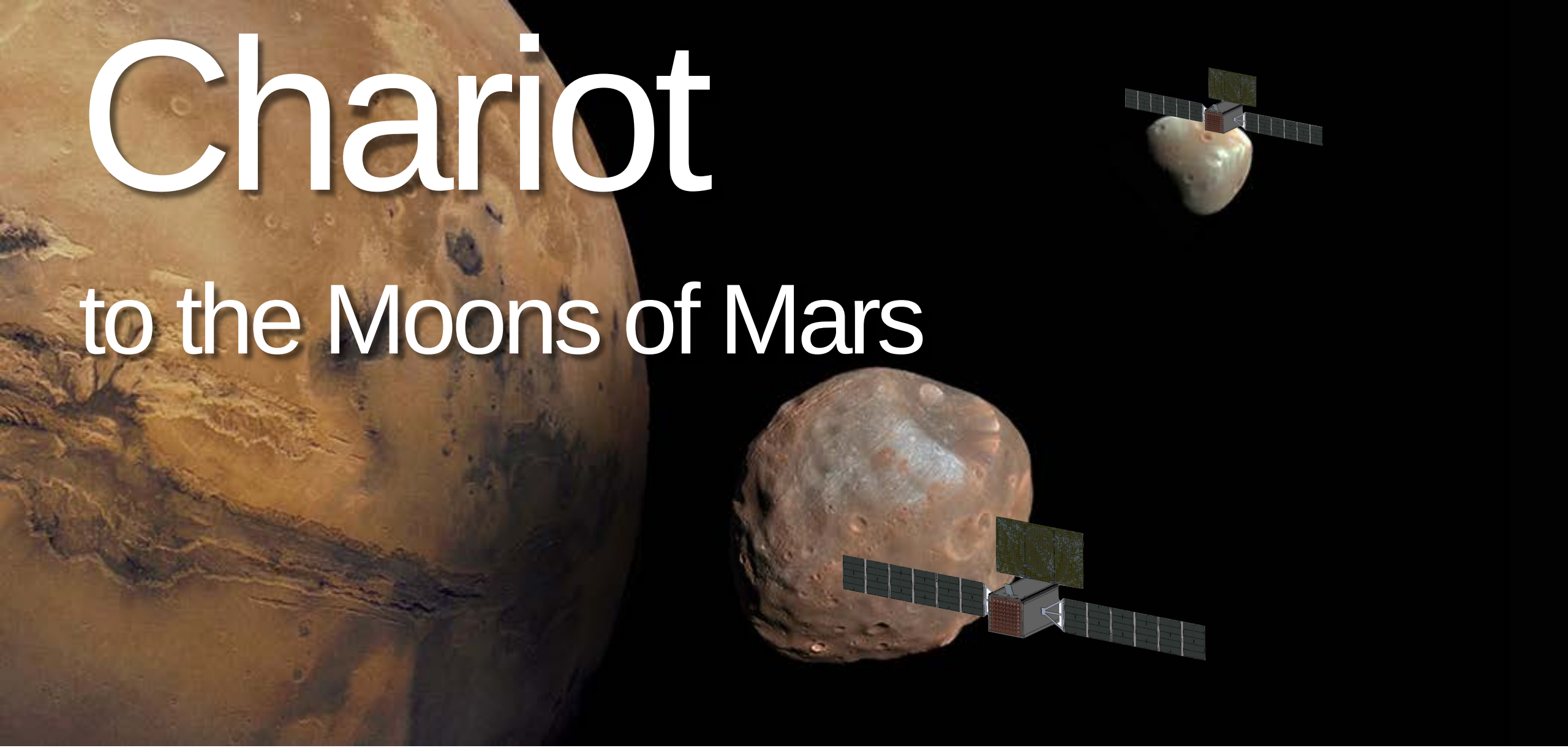
Chariot

to the Moons of Mars



A NASA Planetary Sciences Deep Space SmallSat Studies Mission Concept

The Chariot Team

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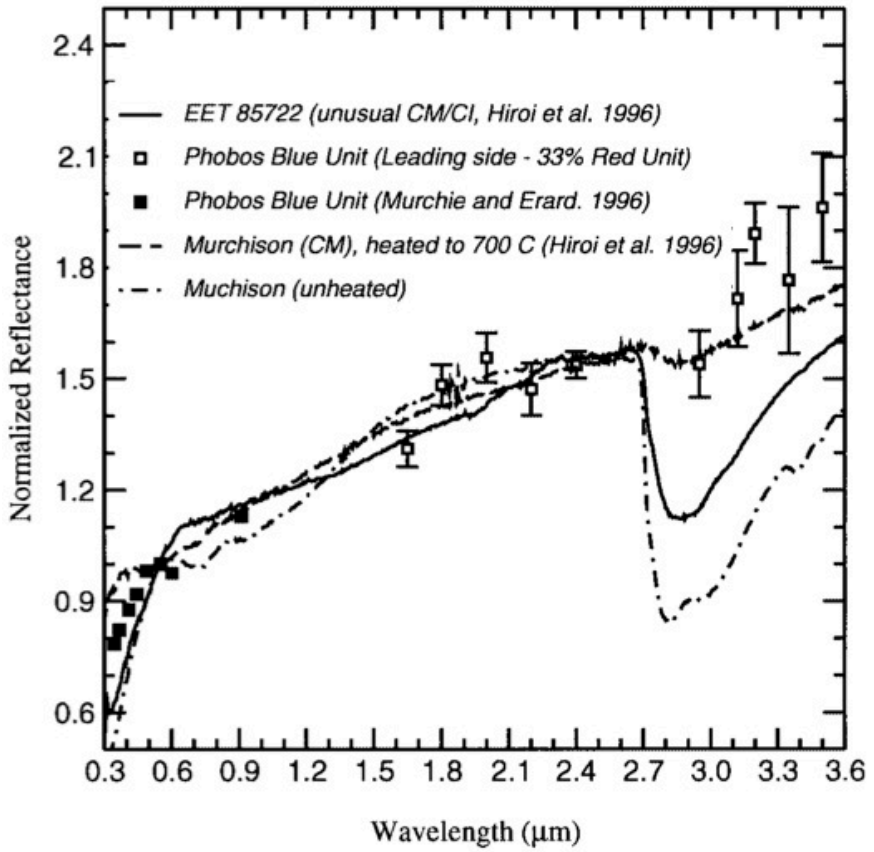
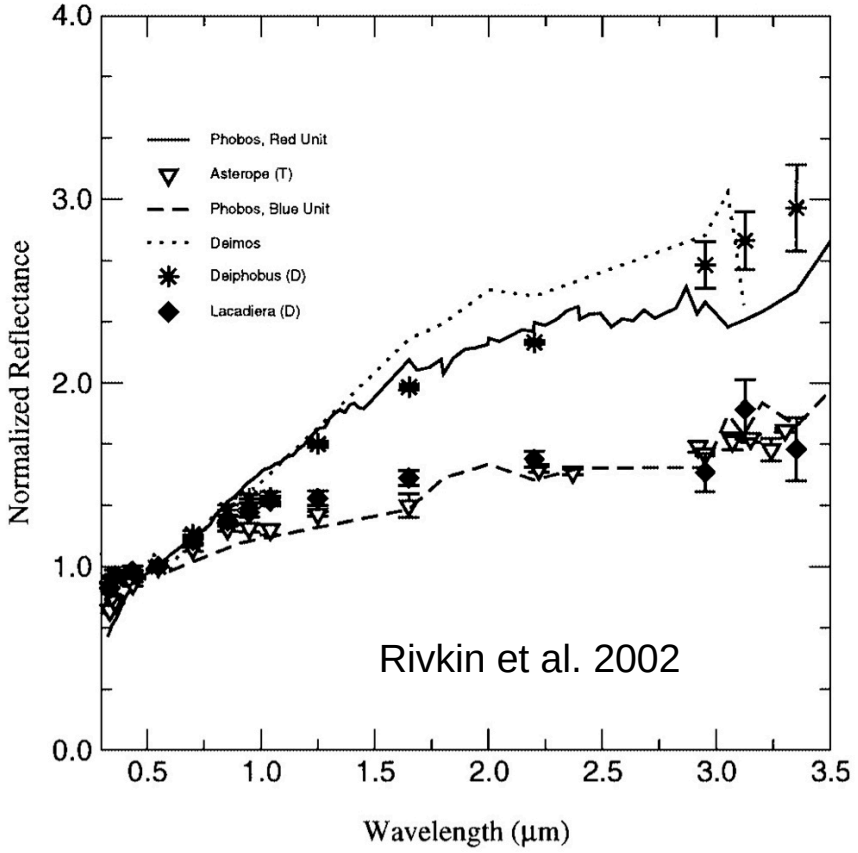
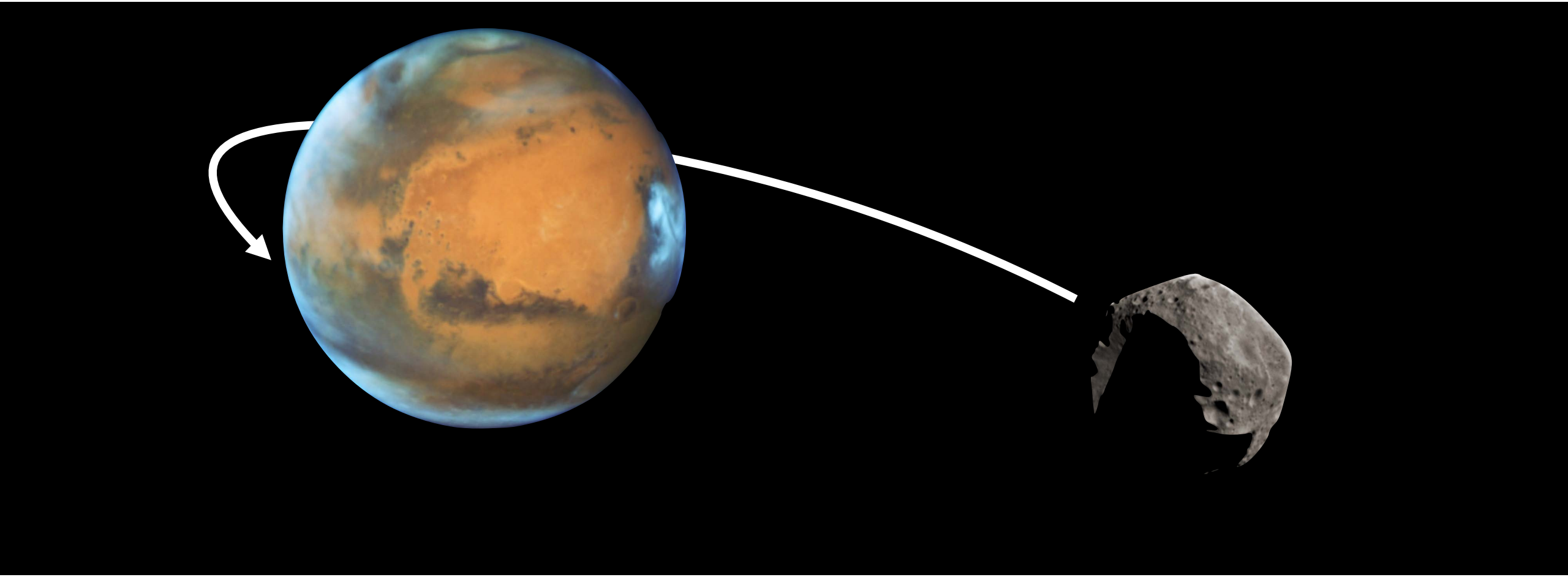
The origin of Phobos and Deimos remain highly uncertain

VIS/IR spectra of Phobos and Deimos are similar to carbonaceous meteorites and their asteroid analogues



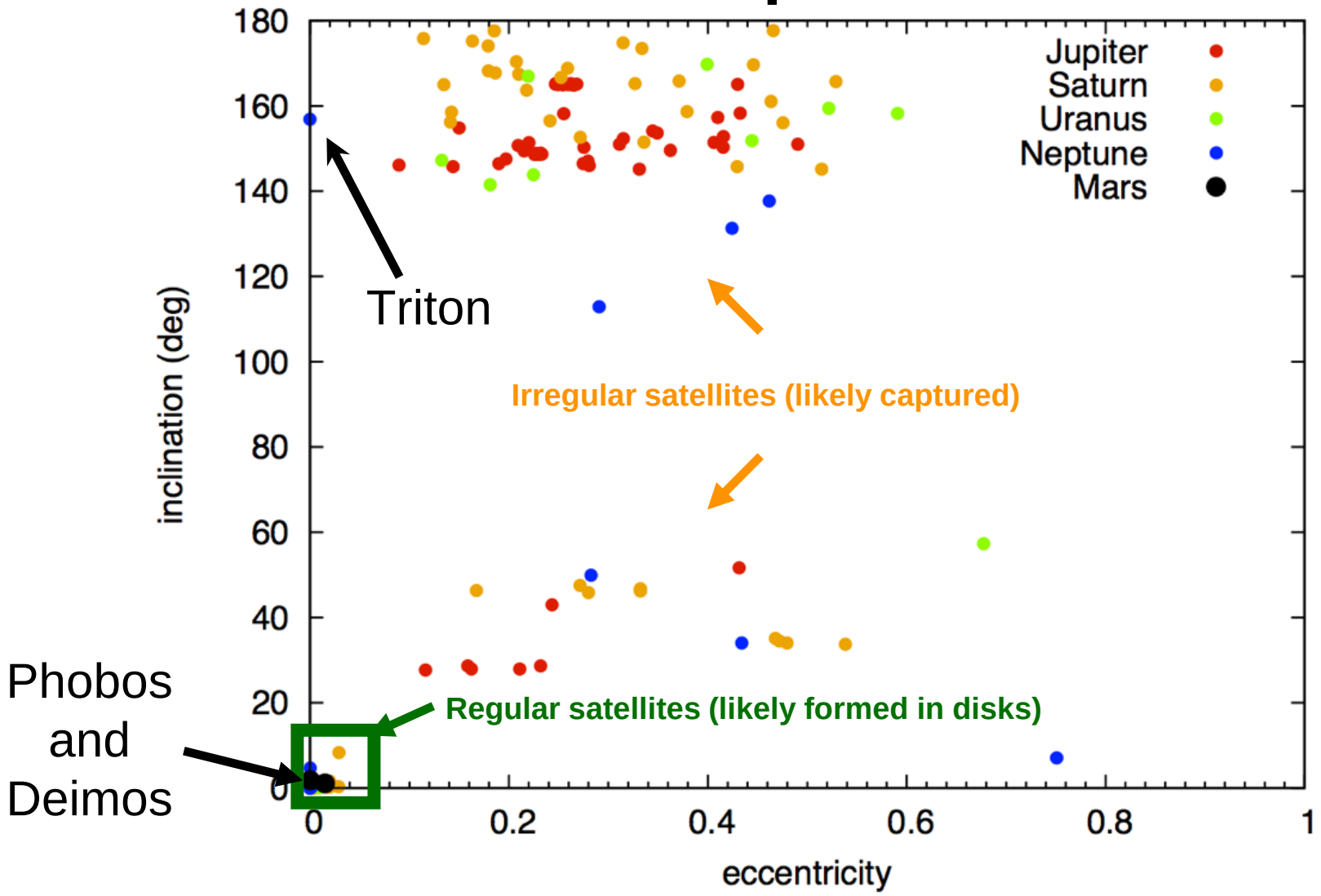


The spectral similarity between Phobos and Deimos and carbonaceous asteroids is the basis of the Intact Capture Hypothesis for their origin

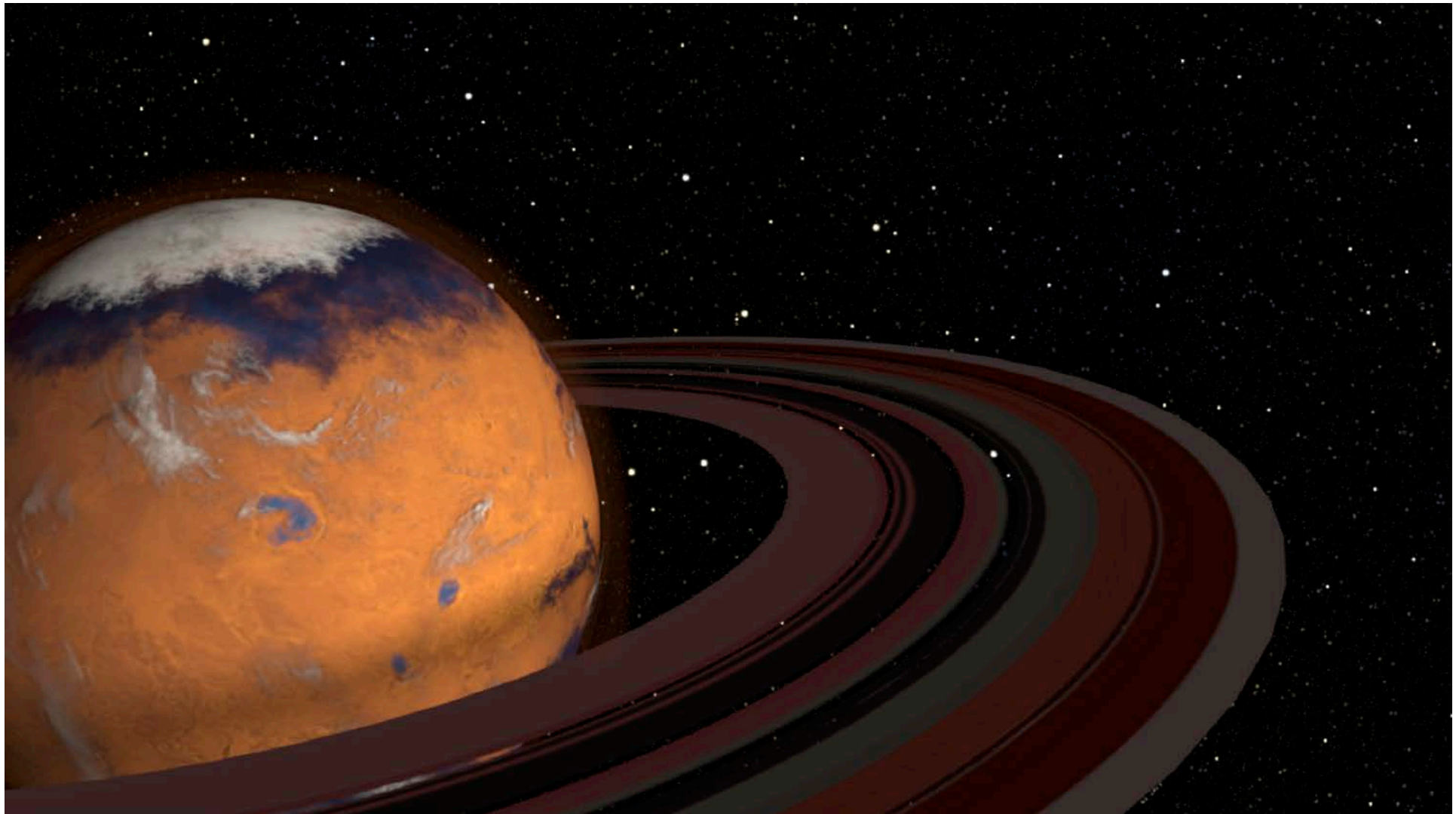


Under the intact capture hypothesis, the two satellites likely have analogues in the asteroid belt, and possibly also analogues in the meteorite collection

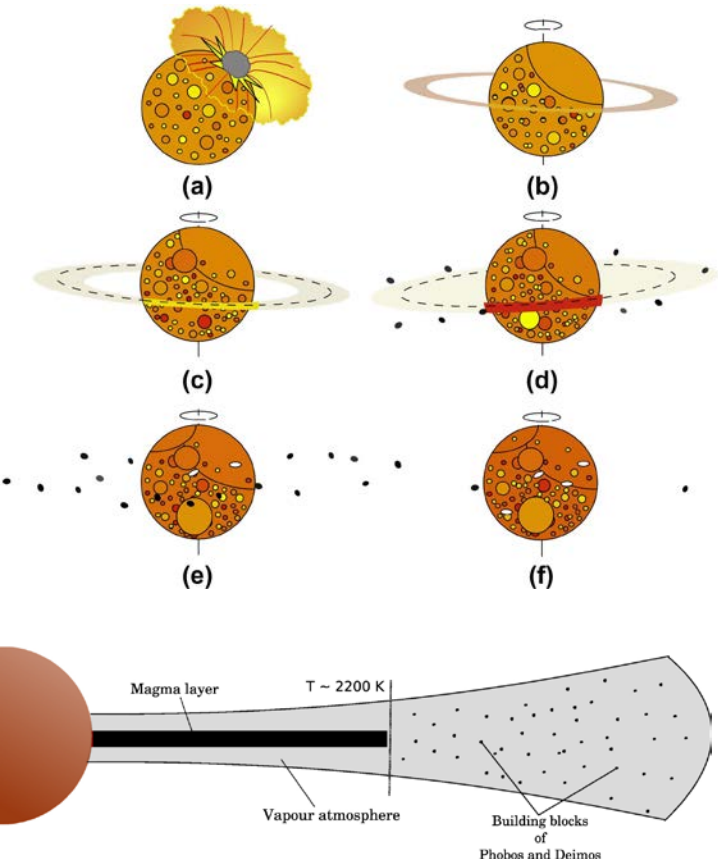
The orbits of Phobos and Deimos do not resemble captured satellites



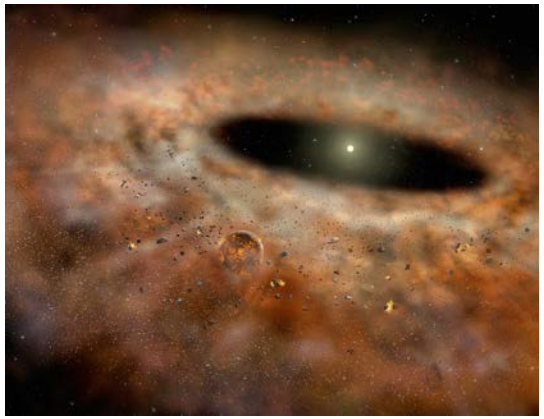
The “regular” orbits of Phobos and Deimos suggest they formed from a protosatellite disk in orbit of Mars



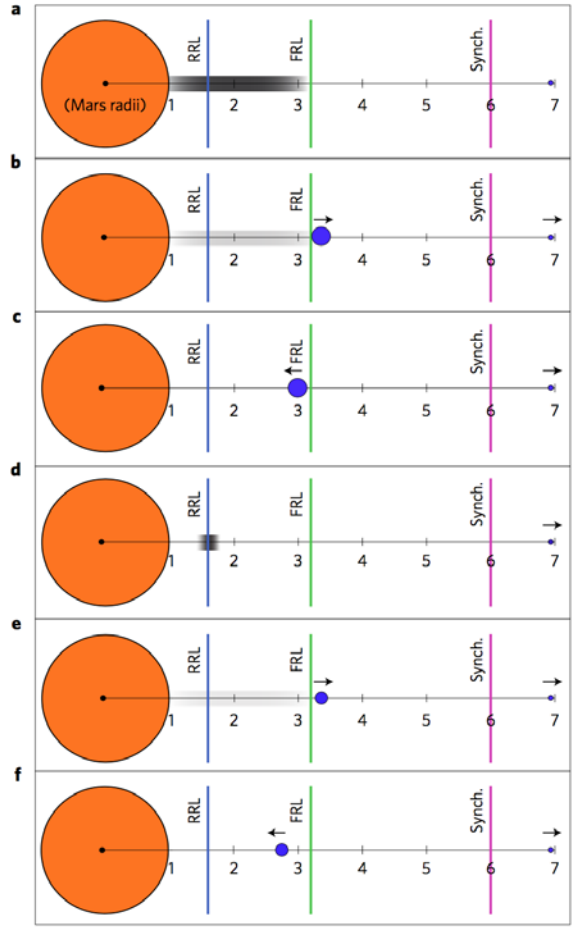
There are many different protosatellite disk origin models in the literature



Formation from giant impact ejecta (Canup and Salmon, 2016, 2018; Citron et al., 2015; Craddock, 2011; Rosenblatt et al., 2016; Ronnet et al., 2016)



In-situ formation alongside Mars (Ronnet et al., 2016)



Giant impact formation with a cyclic breakup and re-formation of Phobos (Hesselbrock and Minton, 2017).

Each origin model implies something different about the bulk composition of Phobos and Deimos

Body		Capture	In-Situ	Impact	Ring Cycle
Phobos	Surface	Well-weathered, red-sloped	Well-weathered, some hydration possible	Well-weathered, some hydration possible	Well-weathered, dry
	Interior	Volatiles and organics, less weathered, D-type	Less-weathered, bulk Mars, olivine, pyroxene, iron-nickel, water-poor chondritic or achondrites	Less-weathered, Martian crust/mantle, basalt, free of volatiles, feldspar	Well-weathered, dry
Deimos	Surface	Well-weathered, red-sloped	Well-weathered, some hydration possible	Well-weathered, some hydration possible	Well-weathered
	Interior	Volatiles and organics, less weathered, D-type	Less-weathered, bulk Mars, olivine, pyroxene, iron-nickel	Less-weathered, Martian crust/mantle, basalt, free of volatiles, feldspar	Un-weathered

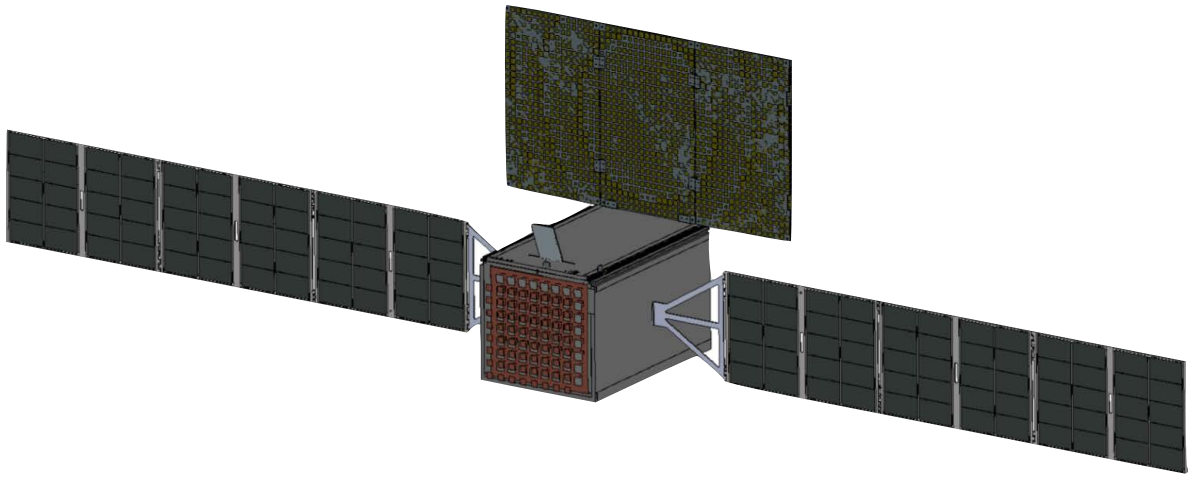
See also Pignatale et al. (2018). ApJ, *853*(2), 118.

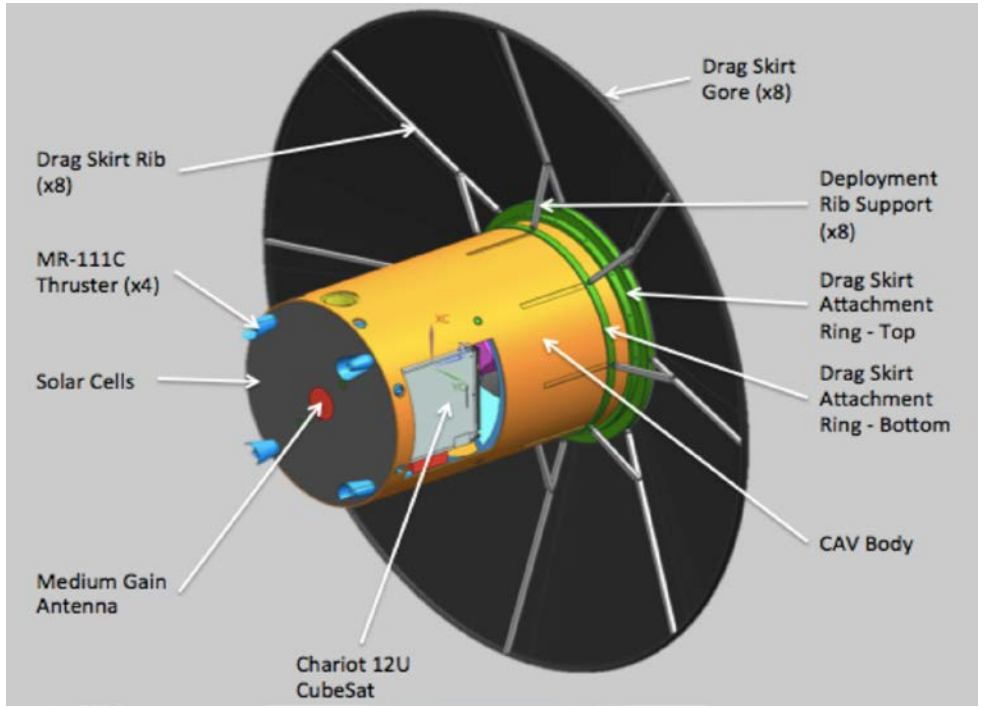
Testing these hypothesized origins will require a dedicated multispectral survey of both Phobos and Deimos.

Is a remote sensing SmallSat/CubeSat mission in Mars orbit feasible?

Yes!

Chariot to the Moons of Mars

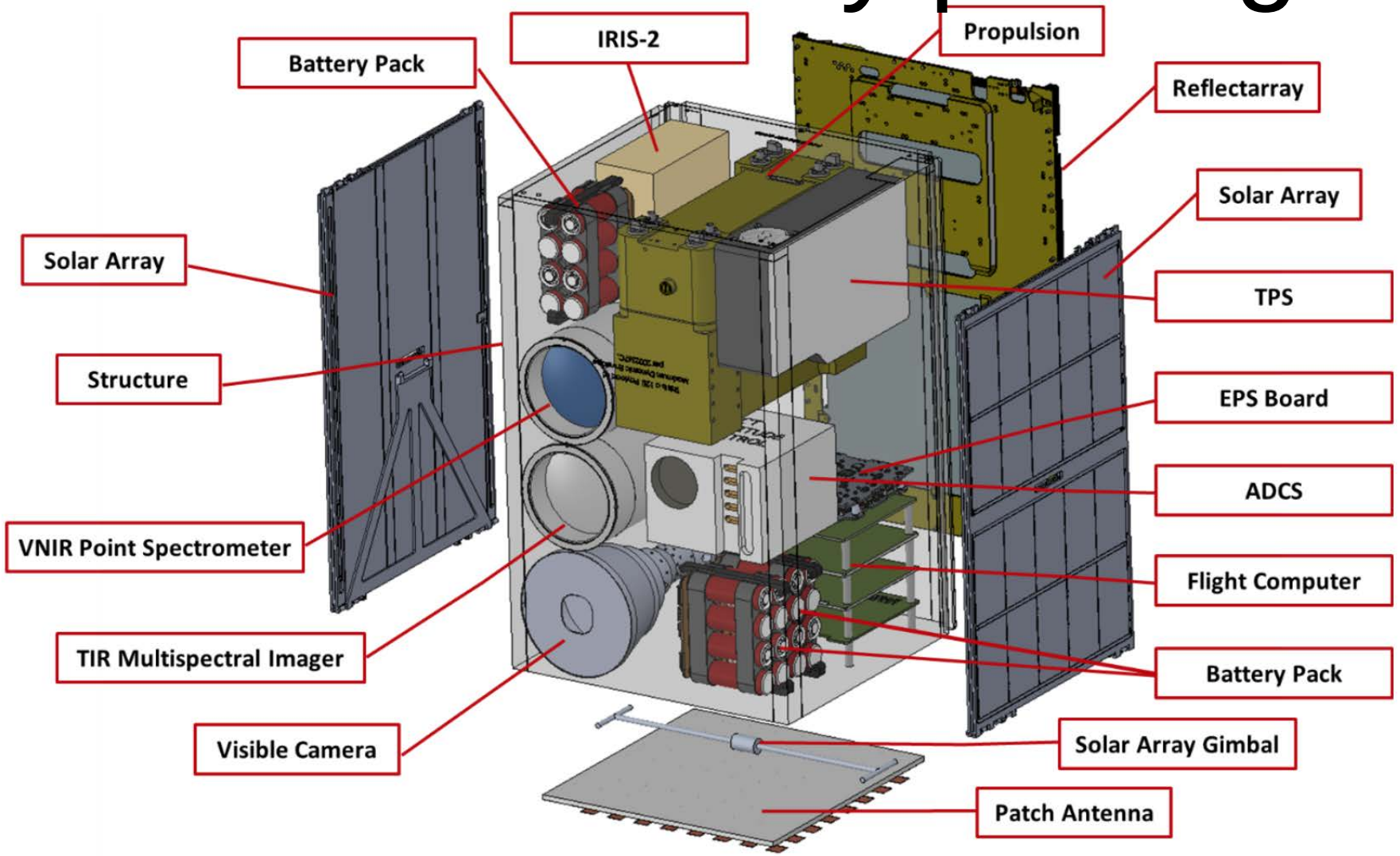




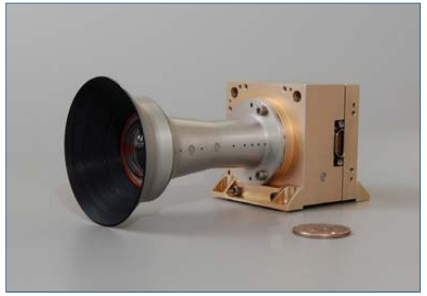
3-axis stabilized 12U CubeSat
3 remote sensing instruments
Cold gas propulsion for maneuvering.
Direct-to-Earth communication downlink

Cruise-Aerocapture Vehicle (CAV)
Free-flyer cruise from Earth to Mars
Autonomous 12U CubeSat delivery to Mars orbit via aerocapture

Chariot is a big remote sensing mission in a tiny package



Chariot will produce visible and thermal imagery as well as VNIR and TIR spectra using a COTS payload



Color Camera
(Malin ECAM C-50)

- Global color mosaic - 9 m/pix
- Targeted imagery - <1 m/pix
- Morphology and geology
- Heritage: OSIRIS-Rex/ TAGCAMS

TIR Multispectral Imager
(Modified FLIR Tau 2)

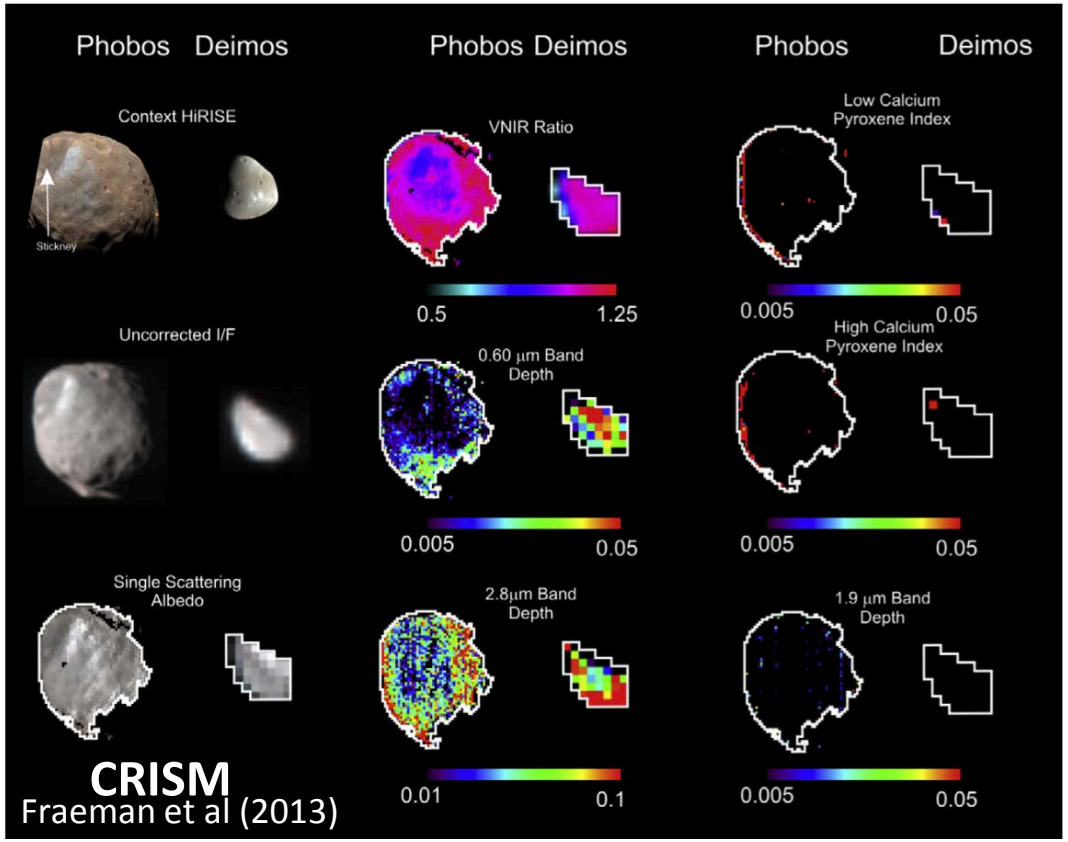
- Global 8-band day & 1-band night mosaics - 20 m/pixel
- Targeted imagery - 2 m/pixel
- Regolith thermophysics, variability in bulk composition
- Heritage: ODY/THEMIS

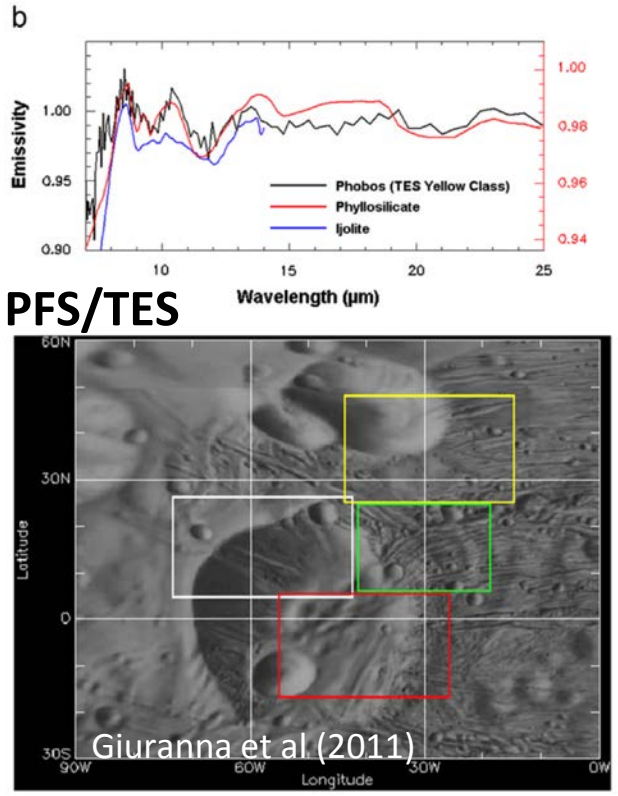
VNIR Point Spectrometer
(Ocean Optics QEPro)

- Global moasic - 5 km/pixel
- Targeted spectra - 200 m/pixel
- Mafic and hydrated minerals, space weathering
- Heritage: MSL/ChemCam, LCROSS/Alice

**All resolutions for Phobos*

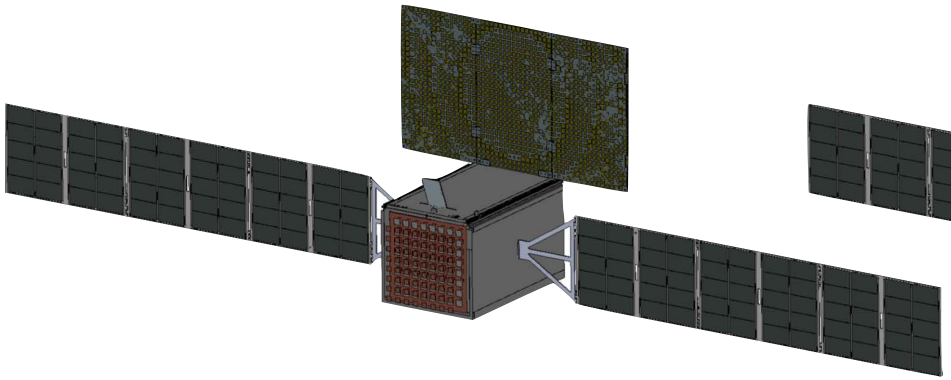
Chariot will expand on existing VNIR/TIR spectral data that indicates significant spectral variability on both moons



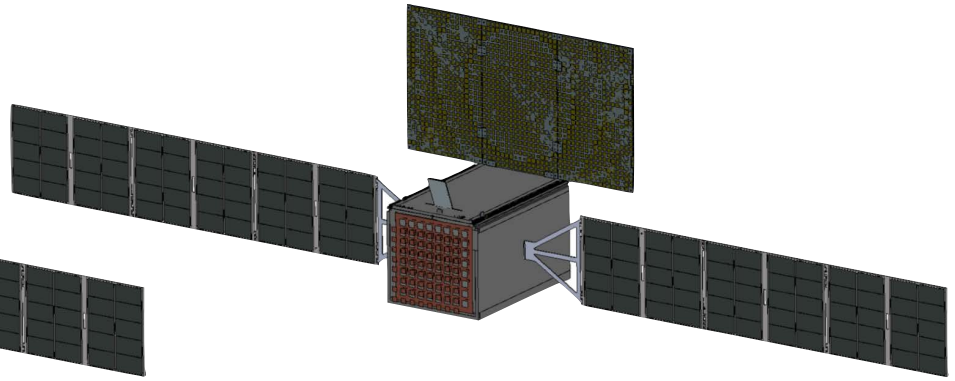


The specific mineralogy leading to this diversity and the origin of the differences in mineralogy is poorly understood.

Chariot will address major science questions that require observations of *both* Phobos and Deimos



Chariot to Phobos



Chariot to Deimos

The Chariot Mission has three high-level science goals

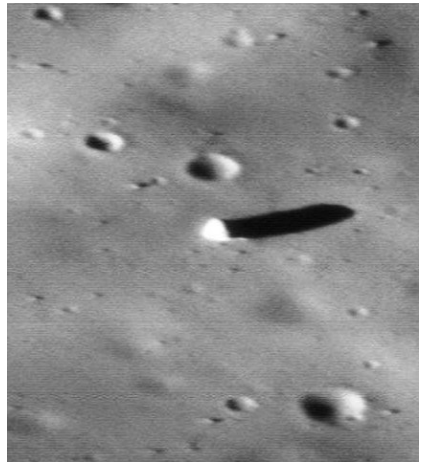
1. **Constrain the origin of Phobos and Deimos**
2. **Evaluate the feasibility of ISRU on Phobos and Deimos**
3. **Evaluate processes contributing to the ongoing evolution of the Phobos-Deimos system**

Specific observations of both Phobos and Deimos from Chariot are designed to address our major objectives

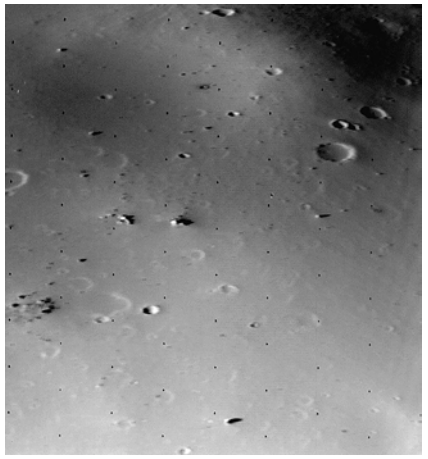
Spectral variability

Space weathering

Boulders



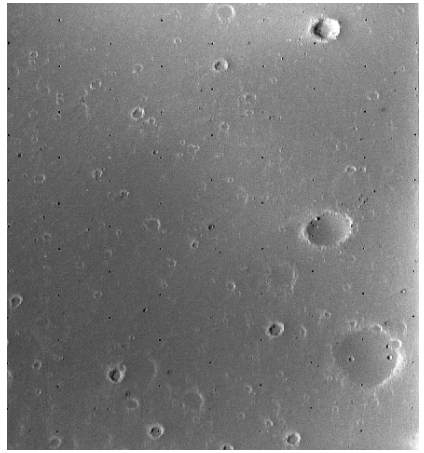
Regolith properties



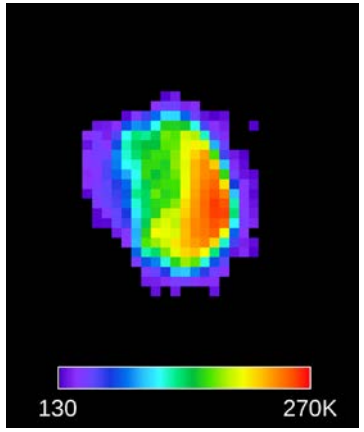
Mass wasting

Tectonics

Craters

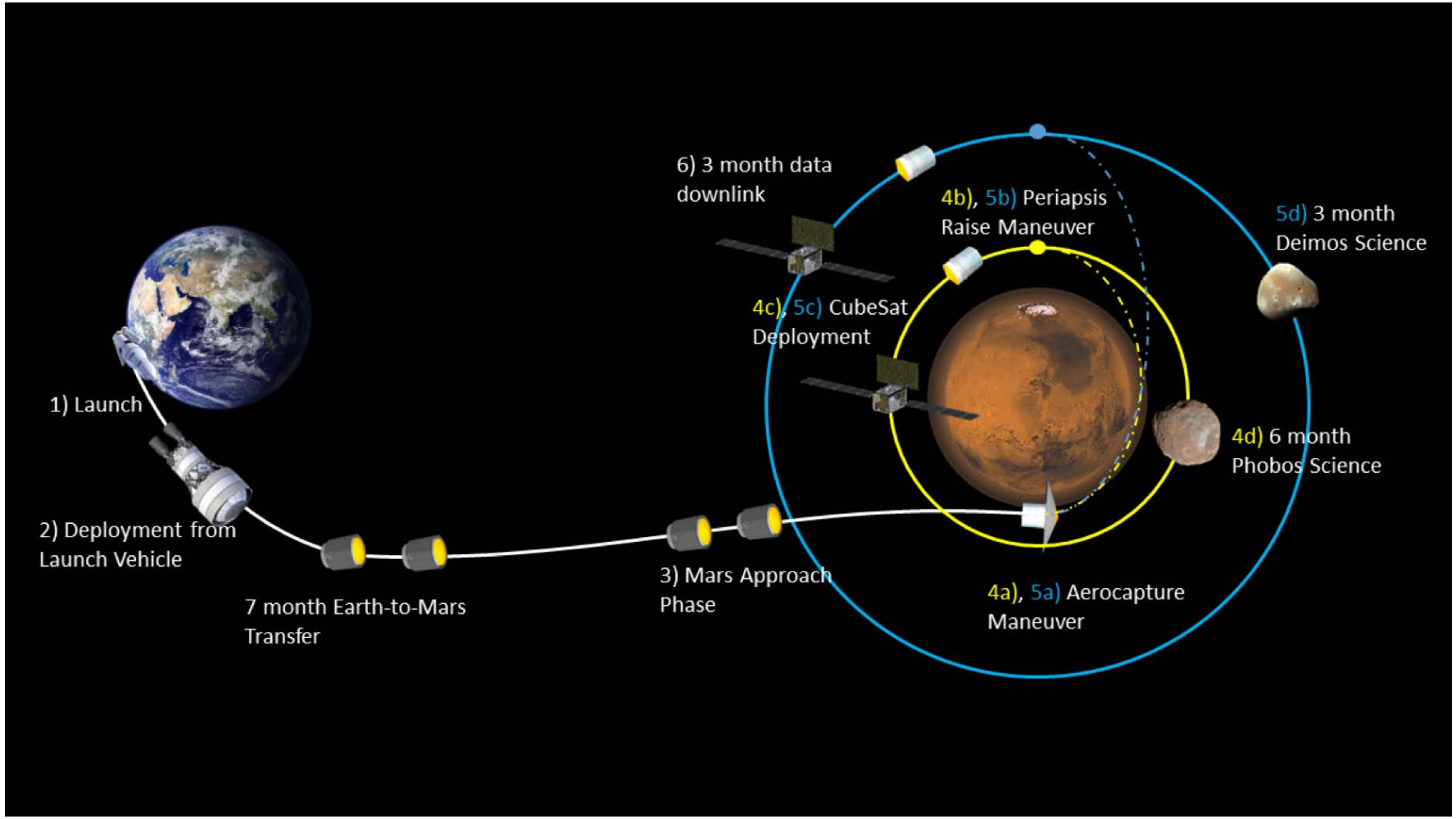


Thermal environment

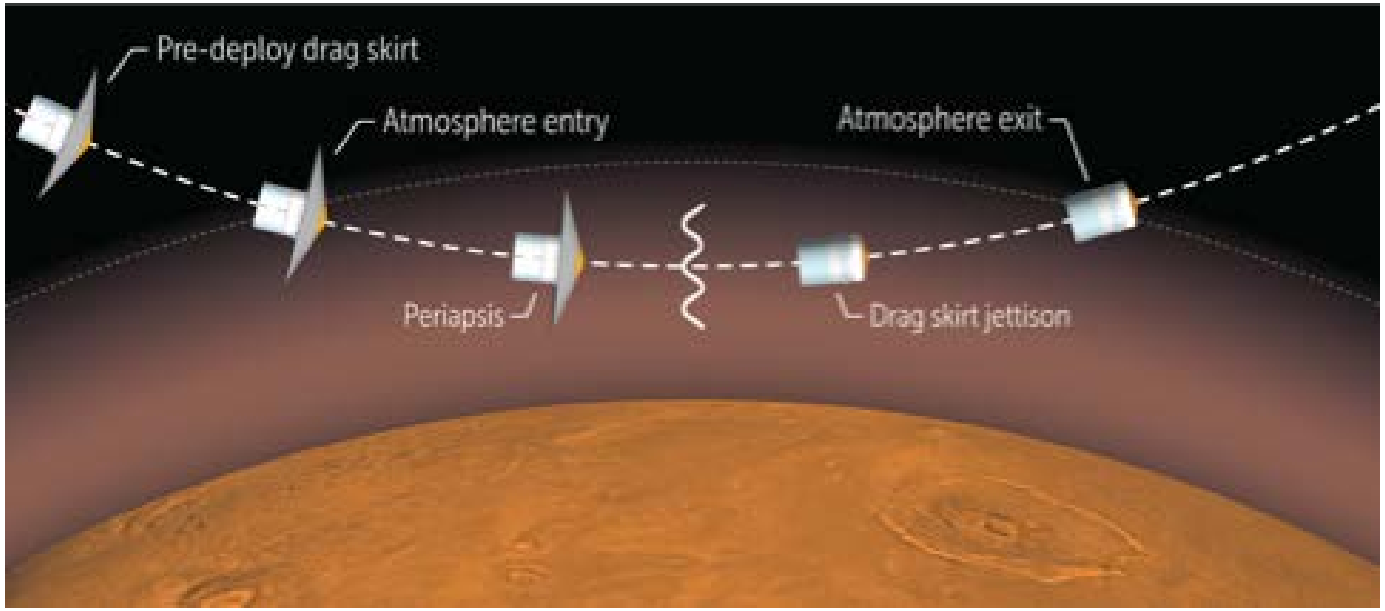


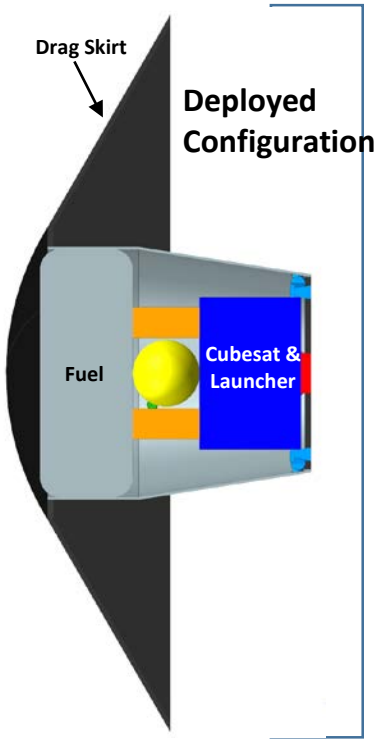
Chariot to the Moons of Mars

The baseline Chariot mission architecture involves two identical spacecraft, one each to Phobos and Deimos



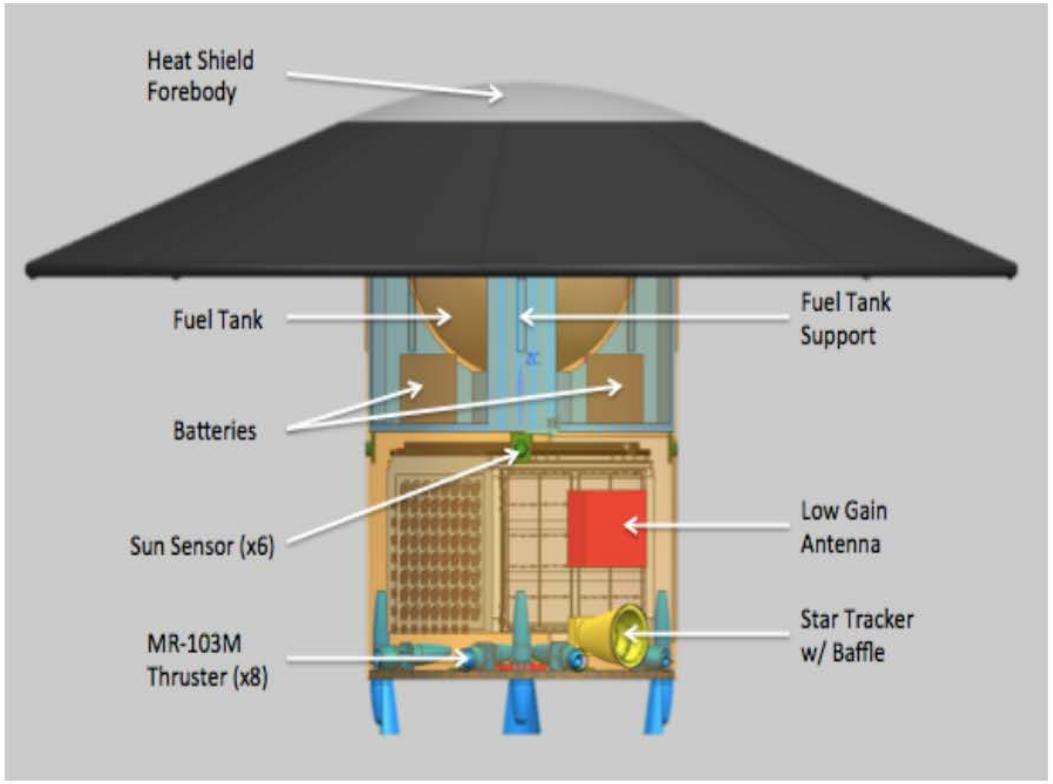
Chariot would represent the first demonstration of aerocapture, a critical technology in NASA's human exploration roadmap.

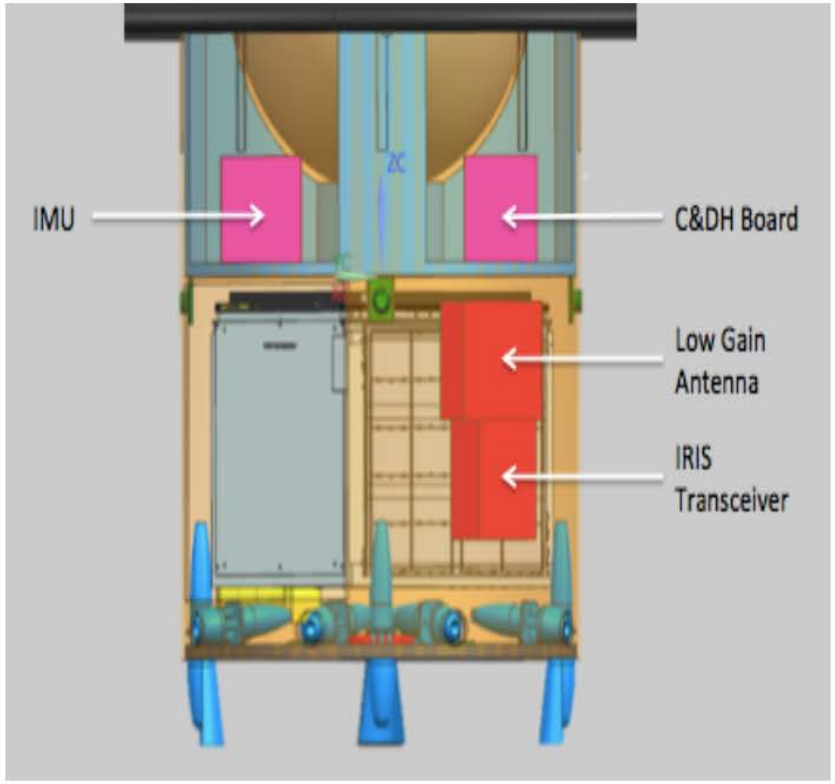




Unlike aerobraking, which occurs over a prolonged period, aerocapture uses a single atmospheric pass to circularize the orbit

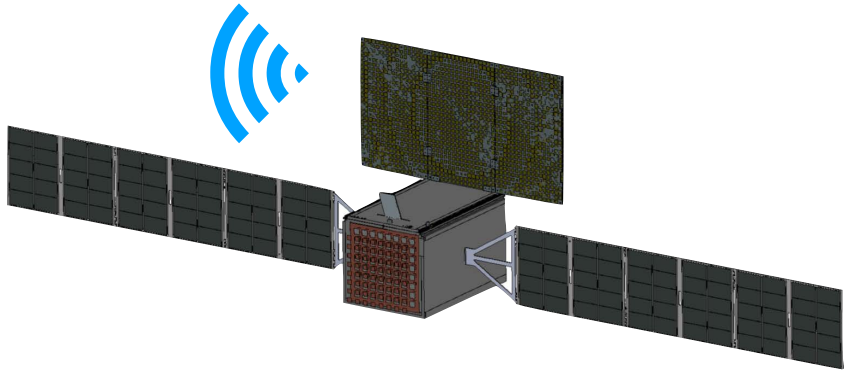
The Cruise-Aerocapture Vehicle would enable future exploration of Mars with Cubesats





Despite the challenges of a CubeSat platform (power, thermal, telecomm) we *can* meet all our high level objectives!

~2 kbps



If we could use Mars orbiting data relays it would be better, but they were designed to communicate “down” to rovers/landers, not “up” to spacecraft at Phobos and Deimos.

Chariot to the Moons of Mars would be a groundbreaking mission for both Mars science and cubesat technology

- Chariot would provide critical new constraints on the origin and evolution of Phobos and Deimos through a dedicated remote sensing mission to both moons utilizing a novel aerocapture approach

- Our PSDS3 study has shown that:
  1)An imaging-based CubeSat mission with high science return is possible at Mars with existing technology and telecom support
  2)A CubeSat mission to the moons of Mars could address many high-priority NASA/MEPAG/SBAG goals for science and human exploration
  3)CubeSats are not adequately supported by the existing Mars and DSN telecom architecture

Chariot would be managed and operated out of Purdue!

Interplanetary SmallSats are a new platform to bring greater University engagement in planetary science and engineering