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Original Article

A Statistical Analysis on the Number of Earth and Jupiter Type Exoplanets Detected by the Kepler Space Telescope

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Abstract *- Exoplanets are located outside the solar system, with local star systems. The first exoplanet was detected around the pulsar PSR 1257+12, a magnetized neutron star. Exoplanetary detection techniques include radial velocity, transit spectroscopy, gravitational microlensing, etc. The widely used transit method uses the light curve of the parent star as a reference. Fluctuations are due to the exoplanet's motion in front of the star. Exoplanets are of two types - terrestrial like Earth and Mars and gas giants like Jupiter and Neptune. Launched in 2009, NASA's Kepler Space Telescope aimed to detect Earth-type exoplanets around Sun-like stars. Decommissioned in 2018, it confirmed 2741 exoplanets. This research provides a statistical analysis of the exoplanets detected by the Kepler Telescope. To this, Earth-type and Jupiter-type exoplanets are defined within ±25% of the radius of Earth or Jupiter, respectively. This study reveals that the number of Earth and Jupiter-type exoplanets detected are 341 and 94, respectively. The mean exoplanet radius is 2.84 Earth radii with an orbital period of 27.77 Earth days and a stellar radius of 1.05 solar radii. 95.4% of the confirmed exoplanets are smaller than Jupiter-type planets, suggesting a higher possibility of terrestrial exoplanets than gaseous exoplanets.*

Keywords *- Exoplanet, Earth-type, Jupiter-type, Kepler space telescope, NASA, Transit method.*

1. Introduction

Humanity's earlier ancestors appeared on planet Earth between 5 and 7 million years ago[1]. From the time that humans have looked up into the stars, the quest to discover what lies beyond has been at the forefront of every single civilization, from the Eastern regions of ancient India to European countries like Greece and England[2]. Throughout ancient science, art, and literature, the theme of space exploration has always been present. Scientists from ancient civilizations helped establish the founding blocks for modern-day research.

Since the 17th century, there has been a rapid increase in the push to understand outer space more. It began with the discovery of Jupiter's Moons, lunar craters, and phases of Venus by Galileo Galilei in 1609, which eventually led to the proof of the existence of a heliocentric model of the solar system[3]. In 1826, Heinrich Wilhelm Olbers put forward Olber's Paradox, which argued against the concept of a static universe. Between 1905 and 1915, Albert Einstein put forward his special and general theories of relativity, which proved space-time as a collective continuum and that energy density warps space-time. In 1923, Edwin Hubble discovered that the universe is expanding based on his calculations of the distances and apparent magnitude of galaxies, which led to the theory of the creation of the universe from the Big Bang. In 1961, Yuri Gagarin became the first human to journey into outer space. Neil Armstrong became the first human to step on the moon by the decade's end. In 2012, Voyager 1 became the first spacecraft to leave the heliosphere and enter interstellar space. Now, in 2023, it lies on the brink of the Artemis Missions, which would mark the return of humans to the moon and, later, the human landing on Mars in the early 2030's.[4]. Of these advancements in space technology, few come close to that of exoplanet detection.

An exoplanet is a planet outside the solar system, rotating around a local star. It may only be a singular planet or a group of planets rotating around a star in different orbits, like our solar system. The first exoplanet was detected in 1992 by radio astronomers Aleksander Wolszczan and Dale Frail, who announced the discovery of two planets orbiting the pulsar PSR 1257+12, which is a highly magnetized rotating neutron star[5]. There are multiple methods of detecting an exoplanet, with newer methods being developed as of the writing of this paper. Of the most different methods of exoplanet detection, 5 methods stand out to be the most effective. Oftentimes, different methods are used in combination to calculate multiple parameters of the exoplanet. The first detection method is the radial velocity method, also referred to as Doppler spectroscopy [6]. As a result of the gravitational influence of an exoplanet on its host star, the star experiences a slight wobble, which either periodically moves it towards or away from the Earth. This movement of the star is detected by a corresponding shift in the spectral lines of the electromagnetic waves. When the planet moves towards the Earth, the spectral lines move towards the blue end of the electromagnetic spectrum, classified as blueshift. When the planet moves away from the Earth, the spectral lines move towards the red end of the electromagnetic spectrum, classified as redshift. It allows astronomers to detect the planet, its minimum mass, and the inclination of its orbit.

The second method of detection is known as transit photometry[7]. When a star is detected, it will tend to emit roughly the same amount of light over a long period of time. If an exoplanet were to pass in front of that star, it would mean that some of the light emitted by the star would be blocked.

When a graph measuring the star's emitted light intensity is plotted, the movement of a planet in front of the star will result in a dip in the light curve. These changes are periodic; the planet will cause the same dip in the light curve over multiple detections for the same amount of time. This method helps to determine the planet's diameter and even its atmospheric composition. Transit photometry is generally regarded as the most reliable method of exoplanet detection to date.

The third method is known as direct imaging [8]. As the name suggests, the method involves capturing images of an exoplanet directly by detecting the infrared waves emitted by the exoplanet. The fourth method of detection is known as gravitational microlensing. This method, which works in accordance with Einstein's Theory of General Relativity[9][10], measures the bending of light and a change in its focus as caused by the gravitational influence of the exoplanet. It is very useful to detect exoplanets that are at especially large distances away from our solar system.

The fifth method of detection is known as Pulsar Timings[11]. This method and the radial velocity method were used to detect the first exoplanet in 1992. This method works solely for systems that have a rapidly rotating neutron star, otherwise known as a pulsar. As a neutron star rotates, it emits regular and very accurate pulses of electromagnetic waves. Any periodic variations in these pulses hint at the back-and-forth movement of a pulsar. This movement suggests that the pulsar is moving because of the influence of a planet or multiple planets orbiting it. The method can be used to calculate the orbit and the mass of orbiting exoplanets of a wide spectrum of sizes.

Many of the discoveries made in recent times have been down to scientists' ability to peer into the deepest parts of the known universe without having to travel there physically. Herein, the role of space telescopes becomes pivotal. First suggested in 1946, the first telescope was the American Orbiting Astronomical Laboratory (OAO - 2) in 1968. Space Telescopes[12], while large and expensive to build, avoid the scintillation of electromagnetic waves along with light pollution caused by Earth's atmosphere and human habitat when they make observations and calculations. These advantages have led to a plethora of breakthrough discoveries. Some of the first few notable space telescopes include Uhuru (X-Ray Orbital Observatory), SAS - 2 (Gamma Ray Orbital Observatory), and the IRAS (Infrared Orbital Observatory) launched in 1970, 1972, and 1983. In 1990, the Hubble Space Telescope [13] was launched into a low Earth orbit.

One of NASA's four 'Great Observatories,' the Hubble Telescope, makes observations in the visible light and the near ultraviolet spectrum. Using it, scientists have been able to put down an estimate of the age of the universe, detecting supermassive black holes, the rate of expansion of the universe, and so on. As the technological barriers broke, other telescopes serving different purposes were sent. As of 2023, there are more than 20 space telescopes orbiting the Earth[14]. Other than the Hubble Space Telescope, these include the Event Horizon Telescope, which was used to produce the first direct image of a black hole and its vicinity in 2019, and the James Webb Telescope, which aims to use its advanced infrared detection and integrated apparatus to study the formation of the earliest galaxies and the stars forming planetary systems[15]. With reference to this paper, the Kepler Telescope is of particular importance[16]. The telescope, launched in 2009, specialized in detecting and performing calculations on exoplanets and their host stars. As of November 15, 2018, the last day of its commission before it was launched on a safe orbit away from Earth, it has observed 530,506 stars and detected 2,778 confirmed exoplanets.

2. Methodology

2.1. Aim of the Study

This study aims to provide a statistical analysis of Earth-sized and Jupiter-sized planets as detected by the Kepler Space Telescope. It also aims to provide possible explanations for the outcome of the statistical data with special emphasis on discovering terrestrial planets that could potentially be habitable and look into the future implications of the telescope's discoveries. The research gap that this paper aims to address is to succinctly provide a detailed analysis of exoplanets and their possible characteristics using commonly used measures of statistical central tendency along with scatterplots and histograms that are easy to understand to the common public.

2.2. Research Design

This research study primarily uses primary source information from NASA's Exoplanet Archive to calculate the number of Earth and Jupiter size exoplanets detected by the Kepler Space Telescope. It uses secondary source information from peer-reviewed research papers available on Google Scholar as the information needed to draw analysis based on the conclusions presented from the available data[17]. A margin must be established to categorize them based on the planet's radius to perform statistical analysis on detecting Earth and Jupiter-sized planets. For the purposes of this research paper, the error margin is set to ± 25% of the radii of Earth and Jupiter.

2.3. Hypothesis

2.3.1. Null Hypothesis (Ho) 1

There are more Earth-sized planets compared to Jupiter-sized planets.

2.3.2. Alternate Hypothesis (H1) 1

There are most Jupiter-sized planets compared to Earth-sized planets.

2.3.3. Null Hypothesis (Ho) 2

Most of the exoplanets detected by the Kepler Telescope fall into the parameter of being within ±25% of the radius of either Earth radius.

2.3.4. Alternate Hypothesis (H1) 2

Most of the exoplanets detected by the Kepler Telescope do not fall into the parameter of being within ±25% of the radius of Earth radius.

2.4. Data Collection Procedure

The NASA Exoplanet Archive was used as the source of the statistical data[18]. The Kepler KOI Cumulative Table provided the required data in the NASA Exoplanet Archive. All the data was downloaded in a csv. Format. Python, with PyCharm as its Integrated Development Environment, was used to process the data. In PyCharm, the data was used to plot scatter plots histograms and calculate measurements of central tendency[19]. Importantly, the number of Earth-sized and Jupiter-sized planets under the given parameter was calculated. The number of exoplanets that did not fall into the given criteria was also calculated and displayed. The number of exoplanets that had a radius less than Jupiter was also calculated, as they had the potential to be terrestrial planets. This is further discussed in the Results section.

3. Results

To perform an analysis of the number of Earth and Jupiter-sized planets, the variables that have been taken into consideration must be defined. The most important variable is the Planetary Radius. It measures the radius of any detected exoplanet in terms of Earth's Radii. Earth's radius is taken to be 1, and Jupiter's radius is taken to be 11.2 Earth Radii[20]. In Earth days, the Orbital Period measures the time it takes for an exoplanet to rotate around its host star. Earth has an orbital period of 365.265 days, while Jupiter has an orbital period of about 12 Earth years (4,333 Earth days)[21]. The Transit Duration refers to the amount of time that an exoplanet partially or fully obscures an exoplanet in the line of sight of its observer (which is, of course, Earth)[22].

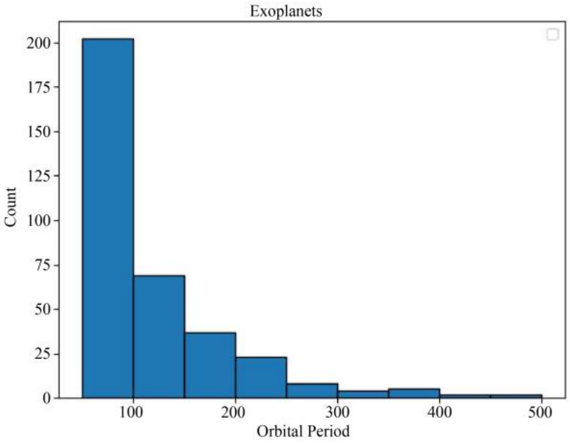

Fig. 1 Orbital period histogram

Before the results are discussed, it is important to look over the measurements of central tendency as they prove crucial to analysis that can be later drawn. All measurements have been made in Python. The measure of central tendency is the mean, median, and standard deviation(See appendix and refer Code 1):

The results of the calculations are shown in Table 1:

Table. 1. Mean, median, and standard deviation calculations of planetary radius, orbital period, stellar radius, and transit duration

S. No.	Variable	Mean	Median	Standard Deviation
1	Planetary Radius (Earth Radii)	2.84	2.15	3.36
2	Orbital Period (Days)	27.77	11.32	56.26
3	Stellar Radius (Solar Radii)	1.05	0.96	0.61
4	Transit Duration (Hours)	4.23	3.48	2.71

A comparison of the two measures of central tendency with the represented histograms provides evidence for the natural tendencies of exoplanets as detected by the Kepler Telescope. As calculated in Table 1, the mean radius of exoplanets (in terms of Earth radii) is 2.8, which is outside of the upper bound of the parameter required to classify it as an Earth-sized planet (1.25 Earth Radii) and lower than the lower bound of the parameter required to classify it as a Jupiter sized planet (8.4 Earth Radii). This shows that most planets lay in the region between the parameter set for them to either classify as an Earth-sized planet or a Jupiter-sized planet.

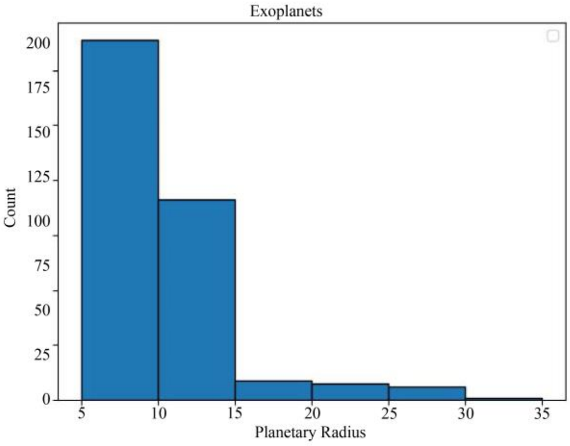

Fig. 2 Planetary radius histogram

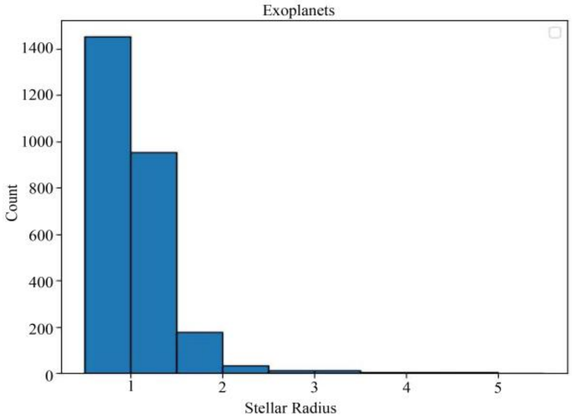

Fig. 3 Stellar radius histogram

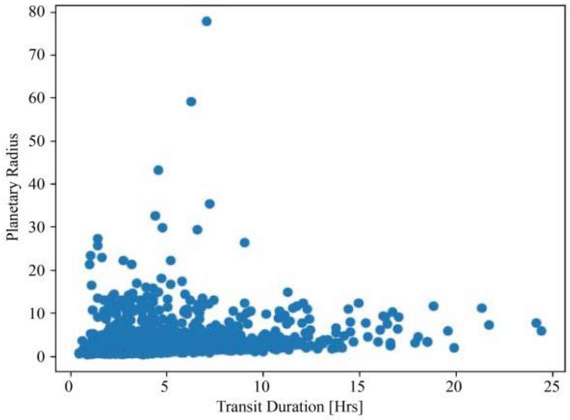

Fig. 6 Planetary radius vs Transit duration

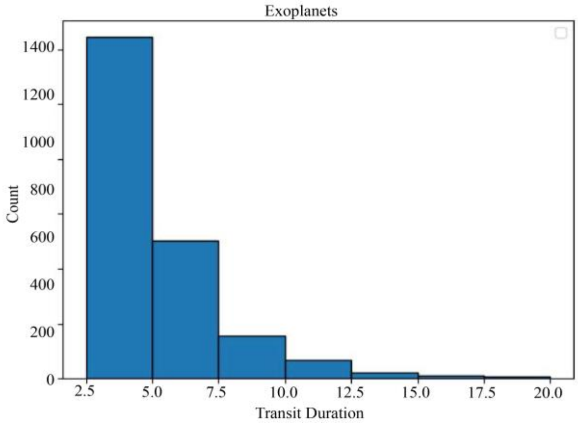

Fig. 4 Transit duration histogram

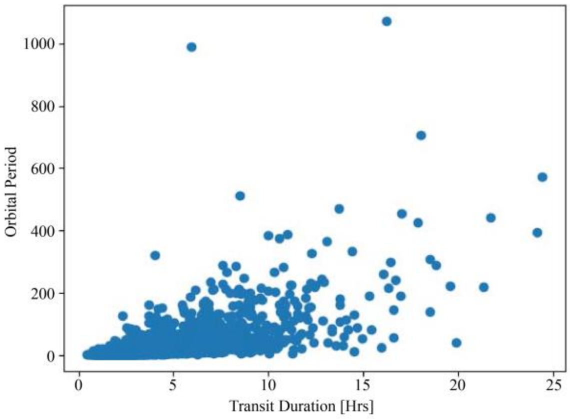

Fig. 7 Orbital period vs Transit duration

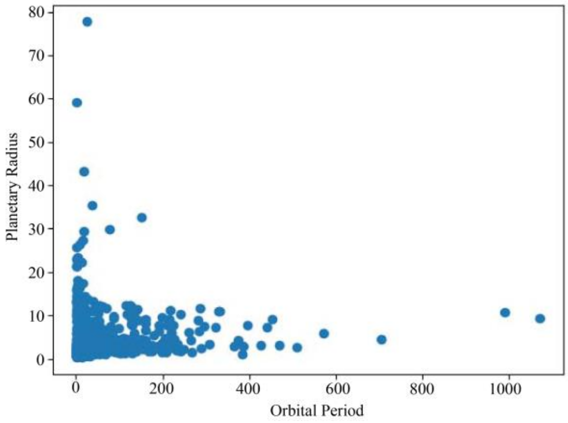

Fig. 5 Planetary radius vs Orbital period

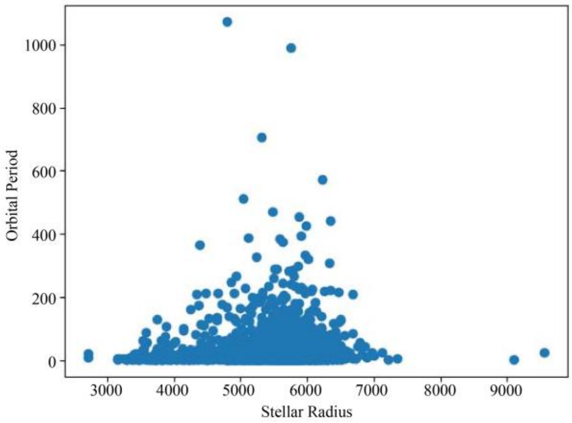

Fig. 8 Orbital period vs Stellar radius

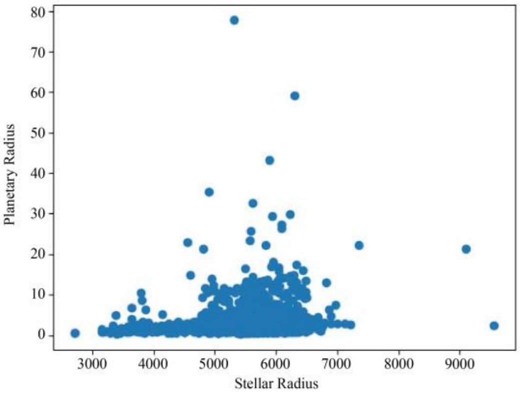

Fig. 9 Planetary radius vs Stellar radius

At the risk of the mean being affected by outliers, it is important to look at the median, which will not get skewed due to extreme values. The median supports the inference made above. The median, shown as 2.15 Earth Radii in Table 1, also shows the natural tendency of exoplanets to be in the region between the upper limit of Earth's parameter and the lower limit of Jupiter's parameter. This is further supported by Figure. 2, a histogram of the Planetary Radius, which shows the maximum concentration of exoplanets around the first bar of 2.5 Earth Radius units. The graph follows a general exponential decreasing trend. As calculated in Table 1, the mean orbital period of exoplanets (in Earth days) is 27.77, significantly lower than Earth's and Jupiter's orbital periods.

Earth has an orbital period of about 365.25 days, and Jupiter has an orbital period of 4330.59 days (Tropical orbital period)[23, 24, 25]. The median orbital period is even lower, with an orbital period of 11.32 days to 4 significant figures, as calculated in Table 1, which suggests that the mean has been affected by upper-side outliers. As seen in Figure. 1, a histogram for the Orbital Period, shows that the greatest concentration of orbital periods is between 10 and 20 days. The graph follows a general exponential decreasing trend.

Furthermore, the stellar radius paints an important picture in telling one about the size of the host stars that provide habitat to the exoplanets. Assuming the sun, a yellow main-sequence dwarf [26], to have a stellar radius of 1, the calculations in Table 1 show that the mean of the stellar radius is 1.059 solar radius to 4 significant figures. The median reflects a value very close to the mean. Table 1 shows the median value of stellar radius to be 0.961 solar radii. Further, both these are supported by Figure. 3, which shows that the maximum concentration of host stars having a stellar radius is around 1.

This graph also follows a general exponential decrease. From the given analysis of mean, median, and their respective evidence from the plotted histograms of orbital period, planetary radius, and stellar radius shows that the exoplanets tend to have, on average, double or more the Earth's radius, which renders them out of the parameters of being classified as either being Earth or Jupiter sized. In addition, the planets, on average, tend to have low orbital periods, many times lesser than Earth's orbital period and exponentially lower than that of Jupiter, which means that most of the planets are closer to their parent star. Finally, these exoplanets orbit host stars whose size tends to be, on average, in and around the sun's size.

A perfect example of this happens to be the Centauri System, where the binary star system Alpha Centauri AB forms a triple star system with Proxima Centauri, the closest star to the solar system, all are between 0.9 and 1.1 times the sun's size[27]. Further relationships can be established based on the scatter plots plotted where the orbital period, planetary radius, stellar radius, and transit duration have been plotted.

Figure. 5, which shows the plot of the Orbital period against Planetary radius, further solidifies the inference made above. The maximum concentration of planets appears to be in the bottom left of the scatter plot, with low orbital periods and low planetary radii. It appears to establish a direct correlation between the two variables, at least based on the data given. Figure. 7, which shows the plot of Transit Duration against

The orbital period is quite interesting. While most planets are focused on the lower half of the scatter plot because of the orbital period variable, the variable of transit duration spreads the data over a range of values. There appears to be an even concentration of data spread between values greater than 0 and less than 15 hours, which shows that the detected exoplanets follow a wide range of transit duration values. The concentration of data, though, appears to thin out as data moves towards higher values of transit duration.

A similar trend appears to be followed in Figure. 6, which is a plot between Transit Duration and Planetary Radius. A plot follows the same concentration on the bottom quarter of the graph with a spread of data because of the varied transit durations of the detected exoplanets. With these in mind, it is important to revisit the main aims of Kepler's mission to evaluate the extent of its success further. The Kepler mission was mainly aimed at detecting Earth and Terrestrial-sized planets across a portion of the Milky Way in the habitable zones of their host stars[28][29]. In addition, it aimed to discover more star systems, detect the number of planets in the star system, and decipher the properties of these stars.

Table 2. Classification of the number of earth-size and jupiter-sized planets

S.No	Parameter	Count
1	Total Number of Planets Detected	2741
2	Total Number of Earth-Sized Planets	341
3	Total Number of Jupiter-Sized Planets	94
4	No. of Planets with Radius Less than Jupiter	2615
5	No. Planets that were neither of Earth nor Jupiter's Size	2306

The Kepler Space Telescope was aimed to detect Earth-type exoplanets. It has detected and confirmed a total of 2741 exoplanets. The total number of Earth-type and Jupiter-type exoplanets are provided in Table 2 (See appendix, refer code 4 and 5).

Using the data from Table 2, the following conclusions were drawn:

Null Hypothesis 1 has proved to be true, which states that there are more Earth-sized planets compared to Jupiter-sized planets. There were 341 detected Earth-sized exoplanets, whereas only 94 detected Jupiter-sized planets.

Null hypothesis 2 has proven to be false, which states that most of the exoplanets detected by the Kepler Telescope fall into the parameter of being with ±25% of the radius of Earth. 341 planets fall into the parameter of Earth-sized, while 2306 planets do not fall into the set parameter. In addition, the hypothesis also stated that there would be that most of the planets have a radius more than that of Jupiter. However, 2615 out of 2741 planets had less radii than Jupiter. Thus, the Alternate Hypothesis is to be accepted.

4. Discussion

Terrestrial planets contain a rocky and compact surface [30]. They can have geological landforms like canyons, valleys, and cores made of iron or silicate material. In addition to this, the terrestrial planets also have a specific size specification. They need to be between half of Earth's size and about 2 times Earth's size. Any exoplanet above 2 times Earth's size is referred to as a Super Earth[31]. The size of a Super Earth is generally capped to be below 10 times Earth's size or about 69% of Uranus's mass. Also, any planet substantially smaller than Earth, or Venus since Earth and Venus are roughly the same size, is called a Sub-Earth. Generally, a Sub-Earth is about 0.15 times Earth's radius[32].

In contrast, a gas giant, or Jovian planets as they are also referred to, tend to be primarily made of hydrogen and helium[33]. In addition to most of their composition being that of gas, they may contain a layer of liquid metals above their core. Gas giants, like Jupiter, Saturn, Uranus, and Neptune, have rings around them as a result of a portion of dust and particles that could not be squashed by the effects of the planet's gravity. In fact, the earliest known gas giant exoplanets were known to orbit in extremely tight orbits around their host stars, such that they could exert meaningful gravitational influence on them. This was the basis for developing the Radial Velocity method of exoplanet detection. As shown above, only 94 planets qualify to be Jupiter-sized, while 341 qualify to be Earth-sized. While it may appear to be a very small percentage of the overall 2741 planets used in the data analysis, it is important to recall that very narrow parameters of ±25% were used. The number of planets that fall below the lower bound of Jupiter's radius (75% of Jupiter's radius) is 2615. Out of 2741 planets, 2615 have radii less than that of Jupiter, which equates to about 95.4%. In addition, the mean and median calculations show that the average exoplanet is only about twice the size of Earth's radius. Finally, Table 1 shows the data has a standard deviation of 3.363 to 4 significant figures. This shows that the average exoplanet is well below the bounds of being qualified as a gas giant like Jupiter. Thus, it can be deduced that the majority of the 95.4% of planets that were calculated, as shown above, could be majorly terrestrial planets. These terrestrial planets can, naturally, be qualified to be either Sub-Earths or Super-Earths. Crucially, however, it highlights the successes of the Kepler Telescope's mission[39]. Of course, the Kepler mission has brought new insights to understand the cosmos. It added valuable knowledge to the composition of stars, proved that there were more planets than stars in the universe, and discovered another solar system with 8 planets like ours.

Most importantly, it proved, as shown above, that there appear to be smaller, Earth-sized planets than Jupiter-sized planets. Not only does this provide vital knowledge into the formation of planets after the Big Bang, but it also opens the possibilities of discovering other potential homes to house future civilizations, should technological advancement enable us to do so in the centuries to come. In a conference in 2013, it was concluded that 1 in every 5 Earth-sized exoplanets detected by the Kepler Telescope lay in the planet's habitable zone[35]. Subsequent conferences in 2014 and 2017 have further revealed more such planets that check the boxes required to house a civilization like ours[36][37]. The Kepler Telescope's discoveries, therefore, provide us insight in the truest sense of our place in the fabric of the universe and provide a strong argument, based on its ground-breaking research into exoplanet size and their possible planetary conditions, of the possibilities of other civilizations co-existing with us in our vast cosmos.

Importantly, while this paper does not aim to further the discoveries of the advanced detection methods mentioned, it accomplishes its task of establishing relationships between planetary variables; they may appear obvious, but they provide crucial information regarding the nature of exoplanets and can temper the expectations of scientists for the future of exoplanetary detection.

5. Conclusion

This paper aimed to provide a statistical analysis of the detection of Earth and Jupiter-sized planets performed by the Kepler Telescope during its years of commission between 2009 and 2018. The test was carried out by defining ±25% of Earth and Jupiter radius planets as Earth and Jupiter-type planets, respectively. As mentioned before, one of the two hypotheses holds true. The first hypothesis, which states 'There are more Earth-sized planets compared to Jupiter-sized planets.' holds true, whereas the second hypothesis, which states 'A majority of the exoplanets detected by the Kepler Telescope fall into the parameter of being within ±25% of the radius of Earth' is false. Instead, the alternate hypothesis of the second hypothesis, 'A majority of the exoplanets detected by the Kepler Telescope do not fall into the parameter of being within ±25% of the radius of either Earth or Jupiter,' is to be accepted.

The novelty of this paper is that it establishes complex relationships between variables that would otherwise require detailed data collection procedures using the complex techniques mentioned in the Introduction. Unlike other high school research papers centred around the field of astrophysics, this paper aims to simplify the problem presented to it using detailed analysis rather than just performing calculations on large quantities of data.

Kepler has detected and confirmed a total of 2741. A total of 341 Earth-sized planets were detected compared to 94 Jupiter-sized planets. 2306 planets are neither Earth-sized nor Jupiter-sized planets. 2615 planets, or 95.4% of the planets, have a radius lesser than three-fourths of Jupiter's radius. This can be used to prove that a large percentage of planets are terrestrial planets that can be divided into Super-Earth and Sun-Earth, which can be supported by calculations of central tendency. These thus render the Kepler Space Telescope's mission successful and prove instrumental in scientists' quest to decipher mysteries of the universe.

Limitations

This research has primarily been limited by the data available. Since the Kepler telescope was discharged out of commission in 2018, the data used, as of the writing of this paper, is 5 years old. This restricted access to data from more recent sources that could have delivered a different or more accurate result.

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References

[1] John Noble Wilford, "When Humans Became Human," *The New York Times*, 2002. [Google Scholar] [Publisher Link]

[2] 7 Ancient Cultures and How they Shaped Astronomy, Office of Astronomy for Development, 2018. [Online]. Available: https://www.astro4dev.org/7-ancient-cultures-and-how-they-shaped-astronomy-guest-blog/

[3] A Brief History of High-Energy Astronomy: 1600 - 1699 Era, National Aeronautics and Space Administration. [Online]. Available: https://heasarc.gsfc.nasa.gov/docs/heasarc/headates/1600.html#:~:text=Galileo%20Galilei%20builds%20his%20telescope,of%20sunspots%20on%20the%20Sun

[4] Gonzalo Munevar, "An Obligation to Colonize Outer Space," *Futures*, vol. 110, pp. 38-40, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[5] Historic Timeline, NASA Exoplanet Exploration: Planets beyond Our Solar System, 1984. [Online]. Available: https://exoplanets.nasa.gov/alien-worlds/historic-timeline/#first-planetary-disk-observed

[6] Color-Shifting Stars: The Radial-Velocity Method, The Planetary Society, 2020. [Online]. Available: https://www.planetary.org/articles/color-shifting-stars-the-radial-velocity-method

[7] Down in Front!: The Transit Photometry Method, The Planetary Society, 2020. [Online]. Available: https://www.planetary.org/articles/down-in-front-the-transit-photometry-method

[8] Fireflies Next to Spotlights: The Direct Imaging Method, The Planetary Society, 2020. [Online]. Available: https://www.planetary.org/articles/fireflies-next-to-spotlights-the-direct-imaging-method

[9] Space-Warping Planets: The Microlensing Method, The Planetary Society, 2020. [Online]. Available: https://www.planetary.org/articles/space-warping-planets-the-microlensing-method

[10] Nola Taylor Tillman, Meghan Bartels, and Scott Dutfield, What is the Theory of General Relativity?, Space.com, 2023. [Online]. Available: https://www.space.com/17661-theory-general-relativity.html

[11] Pulsar Timing Method, Las Cumbres Observatory. [Online]. Available: https://lco.global/spacebook/exoplanets/pulsar-timing-method/

[12] NASA - Telescope History. [Online]. Available: https://www.nasa.gov/audience/forstudents/9-12/features/telescope_feature_912.html

[13] Hubble Space Telescope, NASA Hubble Site, 2023. [Online]. Available: https://hubblesite.org/home

[14] Telescopes Used, Cosmos. [Online]. Available: https://cosmos.astro.caltech.edu/page/telescopes

[15] Webb Space Telescope, Goddard Space Flight Center, NASA. [Online]. Available: https://webb.nasa.gov/

[16] Kepler / K2 in Depth, NASA. [Online]. Available: https://www.nasa.gov/mission_pages/kepler/overview/index.html

[17] *Google Scholar*. (n.d.). https://scholar.google.com/

[18] NASA Exoplanet Archive, Data Resources in the Exoplanet Archive. [Online]. Available: https://exoplanetarchive.ipac.caltech.edu/docs/data.html

[19] PyCharm: The Python IDE for Professional Developers, JetBrains, 2021. [Online]. Available: https://www.jetbrains.com/pycharm/

[20] Abby Cessna, Radius of the Planets, Universe Today, 2015. [Online]. Available: https://www.universetoday.com/37120/radius-of-the-planets/

[21] Orbital Period - Astronomy, Encyclopedia Britannica. [Online]. Available: https://www.britannica.com/science/orbital-period

[22] Transit Duration and Inclination, Astro Education. [Online]. Available: https://astro.unl.edu/newRTs/Transits/background/Transit2.html

[23] Earth, NASA Solar System Exploration. [Online]. Available: https://science.nasa.gov/earth/

[24] Jupiter Fact Sheet, NASA Goddard Space Flight Center, 2023. [Online]. Available: https://nssdc.gsfc.nasa.gov/planetary/factsheet/jupiterfact.html

[25] Charles Hakes, The Difference between a Tropical Year and a Sidereal Year, Durango Herald, 2022. [Online]. Available: https://www.durangoherald.com/articles/the-difference-between-a-tropical-year-and-a-sidereal-year/#:~:text=A%20sidereal%20year%20is%20the,longer%20than%20a%20tropical%20year

[26] Ben Biggs, and Nola Taylor Tillman, Main Sequence Stars: Definition and Life Cycle, Space.com, 2022. [Online]. Available: https://www.space.com/22437-main-sequence-star.html

[27] Robert Lea, Alpha Centauri: Facts about the Stars Next Door, Space.com, 2023. [Online]. Available: https://www.space.com/18090-alpha-centauri-nearest-star-system.html

[28] The Habitable Zone - The Search for Life - Exoplanet Exploration: Planets beyond our Solar System. [Online]. Available: https://exoplanets.nasa.gov/search-for-life/habitable-zone/#:~:text=The%20definition%20of%20%E2%80%9Chabitable%20zone,nor%20too%20cold%20%E2%80%93%20for%20life

[29] In Depth - Kepler/K2, NASA Solar System Exploration, 2018. [Online]. Available: https://science.nasa.gov/mission/kepler/

[30] Terrestrial - Planet Types, NASA Exoplanet Exploration: Planets beyond our Solar System. [Online]. Available: https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/terrestrial/

[31] Super-Earth - Planet Types, NASA Exoplanet Exploration: Planets beyond our Solar System. [Online]. Available: https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/super-earth/

[32] Discovery of Sub-Earth Planet: Ultra-Light and Super-Fast Exoplanet is Not Like Anything in Our Solar System, SciTechDaily, 2022. [Online]. Available: https://scitechdaily.com/discovery-of-sub-earth-planet-ultra-light-and-super-fast-exoplanet-is-not-like-anything-in-our-solar-system/

[33] Gas Giant - Planet Types, NASA Exoplanet Exploration: Planets beyond our Solar System. [Online]. Available: https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/gas-giant/

[34] Kepler Space Telescope, NASA Exoplanet Exploration: Planets beyond Our Solar System. [Online]. Available: https://exoplanets.nasa.gov/keplerscience/#:~:text=Kepler%20has%20discovered%20a%20diversity,Solar%20systems%20are%20diverse%20too

[35] One in Five Stars Has Earth-Sized Planet in Habitable Zone - W.M. Keck Observatory, 2013. [Online]. Available: https://keckobservatory.org/one_in_five_stars_has_earth_sized_planet_in_habitable_zone/

[36] Natalie M. Batalha, “Exploring Exoplanet Populations with NASA’s Kepler Mission, *Proceedings of the National Academy of Sciences of the United States of America*, vol. 111, no. 35, pp. 12647-12654, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[37] NASA Telescope Reveals Largest Batch of Earth-Size, Habitable-Zone Planets around Single Star, NASA, 2017. [Online]. Available: https://www.nasa.gov/news-release/nasa-telescope-reveals-largest-batch-of-earth-size-habitable-zone-planets-around-single-star/

[38] Ian O’Neill, Has Kepler Discovered an Alien Megastructure?, Seeker, 2015. [Online]. Available: https://www.seeker.com/has-kepler-discovered-an-alien-megastructure-1770345251.html

[39] Revathy P. Nair, Lilly Theresa Saviour, and Narain Ponraj, “A Comparative Analysis and Study on Martian Satellites,” *International Journal of Engineering Trends and Technology*, vol. 9, no. 6, pp. 260-266, 2014. [CrossRef] [Google Scholar] [Publisher Link]

Appendix

Code 1: To calculate the mean, median, and mode of Planetary Radius, Orbital Period

```
import pandas as pd

# Read a csv file in pandas
f = pd.read_csv("NASA Exoplanet Plots.csv")
radius = f['koi_prad']
print(radius)

# Calculate the mean using the mean() function
print("Mean of Planetary Radius is", f['koi_prad'].mean())
print("Mean of Orbital Period is", f['koi_period'].mean())
print("Mean of Stellar Radius is", f['koi_srad'].mean())
print("Mean of Transit Duration is", f['koi_duration'].mean())

# Calculate the median using the median() function
print("Median of Planetary Radius is", f['koi_prad'].median())
print("Median of Orbital Period is", f['koi_period'].median())
print("Median of Stellar Radius is", f['koi_srad'].median())
print("Median of Transit Duration is", f['koi_duration'].median())

# Calculate the standard deviation using the std(ddod = 0) function
print("Standard Deviation of Planetary Radius is", f['koi_prad'].std(ddof=0))
```

```
print("Standard Deviation of Orbital Period is", f['koi_period'].std(ddof=0))
print("Standard Deviation of Stellar Radius is", f['koi_srad'].std(ddof=0))
print("Standard Deviation of Transit Duration is", f['koi_duration'].std(ddof=0))
print()
```

Code 2: Sample code to plot a histogram(For Orbital Period)

```
import pandas as pd
import matplotlib.pyplot as plt
# Reading the CSV File
data = pd.read_csv("NASA Exoplanet Plots.csv")
Count = data['Count']
Variable  = data['koi_period']
bins = [50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550]

plt.hist(Variable, bins=bins, edgecolor='black')
plt.legend()
plt.title('Exoplanets')
plt.xlabel('Orbital Period (Days)')
plt.ylabel('Count')
plt.show()
```

Note: Only changes to the variable ‘variable’ and ‘bins’ need to be made in order to obtain the histograms for Planetary Radius, Transit Duration, and Stellar Radius

Code 3: Sample Code to plot the scatter plot(For ‘Orbital Period’ against ‘Planetary Radius’)

```
import pandas as pd
import matplotlib.pyplot as plt

# Read the CSV File
data = pd.read_csv('NASA Exoplanet Plots.csv')
print(data.shape)
print(data.head(2742))

# Creation of a Scatter Plot
x = data['koi_period']
y = data['koi_prad']
plt.xlabel('Orbital Period (Days)')
plt.ylabel('Planetary Radius')
plt.scatter(x,y)
plt.show()
```

Code 4: To count the Number of Earth and Jupiter-sized exoplanets by the Kepler Data

```
import pandas as pd
import numpy as np

# Reading the CSV File
f = pd.read_csv('NASA Exoplanet Plots.csv')
planet_radius = f['koi_prad']

# Setting the classification
# Range is between 75% and 125% of Earth’s and Jupiter’s Radius

earth_lower_bound = 1*0.75
earth_upper_bound = 1*1.25

# Jupiter is 11.2 times Earth’s size
jupiter_lower_bound = 11.2*0.75
jupiter_upper_bound = 11.2*1.25
```

```
# For loop requires an iterator which can be represented with i
# There are 2741 columns in the planetary radius column
c_j = 0 # Counter for Jupiter
c_e = 0 # Counter for Earth

for i in planet_radius:
if earth_lower_bound <= i <= earth_upper_bound:
c_e = c_e + 1
elif jupiter_lower_bound <= i <= jupiter_upper_bound:
c_j = c_j + 1

print("The total number of planets used in the date were ", len(planet_radius))
print("The number of Earth sized planets are", c_e)
print("The number of Earth sized planets are", c_j)
print("The number of planets that are neither Earth or Jupiter sized are", len(planet_radius) - (c_e + c_j))
```

Code 5: Code to Calculate the Number of Planets Lesser than Jupiter-Sized Planets

```
import pandas as pd
import numpy as np

# Reading the CSV File
f = pd.read_csv('NASA Exoplanet Plots.csv')
planet_radius = f['koi_prad']

# Setting the classification
# Range is between 75% and 125% of Earth’s and Jupiter’s Radius

earth_lower_bound = 1*0.75
earth_upper_bound = 1*1.25

# Jupiter is 11.2 times Earth’s size
jupiter_lower_bound = 11.2*0.75
jupiter_upper_bound = 11.2*1.25

# For loop requires an iterator which can be represented with i
# There are 2741 columns in the planetary radius column
c_j = 0 # Counter for Jupiter
c_e = 0 # Counter for Earth

for i in planet_radius:
    if earth_lower_bound <= i <= earth_upper_bound:
        c_e = c_e + 1
    elif jupiter_lower_bound <= i <= jupiter_upper_bound:
        c_j = c_j + 1

print("The total number of planets used in the date were ", len(planet_radius))
print("The number of Earth sized planets are", c_e)
print("The number of Earth sized planets are", c_j)
print("The number of planets that are neither Earth or Jupiter sized are", len(planet_radius) - (c_e + c_j))

x = (c_j / len(planet_radius))*100
print(x,"%")
```