Autonomous Power Controller For the NASA Human Deep Space Gateway

Jeffrey Csank, James Soeder, Jeffrey Follo, Matthew Muscatello, Marc Carbone, and Yu Hin {Billy} Hau
NASA Glenn Research Center
Cleveland, OH

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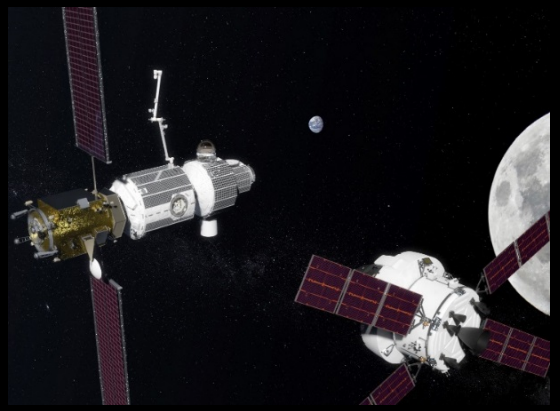
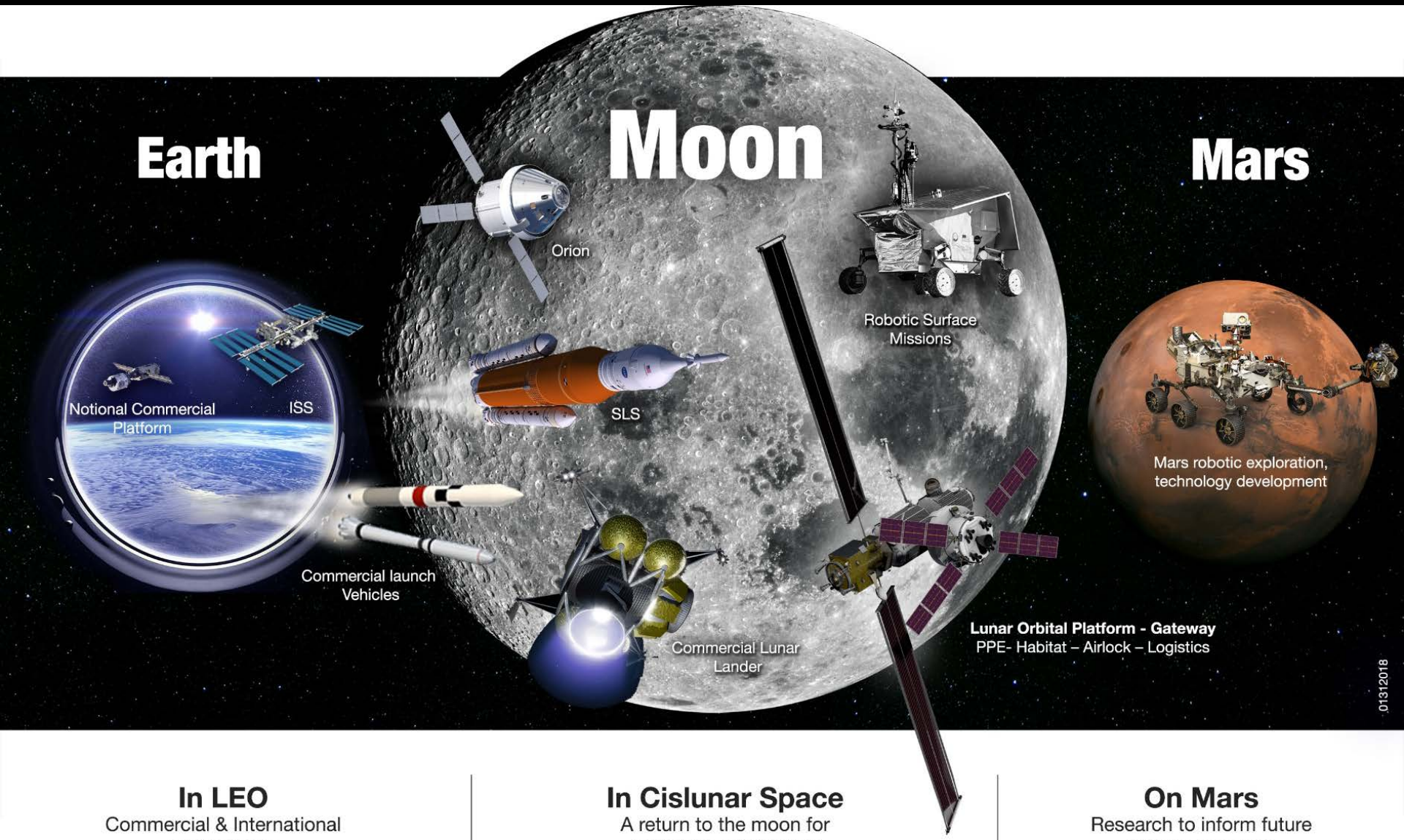
Agenda

- **Future of Human Exploration**
  - Lunar Orbiting Platform – Gateway (LOP-G)
  - Challenge of deep space human exploration



- **Autonomous Power Control**
  - What is autonomous power control
  - Autonomous power control architecture
  - Ongoing efforts in autonomy for power
  - Demonstration results

NASA's Vision of Future of Human Exploration



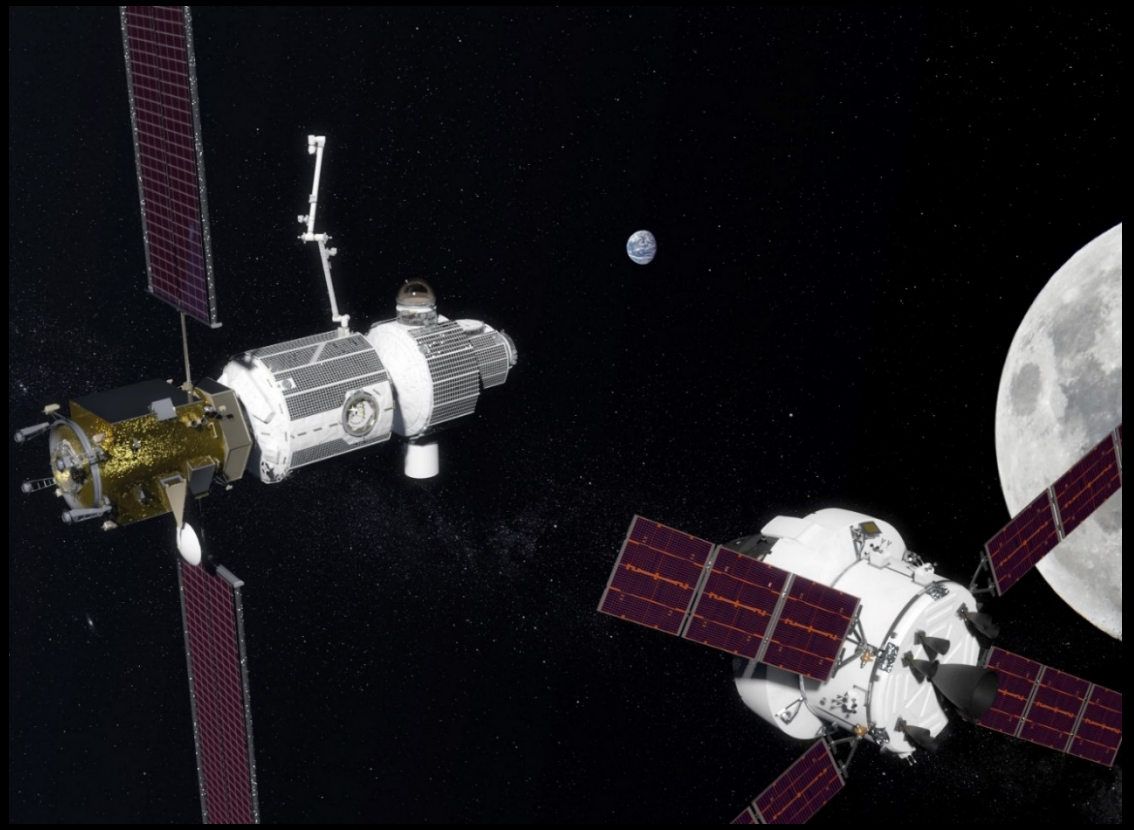
In LEO
Commercial & International partnerships

In Cislunar Space
A return to the moon for long-term exploration

On Mars
Research to inform future crewed missions

Lunar Orbiting Platform - Gateway

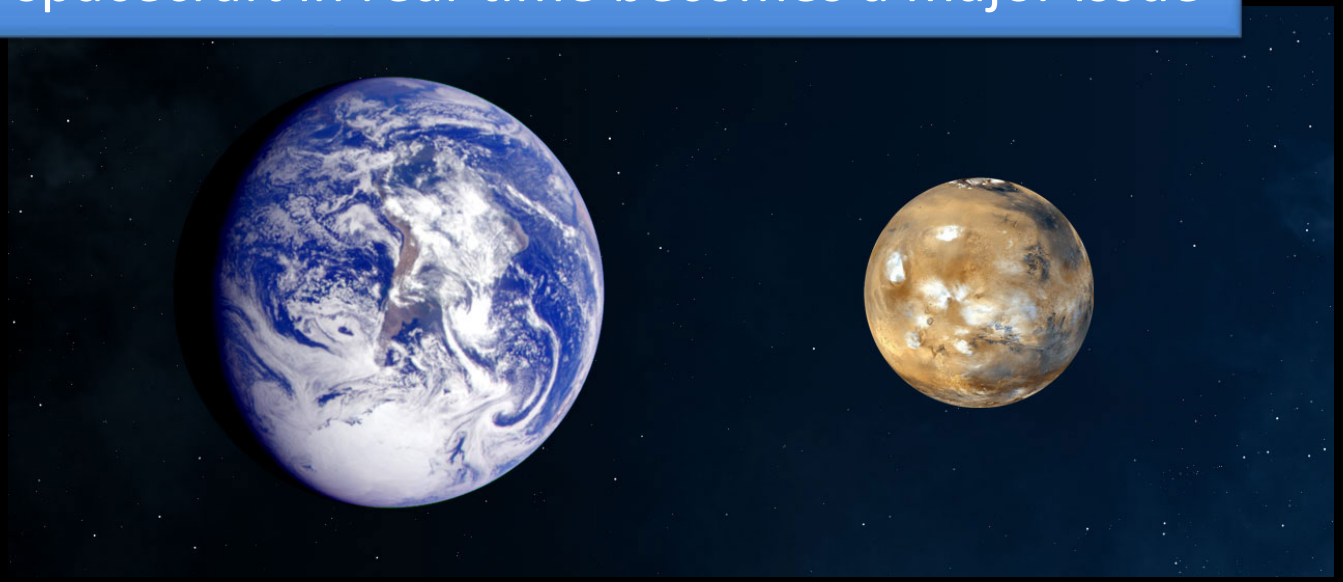
- **Docking station for deep space exploration and consists of**
  - PPE
  - Habitat
  - Airlock
- **NRHO Orbit**
  - Earth eclipses
  - Moon eclipses
- **Used as a staging ground for robotic and crewed lunar surface missions and for travel to Mars**



Human Space Exploration

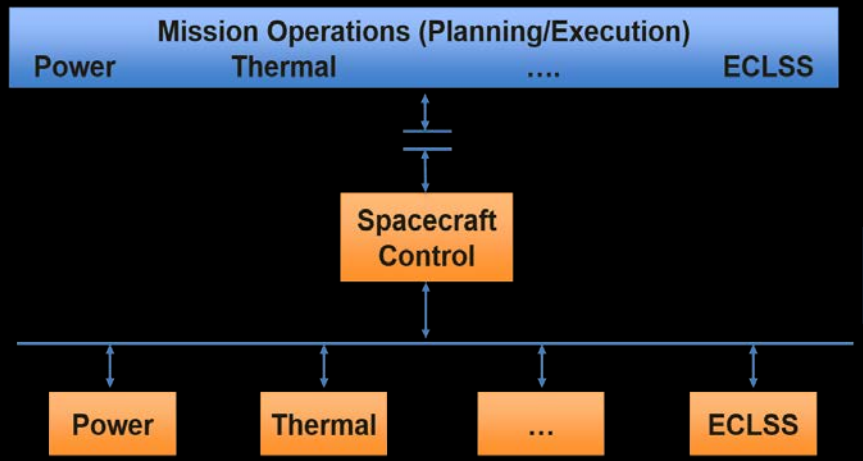
- **International Space Station (Low Earth Orbit)**
  - Distance – 71,322 km
  - One-Way Light Time – 0.24 seconds (TDRS)
- **MARS**
  - Distance 54.6 Million km to 401 Million km
  - One-Way Light Time – 3.04 min to 22.29 min

Ability to communicate and control the spacecraft in real-time becomes a major issue

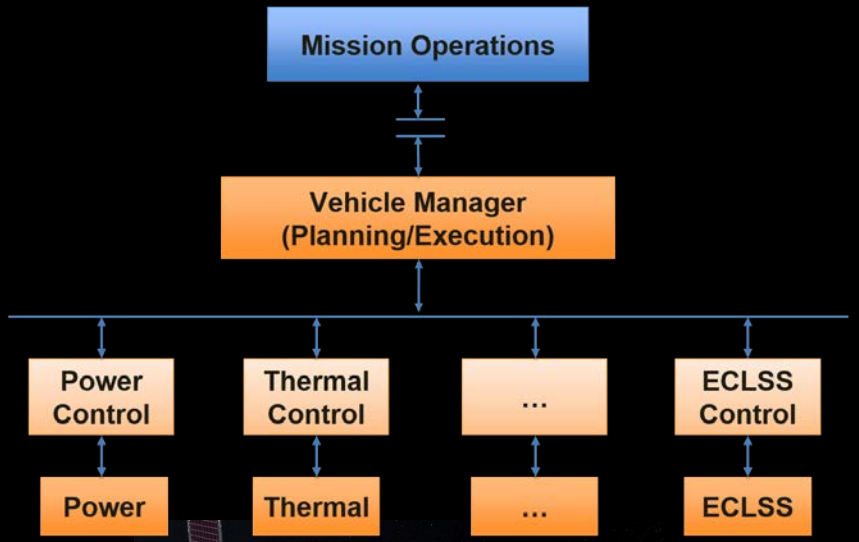


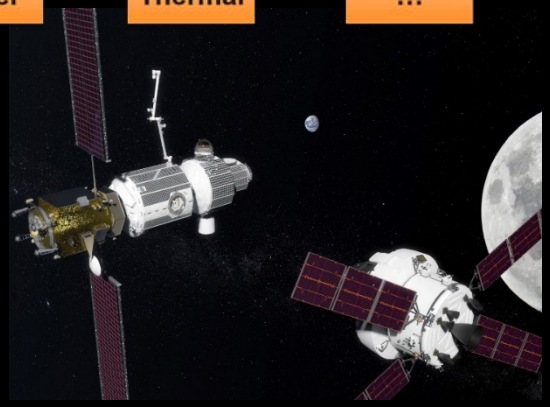
Traditional vs Autonomous Spacecraft Architecture

Traditional Spacecraft Architecture



Autonomous Spacecraft Architecture





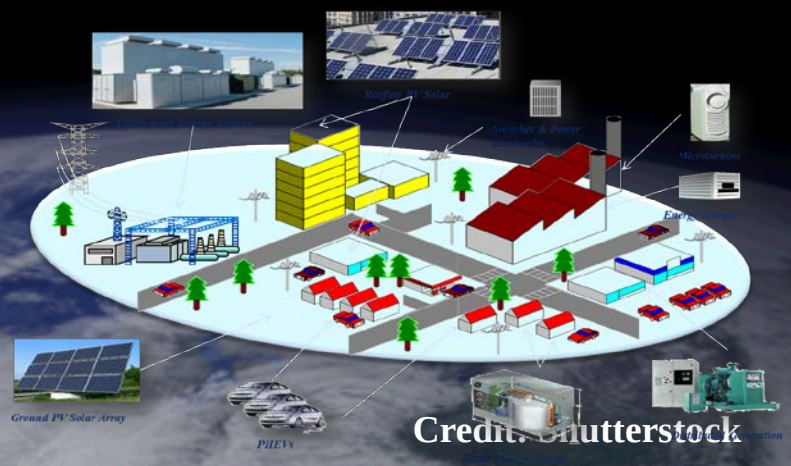
Rely on automation and autonomous systems technology to safely operate spacecraft

Autonomous Power Control

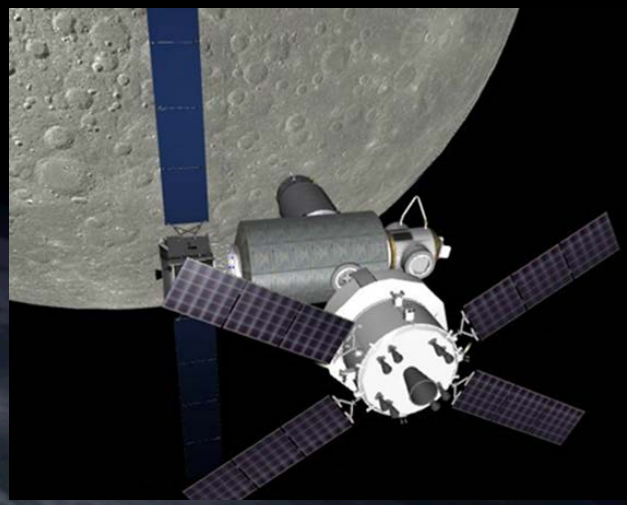
What is an Autonomous Power System?

- **Power System Needs**
  - Operate safely at all times
  - Service the highest priority loads within the constraints of the generation and distribution system
  - Permit humans to consent to any operations / actions during habitation

- **Power System Control Needs**
  - Interact with the System (Vehicle) Manager to safely execute the mission
  - Oversee/control the power system to provide desired capability without human intervention

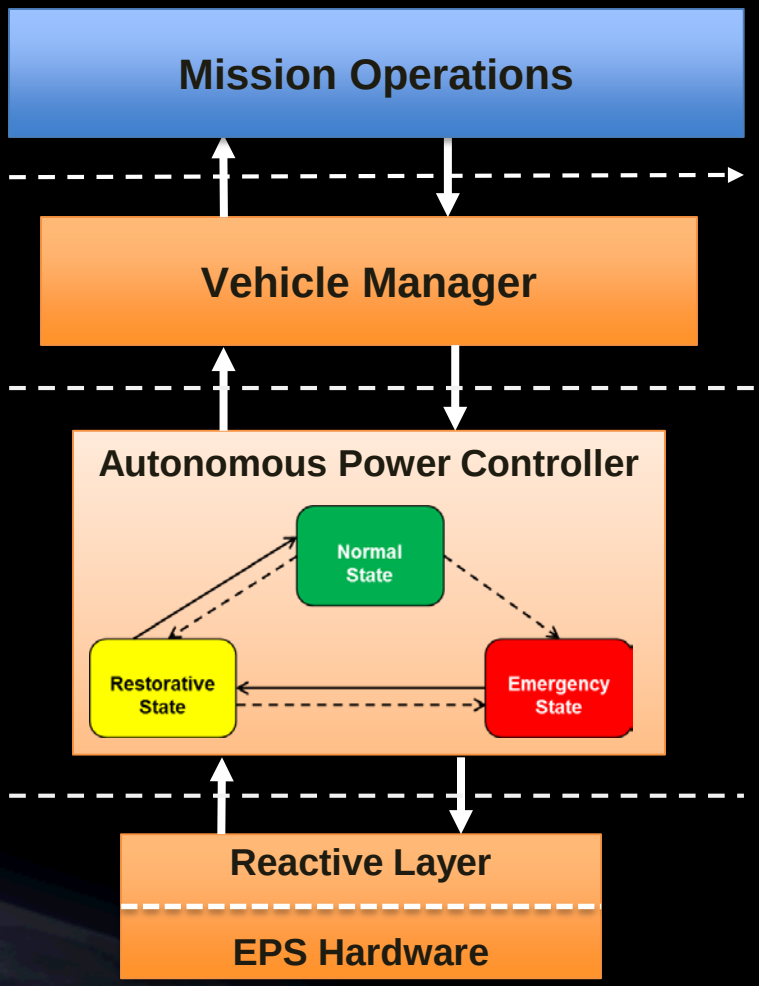


Credit: Shutterstock

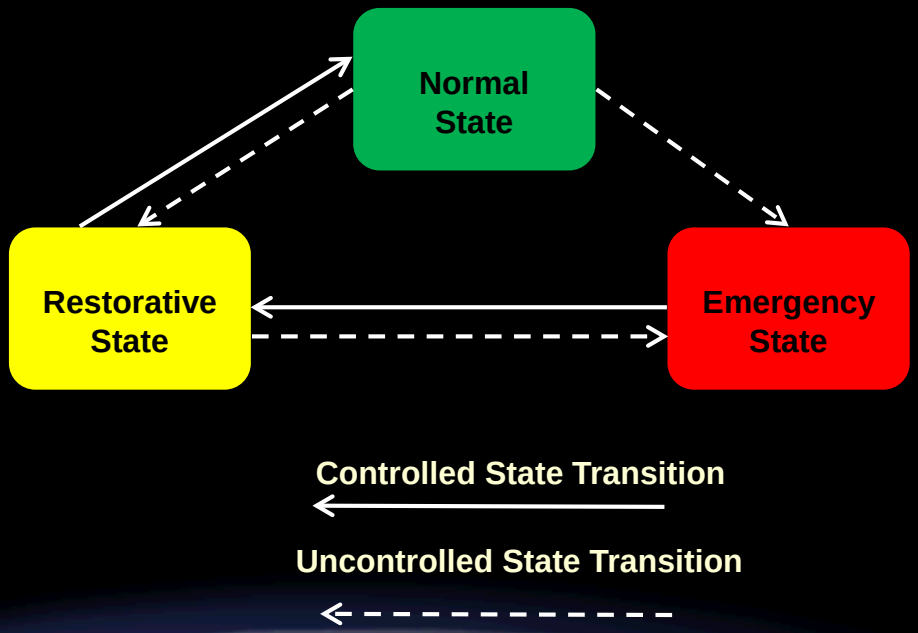


Vehicle Autonomous Power Control Architecture

- **Mission Operations**
  - Monitors vehicle operations
  - Adjusts long term mission objectives
- **Vehicle Manager**
  - Plan vehicle operation (Load Schedules, etc) to achieve mission objectives
  - 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 close-loop control of the EPS hardware
  - Protect EPS from hard faults (safe the system)



Autonomous Control State Diagram



Normal State:

- System operating properly
- Calculates and provides an energy availability and power profile
- Analyzes proposed load schedules
- With no failures, continue 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:

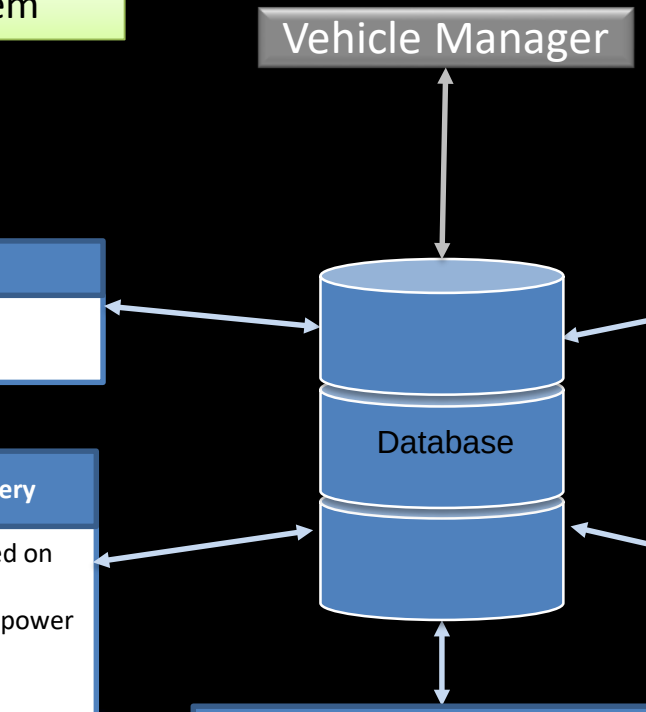
- System is in a reduced power state and may not be servicing the complete normal load
- APC can perform all the operations of the normal state, with reduced power constraints.

Autonomous Power System

Autonomous Power Controller

Electrical Power System

Note: *Future Capability*



Executioner

- Oversee operation of the APC
- Manage APC system state

Reactive Layer (Hardware)

- Provide power system data
- Execute set points
- Safe hardware (automatic fault protection for hard faults)

Maintenance, Mitigation, & Recovery

- Develop system configuration based on system state (fault)
- Shed loads based on priorities and power available
- *Planned maintenance*

Energy Management

- Predict power/energy availability into the future
- Monitor power generation and energy assets
- *Optimize battery state of charge*
- *Evaluate load schedule for issues?*

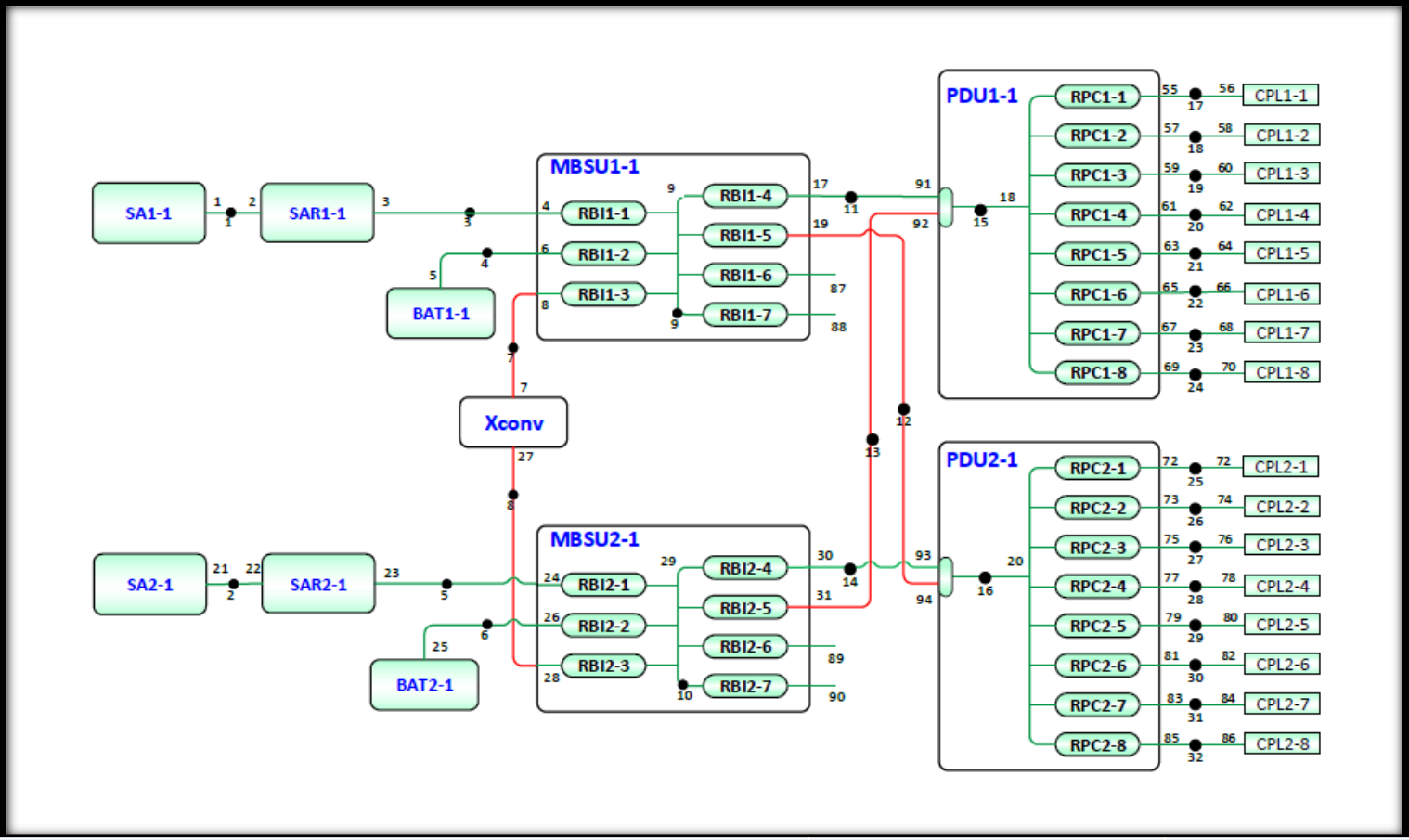
Fault Management

- Monitor and response to EPS faults
- *Distributed fault management*

- Store historical EPS data for advanced fault management
- Store current load schedule

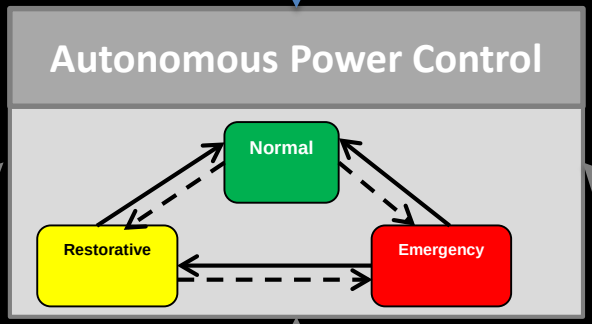
Autonomous Power Control Verification

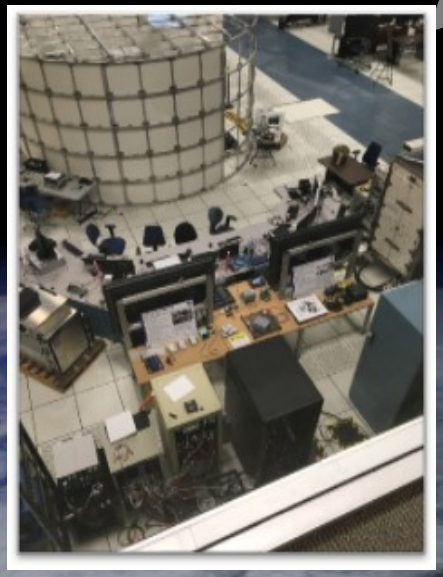
EPS 2-String System Architecture



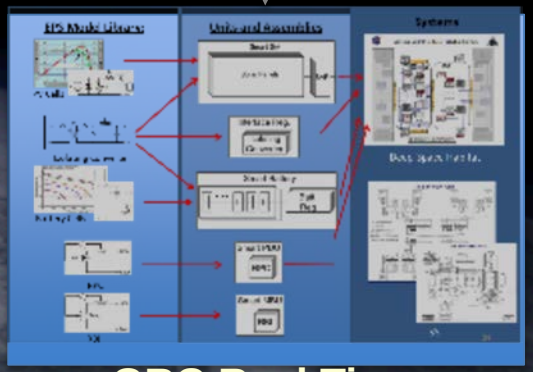
Power System Ratings	Peak	Nominal
RPC Current Rating (Amps)	4	3.2
RPC Power Rating @ 120V (kW)	0.48	0.384
PDU Current Rating (Amps)	32	24
PDU Power Rating @ 120V (kW)	3.84	2.88
Total Power to Loads (kW)	7.68	5.76

System Integration Capability





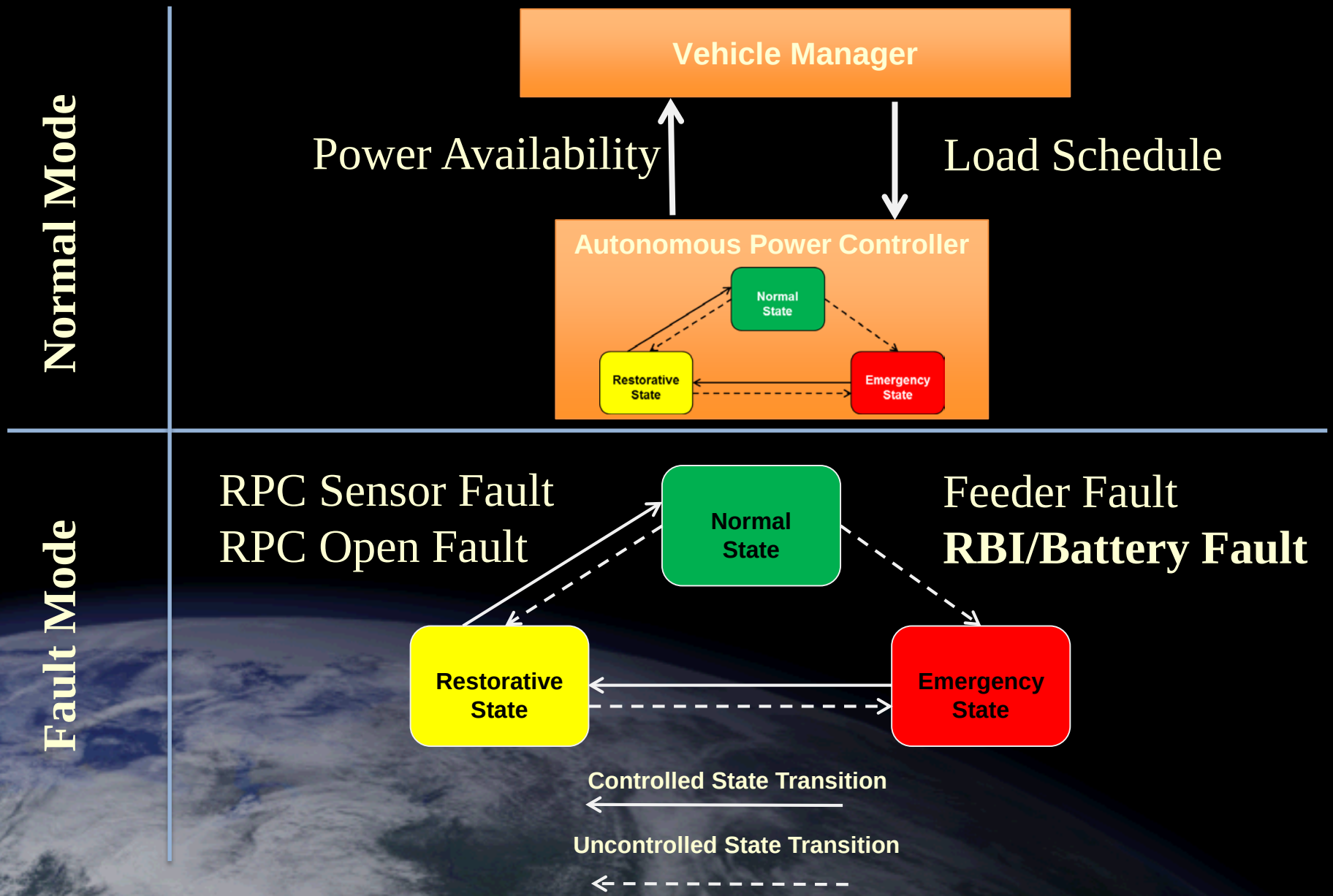
JSC iPAS Test Bed



GRC Real Time Simulation

GRC Deep Space Vehicle Power System Test Bed

Demonstrations



Normal Mode

- VM Requests Energy Availability Profile
- APC responds

time	Peak (kw)	Nominal (kw)	PDU1	PDU2
1	7.68	5.76	Null	Null
2	7.68	5.76	Null	Null
3	7.68	5.76	Null	Null
4	7.68	5.76	Null	Null
…				
24	7.68	5.76	Null	Null

Total energy (kW tu)	138.24

Normal Mode

- VM creates and proposes new load schedule
- APC analyzes and accepts new load schedule

PDU	RPC	Tu1	Tu2	Tu3	Tu4	Tu5	Tu6	Tu23	Tu24
1	1	7	0	7	0	7	0	7	0
1	2	1	1	1	1	1	1	1	1
1	3	0	7	0	7	0	7	0	7
1	4	2	2	2	2	2	2	2	2
1	5	9	9	9	9	9	9	9	9
1	6	11	11	11	11	11	11	11	11
1	7	6	6	6	6	6	6	6	6
1	8	0	0	0	0	0	0	0	0
2	1	8	0	8	0	8	0	8	0
2	2	5	5	5	5	5	5	5	5
2	3	0	8	0	8	0	8	0	8
2	4	4	4	4	4	4	4	4	4
2	5	12	12	12	12	12	12	12	12
2	6	10	10	10	10	10	10	10	10
2	7	3	3	3	3	3	3	3	3
2	8	0	0	0	0	0	0	0	0

RBI Battery Fault

- Fault inserted between Battery and MBSU. Removes 1 of 2 power sources from service.
- APC must shed loads

PDU	RPC	Tu1	Tu2	Tu3	Tu4	Tu5	Tu6	Tu23	Tu24
1	1	7	0	7	0	7	0	7	0
1	2	1	1	1	1	1	1	1	1
1	3	0	7	0	7	0	7	0	7
1	4	2	2	2	2	2	2	2	2
1	5	9	9	9	9	9	9	9	9
1	6	11	11	11	11	11	11	11	11
1	7	6	6	6	6	6	6	6	6
1	8	0	0	0	0	0	0	0	0
2	1	8	0	8	0	8	0	8	0
2	2	5	5	5	5	5	5	5	5
2	3	0	8	0	8	0	8	0	8
2	4	4	4	4	4	4	4	4	4
2	5	12	12	12	12	12	12	12	12
2	6	10	10	10	10	10	10	10	10
2	7	3	3	3	3	3	3	3	3
2	8	0	0	0	0	0	0	0	0

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1	2	1	1	1	1	1	1	1	1
1	3	0	7	0	7	0	7	0	7
1	4	2	2	2	2	2	2	2	2
1	5	9	9	9	9	9	9	9	9
1	6	11	11	11	11	11	11	11	11
1	7	6	6	6	6	6	6	6	6
1	8	0	0	0	0	0	0	0	0
2	1	8	0	8	0	8	0	8	0
2	2	5	5	5	5	5	5	5	5
2	3	0	8	0	8	0	8	0	8
2	4	4	4	4	4	4	4	4	4
2	5	12	12	12	12	12	12	12	12
2	6	10	10	10	10	10	10	10	10
2	7	3	3	3	3	3	3	3	3
2	8	0	0	0	0	0	0	0	0

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1	2	1	1	1	1	1	1	1	1
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1	5	9	9	9	9	9	9	9	9
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1	8	0	0	0	0	0	0	0	0
2	1	8	0	8	0	8	0	8	0
2	2	5	5	5	5	5	5	5	5
2	3	0	8	0	8	0	8	0	8
2	4	4	4	4	4	4	4	4	4
2	5	12	12	12	12	12	12	12	12
2	6	10	10	10	10	10	10	10	10
2	7	3	3	3	3	3	3	3	3
2	8	0	0	0	0	0	0	0	0

RBI Battery Fault Response

- Send VM updated energy profile.
- VM creates and proposes a new load schedule

time	Peak (kw)	Nominal (kw)	PDU1	PDU2
1	7.68	2.88	Null	Null
2	7.68	2.88	Null	Null
3	7.68	2.88	Null	Null
4	7.68	2.88	Null	Null
…				
24	7.68	2.88	Null	Null

Total energy (kW tu)	69.12

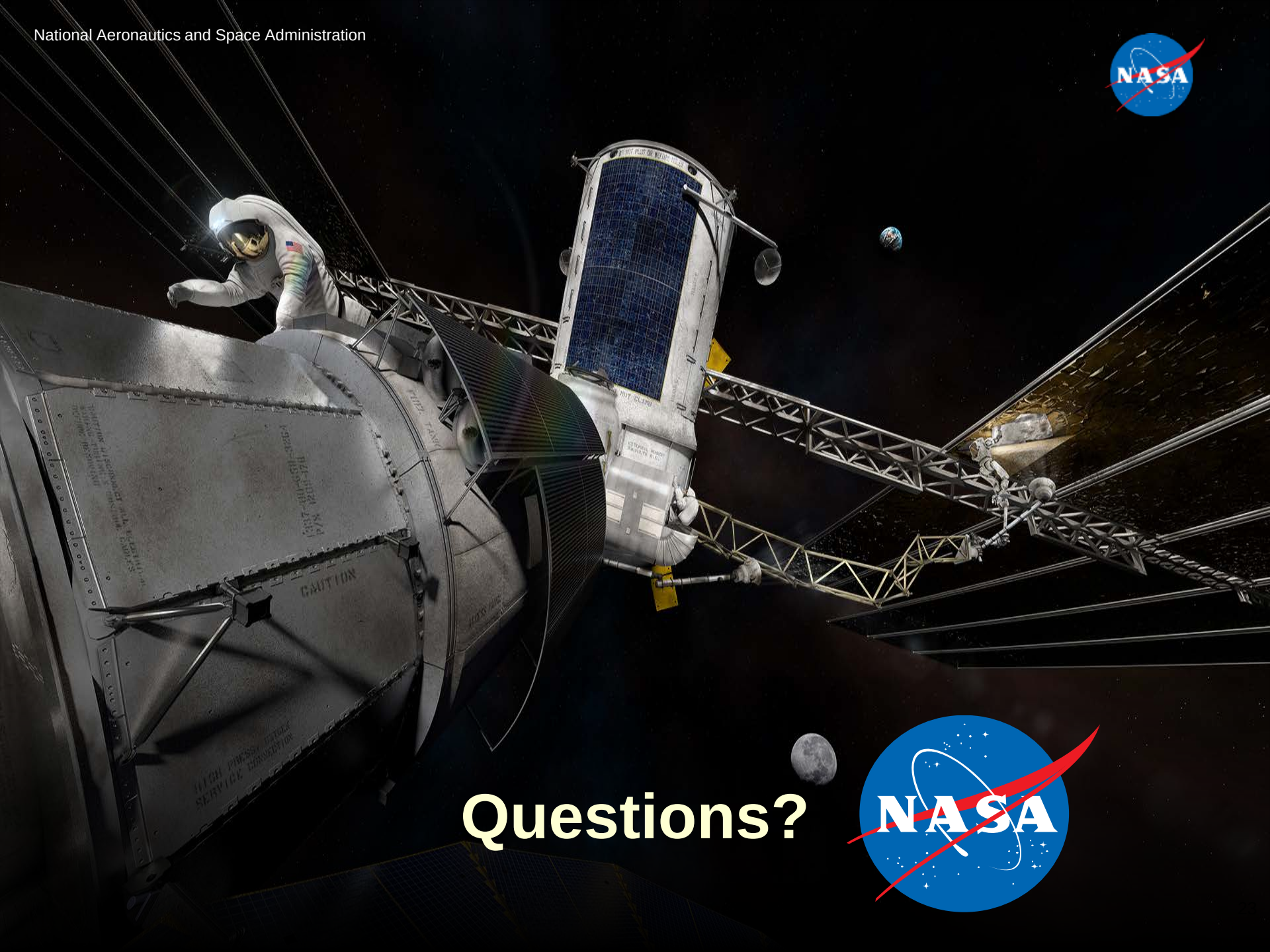
Conclusion

•Intelligent Power Systems capability is required for long term operation far from earth

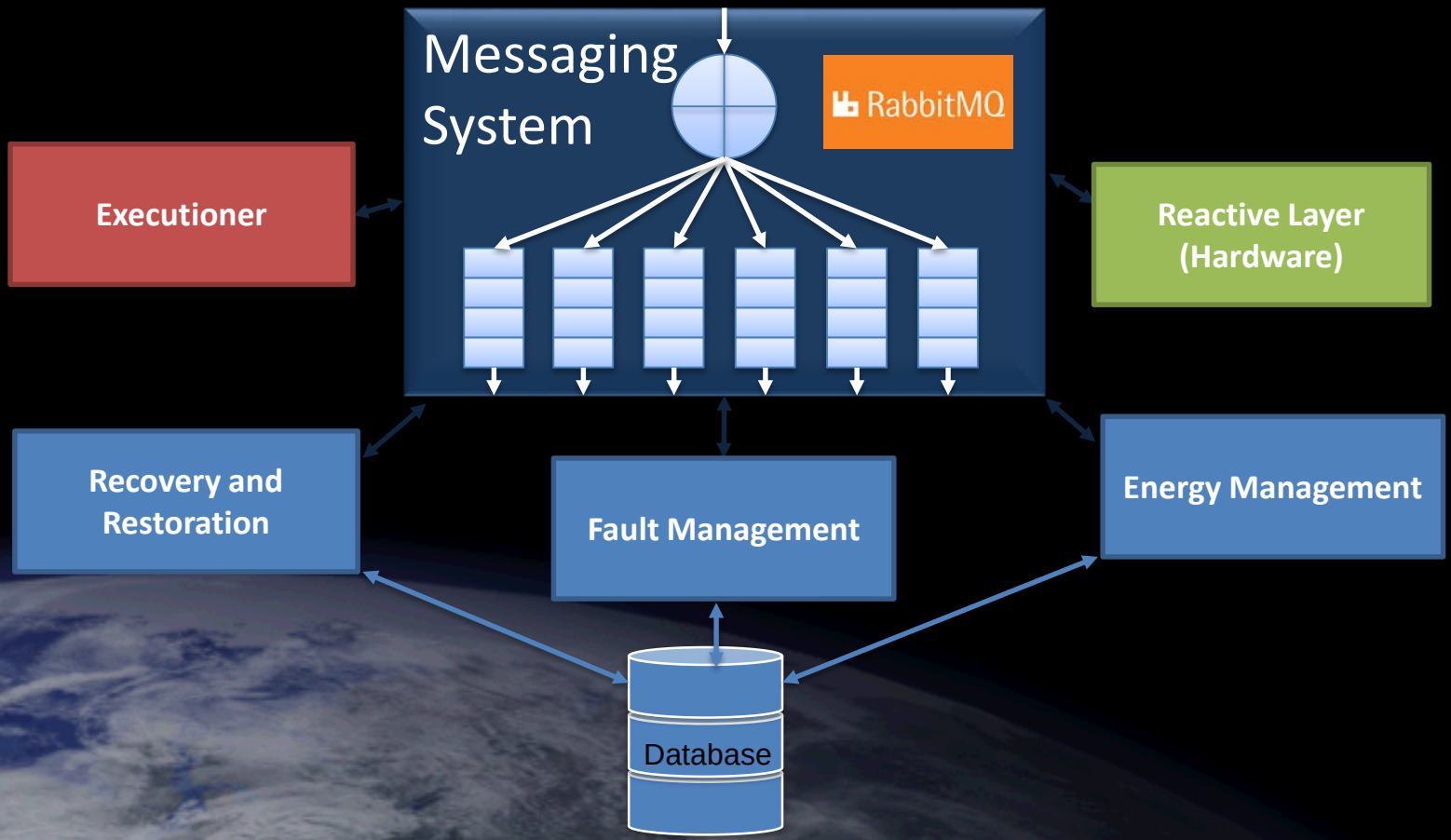
• Initial autonomous power controller using real-time simulations and hardware in the loop has been demonstrated for simplified hardware configuration.

• Technology to operate proposed deep space exploration vehicles can be extended for use with Hybrid Electric Airplanes and operating micro-grids.

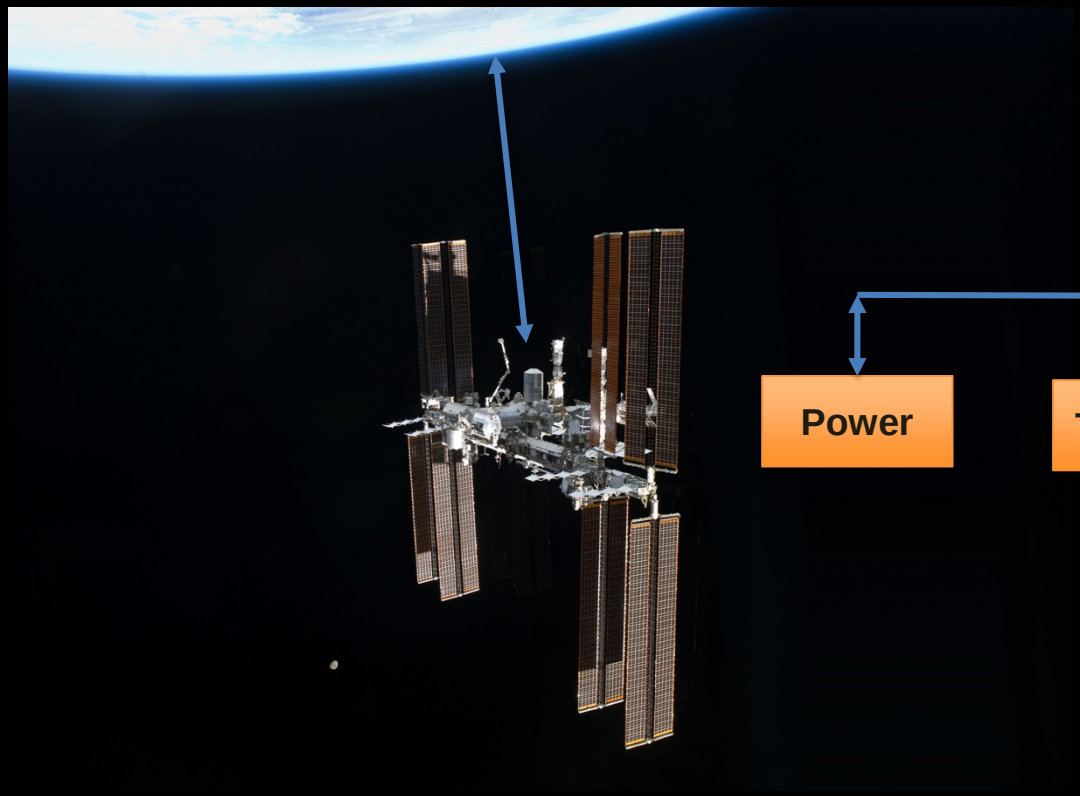
National Aeronautics and Space Administration

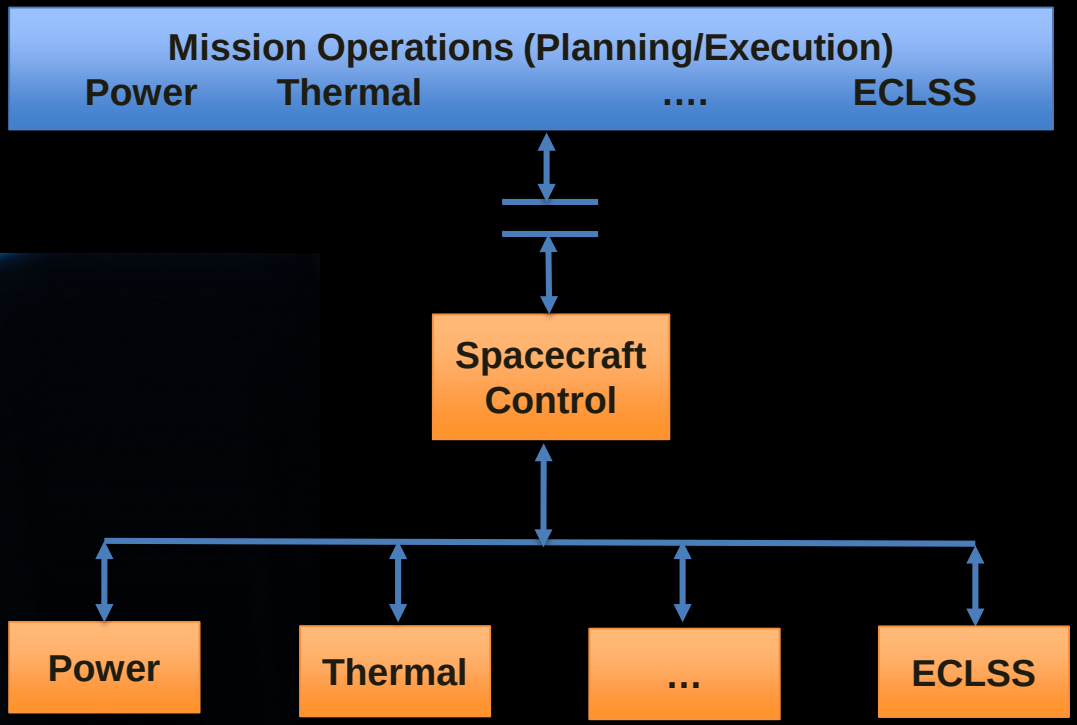


Autonomous Power Control Architecture (Conceptual)



Typical Spacecraft Control Architecture





Autonomous Power System (Conceptual)

Autonomous Power Controller

Electrical Power System

Note: *Future Capability*