Hayabusa's Earth Return

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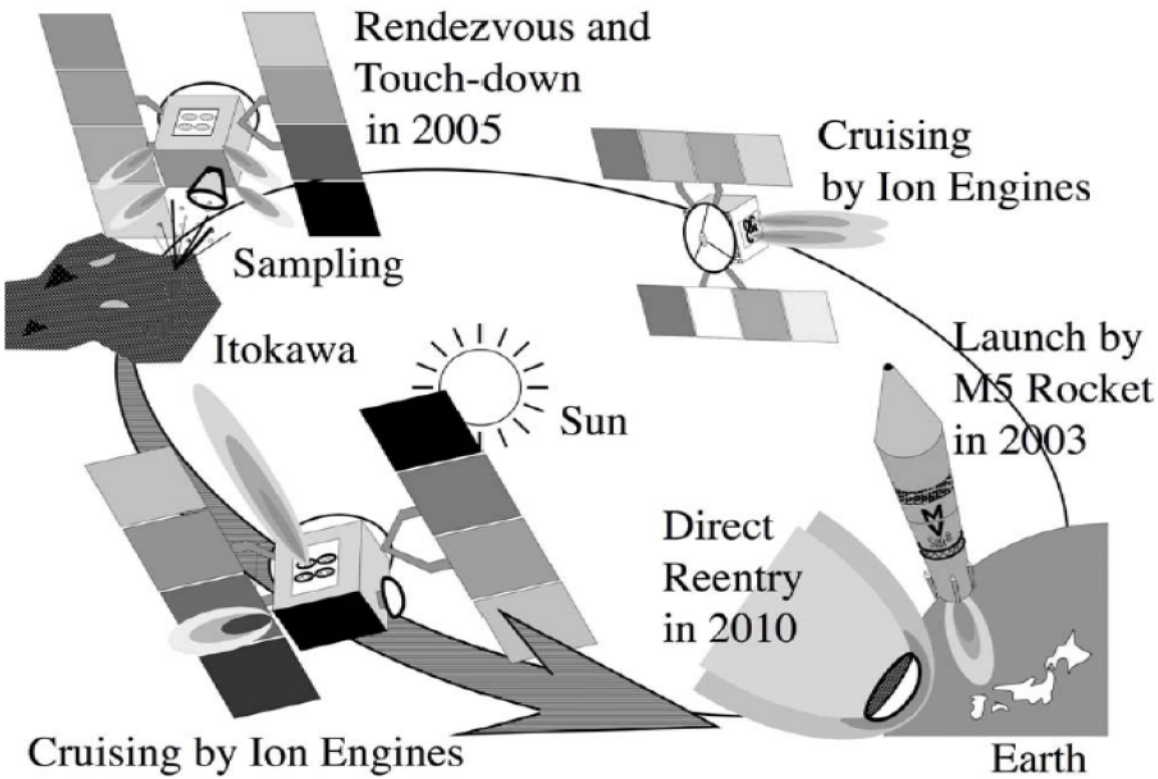
Hayabusa Overview

- Japan Aerospace Exploration Agency (JAXA) mission

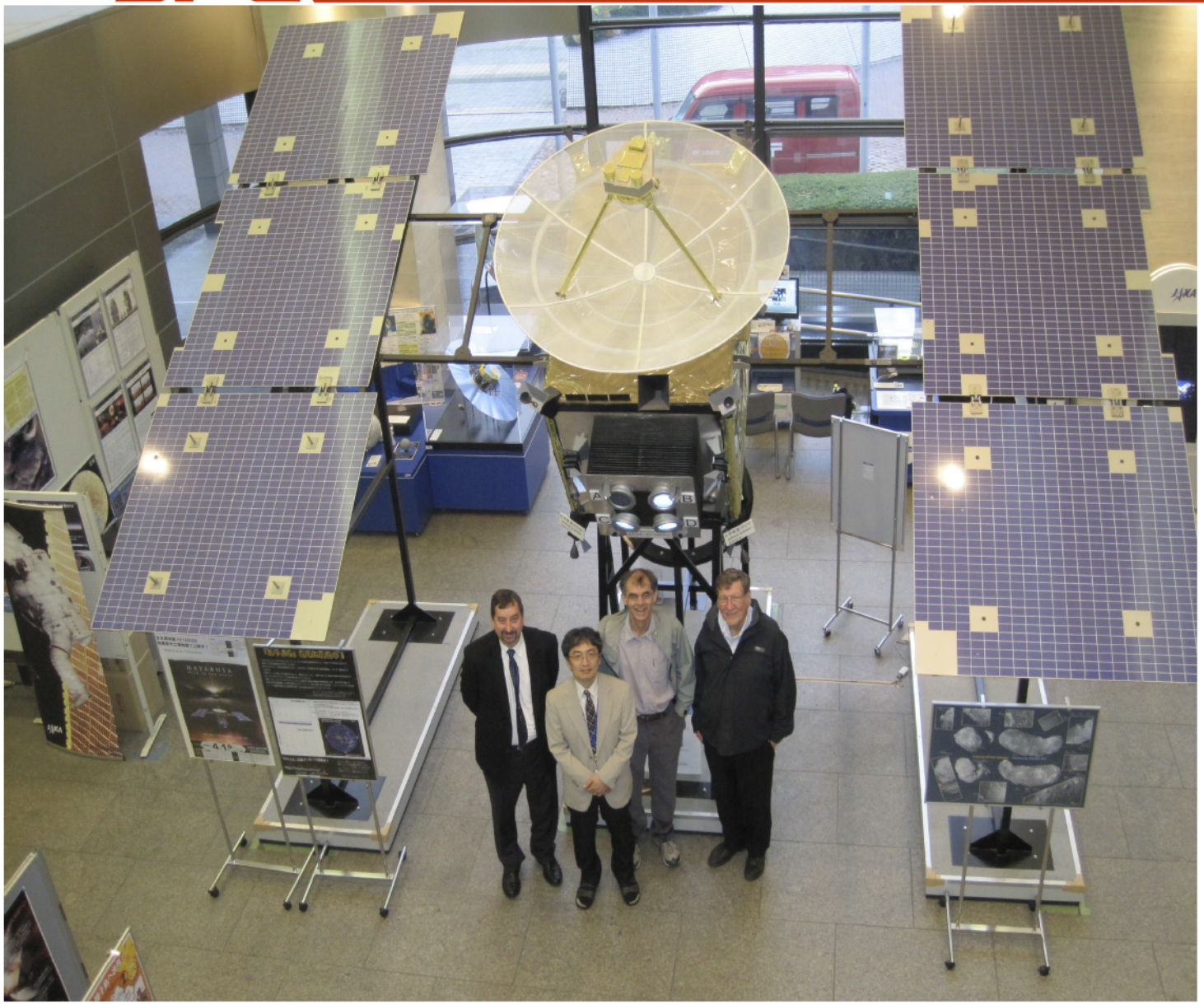
- Asteroid sample-return technology demonstrator

- JPL had a navigation role during the Earth-return phase



Spacecraft

(life-size mockup)



Propulsion
- -low-thrust ion engines (4x)
- -thrust: 7 mN per engine

Attitude control
- -reaction wheels (3x)
- -RCS thusters

Wet mass: 510 kg
- -chemical propellant: 70 kg
- -Xe propellant: 60 kg

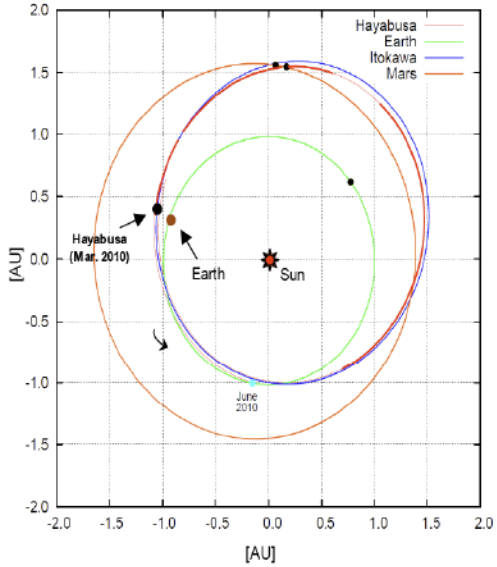
RF: X-band

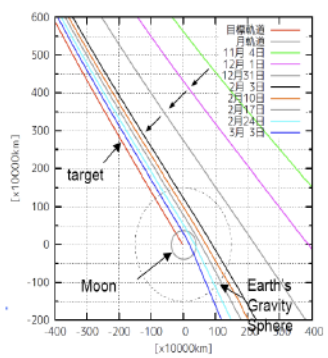
Power: 2.6 kW panels (1 AU)
- -panels not articulated
- - also backup battery

1 Sample Release Capsule

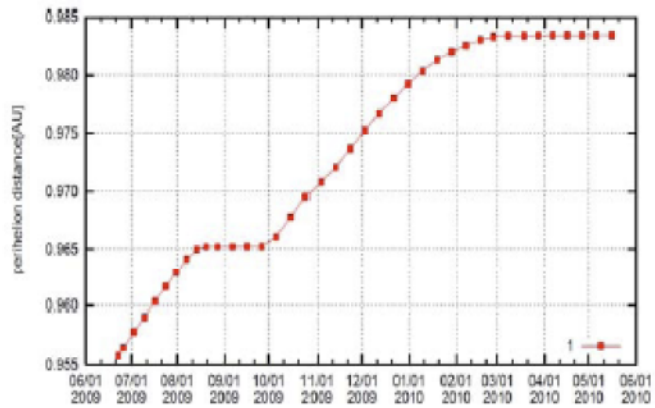
Trajectory & Targeting

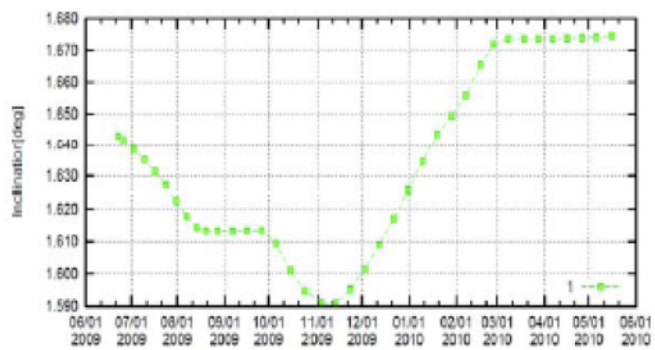
Orbits

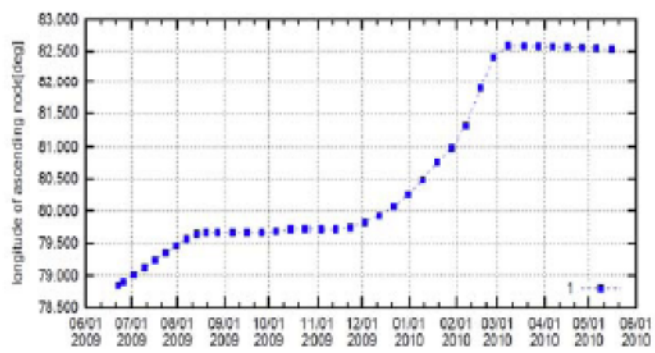


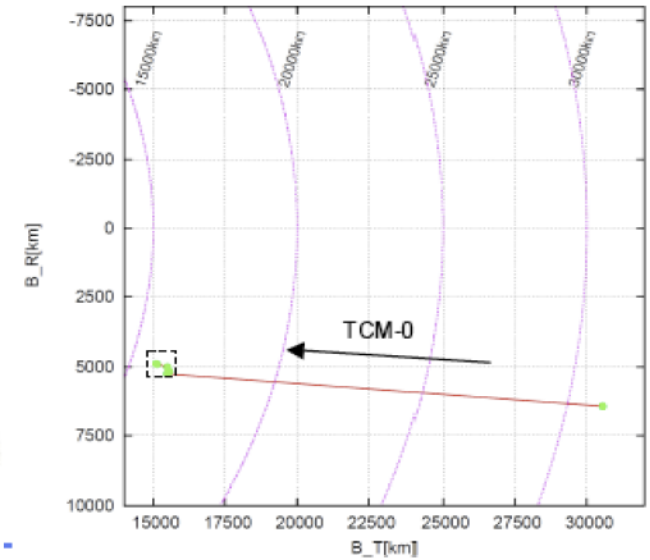


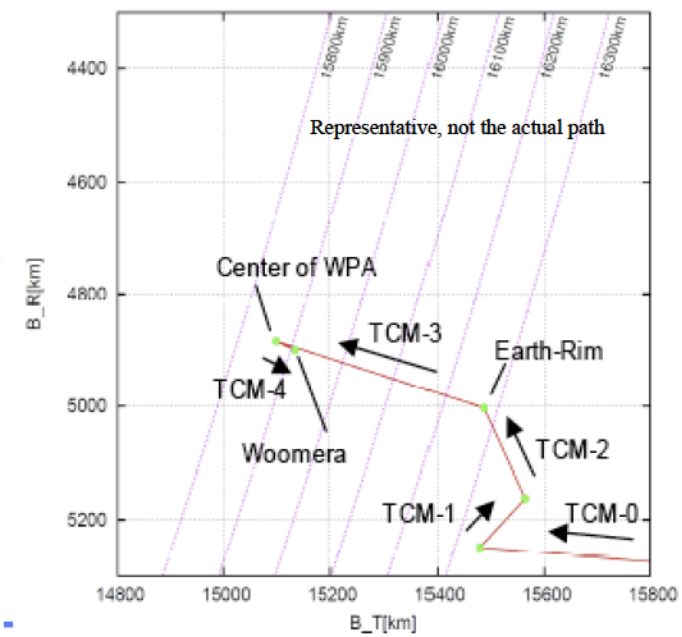
Osculating Elements



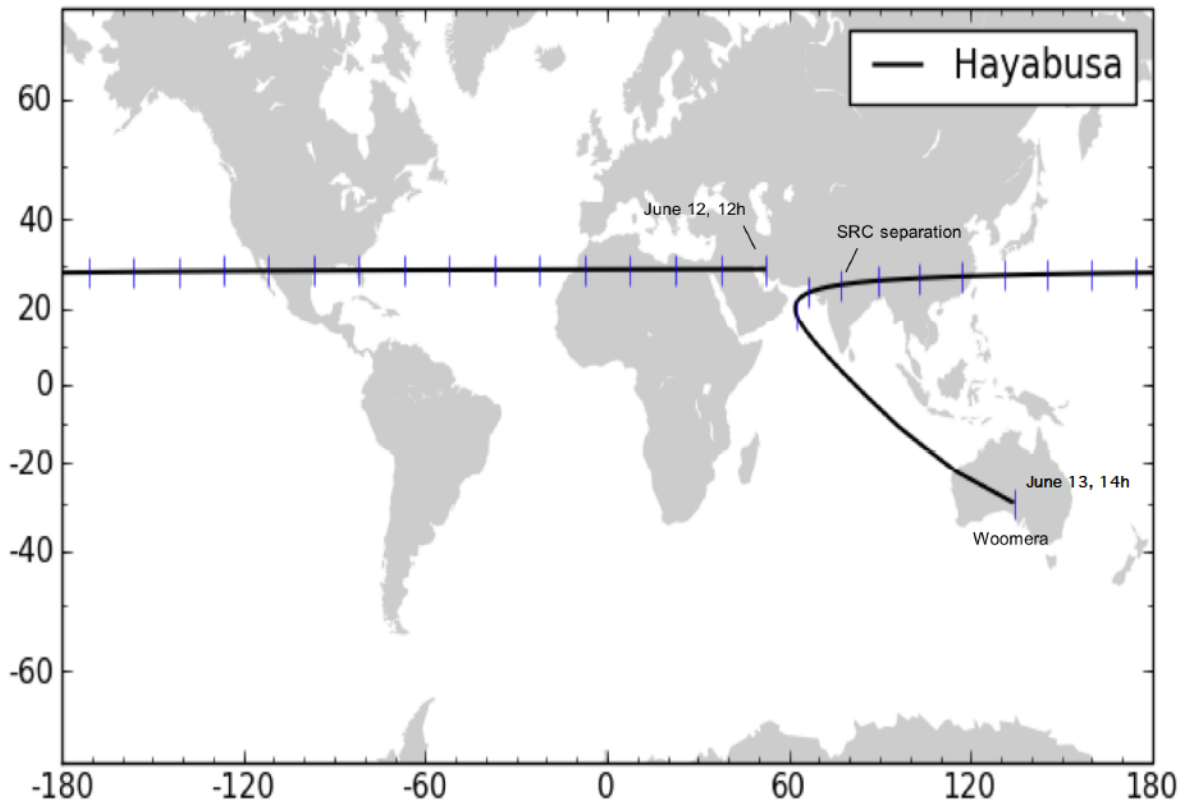




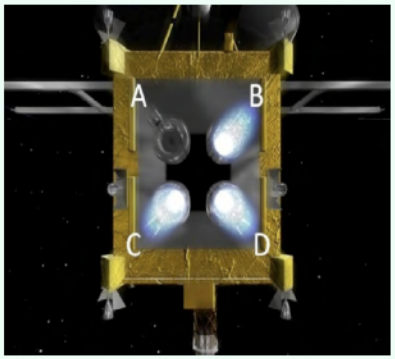




Ground Track, Last Day

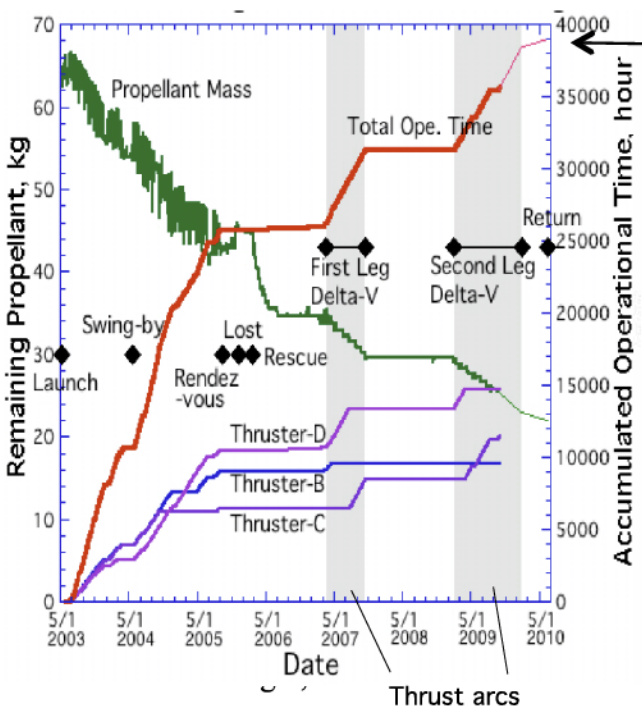


Ion Engine



Layout of Ion Thruster Heads

A: Never worked (ion source defective)
B: Failed, April 2007 (neutralizer voltage exceeded power supply)
C: Very degraded - only 50% functional (turned off Oct 2009)
D: Failed, Nov 4 2009 (neutralizer voltage exceeded power supply)



Final total time = 39,700 hrs

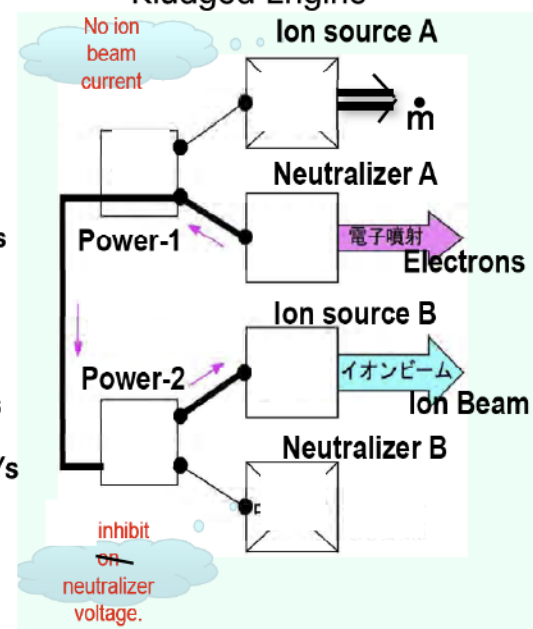
Final total ΔV = 2130 m/s

Total time on A+B = 3160 hrs

Total ΔV on A+B = 30 m/s

V ~ 35 volts
I ~ 130 mA
mdot ~ 0.27 mg/s

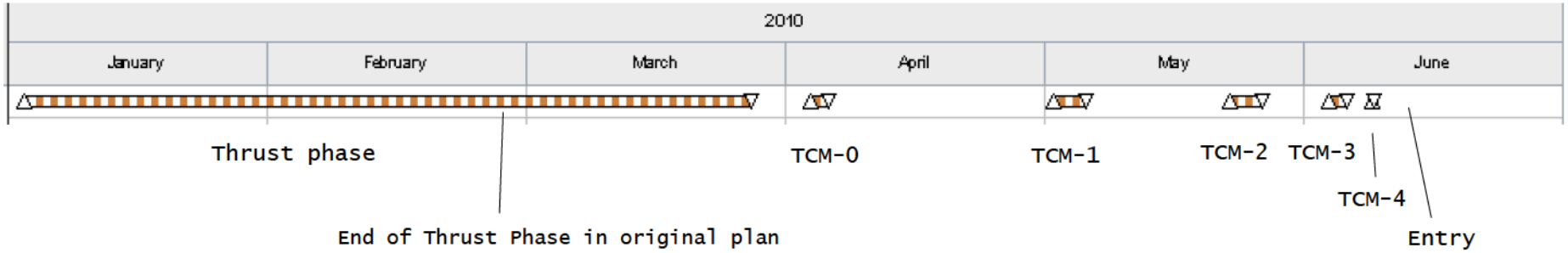
Kludged Engine



Spacecraft Status (as of Jan 1, 2010)

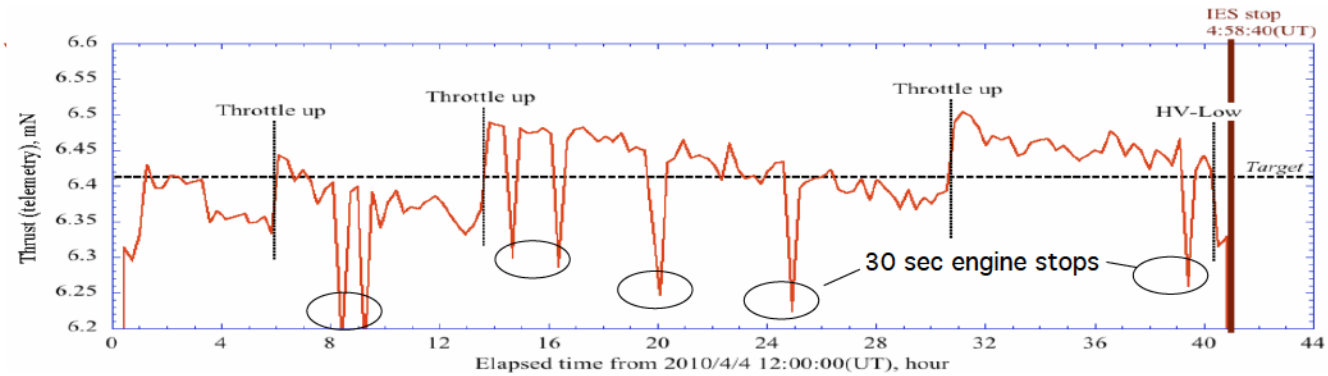
Sub-system	*Status*	*Work-around*
Attitude Control	2 of 3 reaction wheels failed. Chemical RCS thrusters: no propellant. Star trackers: operational.	Stabilized with solar radiation pressure and neutralizer jets (cold gas). Single remaining wheel useful for Zaxis turns.
Power	Batteries dead. Solar panels degraded.	Solar power only. Point solar panels within ±10° of Sun to provide sufficient power.
TCMs	Chemical RCS thrusters: no propellant.	Use ion engines. Attitude during TCM controlled by SRP & thruster gimbals. Request NASA-JPL support for TCM real-time monitoring.
Ion Propulsion	3 of 4 thrusters inoperable; remaining thruster functions at low level only; some components OK.	Combine Neutralizer A with Ion Source B to yield ~90% of nominal single-engine thrust.
Thermal	Passive only. Sunlight cannot enter IES nozzles (eliminating vectorized maneuvers).	Maintain solar panel normal vector within ±3° of Sun. Down-track ΔV only.
Telecom	HGA functional but unusable because of pointing, power, & thermal constraints.	Rely on low-gain antennas. Request NASA-DSN support for tracking & commanding.
Bus	All sub-systems reduced to single-string.	None.
Sample Return Capsule	Unknown (no telemetry).	None.

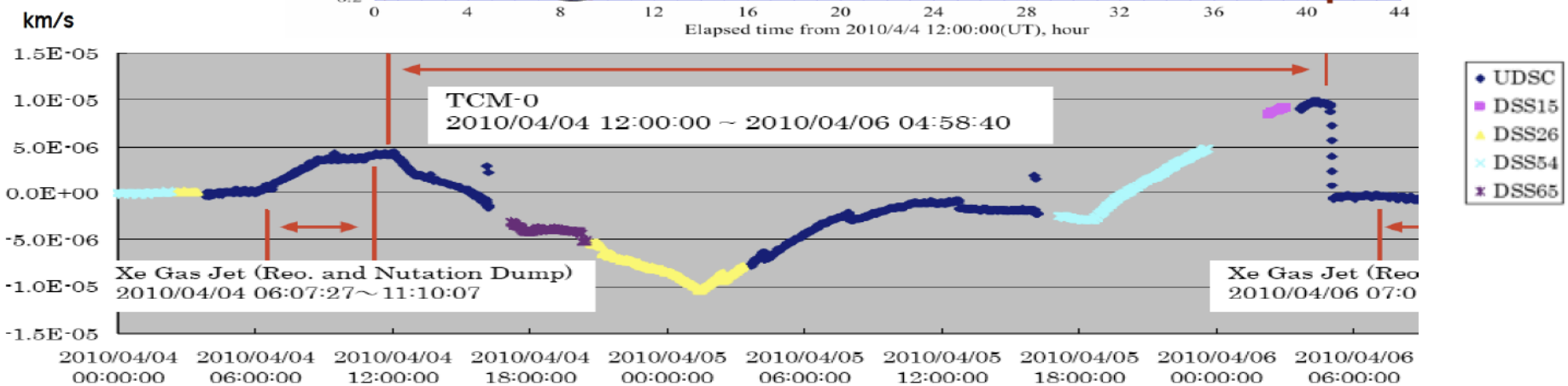
Thrusting Sequence in 2010



Event	Date	Duration	ΔV [m/s]	Target [km]
Thrust Phase II	Ended March 27	1 year	420	altitude=12,500
TCM-0	April 3, 12 UTC	41 hours	2.07	altitude=4,500
TCM-1	May 1, 11 UTC	64 hours	3.38	altitude=3,280
TCM-2	May 22, 22 UTC	92.5 hours	5.07	altitude= 638
TCM-3	June 3, 03 UTC	50 hours	2.75	center of WPA
TCM-4	June 9, 03 UTC	2.5 hours	0.14	SE corner WPA
Capsule release	June 13, 10:50 UTC	instantaneous	0.17 on capsule	SE corner WPA
Entry	June 13, 13:51 UTC			FPA = -12.35° Radius = 6576 km

TCM-0 Summary





Thrust level is determined by comparing real-time doppler residuals with engine performance, and adjusting as necessary.

Thrust data (from telemetry) is averaged over 17 minutes.

Thrust level is controlled either by throttling (mass flow change) or varying Neutralizer voltage.

This joy-sticking method could produce a total ΔV accurate to within 1 mm/s of the desired magnitude.

Some Requirements

TCM-3 Delivery: 4σ Ground Dispersions must fit within WPA

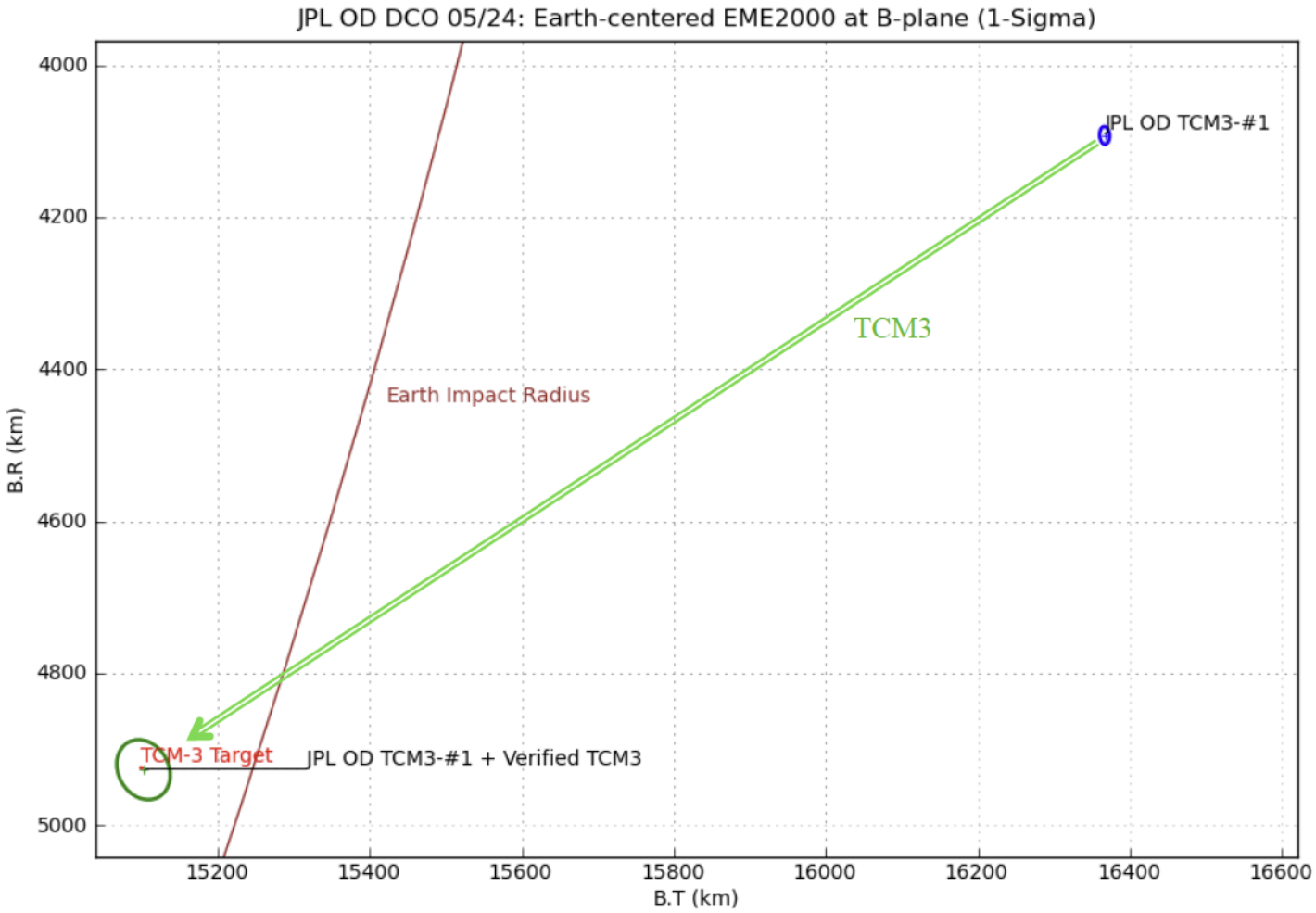
TCM-4 Delivery: 4σ Ground Dispersions must nestle within south-east corner of WPA

- target = (-30.45º, 136.0ºE)

eFPA = -12.55º± 0.33º (1σ) at altitude = 200 km

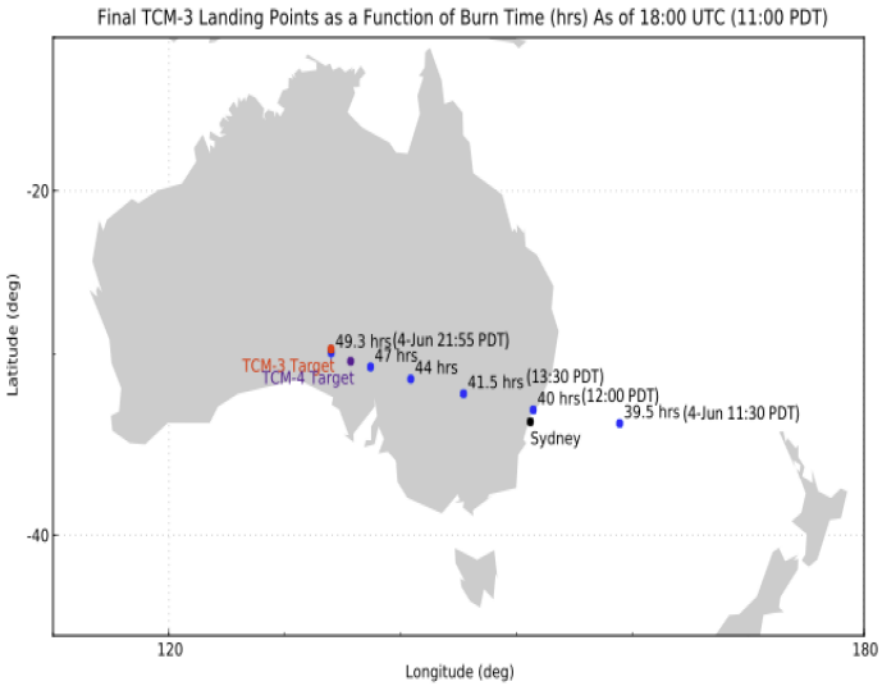
v_{entry} = 11.65 km/s

TCM-3 Delivery, to Center of WPA



OD033_v3

Ground Plot During TCM-3 Burn



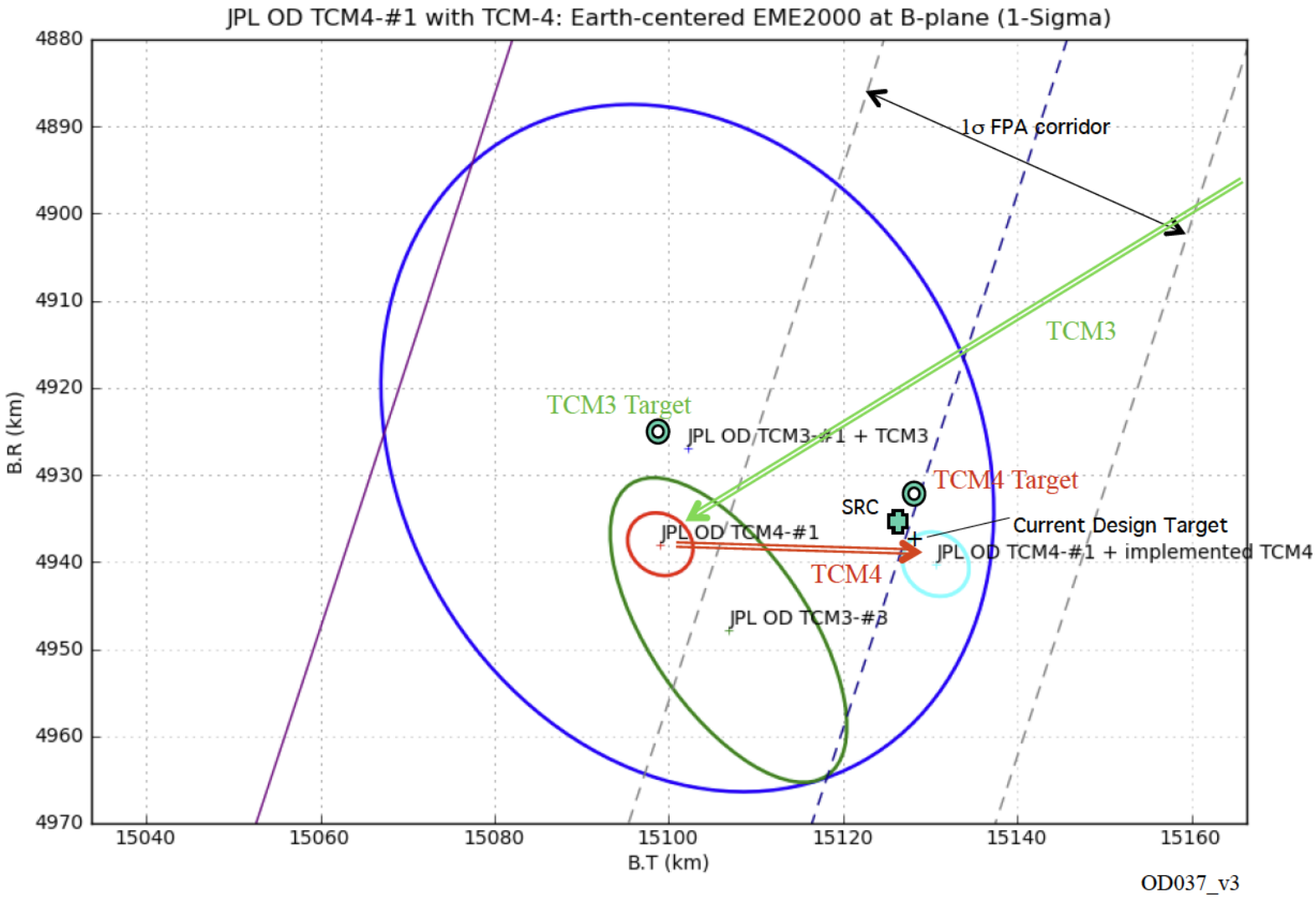
Nominal burn duration of 50 hours goes to the TCM-3 target (shown in Figure)

A burn duration of < 39.5 hours yields a skip-out (swing-by) trajectory

If TCM-3 terminated prematurely between 39.5 and 49.3 hours (and IES would not re-start), the s/c would impact at one of the indicated intermediate locations

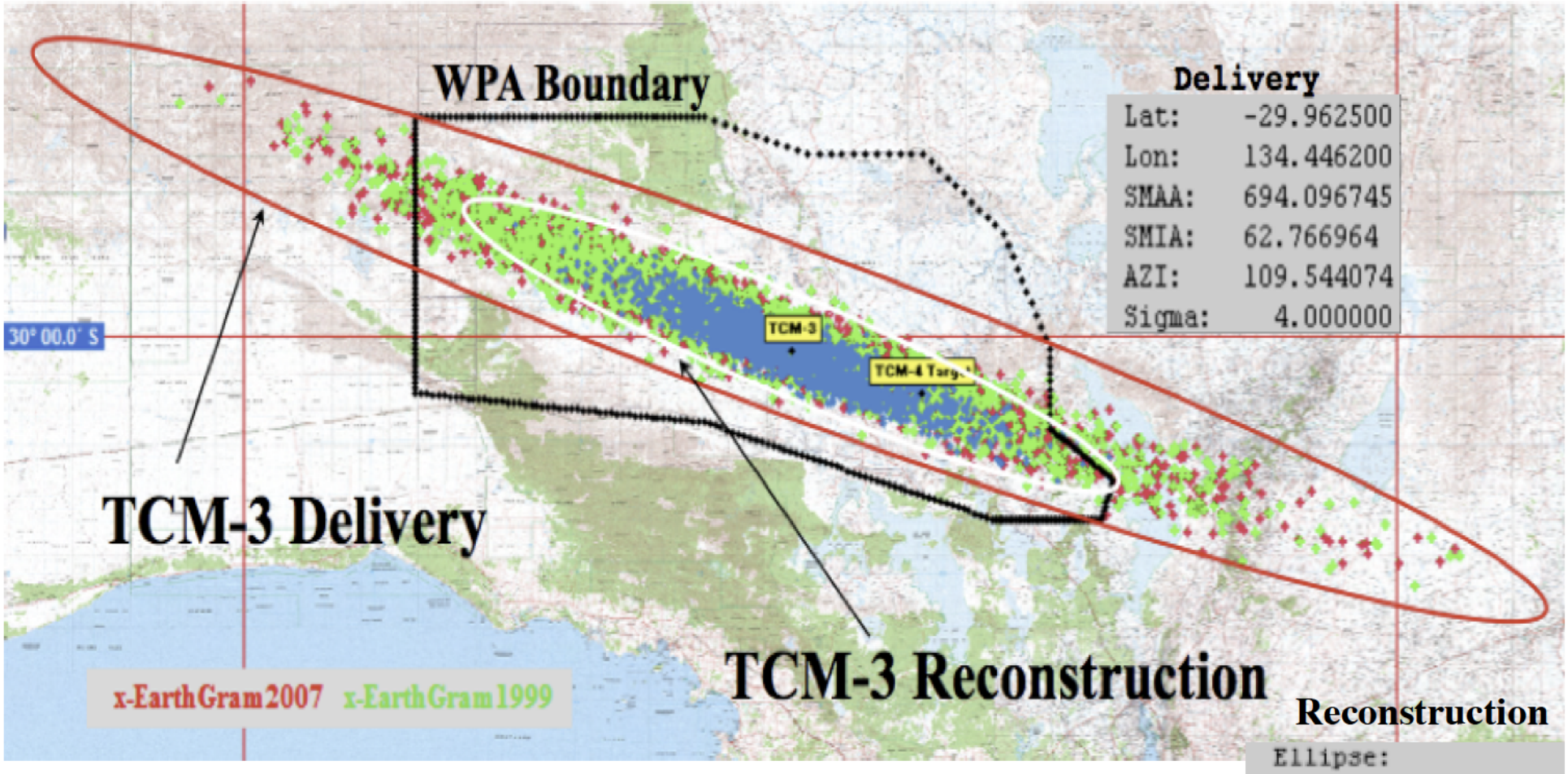
The target lies within the Woomera Protected Area

TCM-3 Reconstruction & TCM-4 Delivery (to SE corner of WPA)



OD037_v3

TCM-3 Delivery, Ground Dispersions



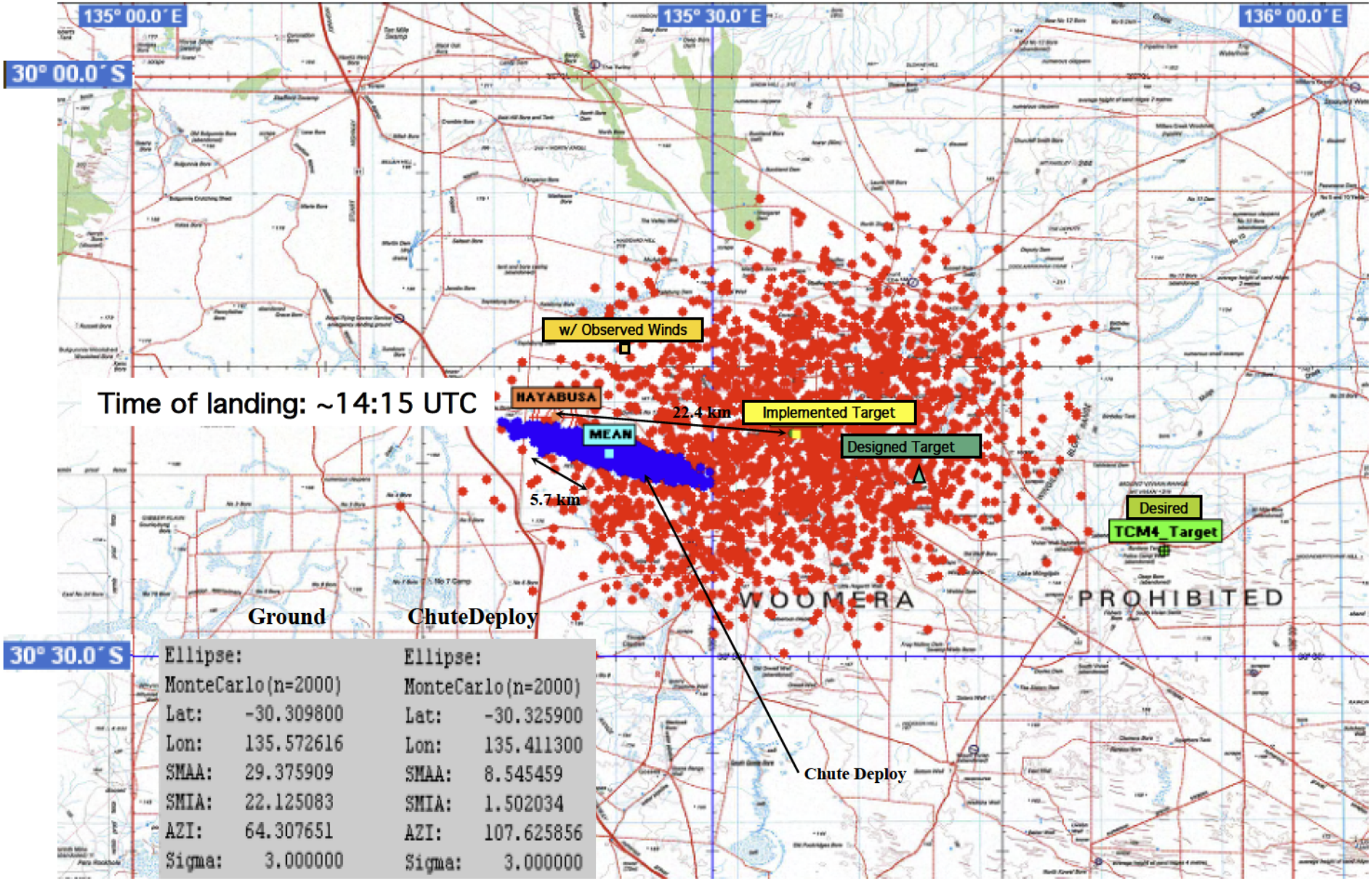
Reconstruction

Ellipse:	
Lat:	-30.117800
Lon:	134.763600
SMAA:	303.539038
SMIA:	38.144841
AZI:	110.748445
Sigma:	4.000000

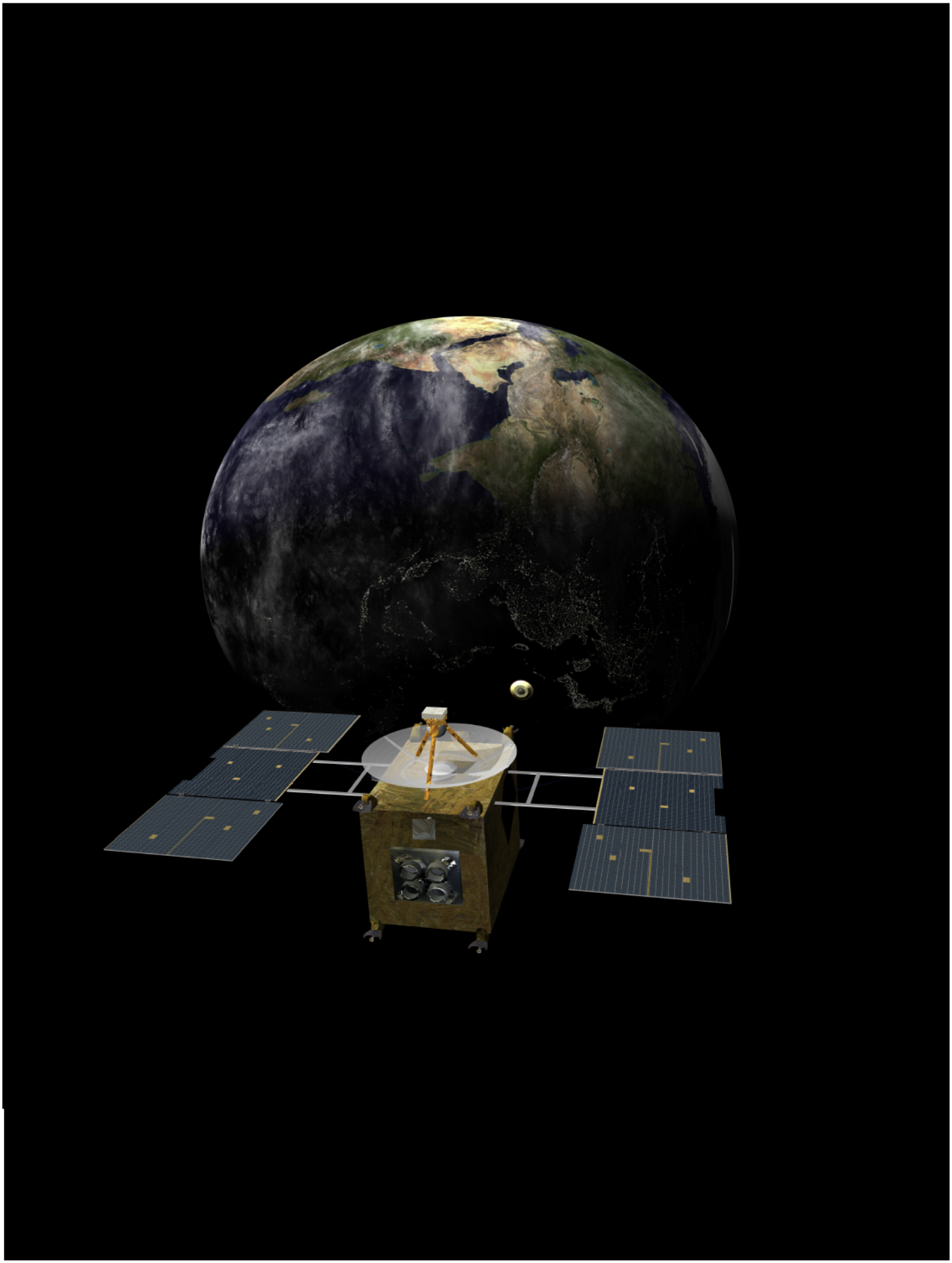
Delivery exceeds WPA boundary!

Final Ground Dispersions

Data to Entry



Ground		ChuteDeploy	
Ellipse:		Ellipse:	
MonteCarlo(n=2000)		MonteCarlo(n=2000)	
Lat:	-30.309800	Lat:	-30.325900
Lon:	135.572616	Lon:	135.411300
SMAA:	29.375909	SMAA:	8.545459
SMIA:	22.125083	SMIA:	1.502034
AZI:	64.307651	AZI:	107.625856
Sigma:	3.000000	Sigma:	3.000000



JAXA

Re-entry Videos

http://www.youtube.com/watch?v=yvC59g5X5Wk&feature=related

http://www.youtube.com/watch?v=48eclsiwf6U&feature=related

JAXA has approved a Hayabusa-2 mission

Summary

Capsule successfully returned to Earth on June 13, ~11:15 pm ACT

Re-entry fireball observed and recorded by NASA-Ames DC-8

Capsule was spotted on the ground within 30 minutes of landing

- actual physical recovery occurred later in the day, during daylight
- capsule contains (minute) extra-terrestrial samples!

Recovery site:

- 22 km from implemented target (~2.5σ miss)
  - most of discrepancy due to contrary winds
- only 8 km delta when observed winds applied
- only 6 km from the Stuart Highway!

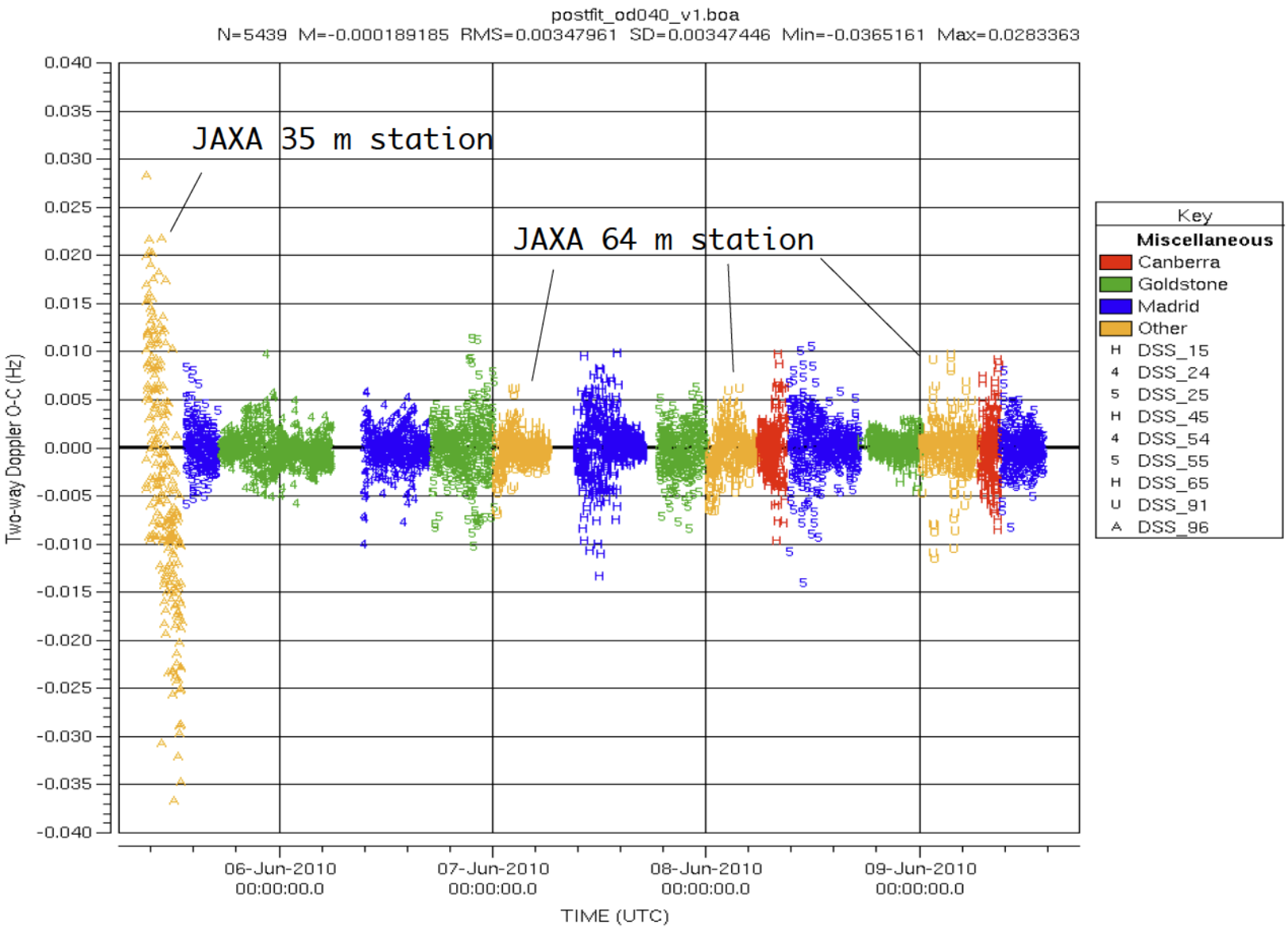
One Nav Requirement not achieved:

keeping 4σ TCM-3 Delivery ground dispersions within WPA

- extenuating reasons …

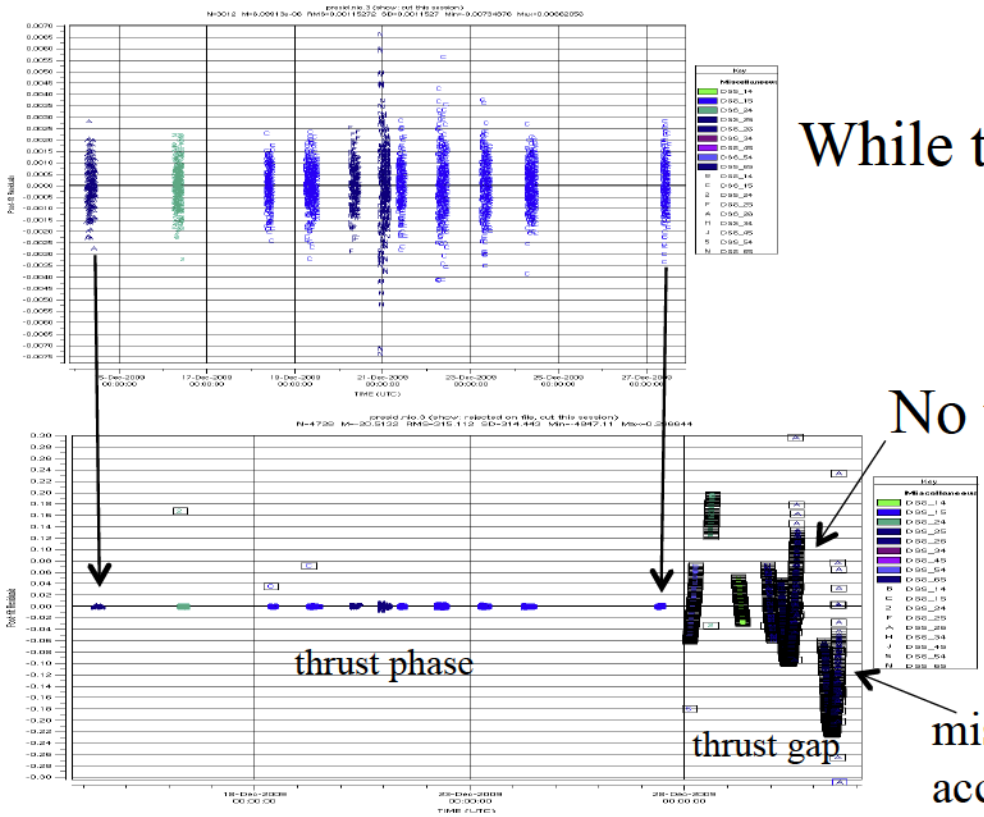
Back-up

Tracking Data in Quiescent Cruise



Tracking Data During Thrusting

- JAXA not able to perform OD while s/c was thrusting
- JPL could perform OD while thrusting
  - tracking data noisy, but solvable
    - large state uncertainty (but errors decreased with longer arc)
    - not a normal procedure, but crude OD available for contingencies



While thrusting: F2 RMS < 0.1 mm/s

No thrusting (F2 pass-through)
- F2 RMS ~5 mm/s

mis-modeling due to error in thrust acceleration estimate

Comparison of State Estimates for Thrust v. No-thrust Fits

Mapping Epoch is Jan 1 2010, 0h

1 sigma

	RSS Position Uncertainty (km)	RSS Velocity Uncertainty (m/s)
Dec 14-27 Fit:	±3900	±4.1
Dec 28-31 Fit:	±6	±0.04

Deterministic State Difference, Computed at Jan 1 2010, 0h

$\Delta X = 1000$ km

$\Delta Y = 600$ km

$\Delta Z = 2000$ km

$\Delta DX = 0.9$ m/s

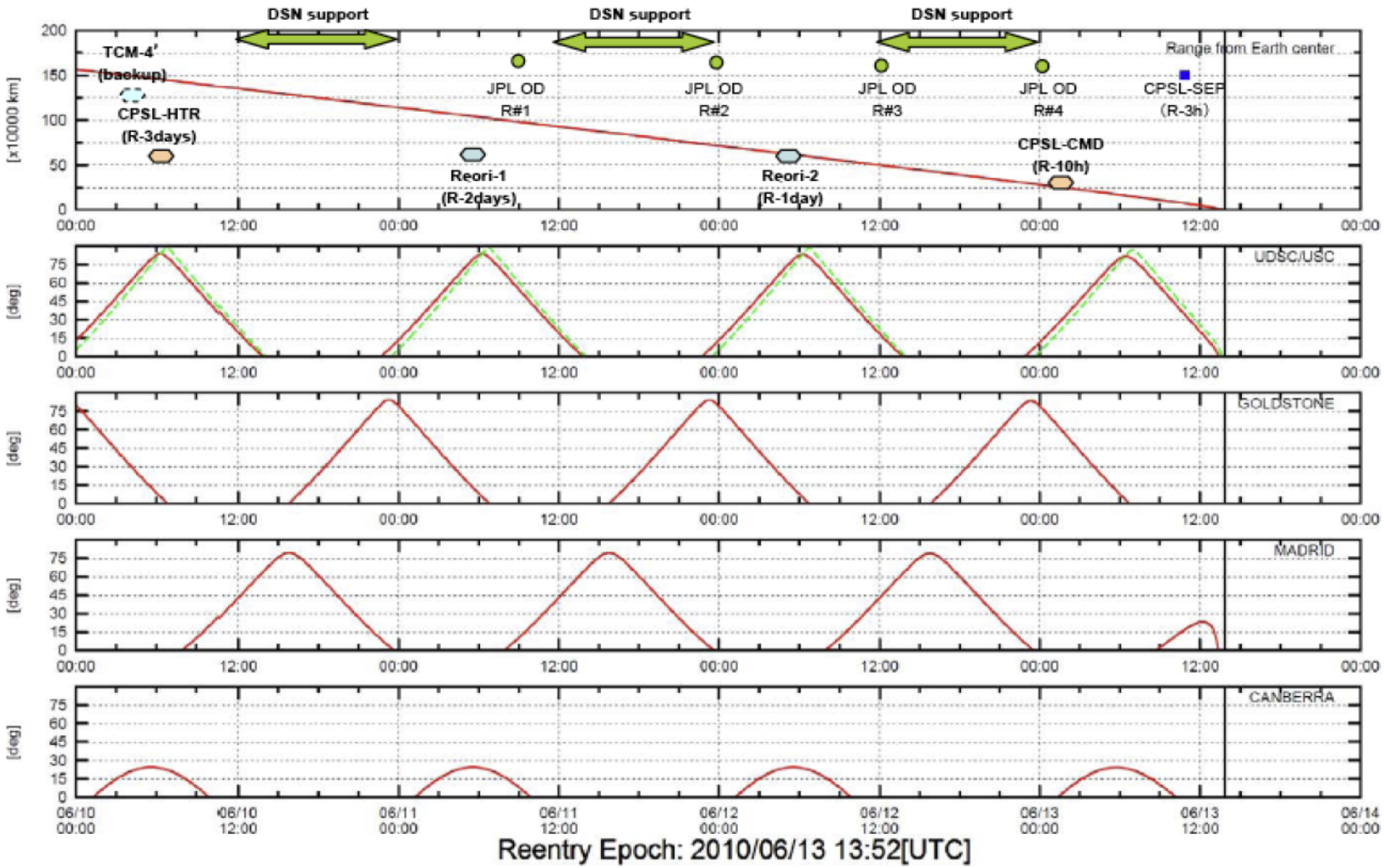
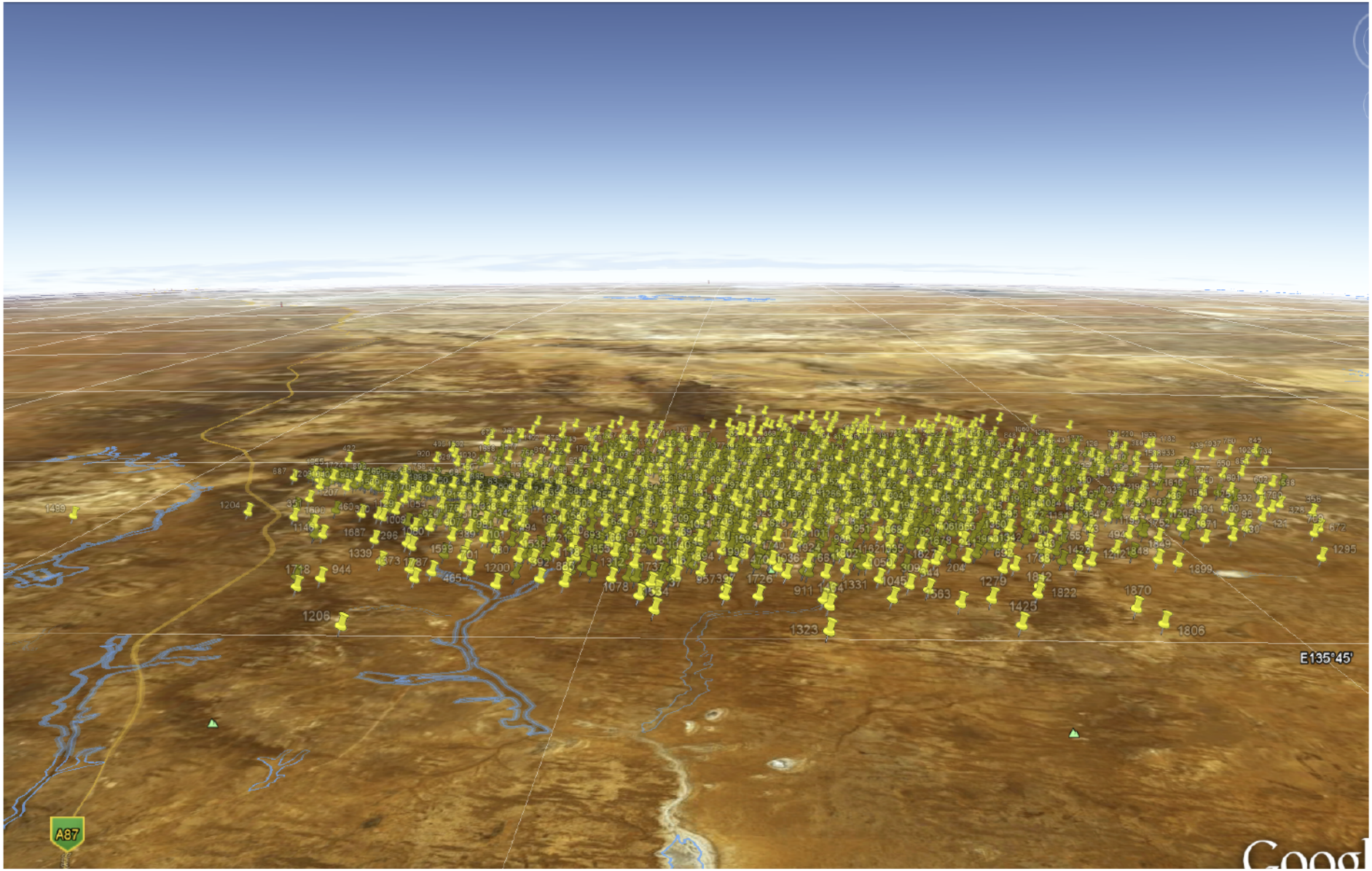
$\Delta DY = 0.9$ m/s

$\Delta DZ = 0.1$ m/s

⇒Prediction from thrust arc solution is consistent with statistics.

⇒Crude navigation is possible while IES operates.

DSN Scheduling



pushpins