# Project Brief

Project Title: Modeling Exomoons: A Search for Habitable Moons Outside of the Solar System using Python
Author: Julia Rasmussen

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## Abstract:

Even though hundreds of moons exist in our solar system, and more than 4,000 planets outside the solar system have been found, no exomoons have yet confirmed. This project aims to help find exomoons by utilising patterns found by modelling a planet-moon-sun system into an algorithm that finds a suitable match for a given system. First, a model with adjustable orbital parameters was made using VPython through the GlowScript 2.9 IDE. Then, the TTVs and TDVs of different orbital parameters were analyzed. Finally, these were used to create the algorithm that searches for exomoons.

## Research Question:

How does the presence of an exomoon affect the light curve of a star in an n-body system?

## Project Definition:

## Background:

Ever since antiquity, humankind has looked to the stars for inspiration and the answer to the burning question of: Are we alone? As the field of astronomy has progressed, this question has been in the center of it. Advancements such as being able to detect elements using spectroscopy, and understanding more about how our solar system was formed have created a basis for the current study of exoplanets, the focus of modern astrobiology. However, exoplanets should The overall aim of this project is to engineer a way to detect exomoons in a transit curve. The goal is to find a correlation between changes in the orbital parameters of an exomoon and the resulting TTV and TDVs of the system.

not be the end-all be-all in the search for extraterrestrial life. Exomoons are also viable options, as seen with the numerous moons in our own solar system that are potentially habitable.

The aim of this project is to try to find an exomoon through computer modelling. I will address the question of: How does the presence of an exomoon affect the light curve of a star in an n-body system?

Exoplanetary science has evolved under the assumption that Earth and our solar system are not special cases. It is assumed that there exist other planets around stars that could potentially be habitable by life. The very first exoplanet found orbiting around a sun-like star, 51 Pegasib, was discovered in 1997 (Marcy, 1997) by finding the wobble of the star that was caused by the planet. Since then, more methods for finding exoplanets have been employed. The most successful, the transiting method, has found thousands of exoplanets, most notably through data collected by NASA's Kepler spacecraft. The transiting method measures the amount of light emitted from a star over a certain interval of time. This is then graphed onto a "transit curve". Researchers then look for periodic dips in the data, known as "transits", which could be caused by an exoplanet orbiting the star, and thus blocking part of its light as it crosses it. This method finds the period, radius, and semi-major axis of the exoplanet's orbit, but needs to be cross-referenced with another method of detection in order to prove that the exoplanet exists. There are major drawbacks to this method, such as its reliance on the orbital inclination of the planetary system being such that these "transits" actually appear from our field of view, and the inherent presence of noise in the observational data. However, this method has found many more exoplanets than any other method combined. Given that only a fraction of possible exoplanets can be found using the transiting method, this means that, statistically, many more exoplanets exist. This also supports the theory that our planetary system is not a unique one, and that life could exist outside of it.

Our only model for a planet that harbors life is our own, the Earth, though Mars could have been habitable in its past. There are also multiple moons that could be habitable: Europa, Enceladus, Titan, Io, and possibly Ganymede. As such, in order to try to find a celestial body that could harbor life, it is important to try to find habitable moons as well, especially considering their vast numbers in the solar system. The same methods to detect exoplanets could potentially be applied to the discovery of exomoons. However, though various methods have been suggested to detect them, no exomoon has ever been confirmed. Whether or not a planet could be habitable depends on multiple factors: the type of planet and whether it has the chemicals needed for life in an appropriate state. Likewise, whether or not an exomoon is potentially habitable relies on its initial composition. Additionally, the potential habitability of an exomoon depends on the distance from its star and planet and radius (Lammer, 2014), as well as the stability of its orbit and the maximum orbital separation (Kaltenegger, 2010).

Methods for detecting an exomoon that have been proposed so far revolve around two ways that the presence of an exomoon changes the transit curve of its exoplanet: Transit Timing Variation (TTV) and Transit Duration Variation (TDV) (Kipping, 2011). The first, TTV, focuses on how the time intervals between each transit could fluctuate based on how an exomoon would orbit the planet. However, there are other phenomena besides a moon that have been known to cause TTVs, such as trojans (very small bodies that orbit on a planet's outer Lagrangian points) and solar activity. An analysis of a system's TTVs can also lead to finding other exoplanets because of their gravitational effects on other planets (Nesvorný, 2013). The second way an exomoon could affect a transit curve, TDV, focuses on how an exomoon could change the length of transiting itself. When TTV and TDV effects agree with each other well, it is very possible that the exomoon could exist.

What I want to do is create a flexible model of a sun-planet-moon system that can take various initial conditions, such as the semi-major axes of the planet and moon, the radii of the sun, planet, and moon, the masses of the sun, planet, and moon, and the luminosity of the star. I will then see if the TTVs and TDVs of a system are dependent on any of these factors, and if so, which factors affect them the most, and why. I will then try to find exomoons by looking at a wide spread of available exoplanet transiting data, model the given two body exoplanet-sun system, and if that light curve is far enough away from the actual light curve, I will add an exomoon to my model, find the light curve again, and see if this light curve is more similar to the observed transit curve.

A challenge in modelling a star-planet-moon system is that there are more than two bodies acting upon each other. When two bodies act upon each other, the resulting model is predictable. However, when more bodies act upon each other, the system is ever-changing and cannot be predicted. The “three body problem,” a case where three bodies act upon each other, has been especially researched. There are special cases for three body systems in which the model is periodic and solvable. In fact, 13 additional families of solutions (Šuvakov, 2013) to the three body problem were discovered in 2013, adding to the previous three that were already known.

## Hypothesis:

The changes in the TTV and TDVs of a light curve in a system containing an exomoon will be directly proportional to changes in the exomoon’s radius and mass.

## Experimental Design/Research Plan Goals:

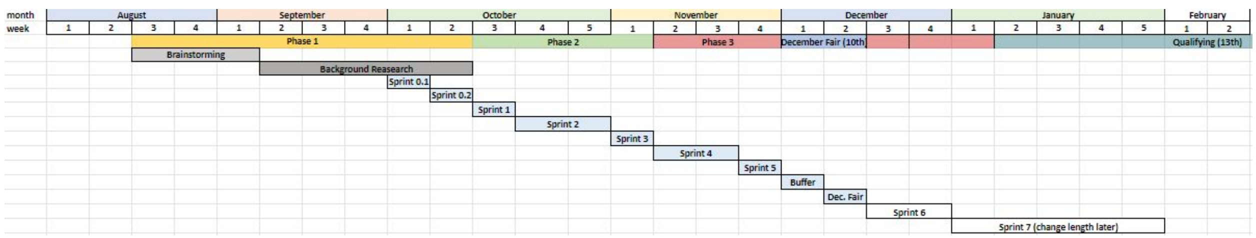
Major Parts of the Project (rough outline) will continue to evolve over time and should be updated frequently. Make sure the goals are SMART oriented.

1. Learn how to model gravity and light in Python.
2. Learn what other models have been used in exomoon/exoplanet literature.
3. Learn about tidal locking is and how possibly two tidally locked bodies could be thought of as one body.
4. Make a working model of a three-body system that approximates the positions of the three bodies to a reasonable precision.
5. Choose at least one:
    a. Model how changes in the radii, semi-major axis, or mass of the planet/exomoon/star could affect the transit curve.
    b. Find out how tidal locking changes the transit curve.
    c. Find out how multiple moons/multiple surrounding planets change the transit curve.

<u>Timeline:</u> (with action steps identified- sub-deadlines will continue to evolve):

Rough timeline of major phases. As these phases get established, specific tasks under these phases will be defined further.

Sprint 1: Model a 2-body orbiting system using Java
Sprint 2: Model the projected transit curves for the system
Sprint 3: Model a moon (approximately to a reasonable extent)
Sprint 4: Automate the program to accept multiple inputs
Sprint 5: Collect and analyze data that depends on either the radii, tidal locking, or multiple moons.
Sprint 6: Redefine the Data
Sprint 7: Search for an exomoon




## <u>Background Knowledge Goals:</u>

| **Date** | **Topic** | **Completed Date** |
|---|---|---|
| 9/30/19 | Preliminary research on existing papers on exomoons | 10/04/19 |
| 9/30/19 | Modelling transiting | 10/04/19 |
| 10/07/19 | Tidal locking | 11/08/19 |
| 10/14/19 | 3-body problem | 10/20/19 |
| 10/21/19 | How to model using Java | N/A |
| 10/28/19 | Topics that need to be researched further | 11/08/19 |

| **Don’t Want to Use** | **Why?** |
|---|---|
| Mass is negligible. | Might be good initially for an approximation, but is a bad assumption to make if looking at different TTVs. |

(if I weren't to choose the exomoon project + if I were to)

| **Want to use to Develop Further?** | **Why?** | **Assumptions Making with this idea** | **How can these assumptions be challenged?** |
|---|---|---|---|
| How to take away the algae without harming the ecosystem and targeting only algae. | The reason to take away the algae would be to help the environment; you would not want to hurt it in the process. | - Algae blooms are harmful.<br>- Algae is not interconnected with the ecosystem around it. | - If algae is somehow beneficial.<br>- If parts of the ecosystem rely on algae to survive. |
| Health risks of an algae filter. | Do not want to harm the environment, and also do not want to harm the humans that will drink the water. | - Algae is bad for human health.<br>- Filtration can potentially be harmful.<br>- Chemicals in filtration systems can seep into the water. | - If algae is somehow beneficial to humans.<br>- If some sort of safe/bio-friendly chemical or other filtration method can be used to filter out the algae (magnets/electricity???). |
| Use beneficial chemicals. | It would solve the previous problem. | - A naturally occuring chemical that is toxic to algae but beneficial to the rest of the ecosystem exists. | - No such chemical exists. |
| Introduce more natural predators of algae into the ecosystem. | It's a natural way to get rid of excess algae. | - The predators will not disrupt the ecosystem/food chain. | - Ecosystems are very fragile and even the slightest change can have unforeseen consequences. If even a single thing is changed, the whole ecosystem could go into disarray. |
| Approximate the 3-body problem | The 3-body problem is currently unsolvable | - I cannot solve the 3-body problem<br>- An approximation will be good enough<br>- The bodies will behave approximately the same with the approximation of the orbits and the actual orbits | - If I learn the math required to understand why the three body problem has not been solved.<br>- If the approximation is not good enough. |
| Use a 3d model | It allows the whole | - Having the system | - Doing it by |

| | | | |
|---|---|---|---|
| | system to be visual. | be visual allows for easier debugging.<br>- Transit curves can be found by using a visual representation. | hand/calculating the amount of light transited is easier<br>- Only need to look at the transit part itself to find the transit curve; assume that no TTV will occur, or will be recognized and readjusted; start with the moon at different angles relative to the star and planet right before the planet starts transiting. |