PMCS - MORIE

Planetary Mission Concept Study:

Mars Orbiter for Resources, Ices and Environments

Wendy Calvin for Decadal Survey Steering Committee May 27, 2021

See also recently published PSJ article: https://iopscience.iop.org/article/10.3847/PSJ/abe4db

TEAM

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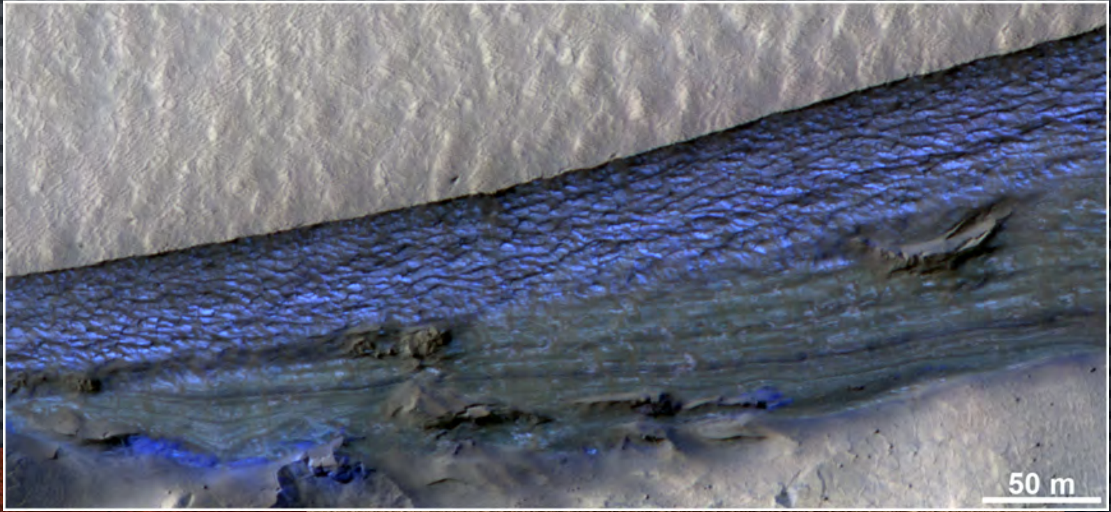
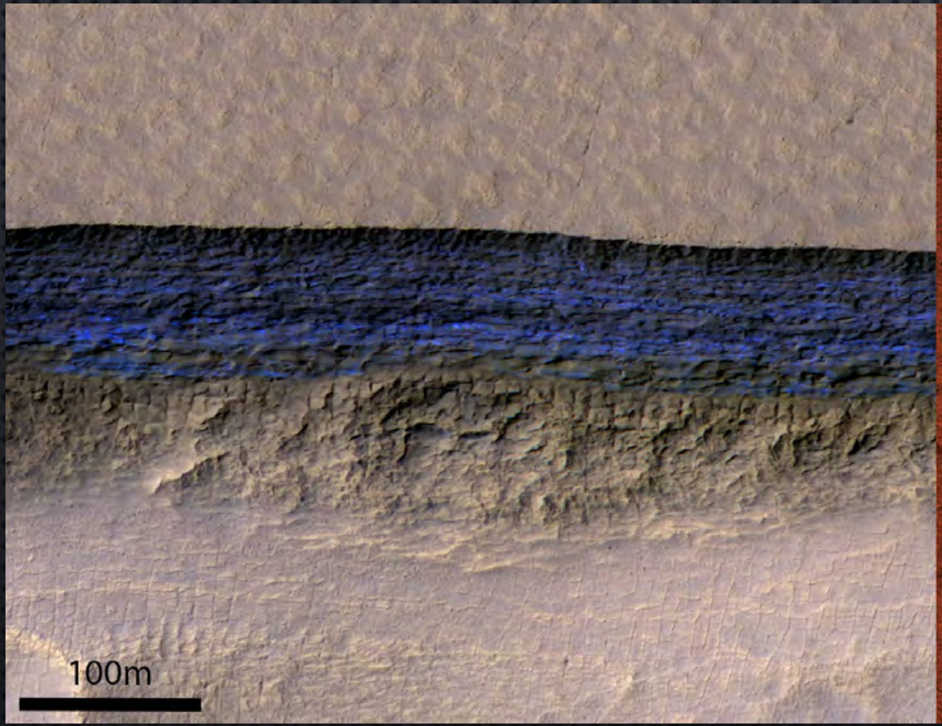
Team has worked NEX-SAG, ICE-SAG and other various activities recommending this science. Deliberately small to facilitate discussion.

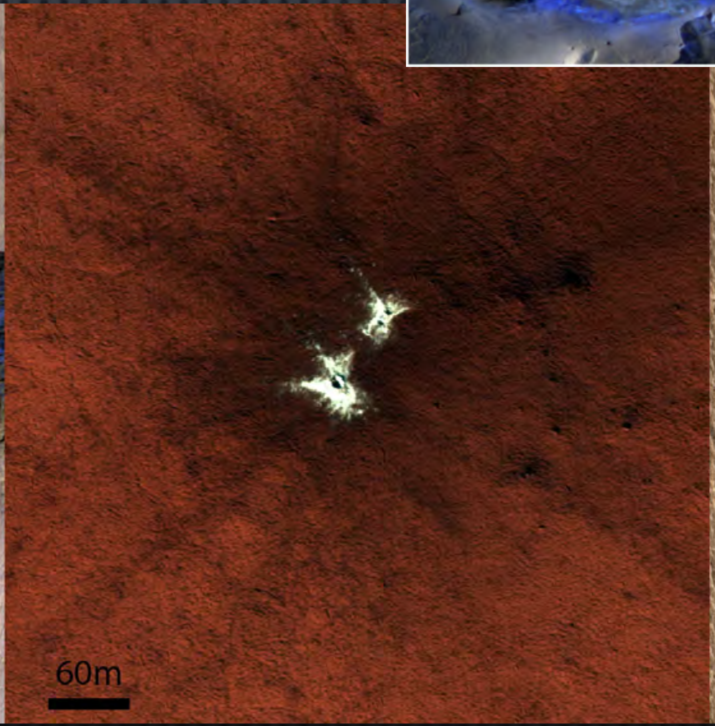
MOTIVATION: DISCOVERIES OF ICE IN NEW PLACES

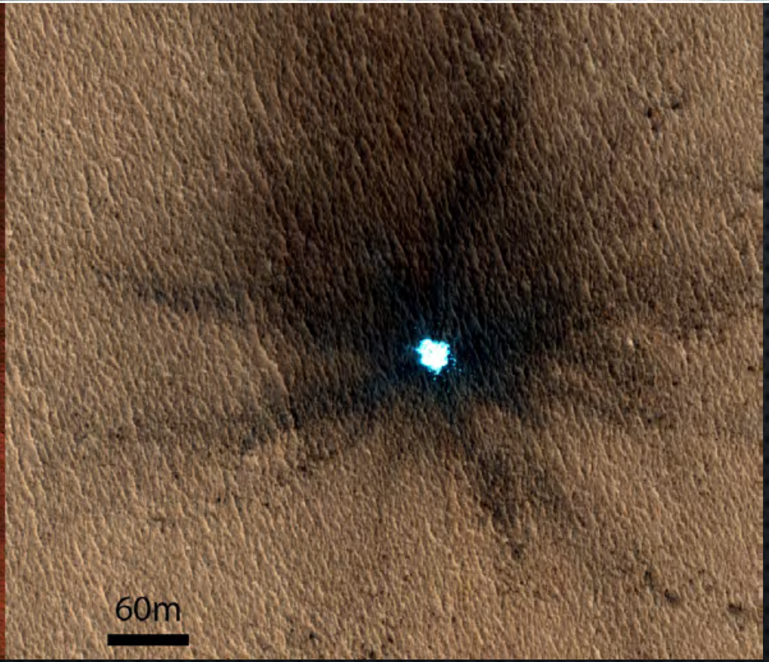
Dundas et al. 2021

- Regional-scale buried ice sheets in the mid-latitudes
- Scarps expose buried ground ice
- Impacts expose ice down to 39°N
- Ice is ubiquitous in Lobate Debris Aprons





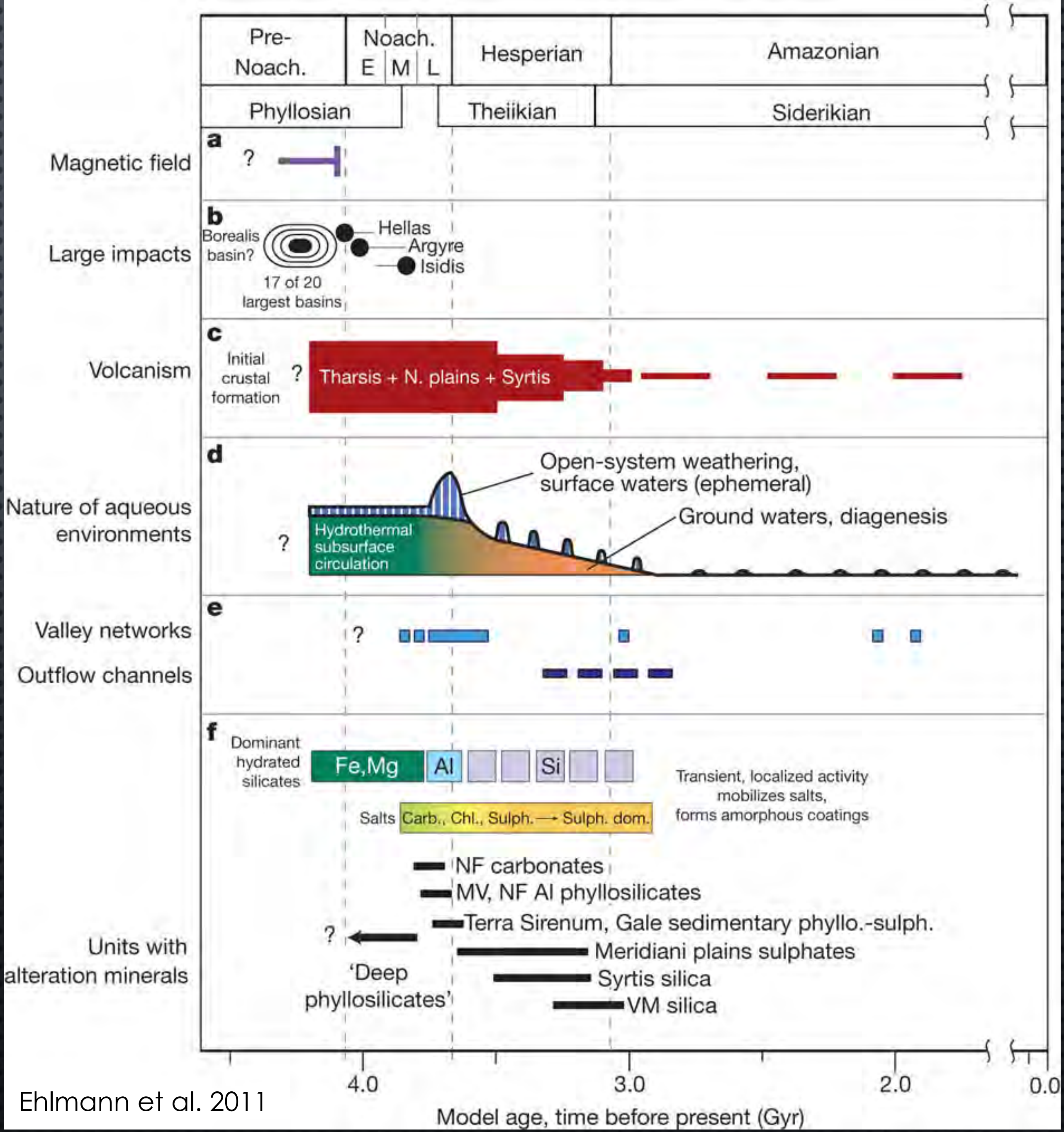




A MORE COMPLICATED HISTORY AND DIVERSE AQUEOUS ENVIRONMENTS

MER, MRO, MSL show multiple aqueous, habitable environments in the 1st billion years.

- Persistent lake in Gale, ~ 1Ma.
- Transient wet/dry at Meridiani Planum.
- Paleoclimate models don't predict persistent warm conditions.
- Major uncertainty in timing, duration and nature of early aqueous processes on Mars and transitions between them.

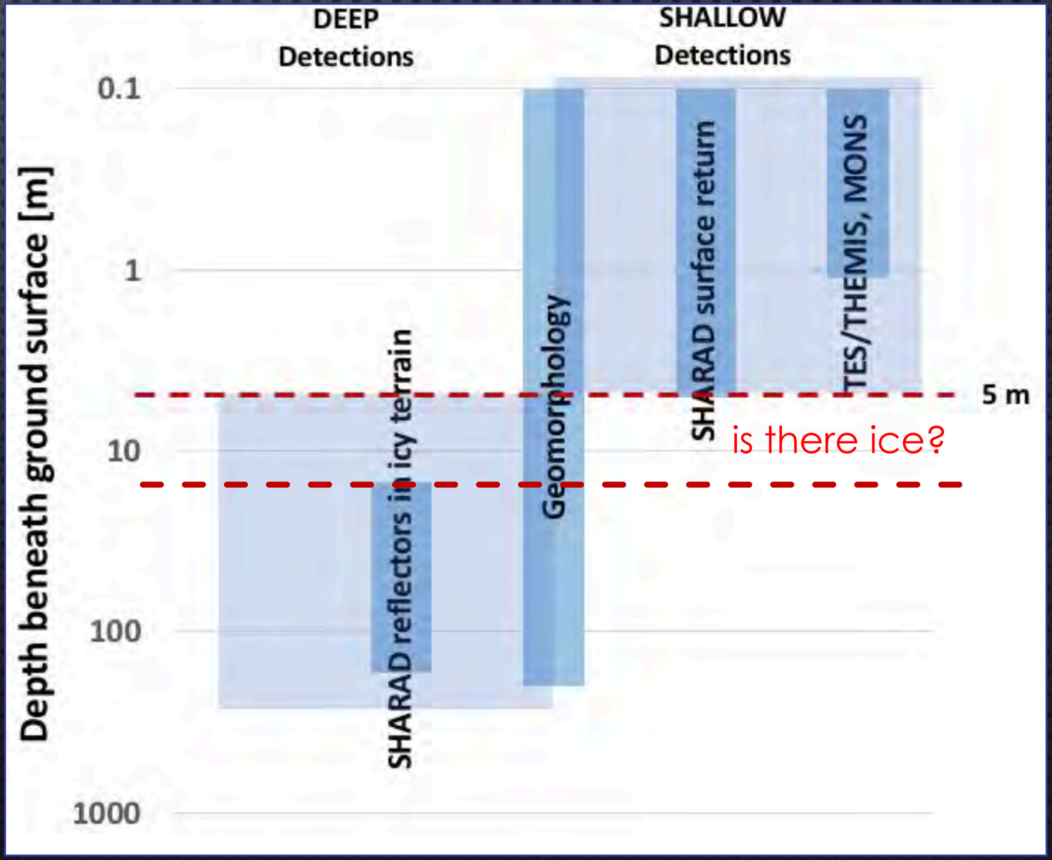


Ehlmann et al. 2011

SUBSURFACE WATER ICE AS A RESOURCE

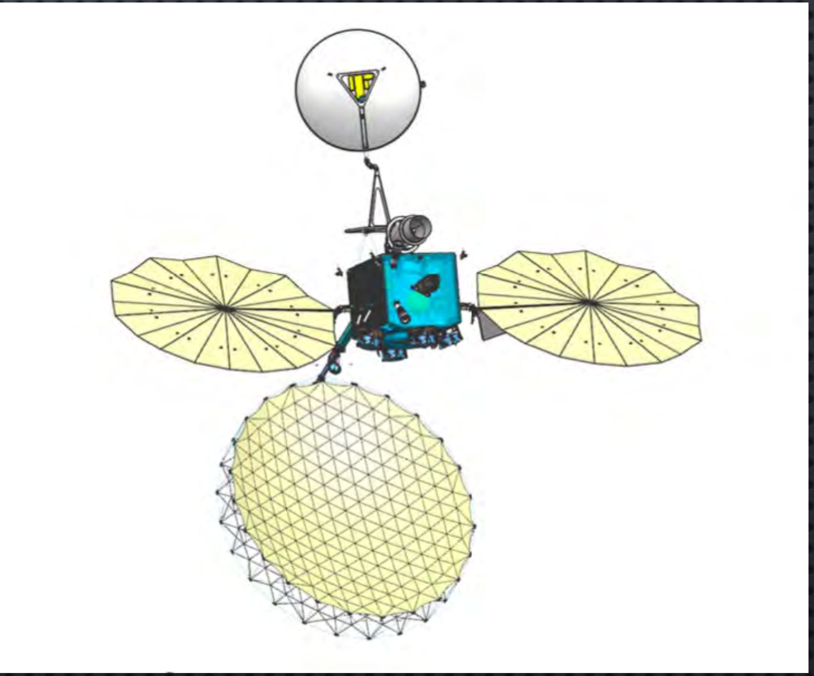
AVAILABLE DATA SETS LEAVE A SENSING GAP FOR DEPTHS BETWEEN 5M AND 20M.

- THE MARS SUBSURFACE WATER ICE MAPPING (SWIM) PROJECT INTEGRATES BEST AVAILABLE DATA FROM 3 MISSIONS (MGS, ODY, MRO) TO FIND BURIED WATER ICE THAT MAY BE USED AS A RESOURCE TO SUPPORT FUTURE HUMAN MISSIONS.
- NEW RESULTS FROM SWIM AND PIQUEUX ET AL. (2019) ARE EXTENDING THE BOUNDARY OF KNOWN BURIED ICE CLOSER TO EQUATOR.



Address multiple water related themes

- Numerous past studies highlight this science
  - NEX-SAG (2015)
  - NASEM CAPS "Getting Ready" report (2017)
  - NASEM Decadal Midterm Review (2018)
  - NASEM Astrobiology Strategy (2018)
  - ICE-SAG Orbiter (2019)
  - Keck Workshop ("Unlocking the climate record in the PLD")
- **Global distribution, structure and formation conditions for surface and subsurface ice reservoirs**
- **More advanced mineral detection techniques and better stratigraphic reconstructions of the geologic, sedimentary and geochemical record.**
- **Can provide resource mapping that requires the same information.**



Science Theme: Evolution of a Habitable World

- When did elements of the cryosphere form and how are ice deposits linked to current, recent and ancient climate?
- How does the crust record the evolution of surface environments and their transition through time?

Resource Theme: Fueling Future Exploration

- Where could ground ice serve as a resource for landed missions?
- Can hydrated mineral deposits provide a viable resource for landed missions?
- How do materials at the surface affect landing site trafficability and access to resources?

Key questions were traced to primary science objectives.

MORIE Science Traceability Matrix

Relation to NASA Goals	Theme	Key Question	Objectives	Observables and Physical Parameters	Measurement Approach
MEPAG 2020 ICE-SAG NEX-SAG	*Science: Evolution of a habitable world*	When did elements of the cryosphere form and how are ice deposits linked to current, recent and ancient climate?	Determine the global distribution and volume of subsurface ice, especially near the surface (1-20m).	Extent and volume of mid-latitude water ice at depth	Sounding radar with stereo imaging for clutter mitigation
					Imaging radar (SAR) for mapping
					Thermal inertia for shallow ice detection
				Identify new impact craters in mid-latitudes	Imaging
			Identify the vertical and lateral structure of ice deposits at the poles and mid-latitudes.	Shallow subsurface structure of water and CO_2 ice in the polar cap & layered terrain	Sounding radar with stereo imaging for clutter mitigation
					Imaging radar (SAR)
				Improved mapping of ice cap and PLD surface composition	Multi-band imaging with IR colors to distinguish H_2O and CO_2 ices at CTX or better scales.
					Imaging radar (SAR) for penetration through PLD, mapping
			Record the annual cycling of volatiles and dust between the surface and atmosphere.	Seasonal mapping of surface water, dust & CO_2 frost deposition and sublimation	MARCI like imager with additional IR channels to distinguish H_2O and CO_2 ices
				Monitor scarp avalanches, seasonal cap venting, and other processes that loft material into the lower atmosphere.	Color imaging at ~ 1m / pixel
			Link ice reservoirs to their formation processes and history.	Identify periodicity in stratigraphic layers and correlate those to climate cycles.	Combine old data with new imaging and higher resolution radar for improved stratigraphy.
MEPAG 2020 NEX-SAG		How does the crust record the evolution of surface environments and their transition through time?	Constrain the nature and timing of ancient aqueous deposits and major environmental transitions.	Determine composition of primary minerals and their alteration products across environments and ages.	Map mafic and alteration mineralogy at higher spatial resolution than currently available. Target high priority sites identified by CRISM/OMEGA/THEMIS VNIR for iron oxides, mafic minerals with sufficient channels to cover broad features. SWIR for distinguishing phyllosilicates, evaporative sequences, sufficient spectral resolution for mineral discrimination and solid solution chemistry. TIR required for igneous petrology (e.g. feldspars) quantitative mineral abundances when combined with SWIR
				Fine-scale composition & morphology in ancient terrain, especially aqueous alteration products.	
			Observe which intervals in the geologic record preserve environments that were conducive to the possible origin and evolution of life.	Use mineralogy as a proxy for clement and/or habitable environmental conditions.	
			Identify how igneous rocks record the evolution of magmatic sources and crustal modification over time.	Measure compositional and structural changes in volcanic constructs and lava flows.	Same spectral requirements as above, plus imaging radar (SAR) for volcanic structures and composition in dust covered areas.
			Observe how modern processes are reshaping the surface today.	Continued observation of dynamic processes such as RSL, gullies, avalanches, new craters.	Use "super resolution" mode to achieve near-HiRISE level imaging scales. Monitoring limited number of known sites. Observe potential changes in hydration and/or frosts at these locations.
MEPAG 2020 NEX-SAG SKG: Water resources, ISRU, Civil Eng	Resources: Fueling Future Exploration	Where could ground ice serve as a resource for landed missions?	Determine the near-surface distribution and depth of mid-latitude ice.	Identification of regions with water ice present within 10 m of the surface	Same techniques as Science Question 1
				Identification of regions where depth of dry overburden is <2 m.	
		Can hydrated mineral deposits provide a viable resource for landed missions?	Determine the type, distribution, abundance and volume of hydrated minerals at the surface.	Identification of hydrous minerals exposed at the surface and estimate their subsurface distribution.	Same techniques as Science Question 2
		How do materials at the surface affect landing site trafficability and access to resources?	Constrain geotechnical properties of the near surface to characterize landing sites and resource accessibility.	Determine particle sizes, slopes, texture, thermal properties and estimate material thickness & consolidation over buried ice deposits.	Same techniques as Science Questions 1 and 2.

Objectives were traced to observables, measurement approach and requirements.

MORIE Science Traceability Matrix

✓ = Primary, S=Supporting

Relation to NASA Goals	Theme	Key Question	Objectives	SAR Imager	Radar Sounder	1-m multiband VNIR imager	SWIR+TIR Spectrometer	Wide-angle Color Imager	5-m Stereo Context Cameras
MEPAG 2020 ICE-SAG NEX-SAG	*Science: Evolution of a habitable world*	When did elements of the cryosphere form and how are ice deposits linked to current, recent and ancient climate?	Determine the global distribution and volume of subsurface ice, especially near the surface (1-20m).	✓	✓	S	S		S
			Identify the vertical and lateral structure of ice deposits at the poles and mid-latitudes.	✓	✓	✓			✓
			Record the annual cycling of volatiles and dust between the surface and atmosphere.			✓		✓	
			Link ice reservoirs to their formation processes and history.		✓	✓			S
MEPAG 2020 NEX-SAG		How does the crust record the evolution of surface environments and their transition through time?	Constrain the nature and timing of ancient aqueous deposits and major environmental transitions.			✓	✓		
			Observe which intervals in the geologic record preserve environments that were conducive to the possible origin and evolution of life.			✓	✓		
			Identify how igneous rocks record the evolution of magmatic sources and crustal modification over time.	S		✓	✓		
			Observe how modern processes are reshaping the surface today.			✓		S	
MEPAG 2020 NEX-SAG SKG: Water resources, ISRU, Civil Eng	**Resources: Fueling Future Exploration**	Where could ground ice serve as a resource for landed missions?	Determine the near-surface distribution and depth of mid-latitude ice.	✓	✓	S	S		S
		Can hydrated mineral deposits provide a viable resource for landed missions?	Determine the type, distribution, abundance and volume of hydrated minerals at the surface.	S		✓	✓		
		How do materials at the surface affect landing site trafficability and access to resources?	Constrain geotechnical properties of the near surface to characterize landing sites and resource accessibility.	✓	✓	✓	S	S	S

Measurement requirements lead to payload instruments.

RADAR INSTRUMENTS

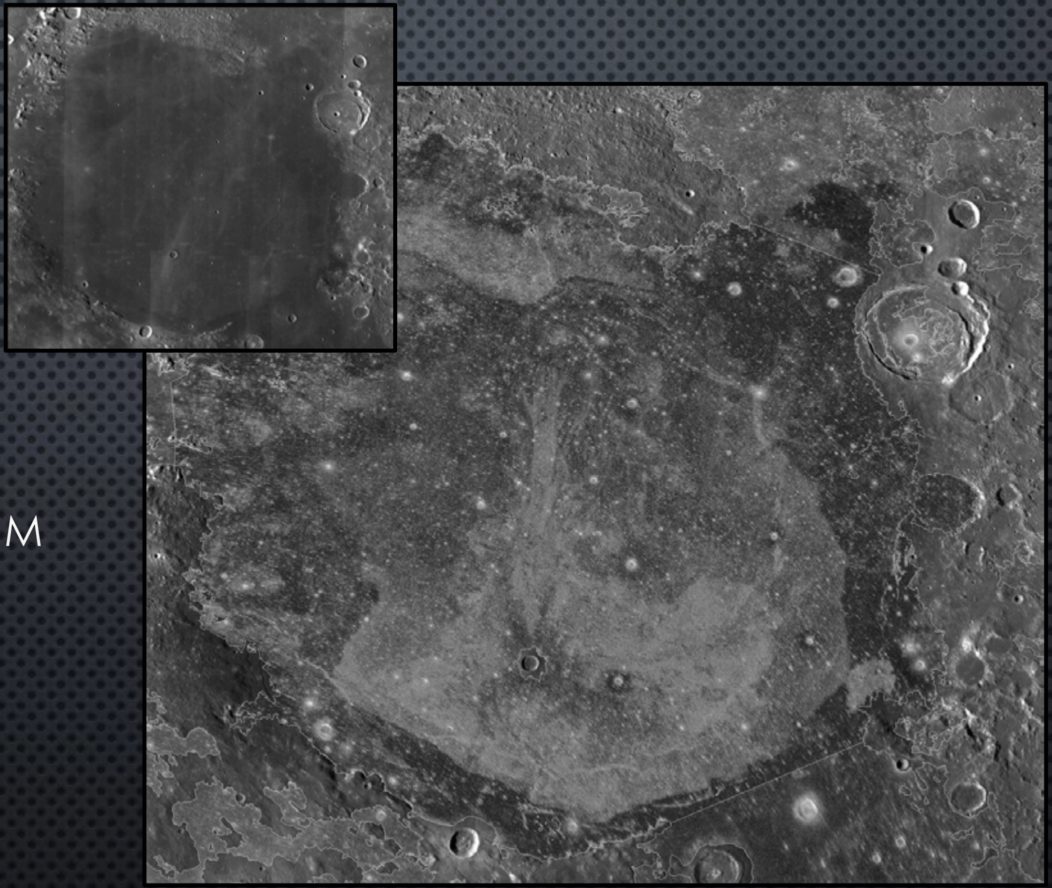
RaSo

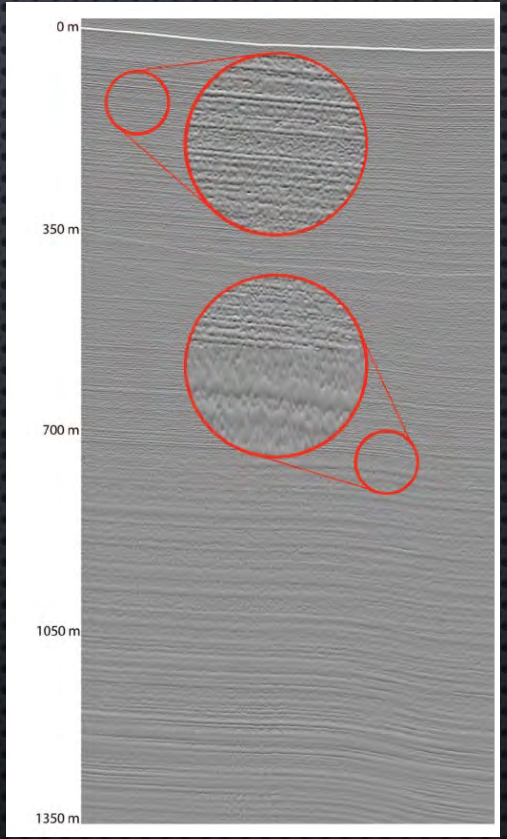
- P-band Radar Sounder with 0.5 m vertical Resolution in Ice

Polar-SAR

- Full polarization P-band SAR, 100 m spatial res w/ spotlight mode

Can accomplish both modes with a single instrument 400 & 200 MHz



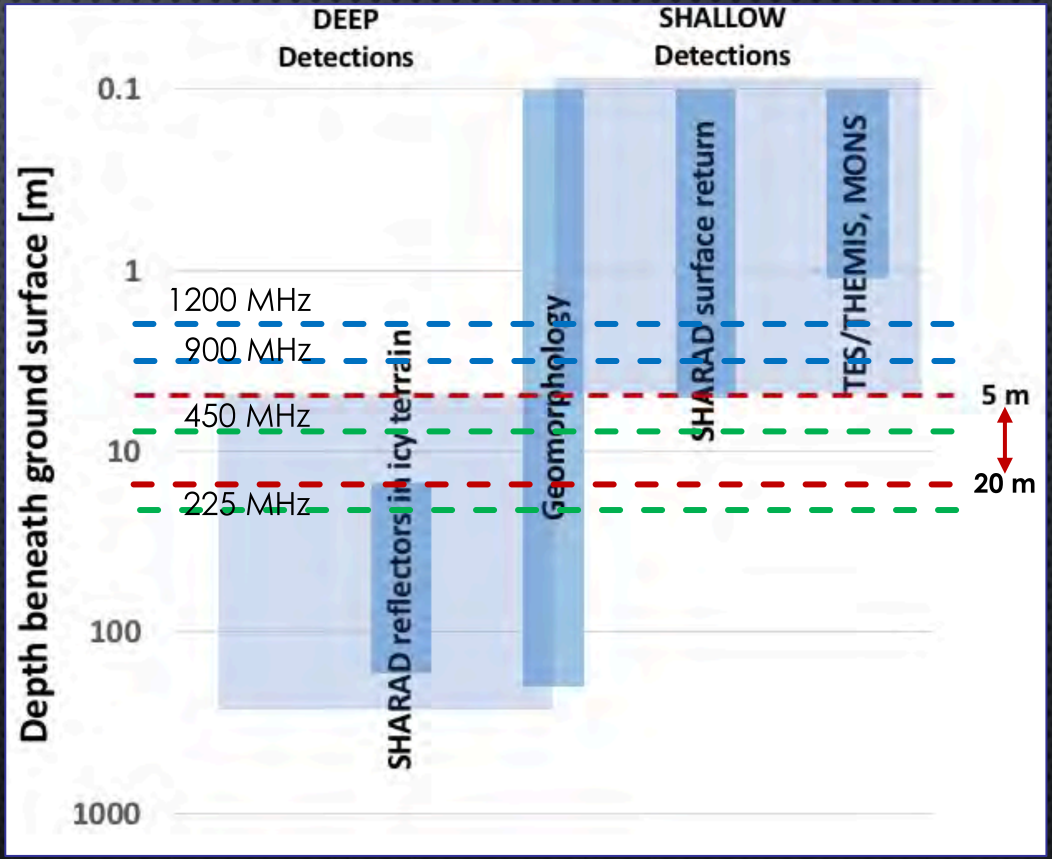


(NASA LRO/LROC; Arecibo/NAIC)

The left side contrasts visible imagery with that obtained using PSAR of the same location on the moon (Campbell et al. 2014). The right side shows resolution of sub-meter scale layers in the Greenland ice sheet using P-band sounding (Dall et al., 2018).

WHY P-BAND SAR / SOUNDER

- Depth of penetration – Dry Soil w/ Scatters
  - 225MHz – 25m, 450 MHz – 8.4m
  - 900 MHz – 4.1m 1200MHz – 3.1
    - (Pettinelli et al. 2007)
  - Numerous other prior studies support central frequencies from 400 to 500 MHz
- Vertical resolution in ice
  - Resolve layers in the PLD better than SHARAD
- Less sensitive to surface scatterers
- Address key questions
  - Ice Extent & Volume
  - Define the lowest latitudes where the ice near the surface is under few m of dry overburden



SPECTROSCOPY

NGSWIS (Next Gen Short-Wave infrared Imaging Spectrometer)

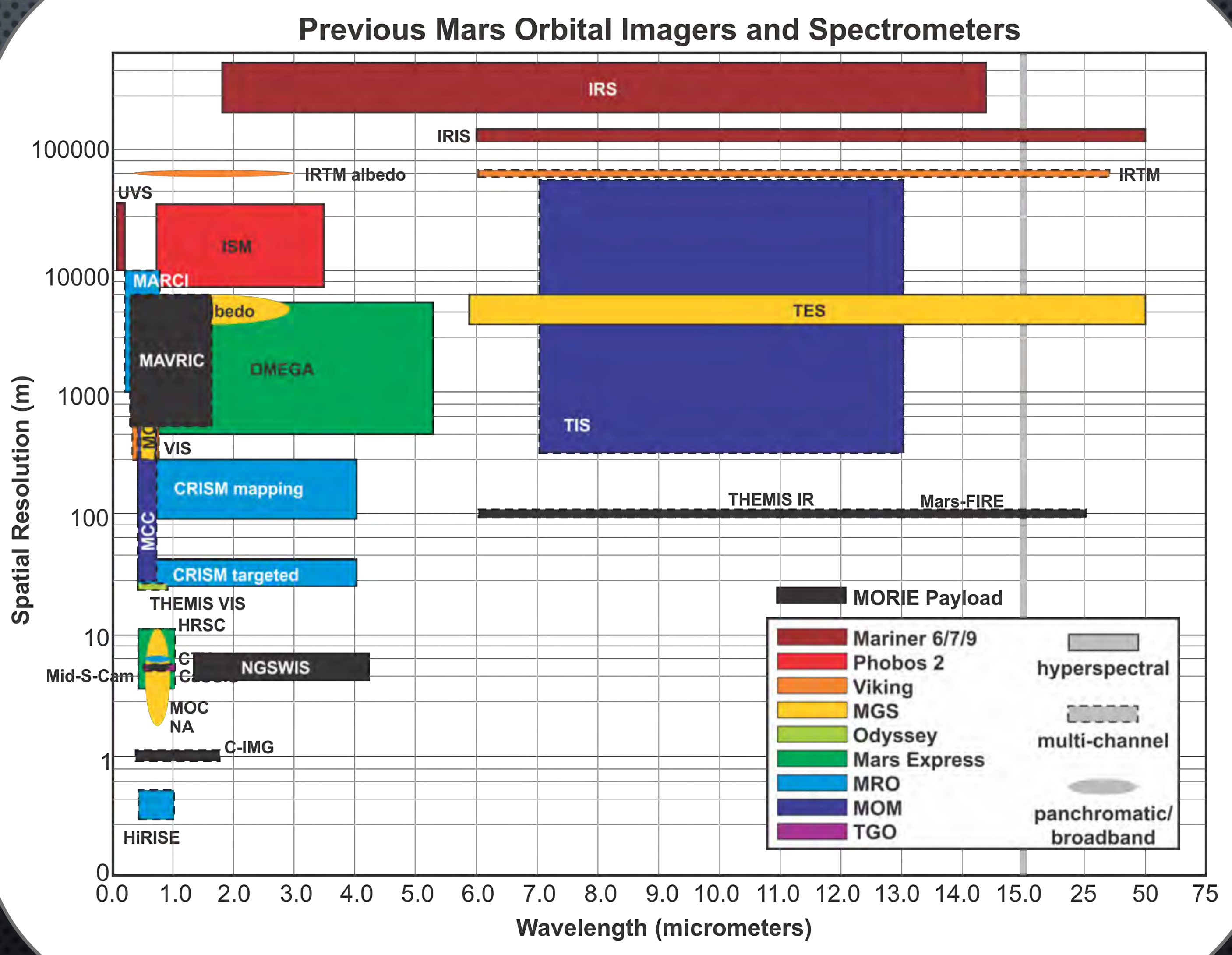
- 1.3 to 4.2 μm spectrometer
- ≤ 10 nm spectral
- ≤5 m spatial
- Best for Alteration

Mars-FIRE (Far InfraRed Emission imager)

- Shared telescope with NGSWIS
- 6-25 μm
- 20 channels < 1 μm bandpass
- ≤ 100 m spatial
- Best for primary silicates

Key Questions:

- Nature of water/atmospheric chemistry driving alteration?
- Were transitions continuous or episodic?



CAMERAS

C-IMG

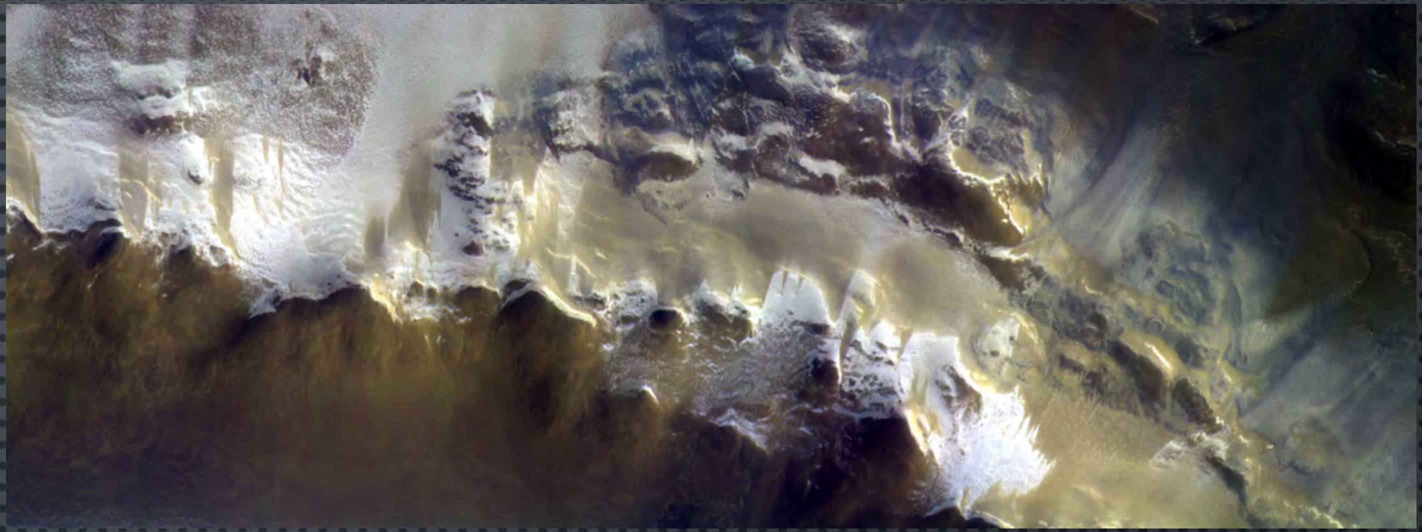
- 1-m Color imager 0.4 to 1.7 μm
    - Complements spectral instruments
    - Better res than CaSSIS with more colors
- 20 channels at 10-60 nm band pass
- + super-res mode
    - Can approach HiRISE res

MAVRIC

- WA camera for daily global map with filters for H_2O+CO_2 ices

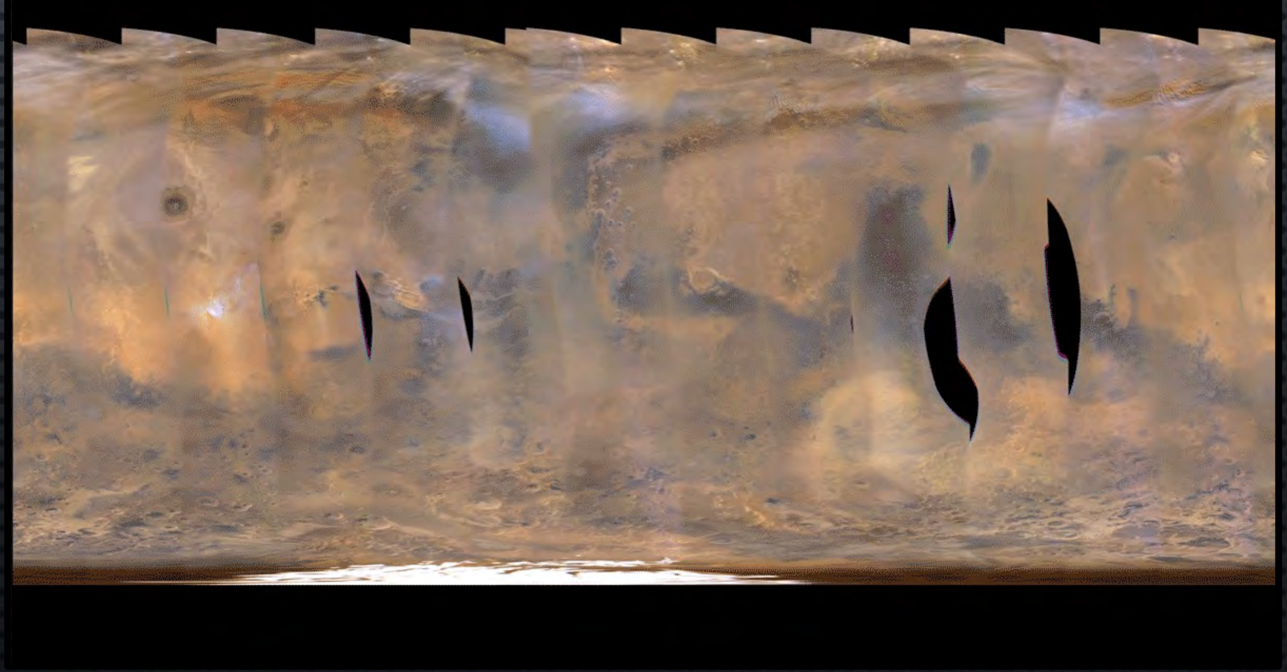
Mid-S-Cam

- Dual B/W cameras for stereo-DEM ~ 5 m/pixel
- Clutter mitigation
- New ice exposing craters
- Better DEMs in the PLD



(ESA / Roscosmos / CaSSIS Image)

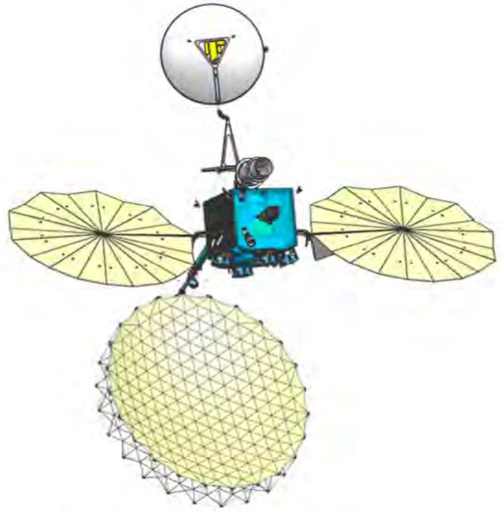
(MARCI / MSSS)

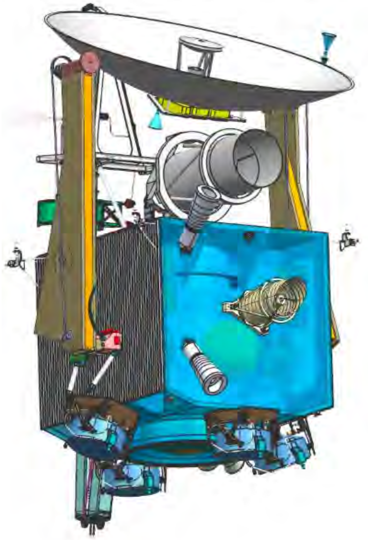


TEAM X STUDIES

- Architecture study with payload instruments using analogues from past missions
  - CTX, MOC-NA, HiRISE, MARCI, CRISM, THEMIS, Eagle(Psar), Sharad
  - Power and Mass as Proxy for cost, what might fit?
  - Solar Electric over Chemical propulsion (no significant cost delta)
- Team X Mission Study
  - Full up Mission
    - All instruments
  - "Ice Focused" mission
    - Dual SAR/Sounder and Stereo Cameras

DESIGN SUMMARY





- Instruments

  Full payload with combined SAR/Sounder

- CDS
  - Fully dual-string
  - RAD750 avionics
  - 128Gbyte memory card (1 per string)
- Ground Systems
  - Ground Network = DSN
  - Two 8-hr passes per day

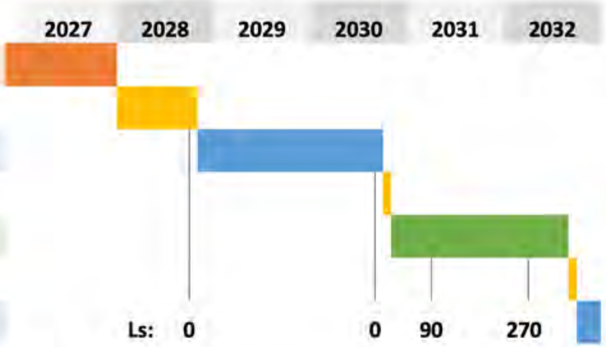
- Telecom
  - 3m Ka-band HGA, 2-axis gimbaled, with $200W_{RF}$ TWTA
  - X-band MGA, with $25W_{RF}$ TWTA
- ACS
  - Sun sensors, star trackers, IMUs, RWAs, gimbal drive electronics (for SAs, HGA, instrument scan platform)
- Structures
  - Primary Structure Mass MEV= 262 kg
  - Secondary Structure Mass MEV = 26 kg
  - Mechanisms
    - Solar array gimbals (2-axis)
    - HGA gimbals (2-axis)
    - Instrument scan platform (1-axis)
- Thermal
  - Passive thermal control (MLI, heaters, thermal surfaces)
  - Assume one bus face is always in shadow
- Power
  - Two deployable 5.7m UltraFlex, total area = 47 m^2
    - Sized to "Thrusting at Earth" mode
  - Dual-string Li-Ion Battery
    - Sized for "Launch" mode
- Propulsion
  - SEP system with 4x SPT-140 engines
  - Small Hydrazine RCS system for RW desats and attitude control in safe mode

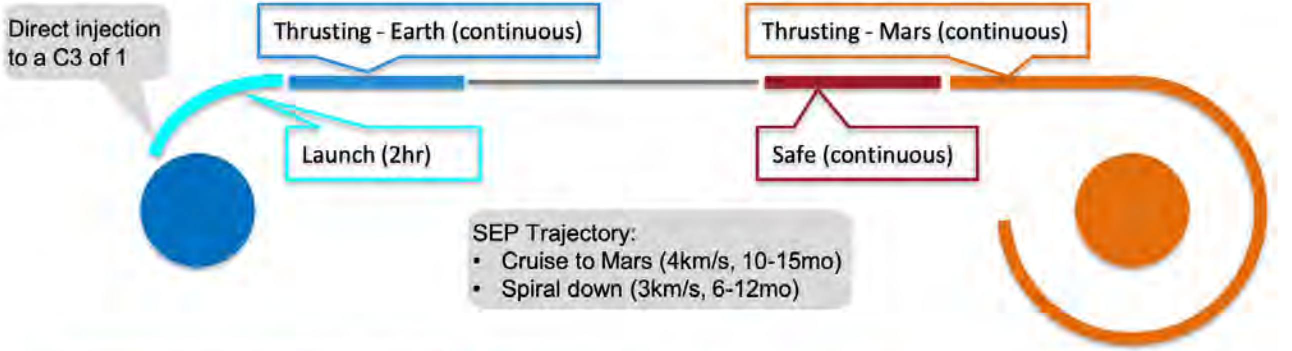
MISSION DURATION – TYPICAL ORBIT

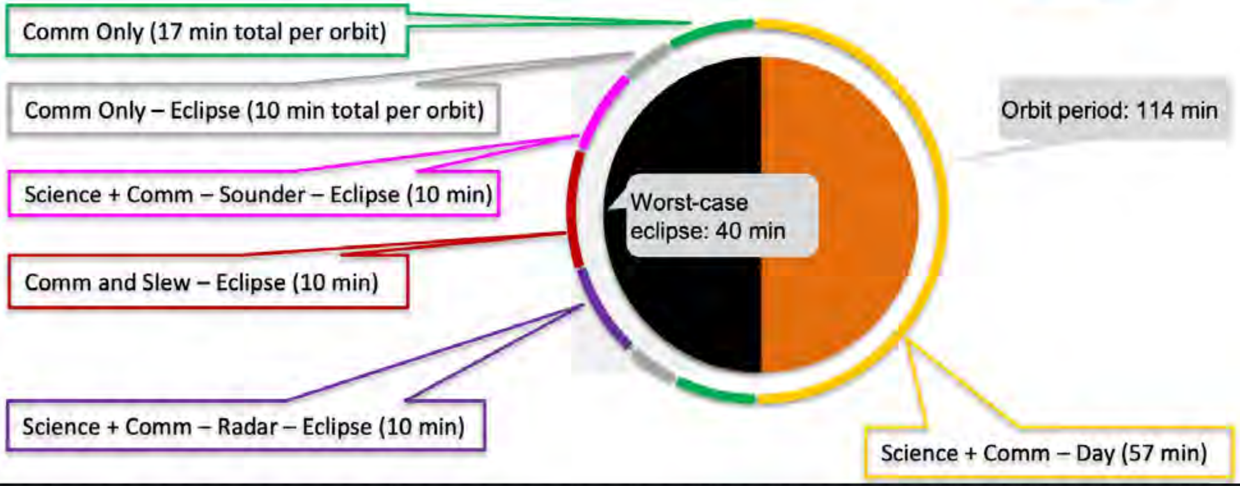
- Launch Years: 2026-2035
- Typical Durations:
  - Cruise: 10 – 15 mos.
  - Spiral: 6 – 12 mos.
  - Total ~ 2 years

Dates and durations are SUPER sensitive to mass, power, and SEP assumptions

Phase	Start	Duration [m]
Heliocentric	11/20/2026	13.2
Spiral Down	12/22/2027	9.7
3PM SS	10/7/2028	23.0
Inc. Transfer	8/27/2030	1.4
90 deg	10/8/2030	21.5
Inc. Transfer	7/14/2032	1.4
3PM SS	8/25/2032	







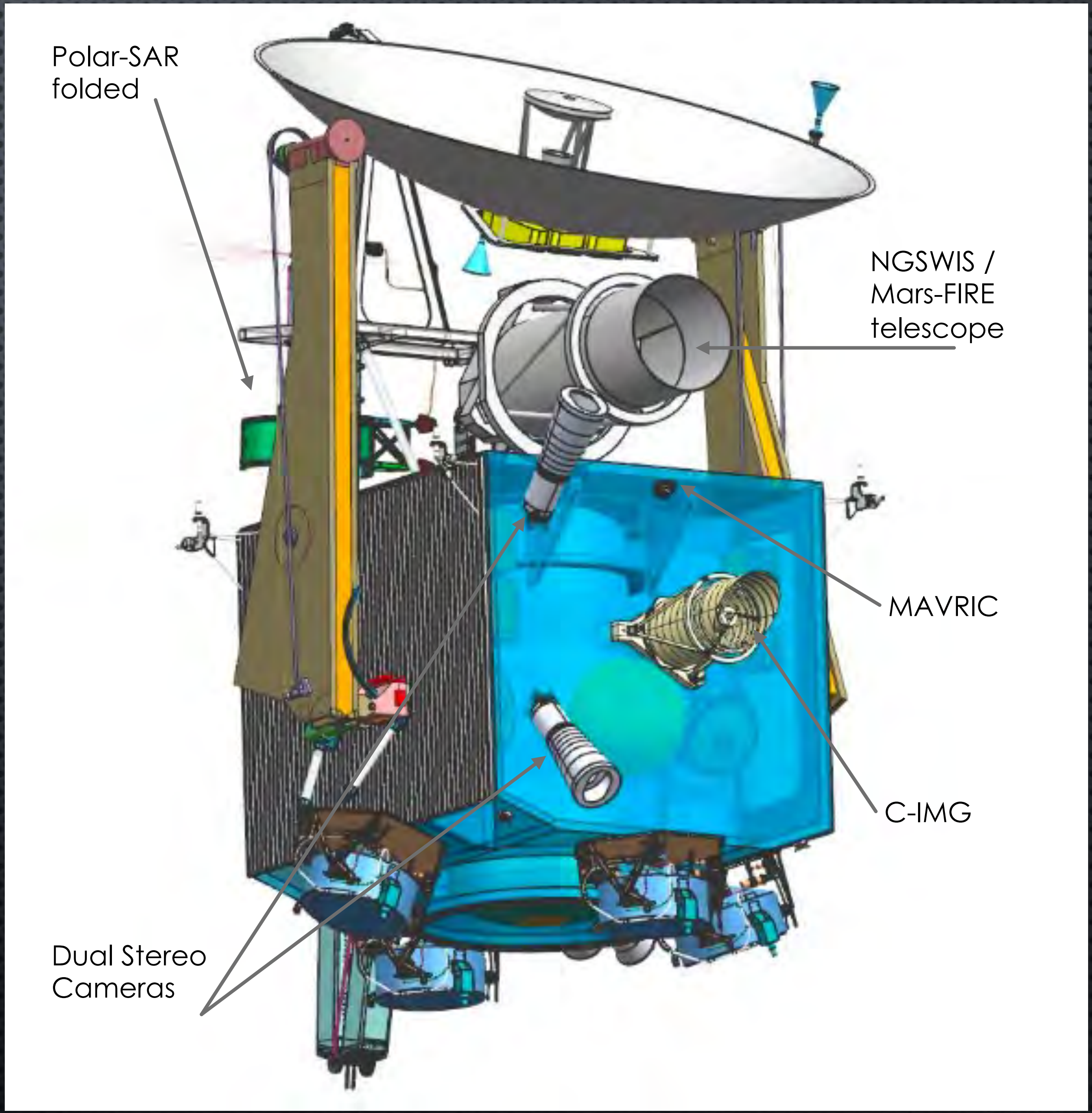
SEP allows an orbit change from sun-synchronous to 90 degree to get nadir views directly over the poles.

Strong support for this mode - this will walk the orbit earlier about 1hr/month allowing time of day coverage.

DATA AND COVERAGE

- Spectrometers and C-IMG collect targeted observations, 8-80/sol, depending on Earth-Mars Distance
- Mars-FIRE also observes targets on night side for thermal inertia
- Polar-SAR operates at night, alternating sounding and SAR modes
- MAVRIC collects continuously on dayside for daily global image

- At the end of the nominal mission will have fully mapped the planet with SAR, Sounder, and stereo (5m/pixel)
- ≥ 50,000 targeted sites



MORIE TAKE-AWAYS

- Mission can answer fundamental questions related to water.
  - Lateral extent and volume of subsurface ice
  - Better vertical resolution of layers in the PLD (plus close 3° gap)
  - Nature and timing of environmental transitions
- Design is straight forward and does not present any novel technical risks
  - SEP not yet used for Mars but should present no major tech challenges
- Full up Mission out of NF cost Box (FY25, 50% margin), but could be within scope with contributions of instruments or hardware and further design maturity
- Ice-Focused Mission fit in NF costs
  - Costs, Particularly for Radar, are uncertain