AE502 Advanced Orbital Mechanics - HW Project 1

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1 Introduction

Interstellar objects passing through our Solar System have been one of the most amazing scientific discoveries of the last decade. Interstellar objects originate beyond our Solar System and travel on hyperbolic trajectories with respect to our Sun. 1I/'Oumuamua is a strange object that passed through our solar system in 2017, and is believed to be the first known interstellar object to have entered our solar system. The object was discovered on October 19, 2017, by the Pan-STARRS1 telescope in Hawaii [1]. It was initially thought to be a comet, but later observations showed that it did not have the expected coma, or cloud of gas and dust, that is typically associated with comets. Instead, it was determined to be an asteroid, although it was unlike any asteroid that had been seen before. One of the most puzzling aspects of 'Oumuamua is its trajectory. It came from the direction of the constellation Lyra, and its high speed and trajectory suggest that it did not originate in our solar system. Instead, it is believed to have come from another star system and was just passing through our solar system on its way to somewhere else.

Another such interstellar object was 2I/Borisov. Borisov is a comet that was discovered in August 2019 by Gennady Borisov [2]. It is believed to be the second known interstellar object to have entered our solar system. It was first spotted by the MARGO observatory in Nauchnij, Crimea [2]. Comet Borisov made its closest approach to the Sun in December 2019 and was visible from Earth for several months as it passed through our solar system. It was observed to have a coma, or a cloud of gas and dust that is typical of comets, as well as a long, faint tail. Since the discovery of comet Borisov, astronomers have been closely studying it in order to learn more about its composition, structure, and origin. The study of interstellar objects like asteroid Borisov is of great interest to scientists, as it can provide insight into the formation and evolution of other star systems in our galaxy.

2 Mission Interest

Studying interstellar objects passing through our solar system is important for several reasons. By studying these objects, scientists can gain insights into the processes that led to the formation of other solar systems and the conditions that existed in the early universe. Interstellar objects can provide clues about the composition, structure, and properties of other star systems in our galaxy. Interstellar objects may provide opportunities for future missions to explore and study objects outside of our own solar system. By studying these objects, scientists can identify potential targets for future missions and develop technologies and techniques for exploring the universe beyond our own backyard.

This report will try and determine whether a rendezvous or fly-by mission to such objects is feasible.

3 Methodology

To determine that these objects were indeed interstellar, the orbital elements of the objects were calculated. Subsequently, in order to determine whether a rendezvous or fly-by mission to such objects is feasible, several calculations were performed using established methods from Curtis, 2013 [3]. A Universal Variable two-body propagator was initially generated using Algorithms 3.3 and 3.4, followed by the use of a Lambert's solver based on Algorithm 5.2, to generate a range of departure and arrival dates and their corresponding ΔV values [3]. These results are presented in the next section.

4 Results

Initial state vectors for the epoch of 2017-January-01 at 00:00:00:0000 UTC i.e, JD 2457754.5 were considered. $r_E$and v_E are the initial state vectors of Earth. The units are in AU and AU/Day.

$$r_{1I} = \left[3.515868886595499 \times 10^{-2}, -3.162046390773074, 4.493983111703389\right]$$

$$v_{1I} = \left[-2.317577766980901 \times 10^{-3}, 9.843360903693031 \times 10^{-3}, -1.541856855538041 \times 10^{-2}\right]$$

$$r_{2I} = [7.249472033259724, 14.61063037906177, 14.24274452216359]$$

$$v_{2I} = \left[-8.241709369476881 \times 10^{-3}, -1.156219024581502 \times 10^{-2}, -1.317135977481448 \times 10^{-2}\right]$$

$$r_E = \left[-1.796136509111975 \times 10^{-1}, 9.667949206859814 \times 10^{-1}, -3.668681017942158 \times 10^{-5}\right]$$

$$v_E = \left[-1.720038360888334 \times 10^{-2}, -3.211186197806460 \times 10^{-3}, 7.927736735960840 \times 10^{-7}\right]$$

4.1 Orbital Elements

The orbital elements of the two objects were calculated to be -

	a(AU)	e	i (rad)	Ω(rad)	ω(rad)	f(rad)
1I/'Oumuamua	-1.2738	1.2009	2.1423	0.4292	4.2215	3.8683
2I/Borisov	-0.8509	3.3595	0.7682	5.3802	3.6482	4.5341

Table 1: Orbital Elements of 1I/'Oumuamua and 2I/Borisov.

The negative semi-major axis and an eccentricity $>$ 1 of the two objects implies that they are indeed on hyperbolic trajectories w.r.t the Sun, passing through the solar system.

4.2 Lambert's Solver

Pork chop plot with Δv values for 1I/'Oumuamua with departure dates from Earth in the range of January 2017 - December 2017 vs arrival dates in August 2017 - January 2019 for rendezvous $\left(\Delta v \leq 50\frac{km}{s}\right)$ and fly-by $\left(\Delta v \leq 20\frac{km}{s}\right)$ are as follows:

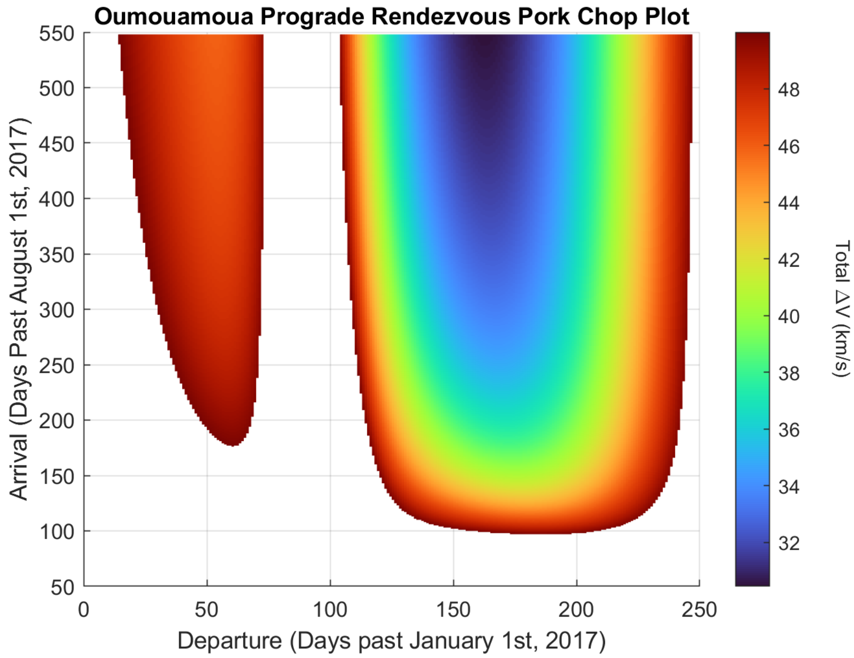

Figure 1: 1I/'Oumuamua rendezvous pork chop plot.

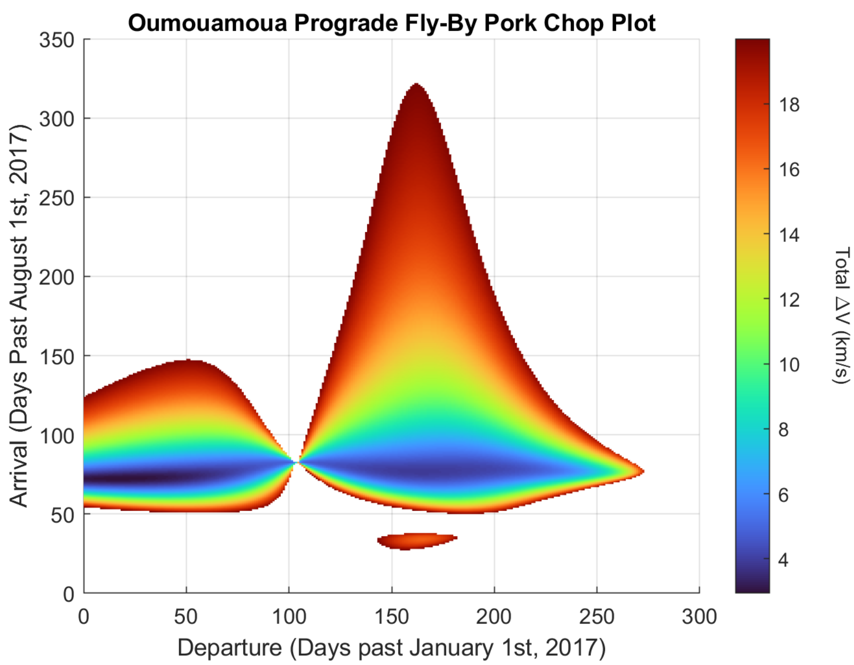

Figure 2: 1I/'Oumuamua fly-by pork chop plot.

Pork chop plot with Δv values for 2I/Borisov with departure dates from Earth in the range of January 2017 - July 2020 vs arrival dates in June 2019 - January 2022 for rendezvous $\left(\Delta v \leq 60\frac{km}{sec}\right)$ and fly-by $\left(\Delta v \leq 20\frac{km}{sec}\right)$ are as follows:

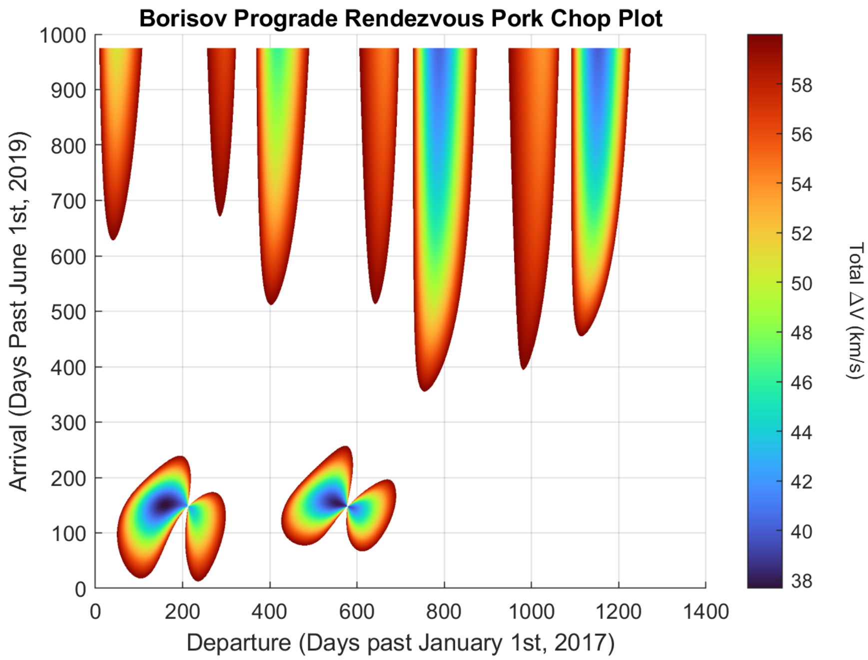

Figure 3: 2I/Borisov rendezvous pork chop plot.

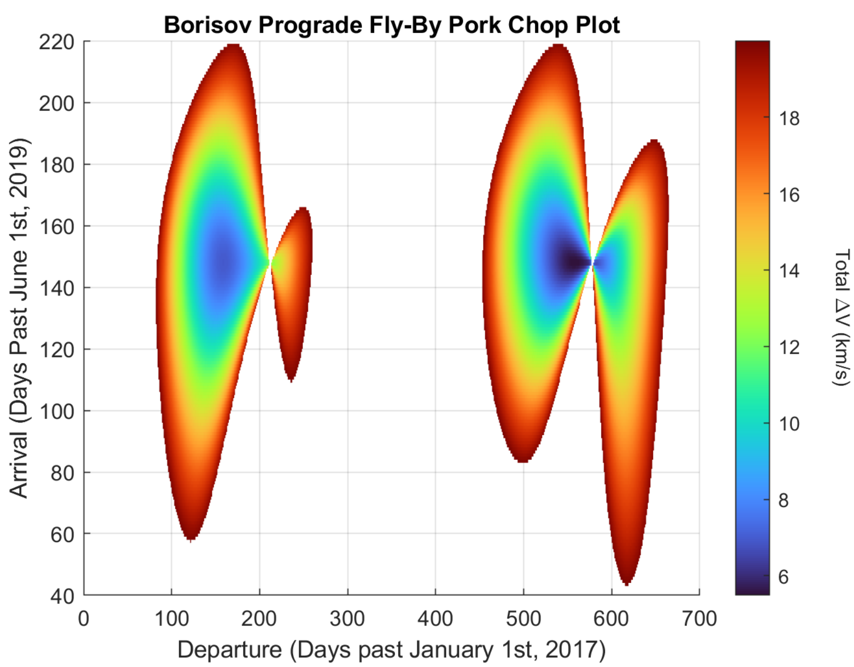

Figure 4: 2I/Borisov fly-by pork chop plot.

Looking at the above plots, rendezvous and fly-by missions to both the objects are feasible and realistic with the available mission Δv. Considering the extra Δv needed for rendezvous, the optimal mission type would be a fly-by to both the objects. As it is clear from the fly-by to 1I/'Oumuamua plot, there are a few departure and arrival windows (departing January-March

2017, and arriving October-November, 2017) where the Δv required is $\leq 4\frac{km}{s}$. This would be the ideal mission if minimizing Δv is the top priority.

5 Conclusion

In conclusion, studying interstellar objects passing through our solar system is important for a variety of reasons, including expanding our knowledge of other star systems and their formation, understanding the early history of our own solar system, and potentially detecting signs of life elsewhere in the universe. Additionally, studying these objects helps us to improve our detection and tracking capabilities, which is essential for protecting our planet from potential impacts. This report has determined that rendezvous and fly-by missions to both 1I/'Oumuamua and 2I/Borisov is realistic and feasible. As more interstellar objects are discovered and studied, we can expect to gain even more insights into the mysteries of our universe and our place within it.

References

[1] Karen J Meech, Robert Weryk, Marco Micheli, Jan T Kleyna, Olivier R Hainaut, Robert Jedicke, Richard J Wainscoat, Kenneth C Chambers, Jacqueline V Keane, Andreea Petric, et al. A brief visit from a red and extremely elongated interstellar asteroid. *Nature*, 552(7685):378–381, 2017.

[2] Cyrielle Opitom, Alan Fitzsimmons, Emmanuel Jehin, Youssef Moulane, Olivier Hainaut, Karen J Meech, Bin Yang, Colin Snodgrass, Marco Micheli, Jacqueline V Keane, et al. 2i/borisov: A c2-depleted interstellar comet. *Astronomy & Astrophysics*, 631:L8, 2019.

[3] Howard Curtis. *Orbital mechanics for engineering students*. Butterworth Heinemann, 2013.

Appendix

Link to GitHub repository:
https://github.com/ruthvik-bommena/AE502-Advanced-Orbital-Mechanics/tree/main/AE%20502%20HW%201