National Aeronautics and Space Administration

AutoNav Across the Solar System

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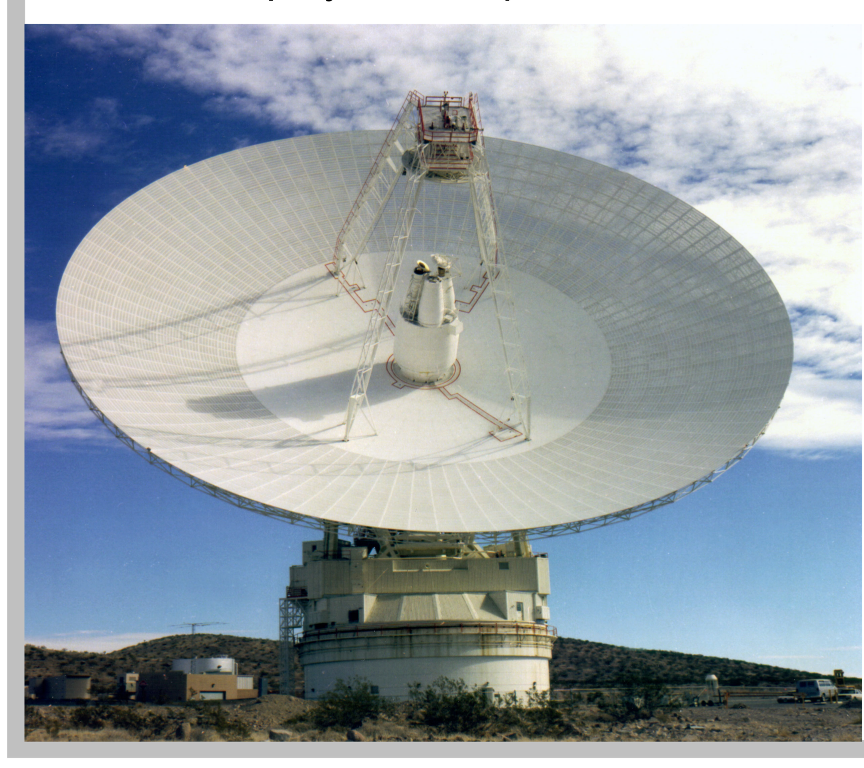
Program: Strategic Initiative

Project Objective

Demonstrate that an onboard navigation system using **only optical images** of natural or artificial objects can be used to navigate a spacecraft **anywhere in the Solar System**

- Characterize performance of such a system for wide variety of mission scenarios
- Develop system requirements for onboard navigation

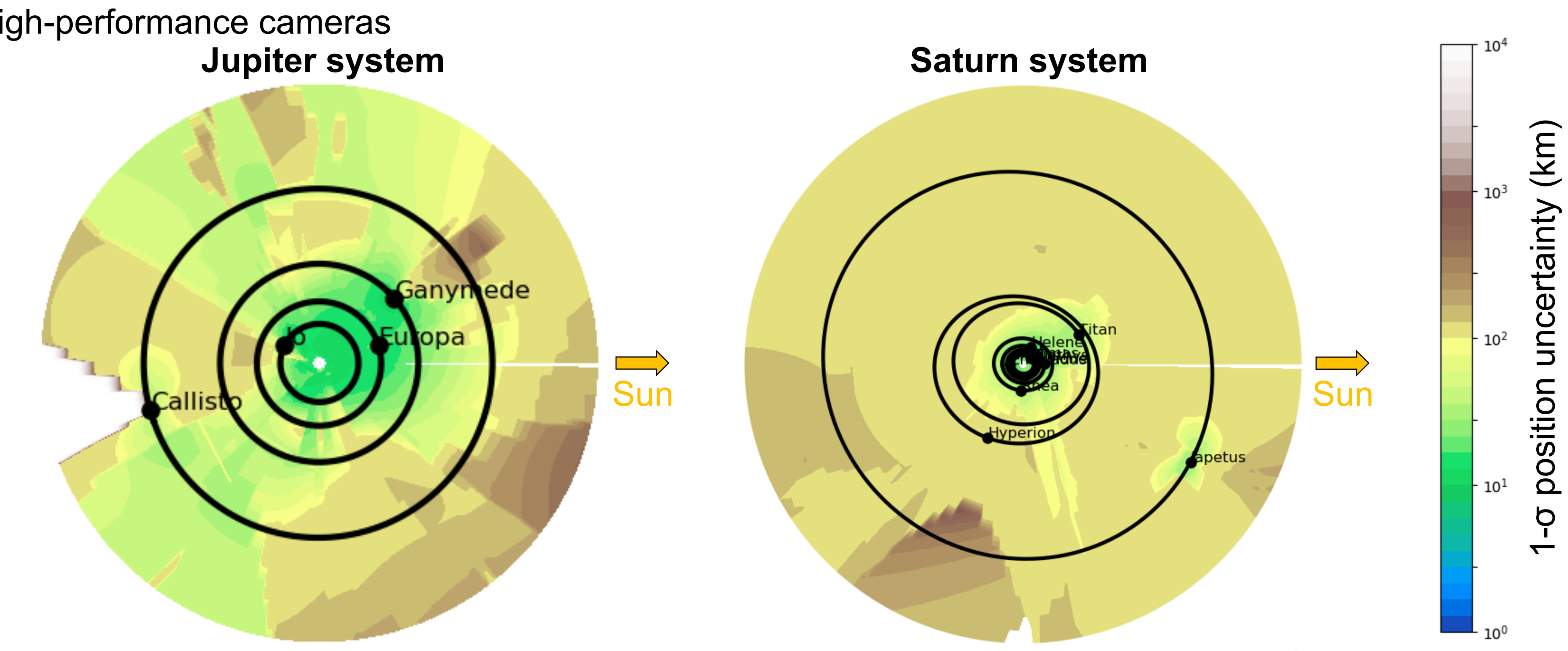


Current state-of-art is to use ground-based navigation with stations like this DSN antenna

Navigation for Gas Giant Approach and Tours (FY18-19)

Results indicate that navigational accuracy on **approach** to Jupiter or Saturn can be achieved with relatively modest cameras used for imaging

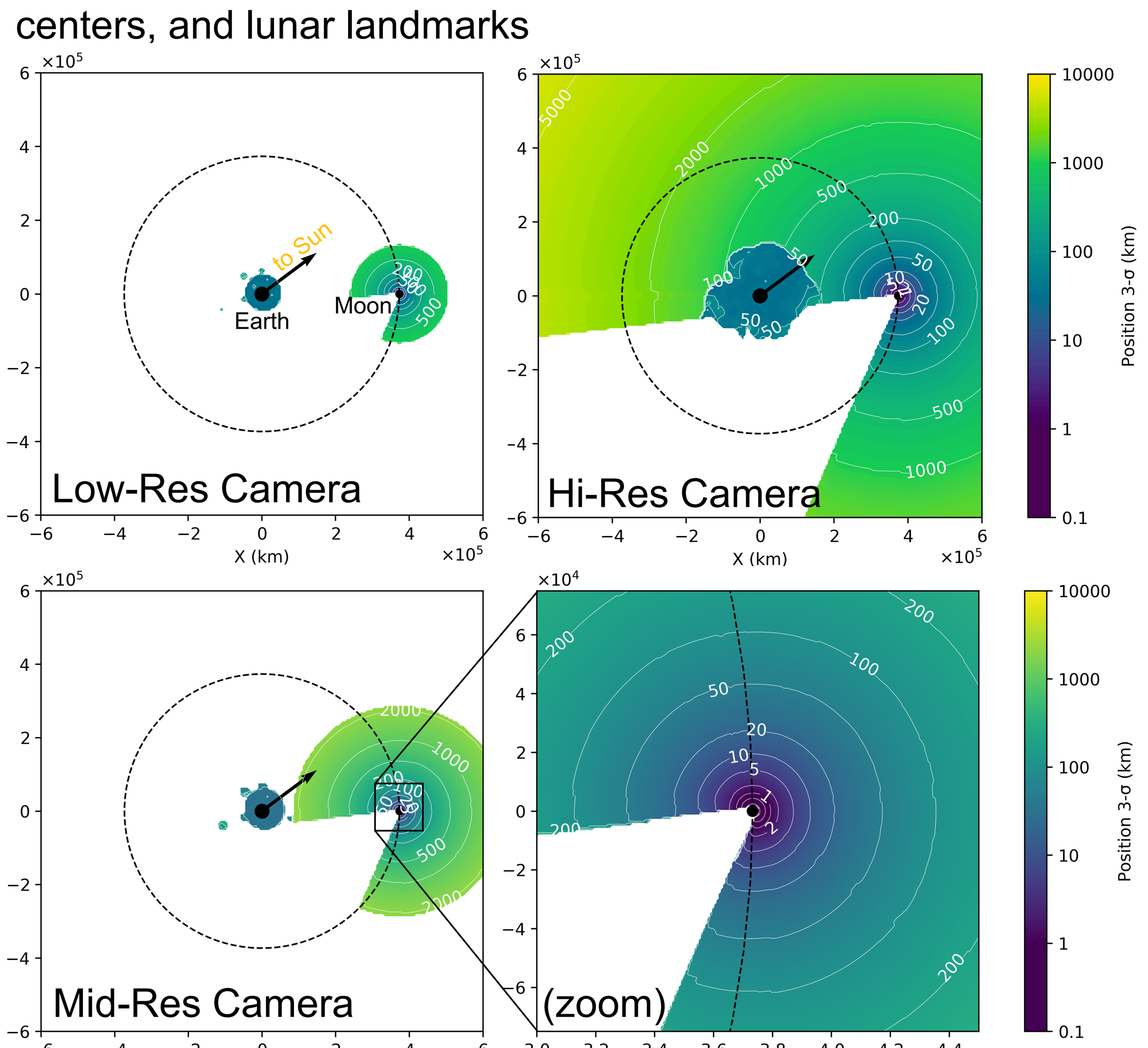
For **satellite tours**, Jupiter performance is inconsistent due to the low number of visible satellites, but Saturn performance is consistent (about 10 km accuracy near Saturn and 100 km elsewhere) and feasible with mid- to high-performance cameras



(above plots show kinematic position accuracies at sample epoch using high-res camera)

Navigation in Cis-Lunar Space (FY19)

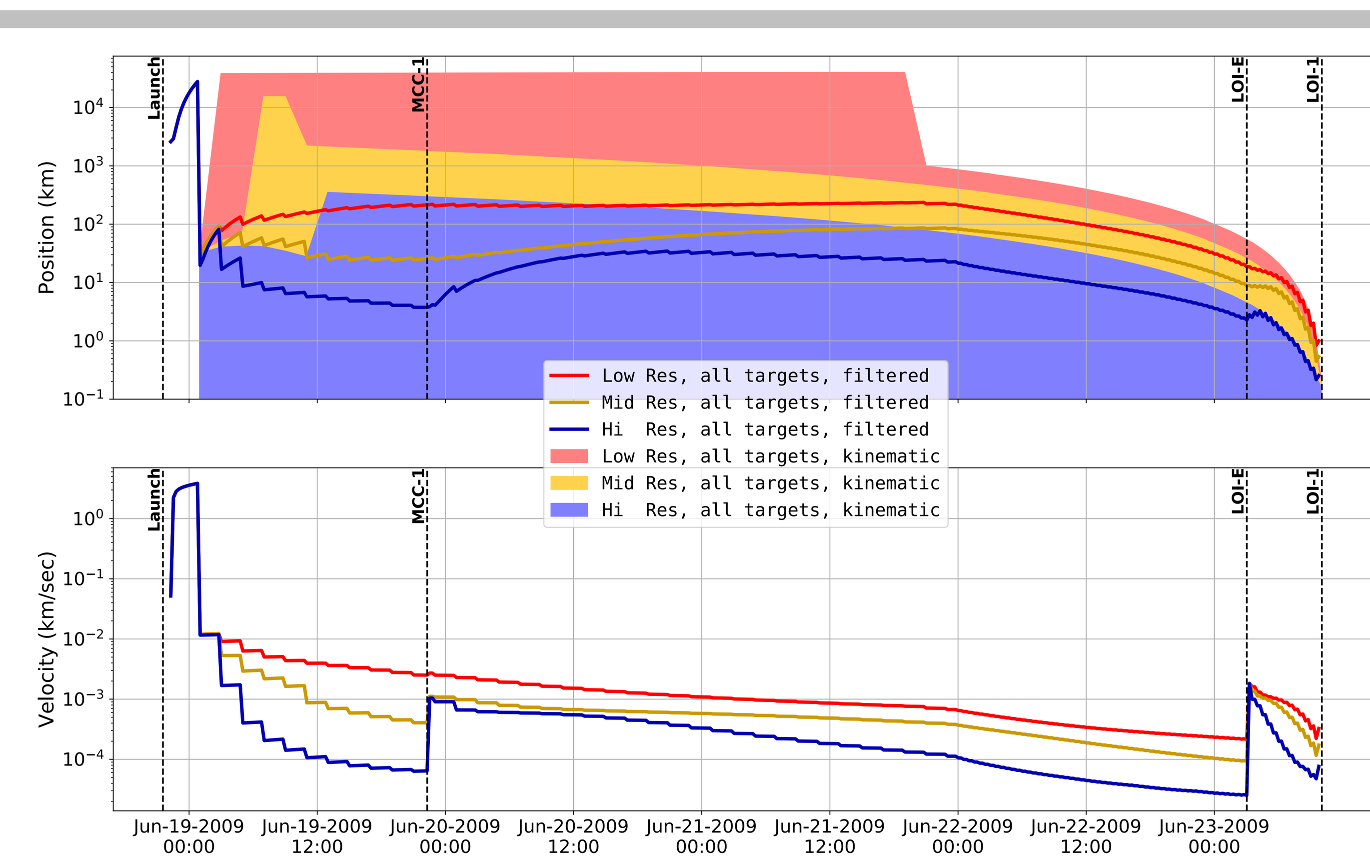
Step 1: Determine general geometric position accuracy across cis-lunar space using combination of artificial satellites, lunar centers, and lunar landmarks



Limited capability for positioning using low-res, but good coverage for mid-res and very good coverage high-res cameras

Step 2: Use specific trajectory to the moon (LRO for this example) to see position and velocity accuracies achievable using full navigation filter

Full navigation filter improves on simple geometric positioning (shaded region) and also enables estimating spacecraft velocity



Step 3: Analyze fuel requirements for optical-only approach for same LRO trajectory

Case	Asteroids	Satellites	Moon centers	Landmarks
Case 1	✓			
Case 2	✓	✓		
Case 3	✓		✓	
Case 4	✓	✓	✓	
Case 5	✓		✓	✓
Case 6		✓	✓	
Case 7		✓	✓	✓
Case 8	✓	✓	✓	✓

Camera	Case	MCC-1 (m/s)	LOI-E (m/s)	Total (m/s)	Post-LOI-1 delivery error (1-σ)		
					Period (sec)	Periapsis (km)	Inc. (deg)
Mid Res	1	142.283	2007.074	2149.359	27702.5	1414.9	17.70
Mid Res	2	7.863	107.998	114.485	1957.5	98.6	7.54
Mid Res	3	4.367	35.020	37.891	935.4	46.8	0.15
Mid Res	4	4.032	10.917	13.088	163.0	7.8	0.06
Mid Res	5	4.095	25.268	27.428	647.0	32.4	0.10
Mid Res	6	4.035	10.905	13.049	162.5	7.8	0.06
Mid Res	7	4.027	9.790	12.161	139.1	7.1	0.05
Mid Res	8	4.030	9.765	12.242	139.4	7.2	0.05
Low Res	8	4.493	39.637	42.625	1028.1	51.6	0.19
Hi Res	8	4.020	7.270	10.531	57.1	3.2	0.04
Perfect OD		4.005	7.054	10.397	52.4	3.0	0.04

(Red indicates prohibitive fuel amounts / delivery errors, green indicates reasonable fuel requirements)

Benefits to NASA and JPL

- An optical-only, onboard approach to deep space navigation is feasible with current technologies
- Specific requirements on camera performance can be analyzed and tailored for individual missions
- Results for cis-lunar space indicate that future lunar mission architectures can take advantage of this approach to minimize DSN and other ground asset tracking needs for navigation

Publications

1. 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, 2019, DOI: http://arc.aiaa.org/doi/abs/10.2514/1.A34354.
2. N. Bradley, S. Bhaskaran, Z. Olikara, S. Broschart, "Navigation Accuracy at Jupiter and Saturn Using Optical Observations of Planetary Satellites", Paper AAS 19-231, Presented at the AAS/AIAA Spaceflight Mechanics Meeting, January 2019.
3. N. Bradley, Z. Olikara, S. Bhaskaran, B. Young, "Cis-Lunar Navigation Accuracy Using Optical Observations of Natural and Artificial Satellites", Paper AAS 19-643, Presented at the AAS/AIAA Astrodynamics Specialist Conference, August 2019.

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