MRO: Continuing Discoveries at Mars

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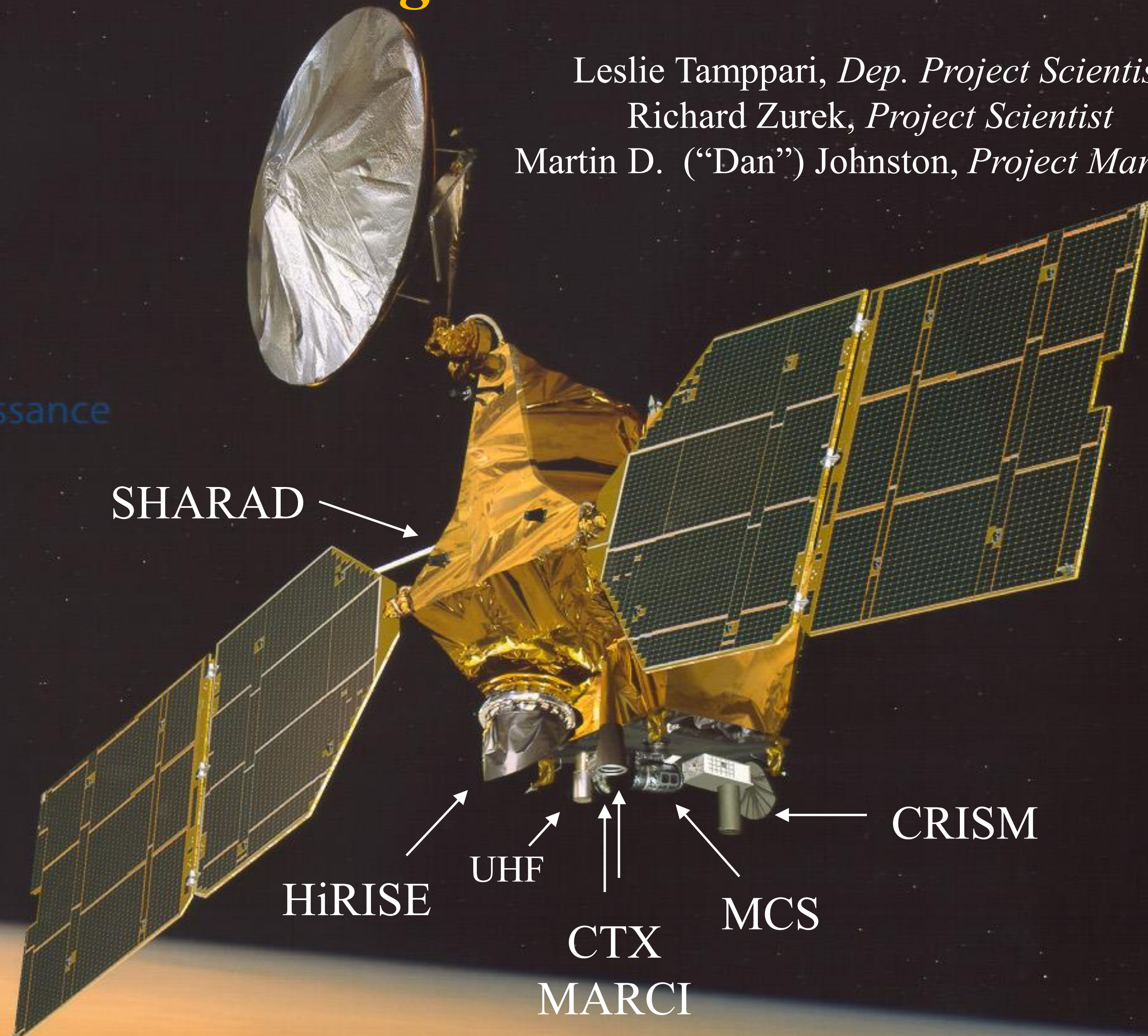
Mars
Reconnaissance
Orbiter



Presentation
to MEPAG
April 3-5, 2018

CL#

THE UNIVERSITY OF ARIZONA.
MIT
Malin Space Science Systems
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LOCKHEED MARTIN

Jet Propulsion Laboratory/California Institute of Technology

MRO Project Description

MRO Mission Overview

- **Category: II, Risk Class: B, Mission Phases:**
  - Launched August 12, 2005; entered Mars orbit, March 10, 2006
  - Primary Science Phase (PSP): November 2006 to November 2008
  - Extended Science Phase (ESP): December 2008-September 2010
  - Extended Mission Phase (EM1): October 2010 to September 2012
  - Extended Mission Phase (EM2): October 2012 to September 2014
  - Extended Mission Phase (EM3): October 2014 to September 2016
  - Extended Mission Phase (EM4): October 2016 to September 2018

Program Support Objectives

- Provide high-volume relay for surface platforms;
- Characterize/certify landing sites for future Mars landers & rovers;
- Monitor and record mission critical events at Mars via relay and imaging; identify post-landing hardware and monitor roving
- Provide environmental data for mission design & operations.

MRO has both Programmatic and Scientific Objectives using key spacecraft and payload capabilities:

- *7 science investigations including*
  - *6 Instruments viewing in 4 modes:*
  - *Ultra-high-resolution targeting*
  - *High resolution survey*
  - *Subsurface radar profiling*
  - *Global atmospheric coverage*
- *Spacecraft Capabilities*
  - *High volume data return (320 Tb)*
  - *Rolls target almost any place on Mars in 2 week cycles*
  - *UHF-relay for surface assets*

EM4 Science Objectives: Mars in Transition

- Ancient Mars: Environmental Transitions and Habitability
- Amazonian Period: Ice, Volcanism, and Climate
- Modern Surface Changes and Implications
- Modern Atmospheric and Polar Processes

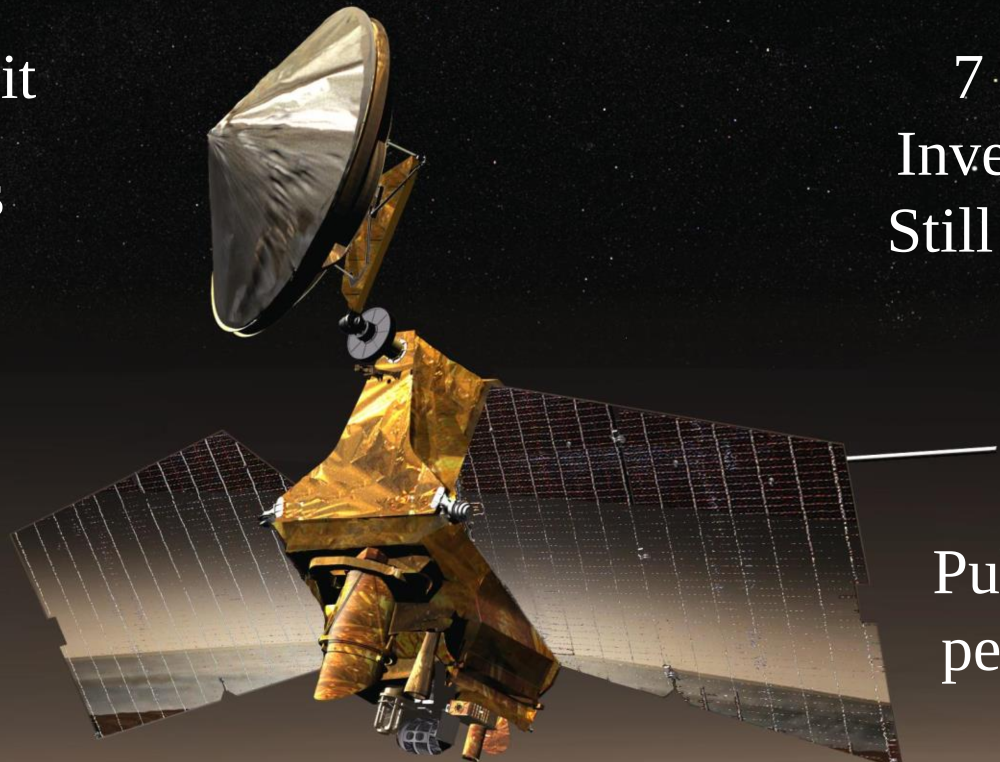
Rated "Excellent" in 2016 Planetary Mission Senior Review

12 Years in Orbit

>53,000 orbits

320 Tb of Science Data Returned

~200 kg of Usable Fuel still in the Tank



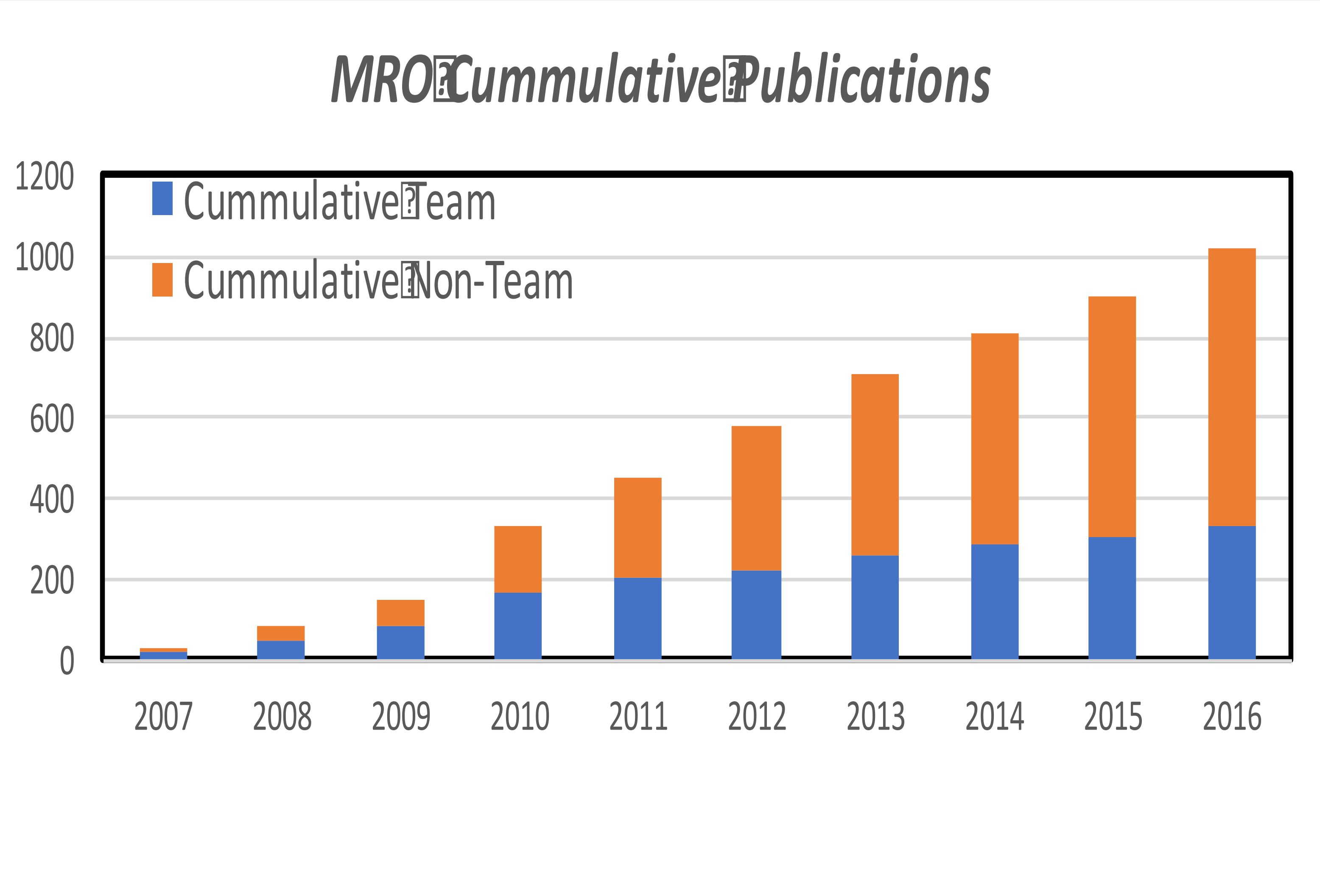
7 Science Investigations Still Returning Data

>1200 Publications in peer-reviewed Journals

Mars Reconnaissance Orbiter

Government sponsorship acknowledged.

Publications over time



MRO Science Investigations

HIRISE
~54,000 images
(~5400 stereo)
~2.98% of Mars
RSL, Gullies,
Dunes, Polar Caps

SHARAD
~21,200 Observing Strips
Buried CO_2 Ice
Polar Cap Internal
Structure
Mid-latitude Ice

CRISM
~85% msp IR
~39% hsp IR
~99% msp VNIR
Limb Scans
Ancient Aqueous Minerals
ATO's (6-12 m/pixel)

MCS
~163 M Soundings
~94% of 5.8 MYrs
Vert. Dust Profiles
Dust Storm Patterns
Tidal Structure
CO2 snow and frost

CTX
~100,000 images ~99% of
Mars covered
Stratigraphy
New Impacts

MARCI
~52,000 images
5.8 Myrs
~3600 Daily Global Maps
Dust & Ice Clouds
Dust Storm Tracks

MRO Mission Status

- **MRO is now regarded as a milestone mission (*i.e., absolutely necessary*) for future Mars missions (Mars 2020 Rover, etc.)**
  - Keeping the spacecraft operational for relay & critical event coverage until 2027 is now MEP's top priority for the mission
  - Provides opportunity for extended science observations
- **Key actions taken to achieving this longevity:**
  - Decreased power loads during eclipse (~40 minutes of each 112 minute orbit)
    - E.g., moved HiRISE warm-up images out of eclipse; power generation by solar arrays is not currently an issue
      - May eventually change orbit to shorten eclipse, moving to later local times (e.g., 4:30 a.m./p.m.); decision will be made prior to Mars 2020 arrival
    - Building battery capacity
  - Conserve limited inertial measurement units (IMU) life => switched to all-stellar mode (uses star trackers exclusively for inertial guidance) last month
  - Large fuel reserves (200 kg.) should support >10 more years of operation

MRO Instrument Status (1 of 2)

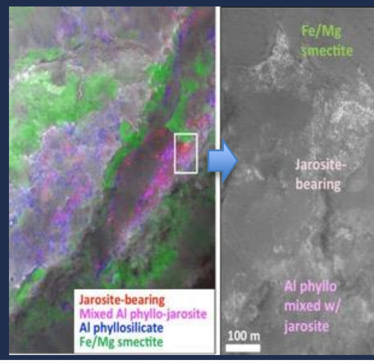
- **Last of 3 CRISM coolers no longer reaching and holding temperatures low enough to achieve good signal-to-noise (~125K)**
  - MRO has ended CRISM limb scans and IR "cold cycles"
  - Proceeding with VNIR-only observing
    - Building 100-m/pixel global map in visible/near IR channels
    - Still addresses aqueous mineralogy thru iron-bearing minerals (e.g., hematite) detectable with VNIR spectrometer
- **MCS has encountered position errors in their scanning mechanisms, but have been able to work around them by skipping or "healing" the problematic steps**
  - Latest issues were with the azimuth scanning, which is used to broaden local time coverage by ±1.5 hr by viewing cross-track
  - Currently routinely observing in-track while addressing cross-track issues
- **MARCI, CTX, and SHARAD have had no discernable degradation in their capabilities**

MRO Instrument Status (2 of 2)

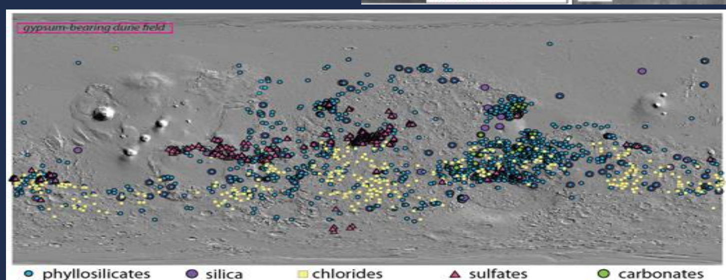
- **HiRISE issues**
  - No further loss of CCD memory modules (now 5.4 km FOV width)
  - Bit-flip errors addressed by pre-warming focal plane prior to taking the “real” images
  - HiRISE image blur experienced in 2017 and early 2018 traced to temperature effects on focus due to movement of warm-up images out of eclipse
  - More thermal changes in development as HiRISE temperature set-points are adjusted to aid battery management; will adjust and re-calibrate focus

MRO: Four Goals to Study *Mars in Transition*

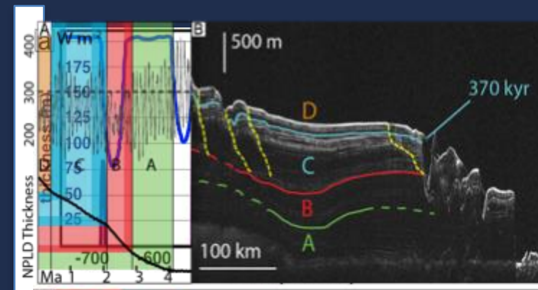
1. Ancient Mars: Environmental Transitions and Habitability

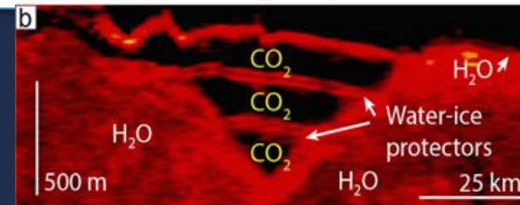


Aqueous Minerals



2. Amazonian Mars Climate: Ice and Volcanism



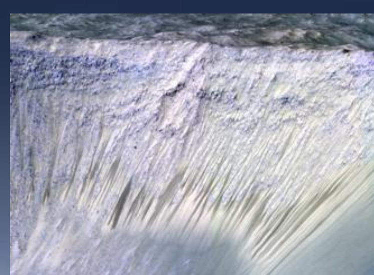


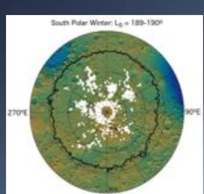
Ice Ages

Volatile Reservoirs

Climate Change

3. Modern Mars: Surface Changes and Implications

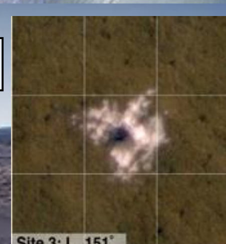




Volatiles

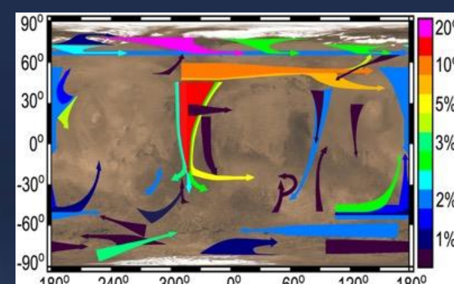
Water Environments?

New Impacts

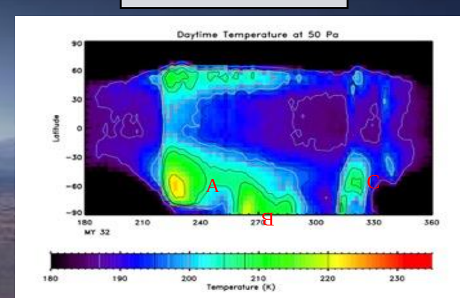


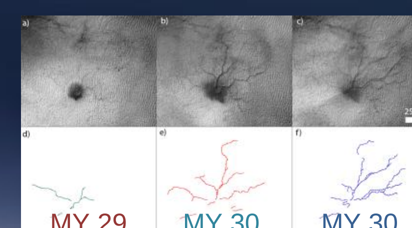
4. Modern Mars: Atmospheric and Polar Processes

Storm Tracks



Dust Storms





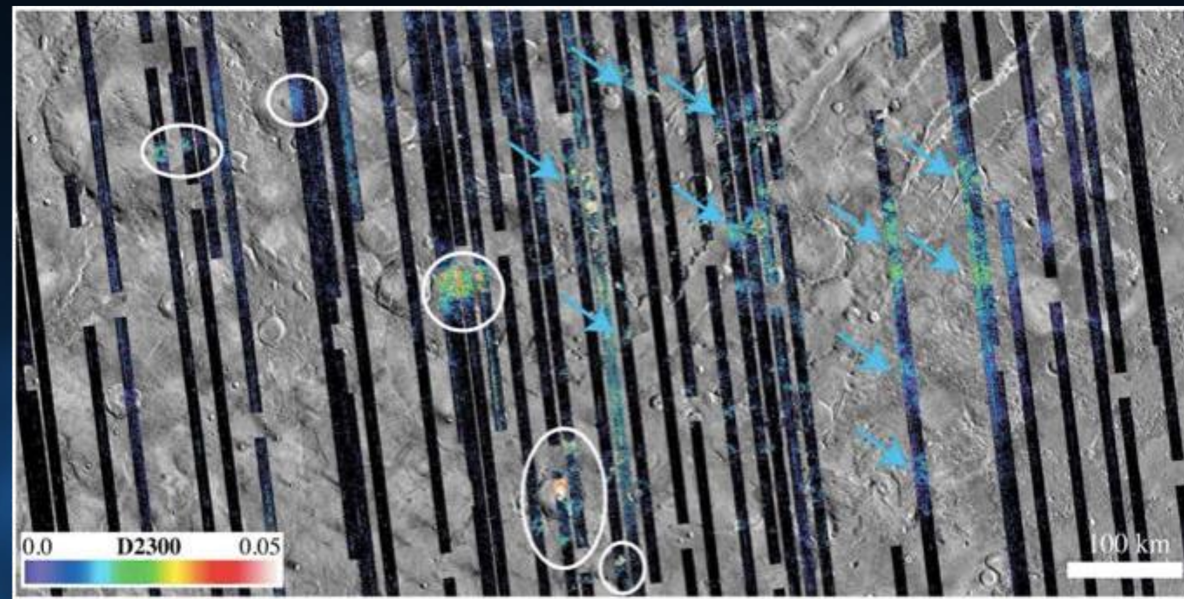
Polar Changes

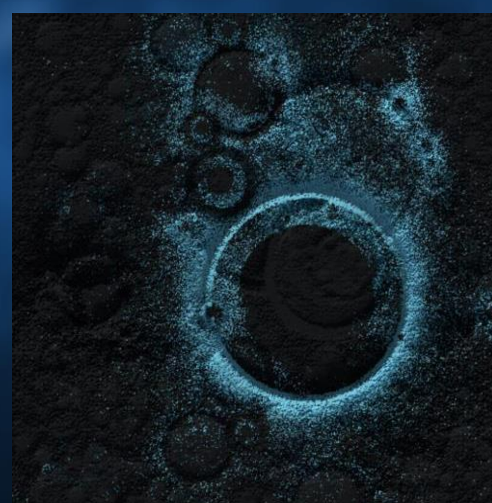
Mars Crustal Clays Formed During an Early Steam Atmosphere Phase

Some crustal clays exposed on Mars may have formed in the pre-Noachian Period ~4.5 billion years ago, during a steam atmosphere phase coincident with magma ocean cooling.

Laboratory and modeling results show that a thick layer of clay buried in the crust would be excavated by impacts and distributed in patterns that match clay detections from orbit.

If significant amounts of Martian clays formed early in the pre-Noachian, it would be consistent with a cooler, drier environment later in the Noachian period. Instead, this new work suggests intense aqueous alteration in an early reducing atmosphere that may have condensed to form hot oceans.





Top: CRISM mapping data showing clay detections (white circles, blue arrows) in the Nili Fossae region.

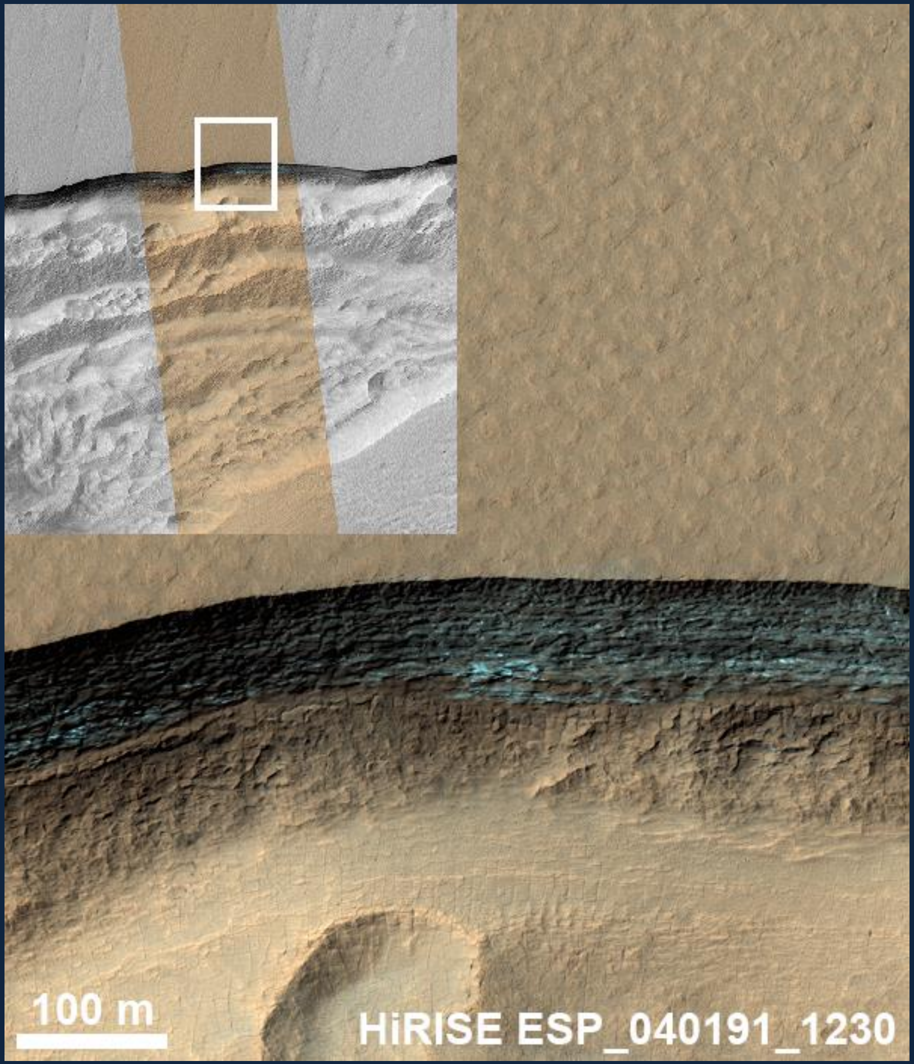
Left: Results of crustal evolution modeling showing predicted surface distribution of clays (blues) excavated from depth by impact craters and basins.

Cannon, K. M., S. W. Parman, and J. F. Mustard (2017), *Nature* 552, 88-91

Exposed Mid-Latitude Ice Sheets on Mars

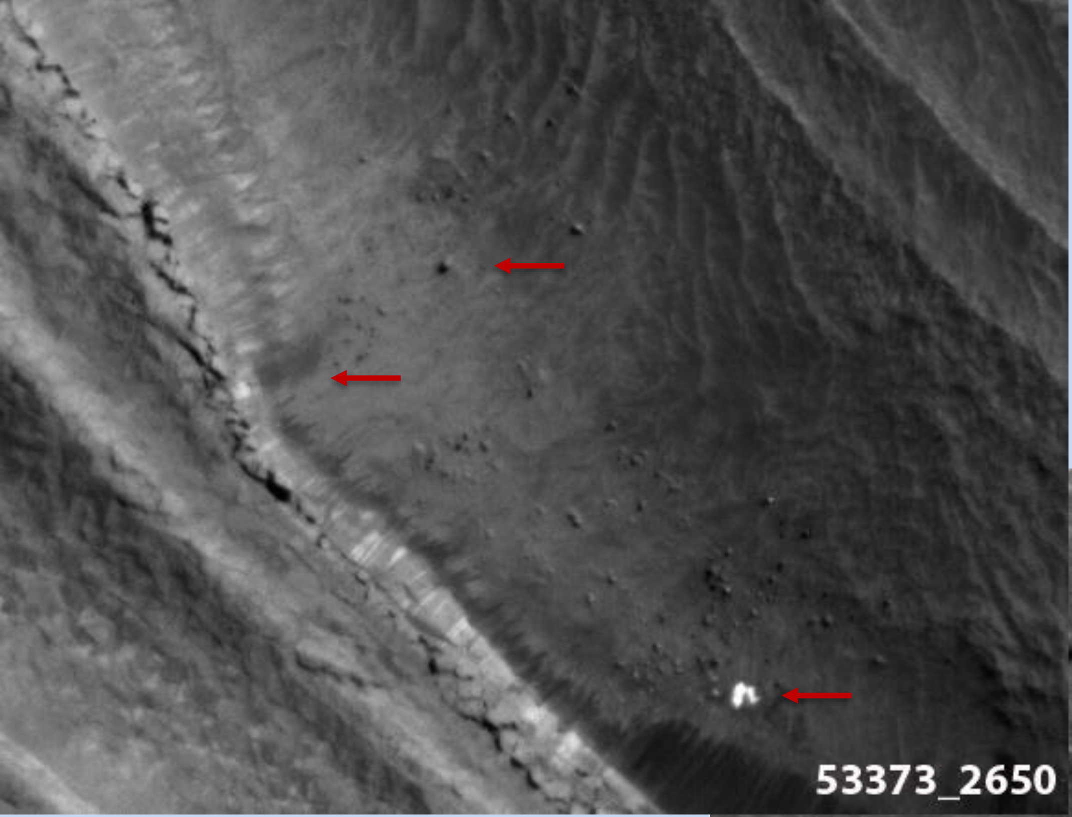
- Data from HiRISE, CRISM, SHARAD, and THEMIS demonstrates that erosional scarps expose hundred-meter-thick sections of water ice in the Martian mid-latitudes in both northern and southern hemispheres.
- The ice is interpreted as geologically recent remnant deposits, likely laid down at high obliquity, and may preserve an accessible record of climate variations.
- The ice can be layered or massive, but has a low lithic content and is covered by only a thin (<1-2 m) layer of dust and regolith.
- Ice detected by CRISM using both Near-IR and VNIR-only data.
- This supports SHARAD evidence for thick regional ice sheets elsewhere on Mars and suggests that they may be more widespread than previously thought.
- These scarps and the associated ice sheets represent both a potential target and a possible resource for exploration, important to NASA strategic goals for Mars exploration.

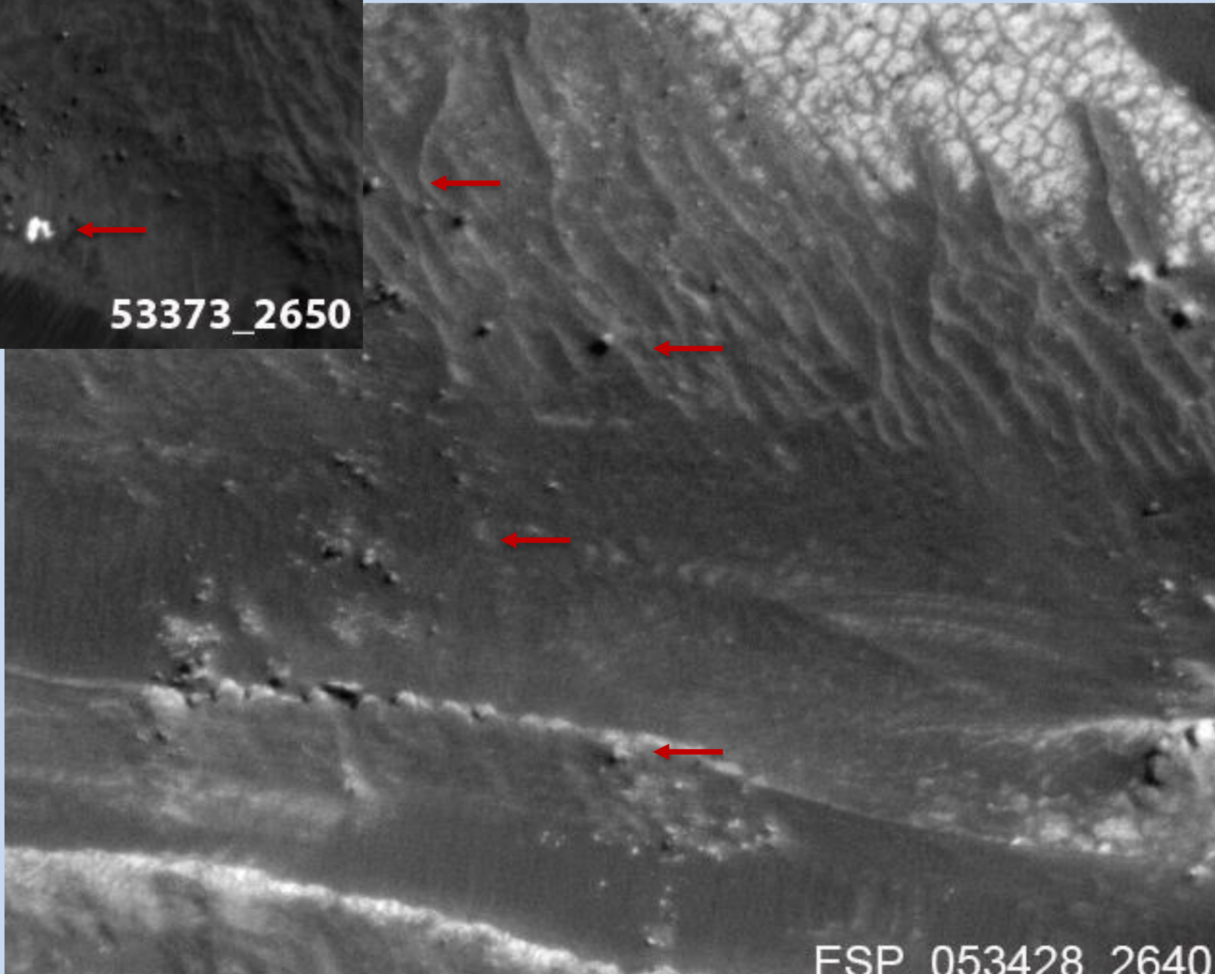
Dundas, C. M., et al. (2018), Exposed subsurface ice sheets in the Martian mid-latitudes, Science, 359, 199-201



North Polar Cap Edge Cliffs

HiRISE / LPL / U. Arizona / JPL / NASA



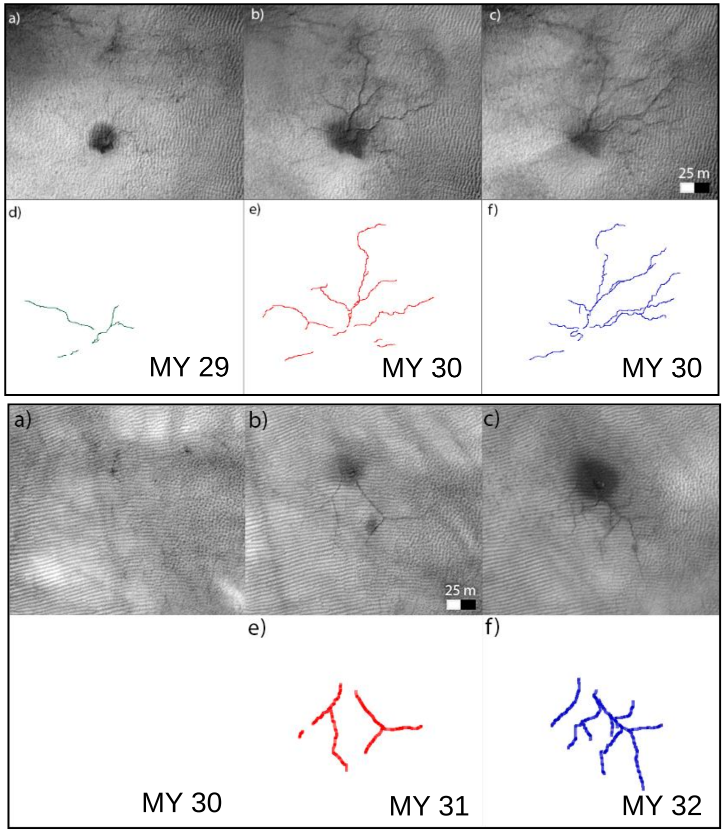


Change Detection Campaign Continues – Looking for:

- Ice-block falls and sublimation (see images above and to right; arrows identify some prominent changes)
- Ice slab avalanches
- Mass wasting in craters and canyons
- Sand Dune movement
- Other

Cold CO_2 Jets Create New "Spiders"

HiRISE detected new dendritic troughs during seasonal spring monitoring of the polar areas.



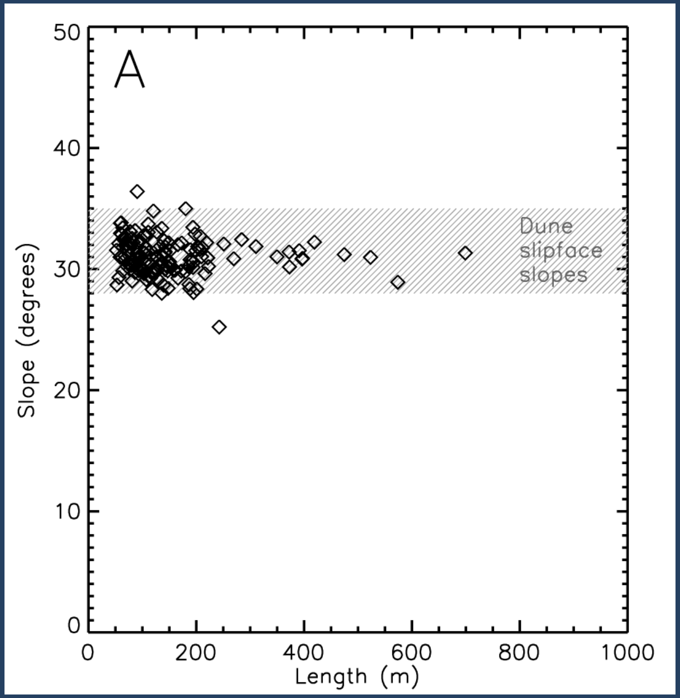
Examples of development of dendritic troughs from one Martian year (MY) to the next.

- Several years of HiRISE observations provide information about the current rate of erosion by cold CO_2 jets.
- Persistent changes in the polar landscape with direct connection to CO_2 cold jets have been observed for the first time.
- The newly detected troughs are small shallow branching troughs (approx. 1.4 meters wide) similar to the seasonal furrows on the dunes in the northern hemisphere.
- The essential difference between the new troughs and furrows is that the troughs in the south are persistent while the northern furrows are erased each Martian year by sand movement due to summer winds.

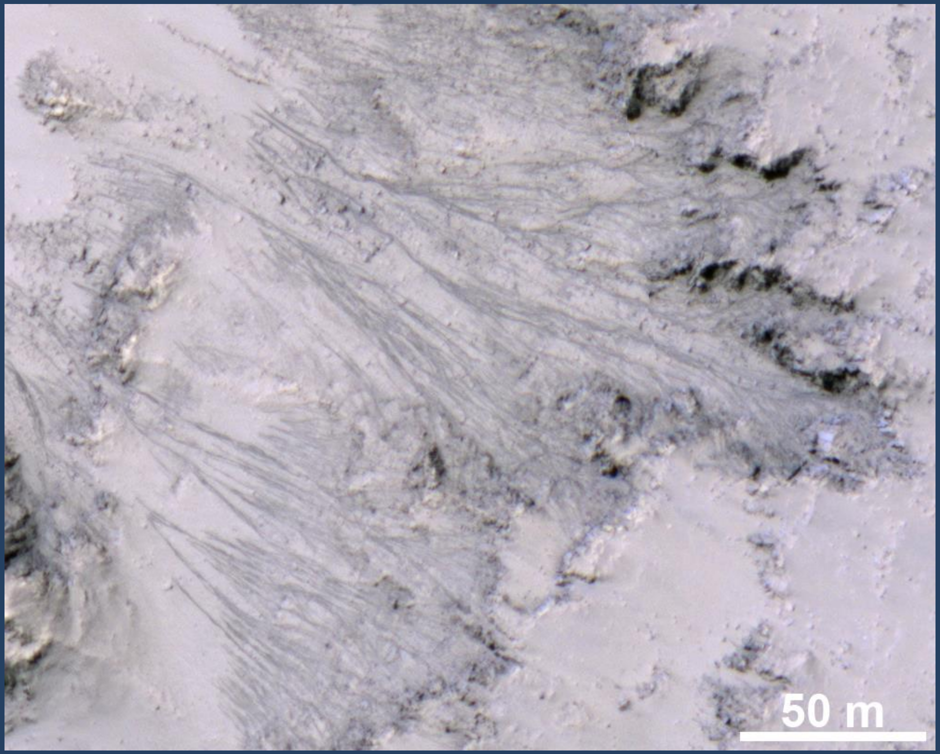
G. Portyankina et al. (2016), *Icarus*, Volume 282, 15 January 2017, Pages 93-103, ISSN 0019-1035, http://dx.doi.org/10.1016/j.icarus.2016.09.007

Evidence for Granular Flows at RSL sites on Mars

- Recurring Slope Lineae (RSL) are flows that recur annually, grow incrementally, and then fade.
- New observations show that they terminate on slopes that match the angle of repose for dry sand. This suggests that they are granular flows.



Terminal slopes for RSL compared with Martian sand dune avalanche slopes



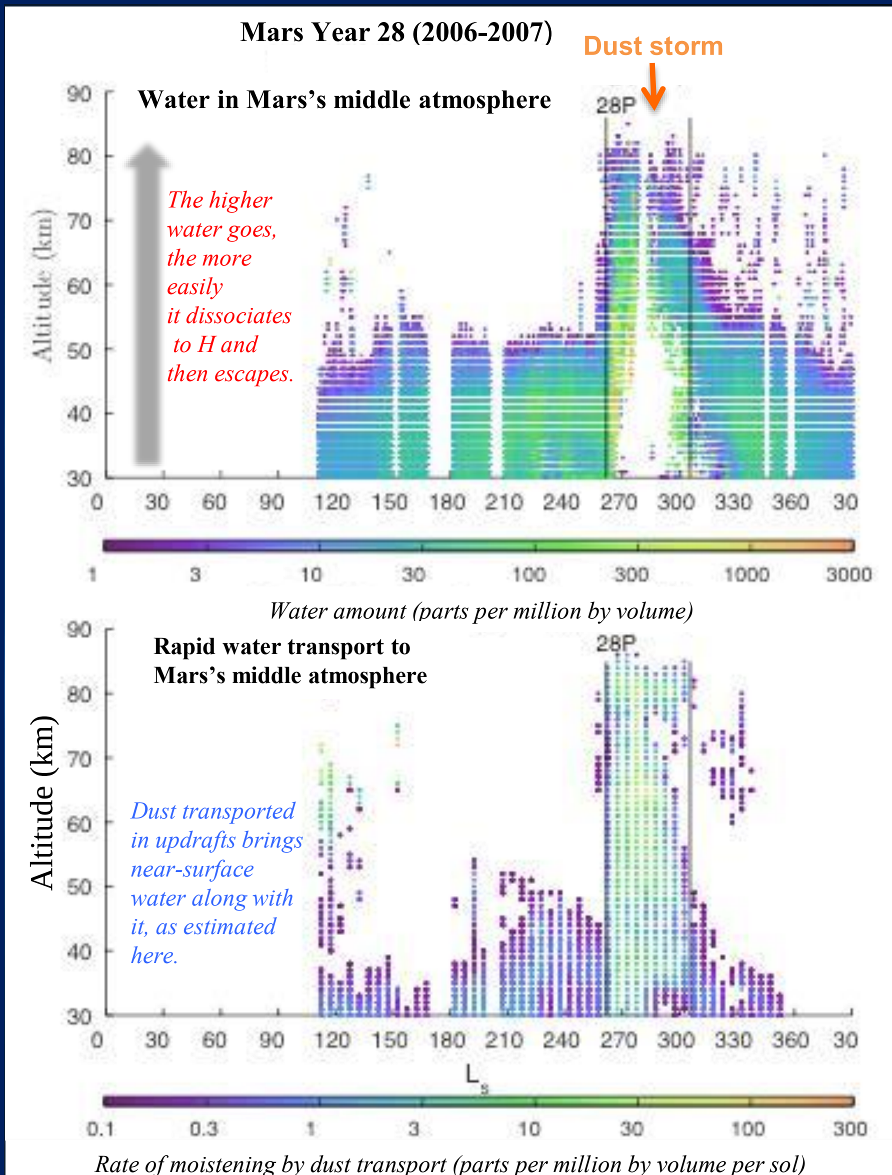
RSL in Palikir crater

- The triggering mechanism of the granular flows remains uncertain and could be connected to previously detected hydrated salts and/or deliquesced water.
- However, RSL likely involve little or no liquid flow.

HiRISE

Dundas, C. M., et al., 2017. Granular flows at Recurring Slope Lineae on Mars indicate a limited role for liquid water. *Nature Geosci.*, 10, 903-908.

Dust Storms Enhance Water Loss



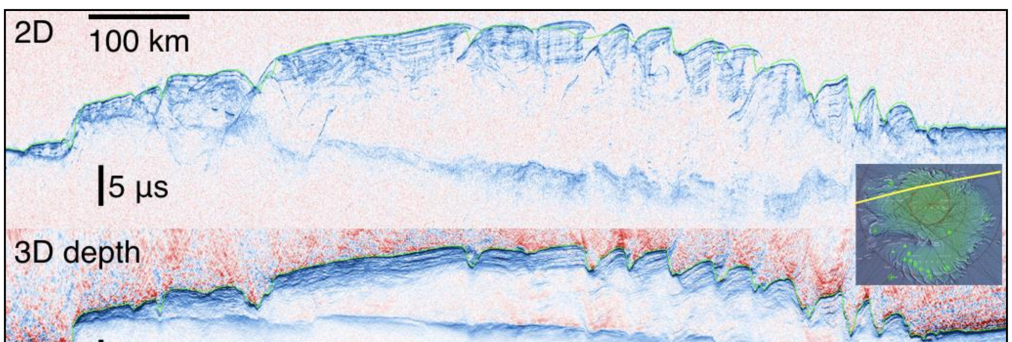
- Mars Express, Hubble Space Telescope, and MAVEN have observed unexpected seasonal variability in current hydrogen escape from the Mars upper atmosphere.
- Hydrogen comes from photolysis of water vapor
- MRO MCS & CRISM show water vapor is injected into the middle atmosphere during major dust events, like the MY28 global event (shown at left)

Heavens *et al*, Hydrogen escape from Mars enhanced by deep convection in dust storms. *Nature Astronomy , 2018*

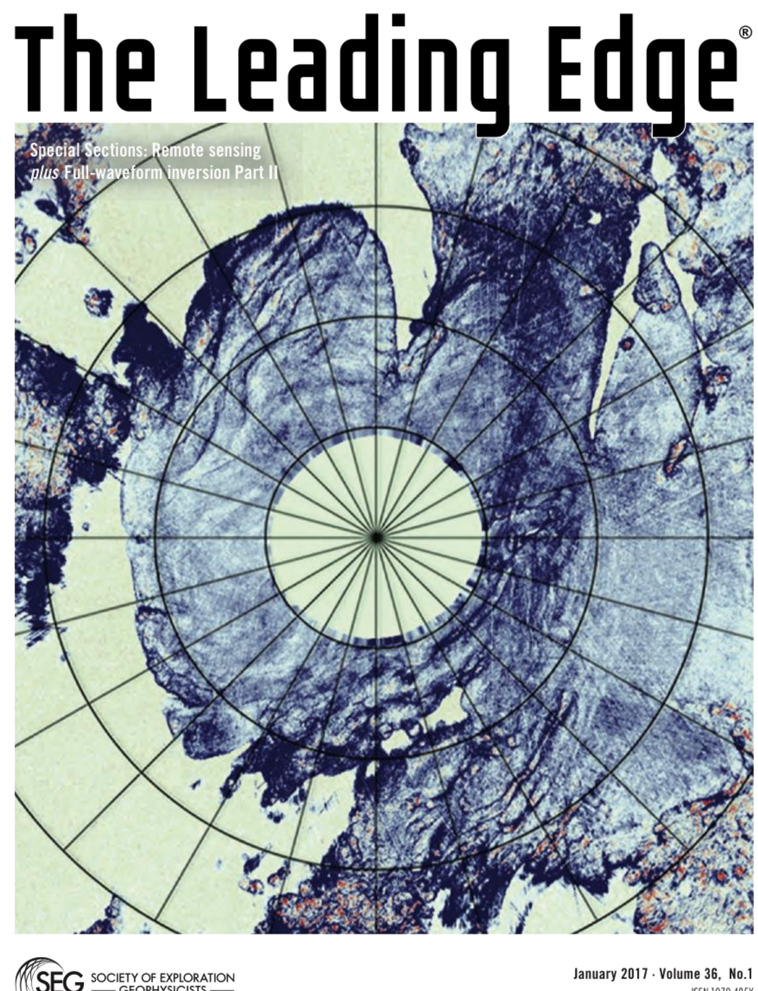
3-D imaging of Martian polar-cap interiors shedding new light on climate history

Mission & Instrument:
MRO Shallow Radar (SHARAD)

- **3-D Volumes:** Using SHARAD data from more than 2000 2-D orbit passes over each pole, we created 3-D images of the interior of both polar caps. Each volume covers more than 600 times the area of Earth's largest 3-D seismic survey.
  - **Initial Findings**: Geometric corrections and summing provided by 3-D radar imaging are revealing layering and structures such as a larger volume of sequestered CO_2 ice in the south and likely buried impact craters in both caps.
- **Importance**: The climate history of Mars is recorded in polar-cap layering and CO_2 ice deposits. Volumetric cratering records may be used to determine the age of each polar ice cap independently of climate models.
  - **Reference**: Foss II, F.J., Putzig, N.E., Campbell, B.A., Phillips, R.J., 2017. 3-D Imaging of Mars' Polar Ice Caps Using Orbital Radar Data. *The Leading Edge* 36, 43-57.



North polar transect



South polar 3-D timeslice view

MRO – more to come!

MRO continues a dual-purpose mission of scientific observation and programmatic support

- ***MRO is working to ensure orbiter operability through 2027***
  - Issues of an aging spacecraft (IMUs, batteries, etc.) are being successfully mitigated; onboard fuel is adequate
  - Most key instrument capabilities remain (CRISM coolers were the one major “consumable”)
- ***Programmatically, MRO will:***
  - Complete landing site reconnaissance for *InSight*, *2020 Mars* & *ExoMars* rovers
  - Continue relay support for *Opportunity* and *Curiosity* rovers
  - Support EDL and surface relay for *InSight*
  - Prepare to support future landed missions (e.g., NASA & ExoMars 2020 rovers)
- ***Scientifically, MRO will:***
  - Complete and Improve global surveys by CTX and CRISM VNIR
  - Continue to detect and characterize seasonal and inter-annual surface change
  - Cover another ”great dust storm” season (overdue for a planet-encircling event)
  - Extend the climate record with daily global imaging and atmospheric profiling into several more Mars years

Back-Up

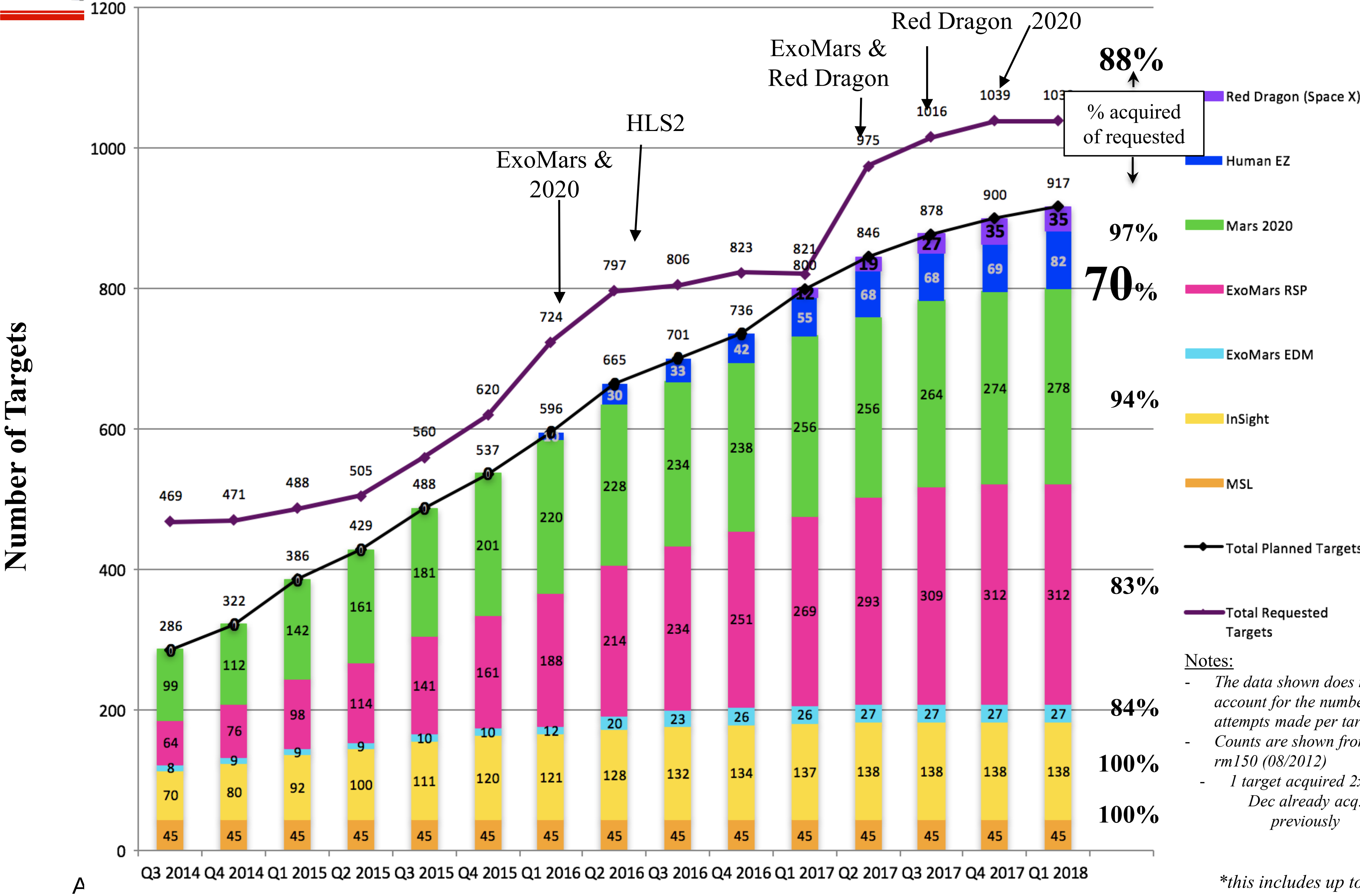
4th Extended Mission: *Mars In Transition*
Oct. 2016 – Sept. 2018

- ***Goal 1: Ancient Mars: Environmental Transitions and Habitability***
  - Focus on the formation history of younger aqueous deposits, weathered glass deposits, and older layered clays and sulfate deposits.
- ***Goal 2. Amazonian Volatiles, Volcanism, and Climate***
  - Refine our understanding of Amazonian climate signals by addressing near-surface ice deposits, polar cap layering and composition, and the potential for volcanic flows to have contributed substantial greenhouse gases to the climate.
- ***Goal 3: Modern Dynamic Mars: Surface***
  - Expand our understanding of possible liquid water on Mars today, evaluate surface change resulting from large dust events, and continue to monitor known sites while searching for new dynamic surface events indicative of ongoing transitions.
- ***Goal 4: Modern Dynamic Mars: Atmosphere and Polar Processes***
  - Observe interannual variability in a greater number of local times, via standardization of augmented local time measurements
  - Examine the influence of CO_2 snowfall on the caps and on surface changes
  - Collaborate with other missions (e.g., TGO, MAVEN) to understanding of atmospheric energy transport and chemistry, enhancing the scientific return of each mission

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Mars Reconnaissance Orbiter

Progress on Landing Site Surveys



Notes:

- *The data shown does not account for the number of attempts made per target.*
- *Counts are shown from rm150 (08/2012)*
- *1 target acquired 2x in Dec already acq. previously*

**this includes up to rm297_1b final IPTFs*