# Interstellar Interceptors
## Mission design for rendezvous with objects in hyperbolic orbits

Jorge Martínez

Supervised by:

Josep M. Trigo-Rodríguez (ICE-CSIC/IEEC)
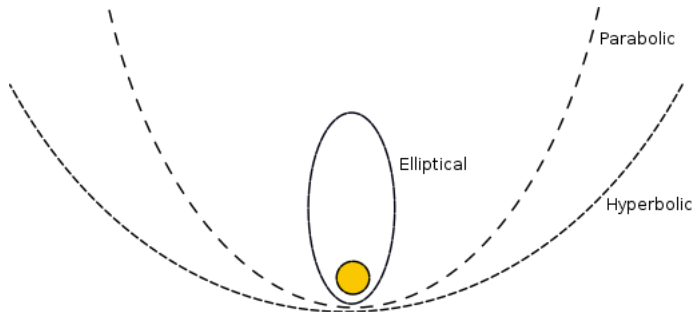Eloy Peña-Asensio (Politecnico di Milano)

Universidad Internacional de Valencia

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# What are interstellar objects?

**Definition**

Interstellar objects (ISOs) are asteroids, comets or planetary bodies moving through interstellar medium (ISM) without being gravitationally bound to a star.



ISOs follow hyperbolic orbits

# Why are interstellar objects important?

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- Exploring their physical and chemical composition
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## Motivation of this work

Design orbits for rendezvous with ISOs to study their physical properties.

There are two confirmed ISOs to this day:



1I/'Oumuamua

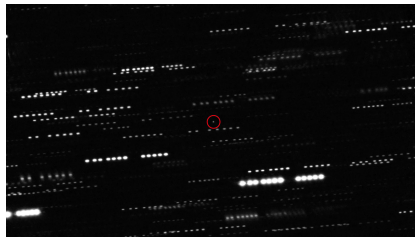ESO's VLT and GST Telescopes



2I/Borisov

NASA Hubble Space Telescope

# Discovered interstellar objects

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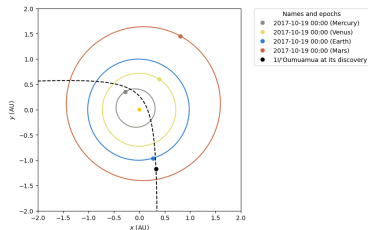ESO's VLT and GST Telescopes
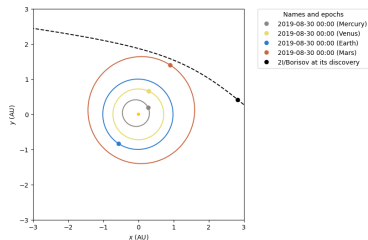


2I/Borisov

NASA Hubble Space Telescope

These interlopers present the following orbit attributes:

- Hyperbolic orbits
- High relative velocity w.r.t. the Sun
- Random inclination
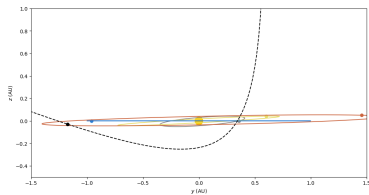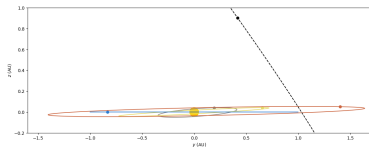- Discovered close to the direction of the Solar Apex

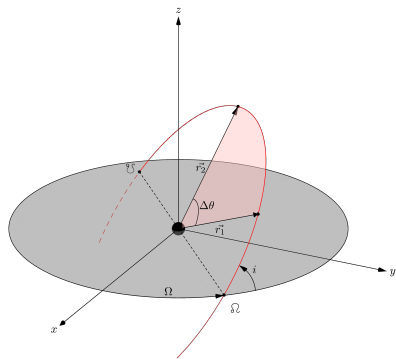1I/'Oumuamua orbit top view



1I/'Oumuamua orbit side view



2I/Borisov orbit top view



2I/Borisov orbit side view

# Navigating through space: the Lambert's problem

Lambert's problem is the Boundary Value Problem (BVP) in the context of the restricted two-body problem dynamics.



$$\ddot{\vec{r}} = -\frac{\mu}{r^3}\vec{r} \quad \left\{ \begin{array}{l} \vec{r}\left(t_1\right) = \vec{r_1} \\ \vec{r}\left(t_2\right) = \vec{r_2} \end{array} \right.$$

Geometry of the Lambert's problem

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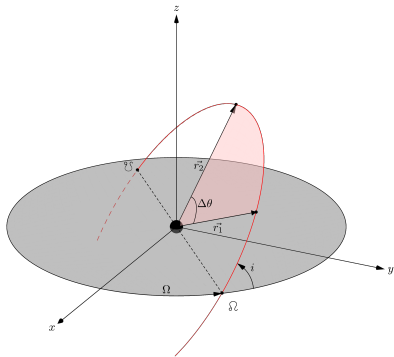


Geometry of the Lambert's problem

$$\ddot{\vec{r}} = -\frac{\mu}{r^3}\vec{r} \quad \begin{cases} \vec{r}(t_1) = \vec{r_1} \\ \vec{r}(t_2) = \vec{r_2} \end{cases}$$

Solve for the orbit which passes through $\vec{r_1}$ and $\vec{r_2}$ over a finite amount of time $\Delta t = t_2 - t_1$.

# Estimating the cost of the maneuver using the $C_3$ energy

Lambert's problem computes the initial velocity $\vec{v_1}$ and final velocity $\vec{v_2}$ of the orbit.

- First impulse: $\Delta v_1 = \| v_1 - v_{\text{origin}} \|$
- Last impulse: $\Delta v_2 = \| v_2 - v_{\text{iso}} \|$

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The total cost of the maneuver is $\Delta v = \Delta v_1 + \Delta v_2$. This relates with the fuel mass via the Tsiolkovsky rocket equation:

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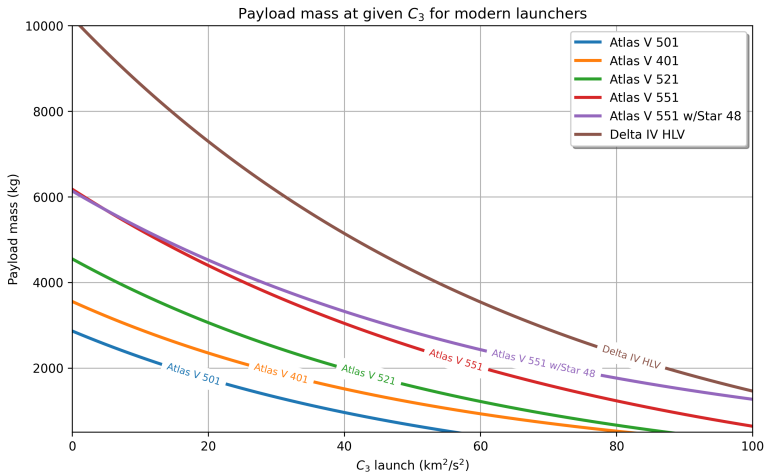- Last impulse: $\Delta v_2 = \|v_2 - v_{\text{iso}}\|$

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The characteristic energy for hyperbolic orbits $C_3$ is defined as:

$$C_3 = v_\infty^2$$

# Modern launching technologies



Maximum payload mass vs. $C_3$ energy for different launchers

# Minimizing the cost of the maneuver

Porkchop plots are used to find the optimal launch and arrival dates by solving Lambert's problem for a variety of trajectories.

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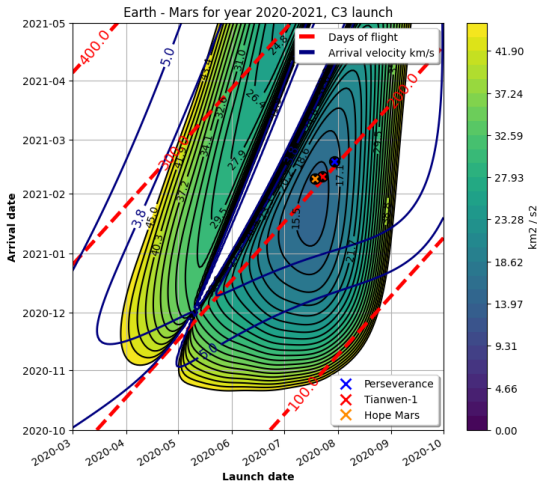


Porkchop plot between Earth and Mars

## Analyzed scenarios

The analyzed scenarios in this work for each discovered ISO include:

- Direct transfer between the Earth and the ISO
- Direct transfer between the L2 point and the ISO

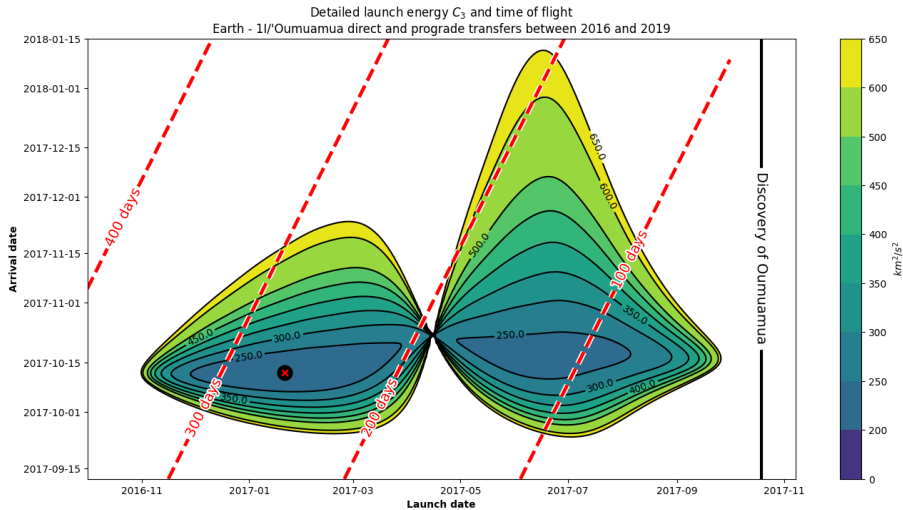# Analyzed scenarios

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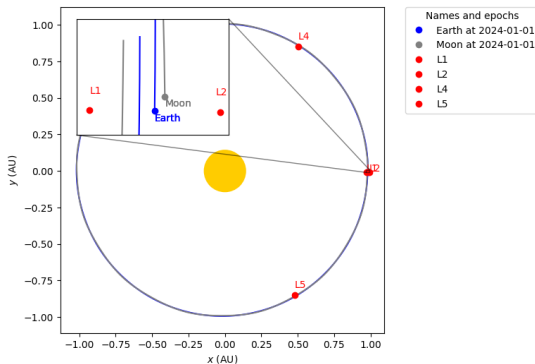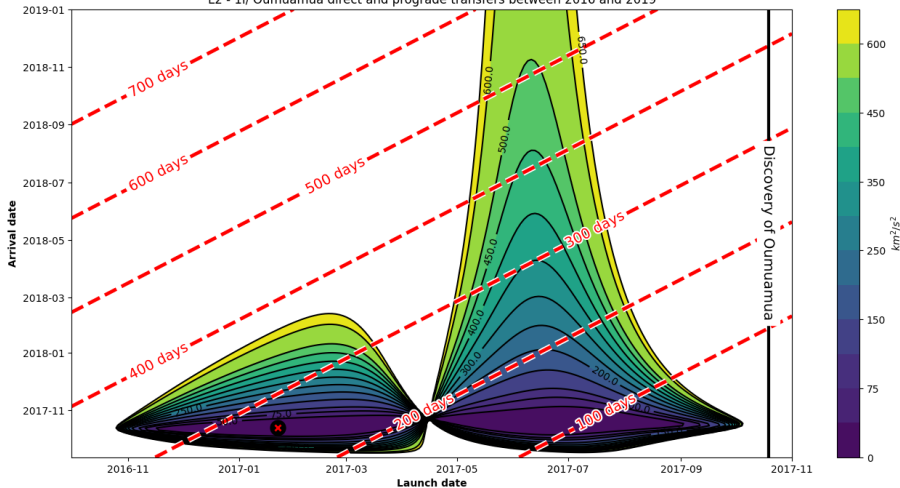


Lagrange points for the Sun Earth-Moon system

Direct transfer from Earth

Direct transfer from L2

# 1I/'Oumuamua: summary of results

| $\Delta v$ launch Earth [km/s] | $\Delta v$ launch L2 [km/s] | Reduction [%] |
|---|---|---|
| 13.85 | 3.80 | 72.56 |

Launch energy comparison

| $\Delta V$ arrival Earth [km/s] | $\Delta V$ arrival L2 [km/s] | Reduction [%] |
|---|---|---|
| 62.33 | 61.46 | 1.40 |

Arrival velocity comparison

| $C_3$ launch Earth [km$^2$/s$^2$] | $C_3$ launch L2 [km$^2$/s$^2$] | Reduction [%] |
|---|---|---|
| 192.00 | 14.41 | 92.51 |

Characteristic energy comparison

Direct transfer from Earth
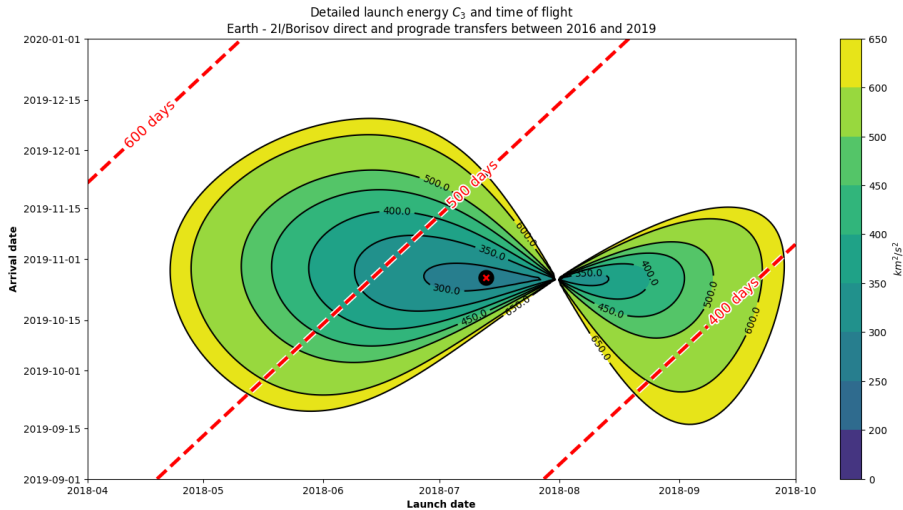
Direct transfer from Earth

# 2I/Borisov: summary of results

| $\Delta v$ launch Earth [km/s] | $\Delta v$ launch L2 [km/s] | Reduction [%] |
|---|---|---|
| 16.90 | 5.85 | 65.38 |

Launch energy comparison

| $\Delta V$ arrival Earth [km/s] | $\Delta V$ arrival L2 [km/s] | Reduction [%] |
|---|---|---|
| 33.00 | 33.02 | -0.06 |

Arrival velocity comparison

| $C_3$ launch Earth [km$^2$/s$^2$] | $C_3$ launch L2 [km$^2$/s$^2$] | Reduction [%] |
|---|---|---|
| 286.00 | 34.30 | 88.08 |

Characteristic energy comparison

# Conclusions

## L2 as the optimal launching point

Launching an intercepting spacecraft from L2 is more fuel efficient. These results agree with the ones presented by the Comet Interceptor mission.

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## Need of increased vigilance in the search for ISOs

Both optimum transfer dates take place prior the discovery of 1I/'Oumuamua and 2I/Borisov. Surveillance of the sky is crucial to detect future ISOs.

# Future work

## Generating a synthetic population of ISOs

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## Drafting optimum transfers

Optimum transfers can be solved for previous synthetic data. Solutions would be used by future missions parked at L2.

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## Trajectory optimization

A combination of multiple gravity assists and deep space maneuvers may allow for a more efficient transfer to an ISO, depending on the scenario.

# References

All this work is reproducible, including figures and results.
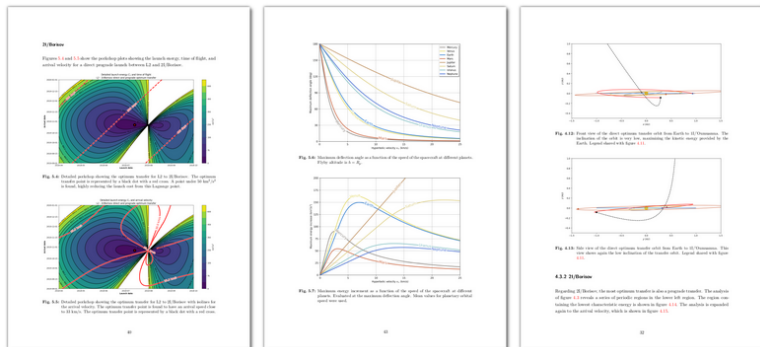


Document and figures generated via LaTeX and Python

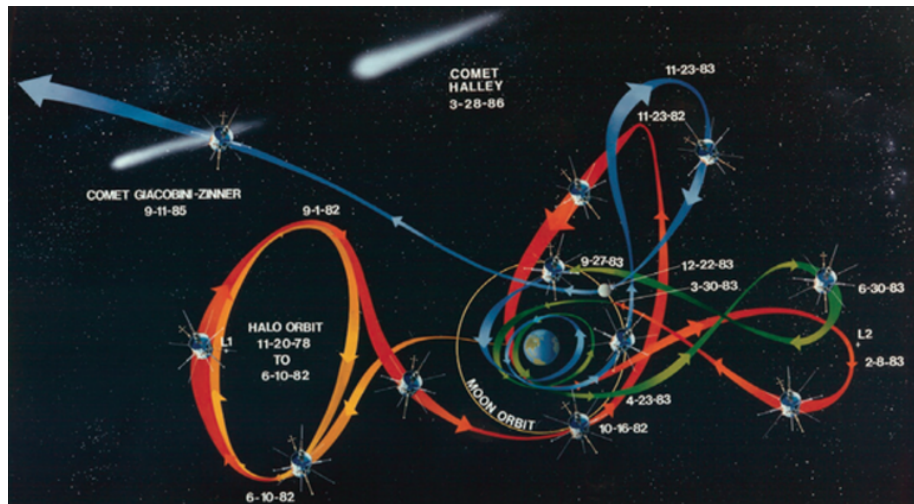## Official repository

All source code is hosted in **https://github.com/jorgepiloto/tfm**

1I/'Oumuamua shape
Illustration by William Hartmann/Michael Belton/AP

ISEE-3 mission
Illustration by NASA
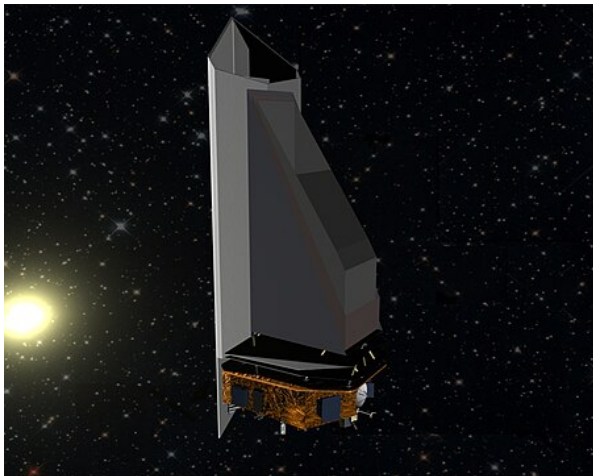
NEO surveyor
Illustration by NASA
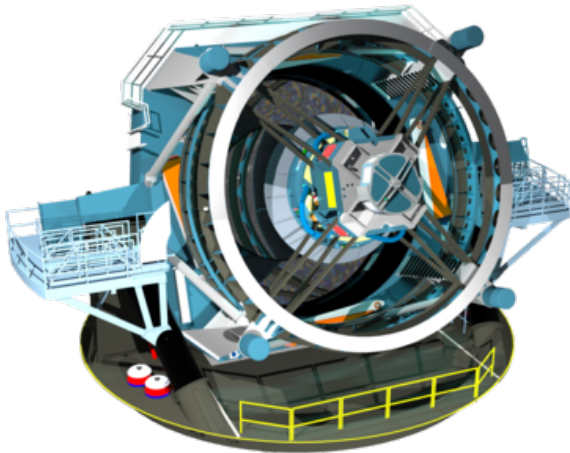
LSST
Illustration by LSST Project Office