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Comparing Exoplanets to Earth Based upon Habitability

By

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For generations now, humanity has yearned for space exploration. Throughout history, exploration has led to the eventual colonization of areas that present humanity with the opportunity to learn, grow, and thrive. It is only sufficient, that now that the majority of the world rests under our domain, that we would yearn for continued growth. Inside our own solar system, key bodies have proven feasible for human expansion but each comes with their own hardships. Our research is focused on exoplanets, stellar bodies outside our own solar system. While the means to reach them are currently out of our technological reach, the ability to understand them is not. Our goal is to determine which exoplanets that have been found to date, have the ability to sustain human life with our current physics bounded requirements.

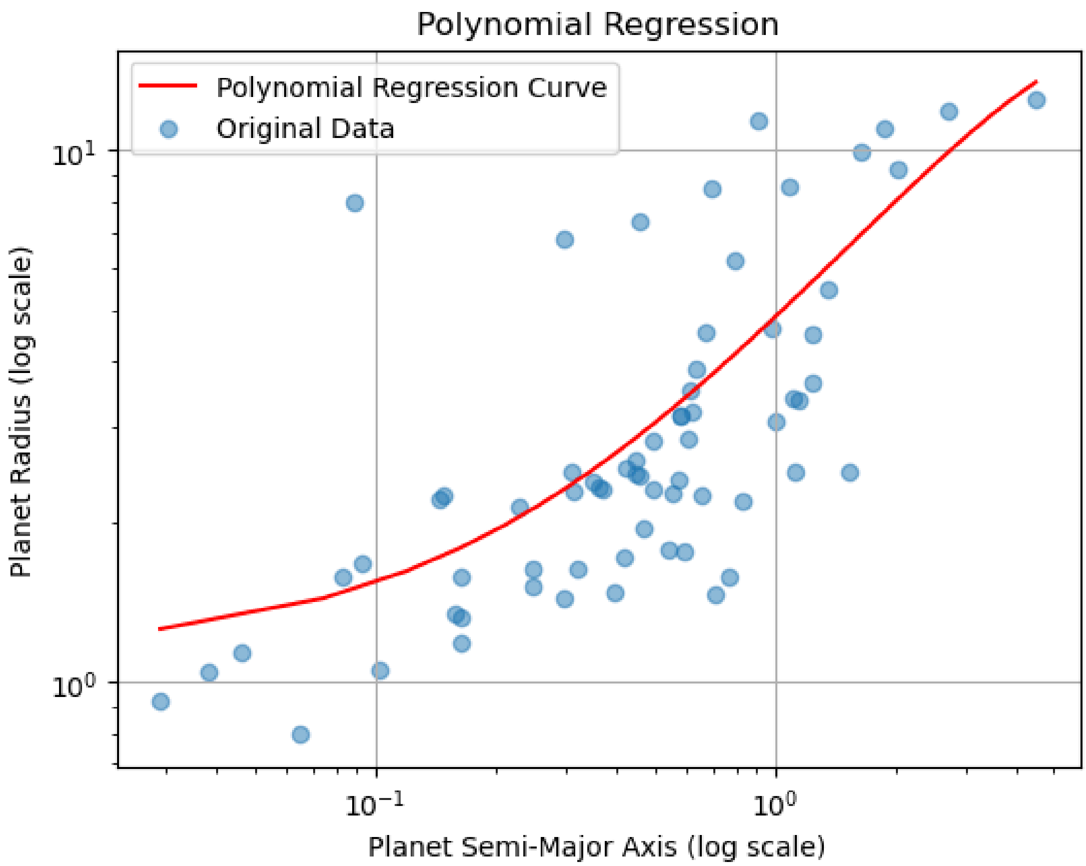
An understanding of the Goldilocks zone is a key requirement for our project.The Goldilocks zone, also known as the habitable zone, is a region around a star where conditions are just right for the existence of liquid water on the surface of terrestrial planets. This zone is neither too close to the star, where water would evaporate, nor too far, where water would freeze. Within the Goldilocks zone, temperatures are optimal for the presence of liquid water, a crucial ingredient for life as we know it.

Simultaneously, another major factor is a planet's surface gravity. This is important due to the limitations of the human circulatory system. Any body with five times the amount of gravity as Earth will prevent our heart from being able to pump blood to our vital organs. As such we are using a marker of habitability as any planet with less than four times Earth's surface gravity.

This observational data has been collected over the past 30 years by NASA, all archived in one place. This data has been collected in multiple areas around the earth and space, primarily by the Kepler space telescope and more recently by the Transiting Exoplanet Survey Satellite. Observing exoplanets is super useful to astronomers because it allows them to learn about how other solar systems behave and compare that to our current understanding of our own solar system. We hope to answer which exoplanets that we know of have the best chance for being habitable for life and humanities expansion through the stars.

The data we used is directly from the NASA exoplanet archive. We selected the parameters we wanted and downloaded all of those parameters into a csv file. Currently, the data that NASA has, accounts for roughly 36,000 data collections on exoplanets. It was easy to determine that there were a vast array of duplicates in the data. In such cases, the means of their data was calculated to determine an appropriate average across multiple collections. Now with around 5,800 exo-planets, it became necessary to apply our filters for equilibrium temperature (measure of our Goldilocks zone) and planetary surface gravity. Using averages of stellar temperatures and the distance a planet is from its star, equilibrium temperatures that were missing were able to be approximated. We were then able to filter the planets out that were either too hot or too cold to support human life.

Next was to determine planetary surface gravity. However, to do that, one needs both mass and density. With only 212 planets fulfilling the necessary equilibrium temperature requirements, and many of them missing either planetary radius or planetary mass it became necessary to interpolate the data based upon the trends in their correlations. While this was able to be done with a polynomial regression of degree two for planetary radius, multiple forms of regression models failed to plot for planetary mass. However, we were still able to acquire 164 planets and calculate their respective surface gravities.



After filtering out surface gravities above four times the amount of Earth's surface gravity, we were left with 48 planets. This data was then fit through an OLS regression and 95% confidence interval to determine a comparison to Earth's habitability. The remaining 48 planets were then ranked in accordance to how closely they compare to Earth.

	index	Planet Name	Earth Similarity	Equilibrium Temperature	Surface Gravity	Planet Mass	Planet Radius
0	14	Teegarden's Star c	79.032492	209.000000	6.078773	1.080000	1.319415
1	20	55 Cnc f	76.192468	251.548888	27.925416	47.391256	4.077808
2	32	HD 10180 g	75.132223	225.614301	5.590494	22.332580	6.256363
3	12	Proxima Cen b	72.382194	225.000000	6.138345	1.113333	1.333105
4	43	HD 11964 b	69.239590	182.838570	15.458893	194.436152	11.101377
5	24	GJ 273 b	58.746824	260.907422	12.551672	2.890000	1.502020
6	22	GJ 1061 d	55.660937	219.786980	8.746109	1.640000	1.355477
7	26	GJ 3293 d	52.785614	215.228739	20.537676	7.600000	1.904183
8	9	HD 86226 b	41.192672	176.000000	30.219996	304.046167	9.928876
9	3	GJ 514 b	22.726247	202.000000	6.617147	5.200000	2.774878
10	6	HD 192310 c	18.441217	185.000000	7.890494	24.000000	5.459226
11	27	GJ 3323 b	16.414507	261.183877	12.243127	2.020000	1.271473
12	46	HD 126614 b	11.606181	176.115860	14.650166	117.800260	8.876247
13	45	HD 126525 b	8.814867	178.056952	13.033404	75.325710	7.525238
14	10	HN Lib b	6.645332	234.000000	18.498055	5.460000	1.700634
15	52	HD 134606 d	NaN	186.386475	7.159784	44.800000	7.830087

To calculate these ground temperatures we are making a few assumptions, a few of them were at the advice of an Atmospheres professor, Nick Schneider. We followed the steps from one of the homework we did in class but on a much larger scale, including calculating the uncertainties of some planets along the way. The calculated Ground Temperatures assume that the exoplanets have a similar amount of water as earth and that the greenhouse gas effect can be approximated to be just from water. These assumptions are useful because in order for a planet to be inhabitable to life similar to earth, as we know it the planet would need to have a good amount of water.

[10]:

	Planet Name	Saturation Pressure	Optical Depth	Ground Temperature [K]	Ground Temperature Upper Bound [K]	Ground Temperature Lower Bound [K]	Equilibrium Temperature [K]	Equilibrium Temperature Upper Unc. [K]	Equilibrium Temperature Lower Unc. [K]
33375	Proxima Cen b	0.000040	0.001648	216.088910	406.727363	117.000000	216.0	91.0	-99.0
26667	Kepler-539 c	0.001340	0.055845	256.460532	304.889446	226.269811	253.0	27.0	-27.0
33860	TOI-2257 b	0.001706	0.071066	260.431825	463.026220	239.993920	256.0	61.0	-17.0
1861	HD 109286 b	0.002158	0.089933	264.636494	273.928681	256.460532	259.0	6.0	-6.0
14043	Kepler-1593 b	0.002332	0.097159	266.097440	315.717090	242.199257	260.0	24.0	-19.0
2964	HD 27969 b	0.002518	0.104902	267.590983	286.735035	252.683384	261.0	11.0	-11.0
28967	Kepler-705 b	0.003402	0.141738	273.928681	321.627282	245.579821	265.0	21.0	-21.0
25513	Kepler-452 b	0.003402	0.141738	273.928681	304.889446	255.181699	265.0	15.0	-13.0
4936	K2-332 b	0.003662	0.152598	275.613876	284.750166	263.206372	266.0	5.0	-8.0
14652	Kepler-1652 b	0.004238	0.176585	279.119763	352.737266	250.256085	268.0	27.0	-20.0
13511	Kepler-1544 b	0.004555	0.189802	280.944797	348.897526	251.461436	269.0	25.0	-20.0
34208	TOI-700 d	0.004555	0.189802	280.944797	297.573144	267.590983	269.0	8.0	-8.0
27923	Kepler-62 e	0.004894	0.203901	282.820846	318.629233	259.084174	270.0	15.0	-15.0
32772	LP 890-9 c	0.005639	0.234944	286.735035	290.880611	282.820846	272.0	2.0	-2.0
27725	Kepler-61 b	0.006048	0.252000	288.777749	321.627282	266.097440	273.0	13.0	-13.0
21561	Kepler-296 f	0.006484	0.270155	290.880611	331.154120	264.636494	274.0	15.0	-15.0
34339	Teegarden's Star b	0.007964	0.331852	297.573144	310.143040	286.735035	277.0	5.0	-5.0
2589	HD 191939 g	0.008521	0.355052	299.939603	315.717090	286.735035	278.0	6.0	-6.0
18997	Kepler-22 b	0.009113	0.379691	302.377633	312.889001	293.045930	279.0	4.0	-4.0
33347	PH2 b	0.010406	0.433595	307.477208	327.888088	290.880611	281.0	7.0	-7.0
4842	K2-3 d	0.011113	0.463025	310.143040	401.662295	263.206372	282.0	24.0	-24.0
14656	Kepler-1653 b	0.012655	0.527281	315.717090	417.167295	270.683253	284.0	25.0	-21.0
5501	K2-9 b	0.012655	0.527281	315.717090	364.855713	282.820846	284.0	14.0	-14.0
33866	TOI-2285 b	0.012655	0.527281	315.717090	334.512599	299.939603	284.0	6.0	-6.0
13576	Kepler-155 c	0.014385	0.599364	321.627282	566.162654	246.729061	286.0	46.0	-41.0
34306	TRAPPIST-1 d	0.016322	0.680090	327.888088	348.897526	310.143040	288.0	6.0	-6.0
11885	Kepler-1410 b	0.018488	0.770345	334.512599	428.019250	275.613876	290.0	21.0	-24.0
11479	Kepler-138 e	0.020906	0.871089	341.512407	360.715607	321.627282	292.0	5.0	-6.0
4042	K2-133 e	0.026599	1.108291	356.676360	401.662295	321.627282	296.0	10.0	-10.0
33804	TOI-2095 c	0.028221	1.175875	360.715607	396.700600	331.154120	297.0	8.0	-8.0
27029	Kepler-560 b	0.029930	1.247085	364.855713	481.891025	275.613876	298.0	22.0	-32.0
12386	Kepler-1455 b	0.029930	1.247085	364.855713	522.287471	282.820846	298.0	28.0	-28.0
506	GJ 1132 c	0.033625	1.401056	373.440845	396.700600	352.737266	300.0	5.0	-5.0
14485	Kepler-1638 b	0.042246	1.760266	391.842291	655.359426	288.777749	304.0	39.0	-31.0
19569	Kepler-235 e	0.047248	1.968647	401.662295	551.156595	307.477208	306.0	24.0	-25.0
14598	Kepler-1649 b	0.049939	2.080776	406.727363	573.807196	307.477208	307.0	26.0	-26.0
642	GJ 414 A b	0.055729	2.322057	417.167295	655.359426	293.045930	309.0	34.0	-34.0
4915	K2-323 b	0.089760	3.739991	469.214573	646.791018	293.045930	318.0	24.0	-43.0
13107	Kepler-1512 b	0.109993	4.583057	494.964303	708.668816	310.143040	322.0	27.0	-40.0
14173	Kepler-1606 b	0.121532	5.063842	508.430942	736.534820	341.512407	324.0	28.0	-32.0
28797	Kepler-69 c	0.127689	5.320379	515.310686	814.750457	364.855713	325.0	35.0	-27.0
2380	HD 169830 b	0.323054	13.460591	672.768430	1430.269555	304.889446	345.0	65.0	-65.0
568	GJ 3021 b	0.400735	16.697287	717.868200	1903.790622	266.097440	350.0	90.0	-90.0

To predict the planetary radius, a polynomial regression line was made based upon the correlation between planetary radius and planetary semi-major axis. To predict the ground temperatures of exoplanets, we used a mixture of Error analysis and Confidence intervals along with some assumptions about the planets to output a range of ground temperatures these planets could have. A big assumption

With 95% certainty we can say that these planets have a habitability comparison to Earth as rated above. While this does not answer the needed questions of whether the planet has a viable atmosphere or whether liquid water exists on the planet, from a temperature and gravity based requirement for human habitation these planets could support human presence. While our analysis provides compelling evidence suggesting that these planets exhibit characteristics akin to Earth's surface gravity and equilibrium temperature, it's crucial to acknowledge the limitations of our methodology.

Firstly, our assessment solely relies on surface gravity and equilibrium temperature as proxies for habitability, overlooking other critical factors such as atmospheric composition, presence of liquid water, and geological stability. The absence of these factors in our analysis underscores the need for comprehensive studies to ascertain the true habitability potential of these exoplanets. While our analysis offers insights into the comparative similarity of these exoplanets to Earth, it's imperative to approach the concept of habitability with caution. Habitability is a multifaceted concept that encompasses a myriad of environmental, geological, and astrophysical considerations. Thus, while our findings suggest potential habitability based on temperature and gravity, further investigation is warranted to validate these assertions. Our study serves as a foundational step towards identifying promising candidates for future exploration and colonization efforts. By highlighting exoplanets that exhibit Earth-like conditions in terms of temperature and gravity, we provide valuable guidance for prioritizing targets for further observation and research.

In summary, while our analysis provides compelling evidence suggesting habitability comparisons to Earth based on surface gravity and equilibrium temperature, it's essential to recognize the inherent uncertainties and complexities involved in assessing habitability beyond our home planet. Continued research and exploration are essential to unraveling the mysteries of exoplanetary habitability and advancing our understanding of the universe's potential to harbor life.

One way to extend this research project is to incorporate atmospheric data of exoplanets and attempt to approximate the effect of the greenhouse gasses that exist in their atmospheres. This data is less available but can be calculated during transiting exoplanets observations. The NASA exoplanet archive has an Atmospheric Spectroscopy dataset and along with some other data about how each gas works towards the greenhouse effect. This would allow us to make better assumptions about the ground temperatures of each planet instead of assuming aspects about each planet's atmosphere to be the same(heavily dominated by water similar to earth).

Our results stand on a few assumptions that could easily be false, but when working with limited exoplanet data it is difficult to make any claims without any claims that could be faulty. For example, when we interpolate planetary radius, the data we are basing this on could easily have a sampling bias since some types of planets are much easier to detect with the methods predominantly used than others. Additionally we are making some assumptions about the atmospheres that would likely turn out to be wrong but they are useful to create a ballpark guess. Additionally, while we do have a lot of data about exoplanets, we do not have true values for much of the information we seek to calculate, which hinders our ability to use certain Numerical Computation tools effectively.

This project was a fun tool to practice some of the Numerical Computation techniques we have learned throughout the semester to support the main data science techniques used to answer our questions on our data. This is similar to the true nature of Numerical Computation which is generally done not for its own sake but to support the scientific works in other areas.

GITHUB LINK:

https://github.com/brsm3129/HabitablePlanets.git

YOUTUBE LINK:

https://www.youtube.com/watch?v=IBxFImxy6Y8

Works Cited

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This research has made use of the NASA Exoplanet Archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program. https://exoplanetarchive.ipac.caltech.edu/