Physics IA

The habitable zone and the physics behind potential for life

Research Question: How do diverse planetary setups in a solar system affect planets habitable zone and ability to retain life?

Personal Engagement:

When I first was told about the Physics IA, I went home and did an extreme amount of research to find a topic that I was personally interested in; however I knew right off the bat that I wanted to do something concerning the idea of space and all the mysteries of which it holds. I felt this way because when I was younger, space was one of the things that absolutely interested me most. This is definitely partially due to the fact that I had an uncle, before he passed away, whom I was extremely close to when I was younger that often taught me much about the wonders of space. My brother and I also loved using our telescopes, and looking at the stars, eclipses, etc. The planetarium was one of my favorite places to be, and this topic is especially important to me as the concept that has always fascinated me the most about space is this idea of other life forms existing in the galaxy and "Aliens." I loved to watch movies and play games revolving around this topic, and as my personal engagement for this IA, I utilized Keplers various databases and finds to see how these factors have affected their habitable zone and I also engaged in online simulations. I contemplated creating dioramas of some of their finds, and possibly even our own solar system as I would need a way to base their systems off of our system and make a scale ideally using Jupiter, our sun and Earth to compare to Kepler's systems. I was going do this is an attempt to make the scale understandable to us as we only understand what we know, and what we know is our solar system. I still currently am intrigued by space, as on September 27th, 2015, I went outside to watch the eclipse unfold. For this reason, there is no question as to why I chose astrophysics as my topic.

Exploration and Investigation:

Investigation: This investigation attempted to prove whether or not life can exist with a lack of a habitable zone, through sources like *Kepler*.

Hypothesis: It is conceivable for life to exist outside of a habitable zone as long as other natural phenomena allow it to.

Procedure:

1) I provided much background on the topic, and answered questions that most commonly confuse people in regards to the habitable zone.
2) As this topic is about space and its planets, data could not be taken first hand so I had to utilize online databases and sources like the Kepler Satellite to find a surplus of my calculations and data.
3) Once I collected my various data aspects, I put them to test.
4) As, again, this topic is about space, I couldn't test it firsthand so I had to utilize the sources provided to me in the form of online simulations.
5) I utilized a Habitable Zone simulation and a Habitable Zone calculator to test what Kepler provided me with, which terminally proved my hypothesis correct.
6) I then evaluated my investigation, flaws and all, and focused on how it could be improved in the future.

What is and where is the habitable zone?

The habitable zone is, by definition, the range of distances around the star at which a planet could potentially have surface temperatures that would allow for abundant liquid water. The habitable zone relates to water as water is a necessity to sustain life, wherever you are. This zone also can be referred to as the Goldilocks zone. If a planet is too far from its star, water freezes. If a planet is too close to its star, water evaporates. A planet must stay in the Habitable-Zone throughout its orbit in order for water to remain a liquid. The distance at which a planet can have water is determined by how much energy is given off by the star. This distance is measured in astronomical units or AU. **An astronomical unit** is the average distance from Earth to the Sun, which is equal **to 149,598,770 km or 3,000,000 miles**. These will vary for each different location, however in terms of cooler red dwarfs, the Habitable Zone is so close to the star that solar flares and radiation from the star would destroy life.

Background

Can life exist outside the habitable zone?

Yes, life can exist outside of the habitable zone so long as other natural phenomena allow it to. One example of an intriguing possibility that exists in our solar system itself is on Europa, the smallest of Jupiter's four Galilean moons. The moon has a smooth and icy surface that scientists discovered contains a liquid ocean underneath. The Galileo spacecraft had seen a weak magnetic field that varies as Europa goes through Jupiter's strong magnetic field, suggesting Europa has a subsurface ocean of salty water. Scientists have claimed microbes could exist in this ocean the exact way they do around hydrothermal vents in the oceans here on earth. Any life existing in the subterranean water would be hidden away from what little solar energy reaches this part of the Solar System. Anything is possible here, as Life has been found deep in our own oceans receiving no sunlight whatsoever. Instead, its energy supply is the stream of minerals seeping out of cracks in the Earth's crust within the ocean floor. It is also

possible the phenomena of volcanic activities have added to the proclivity of life as volcanoes heat up the water itself on the planet and there could even be a supply of oxygen too.

Jupiter's Moon: Europa

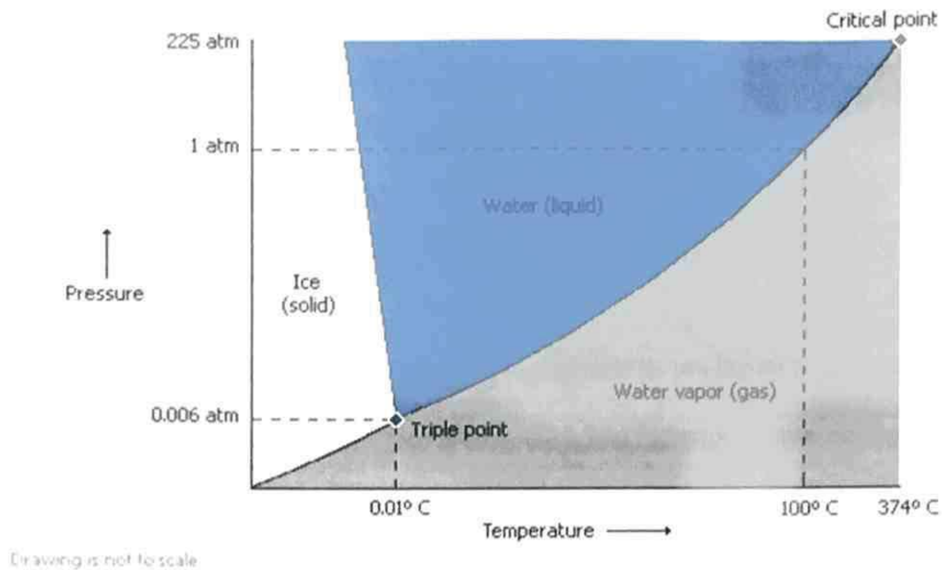
What makes a world habitable?

There are many underlying factors that go into what makes a world able to sustain life. For example, one imperative factor that cannot be overlooked is temperature. Cold temperatures cause chemicals in a living cell to react too slowly to support the reactions necessary for life. Thus, life seems to be limited to a temperature range of about minus **15°C to 115°C**. Not only does temperature affect this, but it also impacts a planets ability to attain water. If the planet is too hot, the water will evaporate and if the water is too cold, the water will freeze meaning for the planet to be habitable, the temperature must be within a certain range. On a cold planet or moon, there must be internal heat to melt ice or permafrost. On a hot planet or moon, the water will boil away or evaporate unless it is far beneath the surface. Another enormous factor that goes into making a planet habitable is its atmosphere. Atmospheres can insulate a planet or moon and protect life from harmful ultraviolet radiation and small- and medium-sized meteorite impacts. Atmospheres moderate day-night and seasonal temperature swings but in order to aid as an operative shield or insulator, the atmosphere has to be substantial, the way it is on Earth. A planet or moon relies on its gravity to sustain an atmosphere. A small-sized body such as Earth's moon has too little gravity to hold an atmosphere, making life on or near the surface exceedingly difficult. The mass of the sun and satellite planets are also huge factors, and the distance between them is of the utmost importance. It's not just about the one possible habitable planet in the system, as the other planets in the system and then sun have huge effects on the possibility of life so those must be kept In mind. The speed of revolving planets is also another factor, as it must not be too fast as different laws of physics have discussed before. The planetary orbit must be circular and kept consistent and tidal forces also can have affects, along with the radius and planetary periods. The radiation intensity affects whether or not a world is habitable. The intensity of light is like the inverse square of the distance from the source.

Examples:

1) Mercury's average distance from Sun is 0.39 times Earth's Average intensity 1/(0.39)2=6.6 times Earth's

2) Mars's average distance from Sun is 1.52 times Earth's Average intensity 1/(1.52)2=0.43 times Earth's



Luminosity is energy radiated per unit time and includes all wavelengths.

L_{Sun} = **$3.845 \times 10^{33} erg_{/s}$ = 3.845×10^{26} J/s**

Luminosity can help to discover temperature

The temperature of the surface and atmosphere of a planet is determined by the balance between the energy that is absorbed and the energy that is emitted. If a planet has little to no significant source of internal heat then the source of most of the energy reaching the atmosphere and the surface is the Sun. According to databases within NASA, the solar flux density at the top of the Earth's atmosphere is about 1.38 × 103Wm−2. Some of this energy is reflected back to space, the atmosphere absorbs some, and the rest reaches the surface, where it is either reflected or absorbed. The absorbed radiation heats the surface, which then re-radiates this energy, mainly in the infrared region.

On the assumption that a planet undergoes no net heating or cooling in the short term, it is possible to estimate the temperature necessary for a planet to re-radiate all of the energy absorbed by the atmosphere and the surface. This temperature, called the effective temperature, Te, is defined as follows:

Te4 = L / 4πR2 × 5.67 × 10−8

In this rather complex formula L is the total power radiated by the planet in watts, R is the radius of the planet in metres (its surface area is 4πR2, and radiation is emitted from the whole surface) And 5.67 × 10−8 is a constant.

Why are some planets in the habitable zone uninhabitable?

Being in the habitable zone for a planets full orbit does not necessarily mean it can sustain life. There are multiple reasons a planet in the habitable zone may be still inhabitable. For example, on Venus the runaway greenhouse effect ruined its chances of sustaining water to be habitable. A runaway greenhouse effect, by definition, is "a process in which a net positive feedback between surface temperature and atmospheric opacity increases the strength of the greenhouse effect on a planet until its oceans boil away." This process can terminally superheat a planet. Some planets in the habitable zone also can be uninhabitable depending on if the planet is a gas giant or not. For example, gas giants are unstable for sustaining life, which is why Jupiter cannot sustain life. If there is a gas giant within a planets gravitational pull and orbit, it can create havoc while if it is outside it can protect the planet. The planet may not even have water on it to begin with, or the water it has may not be liquid. This is true, for example, in mars, as it possesses a low surface pressure and water cannot be a liquid on the surface. Water goes from a solid to a gas without ever being liquid. The planet also may not have the proper form of an atmosphere and thus may also not be the right size to hold on to the atmosphere that humans need. There are also always other dangers, such as larger planets, solar flares or radiation, from which humans need protection. The planet cannot be habitable if it doesn't have an electric field, as this would strip away the atmosphere. A planet can also be uninhabitable if it is overall unstable and isn't a system that can last a long enough duration to evolve and be consistent and stable.

In this investigation, the pressure in a planet's atmosphere had to be considered, and is given by **P = nkT**, where n is the number density of particles, and k is Boltzmann's constant.

Why is Earth a perfect world suited for life?

Many factors go into the fact that Earth is the perfect planet for sustaining life. Why? Well, any habitable planet needs some kind of liquid that things like DNA and proteins can swim around and interact with each other to fulfill reactions needed for life to happen. The most common contender for this task is the solvent that earth utilizes, water. Since water can float when frozen, unlike many liquids, ice can insulate the inner fluid from freezing further. If water instead sunk when frozen, this would allow a different layer of water to freeze and sink, and all the water would get frozen, making the chemical reactions behind life next to impossible. Water exists as a liquid between **273K and 373K**, unless the water sublimates into gaseous water vapor due to the pressure being extremely low. Earth happened to hit the Goldilocks mark, forming within the sun's habitable zone. Mars and Venus lie outside it. This depicts the idea that if Earth's orbit had been just a bit further inside or outside of where it is, life may likely never have arisen and Earth today would be extremely different from what we are used to. Other factors researchers have discovered for why life succeeded on Earth include how little variation there is in our sun's radiation compared with more unstable stars. Also, our planet has a magnetic field that guards us from any arrays of charged particles from the sun. Violent bursts of radiation could have scoured life from Earth in its early, fragile stages. Earth is also remarkably stable with its perfect electromagnetic field that allows it to change seasons and sustain life. Earth also has a system that lasts a long enough time for life to evolve. It took earth almost four billion years, but Earth has the perfect period for sustaining life. Earth remains the only known planet to host life, due to an imperative combination of factors. However, continued monitoring of other worlds might one day change that, by discovering planets that have these attributes in common or by discovering other ways that life has found to thrive in the universe itself.

Kepler Mission overview

The centuries-old quest for other worlds like our Earth has been rejuvenated by the excitement and interest surrounding the discovery of hundreds of planets orbiting other stars. According to the Kepler Mission, there is now clear evidence for substantial numbers of three types of exoplanets; gas giants, hot-super-Earths in short period orbits, and ice giants. The challenge now is to find terrestrial planets (i.e., those one half to twice the size of the Earth), especially those in the habitable zone of their stars where liquid water might exist on the surface of the planet.

The Kepler Mission, NASA Discovery mission #10, is specifically designed to survey our region of the Milky Way galaxy to discover hundreds of Earth-size and smaller planets in or near the habitable zone and determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets.

When a planet crosses in front of its star as viewed by an observer, the event is called a transit. Transits by terrestrial planets produce a small change in a star's brightness of about 1/10,000 **(100 parts per million, ppm),** lasting for 2 to 16 hours.

Our solar system isn't the model for others like we originally believed:

NASA launched the Kepler spacecraft March 6, 2009, with the goal of finding Earth-like planets. The satellite observed around 160,000 stars for nearly four years, looking for tiny dips in brightness. A decrease in light could result from an exoplanet crossing between its star and Kepler during the planet's orbit; a transit. As a member from the Kepler Team said, "Researchers need at least three "dips" to catalog a source as a possible planet-hosting star — each "dip" represents one orbit. So, if an Earth-sized world orbits a Sun-like star at the distance where liquid water could exist on the surface — essentially just like our planet — it would take at least three Earth years of data to see three transits." Every year, the number of planets observed by Kepler increases rapidly, and some of the planets even have potential to sustain life; yes, life. Unlike many scientists believed, these possibly habitable systems vary greatly from our solar system, showing how variations exist in planetary setups and that ours is not the basis for all systems.

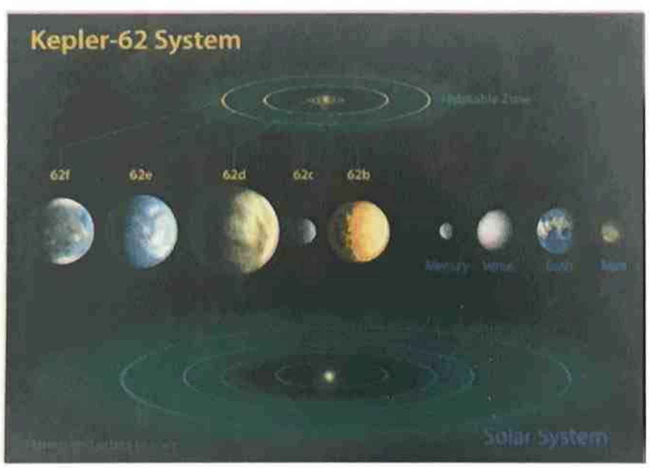
<u>Data and Calculations</u>:

(all images and information are from the NASA online database of Kepler and online simulations)

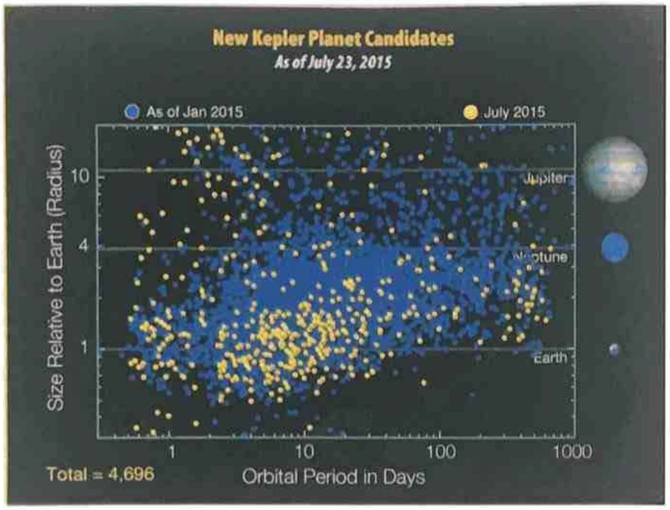
How many exoplanets has Kepler discovered?

Kepler mission:

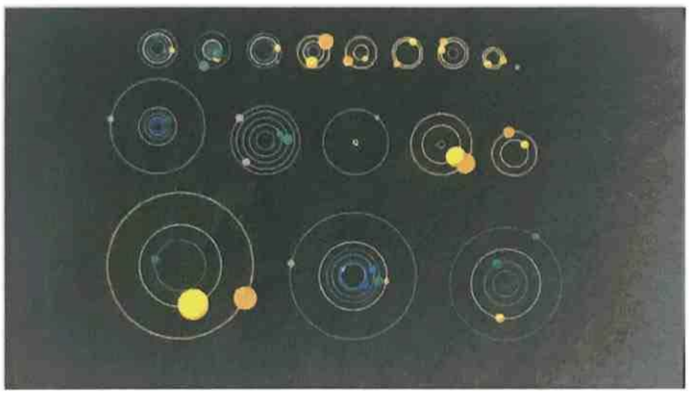
- Confirmed exoplanets: 1,030
- Candidate exoplanets: 4,696
- Confirmed exoplanets less than twice Earth-size in the habitable zone: 12



The diagram compares the planets of our inner solar system to Kepler-62, a five-planet system about 1,200 light-years from Earth in the constellation Lyra.

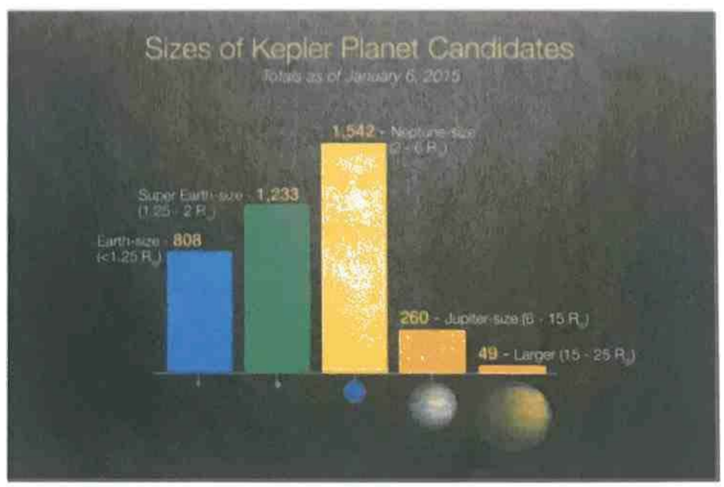


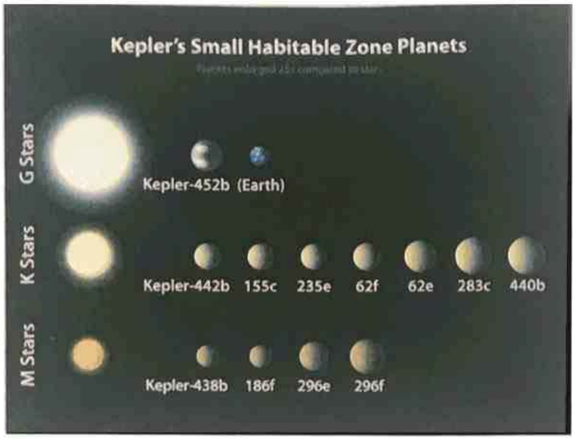
According to the reliable source of Kepler itself, there are **4,696 planet candidates** now known with the release of the seventh Kepler planet candidate catalog - an increase of 521 since the release of the previous catalog in Jan. 2015. The blue dots show planet candidates from previous catalogs, while the yellow dots show new candidates from the seventh catalog. "New planet candidates continue to be found at all periods and sizes due to continued improvement in the detection techniques. Notably, several of these new candidates are near-Earth-sized and at long orbital periods, where they have a chance of being rocky with liquid water on their surface", according to Kepler.



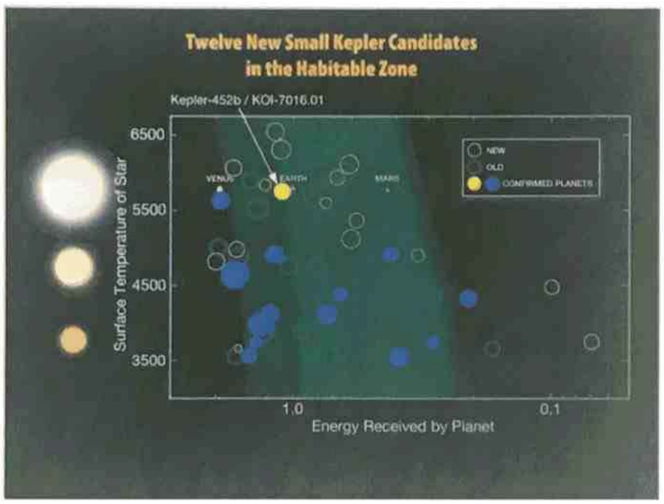
The image shows an overhead view of orbital positions of the planets in systems with multiple transiting planets discovered by NASA's Kepler mission.

Graph shows variation in sizes of planet candidates



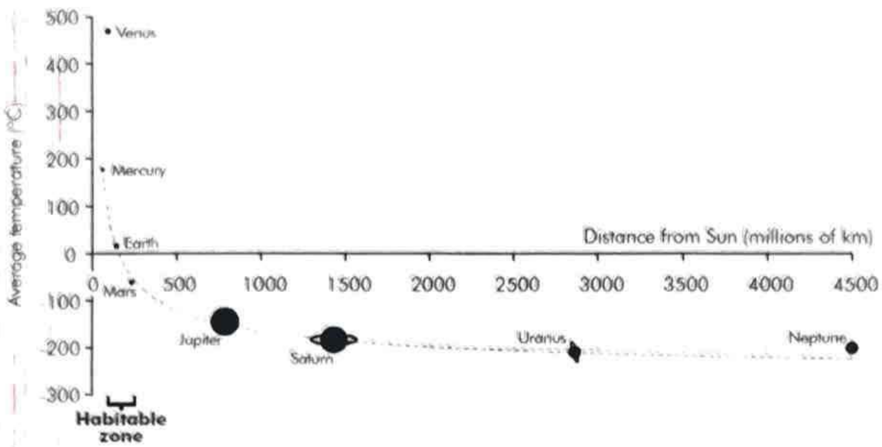


Of the 1,030 confirmed planets from Kepler, a dozen are less than twice the size of Earth and reside in the habitable zone of their host stars. In this diagram, the sizes of the exoplanets are represented by the size of each sphere. These are arranged by size from left to right, and by the type of star they orbit, from the M stars that are significantly cooler and smaller than the sun, to the K stars that are somewhat cooler and smaller than the sun, to the G stars that include the sun. The Earth is displayed here for reference, and the sizes of the planets are enlarged by 25 times compared to the stars.



Highlighted above are 12 new planet candidates from the seventh Kepler planet candidate catalog that are less than twice the size of Earth and orbit in the stars' habitable zone. Note that the new candidates tend to be around stars more similar to the sun, representing progress in finding planets that are "similar to the Earth in size and temperature that orbit sun-like stars."

For life to flourish, an **exoplanet** must be at just the right distance from its star, in the star's 'habitable zone'.



Note: The size of the planets is not shown to scale.

As this topic is one concerning outer space, it was unable to be firsthand experimented on in this investigation. However, throughout the procedure there were various online simulations in regards to the habitable zone utilized to prove my hypothesis correct. One simulator used was the "Circumstellar Habitable Zone Simulator", which was provided to me by the Astronomy Education at the University of Nebraska-Lincoln. In this simulation, I was able to utilize the many variables this allowed me to fluctuate, like mass, distance, temperature, radius, etc. This allowed me to prove my hypothesis, as I tested many aspects which supported the data of habitable planets given to me by Kepler. This really was the principal source that allowed for the basis of my investigation, along with the data I collected from the Kepler Satellite, and allowed me to fully grasp the concept of the Physics behind the habitability of specific planets. I also exploited an online "Habitable Zone Calculator" to allow me to further develop my ideas and allow me to get as close as a first-hand experience gets with the topic of outer space.

Evaluation:

While this investigation ran fairly smoothly, like all investigations, there are still multiple areas in which it could be further improved in the future. One way in which it could be improved in the future would be if one could actually test this firsthand somehow, but for now that remains exceedingly difficult considering the experiment revolves around space. In my research question I mention planetary setups, and while i do discuss that in my data and experiment, it could be even better in the future if one was able to further explore even more setups and diverse designs.

This investigation may be able to be altered and improved in the future, however it still possessed its strengths and weaknesses. One strength it definitely had was utilizing Kepler and collecting as much data and calculations from that source as possible, however it was weakened in that I had to utilize online simulators instead of a firsthand account. While Kepler and these simulations offered a tremendous amount of information, my topic didn't have as many mathematical calculations as I had hoped seeing that the calculations were done by a Satellite in space that I collected my data for. The main source of proving my hypothesis about habitable zones was from Kepler, not mathematical equations themselves. An analysis of this overall topic easily led to a vast amount of uncertainty in my data, as while this Satellite is positively viewed and many scientists support it, it is still somewhat speculation as humans don't truly know what lies beyond what we are used to, as we are in our own little bubble.

There can be error found everywhere, whether it is from humans miscalculating within Kepler itself, or one of the many other various possibilities to develop error.

Conclusion:

Although we don't yet know whether life exists any place besides Earth, we've seen that current science, most importantly Physics, offers reasons to think it should. We can examine the nature of life on Earth—its building blocks and how it originated—and understand the environmental conditions in which life can exist. In this experiment, other planets and moons in solar systems were looked at and determine whether the conditions of Physics truthfully exist there. This experiment has discussed planets around other stars, teaching how abundant they are and how they form, and determining whether some of them might be Earth-like planets that could be capable of supporting living things, according to the data and calculations collected by Kepler. Life on Earth thrives under a wide range of conditions that we once considered too extreme to be capable of supporting life, and many of these types of environments are likely to be found on other planets in our own solar system and beyond, which is definitively supported by Kepler. While the habitable zone is not a finished concept with one final answer, as every day humans discover more and more possibly candidates for life with the help of Kepler, it is still completely viable and supported in this investigation that life most likely can exist out there in other planets. With all the combinations of worlds out there, to believe we live on the only planet able to develop such life forms is completely far-fetched.