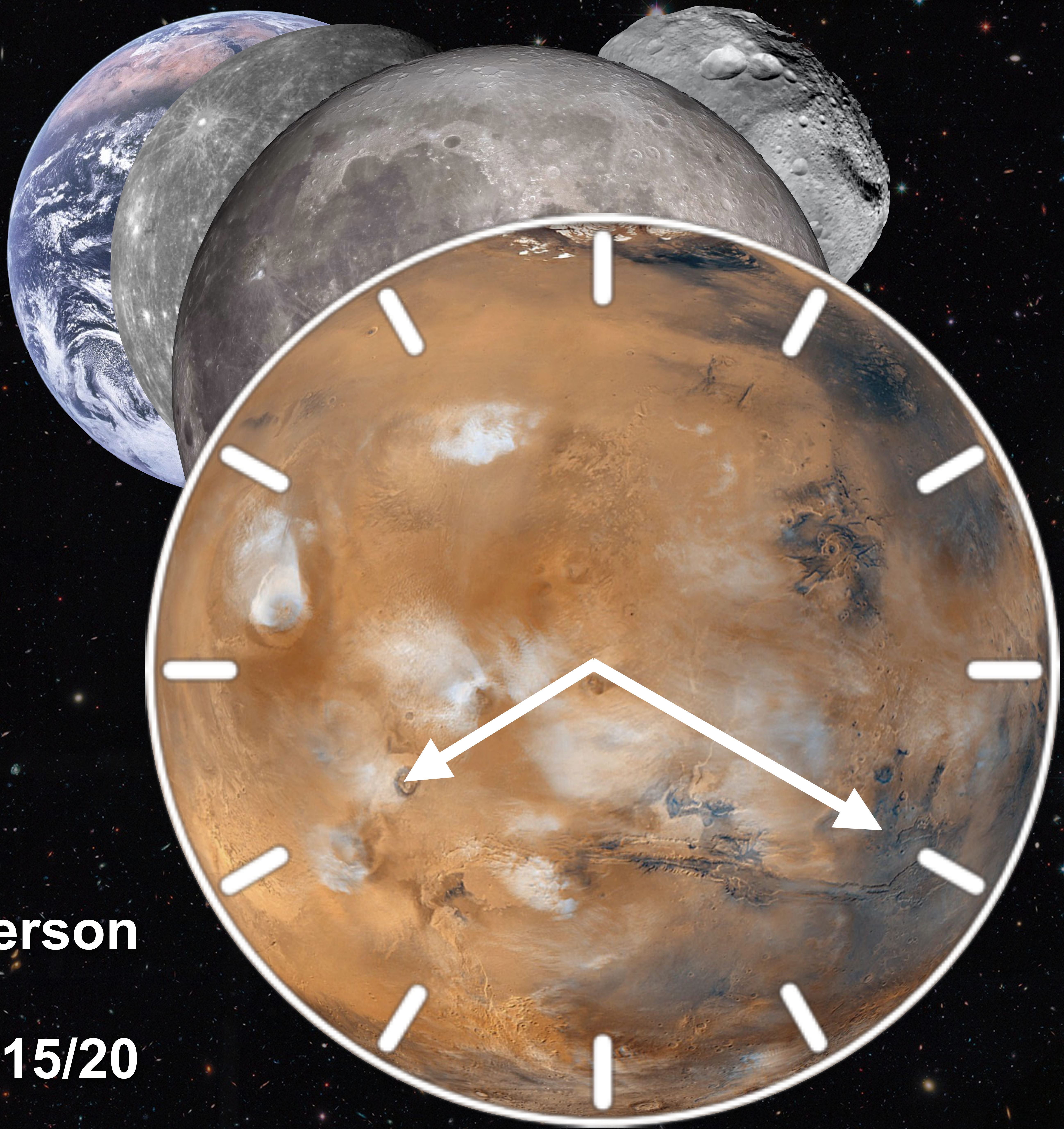
The Scientific Importance of Additional Chronology Measurements at Mars



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Introduction

- Chronology is a through-going theme of planetary science, and yet has some foundational cracks that new measurements at Mars could address
- Summary of in-situ and upcoming radiometric dates
- Science opportunity types
  1. Multi-body Chronology Issues: Implications for the inner solar system and asteroid belt
  2. Global Chronology Issues: Broad implications for Mars
  3. Local: Of geologic importance (fairly obvious, not discussed here further)
- Importance of chronology as a framework

Existing Mars In-Situ Dates

- First In-Situ Dates from Mars Science Laboratory SAM:

TABLE 1. SUMMARY OF CURIOSITY RADIOMETRIC AND COSMIC-RAY EXPOSURE AGE EXPERIMENTS

Location	*Aliquot*	*Radiometric age (Ma)*	*CRE age (Ma)*	*Interpretation*
Cumberland		4210 ± 350 (8.3%)	78 ± 6 (7.7%)	Crystallization age of detrital minerals from basaltic precursor; mm to cm/Ma denudation by scarp retreat
Windjana	Aliquot 1 Aliquot 2	627 ± 50 (8.0%) 1710 ± 110 (6.4%)	145 ± 203 (140%)	Radiometric ages inaccurate due to incomplete degassing and/or mineralogic fractionation during sample handling
Mojave 2	Plagioclase	4070 ± 630 (16%)	300 (^{36}Ar) to 1000 (^{3}He)	Crystallization age of detrital minerals from basaltic precusor; pre-burial exposure
	Jarosite	2120 ± 360 (17%)		Fluid flow through the Murray bedrock

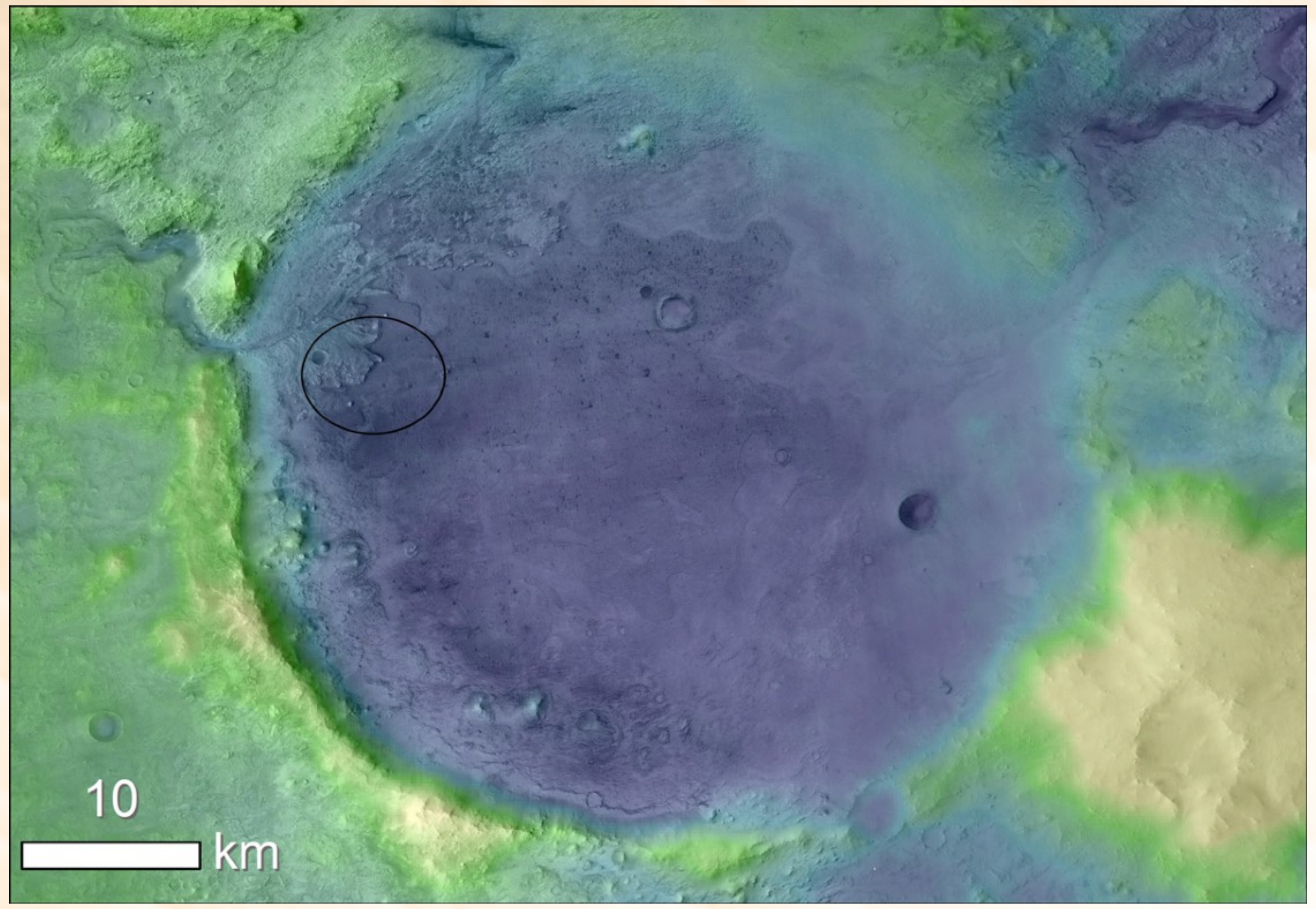
Ma, millions of years before present.

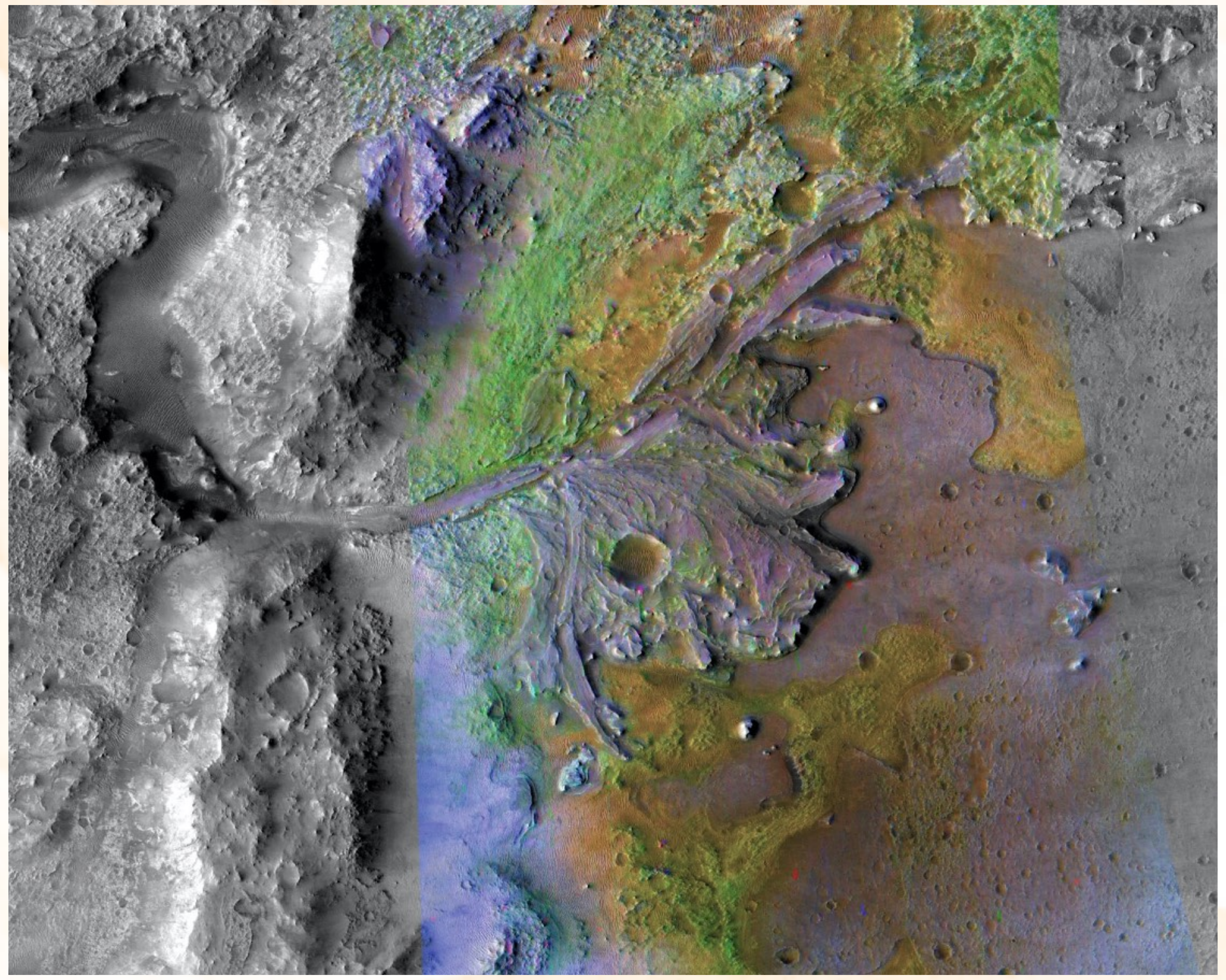
from Cohen et al, 2019

- Dates:
  - Cumberland and the Mojave 2 Jarosite broadly consistent with previous geologic interpretation
- Exposure ages:
  - Cumberland and Windjana provided constraints on scarp retreat
- Represent pathfinding demonstration of future purpose built dating instruments that will have better precision

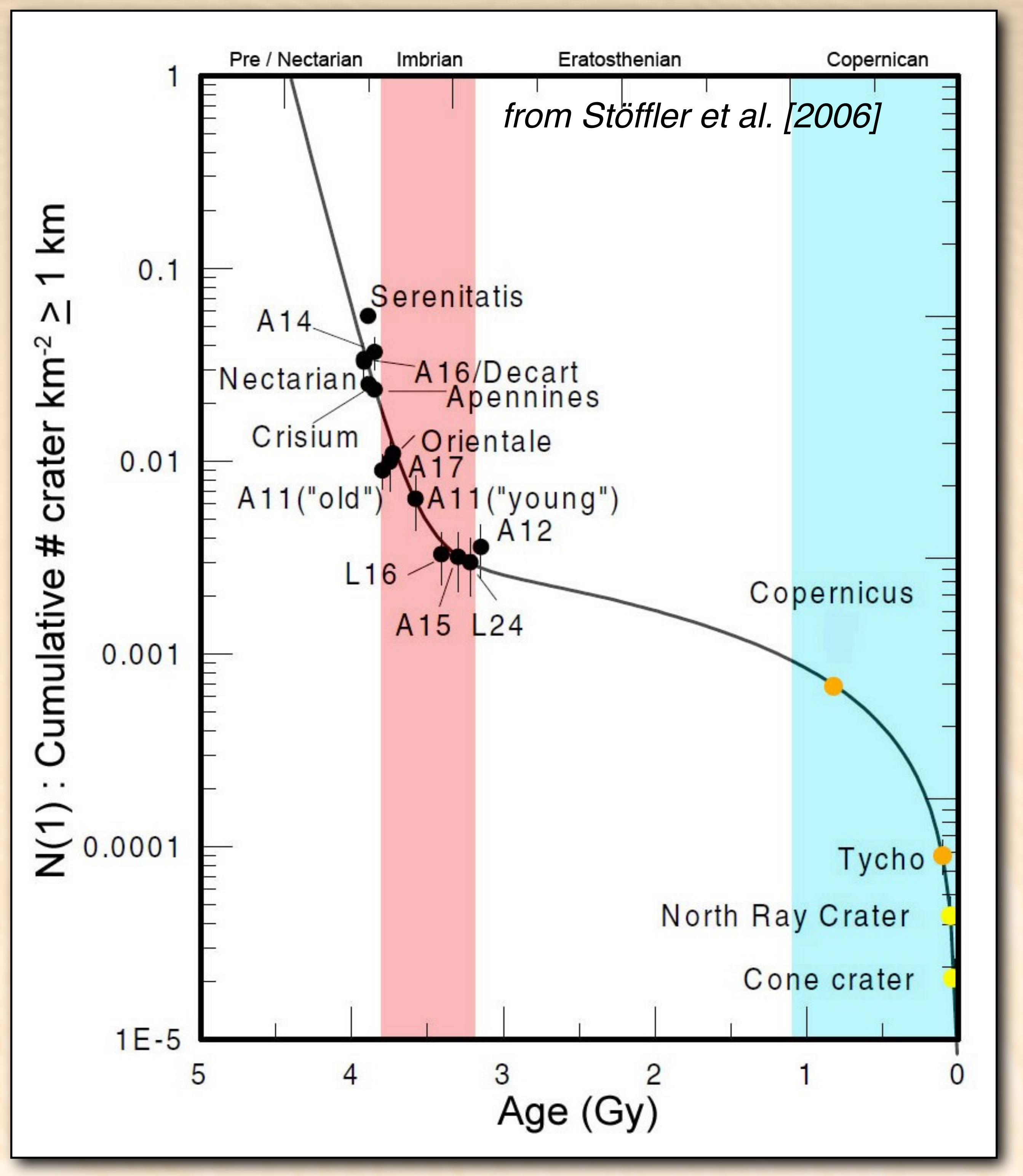
Upcoming Radiometric Dates from Sample Return

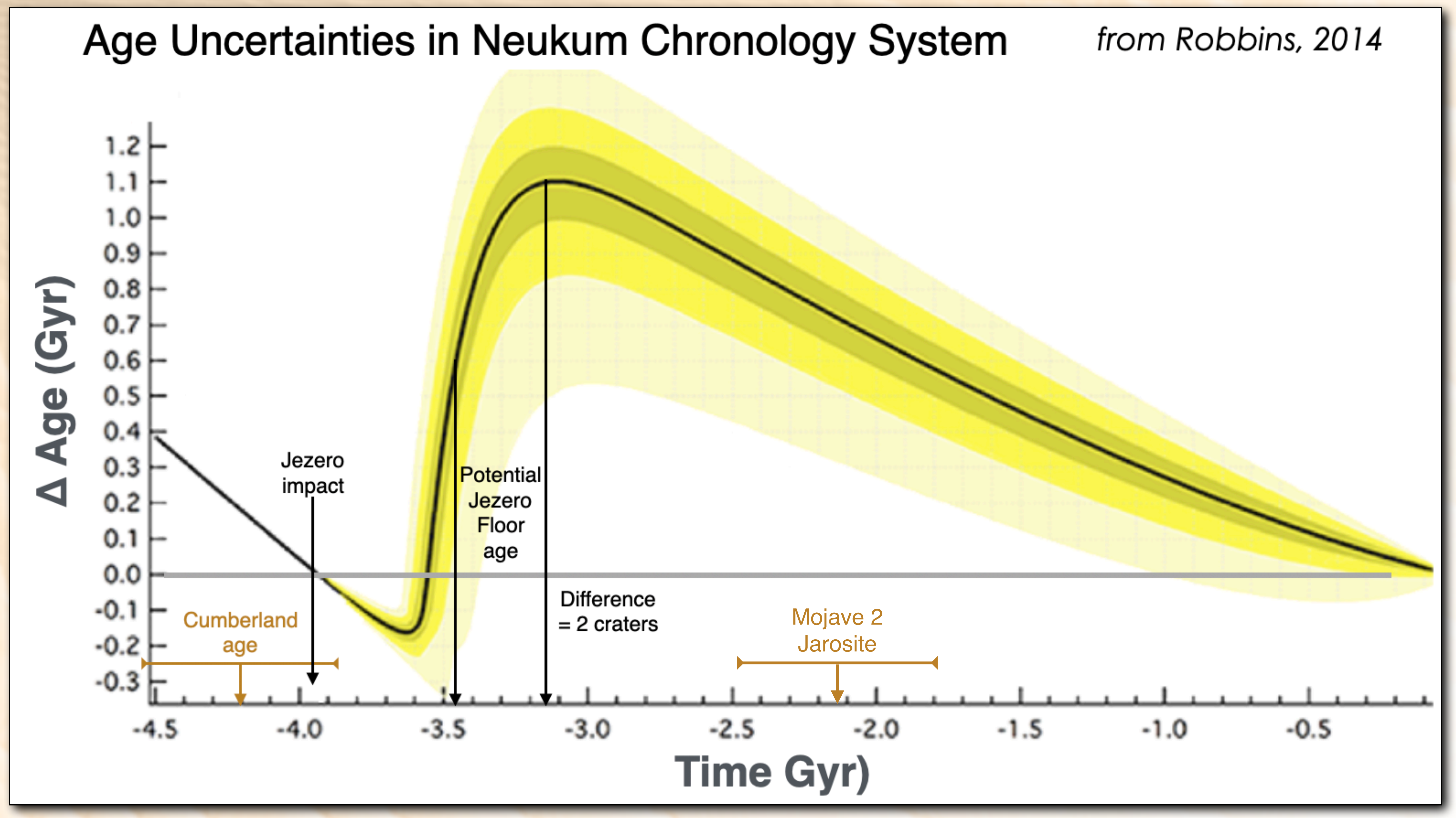
- Mars 2020 at Jezero Crater
- Samples will provide new constraints on:
  - Formation age of Jezero <3.96-3.97 Ga (Fasset and Head, 2011)
  - Fluvial cessation ~3.8 Ga (Fasset and Head, 2008)
  - Paleolake and deltaic deposits
  - New radiometric dates of volcanic floor may constrain crater counts
    - 2.6±0.5 Ga (Shahrzad et al, 2020; ~3.15 in Neukum)
    - 3.45 +0.12/-0.67 Ga (Goudge et al, 2015)





Multi-body Chronology Issues





- Lunar crater density to age curve
- Extrapolated to Mars and throughout the solar system
- White regions are largely unconstrained
- Uncertainties in the curve lead to big differences in Mars history
- New Mars data could constrain the LHB or 1-3 Ga period

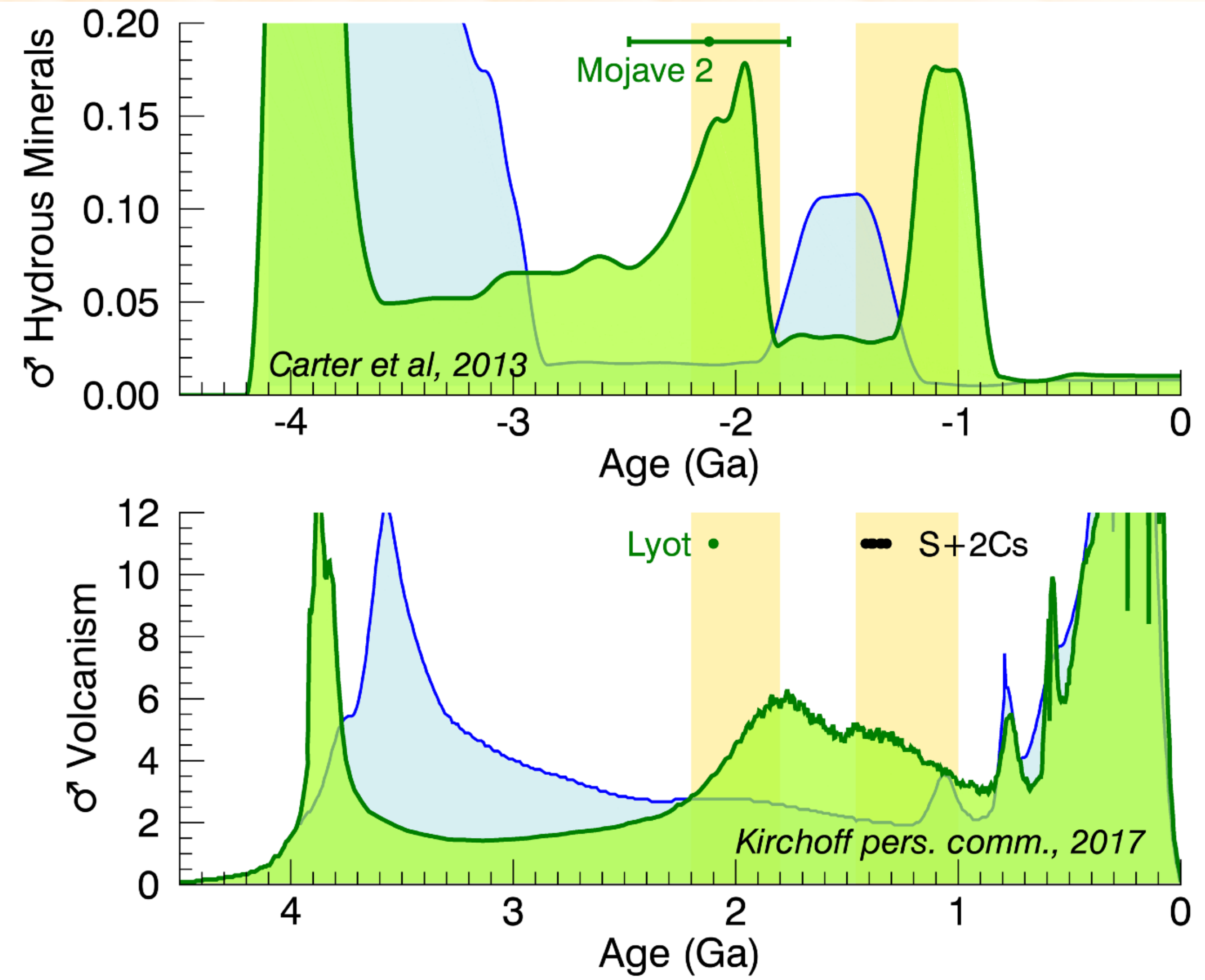
- Answering these questions could provide new constraints on the age of surfaces throughout the inner solar system
- Jezero may provide one constraint, but more will be needed!
- Lets consider how this curve effects histograms of geologic processes on Mars

Effect of New Chronology on Mars

- Blue = Neukum chronology
- Green = Robbins chronology
- Area of hydrous minerals vs age
- Area of volcanic units vs age
- Mojave, Shergotites, 2 Chassignites fixed in age
- Lyot shown in Robbins chronology
- Yellow bars for reference

- Moves events from 3.5-2.5 Ga to the right
- Results in "events" at 2 Ga and 1.4 Ga
- Did volcanism and habitability have a resurgence at 1-2 Ga?

- But is it true? Because these are billion year time changes, we can easily test with in-situ dating
- IF we confirmed this, what would it mean for the Moon?

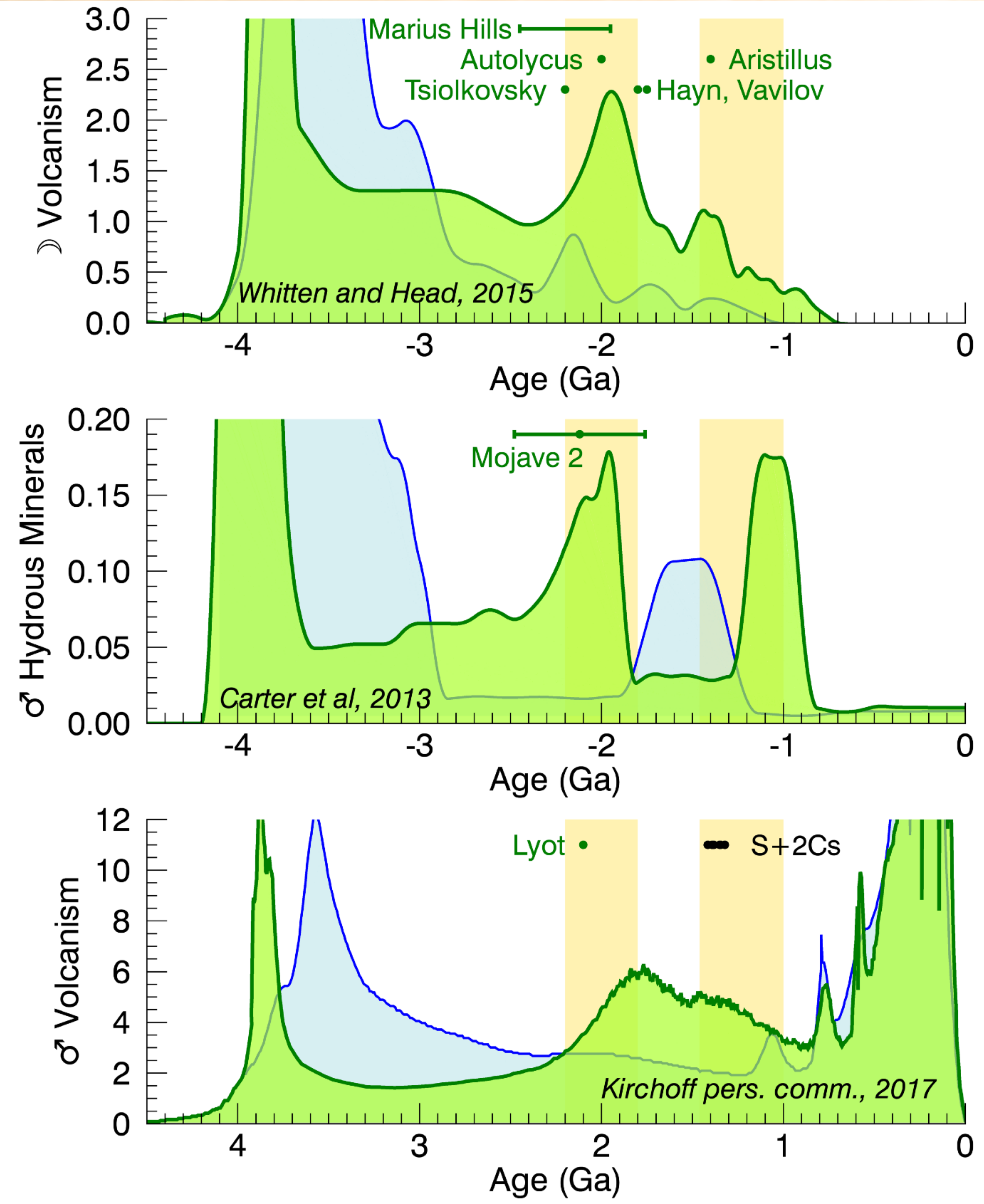


Effect of New Mars Chronology on the Moon

- Blue = Neukum chronology
- Green = Robbins chronology
- Frequency of volcanic units vs age
- Lunar craters and MH shown in Robbins chronology

- Again, “events” at 2 Ga and 1.4 Ga
- Is large scale volcanism partially related to impacts?

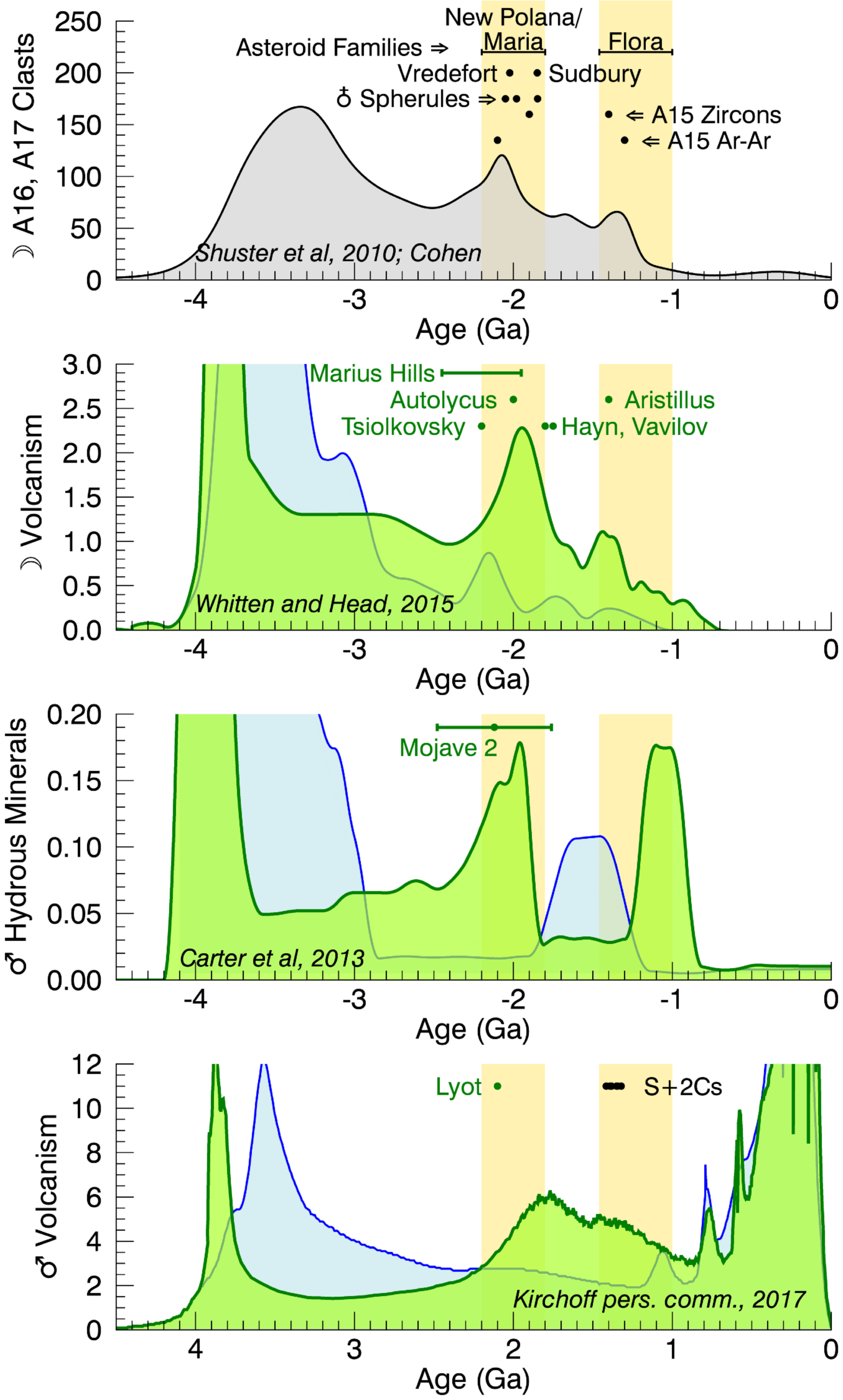
- What if we compared with known terrestrial events?



Relationship to Earth and Asteroids

- Events at 2 and 1.4 Ga produce a consistent story with terrestrial impacts, spherules, and some Apollo clasts and Zircons (note: class data smoothed to 250 Ma uncertainty of Robbins curve)
- If impacts are causing these events, New Polana/Maria and Flora asteroid families may be the source

- A few Mars dates can inform volcanology, thermal evolution, the history of volatiles and habitability, lunar volcanism and history, and asteroid dynamics



Global Chronology Issues

- Age of Tharsis volcanism
  - When did the era of volcanism end
- Duration of Valles Marineris formation
  - Current factor of two or more results in dramatic differences in thermal and chemical evolution of the lithosphere
- Can we constrain when global magmatism ended and if impacts were related?
- Can we constrain the era of volatiles and habitability?
- Locations with easy access to diverse and extensive stratigraphies that could be used to place global processes in context
  - Nili Fossae Trough
  - Mawrth Vallis
  - NE Syrtis
- Many more!

Chronology Opportunities and as a Framework

- Deeper exploration of new chronologies needed because they change interpretation of solar system wide events; likely requires sampling from multiple global localities
- Initially, any dates will be crucial data points
- Testable hypotheses for age are critical for assessing the tool required to solve the problem
  - In-situ instruments or sample return: $precision \leq (Age_1 - Age_2)/(2 \times \sigma)$
- Numerous problems can be solved by in-situ approaches
- In-situ dating can drive the scientific excitement needed to motivate future sample returns
- Most fields of Mars science attempt to place their observations in a temporal context; revising chronology will be important for many of them
- Hence, because chronology touches many other fields, and we know we can find datable rocks, it can be used as a motivating framework