MEPAG Science Analysis Group Updates on a potential Next Mars Orbiter

July 13, 2017

Next Mars Orbiter SAG: NEX-SAG, Report 12/2015
Mars International Collaboration Analysis Group: MIC-SAG, Report February 2017
https://mepag.jpl.nasa.gov/reports.cfm

Richard Zurek
Jet Propulsion Laboratory
California Institute of Technology

Recent MEPAG Science Analyses on Mars Architecture

Two recent studies are:

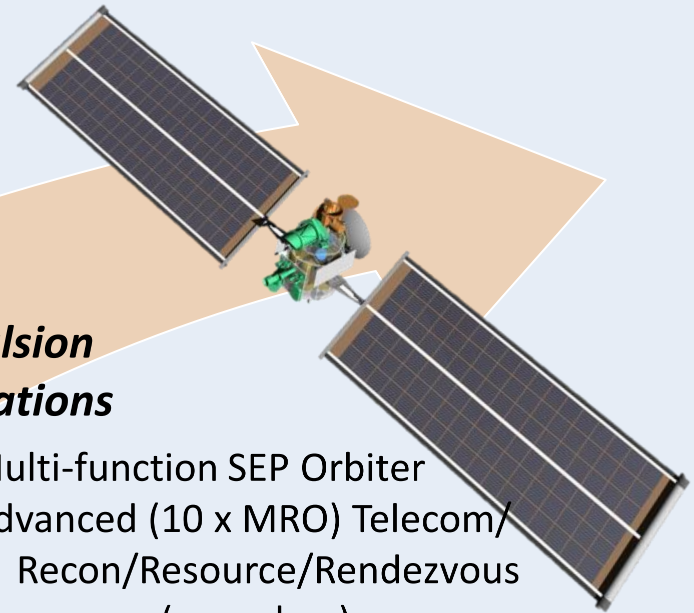
- **NEX-SAG: Next Mars Orbiter MEPAG Science Analysis Group**
  - Chartered in April 2015 by SMD & HEOMD
  - Task: Analyze possible science objectives and their synergies with other components, including resource characterization, of a potential multi-function, next-generation Mars Orbiter, to be launched in the early 2020's
  - SAG Co-chaired by Bruce Campbell (Smithsonian Institution) and Rich Zurek (MPO, JPL); interacted with ISRU-Civil Engineering Working Group thru Steve Hoffman
- **MIC-SAG: Mars International Collaboration Science Analysis Group**
  - Task: Assess options for international Mars mission collaborations
    - Not discussed here in detail except in the context of the next Mars orbiter
  - Chaired by Bruce Jakosky (U. Colorado), supported by R. Zurek (MPO-JPL)
- **Reports are available on https://mepag.jpl.nasa.gov/reports.cfm**

NEX-SAG Charter Directives

- **Replenishment of Infrastructure**
  - Telecom (5-year lifetime)
  - Reconnaissance (surface; atmosphere)
    - Characterize/certify future landing sites & exploration zones
    - Provide critical environmental data for mission design and surface ops
- **Resource Prospecting & Strategic Knowledge Gaps (SKGs)**
  - The primary resource interest is accessible water (shallow ice or hydrated mineral deposits)
  - Considered additional SKGs 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 as recommended in *V&V2011*
    - Polar Science
  - Follow-up on new discoveries (e.g., RSL, Ice Ages, Mineral Diversity)
- **Consider a Range of Mission Capabilities:**
  - Low-cost mission, with chemical propulsion supporting telecom and reconnaissance payload
  - Discovery to NF cost-class mission, with advanced telecom, reconnaissance, and added remote sensing payload, utilizing Solar Electric Propulsion (SEP)

Mission Capability Concepts for a Potential Mars Orbiter

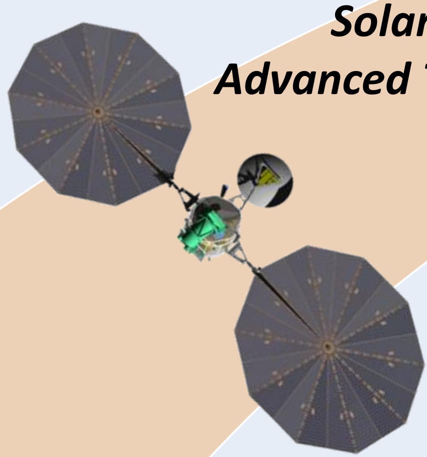
Class 3:
Exploration SEP
NASA Components
1000 – 2000 kg Bus
200 – 800 kg P/L
>5 kW for P/L



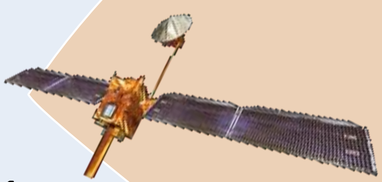
Solar Electric Propulsion
Advanced Telecommunications

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

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)

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Vision & Voyages (2011) on the Priority for 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. <u>Return of an actual cache of Mars samples would fulfill the Decadal Survey's highest flagship priority.</u>***

NEXT ORBITER SAG: Science Objectives

In addition to relay, reconnaissance, and sample return objectives, NEX-SAG recommended the following as possible science objectives for future orbiter missions:

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]

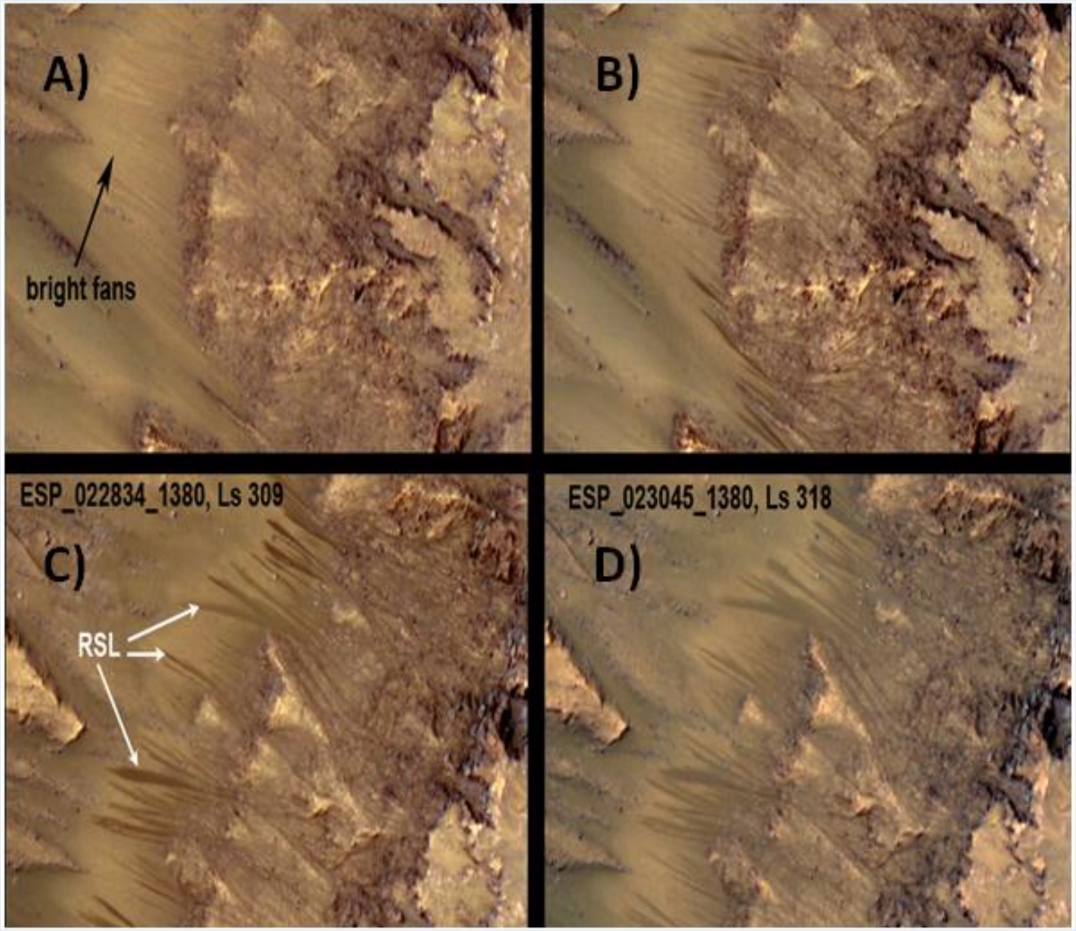
B. Detect and characterize areas of **possible brine flow**, and link these observations with ground ice, temperature, and atmospheric properties to understand the distribution and potential for habitability of volatile reservoirs; representative coverage at different times of day is key. [#7-8]

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



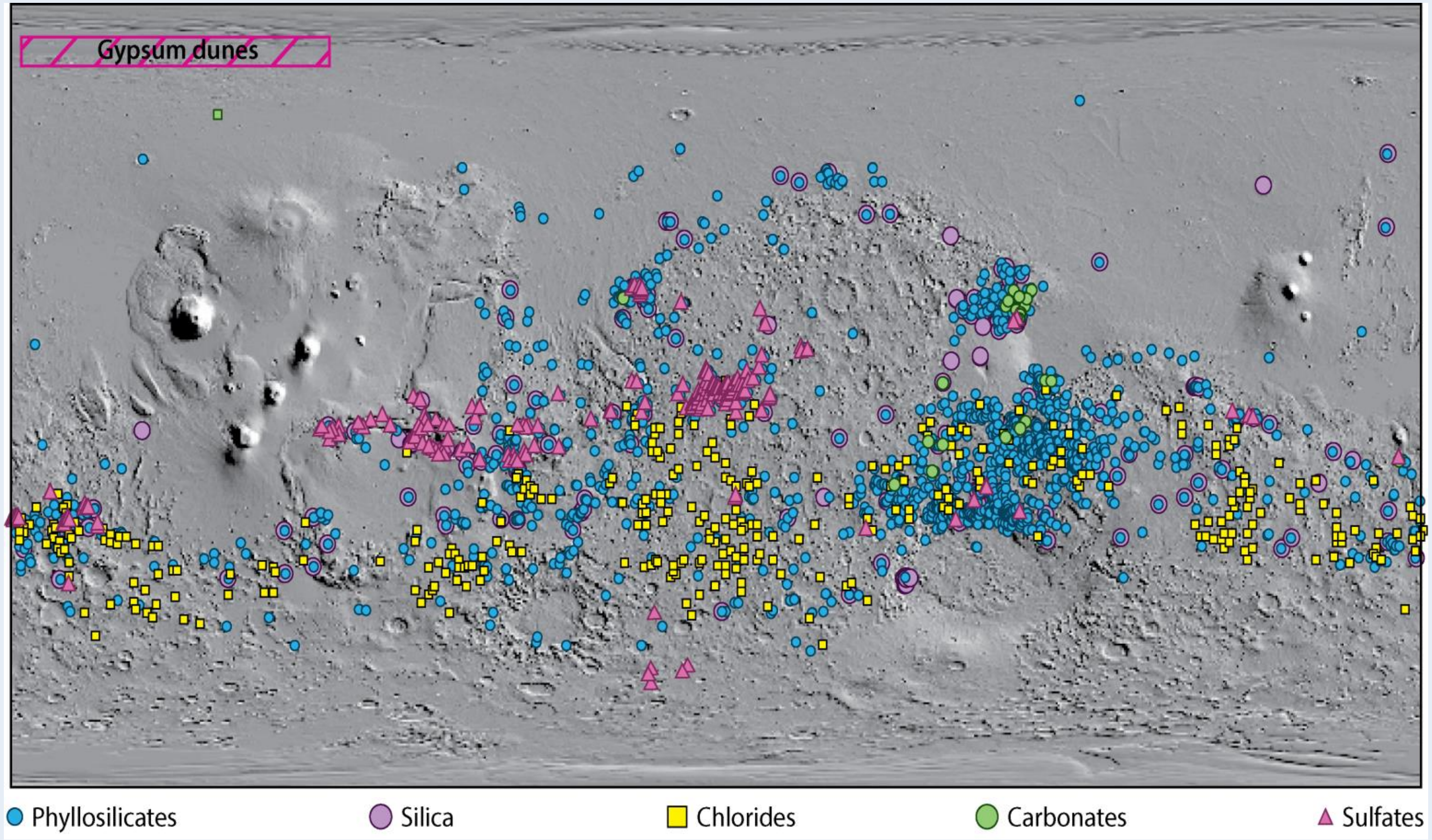
Series of orthorectified images of Palikir Crater in Newton Basin
NASA / JPL / U. Arizona / MRO HiRISE

Status:

A. Pro-brine
- *Warm temperature phenomena*
- *Downslope elongation & fade*
- *Associated with changes in salt hydration state*

B. Anti-brine
- *Thermal Inertia => little H_2O*
- *Lower slopes at angle of response => dry avalanching*

A Possible Resource: Hydrated Minerals



Observed Outcrops of Minerals That Formed in Liquid Water.
These deposits could yield resources for future human missions.
Figure is from Ehlmann & Edwards (2014).

Table 1: 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		
(non-MSR) **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	

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NEXT ORBITER SAG: Resource & SKG Objectives

The highest priority resource identified by the* HEOMD ISRU (In Situ Resource Utilization)-Civil Engineering Working Group *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]

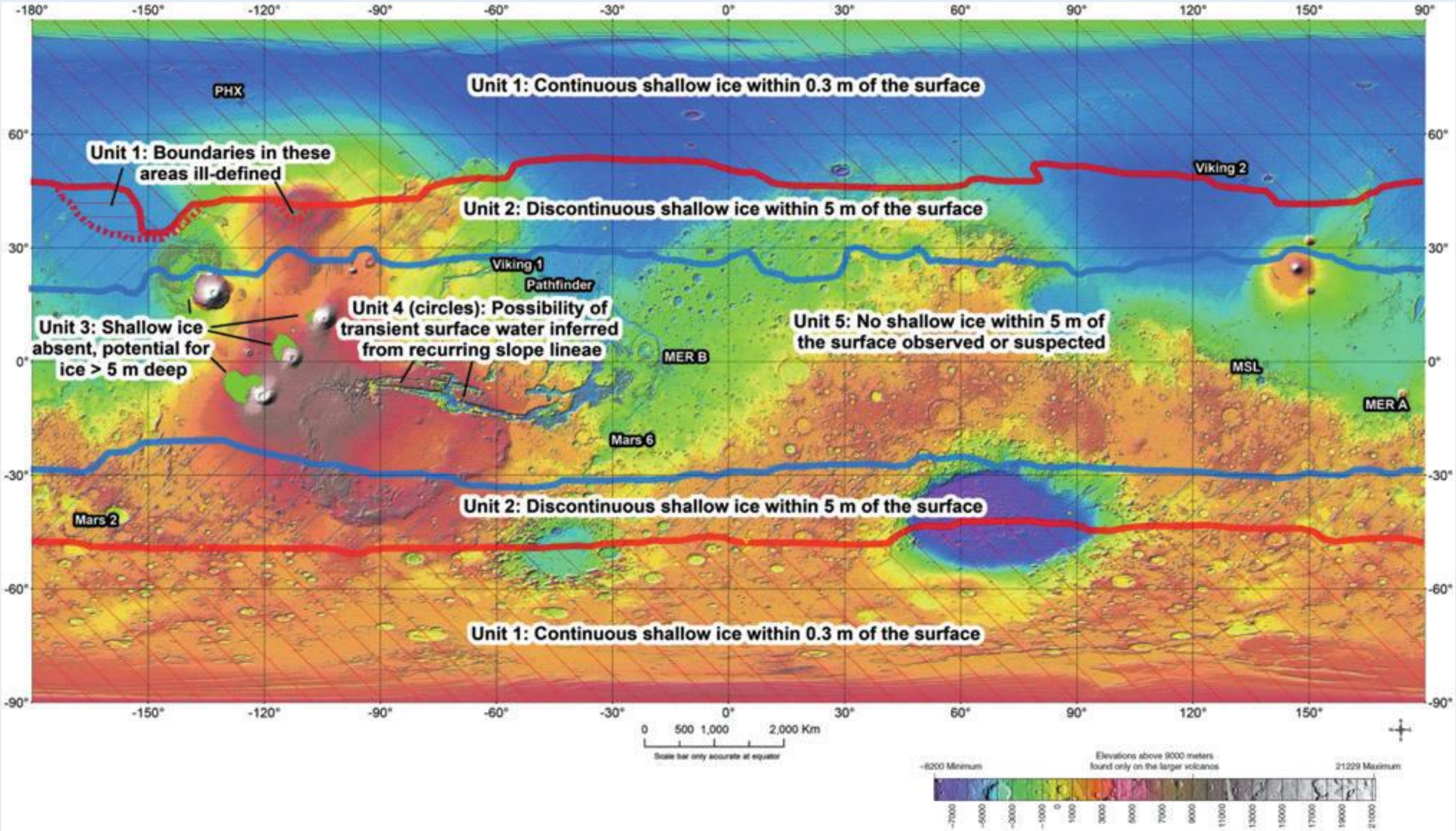
B. Identify deposits of **hydrated minerals as a water resource**, and potential contaminants; map the distributions of possible special regions (e.g., RSL). [#16]

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]

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: 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.***

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); stereo and color imaging needed;
- ***Polarimetric radar imaging (SAR)*** with penetration depth of a few (<10) meters and spatial resolution of ~15 m/pixel; key to both science & resources;
- ***Short-wave IR mapping*** with a spatial resolution of ~6 m/pixel with sufficient spectral resolution to detect key minerals, needed for science & resources;
- ***Long-wave (e.g., sub-mm) atmospheric sounding*** for first wind fields and for temperature & water vapor profiles, even in the presence of airborne dust; key to model validation;
- ***Thermal IR sounding*** for mapping of aerosols, which affect atmospheric state;
- ***Multi-band thermal IR mapping*** of thermo-physical surface properties (e.g., ice overburden) and surface composition;
- Global, km-scale, ***wide-angle imaging*** to extend weather monitor monitoring.

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

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 C:1	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)
Modern/Ancient Water Environ. C:2	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 C:3	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)

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NEX-SAG "Proof-of-Concept" Measurement Template

Instrument	Purpose	Wavelength	Spatial Resolution	Best when combined with
Visible Imager (camera)	**Required:** High spatial resolution at high signal-to-noise for science & site certification; color and stereo required (ability to resolve 1-m scale features)	**Required:** Multiple visible/NIR bands (minimum 2). **Highly desired:** ≥3 color bands.	**Required:** ≤0.3 m/pixel, including color, with high SNR (≥100) **Desired:** 10-15 cm/pixel at high SNR	With any/all payload 1,2,3
Polarimetric Synthetic Aperture Radar (PSAR)	**Required:** Detect and map relatively pure shallow water ice for science and resource utilization	**Required:** 20 < λ < 100 cm in free space, dual circular polarization. **Highly Desired:** ~60 cm free space, full polarization.	**Required:** Detection of ice within 5-10 m of the surface. 30 m/pixel horizontal resolution. **Highly Desired:** Detection of ice layers within 2 m of the surface. ~15 m/pixel horizontal resolution. **Desired:** Sounding mode (single received polarization OK)	Combination 1 (Ice Science/Resources)
Wide Angle Imager (weather camera)	**Required:** Ability to create daily global maps of Mars weather	**Required:** Visible bands. Desired: Additional UV band for Ozone; SWIR bands for frost	**Required:** ~1 km/pixel, wide FOV for daily global maps	Combination 3 Can be packaged with other combinations.
Microwave Radiometer	**Required:** Water vapor & temperature profiles. **Highly Desired:** Wind profiles.	**Required:** Minimal sensitivity to atmospheric dust and ice particles. Likely requires operation at microwave to submillimeter wavelengths. H	**Required:** ~10 km vertical resolution from 0-50 km. **Highly Desired:** ~5 km vertical resolution of profiles from 80 km to within 5 km of surface. **Highly Desired:** Wind profiles with accuracy of ≤20 m/s below 50 km and vertical resolution ≤10 km.	Combination 3 Should be flown with an aerosol mapper (e.g., IR Sounder).
IR Sounder (Atmosphere)	**Required:** Atmospheric temperature & aerosol vertical profiles. **Highly Desired:** Water vapor profiles at similar vertical resolutions	**Required:** Thermal IR channels; selected bands or spectrally resolved channels for temperature and water ice. **Highly Desired:** Thermal IR channels to profile water vapor.	**Required:** ~10 km vertical resolution from 0-50 km. **Highly Desired:** ~5 km vertical resolution of temperature & aerosol profiles from 80 km to within 5 km of surface. Water vapor ≤30 km.	Combination 3 (Atmosphere Sci/SKG)
IR Mapper Radiometer/Spectrometer (Surface)	**Required:** Map thermal inertia at high spatial resolution	**Required:** Thermal IR channels to measure ground temperatures.	**Required:** ≤30 m/pixel. **Highly Desired:** ~15 m/pixel.	Combinations 1,2
SWIR Spectrometer	**Required:** Detection of aqueous minerals for science & resource utilization	**Required:** SWIR (solar reflected) bands or spectrum in the 1-4 µm needed to detect aqueous minerals (e.g., hydrated sulfates, phyllosilicates, carbonates). **Desired:** Spectral resoltuion adequate to detect both primary and secondary minerals, salts & ices (≤10 nm).	**Required:** ~6 m/pixel; good SNR at various times of day (light)	Combination 2 (Geological Science/Resources)

Legend

NEX-SAG view:	**Required:** Addresses Objective	**Highly Desired:** Really want these additions/improvements	**Desired:** Additionally Desired Capability

NEXT ORBITER SAG: Two Mission Scenarios

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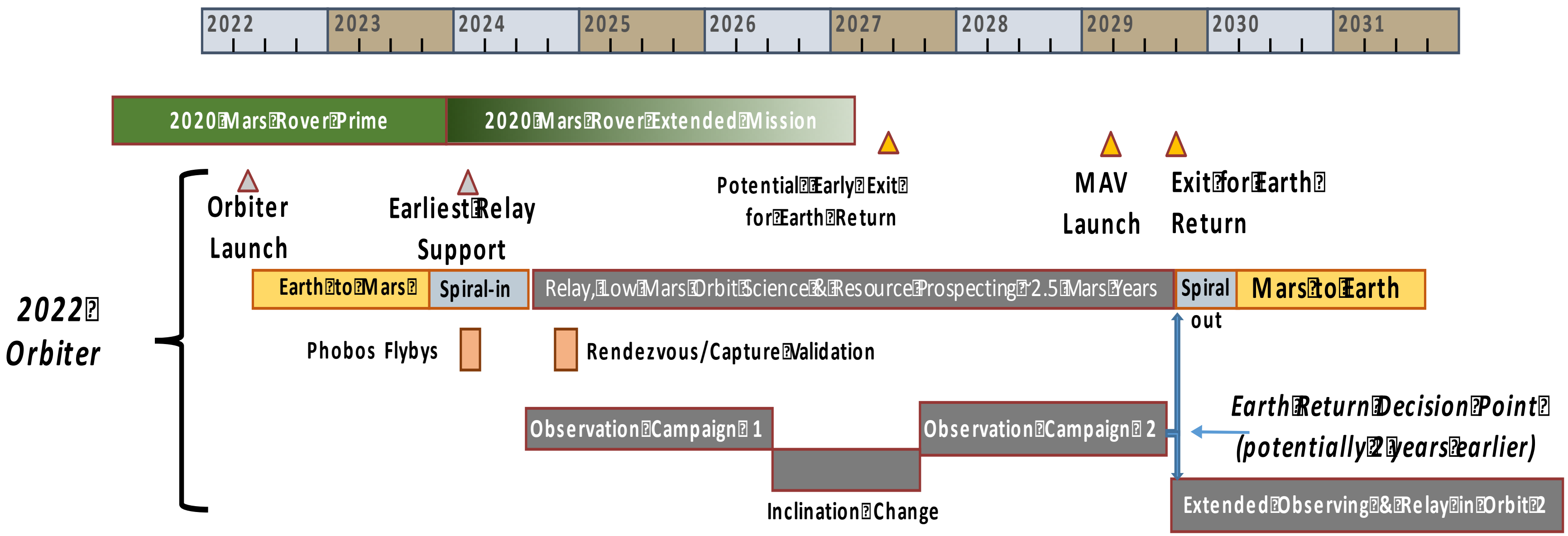
Mars Exploration in the 2020s: Orbiter with SR Option



NEX-SAG recommended a launch in 2022 because that would:

- Support relay for ongoing missions, including the Mars 2020 rover in its first extended mission
- Support a landed fetch rover and MAV in a timely way to potentially return Mars samples to Earth by ~2031
- Make good progress on landing site & environmental information to plan for possible human exploration in the 2030's

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.*** ***[Consistent with MEPAG MIC-SAG study.]***

- 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. ***[This awaits commitment to a project.]***
  - It is clear that solar electric propulsion and advanced telecom would likely be required to support any mission beyond basic relay-reconnaissance (certification) functions. ***[This was confirmed for SEP by inputs to the MPO from 5 major contractors in response to a RFP.]***
- *The major limitation to exploiting the full capabilities of a SEP mission is likely to be payload cost, not mass or power.* ***[Cost, especially if seen as a commitment to the possible return of samples, is a key issue.]***

NEX-SAG Summary

An optimal multi-purpose orbital mission in the early 2020's could:

1) ***Provide reliable telecommunications and reconnaissance for robotic missions which:***
   a) ***Explore Mars, including a possible extended mission of the 2020 Mars rover***
   b) ***Aid planning for possible human missions to the planet***
2) ***Pioneer resource identification that could aid plans for exploration by humans on Mars, and***
3) ***Advance our scientific understanding of Mars and its evolution in a major way.***

NEX-SAG notes that such a mission would, if it were to actually return the samples cached by the 2020 Mars rover, fulfill the Decadal Survey's highest flagship priority for Mars.

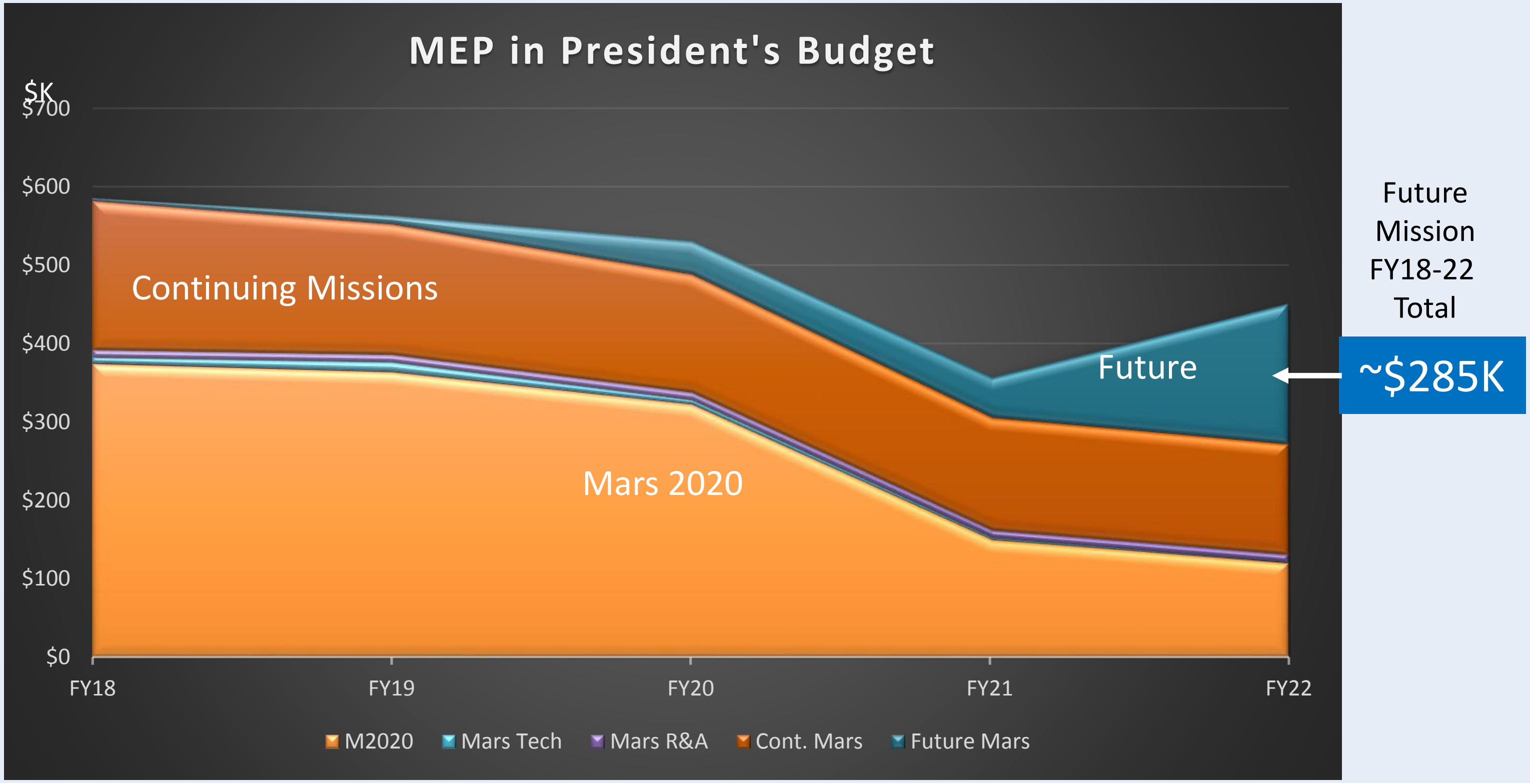
Where are we today?

There are no approved Mars flight projects after Mars 2020.

With respect to a next Mars orbiter:

- **Orbiter concepts are being studied at a low level**
  - There is no formal pre-project
  - SEP still looks like an enabling approach to Mars orbital missions
- **The out-year funding wedge in the President's FY18 budget:**
  - Does not specify a mission and does not support a Mars launch in 2022
  - If for a 2024 launch, the wedge appears inadequate to support rendezvous and capture of an orbiting cache, and
  - Remote sensing beyond imaging would likely have to be provided by international partners;
    - MIC-SAG noted that early agreement with partners and clear lines of authority would be essential to mission success.
    - MIC-SAG argued for well-defined, funded opportunities for US investigators to participate as a means of preserving national capabilities
- **MEP/PSD is discussing options with other space agencies for payload elements and possibly spacecraft subsystems**
  - NEX-SAG "proof-of-concept" payload is used in those discussions
  - However, it is difficult for others to commit before NASA does

FY2018 President's Budget Request Summary



Graph generated from numbers presented within
https://www.nasa.gov/sites/default/files/atoms/files/fy_2018_budget_estimates.pdf
"NASA FY 2018 Budget Estimates"

Back-Up

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

MIC-SAG membership

MIC-SAG members	
Bruce Jakosky	University of Colorado, Boulder; *Chair*
Jim Bell	Arizona State University
Barbara Cohen	Goddard Space Flight Center
Joy Crisp	Jet Propulsion Laboratory
Frank Eparvier	University of Colorado, Boulder
Don Hassler	Southwest Research Institute
Alfred McEwen	University of Arizona
Kim Seelos	Johns Hopkins University Applied Physics Laboratory
Roger Yelle	University of Arizona
MIC-SAG Ex Officio	
Rich Zurek	Mars Program Office, Jet Propulsion Laboratory; *Lead*
Serina Diniega	Mars Program Office, Jet Propulsion Laboratory
Jeffrey Johnson	Johns Hopkins University Applied Physics Laboratory; *MEPAG Chair*
Michael Meyer	NASA Headquarters; *MEP Lead Scientist*