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Intercepting 3I/ATLAS at Closest Approach to Jupiter with the Juno spacecraft

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ABSTRACT

The interstellar object 3I/ATLAS is expected to arrive at a distance of 53.56($\pm$0.45) million km (0.358 ± 0.003 au) from Jupiter on March 16, 2026. We show that applying a total thrust ΔV of 2.6755 km s^{-1} to lower perijove on September 9, 2025 and then execute a Jupiter Oberth Maneuver, can bring the Juno spacecraft from its orbit around Jupiter to intercept the path of 3I/ATLAS on March 14, 2026. We further show that it is possible for Juno to come much closer to 3I/ATLAS ($\sim$ 27 million km) with 110 kg of remaining propellant, merely 5.4% of the initial fuel reservoir. We find that for low available ΔV there is no particular benefit in application of a double impulse (for example to reach $\sim$ 27 million km from 3I/ATLAS), however if Juno has a higher ΔV capability there is significant advantage to a second impulse with typically a saving of propellant by a factor of a half. A close fly-by might be able to probe the nature of 3I/ATLAS far better than telescopes on Earth.

1. INTRODUCTION

The interstellar object 3I/ATLAS[1] was discovered on July 1, 2025 (Seligman et al. 2025; Loeb 2025; Bolin et al. 2025; Alvarez-Candal et al. 2025; Opitom et al. 2025; Chandler et al. 2025; Belyakov et al. 2025). It is expected[2] to arrive at a distance of 53.56($\pm$0.45) million km (0.358 ± 0.003 au) from Jupiter on March 16, 2026.

This close encounter provides a rare opportunity to shift the spacecraft Juno[3] from its current orbit around Jupiter to intercept the path of 3I/ATLAS at its closest approach to Jupiter. The instruments available on Juno, namely a near-infrared spectrometer, magnetometer, microwave radiometer, gravity science instrument, energetic particle detector, radio and plasma wave sensor, UV spectrograph and visible light camera/telescope, can all be used to probe the nature of 3I/ATLAS from a close distance.

Below we study the thrust required to shift Juno from its current orbit around Jupiter to a path that will intercept 3I/ATLAS in mid-March, 2026.

2. ORBIT CALCULATION

Our analysis exploits the software package known as *Optimum Interplanetary Trajectory Software* (OITS). Further information regarding OITS is provided by Hibberd (2017, 2022) and Hibberd et al. (2021). Two possible Non-Linear Problem (NLP) solver options are available for the work conducted here, namely NOMAD (Le Digabel 2011) or MIDACO (Schlueter et al. 2009; Schlueter & Gerdts 2010; Schlueter et al. 2013). This is a modified version of OITS in that the central body of interest is not the Sun but Jupiter. The data for Juno is taken from the SPICE data website (NAIF 2025), using the file *juno_pred_orbit.bsp*.

OITS solves the Lambert problem for one orbital cycle only: given two times t_1 and t_2, what are the 2 orbital arcs that connect them? Assuming that the positions at the beginning of the arc and the end of the arc are known, then there are 2 solutions, a short way and a long way, equivalent to an angular sweep, θ, and the retrograde angular sweep, $2\pi - \theta$. Here θ is found from the dot product of the initial and final position vector. Having determined the short way

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Number	Planet	Time	Arrival speed m/s	Departure speed m/s	ΔV m/s	Distance from Jupiter km	Perijove km
1	Juno	2025 AUG 11 03:19:36	0	3259.3	3259.3	2303610	63276
2	3I/ATLAS	2026 MAR 16 01:32:30	66129.2	66129.2	0	53392590	63276

Table 1. Pertinent trajectory data for an intercept of 3I/ATLAS with ΔV applied in mid-August, refer to the middle trough in Figure 2.

Number	Planet	Time	Arrival speed m/s	Departure speed m/s	ΔV m/s	Distance from Jupiter km	Perijove km
1	Juno	2025 SEP 12 22:29:49	0	3306.5	3306.5	2235639	60390
2	3I/ATLAS	2026 MAR 16 11:45:48	66068.9	66068.9	0	53331939	60390

Table 2. Trajectory data for an intercept of 3I/ATLAS with ΔV applied in mid-September, the trough on the right in Figure 2.

Number	Planet	Time	Arrival speed m/s	Departure speed m/s	ΔV m/s	Perijove km
1	Juno	2025 SEP 09 22:40:01	0	2157.4	2157.4	
2	2.68 Jupiter Radii	2025 SEP 14 18:37:14	35881.8	36388.6	518.1	120103
3	3I/ATLAS	2026 MAR 14 12:51:04	66536.8	66536.8	0	88660

Table 3. Jupiter Oberth Maneuver offers a lower ΔV requirement than the direct option

and long way solutions, the way with the maximum ΔV is rejected, leaving the desired, lowest ΔV, solution. This procedure is conducted iteratively with different trial values of t_1 and t_2 (within user-specified bounds), until OITS has converged on the overall minimum ΔV solution.

To solve the Lambert problem, the Universal Variable formulation is followed (Bate et al. 1971). We focus on an intercept (i.e. a flyby) since a rendezvous, where the target's velocity is matched by the spacecraft, is out-of-the-question, owing to the excessively high hyperbolic speed of 3I/ATLAS relative to Jupiter ($\sim 65.9\ \mathrm{km\,s^{-1}}$).

The binary SPICE kernel file for the interstellar object 3I/ATLAS was also extracted from the NASA Horizons service, on July 18, 2025.

Using the approach outlined above, color contour maps were generated by OITS for a Juno ΔV application window covering the present as at the time of writing (July 27, 2025) to the point at which the data in the binary SPICE file for Juno expires (September 17, 2025), marking the possible end of the mission which is currently scheduled to occur around that time.

The feasibility of intercepting 3I/ATLAS depends on the current amount of fuel available from the propulsion system of Juno. However, some inferences can be drawn from the total ΔV available at the beginning of the Juno mission. On its interplanetary trajectory, Juno conducted 2 Deep Space Maneuvers (DSMs), and 1 Jupiter orbital insertion, both of which would have placed a significant demand on the chemical propulsion employed by Juno (Hydrazine and oxidizer nitrogen tetroxide).

Let us assume a total initial wet mass of the spacecraft M_{tot}, a dry mass of M_{dry}, and a specific impulse given by I_{sp}, then the total ΔV available to Juno is given by:

$$\Delta V = I_{sp}\ g\ ln\left(\frac{M_{tot}}{M_{dry}}\right) \tag{1}$$

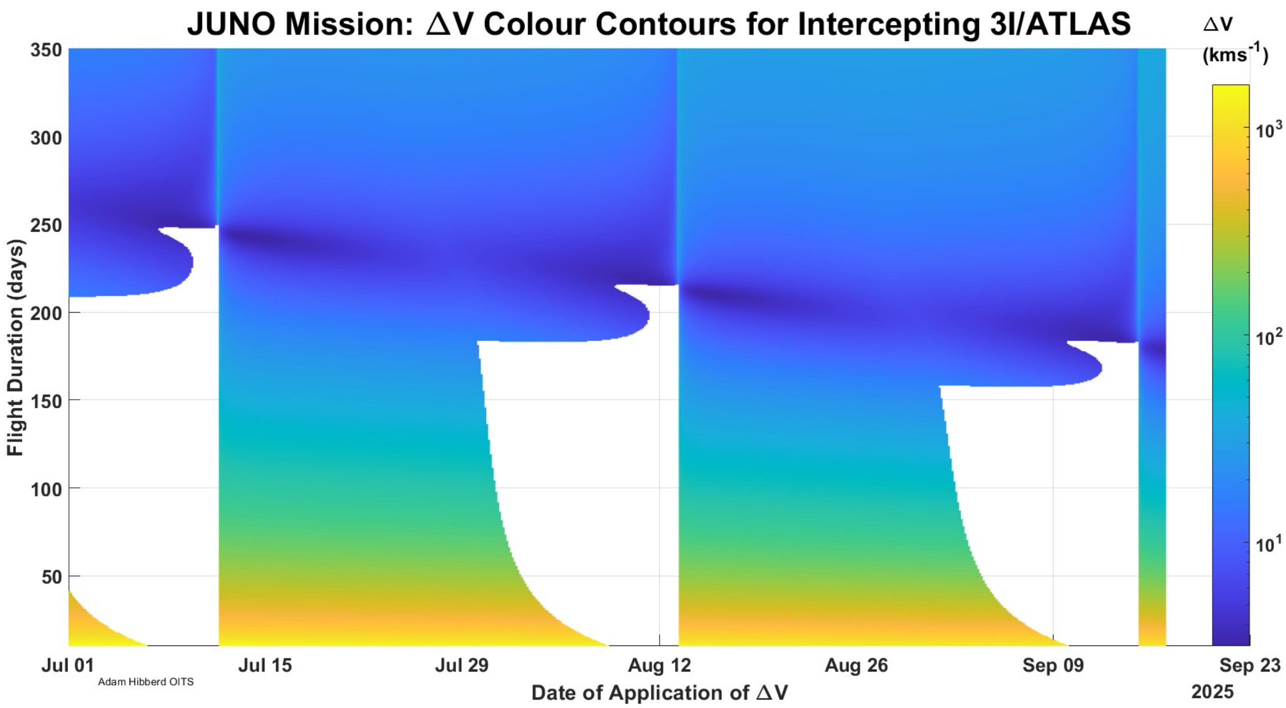

Figure 1. Pork Chop indicating required ΔV for the JUNO spacecraft to intercept 3I/ATLAS (logarithmic scale).

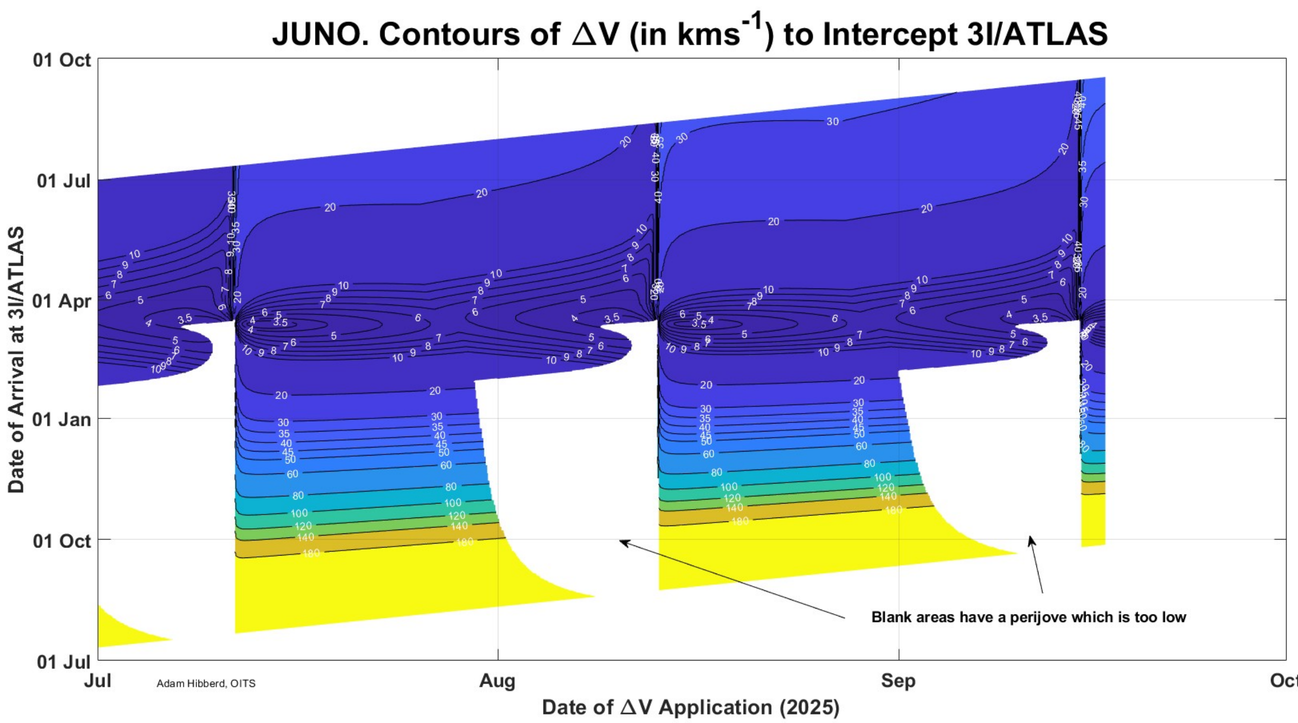

Figure 2. Contours of ΔV needed to intercept 3I/ATLAS, note there are two opportunities before the binary SPICE kernel data ends on September 17, 2025.

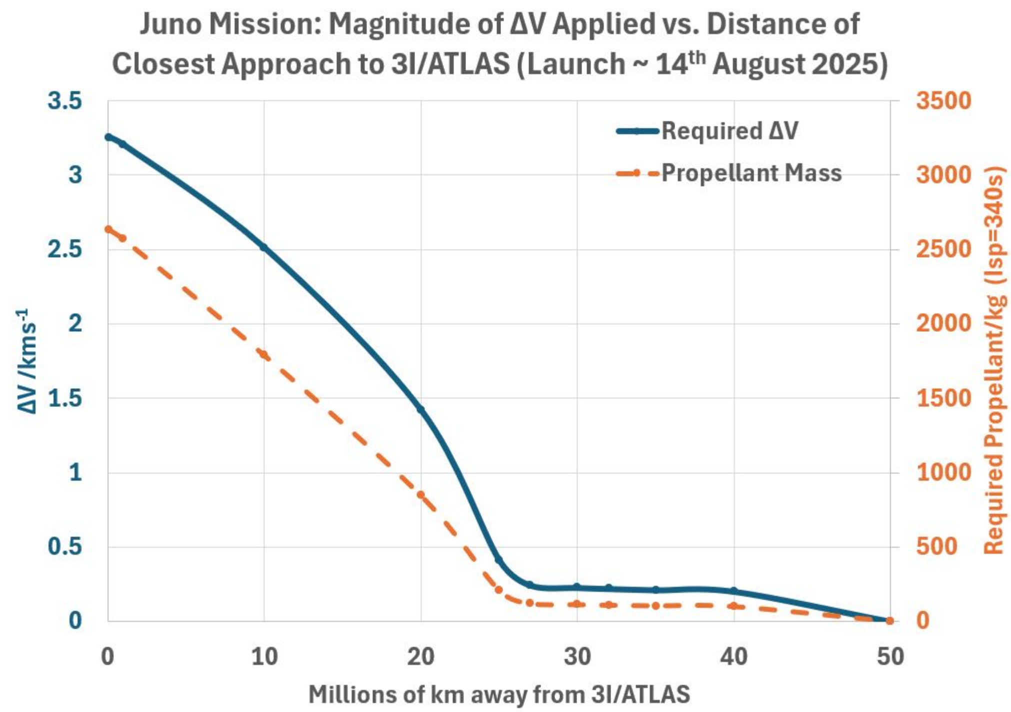

Figure 3. Thrust impulse ΔV (left vertical axis) and propellant mass (right vertical axis) needed for Juno to come within a range of distances from 3I/ATLAS (horizontal axis). The launch date is assumed to be August, 14 2025.

where $g = 9.8\ \mathrm{m\,s^{-2}}$.

The data for the above parameters can be sourced from Earth Observation Portal (2021). Thus, we have $M_{tot} = 3625$ kg and $M_{dry} = 1593$ kg. For the specific impulse we assume an optimistic $I_{sp} = 340$ s, giving an overall initial ΔV available of $2.74\ \mathrm{km\,s^{-1}}$.

This value is similar to the required ΔV for Juno to intercept 3I/ATLAS, given in Tables 1-3. Although the engine of Juno was not operated since 2016, the required ΔV might potentially be within Juno's performance envelope. In that case, Juno would be able to get close to 3I/ATLAS and use its instruments to probe the nature of the interstellar object and any cloud of gas or dust around it.

The optimal option involves a Jupiter Oberth Maneuver which requires an application of ΔV on September 9, 2025, only 8 days prior to the originally intended termination date for Juno's plunge into the atmosphere of Jupiter. Having delivered this thrust to diminish Juno's altitude, a further ΔV is subsequently delivered, constituting a Jupiter Oberth Maneuver and resulting in an eventual intercept of the target 3I/ATLAS on March 14, 2026. Refer to Table 3 for more details. In total, an overall ΔV of $(2.1574 + 0.5181) = 2.6755\ \mathrm{km\,s^{-1}}$ is utilized.

If doable, this exciting new goal will rejuvenate Juno's mission and extend its scientific lifespan beyond March 14, 2026.

So far, we have examined a zero distance intercept of Juno with 3I/ATLAS. It is salient at this juncture to ask the question: "how close can Juno approach 3I/ATLAS, given that it has a limited remaining propellant mass, and so a restricted ΔV?".

We investigate the mid-August 2025 opportunity first. Figure 3 assumes a rocket specific impulse, $I_{sp} = 340$s and uses equation (1) to derive the required propellant mass for a given ΔV. We find that a relatively low ΔV is needed ($< 0.23\ \mathrm{km\,s^{-1}}$, equivalent to a propellant mass of ~ 110 kg which is merely 5.4% of the initial fuel reservoir)

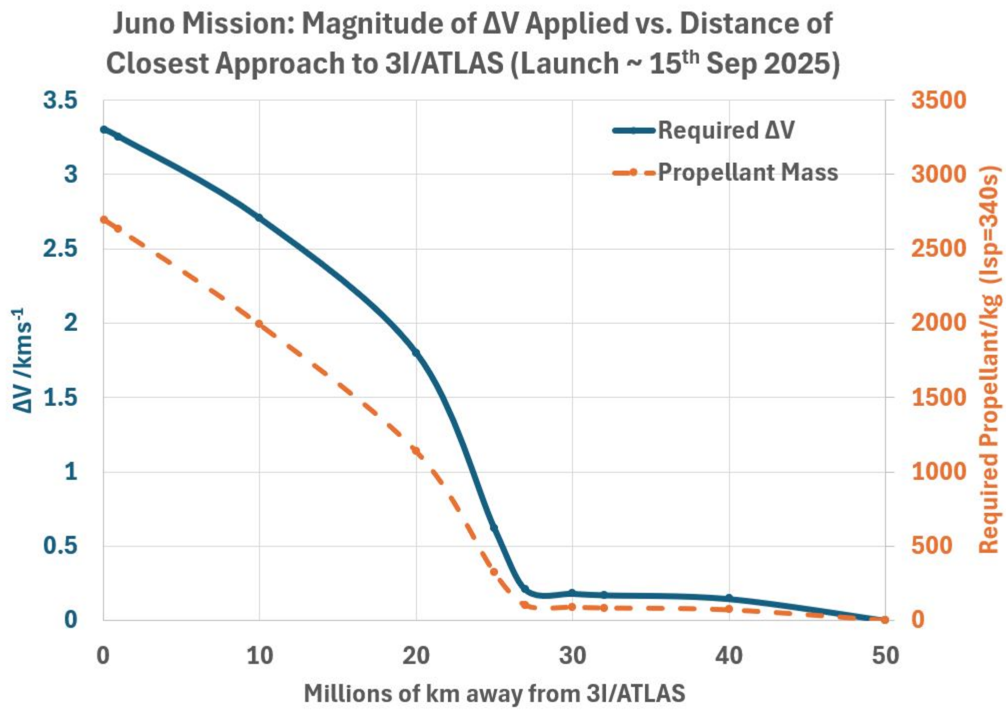

Figure 4. Thrust impulse ΔV (left vertical axis) and propellant mass (right vertical axis) needed for Juno to come within a range of distances from 3I/ATLAS (horizontal axis).The launch date is assumed to be September 15, 2025.

to approach 3I/ATLAS within a distance of 27 million km. Below $\sim$ 27 million km, the required ΔV rises significantly until it reaches 3.3 $\mathrm{km\,s^{-1}}$ at zero distance as determined in the preceding analysis results, presented in Table 1.

Figure 4 refers to the September 2025 opportunity and shows a similar behavior with similar levels of required ΔV and propellant mass, though the advantage of this option is that it provides a month of extra time to prepare for the maneuver.

There would potentially be a lower overall ΔV requirement with more than one impulse application. For simplicity, we investigate here only the double impulse case and focus on the mid-September 2025 launch. Figure 5 compares the ΔVs of the double impulse with the single impulse option. There is a significant drop in the required ΔV for the double impulse scenario. Figure 6 shows how this ΔV translates to required propellant, implying a factor of a half reduction in needed propellant mass in order to get to a distance of 10 million km from 3I/ATLAS.

Figure 7 shows the distribution of ΔV between the 1^{st} impulse (blue section) and 2^{nd} impulse (red section), indicating that for the situation where only small ΔVs are available (i.e. closest approach to 3I/ATLAS $>$ 25 million km) there is no benefit at all with choosing the additional impulse. We note that the double impulse is more challenging to realize given the limited time remaining for preparation.

3. DISCUSSION

We have found that the application of a thrust of 2.6755 km $\mathrm{s^{-1}}$ on September 9, 2025, can potentially shift the Juno spacecraft from its orbit around Jupiter to intercept the path of 3I/ATLAS on March 14, 2026. With Juno's many instruments, a fly-by can probe the nature of 3I/ATLAS far better than telescopes on Earth.

We have further shown that much closer distances to 3I/ATLAS ($\sim$ 27 million km) can be achieved with smaller ΔV requirements should Juno have a relatively low level of propellant mass remaining.

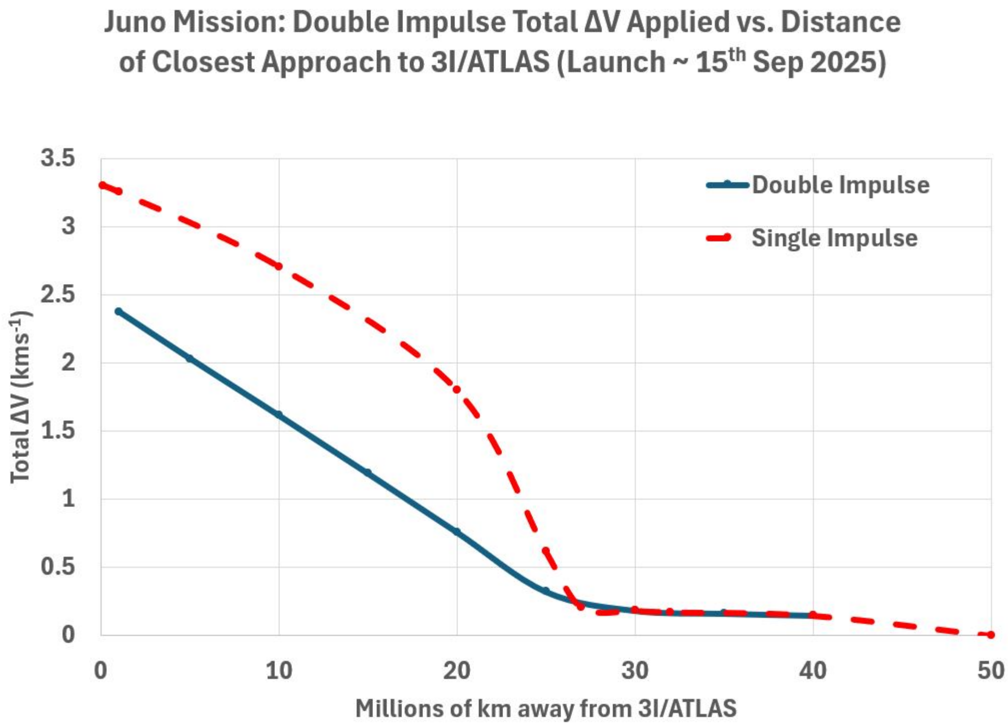

Figure 5. Double Impulse scenario (assuming the opportunity around September 15, 2025) compared to the single impulse option, implying a significant reduction in required total ΔV.

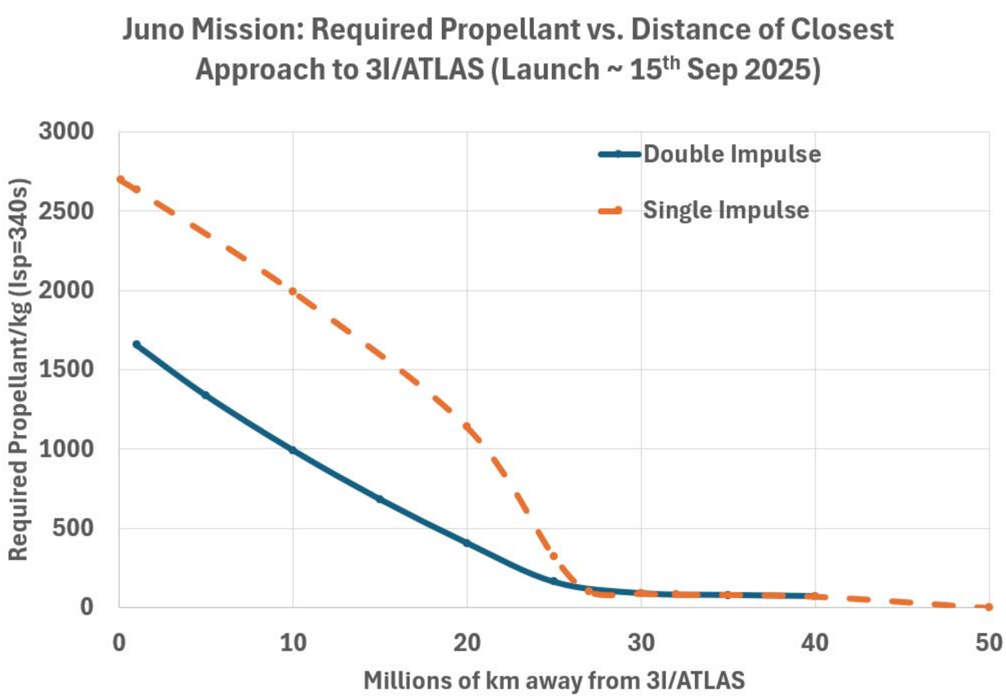

Figure 6. Double Impulse scenario compared with the single impulse option, as for Figure 5, in terms of required propellant mass.

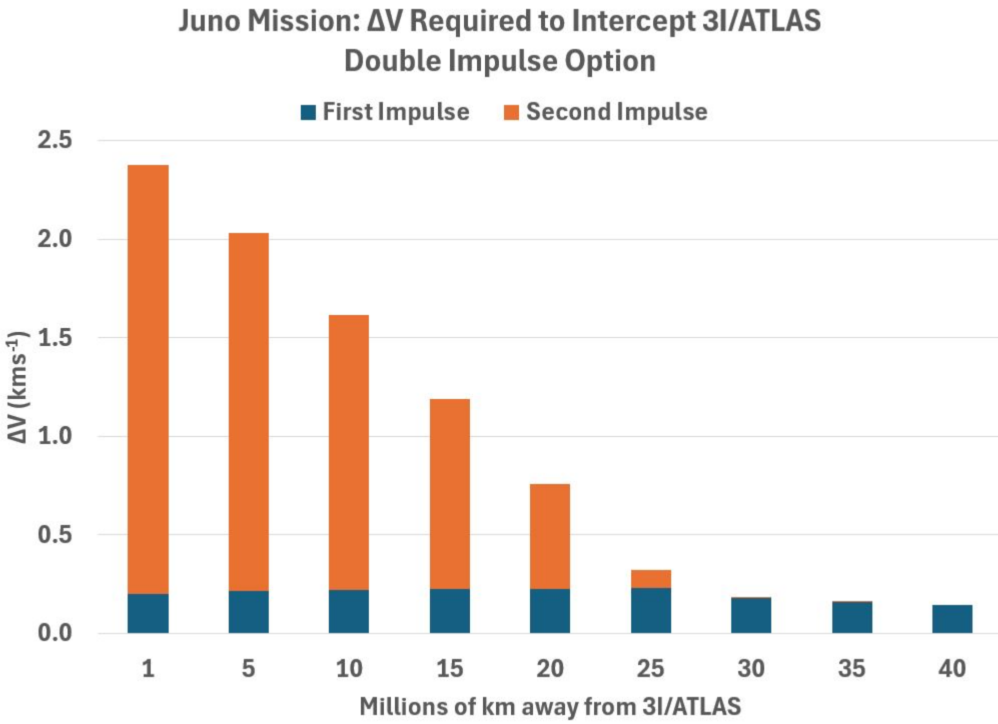

Figure 7. Double Impulse scenario: how the ΔV is distributed between the 1^{st} impulse (blue section) and 2^{nd} impulse (red section).

Small corrections to Juno's path might be needed if cometary activity of 3I/ATLAS will be intensified as it comes closer to the Sun and its non-gravitational acceleration will change its expected trajectory.

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REFERENCES

Alvarez-Candal, A., Rizos, J. L., Lara, L. M., et al. 2025, X-SHOOTER Spectrum of Comet C/2025 N1: Insights into a Distant Interstellar Visitor. https://arxiv.org/abs/2507.07312

Bate, R. R., Mueller, D. D., & White, J. E. 1971, Fundamentals of astrodynamics (New York: Dover Publications)

Belyakov, M., Fremling, C., Graham, M. J., et al. 2025, Research Notes of the American Astronomical Society, 9, 194, doi: 10.3847/2515-5172/adf059

Bolin, B. T., Belyakov, M., Fremling, C., et al. 2025, Interstellar comet 3I/ATLAS: discovery and physical description. https://arxiv.org/abs/2507.05252

Chandler, C. O., Bernardinelli, P. H., Jurić, M., et al. 2025, arXiv e-prints, arXiv:2507.13409, doi: 10.48550/arXiv.2507.13409

Earth Observation Portal. 2021, Juno Mission to Jupiter. https://www.eoportal.org/satellite-missions/juno#launch

Hibberd, A. 2017, Github repository for OITS. https://github.com/AdamHibberd/Optimum_Interplanetary_Trajectory

Hibberd, A. 2022, arXiv e-prints, arXiv:2205.10220. https://arxiv.org/abs/2205.10220

[4] https://lweb.cfa.harvard.edu/~loeb/APL_NASA.pdf

Hibberd, A., Perakis, N., & Hein, A. M. 2021, Acta Astronautica, 189, 584, doi: https://doi.org/10.1016/j.actaastro.2021.09.006

Le Digabel, S. 2011, ACM Transactions on Mathematical Software (TOMS), 37, 44

Loeb, A. 2025, Research Notes of the AAS, 9, 178, doi: 10.3847/2515-5172/adee06

NAIF. 2025, PLanetary Data System Navigation Node. https://naif.jpl.nasa.gov/pub/naif/JUNO/kernels/spk/

Opitom, C., Snodgrass, C., Jehin, E., et al. 2025, Snapshot of a new interstellar comet: 3I/ATLAS has a red and featureless spectrum. https://arxiv.org/abs/2507.05226

Schlueter, M., Egea, J., & Banga, J. 2009, Computers and Operations Research, 36, 2217, doi: 10.1016/j.cor.2008.08.015

Schlueter, M., Erb, S., Gerdts, M., Kemble, S., & Ruckmann, J. 2013, Advances in Space Research, 51, 1116, doi: 10.1016/j.asr.2012.11.006

Schlueter, M., & Gerdts, M. 2010, Journal of Global Optimization, 47, 293, doi: 10.1007/s10898-009-9477-0

Seligman, D. Z., Micheli, M., Farnocchia, D., et al. 2025, Discovery and Preliminary Characterization of a Third Interstellar Object: 3I/ATLAS. https://arxiv.org/abs/2507.02757