Mars Next Orbiter Science Analysis Group
(NEX-SAG)

White Paper Report to the 2023-2032 Planetary Sciences and Astrobiology Decadal Survey

Bruce Campbell[1] and Richard Zurek[2]

NEX-SAG Co-Chairs

[1]Smithsonian Institution

[2]Jet Propulsion Laboratory, California Institute of Technology

Primary Contact: Richard Zurek[2], richard.w.zurek@jpl.nasa.gov, 818-395-5041

Based on the MEPAG NEX-SAG Report

Next Mars Orbiter Report

Finalized and Published online, December, 2015

Members of the NEX-SAG

Nathan Bridges	Johns Hopkins U. Applied Physics Laboratory (deceased)
Shane Byrne	University of Arizona
Wendy Calvin	University of Nevada, Reno
Lynn Carter	University of Arizona (then at NASA GSFC)
R. Todd Clancy	Space Science Institute
Bethany Ehlmann	California Institute of Technology/JPL
Jim Garvin	NASA Goddard Space Flight Center
Melinda Kahre	NASA Ames Research Center
Laura Kerber	Caltech/Jet Propulsion Laboratory
Scott Murchie	Johns Hopkins U. Applied Physics Laboratory
Nathaniel Putzig	Planetary Science Institute (then at SwRI-Boulder)
Mark Salvatore	Northern Arizona U. (then at U. Michigan, Dearborn)
Michael Smith	NASA Goddard Space Flight Center
Leslie Tamppari	Caltech/Jet Propulsion Laboratory
Brad Thomson	University of Tennessee, Knoxville (then at Boston U.)
Ryan Whitley	NASA Johnson Space Center

Ex Officio

Ben Bussey	NASA Headquarters, HEO Chief Exploration Scientist
Serina Diniega	Mars Program Office, JPL, Executive Officer
Robert Lock	Mars Program Office, JPL, Orbiter Study Lead
Michael Meyer	NASA Headquarters, MEP Lead Scientist
Lisa Pratt	MEPAG Chair

This report and update were supported by NASA, including a contract with the Jet Propulsion Laboratory, California Institute of Technology.

Postscript to the NEX-SAG Report (5 years later)

The Mars Exploration Program Analysis Group (MEPAG) Next Orbiter Science Analysis Group (NEX-SAG) was formed in 2015 at the request of both the NASA Science Mission and the Human Exploration & Operations Mission Directorates (SMD & HEOMD) to analyze possible synergistic objectives of a multi-function orbiter to Mars, possibly powered by the rapidly developing Solar Electric Propulsion (SEP) technology (Fig. 1).

Science objectives were to be traceable (Table I in the report and on Slide 6 below) to *Visions & Voyages* (2011) and to the MEPAG Goals Document. Generally, the science objectives grouped around: a) the nature and extent of ice deposits on and beneath the Mars surface; b) improved records of Mars climatology (adding water vapor & winds); and c) intensive exploration of the now known diversity of potentially habitable environments on early Mars.

Resource objectives were traceable (Table II in report) to goals defined by a HEOMD In-Situ Resource Utilization (ISRU) & Civil Engineering Working Group (ICE-WG--not to be confused with the MEPAG ICE-SAG). These objectives mainly focused on ice detection and, to a lesser extent, on hydrated minerals as a water resource, and also on filling various strategic knowledge gaps on the Mars environment, surface and atmosphere.

A mission concept that addressed all major objectives identified by NEX-SAG for both science and resource mapping was an orbiter with the following candidate instrumentation (Table V, pg. 7 below): 1) a P-band polarimetric Synthetic Aperture Radar (SAR) to detect ice in the subsurface, potentially within easy reach (< 10 m) for resource exploitation; 2) a Thermal IR mapper to reveal shallow ice (< 1 m) at high spatial resolution through the effect of ground ice on surface brightness temperatures; 3) a Thermal IR sounder and 4) a wide-angle camera, both to extend the present-day climate observation baseline into a second Mars decade; 5) a submillimeter sounder to vertically profile temperature and water vapor, even in a dusty atmosphere, as well as horizontal wind components; 6) a Short-Wave IR mapper at ~ 6 m/pixel to improve upon the best available data from orbit (MRO CRISM) and thereby match the higher resolution global visible imaging maps (e.g., MRO CTX); and 7) a very-high-resolution imager (MRO HiRISE class at ~30 cm/pixel; some argued for 10-15 cm/pixel) to reveal detailed morphology over limited areas for science and site reconnaissance.

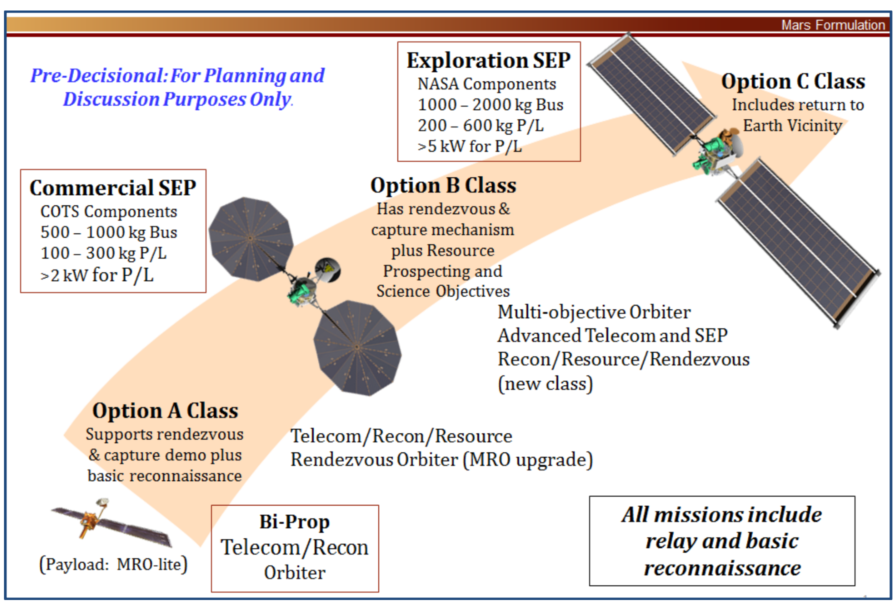
To fly all these instruments was thought to require the capabilities and resources of a New Frontiers class mission or perhaps even a flagship. However, NEX-SAG members felt that there were also different instrument combinations that could definitely achieve some of the high-priority science and resource objectives within the capabilities and costs of a New Frontiers or, possibly even of a Discovery, mission scope. (See Table V, pg. 7, where "Threshold" denotes the minimum capabilities needed to make *significant* progress on the objectives, while "Baseline" included added capabilities needed to make *substantial* progress.) However, no detailed costing of any option was done by NEX-SAG.

In 2019, the "ice science" objectives considered by NEX-SAG were further developed within the MEPAG-chartered ICE-SAG (the Ice and Climate Evolution SAG; ICE-SAG Report). Many of the objectives endorsed in this report are being actively studied in two pre-decisional Planetary Mission Concept Studies: Mars Orbiter for Resources, Ices and Environment (MORIE, Wendy Calvin, PI) and Mars Orbiters for Surface-Atmosphere-Ionosphere Interactions (MOSAIC, Rob Lillis, PI). Also, the President's 2021 proposed budget for NASA includes study money for a Mars Ice Mapper (MIM) orbiter mission concept, provisionally envisioned to survey Mars for shallow ice that could be used as a resource by humans exploring on Mars. These studies and proposals have highlighted an ongoing debate about the nature of the radar needed to achieve the objectives. Typically, resource mapping emphasizes the ability simply to detect the shallowest ice, whereas deeper penetration is needed to fully characterize the ice inventory. There are optimum radar operating characteristics for each approach, but not necessarily one set that is optimal for both shallow detection and deep characterization goals. Those trade-offs are an area of active study.

NEX-SAG found SEP to be a promising technology that could bring more payload mass and power into Mars orbit, with the opportunity to change orbital inclination during the mission, thereby affording both sun-fixed polar/global observations and, at a different mission phase, access to all times of day at lower latitudes. Interest in the Martian moons, both for science and as a potential base for humans operating in Mars vicinity could also be accommodated with a SEP mission, which would pass Deimos and Phobos as it spiraled down into low Mars orbit (see update below). With the larger payload capability, NASA was also looking for a way at that time to advance the next steps in a potential Mars Sample Return (MSR) campaign by considering whether this science/resource mapper could also be the Sample Return Orbiter; this would require hosting a large (~70 kg) rendezvous/encapsulation device to capture an orbiting sample cache. This goal is now conceptually assigned to an ESA Earth Return Orbiter in a provisional joint NASA-ESA MSR Campaign, thus simplifying the mission concepts studied by NEX-SAG.

To close, the Executive Summary of the report is provided here (with some boxed updates), together with two of the key tables. The full report can be found at Next Mars Orbiter Report.

Fig. 1: <u>Artist-Conception of Potential Orbiters</u>
This graphic shows the increase in deliverable mass and power from a bi-prop mission like Mars Reconnaissance Orbiter thru commercial Solar Electric Propulsion systems (considered a sweet spot in mission architecture) to a NASA-studied SEP system to be considered for human mission asteroid rendezvous.



Mars Next Orbiter Science Analysis Group Report

Executive Summary

This is the final report of the Mars Exploration Program Analysis Group (MEPAG) Science Analysis Group (SAG) that was formed at the request of NASA to analyze possible science objectives and their synergies with other components of a multi-function next-generation

Mars Orbiter. If approved, this orbiter could be launched as early as 2022. Through telecons, one face-to-face meeting, and discussions with experts in and out of appropriate HEOMD and SMD working groups, NEX-SAG finds the following:

A Mars Orbiter, utilizing Solar Electric Propulsion (SEP) and advanced telecom in a 5-year mission in low Mars orbit, could provide exciting new science and resource identification in addition to other programmatic functions. Such a multi-function mission should be launched in 2022 with the following goals:

- Replenish and advance the telecommunications and reconnaissance capability. Launched in 2022, this orbiter could back-up aging relay capabilities for a 2020 Mars rover in extended mission and for future spacecraft missions, whether for sample return or in preparation for exploration by humans at Mars.
- Demonstrate progress in Mars orbit towards potential sample return, via release, rendezvous, and capture of a simulated orbiting container, or—if possible—the actual return of an orbiting sample cache to Earth vicinity. Mars sample return is the *NRC Planetary Science Decadal Survey's* highest priority for flagship missions, and actual capture and return of an orbiting sample cache would be a major achievement for NASA and its industrial and international partners.

Update: This goal is now conceptually assigned to an ESA Earth Return Orbiter in a provisional joint NASA-ESA MSR Campaign.

- Conduct new science investigations motivated by discoveries made since the *NRC Planetary Science Decadal Survey* published in 2011, consistent with high priority questions of that Decadal Survey and the recently updated MEPAG goals. The compelling science objectives (S-#) are:

S-A. Map and quantify shallow ground ice deposits across Mars together with shallow layering of water and CO_2 ices at the poles to better understand the global water inventory and atmospheric exchange today, and how ground ice records climate change on geologically younger Mars (e.g., over obliquity variation cycles);

S-B. Detect and characterize areas of possible present-day liquid water flow (recurring slope lineae: RSL) and link these observations with ground ice, temperature, surface composition (e.g., salts) and atmospheric properties to understand the distribution and potential for habitability of these volatile reservoirs;

Update: While debate continues, RSL now appear to be most consistent with dry flows.

S-C. Measure winds and characterize transport and other dynamic processes to understand current climate, water, and dust cycles, with extrapolation to past climates;

S-D. Characterize the occurrence and timing of major environmental transitions recorded in compositional stratigraphic records, such as discrete hydrated mineral assemblages and sedimentary bedding;

S-E. Carry out high-value, close-approach investigations of Phobos and Deimos.

Update: This goal is addressed by the JAXA Mars Moon eXplorer (MMX) mission, in development for launch in 2024.

- Find resources on Mars for future missions, especially in support of human surface exploration, and address Strategic Knowledge Gaps (SKGs). The key resource is water, which could make significant contributions to sustainable exploration when used in such diverse applications as life support, surface construction, and propellants for surface operations and ascent from Mars. Materials for civil engineering purposes are also of interest. Thus, locating the following resources are identified as orbiter Resource/SKG objectives (RS-#):

  RS-A. Find and quantify the extent of shallow ground ice within a few meters of the surface and characterize its ice-free overburden;

  RS-B. Identify deposits with hydrated minerals as a water resource, and potential contaminants within these deposits;

  RS-C. Identify site-specific mineral resources and geotechnical properties.

  Pursuit of the above resource prospecting and science objectives could also fill key Strategic Knowledge Gaps (SKGs) that have high priority for human exploration, leading to two more resource/SKG objectives (RS-#):

  RS-D. Extend the atmospheric climatology with diurnal coverage and wind measurements;

  RS-E. (SEP only) Address gravity and surface characteristic SKGs for the Martian moons.

NEX-SAG finds a high degree of overlap between the science goals identified and the human exploration resource prospecting interests and derived objectives. The considerable synergy between requested functions enables selection of instruments that may individually address multiple science, resource/SKG, and reconnaissance needs, thereby providing a more cost-effective way to achieve the full set of objectives.

Given the above resource/SKG and science objectives, NEX-SAG identified measurement capabilities or approaches needed to address them. It then identified, at a high level, proof-of-concept measurement techniques mature enough for development of an orbiter for launch in 2022. These proof-of-concept instrument types are:

  - Visible imaging of HiRISE-class (30 cm/pixel) or better (~10-15 cm/pixel);
  - Polarimetric radar imaging with penetration depth of a few (<10) meters and spatial resolution of ~15 m/pixel to detect ices and brines; a radar sounding mode would aid characterization of the overburden mantling a subsurface ice layer;
  - Short-wave IR mapping with a spatial resolution of ~6 m/pixel with sufficient spectral resolution to detect key primary and secondary minerals, salts, and ices;
  - Long-wave atmospheric sounding for wind, temperature, & water-vapor profiles;
  - Thermal IR sounding for aerosol profiles;
  - Multi-band thermal IR mapping of thermophysical surface properties (e.g., ice overburden and thermal inertia) and surface composition;
  - Global, km-scale, wide-angle imaging to monitor weather, dust storms, and surface frosts.

Other instrument types may be applicable and may appear in preparation for, or in response to, an openly competitive Announcement of Opportunity.

NEX-SAG assessed these conceptual measurement capabilities described within the range of spacecraft being studied, from a MRO/MAVEN chemical propulsion derivative to spacecraft powered by commercially available or advanced Solar Electric Propulsion.

Such an ambitious multi-function orbiter mission, with telecommunications, reconnaissance, science and resource prospecting objectives, appears feasible only with advanced telecommunications capability and the first-time use of SEP for a Mars mission.

- Advanced telecommunication capabilities are needed to support high-resolution instruments while achieving acceptable spatial coverage. Such a telecom system would easily accommodate data returned by surface missions.
- The use of SEP for Mars missions is transformative, opening up new possibilities for improved, novel, and collaborative measurement capabilities in pursuit of the mission objectives, which include:
  - Bringing significantly more payload mass and power to low Mars orbit, which is needed to address the multiple functions and objectives of this orbiter.
  - The possibility of actually returning an orbiting sample container/cache to Earth vicinity at the end of a mission in low Mars orbit.
  - Supporting additional science investigations and technology demonstrations, including daughter craft, if this can be done without impacting the main objectives.
  - Enabling successive campaigns through the ability to vary orbital parameters; e.g., gaining representative local time coverage from an inclined orbit and then polar coverage in a sun-synchronous orbit.
  - Enabling observations of the Martian moons during fly-bys as the orbiter spirals in closer to Mars.

A multi-purpose, SEP-powered, orbital mission as described here could make major advances in our scientific understanding of Mars and its evolution, while providing reliable telecommunications, reconnaissance, and resource location for future human and robotic missions on Mars.

The crucial discriminator between what can and should be flown is the funding available and the objectives of the funding directorates. Cross-directorate support is appropriate and crucial for the multiple objectives envisioned here.

In addition, NEX-SAG notes that international partners could provide several of the instrument types and spacecraft subsystems needed to achieve the objectives of this multi-faceted mission. Such partnering could also set in motion collaborations needed for the longer-term exploration of Mars by humans operating on its surface.

End of Executive Summary: The full report can be found at Next Mars Orbiter Report.

Table I: Traceability of Measurement Objectives for Science

Program Aspect	Relation. to NASA Goals	Science or Exploration Objective	Investigation	Required Measurements	
MSR	Primary Decadal Survey Priority	Progress on Sample Return	Rendezvous & Capture in Mars orbit		
Science	High Decadal Survey Priority	**S-A.** Distribution & Origin of Ice Reservoirs	**A1.** Distribution of buried water & CO_2 ice plus relationship to surficial polar deposits	Extent & volume of water ice in non-polar regions	
				Extent & volume of buried CO_2 ice in the polar caps	
				Shallow subsurface structure of polar cap & layered terrain	
				Improved mapping of cap morphology, structure, & composition - as a function of season	
			A2. Volatile cycling between high & low latitudes	Seasonal mapping of surface water & CO_2 frost	
				Polar radiative balance: visible & thermal IR wavelengths	
				Polar atmospheric environment: Water vapor, temperature, wind, clouds	
	New Discoveries /High MEPAG priority	**S-B.** Dynamic Surface Processes on Modern Mars	**B1.** Role of liquid water in Recurring Slope Lineae (RSL)	Fine scale morphology	as a function of season & time of day
				Mineralogy, hydration state, & surface temp.	
				Water vapor changes within lowermost atmos.	
			B2. Active sediment transport & surface change processes	Sediment flux in key locales: including dunes, gullies, dust streaks	
		S-C. Dynamic Processes in Current Martian Atmosphere	**C1.** Atmospheric circulation	Vertical profiles of horizontal wind components & T(p) with good precision, even in dusty atmosphere changes	
			C2. Atm. transport & state	Vertical profiles of aerosol (dust & ice) & water vapor	
			C3. Daily global weather	Daily global mapping of dust, clouds, & surface frost	
		S-D. Geologic Evidence for Environmental Transitions	Diversity of ancient aqueous deposits	Fine-scale composition & morphology in ancient terrain	
	Martian moons	**S-E.** Phobos/ Deimos Fly-by Science (with SEP)	**E1.** Comparative bulk densities of satellites	Satellite shape, morphology, gravity	
			E2. Satellite composition & regolith properties	Satellite mineral composition & thermophysical properties	

Table I from NEX-SAG REPORT (pg. 37)

Table V: Mission Concepts

Mission Concept	***Investigations Addressed (See Tables III-IV)***	Imaging	PSAR (Radar)	SWIR Mapper	Thermal-IR Mapper	Wide Angle Camera	Sub-mm: T, wind, water (v)	Thermal-IR Sounder	Time-of-day Coverage	Nadir Polar Coverage	Estimated Payload Mass [kg] for Threshold (and Baseline)
ALL	**All Functions and Objectives**	T	T	T	T	T	T	T	✓	✓	225
Ground Ice	Detection of very shallow ice, structure, and overburden: RS-A1, RS-A2, S-A1; baseline adds S-A2 (partial: frost)	T	T	B	T	B			✓	✓	130 (175)
Signs of current and ancient water	RSL & Environmental Transitions (mineralogy & stratigraphy): RS-B, RS-C, S-B1, S-B2, S-D	T	B	T	T		B		✔		105 (210)
Atmosphere Science & SKGs +Recon	Current Martian Atmosphere studies and global monitoring: RS-D, S-C1, S-C2, S-C3, S-B2 + Reconnaissance (partial: certify sites)	T				T	T	T	✓	✓	105 (105)
Phobos-Deimos (SEP only)	Identify geologic units and constrain densities of Mars moons: RS-E, S-E	T	B	T	T	B					105 (175)
Basic Reconnaissance	Reconnaissance (threshold: Certification and S-B2; baseline adds character-ization of new sites and atmospheric conditions)	T	B	B	B	B	B (one of these)		✓		50 (185 or 215)
	Estimated instrument mass [kg]	50	65	40	15	5	40	10			

Legend for Tables III-V:	Investigation: S=Science/RS= Resource & SKGs, -N# = Objective/Investigation	T = Threshold	B = Baseline (includes Threshold)

Table V from NEX-SAG REPORT (pg. 52)