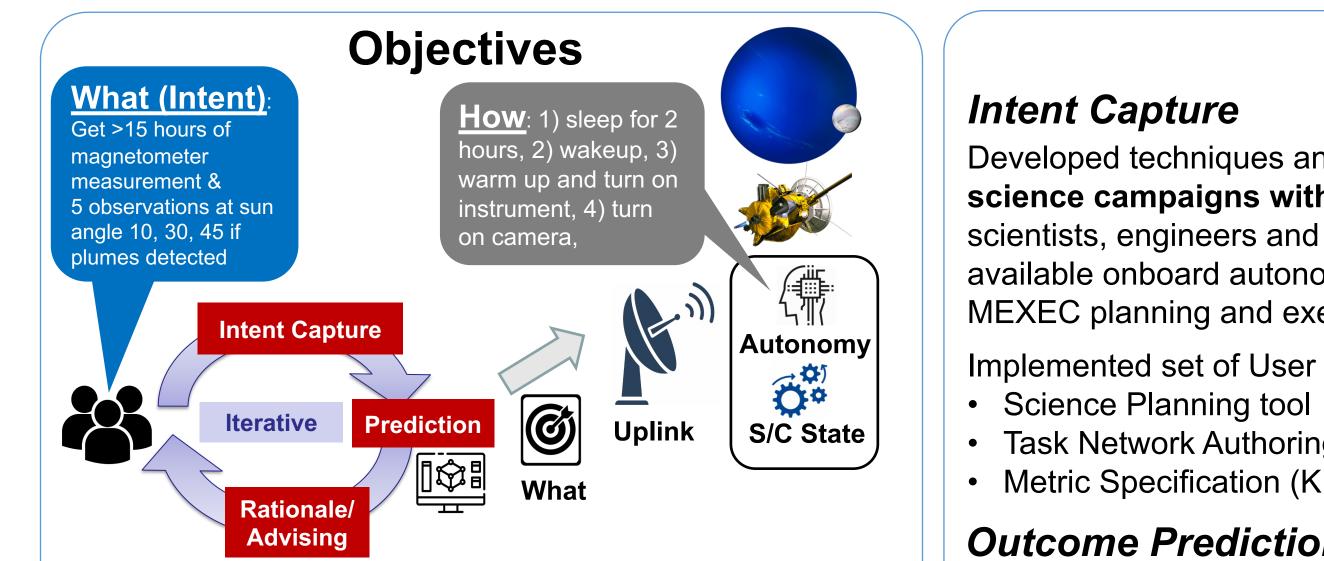


Mission Operations Planning for Increasingly Autonomous Spacecraft

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Program: FY22 R&TD Strategic Initiative

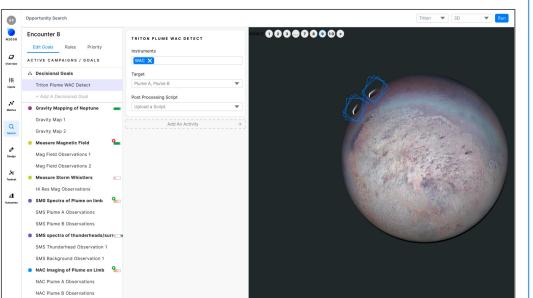
Strategic Focus Area: Operations for Autonomous Spacecraft - Strategic Initiative Leader: Rebecca Castano



Approach and Results

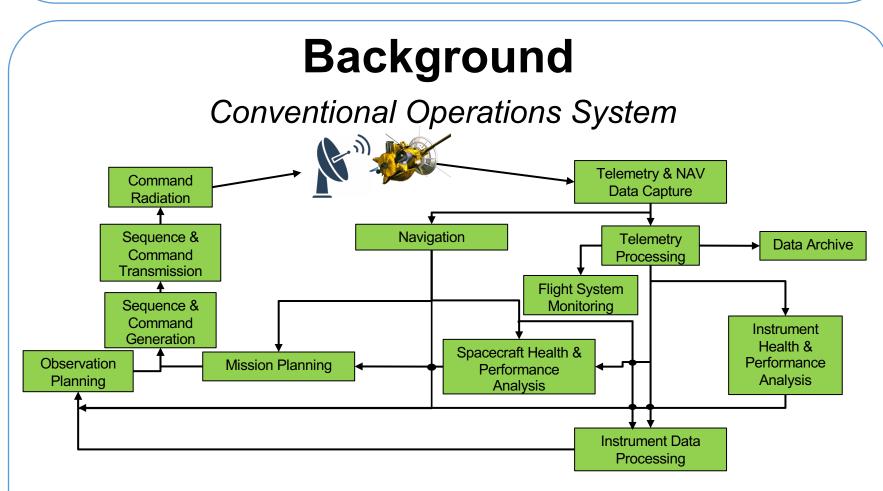
Developed techniques and software tools to capture science campaigns with hierarchical goals from scientists, engineers and operators based on the available onboard autonomy capabilities (e.g. MEXEC planning and execution system).

Implemented set of User Interfaces (leverages [1]):

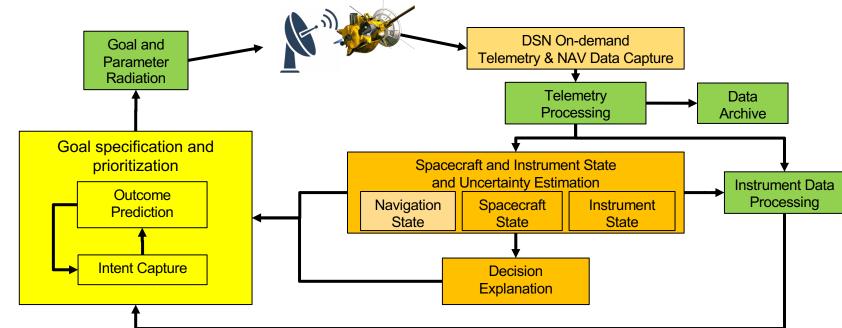


Objective: Develop technology to enable operations to

- Capture, model and communicate science and engineering intents to the spacecraft.
- Predict and understand the possible executions and outcomes to help them reassure that the spacecraft will achieve the target intents.



Future Operations System for Autonomous Spacecraft



- Task Network Authoring tool
- Metric Specification (KPI) tool

Outcome Prediction

Developed techniques to compute and communicate range of possible executed behaviors and outcomes based on uncertainty models to confirm that the plan is safe, suitable, sufficient, and to adjust the goals when those criteria are not met.

Implemented Prediction Engine (leverages [2]):

- Monte Carlo Simulation approach
- Environmental, science and engineering variability
- Cloud computing for scalability

Implemented set of User Interfaces:

- Variability Specification tool
- Prediction Results tool
- Mission Impact tool

User Study

Developed scenario with competing goals for two uplink-downlink cycles for a notional Neptune-Triton multi-flyby mission exercising:

- Onboard planning and scheduling;
- Science event detection:
- Plume, storm, gravity, magnetic field observations.

Developed a detailed **simulation environment**.

Assessed the performance of the proposed tools with JPL scientists, engineers and operators.

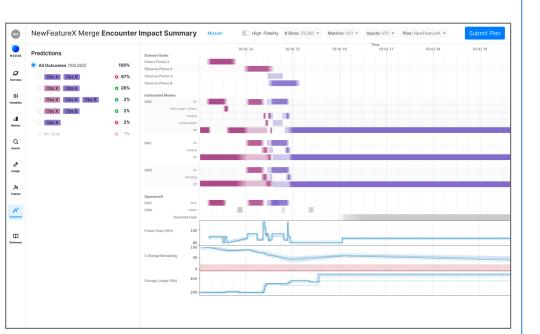
Science Planning tool

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Task Network Authoring tool

	Science Objective	The Phys	nes iical Parameters	Observables		Approaches						
	Constrain the structure and characteristics of the planet's interior, including layering, locations of convective and stable regions, internal dynamics	1 Gravity moments, J2-J6 (not a driver at Uranus)		Perturbations to s/c orbit	1A	Gravity Mapping of Neptune +	Metric Metric Name Gravity Mapping of Neptune					
				Astrometric observations of rings and satellites	18	NAC/WAC Observations of rings and sat	Goals and Campaigns Search for goals and Campaigns					
	Improve knowledge of the planetary dynamo (Neptune)		In situ magnetic field direction and magnitude. Magnetic moments	Magnetic field direction and magnitude	1A	Measure Magnetic Field +	× Gravity Map of Neptune					
			Mugnetic moments				Progress M	easure	ment			
	Determine surface composition of rings and moons, including organics; search for variations among moons, past and current modification, and evidence of long-term mass exchange / volatile transport	 Search for plumes and identify spatial and temporal variability in activity and dynamics 		Scattered sunlight from al plumes	14	WAC Spatial coverage - looking for plur			Script			
			O R Scattered sunlight from	18		Measured Quantity calculateCoverage.py						
	transport			plumes	18	SMS Spatial coverage - looking for plur						
		2	Structure and Composition of plumes and temporal variability	Spectral lines of water and other species	14	SMS spectra of plume on limb +	Required Guideline		≥ ♥	2	Periapses/ Periapses/	
				Scattered sunlight from plumes	18	NAC Imaging of Plume on Limb +	Duration	Ŧ	2.	30		n
							Altitude		<	1000		3
	Understand heat flow and radiation balance in giant planets.	1	Vertical motions and composition of the atmosphere	Clouds, thunderheads, lightning. Spatial distribution of key species (water,	14	SMS spectra of thunderheads/surround WAC Imaging of storm +	New Paran	neter				
			autospilere	ammonia, etc)		The imaging of storm	Metrics Pro	gress				
		AND					Progress to	date				
		2	Large scale horizontal motions	Cloud tracking	2 A	WAC images of entire disc +	Required		-			
							NEPTUN BI STORM	E				

Metric Specification tool



Onboard *autonomy enables* missions such as outer planets flybys and surface operations in adverse environments when ground-in-the-loop operations are not feasible due to to *bandwidth*, *latency*, limited *lifetime*.

Current operational capabilities are not designed for spacecraft with such onboard autonomous capabilities.

New tools and workflows are needed to support the iterative design process of intents in order to gain operator/scientist trust in the onboard autonomy.

Results: tools successfully supported the necessary uplink tasks and helped users gain trust in the autonomy capabilities.

Prediction Results tool

Significance/Benefits to JPL and NASA

- Ability to make **full use of autonomy capabilities**, and to achieve missions that require such autonomy.
- Provides a practical path to 'trusting' the autonomy.
- Path to reduced operations costs.
- Working closely with MGSS towards future integration with AMMOS.
- Ongoing discussions on infusion possibilities with autonomy projects and mission concepts at JPL including CADRE, DARE, EELS.

References: [1] Chien, S., et al. Activity-based Scheduling of Science Campaigns for the Rosetta Orbiter. Int. Joint Conf. on Artificial Intelligence (IJCAI), 2015. [2] Chi, W., et al. Active Learning and Importance Sampling Applied to Monte Carlo Simulations of Automated Scheduling, JPL Data Sciences Working Group, 2019.

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Publications:

[A] Castano, R. et al.. Operations For Autonomous Spacecraft: Workflows And Tools For A Neptune Tour Case Study. Lunar and Planetary Science Conference, 2022. [B] Castano, R. et al. Operations for Autonomous Spacecraft. IEEE Aero Conf., 2022. [C] Vaguero, T. S. et al. A Knowledge Engineering Framework for Mission Operations of Increasingly Autonomous Spacecraft. In KEPS workshop, Int. Conf. on Auto. Plan. and Sch., 2022.

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