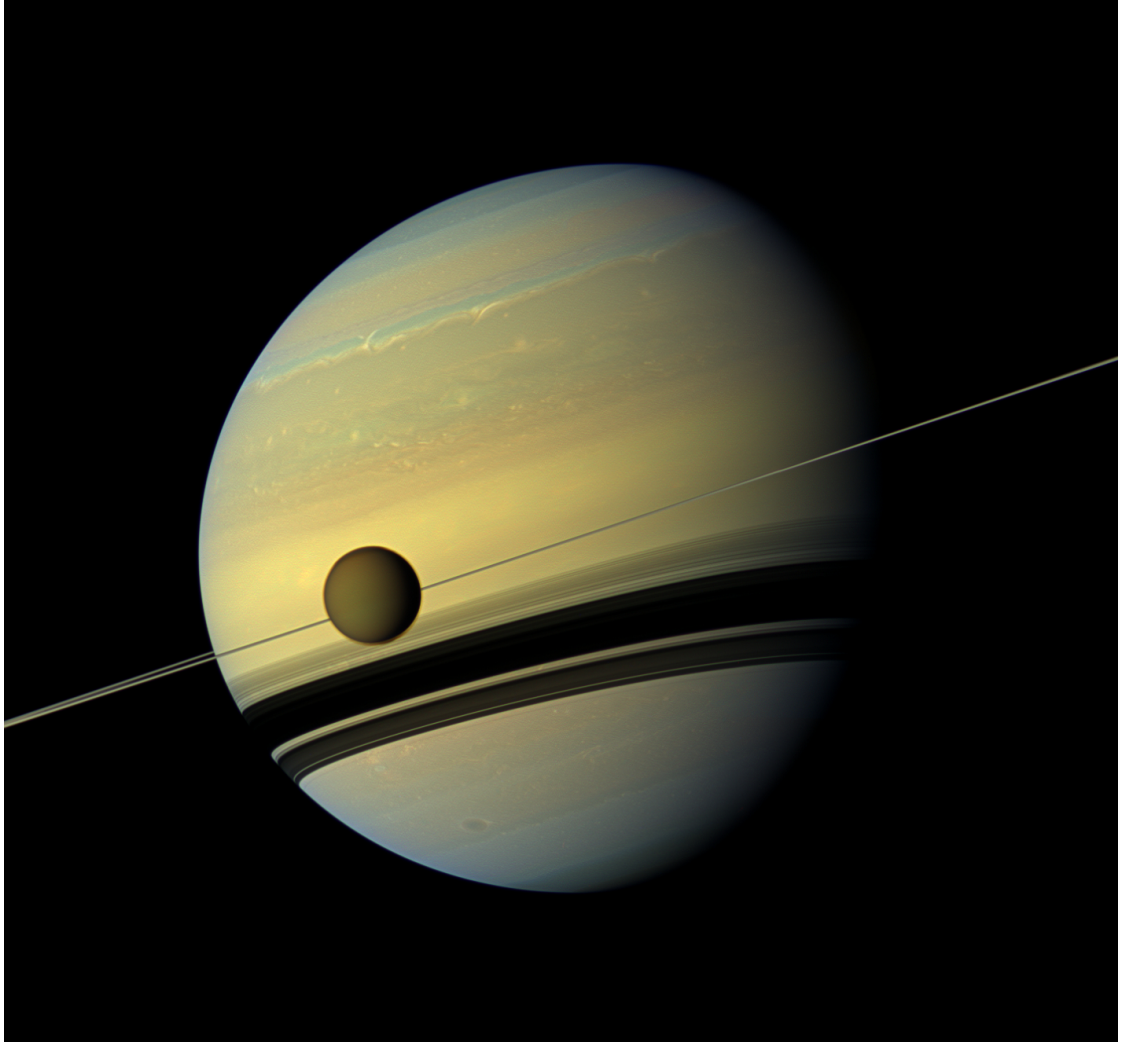


Resolution of Orbit Determination Prediction Instabilities at Titan During Cassini's Solstice Mission

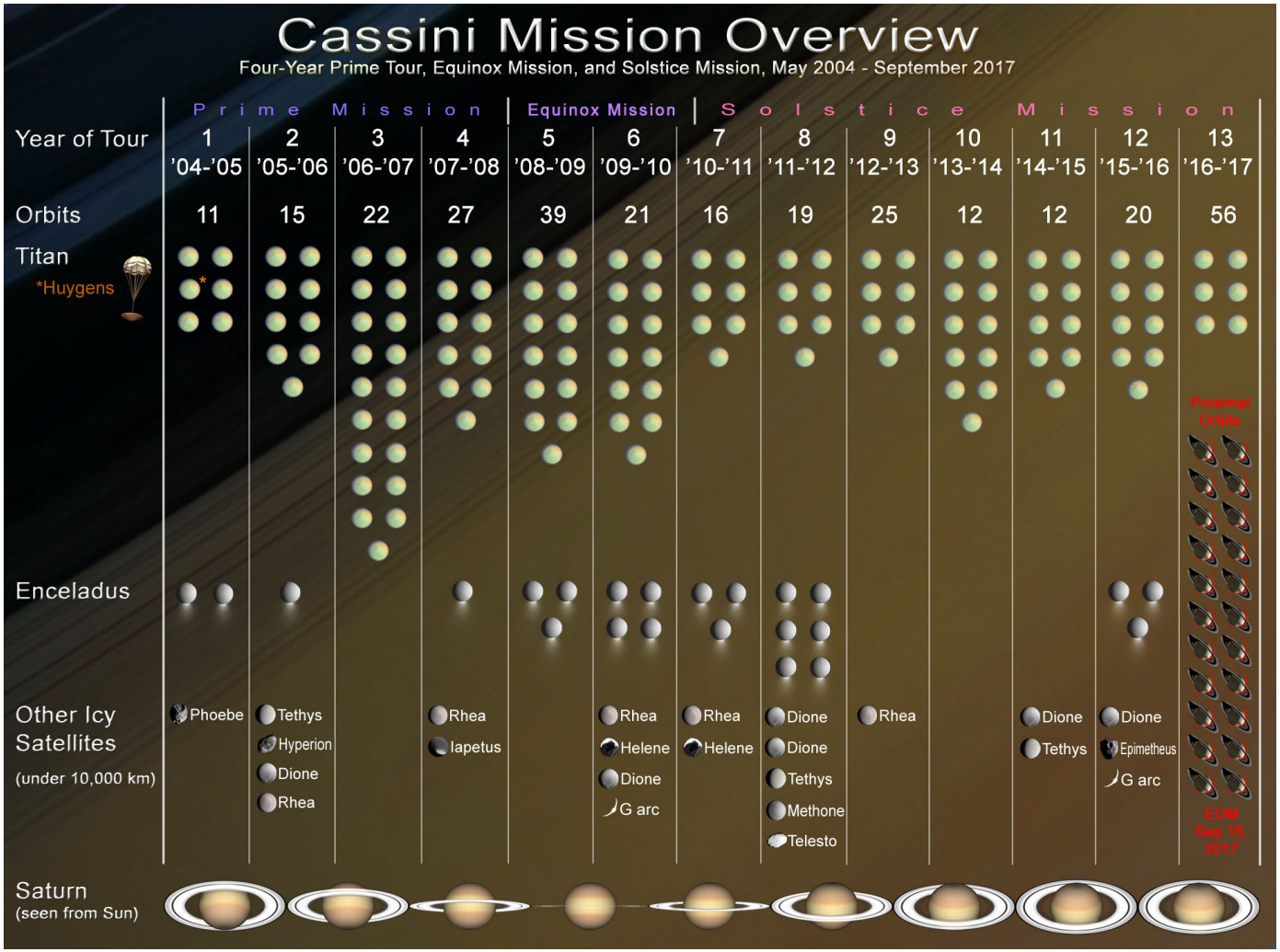
Dylan Boone, Julie Bellerose, and Duane Roth - Cassini Navigation Team

ISSFD 2017 – Matsuyama, Japan

Jet Propulsion Laboratory
California Institute of Technology

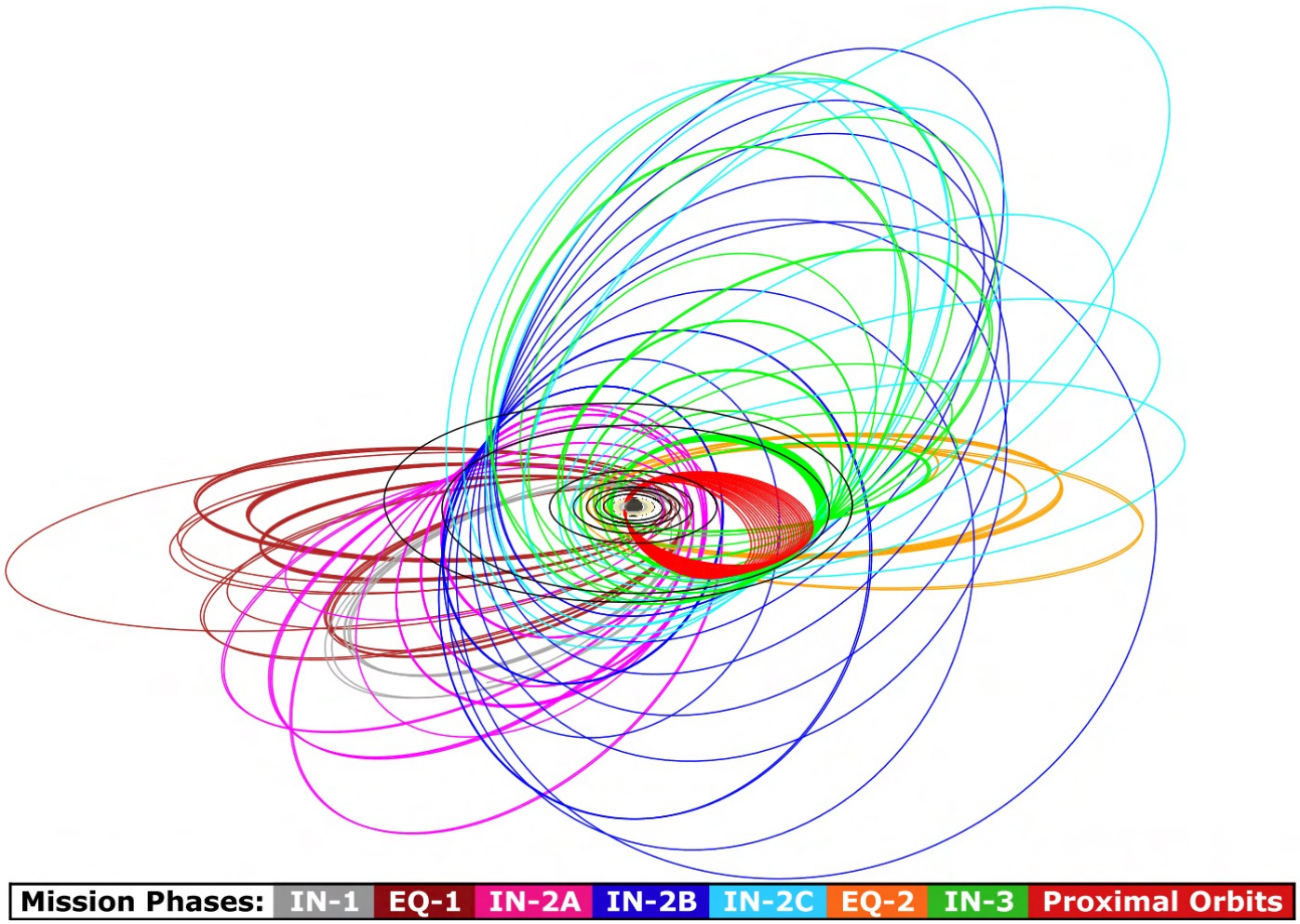
Background

Satellite Encounters by Mission Phase



Background

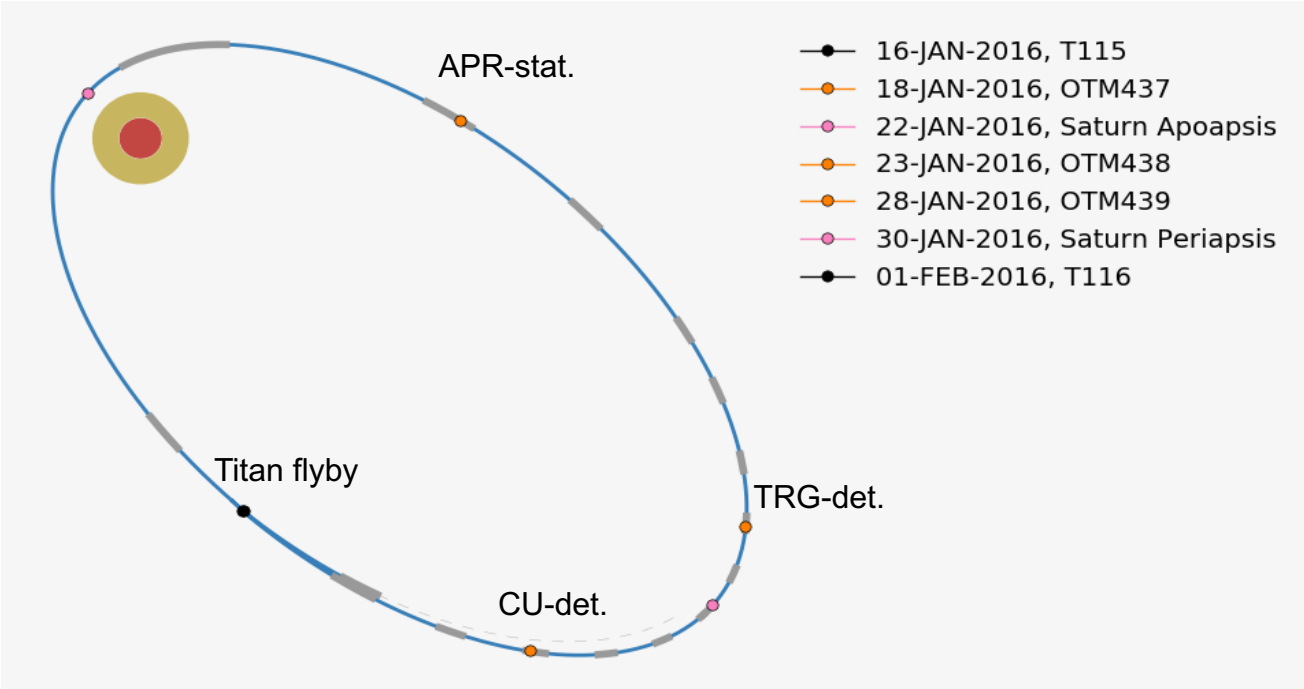
Solstice Mission Reference Trajectory



Background

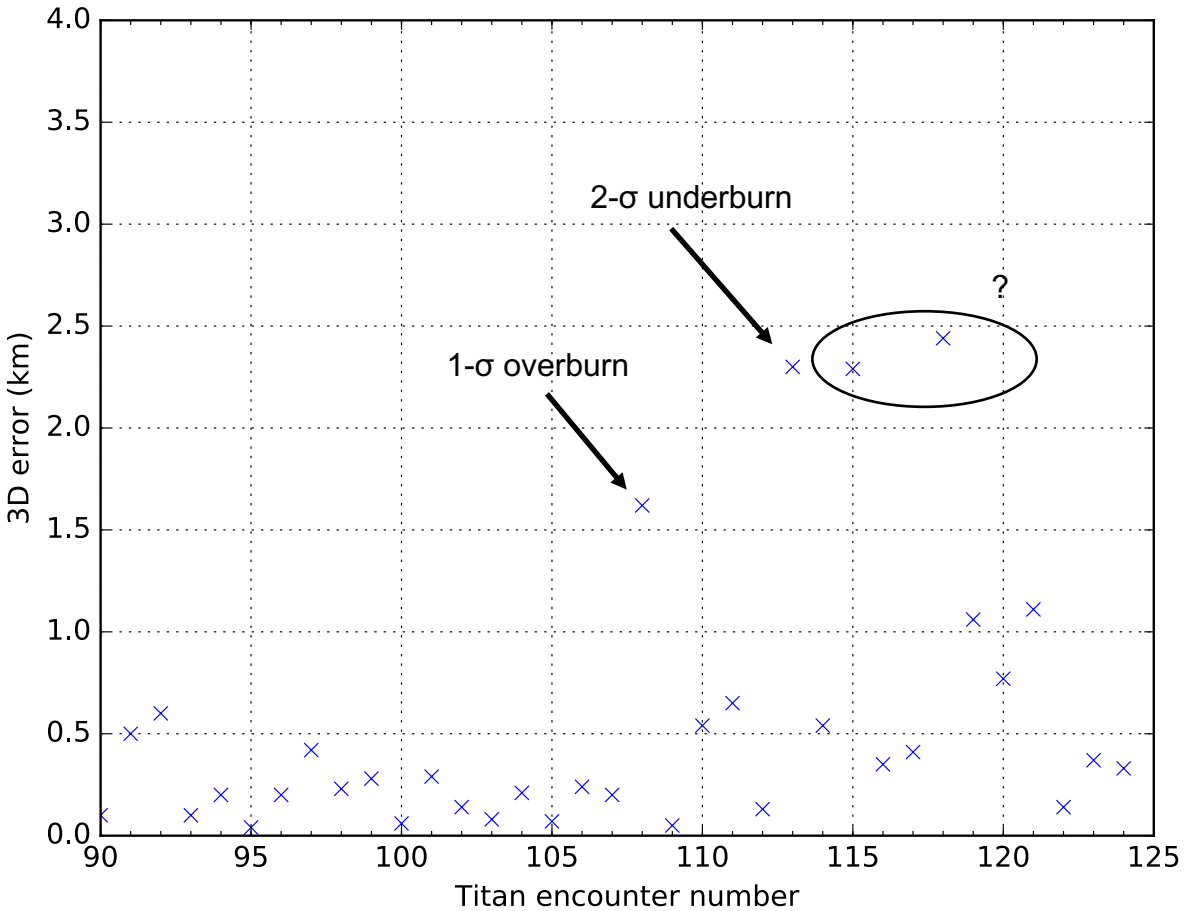
Navigation Operations Overview

- Example: 16 day transfer from T115 to T116
  - Two deterministic maneuvers: Cleanup and Targeting
  - One statistical maneuver: Approach



Motivation

Target miss at Titan for recent encounters



Motivation

Titan Encounter Performance

- No obvious factors correlate to misses at T116 and T119
- Flybys distributed in:
  - Altitude at Titan (high vs. low)
  - Saturn orbit inclination (16° vs. 35°)
  - Titan lat./lon. geometry

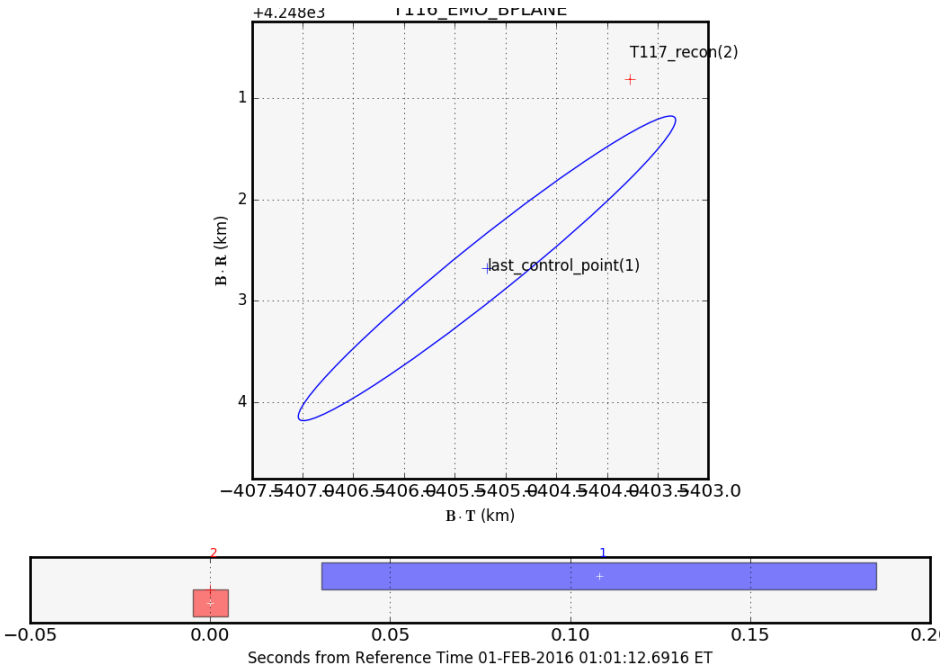
Table 1 Titan Encounter Performance Summary.

Titan Flyby	Altitude (km)	3D error (km)	3D sigma level
T115	3548.1	0.54	2.5
T116	1400.0	2.29	4.8
T117	1018.0	0.35	2.2
T118	990.0	0.41	0.9
T119	971.0	2.44	5.8
T120	975.0	1.06	2.9
T121	976.0	0.77	2.8
T122	1697.7	1.11	0.5
T123	1773.9	0.14	1.6
T124	1584.8	0.37	1.2

Motivation

Large target miss at T116 encounter

- Delivered solutions considered satellite system error
  - Target defined in B-plane coordinates: B.R, B.T, TOF
  - Targeted ellipse in blue, reconstructed solution in red
  - 2.29 km (4.8σ) reconstructed miss using post-flyby tracking data



Orbit Determination Filter Setup

- Parameters in each Titan to Titan OD arc
  - Estimated parameters have *a priori* uncertainty reduced in filter
  - Considered parameters only contribute uncertainty
  - Satellites parameters include GMs, Saturn pole and harmonics

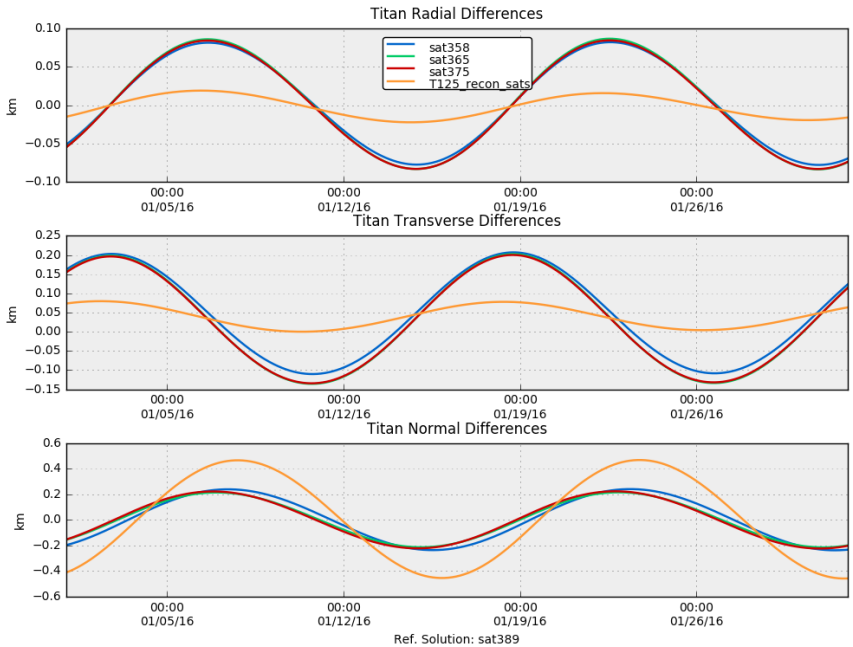
Table 1. OD Filter Setup.

Parameter	Unit	Est/Cons	1-sigma error
Epoch S/C state	km, cm/s	Estimated	<5 pos, <20 vel
RCS OTM	%, mm/s	Estimated	0.02% prop., 3.5 fixed
ME OTM	%, mm/s	Estimated	0.4% prop., 0.5 fixed
Small Forces	mm/s	Estimated	0.25-1.20
Stochastic Accelerations	km/s^2	Estimated	$5x10^{-13}$
Transponder Range Bias	m	Estimated	500
Satellites Ephemeris Sys.	km,km/s	Est / Cons	varies by set
DSN Station Locations	cm	Considered	2-5
Earth Media Calibrations	cm	Considered	1-5
Earth Pole Orientation	cm	Considered	10 per axis
Saturn Ephemeris	km	Considered	0.2

A priori Satellite Ephemerides

Variation in satXXX deliveries

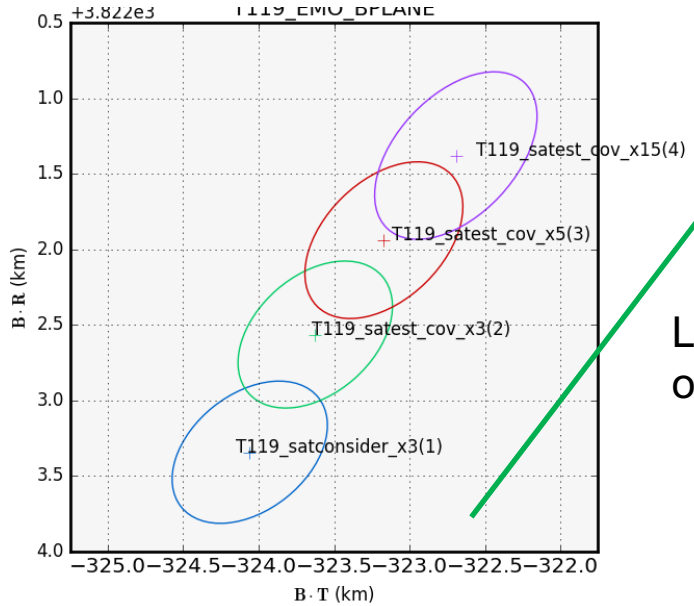
- Most recent reconstructed ephemeris in orange
- Ephemerides differ by hundreds of meters out of plane
- Formal error on order of tens of meters
- Suggests system covariance is too constrained
- Sat375 used as *a priori* for presented estimation results



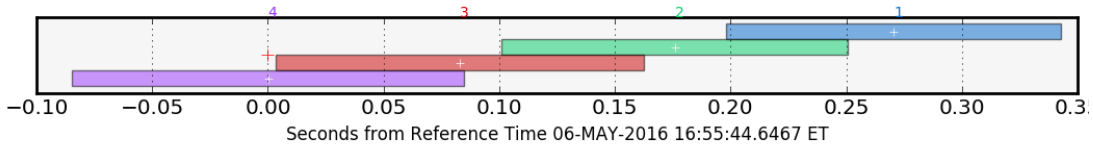
Satellite System Covariance Scaling Results

T119 B-plane solutions

- B-plane results with scaling of formal system covariance
- Affects satellite states as well as Saturn pole/harmonics
- Scale of x15 results in ~200 m Titan position *a priori* 1σ



Larger scale factor on covariance



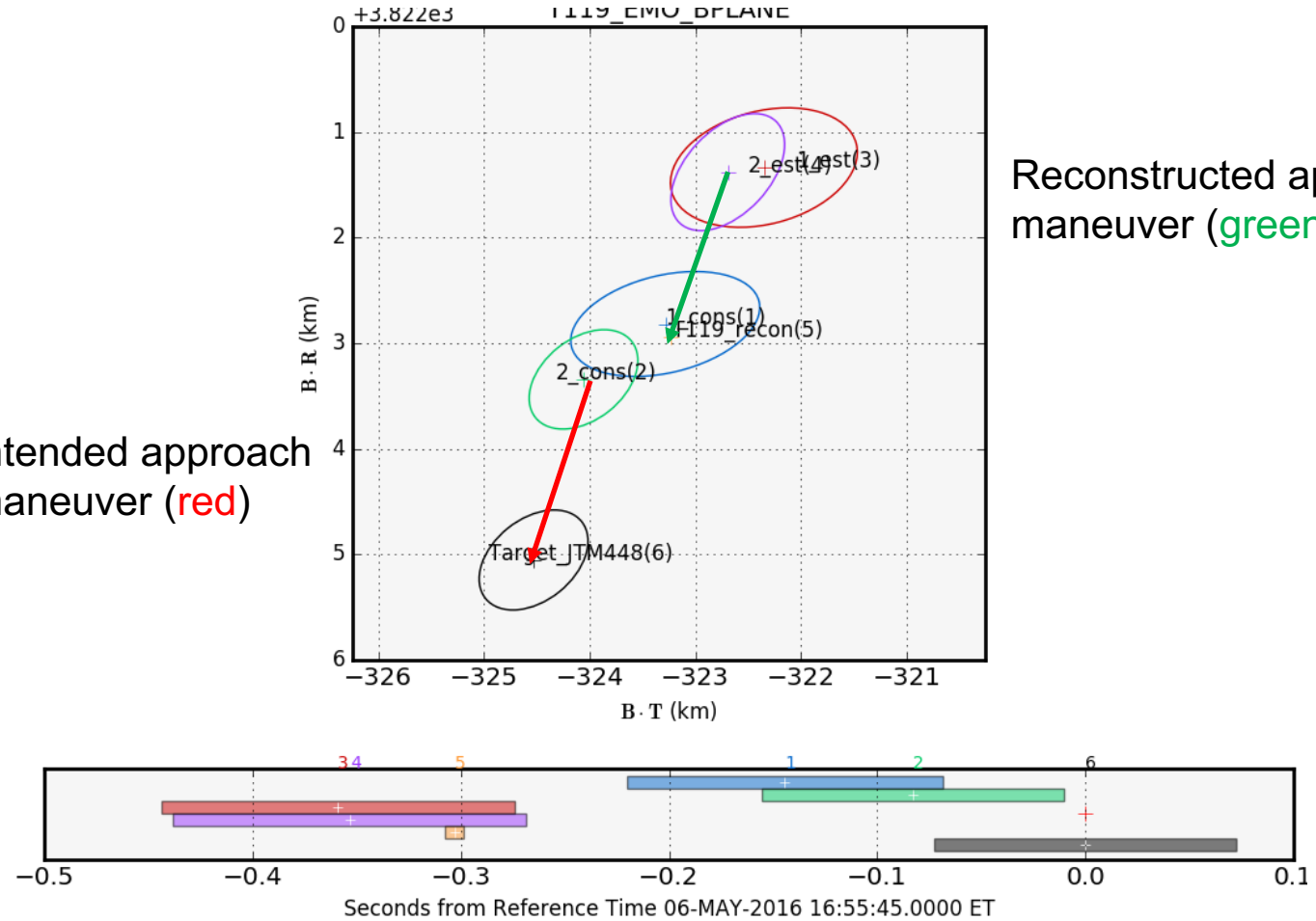
Satellite System Covariance Scaling Results

T119 B-plane results with and without satellite estimation

- Solution that considers satellites shows motion at DCO

Reconstructed approach maneuver (green)

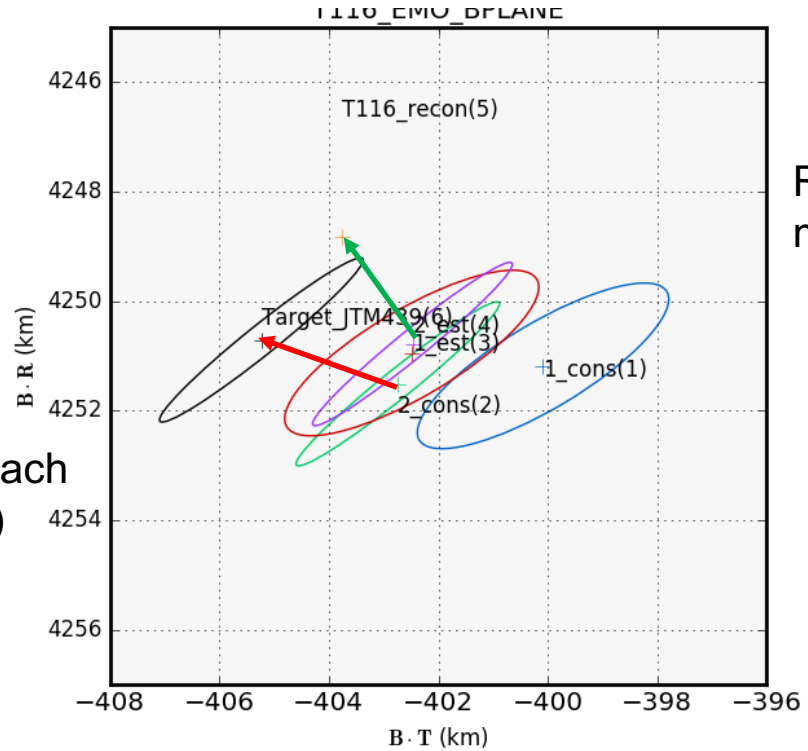
Intended approach maneuver (red)



Satellite System Covariance Scaling Results

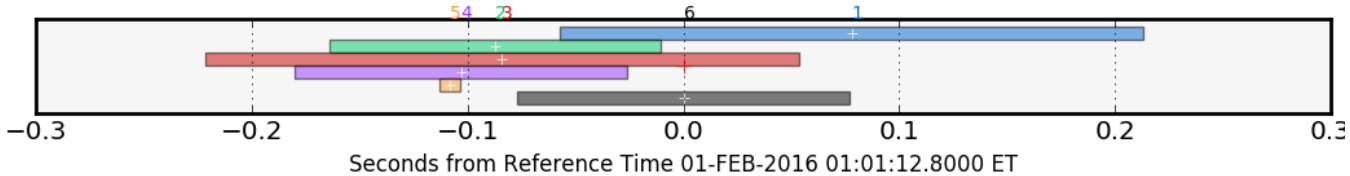
T116 B-plane results with and without satellite estimation

- Solution that considers satellites shows motion at DCO



Reconstructed approach maneuver (green)

Intended approach maneuver (red)

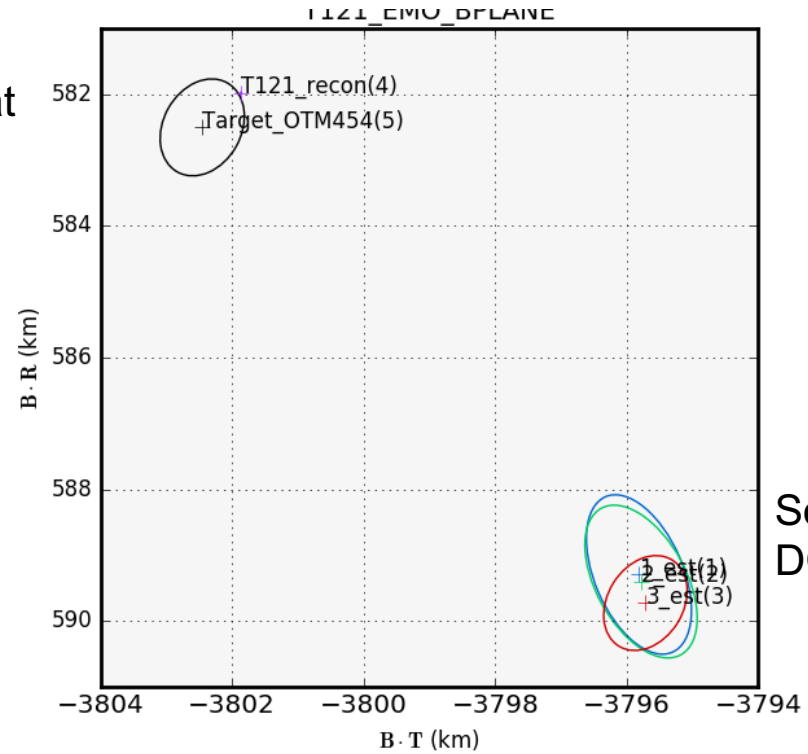


Satellite System Covariance Scaling Results

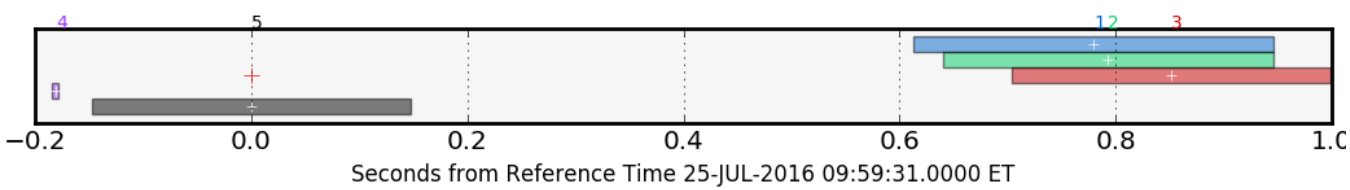
T121 B-plane results with delivered satellite estimation cases

- Solution is stable, error due to maneuver pointing

Reconstructed solution at edge of 1σ target ellipse



Solutions with cov x15, DCOs advancing in time



Summary

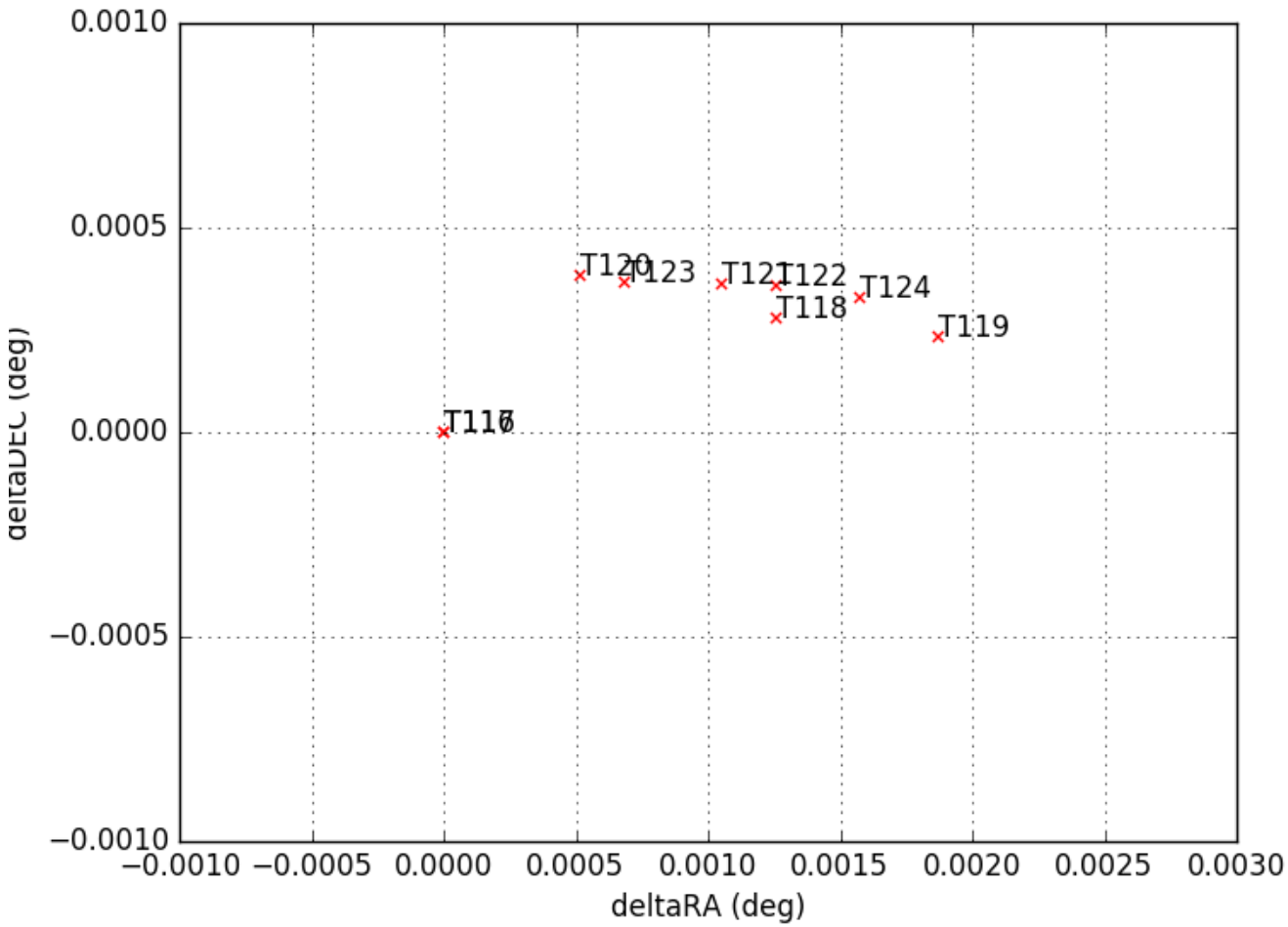
- Past solutions which considered satellite ephemeris error had “large” target misses
- Science return not impacted by target misses, only “large” compared to routine sub-500 m deliveries
- Hundreds of meters difference between Titan ephemeris deliveries, with formal uncertainty of tens of meters
- Solutions now delivered with satellite ephemeris estimation, formal covariance scaled by factor of 15
- Subsequent flybys have error capped at 1.11 km
- Additional potential error source in drift rate of Saturn pole – not estimated

Jet Propulsion Laboratory
California Institute of Technology

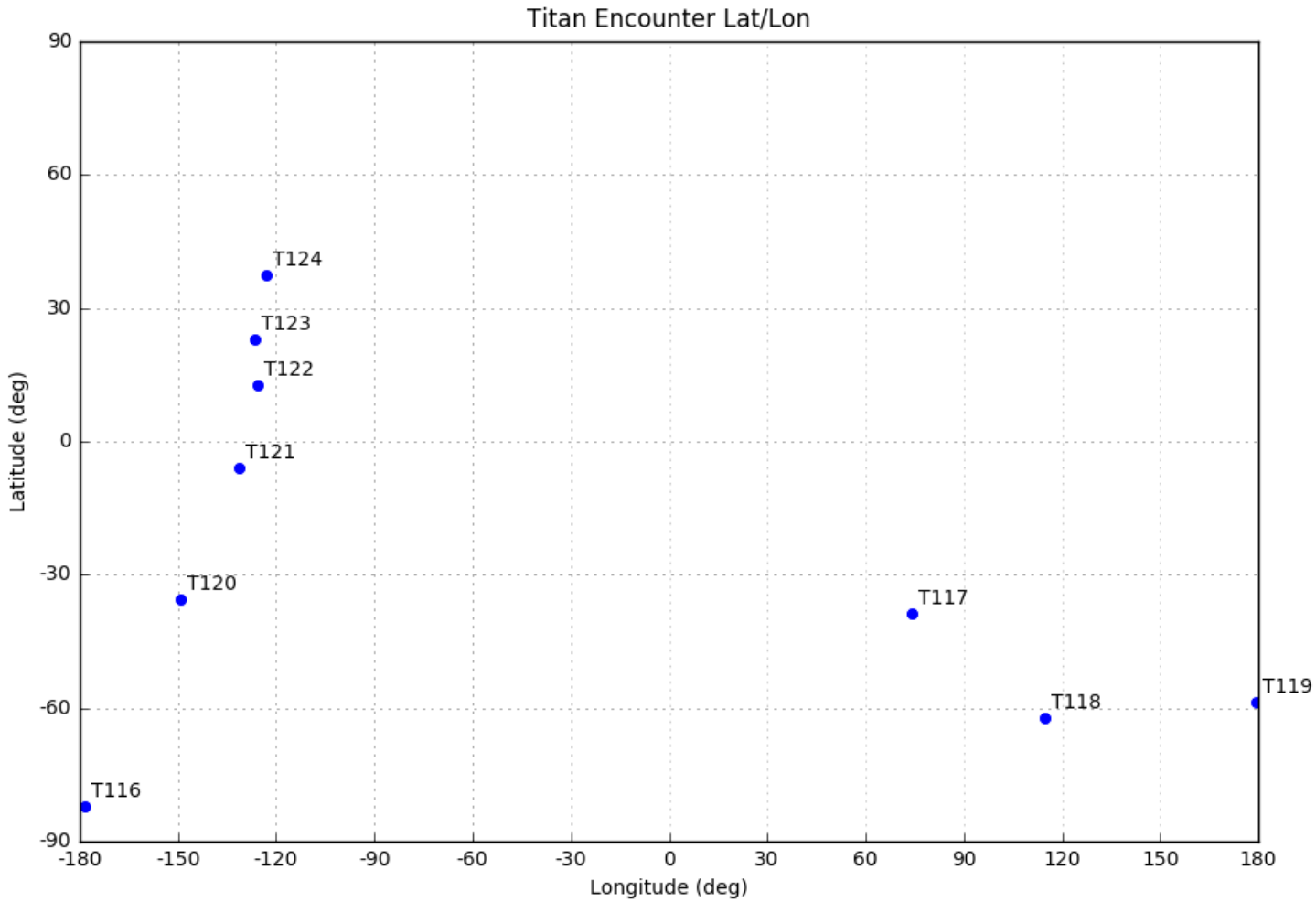
© 2017 California Institute of Technology. Government sponsorship acknowledged.

Backup

Saturn Pole Estimates – delta RA/DEC from nominal values



Backup


Titan Encounter Lat/Lon
Latitude (deg)
Longitude (deg)
90
60
30
0
-30
-60
-90
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
T124
T123
T122
T121
T120
T117
T118
T119
T116