Overview of Intelligent Power Controller Development for the Deep Space Gateway

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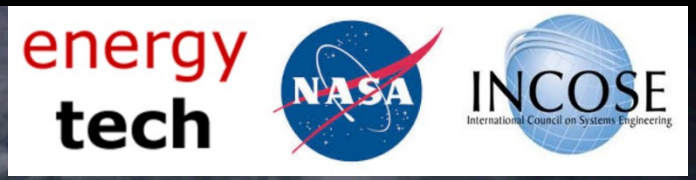


Agenda

- Overview of NASA Vision
- Deep Space Exploration
- The Autonomous Power Control Concept
- Autonomous Power Control Development
- Verification
- Applicability to Hybrid-Electric Propulsion

Exploring Space In Partnership

Now

Using the International Space Station

2020s

Operating in the Lunar Vicinity

2030s

Leaving the Earth-Moon System and Reaching Mars Orbit

Advancing technologies, discovery and creating economic opportunities

Phase 0

Solve exploration mission challenges through research and systems testing on the ISS. Understand if and when lunar resources are available

Phase 1

Conduct missions in cislunar space; assemble Deep Space Gateway and Deep Space Transport

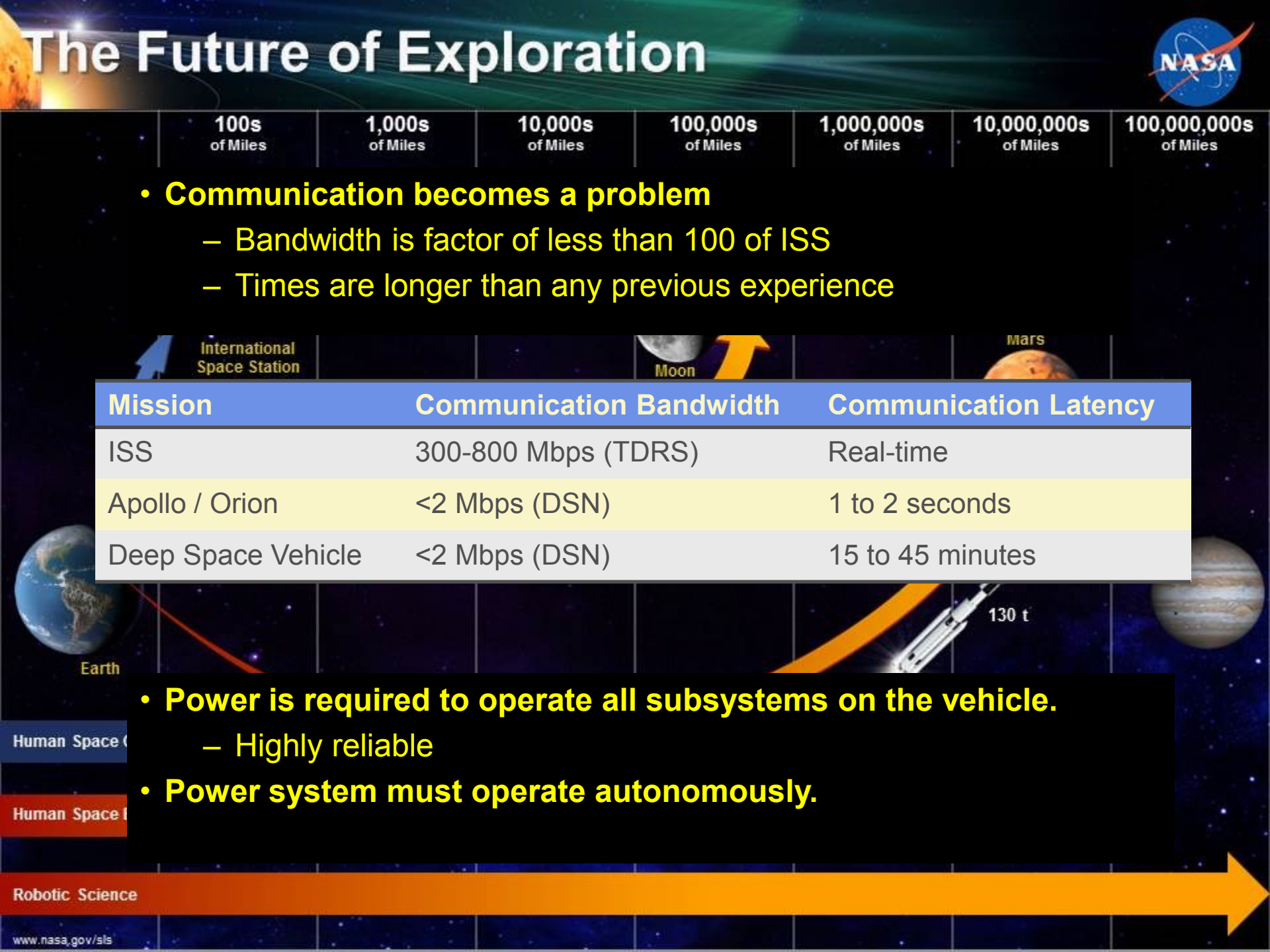
Phase 2

Complete Deep Space Transport and conduct Mars verification mission

Phases 3 and 4

Missions to the Mars system, the surface of Mars

The Future of Exploration

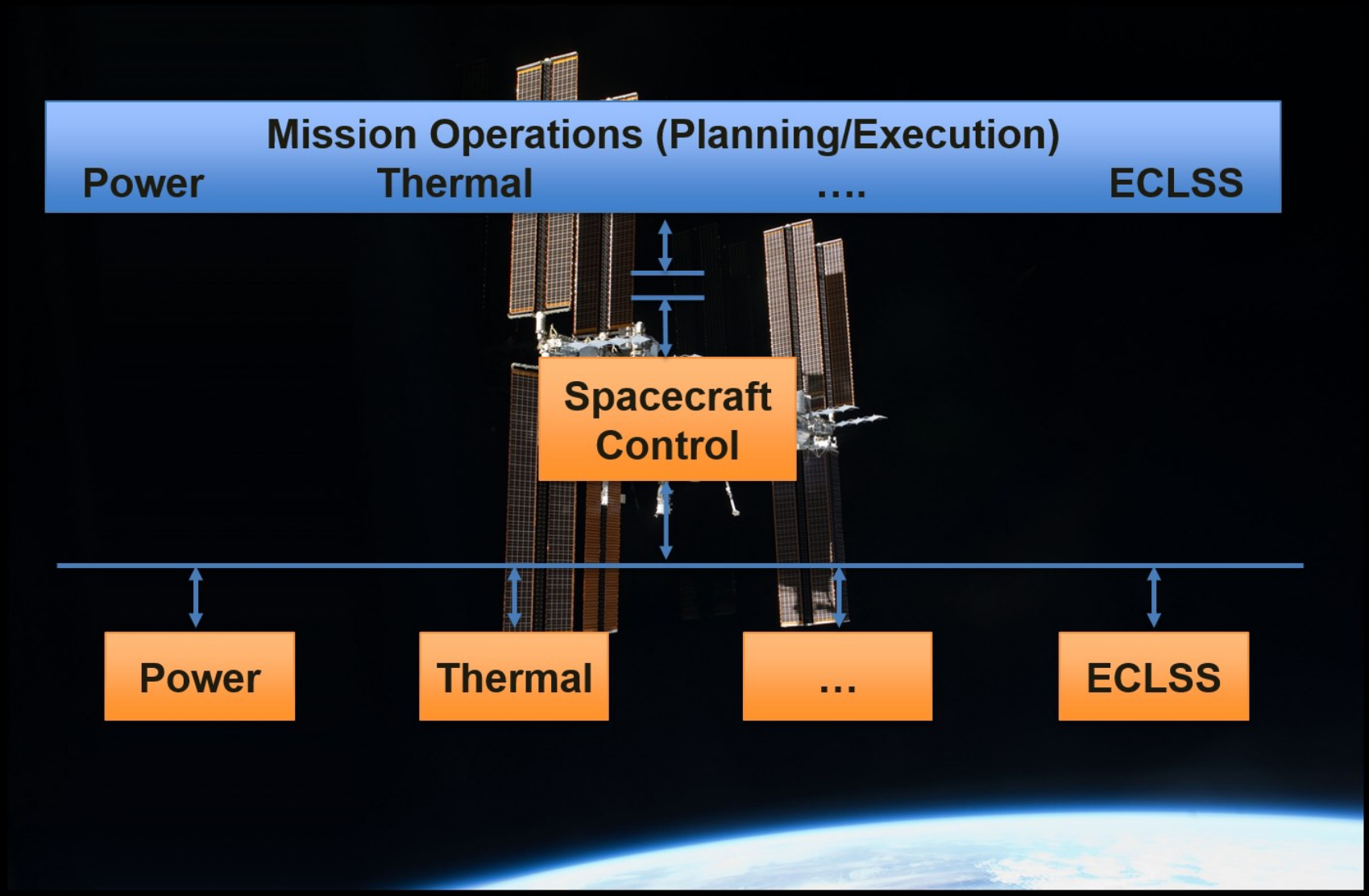


- **Communication becomes a problem**
  - Bandwidth is factor of less than 100 of ISS
  - Times are longer than any previous experience

Mission	Communication Bandwidth	Communication Latency
ISS	300-800 Mbps (TDRS)	Real-time
Apollo / Orion	<2 Mbps (DSN)	1 to 2 seconds
Deep Space Vehicle	<2 Mbps (DSN)	15 to 45 minutes

- **Power is required to operate all subsystems on the vehicle.**
  - Highly reliable
- **Power system must operate autonomously.**

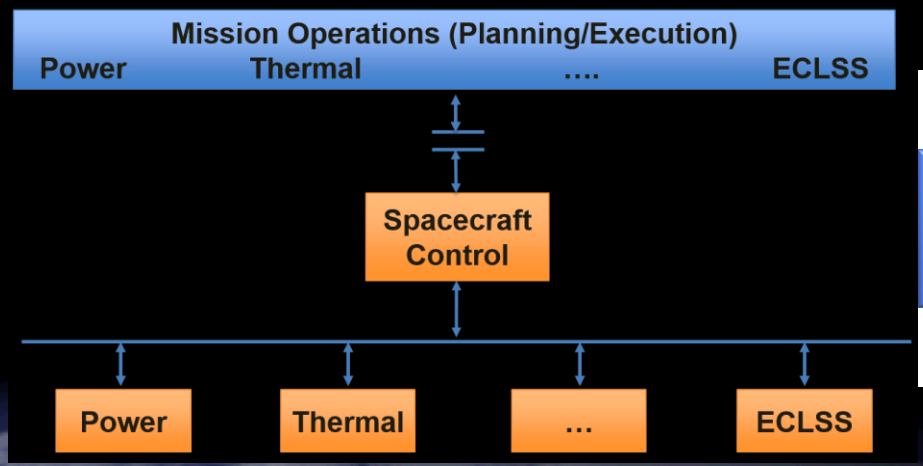
Typical Spacecraft Control Architecture



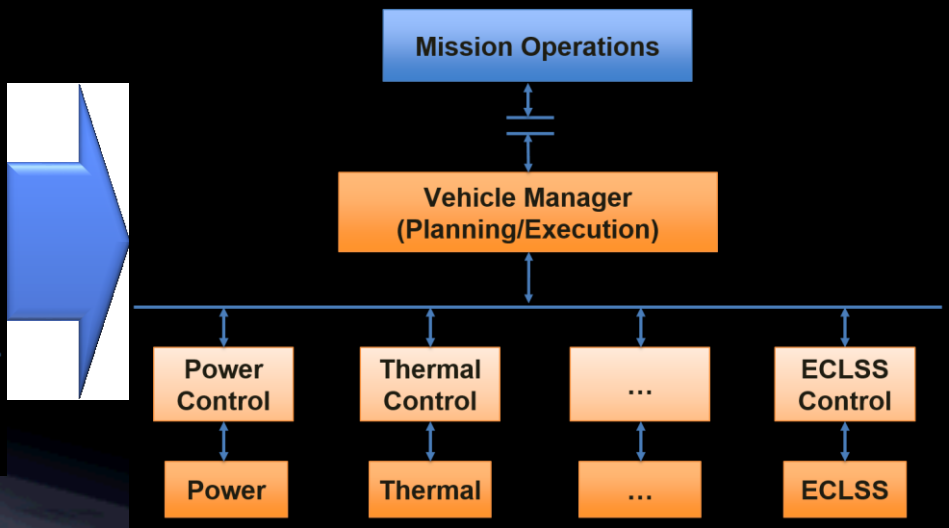
Traditional vs Autonomous Spacecraft Controller

Transition ground based control functions to the vehicle

Traditional Spacecraft Controller Architecture



Autonomous Spacecraft Controller Architecture



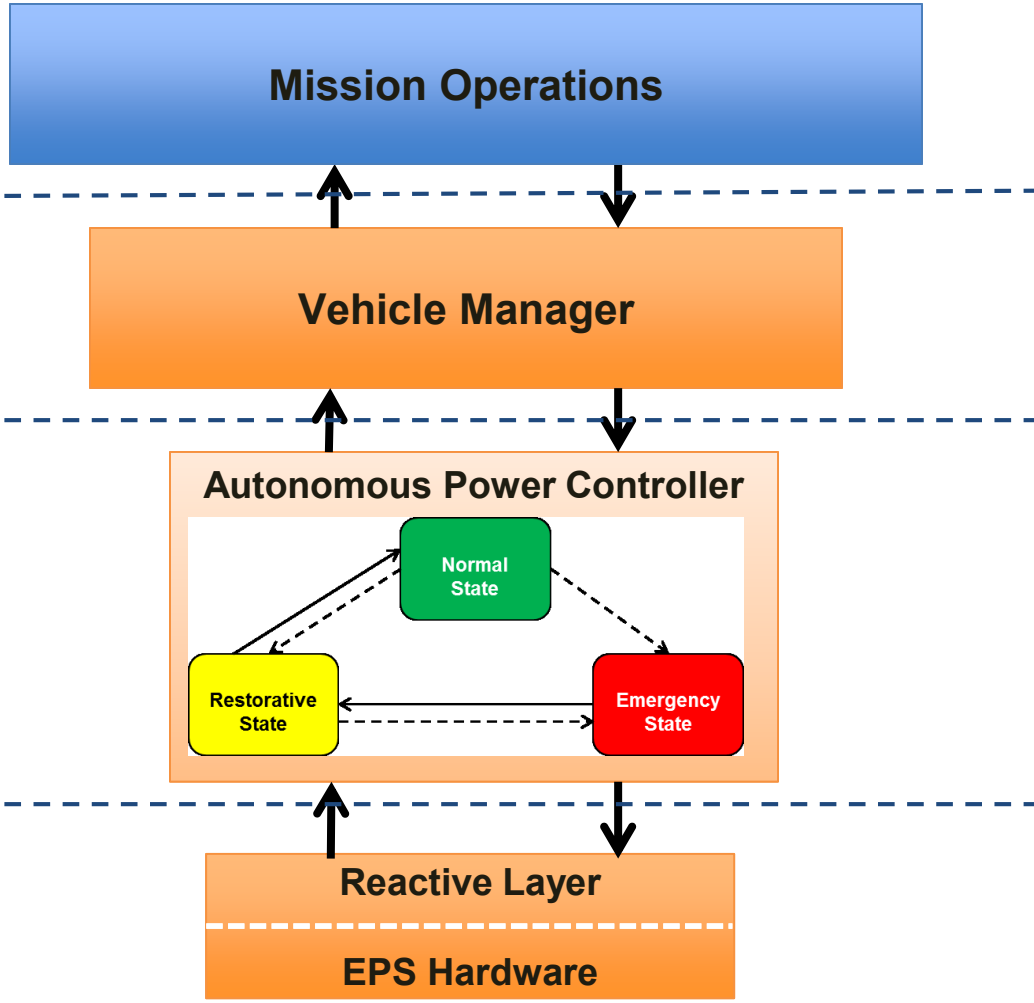
Vehicle Autonomous Power Control Architecture

Mission Operations
- Monitors vehicle operations.
- Adjusts long term mission objectives.

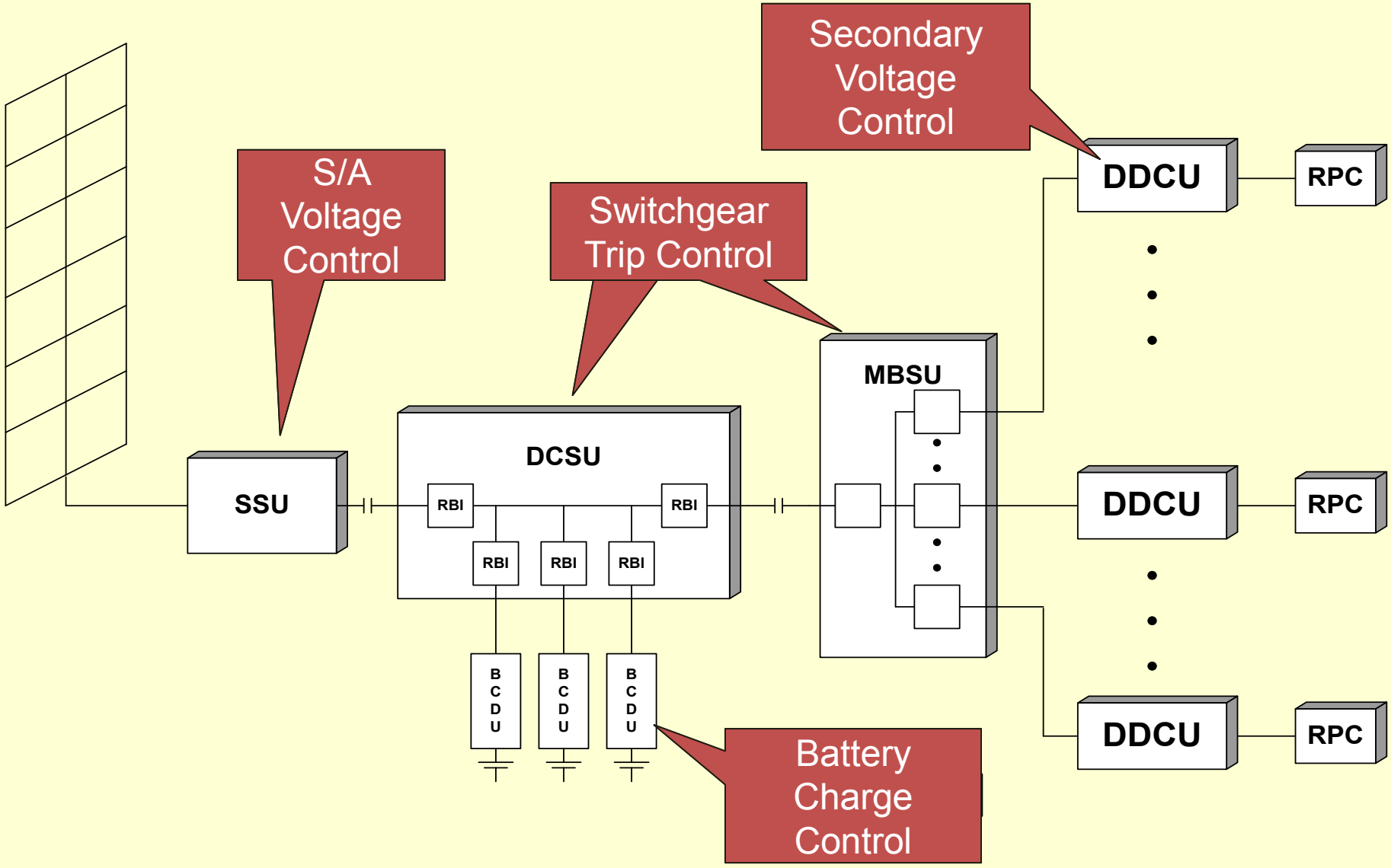
Vehicle Manager
- Plan vehicle operation(s) to achieve mission objectives (e.g. Load Schedules).
- Coordinate vehicle subsystems.

Autonomous Power Controller
- Forecast energy availability and provide power to the highest priority loads.
- Safely operate the EPS hardware.

Reactive Layer (Full Digital Control)
- Provides closed-loop control of the EPS hardware.
- Protect EPS from hard faults (safe the system).



Power System Reactive Layer Controller



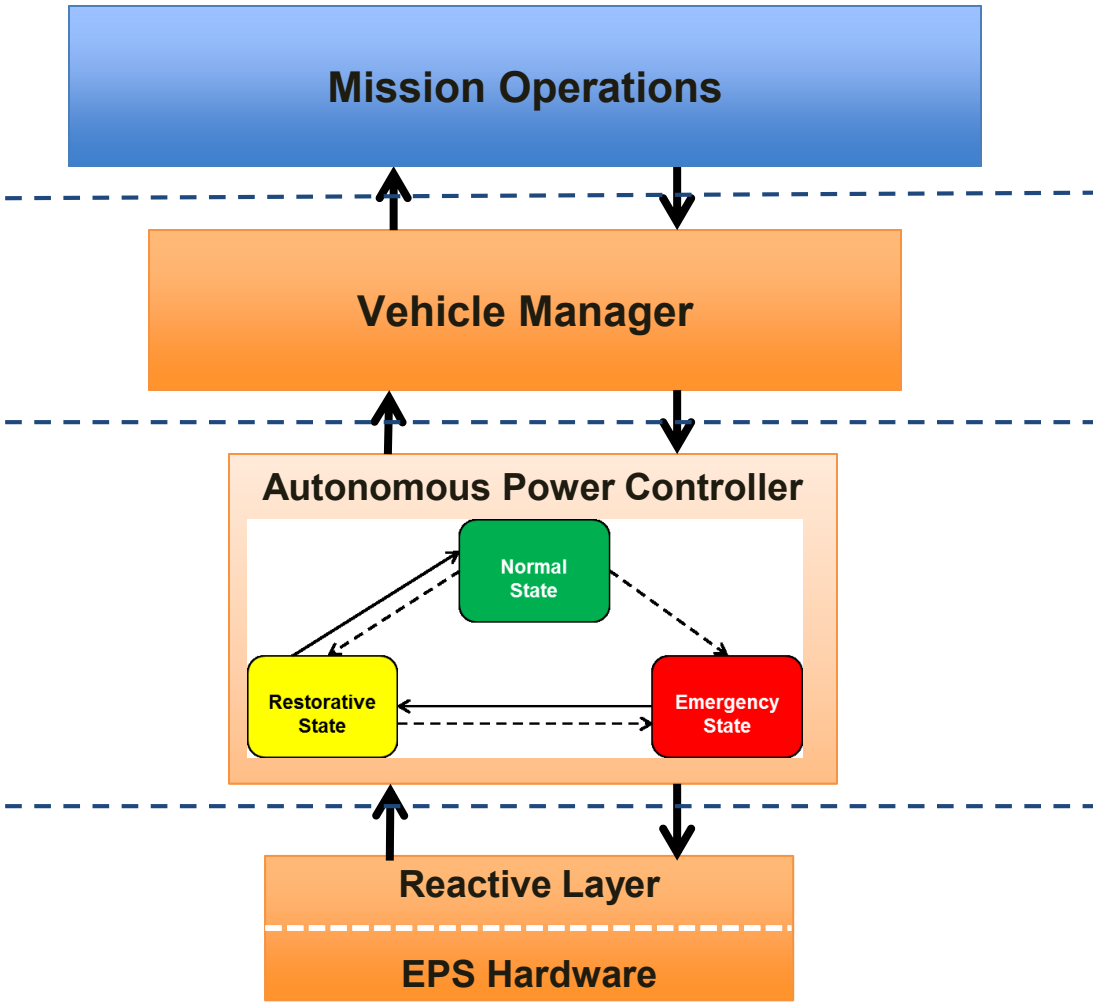
APC Normal Mode Functions

Coordinate with Vehicle Manager

- Predicts power availability
- Develop a workable load schedule
- Executes load schedule

Safely Operate EPS

- Optimizes energy utilization and distribution system utilization
- Receives data and sends configuration information to the reactive layer control
- Continuously monitors for faults within the EPS



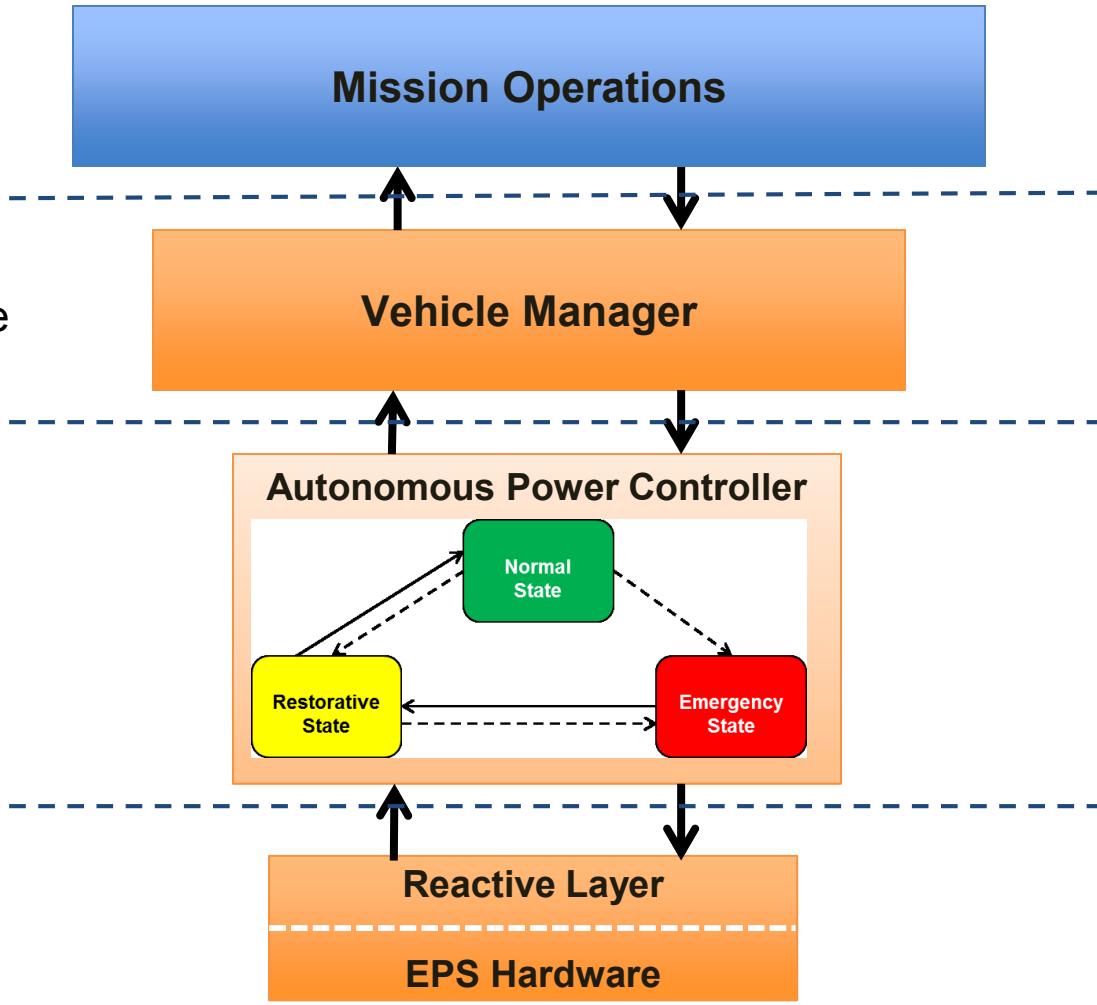
APC Failure Mode Functions

APC Response

- Safe the system (hard faults) and Identifies and reacts to other soft faults
- Develops recovery plans to optimize the servicing of the remaining loads
- Develop recovery plan
- Reports “Emergency State” to the Vehicle Manager

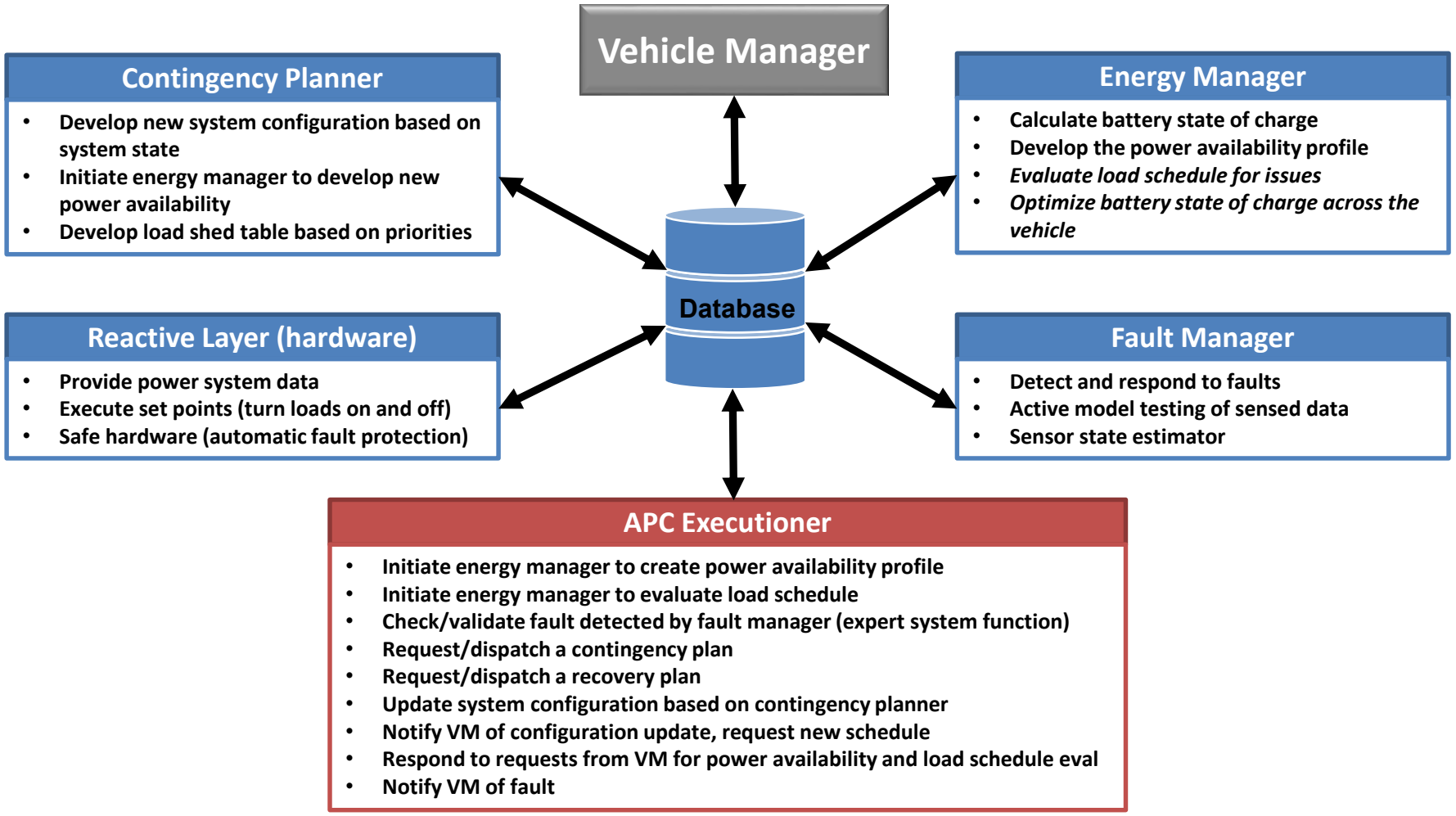
Vehicle Response

- VM develops restoration schedule based on fault information
- APC Executes the restoration schedule

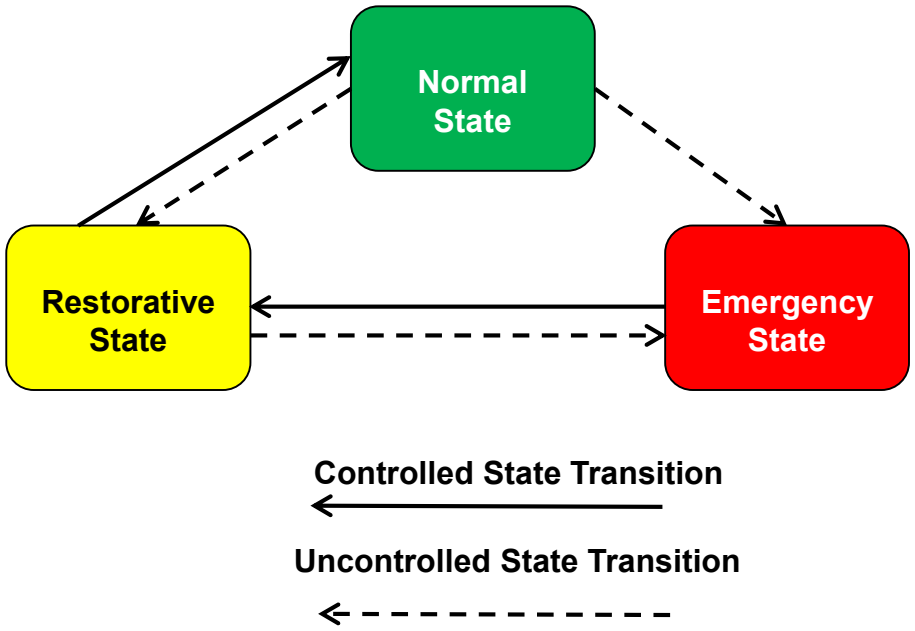


Autonomous Power Controller Development and Configuration

APC Controller Architecture



Autonomous Control State Diagram



Normal State:

- Operating properly
- Provides an energy availability and power profile
- Analyzes proposed load schedules
- With no failures, the APC could continue in the state indefinitely.

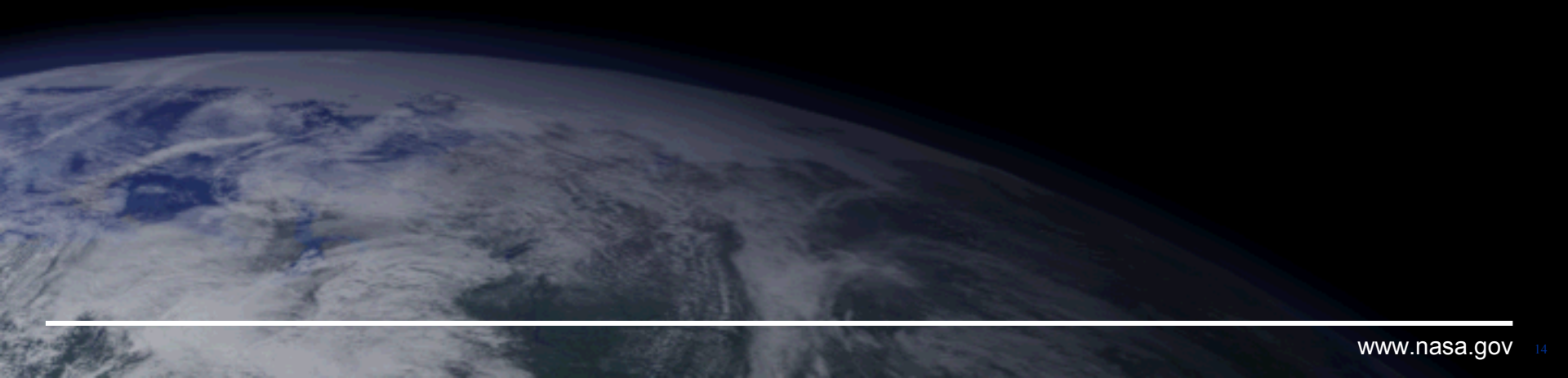
Emergency State:

- Failure has occurred in the EPS
- Reactive control will respond to any immediate faults and temporarily put the system in safe mode.
- APC reconfigures the system

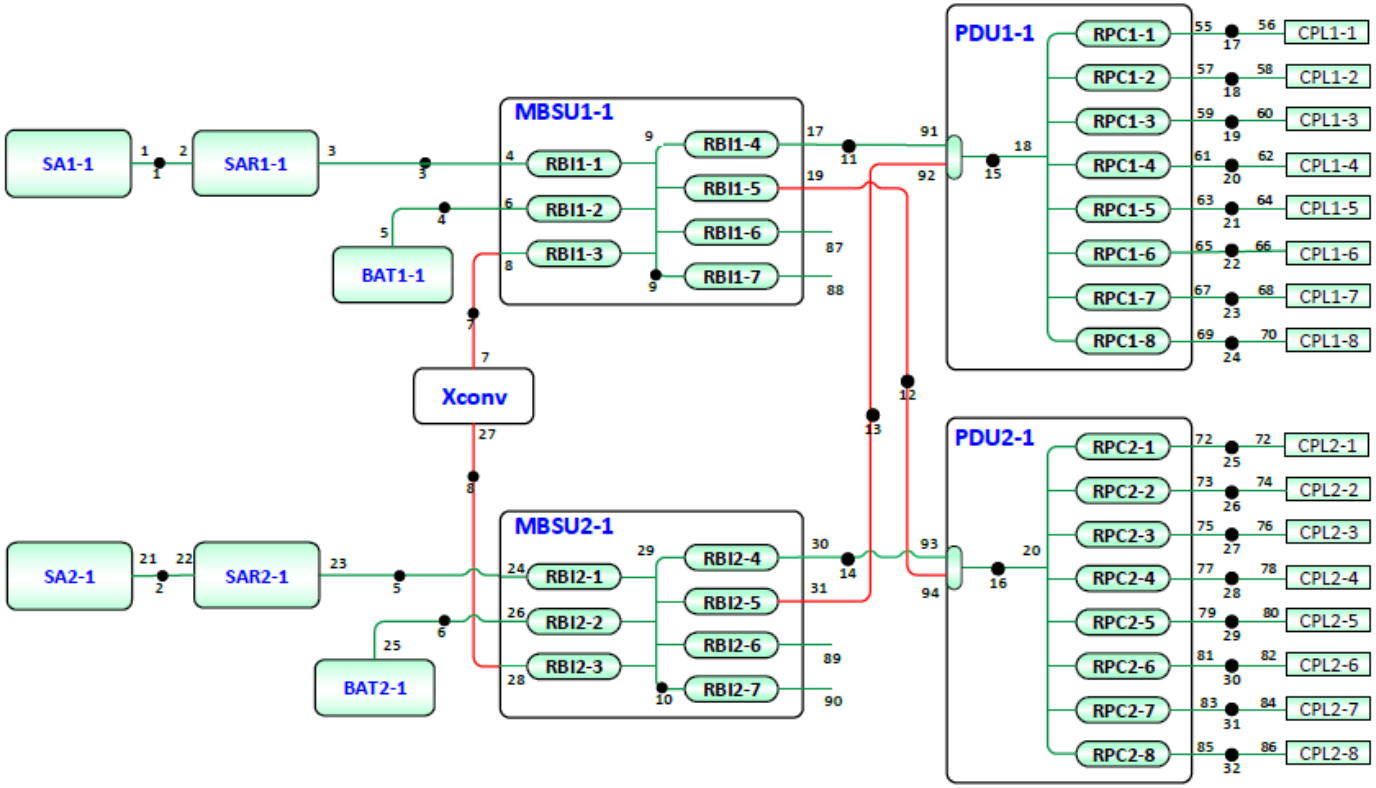
Restorative State:

- System is in a reduced power state and may not be servicing the complete normal load
- APC can perform all the operations of the normal state, with reduced power constraints.

Autonomous Power Controller Verification Approach



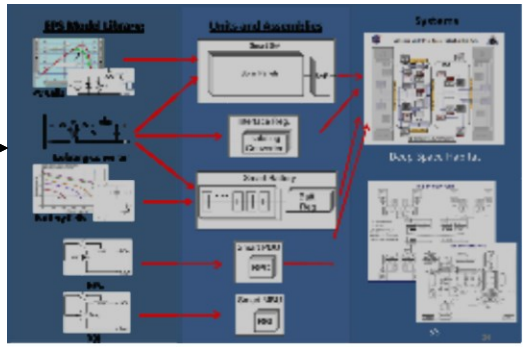
EPS 2-String System Architecture



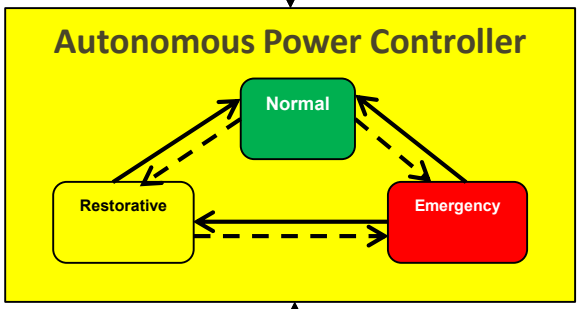
Power System Ratings	Peak	Nominal
RPC Current Rating (Amps)	4	3.2
RPC Power Rating @ 120V (kW)	0.48	0.384
PDU Current Rating (Amps)	32	24
PDU Power Rating @ 120V (kW)	3.84	2.88
Total Power to Loads (kW)	7.68	5.76

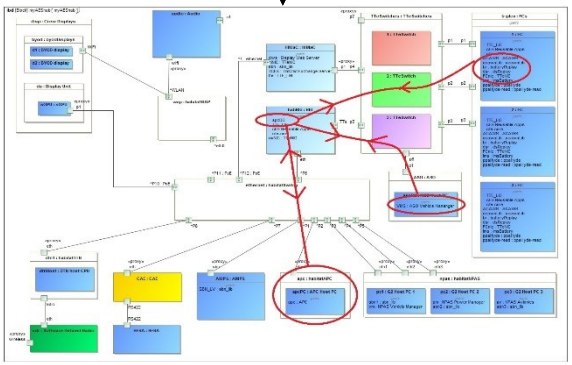
Test and Evaluation Approach

GRC Deep Space Vehicle Power System Test Bed



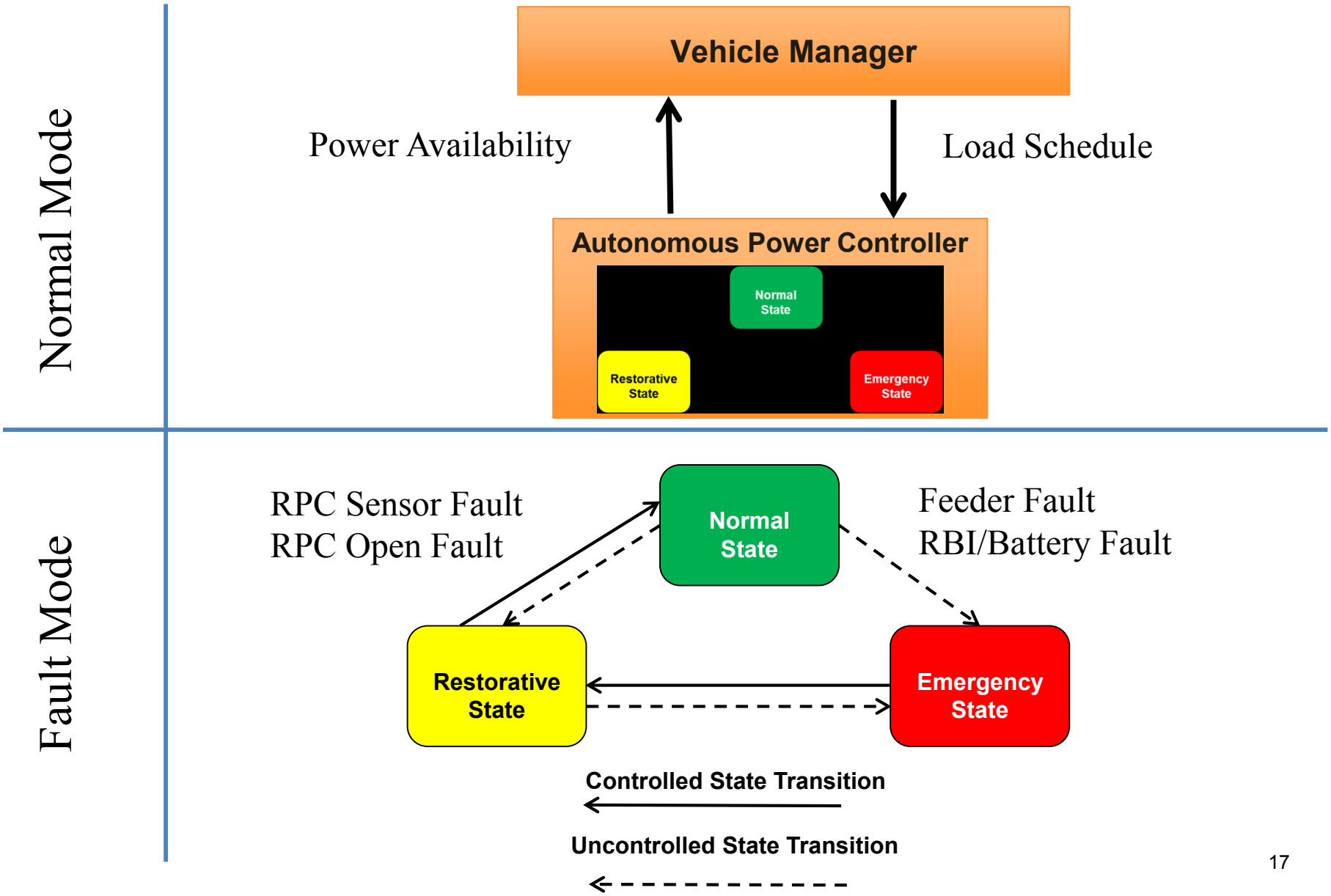
GRC Real Time Simulation



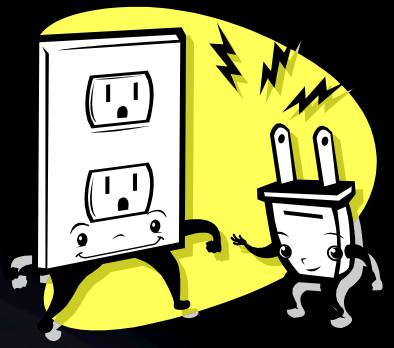


JSC iPAS Test Bed

Demonstrations



Extensions to Hybrid Electric Propulsion

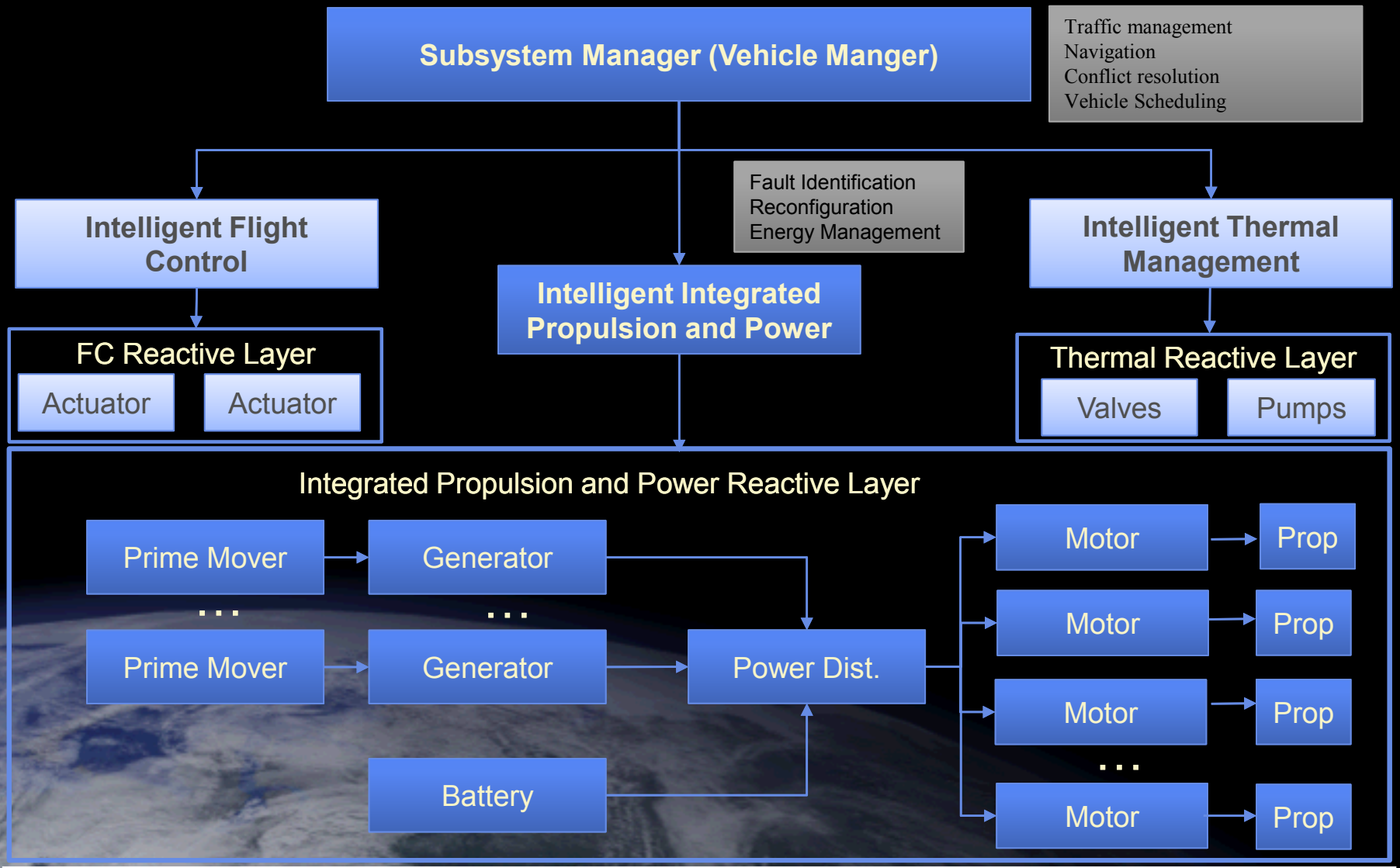


Hybrid Electric Aircraft

Hybrid Electric Aircraft have very similar needs to space vehicle power systems. Both Aero and Space Power Systems need to:

- Function autonomously for extended periods of time
- Manage distributed energy resources
- Manage loads over constrained capacity and time horizons
- Fault management
  - Guarantee that the network is safely managed
  - Detect, isolate, reconfigure and accommodate faults

Hybrid-Electric Architecture

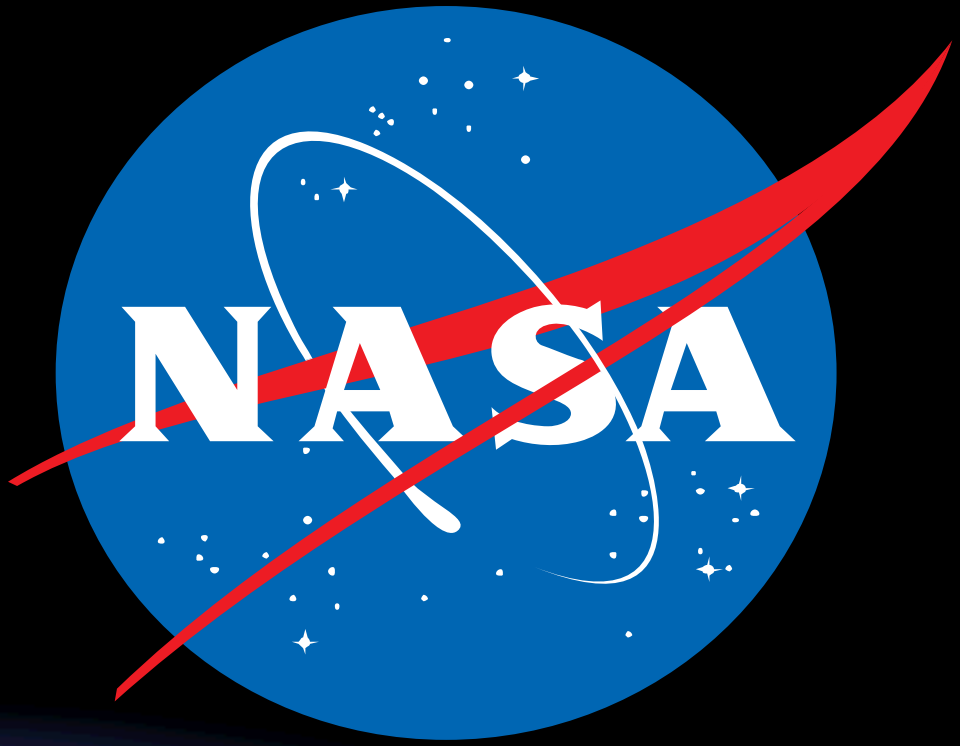


Wrap-up

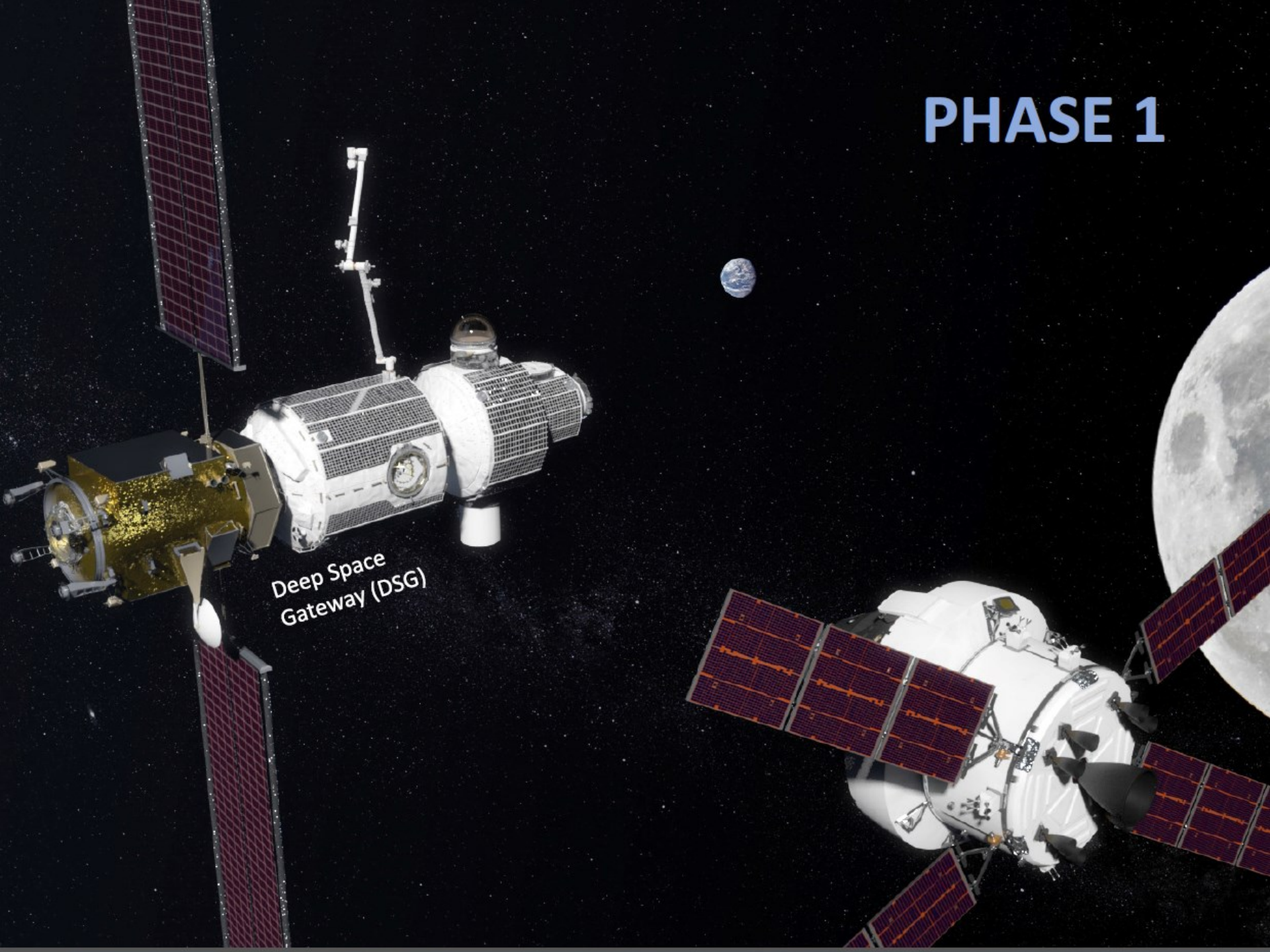
- We need Intelligent Power Systems for long term operation far from earth

- Initial autonomous power controller using real-time simulations and hardware in the loop has been demonstrated for simplified hardware configuration.

- Technology to operate proposed deep space exploration vehicles can be extended for use with Hybrid Electric Airplanes



Questions?


PHASE 1
Deep Space
Gateway (DSG)