Interplanetary Departure Stage Navigation by means of LiAISON Orbit Determination Architecture

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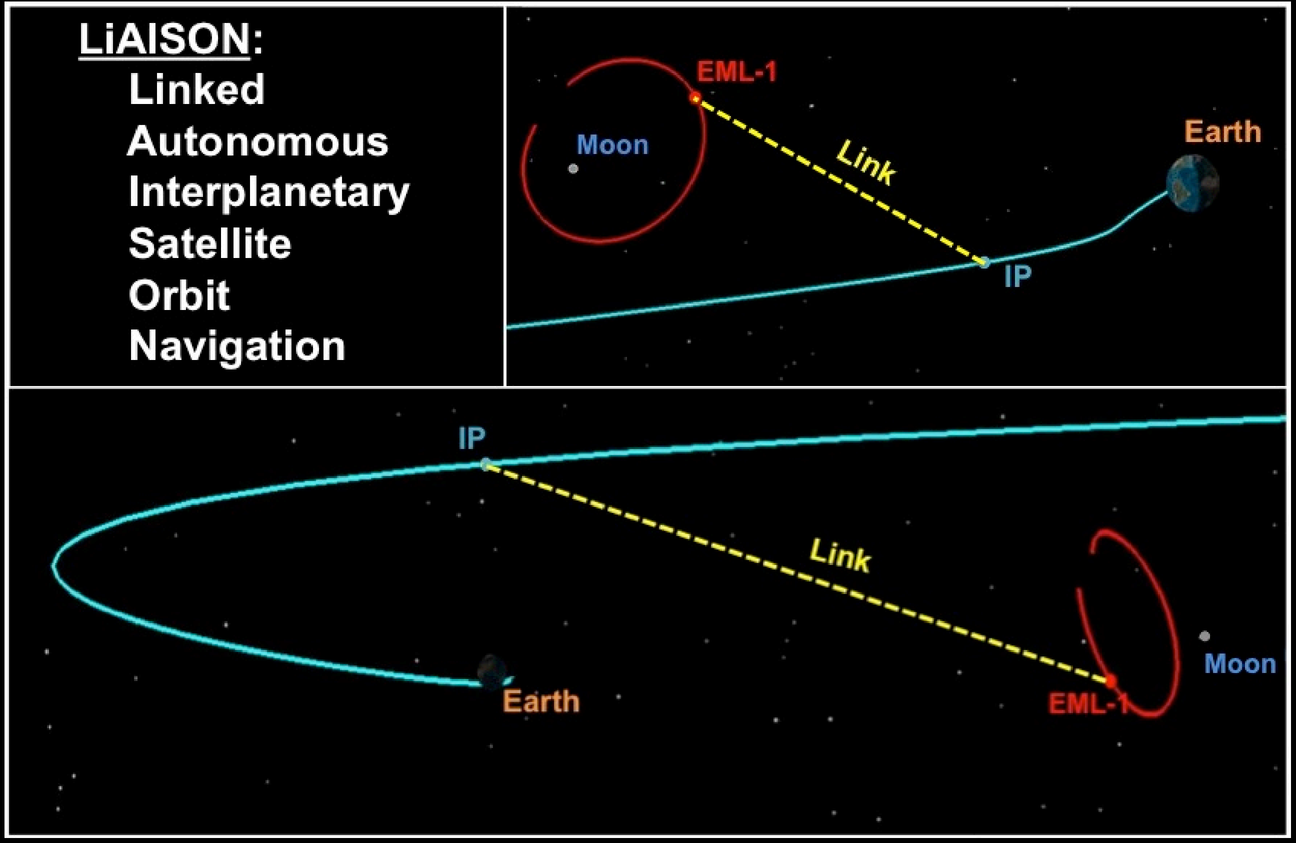
Outline

- Focus
- Linked Autonomous Interplanetary Satellite Orbit Navigation (LiAISON)
- Background
- Simulation Set-up
- Navigation Results
- Performance Comparison



Study Overview

- **Focus:**
  - Explore utilization of LiAISON for outbound interplanetary trajectories

- **Solution Method:**
  - Reconstruct Cassini, MER A, and MSL from published trajectories
  - Use EML-1 satellite for LiAISON OD, Simulated DSN stations for ground OD
  - High-fidelity measurement and dynamical models
  - Conventional Kalman filter

- **Objectives:**
  - Measure LiAISON performance in high fidelity simulation
  - Quantify cost and accuracy with ground-only tracking
  - Study realistic mission situations

- **Conclusions:**
  - LiAISON can improve ground-only tracking
  - Extent of improvement dependent on geometry present
  - Dedicated navigation satellite at EM LPOs significant link in nav architecture near Earth

LiAISON Background

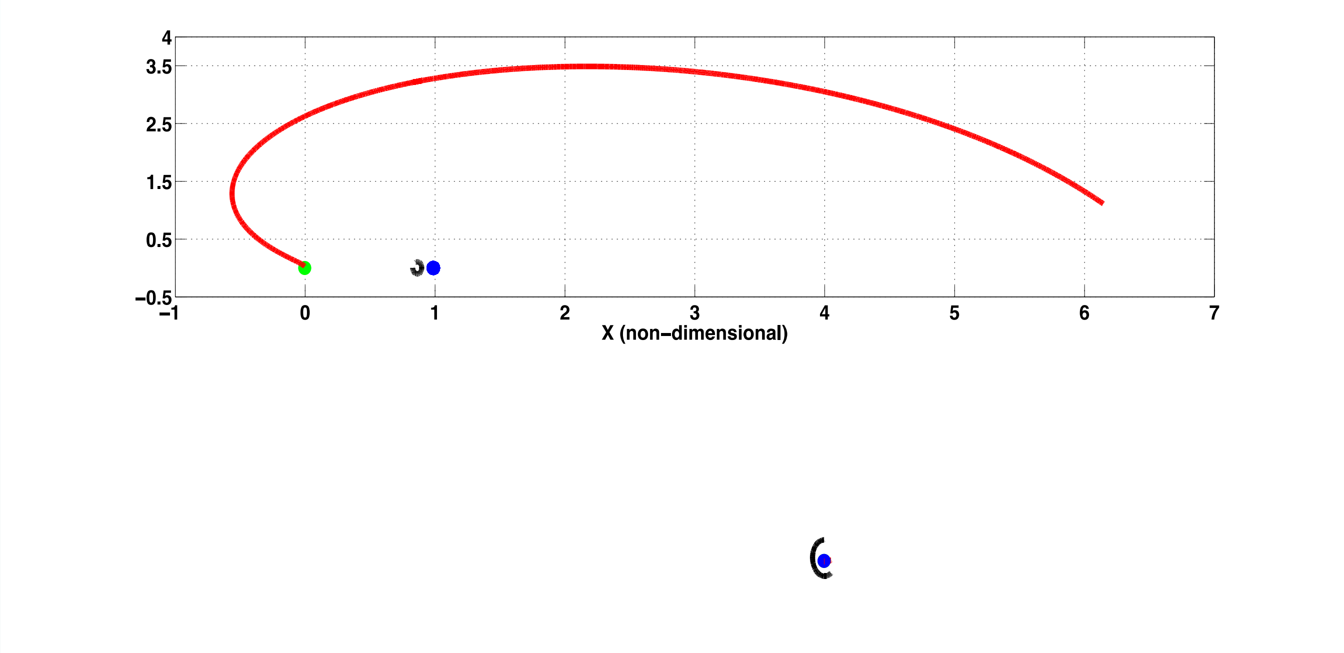
- What is LiAISON?

- Costs
  - Navigation satellite at EML-point required
  - Customer satellite may require additional hardware, like GPS receiver

- Benefits
  - Unique, advantageous geometry with respect to ground tracking
  - Improved navigation accuracy
  - All operations performed autonomously
  - If equipped with highly-stable clocks, any number of customer satellites can be serviced by single navigation satellite

Background

- Departure trajectories recreated from published trajectories
  - MER A
  - MSL
  - Cassini



Views of the MER A simulation geometry in the Earth-Moon rotating frame with nondimensional coordinates. The X-Y plane (top), X-Z plane (bottom left), and Y-Z frame (bottom right) are shown.

Simulation Set-up: Dynamical Model

- State Parameters

$$\mathbf{X} = \left[x_{ip},\ y_{ip},\ z_{ip},\ \dot{x}_{ip},\ \dot{y}_{ip},\ \dot{z}_{ip},\ x_h,\ y_h,\ z_h,\ \dot{x}_h,\ \dot{y}_h,\ \dot{z}_h\right]$$

- Force Model

$$\begin{bmatrix}\dot{\mathbf{r}}_i \\ \dot{\mathbf{v}}_i\end{bmatrix} = \begin{bmatrix}\mathbf{v}_i \\ \mathbf{a}_{2\text{-}body}(t, \mathbf{r}_i) + \mathbf{a}_{n\text{-}body}(t, \mathbf{r}_i) + \mathbf{a}_{SRP}(t, \mathbf{r}_i)\end{bmatrix}$$

Earth's Gravitational Pull (2-Body) • Bodies outside spacecraft-Earth system • Solar Radiation Pressure

All bodies' position given by JPL DE405
Constant area-constant reflectance SRP model with shadow model incorporated

- Dynamical Equation

$$\dot{\mathbf{X}}(t) = \boldsymbol{f}(t, \mathbf{X}(t), \mathbf{u}(t))$$

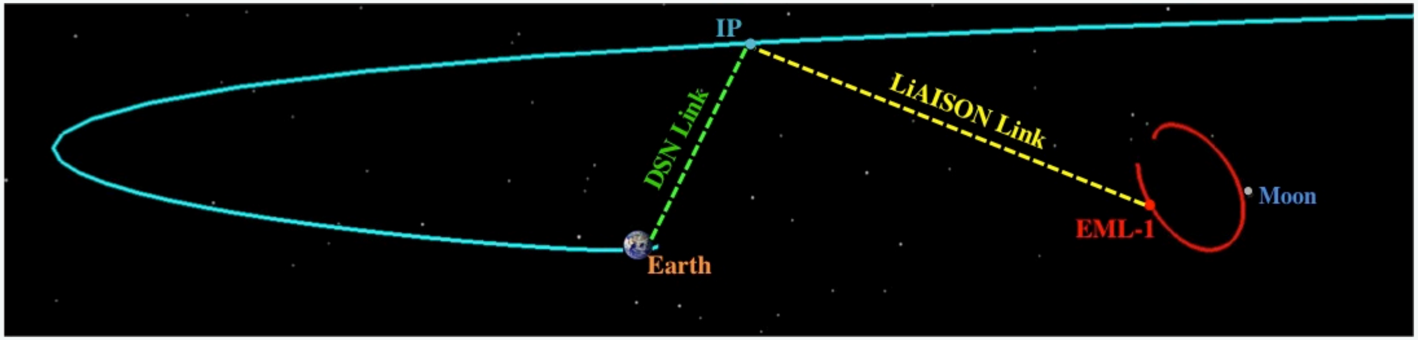
Simulation Set-up: Observational Model

- Observables
  - Instantaneous range and range-rate

$$\mathbf{Y}_o(t) = \mathbf{h}(t, \mathbf{X}(t)) = \begin{bmatrix} \rho(t) + \rho_{noise} + \rho_{bias} \\ \dot{\rho}(t) + \dot{\rho}_{noise} \end{bmatrix}$$

- Ground stations
  - DSN stations Goldstone, Madrid, and Canberra

- Satellite-to-satellite tracking (SST)
  - Between EML-1 and simulated Cassini, MER A, and MSL



Simulation Set-up: Filter Model

- Conventional Kalman filter

Initial State

a priori Uncertainty

- EML-1: 40 *m* in position, 0.1 *mm/s* in velocity
- IP: 100 *m* in position, 0.1 *m/s* in velocity

a priori uncertainty (1-σ):
- EML-1: 20 *m* and 0.1 *mm/s*
- IP: 1000 *m* and 10 *m/s*

↓

Propagate to Next Epoch

- Dynamical modeling errors
- State noise compensation added for un-modeled accelerations

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Process Observation

- Every 1000 seconds for 9 day data arc
- Range and range-rate uncertainties (1-σ):
  - SST: 1 *m* and 1 *mm/s*
  - DSN: 10 *m* and 0.5 *mm/s*

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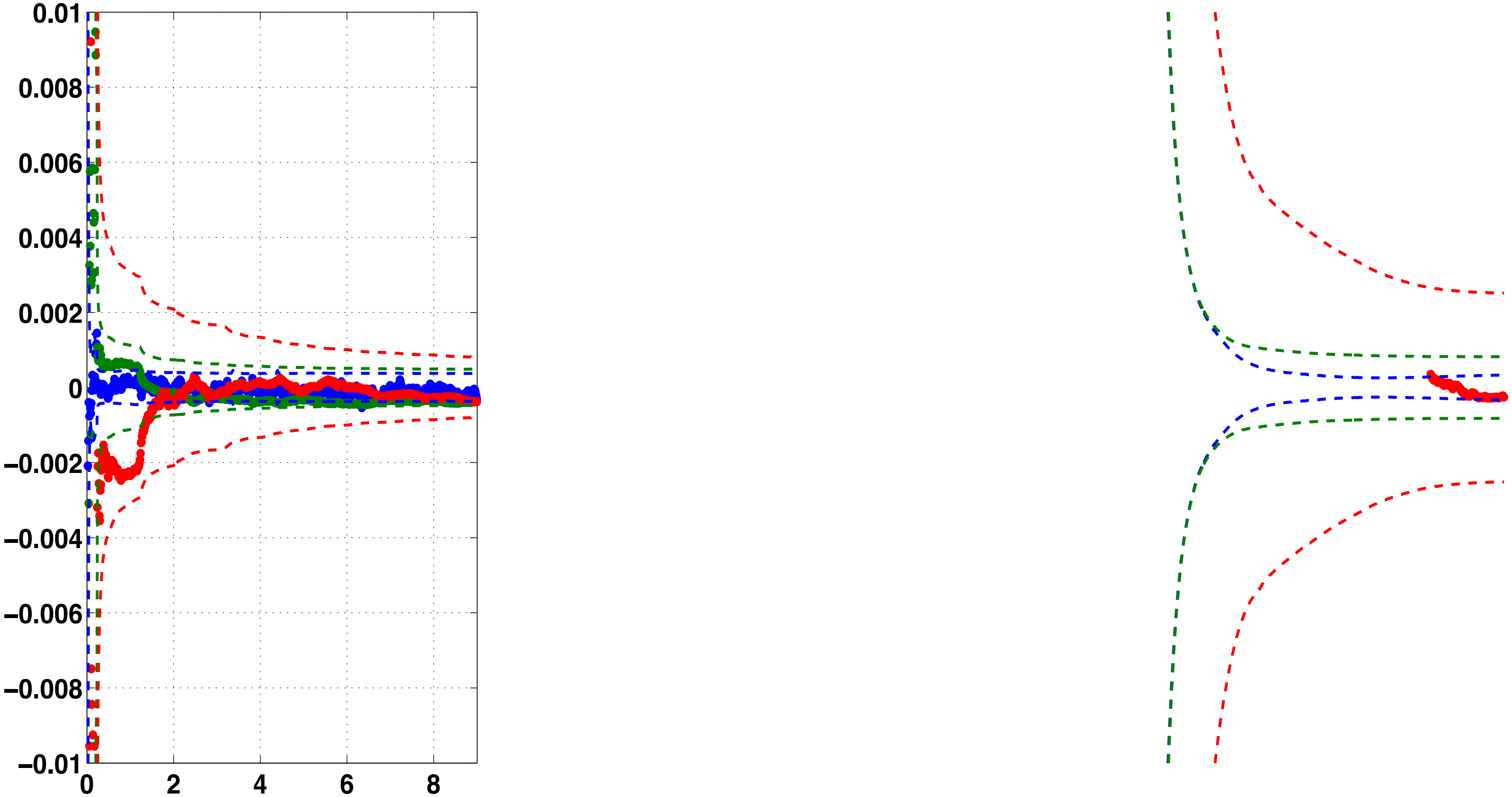
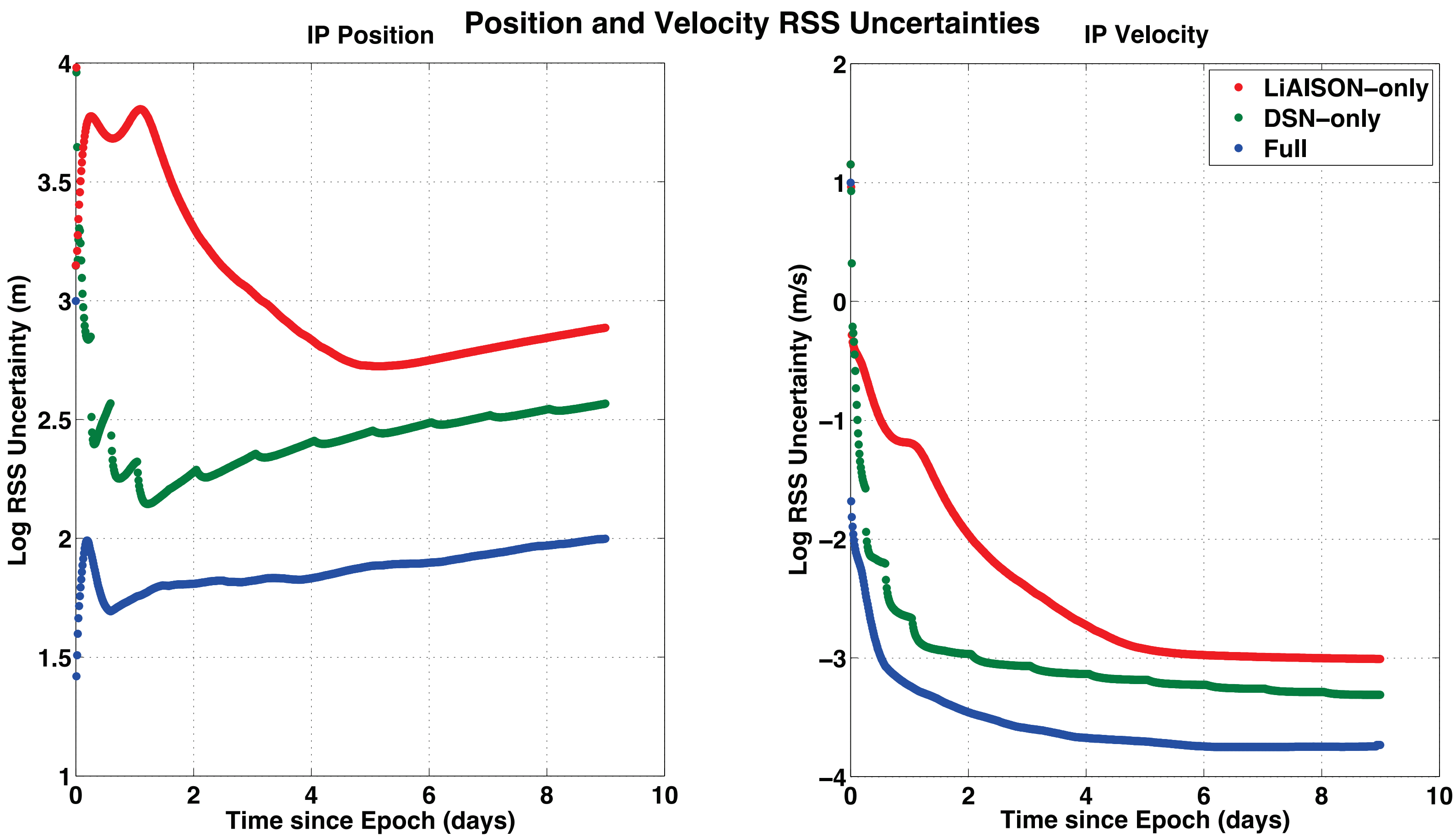
Update State

Results: MER A



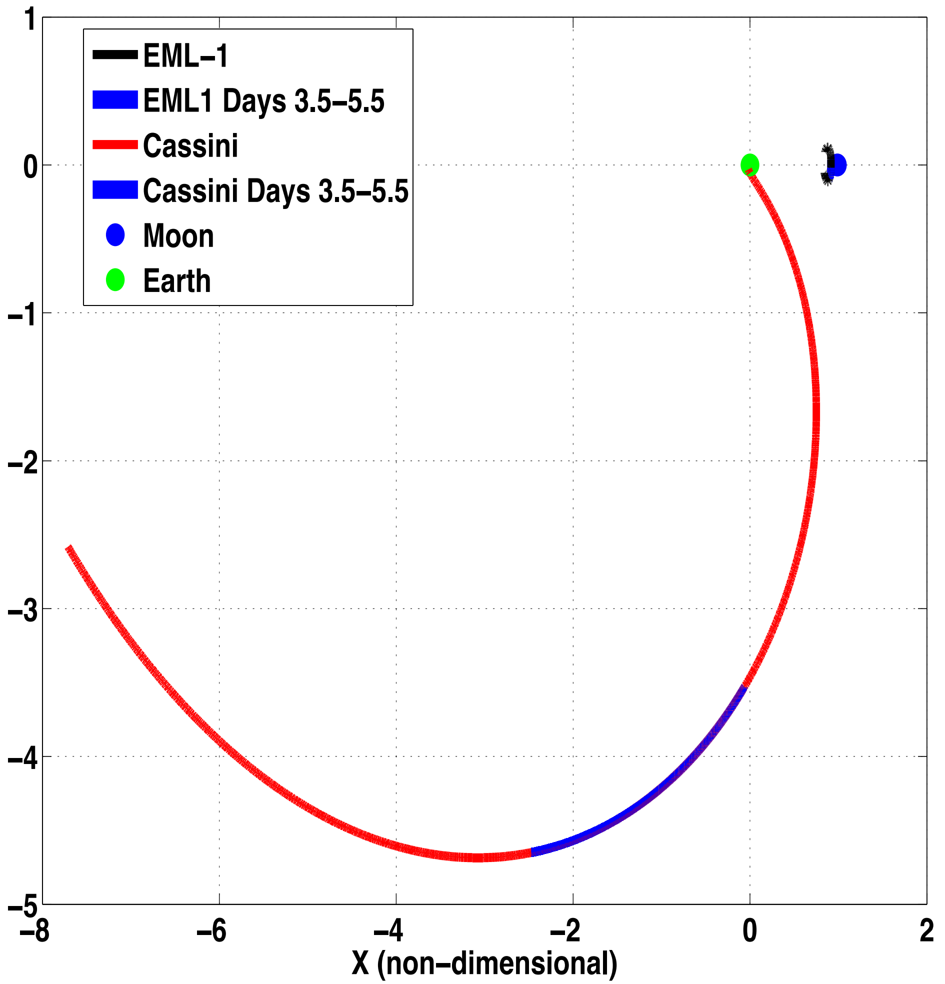
Interplanetary satellite velocity accuracies (truth - estimated) and 3-sigma uncertainty envelopes for the full (left), DSN-only (middle), and LiAISON-only (right) MER A mission simulations.

Results: MSL

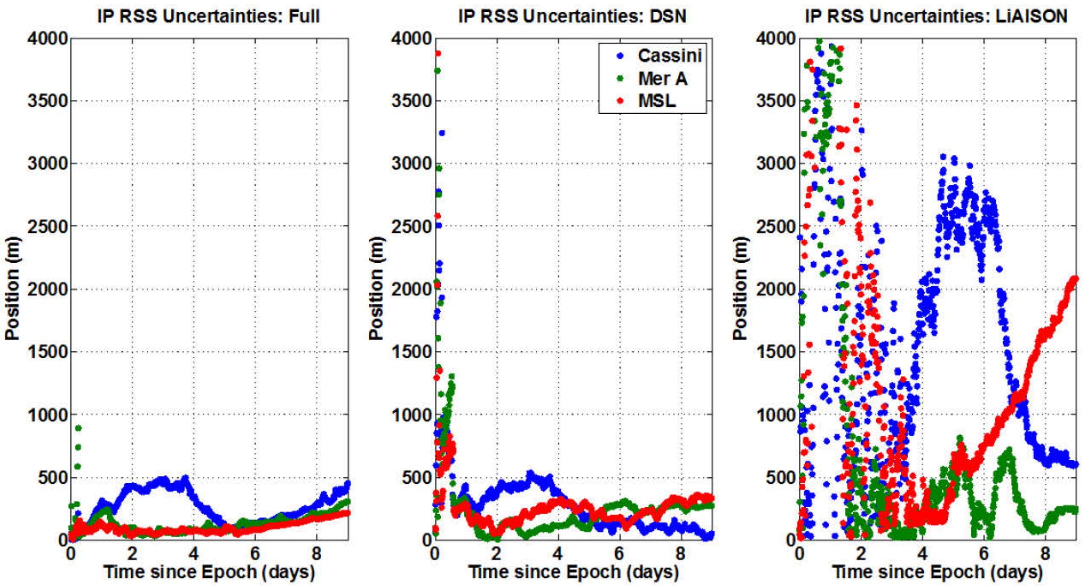


1-sigma log RSS uncertainties for the MSL mission simulations. Uncertainties in the position (left) and velocity (right) are given for the interplanetary satellite.

Results: Cassini



Results: Mission Comparison



3D position RMS values for the second half of each simulation. (3D position RMS uncertainties for entire 9 day arc.)			
Mission	**Full Simulation (m)**	**DSN-only (m)**	**LiAISON-only (m)**
Cassini	**228 (232)**	**130 (706)**	**1874 (3892)**
MSL	**133 (84)**	**254 (494)**	**1211 (2393)**
MER A	**170 (194)**	**244 (628)**	**374 (1585)**

Summary

- LiAISON tracking of interplanetary departure trajectories was explored
- Simulations were run to analyze OD performance under different tracking routines
  - LiAISON-only, DSN-only, Full
- Three historical missions were recreated and examined
- LiAISON was shown to improve navigation performance
  - Widely varying relative motion needed for geometrically diverse observations
- LiAISON shown to be a potential aid to ground tracking for interplanetary trajectories

Thank You

Questions?

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