National Aeronautics and Space Administration

Mission Operations Planning for Increasingly Autonomous Spacecraft

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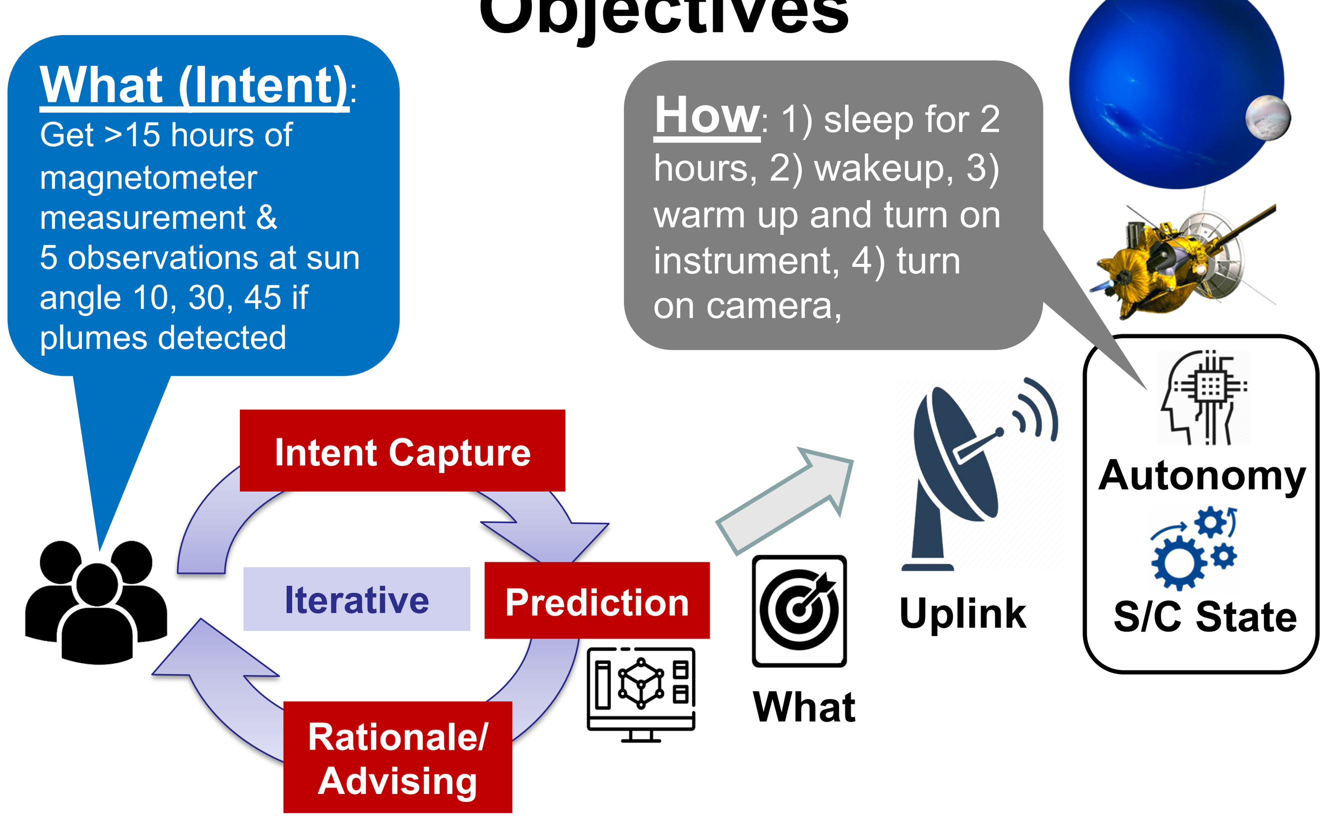
Program: FY22 R&TD Strategic Initiative

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

Objectives

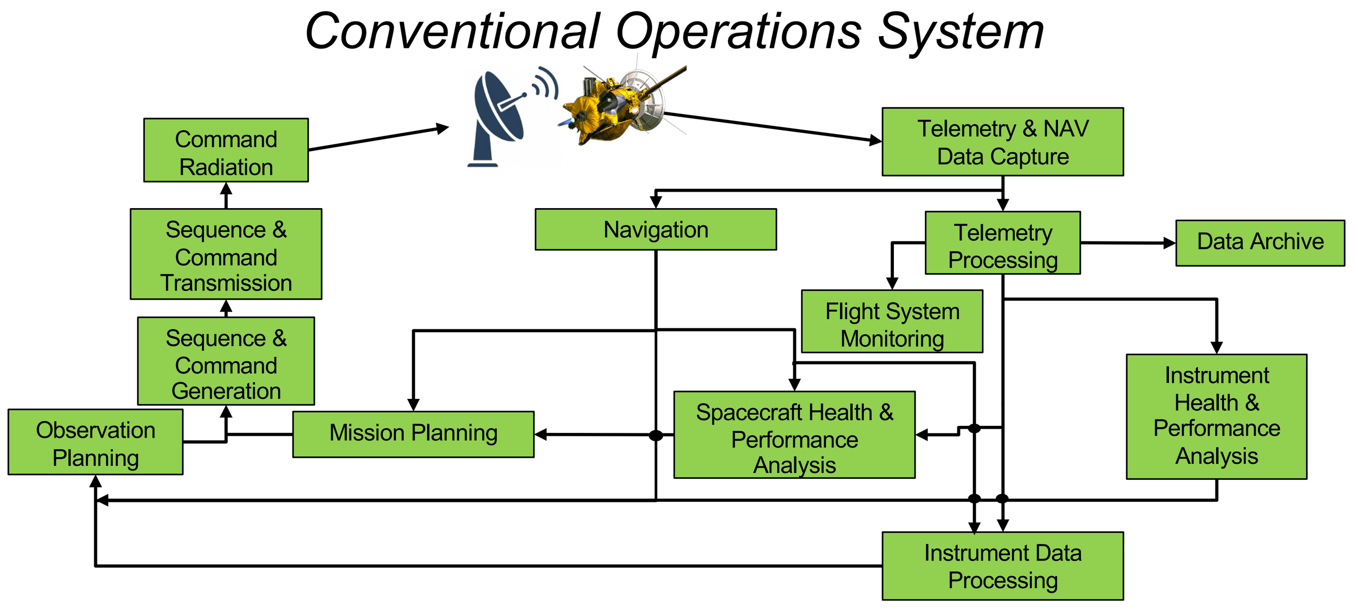


Objective: Develop technology to enable operations to

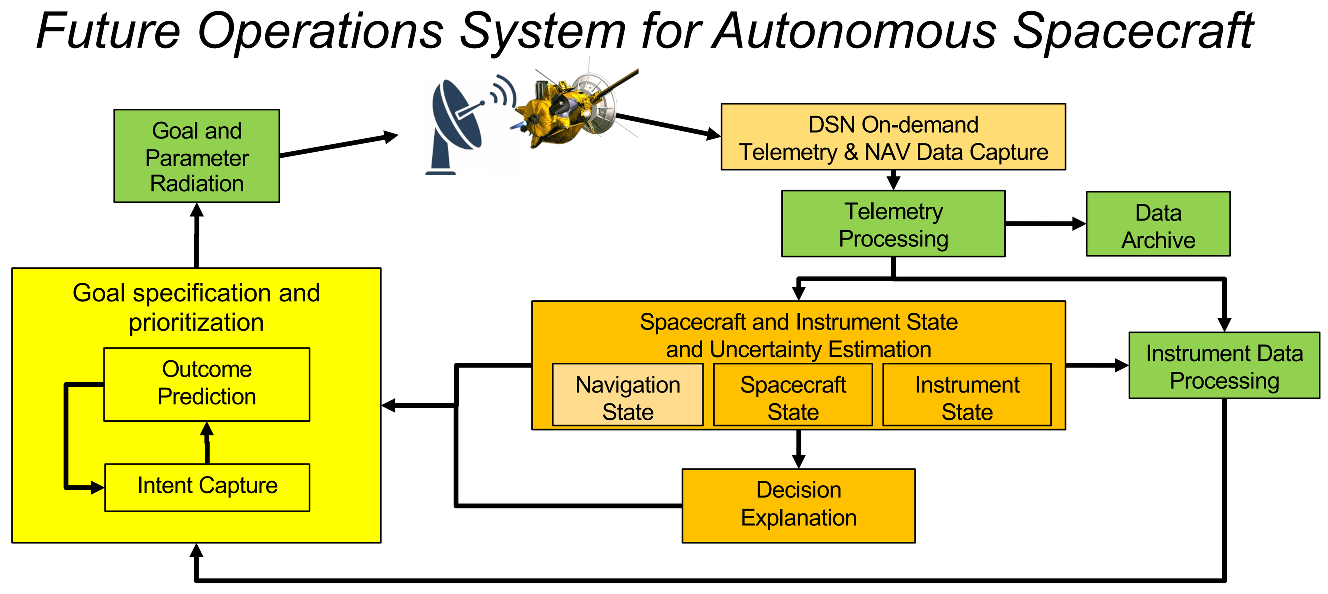
- *Capture*, model and communicate *science and engineering intents* to the spacecraft.
- *Predict* and understand the *possible executions and outcomes to help them reassure that the spacecraft will achieve the target intents.*

Background

Conventional Operations System



Future Operations System for Autonomous Spacecraft



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*.

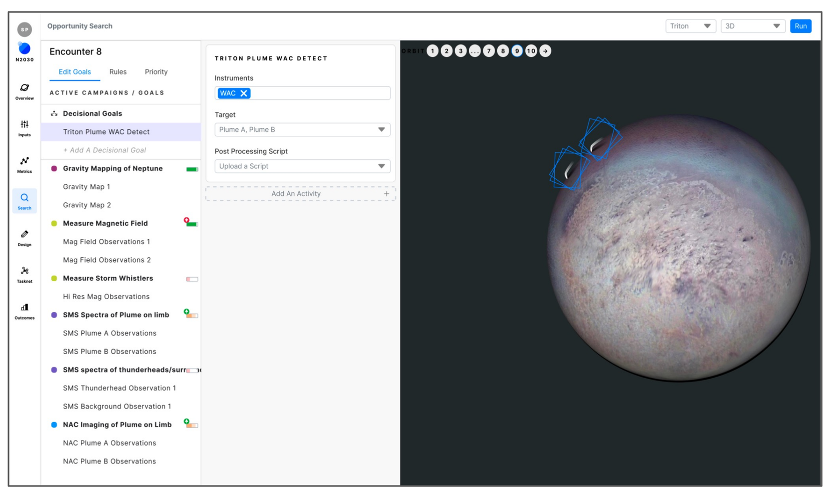
Approach and Results

Intent Capture

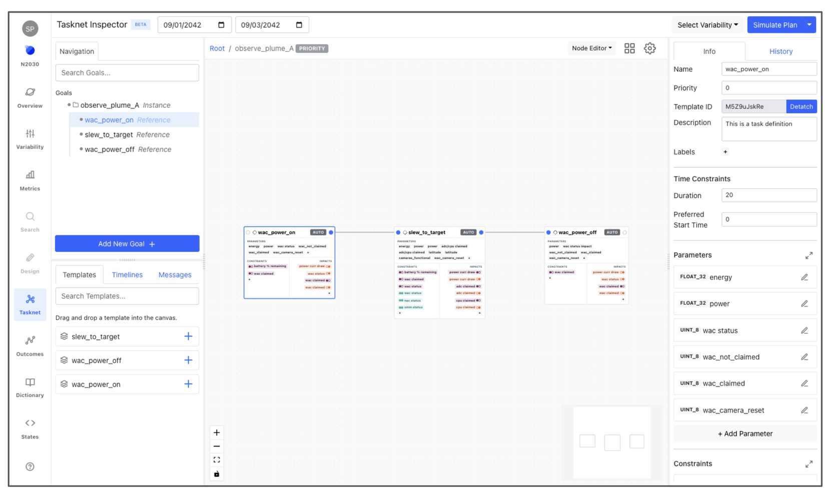
Developed techniques and software tools to capture **science campaigns with hierarchical goals** from scientists, engineers and operators based on the available onboard autonomy capabilities (e.g. MEXEC planning and execution system).

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

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



Science Planning tool



Task Network Authoring tool

Outcome Prediction

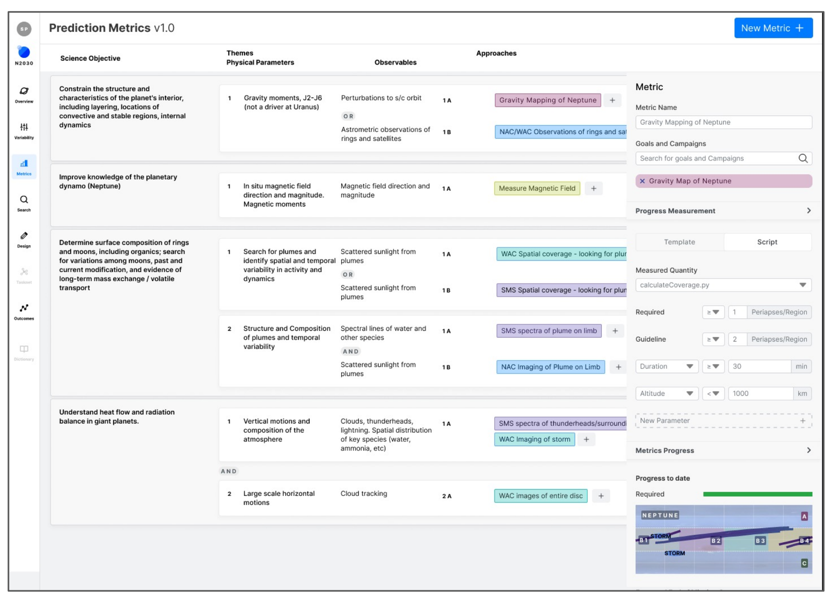
Developed techniques to compute and communicate **range of possible executed behaviors and outcomes** based on uncertainty models to confirm that the plan is safe, suitable, sufficient, and to adjust the goals when those criteria are not met.

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



Metric Specification tool

User Study

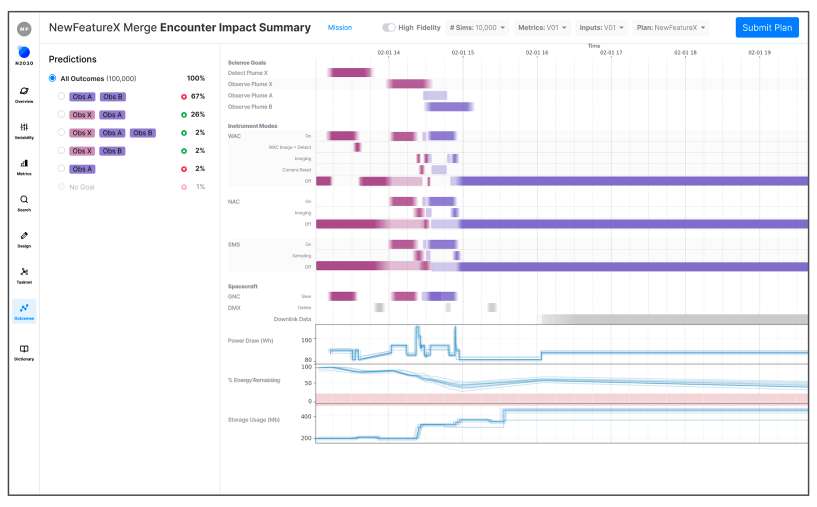
Developed **scenario with competing goals for two uplink-downlink cycles** for a notional Neptune-Triton multi-flyby mission exercising:

- 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.

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] Vaquero, 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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