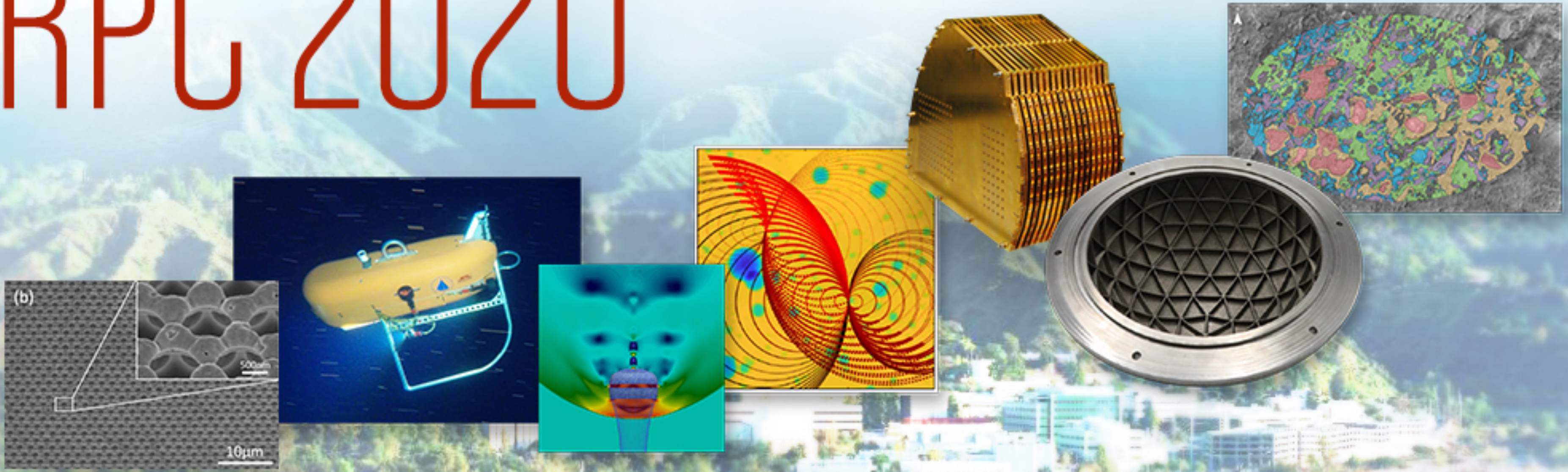
RPC 2020



Virtual Research Presentation Conference

AutoNAV Across the Solar System

Principal Investigator: Shyam Bhaskaran (392J)
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Program: Strategic Initiative

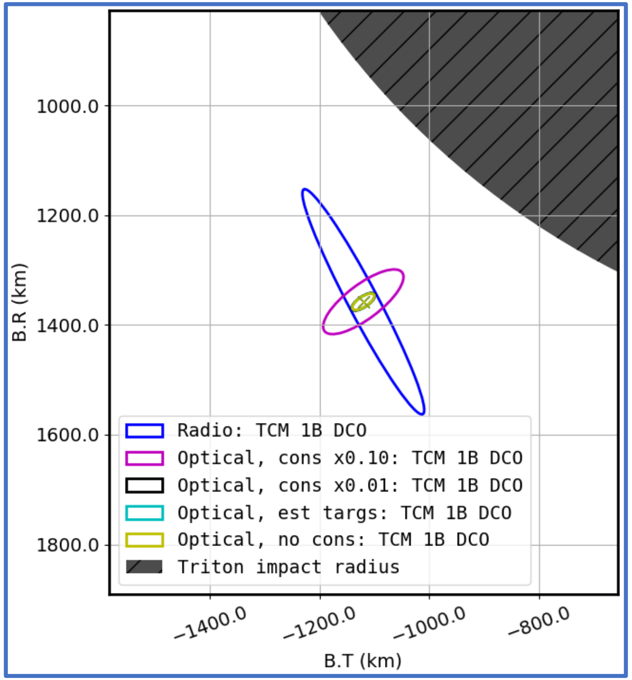
Assigned Presentation # RPC-113

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

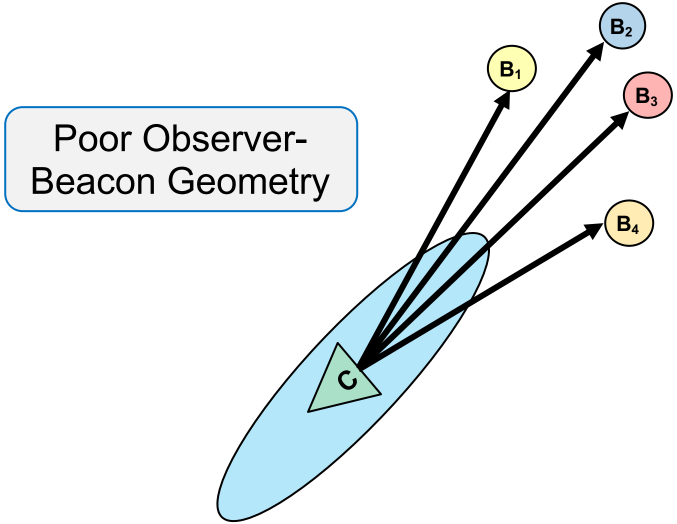
Optical autonomous navigation (AutoNAV) involves using on-board imager(s) to observe known celestial beacons (e.g., asteroids, planetary satellites, and other spacecraft), which can then be used to estimate the state of the observer and possibly additional parameters. Unlike traditional ground-based approaches, optical AutoNAV is essentially independent of ground-based resources (e.g., Deep Space Network). This can help to reduce mission costs, alleviate the strain on deep-space communication systems, and enable more dynamic mission profiles that are not limited by communication delays with the Earth. Through this research initiative, we focused on building analysis tools that were then used to quantify optical AutoNAV performance and develop requirements for various deep-space exploration environments (e.g., interplanetary cruise, Gas Giant systems, cis-lunar, etc.). Our specific emphasis for FY20 was on the Ice Giant systems, which are a particular focus area of the upcoming NASA decadal survey. Our results demonstrated that exploration of these systems via optical AutoNAV is feasible with the right combination of camera parameters and planetary satellite ephemeris knowledge. In fact, the navigation performance is comparable to typical ground-based radiometric approaches.



Delivery uncertainties (1-sigma) for a Triton flyby during a Neptune tour scenario using ground-based (Radio) and Optical AutoNAV.

Problem Description

- Optical Autonomous Navigation (AutoNAV):
  - **Description:** Navigate relative to known beacons (e.g., asteroids, planetary satellites, and other spacecraft) by imaging them with an on-board camera
  - **Research Goals:** Determine optical AutoNAV feasibility in a variety of deep space environments and define requirements for a feasible mission profile (e.g., camera parameters, beacon ephemeris uncertainty, etc.)
- Benefits relative to standard ground-based radiometric navigation:
  - Reduced mission costs
  - Mitigates strain of deep space communication networks (e.g., DSN)
  - Enables more dynamic mission profiles
- Research focused on Ice Giant exploration in FY20
  - Focus area for the upcoming NASA Decadal Survey
  - New research suggests unique magnetic field properties near Uranus



Camera Models

Camera	Focal Length (m)	FOV (deg)	IFOV (μrad)	M_{max}
Hi-Res	2.1011	0.6	10.0	13.5
Mid-Res	0.50	7.0	60.0	10.5
Low-Res	0.0502	26.9	128.0	9.5

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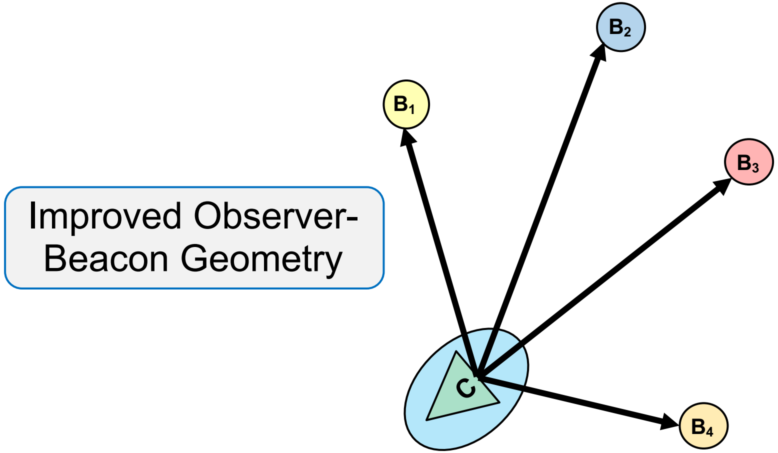

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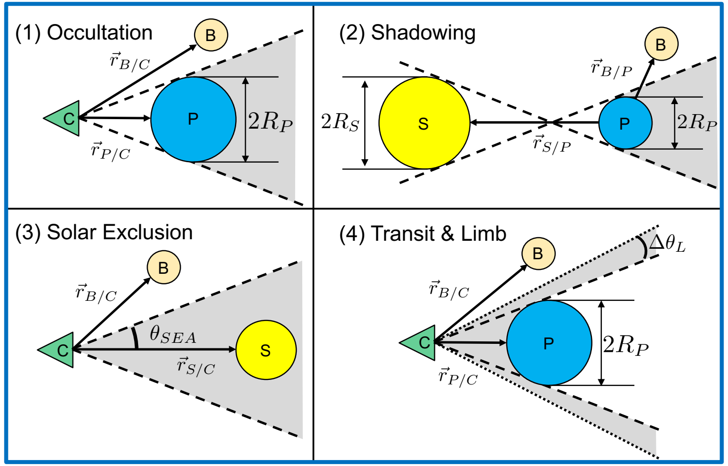
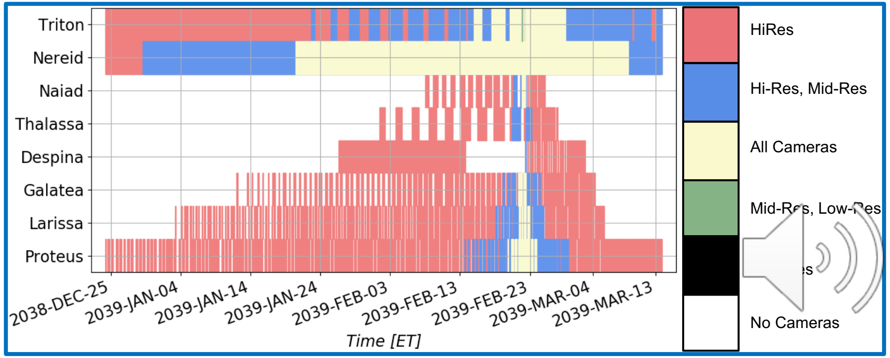
Methodology

- Optical AutoNAV Evaluation Process:
  - Determine which beacons are visible
  - Down-select to the imaged beacons
  - Extract measurements (e.g., centroid) from the images
  - Process the measurements and quantify navigation performance
  - Determine scenario feasibility
- For both Uranus and Neptune, we simulate:
  - *Kinematic Positioning*: How well can I determine my position at a given time and location?
  - *Approach Scenario*: Given measurements over time, can I successfully enter into orbit about the primary?
  - *Tour Scenario*: Given measurements over time, can I successfully observe/flyby the system's satellites?

Sample Visibility Constraints



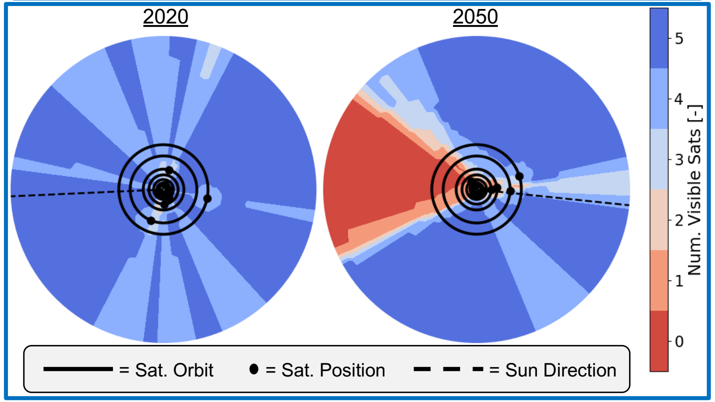
Neptune Approach Beacon Visibility



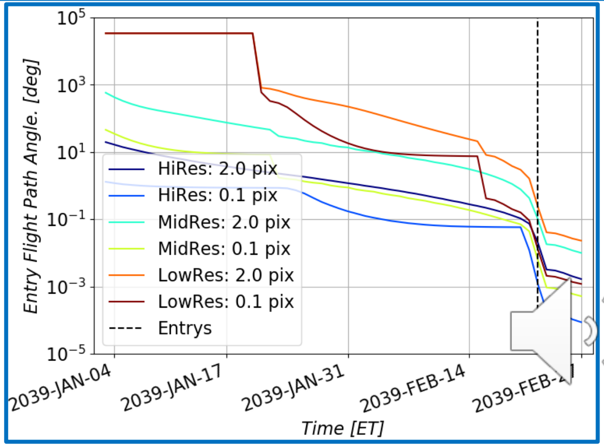
Results

- Significant Conclusions:
  - Intense seasonal lighting variations make Uranus mission timing important
  - Neptune approach is the most difficult case, but cameras that could support it already exist
  - Optical AutoNAV can feasibly enable exploration of the Ice Giant systems given an appropriate camera and achievable improvements in the ephemeris knowledge of the systems' satellites
  - Using the Hi-Res camera model, optical AutoNAV performance is comparable to (or at times better than) ground-based methods
- These results, in combination with accomplishments from previous years:
  - Demonstrate a successful completion of this research initiatives goals with many potential scenarios thoroughly analyzed (e.g., interplanetary cruise, Gas Giants, cis-lunar, and Ice Giants)
  - Supports a renewed push for AutoNAV usage in flight
    - Several missions have/will employ aspects of AutoNAV for limited portions of their missions (e.g., Deep Space 1, Stardust, OSIRIS-REx, and DART)

Uranus Kinematic Results in 2020 and 2050



Neptune Flight Path Angle Uncertainty at Entry



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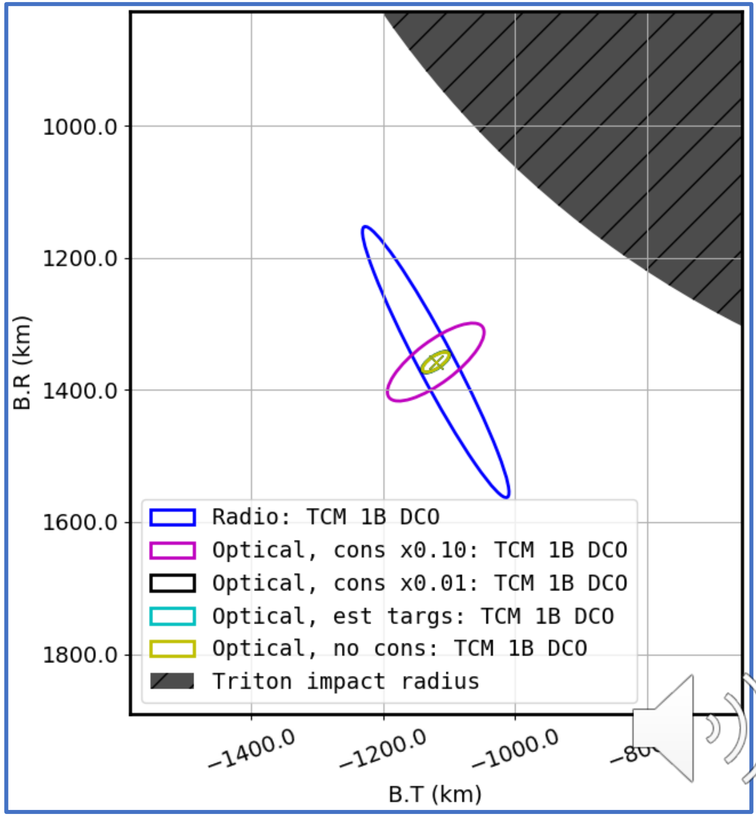
Triton Flyby Delivery Uncertainties in Neptune Tour



Publications and References

[1] S. Broschart, N. Bradley and S. Bhaskaran, "Optical-Based Kinematic Positioning for Deep-Space Navigation," in *Proceedings of the 2017 AAS/AIAA Astrodynamics Specialist Conference*, Stevenson, WA, 2017.

[2] N. Bradley, S. Bhaskaran, Z. Olikara and S. Broschart, "Navigation Accuracy at Jupiter and Saturn Using Optical Observations of Planetary Satellites," in *Proceedings of the 2019 AAS/AIAA Space Flight Mechanics Meeting*, Ka'anapali, Maui, HI, 2019.

[3] N. Bradley, Z. Olikara, S. Bhaskaran and B. Young, "Cis-Lunar Navigation Accuracy using Optical Observations of Natural and Artificial Targets," in *Proceedings of the 2019 Astrodynamics Specialist Conference*, Portland, ME, 2019.

[4] S. Broschart, N. Bradley and S. Bhaskaran, "A Kinematic Approximation of Position Accuracy Achieved using Optical Observations of Distant Asteroids," *Journal of Spacecraft and Rockets,* vol. 56, no. 5, pp. 1383-1392, 2019.

[5] N. Bradley, Z. Olikara, S. Bhaskaran, and B. Young, “Cislunar Navigation Accuracy Using Optical Observations of Natural and Artificial Targets,” *Journal of Spacecraft and Rockets*, Vol. 57, No. 4, 2020, pp. 777–792, 10.2514/1.A34694.

[6] D. Lubey, S. Bhaskaran, N. Bradley, Z. Olikara, "Ice Giant Exploration Via Autonomous Optical Navigation", Paper AAS 20-673, AAS/AIAA Astrodynamics Specialist Conference, August 2020.

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