MEPAG Next Orbiter Science Analysis Group (NEX-SAG)

Overview of the Final Report

March 2, 2016

Bruce Campbell and Rich Zurek, Co-Chairs

Steve Hoffman, ICE-WG Liaison

Robert Lock, Orbiter Study Team Liaison

Serina Diniega, Executive Officer

NEXT ORBITER SAG (NEX-SAG)

- **MEPAG Science Analysis Group Chartered by HEOMD & SMD**
  - Ben Bussey, HEOMD Chief Scientist for Exploration
  - Michael Meyer, SMD Lead Scientist for Mars
  - Charter accepted April 2015, by Lisa Pratt, MEPAG Chair
- **Task:**
  - Analyze possible science objectives and their synergies with other components of a multi-function next-generation Mars Orbiter, to be launched in the early 2020's
  - Consider the possible infusion of new technologies, such as Solar Electric propulsion (SEP) and advanced telecommunications
- **Approach**
  - Conducted weekly telecons, one face-to-face meeting, and discussions with experts in and out of appropriate HEOMD and SMD working groups
- ***Summary Finding:***

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.

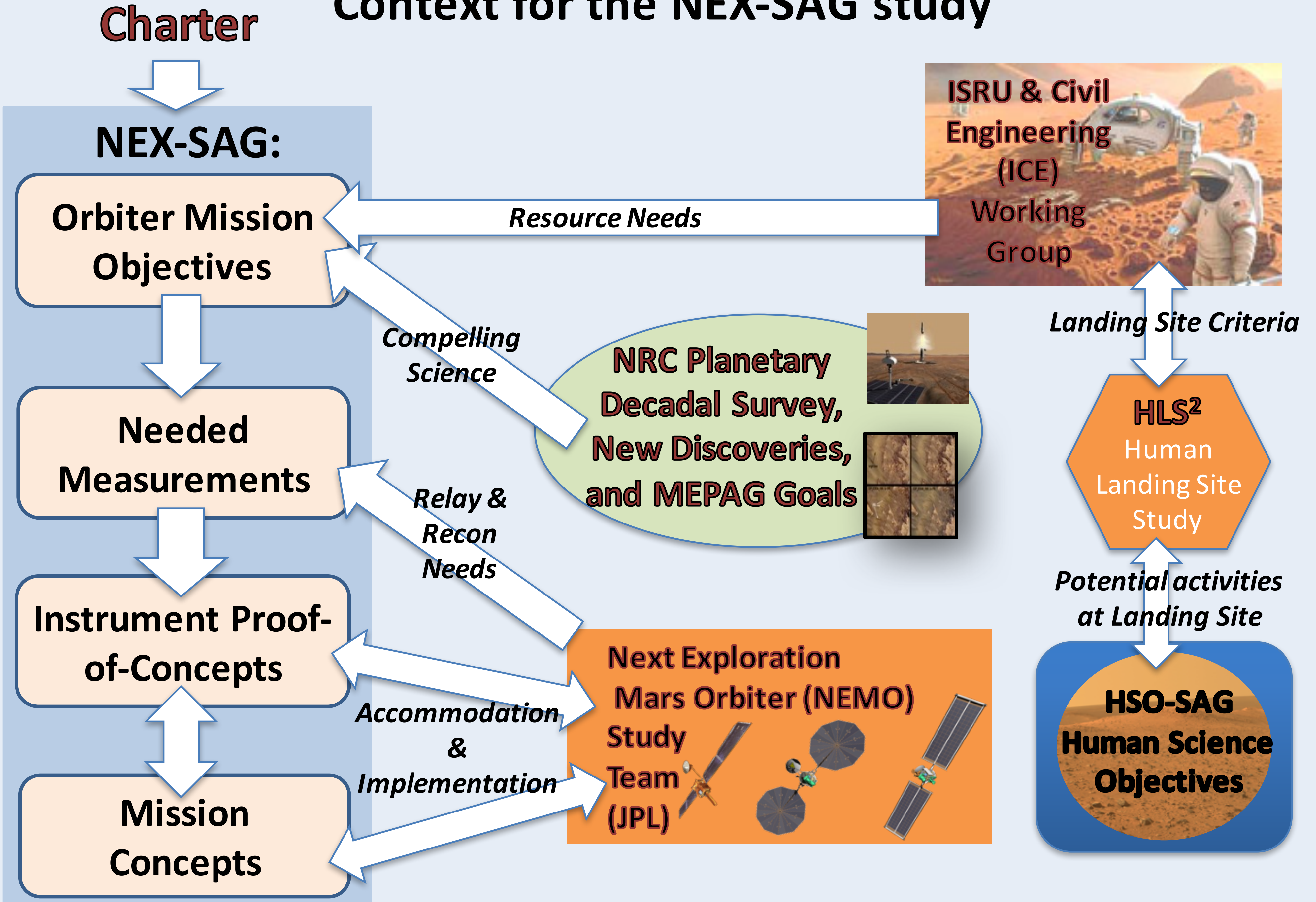
NEX-SAG Charter Directives

- **Replenishment of Infrastructure**
  - Telecom (5-year lifetime)
  - Reconnaissance (surface; atmosphere)
    - Characterize/certify landing sites & exploration zones for future missions
    - Provide critical environmental data for mission design and surface operations
- **Resource Prospecting & Strategic Knowledge Gaps (SKGs)**
  - Location and quantification of *in situ* resources for future missions (robotic and humans); the primary resource interest is accessible water
  - Objectives to address SKGs were based on Precursor SAG Report and the updated MEPAG Goal IV (Preparation for Human Exploration)
- **Science Objectives**
  - Aligned with NRC Planetary Science Decadal Survey priorities
    - Includes making progress towards sample return
    - Polar Science
  - Follow-up on new discoveries (e.g., Recurring Slope Lineae/RSL)
- **Consider the possible infusion of new technologies, such as Solar Electric propulsion (SEP) and advanced telecommunications**

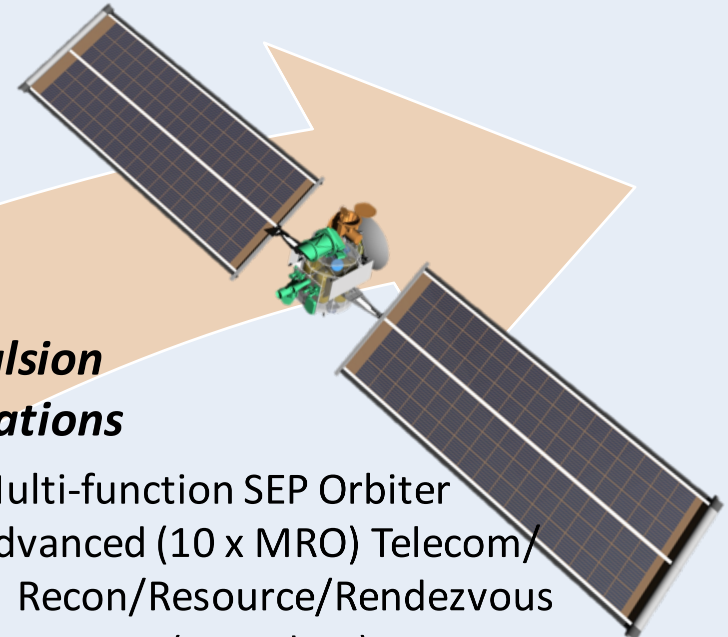
NEX-SAG Membership

Co-chairs/Support			
Co-chair	Bruce	Campbell	Smithsonian Institution
Co-chair	Rich	Zurek	JPL[1]/Mars Program Office
Orbiter Study Team	Rob	Lock	JPL[1]/Mars Program Office
Executive Officer	Serina	Diniega	JPL[1]/Mars Program Office
			[1]Jet Propulsion Laboratory, California Institute of Technology
Members of NEX-SAG			
Aeolian Processes	Nathan	Bridges	JHU Applied Physics Laboratory
Polar Science	Shane	Byrne	University of Arizona
Prior Orbiter SAG / Geology	Wendy	Calvin	University of Nevada, Reno
Radar / Geology	Lynn	Carter	NASA Goddard Space Flight Center
Photochemistry	Todd	Clancy	Space Science Institute
Geology / Mineralogy	Bethany	Ehlmann	Caltech & JPL[1]
Polar Science / Radar	Jim	Garvin	NASA Goddard Space Flight Center
GCM / Climate Modeling	Melinda	Kahre	NASA Ames Research Center
Climate Modeling / Geology	Laura	Kerber	JPL[1]/Mars Program Office
VIS-NIR / Geology	Scott	Murchie	JHU Applied Physics Laboratory
Subsurface Ice / Geology	Nathaniel	Putzig	SWRI-Boulder
Thermal IR / Geology	Mark	Salvatore	University of Michigan, Dearborn
Prior Orbiter SDT	Michael	Smith	NASA Goddard Space Flight Center
Atmosphere	Leslie	Tamppari	JPL[1]
Radar/Geology	Brad	Thomson	Boston University
Prep for Humans	Ryan	Whitley	NASA Johnson Space Center
Imaging / Geology	Becky	Williams	Planetary Science Institute
Upper Atmosphere	Paul	Withers	Boston University
Mineralogy / Geology	James	Wray	Georgia Tech
Ex-Officio			
HEOMD	Ben	Bussey	NASA Headquarters
Mars/SMD	Michael	Meyer	NASA Headquarters
MEPAG Chair	Lisa	Pratt	Indiana University

Context for the NEX-SAG study



Capability and Mission Range for Possible Next Orbiter

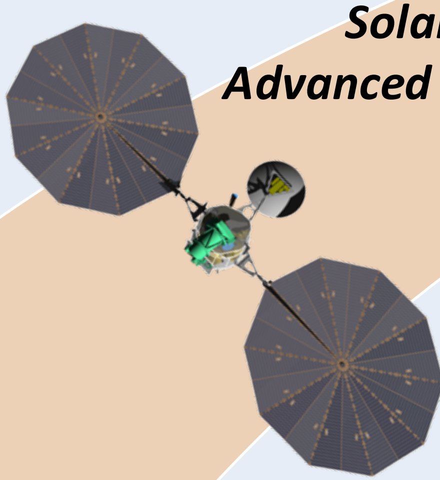


Class 3:
Exploration SEP

NASA Components
1000 – 2000 kg Bus
200 – 800 kg P/L
>5 kW for P/L

Multi-function SEP Orbiter
Advanced (10 x MRO) Telecom/
Recon/Resource/Rendezvous
(new class)

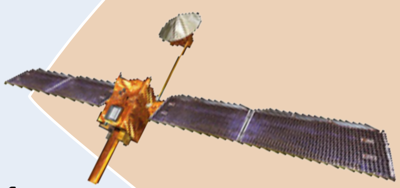
Solar Electric Propulsion
Advanced Telecommunications



Class 2:
Commercial SEP

COTS Components
500 – 1000 kg Bus
100 – 200 kg P/L
>2 kW for P/L

Telecom (3 x MRO) /Recon/Resource/Science
Rendezvous Orbiter (MRO upgrade)



Class 1:
Chemical Propulsion

800 kg Bus
80 kg P/L
~150 W for P/L

Telecom/Recon/Science
Orbiter (MRO-class)

Pre-decisional; for discussion purposes only

Vision & Voyages for Planetary Science: Sample Return

The Decadal Survey stated that:

"The analysis of carefully selected and well-documented samples from a well-characterized site will provide the highest science return on investment for understanding Mars in the context of solar system evolution and for addressing the question of whether Mars has ever been an abode of life." (NRC 2011, p. 158) The Decadal Survey thus gave its highest priority for flagship missions to "the elements of the Mars Sample Return campaign" (NRC 2011, p. 164).

Finding [#1]: ***NEX-SAG finds that a demonstration of rendezvous and capture or actual return of a retrieved container/cache to Earth vicinity would likely require SEP capability, especially if other high-priority resource and science objectives are to be pursued. Return of an actual cache of Mars samples would fulfill the Decadal Survey's highest flagship priority.***

When to Launch?

[#2]: ***NEX-SAG finds that an orbiter launched in 2022 could be needed to provide critical support for the 2020 Mars rover and would help accelerate both potential sample return and preparations for human missions to Mars. A 2022 launch would also provide opportunities for inter-comparison and synergistic observations with existing orbiters, nearing their end-of-life.***

- Emplacement of telecommunications infrastructure for robotic and human exploration missions;
  - Includes back-up for 2020 Mars rover operations (risk mitigation for operations beyond 2nd year).
- Early acquisition of critical data to inform future robotic and human exploration mission design and implementation;
  - Precursor landings to potential exploration zones and landing sites;
  - Support for missions returning samples from Mars.
- Gain early experience with operations using SEP in high and low Mars orbits. Includes:
  - Lessons-learned from rendezvous/capture demonstration;
  - Multiple fly-bys of the Martian moons.

NEXT ORBITER SAG: Science Objectives

In addition to relay, reconnaissance, and progress on future Sample Return, the compelling new science objectives are:

A. Map and quantify **shallow ground ice deposits** across Mars to better understand the global water inventory and atmospheric exchange today and how ground ice records climate change on longer time scales (e.g., obliquity variation). [#3-6]

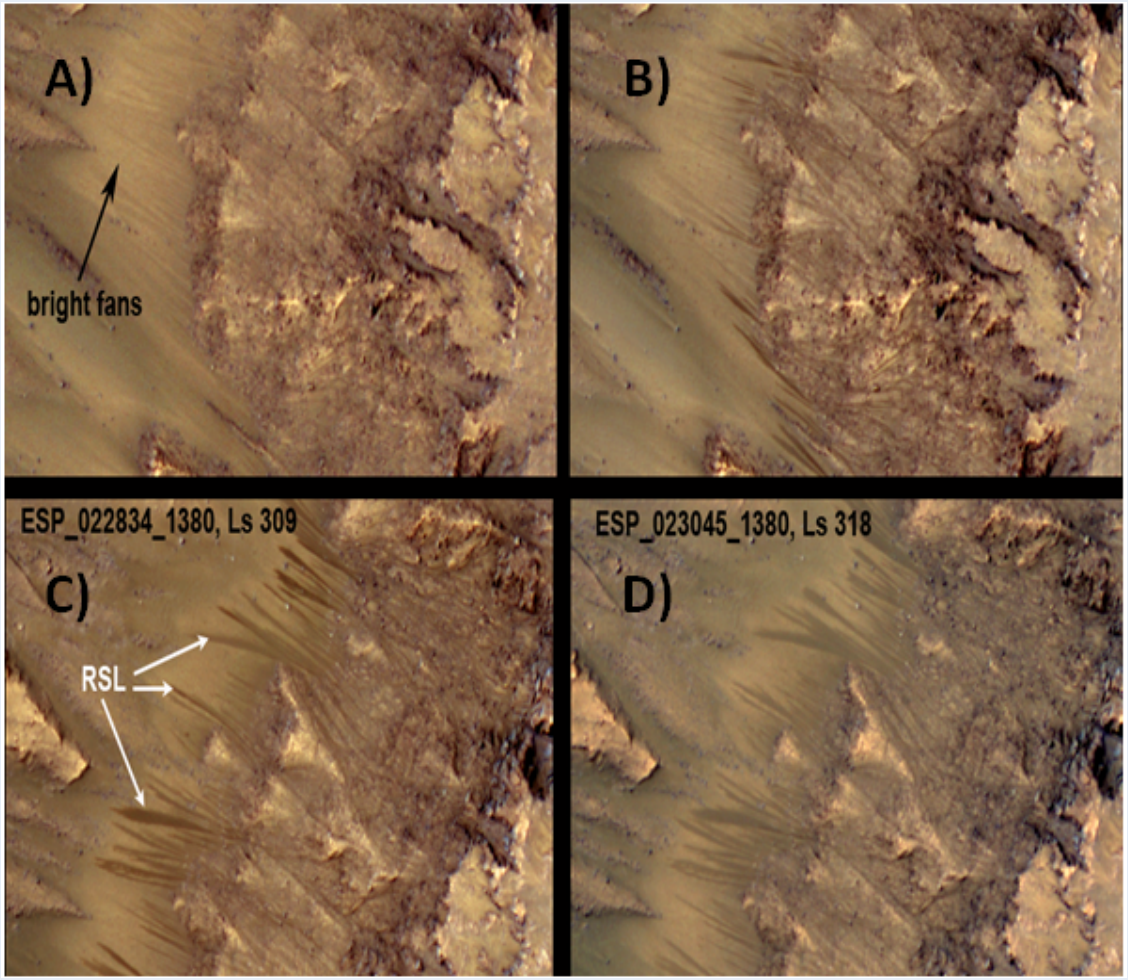
B. Detect and characterize areas of **possible brine flow**, and link these observations with ground ice, temperature, and atmospheric properties to understand the distribution and potential for habitability of volatile reservoirs; representative coverage at different times of day is key. [#7-8]

C. Characterize **dynamic atmospheric processes and transport**, to understand current climate, water, and dust cycles, with extrapolation to past climates. [#9-12]

D. Characterize the **occurrence and timing of major environmental transitions** recorded in compositional stratigraphic records, such as discrete hydrated mineral assemblages, sedimentary bedding, and shallow polar cap layering. [#13]

E. In SEP missions, carry out high-value, close-approach **investigations of Phobos and Deimos.** [#14]

New Discoveries: E.g., Recurring Slope Lineae

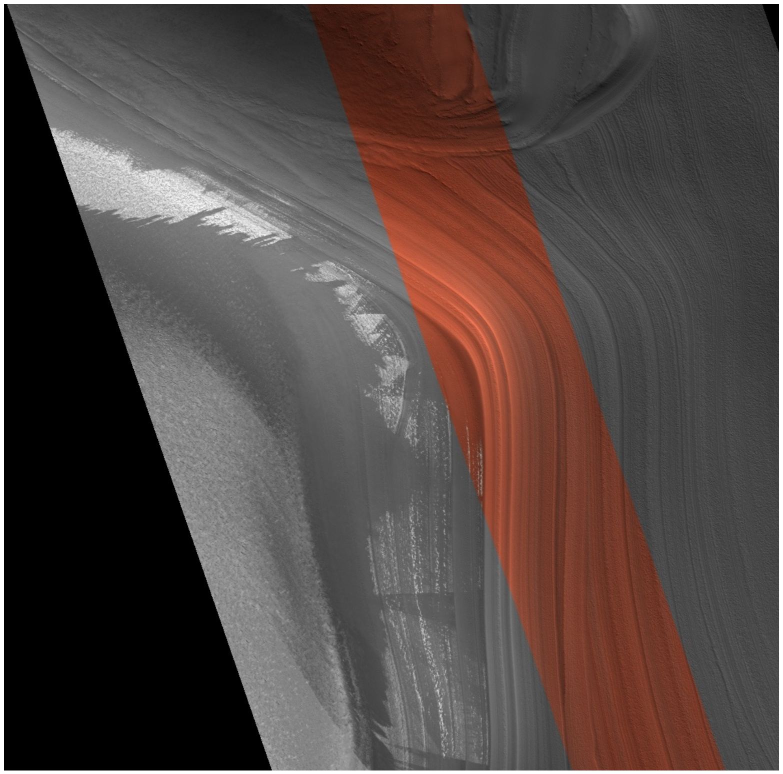


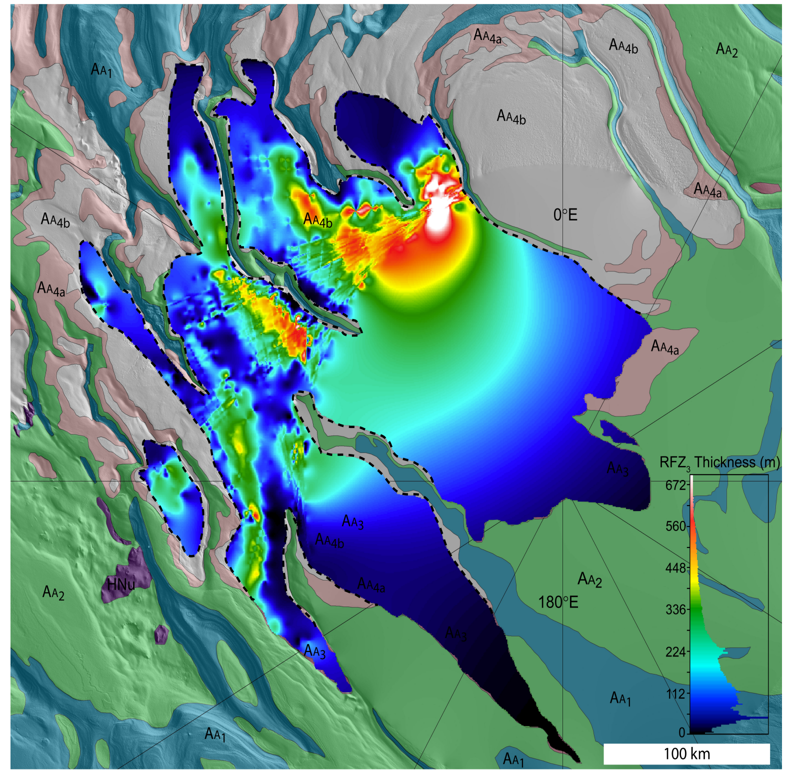
Series of orthorectified images of Palikir Crater in Newton Basin
NASA / JPL / U. Arizona::MRO HiRISE

A. *Faded RSL on bright fans from the previous Mars year and a hint of new RSL in bed-rock regions;*
B. *New RSL appear;*
C. *The RSL lengthen downslope in early southern summer;*
D. *The RSL are fading by mid-summer.*

Changes in hydration state of perchlorate salts have been detected in association with the RSL
(MRO CRISM)
Ohja et al. (2015, Nature Geoscience)

Vision & Voyages for Planetary Science: Polar Sciences



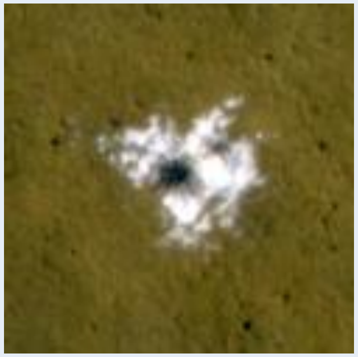


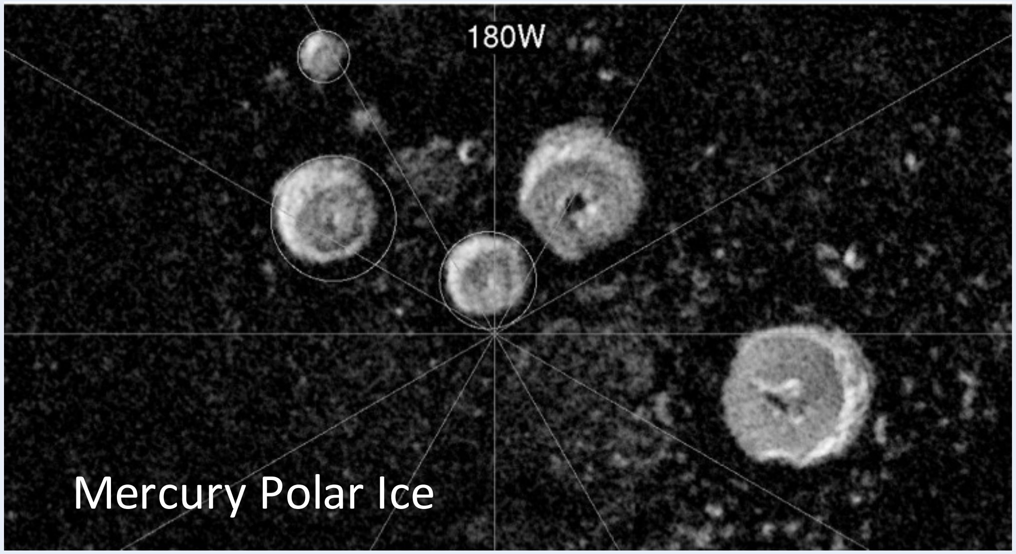
Polar Phenomena

(left) MRO HiRISE image with 1.2 km wide false color strip showing the top of the north polar ice cap and the many fine icy layers exposed at the cap edge (U. Arizona/JPL/NASA). (right) Color shows the thickness of a radar echo-free zone beneath the south polar residual cap, believed to be a buried reservoir of CO_2 ice. The horizontal extent of the reservoir is correlated with a surface geologic unit (Phillips et al., 2011).

Ground Ice Detection and Mapping

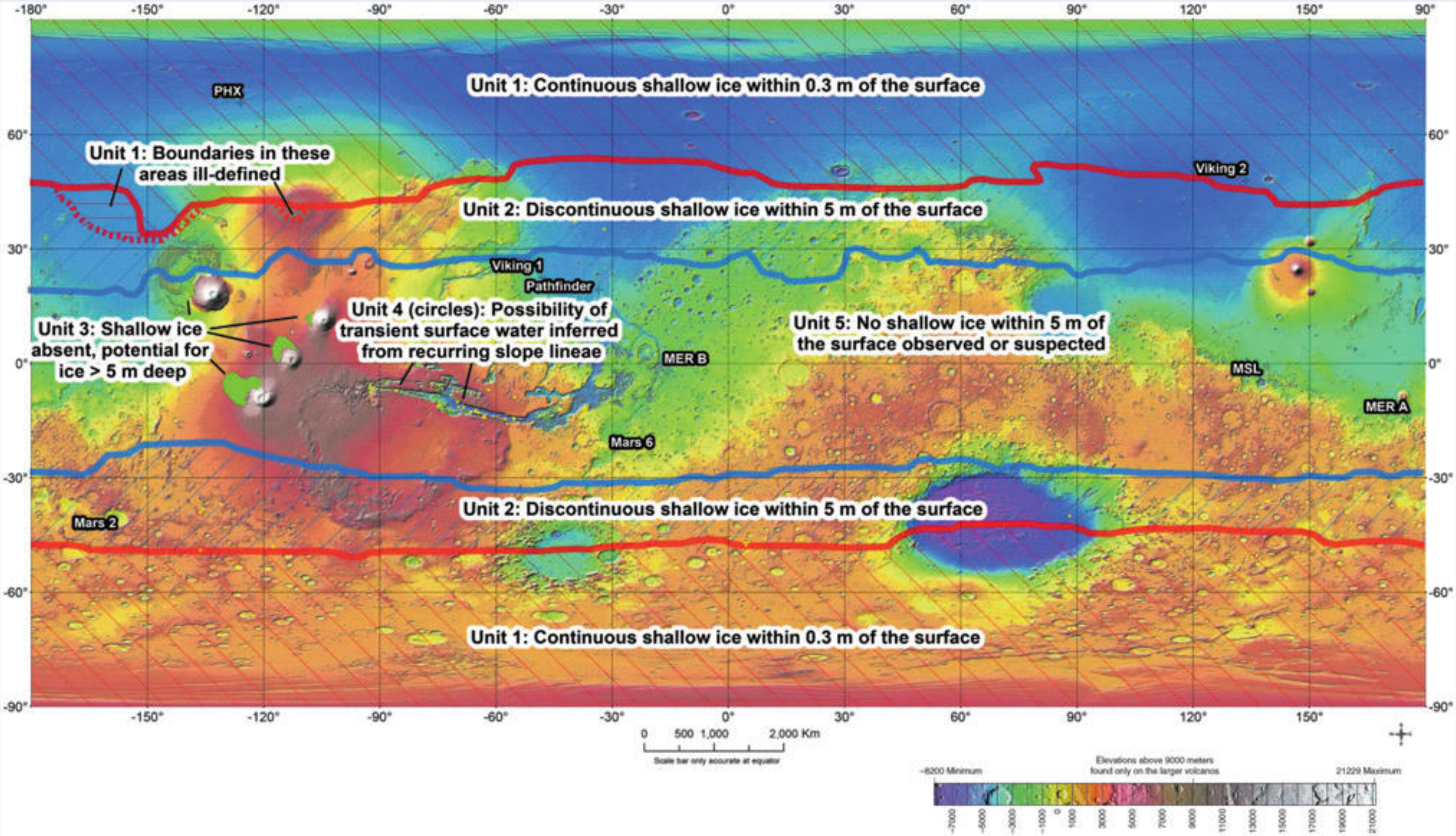
Shallow deposits of clean ice at shallow depth:
- represent a major potential resource for ISRU
- may harbor evidence of past life and climate conditions
- may supply transient outflows (RSL)





DECADAL: Do habitable environments exist today that may be identified by atmospheric gases, exhumed subsurface materials, or **geophysical observations of the subsurface**? What is the global history of ice on Mars? What is the origin of the latitude-dependent ice mantle?

Shallow Ground Ice Distribution



[*Characteristic Regions of Subsurface Ice Near the Surface*]

The map is based on orbiter data and model inference of the depth and spatial continuity of shallow ground ice or potential transient surface water. Map background is MOLA digital elevation model of Mars in simple cylindrical projection. Figure is from Rummel et al. (2014).

NEXT ORBITER SAG: Resource & SKG Objectives

The highest priority resource is water for surface operations, life support, and ascent from Mars. Materials for civil engineering purposes are also of interest. Thus, the following are identified as orbiter objectives:

A. Find and quantify the **extent of shallow ground ice** within a few meters of the surface and its ice-free overburden. [#15]

B. Identify deposits of **hydrated minerals as a water resource**, and potential contaminants; map the distributions of possible special regions (e.g., RSL). [#16]

C. Identify **site-specific mineral resources and geotechnical properties**. [#17]

D. Provide **key information about the Martian moons**. [#14,18]

E. Extend the atmospheric climatology with **diurnal coverage and wind measurements**. [#7,9]

NEXT ORBITER SAG: Measurement Proof-of-Concepts

NEX-SAG identified instrument proof-of-concept measurement capabilities required to address the resource, science, and reconnaissance objectives:

- ***Visible imaging*** of HiRISE-class (30 cm/pixel) or better (~15 cm/pixel);
- ***Polarimetric radar imaging (SAR)*** with penetration depth of a few (<10) meters and spatial resolution of ~15 m/pixel;
- ***Short-wave IR mapping*** with a spatial resolution of ~6 m/pixel with sufficient spectral resolution to detect key minerals;
- ***Long-wave (e.g., sub-mm) atmospheric sounding*** for wind, temperature, & water vapor profiles;
- ***Thermal IR sounding*** for aerosol profiles;
- ***Multi-band thermal IR mapping*** of thermo-physical surface properties (e.g., ice overburden) and surface composition;
- Global, km-scale, ***wide-angle imaging*** to monitor weather and surface frosts.

These proof-of-concept instrument approaches were identified; other approaches may apply.

Such a multi-function orbiter mission appears feasible only with advanced telecommunications capability & the use of Solar Electric Propulsion. [#23-24]

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	**E1.** Comparative bulk densities of satellites	Satellite shape, morphology, gravity	

Table II: Mapping Measurement Requirements to Instrument Type/Proof-of-Concept for Science

Investigation	***Required Measurements (from Table I)***		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
S-A1	Extent & volume of water ice in non-polar regions		B	T		T				✓	✓
	Extent & Volume of buried CO_2 ice in the polar caps		B	T	B	B					✓
	Shallow subsurface structure of polar cap & layered terrain (PLDs)		B	T							✓
	Improved mapping of cap morphology, structure, & composition - as a function of season		T		B	B					✓
S-A2	Seasonal mapping of surface water & CO_2 frost		B		T	T	T			✓	✓
	Polar Radiative Balance				B	T		B	T	✓	✓
	Polar Atmospheric Environment: water vapor, temperature, wind, clouds					B	B	T	T	✓	✓
S-B1	Fine scale morphology	as a function of season & time of day	T							✓	
	Mineralogy, hydration state, & surface temperature		B	B	T	T				✓	
	Water vapor changes in lowermost atmosphere							B		✓	
S-B2	Sediment flux in key locales: including dunes, gullies, dust streaks		T								
S-C1	Vertical profiles of horizontal wind components & T(p) with good precision even in dusty atmosphere;							T		✓	✓
S-C2	Vertical profiles of aerosol (dust & ice), & water vapor							T	T	✓	✓
S-C3	Daily global mapping of dust, clouds, & surface frost						T			✓	✓
S-D	Fine-scale composition & morphology in ancient terrain		T	B	T	B					
S-E1	Phobos/Deimos shape, morphology, gravity		T	B			B				

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

Table III: Traceability of Measurement Objectives for Resources, Telecom, and Reconnaissance

Programmatic Aspect	Relationship to NASA Goals	Science or Exploration Objective	Investigation	Measurable or Required Quantity
Resource Finding & SKGs	Water resources (ISRU), Civil Engineering Priorities	**RS-A.** Ground Ice	**A1.** Detection of very shallow water ice	Identification of regions with water ice present within 10 m of the surface
			A2. Characterize material properties & thickness of dry overburden	Identification of regions where depth of dry overburden is <2 m, and estimation of material thickness & consolidation
		RS-B. Hydrated Minerals	Characterization of water in hydrated minerals	Identification of hydrous minerals exposed at the surface & and estimation of their subsurface distribution
		RS-C. Mineral Resources & Geotechnical Properties	Minerals & surface properties	Mineral abundances & particle sizes; slopes; surface texture, & load bearing strength
	SKGs (atmosphere and moons)	**RS-D.** Characterization of the Martian atmosphere	Enable accurate models of the atmosphere for landing & other such activities	Globally monitor dust, temperature, & wind at all local times & under very dusty conditions
		RS-E. Exploration of the Martian Moons, Phobos & Deimos	**E1.** Shape, morphology, gravity	Gravity field, density, & internal structure of the moons
			E2. Surface composition/properties & resource potential	Identification of geologic units on Phobos & determine regolith physical properties and composition within those units
Telecom & Recon	Program Requirement	Telecom / Relay	Commands/Data Return	Daily contact
		Site Certification	Surface Hazards	Imaging with <1 m spatial resolution (≤30 cm/pixel)
	Program Continuation	Site Characterization & Identification	Potential for Future Discovery or Exploitation	Morphology, mineral composition & abundances, particle sizes, induration, geologic context
		Critical Event Environment & Coverage	Atmospheric Environment at Season of Arrival	Atmospheric density & winds as a function of season & time of day
				Weather
	Possible Program	Planning Rover Traverses from Orbital	Hazard Detection	Ultra-high resolution imaging to plan rover traverses before landing from orbital data alone

Table IV: Mapping Measurement Requirements to Instrument Type/Proof-of-Concept for Resources, SKGs & Reconnaissance

Investigation	***Required Measurements (from Table II)***	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
RS-A1	Detection of very shallow (<10 m depth) water ice	B	T		B				✓	
RS-A2	Characterize material properties & thickness of dry overburden	B	B		T				✓	
RS-B	Characterization of water in hydrated minerals	B		T	B				✓	
RS-C	Mineral abundances and particle sizes; slopes; surface texture, and load bearing strength	T	B	T	T				✓	
RS-D	Globally monitor dust, temperature, and wind at all local times and under very dusty conditions					T	T	T	✔	✔
RS-E1	Gravity field, density, & internal structure of the Phobos and Deimos	T	B			B				
RS-E2	Identification of geologic units on Phobos & determine regolith physical properties and composition within those units	T		T	T					
Reconnaissance	Site Certification: ≤30 cm/pixel resolution required	T								
	Site Characterization: Morphology, mineral composition & abundances, particle sizes, induration, geologic context	T	B	T	T				✓	
	Site Environment: Atmospheric density & winds						T	B	✓	
	Site Environment: Weather					T			✓	

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

NEXT ORBITER SAG: Reconnaissance and Telecom

The findings by NEX-SAG with regard to these mandated functions are:

[#19] ***Improved telecom is required** to acquire the higher-spatial resolution data sets needed to make significant progress on key resource and science objectives. A full order of magnitude increase, through systems such as optical communications, would be required to achieve spatial coverage, at these higher-spatial resolutions, beyond a few percent of the planet.*

[#20] ***HiRISE-class imaging (~30 cm/pixel) is required** for landing site certification for future missions. An improvement to ~10-15-cm resolution would enable significant advances in science, and may be technically feasible so should be considered as resources permit.* [#21] ***NEX-SAG concluded that ultra-high-resolution optical imaging (~5 cm/pixel or better) poses major accommodation challenges.***

[#22] ***Identification and characterization of future landing sites should include atmospheric monitoring to improve environmental models, ground ice prospecting, and mineral mapping to characterize potential landing sites in terms of resource access and of scientific regions of interest. Orbital monitoring of dust storms and of surface asset location would aid planning for missions while operating on the surface.***

NEXT ORBITER SAG: Synergies

[#18] ***NEX-SAG finds that there is strong synergy between the various required functions as a single instrument may address one or more of the science objectives and one or more of the resource, and reconnaissance needs.***

Five particularly strong areas of synergy include:

i. ***High-resolution imaging for site safety, resource access and surface science potential***
ii. ***Locating ground ice***
iii. ***Characterizing hydrated minerals***
iv. ***Mapping out the structure and dynamics of the lower atmosphere, especially with winds & diurnal coverage***
v. ***Further characterization of the moons of Mars.***

Accommodation & Affordability

[#26] ***NEX-SAG notes that there are many possible contributions by international partners, both for spacecraft subsystems and for the payload elements needed to meet the recommended mission measurement objectives.***

- There are major accommodation issues with the full payload, given the possibility of multiple antennas and of conflicting space and planet view desires. These are a natural part of this mission with its desired multiple functions.
  - Early definition of the spacecraft capability will provide the needed scope for a Resource-Science Definition Team to see what fits and to prioritize accordingly.
  - It is clear that solar electric propulsion and advanced telecom would likely be required to support any mission beyond basic relay-reconnaissance (certification) functions.
- *The major limitation to exploiting the full capabilities of a SEP mission is likely to be payload cost, not mass or power.*

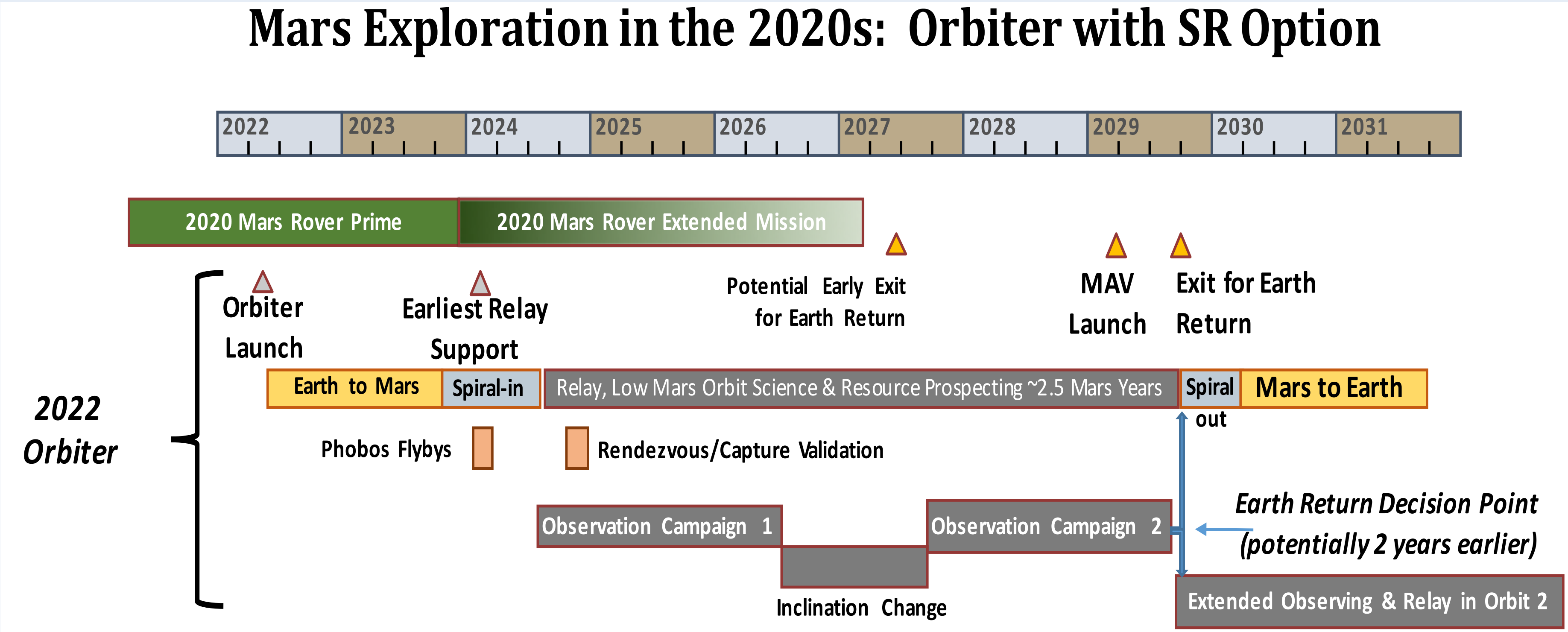
Table V: Mission Concepts—Required Measurement Approaches

Mission Concept	*Investigations Addressed (See Tables III-IV)*	Imaging	Very Shallow Radar	NIR Mineral Mapping	Thermal-IR mapper	Wide Angle Camera	Sub-mm: T,wind, water (v)	Thermal-IR Sounder	LTOD Coverage	Nadir Polar Coverage	Payload (kg) T(B)
ALL	All Functions/Objectives (Including Phobos & Deimos with SEP)	T	T	T	T	T	T	T	✔	✔	225 kg
Ground Ice	Find shallow ground ice and overburden outside pole; RS-A1, RS-A2, S-A1, S-A2 (partial: frost), S-B2	T	T	B	T	B				✔	130 (175)
RSL	RSL fine structure & hydration state; Environmental Transitions; RS-B, RS-C, S-B1, S-B2, S-D	T	B	T	T		B		✔		105 (210)
Atmosphere+AtmSKG +Recon	Winds, temperature & aerosol profiles, RS-E, S-C1,2,3, S-B2	T				T	T	T	✔	✔	105 (105)
Phobos-Deimos	Identify geologic units and constrain densities; RS-D, S-E	T	B	T	T						105 (170)
Reconnaissance	Certify sites (T); characterize new ones(baseline): RS-B, RS-C, RS-E (baseline), S-B2	T		B	B	B	B or B		✔		50 (120 or 150)
R= Resource, S=Science, N = Objective (A,B,C,D,E), #=1 or 2		T = Threshold					B = Baseline (includes Threshold)				
	Instrument Concept Estimated Mass	50	65	40	15	5	40	10			

Legend for Tables III-V:

Investigation: S=Science/RS= Resource & SKGs, -# = Objective/Investigation	T = Threshold	B = Baseline (includes Threshold)

NEXT ORBITER SAG: Two Mission Scenarios



Pre-decisional; for discussion purposes only

New Mission Capabilities

- **Orbiter:**
  - ***First-time use of SEP in Mars orbit:***
    - Numerous fly-bys during spiral-in to low Mars orbit (SKG & moons)
    - Capability to return cache to Earth vicinity
    - Fuel-efficient orbital inclination changes: Diurnal coverage followed by polar coverage
  - ***Advanced telecom:*** Provides adequate coverage even with high-data-volume instruments

- **Payload**
  - ***Imaging:*** Greater HiRISE-class spatial coverage (*Reconnaissance, Site certification, Science & Resources*)
  - ***Very shallow radar:*** First use of polarimetric radar imaging to characterize ice within a few meters of the surface (*Resources & Science*)
  - ***Improved resolution of near and thermal IR mapping:*** Bring compositional spatial resolutions closer to those of visual imaging (*Resources & Science*)
  - ***Sub-mm profiling:*** First acquisition of global measurements of winds and of vertical profiles of temperature and water vapor even in the presence of atmospheric dust (*Science & SKG, model validation*)
  - ***Wide-angle imaging, thermal IR sounding:*** Extended near-simultaneous weather and aerosol profile data (*Science & SKG, model validation*)

NEXT ORBITER SAG: Summary

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

- Replenish the telecommunications and reconnaissance capability currently provided by orbiters now well into their extended missions.
- Find resources on Mars for future missions, especially in support of human surface exploration. The key resource is water, as ice or hydrated material.
  - Conduct survey of Phobos and Deimos through remote sensing on multiple close fly-bys of the moons for both human exploration and science goals.
- Conduct new science investigations, consistent with high priority questions of the Decadal Survey and the recently updated MEPAG goals.
- Demonstrate progress towards potential sample return in Mars orbit, thru:
  - Relay back-up for the 2020 Mars caching rover & nominal relay for future missions, including one that takes the sample cache into orbit.
  - Rendezvous and capture capability for return of Mars samples to Earth.

A multi-purpose orbital mission in the early 2020's would pioneer resource prospecting for humans on Mars and would make major advances in our scientific understanding of Mars and its evolution, while providing reliable telecommunications and reconnaissance for future human and robotic missions exploring Mars.

NEX-SAG Findings

from

Final Report (December 14, 2015)

http://mepag.nasa.gov/reports.cfm

Findings 1-8

Finding # / report pg.	TEXT of FINDING
1/ p10	NEX-SAG finds that a demonstration of rendezvous and capture or actual return of a retrieved container/cache to Earth vicinity would likely require SEP capability, especially if other high-priority resource and science objectives are to be pursued. Return of an actual cache of Mars samples would fulfill the Decadal Survey's highest flagship priority.
2 / p11	NEX-SAG finds that an orbiter launched in 2022 could be needed to provide critical support for the 2020 Mars rover and would help accelerate both potential sample return and preparations for human missions to Mars. A 2022 launch would also provide opportunities for inter-comparison and synergistic observations with existing orbiters, nearing their end-of-life.
I. Science	
3 / p15	Measurements that could determine the location, thickness, concentration, and depth of buried ground ice – as well as the chemistry of associated mineral alteration and salts – are important for understanding the current climate and past climate cycles on Mars.
4 / p15	Measuring the precise volume of the recently-discovered polar CO_2 ice reservoirs would better constrain atmospheric density during prior epochs, when obliquity cycle variations could have sublimated the current or similar buried CO_2 ice deposits and enabled liquid water to be stable for longer periods over more of the planet.
5 / p17	Knowing the timing of geologically recent climate variations is fundamentally important to understanding Mars. Measurements of the polar layers and the seasonal and annual evolution of near-surface layers are needed to understand the evolution of the poles and the formation of lower latitude surface and subsurface ice deposits.
6 / p17	Measurements over the diurnal cycle at sub-seasonal timescales are necessary to understand the recent climate history of Mars. Formation of snow and frost are highly sensitive to temperature change, as is volatile transport through the atmosphere. Characterizing the cumulative effect of these diurnally varying processes may be key to understanding the overall exchange between the, poles and non-polar latitudes.
7 / p18	Recurring Slope Lineae (RSL) are a significant discovery since the Decadal Survey. Their morphology and spectral properties are most consistent with flow on Mars today of liquid water, enabled by deliquescent salts or some other process. Understanding RSL processes and sources requires seasonal measurements of their morphology, chemistry, and temperature at high spatial resolution and as a function of time of day.
8 / p20	Continued monitoring of dynamic processes in sand dunes, ripples, dust devils and localized regions of high dust loading will help in understanding aeolian volumetric sediment transport, near-surface convection, dust lifting, and dust storm initiation. Repeat imaging of dynamic surface changes, including gullies, will constrain the role of volatiles and sediment transport processes.

Findings 9-16

Finding # / report page	TEXT of FINDING
9 / p21	Observation of wind velocity is the single most valuable new measurement that can be made to advance knowledge of atmospheric dynamic processes. Near-simultaneous observations of atmospheric wind velocities, temperatures, aerosols, and water vapor with global coverage are required to properly understand the complex interactions that define the current climate.
10 / p22	Current orbiter remote sensing can provide boundary conditions for modeling exchange between the surface and atmosphere, but cannot achieve the vertical resolution needed for direct determination of fluxes of volatiles, mass and energy close to the surface.
11 / p23	Representative diurnal sampling on a timescale less than a Martian season is required to identify how atmospheric phenomena change with varying solar input and to remove aliasing associated with key measurements such as atmospheric temperatures and winds in the context of thermal tides.
12/ p23	Continued observation of the general atmospheric state is required to evaluate further the degree of interannual variability and the presence of secular trends. A minimum set of daily global visual imaging, atmospheric temperature profiles, and daytime column amounts of dust, water ice, and water vapor is required to maintain the decades-long record begun by MGS, Odyssey, and MRO.
13 / p24	Recent exploration has revealed enormous diversity in secondary mineralogies formed by reaction of liquid water with the ancient crust. Higher spatial resolution and broader wavelength range measurements of stratigraphy, mineralogy, and texture are required to understand environmental settings and biosignature preservation potentials of distinctive aqueous deposits >3.5 Ga in age.
14 / p26	The use of SEP and the payload capabilities needed to address the reconnaissance, resource, and science objectives at Mars allow high-value science observations of Phobos and Deimos necessary to plan future missions to these moons.
II. Resources, Strategic Knowledge Gaps	
15 / p31	A combination of thermal IR mapping and polarimetric imaging radar, especially if augmented with a sounding mode, should be able to detect ice within a few meters of the surface and to estimate the depth and physical character of dry material above it (overburden).
16 / p31	High-spatial-resolution observations in the short-wave IR with sufficient spectral resolution, aided by thermal IR spectral mapping, can identify hydrous minerals exposed at the surface, although with uncertainties in extrapolation to water content at depth. Extrapolating hydration at the optical surface to the subsurface accurately depends on the types of minerals present, dust cover, and the presence of adsorbed water especially at low latitude.

Findings 17-22

Finding # / report pg.	TEXT of FINDING
17 / p32	A better understanding of which hydrated minerals can provide a practical resource to support humans on Mars is required, so that prospecting from orbit can be focused appropriately.
18 / p34	NEX-SAG finds that there is strong synergy between the various required functions as a single instrument may address one or more of the science objectives and one or more of the resource, and reconnaissance needs. Four particularly strong areas of synergy include: i) the location of ground ice, ii) the characterization of hydrated minerals, iii) the structure and dynamics of the lower atmosphere, and iv) the moons of Mars.
II. Reconnaissance and Telecom	
19 / p34	Improved telecom is required to acquire the higher-spatial resolution data sets needed to make significant progress on key resource and science objectives. A full order of magnitude increase, through systems such as optical communications, would be required to achieve spatial coverage, at these higher-spatial resolutions, beyond a few percent of the planet.
20 / p35	HiRISE-class imaging (~30 cm/pixel) is required for landing site certification for future missions. An improvement to ~10-15-cm resolution would enable significant advances in science, and may be technically feasible so should be considered as resources permit.
21 / p35	Although enhancing for many science objectives and helpful for rover operations planning, NEX-SAG concluded that ultra-high-resolution optical imaging (~5 cm/pixel or better) poses major accommodation challenges.
22 / p36	Identification and characterization of future landing sites should include atmospheric monitoring to improve environmental models, ground ice prospecting, and mineral mapping to characterize potential landing sites in terms of resource access and of scientific regions of interest. Orbital monitoring of dust storms and of surface asset location would aid planning for missions while operating on the surface.

Findings 23-26

Finding # / report page	TEXT of FINDING
IV. Mission Scenarios and **V. Mission Concepts**	
23 / p46	Accomplishing all the highest-priority science objectives on a single mission will require a phased mission design. For example, investigation of both RSL and volatile cycling processes requires sampling across the full diurnal cycle repeatedly within each Mars season, from a moderately inclined orbit, as well as observations from a high-inclination orbit for polar science.
24 / p49	Accomplishing a substantial subset of the desired measurement objectives (described above) will require a spacecraft and payload more capable than MAVEN/MRO. Only a SEP-powered system has the necessary resources (payload and mass) to support the full complement or a majority of the payload measurement approaches and the orbital configurations that NEX-SAG finds necessary to meet the multi-function mission objectives.
25 / p50	In the event of "extra" spacecraft capability, an openly competed call promoting the submission of daughtercraft concepts within defined constraints would expand the opportunities for the scientific and exploration community and promote opportunities for innovative Mars system exploration concepts. This should not displace the capabilities and funding needed to accomplish the strategic objectives proposed by NEX-SAG for a 2022 Orbiter.
26 / p50	NEX-SAG notes that there are many possible contributions by international partners, both for spacecraft subsystems and for the payload elements needed to meet the recommended mission measurement objectives.