Dawn Maneuver Design Performance at Vesta

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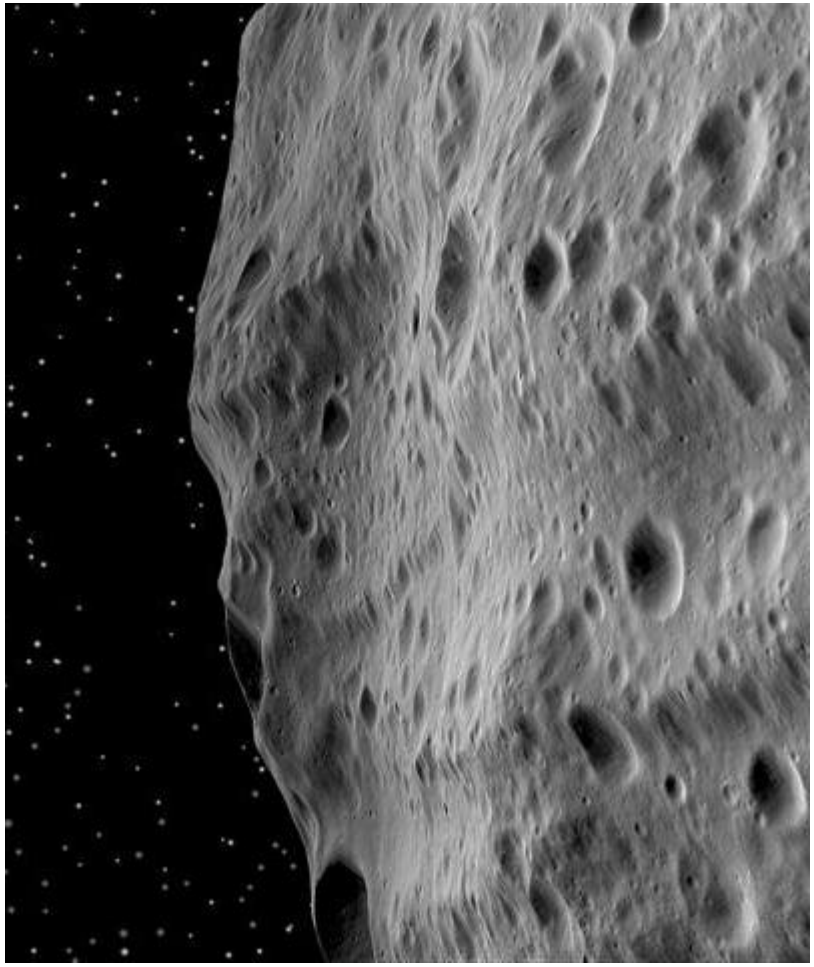
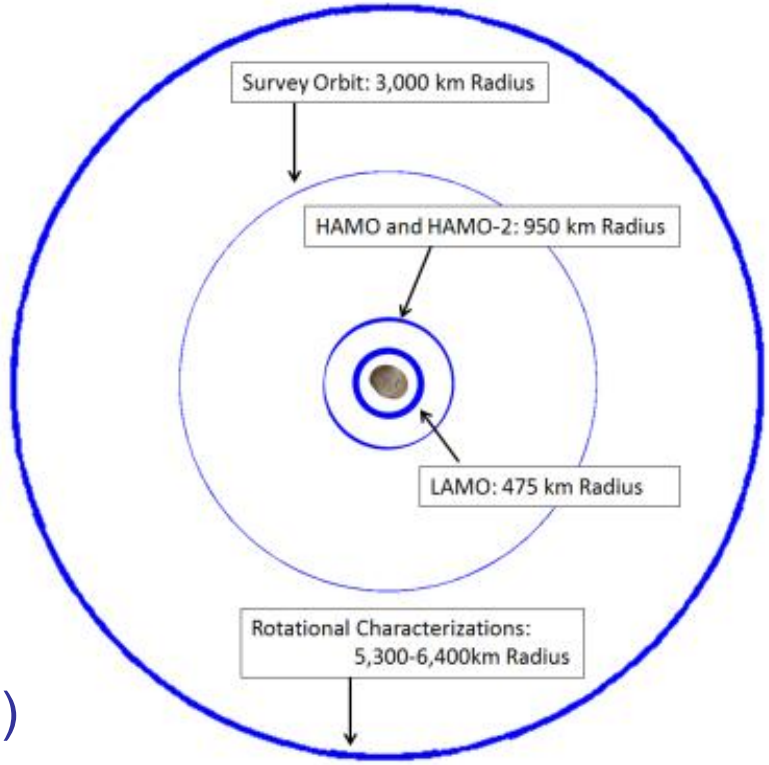
Vesta Mission Overview

- Solar Electric Ion Propulsion System Performed:
  - 6.7 km/s ΔV from launch to Vesta
  - 0.35 km/s ΔV during Vesta Operations
  - 4 km/s ΔV remaining planned for the mission.
- Arrived at Vesta: July 16, 2011
- Departed Vesta: Sept. 5, 2012
- 6 Targeted Orbits
  - 2 Rotational Characterizations
  - 4 Science Observation Orbits



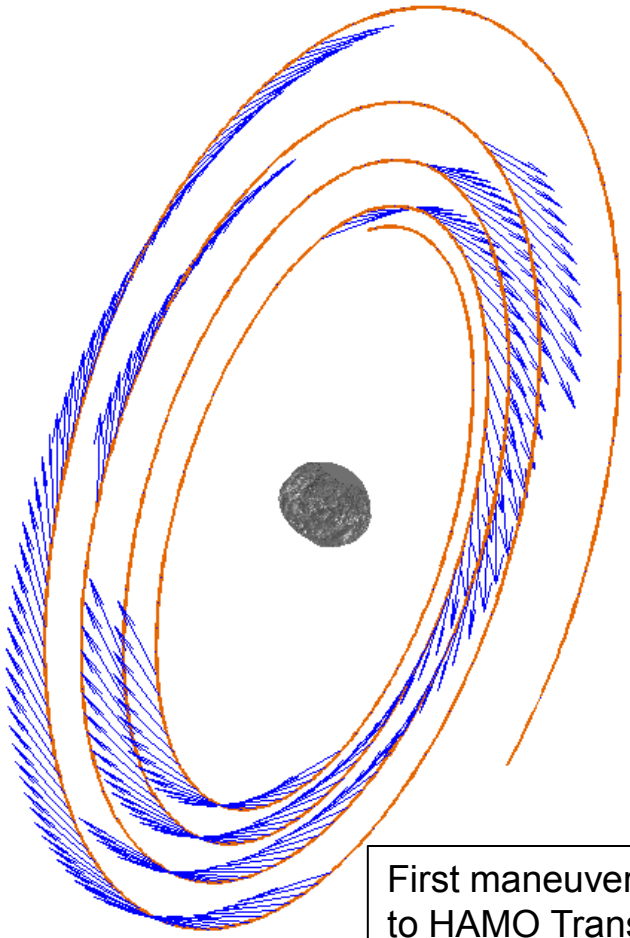
Vesta Mission Overview (2)

- Rotational Characterization
  - 5,500 km orbital semi-major axis
  - Observe Vesta's Pole and rotation rate
- Survey
  - 3000 km Orbital Radius
  - Highest Altitude Science Orbit
  - Prime Instrument: Visible and Infrared Spectrometer
- High Altitude Mapping Orbit (HAMO)
  - 950 km Orbital Radius
  - Prime Instrument: Framing Camera
  - Visual and Topographic Mapping
- Low Altitude Mapping Orbit (LAMO)
  - 475 km Orbital Radius
  - Prime Instrument: Gamma Ray and Neutron Detector
  - Precision Gravity Determination
- High Altitude Mapping Orbit 2 (HAMO-2)
  - 950 km Orbital Radius
  - Prime Instrument: Framing Camera
  - Visual and Topographic Mapping
  - Later timing offers improved northern latitude lighting
- Rotational Characterization
  - 5,500 km orbital semi-major axis
  - Observe Vesta's northern latitudes with improved lighting



Navigation Concept

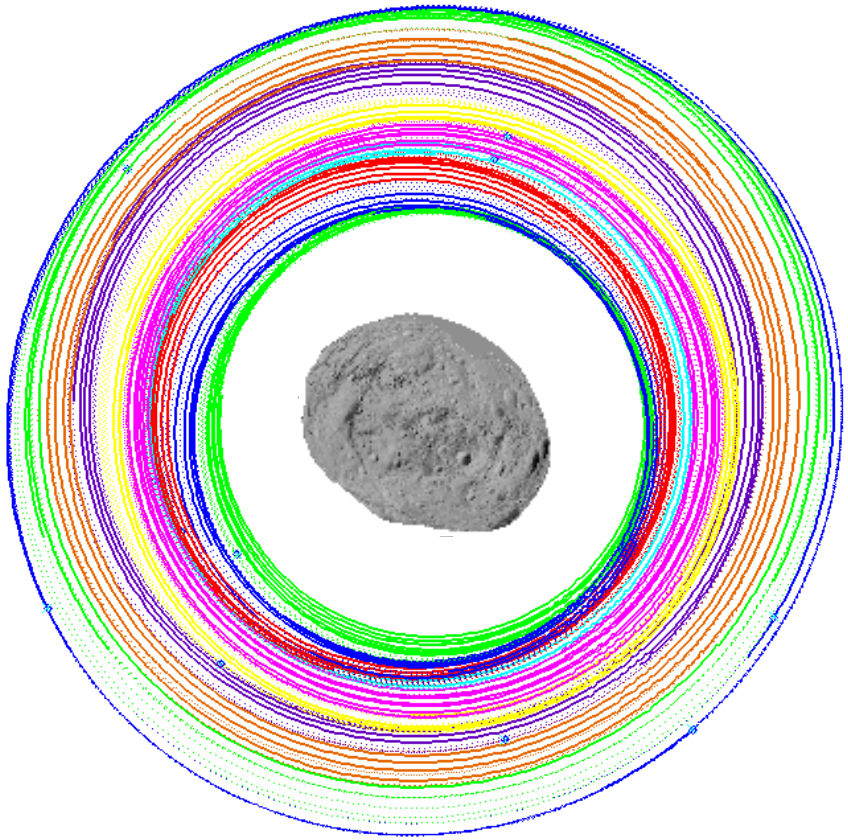
- Orbit-to-Orbit transfers flown in segments called maneuvers.
- Each maneuver flies back to the reference transfer.
- Maneuvers target Waypoints on the transfer.
- Spacecraft attitude changes throughout the maneuver to achieve optimal thrust directions.



First maneuver in Survey to HAMO Transfer

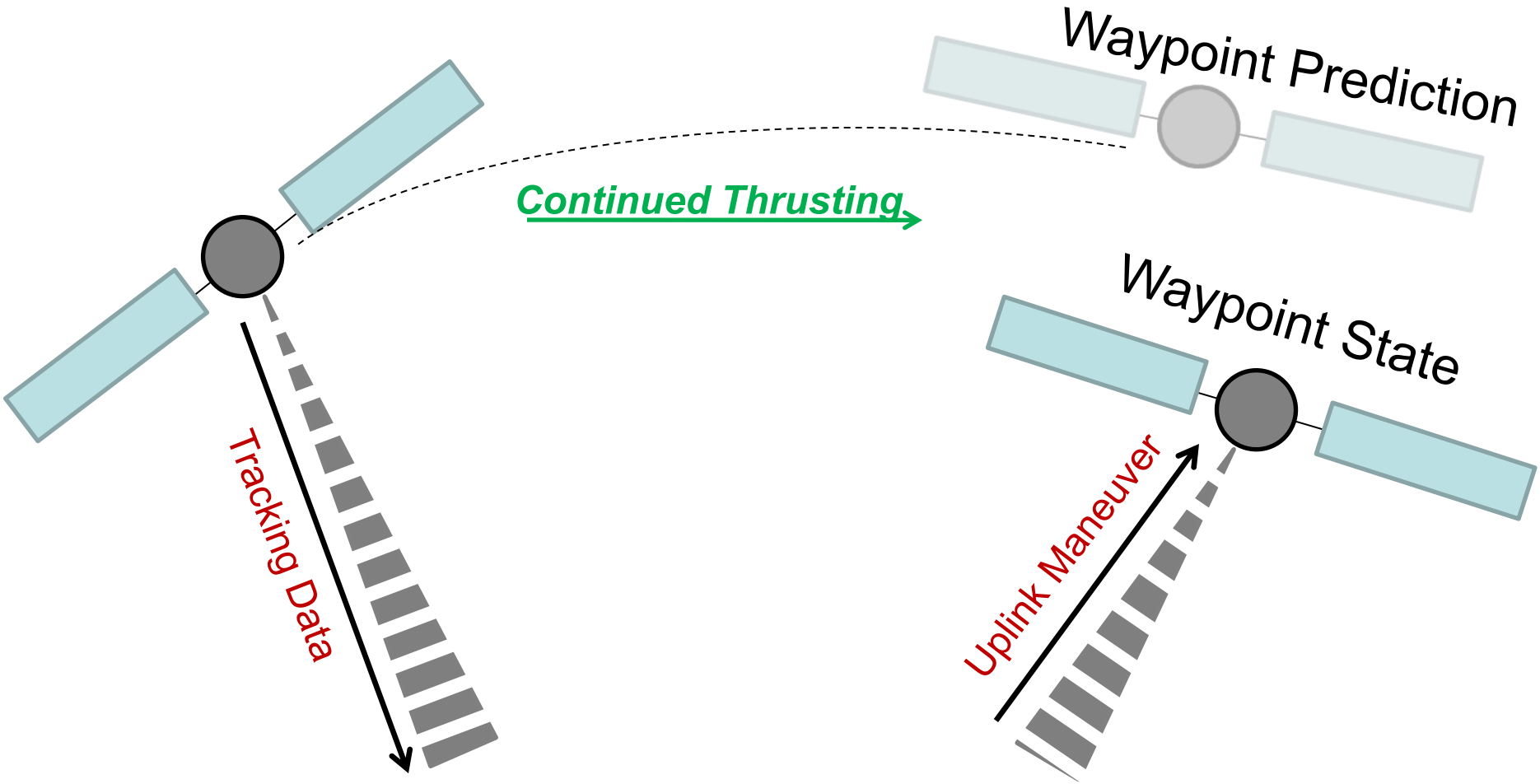
LAMO to HAMO-2 Trajectory

- Example trajectory: LAMO to HAMO-2
  - Paper also discusses Survey to HAMO, HAMO to LAMO, and LAMO maintenance
- LAMO to HAMO-2 was flown in 11 maneuvers targeting Waypoints on the reference.
- Individual maneuvers spanned as many as 13 revs during this transfer.



Each color represents a single maneuver

Maneuver Design Process



Ground Process:
Perform Orbit Determination
Design & Build New Thrust Sequence

Waypoint Prediction and Delivery

LAMO to HAMO-2 Waypoint	Modeled Waypoint prediction Uncertainty (km, 1σ)	Distance between OD prediction and Waypoint (km)*	Modeled Delivery Dispersion (km) from Reference Trajectory (1σ)	Actual Delivery Distance (km) from Reference Trajectory*
LAMO End	4.1	0.9	--	--
Waypoint 1	15.9	1.8	13.5	21.3
Waypoint 2	1.7	0.1	22.0	13.7
Waypoint 3	17.2	1.9	11.2	5.6
Waypoint 4	6.3	2.0	22.0	5.6
Waypoint 5	17.4	0.3	30.5	4.4
Waypoint 6	17.5	4.5	52.6	30.4
Waypoint 7	17.6	7.3	55.0	30.8
Waypoint 8	26.2	12.9	39.4	22.0
Waypoint 9	13.1	0.5	50.7	29.9
Waypoint 10	5.2	0.1	39.1	5.0
HAMO-2	--	--	5.9	14.1†

* Based on orbit determination reconstruction, with uncertainty below 50 m and 1 cm/s 1σ

† Cancelled maneuver – deviation was determined to be acceptable.

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Waypoint prediction significantly more accurate than modeled

* Based on orbit determination reconstruction, with uncertainty below 50 m and 1 cm/s 1σ

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Waypoint delivery more accurate than modeled

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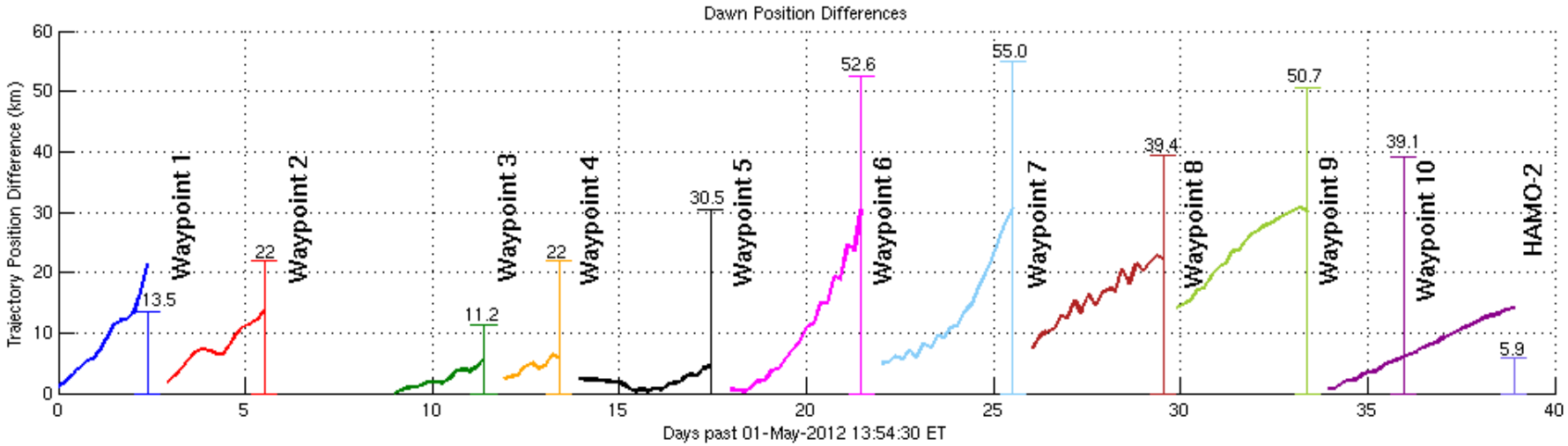
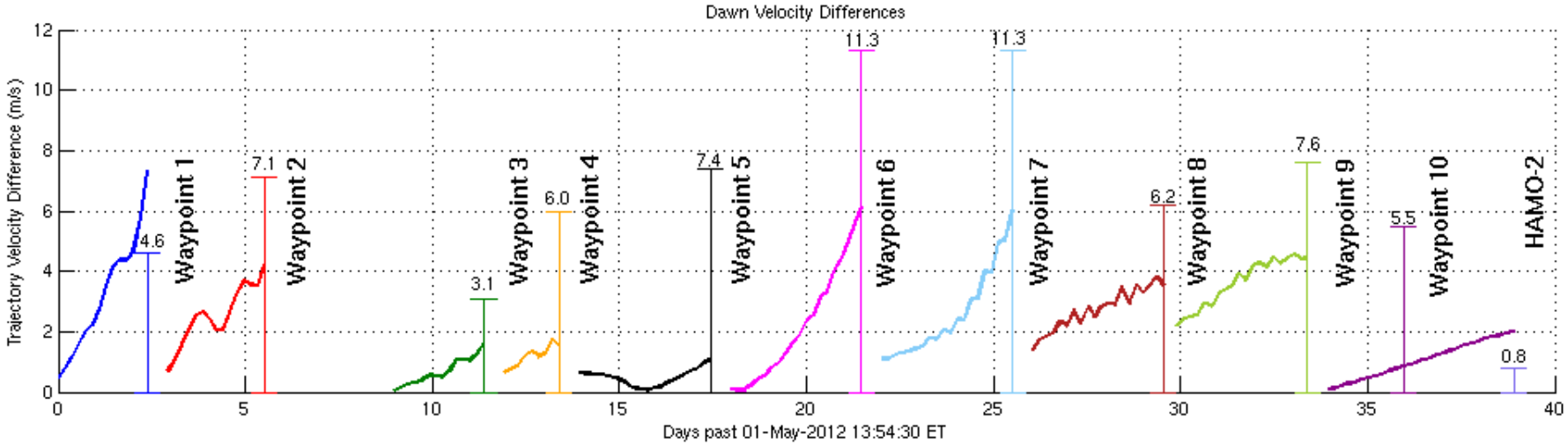
Maneuver Designs vs. Transfer Reconstruction

LAMO to HAMO-2 Transfer

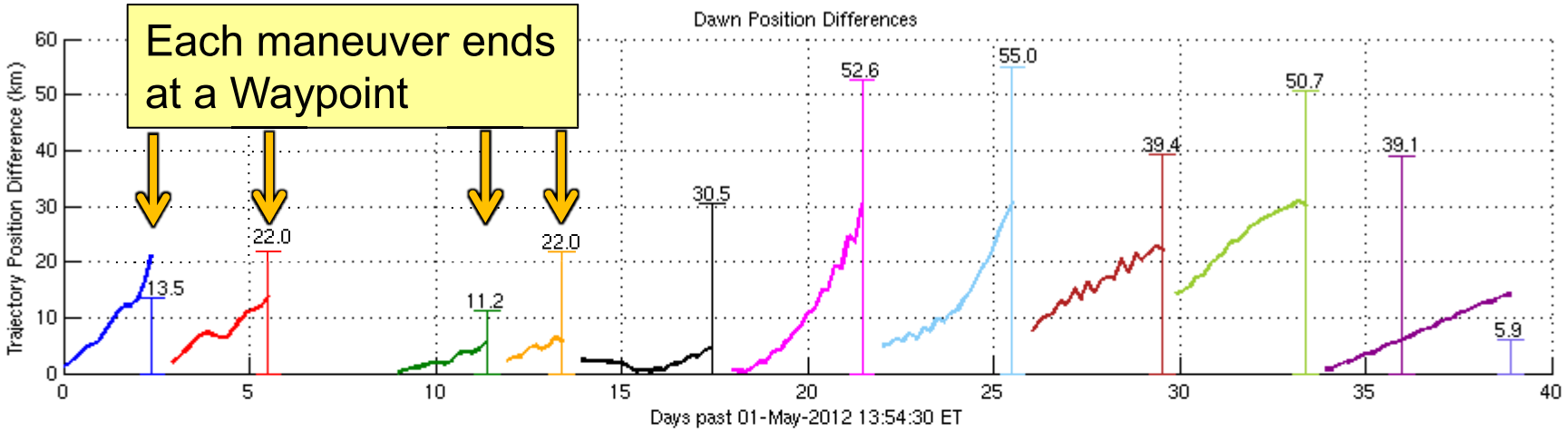


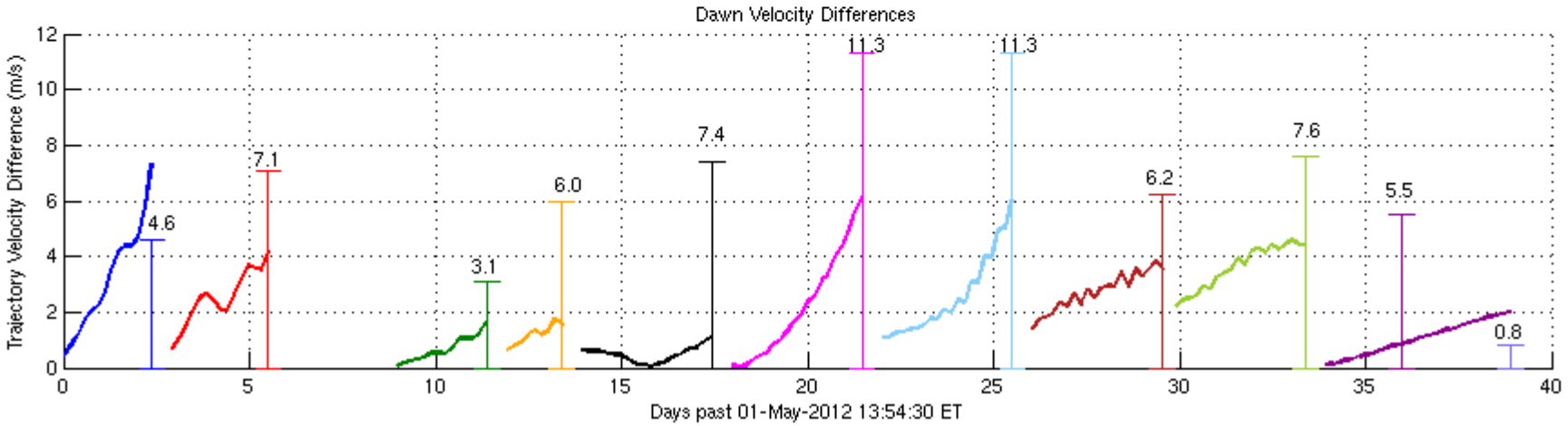


Maneuver Designs vs. Transfer Reconstruction

LAMO to HAMO-2 Transfer

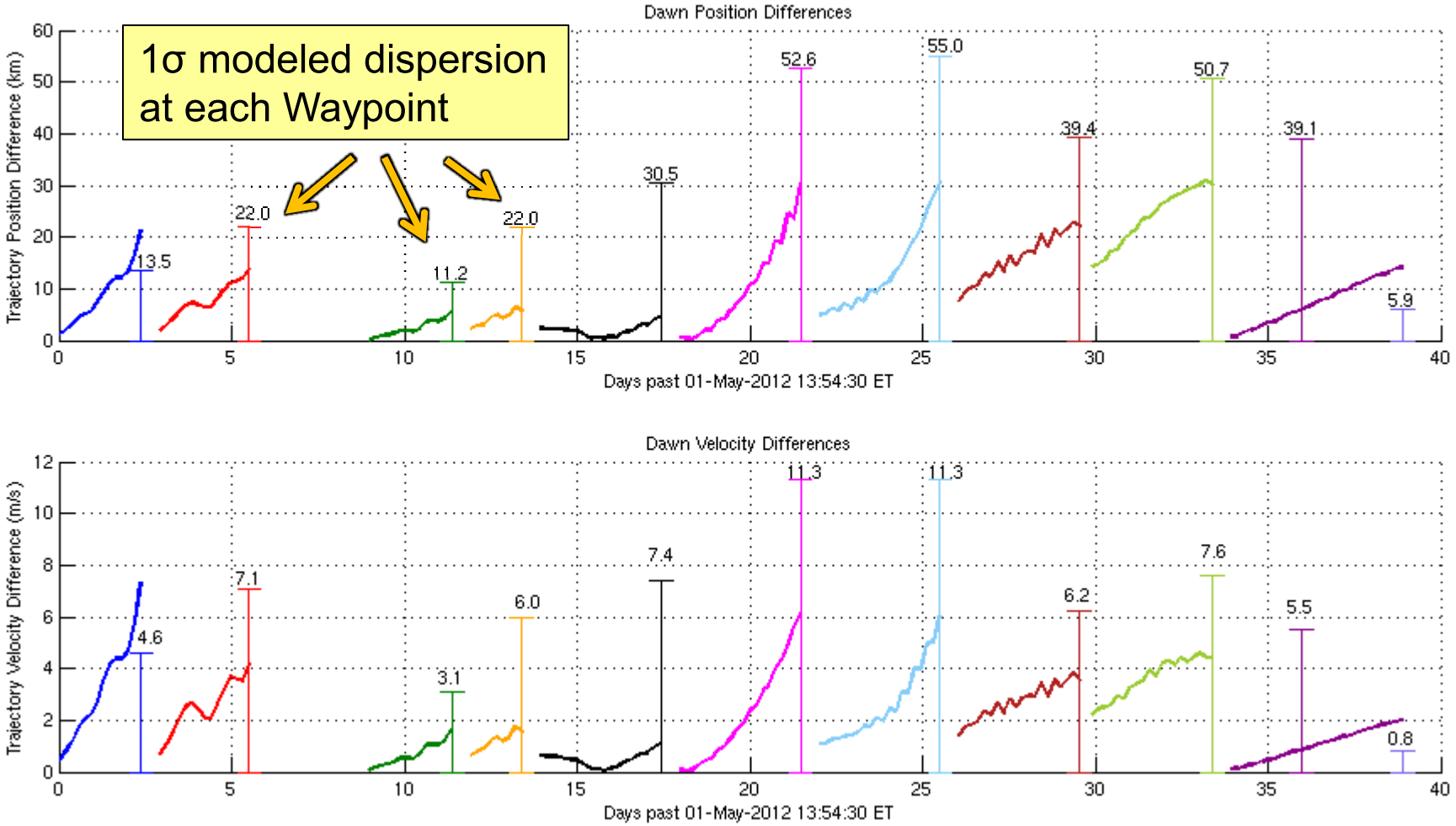
Each maneuver ends at a Waypoint





Maneuver Designs vs. Transfer Reconstruction

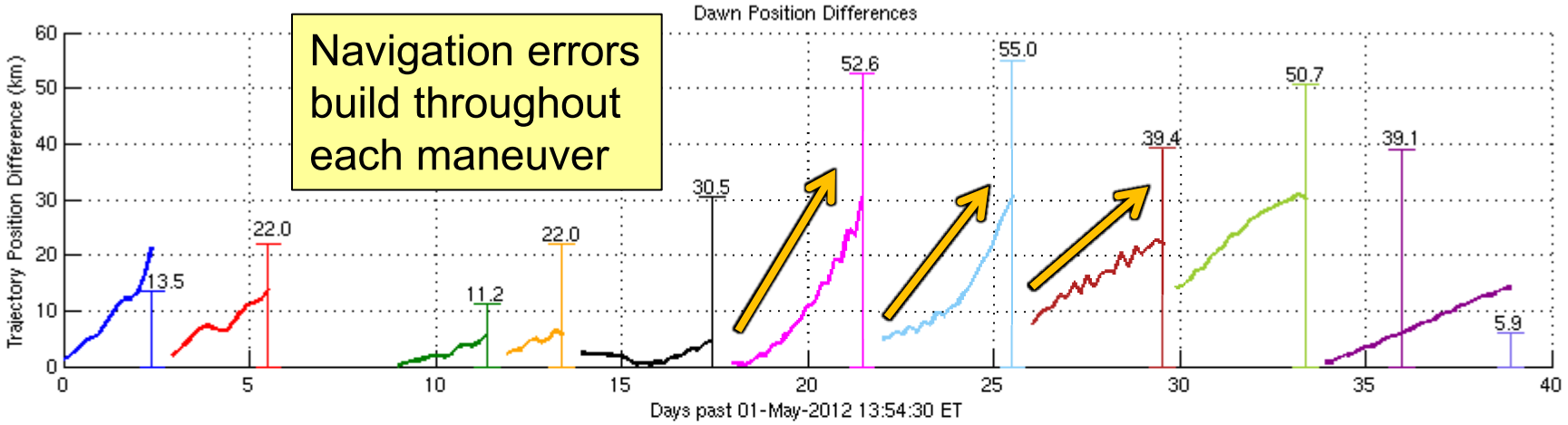
LAMO to HAMO-2 Transfer

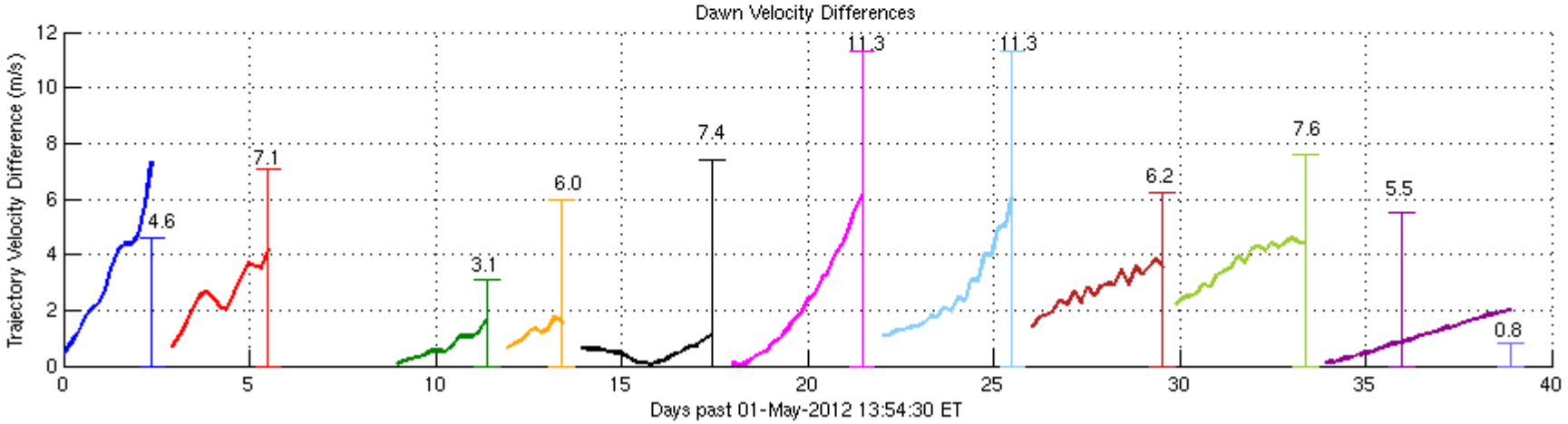


Maneuver Designs vs. Transfer Reconstruction

LAMO to HAMO-2 Transfer

Navigation errors build throughout each maneuver

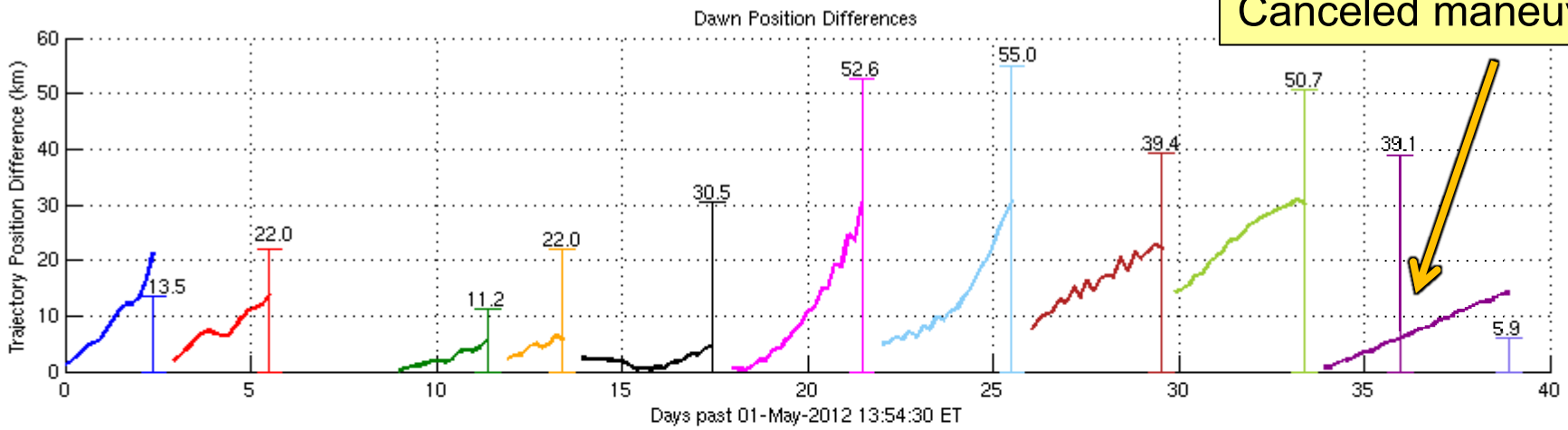


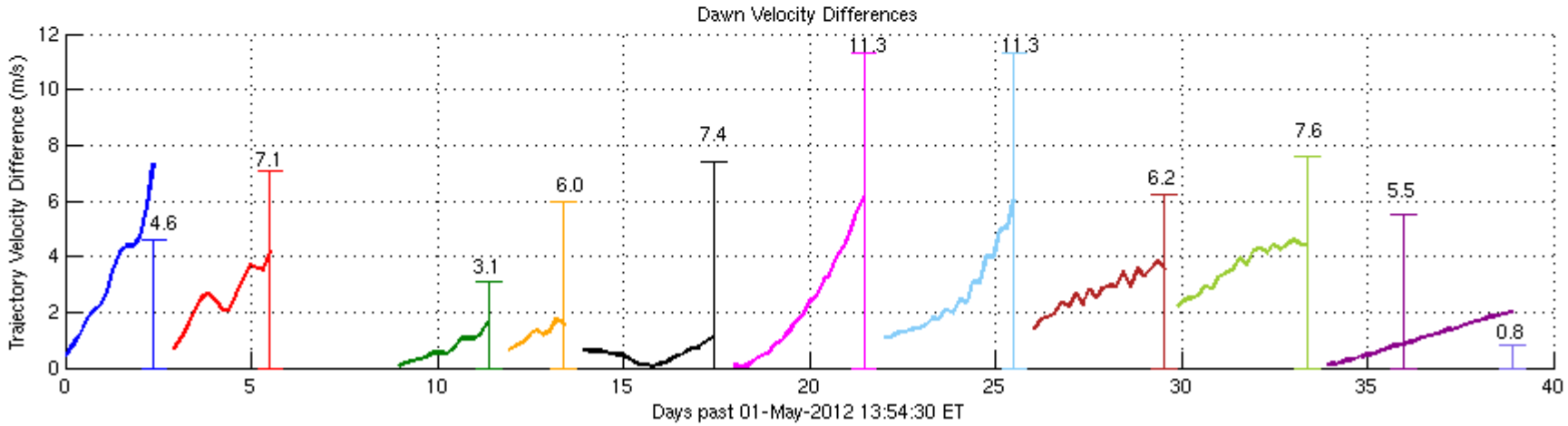


Maneuver Designs vs. Transfer Reconstruction

LAMO to HAMO-2 Transfer

Canceled maneuver

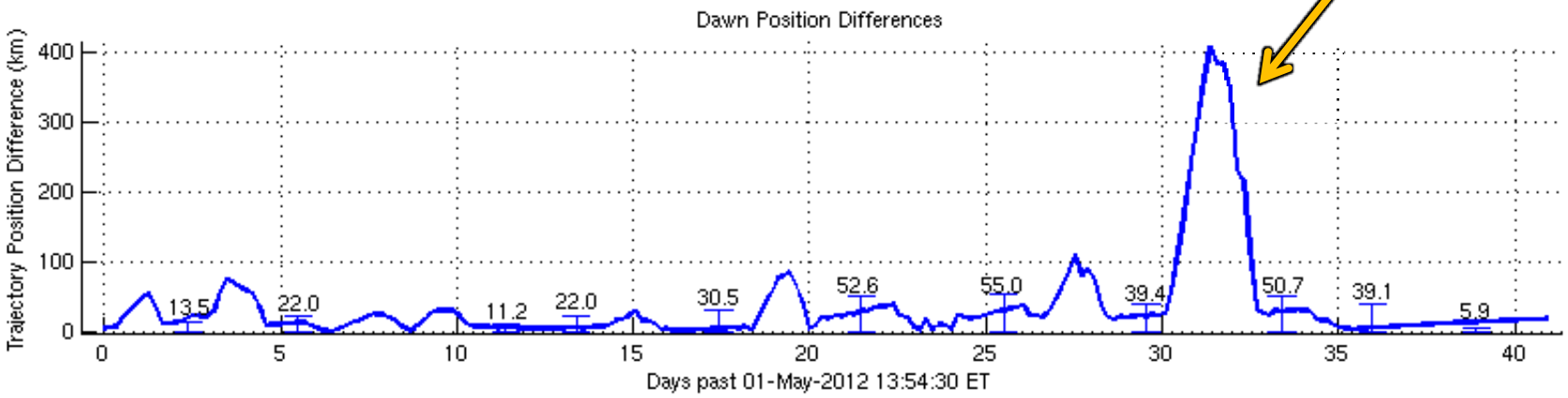


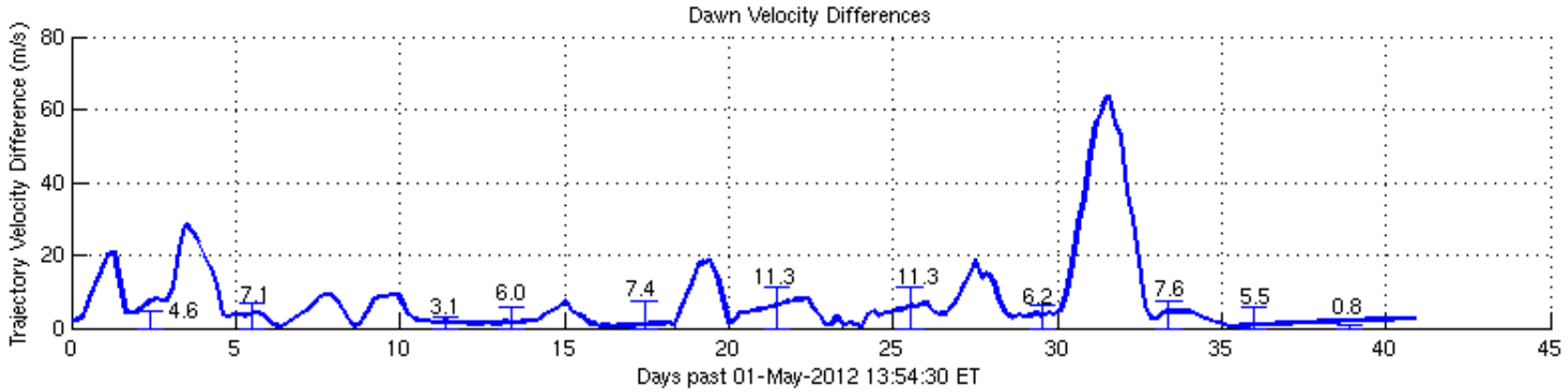


Reference Trajectory vs. Reconstruction

LAMO to HAMO-2 Transfer

400 km deviation from reference due to thrust direction optimization.



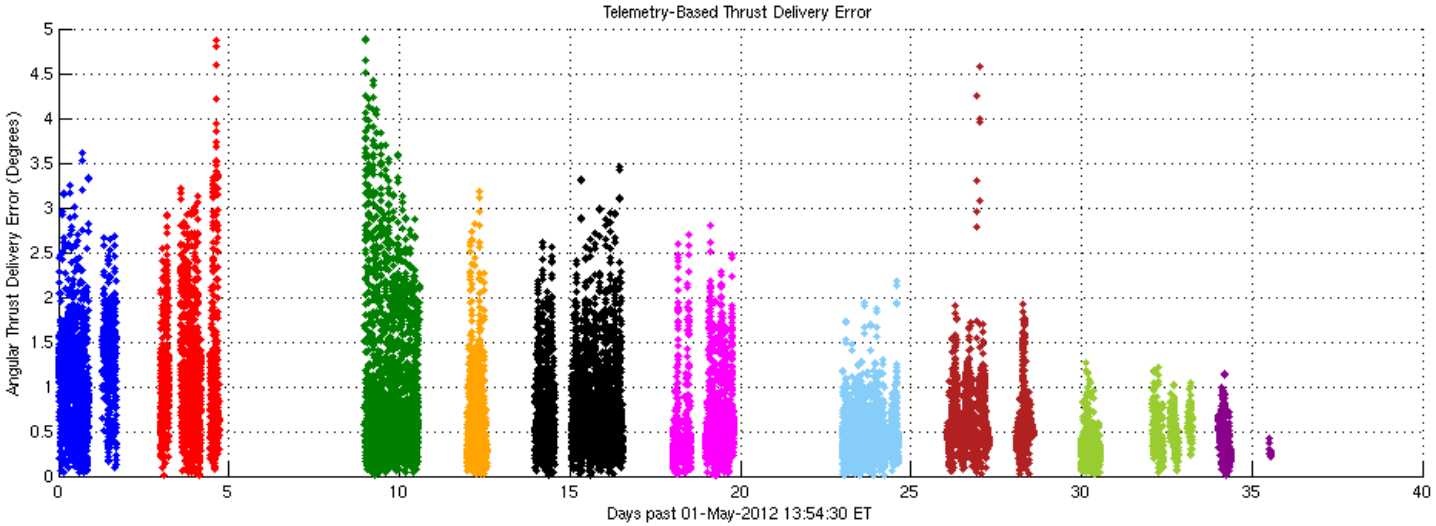


Waypoint Delivery Results

- Waypoint prediction and deliveries often well within statistical predictions.
- Largest statistical deviation for LAMO to HAMO-2 was 1.5σ, most were only a fraction of 1σ.
- Significant deviations from reference trajectory between Waypoints could compromise reference trajectory characteristics.
  - Some Maneuvers were designed with direction optimization targeting waypoints
  - Reference trajectory was designed with mass optimization targeting science orbits.
- Reference trajectory characteristics that could be compromised by deviating from reference.
  - Powered flight stability
  - Distance from entering shadow

Maneuver Execution Errors

LAMO to HAMO-2 Transfer



- Angular difference between designed thrust vectors and spacecraft telemetry during the maneuver.
- Monte-Carlo execution error model:
  - Always above 1^{o}
  - Above 3^{o} 10% of the time
  - Occasional deviations above 10^{o}.
- Telemetry results:
  - Below 1^{o} 76% of the time.
  - Over 3^{o} 1% of the time
  - Never exceed 5^{o}

Conclusions

- Waypoint prediction and delivery dispersion models were conservative.
- Conservative maneuver execution error models contributed to inflated Waypoint dispersion predictions.
- Thrust direction optimization was employed to satisfy attitude control constraints for maneuvers.
- Thrust direction optimization resulted in significant deviations from the reference trajectory between Waypoints.
  - Significant deviations from the reference trajectory can result in loss of desired reference trajectory characteristics.
  - Dawn maneuvers that strayed from the reference trajectory were evaluated and determined to be safe.

Questions