Enhancing Space Navigation with Lunar Occultation

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Introduction

Space navigation has traditionally relied on radio ranging, which is often hindered by signal delays and susceptibility to interference. My research involves using Lunar Occultation leverages the Moon's predictable movements to achieve precise spacecraft positioning and distance measurements. This method offers enhanced accuracy, reduced interference, and greater reliability, making it a superior alternative for future space missions.

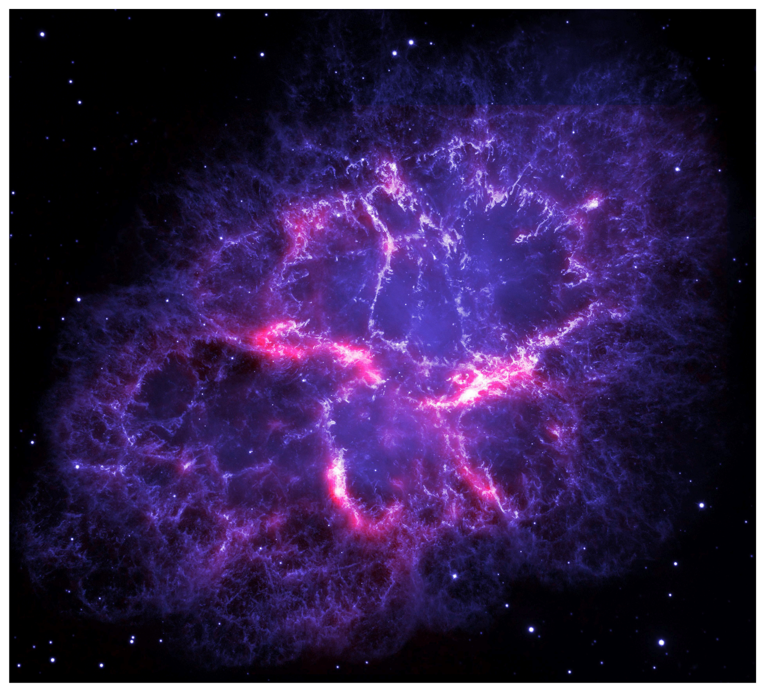

Figure1. Crab Nebula: A Key Occultation Source for Autonomous Navigation.

- The Crab Nebula serves as an ideal occultation source for autonomous navigation using Lunar Occultation. By monitoring when the Moon passes in front of the Crab Nebula, spacecraft can accurately determine their positions without relying on radio signals. This method enhances navigation precision and autonomy, ensuring reliable and efficient maneuvering in deep space missions.

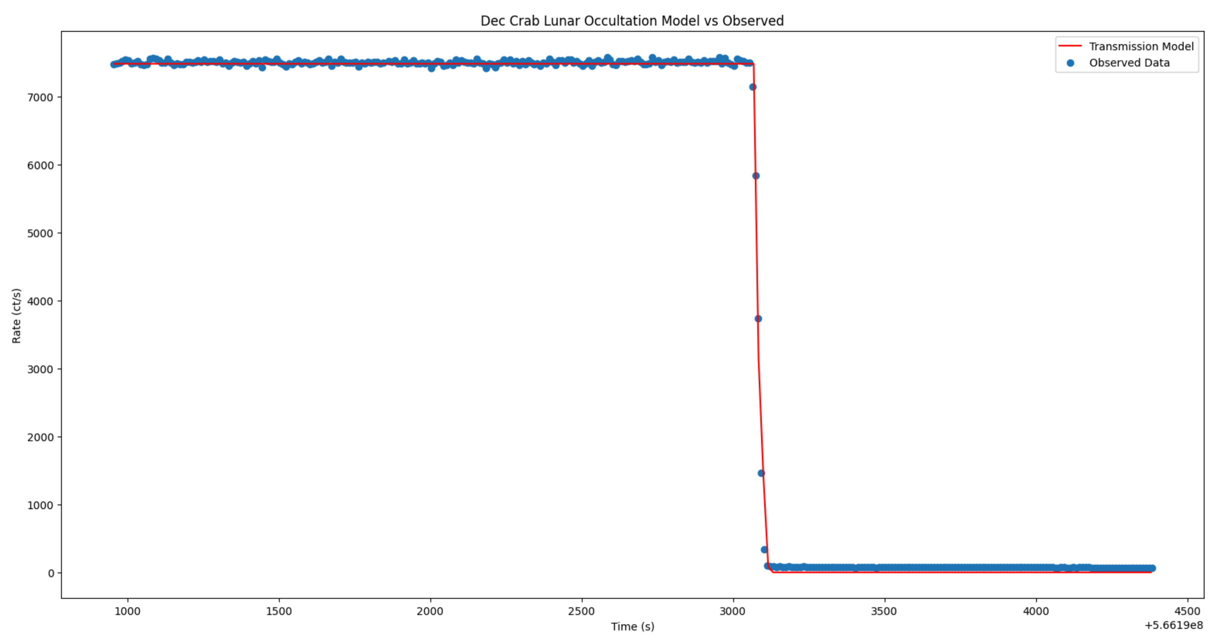

Figure 2. Light curve of Crab Nebula occultation model as compared to what was observed

- Occultations, where one celestial body passes in front of another from an observer's viewpoint, are invaluable for studying the properties of astronomical objects. Currently, most occultation observations are made from Earth's orbit using instruments like the Rossi X-ray Timing Explorer (RXTE), which produces detailed lightcurves. These lightcurves help scientists determine the sizes, shapes, and atmospheric conditions of the occulted objects by analyzing the changes in light intensity during the event.

Methods

We developed an algorithm to determine whether a celestial source is occulted by the Moon based on spacecraft position data. For each time step, the algorithm calculates the distance between the spacecraft and the Moon (**dspacecraft-moon**), the unit vector pointing towards the celestial source (**usource**), and the magnitude of the projection along the line of sight (**half_los_mag**). These calculations determine the occultation status, which is then plotted over time to visualize occultation events.

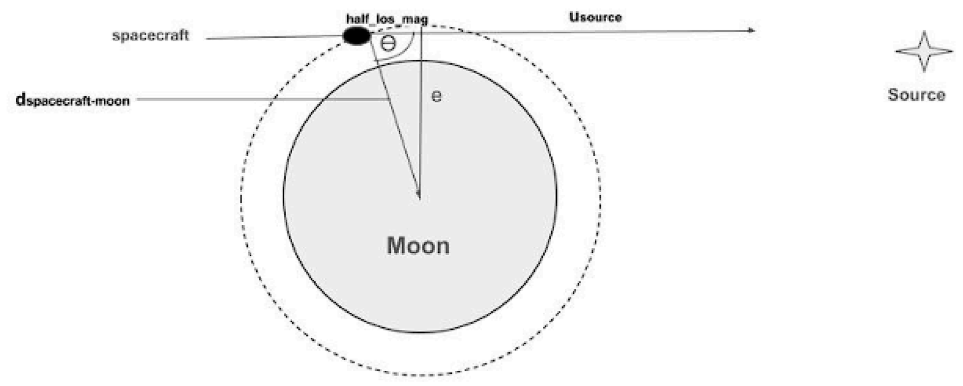

Figure 3. Diagram of the occultation process

To improve occultation detection, we developed an algorithm that targets orbits with small semi-major axes. These orbits are more likely to result in occultation events due to their proximity and increased interaction frequency with celestial bodies. The figure below illustrates these orbits in Earth-Centered Inertial (ECI) coordinates, highlighting their potential for frequent occultations.

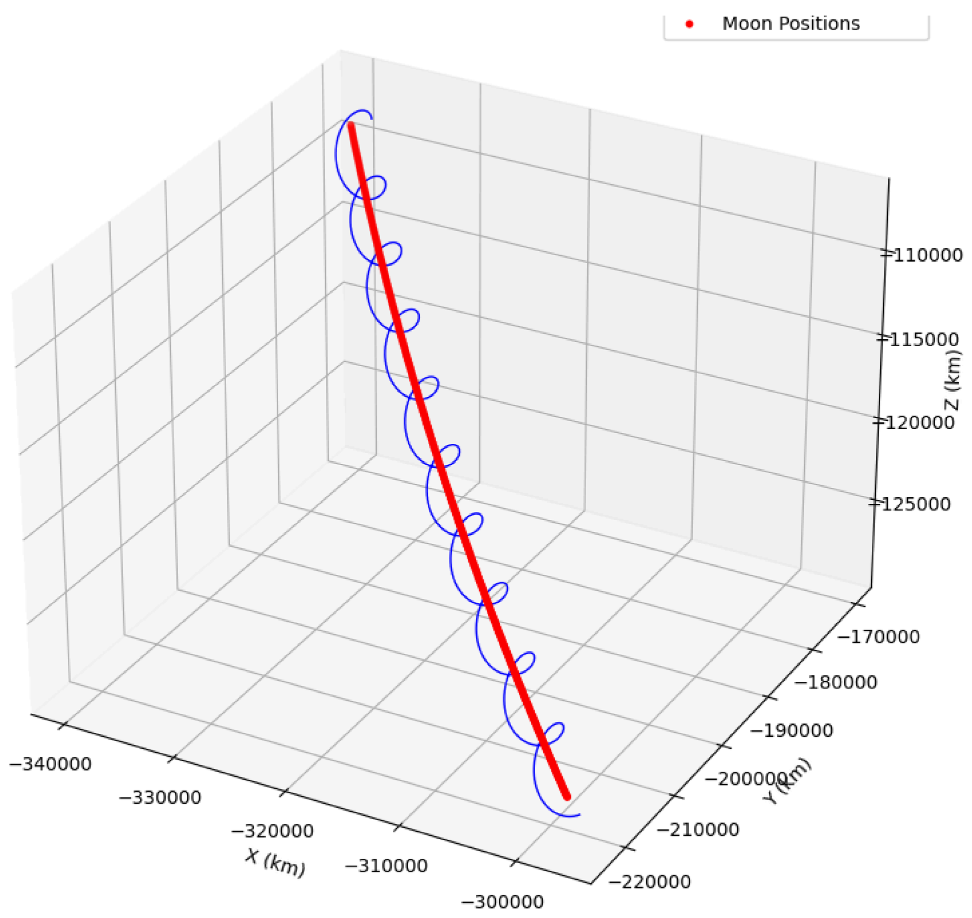

Figure 4. Spacecraft trajectory and moon positions for a small semi-major axis

Results

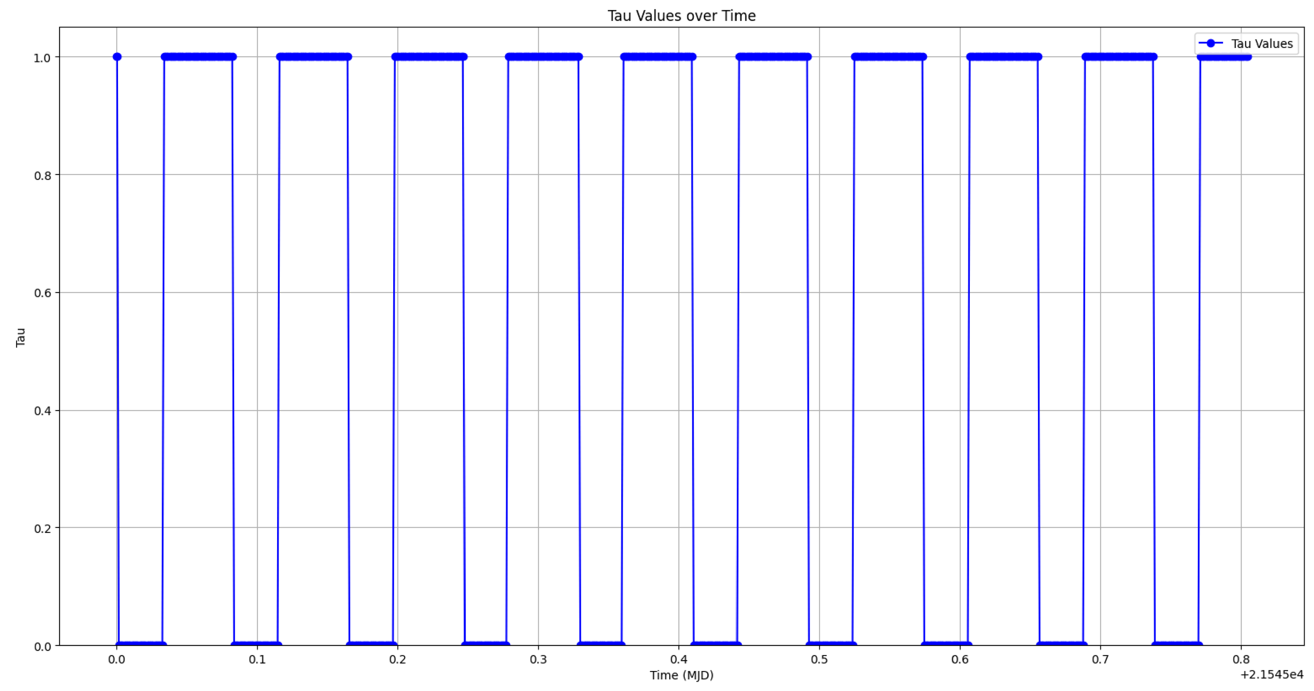

Figure 5. Luna Occultaiton plot without the terrain model

The algorithm was tested under two conditions: one assuming a perfectly spherical Moon and the other incorporating the lunar terrain model. The spherical model provides a simplified view of occultations, while the terrain model accounts for surface features like mountains and craters, offering a more accurate prediction.
Comparing both approaches shows how the Moon's terrain affects the timing and duration of occultations. A plot of the results without the terrain model is provided.

References

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[1] Allen Gift. An Archival Search and Analysis of X-Ray Occultations. 2025,Haverford College

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