Near Real-Time State Models: A foundational technology for space automation and robotics

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Outline

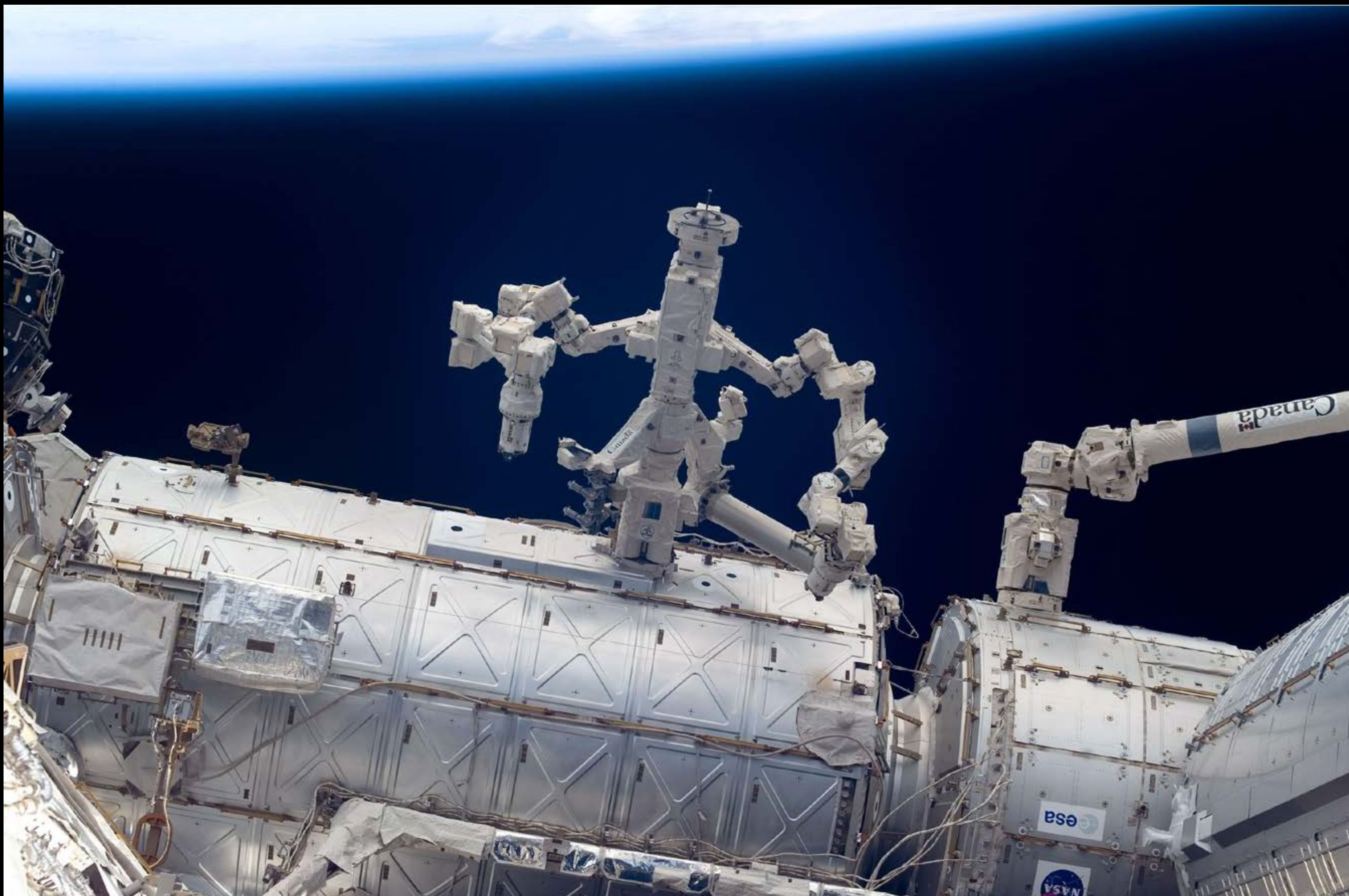
- The Problem Space
- DEXTRE is missing something
- Making it real . . .
- Building near realtime state models
- Relationship with NASA
- Relevance
- XISP-Inc MOCA Supported Missions
- Next Steps
- Reality Check
- Conclusion
- Backup Slides – Additional MOCA & Supported Mission Details

The Problem . . .

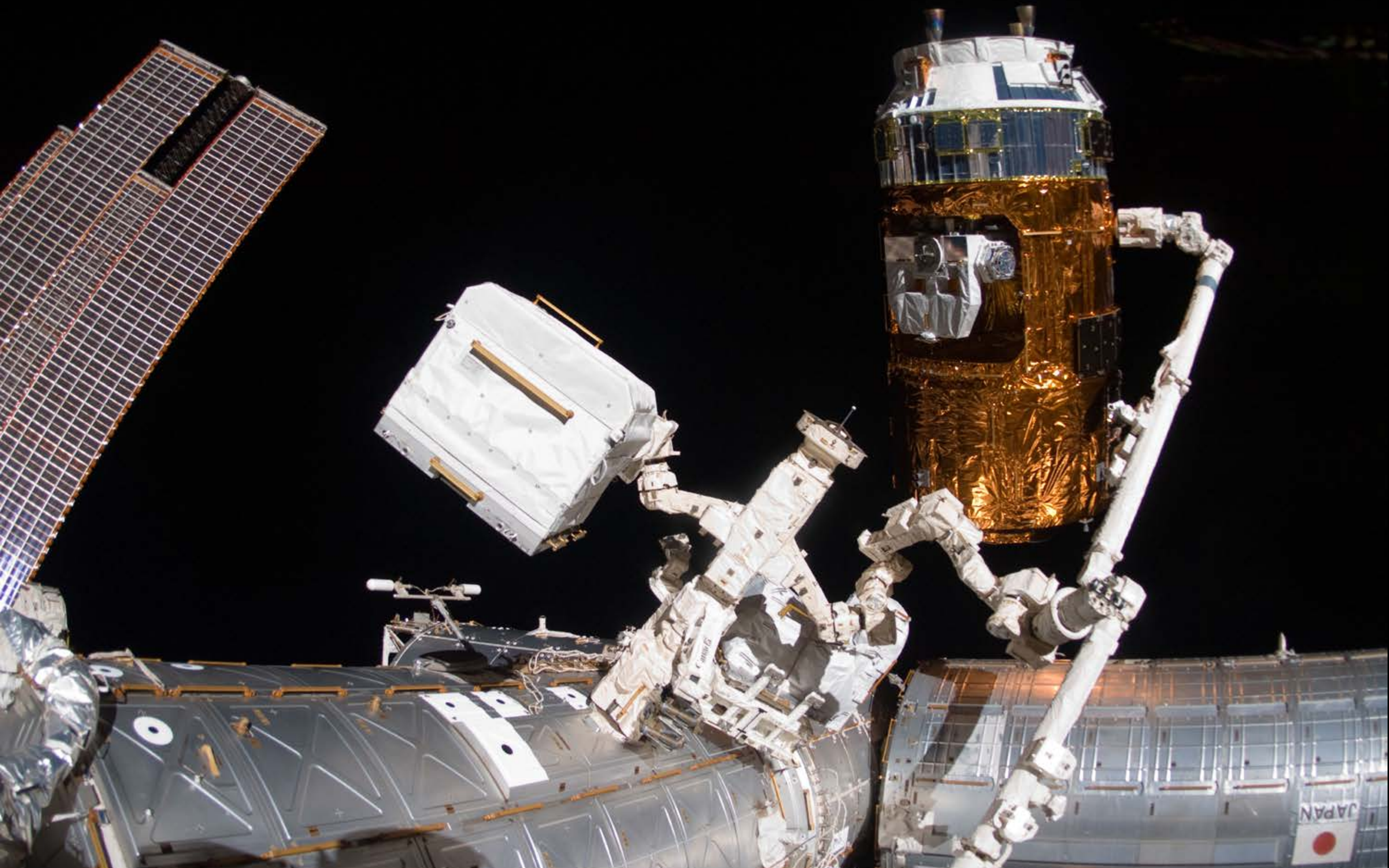
- N-Dimensional interaction problems (i.e., an arbitrary number of objects interacting in an arbitrary number of ways) are a class of problems for which the generalized solution space is typically computationally intractable in any time frame.
- Space automation and robotics present a subset of these problems that exacerbates the situation by requiring near real-time solutions in many instances.

Reality is not a convenient problem or solution space . . .

Extra Vehicular Robotics . . .



EVR Tasking . . .



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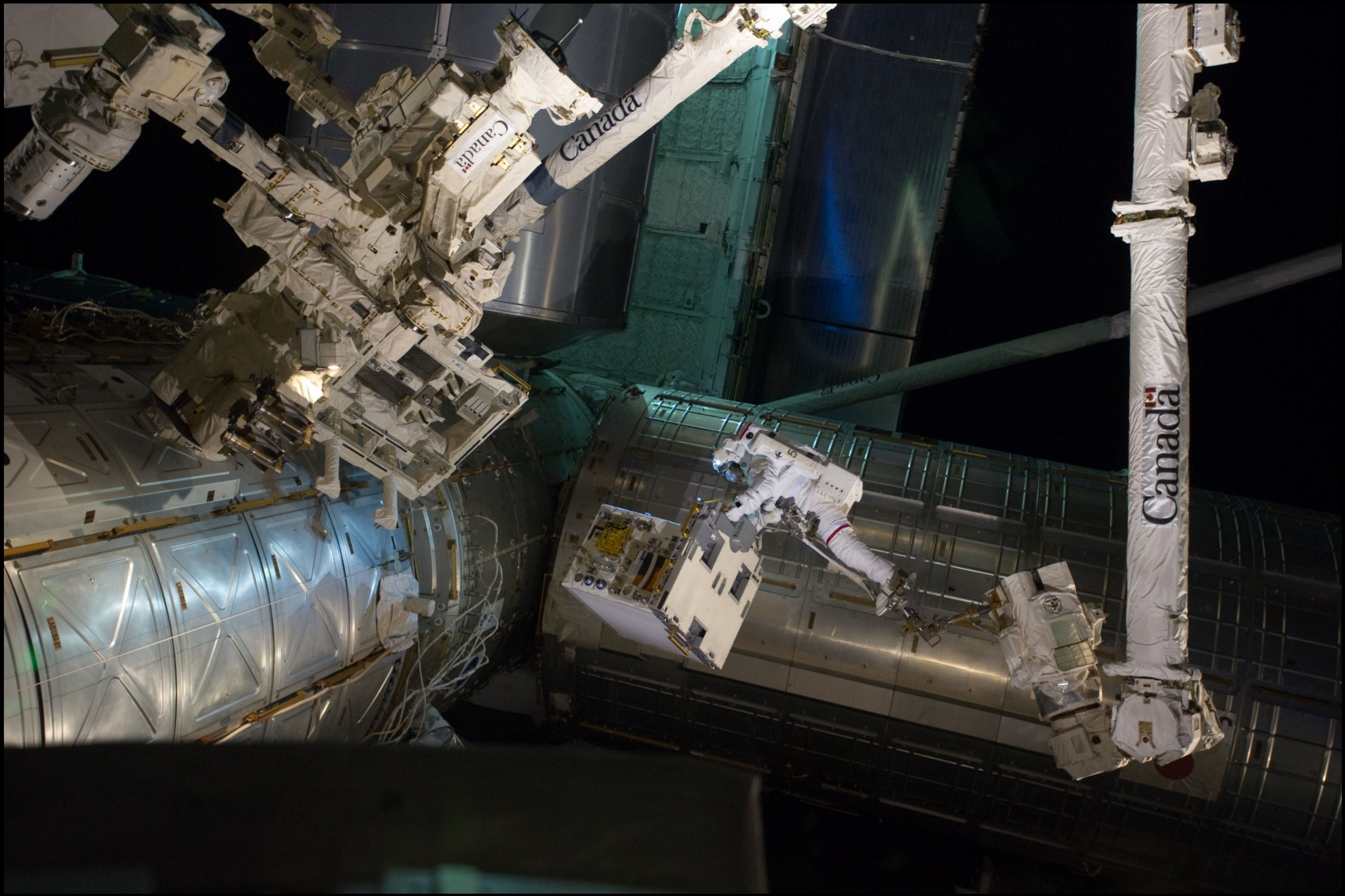
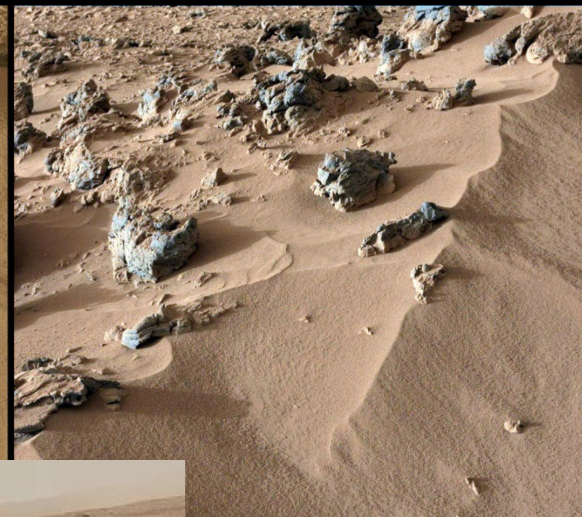
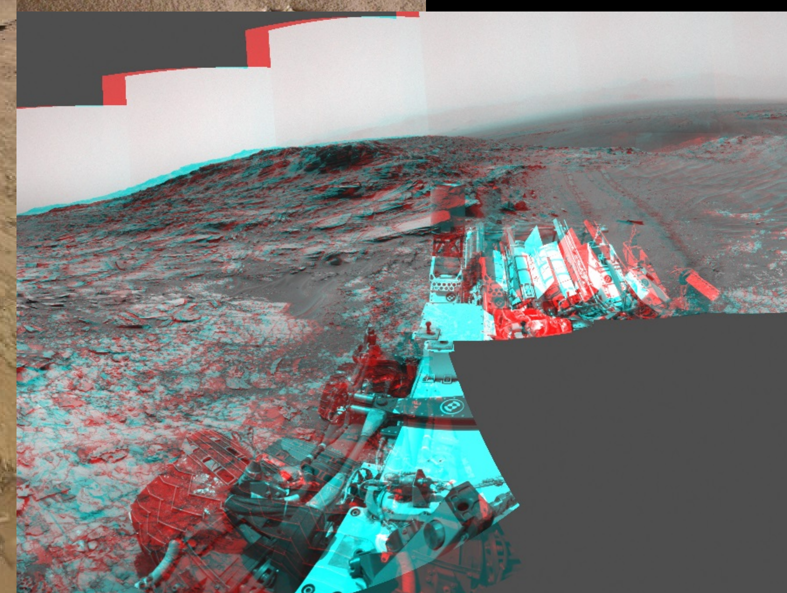
Robotics & EVA Crew . . .



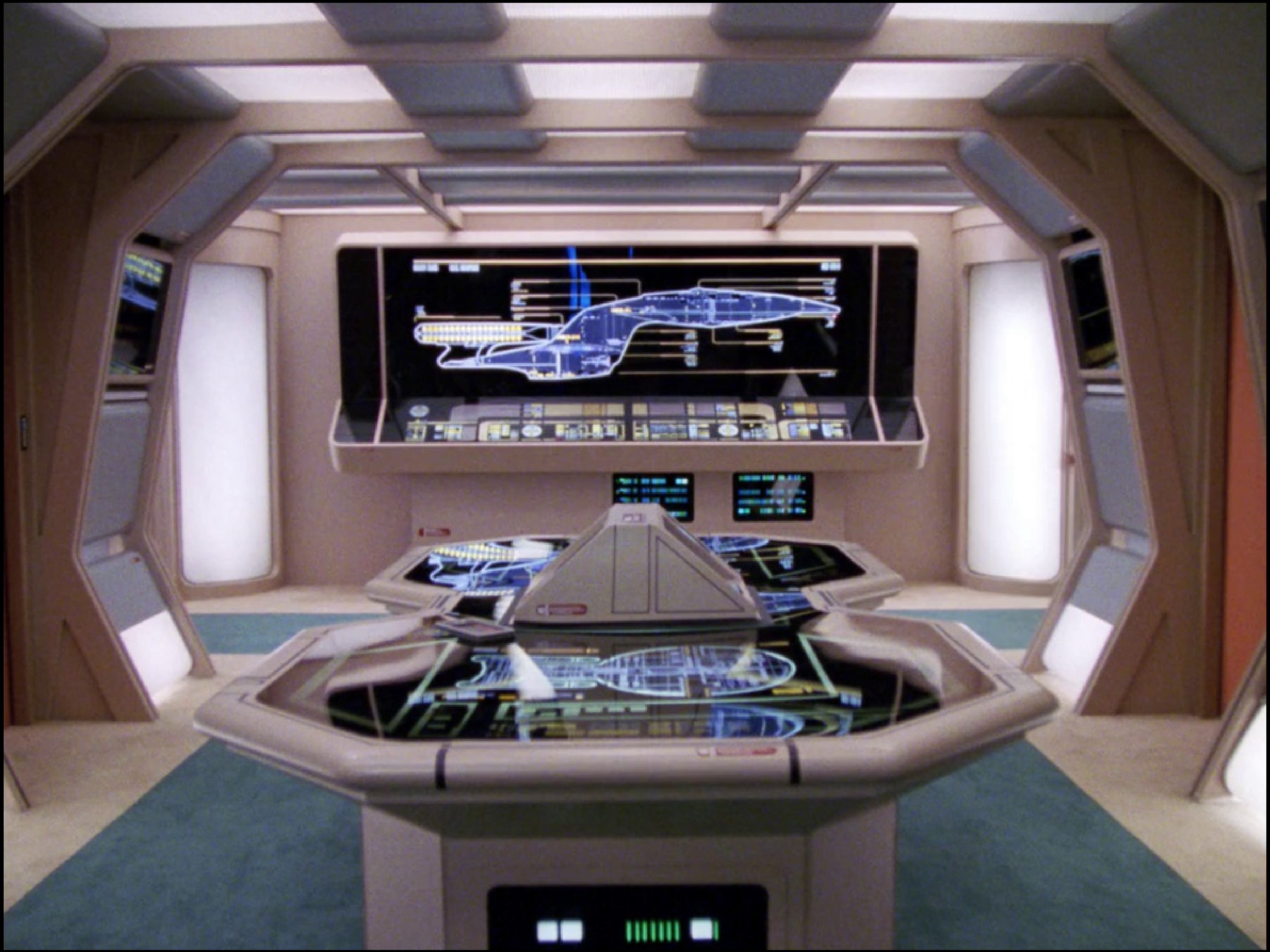
So you want to roam . . .



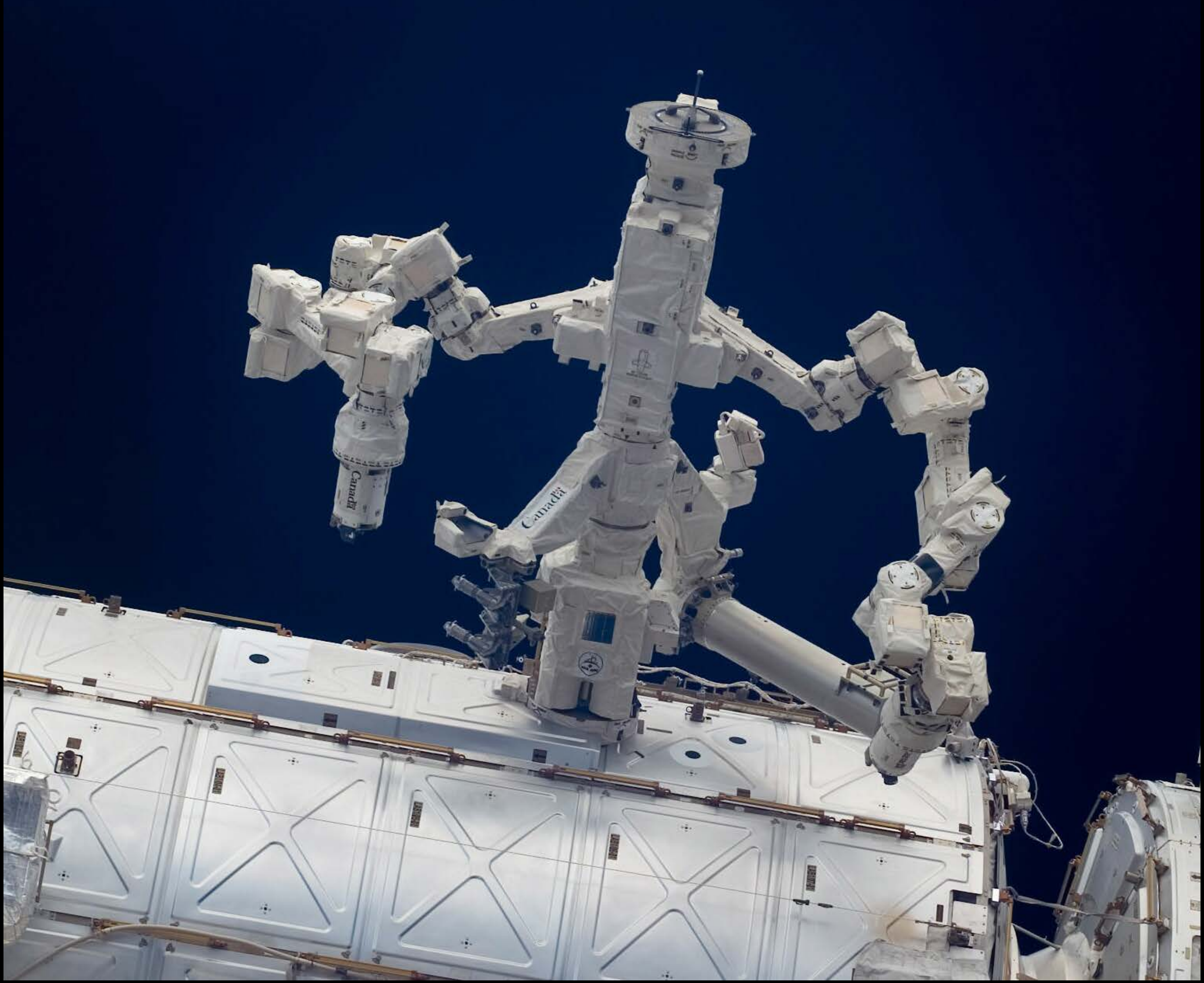


Going to Low Earth Orbit and Beyond . . .

Perhaps even run a starship?

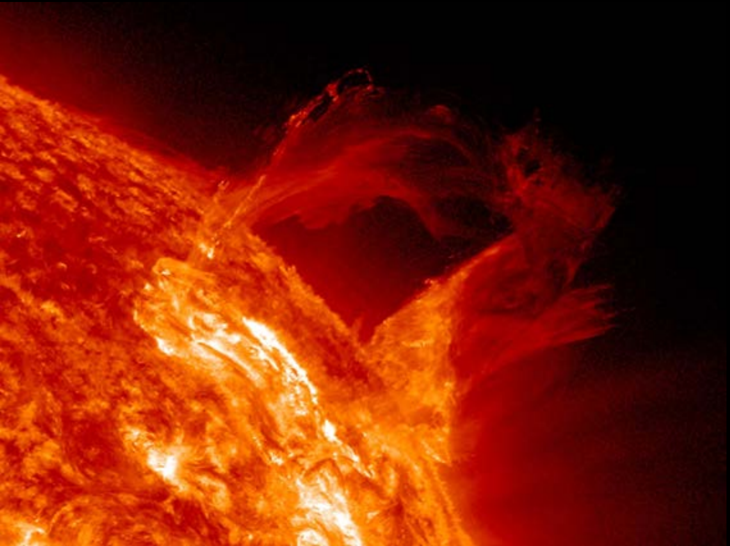


So let’s get real -- do you want to dance?



DEXTRE is missing something?

- The Special Purpose Dexterous Manipulator (SPDM) aka DEXTRE was designed to have an Advanced Vision Unit (AVU)
- The AVU was to provide a near realtime state model of the systems-of-systems that made up the SPDM – effectively an autonomic nervous system
- In addition, it would have the ability to dynamically build up a world model of an assigned task area and it's intersection with the environment
- The combination of these two capabilities with the appropriate sensors/cameras/tags/targets/interfaces and the as-built documentation of the International Space Station was intended to support a mutable locus of control between full teleoperation and full autonomy



The AVU was intended to allow the SPDM to effectively break dance with an EVA astronaut rather making paint drying seem like a spectator sport.

DEXTRE is missing something? - 2

- Alas, it was estimated proximate to 1995 that implementing the AVU as intended would only take 25 times the anticipated available computational capacity of the International Space Station (ISS).
- However, implementing the AVU using 2016 technology should and would be a much more straight forward proposition given . . .
  - Multiple space qualified multi-core thermally managed processors
  - Highly reliable registered Error Correcting Code (ECC) memory
  - Solid state data storage systems
  - Open source multi-threaded operating system amenable to near-realtime operations
  - Multi-fault tolerant virtualizable functions and a generalized control architecture designed for failure tolerance
  - Pervasively networked environment with access to as-built configuration data and relevant ISS operations and environmental data

The same logic is applicable to any EVA/IVA robotics as well any advanced automated system

Making It Real . . .

The order of the problem to be solved must be reduced to something tractable

- Breakup problem space into many sub-problems suitable for parallel processing
- Focus on the sub-problems that matter
- Use boundary conditions, initial conditions, symmetry, known geometry, established datums, etc. to further reduce complexity

The key is to propagate constraints as rapidly as possible

Making It Real . . .

A mutable locus of control is required between:

- Teleoperated and Autonomous Operations
- Ground and Inflight Operations
- Scheduled and Dynamic Operations
- Defined and Sensed Environments
- Referenced/Predicted/Sensed Geometry
- Toggled and Shared Control

This necessitates near realtime state models of the involved systems and the environment

Making It Real . . .

- N-Dimensional interaction problems do not have to be intractable.
- With appropriate metadata, transforms can be applied.
  - *Data is a set of ordered symbols*
  - *Data in context is information*
  - *Information in perspective is knowledge*
- Problems of interest can be recast and structured as:
  (Items(Attributes(Values)))   -- LISP transform
- They can then be modeled as a set of process flow problems.
- Inference driven constraint propagation can then be applied to reduce the generalized solution space to a computationally tractable scale.

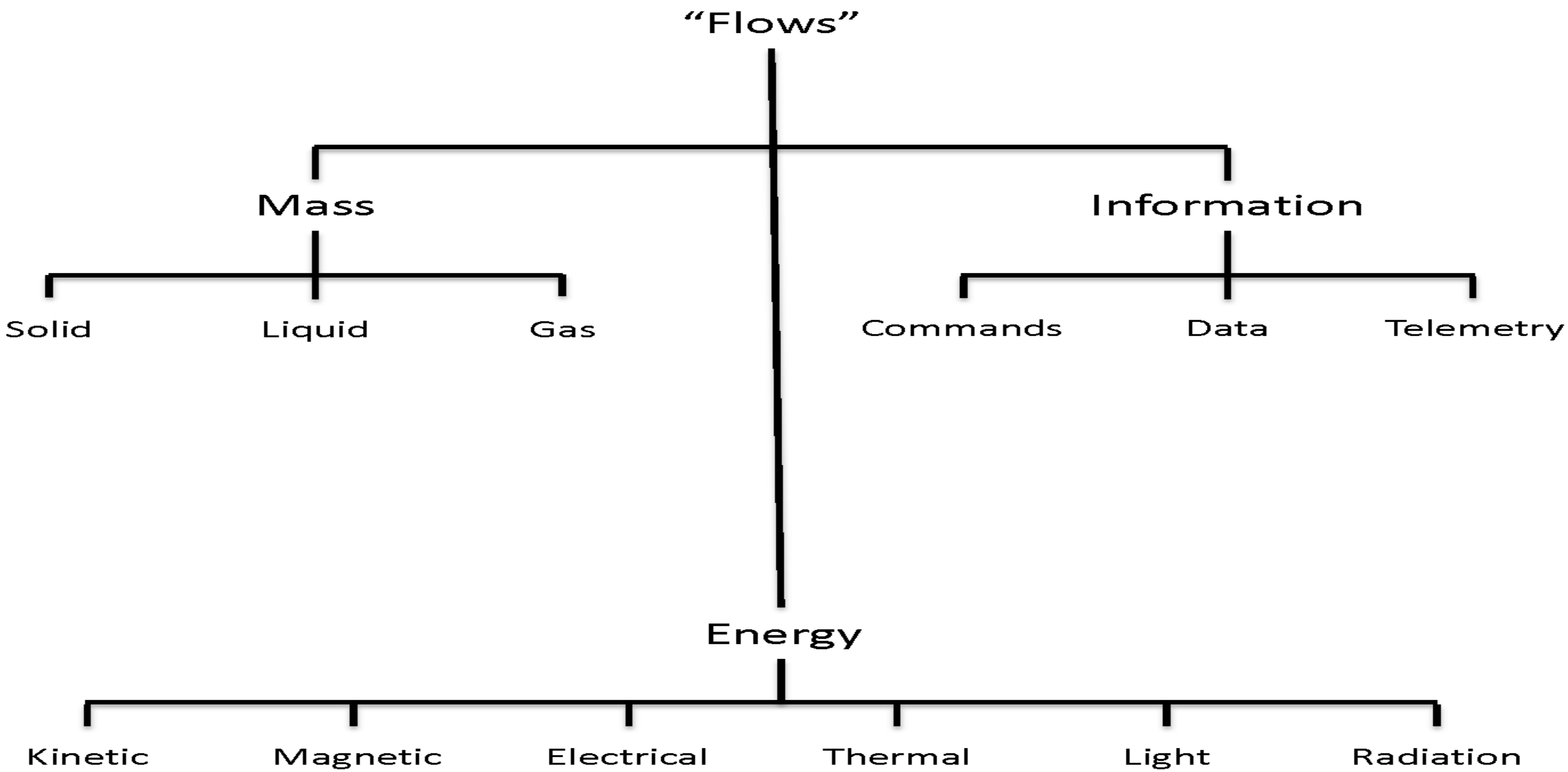
The structure and ordering of knowledge makes a very real difference . . .

Building Near-Realtime State Models . . .

- Systems-of-systems can be bounded as a finite set of state transitions
- Systems can be modeled as a set of flows across defined interfaces
- A taxonomy of flows can be defined as either energy, mass, or information and then further subdivided into individual types
- Each type of flow can be defined by a specific set of qualitative and quantitative attributes, independent of the source and terminus

Each set of characterized flows can be associated with corresponding states and allowable transitions.

Figure 10.
Sub-System "Flow" Taxonomy



Relationship with NASA

- The NASA ARC Mission Control Technologies (MCT) Open MCT Web is the web based modular programming environment that is being enhanced by XISP-Inc to incorporate near realtime state model extensions.

- This work is germane to the NASA ARC / XISP-Inc Space Act Agreement on Management Operations Control Applications (MOCA) and the family of supported commercial missions under development.

Relevance

This body of work is an opportunity to craft viable technology demonstrations that will establish the basis for a confluence of interest between real mission users and the technology development effort.

This can lead to a range of technology development missions on ISS and subsequent flight opportunities that can make efficient and effective use of near realtime state models and the enhanced Open MCT Web Software suite

XISP-Inc Evolving TD^3 Mission Set

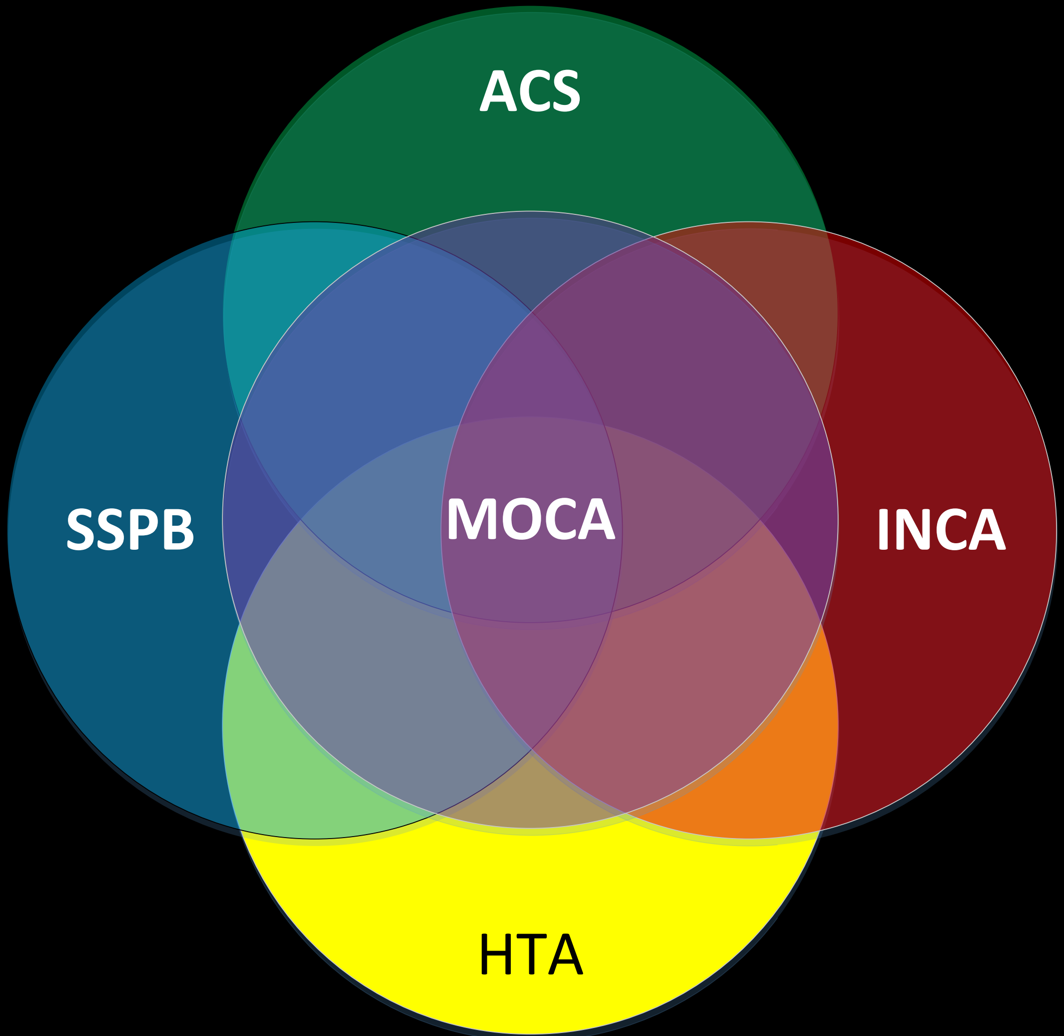
Alpha CubeSat (ACS)

Space-to-Space Power Beaming (SSPB)

Halfway To Anywhere (HTA)

Interoperable Network Communication Architecture (INCA)

Mission Operations Control Applications (MOCA)



XISP-Inc MOCA Supported Missions

- Team Alpha CubeSat (ACS) Technology Demonstration System
  - NASA Cube Quest Challenge Entry

  ➔ Virtual Operations Center
- Space-to-Space Power Beaming (SSPB)
  - Effective use of radiant energy beam components

  ➔ Cislunar Electrical Utility - Lunar Power & Light Company
- Interoperable Network Communications Architecture (INCA)
  - Pervasively networked DTN gateway/QoS Router

  ➔ Space Based Automated Telco Central Office Testbed
- Advanced Vision and Task Area Recognition (AVaTAR)
  - Framework for supporting a mutable locus of control between teleoperation and autonomy on a shared control basis

    ➔ Dramatic improvements in speed, efficiency, and safety for EVR and combined EVA/EVR tasks

MOCA Mission Initial Objectives

1. Defining and prototyping parametric state models for integrated end-to-end mission operations control applications.
2. Implementing the parametric state models for technology development and demonstration mission prototypes, test and flight articles.
3. This effort includes the incremental, iterative, and recursive development of near real-time state models of all the supported mission components operating within the MCT framework/environment

MOCA Initial Products for Supported Missions*

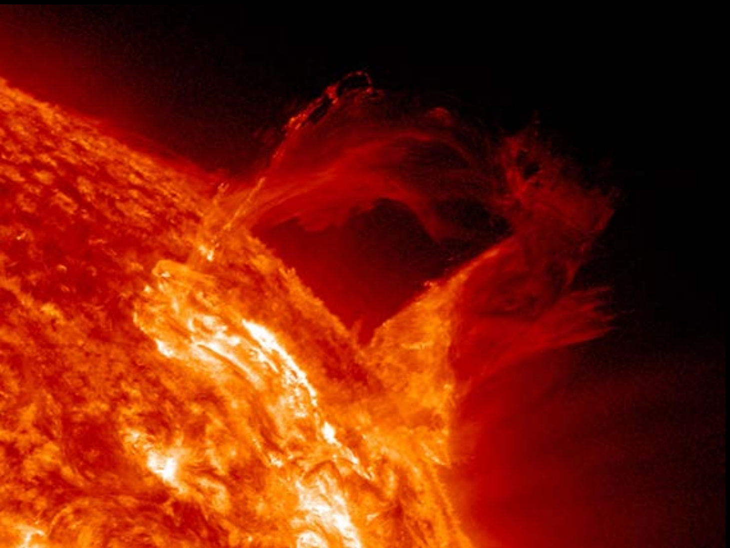
1. Development of a paper model and individual element protocode;
2. Development of functioning individual element models and an end-to-end model protocode;
3. Optimization of individual element models and a functioning end-to-end model;
4. Testing of the optimized end-to-end model and individual element models in mixed modes (protoflight hardware and software with simulation as needed).

** MOCA progress for each supported mission is being driven by the status and schedule of each mission and the availability of resources.*

MOCA Extended Activities

MOCA extended activities will focus on actual on-orbit demonstrations and testing the efficacy of the near realtime parametric state models developed for the supported missions.

Follow-on activities will focus on assessing, reviewing, and establishing the efficacy of applying the near real-time parametric state modelling tools to other current and future technology development missions.



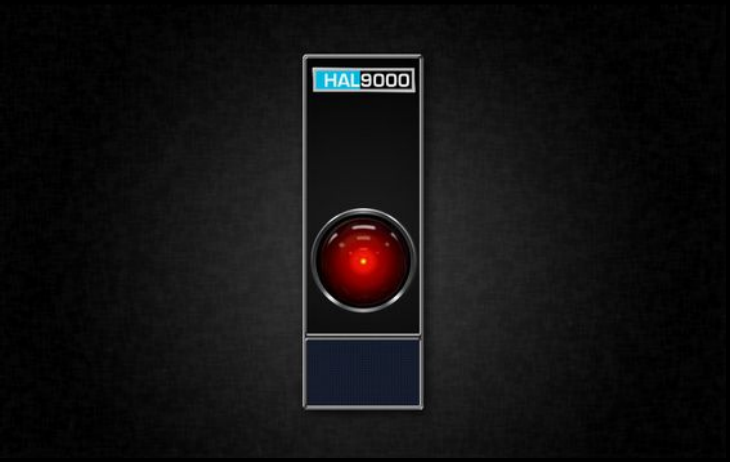
Next Steps

- MOCA is now a commercial mission that will be worked with NASA through a combination of established and proposed Space Act Agreements.
- MOCA is intended to be a foundation for moving forward with the AVaTAR mission
- Additional partners/participants are being sought in the commercial, academic, non-profit, and government sectors.
- Use of ISS helps ensure that this is an international cooperative/collaborative research effort.

Reality Check

- Reducing the number of perceived "impossible things that have to be accepted before breakfast"* is a way of incrementally disabusing people of unfounded notions.

- Doing something real with the technology that is of demonstrable value can help to establish the confluence of interests necessary to mature the technology for more advanced applications.



* Allusion to "Alice in Wonderland" by Lewis Carroll. "Alice laughed: "There's no use trying," she said; "one can't believe impossible things."
"I daresay you haven't had much practice," said the Queen. "When I was younger, I always did it for half an hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."

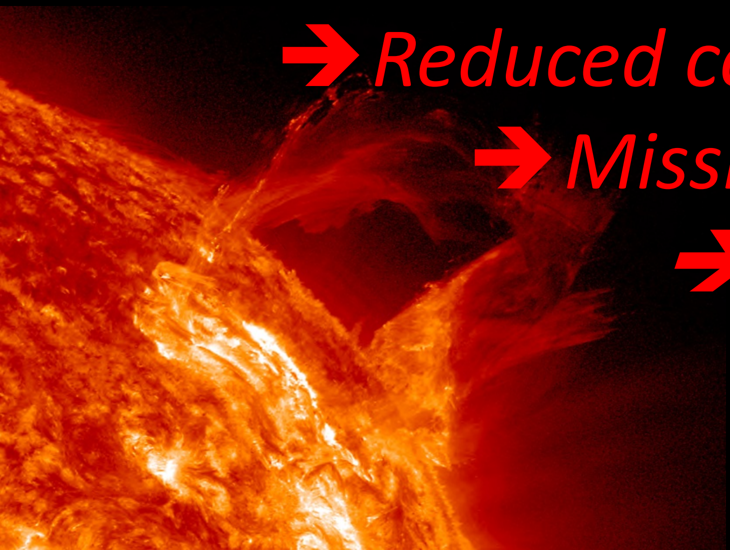
Conclusion

- An incremental investment in the development of near realtime state modelling capabilities that meet real mission requirements can serve as a foundational technology for evolving space automation and robotics capabilities.
- *This work can deliver:*

  ➔ *Reduced cost, schedule & technical risk*

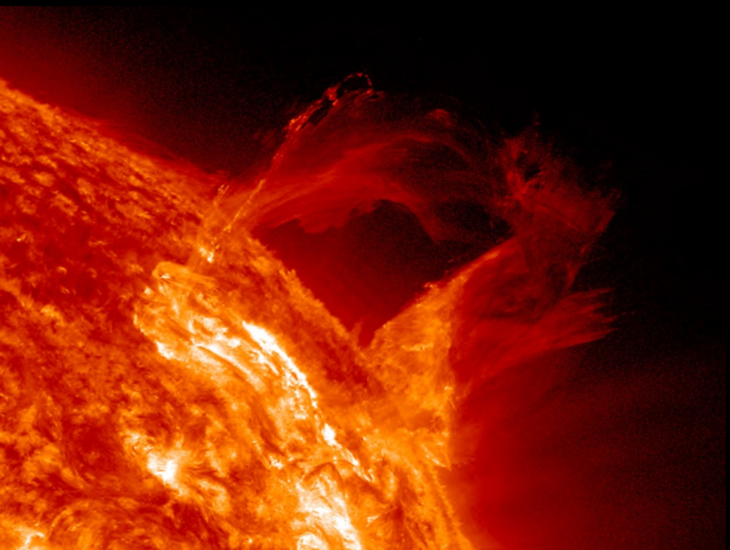
  ➔ *Mission enhancing technology*

  ➔ *Mission enabling technology*



Backup Slides

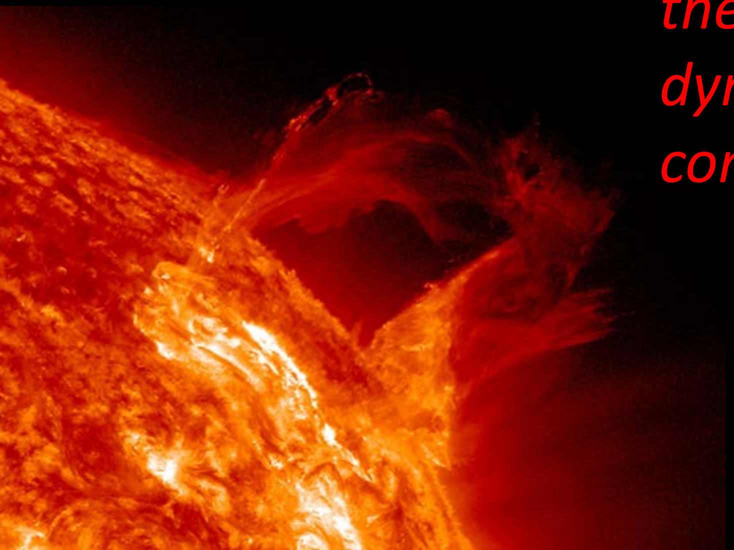
- Additional MOCA & Supported Mission Details



Mission Operations Control Applications (MOCA)

- MOCA provides TD^3 near realtime state models, mutable locus of control, and virtual operations center for ACS, HTA, INCA, and SSPB
- MOCA facilitates crewed, tele-operated/shared control, and autonomous in situ operations reducing crew time required for experiments and increasing ISS and ground operations productivity.

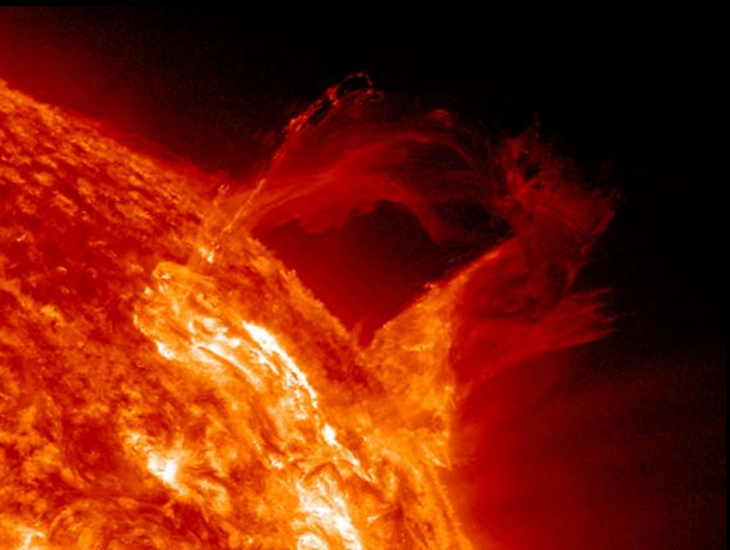
➔ *MOCA can be a resource for furthering the TD^3 of "AutoNAV" and the evolution to dynamically scheduled QoS driven communications and navigation services.*



Interoperable Network Communications Architecture (INCA)

INCA elements can support:

- Enhanced automated/autonomous Communications & Navigation state models,
- Dynamically assignable and characterizable resources,
- QoS driven virtualized function support , and
- Cost effective Earth facing, on-orbit, and beyond Earth ad hoc mesh mission support/networks.



INCA Experiment Elements

Function: Internet Banking
Purpose: Source of Real World Performance/Availability/Security Requirements
Value: Testing, which supports the verification, and validation of INCA Architecture with real interoperating network requirements

Function: Pervasively Networked DTN Gateway
Purpose: Enables INCA QoS Based Routing
Value: Testing INCA Architecture for LEO/MEO/GEO Use

ITERATIVE & RECURSIVE

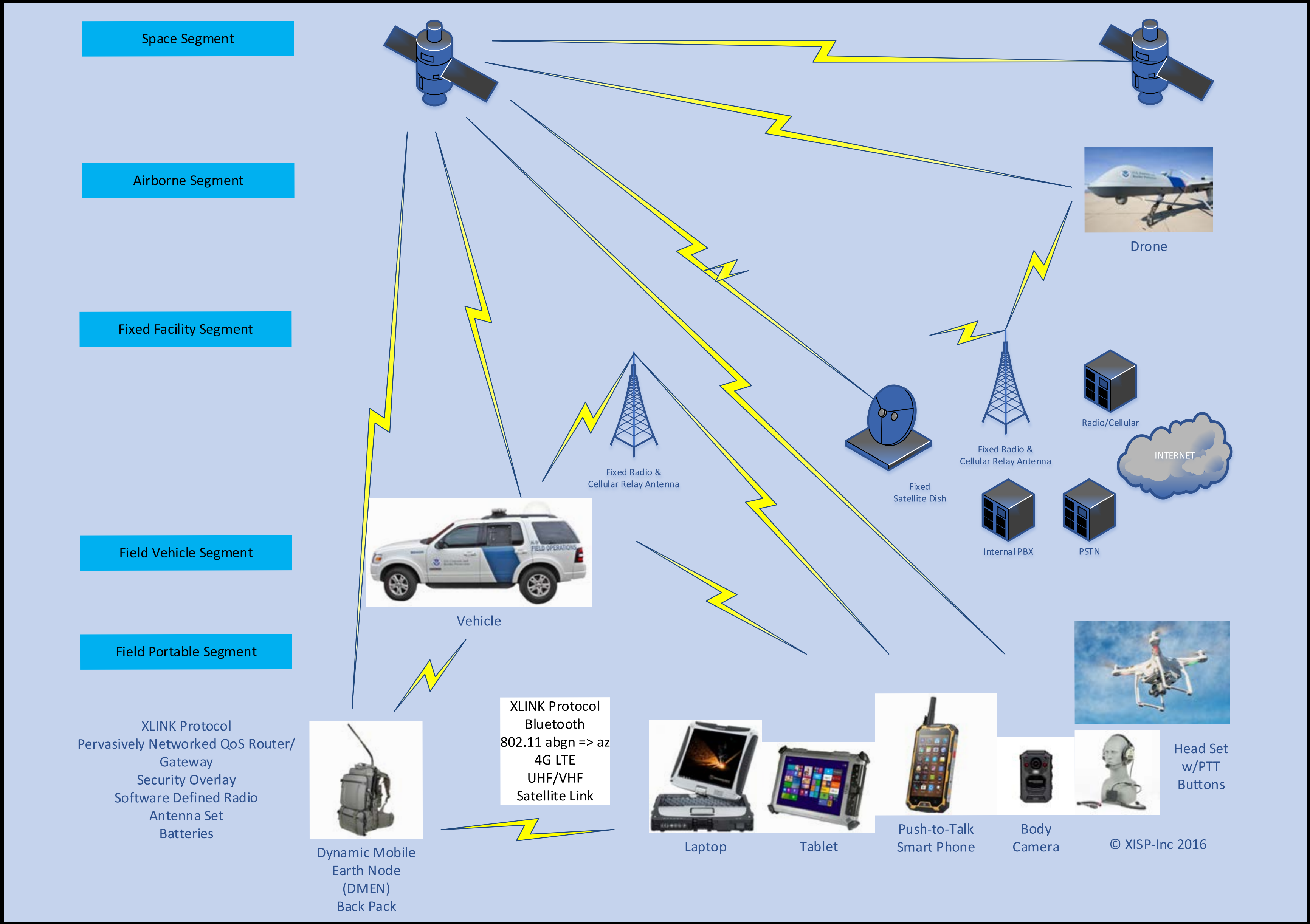
Function: Cis-Lunar Pervasively Networked Communications Interface
Purpose: Enables & Demonstrates BEO Application
Value: Testing INCA Architecture for BEO Flight Project Use

Function: Near-Earth Emergency Preparedness and Response Network
Purpose: Enables & Demonstrates Terrestrial Application
Value: Testing INCA Architecture for Terrestrial Use

XISP-Inc Crosslink Protocol (XLINK)

OSI 7 Layer Model	Layer Examples	Pervasively Networked QoS Based Gateway	Input / Output	Process Examples	DOD 4 Layer Model
FUNCTION		Function Models	⇄	State Management	FUNCTION
APPLICATION	End User Layer(s)	Application Models	⇄	DHCP, DNS, FTP, HTTP, IMAP4, POP3, SMTP, SNMP, SSH, NTP	Process / Application
PRESENTATION	Syntax Layer	Presentation Models	⇄	IPSEC/AES – Encrypt/Decrypt	
SESSION	Sync & Send to Ports	Session Models	⇄	DTN – Bundle/Unbundle	
TRANSPORT	TCP	Transport Models	⇄	TCP, UDP	Host-to-Host
NETWORK	Packets	Network Models	⇄	IPv4, IPv6, OSPF, ICMP, IGMP, ARP, RARP, BOOTP	Internet
DATA LINK	Frames	Data Link Models	⇄	802.11, ATM, PPTP, L2TP, 10/100/1000 BaseT, 4/10/40G	Network
PHYSICAL	Physical Structure	Physical Models	⇄	Fiber Optic, Coaxial, Twisted Pair, Space Wire	

Earth Facing INCA System Concept of Operations Example

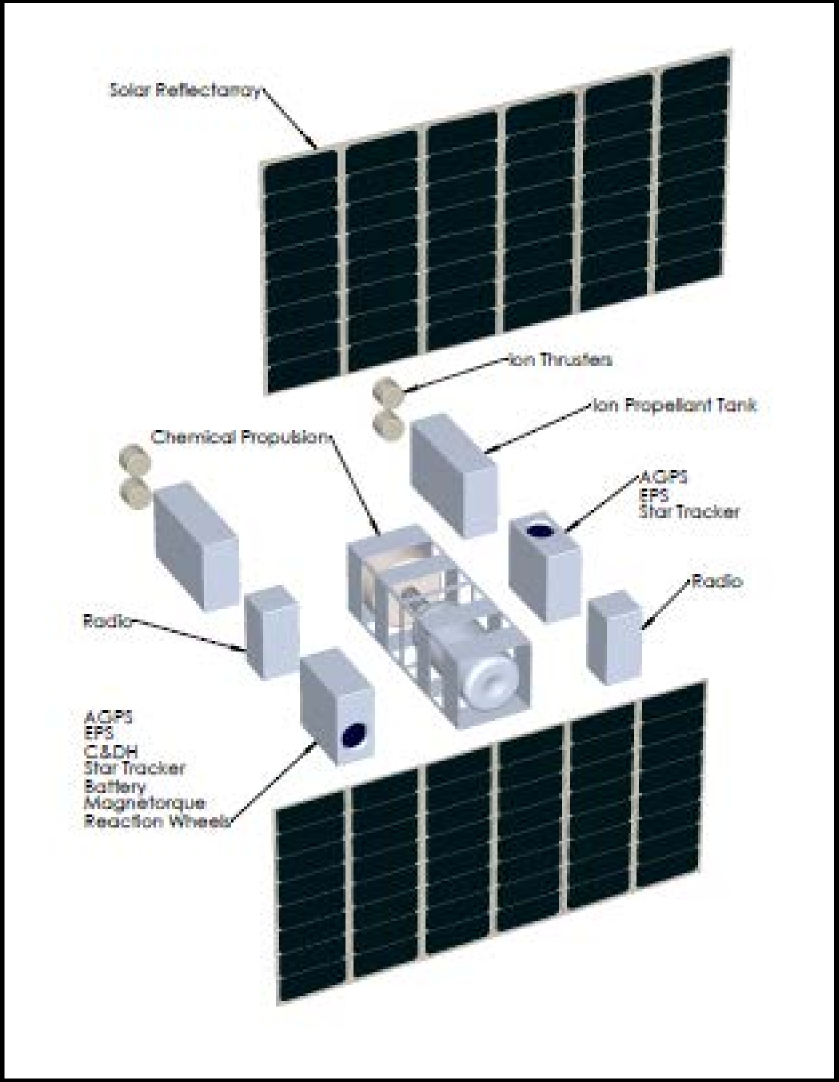


Alpha Cube Satellite (ACS)

- ACS provides a technology development, demonstration, and deployment (TD3) spacecraft bus for HTA, INCA, MOCA, and SSPB
- ACS Low cost highly configurable small spacecraft for Earth facing, Cislunar infrastructure, and beyond Earth orbit applications.
- TD^3 work includes: beyond Earth Orbit SDR through Ka Band and more (W band, laser, etc.), laser retroreflector host and testbed, user hardware & software extensible linux based avionics system (GN&C, ACS, Power, DMS), non-toxic propulsion systems, Virtual Operations Center (based on Open Web MCT & Xrosslink protocol), reflectarray solar/TX&Rx/Rectenna

➔ *ACS is low cost extensible Comm and Nav infrastructure suitable for prototyping applications/services on-orbit, in Cis-lunar space, and beyond.*

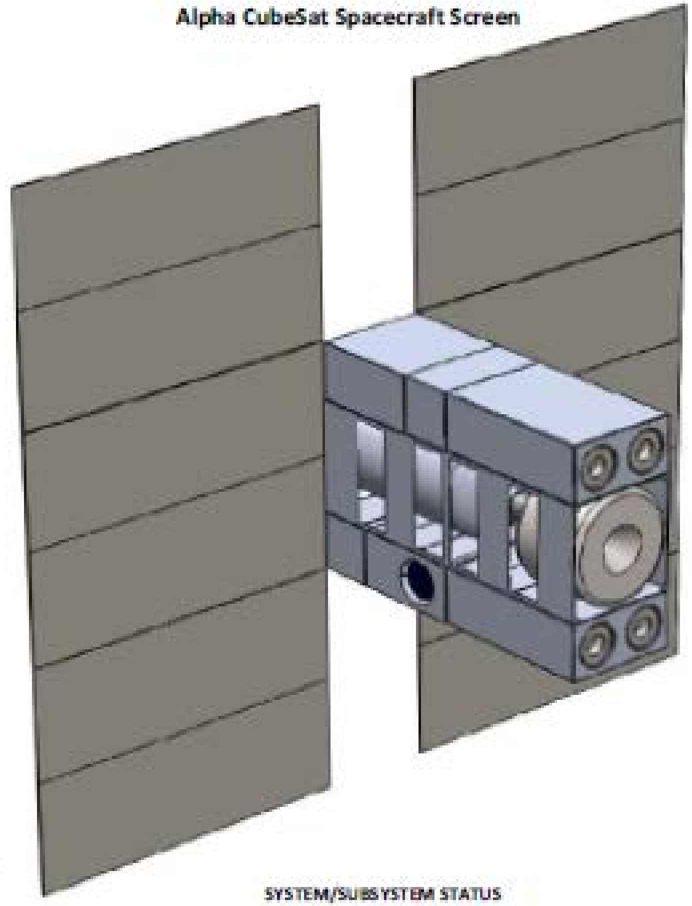
Alpha CubeSat Derived Flight Test Articles*



* Alternate 6U flight test article concept derived from NASA CubeQuest Challenge Team Alpha CubeSat design

MANAGEMENT OPERATIONS CONTROL ARCHITECTURE (MOCA) MISSION STATUS

Alpha CubeSat Spacecraft Screen



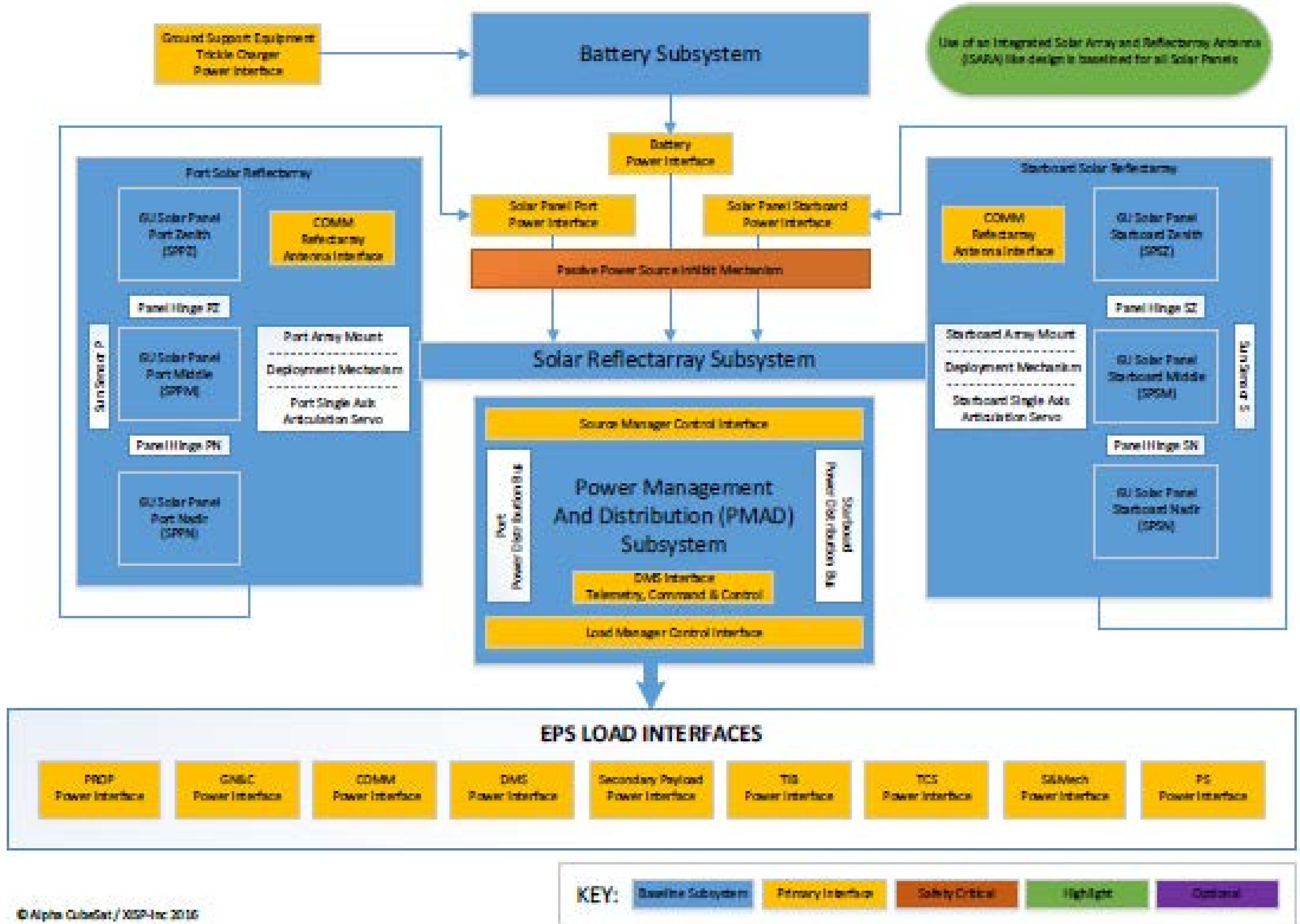
SYSTEM/SUBSYSTEM STATUS

COMM	EPS	DMS	GN&C	S&Mech	PROP	TCS	GS	LSP

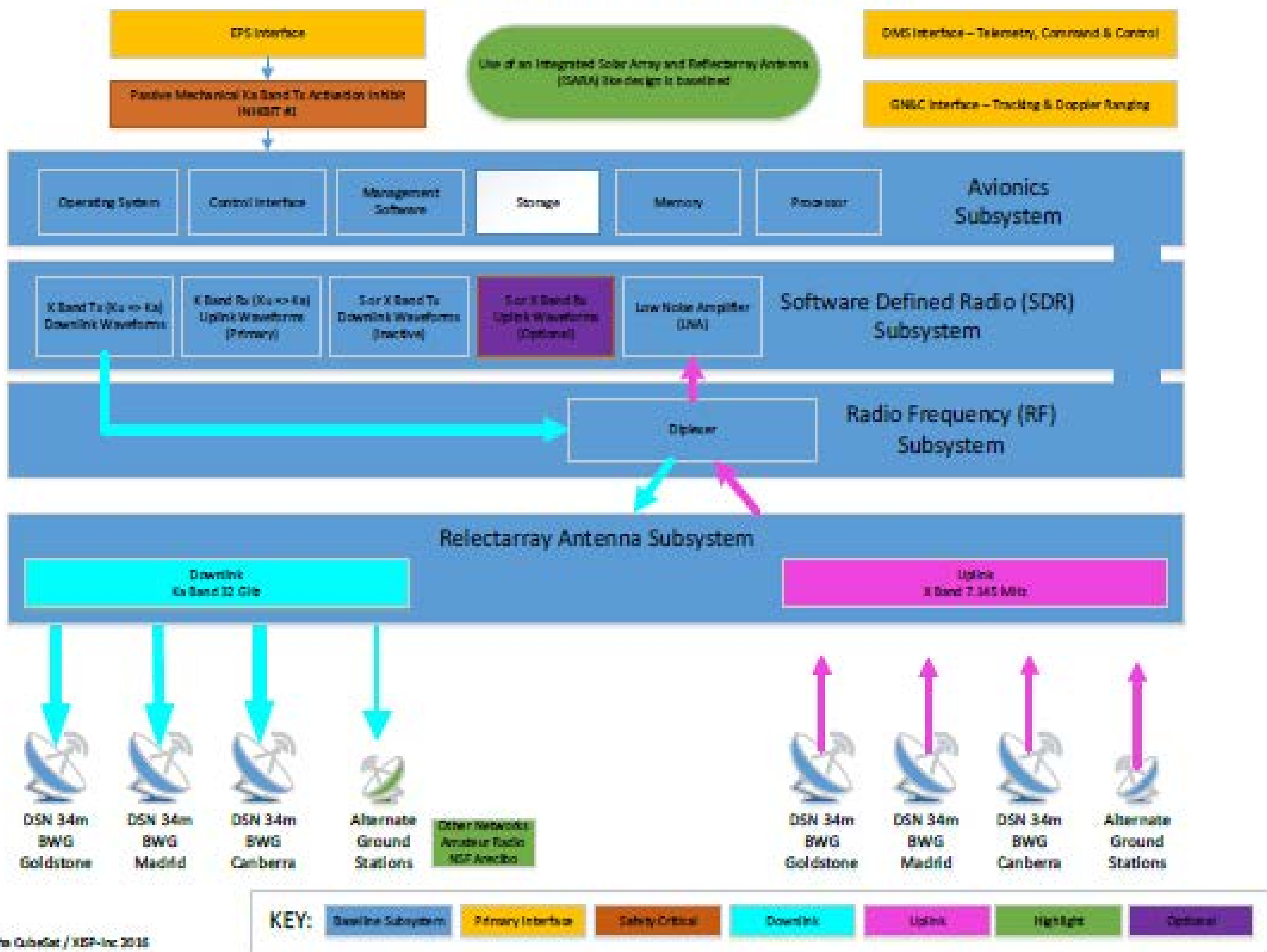
PAYLOADS:

CUBE QUEST	VENDOR	SCIENCE	MEMORIAL	SPARE	SPARE	SPARE

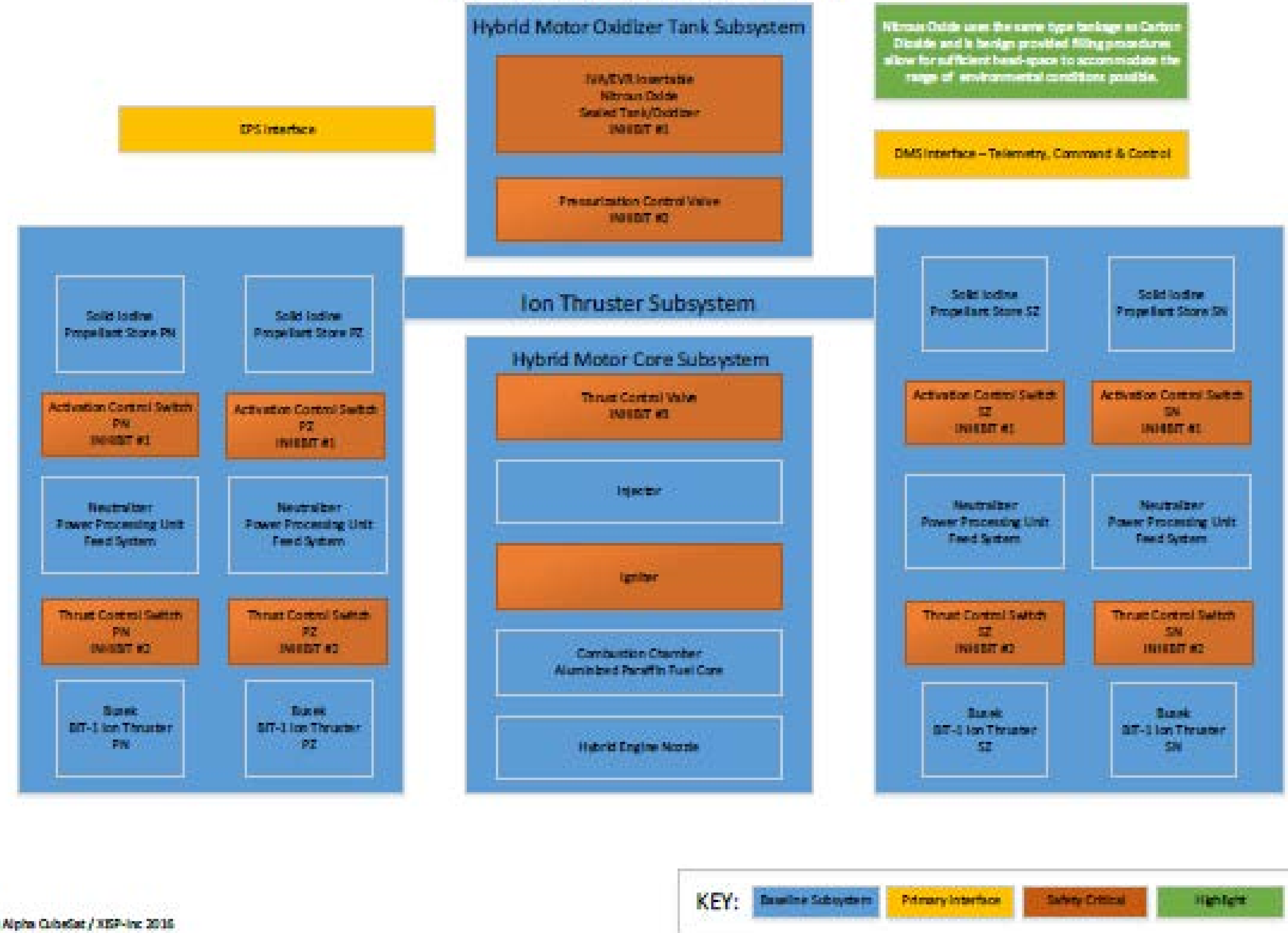
Alpha CubeSat Electrical Power System (EPS)



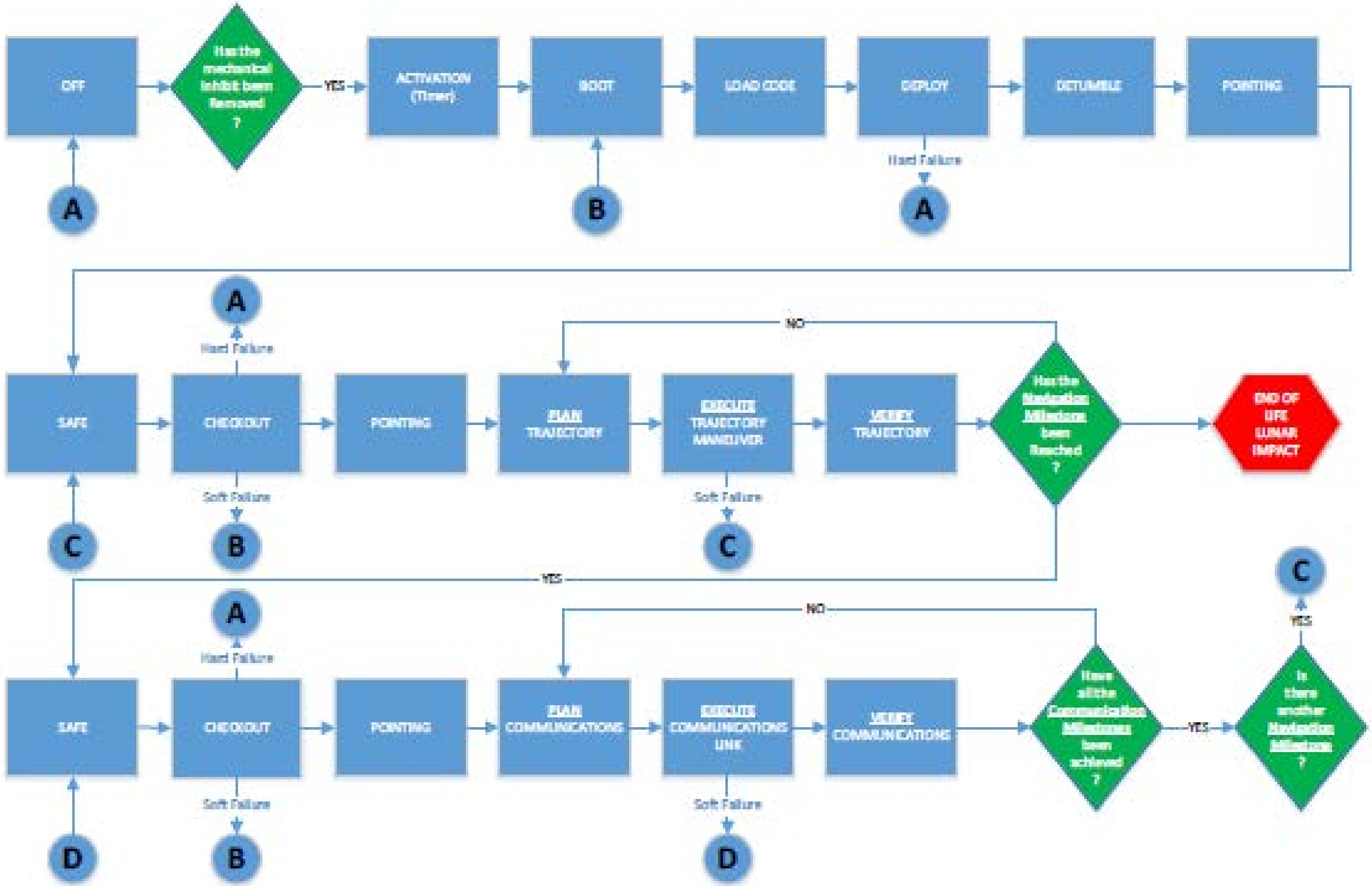
Alpha CubeSat Communications System (COMM)



Alpha CubeSat Propulsion System (PROP)



Alpha CubeSat Mode / State Transitions



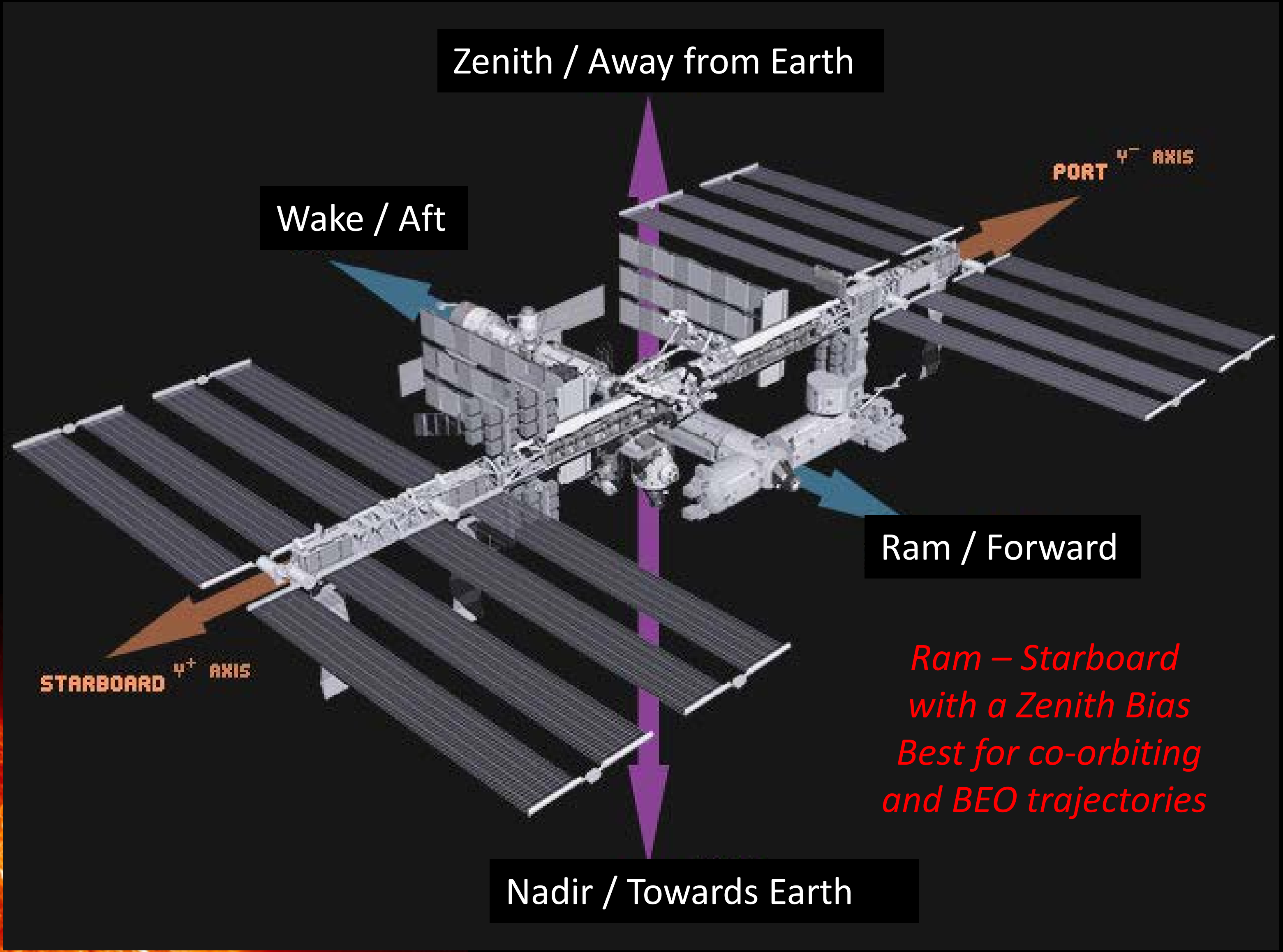
Space-to-Space Power Beaming (SSPB)

- SSPB provides TD^3 radiant energy beaming testbed, and electrical as well as other utilities (Comm, Nav, etc.) as applicable for ACS, HTA, INCA, and MOCA
- SSPB retire real and perceived technical, cost, and schedule risk associated with radiant energy beaming utilities
- SSPB mission evolution supports ISS co-orbiting free-flyers, Earth facing platforms and/or fractionated systems with LEO/MEO/GEO power augmentation and alternate bus systems, Cis-lunar and lunar surface operations, asteroidal assay mission operations and propulsion augmentation.

➔ *SSPB forges a TD^3 path to Space-to-Space and Space-to-Alternate surface electrical, communications, and navigation utilities.*

➔ *SSPB work is intended to be frequency agnostic from Ka band through optical.*

ISS as a Launch Platform - 2

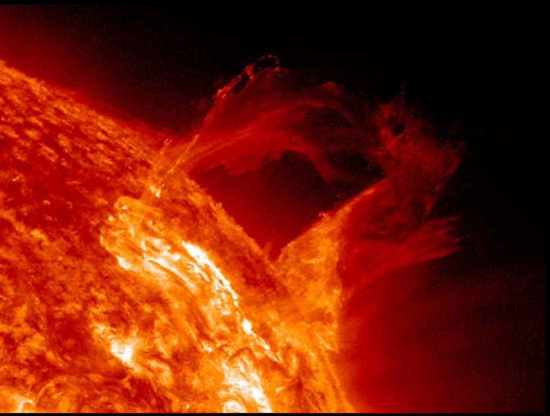


Ram – Starboard with a Zenith Bias Best for co-orbiting and BEO trajectories

What's Next?

Lunar Power & Light Company

an XISP-Inc Consortium



Don't wait for the future, help us build it!

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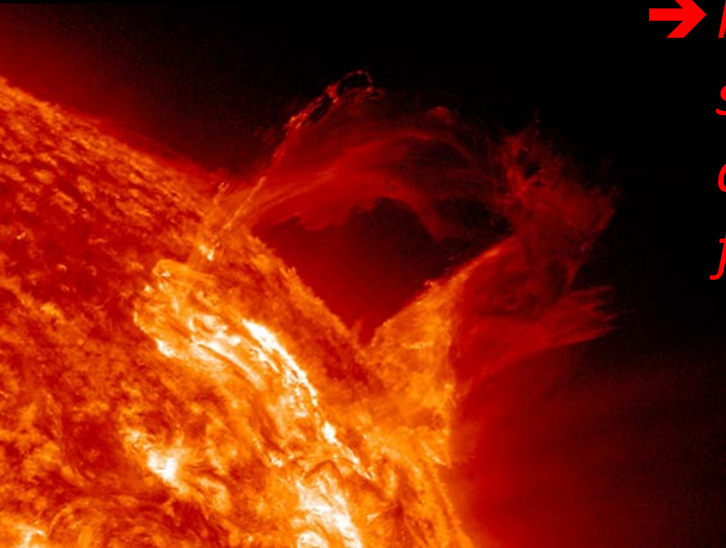
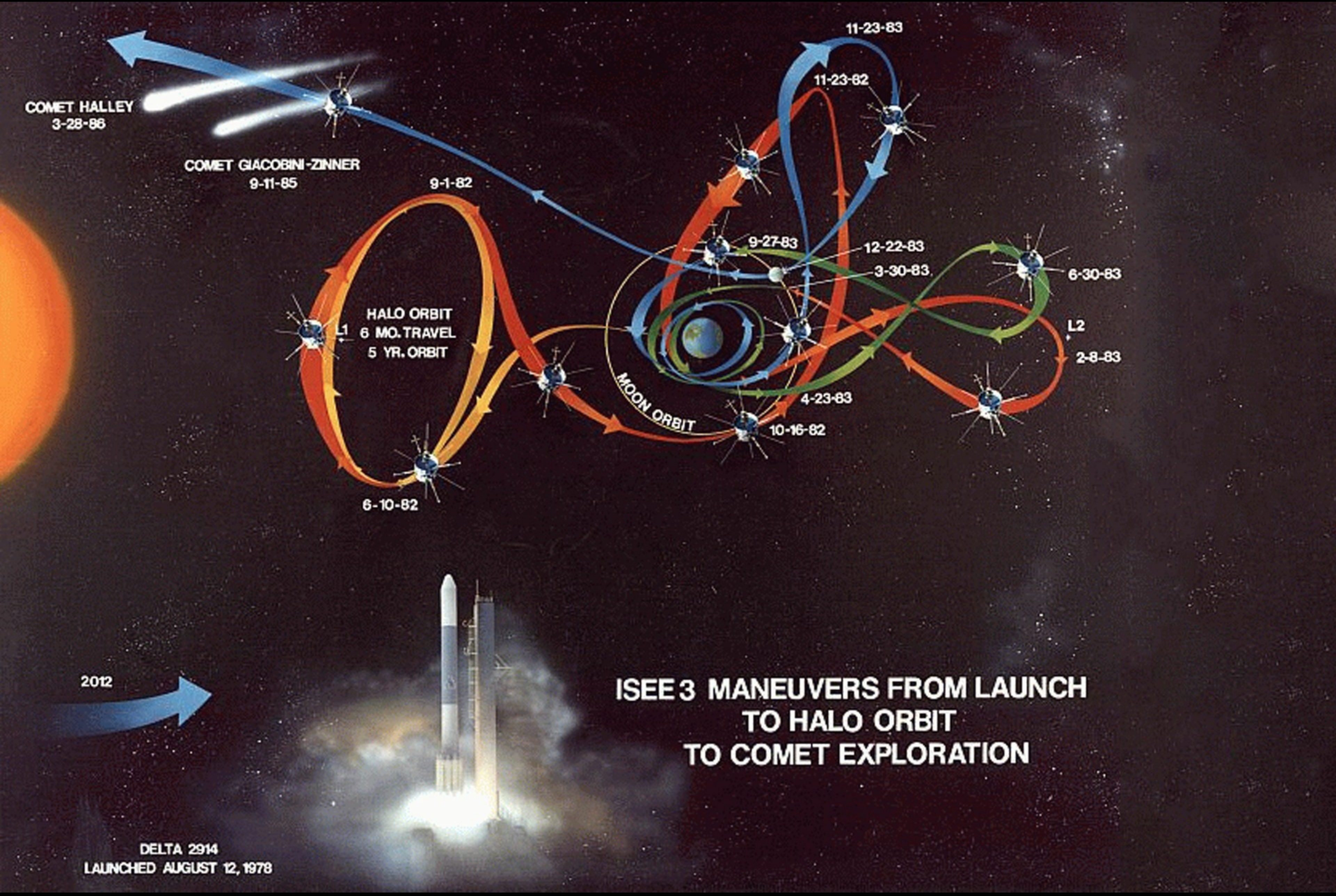
Halfway To Anywhere (HTA)

- HTA provides TD^3 propulsion testbed, trajectory insertion bus, alternate minimum energy trajectories, and resonance orbits for ACS, INCA, MOCA and SSPB.
- *HTA leads to the use of ISS as a transportation node for low cost, readily deployable Earth orbit, cislunar and beyond Earth orbit mission support.*

→ *HTA helps draws out the requirements for space-to-space electrical, communications, and navigation utilities for LEO/MEO/GEO, and beyond.*




COMET HALLEY
3-28-86
COMET GIACOBINI-ZINNER
9-11-85
11-23-83
11-23-82
9-1-82
HALO ORBIT
6 MO. TRAVEL
5 YR. ORBIT
L1
9-27-83
12-22-83
3-30-83
6-30-83
L2
2-8-83
MOON ORBIT
4-23-83
10-16-82
6-10-82
2012
ISEE 3 MANEUVERS FROM LAUNCH
TO HALO ORBIT
TO COMET EXPLORATION
DELTA 2914
LAUNCHED AUGUST 12, 1978

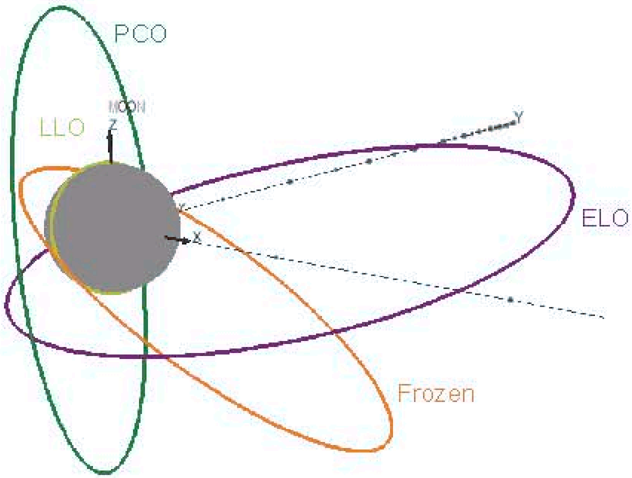
ISS as a Launch Platform - 1

- 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)
  - Optimized access to alternative minimum energy trajectories
  - Single & Multi-use Trajectory Insertion Buses
  - Opportunities for Low Cost Earth Applications, Space Operations, and Space Exploration Missions

LUNAR RESONANCE ORBITS

Smaller Cislunar (Lunar Two-body) Orbits

Orbit Type	Orbit Period	Amplitude Range	E-M Orientation
Low Lunar Orbit (LLO)	~2 hrs	100 km	Any inclination
Prograde Circular (PCO)	11 hrs	3,000 to 5,000 km	~ 75 ° inclination
Frozen Lunar Orbit	~13 hrs	880 to 8,800 km	40° inclination
Elliptical Lunar Orbit (ELO)	~14 hrs	100 to 10,000 km	Equatorial



Low Lunar Orbit (LLO): LLO is defined as a circular orbit of an altitude around 100 km. LLOs are favorable for surface access and polar orbit inclinations offer global landing site access.

An Elliptical Lunar Orbit (ELO), such as the 100 x 10,000 km shown, trades insertion costs with transfer cost to lunar surface.

Prograde Circular Orbits (PCOs) are defined as circular orbits of various sizes that rotate in the prograde direction and are highly stable, requiring few to zero corrections to be maintained.

Frozen orbits are similar but need not be circular and have orbital parameters that oscillate around fixed values.

New Twists:

Frozen orbits include Lunar Resonance Orbits that work from at least four inclinations 27º, 50º, 76º, and 86º Spacecraft in these orbits can stay in lunar orbit indefinitely with little or no makeup propulsion.