“Kepler, TESS, and Keck Observatory

Driving Our Understanding of Exoplanetary Systems”

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W. M. Keck Observatory Astronomy Talk

March 4, 2021

ANSWERS TO QUESTIONS FROM THE ONLINE AUDIENCE

With the systems that David is discussing being so compact - does that mean that planets contained in those systems would probably be too close to their Suns to sustain life?

It depends a little bit on the star. For many of the systems where the star is a lot like the Sun, the answer to that is yes, those planets are almost certainly too hot, to maintain liquid water which, at the very least, is what we think is necessary for life as we know it.

But there are other stars that are much cooler, known as the M dwarfs. Instead of being 5500-5600 degrees Kelvin, they're more like 3000 to 4000 degrees Kelvin, so they’re significantly cooler and as a result their planets are cooler.

There's a system called TRAPPIST-1, which is extremely compact, that has 7 planets. It wasn't discovered by Kepler, but that's ok. It has a planet that is likely in the habitable zone of that system. There is a wrinkle with all that, which is that the cooler M stars also tend to be a little bit more active. Our Sun has star spots and can have these small flares. Well, M stars are much more active and they can have very large star spots and very large flares, and if those flares have large amounts of high energy from X-rays and ultraviolet, it may be that those very active M stars may destroy the ability for planets to be able to have life. It's one of the big unknown questions. Can you have life in those very active systems? I think what you're going to find over the next several years as you continue to go to these talks, you're going to hear more and more about these efforts to try to understand whether these planets can hold life.

And I'm kind of hopeful that will know the answer before I retire.

Radial velocity obviously finds large planets near their stars more easily. Does transit photometry have similar difficulty finding slower, Earth-sized planets?

Yes, that’s exactly right. Part of the problem with astronomy is that we have all of these observational biases. Radial velocities more easily find large planets in short orbital periods.

The same thing is true for transits, because the bigger planets block out more of the light and those dips are bigger, so those are easier to find.

In addition, as you move the planets further out, instead of the transit happening once every few days or even every few weeks, the transit happens once a year or once every 5 years, and so you end up having your data being biased towards larger planets in shorter orbital periods, and you have to correct for those biases. You need to understand the limitations of your technique, limitations of your data, and try to back correct so that you understand those limitations. So many of the plots that I showed today, especially the one that had that double hump, they *did* that correction to try to understand what they would have missed.

O'Meara: And David, it's the case that the Kepler mission was designed to have the lifetime that it did so that we could try to get some of those longer period planets.

Ciardi: That's right, so the Kepler mission was originally designed to be 4 years long. Well 3 1/2 years long, but 4 years long so that you could get at least 3 transits of an Earth-like planet in a 365-day orbit.

Turns out that there are other problems with that. Kepler was in an orbit that was trailing behind the Earth, and so Kepler itself went around the Sun every 365 days. As a result, it had these artifacts in its data that occurred once every 370 days. And so now you're looking for a signal from a planet, it's very hard to see, that occurs only once every 360 days, and on top of that the spacecraft has introduced its own signal which buries on top of it. It was a very difficult experiment to perform. And Kepler was an amazingly successful machine given the difficulty of the experiment.

Could the dearth of large planetary systems be due to the lower probability of larger orbit planets transiting their Sun? (Is the probability of Earth-sized planets lower and that's why we're not seeing them as often?)

Yes is the short answer. It's one of the questions that we are still trying to answer today. What's the frequency of Earth-sized planets in the universe? Current estimates range between something like 10% of all stars have an Earth-like planet to 90% of all stars have an Earth-like planet. That's a big range, from 10% to 90%. The reality of the answer is probably somewhere in the middle. It's probably something like 20% or 30%, but it also depends on the kind of star that we're talking about.

For the very large planets like Jupiters, while they are easier to find, they are actually more rare than the small planets. It takes a lot more energy and effort for the universe to make something that's really big than a bunch of small rocks. The fact that we're finding so many systems that have large planets probably indicates that there are large numbers of systems that have small planets. So you're absolutely right, it is much harder to find these small rocks in large orbits, and that's part of the problem.

If most planetary systems are much more compact than ours, does that mean our system is an outlier, or can we not yet make that conclusion?

So again, here's another observational bias that took place. Kepler found a very large number of super compact systems because it's relatively easy to find them in comparison to something like the solar system. So it turns out that if you were to put the solar system out into the Kepler field and we were to go to the Kepler field and observe the solar system, you would see Jupiter transit once every 12 years. It turns out you would not actually see the Earth transit. The tilt of Jupiter's orbit and the tilt of Earth's orbit with respect to the Sun are sufficiently different that if one transited the other one wouldn't. You would never know that there would be an Earth there if you saw Jupiter transit, and vice versa; if you saw the Earth transit, you would never know that Jupiter existed. What's weird about these systems that Kepler discovered is not only are they incredibly compact, but they're also incredibly flat, that you have these six planets, and yet they all transit. And if you were to do that in our solar system, that would not be the case.

There's something that happened in those systems to produce those incredibly flat systems that didn't happen in our system, or vice versa; something happened in our system that didn't happen in their system.

Has there been any connection between results from these observations and conclusions and SETI work looking for different information? Are the observed systems too distant for such searches?

One of the things that's really exciting about TESS is it's discovering planets that are much closer to the Earth. The Kepler systems are very far away. What makes Kepler really interesting is just the large number of statistics and the conclusions that we can draw from discovering so many planets.

The planets that were discovered with TESS allows us to do these kinds of experiments where I want to go search for signs of intelligent life around *that* particular system or *that* series of systems, and you know, it's still a very hard experiment to do.

We've been running this study for a long time now. There has been in recent months the exciting possibility that SETI did discover some kind of unexplainable signal around a nearby system. Still, at this point, unexplained, at least that I know of.

The exciting part about TESS and where we're going from where we are today is that we're moving from simply discovering planets to trying to understand individual systems and individual planets and really characterize them. I think there's a real chance that with these new systems that are being discovered by TESS that the dedicated efforts of the SETI organization and all the folks that are working to detect intelligent life and techno-signatures have a real chance of discovering something. Now, discovering something and actually *understanding* it are two very different things, right? I think there's a larger chance of discovering something that is intriguing, but we just don't know what it means.

What are the closest and most distant exoplanets discovered? How much atmospheric data is the new James Webb Telescope designed to discover?

The closest system known is around Proxima Centauri. There's a system in the south called Alpha Centauri. It's a pair of stars that are very similar to the Sun. And then there's a third star in that system, which is quite a ways out from it. It's many times the size of our solar system away, but it orbits those two Sun-like stars. That small little star, the third star, has a planet, and it may actually have more than one planet, and that's the closest. That system is like 3 or 4 light years away, something on that order.

Then the most distant, there have been planets discovered around stars in our closest nearby galaxies. Those are really hard to find. There's one in the Magellanic Cloud (163,000-206,000 light-years away), I believe. They are incredibly difficult to find because they're so far away. Kepler actually found some of the more distant planets, but not all the more distant planets. Typically, most of the planets that we know about are within a few 100 to a few thousand light years of the Sun.

Do you think intelligent life necessarily occurs in the Earth-like habitable zone?

So, I'm going to change your question a little bit. You inserted the word necessarily, and that's hard to address. I think the likelihood that there is life is really high. One of the things that's really interesting about the Earth is that we find life in all sorts of conditions that you and I would personally be unable to live in. Life has found a way in places that are extremely cold, areas that are dark, areas that have very little oxygen, and it's all based on the availability of liquid water. It's water that provides the environment in which life exists. Some of that life is microbial, some of that life is large like we are, but it's all driven by water. So the fact that a planet is in the habitable zone of its system gives us the high likelihood that water could exist on that planet.

The real question is, does the planet have water? Earth almost certainly had its water delivered to it after its formation. There was a bombardment of small bodies onto the Earth which delivered the water. Is that a common thing that happens in other systems? I don't know the answer to that, so I would change your question a little bit from necessarily to likely.

And if the question is <u>likely</u> to have life, I think the answer is yes. I think necessarily to have life is a much more open question that is much harder to answer. The universe provides such a variety of ways for things to form that it's hard to predict at that level what the universe would do. At some level, the formation of planetary systems and the eventual formation of life is likely a chaotic process. It's very hard to predict *that*, but it doesn't mean it's not likely. It just might mean it's not a requirement.

I would be extraordinarily shocked if we are the only planet that has life. To quote Carl Sagan from *Contact* both in the book and in the movie, it would be an awful waste of space if we were the only planet that had life. ("If we are alone in the universe, it sure seems like an awful waste of space." ~Carl Sagan)