

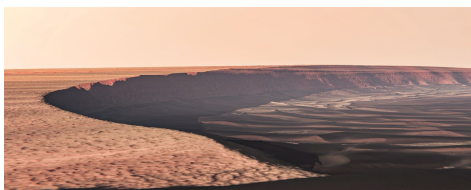
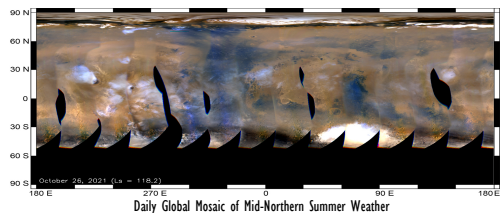
Proposal to Planetary Science Division & Mars Exploration Program  
Prepared for the National Aeronautics and Space Administration



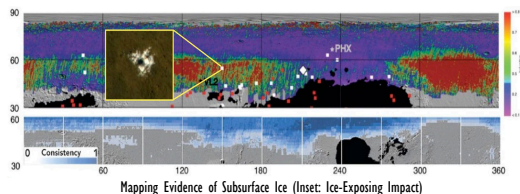
## MARS RECONNAISSANCE ORBITER

### 6<sup>th</sup> Extended Mission Proposal FY23–25: *Mars Fundamentals for Future Exploration*

January 2022 Proposal for the 2022 Planetary Mission Senior Review



Edge of North Polar Cap Edge and Adjacent Dunes



Prepared by



JET PROPULSION LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA



## MRO: EM5 Accomplishments EM6 Plans

Presented to MEPAG VM14  
by R. Zurek  
*MRO Project Scientist*  
*Jet Propulsion Laboratory*  
*California Institute of Technology*

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# MRO Mission Objectives for Extended Mission 6

“Mars Fundamentals for Future Exploration”

## MRO Mission Overview: Category 2, Risk Class B

- Launched August 12, 2005; entered Mars orbit, March 10, 2006
- Primary + Extended Science Phase (PSP): Nov. 2006 to Sept. 2010
- Extended Mission Phases
  - EM1: 10-2010 to 09-2012
  - EM2: 10-2012 to 09-2014
  - EM3: 10-2014 to 09-2016
  - EM4/E: 10-2016 to 09-2019
  - EM5: 10-2019 to 09-2022
  - **EM6: 10-2022 to 09-2025**

*Extended Mission Phase (EM6) Proposed submitted January, 2022*

## Programmatic Support Objectives

- Communications support (relay) for surface platforms
- Critical event coverage for spacecraft landing on Mars
- Landing Site Reconnaissance for future robotic and human missions
- Resource mapping for possible in situ exploitation
- Environmental databases for mission design and operations
- Operations support: Traverse planning and weather watch



*MRO is a dual-purpose mission for the Mars Exploration Program with both Program Support & Science Objectives.*



*This would continue to be the case in a 6<sup>th</sup> extended mission.*



*5+1 Instruments using 4 observation modes:*

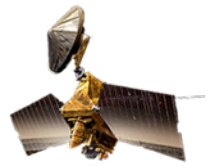
- Ultra-high-resolution targeting
- High resolution survey
- Subsurface radar profiling
- Global atmospheric Coverage

## EM6 Science Goals: Mars Fundamentals for Future Exploration

- Mars Surface and Climate through Time: Characterize stratigraphy, geomorphology, volcanism and water
- Evolution of Mars Ice: Map volatile ices & determine processes that control them
- Explore Active Geologic Processes: Test hypotheses for active slope and aeolian processes
- Modern Mars Atmosphere and Climate: Extend the Mars climate record and understand the controlling processes



# Project Status



## Technical:

- Flight System is healthy—all subsystems performing as required; most subsystem redundancy remains; significant fuel reserves
  - All-stellar mode preserving IMU-life
- Ground System (uplink, downlink, & data distribution) functioning nominally
- Risk Review conducted in November 2021; no concerns for MRO EM6

## Science

- All Teams are making their regular PDS delivery commitments; community is using the data
- On plan to complete EM5 activities; MRO is back in nominal 3 p.m. LMST orbit corridor

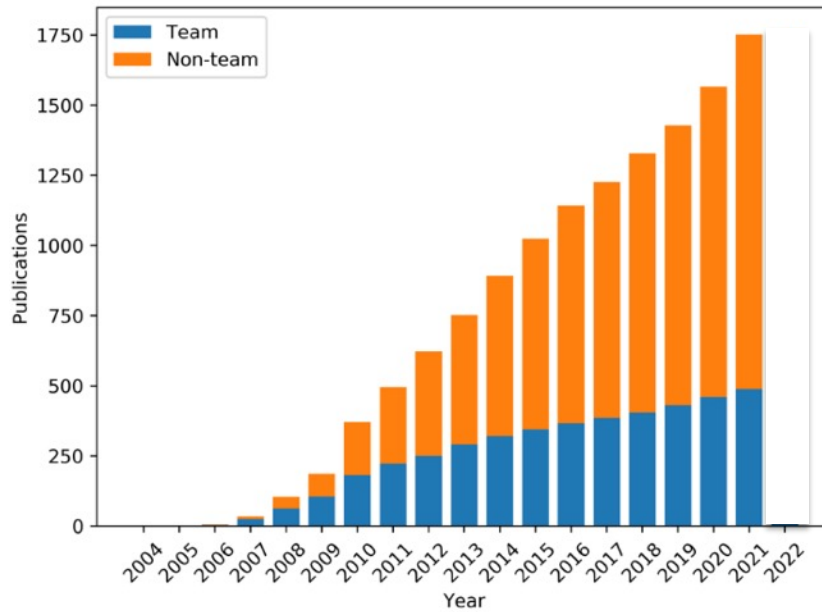
## Programmatic:

- Performed “bent-pipe” relay of M2020 data during the latter’s EDL
- Performing relay for M2020, MSL and on occasion InSight
- NASA has tasked MRO to retain the ability to provide essential programmatic support for future missions until 2031
- Finished landing site coverage for Mars Sample Return; augmenting coverage for ExoMars

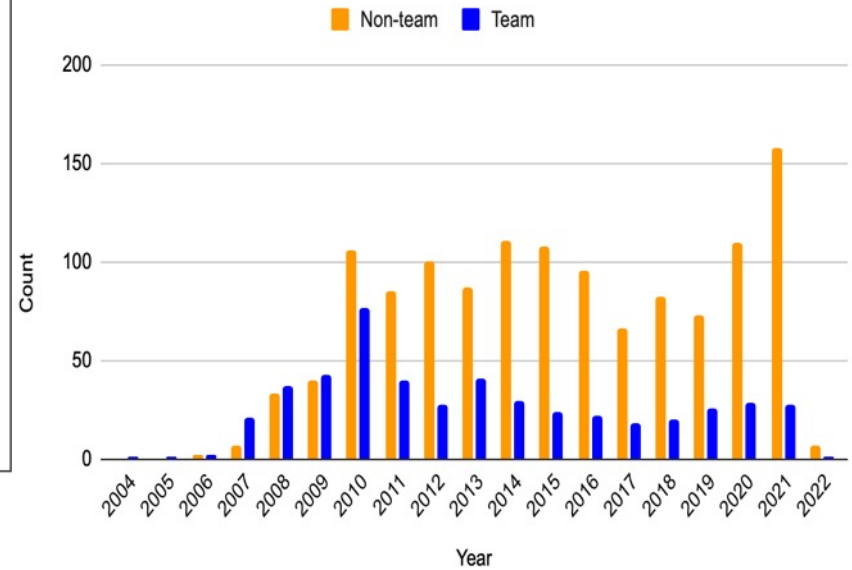
## Issues:

- Keeping key personnel; training/integrating replacements
- Declining science budget—may lose the CRISM investigation; most analysis funded elsewhere
- Handling new software/PDS and cyber-security requirements within guideline budget

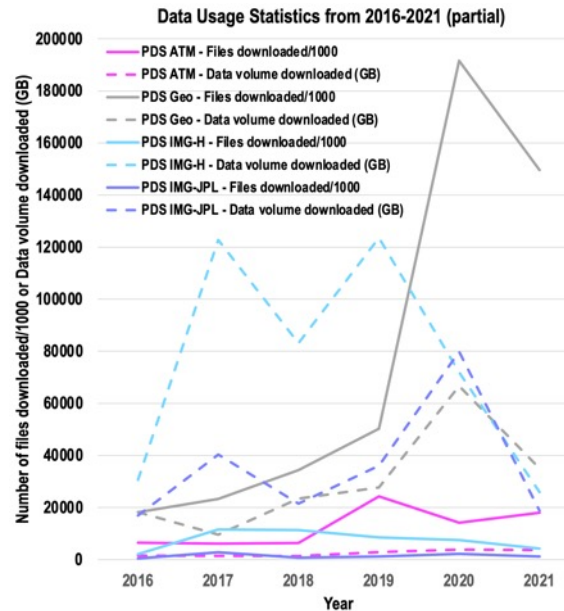
# Publications



MRO Publication Counts per Year

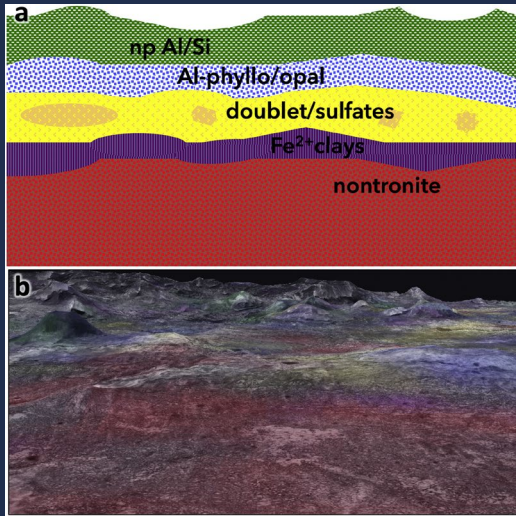


## PDS Data Usage





# EM5 Discoveries: Motivations for EM6



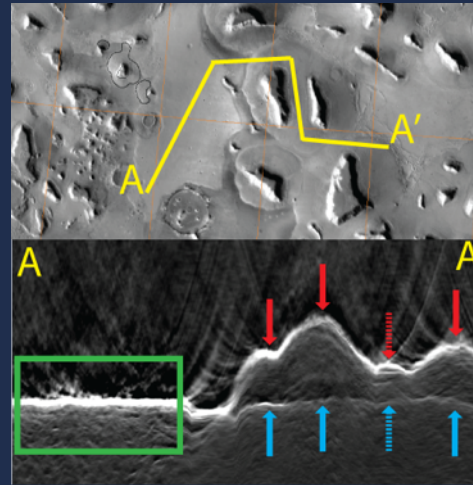
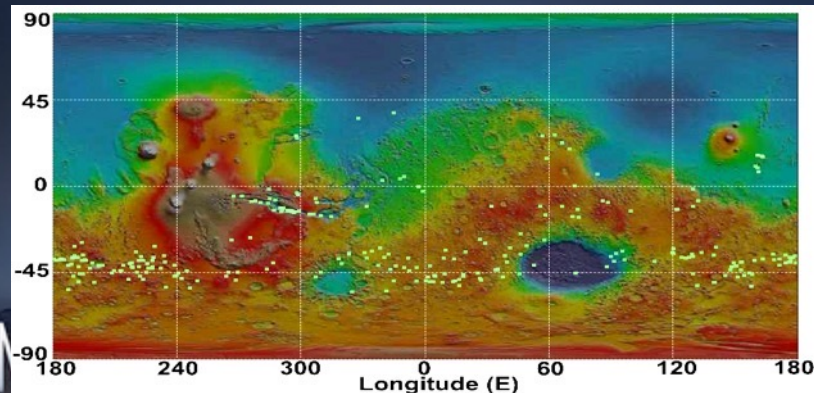
Environmental Change from chemically neutral to cold & acidic to warm & acidic to cold & arid

CRISM false-color mineral indicators overlain on HiRISE imagery of Mawrth Valles

**Ancient Mars, Environmental Transitions & Habitability**

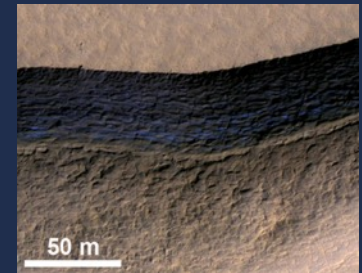
**Modern Dynamic Mars: Surface**

Active RSL Sites after 2018 PEDE

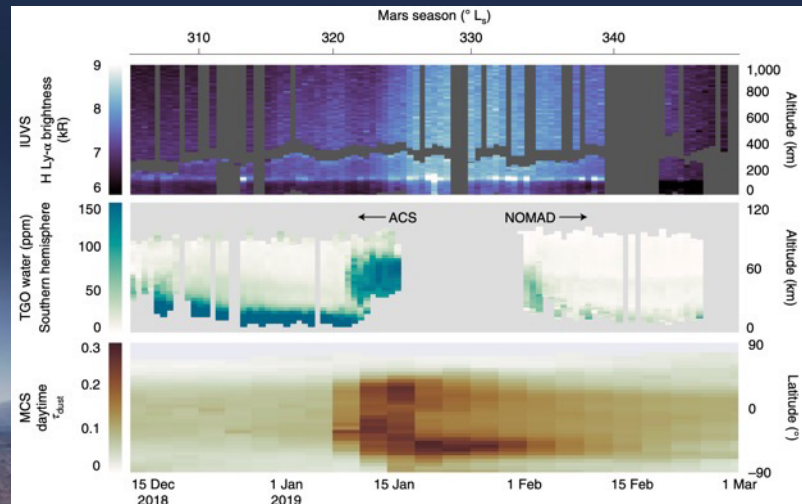


Icy Reservoirs => Climate Change => Ice Ages

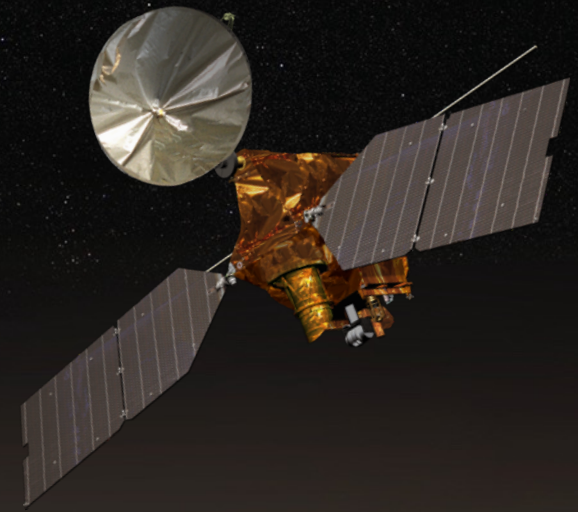
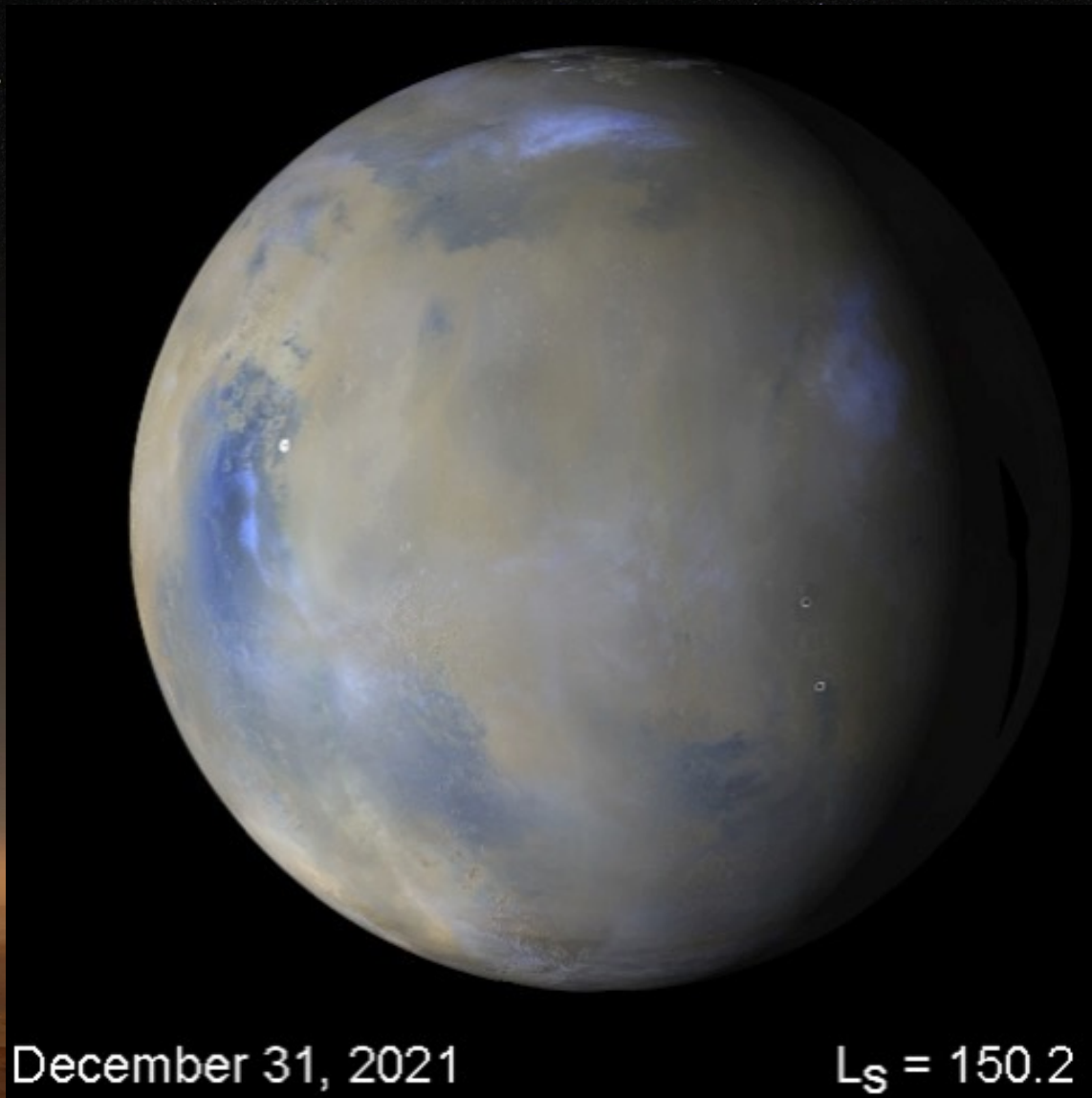
**Amazonian Volatiles, Volcanism and Climate**



**Modern Dynamic Mars: Atmosphere & Polar Processes**



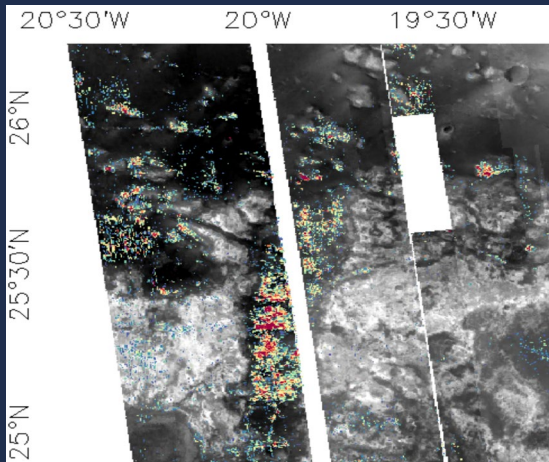
Three missions combine to show H loss to space enhanced during regional dust storms



- Jan. 1: Dust storm develops along SP seasonal cap edge
- Jan. 3: Storm expanded N and E, crossed the equator
- Jan. 7: Storm at max extent
- Jan. 12: Dust-lifting abated
- Jan. 17: Opacities dropped, dust slowing clearly

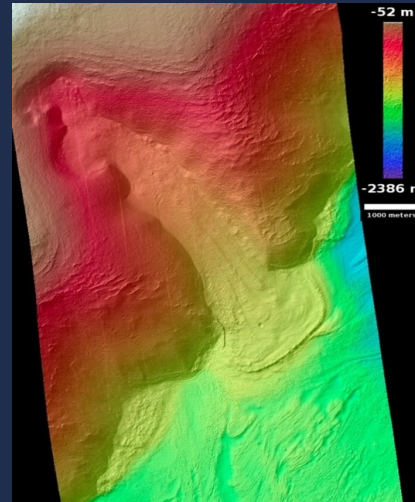


# EM6 Science Objectives



Multi-spectral  
180 m/pixel  
map of  
crystalline  
ferric minerals  
in Mawrth  
Vallis

Better map  
(~90 m/pixel)  
coming!



Icy Reservoirs => Do They Flow?

## Evolution of Mars Ice



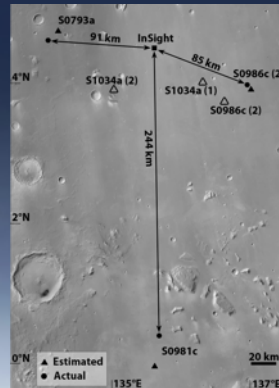
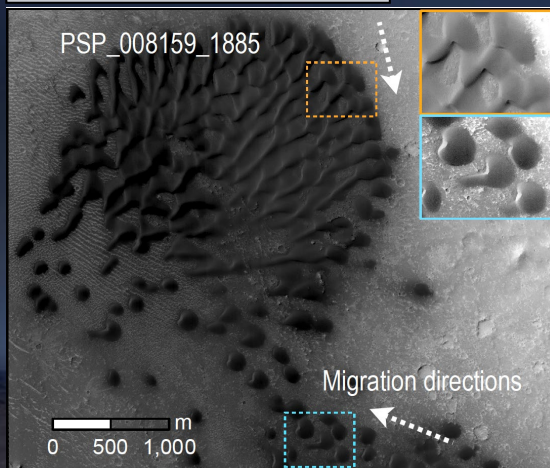
Understanding the  
Distinct Patterns  
of Seasonal  
Defrosting



## Mars Surface and Climate through Time

### Active Geological Processes

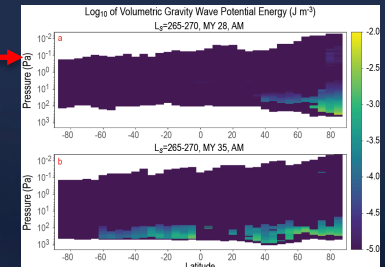
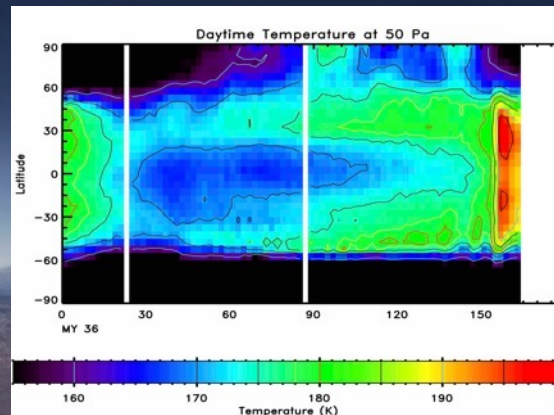
#### Ripple Displacement & Winds



New Impact Craters  
near InSight

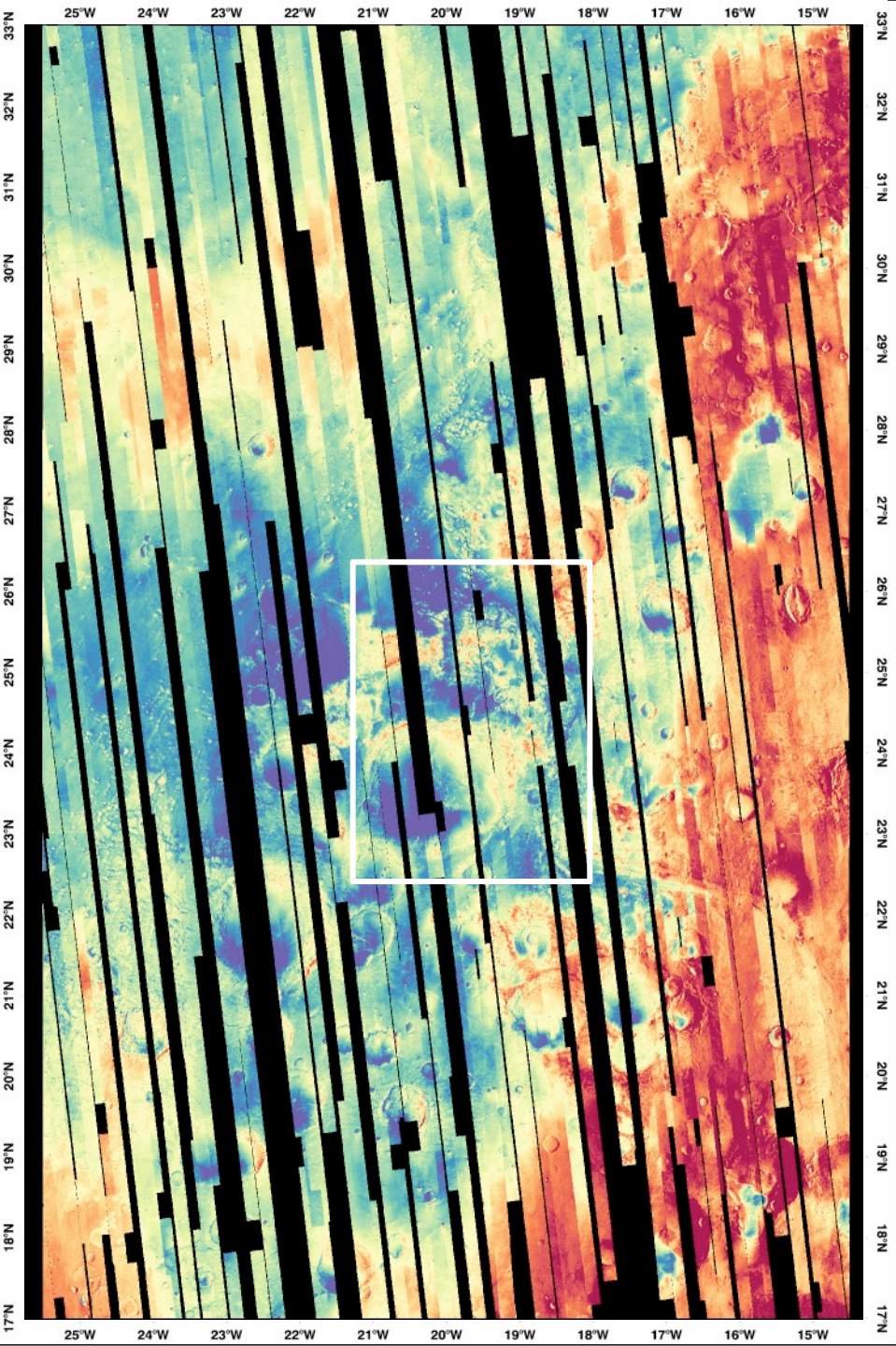
### Modern Mars Atmosphere and Climate

Gravity Wave Mapping: How  
do small-scale waves affect  
the general circulation?



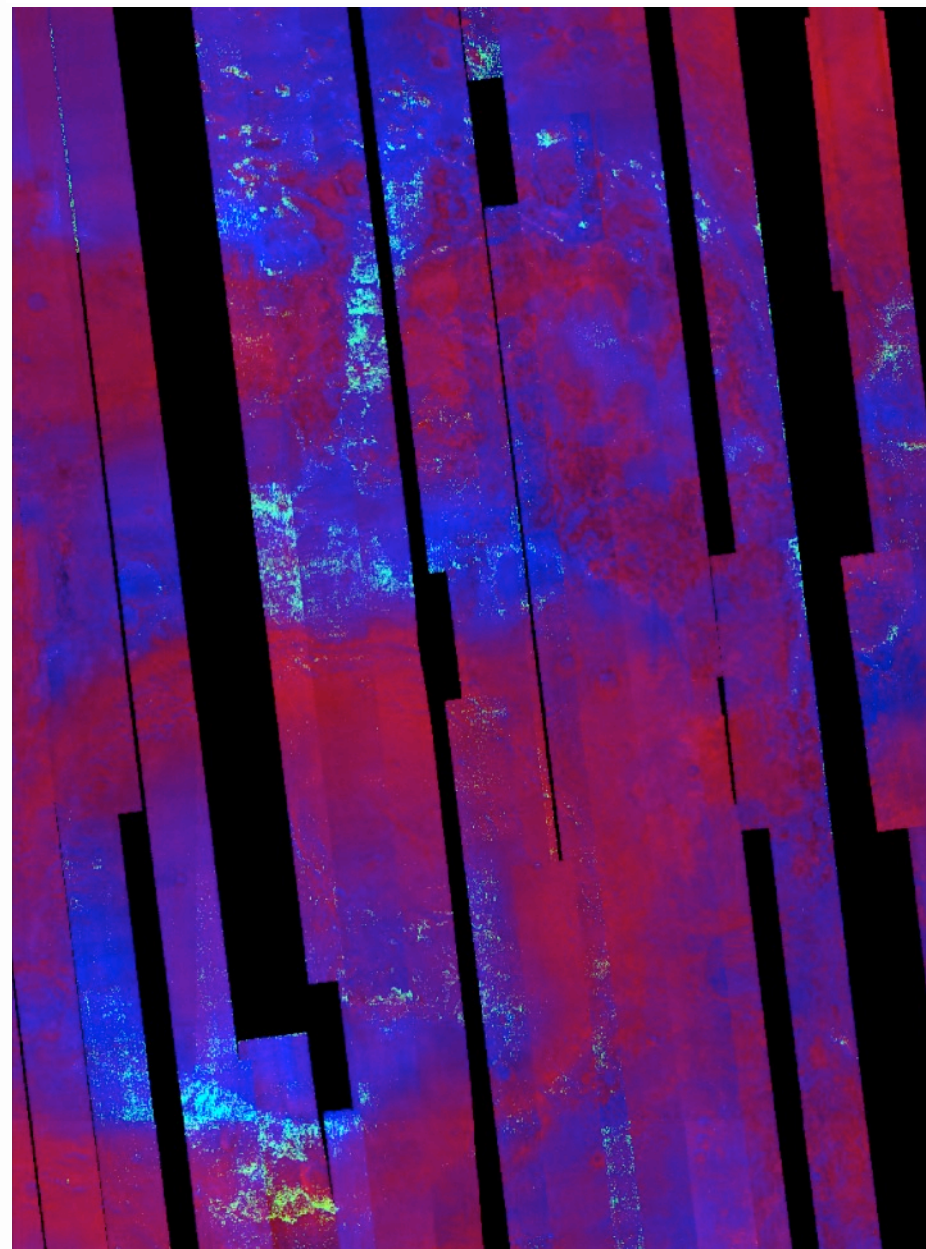
Observing Mars  
dust storms for a  
9<sup>th</sup> Mars Year –  
establishing  
patterns of  
occurrence





← R770 on rainbow color ramp

↓ FM2 browse product (ferric/ferrous mineralogy/grain size)  
(R:BD530, G:BD920, B:BD11000VIS)





# MRO 6<sup>th</sup> Extended Mission Science Investigations

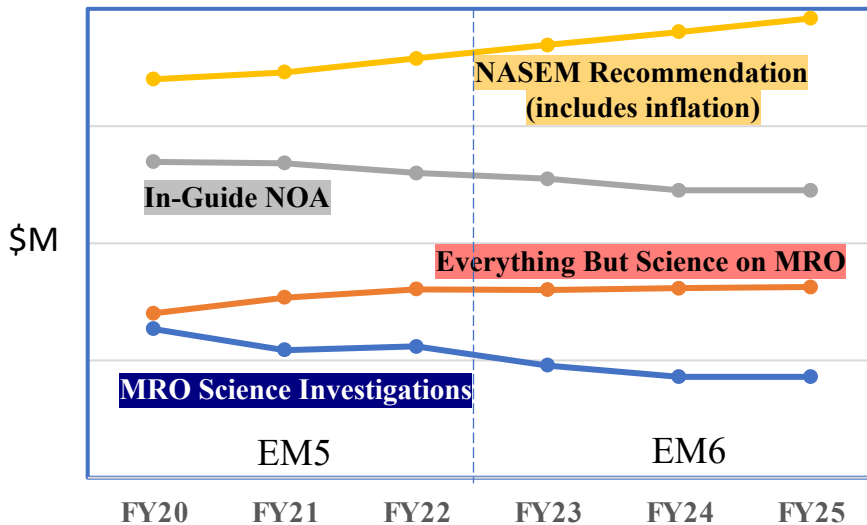
- **Mars Fundamentals for Future Exploration** **EM6: FY23-25**
- 17 Investigations addressing processes operating throughout Mars history

Mars Surface and Climate Thru Time	<ol style="list-style-type: none"> <li>1. Understand Layered Sediments (HiRISE + SHARAD)</li> <li>2. Understand formation mechanisms of hydrated mineral exposures (HiRISE)</li> <li>3. Understand Ionospheric Response to Solar Events; Map Crustal Magnetic Field (SHARAD)</li> <li>4. Investigate Late Fluvial Activity (HiRISE + SHARAD)</li> <li>5. Establish Volcanic Evolution &amp; Potential for Present Activity (HiRISE + CTX + SHARAD)</li> <li>6. Investigate Potential Caves (HiRISE + SHARAD)</li> <li>7. Enable Co-Analysis with Landed Assets (All)</li> </ol>	<ol style="list-style-type: none"> <li>11. Test Hypotheses for Active Slope Processes (HiRISE, CTX)</li> <li>12. Test Hypotheses for Active Aeolian Processes (HiRISE + CTX + MARCI)</li> <li>13. Test Hypotheses about Impact Cratering (CTX + HiRISE)</li> </ol>	Explore Active Geologic Processes
	<ol style="list-style-type: none"> <li>8. Investigate Perennial Ice (HiRISE + SHARAD + CTX + CRISM/Over-Guide)</li> <li>9. Characterize Seasonal Ice (All including C/OG)</li> <li>10. Constrain the nature &amp; extent of mid-latitude ice (HiRISE + SHARAD + MCS + CTX)</li> </ol>	<ol style="list-style-type: none"> <li>14. Track Current Climatology &amp; Weather (MCS + MARCI + CTX + HiRISE)</li> <li>15. Understand Energy, Momentum &amp; Mass Transport thru the Atmosphere (MARCI + MCS + Joint Observations)</li> <li>16. Understand the Source and Effects of Gravity Waves (MCS + MARCI)</li> <li>17. Understand Middle Atmosphere Processes (MCS + MARCI + TGO + MAVEN)</li> </ol>	Modern Mars Atmosphere and Climate

## Requires:

- Frequent observations in every season by every instrument;
- Integration of daily global observing, survey, and rolled high-resolution targeted observations;
- Return of large data volumes (>50 Tb in EM6).

# MRO Issues – In-Guide Budget



## Declining NOA and rising costs to deal with an aging spacecraft & legacy ground system impacts science

### Figure:

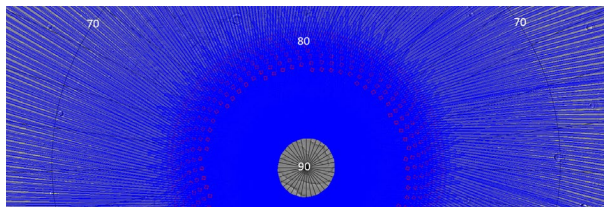
- Science teams budget (including bypass); no adjustment for inflation
- EBS = Everything but science (Flight, MOS, GDS, etc.)
- NOA = New Obligational Authority
- NASEM => Report recommendation to keep extended mission funding after the first 2 extensions flat in constant \$ (i.e., cover inflation)

## Project has new cost challenges and issues

- Science: Fewer Co-I's funded; less funding for those that get support; analysis largely funded outside MRO; focus is on acquiring the right data
- GDS: To achieve compliance with cyber-security requirements requires operating system upgrades and patches, MMOLMWEB overhaul, and hardware replenishments for failed/end of life or systems
- PDS: Must archive EM6 science data in PDS4 format
- SPD-41 potentially requires future unfunded mandates
  - Converting all prior MRO data archived to PDS to PDS4 format (est. ~ a few \$M)
  - Archiving all data product software (production pipelines) in an appropriate archive (unknown cost)
- ***Despite their value, without added funding, this diverts support from collecting useful science data.***

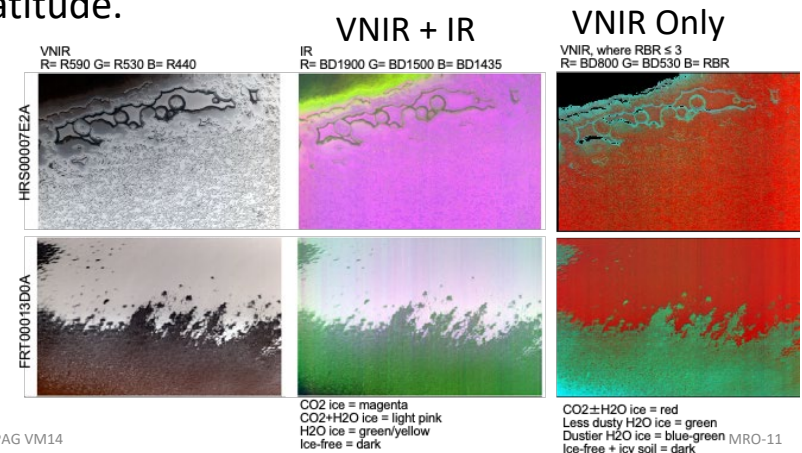
# MRO Issues –Budget

- To meet in-guide budget guideline, MRO PSG (reluctantly) recommended to the PMSR closing out the CRISM Science Investigation
  - CRISM last (of 3) cyro-coolers failed in 2017 => no useful IR spectrometer data
  - VNIR spectrometer operable, but limited gimbal range makes high-resolution targeting difficult
  - Team building new high-resolution, hyperspectral CRISM VNIR mineral survey.
    - In-Guide budget does cover production of the new VNIR map in FY23 as part of the investigation close-out*
  - Few other options to absorbing the budget hit; assessed that 23% decrease across the board was more damaging overall to the mission science.
- OG1:** MRO requested an over-guide to continue CRISM Investigation via a high-latitude mapping of seasonal water and carbon dioxide ice
  - Directly addresses MRO goal of Mars Ice Evolution by systematic mapping of water and carbon dioxide ice deposition and sublimation at high latitude.



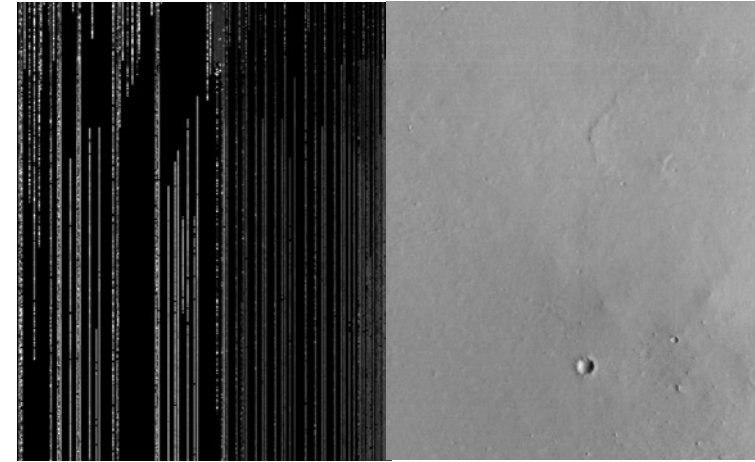
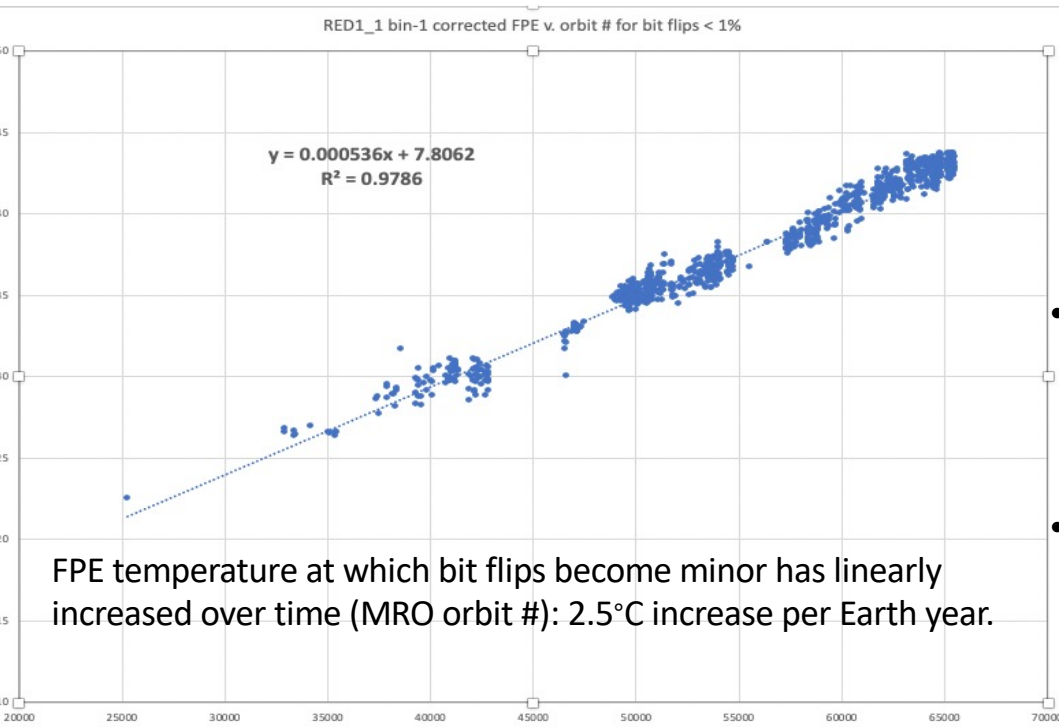
Proposed CRISM Coverage  
every 30° of Ls

Comparing  
ability to  
distinguish CO<sub>2</sub>  
from H<sub>2</sub>O ice at  
2 test locations



# MRO Technical Issue: HiRISE bit-flips

HiRISE ADCs produce bad data (bit flips) leading to useless images except when warmed up sufficiently. Bit flips have become steadily worse over time, mitigated until 2019 by raising the FPE starting temperature before imaging and by a new ADC setting since then. Note: Different detectors are degrading at different rates.



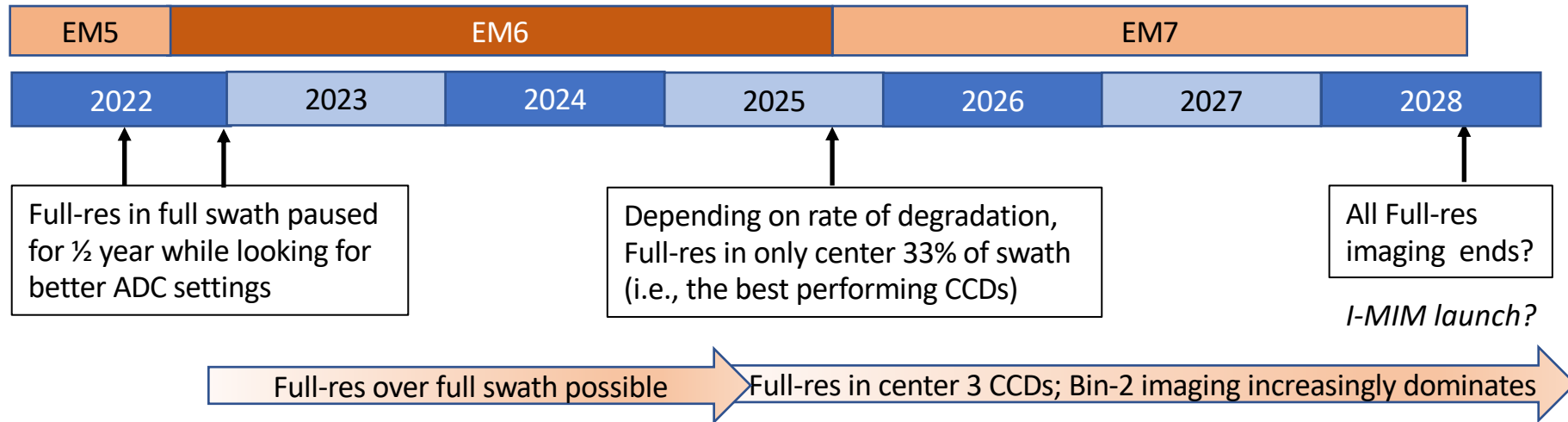
Improvement (in 2019) of Red1\_1 at FPE 37 C : 54\_54 (left) vs. 74\_74 (right)

- New ADC sampling point selection has been shown to help mitigate (images above)
  - 74\_74 reduced needed FPE-T by ~4 C in 2020 (but back to prior state in ~1.6 years)
- >1000 ADC settings need to be tested to find the best choices
  - New commanding software to make this efficient is operational
  - Many new test images starting Feb 2022
  - Expect results and new settings in ~1 year
  - At least modest improvement already known to be possible

- HiRISE cannot keep raising FPE temperatures before imaging
  - Operational limits and risky to the electronics
  - Binning images helps (but lower resolution)



# Possible Future of HiRISE Imaging



- For science, Bin-2 images (~0.6 m/pixel) are still superior to anything else flying in Mars orbit (Tienwen-1 at periapsis may come close). Bin-2 covers 4 times as much Mars surface for the same data volume as Bin-1, so more coverage at high resolution.
- **The 1 meter-scale hazard value of Bin-2 images is greatly reduced from that of Bin-1 images, making it difficult to fully characterize/certify future landing sites.**
- After EM7, maybe best to only return data from center red CCDs (which overall have the best performance) while including BG and IR CCDs for color, all binned, and accept the risk of higher temperatures.

# Summary

- **Flight System** is in very good health.
  - Currently fully functional in all operational modes; expected to be fully capable of carrying out EM6 (FY23-FY25) proposed activities
- **Ground Data System** (“Legacy”) striving to meet evolving IT Security requirements
- **Science:**
  - With the in-guide budget, HiRISE, CTX, MARCI, MCS, SHARAD can acquire the data needed for the 17 investigations proposed for EM6
    - *Analysis will continue to need funding outside the project (as reflected in the publication count)*
  - More can be done if the over-guide to continue CRISM observations (high-latitude, systematic mapping of seasonal ices) is approved
- **Programmatic:**
  - Electra: No issues with regard to relay support for M2020, MSL, InSight, Exomars
  - ExoMars EDL will be covered—MRO will capture EDL telemetry
    - Shift in LMST to 3 p.m. will keep MRO in the proper LMST corridor for science (3 p.m.  $\pm$  15 min.)
  - HiRISE bit-flip degradation may affect hazard detection by end of EM6.

***MRO is ready to conduct its proposed 6th Extended Mission.***