Low-Energy Transfers for Expanding the Orbital Regime of CubeSat Missions

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Introduction

- This presentation discusses a method for small satellite missions to potentially reach regions of space that are unreachable by traditional methods

- By taking advantage of “Low Energy Transfers” between the Earth’s and Moon’s Lagrange points, CubeSat missions are able to extend their reach into space

CubeSat Missions

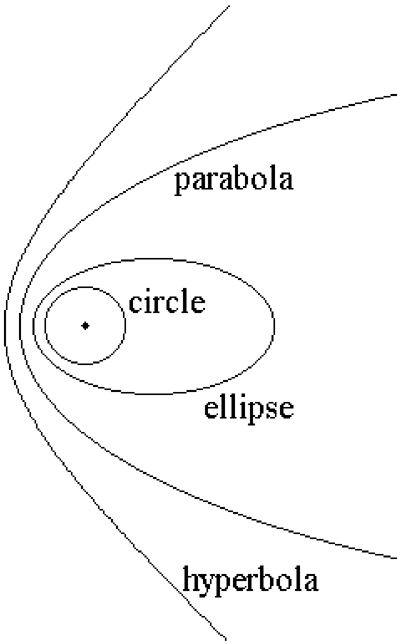
- The majority of CubeSats are designed for Low-Earth orbit missions
- Mass and volume constraints are the limiting factor because of fuel considerations
- Previously, propulsion systems either were not allowed or could not support much more than attitude control at the sizes required by CubeSats

Motivation

- As the CubeSat community grows, the level of sophistication of CubeSat missions continues to increase
- By expanding the orbital regime of potential CubeSat missions, we can further the impact that these missions have on the scientific community

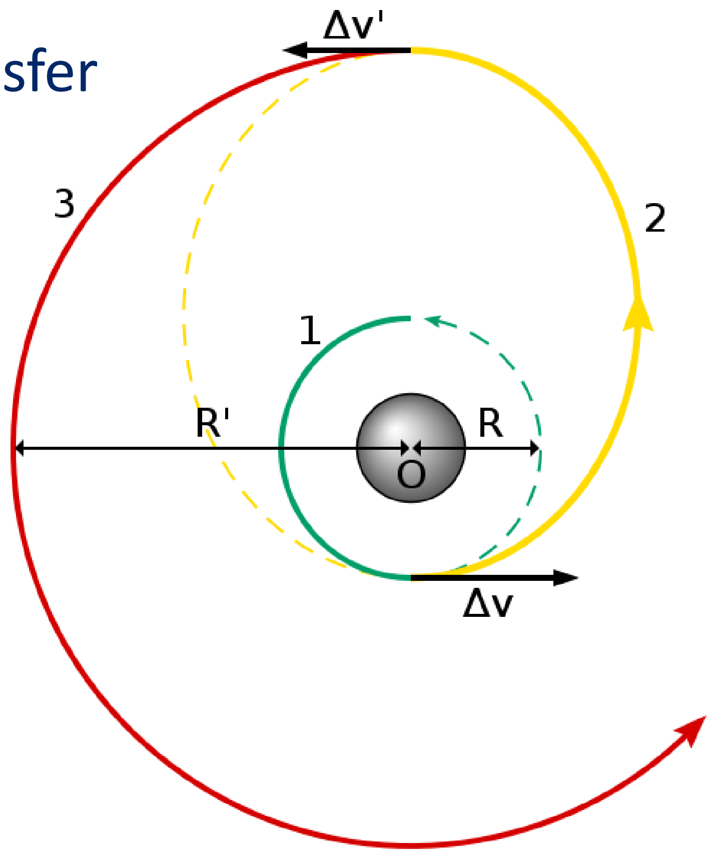
Background

- Traditional Orbital Mechanics
  - Two-body problem
    - Simple, practical , fairly accurate for some orbits
    - Limited to a small class of orbits and trajectories
    - Generally used to determine orbits about a massive central body (i.e.- satellite around Earth)



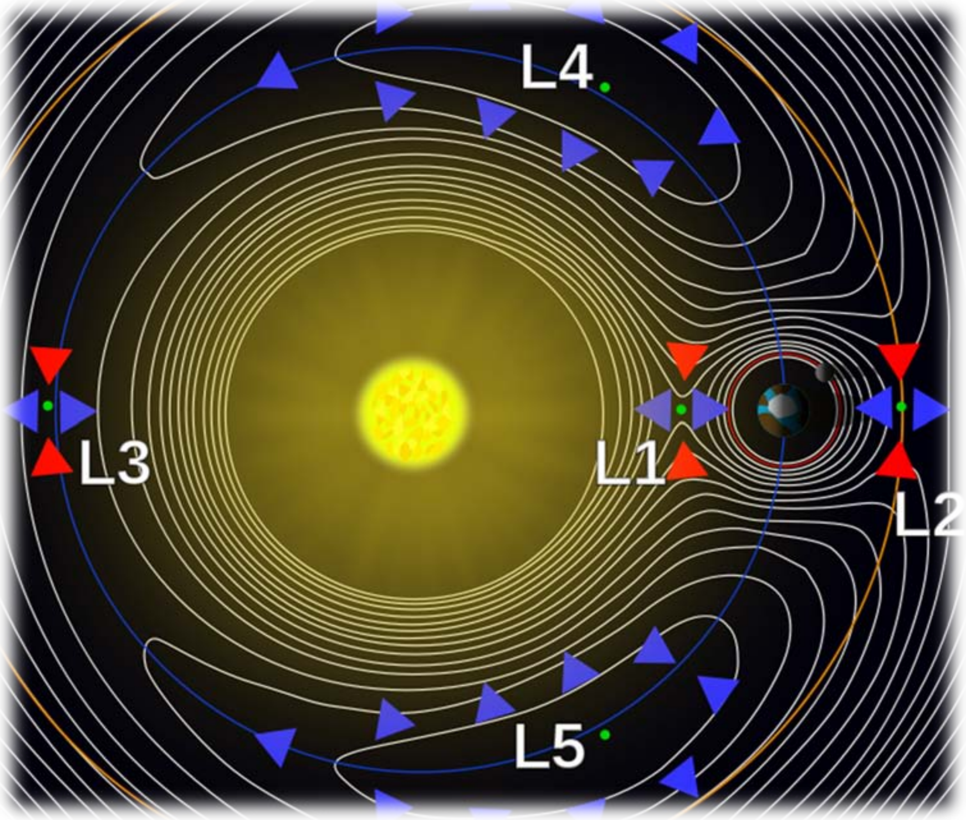
Hohmann Transfer

- Traditional orbital transfers
- Offers the most energy efficient* transfer between two coplanar orbits
  - *Under certain assumptions!



Lagrange Points

- Gravitational “balance” points
- In a rotating system, there are 5 Lagrange points
- $L_1 – L_3$ are unstable
- L_4 and L_5 are stable



Low Energy Transfers

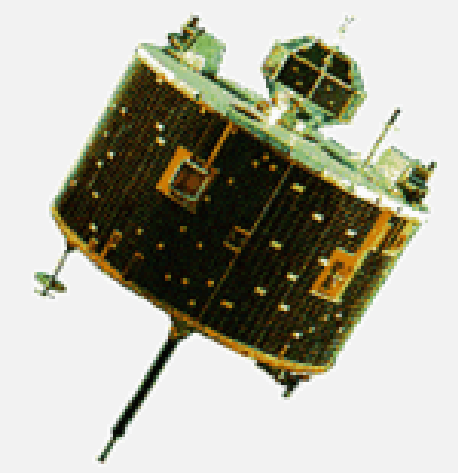
- Also known as “Weak-Stability Boundary” trajectories
- Takes advantage of the complex dynamics around planetary Lagrange points
- They form gravitational “pathways” that link the Lagrange points between planets and moons

Interplanetary Transport Network

- The collection of low energy trajectories that link Lagrange points throughout the Solar System

Hiten Mission

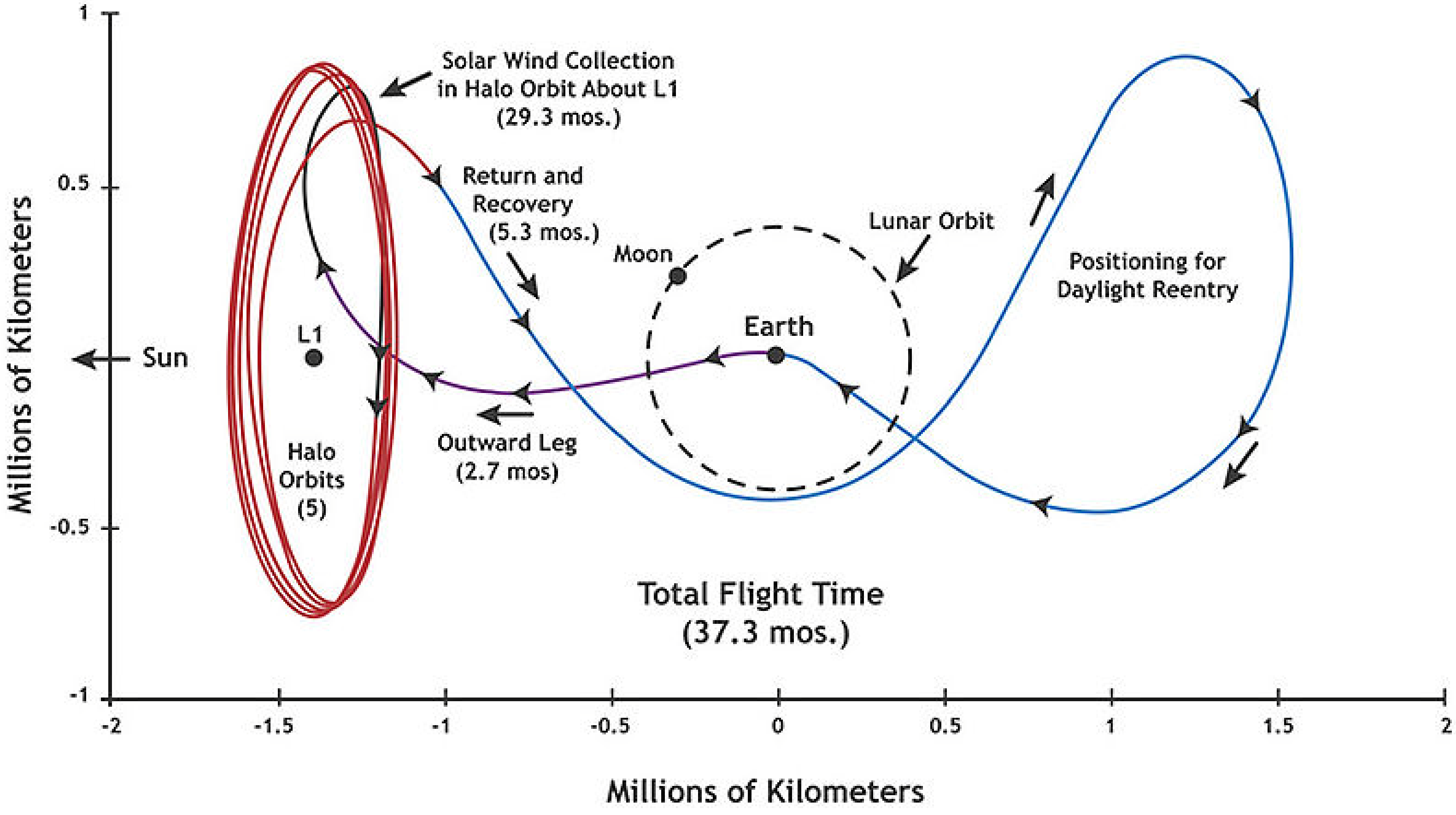
- Japanese spacecraft targeted at the Moon
- An error at orbit insertion caused a delta-V deficiency
- Edward Delbruno (Princeton) designed a low-energy transfer trajectory to guide the spacecraft into lunar orbit with nearly ZERO delta-V



Genesis Mission

- Scientific mission sent to the Earth-Sun L_1 point to collect samples
- Employed a low-energy transfer to return to Earth at the end of mission for very little fuel

Genesis Trajectory

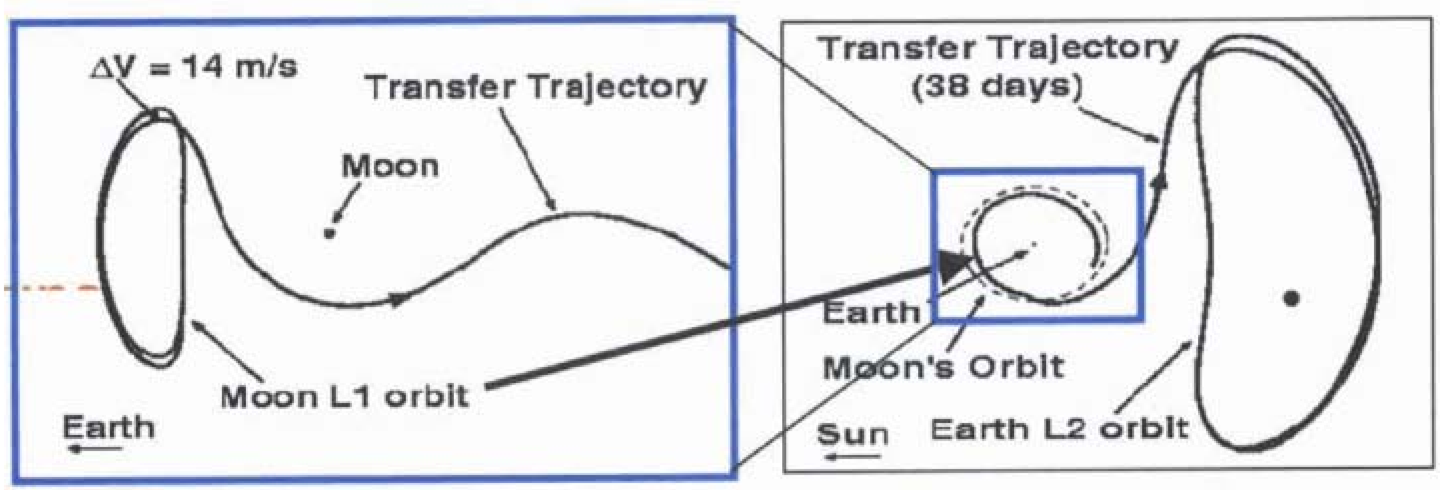


Lunar-L_1 Gateway

- The Lunar-L_1 Lagrange point serves as a "gateway" to Lunar and interplanetary space
- For instance, Lunar-L_1 is separated by Earth-L_1 by only 50 m/s delta-V!
  - i.e.- the gravitational potential difference of the two points can be bridged with 50 m/s delta-V

Lunar-L_1 Gateway (cont'd)

- In other words, if a spacecraft is able to reach Lunar-L_1 , it will be able to reach Earth-L_1 , provided that it can produce 50 m/s thrust!



Applicability to CubeSats

- Advantages of Low-energy transfer
  - Low fuel requirements
  - Access to interplanetary space
  - More flexible mission profile (can stall at Lagrange points if needed)
- Disadvantages
  - Longer time of flight (if time is a constraint)

Feasibility

- Since CubeSats generally "piggy-back" on rocket launches with primary payloads, we can use common parking orbits as a baseline
- From a Geostationary Transfer Orbit (GTO), about 5 km/s delta-V is needed to reach the Lunar-L_1 Gateway

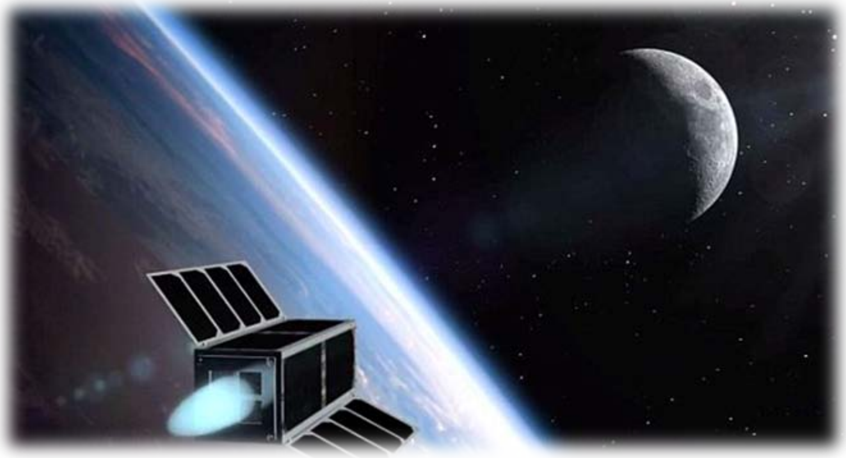
CubeSat Propulsion

- Can a CubeSat propulsion system generate enough delta-V to get to L_1?

- Electric propulsion (uPPT):
  - ~1000 s Specific Impulse
- Micro-ion engines:
  - ~3000 s Specific Impulse

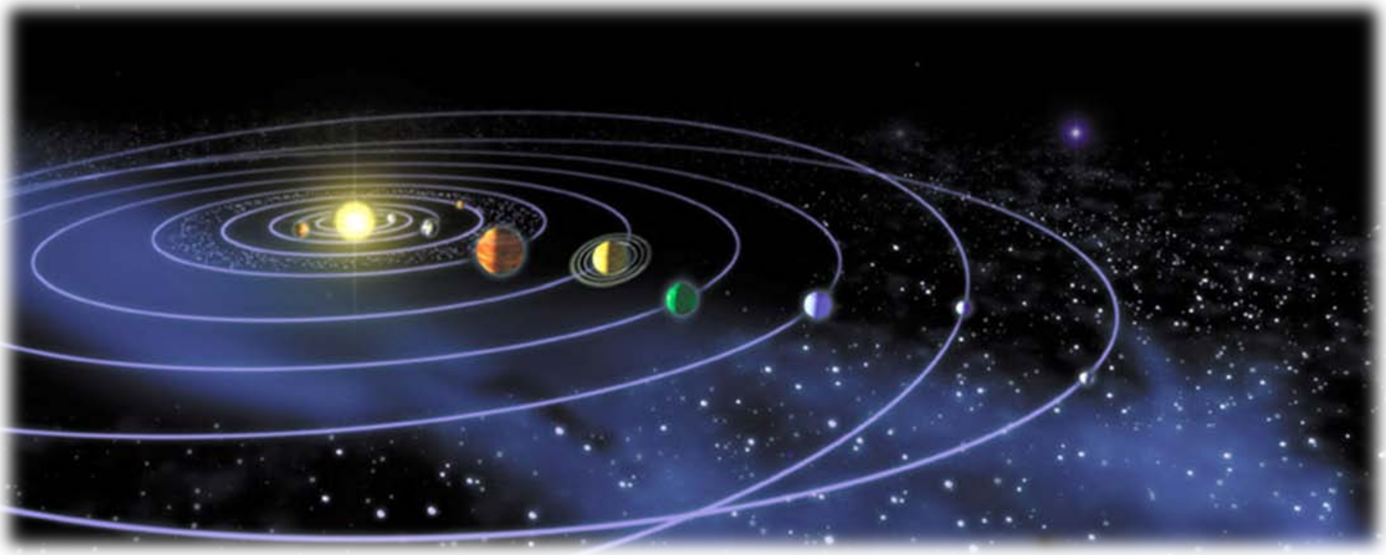
CubeSat Propulsion

- Electric propulsion (uPPT):
  - ~1000 s Specific Impulse
    - Delta-V = ~2.2 km/s
- Micro-ion engines:
  - ~3000 s Specific Impulse
    - Delta-V = ~5.4 km/s



Implications

- If you equip your CubeSat with a propulsion system, you may be able to reach interplanetary space by passing through the Lunar-L_1 Gateway



Conclusion

- CubeSat missions are no longer restricted to Low-Earth orbit
- Keep the Low-energy transfers in mind when designing new CubeSat missions
- Go out and do some awesome science!

Questions?

Thank you!