Orbital Ice and Climate Science

With Emphasis on the MORIE PMCS

Wendy Calvin for the Mars Panel

of the Planetary Science Decadal Survey

Nov 23, 2020

PAST STUDIES

- NEX-SAG 2015
- NASEM CAPS "Getting Ready" report 2017
- NASEM Decadal Mid-Term Review 2018
- NASEM Astrobiology Strategy 2018
- Keck Study – Unlocking Mars Climate Record in PLD (2017, 2020)
- ICE-SAG 2019

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 III: 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				
S-E2	Phobos/Deimos surface mineral composition & thermophysical properties				T	T					

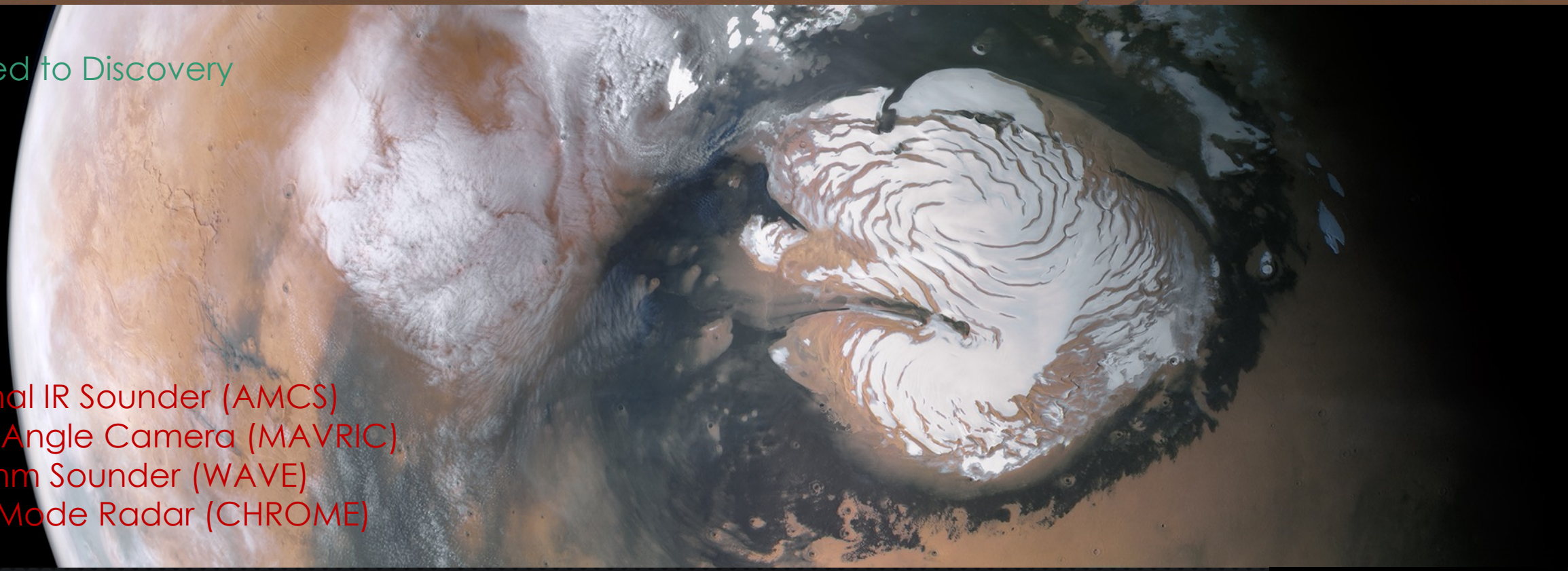
Can't do it all – Ice & winds

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);
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;
C. Measure winds and characterize transport and other dynamic processes to understand current climate, water, and dust cycles, with extrapolation to past climates;
D. Characterize the occurrence and timing of major environmental transitions recorded in compositional stratigraphic records, such as discrete hydrated mineral assemblages and sedimentary bedding;
E. Carry out high-value, close-approach investigations of Phobos and Deimos.

COMPASS

Climate Orbiter for Mars Polar Atmospheric and Subsurface Science

Submitted to Discovery



- Thermal IR Sounder (AMCS)
- Wide Angle Camera (MAVRIC)
- Sub-mm Sounder (WAVE)
- Dual-Mode Radar (CHROME)

UA SCIENCE
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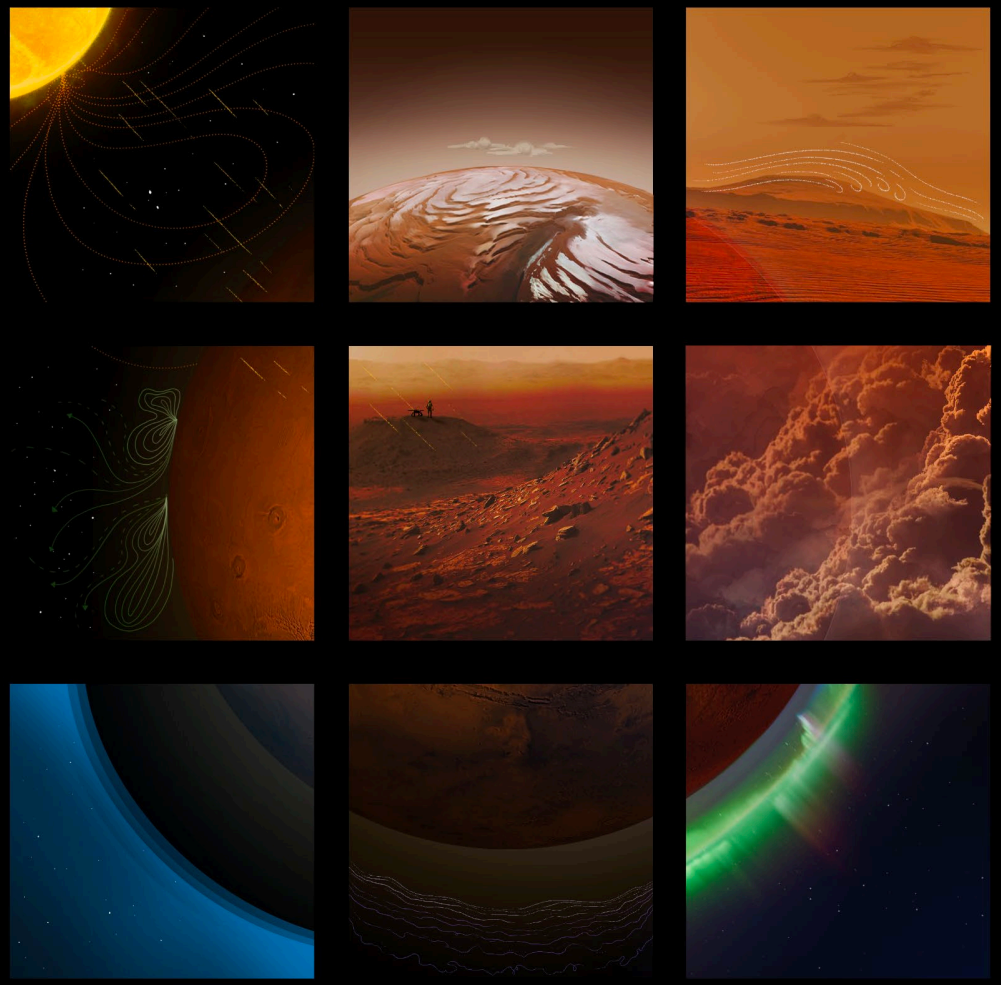

MOSAIC

MARS ORBITERS FOR
SURFACE-ATMOSPHERE-IONOSPHERE
CONNECTIONS

AUGUST 2020
Mission Concept Study
Planetary Science Decadal Survey

National Aeronautics and Space Administration
www.nasa.gov

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- MOSAIC will characterize the Martian climate system variability both diurnally and seasonally, on meso-, regional, and global scales.
- 8 linked investigations from the subsurface (ice) to the exosphere and space weather.
- 10 spacecraft, one large mothership with small spacecraft in various orbits (polar, elliptical, aerostationary).
- 49 Science Instruments
- Mothership (surface, lower-middle atmosphere, thermosphere)
  - P-band SAR/Sounder
  - Wide angle imager
  - Wind Lidar
  - Thermal IR radiometer
  - Sub-mm sounder
  - NIR spectrometer
  - Wind doppler interferometer
  - FUV/MUV spectrograph

MORIE – Ice & Environments

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);
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MORIE MOTIVATION - Water is the Key Link

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?

Key questions were traced to primary science objectives.

MORIE Payload

Instrument	Description	Center Freq or Range	Spatial Resolution	Acquisition Mode	Science Objectives
Polar-SAR	Full polarization synthetic aperture radar	400 MHz	100 m, sense ice within 3 m of the surface	Continuous nightside	C1, C2, E3, supports E1, E2
RaSo	Radar Sounder	400 & 200 MHz	2 km, 0.5 to 1m vertical resolution in ice	Continuous nightside	C1, C2, C4, supports E1, E3
C-IMG	1-m/pix color imager	0.4 to 1.7 μm in 20 channels	1 m	Selected targets	C2-C4; E1-E4; supports C1
NGSWIS	Next Generation Short Wave Infrared Imaging Spectrometer	1.3 to 4.2 μm, at < 10nm spectral resolution	≤ 5 m	Selected targets	E1-E3; supports C1, C3
MarsFire	Mars Far Infrared Emission Imager	6 to 25 μm in 20 channels, < 1 μm bandpass	≤ 100 m	Selected targets	E1-E3; supports C1, C3
MAVRIC	Mars Atmosphere Volatile and Resource Investigation Camera	0.4 to 1.7 μm in 6 to 12 channels	1 km	Continuous dayside	C3, supports E4
Mid-S-Cam	Dual Stereo Monochrome Cameras	Pan	5 m	Continuous dayside	C2, supports C1, C4

RADAR INSTRUMENTS

RaSo

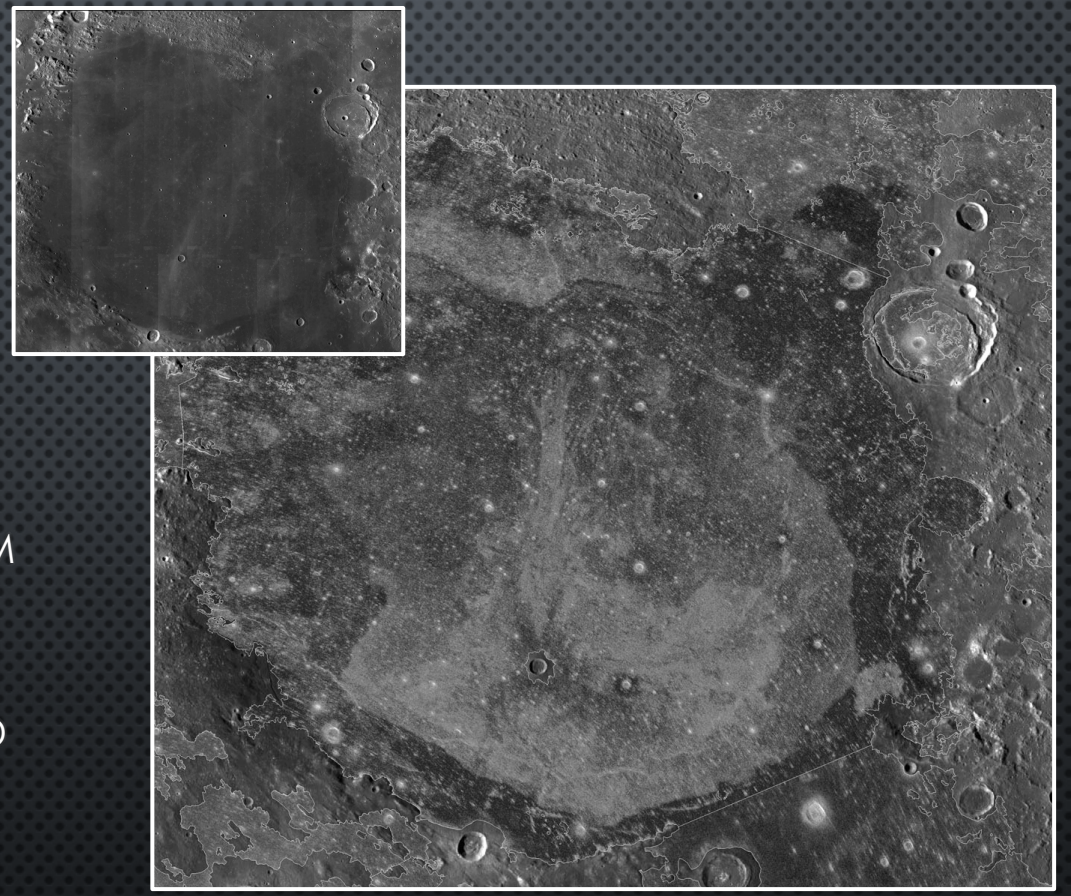
- P-band Radar Sounder with 0.5 m vertical Resolution in Ice

Polar-SAR

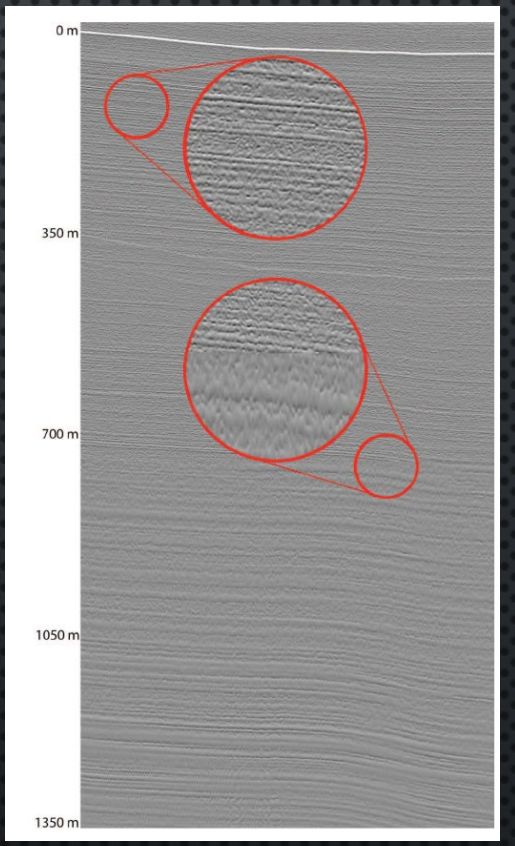
- Full polarization P-band SAR, 100 m spatial res w/ spotlight mode

Both MORIE and MOSAIC converged on a dual Frequency system

- 400 MHz PSAR
- 200, 400 MHz Sounding



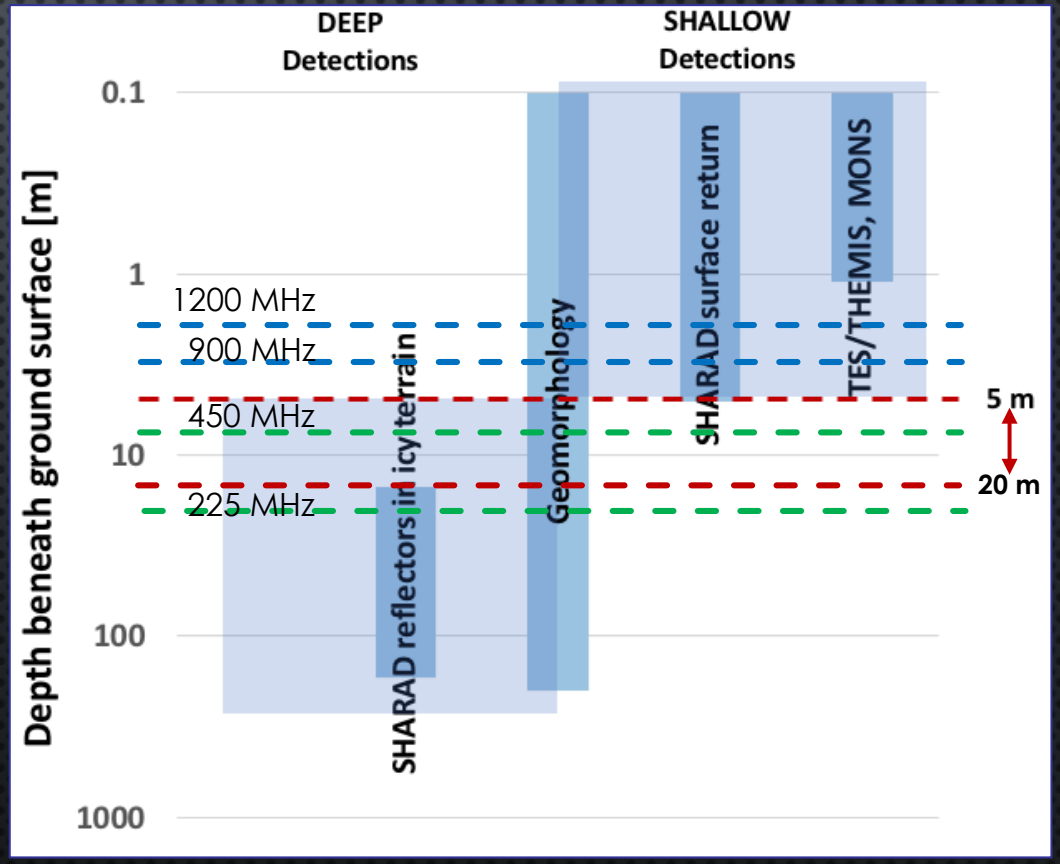
(NASA LRO/LROC; Arecibo/NAIC)



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).

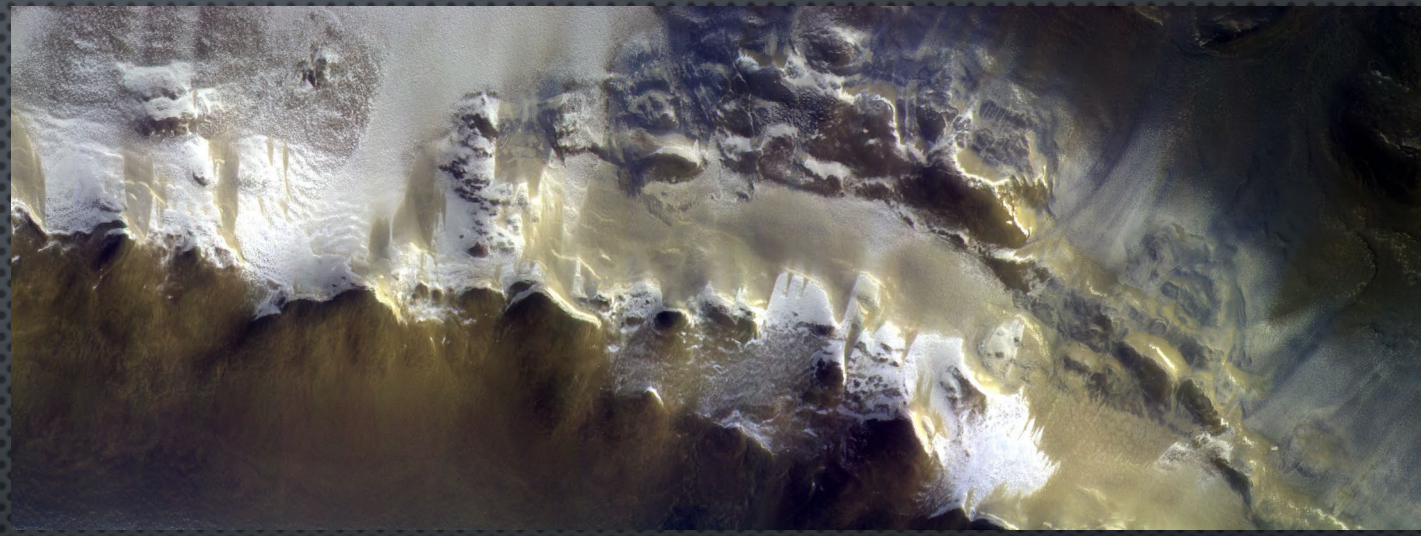
WHY P-BAND SAR / SOUNDER

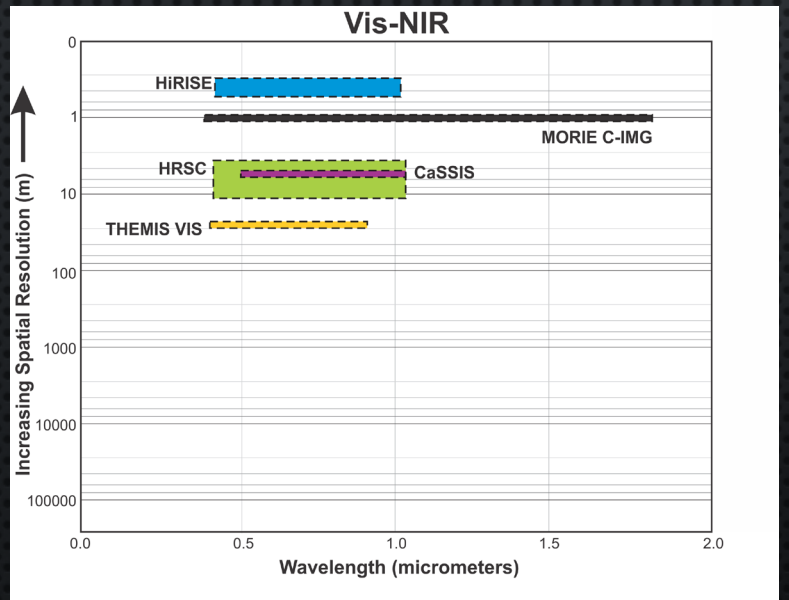
- Depth of penetration – Dry Soil w/ Scatters
  - 225MHz – 25m, 450 MHz – 8.4m
  - 900 MHz – 4.1m 1200MHz – 3.1
    - (Pettinelli et al. 2007)
  - Numerous other prior studies support central frequencies from 400 to 500 MHz
- Vertical resolution in ice
  - Resolve layers in the PLD better than SHARAD
- 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

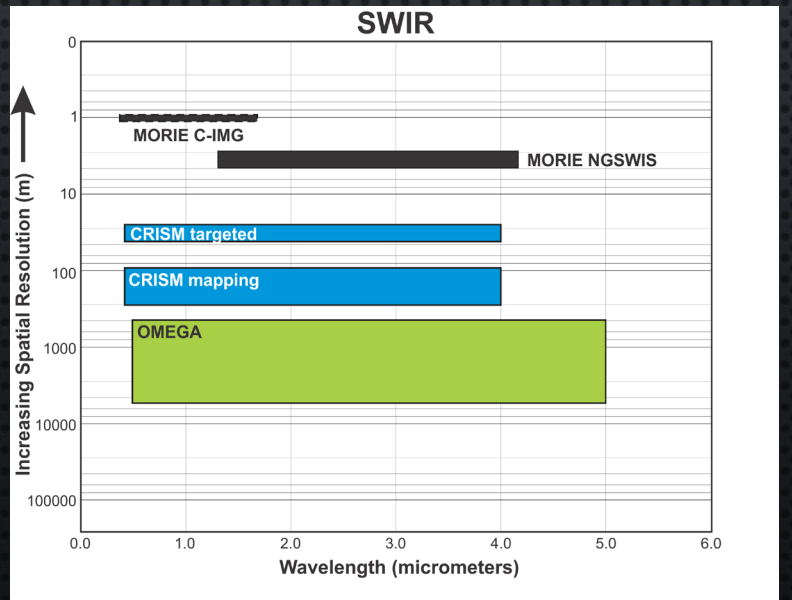


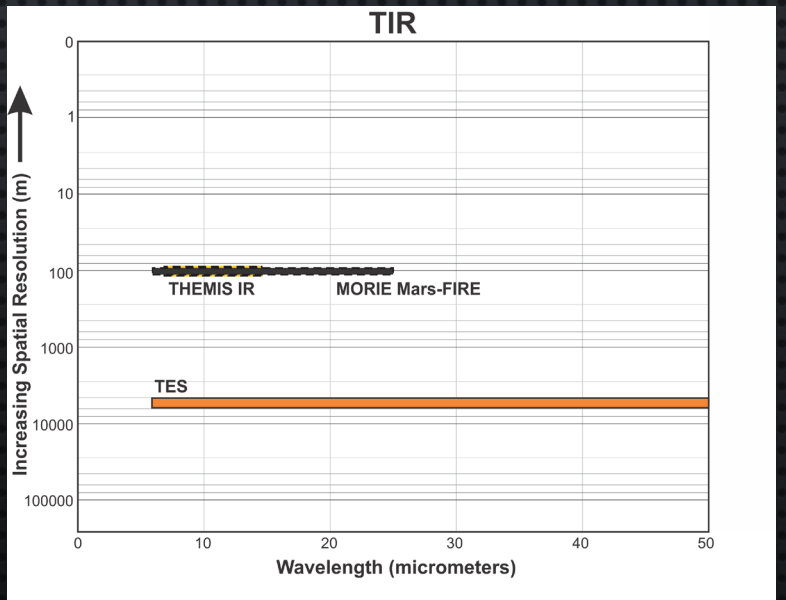
IMAGING & SPECTROSCOPY

- 1m/pix imager with 20 channels, better than CaSSIS with IR
- Shared telescope SWIR/TIR spectrometers
  - Improves spatial resolution & spectral resolution over current observations.
- Dual stereo 5 m/pix
- Wide angle with 12 colors – UV-SWIR



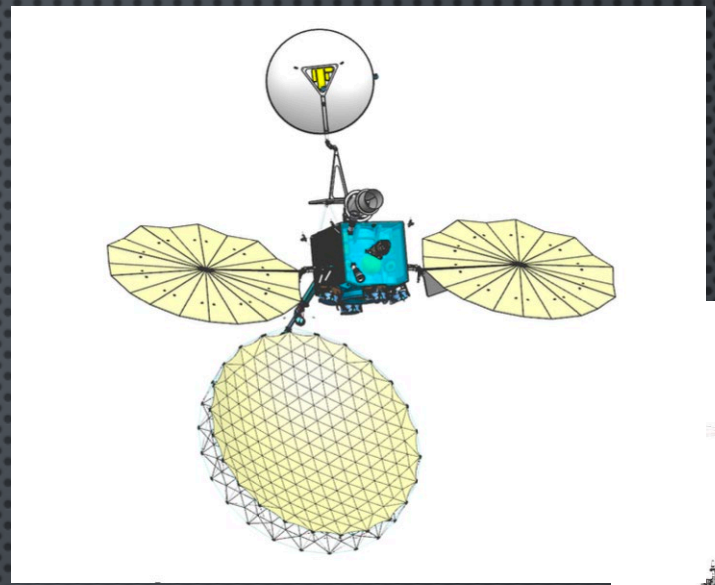


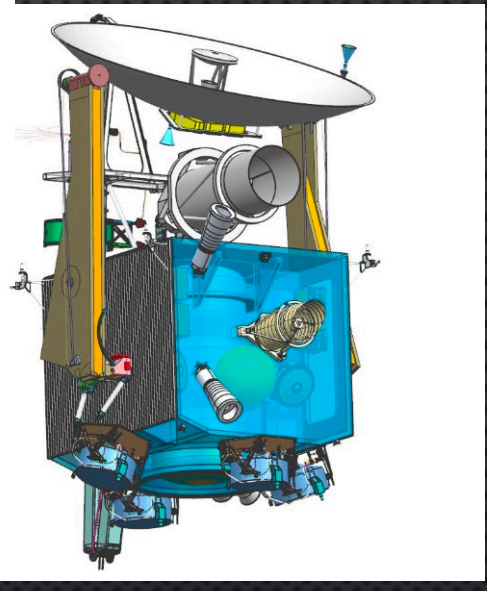




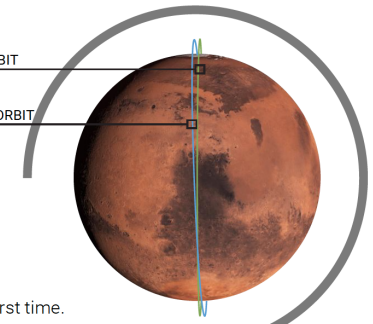
MISSION SUMMARY

- Solar Electric Propulsion enables power for PSAR and sounding, and orbital plane change to sound directly over the poles.
- Shared telescope SWIR/TIR reduces mass and allows concurrent images for full mineralogical determination of transition environments.
- 2 MY mission returns 12x more data than MRO
  - First radar imaging from orbit
  - Resolves current gap in sensing depth to ice
  - Refines PLD stratigraphy with better vertical resolution in ice.
  - Maps critical environmental transitions at unprecedented spatial scales.
- With 50% reserves, full mission is out of NF cost box
- Ice-Focused mission within cap





PHASE	DURATION	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
Heliocentric	13.2 mo	cruise					
Spiral Down	9.7 mo		spiral				
3pm Sun Sync	23 mo			primary sci orbit			
Inc. Transfer	1.4 mo						
90 Degree	21.5 mo				polar science		
Inc. Transfer	1.4 mo						
3pm Sun Sync							



TWO MARS YEARS OF SCIENCE RETURNS.

YEAR 1 AT MARS: 92.7 degree inclination, 3pm sun-synchronous orbit.
YEAR 2 AT MARS: 90 degree inclination, full coverage of poles for the first time.

DIRECT INJECTION TO A C3 OF 1 | LAUNCH (2HRS) | THRUSTING - EARTH (CONTINUOUS) | CRUISE TO MARS (4KM/S, 10-15 MO) | SPIRAL DOWN (3KM/S, 6-12 MO) | SAFE (CONTINUOUS) | THRUSTING - MARS (CONTINUOUS)

NOT TO SCALE