2020 Undergraduate Research Showcase

Undergraduate Research and Scholarship Showcases

4-24-2020

Stellar Composition May Reveal Origins of Bizarre Planets

Ciera Partyka-Worley
Boise State University

Brian Jackson
Boise State University

Sevio Stanton
College of Western Idaho

Stellar Composition May Reveal Origins of Bizarre Planets

Abstract

The current hypothesis for the formation of Ultra-Short Period Planets, USPs (exoplanets with periods less than 1 day) is that they are remnants of hot Jupiters (gas giants with periods between 1 and 10 days) that experienced tidal decay. Winn et al. (2017) tested this hypothesis by asking whether USPs are associated with metal-rich stars, as has long been observed for hot Jupiters. They gathered stellar metallicity data based on Keck spectroscopy of stars observed by the Kepler mission, then compared the stellar metallicities of USP host stars and hot Jupiter host stars. They concluded that USPs and hot Jupiters are two different types of planets based on their metallicity analysis. We attempted to replicate Winn et al.'s data with a larger sample size to explore how statistically robust their calculations are.

Stellar Composition May Reveal Origins of Bizarre Planets

Ciera Partyka-Worley[1], in collaboration with Brian Jackson[1], Sevio Stanton[2]
[1]Department of Physics, Boise State University [2]College of Western Idaho

1. What are USPs? Where do they come from?

- USPs are Ultra-Short Period planets which have an orbital period of less than 1 day. [3]
- The current hypothesis states that USPs are remnants of Hot Jupiters (gas giants with periods between 1 and 10 days) that experienced tidal decay.[1, 2, 5]

2. How might stellar metallicities reveal origins?

- Stellar metallicity is an intrinsic quality of each star. Hot Jupiters have been observed usually associating with high metallicity stars. [1]
- If all USP planets are the cores of former Hot Jupiters, we should observe similar metallicity distributions for the hosts of USPs and Hot Jupiters. [2]

3. State of Knowledge

- Joshua Winn et al. tested that hypothesis, through Kolmogorov-Smirnov Tests and concluded that they are two different types of planets based on their nominal host stars metallicities.[2]
- To ensure Winn et al.'s conclusions are accurate, we should attempt to replicate it, preferably with a larger sample size.

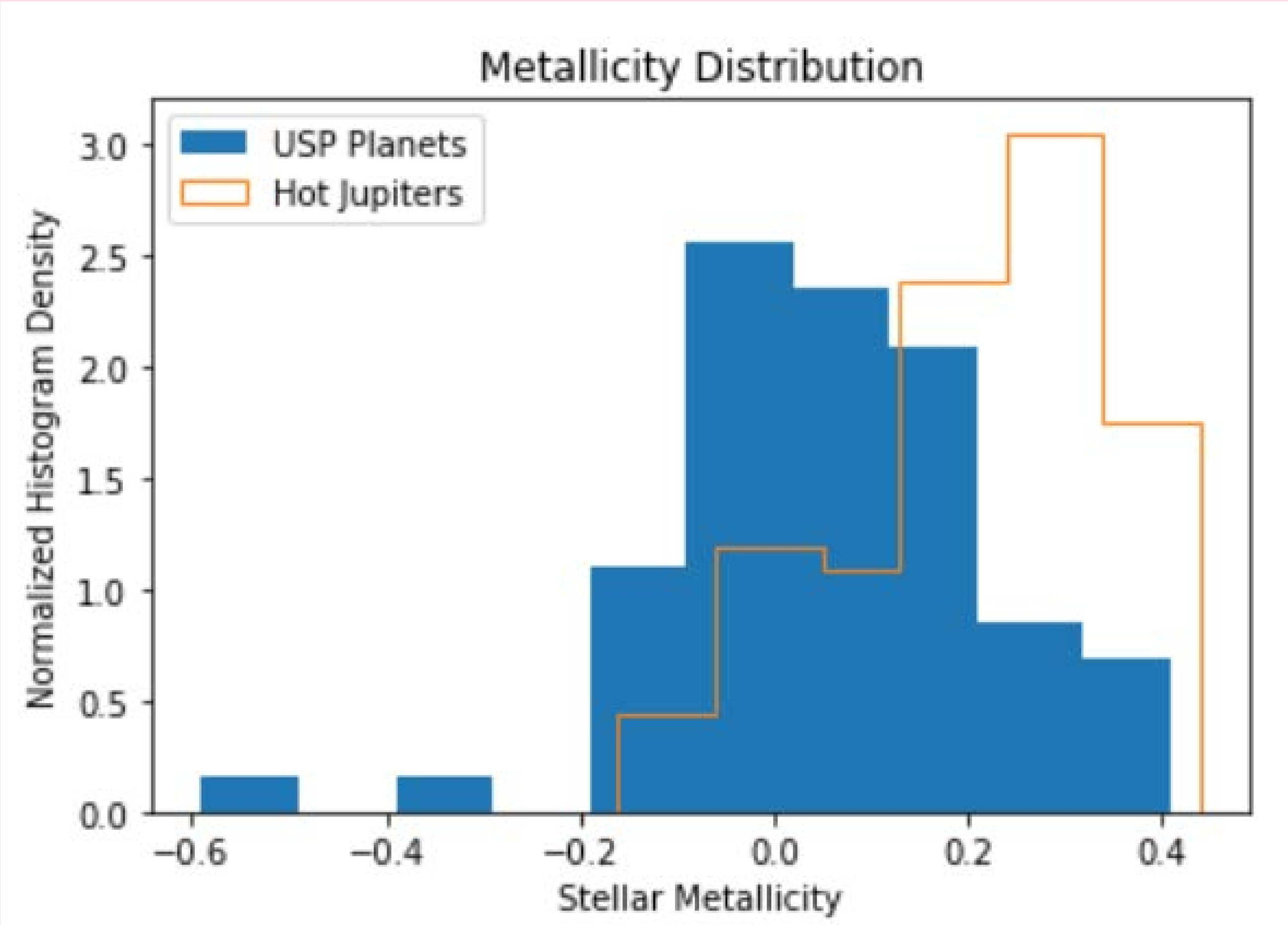

Figure 1. Metallicity distributions of the two statistical samples. The Hot Jupiter hosts have a different metallicity distribution than the hosts of USP planets. [2]

4. Bootstrap Resampling

- Bootstrap resampling is a type of Monte Carlo simulation that generates a synthetic data set based on given nominal data sets and uncertainties.
- The algorithm randomly generates a value within the upper and lower uncertainty, and adds it to each of the nominal data points, thus creating a new, very similar, data set.
- I performed bootstrap resampling 1000 times on the Hot Jupiter and USP host metallicities to ensure that Winn's conclusions were not specific to the exact numbers in their data.

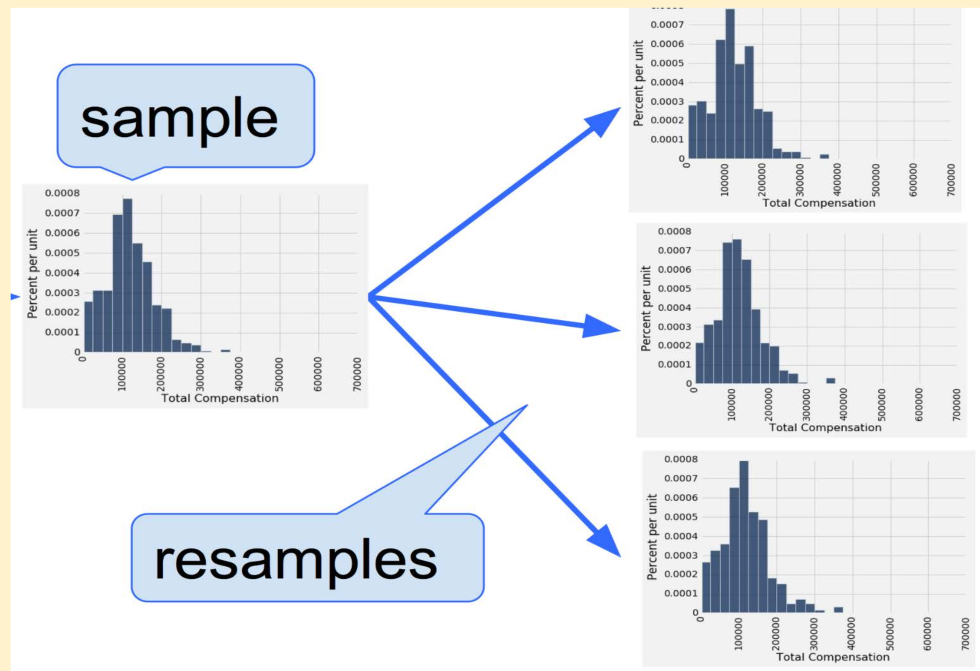

Figure 2: Example of bootstrap resampling. Synthetic data sets, similar to the original data, are generated based on random values within the upper and lower uncertainties. Credit: The Jupyter Book Community

5. Kolmogorov-Smirnov Test

- The KS Test is very similar to the t-test, but better for this data that shows no patterns. The resulting P value will tell you how similar the two data sets are. If P is small, reject the null hypothesis.[4]
- After every bootstrap resample of the Hot Jupiters and USPs, I performed a 2-sample KS test on them, resulting in 1000 different P values to plot as a histogram.
- Winn et al. concluded a P value of 0.0003. Fig 3 shows that the median P value is close to Winn's.[2]

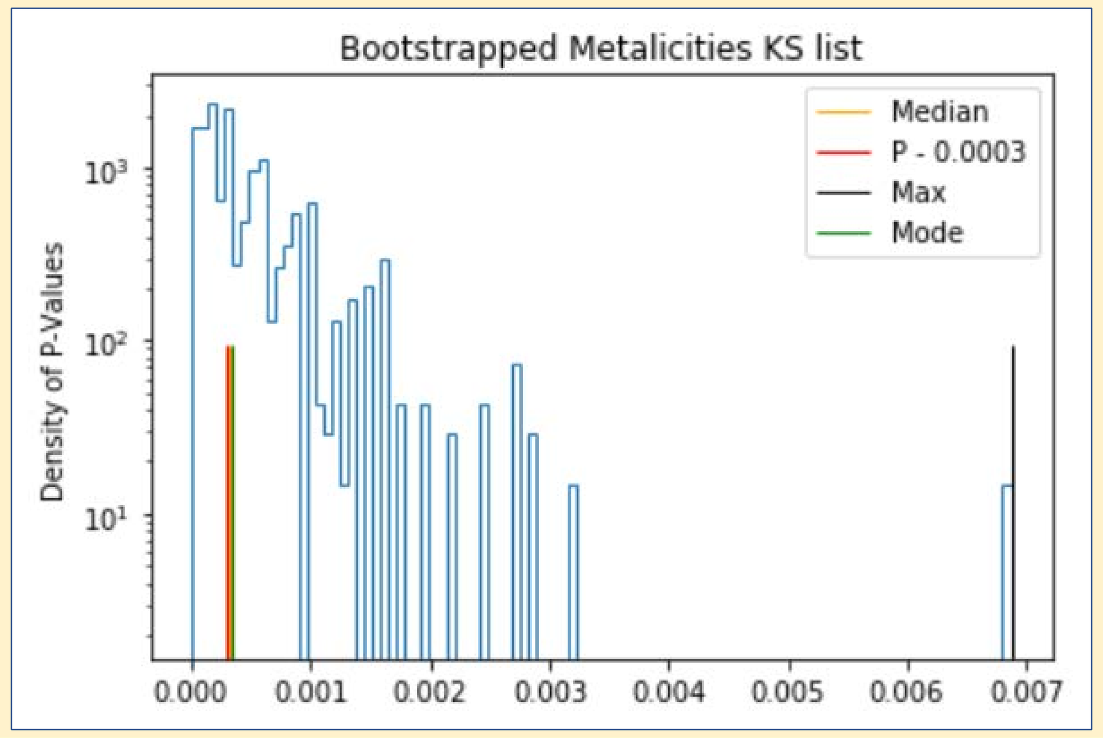

Figure 3: The resulting normalized histogram of 1000 P values, each from a different resampled data set.

6. Preliminary Results

- Another way we tested the data for similarity was to incrementally replace random USP metallicity values with random hot Jupiter metallicity values, then resample and perform KS tests as previously stated.[1]

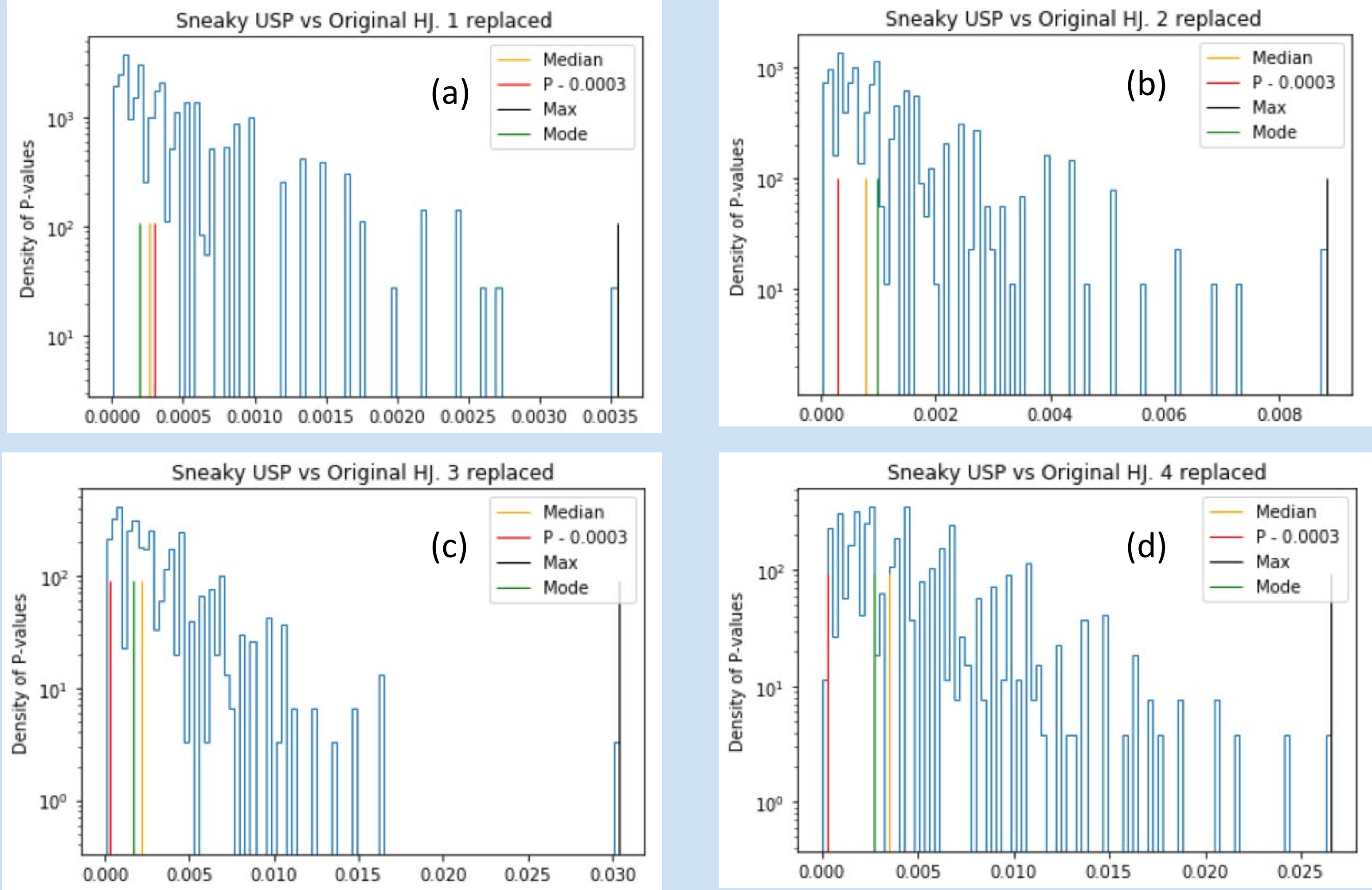

Figure 4: Resulting histograms of 1000 P values after incrementally replacing USP metallicities with HJ metallicities, then resampling. (a) 1 replacement. (b) 2 replacements. (c) 3 replacements. (d) 4 replacements.

- If the populations are the same, the mean of the P values will move closer to 1 as we increase the number of USP metallicities replaced with Hot Jupiter metallicities. They appear to be doing so, which suggests that the populations are the same, disproving Winn's conclusion [2], and reaffirming the current hypothesis of USP planet formation.

7. What's next?

- Use Bayesian Blocks for more accurate histograms
- Compare bootstrapped USPs to other bootstrapped USPs to evaluate intrinsic statistical skewing.
- Repeat process using statistical tests such as Anderson-Darling, and Shapiro-Wilk tests that could be better suited for the data.

References

[1] B. Jackson, private communication
[2] J. Winn et al. (August 2017), *"Absence of a Metallicity Effect for Ultra-short-period Planets"*
[3] J. Winn et al. (January 2019), *"Kepler-78 and the Ultra-Short Period Planets"*
[4] College of Saint Benedict and Saint John University, *"Kolmogorov-Smirnov Test"*, http://www.physics.csbsju.edu/stats/KS-test.html
[5] B. Jackson (2016), *"Unstable Roche-Lobe Overflow of Gaseous Planets"*