Early Mars as a Key to Understanding Planetary Habitability

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Outline: Early Mars as a Key to Understanding Planetary Habitability

- What we have learned and what we can learn about early Mars [15 min]
- Suggested exploration plans [5 min]
- Questions/Discussion [10 min]

Key Discoveries in Mars Science since 2010

*Publication date of last Mars references in *V&V*

- Extent and diversity of potential ancient habitats (lakes, rivers, aquifers, hydrothermal systems, soil formation)
- Mafic, Ultramafic, and Felsic igneous rocks
- Modern liquid water
- Recent Ice Ages and Episodicity of Climates above the Triple Point of Water
- Modern active methane, likely with local sources
- Modern active surface processes
- Modern atmospheric loss rates

See also MEPAG report to V&V Decadal Midterm (May 4, 2017):
https://mepag.jpl.nasa.gov/meeting/2017-07/MEPAG_Johnson_MTDS_v04.pdf

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- Modern liquid water
- Recent Ice Ages and Episodicity of Climates above the Triple Point of Water *[see also Byrne talk, next]*
- Modern active methane, likely with local sources
- Modern active surface processes
- Modern atmospheric loss rates *[see Jakosky talk, next]*

Ancient

Modern

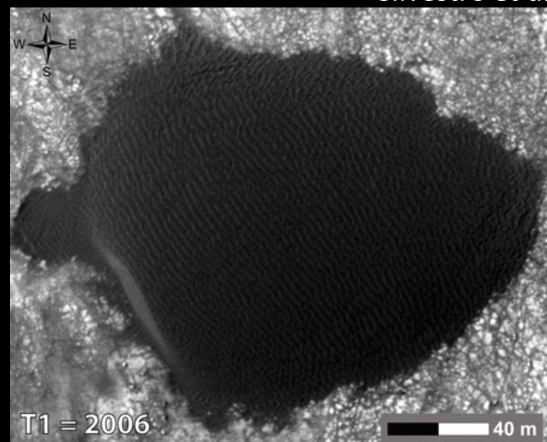
See also MEPAG report to V&V Decadal Midterm (May 4, 2017):
https://mepag.jpl.nasa.gov/meeting/2017-07/MEPAG_Johnson_MTDS_v04.pdf

Key Finding since *V&V*: Modern Mars is active (methane, geomorphology, ice, water)

Mass wasting of the N. Polar Cap

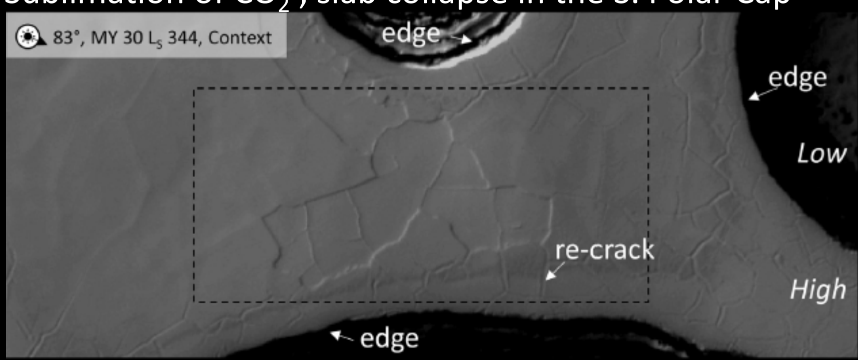
Migrating Sand Dunes

Bridges et al., 2011; 2012
Silvestro et al., 2013



NASA/JPL/University of Arizona

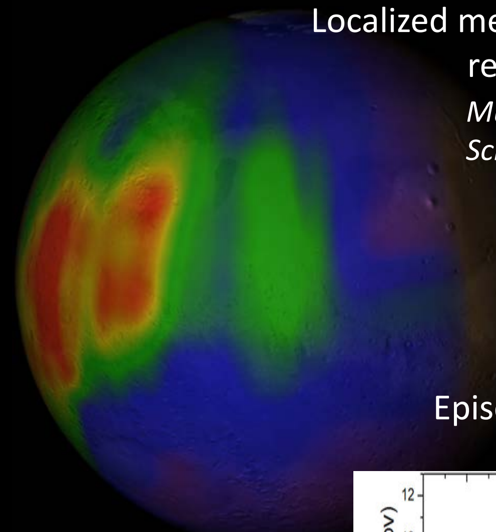
Sublimation of CO_2 , slab collapse in the S. Polar Cap



Buhler et al., 2017 (and Thomas et al., 2011; 2015)

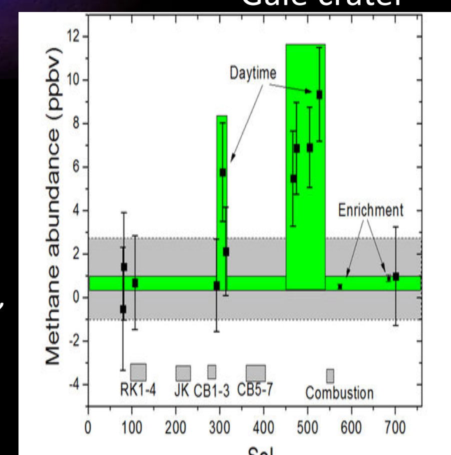
Localized methane release?

Mumma et al., 2009, Science



Episodic methane at Gale crater

Webster et al., 2015, Science



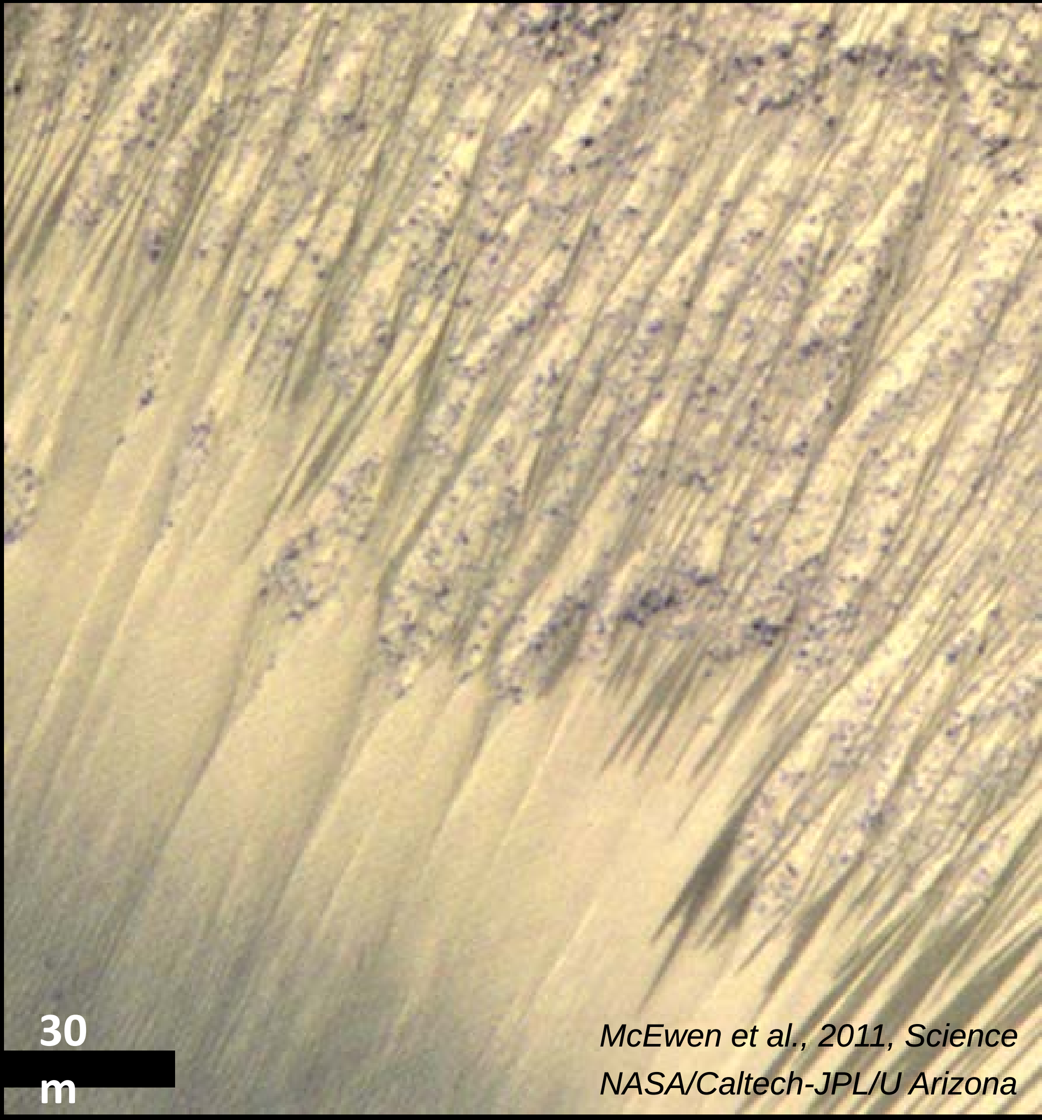
➢ **Mars** is far from a “dead planet”: it **is an active world**

Key Finding since *V&V*: Modern Mars "on the edge", liquid water today or in the near past would mean Mars is by definition habitable

Recurring slope lineae (RSLs) may be wet
Additional evidence of recent water:

- ❑ Perchlorate salts [*Martin-Torres et al., 2015, Nature Geosci.*]
- ❑ S, Cl, Br salts in loose soils at Gusev crater [*Arvidson et al., 2010, JGR]*
- ❑ <1 Ma alluvial fans *[Schon et al., 2009, Geology]*

- ➢ Subsurface liquid water is likely today
- ➢ Surface liquid water is thermodynamically permitted and may be present today
- ➢ Higher obliquity and likely thicker atmosphere ~600kya *[Bierson et al., 2016, GRL]* would favor surface water



McEwen et al., 2011, Science
NASA/Caltech-JPL/U Arizona

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RSLs are rightfully debated now as current data in the late afternoon of Mars do not permit assessing water directly (orbiter with variable time of day; high resolution spectroscopy, radar req'd)

But there are several other lines of evidence for modern, ephemeral liquid water, consistent with modeling

- ➢ Subsurface liquid water is likely today
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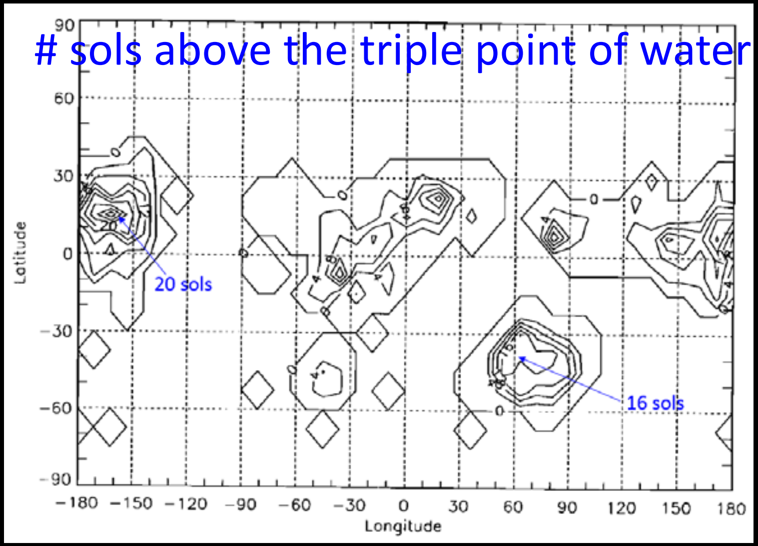
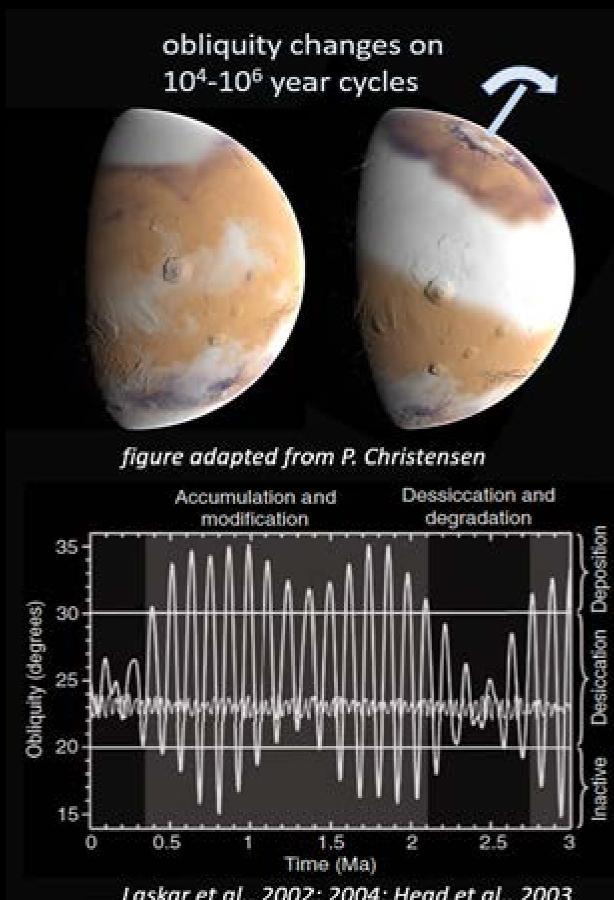


Haberle et al., 2001

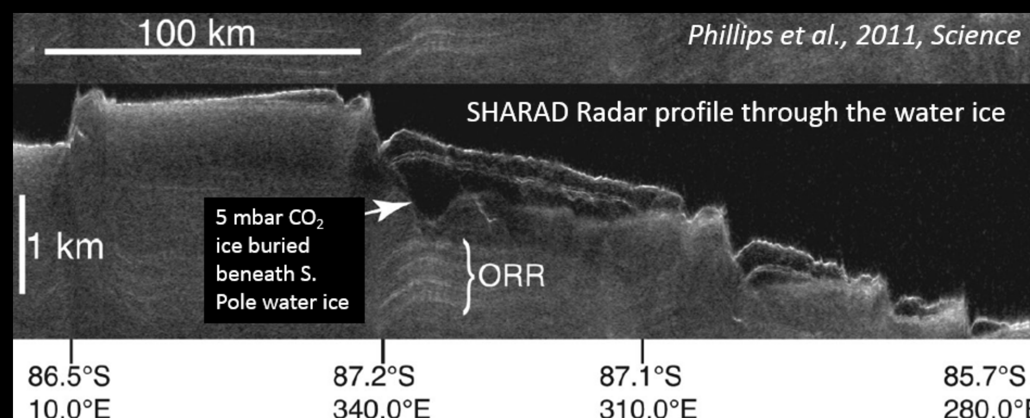
Key Finding since *V&V*: Modern Mars "on the edge", liquid water today or in the near past means Mars is by definition habitable

- We know cycles of greater atmospheric pressure with more of the surface above the triple point occurred, and recently

See Byrne talk to follow



Discovery of sufficient CO_2 shallowly buried in the S Polar Cap to double atmospheric pressure



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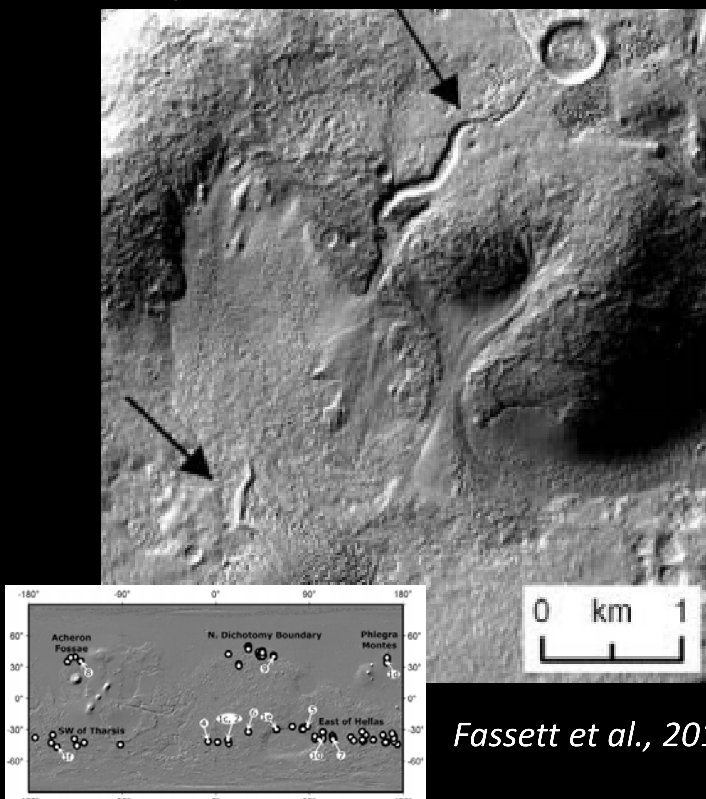
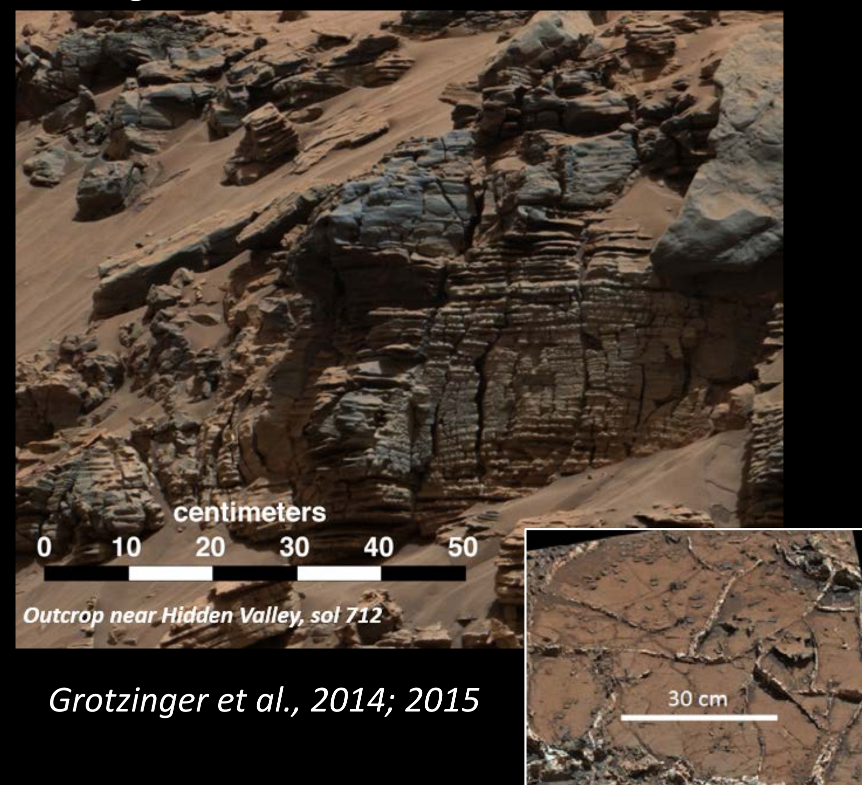
Amazonian (<3Ga) Glacial-Fluvial Valleys



Fassett et al., 2010

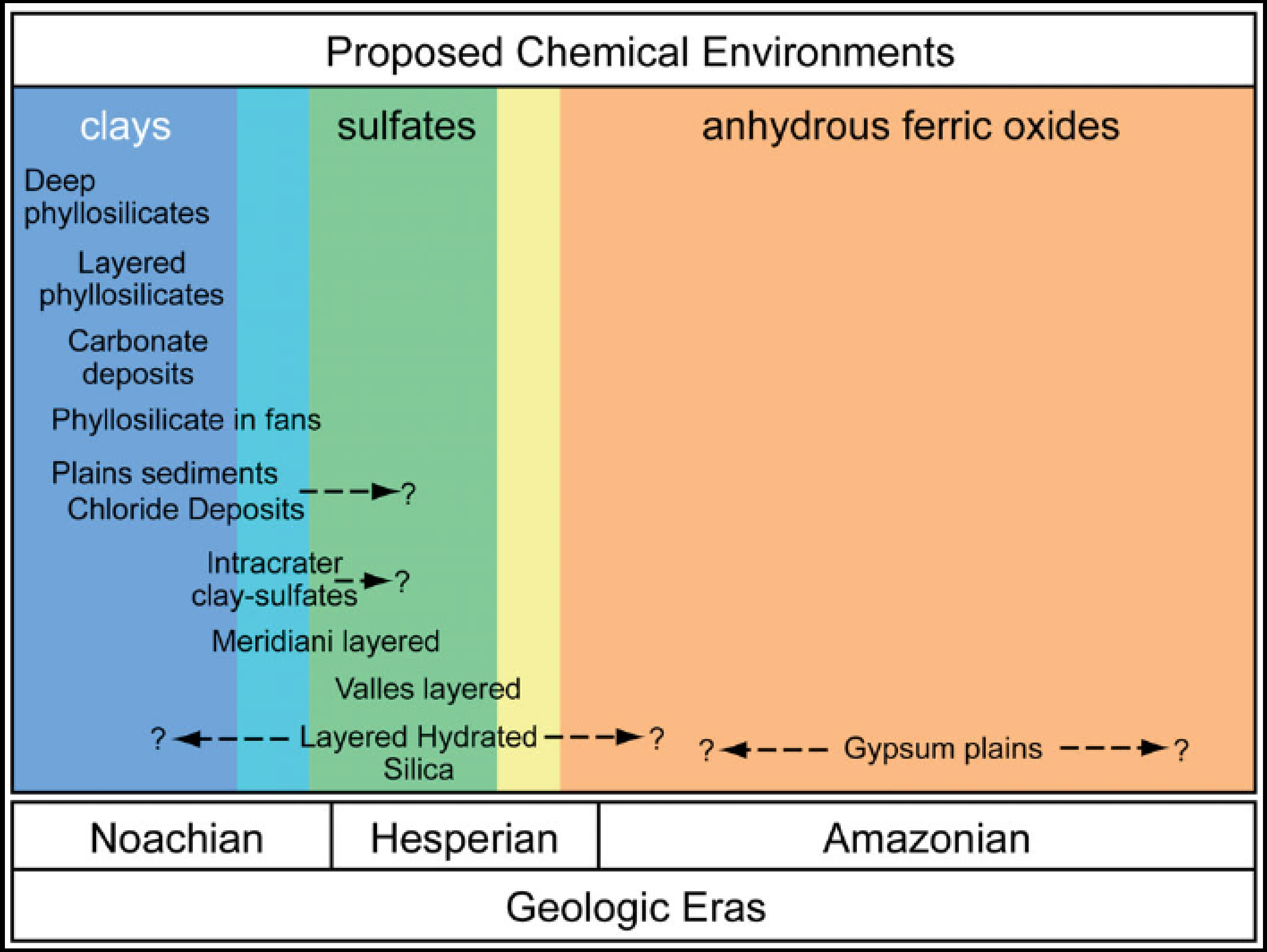
Finely Layered Sedimentary Rocks indicate ~3 Ga Lake Gale and veins indicate even longer-lived groundwaters



Grotzinger et al., 2014; 2015

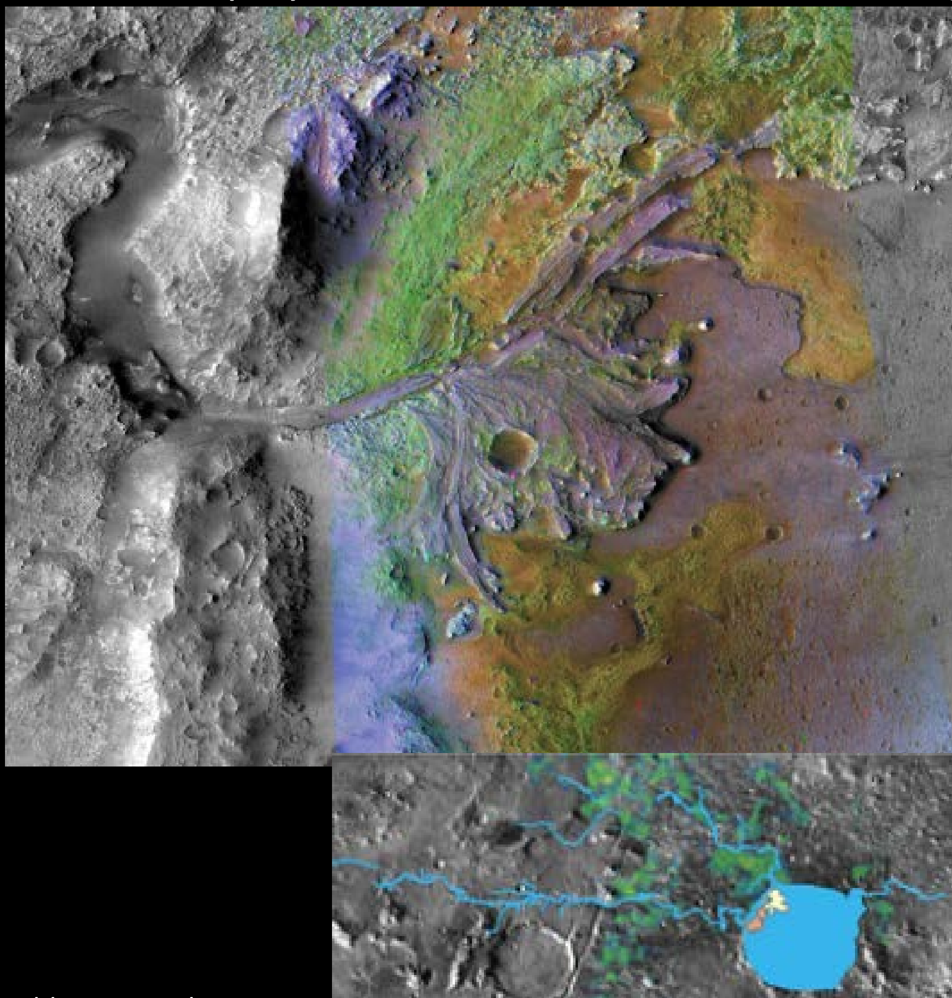
Key Finding since *V&V*: Extent and diversity of potential ancient habitats (lakes, rivers, aquifers, hydrothermal systems, soil formation)

Murchie et al., 2009, as cited in V&V

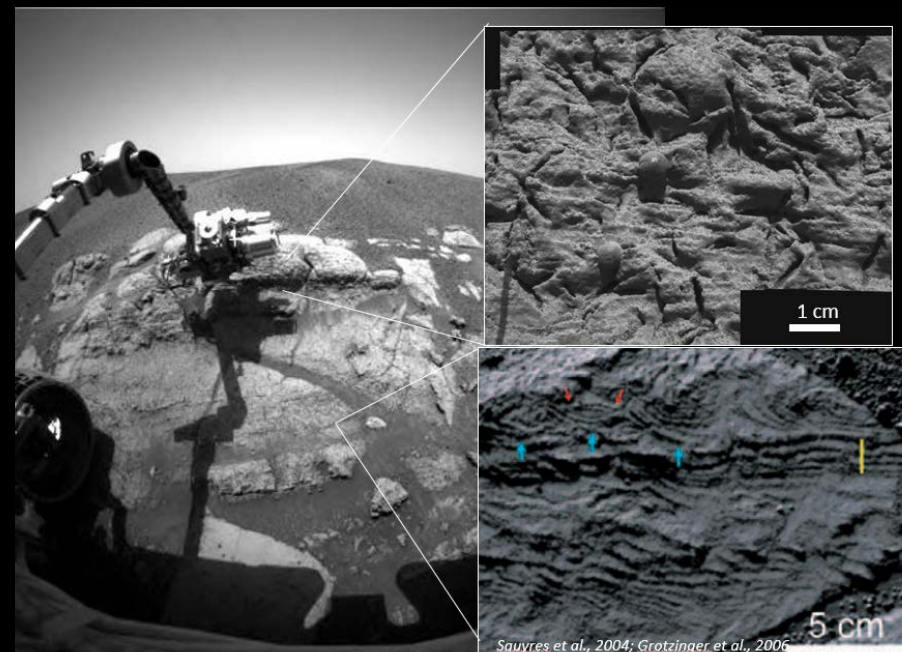


Key Finding since *V&V*: Extent and diversity of potential ancient habitats (lakes, rivers, aquifers, hydrothermal systems, soil formation)

Lakes and playas were well-known at the writing of V&V



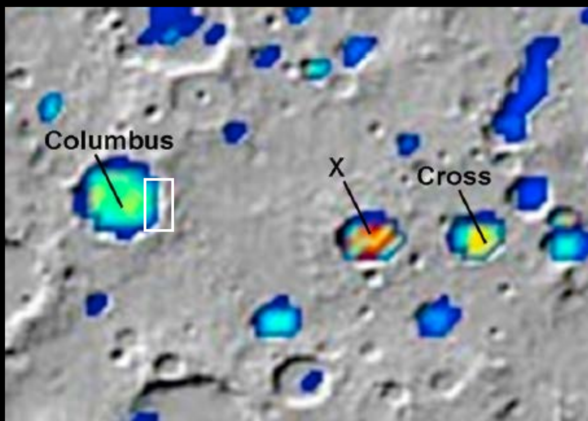
Ehlmann et al., 2008

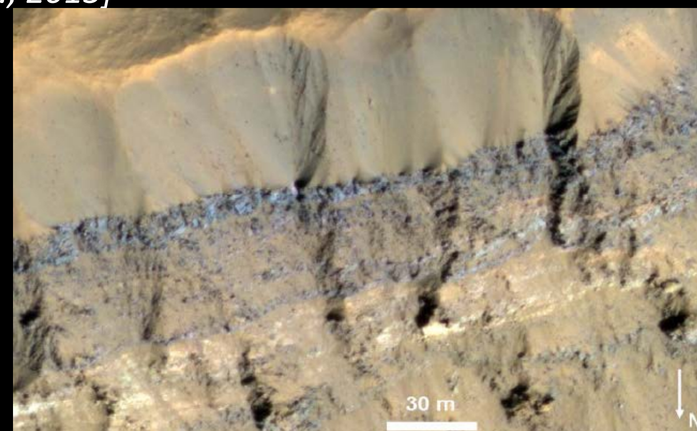


Squyres et al., 2004; Grotzinger et al., 2005; McLennan et al., 2005

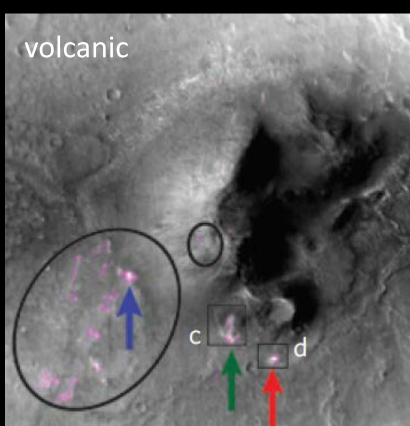
Key Finding since *V&V*: Extent and diversity of potential ancient habitats (lakes, rivers, aquifers, hydrothermal systems, soil formation)

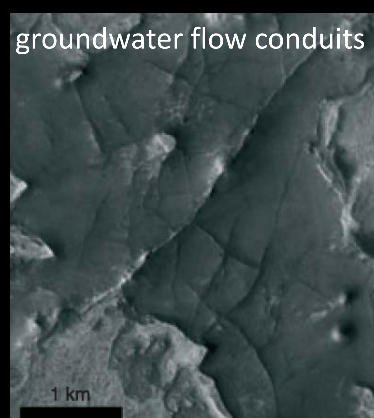
Groundwater-fed acid lakes *[Wray et al., 2011; Ehlmann, Swayze et al., 2016]*
Groundwater fed alkaline lakes *[Michalski et al., 2013]*



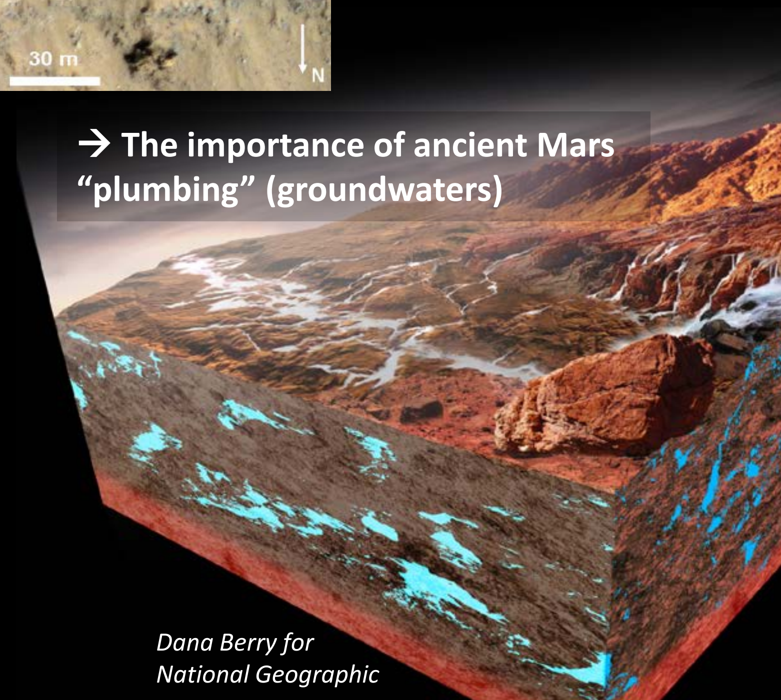


Widespread aquifer and hydrothermal systems of different types and water chemistries *[Skok et al., 2010; Ehlmann et al., 2011; Thollot et al., 2011; Saper & Mustard, 2013; Quinn & Ehlmann, in prep.]*



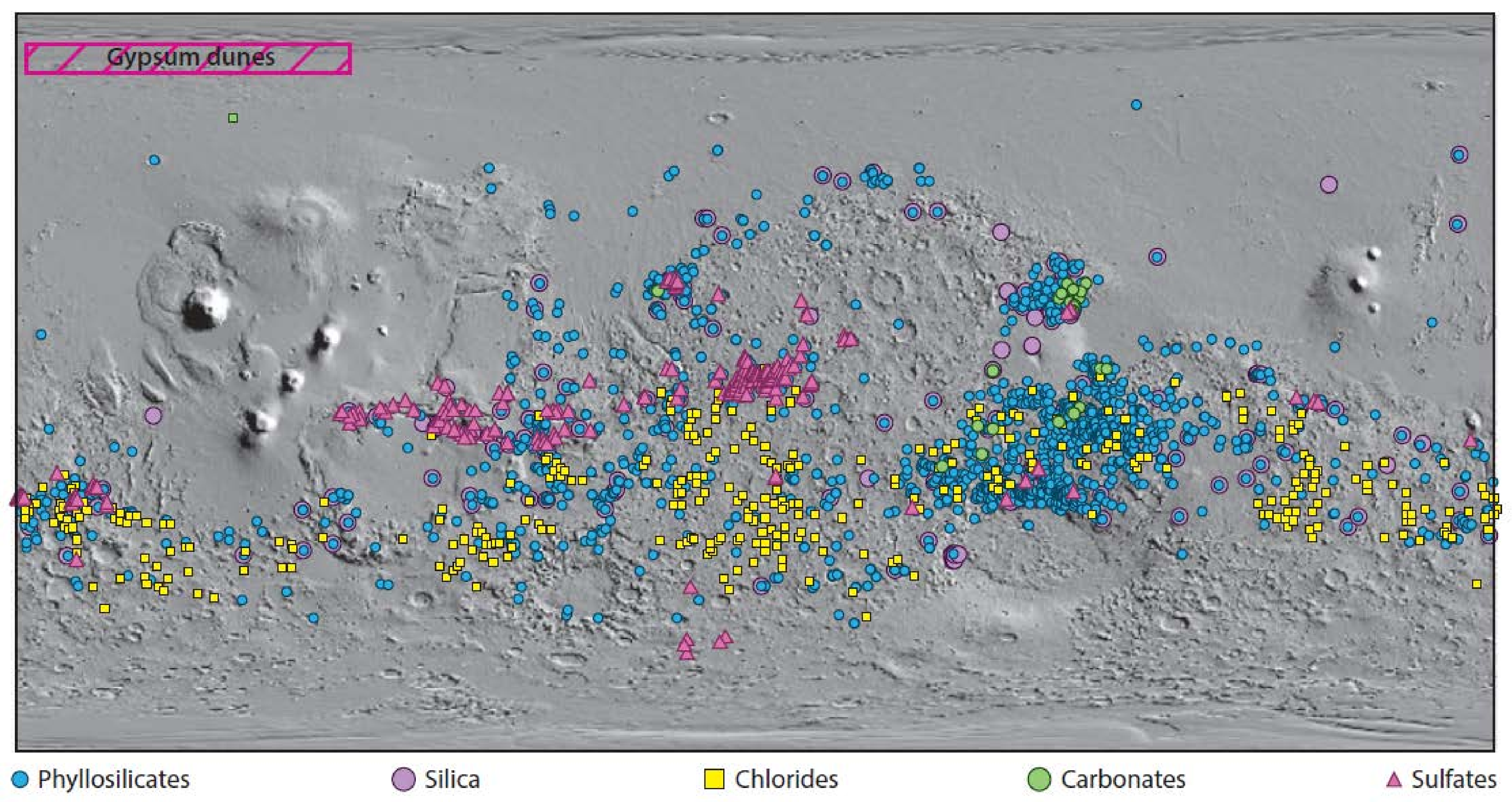


→ The importance of ancient Mars "plumbing" (groundwaters)



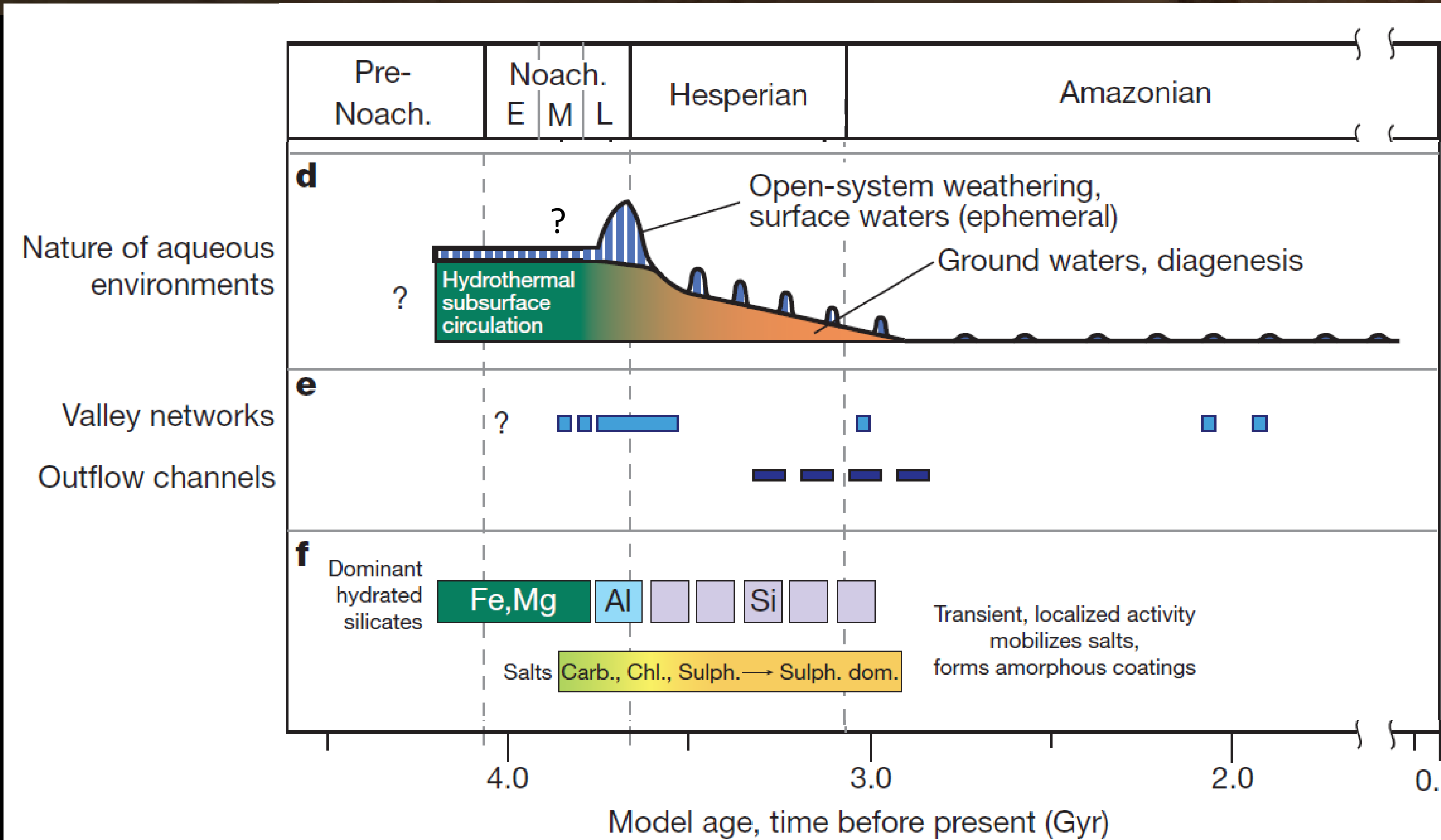
Dana Berry for National Geographic

Key Finding since *V&V*: Extent and diversity of potential ancient habitats (lakes, rivers, aquifers, hydrothermal systems, soil formation)



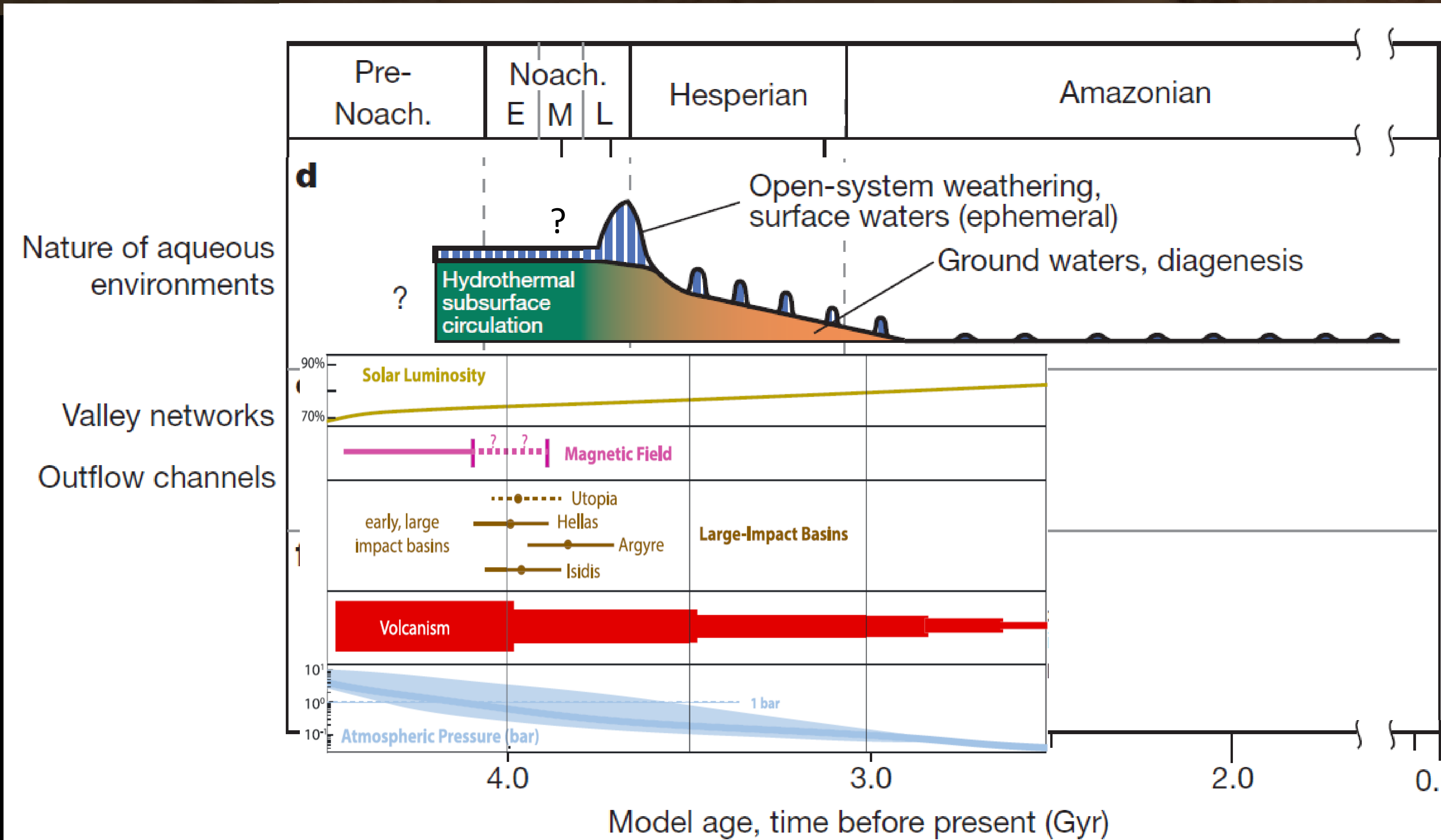
Ehlmann & Edwards, 2014, Ann. Rev. Earth & Plan. Sci.

Timeline of change



Ehlmann et al., 2011, Nature

Timeline of change-why?



Ehlmann et al., 2011, Nature; Ehlmann et al., 2016, JGR

The Terrestrial Planets with Atmospheres

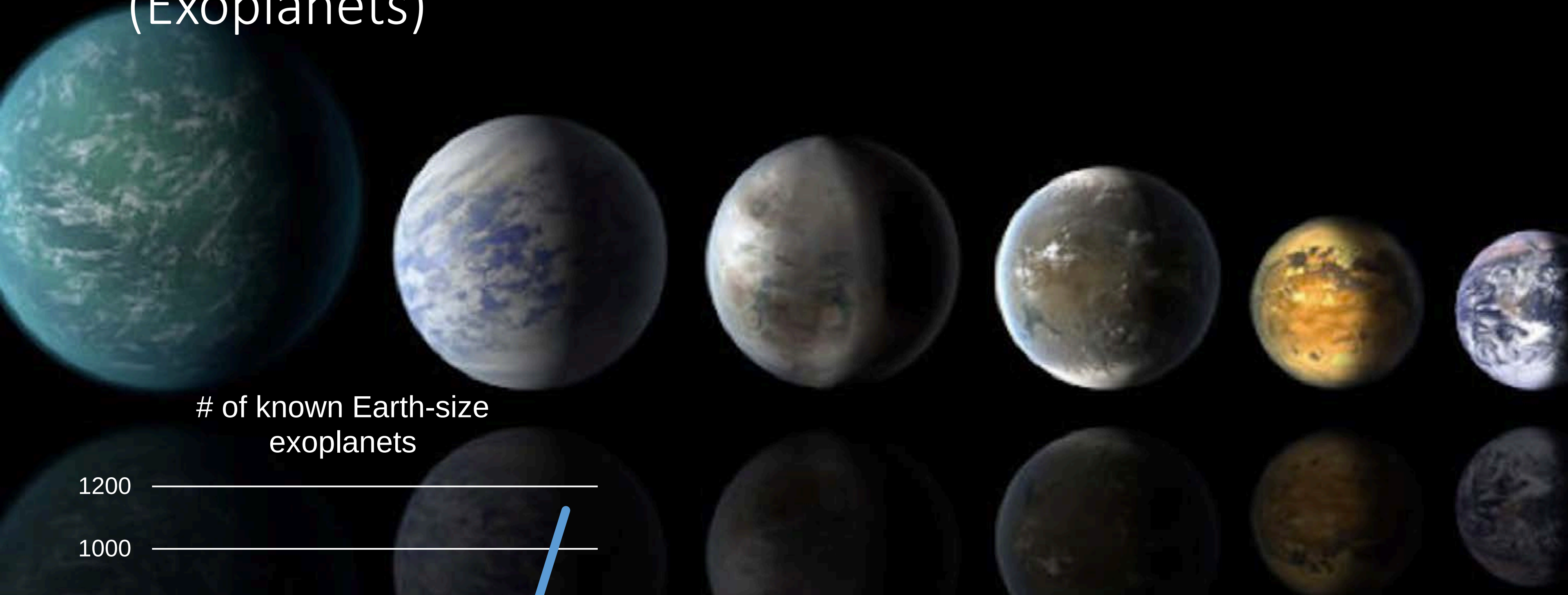
Venus likely had early habitats, and is now not habitable (possible refugia in the atmosphere?)

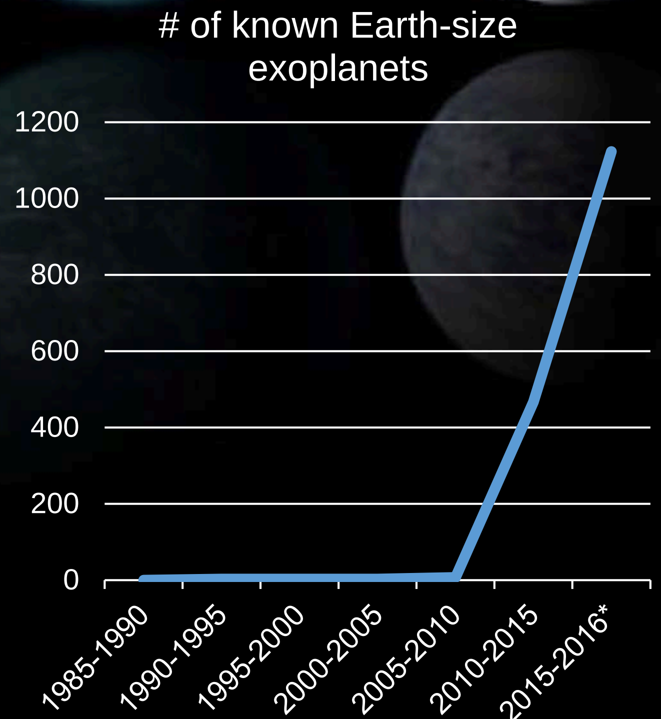
Earth has maintained a habitable and inhabited environment for at least 3.5 Ga

Mars had Earth-like habitats for 1-1.5 Ga, and is now at the edge of habitability (does it/did it host life?)

<u>Habitable zones are not static</u>

Key Developments in Planetary Science since 2010 (Exoplanets)





Are these "Earth-sized" Planets Habitable?

- We cannot explore the geologic history of terrestrial exoplanets, merely observe their present day state
- **The *geologic records of rocky bodies with atmospheres in our solar system* are the linchpins for understanding the *evolution* of habitability and thus likelihood for hosting life**

The Big Mars Questions

- Was there life on Mars?
  - See Eigenbrode Talk from Tuesday for Exploration Approaches
  - Are uninhabited habitats rare or common in the universe? The chemical and physical processes that generate uninhabited habitats are equally important for understanding the prevalence of life in the universe
- What sustains a habitable planet through time?
  - In contrast to the Moon, Mercury or icy satellites, the early crustal record of Mars records the evolution of a body with a substantial atmosphere and rocky surface with liquid water.
  - Mars' geologic record is weighted toward the first 1 Gyr of planetary evolution, a period that is disproportionately important for the long-term evolution of planetary habitability because rapid changes in mantle temperature and volatile inventory occur early on (impacts, changing solar environment).
  - Unlike Earth and Venus, large swaths of crust from Mars' first billion years are preserved with stratigraphic context at the surface or near surface, accessible for exploration (50% of current surface; Tanaka et al., 2014)

AGU PUBLICATIONS

http://onlinelibrary.wiley.com/doi/10.1002/2016JE005134/abstract

JGR

Journal of Geophysical Research: Planets

REVIEW ARTICLE
10.1002/2016JE005134

Special Section:
JGR-Planets 25th Anniversary

Key Points:
- Understanding the solar system terrestrial planets is crucial for interpretation of the history and habitability of rocky exoplanets
- Mars' accessible geologic record extends back past 4 Ga and possibly to as long ago as 5 Myr after solar system formation
- Mars is key for testing theories of planetary evolution and processes that sustain habitability (or not) on rocky planets with atmospheres

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The sustainability of habitability on terrestrial planets: Insights, questions, and needed measurements from Mars for understanding the evolution of Earth-like worlds

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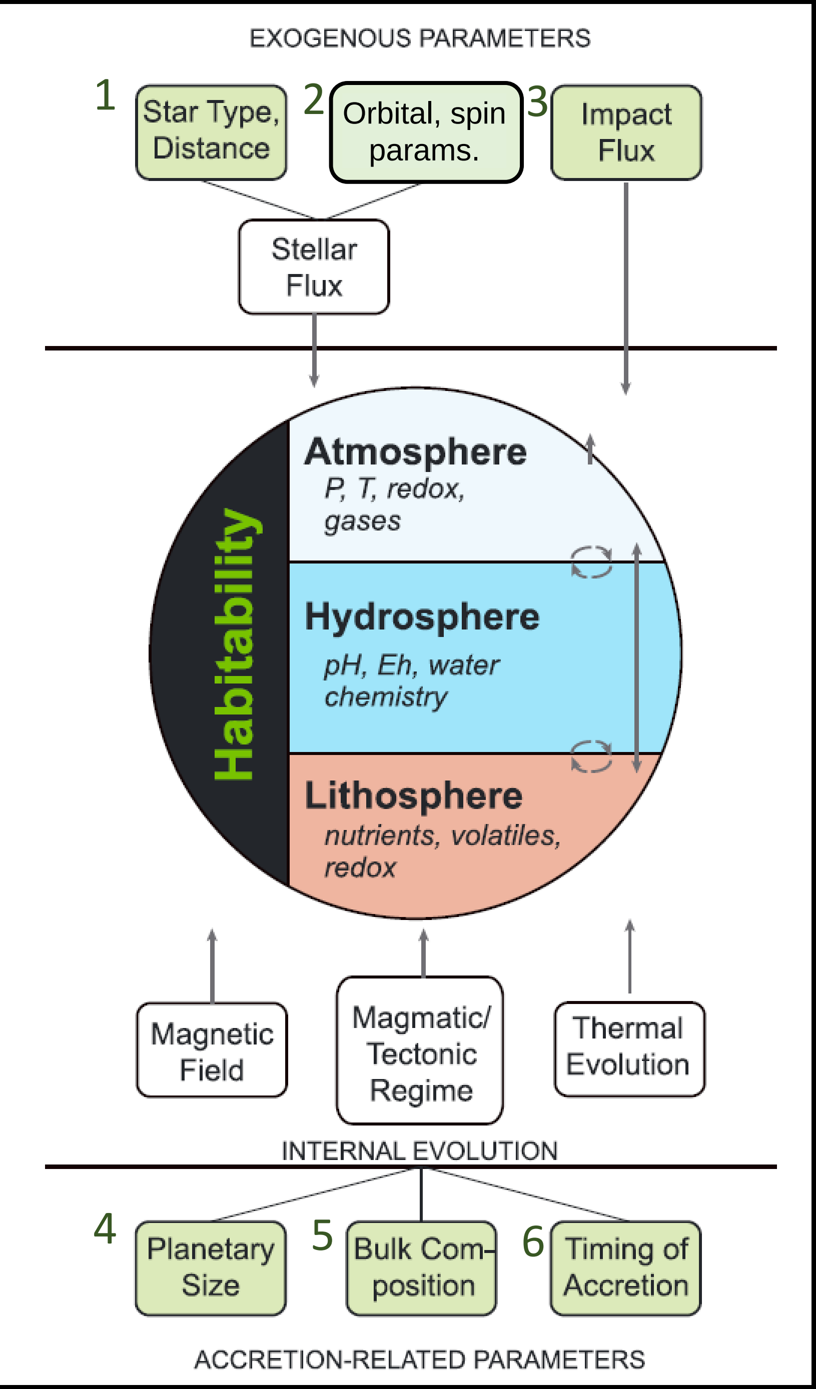


6 Parameters set Habitability

How do they interact?

Key Questions

1. Is small size fatal? (crust-mantle exchange; atmospheric speciation)
2. Why do planetary magnetic fields exist and do they strongly control atmospheric loss rates?
3. Is accretion composition (initial metal:rock:volatile ratio) destiny? (availability of H_2O, organics; geochemical cycles)
4. What are the effects of stellar evolution on planetary climate (e.g., on Earth and Mars, a late climate optimum from evolution of a faint young stars)
5. What is the role of impacts in setting planetary habitability? (beneficial or deleterious; timing)
6. What are the consequences of obliquity, eccentricity, and rotation cycles, which may result in only cyclical habitable conditions?

Key Investigations for Early Mars

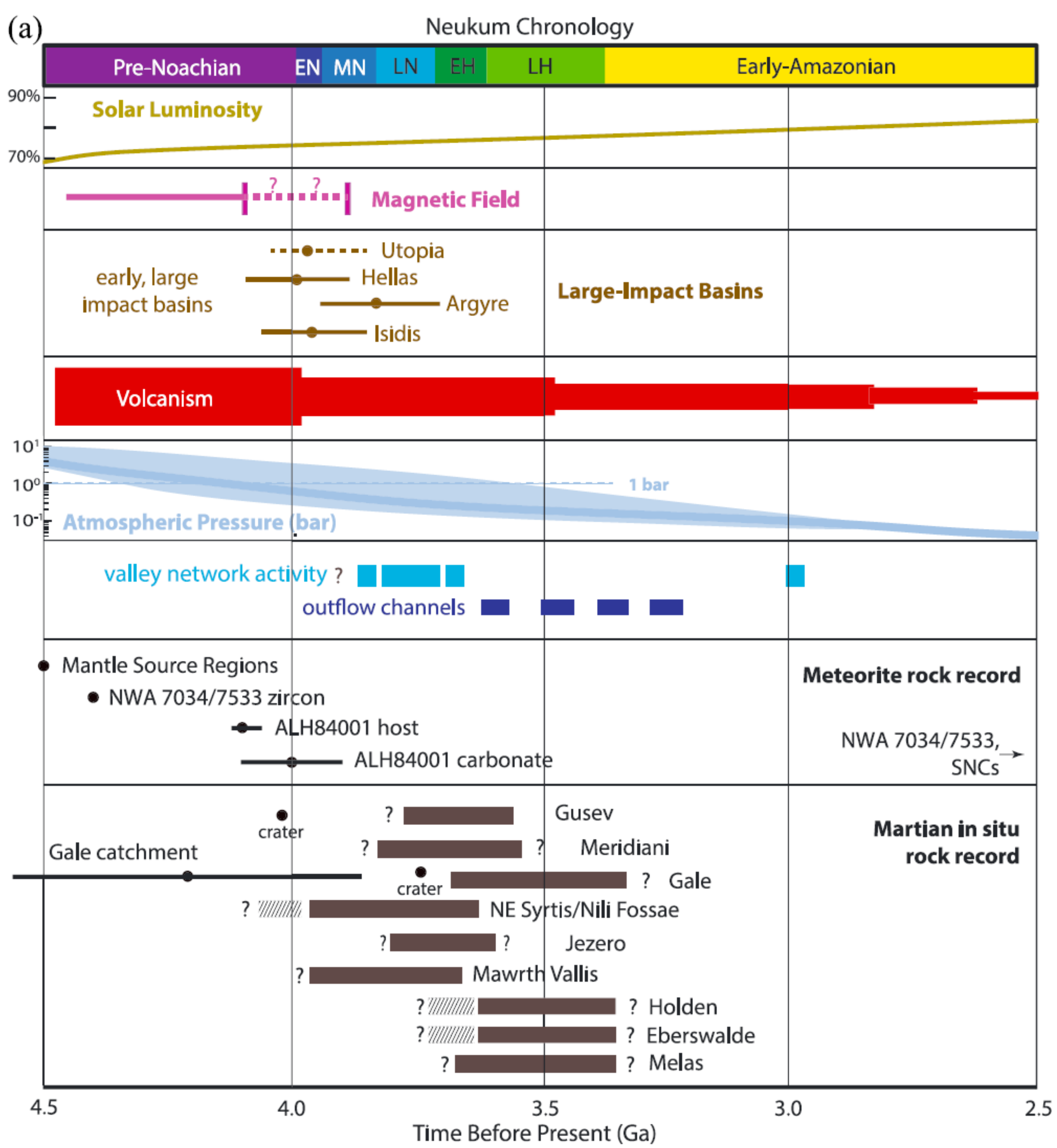
Mars Rock Record Allows Examination of these crucial questions

- **Petrology at Multiple Sites**: What Environments Occurred When and Where?
- **Follow the Volatiles to Track Geochemical and Climate Change**: Inventories, Isotopes, and Submeter Scale Stratigraphies
  - Isotopes in the rock record track atmospheric loss
- **Timing is Everything**: Understanding of Processes on Mars and Across the Inner Solar System by **Measuring Ages**
  - On Mars, can access stratigraphies before and after the magnetic field decline and at different points in atmospheric loss
- The **Coupling of Interior and Surface Evolution**

As on Earth, different time periods and are environments accessible at different geographical locations, single site sample return is insufficient alone to address all key questions posed here. Reconnaissance and measurements (but not at flagship level) will be required

An accessible rock record during early planetary evolution

We have not yet visited oldest Mars with a landed mission



Ehlmann et al., 2016, JGR

Mars Exploration Next Steps

See full Ehlmann et al. V2050 presentation

See Beaty & Ehlmann summary of all Mars presenations at V2050

Suggested Implementation Principles

1. The **engine driving SMD Mars Exploration Program** is and will remain **the most fundamental science questions** that can only be answered on Mars

2. In 2017, **we are at a point of natural HEOMD, SMD, and "new space" commercial synergy** in questions and needed technologies. With well-thought out, continued coordination, **this can be a tremendous boon to Mars science and exploration**

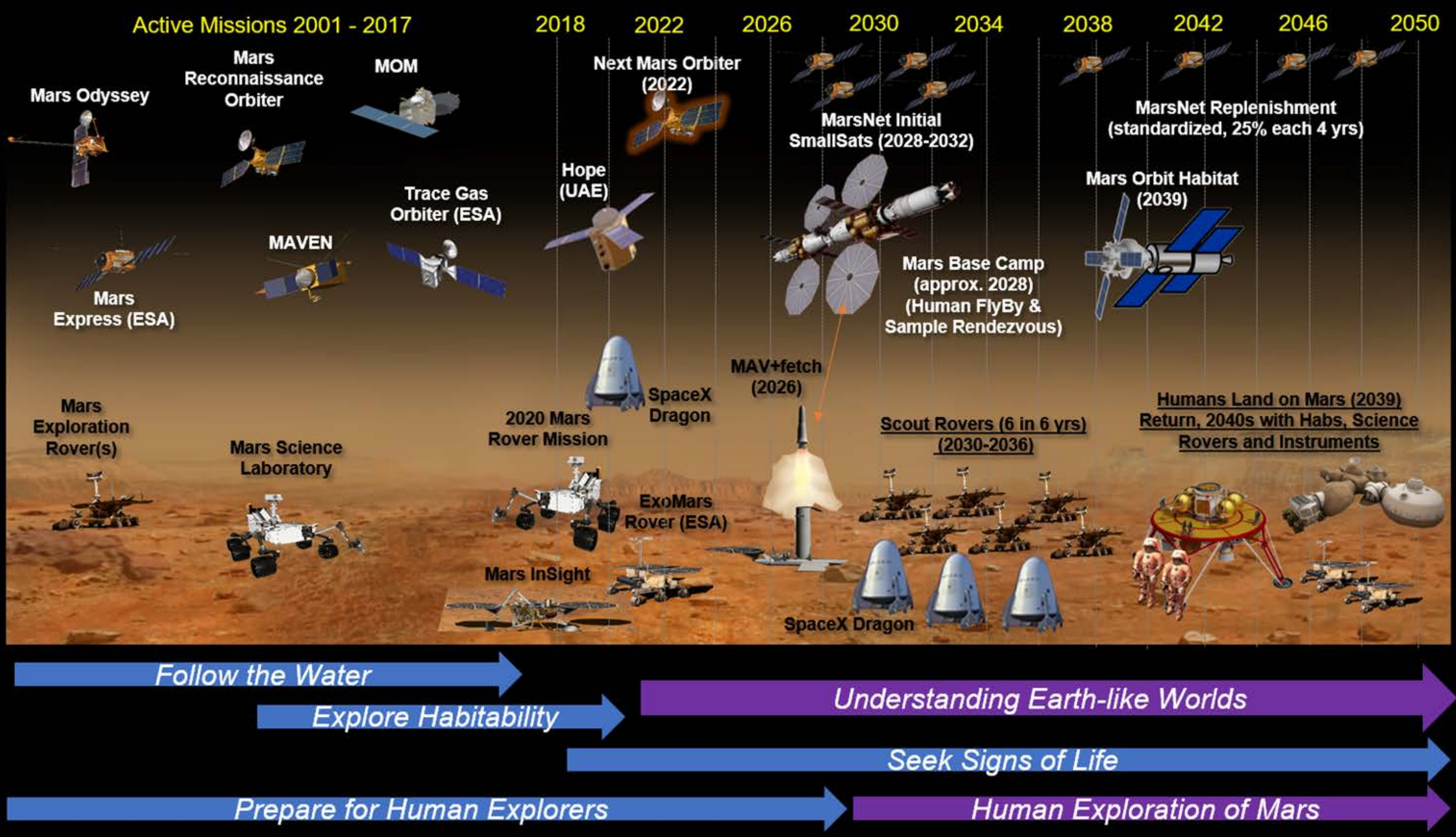
3. **Robotic sample return** should be performed **at least once, as rapidly and cost-effectively as possible, by leveraging support** from international, commercial partners, and HEOMD

4. **The current juncture in science must recognize Mars is diverse**, requiring tens of science mission opportunities in 2020-2050, **enabled by a return to the cost-saving paradigm of multiple small craft**

See full Ehlmann et al. V2050 presentation

See Beaty & Ehlmann summary of all Mars presenations at V2050

One possible timeline



Robotic Programs

- **NeMO: Mars Orbiter for Water/Volatiles + Telecom (mid-size) (2022)**
- **MAV+sample fetch+return,** with international HEOMD/commercial collaboration **(2026; 2030)**
- **MarsNet: A global network of <u>small</u> satellites (2028+)**
  - Global telecommunication (with backup)
  - Weather monitoring and climate dynamics
  - Mostly low-cost, small-sats; commercial contract to build en masse, competed small instruments in standard slots, replace 25% every 4yrs
  - MARCO 12U build for 2018 InSight Mission is the model (not even Discovery class)
- **ScoutRovers: multiple MER-class or Scout-class mobile explorers (collective 1 flagship)** +/- commercial landers **(2030-2036)**
  - Near-simultaneous build) w/ std. instrument slots
  - Launch 6 in 6 yrs (2 per opportunity)
  - Set #1: Modern Life Detection/Habitability Prior to Human Landing
  - Set #2: Volatiles, Habitability and Ancient Life Explorers
- **Science payloads with human missions (2039-2050)**

1. Increased coupling with commercial and HEOMD

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2. Low cost is enabled by standardization of the “bus” (ala, Mariners, Pioneers)

Use of COTS technology and capable CubeSats/small sats

New science is achieved by miniaturized instruments at many locales

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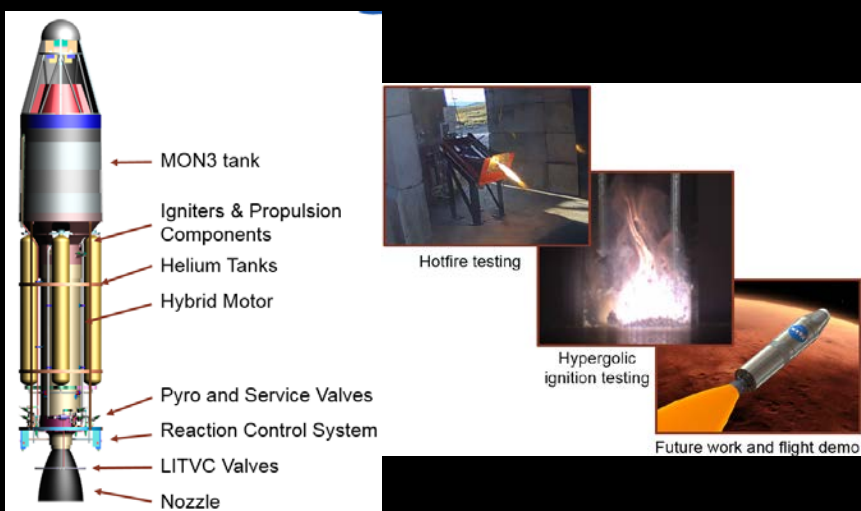
3. Essential actions for the rest of this decade are to

a. Maintain telecom presence
b. Accomplish volatiles inventory/water resources science
c. Architect the sample return, heavily leveraging partnerships to fit within an SMD PS budget

Enabling Sample Return

(or, how I personally came to believe this is implementable in the next decade without blowing the whole PS program)

- Existing technology investment in the necessary infrastructure by several parties shows clear potential to use technologies developed by NASA (SMD, HEOMD) and foreign partners in a modular, multi-agency approach (e.g., NASA delivery of CSA fetch rover with NASA MAV, launching to ESA rendezvous satellite)
- Now, need for NASA to architect the strategic plan

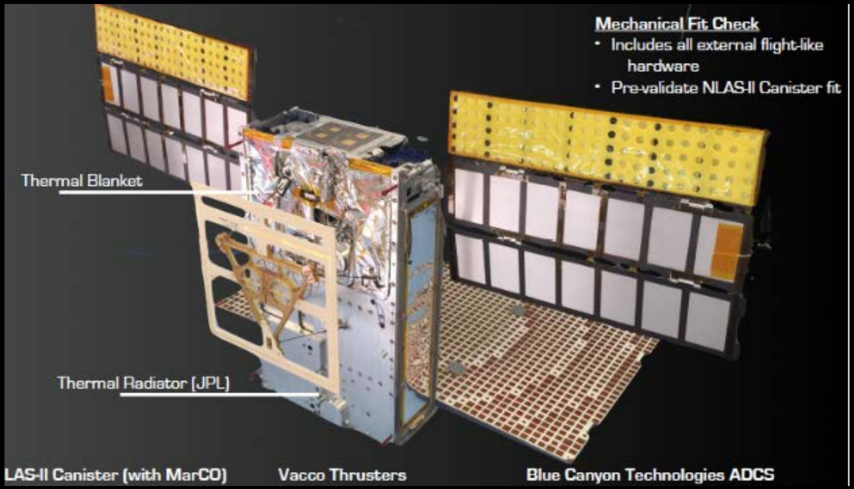


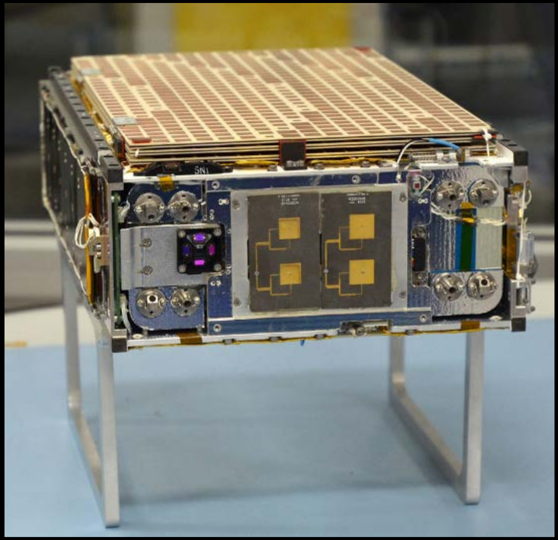
JPL+NASA/Marshall MAV+MAV prop development (TRL 4 by 2017; demo TRL 6 by early 2020s)
Karp et al. ppt | pdf from 2017 AIAA conference

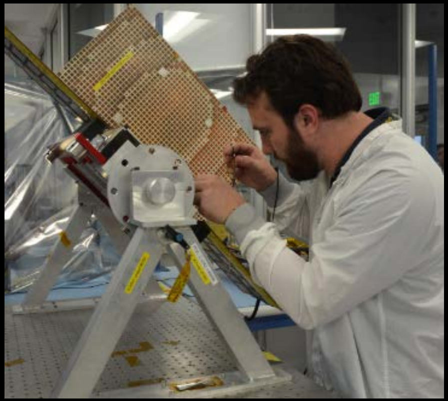
CSA video https://tinyurl.com/ydh4s4xt

Enabling multiple explorers to understand the diversity

- Major technological progress on explorers systems and insturments has been made to do in situ science
  - Access: precision landing, mobility, helicopters
  - In Situ Age Dating (3 instruments proposed for 2020)
  - In Situ Isotopes (on MSL, Rosetta)
  - In Situ Petrology (on M2020)
- Commercial space is driving the capabilities of small satellites for communications and imaging







Final thoughts

- Mars has only become more interesting the closer we have looked
- Because of its extensive and organized rock record from the first billion years, Mars is a linchpin for understanding how early planetary processes (faint young suns, large impacts, changing atmospheres and magnetic fields) influence the evolution of habitability and potential for life
- Technologies exist and pathways exist for implementation of a nimble and robust Mars Exploration Program within a diverse portfolio of planetary exploration objectives
- In urgent need of an strategic architecture to shape the remainder of this decade and the next so that the pace of discovery and exploration continues

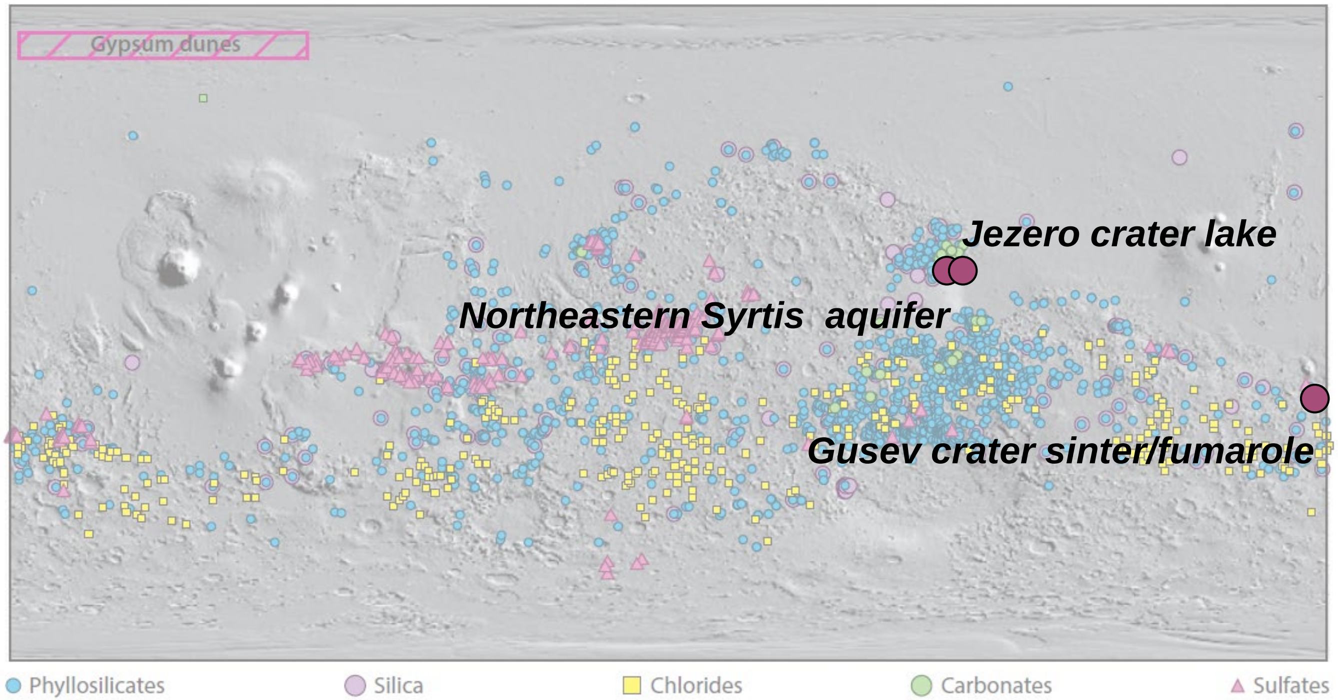
EXTRAS

Exploration Strategy for Early Mars

- Sample return remains important. Several of the questions can only be addressed with terrestrial laboratory techniques on a decadal timescale
    - Likely required for unambiguous biosignature detection
- Major technological progress has been made to do in situ science that can make great progress in understanding environmental history and the evolution of habitability
    - Access: precision landing, mobility, helicopters
    - In Situ Age Dating
    - In Situ Isotopes
    - In Situ Petrology
- As on Earth, different time periods and are environments available at different geographical locations, single site sample return is insufficient to address all key questions posed here. Rather, as on Earth, disentangling local unique environments from truly global change is fundamentally a question of interrogation of multiple stratigraphies.
    - Sample return is essential for many questions The cost and programmatic effectiveness of several in situ missions with highly capable rovers or several sample return missions, possibly with less capable rovers or tied with human missions, is a programmatic choice.

1.Fundamental Science: Driver of the SMD-MEP

1. Are we alone?
Was/is there life on Mars?



- ➢ Multiple habitat-types to explore for potential life on Mars
- ➢ **Mars-2020 is the start of the search for past biosignatures, not the end!**

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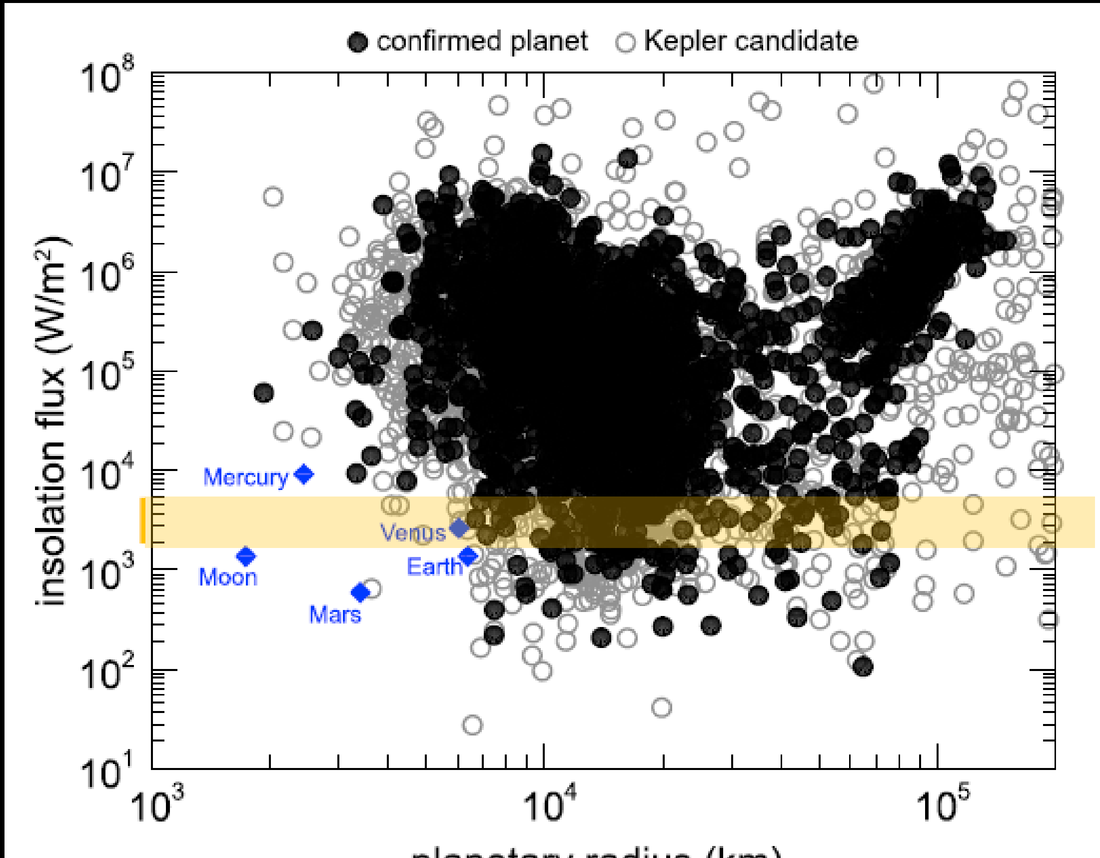
Habitat Types Discovered In Ancient Mars Rocks

- Multiple habitat-types to explore for potential life on Mars
- **Mars-2020 is the start of the search for past biosignatures, not the end!**

Lessons from our own solar system



Ehlmann et al., 2016, JGR

- In basic measurable parameters, confirmed planets are becoming closer twins to solar system planets
- However, we know composition, dynamics, and historical factors must play a hugely important role