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

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Outline

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- DEXTRE is missing something
- Making it real . . .
- Building near realtime state models
- Relationship with NASA
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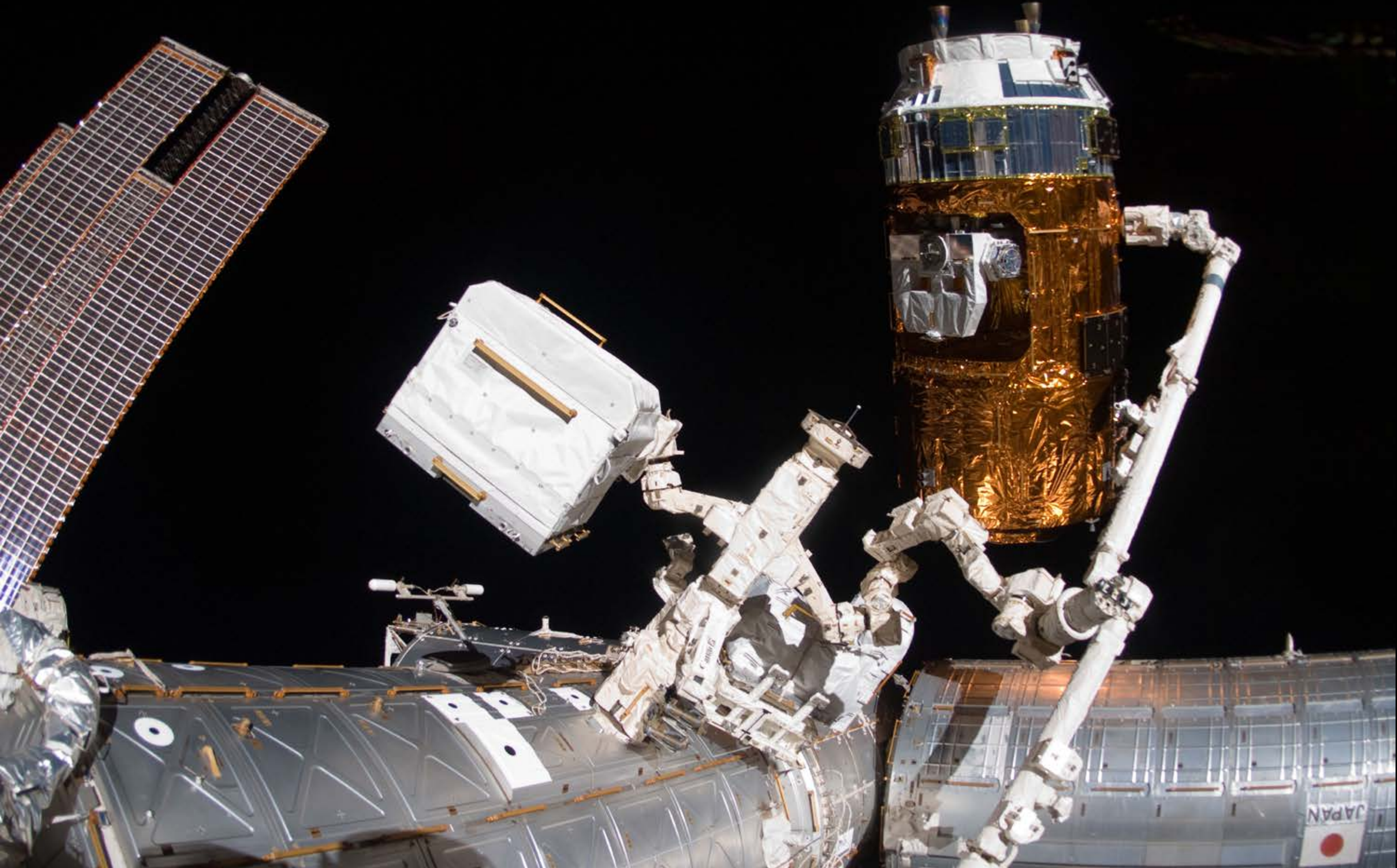
- Next Steps
- Reality Check
- Conclusion

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 . . .

EVA Robotics . . .



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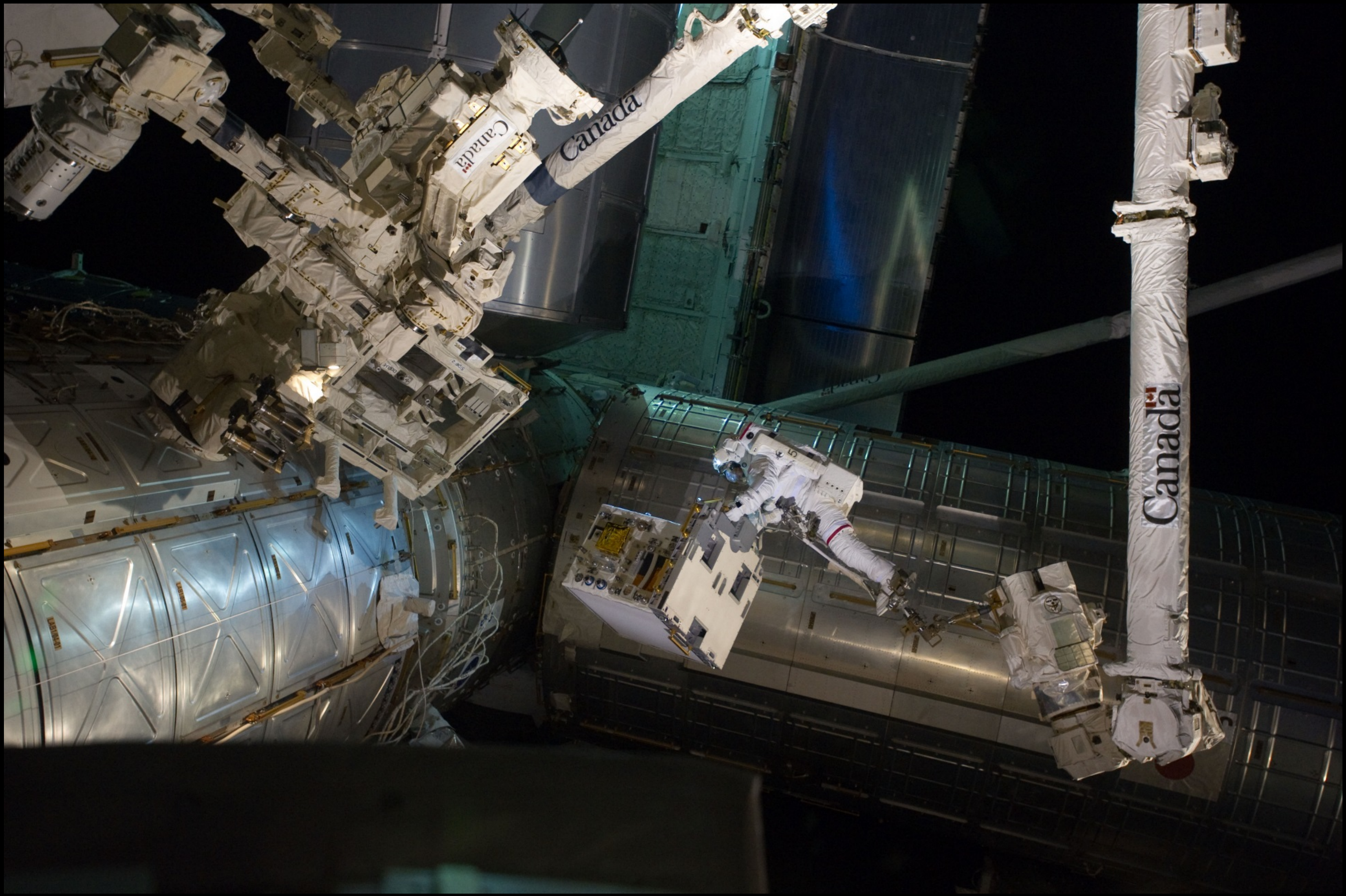
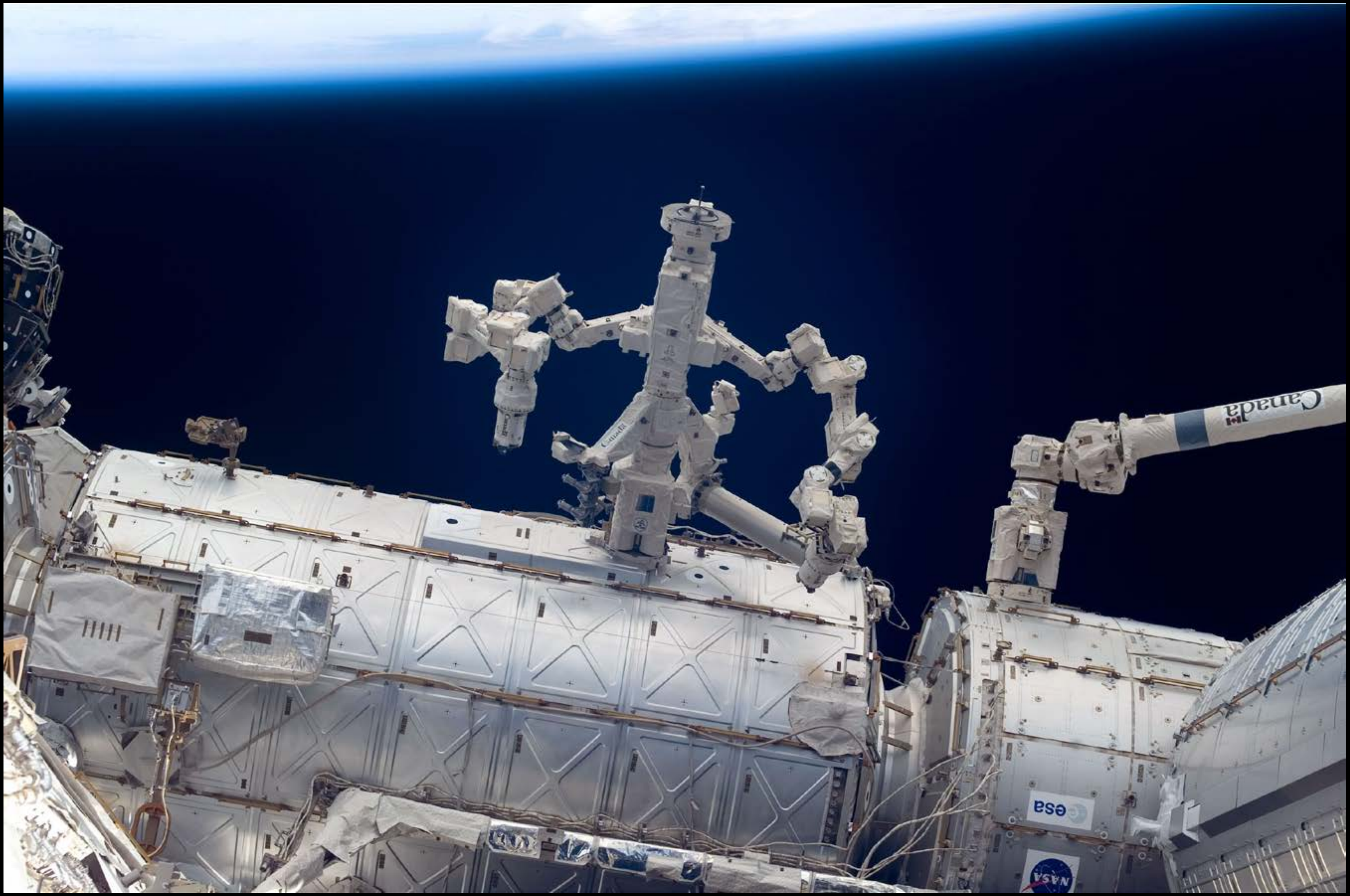
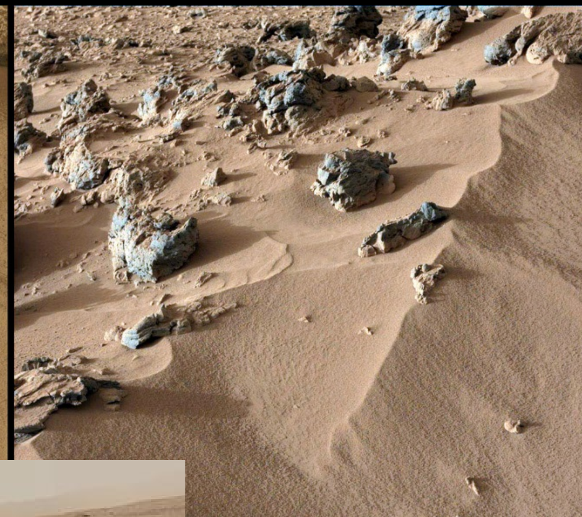
EVA Robotics & Crew . . .

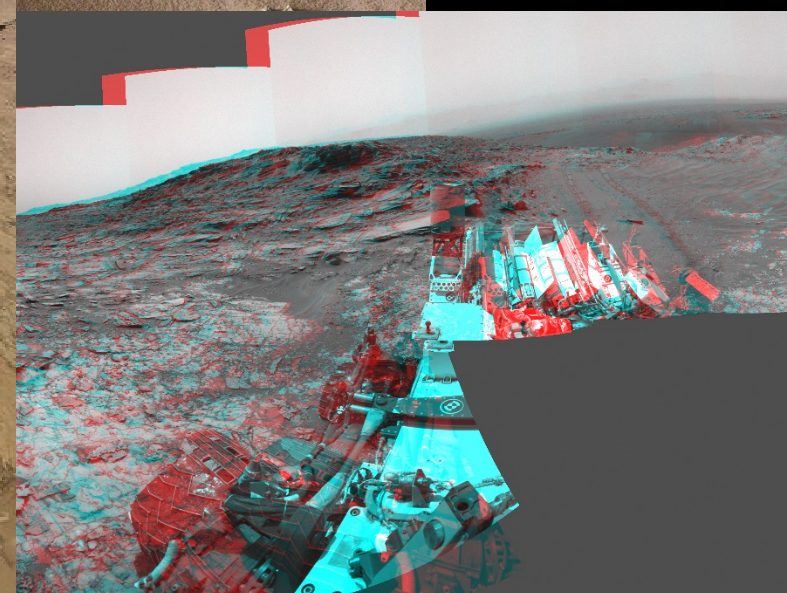


EVA Robotics . . .



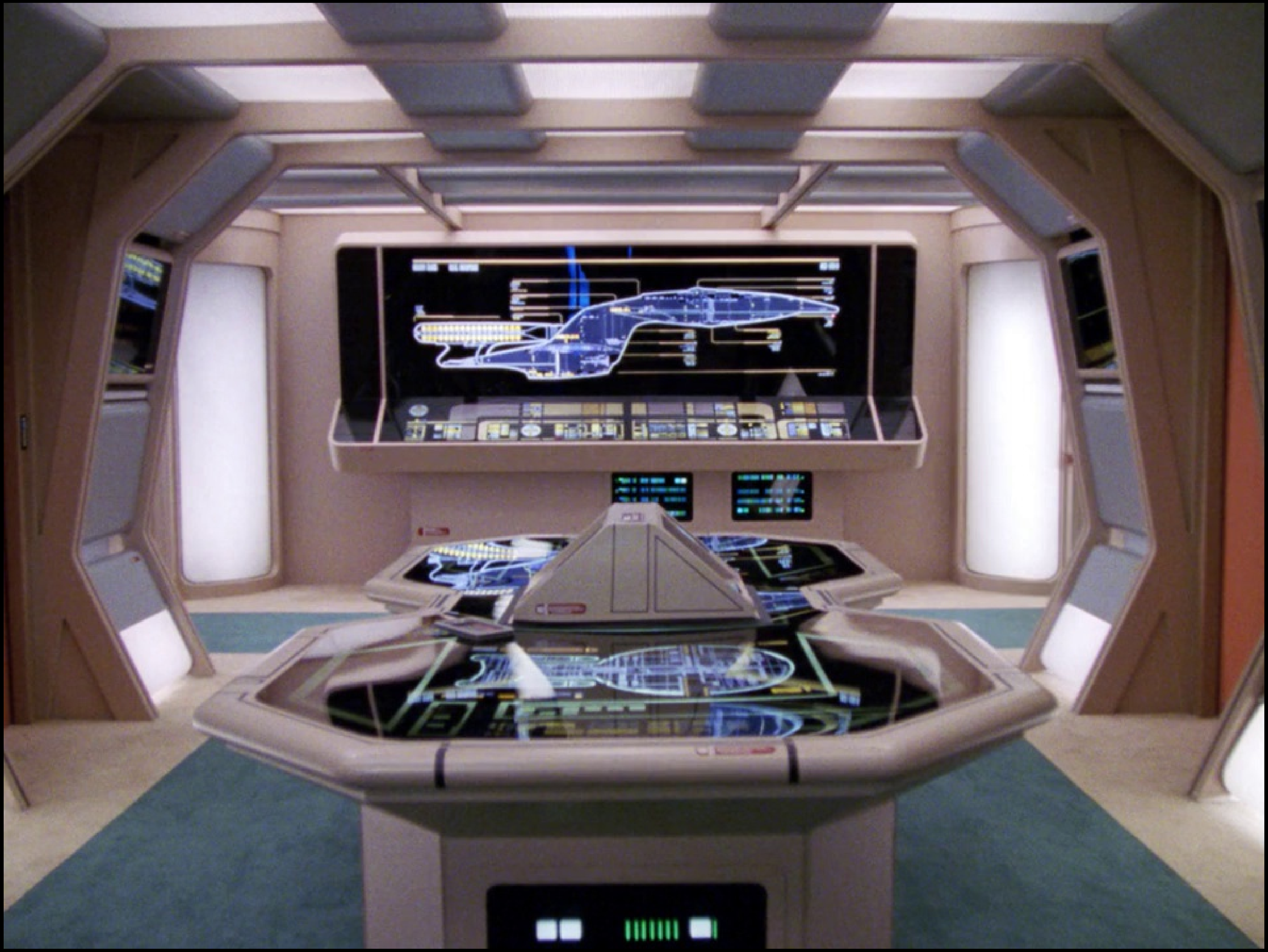
So you want to roam . . .





Going to Low Earth Orbit and Beyond . . .

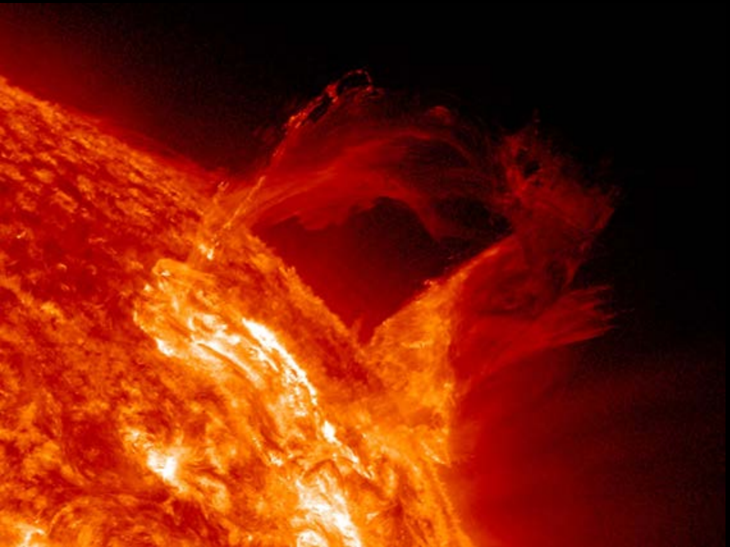
Perhaps even run a starship?



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.

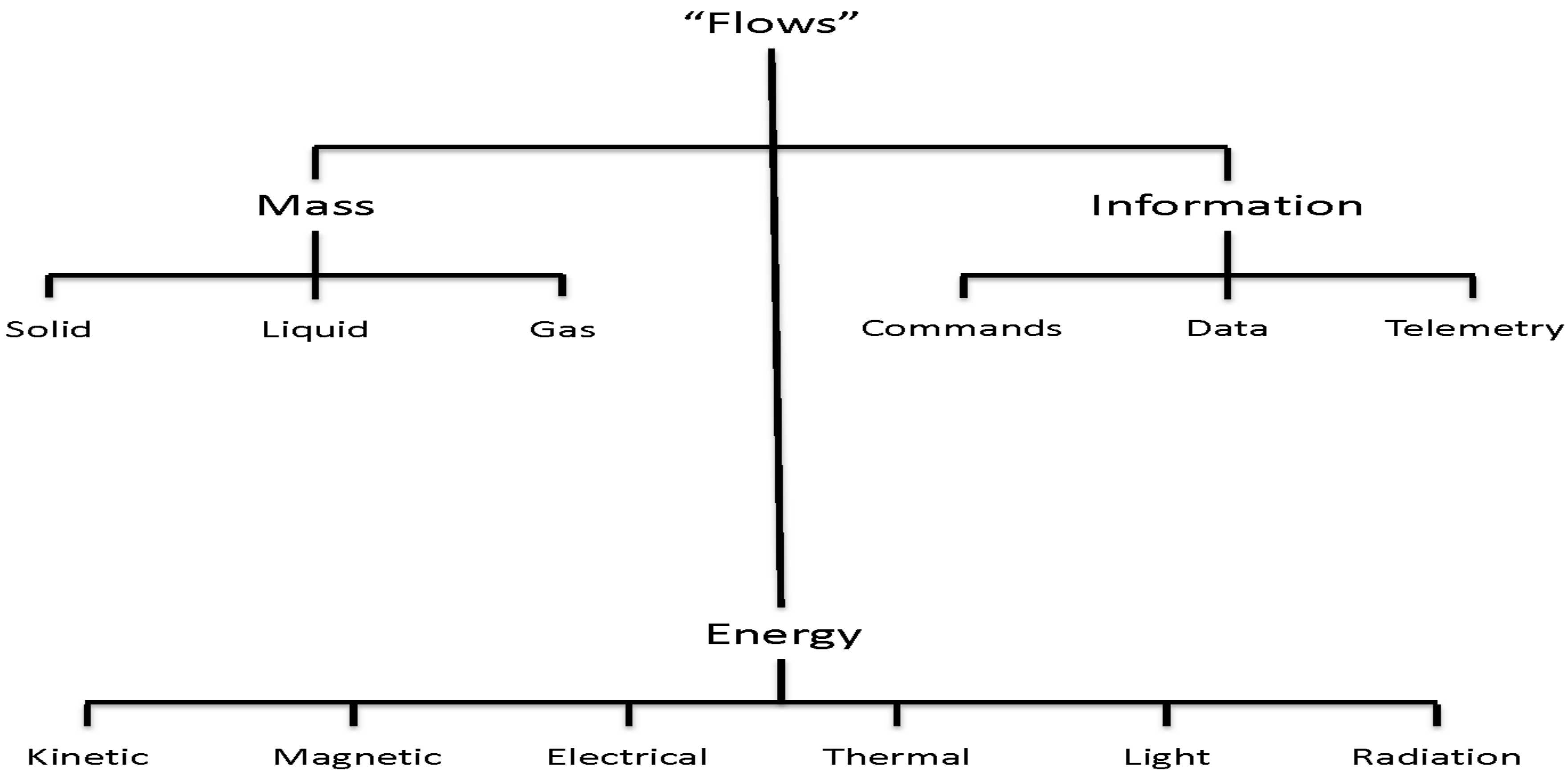
The structure and ordering of knowledge makes a very real difference . . .

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 an overarching Space Act Umbrella Agreement under negotiation between NASA Headquarters and XISP-Inc.

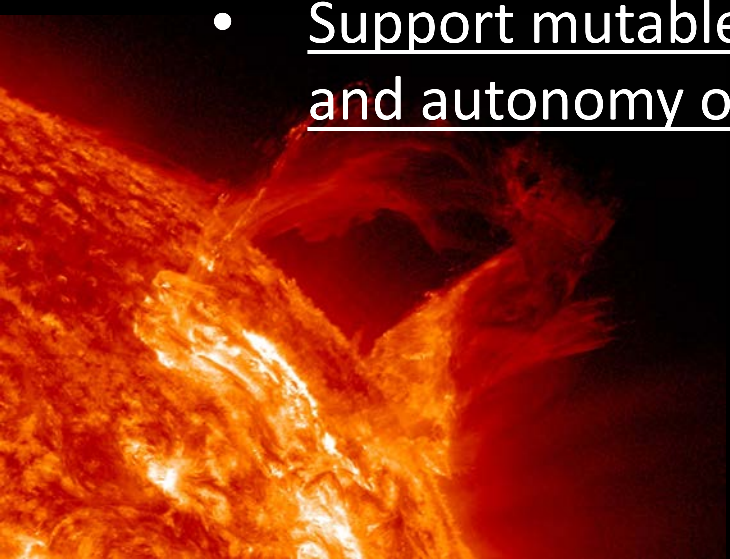
Relevance

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 MOCA Supported Missions

- Team Alpha CubeSat (ACS) NASA Cube Quest Challenge
  - Operations of 6U Cubesat
- Space-to-Space Power Beaming (SSPB)
  - Effective use of radiant energy beam components
- Interoperable Network Communications Architecture (INCA)
  - Testing DTN with real world requirements
  - Pervasively networked DTN gateway
- Advanced Vision and Task Area Recognition (AVaTAR)
  - Support mutable locus of control between teleoperation and autonomy on a shared control basis



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, a 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*

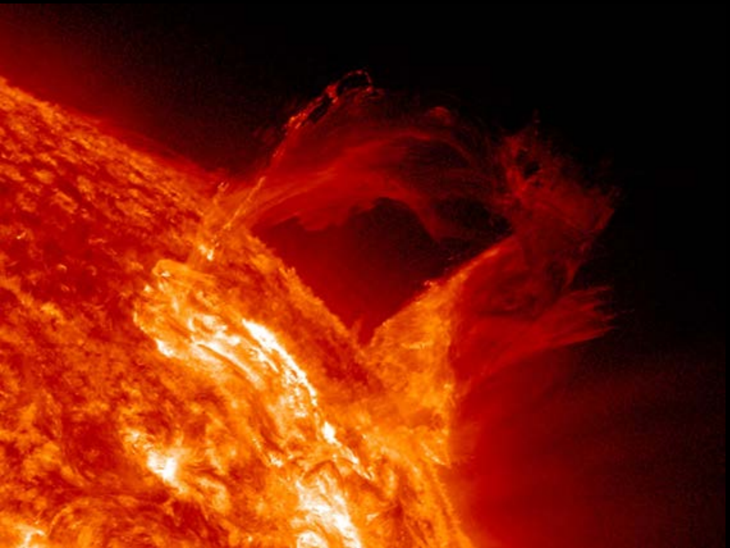
1. Development of a paper model and individual element protocode;
2. Development of functioning individual element models and an end-to-end model protocode;
3. Optimization of individual element models and a functioning end-to-end model;
4. Testing of the optimized end-to-end model and individual element 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

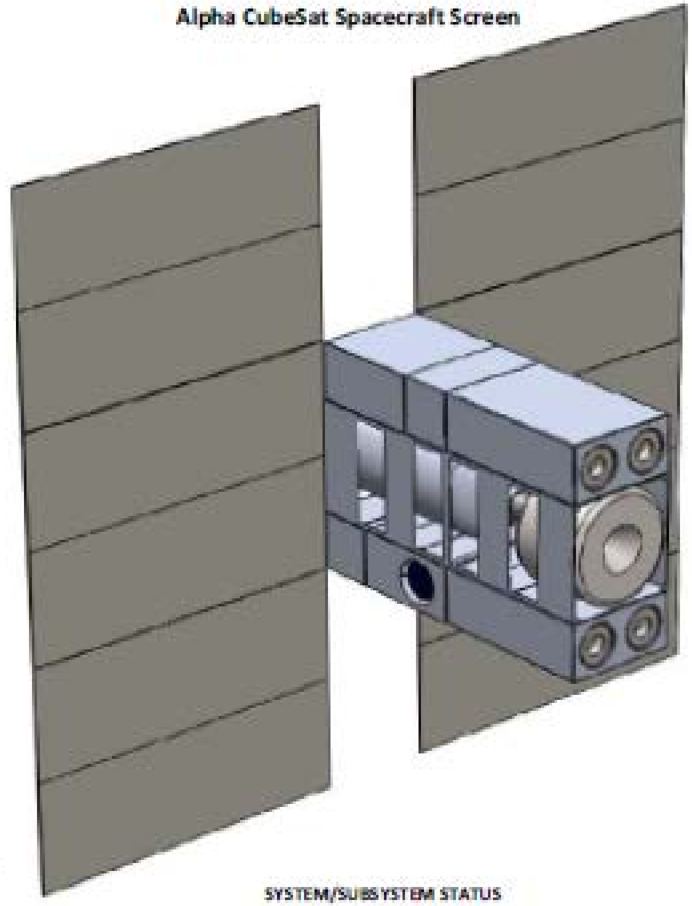
MOCA extended activities will focus on actual on-orbit demonstrations and testing the efficacy of the near realtime parametric state models developed for the supported missions.

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.



MANAGEMENT OPERATIONS CONTROL ARCHITECTURE (MOCA) MISSION STATUS

Alpha CubeSat Spacecraft Screen



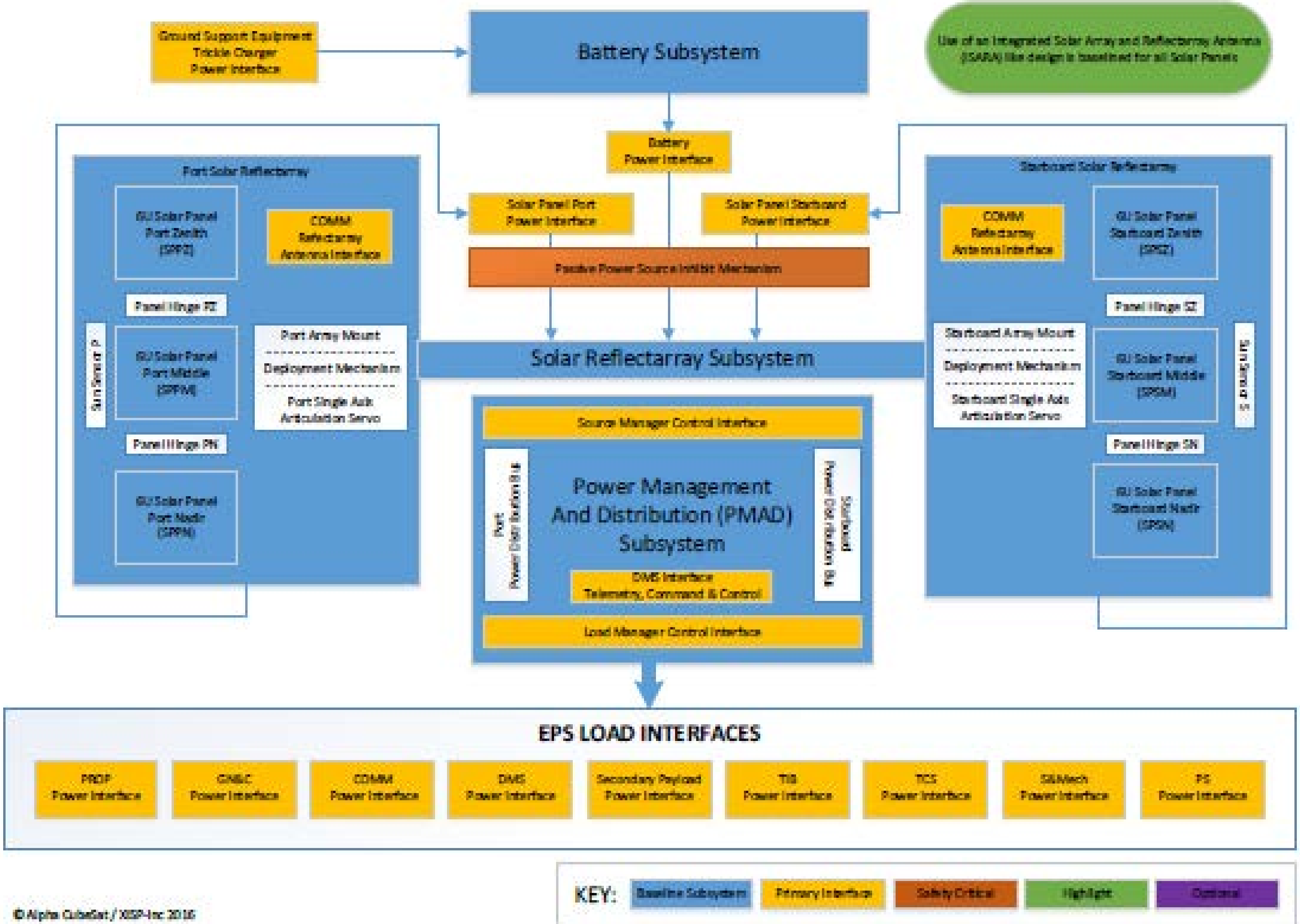
SYSTEM/SUBSYSTEM STATUS

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

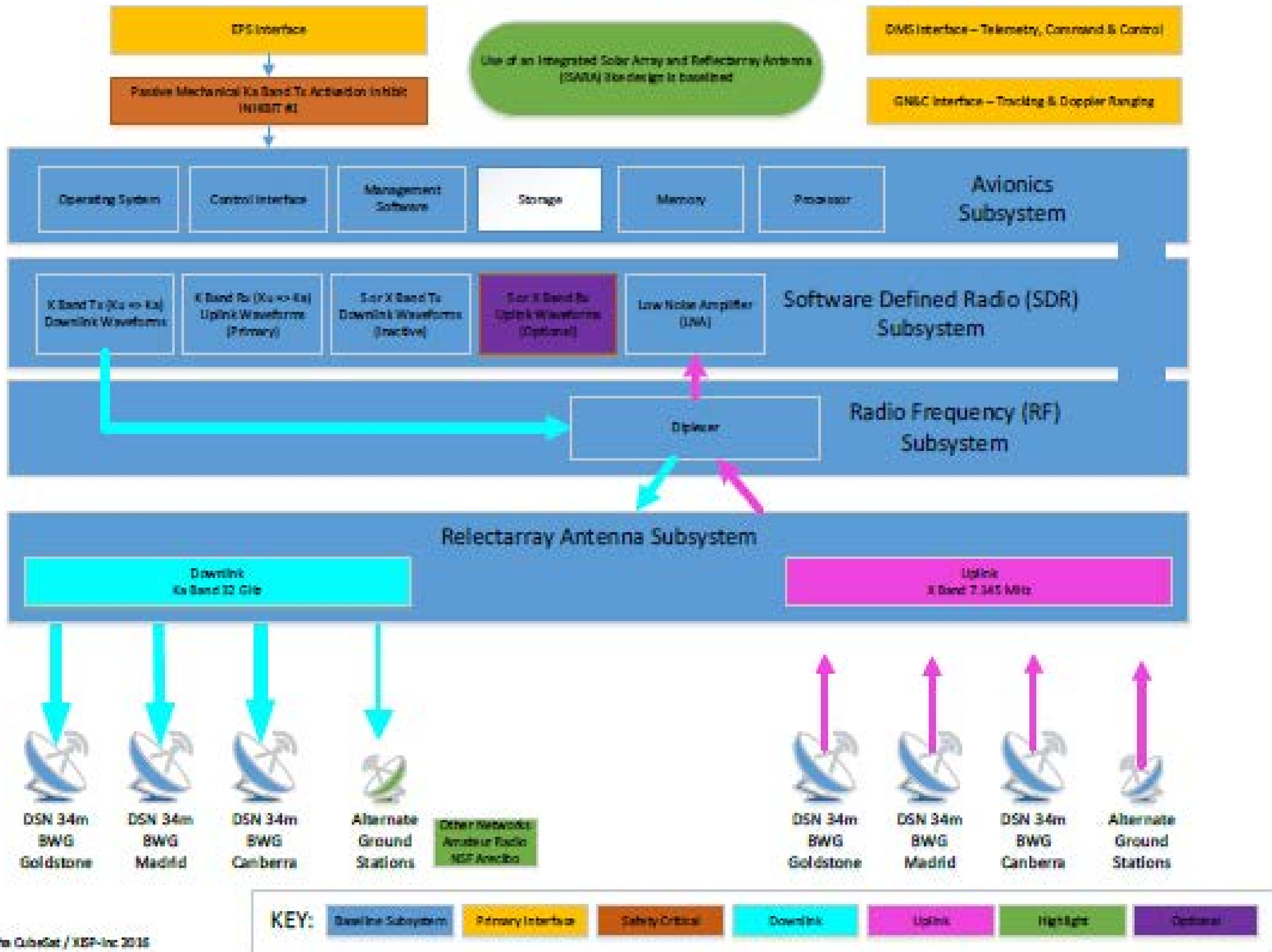
PAYLOADS:

CUBE QUEST	VENDOR	SCIENCE	MEMORIAL	SPARE	SPARE	SPARE

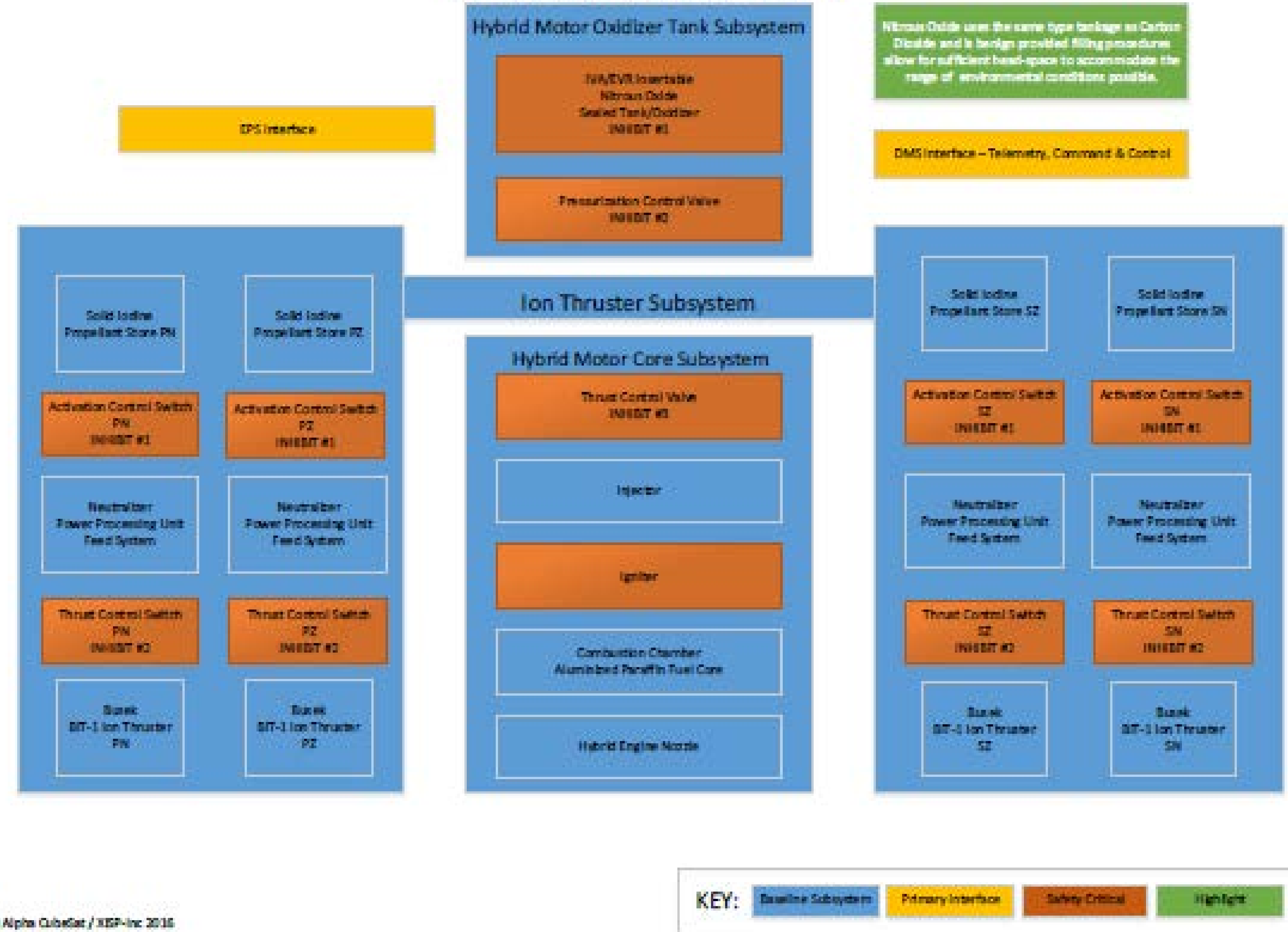
Alpha CubeSat Electrical Power System (EPS)



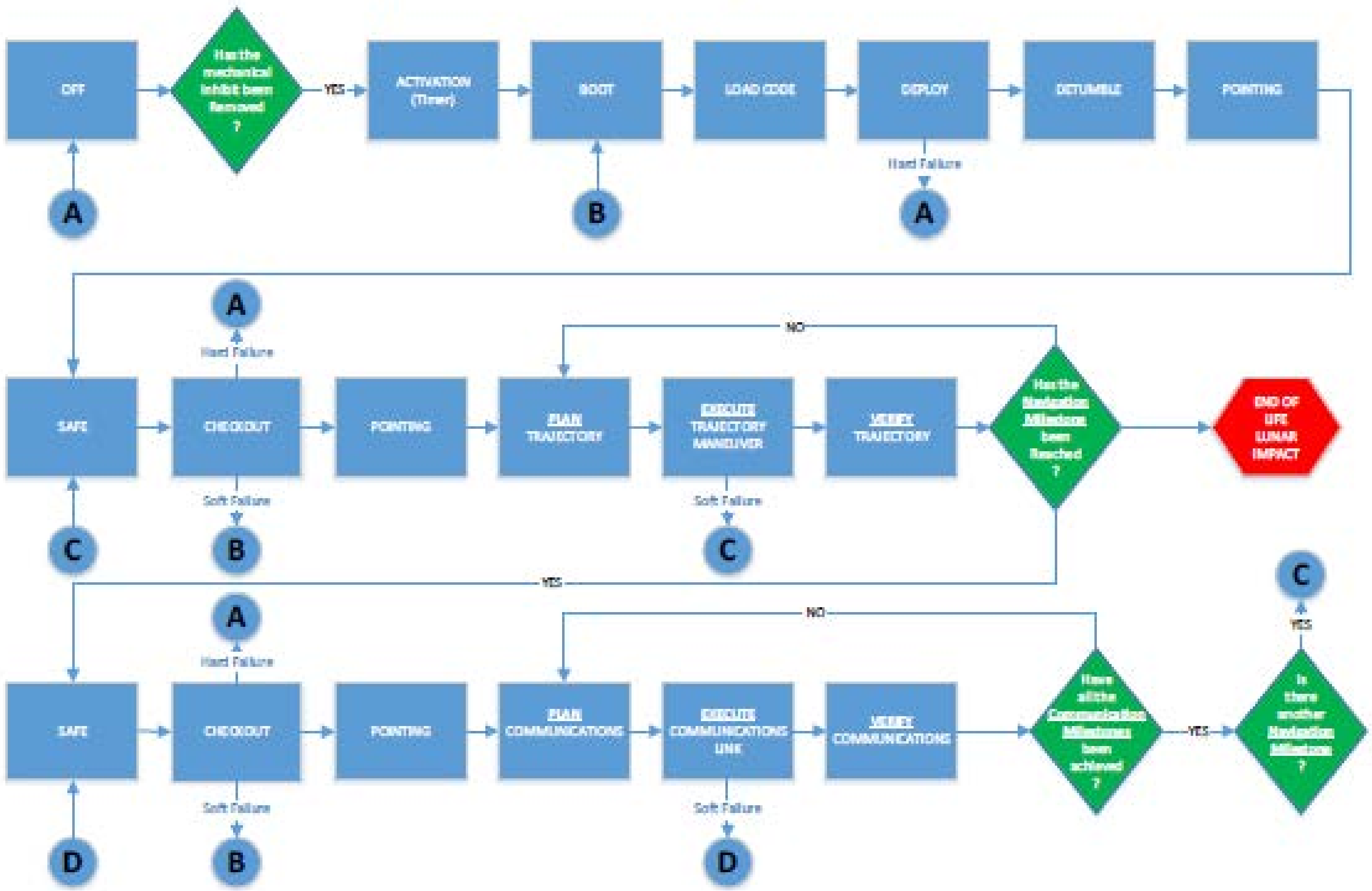
Alpha CubeSat Communications System (COMM)



Alpha CubeSat Propulsion System (PROP)



Alpha CubeSat Mode / State Transitions

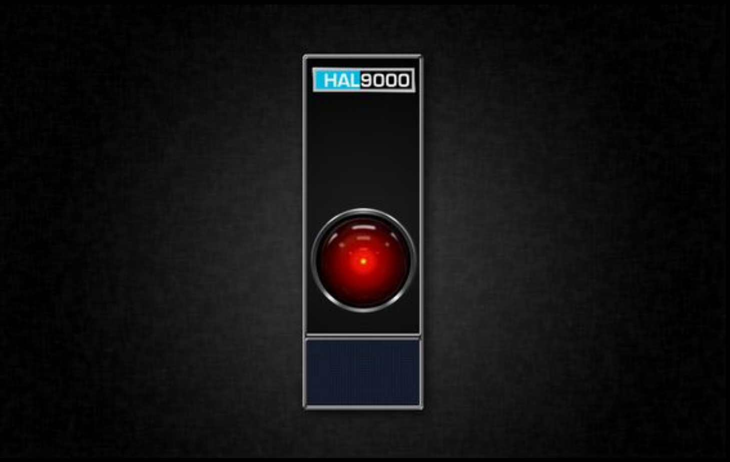


Next Steps

- 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*