National Aeronautics and Space Administration

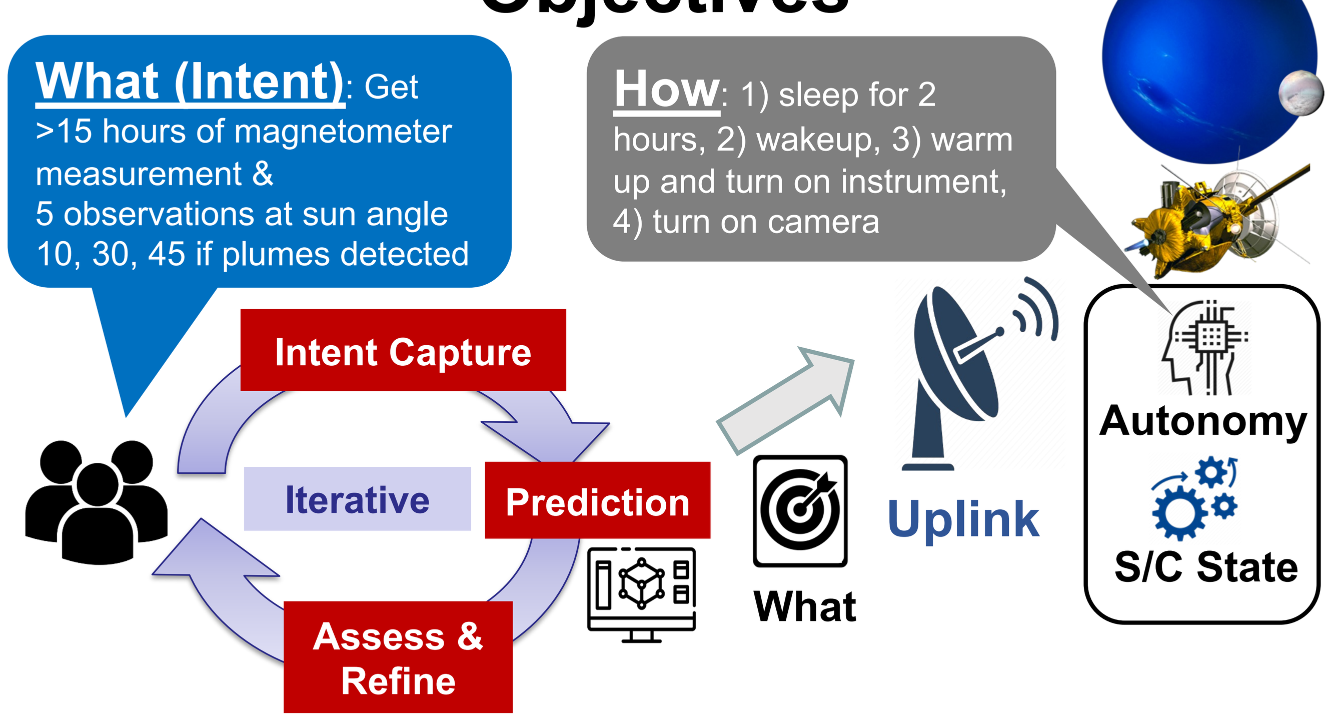
FY23 Strategic Initiatives Research and Technology Development (SRTD)

Mission Operations Planning for Increasingly Autonomous Spacecraft

Principal Investigator: Tiago Stegun Vaquero (397)**; Co-Investigators:** Steve Chien (397), Raymond Francis (397), Rashied Amini (312), Julie Castillo (400), Trina Ray (394), Mark Hofstadter (322), Mathieu Choukroun (322)

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

Objectives

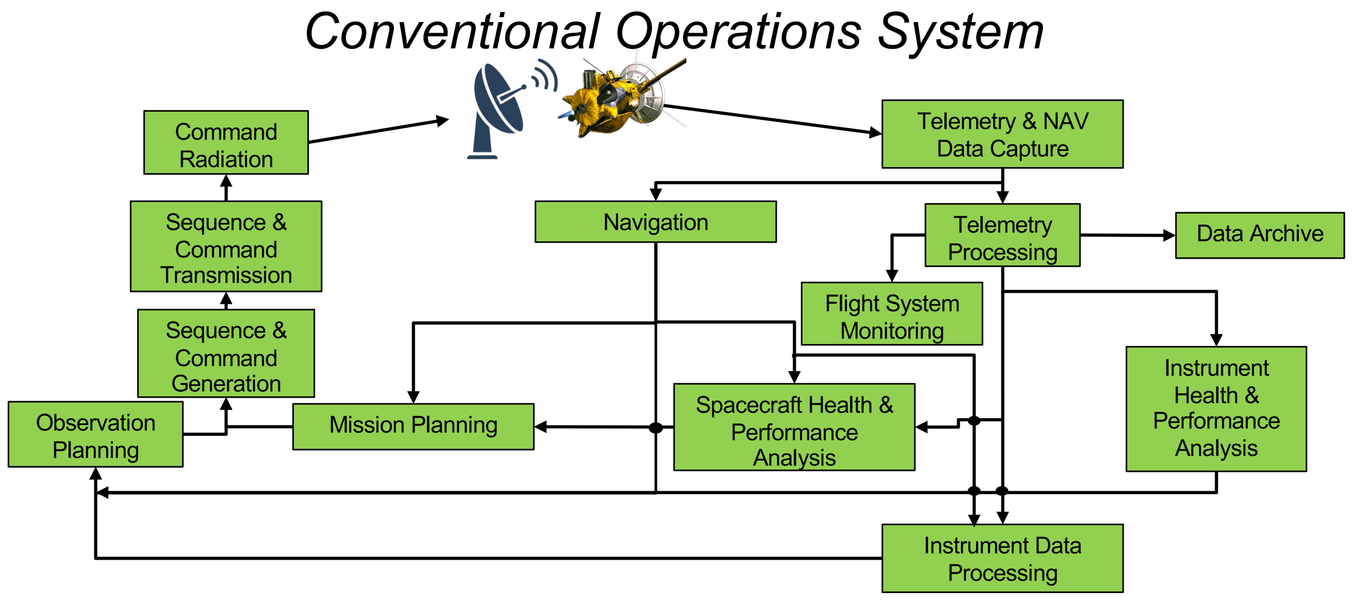


Objective: Develop technology to enable operations to

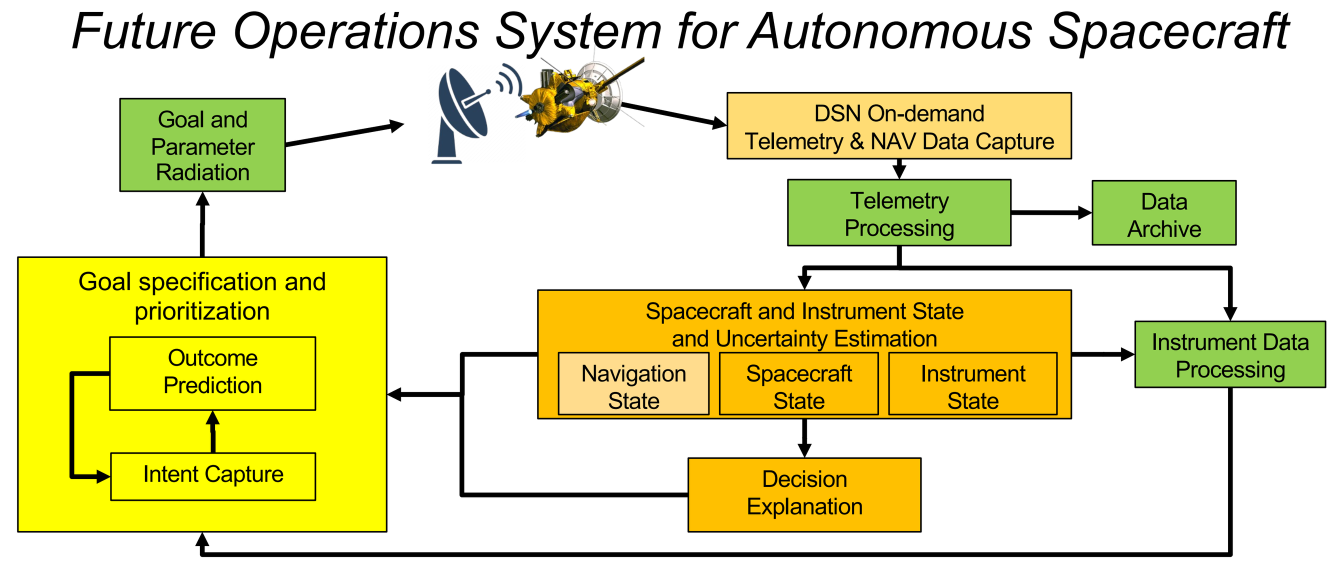
- *Capture*, model and communicate *science and engineering intents* to the spacecraft.
- *Predict* and understand the *possible executions and outcomes to help them reassure that the spacecraft will achieve the target intents.*

Background

Conventional Operations System



Future Operations System for Autonomous Spacecraft



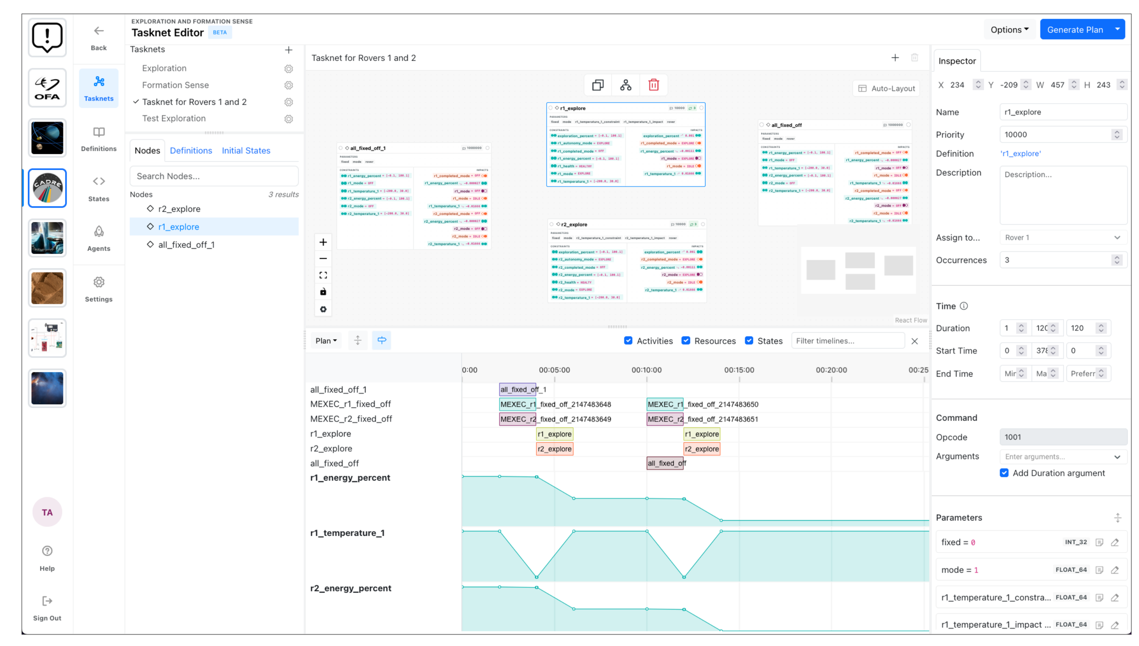
Onboard *autonomy enables missions in adverse environments* when ground-in-the-loop operations are not feasible due to *bandwidth, latency,* limited *lifetime.* Current operational capabilities are not designed for spacecraft with such onboard autonomous capabilities.

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

Approach and Results

Intent Capture

Developed *software tool* to capture **intent** with hierarchical goals, **in the form of Task Networks,** from scientists, engineers and operators based on the onboard autonomy capability: **MEXEC planning and execution system**. Leverages [1]



Task Network tool

Task Network authoring tool capabilities:

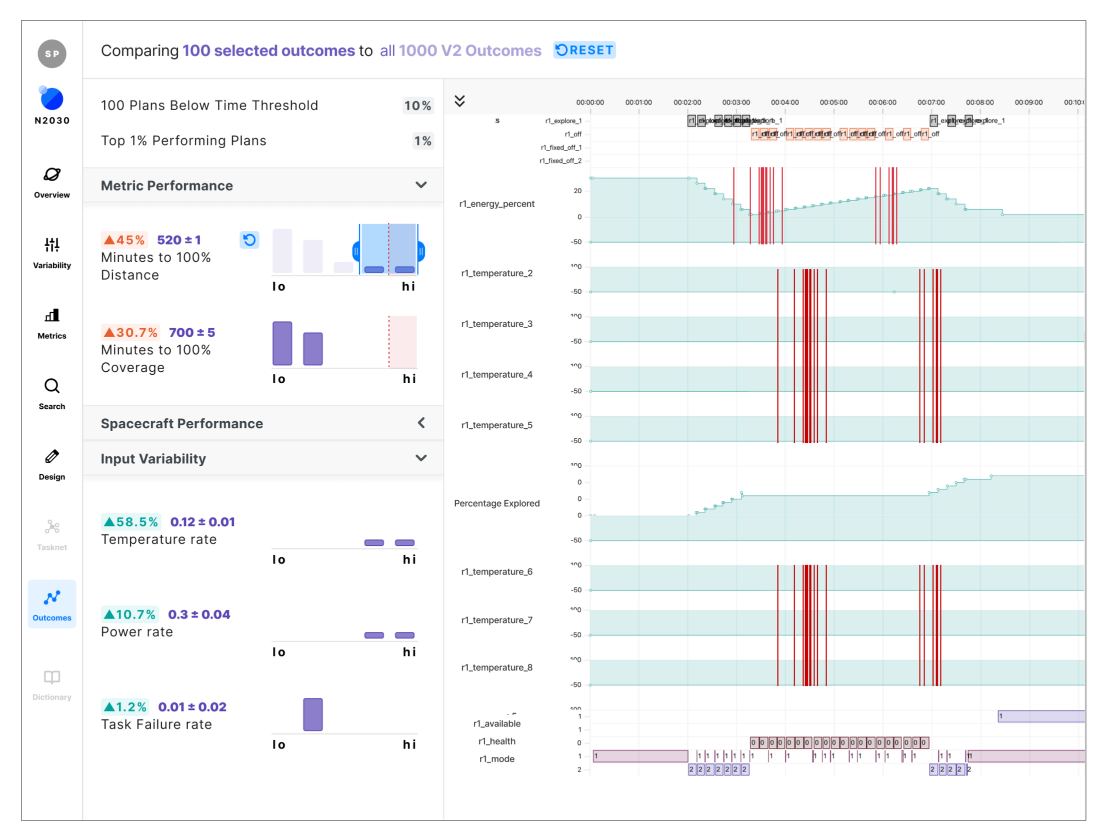
- **Specifies goals/tasks**, constraints, impacts, priorities, single and multi-agent scenarios.
- **Web-based, multi-mission, collaborative** environment.
- Integrated with MEXEC planner – plan visualization.

Outcome Prediction

Developed *algorithms and software tools* to compute, communicate and interact with **range of possible outcomes** based on uncertainty models to confirm that the plan is safe/suitable, and to adjust the goals when those criteria are not met. Leverages [2].

Prediction Results system:

- Monte Carlo Simulation approach.
- **Correlates metrics/KPIs to** environmental, science and engineering **variability**.
- **Organizes outcomes into clusters**.
- **Learns to predict** to allow efficient and **targeted sampling**.



Prediction Results tool

Infusion and Testing

Task Network tool infused into CADRE Strategic Planning and other JPL R&TD tasks. Qualitative **results**:

- Drastic improvement wrt modeling time.
- Easy to use.
- Improves communication and inspection of goals and constraints.
- Allows non-planning-experts and experts to model and collaborate.

Recommendations

Ops for autonomy recommendations. Summary:

- **Don't underestimate** intent modeling.
- Provide **training** on autonomy early on.
- Allow sequence and high level tasks definition.
- Have very **close integration** of downlink-uplink.
- **Support explanation** of specific outcomes and correction between KPIs and variability.
- **Support model refinement** given predicts.
- **Support assessment** of different goals.

Significance/Benefits to JPL and NASA

- Ability to make **full use of autonomy** and achieve missions that require such autonomy.
- Provides a **practical path to 'trusting' the autonomy**.
- Proposed tools can **directly feed into future missions** that rely on autonomy.
- Path **to reduced operations costs**.
- Ongoing discussions on infusion possibilities with AMMOS, EELS and Endurance-A.

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.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#23-5360
Poster Number: RPC#

Publications:

[A] Rossi, F. et al. Workflows, User Interfaces, and Algorithms for Operations of Autonomous Spacecraft, IEEE Aerospace Conf., 2023.
[B] Castano, R. et al. Operating Deep Space Autonomous Spacecraft: Ground Processes and Tools for Operability and Trust, *Int. Conf. on SpaceOps*, 2023.
[C] Candela, A. et al. Outcome Prediction and Explainability for Mission Operations of Autonomous Spacecraft, *HAXP workshop, Intl. Conf. Auto. Plan. Sch.* (ICAPS), 2023.

PI/Task Mgr. Contact Information:

818-850-3377 tiago.stegun.vaquero@jpl.nasa.gov