Jet Propulsion Laboratory
California Institute of Technology

Searching for Life on Mars

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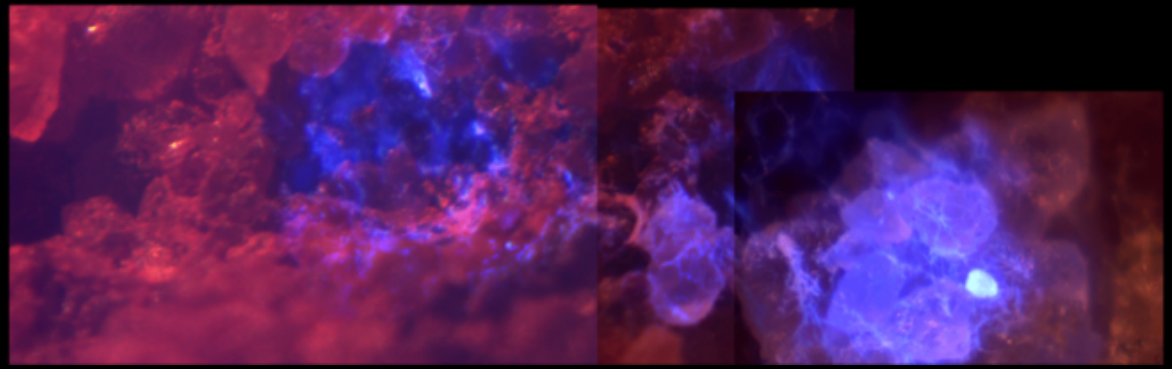
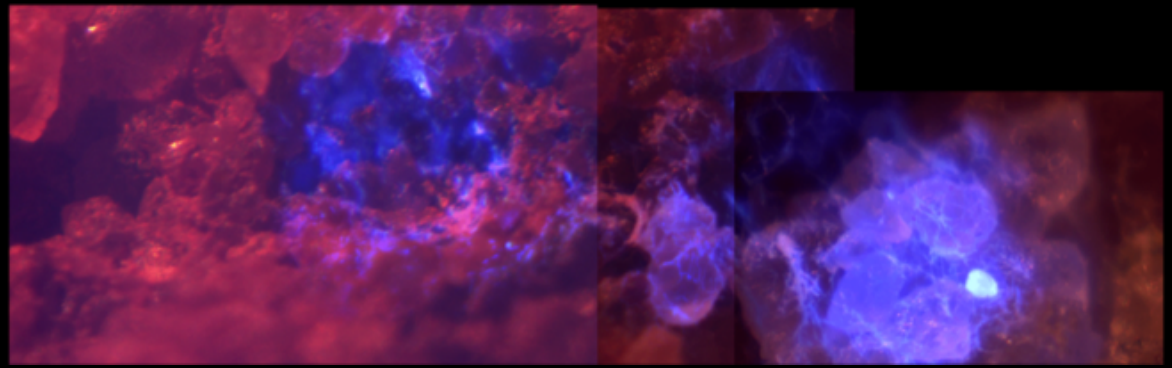


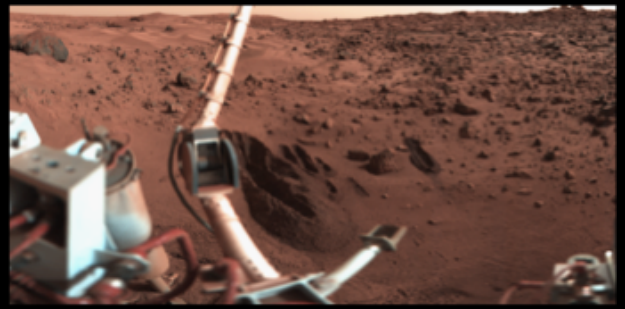
What to take away from this talk

- Life tends to “clump” in fractures/voids. Getting spatial context combined with chemistry is necessary.
- There is no one “best” method of analysis: Each technique has its unique capabilities and its challenges…. So combine them.
- What targets can be measured to search for life and what are the challenges



Signatures of Life on Mars?

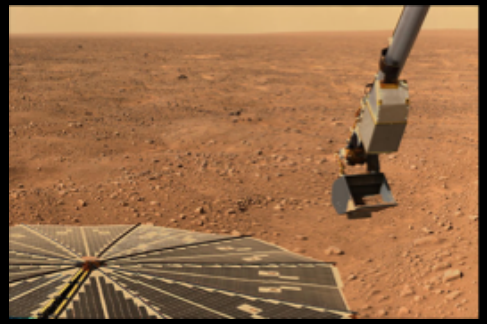
Viking Landers



GC/MS + Sample Handling

Organics: Inconclusive
Indications of a highly oxidizing environment

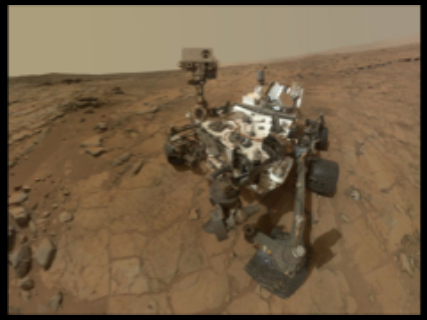
Phoenix Lander



GC/MS + Sample Handling

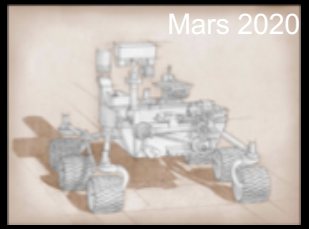
Organics: Inconclusive
Detection of Perchlorates

Curiosity/MSL



GC/MS + Sample Handling

Organics: Yes
Organics altered by Perchlorates

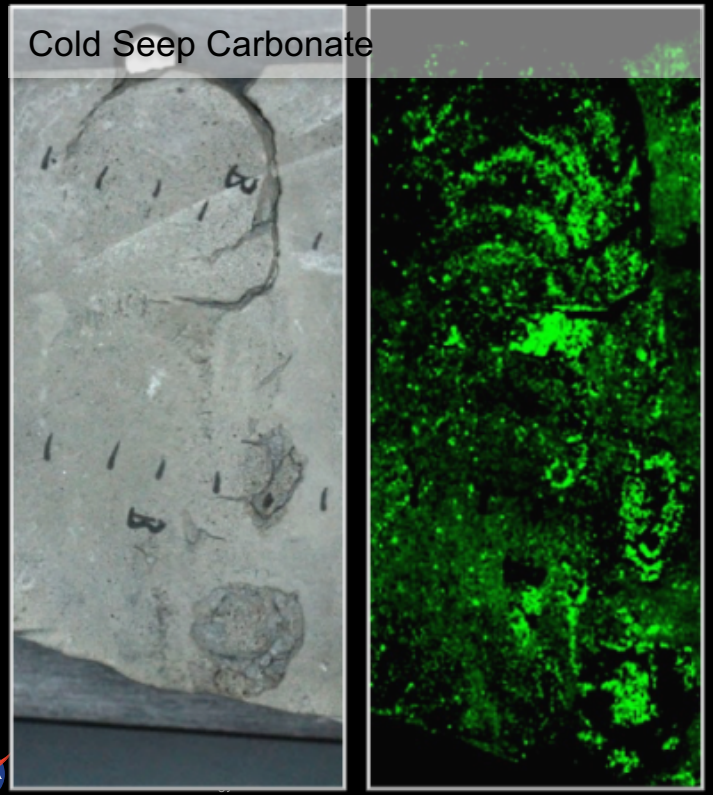


SHERLOC: Deep UV Fluorescence/Raman Mapping
PIXL: X-ray Fluorescence Mapping
SuperCam: Time-gated Visible Raman spectroscopy

Searching for Biosignatures

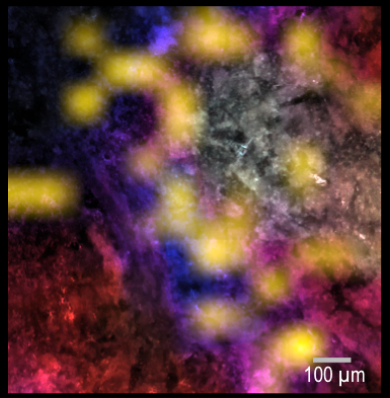
Which of these have life or possibly signs of life, and how to do you know where to start?

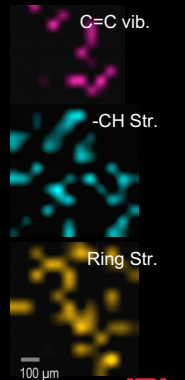
Cold Seep Carbonate

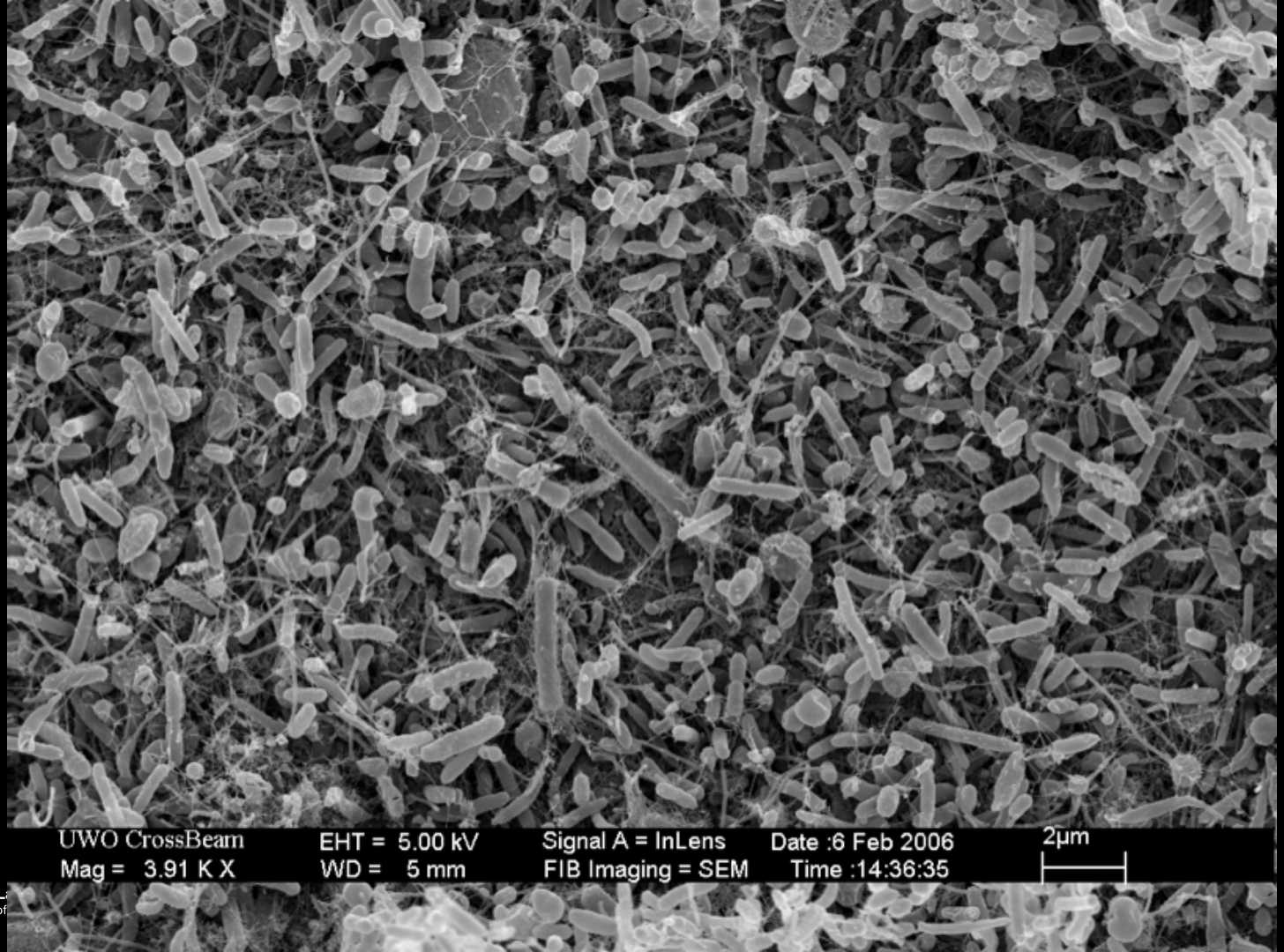


Subsurface Ice

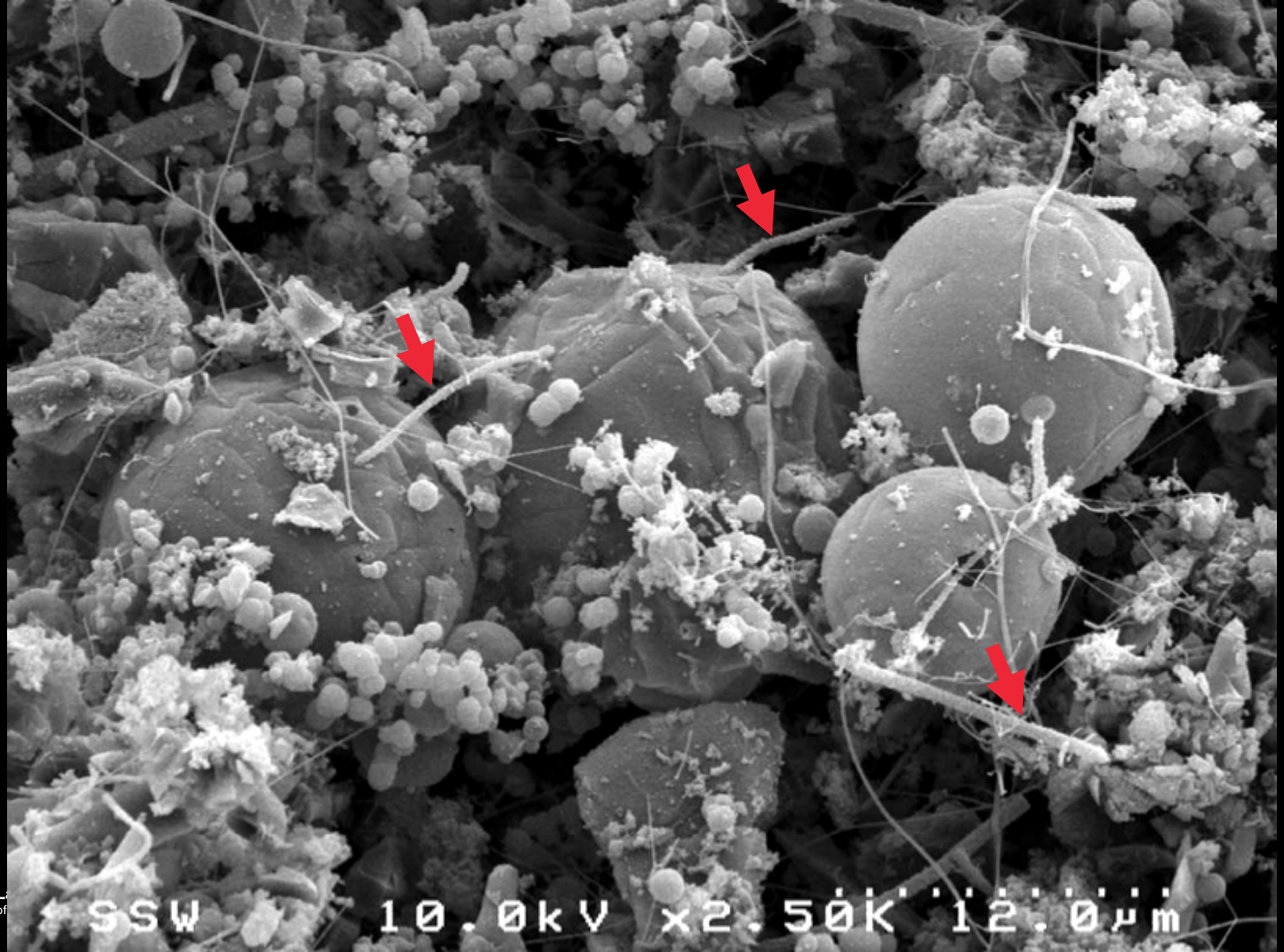
Tissint

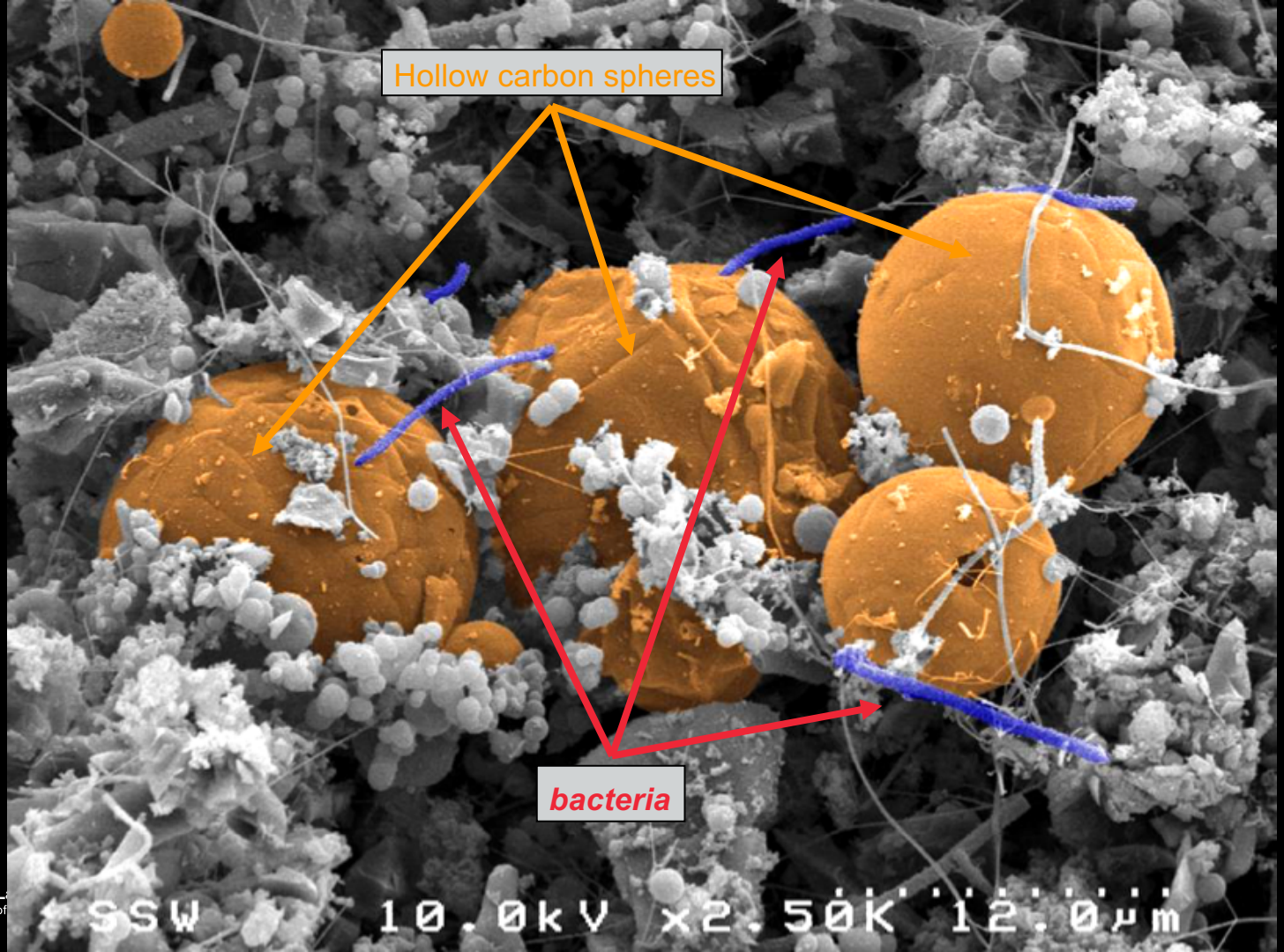





UWO CrossBeam
Mag = 3.91 K X
EHT = 5.00 kV
WD = 5 mm
Signal A = InLens
FIB Imaging = SEM
Date :6 Feb 2006
Time :14:36:35
2µm


SSW 10.0kV x2.50K 12.0µm


SSW 10.0kV x2.50K 12.0µm


Hollow carbon spheres
bacteria
SSW 10.0kV x2.50K 12.0µm

Searching for Life through Biosignatures

- **Biosignature:** any substance – such as an element, isotope, molecule, or phenomenon – that provides scientific evidence of past or present life.

- **Bulk Analysis Methods:** (GCMS/LC/CE/etc.) detection and identification of specific molecules, ratios of specific organics, organic inventory, etc.

- **Mapping/Imaging Methods:** (Raman/XRF/SIMS/SEM EDS/Microscopy etc.) detection and identification and spatial distributions of molecules and elements and provides morphology with chemistry

*apologies for not listing all possible instruments – suffice it to say there are many options out there

Bulk and Mapping/Imaging analyses

Its not a matter of which is “better”

Bulk analysis:

- Ingests a sample → Extracts materials of interest → Concentrates → Detects
- Enables separation of mixed materials by chromatography
- Detection observes extracted and processed material at *ppb to ppt levels*
- Loss of mineral/organics spatial context
- Cross reactions/alteration from matrix possible

Mapping/Imaging:

- Illuminate sample → Detect signal → Move to next volume
- Maintains mineral/organics spatial context
- Detection of material down to 1 cell/view volume
- Small volume analysis: need to illuminate material of interest to detect
- Identification difficult in mixed systems without increased spatial resolution

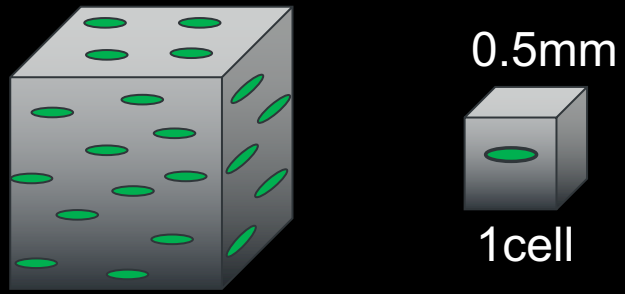
Bulk and Mapping/Imaging analyses

Its not a matter of which is “better”

Deep Biosphere/Subsurface Ice Environments on Earth

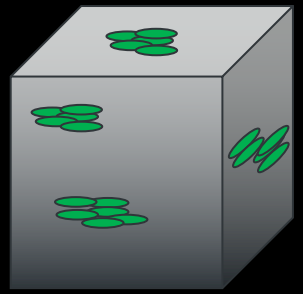
- Bioload is ~ $1x10^3$ to $1x10^4$ cells/cm^3
- Assume 1 cell has 200fg C ($2x10^{-13}$ g C) and rock is ~2.5g/cm3
- *But what is the distribution?*

Assuming Even Distribution



Bulk: Detection by concentration (sub ppb)
Scanning/mapping: Single cell detection needed
Thus requires 10million analyses/cm^3

Assuming Clustering

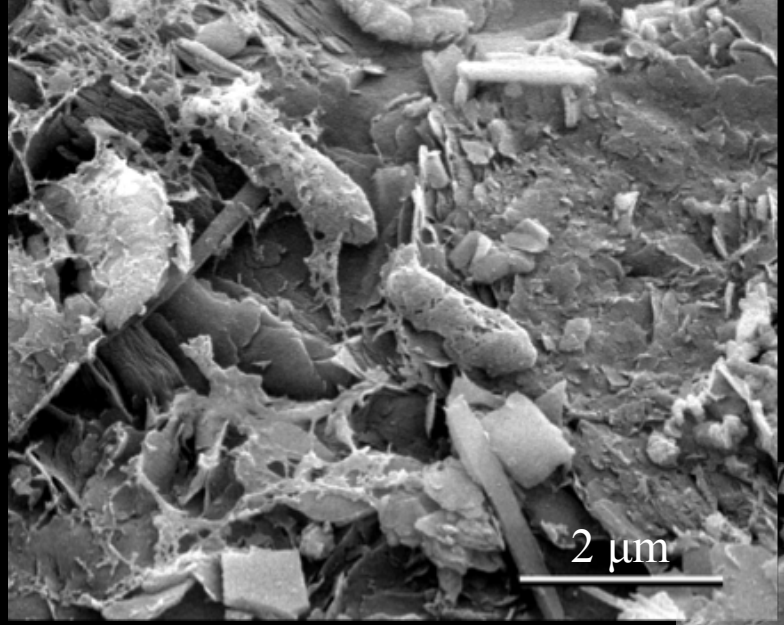


100-1000cells/cluster

Bulk: Detection but will loose knowledge of clusters
Scanning/mapping: single cell detection not needed
Use in conjunction (Scan to target bulk analysis)

Life in Fractures/voids

Life in the fractures



- 10^4 cells/cm^2 on the fracture surface
- Sessile population is 100-1000x the number of planktonic cells measured in the borehole water
- Very slow doubling times (Kieft & Phelps, 1997)

Defining Life: What do we look for?

"Life is a self sustaining chemical system capable of Darwinian evolution"

1. Life as we know it on Earth
    - contains DNA/RNA/proteins/fatty acids
    - key biosigs example hopanes/isotopes
    - *Note: We are continuously learning about life on Earth*

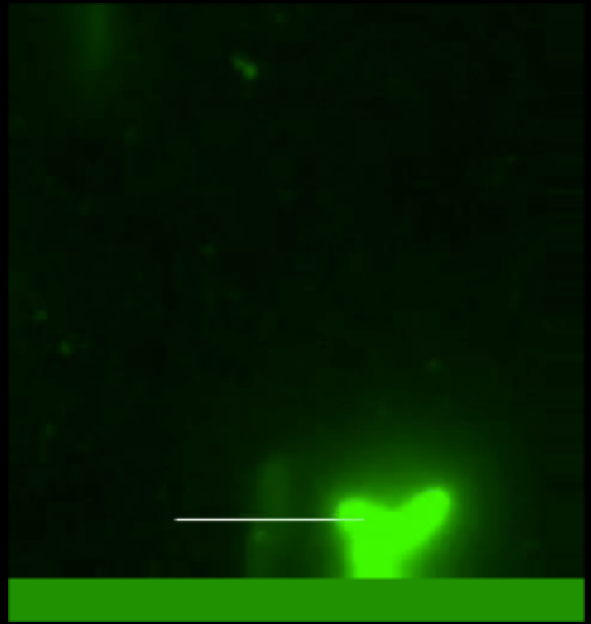
2. Non-Earth Centric approach (General Life)
    - assume life on Earth is not the only solution
        - another set of amino acids to another structure
    - detection of "patterns" that are indicators of life

Both approaches are necessary

What can you measure?
Astrobiology Ladder

- Growth/Reproduction
- Metabolism

- Functional Molecules
- Potential Biomolecules components
- General Indicators



S. Pirbadian et al 2014 Sep 2; 111(35): 12883–12888. doi: 10.1073/pnas.1410551111

Technique: Labeled Fluorescence Microscopy

https://astrobiology.nasa.gov/research/life-detection/ladder/

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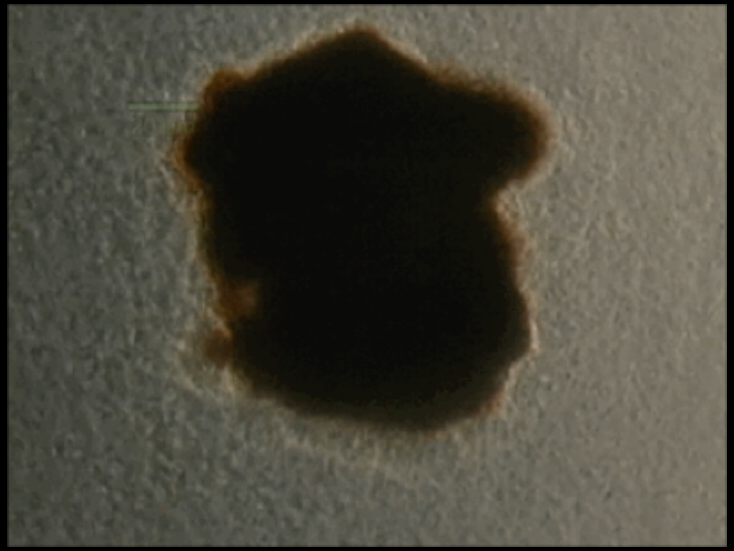

Technique: Time-lapse DIC Microscopy/SIMS

https://astrobiology.nasa.gov/research/life-detection/ladder/

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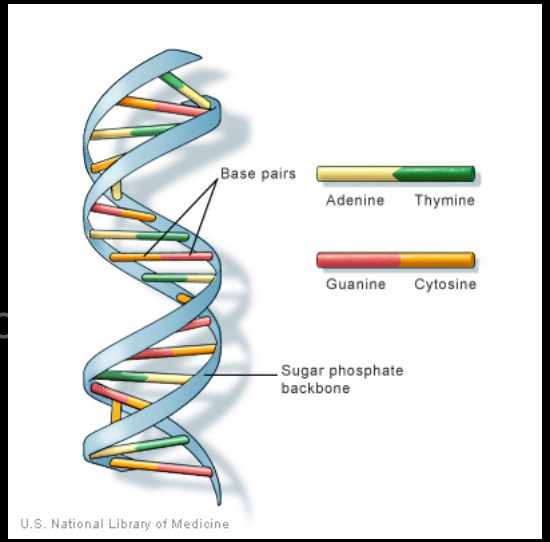
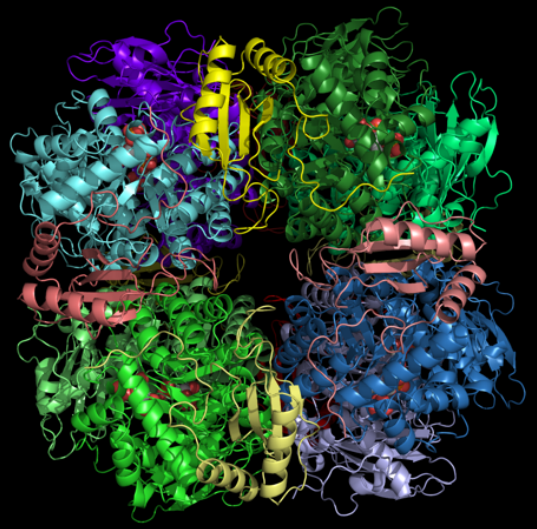


DNA



Proteins

Technique: OMICs/MS/Raman/IR/CE

Adapted from https://astrobiology.nasa.gov/research/life-detection/ladder/

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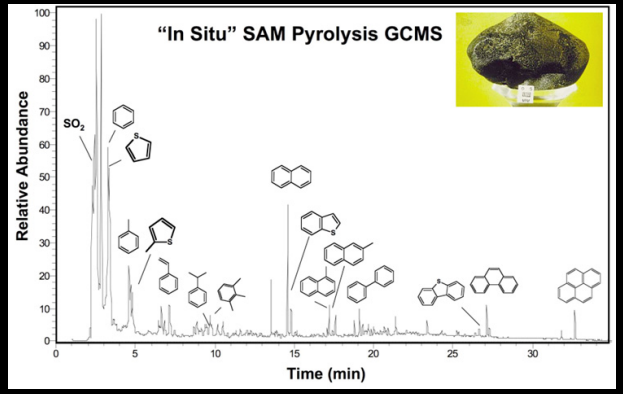

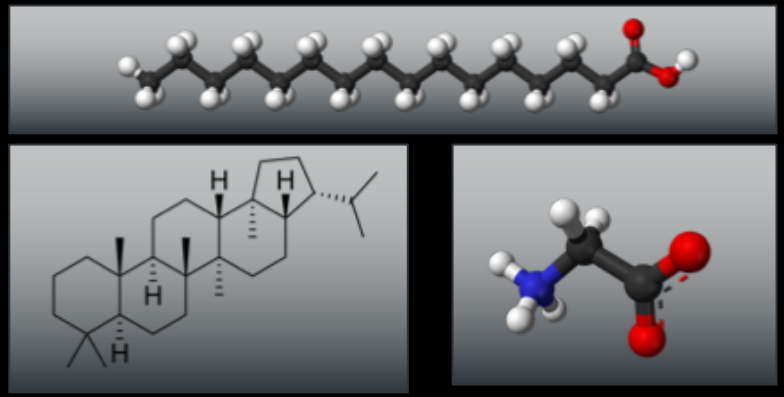

Technique: Raman/MS/IR/CE

Adapted from https://astrobiology.nasa.gov/research/life-detection/ladder/

What can you measure?

Astrobiology Ladder

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- Metabolism

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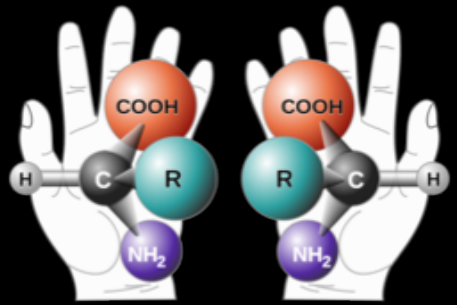
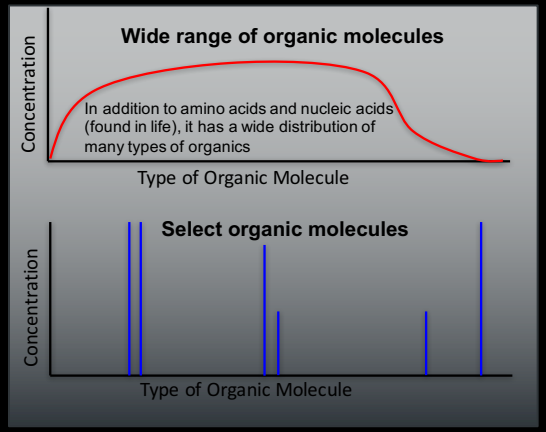
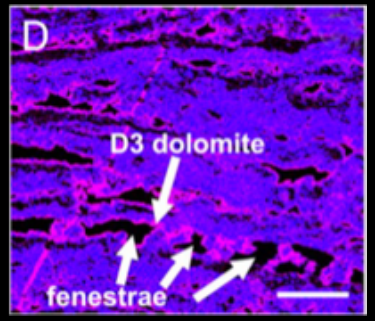
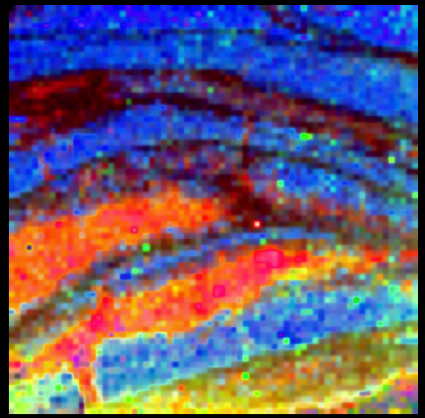








Technique: Mass Spec/LC/XRF/Raman

Adapted from https://astrobiology.nasa.gov/research/life-detection/ladder/

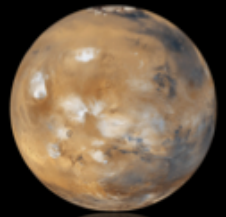
Organics: Abiotic vs. Potential Biosignatures

Abiotic Synthesis

Asteroids/Comets/IDPs*

infall

Native Planetary Processes



Polyaromatic Hydrocarbons
Amino Acids
Nucleic Acids
Chemistry Gone "wild"

Time/Pressure/Heat

Cosmic Radiation/UV

Altered Product

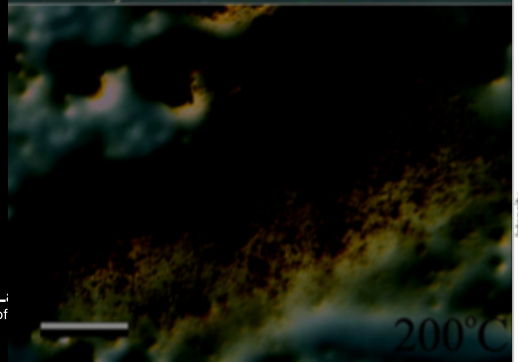
Life

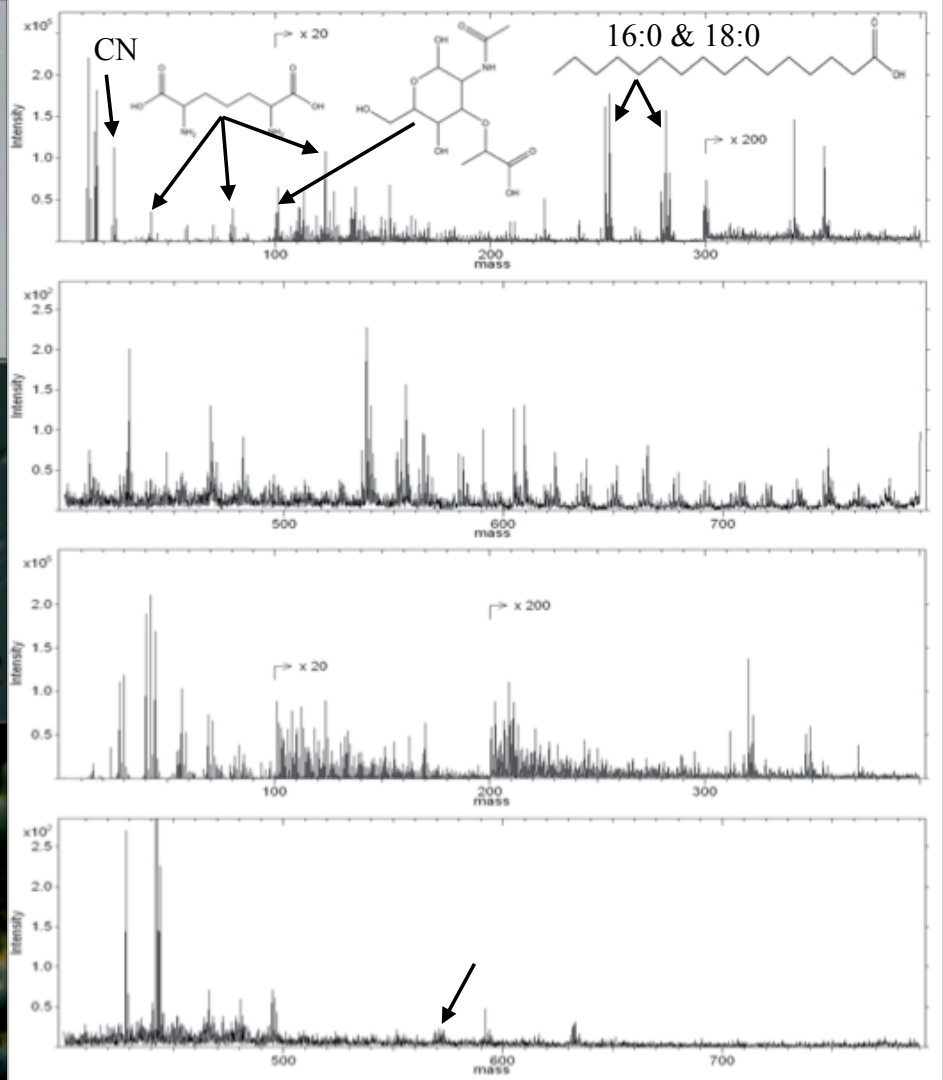
Microbes: small discrete packages of organics
Proteins/DNA: 2º/3º assemblies
Amino Acids : 20 specific ones
Nucleic Acids: 5 specific ones
Fatty acids
Organized Chemistry

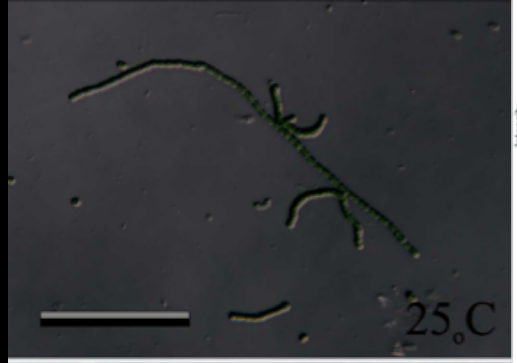
*IDPs: Interplanetary Dust Particles


25°C

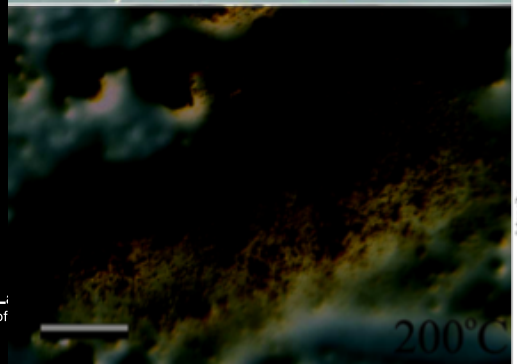

121°C


200°C


CN
16:0 & 18:0
x 20
x 200
Intensity
mass


25°C


121°C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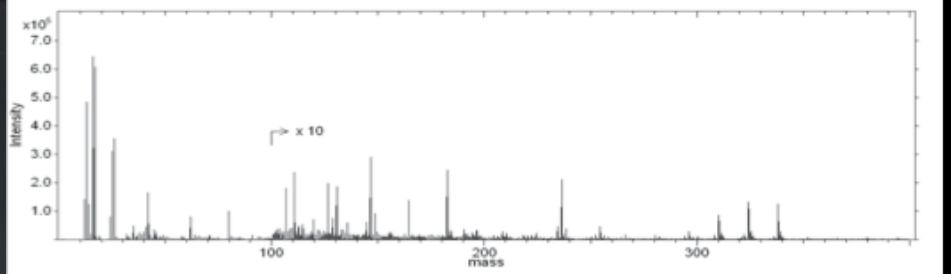
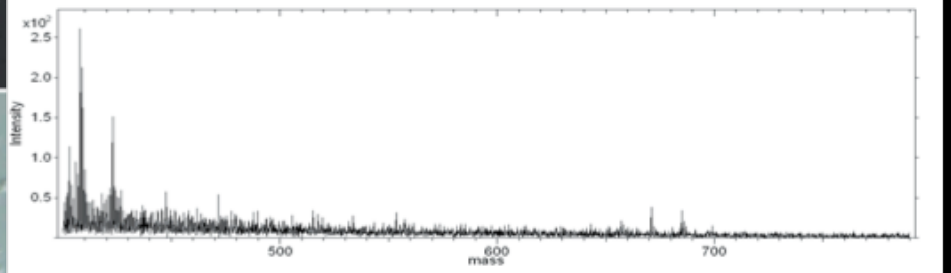
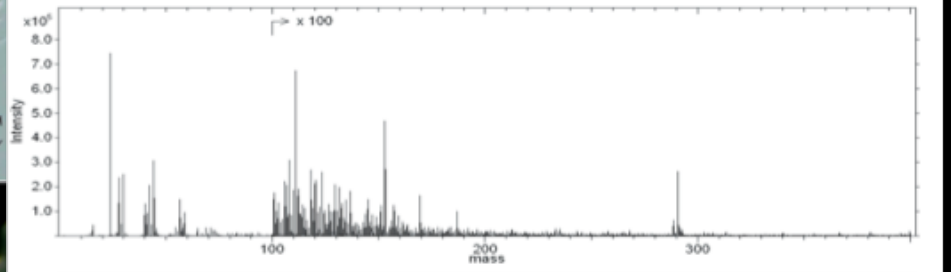
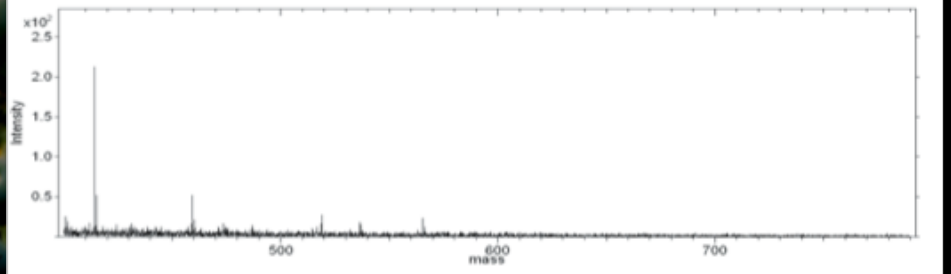
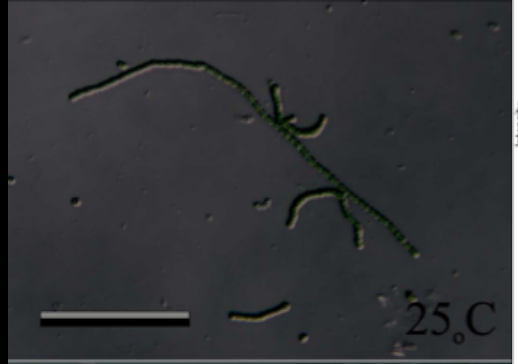

x10^5
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Intensity
x 10
100
200
300
mass

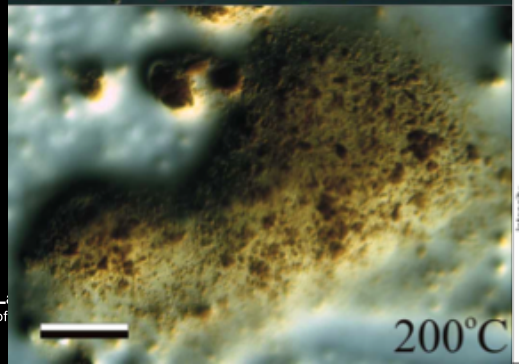

x10^2
2.5
2.0
1.5
1.0
0.5
Intensity
500
600
700
mass

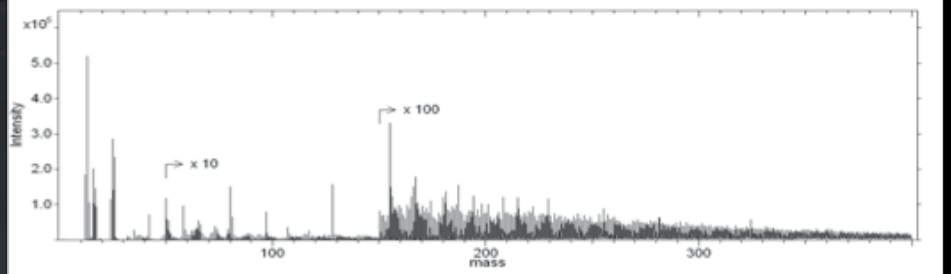

x10^5
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Intensity
x 100
100
200
300
mass

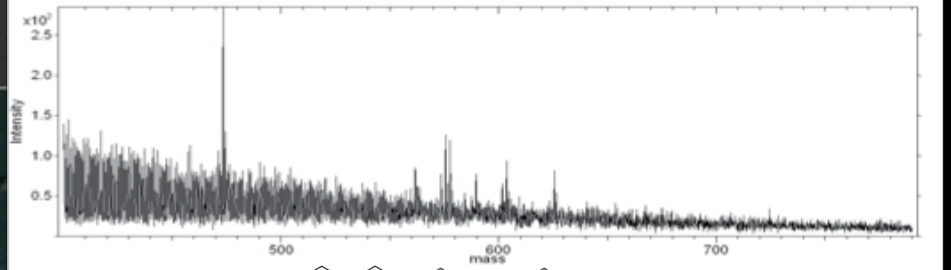

x10^2
2.5
2.0
1.5
1.0
0.5
Intensity
500
600
700
mass

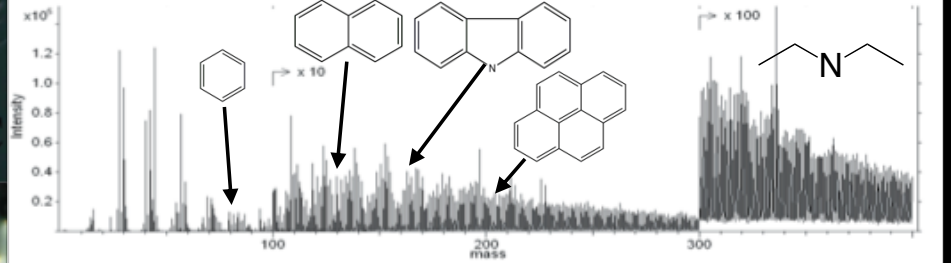

25°C

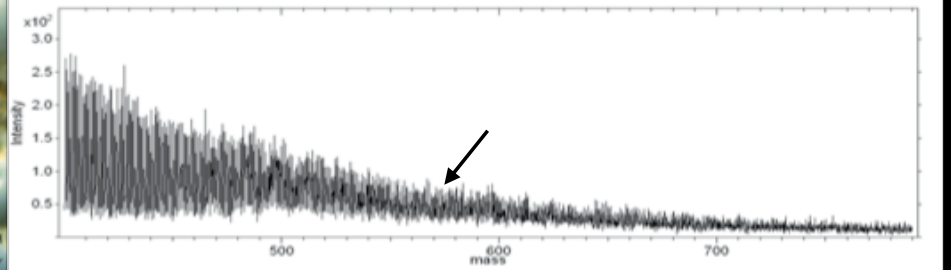

121°C

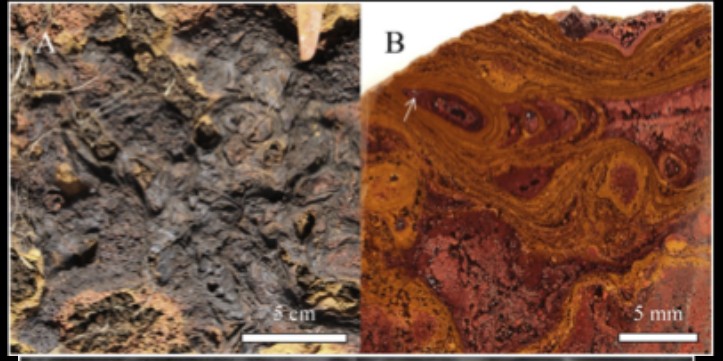

200°C

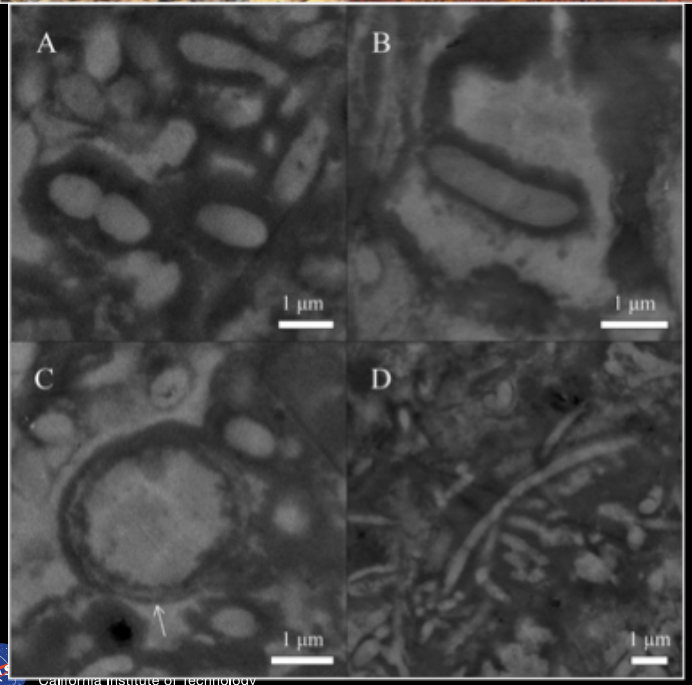

x10^5
5.0
4.0
3.0
2.0
1.0
Intensity
x 10
x 100
100
200
300
mass


x10^2
2.5
2.0
1.5
1.0
0.5
Intensity
500
600
700
mass

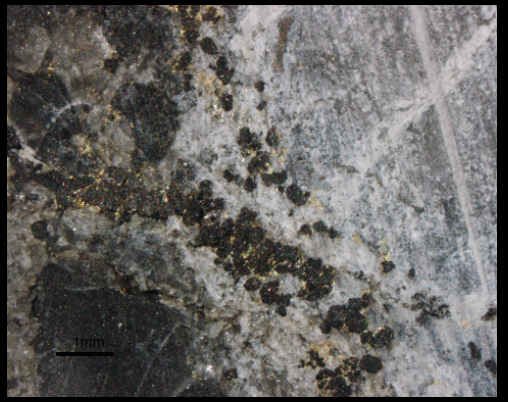

x10^5
1.2
1.0
0.8
0.6
0.4
0.2
Intensity
x 10
x 100
N
100
200
300
mass

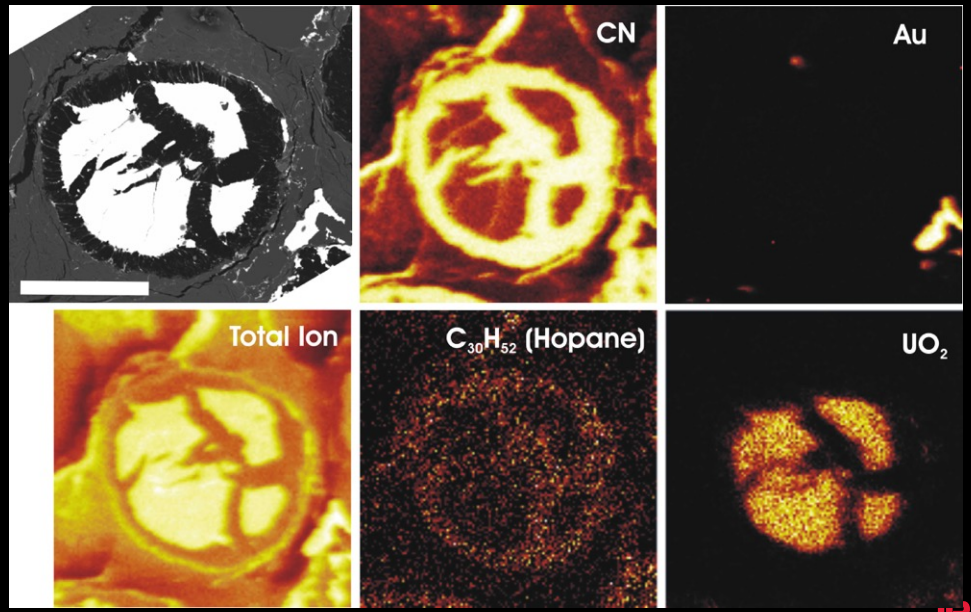

x10^2
3.0
2.5
2.0
1.5
1.0
0.5
Intensity
500
600
700
mass





Levett *et al*. 2016

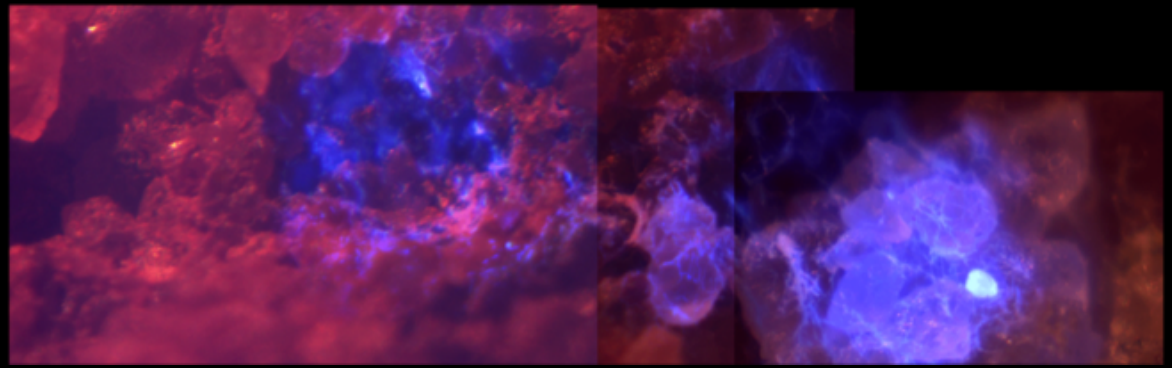




Wanger *et al*. 2008

Conclusions

- Life tends to “clump” in fractures/voids. Getting spatial context combined with chemistry is necessary.
- There is no one “best” method of analysis: Leverage the clumped nature of life to couple mapping and bulk methods.
- Use both terrestrial focused targets and non-earth centric approaches to search for life.



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NAI – Life Underground

PSTAR – WATSON

M2020- SHERLOC

Questions?


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