CURIOSITY

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Planetary Protection Subcommittee

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NASA

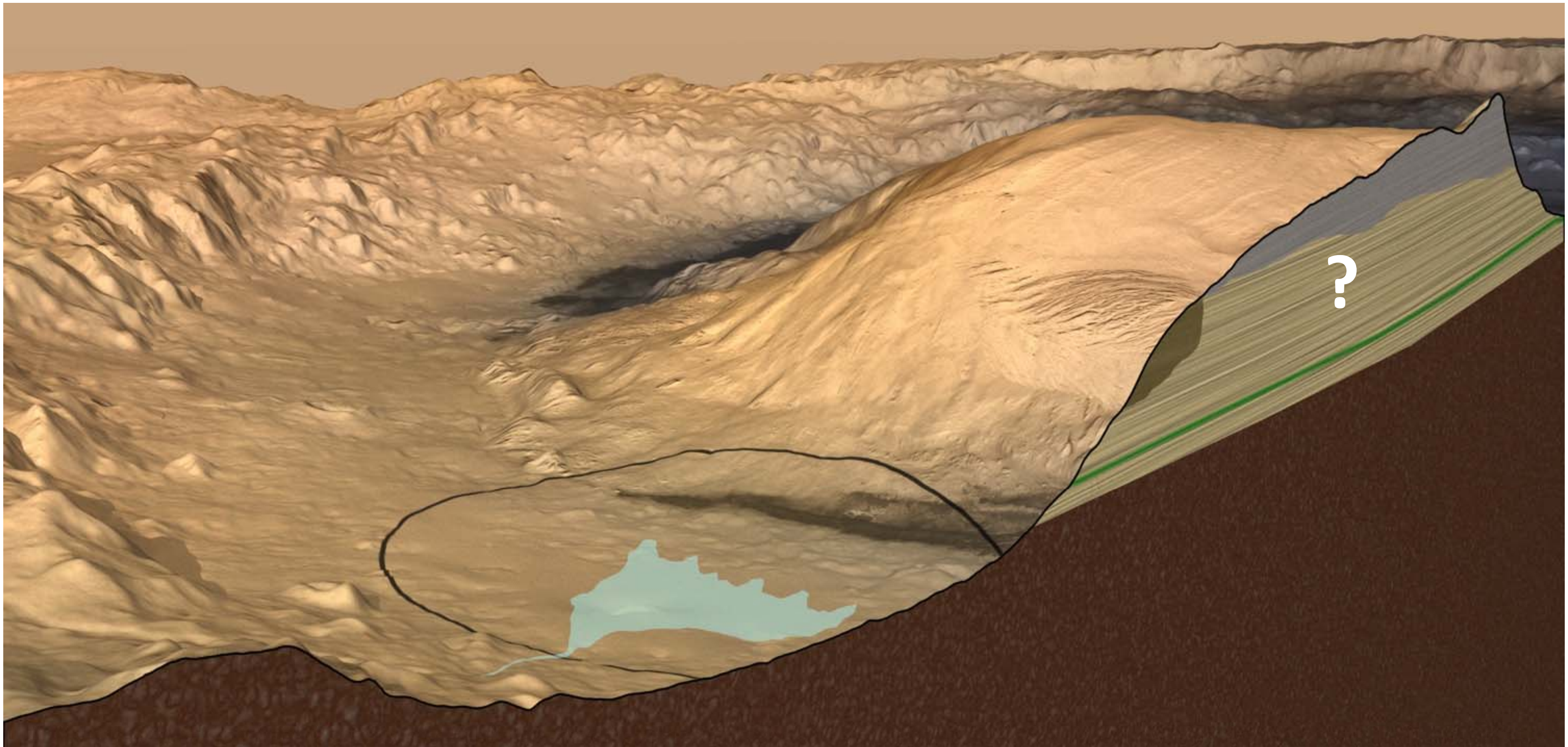
Exploring Ancient and Modern Mars with the Curiosity Rover: Early Results from the SAM Investigation at Gale Crater

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

- Biological potential
- Geology and geochemistry
- Role of water

Surface radiation
(humans to Mars)

Curiosity's Science Objectives



150-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound vary in mineralogy and texture, suggesting that they may have recorded environmental changes over time. Curiosity will investigate this record for clues about habitability, and the ability of Mars to preserve evidence about habitability or life.

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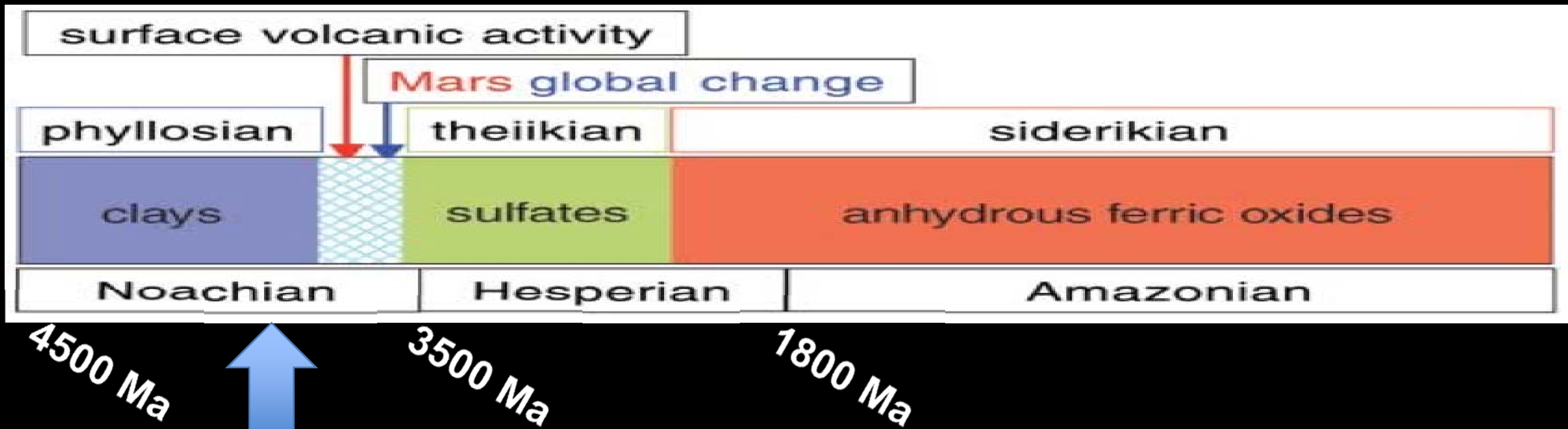
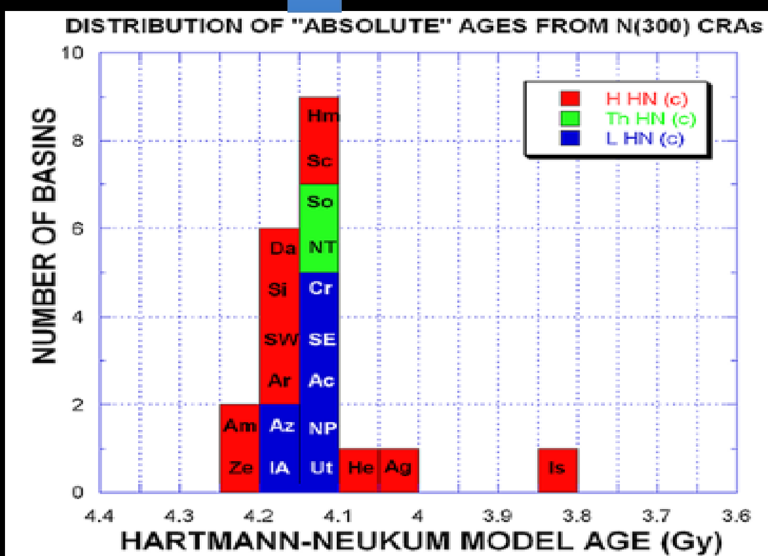
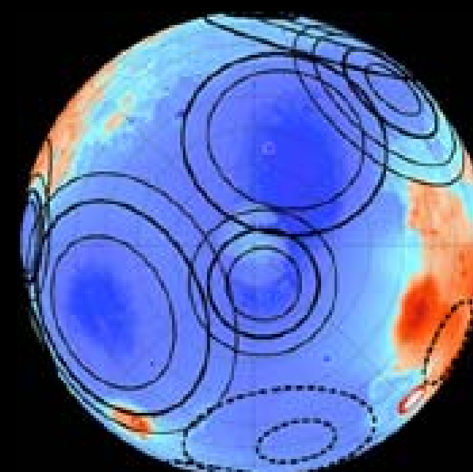
Target: Gale Crater and Mount Sharp

Bibring et al (2006) from Mars Express IR observations

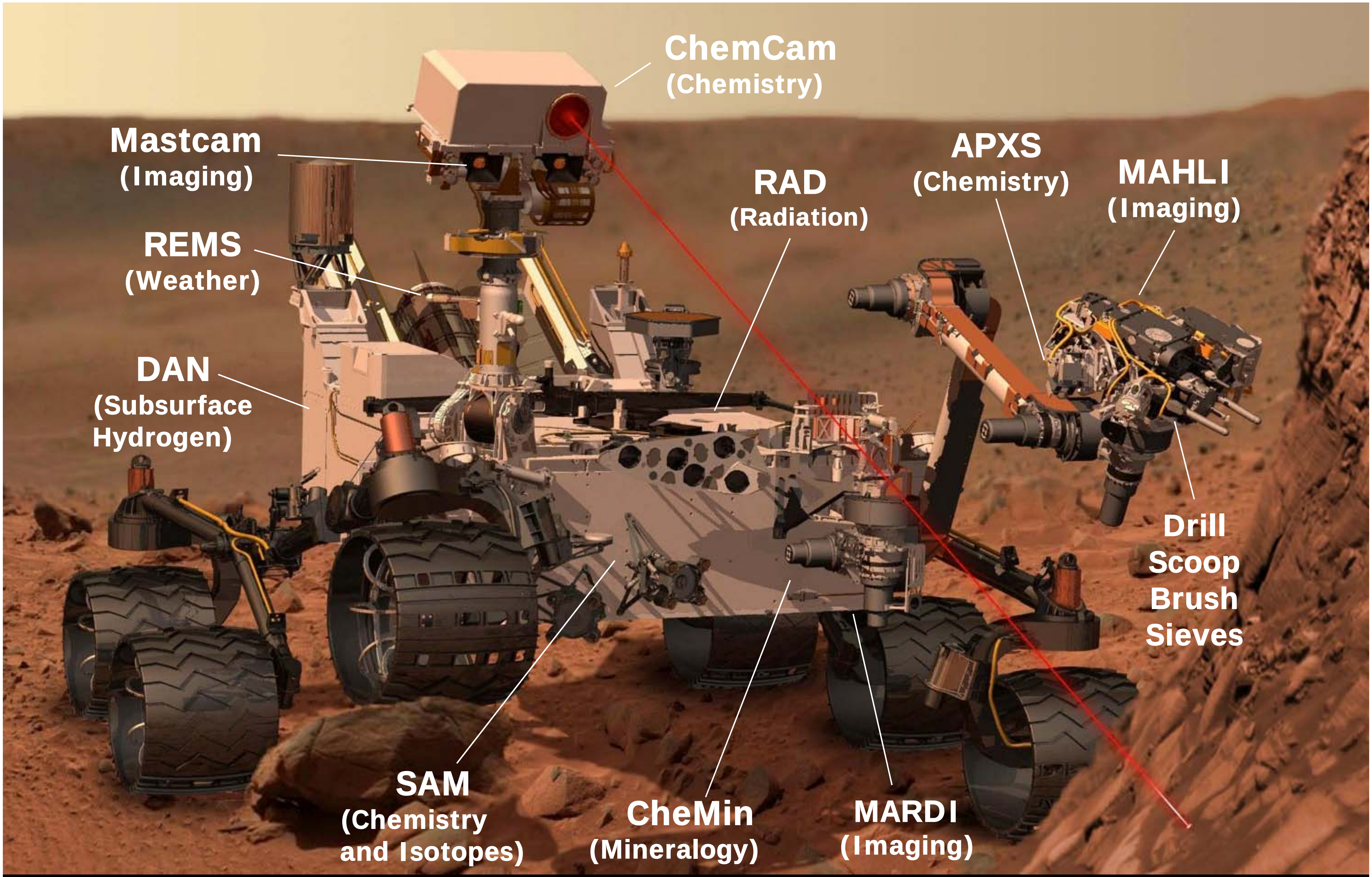




Narrow distribution of large impact basins Frey (2008)



Gale Crater strata may record a critical transition in the history of the martian surface



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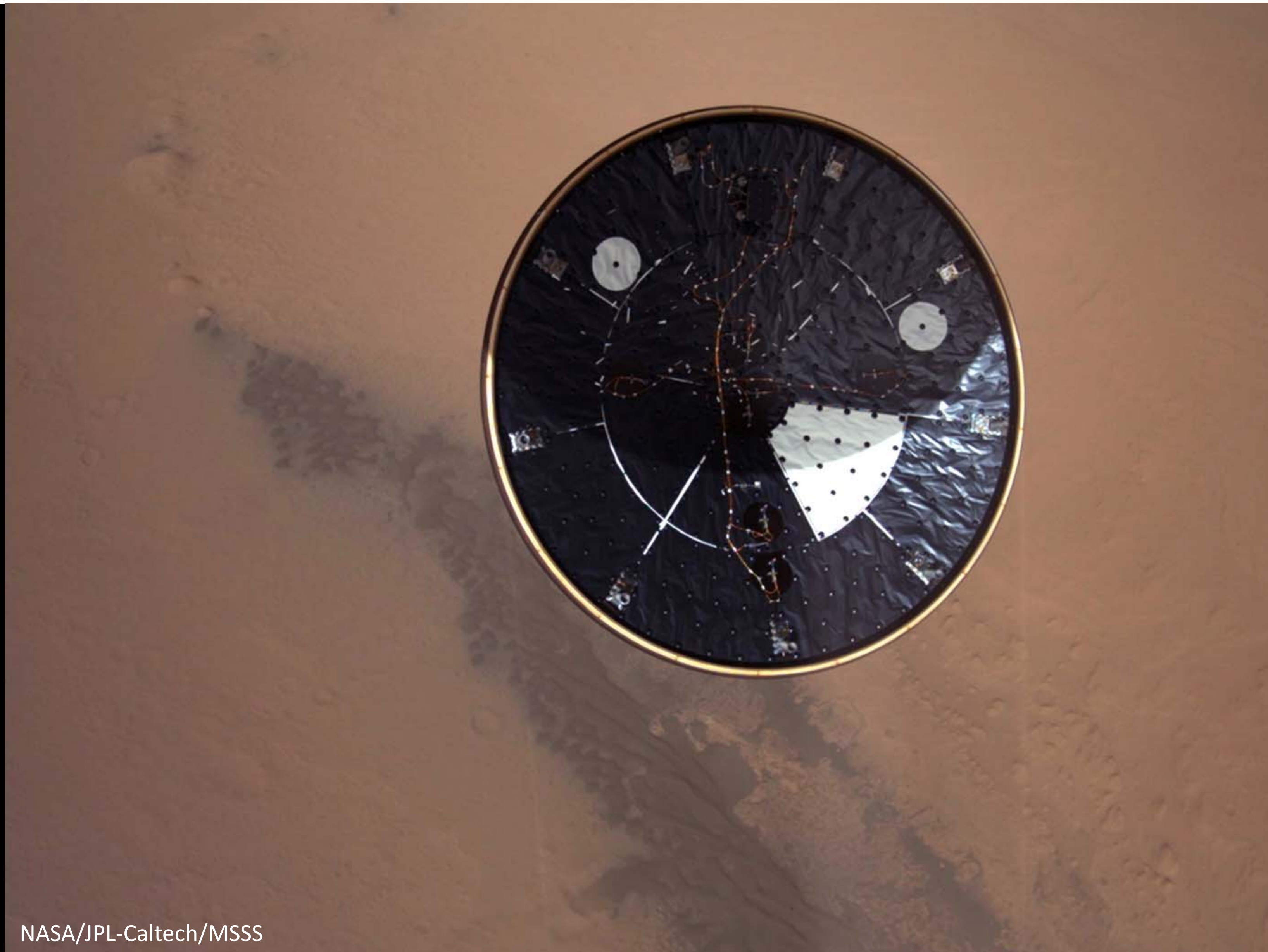
Curiosity’s Science Payload

November 26, 2011 the Atlas V launch



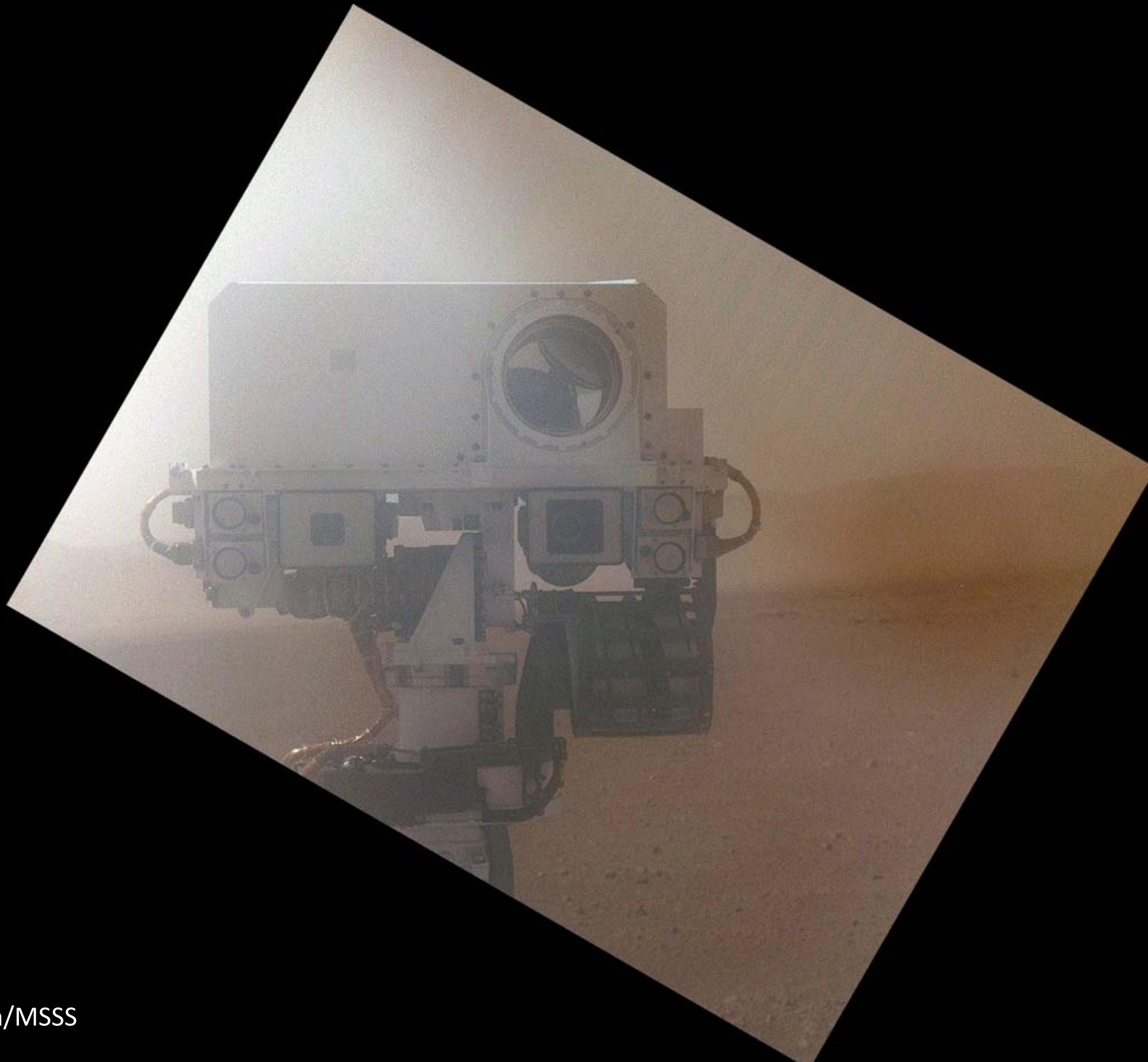
Heat shield separation captured by Curiosity’s Mars Descent Imager

Kicking up dust just prior to landing

The SAM team celebrates touchdown

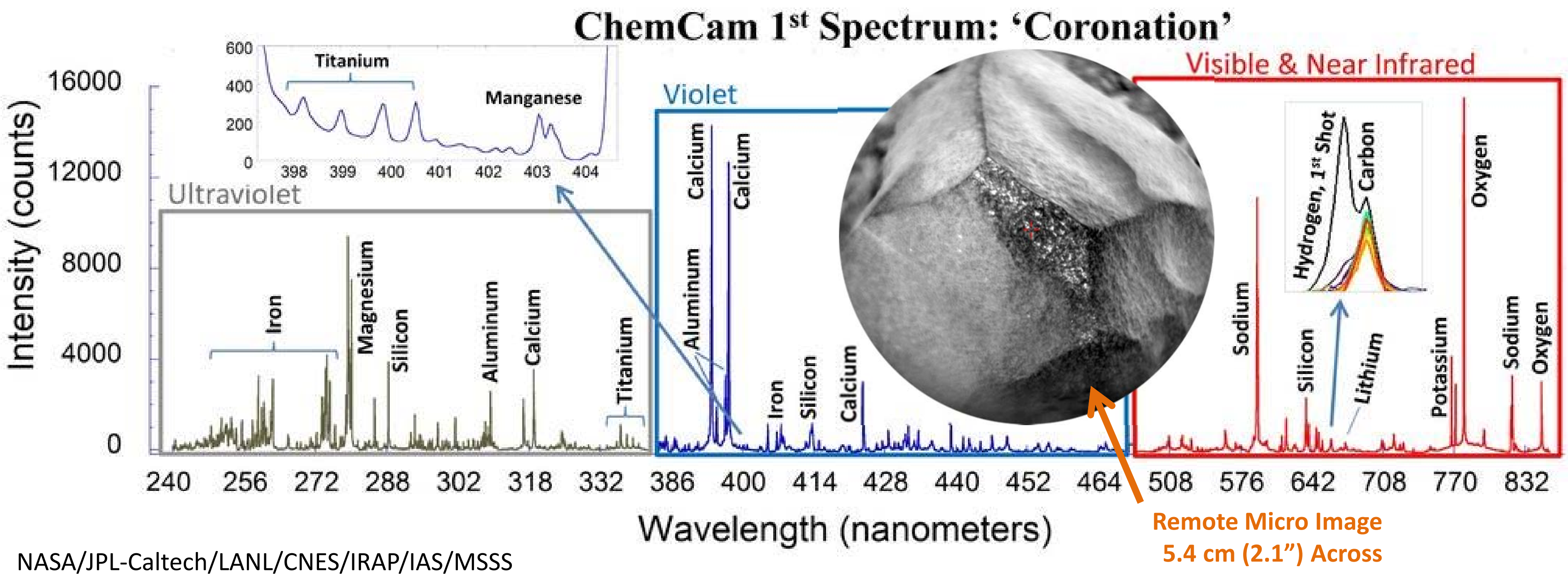
NASA/JPL-Caltech/MSSS

Mastcam mosaic of Mount Sharp, descent rocket scours, and rover shadow



NASA/JPL-Caltech/MSSS

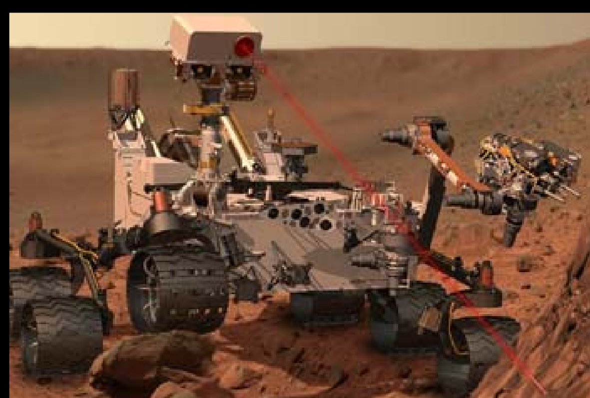
Curiosity self-portrait using the arm-mounted Mars Hand-Lens Imager, through dust cover

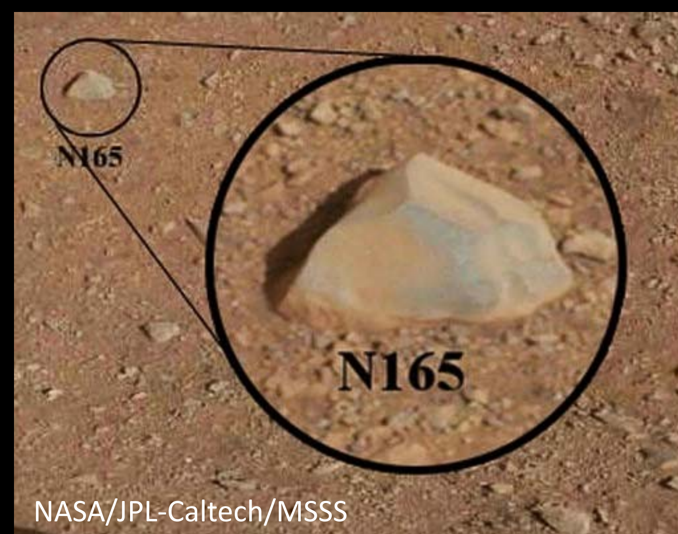


NASA/JPL-Caltech/LANL/CNES/IRAP/IAS/MSSS

ChemCam spectra of Coronation

Target: Coronation (N165)
Sol 13
Shots: 30

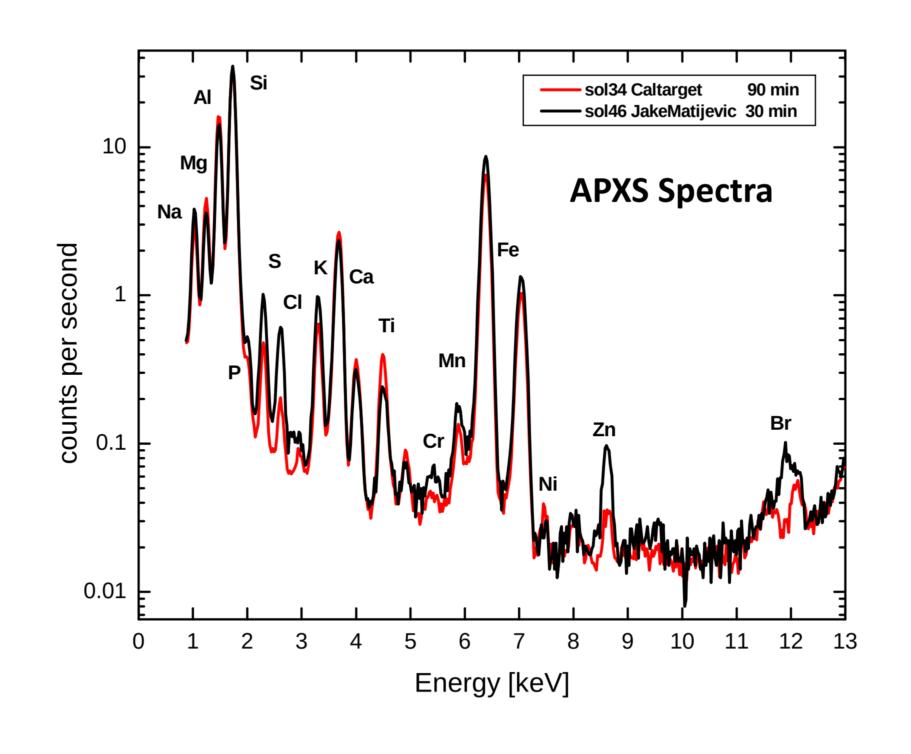




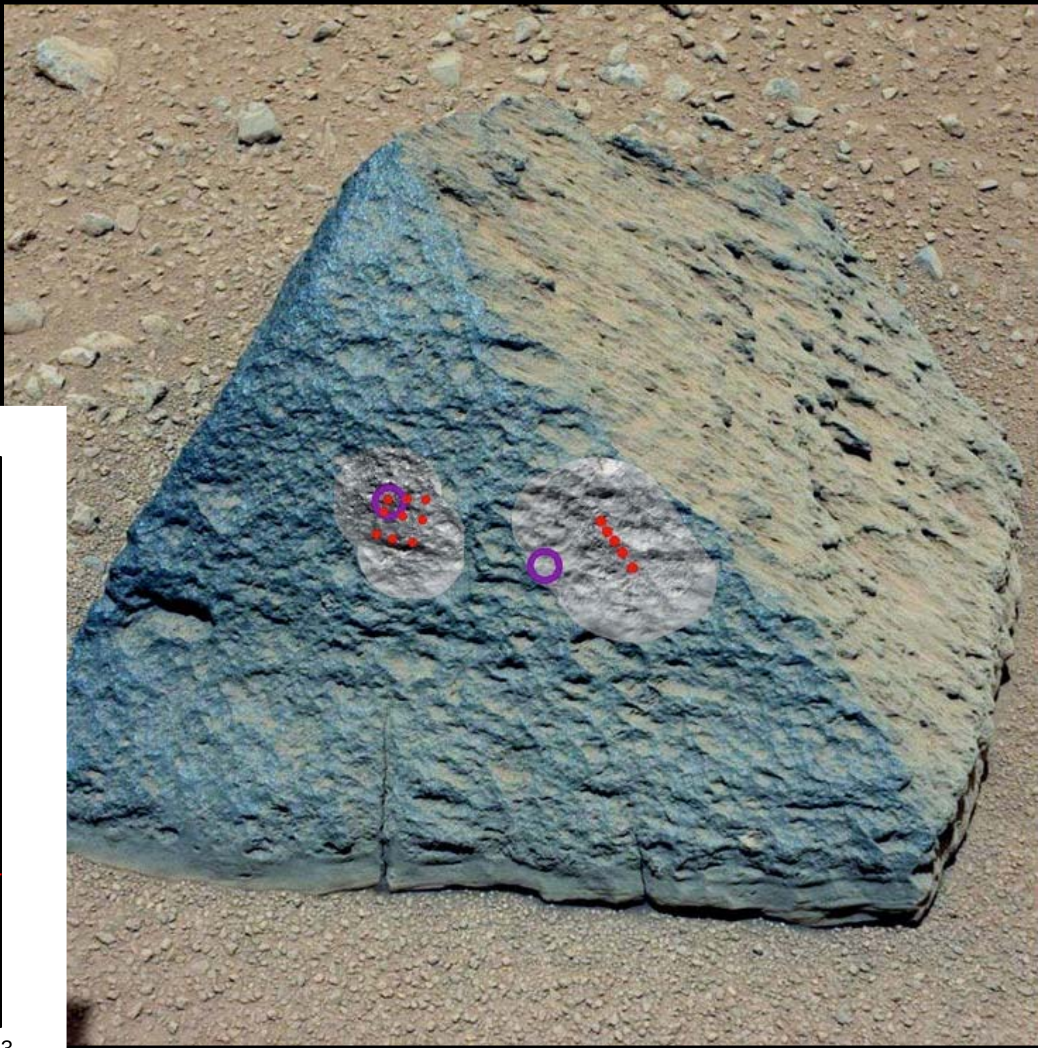
Jake Matijevic also studied by Mastcam (image), APXS, and ChemCam

APXS – alpha particle & X-ray spectrometer a Canadian contribution

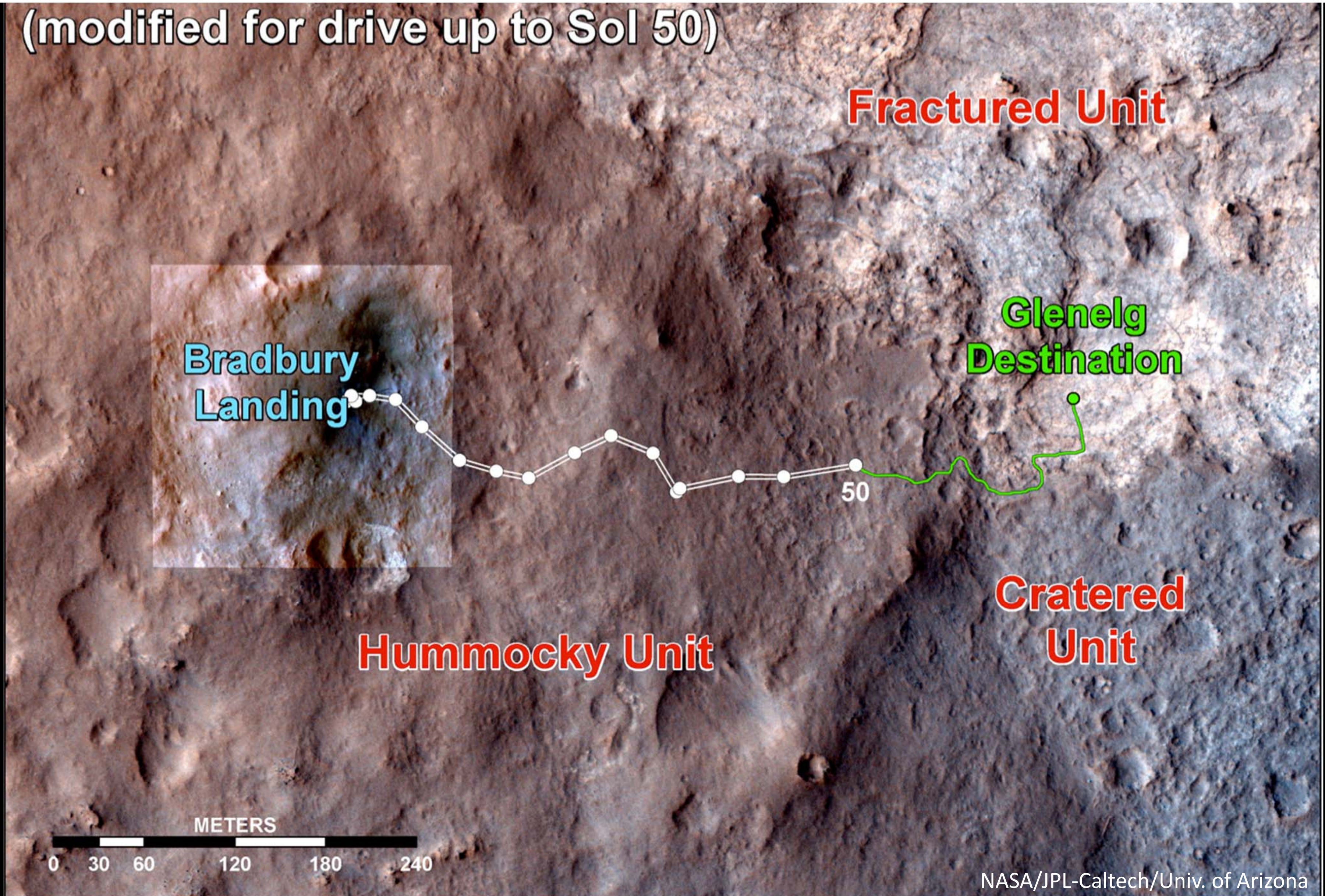
Composition is similar to alkaline basalts on Earth produced by partial melting of the mantle



NASA/JPL-Caltech/U. Guelph



NASA/JPL-Caltech/MSSS



Curiosity roved early on to Glenelg, where three distinct terrain types meet to initiate her drill campaign

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The conglomerate "Link" with associated loose, rounded pebbles

Wheel scuff to prepare for safe scooping

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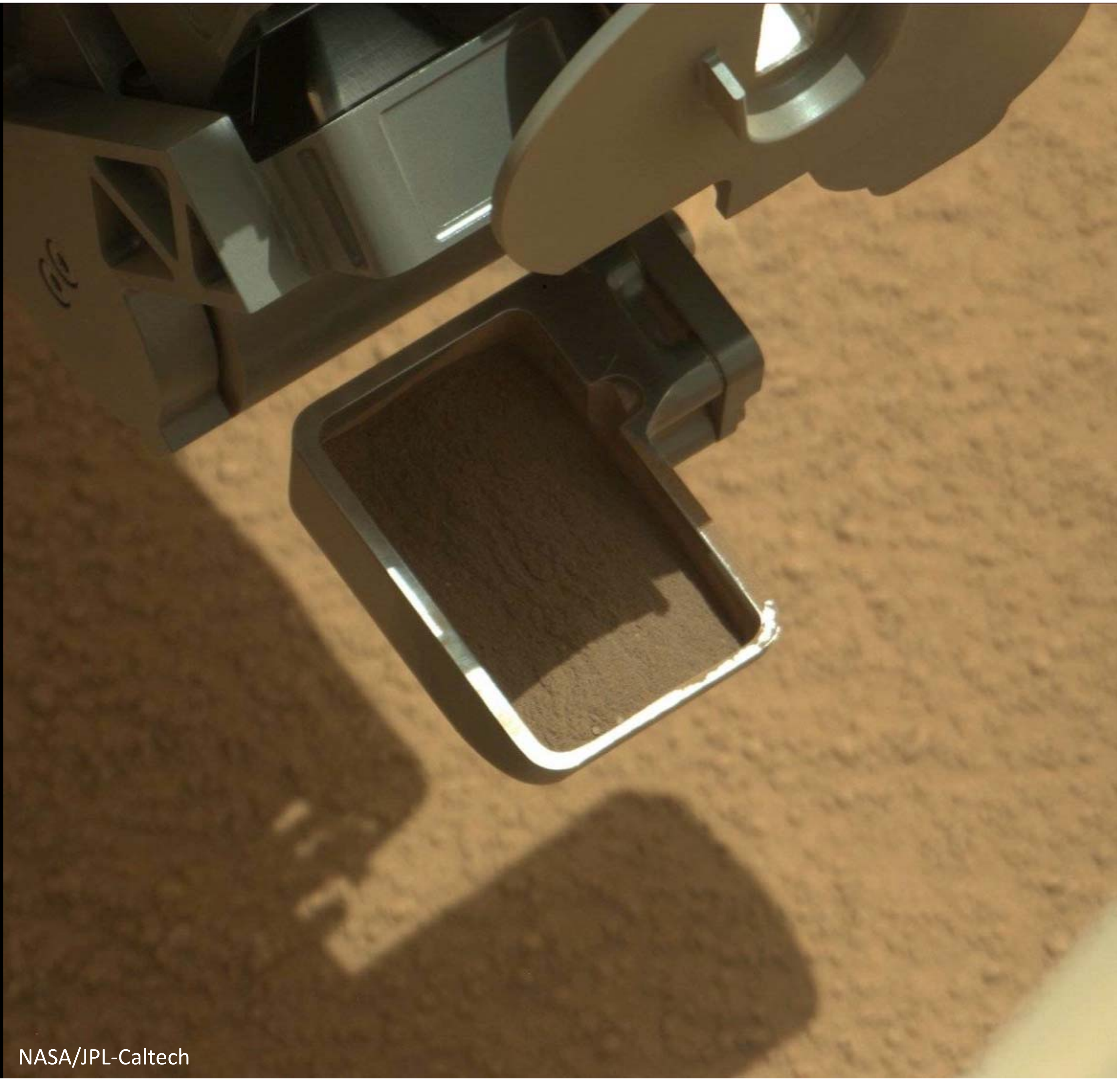
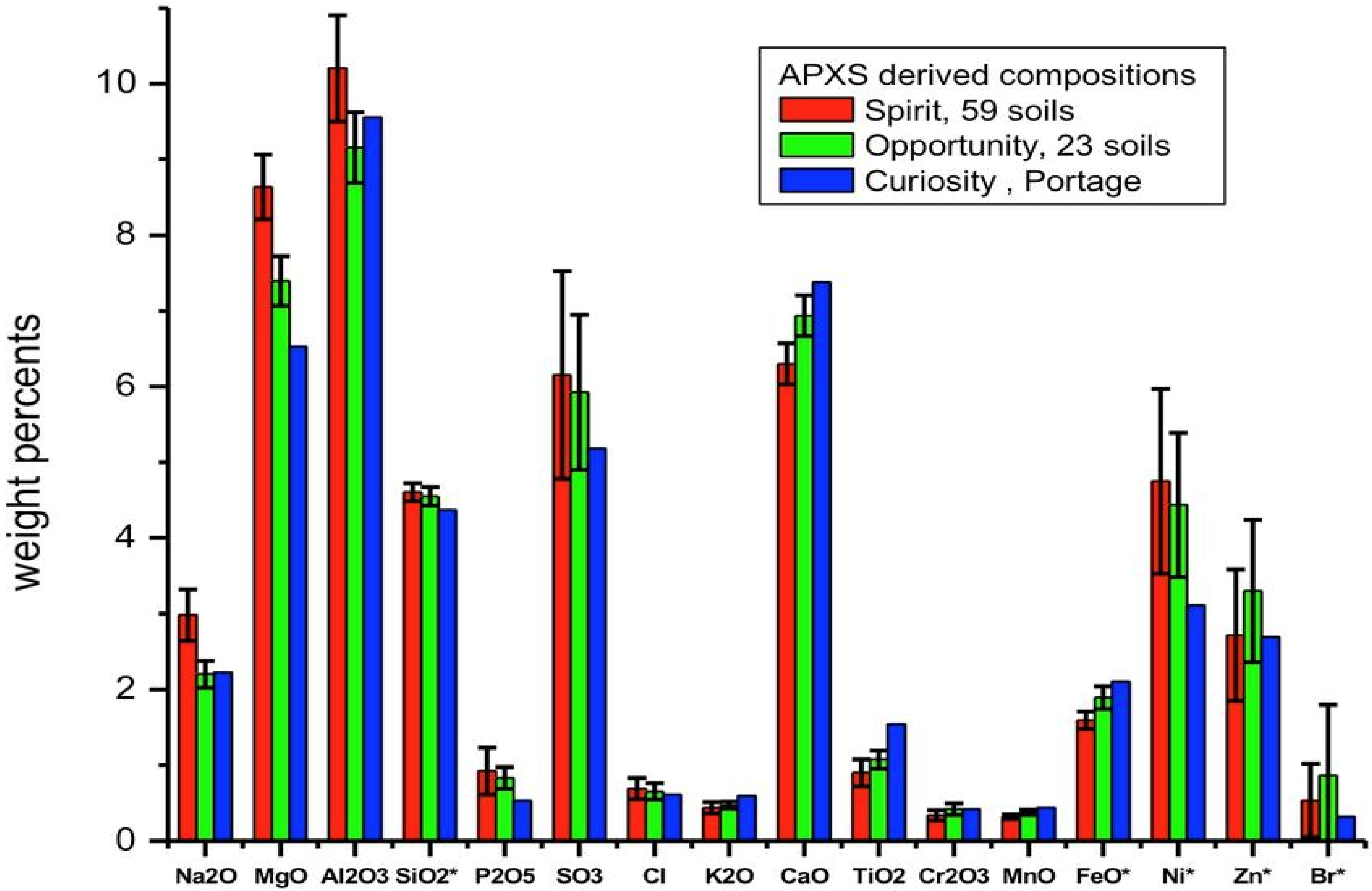
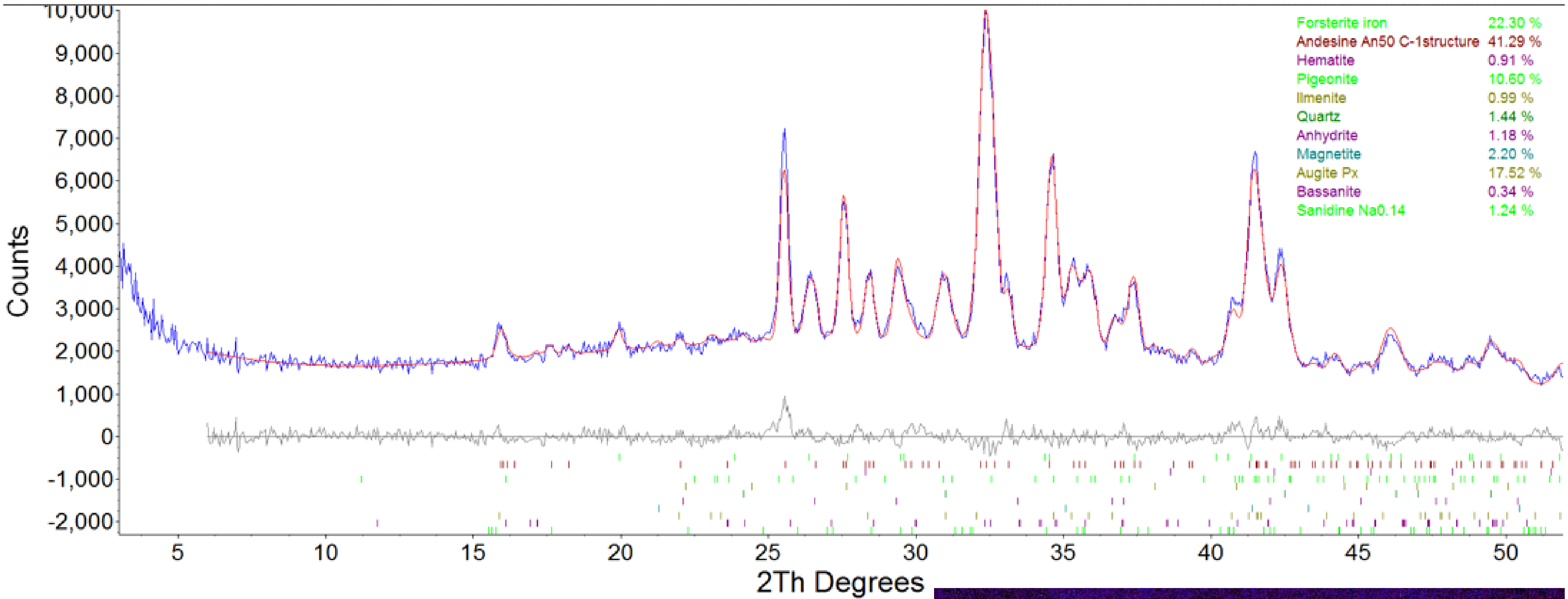
A scoop full of Mars sand


NASA/JPL-Caltech

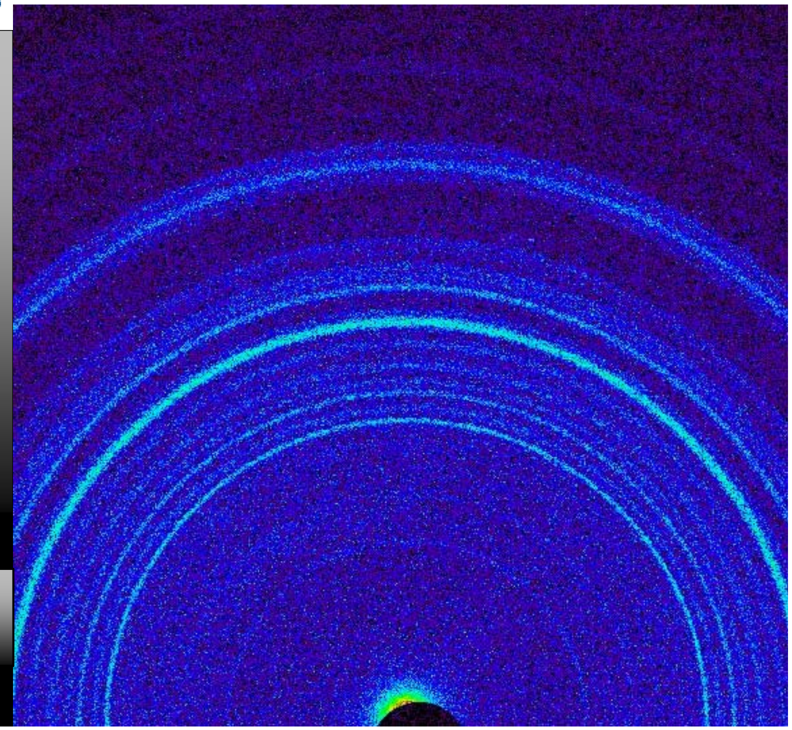


Elemental analysis from APXS on three missions shows similar compositions in martian fines



First XRD experiments on Mars from the Rocknest fines show weathered basalt (pyroxene, olivine, such as found inEarth's mantle, and plagioclase feldspar also found in Earth's crust

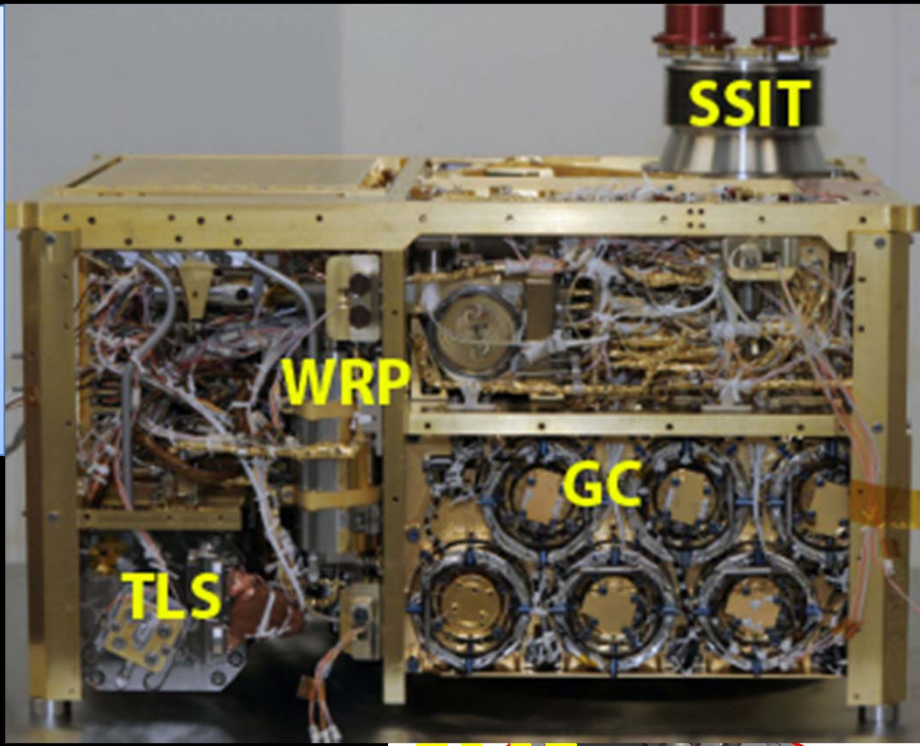
XRD pattern on CCD →

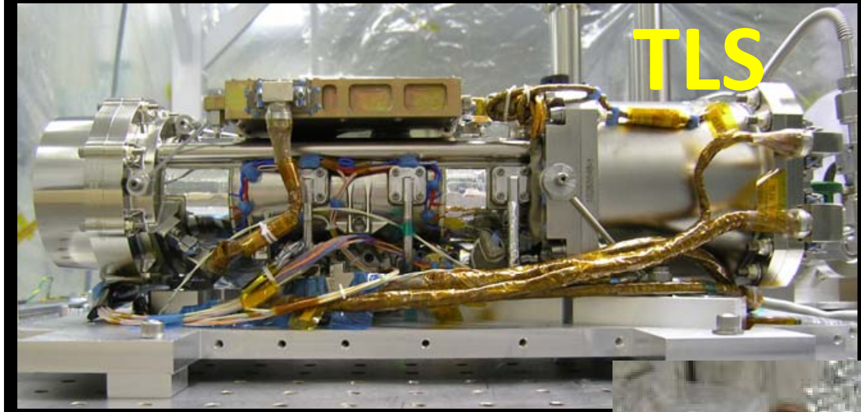


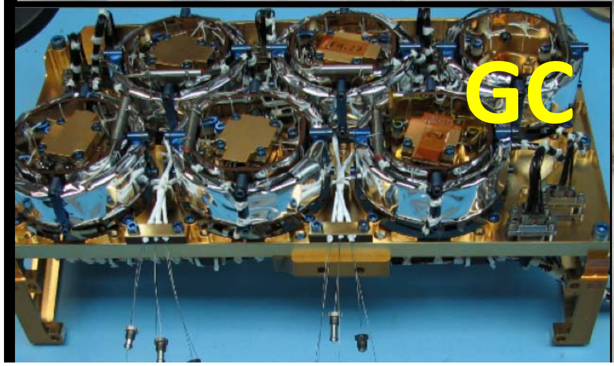
The SAM suite

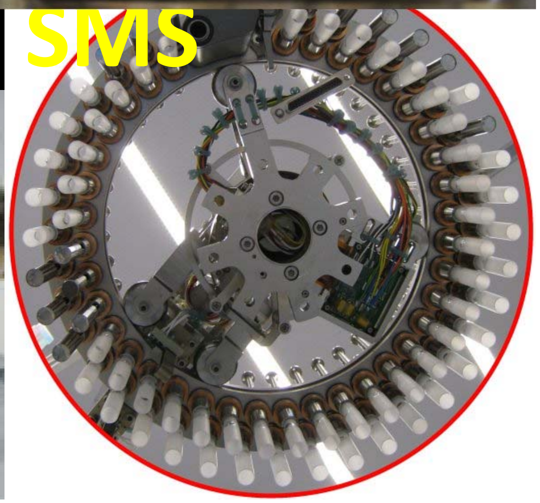
SAM suite instruments and major subsystems

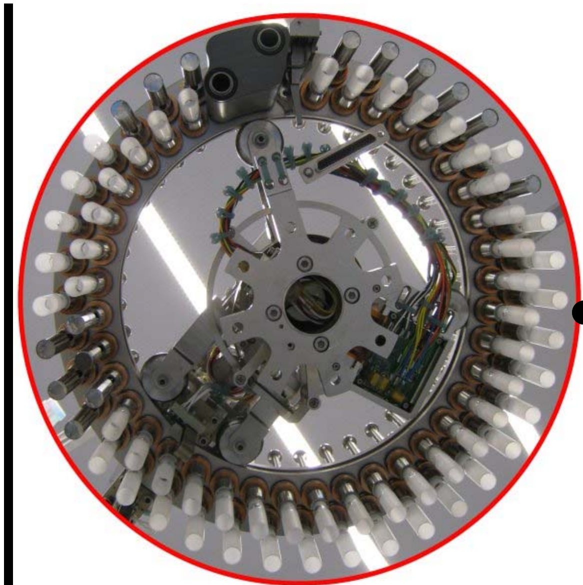
- Quadrupole Mass Spectrometer
- 6-column Gas Chromatograph
- 2-channel Tunable Laser Spectrometer
- Gas Processing System
- Sample Manipulation System











Scooped Rocknest sample

SAM analyzes atmospheric gas or vapors extracted from solids for analysis in 3 instruments

SAM sample manipulation system

Gases are released as samples are heated in SAM's oven

Oven

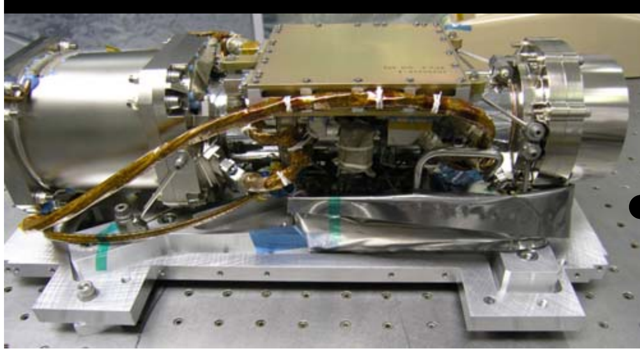
He carrier gas for both EGA and GCMS

Mass spectrometer (QMS)

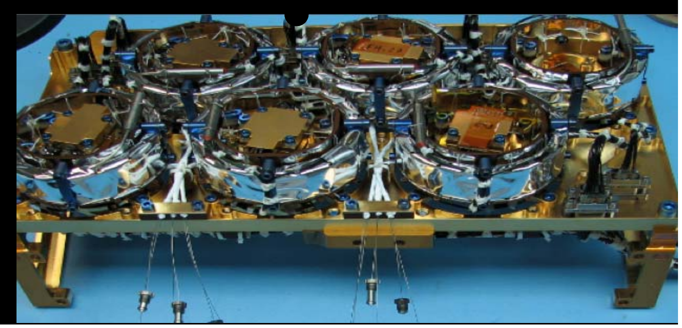
Measurement order for Rocknest
- EGA with QMS
- TLS
- Combined GC and QMS

Hydrocarbon trap

Gas chromatograph (GC)



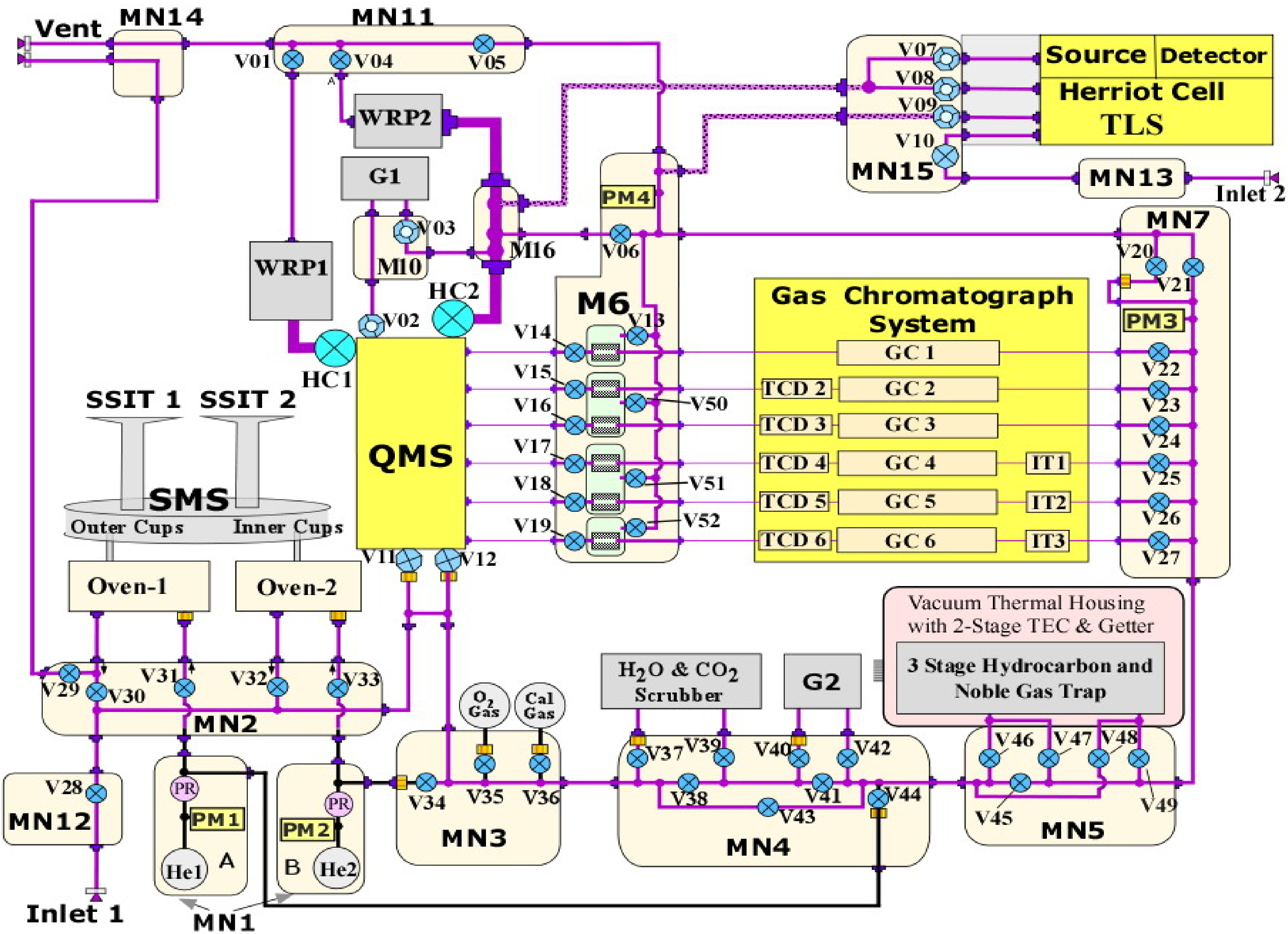
Tunable laser spectrometer (TLS)



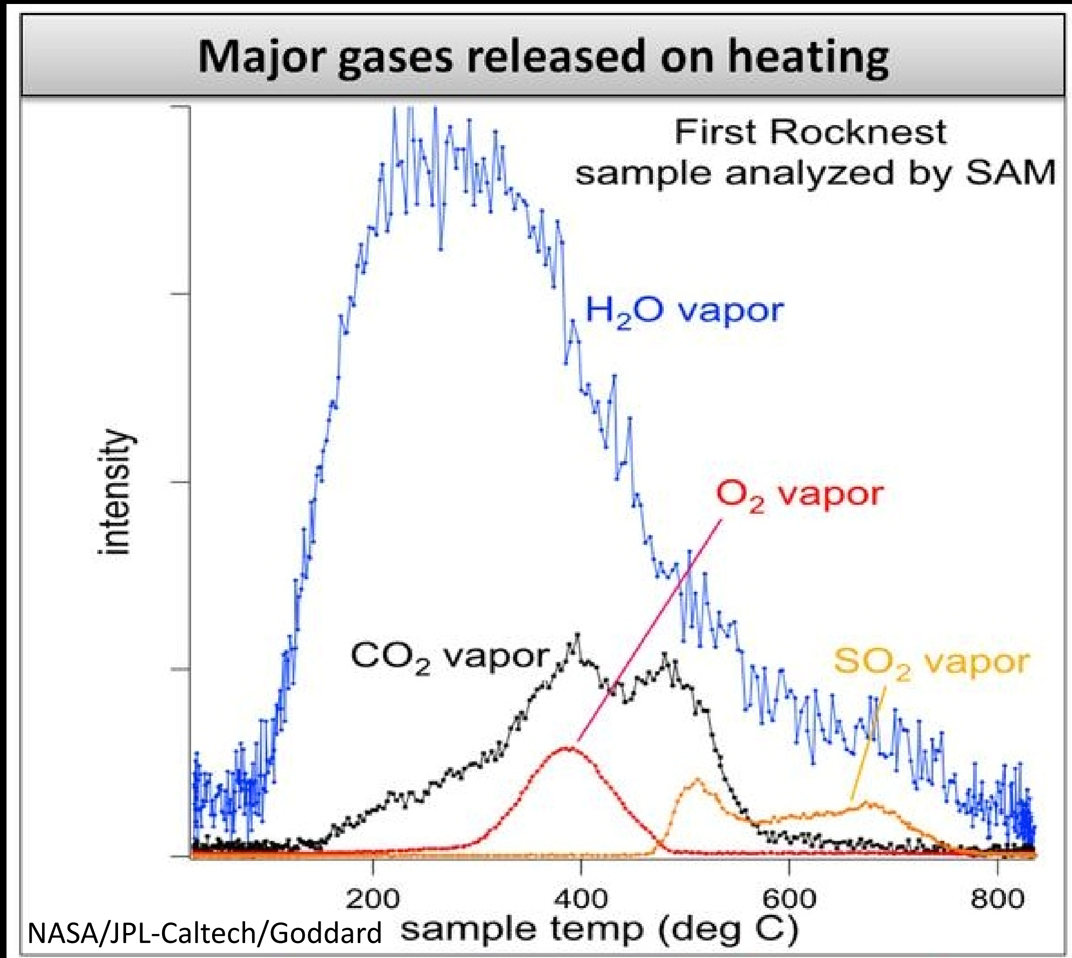
SAM Integration


SAM integrated into rover January 2011

The SAM gas flow diagram



SAM's commanding language allows us great flexibility in generation of new sequences on Mars as we make discoveries – we keep a duplicate SAM operational at NASA Goddard to test these scripts



Water

Oxygen

Sulfate

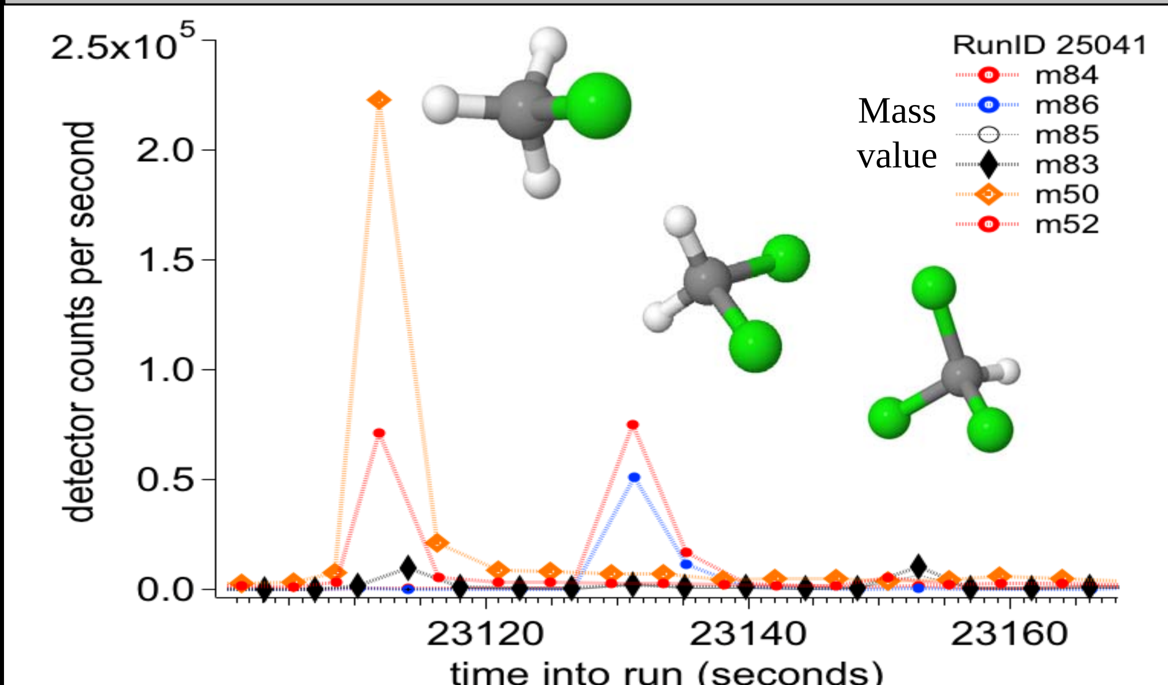
Hot → Hotter

SAM found water, sulfates, carbonates, and potentially perchlorates

Gases released during SAM experiments

Chlorinated compounds CH_3Cl, CH_2Cl_2, $CHCl_3$, and a 4 carbon chlorine containing compound are detected by SAM

Chlorine compounds found in Rocknest



Although the Cl in these organic compounds is Martian, it is presently unclear whether the carbon is Martian or terrestrial. This remains to be established with ongoing analysis, future laboratory work, and experiments on Mars.

The Curiosity search for organics in other environments and samples continues

SAM results show that the Rocknest sand drift does NOT contain abundant organics

Organic compounds that arrive from space in the form of micrometeorites may be transformed by a variety of mechanisms

- **Cosmic radiation**
- **Ultraviolet radiation**
- **Hydrogen peroxide**
- **Dust induced electrical discharges**
- **Other oxidants in soil/dust**

Summary of SAM Rocknest results

Isotopic and Chemical Composition of Rocknest Soil – Significant Findings		
Measurement	**Interpretation/Significance**	**Documentation**
Water EGA*	1.5-3 wt. % resource for future humans on Mars	Leshin et al. Science 9/2013
Water isotopes	D/H > 5 x terrestrial → atmosphere exchange	
Carbon Dioxide	Iron or magnesium carbonates	
Oxygen & HCl	Oxychloride phase likely hydrated Ca perchlorate	Glavin et al. JGR 9/2013
SO_2 and H_2S	Fe-sulfates or sulfites / reduced sulfur phases	McAdam et al. sub. JGR
Major/Minor Gases	H_2O, SO_2, CO_2, & O_2, plus minor gases H_2S, HCl, NH_3, NO, & HCN → chemical disequilibrium	Archer et al. submitted JGR
Organics with EGA & GCMS	No indigenous organics detected in Rocknest. Validation of GCMS performance#	Glavin et al. JGR 9/2013 Leshin et al. Science 9/2013

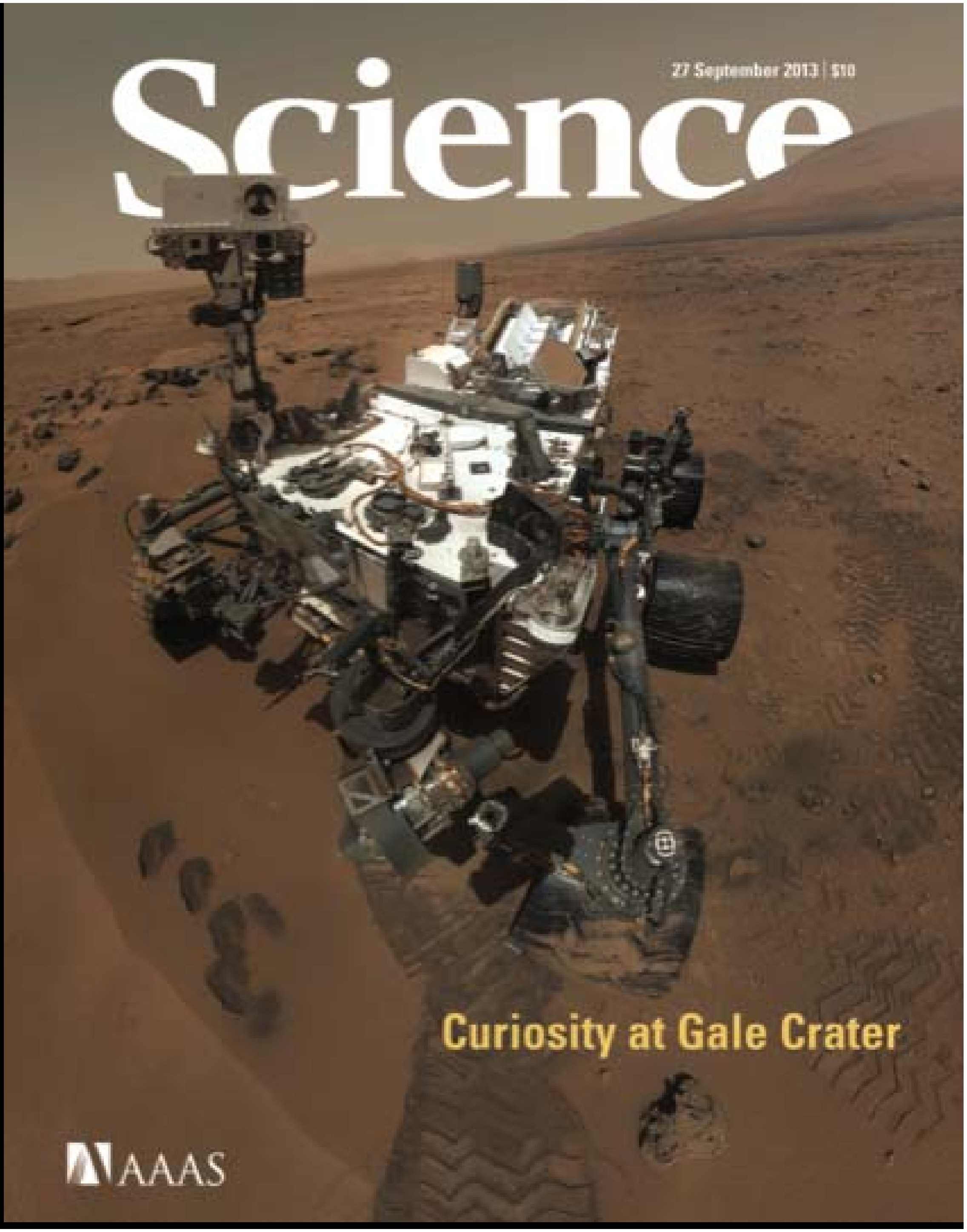
*EGA = evolved gas analysis **GCMS = gas chromatograph mass spectrometer analysis
#detection of simple chlorohydrocarbons with Cl from oxychloride phase and C mostly from traces of derivatization compound in sample manipulation system.

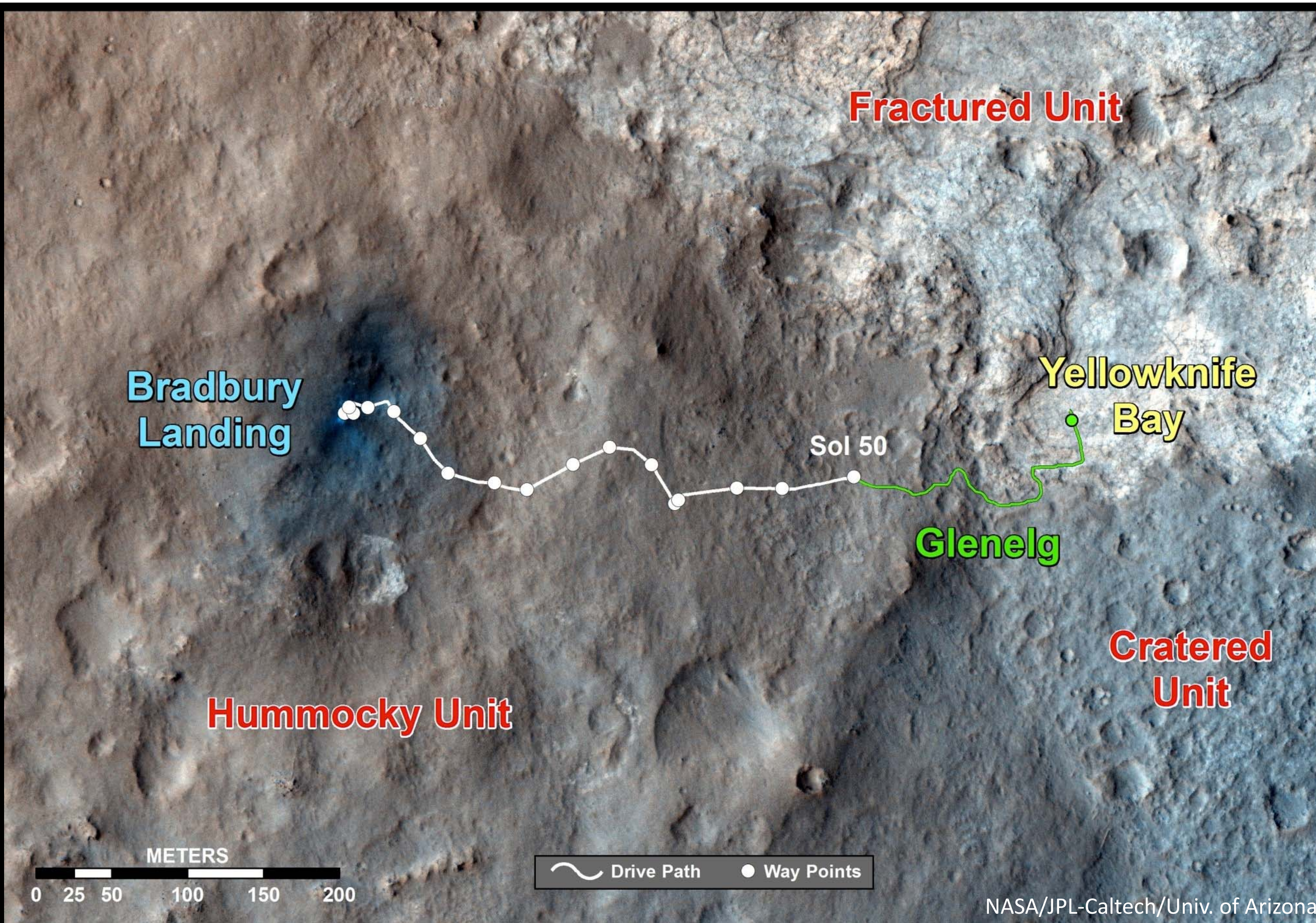
Curiosity

self-portrait at Rocknest

from 55 MAHLI images

showing four scoop bites and wheel scuff



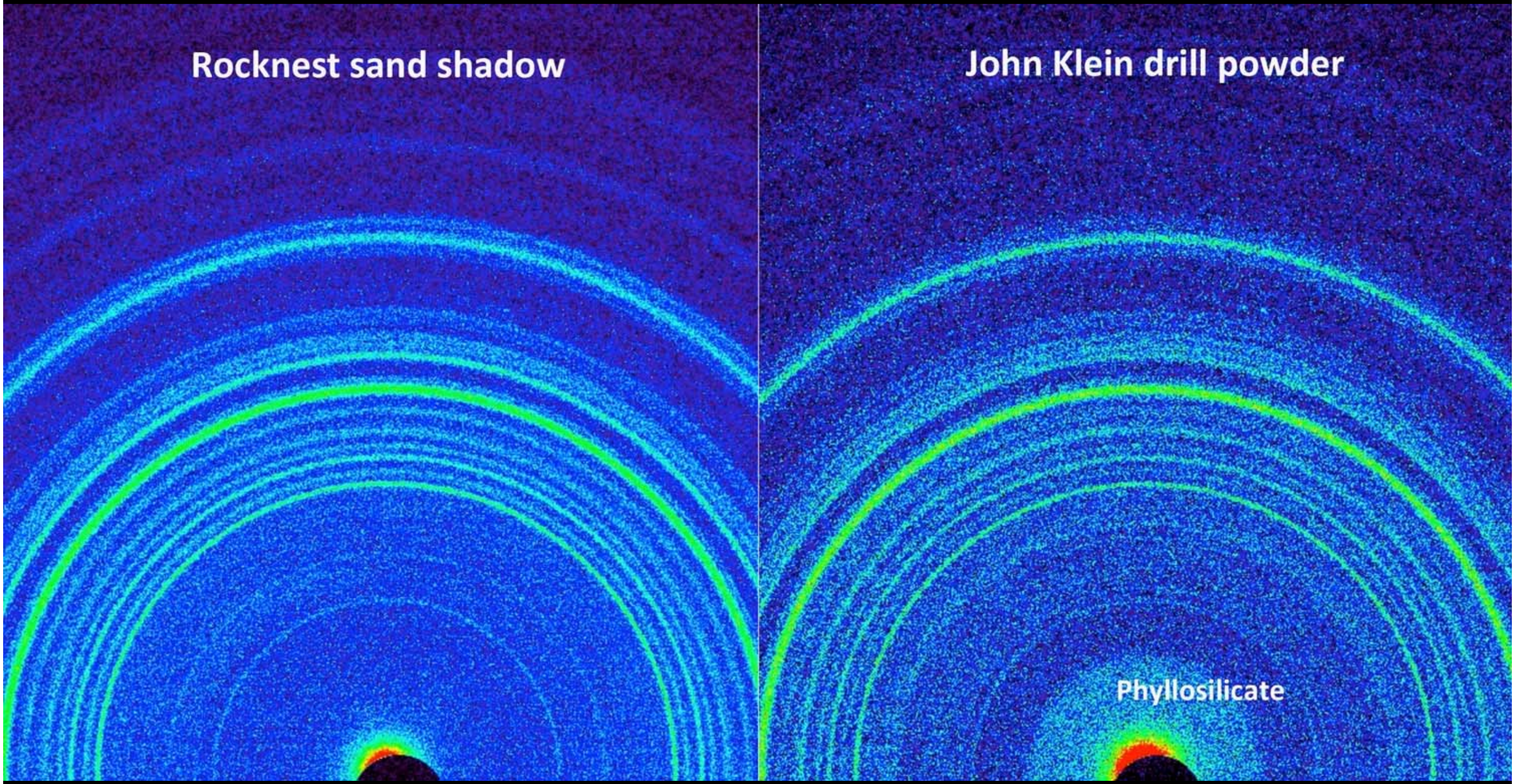


Curiosity progressed toward Glenelg, where three distinct terrain types meet

White (gypsum?) veins in Yellowknife Bay

Crossbedded layers in Yellowknife Bay

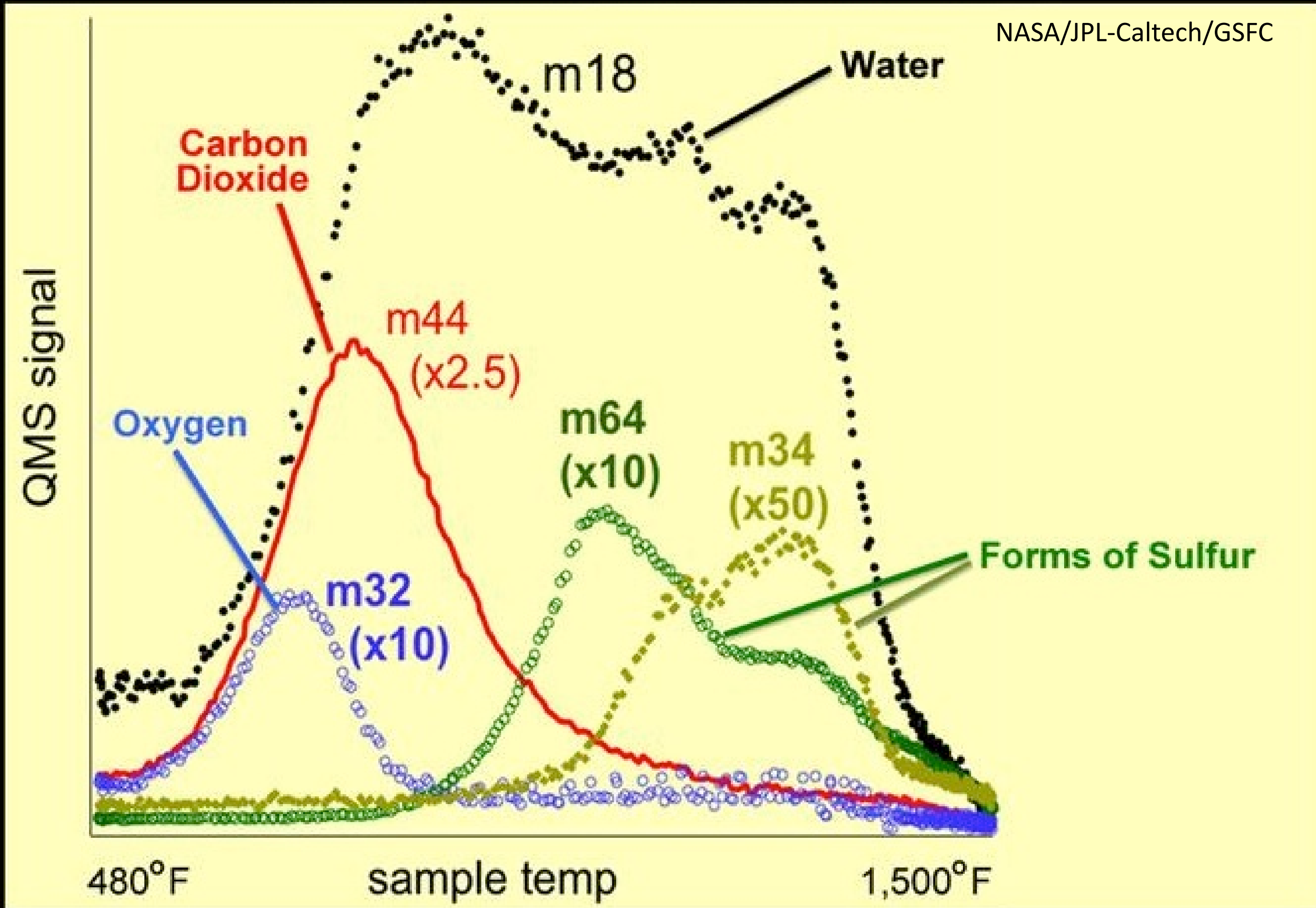
First drilled hole on Mars – February 6, 2013



NASA/JPL-Caltech/Ames

The drill powder contains abundant phyllosilicates (clay minerals), indicating sustained interaction with water

X-ray diffraction patterns from Rocknest (left) and John Klein (right)



SAM analysis of the drilled rock sample reveals water, carbon dioxide, oxygen, sulfur dioxide, and hydrogen sulfide released on heating. The release of water at high temperature is consistent with smectite clay minerals.

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Major gases released from John Klein sample and analyzed by SAM

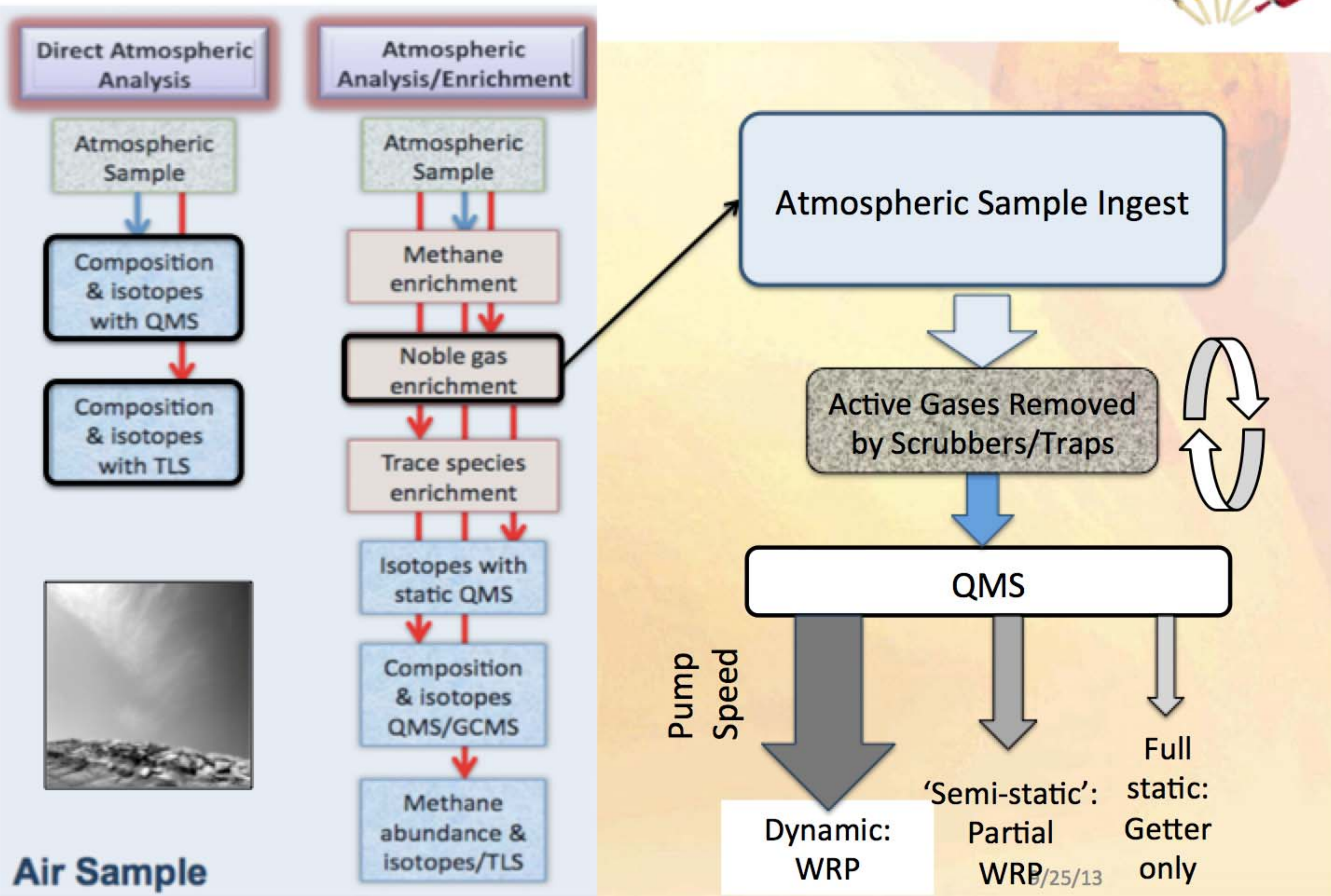
An Ancient Habitable Environment at Yellowknife Bay

- The regional geology and fine-grained rock suggest that the John Klein site was at the end of an ancient river system or within an intermittently wet lake bed
- The mineralogy indicates sustained interaction with liquid water that was not too acidic or alkaline, and low salinity. Further, conditions were not strongly oxidizing
- Key chemical ingredients for life are present, such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur
- The presence of minerals in various states or oxidation would provide a source of energy for primitive biology

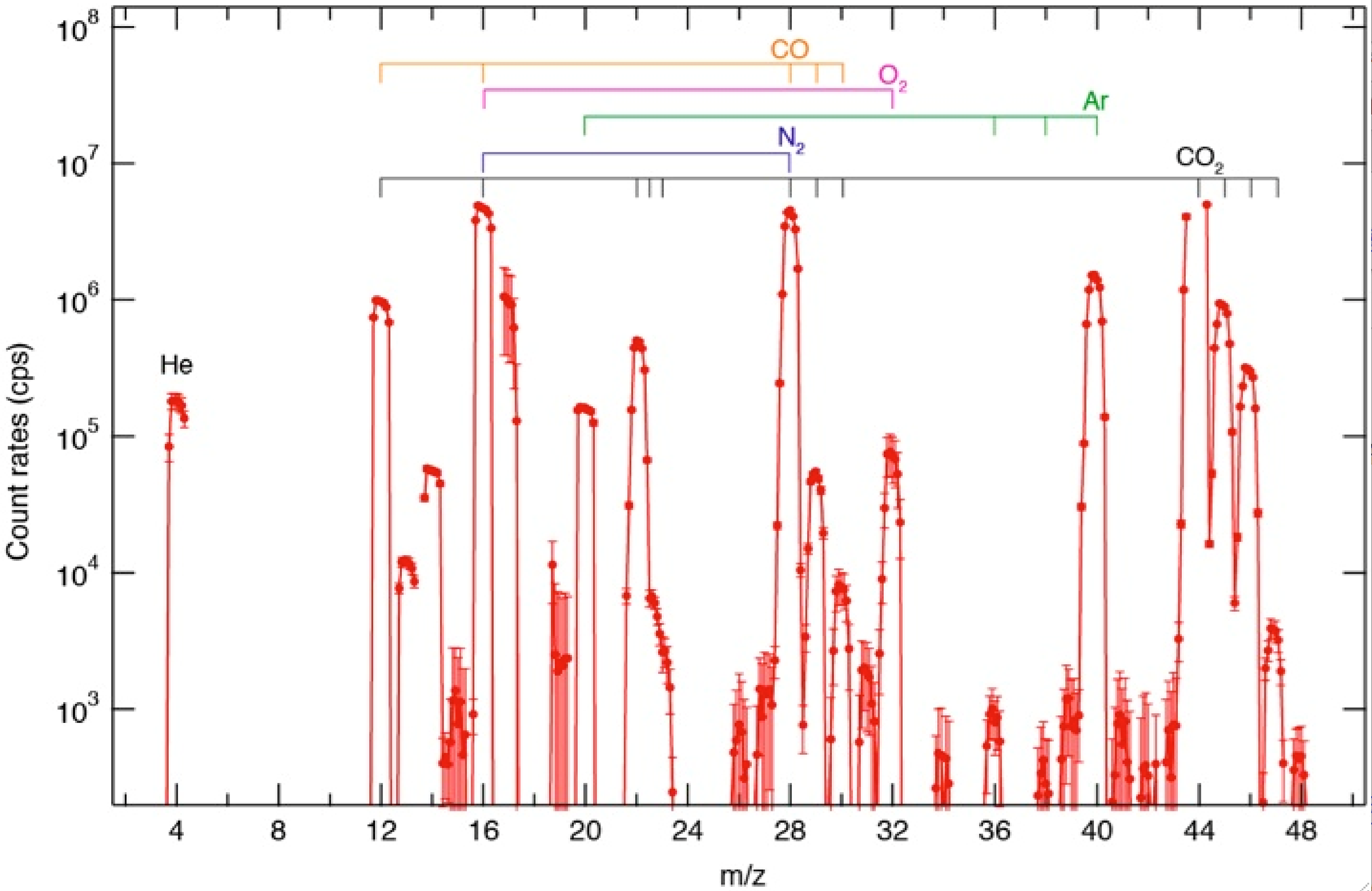
Detailed discussion of Yellowknife Bay results

- Stay tuned -

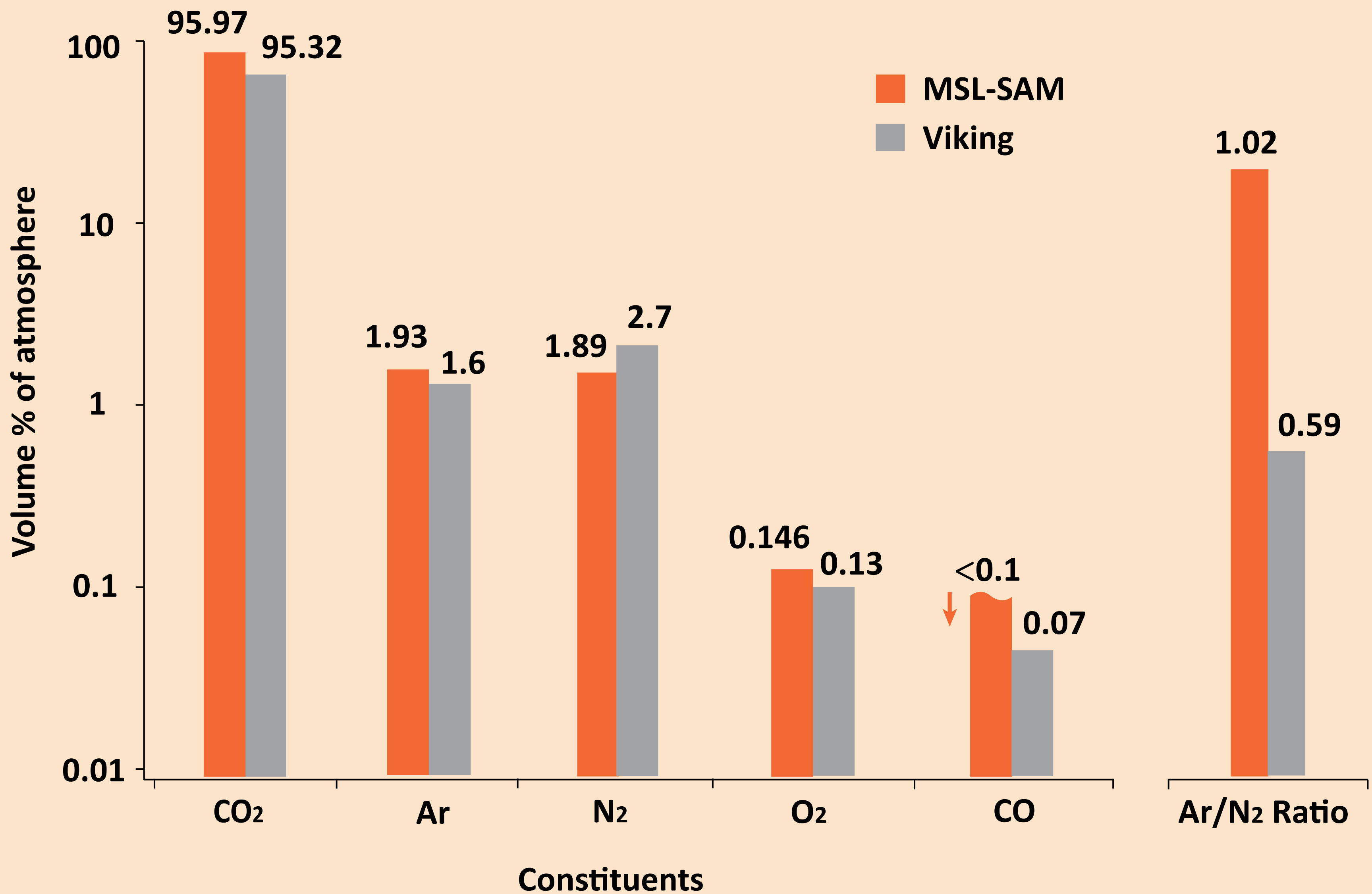
‘Flavors’ of SAM Atmospheric Measurements



SAM QMS mass spectrum for Sol 45

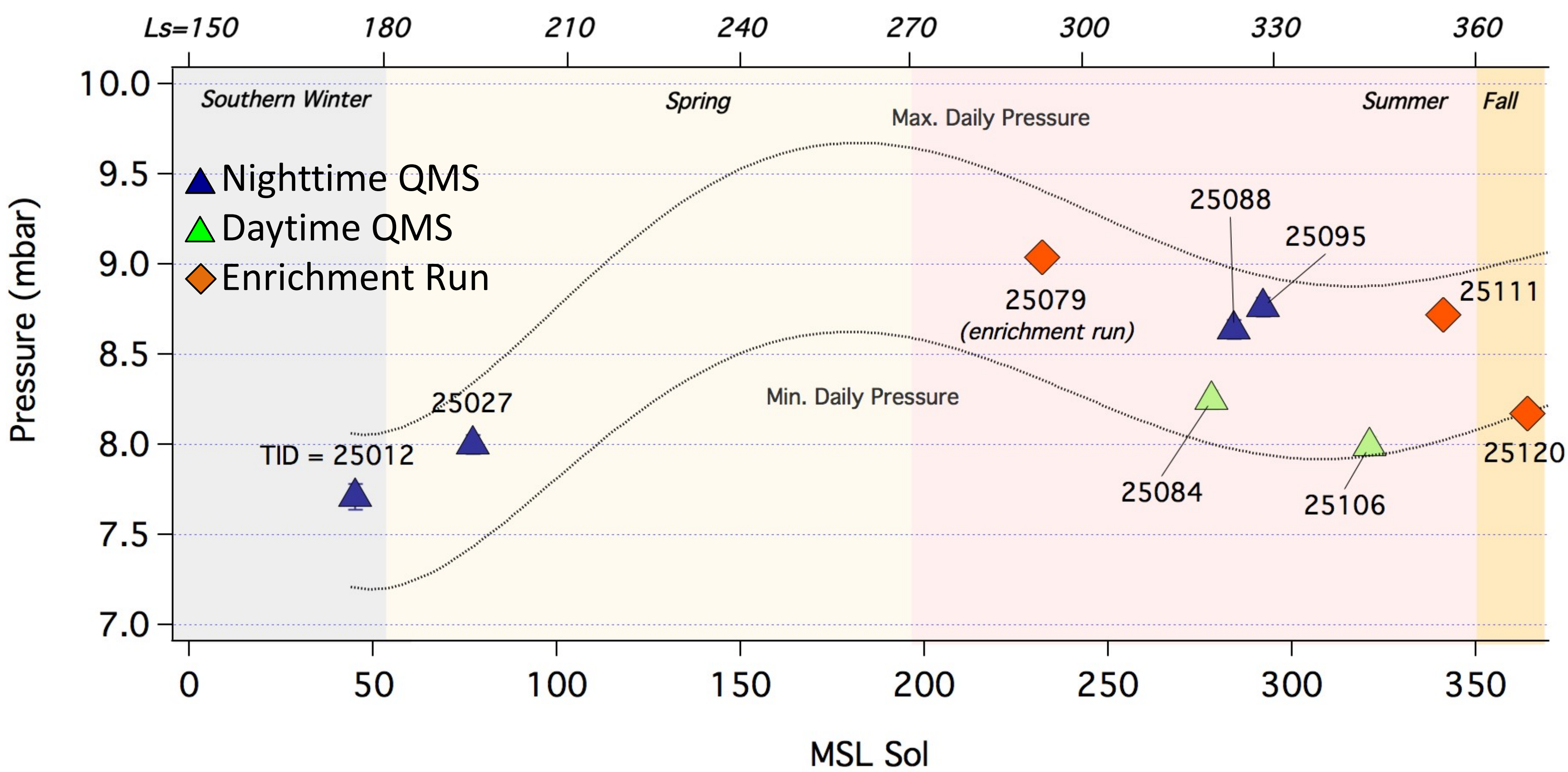


MSL's N_2 lower & Ar greater than Viking's, but Ar/N_2?

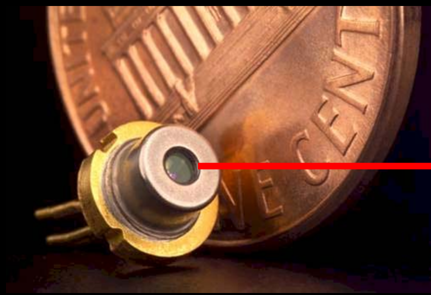


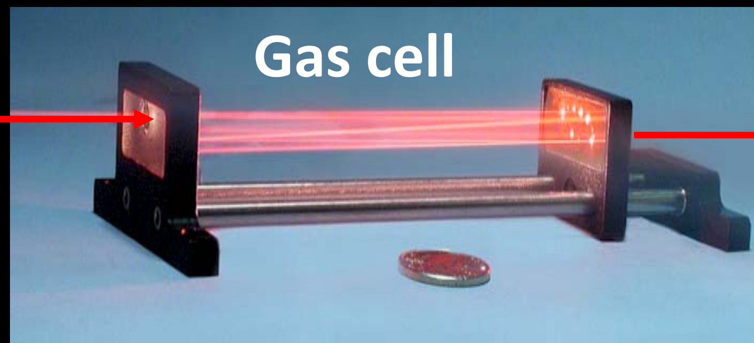
SAM/QMS Atmospheric Measurements - *temporal*

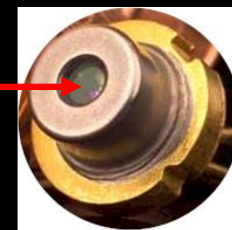
- Recent measurements span almost the full Southern Summer season, with day/night coverage



Laser Absorption Spectroscopy

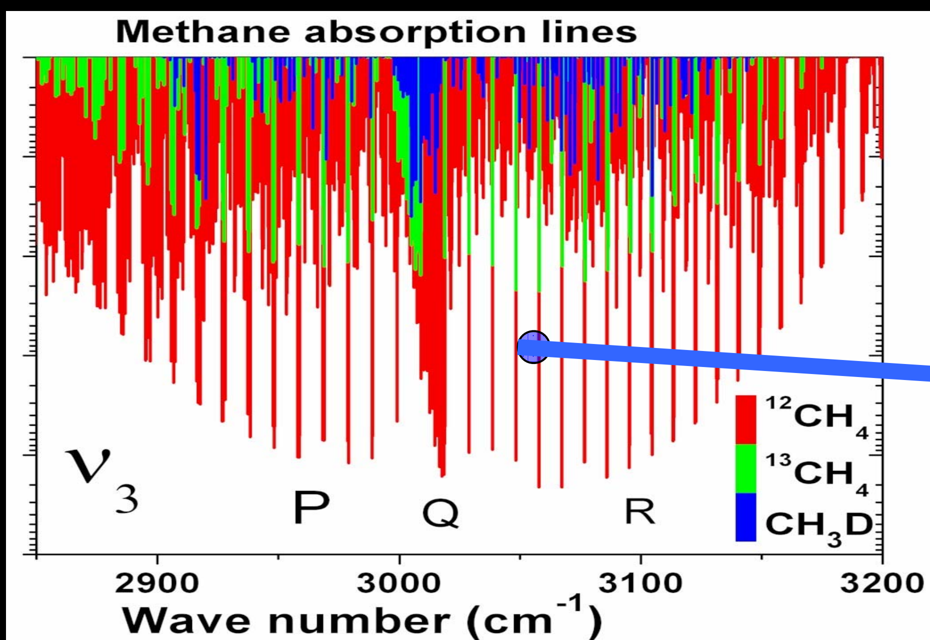


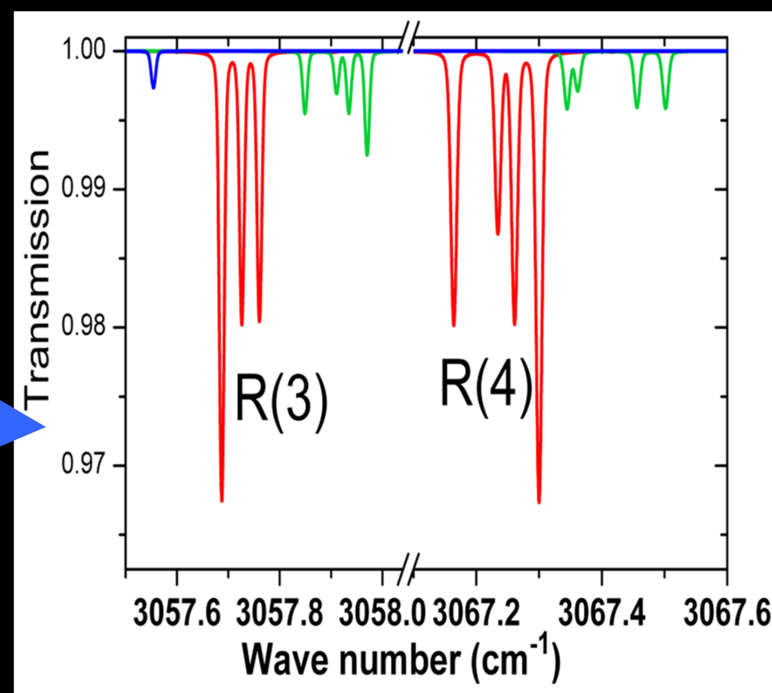




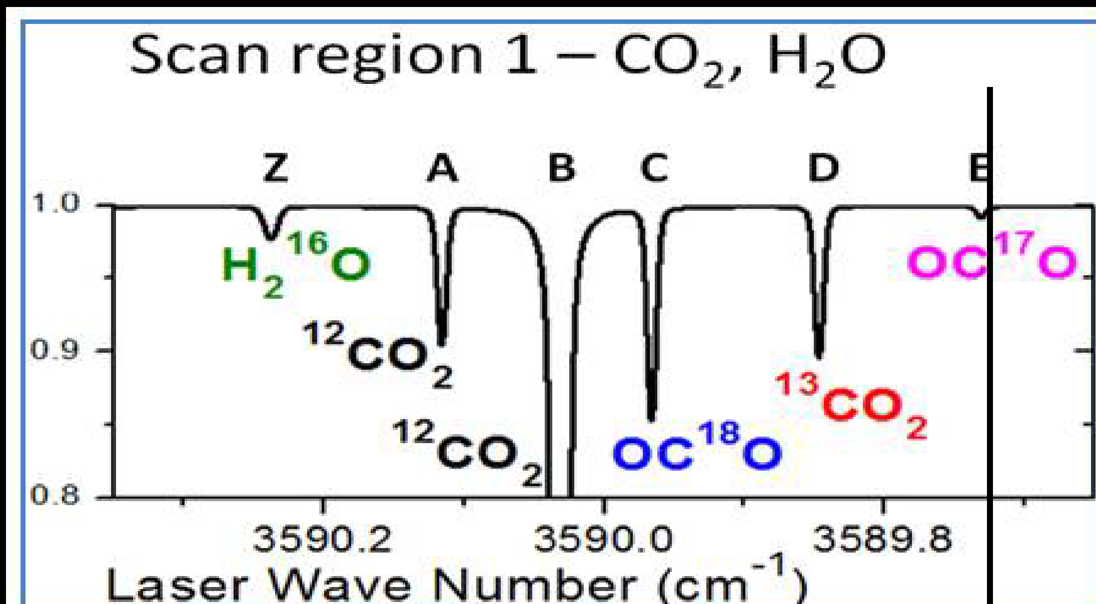
Detector

Tunable laser
1-12 μm

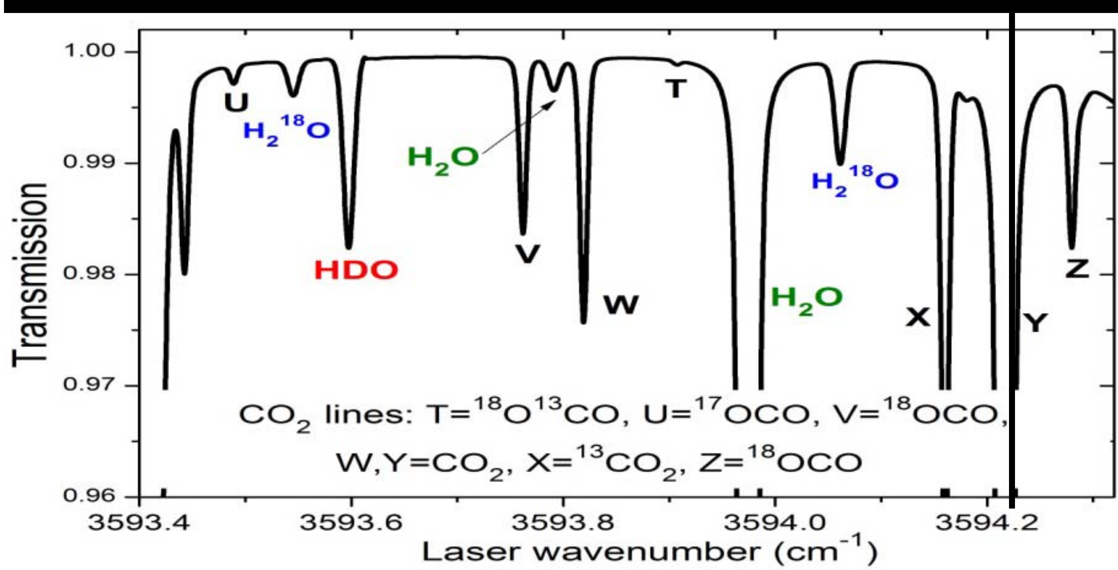




TLS CO_2, H_2O spectral regions

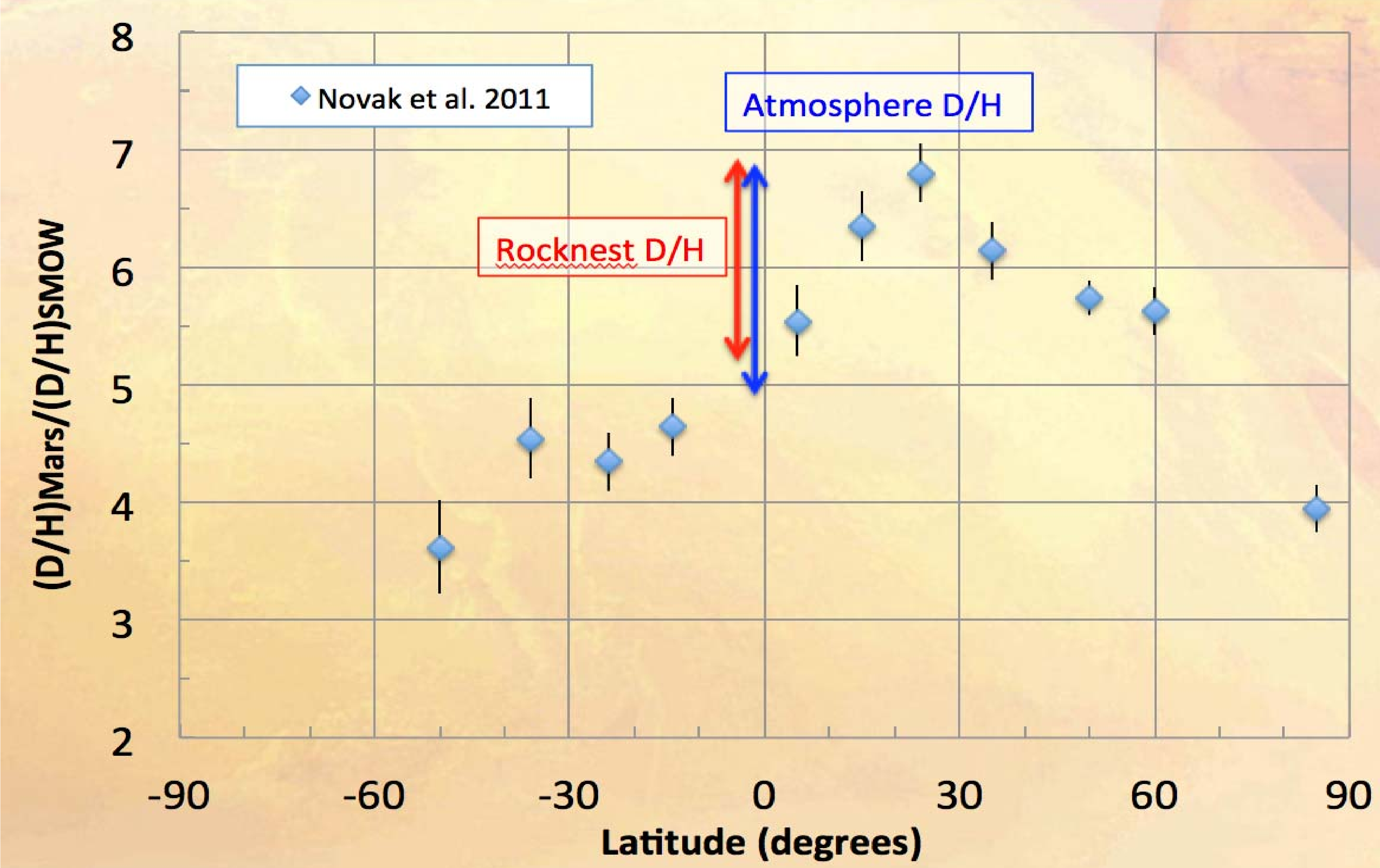


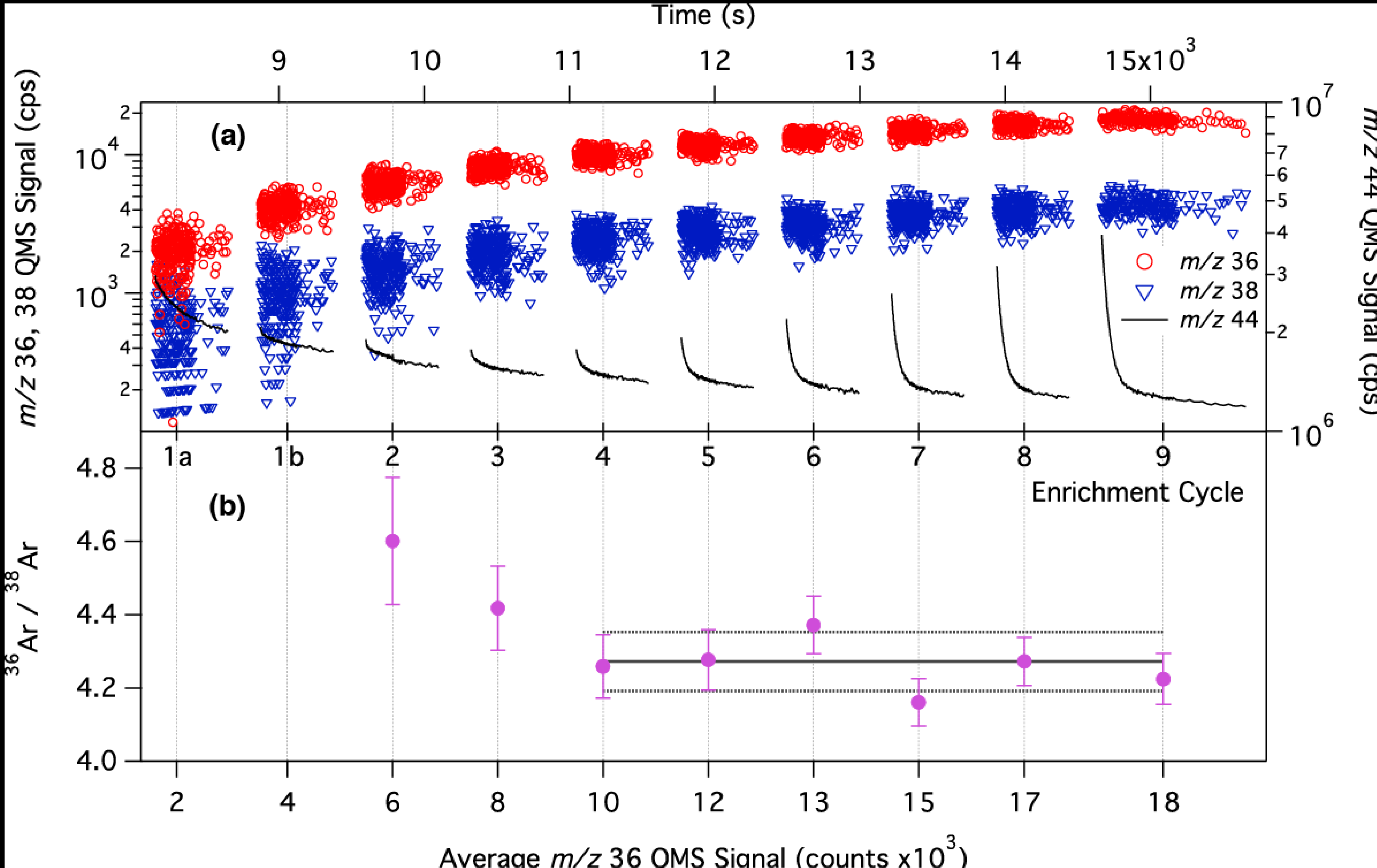
Scan region 1 - 3590 cm^{-1}
CO_2 isotopes



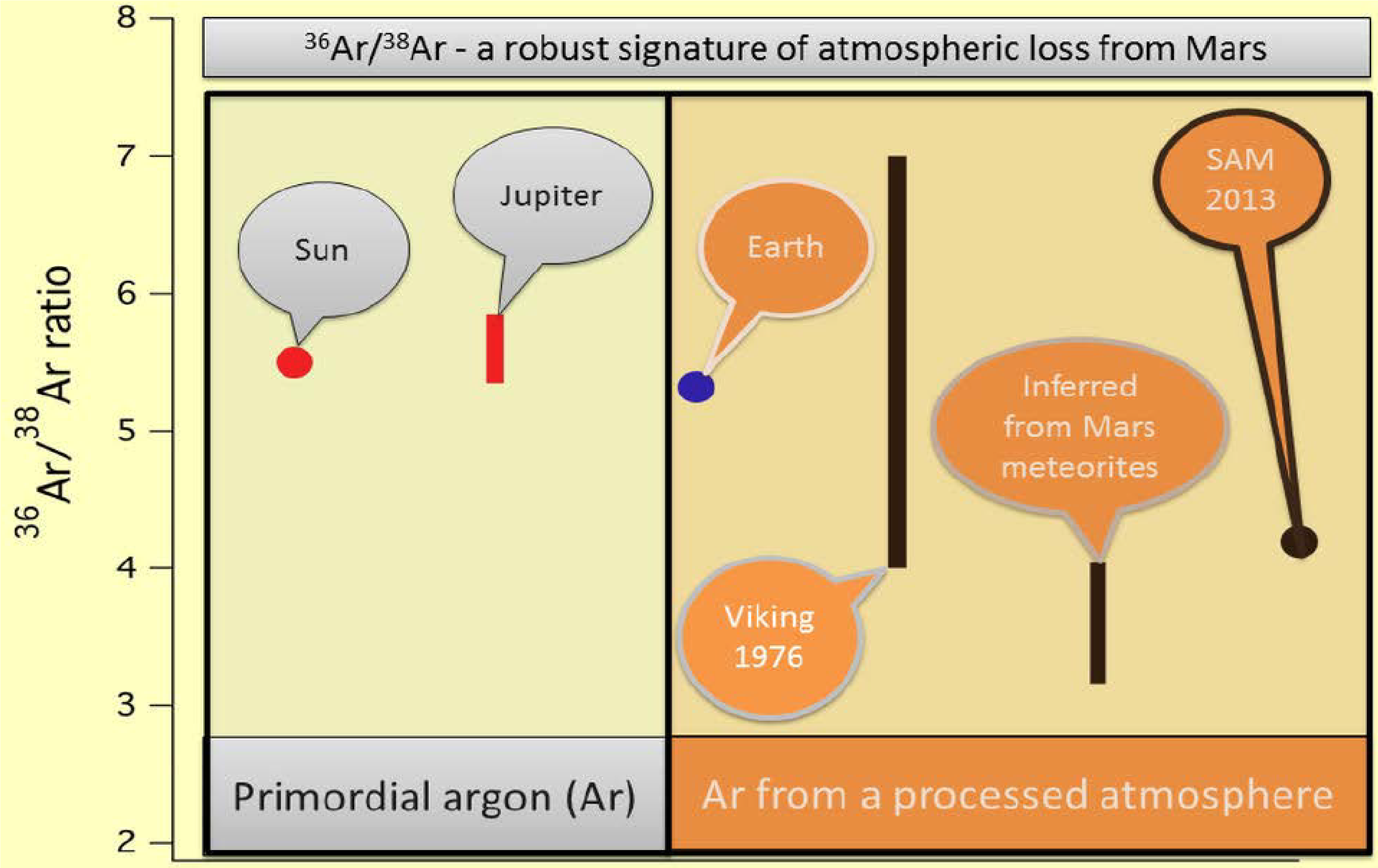
Scan region 2 - 3593 cm^{-1}
CO_2, H_2O isotopes

TLS D/H Data Compare Well with Previous Telescopic Measurements

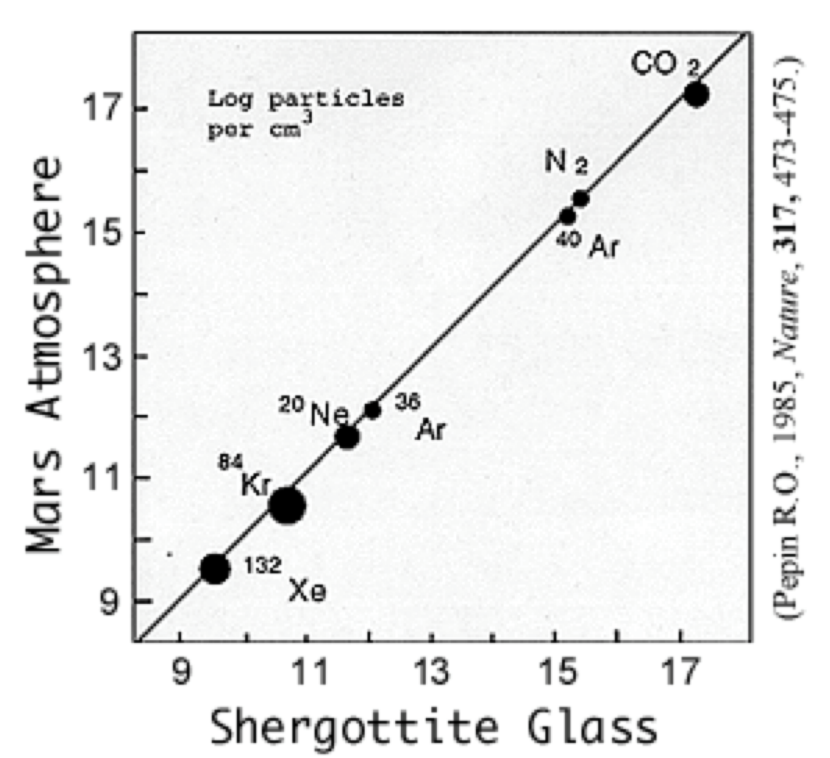


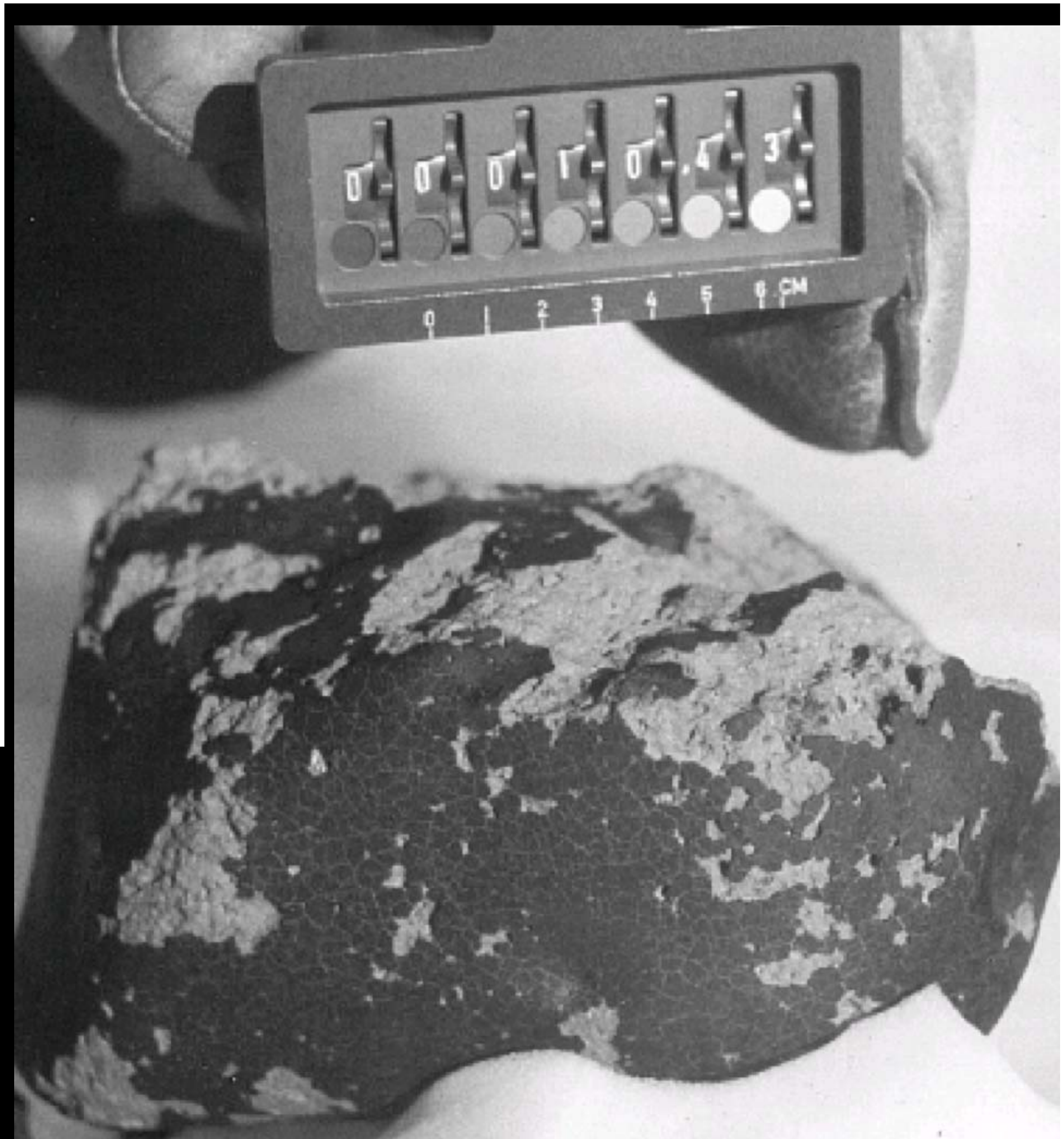


MSL/SAM QMS enrichment experiment on sol 231 (Atreya et al. 2013)



Heavy and light versions of atoms (ISOTOPES) in carbon dioxide and argon are key signatures of atmospheric loss



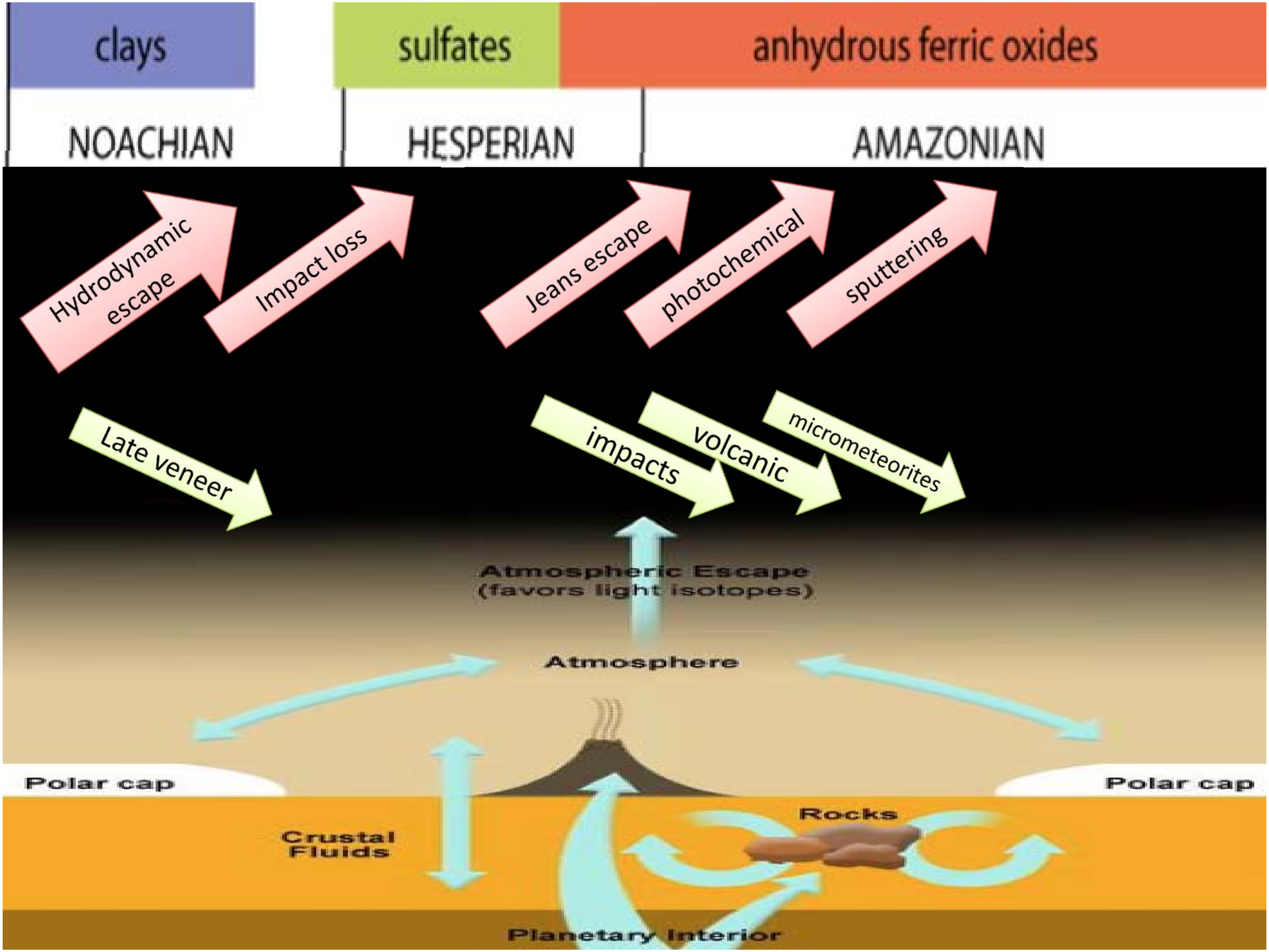


EETA79001 (1979 ANSMET expedition) found on Antarctica ice contains martian atmospheric gas

Isotopes point to atmospheric loss

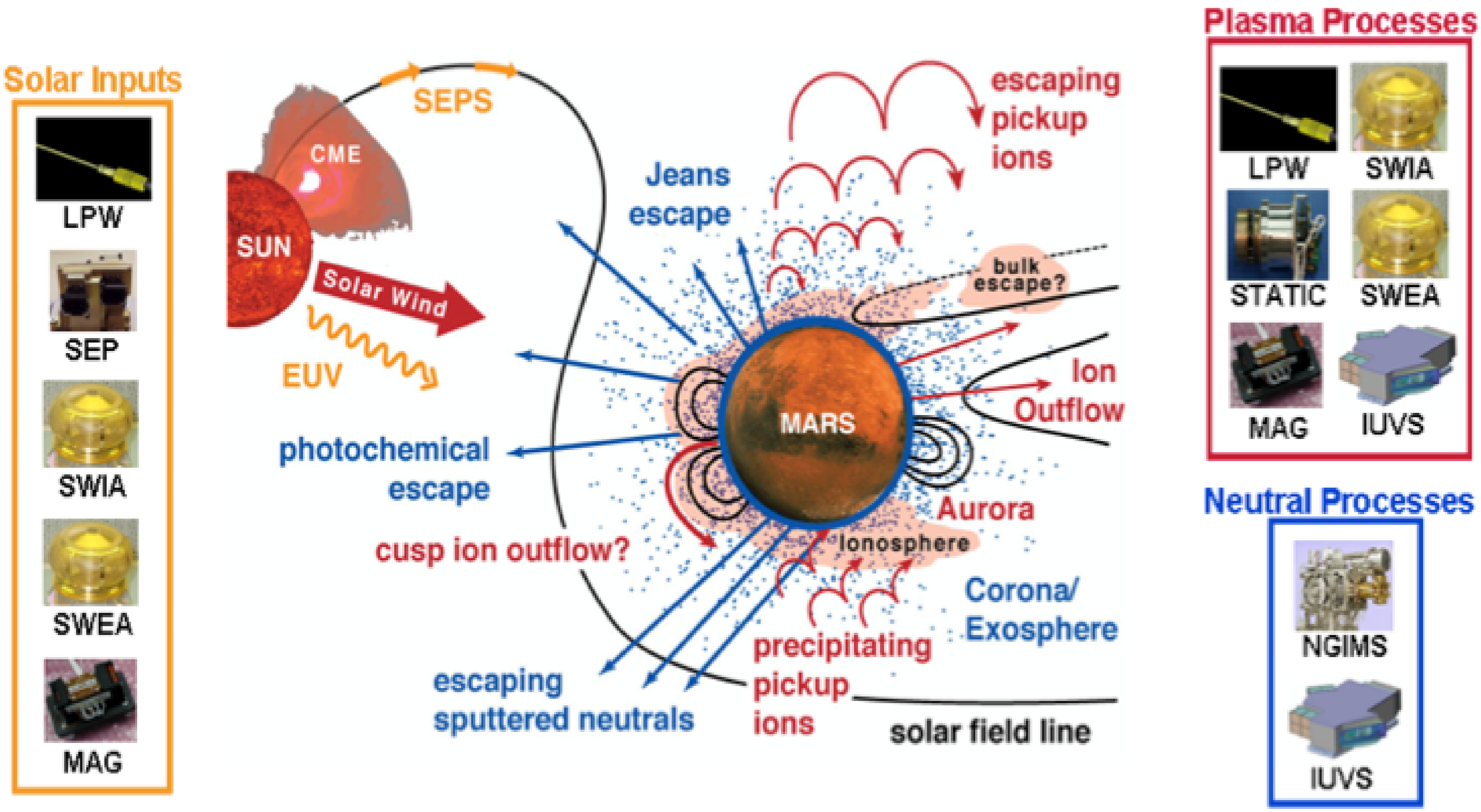
Isotopes	Mars value	SAM instrument	Reference
$^{36}Ar/^{38}Ar$	4.2 ± 0.1	QMS	Atreya et al. (2013, *GRL*)
$^{40}Ar/^{36}Ar$	1900 ± 300	QMS	Mahaffy et al. (2013, *Science*)
$^{14}N/^{15}N$	173 ± 9	QMS	Wong et al. (2013, *GRL*, submitted)
δD	4950 ± 1080	TLS	Webster et al. (2013, *Science*)
$\delta^{13}C_{VPDB}$	45 ± 12 ‰	QMS	Mahaffy et al. (2013, *Science*)
$\delta^{13}C_{VPDB}$	46 ± 4 ‰	TLS	Webster et al. (2013, *Science*)
$\delta^{18}O_{SMOW}$	48 ± 5 ‰	TLS	Webster et al. (2013, *Science*)

The SAM instrument suite measures atmospheric isotope ratios

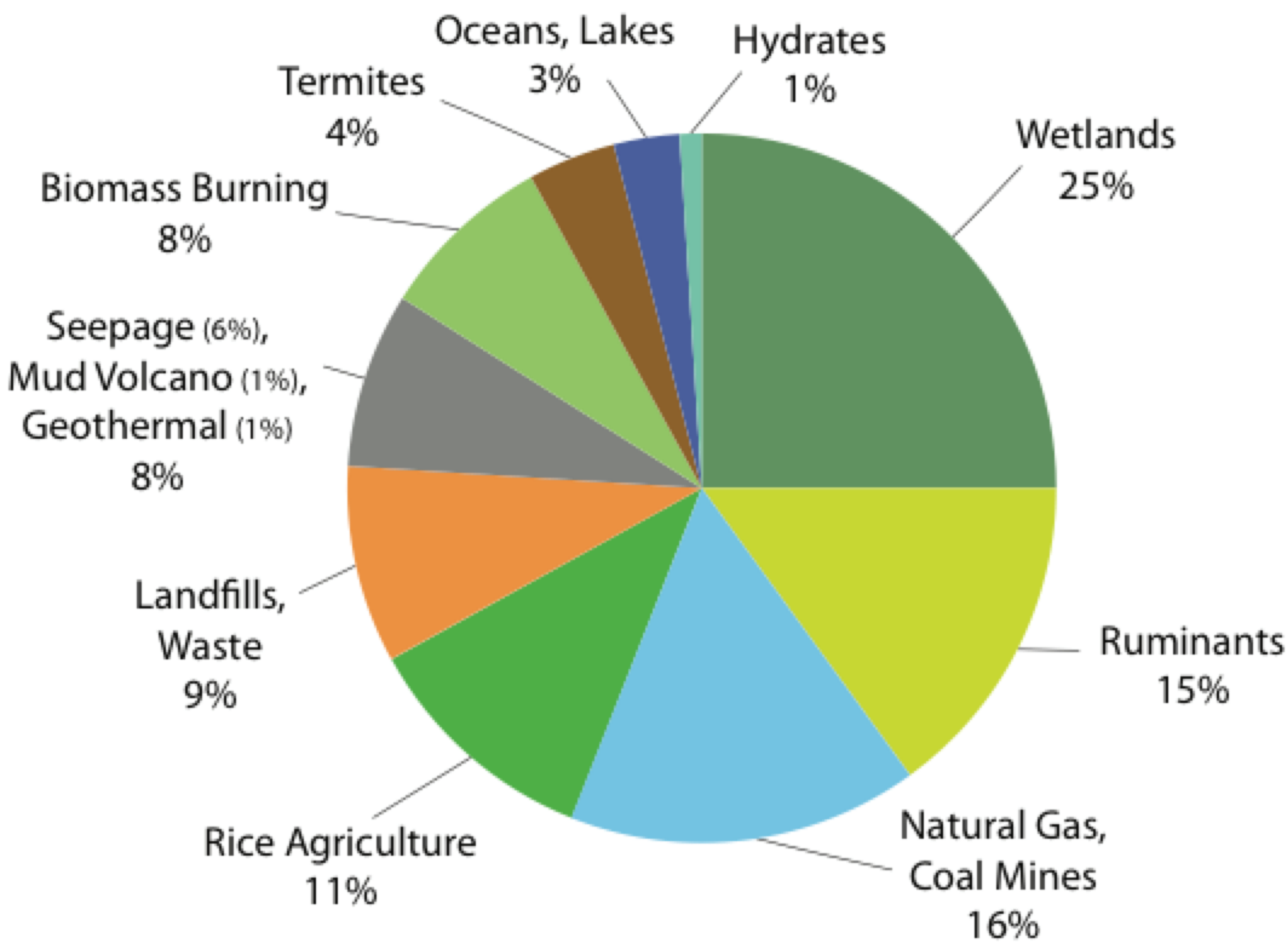


clays
sulfates
anhydrous ferric oxides
NOACHIAN
HESPERIAN
AMAZONIAN
Hydrodynamic escape
Impact loss
Jeans escape
photochemical
sputtering
Late veneer
impacts
volcanic
micrometeorites
Atmospheric Escape (favors light isotopes)
Atmosphere
Polar cap
Polar cap
Rocks
Crustal Fluids
Planetary Interior

MAVEN Will Measure the Drivers, Reservoirs, and Escape Rates



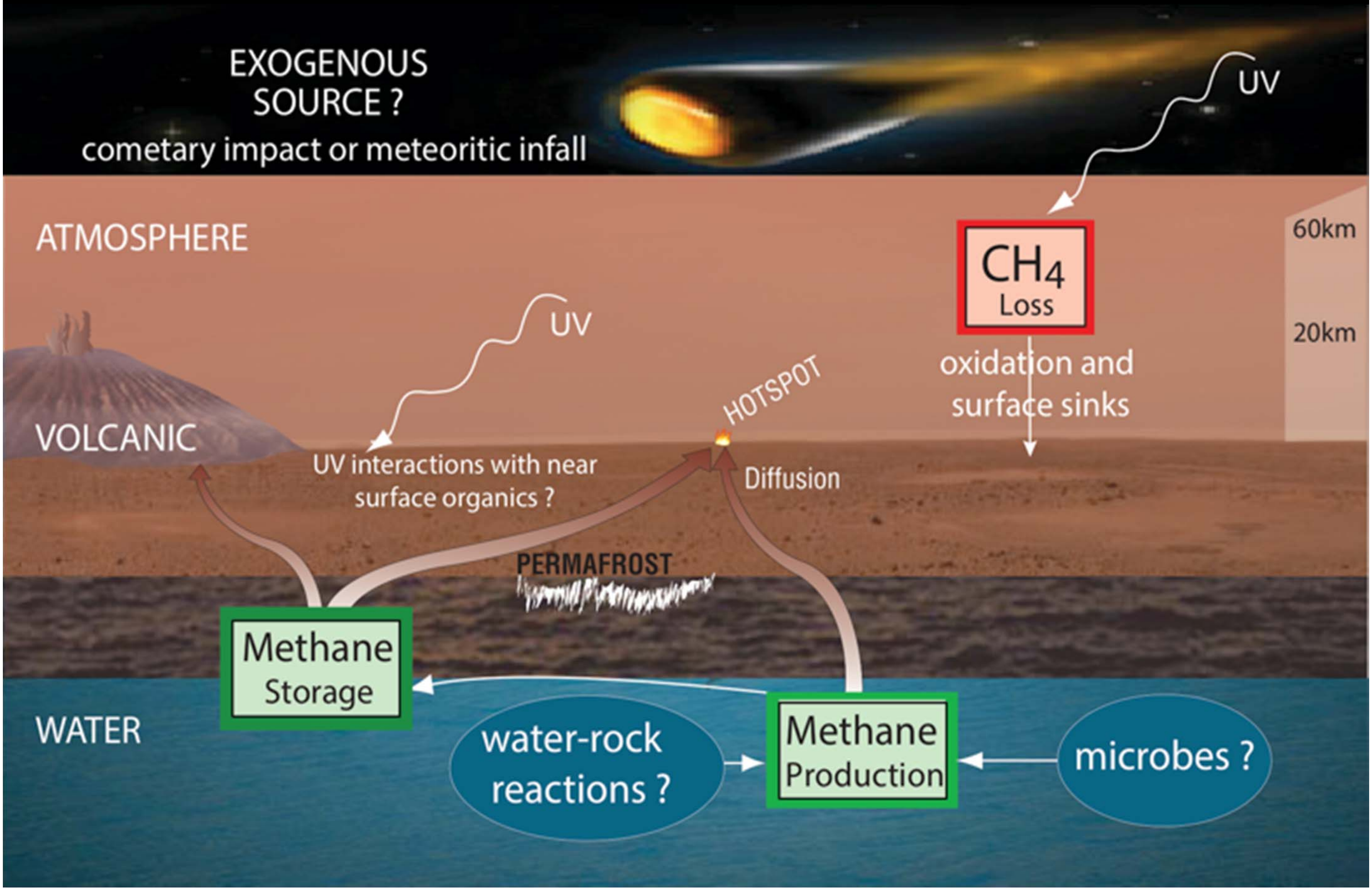
- MAVEN will determine the present state of the upper atmosphere and today's rates of loss to space.
- Essential measurements allow determination of the net integrated loss to space through time.



Life as we know it produces methane,
90-95% of 1750 ppbv on Earth

Methane, a potential biomarker

Water-rock reactions; UV degradation of surface organics; Methanogenesis



Science Express 9/19/2013

<1.3 ppbv methane on Mars from 6 SAM/TLS Datasets

Compared with 2009 Mumma et al. report of plumes from 2003 IRTF obs.

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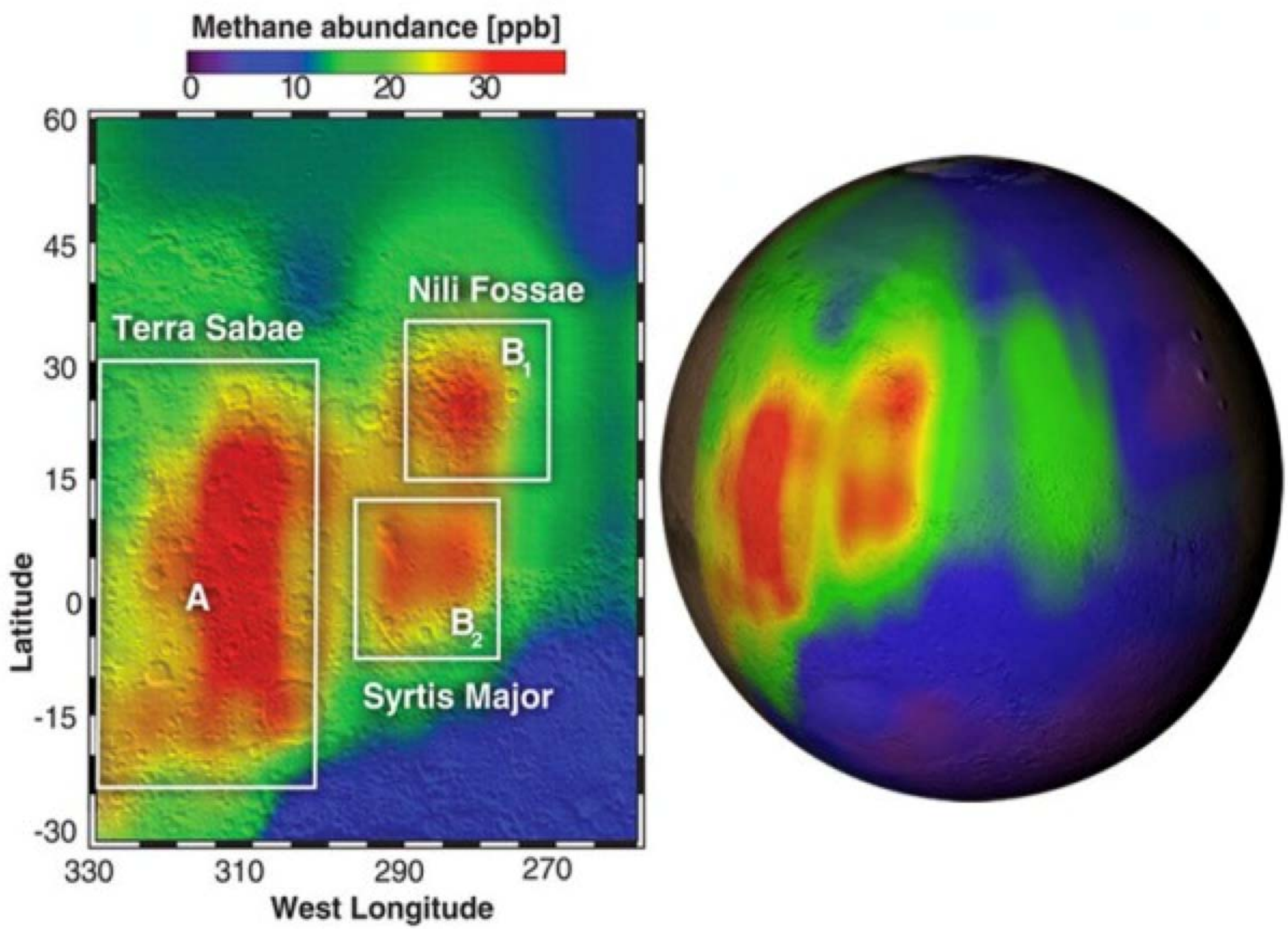
Mars Rover Finds No Evidence of Burps and Farts

2013-09-19 14:00 | 1 Comment

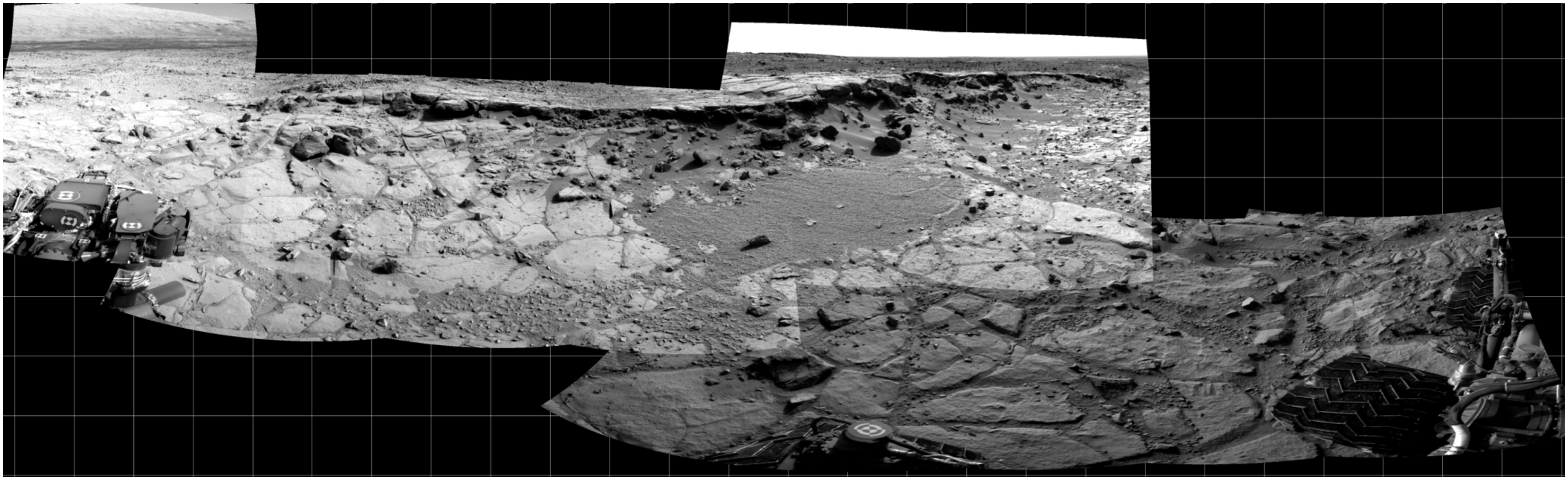


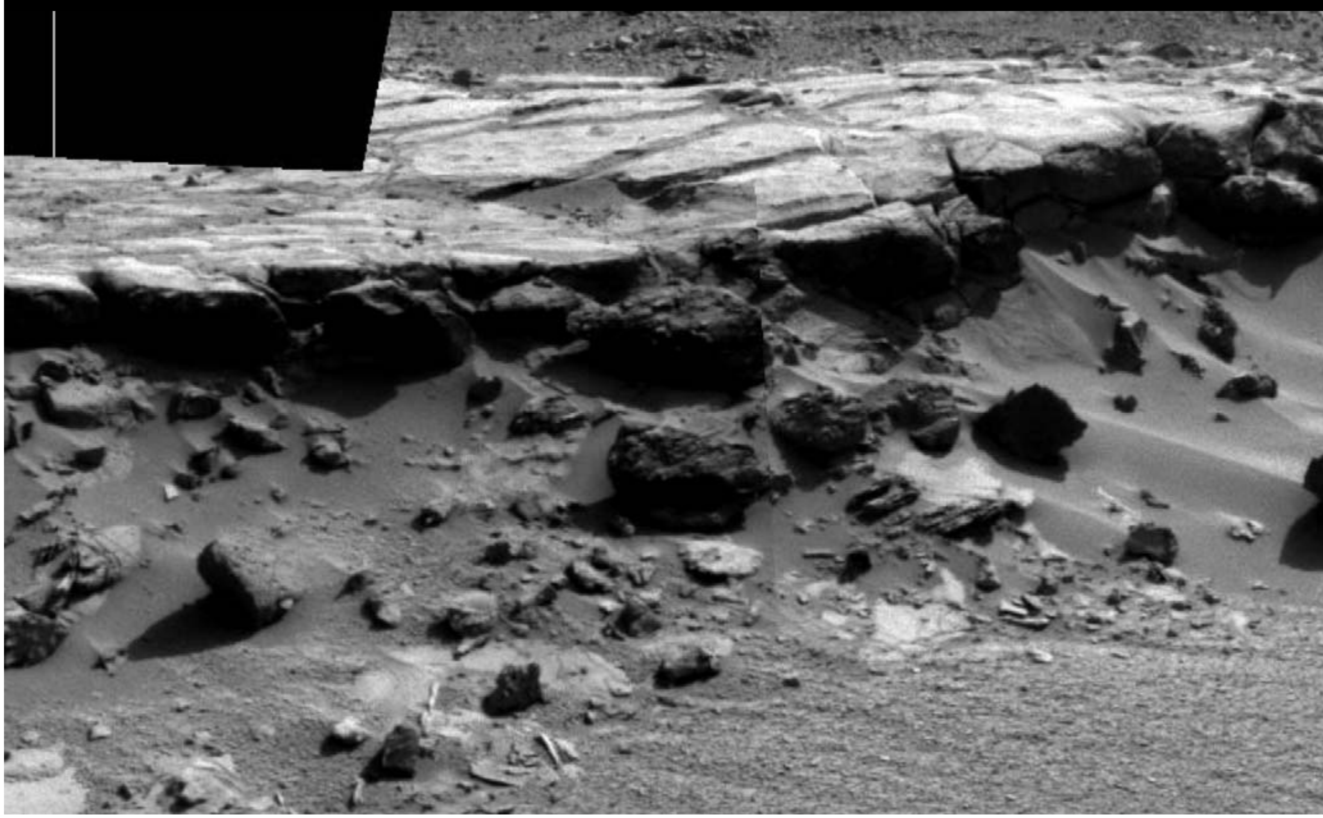
Summary of SAM atmospheric results

Atmospheric Volatile and Isotope Composition – Significant Findings		
Measurement	**Interpretation/Significance**	**Documentation**
Volatiles: ^{40}Ar, N_2, $^{40}Ar/N_2$	^{40}Ar and N_2 are each measured at 2% by volume, giving $^{40}Ar/N_2$=1, which is 70% greater than the Viking value, implying a more vigorous rate of ^{40}Ar outgassing.	Mahaffy et al., *Science* 2013; Atreya et al., *LPSC* 2013
Volatiles: Methane (CH_4)	No methane was detected. An upper limit of 1.3 ppbv is calculated, which implies reduced levels of methanogenesis, serpentinization and/or UV degradation of surface organics, if any.	Webster et al., *Science* 2013
Volatiles: CO_2, ^{40}Ar, N_2	CO_2 tracks the seasonal change in surface pressure, and ^{40}Ar and N_2 track each other and the CO_2, clearly indicating seasonal change of volatiles.	Trainer et al., *in prep.* 2013
Isotopes: Primordial argon $^{36}Ar/^{38}Ar$	$^{36}Ar/^{38}Ar$=4.2±0.1 is the first high precision measurements of this ratio, and provides the most compelling evidence yet that "martian' meteorites are from Mars, and clearest signature of substantial loss of atmosphere in the past 4 Byr.	Atreya et al., *GRL* 2013
Isotopes: $\delta^{13}C$, $\delta^{18}O$, δD	The CO_2 and H_2O isotopes, measured at $\delta^{13}C$=46±4 ‰, $\delta^{18}O$=48±5 ‰ and δD=4950±1080, provide additional strong evidence of loss of atmosphere in the past 4 Byr.	Mahaffy et al., *Science* 2013; Webster et al., *Science* 2013; Franz et al., *Planet. Space Sci.* 2013
Isotopes: nitrogen $^{14}N/^{15}N$	$^{14}N/^{15}N$= 173±13 ratio is similar to Viking data, but more precise. Combined with SAM's ^{40}Ar data, it requires reassessment of the degree of mixing between the atmospheric and mantle gas components in certain martian meteorites.	Wong et al., *GRL* 2013
Isotopes: $^{40}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$ =1900±300 is 60% of the Viking value, but in far better agreement with SNC's.	Mahaffy et al., *Science* 2013

Unfinished business - Atmosphere

- Seasonal monitoring of volatiles over one Mars year
- Seasonal and diurnal monitoring of CO_2 and H_2O isotopes
- Enrichment experiments to measure Xe and Kr isotopes
- Enrichment experiments to measure D/H precisely
- Pre-enrichment to increase CH_4 detectability to 0.1 - 0.02 ppbv





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CURIOSITY

Curiosity is now on its way to study the Layers, Canyons, and Buttes of Mount Sharp