MRO: Continuing Discoveries at Mars

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Mars Reconnaissance Orbiter

AAS GN&C Conference
Breckinridge, CO
February 5, 2017

The University of Arizona · Malin Space Science Systems · The Johns Hopkins University · agenzia spaziale italiana · California Institute of Technology · GWU · MIT · Lockheed Martin

4 MARS SCIENCE GOALS

1 **LIFE**
Determine if life ever arose on Mars

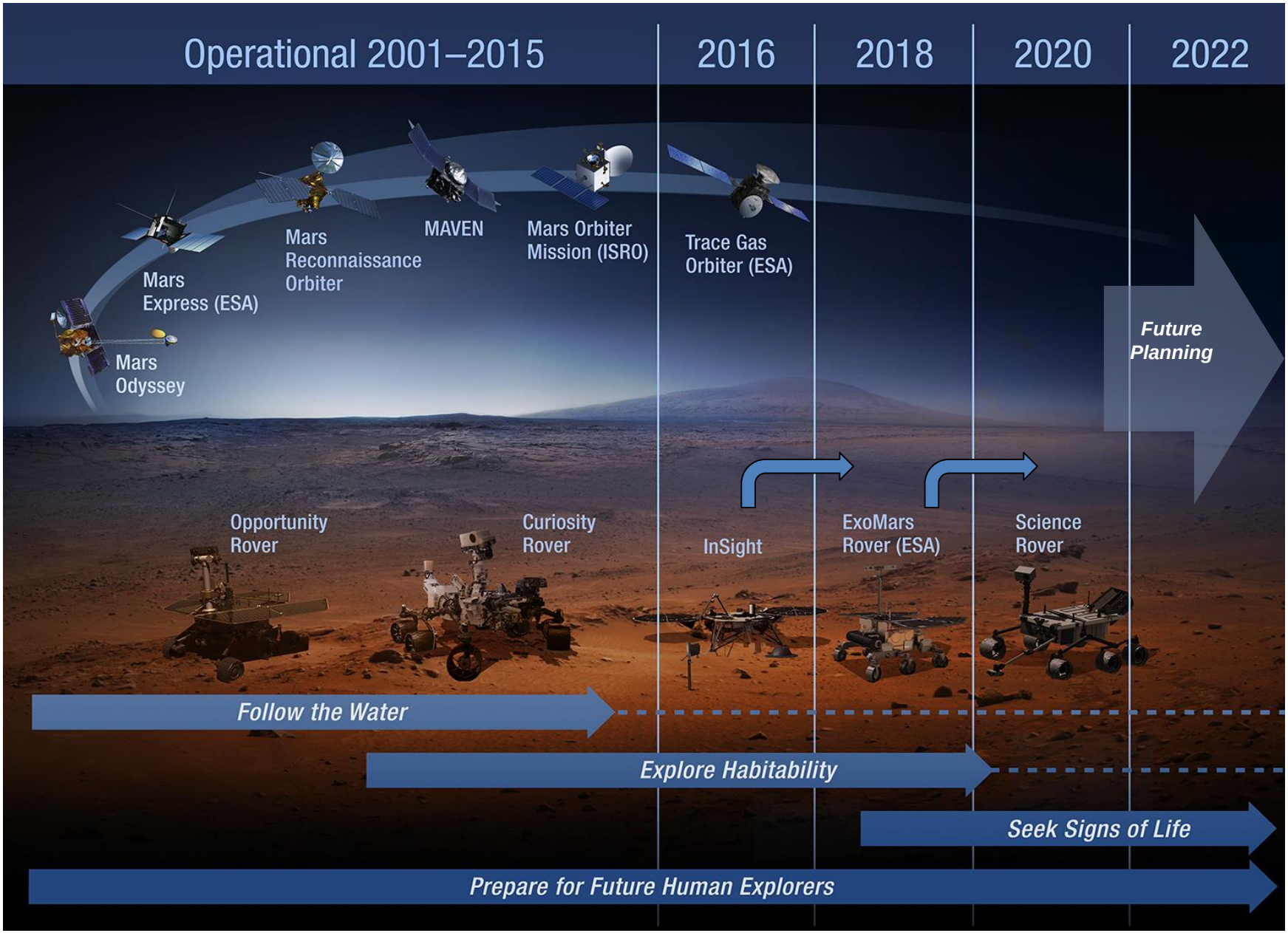
2 **CLIMATE**
Understand Martian climate processes and history

3 **GEOLOGY**
Determine how the surface and interior of Mars evolved

4 **HUMANS**
Prepare for human exploration

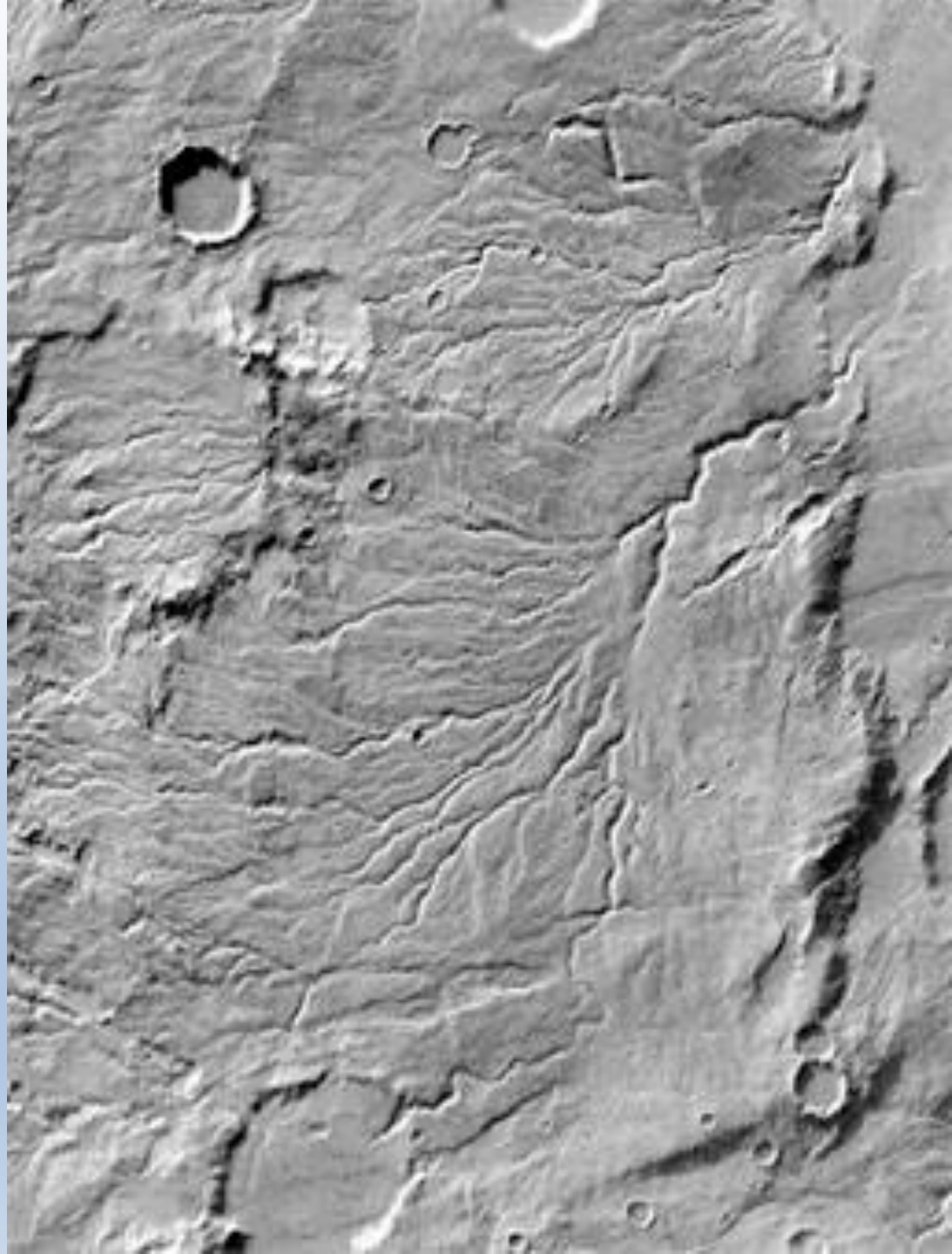
WATER ✓
HABITABLE ZONES ✓
SIGNS OF LIFE ?

EVOLVING THEMES

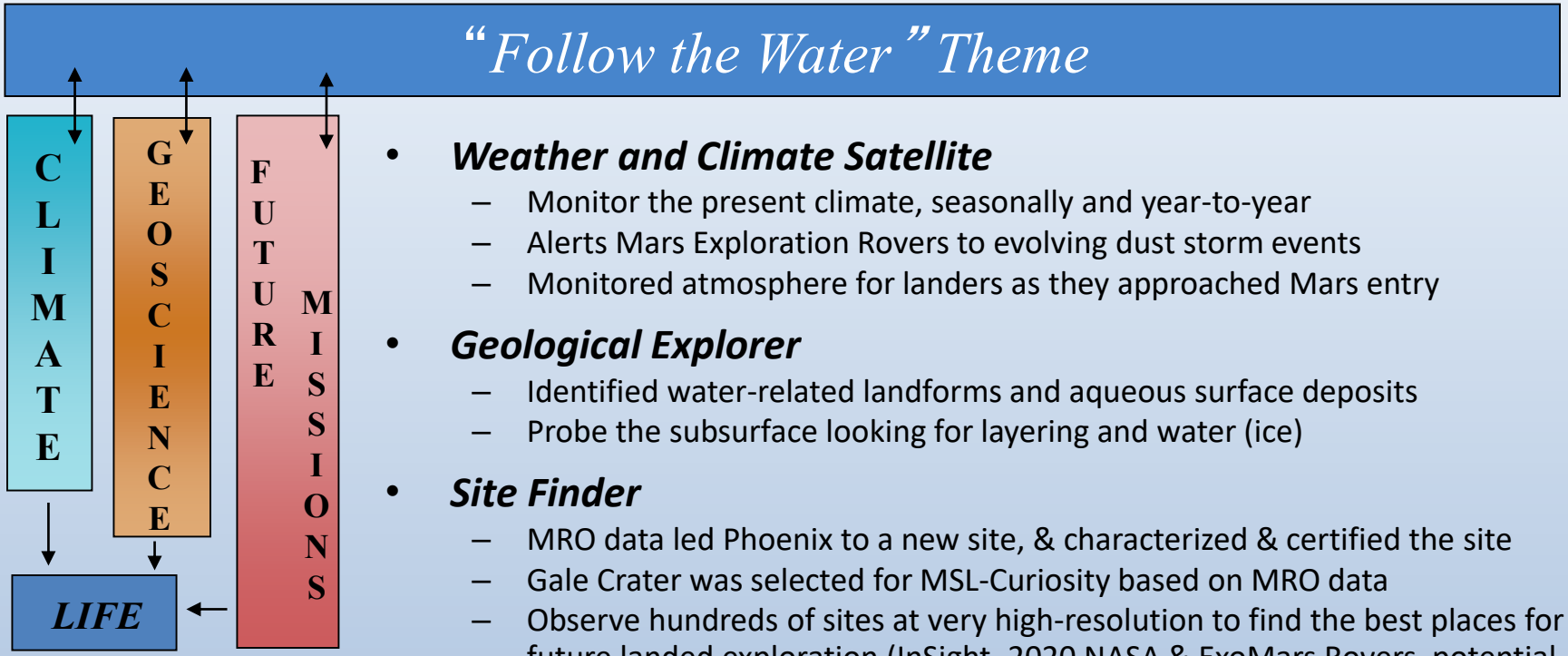

Operational 2001–2015
2016
2018
2020
2022
Mars Express (ESA)
Mars Odyssey
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA)
Future Planning
Opportunity Rover
Curiosity Rover
InSight
ExoMars Rover (ESA)
Science Rover
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

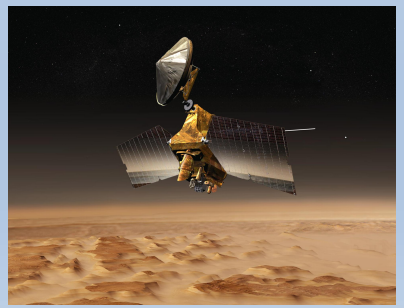
What did we know about Mars in 2005?

- Ancient Mars
  - Wet, but when & for how long, were the locations habitable?
- Geologically Recent Mars
  - Layering seen in polar cap edges, but composition, depth, formation unknown
  - Mid-latitude ice was a possibility, but not certain
- Present Mars
  - Dunes, but thought to be frozen from some ancient time
  - Gullies formed, but when?
  - Vertical distribution of dust and water-ice unknown
  - Was there CO2 snowfall in polar regions (not just frost)?
  - No liquid water on Mars today



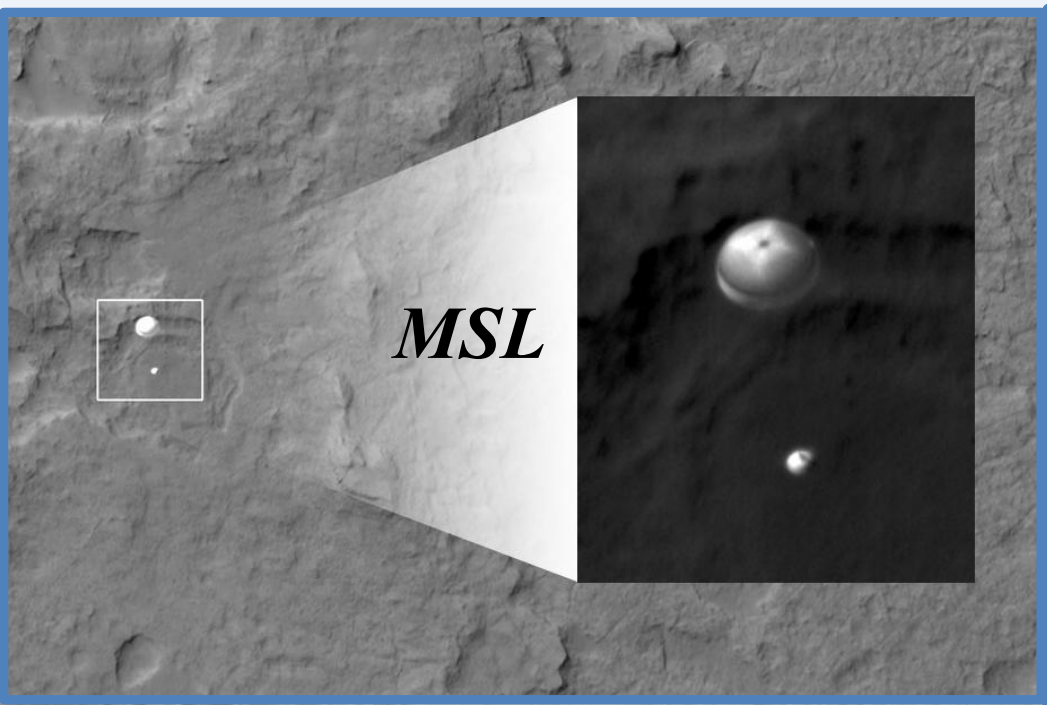
MRO Has Many Roles

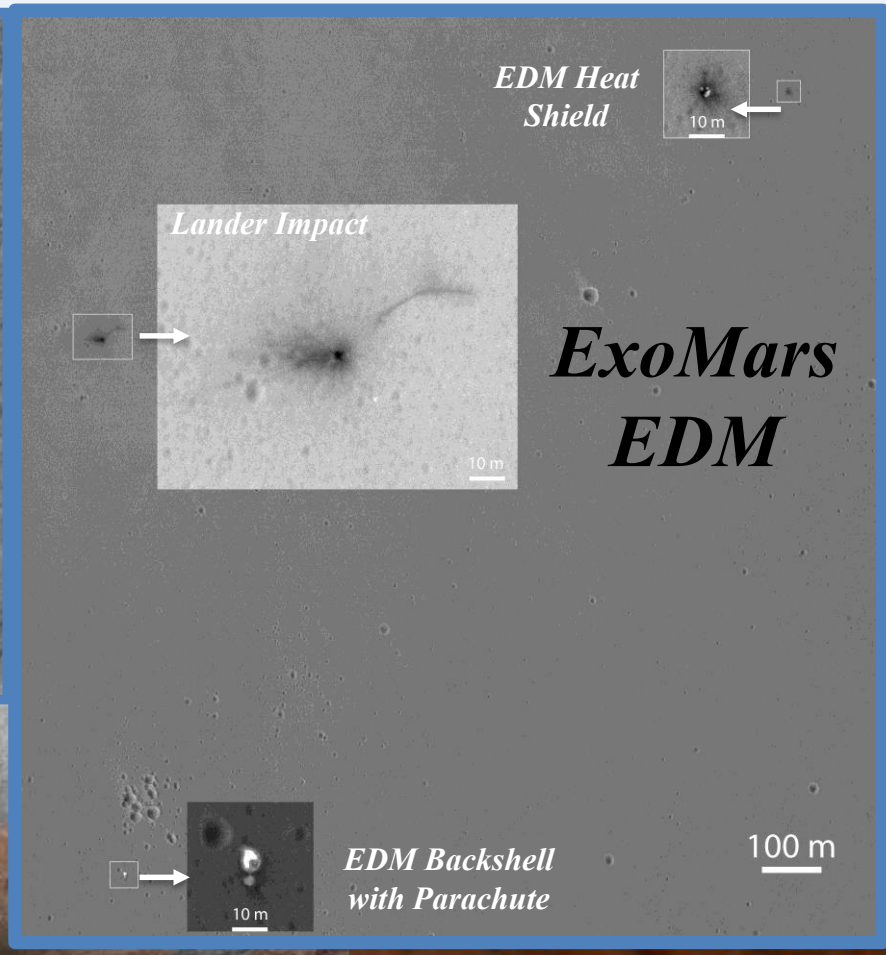




- ***Weather and Climate Satellite***
  - Monitor the present climate, seasonally and year-to-year
  - Alerts Mars Exploration Rovers to evolving dust storm events
  - Monitored atmosphere for landers as they approached Mars entry
- ***Geological Explorer***
  - Identified water-related landforms and aqueous surface deposits
  - Probe the subsurface looking for layering and water (ice)
- ***Site Finder***
  - MRO data led Phoenix to a new site, & characterized & certified the site
  - Gale Crater was selected for MSL-Curiosity based on MRO data
  - Observe hundreds of sites at very high-resolution to find the best places for future landed exploration (InSight, 2020 NASA & ExoMars Rovers, potential human exploration zones)
- ***Communications Satellite***
  - Provided critical event coverage (entry, descent and landing) and relay for both Phoenix and provides relay for Mars Science Laboratory (~450 Mb/sol)
- ***Technology Pathfinder***
  - Demonstrated optical navigation and use of new telecom frequencies (Ka-band) for future missions

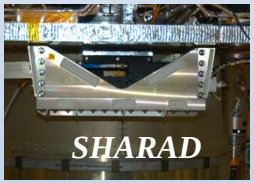
MARS Program Support by MRO





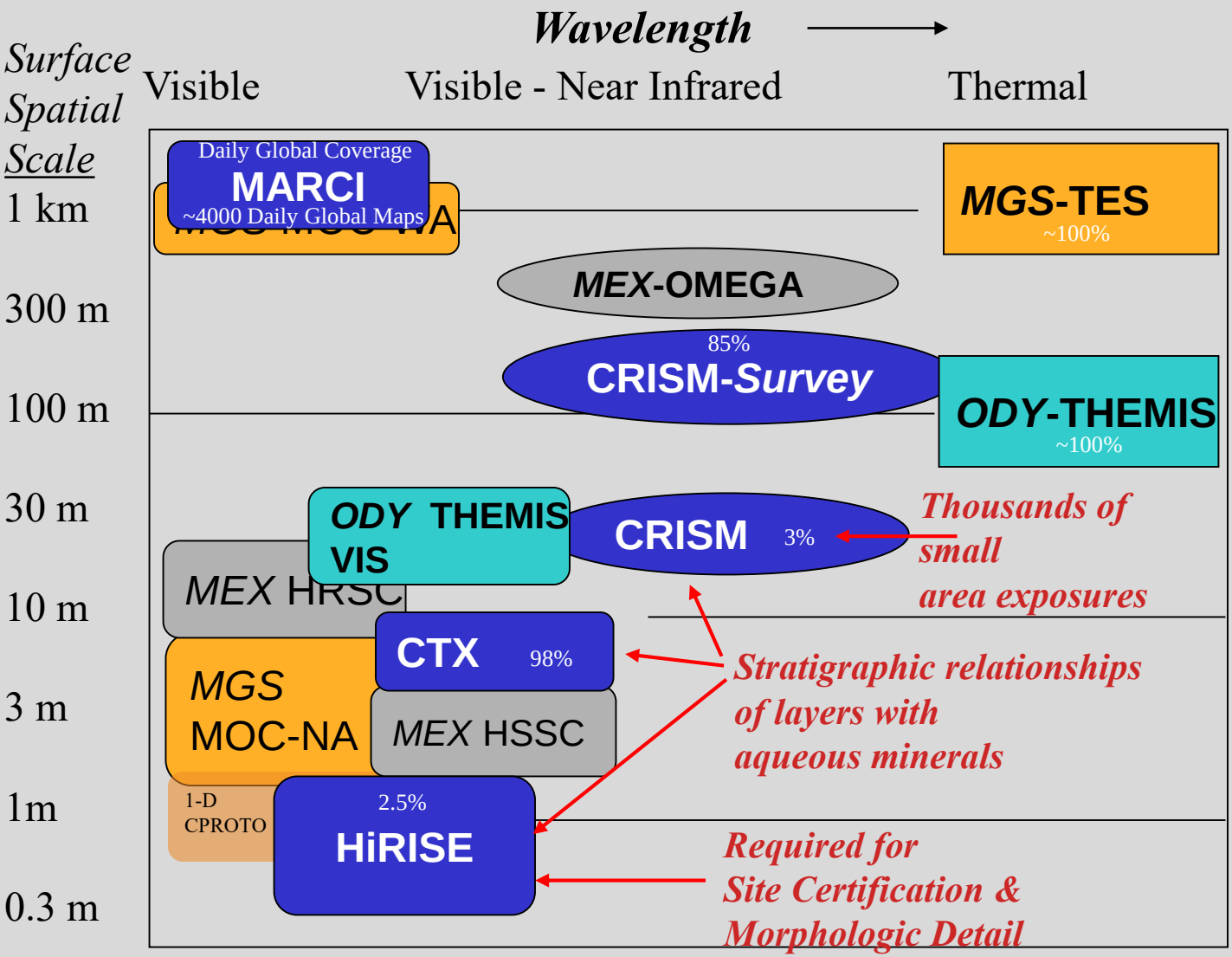
MRO Science Investigations

Instrument	*Type*	*PI/TL, Institution*	*Attributes*
CRISM	**Hyper-Spectral Imaging VIS-NIR Spectrometers**	***Scott Murchie, PI*** **APL / Johns Hopkins University**	**Targeted Observing @ 18 m/pixel Regional Survey @ 100-200 m/pixel Very High Data Rate 85% of Mars surveyed in 72 channels**
HiRISE	**Very High Resolution Imaging**	***Alfred McEwen, PI*** **University of Arizona**	**Targeted Imaging @ 30 cm/pixel Swath: 5.4 km w. 1.2 km 3-color strip Very High Data Rate / 2.7% of Mars**
SHARAD	**Shallow Subsurface RADAR** ***(Provided by ASI)***	***Roberto Seu, TL/PI*** **University of Rome** ***Roger Phillips, rDTL*** ***Nathaniel Putzig, aDTL***	**Regional Radar Profiling of Subsurface Profiles to 0.5 km in regolith / 1.5 km in ice @ ~10 m vertical resolution High Data Rate**
CTX	**High-Resolution Context Imager**	***Michael Malin, TL*** **Malin Space Science Systems**	**Targeted & Regional Survey 6 m/pixel, panchromatic in 30 km swath High Data Rate / 98% of Mars**
MARCI	**Mars Color Imager**	***Michael Malin, PI*** **Malin Space Science Systems**	**Daily Global Mapping ~1 km/pixel in 7 color bands Moderate Data Rate / > 5.4 Mars yrs.**
MCS	**Mars Climate Sounder**	***Daniel McCleese, PI*** **JPL / Caltech**	**Daily Global Sounding (T, p, aerosols) ~5 to 80 km Low-Data Rate / > 5.4 Mars yrs.**
ACCEL	**Facility Science Team Investigation**	***Gerald Keating*, TL*** **GWU / LaRC**	**Profiled upper atmosphere using S/C Accelerometers during Aerobraking. (complete)**
Gravity Science	**Facility Science Team Investigation**	***Maria Zuber, TL*** **MIT / GSFC**	**Data from DSN tracking using Spacecraft X Band Telecom**



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

Gains in Resolution



Phenomena

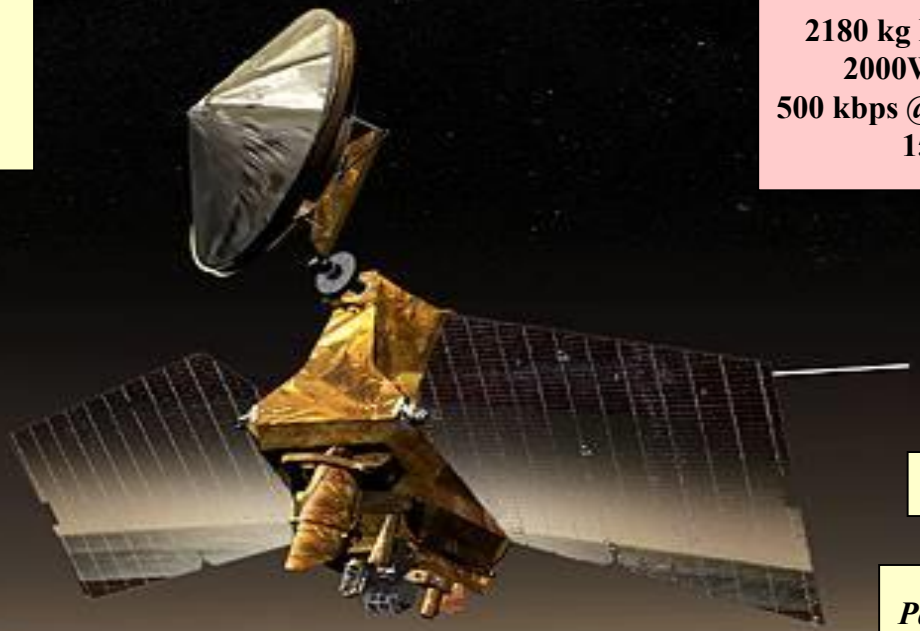
Sea beds?
Channels

Polar Layering
Paleolakes?
Salt Flats?

Layering
Vents/Springs?
Mineral Deposits

Gullies
Debris Fans
Fine Layering
Rocks

Patterned Ground
Fractures



***Telecom*:**
X, Ka-Band & UHF
100 W X-Band TWTAs
3-m diameter High Gain Antenna

~300 Tb of Science Data Returned

***Power*:**
Dual 50 A-Hr NH_2 Batteries
20 m^2 of GaAs 3J Solar Cells

Supports Continuous Payload Operations

***Propulsion*:**
Single-Tank Mono Prop Design
20 Yrs Consumables

Fuel Not a Limit

***Targeting*:**
Ephemeris-Based Targeting
Time-Tagged Sequence Fully Supported

Precise targeting of almost any small target on Mars within a 2 week planning cycle

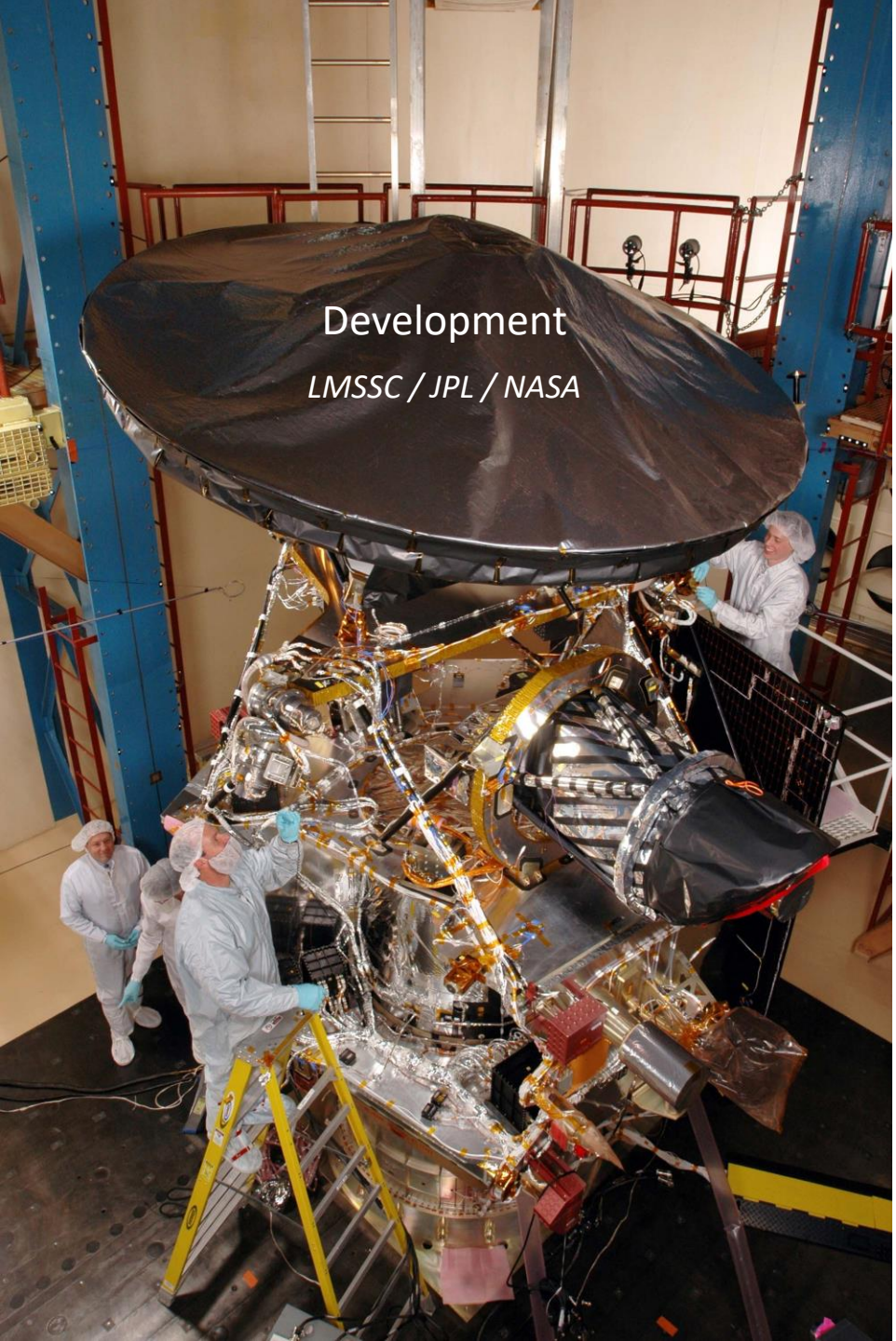
2180 kg Launch Mass (Atlas V)
2000W Array at Aphelion
500 kbps @max Mars-Earth Range
1551 m/s Delta-V

10 m radar antenna

***Payload*:**
6 Science Payloads
2 Eng Payload
Electra Eng SS
Simultaneous Operations
Nested Targeting

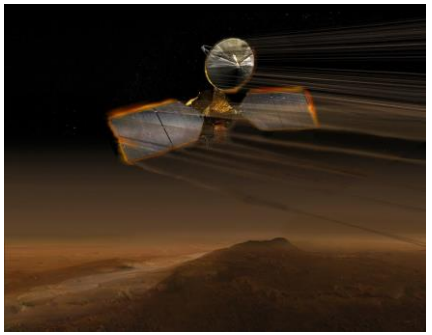
All instruments still operating after 10 yrs

***Command/Data Handling*:**
RAD750 FPC
160 Gbit SSR
100 Mbps Science I/F

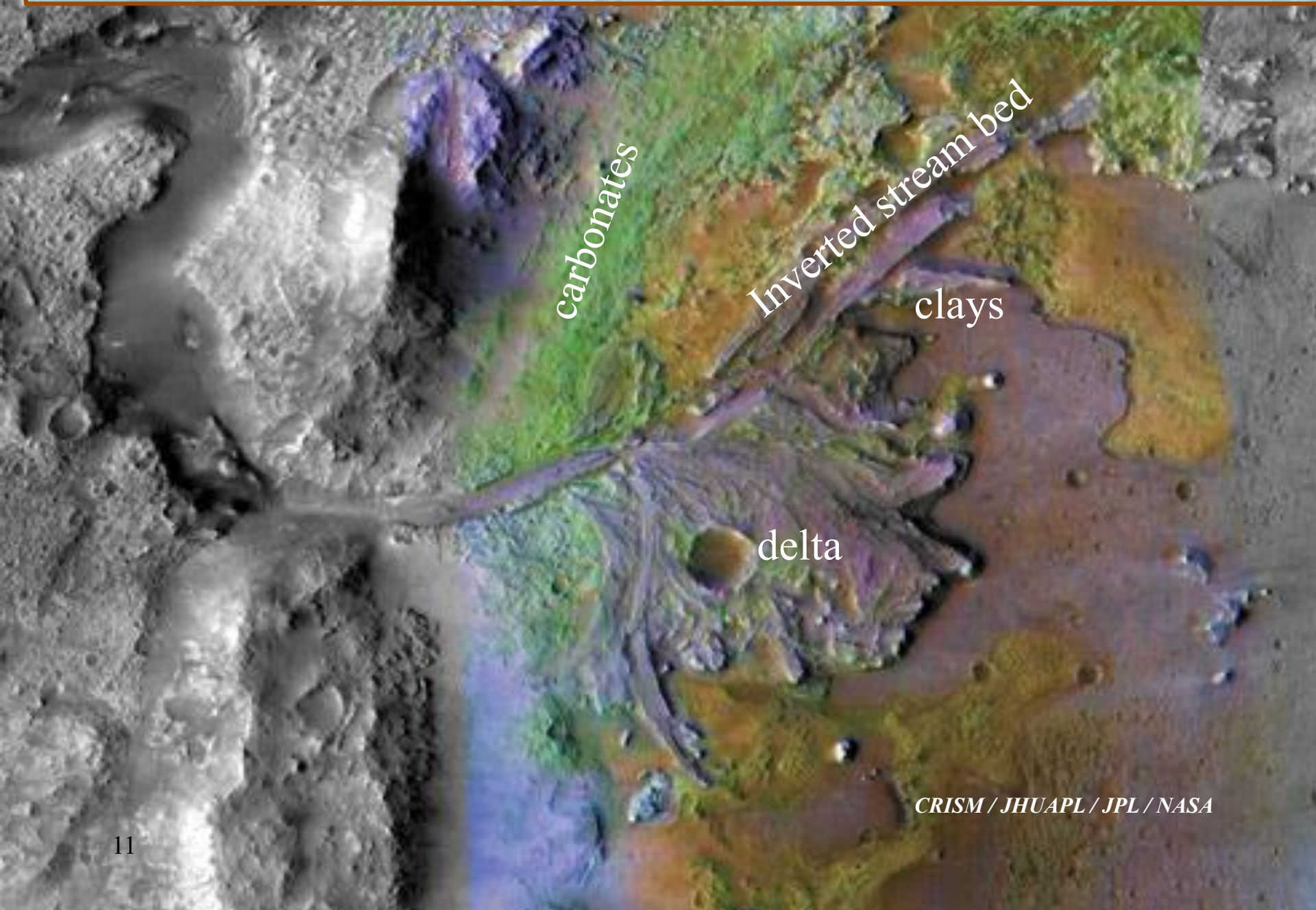


Orbit Insertion
March 10, 2006
(artist concept)

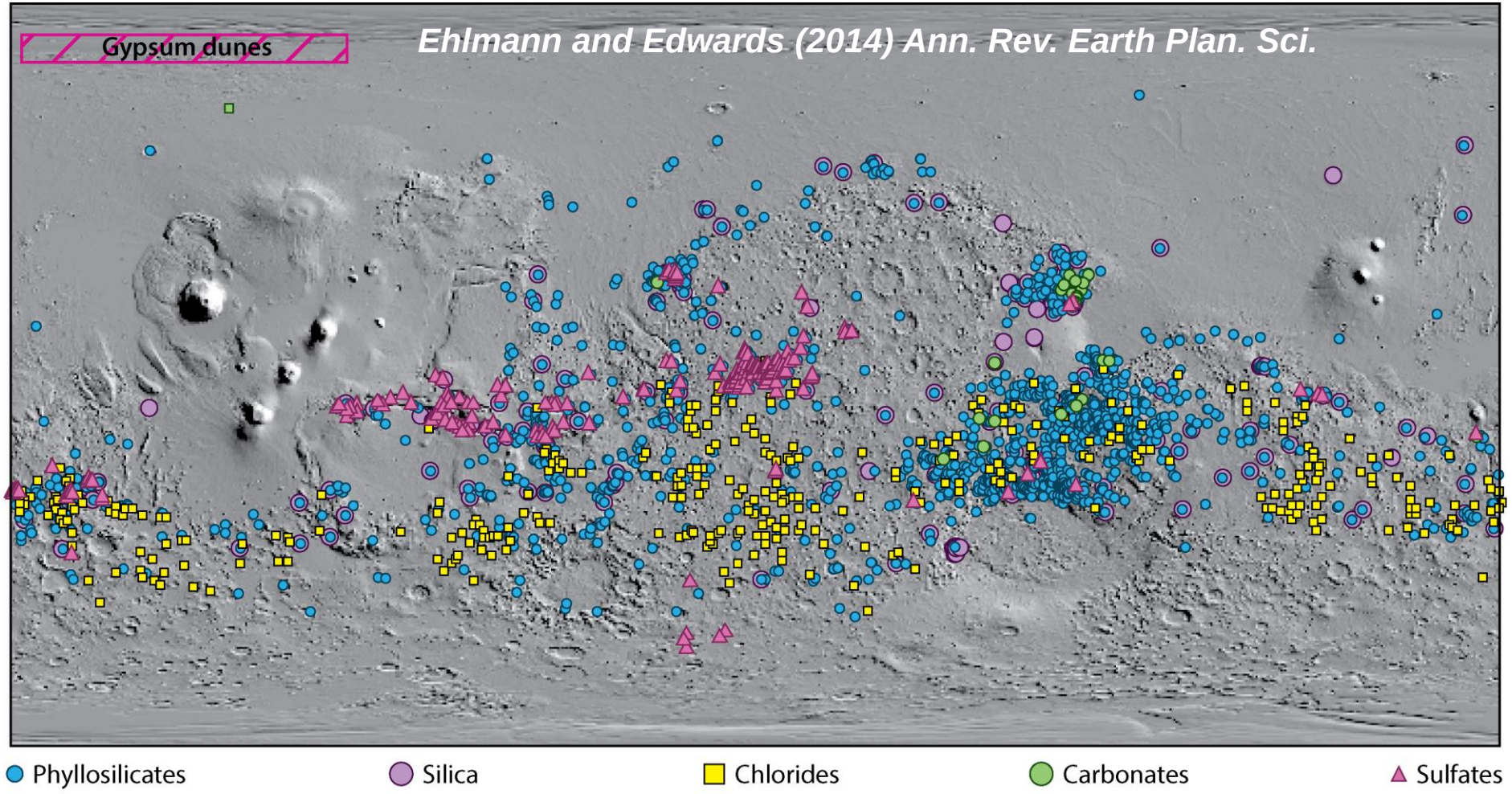
Aerobraking
March -August, 2006
(artist concept)



Ancient Mars: A Diversity of Water-Related Environment

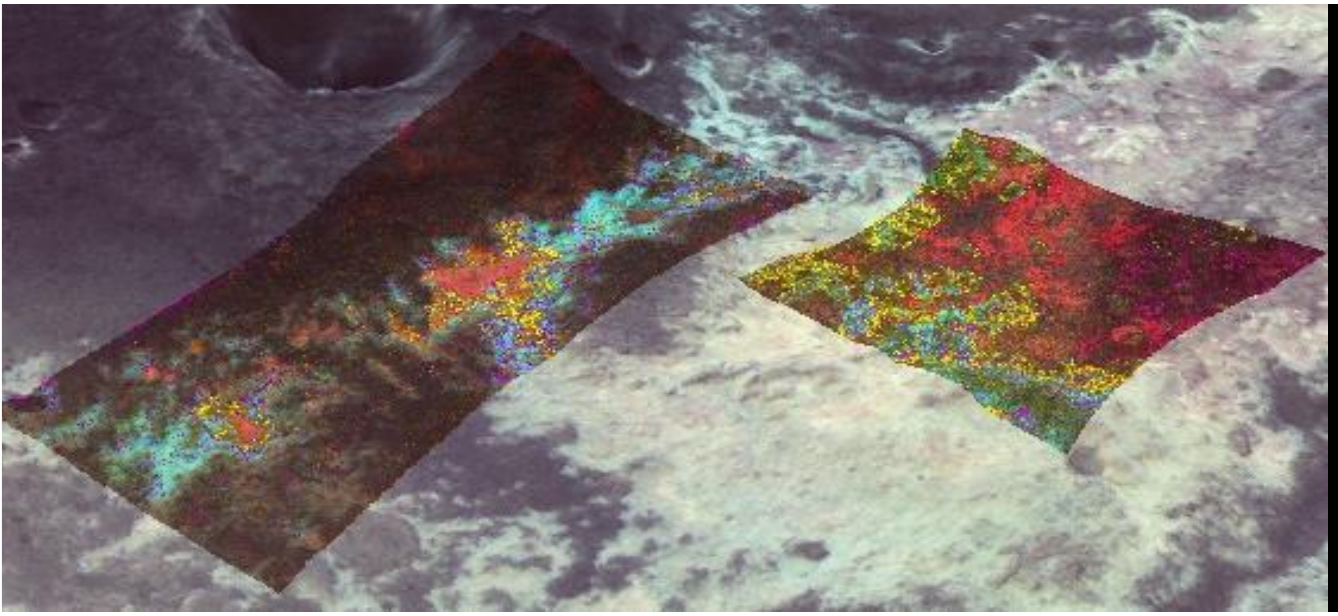


MRO CRISM, MEX OMEGA, and ODY THEMIS have mapped thousands of outcrops of minerals that must have formed in liquid water



Their sequence in time tells the story of Mars' habitability

Layered Phyllosilicate Deposits



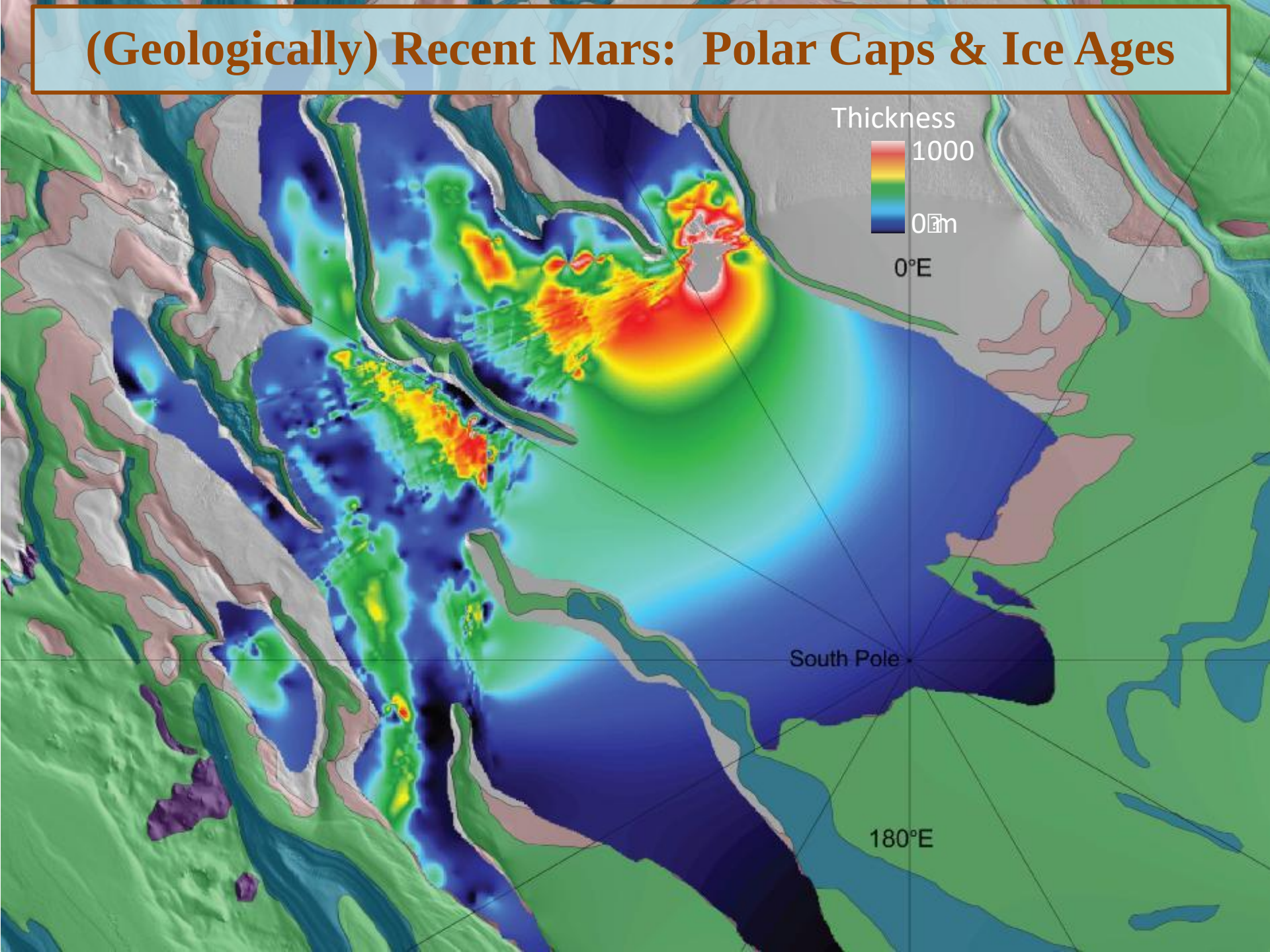
Vertical Sequence:

- Fe/Mg-clay in differing oxidation states
- Acid-altered clay
- Al-clay + silica
- Amorphous material

- This vertical sequence is consistent with weathering of basalt or ash to clay, then changing oxidation conditions and increasing acidity
- A lot of water is required implying a brief wet period – age coincides with valley networks and lakes

✓ Good candidate for habitability: redox gradients, water, pH moderate at least early on. Plus, clay minerals can serve as a substrate for pre-biotic chemistry and can fossilize microbes.

(Geologically) Recent Mars: Polar Caps & Ice Ages

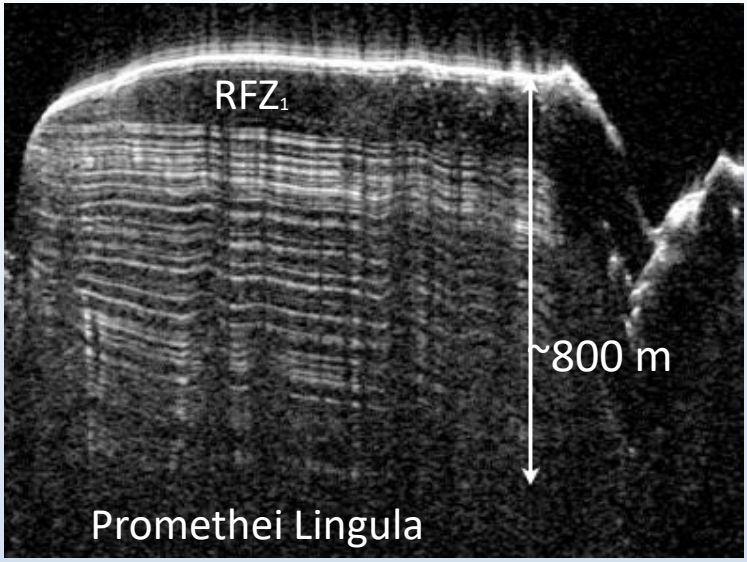


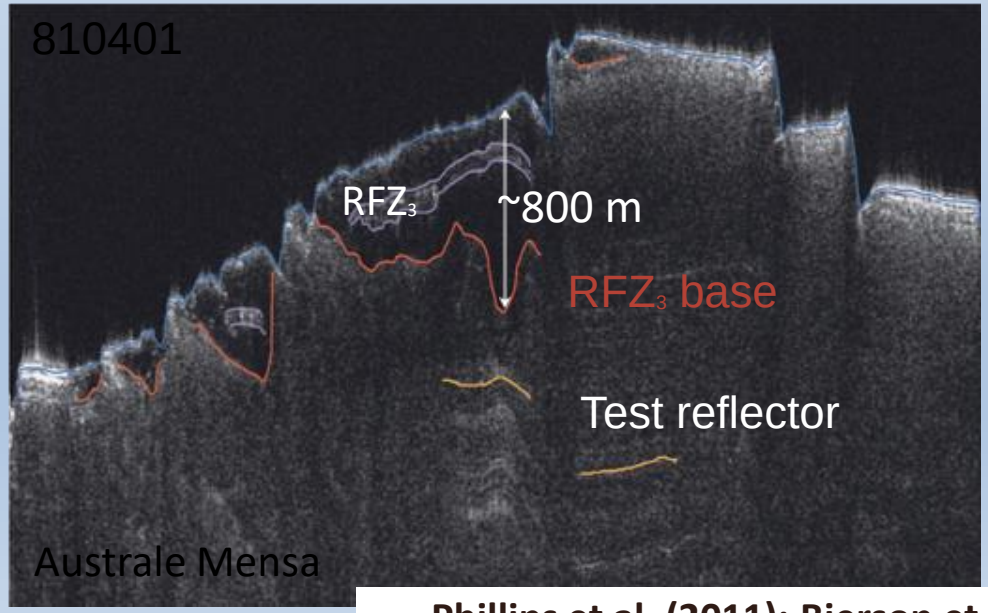
South Polar Buried CO_2

- Layering is discontinuous, sometimes truncated just below the surface.

  » **Likely much older than NPLD.**

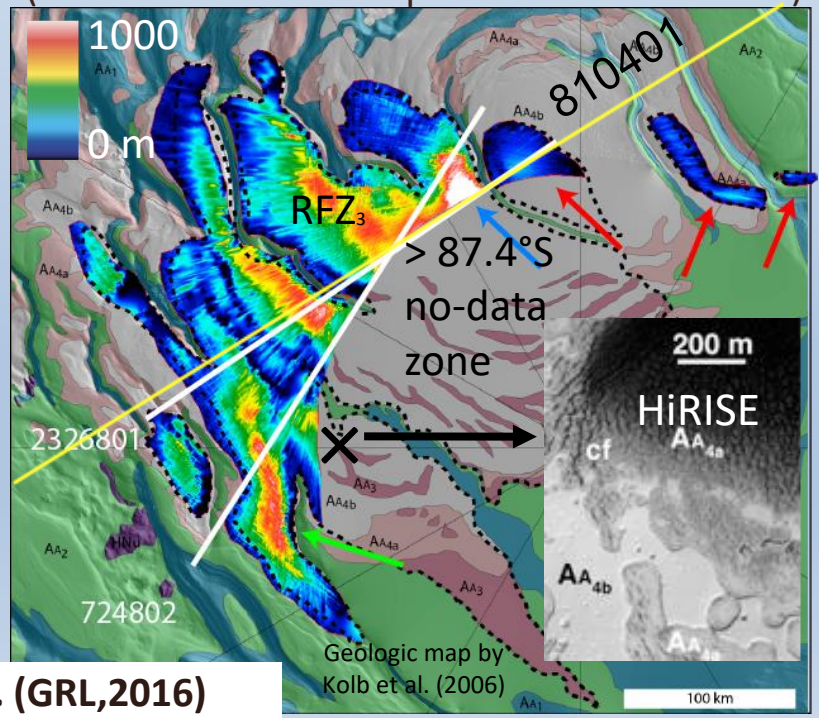
- Odd reflection-free zones (RFZs) occur near surface. In Australe Mensa, **RFZ_3 has dielectric properties of CO_2**, maps to a unit with CO_2 sublimation features.





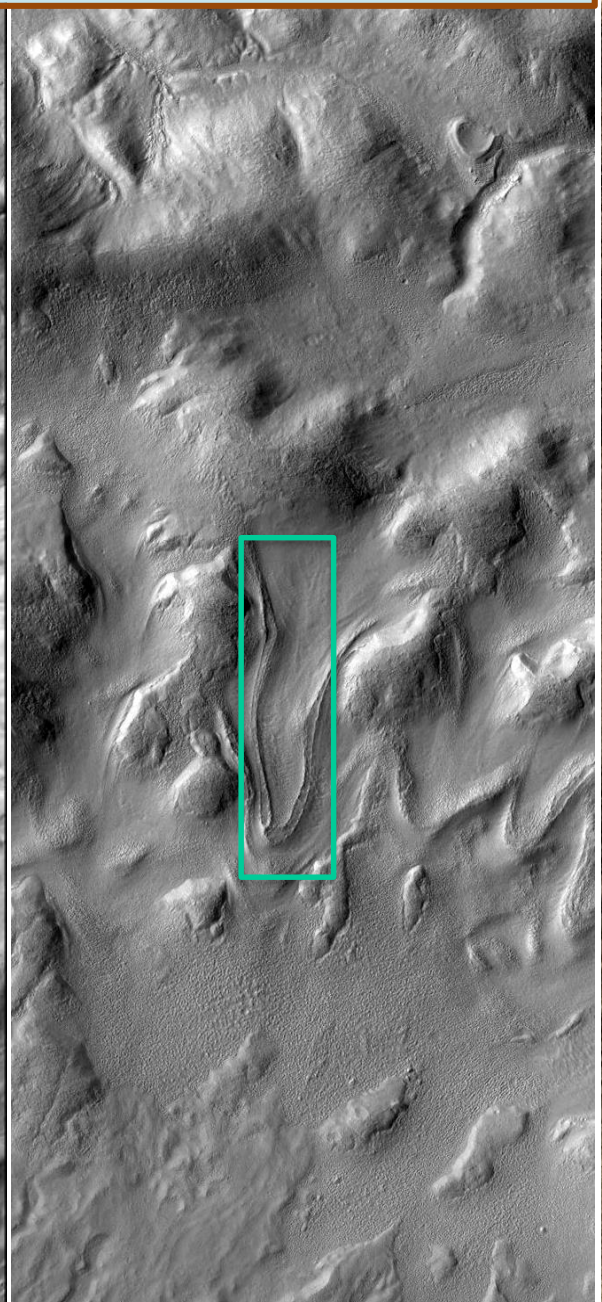
Amount > 6 mbar of CO_2!

(> 2 X current surface pressure if sublimated)



Phillips et al. (2011); Bierson et al. (GRL,2016)

Recent Mars: Mid-latitude Ice



The North Polar Region of Mars

Mosaic of Mars Orbiter Camera images

180°E

270°E

0°E

75°N

Olympia Undae *sand dunes*

main lobe

Planum Boreum

Chasma Boreale

200 km

Gemina Lingula

Vastitas Borealis

MOC: NASA/JPL/Malin Space Science Systems

HiRISE images: NASA/JPL/University of Arizona

500 m

Basaltic sand dunes
eroded from
unit (BU)

ISE
009656_2780

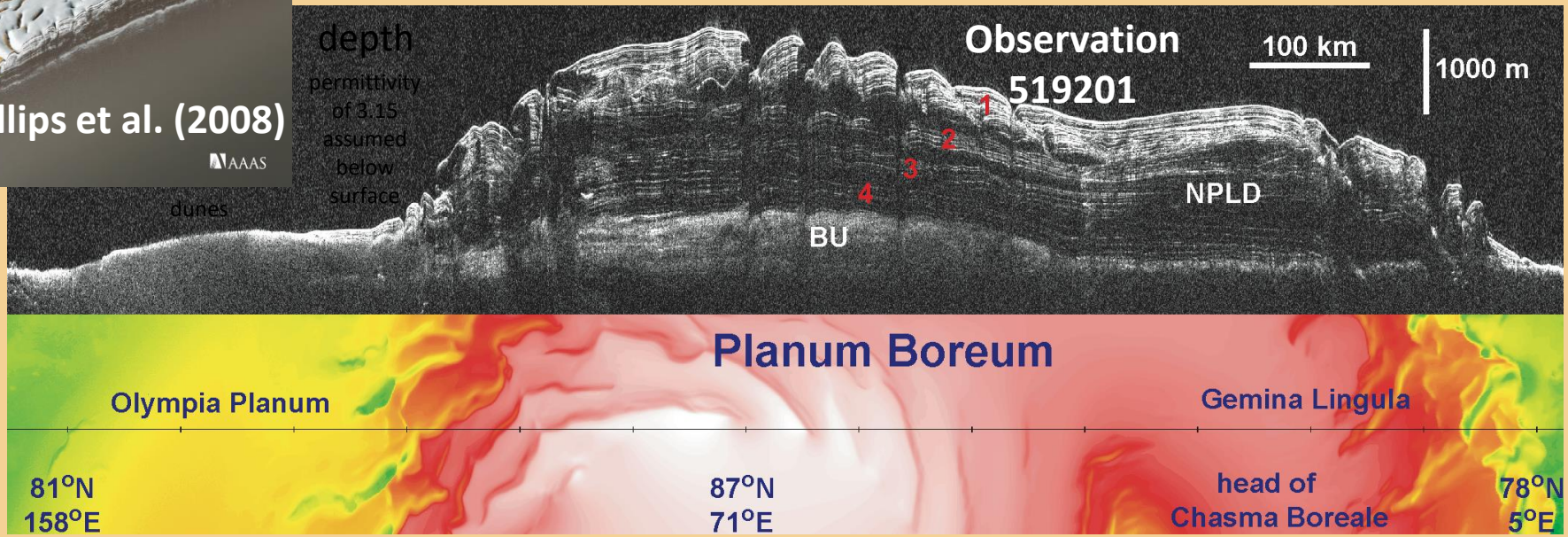
500 m

HiRISE / U. Arizona / JPL / NASA

Finely layered deposits (NPLD) exposed in a polar trough

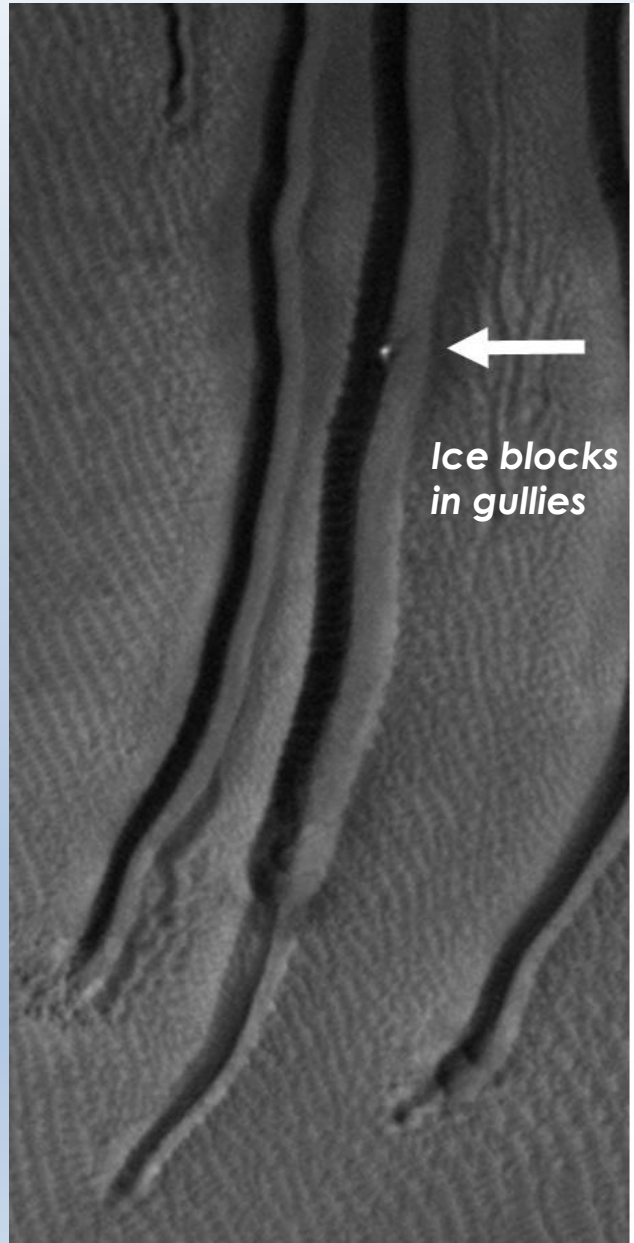
HiRISE PSP_001871_2670

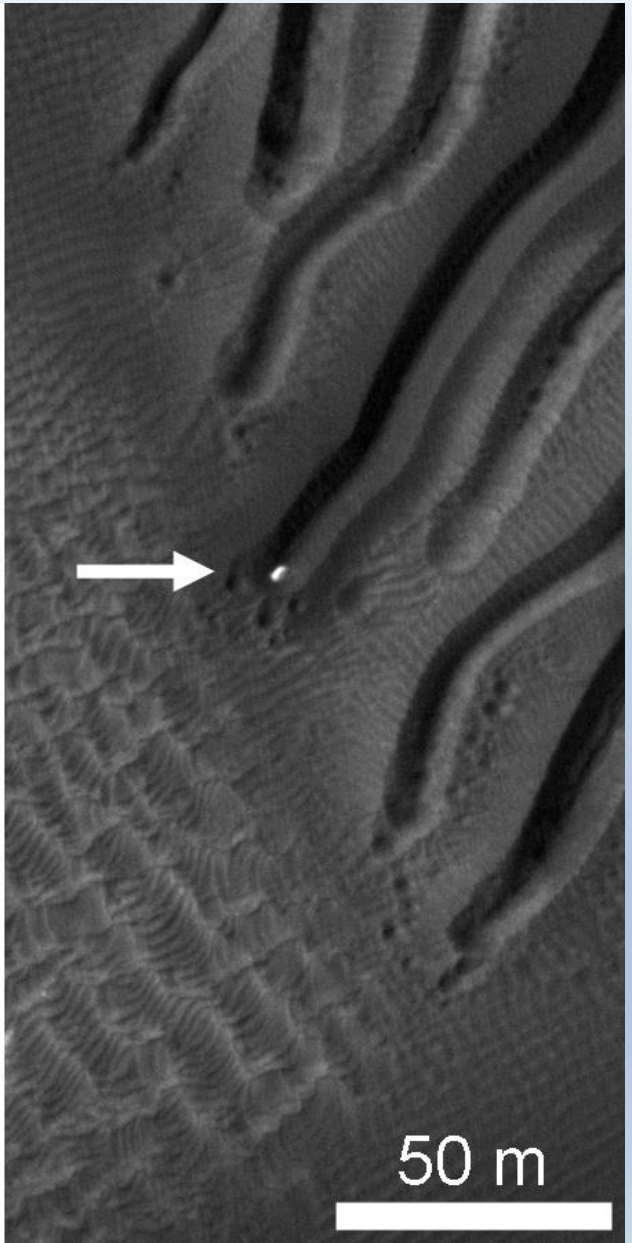
In 2007, SHARAD began revealing the internal structure of the NPLD



- Strong basal returns imply relatively pure ice (<~5% rock/dust)
- NPLD layer-packet structure likely related to climate
- Older basal unit rarely layered, missing below >1/3 of NPLD
- **Flat basal boundary has ~ 0 flexure ⇒ very low heat flow**

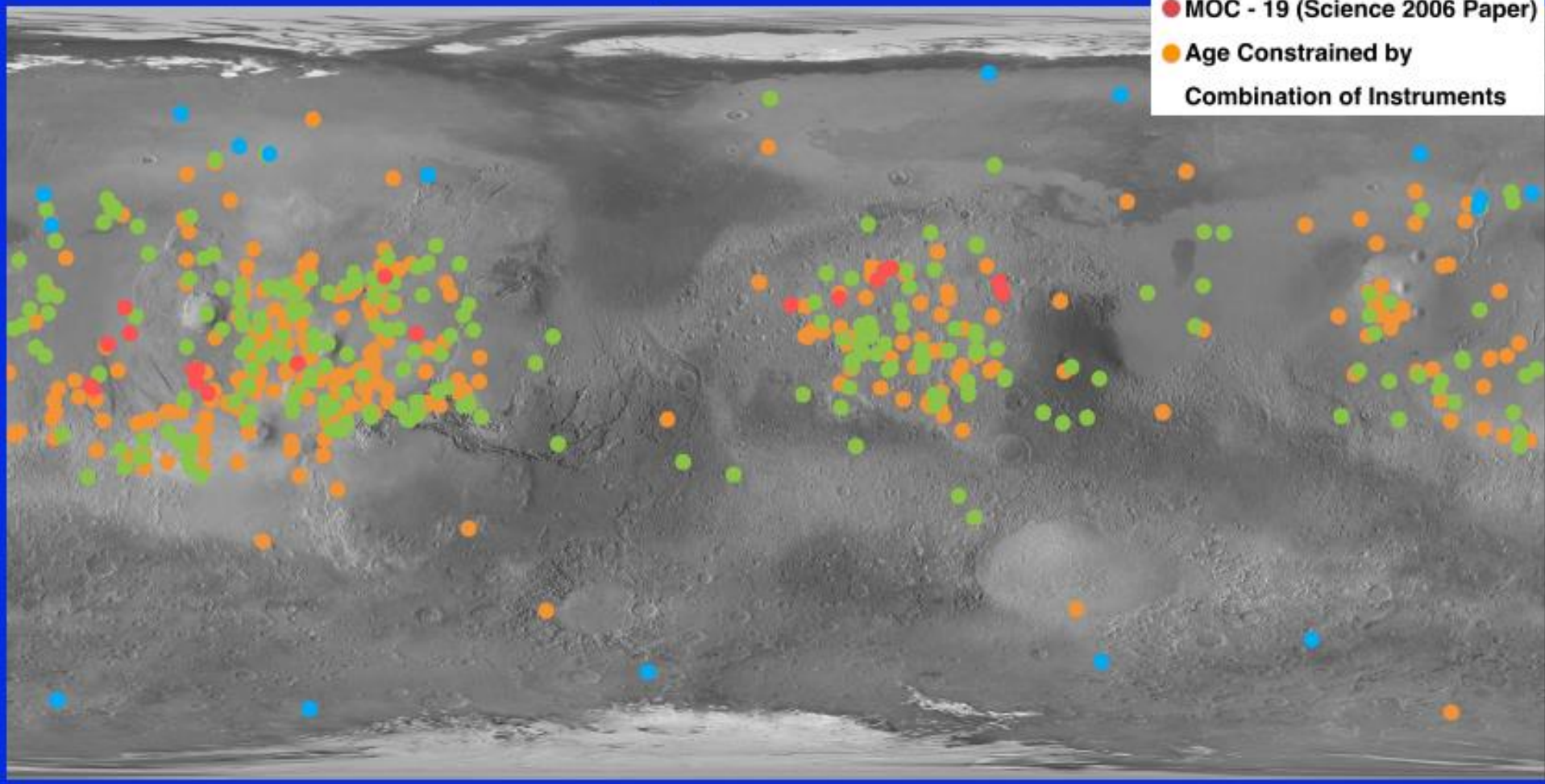
Recent Mars: Changing Landforms



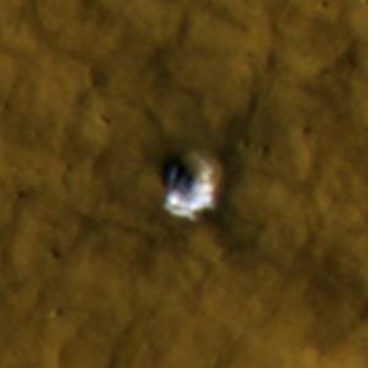
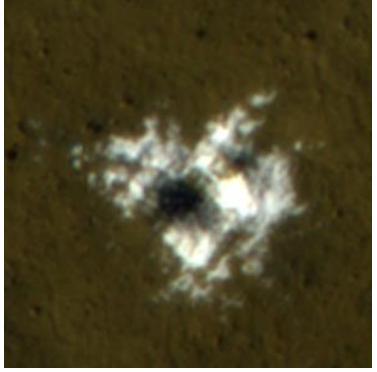
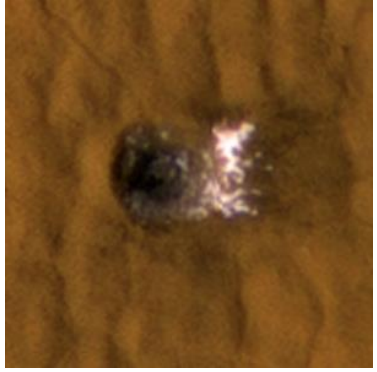
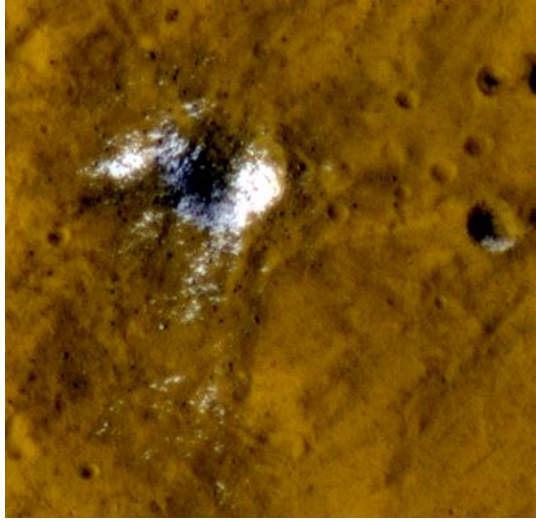


Linear gullies on sand dunes from sliding blocks of CO_2 ice
(Diniega et al., 2013)

New Impact Site Distribution

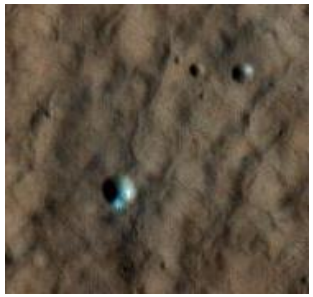


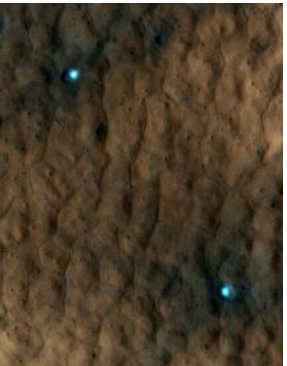
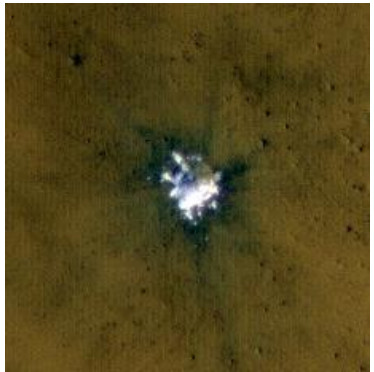
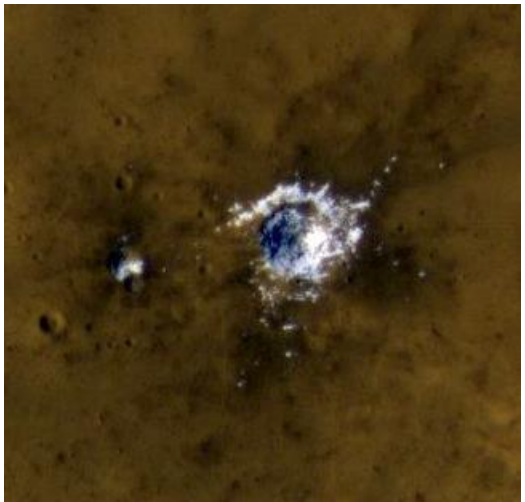
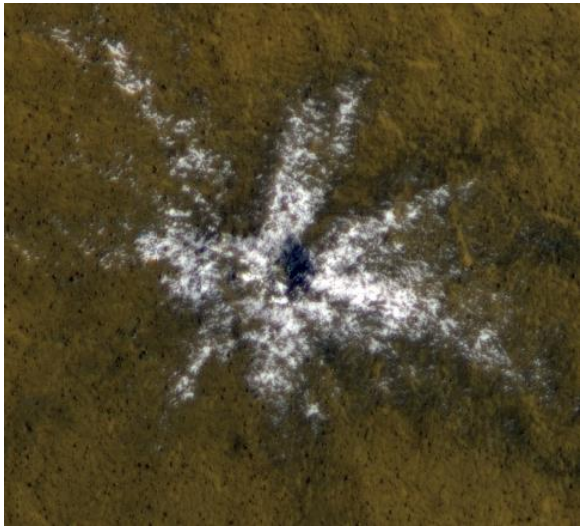
547 candidate impact sites found by CTX
489 impacts confirmed by HiRISE so far

Ice Exposed by New Impacts

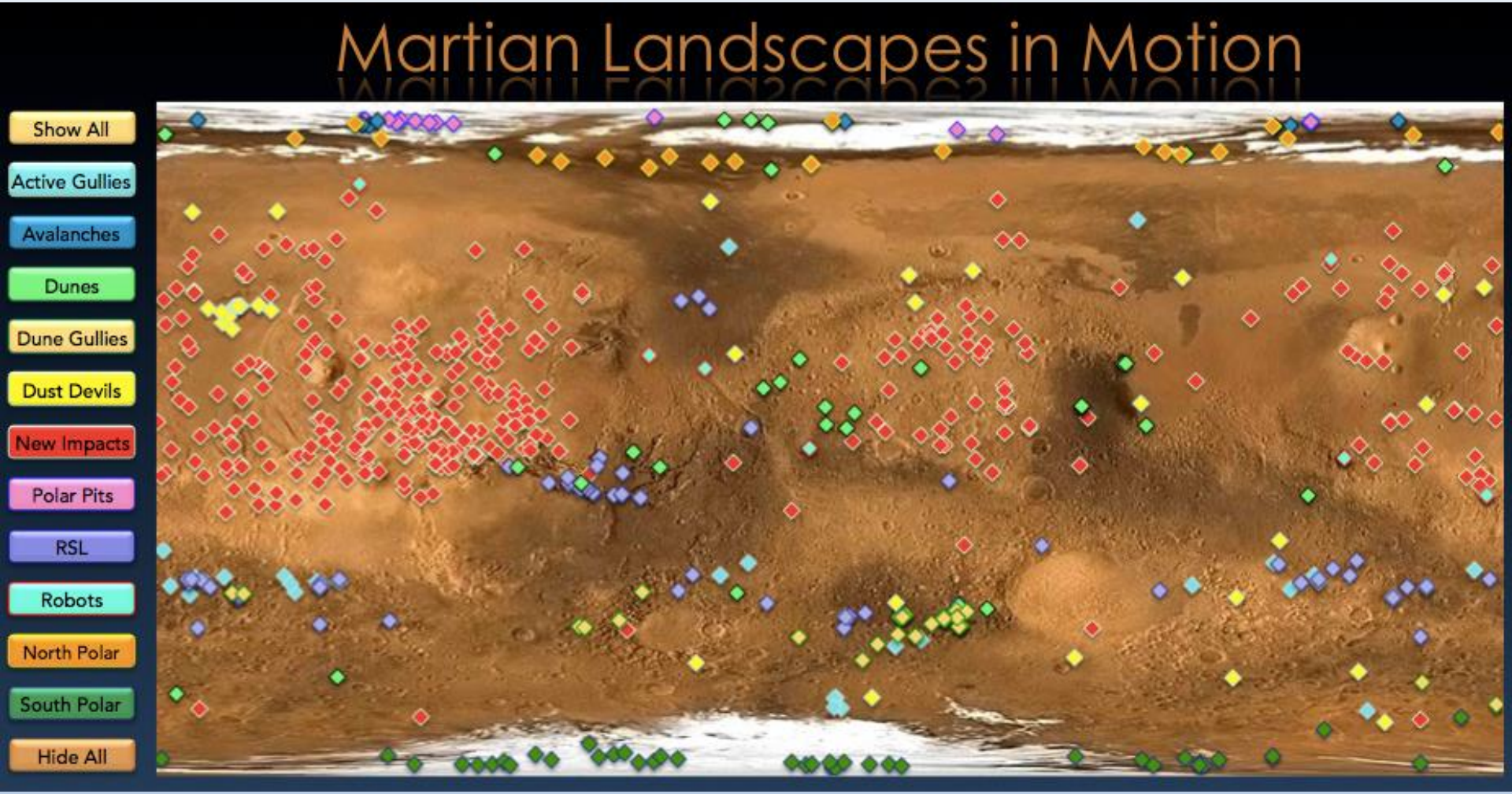
- New impacts north of 39 N have distinct ice patches.
- Distribution and depth of ice is consistent with model calculations for an atmosphere slightly more humid than present.
- Image sequences show that the ice fades over time.
- Sublimation modeling indicate that mm of ice sublimate before it fades, indicating clean ice.
- Ice in a critical resource to possible human explorers of Mars.

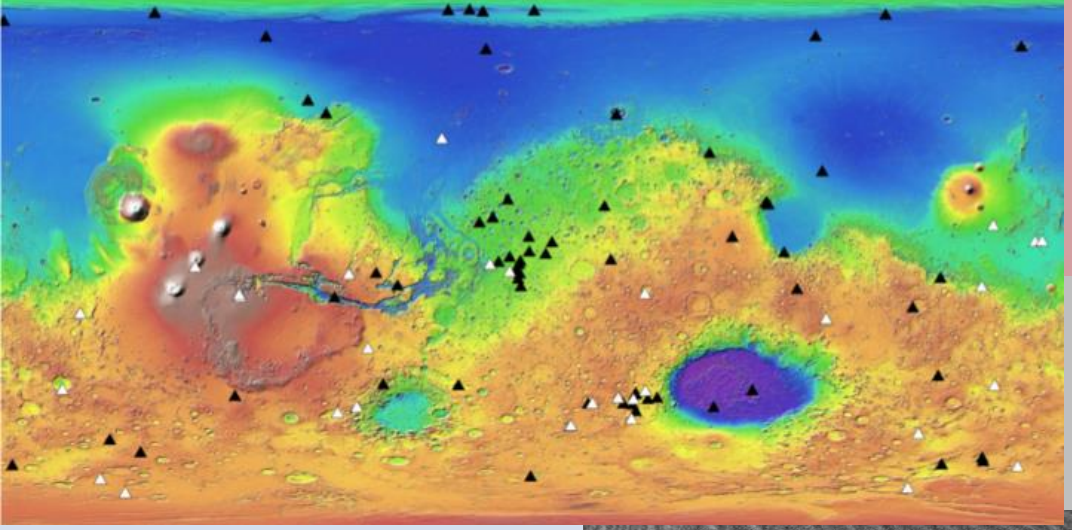


Many Martian Landscapes in Motion

(monitored by MRO/HiRISE)



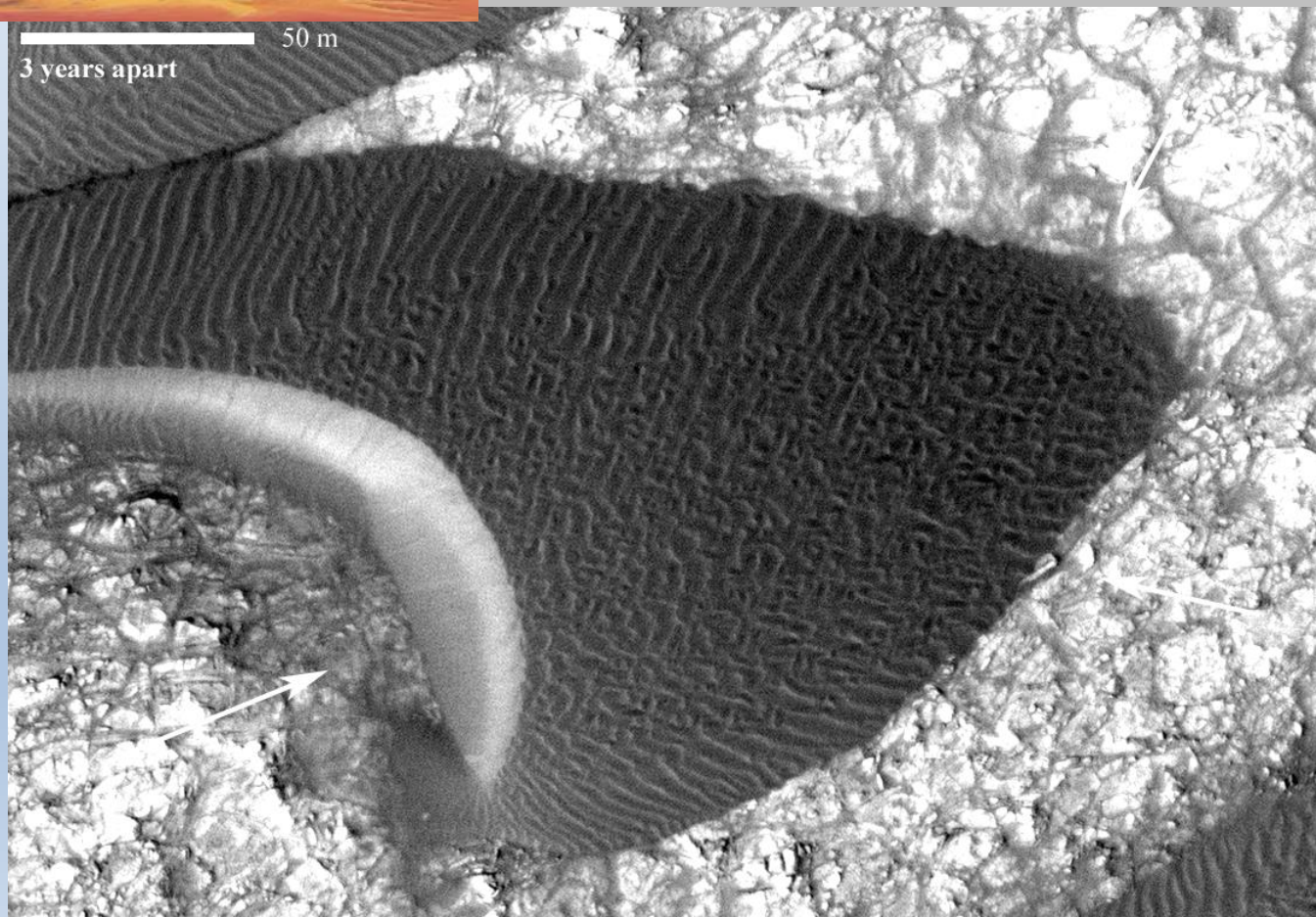


Windy Mars

Dune motion observed globally

- Black = active
- White = no activity observed (yet)

Dune Movement

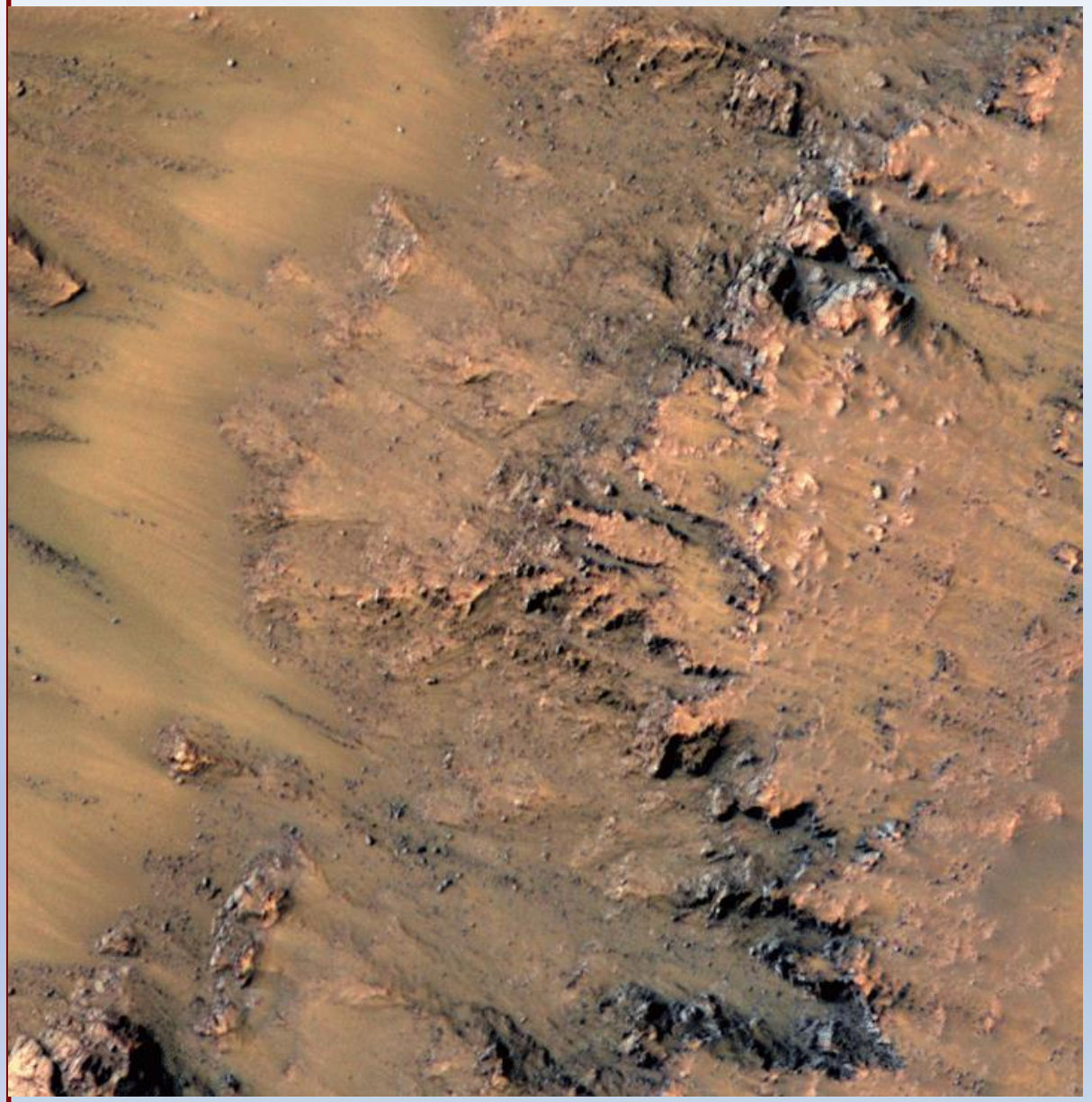


Seasonal Flows on Warm Martian Slopes

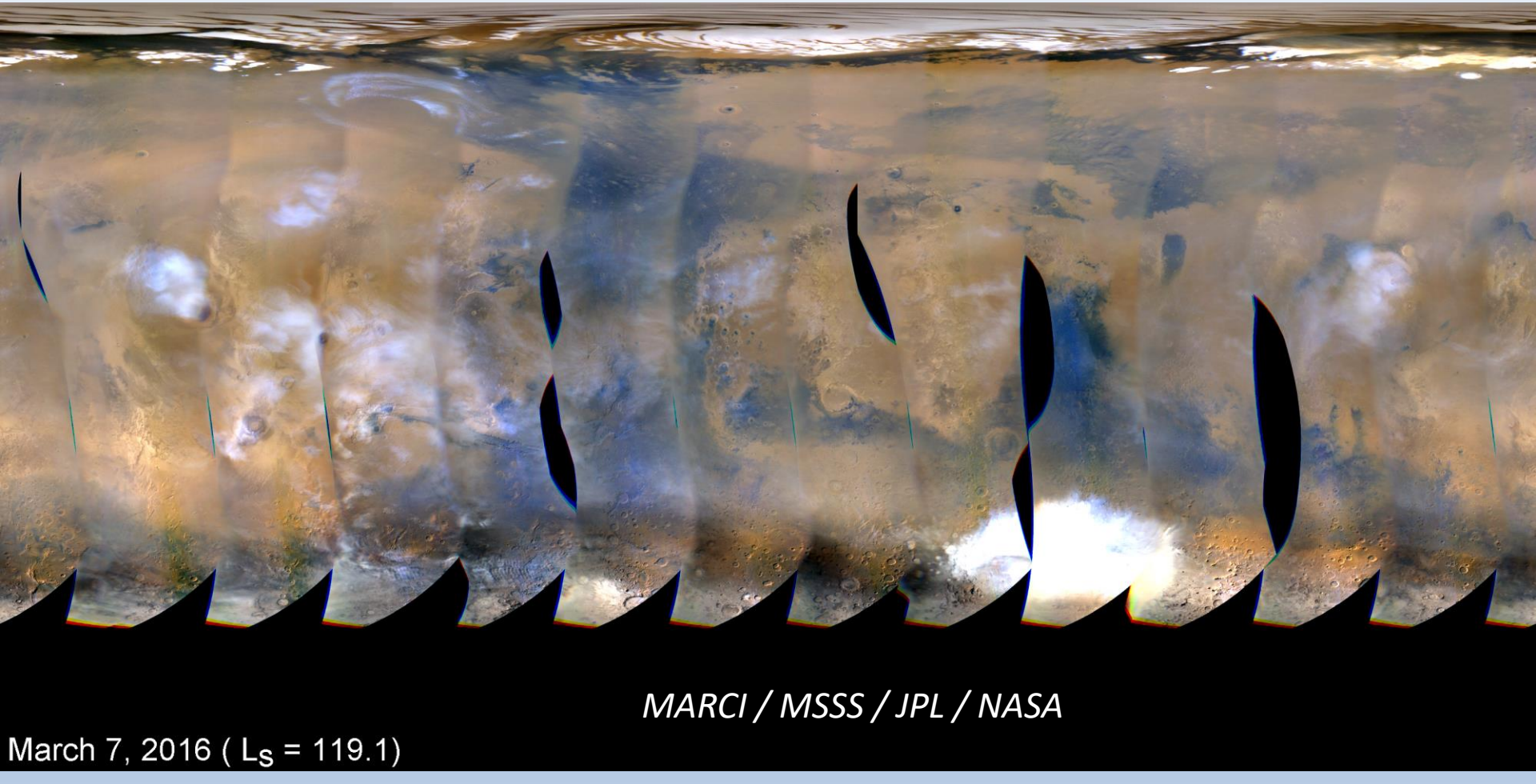
(McEwen et al., Science, 5 Aug 2011)

Recurring Slope Lineae (RSL)

- RSL are narrow (0.5-5 m), dark markings on steep slopes (>25°)
- Form and incrementally grow in late spring to summer, then fade or disappear in fall.
- Reform at nearly same locations in multiple Mars years.
- Extend downslope from bedrock outcrops or rocky areas; often associated with small channels.
- Form and grow at temperatures at which brines would be liquid.
- CRISM has detected hydrated perchlorates
  - Deliquescent -> easily takes up water from atmosphere
  - Depresses freezing point to -70 C
- However, ODY sees no effect on thermal inertia => little water
- Exact mechanism for RSL is not understood, but activity of brines is still current best model.

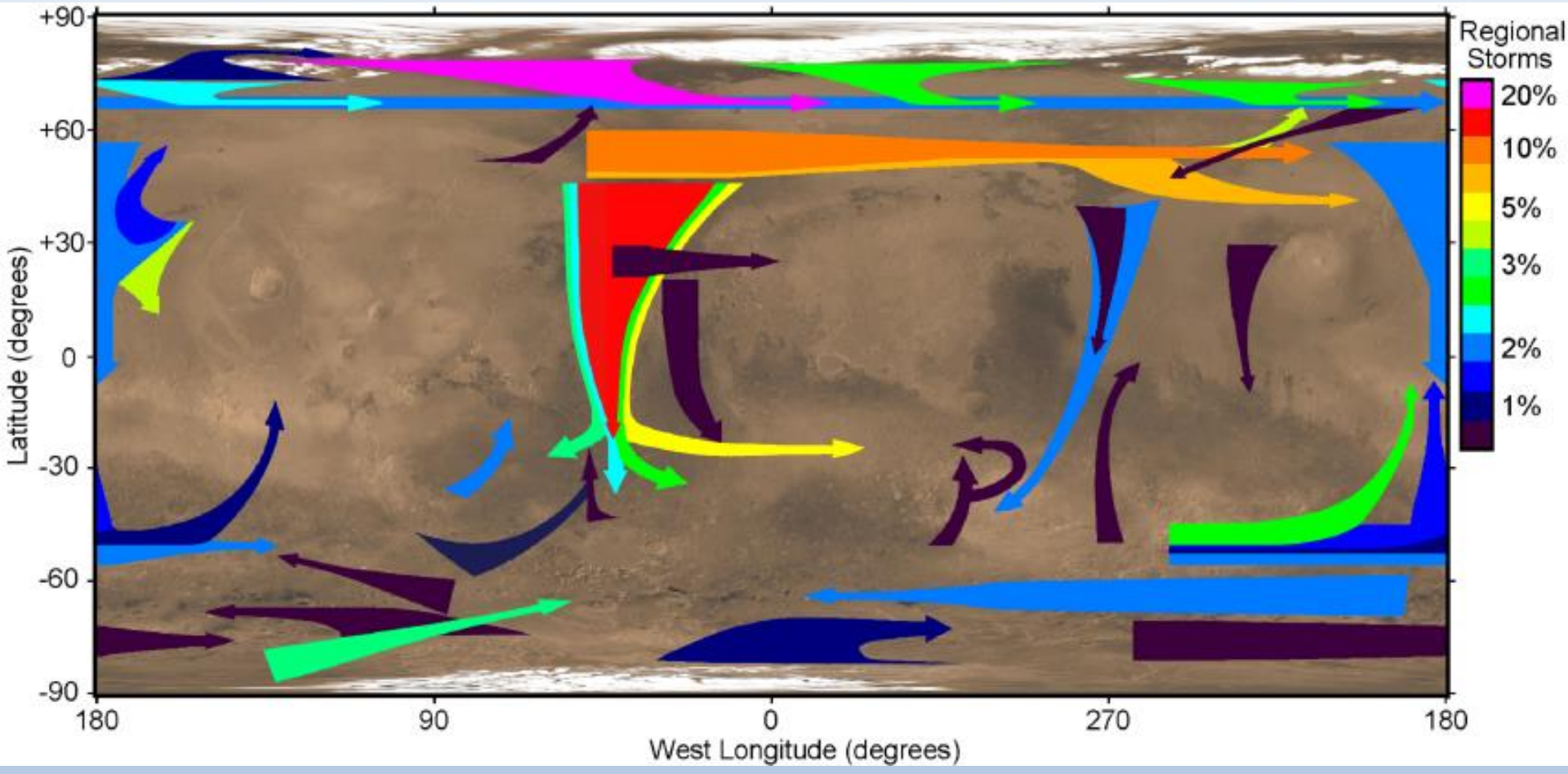


Recent MARCI global weather map



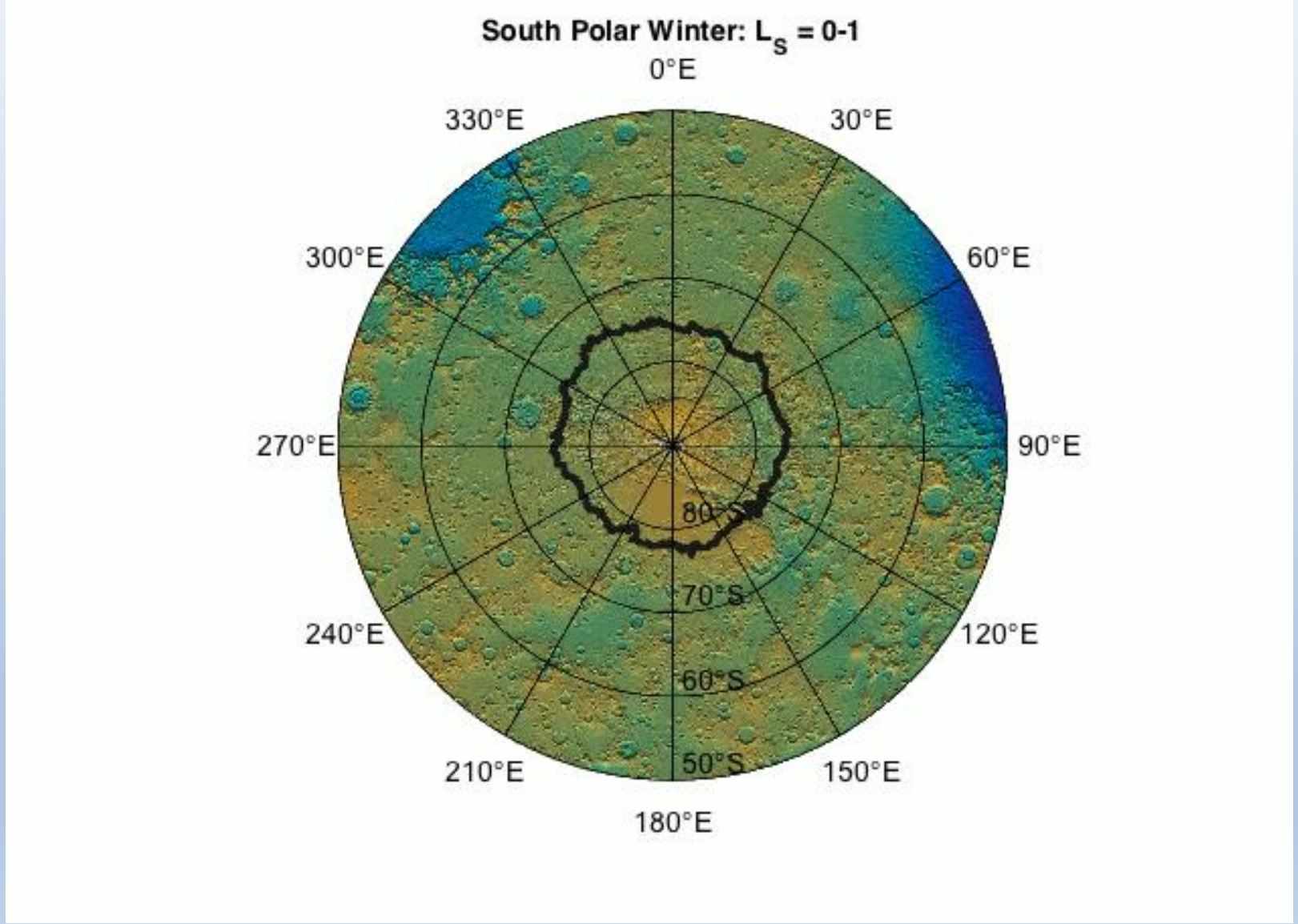
Primary Dust Storm Tracks

MARCI / MSSS / JPL / NASA



CO_2 Snow Clouds and Surface Snow: South Pole

Mars Climate Sounder / Caltech / JPL / NASA



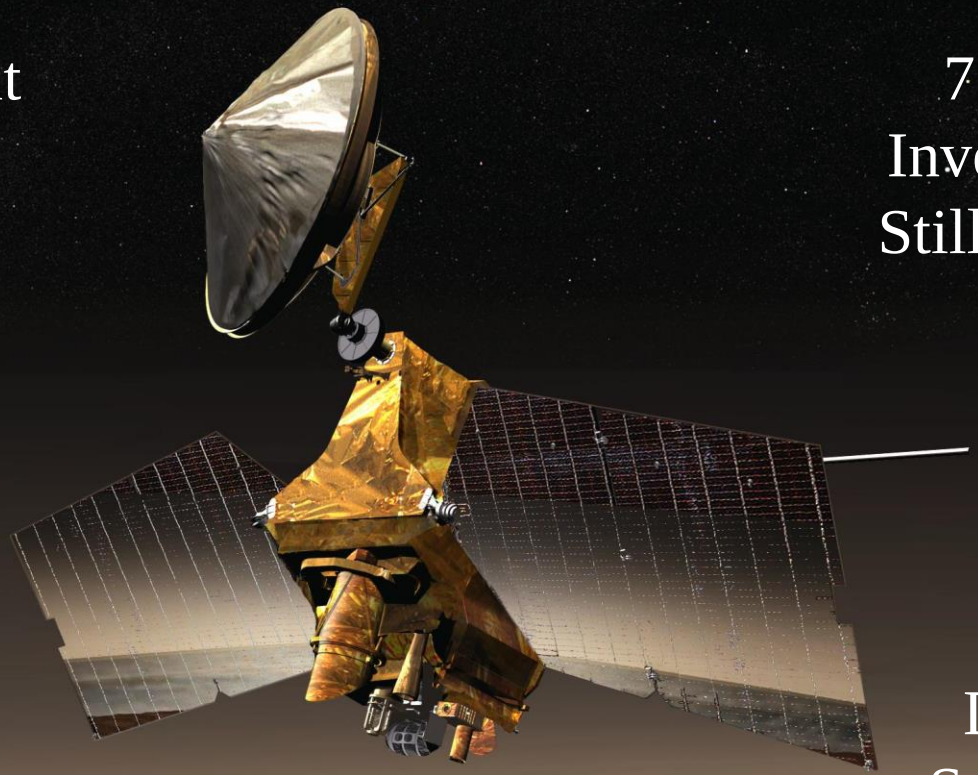
Paul Hayne & MCS Team

11 Years in Orbit

~50,000 orbits

300 Tb of Science Data Returned

~200 kg of Usuable Fuel still in the Tank



7 Science Investigations Still Returning Data

More Discoveries Sure to Come!

Mars Reconnaissance Orbiter