Yale College – Summer 2015

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Project Report on the Characterization of Transiting Planets Discovered by the Kepler-2 Mission
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This past summer, I had the opportunity to conduct research at the Astronomy Department of the University of California at Berkeley. I have worked under the supervision of NASA Carl Sagan Fellow Roberto Sanchís-Ojeda, and I had the privilege to be on a scientific team led by the world-renowned astronomer Dr. Geoffrey Marcy. My internship would not have been possible without the Class of 1960 Summer Traveling Fellowship, so I am extremely grateful for the generous help I have received.

My research dealt with extrasolar planets – planets that orbit a star other than the Sun. Since the discovery of the first exoplanet in 1995, over two thousand more have been detected and several hundreds are in the process of being confirmed. As evidenced by these numbers, the field of exoplanets has grown rapidly over the years and is now one of the most active research areas in astronomy. One of the key factors in this development has been the NASA *Kepler* Mission, which was launched in 2009 to detect Earth-like planets in the habitable zone of their parent stars. The *Kepler* telescope was designed to point at one area of the sky and record the brightness of thousands of stars over short periods of time. Given that the stellar luminosity experiences a sudden drop when a planet transits in front of or behind a star, astronomers can infer the presence of exoplanets by studying *Kepler* data.

After four years of observation, which resulted in the discovery of most of the exoplanets known to date, the *Kepler* Mission came to an end in 2013 with the failure of two of the reaction wheels used to maintain the telescope stable. Although the spacecraft was no longer able to continuously focus on the original *Kepler* field of view, it was still operable, which encouraged NASA to create a new Mission called *Kepler-2* (or K2). For this extension, the telescope would turn to a different part of the sky every three months. Since the beginning of the first K2 campaign, *Kepler* has observed a large number of stellar systems, providing the astronomical community with new and reliable scientific data. During the original *Kepler* Mission, engineers at the NASA Ames Research Center processed the data before making it available to the public. Today, K2 data releases are published in raw form mainly as a result of NASA's financial constraints. The lack of processing techniques has forced astronomers to come up with their own data reduction pipelines and to create their own lists of planet candidates. These lists are very important in establishing which stars may host interesting planets and thus deserve more follow-up observations with ground-based telescopes.

With no standardized techniques to consolidate K2 data, no publicly available lists of planet candidates, and with some of the most crucial existential questions yet to be resolved – such as "are we alone in the Universe?" or "is there an Earth 2.0?"— competition has increased in the field of exoplanets as groups of astronomers have started to become more independent from one another. This summer, I have been lucky to work on a team that seeks to restore the value of collaboration in the study of exoplanets and *Kepler* data. The team's commitment to work as openly as possible is reflected by its local and international partnerships, and by the fact that most of its

research can be found on a web-based repository called *GitHub*. I deeply believe in the power of teamwork, so I quickly embraced the philosophy of my group and applied it to my summer project. Indeed, my work is available on my personal *GitHub* account[1] and is the result of exchanging ideas not only with my closest mentors, but also with astronomers from all over the world.

The main goal of my research was to characterize three exoplanetary systems observed during the first K2 campaign: EPIC 201546283, EPIC 201295312, and EPIC 201577035. These systems are an important part of ESPRINT,[2] a project created by an international group of scientists – including Dr. Marcy's team— to better understand the population and properties of exoplanets. Using a programming language called Python, I created a code that would process K2 measurements and calculate the best estimates for the most relevant physical parameters of the three systems given few initial properties of the planet candidates and their respective host stars. To improve the quality of my results, I incorporated several free Python routines that are commonly used in exoplanetary research (e.g. *AstroPy*, *AstroML*, or *EMCEE*). As previously mentioned, the final version of my code and the results I obtained for each EPIC system can be found on my *GitHub* account.

While in Berkeley, I also had the opportunity to meet wonderful people, some of them with similar interests and aspirations to mine. In addition, I was able to explore San Francisco – a beautiful city that I hope to visit again— and to travel to cities such as Santa Cruz, Los Angeles, and San Diego. These trips provided me with a more accurate

[1] https://github.com/mbadenas/Transit-Analysis
[2] *Equipo de Seguimiento de Planetas Rocosos Interpretando sus Tránsitos* (for more information, see Sanchis-Ojeda et al. 2015)

and holistic view of what it means to live and work in California. Without a doubt, the West Coast has now become one of my favorite regions of the United States.

All in all, this summer was an invaluable and wonderful experience. Academically, I was able to conduct research in the scientific discipline that I am most passionate about, gaining a better insight of the theoretical and observational foundations underlying the field of exoplanets. Working at UC Berkeley has also furthered my interest in pursuing a specialized degree in Astrophysics. I am extremely happy to announce that my research has been used in an article that will be published next year in a peer-reviewed journal and will likely strengthen my graduate school applications. Finally, I met people who broadened my understanding of the space community and the professional opportunities therein.

Once again, my summer experience could not have happened without the financial support I received from the Class of 1960 Travel Fellowship, so I want to extend my sincerest thanks to the members of the fellowship selection committee, the donors, and the Office of International Education and Fellowships for making my internship possible as part of my undergraduate career.

Thank you,

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