To the Moon and beyond by CubeSats: Advantage or Adventure?

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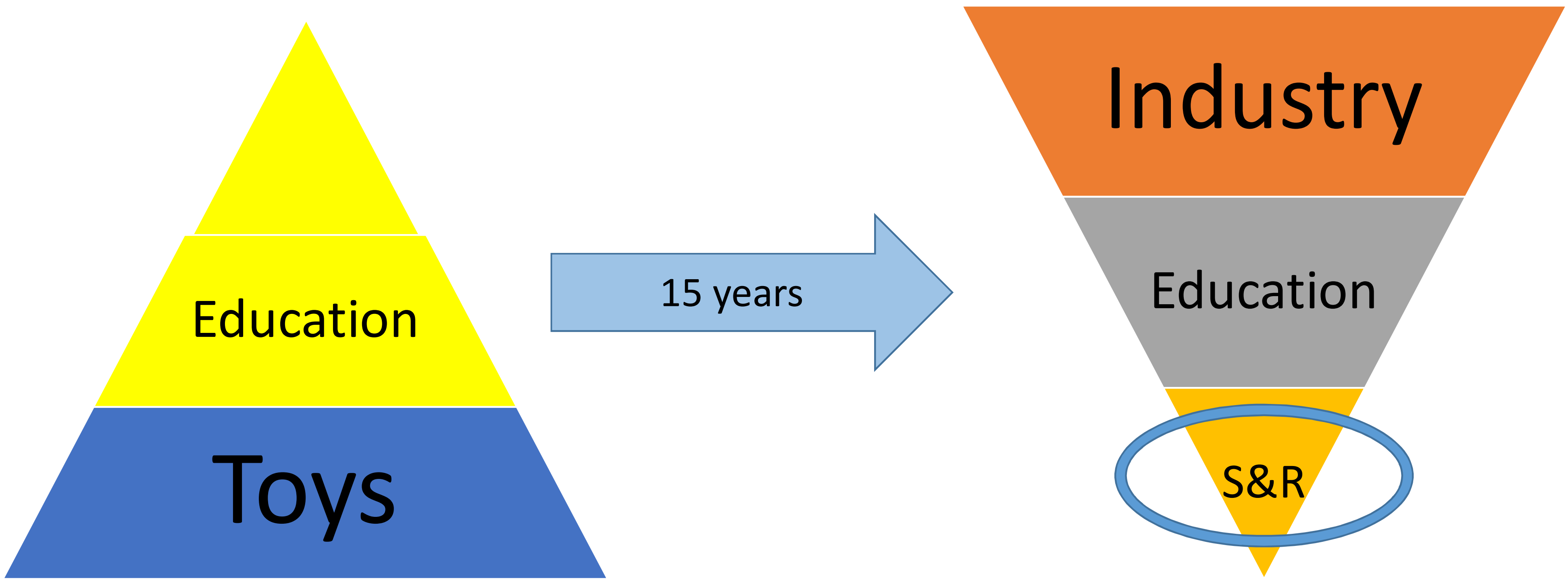
The motto of the 5th IAA Conference on University Satellite Missions:

Getting closer to Mars,

i.e. Cubesats and microsats for interplanetary missions

Cubesats Evolution



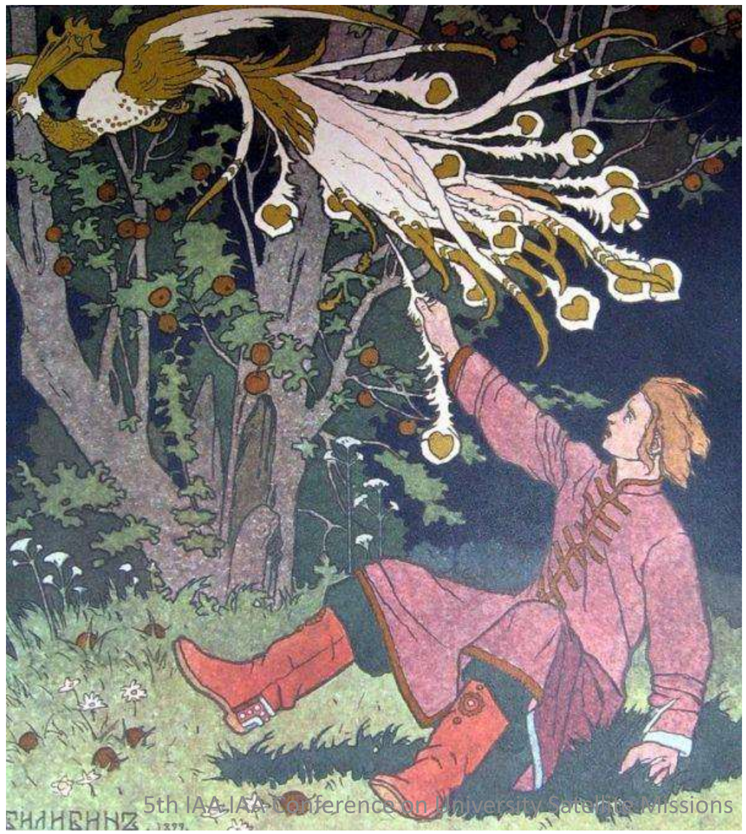
Science & Research

- Interplanetary missions require an extreme effort in various branches of science and technology due to unknown factors effecting the satellite

- Cubesats’ small size, mass and other limitations and constrains aggravate the difficulty of mission design

- The interplanetary missions based on Cubesats is the guiding star for research and, consequently, for invention and new scientific and technological results

We still have a chance to count Cubesats-candidates for interplanetary missions …

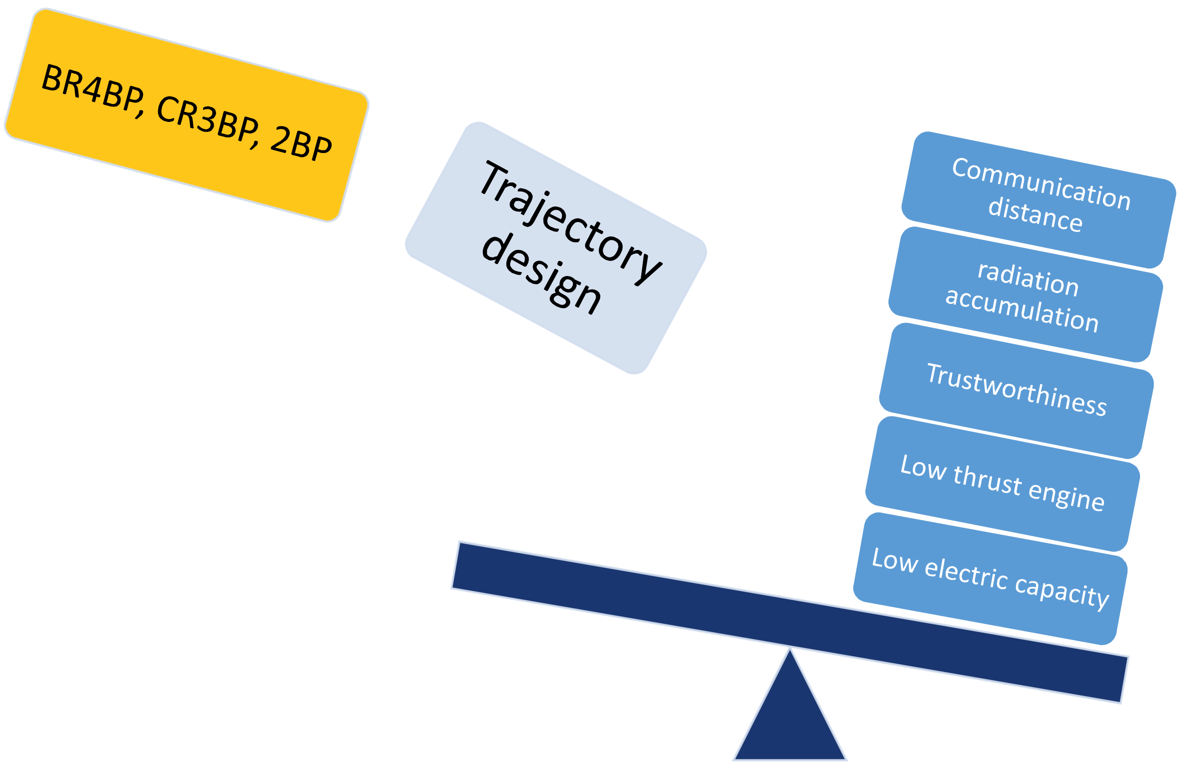


…like when Ivan Tsarevich was lucky to see and to grab the Firebird by the tail but only a feather of a wonderful bird remained in his hand

The“feather” generates two meanings

- Cubesats for the interplanetary missions as a subset of Cubesats
- Among a variety of problems to be solved while developing an interplanetary mission, the “necessary” condition for the mission to be developed is a required transportation trajectory design

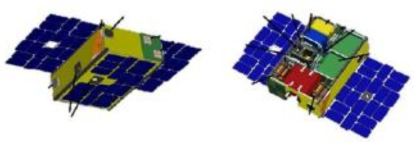
Constrains & limitations to overcome



Primary interplanetary Cubesat missions

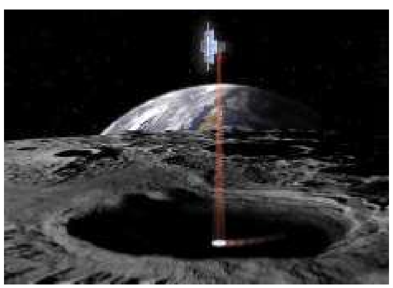
- To the Moon
- To Mars

ESA Cubesat missions to the Moon (2017)

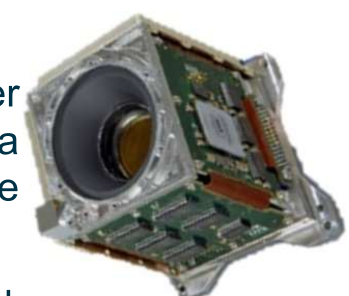


Probing radiation environment - MoonCARE, a trio of 6U-CubeSats to measure the radiation environment

Radio explorers - the CubeSat Low-frequency Explorer of three 12U- satellites to create the radio telescope over the radio-quiet far side to image the sky below 30 MHz



Ice mapper - the 12U Volatile and Mineralogy Mapping Orbiter to chart the Moon's surface minerals and frozen gases such as water ice



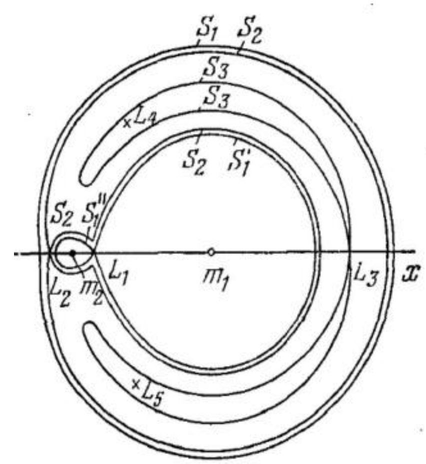
Impact detector - the Lunar Meteoroid Impacts Observer is a single 12U-CubeSat carrying a sophisticated camera to capture the flashes of meteoroids impacting the far side

NB: The challenge assumes that the delivery of the Cubesats into lunar orbit and the relay of their data back to the Earth are provided by a larger "mothership"

13 Cubesats to the Moon by SLS under NASA support

After being deployed from the second stage of the NASA heavy lift launch vehicle (SLS) in 2021 13 Cubesats would approach the Moon with various mission goals

The critical aspect of the campaign is a required 1.5 km/s Delta-V in order Cubesats to be captured by the Moon



Possibilities available to approach the Moon

- Direct transfer
- Fast escape from the Earth's gravisphere and braking near the Moon in order the Cubesat to be captured
- Spiral escape of the Earth and spiral braking to draw near to the Moon

1959: first picture of the Moon far side & first fly-by maneuver

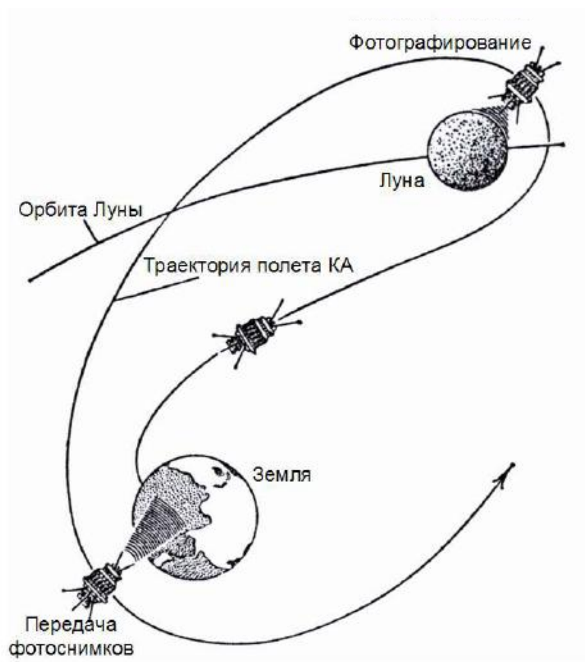
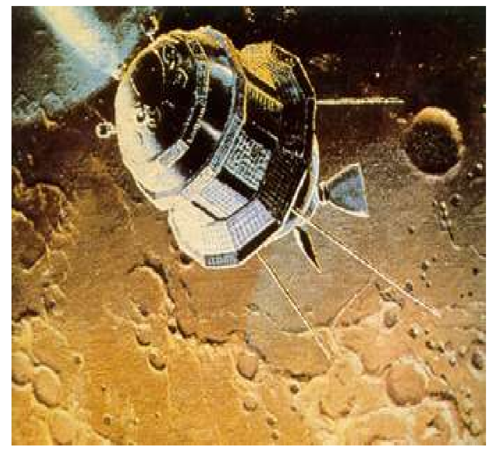
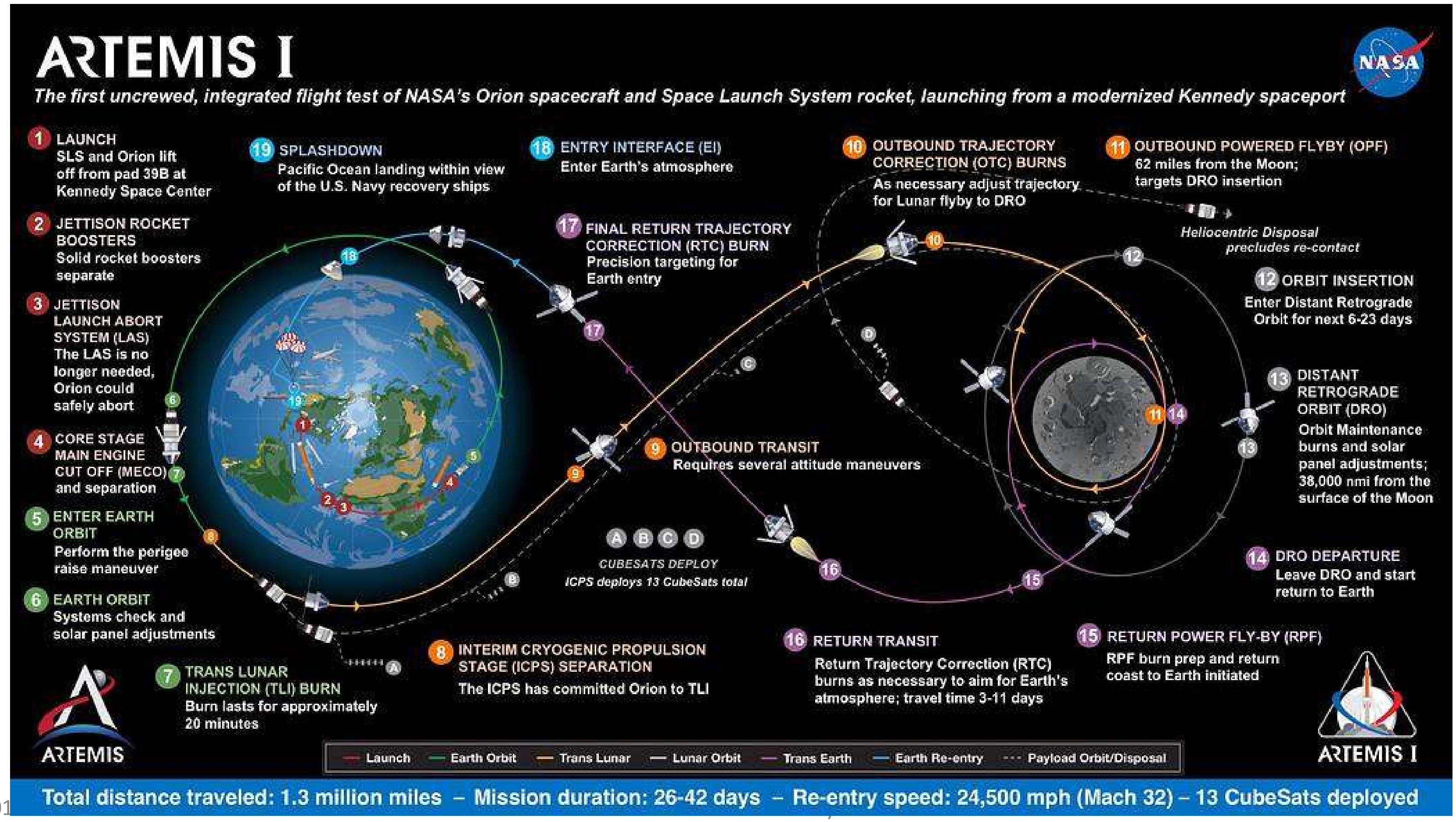


Схема полета КА «Луна-3»

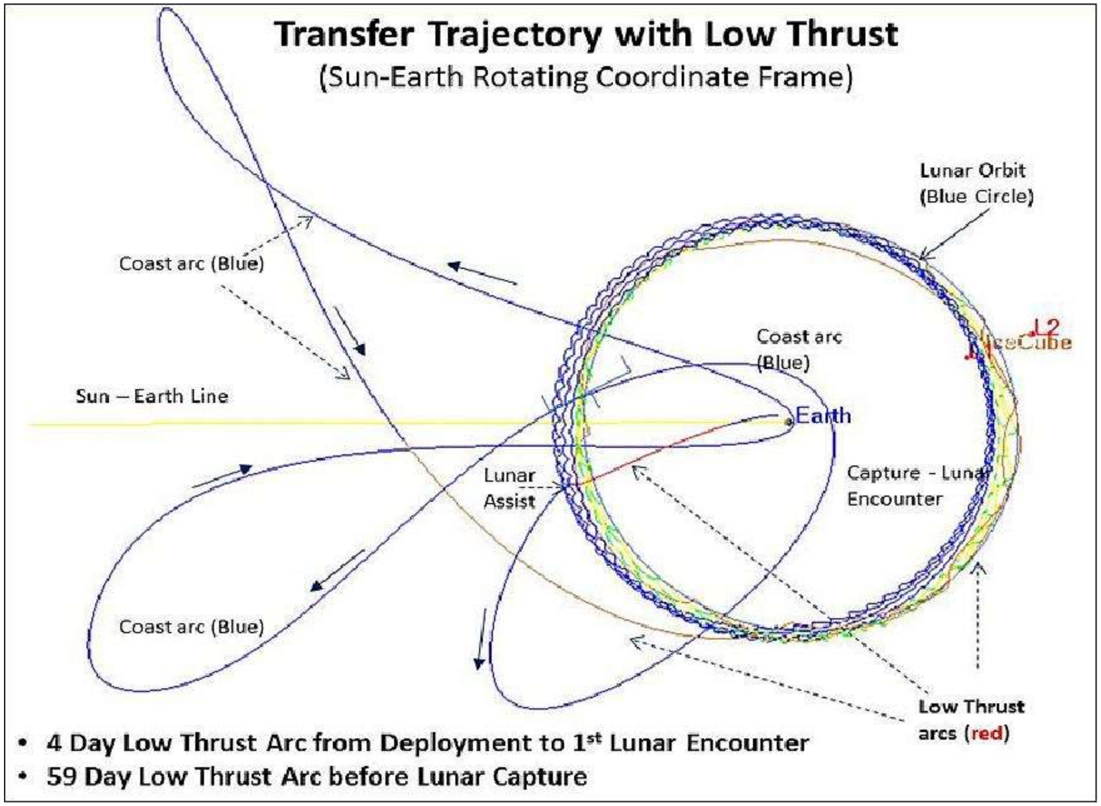


Luna-3 exterior

13 Cubesats deployment during Artemis 1 mission



6U IceCube (Morehead State University)



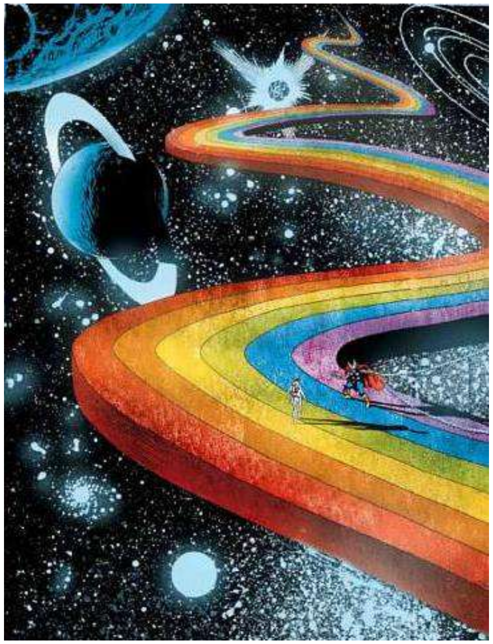
D.C. Folta, N. Bosanac, A. Cox, K.C. Howell. The lunar IceCube mission design: construction of feasible transfer trajectories with a constrained departure, 26th AAS/AIAA Space Flight Mechanics Meeting, February 2016, AAS 16-285, 19p.

Bifrost: bridge to the Moon (Atlas Beyond+IRF+...)

The mission is a complex measurement campaign for the lunar environment (it is still basically untouched, but massive lunar exploration is about to come).

Scientific payload instruments:

- Energetic Neutral Atom detector
- Ion analyzer
- Neutral gas mass spectrometer
- FIR (H2O absorption line) imager/spectrometer
- Wide angle camera for context imaging and transient monitoring



Bifrost in Norse mythology is a burning rainbow bridge that connects Midgard (the Earth) and Asgard (the realm of the gods)

More challenging than SMART-1

The mission scenario is somewhat similar to the one of SMART-1, but important differences exist:

- Microspacecraft 35-37 kg, 10 times smaller than SMART-1
- Smaller thrust acceleration (0.14 mm/s^2)
- Very challenging maneuvering in low lunar orbits (several working orbits required, at least some of them are not frozen)
- The total amount of fuel available for the transfer and LLO maneuvering is strictly limited to 5.2 kg

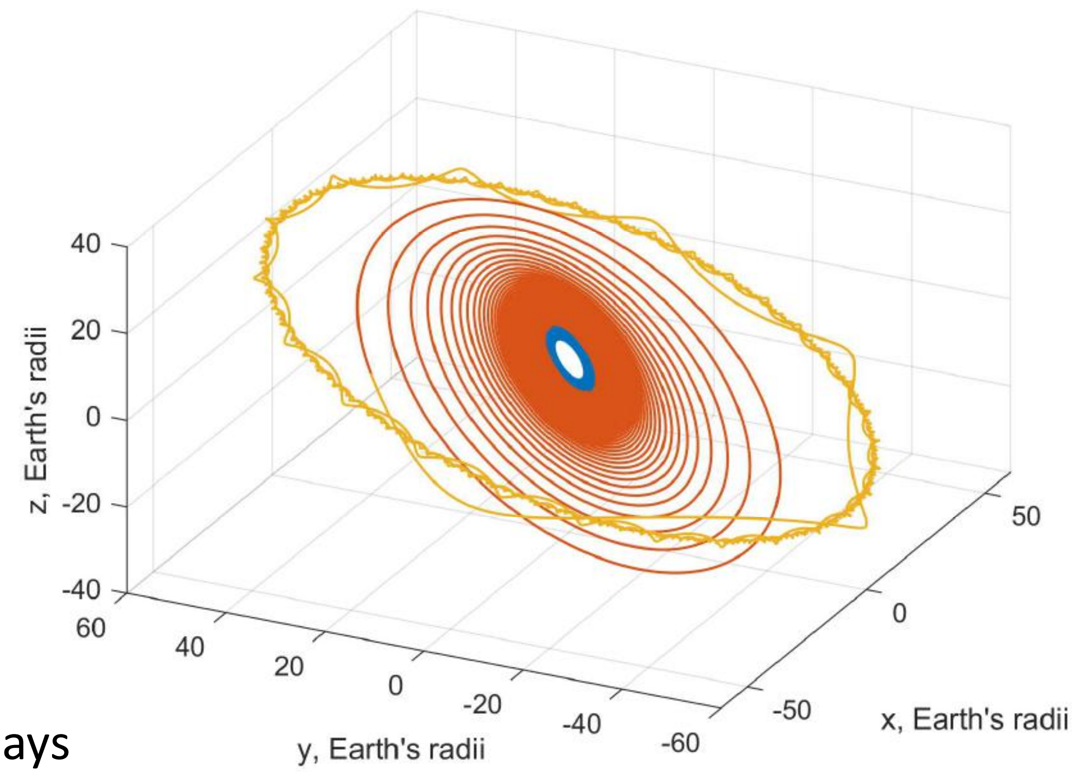
MEO-LLO transfer trajectory

MEO:
i=55 deg
h=23,200 km
e=0

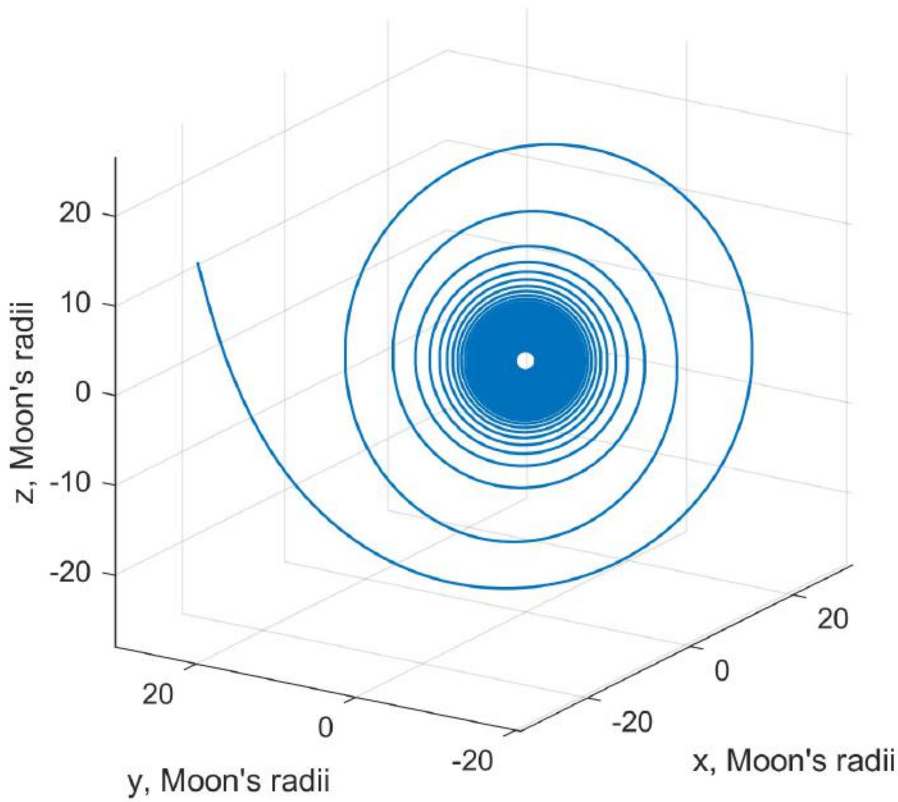
Target LLO:
polar, 100 km

Spacecraft:
m0 = 35 kg
mf = 30.6 kg

TOF (total): 443 days



Spiraling down to the 100 km LLO



Antivelocity thrust
F = 4.9 mN

TOF since passing the L1 bottleneck: ≈100 days

First working LLO to start science: polar, 100 km

Everyday corrections seem to be required

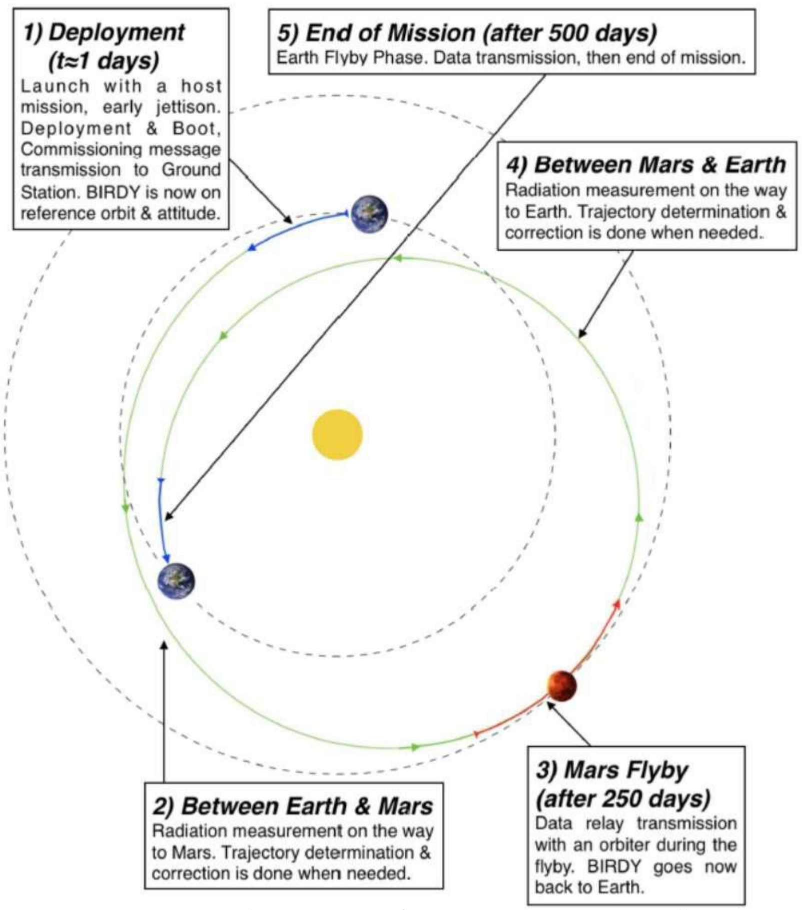
Next step beyond the Moon: Flight to Mars

- Orbiting in LEO-MEO-GTO:
  - Low thrust by engine and/or solar sail by spiral approaching Mars
- Piggy-back launching with escape velocity
  - The Hohmann transfer with the hyperbolic closing velocity:
    - Closing as a piggy-back or fly-by like *MarCO-A* and *MarCO-B*
    - Free-return to the Earth trajectory like *BIRDY*
    - Pulse braking in combination with the atmospheric resistance

Next step beyond the Moon: Flight to Mars (cntd)

- No intersection of the invariant manifold of the Sun-Earth and the Sun-Mars systems but flight results of *GENESIS*, *MAP* and WIND increased the trust to dynamical systems theory:
  - To link the manifolds a pulse is demanded [F. Topputo, E. Belbruno, Earth–Mars transfers with ballistic capture, Celest. Mech. Dyn. Astr., V.121, 2015, pp.329–346]
  - Transfer from the Earth-Moon L2 to the Sun-EarthL1/L2 Halo orbit and next direct flight to Mars [M. Kakoi, K.C. Howell, D. Folta, Access to Mars from Earth–Moon libration point orbits: Manifold and direct options, Acta Astronautica, V.102, 2014, pp.269-286]

Typical free-return trajectory for BIRDY



Finally, *Advantage or Adventure?*

Advantage AND Adventure!

Thank you for your attention!

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