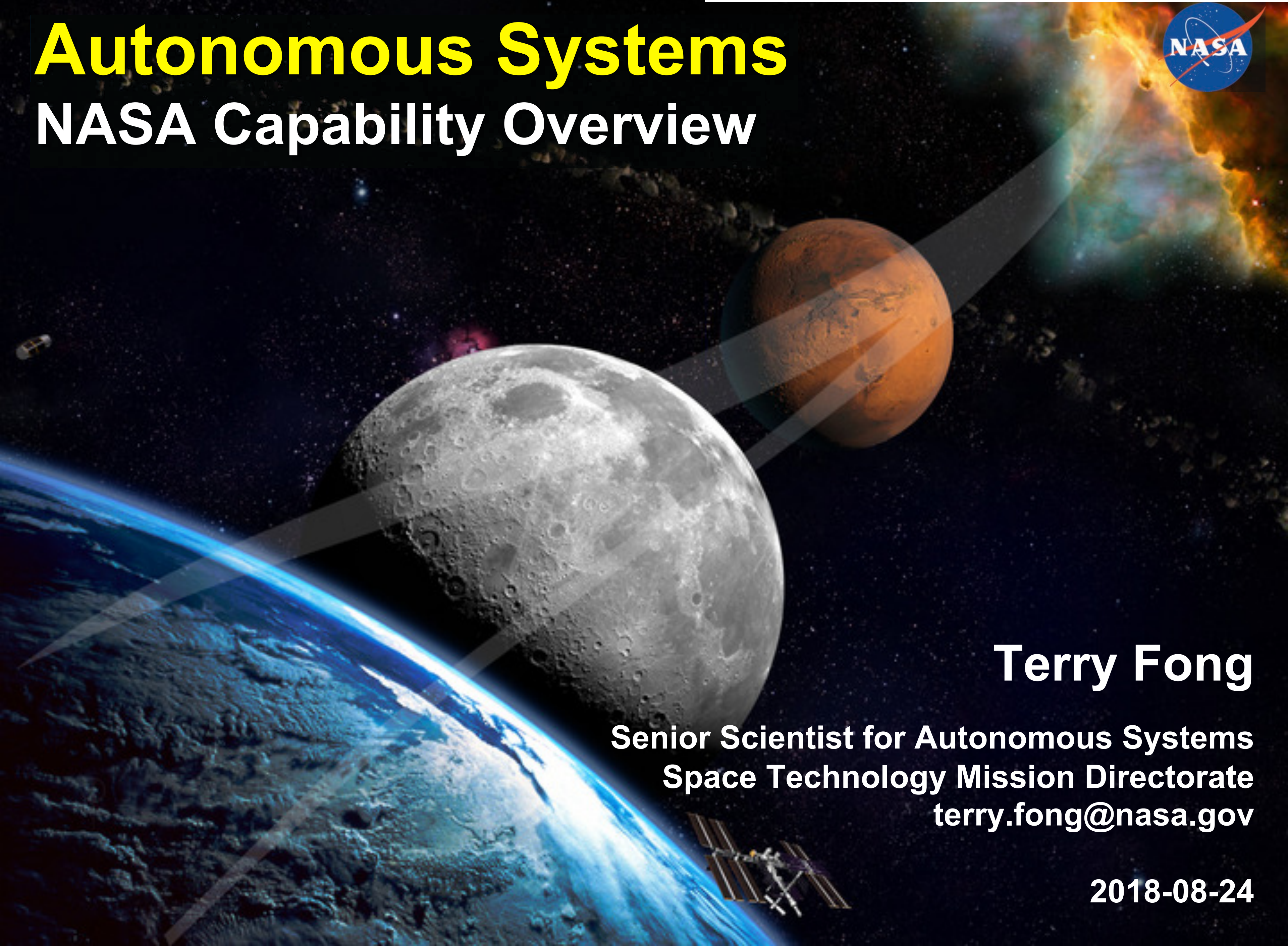
Autonomous Systems
NASA Capability Overview



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Autonomous Systems SCLT

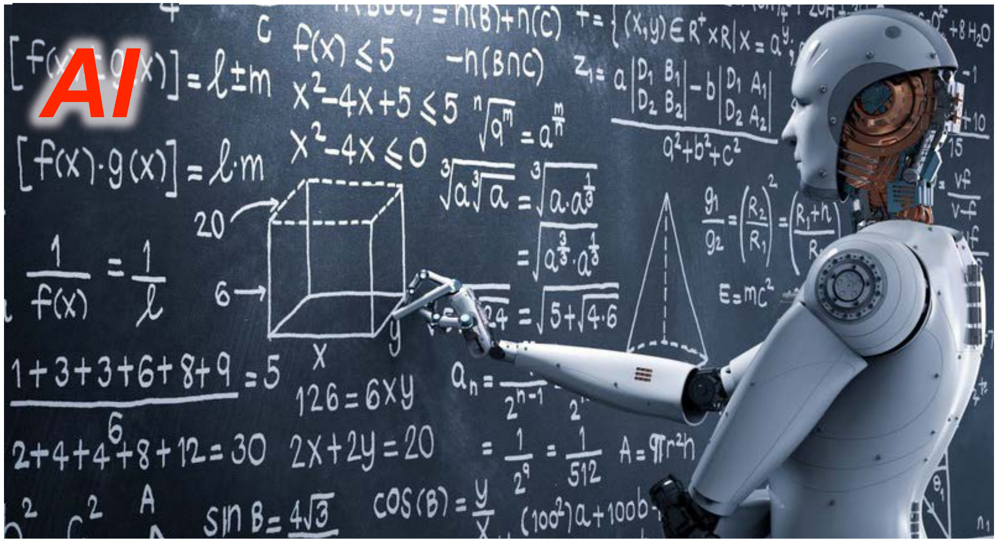
Systems Capability Leadership Team

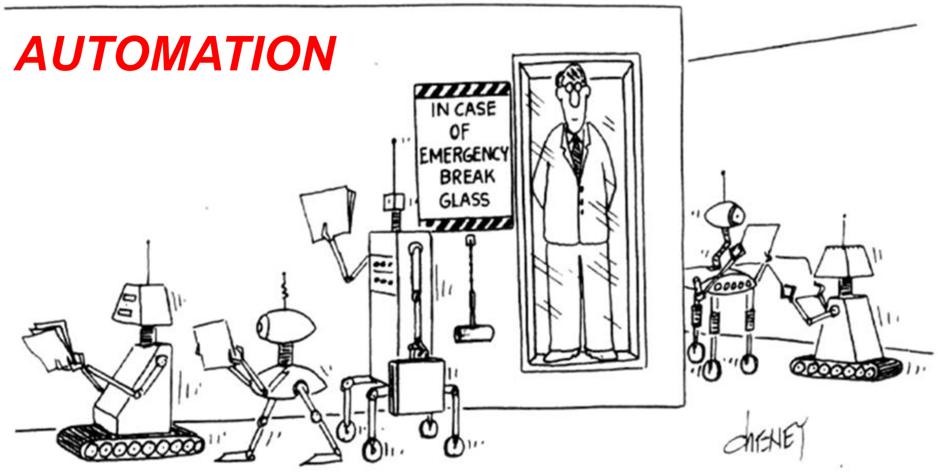
- Serve as a **community of practice** in autonomous systems
- **Identify barriers** that impact the development and infusion of autonomy capabilities into mission systems
- Identify and **assess the NASA workforce** and facilities needed to advance autonomous systems
- **Recommend research and development** in autonomous systems technology for NASA
- **Recommend investment/divestment** to improve the use of autonomous systems in aeronautics (ARMD), human exploration (HEOMD), science (SMD), and space technology (STMD)

Structure

- Lead: **Terry Fong** (STMD)
- Deputy: **Danette Allen** (LaRC)
- Members (34): Center SMEs, (S)CLT leads, Mission Directorate reps

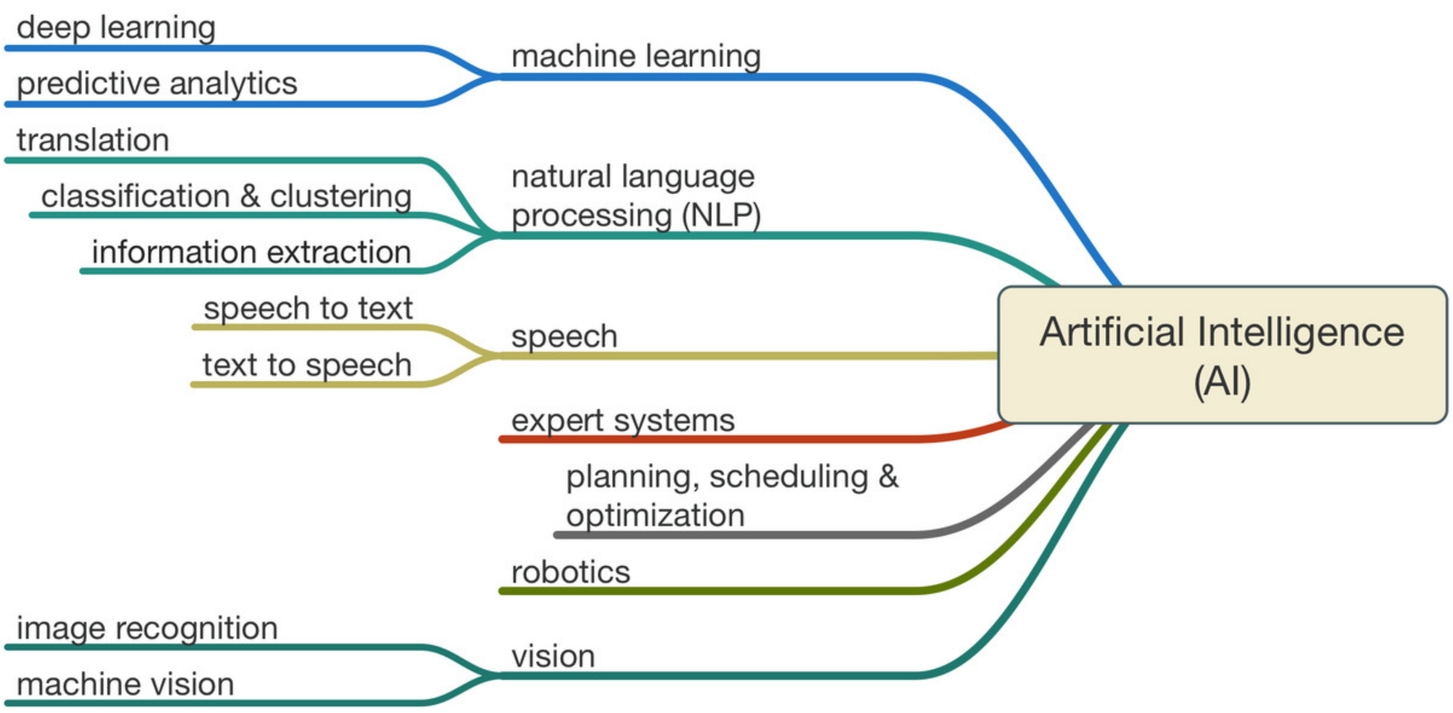
AI, Automation, and Autonomy





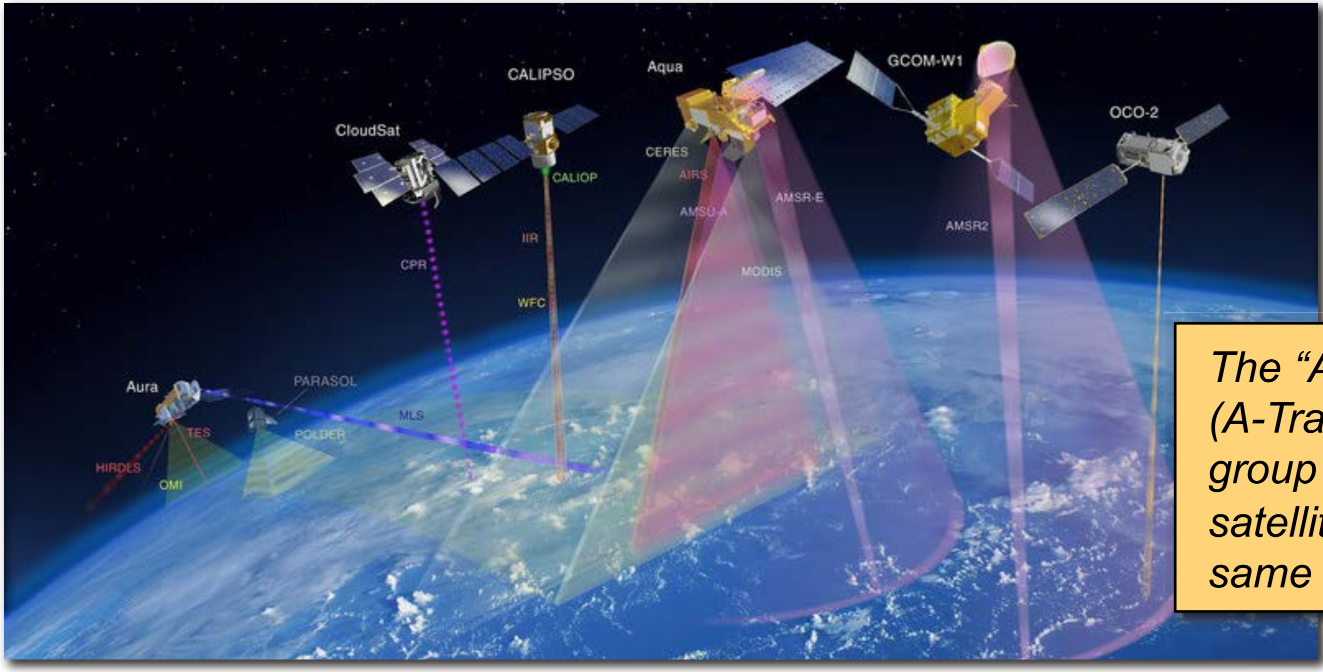
Artificial Intelligence (AI)

- **AI does NOT have a single, simple, universally accepted definition.**
- AI is the "capability of computer systems to perform tasks that normally require human intelligence (e.g., perception, conversation, decision-making." – *Defense Science Board 2016*
- AI encompasses **many technologies** and **many applications**:



Automation

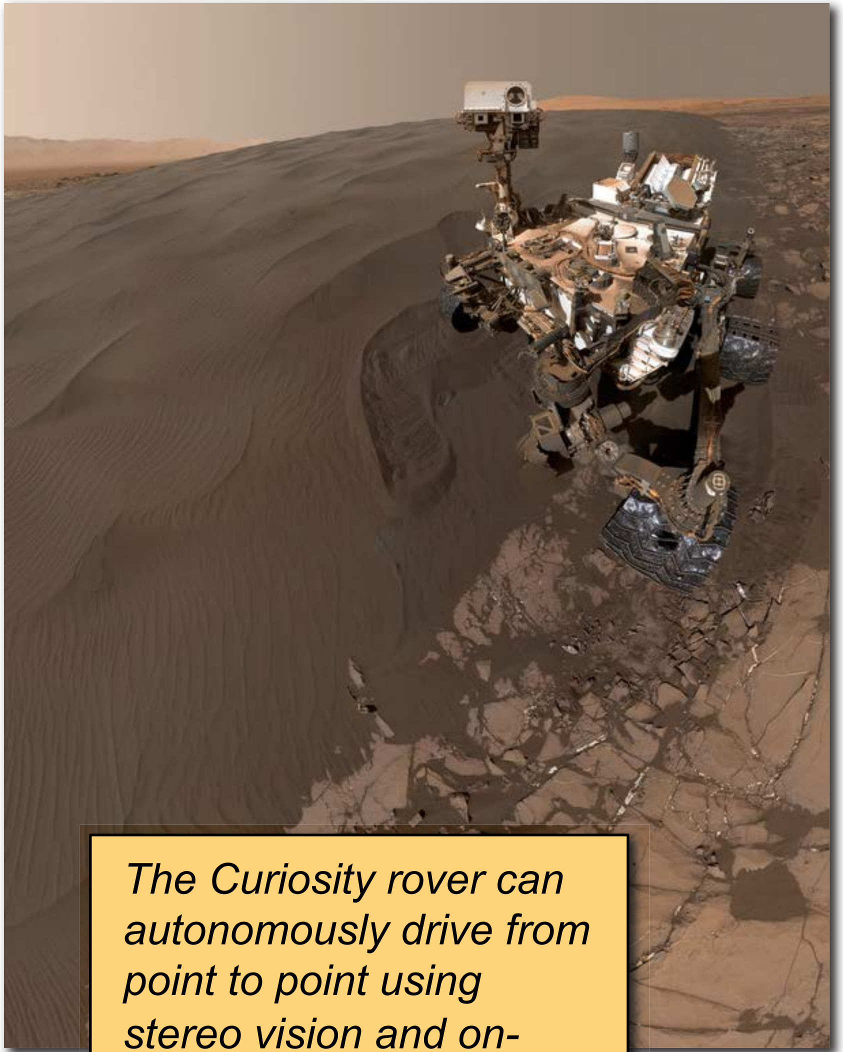
- **Automation is the automatically-controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor** – *Merriam-Webster*
- Automation is not “self-directed”, but instead requires command and control (e.g., a pre-planned set of instructions)
- A system can be automated without being autonomous



The “Afternoon Train” (A-Train) is a coordinated group of Earth observing satellites that follows the same orbital “track”.

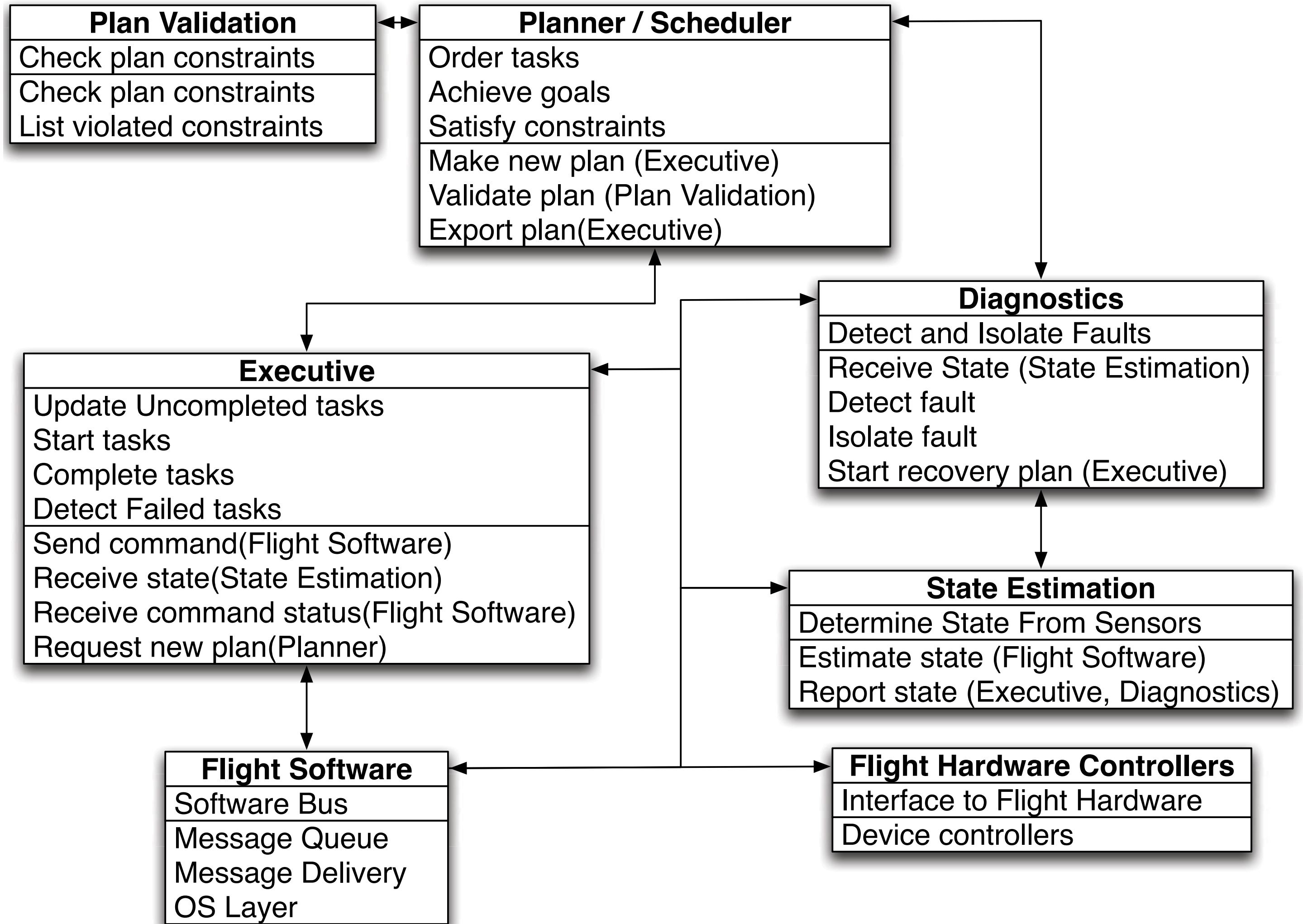
Autonomy

- **Autonomy is the ability of a system to achieve goals while operating independently of external control.** – *2015 NASA Technology Roadmaps*
  - Requires **self-directedness** (*to achieve goals)*
  - Requires **self-sufficiency** (*to operate independently)*
- A **system** is the combination of **elements** that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose – *2016 NASA Sys. Eng. Handbook*



The Curiosity rover can autonomously drive from point to point using stereo vision and on-board path planning.

Autonomy involves many functions …



… that can be performed by humans or software

What is NOT autonomy?

Autonomy is NOT artificial intelligence, but may use AI

- Machine learning (deep learning, reinforcement learning, etc.)
- Perception (object recognition, speech recognition, vision, etc.)
- Search, probabilistic methods, classification, neural networks, etc.

Autonomy is NOT automation, but often relies on automation

- Most robotic space missions rely on automation
- Command sequencing (event, order, time triggered)

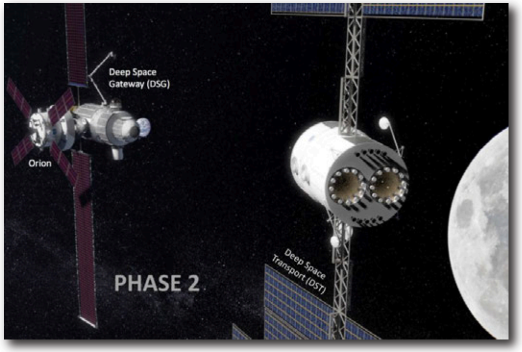
Autonomy is NOT only about making systems "adaptive", "intelligent", "smart", or "unmanned / uncrewed"

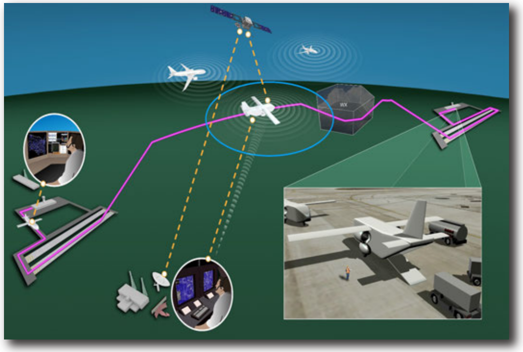
- Autonomy is about making systems **self-directed** & **self-sufficient**
- Systems **can include humans** as an integral element (human-system integration / interaction, human-autonomy teaming, etc.)
- Software (e.g., decision support) can make **humans more autonomous** of other humans (air traffic control, mission control, etc.)

Why autonomy?

Autonomy is needed …

- When the cadence of decision making exceeds **communication constraints** (delays, bandwidth, and communication windows)
- When **time-critical decisions** (control, health, life-support, etc) must be made on-board the system, vehicle, etc.
- When decisions can be better made using **rich on-board data** compared to limited downlinked data (e.g., adaptive science)
- When local decisions **improve robustness** and **reduces complexity** of system architecture
- When autonomous decision making can **reduce system cost** or **improve performance**
- When **variability in training, proficiency**, etc. associated with manual control is unacceptable





Where can NASA use Autonomy?

EARTH LAUNCH AND LANDING SYSTEMS

- Launch Vehicles
- Launch Abort Systems
- Entry, Descent and Landing

EARTH ATMOSPHERIC SYSTEMS

- Unmanned Aerial Systems
- Vehicle Mission Safety
- Vehicle Performance Enhance
- Human-machine teaming
- National Airspace Management
- Distributed Large-scale Collaborative Systems

GROUND SYSTEMS

- Mission Operations
- Visualization and Interaction
- Robotic Inspection and Repair
- Propellant/Commodity Loading

ROBOTIC EARTH-ORBITING SYSTEMS

- Formation Flying
- Constellations and Swarms
- Rendezvous and Docking
- On-Orbit Servicing
- In-Space Assembly
- In-Space Manufacturing
- Instrument Data Analysis
- Sensor Web

HUMAN EARTH-ORBITING SYSTEMS

- Life Support
- Rendezvous and Docking
- On-Orbit Servicing
- Visualization and Interaction
- Robotic Assistants
- Mission and Data Analysis
- In-space Manufacturing
- In-space Assembly

ROBOTIC SPACE SYSTEMS

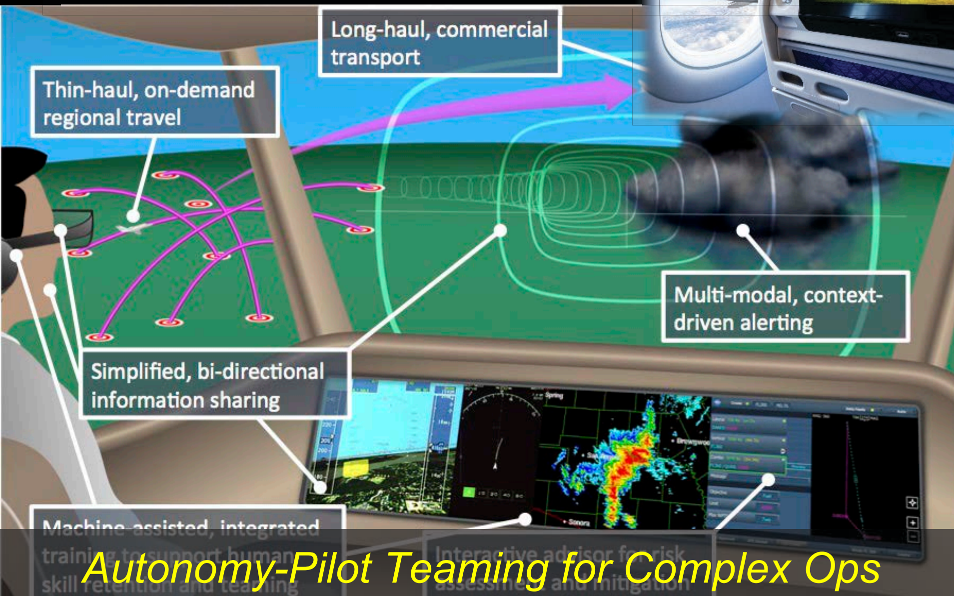
- Planetary Ascent Vehicles
- Rendezvous and Docking
- Entry, Descent & Landing
- In Situ Access
- Sample Collection
- Orbital Navigation
- Instrument Data Analysis
- In Situ Resource Utilization

HUMAN SPACE SYSTEMS

- Planetary Ascent Vehicles
- Life Support
- Rendezvous and Docking
- Entry, Descent & Landing
- Surface Transport
- Robotic Assistants
- Mission and Data Analysis
- In Situ Resource Utilization

Aeronautics

Transforming civil aviation



Autonomy-Pilot Teaming for Complex Ops

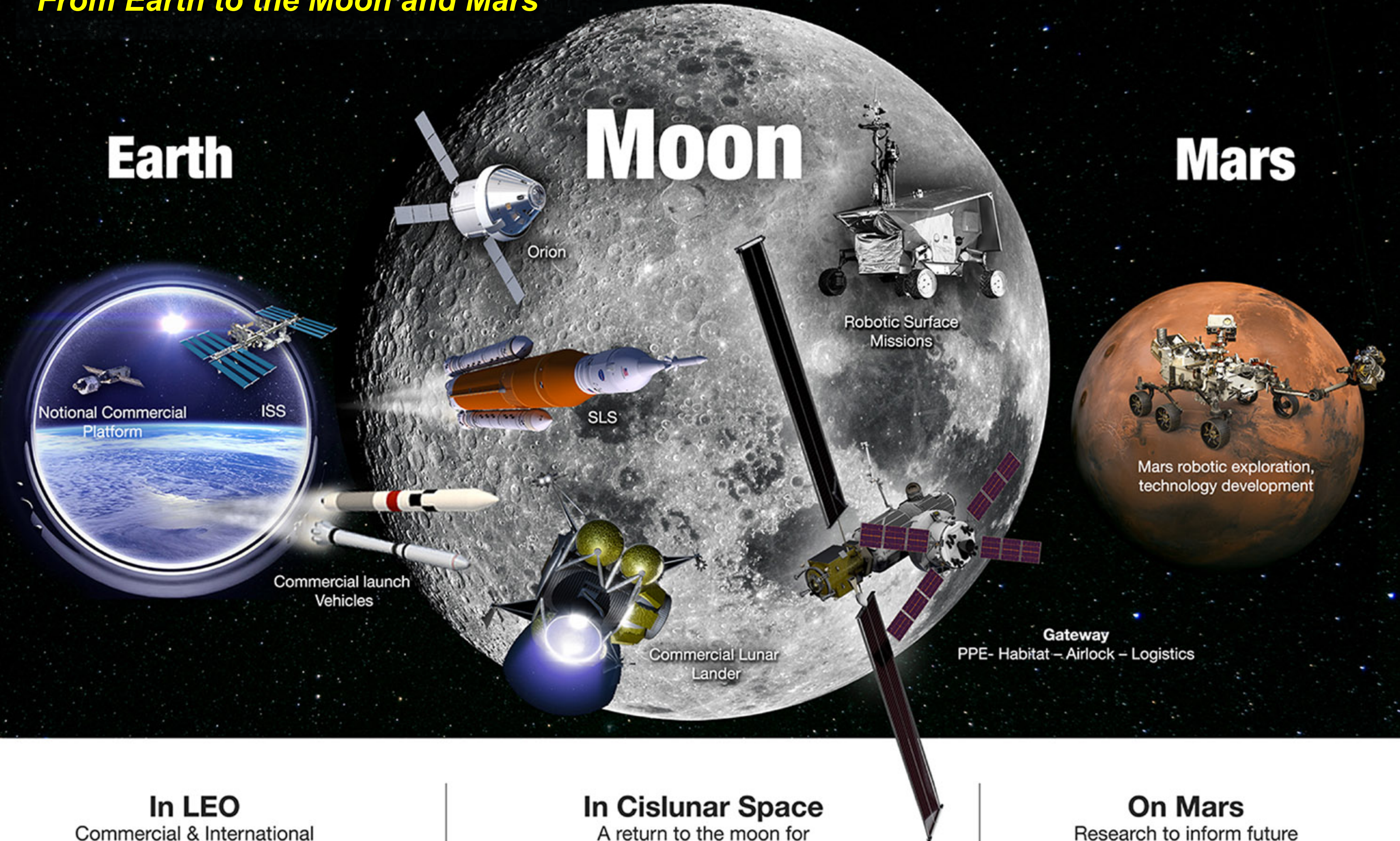
Urban Air Mobility (UAM)

UAS Traffic Management (UTM)

Autonomy-Enabled ATM

Human Exploration

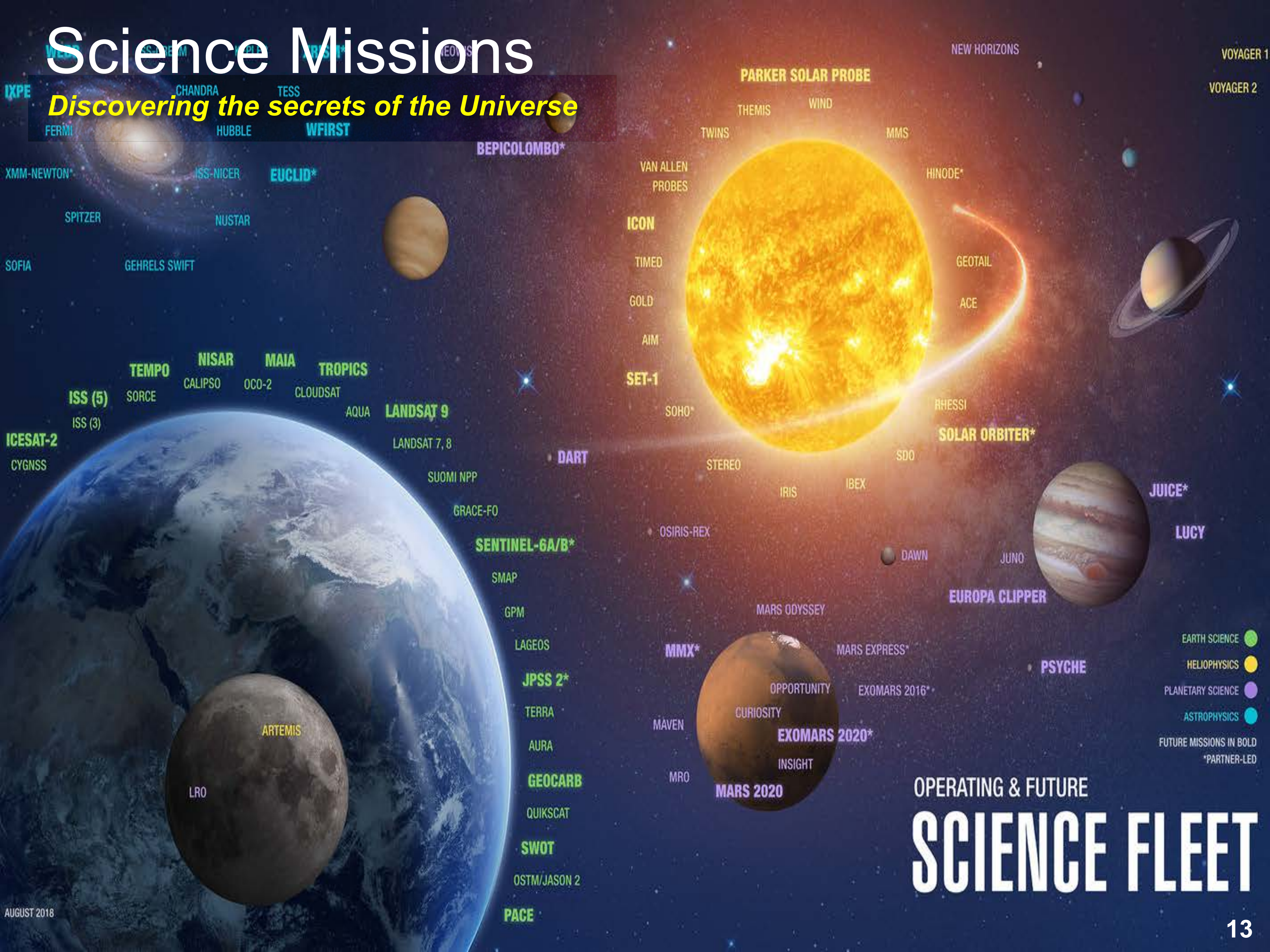
From Earth to the Moon and Mars



In LEO	In Cislunar Space	On Mars
Commercial & International partnerships	A return to the moon for long-term exploration	Research to inform future crewed missions

Science Missions

Discovering the secrets of the Universe



Space Technology

Technology drives innovation

SBIR/STTR

Partnerships & Technology Transfer

- Technology Transfer
- Prizes and Challenges
- iTech

Early Stage Innovation

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

Technology Demonstrations

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

Technology Maturation

- Game Changing Development

TECHNOLOGY PIPEPINE

NASA Programs with Autonomy R&D

New algorithms (TRL 1-3)

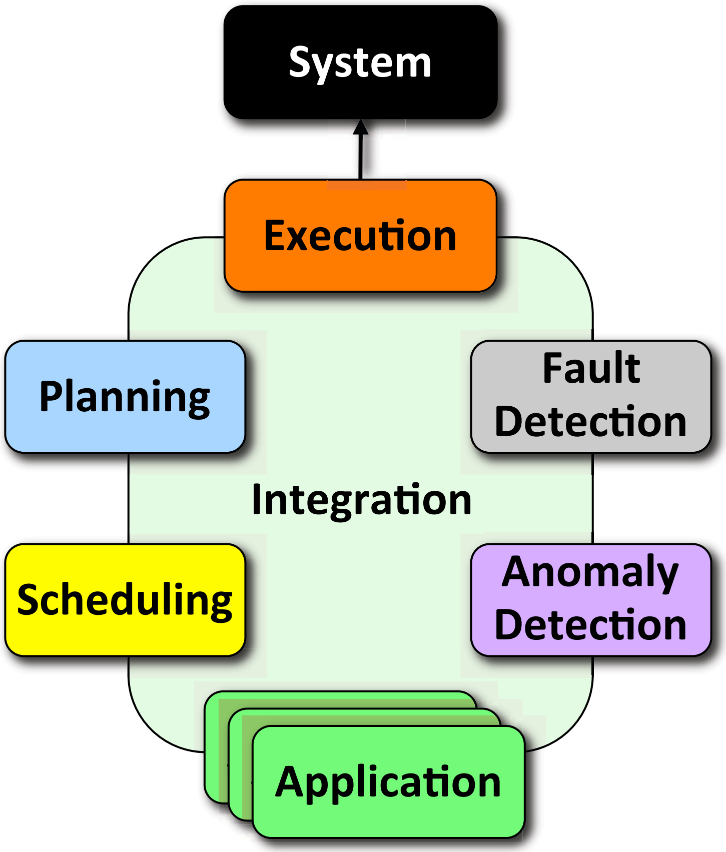
- **ARMD**: Transformative Aero Concepts
- **SMD**: Planetary Science and Technology from Analog Research, COLDTech
- **STMD**: Space Tech Research Grants

Scaling the technology (TRL 4-7)

- **ARMD:** Airspace Operations & Safety
- **HEOMD**: Adv. Exploration Systems
- **STMD**: Game Changing Development

Flight systems (TRL 8-9)

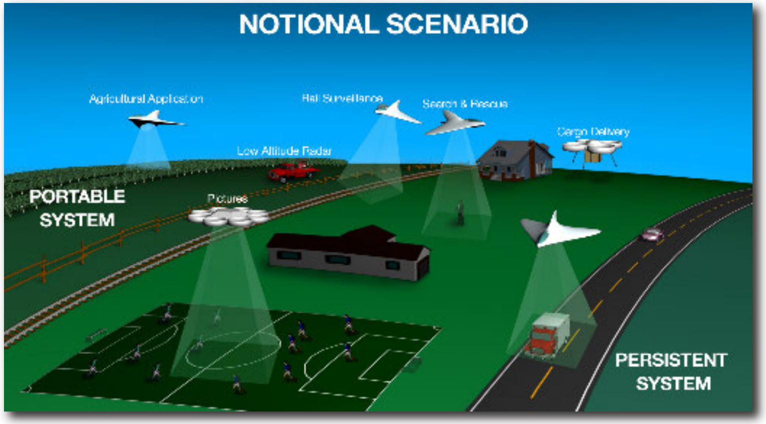
- **HEOMD**: Adv. Exploration Systems
- **STMD**: Small Satellite Technology

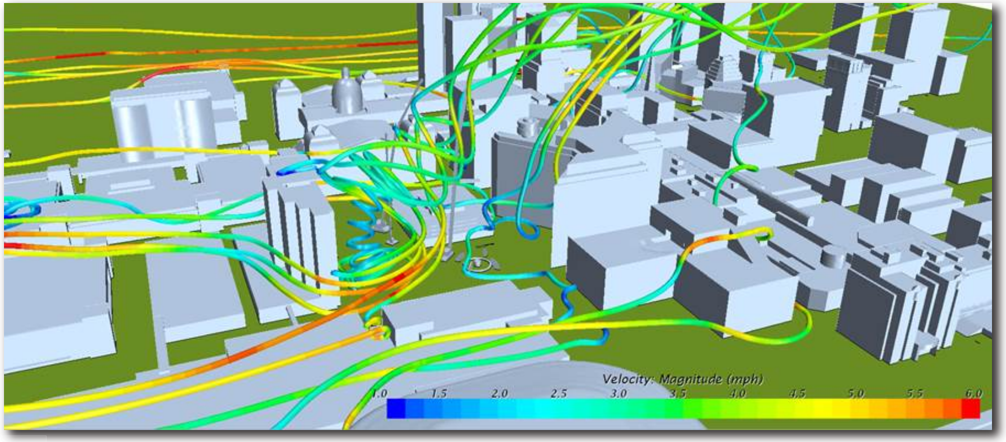


UAS Air Traffic Management (ARMD)

Overview

- The UTM architecture addresses mission planning and execution strategies for UAS operations
- Provide cooperative, interoperable, digital ability to plan and schedule airspace resources; track vehicles; and assist with contingencies
- Support autonomous and remotely piloted vehicle operations





Research Focus

- Capability for operators to interact with each other through predefined data exchanges and application protocol interfaces
- Provide complete situation awareness of airspace use and constraints
- Urban environments and high density operations

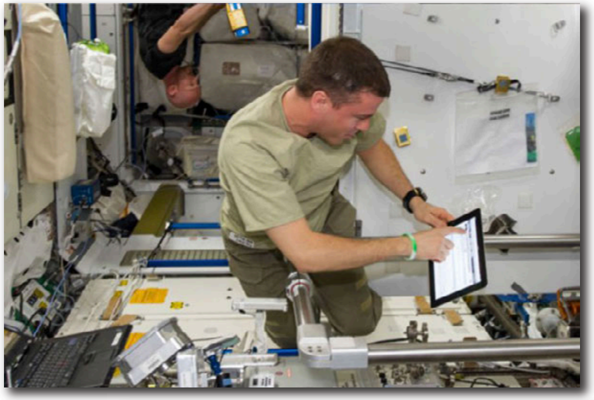
Autonomous Systems & Ops (HEOMD)

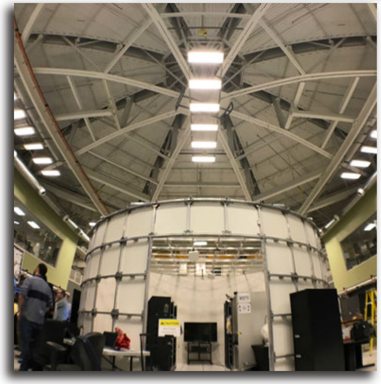
Objectives

- Advance autonomy technology for human spaceflight (crew and vehicle)
- Planning and scheduling, fault detection, isolation and impact reasoning, plan execution, and crew decision support

Current activities

- Demonstrate crew decision support system on-board the ISS
- Demonstrate advanced caution and warning for infusion into Orion (for EM-2)
- Demonstrate vehicle systems automation in the iPAS simulation facility (JSC)





Astrobee (STMD)

Free-flying robot for ISS IVA

- 3 robots + docking station
- Open-source software
- Autonomous / telerobotic operations

IVA tasks in human spacecraft

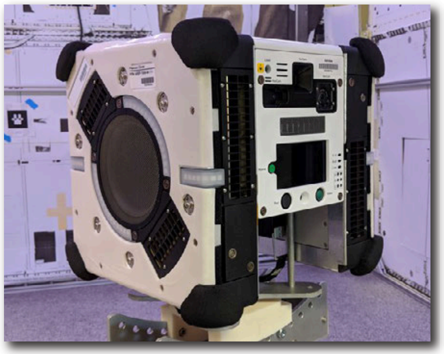
- Mobile surveys (inventory + IVA environment monitoring)
- Mobile camera for mission control

Successor to SPHERES

- Multiple ports for new payloads
- Perform experiments without crew
- 7 guest science projects in devel.

Tech development for Gateway

- Support IVA robotics engineering
- Autonomous caretaking during uncrewed periods
- In-flight maintenance



Certification Unit (8/2018)

Two Astrobees moving cargo (artist concept)

Launch: NG-11 in April 2019

Distributed Spacecraft Autonomy (STMD)

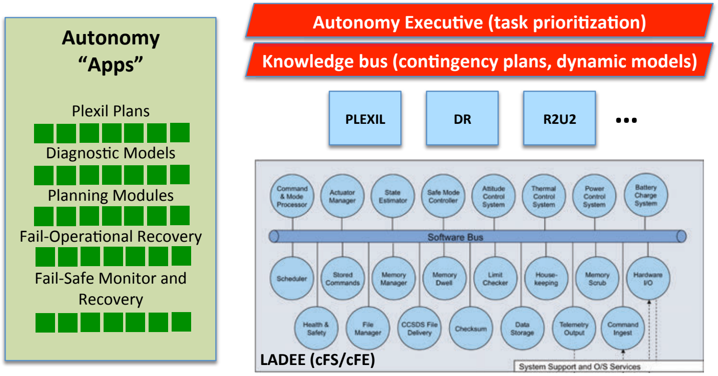
NEW

Scaleable autonomy for multi-spacecraft

- Comm: resilient data distribution
- Fault management: distributed diagnostics engine
- Distributed planning, scheduling, and task execution
- Ops: scaleable ground data system and human-system interaction

Flight demonstration

- Integrated to Starling / Shiver mission
- Reusable core software stack
- Dynamic inter-spacecraft coordination for monitoring variable RF signals



Note: project is completing formulation for FY19 start

Integrated System for Autonomous and Adaptive Caretaking (STMD)

NEW

Caretaking of exploration spacecraft

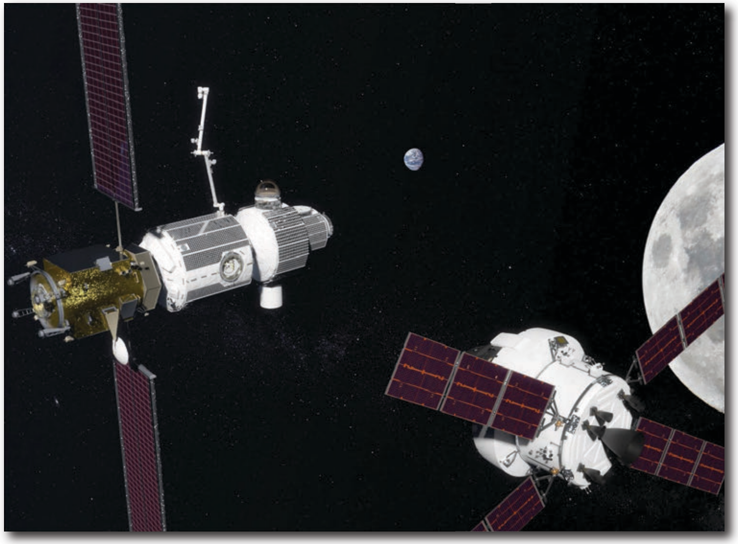
- Autonomous robots + spacecraft infrastructure (avionics, sensors, networking) + ground control
- Develop and test on ISS for future infusion to Gateway

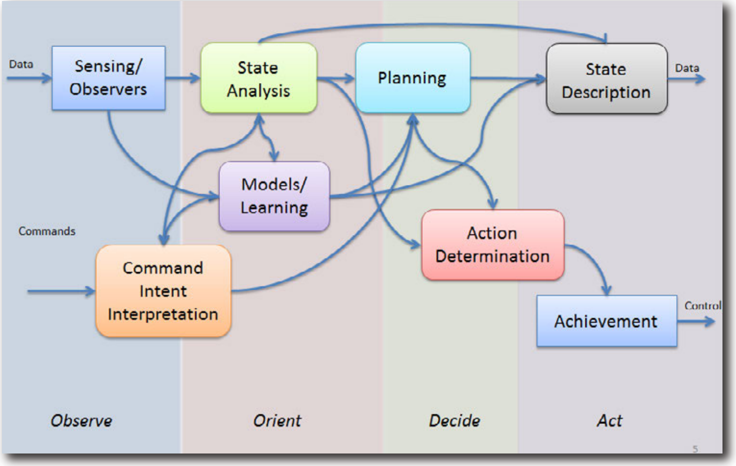
Crewed periods

- Off-load routine work from astronauts
- Tech: safe human-robot interaction, robust navigation

Uncrewed ("dormant") periods

- Monitor and maintain systems in the absence of astronauts
- Tech: sw architecture, diagnostics/ prognostics, smart downlink



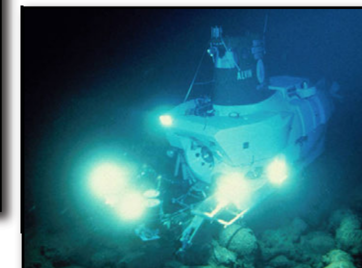


Future Autonomy R&D ?

SUBSYSTEM

Perception for Extreme Environments

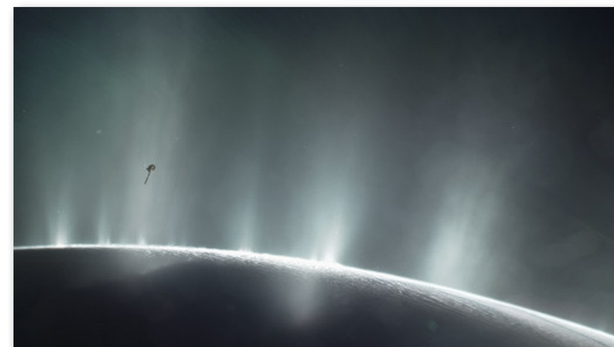
- **Autonomous nav** or **target selection** for icy worlds, interior oceans, caves, pits, etc.
- Requires new 3D sensors (lidar, time-of-flight cameras, etc.) & high-performance computing



SPACECRAFT

Reactive Science

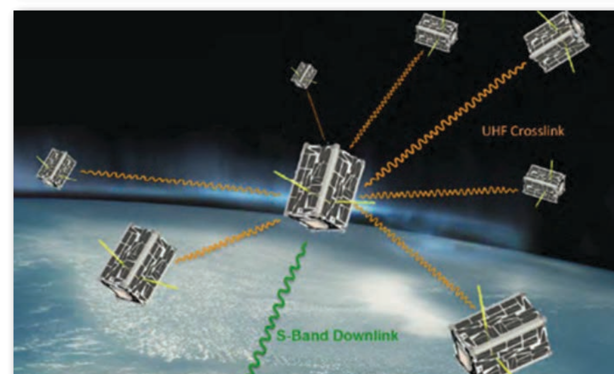
- Observe and/or sample **dynamic** & **transient phenomena** (plumes, seeps, weather, etc)
- Requires autonomous on-board decision making (planning, scheduling & execution)
- Must manage risk and uncertainty on-board



MISSION LEVEL

Collective Operations

- Enable a spacecraft swarm (10-100+) to **collectively perform** distributed activities
- Requires a distributed autonomy architecture (including coordination and collaboration)
- Must perform planning, scheduling, health management, etc. at a "collective" level



Autonomous Systems SCLT Activities

ARMD

- TACP TTT: “Autonomous Systems” subproject planning

HEOMD

- Deep Space Gateway Technology Utilization Working Group
- Exploration Capabilities Coordination Group (ExCCG)

SMD

- 2018 “Autonomy for Future Science Missions” workshop

STMD

- “Autonomous Operations” R&D planning (focus on STRG and GCD)
- STRG ESI 2018: "Smart and Autonomous Systems for Space” solicitation
- STRG STRI 2018: "Smart Deep Space Habitats” solicitation
- NSTRF TA04 topic chair
- GCD: advice/feedback to current and proposed projects
- Partnerships: review proposed agreement abstracts

Autonomous Systems SCLT Activities

OCE

- Autonomous Systems taxonomy development and infusion (to OCT, MDs, etc)
- Baseline assessment: state of capability in NASA

OCT

- Interagency Space Science & Technology Partnership Forum

External engagement

- DoD: Autonomy Community of Interest (CoI)
- DARPA: Robotic Servicing of Geosynchronous Satellites *(SME support)*
- NSF: Joint solicitation for the "Smart and Autonomous Systems" *(ESI 2018 topic is a pilot for larger NASA collaboration in FY19+)*
- Briefings from AFRL, ONR, etc.

Autonomous Systems Taxonomy

- **1.0 Situation and Self Awareness**
  - 1.1 Sensing and Perception
  - 1.2 State Estimation and Monitoring
  - 1.3 Knowledge and Model Building
  - 1.4 Hazard Assessment
  - 1.5 Event and Trend Identification
  - 1.6 Anomaly Detection
- **2.0 Reasoning and Acting**
  - 2.1 Mission Planning
  - 2.2 Activity and Resource Planning and Scheduling
  - 2.3 Motion Planning
  - 2.4 Execution and Control
  - 2.5 Fault Diagnosis and Prognosis
  - 2.6 Fault Response
  - 2.7 Learning and Adapting
- **3.0 Collaboration and Interaction**
  - 3.1 Joint Knowledge and Understanding
  - 3.2 Behavior and Intent Prediction
  - 3.3 Goal and Task Negotiation
  - 3.4 Operational Trust Building
- **4.0 Engineering and Integrity**
  - 4.1 Verification and Validation
  - 4.2 Test and Evaluation
  - 4.3 Operational Assurance
  - 4.4 Modeling and Simulation
  - 4.5 Architecture and Design

Top Technical Challenges

Situation and Self Awareness

- The availability of qualified sensors (e.g., lidar for planetary rovers) and difficulty assuring data directly impacts perception performance

Reasoning and Acting

- Scaling to handle more complex problems (# of constraints, etc) with uncertainty (dynamic environments, etc) is an unsolved problem
- Performance is limited by mission computing (CPU, storage, comm)

Collaboration and Interaction

- Humans are complex, but they are a part of any autonomous system. What works for one person may not work for all.
- Human-system integration is a key challenge for NASA (HRP “Risk of Inadequate Design of Human and Automation/Robotic Integration”)

Engineering and Integrity

- Autonomous systems are difficult to V&V and to assure
- Autonomy capability cannot simply be “added” as an afterthought

Questions?