Sending a Spacecraft to Interstellar Comet C/2019 Q4 (Borisov)

Adam Hibberd¹, Nikolaos Perakis¹, and Andreas M. Hein^{*1}

¹Initiative for Interstellar Studies, 27-29 South Lambeth Road, London SW8 1SZ, United Kingdom

12th September 2019

Abstract

A potential second interstellar object C/2019 Q4 (Borisov) was discovered after the first known interstellar object 11/'Oumuamua. Can we send a spacecraft to this object, using existing technologies? In this paper, we assess the technical feasibility of a mission to C/2019 Q4 (Borisov), using existing technologies. We apply the Optimum Interplanetary Trajectory Software (OITS) tool to generate trajectories to C/2019 Q4 (Borisov). As results, we get the minimal DeltaV trajectory with a launch date in July 2018. For this trajectory, a Falcon Heavy launcher could have hauled a 2 ton spacecraft to C/2019 Q4 (Borisov). For a later launch date, results for a combined powered Jupiter flyby with a Solar Oberth maneuver are presented. For a launch in 2030, we could reach C/2019 Q4 (Borisov) in 2045, using the Space Launch System, up-scaled Parker probe heatshield technology, and solid propulsion engines. A CubeSat-class spacecraft with a mass of 3 kg could be sent to C/2019 Q4 (Borisov). If C/2019 Q4 (Borisov) turns out to be indeed an interstellar object, its discovery shortly after the discovery of 11/'Oumuamua implies that the next interstellar object might be discovered in the near future. The feasibility of a mission to both, 11/'Oumuamua and C/2019 Q4 (Borisov) using existing technologies indicates that missions to further interstellar objects are likely to be feasible as well.

1 Introduction

On October 19th, 2017, the first interstellar object 1I/'Oumuamua was discovered [4, 1, 6]. Almost two years later, a potential second interstellar object has been discovered. Due to their origin, interstellar objects might provide unique insights into properties of other star systems and the interstellar environment. Close-up observations of such objects would only be possible via spacecraft that perform a flyby or rendezvous with the interstellar object. We have previously shown that missions to 1I/'Oumuamua would be feasible using existing and near-term technologies with launch dates from today to several decades into the future [2, 3]. Seligman and Laughlin [5] have shown that missions to interstellar objects are feasible on short notice.

In this paper, we assess the principle feasibility of a mission to C/2019 Q4 (Borisov) using existing technologies.

2 Approach

We used the Optimum Interplanetary Trajectory Software (OITS) developed by Adam Hibberd for calculating the trajectory. OITS is based on a patched conic approximation. In other words, within the sphere of influence of a celestial body, only its respective gravitational attraction is taken into account. The gravitational attraction of other bodies is

^{*}Corresponding author. E-mail: andreas.hein@i4is.org

	rabie if failab for minimar bereat anote trajectory								
	Celestial body	Time	Arrival speed	Departure speed	DeltaV				
1	Earth	2018 JUL 13	0	5532.6	5532.6				
2	C/2019 Q4	2019 OCT 26	33581.7	33581.7	0				

Table 1: Values for minimal DeltaV direct trajectory

neglected. The trajectory connecting each pair of celestial bodies is determined by solving the Lambert problem using the Universal Variable Formulation [?], the resulting non-linear global optimization problem with inequality constraints is solved by the NOMAD solver [?].

3 Results

3.1 Direct transfer DeltaV surface

Figure 1 shows the DeltaV surface for a direct transfer from Earth to C/2019 Q4 (Borisov) with respect to flight durations ranging from 0 to 10,000 days (27 years) and launch dates from 2015 to 2050. The annual wave-like surface in the direction of the launch date indicates the DeltaV variation with respect to the Earth's position to the interstellar object. It can be seen that for flight durations of more than 20 years, the total DeltaV can be kept below 100 km/s, even for launch dates in 2050. However, these DeltaV values are still too high to achieve for existing chemical propulsion. In the following section, we will present one minimal DeltaV trajectory to C/2019 Q4 (Borisov), which would be feasible with existing chemical propulsion.



Figure 1: DeltaV surface for trajectories to C/2019 Q4 (Borisov)

3.2 Optimal direct trajectory

Figure 2 shows the result for an optimal DeltaV spacecraft trajectory (solid line) from Earth to recently discovered interstellar object C/2019 Q4 (Borisov). No constraints on the launch date and launch duration were imposed. The launch date for this optimal trajectory was in July 2018. Hence, we have missed the opportunity to send a spacecraft to Borisov directly at minimum DeltaV.

Table 1 shows key parameters for the trajectory. The spacecraft departs from Earth with a hyperbolic excess velocity of 5532.6 m/s. Arrival at C/2019 Q4 (Borisov) is about one year later in October 2019.

With a C3 of 30.6 km^2/s^2 , an existing Falcon Heavy launcher would be able to haul a payload of about two tons to C/2019 Q4 (Borisov).



Figure 2: Trajectory to C/2019 Q4 (Borisov)

	Fable 2. Values for Solar Oberth maneaver with powered supreer hysy							
	Celestial	Time	Arrival speed	Departure speed	DeltaV	Cumulative		
	body		[m/s]	[m/s]	[m/s]	DeltaV [m/s]		
1	Earth	2030 JAN 16	0	9201	9201	9201		
2	Jupiter	2031 NOV 13	8764	29860	6446	15646		
3	3SR	2032 JUL 22	356585	362199	5701	21348		
4	$\mathrm{C}/2019~\mathrm{Q4}$	2045 MAR 21	33616	33616	0	21348		

Table 2: Values for Solar Oberth maneuver with powered Jupiter flyby

3.3 Optimal trajectories for later launch dates

For later launch dates, the DeltaV increases to levels where no existing chemical propulsion system would be able to deliver the required DeltaV. One possibility to still reach an interstellar object is to use an Oberth maneuver. For an Oberth maneuver, the spacecraft is injected into a trajectory with a Perigee close to the Sun, where the spacecraft applies a boost. The closer the boost is applied to the Sun, the larger the gain in DeltaV. Additional flyby maneuvers are used to bring the spacecraft on the initial heliocentric trajectory. We have previously shown that using a combination of planetary flybys and a Solar Oberth maneuver, 1I/'Oumuamua can be reached with flight durations below 20 years and launch dates beyond 2030 [2, 3].

Here, we will use a combined Jupiter flyby and Solar Oberth maneuver to catch C/2019 Q4 (Borisov). Table 2 shows the results.

Figure 3 shows the corresponding trajectory. The green solid line depicts the outbound trajectory from Earth to Jupiter. The powered Jupiter flyby decelerates the spacecraft towards the Sun (blue solid line). At Perigee, the Oberth maneuver is performed and the spacecraft hauled out of the Solar system (solid red line).

The C3 of 84.7 km^2/s^2 , requires a Space Launch System (SLS) class launcher. A SLS Block 1 with a Delta Cryogenic Second Stage (DCSS) would result in a 6 ton payload. Using Star-type solid rocket boosters (Isp of 292 s) and an up-scaled Parker Probe heats hield, a spacecraft with a mass of about 3 kg can reach C/2019 Q4 (Borisov), as shown in Table 3. This much lower mass compared to the results for 1I/'Oumuamua (launch of a New Horizons-class spacecraft possible with SLS[2, 3]) is a consequence of the higher inclination of C/2019 Q4 (Borisov) and its higher hyperbolic excess velocity (30.7 km/s compared to 26.33 km/s for 1I/'Oumuamua).



Figure 3: Trajectory to C/2019 Q4 (Borisov) using a Jupiter flyby and Solar Oberth maneuver

Despite this very low mass, a CubeSat-scale spacecraft could be sent to the interstellar object. Existing interplanetary CubeSats (Mars Cube One) show that there is no principle obstacle against using such a small spacecraft to deep space. As previously indicated, the need for a significantly large aperture for detecting the interstellar object in deep space might constrain the minimal size of the spacecraft [2].

4 Conclusion

This paper assesses the technical feasibility of a mission to C/2019 Q4 (Borisov), using existing technologies. We apply the Optimum Interplanetary Trajectory Software (OITS) tool to generate direct and indirect trajectories to C/2019 Q4 (Borisov). The direct trajectory with a minimal DeltaV is identified as the one with a launch date in July 2018. For this trajectory, a Falcon Heavy launcher could have hauled a 2 ton spacecraft to C/2019 Q4 (Borisov). For indirect trajectories with a later launch date, results for a combined powered Jupiter flyby with a Solar Oberth maneuver are presented. For a launch in 2030, we could reach C/2019 Q4 (Borisov) in 2045, using the Space Launch System, up-scaled Parker probe heatshield technology, and solid propulsion engines. A CubeSat-class spacecraft with a mass of 3 kg could be sent to C/2019 Q4 (Borisov). If C/2019 Q4 (Borisov) turns out to be indeed an interstellar object, its discovery roughly two years after the discovery of 1I/'Oumuamua increases the likelihood that the next interstellar object might be discovered in the near

	Jupiter flyby	Solar Oberth
DeltaV [m/s]	6446	
Isp [s]	292	292
g $[m/s^2]$	9.81	9.81
Mass ratio	$_{9,5}$	7,3
Initial mass [kg]	6000	149
Final mass [kg]	632	20
Propellant mass [kg]	5368	129
Solid rocket booster dry mass [kg] (9 per cent)	483	12
Solid rocket booster wet mass [kg]	5851	140
Final mass [kg]		9
Heat shield mass [kg]		6
Spacecraft mass [kg]		3

Table 3: Results for a mission based on a SLS Block 1 and DCSS upper stage

future. The feasibility of a mission to both, 1I/'Oumuamua and C/2019 Q4 (Borisov) using existing technologies indicates that missions to further interstellar objects are likely to be feasible as well.

References

- Fabo Feng and Hugh R. A. Jones. 'Oumuamua as a messenger from the Local Association. The Astrophysical Journal Letters, 852(2):L27, nov 2017.
- [2] A.M. Hein, N. Perakis, T.M. Eubanks, A. Hibberd, A. Crowl, K. Hayward, R.G. Kennedy III, and R. Osborne. Project Lyra: Sending a spacecraft to 11/'Oumuamua (former A/2017 U1), the interstellar asteroid. Acta Astronautica, 2019.
- [3] A. Hibberd, A. M. Hein, and T. M. Eubanks. Project Lyra: Catching 1I/'Oumuamua-Mission Opportunities After 2024. arXiv preprint, 1902.04935, 2019.
- [4] J. Schneider. Is 1I/2017 U1 really of interstellar origin? Research Notes of the AAS, 1(1):18, 2017.
- [5] D. Seligman and G. Laughlin. The Feasibility and Benefits of In Situ Exploration of 'Oumuamua-like Objects. *The Astronomical Journal*, 155(5):217, 2018.
- [6] J. T. Wright. On Distinguishing Interstellar Objects Like 'Oumuamua From Products of Solar System Scattering. *Research Notes of the AAS*, 1(1):38, 2017.