Biosignature “Detection” and the Search for Life on Mars

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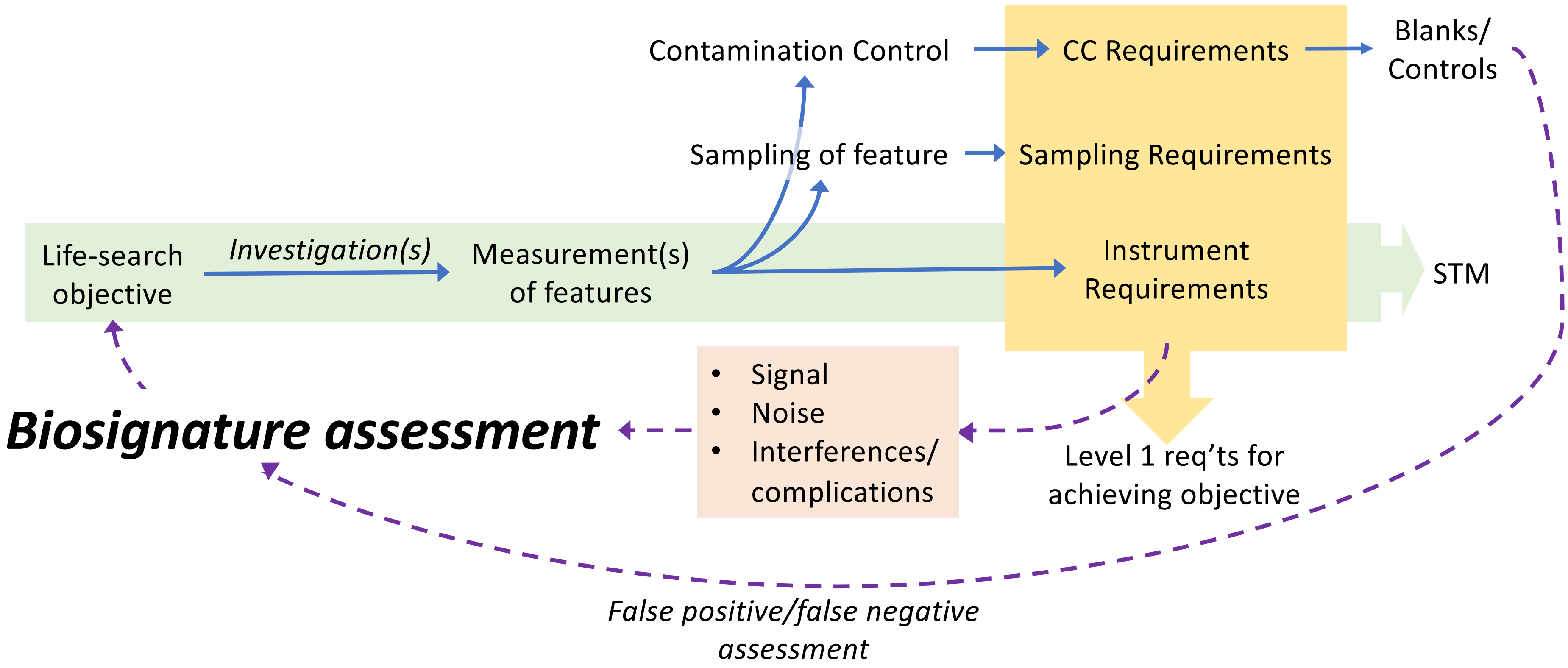
“Hottat” target, Gale crater. Conglomerate. Image credit: NASA/JPL-Caltech/MSSS

Mission Elements of Biosignature "Detection"

TRACEABILITY



Contamination Control

CC Requirements

Blanks/
Controls

Sampling of feature

Sampling Requirements

Life-search
objective

Investigation(s)

Measurement(s)
of features

Instrument
Requirements

STM

- Signal
- Noise
- Interferences/
  complications

Biosignature assessment

Level 1 req'ts for
achieving objective

False positive/false negative
assessment

Mission Elements of Biosignature "Detection"

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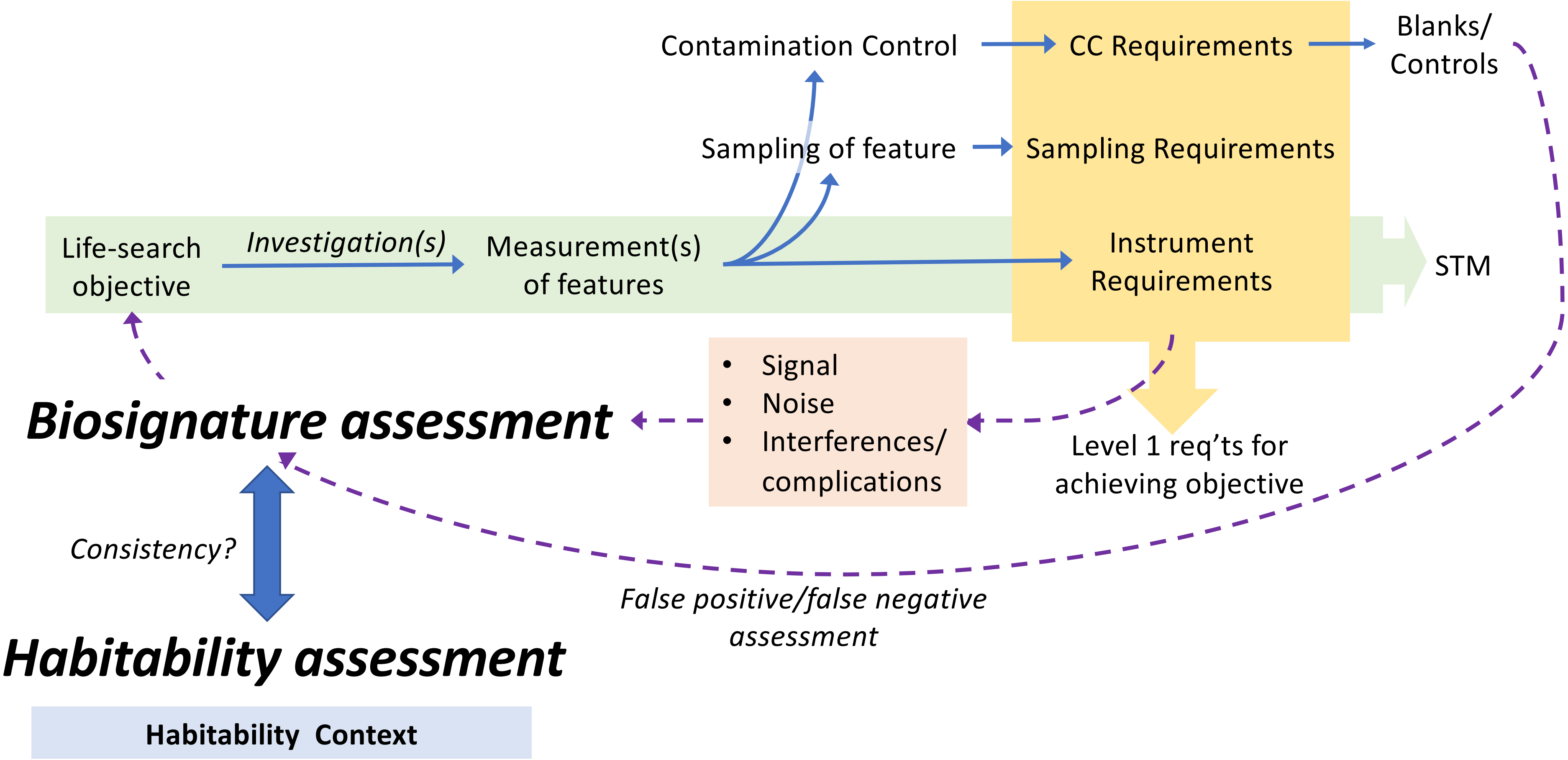

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Level 1 req'ts for
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Biosignature assessment

Consistency?

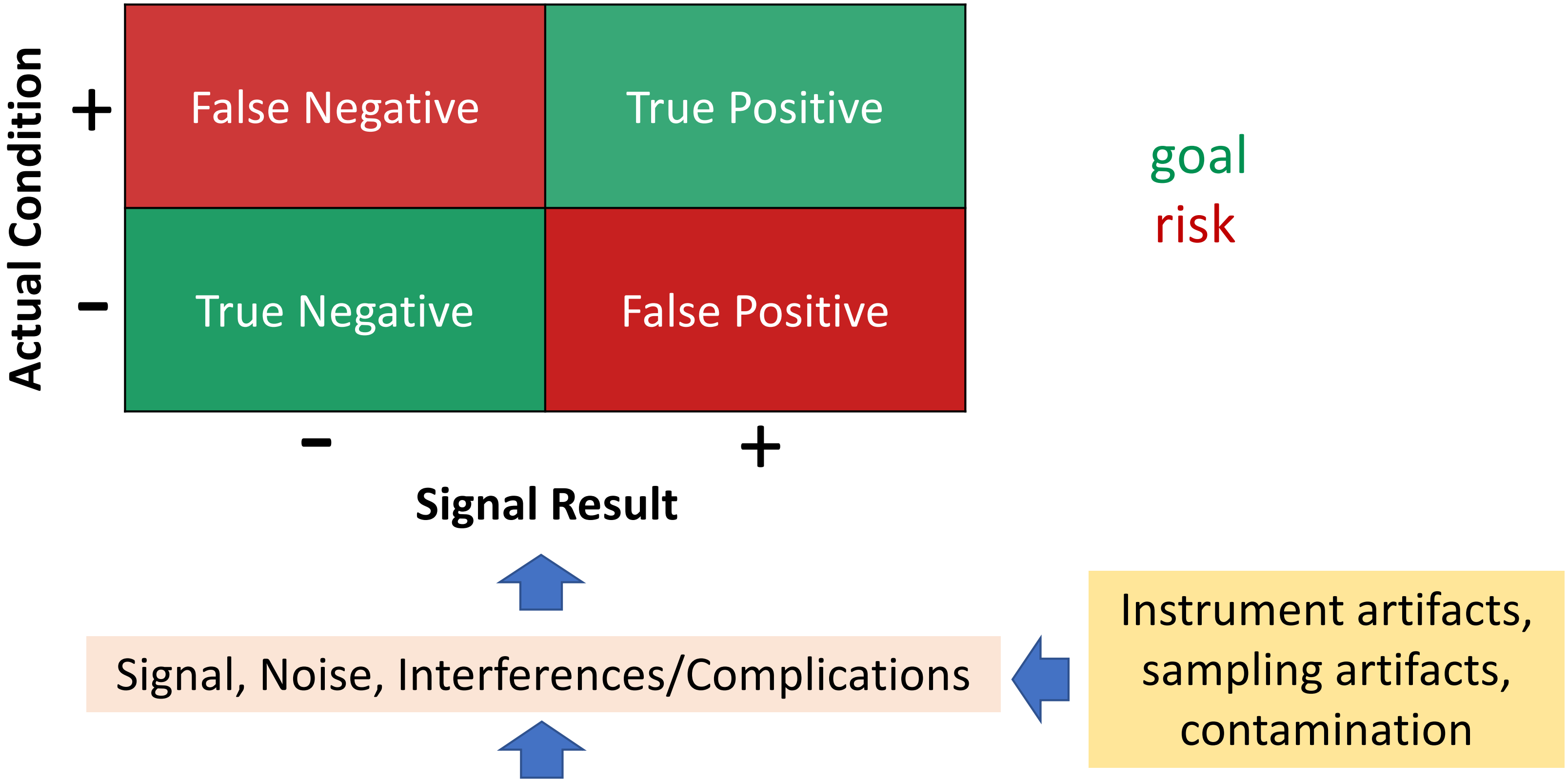
*False positive/false negative
assessment*

Habitability assessment

Habitability Context

TRACEABILITY

Factors that influence signal



		−	+
Actual Condition	+	False Negative	True Positive
	−	True Negative	False Positive

Signal Result

goal

risk

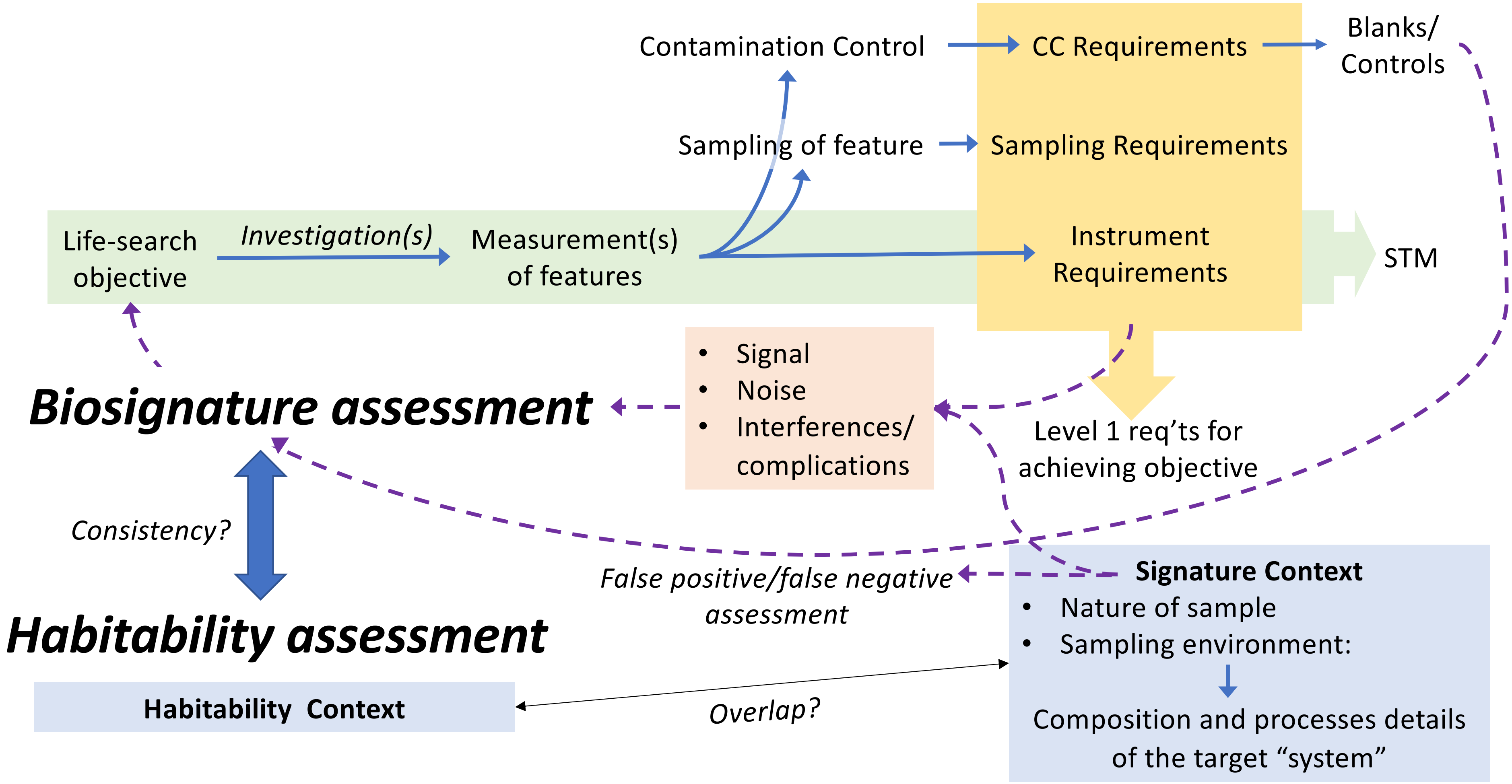
Signal, Noise, Interferences/Complications

Instrument artifacts, sampling artifacts, contamination

Sample composition and environmental factors can also influence the risk of false negatives and positives.

TRACEABILITY

Mission Elements of Biosignature “Detection”



Contamination Control

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Sampling of feature

Sampling Requirements

Life-search objective

Investigation(s)

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Instrument Requirements

STM

- Signal
- Noise
- Interferences/ complications

Level 1 req’ts for achieving objective

Biosignature assessment

Consistency?

Habitability assessment

Habitability Context

False positive/false negative assessment

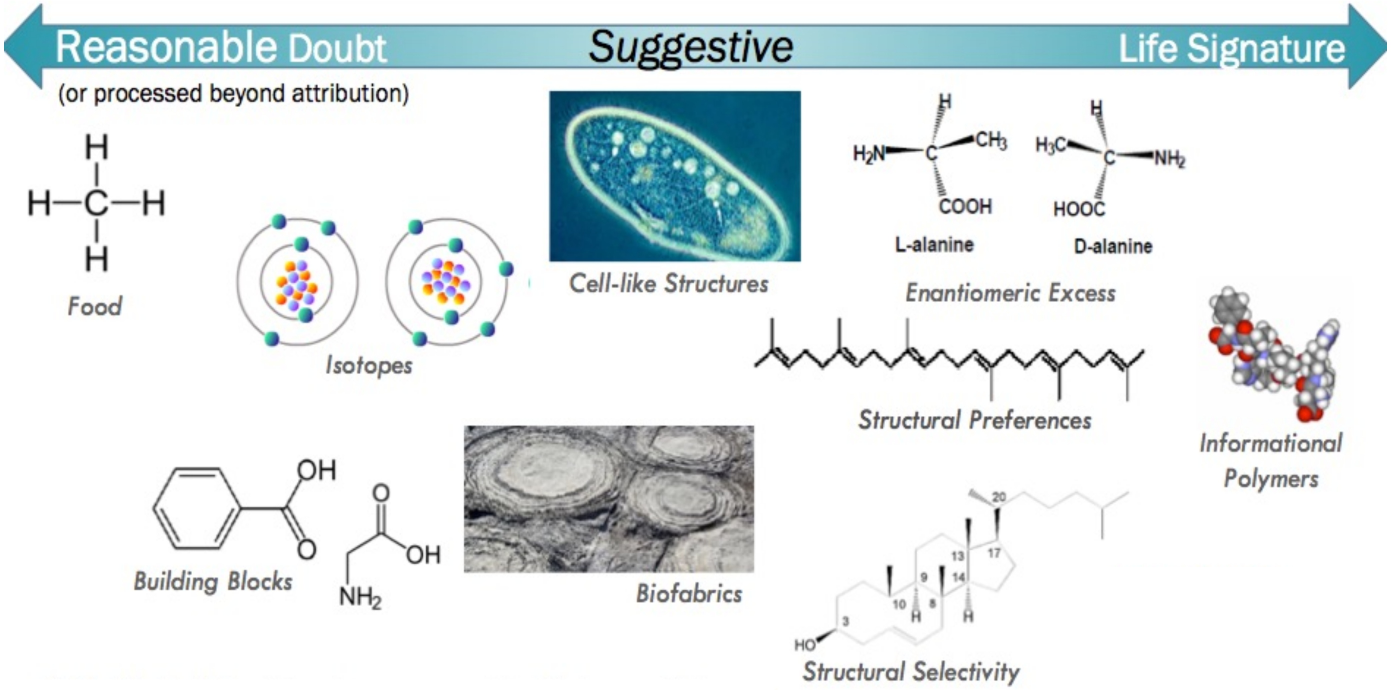
Overlap?

Signature Context

- Nature of sample
- Sampling environment:

Composition and processes details of the target “system”

Strategies to Biosignature Assessment to overcome issues of probability



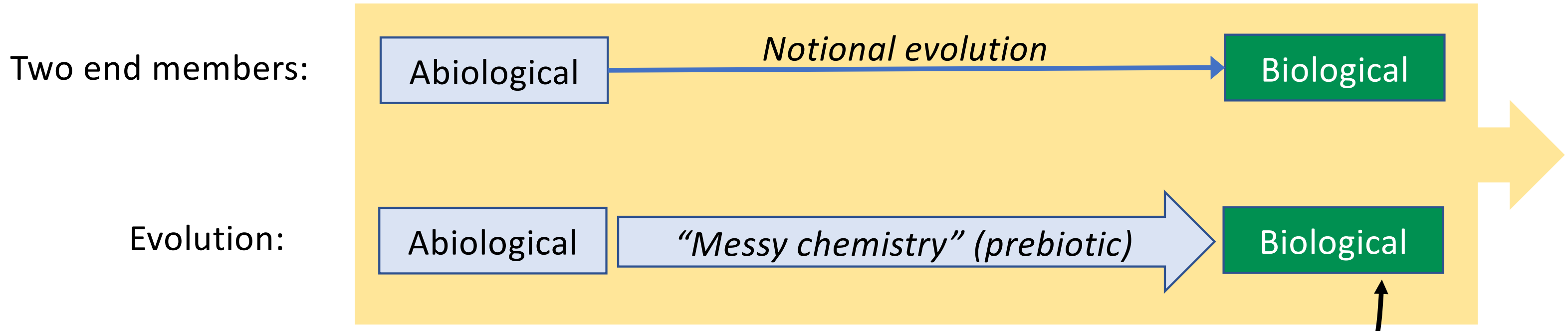
Strategic approaches commonly cited are:

- Independent measurements of a feature
- Measurements supporting multiple biosignature assessment
- Orthogonal lines of evidence
- Interpretive potential

- Definitive biosignature for extraterrestrial life do not exist (yet) because the definitive nature requires validation.
- A more comprehensive strategy for implementation and an interpretive framework are needed to instill confidence in the interpretations of mission data.

Adding a systems approach to biosignature assessment by expanding context to address Biological Potential

PROBABILITIES



Two end members: Abiological → *Notional evolution* → Biological

Evolution: Abiological → *"Messy chemistry" (prebiotic)* → Biological

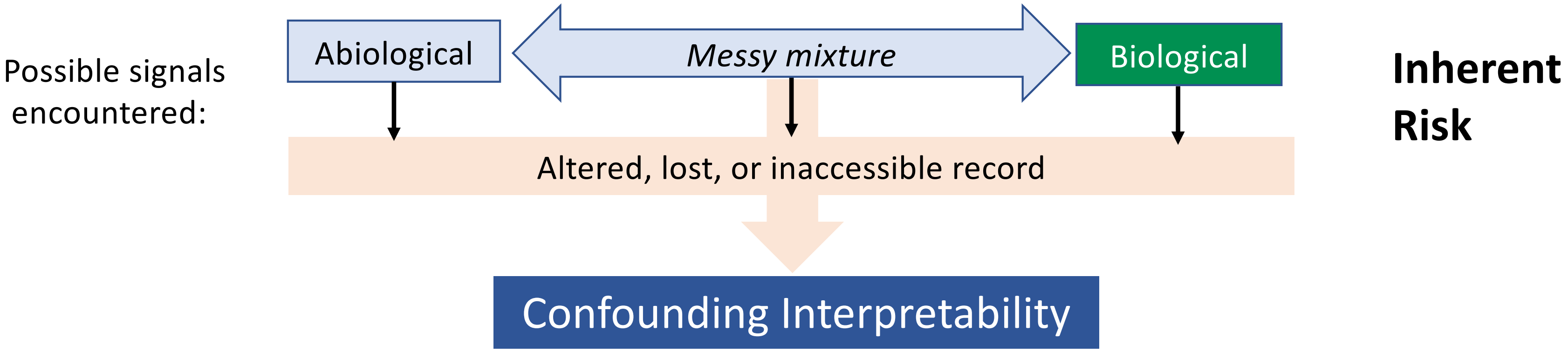
Goal: To understand **biological potential** through time

Ultimately, we want to know if life exists or ever existed beyond Earth.

-To answer this, we aim to test a null hypothesis. → scientific method, good science

But missions are a balance between science and exploration and models suggest a more complicated set of possibilities—each a hypothesis that warrants study, if possible. We need to explore multiple hypotheses too.

Preservation/Alteration Potential



Possible signals encountered:

Abiological

Messy mixture

Biological

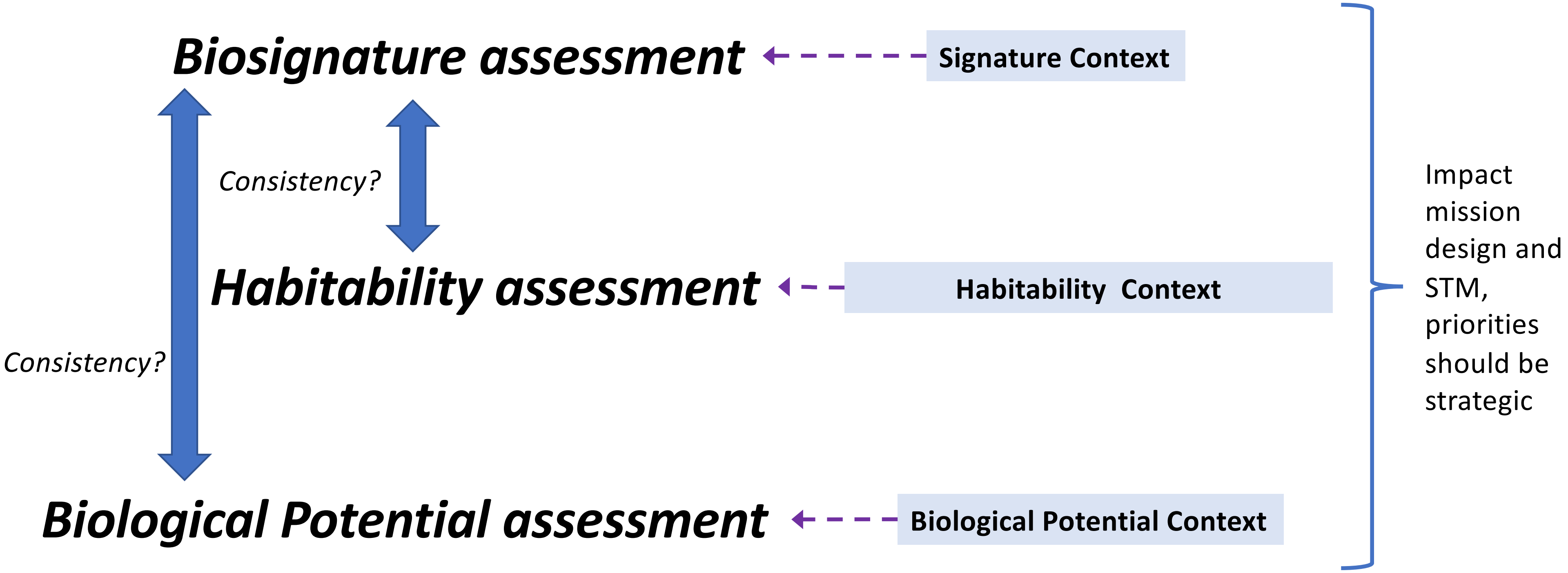
Inherent Risk

Altered, lost, or inaccessible record

Confounding Interpretability

STRATEGY

Expanding set of objectives for “Life-Detection”



Biosignature assessment

Signature Context

Consistency?

Habitability assessment

Habitability Context

Consistency?

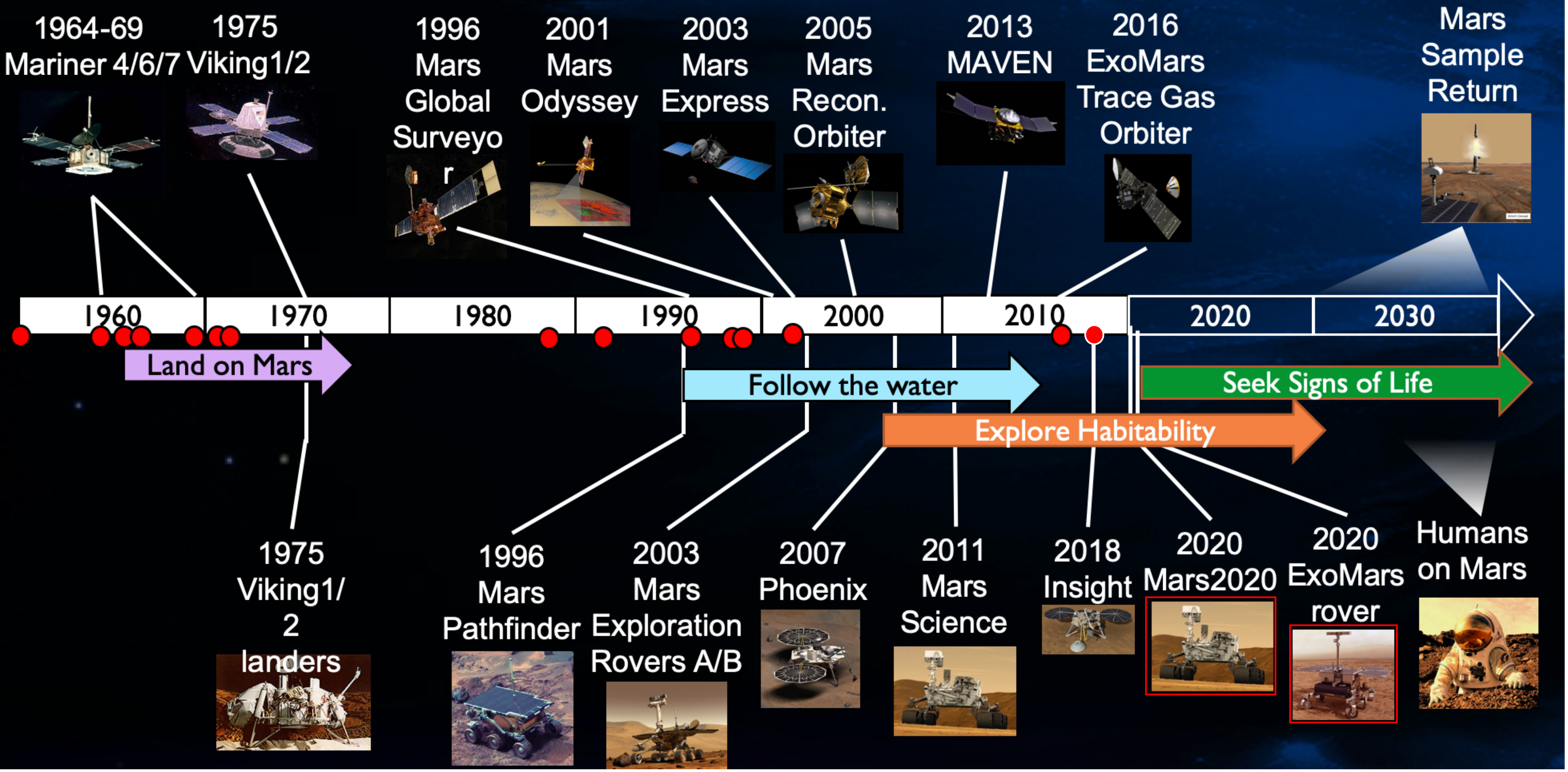
Biological Potential assessment

Biological Potential Context

Impact mission design and STM, priorities should be strategic

- Multiple mission architectures that allow incremental mission designs that respond to discoveries are likely to provide the greatest science return. Example: In situ x *n* → sample return
  - Are multiple mission scenarios possible? (funding, technology)
  - Open the door to utilizing a wide range of mission sizes and types to address the science goals.

MARS EXPLORATION TIMELINE



1964-69 Mariner 4/6/7

1975 Viking1/2

1996 Mars Global Surveyor

2001 Mars Odyssey

2003 Mars Express

2005 Mars Recon. Orbiter

2013 MAVEN

2016 ExoMars Trace Gas Orbiter

Mars Sample Return

1975 Viking1/2 landers

1996 Mars Pathfinder

2003 Mars Exploration Rovers A/B

2007 Phoenix

2011 Mars Science

2018 Insight

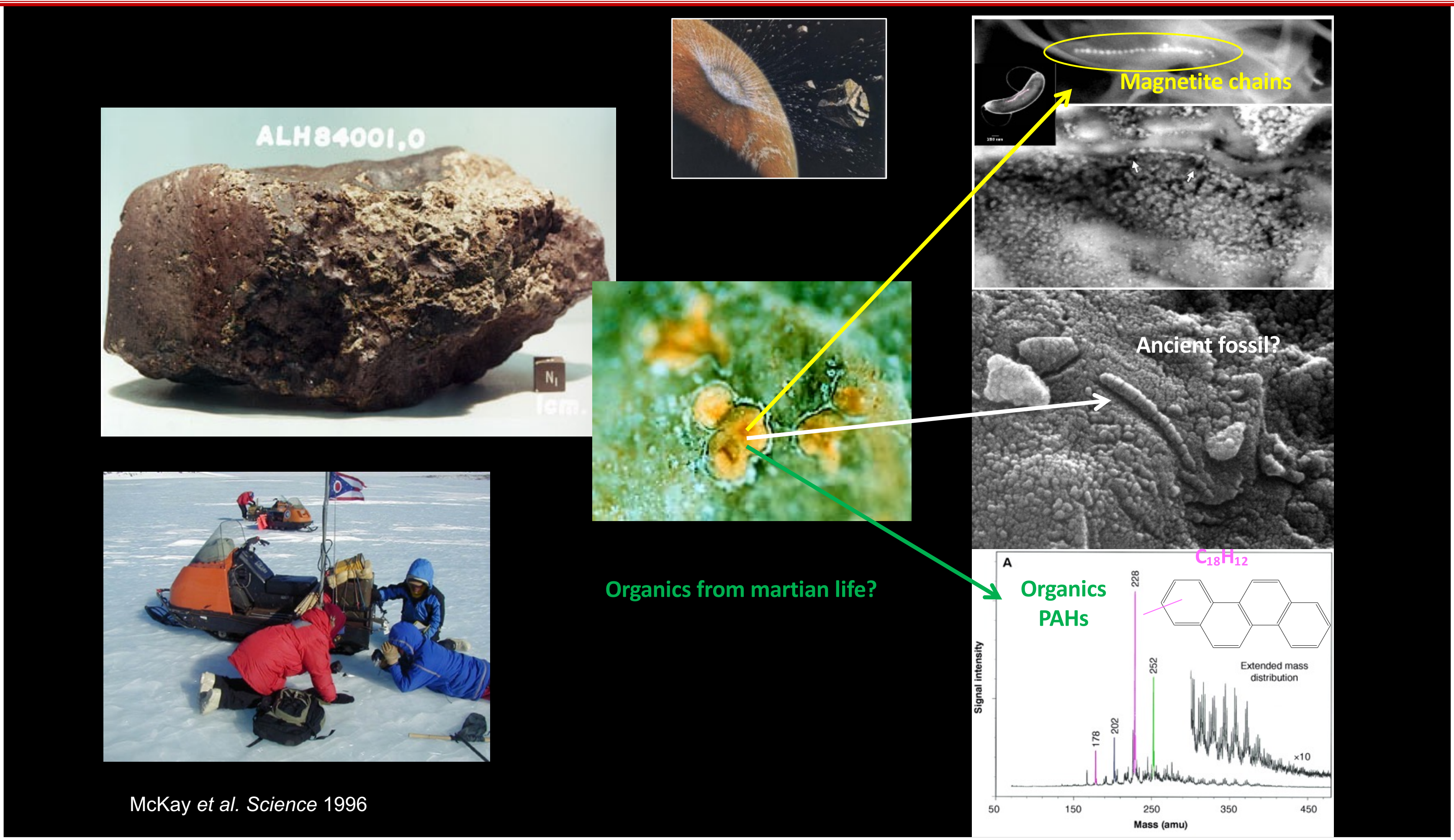
2020 Mars2020

2020 ExoMars rover

Humans on Mars

The Search for Organics on Mars as a step towards the search for life

Extinct Life in Martian Meteorite ALH 84001?



Magnetite chains

Ancient fossil?

Organics from martian life?

Organics
PAHs

$C_{18}H_{12}$

McKay *et al. Science* 1996

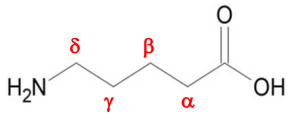
Slide provided by D. Glavin

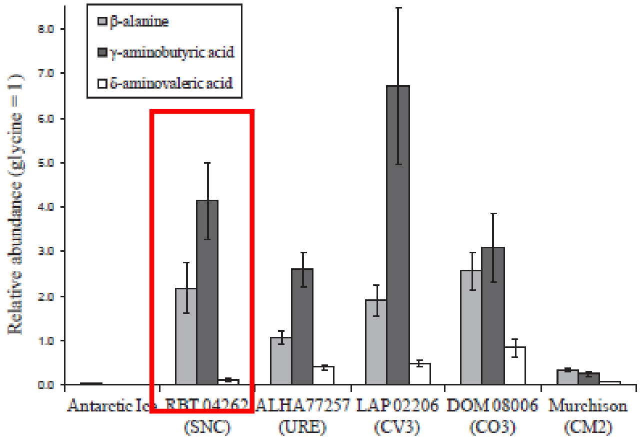
A Reason for Optimism…

Roberts Massif (RBT) 04262

- relatively young shergottite (~225 Mya).
- Ejected from Mars ~2.9 Mya and landed in Antarctica 700 kya.

Identified straight-chain, *n*-ω-amino acids (up to C_5). 1st evidence for extraterrestrial amino acids in a martian meteorite.





Callahan *et al.* *MAPS* (2013) 48: 786

Photo of RBT 04262 (Credit: ANSMET)

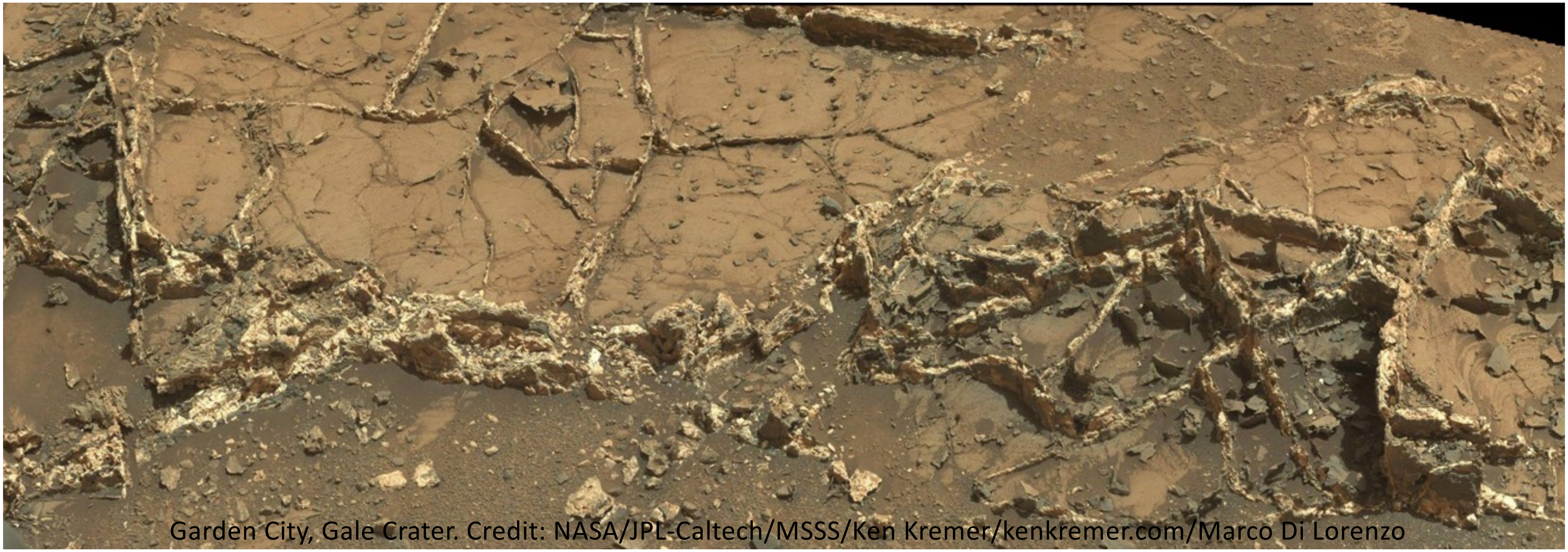
- Elevated abundances (~4 to 130 ppb)
- Unique distribution of amino acids compared to Antarctic ice, but similar to those found in thermally-altered carbonaceous chondrites.
- RBT 04262 amino acids are all achiral and likely of a non-biological, high temperature origin.

Slide details provided by D. Glavin

DIAGENESIS

Ancient Biosignature Preservation at Risk

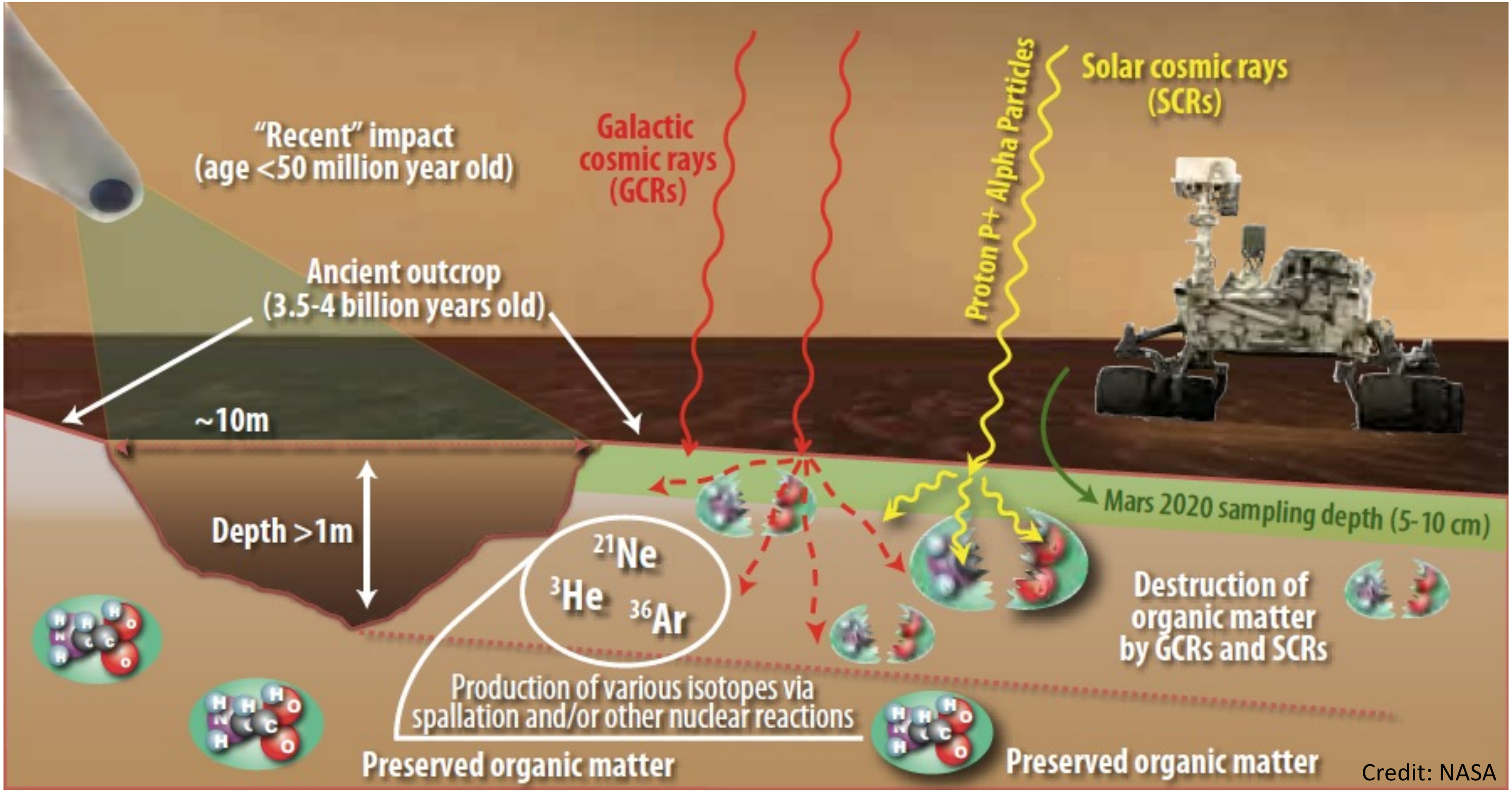
Aqueous Diagenesis and Ionizing Radiation



Garden City, Gale Crater. Credit: NASA/JPL-Caltech/MSSS/Ken Kremer/kenkremer.com/Marco Di Lorenzo

Cosmic ray degradation of organics in near-surface

DIAGENESIS



Credit: NASA

SAM EXPOSURE AGE OF CUMBERLAND (Ma) = ^{3}He 72 ± 15, ^{21}Ne 84 ± 28, ^{36}Ar 78 ± 24

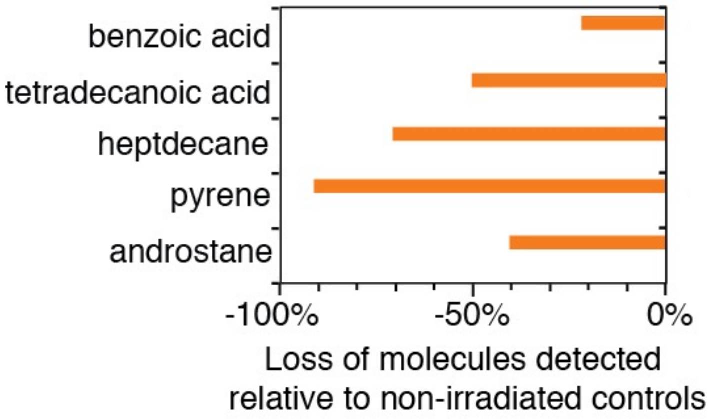
Farley *et al. Science* (2014) 343: 1247166

Slide provided by D. Glavin

Cosmic radiation can greatly impact biosignature preservation

DIAGENESIS

Loss of “free” molecules after 250 kGy (~4 Myr) of 200-MeV proton radiation

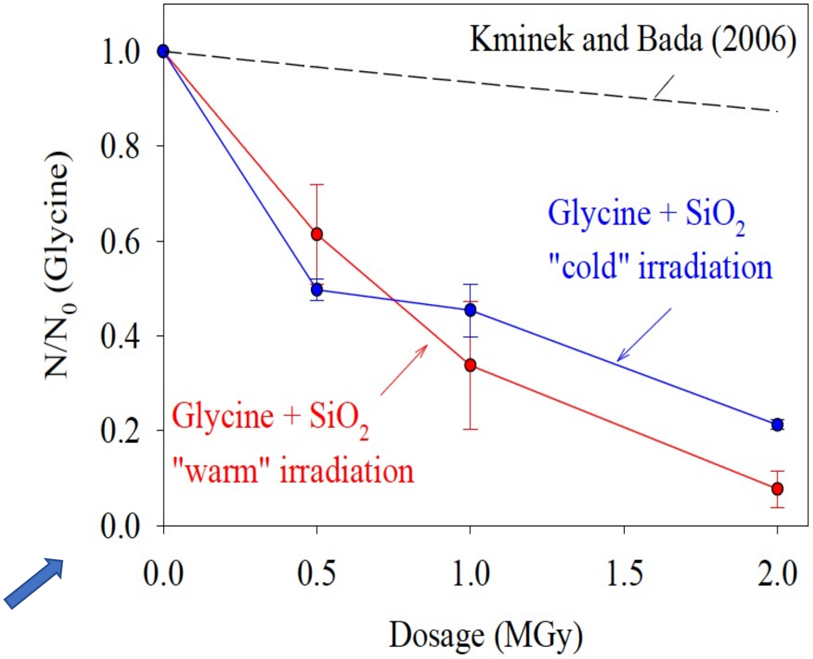


Eigenbrode et al, AbSciCon, 2015

1)Amino acids that were either produced on Mars (biotic or abiotic synthesis) or delivered by meteorites >50-100 million years ago would have low chance of preservation in near-surface Martian rocks or sediments.

2)Perchlorates (2 wt.%) will increase the rate of degradation by a factor of 3-5.

Gamma irradiation of amino acids in fused silica powder



Pavlov *et al.* (2016) 47th LPSC, #2577

Surviving fraction of glycine vs. gamma dosage

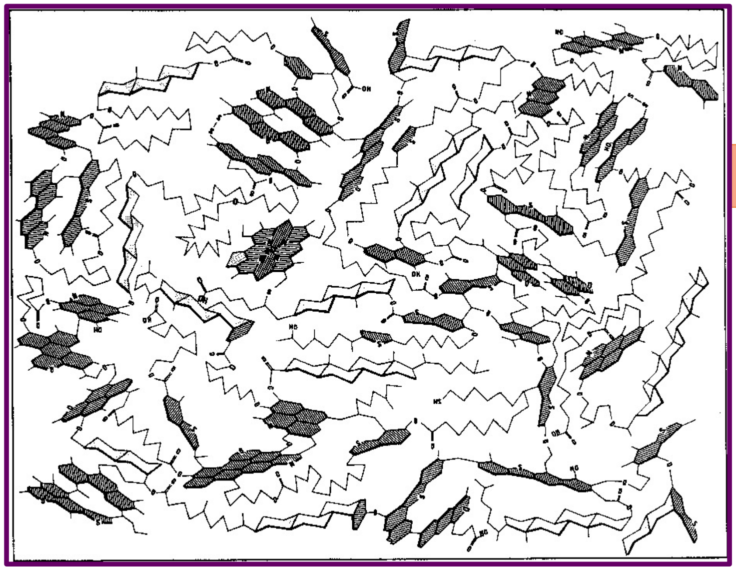
2 MGy will be accumulated in top 5 cm of Martian rocks in **~40 million years**. Temperature has an effect but not enough to slow destruction significantly.

Slide details provided by D. Glavin

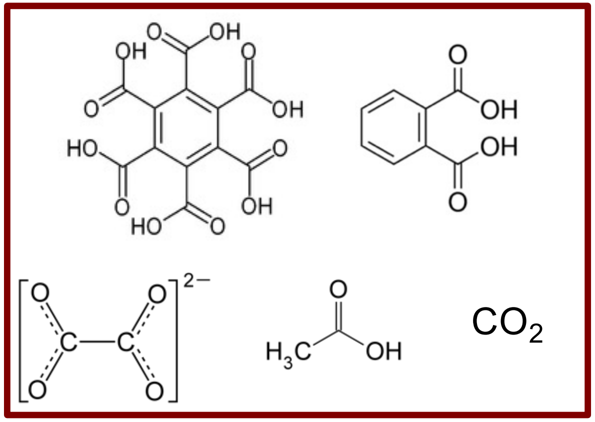
Theoretical prediction and experimental verification for the breakdown of macromolecules

DIAGENESIS

Macromolecules (aka, kerogen)

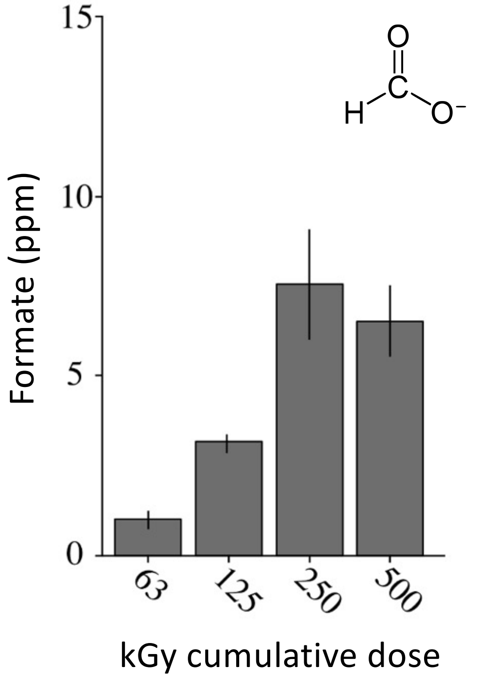


Fenton-like Reactions:
Ionizing radiation + Oxidants + metal catalyst



Benner et al., 2000, PNAS (via UV)

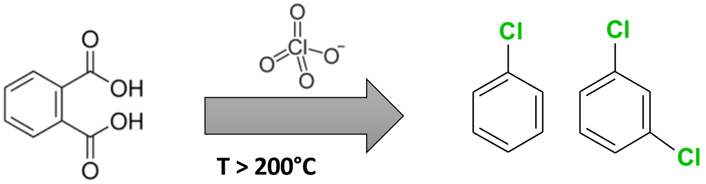
200-MeV proton irradiated kerogen in fused silica



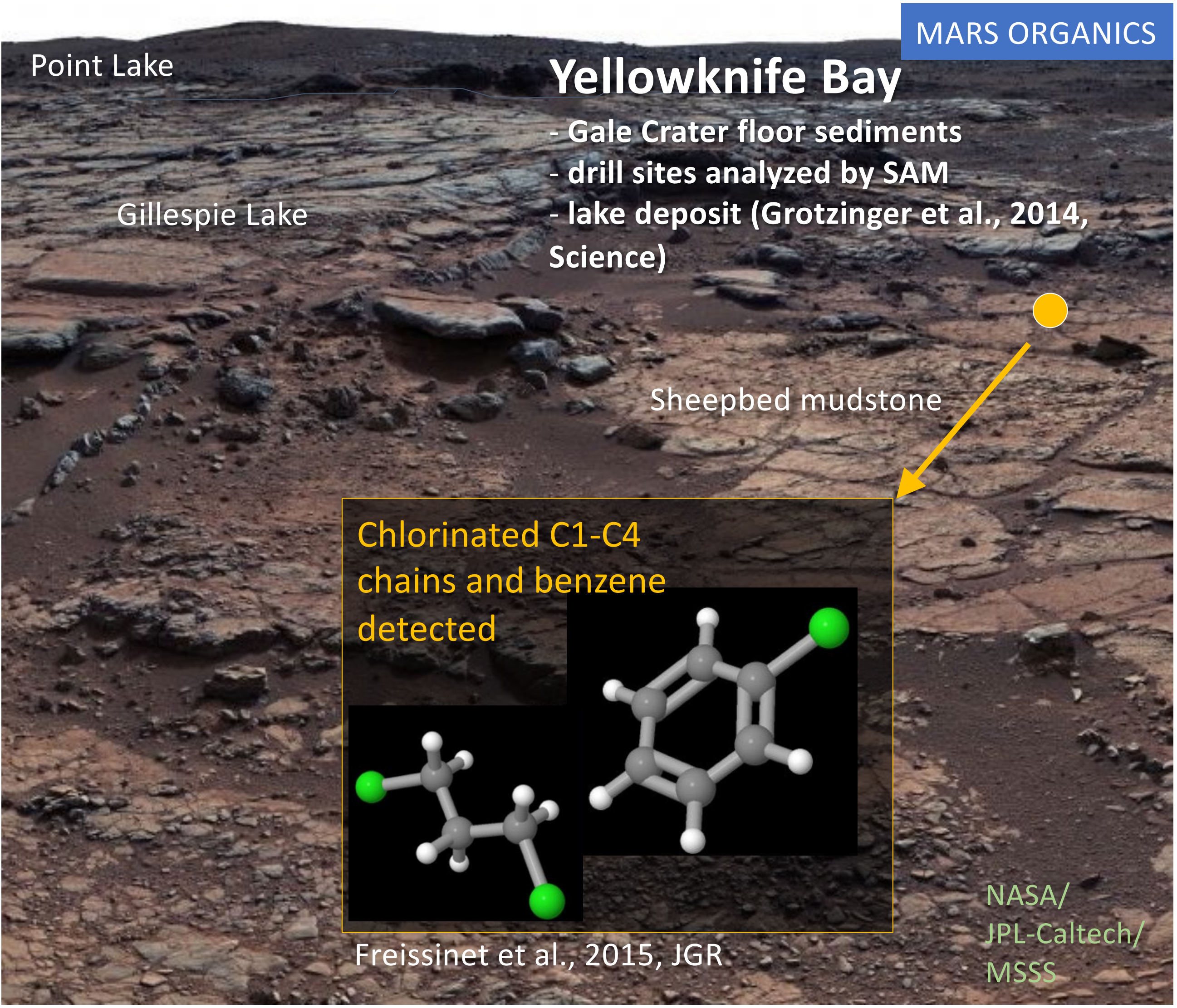
Fox et al., 2019, JGR

Chlorohydrocarbon detections

Data from Curiosity rover (2012 -) and lab experiments confirm that **chlorinated hydrocarbons form by reactions between perchlorates and organics** during pyrolysis (Navarro-Gonzalez *et al.* 2010; Glavin *et al.* 2013, Miller et al., 2016)



MARS ORGANICS



Yellowknife Bay

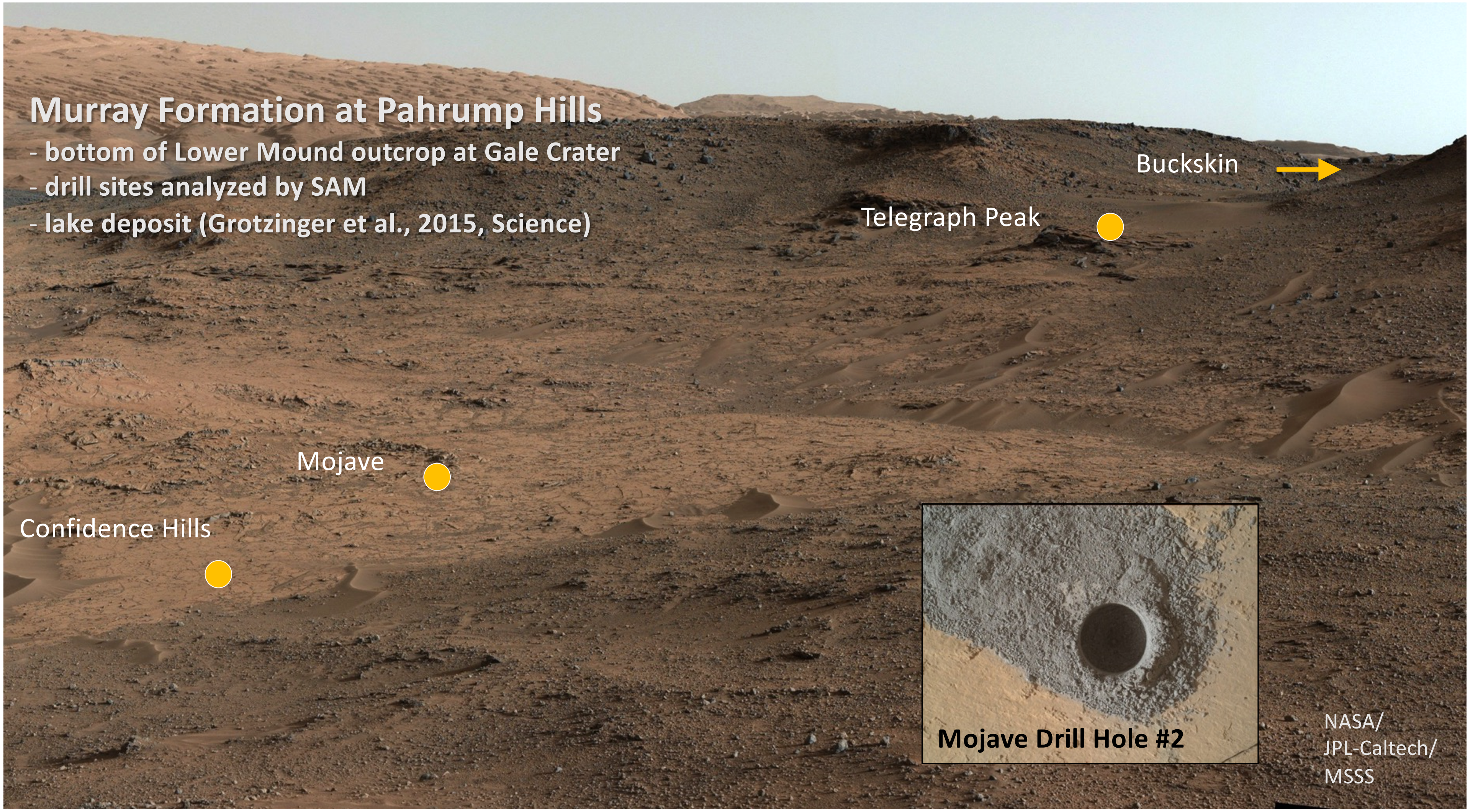
- Gale Crater floor sediments
- drill sites analyzed by SAM
- lake deposit (Grotzinger et al., 2014, Science)

Chlorinated C1-C4 chains and benzene detected

Freissinet et al., 2015, JGR

NASA/
JPL-Caltech/
MSSS

Organic Matter in Lacustrine Murray Mudstone



Murray Formation at Pahrump Hills

- bottom of Lower Mound outcrop at Gale Crater
- drill sites analyzed by SAM
- lake deposit (Grotzinger et al., 2015, Science)

NASA/
JPL-Caltech/
MSSS

Organic Matter in Lacustrine Murray Mudstone

Aromatic, aliphatic, and S-organic compounds released from mudstone at high T > 550°C

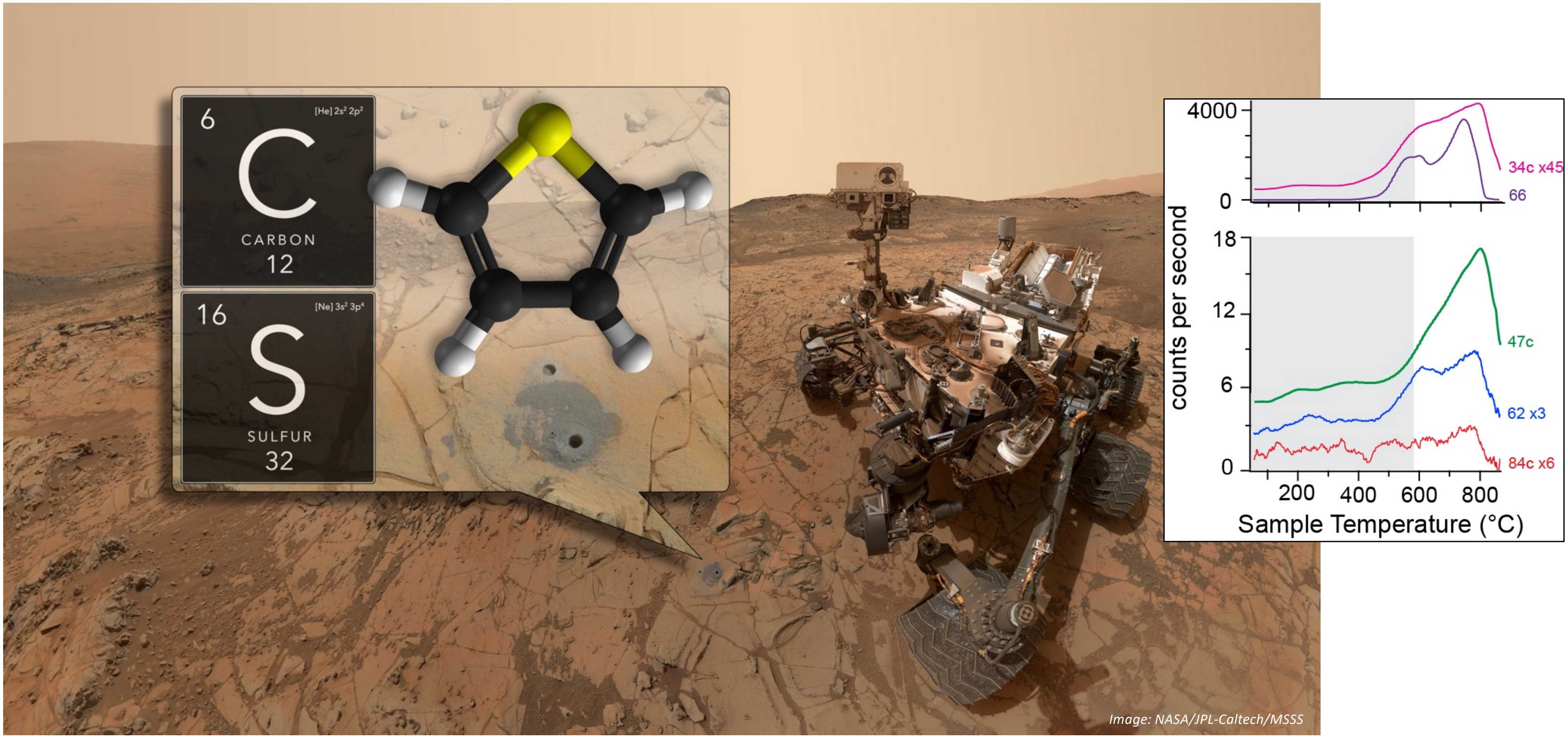


Image: NASA/JPL-Caltech/MSSS

Eigenbrode *et al. Science* (2018) 360: 1096

Comparison to Analogs

MARS ORGANICS

SAM-like analysis of meteorites and sedimentary kerogens show similar high temperature releases
→ source unclear

Tissint martian meteorite

See Steele presentation today for example results

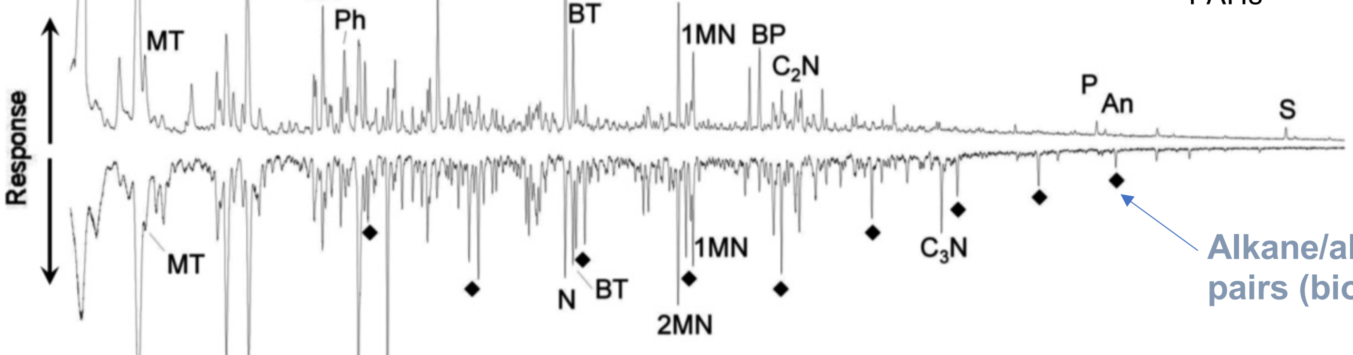
Murchison carbonaceous chondrite

Isolated kerogen of a Jurassic Paleosol (Type IV)

Distinguishing between biotic and abiotic sources

MARS ORGANICS

Compounds identified by GCMS after pyrolysis to 600°C



Alkane/alkene pairs (biology)

Matthewman *et al. Astrobiology* (2013) 13: 324

Murchison (CM2 meteorite)
- LMW units
- Alkyl benzenes
- Thiophenes
- Phenols
- PAHs

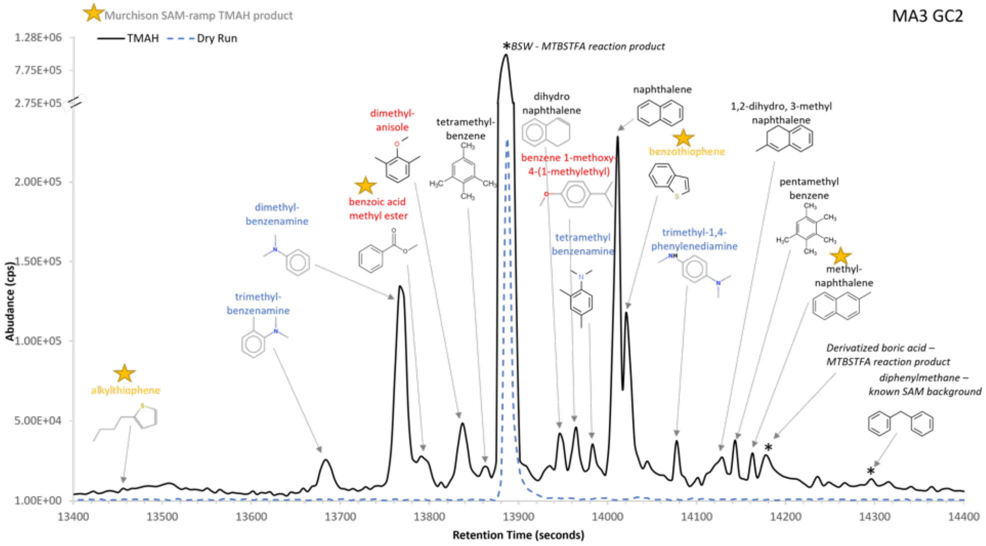
Type IV kerogen from Earth
- LMW units
- Alkyl benzenes
- Thiophenes
- Phenols
- PAHs
- Residual n-alkanes/alkenes

Slide provided by D. Glavin

Organic Molecular Detections by SAM

SAM TMAH thermochemolysis experiment

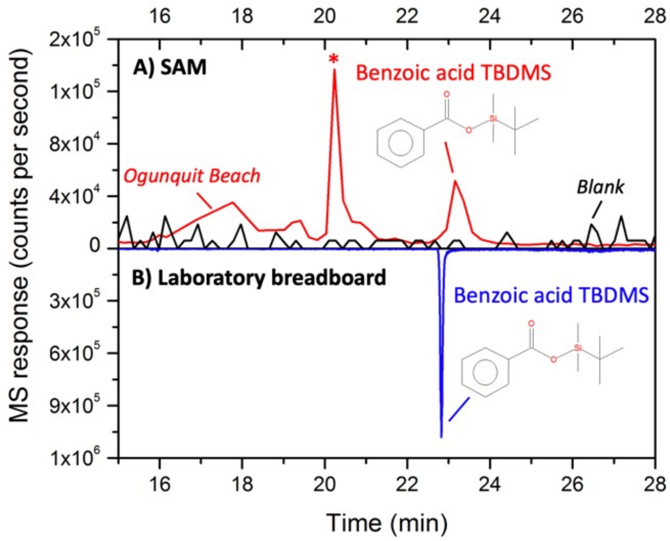
Initial Detections: A variety of organic molecules were detected including methylnaphthalene, benzothiophene, benzoic acid methyl ester, et al. Detailed workup in progress



Williams et al 2021 (LPSC), 2020 (AGU)
Slide details provided by A. Williams

SAM MTBSTFA derivatization experiment at Bagnold Dunes

Benzoic acid detection

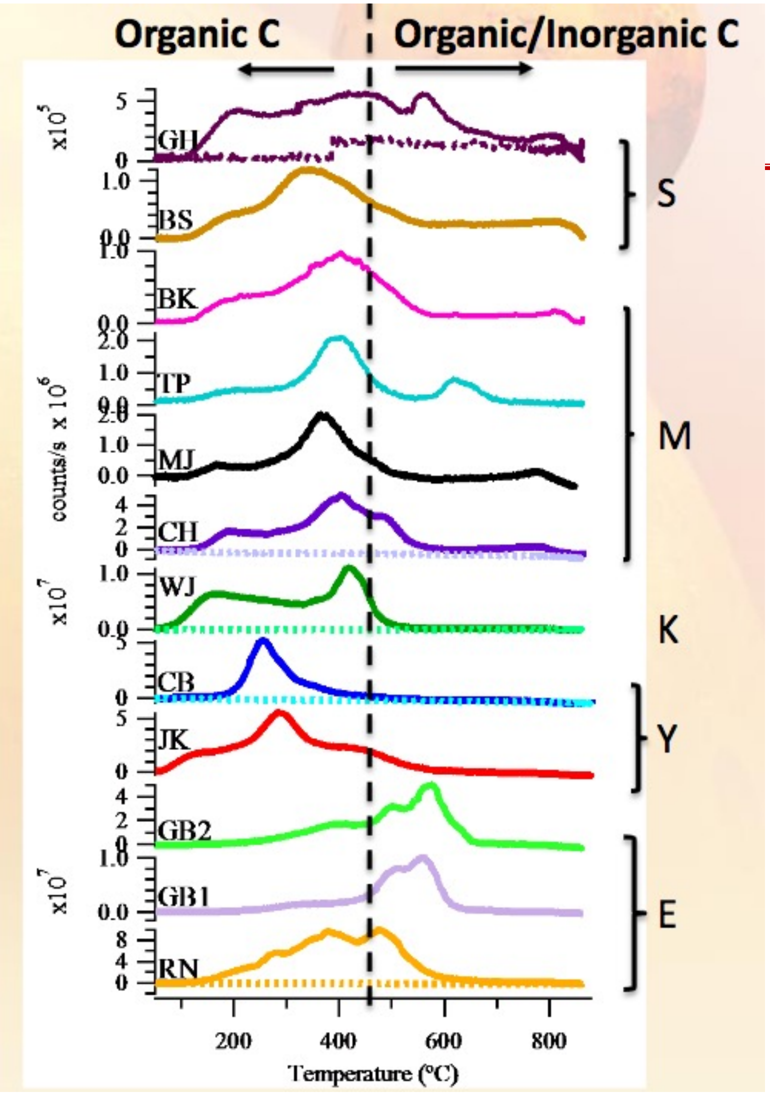


Millan et al., 2021, Nature Astronomy
Slide details provided by M. Millan

CO_2 and CO thermally evolved from samples during SAM EGA

- **~200 to 2400 µg C/g (ppm)**
    - **More C than predicted from meteoritic input (60 ppm, Steininger *et al.* 2012)**
- Co-evolution of low temp CO_2 and CO consistent with combusted organic carbon
- Some consistent with inorganic C (carbonate < 0.7 wt.%)

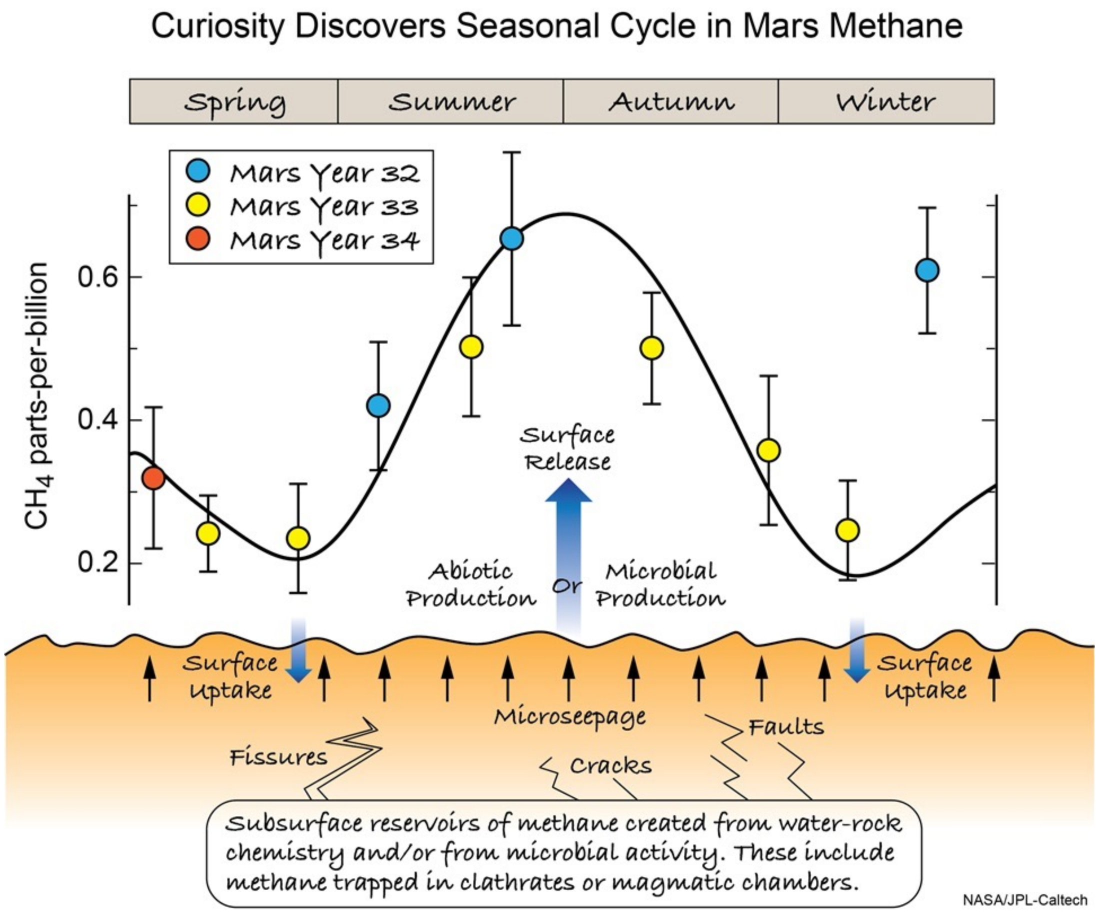
A finer level of detailed chemistry would help resolve the C species inventory in the sediment
→ Independent, multiple measurements



Sutter et al. 2017, JGR

Mysterious Methane…

MARS ORGANICS



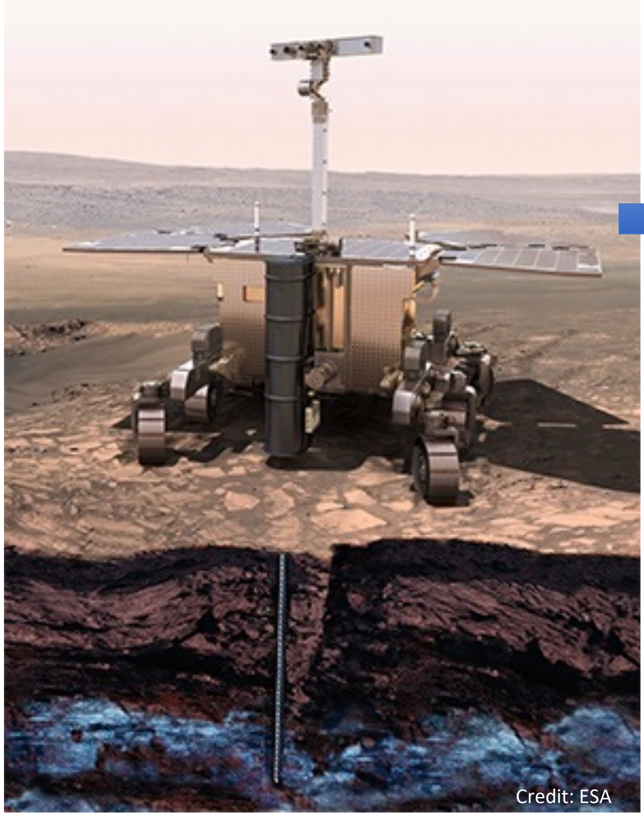
20 ppm night time SAM-TLS measurement

TGO, no correlative daytime detection

Example of missing context, in this case unknown unknowns.

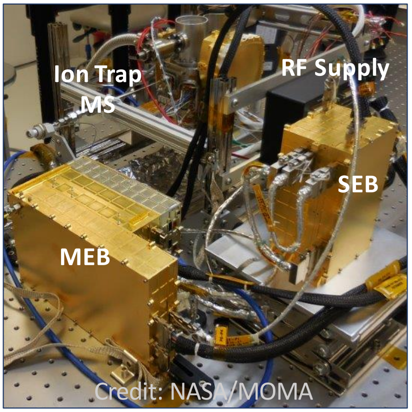
See Webster, et al. 2018, Science and Trainer et al., 2019, JGR

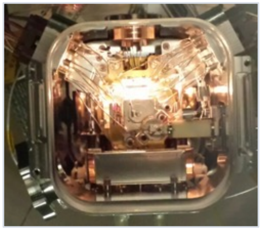
ExoMars rover and MOMA…



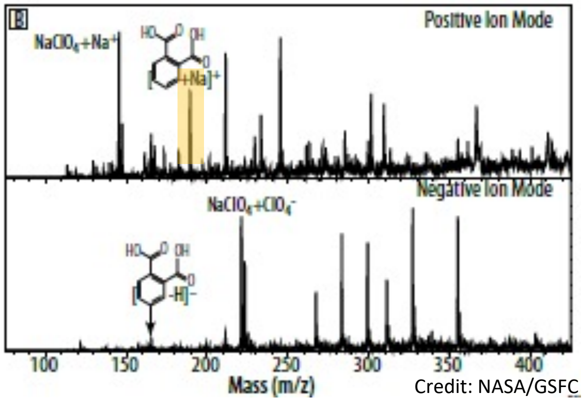
ExoMars rover will acquire subsurface samples up to 2 m depth

Mars Organic Molecule Analyzer (MOMA)





Linear Ion Trap MS
50 - 1000 Da
Inlets for LD and GC



Credit: NASA/GSFC

Phthalic acid identified in 1 wt% Na-perchlorate basalt mixture after laser desorption/ionization

Credit: NASA/MOMA

Slide provided by D. Glavin

Mars 2020 and Sample Return…

MARS SEARCH FOR LIFE

Mars 2020

- capable of detecting possible ancient microbial mats (stromatolites)
- how organic matter is packaged in sediments.
- sample caching capability.

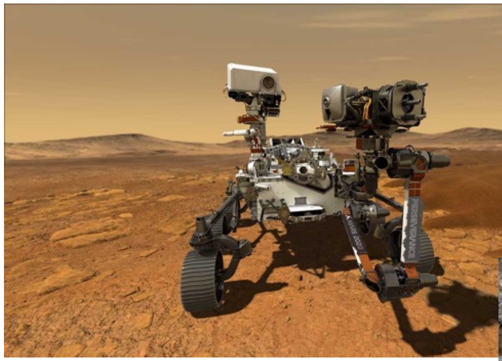


Image Credit: NASA/JPL-Caltech

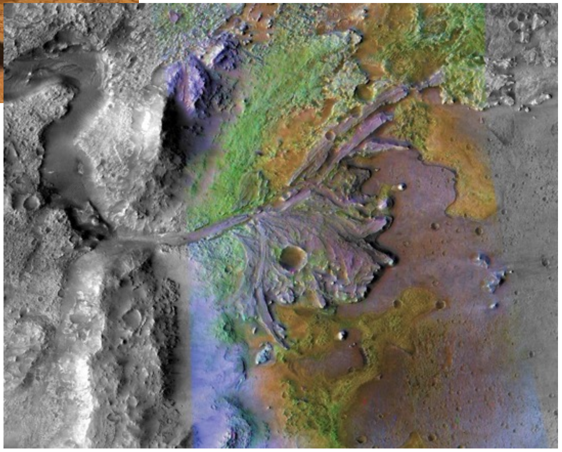
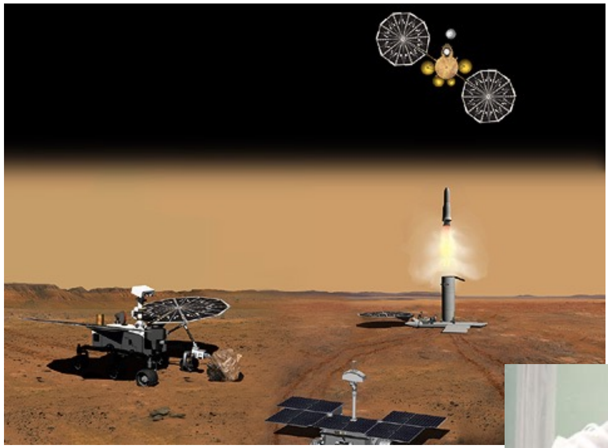


Image Credit: NASA/JPL-Caltech/ASU

Mars Sample Return

Returned samples will go through Planetary Protection testing that will test for life signatures and some context. If approved for release, earth-based laboratory analyses will be able to conduct more comprehensive measurements.



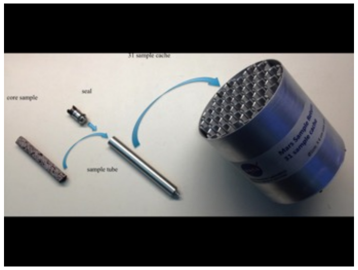


Image Credits: NASA

Slide details provided by D. Glavin

MARS SEARCH FOR EXTANT LIFE

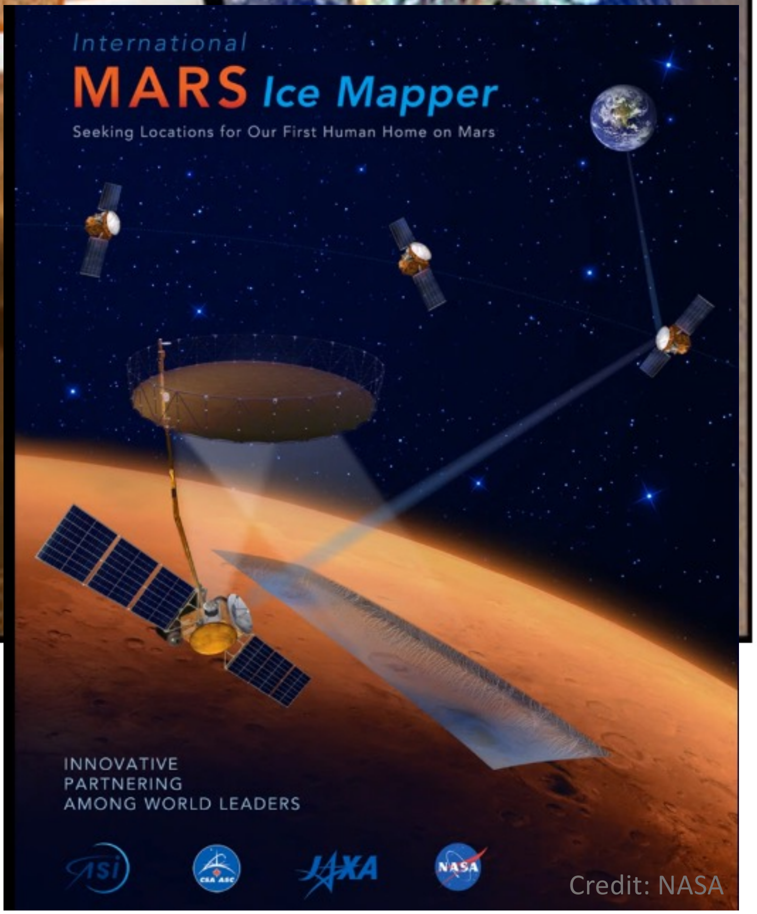
Credit: NASA/JPL-Caltech

Carrier et al., 2020, Astrobiology

- Salt
- Ice
- Deep subsurface
- Caves

Some overlap (Salt, Ice, Deep subsurface)

MIM Mission is in pre-Phase A with a measurement definition team (MDT) in progress.



Credit: NASA

Credit: NASA

How do we best leverage low latency science investigations by humans for astrobiology without contaminating samples and their context?

Acknowledgements

MSL team, SAM team, and colleagues that have engaged in discussions of organic and life signature mission design.

Thanks to Danny Glavin, Amy Williams, and Maeva Millan for specific contributions to the slides.

NASA/
JPL-Caltech/
MSSS