James Webb Space Telescope Orbit Determination Analysis

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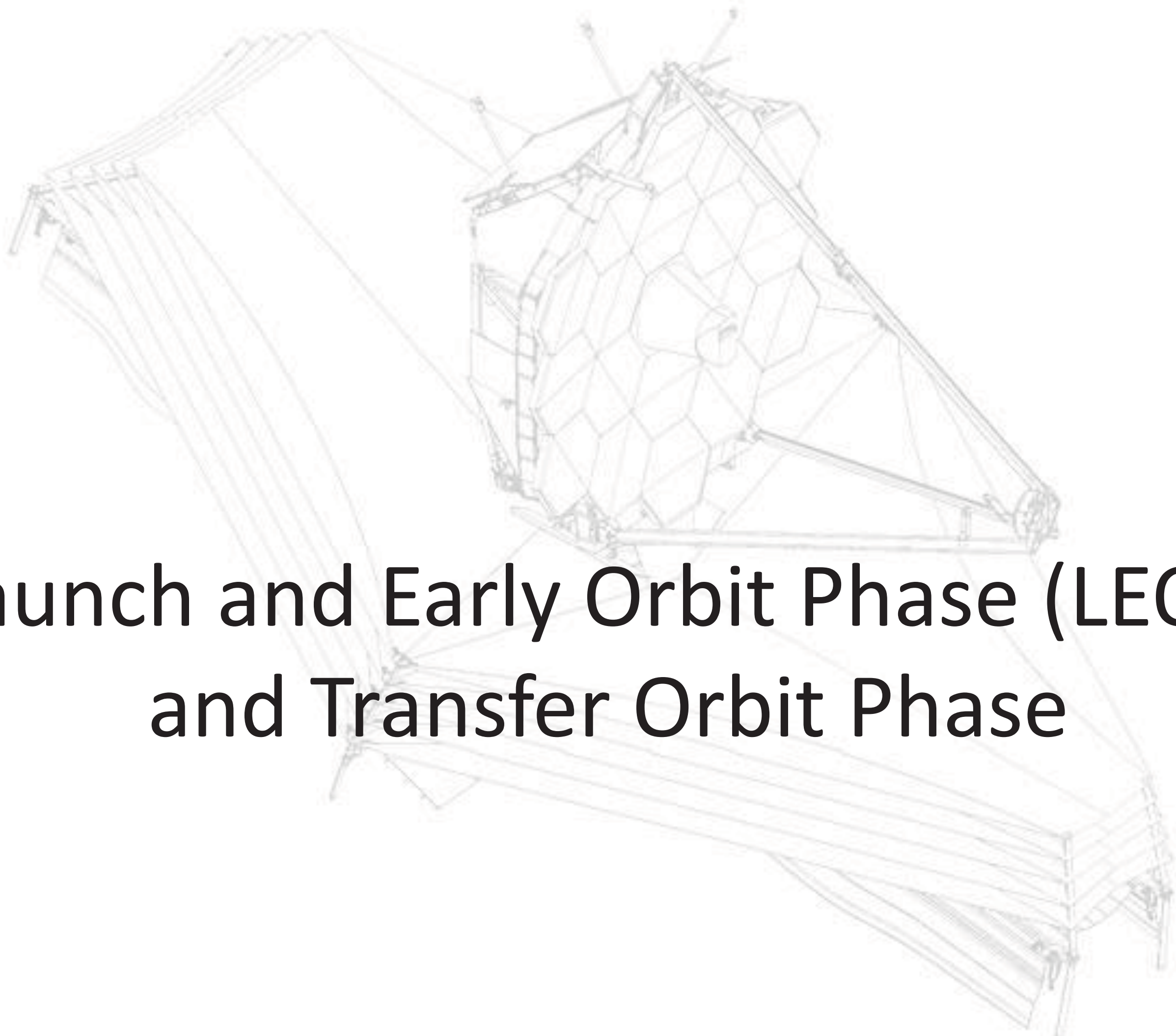
Purpose of the Work

- JWST is not an astrometric mission and there is no pos/vel determination performance requirement for science.
- There is a position prediction requirement (not investigated in this work)
- Accurate velocity information is critical to maneuver design
  - Three Mid-Cource Correction maneuvers to bring JWST from the Earth orbit to LPO
  - Stationkeeping maneuvers every 21 days to keep JWST in LPO
- Better velocity determination performance

  → fuel saving → longer mission

Outline

- JWST Orbit Determination Analysis for
  1. Launch and Early Orbit Phase (LEOP) and Transfer Orbit Phase
     1) Description of the phase
     2) OD Analysis Method
     3) Results
     4) Future work
  2. Science Operations Phase
     1) Description of the phase
     2) OD Analysis Method
     3) Results
     4) Future work



Launch and Early Orbit Phase (LEOP) and Transfer Orbit Phase

Introduction

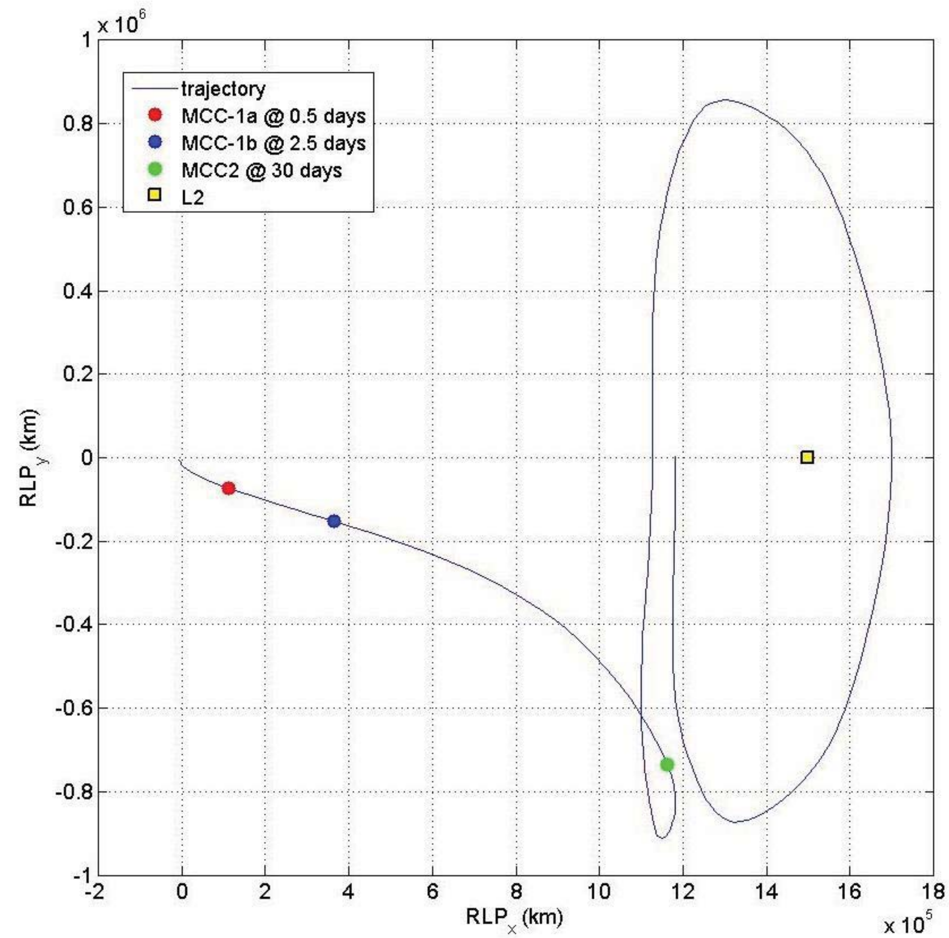
LEOP and Transfer Orbit Phase

Launch and Early Orbit Phase (LEOP)

- From launch until MCC-1a (L+12 hours)
- Tracking from L+45 minutes
- OD ready by L+8 hours

Transfer Orbit Phase

- After MCC-1a (L+12 hours) until MCC-2 (L+30 days)
- MCC-1b (L+2.5 days)
- Sunshield deploy (around L+3 days)
- OD ready by 1 day before each MCC maneuvers



OD Analysis Method

LEOP and Transfer Orbit Phase

- Covariance analysis using batch least-square method in FreeFlyer®.
- Reference ephemeris was generated using nominal MCC-1a and MCC-1b maneuvers.
- Tracking Assets
  - Northern hemisphere – Goldstone, Madrid
  - Southern hemisphere – Canberra
- Simulated range and range rate measurement with Gaussian random noise.
- Initial covariance to support the following MCC's came from:
  - MCC-1a : powered flight ephem from Arianespace (Launch vehicle manufacturer)
  - MCC-1b and MCC-2 : arbitrarily large covariance (worst case scenario) with no correlation

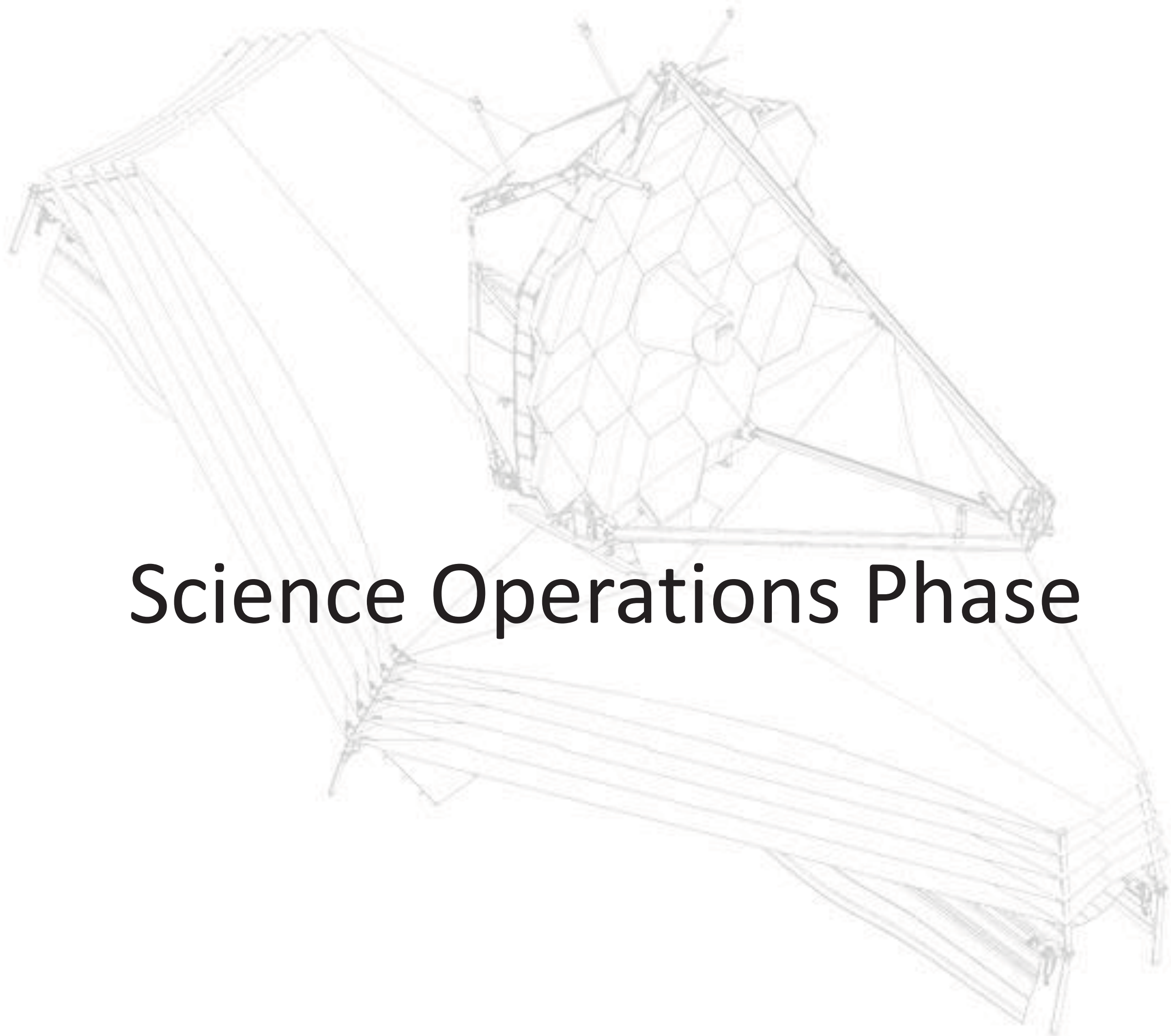
Results and Future Work

LEOP and Transfer Orbit Phase

Standard Deviations at the following MCC's

	Position	Velocity
MCC-1a	1.6 km	2.3 cm/sec
MCC-1b	1.5 km	0.9 cm/sec
MCC-2	9.7 km	7.2 cm/sec

- OD accuracies are adequate to support the MCC maneuvers.
- Future work
  - Assess the impact of additional tracking assets, such as TDRS and/or Malindi ground station
  - Employ more rigorous measurement error modeling
  - Estimate SRP coefficient during the transfer orbit phase



Science Operations Phase

Introduction

Science Operations Phase

Science Operations Phase
- After MCC-2 until the end of the mission
- Orbit around L2 (about 1.5 million kilometer from the Earth)

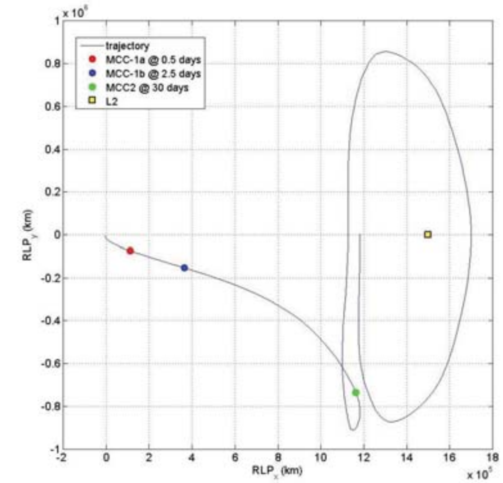
OD Challenges
- Large solar radiation pressure acting on huge sunshield (~ 163 m^2)
- Frequent attitude reorientation to point science targets
- Frequent momentum unloading maneuvers
- Stationkeeping maneuvers every 21 days

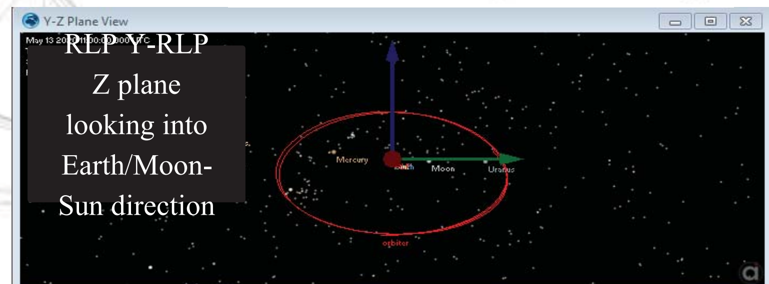
OD Requirements
- Position – No deterministic OD requirement (Prediction requirement not discussed in this paper)
- Velocity – 2 cm/sec (for stationkeeping maneuver design purpose)

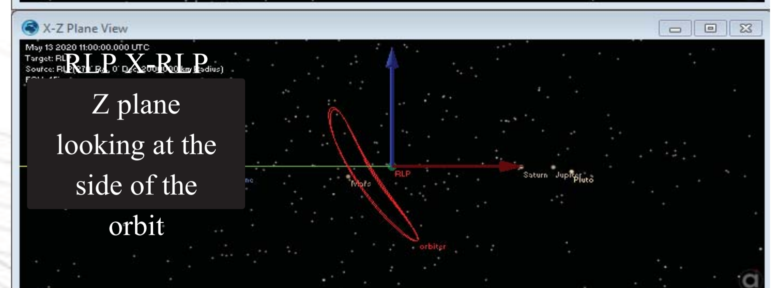
OD Analysis Method (Reference Trajectory)

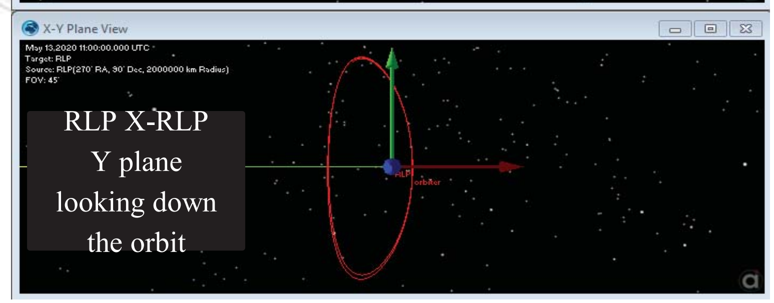
Science Operations Phase

- Monte Carlo analysis using the Extended Kalman Filter in ODTK®
  - EKF over batch filter to accommodate frequent MU maneuvers
- A single trajectory from the stationkeeping analysis as a reference trajectory
- Time span: 14 months (Mar 20, 2019 ~ May 20, 2020)
- 19 stationkeeping (SK) maneuvers with 2 ~ 6 momentum unloading maneuvers between SK maneuvers
- Solar Pressure and Aerodynamic Drag (SPAD) tool (developed by NASA) used to model the solar radiation pressure (SRP)









OD Analysis Method (Simulation and Filter Setup)

Science Operations Phase

- Tracking scenario
  - two contacts each day, one from Goldstone and the other from Madrid (both in Northern Hemisphere)
  - Every three days, Canberra tracking (Southern hemisphere) will replace one of the two daily passes.
- The following parameters were varied randomly: initial states, transponder delay, measurement bias with white noise, troposphere bias, measurement time bias
- Estimated states: three position components, three velocity components, SRP coefficient, MU and SK maneuver ΔV vectors, range and range rate biases.

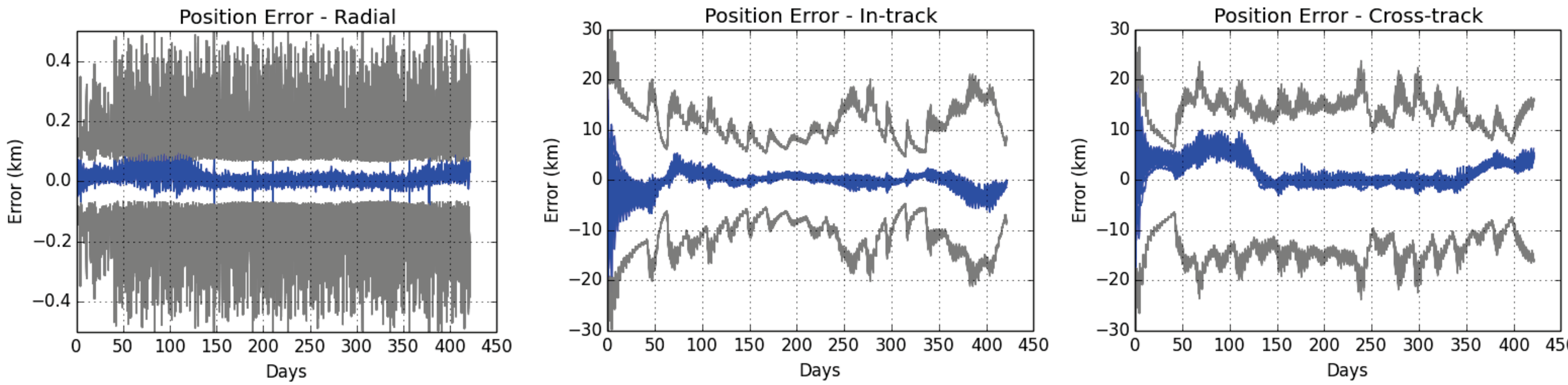
Test Cases

	SRP Model Error (1σ)	Tracking Schedule
Case 1	1% magnitude, 1˚ direction error	2x 3 hour contacts
Case 2	1% magnitude, 1˚ direction error	2x 30 min contacts
Case 3	5% magnitude, 5˚ direction error	2x 3 hour contacts
Case 4	5% magnitude, 5˚ direction error	2x 30 min contacts

Results – Position Error

Science Operations Phase

Results from Case 1



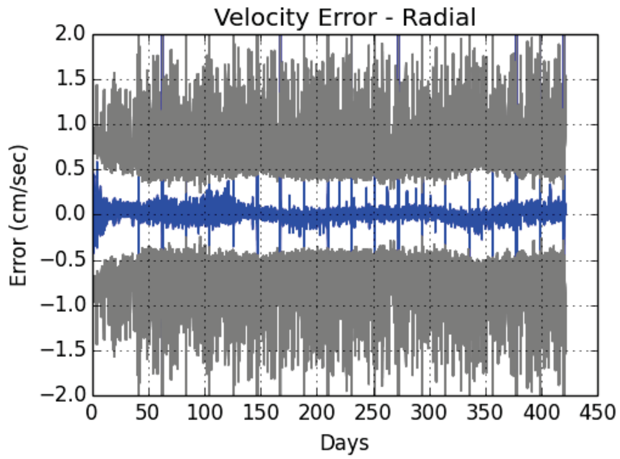
$$\mathrm{MAX} = \sqrt{(Error\ Max_R)^2 + (Error\ Max_I)^2 + (Error\ Max_C)^2}$$

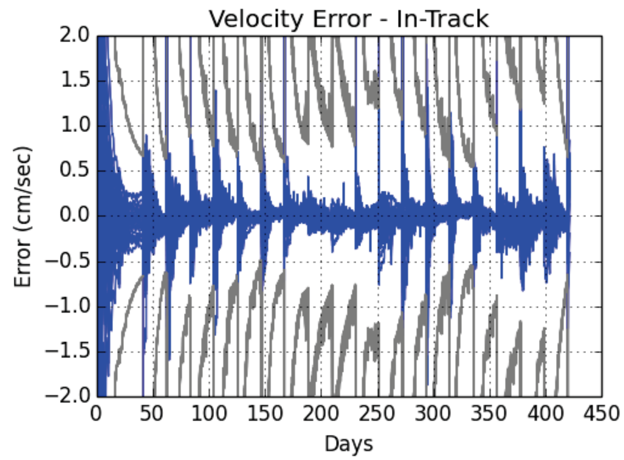
	2x 3 hour Contacts	2x 30 min Contacts
Small SRP Error	11.95 km (case 1)	11.73 km (case 2)
Large SRP Error	12.53 km (case 3)	11.93 km (case 4)

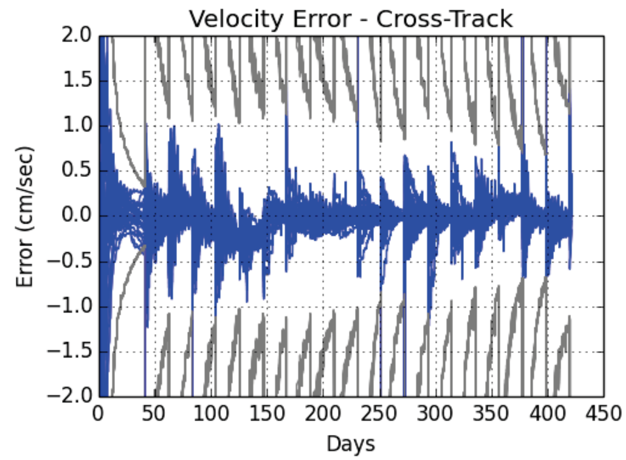
Results – Velocity Error

Science Operations Phase

Results from Case 1







$$\mathrm{MAX} = \sqrt{(Error\ Max_R)^2 + (Error\ Max_I)^2 + (Error\ Max_C)^2}$$

Point of Interests : At 26 hours before stationkeeping maneuver executions

	2x 3 hour Contacts	2x 30 min Contacts
Small SRP Error	0.47 cm/sec (case 1)	0.51 cm/sec (case 2)
Large SRP Error	0.67 cm/sec (case 3)	0.78 cm/sec (case 4)

Conclusions and Future Work

Science Operations Phase

- Conclusions
  - Position determination performance is about 10 km.
  - Velocity determination performance meets 2 cm/sec requirement.
  - The expected Position/velocity determination performance is consistent with OD performance of other L2 missions (MAP, Planck, Gaia) in spite of OD challenges

- Future Work
  - Use more than one reference ephemeris
  - Simulate ionospheric effect in measurement simulation
  - Analyze contingency cases (missing ground contacts, more dense momentum unloading maneuvers)