2024 Exoplanet Research

Results Under My Internship with Dr. Jiang

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Exoplanets and Exoplanet Classification

Ongoing effort to categorize and study newly-discovered exoplanets in the NASA exoplanet archive.

- Improve theoretical models.

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$$T_{surf,ave} = kT_{\odot}(1-A)^{0.25}(\frac{R_{\odot}}{2d})^{0.5}, \tag{1}$$

where:

- d = the distance from exoplanet to its host star
- $T_{\odot}$ = the host star's effective surface temperature
- $R_{\odot}$ = the host star's radius
- A the exoplanet albedo
- k the additional scaler to account for bulk atmospheric greenhouse gas

Categorizing Exoplanets

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- **Gas giants:**
  - radius compared to Earth: ≥ 9.14 times

First Look at the Figure

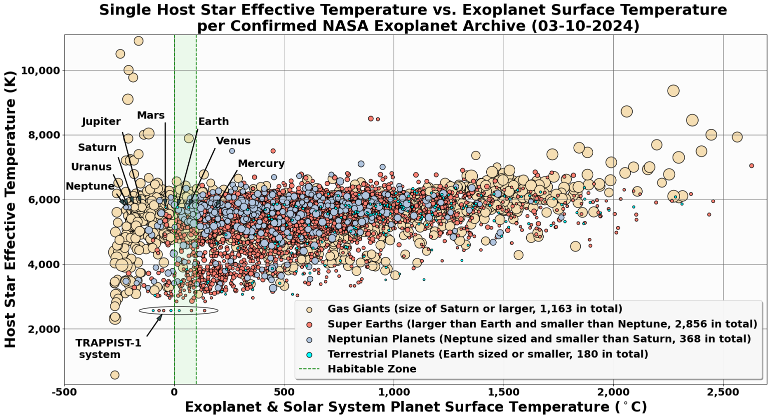
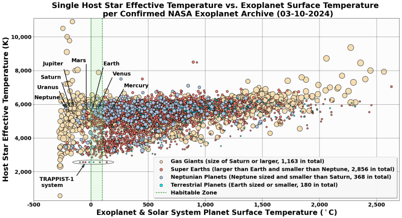


Figure: Single Host Star Effective Temperature vs. Exoplanet and Earth Surface Temperature. Positions of the Earth and all other solar system planets labeled for reference, along with habitable zone range indicated by green dashed lines. The size of each point represents the relative size of the exoplanet.

Included Items



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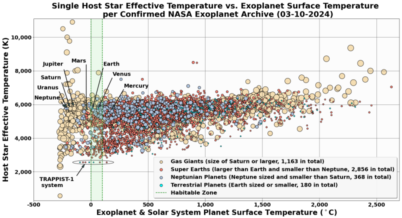

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  - Temperatures, sizes, and general data from official NASA figures
  - Venus.

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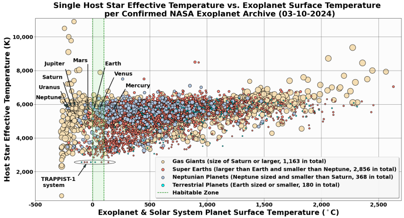

- All of the solar system planets:
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  - Venus.
- TRAPPIST-1 star system:
  - 7 terrestrial, Earth-sized planets discovered orbiting the red dwarf star TRAPPIST-1
  - 3 confirmed habitable by NASA, 2 by our calculations

The Numbers

Of the 4567 total data points...

Exoplanet HZ Status:

- **Too hot:** 3942
- **Too cold:** 399
- **In HZ:** 226

Planetary type:

- **Terrestrial planets:** 180
- **Super-Earths:** 2856
- **Neptunian planets:** 368
- **Gas giants:** 1163

The Venus Conundrum

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2.6 Assumptions and Limitations

Our analysis was underpinned by several assumptions, notably adopting Earth's albedo ($A = 0.306$) as a baseline for exoplanets as well as accounting for the atmospheric greenhouse gas effect through the bulk temperature factor ($k = 1.13$), again using Earth as the standard. Recognizing that our empirical relationships, based on a large but nonetheless limited dataset, might introduce certain biases, we were careful to frame our findings within these constraints.

Venus in the Habitable Zone

- Venus's atmosphere is extremely heavy, which means that its k value should have been much higher than the Earth standard we used across the solar system $\rightarrow k = 3.17$

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- But in general, we weren't too off:

MERCURY	0	188.396908
VENUS	1	64.527543
EARTH	2	13.975212
MARS	3	-40.566530
JUPITER	4	-147.285665
SATURN	5	-180.398576
URANUS	6	-207.607572
NEPTUNE	7	-220.789400

^^ FORMULA RESULTS ^^

- Mercury: 333°F (167°C)
- Venus: 867°F (464°C)
- Earth: 59°F (15°C)
- Mars: Minus 85°F (-65°C)
- Jupiter: Minus 166°F (-110°C)
- Saturn: Minus 220°F (-140°C)
- Uranus: Minus 320°F (-195°C)
- Neptune: Minus 330°F (-200°C)
- Dwarf Planet Pluto: Minus 375°F (-225°C)

^^ NASA DATA ^^

The Venus Paragraph

methodologies to discover and characterize exoplanets within the HZ. Future missions equipped with direct imaging capabilities and improved sensitivity are essential to identifying and studying Earth-like planets in habitable zones of a broader range of stellar types.

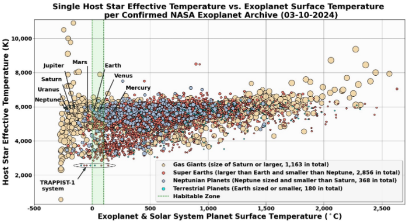

Figure 10: Single Host Star Effective Temperature vs. Exoplanet & Earth Surface Temperature. This scatter plot shows the effective temperature of single host stars versus the surface temperature of their corresponding exoplanets. Exoplanets are grouped by types: Gas Giants (size of Saturn or larger), Neptunian Planets (Neptune-sized, smaller than Saturn), Super-Earths (larger than Earth, smaller than Neptune), and Terrestrial Planets (Earth-sized or smaller). The positions of the Earth and all other solar system planets are labeled for reference, along with the habitable zone (HZ) range indicated by green dashed lines. The size of each point represents the relative size of the exoplanet. Note: The seven known planets of the TRAPPIST-1 system are indicated at lower left.

This figure also brings attention to assumption limitations introduced earlier in this paper. For the planets in our solar system, surface temperatures calculated with Equation (1) generally align with known mean temperatures (https://science.nasa.gov/resource/solar-system-temperatures/) with a 6-37% difference. However, Venus is an exception. Although its surface is too hot for life as we know it, Equation (1) flags the planet as within the habitable zone. This discrepancy arises from the assumption of a standardized bulk temperature factor (k=1.13k) based on Earth's values when accounting for the atmospheric greenhouse effect. In reality, Venus has a very thick atmosphere composed primarily of CO_2, trapping heat and resulting in a much higher bulk temperature factor (k=3.17). This limitation is discussed earlier in section 2.6. Bracketing the inner Solar System-based atmospheric greenhouse assumption, this on the cooler end, is Mars. While the atmosphere of Mars is also predominantly composed of CO_2, it is far less dense and accordingly much less capable of trapping solar radiation. The particular exception of Venus indicates that variations in the atmospheric greenhouse effect will need to be further considered to better determine exoplanet surface temperatures.

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Early Exploration

Early things I explored that produced *interesting* results that I haven't looked very deeply into.

- Early studying of the relationship between different exoplanet features and the number of exoplanets that share that trait.

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- Early studying of the relationship between different exoplanet features and the number of exoplanets that share that trait.
- Building basic machine learning models (Decision Tree) to help identify patterns in discoveries.
- Stellar age and orbital period affecting exoplanet habitability.

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Decision Tree Classifier Results

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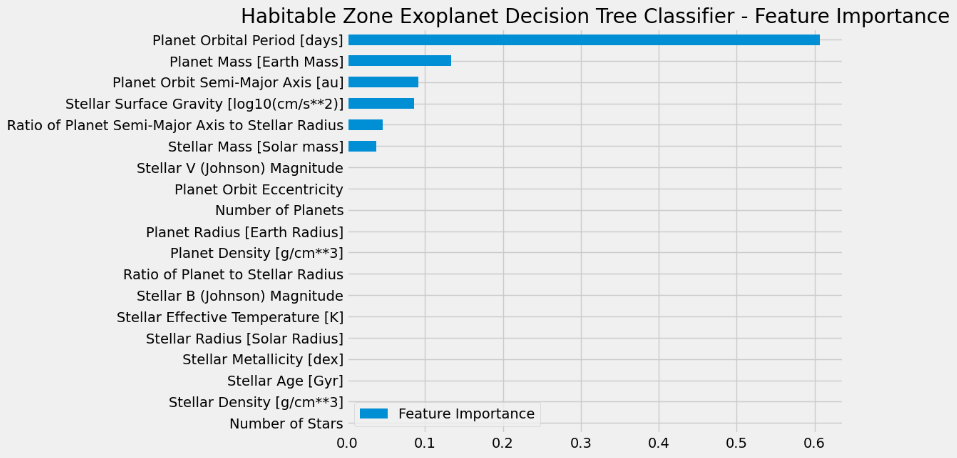
Background Information

Results on Habitability

Further Research Opportunities



Decision Tree Classifier Results


```
Decision Tree Classifier Accuracy:  0.8877551020408163

Decision Tree Classification Report :
              precision    recall  f1-score   support

         0.0       0.91      0.96      0.94        83
         1.0       0.70      0.47      0.56        15

    accuracy                           0.89        98
   macro avg       0.80      0.72      0.75        98
weighted avg       0.88      0.89      0.88        98
```

The Future

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- Focus on possibly more **machine-learning things** $\rightarrow$ using larger datasets (current model has only 213 data points for training)