# Autonomous Systems and Artificial Intelligence at JPL

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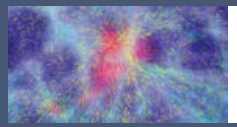
# JPL Quests

Long-term endeavors in support of the JPL Vision to “explore space in pursuit of scientific discoveries that benefit humanity”

**Understand how Earth works as a system and how it is changing**

**Understand the diversity of planetary systems in our Galaxy**

**Help pave the way for human exploration of space**



**Understand how the Universe began and how it is evolving**

**Understand how our Solar System formed and how it is evolving**

**Use our unique expertise to benefit the nation and planet Earth**

**Understand how life emerged on Earth and possibly elsewhere in our Solar System**

JPL Strategic Implementation Plan, 2018

# JPL's Quests and Autonomy Challenges

| Quest | Autonomy Challenge |
|---|---|
| **Earth Science & Applications** | Handle *big data* from space-borne assets<br>Enable *rapid response* and follow-on observations with multiple assets |
| **Mars Exploration** | Explore diverse geologic regions: *extreme terrains* and *sub-surface* caves<br>Collect *global* measurements (e.g., global 3D wind measurements) with *networked* assets<br>Increase *pace* of robotic exploration and enable sample return |
| **Solar System Exploration** | *Low bandwidth, high latency* environment:<br>• Autonomous *navigation*<br>• Autonomous data *filtering* and *prioritization*<br>• System-level and swarm-level autonomy for small spacecraft *constellations/swarms* |
| **Astronomy & Physics** | Control and autonomy for *distributed* instruments :<br>• telescope-occulter<br>• distributed aperture telescopes<br>• interferometers |
| **Interplanetary Network** | Autonomous multi-hop communication and *delay-tolerant networking*<br>Reduce *operator load* and enable increased throughout<br>*Distributed* in-space *computing* |

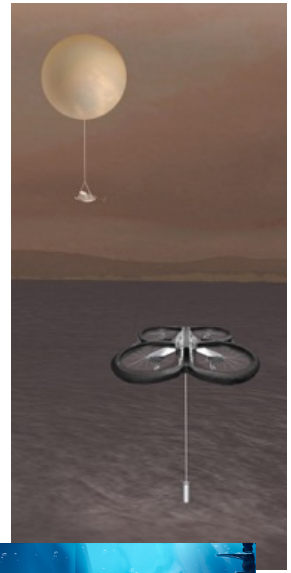
# Autonomous Systems at JPL

- Space exploration involves spacecraft operating in harsh and unforgiving environments

- JPL has a long history in deploying and operating autonomous systems that:
  - Protect systems from detected faults and hazardous conditions
  - Perform critical events despite the presence of failures
  - Increase mission utility

- JPL is pioneering resilient, self-aware, and autonomous systems able to weigh risk and make decisions locally to ensure that tomorrow's missions are a success

- Our strategy is organized into three focus areas:
  - **System-level Autonomy**
  - **Autonomous Robots**
  - **Autonomous Sciencecraft**



# System-level Autonomy

## Description

- Technologies such as perception prediction, system-health assessment, and risk-awareness enable on-board decisions and choosing actions with consideration of uncertainty in knowledge of self and the environment
- Using probabilistic reasoning across subsystems, the system can arrive at decisions that meet user-specified safety criteria

## Areas of Focus

- Architectural Principles and Patterns
- Goal-directed operation, allowing operators to focus on objectives and oversight
- Self-sufficient planning, scheduling, and control
  - including internal management of resources and redundancy, coordination of both engineering tasks and science observations, and recovery from anomalies
- Health state awareness via model-based reasoning
- Hypothesis-driven Science Activity Planning
- Assurance Techniques for Autonomous Systems

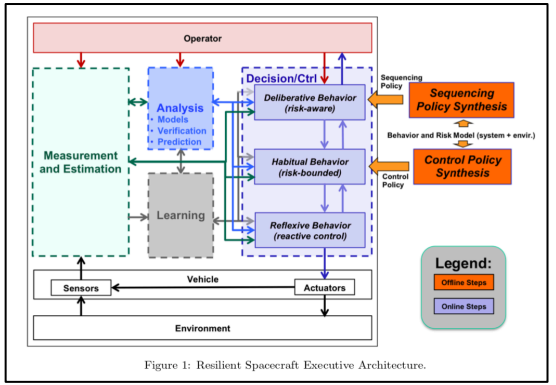
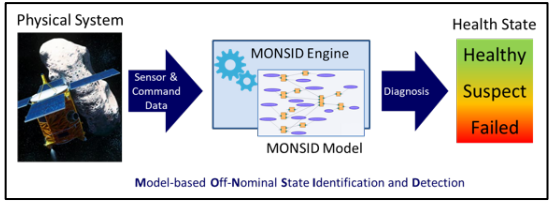
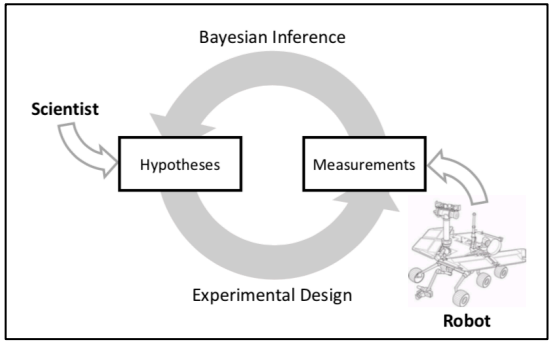


Figure 1: Resilient Spacecraft Executive Architecture.



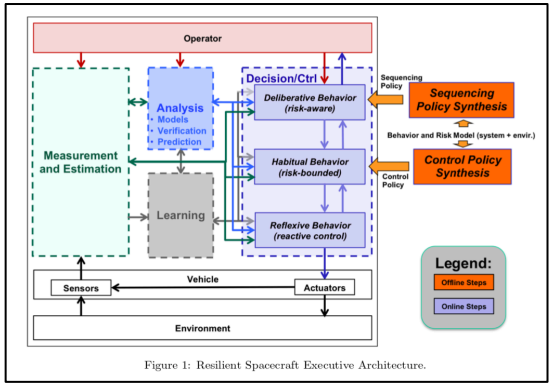



# System-level Autonomy

## Examples of JPL research activities

(a non-exhaustive list)

- Resilient Spacecraft Executive Architecture
  - PoC: Maged E Elaasar
- Model-based Off-Nominal State Identification and Detection
  - PoC: Lorraine Fesq, Ryan Mackey
- MEXEC on-board (re)planning and execution
  - PoC: Rashied Amini



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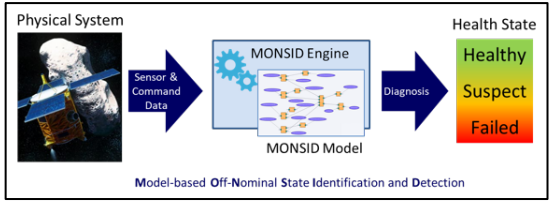
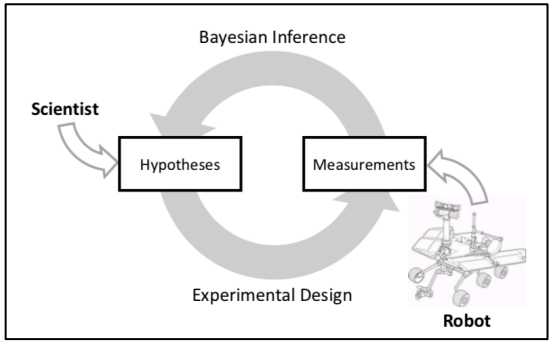


Model-based Off-Nominal State Identification and Detection



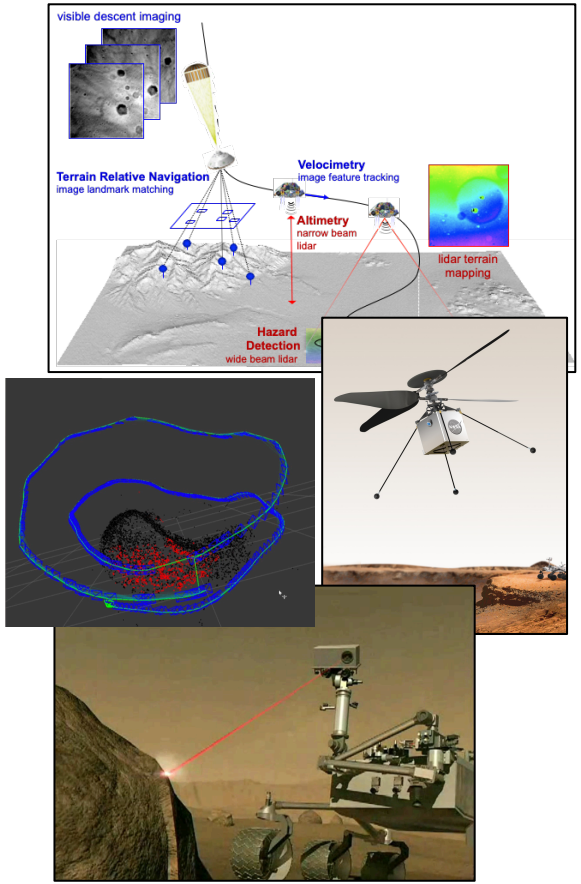
# Autonomous Robots

## Description:

- Autonomous navigation and manipulation technologies enable efficient and reliable access to targets of scientific interests on planetary surfaces.
- Using advances in sensing, perception, estimation, learning, reasoning, mobility, and manipulation, robots are able to perceive and classify terrains, assess hazards, plan safe trajectories, reach targets of interest, and improve performance by learning from past experiences

## Areas of Focus

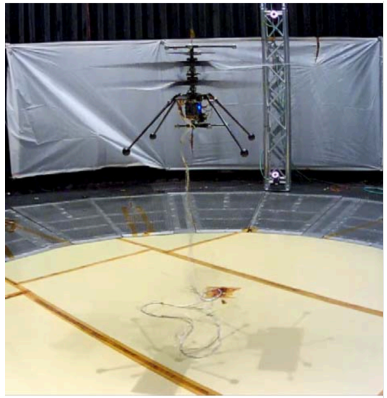
- Entry, Descent and Landing
- Proximity Operations
- Mobility – Surface, Aerial, Underwater, Extreme terrain
- Manipulation and Sampling
- Opportunistic Science



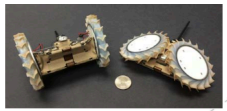
# Autonomous Robots

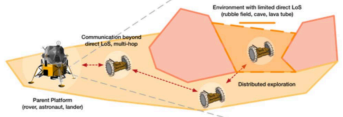
**Examples of JPL research activities** (a non-exhaustive list):

- Mars Helicopter: vision-based estimation, landing site selection. On Mars 2020.
  - PoC: Bob Balaram
- Innovative Legged and Limbed Mobility and Planning
  - POC Brett Kennedy
- Sensing and Control for Autonomous Boats
  - PoC Mike Wolf, Curtis Padgett, Gail Woodward
- Teaming and Multi-Agent Autonomous Systems
  - PoC Mike Wolf, Amir Rahmani, JP de la Croix, Josh Vander Hook
- Underwater and Intelligent Manipulation
  - PoC Renaud Detry, Matt Gildner
- Perception and Control for Aerial Vehicles
  - PoC Larry Matthies, Ali Agha
- In-Space Assembly
  - PoC Rudra Mukherjee
- Extreme Terrain Traversability Estimation (on Mars 2020)
  - PoC Mike McHenry, Hiro Ono









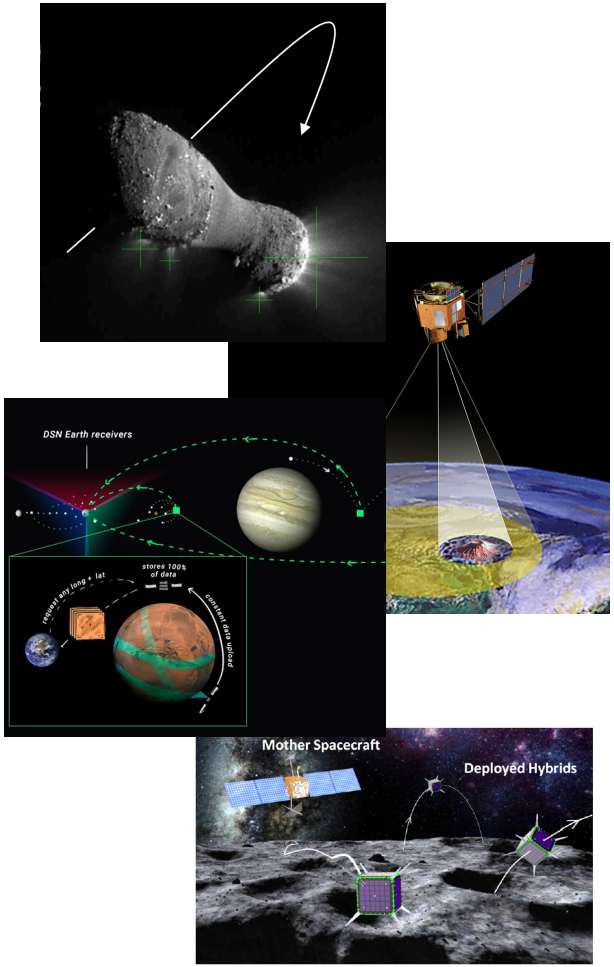

# Autonomous Sciencecraft

**Description:**

- Autonomy software technologies that enable operations analysis to optimize spacecraft and mission design (trajectory, coverage, spacecraft design, particularly for constellations/swarms), and
- Enable onboard data analysis and response (scheduling and execution) for novel science and in-situ exploration of unknown, unpredictable environments

**Areas of Focus**

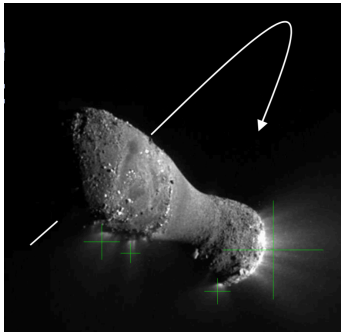
- Onboard data analysis to recognize and respond to science events via automated task re-planning
- Automated ground-based, resource-aware scheduling for science planning
- Distributed system computation and control
- Sensorwebs – integrate measurements from varied assets (orbital, aerial, ground, and marine)

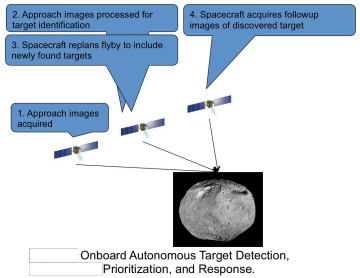


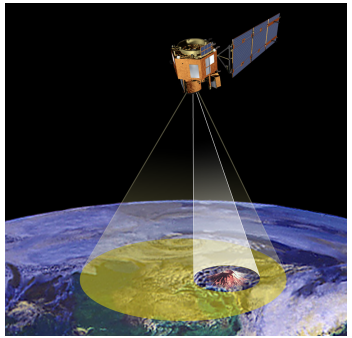
# Autonomous Sciencecraft

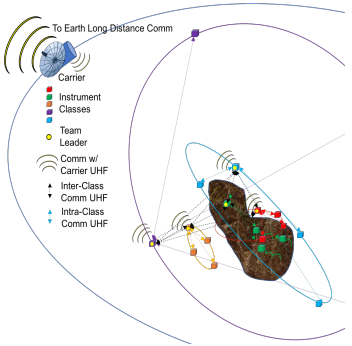
**Examples of JPL research activities**: (a non-exhaustive list)

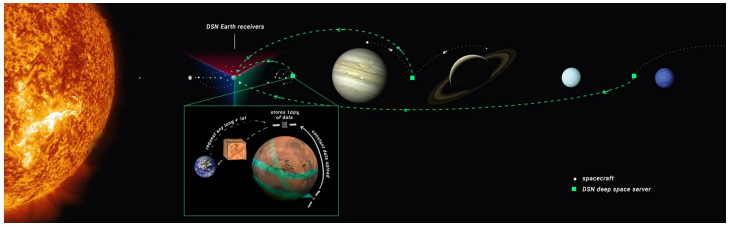
- Autonomous vision-based spacecraft and rover navigation: **AutoNav**
  - PoC: Hiro Ono, Shyam Bhaskaran
- On-board planning and scheduling: **Agile Science**
  - PoC: Steve Chien
- On-board **event detection**, data synthesis, and compression
  - PoC: Lucas Mandrake, Tara Estlin, Steve Chien
- Distributed heterogeneous computing and “archive in the sky”: **MOSAIC**
  - POC: Josh Vander Hook
- Sensor networks for autonomous satellite observation response: **Volcano SensorWeb**
  - PoC: Steve Chien
- **Integrated communication** and **control** in multi-spacecraft systems
  - PoC: Amir Rahmani





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