Halfway to Anywhere - Cis-Lunar and Deep Space Cubesats Missions From ISS

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Outline

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- Background & Motivation
- Advantages & Disadvantages
- Team Alpha CubeSat Example
- ISS as a launch platform
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Introduction

Science fiction author Robert Heinlein once said, ”Once you're in low Earth orbit you're halfway to anywhere.”

This statement while playing a bit fast and loose with a strict accounting of kinetic energy requirements, is far from hyperbole.

This presentation examines both how to leverage the advantages and mitigate the disadvantages of using the International Space Station (ISS) as a beyond Earth orbit transportation node for multiple applications.

Background & Motivation - 1

Historically, most space missions have focused on single-use Earth-to-destination transportation

To develop a fully space-faring civilization, we need to evolve toward reusable, refueled, space vehicles that can provide transportation between multiple destinations - a different kind of space transportation architecture

This kind of transportation architecture is important for space development, space resource use, and space .

Background & Motivation - 2

Elements of these kind of space architectures have been proposed or used in the past (Lunar orbit rendezvous and the LEM, ‘Earth orbit rendezvous’, Space Transportation System - Shuttle+Station+OTV, etc.).

Previously, the assembly and deployment of lunar and deep space vehicles was a major mission of the space station - but these missions were deferred as ISS was built

New opportunities with cubesats (including deployment from ISS) allow elements of these transportation architectures to be demonstrated e.g. propellant option demos, and isolate from developing infrastructure for test

Advantages & Disadvantages - 1

Spacecraft design:

- Assemble 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-propellents (non-toxic, non-hazardous)
- solar sails

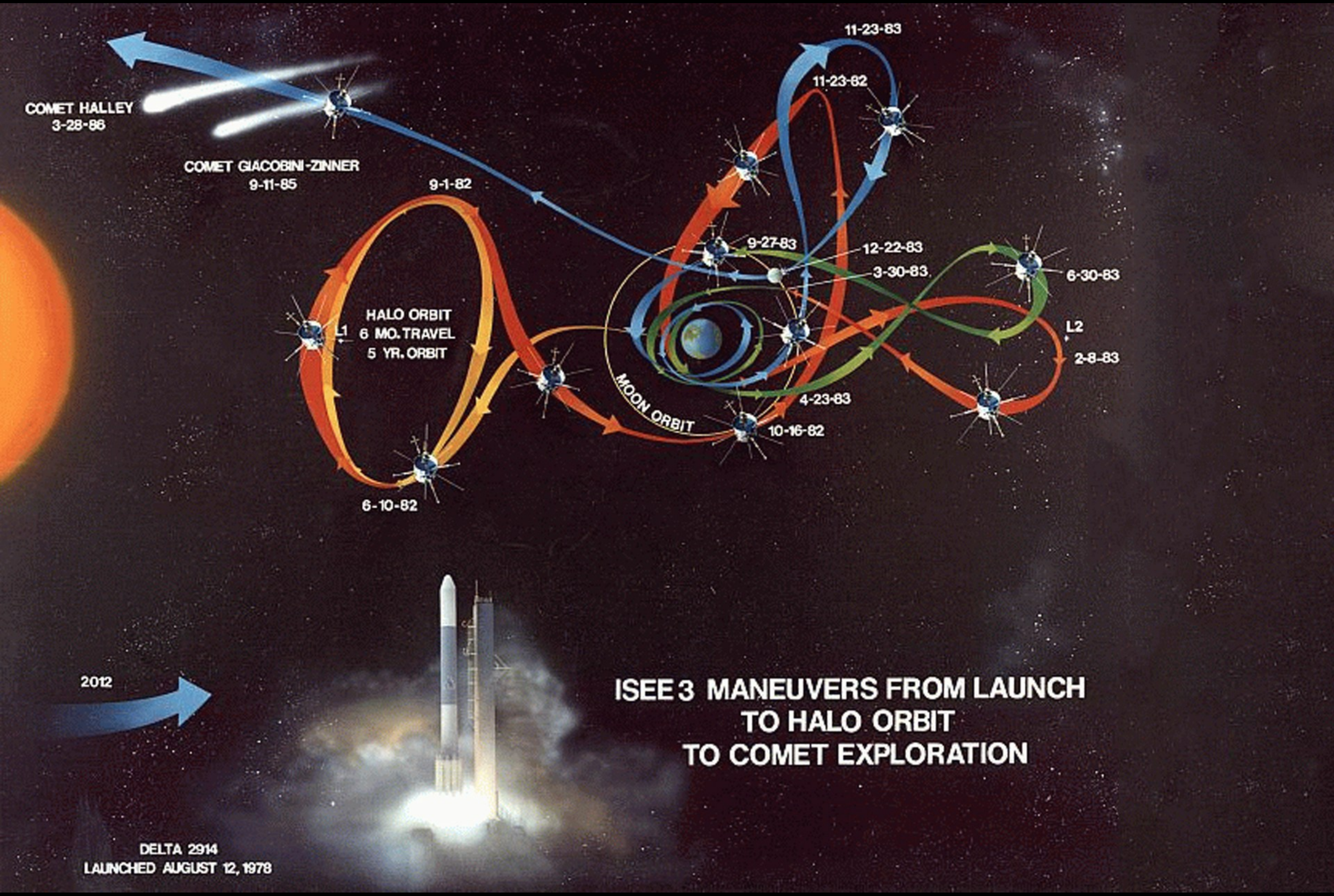
Provides for a wide range of low and high thrust options

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 becomes 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

There is an intersection between orbital dynamics and art . . .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HALO ORBIT
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MOON ORBIT
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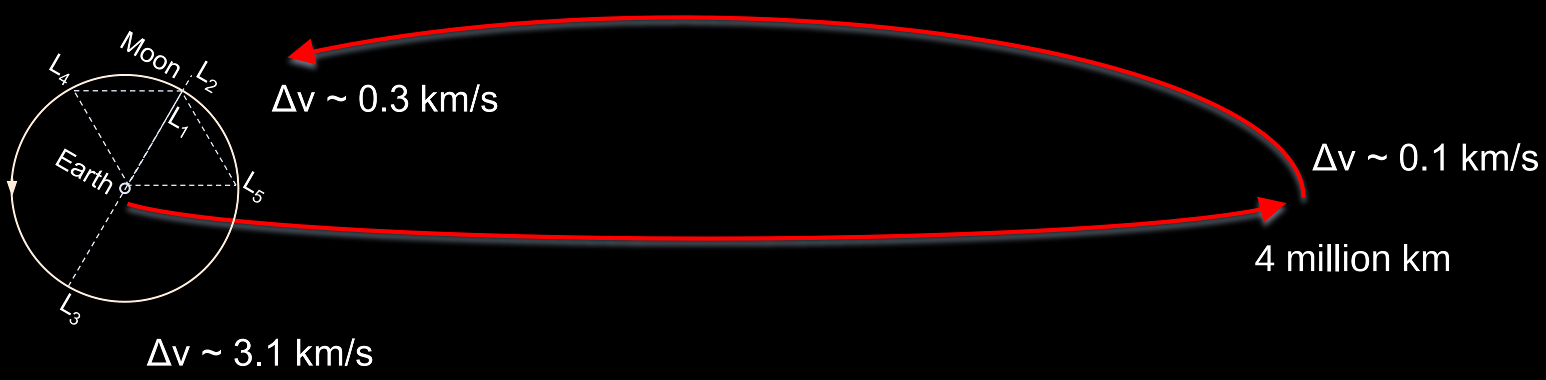
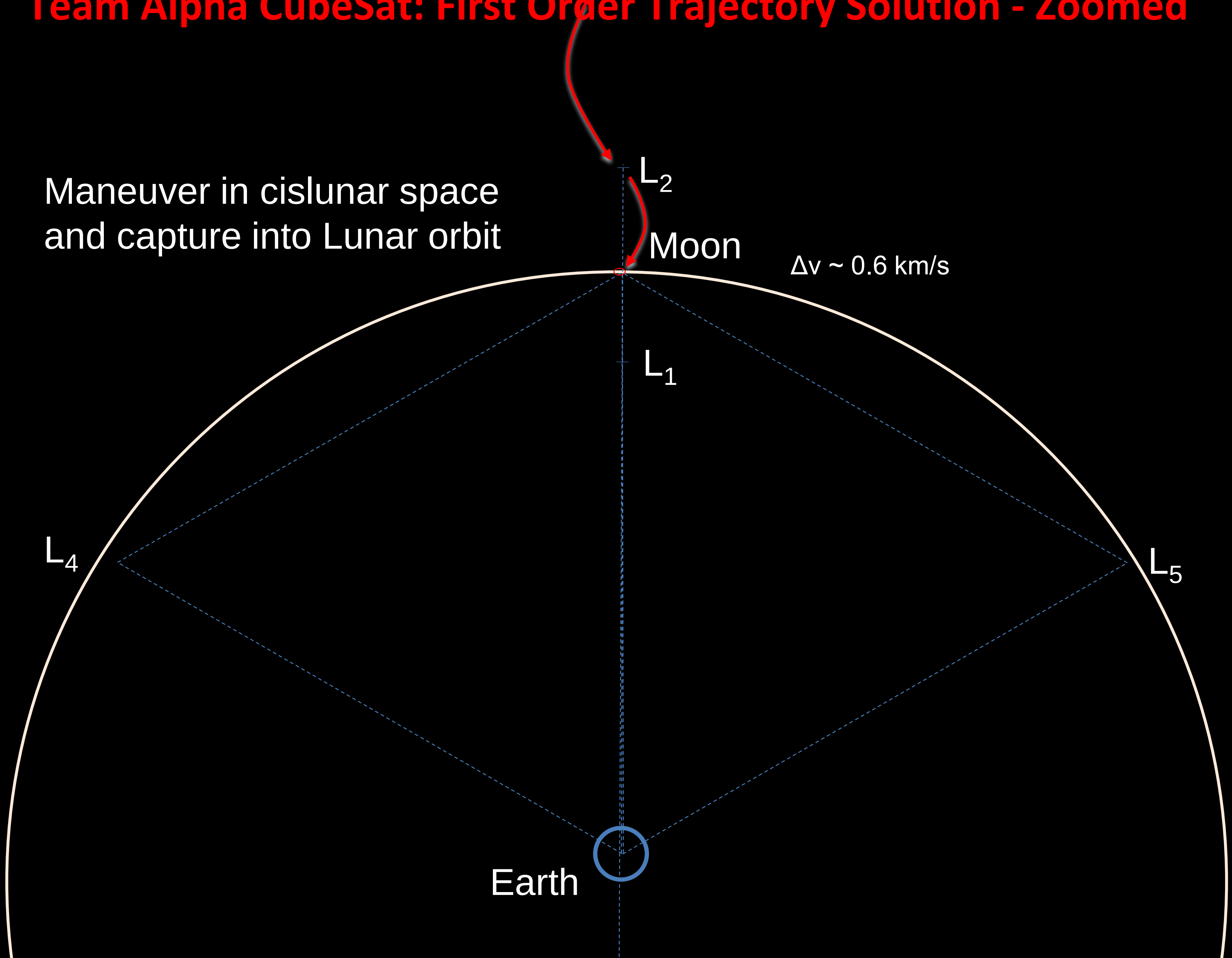
TO COMET EXPLORATION
DELTA 2914
LAUNCHED AUGUST 12, 1978

Team Alpha CubeSat: First Order Trajectory Solution



Team Alpha CubeSat: First Order Trajectory Solution - Zoomed

Maneuver in cislunar space
and capture into Lunar orbit



Team Alpha CubeSat: Approximate Δv in Cis-Lunar Space

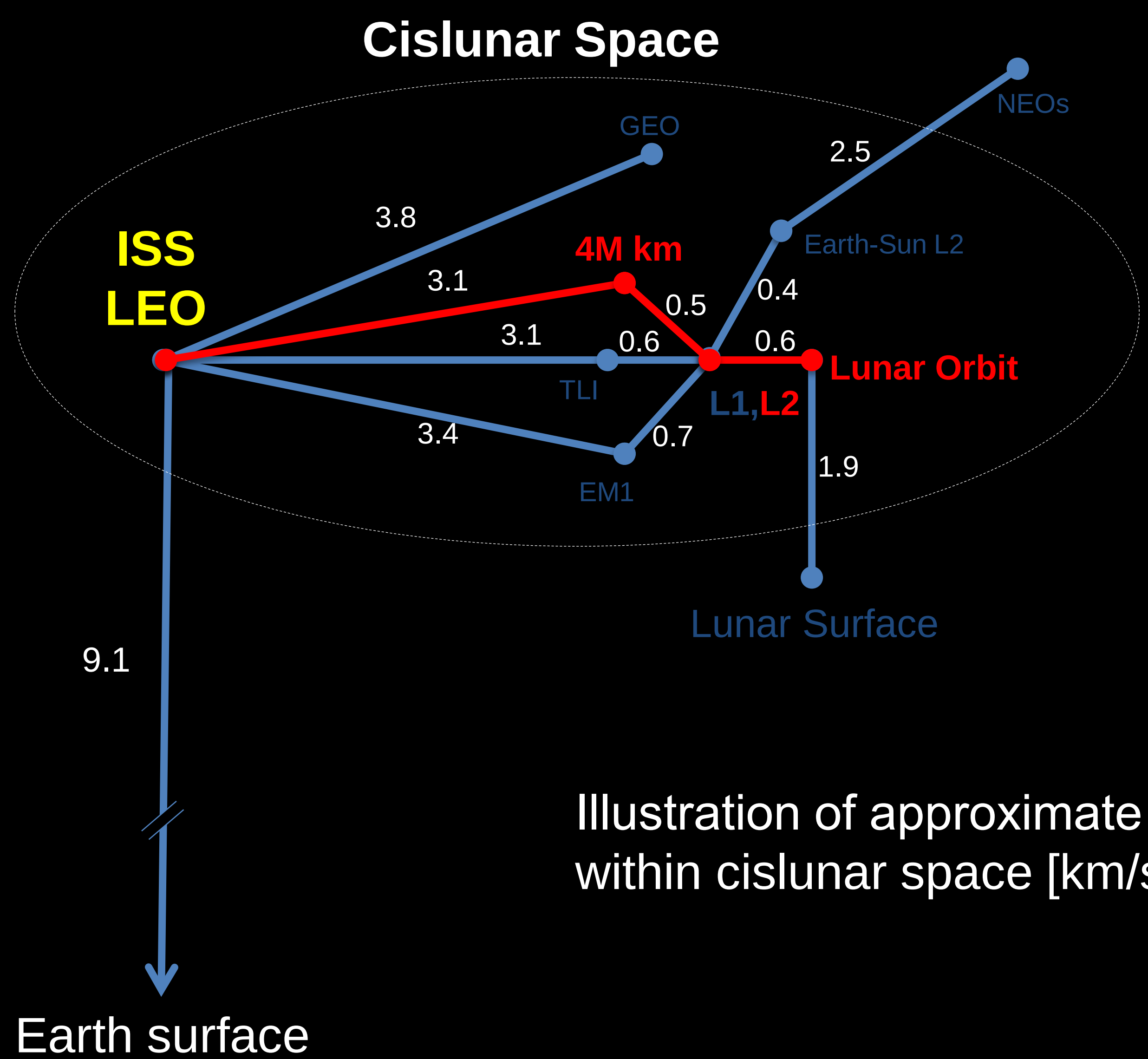


Illustration of approximate Δv within cislunar space [km/s]

Team Alpha CubeSat:
Propulsion System Conceptualization - 1

Using the conceptualized trajectory, we have the following definitions:

- Total Δv is 4.1 km/s
- Use chemical propulsion as trajectory uses impulsive transfers.
- Use 2 stages; 1st to travel to 4Mkm waypoint, 2nd to travel onwards to LLO.
- Need an I_{sp} of 350 seconds to achieve propellant mass fraction goals of 60% for 1st Stage and 25% for 2nd Stage.

Team Alpha CubeSat:
Propulsion System Conceptualization - 2

Stage 2 assumes a staged mass of 1 kg from Stage 1 separation.

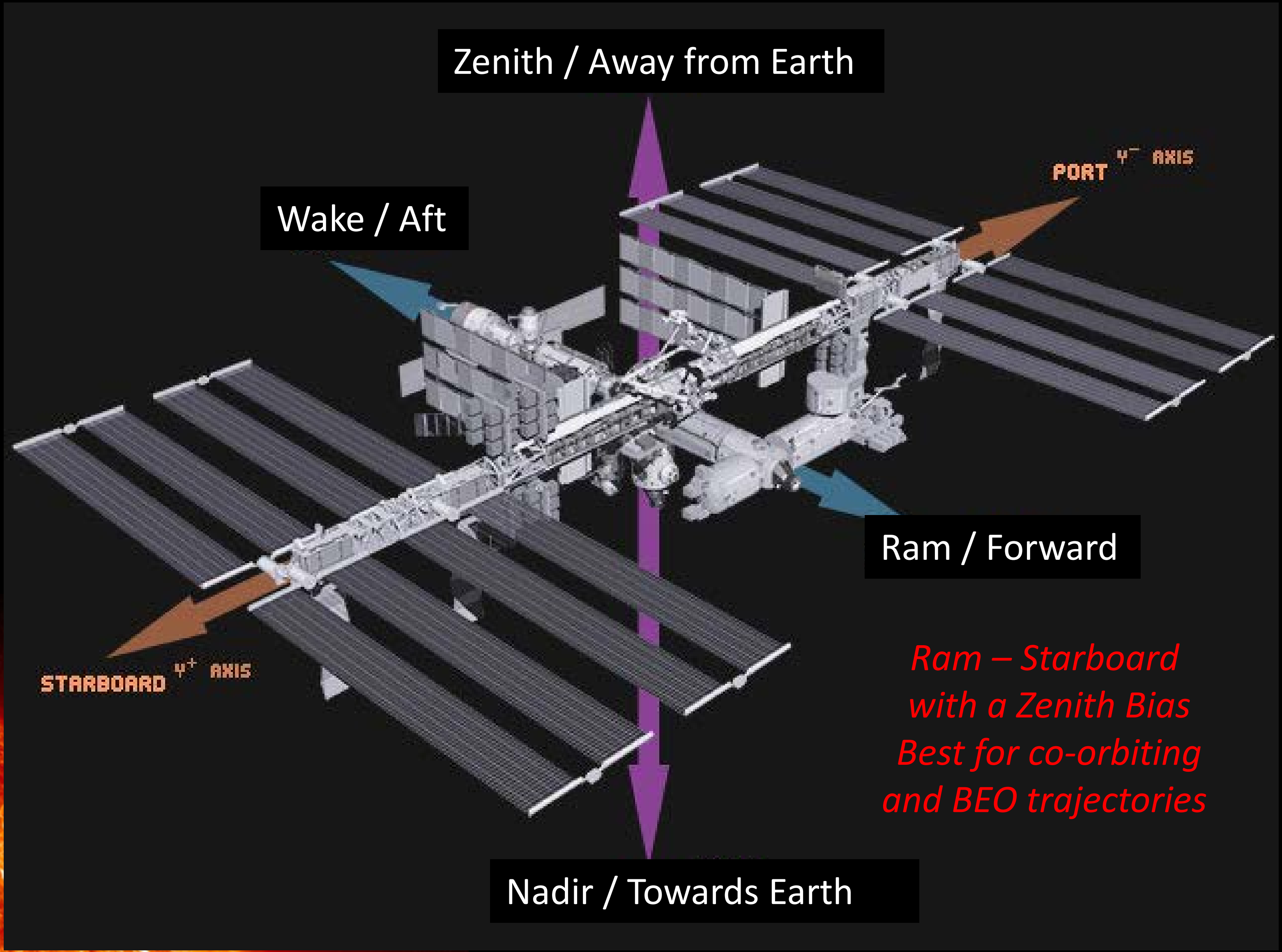
Team Alpha CubeSat:
Propulsion System Conceptualization - 3

- Current propulsion analysis shows that the first order trajectory is likely tractable.
- Furthermore, as the Interplanetary Highway is composed of Libration Points, for us to get there, we need start our journey from LEO to EML-1,2,3,4,5 using an impulsive, high-thrust, low-I_sp, chemical propulsion system.
- Savings can be had on this leg using the Farquhar trajectories.
- From there, we can then use a long-term thrust low-thrust, high-I_sp electric or multiple impulse high-thrust, low-I_sp chemical propulsion system to cruise the Interplanetary Highway.

ISS as a Launch Platform - 1

- 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)

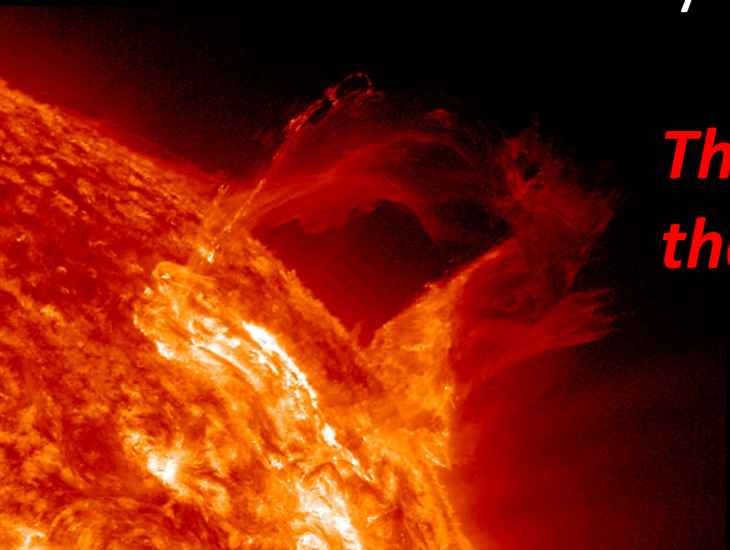
ISS as a Launch Platform - 2



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

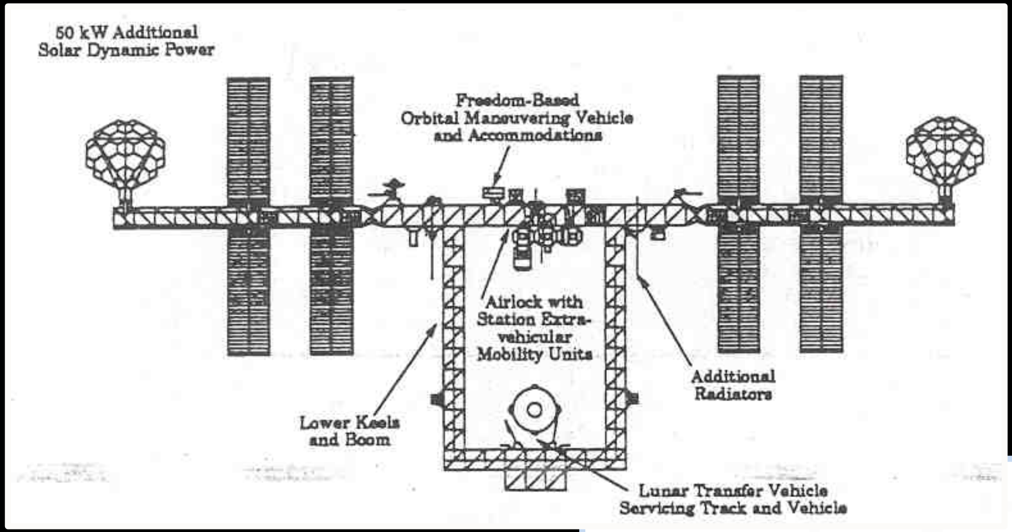
Conclusion

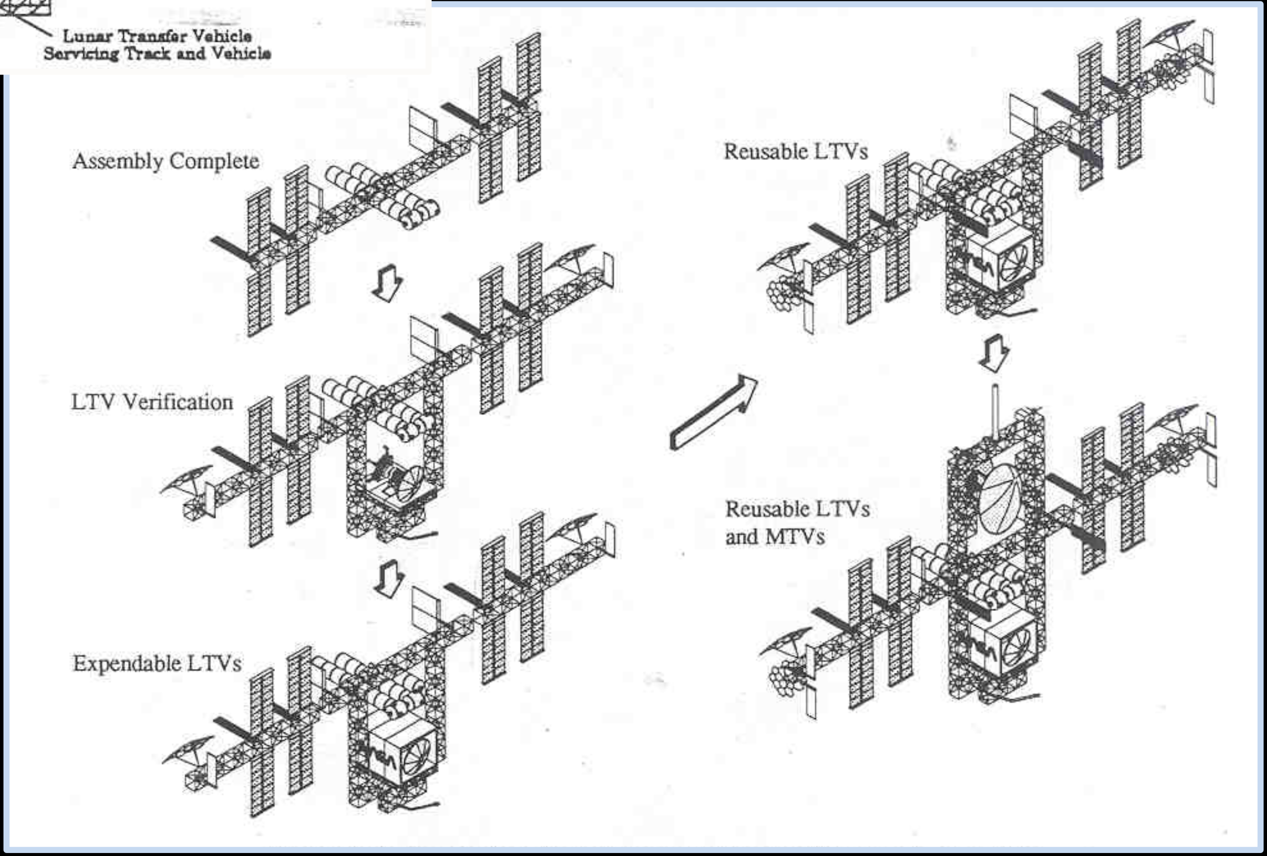
- Multiple solutions exist for ISS launch in theory, in practice we need to test & optimize alternatives
- We need to learn how to scale to larger systems
- We need to create opportunities for collaboration
- We need to find ways to do more with less resources
- On-orbit final assembly and checkout needs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



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

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





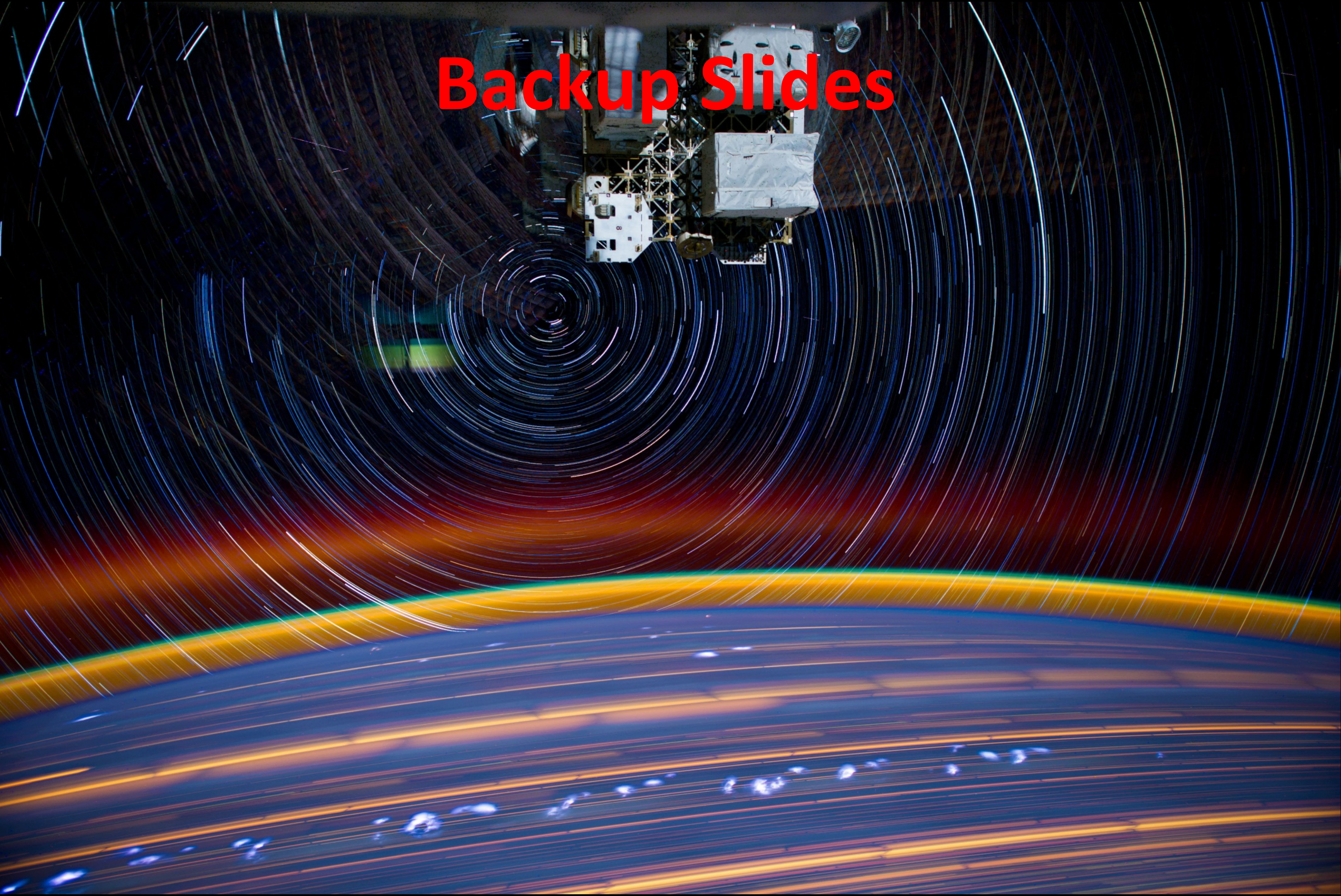
Next Steps

- 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

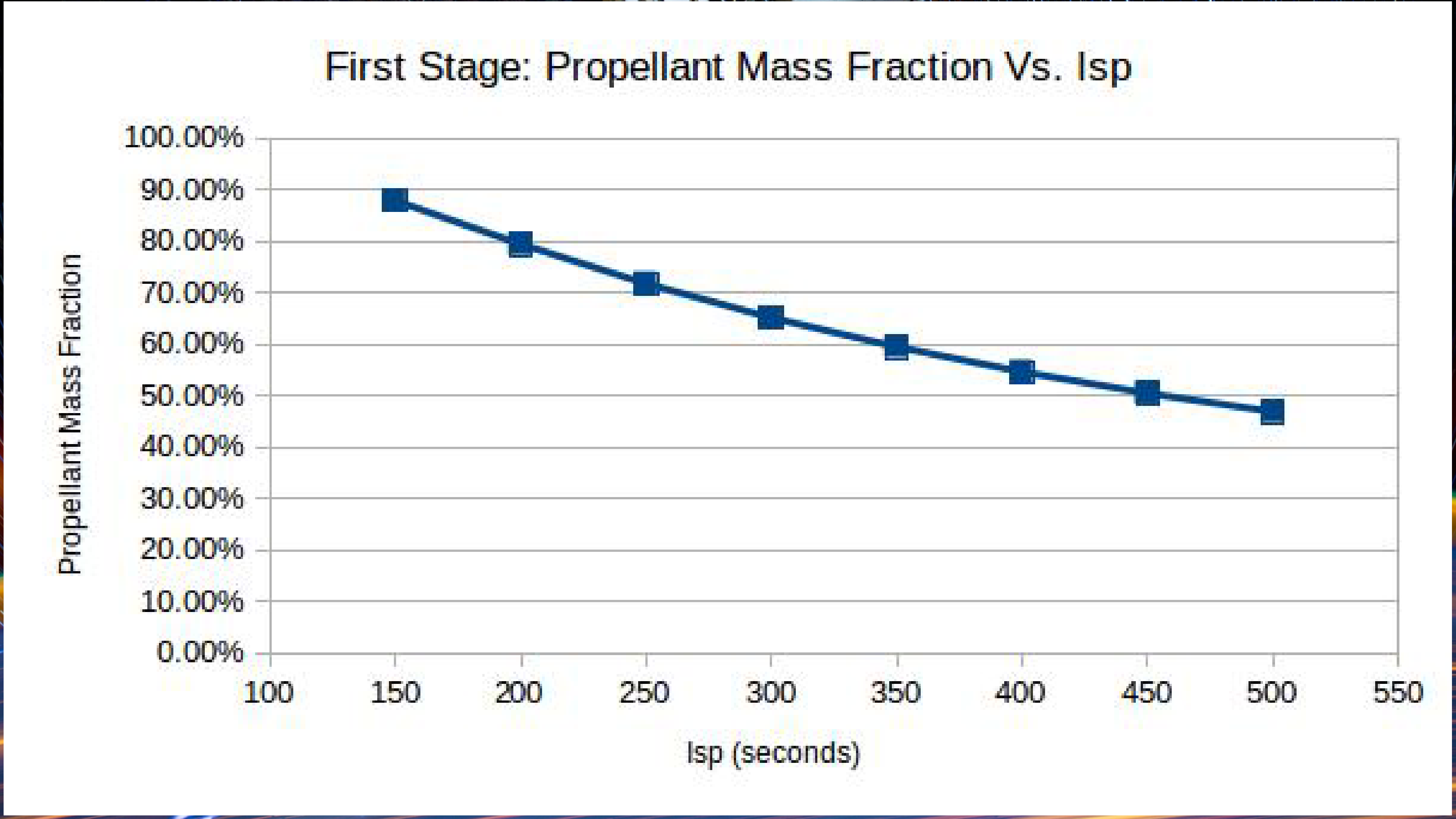
"Once you're in low Earth orbit halfway to anywhere."

– Robert Heinlein

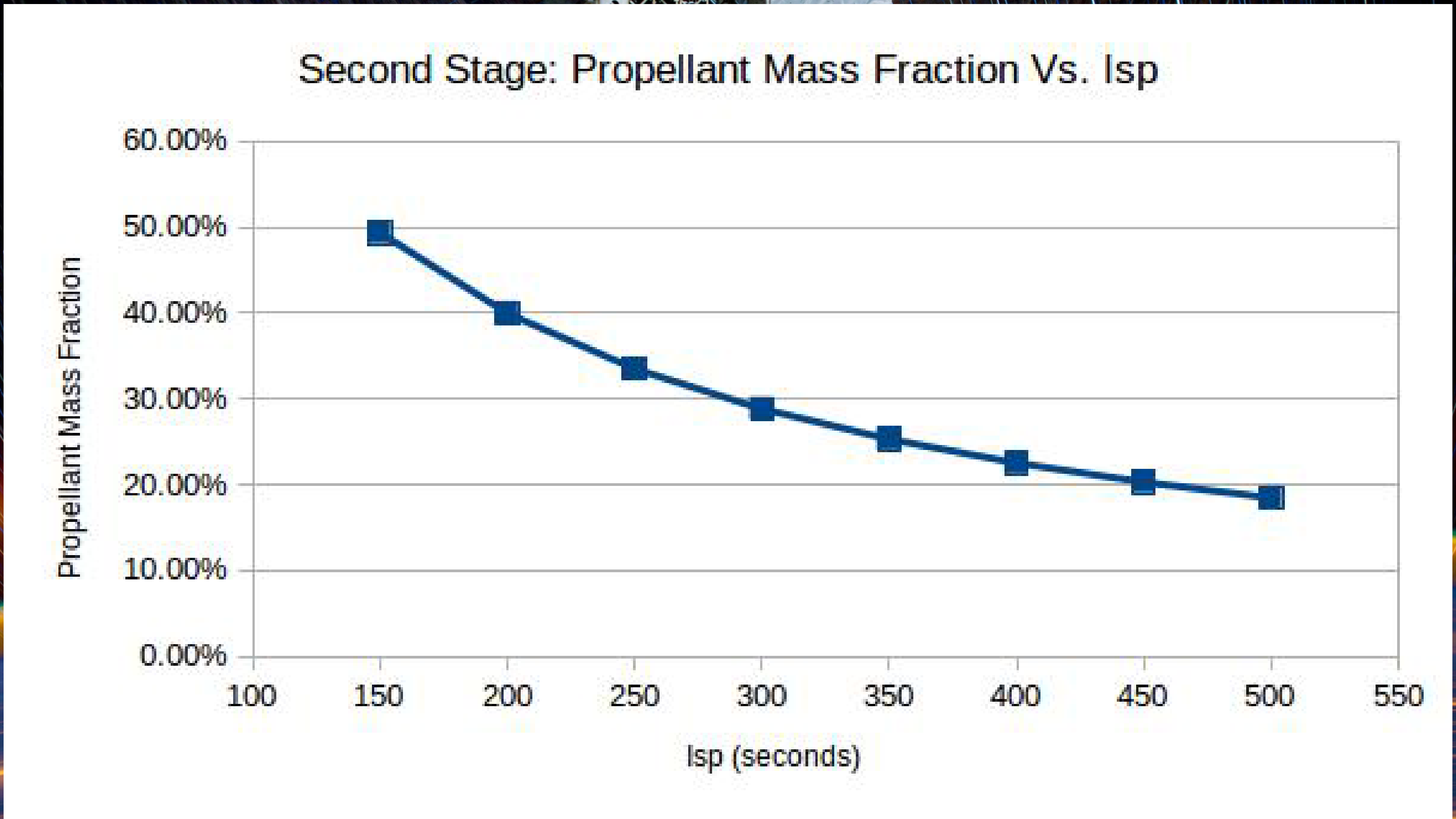
Backup Slides



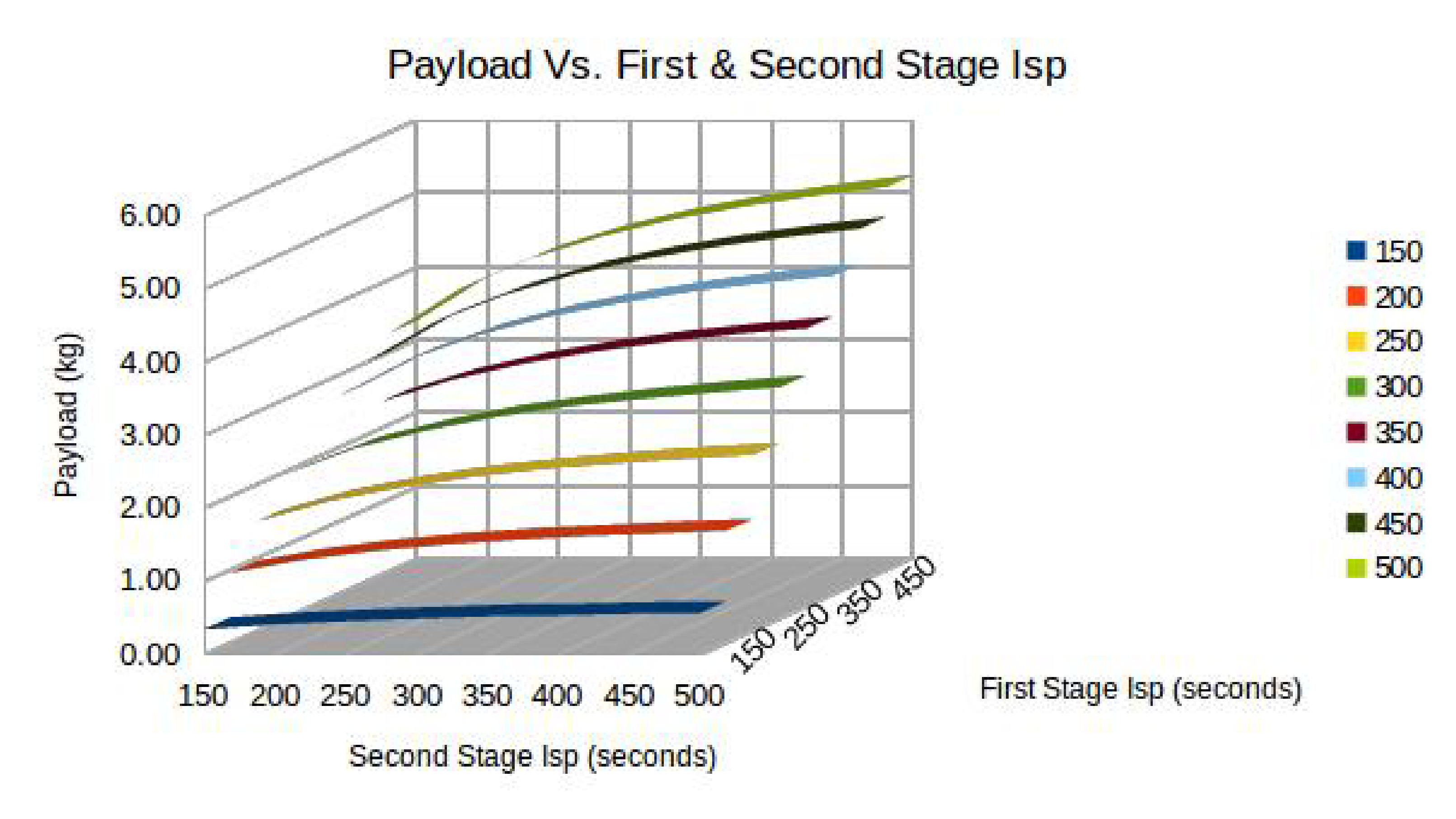
Propulsion Backup - 1



Propulsion Backup - 2



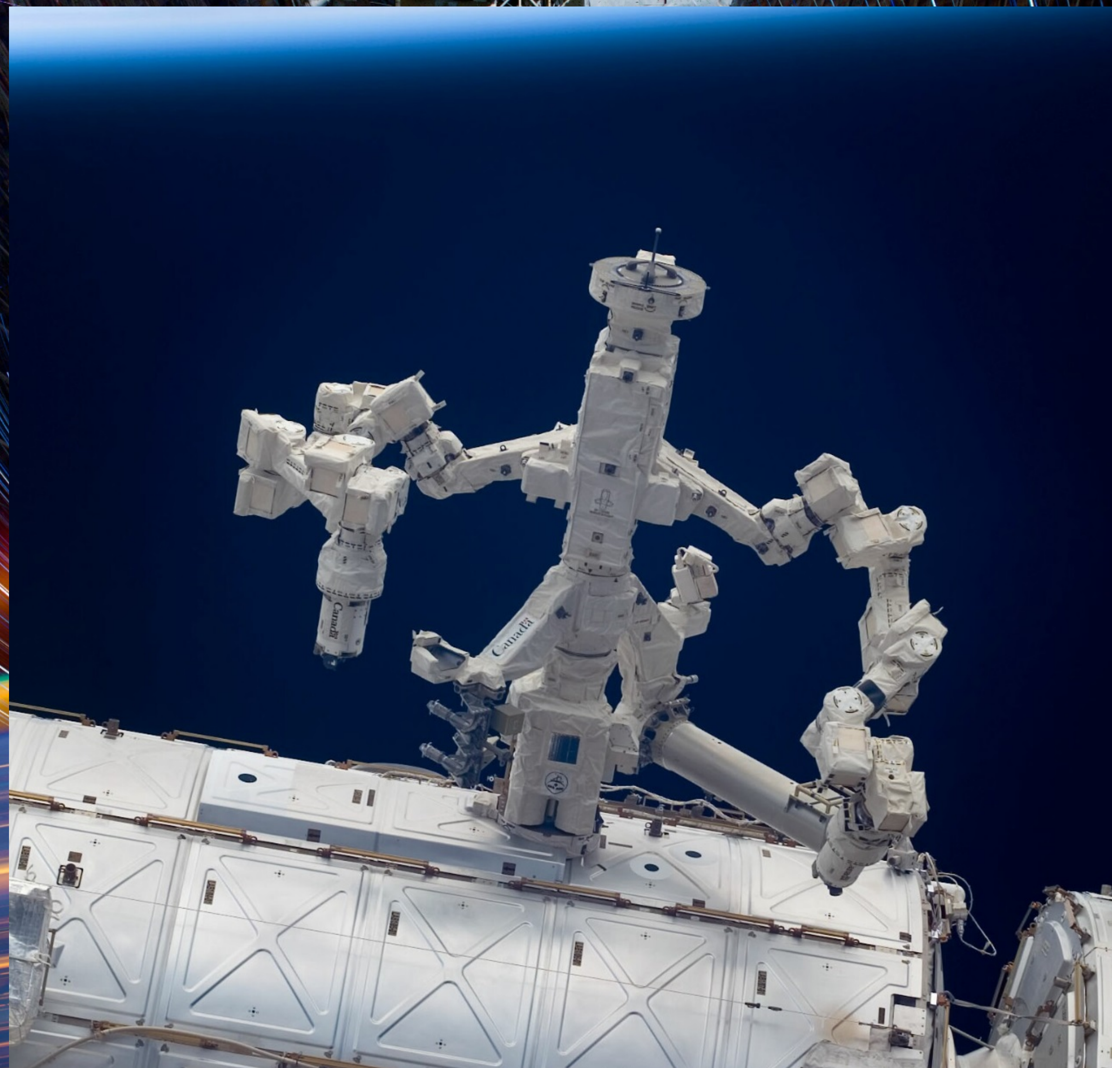
Propulsion Backup - 3



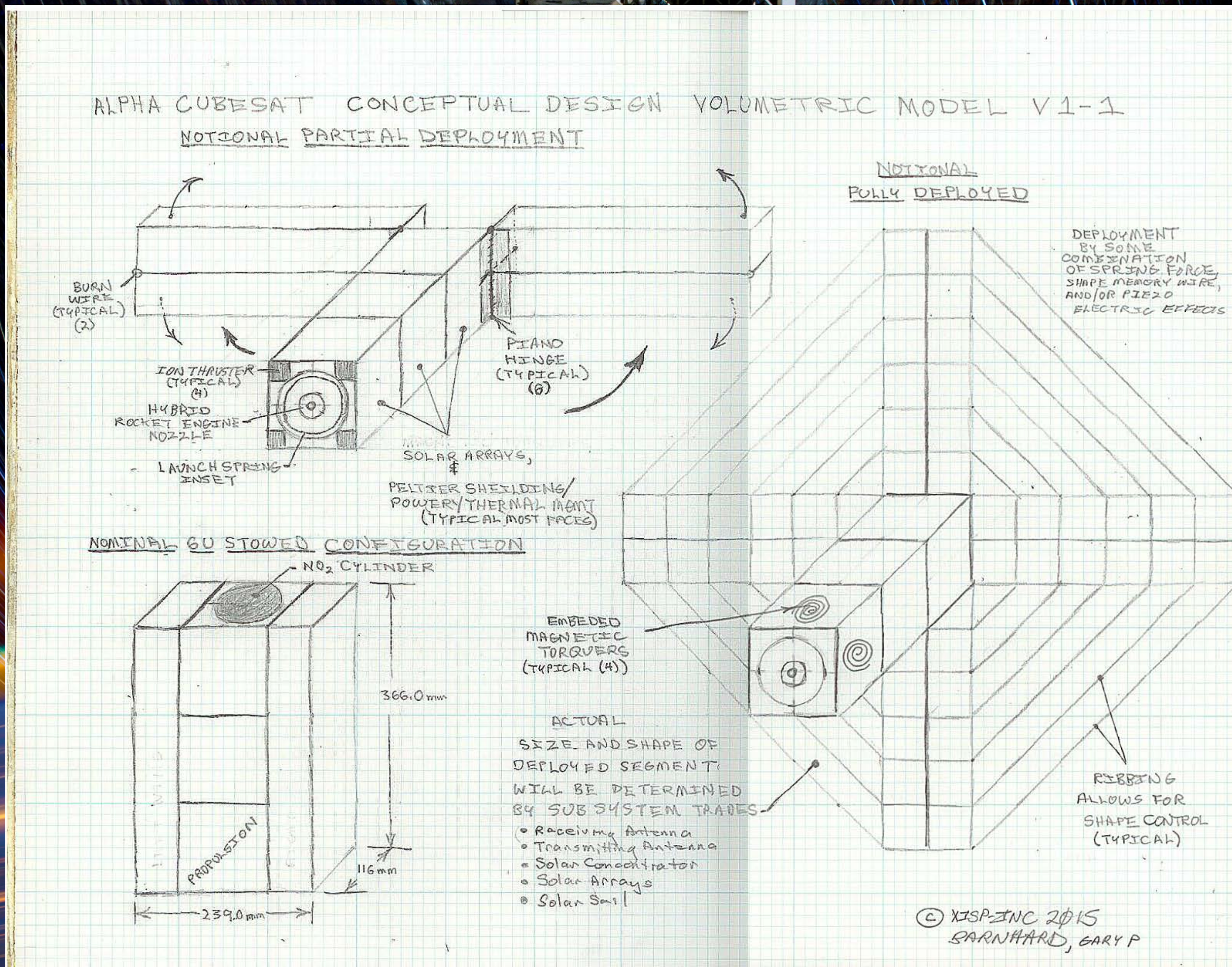
Dextre & Space Station Remote Manipulator System (SSRMS)

ISS026E028057

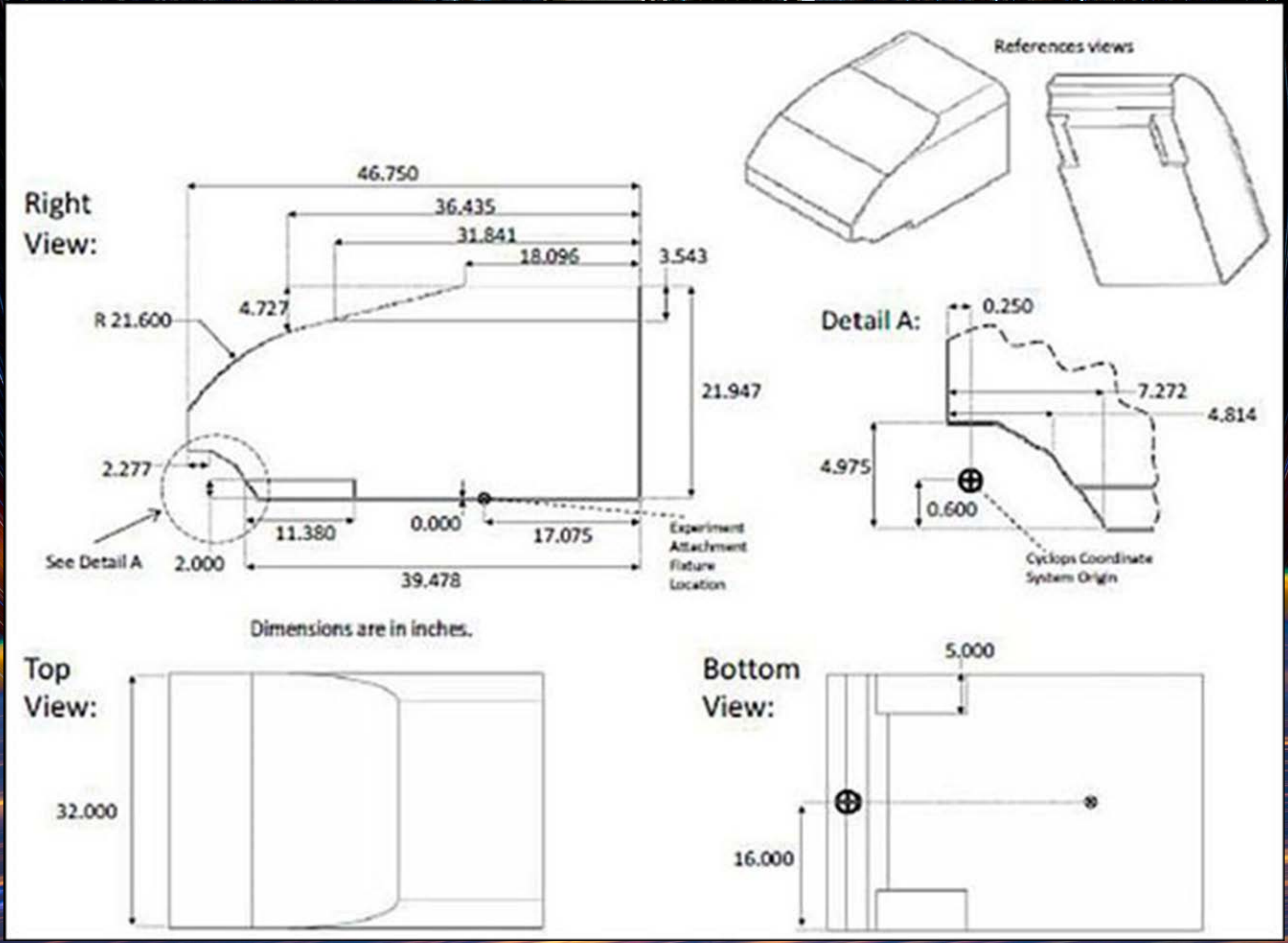
Dextre – Special Purpose Dexterous Manipulator



Alpha CubeSat Notional Volumetric Model



CYCLOPS JEM Airlock IVA-EVR Transition



Common Trajectories by the Numbers