Science/Recon to Enable Mars Human Landing Site Selection
Space Resources Roundtable 2019

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The Real Mars

Gale Crater, Mars

The panorama to the left is from Curiosity, and sometimes makes Mars seem like the deserts on Earth.

We must not be fooled into thinking it is easy- Mars is closer to the extreme heights of the Himalayas than it is to the peaceful (if hot) deserts of the American Southwest.

Wadi Rum, Jordan

K2, Himalayas

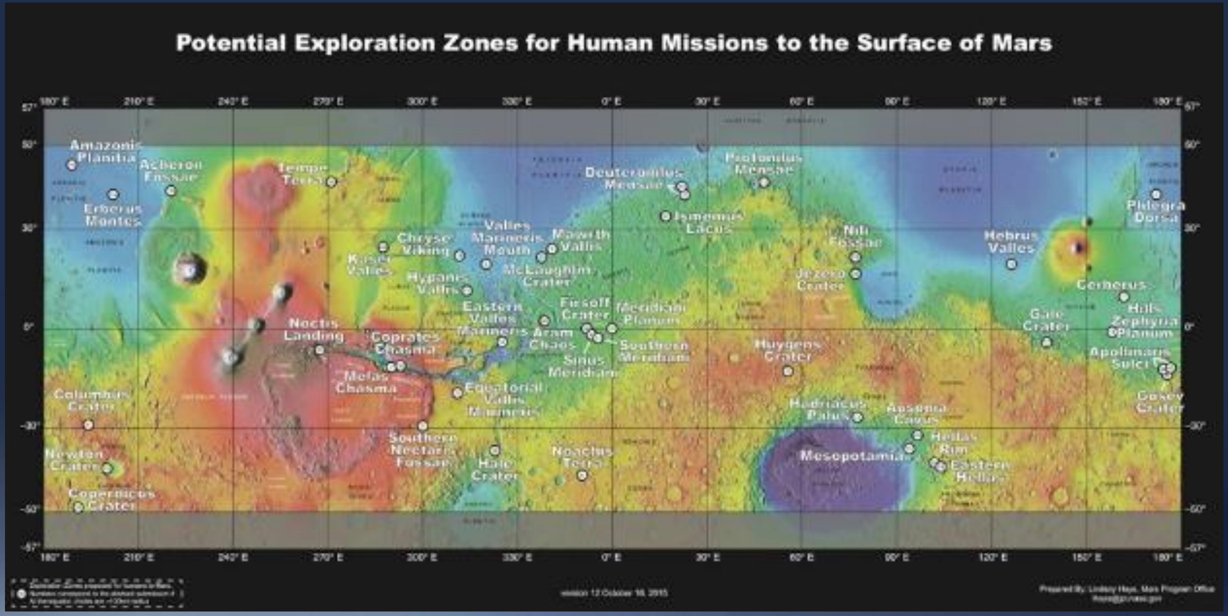
MARS

Where We Are Now

Water and the Human Landing Sites Study (HLS2)

Goal of Study: Identify landing sites for human surface exploration of Mars.

- These landing sites provide access to Exploration Zones (EZs) which are regions on Mars that contain multiple sites of scientific interest as well as satisfying engineering and human constraints for human exploration.
- Leverage Mars Reconnaissance Orbiter (MRO) data collection capabilities to acquire data of potential prioritized human Mars landing sites within the exploration zones
- Establish a database of high interest sites—science and resources, which can easily be updated as we learn more about Mars and what is needed to support humans on the planet
- Inform future reconnaissance needs (particularly water) at Mars—orbital and landed missions



This effort is a joint Human Exploration and Operations Mission Directorate (HEOMD) / Science Mission Directorate (SMD) study

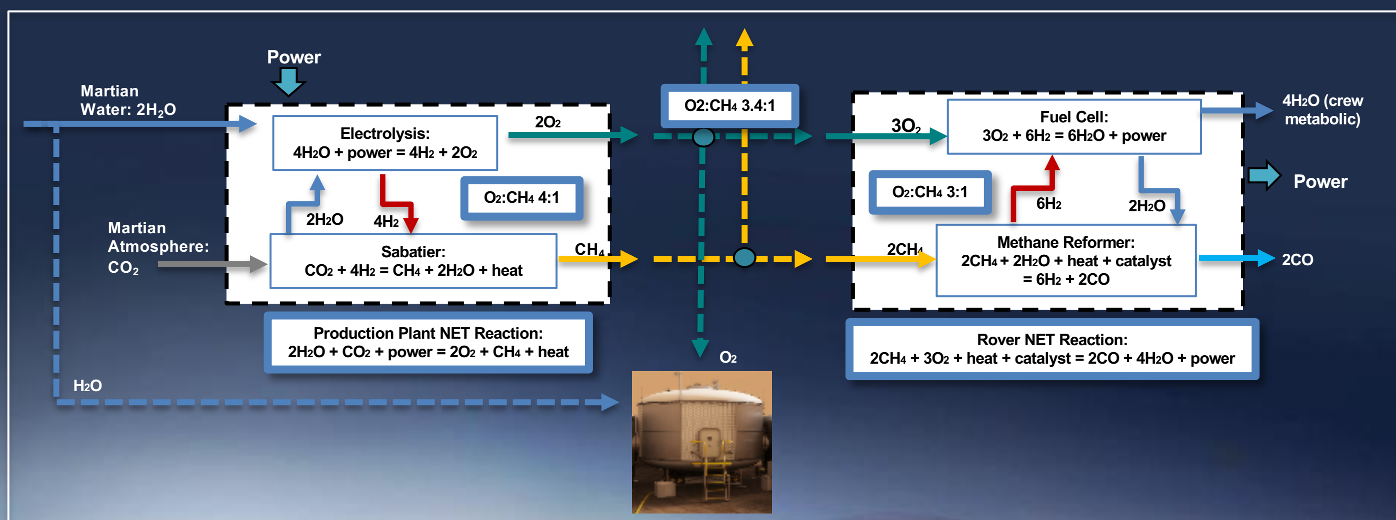
Workshop Significantly Increased Awareness of Importance of Water

- Four Major Questions:
  - Is it really there?
  - Can you really produce it economically?
  - How much water do you need?
  - If the feedstock drives location, what does that mean for landing, launching to go home, and living there?

MARS

How Would a Mars Mission Use Abundant Water?

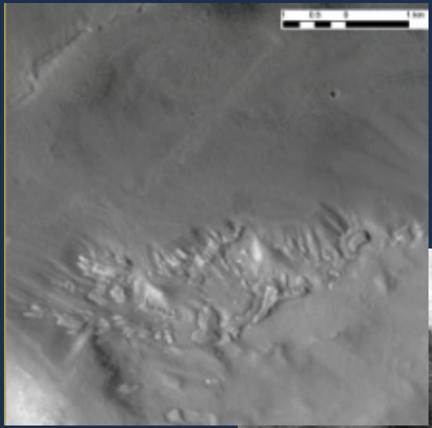
- Highest water mass requirements:
  - Propellant for Mars Ascent Vehicle (MAV) (~20 tons for a four-person crew)
  - Eventually: agriculture/hydroponics
- Other major uses:
  - Crew health, hydration, and hygiene
  - Regulating oxygen, pressure, and humidity
  - Material for construction and radiation shielding
  - Cooling for space suits and other equipment

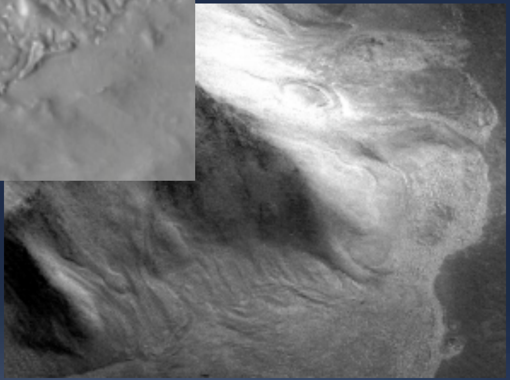


Mars has Several Water Feedstock Options

Subsurface Ice

“Sheet” Ice

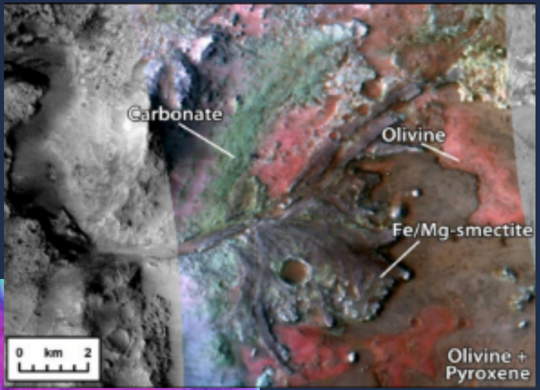


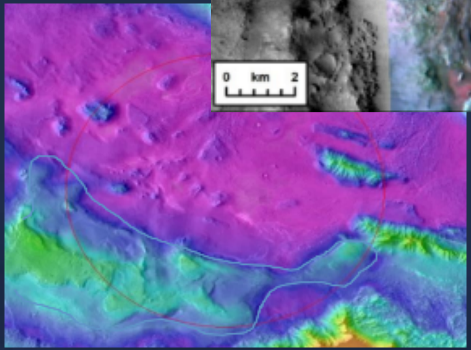


Debris-Covered Glaciers

Hydrated Minerals

Other Hydrated Minerals



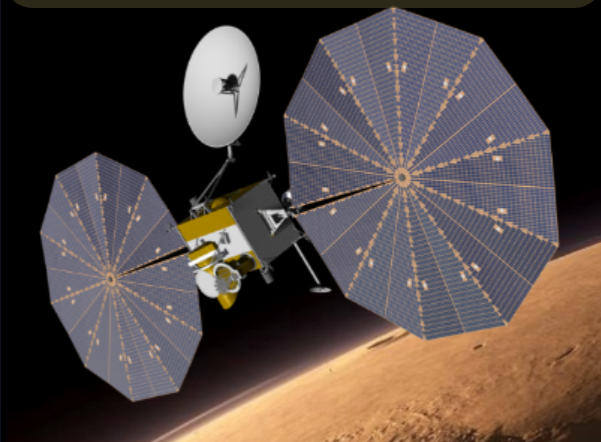


Poly-hydrated Sulfates

Many EZs have multiple water feedstock types

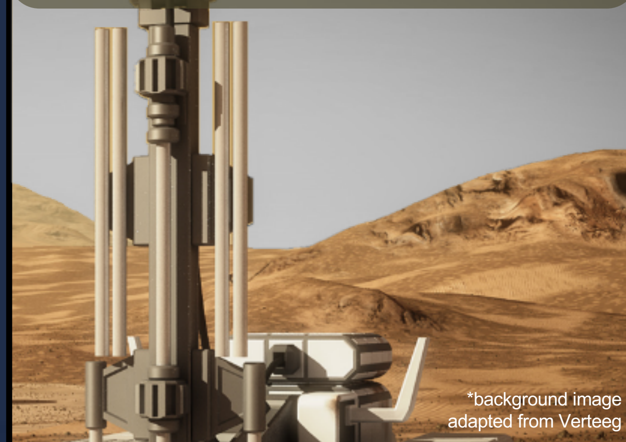
Potential Future Uses of Mars Water Maps

Informing Future Orbital Science / Reconnaissance



Provide targets and requirements for potential future orbiter mission(s) carrying new instruments to better characterize the distribution and depth of hydrated minerals and subsurface water ice deposits

Guiding Future Surface Science / Reconnaissance



*background image adapted from Verteeg

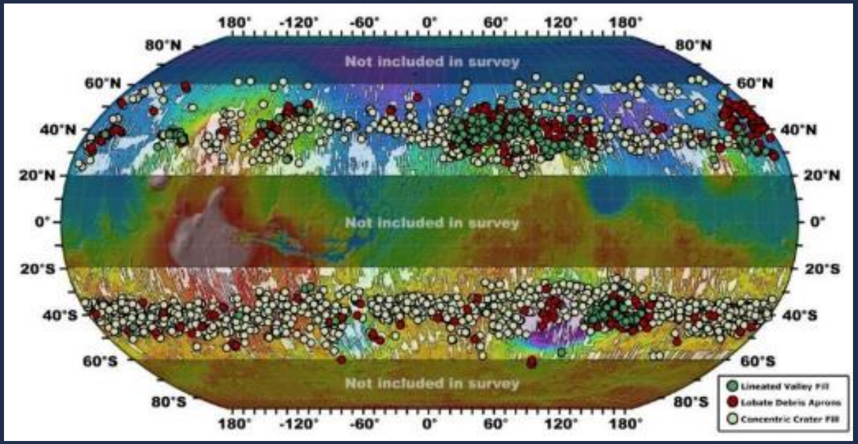
Revealing landing site options for a potential future landed ground truthing mission that will validate orbital measurements and further characterize possible water feedstocks

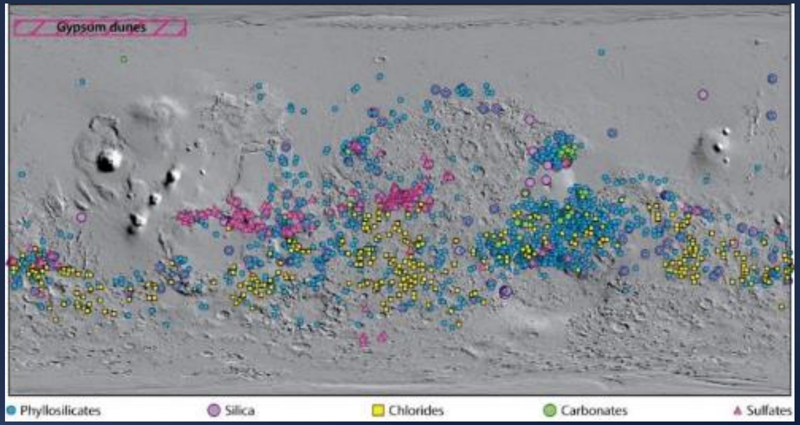
Selecting Humans Landing Sites / Exploration Zones

Supporting human landing site selection activities and ongoing architecture studies for future human surface systems

Mars Water Mapping Projects

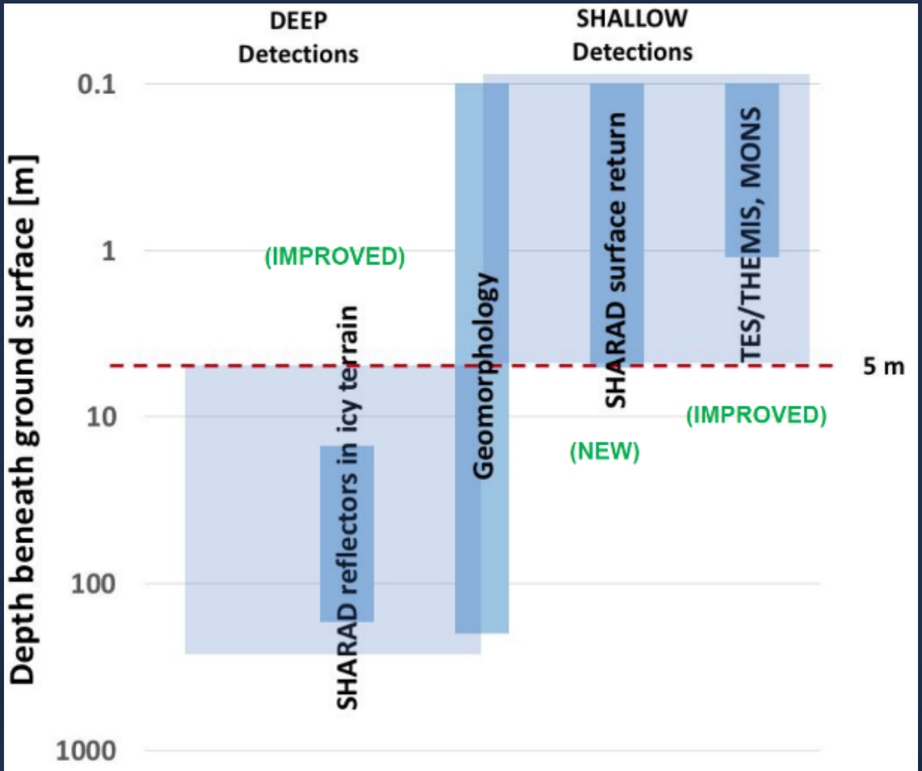
- Ongoing projects to create the best possible maps of water distribution by combining currently available orbiter data
  - Low cost option for increasing our understanding of water distribution across Mars
- Two types of mapping projects identified as highest priority:
  - **Task A – Subsurface Ice Map** (Proof of Concept)
    - *Within a single 5-10° wide longitudinal swath from 0°-60°N latitude, generate a map that identifies potential locations of subsurface water ice at low- to mid-latitudes and characterizes the nature of the gradational boundary from regions of continuous ice to discontinuous ice, through to regions of no ice.*
  - **Task B – Hydrated Minerals (Global Map)**
    - *Develop algorithms to partially automate the processing of spectra of hydrated mineral detections. Use developed algorithms to generate global map of all existing near-surface hydrated mineral detections*
- Maps expected mid-2019





Subsurface Water Ice Mapping (SWIM) Project

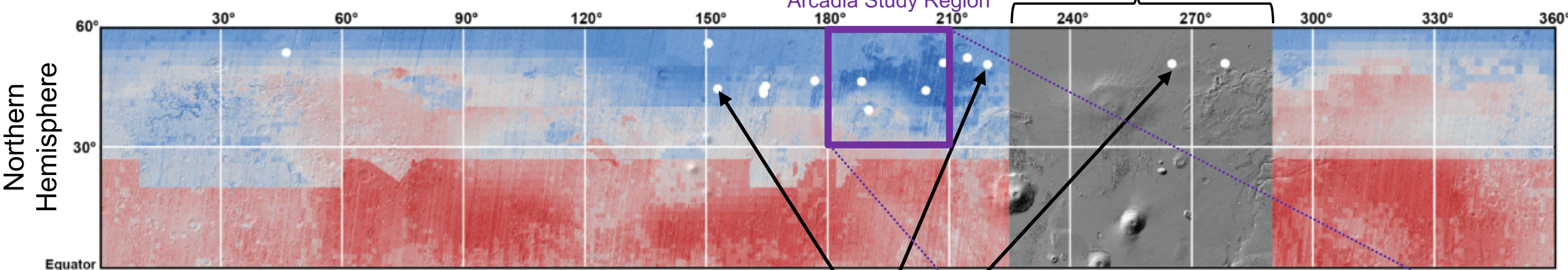
- Comprehensive effort to map subsurface ice on Mars by:
- Improving previous mapping techniques used to detect ice across depths of millimeters to 100 meters
- Contributing three new ice detection techniques
  - Measuring ***SHARAD surface power return*** to infer ice presence within the top 5m
  - State-of-the-art ***super-resolution processing*** techniques that increase data resolution of radar data to a level that can potentially resolve the top of the ice layer
  - The ***"split-chirp" sub-band processing*** technique that measures material loss properties, thereby constraining bulk composition
- Extending coverage of existing mapping techniques to cover the entire Northern Hemisphere of Mars
- Combining results from all ice detection methods into a single measure of "ice consistency" over each pixel of an integrated map



Subsurface Water Ice – Preliminary Northern Hemisphere Map

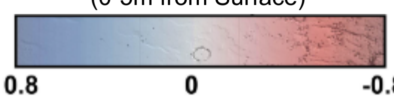
Datasets used: MONS, TES, THEMIS, SHARAD, Geomorphology (imagery and elevation data)

Region not mapped due to high elevation (not landable by human-class vehicles)



Ice Consistency

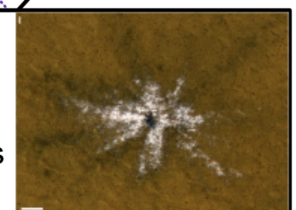
(0-5m from Surface)



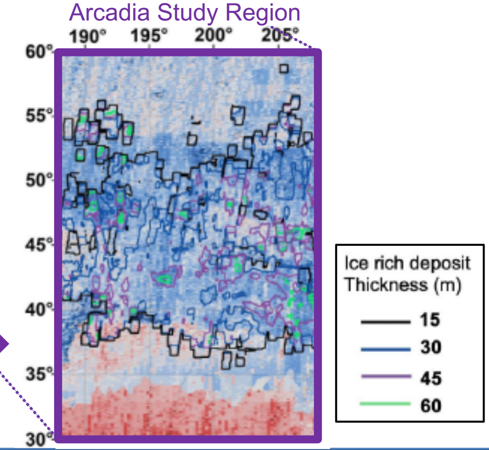
Multiple datasets show indications of ice within 0-5m of surface

Multiple datasets show indications of no ice within 0-5m of surface

White dots = Fresh ice exposing impacts mapped by Dundas et al. [2014] showing good agreement between this map and observed data



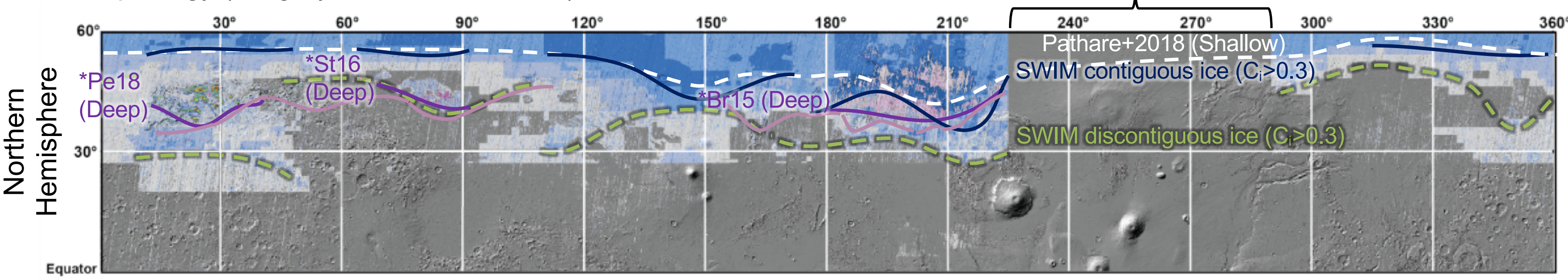
Map of boundaries of thickness of ice-rich deposits over the Arcadia study region, indicating a subsurface ice-rich deposit of 15-60m thickness throughout the region



Pushing the Ice-Boundary Line Equatorward

Datasets used: MONS, TES, THEMIS, SHARAD, Geomorphology (imagery and elevation data)

Region not mapped due to high elevation (not landable by human-class vehicles)



Legend

- Prior shallow (<1 m) ice from neutrons
- SWIM contiguous ice consistency >0.3
- SWIM discontiguous ice consistency >0.3
- Previously published deep (>15m) ice southern boundary
- SWIM detected deep (>15m) ice southern boundary

Ice Consistency (C_i)
(0-5m from Surface)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

Depth to Base of Ice (m)
Derived from SWIM Radar Analysis
15 800

The SWIM Project has:

- Detected more **equatorward contiguous and discontiguous shallow** (<5 m) **ice** than previously found across the Northern Hemisphere
- Increased radar reflector coverage across the Northern Hemisphere, detecting more **equatorward deep ice**, and improving estimates of material composition

*Pe18: Peterson et al. 2018; St16: Stuurman et al. 2016; Br15: Bramson et al. 2015

Hydrated Minerals Mapping

Main Mapping Technique: Reflectance Spectroscopy using data from OMEGA (Mars Express) and CRISM (MRO)

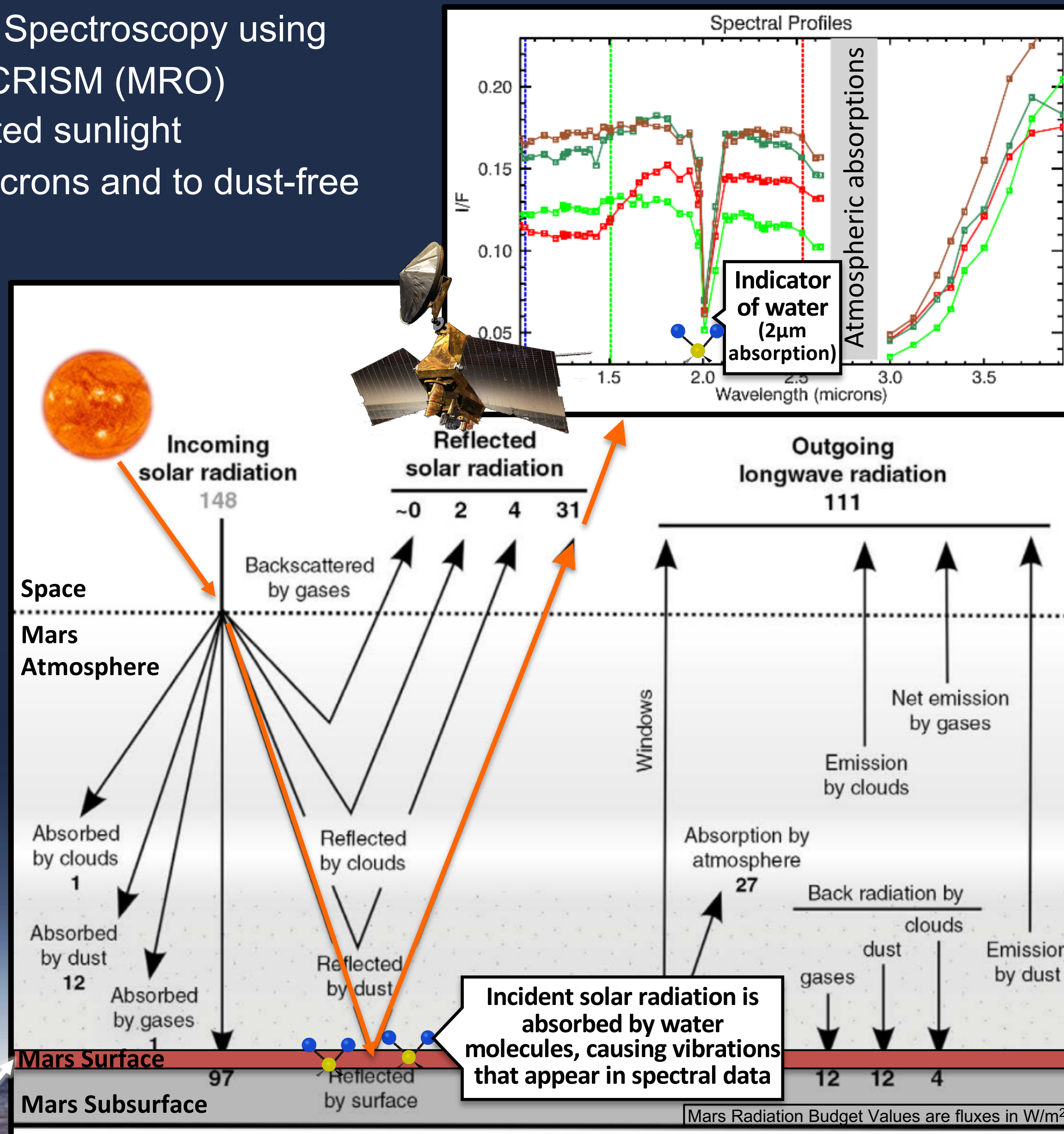
- Based on analyzing spectra of reflected sunlight
- Method limited to depths of 10s of microns and to dust-free pixels

Prior to this project:

- Spectra studied on an image-by-image basis
- Only detections of different minerals made (i.e. is it there or not?)
  - Limited information on content (i.e. how much of a mineral is present?)

Achievements of this project:

- Global mapping of hydrated mineral detections through two unique methods and datasets
- Preliminary attempt at globally mapping mineral water abundance (i.e. H_2O wt%)



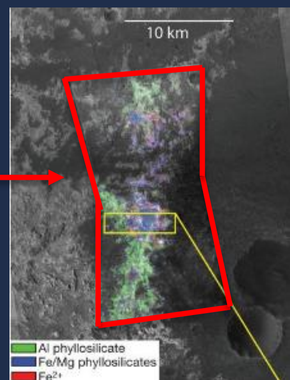
10s microns skin depth

Hydrated Minerals Mapping – Before and After

CRISM (MRO) Data

Before: Image by Image Analysis

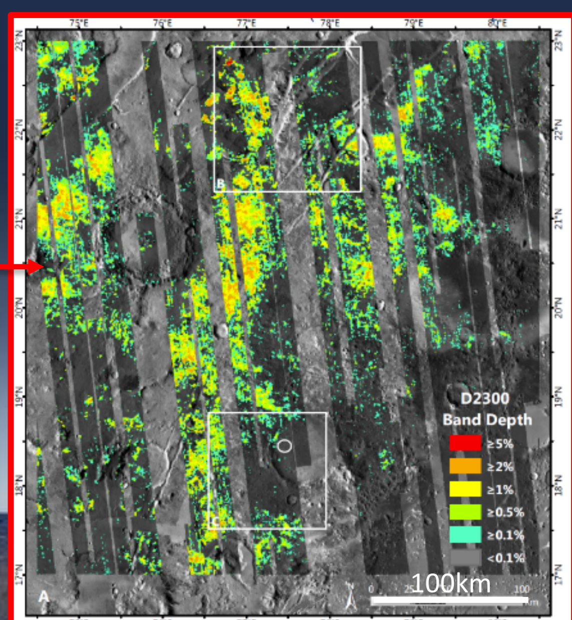
CRISM High-Resolution Targeted Hyperspectral Image



Credit: Mustard et al., Nature 454, 305-309

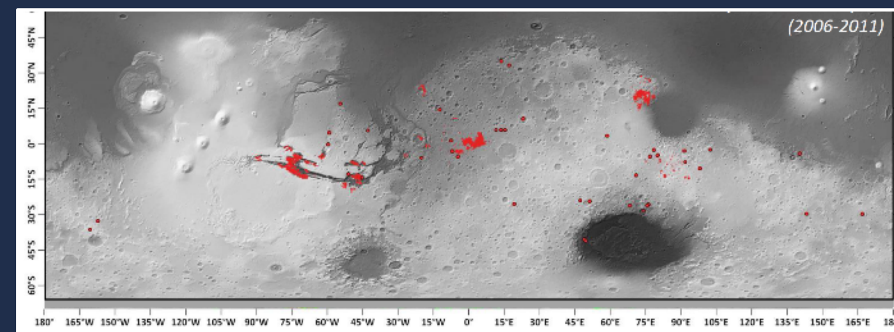
Now: All CRISM data radiometrically tied together to enable global hydrated minerals mapping

Map of Fe/Mg phyllosilicate and Mg-Carbonate spectral signatures over the broader Jezero – Nili Fossae Region

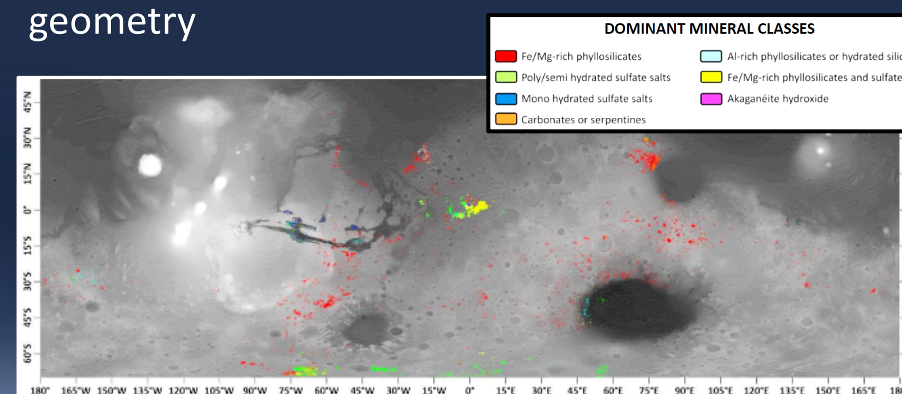


OMEGA (Mars Express) Data

Before: ~1000 sites with aqueous mineral deposits identified as pinpoints on a map

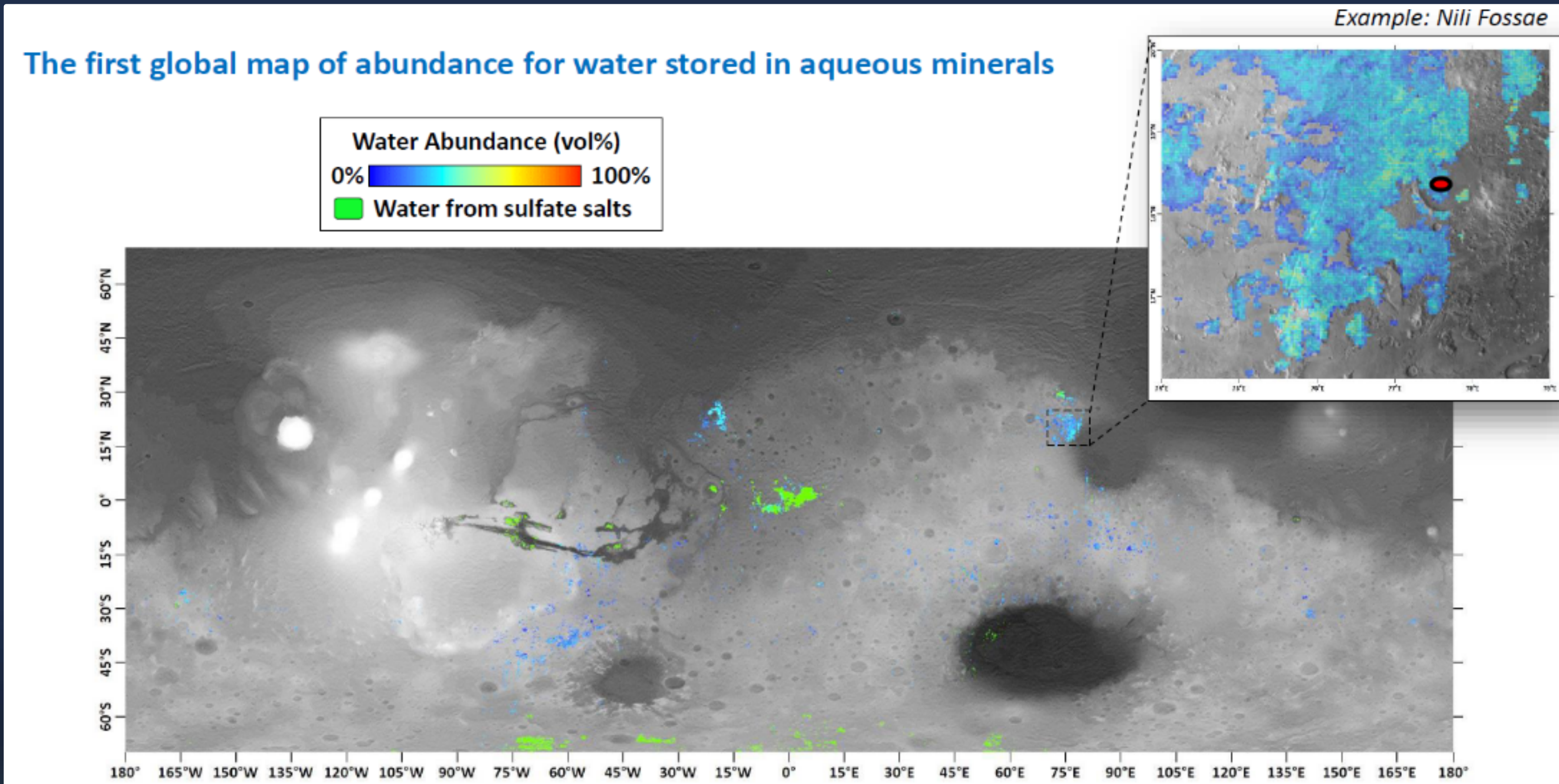


Now: Several 100,000s hydrated mineral sites characterized and mapped, showing their 2D geometry



Now: Preliminary global map of water abundance in hydrated minerals (see next slide)

Global Hydrated Mineral Water Abundance Map



From: Carter et al., IAS Paris-Sud University

NOTE: Water abundance is only calculated for pixels made up of minerals that are cataloged within existing optical constant libraries used in radiative transfer modeling. Optical constants for other minerals are currently being measured. Uncolored pixels do not necessarily represent regions with zero water abundance.

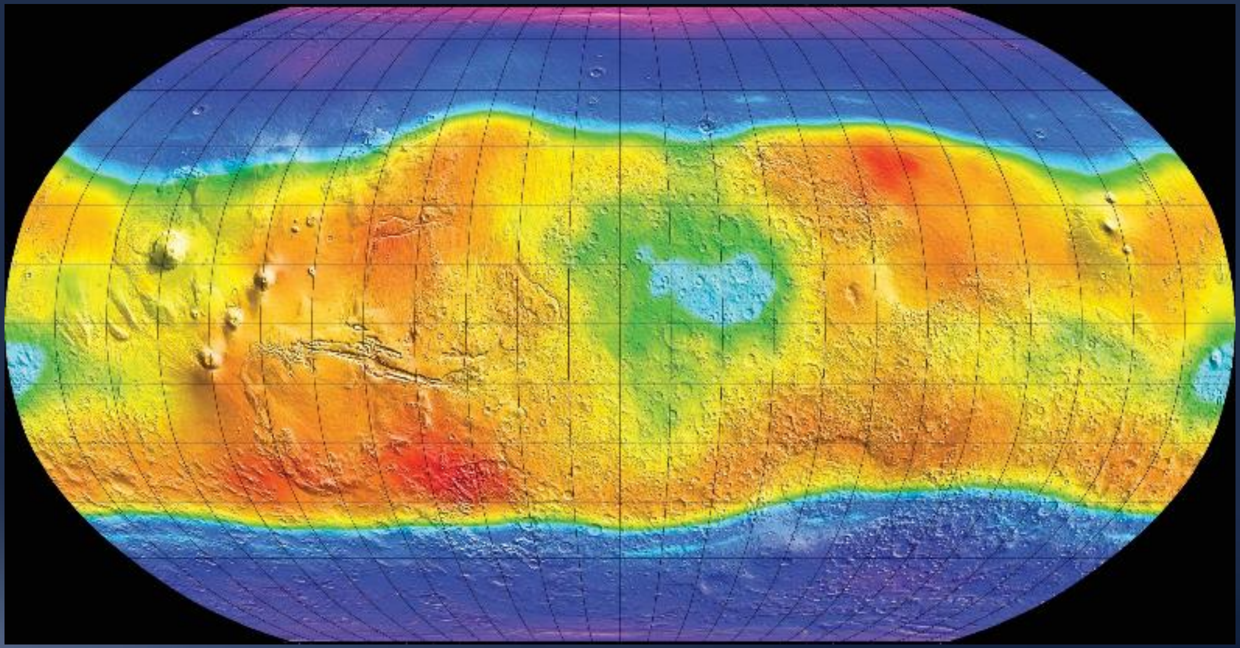
Next Steps

- Northern Hemisphere Subsurface Ice Maps and materials available at: https://swim.psi.edu
  - Currently evaluating potential extension activities to this project that will increase coverage to the Southern Hemisphere and incorporate additional, improved mapping techniques
- Global Hydrated Minerals Maps to be publicly released by mid-2019
- Future studies based on new knowledge revealed by these water mapping projects are currently being considered. Examples of possible follow-on studies/activities include:
  - A potential update to the Mars Water ISRU Planning (M-WIP) Study to better characterize the operational complexity of ISRU equipment required to extract water from feedstocks identified by these maps
  - A potential second Mars human landing site selection workshop to solicit feedback from the broader community on suitable landing sites given the new insights provided by these water maps

Potentially Needed Future Missions

From International Mars Exploration Working Group

- Mars Sample Return
  - Accomplish Decadal Science Priorities
  - In addition, MSR is probably needed to confirm the mechanical properties of the regolith/dust (abrasiveness, oxidizing potential particle size, etc.), how it will interact with surface systems (e.g., suits, rovers, habitats, etc.), and potential human health hazards (toxicity, respiratory, potential extant life, etc.)
- Water Recon
  - Identify near surface ice
  - Assess Potential of Hydrated Minerals
  - Ground Truthing
  - Ease of access
- Special Regions Drill
  - Search for life
  - Characterize the water
    - For ISRU
    - For potential human use
- Next-Gen Weather Capabilities (Orbital and Surface)
  - Density Profiles
    - (EDL)
  - Winds Aloft
  - Potential Microbial Transport
- Improved Communications
  - Increased data rate



MARS

Creatively Using the Tools Available to Us

- Creative Partnerships (International and Commercial)
- Small Missions
- STEM Programs and Competitions
- Analog Missions
- Others??

MARS

For More Information

Visit our website:

http://www.nasa.gov/journeytomars/mars-exploration-zones

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Join our distribution list, by contacting us at:

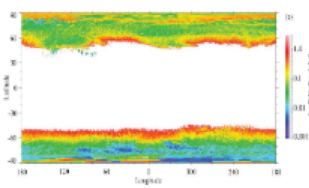
NASA-Mars-Exploration-Zones@mail.nasa.gov

Back up Information

Previous Methods used to Detect Martian Ice

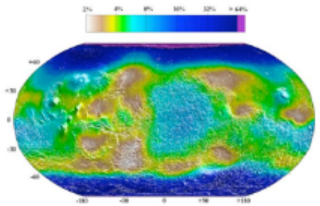
1960-1990s
Theory + Thermal (TES) data predicts likely ice in high (>50°) latitudes of Mars

Detection Depth:
Top mm-cm



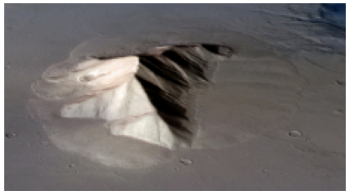
Early 2000s
Neutron Spectrometer (MONS) data finds clear indications of hydrogen in the form of water ice in the same regions

Detection Depth:
Top ~1m



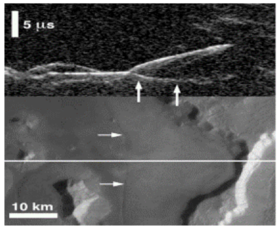
Since Early 2000s
Geomorphological analysis of glacial and non-glacial features captured by high resolution imagers HRSC and HiRISE show evidence of ice in the mid-latitudes

Detection Depth:
Top 1-100s meters



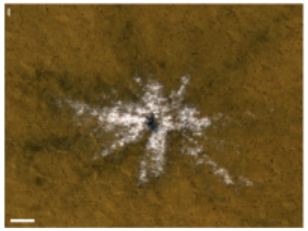
Since 2008
Shallow Radar (SHARAD) Time Delay Data detects subsurface water ice layers over high latitude glacial features and some mid-latitude non-glacial features

Detection Depth:
~20 to 100s meters detection of base of subsurface reflector



Since 2009
High Resolution Images (HiRISE) detect fresh ice-exposing craters, sometimes at lower latitudes

Detection Depth:
Top ~10m



Pre-Decisional Information -- For Planning and Discussion Purposes Only

MARS

Combining Measurement Techniques into a Single Metric

We introduce **the SWIM Equation**, in the spirit of the famous Drake Equation.

$C_I = (C_N + C_T + C_G + C_{RS} + C_{RD}) \div 5$ Consistency of data with the presence of buried ice

We map **consistency values** for each dataset:

C_N	Consistency of neutron-detected hydrogen with shallow (< 1 m) ice
C_T	Consistency of thermal behavior with shallow (< 1 m) ice
C_G	Consistency of geomorphology with shallow and deep ice
C_{RS}	Consistency of radar surface echoes with shallow (< 5 m) ice
C_{RD}	Consistency of radar dielectric properties with deep (> 5 m) ice

Confidence values range between -1 and +1, where:

-1	Data are ***consistent*** with the presence of ice
0	Data are absent or gives no indicators of ice presence or absence
+1	Data are ***inconsistent*** with the presence of ice