Honors Thesis Proposal

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1 Prospectus

Exoplanetary astrophysics was a field that barely existed 20 years ago, and now it has become one of the most exciting fields in astrophysics. Until the Kepler mission, it was thought that exoplanets were rare, but we have since found there is about 100 billion exoplanets just in the Milky Way [1]. While most observed exoplanets are large gas giants close to their parent star, so called “Hot Jupiters”, several terrestrial planets have also been found. Terrestrial exoplanets which receive similar solar insolation to that of Earth are ~~currently~~ the most likely candidates in the search for habitable worlds ~~beyond Earth.~~ To date, the list of exoplanets in the classical habitable zone is countably small, and not all of them are very close to Earth, but this will soon change with the ~~recently~~ launch of the Transiting Exoplanet Survey Satellite (TESS). TESS is expected discover thousands of exoplanets smaller than Neptune and dozens of Earth sized planets [2]. In conjunction with James Webb Space Telescope (JWST), we ~~will~~ expect to have precise observations on a number of potentially habitable worlds in nearby star systems. However, it is known that exoplanets are likely to be tidally locked, as in they don’t rotate relative to their star. They will have a substellar point, which always gets direct sunlight, a terminator, which gets a perpetual sunset, and an entire half of the planet will live in perpetual night. Such an exotic world can’t be compared to Earth, or any other planet or moon in the solar system. With such a new case for planetary atmosphere parameters, the only ~~real~~ way to characterize exoplanets is via coupled global circulation models (GCMs). These models have demonstrated that they are very different than what we would expect from the Earth, and our most Earth-like planet, TRAPPIST-1 d, is less likely to be habitable than TRAPPIST-1 e, a planet that receives 60% of the solar irradiance of Earth[3].

Using GCMs for TRAPPIST-1 d, e, and f provided by Eric Wolf and the Planetary Spectrum Generator (PSG), a tool provided by NASA Goddard, I have created a data pipeline that can produce an exoplanet transit Spectra, simulating what telescopes like JWST will see during transits. In order to produce accurate spectra, ~~an accurate~~ GCM is essential, and simply assuming an exoplanet is "Earth-like" is unreasonable. Using this transit simulator, analysis can be done on the observable spectral features that JWST can detect, and signal to noise analysis will help the astrophysics community help prioritize their time on JWST.

In addition to exoplanet spectra, GCMs can provide other windows into studying exoplanetary atmospheres. A GCM provides full global resolution of an exoplanet's surface, so in addition to a terminator atmosphere profile, Earth-facing atmosphere profiles can be made, which can be used to determine the change of the planet's thermal emission over the course of a year. ~~So-called~~ thermal phase curves measure the change in thermal brightness of a planet as it orbits its star, and can be ~~significantly~~ variable in a way that could be detected with JWST. Thermal phase curves have the advantage of strong signal to noise due to large binning and long observation times. Using my pipeline, I can easily simulate thermal phase curves and use them to determine if there are clouds in the atmosphere and how those clouds are moving.

I will explore these two topics, transit spectra and thermal phase curves, in my honors thesis. Although the topics are slightly different branches of research, they're both competing techniques at analyzing exoplanets, and both will likely serve a major role in the coming years for JWST-era research. I anticipate my thesis will be broken into the following parts. In 1), I will explain the background of exoplanets, with an emphasis on the variables significant to thermal phase curves and transits. In 2), I will show Eric Wolf's climate models, and particularly focus on the terminator atmosphere profile and the global cloud patterns, particularly with regards to fast rotators, which have smaller clouds formations, and slow rotators, which have large, permanent cloud patterns. In 3), I will explain the data pipeline I made and the PSG as a tool to simulate spectra, ~~perhaps with a little discussion on the telescopes used.~~ In 4), I will show transit spectra results, analyze their behavior, and identify and measure prominent features. In 5), I will do the equivalent analysis for thermal phase curves, and compare slow rotators versus fast rotators here. In 6), I will get into a noise analysis, and compare the reliability of the results of transits to that of thermal phase curves. Then I will conclude, stating the advantages of each and which tool will be useful where for JWST.

Timeline

In addition to the honors council, I will be submitting part ~~or all~~ of my honors thesis for the class PHYS 3050: ~~Physics Writing.~~ For this, I have a number of deadlines ~~for that class specifically~~ that will serve two purposes. Italics dates will indicate that they are set by PHYS 3050.

2018-9-17: Topic Brainstorm

Answer bullet-point questions about the project

2018-10-15: First Draft

With an emphasis on the introduction and outline only

2018-10-31: Second Draft

With an emphasis on completing sections 1-3

2018-10-29: Third Draft

Completed and revised sections 1-3, with compiled plots and figures for part 4

2018-12-18: Class Final

Completed sections 1-4, and a sufficient conclusion for it to be a complete paper worthy of submission, excluding thermal phase curves

2018-1-10: Research Completed

Using the time over winter break to finish any necessary research, write a first complete draft of the paper including all sections

2018-2-15: Second Complete Draft

Having completed the entire paper, continue the revision process

2018-3-15: Complete Final Draft

The final draft ready for submission to the review board

2018-3-25: Earliest Possible Defense

Subject to the approval of my board members

2018-4-8: Submit to Honors Program

Including defense copy, thesis copy, and title page

References

[1] M. Woo. Planets Abound. 2013.

[2] G. R. Ricker, J. N. Winn, R. Vanderspek, D. W. Latham, G. Á. Bakos, J. L. Bean, Z. K. Berta-Thompson, T. M. Brown, L. Buchhave, N. R. Butler, R. P. Butler, W. J. Chaplin, D. Charbonneau, J. Christensen-Dalsgaard, M. Clampin, D. Deming, J. Doty, N. De Lee, C. Dressing, E. W. Dunham, M. Endl, F. Fressin, J. Ge, T. Henning, M. J. Holman, A. W. Howard, S. Ida, J. Jenkins, G. Jernigan, J. A. Johnson, L. Kaltenegger, N. Kawai, H. Kjeldsen, G. Laughlin, A. M. Levine, D. Lin, J. J. Lissauer, P. MacQueen, G. Marcy, P. R. McCullough, T. D. Morton, N. Narita, M. Paegert, E. Palle, F. Pepe, J. Pepper, A. Quirrenbach, S. A. Rinehart, D. Sasselov, B. Sato, S. Seager, A. Sozzetti, K. G. Stassun, P. Sullivan, A. Szentgyorgyi, G. Torres, S. Udry, and J. Villasenor. Transiting Exoplanet Survey Satellite (TESS). 9143:914320, August 2014.

[3] E. T. Wolf. Assessing the habitability of the trappist-1 system using a 3d climate model. *Astrophysical Journal Letters*, 839:L1, April 2017.