Rob: Welcome to the After On Podcast. I'm your host, Rob Reid, and this is a series of conversations with thinkers, founders, and scientists. Take a little time and stretch out, because these talks are unhurried and meant to bring you to a top percentile understanding of something important.

So, whether you're into startups or ideas, a techie or a lit major, take your time, engage your mind, and you'll be glad you did, especially this week, when we'll be talking to Harvard astronomy department chairman, Avi Loeb.

As his title indicates, Avi's an extremely credentialed astronomer, so when he asserted than an object currently passing through our solar system could well be the artificial product of an alien intelligence, eyebrows went up, including my own. He made this argument in a scientific paper published on the 12th of this month in the Astrophysical Journal, which itself is one of the top research publications in all of astronomy.

I got wind of this paper before its official release date and reached out to Avi, and we ended up having the longest and most in depth interview he's given on this fascinating topic thus far. And also, he noted in an email to me yesterday and invited me to share this characterization, the most intellectually stimulating interview from his personal standpoint.

Now, I was delighted to hear this, because like anything connected to aliens, this story has inevitably led to an avalanche of sound bytes and click bait. It's also triggered a fair amount of controversy amongst professional astronomers.

The negative reactions have ranged from skepticism to something verging on moral outrage, but adversarial debate is one of the key mechanisms by which science advances. There have been periods stretching for decades when the field of astronomy itself was divided some of the most basic aspects of the cosmos. Is the universe expanding? Was there or was there not a big bang? Are black holes a thing, or just a theoretical toy? Great minds lined up on opposite sides of these questions for large proportions of their careers.

Luckily, we won't have to spend quite so long on the edge of our seats, because the debate Avi has triggered has a sell by date. As we'll discuss toward the end of the interview, much of the mystery surrounding his arguments should be dispelled in a bit over three years, when a powerful new telescope comes online.

After hearing this interview, you should be equipped to make up your own mind about what you expect the new telescope to reveal, if anything, and to follow this story as it unfolds and to debate it in an informed way if you wish for as long as it remains a mystery.

Before we start, two quick notes. One for my most committed listeners and a second for my newest listeners. First, you old timers, if you are backing this show on Patreon at a level of $5 per month or more, I urge you to turn this version of the episode off right now and go to the episode in the private Patreon podcast feed. As is often the case, that version of the show is significantly longer, specifically the main body of the interview excluding the intro and outro is probably about 20% longer. That's 20% more controversy, 20% more astrophysics, perhaps even 20% more aliens.

I also posted a Patreon version several days earlier and the main feed version as a second way to thank my patrons for making this show financially possible. So, patrons, either go to the podcast feed on your smartphone or go to Patreon.com/RobReid, R-E-I-D, to get what you paid for.

As for those of you who are new to the show, welcome. I'll tell you more about Patreon and all that stuff at the end of the show, but for now, suffice it to say that you have stumbled upon a podcast which features in depth conversations with world class experts about their domains of knowledge. In each episode, I try to bring you and myself a serious grounding in something complex and important that we should all probably understand a bit better.

If you enjoy this episode, please browse the show's archives at after-on.com or in your favorite podcasting app, you'll find an archive of fascinating conversations with some of the top people in robotics, neuroscience, cryptocurrency, drones, augmented reality, synthetic biology, and many other fields. If you're interested in these sorts of things, I hope you'll consider subscribing to the show.

Finally, some quick background for everyone before we start. The mysterious space object which is causing all the excitement is called 'Oumuamua, a name Avi and I will cite frequently. It's a Hawaiian name chosen because the observing system that discovered it is based in Hawaii. Avi and I will refer to that observing system as Pan-STARRS, which is a complicated acronym.

'Oumuamua got its first burst of attention when it showed up about a year ago because it's the first interstellar object, which is to say the first object from another star system, definitively identified within our own solar system. And so with that background, I bring you Avi Loeb.

Avi, thank you so much for inviting me to your office on what I'm sure must be one of the crazier weeks of your career, but before we get into that, I'd like to briefly review your background, just to set some context for our listeners. Starting with the most basic thing, what is your title here at Harvard?

Avi: I'm the [inaudible 00:05:25] professor of science. I'm the chair of the astronomy department at Harvard, and director of the Institute for Theory and Computation, and the founding director of the Black Hole Initiative at Harvard.

Rob: And how long have you been the chairman of the astronomy department?

Avi: Eight years.

Rob: Eight years. How many academic papers have you published in your career?

Avi: My first paper was in 1985, and since then, I published over 700 papers, and then wrote four books. The First Stars to Forming the Universe, that was my early interest. When I came faculty of Harvard, not many people were interested in the first stars, and I thought of it as an exciting frontier because it's the scientific version of the story of Genesis, how the first light was produced.

Most recently, I got interested in the search for life, and in fact right now, I'm writing a textbook with my post-doc [inaudible 00:06:21] on extraterrestrial life from biological signatures to technological signatures.

Rob: When is that coming out?

Avi: We hope to finish it by next summer, summer of 2019. I don't see this subject as speculative at all. I think life is likely to exist out there. We better understand where to look for it, and by the way, an interesting lesson from astrophysics is that the laws of nature were found in laboratory experiments, and then we found them to hold when looking at the universe and interpreting the data that we collect on the universe.

And the same thing may happen in the context of the search for life. There are several groups around the world trying to produce artificial life in the laboratory, and if we are successful, then this will demonstrate to us under which circumstances life may develop, and then we can look out in the universe at environments that provide these circumstances, and again, our imagination would be guided by what we achieve here in laboratories.

Rob: Is this gonna be something that's really for an expert audience as opposed to a popular audience?

Avi: Well, there would be parts of it where a popular audience would be able to follow everything, and there would be parts that have equations.

Rob: Well, I'll look forward to reading all the non-mathematical parts of that, but meanwhile, let's talk about this mysterious lump of matter that's passing through our solar system called 'Oumuamua and the response to what you just published about it.

Avi: Yes, and this was unexpected. I just wrote a paper that was one out of the 40 papers I wrote over the past year and was surprised to see the reaction.

Rob: Well, it's been quite a reaction, and to talk about this amazing object, why don't we start with what happened a year ago, roughly, October 19th of last year?

Avi: The Pan-STARRS survey monitors the sky, and the purpose is primarily to find the asteroids that may in fact impact the earth. They noticed an object that moves so fast that it's unbound to the sun. Therefore, must be of interstellar origin from outside the solar system.

Rob: It was moving so fast that it was going beyond the escape velocity for the solar system. It was 26 kilometers per second or something like that.

Avi: Correct. It's the only thing that we spotted that comes from outside the solar system.

Rob: And by the way, this kind of blows my mind. A bit of an astrophysics fanboy. Always been fascinated by astronomy and so forth, and when 'Oumuamua first became a story a year ago, it kind of astonished me that somehow over the centuries that we've been gazing at the sky, we had never found something that was definitively from outside the galaxy. I was amazed that it took until 2017 for that to happen.

Avi: Well, the reason is simple. These are small objects and only when they pass close to the sun or close to us we can notice them. There might be a lot of traffic out there and it's just that we can't see them very far because we need the sun to serve as a lamppost that illuminates them and they need to come close to us for us to see them.

Rob: Close enough for us to see, and or close enough to the sun to be illuminated.

Avi: Right.

Rob: And this one was spotted by a newish telescope. You mentioned it's called Pan-STARRS. It's been up I guess since 2010 or so. So assuming for the moment that 'Oumuamua is just a typical rock from another star system, how do we imagine it would've found its way here?

Avi: Now, these objects, most of them are expected to be ejected from the periphery of the star. That's where objects are not bound very strongly to the star. For example, the Oort Cloud has a lot of asteroids in it.

Rob: The Oort Cloud being very, very distant, way beyond Pluto, where most of the comets hang out, right, when they're not zipping around the sun.

Avi: It's about 100000 times farther than the earth sun separation, and so that's the outermost edge of the solar system, and it's actually roughly halfway to the nearest star. So you can think of stars having these spheres around them, and they're almost touching each other.

Rob: The outer spheres, the Oort Clouds, almost touch each other even though the stars are extraordinarily distant.

Avi: Exactly, and the outer part of the Oort Cloud is where you expect most of the ejections of asteroids to take place because they're very weakly bound to the sun. A kick by only a few kilometers per second can get them out, or even less than that.

Rob: So just to clarify, if something does come through our solar system from another solar system, the expectation would be that it came out of that solar system's Oort Cloud because it's got such a weak binding. And as I just mentioned, it surprised me to learn that it took us until 2017 to identify something from outside the solar system, but you were surprised that we identified our first interstellar object so early.

Avi: Because even if you make optimistic assumptions that all stars are just like the solar system, they have an Oort Cloud, about a decade ago, we made a prediction for how many asteroids should we find with Pan-STARRS. We predicted that we wouldn't find any, and that in fact, we'd have to wait for the next generation, the large synoptic survey telescope that will come online within three years, that will be much more sensitive.

Rob: And to be clear, you made that prediction in a paper you wrote right before the Pan-STARRS telescope went live, and you didn't just calculate that Pan-STARRS was unlikely to spot something interstellar, but you put the odds against it somewhere between 1 and 100 and 1 and 100 million that Pan-STARRS would ever see anything.

Avi: Right.

Rob: So you were, I imagine, personally quite shocked on October 19th of last year when this thing showed up because you had done that calculation 10 years ago.

Avi: Right.

Rob: You were probably viewing this through a different set of eyes because you had this background.

Avi: Right, and the reason that interstellar objects are of interest is just like having a dinner party and inviting people to it and then realizing that one of the guests is from another country, and by examining that guest, you can learn about the culture of that country without spending the time and money to visit that country. So, that offers great prospects for learning about other planetary systems without the need to visit them. With chemical rockets, it would take us 100000 years to reach the nearest star, and so it's a very long journey, and these objects have spent already the time arriving to our door, so why don't we take a look and figure out what's going on?

Rob: This is a very, very interesting dinner guest. Now, the object was first spotted on October 19th. It took about three days for them to determine its speed relative to the sun and to determine from that this is definitely from outside of the solar system. So, let's say it's the 22nd, 23rd, but it got closest to the earth before that. 'Oumuamua's closest approach to the earth was October 14th and its closest approach to the sun, when I assume it would've been brightest, was September 9th. And so we didn't see it until it was already on its way out of the solar system. Why did we miss it when it was on its way in, because we would've gotten so much more data if we'd seen it coming in?

Avi: Well, the survey has an operational mode where it looks at different parts of the sky, different times, and the analysis of the data takes a while and the alert of interesting objects takes a while. So, it was just missing the early parts of the orbit, and so it was just out of the radar. It's sort of like having that dinner guest, but not realizing it until he or she leaves the door, and then you realize, "Oh, that would've been a really interesting person to speak with."

Rob: Unbelievable, a Panamanian. I always wanted to meet a Panamanian and now he's halfway down the driveway.

Avi: Exactly.

Rob: Now I got to go to Panama City. I'm never gonna do that.

Avi: No, you can, because you just need to organize the next dinner party. Perhaps there will be another one. A good aspect of astronomy is that you have classes of objects that keep coming back again and again. Now, this is under the assumption that this is one object out of a random population.

Rob: Once it was established that this was in fact from outside of the solar system, the astronomical community did rally. The woman who was in charge of the apparatus in Hawaii, her name was Karen Meech, right?

Avi: Right.

Rob: She worked very hard, and I'm sure lots of other people worked very hard, to get telescope time on lots and lots of telescopes. Lots of teams started tracking it. The Hubble got involved. How unusual of a surge was that?

Avi: It was not sufficiently unusual. I think the next one around will get much more attention. In reality, it's a very peculiar object because it reflected sunlight and it rotated roughly every eight hours, and its brightness changed by a factor of 10 as the object rotated, and so that told us that it has a very extreme shape. It's at least 5 to 10 times longer than it is wide.

Rob: So, it's sort of flashing. It's flashing somewhat erratically, and if I'm not mistaken, the aspect ratio of ranging from 5 to 10 to 1, that's really weird.

Avi: It's unusual.

Rob: The outer limit for natural objects that we're familiar with is 5 to 1, right? And if it was as long as 10 to 1, is that unprecedented [crosstalk 00:15:21]?

Avi: It's unprecedented. So, there is actually no other object, an asteroid or a comet, in the solar system that had such an unusual axis ratio.

Rob: And another unusual thing was 'Oumuamua's speed in relation to our immediate neighborhood in the galaxy.

Avi: Yes. The speed is an interesting story by itself, because this happens to be the so-called local standard of rest you get when you average over all the stars into [inaudible

00:15:45]. So, stars have relative motion to each other, and so you can take the average of that motion and find the local standard of rest, and it so happens that 'Oumuamua is originating from that frame of reference. It's almost at rest, or at the local standard of rest, and only 1 in 500 stars is so slow relative to this frame of reference.

Now, if you wanted to camouflage your origins and hide where you came from, you would be in that frame, because that frame does not belong to any star. Only 1 in 500 stars is in that frame, and 'Oumuamua is in that frame. It's sort of like a buoy sitting on the surface of an ocean. That fact by itself is very peculiar because the speed of a star is typically 20 kilometers per second, like the sun is moving relative to that frame of reference.

Rob: So let's say 'Oumuamua was ejected from an ordinary star, not one of the very rare stars that happened to be traveling at precisely the local standard of rest. What would happen next?

Avi: For these objects to be ejected, they need a very small kick, and so they would primarily move at the speed of the star itself.

Rob: The star that they're orbiting?

Avi: Yes. And so, then it would be surprising to find 'Oumuamua as the very first encounter being at rest in this local standard of rest because it would have the characteristic speed of its host parent star from where it came. And so, just the velocity tells the whole story that it's completely unexpected.

Rob: How large of an area does the local standard of rest apply to? Is it the entire galaxy?

Avi: No.

Rob: Or 500 light year sphere?

Avi: The stars move relative to each other, but they all move around the center of the galaxy together.

Rob: They move around the center of the galaxy together. So, the region that defines the local standard of rest is about 100, 200 stars roughly?

Avi: There could be more. Altogether, it could be thousands of stars over which you average.

Rob: It's a pack of stars.

Avi: Right.

Rob: They're moving kind of as a pack, but they're also moving at pretty high speeds relative to one another, and when you look at that pack, the definition of the local standard of rest is averaging out all of those different speeds, and then what's remarkable about 'Oumuamua is in one way of looking at it, it's not moving, it's stationary.

Avi: Right.

Rob: It's at that local standard of rest, and you said within our pack, it's only one star out of 500.

Avi: Right.

Rob: There's really just a .2% chance that by sheer happenstance, it would be at the local standard of rest.

Avi: Yes, and moreover, you need the directions to coincide. So in other words, it could be that there is one star out of 500, but at a completely different direction. So, there are coincidences you need to arrange, one in velocity space and the other one in position space.

Rob: So, by being at this local standard of rest, 'Oumuamua by one definition in relation to our pack is stationary, and when it comes through our solar system, it looks to us like it's coming through at 26 kilometers per second, but another way of looking at it and perhaps more accurate is our solar system is sweeping past it at 26 kilometers per second. So when you learn these strange things about 'Oumuamua, the local standard of rest angle, its bizarre axis ratio of up to 10 to 1, et cetera, let's talk about who you reached out to.

Avi: I was so surprised by the unusual properties of this object that I wrote to Yuri Milner.

Rob: Can you give folks who don't know a brief background on who Yuri is and what his breakthrough initiatives are?

Avi: So, Yuri is an entrepreneur from Silicon Valley that has a background in physics, and he's particularly interested in the search for life in the universe and has initiatives that he's funding at the level of $100 million each, one of which is breakthrough listen to try and search for extraterrestrial civilizations, looking for the radio signals, maybe optical signals.

And the second initiative that is prominent is called Breakthrough Starshot, that he asked me to lead, which is an attempt to visit the nearest stars and take photos of the habitable planets in it. So, for example, Proxima Centauri has a habitable planet next to it, Proxima B, and the idea is to send a probe that will take a photograph of it. He asked me to lead the Breakthrough Starshot initiative and see if there is a technology that allows us to reach a fraction of the speed of light such that within our lifetime, both Yuri and I are 50, 60 years old, within our lifetime, we would see the image of that planet. And since the nearest star is four light years away, you need to move the spacecraft at least a fifth of the speed of light so that it will get there within 20 years or so. And so, I agreed to look into the possible technologies and found just one, and I recommended that we explore or develop the technology of light sails pushed by a powerful laser beam.

Rob: Let's talk about how that works, if you don't mind. The basic idea is that you launch something that unfurls something like it's a sail. It's got a big surface area, and then you fire photons. You fire light at that thing from the earth from a very powerful laser, and those photons, even though they're almost completely immaterial compared to anything that we deal with in our normal lives, each time one of those hits that sail, it does exert a little bit of force and as with wind pushing a normal sail, you can fire that laser over a period of time and that thing will accelerate and accelerate. How long do you fire the laser at that sail to get it to its top speed after it leaves the earth?

Avi: It will just take a few minutes.

Rob: Really? That's it?

Avi: Yeah, and the laser has to have a power of 100 gigawatt or so, and that's roughly the amount of power that was needed to lift off the space shuttle in the same amount of time, a few minutes, except that it's delivered to a single gram of matter such that it reaches a fifth of the speed of light.

Rob: So, the gram is the pay load.

Avi: Yes.

Rob: All the electronics and sensors and things that science can miniaturize in the intermediate future.

Avi: We already have that in cell phones. It's basically a camera and navigation device and a communication device, and that can be packed into a single gram, and then another gram would be the sail itself.

Rob: What would the diameter of that sail be, roughly?

Avi: Of the order of four meters or so.

Rob: Four meters, and that's another gram. Literally in just those few minutes, it's already to a fifth of the speed of light?

Avi: Yes.

Rob: You're kidding.

Avi: At five times the distance to the moon, that's the launch distance.

Rob: Sorry, this is blowing my mind. Okay, so you launch this thing. Well, it's probably in orbit. You've probably put it up in the satellite. It's in orbit. It's unfurled. It's ready to get zapped, right?

Avi: There is a mothership that releases [crosstalk 00:22:06].

Rob: There's a mothership that releases. It's not like we have a two gram rocket ship. So it's out there. You point a laser at that thing, and within five, six, seven minutes, it is going at a fifth the speed of light and it is five times past the moon?

Avi: Right.

Rob: Whoa.

Avi: After the first few minutes, there is a journey of 20 years to get to the star, so it's 20 minutes of excitement and then 20 years of waiting period, and then once it takes the photos, it takes another four years for the signal to reach us.

Rob: So it's 24 years after launch.

Avi: Yes.

Rob: There is actually a history already of functional solar sails because the Japanese space agency put together the Icarus Project, wasn't it, in 2010?

Avi: Right.

Rob: And that was the first deployment of a solar sail, and it was fairly successful, correct?

Avi: Yeah. It was a demonstration that sunlight can push on a sail and bring it to the higher speed.

Rob: So that wasn't using the laser or any of that. It was a more traditionally dimensioned spacecraft. What was it, to Mercury or Venus or something like that?

Avi: Well, yeah, but the sail was relatively far from the sun and so the push was not very significant. It was just a demonstration of the principle.

Rob: But it got up there and it was catching solar photons as opposed to laser photons.

Avi: Reflecting.

Rob: Reflecting.

Avi: Yes.

Rob: And they were able to demonstrate, "Hey, this works."

Avi: Exactly.

Rob: By the time 'Oumuamua had disappeared from Hubble's view in January, the consensus view in the broader astronomical community was like, "It's an asteroid or it's a comet. It's a comet or an asteroid." That was generally where the debate was, correct?

Avi: Yes.

Rob: And then the commentary explanation got a great deal of momentum in the June timeframe when a paper came out in Nature, one of the very best regarded publications in the world of science, that analyzed a great deal of data that had been gathered during these few months of observation pretty rigorously. There were a lot of names on that paper, a lot of very well-regarded scientists including Karen Meech, and that paper made the astonishing conclusion that as 'Oumuamua was leaving the solar system, exiting away from the sun, it started to ...

PART 1 OF 3 ENDS [00:24:04]

Rob: ... leaving the solar system, exiting away from the sun, it started to accelerate, which is not what you normally expect to see happen. Analyzing that acceleration, this team came to the conclusion that Oumuamua was a comet. Would you care to explain how they got to that conclusion?

Avi: Yes, so comets have ice on their surface and this ice, when it's warmed up by the sunlight it evaporates and you end up with situation similar to a rocket where there is gas flowing in one direction and pushing on the exhaust in the other direction. So, the idea is that in principle comets deviate from an orbit that is shaped purely by the sun's gravity because they have this extra push from the gas.

Rob: Which is called off gassing correct?

Avi: Out gas.

Rob: Out gassing, yeah.

Avi: Now, the only problem with this idea is that we haven't seen any cometary tail. There was no evidence for either gas molecules in the vicinity of Oumuamua or dust, which is often accompanying the evaporation process.

Rob: Did we look closely enough that we really should have seen it?

Avi: Yes.

Rob: I mean, we had all those telescopes pointing at it.

Avi: Yes.

Rob: Also, there was no coma, which is the fuzzy area that surrounds the front of a comet where stuff is also out gassing, correct?

Avi: Right. Also, just the other day I made a rough estimate. If you ask which fraction of the mass of Oumuamua needs to be evaporated in order for it to get enough push, it's actually substantial, it's more than a tenth of it's mass.

Rob: Would of had to out gas in order for it to get that thrust.

Avi: Yes.

Rob: And is that atypical of what usually out gasses from a comet?

Avi: Well, not so much that, but you would notice it because there would be a lot of stuff.

Rob: Yeah. When the paper came out, I read interviews with a couple of the scientists and they did acknowledge, "Hey, it is kind of weird that there was not tail." One of them said, "Well, that might be because instead of small particles, which for whatever reason are easier to see, the tail may have been comprised of large particles which are hard to see." I'm not equipped to parse that argument. How do you respond to that?

Avi: Well, there are other effects that the out gassing has on an object, because usually the comets are not symmetric. So, they're not pushed just away from the sun, they are also pushed sideways. But moreover they get spun up, or spun down. There is a change in the spin period of these comets.

Rob: There's an eccentricity to the rate of which it's spinning?

Avi: Yeah. Well, the force is not even on the two ends of the comet.

Rob: As a result of the out gassing?

Avi: Yes. As a result of that, the period of rotation is changing. The change should have been easily noticed. That didn't show up.

Rob: And a couple of other things that I've seen noted, was it had different reflectance from typical comets. I think a comet is typical in the range of 4%. This had a reflectance of 10%.

Avi: Or even more.

Rob: And tell us what reflectance is, and the consequence of that to your mind.

Avi: Yeah, so sunlight is shining on the object and fraction feed gets absorbed and that heats up the surface, and the rest gets reflected. In principal, the reflectance is what we see as observers. The absorption heats up the object. Now the Spitzer Space Telescope looked at the heat that this object radiates and they didn't detect anything. From that they inferred that the absorption of sunlight by the object is smaller than one gets typically in comets. In fact, it reflects much more of the light that falls on it.

Now, the fact that they haven't detected any heat or any emission from the object sets an upper limit on it's size, and implies that it's size could actually be smaller than previously thought. So, previously when people estimate a length of a few hundred meters and a width that is ten times smaller, they based it on the typical [inaudible 00:27:48] or reflectance of rock. The way we see in asteroids. If this parameter is different, if you have perfect reflectance for example, then the object can be 20 meters in size.

So, the question is how big was it?

Rob: This became something of a mystery. Now, my understanding is until this paper came out in June it wasn't widely known at all that this thing had started accelerating.

Avi: True.

Rob: So that was the first you'd heard about it?

Avi: Right.

Rob: You had some interesting thoughts about it when it first showed up, but this nature paper comes out in June. It shows demonstrably that the acceleration was there. The authors pointed strongly at the cometary theory. We've obviously talked through some of the visible arguments against it being a comet. In addition to that, what led you to think this might be a completely different force that's causing this acceleration?

Avi: It was a paper that appeared on the archive arguing that indeed the spin rate of this object should have changed if there was out gassing.

Rob: The spin rate argument, did that appear at the same time as-

Avi: No, it appeared just a couple of months ago, and was written by [Roman Rafikov 00:28:52] from the University of Cambridge in England. That to me was a red alert, because what is then providing the extra push? It's always possible that the observers got it wrong, but they claim very high statistical significance for the detection. 30 standard deviations. We are usually happy with three to five standard deviations. To give the Nobel Prize to discovery, right? Here it's 30, so it was beyond any reasonable doubt that there was a deviation from the orbit shape just by gravity.

So, then the question rises as what gives it a push. The first thing I thought about was maybe if the object breaks into pieces so that one piece gives a kick to the other. The problem is that it would be an impulsive kick.

Rob: What does that mean an impulsive kick?

Avi: That it happens at one particular point in time.

Rob: There's a solitary kick if it breaks apart?

Avi: Exactly, a sudden push. Instead of what was observed which was a steady push across an extended period of time. So, it cannot be a sudden event, therefore this explanation does not hold water. The only other thing I could think of was that it's the sunlight pushing on it. Of course, I was inspired to think in this direction because of the involvement in Breakthrough Starshot.

We are always limited in our imagination by what we know. I admit that, and that's true for everyone. But it doesn't mean that what we imagine is not true.

Rob: In order to explain the data that the nature team had established.

Avi: Exactly.

Rob: Your question is if it's solar radiation, which I imagine is a much smaller force than out gassing, is that correct?

Avi: Yes.

Rob: So if it's this much smaller force and if the nature data is right, what would the dimensions of this object have to have been?

Avi: It needs to be a thinner object than a chunk of rock, because the force is smaller so you want the amount of mass associated with the object to be smaller for the same surface area. Now, if it's a good reflector the size of the object needs to be only 20 meters, not hundreds of meters. The hundreds of meters estimate was obtained assuming that it's a rock.

Rob: By assuming it was a rock, they assumed that it had the average reflectance of the typical asteroid in our solar system.

Avi: Exactly. So this one potentially could be just 20 meters if it's a perfect reflector. Then the question is how thin should it be? We calculated that it should be thinner than a millimeter.

Rob: Could we talk about what might produce such a thing naturally?

Avi: Right, so I tried to think about that, and I'm a pretty imaginative guy. I wrote over 700 papers in my career, and I just couldn't think of anything natural that would produce it. It doesn't mean that it doesn't exist, but in the interstellar medium or in the planetary environment, you often make round objects. Okay, because round objects tend to be more sturdy. They survive their environment. Also gravity makes things rounder. So, it's very difficult to imagine the sheet matter being assembled. We do manufacture such sheets of matter industrially, but it requires very special conditions that do not arise naturally.

Rob: So, we have not seen any 20 millimeter thick disks?

Avi: Right. The only question is who produced it?

Rob: Right. And you said this could well be an extraterrestrial artificial object. A solar sail, perhaps debris kind of like you might find an ancient sail floating on the ocean from a long ago shipwreck. This might be debris from an alien spaceship.

Avi: Well, yes, a few months earlier I wrote an article in Scientific American where I talked about space archeology, which is an interesting concept. In the past, people thought about searching for alien civilizations by listening, trying to find signals. But it occurred to me that maybe the reason we don't find signals easily is because these civilizations are short lived. Just like our civilization, once we started developing the advanced technologies that we have now, the rate of progress is accelerating, it's exponential.

So that implies that very quickly a civilization reaches the point where it can easily destroy itself. Either through nuclear wars, or through changing the climate of its planet, or polluting its atmosphere. It would mean that when you look at planets that used to have living civilizations, you might find debris or some infrastructure that was developed. Even though there is no life there, you would see evidence for poisoned atmospheres for mega structures for [inaudible 00:33:12] cells coating the surface. All kinds of things that you can see from a distance, and finding those relics of dead civilizations would serve a very important purpose. It would teach us a lesson to get our act together, and to get along with each other so that we don't share the same fate as those dead civilizations.

Rob: So, you not only made the solar radiation argument and pointed out these exotic dimensions, but then you took it another step according directly from your paper a more exotic scenario. Is it Oumuamua? Maybe a fully operational probe sent intentionally to Earth. Probably not a sentence that typically appears in peer reviewed academic journals.

Avi: I'd be glad to explain it.

Rob: I'd be mortified if you didn't explain it.

Avi: You just assume that the object is one out of a random population of objects. You need 10 to the power 15 such objects to be ejected per star in the Milky Way galaxy.

Rob: Is that quadrillions, or quintillions? 10 to the 15?

Avi: It's 1000 trillions if you want.

Rob: So quadrillion, very, very large number.

Avi: Yeah, yeah.

Rob: In order for some things to just happen to come close enough to us for us to see it-

Avi: On the period of time that Pan-STARRS was operated?

Rob: Yeah, during the now eight year life of Pan-STARRS. If Pan-STARRS has been operating for eight years, it has a limited range of view. So limited that we didn't even see Oumuamua until it was well on its way out. This is a calculation you did before Pan-STARRS switched on, right?

Avi: Right.

Rob: So, if you take that period, and you say, "What are the odds that we're going to see something eject the expected manner leaping from a north cloud." Every star would have to create a quadrillion objects that fly out randomly. Every star in our pack.

Avi: No, in the Milky Way galaxy.

Rob: Oh, in the Milky Way galaxy, there should be a see of these things zipping around?

Avi: Exactly.

Rob: Your calculation was that every star in its lifetime, not in one year, but over the course of its multi billion year lifetime, would have to create one quadrillion objects, and that's a lot.

Avi: It's a lot.

Rob: And your estimate was what?

Avi: 100 to 100 million times smaller. There were uncertainties in that estimate. Even all the uncertainties, we expected an abundance, which is far smaller. But observing Oumuamua allows us to calibrate how many such objects should be out there.

Now, this is unusually high, both for natural origins as well as for artificial origin. Because if you imagine launching sails, but you need to do it every hour or so to reach huge numbers and it just doesn't sound reasonable.

Rob: So that's an interesting point. So, if your calculations were correct and stars simply aren't launching this much stuff, we could get imaginative and say, "Okay, little green men are launching these things. They're launching these sails, and they're launching them all over the place." But they would have to be launching a staggering of them for us to just happen to see one, by your calculations.

Avi: Right. They would need to do it every few minutes to an hour in order to reach the abundance necessary. So, imagine how many such sails should be launched per star.

That's assuming that the civilization lives the full age of the universe. In fact, if it's short lived it doesn't have as much time.

So, this doesn't sound quite reasonable, so how do you avoid that? Again, I'm going in a path very similarly to the maxim of Sherlock Holmes, "Whenever you rule out the impossible, whatever remains, however improbable must be the truth." That's what Sherlock Holmes said. So, here I'm following this logical path and if I want to avoid this huge number, then the only way out would be to say, "Well, it's a special object that was sent with a purpose." It's targeting the central part of the solar system. That the habitable region where life could potentially exist. This is a probe that is on a reconnaissance mission.

Rob: And that would be explain the sheer happenstance. Now let's talk about your paper and first of all, it's history it's timeline, the nature paper analyzing the motion, the acceleration, all that came out in June. It was I think you said about two months ago that the second paper came out that said that we did not see the rotation that we should expect in a comet. That was really what triggered your thinking, I'm guessing?

Avi: Yes.

Rob: So, you and your post doc, finished your paper and on Friday the 26th of October, you submitted it to-

Avi: The Astrophysical Journal Letters, which is the most prestigious journal for rapid communications in astrophysics.

Rob: When you say for rapid communications, what does that mean?

Avi: Usually the letter section involved shorter papers that are on a timely subject that needs the attention of the community on a short basis so that you don't need to wait a lot of months before the paper comes out.

Rob: So, Astrophysical Journal Letters section, this is for things that are timely. You also put it up on-

Avi: The Archive.

Rob: On The Archive. Tell folks what The Archive is.

Avi: The Archive is an online service where we post our papers such that members of the community that work in astrophysics can look at the paper and send us any critical comments they might have. The paper is basically available online for anyone to read.

Rob: From the moment you submit it to a journal?

Avi: Yes.

Rob: And that's typical process in astrophysics?

Avi: Well, I prefer to do that at the time of submission to the journal because if I get any comments from the community then I can make changes. If I do it after it was accepted for publication, then you cannot revise it.

Rob: Got it.

Avi: I care mostly about the substance in the paper, so I want to receive as much critical comments as possible. Some people prefer to get the comments from the referee. Because at least it went through one layer of criticism.

Rob: To drill down on that, for those who are less familiar with the academic process. That means that when you submit it to a journal, you typically get comments back from a peer review type of thing. So some people may not want to put it under The Archive until after they've gotten that first round of feedback.

Avi: Exactly.

Rob: Maybe they made a silly mistake that the referee pointed out. But your personal practice is to put them up at the moment you submit?

Avi: Yeah, and the reason is that by now I have a good intuition and a lot of experience. Also, frankly I realized over the years many times my colleagues are less kind to innovative ideas than mother nature is. So, it's best to put out an idea without suppressing it. Unlike politics, I should emphasize, in science we thrive for information. The more information we have about anything, the better is our understanding.

The problem is that most of the time you don't have enough information. So there is a period of uncertainty. Some of my colleagues, they prefer shut the doors, not tell the public until we have a clear understanding of the outcome. Because the argument is well, if they see that there are some unsettled issues that the community is not sure about, then the public will not believe global warming. I say exactly the opposite. I say that if the public realizes that it's a completely transpiring process, then the public will give you much more credibility.

Part of the problem we have these days is that the public feels that science is the occupation of the elite. That somehow information is being processed in a way that is not transpired. I would like to show the scientific process as it unfolds. There are long periods of uncertainty when you don't have enough data.

I'm not afraid to be wrong, you just need to put on the table all the options, all the possible interpretations of the limited evidence you have. Collect more data on Oumuamua, or other objects in its class in the future, and eventually figure out the truth.

Rob: So your paper was submitted. It was accepted rapidly, you said three days, right?

Avi: Yes.

Rob: Now, this is the rapid response team of astrophysical journal. Is three days typical for them?

Avi: No, it's very unusual. Normal is a few weeks or a month for the response. We're talking about a factor of 10 faster response than usual, but moreover it was actually published two weeks after submission.

Rob: Two days ago, right?

Avi: Yes, so it's about 16 days after submission. That's extremely unusual. I had another paper that was similarly fast.

Rob: You've published over 600 papers, right?

Avi: 700.

Rob: 700. So this is in the top 350 in terms of speed for your own personal-

Avi: Right. To tell you the truth, I didn't plan on having any press release.

Rob: Are there typically press releases for papers? Like what percentage of papers might have a press release?

Avi: One out of several tens, or one of out one hundred. I have decide ahead of time. First of all, we don't have a public affairs officer right now, here at the Center For Astrophysics. So there was nobody to actually process a press release. Moreover, we don't have clear evidence that it's artificial. So, I didn't want to make a big fuss about it. Then, there were a couple of bloggers-

Rob: And I have to give them shout outs. Centauri Dreams was the first one to pick up on it. A blog I had not heard of before, they picked up on October 29th, so three days after you put it up on The Archive. I will say, I read a ton of responses to your paper preparing for this conversation. To this day, I have to say, Centauri Dreams did the most rigorous, imaginative, careful, deep dive of anything I've read. So, Centauri Dreams and then another great blog, Universe Today, a couple days later come out. So, four or five days go by, these two blogs are writing about it.

Avi: The same bloggers wrote about my previous papers. One is Paul Gilster, and another is Matt Williams. So I thought that would be it.

Rob: But then it broke in to the mainstream press, I want to say around the 5th or 6th. So the bloggers pick up on it, there's a few days of relative silence, and then do you have any idea how or why it broke into the mainstream press?

Avi: I believe it must be social media. I have no direct evidence because I don't have any social media presence. So I have no clue as to why it went viral, but I was supposed to go to Germany, Berlin, to give a key note lecture on Starshot and space exploration. So, I was about to leave to that trip and at 6:00 am I started getting requests for interviews. By 10:00 am I have four television crews come to my office here at Harvard. Then, another one came to my home just before I boarded the taxi to the airport.

I use this as a platform to explain the scientific methodology of an anomaly appearing in the daytime. The standard explanation in this case is cometary out gassing. Not being able to explain it, and then seeking an alternative interpretation. Publishing a paper about it and looking forward to having more data to decide whether it's right or wrong. This period of uncertainty is an integrated part of science. I wanted to explain that.

I regard being a scientist as a great privilege of maintaining your childhood curiosity, because children ask questions. They are not afraid of being wrong. Somehow, when they become adults, adults lose that inner sense. That includes scientists as well. Many of my colleagues are not willing to take risks. Not daring to be wrong, and that's a problem, because sometimes we just don't know in advance what's right and what's wrong. We have to take the risk in order to make discoveries, because what I want to understand is what Oumuamua is. For that purpose, it doesn't really matter how popular is one idea verus the other on Twitter. It is what it is and we want to find out.

Rob: Now, you're alluding to Twitter. As I started researching the story, one of the things that first took be aback was like, "Wow there is a lot of negative reaction to this." The first really harsh rebuttal I personally saw was in The Washington Post, and it was very widely quoted beyond that, and a lot of online publications that I respect. What it said was the following, "No, Oumuamua is not an alien spaceship, and the authors of the paper insult on a scientific inquiry to even suggest it." I was like, "Wow, we have a brawl here."

And at that point I had spent well over an hour reading your paper and its dozens of citations and the frankly terrifying math that it has, which went over my head. I wanted to dig into this contrary case. This is The Washington Post, right? It turned out that The Washington Post's authoritative carefully researched source turned out to be a Tweet. A Tweet which featured no link to an article, or any other support of this very definitive vicious and rather ad hominem attack.

So, I started digging deeper and it turned out that the Tweeter, someone who works at a family oriented science museum in Columbus, Ohio. He claims some sort of Ohio state affiliation. Now, I'm going to be very clear, I am not a credentialist. The fact that you're chair of the astronomy department at Harvard is meaningful to me, and I certainly respect it, but I would never take an audacious claim from you as received wisdom merely because you said it. Likewise, I would never reject any rigorous, original argument merely because it came from somebody at a science museum. I mean, Einstein was a patent clerk, genius is everywhere, right?

So, I'm not trying to be elitist about the credentials, but it was astonishing to me that The Post presented this as a counter balance to your rigorously researched paper. I dug deeper because I figured this guy must have done some kind of very measured rebuttal that I'm just not finding. All I could personally find was a weird, rambling video in which he made statements about what you must have been thinking when you wrote this.

So, I cite that as a little bit of dismay about how the press works in this day. Where somebody might do a long investigative piece and then somebody else might say, "Nah, fake news." And those are considered to be equal things. But also, I point to that as just a sign of the fact that there is some genuine anger that your paper released, visceral anger. By the way, this gentleman is a PhD, he's not an outsider to the field, he is pissed. Where does that anger come from? Is it using the A word? Is there a thing I astrophysics "Alien", you're not supposed to say that?

Avi: I would say it's prejudice. Many people think they know the answer in advance. In that sense, we haven't progressed much since the days of Galileo. Even though we have science as one of the most important achievements of humanity. People still have a lot of prejudice about what the outcome of science should be, and they want to see that answer.

Quantum mechanics was discovered as a result of experiments. Einstein had this emotional reaction to it, he didn't like that theory, he thought that something is wrong with it. He wrote papers about it, but Einstein was wrong. So, Einstein made mistakes and the reason I point this out is that anyone can make mistakes.

Therefore, one should remain humble. The academic community has this concept of tenure, where someone has faculty position for life, you're respective of what happens, okay? As long as that person doesn't commit a crime. That is a great privilege. It's a privilege to follow ideas to where they lead you without worrying about what other people think.

However, many practitioners in academia do not use that privilege. Once they get to the position of tenure, they worry about their image and about not being wrong. By doing so, they betray the purpose of their profession. The tenure process is aimed at allowing you the freedom of coming up with your own-

PART 2 OF 3 ENDS [00:48:04]

Avi: ... Process is aimed at allowing you the freedom of coming up with your own conclusions and therefore, if people have a problem with this idea, they should come up with a specific alternative interpretation of the extra push that Oumuamua has, rather than calling names or saying things without scientific context.

At the same time, the public would appreciate a honest debate. Many of my colleagues would say, "If the public is interested, it's not sophisticated enough and therefore it should not be explored."

I say, "Who cares about what people say? Nature is what nature is." I try to understand it and if it happens to be alien civilizations and people are very excited about it, that's great. If it happens to be the nature of dark matter and people don't care about it. That's fine with me.

I don't care about Twitter, Facebook, what people say, I want to understand nature, and I think nature is always beautiful, the only thing that can be ugly is human made.

One of the reasons to explore space is because you can see nature left on its own. But if you go to the beach, and I like to do that on vacation with my daughters, and you looked at seashells that were swept ashore, you see all kinds of seashells that came from different origins and every now and then, you see a plastic bottle, which came from an artificial origin.

I think the same approach should be adapted in the context of looking at all the interstellar objects that arrive at our door and examining each and every one of them. Even if Oumuamua is natural in origin.

First, we learn about the completely different process that makes these weird class of objects with much larger abundance than we ever expected. But in the more interesting case we might learn about another civilization and without a prejudice, we are just collecting data about the universe.

Rob: Now some of the folks who have come out negative on your interpretation are very well regarded people and I'll quote one person that I happen to know, I don't know him terribly well, but Seth Shostack, who is with the SETI project. I did a little bit of work actually with SETI when they were doing something with the Ted conference, got to know Joel Tarder [inaudible 00:50:03] which was really fun and a huge honor and I met Seth a couple times since then. I think you both wrote in notes to something, trying to remember, it was like Galaxy Today or another really cool blog that I discovered through reading all this.

Seth said, and I'm quoting from his email that was reported in this blog, "It's true that the Harvard paper suggesting that this object might be engineered, rather than simply the ten millionth rock from the sun," and I'm going to skip a little bit. He then later says, "The idea of alien companies perennially been interesting to the public, personally I think that's because we're hardwired to be curious about potential competitors or if you're in the abduction mindset, mates," and then I'll skip down a little bit further.

"We wish to believe that homo sapiens as interesting and significant enough to warrant visitors from some other world, obviously that's kind of self-centered." Now again I'll say Seth is very well regarded, he works for the Search for Extraterrestrial Intelligence. So he is not somebody who is going to deny the likelihood or the existence of aliens outright. How do you respond to that kind of a signal from him as opposed to a completely unresearched and unattributed-

Avi: This is very interesting because I interacted with the SETI community for a while and it looks to me that they have a reverse psychology where they try to deny any evidence, because they are worried about the, "Cry Wolf."

I'm guided here by my science. I basically follow the method that I will use to interpret data on the first stars in the universe or data on the [inaudible 00:51:32].

I tried to come up with a theoretical interpretation that appears to me as the most likely and in this case it's the most likely because I couldn't think of anything else.

The point that is most important to me is that this is not a speculation. We know that we exist, that there is both primitive microbial life as well as advanced life here on earth. We know that about a quarter of all the stars in the Milky Way galaxy have a planet of the size of the earth in the habitable zone of their host stars, so that they can have liquid water on the surface and the chemistry of life as we know it.

So if you roll the dice so many times, what's the chance that we are unique. I don't think we are special, I think out of modesty we should admit that this is not a speculation, that in fact we just need to go out and find evidence for life, including intelligent life.

Now if you look at speculations in science, there are plenty of speculations these days. For example, the mainstream of theoretical physics, advocates extra dimensions, beyond the three spatial dimensions and the one time dimension that we live in.

That to me sounds like a wild speculation because we have no evidence for it. Searching for another civilization that is similar or more advanced than ours, under conditions that we find to be exhibited in many other planets? It's not a speculation, it's just looking for another system that resembles a system that we know exists.

So I don't regard the search for life as a speculation, because we know that it's quite likely that we are not special. Whenever we thought that we are special, we were proven wrong. When we thought that we are the center of the universe, it turned out to be wrong. We are not at the center of the physical universe and why would we believe that we are the center of the living universe, the biological universe.

Rob: Right. Let's assume momentarily this does turn out to be one of those false alarms, what are a few of the things that could turn out to make this mundane? You did base your calculations on this work in nature.

Avi: Right.

Rob: They came out with 30 sigmas, I mean they were very, very certain of their data. But it's not out of the question that there was something wrong in their math.

Avi: Definitely and so that's the first thing that one should worry about and I encourage other groups to analyze the same data and figure out if they agree.

Rob: Another thing, I want to say June, around the time that the nature paper came out, I started reading about all things that were anomalous about the comet: the lack of the tail, "Well it could be explained by larger dust," the lack of gas, particularly a gas called

CN gas, which is often looked for because it's particularly bright and easy to spot, but it also is highly indicative of the presence of water.

So it seems that this thing was a waterless comet, which is a very unusual thing. The reflectivity of being ten percent, well has very unusual thermal dynamics for a comet.

So that at first really threw me. But then I saw a couple quotes that like, "Okay this is coming from somebody else's Oort cloud." We know little enough about what's in our Oort cloud. We know nothing about the chemical and other attributes of things in a distant Oort cloud.

So my question to you is, do we presume that there's a fairly homologous presence of chemicals and planetary system and solar system development processes that would make us presume that other Oort clouds have similar objects, or is the fact that this a Panamanian at our dinner party, might just account for a whole bunch of things that would otherwise seem weird, if we knew it was a next door neighbor.

Avi: There could be conditions under which you produce unusual objects but the first visitor should not be an outlier. Statistically speaking, you expect it to be typical.

Moreover, the fact that this is the local of standard of rest, this object, means that you can't just eject it from the edge of the Oort cloud without giving it a significant kick in exactly the opposite direction from the motion of its parent star, such that it will be at the local standard of rest.

So there are many peculiar things, so the point is that this is not what you expected for your dinner party. Why don't we discuss it, why don't we put all the options on the table? Since we don't know if we're alone, why don't we put that option as well? What is there to lose?

To me it sounds like a logical possibility given that we exist and that we had Voyager 1 and Voyager 2 that left the solar system, why won't we consider the possibility that it's artificial? What is there to lose by having that option on the table?

Rob: This reminds me, there is one element of the local standard of rest argument that we didn't get to that I don't quite understand. So if it is at the local standard of rest, we've already established that the odds of that happening naturally are roughly 1 in 500. Why might somebody doing things artificially, want to target the local standard of rest? Would that make it for a more efficient journey or make it easier to sneak up on us?

Avi: Well if you establish a relay system for example of posts, where you have an array of such stations. Then you place them at the rest frame. If you put the buoys on the surface of an ocean, you put them there at rest because stars will wiz by, but they remain there.

Rob: So that might be a navigation system.

Avi: There could be a purpose behind it, but first we need to figure out if it's natural or not. Whenever there is a reason behind something, if it has a purpose, then the likelihood of having it naturally is very small.

So a signature of something artificial is it's not easily produced naturally and we see that for example when we have industrial pollution. The molecules that pollute our atmosphere, can not be easily produced naturally and that's why in principle, if we detect these molecules in the atmosphere of another planet, that would indicate an advanced civilization over there.

Rob: So what should we do now? We've seen this anomalous object, at a minimum, it's the first thing to come from outside of the solar system, and that's exciting. It may well be artificial in your view, it almost certainly isn't in the view of others in your field, everybody's intrigued though. So what should be the research agenda over the coming decades to nail down more understanding of extra solar system objects?

Avi: Yeah so the importance of my paper, the way I see it, is that it alerts people to the importance of getting more data and more information on objects of this class. That means that when the next one is spotted, the best telescopes on earth will collect the data on it. So I think the way is to proceed is to find more of them.

Indeed the astronomical community's constructing right now the large synoptic survey telescope that within three years, will start giving us data and digging through that data would be very exciting. So I very much look forward to that.

Rob: Is it earthbound? Or is it-

Avi: It's earthbound and it's the highest priority in a process that the astronomy community goes through every ten years where the astronomy community defines its goals.

The large synoptic survey telescope was recommended as top priority in the previous [inaudible 00:58:08] survey and it's now being completed. Within three years, we start having data and now we have another target for it which is to search for those interstellar objects and that would be very exciting.

Rob: So this will be far better than Pan-STARRS at finding things?

Avi: Yes much fainter things can be found by it than Pan-STARRS can and moreover it will monitor the sky more frequently with better cadence and better sensitivity so overall it's a much better survey telescope than Pan-STARRS is.

Rob: So take just sort of, an arbitrary number. If Pan-STARRS is configured to spot one Oumuamua out of a thousand, the large synoptic survey telescope, is it configured to maybe spot 10 out of 1,000?

Avi: It's a little more complicated because since it's much more sensitive, it could see objects at a smaller-

Rob: Smaller still yeah.

Avi: Yes and we need to know the size distribution, how many more smaller objects you have relative to big objects. It's many [inaudible 00:59:01] of better prospects for detection with LSST than with Pan-STARRS and the exact number depends on the size distribution of object.

Rob: So was the large synoptic survey telescope specifically designed to find objects from outside of the solar system?

Avi: No.

Rob: Is that it's principle mission?

Avi: No, it's principle mission is to monitor exploding stars.

Rob: Super novas and-

Avi: Super novi or other transient events at great distances.

Rob: Gamma ray bursts, things that happen suddenly, briefly and rarely, it's meant to capture a higher percentage of those.

Avi: Yeah flares of different sorts that result from explosions of stars or other sources. So that's the transient universe. You're don't just take a single snapshot of the universe, but you take many snapshots, multiple nights of the sky and it opens the door for finding out how the sky changes. In the meantime you can also see moving objects, if they are close to you. That's how Pan-STARRS found Oumuamua.

Rob: So with the LSST coming online, even though it wasn't specifically designed to look exclusively for items outside of the solar system, it sounds like it's going to be a lot more sensitive than Pan-STARRS. So if Pan-STARRS, in it's ten year history was able to find one Oumuamua-like object, how many Oumuamua-like objects would you expect the LSST to find over, lets say a ten year span?

Avi: Well [inaudible 01:00:25] of magnitude more.

Rob: Tens, hundreds, thousands.

Avi: Even more than that, it depends on the size distribution of those objects because there are many more smaller objects than big objects. Than you would find them nearby because they would pass near us, they are much more numerous, so they have a better chance of passing near the earth-

Rob: And Pan-STARRS would have missed those smaller things because it can only see Oumuamua and bigger lets say.

Avi: Exactly so the sensitivity of the telescope allows LSST to see smaller things. As a result it would see even more things and the question is to how many more objects that are interstellar it could find depends on the distribution of sizes. Those objects that we don't know it for sure but it will definitely be oldest of magnitude thousands or more, millions depending on the size distribution and that would open a completely new window into the origin of these objects because we will have a whole collection and perhaps even a small minority of those that look peculiar would be of great interesting.

Having a large number of them would help us statistically speaking, figure out where they came from, what could be the circumstances that allowed them to exist in the first place.

Rob: So with many orders of magnitude and more objects likely to be spotted, within really just a few weeks, or even a few days of that telescope coming fully online, we should expect to start seeing things.

Avi: That's right.

Rob: And if a long span of time goes by and we see nothing, let say ten years go by, we see no more Oumuamua-like objects of any size, what does that tell us?

Avi: Well it tells us that the guest we had for dinner was very special and had a purpose for visiting us.

Rob: Well Avi, I know with the news that has broken and all the attention that your paper has gotten, again as I said at the beginning, this has to be one of the craziest weeks of your professional life. So I really want to thank you for taking out so much time to explain your perspective on all this and where you think this is going.

Avi: My pleasure.

Rob: So what does it mean if we turn on the big telescope in three years and we see nothing quite like the strange object we found in the small telescope? Say it again Avi.

Avi: Well it tells us that the guest we had for dinner was very special and had a purpose for visiting us.

Rob: That certainly ranks as one of the cooler sentences I've been on hand to hear. I mean it would be a great line in a movie. But this is real life and that was the chairman of the astronomy department at Harvard talking about an interstellar object, that passed fairly close to earth about a year ago. If that just doesn't give you a little bit of a shiver, then you're not a science fiction writer. I know most of you aren't and be grateful for that, it's an affliction, believe me.

Anyway, as we discussed during our interview, Avi has gotten a certain amount of heat from the astrophysical community for his heterodox interpretation of Oumuamua's origin and in retrospect, I can't help but wonder if aliens aren't just something of a third rail topic in his professional community.

For instance, I'm sure astronomers get tired of people buttonholing the at parties, wanting to talk about UFOs and their alien pilots. Surveys indicate that somewhere between a quarter to a half of american adults believe that aliens have visited the earth, whereas I personally haven't ever met a professional astronomer who shares that belief.

On the flip side, another very large group of people is fond of ridiculing the very concept of aliens. Possibly because the first group contains so many irritating weirdos.

But astrophysicists are deeply aware of the immensity of space, the yawning abundance of habitable planets and the vast timescales that the universe has had to experiment with life.

This makes them very open to the possibility that intelligent life is widespread out there, even if they do not believe that UFOs constitute proof of this. So this is a formula for a very different set of frustrating conversations with clueless members of the general public, who have very strident opinions about something connected to the astronomical profession.

If I were an astrophysicist, I'd be tempted to suggest that we all take a secret professional vow to stay mum on this toxic topic, unless somebody comes up with some form of overwhelming proof, which of course is exactly the sort of conspiracy, that the X-Files crowd would expect.

So maybe all of that is a source of at least some of the frustration that Avi has encountered from his colleagues, or maybe I'm just trying a bit too hard to be a shrink here.

Whatever you think about this controversy. We should all be relieved that Avi has put something of a sell-by-date on it as I mentioned in my introduction. By his own calculations, calculations he's been working on off and on, for over a decade, an argument settling number of observations should be made very soon after the large synoptic survey telescope points its gaze deep into the sky over Chile in 2022.

If Oumuamua is a natural object of a sort that's created by the universe at a steady regular cadence, we will see many of its cousins, shortly after we turn that sucker on. If we do see lots of Oumuamuas we'll be able to track them closely, we'll be able to see how normal it is, for them to accelerate as they leave our solar system, we'll see if they typically have tails or not, or if they have tails which for some reason are invisible to normal telescopes, we'll learn if interstellar objects tend to have water on them, like our local comets, if they tend to have the reflective properties of objects in our own solar system etc.

After learning all these things, we should be able to established whether Oumuamua was a mundane object or that very special dinner guest that had a purpose for visiting us and most exciting this fascinating resolution should come around in a bit more than three years than now, roughly January of 2022, probably a few months after that.

Game of Thrones fans, are used to waiting much longer than that for new books. So this is not a delay of cosmic proportions.

Now you have just finished listening to the short version of my interview with Avi, I often post abridged versions of my episodes to the main feed of my podcast out of respect for the time of my more casual listeners who sometimes get ancy if we get too far past the one hour mark.

Committed listeners to this show on the other hand, tend to view more depth and detail as being a feature, rather than a bug. Those who make this show possible with contributions of five dollars per month or more, can access longer versions of six or seven of my shows including this one, along with many, many other hours of bonus content, which is only available to supporters.

These recordings drop right into your smartphone like any other podcast, which you subscribe to via a private link that Patreon sends you when you sign up. So it's really seamless, it's really portable and it's really cool.

If you sign up, you'll get access to the entire archive of bonus material going clear back to February and I add to that archive every time I post a new episode. Sometimes, it's an entirely free standing mini-episode and increasingly often, it's an extended version of the interview from the main podcast feed, like today.

I'm leaning into this extended version model more and more. Because as the show's reputation is becoming more established and as I'm gaining confidence as an interviewer, I'm starting to get a lot of time from my guests.

Now I don't want to overwhelm casual listeners of this show with super long episodes. But no way am I going to throw away any of the exquisite insights that my guests share with us. Because their time is priceless and by the way so is yours. So the extended versions are absolutely worth the additional time, for those who wish to access them.

All of this is doubly important because for now this show is free of advertising as you have hopefully noticed. So the only way I can support it is through backing at patreon.com, which for those of you who don't know the site, as you've probably inferred by now, it's a site that enables precisely this sort of voluntary support. It's a bit like Kickstarter, only for episodic content, like podcasts. It is spelled P-A-T-R-E-O-N.com, and you can find my page at patreon.com/robreid and Reid is R-E-I-D.

Thanks to my backers, this show's doing a bit better than break even. But due to the time requirements of each episode, I'm roughly clearing my hometown's minimum wage for the time I put into it.

Now New York City minimum wage is quite high, compared to most communities. But it's not very high compared to New York City rent. So long term, this won't be sustainable unless I continue to gather more backers and or allow ads on the show. As I've explained in earlier episodes, the show's audience is big enough to attract some advertising, but I'm determined not to allow any advertising until I can really do it in a quality way.

So as many of you have heard, many times, I need to grow my audience. So if you're not financially able or just not inclined to back the show financially, you can still help it a lot, by spreading the word about it.

For each episode, I post a very self-contained tweet, which carefully describes the current show and the tweet for Avi's episode is already up in my feed at twitter.com/robreid.

So please consider helping this show, light up new neurons out there, by forwarding these little synopses around. Most of my episodes are only retweeted a few dozen times actually. So I absolutely notice and deeply appreciate all relevant activity on twitter.

The last and most simple, easy, time efficient and free thing you can do to help this show expand its audience is to rate it on iTunes, or on Apple's podcasts app. Both of those apps frankly, have rather squirrel-ly UIs, but if you made it through today's episode or frankly any of my episodes, you're definitely smart enough to figure it out, I promise. These ratings matter to Apple's promotional algorithm and therefore really do help the show expand.

For those of you who are in the US, happy slightly belated Thanksgiving, and for all of you wherever you may be, especially my new listeners on Oumuamua, I hope you join me for my next episode in early December.

PART 3 OF 3 ENDS [01:10:34]