OPERATIONS FOR AUTONOMOUS SPACECRAFT: A NEPTUNE TOUR CASE STUDY. R. Castano, T. Vaquero, V. Verma, F. Rossi, D. Allard, R. Amini, A. Barrett, J. Castillo-Rogez, M. Choukroun, A. Dadaian, N. Dhamani, R. Francis, R. Hewitt, M. Hofstadter, M. Ingham, C. Sorice, E. Van Wyk, S. Chien, Jet Propulsion Laboratory, California Institute of Technology (Rebecca.Castano@jpl.nasa.gov)

Introduction: Onboard autonomy capabilities such as autonomous resource and fault management, planning, scheduling, and execution, onboard detection of scientific targets, and data summarization, hold promise to enable and enhance missions by augmenting traditional ground-in-the-loop operations cycles. Potential benefits include increased science returns, improved spacecraft reliability, and reduced operation costs. As a compelling example, autonomy has already significantly increased the capabilities of Mars rover missions, enabling them to perform autonomous long-distance navigation and autonomous data collection on new science targets.

The impact of such onboard autonomous capabilities on ground operations and the challenge of operating such capabilities is rarely addressed to a level of detail sufficient for consideration in mission concepts. Scientists and engineers must not only understand the behavior of the autonomy capabilities, they must also develop a trust that the capability will execute their desired intent. Through the use of a Neptune-Triton tour mission case study, we are developing new operations tools and workflows, for both uplink and downlink teams, to enable a shared understanding of algorithm behavior between humans and the autonomous system, in order to achieve mission goals for a spacecraft with onboard autonomy.

Mission Case Study: Leveraging several prior mission concepts including the Neptune Odyssey mission concept [1], Trident Mission concept [2] and Ice Giants Study [3], a subset of representative instruments and tour orbits were selected. Five classes of science campaigns that could involve varying autonomy capabilities were selected: monitoring, mapping, targeted observations, event-driven opportunistic observations, opportunistic monitoring. Using these campaigns, 14 specific scenarios exercising the instrument suite and variability in the perceived state of the environment, instruments, and spacecraft were defined. Examples of variable scientific events impacting observation time, power, and data volume include detecting plumes on the limb of Triton, magnetospheric variability, and storm detection at Neptune. Scenarios with anomalous instrument or spacecraft behavior were also included. For this exercise, we assumed that the trajectory is fixed and can only be adjusted by ground operations, although this could be changed in the future.

Uplink Operations: Uplink teams must communicate science and engineering intent to onboard autonomy software and assess the expected impact of such intent on the spacecraft state. The proposed uplink tools leverage previous JPL research on modeling plans to facilitate an iterative design process of science intent, including capturing intent and constructing plans with that intent. We focus on workflows for outcome/execution prediction, visualization, explanation, as well as advisory techniques (e.g., “to fix undesirable behavior, add/change this constraint”), to facilitate the operators’ learning process, while helping reassuring them that the spacecraft will achieve the target intents and complete the plan successfully.

Downlink Operations: Downlink teams must explain what decisions were made by onboard autonomy algorithms, reconstruct what happened on board, and identify anomalies that may otherwise be hidden by autonomous decisions. The new downlink tools and workflows focus on two thrusts. The first thrust is *estimation* and *propagation of the spacecraft state (including available energy, temperatures, health of spacecraft subsystems, and consumption of on-board resources)*. Enabling ground personnel to gain a reliable understanding of the spacecraft state is a challenging problem as the onboard autonomy may alter the spacecraft state in response to information that is not immediately available on the ground. The second thrust is *explanation* of the decisions taken by onboard autonomy, through user interfaces that capture *what* decisions were made by autonomy, and relate *why* the decisions were made to the intent provided by ground operators, the spacecraft state (including possible anomalies), and the perceived state of the external environment (e.g., events of interest detected by the on-board autonomy).

Conclusion: Lessons learned, along with the tools and workflows developed under this effort, will directly inform future science and exploration missions across a variety of mission classes, including surface missions (e.g., Europa and other Icy World Lander, Mars surface missions, and Venus Lander), and small body exploration (e.g., fast flybys, Centaur rendezvous).

Acknowledgments: This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References:

[1] Rymer, A., et al. Neptune Odyssey (2020) PSJ. [2] Prockter, L., et al. (2019) *LPS* 50, 3188. [3] Ice Giants Study (NASA 2017).