# The Role of Small Satellites in Addressing Mars Science Goals

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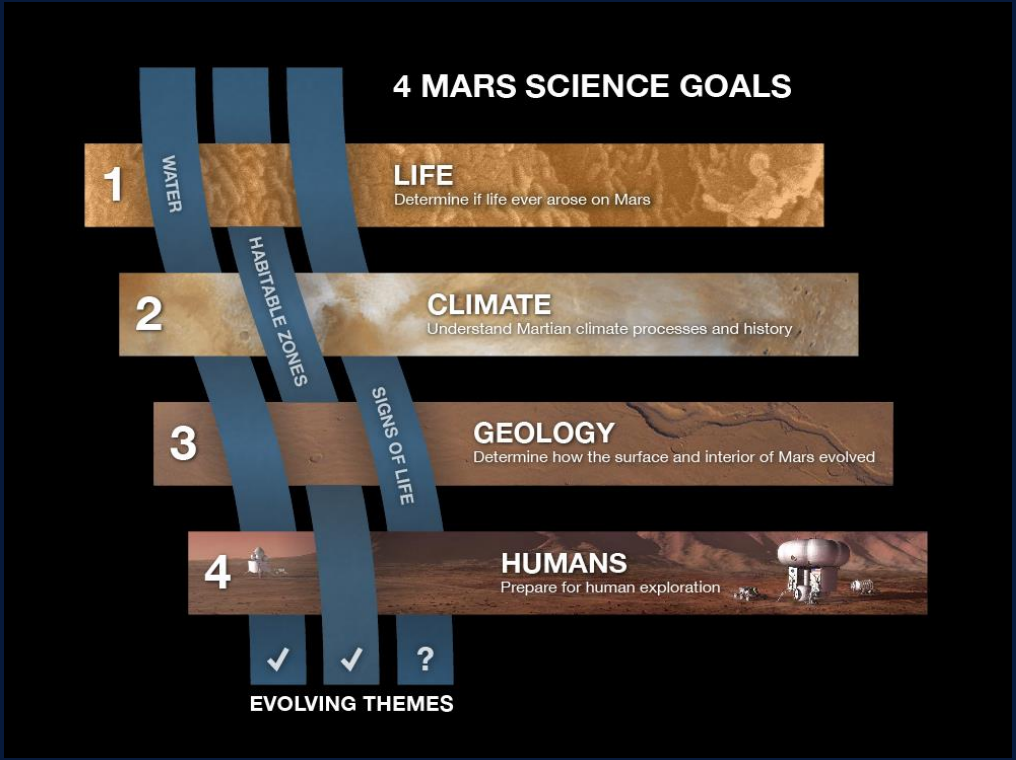
# Outline

- Review of Mars science goals
  - Planetary Science Decadal Survey
  - MEPAG Goals Document
- Examples of science goals that could be addressed by small satellites
- Review of recent small satellite studies addressing the Mars system
  - Small Innovative Missions for Planetary Exploration (SIMPLEx)
  - Planetary Science Deep Space SmallSat Studies (PSDS3) program
- Mars-related presentations at this meeting
- Summary

# Review of Mars Science Goals: Decadal Survey [2013-2022]

1) Determine if life ever arose on Mars
   - If yes, it will be important to know where and for how long life evolved, and how the development of life relates to the planet's evolution
2) Understand the processes and history of climate
   - Key to understanding how planet may have been suited for life and evolution of surface features
   - Relevant to our understanding of the past, present, and future climate of Earth
   - Necessary for the safe implementation of future robotic and human spacecraft missions
3) Determine evolution of surface and interior of an evolving, Earth-like planet
   - Fundamental to understanding solar system as a whole; provides context for Earth history/processes
   - Requires analyses of heat flow, loss of a global magnetic field, pathways of water-rock interaction, and sources and cycling of volatiles (water, carbon dioxide and hydrocarbons)
   - ➢ Mars has a rich and accessible geologic record of the igneous, sedimentary, and cratering processes that occurred during the early history of the solar system

# Review of Mars Science Goals: MEPAG Goals Document




***I) Understand whether Mars was ever an abode for life***

***II) Characterize the present and past climate and climate processes***

***III) Understand the geological processes affecting Mars' interior, crust, and surface***

***IV) Develop knowledge & technology necessary for eventual human exploration***

# Mars Science Goals & Current Strategies: Goal I (Life)

- A key element in evaluating potential signs of ancient life on Mars (whether or not it also exists today) is the Mars Sample Return (MSR) campaign.

- Current strategies regarding possible modern life are focused on high-precision measurement of trace gases in the martian atmosphere from, e.g., Trace Gas Orbiter (TGO)

# Mars Science Goals & Current Strategies: Goal II (Climate)

- Orbital monitoring of atmospheric dynamics
  - Transfer of mass and energy to/from the polar ice caps
  - Atmosphere-surface interactions
  - Understanding extreme weather events (causes, magnitudes, predictability)
- New instrumentation (either orbital or landed) is needed to fill important science and Strategic Knowledge Gaps (SKGs)
  - Near-surface winds and water vapor distributions
  - Dust properties and distribution; dust storm prediction
- Orbital and landed assets to monitor martian weather
  - Extend the temporal baseline and increase temporal/spatial coverage (e.g., networks)
  - Water vapor in dusty atmospheres, wind measurements
- Validate and improve model simulations; update engineering models

# Mars Science Goals & Current Strategies: Goal III (Geology)

- Martian geology has wonderful and complicated planetary-scale variations in age, lithology, past/present geologic processes, hydrology, and landform evolution.

- It is a diverse system with an ancient geologic record of its early, evolving environments.

- In order to understand Mars as a global geological system, landings in multiple geologic provinces are required, as is characterizing the geologic context of in-situ measurements with sufficient high-resolution orbital data.

- Mars Sample Return will provide important answers for one site in the areas of geochronology, geochemistry, petrogenesis, paleomagnetism, and environmental evolution.

# Mars Goals & Current Strategies: Goal IV (Support Humans)

- Much depends on the still evolving mission architectures for human exploration at Mars
- In situ resource utilization (ISRU)
  - Radiation measurements in orbit (ODY MARIE) and on the surface (MSL RAD)
  - ISRU of atmospheric carbon dioxide to make oxygen (M2020 MOXIE)
  - Dust contamination effects (M2020 MEDA)
- Dust considerations: Distribution, shape, size, composition, impact on atmosphere
  - Monitoring of the atmosphere (ODY THEMIS, MRO MCS / MARCI / CRISM, MER / MSL / M2020 dusty sky measurements)
- Atmospheric and surface environments
  - Instrumenting landers to record performance during Entry, Descent & Landing; meteorological networks
- Science operation studies from orbit/moons/surface

# Summary of new relevant discoveries since *Decadal Survey 2011*

- *Mars was habitable. The question remains: Was it inhabited?*
  - Exposures of aqueously altered rocks point to possible preservation of organics.

- *The Martian climate and surface/subsurface changed over time, with diverse environments (some acidic, some not) and with episodic periods of water activity*
  - The early climate may often have been cold and wet—not warm.
  - Escape processes have removed much of the atmosphere.
    - But considerable volumes of water are still present in the caps and in the ground.
    - Significant transfers between the poles and lower latitudes (ice ages) in more recent geologic time.

- *The Mars climate today still is dynamically active*
  - The wind and volatility of $CO_2$ ice are major agents of change today.
  - Open question of whether (briny?) water is liquid for specific times and places on modern Mars.
  - A decade of atmospheric observations provides partial validation for climate models.

# New relevant discoveries/activities since *Decadal Survey 2011*

- ***Preparation for Humans***
  - Discoveries addressing SKGs:
    - Detection from orbit of subsurface ice and hydrated minerals
      - Points to possible *in situ* resources for future Mars missions
      - Verification is likely required before committing missions with humans landing there
    - Ongoing characterization of Martian climate and weather has provided partial (incomplete) constraints on engineering models for the design and simulation of future missions
      - Characterizing infrequent, but extreme events can reduce risk and cost
    - Rover operations have characterized surface environments and gained practical operational experience in Mars environments

# Discoveries/Questions That Require Follow-up as of 2017 *(1/2)*

- Did Mars ever have life? Is it still there?
  - Science-driven sample return is critical to answering this question.
- How, when, and how often did Mars experience great transition(s) from a much wetter environment to cold, dry, oxidizing world of today?
  - We have discovered 10+ distinct potential habitats, comprising a key environmental record in the strata from first billion years.
  - How many more of these habitats are there and what is their time history?
  - Need to characterize and date materials from many different locations.
- How do terrestrial planets like Mars respond to early processes like giant impacts and warming from a faint young sun in our solar system?
  - What is the timing/intensity of these processes?
  - How did different Mars habitats respond to these changes?

# Discoveries/Questions That Require Follow-up as of 2017 *(2/2)*

- How is water involved in the near-surface today?
  - RSLs: what are these seasonally changing streaks? Gullies and salts in last few million years?
- Do obliquity cycles raise atmospheric pressure and drive episodic modern water availability?
  - Massive polar traps of $CO_2$
- What does water ice on Mars tell us about the earlier climate and environmental changes?
- What is the temporal variability, amount, and source of methane?
  - What is the nature of the source (biological or geochemical)?
  - How can it disappear so quickly?

# Areas of Need: Atmospheric observations

- Atmosphere
  - Extend the Climate Record: Build on 2 decades of atmospheric remote sensing from orbit to capture extreme events and to characterize interannual variations (e.g., major dust events)
  - Improve the Climate Record: Add routine observation of water vapor and temperature, even in dusty periods.
    - Measure winds!
    - Observations throughout the diurnal cycle, year, and decade
  - Inventory trace gases (e.g., Methane), their sources and changes
  - Characterize near-surface meteorological fields and exchanges of mass, momentum and energy at the surface in both polar and non-polar environments.
- Aerosols:
  - Better characterize the shape, size and composition of atmospheric dust
  - Better characterize ice particle/cloud properties
    - proving to be a major radiative drive for the atmospheric circulation

# Areas of Need: Observations at/of the Surface

- Validate surface environments that could support human exploration
  - Where are the water resources (ice or hydrated minerals) that humans could exploit?
  - What are the load-bearing properties of the surface?
  - Can surface materials be used for construction purposes?
- Characterize mass, energy, and momentum exchanges at/near the surface
- Improve understanding of planet’s internal structure after *InSight* measurements
- Explore the stratigraphic record at multiple, diverse sites with low-cost landers
- Advance characterization of the surface magnetic properties (e.g., the remnant magnetic stripe-regions) → Deep dives?
- Reveal true nature of Recurring Slope Lineae (RSL)
  - giving due respect to planetary protection needs

# Mars Sample Return (MSR) in the Decadal Survey (2011)

*Vision and Voyages (V&V)* gave the highest flagship priority to the return of carefully selected samples from Mars

- A 3-mission architecture was proposed and the first mission, a caching rover (now the Mars 2020 rover), was given priority for the decade 2013-2022. That rover is going forward for a 2021 landing.
- Follow-on missions were proposed to fetch the collected samples, put them in a Mars Ascent Vehicle (MAV) that would take the sample collection to orbit, where an orbiter would rendezvous and encapsulate the orbited sample cache (breaking the chain of Mars contamination) for return to Earth.
- At this time NASA has not committed to the fetch/MAV and return orbiter missions.
- As presented to the Decadal Survey, the fetch/MAV mission would be a flagship mission and the orbiter return mission would be somewhere between a Discovery and New Frontiers (NF) class.
- The Decadal Survey did not endorse any NF-class Mars candidate, but it did recognize that there was important science that could be accomplished by Discovery and small satellite class missions.
  - Two areas called out in *V&V* were polar science and science questions addressable by network science

## Relevance of MSR to Low-Cost Mars Missions

A next Mars orbiter (NMO) in support of sample return could address several needs of low-cost missions (LCM) to Mars:

- Telecommunications: An NMO launched in the early 2020's would refresh the aging relay infrastructure at Mars addressing the LCM need to get data back
- Reconnaissance: Flight of a HiRISE-class camera would support characterization and certification (for safety) of new landing sites
- Transportation: An NMO using solar electric propulsion could deliver small satellites to Mars or Mars orbit
- See MEPAG NEX-SAG report: https://mepag.jpl.nasa.gov/reports.cfm

# Review of recent small satellite studies

- Small Innovative Missions for Planetary Exploration (SIMPLEx) Program

  (1-year study)

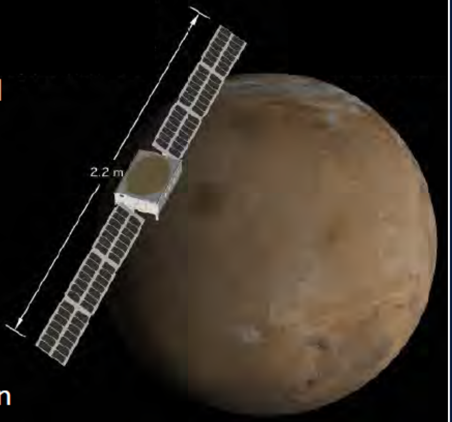
## Mars Micro Orbiter

### PI: Michael Malin, Malin Space Science Systems

The **Mars Micro Orbiter (MMO)** mission uses a 6U-class Cubesat to measure the Mars atmosphere in visible and infrared wavelengths from Mars orbit.

These science measurements will:

(1) Extend the temporal coverage of the global synoptic meteorological record of Mars, which includes atmospheric thermal structure, dust and condensate clouds, and seasonal and perennial polar cap behavior,
(2) Characterize the dynamics and energy budget of the current Mars atmosphere,
(3) Support present and future Mars missions
(4) Characterize present-day habitability




The CubeSat can also act as an orbital communication relay for Mars surface-based missions.

# Review of recent small satellite studies *(1/3)*

- Planetary Science Deep Space SmallSat Studies (PSDS3) program
  - Chariot to the Moons of Mars: 12-unit CubeSat with a deployable drag skirt to produce high-resolution images and surface material composition of Phobos and Deimos, to help understand how they were formed (David Minton, Purdue University)
  - Aeolus: a 24-unit CubeSat to directly measure vertically-resolved global winds to help determine the global energy balance at Mars and understand daily climate variability (Anthony Colaprete, NASA Ames; *09:50 talk in Mars session on Thursday*)
  - Phobos Regolith Ion Sample Mission: 12-unit CubeSat with solar electric propulsion to co-orbit Phobos and identify sample return sites using secondary ion mass spectrometry (Michael Collier, Goddard Space Flight Center)

# Review of recent small satellite studies *(2/3)*

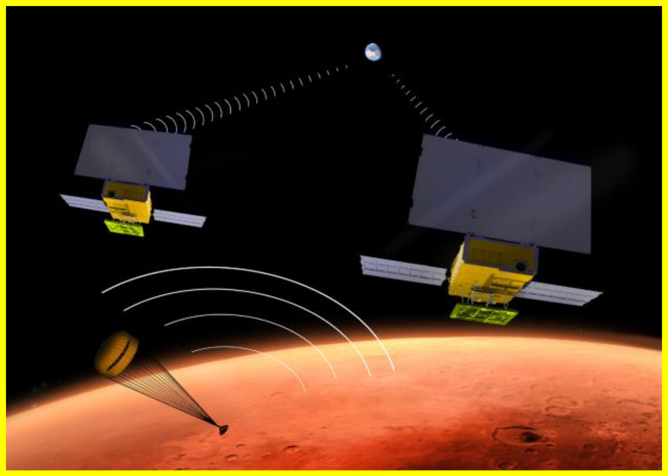
- Planetary Science Deep Space SmallSat Studies (PSDS3) program

  - Mars Ion and Sputtering Escape Network: 6-unit and 12-unit study using plasma ion sensor and magnetometer to address global variations of heavy ion and sputtering escape under different solar wind and space weather conditions (MISEN; Robert Lillis, SSL, UC-Berkeley)

  - Mars Aerosol Tracker: 12-unit CubeSat in areostationary orbit using solar electric propulsion to analyze time evolution of dust and water ice aersols associated with dust storms and water ice clouds in the atmosphere and resulting albedo changes on surface (MAT; Luca Montabone, Space Science Institute)

# Review of recent small satellite studies *(3/3)*

- Mars Cube One (MarCO; JPL)
  - Scheduled for flight on *InSight* mission as first deep space CubeSats
  - Twin, six-unit CubeSats separate after launch travel on own trajectories to Mars
  - Radios provide UHF reception and X-band receive/transmit function allowing immediate relay of information during *InSight* Entry/Descent/Landing (EDL)



- See additional studies from 2014 CubeSat/Nanosat workshop:

https://marscubesatworkshop.jpl.nasa.gov/

# Mars-related presentations upcoming: Tuesday

- Archiving low-cost mission data in NASA's planetary data system
  - Chanover, 11:15
- SPICE can help smallsat missions obtain important, accurate observation geometry
  - Acton, 11:35

# Mars-related presentations upcoming: Wednesday

- Electromagnetic handling of regolith particles on Moon, Mars, Asteroids, and Comets
  - (Kawamoto, 09:10)
- Radio emissions from electrical activity in martian dust storms
  - (Arabshahi, 10:10)
- Flexible camera architecture for generic space imaging applications
  - (Staehle, 11:10)
- The Advanced Multispectral Infrared Microimager (AMIM) for future in situ exploration of planetary surfaces
  - (Núñez, 11:30)
- Combustion joining of regolith tiles for the in-situ fabrication of launch/landing pads on the Moon and Mars
  - (Ferguson, 16:00)

# Mars-related presentations upcoming: Thursday session

- An Interplanetary CubeSat mission to Phobos
  - (Thanga, 08:30)
- Deep Space 9 Mission Concept–Secondary Payload study for the proposed Next Mars Orbiter
  - (Arteaga Garcia et al., 08:50)
- Radio occultation mission to Mars using CubeSats
  - (Williamson, 09:10)
- Mars DartDrop: Probing contemporary habitability at recurring slope lineae
  - (Grimm, 09:30)
- Aeolus - a mission to study the thermal and wind environment of Mars
  - (Colaprete, 09:50)
- Benefits offered by a network of CubeSat-class rovers for planetary cave exploration
  - (Fraeman, 10:10)

# Summary

- There are fundamental science questions and needs that can be addressed by low-cost missions at Mars
    - The science can be consistent with MEPAG goals and Decadal Survey objectives
    - Mars Scouts (Phoenix, MAVEN) have previously shown how productive lower cost, scientifically focused missions can be
- Strategic Mars missions could enable low-cost missions by providing telecom infrastructure, reconnaissance and transportation
- There are still major technical challenges, particularly with regard to low-cost landing
    - Recent rapid advances in small mission capabilities may provide new landed opportunities