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Lewis and Clark Fund for Exploration and Field Research in Astrobiology

Exploring the Formation of Rocky Worlds with the Solar Twin Planet Search
Project Report:

Support from the Lewis and Clark Fund was used for two observing trips to Chile in October 2016 and February 2017. These were the final observing runs in a five-year-long program using the HARPS spectrograph on the ESO 3.6m telescope. This telescope is located near the southern edge of the Atacama desert of Chile, at La Silla Observatory (29.2563° S, 70.7380° W; shown in Figures 1 & 2). The goal of the observing program was to monitor "solar twins," or stars which are spectrally identical to the Sun, in an effort to find exoplanets around them.

We chose to target solar twins exclusively because they offer a unique advantage in characterization. Since these stars have physical properties (like temperature, mass, and radius) very similar to those of the Sun, we can essentially use the same theoretical models to represent the physics of their atmospheres. Stellar models are a chief source of uncertainty when analyzing the spectra of stars, so by "cutting out the middleman" and restricting our sample to stars which use the solar model, we can drastically reduce errors in the properties inferred from spectra. Specifically, we can measure the chemical abundances of these stars to the 1-2% level of precision, a factor of five better than a standard stellar analysis. The combination of detailed knowledge about the chemical composition of the star and constraints on its planetary system promises unique insights into the planet formation process and especially the conditions required for the formation of rocky planets.

During my time in Chile, I spent a cumulative five nights observing solar twins from our target list. I took an average of about 30 observations per night of different stars, with each observation yielding a stellar spectrum and a measurement of the star's radial velocity (RV). From the resulting time series of RVs, I was able to infer each star's motion over time – motion that is potentially caused by the orbit of a planet around it.

The two observing runs generously supported by the Lewis and Clark Fund were particularly critical to the success of our observing program because they enabled us to follow-up interesting planet candidates from our previous runs and conclude our program with the maximum possible information on these crucial systems. The resulting data are still being analyzed and will be published in forthcoming papers, but a summary of some results follows.

Figure 1. View of La Silla Observatory during daytime. The ESO 3.6m telescope used in this work can be seen clearly from 1 km away! (large dome on the right-most peak).

Figure 2. View of La Silla Observatory at night. Despite my very amateur astrophotography skills, the Milky Way is easily visible. The Chilean Atacama hosts some of the best astronomical seeing on Earth.

Planets and Planet Candidates

From the time-series RV measurements obtained with HARPS, we have been able to identify several periodic signals potentially caused by exoplanets (Figure 3). Two systems had already shown strong signs of hosting planets prior to our 2016-2017 observing season: the star HIP11915 has a Jupiter-mass planet on a Jupiter-like orbit, making it a particularly good candidate for a “Solar System twin” with smaller, yet-undetected planets. On the other hand, the star HIP68468 appears to host two planets of super-Neptune and super-Earth masses on orbital periods much shorter than those of their analogous solar system planets. We continued to follow both of these systems in our 2016-2017 runs, refining the orbital parameters and searching for additional planets.

We also identified new planet candidates from the data set thanks in large part to the RVs collected during the Lewis and Clark funded observing runs. These candidates, shown in the right column of Figure 3, range from a Neptune-mass planet on a sub-Mercury orbit to a planet 10% of Jupiter’s mass on a Mars-like orbit. The extreme diversity of exoplanetary systems has been a chief result of exoplanet exploration studies over the past two decades, and while the extension of this diversity even among solar twin stars is not surprising, it has strong implications for the expected rarity of Earths throughout the galaxy.

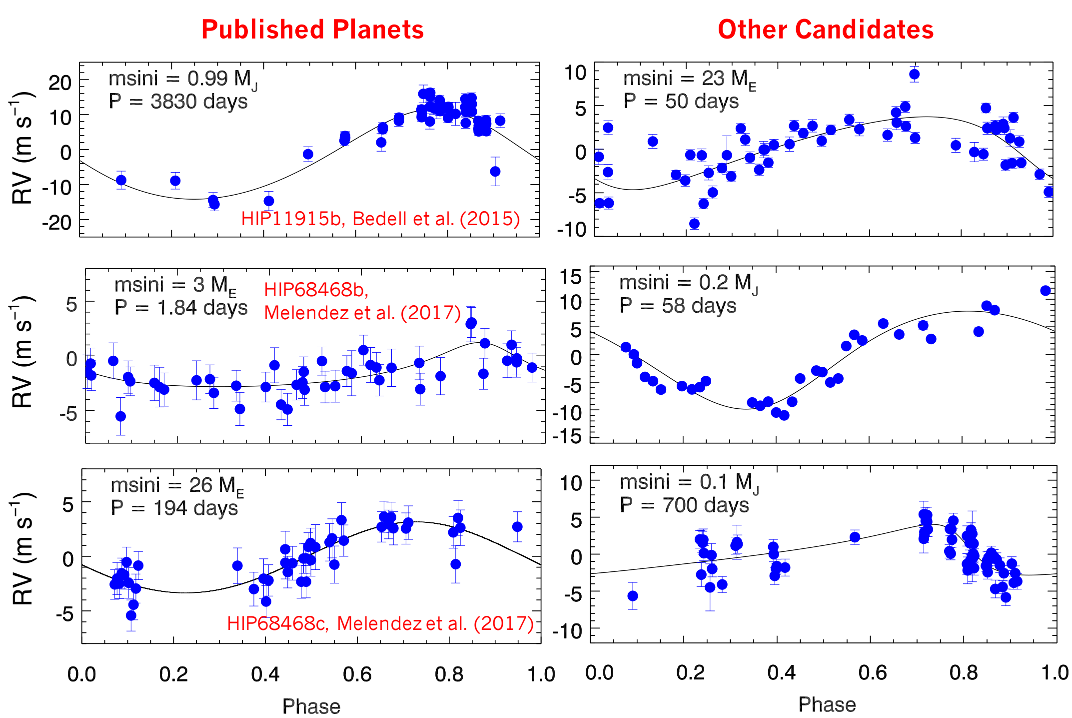

Figure 3. Planets and planet candidates discovered among the Solar Twin Planet Search data. The radial velocity (RV) of the star is phase-folded to the planet signal in these plots. The minimum mass (“msini”) and orbital period of each signal are given.

Solar Twin Studies

The spectra obtained with HARPS during these runs not only provided us with more time-series RVs for planet hunting, they also enabled us to embark on the second component of the Solar Twin Planet Search: detailed characterization of a large set of solar twin stars and their compositions. The same high-resolution spectra required for RVs can also be stacked for each star and used as extremely high-quality master spectra for the purpose of measuring chemical abundances in the atmospheres of the stars. While this work is labor-intensive and still ongoing, I expect to have fully measured abundances of over 20 elements in each of the 63 solar twins observed through our planet search for my thesis in July 2017. This will enable us to draw connections between the compositions of stars and the types of planets they form, and will test our hypothesis that the Sun's unique abundance pattern is linked to its history of forming rocky planets (i.e. the Earth).

We deeply appreciate the financial support of the American Philosophical Society and the NASA Astrobiology Institute. All future publications making use of these data will acknowledge the Lewis and Clark Fund grant.