home hypothesis to be a valid explanation of the Fermi paradox, it would have to be true for *all* civilizations that might emerge in the Galaxy. We have a hard time understanding how a *single* civilization might behave, let alone alone of them!

3.2 Why Aren't They out There?

So far, we've focused on reasons why the aliens aren't *here*; maybe, for one reason or another, it's impossible to get here. But that doesn't explain why we don't seem to detect any signs of their presence out *there*. Naturally, a number of explanations have been proposed for this, too. But, first, a little background.

The enterprise of trying to listen for signs of extraterrestrial intelligence from space has been going on for over 40 years. Certainly the most famous endeavor of this type is known as SETI (the Search for ExtraTerrestrial Intelligence). There are a number of programs that SETI has tried throughout the years, and they've all tried to listen for signals that are electromagnetic in nature. This includes radio waves, visible light, microwaves, and so on. Electromagnetic waves travel at the speed of light — the fastest speed anything can travel — so it seems reasonable that extraterrestrials would want to send signals encoded in them.

Determining precisely how to look for these waves is a tricky business, however. What frequencies should we listen for, how sensitively should we try to listen for them, and where should we point our ears for them? There are no clear answers to these questions. As for the question of *what* we should be listening for, many people have proposed that we listen for various "natural" but uncommon frequencies. These are frequencies that are, in some sense, fundamental — for example, a frequency of light that results from a certain transition in hydrogen atoms — but which do not occur often in the Universe. The idea is that, if we saw one of these frequencies (and could be sure it wasn't just a statistical fluke), then this would be circumstantial evidence for an extraterrestrial source.

One problem that emerges is that there are just *so many* of these "natural" frequencies, and we have only limited resources; that is, we're only able to search in a small range of frequencies compared with the *whole* range of the electromagnetic spectrum. Another problem is that, even if there are extraterrestrial signals out there encoded in "natural" frequencies, they might be too faint for us to detect. The obvious solution to this is, of course, simply to increase our sensitivity. But, because of limited resources, this comes at the cost of being unable to scan as wide an area of the sky, thereby possibly missing signals from places we're not listening to. So, there's always a tradeoff between sensitivity and scope, and determining the optimal tradeoff isn't exactly clear.

Given these difficulties, all of the SETI searches have understandably turned out negative. The optimists say that we should continue our searches, as technological improvements will increase our chances the longer we search, while the naysayers respond that if the aliens are out there, we would have seen them by now, or else we'll never see them. At any rate, one thing is certain: detecting aliens (if there are any) is some tricky business.

Maybe we're approaching all of this in the wrong way, though. As I mentioned earlier, the SETI searches have all been based on trying to detect signals encoded in electromagnetic waves. Maybe the aliens (if they exist) are transmitting signals in some *other* form. Perhaps they're use gravitational waves, for example. Gravitational waves are "ripples" in spacetime that general relativity predicts should result from "shaking" a mass violently. They've never been directly detected, but we do have very good indirect evidence that they exist. The reason we've never directly detected them is simply that they're *extremely, extremely* weak. However, there is currently a *huge* ongoing effort to directly detect them, and it's very possible that within the next few years we finally will. The point is that it *could* be that aliens are sending us gravitational waves (or even something else, like neutrinos), and we'd never know it today.

4 We Are Alone

Finally, we reach the last possible answer to the Fermi paradox: we don't see any aliens *here* and we don't see any of them *there* because there *aren't* any aliens; we are alone. This is a rather somber explanation, but it's a very real possibility that no other intelligent life exists in our universe.

4.1 Intelligent Life Is Extremely Rare

It could be that the emergence of intelligent life is extremely rare. The modern, scientific understanding of the origin of life is that every living thing today is a descendent of more primitive forms of life in Earth's history. And those primitive life forms were descendants of even more primitive life forms. Furthermore, if you rewind the history of the Earth *way* far back, the only life that existed was in the form of extremely simple bacteria. Before these bacteria, there was no life. There was just a vast sea of molecules floating around, moving about and interacting with each other in random ways.

However, *occasionally*, from these random interactions, the molecules organized themselves in stable configurations that we now recognize as forming the basic components of life. For example, *occasionally* amino acids would form. And, *occasionally*, such "higher-level" molecules would organize themselves into an even higher-level, stable structure that today we'd call a cell. So, through sheer randomness, life emerged from non-life. Now, once simple cells emerged, the stage was set for random processes to produce more complicated cells. Eventually, *eukaryotic* cells — cells with a nucleus — emerged, and eventually so did *multicellular* organisms. And so on and so forth, eventually creating the diversity of life we see today. This is, in a very gisty gist, the process known as evolution, and it's an absolutely cornerstone piece of modern biology. It's an extremely surprising phenomenon, for sure, but if you wait a long enough time, even the most improbable things happen — Earth had to wait 4.5 *billion years* for man to form.

Now, it could be that one or more steps in the evolution to intelligent life are intrinsically extremely improbable, so that there's some kind of a "Great Filer" leading to ultimate development. Where might the Great Filter be? Nobody really knows, but people have suggested several candidiates. For example, perhaps it's that stage in which life emerges from non-life. Or perhaps it's the transition from unicellular to multicellular, or maybe at the stage where animals develop bigger brains. The point is that, although there may be many habitable, Earth-like planets in our universe, it could be that, even with those perfectly ripe conditions, intelligent life is extremely unlikely to emerge. *We're* here, so it's obviously not *impossible* for it to happen, but there doesn't seem to be anyone else. So maybe we are the sole intelligent beings in our universe.[2]

The Great Filter can actually act in another, far gloomier way. Maybe it doesn't act so strongly on the steps to produce intelligent life, but it acts on the intelligent life itself. For instance, it might be that once intelligent life forms, it inevitably tends to destroy itself before it's able to colonize its galaxy or communicate with other intelligent civilizations. Based on our own civilization, we certainly know that this possibility is very conceivable. So, from these considerations, we can make a very interesting conclusion: *The*

[2]Of course, much more could be said about this "Rare Earth" hypothesis. Asking whether the evolution to intelligent life is intrinsically unbelievably improbable is actually a scientific question that evolutionary biologists, astrobiologists, *etc.* can tackle. It's obviously a very *hard* question, but people are working on it. Let's give them moral support!

greater the probability it was for life to evolve to our present stage, the worse our future chances of survival probably are. For this reason, for example, it would be *very* bad news for humanity if we found life on Mars, as scientifically interesting it would be.

4.2 The Universe Is Dangerous!

But maybe intelligent life doesn't inevitably destroy itself. Maybe it's the *Universe* that inevitably destroys intelligent life — after all, the Universe is a pretty dangerous place! Living on a planet presents a number of risks, for example. At any given moment in time, one has to deal with the threat of apocalyptic meteors crashes, supervolcanic eruptions, and so on. Yet these dangers pale in comparison to a discovery of astronomers known as "gamma ray bursts."

These outbursts of electromagnetic energy in the form of gamma rays are the absolute, most energetic sources of energy known in the Universe. The amount of energy that gamma ray burst puts out in a few seconds is more than the Sun ever will in its entire lifetime. Now, all gamma ray bursts ever observed have been far away from our own Galaxy, but it's possible that a gamma ray burst could happen in our Galaxy. Nobody really knows — there's still a lot to be learned about gamma ray bursts. However, *should* such an event happen . . . that would not be good news. A nearby gamma ray burst could very well wipe out our entire civilization. And perhaps gamma ray bursts *have* wiped out entire civilizations, and perhaps *this* is the solution to the Fermi paradox.

And there are many other possibilities; I've barely scratched the surface of the Fermi paradox. A highly readable, comprehensive (and non-mathematical) book that goes into far greater detail than I have here is *Where Is Everybody?: Fifty Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life* by Stephen Webb — I highly recommend it.

I suppose the main lesson to take away from all of this is that the Fermi paradox is a real problem, with a variety of subtleties that make it both difficult and interesting. The question of whether we are alone in the Universe is, I feel, an extremely important one that we've all wondered about at least some point in our lives. We don't yet know the answer to it — and we may well never — but the quest for the answer is certainly an intriguing one.

The Big Questions
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