Student questions: Michael Line colloquium on "The Worlds Way Out There"

3/24/21

Are individual planets in multi-planet solar systems harder to detect?

Yes and no. They are easier to "find" by leveraging an effect called "transit-timing-variations" whereby the planets in the system gravitational "tug" on eachother, creating a timing change (earlier or later) in the ingress/egress of the transit. It could be harder to characterize multiple planets in some cases if they transit at the same time making it difficult to disentangle their spectra.

Because Earth sized planets are nearly impossible to detect during the transit method, do you think there could be a higher percentage of highly habitable planets than we know of now?

Most definitely. However, exoplanet scientists (really, statisticians at this point) use that information to "backout" the fraction of stars that "likely" have those types of worlds.

What kind of bio-signatures would we be able to hypothetically see in the atmosphere of an exoplanet?

Most scientists want to search for oxygen in the form of ozone. Generally we all agree that we need to see more than one "biosignature". Detecting the combination of ozone and methane, and a lack of carbon-monoxide is a pretty hard combination to produce abiotically.

Why is the amount of H2O in Jupiter's atmosphere significant?

Understanding the elemental compositions of planets and their ratios (e.g., carbon/oxygen/nitrogen) are important for understanding how the planet formed. For instance, did it primarily accrete naicent disk gas or were other processes at work that contaminated the pristine "solar composition" gas? For Jupiter we've been able to measure C, N, S, and a few other species, but we have not measured O b/c it is locked up as liquid/ice clouds in the deeper atmosphere where we cannot see. H2O is the dominant O bearing molecule. If you measure H2O in Jupiter, you are basically measuring most of the oxygen.

How do you parse between planets and their contribution to stellar wobble if there are many planets around a single star (such as in our solar system)?

*Excellent question. The whole system acts like a sum of sine waves. Each planet induces a sinusoidal pattern in the stellar velocity. Planets with different periods and mass will produce different radial-velocity amplitudes and periods. Think of it as decomposing the sum of "A_i*sin(2*pi/period_i)". One could do a fourier transform to identify the dominant periods, hence existence of planets. This is called a "periodogram".*

Can you elaborate a little more on the workings of the new inference paradigm that was mentioned near the end of the presentation?

For a good long while, exoplanet atmosphere characterization was only robustly done from space telescopes (Hubble, Spitzer), due to the challenges with observing from the ground (earth's atmosphere). However they are limited in size and wavelength coverage. Ground based telescopes on the other hand can be really really big (10+ meters) and can have much more sophisticated spectrographs or other instruments that would be too heavy to cheaply put into space. The "new paradigm" I introduced was a "data processing" framework that enabled this ground based technique (of which had been around for a decade) to produce the same "data products" as we get from space based telescopes, but at much higher precision. The novelty was the ability to translate molecule "detections" into quantitative abundance determinations. This was not something that was do-able pre 2019.

Going to the "What are their temperatures" slide. It kind of looks like some type of phase diagram (I know it is not). But, just looking at this slide and comparing the Earth and other planets and where water can form and the temperatures and what to expect from them. What would a planet look like if it was in the middle of the Rocky/Gas line where there is liquid water? Like, looking at the slide and seeing Earth but just move it up to where it hits that line. What kind of planet would that be?

One could call these "water worlds". Not really "liquid water" but they would possess water in odd high pressure phases. They likely are a mix of rock, high pressure water, and some hydrogen envelope.

Is it possible to make this ground-based spectroscopy or something similar but for a satellite? Because of what you said there are a lot of advantages to being on Earth. But, there is to be away for this to work out into space.

Indeed, it could be possible. However, these instruments have exquisite precision at high resolutions, enabled by very stable vacuum chambers and thermal balance. The spectrographs themselves, along with all of these "stability" requirements make them very large and heavy in general. It's the equivalent of someone trying to put a nano-SIMS in space—we'd love to do it, but it's hard.

A far future with spacecrafts advanced enough to go to these exoplanets was mentioned briefly, how do you think the research questions we are trying to answer would change?

The questions would shift towards similar questions about our solar system planets…which in fact, are already similar to what we are trying to do with the exoplanets (circular…). E.g., we want to know the oxygen abundance in the giant planets in the solar system. We want to understand the "weather" and "climate" on them as well. This is planetary science. I suppose what will change most is looking in more detail at potentially habitable worlds. Sending a *spaceship to take a picture of a blue marble with continents/oceans/trees is more informative than simply detecting methane or oxygen.*

How do we choose elements we look for in spectral data, is it simply looking for abundance of things we are familiar with?

Good question. You look for things that you would "predict" are there in order to address a particular important question. E.g., the scientific method. "We predict that at this temperature, water and carbon-monoxide should exist on this planet". You then test that prediction/hypothesis. Of course, we understand we don't know everything, so part of it is indeed a little exploration and a little luck, sometimes we find things we don't expect when our "hypothesis" model doesn't fit the data.

Given that there will be many exoplanets observable in the near future, do you think their atmospheres will be categorizable into distinct groups or will they form more of a continuous spectrum?

Good question. A little bit of both. I like continuua. But there will be "classes" of planets through a continuum.

You said that stars like our Sun are rare in the galaxy/universe, what is the closest star to us that is similar to our Sun with exoplanets orbiting it?

Good question. I am not sure off the top of my head. There should be on the order of a couple dozen within 10 parsecs.

You mentioned that gas giants bigger than Earth but smaller than Neptune are of the most common exoplanets found so far. How would you explain this abundance of these kinds of exoplanets in terms of the planet formation/core accretion process?

It's a balance accretion of nebular gas before the gas dissipates and also loss of mass from photoevaporation. This is a strong function of where they end up forming and how they migrate. The details are still being hashed out and is an active area of research today "the origins of super earths" .

Are gas wavelength absorptions calibrated using real experimental systems (I.e. concentration of CO2 in Earth atmosphere) or is it mainly just modeling?

Yes. The absorption cross sections (how strongly the absorbed at which wavelengths) are validated against laboratory experiments. For the Earth/solar system there is an extensive database called "HITRAN" that contains such information and where they get their data.

What other exoplanet isotope systems are on the horizon to be investigated?

I love this question. Like the solar system, many people are after the D/H ratio (and in fact have been proposed with JWST). This is because D fractionation is strongly temperature dependent and is diagnostic of where something formed in the disk. O (16 vs. 18) is another one as well. In short, they are very sensitive thermometers (which is why the geochemists love isotopes) that preserve the "thermal history" of an object.

How much longer will it take for Voyager1 to reach Proxima Centauri b? Can it actually survive that long?

A hunk of metal can survive…the electronics are another story. It's been traveling for ~50 years and it's got 2300x that distance to go…you do the math. I encourage you to watch the first star-trek movie.

Is there a preferred detection method of exoplanets (direct imaging vs radial velocity vs...) for the planets that are further away?

Direct imaging is best suited for the wide separation planets, followed by radial velocity. Though we can't see a "full year" for those planets in RV, we can see what's called an "acceleration" of the star. E.g., we see a "slope" on part of the RV sine wave that is indicative of a planet being there. However it's hard to pull out detailed specs on the mass/orbit. Microlensing is another method I didn't mention. A star-planet system can pass in front of another background star (stars are moving..). When that happens the foreground star and planet can gravitationally "lens" the background star and you see a "brightening" of that background star (kind of like how galaxy clusters bend the light from distant galaxies).

With all the interest in the return to the Moon with Artemis, and following up on the ground-based question earlier, what do you think about a telescope on the farside of the Moon?

I'm all for it! It would be the best of both worlds. Now, we still have to get all the materials to the moon….not sure what the prospects for glass-making on the moon are.

When you were talking about atmospheric compositions, there were only a few compounds mentioned, namely water and methane. What are the most common compounds – other than the aforementioned two – found in exoplanet atmospheres?

H, He, H2O, CO, CH4, HCN, NH3, Na, K, TiO, Fe, Ti, Mg…..many species have been found.

Is it possible to model the interior of an exoplanet from its atmospheric composition?

Loosely. The metal enrichment in the envelope, along with the measured mass and radius can place tighter constraints on the core mass. Beyond that it gets very heavily model dependent.

Do star activities such as flare affect the atmospheric measurement of exoplanets?

Yes! The flares themselves can influence the planetary atmosphere by destroying certain molecules and causing some atmosphere to escape. In terms of observability, "star sports" can induce additional "wiggles" into the transmission spectra that we have to correct for. This is mostly a problem around M-dwarf stars which are heavily spotted.

Could the current number of stars like the sun (only 10%) be due to the majority of these stars exhausting their fuel and collapsing or rather the formation is less likely to create Sun-like stars.

Star formation tends to produce lower mass stars in abundance compared to higher mass stars, so it's a "formation" thing. It has to do with how blobs (aka, density perturbations) form and grow in a cloud of gas and dust.

Does the presence of planets that do not have a habitable environment help indicate whether or not there is a Earthlike planet in other solar systems/galaxies.

Yes! Both finding and "not finding" what we are looking for (provided we are looking for it) places valuable constraints on the "occurrence rate" of what we are looking for. If we built a telescope that had the sensitivity to detect 10 planets within 10 parsecs of the earth, and didn't find any, that would place useful upper limit constraints on the abundance of those worlds.

Why are there twice as many rocky planets as gas planets?

It's easier to build smaller things than big things, in short. It comes down to planet formation. Rocky cores form first in protoplanetary disks. Whether or not they grow large enough to gobble up nebular gas to become a jupiter depends on where and when they start to form. There are more of them because that's the part of the process that happens first.

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What is the benefit of knowing the composition of an exoplanet's atmosphere?

The composition is diagnostic of how/where/when a planet formed. The composition also governs the efficiency of energy absorption from the star and re-radiation from the planet. E.g., CO2 in Earth's atmosphere is a green-house gas that causes warming. Ozone is a source of heating. Knowing how much CO2/Ozone are in Earth's atmosphere is important for predicting future climate. Same goes for other planets.

Given that some planets have a year that lasts around 10 days, would an Earth-like planet be able to sustain life if the year is significantly shorter than it is here?

Depends on what kind of star that 10 day year is around. 10 days around the sun would be too hot. 10 days around a very low temperature M-dwarf would be "cool enough" (but not too cold) to support liquid water. An interesting aspect is that such "close in" planets are tidally locked which means one face of the planet always faces the star (like the moon does the Earth). This could mean there's a "perpetual dayside" and "nightside". That could influence the climate and weather patterns on such a world. How that would influence lifeyness, is a current area of research.

Do you think the percentages of each planet type will hold up as remote sensing technology advances?

Generally yes. The role of the Kepler mission (which I did not have time to talk about) was to determine exoplanet demographics. We are getting similar results with ground based surveys (transits and radial velocity) and also the TESS planet hunting space craft (the successor to Kepler).

In response to the answer I got from my question above, what types of discrepancies are you seeing between old and new exoplanetary atmospheric data, and why do you think these discrepancies have shown up?

I alluded to this in the talk a bit. Generally a lot of it has to do with the assumptions made in the raw data processing. There is a lot that goes into that. Trying to squeeze out very small signals from instruments not originally designed to measure such small signals. Another issue is that the data itself is rather sparse. Often we want to know more things than the data can support (e.g., imagine you have a single data point on a graph, and you are tasked with determining the slope of a line that can go through it….). In this situation, our answers are highly assumption dependent (e.g., I only think positive slopes can exist, or I think no slope, in the above example). As we get more data this problem goes away (e.g., you are now given 10 points…you most certainly can determine a slope then).

What is the Bayesian method?

Take my astrostatstics class (SES 494/598) this fall =)

What gas absorbs the most amount of light?

Water water everywhere, at least in planetary atmospheres, and in the infrared.

What gas is the most abundant on exoplanets?

See above (after hydrogen and helium of course).

Are there biosignatures in atmospheric compositions that could actually be false flags, or caused by some other natural processes?

Yes! There's a whole sub-field trying to identify "false biosignatures". For instance, detecting oxygen by-itself is not a biosignature. Oxygen can be produced abiotically through various geochemical processes. So can methane. The key is looking for particular combinations of gases (or rather their relative abundances) that can break the "biotic" vs. "abiotic" degeneracy.