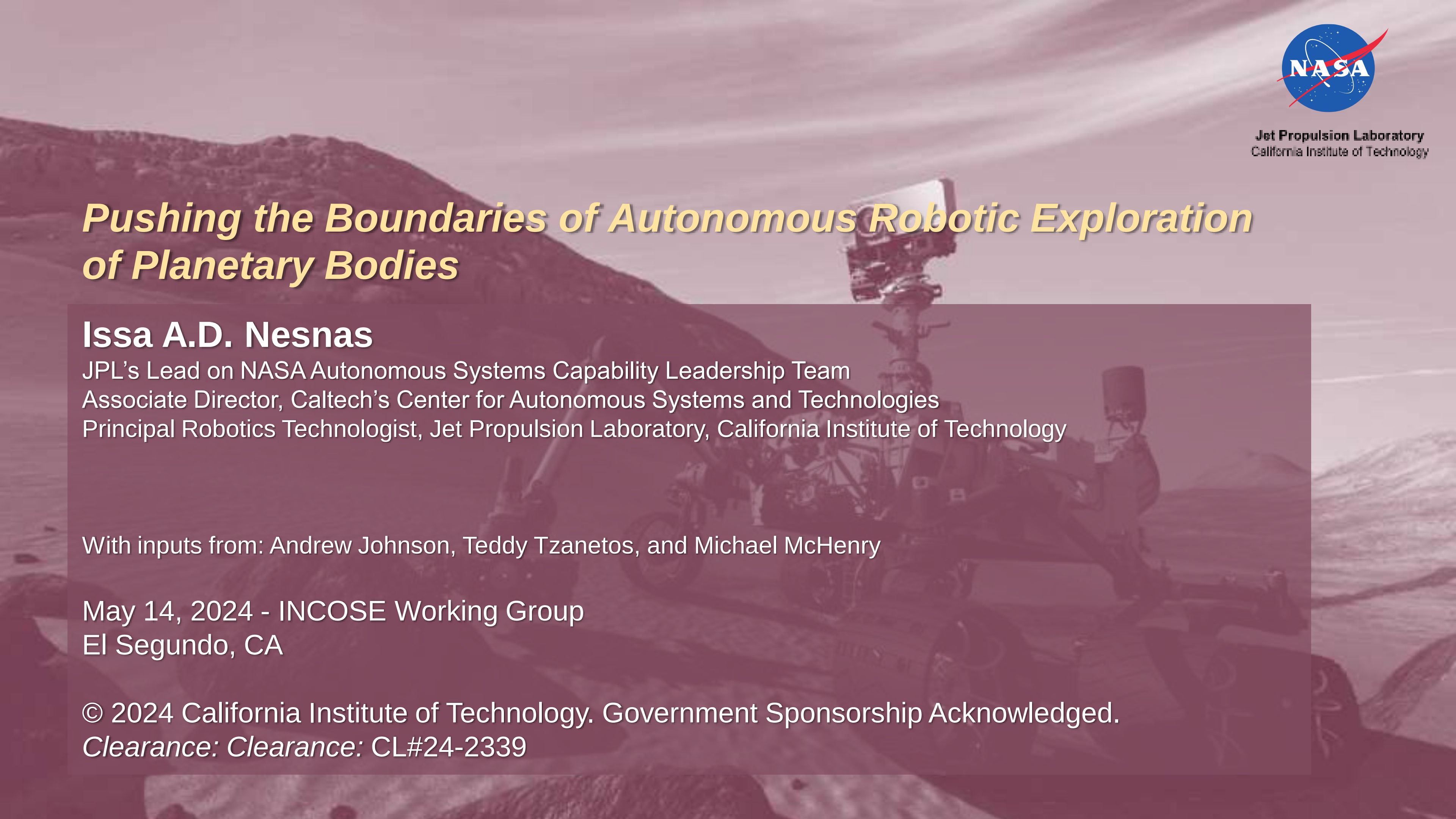


Jet Propulsion Laboratory
California Institute of Technology

Pushing the Boundaries of Autonomous Robotic Exploration of Planetary Bodies

Issa A.D. Nesnas
JPL's Lead on NASA Autonomous Systems Capability Leadership Team
Associate Director, Caltech's Center for Autonomous Systems and Technologies
Principal Robotics Technologist, Jet Propulsion Laboratory, California Institute of Technology

With inputs from: Andrew Johnson, Teddy Tzanetos, and Michael McHenry

May 14, 2024 - INCOSE Working Group
El Segundo, CA

Clearance: Clearance: CL#24-2339

Outline

- About the Jet Propulsion Laboratory
- What is autonomy, when do we need it, and why
- Recent highlights of JPL autonomous capabilities
- Architecting autonomous systems
- Principles for architecting autonomous systems
- System-level/function-level autonomy
- Next steps
- Concluding thoughts

NASA’s Jet Propulsion Laboratory

Pasadena, California
Founded in the 1930s

Federally funded Research and Development Center
Managed by California Institute of Technology

Many Firsts in Space Exploration

1st U.S. Satellite
1958 – Explorer 1

1st Powered Flight on another Planet
2021 – Ingenuity

Voyager 1 & 2

1st Flybys of Neptune/Uranus
1986, 1989 – Voyager 2

1st rover on Mars
1997 – Sojourner

1st Cached Mars Sample for Potential Return
2021 – Perseverance

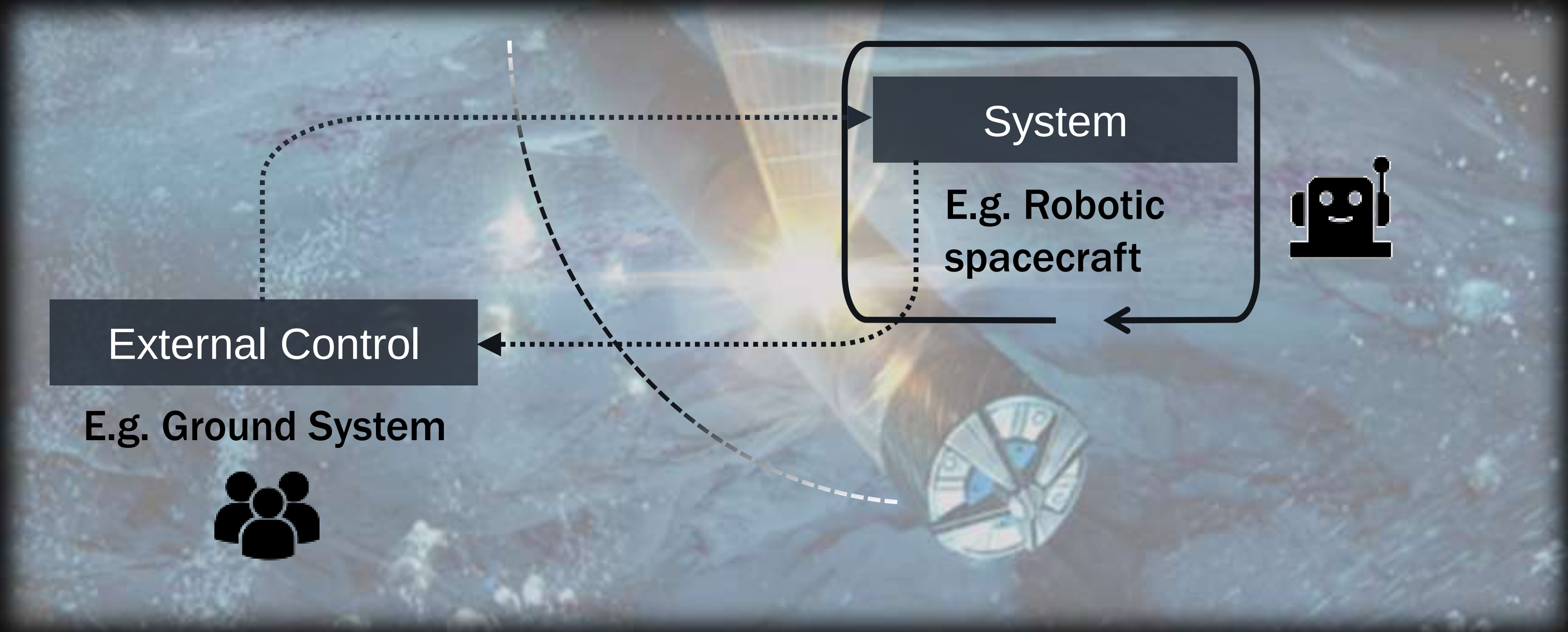
1st orbiter at Saturn
2004 – Cassini

WHAT, WHEN, AND WHY?

What is Autonomy?

Autonomy is the ability of a system to achieve goals while operating independently of external control

NASA Autonomous Systems Taxonomy, Rev 1, 2018



System

E.g. Robotic spacecraft

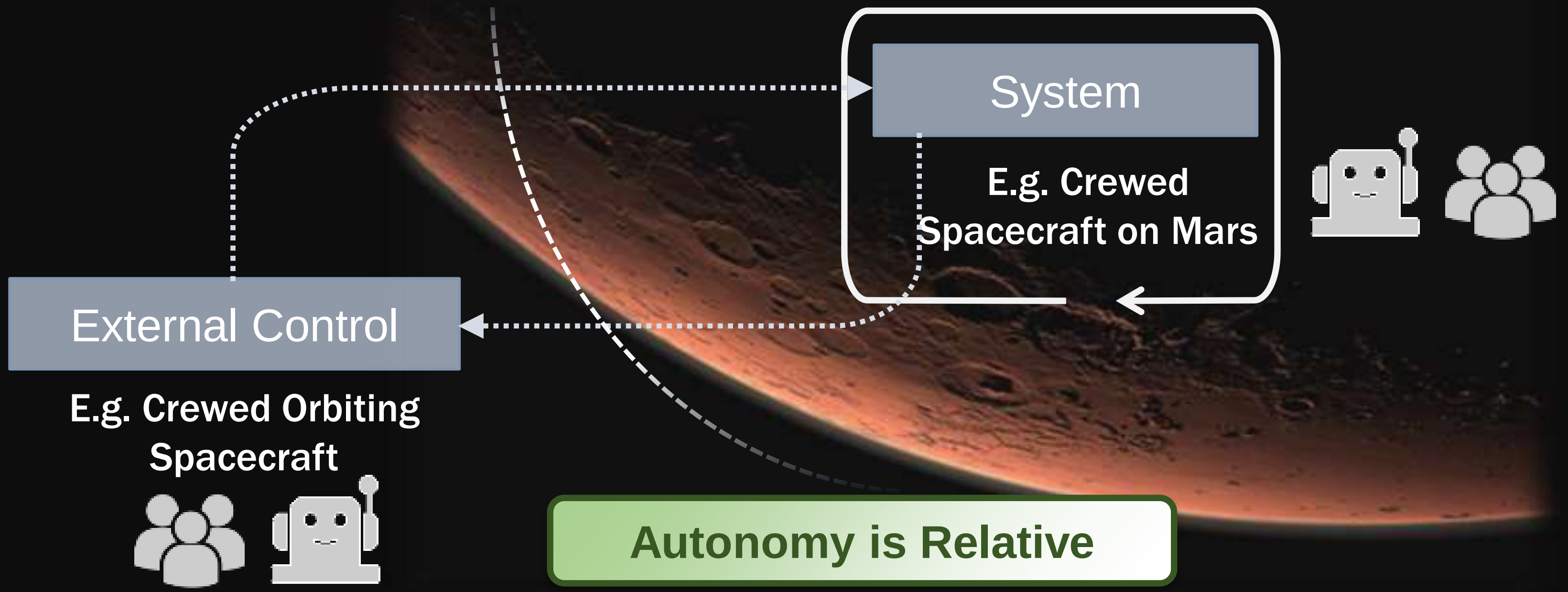
External Control

E.g. Ground System

What is Autonomy?

Autonomy is the ability of a system to achieve goals while operating independently of external control

NASA Autonomous Systems Taxonomy, Rev 1, 2018



System

E.g. Crewed Spacecraft on Mars

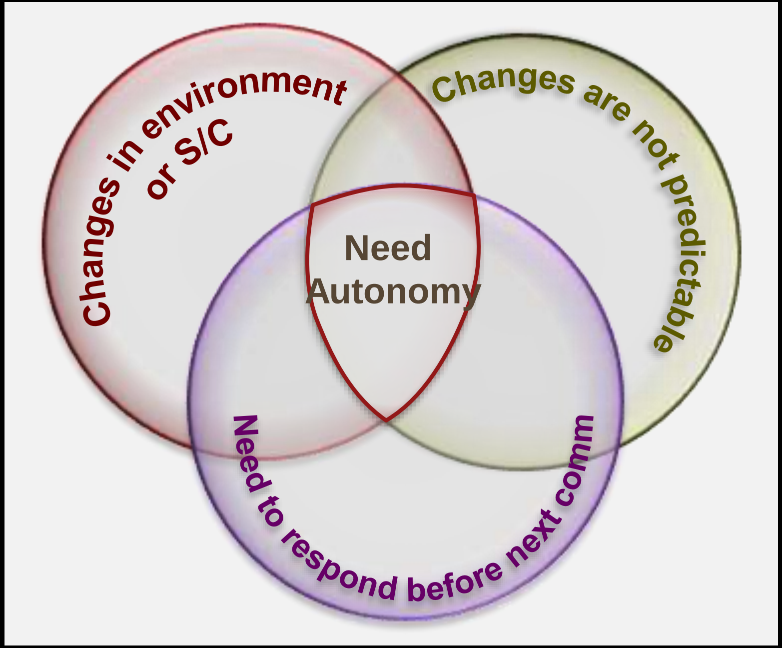
External Control

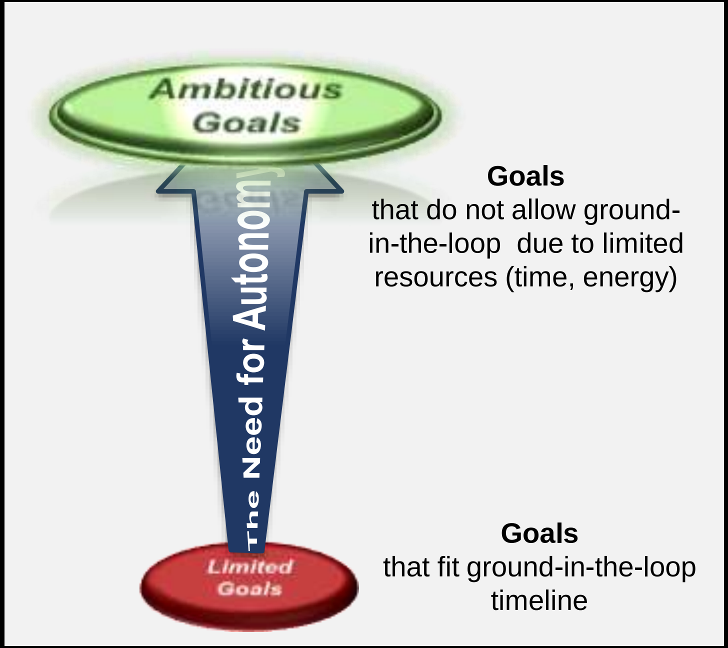
E.g. Crewed Orbiting Spacecraft

Autonomy is Relative

When Do We Need Autonomy?

A or B



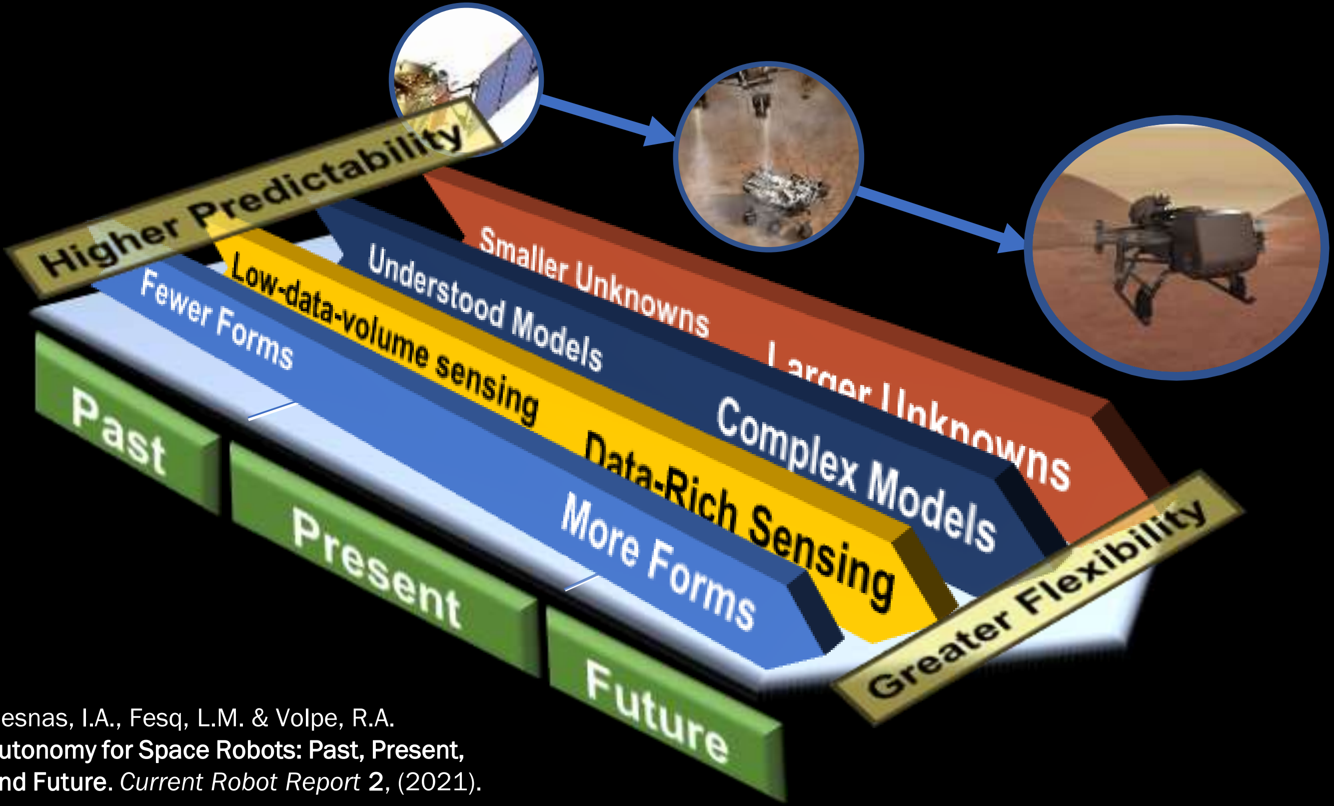


Goals
that do not allow ground-in-the-loop due to limited resources (time, energy)

Goals
that fit ground-in-the-loop timeline

Needs are driven by the spacecraft, environment, and goals

Why Do We Need Autonomy?



Nesnas, I.A., Fesq, L.M. & Volpe, R.A.
Autonomy for Space Robots: Past, Present, and Future. *Current Robot Report* 2, (2021).

Examples

Unknowns
- Terrains
- Materials
- Contact

Models
- Terra-mechanics
- Weather
- Physical contact

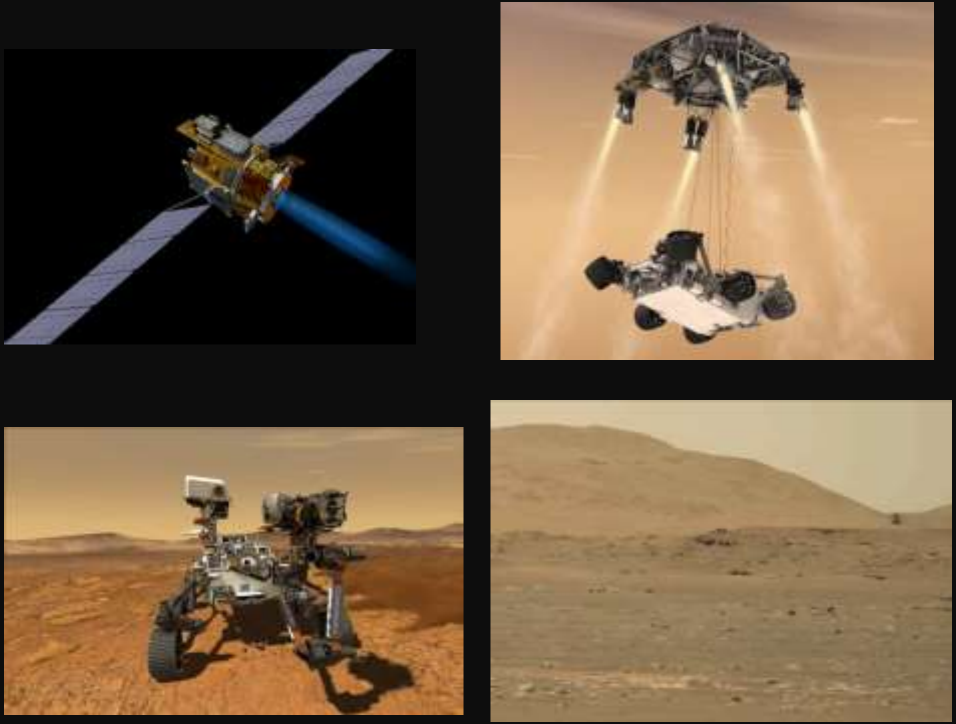
Sensing
- Visual
- 3D mapping
- Traversability
- Object recognition

Forms
- Rovers
- Balloons
- Arms
- Melting probes

RECENT HIGHLIGHTS

Recently Flown Autonomous Capabilities

- Deep space navigation
- Entry, descent and landing
- Surface mobility
- Above-surface mobility



Spacecraft Control

Entry, Descent and Landing

Flight Deployed

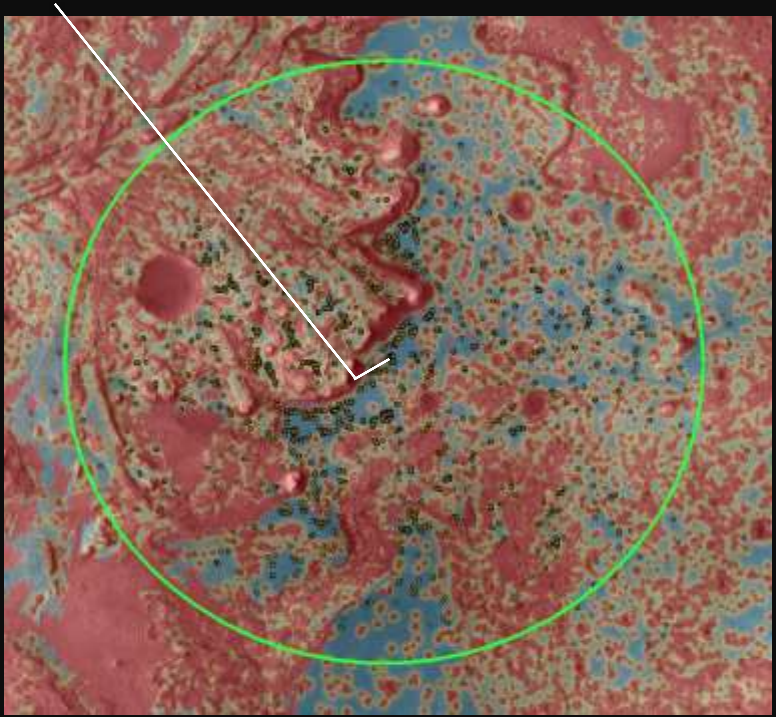
- **2003 Mars Exploration Rover:** descent imagery used to estimate and control horizontal velocity
- **2011 Mars Science Laboratory:** closed-loop guidance, navigation and control (GNC) to guide large lander to a soft touchdown
- **2020 Perseverance Mission:** closed-loop GNC with terrain-relative navigation using orbital maps with divert to a safe landing site, if necessary

Research

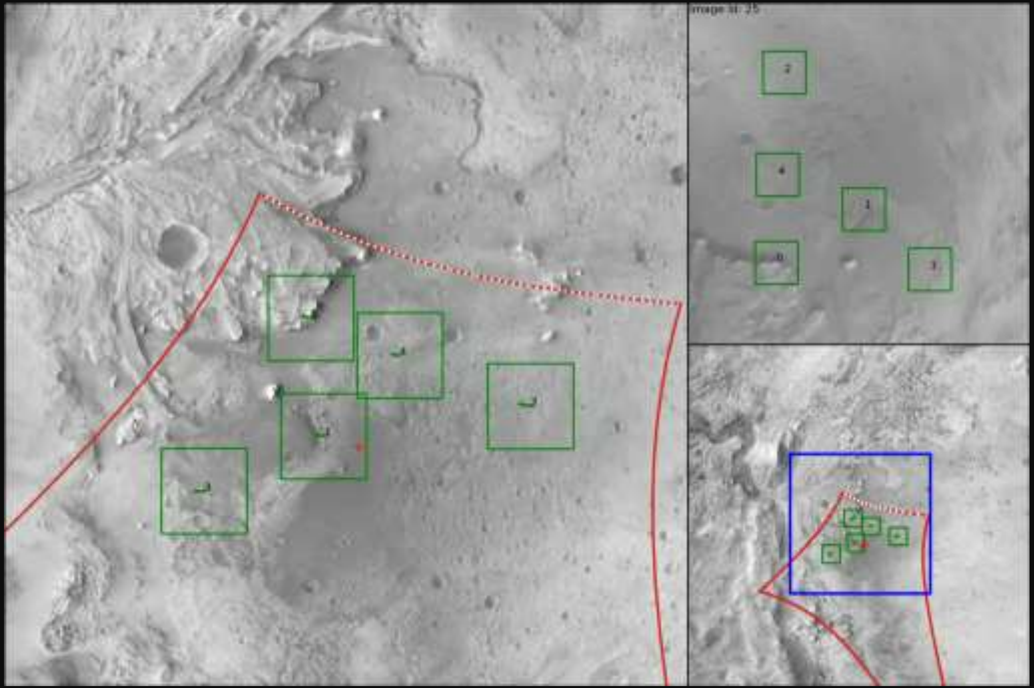
- Pin-point landing using TRN (ocean worlds, lunar landing)
- Sensors and algorithms for real-time detection of hazards not detectable in orbital imagery

Year	Mission	Landing Ellipse
2003	Mars Exploration Rover	150 km × 20 km
2011	Mars Science Lab	20 km × 7 km
2020	Mars 2020	10 km × 10 km

Jezero Cater on Mars

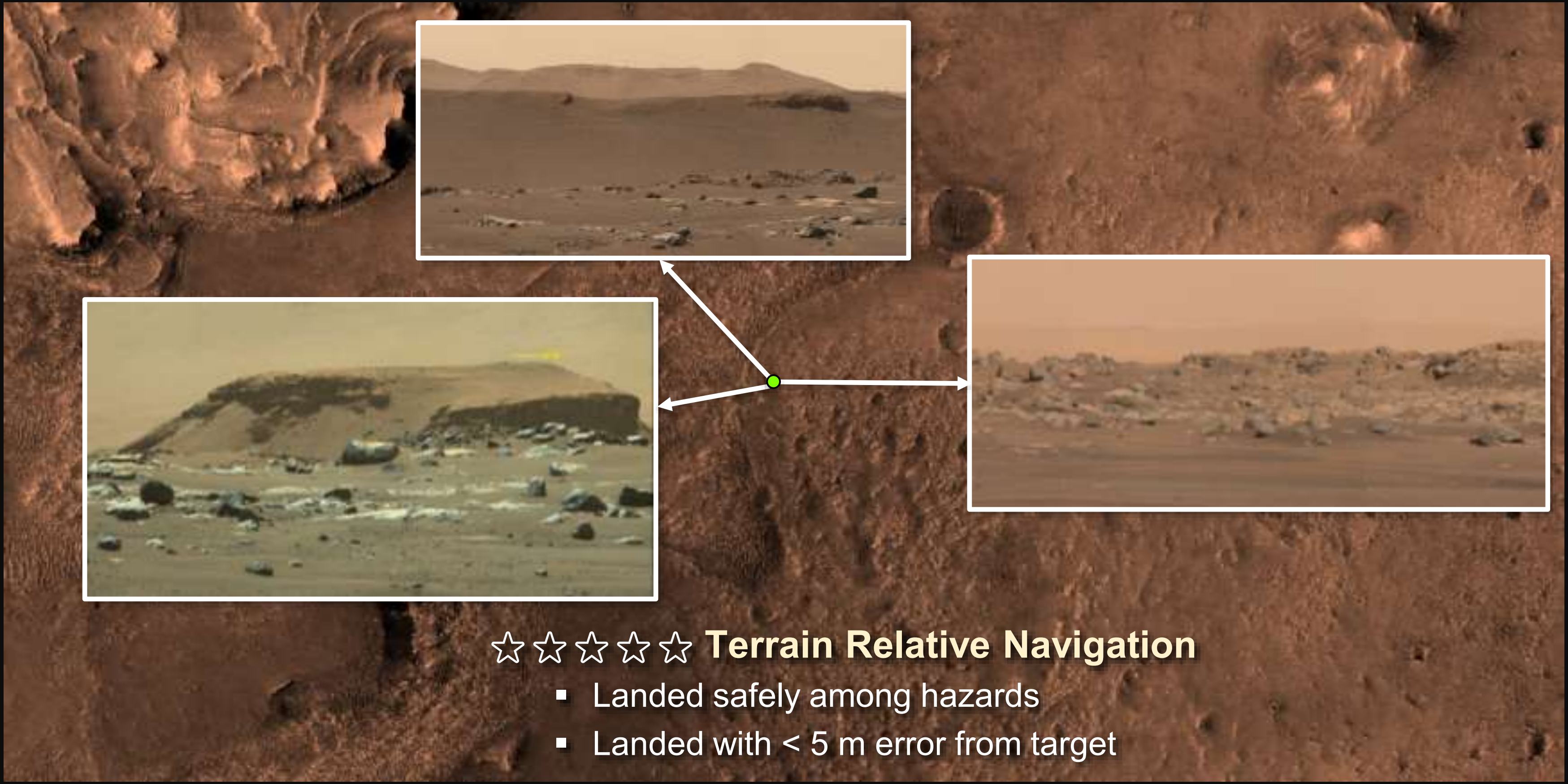


🟩 Landing Ellipse
🟧 Landing Hazards



Credit: Andrew Johnson

Mars 2020 TRN Summary



☆☆☆☆☆ **Terrain Relative Navigation**

- Landed safely among hazards
- Landed with < 5 m error from target

Credit: Andrew Johnson

Robot Control
Surface Mobility and Navigation

Flight Deployed

- **1996 Mars Pathfinder:** obstacle avoidance w/ structured light
- **2003 Mars Exploration Rover:** obstacle avoidance with stereo vision; pose estimation and slip detection with visual odometry; visual target tracking
- **2011 Curiosity Rover:** faster visual odometry
- **2020 Perseverance Rover:** thinking while driving, capability to traverse more complicated terrain

Research

- Long-duration, high-speed, energy-efficient autonomous navigation and localization for lunar and martian missions
- Traversability analysis, on-board terrain classification, motion planning under uncertainty
- Extreme-terrain and microgravity mobility and navigation

Perseverance Autonomous Navigation: Sol 122

Perseverance Autonomous Navigation

Distance record: 655.8 m
as of Sol 717–719
(Feb 27, 2023)

Credit:
Olivier Toupet
Hiro Ono
Tyler del Sesto
Michael McHenry
Mark Maimone,
Josh Vander Hook

Robot Control

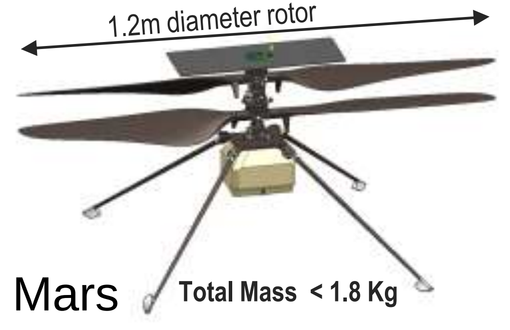
Above-Surface Mobility: Rotorcrafts and Balloons

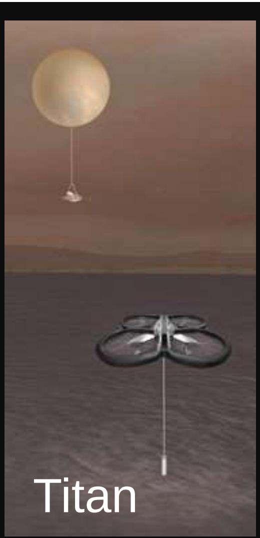
Flight Deployed

- **2020 Ingenuity Mars Helicopter (tech demo):** completed 72 historic flights with a maximum per flight lateral distance of 704 m and 2 hours and 8.8 minutes of flying time. Flew a total of 17 km.

Research

- **Mars Helicopter with Sample Retrieval Capability:** augment helicopter with robotic arm and mobility to collect sealed samples deposited by Perseverance Rover
- **Mars Exploration:** rotorcraft to host ~2–4 kg payloads and fly 1–10 km per sortie for a total system mass of ~30 kg
- **Titan Exploration:** balloon with rotorcraft daughter ship for surface science
- Autonomy for navigation and safe landing with obstacle avoidance in rough and steep terrain





ARCHITECTING AUTONOMOUS SYSTEMS

DEEP-SPACE NAVIGATION

Spacecraft Control

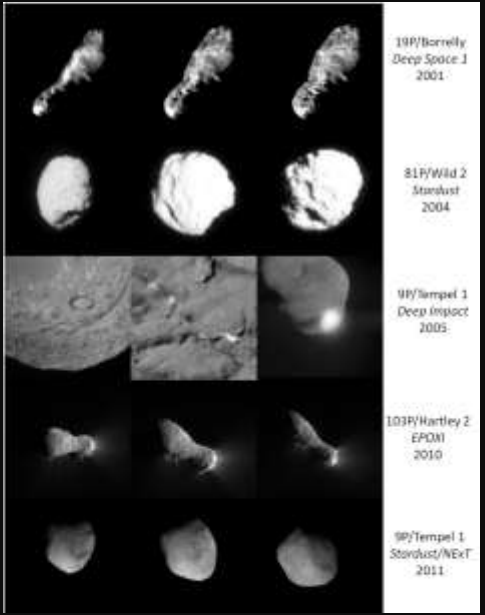
Deep Space Navigation

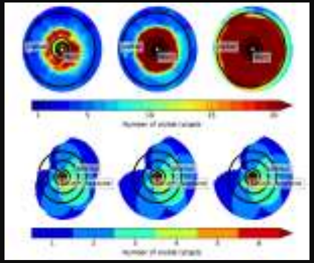
Flight Deployed

- **2002–2011 Stardust:** autonomous navigation for target tracking during flybys of asteroid Annefrank and comets Wild-2 and Tempel 1
- **2005–2010 Deep Impact:** autonomous navigation for DI impactor to hit comet Tempel 1 and track nucleus for flyby of Tempel 1 and comet Hartley 2
- **1998–2001 Deep Space I** (tech demo): autonomous navigation during cruise and flyby of comet Borrelly
- **2019 ASTERIA (tech demo):** autonomous navigation with CubeSat, imaging asteroids, and using geosynchronous satellites as beacons

Research

- Autonomous Touch and Go (TAG) for comet and asteroid sample-return Autonomous navigation across a wide range of solar system missions
- Fusion of optical and one-way radiometric measurements for autonomous navigation





Positioning Accuracies Across Solar System

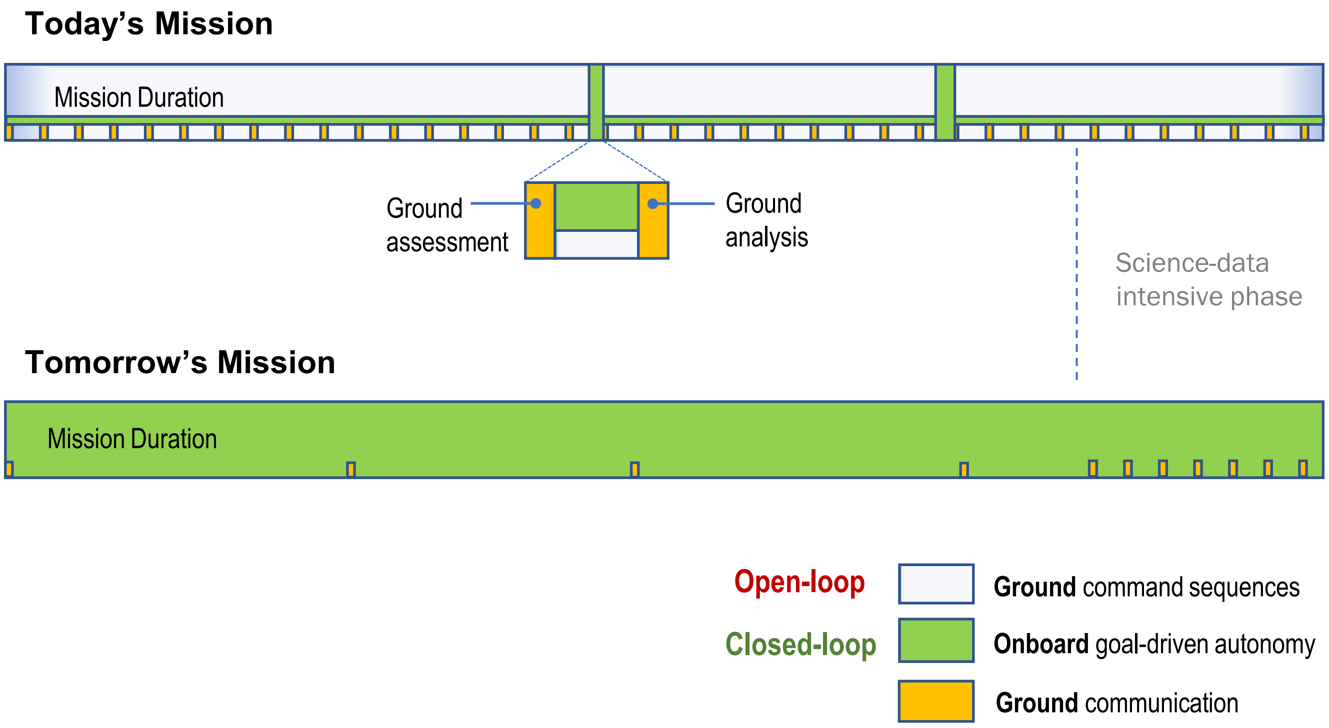
WHERE WE ARE TODAY

FROM

ground-sequenced missions
with large ops teams

TO

autonomous missions
with smaller ops team



Today's Mission

Tomorrow's Mission

Open-loop	☐	**Ground** command sequences
Closed-loop	🟩	**Onboard** goal-driven autonomy
	🟨	**Ground** communication

Principles for Architecting Autonomous Systems

Information and Knowledge:

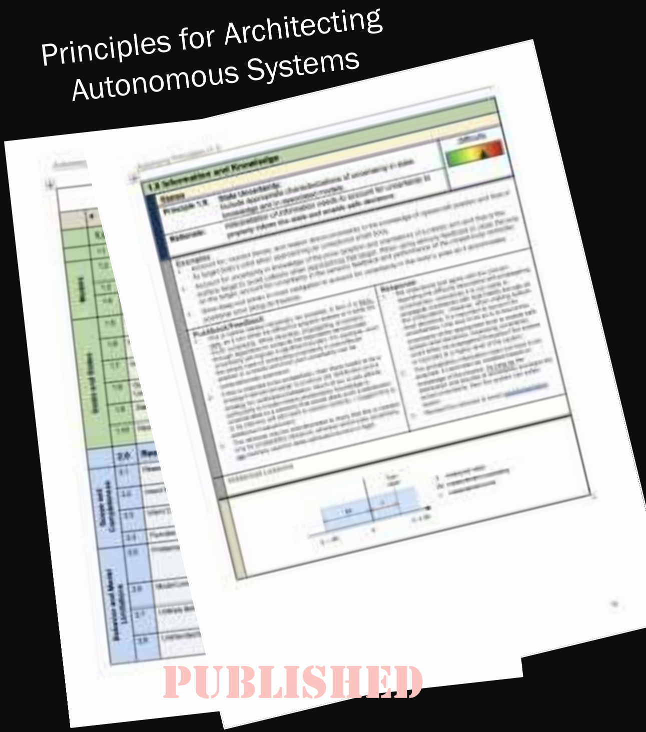
- Be explicit and ensure consistency of information
- Fully represent information (uncertainty, timing, and synchronization)

Reasoning:

- Define reasoning scope, accommodate model limitations, and account fully for all knowledge
- Express and connect intent to action
- Enable flexibility, composability, and traceability
- Ensure resiliency to unknowns/errors from multiple sources (operators, system, devices)
- Explicitly coordinate and synchronize behaviors and actions

Control Behaviors and Actions

- Ensure safety of actions in spite of failures
- Enable management of behaviors and actions
- Understand implications of actions (conflicting, local, long-term)



Nesnas, I. A., Rasmussen, R., & Day, J. (2022). Principles for Architecting Autonomous Systems. AAS

Principles

1. Information and Knowledge

	#	Short Title
	1.1	Explicit Assumptions
Models	1.2	Explicit Models
	1.3	Interconnected Models
	1.4	Abstraction-associated Models
Goals & States	1.5	State Access
	1.6	Fresh Data
	1.7	Goal Uncertainty
	1.8	State Uncertainty
	1.9	Information Delay
	1.10	Reconciled Knowledge

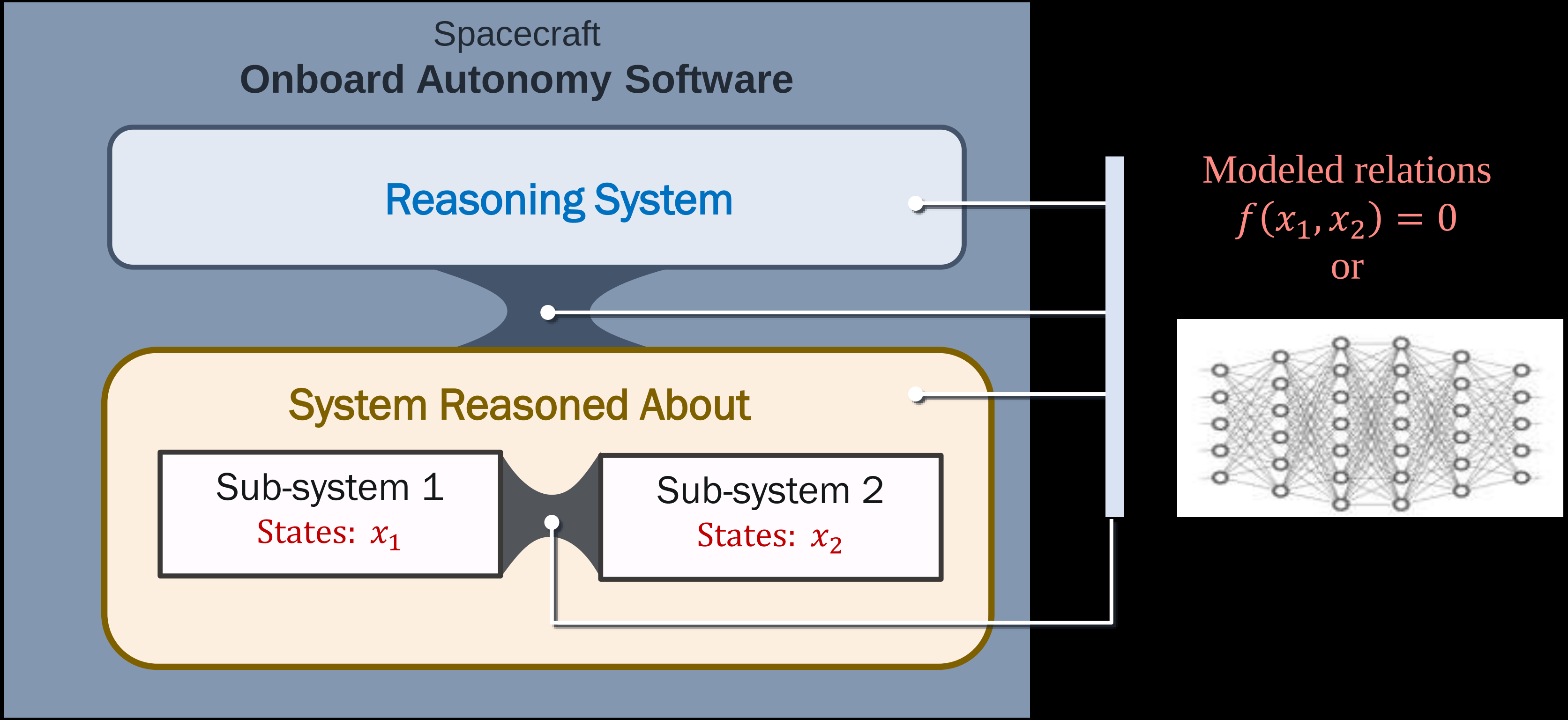
2. Reasoning

	#	Short Title
Scope & Completeness	2.1	Reasoning Scope
	2.2	Intent Elaboration
	2.3	Criteria Completeness
	2.4	Criteria Cognizance
Behavior/ Model Limitations	2.5	Problematic Intent
	2.6	Model Limitations
	2.7	Unlikely Behavior
	2.8	Unintended Behavior
Coherence, Composability, Flexibility, Traceability	2.9	Knowledge-Action Coherence
	2.10	Cooperative Interactions
	2.11	Bidirectional Association
	2.12	Decision Traceability
	2.13	Runtime Flexibility
	2.14	Function Reallocation
Timing	2.15	Temporal Coordination
	2.16	Multi-clock Synchronization
Intelligence	2.17	Least Regret

3. Control Behaviors and Actions

	#	Short Title
Control Behaviors	3.1	Managing Devices/Resources
	3.2	Managing Behaviors
	3.3	Local Behavior
	3.4	Ineffective Behavior
Actions	3.5	Explicit Actions
	3.6	Resolving Conflicts and Addressing Implications

Autonomous Spacecraft Architecture



Spacecraft

Onboard Autonomy Software

Reasoning System

System Reasoned About

Sub-system 1

States: x_1

Sub-system 2

States: x_2

Modeled relations

$f(x_1, x_2) = 0$

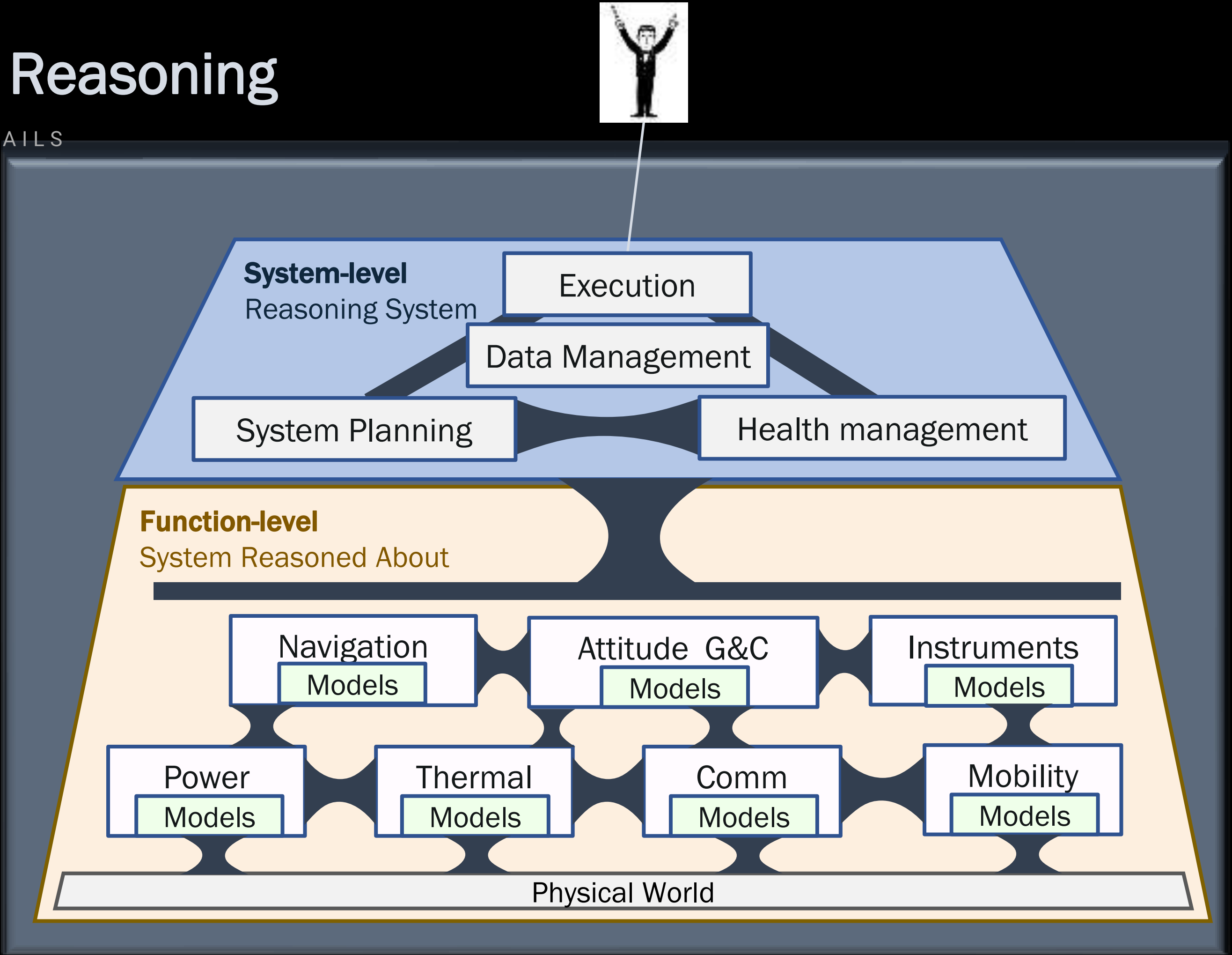
or

Onboard Reasoning

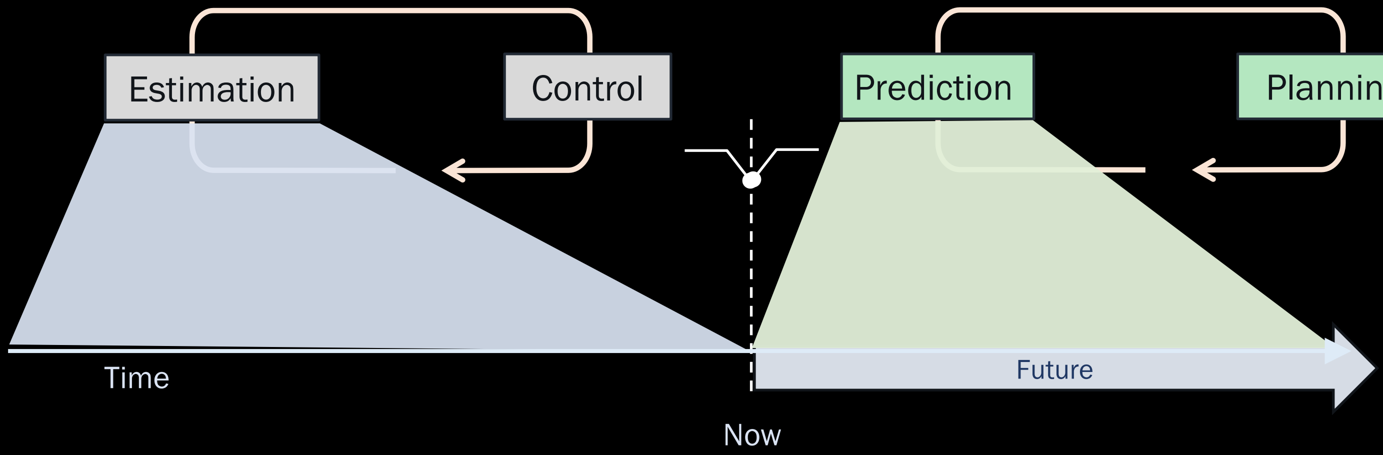
TECHNICAL DETAILS

DOMAIN –
STRUCTURAL VIEW

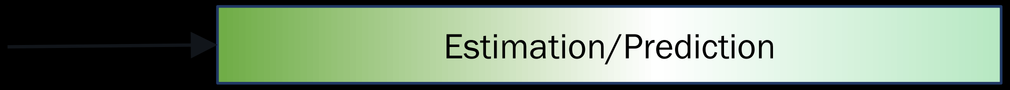
SYSTEM-LEVEL AND
FUNCTION-LEVEL



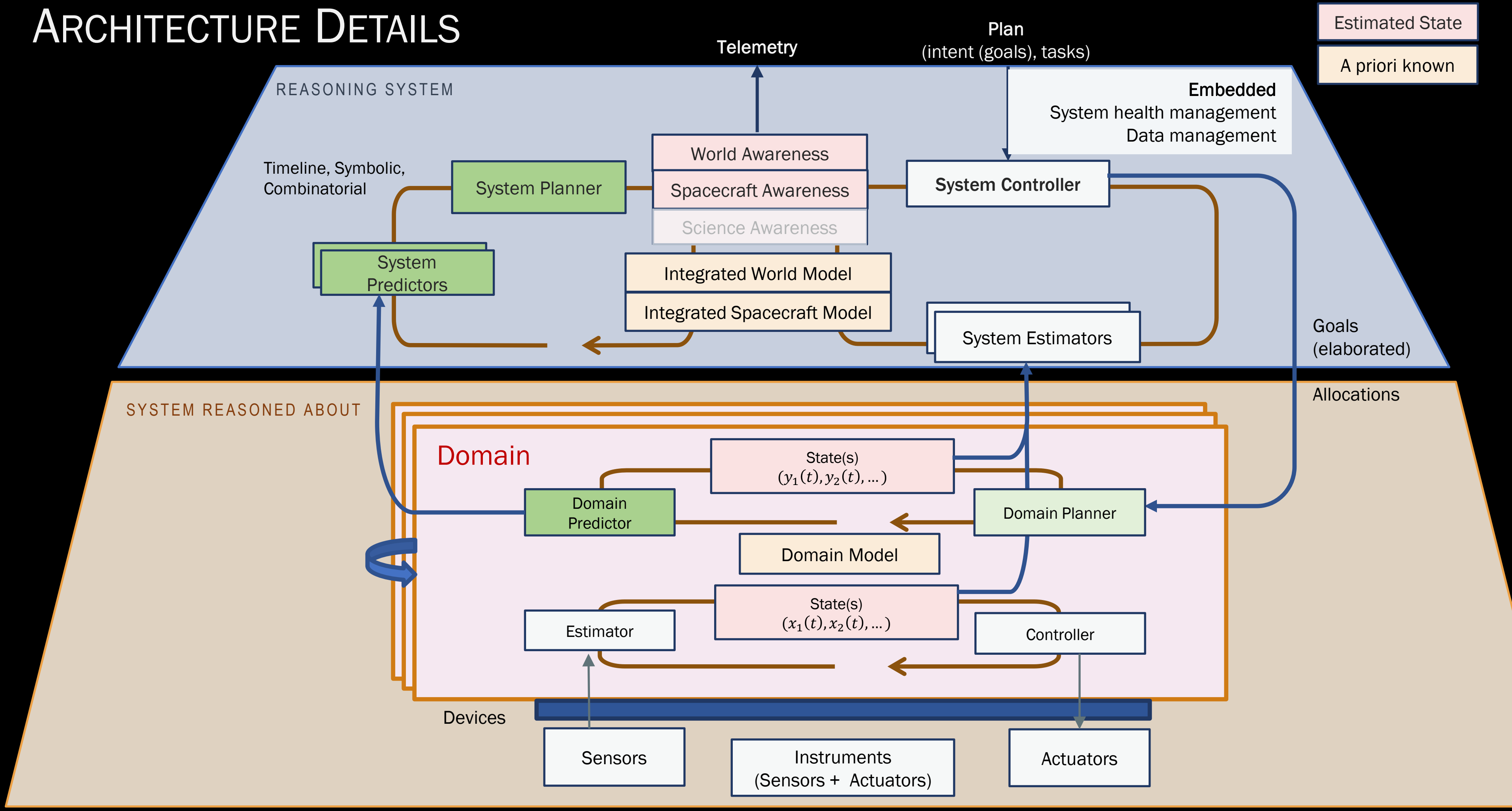
Onboard Reasoning



Sometimes



ARCHITECTURE DETAILS



Estimated State

A priori known

Telemetry

Plan
(intent (goals), tasks)

REASONING SYSTEM

Embedded
System health management
Data management

Timeline, Symbolic,
Combinatorial

System Planner

World Awareness

Spacecraft Awareness

Science Awareness

System Controller

System Predictors

Integrated World Model

Integrated Spacecraft Model

System Estimators

Goals
(elaborated)

Allocations

SYSTEM REASONED ABOUT

Domain

State(s)
$(y_1(t), y_2(t), \ldots)$

Domain Predictor

Domain Planner

Domain Model

State(s)
$(x_1(t), x_2(t), \ldots)$

Estimator

Controller

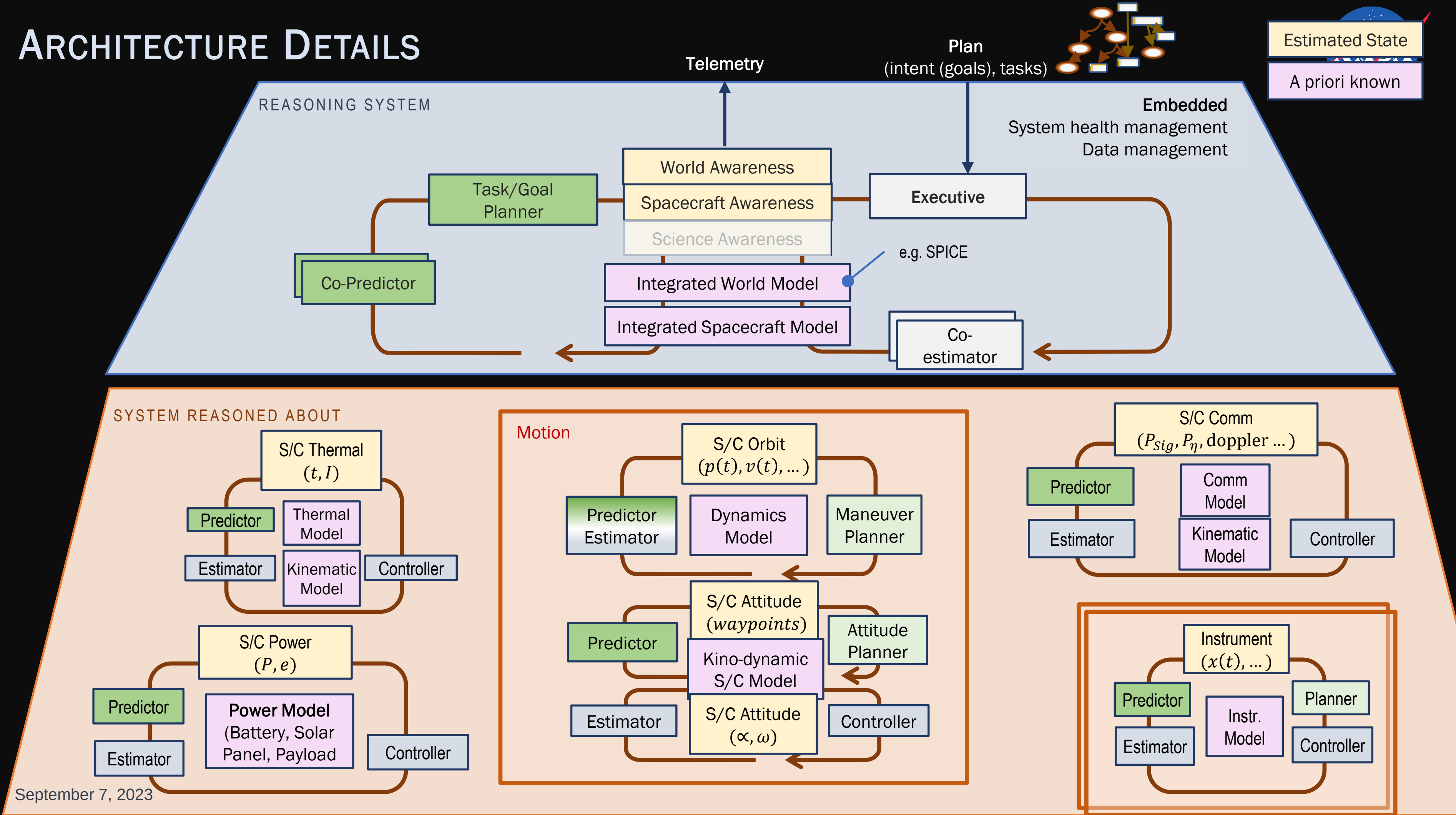
Devices

Sensors

Instruments
(Sensors + Actuators)

Actuators

ARCHITECTURE DETAILS



Estimated State

A priori known

Telemetry

Plan
(intent (goals), tasks)

REASONING SYSTEM

Embedded
System health management
Data management

Task/Goal Planner

World Awareness

Spacecraft Awareness

Science Awareness

Executive

Co-Predictor

Integrated World Model

e.g. SPICE

Integrated Spacecraft Model

Co-estimator

SYSTEM REASONED ABOUT

S/C Thermal
(t, I)

Predictor

Thermal Model

Estimator

Kinematic Model

Controller

S/C Power
(P, e)

Predictor

Power Model
(Battery, Solar Panel, Payload

Estimator

Controller

Motion

S/C Orbit
$(p(t), v(t), \ldots)$

Predictor Estimator

Dynamics Model

Maneuver Planner

S/C Attitude
$(waypoints)$

Predictor

Kino-dynamic S/C Model

Attitude Planner

Estimator

S/C Attitude
$(\propto, \omega)$

Controller

S/C Comm
$(P_{sig}, P_{\eta}, \text{doppler} \ldots)$

Predictor

Comm Model

Estimator

Kinematic Model

Controller

Instrument
$(x(t), \ldots)$

Predictor

Planner

Instr. Model

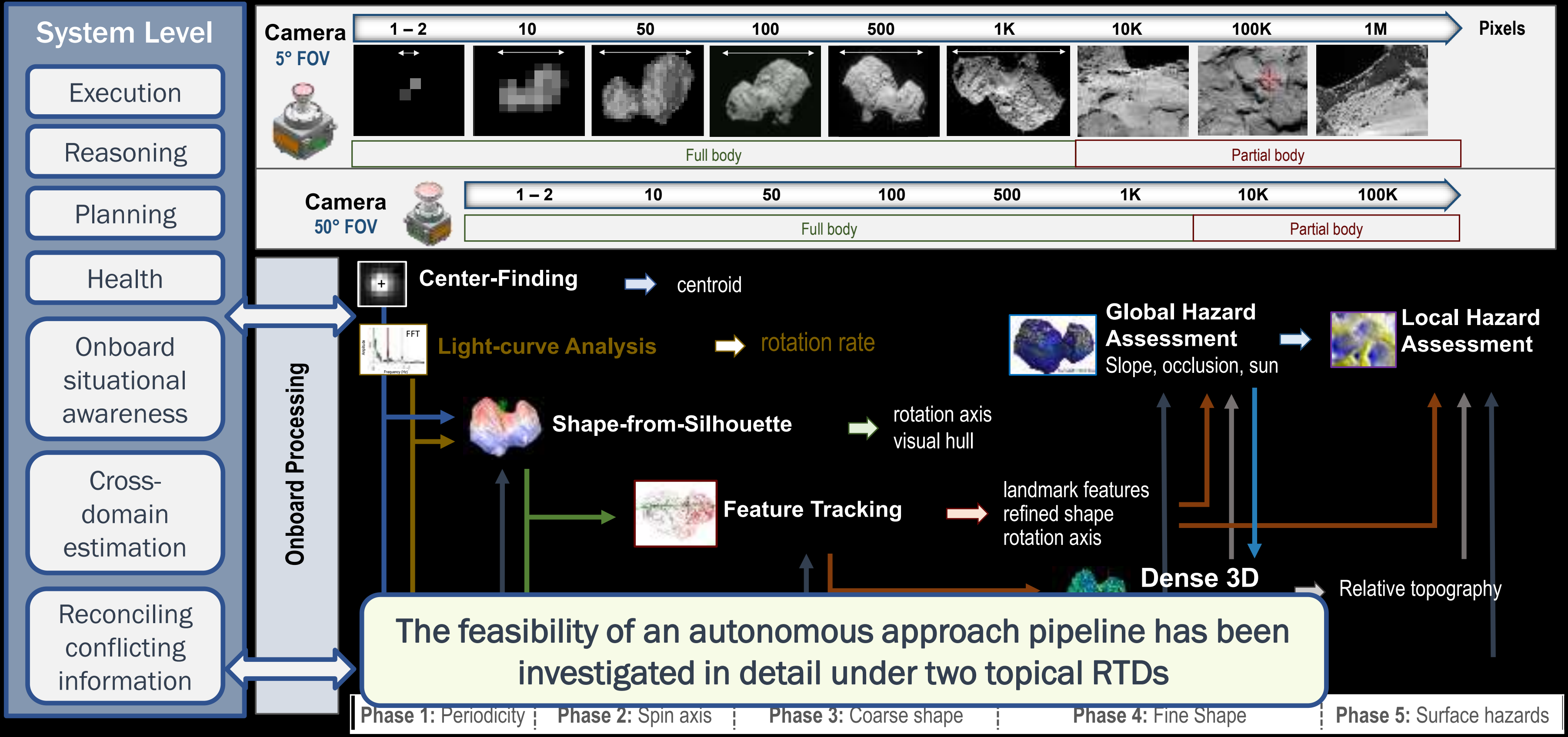
Estimator

Controller

September 7, 2023

FUNCTION EXAMPLE OVERVIEW:

AUTONOMOUS APPROACH NAVIGATION



System Level

- Execution
- Reasoning
- Planning
- Health
- Onboard situational awareness
- Cross-domain estimation
- Reconciling conflicting information

Camera 5° FOV

1 – 2 | 10 | 50 | 100 | 500 | 1K | 10K | 100K | 1M | Pixels

Full body | Partial body

Camera 50° FOV

1 – 2 | 10 | 50 | 100 | 500 | 1K | 10K | 100K

Full body | Partial body

Onboard Processing

Center-Finding → centroid

Light-curve Analysis → rotation rate

Shape-from-Silhouette → rotation axis, visual hull

Feature Tracking → landmark features, refined shape, rotation axis

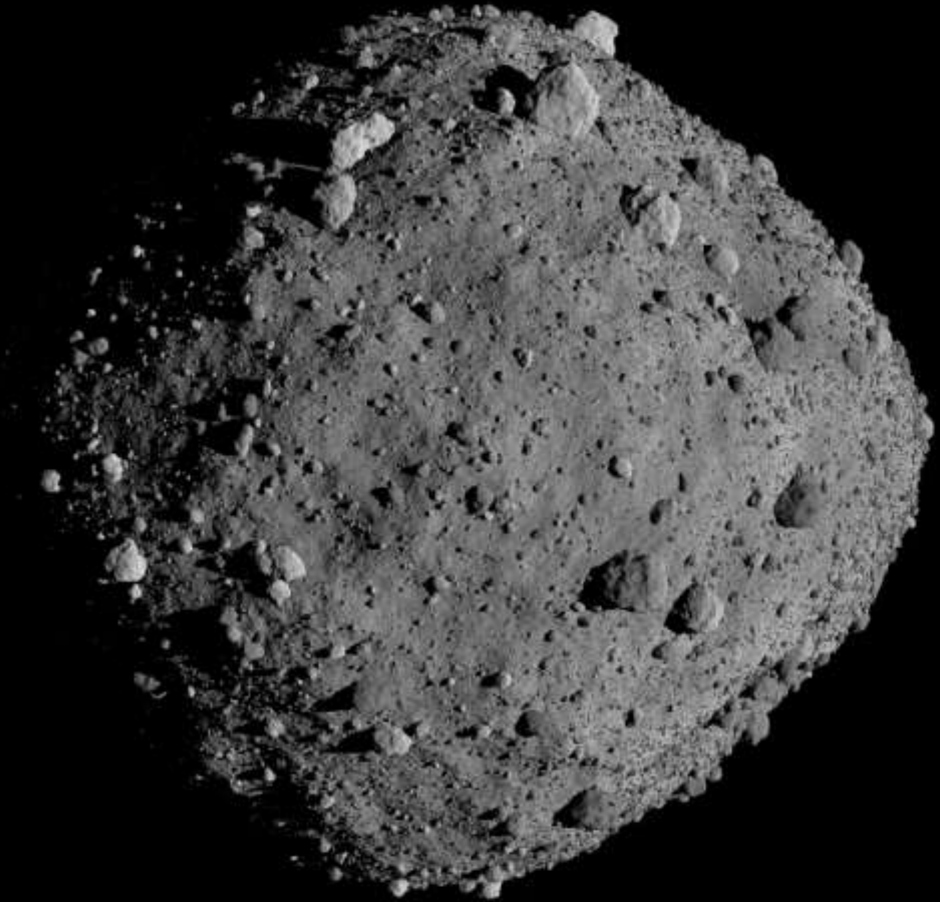
Global Hazard Assessment Slope, occlusion, sun → **Local Hazard Assessment**

Dense 3D → Relative topography

The feasibility of an autonomous approach pipeline has been investigated in detail under two topical RTDs

Phase 1: Periodicity | **Phase 2:** Spin axis | **Phase 3:** Coarse shape | **Phase 4:** Fine Shape | **Phase 5:** Surface hazards

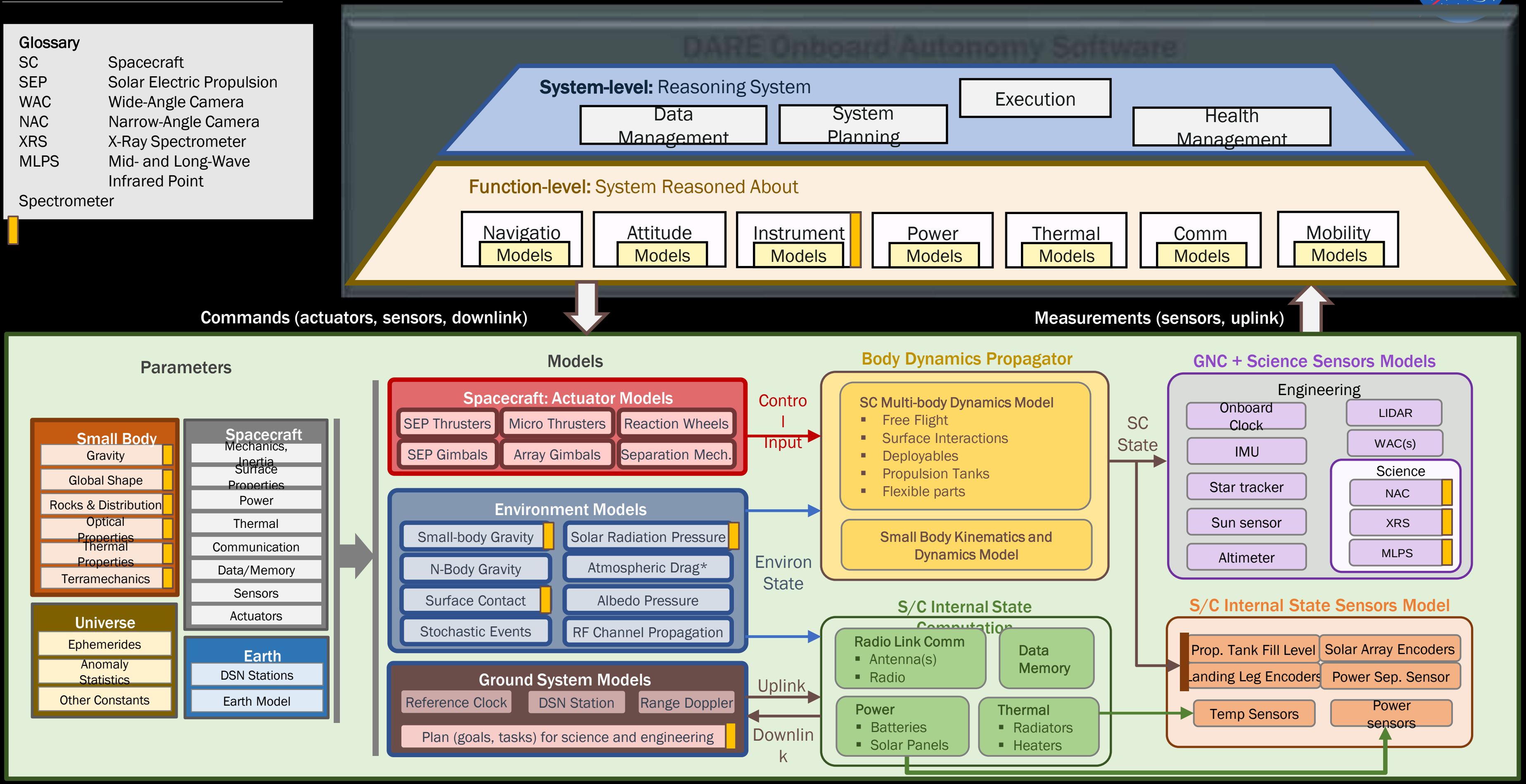
Fully synthetic asteroid based on Bennu shape / noise parameters



DETAILED-LEVEL DESCRIPTION

Glossary

SC	Spacecraft
SEP	Solar Electric Propulsion
WAC	Wide-Angle Camera
NAC	Narrow-Angle Camera
XRS	X-Ray Spectrometer
MLPS	Mid- and Long-Wave Infrared Point Spectrometer



DARE Onboard Autonomy Software

System-level: Reasoning System

Data Management

System Planning

Execution

Health Management

Function-level: System Reasoned About

Navigatio Models

Attitude Models

Instrument Models

Power Models

Thermal Models

Comm Models

Mobility Models

Commands (actuators, sensors, downlink)

Measurements (sensors, uplink)

Parameters

Small Body
- Gravity
- Global Shape
- Rocks & Distribution
- Optical Properties
- Thermal Properties
- Terramechanics

Spacecraft
- Mechanics, Inertia
- Surface Properties
- Power
- Thermal
- Communication
- Data/Memory
- Sensors
- Actuators

Universe
- Ephemerides
- Anomaly Statistics
- Other Constants

Earth
- DSN Stations
- Earth Model

Models

Spacecraft: Actuator Models
- SEP Thrusters
- Micro Thrusters
- Reaction Wheels
- SEP Gimbals
- Array Gimbals
- Separation Mech.

Environment Models
- Small-body Gravity
- Solar Radiation Pressure
- N-Body Gravity
- Atmospheric Drag*
- Surface Contact
- Albedo Pressure
- Stochastic Events
- RF Channel Propagation

Ground System Models
- Reference Clock
- DSN Station
- Range Doppler
- Plan (goals, tasks) for science and engineering

Contro l Input

Environ State

Uplink

Downlin k

Body Dynamics Propagator

SC Multi-body Dynamics Model
- Free Flight
- Surface Interactions
- Deployables
- Propulsion Tanks
- Flexible parts

Small Body Kinematics and Dynamics Model

SC State

S/C Internal State Computation

Radio Link Comm
- Antenna(s)
- Radio

Data Memory

Power
- Batteries
- Solar Panels

Thermal
- Radiators
- Heaters

GNC + Science Sensors Models

Engineering
- Onboard Clock
- IMU
- Star tracker
- Sun sensor
- Altimeter
- LIDAR
- WAC(s)

Science
- NAC
- XRS
- MLPS

S/C Internal State Sensors Model
- Prop. Tank Fill Level
- Solar Array Encoders
- Landing Leg Encoders
- Power Sep. Sensor
- Temp Sensors
- Power sensors

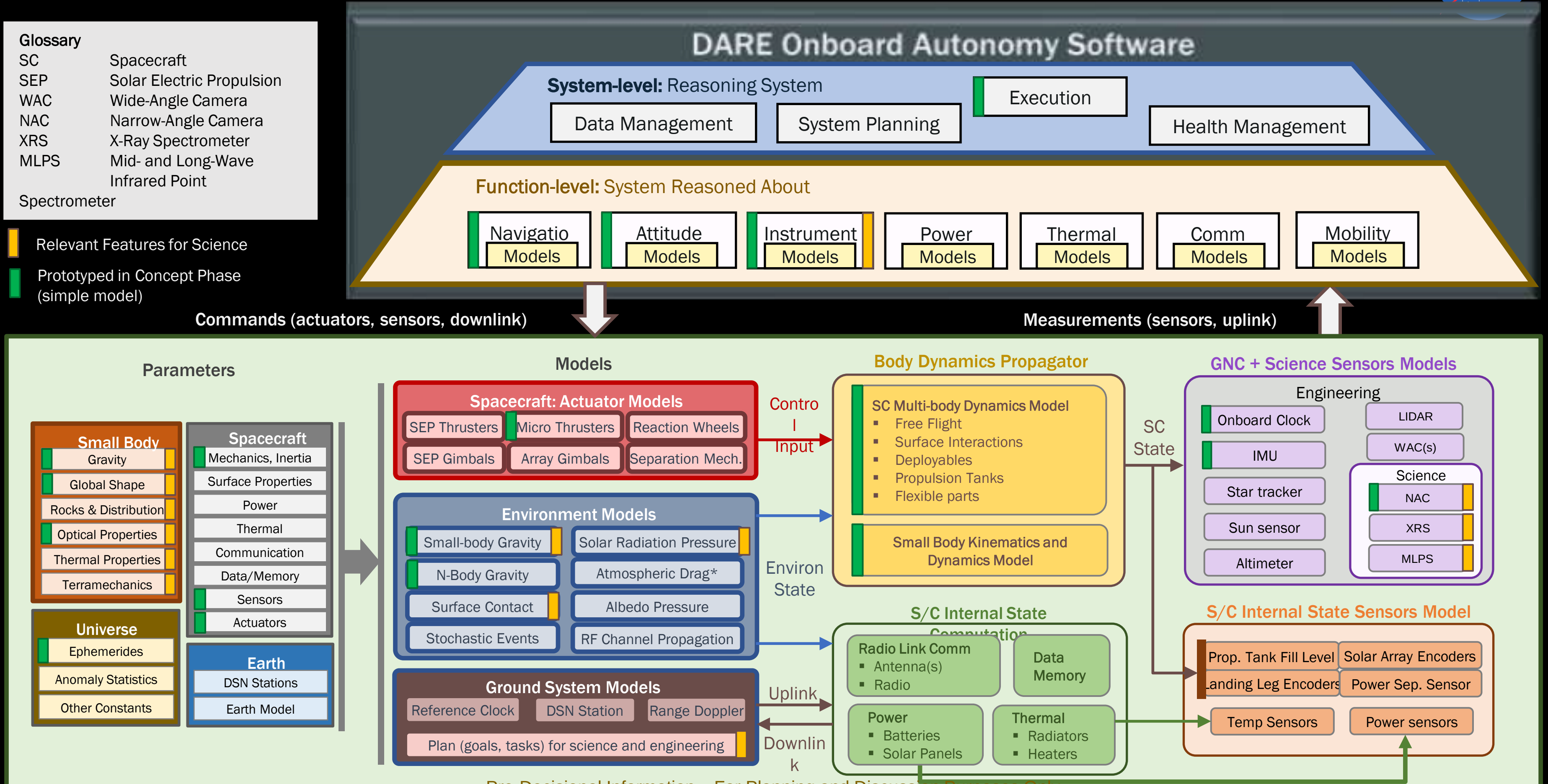
DETAILED-LEVEL DESCRIPTION – PROTOTYPED IN CONCEPT PHASE

Glossary

SC	Spacecraft
SEP	Solar Electric Propulsion
WAC	Wide-Angle Camera
NAC	Narrow-Angle Camera
XRS	X-Ray Spectrometer
MLPS	Mid- and Long-Wave Infrared Point Spectrometer

🟨 Relevant Features for Science

🟩 Prototyped in Concept Phase (simple model)



DARE Onboard Autonomy Software

System-level: Reasoning System

Data Management

System Planning

Execution

Health Management

Function-level: System Reasoned About

Navigatio Models

Attitude Models

Instrument Models

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GNC + Science Sensors Models

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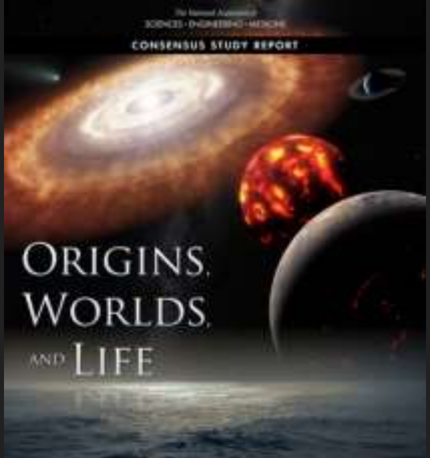
- Temp Sensors
- Power sensors

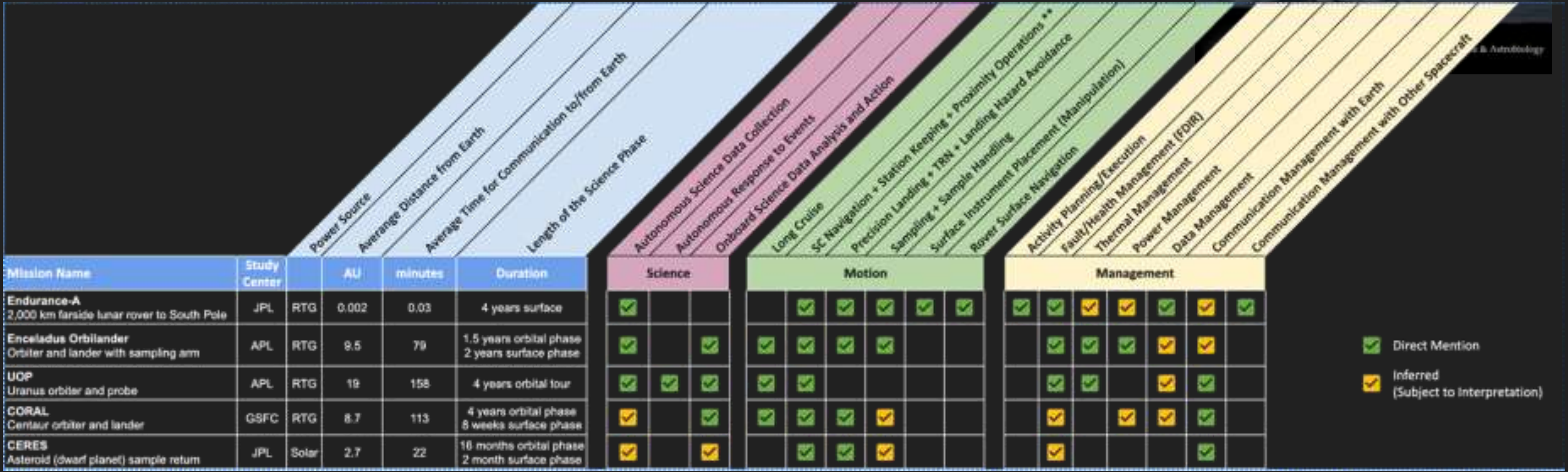
Research

NEXT STEPS

Autonomy Pull in Decadal Mission Concepts

- Direct/indirect references to autonomy needs in mission concepts prioritized by Origins, Worlds and Life decadal survey
- Ranked based on breadth of needs



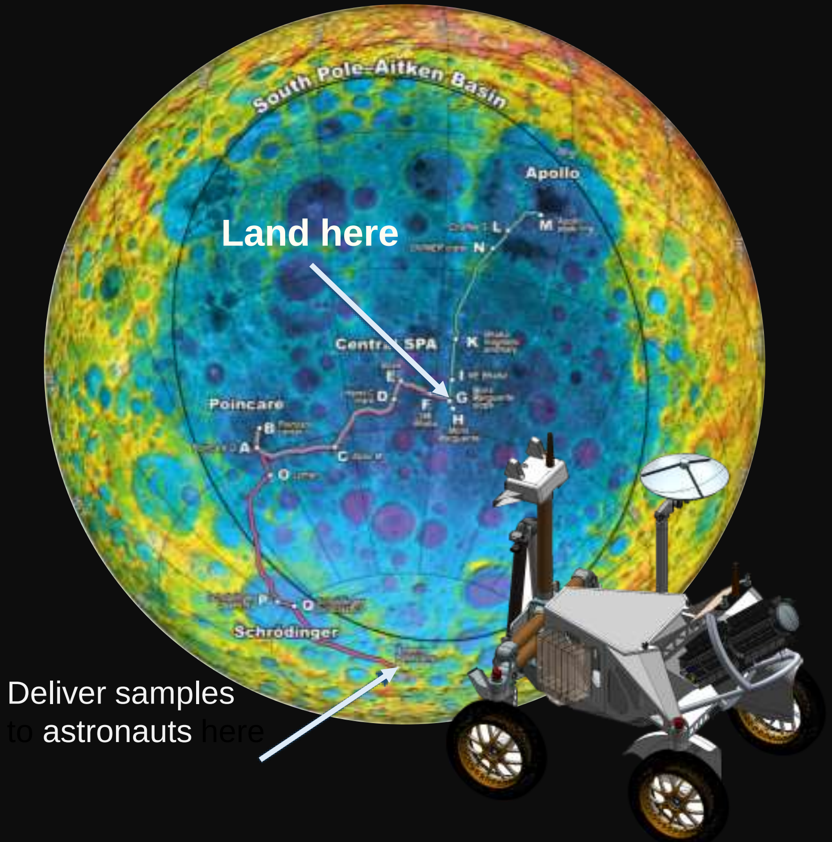


		Power Source	Average Distance from Earth	Average Time for Communication to/from Earth	Length of the Science Phase	Autonomous Science Data Collection	Autonomous Response to Events	Onboard Science Data Analysis and Action	Long Cruise	SC Navigation + Station Keeping + Proximity Operations **	Precision Landing + TRN + Landing Hazard Avoidance	Sampling + Sample Handling	Surface Instrument Placement (Manipulation)	Rover Surface Navigation	Activity Planning/Execution	Fault/Health Management (FDIR)	Thermal Management	Power Management	Data Management	Communication Management with Earth	Communication Management with Other Spacecraft
Mission Name	Study Center		AU	minutes	Duration	Science			Motion						Management						
Endurance-A 2,000 km farside lunar rover to South Pole	JPL	RTG	0.002	0.03	4 years surface	🟩				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟨	🟩
Enceladus Orbilander Orbiter and lander with sampling arm	APL	RTG	9.5	79	1.5 years orbital phase 2 years surface phase	🟩		🟩	🟩	🟩	🟩	🟩				🟩	🟩	🟩	🟨	🟨	
UOP Uranus orbiter and probe	APL	RTG	19	158	4 years orbital tour	🟩	🟩	🟩	🟩	🟩						🟩	🟩		🟨	🟩	
CORAL Centaur orbiter and lander	GSFC	RTG	8.7	113	4 years orbital phase 8 weeks surface phase	🟨		🟩	🟩	🟩	🟩	🟨				🟨		🟨	🟨	🟩	
CERES Asteroid (dwarf planet) sample return	JPL	Solar	2.7	22	18 months orbital phase 2 month surface phase	🟨		🟨		🟩	🟩	🟨				🟨				🟩	

🟩 Direct Mention

🟨 Inferred (Subject to Interpretation)

Endurance: Highest Priority Strategic Medium-Class Mission



Land here

Deliver samples to astronauts here

Scientific Objective

- Determine the age of South Pole-Aitken (SPA) basin, and the other large basins superposing it
- Provide critical new constraints on the Earth and Moon’s bombardment history when life first emerged on Earth

Mission Concept

- A long-range rover that will traverse ~2,000 km across the SPA basin to collect, cache, and bring ~12 samples to the south pole for astronauts to return to Earth

- Rover control
- Rover navigation
- Path planning with continuous replanning
- Terrain Traversability analysis
- Multi-stereo data fusion
- Visual odometry
- Stereovision
- Inertial sensing and estimation
- Manipulation (mast)
- Locomotion
- Mechanism model
- Rover/mast kinematics
- Trajectory generation
- Servo (PID control)
- I/O control

Concluding Thoughts

- Autonomy is becoming increasingly critical for remote exploration, where resources are constrained and environments challenging
- Never-visited-before destinations introduce larger uncertainties
- Exploring the surfaces, sub-surfaces, and extreme environments require decision making without adequate *a priori* data
- Physical contact with planetary surfaces/subsurface is challenging
- Artificial intelligence and machine learning will play a key role in future exploration to handle the aforementioned challenges
- Autonomy will involve reasoning, executing, assessing health, coordinating control and providing assurances
- Autonomy advances will challenge assurance of autonomous spacecraft

Caltech's Center for Autonomous Systems and Technologies (CAST)

Conducts research toward these moonshots

- **Explorers:** terrestrial and space operating in harsh environments
- **Guardians:** monitoring and responding (earthquakes, tsunami)
- **Transformers:** swarm robot collaboration to enable new functions
- **Transporters:** terrestrial and space
- **Partners:** robotic helpers and entertainers

https://cast.caltech.edu/

Explorers: wind tunnel testing

Transporters: flying ambulance

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Mory
Gharib
Caltech


Richard
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Caltech


Dan
Scheeres
UC Boulder


Jay
McMahon
UC Boulder


Marco
Pavone
Stanford

Co-Is and Area Leads


Rashied
Amini
Systems
Eng


Saptarshi
Bandyopadhyay
Simulation


Rob Bocchino
Software


Steve
Chien
System-
level


Ben Hockman
Landing/
surface Phase


Mitch
Ingham
Architecture
V&V

Co-Is and Team Members


Ali Agha


Roxanne
Arellano


David
Bayard


Steve
Chesley


Abhi Jain


Arash
Kalantari


Zach


Scott
Livingston


Dan Lubey


Duy
Nguyen

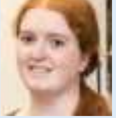

Ben Morrell


Hiro

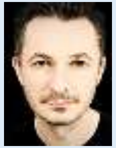

Charles Lee


Gregg
Rabideau


Nicolas
Rouquette


Vivian Steyert


Eric Sunada


Marco Tempest
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Jacopo
Villa


Eric Wood


Zaki Hasnain


Nolan Fey
(intern)

Advisors


Seung Chung


Martin Feather


John Brophy


Lorraine
Fesq


Jeff Levison


Miguel San Martin


Lukas
Mandrake


Marc
Rayman*


Kar-Ming
Cheung


Steve Wissler


Andrew Johnson

BACK SLIDES

Caltech's Center for Autonomous Systems and Technologies (CAST)

Conducts research toward these moonshots

- **Explorers:** terrestrial and space operating in harsh environments
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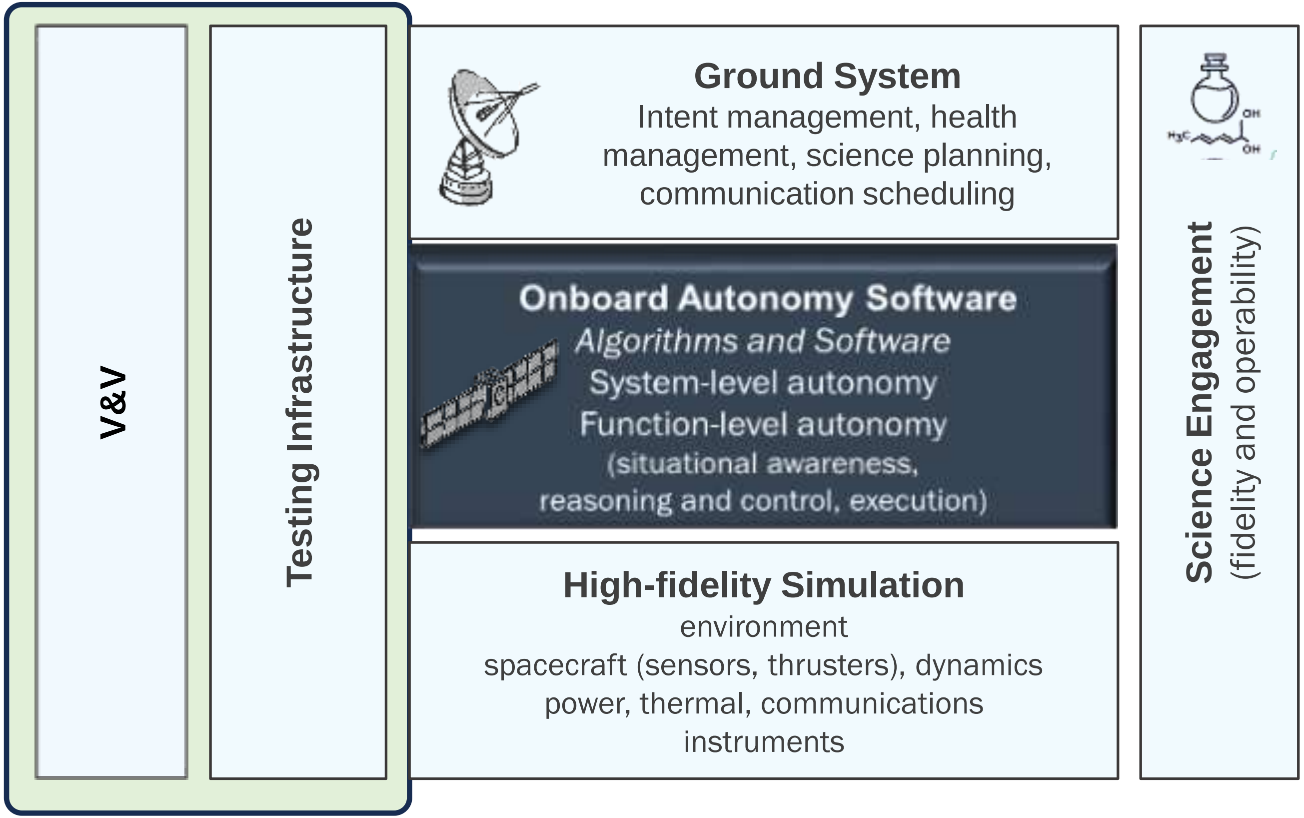
https://cast.caltech.edu/

Explorers: wind tunnel testing

Transporters: flying ambulance

Overall System Perspective



V&V

Testing Infrastructure

Ground System
Intent management, health management, science planning, communication scheduling

Onboard Autonomy Software
Algorithms and Software
System-level autonomy
Function-level autonomy
(situational awareness, reasoning and control, execution)

High-fidelity Simulation
environment
spacecraft (sensors, thrusters), dynamics
power, thermal, communications
instruments

Science Engagement
(fidelity and operability)

What Motivates Planetary Exploration?

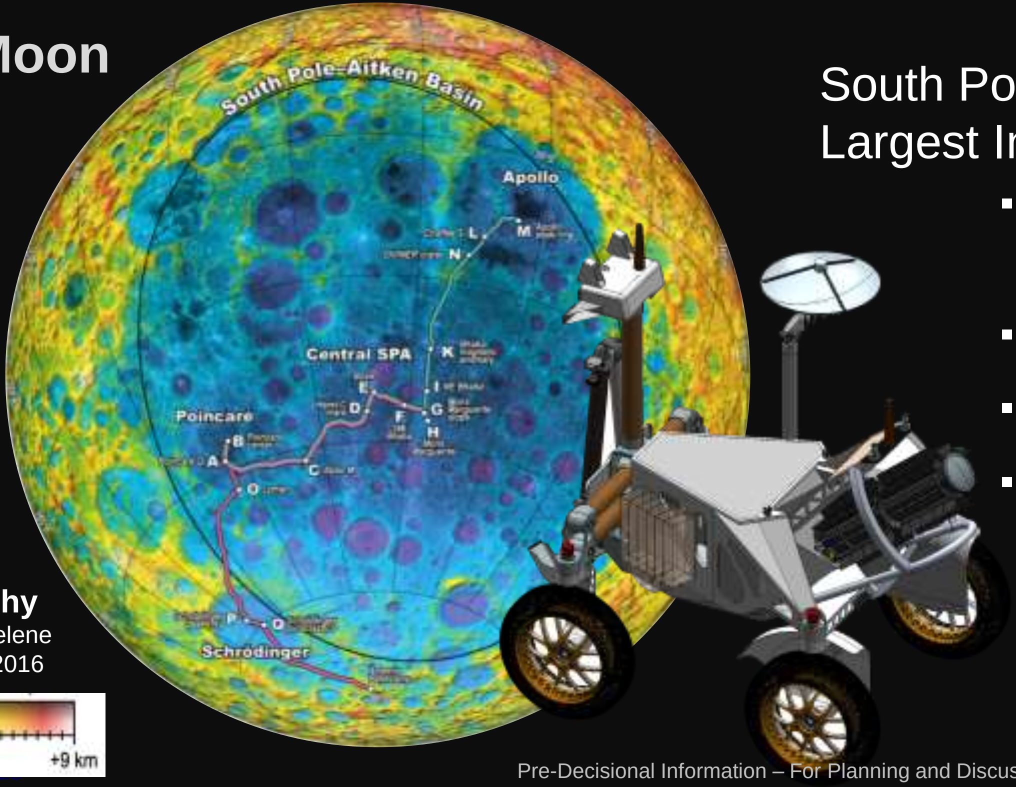
Big science questions:

- Origins
- Worlds and processes
- Life and habitability

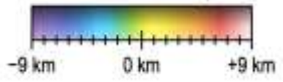
Origins

Example: Endurance – Lunar Sample Return Mission Concept

The Moon



Topography
LRO LOLA / Selene
Barker et al., 2016



South Pole Aitken Basin - oldest and Largest Impact Crater in Solar System

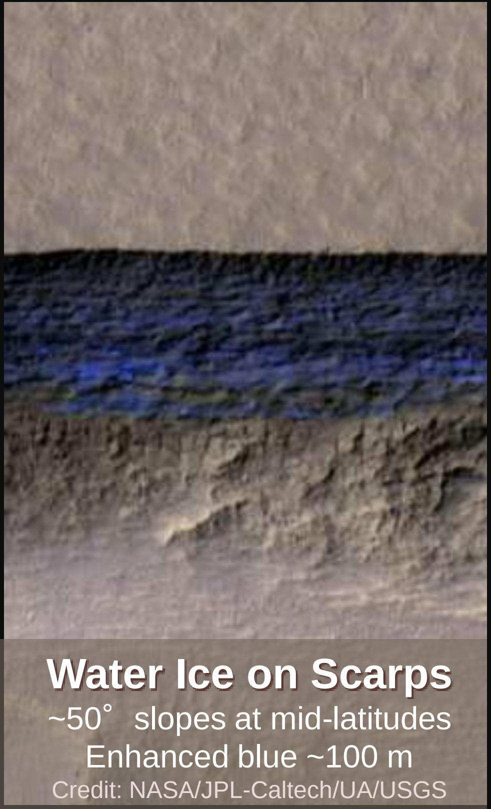
- Collect 12 samples (100 kg) along 2,000 km route
- Drive during day and night
- Bring samples to South Pole
- Astronauts pick up and bring samples to Earth for study

Worlds and Processes

Examples: Uranian System

Evolution of planet, rings, and moons

Martian Ice and Water



Water Ice on Scarps

~50° slopes at mid-latitudes

Enhanced blue ~100 m

Credit: NASA/JPL-Caltech/UA/USGS

Recurring Slope Lineae

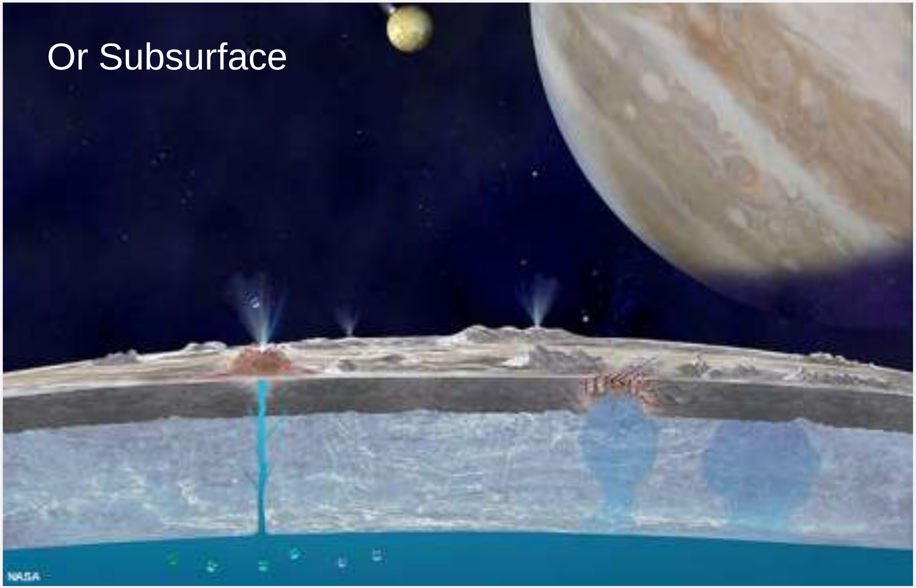
35° slopes

Credit: NASA/JPL-Caltech/UA/USGS
MRO HiRISE

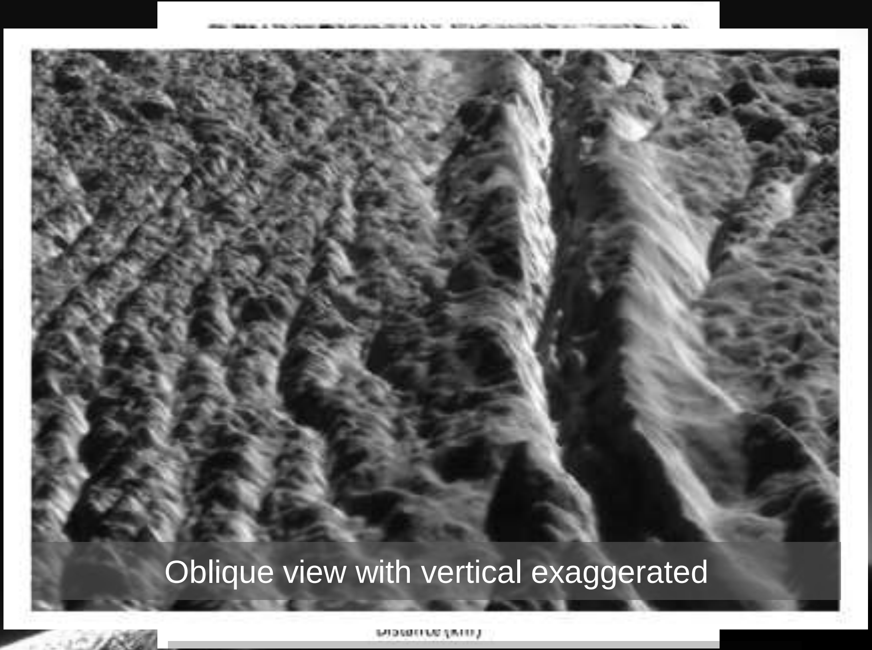
Life and Habitability

Examples: Ocean Worlds

Europa


Or Subsurface

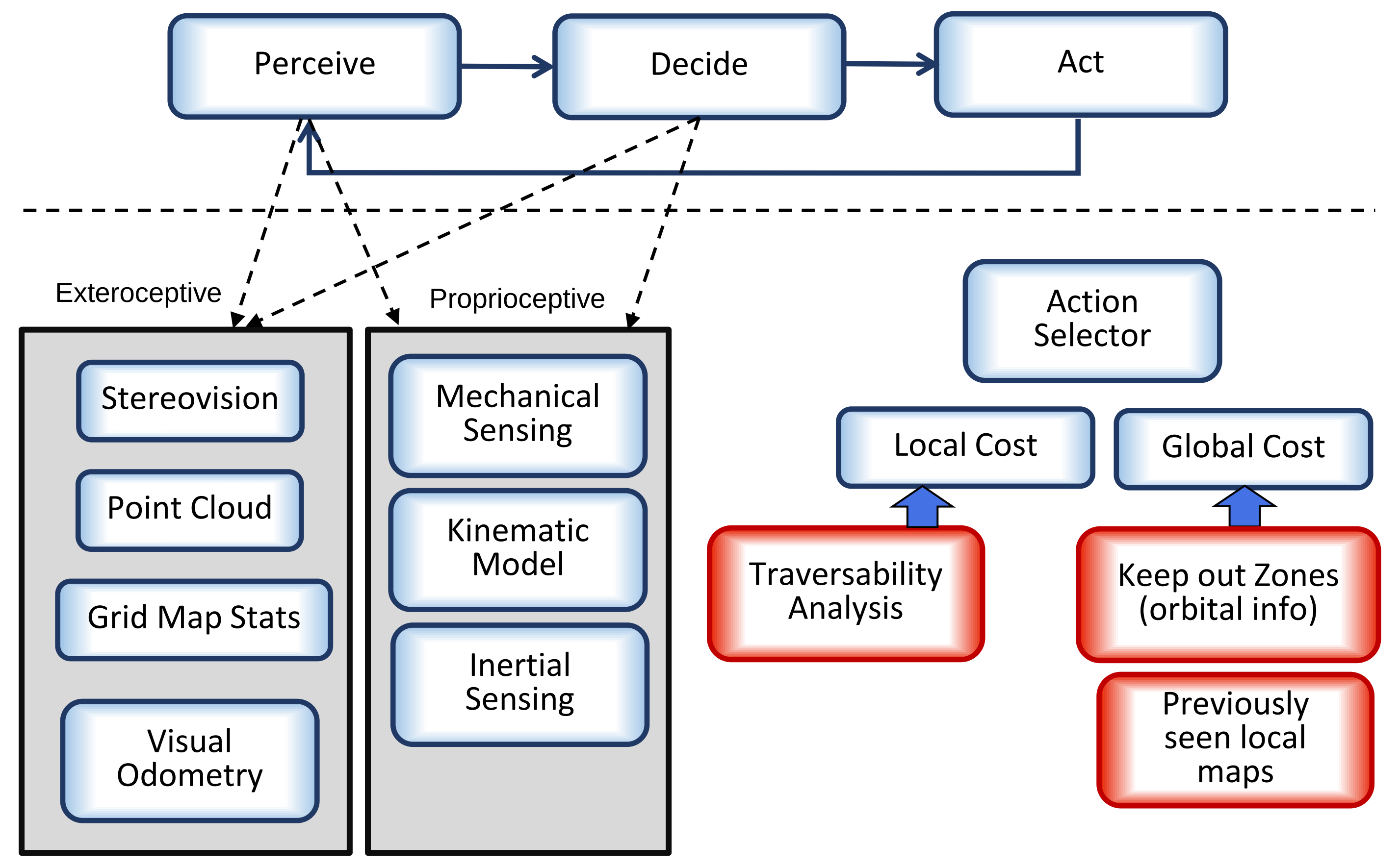
Enceladus


Oblique view with vertical exaggerated

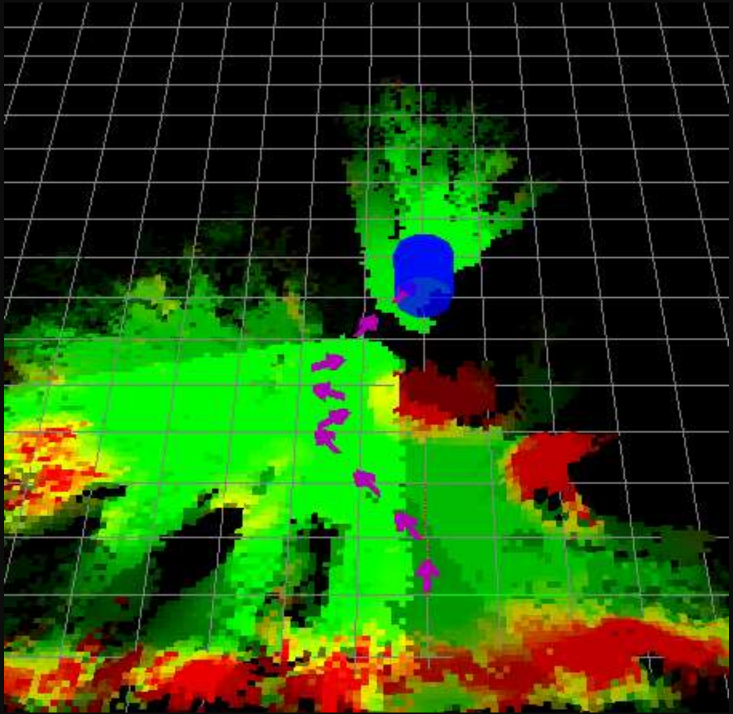
Plumes of Water Ice

Credit: NASA/JPL-Caltech/Space Science Institute

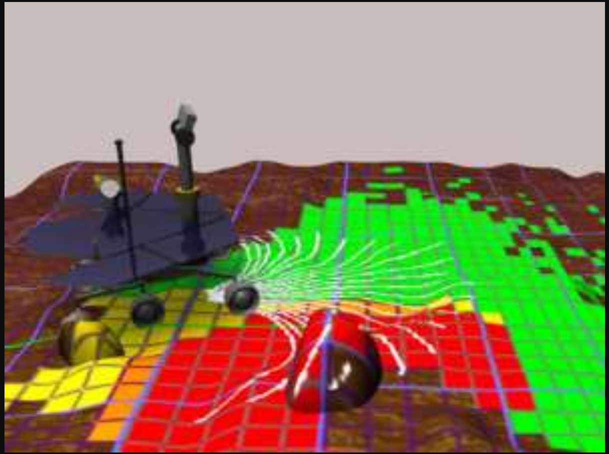
Function-level Autonomy: Onboard Navigation



Terrain Analysis and Hazard Detection

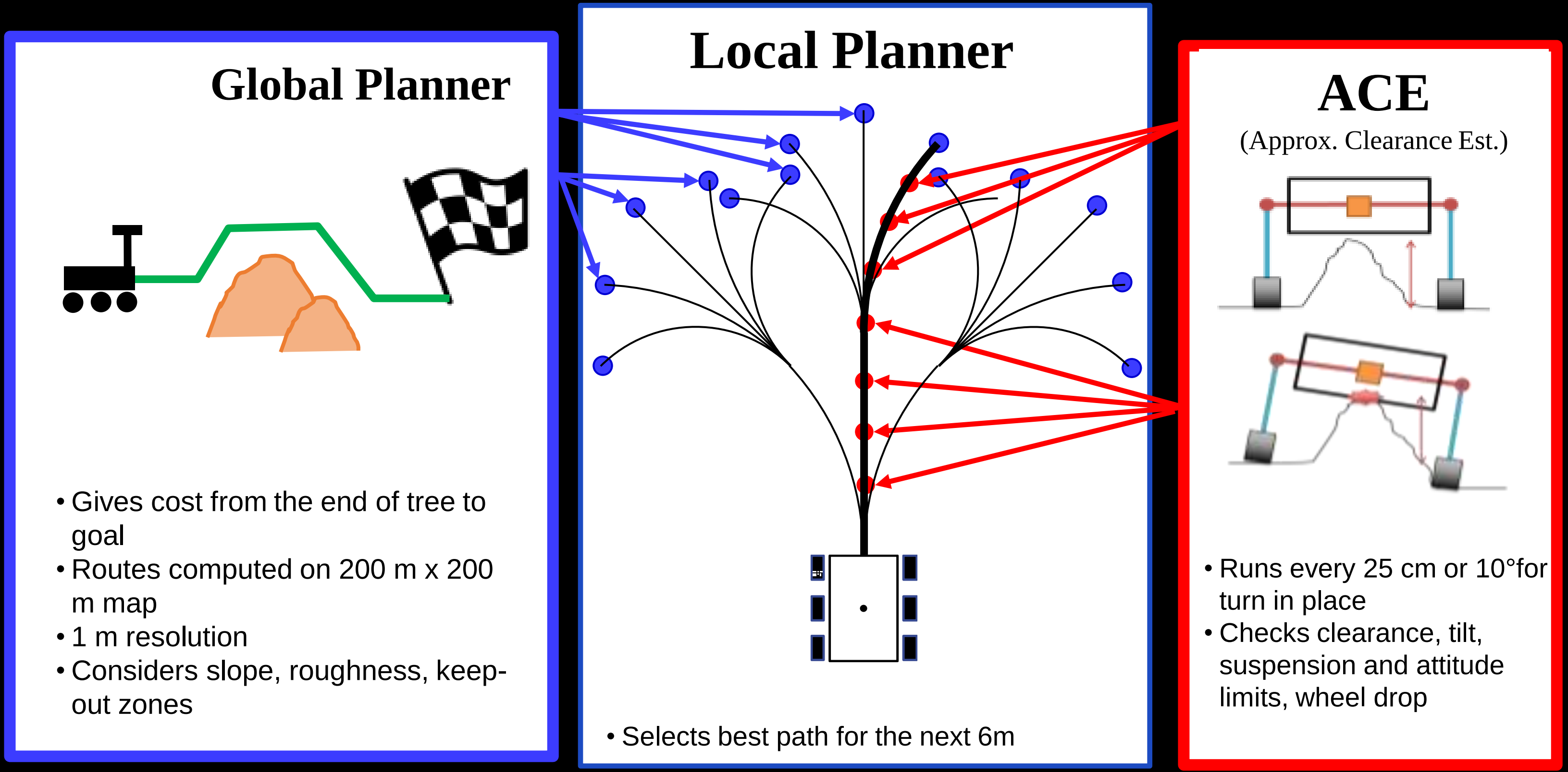


Credit: CLARAty - JPL/Carnegie Mellon – C Urmson, et al.



Credit: JPL/GESTALT navigation – Mark Maimone

Perseverance Enhanced Navigation



Global Planner

- Gives cost from the end of tree to goal
- Routes computed on 200 m x 200 m map
- 1 m resolution
- Considers slope, roughness, keep-out zones

Local Planner

- Selects best path for the next 6m

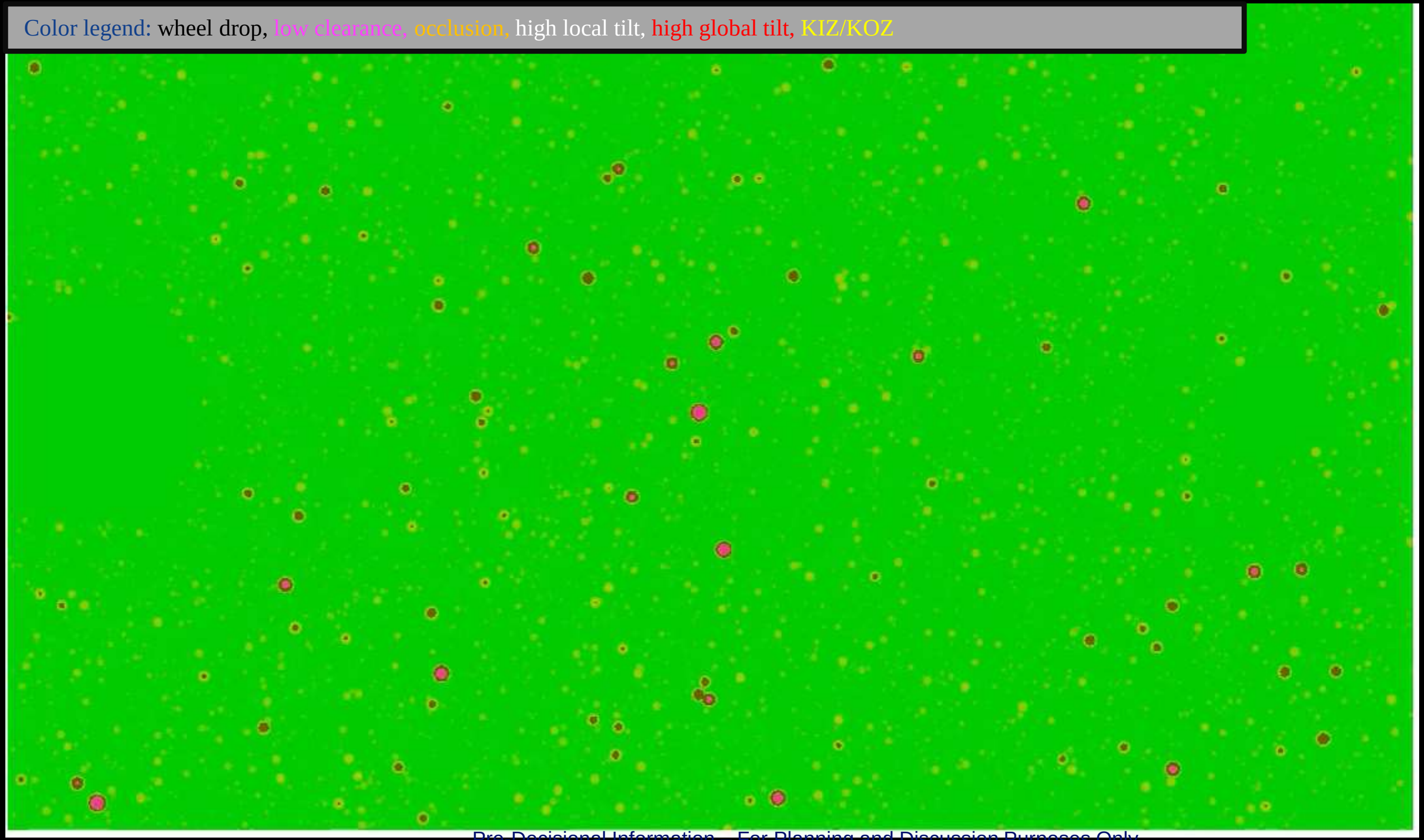
ACE

(Approx. Clearance Est.)

- Runs every 25 cm or 10°for turn in place
- Checks clearance, tilt, suspension and attitude limits, wheel drop

Credit: Olivier Toupet, Hiro Ono, Michael McHenry, Tyler Del Sesto

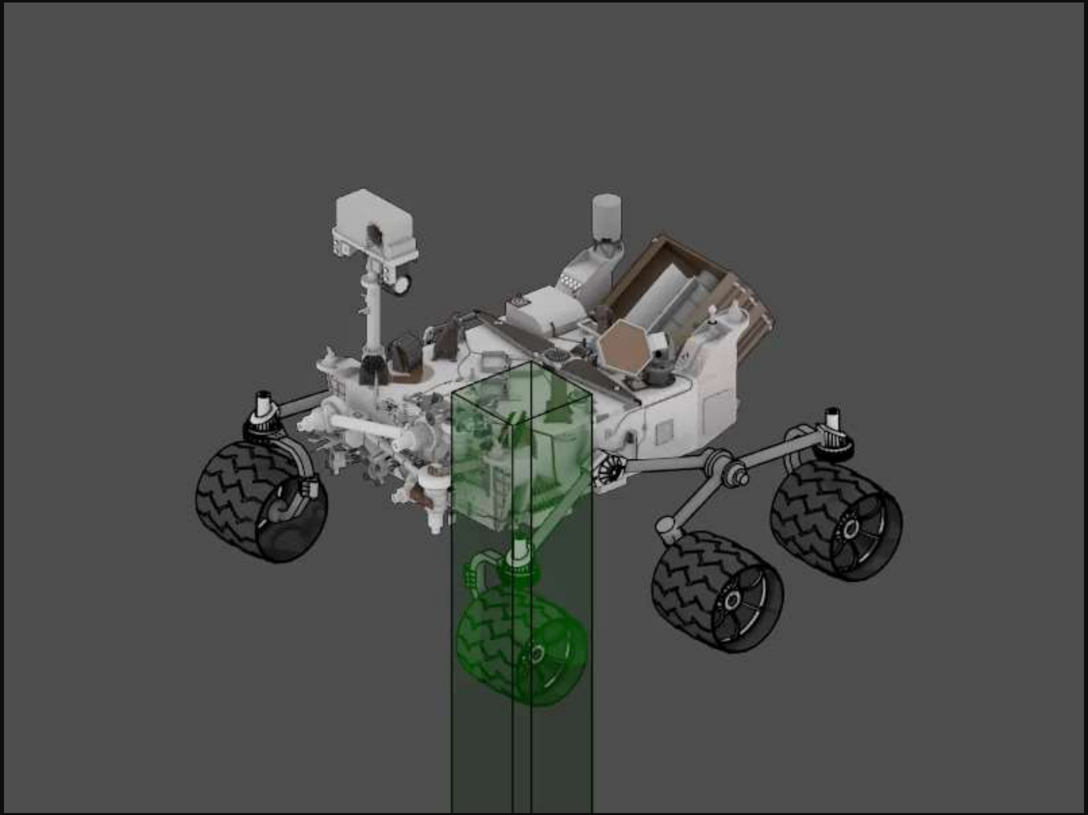
Monte Carlo Simulations



Color legend: wheel drop, low clearance, occlusion, high local tilt, high global tilt, KIZ/KOZ

Credit: Guillaume Matheron, Olivier Toupet, Tyler Del Sesto, Hiro Ono, Michael McHenry

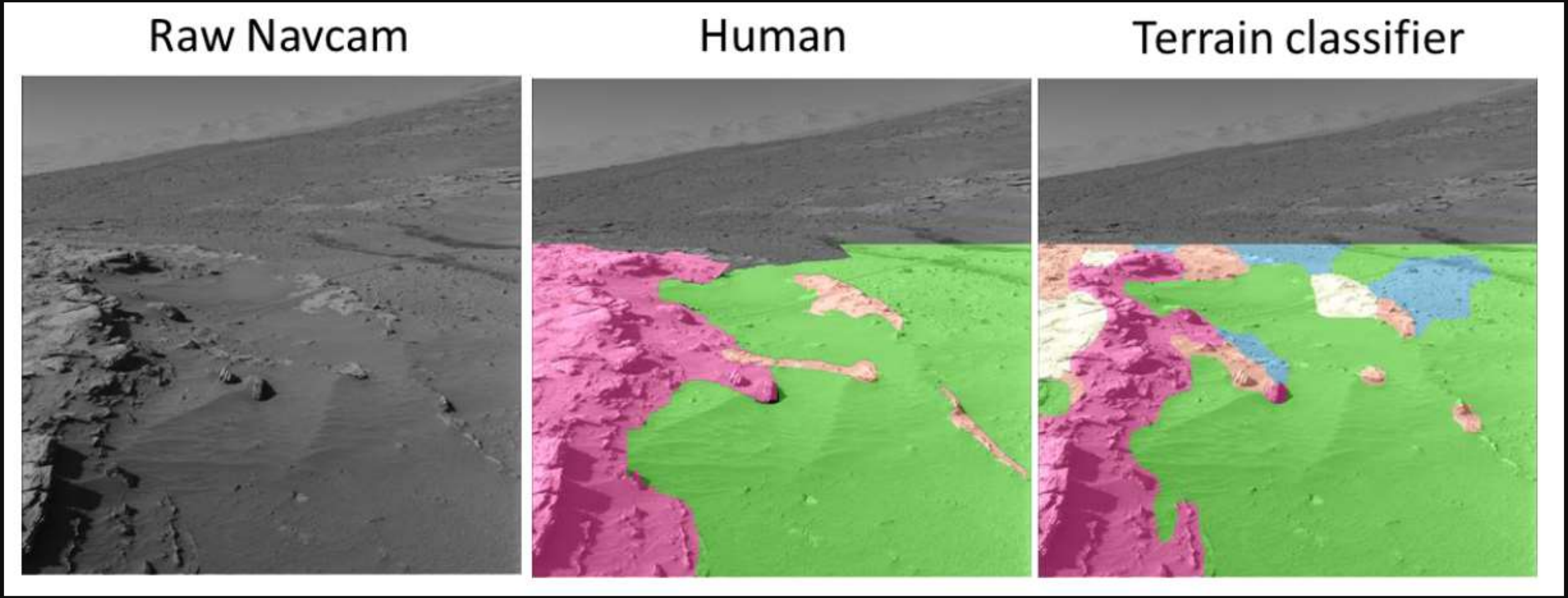
ACE: Approximate Clearance Evaluation



Credit: Guillaume Matheron, Olivier Toupet, Tyler Del Sesto, Hiro Ono, Michael McHenry

Image-based Terrain Classification

Surface Navigation

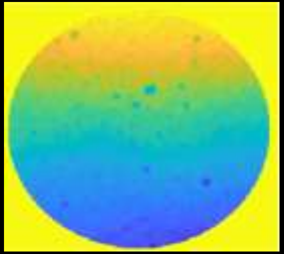


Credit: Hiro Ono

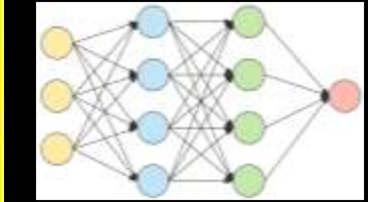
Adaptive Tree Searches

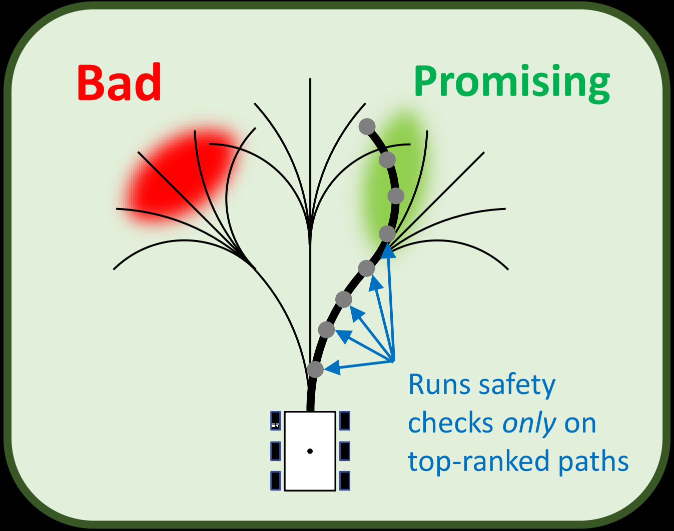
- Machine-learning-based initial terrain assessment to bias search
- Model-based traversability verification

Heightmap

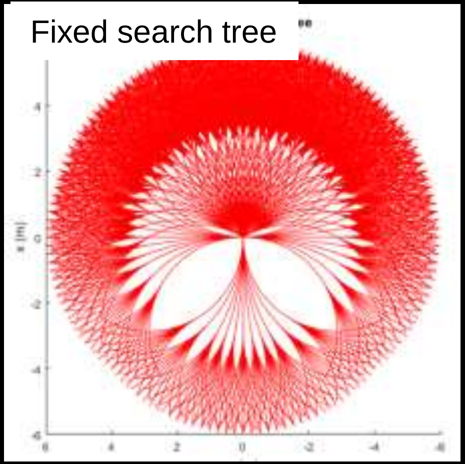


Deep learning

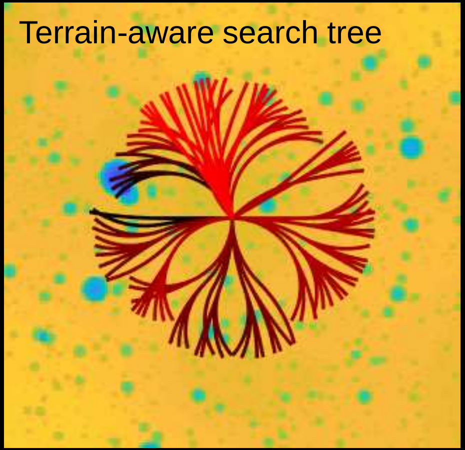




Runs safety checks *only* on top-ranked paths



Fixed search tree



Terrain-aware search tree

N. Abcouwer et al., "Machine Learning Based Path Planning for Improved Rover Navigation," 2021 IEEE Aerospace Conference (50100), 2021, pp. 1-9, doi: 10.1109/AERO50100.2021.9438337.

Mars 2020 Onboard Scheduler

- M2020 Rover mission is developing an onboard scheduler to use remaining resources (time, energy, data volume) from prior onboard execution.
- The Mars 2020 Onboard Scheduler is a (Rabideau and Benowitz 2017)
  - Single-shot, non-backtracking scheduler that
  - schedules in *priority first order* and
  - never removes or moves an activity after it is placed during a single scheduler run.
  - activities are not preempted
  - it does not search except for
    - valid intervals calculations
    - sleep and preheat scheduling.