Beyond Earth Orbit Trajectory Insertion

"Halfway to Anywhere"

International Space Development Conference
Toronto, Canada

22 May 2015

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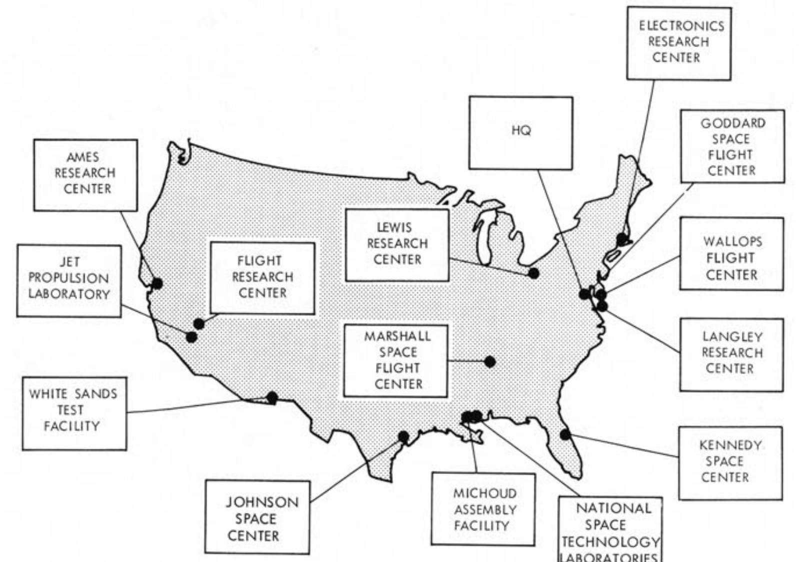
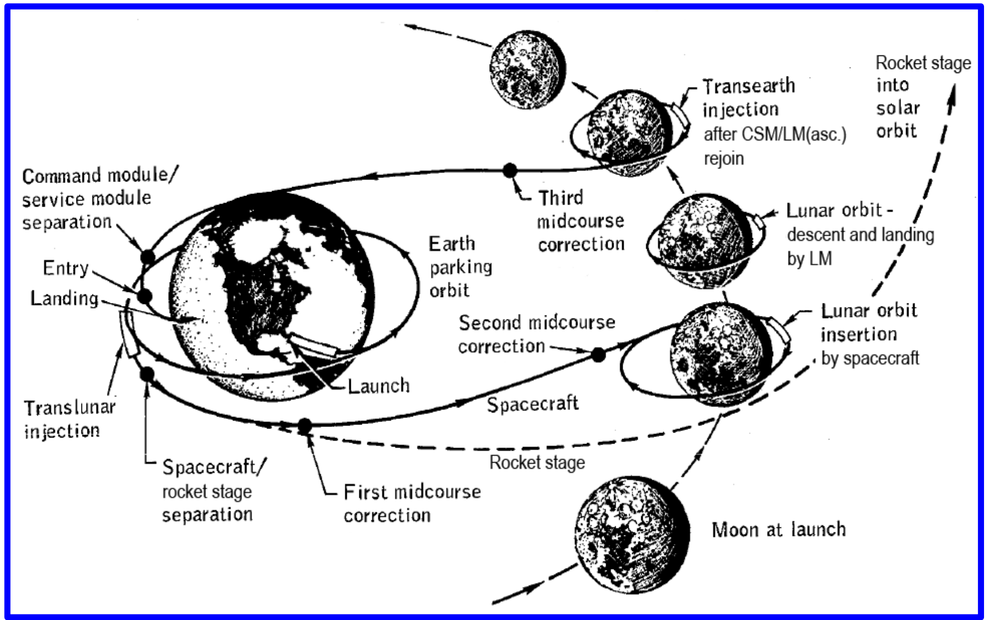
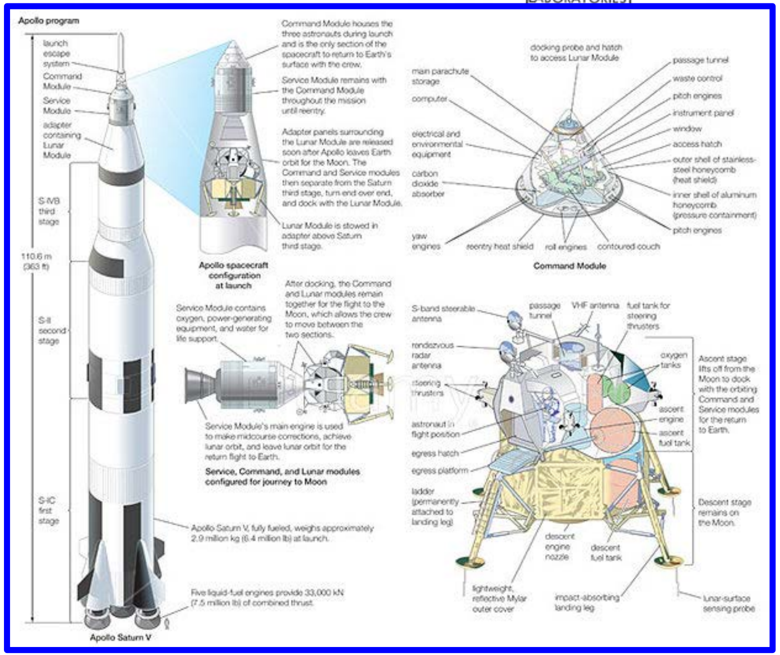
Beyond Earth Orbit

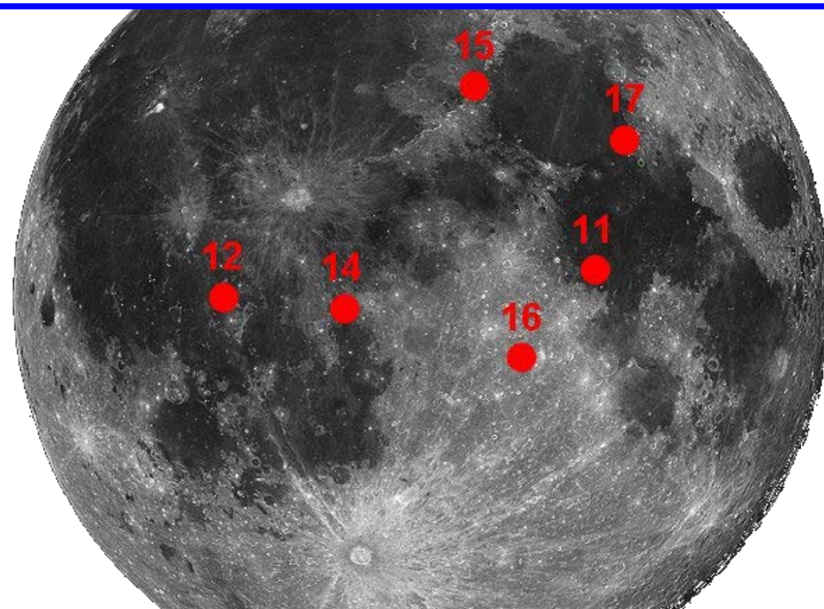
- Grand designs vs incremental steps
- Cislunar space
- Potential demonstrations
- Alpha Cubesat example: from ISS to lunar orbit

Apollo


ELECTRONICS RESEARCH CENTER
HQ
GODDARD SPACE FLIGHT CENTER
AMES RESEARCH CENTER
LEWIS RESEARCH CENTER
WALLOPS FLIGHT CENTER
JET PROPULSION LABORATORY
FLIGHT RESEARCH CENTER
MARSHALL SPACE FLIGHT CENTER
LANGLEY RESEARCH CENTER
WHITE SANDS TEST FACILITY
KENNEDY SPACE CENTER
JOHNSON SPACE CENTER
MICHOUD ASSEMBLY FACILITY
NATIONAL SPACE TECHNOLOGY LABORATORIES


Transearth injection after CSM/LM(asc.) rejoin
Rocket stage into solar orbit
Command module/ service module separation
Third midcourse correction
Earth parking orbit
Lunar orbit - descent and landing by LM
Entry
Landing
Second midcourse correction
Lunar orbit insertion by spacecraft
Launch
Translunar injection
Spacecraft
Rocket stage
Spacecraft/ rocket stage separation
First midcourse correction
Moon at launch


Apollo program
Apollo spacecraft configuration at launch
Command Module
Service, Command, and Lunar modules configured for journey to Moon
Apollo Saturn V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17
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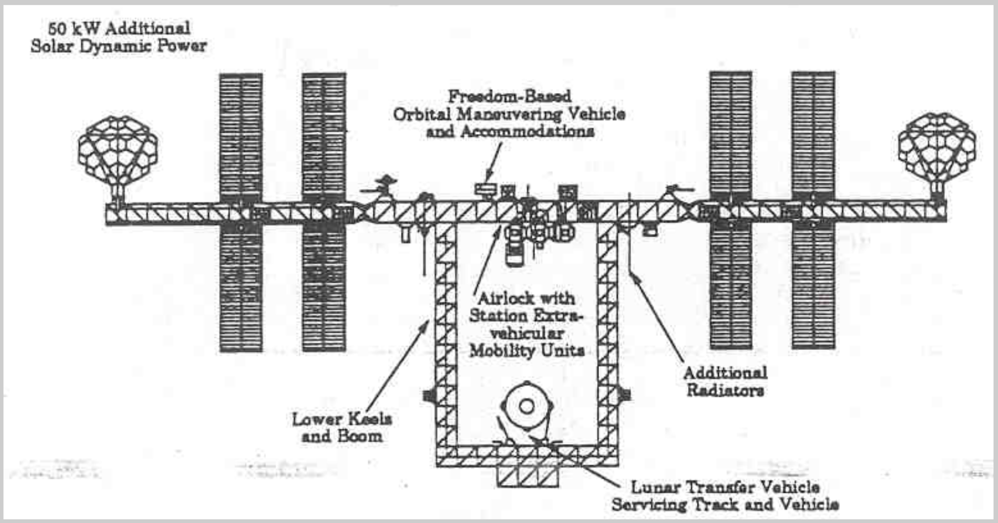
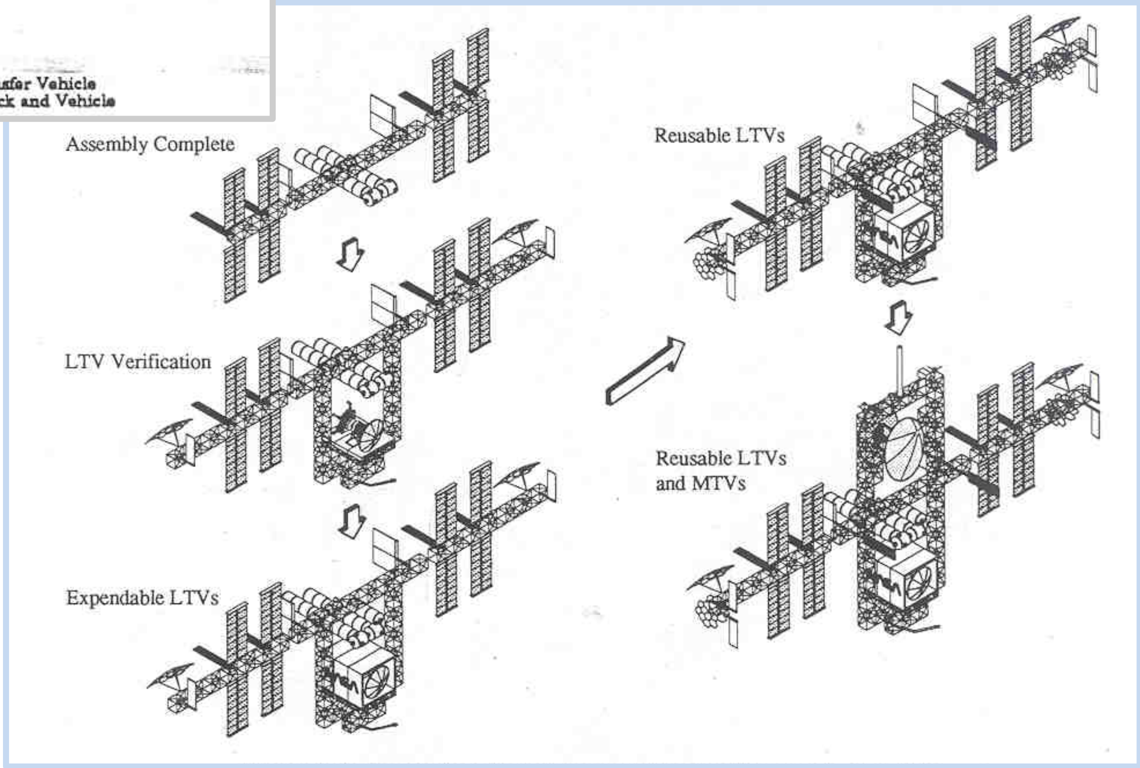
16

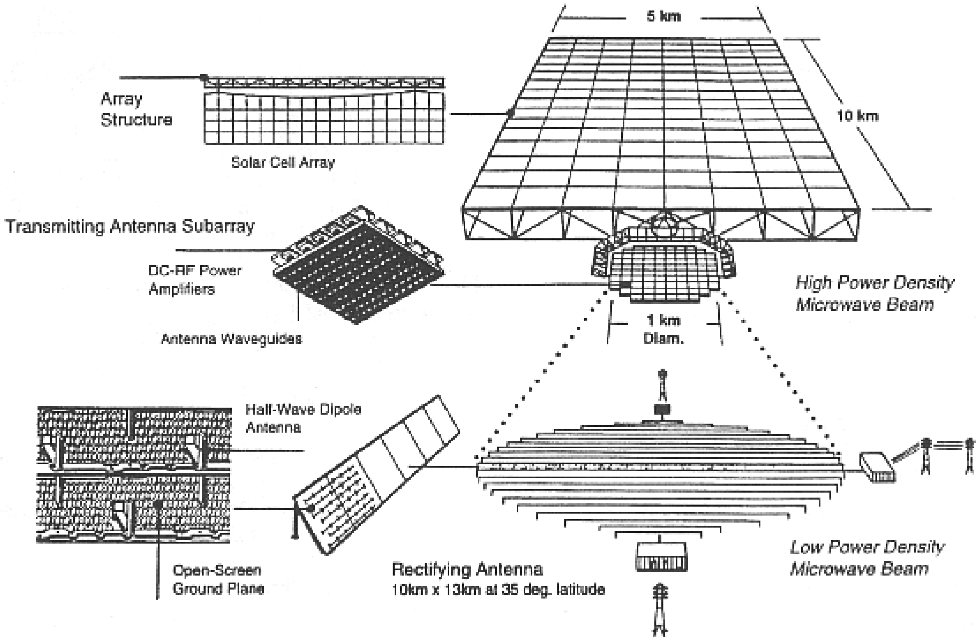
Space Station Transportation Node

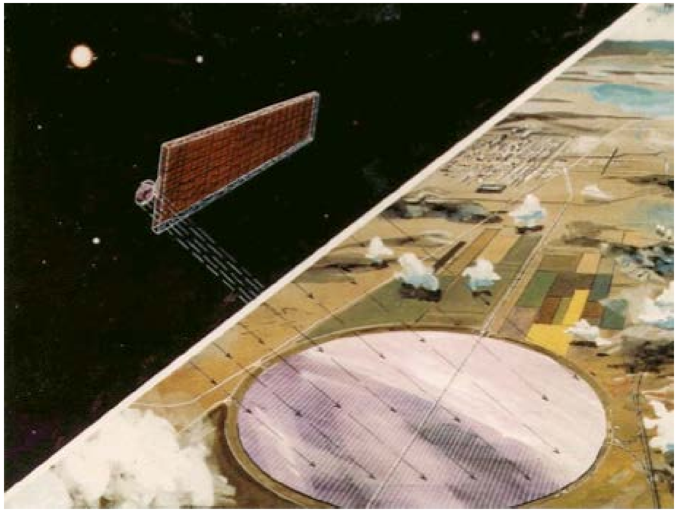


Plans for Space Station Freedom to evolve to become an exploration transportation node (1992)



Space Solar Power Satellite design (1980)





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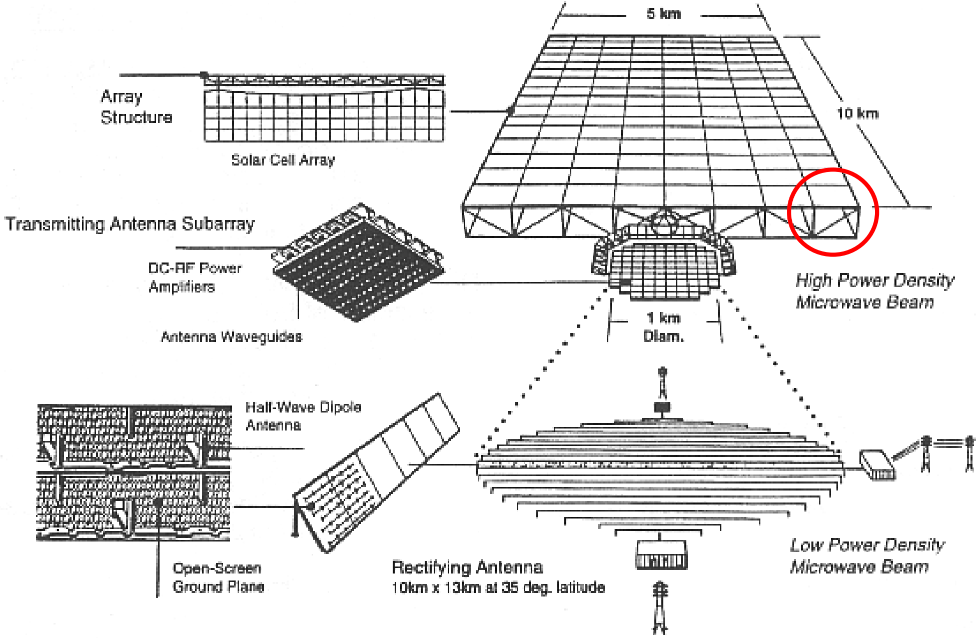

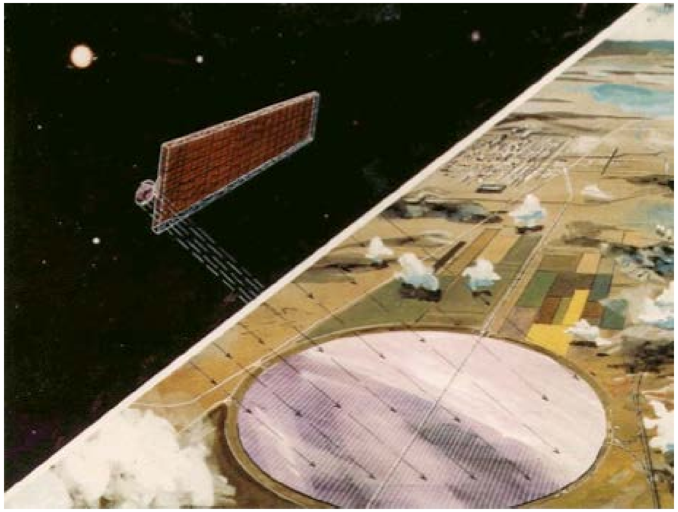

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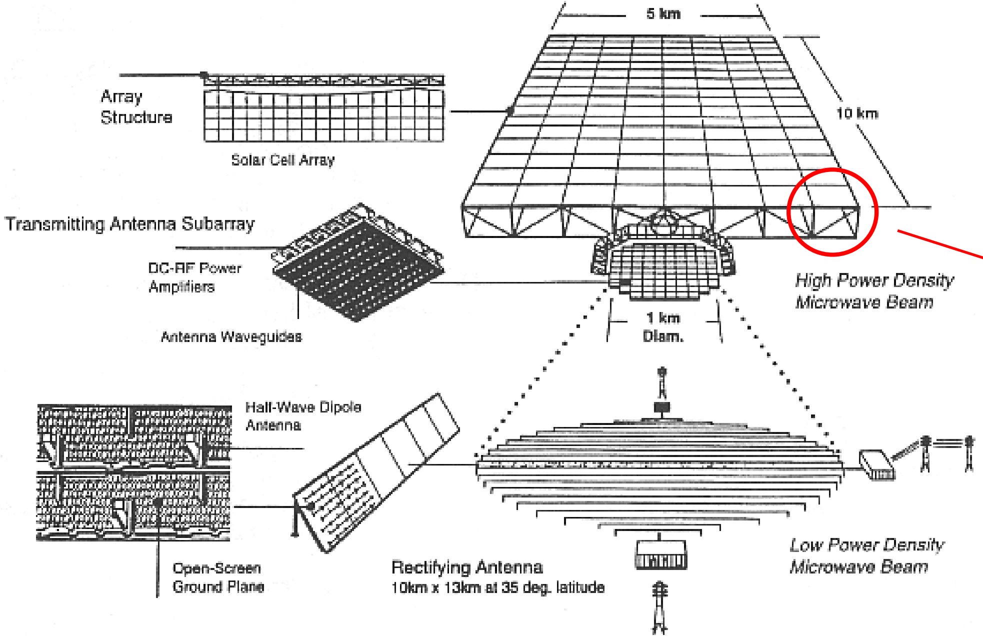

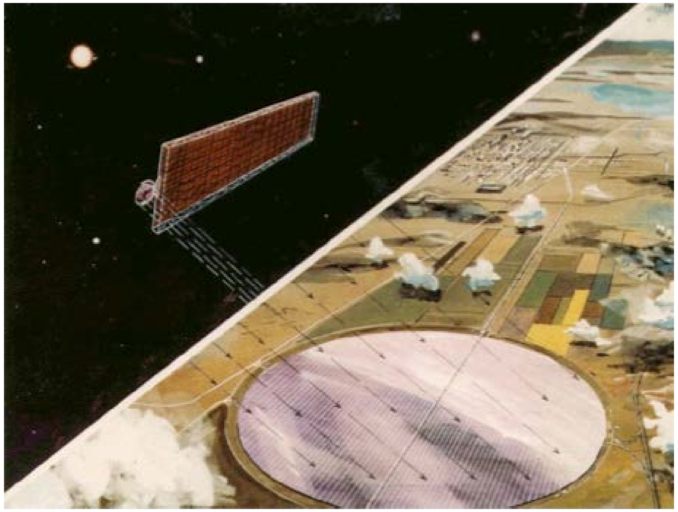

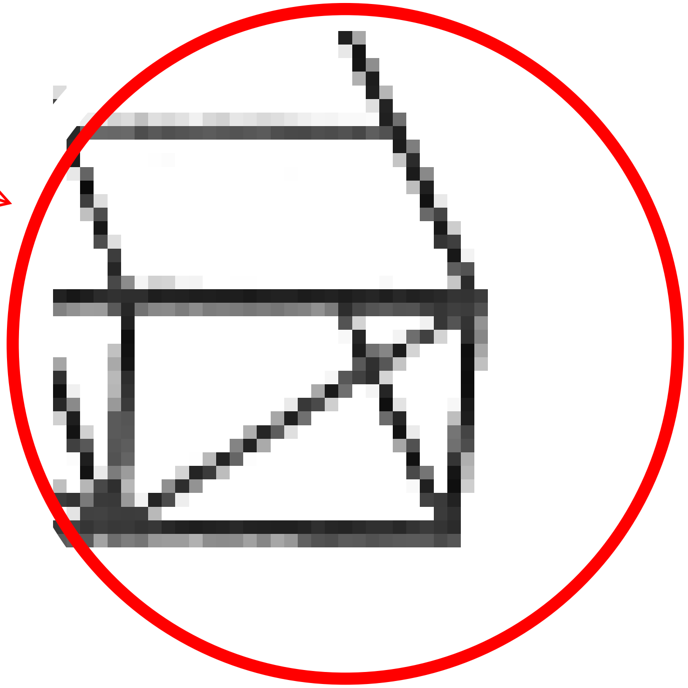

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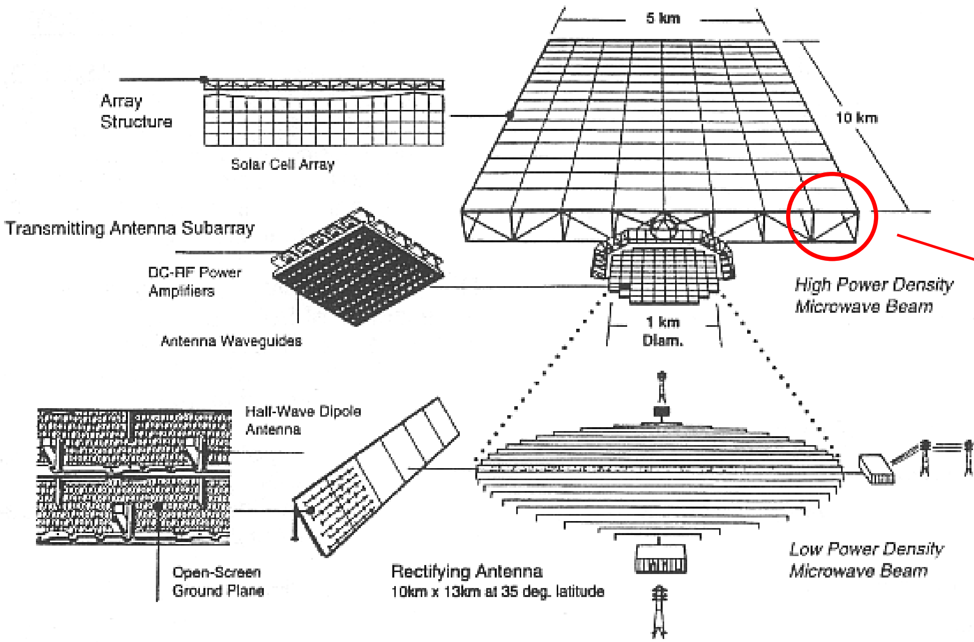
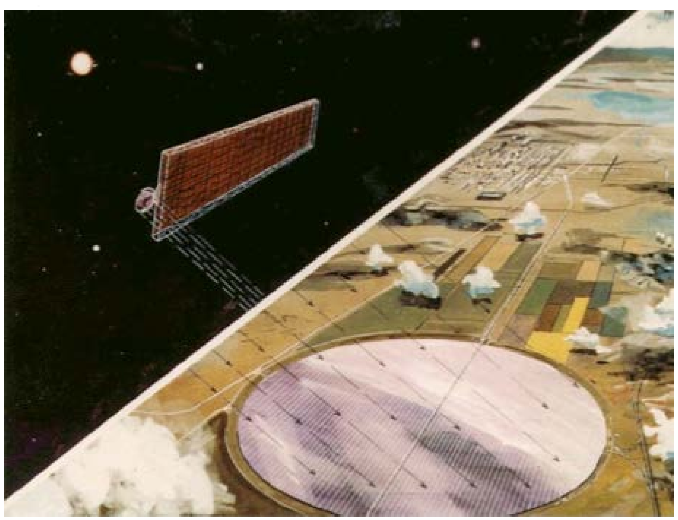
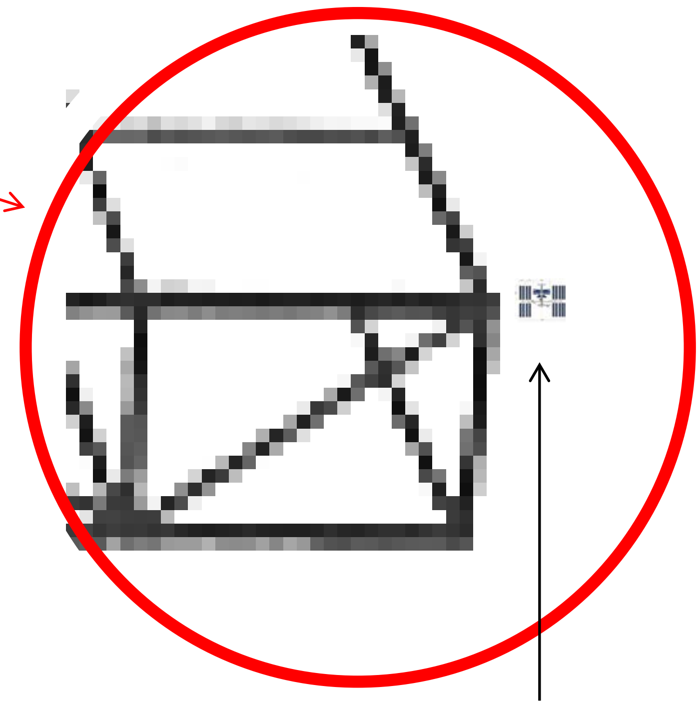




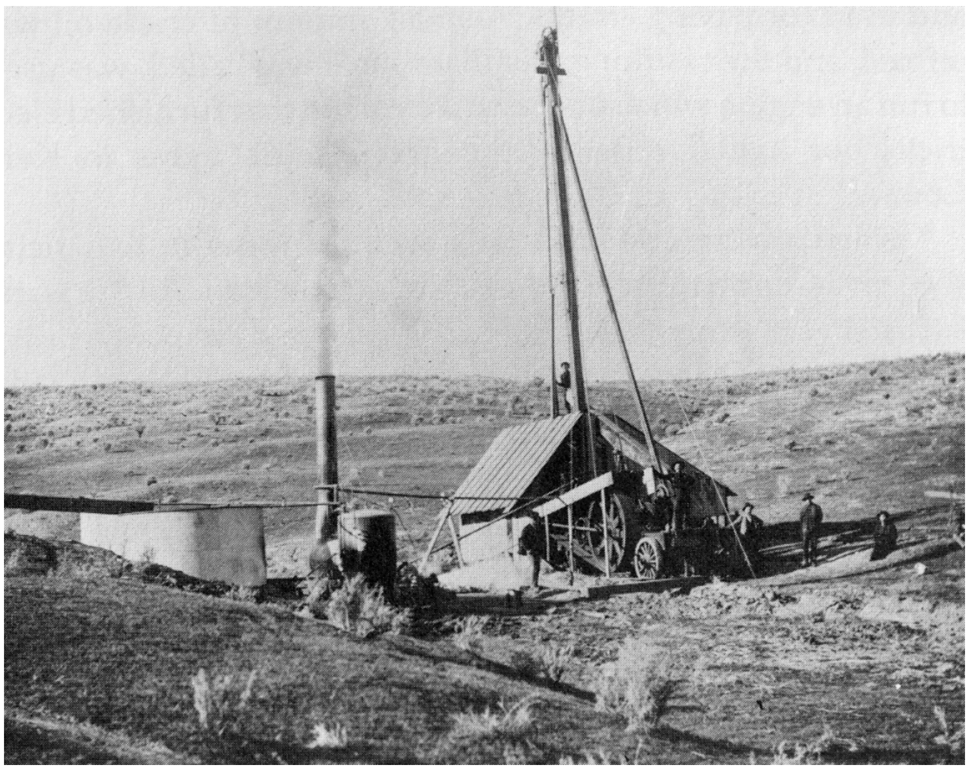


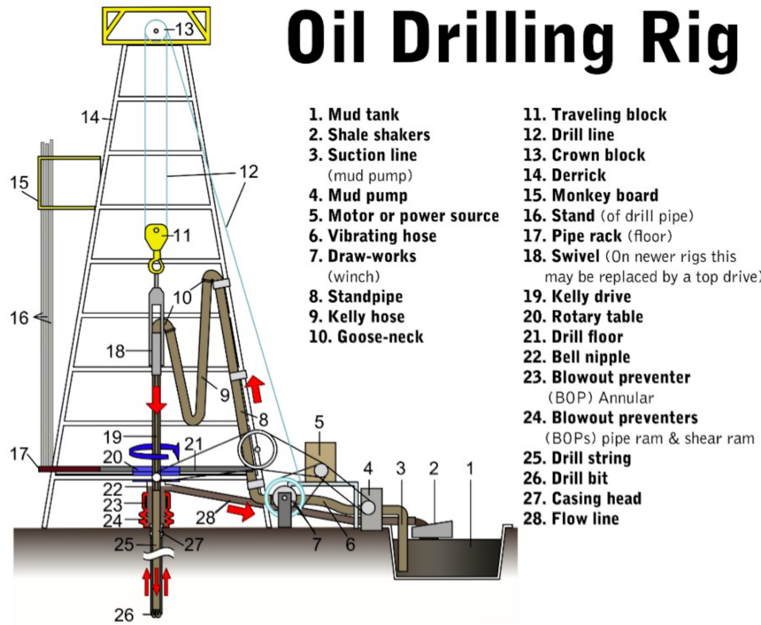
ISS
for scale

Large Investments…

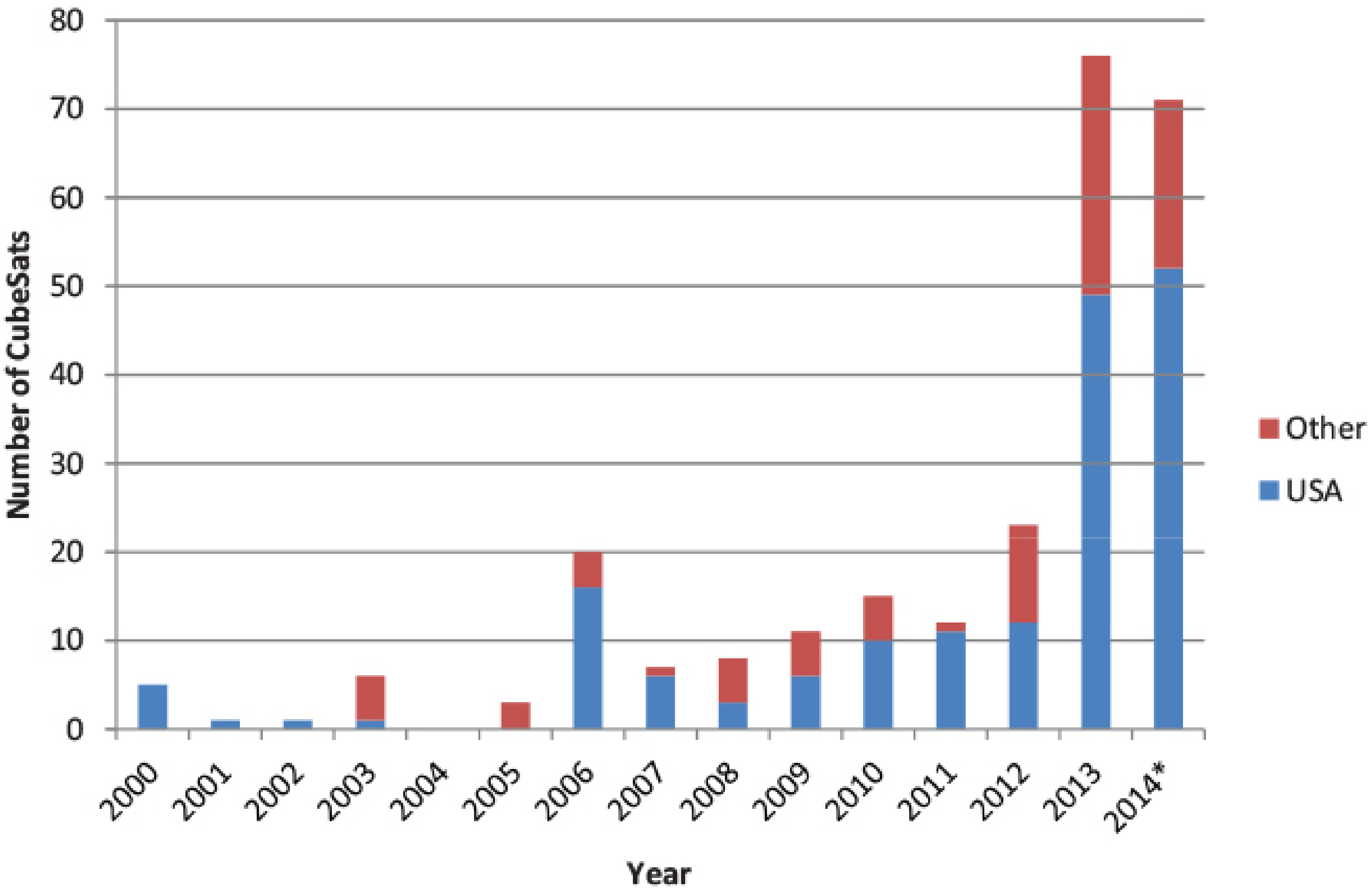

~$3B for one platform
Approaching $1T invested

…start from simple beginnings

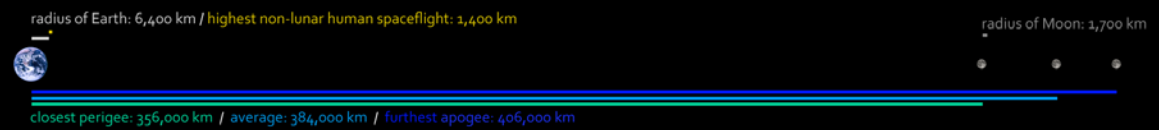




Opportunities for incremental progress



Cislunar Space



Cislunar Space

Orbits and trajectories

LEO, orbital periods, delta-v, MEO, GTO, GEO, inclinations

Earth environment

atmospheric drag, eclipse periods, orbital debris zones, magnetic field

Radiation

Inner and outer radiation belts, solar flares, coronal mass ejections, solar proton events, cosmic rays

Cislunar trajectories

Earth-Moon Lagrange points, Earth-Sun Lagrange points, orbit transfer manifolds, interplanetary superhighway

Lunar surface

Lunar regions, latitudes, day-night cycle, thermal cycle, dust, landing, liftoff

Asteroids and comets

NEOs, orbital elements, synodic periods, asteroid types, surfaces and structure

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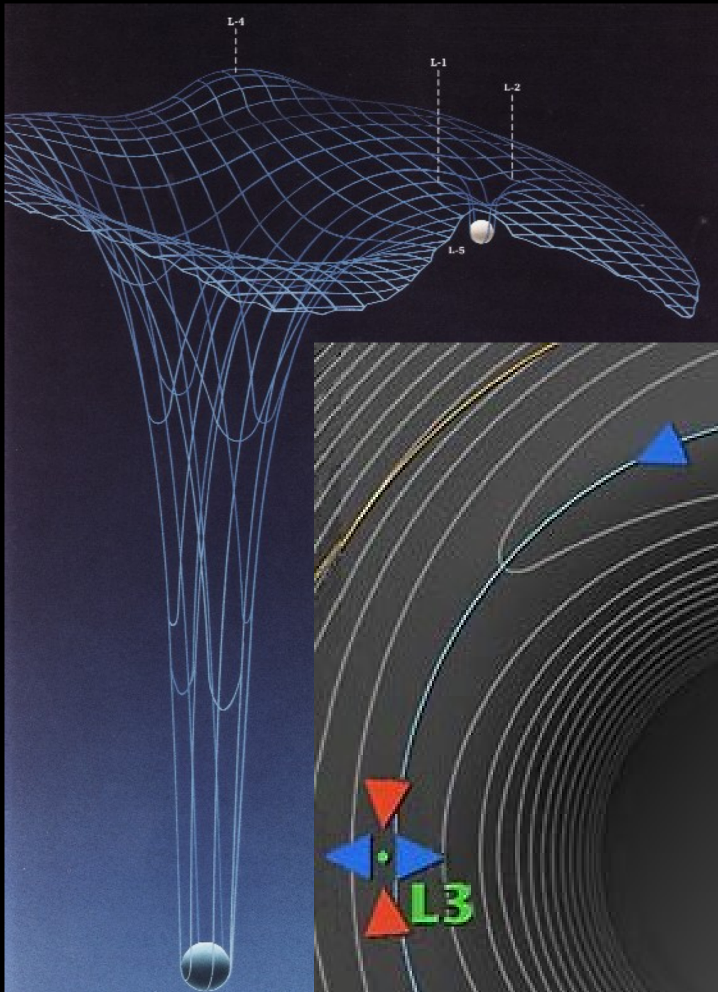
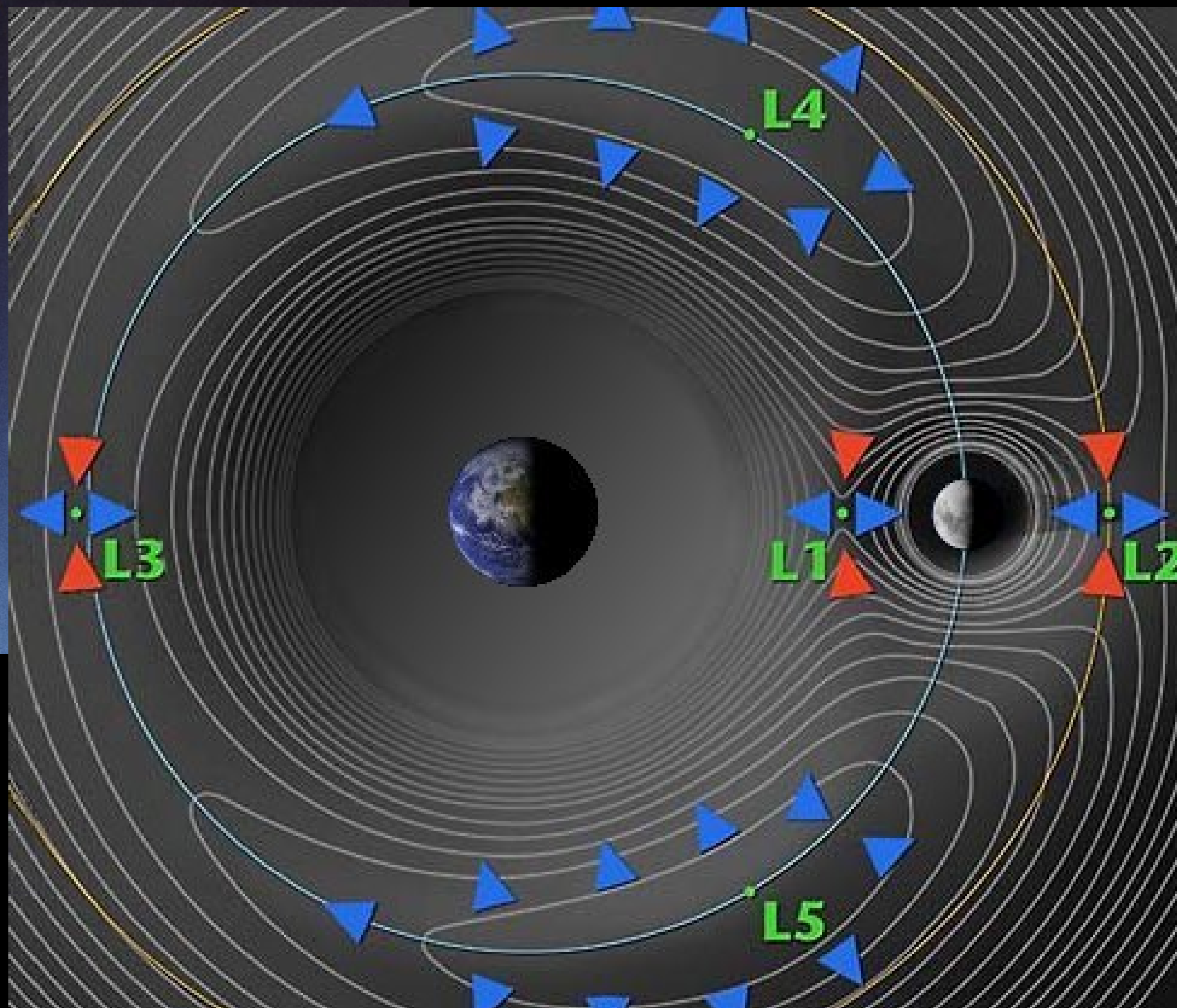
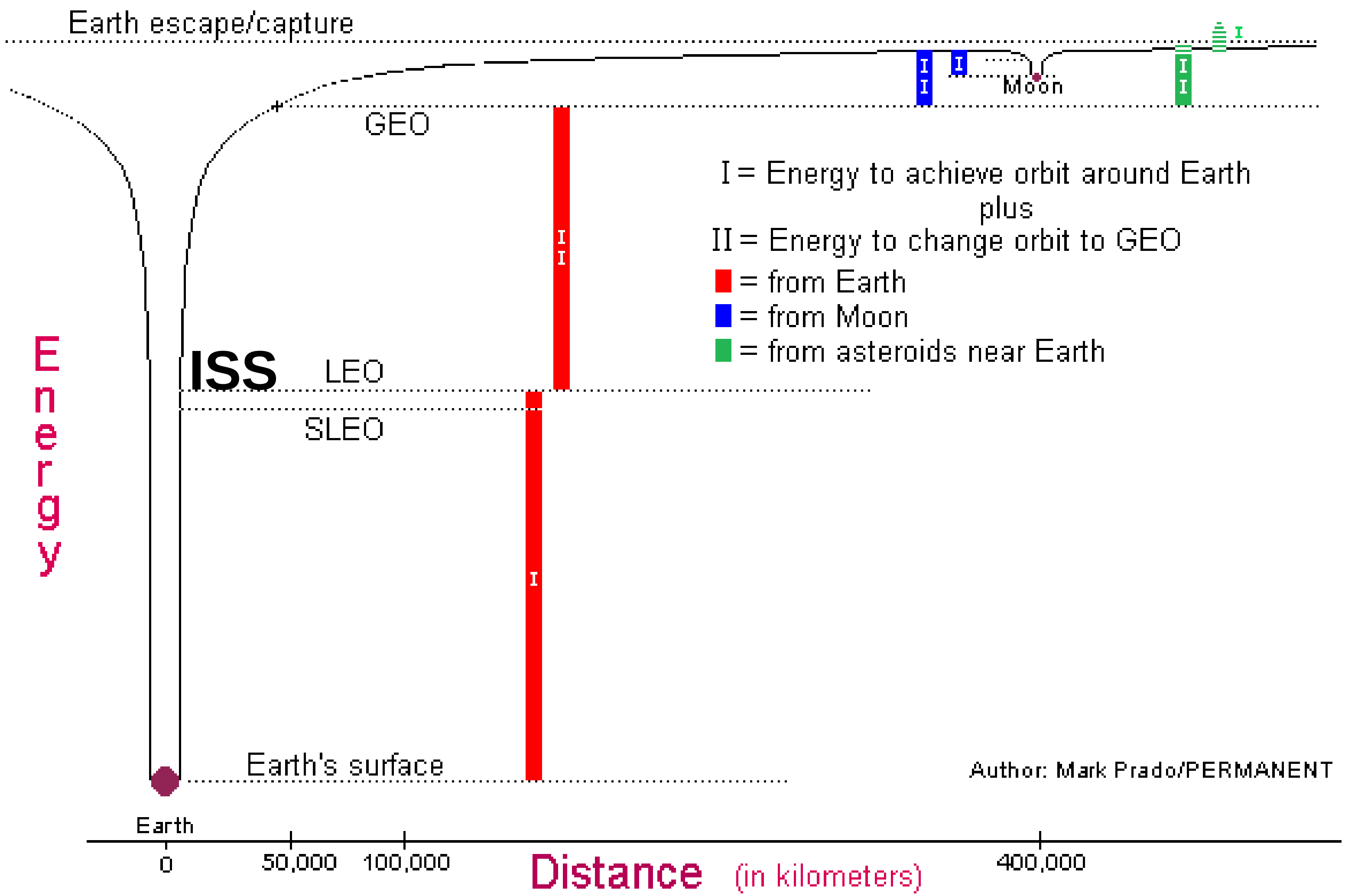
Earth and Moon gravity wells and libration points







Earth escape/capture
GEO
Moon
I = Energy to achieve orbit around Earth
plus
II = Energy to change orbit to GEO
= from Earth
= from Moon
= from asteroids near Earth
Energy
ISS
LEO
SLEO
Earth's surface
Earth
Author: Mark Prado/PERMANENT
0
50,000
100,000
400,000
Distance (in kilometers)

Earth and Moon separation scaled by delta-v

ISS is ‘halfway to anywhere’

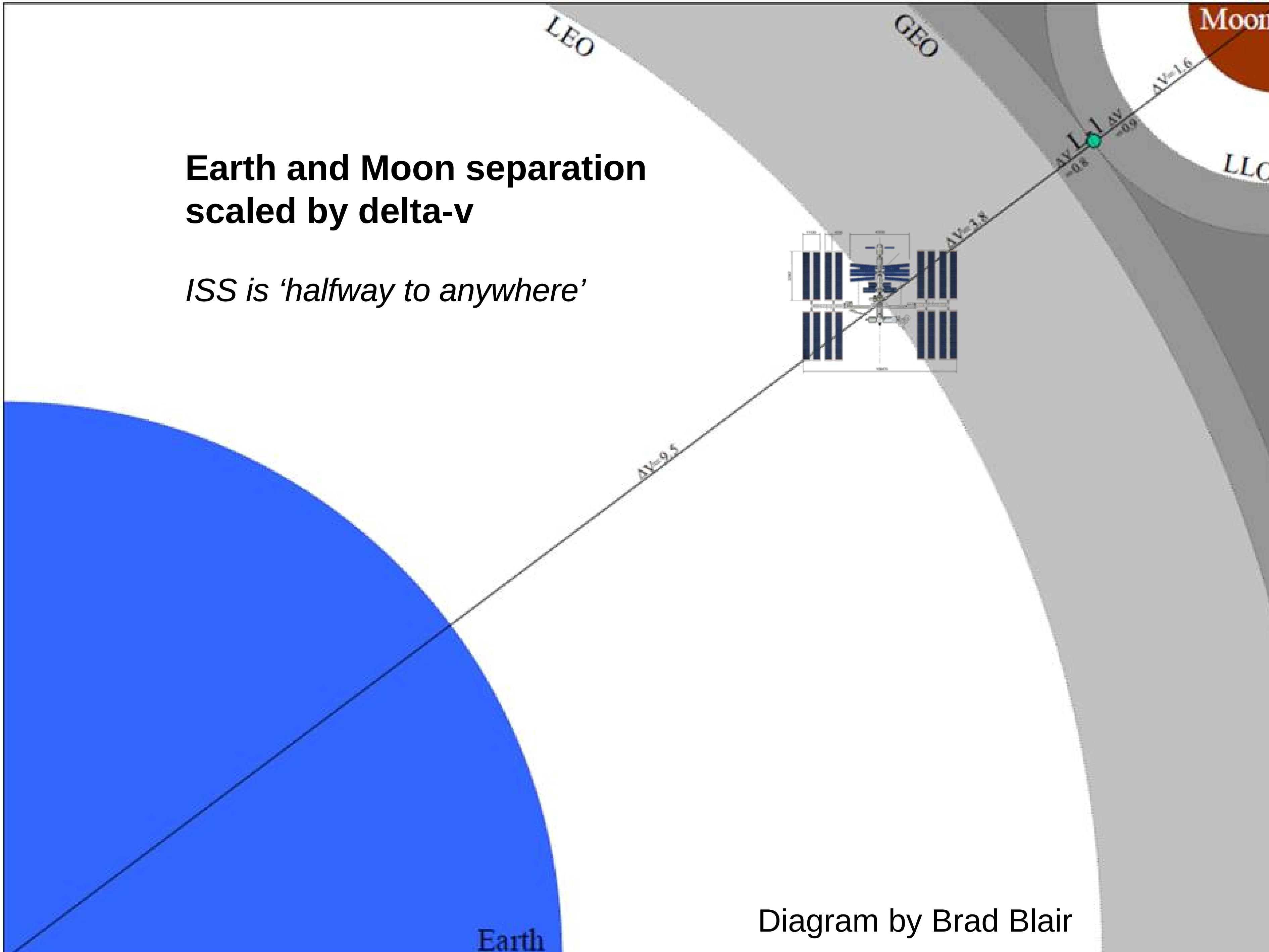
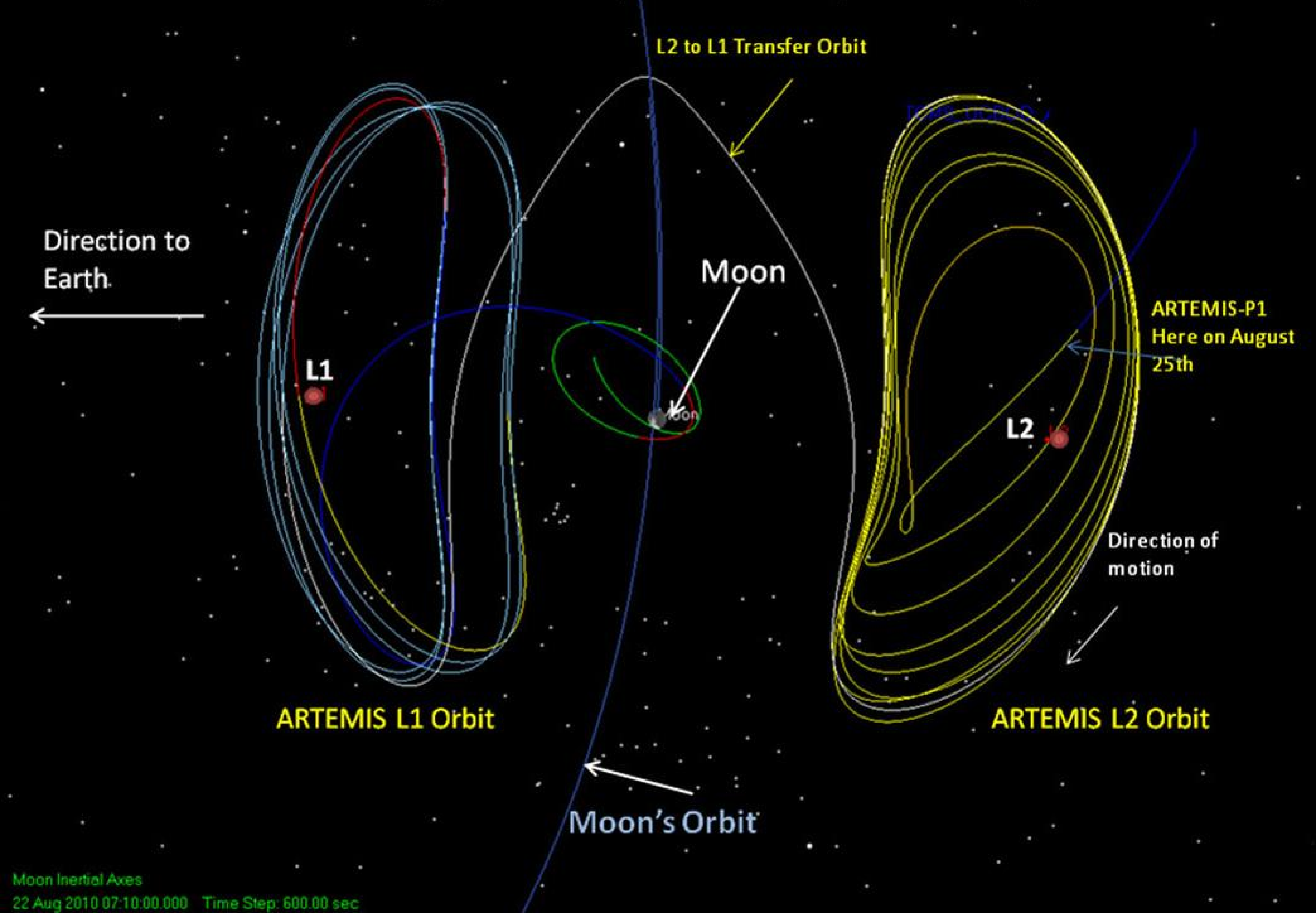
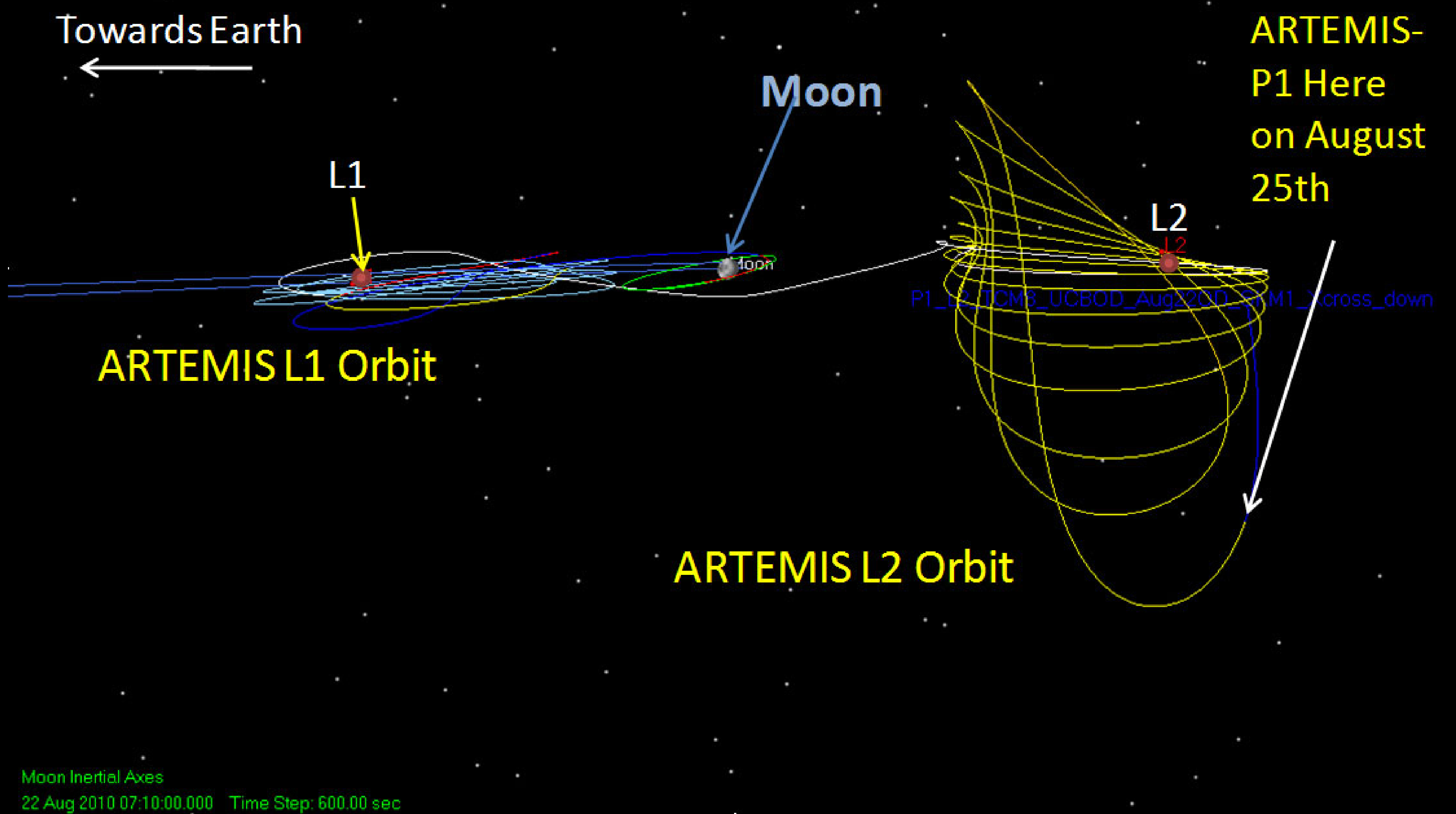


Diagram by Brad Blair

ARTEMIS-P1 Spacecraft's Orbit – Top View



ARTEMIS-P1 Spacecraft's Orbit – Side View



Cislunar Space

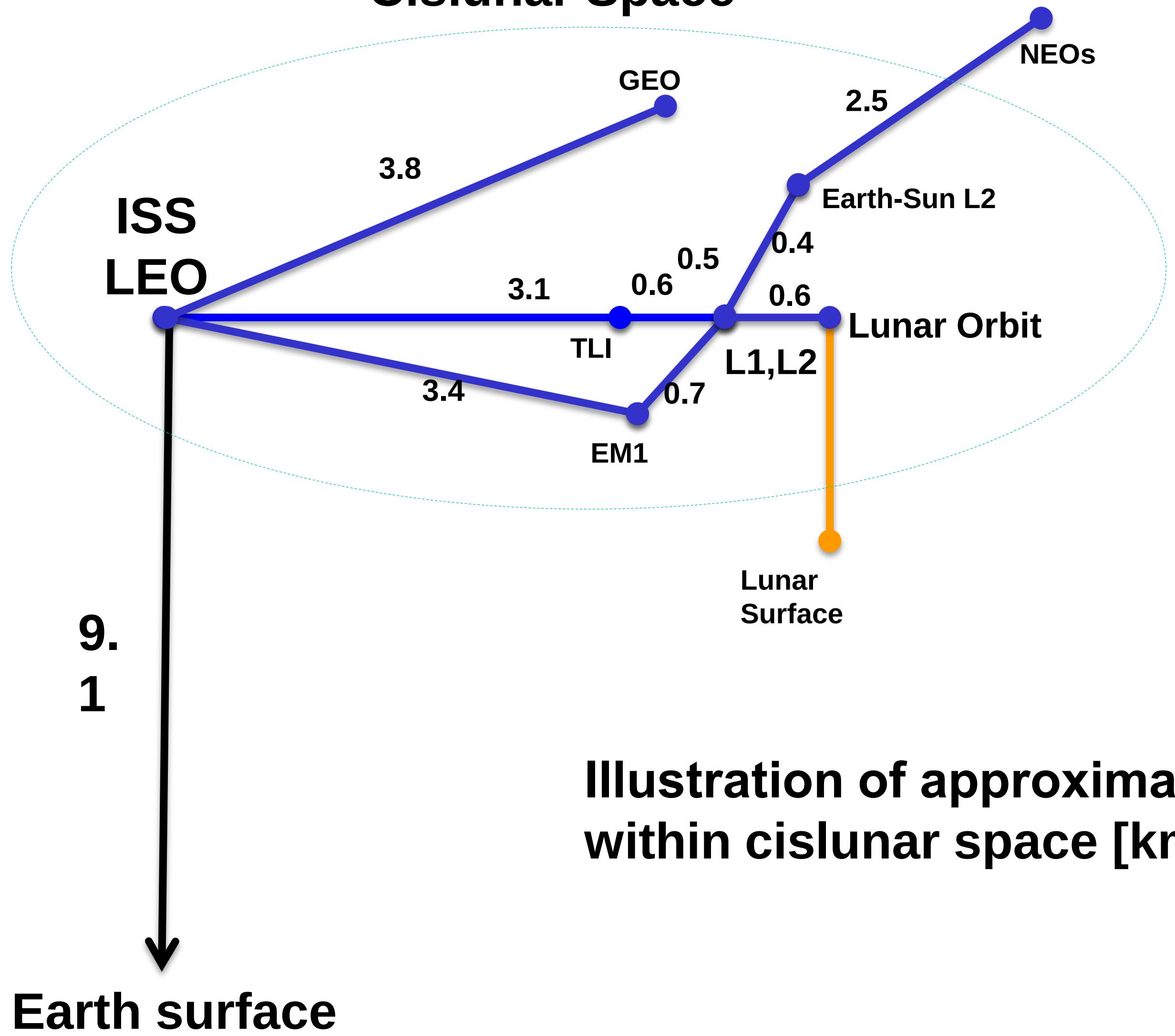
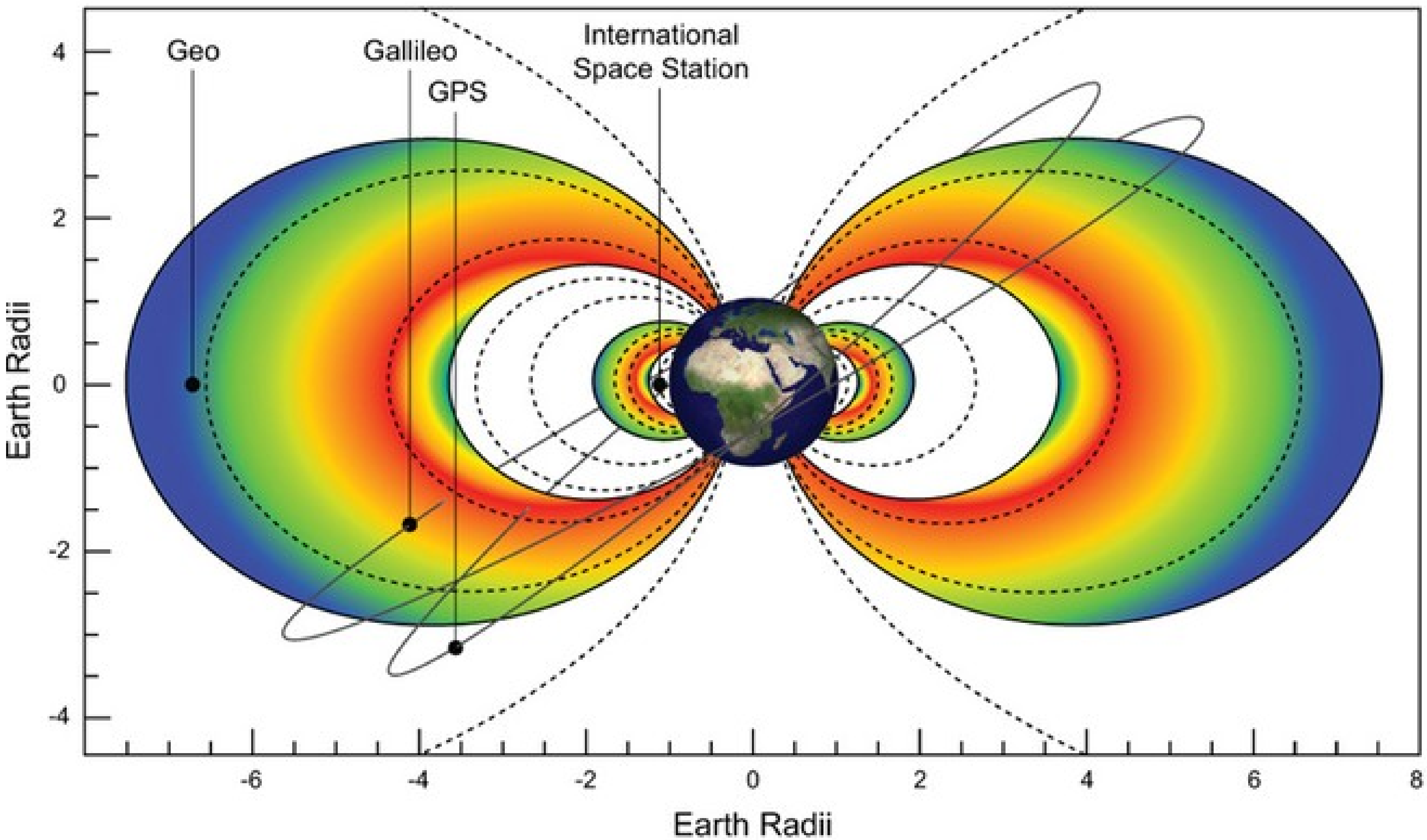
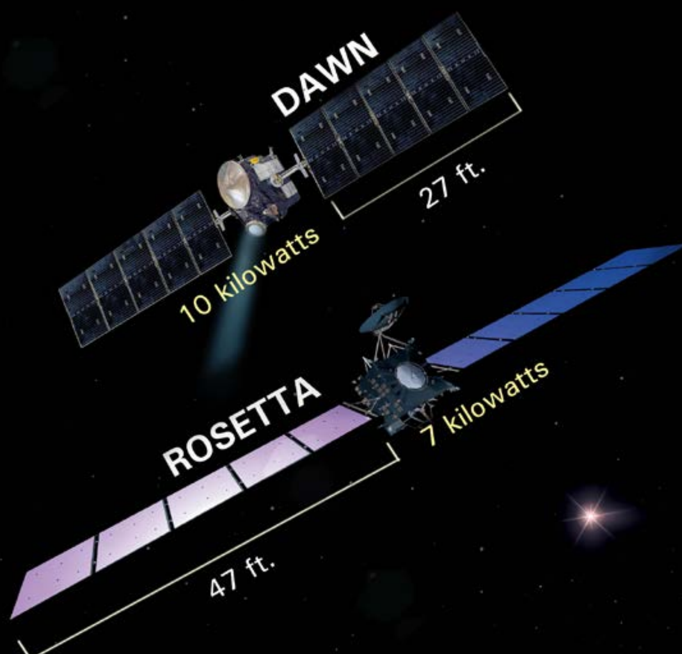


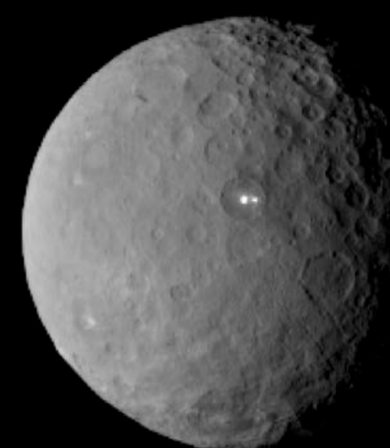
Illustration of approximate Δv within cislunar space [km/s]

The Earth's Electron Radiation Belts




DAWN
NASA
Mars flyby
2011 Dawn orbits Vesta
Journey to the beginning of the Solar System with the Dawn mission. Travel with the Dawn spacecraft as it explores Vesta and Ceres:
2007 Dawn mission launch
2015 Dawn orbits Ceres


DAWN
27 ft.
10 kilowatts
ROSETTA
7 kilowatts
47 ft.



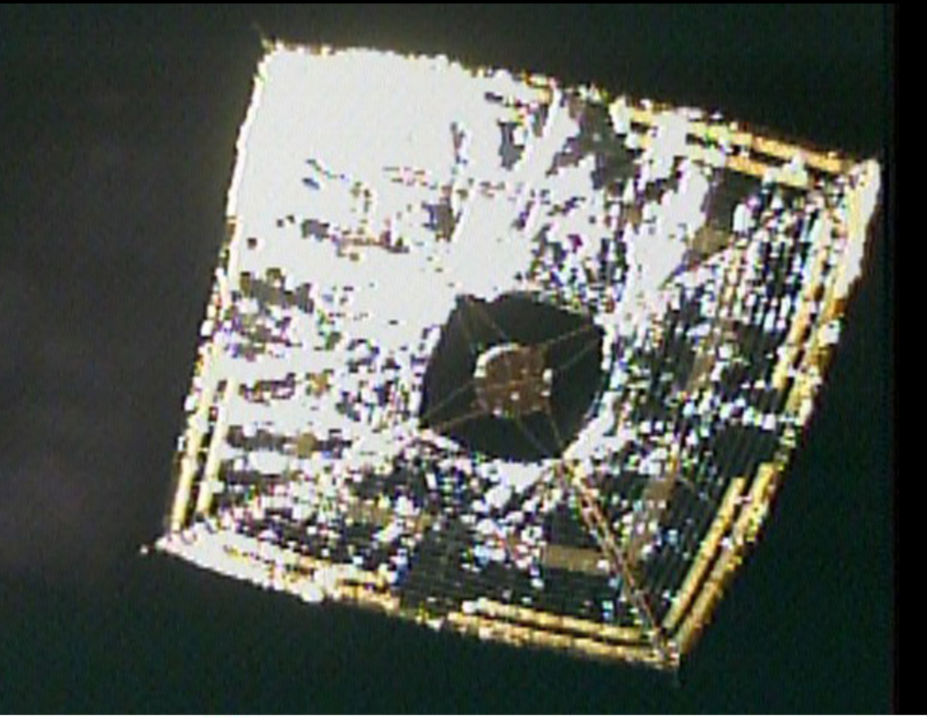
Operational Satellites with Electric Propulsion

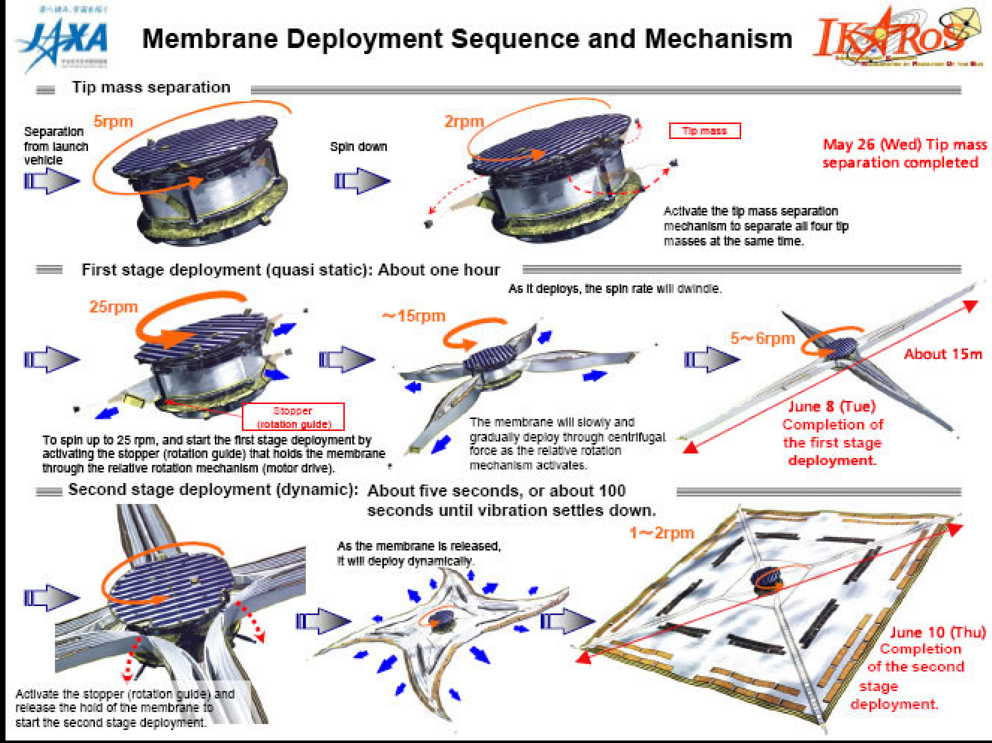
Cumulative Number of Satellites Employing EP = 226
Number of Satellites Employing Aerojet EP = 156

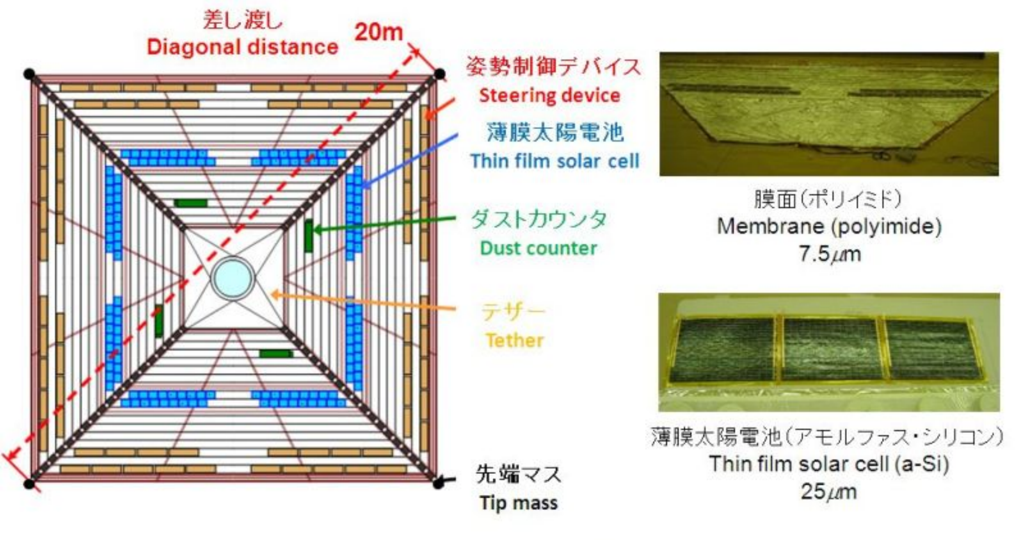
03 / 12 / 08

AEROJET

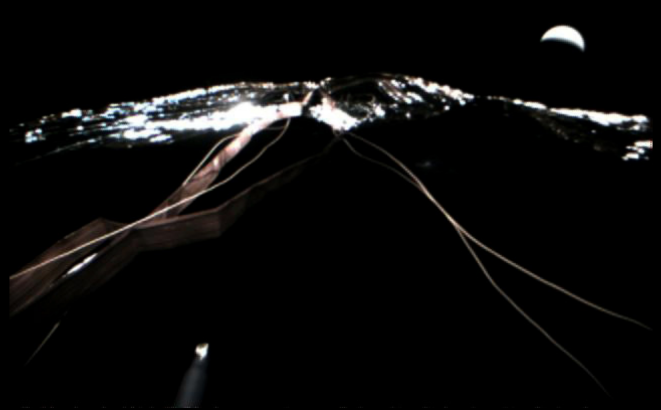
Lightsail Demonstrations



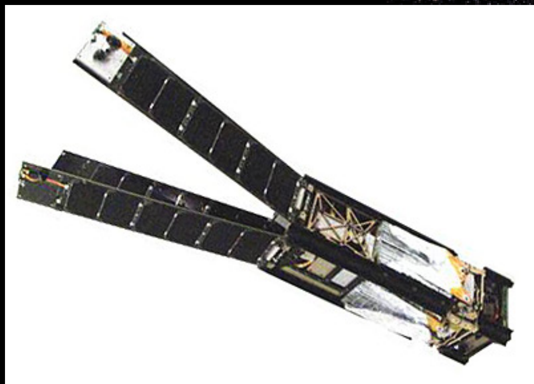


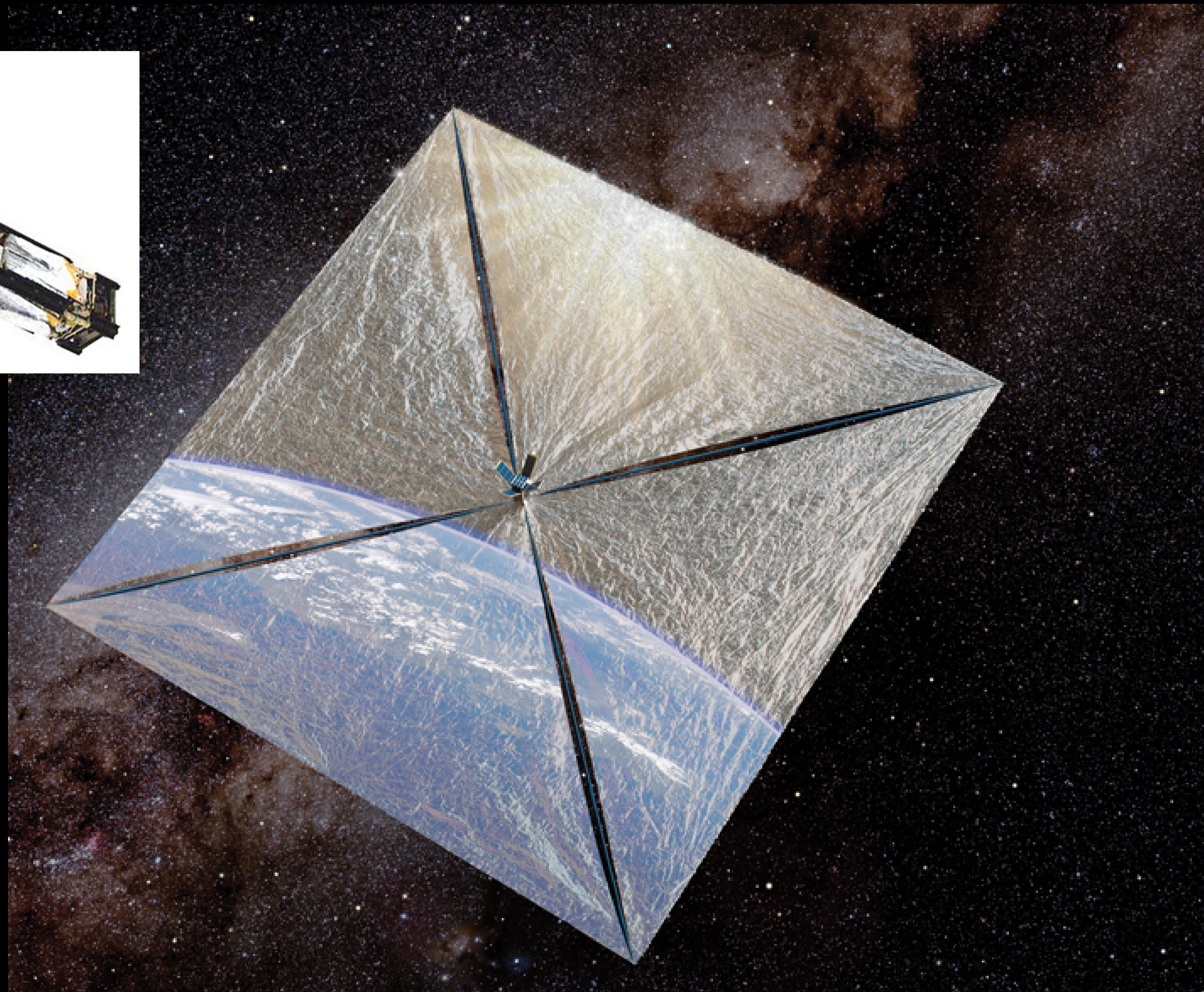


膜面形状・配置
Membrane design

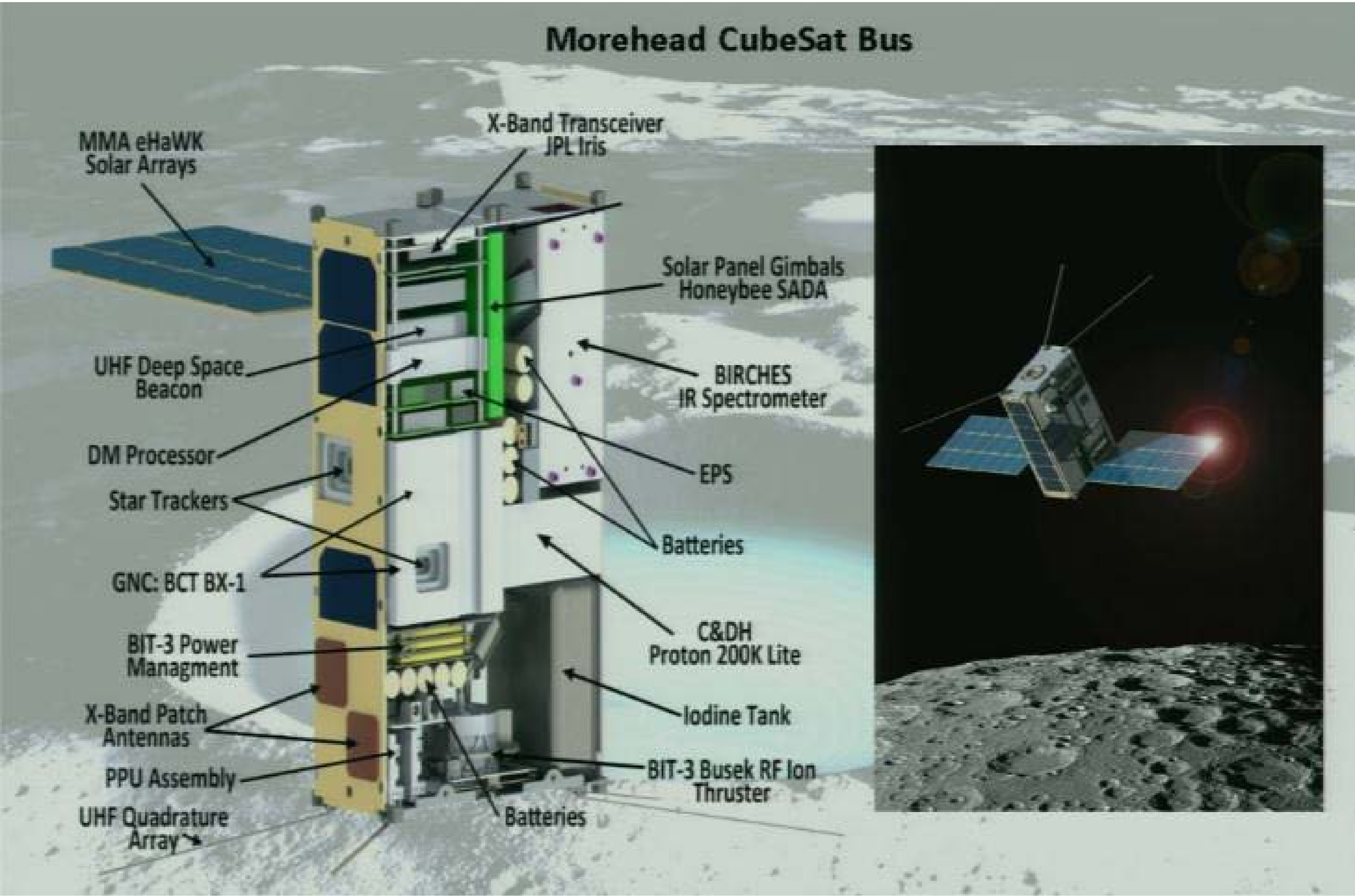


Lightsail Demonstrations

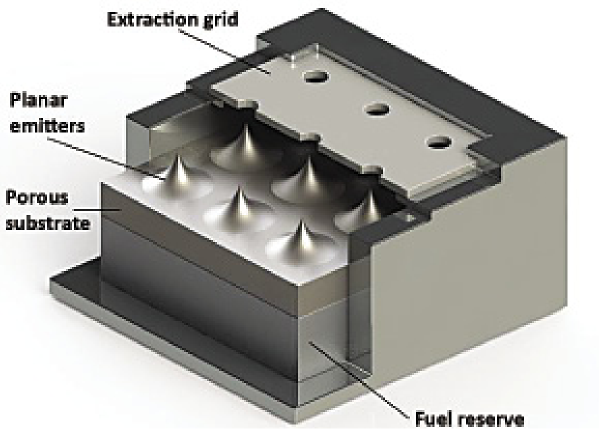


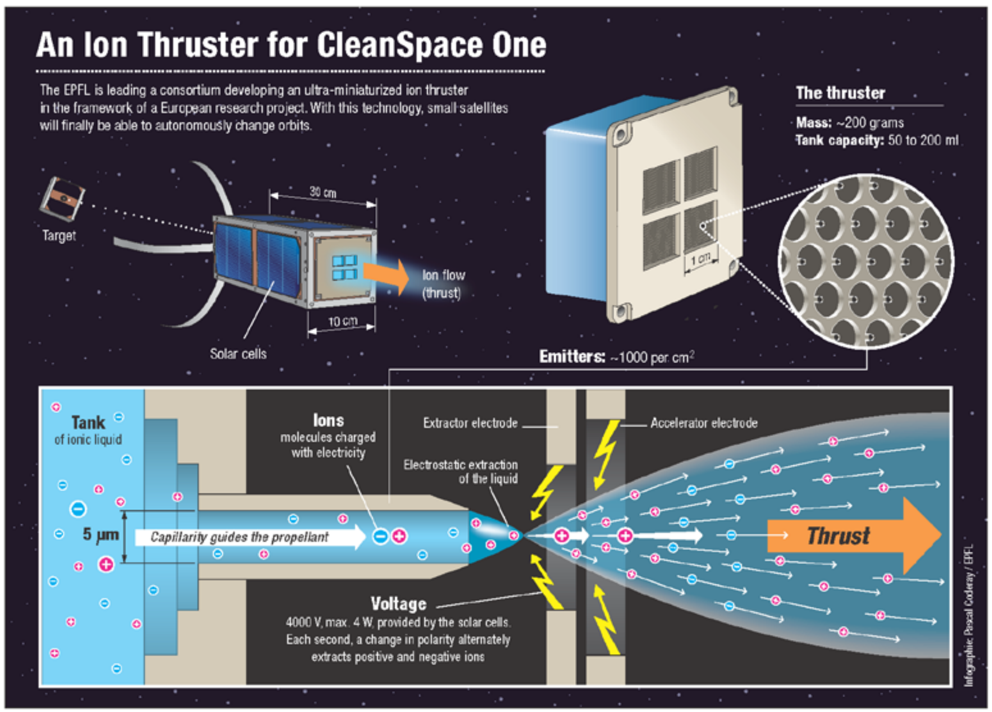


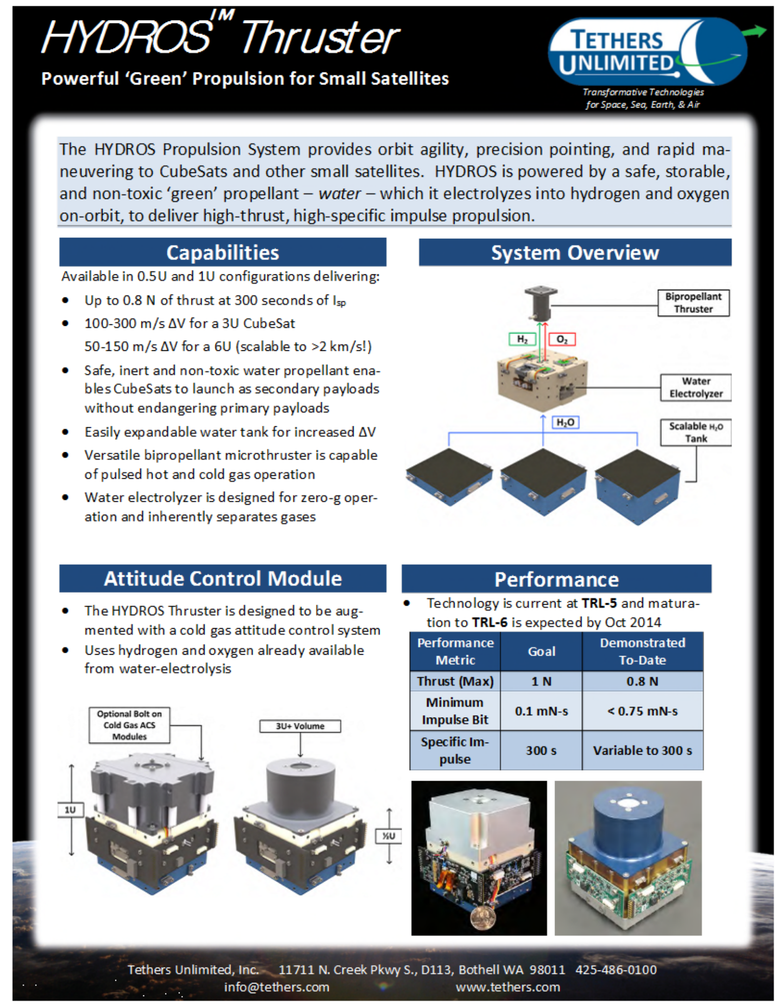
IceCube - Lunar cubesat design



Variety of cubesat propulsion systems being developed







Cubesats deployed from ISS

Advantages & Disadvantages - 1

Spacecraft design:

- **Assemble at ISS (IVA or EVR in LEO)**
- **Avoid aerodynamic loads**
- **Avoid launch loads**
- **Potential for large structures**
- **Design for vacuum**
- **Pure ‘space’ spacecraft**

Different level of design optimization - optimize for in-space use

Advantages & Disadvantages - 2

ISS serves as a Propulsion Test Bed for many options:

- **bi-propellants (non-toxic, non-hazardous)**
- **solar electric/ion thrusters**
- **power beaming**
- **resistojets (e.g., scavenged water, methane, etc.)**
- **mono-propellants (non-toxic, non-hazardous)**
- **solar sails**

Provides for a wide range of low and high thrust options

Advantages & Disadvantages - 3

Trajectory and delta-v implications of starting from LEO:

- Classic “minimum” energy trajectories are not optimal
- Alternate minimum energy trajectories become tractable
- Longevity of spacecraft components more critical
- Non-protected orbit transfers increases exposure time to
    - Orbital debris
    - Radiation belts
- The calculations required are more demanding and must be readily accomplished

Alpha Cubesat example: From ISS to 4M km, then LLO

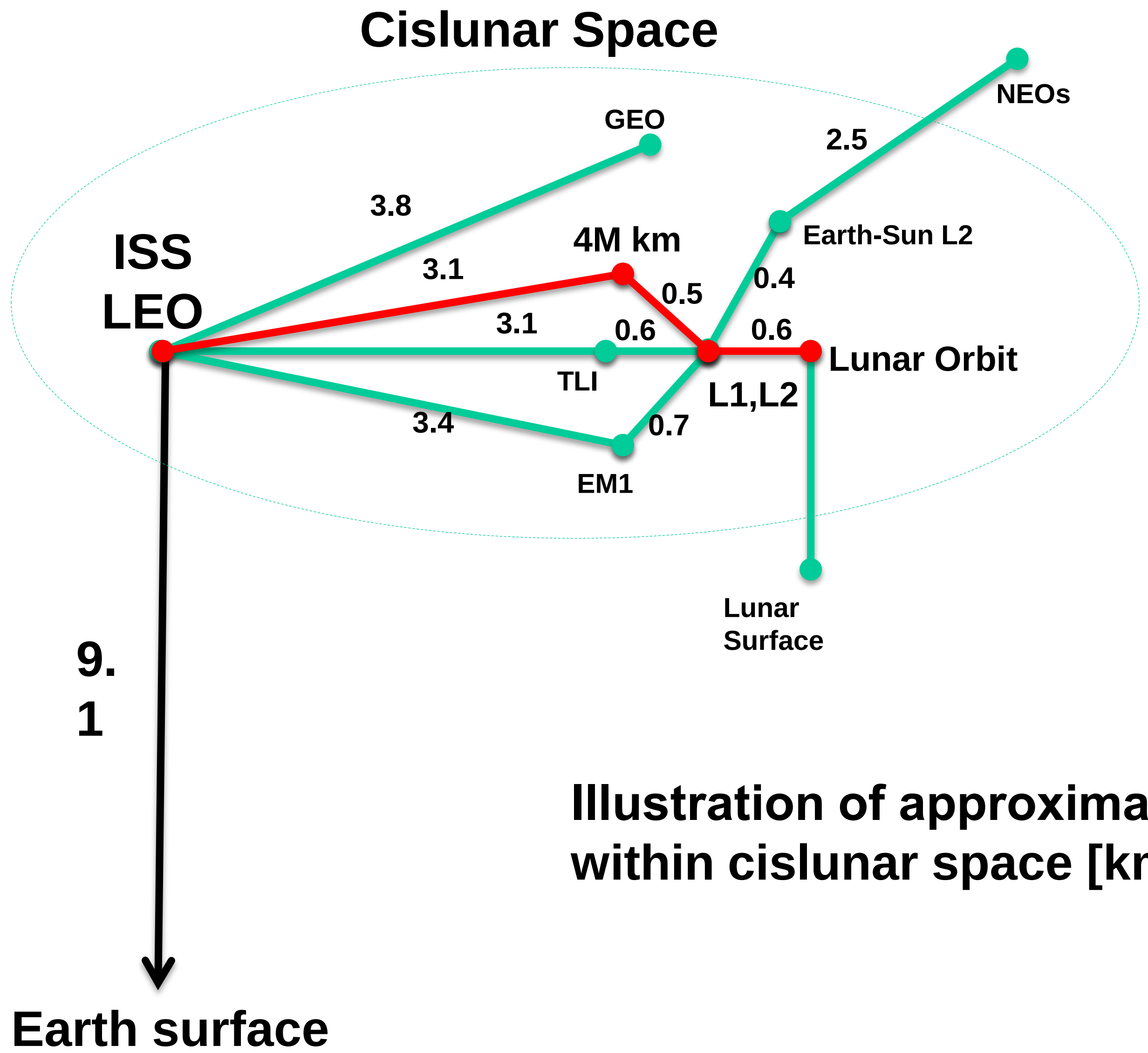
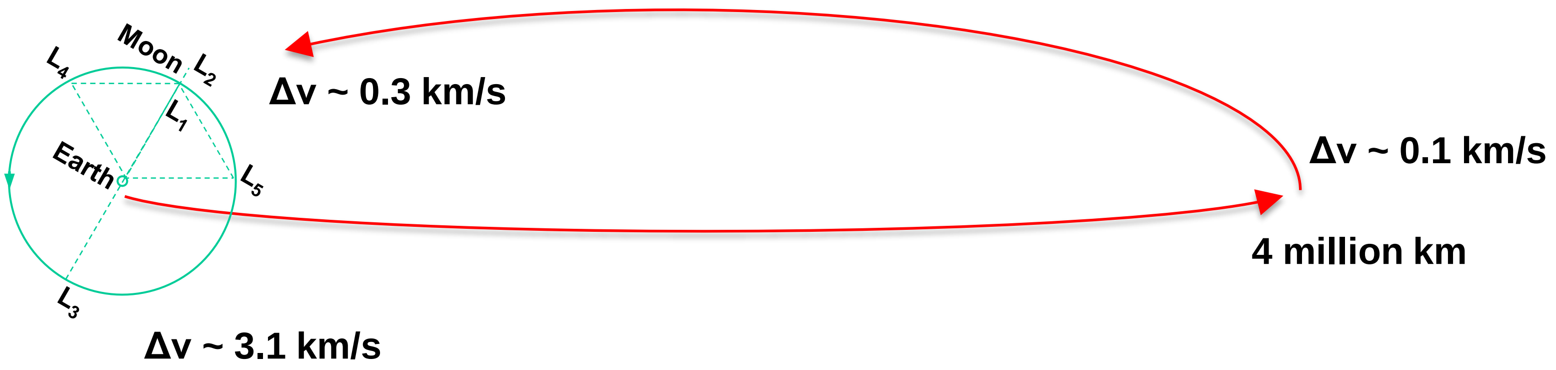
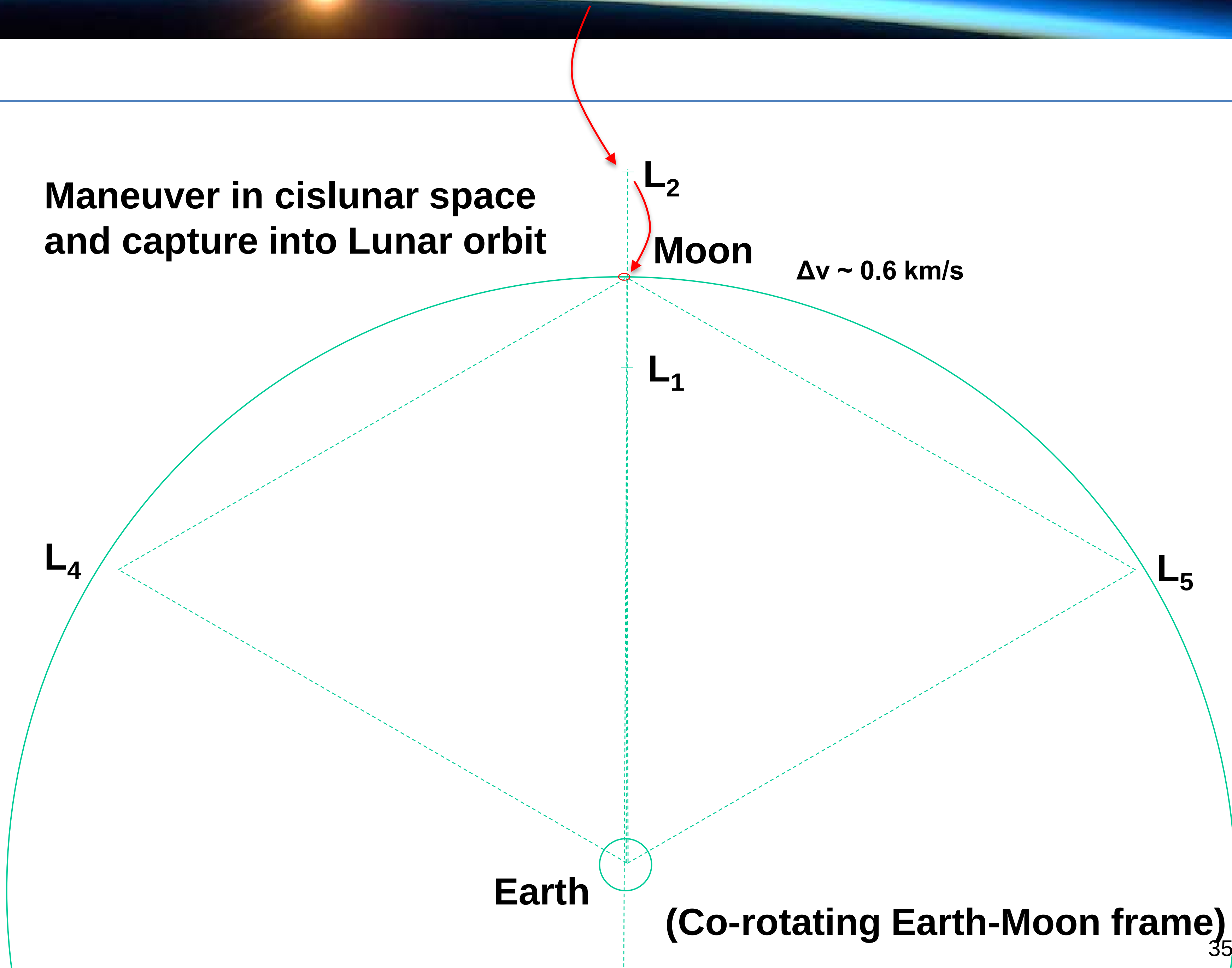


Illustration of approximate Δv within cislunar space [km/s]

Example: Cubesat from ISS to 4M km, then LLO



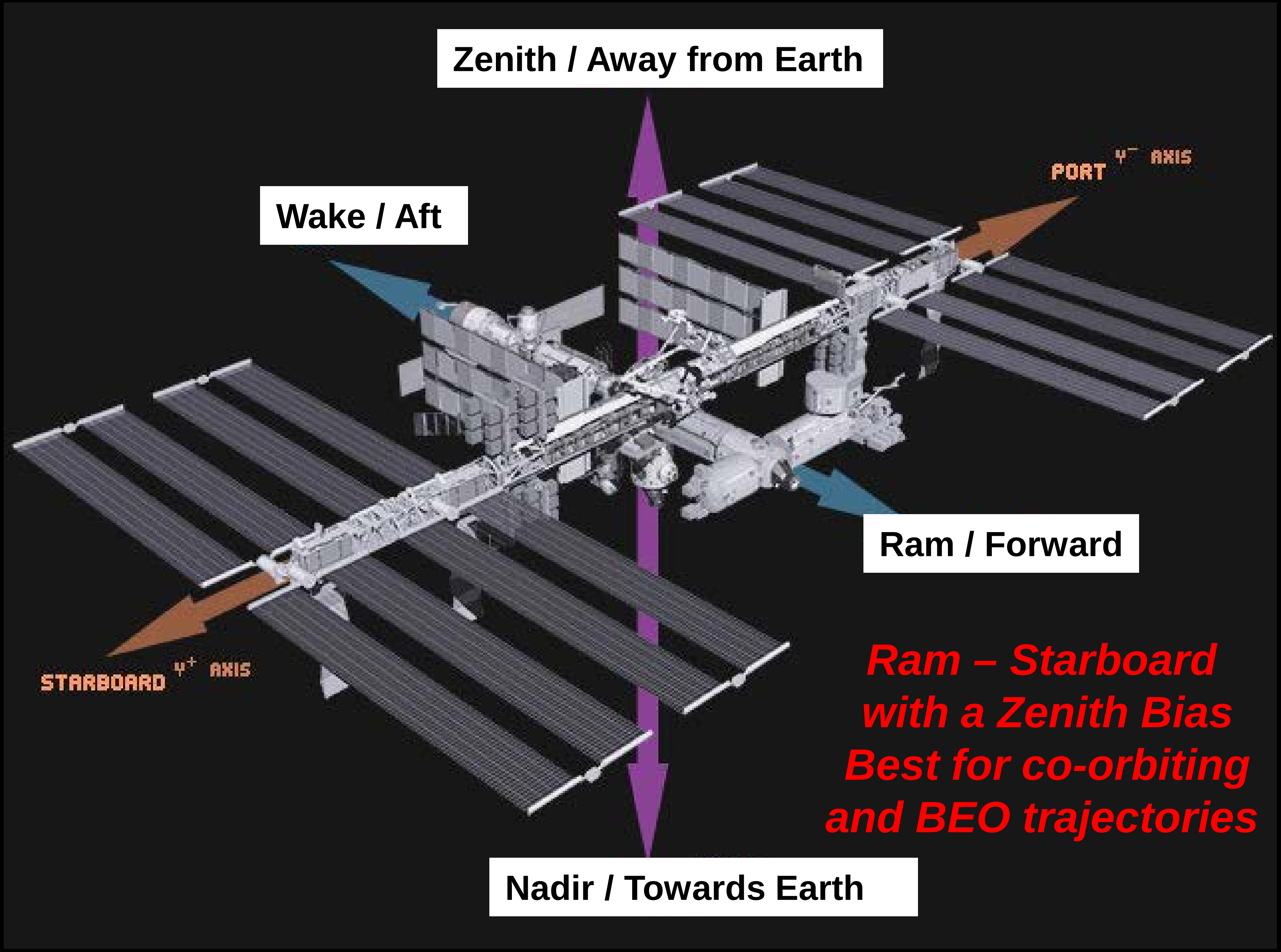
Maneuver in cislunar space and capture into Lunar orbit



(Co-rotating Earth-Moon frame)

ISS as a Launch Platform

- Commercial Cargo Pressurized “Softpack” launch & stow
  - IVA unpack & final assembly
  - CYCLOPS JEM Airlock IVA ➔ EVR Transition
  - EVR handoff to Mobile Servicing Centre (MSC)
- Commercial Cargo Unpressurized Cargo launch & stow
  - EVR unpack & final assembly
  - EVR handoff to Mobile Servicing Centre (MSC)
- Support services
  - EVR MSC relocate & position for deployment
  - MSC SPDM Deployment RAM + Starboard + Zenith Bias
  - Final proximity checkout services (e.g., imaging, communications, navigation & power)



Ram – Starboard with a Zenith Bias Best for co-orbiting and BEO trajectories

Conclusion

- **Multiple solutions exist for ISS launch in theory, in practice we need to test & optimize alternatives**
- **We need to learn how to scale to larger systems**
- **We need to create opportunities for collaboration**
- **We need to find ways to do more with less resources**
- **On-orbit final assembly and checkout needs to be move from theory to practice**

This is a new way of doing business, that we need to learn to leverage . . .

Next Steps

- Design and implement a propulsion testbed environment for ISS
  - Testbed will provide the common infrastructure required
- Safety protocols required for each mission stage must be defined
  - Experiments need a known path to flight
- Each experiment will start with the defined operations and safety protocols augmented as needed based on any mission unique aspects added
- The possibilities for final assembly and checkout support need to be actualized by based on meeting real mission requirements

"Once you're in low Earth orbit you're halfway to anywhere."
– Robert Heinlein