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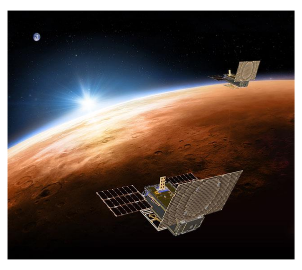
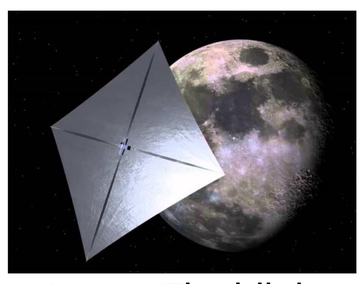
A CubeSat-based Minimal Interstellar Mission

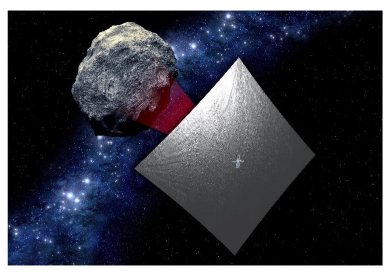
Introduction

CubeSats for interplanetary missions

Mars Cube One, Lunar Flashlight, and NEA Scout.


Mars Cube One


Lunar Flashlight

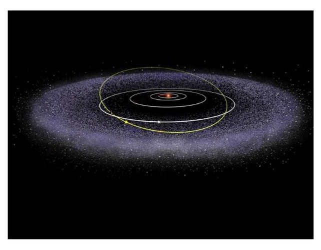

NEA Scout

Images: NASA

Is a CubeSat-based Solar System escape mission feasible?

Potential targets

Images: NASA / ESO


Kuiper belt objects (> 30 AU)


Interstellar objects (1I 'Oumuamua)


Planet Nine (200 – 1200 AU)


Other stars (> 268,000 AU)

For all targets, high **solar system hyperbolic excess velocities > 20 km/s (4.2 AU/a)** are required.

Why a CubeSat?

- Availability of off-the-shelf technologies for deep space missions in the future
- Low mass: launch as secondary payload, low launch cost, multiple spacecraft

Science Objectives

1. Determine properties of the **interstellar medium**
2. Determine properties of the **heliopause**
3. In-situ observations of **minor bodies** (interstellar asteroids / comets, Kuiper belt objects) and **planets** (Planet Nine)
4. In-situ analysis of ejecta of **minor bodies** (interstellar asteroids / comets, Kuiper belt objects)

Potential Science Payload

Payload	Associated science objective
Dust counter	Determine properties of the interstellar medium
Large aperture camera	In-situ observations of minor bodies (interstellar asteroids / comets, Kuiper belt objects) and planets (Planet Nine)
Small Impactor	In-situ analysis of ejecta of minor bodies (interstellar asteroids / comets, Kuiper belt objects)
Mass spectrometer	In-situ analysis of ejecta of minor bodies (interstellar asteroids / comets, Kuiper belt objects)
Magnetometer	a) Determine properties of the heliopause b) In-situ observations of minor bodies (interstellar asteroids / comets, Kuiper belt objects) and planets (Planet Nine)

Potential to use femto and atto-scale spacecraft (ChipSats) swams for distributed measurements.

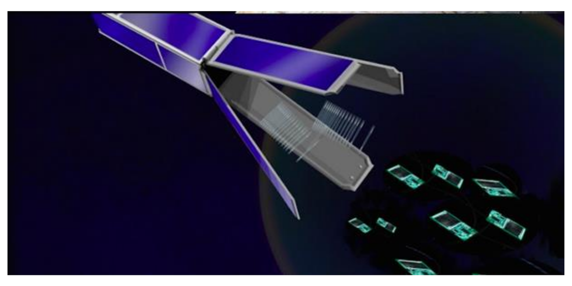


Image: DraperLabs

Key Technologies

Propulsion

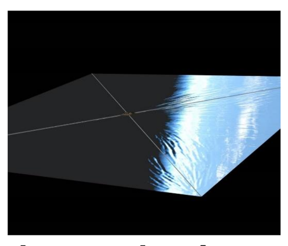

Advanced solar sail
(LightSail-1, LightSail.2, Lunar Flashlight, NEA Scout)

Image: Adrian Mann


Electric sail
(ESTCube-1, ESAIL FP7, ESTCube-2)

Image:Finnish Meteorological Institute

Solar system hyperbolic excess [AU/a] vs trip duration [years]	Kuiper belt objects (30 AU)	'Oumuamua (launch in 2028)	Planet Nine (200-1200 AU)	Proxima Centauri (268,000 AU)
6	5	14	33-200	44,600
7	4	10	29-171	38,230
8	3.7	8	25-150	33,450
9	3.3	6	22-133	29,700
10	3	5	20-120	26,800
11	2.7	5	18-109	24,300

Both technologies are capable of reaching **solar system hyperbolic excess velocities of at least 40 – 50 km/s (8.4 – 10.5 AU/a)**.

Power

Technology	Specific power	Potential
RTG	2-2.2 We/kg	Specific power marginal
Alphavoltaics	0.33 We/kg	Specific power too low
Betavoltaics		Too heavy; too short half-life of Tritium / Promethium-147
CubeSat Nuclear D-cell battery (Thermophotovoltaics)	12-16 We/kg	Acceptable specific power
Microbal battery		Insufficient stability


CubeSat nuclear D-cell battery
(Howe et al., 2012)

Thermophotovoltaics seems to be the most promising technology for deep space CubeSat missions

Communication

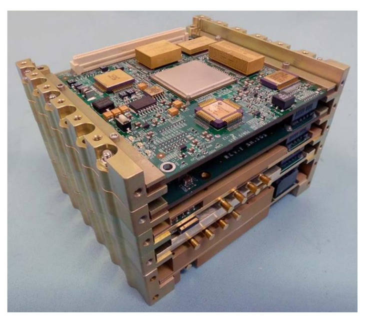

Transponder
(JPL Iris deep space transponder: 0.5 U; 1.2 kg; 26 W)

Image: JPL


Optical communication
(further miniaturization of existing technologies required, e.g. JPL 1U optical com system)

Image: JPL

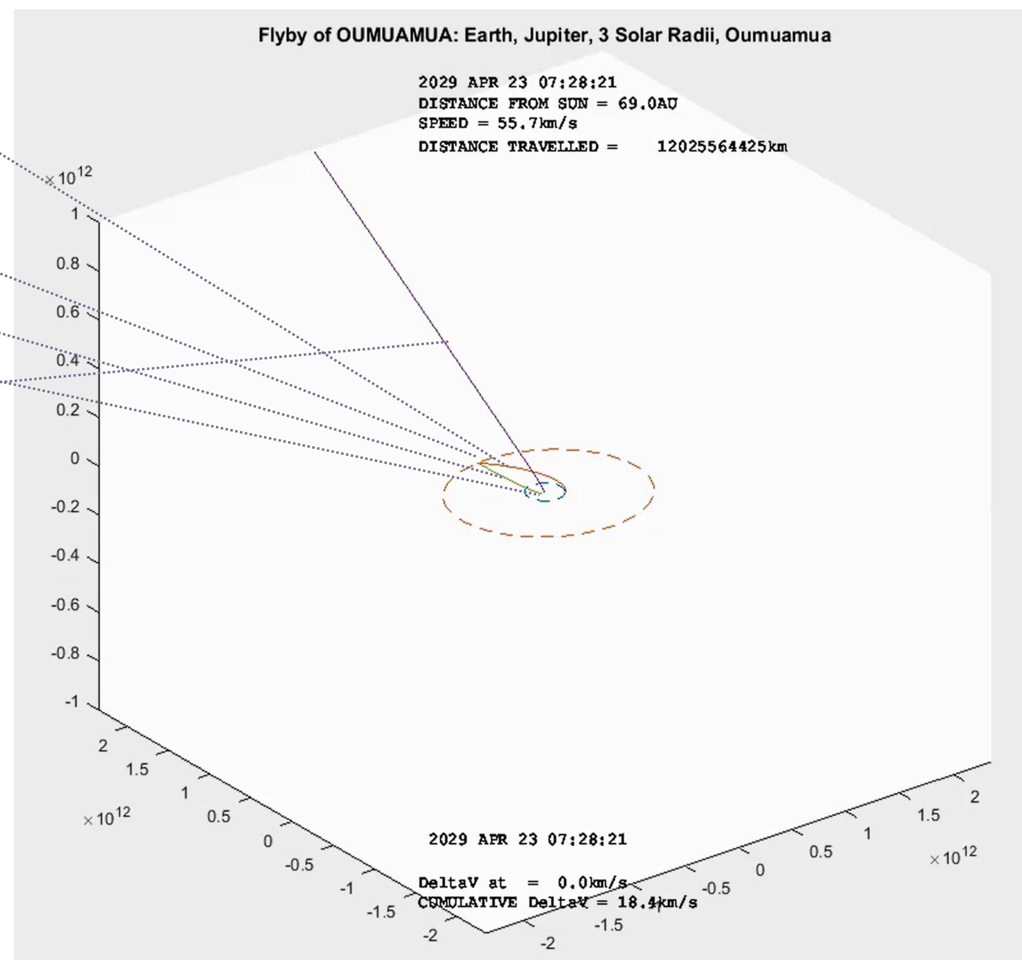
Performance of existing CubeSat optical communication technologies **requires improvement** (pointing accuracy, single-photon detectors)

Sample Mission Concepts

Oberth maneuver 1: Jupiter-Solar Oberth maneuver

Mission phases:

1. Earth escape trajectory to Jupiter
2. Flyby at Jupiter
3. Solar approach trajectory
4. Boost at Perihelion
5. Solar system escape trajectory



(Hein et al., 2017)

Oberth maneuver 2: Starshot prototype laser infrastructure

Mission phases:

1. Geostationary or highly elliptic orbit
2. Laser boost
3. Solar approach trajectory
4. Boost at perihelion
5. Solar system escape trajectory

References

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- A. Rajguru, N. Jerred, S. D. Howe, & A. Faler (2014). Laser Space Communication Concept for deep-space interplanetary missions using CubeSats. In *45th AIAA Plasmadynamics and Lasers Conference* (p. 2234).
- A. Soni, C. Welch, M. Langer, «Minimal Interstellar Precursor Mission», 67th Astronautical Congress (IAC), Guadalajara, Mexico

Conclusions

- CubeSat solar system escape missions are likely feasible in the **next 10-20 years**
- Key technologies are currently **under development** for interplanetary CubeSat missions
- Key technologies require **further performance increase**: optical communication, advanced laser sails, power generation, miniaturized science instruments (impactor), CubeSat-sized heat shield for solar Oberth maneuver

iCubeSat Conference 2018
29.-30.5.2018, École Normale Supérieure / l'Observatoire de Paris, Paris