Small Spacecraft Programs

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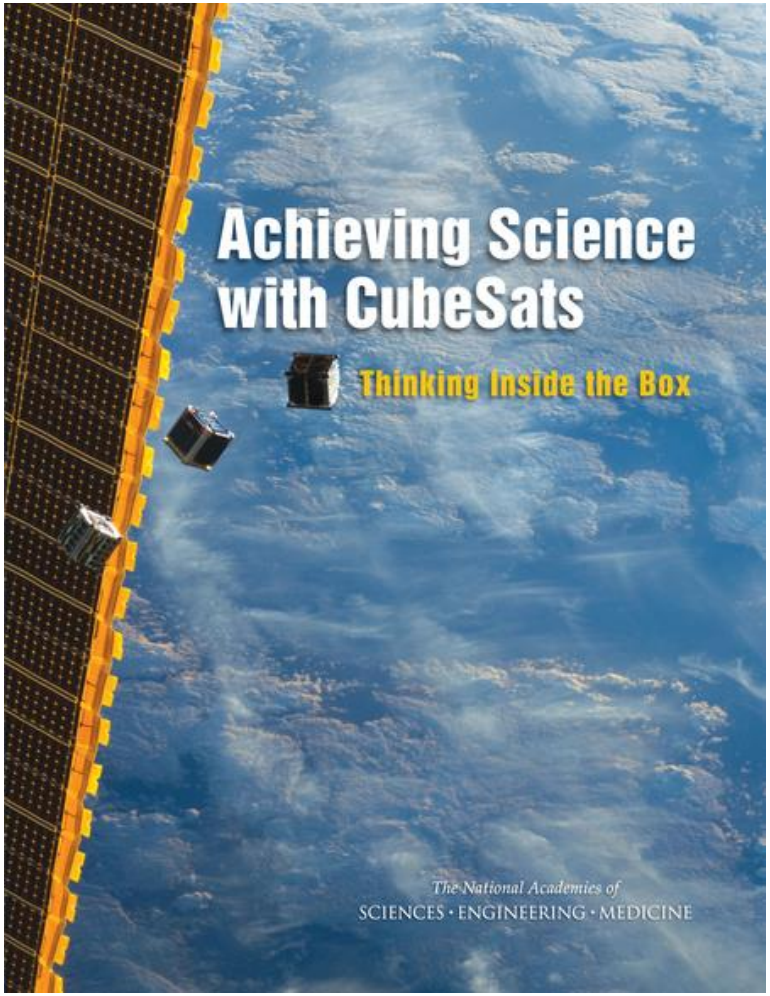
SMD CubeSat/SmallSat Approach

National Academies Report (2016) concluded that CubeSats have proven their ability to produce high-value science:

- Useful as targeted investigations to augment the capabilities of larger missions
- Useful to make highly-specific measurements
- Constellations of 10-100 CubeSat/SmallSat spacecraft have the potential to enable transformational science

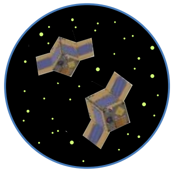
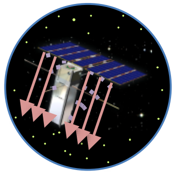
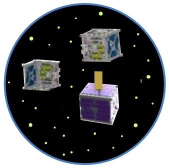
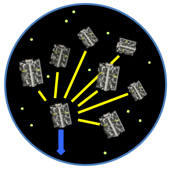


SMD is developing a directorate-wide approach to:

- Identify high-priority science objectives in each discipline that can be addressed with CubeSats/SmallSats
- Manage program with appropriate cost and risk
- Establish a multi-discipline approach and collaboration that helps science teams learn from experiences and grow capability, while avoiding unnecessary duplication
- Leverage and partner with a growing commercial sector to collaboratively drive instrument and sensor innovation

Planetary Science Deep Space SmallSat Studies (PSDS3)

- NASA Research Announcement released August 19, 2016
- Solicited concept studies for potential CubeSats and SmallSats
  - Concepts sought for 1U to ESPA-class missions
  - Up to $100M mission concept studies considered
  - Not constrained to fly with an existing mission
- Objectives:
  - What Planetary Science investigations can be done with SmallSats?
  - What technology development is needed to enable them?
  - What's the anticipated cost range?
- Received 102 proposals
- Funded 19 Studies

Planetary Science
Deep Space SmallSat Studies: Awards

Mars

Robert Lillis, Mars Ion and Sputtering Escape Network (MISEN)
Anthony Colaprete, Aeolus - to study the thermal and wind environment of Mars
Luca Montabone, Mars Aerosol Tracker (MAT)
Michael Collier, PRISM: Phobos Regolith Ion Sample Mission
David Minton, Chariot to the Moons of Mars

Venus

Valeria Cottini, CUVE - Cubesat UV Experiment
Christophe Sotin, Cupid's Arrow
Attila Komjathy, Seismicity Investigation on Venus Using Airglow Measurements
Tibor Kremic, Seismic and Atmospheric Exploration of Venus (SAEVe)

Icy Bodies and Outer Planets

Robert Ebert, JUpiter MagnetosPheric boundary ExploreR (JUMPER)
Kunio Sayanagi, SNAP: Small Next-generation Atmospheric Probe

Small Bodies

Benton Clark, CAESAR: CubeSat Asteroid Encounters for Science and Reconnaissance
Jeffrey Plescia, APEX: Asteroid Probe Experiment
Tilak Hewagama, Primitive Object Volatile Explorer (PrOVE)

Moon

Suzanne Romaine, CubeSat X-ray Telescope (CubeX)
Charles Hibbitts, Lunar Water Assessment, Transportation, and Resource Mission (WATER)
Noah Petro, Mini Lunar Volatiles (MiLUV) Mission
Timothy Stubbs, Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS)
David Draper, Innovative Strategies for Lunar Surface Exploration

Small Innovative Missions For Planetary Exploration (SIMPLEx)

- **Solicit formulation and development of planetary science investigations that require a spaceflight mission that can be accomplished using small spacecraft**
  - ESPA-Class or smaller (< 180Kg)
  - Solicitation for secondary payload on specific primary missions, which will determine:
    - Launch readiness date
    - Initial release trajectory
  - Cost-capped missions: $15M to $55M
  - Continuously Open call with mission-specific deadlines

https://soma.larc.nasa.gov/simplex

SIMPLEx Process (Section 3)

Soon: Release Open Call for proposals
(public comment period on draft closed March 14)

On-going: Regular Panel Reviews of submitted proposals

Mission Specific Milestones:

- L-4 years: Cut-off consideration for a specific mission
  - Select and award ~1 year Phase A/B studies; expected product is PDR-level design
  - Launch Vehicle is unknown

- L-3 years: Down-select secondary mission(s) for specific primary mission
  - May be possible to select multiple secondaries for a given primary mission
  - Selectability coordination with LV selection
  - Provided for Phase C design/build:
    - More detailed Launch Vehicle trajectory, environments and interfaces

- L-2 years: Build/test secondary payload

- L-1 years: Build/test/integrate secondary payload

SIMPLEx Launch Opportunities

Table A-1 https://soma.larc.nasa.gov/simplex

Primary Mission	SIMPLEx Proposal Cut-off Date	Payload Integration /Launch Readiness Dates	Launch Site	Primary Payload Destination	Launch Orbit	Allowed Elements					Po-tential Launch Vehicle
						CubeSat Deployer	ESPA Ring	ESPA Grande	Propulsive ESPA ring	Radioactive elements	
LEO or GTO	On-going	On-going	Various	N/A	LEO or GTO	Y	Y	Y	Y	N	
Lucy	1 July 2018	August 2021 / 16 October 2021	Cape Canaveral Air Force Station	Jupiter L4 and L5 Trojan Swarms	Helio-centric Escape	Y	Y	N	N	N	Atlas V, Falcon 9, Antares, …
Psyche	1 July 2018	June 2022 / August 2022	Cape Canaveral Air Force Station	(16) Psyche, with Mars gravity assist	Elliptic Helio-centric	Y	Y	N	N	N	Atlas V, Falcon 9, Antares, …
IMAP*	TBA	TBD	TBD	TBD	TBD	N	Y	N	N	N	TBD
EM-x	TBA	TBD	Kennedy Space Center	Lunar Orbit	TBD	Y	N	N	N	N	SLS

SIMPLEx Technology

It is expected that new technologies may be required to accomplish planetary science missions proposed under this PEA. Proposals must justify how the proposed technology will contribute to mission success.

For technologies and subsystems that **do not have flight heritage**, the proposal must include a reference to the details and the results of testing and/or analysis that demonstrate performance in a **relevant environment under conditions that simulate all known significant failure modes** of the technology to demonstrate technical maturity of TRL 6. If a combination of this testing and analysis is proposed to be accomplished in Phase A/B, then a reference must be included describing what testing/analysis is planned or has been completed at the time of proposal submission to demonstrate a plan for maturing these systems to TRL 6 by PDR. A summary of the test/analysis should be included in the body of the proposal. Proposals must include a limited life item list and for those items show plans for how they can **meet 1.5 times the worst-case expected operating life of the proposed mission.**

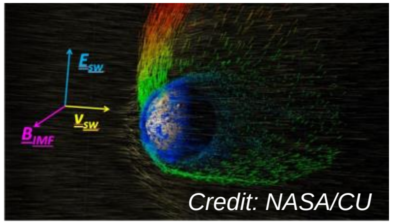
For technologies and subsystems that **do have flight heritage**, claims of heritage must be supported by a description of the **similarities in design and flight environments between the heritage and the proposed mission.**

Section 4.6.1 https://soma.larc.nasa.gov/simplex

MISEN Mars Ion and Sputtering Escape Network

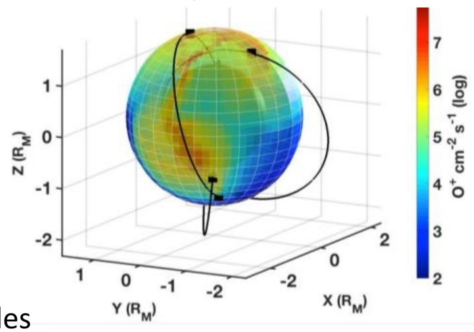
Planetary Science Deep Space SmallSat Studies

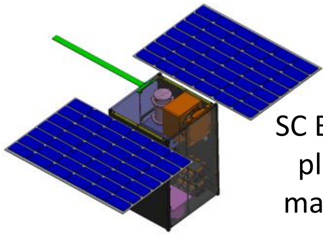
Ion dynamics drives escape and hence climate evolution



Credit: NASA/CU

ion escape flux @ 3000 km





SC Bus enables plasma and magnetic field measurements

3-5 spacecraft. Orbits chosen to maximize coverage

Team Members/Institutions:

UC Berkeley SSL
Principal Investigator: Rob Lillis
Systems Engineer: Dave Curtis
Ion Analyzer Lead: D. Larson
Ion Dynamics: S. Curry, J. Luhmann, D. Brain (collaborator, U. Colorado)

UCLA ESS
Magnetometer lead: Christopher Russell

Tyvak LLC
Lead spacecraft engineer: Jordi Suig-Puari

Advanced Space LLC
Lead mission designer: Jeffrey Parker

Science Objectives:

Use multi-point simultaneous measurements to characterize the magnitude, global patterns, variability, and real-time response to space weather, of:

i) ion escape at Mars

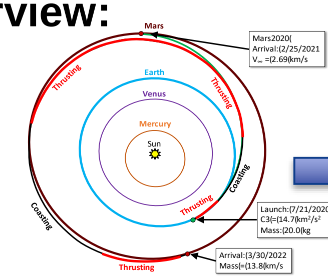
ii) ion precipitation-driven sputtering escape at Mars

As multi-point measurements have revolutionized our understanding of the Earth's magnetosphere, MISEN will build on MAVEN's legacy for a fraction of the cost and, for the first time, reveal the dynamic global picture of ion escape and precipitation at Mars.

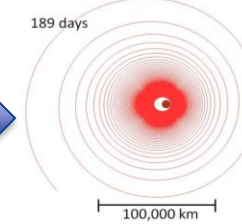
Constellation in situ observations: a revolution in understanding of planetary ion dynamics

Mission Overview:

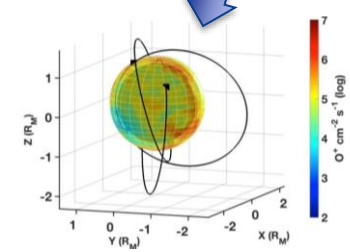
Cruise to Mars via piggyback (6-10 months) or solar electric propulsion (2+ years).



6-month spiral down to final orbits

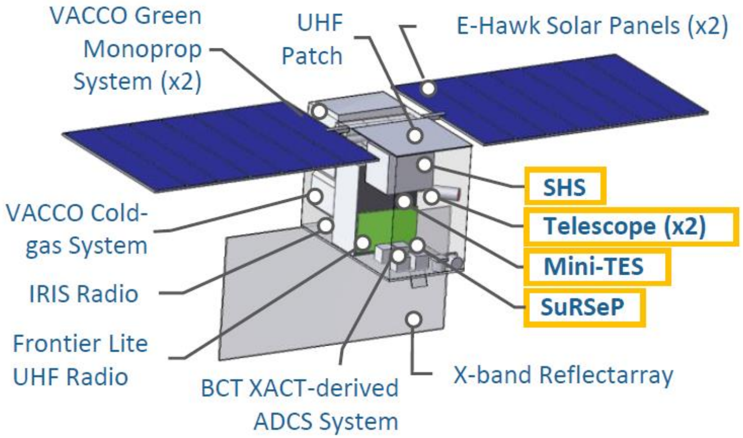


- 2-year primary science mission.
- Navigation: final orbits should precess, no station-keeping.
- Simple ops: spinning spacecraft, constant data collection.
- Telemetry: relay and direct-to-earth options available



The Aeolus Spacecraft

28kkg / 24U / 117W-OAP Spacecraft



Team Members/Institutions:

- PI: Anthony Colaprete (ARC)
- Deputy-PI: Amanda M. Cook (ARC)
- Co-I: Melinda Kahre (ARC)
- Co-I: Robert Haberle (ARC)
- Co-I: Phillip Christensen (ASU)
- Co-I: Greg Mehall (ASU)
- Co-I: David Landis (Draper)
- Mission Design Center Engineering Team (ARC)

Aeolus will make the first direct observations of day and nighttime winds at all local times

Aeolus Science Objectives:

1. Produce a vertically resolved global wind speed map
2. Determine the global energy balance of Mars
3. Correlate wind speeds and surface temperatures with CO2 and H2O clouds and dust column densities

Mission Overview:

- Aeolus's inclined orbit allows observations between ±75° and at all local times
- Spatial Heterodyne Spectrometers (SHS) and Mini-TES scan the atmosphere limb providing wind vectors, temperatures and aerosol/cloud densities
- SurSeP (Surface Radiometric Sensing Package) looks nadir measuring the total upwelling solar and thermal radiance as well as the surface temperature and column aerosol/cloud density

6U Payload

MAT

Mars Aerosol Tracker: An areostationary SmallSat to monitor Martian dust and water ice dynamics.

Planetary Science Deep Space SmallSat Studies

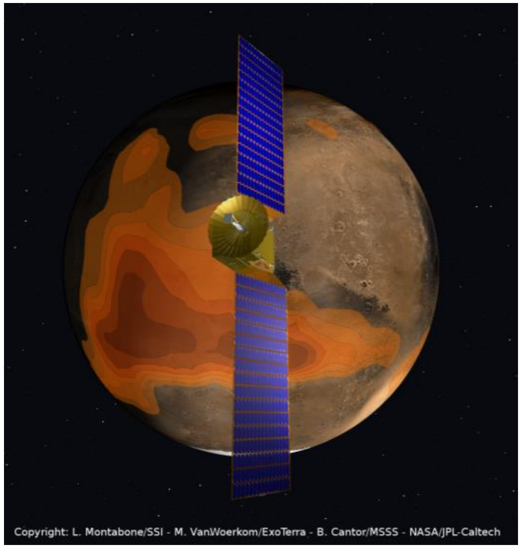


Figure: The MAT SmallSat overviews a regional dust storm on Mars from areostationary orbit, obtaining visible images in daytime and column dust optical depth measurements in daytime as well as nighttime.

Team Members/Institutions:

Principal Investigator:

Luca Montabone (Space Science Institute, CO)

Co-Investigators:

Michael VanWoerkom (ExoTerra Resource LLC, CO)
Bruce A. Cantor (Malin Space Science Systems, CA)
Michael J. Wolff (Space Science Institute, CO)

Collaborators:

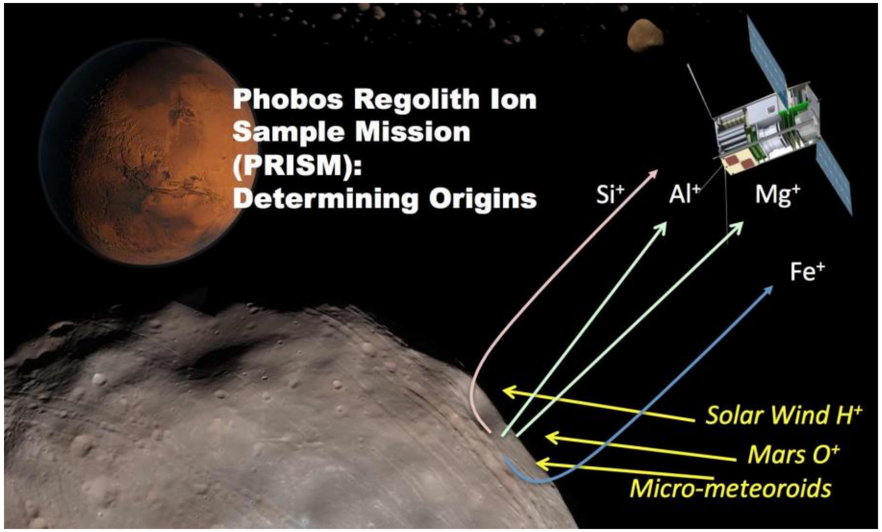
Michael D. Smith (NASA GSFC, MD)
François Forget (CNRS/LMD, France)
Michel Capderou (CNRS/LMD, France)

Science Objectives:

- Monitor a **large, fixed region** of the planet where dust storms and water ice clouds are likely to occur, **using visible and infrared wavelengths** with a **high sampling rate**;
- Observe the **temporal evolution of dust storms and water ice clouds** in the monitored area **throughout the diurnal cycle**;
- Detect **changes in surface physical properties** (e.g. thermal inertia and albedo) **throughout the diurnal cycle**, and particularly after the occurrence and decay of large dust storms.

Mission Overview:

- **Spacecraft**: ESPA-class orbiter; 45 kg; electric propulsion (micro Hall thrusters, Xe gas propellant).
- **Payload**: 1 visible and 2 thermal infrared cameras; filters for 6 IR spectral ranges, from 7.9 to 16 μm.
- **Journey to Mars**: Rideshare on a primary mission to Mars; deployment before Mars capture (baseline).
- **Orbit**: Areostationary (i.e. equatorial, circular, planet-synchronous orbit) at 17,031.5 km above the equator at one of the 2 stable longitudes (baseline).
- **Duration**: 1 Martian year (primary mission).



Team Members/Institutions:

- ***NASA/GSFC:*** *Michael R. Collier, William M. Farrell, David Folta, John Keller, Richard Vondrak, Timothy Stubbs, Rosemary Killen, Menelaos Sarantos*
- ***Morehead St. University, KY:*** *Ben Malphrus*
- ***JHU/APL:*** *Andy Rivkin, Scott Murchie, Dana Hurley*
- ***University of Iowa:*** *Jasper Halekas*
- ***Georgia Institute of Technology:*** *Micah Schaible*
- ***JPL:*** *Pamela Clark*

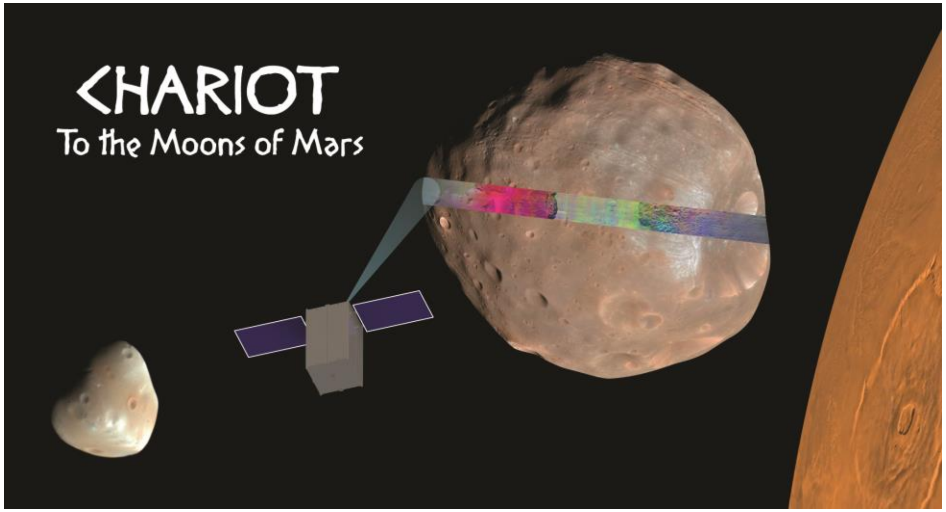
Science Objectives:

The PRISM CubeSat mission will determine the origin of Phobos: Did it form in the outer solar system or *in situ* near Mars, perhaps through a collision or by coalescence of a debris disk left over from the formation of Mars? PRISM will measure Phobos' surface composition using secondary ion mass spectrometry or SIMS and answer this critical question.

Mission Overview:

PRISM, a 12U CubeSat, will be ejected from the upper stage of the launch vehicle a few days after launch and, using a low thrust Solar Electric Propulsion system, will arrive at Mars in about two years and begin taking data during an approximately six-month spiral-in period. At the end of this spiral-in phase, PRISM will be in a Phobos co-orbit, making a pass and measurements near Deimos in the process. PRISM will probe the surface in a Phobos retrograde orbit at a distance as low as 27 km including the Mars facing and far sides of Phobos, both red and blue units, and craters on the leading edge.

Chariot to the Moons of Mars



Team Members/Institutions:

PI: David Minton (Purdue)
Co-Is:
- Briony Horgan (Purdue)
- David Spencer (Purdue)
- Philip Christensen (Arizona State University)
- Zachary Putnam (Univ. of Illinois at Urbana-Champaign)
- Austin Williams (Tyvak Inc.)

Graduate Students
- Jacob Elliot (Purdue), Rohan Deshmukh (Purdue)

Collaborators
- Andrew Rivkin (JHU/APL), Matija Cuk (SETI), Francesca DeMeo (MIT), Erik Asphaug (ASU)

Science Objectives:

1. Determine the origin of moons of Mars, Phobos and Deimos
2. Evaluate the potential for resource extraction to support human exploration on the moons
3. Observe the effects of geologic processes contributing to the ongoing evolution of the Phobos-Deimos system

Mission Overview:

- Will piggyback on another Mars mission for launch, but will be a free flier after separation from the upper stage
- Cruise/aerocapture vehicle with drag modulation trajectory control
- 12U CubeSat, 3-axis stabilized, electric propulsion
- One Mars year mapping mission of Phobos & Deimos
- Remote sensing instrument suite
  - Spectroscopy and visible imaging
- Mission Operations Center at Purdue University
- Science Operations Center at Arizona State University