Planning for the First Human Landing Site on Mars – An Overview of NASA's Mars Water Mapping Projects

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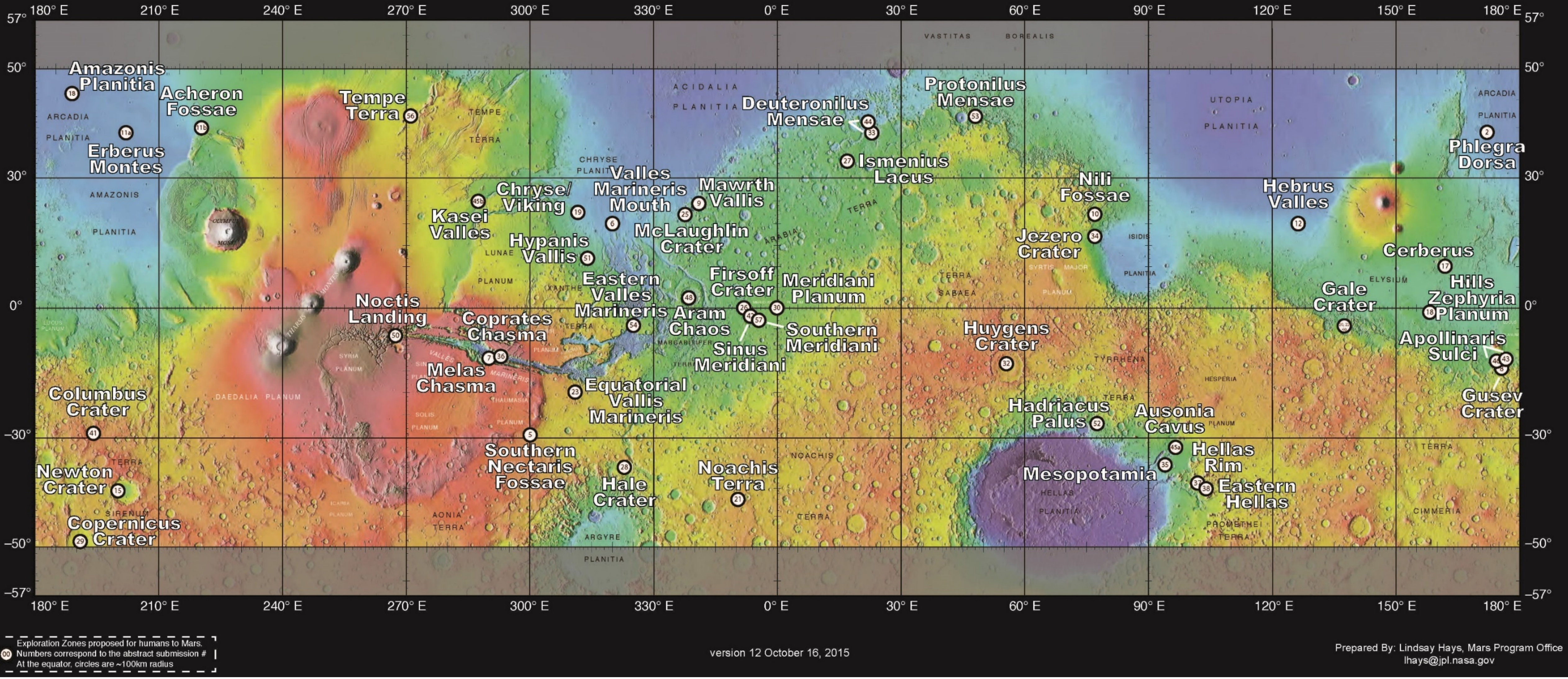
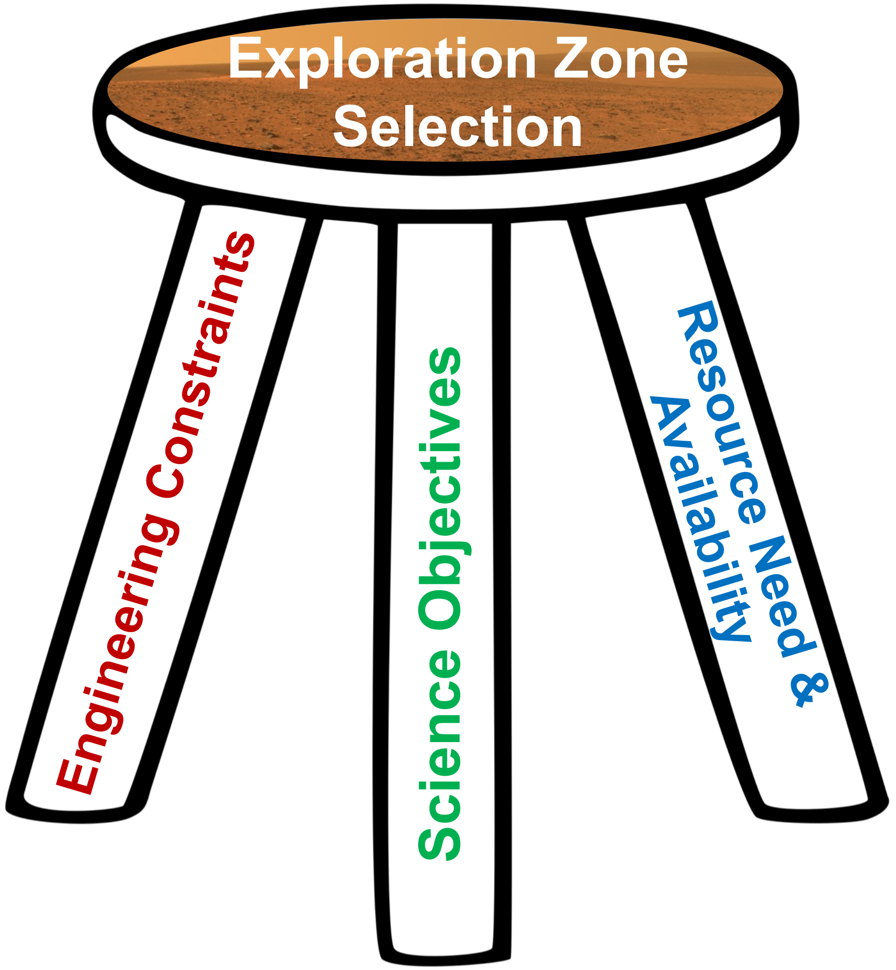
Where should we land humans on Mars?



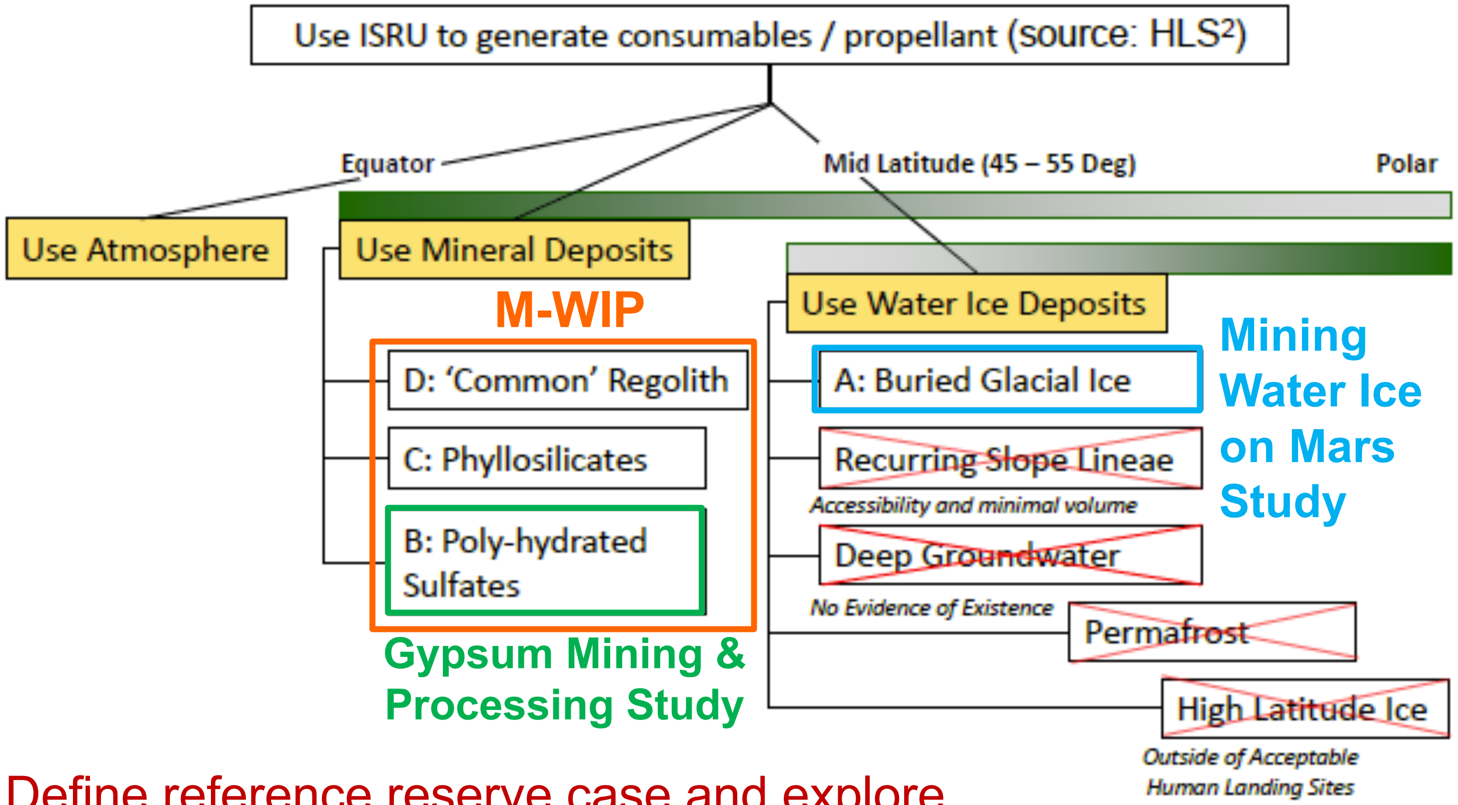
Landing Site Selection for Human Mars Missions

- **Process Started Early 2015**: NASA HEOMD and SMD jointly begin activities to focus efforts on identifying requirements for human landing site selection (HLS2)
- **October 2015**: NASA holds First Mars Human Landing Site/Exploration Zone Workshop. 47 Exploration Zone candidates proposed.
- Recognition that ISRU potential, and especially potential for water, will be a fundamental criterion for prioritizing these candidates.
- Currently planning a potential 2nd Mars Human Landing Site/Exploration Zone Workshop



Overview of Follow-On ISRU Studies

- Defined four most common types of water resource deposits for further exploration



NASA Sponsored ISRU Activities Since:

Jan–April 2016:	Mars Water ISRU Planning (M-WIP) Study
April–July 2016:	Mining Water Ice on Mars Study
Dec 2016:	AGU Mars Water Exploration Workshop
June–Aug 2017:	Gypsum Mining and Processing Study
June 2017–Oct 2018:	Mars Water Mapping Project

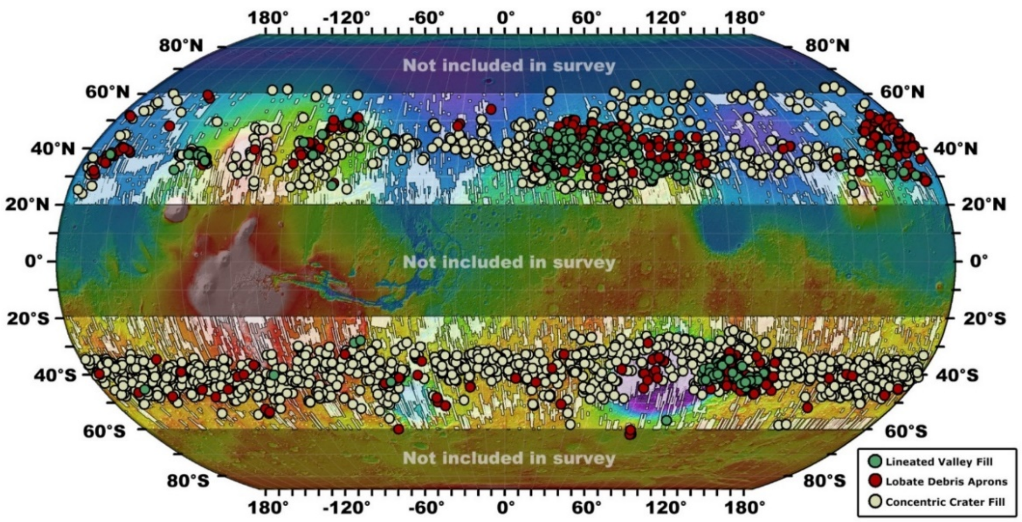
Define reference reserve case and explore feedstock mining and processing techniques

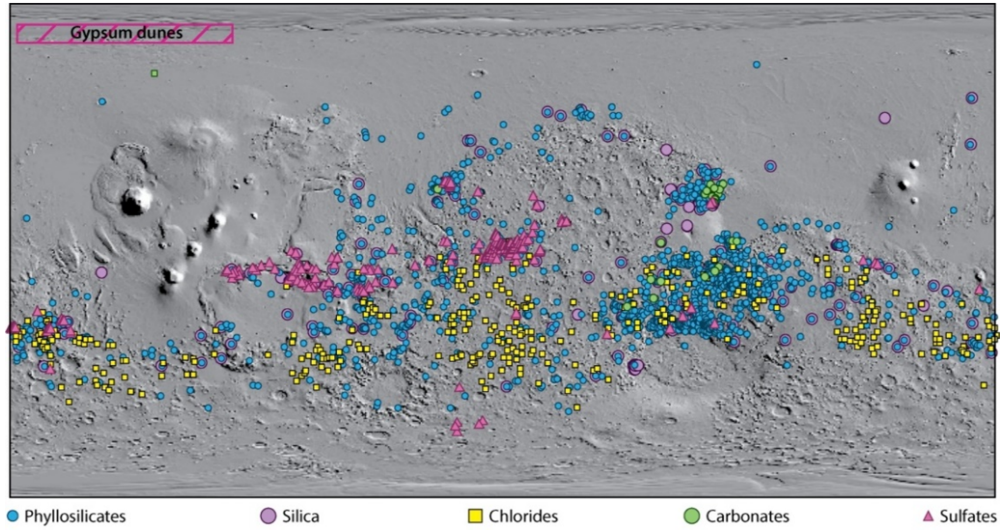
Better understand current distribution of water on Mars and the form in which it exists

Image Source: P. van Susante, M-WIP (2016)

Outcome of 2016 Mars Water Exploration Workshop

- Ongoing projects to create the best possible maps of water distribution by combining currently available orbiter data
- Two types of mapping projects identified as highest priority:
  - **Task A – Subsurface Ice Mapping** (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 April 2019





Mars Water Mapping Competition: Winning Teams

	Task A – Subsurface Ice Mapping	Task B – Hydrated Minerals Mapping
Team 1	Putzig et al. (PSI) *Mapping Buried Water Ice in Arcadia & Beyond with Radar & Thermal Data*	Carter et al. (Paris-Sud Univ.) *A Global Aqueous Mineral Abundance Catalog for Mars*
Team 2	Morgan et al. (PSI) *Local Subsurface Ice Mapping Through the Integration of SHARAD Derived Data Products with Other Datasets*	Seelos et al. (APL) *CRISM-Derived Global Map of Hydrated Mineral Bearing Units*

Task A – Subsurface Ice Mapping

Team 1: Than Putzig, Hanna Sizemore, & Isaac Smith (Planetary Science Institute)

Team 2: Gareth A. Morgan (Planetary Science Institute) and Bruce. A. Campbell (Smithsonian Institution)

Task A (Subsurface Ice) Team 1 (Putzig et al.)

- **Title: Mapping Buried Water Ice in Arcadia & Beyond with Radar & Thermal Data**

- Will study a 600-km-wide swath centered on 198°E focusing on SHARAD, TES, and THEMIS data, using grid-based mapping methods developed by Ramsdale et al. [2017; in review].

- Isaac Smith will lead the SHARAD element,
  Than Putzig will lead the TES element, and
  Hanna Sizemore will lead the THEMIS element.

- U. Roma (Roberto Seu, Marco Mastrogiuseppe, and Marica Raguso) have agreed to collaborate with super-resolution and multi-orbit processing of SHARAD data.

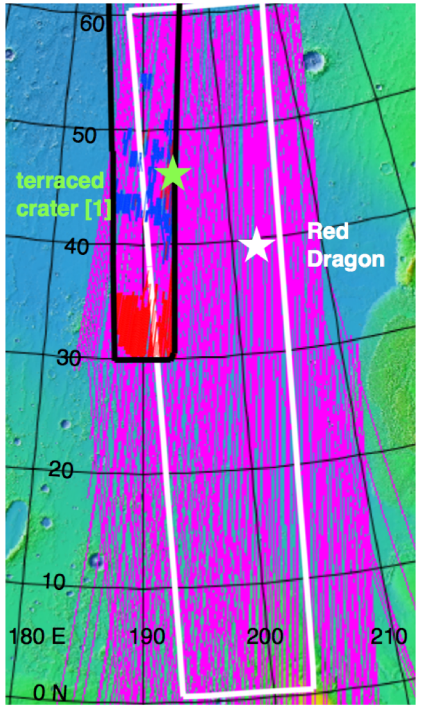
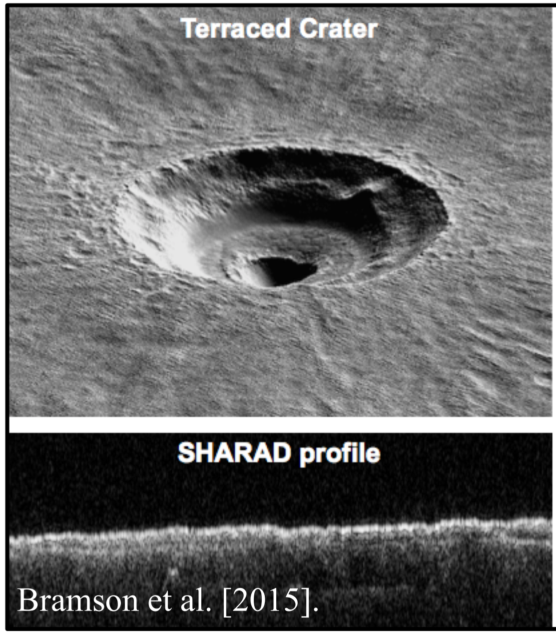


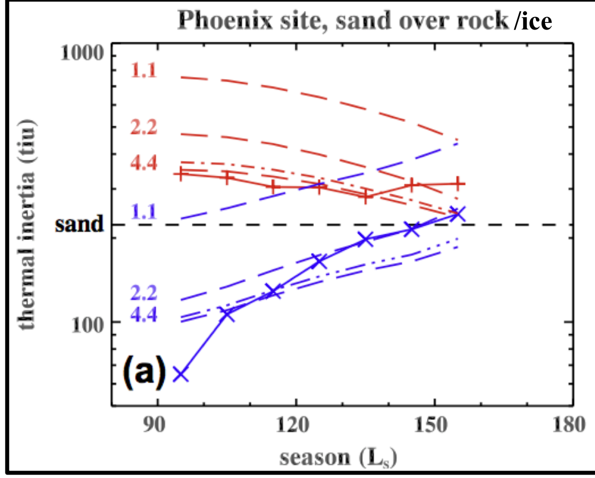
Figure 1. *MOLA elevation map showing Arcadia swath (white box), Balme swath (black box), SHARAD coverage (magenta) with detections of ground ice (blue) and lava flows (red), and two THEMIS-intensive study sites (stars).*

Task A (Subsurface Ice) Team 1 (Putzig et al.)

- The SHARAD element extends prior work [Ramsdale et al., in review; Bramson et al., 2015]. Super-resolution radar may reveal upper interfaces at 3–20 m. The team will verify and fine-tune dielectric values of Bramson et al. [2015], constraining depth to interfaces, composition, and volume fraction of ice.
- The TES element evaluates variations in apparent thermal inertia and their relationships to physical heterogeneity models (mixtures and layering). The team will produce new maps of apparent thermal inertia and best-fitting heterogeneity models to improve lateral and seasonal coverages over that of prior global mapping by Putzig & Mellon [2007].
- The THEMIS element evaluated the thermal properties at higher spatial resolution than TES in mosaics and for all images in representative study areas across the swath. The team will assess surface properties and regions of potential near-surface ice throughout the swath, with intensive study of THEMIS seasonal variations in select study areas.



Terraced crater and SHARAD profile from Arcadia Planitia. The subsurface return in profile is linked to the lower crater terrace.

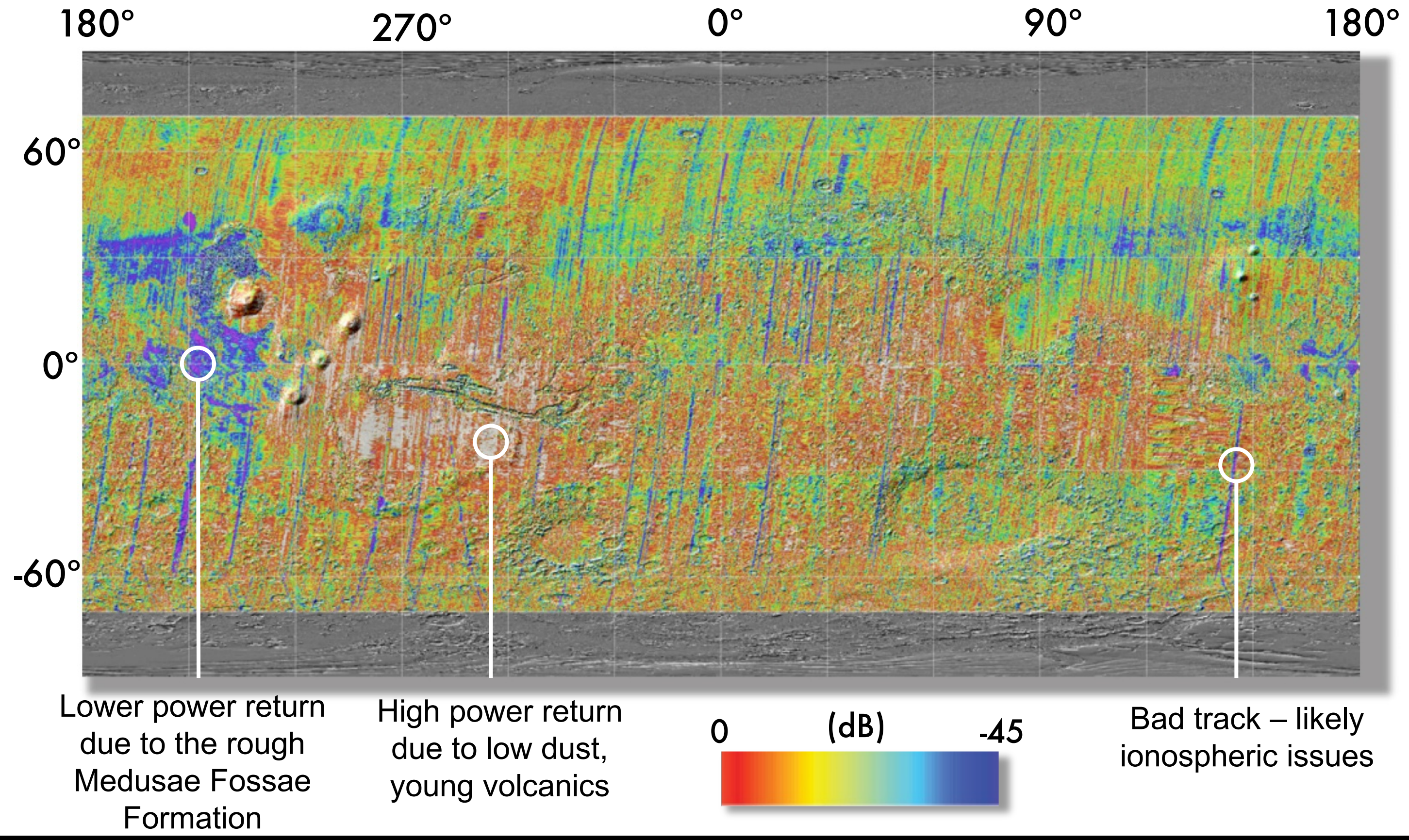


TES (symbols, solid lines) and layered-model (dashed lines) seasonal thermal inertia for Phoenix site at 2AM (blue) and 2PM (red), Upper-layer thickness of ~4 cm sand over ice matches lander observation. After Putzig et al. [2014].

Task A (Subsurface Ice) Team 2 (Morgan et al.)

Title: Local Subsurface Ice Mapping Through the Integration of SHARAD Derived Data Products with Other Datasets

Technical Objectives: Develop an experimental technique to detect subsurface ice, based on isolating Fresnel reflectivity from measurements collected by the SHARAD (MRO) and MARSIS (MEX) sounders.



70ºN – 70ºS distribution of SHARAD surface power return incorporating all data up to MRO orbit 41098

The power return is a function:

- Observing conditions (Positioning of MRO solar arrays, high gain antenna, roll angle etc)
- Ionosphere
- Surface roughness
- Fresnel Reflectivity (related to **composition** and **density** of the near surface)

We will utilize **all** of the available **SHARAD** and **MARSIS** data. Comparing SHARAD and MARSIS data will allow us to investigate the upper **~ 5m - >10m** of the near surface respectively

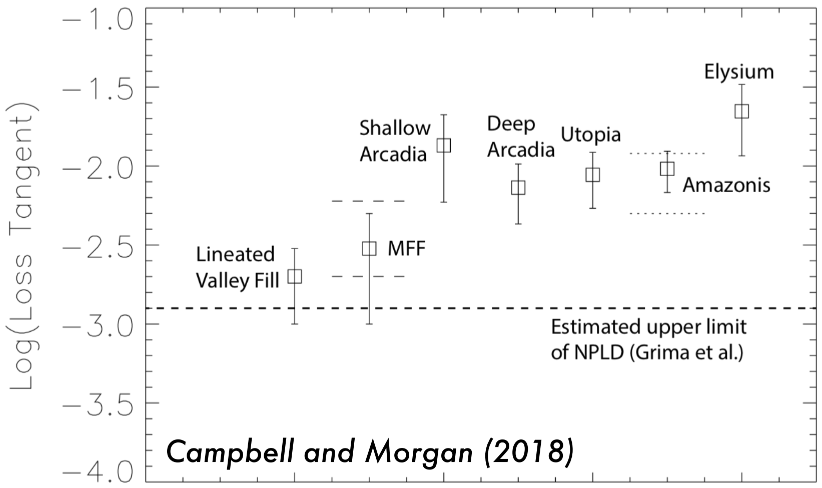
Task A (Subsurface Ice) Team 2 (Morgan et al.)

Key Steps:

- Using MOLA data and a sounder roughness parameter derived by Campbell et al [2013], we will correct the sounder surface power return for surface roughness in order to isolate spatially clustered power anomalies.
- Low power anomalies could indicate regions of reduced density consistent with the presence of ice, and will be investigated in detail using other orbital datasets (HiRISE, CTX, and THEMIS day- and night-time data).
- To build confidence in the detection capabilities of this technique, low power anomalies will be validated against in-situ data taken by the **Phoenix lander** at its Green Valley landing site.
- Finally we will also incorporate the newly developed SHARAD split-chirp technique (Campbell and Morgan, 2018) to search for evidence of the presence of shallow ice. The results of this technique argues against the presence of <u>thick</u> shallow ice in sections of Arcadia.

Team Members:

PI Morgan and Collaborator Campbell are both Co-Is on SHARAD. Morgan has years of terrestrial analog field experience investigating periglacial landforms in Antarctica. Campbell is responsible for processing and delivering the US SHARAD product to the PDS.



Task B – Hydrated Minerals Mapping

Team 1: John Carter, Francois Poulet, Lucie Riu, Giulia Alemano, Rosario Brunetto, and Enric Garcia (Paris-Sud University, Institut d'Astrophysique Spatiale)

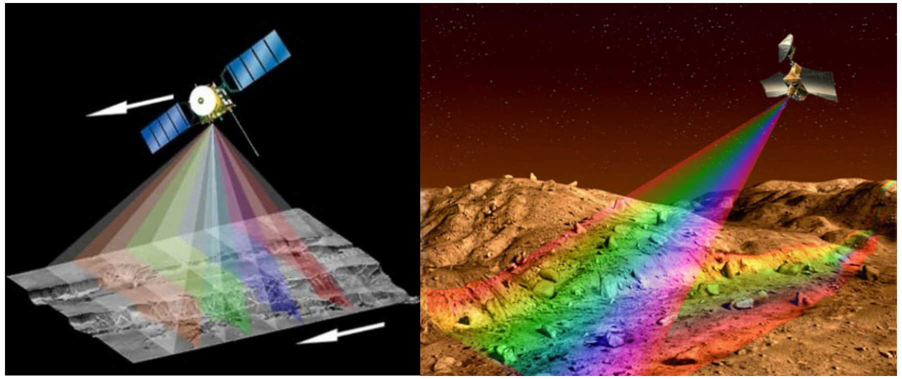
Team 2: Frank Seelos (APL), Noam Izenberg (APL), Ray Arvidson (WU), Janice Bishop (NASA ARC), Bethany Ehlmann (Caltech), Scott Murchie (APL), Kim Seelos (APL), Christina Viviano (APL)

Task B (Hydrated Minerals) Team 1 (Carter et al.)

Title: Mars Orbital Catalog of Chemical Alteration Signatures (MOCCAS)

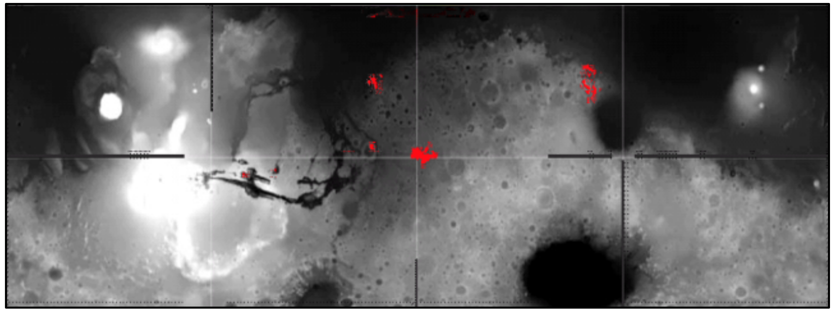
State-of-the-art approach to remote studies of aqueous minerals

- Using VIS-NIR-IR reflectance spectroscopic data from OMEGA (Mars Express), CRISM (MRO) and TES/THEMIS (MGS/ODY)
- Identify “spots” (a few km²) at hundreds of locales at Mars where aqueous minerals are found
- Compare the spectral features (shapes, absorption bands) with laboratory analog spectra and interpret mineralogy

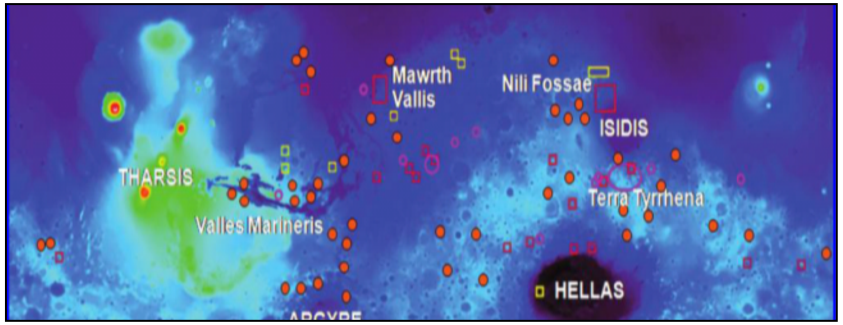


(*maps courtesy OMEGA & CRISM teams*)

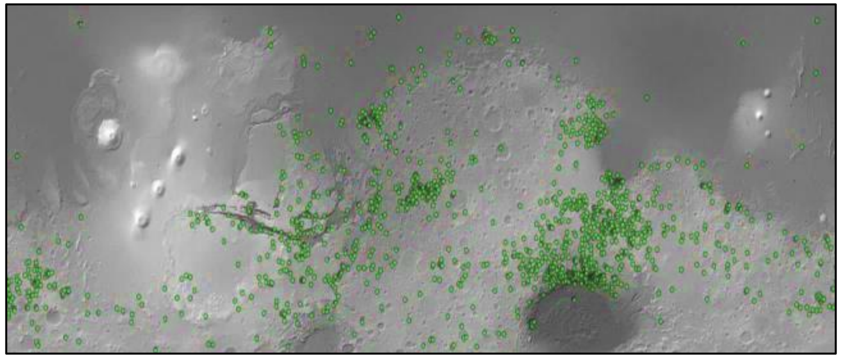
➔ **We have mapped increasingly more aqueous deposits at Mars from orbit**



▶ 2007 *Tens of detections*



▶ 2008-2009 *Hundreds of detections*



2011-2013 *Thousands of detections* ◀

What’s the next step?

Task B (Hydrated Minerals) Team 1 (Carter et al.)

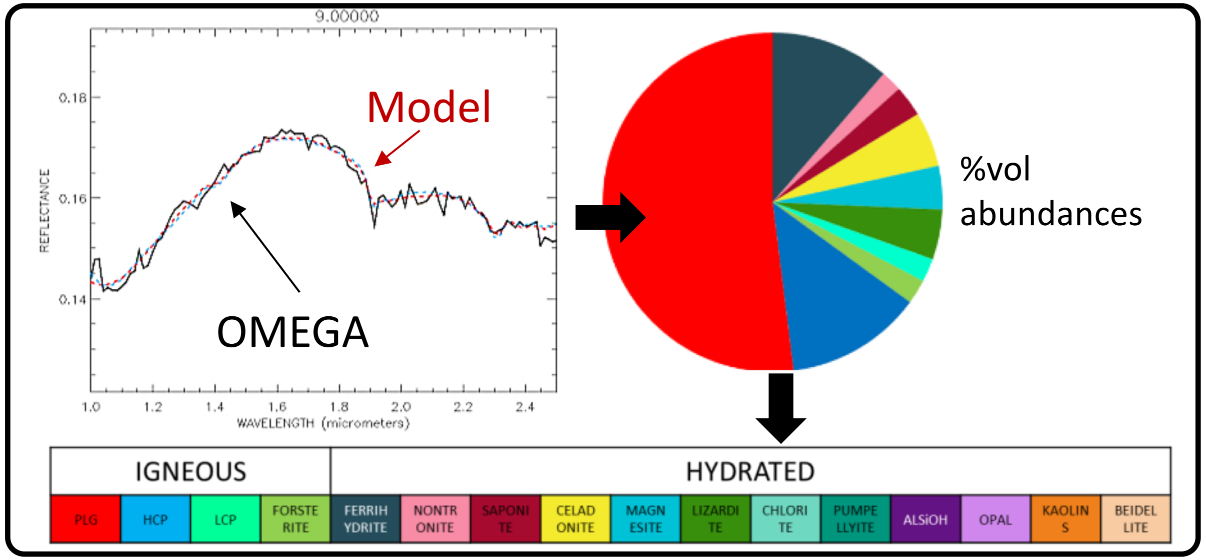
Overcoming limitations from global mapping: a new methodology

1. From qualitative science (identify species) → to **quantitative science** (% abundance of minerals, modal, H_2O)

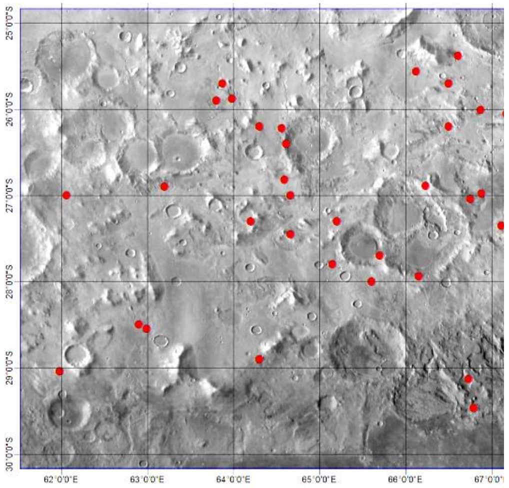
   We use radiative transfer modeling (Shkuratov theory) to invert the reflectance spectra from OMEGA and CRISM

   → *This extracts the volumetric abundance of each species*

   → *From modal abundances, we deduce structural H_2O content*



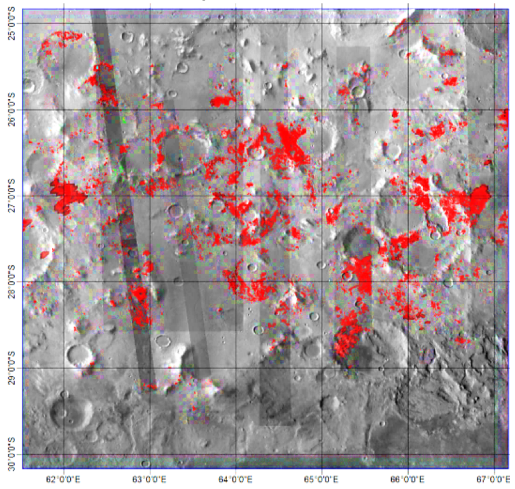
2. From catalog of "points" of aqueous mineral locales at Mars → to an **actual map** (sub km resolution) of their **distribution**



2007-2013

In color: aqueous mineral deposits
From points to maps: this took 7 years!

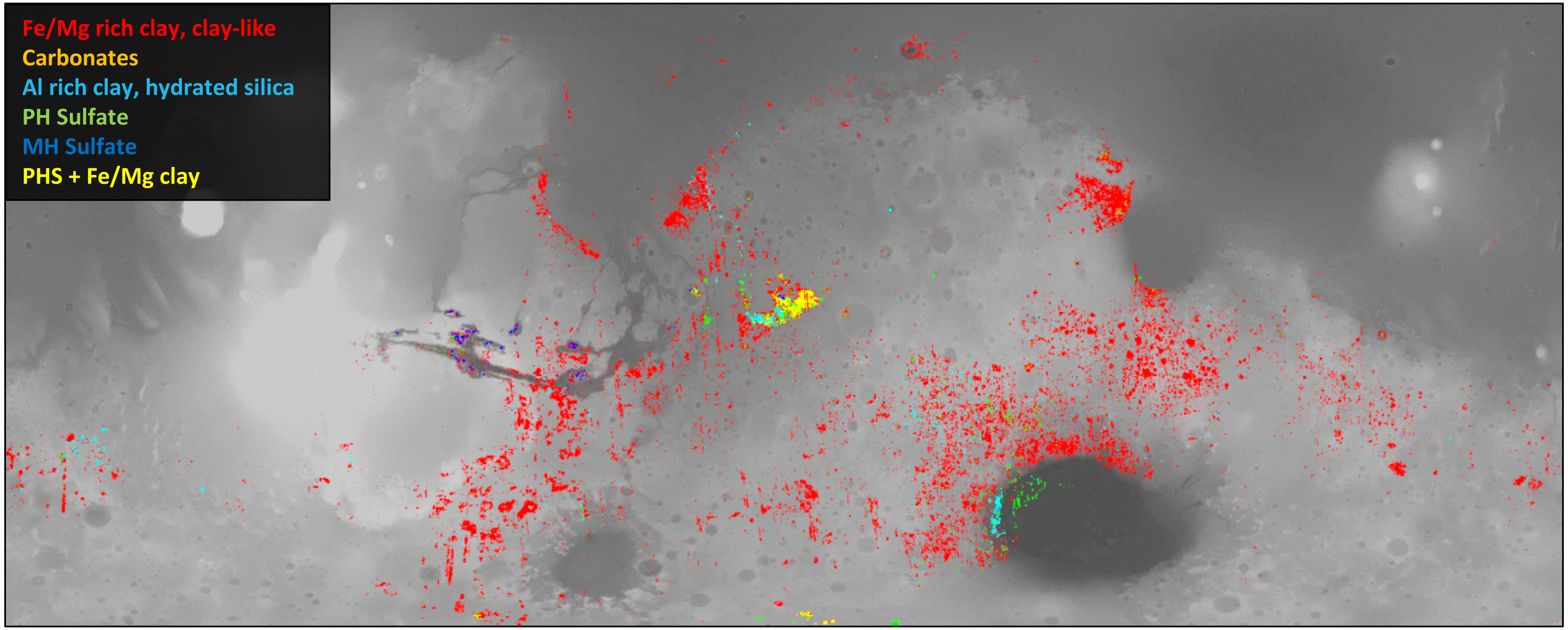
2018 (MOCCAS)



Task B (Hydrated Minerals) Team 1 (Carter et al.)

Combining these two approaches, the project aim is:

- to provide the first global map of aqueous minerals at Mars COMPLETED
- additionally discriminate their mineral composition (salts, clays, etc.) COMPLETED
- and to assess their surficial abundances from which we derive H_2O content relevant for ISRU ON-GOING



Task B (Hydrated Minerals) Team 2 (Seelos et al.)

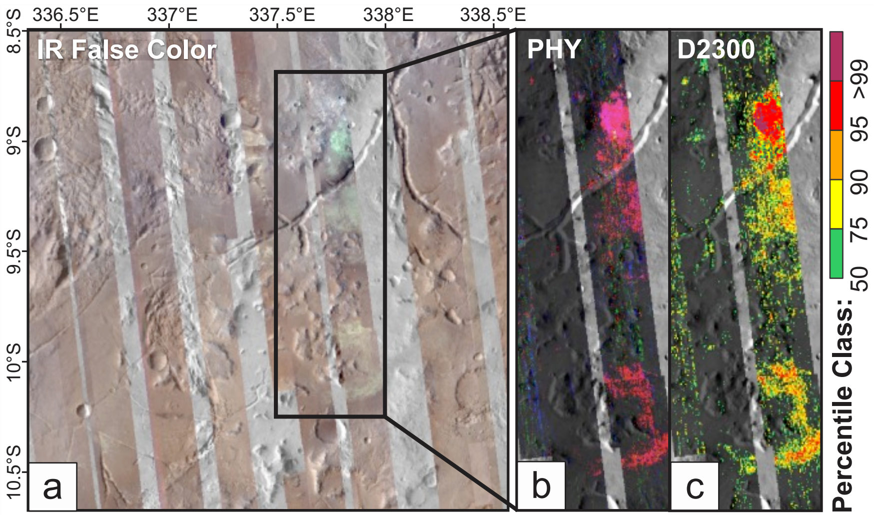
Title: Mars Global Hydrated Mineral Mapping Using CRISM

- Primary Products and Deliverables
  - Set of near-global spectral parameter maps indicative of key hydrated mineral phases derived from the accumulated CRISM multispectral mapping data set (0.44-3.92 μm, 72 wavelengths, ~200 m/pxl, ~87% global coverage acquired over nearly 6 Mars years)

Key hydrated mineral phases, common occurrences, and diagnostic summary parameters

Phase	Common Occurrences	Diagnostic Parameters
Al-smectite	Upper strata of layered clay deposits	BD2210_2, BD1900_2
Fe/Mg-smectite	Layered clay, lower strata; crustal phyllosilicates	D2300, BD1900_2
Polyhydrated sulfate	Valles Marineris ILDs, chaos regions, Meridiani, Mawrth	BD1900_2, SINDEX_2
Monohydrated sulfate	Valles Marineris ILDs, chaos regions, Meridiani	BD2100, SINDEX_2
Hydrated silica	Layered deposits in plains around Valles Marineris	BD2210_2, BD2250, (BD1900_2)
Hydrated carbonate	Nili Fossae, Noachian highlands	D2300, BD2500_2, MIN2295_2480

  - Vectorized parameter threshold ROIs with associated attributes: unit type, 10th, 50th, 75th, 90th, 95th, and 99th parameter distribution percentile values, albedo and spectra of the associated pixels
    - GIS-compatible inventory of hydrated mineral exposures and associated spectra to support further investigation



CRISM multispectral mapping data in the Margaritifer Terra region: (a) data processing results in radiometric continuity across image strips (R: 2.53 μm; G: 1.51 μm; B: 1.08 μm) (b) Phyllosilicate (PHY) spectral parameter composite (R: D2300; G: BD2210_2; B: BD1900_2) highlighting the occurrence of Fe/Mg-phyllosilicate minerals in magenta. (c) D2300 parameter percentile classification map.

Task B (Hydrated Minerals) Team 2 (Seelos et al.)

- Key Data Processing Steps
  - Large scale CRISM multispectral mapping data processing and correction
    - Instrument noise and artifact remediation
    - Atmospheric and photometric correction
      - Processing complexity and correction level are instrument state and time dependent
  - Empirical radiometric reconciliation among overlapping and proximal mapping observations
    - Mitigate processing residuals
    - Reconcile constituent observations to a self-consistent radiometric framework
  - Spectral parameter calculations
    - Thresholding, vectorization, and attribute sampling

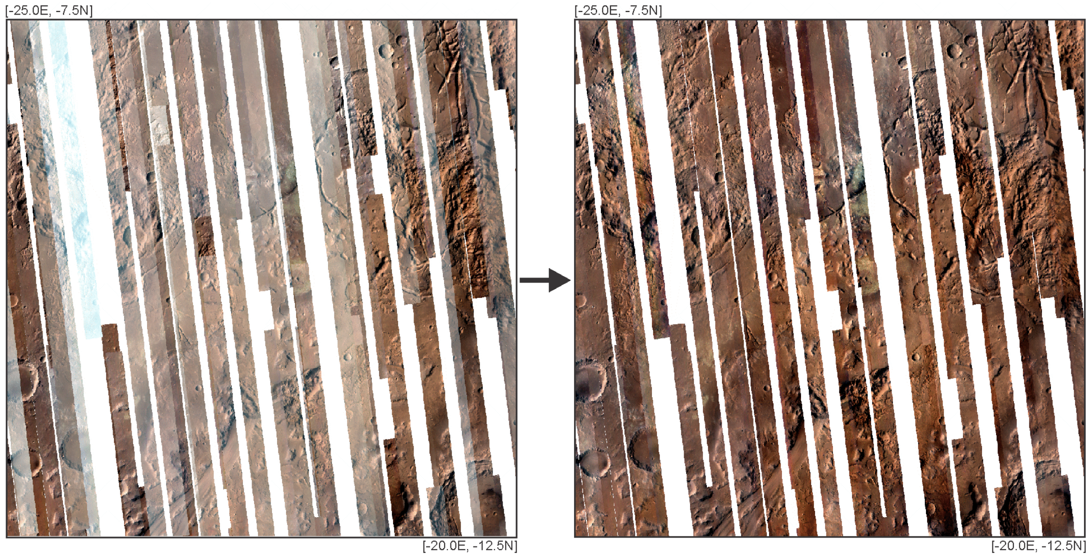
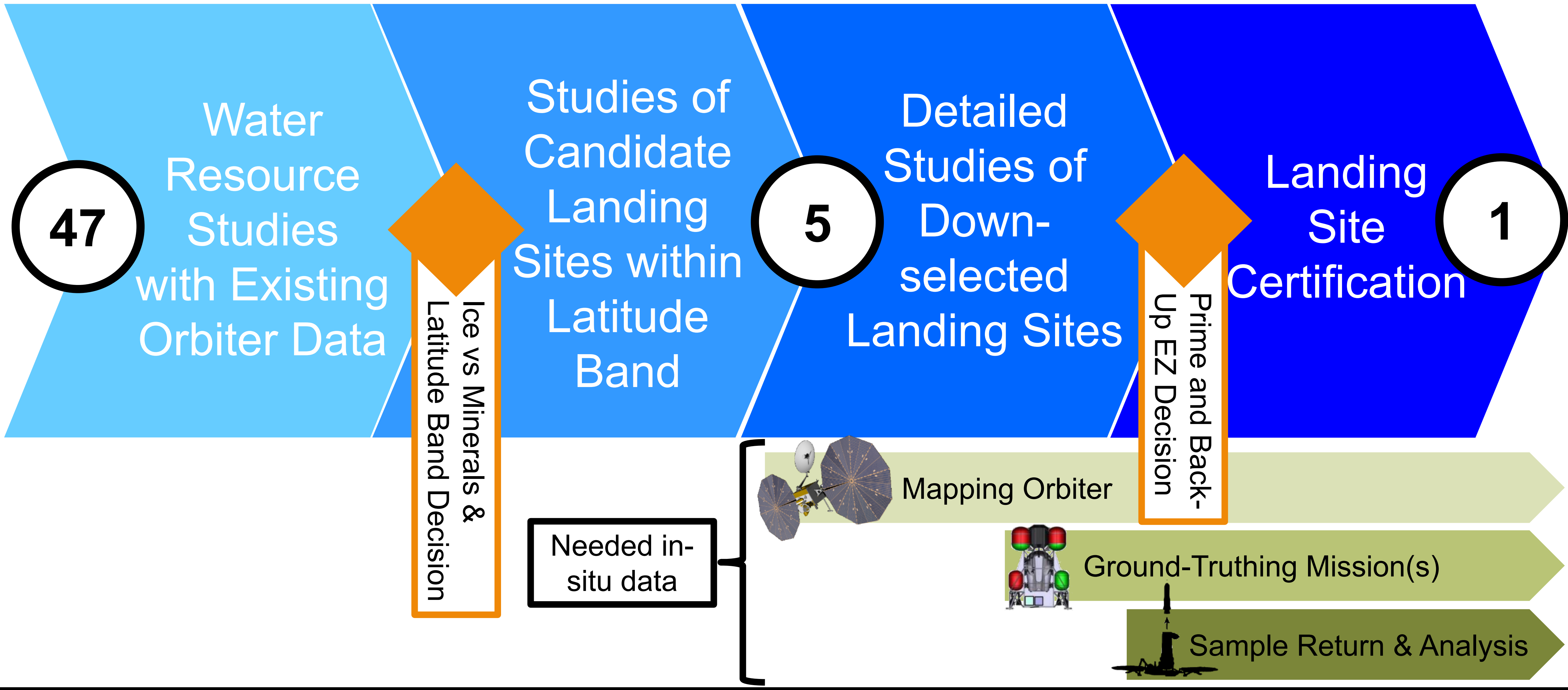


Illustration of the empirical radiometric reconciliation procedure applied to MSP/HSP data for map tile T0870 in Margaritifer Terra

- Novel Technical Aspects
  - The empirical radiometric reconciliation incorporates aspects of graph theory, statistical distribution similarity measures, and linear and non-linear least squares optimization methods

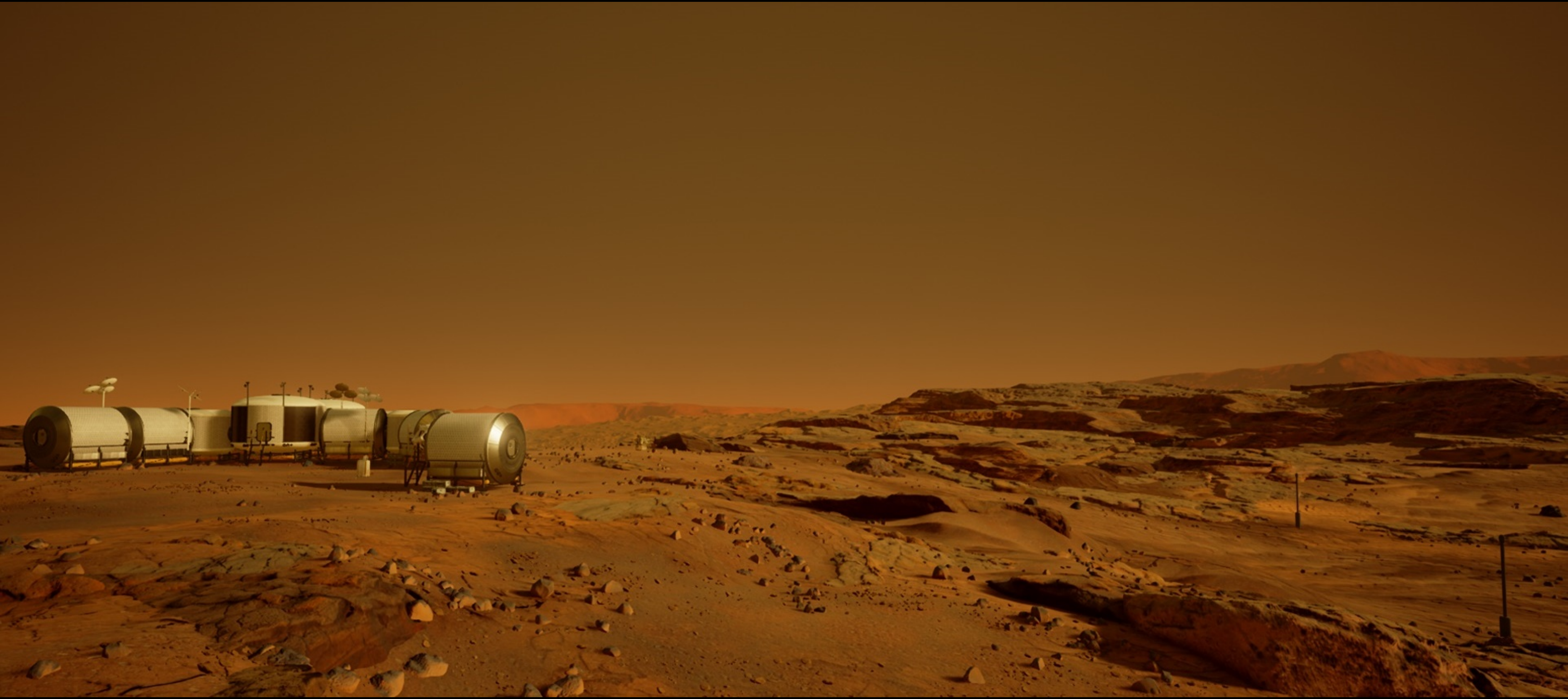
Notional Path Forward for Mars Human Landing Site Selection



Next Steps

- Complete development of Mars water maps (products expected to be publicly released **April 2019**)
- Currently in early planning stages for second Mars human landing site selection workshop
- Ongoing efforts to better characterize the Exploration Zone concept for both subsurface ice-based sites and hydrated minerals-based sites

Thank You!



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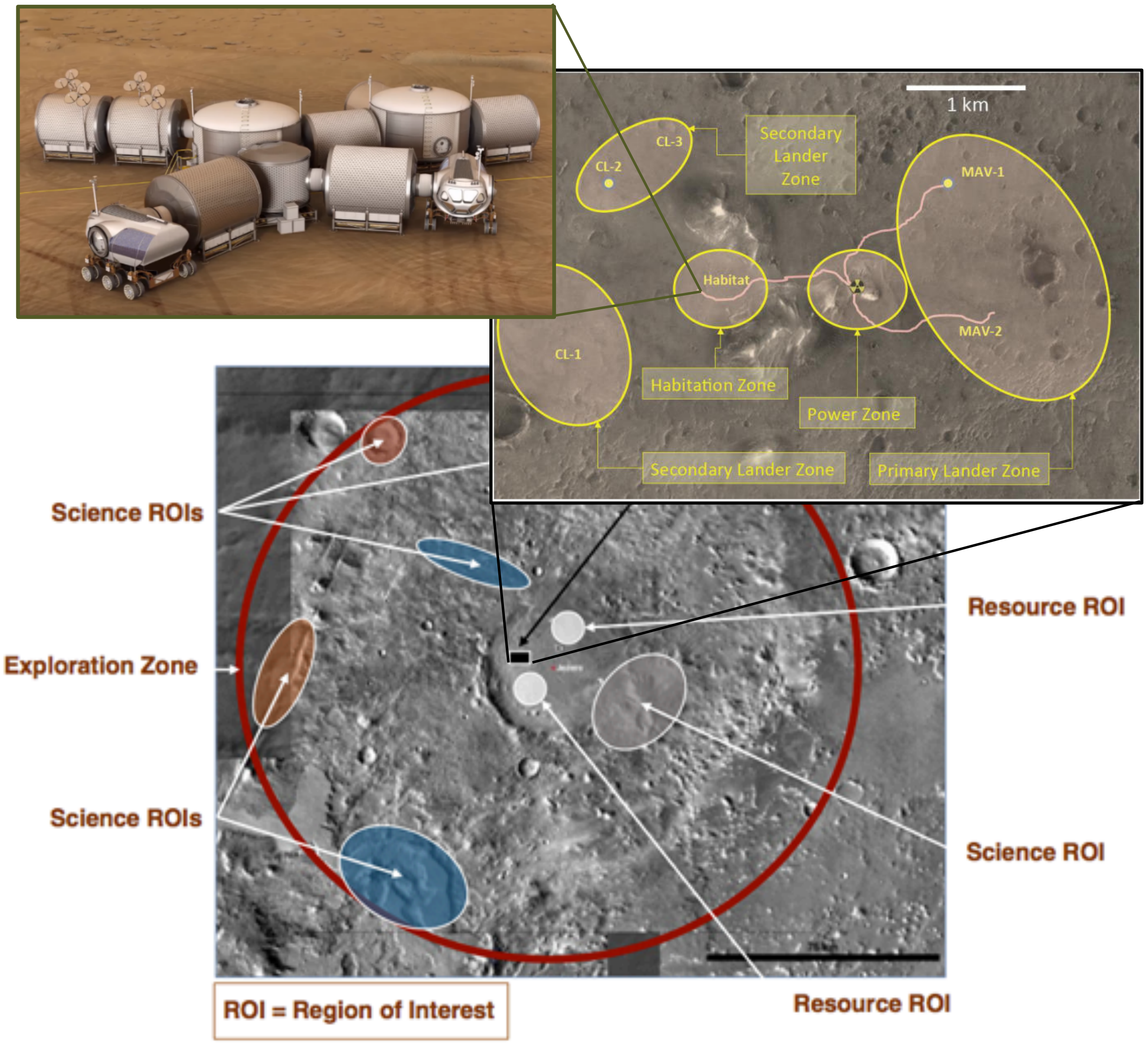
Exploration Zone (EZ) – Current Definition

- 100km radius site at latitude band: ±50°
- Contains:
  - **Habitation Site**: Flat, stable terrain for emplacement of infrastructure, located ≤5km from landing site location
  - **Landing Site(s):** Flat, stable terrain, low rockiness, clear over length scales greater than landing ellipse
  - **Resource Regions of Interest**
    - One or more potential near-surface (≤3m) water resource feedstocks in a form that is minable by highly automated systems, and located within ~1-3km of ISRU processing and power infrastructure. Total extractable water should be ~100MT (supports ~5 missions)
    - Show potential for minable metal/silicon resources, mainly Fe, Al, and Si, located within ~1-2m of the surface
  - **Science Regions of Interest**
    - Related to Astrobiology, Atmospheric Science, and Geoscience



Task B (Hydrated Minerals) Team 1 (Carter et al.)

To achieve this we have 3 tasks :

- Task 1 : Raw data ⇒ Mineralogy

  OMEGA/CRISM

  Global mineralogy map at sub km resolution:
  - typical 1 km/pix

  → Data products

Feed task #1 to task #2 (#1 provides target locations and calibration)

- Task 2 : Mineralogy

  Linear un-mixing for enhanced discrimination of aqueous mineral diversity

  → Data products

Feed task #2 to task #3 (#2 provides target locations and prior for model)

- Task 3 : Modal / H_2O estimates

  Optical constant determination
  Abundance retrieval

  → Data products

Format data, generate documentation

Deliverables