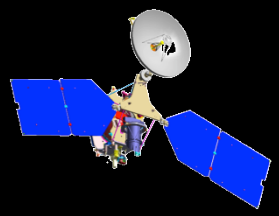
Jet Propulsion Laboratory
California Institute of Technology

The Mars Reconnaissance Orbiter Mission:



10 Years of Exploration from Mars Orbit (IEEEAC Paper #2096)

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18 May 2015

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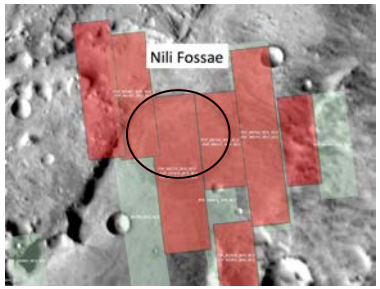
Outline

- Mission/Spacecraft Overview
- Selected Science Results
- Flight Challenges
- Summary

MRO Spacecraft

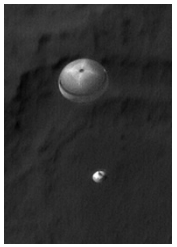
Programmatic Support by MRO

- Landing site identification, characterization & certification



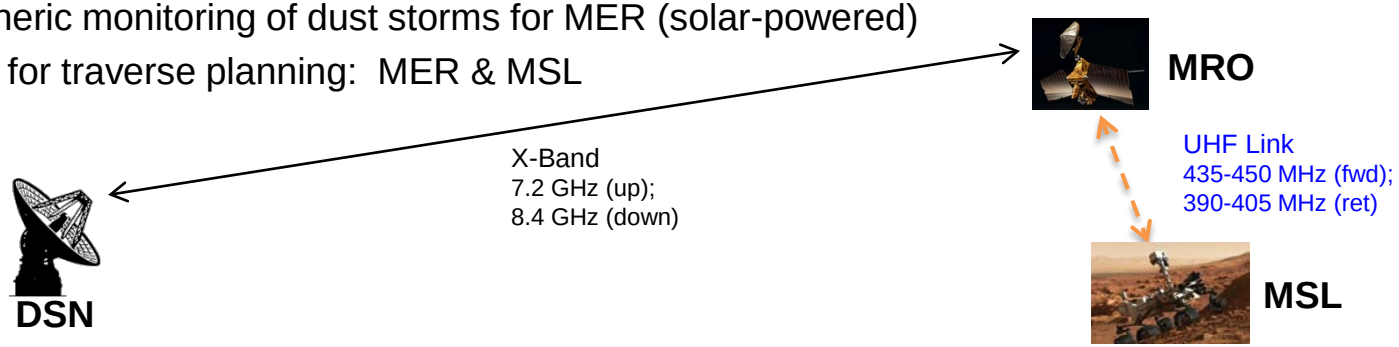
Potential future landing site imaged by MRO HiRISE

- Critical Event (Entry, Descent & Landing) Coverage for landed missions
  - Atmospheric Monitoring on Approach
  - Open Loop Recording
  - Imaging during Descent



MSL imaged on descent by MRO HiRISE

- Support for Surface Operations
  - UHF Surface Relay Capability for the PHX (completed), MSL & MER Missions
  - Atmospheric monitoring of dust storms for MER (solar-powered)
  - Imaging for traverse planning: MER & MSL



- MSL Average Relay Data Return per Pass = ~225 Mbits

Three Major Themes in MRO Recent Science Results

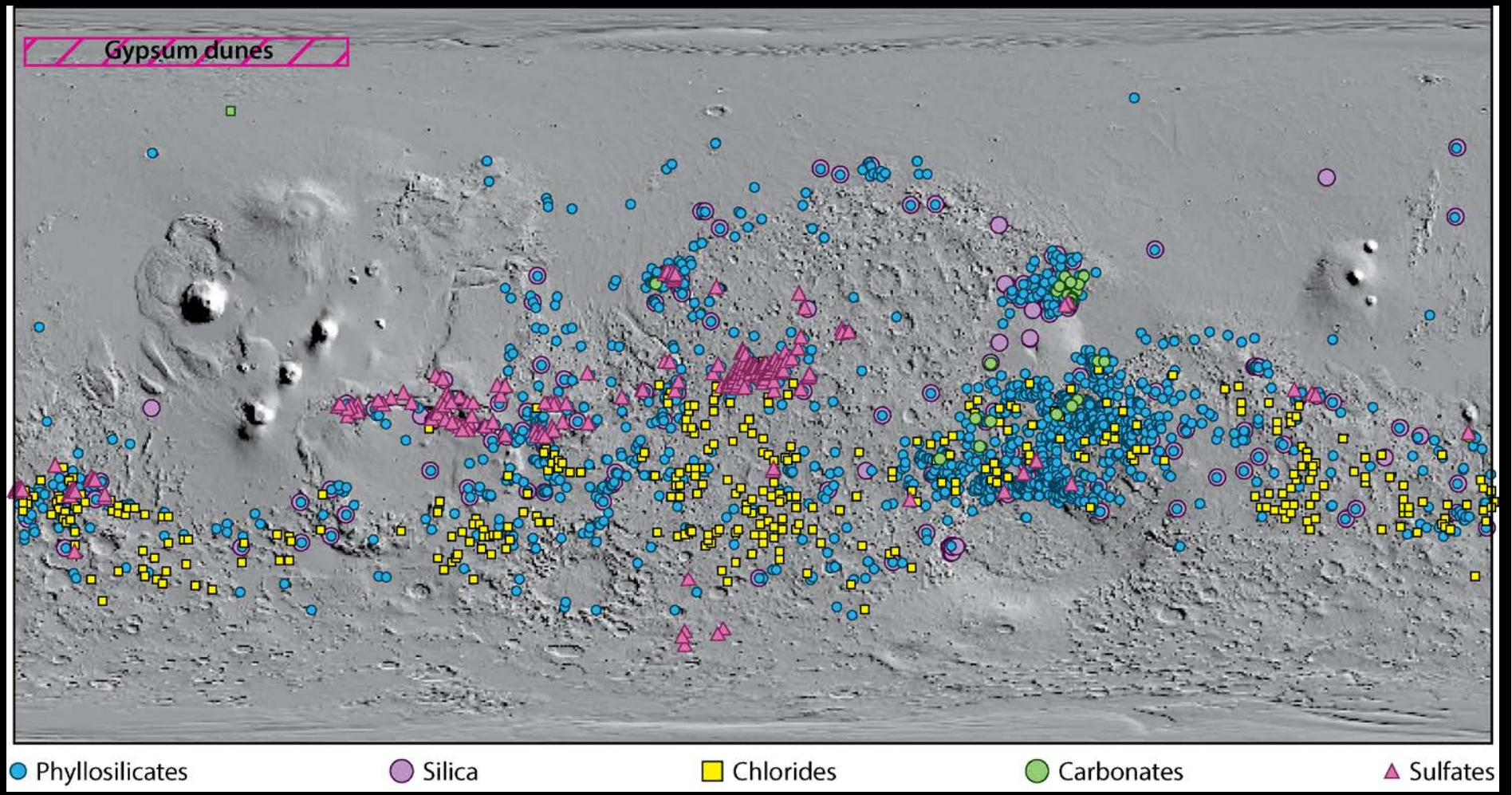
Ancient Mars

Recent Mars

Present Mars

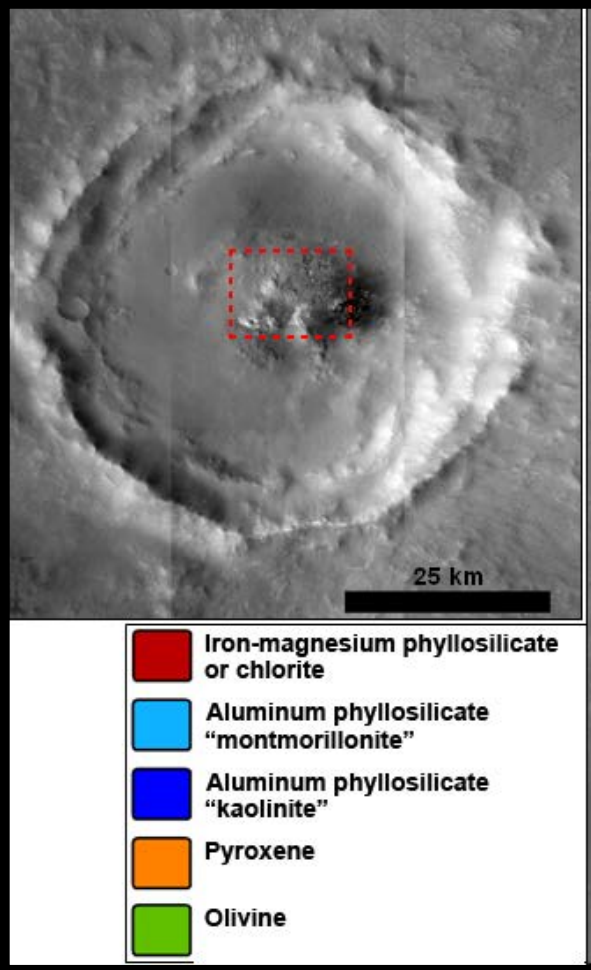
Ancient Mars

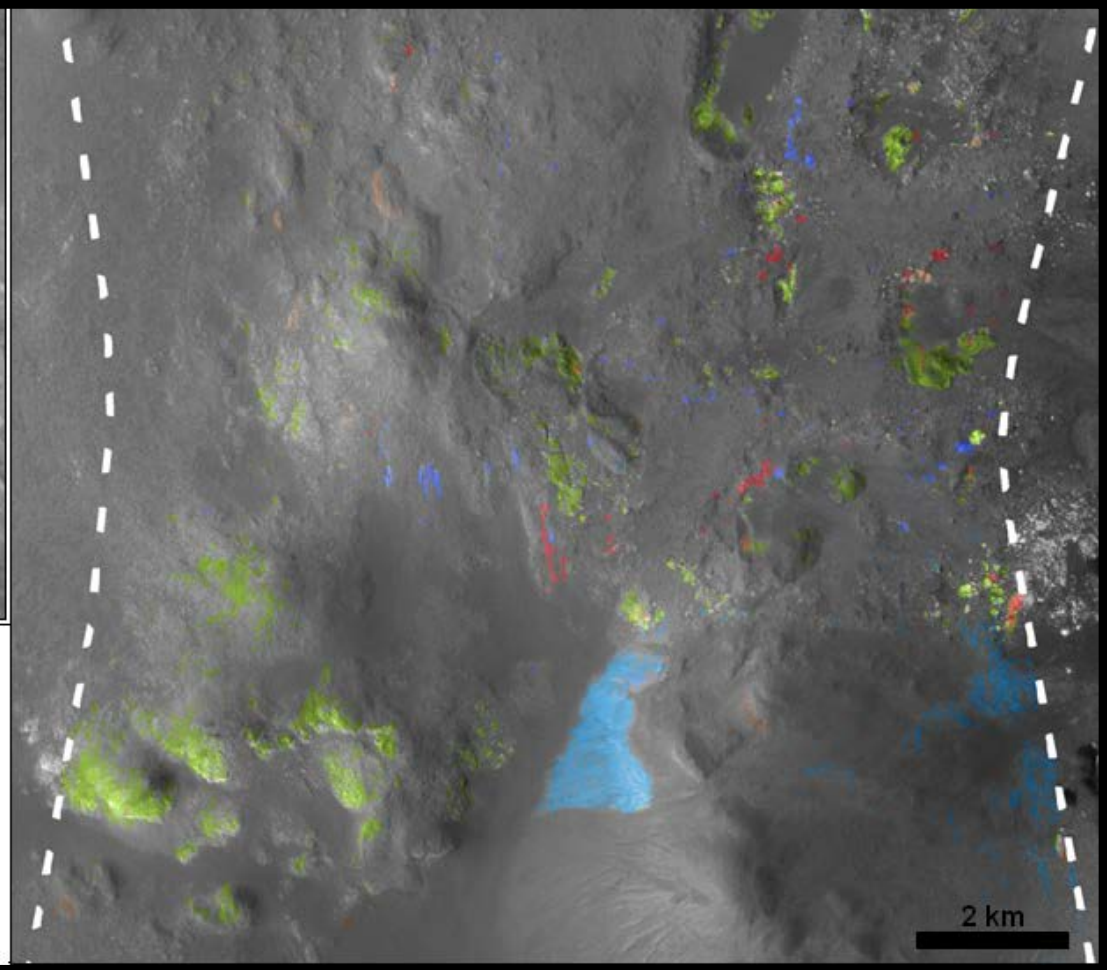
MRO has mapped many thousands of outcrops of minerals that must have formed in liquid water



Ehlmann and Edwards (2014) Ann. Rev. Earth Plan. Sci.

CRISM: Clues to an Ancient Wet Past

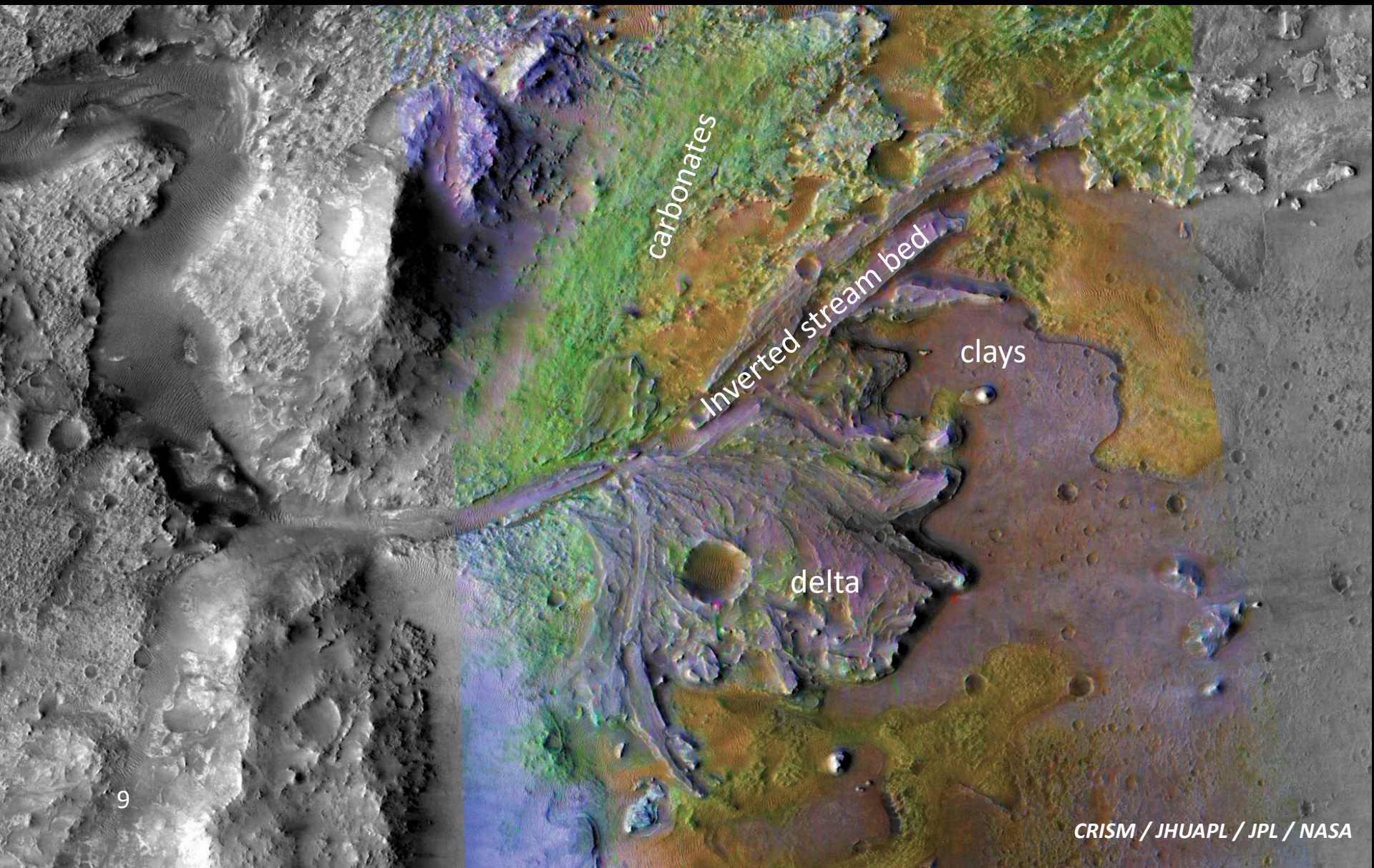




Outcrops of hydrated minerals found in northern lowlands and southern highlands suggest global wet conditions

~ 4 billion years ago

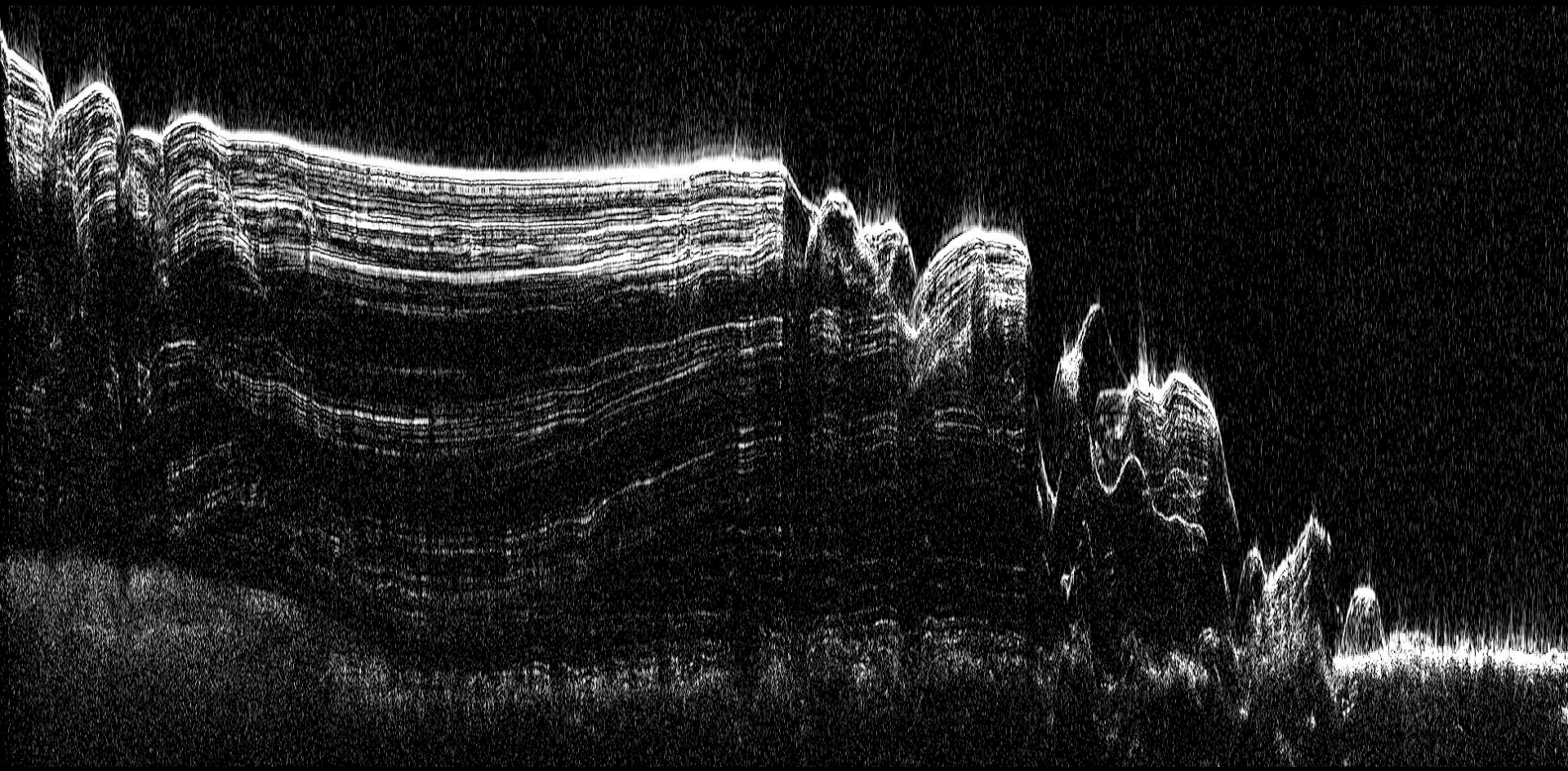
Jezero Crater: Morphology & Mineralogy Indicate Ancient Wet Past



CRISM / JHUAPL / JPL / NASA

Recent Mars

SHARAD:
Studying Climate History at the Poles

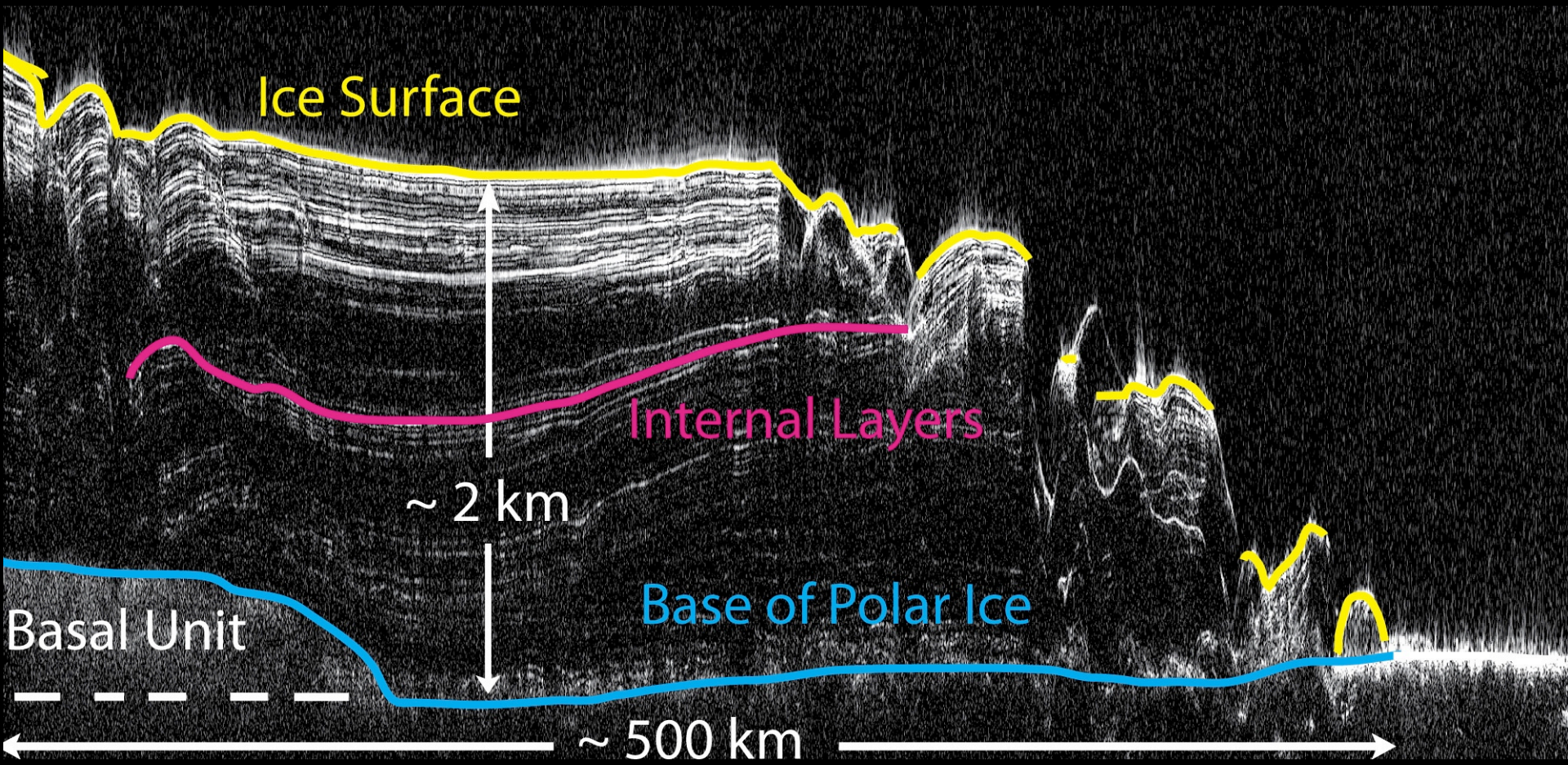


Layers of ice and dust cause radar reflections

Each layer records a different depositional environment

Each layer represents a change in climate

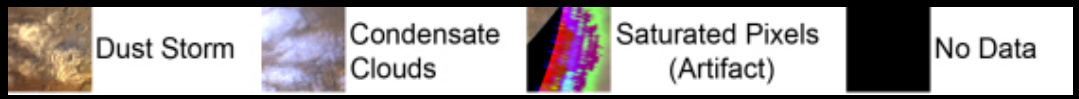
SHARAD:
Studying Climate History at the Poles



Growth and retreat of polar ice tells us about distribution of ice around the planet over time

Active Atmosphere

Weather Conditions for Week of March 19, 2015

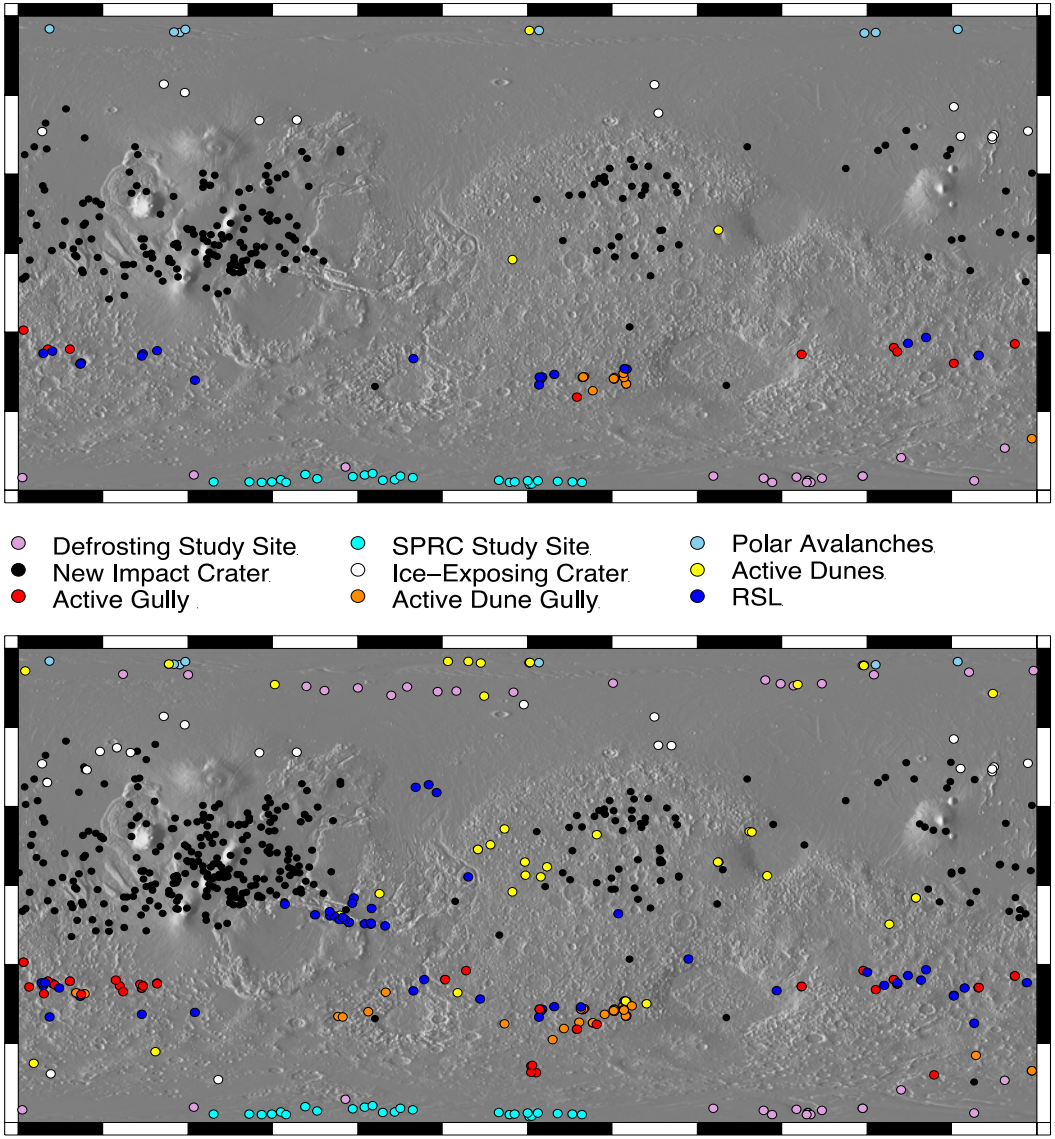


Dust Devil

Active Surface

Surface Changes on Modern Mars

McEwen and Byrne

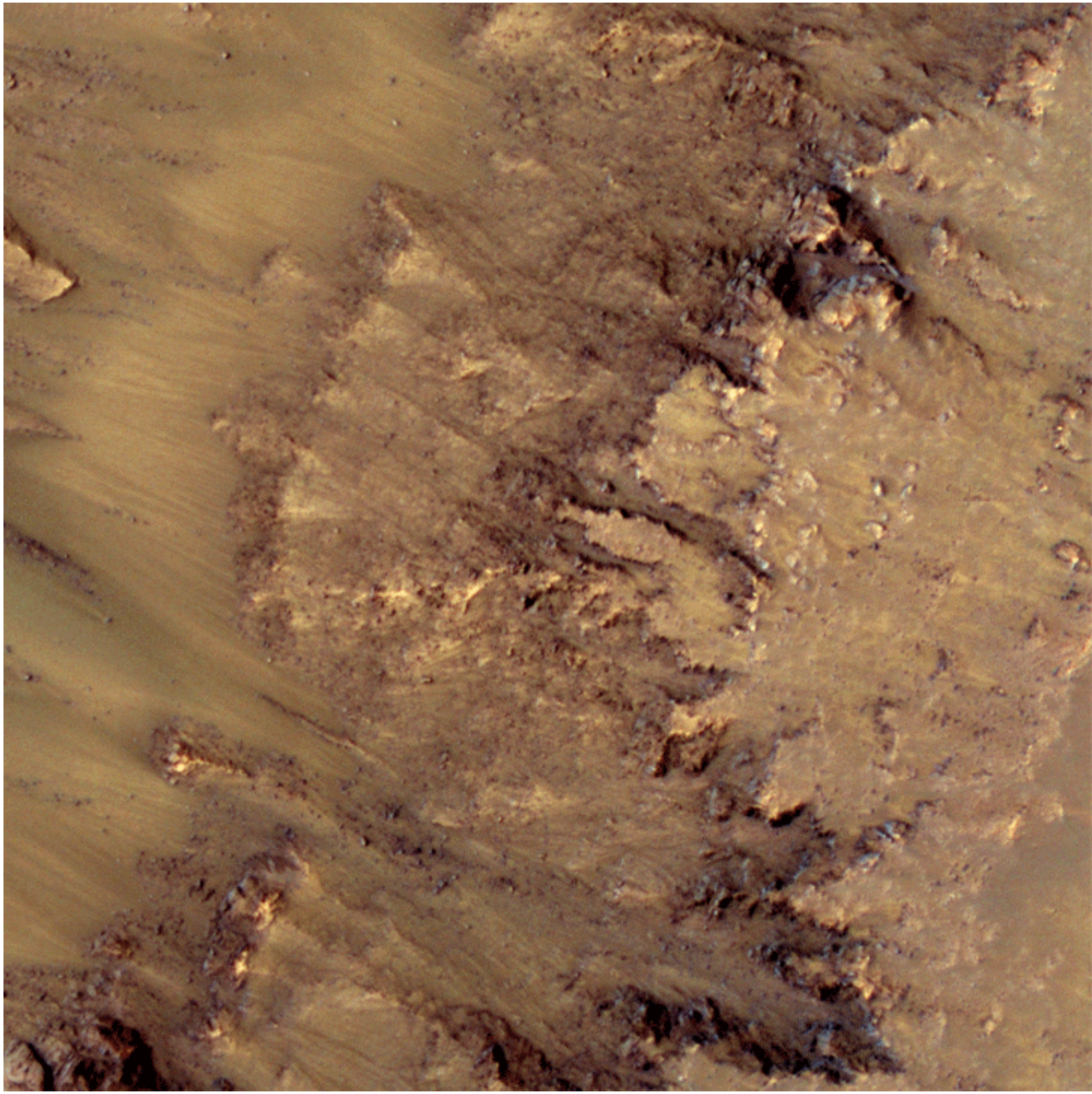


Early 2012 (top) vs. Feb 2014 (bottom)
Message: accelerating progress over time

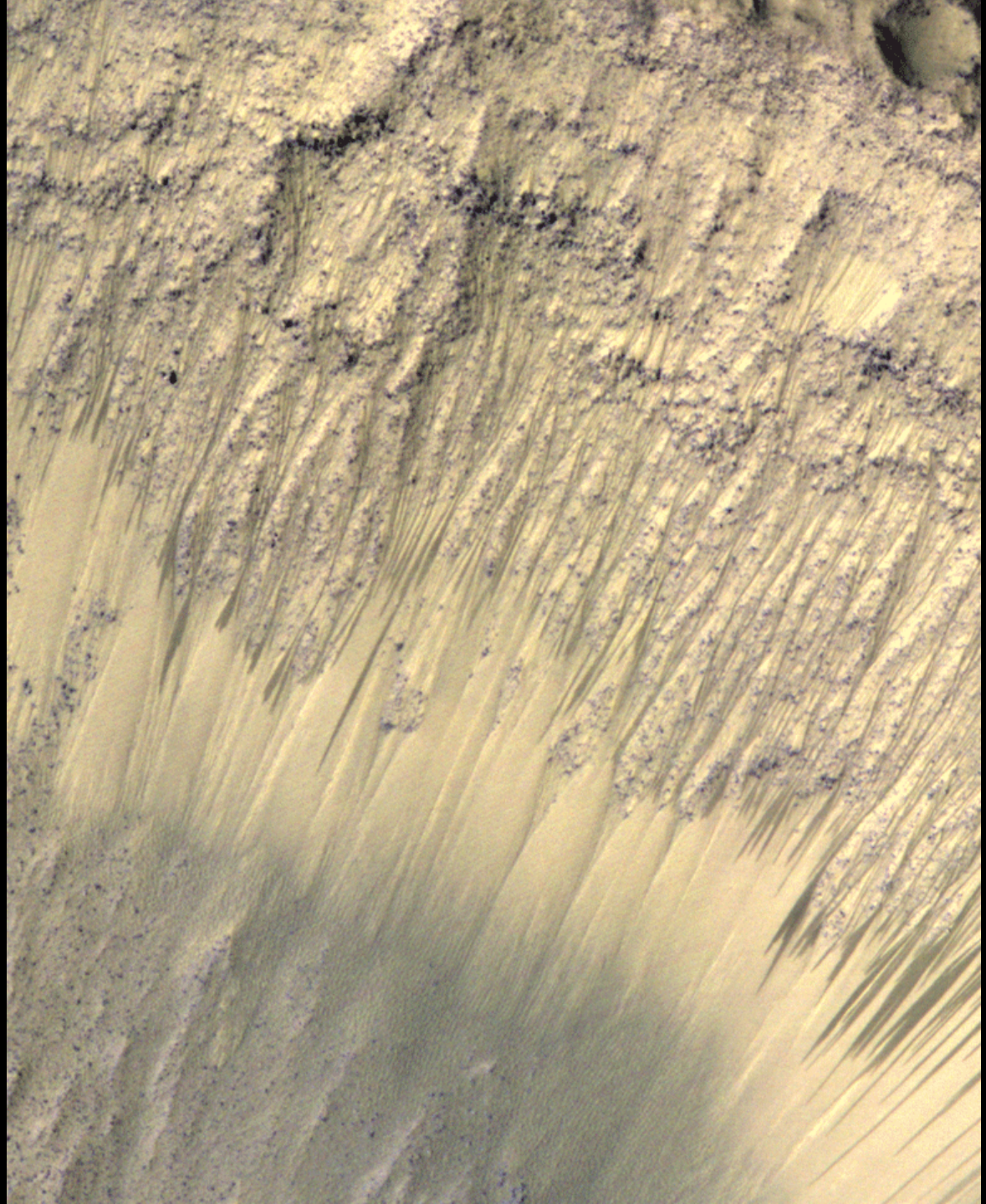
Seasonal Flows on Warm Martian Slopes

(A. McEwen et al., Science, 14 July 2011)

- Recurring Slope Lineae (RSL) are narrow (0.5-5 m), dark markings on steep slopes (>25°)
- Form and incrementally grow in warm seasons (late spring to summer), then fade or disappear in cold seasons.
- Reform at nearly same locations in multiple Mars years.
- Extend downslope from bedrock outcrops or rocky areas; often associated with small channels.
- Concentrated in southern hemisphere (32°S to 48°S), favoring equator-facing slopes.
- Form and grow at temperatures at which brines (salty water) would be liquid.
- Exact mechanism not understood, but activity of brines is current best model.

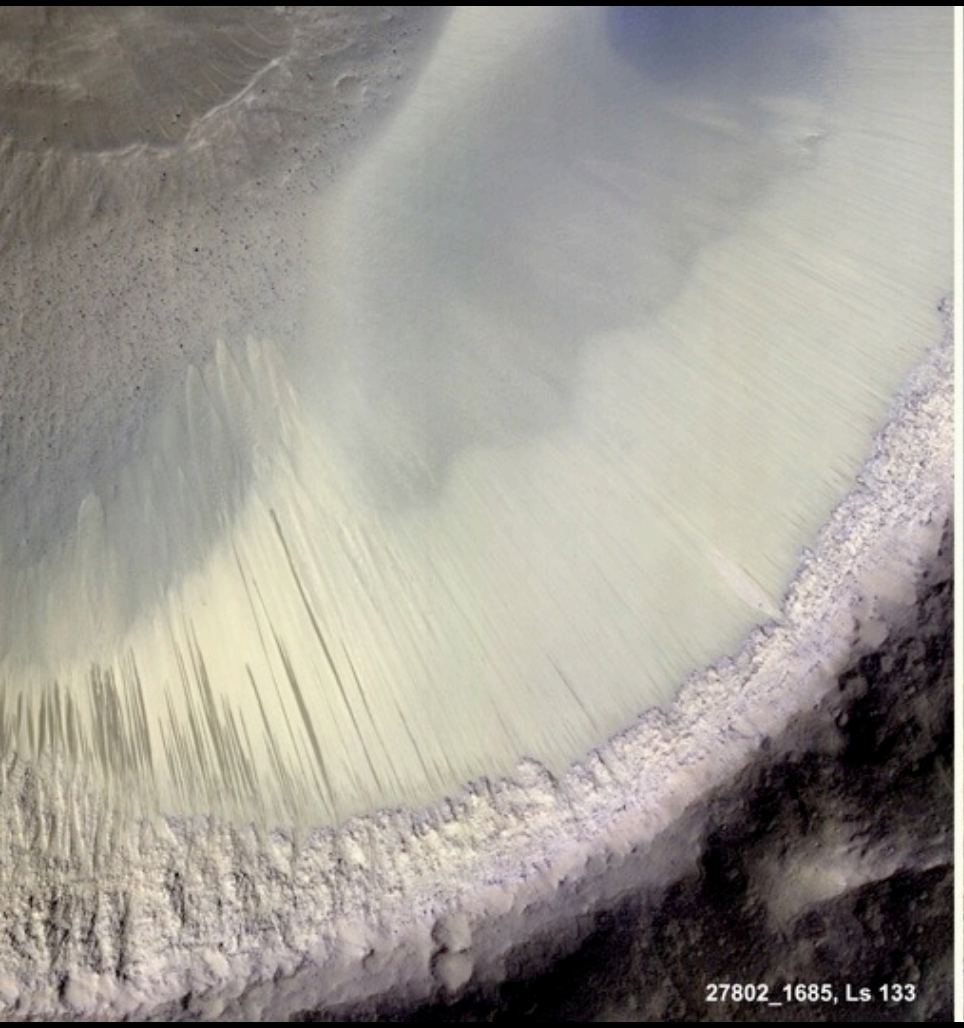


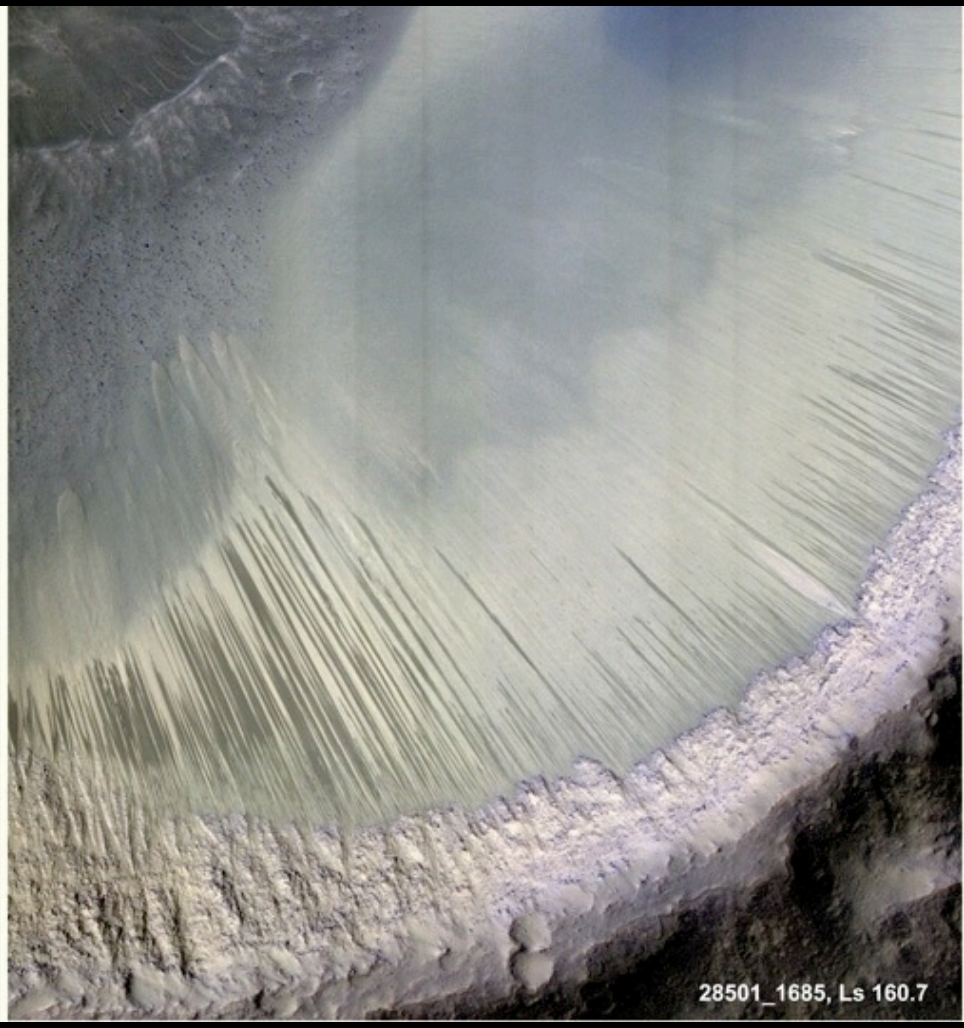
Recurring Slope Lineae



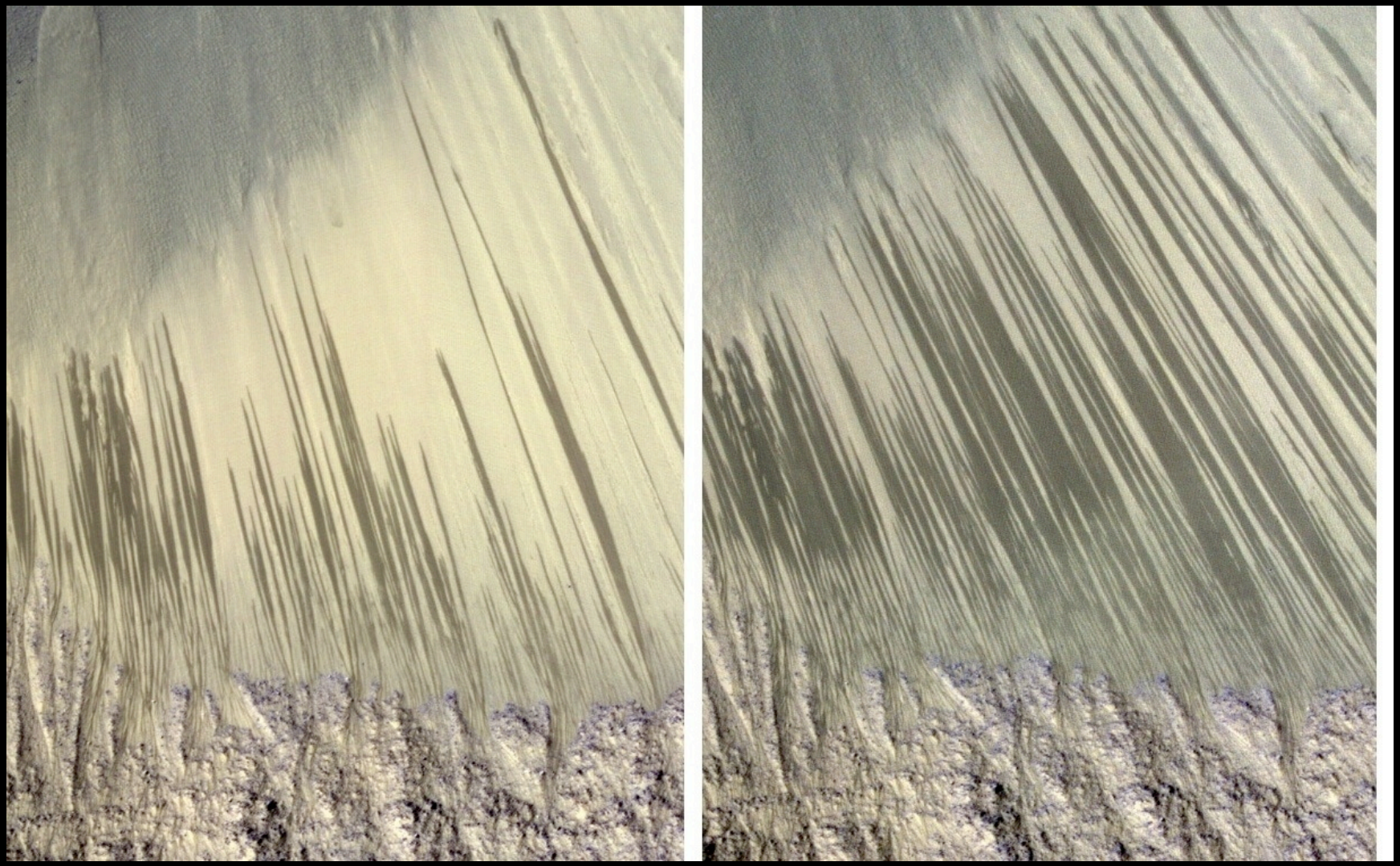
Abundant Active RSL on Crater Floor in Central Valles Marineris

(scene ~1 km wide)





Enlarged Area (~250 m wide)

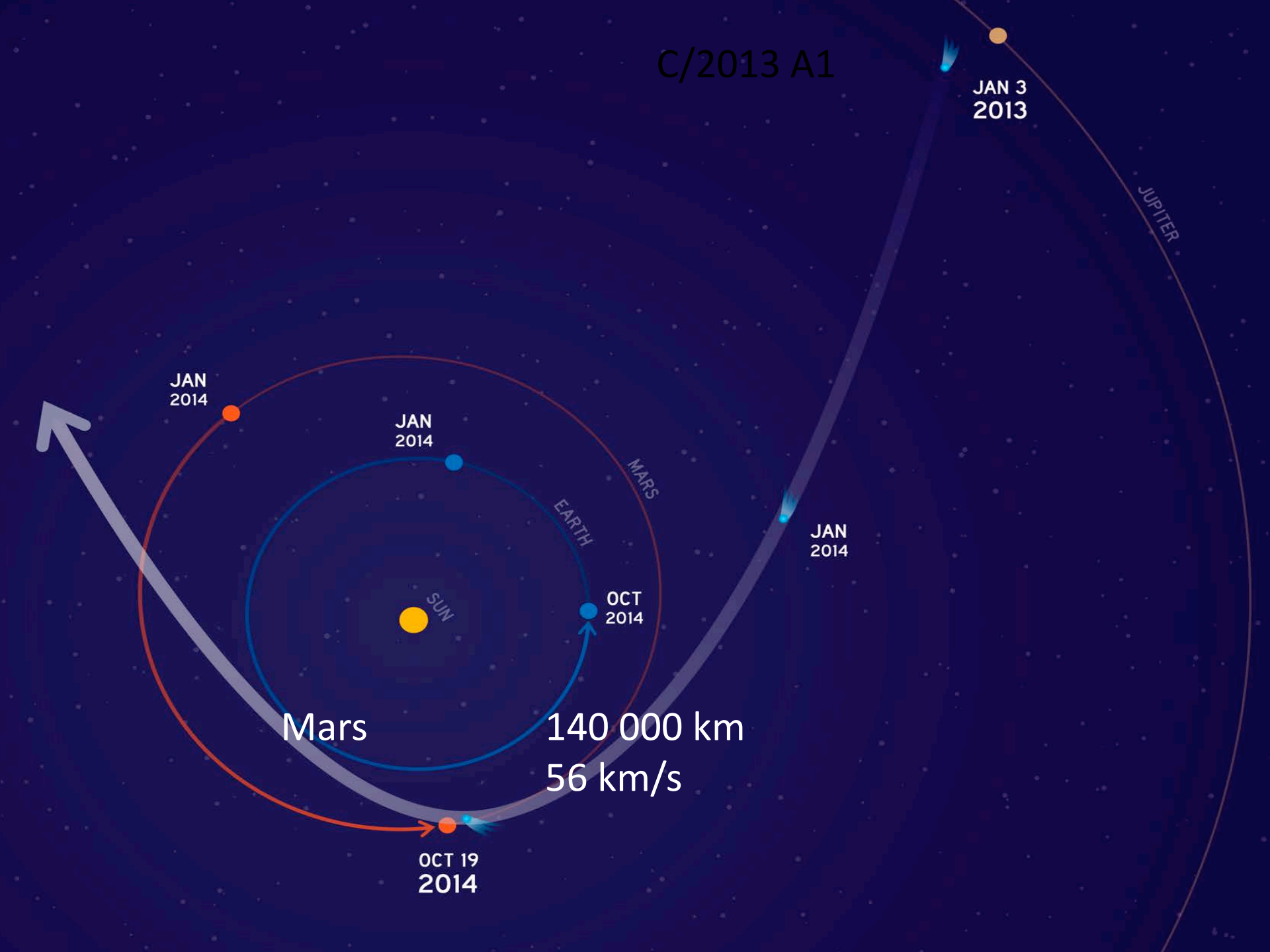


Bonus Science:

Mars Comet Observer

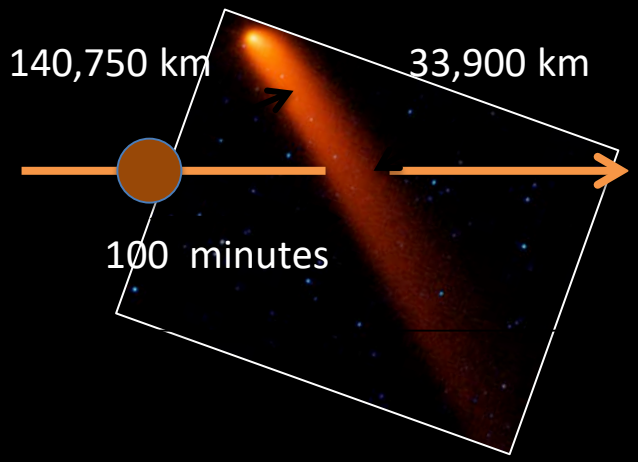
Comet Siding Spring

C/2013 A1

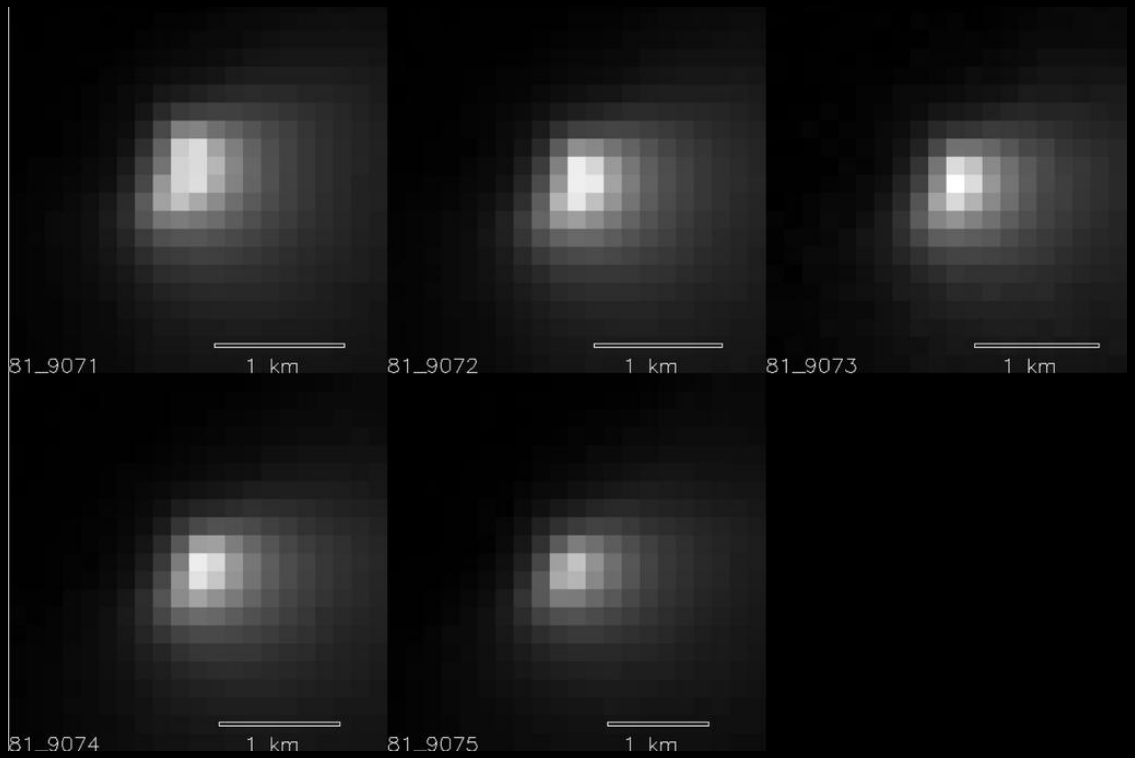

JAN 3
2013
JUPITER
JAN
2014
JAN
2014
MARS
EARTH
JAN
2014
SUN
OCT
2014
Mars
140 000 km
56 km/s
OCT 19
2014

Concerns for spacecraft safety

- **Flyby so close, Mars orbit may intersect with dust tail**
- **MRO was phased to be “behind” Mars from the perspective of any incoming particles**

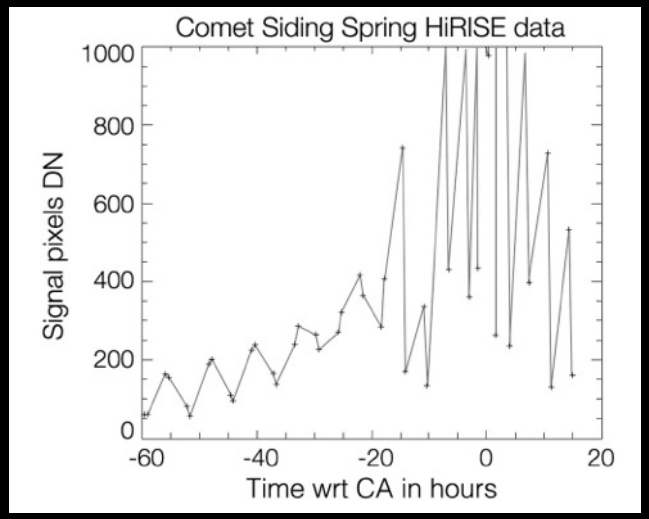


Comet /2013 A1 Siding Spring



MRO HiRISE:

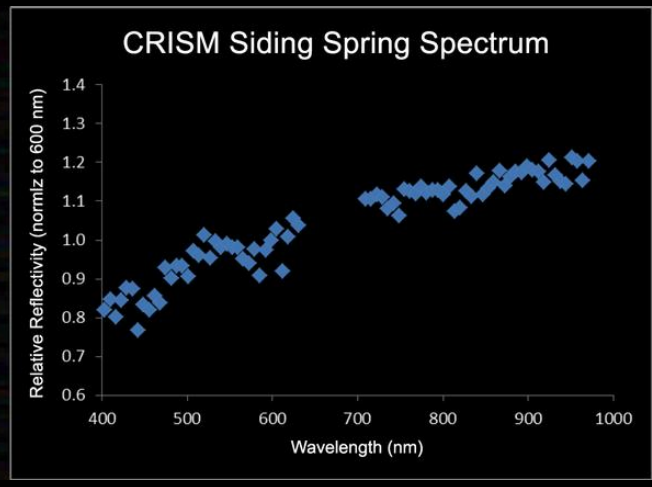
Brightness variation during CSS Encounter



MRO CRISM:

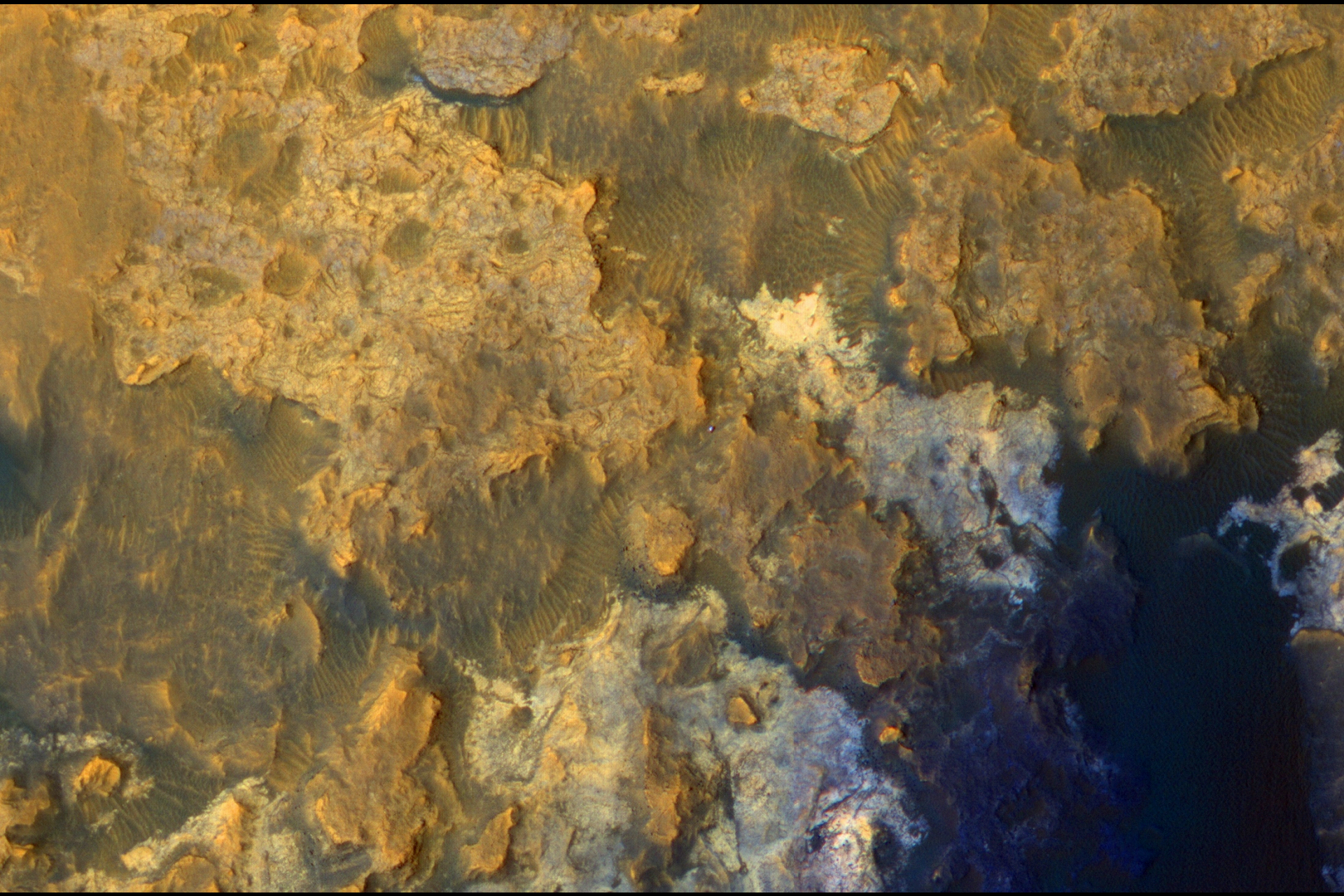
Left: Comet Siding Spring Color Composite From Closest Approach (CA) Images

Right: Composite Spectrum of CSS Reflecting Dust of the Inner Coma

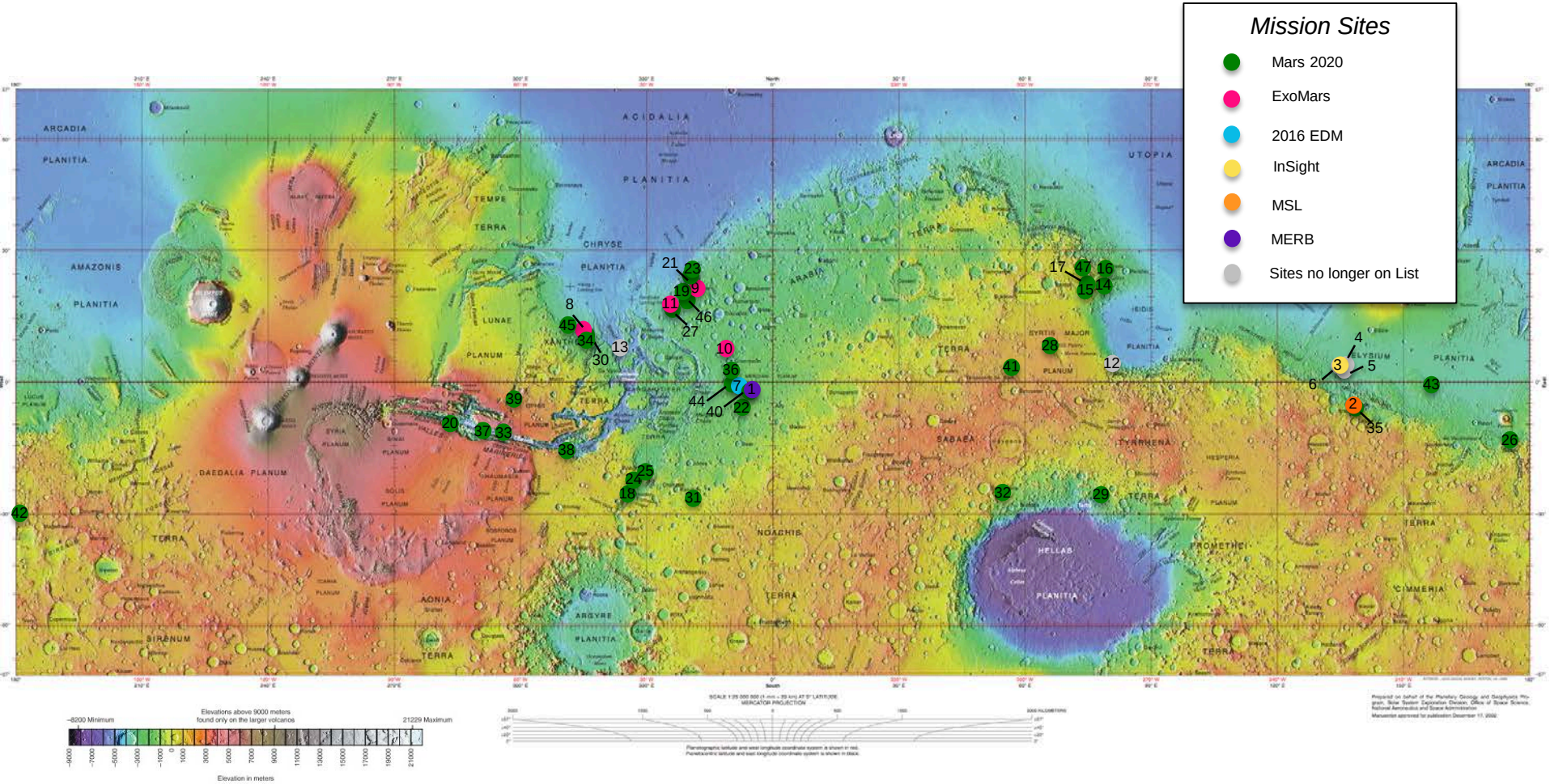


MRO / JPL / NASA

Curiosity on the Move



Map of Future Landing Sites



Flight Challenges – 1/2

Spacecraft Behaviors

- Spacecraft Command & Data Handling (C&DH) Upset Events
  - CMIC Resets
  - C&DH Side-Swaps

  => Developed Expedited Recovery Methods Allows for Spacecraft Recovery in 48-96 hours

- Component Lifetime Limitations
  - Nearly all spacecraft redundancy is in place
  - IMU-1 showing indications of limited life
    - Swap to IMU-2 performed

  ⇒ Developing All-Stellar Attitude Determination Capability

- Instrument-produced EMI impacts on the Electra UHF Link
  - Mitigation methods introduce operations complexity

Flight Challenges – 2/2

- Expansion of UHF Relay Capability
  - From Nadir-oriented to Rolled relay passes
  - From fixed data rates to adjustable data rates (ADR)
  - From a single-vehicle per pass to split-pass (2 vehicles on the same overflight) relay capability

- Human Factors
  - Training and certification of new spacecraft system and subsystem engineers – Certification Standards in Place
  - Rigorous processes for flight product builds and spacecraft commanding

  => Maintaining the corporate knowledge base

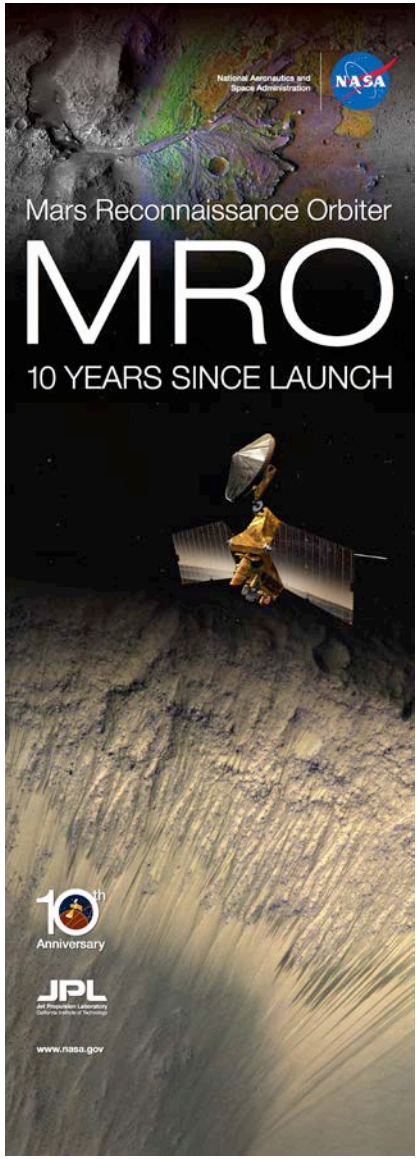
Summary

- Ten Years In Flight …….

  L: August 12, 2005 MOI: March 10, 2006 PSO Establishment: Sept 10, 2006

  - Over 45,000 orbits
- Mars Surface Imaging:
  - 2.4% at 30 cm/pixel – HiRISE
  - 95% at 6 m/pixel – CTX
  - Location of many water related minerals - CRISM
- Extension of the Mars atmospheric climate history
- Over 250 terabytes of science data returned
- Over 950 scientific papers published using MRO data

  => Mars is an active and dynamic planet!

- Over 2900 relay passes (PHX, MER-A, MER-B, & MSL)
  - 75% of all MSL data is returned through MRO
- Landing Site Scout for Phoenix Lander and Curiosity Rover
  - Supporting the next wave of missions to Mars including a peak at potential human exploration zones

MRO Launch – August 12, 2005