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| Tiffany: | All right. Excellent. Thanks for sharing. Thanks, David, for a great talk, and with that we'll transition to the next speaker. |
|  | Okay. Our next speaker is Jason Williams. So Jason graduated with a BS in applied physics from Columbia University and is currently a fourth year at the University of Southern California in residence at Carnegie Observatories. |
|  | His talk today is entitled the Design and Construction of Henrietta, a High-Precision, Low Resolution Near-Infrared Spectrograph to Explore Exoatmospheres, and I imagine you'll unpack all of that in your talk. |
| Jason Williams: | Yeah. [inaudible]. Yeah. |
| Tiffany: | Yeah. Absolutely. Jason, did you want a three minute warning or a five minute warning? |
| Jason Williams: | A five minute warning, please. |
| Tiffany: | Great. Will do. |
| Jason Williams: | Okay. Great. |
| Tiffany: | Go ahead and share your screen, and you can get started. |
| Jason Williams: | Okay. Let me share my screen. Can you see my notes or my screen? |
| Tiffany: | I can see your slides. |
| Jason Williams: | Okay. Great. |
| Tiffany: | [inaudible]. Yeah. Go ahead. |
| Jason Williams: | Okay. Thank you so much, [Tiffany], for the introduction. I just have to do a quick shout out to the exos for our program, our cohort, and the steering and organizing committees. It's been a real pleasure to be a part of it so far so a shout out to you guys. |
|  | So as Tiffany said, my name is Jason Williams. I'm going to talk to you today about our newest [inaudible] we're designing named Henrietta meant to explore exoatmospheres from the ground with high precision. |
|  | Okay. So the outline for my talk is to first talk about the instruments doing [transspectroscopy] now and the instruments that are going to be doing it in the future. Then, of course, talk about our instrument, Henrietta, which seeks to do transspectroscopy from the ground, and then talk about the roadblocks to doing this observation, and then finally some of the results and outcomes. |
|  | So when JWST launches in October of next year it'll be the primary instrument to do precise infrared characterization of exoatmospheres. However, there are currently no dedicated infrared instruments to help prioritize targets for JWST. |
|  | [inaudible] the top of [inaudible] transspectroscopy but isn't a dedicated instrument to doing transspectroscopy. |
|  | Pandora and Ariel will be phenomenal workhorses for a near-infrared exoplanetary [inaudible], but won't be online for another few years. |
|  | On the ground there are a few transpectroscopy surveys, most notably [ACCESS] which is [inaudible] Magellan and the [GTC] transpectroscopy survey which uses [inaudible] GTC. |
|  | However, these surveys are [inaudible] optical, and their infrared complements don't yet exist on the ground. |
|  | So all these considerations have lead us to the conception [inaudible] of Henrietta, which is a near-infrared spectrograph to be deployed at the 1-m Swope Telescope at Las Campanas Observatory in Chile, and it aims to survey the molecular content of exoplanet atmospheres using transmission and maybe emission spectroscopy at near photon-limited precision, and it aims to have the first light in August of 2022. |
|  | So question I imagine a lot of you might have is why are we building this on a one-meter telescope on the ground? And so firstly one-meter telescopes are greatly underutilized as a resource, and therefore we can tend to get a lot of telescope time on them. |
|  | And there's actually evidence by Ariel that one-meter tall telescopes can do exquisite science when they operate near the photon-noise limit and focus mostly on red targets. |
|  | This figure is from Barclay, et al., and it shows the peak of the TESS field. The TESS yield is around 11 TESS mags. So surveying the poor air of these planets left of 11 magnitudes would lead to a huge leap in our statistical understanding of exoplanets. |
|  | And so just really quickly Henrietta was actually an American astronomer who studied variable stars. In particular she measured the period/luminosity relationship for [inaudible] stars which are bright variable stars whose periods of variability relate directly to their intrinsic luminosities. |
|  | This was work was extremely groundbreaking. When she worked Carnegie for several decades, and the one-meter solar telescope was named after her. She donated several securities to develop optical observatory facilities in the southern hemisphere. |
|  | Henrietta the instrument seeks to be a trailblazing instrument in IR. The instrument bears here namesake in hopes that we can do similarly groundbreaking work. |
|  | And so the Henrietta team is made up of myself. I'm the instrument lead and the Co-PI. My advisor, Nick Konidaris, who is the lead PI and co-instrument lead. Johanna Teske who is the project scientist, and Tyson Hare who is our senior engineer. |
|  | In addition and not pictured here are the wonderful staff at Las Campanas Observatory who are absolutely instrumental to the success of this project. |
|  | So the things that drive the first order of design of Henrietta are the wave length range, spectral resolution, field of view, and the throughput. We've chosen the wavelength range to go from the red end of the optical to the K-band as our wavelength range to help constrain apertures and because to constrain aerosols in the atmosphere, and because the planet to star flux ratio often keeps the infrared alignments to obtain a higher signal to noise, and then for the obviously [inaudible] molecular species. |
|  | We plan to try and extend our [inaudible] of one down to 0.6 microns, but this may be way too long of a [inaudible] detector, so we'll see. |
|  | Also note that in this figure there isn't a [Grisom], but there will be on in the actual instrument. |
|  | And so we settled on a spectral resolution of 200 in order to balance spectral information, signal to noise, and minimize the effects of atmospheric extinction, and we also have a field of view of 25 arcminutes by 3 arcminutes, and our total throughput across the entire pass band ranges from 35% to 40%. |
|  | So just looking at this figure really quickly it looks like a typical spectrograph, but what we'll talk about later are a few advances in technology that allow Henrietta to hopefully reach near-photon [inaudible] precision. |
|  | Okay. So next I will talk about the roadblocks to achieving high-precision spectrophotometry. |
|  | So the challenges of detecting exoatmospheres are two-fold. One, your instrument has to be sensitive enough to detect a drop in flux due to the planet itself, and secondly and most importantly for us your instrument should be sensitive enough to detect the modulation due to the wavelength-dependent absorption in the atmosphere. In the exoplanet atmosphere, of course. |
|  | This results in often two different signal to noise ratios as you can see in the figure. The signal to noise constraints to detect the planet itself is much smaller than the signal to noise constraint to detect the atmosphere. |
|  | And so we often end up being in two different signal to noise ratios, so we have to make sure that we aren't limited by... We do our best to be working with as high a signal to noise as possible. |
|  | And so there are a few things we can do to make sure that we're working with a high base signal to noise. So we can operate on lower spectrum resolutions, and we can sew multiple time exposures together, and just in general we just add more photons. The better we can do to add more photons is ideal. |
|  | But today I'm going to be mostly talking about reducing the signal to noise, reducing the noise, to increase the signal to noise because this is the only way to reach the photo-noise limit which is the fundamental limit, obviously. |
|  | So there are plenty of sources of noise and systematics present in ground-based instruments. There's slit loss. In the near-red there's sky emissions. There's differential extinction, but the ones that dominate our noise budget and the ones that we're going to be focusing on today are scintillation noise and intra-pixel quantum efficiency sensitivity in H-2RG [inaudible]. |
|  | So to assess [inaudible] performance and whether or not we can achieve our precision goal, we adopted a noise budget method. To this end we developed a signal to noise pathway that would be useful in illustrating one of the most problematic noise sources in achieving photo-noise limited precision. |
|  | This figure shows the utility in developing this because we can immediately see once we do our simulations and plug in our equations that for bright targets were dominated by scintillation noise, and our sub-pixel noise, our intra-pixel noise. |
|  | And so now I'll discuss how Henrietta plans to mitigate these sources of noise in order to get down to the photon-noise limit. |
|  | So I'm going to play a video here. Hopefully it plays. Maybe it's not playing. Okay. That's okay. But this figure's meant to illustrate the twinkling of a star which we're all very familiar with, and that twinkling is actually scintillation, and it's, again, one of the dominant noise terms in our budget. |
|  | And as mentioned so scintillation is caused by intensity fluctuations across our telescope. As aberrated waveforms propagate a great distance from the top of the atmosphere down to the bottom of the atmosphere we are, and so this leads to a time-dependent noise as the turbulence evolves throughout the night. |
|  | Okay. And so if you carefully look at a star with your eye you will notice, actually, that it changes colors ever so slightly. This is because your eye is simply not big enough to capture both the deflection from the turbulence in the atmosphere and then the refraction on top of that. |
|  | So in this figure I've taken an actual turbulence profile from a night at [inaudible] Observatory and simulated what the intensity fluctuations would look like across your eye at different wavelengths. |
|  | You'll notice, one, that the fluctuations are very high, reaching tenths of percents, which is why you can observe it with your eye, and if you look closely I want you to realize that the flux is uncorrelated between wavelengths. |
|  | However, on large telescopes scintillation is actually highly correlated between wavelengths. This is because now you have a large enough aperture to capture all the light that's refracted after passing through similar patches of turbulence. |
|  | So since the scintillation noise is so highly correlated, it's a common [inaudible] across wavelengths, and you can effectively remove it completely. |
|  | However, things may be different [inaudible], and we assume that we can only decrease it by an order of magnitude, and that we can't eliminate it completely. |
|  | So next we turn to the issue of intra-pixel or sub-pixel sensitivity. So H-2RG detectors are grown with a material called mercury cadmium/cadmium telluride, and this provides a high customizability and high efficiency that's notoriously difficult to grown uniformly. |
|  | Because of this, the sensitivity of the detector not only changes from pixel to pixel, which you could theoretically eliminate with a flat field, but now it changes within the pixels themselves. So depending on where the light hits inside the pixel you will get a different response, and so that leads to these crosshatch patterns as you see in this photo. |
|  | And so this data is data that assimilated from a paper by Shlawin, et. al, in 2020 where they've measured the sub-pixel structure in their H-2RG down to 1/32 of a pixel, and so here what you're looking at is the sub-pixel structure, and here 32 of these sub-pixels is equal to one pixel, and you can see that it varies by several percent across the entire [inaudible]. So this is definitely a problem for us. |
|  | So this causes a problem for [inaudible], and I'm going to play a video here, and hopefully it will work. [inaudible]. And so this causes a problem for in-focused point spread function because the high radians in the point-spread function cause time-varying noise when the location of the PSF moves even slightly across the detector. |
|  | Here I've simulated a two-pixel wide PSF and moved it around on our simulated detector with a standard deviation of 0.4 pixels, and then performed standard aperture photometry. |
|  | From this you can see that for an in-focused PSF this induces this time gradient noise on the order of several hundreds of PPM. |
|  | So if you could fuse the PSF into a top-half over many pixels you can effectively push the variations towards the edge of the PSF where the gradient exists, and now you simply average over the gradiations in the flat top spots. |
|  | Here I've done the exact same simulation as I showed on the previous slide, but just with a diffused PSF, and as you can ultimately see the time gradient noise decreases dramatically. |
|  | So diffusers have already been used on many ground-based telescopes with plenty of success, and this will be the first time a diffuser would be used in a spectrograph, and Henrietta plans to actually test diffusers in multiple locations in the spectrograph to see what gives the best results. |
|  | And so here it's pictured. It's in the columnated beam right before the Grisom, and so we plan to have one there. We plan to have one in front of the camera and right in front of the detector just to see which gives us the best performance. Excuse me. |
|  | And so in addition we also plan to adopt a calibration technique pioneered by the [inaudible] telescope, so highlighted in red here we plan to use two single-mount fibers installed in the Dewar of Henrietta to place an interference pattern onto the detector. |
|  | Since the interference fringe is exactly predicted by physics, we can use this to calibrate our detector. |
|  | So essentially what we're doing is we're [inaudible] this interference pattern across the entire detector and backing out what the sub-pixel structure is based on our detector image. |
|  | So in the strictest sense we can use this to completely map out the entire sub-pixel structure of our detector, but we can also actually just use this in an ad hoc way just to locate particularly bad spots on our detector. |
|  | And based off simulations with both of these techniques the diffuser combined with the calibration technique, we safely say we can reduce the sub-pixel noise by a factor of 10 as well. |
|  | Okay. So what are the results and outcomes of Henrietta? [inaudible]. And so if Henrietta's successful in achieving near-photon noise-limited precision it will actually be very scientifically productive. |
|  | After taking into account the reductions in noise and the noise from our comparison star at a tenth magnitude we can achieve 120 ppm per resolution element, bin to a resolution of 70, and after binning the time resolution to an hour which is great. |
|  | And so here then just to sort of demonstrate this precision I simulated two observations of a clear and a cloudy Neptune-like planet orbiting a star of TESS magnitude 10, an [inaudible] star that has a TESS magnitude of 10. |
|  | I bin the data to a resolution of 70, and bin the, again, the exposure to an hour, and in as little as four as a half trends Henrietta can begin to distinguish between these two types of atmospheres. |
|  | And so with this photon-noise limited precision, Henrietta can actually complete a survey of around 100 exoplanet atmospheres in a year. Again, we have lots of telescope time on this [inaudible], and so we're going to use this to our advantage. |
|  | It can mostly complete a survey of mostly warm Neptunes and hot Jupiters, and uniform observations of such a statistically significant sample of atmospheres would really help us to understand the diversity of exoplanets and help us identify truly unique planets for detailed followups with JWST. |
|  | And so ultimately, however, Henrietta may not be able to achieve photon-noise limited precision. Things happen. We think we identified all the sources of noise, and then the one thing shows up. We can mitigate it. You know? These things have happened. |
|  | But even then Henrietta will prove to be extremely valuable because it will inform the next generation of these dedicated exoatmosphere instruments on the ground which will be much more expensive. |
|  | And so here I'm showing, actually, another instrument that I'm involved in at Carnegie called MIRMOS, the Magellan Infrared Multiobject Spectrograph. It plans to be designed with a lot of the same heritage as Henrietta, and if Henrietta helps it achieve photon-noise limited precision it will achieve similar precisions to JWST throughout the Y and K bands. |
|  | Okay. So currently we just wrapped up the design phase of the instrument, and now we've begun ordering parts from vendors. The most expensive piece of the instrument, the H-2RG, has already arrived, and it's waiting to be tested, and we hope everything will arrive by September '21, and when it will begin integration and testing, and that portion will last for almost a year, and then in August of 2022 we expect to start commissioning the instrument. |
|  | And so just as a recap when we started there are currently no dedicated infrared transpectroscopy instruments to help prioritize JWST, nor are there any ground-based infrared spectrographs dedicated to doing transpectroscopies of all the exoatmospheres and in the future [inaudible]. All the exoatmospheres that they won't get a chance to examine. |
|  | Achieving high precision from the ground is difficult in the infrared, but Henrietta is designed to have... It has specific design choices to help it achieve high spectrophotometric precision, and again will help it prioritize targets for JWST. |
|  | And so if we achieve our goal of the near-photon noise limited precision, Henrietta will be scientifically productive, enabling a survey of mostly warm Neptunes and hot Jupiters, and ultimately Henrietta plans to help... Sorry. Ultimately with this instrument we want to lay the groundwork to help democratize exoatmosphere observation. |
|  | There's so many planets and so many exoatmospheres. It's all way too much for one or even a handful of instruments to tackle on its own, and so the more instruments we can have to do these types of observations the better. |
|  | And so with that I hope I can answer any questions, and feel free to email me about exoplanets, or if you want to talk about the New York Knicks. [inaudible]. Thank you. |
| Tiffany: | Thanks so much, Jason. That was a great talk. |
| Jason Williams: | Yeah. |
| Tiffany: | I see a hand raise from Tom Greene. Tom, go ahead and ask your question. |
| Tom Greene: | Jason, I'd like to thank you for a great talk, and I was also wondering if you could say a little more about what measurements you've done of scintillation noise. You know? And determining also its correlation between different structural elements. |
|  | And what are the plans, then, of reducing that common mode of noise from the Henrietta data? Are you doing some sort of internal calibration? Or is this all going to be just from some sort of analysis in from the pipeline? And [inaudible]. |
| Jason Williams: | Yeah. Of course. That's actually a great question. Yeah. So we haven't done... We're looking, actually, to get on sky with a few other ground-based instruments to do these exact measurements, but there have been a few papers. There's one in particular by [Cortalone], but I forget his first name, but I've read it so many times. It's like a 21-page [inaudible] where he talks about how on large telescopes scintillation is achromatic, and he basically mentioned the scintillation in two different pass-bands, in the B-band and then in the V-band, and they're highly correlated. |
|  | So there's some evidence for this. We haven't done them ourselves. It ends up we plan to do stuff, and then when it comes to this for Henrietta we plan to try and adopt both. I think what I'm leaning towards is not doing this in the data reduction sort of like... Or not use the software to find a common [inaudible] signal, but sort of to just pick off a section of each band and then sort of use that as a calibration for the scintillation noise. So yeah. That's my plan right now, but this may change when we get actual data. |
| Tom Greene: | Thank you. |
| Jason Williams: | Yeah. Of course. |
| Tiffany: | Thanks. A few questions from Ashley. Sorry. I don't know the first name or last name. Ashley, go ahead and ask your question. |
| Ashley Baker: | Hi. This is Ashley Baker. I'm a post doc at Cal Tech. Thanks for the really great talk. I'm really excited to hear about Henrietta. I hadn't heard about it before. |
|  | I was wondering. You might have mentioned this. How do you plan to get simultaneous reference stars? Are you going to have a slit mask like [crosstalk]? |
| Jason Williams: | Oh, yeah. Sorry. Yes. Yeah. I did not mention that. Thank you for bringing that up. Yeah. So we plan to have a slit map, so it'll have both long-slit capabilities and a multi-object capability with the slit mask. |
| Ashley Baker: | Awesome. Thanks. |
| Jason Williams: | Yeah. Of course. |
| Tiffany: | Thanks. Any other questions? I see a hand raised from Vanessa. Vanessa, go ahead. |
| Vanessa: | [inaudible] prerogative. Could you say a little bit more about the range that you went through to choose the R of about 70 resolutions? |
| Jason Williams: | Could you say that again for me? |
| Vanessa: | How did you arrive at choosing a resolution of I think it was about 70? |
| Jason Williams: | Yeah. Yeah. So I guess just from papers that I've read. Unfortunately I guess I don't have the best answer for this, but yeah. It's just when I read a lot of papers that seems to be a common wavelength that people bin to, and so that's just sort of what I did. Unfortunately I don't have a better explanation. |
| Tiffany: | [inaudible] I imagine in the future having simulated observations to go along with your laboratory work would probably help converge on the ideal [crosstalk]. |
| Jason Williams: | Right. Yeah. |
| Tiffany: | [crosstalk]. Yeah. That's why it's important to keep theorists around. |
| Jason Williams: | Yeah. Definitely. Yeah. |
| Tiffany: | All right. Well, thank you Jason for an excellent talk, and thank you again, David, for an excellent talk. And so with that we'll conclude our first session of the ExoExplorer Science Series. |
|  | Our next set of speakers and our next presentations will take place on May 14th. Again, Friday, at 1:00PM Pacific, 4:00PM Eastern, and the speakers that day will be Jules Scholar from UCSC and Rachael Hernandez from University of Arizona [LTL], so please stay tuned for that and hope to see you there. |
|  | With that we'll close, and please enjoy the rest of your afternoon and weekend, and take care. Thanks again. |