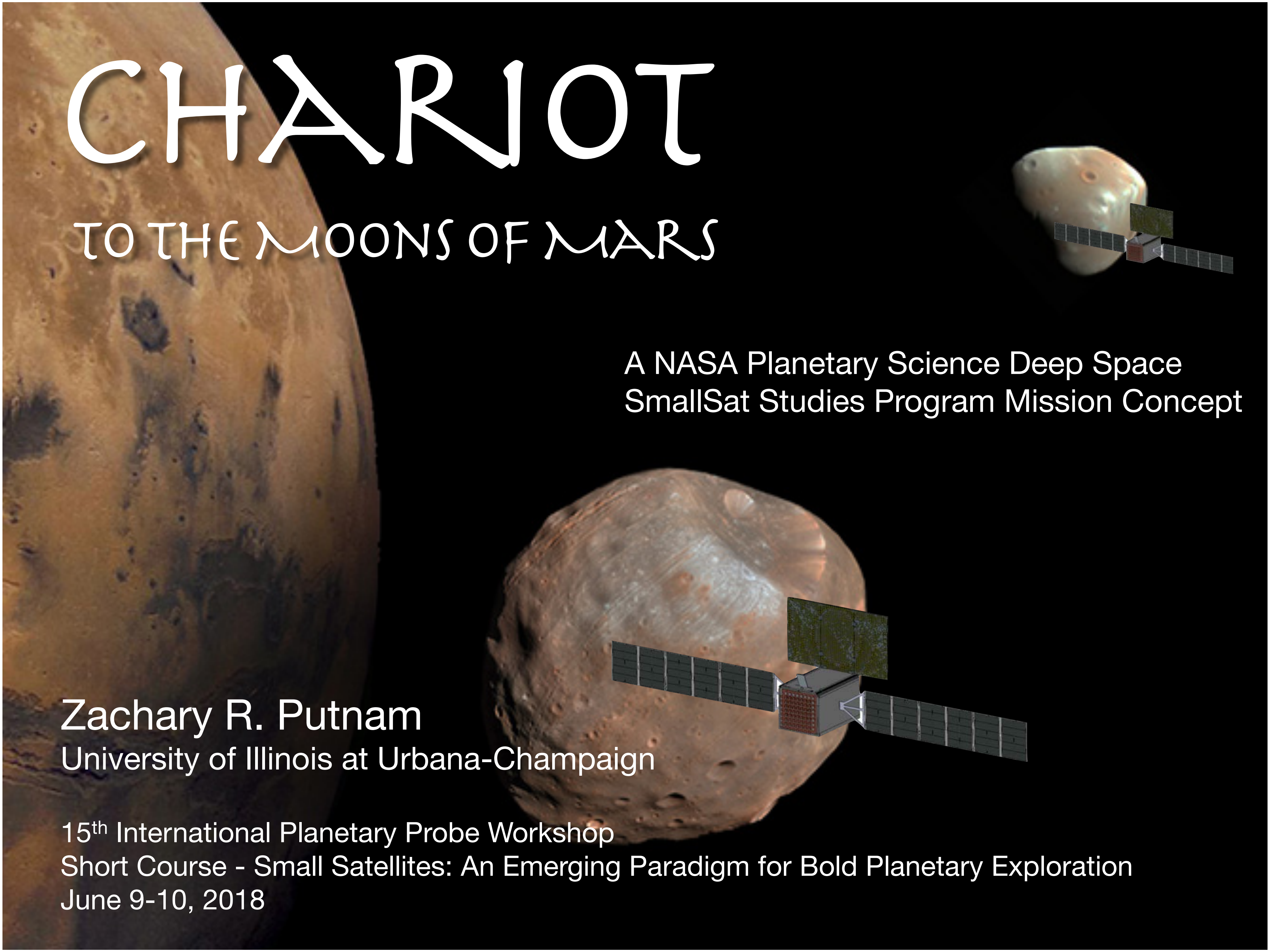


CHARIOT

TO THE MOONS OF MARS

A NASA Planetary Science Deep Space SmallSat Studies Program Mission Concept

Zachary R. Putnam
University of Illinois at Urbana-Champaign

15th International Planetary Probe Workshop
Short Course - Small Satellites: An Emerging Paradigm for Bold Planetary Exploration
June 9-10, 2018

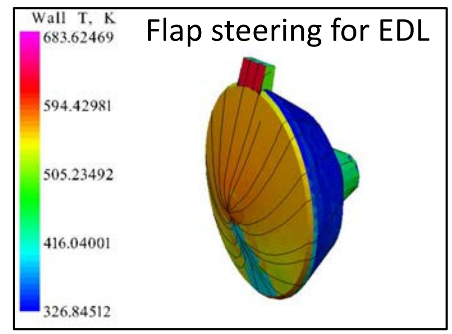
Zachary R. Putnam

Assistant Professor
Department of Aerospace Engineering
University of Illinois at Urbana-Champaign

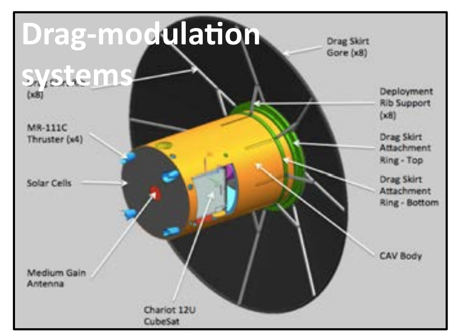
zputnam@illinois.edu
putnam.ae.illinois.edu

104 S. Wright St. MC-236
Urbana, IL 61801

Background
- Georgia Tech: B.S. (2004), M.S. (2006), Ph.D. (2015)
- Technical staff at Draper Laboratory (2006-2010)
- Joined faculty at Illinois in 2015



Research group focuses on hypersonic and space systems
- Flight mechanics
- Vehicle and mission design/optimization
- Vehicle systems, including GNC, TPS
- Modeling and simulation



Chariot PSDS3 Team

PI: David A. Minton
Science Co-I: Briony H. N. Horgan
Systems Engineer Co-I:
David A. Spencer
Students:
Mayank Aggarwal
Rohan Deshmukh
Jacob R. Elliott
Andrew J. Hesselbrock
Connor R. Tinker

CAV/Mission Design Co-I:
Zachary R. Putnam
Students:
Giusy Falcone
Destiny M. Fawley
Elizabeth M. Fleming
Thomas R. Smith
James W. Williams

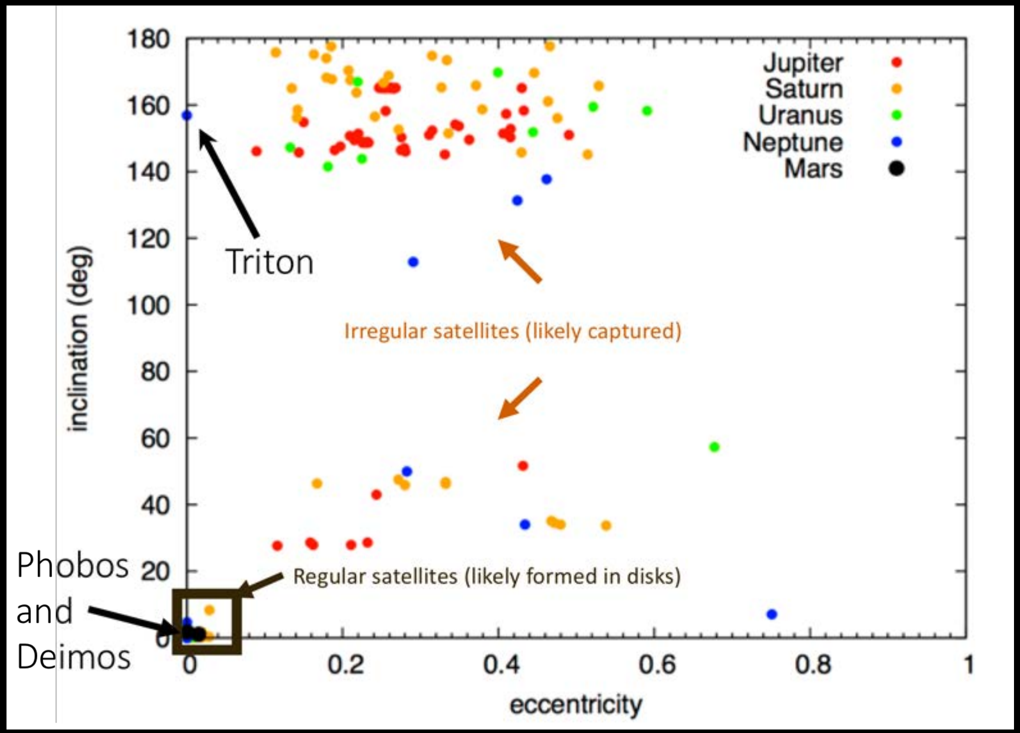
Instrument Co-I:
Philip R. Christensen
Collaborator: Erik Asphaug

Spacecraft Co-I: Austin Williams
Spacecraft Co-I: Jordi Puig-Suari

Collaborators:
Matija Ćuk
Francesca DeMeo
Masatoshi Hirabayashi
Jean-François Smekens
Andrew Rivkin

Investigating the Origins of the Moons of Mars

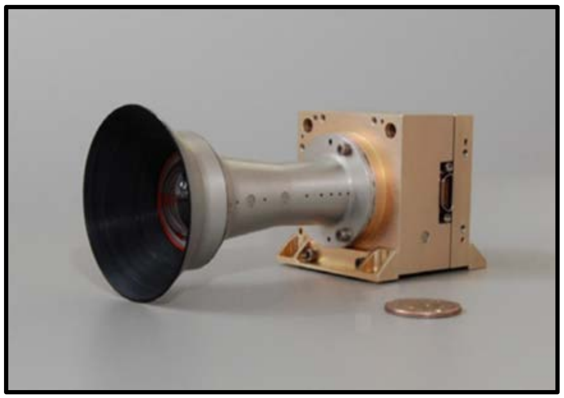
- VIS/IR spectra of Phobos and Deimos suggest similar composition to carbonaceous meteorites and asteroids, supporting capture hypothesis…
- …but orbits suggest formation in protosatellite disk



Chariot Investigation

Chariot was designed to provide high-resolution observations of both **Phobos and Deimos** in order to discriminate among proposed origin models, providing crucial information about the early history of the Mars system.

- COTS/heritage instruments available that meet mission needs
- Relatively large data volume, especially for a smallsat

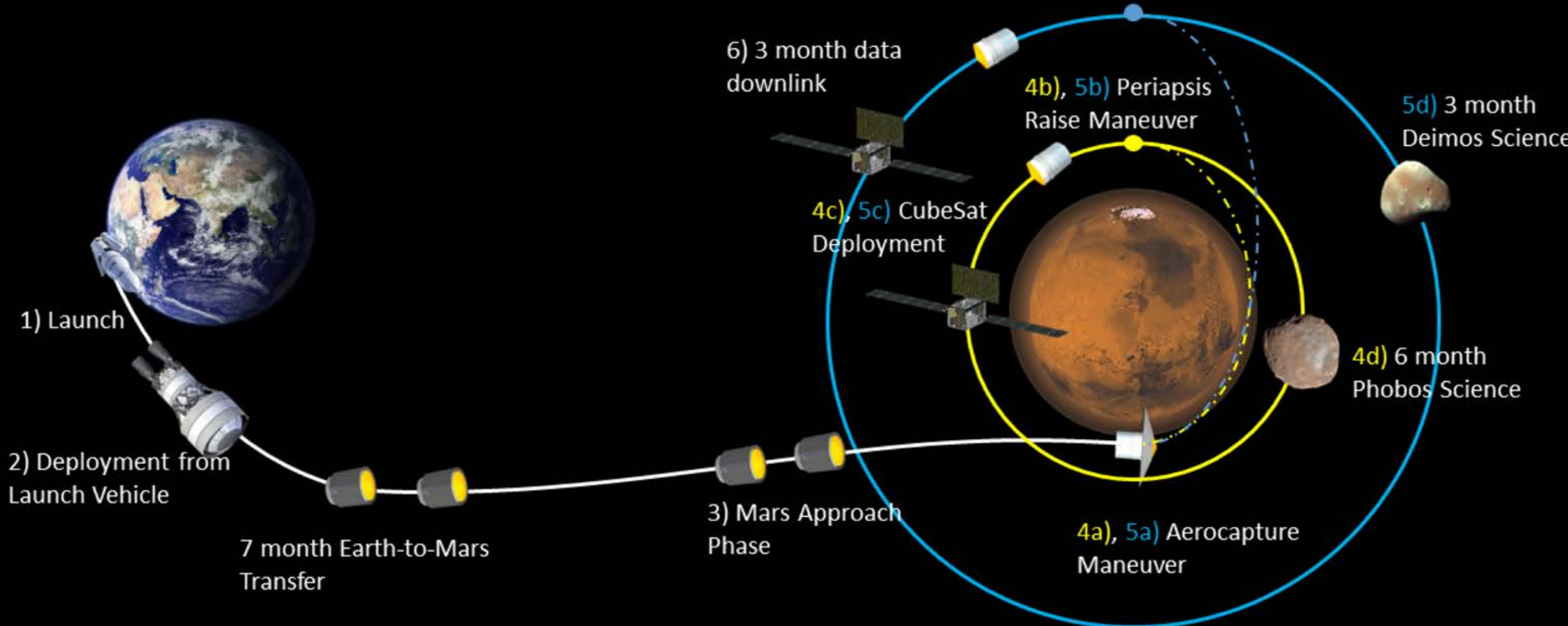


Color Camera
Morphology and geology

TIR Multispectral Imager
Regolith thermophysics, variability in bulk composition

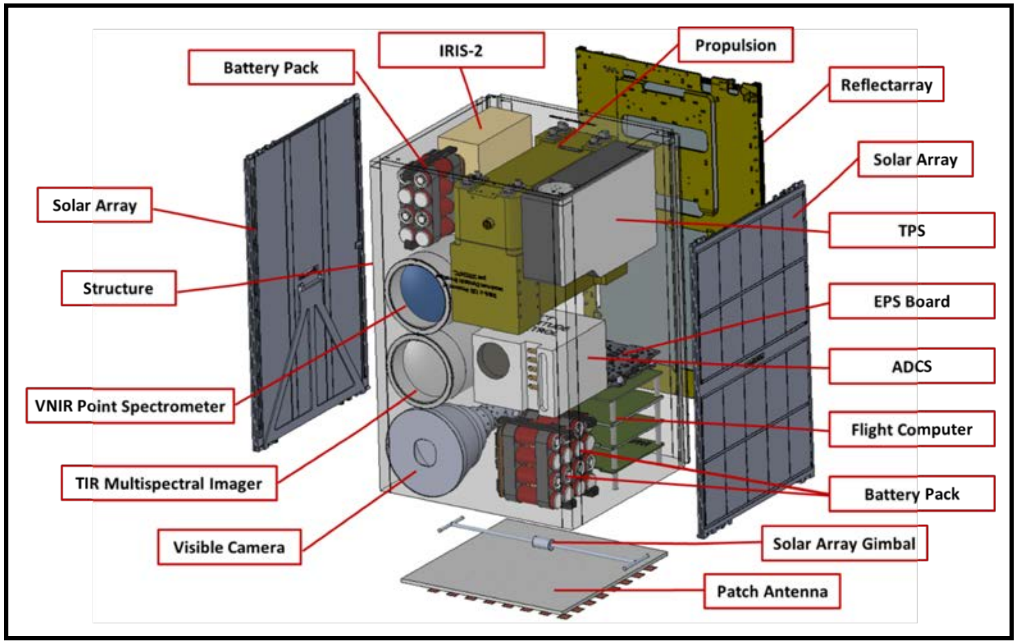
VNIR Point Spectrometer
Mafic and hydrated minerals, space weathering

Chariot Concept of Operations

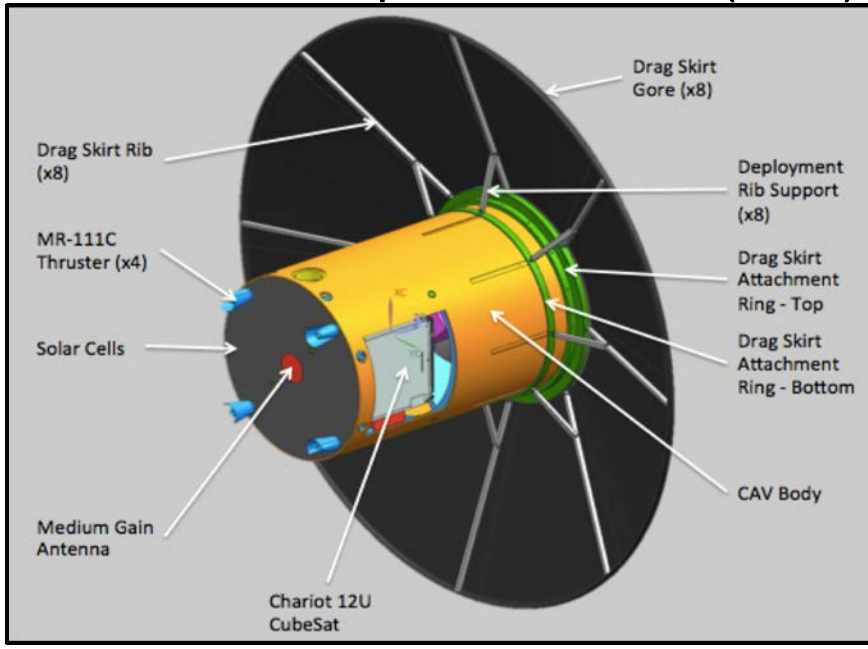


Chariot Vehicle Systems

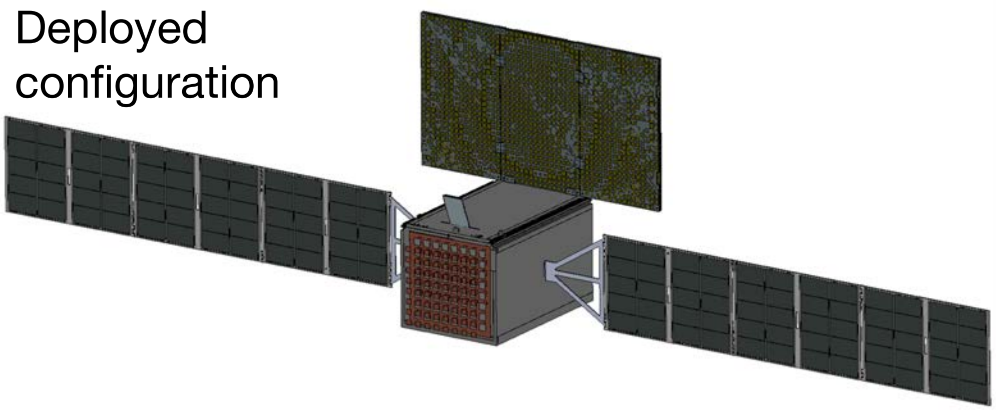
CubeSat



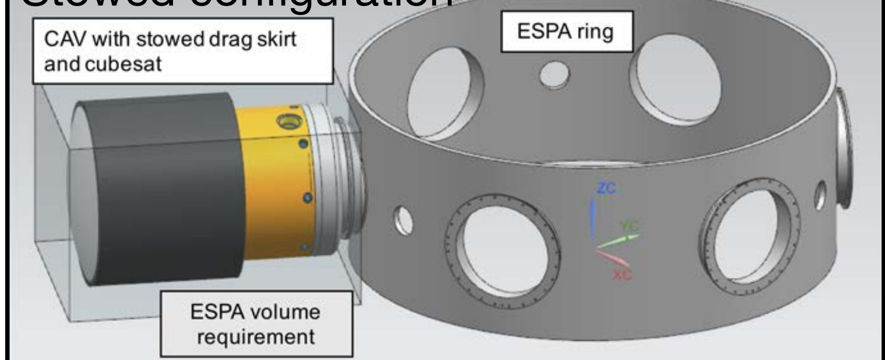
Cruise-Aerocapture Vehicle (CAV)



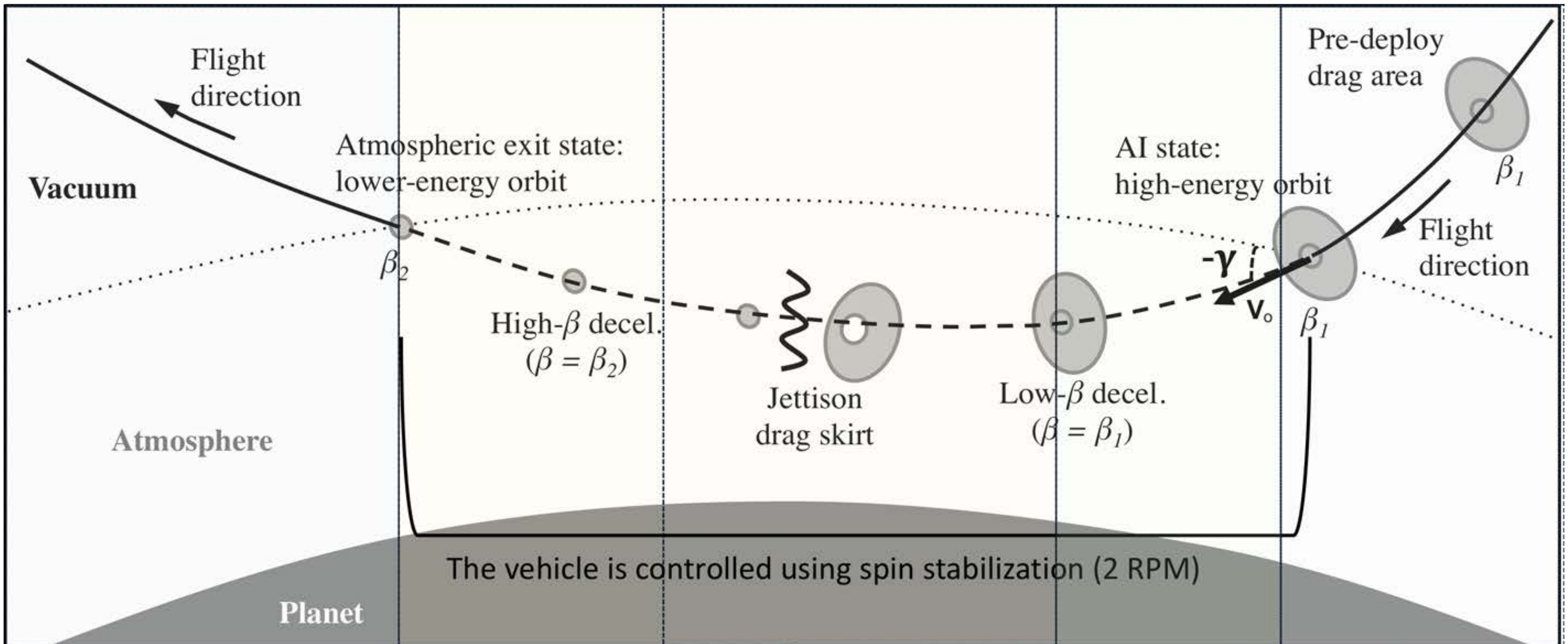
Deployed configuration



Stowed configuration



Aerocapture ConOps



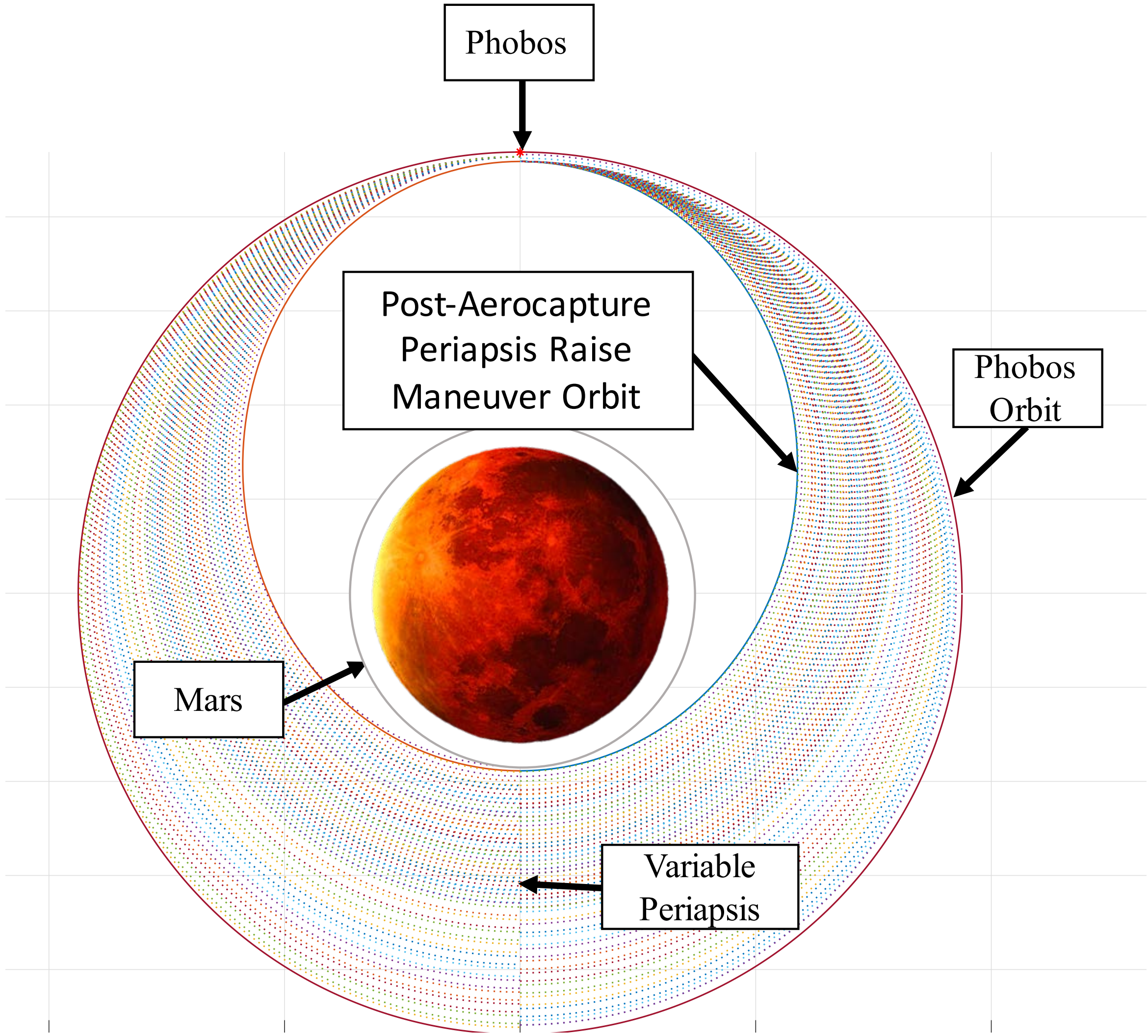
At the exit of the Mars atmosphere, the vehicle performs a 180-degree slew maneuver and a periapsis raise maneuver at apoapsis.	The vehicle is placed into an elliptical transfer orbit with the required apoapsis altitude.	The drag skirt is jettisoned; timing and location of jettison depend on the post-aerocapture target orbit and onboard guidance system	The vehicle will enter the atmosphere of Mars with a defined flight path angle, γ.	Vehicle + drag skirt separate from the host and approaches Mars on a hyperbolic trajectory.

Mars System Operations

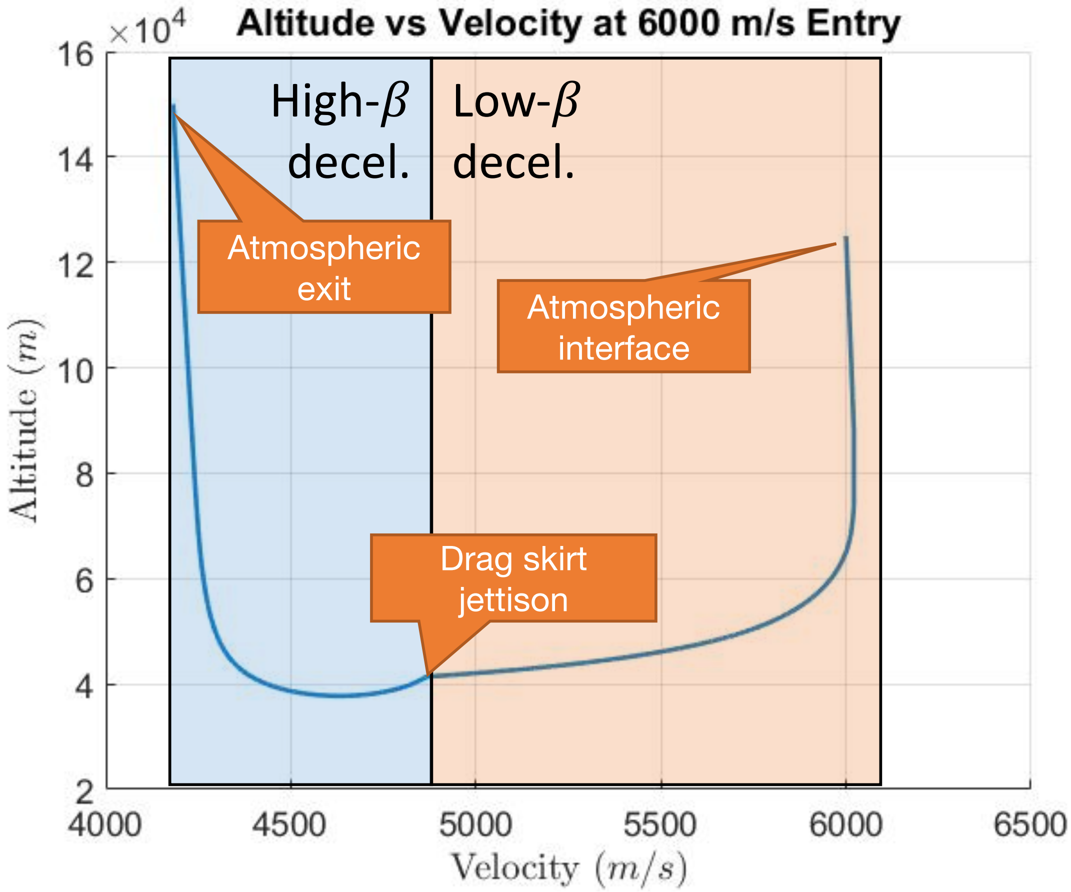
CAV performs 3 propulsive maneuvers in Mars system:

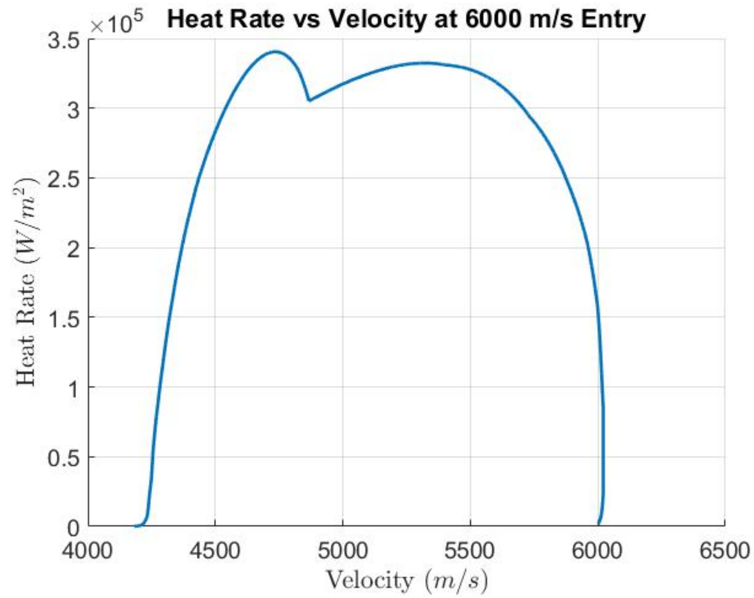
1. Periapsis raise immediately following aerocapture
2. Phasing maneuver 1
3. Phasing maneuver 2

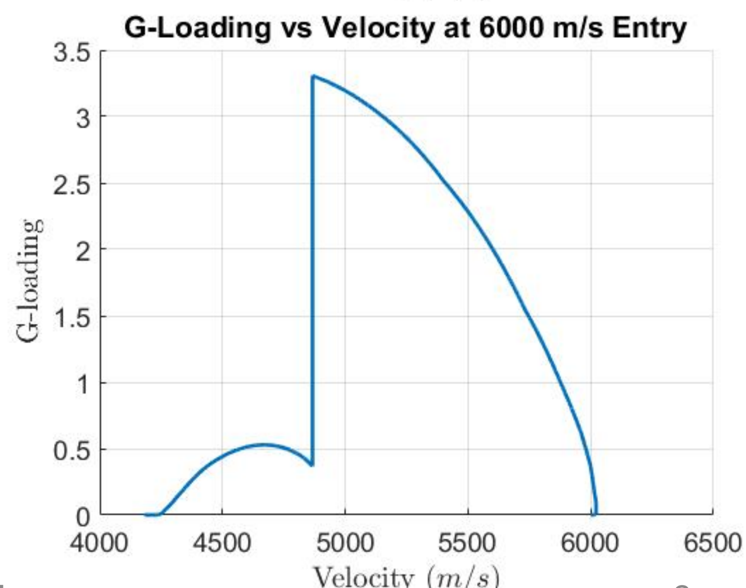
The two phasing maneuvers complete circularization and phasing concurrently while correcting aerocapture apoapsis error, significantly decreasing time to rendezvous for a small delta-V penalty (less than 5 m/s)



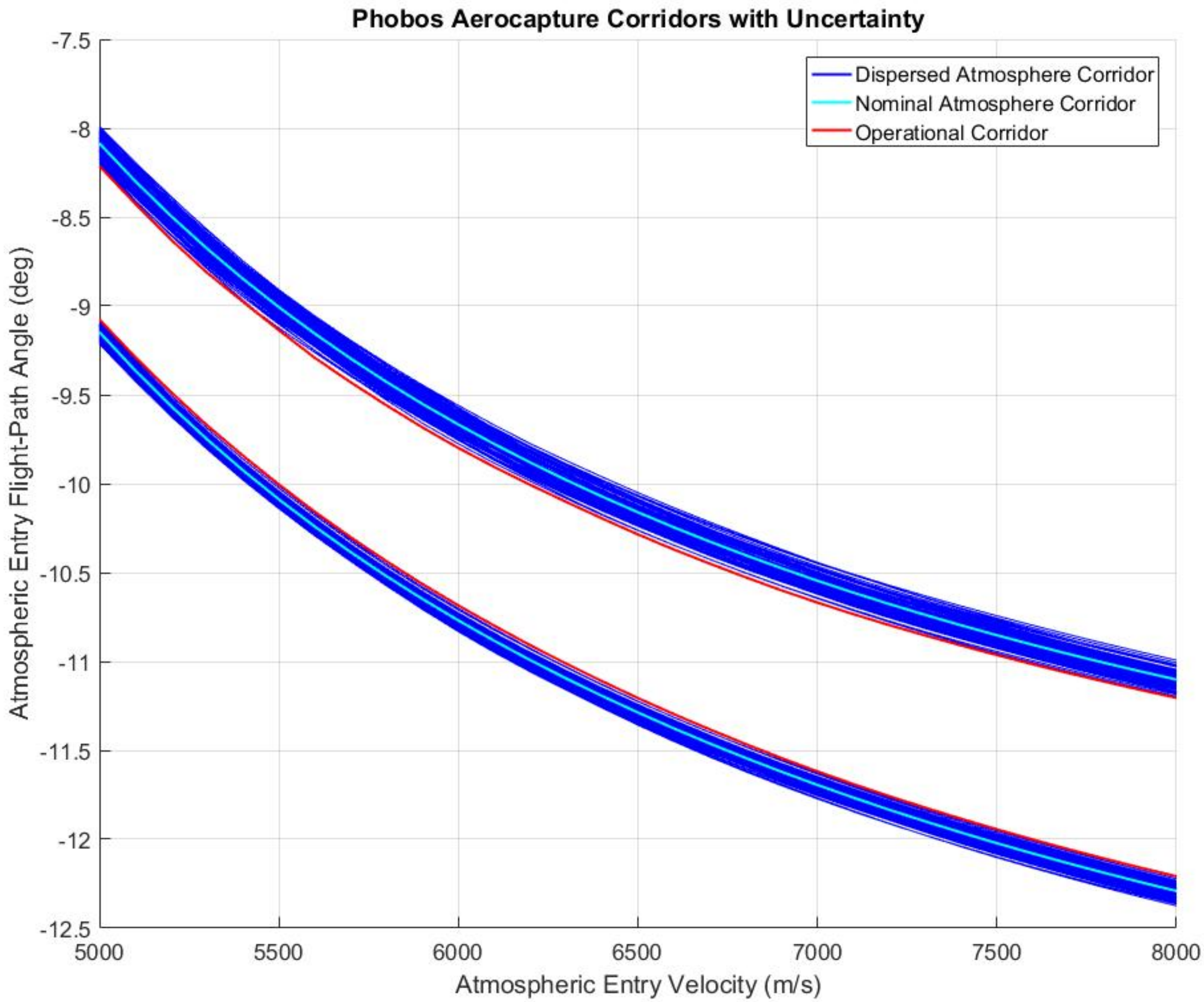
Nominal Aerocapture Trajectory



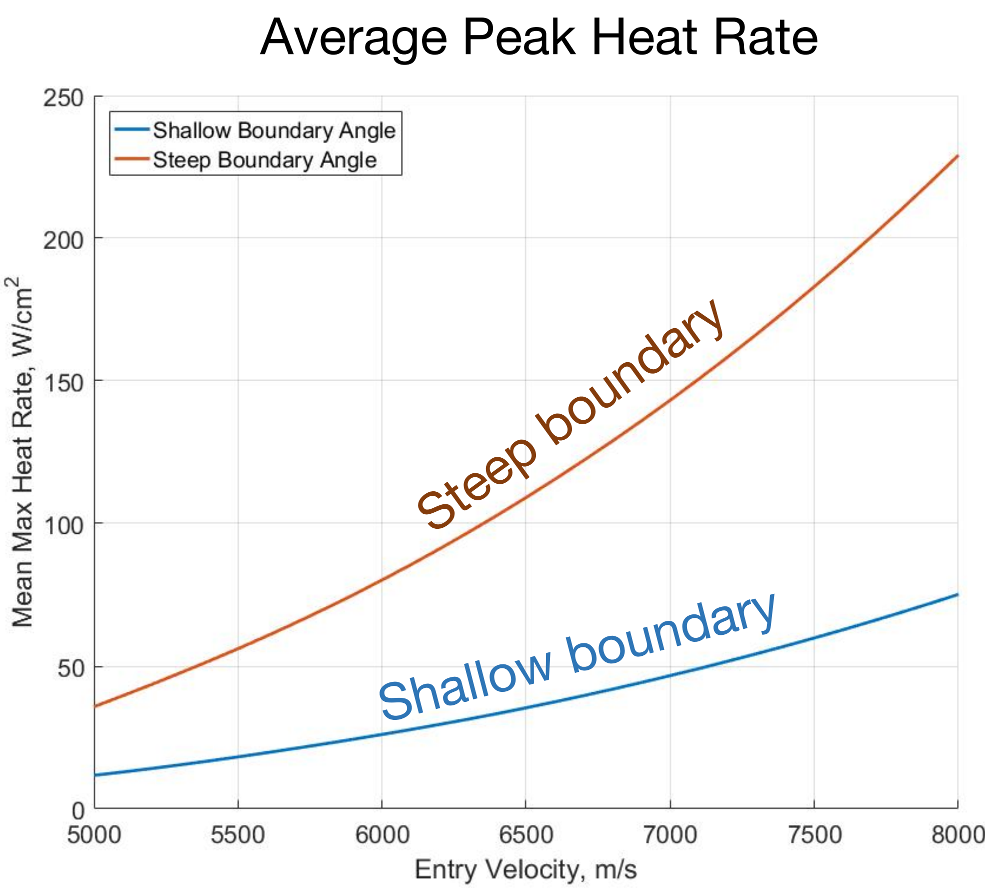


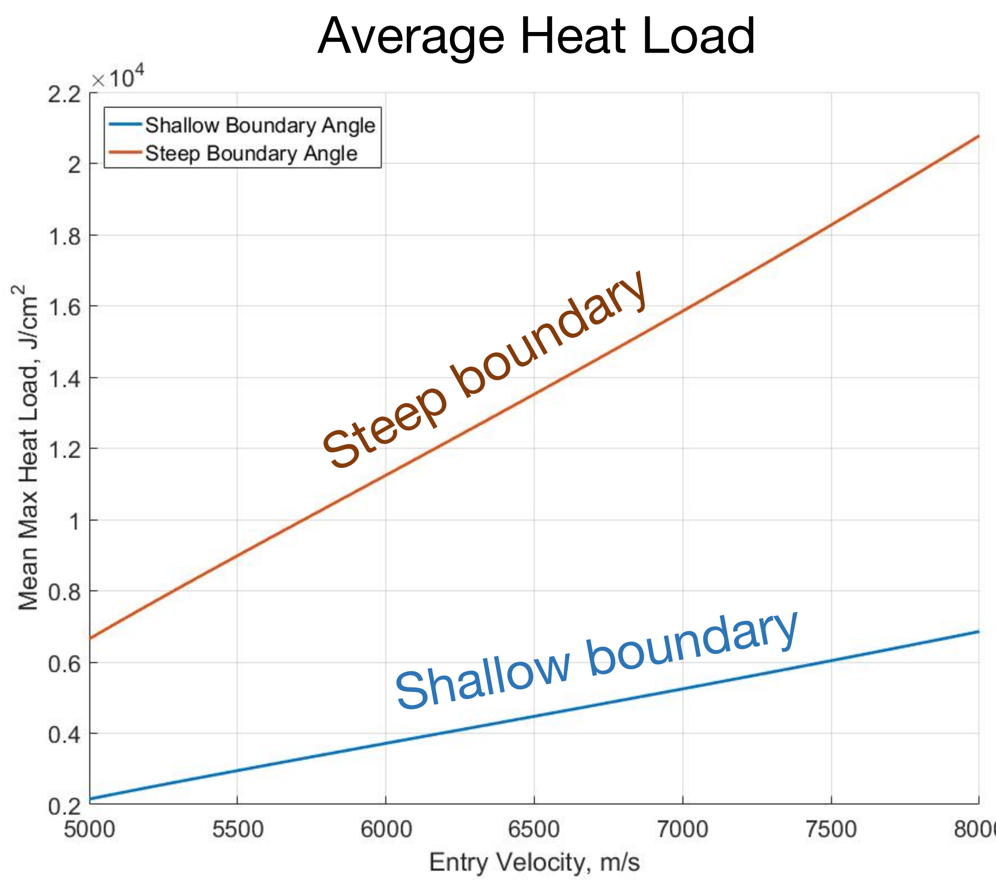


Aerocapture Corridor

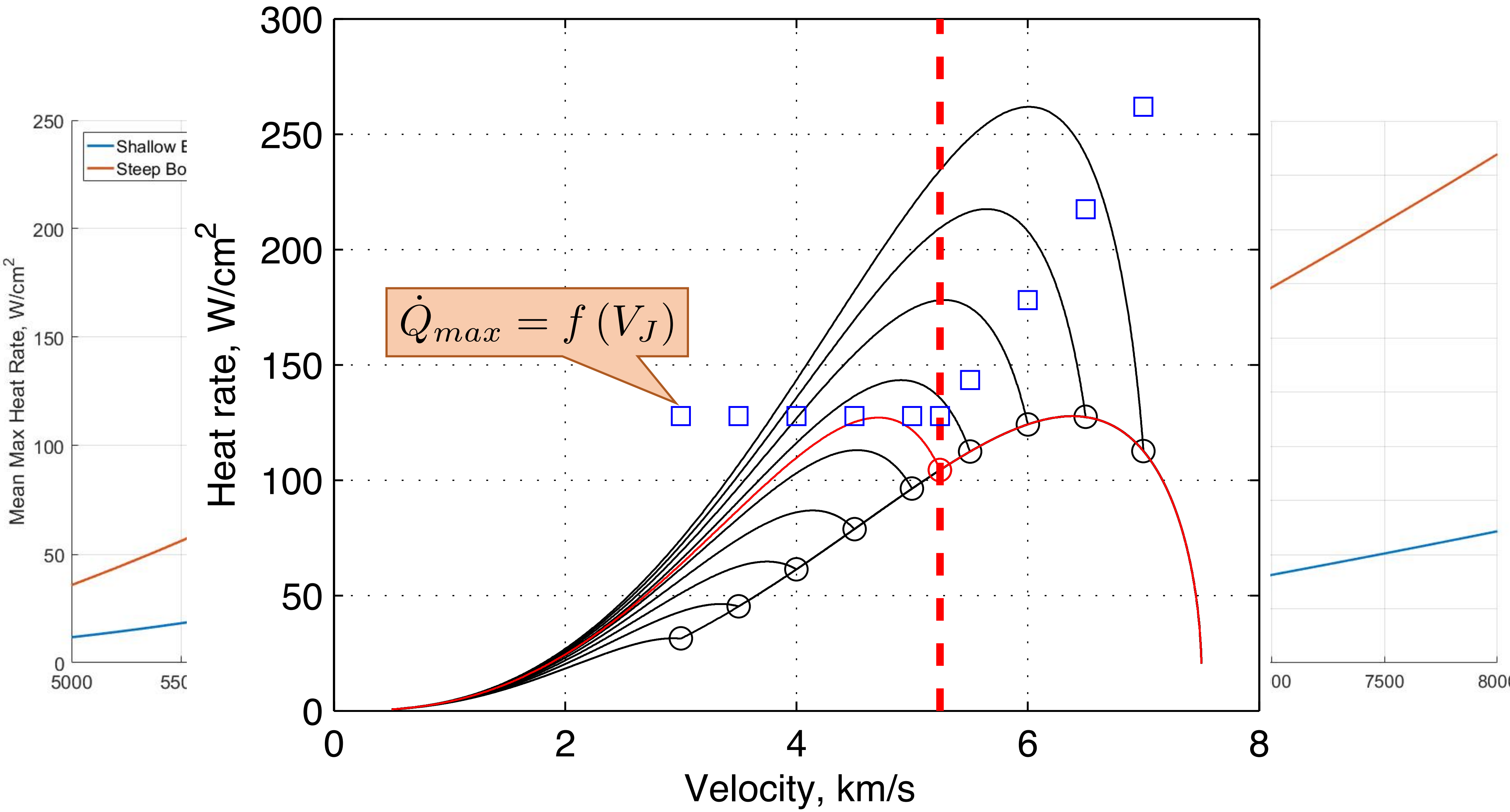


Aerocapture Corridor

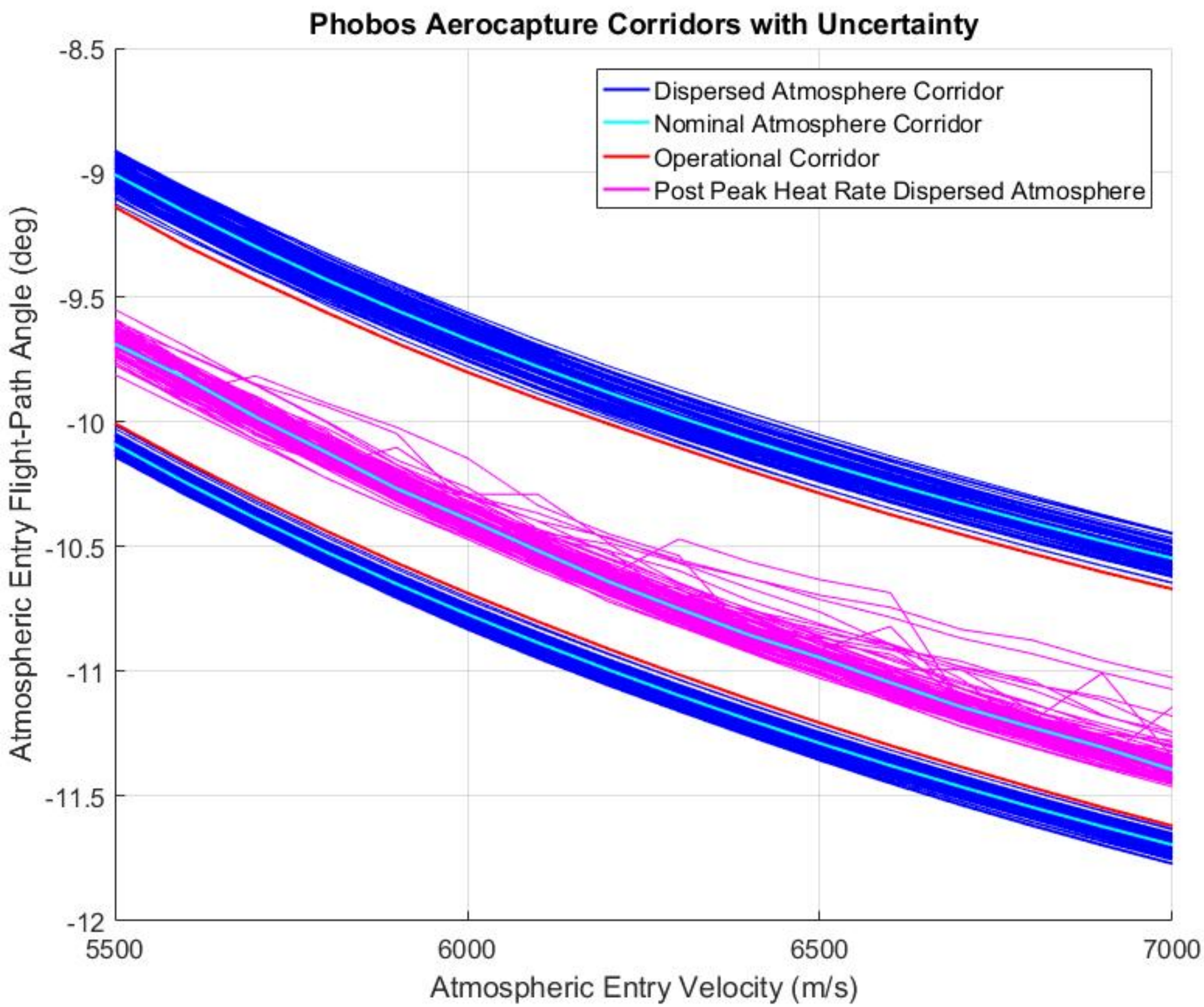




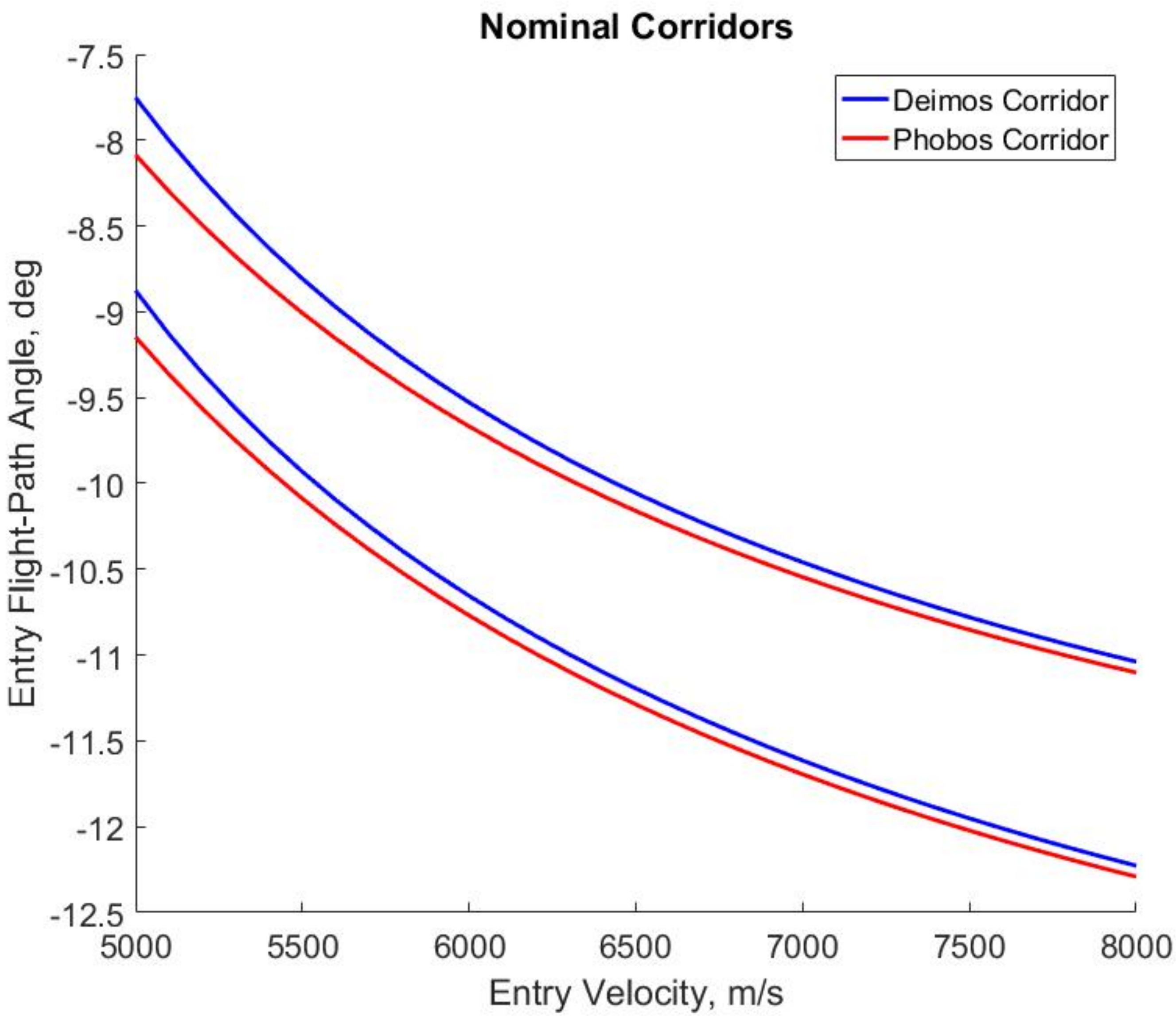
Aerocapture Corridor



Aerocapture Corridor



Corridors for Phobos and Deimos



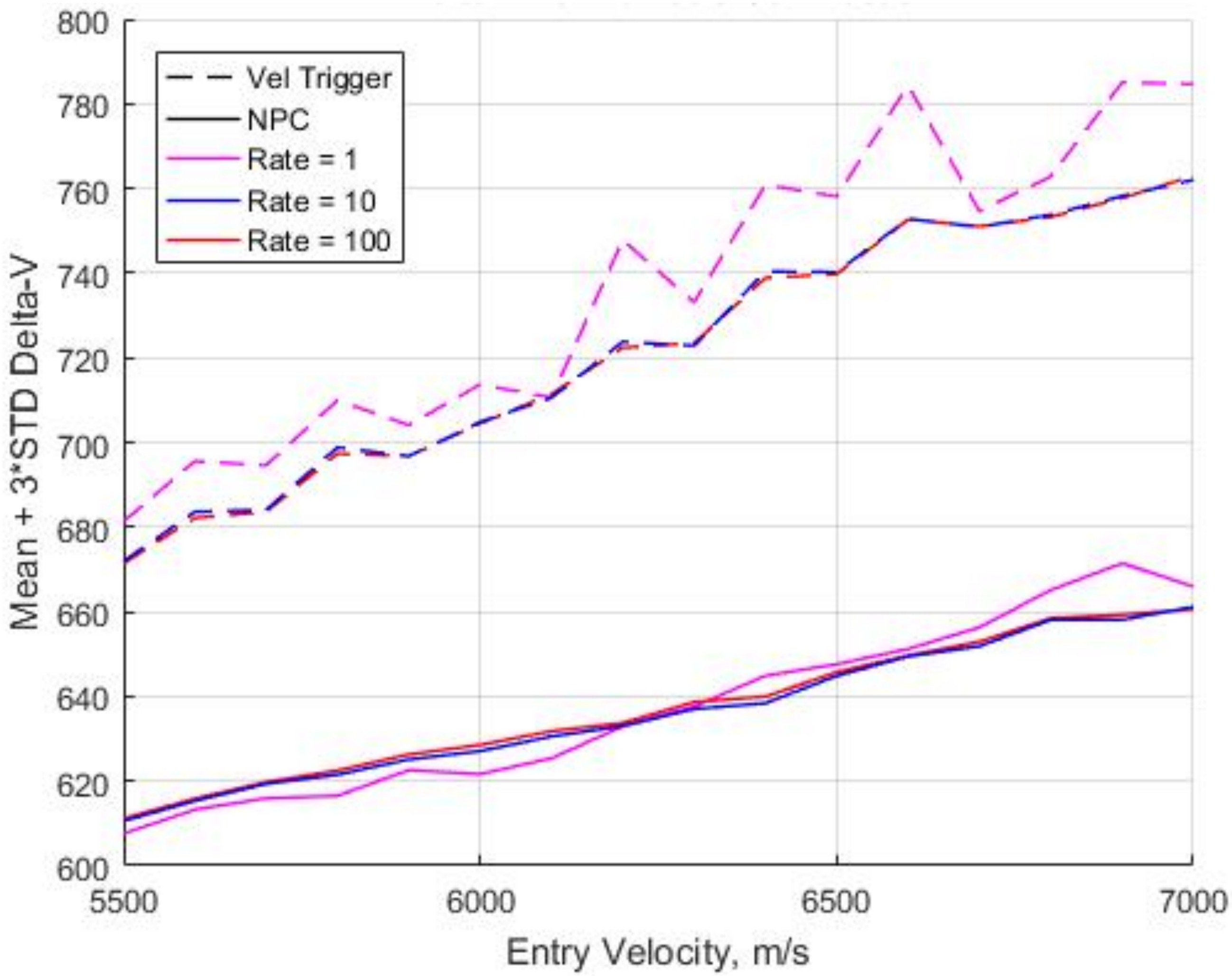
Aerocapture Guidance Trade

- Previous feasibility work showed that a numerical predictor-corrector algorithm could provide required accuracy
- Simple heuristic velocity trigger also investigated

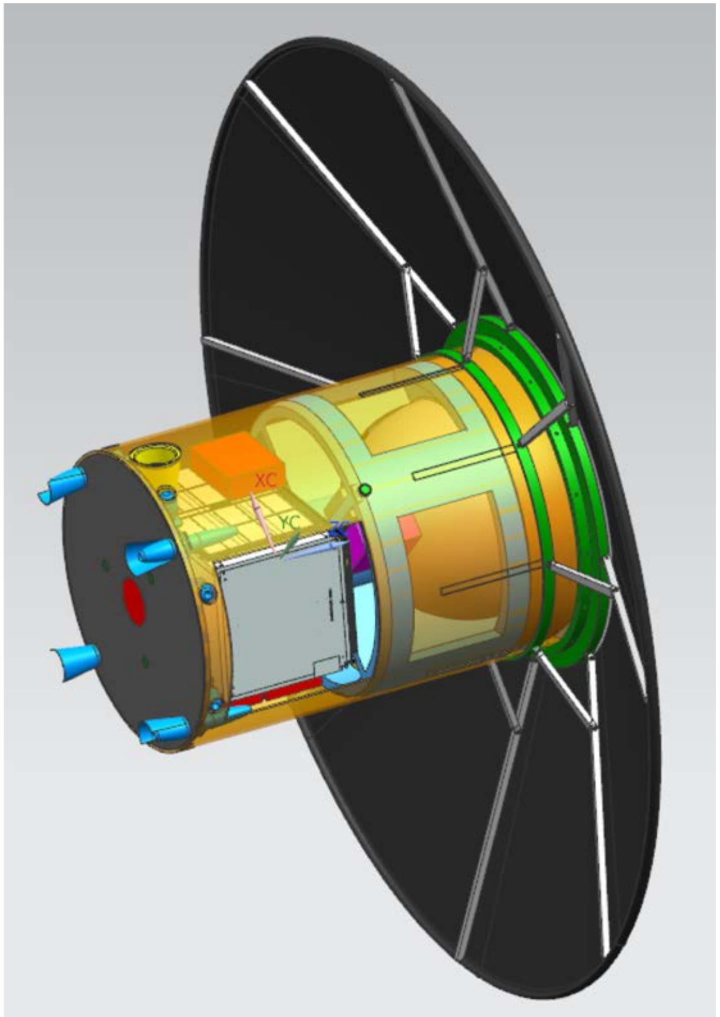
Guidance scheme	Entry Angle	Apoapsis error mean (km)	Apoapsis error std. dev. (km)
NPC	Center of Corridor	708	480
V. Trigger	Center of Corridor	947	1309
NPC	Shallow Edge*	162	93
V. Trigger	Shallow Edge*	235	577

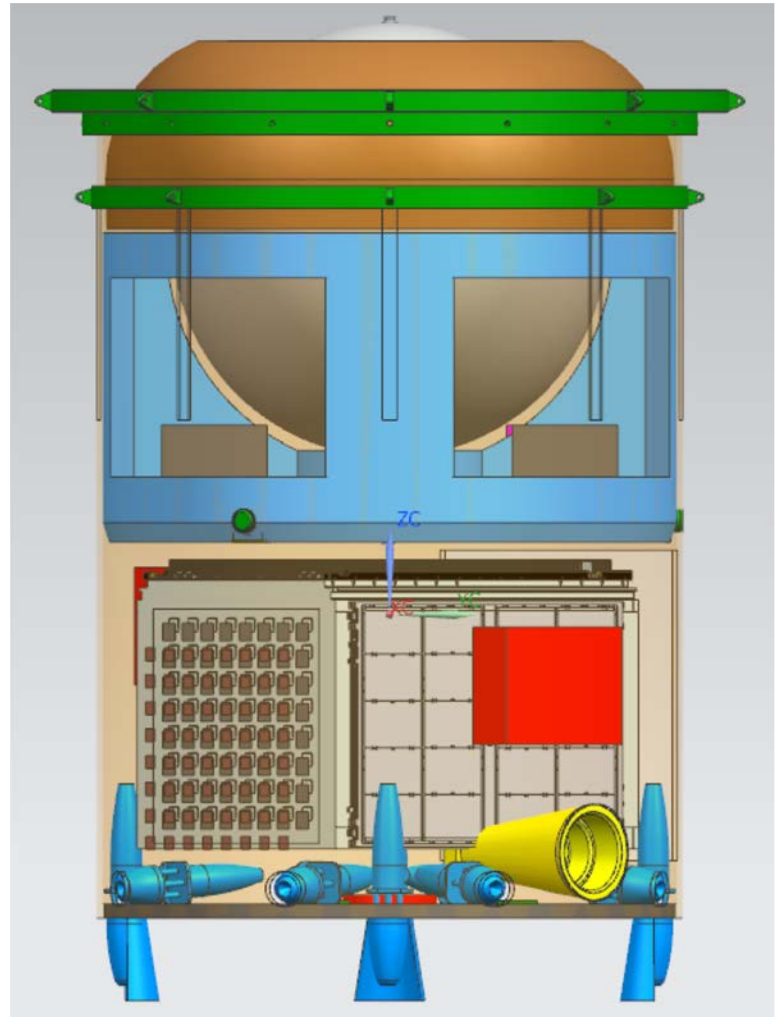
*Shallow edge trajectories target initial flight-path angle -0.1 deg from shallow boundary

Aerocapture Guidance Trade



CAV Packaging





Conclusions

- The Chariot concept is capable of delivering high-resolution observations of Phobos and Deimos for relatively low cost
- Drag-modulation aerocapture can provide a low-cost, independent orbit insertion capability for future planetary rideshare missions

- Challenges
  - **Packaging**: aggressive packaging densities may be required to maintain aerodynamic stability in the absence of a separate cruise stage
  - **Planetary Protection**: aerocapture periapsis between 40 and 60 km altitude
  - **Communication**: current relay orbiters are not configured to interact with spacecraft