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Exploring New Lagrangian Cyclers to Enhance Science: Communications with CubeSat Technology

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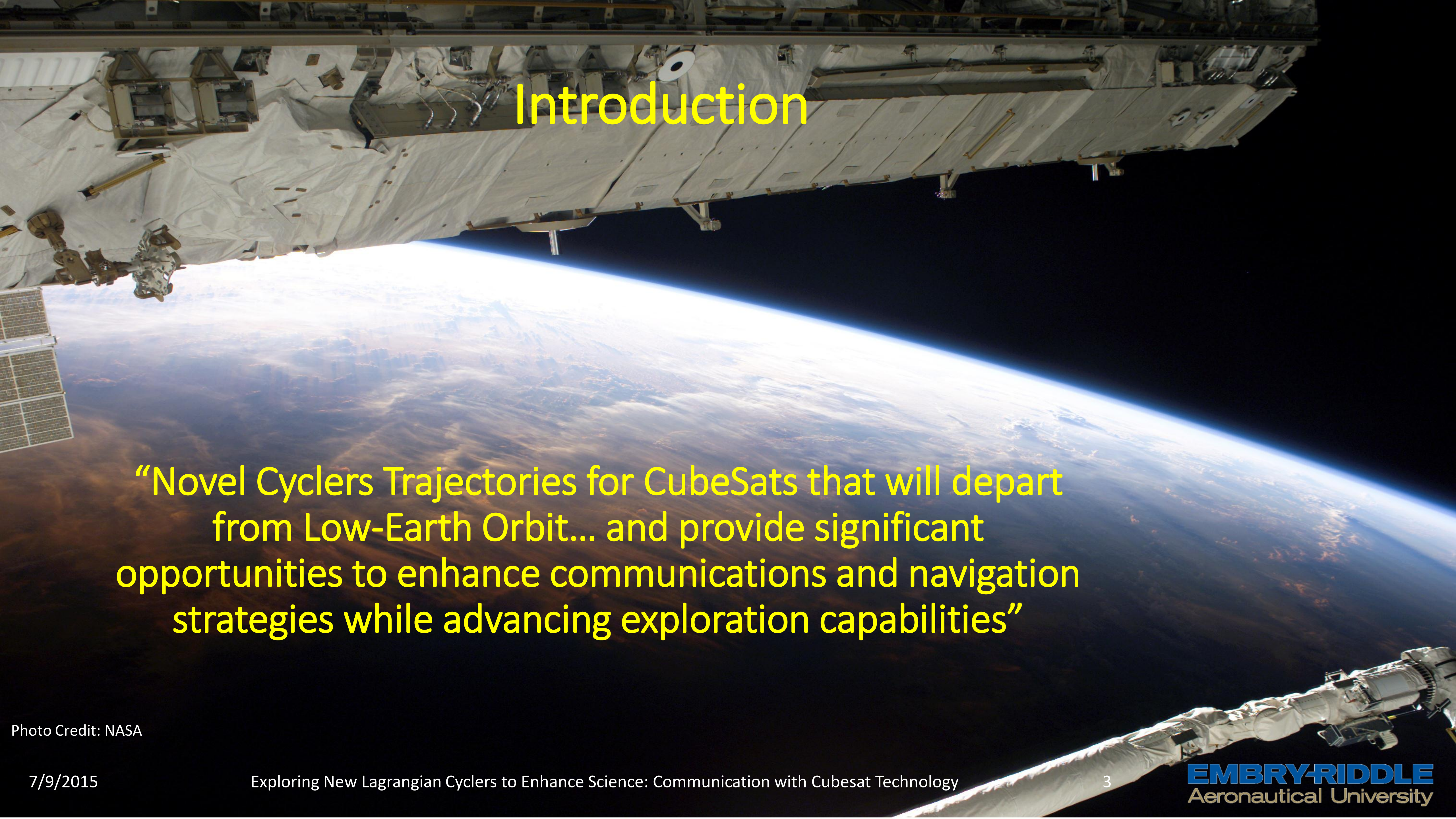
Embry-Riddle Aeronautical University – Daytona Beach, FL

Outline

- Introduction
- CubeSat Technology
- Mathematical Model
- Results (Matlab and STK)
- CubeSat Performance
- Future Work: Applications
- References

Photo Credit: NASA

Introduction



“Novel Cyclers Trajectories for CubeSats that will depart from Low-Earth Orbit… and provide significant opportunities to enhance communications and navigation strategies while advancing exploration capabilities”

Photo Credit: NASA

CubeSat Technology

- Developed by Cal Poly and Stanford University
- Unit: 1U (10cm x 10cm x 10cm) Small Spacecraft
- Accessible for Public, Industry and Government
- High Asset for Spacecraft Flight Opportunities and mission development
- Low Cost

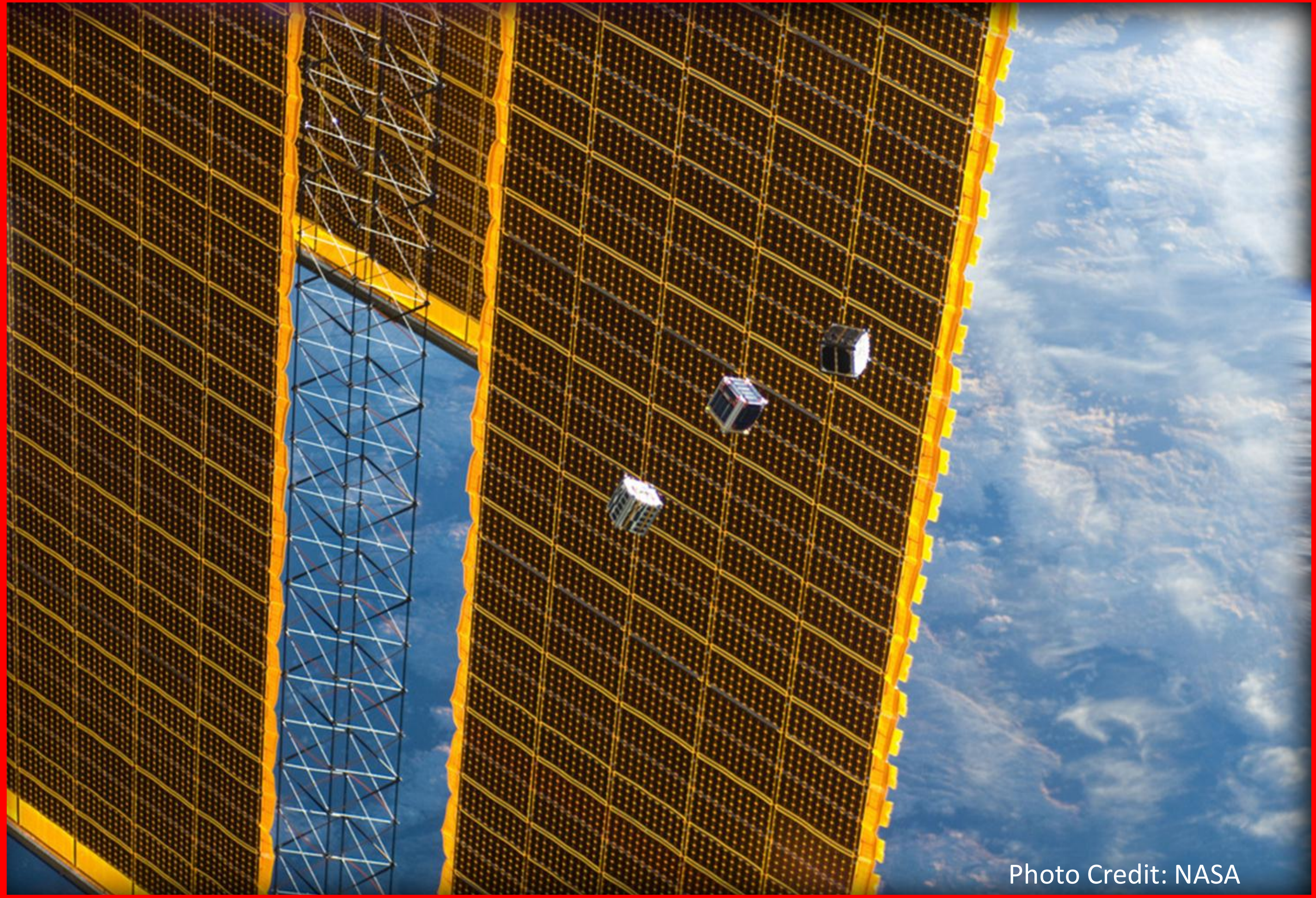


Photo Credit: NASA

Mathematical Model

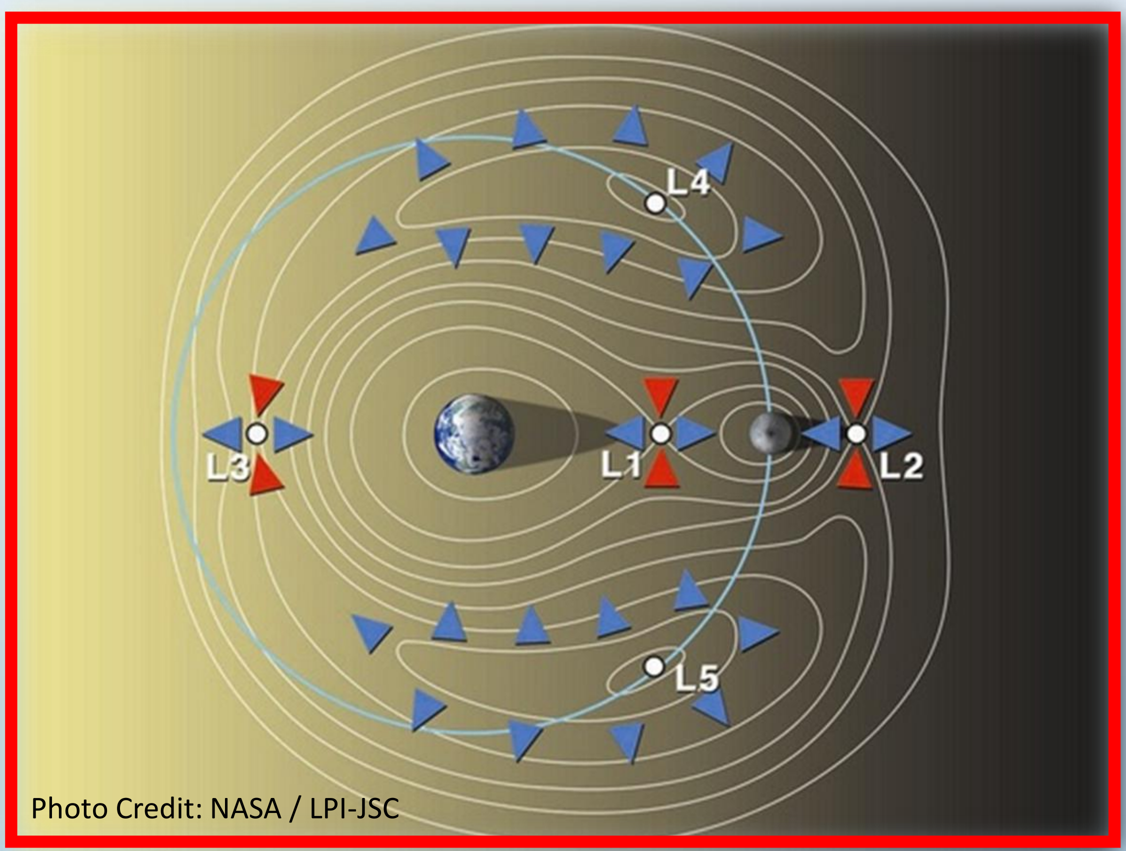
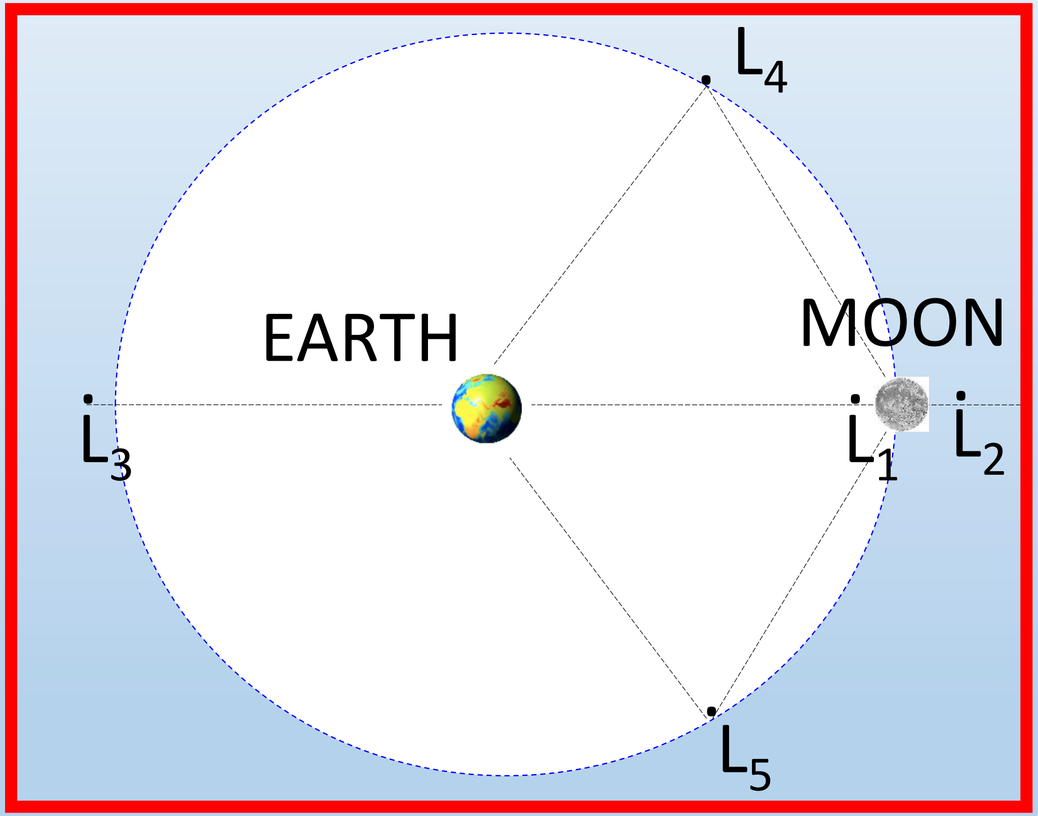


Photo Credit: NASA / LPI-JSC



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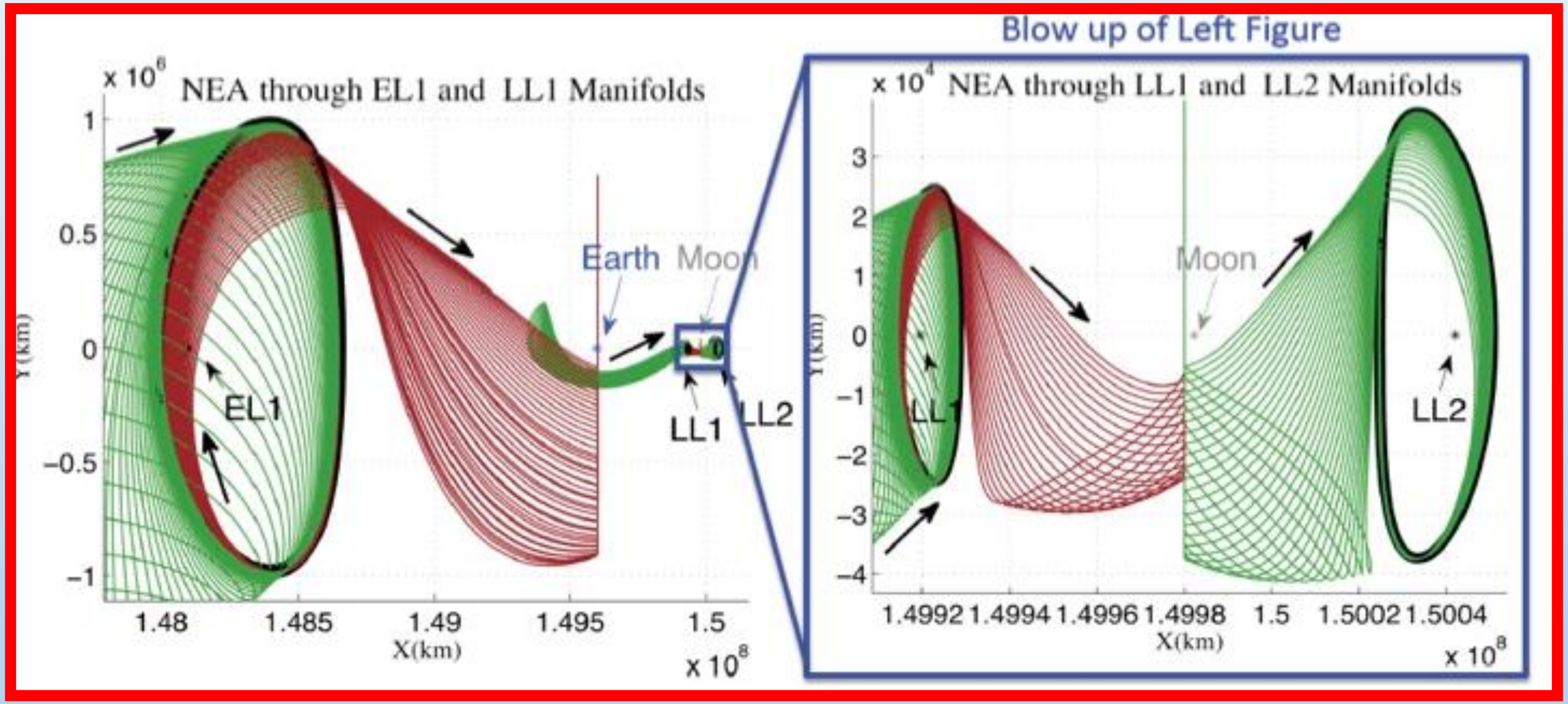
Mathematical Model



Motion of infinitesimal mass in the rotation frame can be described by the governing equation of motion:

- **Circular Restricted Three-Body Problem (CRTBP)**
  - Earth, Moon and CubeSat
  - Rotating frame

$$\ddot{x} - 2\dot{y} = x - (1-\mu)\frac{x - x_1}{r_1^3} - \mu\frac{x - x_2}{r_2^3}$$

$$\ddot{y} + 2\dot{x} = \left(1 - \frac{(1-\mu)}{r_1^3} - \frac{\mu}{r_2^3}\right)y$$

$$\ddot{z} = -\left(\frac{(1-\mu)}{r_1^3} + \frac{\mu}{r_2^3}\right)z$$

$$r_1 = \sqrt{(x+\mu)^2 + y^2 + z^2}$$

$$r_2 = \sqrt{(x-1+\mu)^2 + y^2 + z^2}$$

$$\mu = \frac{M_{Moon}}{M_{Moon} + M_{Earth}}$$

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Results (Matlab and STK)

ISS to Earth-Moon L1

(Scenario 1)

CubeSat departs ISS and does an Orbital Transfer to EML1.

Earth-Moon L2 to Earth-Moon L1

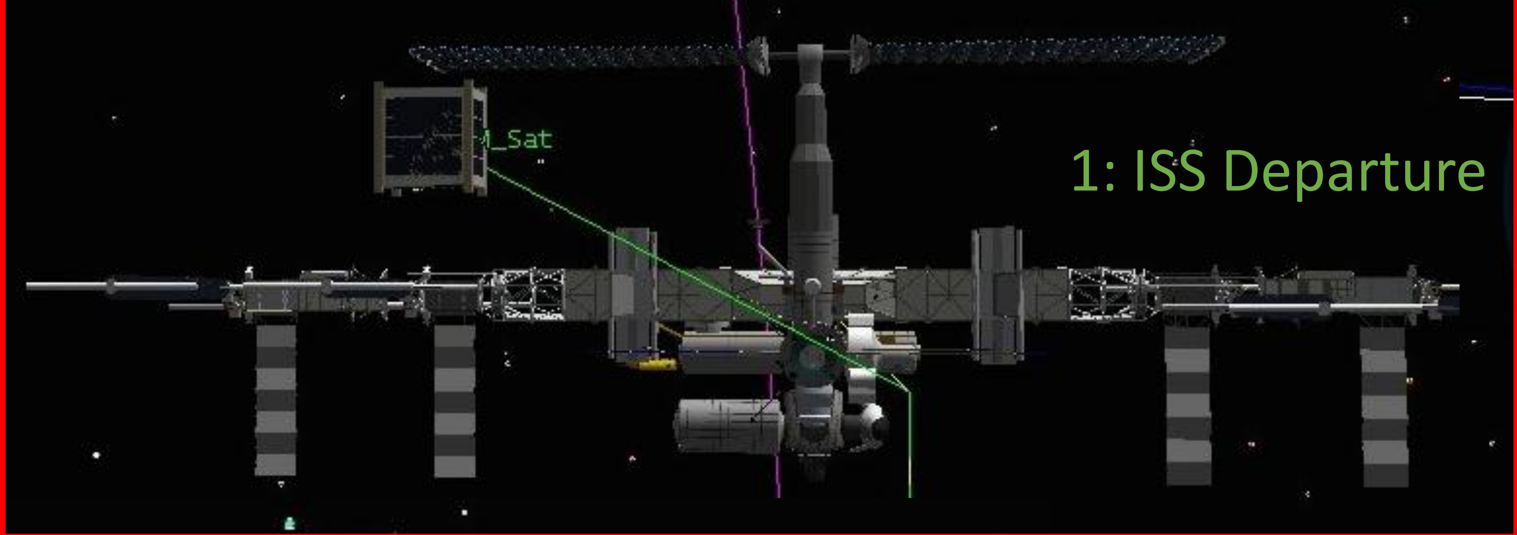
(Scenario 2)

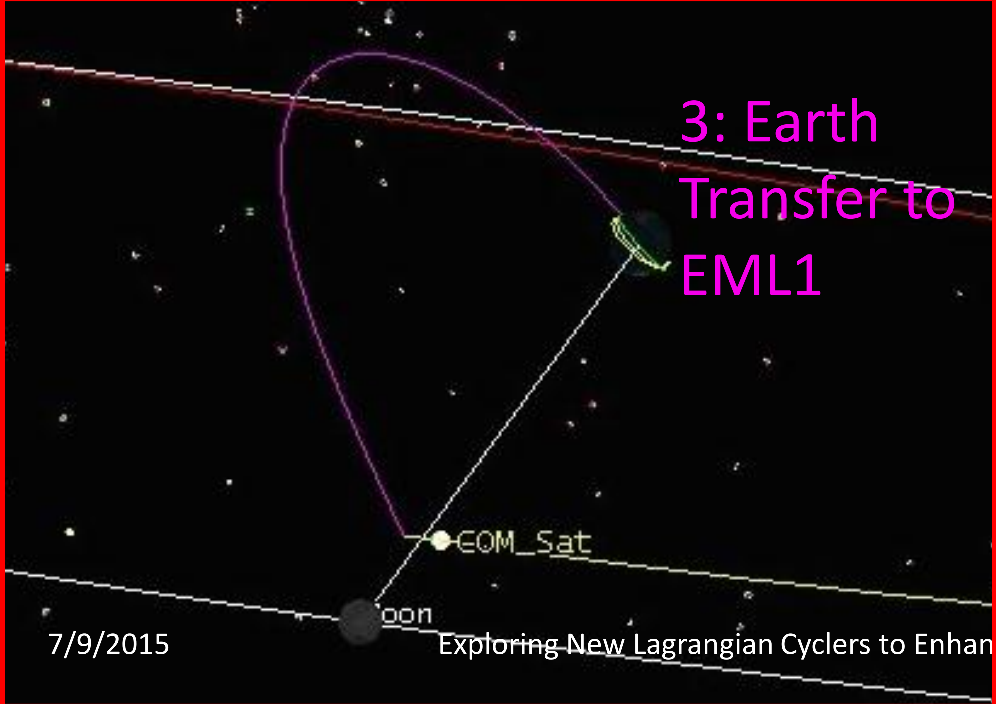
CubeSat shows capability to transfer between Libration Points.

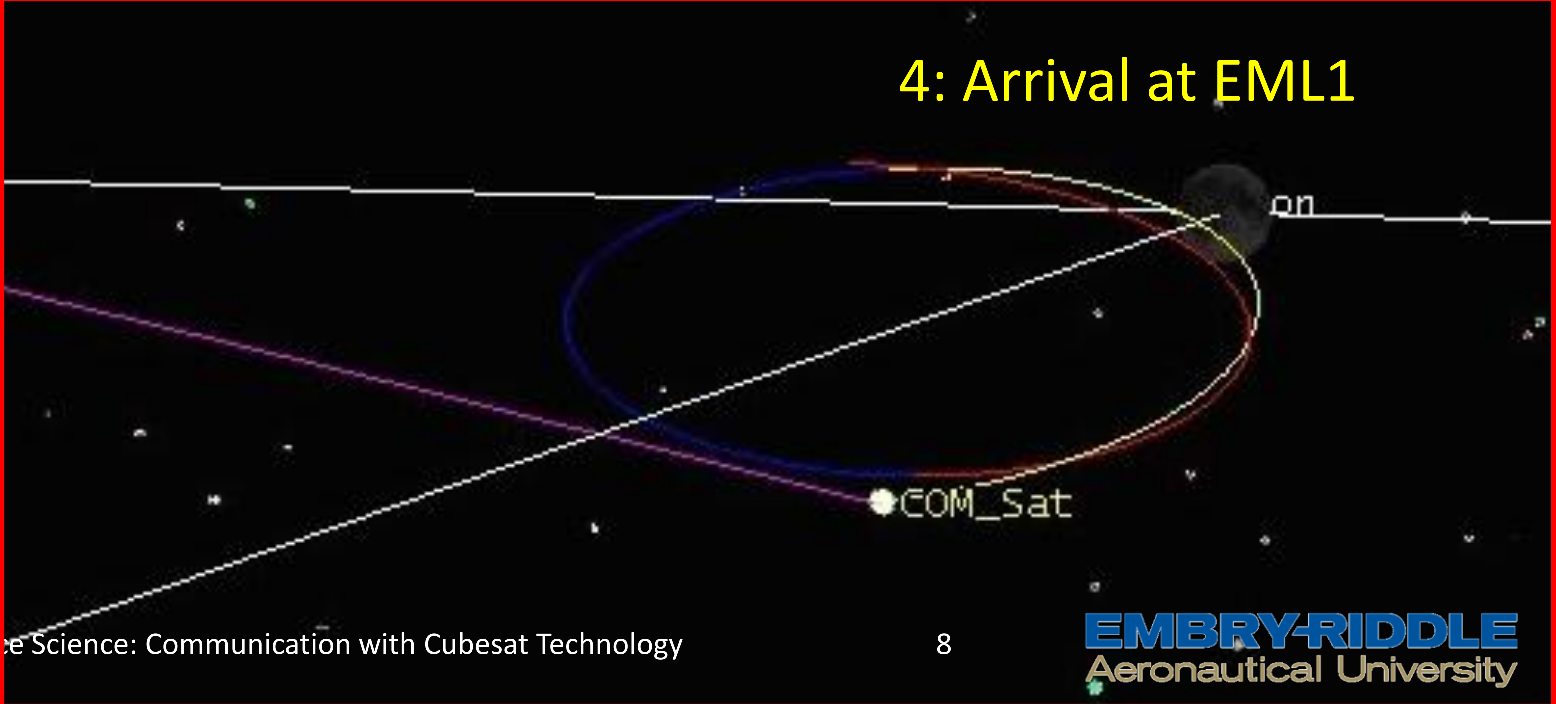
Minor stationkeeping maneuvers for both scenarios with low ΔV

Photo Credit: NASA

Scenario 1 : From ISS to Earth-Moon Lagrange Point L1 (EML1)







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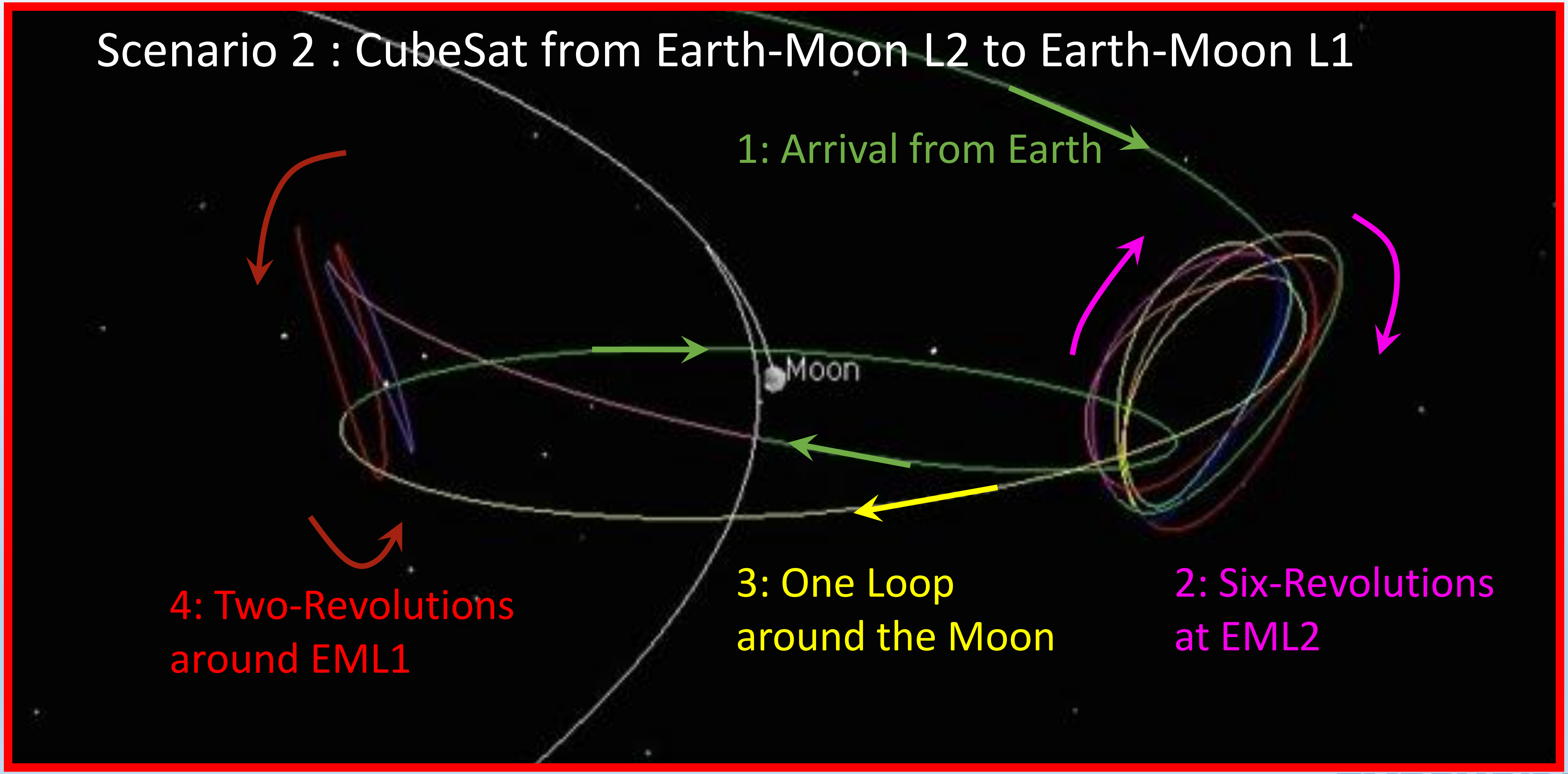
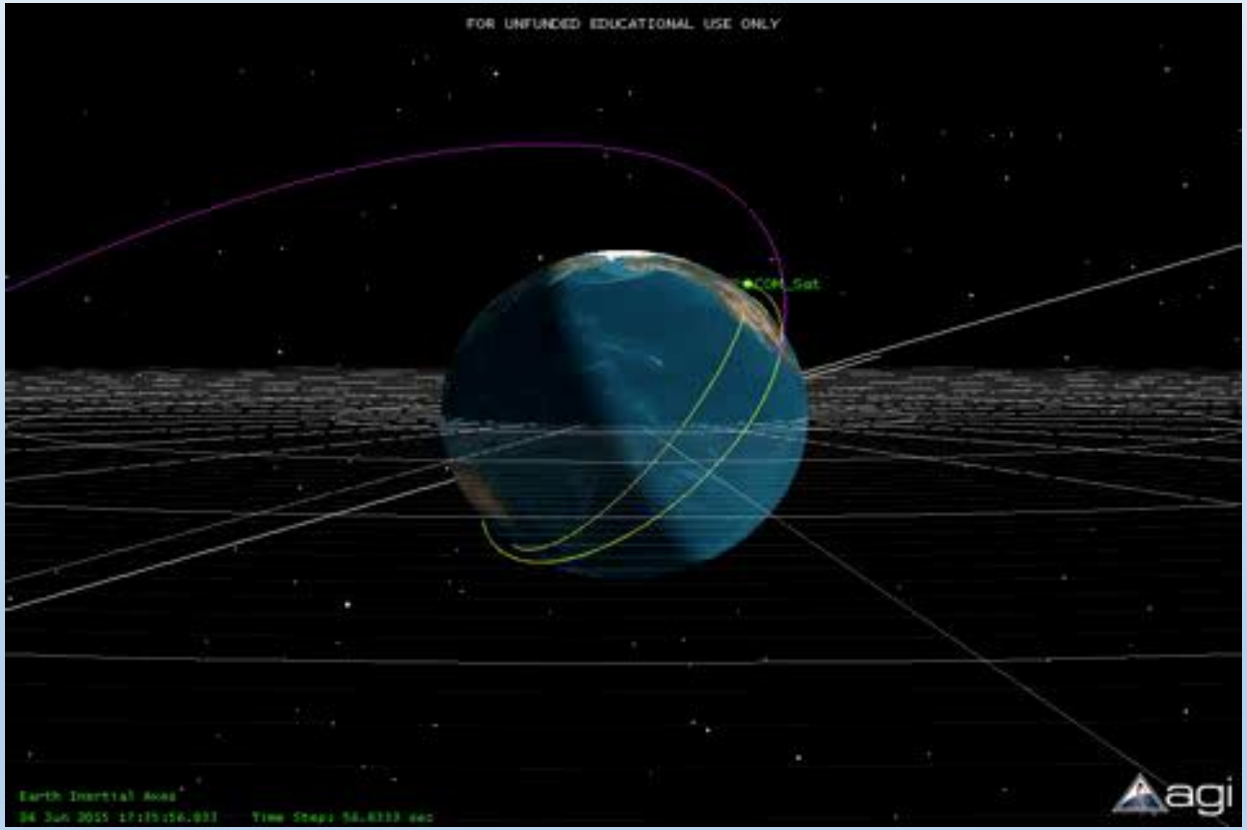
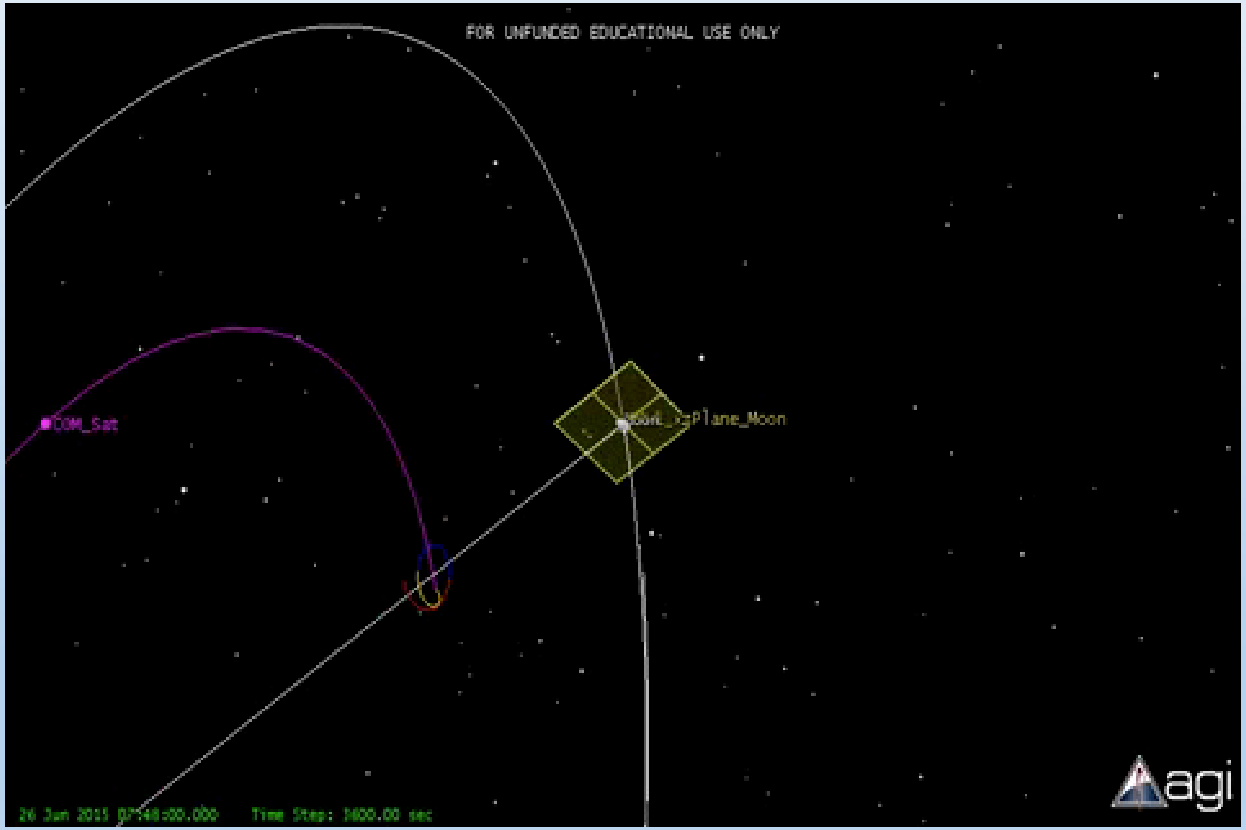
Results (Matlab and STK)



Results: STK Simulations

Scenario 1 (ISS to EML1)





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Results (Matlab and STK)

Scenario 1 (ISS to EML1)

- ISS departure ΔV = 3.120 km/s
- Time of flight = 4 days 9 hours

- EML1 (Orbit Insertion + SK) ΔV = 740 m/s
- Number of Orbits = 2
- Time in Orbit = 17 days and 7 hours

SK=Stationkeeping

Scenario 2 (EML2 to EML1)

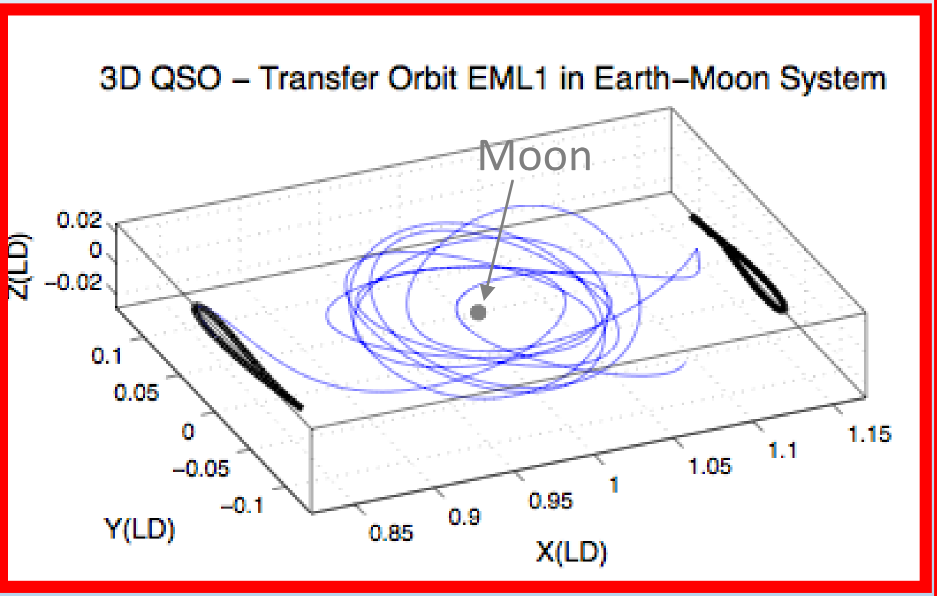
- EML2 (Orbit Insertion + SK) ΔV = 1.065 km/s
- Number of Orbits = 6
- Time in Orbit = 2 months and 11 days

- EML2 to EML1 transfer ΔV = 350 m/s
- Time of Transfer = 17 days

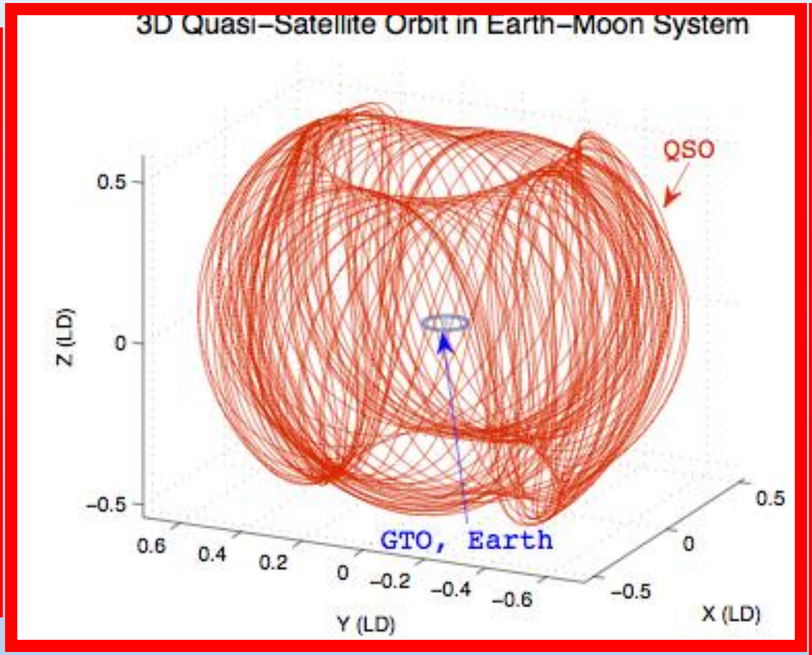
- EML1 (Orbit Insertion + SK) ΔV = 370 m/s
- Number of Orbits = 2
- Time in Orbit = 24 days

Results: Novel Cyclers

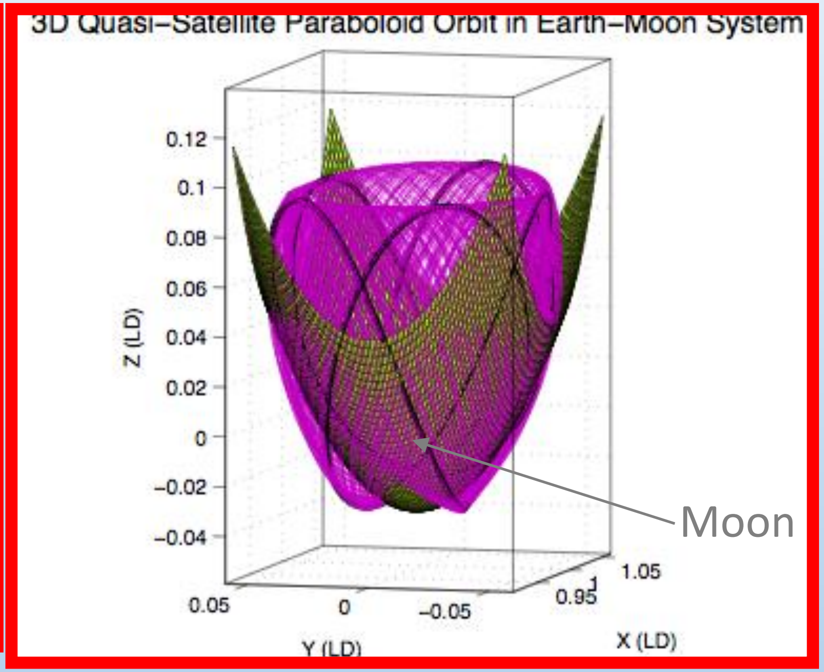
QSO between EML1 and EML2



QSO in Earth's vicinity



QSO Paraboloid



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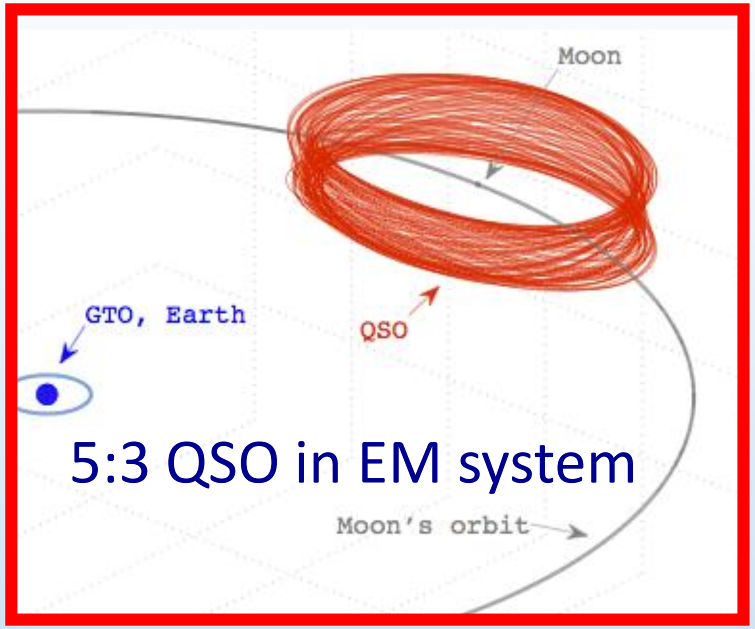
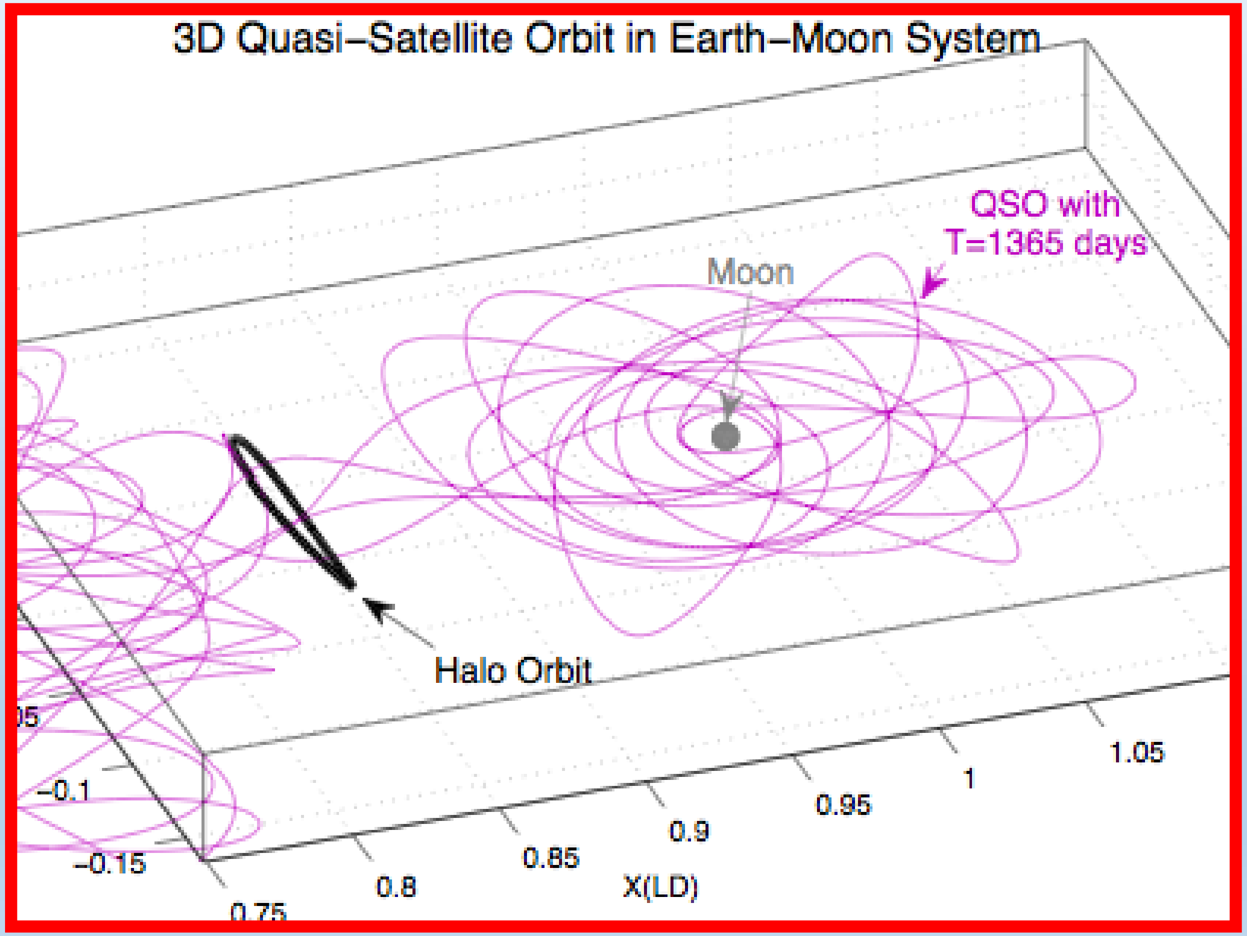
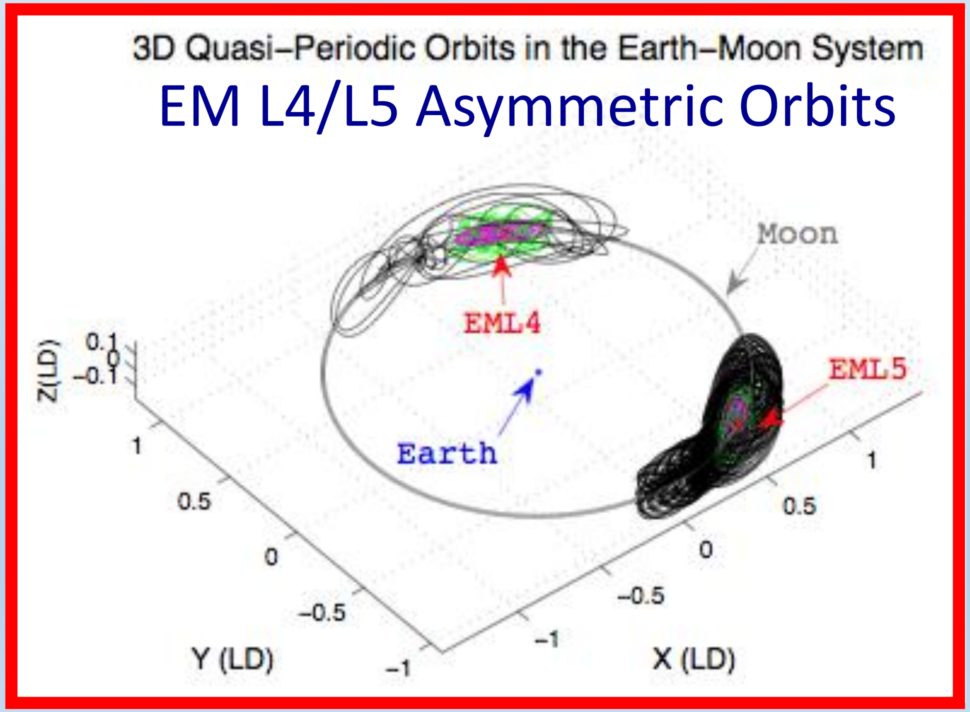
Results: Novel Cyclers

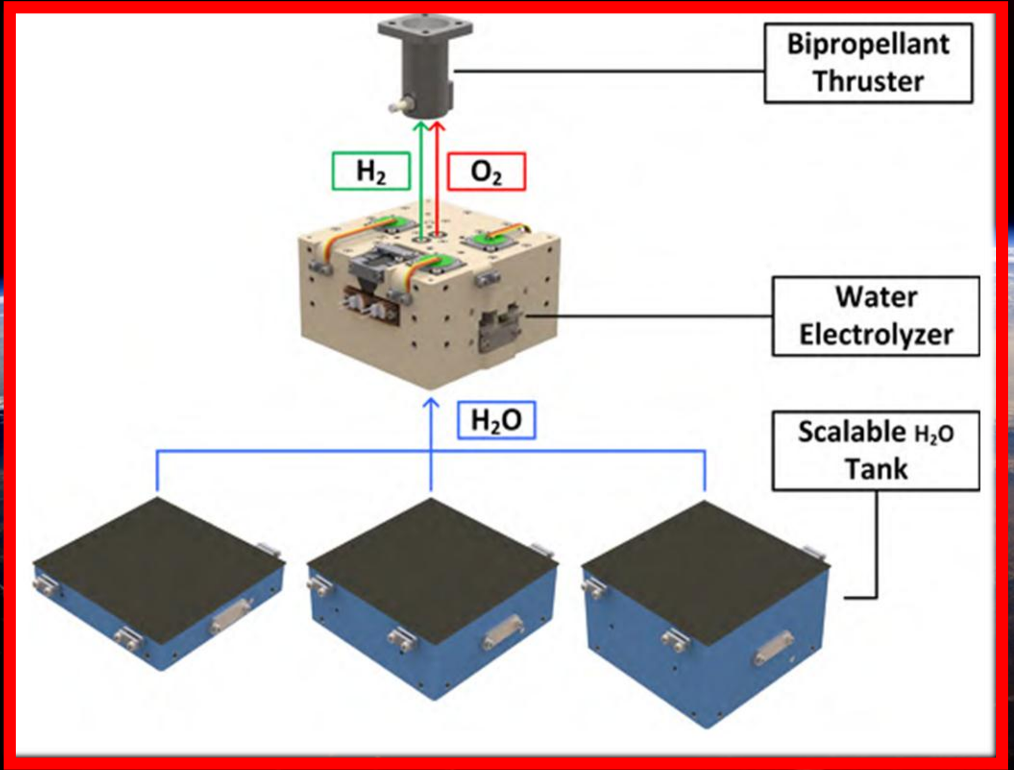


QSO going through gate EML1 connecting Earth & Moon





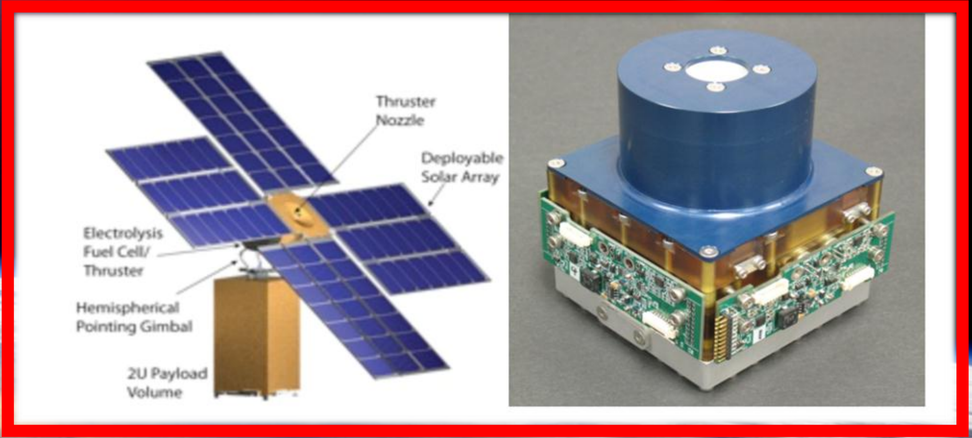
CubeSat Performance



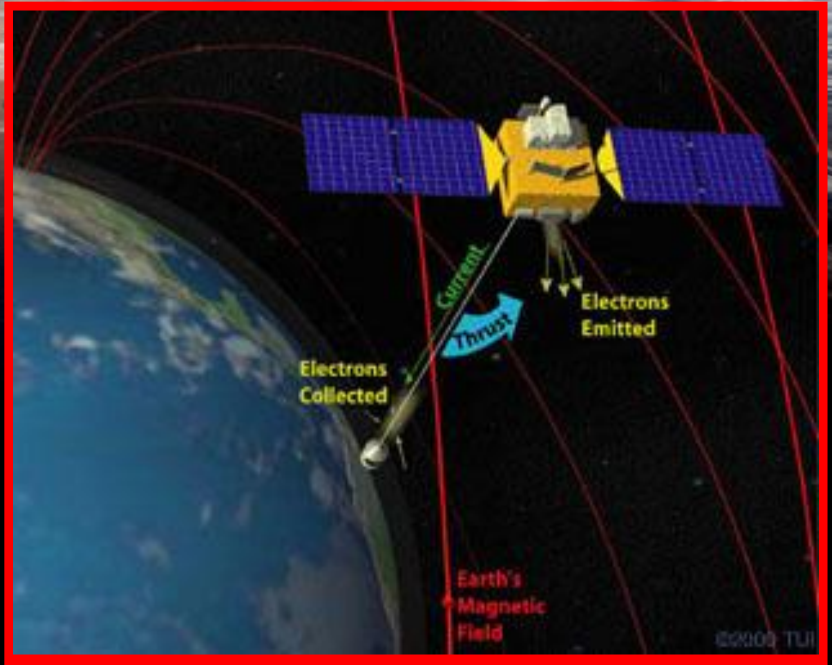
Pictures and Data courtesy of: Tethers Unlimited

HYDROS Thruster - scalable to >2km/s (Electrolysis)

PowerCube – up to 6m/s per orbit (Electrolysis)



MicroPET – raising propellantless system (Electrodynamic Tethers)



Sun-Earth Day 2008: Space Weather Around the World
sunearthday.nasa.gov

Future Work: Applications

- Science and Communication
  - Gravitational Field Mapping
  - Cislunar or Interplanetary CubeSat
  - Space Weather Monitoring
  - Low Data Rate communications with fleet of CubeSat
  - Technology testing for Mars and its Moons (AIAA-2014-4349)

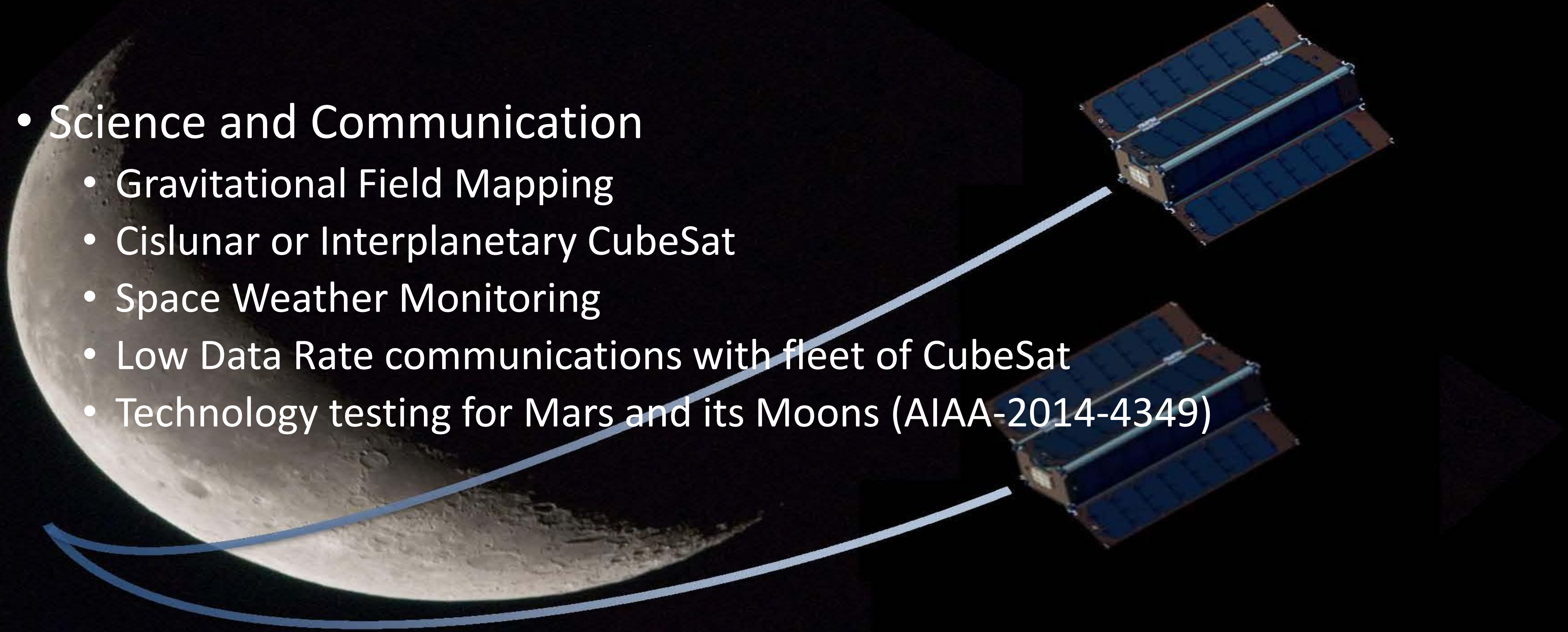


Photo Credit: NASA (INSPIRE) CubeSat project

Future Work: Applications

Orbital Debris Monitoring

- ISS Departure (400km) to Low Earth Orbit (725km)
  - Debris Resistive/Acoustic Grid Orbital Navy Sensor (DRAGONS)
- Better understanding of MicroMeteroid and Orbital Debris (MMOD)
- Impact avoidance for ISS and reduction of collision avoidance maneuvers.

Orbit Maintenance

- CubeSat deployment from ISS (NanoRacks); JEM (Cyclops launcher), Orbital (Jupiter/Exoliner) and Suborbital flight vehicle (example: Lynx Mark III) deploying the CubeSat from its dorsal pod using a dual stage rocket.
- Satellite Stationkeeping, safe deorbit, repair, maintenance.

Picture credit: Lynx

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Thank you for your attention

Questions?

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Photo Credit: ESA

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