Multipoint observations of Europa plumes using FemtoSat swarm

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Motivation

Since the space race, the exploration of the space has been a priority for most countries. Not only the purpose has been to explore, but additionally, to discover new materials and different forms of life to cure incurable diseases nowadays here on Earth. For these purposes, mankind has escaped earth gravitational field and travelled to different planets and moons. One of these is Europa, one of Jupiter's moons, where scientists have discovered water ejected in plumes.

Figure 1: Europa illustrations.

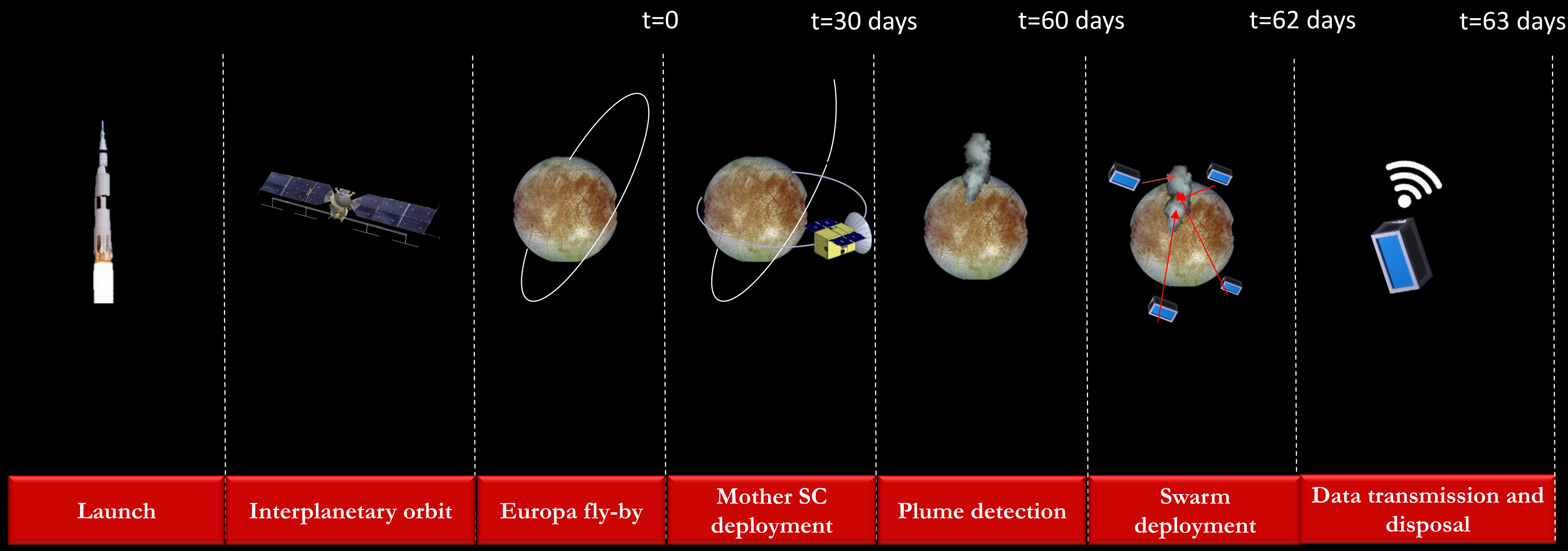
Objective

The main objective of this research is to develop a first design mission to look for life in the plumes of Jupiter's moon, Europa, using a secondary payload in NASA Clipper's mission. For that purpose, a swarm of FemtoSats is used.

Method

The mission design is divided into three parts: modelling Europa's plumes, study the different trajectories that the FemtoSats could follow to study the plume (basically orbit design) and finally in collaboration with Colorado School of Mines design the FemtoSats and build some prototypes.

Concept of operation



Part 1: Modelling Europa plumes

This part looks to recreate the model proposed by [1] to analyze what the shape of the plume is, what is the maximum time of flight (TOF) of a particle, the maximum height that particles can reach and the area over the surface where the particles are placed.

Part 2: Orbit design

Based on the results obtained in part one the aim now is to design an orbit as stable as possible to minimize the fuel consumption to maintain a mother spacecraft in a non-colision trajectory so that if a plume is detected the FemtoSats inside the mother spacecraft are deployed. For this section the main sources are [2] and [3].

Part 3: FemtoSat swarm organization to search for life in plumes

Once a plumed is detected and the FemtoSats are deployed there are multiple strategies consider in first place. First, deploy the FemtoSats in orbit and look for life in each turn. Second, launch the FemtoSats in the opposite direction to the mother board trajectory with the final aim of having a free fall over the plume and the plume would slow down the FemtoSats. There must be noticed that Part 2 and Part 3 are highly coupled due to the fuel consumption.

Plume modeling

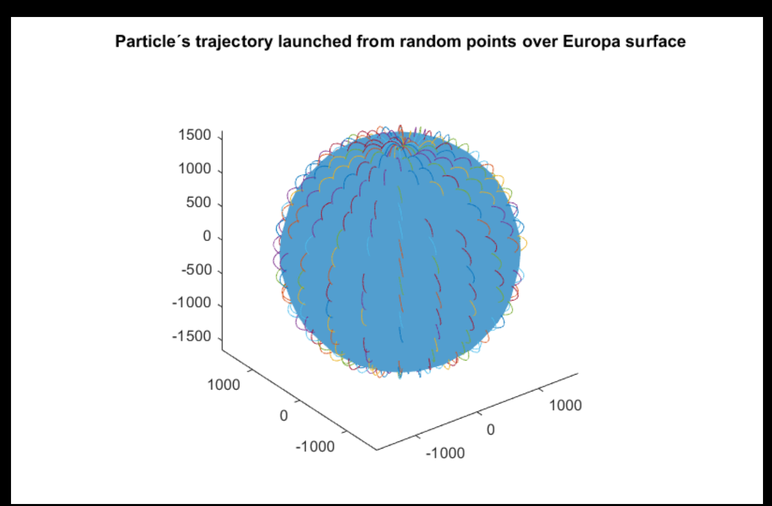
Plumes are modeled based on the data we have from Enceladus. [1] and [2] provide the following probability distribution function (PDF)

$$p(v|r) = \left(1+\frac{r}{r_c}\right)\frac{r}{r_c}\frac{v}{v_{gas}^2}\left(1-\frac{v}{v_{gas}}\right)^{\left\{\frac{r}{r_c}-1\right\}}$$

And for the particle trajectory around Jupiter,

$$\ddot{r} = -\frac{\mu_J}{|\boldsymbol{r}|^5}\left\{\left[|\boldsymbol{r}|^2-\frac{3}{2}J_2R_J^2(5\sin^2\delta-1)\right]\boldsymbol{r}+3J_2R_J^2\boldsymbol{e_z}\boldsymbol{r_z}\right\}-\mu_E\frac{(\boldsymbol{r}-\boldsymbol{r_E})}{|\boldsymbol{r}-\boldsymbol{r_E}|^3}$$

Analysis of time of flight (TOF) as a function of latitude and longitude:



Simulated speed: v_{gas}
Max TOF: 1231 s
Mean TOF: 1229 s
Min TOF: 1228 s

Figure 2: Particle's trajectories for v_{gas}.

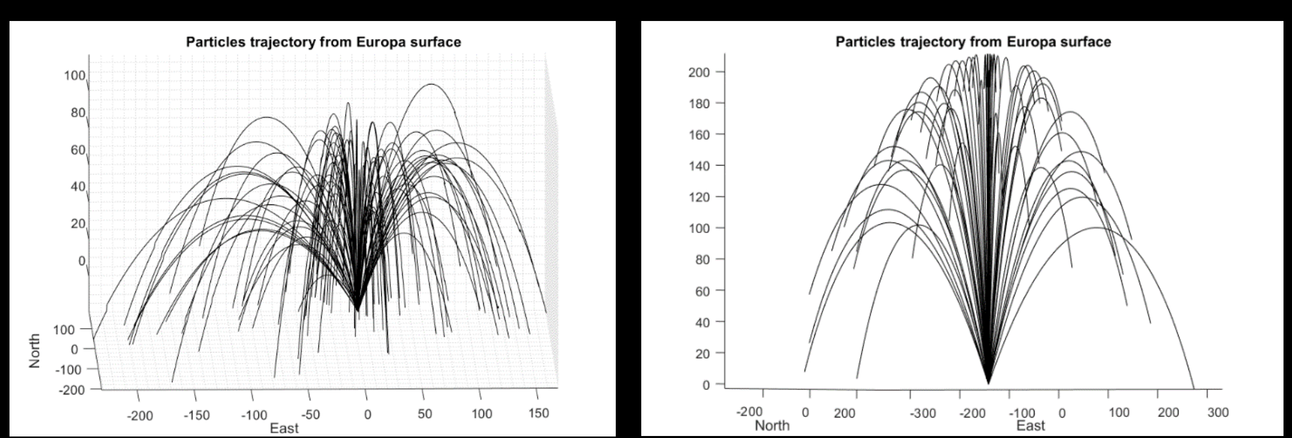


Figure 3: Plumes shape for v_{gas}.

Orbit design

Once the plume shape is known the CubeSat containing the swarm has to be deployed. Then it will follow an orbit that is below 150 km of height so that it can remain in a stable orbit for the maximum period possible minimizing fuel consumption. The challenge here is that Europa's orbits tend to become unstable if the inclination is between 44 and 139 degrees.

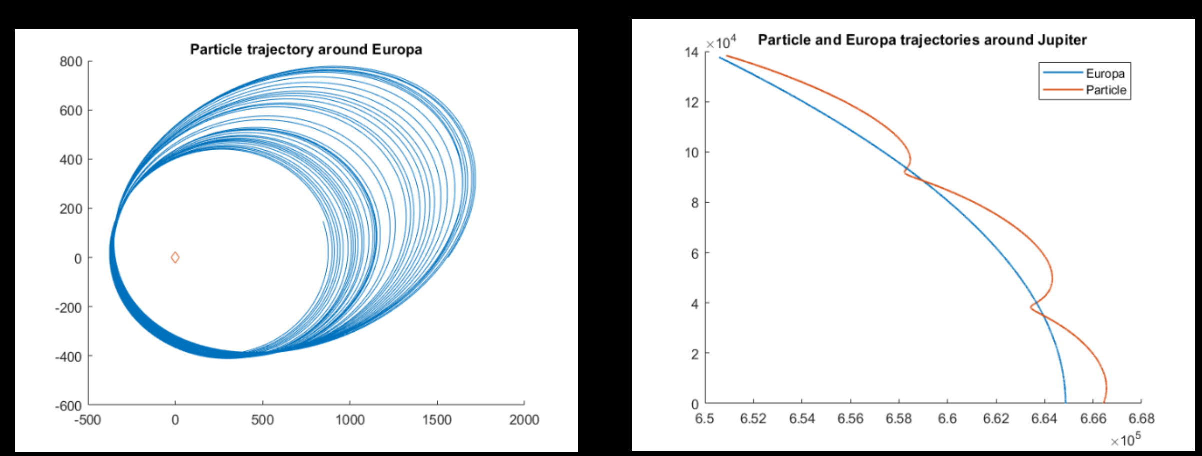


Figure 4: Unstable orbit trajectories around Europa

FemtoSat design

The FemtoSats are mainly equipped with tinyduino software. The main components are a battery, processor, IMU and a spectrometer.

In addition, these FemtoSats would have a radio to transmit the information back to the mother SC and from there it would be sent back to Earth.

FemtoSats characteristics:

- Mass around 100g
- Manufacturing cost around $300 (without spectrometer)
- Launching cost $3000
- Approximate power to keep equipment functioning: 155 mW

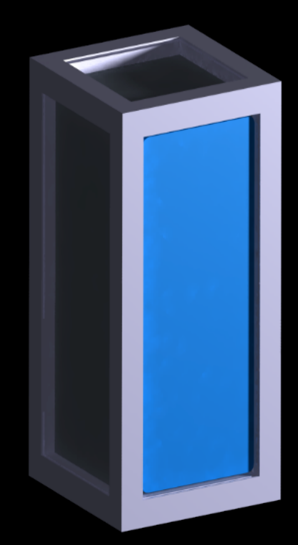


Figure 5: 2F FemtoSat

References

[1] B. S. Southworth, S. Kempf and J. Schimdt, "Modelling Europa's dust plumes" Geophysical Research Letter, vol 42, pp. 10541-10548, 2015.
[2] J. Schimdt, N. Brilliantov, F. Spahn, S. Kempf, "Slow dust in Enceladus' plume from condensation and wall collisions in tiger stripe fractures" Nature, vol 451, 2008