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| Speaker 1: | [inaudible]. Okay. So today, we are super excited to have Courtney Dressing here to talk to you guys. She'll be giving an hour-long presentation in the first half and then you'll have your normal round table discussion for the hour after that. And so Courtney has a career that has touched on a very large range of observational exoplanet astronomy, using both ground and space-based facilities thus far. She got her bachelor's from Princeton and then her PhD from Harvard in 2015. And her thesis work was, I think, some of the earliest constraints on the current rates of small planets orbiting small stars using Kepler. |
|  | She spent 2 years Sagan [inaudible] Fellow at Caltech before moving up to Berkeley as an assistant professor in 2017, and her research group at Berkeley still works on the detection, confirmation, and characterization of planets, most recently focusing on planets discovered by the TESS mission, helping to validate them and also running a hybrid solution imaging surveys, to help us make sure that the host stars of those planets are actually stellar multiples, which can mess up things with the planet radii. |
|  | Courtney was also a member of the science and technology definition team for the LUVOIR final report, and was on the panel for exoplanets, astrobiology, and the solar system for Astro2020. So she's a good resource for learning more about those kinds of large community endeavors as well. |
|  | And so with that, I will turn it over to Courtney and say thank you so much for taking the time to come and talk to us! |
| Speaker 2: | Thanks, Jen, and great to be here with all of you. I hear an echo, I don't know if anyone else hears that when I speak? Okay, it went away, that's great. I'm not a typical Webex user, I'm in the zoom land, so if at any point you have a question and I'm not seeing your comment in the chat, please feel free to interrupt, I actually haven't figured out how to do the chat while I'm doing the presentation. |
|  | So, during the talk I welcome your feedback and interactions. I'm going to talk to about some of the works that my groups has done to find planets around nearby stars, and along the way, I'm going to share the parallel story of how to maintain and work for yourself within a large collaboration. |
|  | I was talking yesterday with my fiance who doesn't work on planets, who's a lawyer, and one thing she asked me was, "Well, you work in teams a lot, how do you still have a voice to yourself if you're working in teams, how do you ever know who did what when you're on these calls with 20, 30 people, how can you get tenure, how can you get the next job that you need if you're part of this large collaboration?" |
|  | This is a conversation I also have a lot with my students, because they want to be sure that when they go on the job markets for whatever they want to do, that they can point to something and say, "Hey, I did this thing." It's one thing to participate in a big team and help towards team goals, but if you're always a small part of the story, it can be difficult to understand how you make that next step, and that's particularly true in some fields in physics research. |
|  | And exoplanets, we're moving towards an era of larger collaboration, but we still tend to have author lists that you're small enough that you can list all the people on one page, which is not true in some of the particle physics experiments. |
|  | So with that said, the two big questions that we're going to discuss today are, question 1, "How common is life?" I don't know the answer to this question, maybe one of you will figure it out for us someday. We're using this question as a framing for the investigations we'll discuss along the way. |
|  | The second big question is "How can I maintain my scientific voice and identity while working in a large collaboration?" I decided to show a globular cluster here, because globular clusters contain many stars, all of which shine brilliantly, but when they're all so close together, it can be difficult to determine the contributions from each star individually, so I thought that was a good analogy. |
|  | I've experienced many different collaborations during my career, and I'm sure that all of you have been working with various teams of one form or another. For reference, I'm going to give you a list of some of the collaborations I've been involved in over the years. This list is partial, and I'm sure that I've left out some very interesting collaborators, and I'm sorry about not being able to fit everyone on this plans. |
|  | In graduate school, I was part of a research group led by my research advisor, Dave Charbonneau. This group had graduate students while I was there, you probably recognize some of these names. Zach Berta-Thompson, the discoverer GJ12-14b, Sarah Ballard, who was just elected to a leadership role within the AAF. Elizabeth Newton, now professor at Dartmouth. Jason Dittman, researcher at MIT, moving to Europe. And Sukrit Ranjan, who ended up leaving the group and starting to work with the [inaudible] looking at the chemistry and biology and early life science. |
|  | We also had a lot of postdocs that passed through while I was at Harvard, including our own [Jessie Christiansen]. I benefited tremendously from talking to these other people, and I'm so glad I started my research career in exoplanets working with a supportive environment, where I felt like I could always go to other group members for help. |
|  | At the research group, we also had the benefit of staff science Jonathan Irwin, who was able to answer any and all questions related to acquiring qualitative data. Our group met regularly, we had weekly meetings, we also would have more social gatherings where we would chat over lunch about topics related to life in academia, but not directly related to papers, and I felt that was helpful for building a sense of collaboration and a sense of support, and a sense of having an environment where it was okay to admit that you didn't always know the answer. |
|  | I also participated some in work with the Kepler Team during graduate school, my thesis advisor Dave was a Kepler participating scientist, which meant that he was invited to go to a lot of Kepler team meetings. |
|  | As an early career grad student, I got to tag along and go to these exciting meetings and learn about the speaker from the Kepler mission before they were published to the community. I also decided I wanted more experience doing ground based and surveying, because Kepler, of course, was up in space, and I couldn't control it directly, so I talked to another scientist at Harvard where I was, and ended up going to Arizona to work with Andrea Dupree on an adaptive-object imaging program. |
|  | This was actually very good news, because it allowed me to learn more about what it was like to ground-based observing, and allowed me to build a connection to a scientist who wasn't my direct advisor, so I was having someone else I could ask for letters in the future. It also allowed me to meet people who worked on this type of science, which was different from what I'd been doing in my graduate. |
|  | I also was part of the HARPS-N Team, which is a radio velocity collaboration, mostly based in Geneva, Switzerland, but with a large branch at Harvard. They had weekly in-person meetings there, as well as monthly collaboration meetings. |
|  | When I was in grad school, those monthly meetings were at 8 AM for me, and I remember thinking that was early. It got a lot earlier when I moved to California and all of a sudden they were at 5 AM. So the price you pay for international collaborations is often very early mornings, and I think it's useful, though, because otherwise we wouldn't have a chance to work with so many scientists if we restricted ourselves to just a single time zone. |
|  | As a Sagan Fellow at Caltech, I maintained some of those collaborations and also started new ones. Many of you probably have made a similar decision when switching institutions. Do you keep working with the people that you worked with before because you know them and you trust them and you like them, or you do start working with a whole new group of people? And if you work with new people, how do you then introduce yourself and how do you find a place for yourself in a collaboration that existed before you arrived? |
|  | It's challenging, but often times when you switch institutions, people expect that there might be a little bit of a lag in your productivity as you get settled in a new place. So I recommend using that to your advantage, because in the long run, even if it's a little bit slower to get started on something new, you'll benefit from having those new connections, and you'll learn more, both about life, being a scientist, and your specific research problems by broadening your network of collaborators. And you'll probably meet some great friends along the way. |
|  | So as a Sagan Fellow, I didn't have a person who I directly reported who told me what to do. What I did have was a research advisor, Heather Knutson, and I worked with her- I decided to treat this like my [inaudible] situation in grad school, where I met with my advisor once a week. Some postdocs choose to have less frequent interactions with their advisor. But I encourage you to meet with them, they want to talk with you, they want to support you, they want to hear what you're working on, and it's advantageous for you to do that, because they often have a lot to teach you. |
|  | It's also good to build relationships with people at your new institutions, because if you have to apply for a job later, people will wonder why you don't have letters from that institution if you've been there for more than a year or so. So definitely try to build those collaborations when you can, even if it can feel a little bit awkward walking in and saying "Mentor me!" You can ask politely, ask what their availability is, set up the media networks for both of you. |
|  | As a member of Heather's group, I also attended her weekly work meetings, and I talked with her grad students about what they were working on. That gave me a lot of ideas for what projects to work on in the future, and it helped me learn about various quirks of the Caltech system, in terms of, what is the over-subscription rate for telescope time, which instruments are the easier to use? Who should I talk to if I have a question about X, Y, or Z? |
|  | I also worked with Heather to co-advise the summer students, so those were the collaborations I had at Cal-Tech proper in the geology and planetary sciences department. Many of you are probably at institutions where people talk a lot about how you could go to a different department and talk to someone over there, but no one actually does it, because you have to cross the street and go outside of your building. I recommend doing that, cross the street, call them, talk to them! We're often stuck in their own departments, but we could learn so much from talking to someone in a neighboring department, and I think that's really true for exoplanet science, because we're now reaching an era where we're trying to ask questions about planetary atmospheres, for instance, where people studying the Earth's atmosphere might have been doing that for a long time, so we should to them. |
|  | When I was a postdoc, I decided to walk down to IPAC, the NASA exoplanet science institute, where I got to talk to people like Jessie, and Jessie can tell you that people form astronomy don't normally leave the astronomy building, I wasn't in the astronomy building, so I think that gave me bit of a leg up, so I had to go to the astronomy building, so I might as well walk a little bit further to go to IPAC. |
|  | Because I did that, I then met more people that I could work with, I went into a lot about observing from talking to Jessie and David Giardi and [inaudible]. I joined two new collaborations about K2, which was the successor to Kepler, and about Spitzer. I never worked with Spitzer data before, despite being at Harvard with Jessie and Sarah as they were talking about Spitzer observations. |
|  | And I started working with new people who I still work with today. If I hadn't done that, if I'd just stuck working with people in grad school, I wouldn't have the same research, that work, that I have today, and I wouldn't have the same skill set. |
|  | I also continued working with the HARPS-N Team, but that was a little more difficult, because our meetings were now 7AM on Tuesdays and 5AM once a month. At the end of my time as a postdoc, I was appointed to the LUVOIR Science and Technology Definition Team, and I continued that as a faculty member. |
|  | On that team, we met in person about every six months or so, and we also had weekly telecoms. This was a project that went on from 2017, up until this past summer. It represented a big chunk of my time, but I think it was worth it, because we were collaborating to try to figure out what should the next generation observatory, the generation after the [inaudible] telescope looked like. As part of this collaboration, I met people who worked at different institutions and in different research areas. I learned more about what the state of the field was, or cosmology and for galaxy studies. |
|  | And I learned a lot of practical advice about how to write compelling proposals and how to design an instrument for a telescope that could possibly launch in the future. It was a great experience and I highly recommend getting involved with big studies thinking about the future of the field, because you are the future of our field and you should have a say in what that looks like. |
|  | Currently I'm part of the TESS-Keck Survey, and Jessie is also part of that. This is collaboration primarily housed in California at Caltech, the University of California. Also the University of Hawaii, and [inaudible] Kansas, with Ian Caulfield whose in that [inaudible] exoplanet explorer [inaudible]. |
|  | We have weekly telephone calls and less frequent all hands meetings, so they used to actually be in person now they're on the internet. And as a group, we've written telescope proposals to get over a hundred nights of tech time. That's actually a lot of telescope time, and the science world that we're investigating wouldn't be possible without that collaboration of so many people together. |
|  | As a member of TKS, I've been advising students working on papers, I've helped lead this proposal, if I look tired today, it's because just submitted a proposal yesterday, I haven't gotten much sleep. And I'm also helping to co-lead the various science cases. Working on TESS-Keck Survey has broadened my understanding of exoplanets because I get to chat with people working on different aspects of the science. Things like eccentricity observations and [inaudible] observations that I don't do directly msyelf. |
|  | I found it to be immensely rewarding to see the students within the collaborations to grow and write fantastic papers, and it's been really fun to work with my colleagues at other institutions. |
|  | At Berkeley, there are a couple people working on exoplanets, and I like chatting with them, but with TESS-Keck Survey, I get to work with 20 or 30 scientists around the world and talk with them every week, and that's great. |
|  | As Jen mentioned, I'm part of the Astro2020 Panel on Exoplanets, Astrobiology, & The Solar System. We had a fantastic chair, Vikki Meadows who spoke to you recently. [Ian Caulfield] was also on the panel, he was talking to a large chunk of this panel, and he might have already asked some questions about the process. |
|  | Well, on the panel, we read a lot of white papers and summarized them. We had meetings with in-person and on the internet, and then we wrote a panel report. I can't tell you what's in the panel report, but if you have questions about what it was like to be part of that panel and how we have discussions about the future of the field, I'd be happy to answer them later. |
|  | I've mentioned a bunch of different collaborations, I wanted to give you a sense for the size of these collaborations. The Astro2020 panel is about 20 people, the TESS-Keck survey is probably about 50 people, if you count all the graduate students, and you should, because they're the ones that are responsible for the bulk of TKS's science output, and the the LUVOIR Science Technology Definition Team is about 30 people. |
|  | The LUVOIR, these folks got to vote on the specific design of things, and we would have polls like, how red should this instrument go, how many instruments should we add, how big should the telescope be. All of us got to vote. We span a variety of institutions across the US in a variety of science interests. We also have representation from international partners, which was key, especially for one of the instruments that's being built. |
|  | Well, would be built, in collaboration with people in Europe. And we had non-voting members at Goddard. And the study would not have been possible without the work of the people in the Study Office at Goddard, who helped us with many of the simulations we needed to do in order to do in order to check what science we could get out with various instrument designs. |
|  | Now that I'm at Berkeley, a large part of my collaboration experience is in leading my own research group. My group is called PALs, for Planets And Life in Space. I spent multiple days thinking about what this acronym should be, and I'm really happy with it, even if some of my colleagues thinks it's too corny. The reason why I like it is that it both embodies my research interests and the sense that I want my students to have about our group. |
|  | I want them to feel like they're working together in pursuit of a common goal, rather than in some cutthroat environment where they have to beat out their peers in order to get that next paper or the job that they want. I want them to support each other rather than compete with each other. |
|  | In my group, we have a variety of graduate students. I have a fourth year student, Steven Giacalone. He recently wrote a paper called TRICERATOPS which validates potential planets as real planets, and I'll talk a little bit more about that later. Steven is currently starting his thesis looking for planets around A-stars and he's been doing a lot of ground-based observing with telescopes at Lick. |
|  | Next up is Andrew Mayo, he's a third year, Andy is particularly interested in planets in somewhat unusual environments. He's measured the masses of planets in long-period orbits and planets that are around young stars, and an upcoming paper that will be about a planet in a very short period orbit. Andy also has a TESS-Keck investigator program that is re-observing stars in cycle 3 of tests that were previously observed in cycle one, to see which planets were missed and what other, longer period planets might orbit other stars. |
|  | Emma Turtelboom is a second year. She previously worked on rotation curves of K2 target stars, and with me, she's working on a really exciting paper using data from TKS where she has 4 Neptune sized planets that all have very different densities. |
|  | I have a first year student as well, Caleb Haradia, who just published a paper around planet atmospheres, based on his work as an undergrad, and is looking for projects to do as a grad student. Right now he's helping out with the TESS comparisons, to see which of those planets down in cycle 1, were later rediscovered in cycle 3 and try to redefine their properties. |
|  | I have a bunch of undergraduates as well, because I think it's important to give undergraduates opportunities towards their research, and one of my favorite things I've seen at Cal is our vibrant undergraduate population, I want to support as many of them as possible. |
|  | Unfortunately, despite my [inaudible] functions, there is only one of me, so I can't work with all of the undergrads. Right now, I have about a dozen students who go to our group meetings and work on team projects. These are designed as introductory research experiences, to give them opportunities to learn how to program in a scientific fashion. Some of them have taken computer science classes before and have a little bit of experience, but they don't know the exoplanet jargon. |
|  | So these tutorials allow them to get more experience for that, and to build the knowledge base they need to then pursue individual projects if you're interested. I have 3 students working on those individual projects with me, and two more students working with Steven on a project using Data, characterizing star approaching planets. |
|  | We have weekly group meetings with everybody, and we have one on one meetings, we also have a Slack channel, which has been super helpful for students to post drafts of things and to get comments and to ask questions of each other, and a team website and shared Overleaf files and Google Docs. |
|  | The takeaway point here is we have a lot of ways for group members to communicate with each other, and it's been very fun to work with all of them. |
|  | Okay, so now that we've done the overview of my experience with collaborations, which was a little dry, we're going to delve into the science. |
|  | I started off with the question of how common is life in the universe, while I can't answer that question today, we can go along a couple intermediate questions. So first off, we could look at where are the nearest planets? Then we can ask, "What are the properties of those planets?" "Which of the planets are rocky?" Meaning, which of them have terrestrial compositions consistent with that of Earth. |
|  | "How frequent are Earth-like planets?" So, how common are planets the same size and same temperature as the Earth. And finally, "How common is life?" |
|  | So for question 1, if we want to find planets, you all have worked with a variety of planet detection methods. Today we're going to focus on the transit method to get planet sizes, and the Radio Velocity method to get planet masses. I know not all of you work in these two methods, so just for reference, the signs of the signal we would get for solar system planets, would be for Jupiter orbiting the Sun, a 1% decrease in the star's brightness, because the passage of the planet in front of the star. This is small, I couldn't see it with my eyes, but it's well within the reach of current telescopes. |
|  | So we could do this easily, as long we caught Jupiter at the right time when it happened to cross in front of the star. And that is extremely unlikely for a planet the distance of Jupiter from the Sun. |
|  | Radio velocity signals from Jupiter is 12 and a half meters per second, that's pretty big. And that's well within the reach of current instruments. The challenge there is just that Jupiter has a rather long period, you would have to look at the stars for multiple years to see this trend turn over and actually confirm the period of Jupiter, rather than just its existence. |
|  | Things are a lot trickier as we go to the Earth. For the Earth, we need to detect the transit depth of 84 parts per million. This can be done with a dedicated facility pointed at that that star for a long period of time that's very precise. So this adjusted the limit of what the Kepler mission could do. This is not something that is easy, but it's something that we've done for a couple cases of planets orbiting quite distant stars. |
|  | For radio velocity, we're not quite there yet. The signal for an Earth orbiting a Sun-like star is 9cm a second. Jen is one of the world's experts on measuring the mass of the planets with RV, and not even Jen can get to 9cm a second yet. But maybe in a couple of years, she'll get there. |
|  | So this felt a little bit daunting. How are we supposed to find Earth around so many stars when the signals are so small? One way is to get better and better at analyzing our RVs, and hopefully with the next generation of instruments and more sophisticated data analysis techniques, we'll get down to smaller and smaller measurements so we're able to detect the signal of the Earth around the Sun from doppler measurements. |
|  | Eventually, we'll also have direct images in space that can look for planets like the Earth orbiting Sun-like stars. But if you're impatient and want to find Earth on a shorter time scale, one thing that you can do is to change the type of star. So if we instead look for planets orbiting smaller stars, that would cause larger signal. And just for fun here, I have a car representing the RV signal caused by Jupiter's motion around the Sun, I think for the Earth would be something like a slug, which is very very slow. |
|  | So with Kepler, I mentioned before that Kepler was just barely able to detect Earth's around Sun-like stars through dedicated study in multiple years. Kepler overall from 2009-2013 found about 5,000 planets and possible planets. That's a huge haul of planets! But because of the design of the Kepler survey and the need to stare at the same star continuously for multiple years to find Earth, Kepler was only looking at a narrow, narrow slice of that. |
|  | And if you're looking in a narrow slice of sky and you want to look at a lot of stars, many of those targets are quite distant. And that means that the Kepler targets are often too faint for it to be the next step of measuring the planet mass to confirm its density, or studying the planet in transmission spectrum to determine what the composition of its atmosphere is. |
|  | If we want to find targets that are more amenable to those investigations, we need to look at the stars closer to us. We need to look a the brighter star. TESS is doing just that. An all-planet sky survey, looking for planets around the closest stars to us, the targets that are the best for follow up observations. |
|  | In its comparison from Zach Barta-Thompson, one of my grad school collaborators, you can see us on the Earth in the center of this blue sphere, and a huge yellow cone showing the representation of where the Kepler targets were. Many of them are thousands of light years away from the Earth, and therefore they're too faint for precise radio velocity observation. The test targets are all in this sphere, which means that they're much, much closer and therefore much brighter and easier targets for mass [inaudible]. |
|  | We're currently in the TESS extended mission, and TESS is already taking a pretty much full view of the sky. I mentioned a little bit, which you can see in this image on the right, here, we don't have test data from this region of the sky, because the moon would have posed a problem, but we have observations from the rest of the sky. |
|  | Most of the time, TESS looks at stars for 27 days, but near the poles, at the center of these images, we get data for almost a year, so that gives you the chance to find planets in orbital periods ranging for less than a day up to about a year, if you're willing to look at something that only has a single transit event, and then try to figure out what the planet period is using auxiliary data. |
|  | I can talk more about TESS in the Q&A if you're interested, but I suspect that you might have already heard a lot about TESS from Ian in a previous presentation. |
|  | For now, we've already found over 2,000 objects with TESS. Here, I'm showing you the declination and rate ascension of these objects using data from the NASA Exoplanet Archives, and this shows you where TESS wasn't looking. TESS has done so many planets that the area without TESS data here really really stands out in this plot. There's planets everywhere! |
|  | They're also reading the spot where there are lots of planets, like here and here, and that's a combination of the change in the density of stars across the sky and how long TESS spent staring at a particular field of view. It's harder to find planets if you're looking at the plane of a galaxy because there's a lot of confusion, so if you look away from the plane of the galaxy and stare at that region for multiple months, you're going to find a lot of planets. |
|  | If we plot the planets with the function planet size vs period, here is what we see form TESS. We go from periods of a day, to ten days, to a hundred days and radii of 1 inch radius to a 10 inch radius. You can see that there's a lot of planets that are Jupiter sized in short period orbit, so these would be hot Jupiters. We also have a lot of planets down here that are smaller. Some of you might also be wondering, well, what are these objects that are 30 Earth radii, and in most cases, those are probably false positives. |
|  | But in order to figure out, we need more observation. We need to do follow up observations from the ground to distinguish which of these blue dots are real planets and which of them are astrophysical contamination. |
|  | And then we also need to characterize the host stars, because with transits, we measure the planet size relative to the star size. We don't know how big the star is and we also don't know the size of the planet. I mentioned that we need to figure out where the false positives are. When we look for transiting planets, the data we get is the brightness of the star vs. time. We infer that a star has a planet because it gets dimmer periodically, and the dimming event had the same depth and lasts for the same duration and occurs in a repeatable fashion. |
|  | That could because there's a planet orbiting a star, but it could also be cause by any of these other scenarios here. One of the more pesky scenarios is a case where you have an eclipsing binary system that causes the eclipsing [inaudible] as one star blocks the other. In close proximity to another star. They don't have to be physically associated, it could just be a chance alignment, but the light from that other star will get into the aperture of TESS and TESS has these huge 20 by 25 thousand pixels, so you can fit a lot of stars in a TESS aperture. |
|  | If this happens, if you had the configuration of an eclipsing binary and then you're by a star, the flux from this nearby star makes the eclipse look shallower. So what happens is you look like you have a planet when you really have a combination of stars eclipsing each other. One of the ways to expose these astrophysical false positives is to take a close look at the TESS spectrometry and try to find signs that you're seeing a binary rather than a planet. |
|  | Grad student Steven Giacalone, just established the TRICERATOPS framework, which takes the TESS spectrometry along with some follow up imaging to try to better determine which of these candidates are real and which ones aren't. Steven's tools are used for vetting, which is rejecting obvious false positives, and for validation, which is when you take a system and you establish that this actually is a planet. |
|  | He's building them the legacy of validation tools like Blender, Pastiche, and the most famous package developed by Tim Morton, which is Vespa. |
|  | So in Steven's paper, and here's a screen shot of the publication from earlier this year, he was able to validate 12 Tess Objects of Interest, so TESS possible planets, identify 125 systems of likely planets, they didn't have any obvious flags that they were bad systems, and he also rejected over 50 nearby false positives, so those are removed from consideration for future radio velocity survey. |
|  | Here are two plots showing Steven's results, on the left here we have a proxy for the brightness vs temperature, and you can see that the validated planets are up near the Sun here, and there's one that surrounds a cool star, and the ones that are likely planets span the entire diagram. |
|  | On the right side, this plot's particularly interesting, it's the planet size vs period, and you can see that even though the population of TESS objects of interests had a lot of very short period objects, Stevens work with Triceratops demonstrates that many of those short period objects were likely false positives, rather than real planets. |
|  | There's a big divide here between the green dots indicating the likely planets and the black dots indicating and they're hitting a likely false positive. The N here stands for nearby, so in this particular case, Steven is identifying systems where there is a star close to the target star, but it's responsible for the decrease in brightness. |
|  | Here's a shot showing how TRICERATOPS actually work. In blue, we have the TESS spectrometry for a particular star. In black, there are multiple light curves showing what the spectrometry would look like for various configurations On the top left panel, the notation in the bottom, the TP indicates that this is a transiting planet. So the system of that were actually caused by a transiting planet, we would see this black curve, which mass is the plot of flux vs time very well. |
|  | In the other panel, these are different false positives. So here in the top middle is an eclipsing binary. Here is an eclipsing binary with twice the period and so forth. For this particular system, if you stare at all these panels and try to find the case where the black line best matches the blue data, you would probably say that it was the top panel here, and you would be right. In this case, this is a real planet candidate. And we find with TRICERATOPS that this is likely to be a planet. |
|  | The second case, though, for this observation, we have data in blue and models in black, and the transiting planet fit is a much shorter duration than the data. We see a large thing in the data, but a very sharp event in the transit profile. So if anyone wants to find what they think is the best match, I'll give you a second to do that. |
|  | You might have picked the bottom right, this is the preferred fit from TRICERATOPS, and in this case we find a false positive probability of over 99%. So this is not a good target for a radio velocity match measurement, because it's not actually a transiting planet. |
|  | At this point in the talk, I wanted to thank everyone involved with the TESS follow up observing program, which includes Jessie, and probably other people on this call, too, I think Jen's been involved with this as well. With TFOP the TESS follow up [inaudible] project, people around the world, both professional astronomers and amateur astronomers with backyard telescopes have been looking at the stars observed by TESS and collecting observations that allow us to build more evidence in favor or against the existence of a transiting planet orbiting a particular star. |
|  | One form of evidence that's been collected by TFOP are adaptive optics, and here you can see an image taken at Keck, by a collaborator, Chaz [inaudible] and a figure was made by my other collaborator that I made at Caltech, David [inaudible]. The figure alone demonstrates the value of making new collaborations when switching institutions.. Here you can the target center in the center, while looking at the view of the sky in declination and [inaudible]. With TESS, the pixels are large enough that we don't always know whether there's one star or many stars in the TESS aperture. |
|  | If we then go to Keck or Lick or Palomar and take an image at higher resolution, we can expose nearby stars and identify possible additional contamination. In some cases, finding a nearby star might mean you don't have a planet at all, in other cases, it means that the planet is real, but it's larger than we originally estimated. |
|  | In this case, we don't see a companion star, so that bolstered the case for having a real planet. In this other image, however, there is the companion star. So the light from this star has to be accounted for when measuring the size of the planet orbiting the star. This is a case where you might initially think, "Oh, there's not a planet there at all." But there is a planet. In fact, this is a hot Jupiter around a mildly involved star. |
|  | And here, the light contribution from this star modestly changes the size of the planet orbiting this star compared to what you might expect from this AO observation. |
|  | My group is involved in these observations as well. We use Keck a little bit, but primarily we use telescopes at Lick Observatory. Here are two of the students in my group, Charles Fortenbach, who just got his master's degree from San Francisco and Arjun Savel who just got his undergraduate degree from Berkeley and is now a first year grad student at University of Maryland, and here they're actually in Berkeley, but they're using a telescope control software in a remote observing room to operate the Lick imager. |
|  | And here you can see on the left a view of the adaptive optics system. |
|  | The reason why we take these observations is two fold. If we want to estimate the frequency of planets orbiting stars, we need to know how many planets are real planets, and we also need to know how many stars we actually searched for planets. If our target stars have other stars next to them, that can both cause us to miscount planet radii, because we're not accounting for their contributions to the flux, and to think that eclipsing binaries are planets when they're not, and it can cause us to be less sensitive to planets than we thought because we have a extra light in the aperture. |
|  | One of the projects I've been working on with Jessie over the past couple years is getting a better handle on which planets are real and how well we search for planets by looking to understand the properties of stellar binaries amongst the sample of stars that we searched for planets that didn't seem to have any detected planets. |
|  | For that project, Arjun wrote up a paper recently, and what he found is he found binaries at relatively close separations for a large number of stars around which Kepler could have detected Earth-like planets and did not. So this is a rather small sample, it's difficult to make a big statistical statement based on only 71 stars, but Jessie and her team at Caltech have been looking at much larger sample, and with that larger sample, we're hoping to get a more robust estimate of the true frequency of Earth-Sized planet orbiting the stars observed by Kepler. |
|  | The next question I posed was what are the compositions of these planets? From our solar system, we can just divide everything into two categories quite neatly. We can say that these small planets are going to be close to the Sun, they're all going to have rocky compositions. And we can say that the big planets are going to be far away and all have volatile rich compositions. |
|  | Unfortunately, the universe is not actually that simple. In our solar system, we don't have any planets with radii between 1 and 4 Earth radii. If we look at the population of planets orbiting other stars, this plot here from the Andrew Howard 2013 paper shows that there are actually a lot of planets in this weird zone that doesn't exist in the solar system. So the question that astronomers had for a long time was, "What are the compositions of these planets?" They're bigger than Earth, they're smaller than Neptune. Are they things with Earth-like compositions that could be called super-Earths, or are they things like Neptune-like compositions that are better described as a Neptune? |
|  | To answer that question, we need to get masses to consider alongside the density. We can then plot them on what we call the mass-radius diagram. Here on the left, we have planet radius, on the bottom, we have planet mass, both in the units of Earth. The different lines here are different compositional models or recipes for building a planet. |
|  | And the points of error bars are measurements of planet radius and mass to a certain position. When we look at this, we can see that many of the smaller objects are close to this yellow line, which is the case of roughly Earth-like compositions, but that the larger objects are up here, indicating that they have more gasses and ices in their compositions and they cannot be described of just scaled up models of the Earth. |
|  | So this looks nice and neat, it looks like we've answered the story, but these are all super, super hot planets, they're all highly irradiated, and they might have been sculpted by the effects of their host star. So if we find a planet that's out of the distance of the Earth and we want to infer what it's composition is from its radius, we need more information. We need to actually know how it is the distribution of planet mass and density and radius change as we move farther and farther away from stars. |
|  | This is something that many researchers around the world are working on, and it was also the topic of one of grad student Anty Mayo's student papers. So here we're looking at a Kepler light curve of the star Kepler-538, showing the transit of Kepler-538b, which a planet that's about 2.2 Earth radii, so based on that diagram before, we would expect this planet to have a volatile rich composition. When we take radio velocity with HARPS-North and it's high res, we see that it would be dense. |
|  | It has a mass of about 10 Earth masses, which means that it is relatively lightweight in terms of its composition. We put this planet on the mass-radius diagram, and now we've changed the color scheme and changed the particular line, but it's the same idea. Things that are high density would be in the lower right, planets that are of low density would be in the upper left. |
|  | The line for Earth-like compositions is somewhere around here, and Kepler 538 B lies up here, so it must have a higher fraction of volatile than the Earth does. The figure here might look like Andy just colored the planet in blue because he wanted it to stand out. But really the point colors are showing you the period of the planets. And Kepler-538b is in a new regime where it's period is a lot longer than that of the periods of most small planets with measured masses. |
|  | So we're pushing the envelope here, pardon the pun, to try to find the compositions of small planets farther from their host stars. |
|  | In Andy's current paper, he's looking at a young system. So here is our representation of that system, it's the K2-136 system, which was previously published by Mann, et al., is the K dwarf and the Hyades, and because the star is in the Hyades, we know the age. The age is approximately 800 million years. Planet b is close to the star. It has a period of 8 days, about the size of Earth. Planet c is about 3 times the size of Earth and a period of 17 days, planet d about at 25 days and has a radius of 1.5 Earth radii. |
|  | Planet b and d are small enough and at long enough periods that we don't have good handles on their masses yet. But Andy has upper limits on them based on his current data sets. He has the mass estimate for planet c, and we're currently holding an additional observation from Espresso that might help us get closer to the masses of planets b and d. |
|  | If we put this system on a chart, it really stands out if we plot stellar age vs planet radius. So here, the place of errors are age estimates and radius estimates or a bunch of smaller planets with measured density. |
|  | There aren't that many of them on the left side of the box overlooking at young system. The system that is super super young is the Kepler-411 system, and those planet masses were determined- the host star age in that case is from [inaudible]. |
|  | This system is preventing the opportunity to look at what happens in the early stages of planetary systems. |
|  | If we put it on the mass to radius diagram, we can see that Kepler-136b is about twice the density of Neptune. So although it is more volatile rich than the Earth which is down here, K2-136c, which is here, is much closer to the Earth-like composition line than Neptune is. Which is a bit strange, because we typically expect a young planet to be [inaudible]. |
|  | One of the things we're doing with this project is we also have collaborates who have HST data which allows us to figure out the high-energy flux from the star. We're still working with them to figure out the answer, but it will be interesting to build a model of the evolution of K2-136c throughout the course of the stars lifetime. And to see what that tells us about atmospheric loss during the existence of the planet as well as the current conditions. |
|  | Unfortunately, this particular planet is a bad target for transmission spectroscopy because the surface gravity is just a little high. |
|  | The next question that you might be having having seen all of these plots from the mass-radius diagram and knowing that Kepler found thousands of planets is "Why is the mass-radius diagram so sparsely populated?" We know that thousands of planets exist, we've measured their radii, so what's the hold up? Why don't we have masses for all of those planets? |
|  | And the answer, as it often is in astronomy, is that many of these stars are just faint. Here is the distribution of magnitudes of the stars from Kepler that host transiting planets. The in KepMag, so we can thing of this as Z-magnitude, or just any visual [inaudible] you want. If I show you the population of these stars that are good targets for Keck, it's this section over here. And really given the choice, we wouldn't look at stars that are 12.5 in KepMag, we could look at a start that's 10 magnitude in KepMag. |
|  | So only 9% of the Kepler targets are what we consider good and bright stars for Keck, and Keck is a big telescope. |
|  | With TESS, though, we're in a much better situation. TESS is looking at nearby stars that are bright, and for that reason, a huge number of facilities have come online recently, or have focused now on following up TESS planets, because they're such great targets for radio velocity mass measurements. |
|  | I mentioned earlier that I'm part of the TESS-Keck survey. This is a multi-institution, many night project from a variety of places in the US, mostly California, but also elsewhere. And together, we're using the population of TESS planets to try to figure out what is the diversity of planet compositions and why do planet compositions vary at the function of orbital period, [inaudible] flux, stellar mass, stellar [inaudible], why do the architectures differ, and why did the dynamical textures of planetary systems differ. |
|  | It's a whole lot of fun, and I'd be happy to answer any questions you might have about TKS. I also wanted to showcase the work of graduate student Emma Turtelboom, working on the TOI-1246. So the representation of the system is on the bottom here. We have a K dwarf and then we have 4 planets all roughly the same size. Emma is a second year at Berkeley. Lauren Weiss is a parent fellow at the University of Hawaii and my co-advisor on this project, so it's been really fun to work with Lauren and to look at this system, because she has a lot of expertise in understanding multi-planet systems. |
|  | With TESS, we have a ton of data for 1246. Most TESS targets are there for about a month, but 1246 was observed in many test specters, and it will be re observed again in cycle 4, so we'll get even more data in about a year. We also have over 40 RVs from HIRES, this number is low now, we just got another observation. And we have collaborators in Europe who have offered to share their HARPS-North data with us. So we're going to be doubling the number of observations and having about 80 observations of this system. |
|  | Which is great, because this system can teach us a lot about how sub-Neptures form an evolve. |
|  | Looking at this system with TESS, here are the light curves of the 4 planets, so you can see here in gray are the individual TESS observations, in black are [inaudible] observations, and in blue are transit models. The labels reach planets and you can see the planet periods on the bottom. The sizes of the planets come in two types. |
|  | We have the two inner planets, the 4.3 and 5.9 days, they're about 2, almost 3 Earth radii, and then the 2 outer planets at 18.6 days and 37.9 days, are about 3.3 Earth-radii. So all similar, but the inner 2 planets are a little smaller, the outer two planets are a little bit bitter. |
|  | With our high res data alone, we have some preliminary estimates of the planet masses. And part of why this system is particularly interesting is that two of the planets, planets b and e are near a 2:1 resonance. |
|  | So the high res date, which where I thought the next slide was, we find that the planet masses are quite distance. We see that in the low mass case, the planet at 4.31 days, had the mass of about 6 Earth masses. But the planet that sat at 37 days has a much larger mass of about 20 Earth masses. This is interesting, and gives us a chance to try to study how we could form 4 planets from the same [inaudible] star, make them all roughly the same size, but give them different masses. |
|  | There is a preliminary version of the mass radius diagrams for this system. You can see Venus, Earth, Uranus, and Neptune, the axis are in unites of Earth radius on the left, Earth mass on the bottom, and you can see that those four planets are set up such that the smallest planet is not the least massive. The least massive planet is one of these two. |
|  | The most massive planet is out over here, and as we get more observation from high-res and from HARPS-North, we're hoping to narrow these error bars, so we can better determine the precise masses for all four planets in the system. |
|  | Putting this four planet system in context of other multi planet systems, here on the right is a figure Emma made showing all the planetary systems with four or more transiting planets. They're ordered by brightness and on the left, the color scaling indicates the masses of those planets. You can see that many of these planets are gray, which means we don't have any understanding of what the planet masses are. |
|  | TOI-1246 is right here in the middle and it has 4 mass measurements, which is particularly helpful for this system, because it's also brighter than many of the multi-planet systems. It's brighter than 93% of 4 planet systems with measured masses. |
|  | So moving along with the questions, the next one was how frequent are Earth-like planets? You got to talk to Dr. Vikki Meadows last time, and Vicky is an expert in habitability, she's really written a textbook, quite literally, on what it takes to build a habitable planet, and how the atmosphere of the planet is sculpted by the influence of the stars that they orbit. |
|  | As we think about planetary habitability, you could think of making a clone of the Earth, but that wouldn't be quite fair. We can imagine that there might be planets that are different in subtle ways, but could still be good places for life. So maybe we should be looking for another set of ingredients. We might want to know all of these different things about a planet. |
|  | Do we want to know what the composition of the atmosphere is, what it's mass is, what is the bulk composition, does it have a magnetic field, does it rotate quickly or slowly, is it old, is it young, does it have strong winds? All of these questions are things that we would like to know about planets. |
|  | Some of them are questions that we did answer in the near future, others are questions that we're really going to need new instruments and new capabilities to understand. |
|  | This is a rather simplistic diagram of what it would take to make a habitable planet. You want a more complicated diagram, you could look at one of Vicky's own papers, Meadows and Barnes in 2018, and then you might realize that you have to consider not just the planet itself, but also the affects of the star on the planet, looking at things like correlations between stellar properties and planet properties and also looking at the spectrum of the stellar radiation and how it affects the planets atmosphere. |
|  | You would also want to know about the whole architecture of the planetary system. Are there other planets orbiting this star, and how do those planets interact? In my group, we're working on a whole bunch of the properties on this diagram. We're trying to find planet masses doing the RV follow up with the TESS-Keck survey. We're also doing observation to planet Eccentricity which will help us point to the planetary systems and looking for sibling planets in our RV data sets. |
|  | On stellar spectroscopy size, we've had a program at the IRTS [inaudible] to try to determine the properties of stars hosting planets, and we can us the data we get for our RV surveys to also measure stellar abundances, which are important for then looking at the composition of planet atmospheres and seeing how planet compositions track with stellar compositions. |
|  | Stellar spectroscopy is also important for understanding stellar activity and the Luminosity Evolution of stars over time. With our AO Imaging at Lick and Keck we're looking for stellar companions. In most cases, those will not be physically associated, but in some cases we'll find systems of two stars in a binary, one of which has a planet. |
|  | And then in the future, as we look to try to understand the habitability of planets, we'll also want spectroscopy of planet atmosphere. We might want to do transmission spectroscopy or omission spectroscopy, and as we get better facilities and newer facilities to allow us to look at the atmosphere of the small planets, we could someday do direct imaging and direct spectroscopy of Earth-like planets orbiting Sun-like stars. |
|  | I see that Natasha is on the call, and I highly encourage you to talk to her if you have questions about understanding planetary atmospheres and simulating what you might be able to see with either HST or James Webb. |
|  | I don't think I have time to talk about it in detail, but the master's student that you saw pictured observing with Lick wrote a paper about 2 years ago where we looked at the set of simulated targets from TESS and we ranked them to see which of them would be the best targets for transmission spectroscopy with Webb. For Charles' Master's Thesis, he developed a framework that took some publicly available tools and then added in a [inaudible] to figure out what the planet mass might be and predicted how long it would take to see the composition of a planet's atmosphere and then rank the target so that if we wanted to look at a certain number of stars and planets in a given category, it would identify the best target list for you. |
|  | The final question I posed was how common is life. This is a question that I hope we can answer in my lifetime using large telescopes on the ground and future telescopes in space. We know what the landscape is now in terms of the fact that planets are frequent around stars. We know how to measure the mass of the planets and how to determine the properties of their host stars. We don't yet know how many Sun-like stars host Earth-like planets that are Earth mass and Earth temperature and have Earth-like atmospheres, but that's something that we could figure out with [inaudible] like LUVOIR or HabEx. |
|  | And if you have questions about how those missions would work or what it was like with some of those collaborations, you can chat about them during the round-table discussion. |
|  | So to summarize, I have a science conclusive slide and a group collaboration slide. So to start off with the science conclusion slide, on the science front, day we reviewed the Kepler mission, finding that small and cool planets are common. We know that TESS is now finding many more planets orbiting bright stars that are amenable to detailed studies like planet masses and atmospheric compositions. |
|  | On the bottom left here is the figure from Steven's TRICERATOPS paper, demonstrating how you can use TESS spectrometry and follow-up data to identify likely planets. We know that ground-based facilities are trying to understand these planetary systems in more detail by measuring the planet masses and also by identifying stellar companions that can contaminate our planet radius estimates. |
|  | On the left is Arjun's image of the nearby star companion found from Lick. On the right is Emma's data set showing the masses of the QI-1246 system, using data from [inaudible]. |
|  | In the future with James Webb, we'll probe planetary atmospheres, and hopefully someday we'll have instruments that can help us search for both inhabitable and inhabited worlds. |
|  | On the collaboration fronts, I mentioned working with a bunch of collaborations, and I know that you all are working with other scientists as well. If I wanted to give you advice for collaborations on a single slide, here's what I would tell you. |
|  | First of all, communication really matters, and that's particularly important in a remote work setting where you don't have the chance to just bump into someone in the hallway. We should communicate regularly with our team, we should delineate tasks, tell people what we expect from them and when, and make sure that every person in a collaboration feels like they know what they're supposed to be doing and why. That means that every person has a role and therefore other people respect and thank that person for doing what they were assigned to do or what they chose to do. |
|  | We also should have meetings, but we shouldn't just meet for the sake of having a meeting, and I think that's a trap that many of us fall into. We really need an agenda with action items and accountability, and if we get through the agenda early, we can end early and then go for a walk outside. |
|  | We also need to maintain a repository of information so we don't have to keep on having the same discussions over and over again. Some tasks happen every six months or so, like telescope proposal, so we should keep records to make it easier for us in the long run. |
|  | This is also really important in academia where group members might be arriving and departing to different institutions, so having a repository helps you maintain knowledge over a timescale longer than a postdoc lifetime. Postdoc's residence time, I like that phrasing much better. All right, and you should have a communication channel that works for you. |
|  | That might be email, that might be slack, whatever it is you should figure it out and stick with it, so people don't have to look for information in 20 different places, they know where to go for a certain type of question. |
|  | You also should make sure your collaborators know what you care about. If you're part of a collaboration and no one appreciates what you've worked on, that's going to be really lonely. So tell them what it is that you're excited about and why it matters. Make sure that you're science goals make it into the goals of the collaboration, because if they don't, maybe that's a collaboration that's really great and exciting and has people you love working with, but is it a good fit for your research interests? |
|  | At the same time, you should learn about the work your teammates are doing and express your interest. And hopefully you can find things to collaborate on together within the collaboration. |
|  | The next thing is to speak up for yourself. This can be hard, especially if you're joining a new institution and there are people that are a lot more senior than you, or people that are a lot more outspoken than you. But it's important, if you're part of a collaboration where you feel like your voice isn't hear, you should tell someone. Find an ally within the collaboration whose opinion you trust, who seems to have a bit more influence with other people than you do, and tell them about your concerns. |
|  | Maybe they can explain things, maybe they can help you clarify ambiguous messages. It might be that you misinterpreted something that wasn't supposed to be offensive, but was written by someone before they had any coffee, or maybe it was offensive, and that person can then go talk to the other collaboration member, and facilitate an intervention on your behalf and make sure that the group dynamics are more appropriate. |
|  | You need to have that awkward conversation about publication plans. You can't be part of collaboration for 2 years expecting to write a paper and someone else also expects to write a paper. It can be awkward to say I did that, I did the work to get the paper, but if you don't have that conversation, no one else is going to bring it up for you, and that's particularly true in your postdoc years. So be brave, be courageous be kind, but also make sure that you're getting the recognition you deserve for the work that you're putting in. |
|  | Pay attention to group dynamics. If there's a way that people typically bring up publication plans. IF you notice that certain topics are discussed on Slack and other topics discussed in the group meeting, you can follow those plans. If you notice that certain collaborators are contentious and might object to your plans, go into a meeting expecting that and have a way to cut off their arguments before they're able to make them, and make sure everyone is treated with respect. If that's not the case, you've got to use the proper reporting channels and try to tell someone about the problem. |
|  | And finally, reassess your interest in the collaboration. This goes in the sense of having time for the collaboration, making sure you're working on topics you find interesting, and most importantly, make sure you're working with people that you want to work with. You can be doing fantastic science, but if it's with someone who doesn't respect you, doesn't treat you well, you can find something else to work on with someone else. It's not worth the struggle. |
|  | Thank you all so much, I'm looking forward to chatting with you! |
|  | There's a lot of silent clapping happening right now! |
| Speaker 1: | Thank you so much for that, I'm going to stop the recording at this point, so let me do that. |