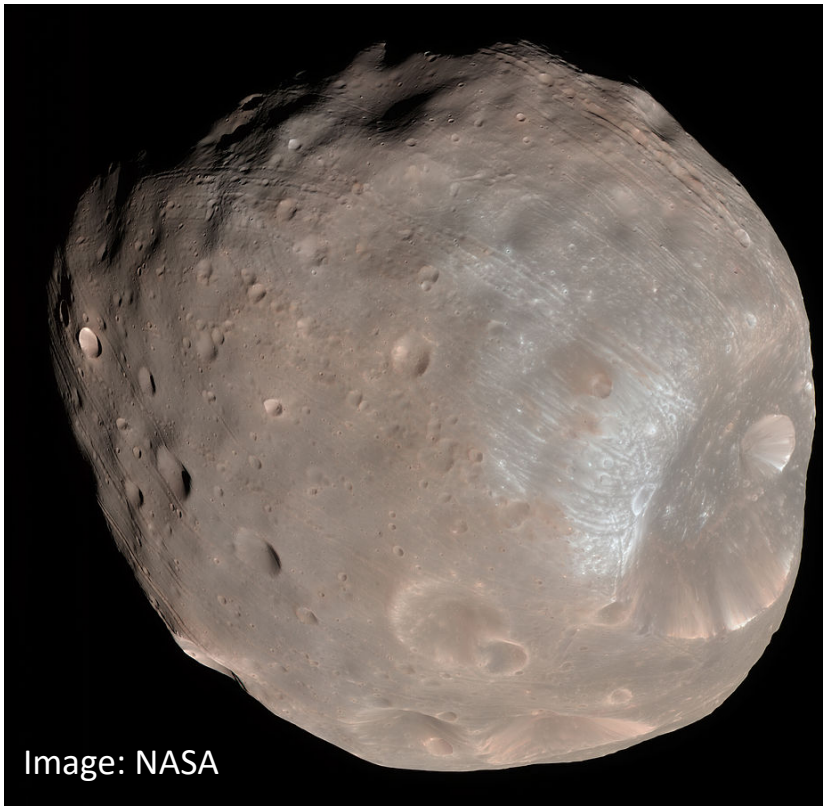
Navigation and Mission Design System Engineering

Mission Design Analysis for the Martian Moon Phobos: Close Flybys, Missed Thrusts, and other In-Flight Entertainment



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Mission Design and Navigation
August 12th, 2015

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Phobos Mission – Why and What

- Martian moon origins unclear, possibilities:
  - Capture
  - Accretion
  - Impact ejecta

Image: NASA

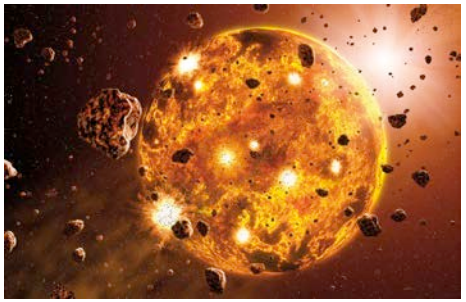


Image: Alan Brandon, Nature

- Potential human missions:
  - Precursor to crewed Mars lander
  - Teleoperation base for Mars rovers
- Mission concept & preliminary analysis:
  - Map surface, determine composition of Phobos
  - Low-thrust, solar-electric propulsion
  - Phobos mapping orbits only, no interplanetary

Dynamics & Control

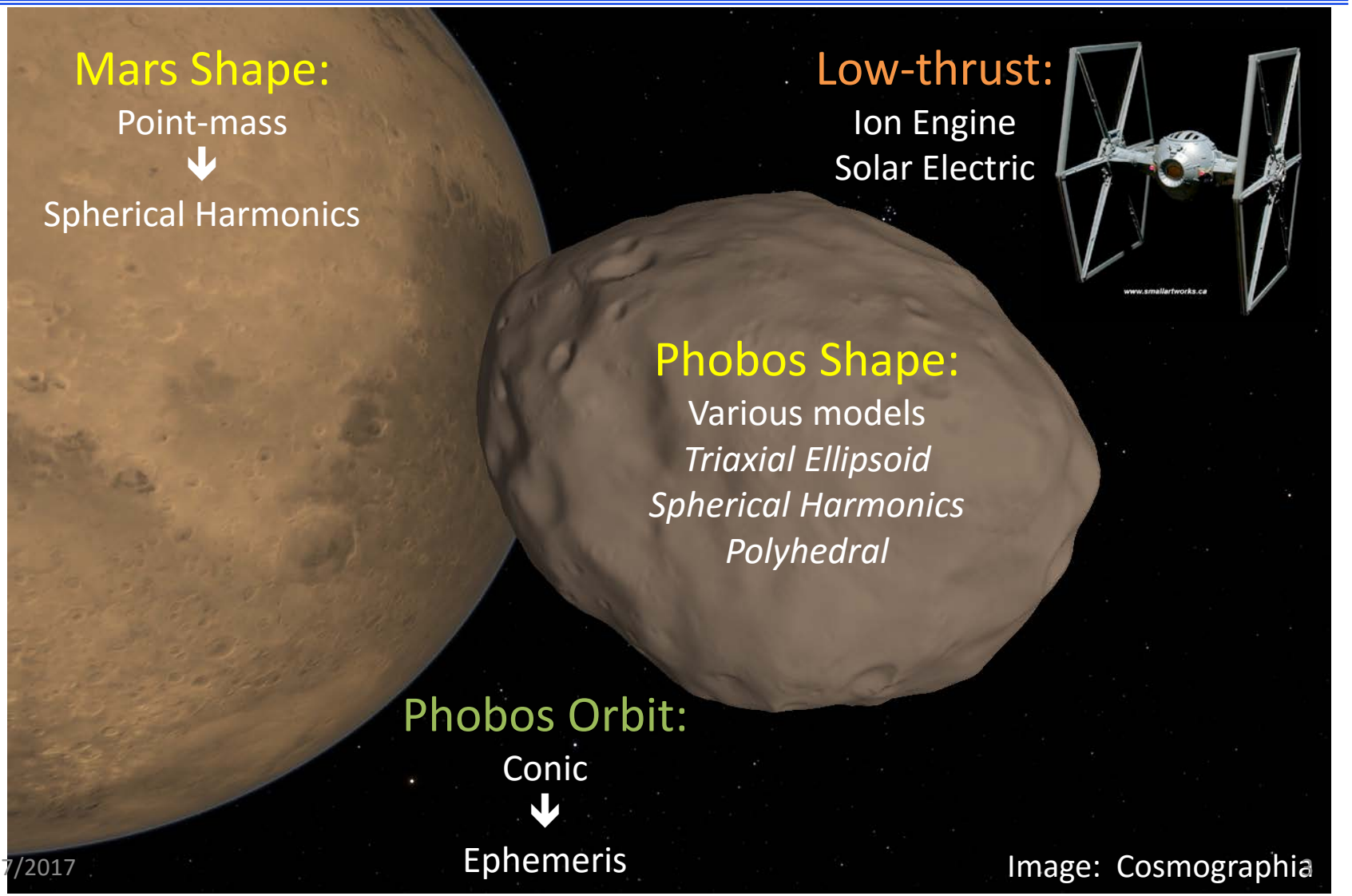
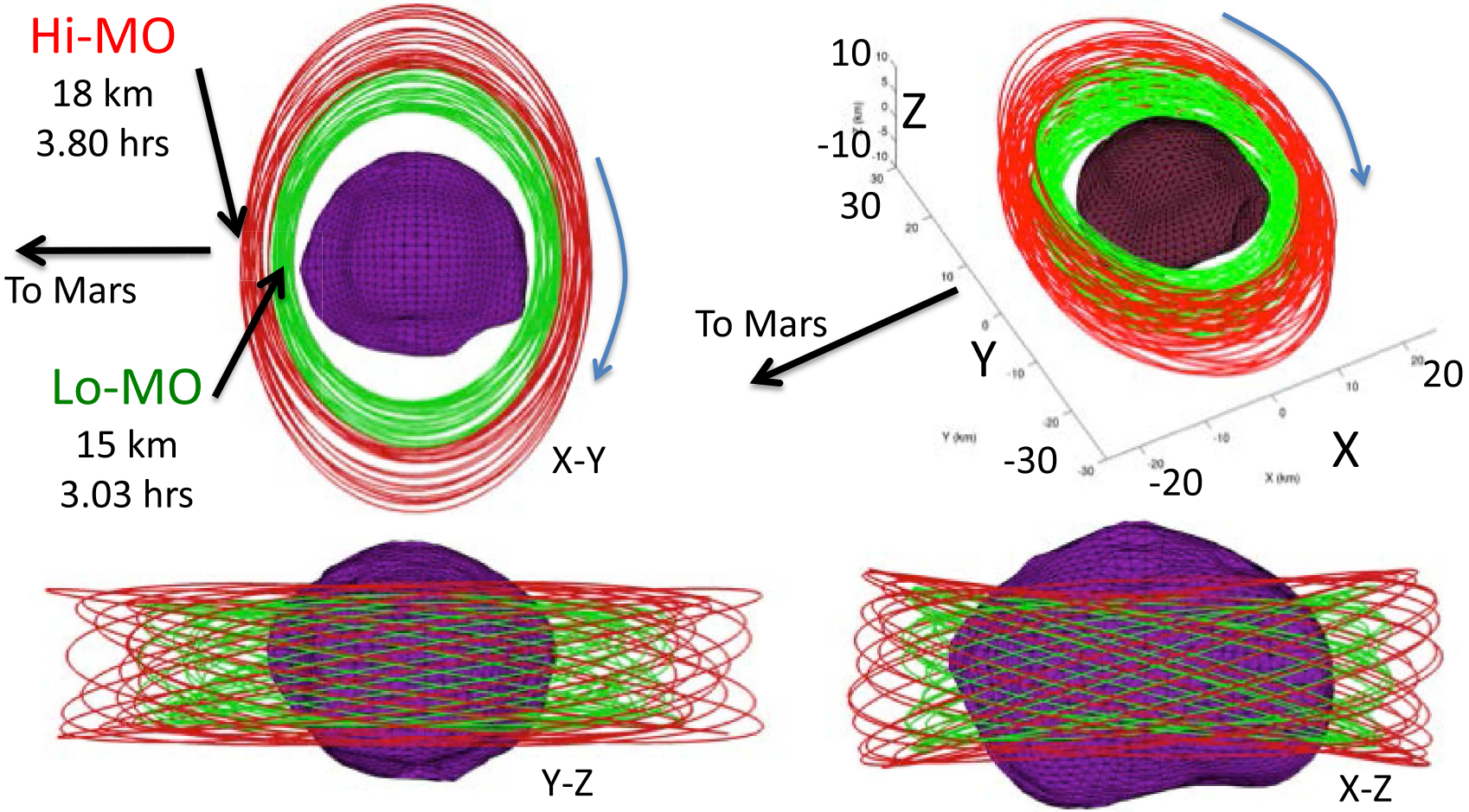


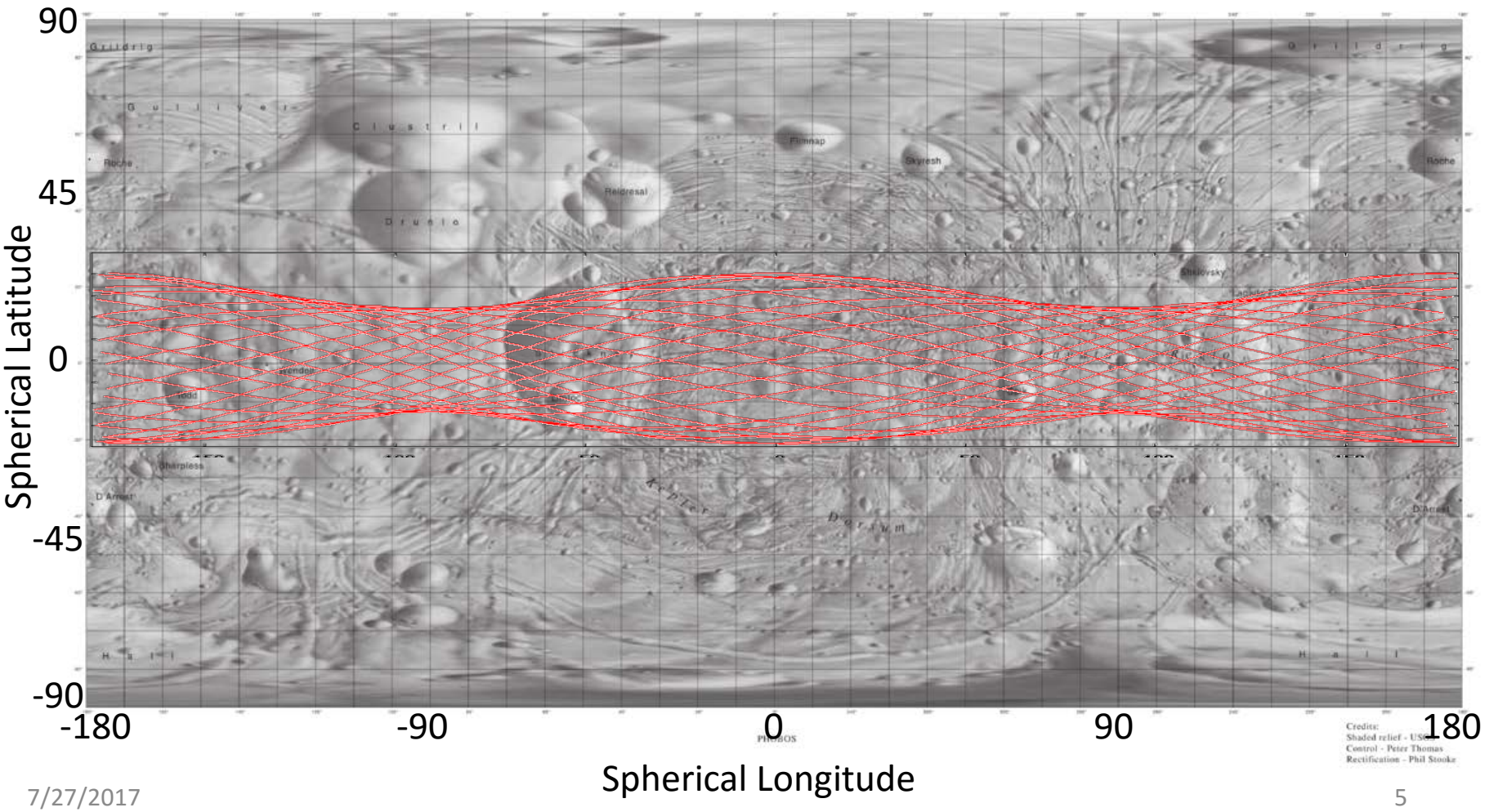
Image: Cosmographia

Mapping Orbits



Mapping "distant" retrograde orbits (DROs) "stable":
initial velocity perturbations 10 cm/s ➔ no crashes or escapes for 30 days

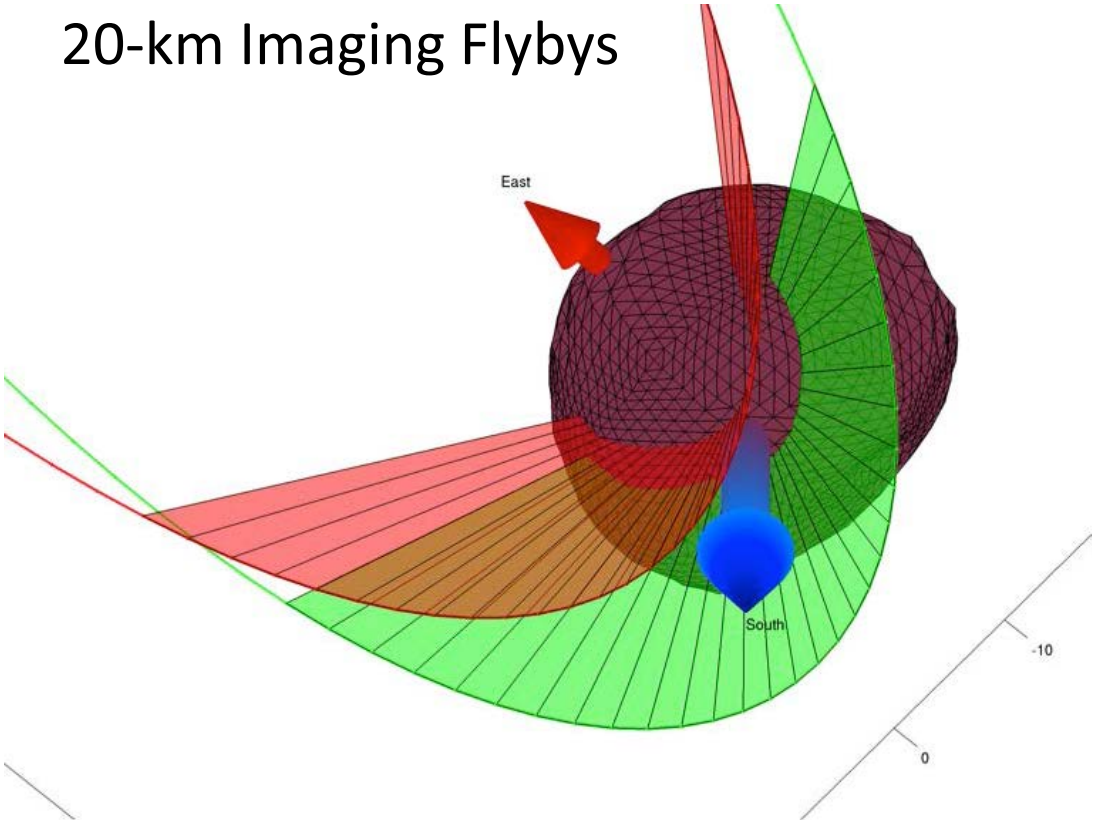
Lo-MO Ground Track



POLAR COVERAGE VIA FLYBY

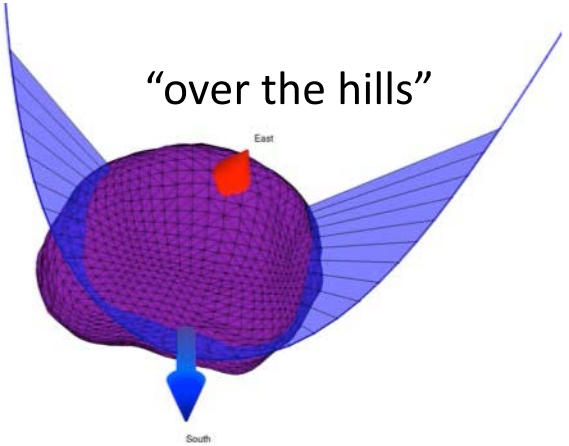
Polar Flyby Campaign

20-km Imaging Flybys

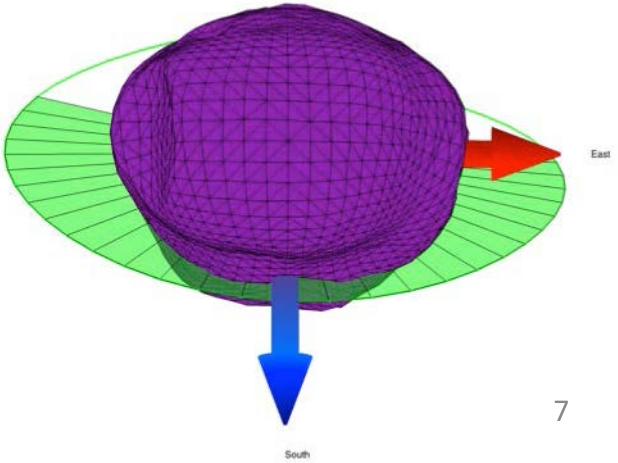


1-km Gravity Science Flybys

"over the hills"

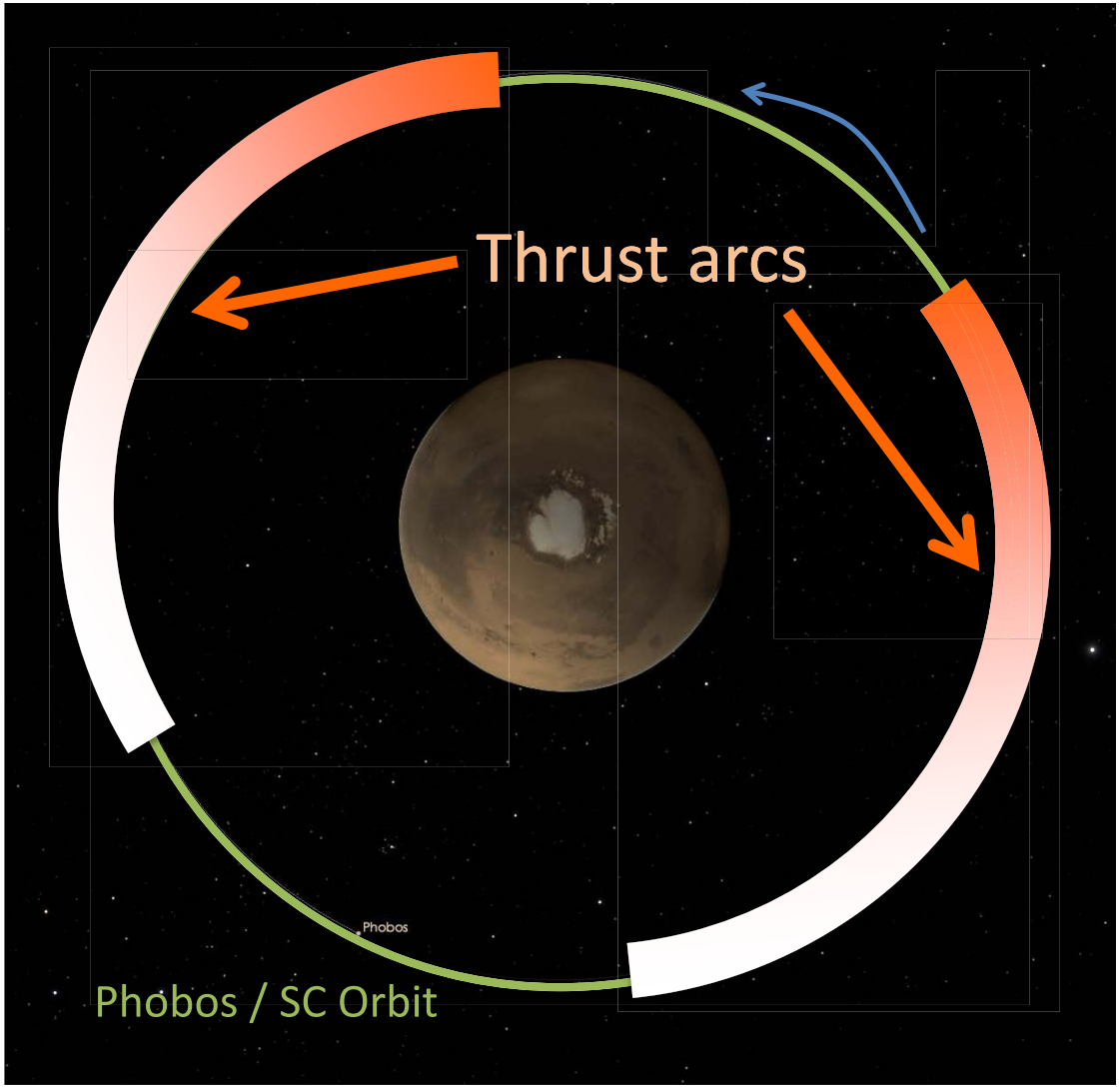


"through the valley"



All flybys shown are over the south pole

Polar Flyby Orbit Correction



Analytic Approximations

Orbit size / period

$$\Delta a = \frac{2a\Delta v_p}{V}\left(\frac{1+2\sqrt{1-k_r^2-k_n^2}}{3}\right)$$

$$\Delta a = 71\ km,\ \ \Delta v = 8.1\ m/s$$

Orbit normal / plane change

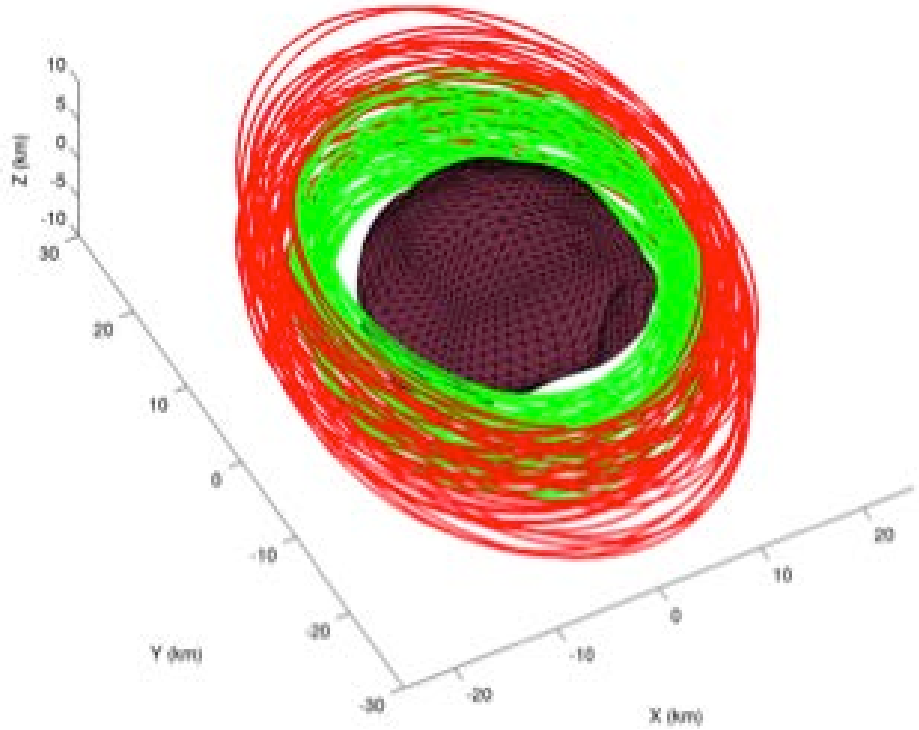
$$\|\Delta\hat{u}_h\| = \frac{\sqrt{3}}{\pi}\frac{\Delta v_p}{V}k_n$$

$$\|\Delta\hat{u}_h\| = 0.13\ deg,\ \ \Delta v = 4.7\ m/s$$

Apse orientation

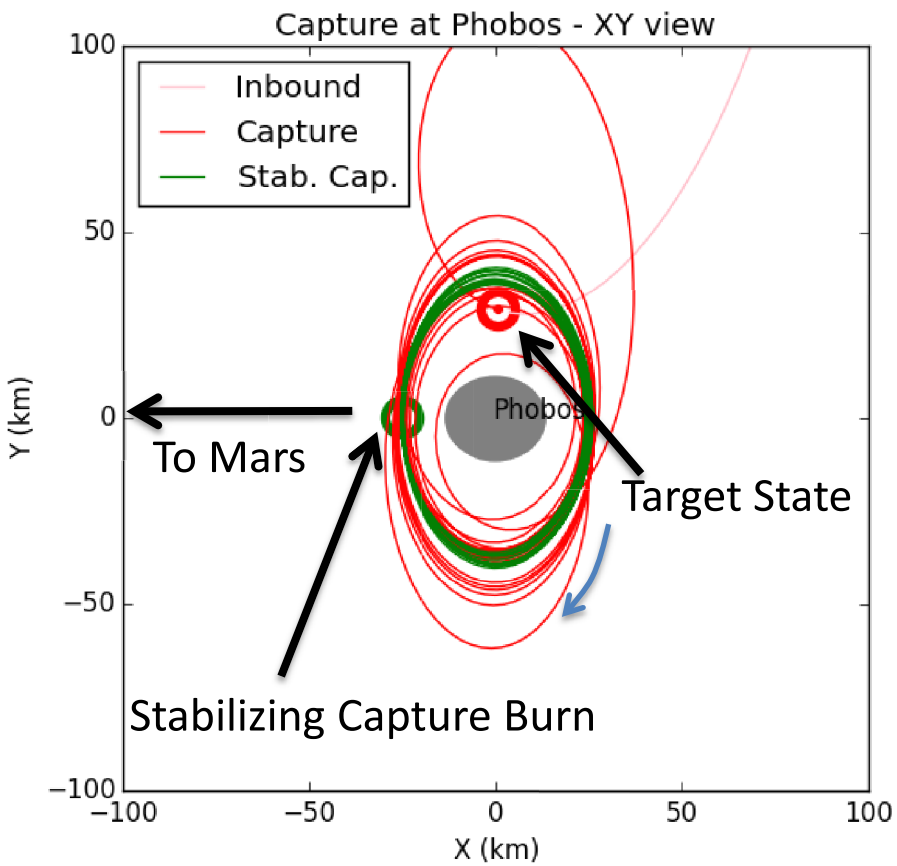
$$\|\Delta\vec{e}\| = \frac{\sqrt{3}}{\pi}\frac{\Delta v_p}{V}k_r$$

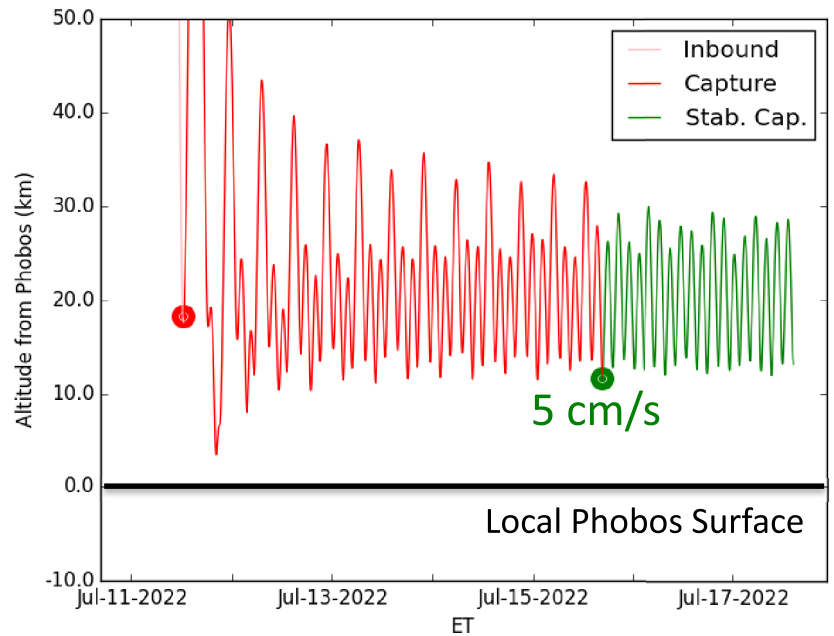
$$\|\Delta\vec{e}\| = 0.0038,\ \ \Delta v = 4.0\ m/s$$



NOMINAL CAPTURE & WALKDOWN TO HI-MO

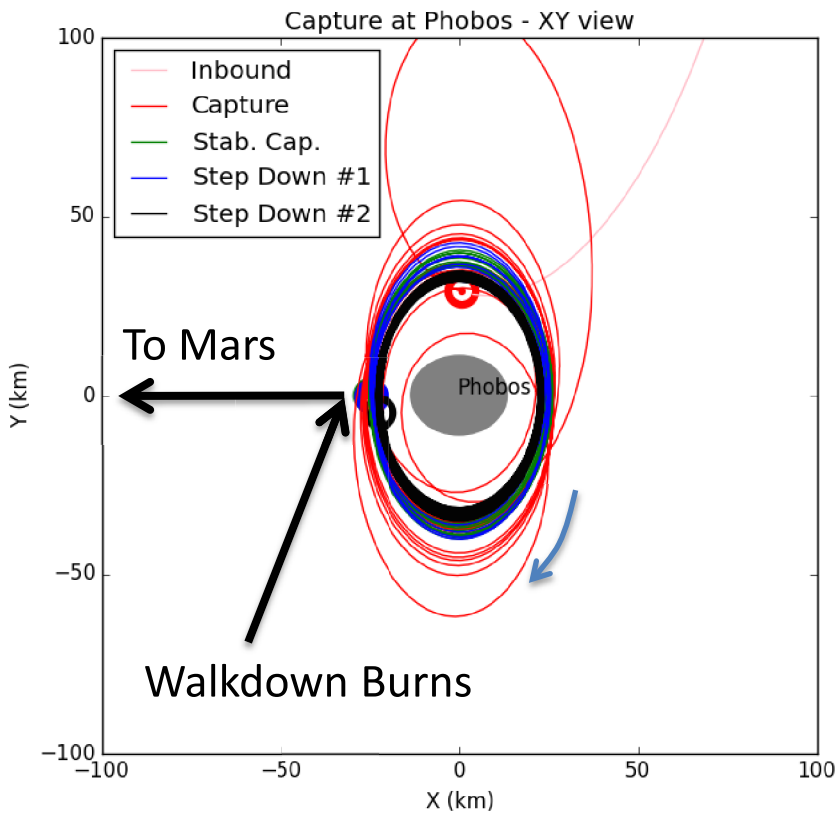
Nominal Capture

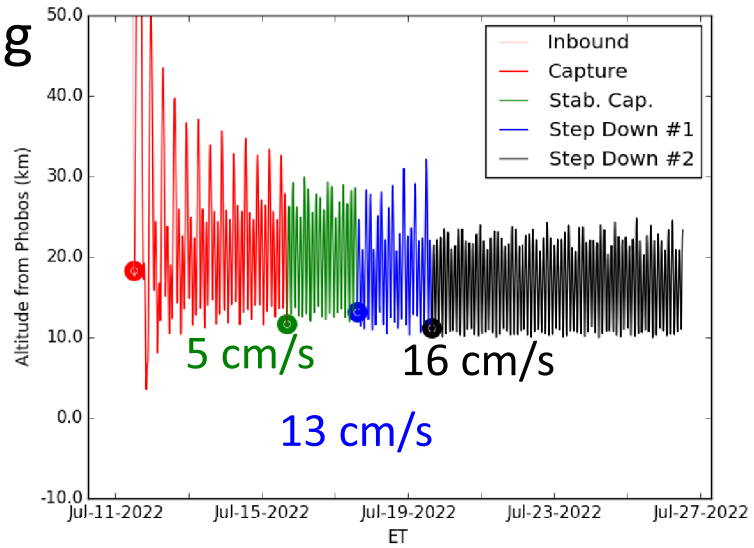




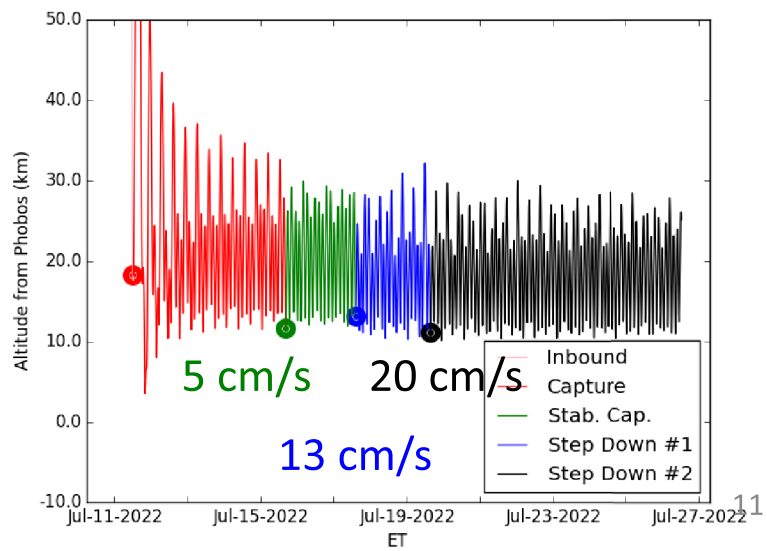
Walkdown Options

Altitude Reducing

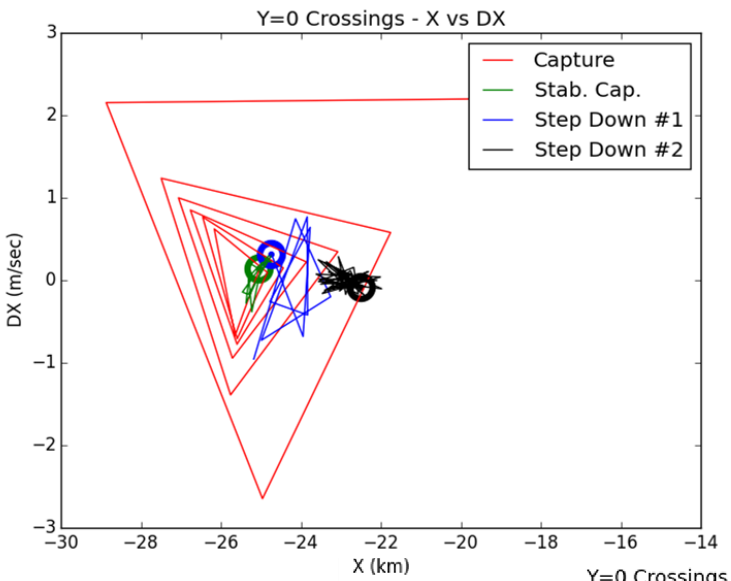


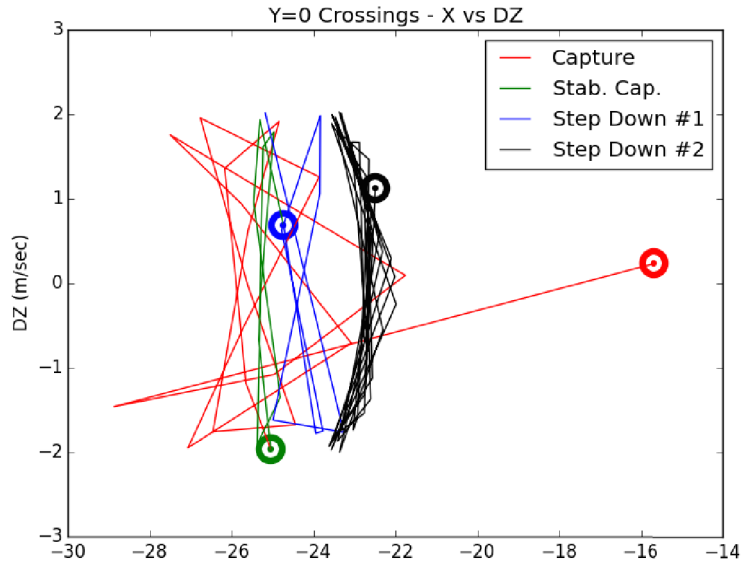


DZ Reducing



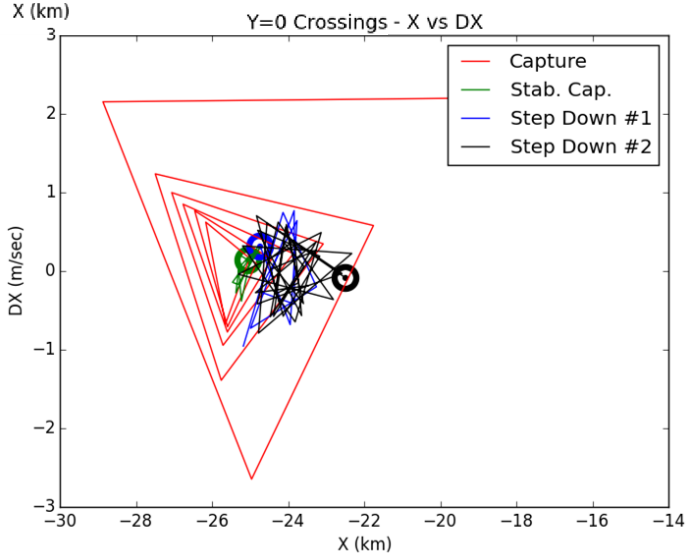
Walkdown Options II: The Revenge

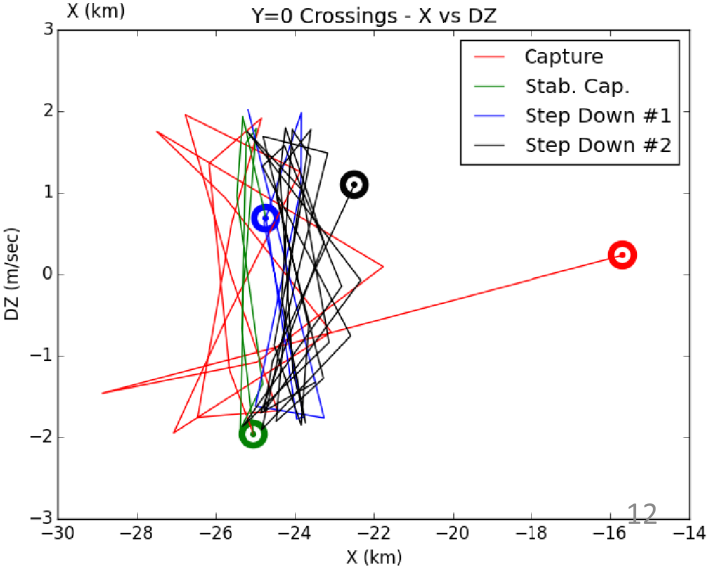




Altitude Reducing

DZ Reducing





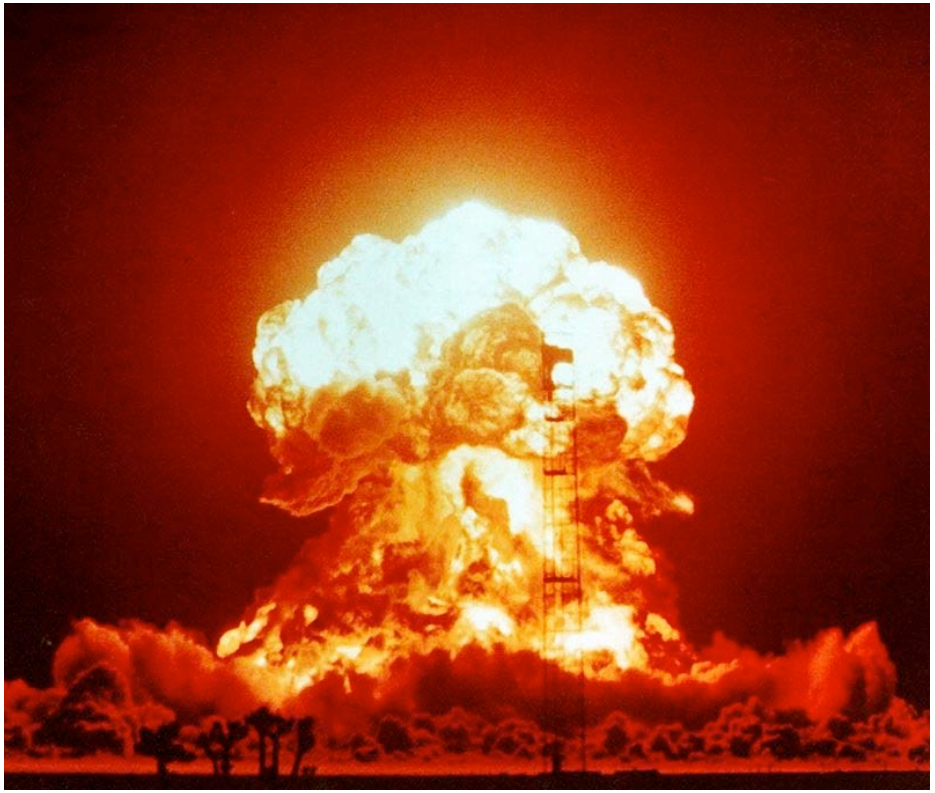
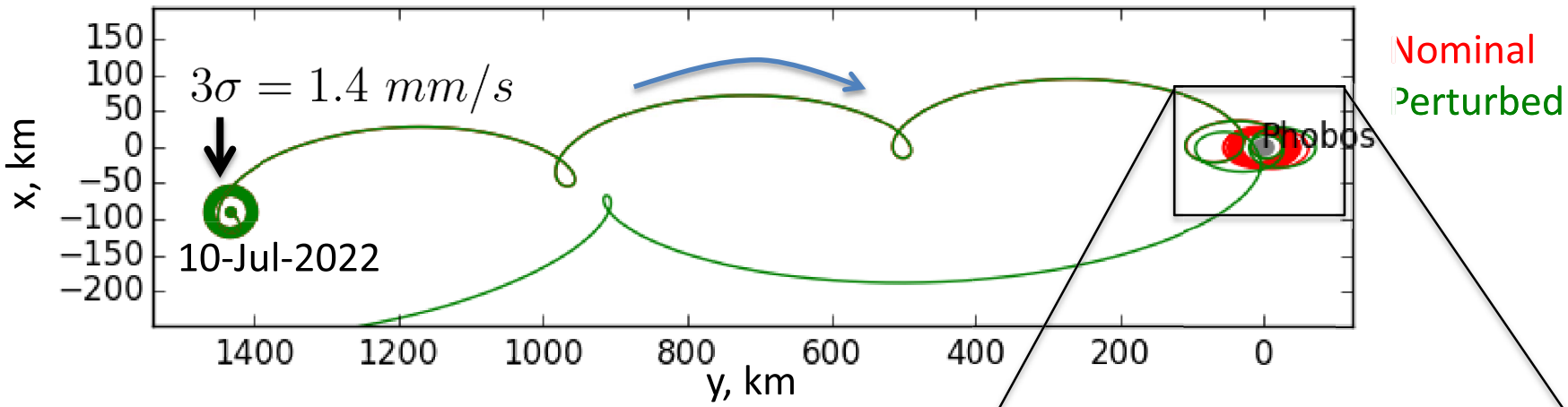
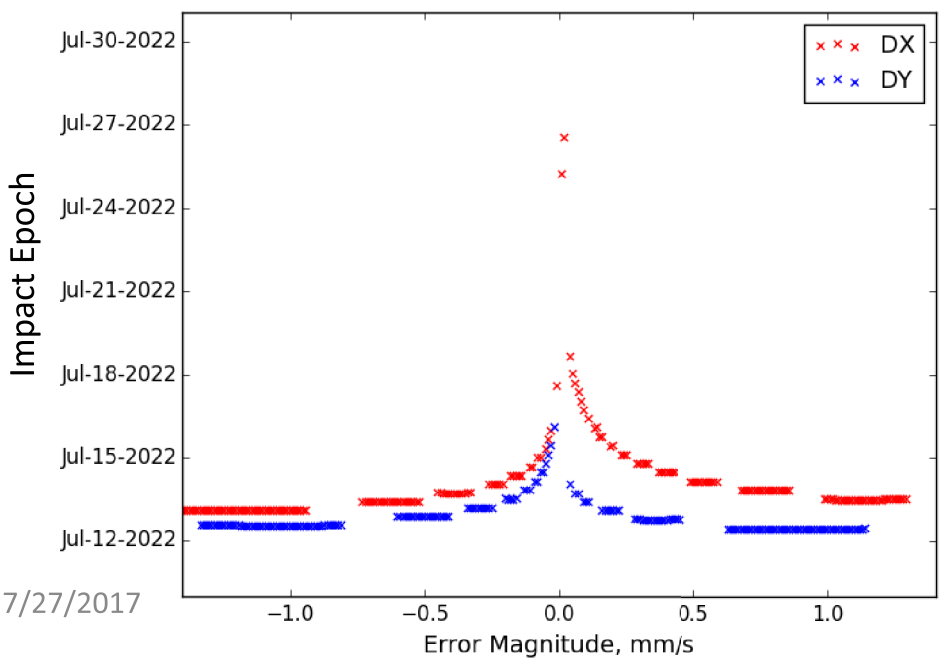


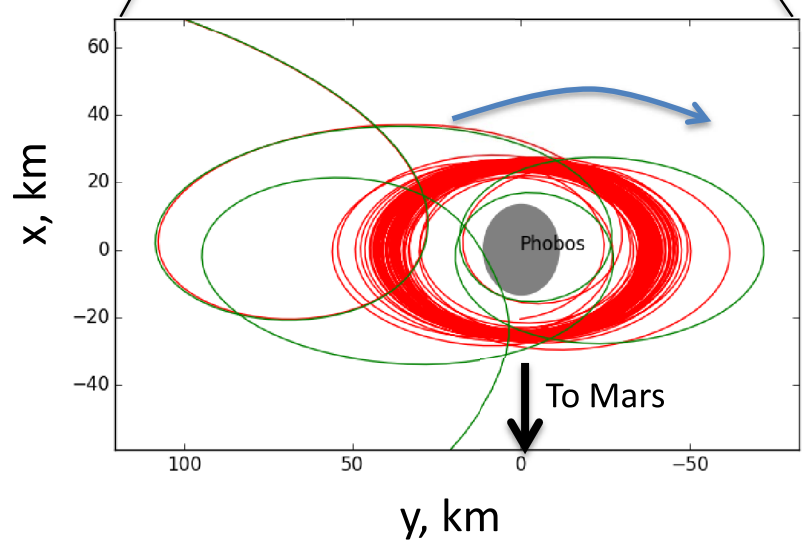
Image: NNSA

CAPTURE MANEUVER ERRORS

Off-Nominal Approaches



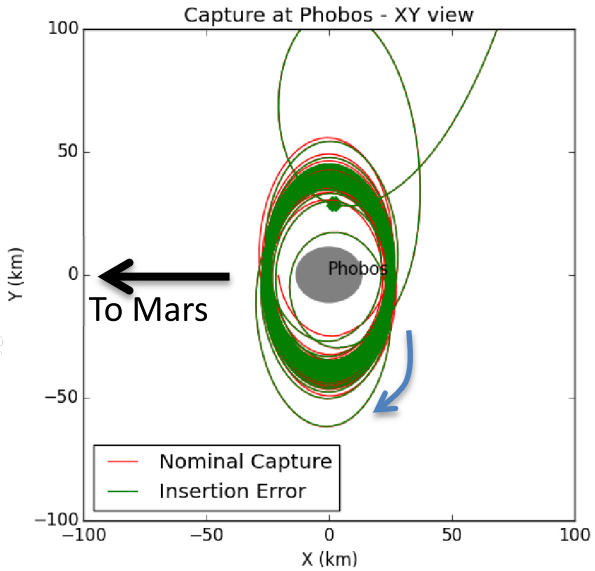


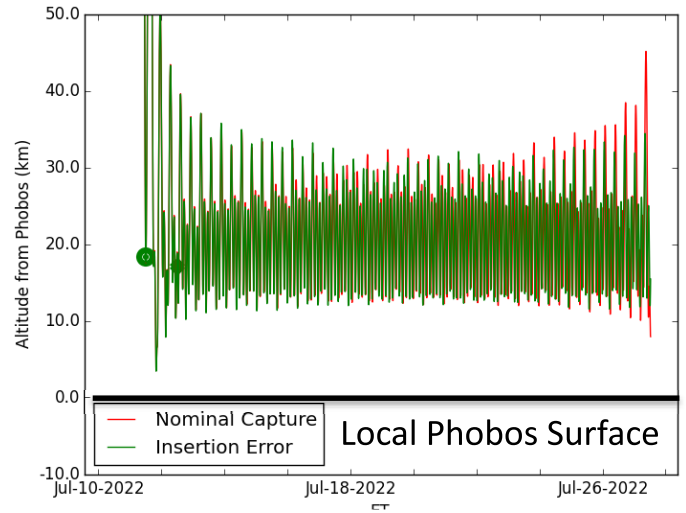


Recovery Options

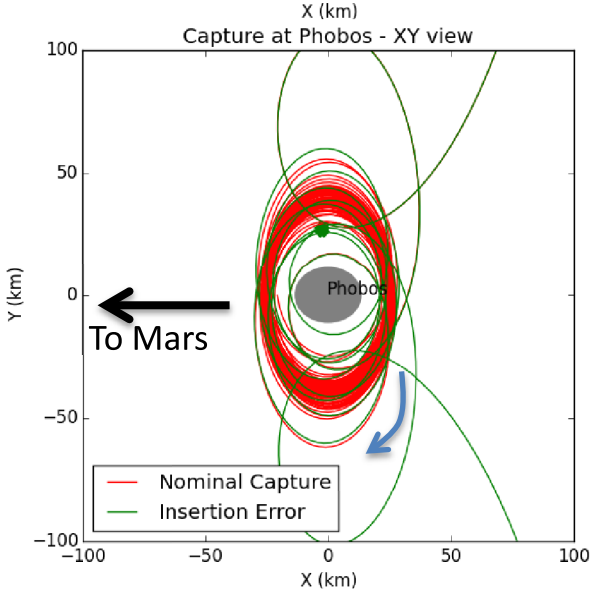
Nominal
Perturbed

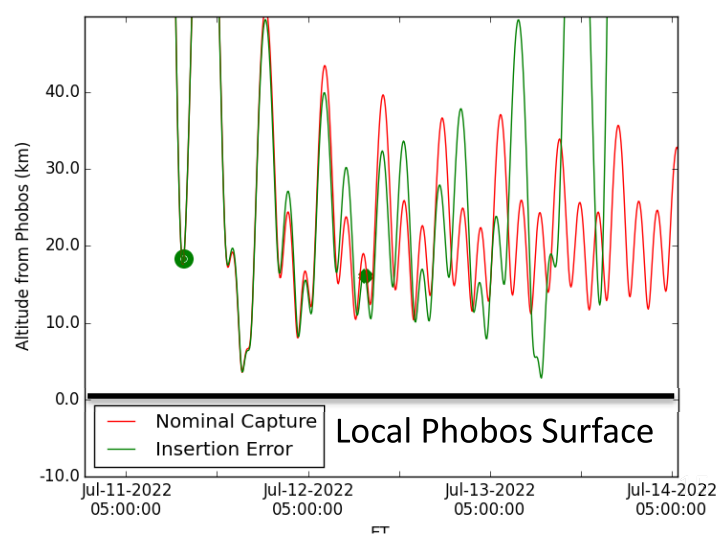
Baseline Recovery
1 cm/s
Restabilizes capture





Backup Recovery
13 cm/s
Safely ejects S/C





Summary

- Mission design concept for Phobos orbiter
  - Mapping orbits
    - DROs cover equatorial region
    - Polar regions not accessed
  - Polar flyby campaign
    - 20 km “high” altitude
    - 1 km “fun” altitude
  - Phobos capture
    - Nominal walkdown
    - Contingency options

Phobos’ Mystery Monolith

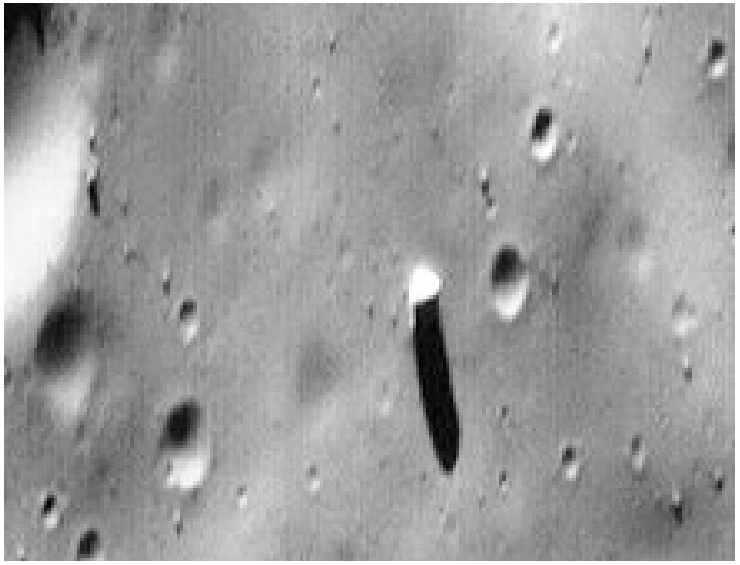


Image: NASA

THANK YOU! QUESTIONS?

BACKUPS

Polar Flyby DV Costs

Parameter	#	Transfer	Semi-major axis	Orbit Plane	Ecc. vector
Difference	1	1st 20-km -DX flyby to	46.53 km	0.1273 deg	0.00017
Ideal ΔV cost		2nd 20-km -DX flyby	5.305 m/s	4.748 m/s	0.185 m/s
Difference	2	2nd 20-km -DX flyby to	58.90 km	0.0714 deg	0.00376
Ideal ΔV cost		1-km +DY flyby	6.715 m/s	2.666 m/s	4.021 m/s
Difference	3	1-km +DY flyby to	58.89 km	0.0715 deg	0.00376
Ideal ΔV cost		20-km +DX flyby	6.714 m/s	2.668 m/s	4.018 m/s
Difference	4	20-km +DX flyby to	58.49 km	0.0433 deg	0.00296
Ideal ΔV cost		1st 1-km +DX flyby	6.668 m/s	1.617 m/s	3.170 m/s
Difference	5	1st 1-km +DX flyby to	70.99 km	0.0180 deg	0.00098
Ideal ΔV cost		2nd 1-km +DX flyby	8.094 m/s	0.671 m/s	1.049 m/s