Fire and Ice . . . and Methane

Exploring Mars and Titan using laboratory and field analogues

Morgan L. Cable, Ph.D.

May 19, 2016

Jet Propulsion Laboratory
California Institute of Technology

Image: NASA/JPL-Caltech/SSI

Analogue Environments

The next best thing to actually being there

Analogue /Analog *(ān'ə-lôg′) n.*

A physical object or quantity used to measure or represent another quantity.

Image: Flickr/indii.org

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Image: NASA/JPL-Caltech/Cornell

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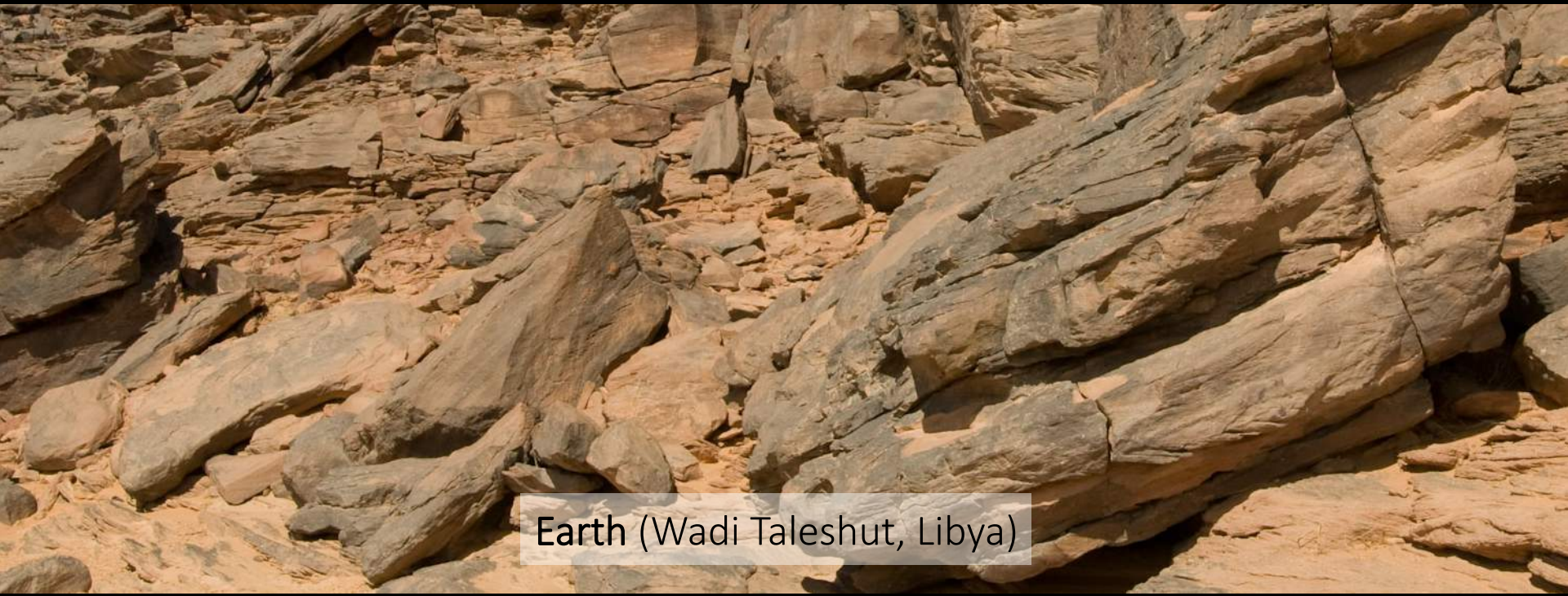

Image: Flickr/H. Pagi

Analogue Environments

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Image: NASA/JPL-Caltech/MSSS

Analogue Environments

The next best thing to actually being there

Analogue /Analog *(ān'ə-lôg′) n.*

A physical object or quantity used to measure or represent another quantity.

Image: C. Platt

Iceland as an Analogue

The Moon

Geology field tests in Iceland were used to prepare Apollo astronauts for lunar surface activities

Mars

Icelandic lava fields are often used as Mars analogue sites (due to properties such as desiccation, low nutrient availability, temperature extremes)

Images: M. Cable

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

Goal: Inform Future Mars Missions in the Search for Life

Georgia Institute of Technology

University of Washington

JPL
Jet Propulsion Laboratory
California Institute of Technology

The Open University

Cranfield University

Stanford University

Stockholm University

Turun yliopisto
University of Turku

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Image: A. Stockton

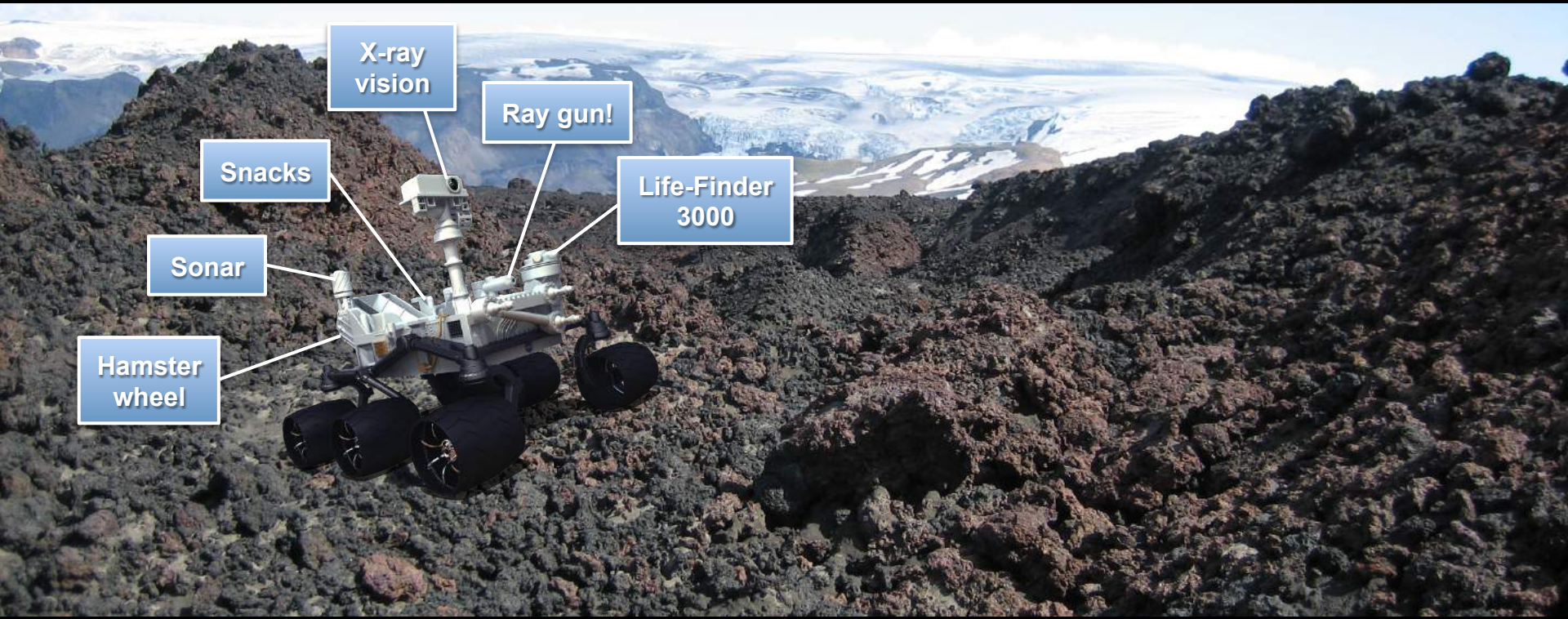
FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

Images: M. Cable, Toys on Fire Ottawa, NASA/JPL-Caltech/Univ. of Arizona, Ollustrator

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

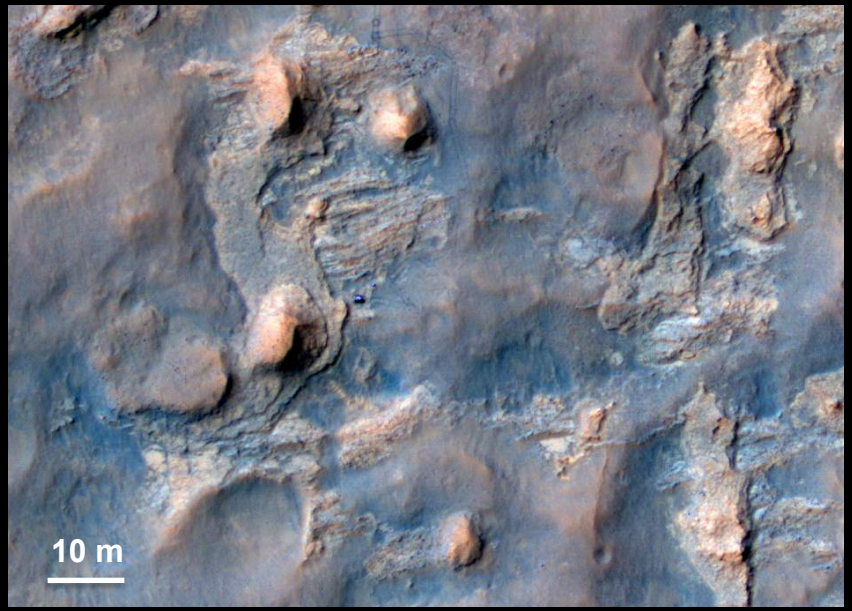


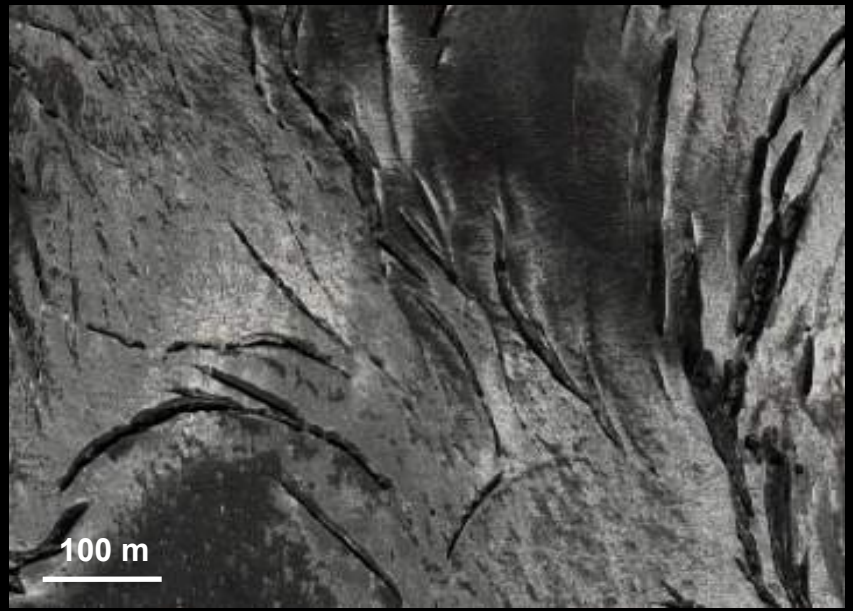
Images: M. Cable, Toys on Fire Ottawa, NASA/JPL-Caltech/Univ. of Arizona, Ollustrator

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

MARS Remote Sensing	EARTH Google Earth

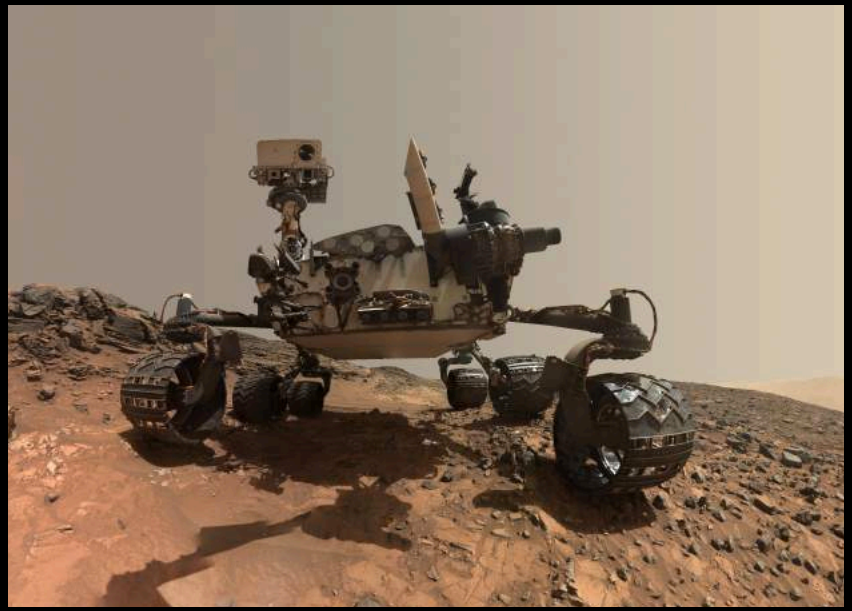




Images: A. Stockton; Google Earth

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

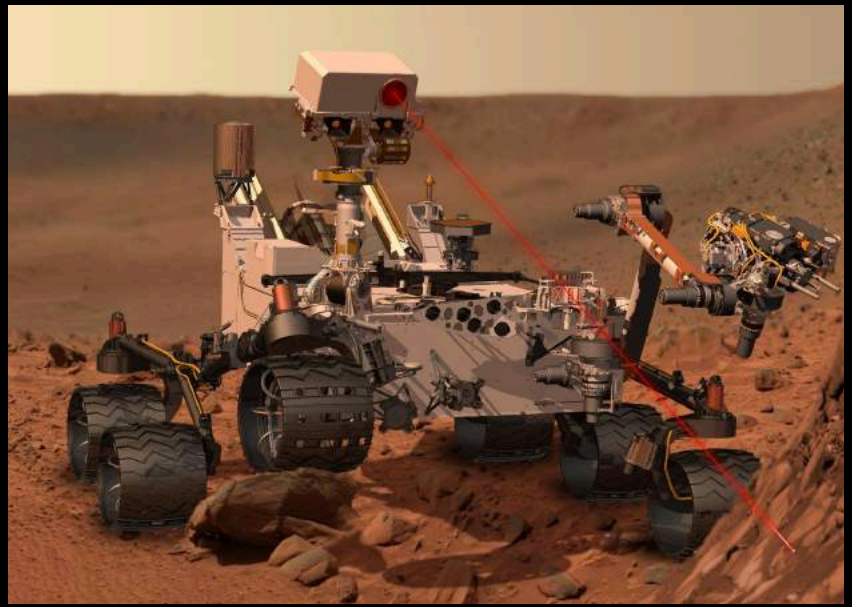
MARS Mars Rover	EARTH Land Rover
	

Images: NASA/JPL-Caltech; M. Cable

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

MARS
Standoff Analysis



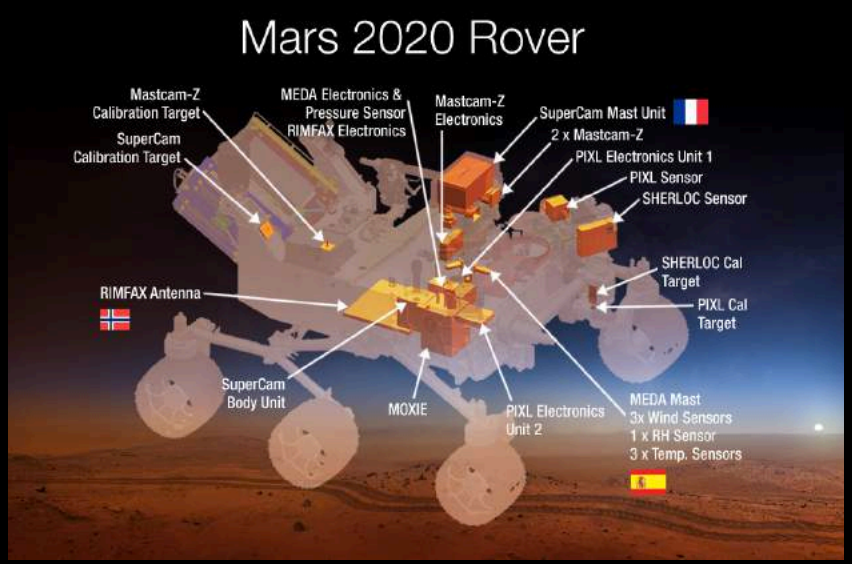
EARTH
Field Portable Instruments

Images: NASA/JPL-Caltech; D. Cullen

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

MARS
In Situ Sample Analysis

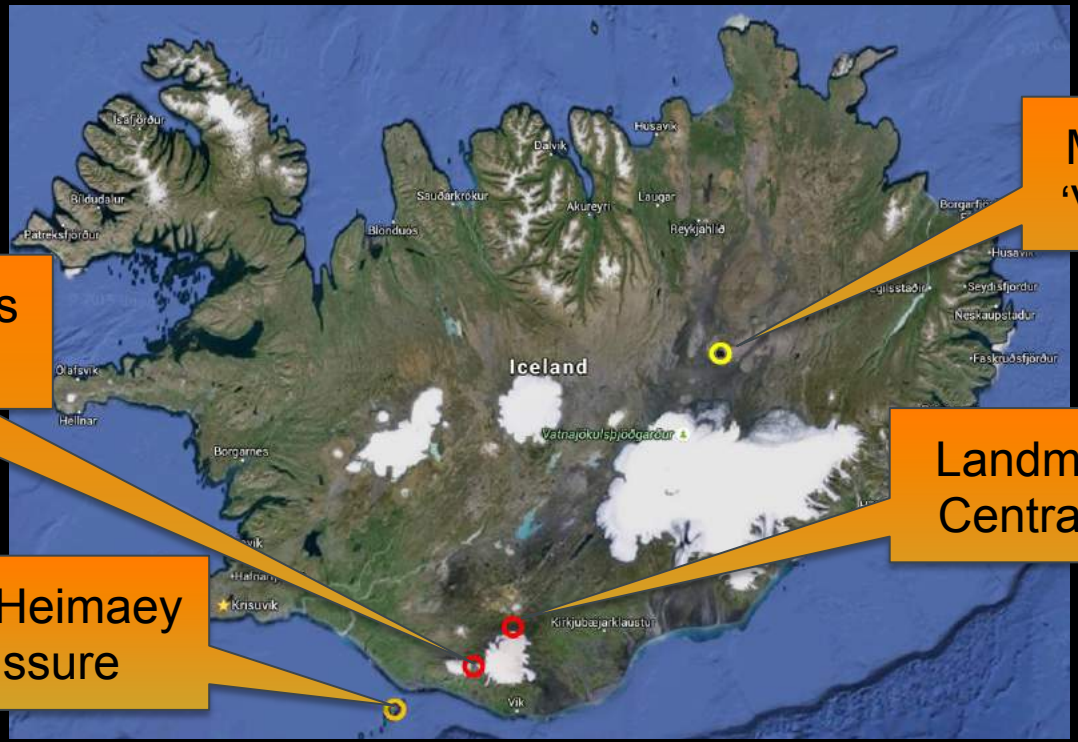


EARTH
Analysis in Field Laboratory

Images: NASA/JPL-Caltech; A. Stockton

FELDSPAR – Sampling Sites

So much lava, so little time . . .



Mælifellssandur
'Volcanic desert'

Fimmvörðuháls
Lava Field

Landmannalaugar
Central Highlands

Eldfell on Heimaey
Lava Fissure

Image: Google Earth

FELDSPAR – Sampling Sites

Images: Google Earth; Hurtigruten

FELDSPAR – Sampling Sites

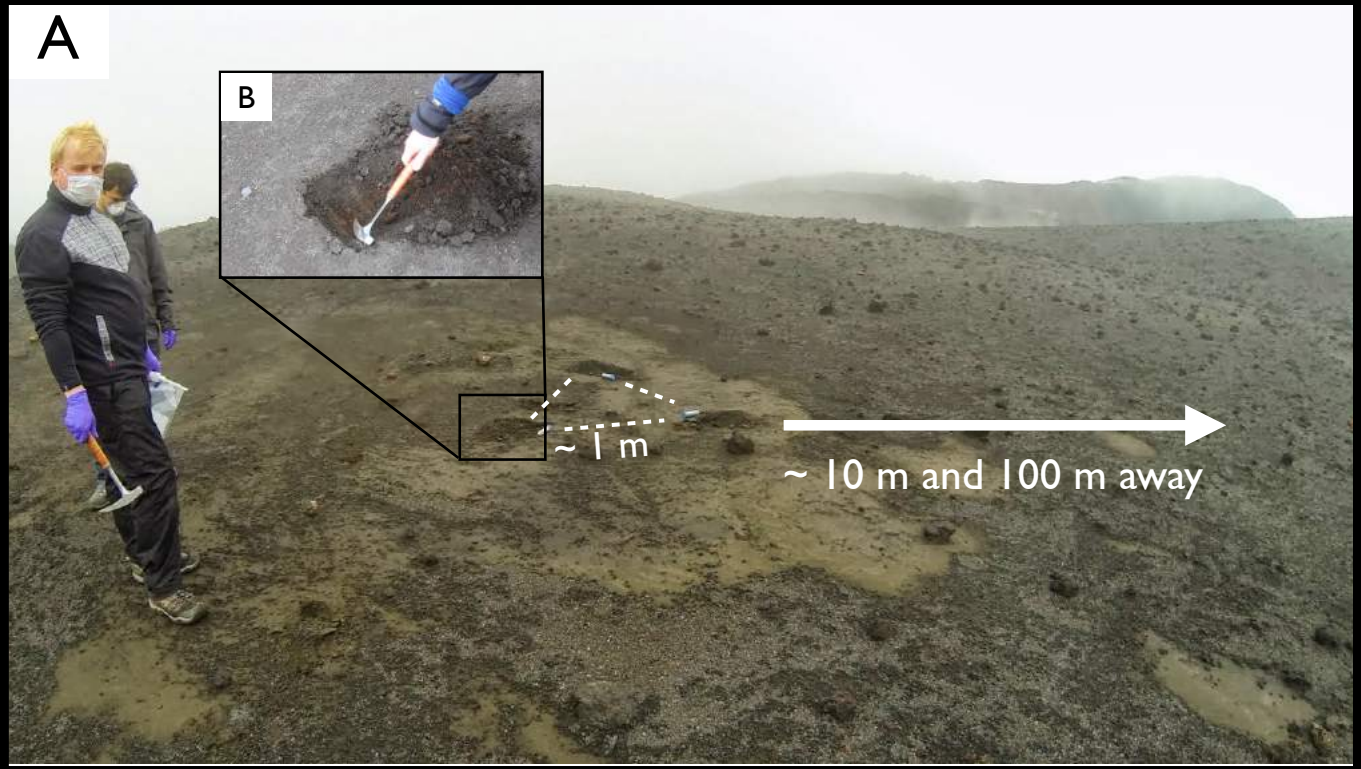
Images: Google Earth; Olikristinn

FELDSPAR – Sampling Sites

Image: D. Cullen

FELDSPAR

We take all the samples, so your Mars rover doesn't have to



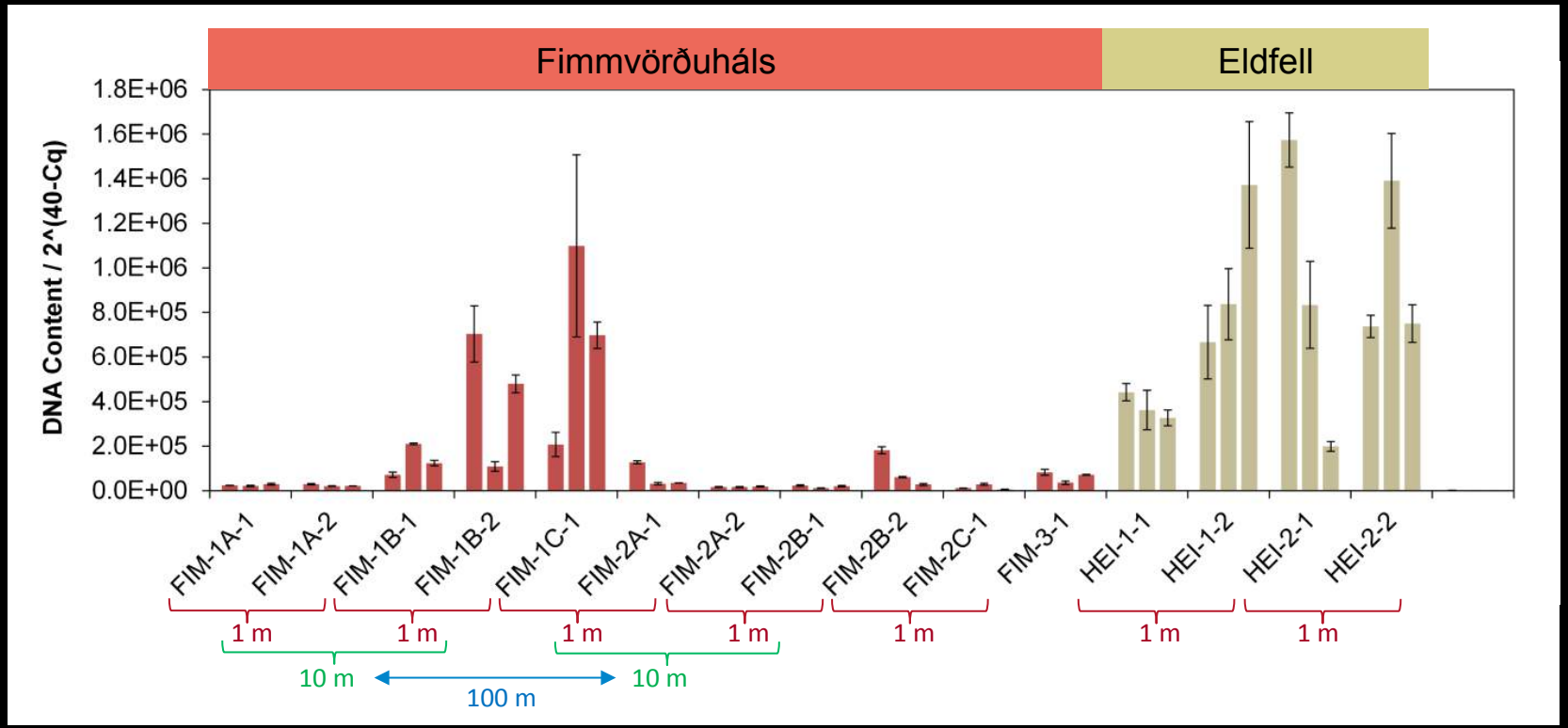
Amador, *et al.*, **2015,** *Planetary and Space Science*, *106*: 1-10.

FELDSPAR – Field Laboratory

Photos: M. Cable; A. Stockton

FELDSPAR – Results

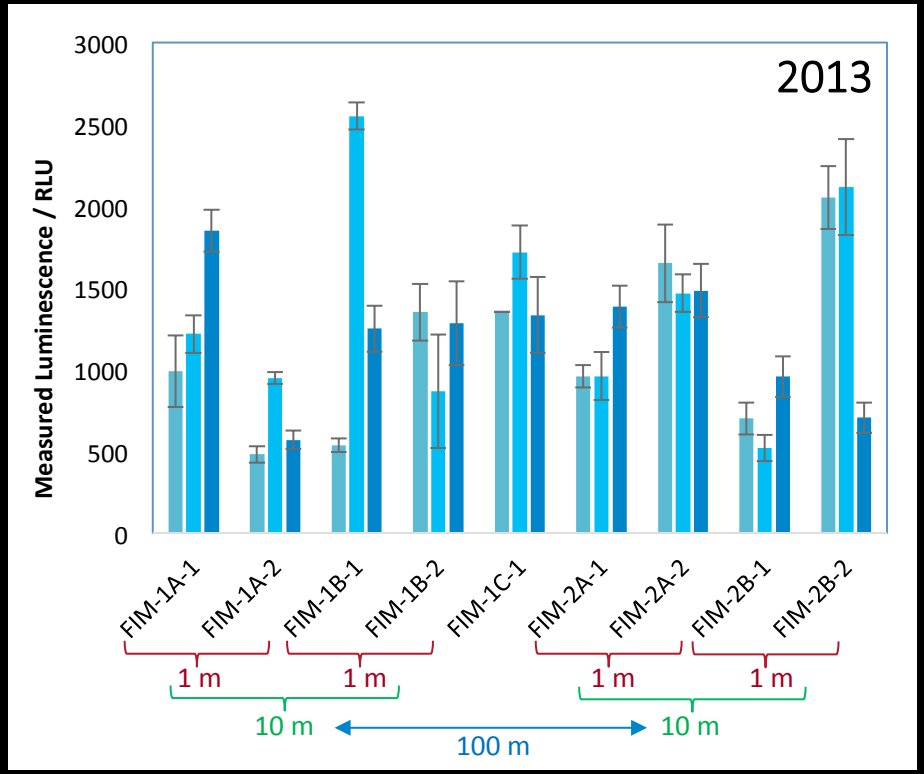
Quantitative PCR – Tells you what kind of life is present, and how much

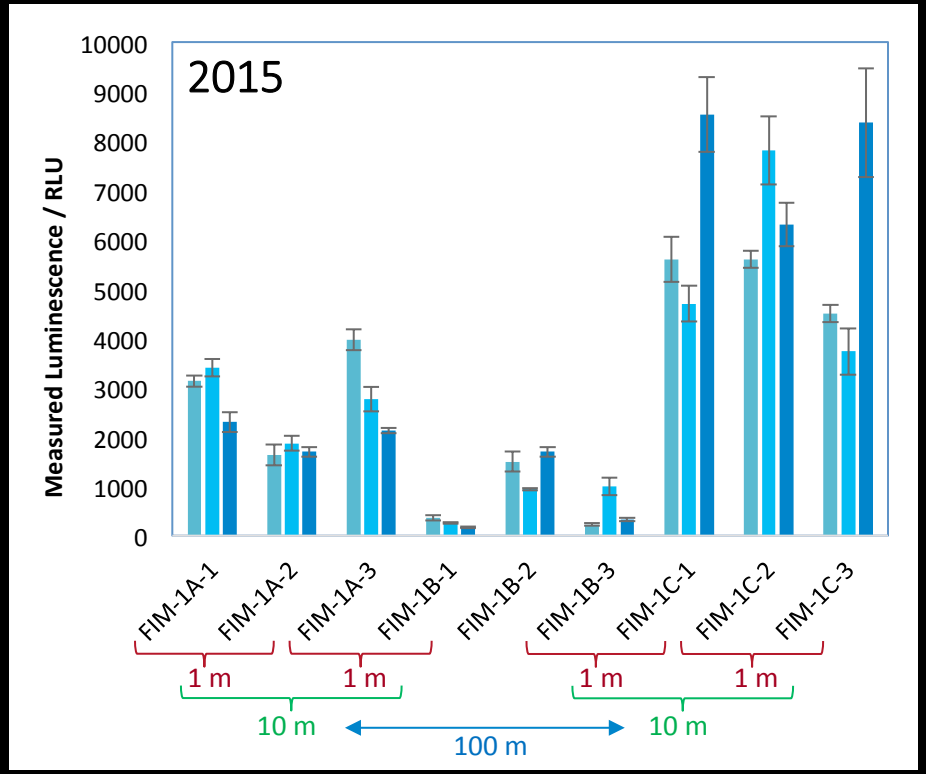


Amador, *et al.*, **2015**, *Planetary and Space Science*, *106*: 1-10. Gentry, *et al.*, **2016**, *Astrobiology, in preparation.*

FELDSPAR – Results

ATP Assay – Tells you how many organisms are actively metabolizing





Amador, *et al.*, **2015**, *Planetary and Space Science, 106*: 1-10. Gentry, *et al.*, **2016**, *Astrobiology, in preparation.*

FELDSPAR – Fimmvörðuháls from the air

Video: A. Stockton

FELDSPAR - Conclusions

More Questions than Answers

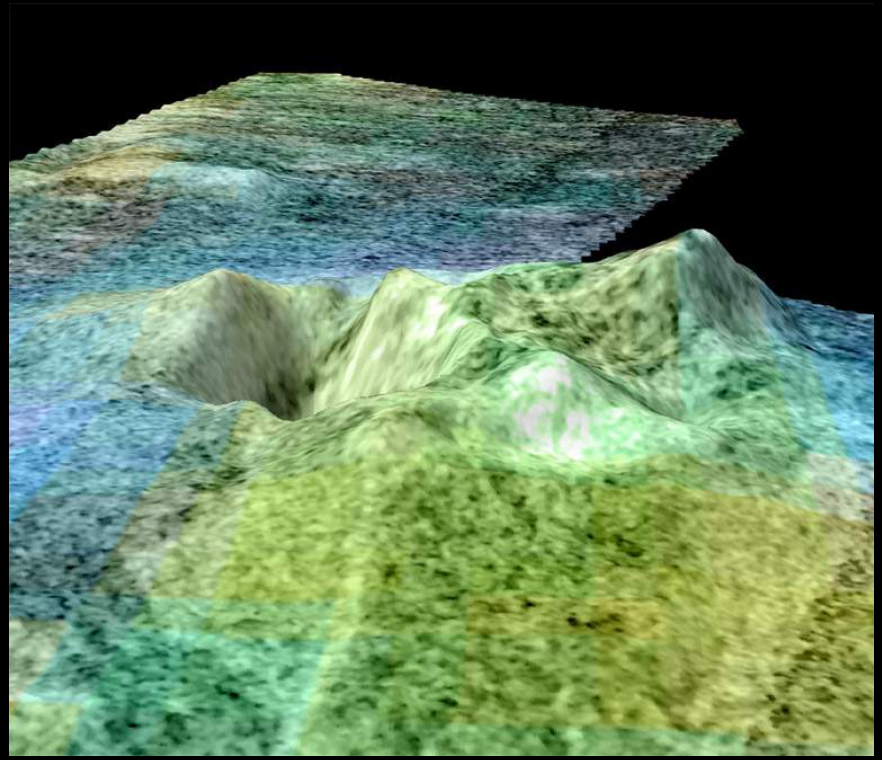
- Old lava fields have contamination
- In young lava fields, life abundance can vary widely (even over 1 meter scales)
- Over time, patterns emerge

The Plan: Monitor emergence of life in fresh lava fields over time

Images: E. Gudmann; J. Gustafsson

What if no Analogue Exists?

- Atmosphere
  - 96% N_2, 4% CH_4
  - 1.5 bar (thicker than Earth)
- Surface
  - Water-ice coated in organics
  - Dunes in the equatorial region
- Hydrologic Cycle
  - Liquid methane, ethane lakes
  - Methane clouds, drizzle
- Putative Cryovolcanoes
  - Slurry of ammonia and water ice, possibly methanol

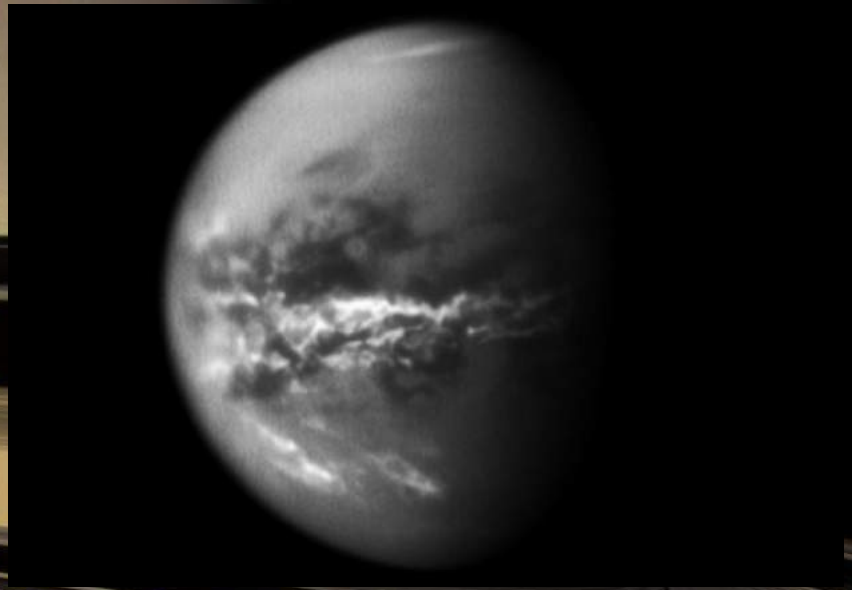


A possible cryovolcano in the Sotra Facula region of Titan (NASA/JPL/Univ. of Arizona/USGS)

TITAN

Familiar, yet alien

TITAN Clouds	EARTH Clouds



Images: NASA/JPL-Caltech/SSI; NASA

TITAN

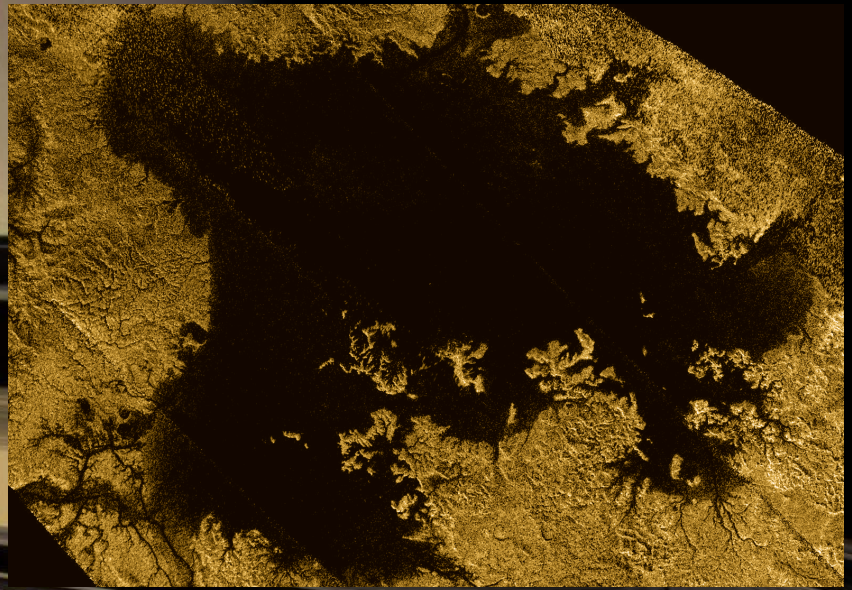
Familiar, yet alien

TITAN River channels	EARTH River channels

Images: NASA/JPL-Caltech; NASA/Landsat

TITAN

Familiar, yet alien

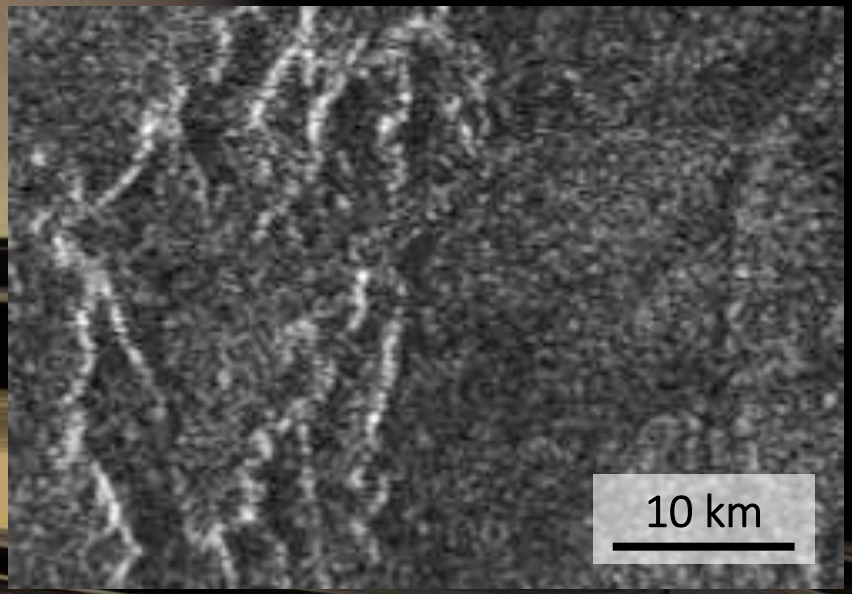
TITAN Lakes and Seas	EARTH Lakes and Seas
	

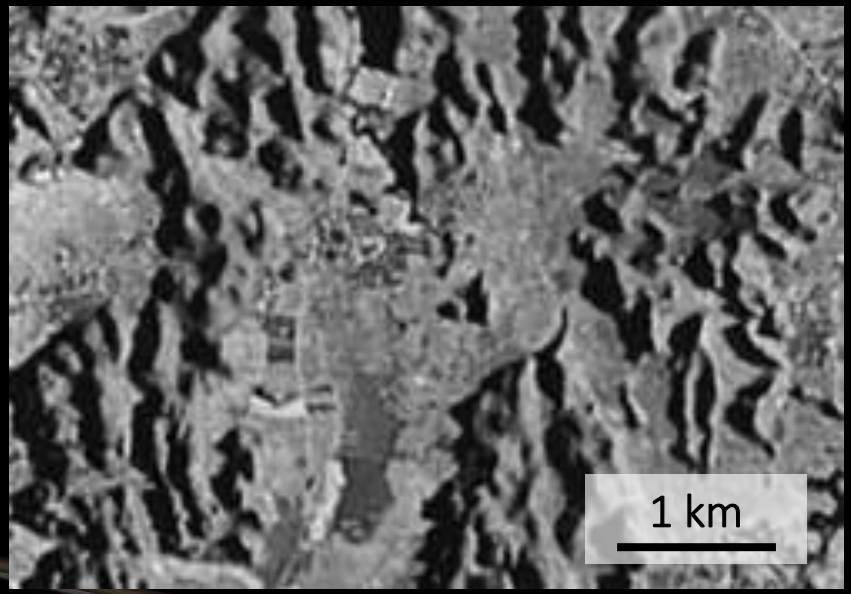
Images: NASA/JPL-Caltech/ASI/Cornell; Google Earth

TITAN

Familiar, yet alien

TITAN Remnants of Ridges (Karst)	EARTH Remnants of Ridges (Karst)





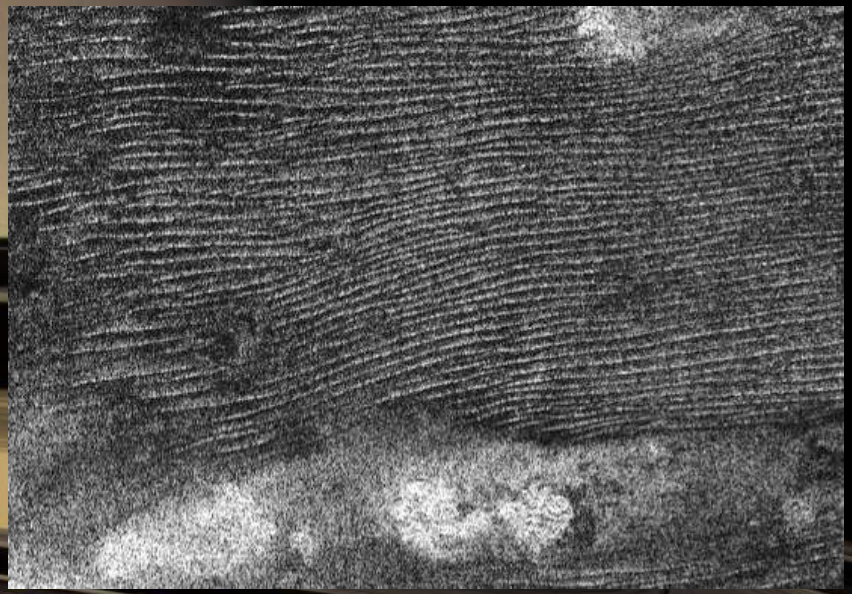
Images: NASA/JPL-Caltech; Google Earth

Malaska et al., LPSC (2010), Abstract 1544

TITAN

Familiar, yet alien

TITAN Dune Fields	EARTH Dune Fields

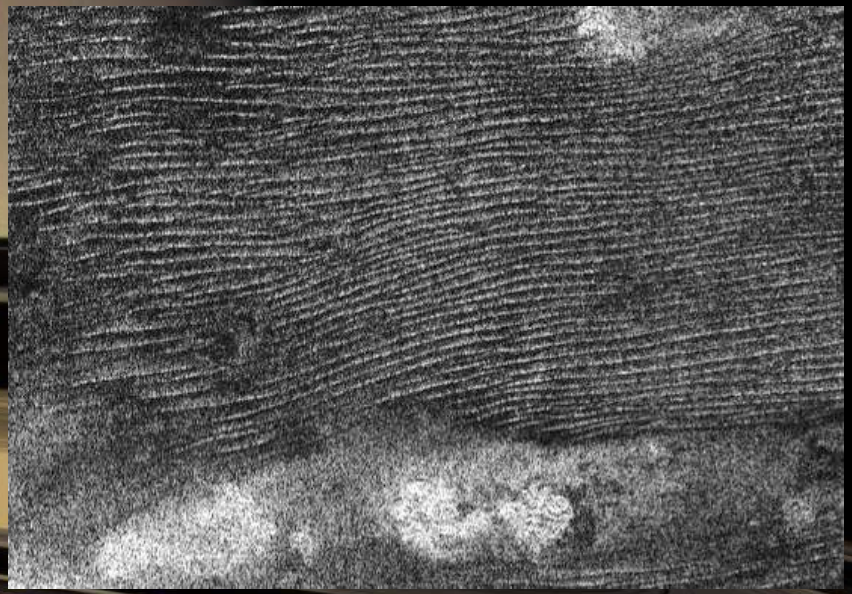


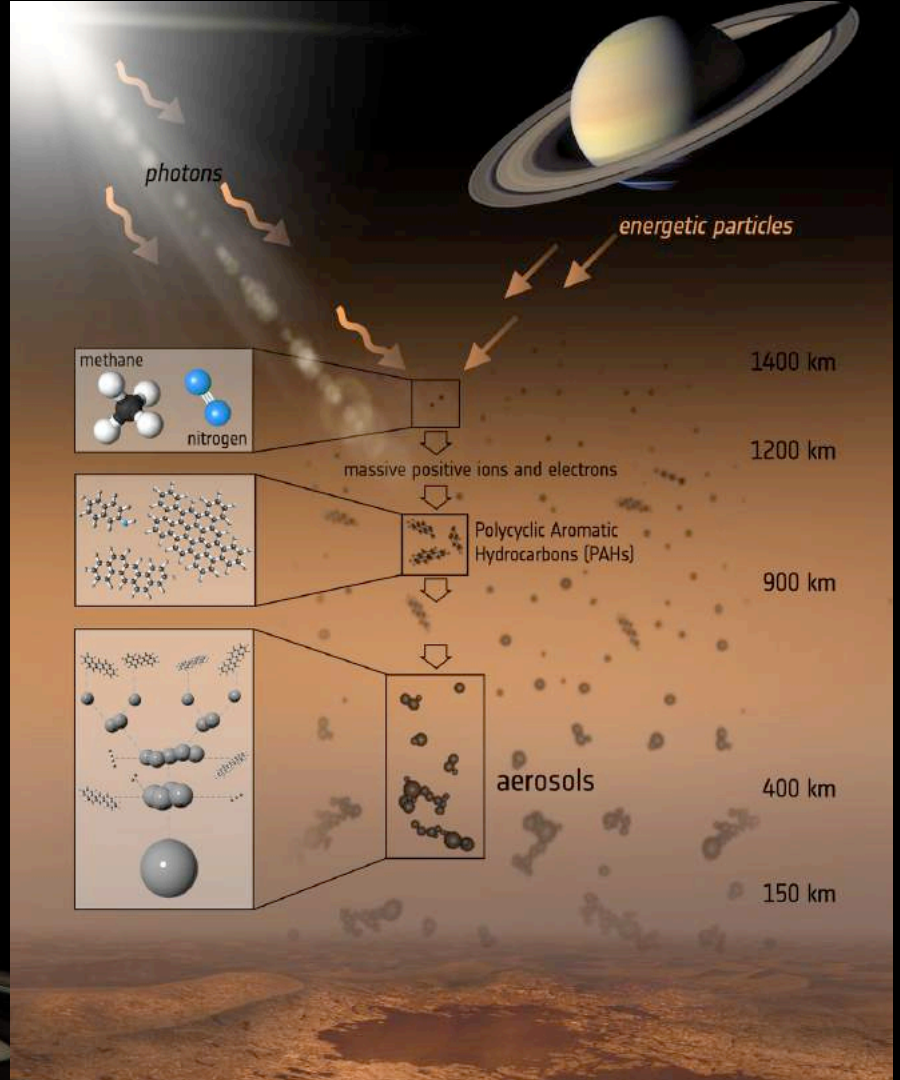
Images: NASA/JPL-Caltech/ASI/Cornell; NASA/Landsat

TITAN

Familiar, yet alien

TITAN
Dune Fields



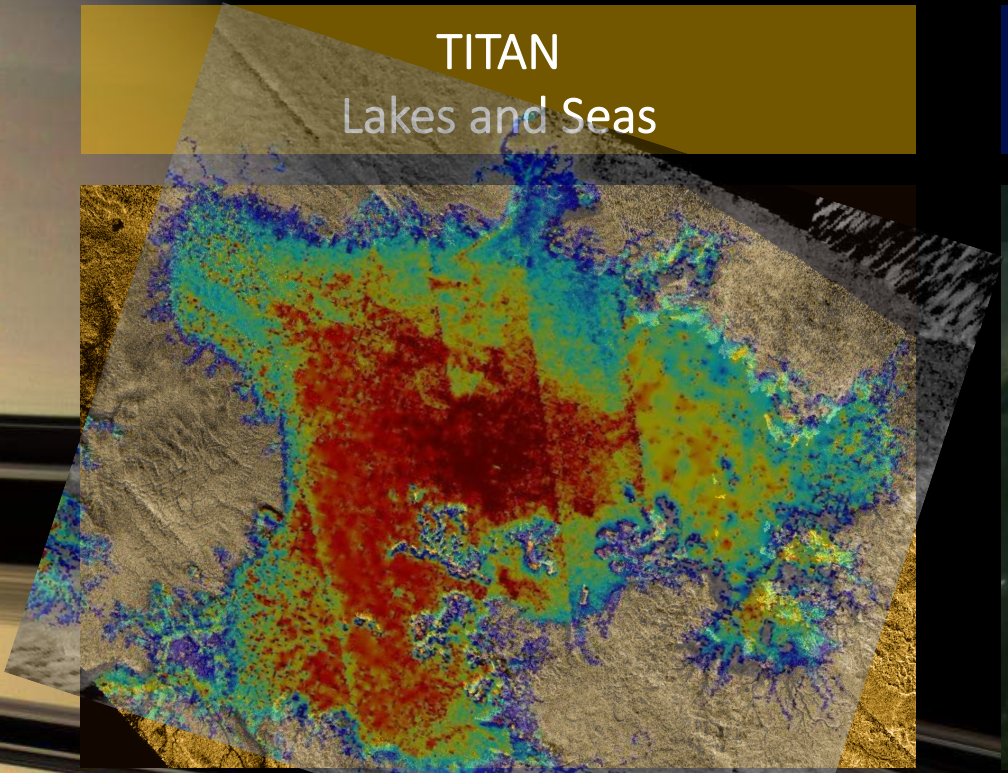


Images: NASA/JPL-Caltech/ASI/Cornell; NASA/Landsat; ESA/ATG Medialab

TITAN

Familiar, yet alien

TITAN
Lakes and Seas



EARTH
Lakes and Seas

Images: NASA/JPL-Caltech/ASI/Cornell; M. Cable

Vu, T. et al., **2014**, *J. Phys. Chem. A*, 118, 4087–4094.

Titan Laboratory Experiments

Tackling Titan's surface chemistry, one experiment at a time

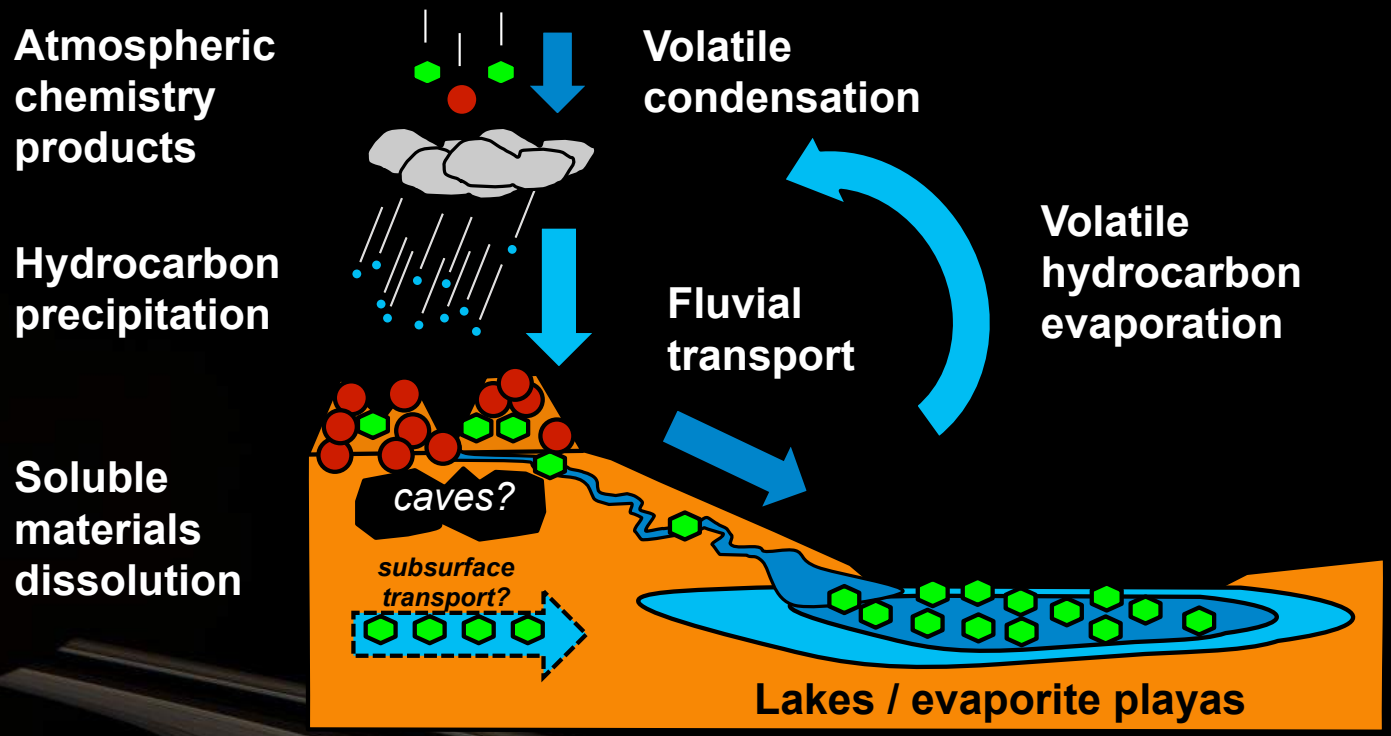


Figure by M. Malaska

Titan Laboratory Experiments: How Things Dissolve

Learning the recipe of Titan's organic soup

Image: M. Malaska

Titan Laboratory Experiments: How Things Dissolve

Learning the recipe of Titan's organic soup

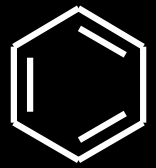
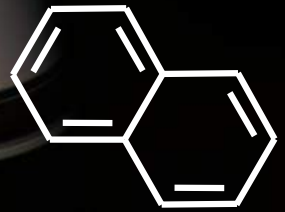
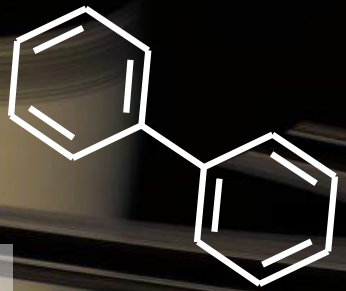
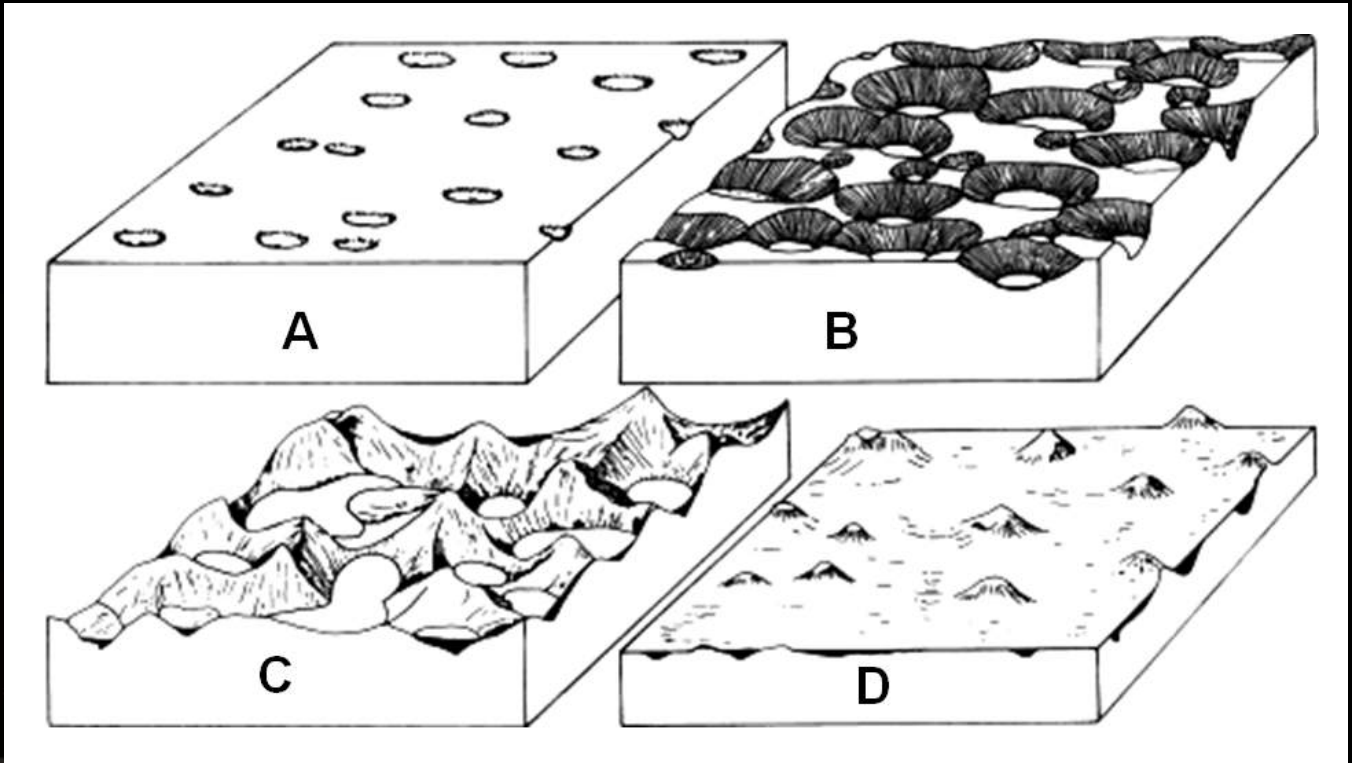
	How much [mg L^{-1}]	How fast [mmol m^{-2} s^{-1}]
 benzene	18.5 (± 1.9)	3×10^{-6}
 naphthalene	0.159 (± 0.003)	4×10^{-8}
 biphenyl	0.039 (± 0.006)	4×10^{-9}

Table by M. Malaska

Malaska and Hodyss, 2014, Icarus 242, 74-81.

Titan Laboratory Experiments: How Things Dissolve

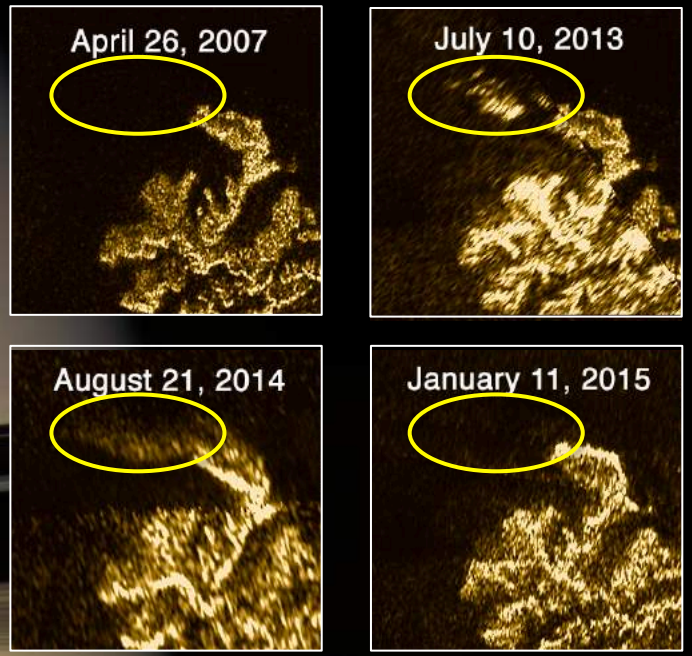
This can tell us how certain terrains may have formed



Ford and Williams, Karst Hydrogeology and Geomorphology, Wiley, 2007. (Fig 9.63)

Titan Laboratory Experiments: How Things Dissolve

May explain Titan's Magic Island



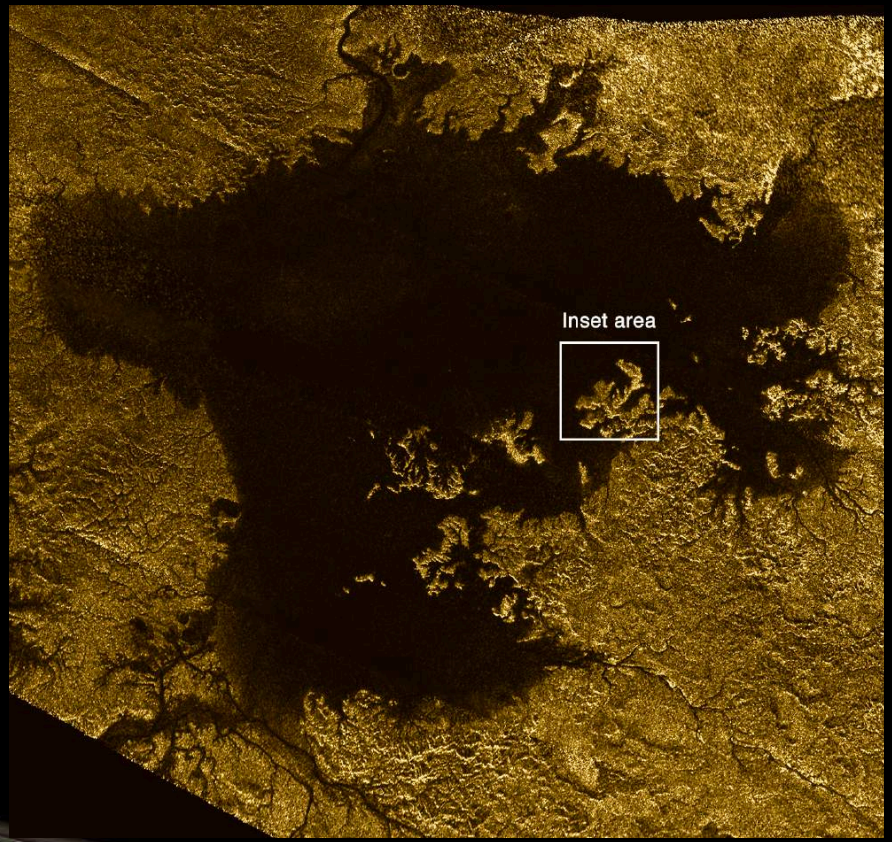
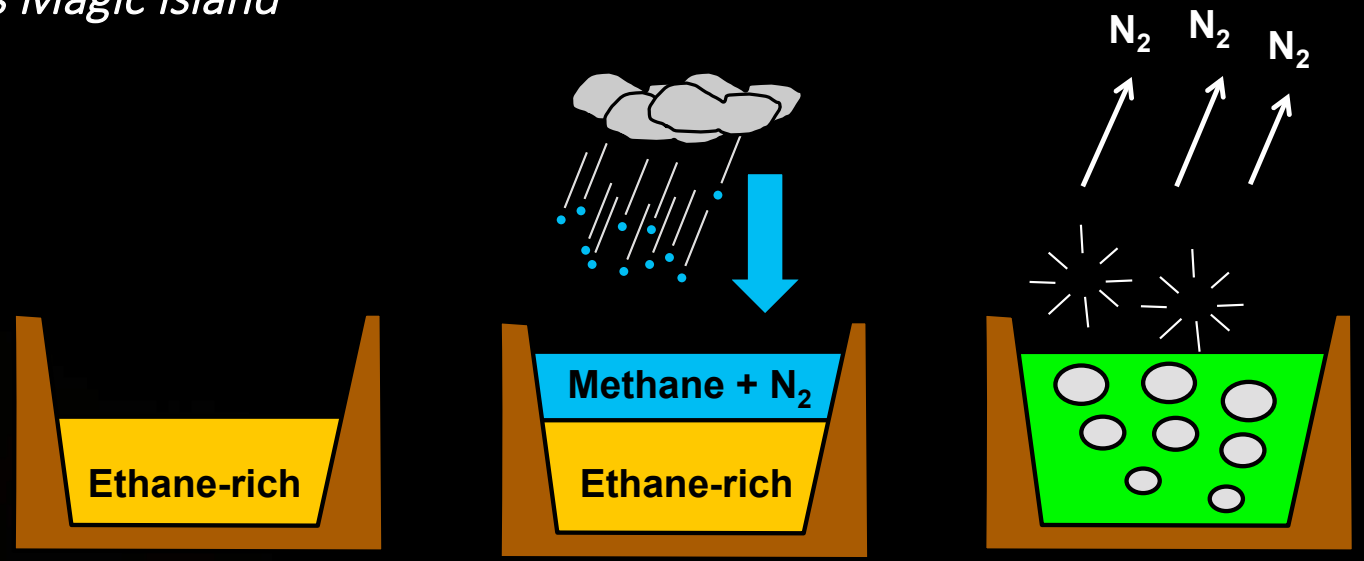


Image: NASA/JPL-Caltech

Hofgartner et al., 2016, *Icarus*, 271, 338-349.

Titan Laboratory Experiments: How Things Dissolve

May explain Titan's Magic Island



1) Ethane-rich lake

2) Methane rainfall

3) Compositional mixing
Nitrogen released
(bubbles)

Image: M. Malaska

Malaska et al., in preparation.

Titan Laboratory Experiments: How Things Dissolve

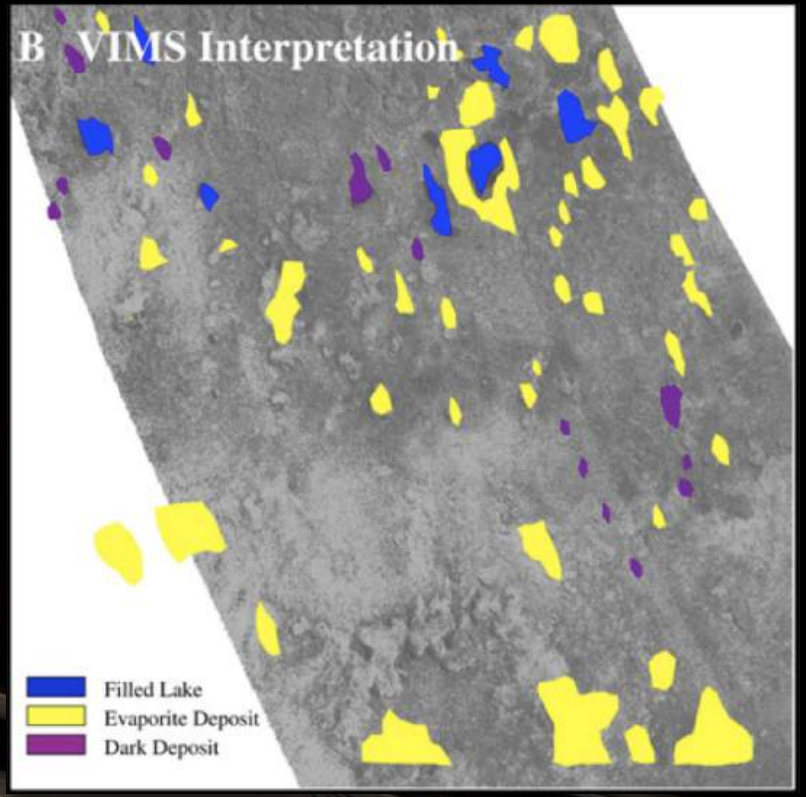
May explain Titan's Magic Island

Video: M. Malaska

Malaska et al., in preparation.

Titan Laboratory Experiments: Surface Deposits

Probing the bathtub rings around Titan's lakes



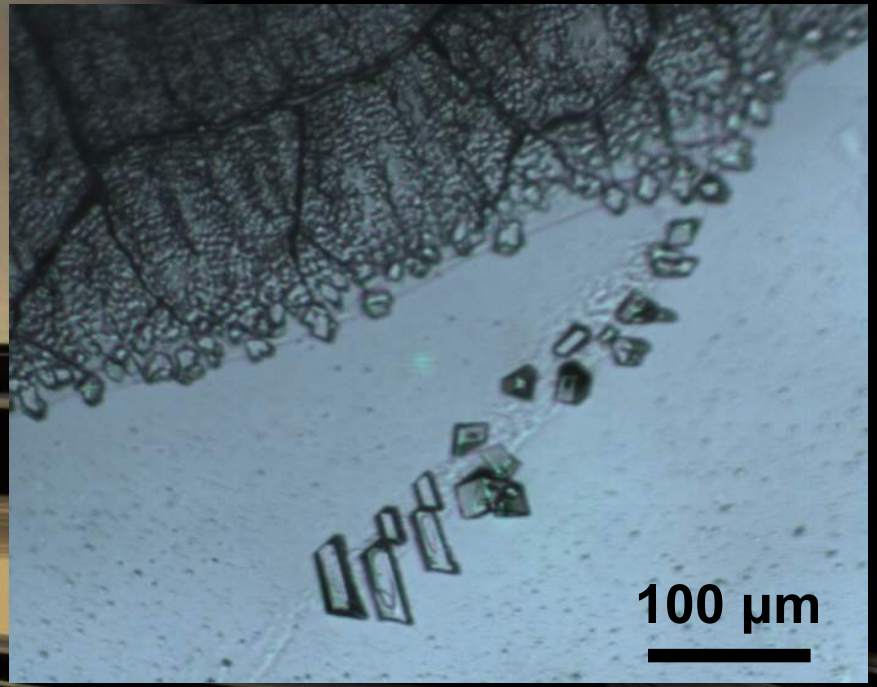
- Solubility of benzene in liquid ethane is low
- Benzene could be an abundant evaporite around the lakes on Titan

Barnes J.W. et al., **2011**, *Icarus,* 216, 136-140.

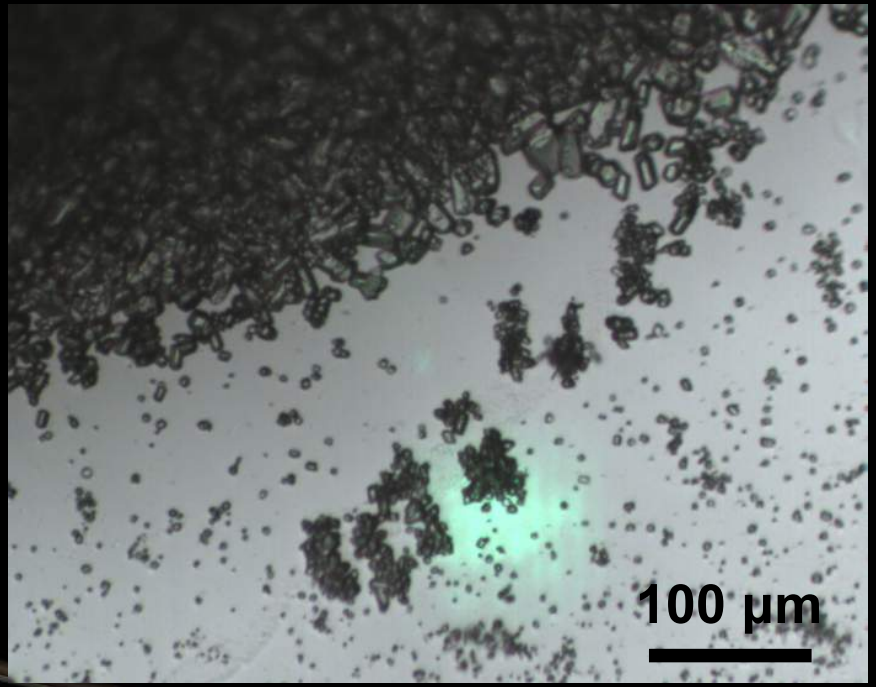
Titan Laboratory Experiments: Surface Deposits

Recrystallization occurs when benzene and ethane are mixed

Before



After 15 minutes



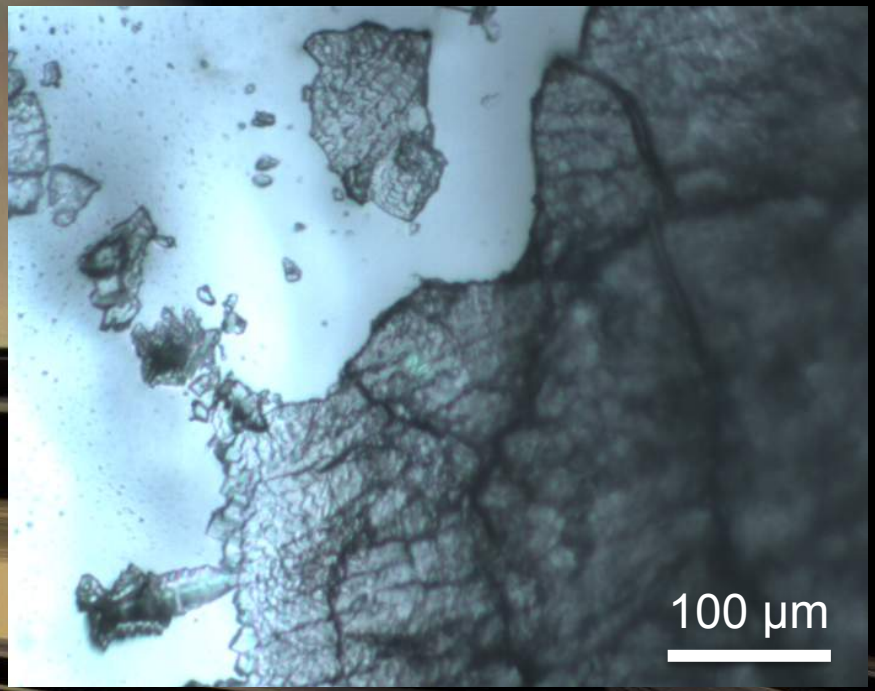
Images: M. Cable, T. Vu

Cable, M. L. et al., **2014**, *Geophys. Res. Lett.*, 41, 5396–5401.

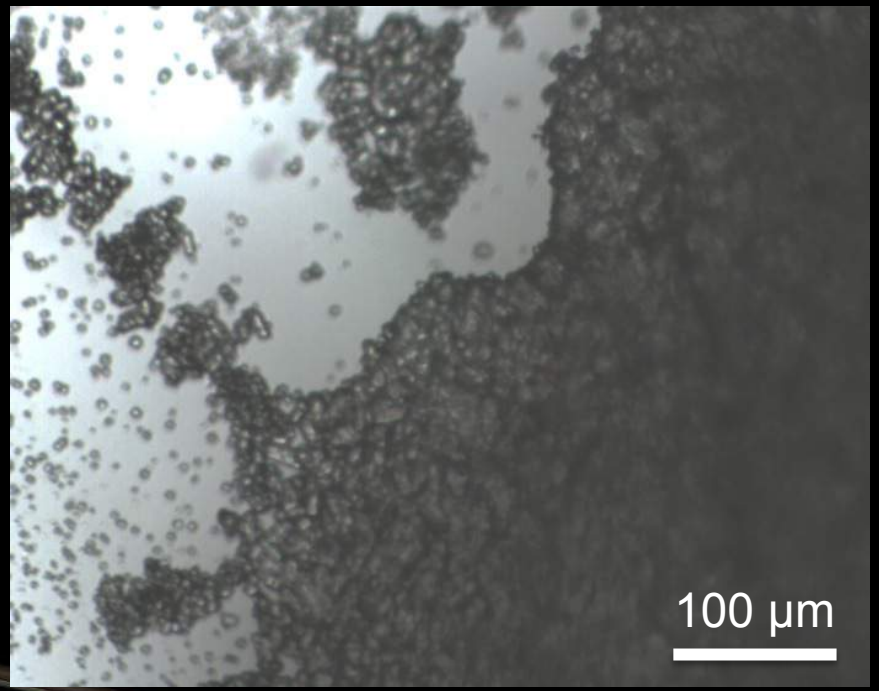
Titan Laboratory Experiments: Surface Deposits

Recrystallization occurs when benzene and ethane are mixed

Before



After 15 minutes



Images: M. Cable, T. Vu

Vu, T. et al., **2014**, *J. Phys. Chem. A*, 118, 4087–4094.

Titan Laboratory Experiments: Surface Deposits

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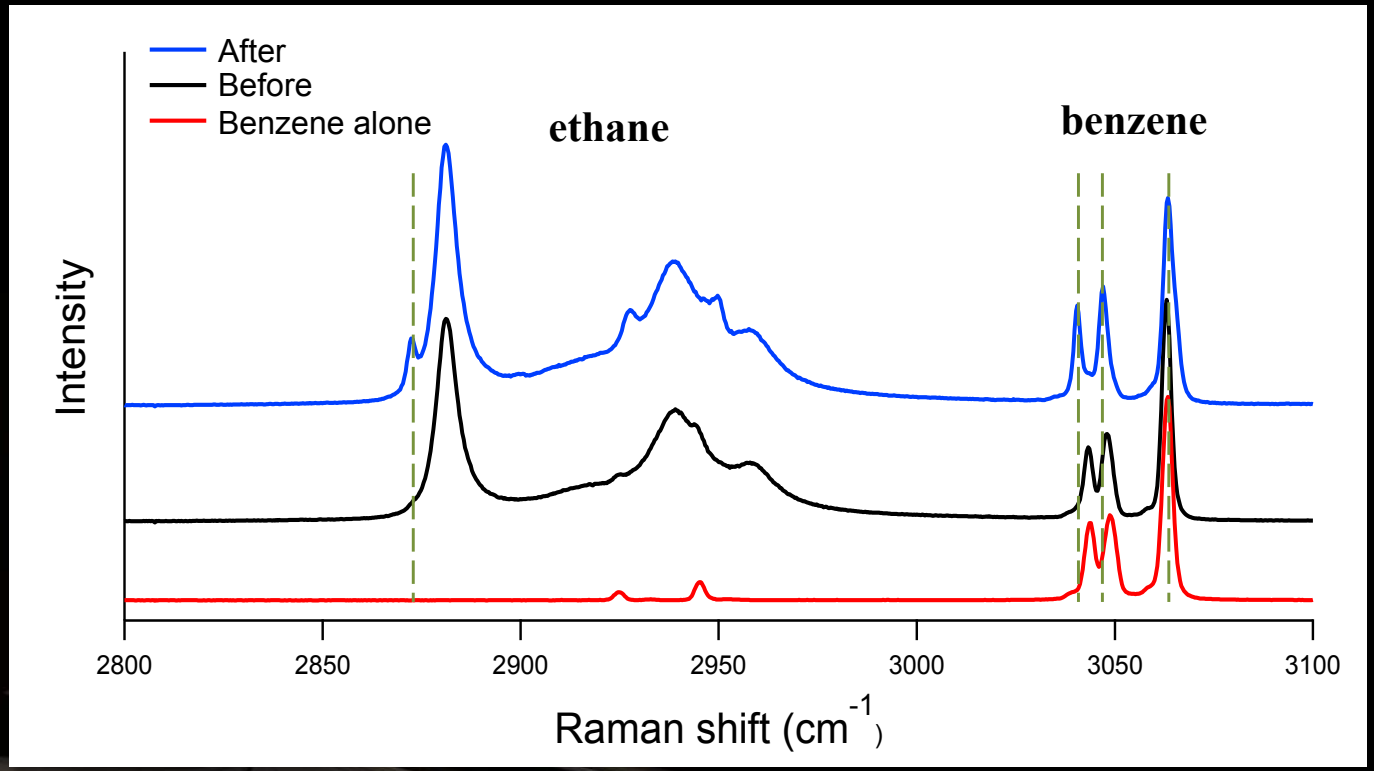
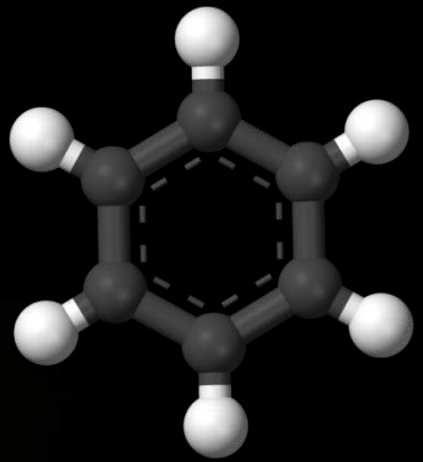


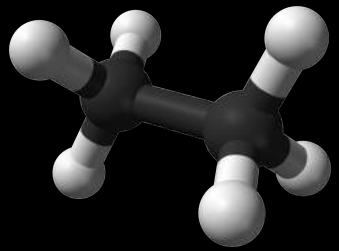
Vu, T. et al., **2014**, *J. Phys. Chem. A*, 118, 4087–4094.

Titan Laboratory Experiments: Surface Deposits

What does it look like?



Benzene (C_6H_6)

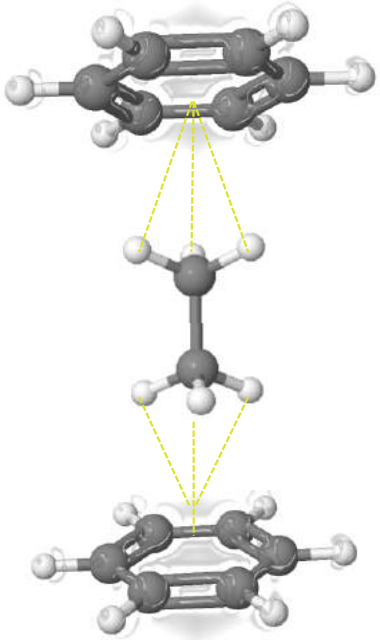


Ethane (C_2H_6)

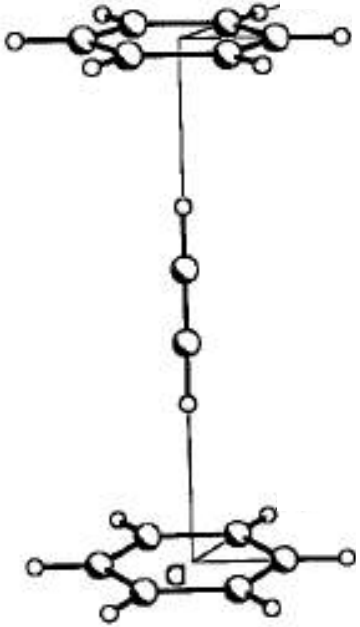
Titan Laboratory Experiments: Surface Deposits

Our best guess . . .

Proposed co-crystal configuration:



Acetylene/benzene co-crystal structure:



Boese et al., 2003, Helv. Chim. Acta, 86, 1085-1100.

Titan Laboratory Experiments: Surface Deposits

Our best guess . . .

Images: R. Hodyss

Titan Laboratory Experiments: Surface Deposits

X-rays, figuring out what stuff is made of since 1912

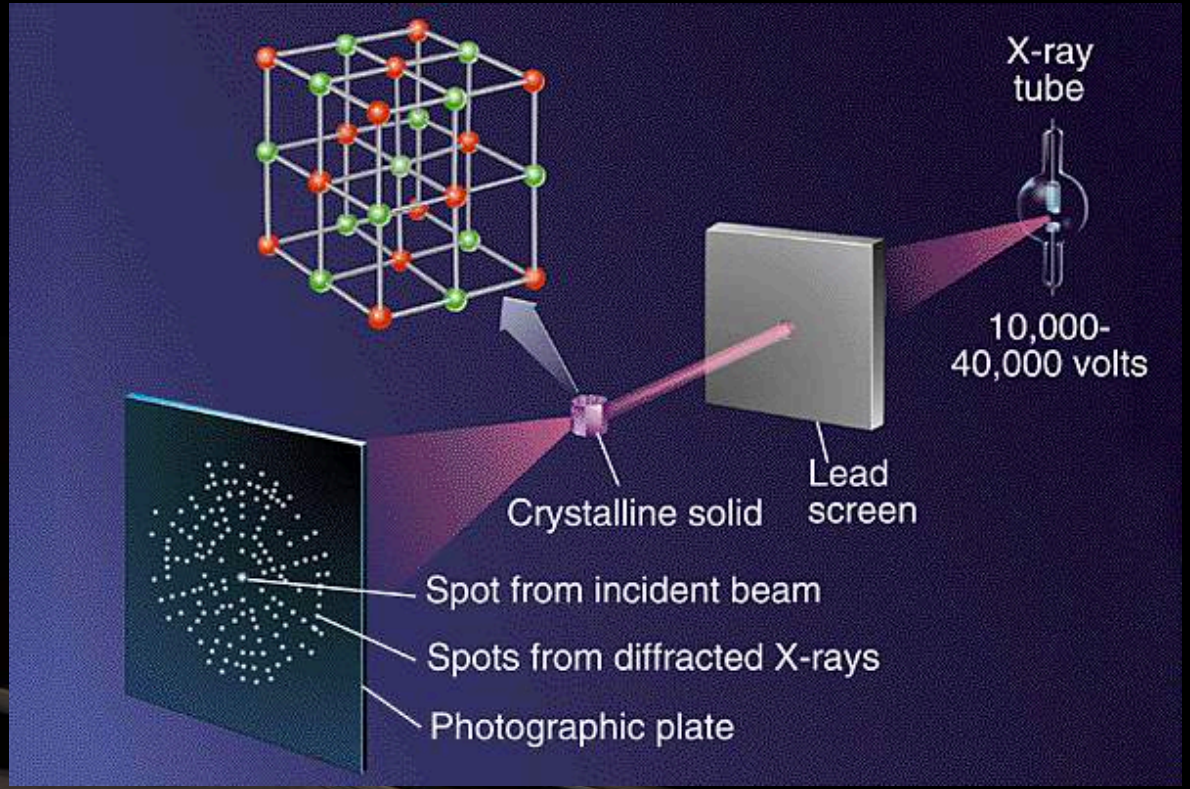
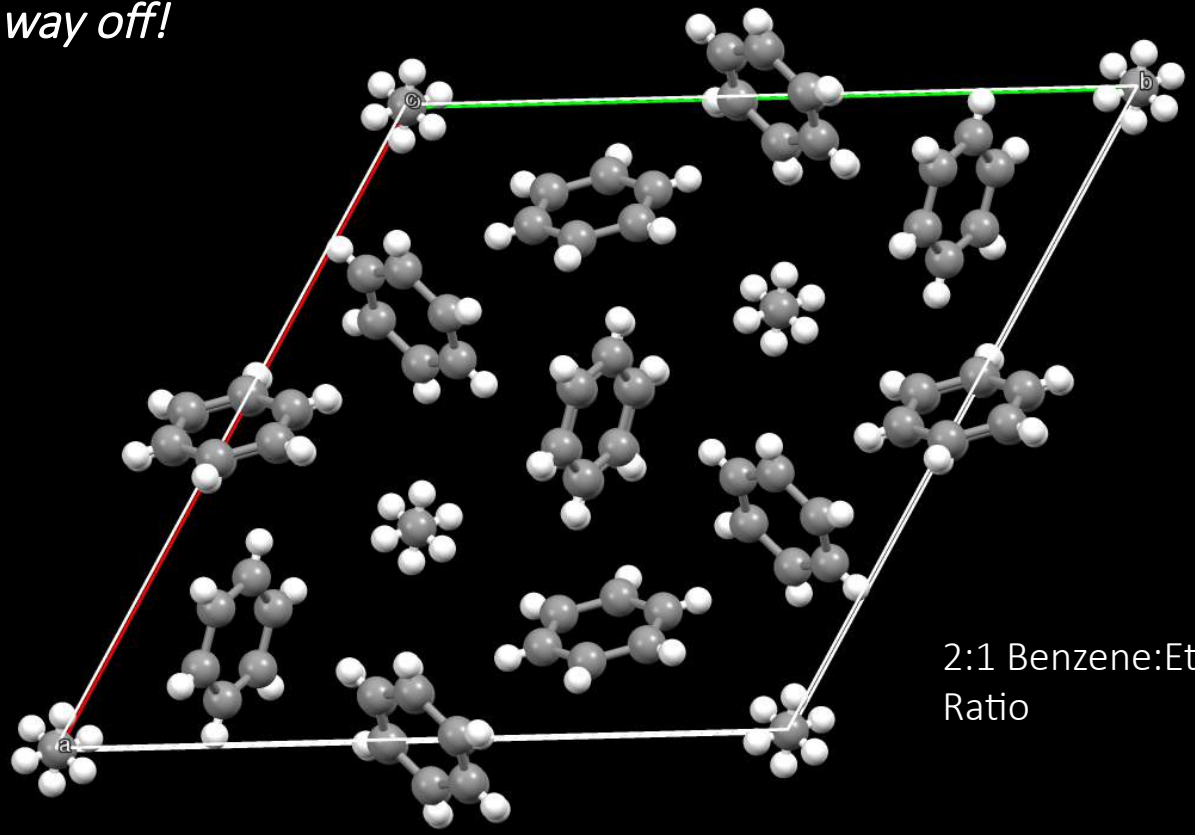


Image: nothingnerdy.wikispaces.com

Titan Laboratory Experiments: Surface Deposits

Our best guess . . . was way off!

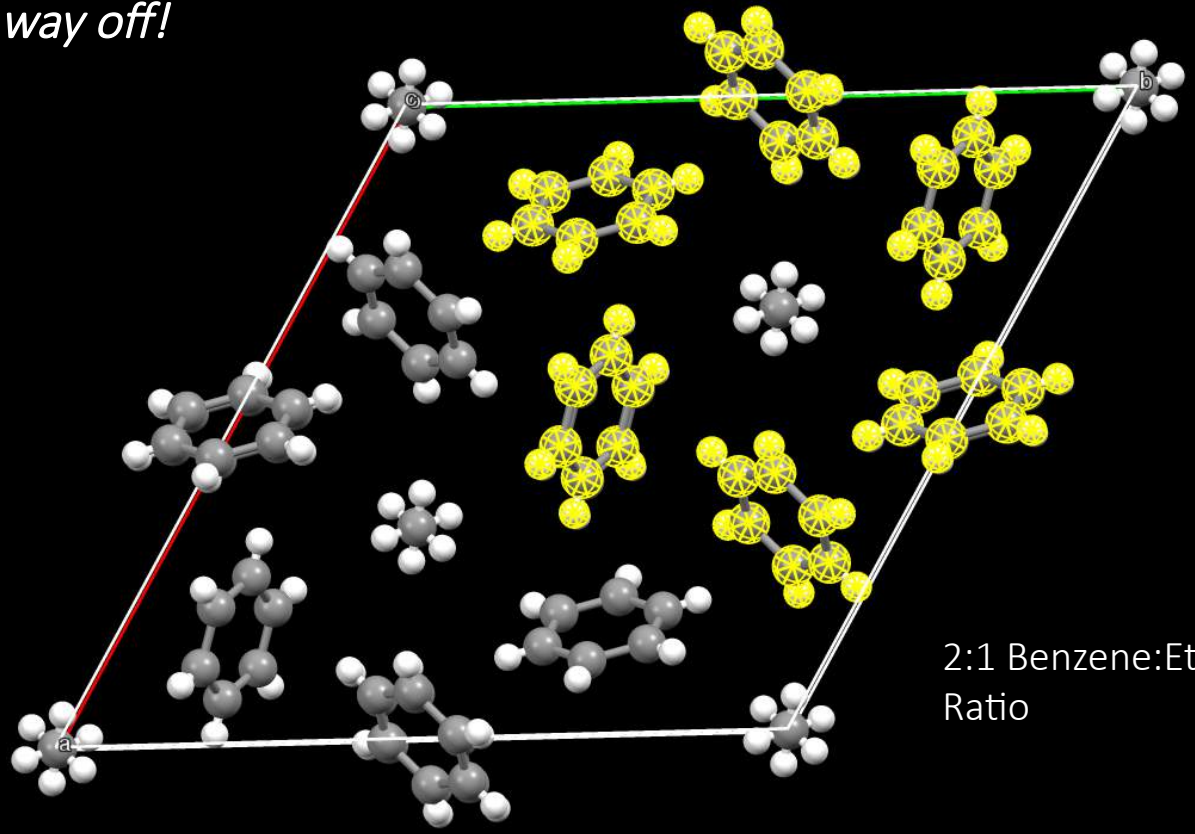


2:1 Benzene:Ethane Ratio

Maynard-Casely et al., **2016**, *Int. Union of Crystallography J.*, 3,1-8.

Titan Laboratory Experiments: Surface Deposits

Our best guess . . . was way off!



2:1 Benzene:Ethane Ratio

Maynard-Casely et al., **2016**, *Int. Union of Crystallography J.*, 3,1-8.

Titan Laboratory Experiments: Surface Deposits

Titan's version of a hydrated mineral

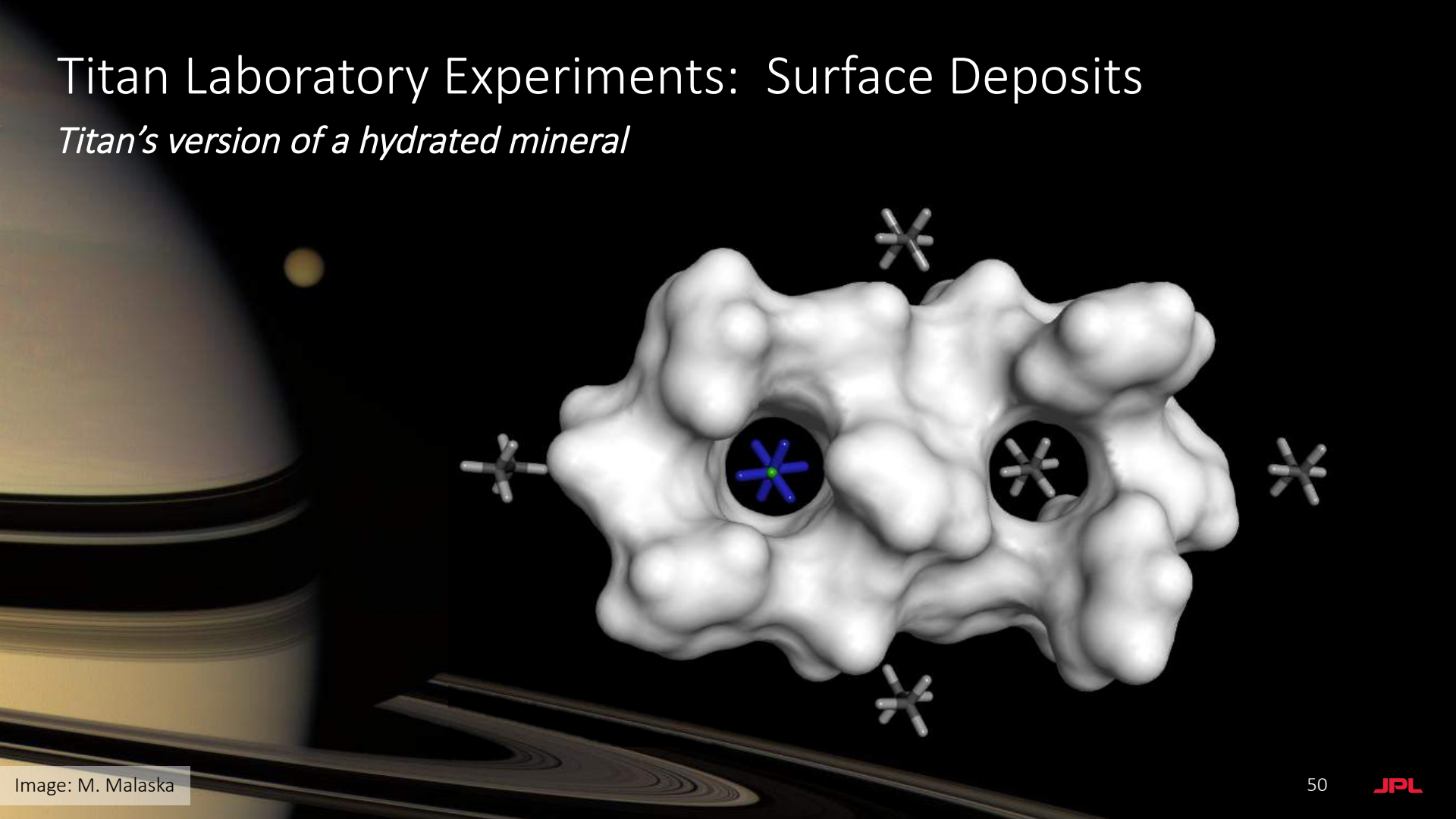


Image: M. Malaska

Titan Laboratory Experiments: Conclusions

Learning what makes Titan tick

- Titan's surface landscape is strongly influenced by a complex organic cycle.
- Molecules dissolve, precipitate and reorganize readily, leading to novel solid geological materials.
- More lab work! Future missions!

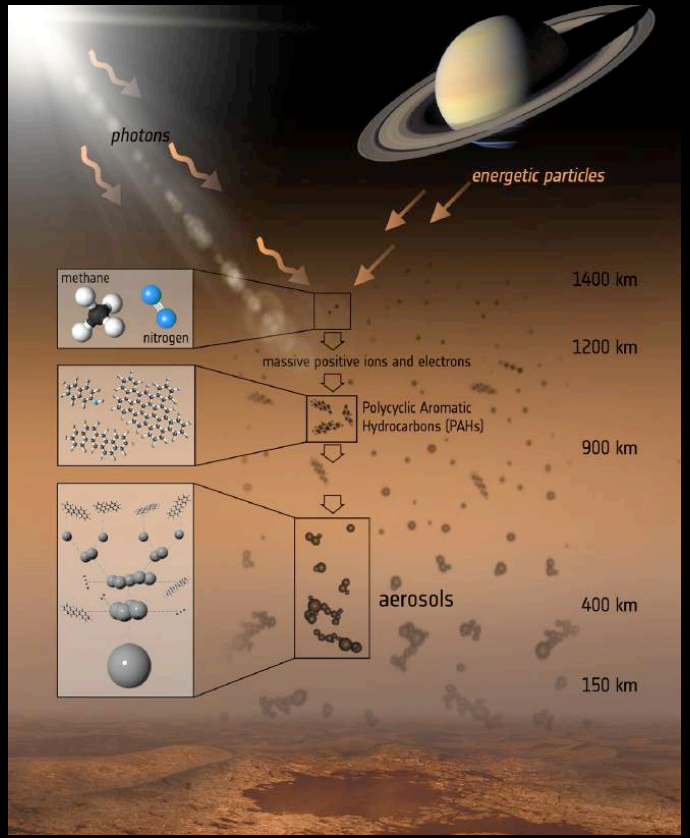


Image: ESA/ATG Medialab

Acknowledgements

There is no 'i' in team . . .

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- Wolf Geppert
- David Cullen
- Adam Stevens
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Titan Laboratory Work

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- Tuan Vu
- Mike Malaska
- Mathieu Choukroun
- Helen Maynard-Casely
- Patricia Beauchamp
- NASA Astrobiology Institute
- NASA Solar System Workings

Jet Propulsion Laboratory
California Institute of Technology

FELDSPAR

Field Exploration and Life Detection Sampling for Planetary and Astrobiology Research

Image: M. Cable

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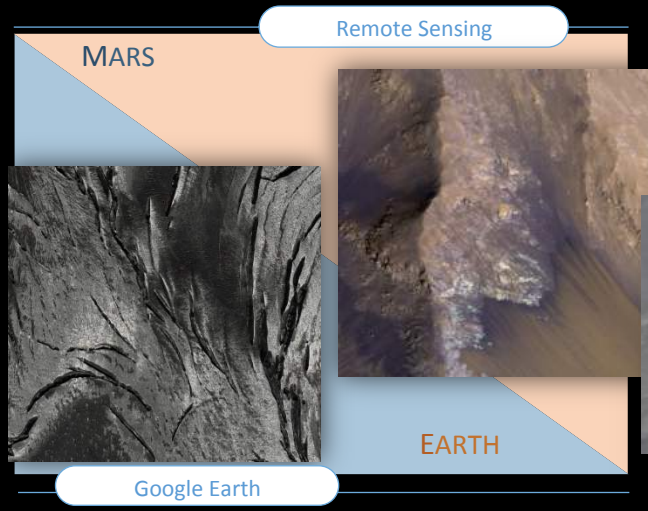

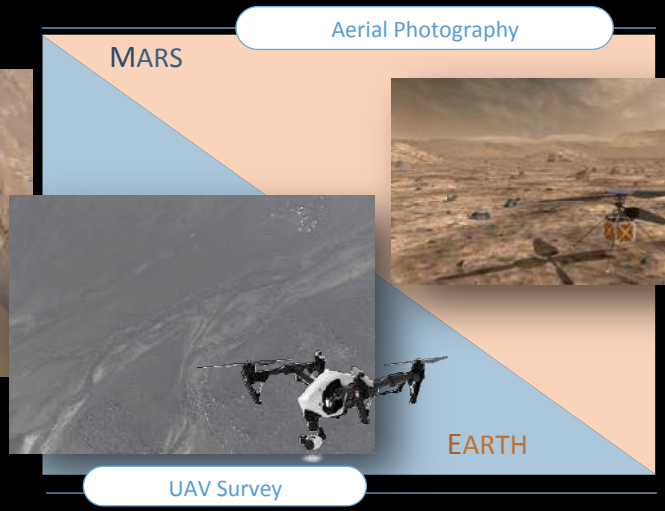

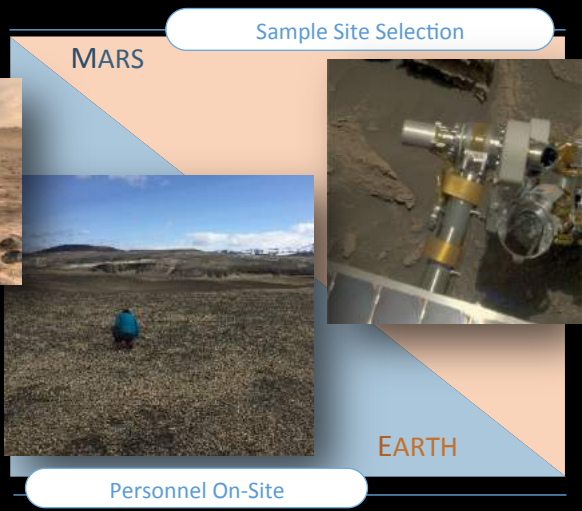

Images: A. Stockton

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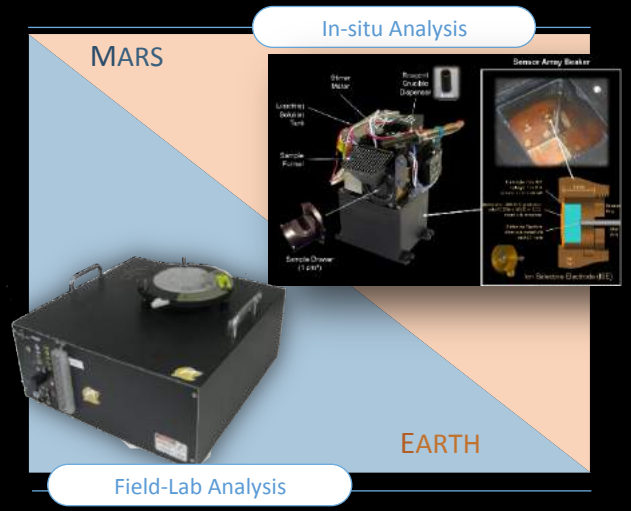

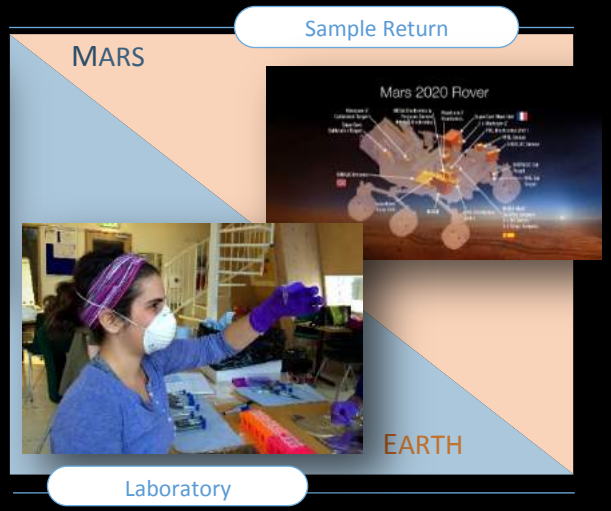

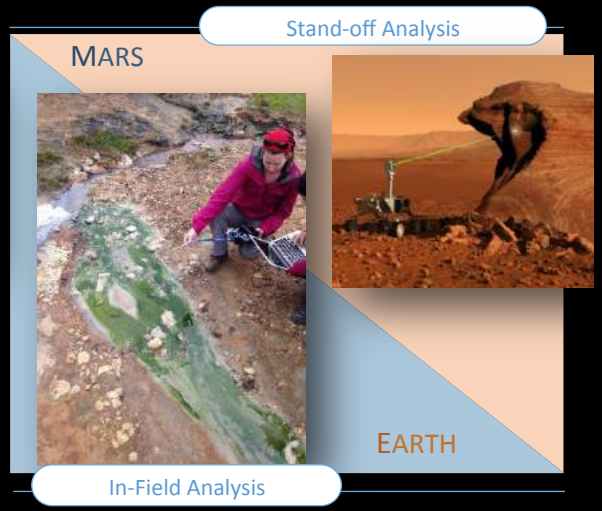

Images: A. Stockton

Earth Analogues – What can they be used for?

- Testing Technology

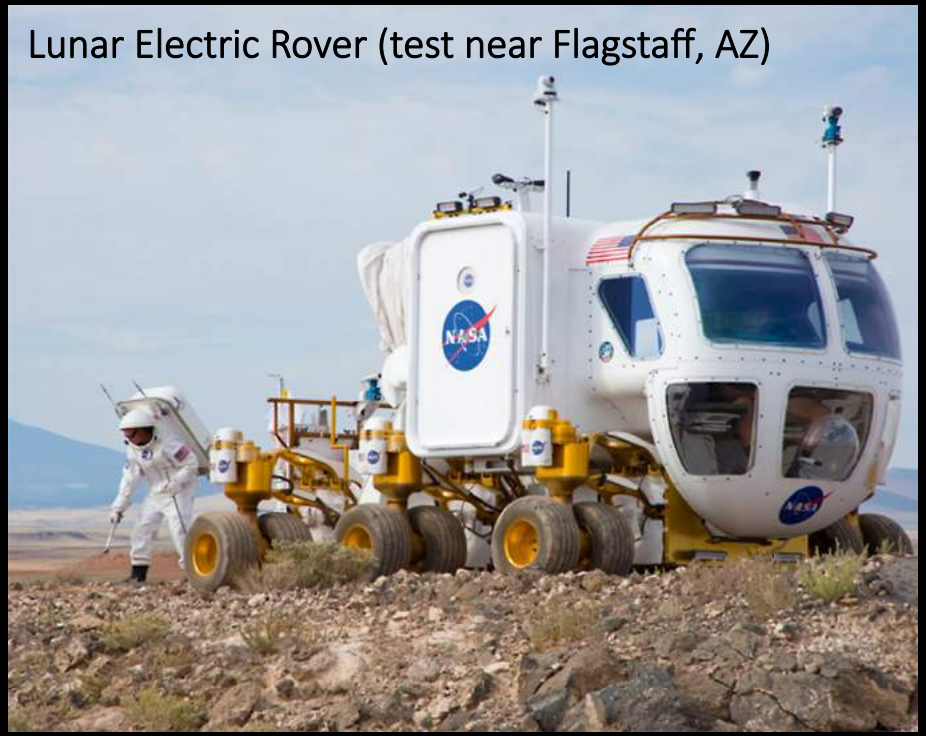

Image: NASA-JSC

Earth Analogues – What can they be used for?

- Testing Technology
- Advancing Instruments

Images: NASA/JPL-Caltech; J. Buffo/Georgia Tech

Earth Analogues – What can they be used for?

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- Improving Science Theories

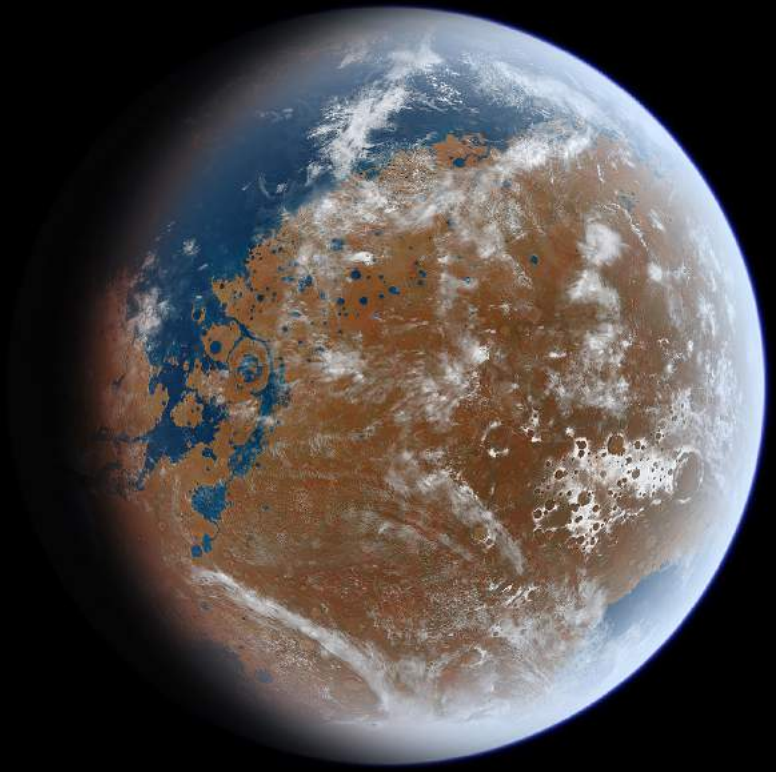

Image: Ittiz

Earth Analogues – What can they be used for?

- Testing Technology
- Advancing Instruments
- Improving Science Theories
- Informing Future Missions

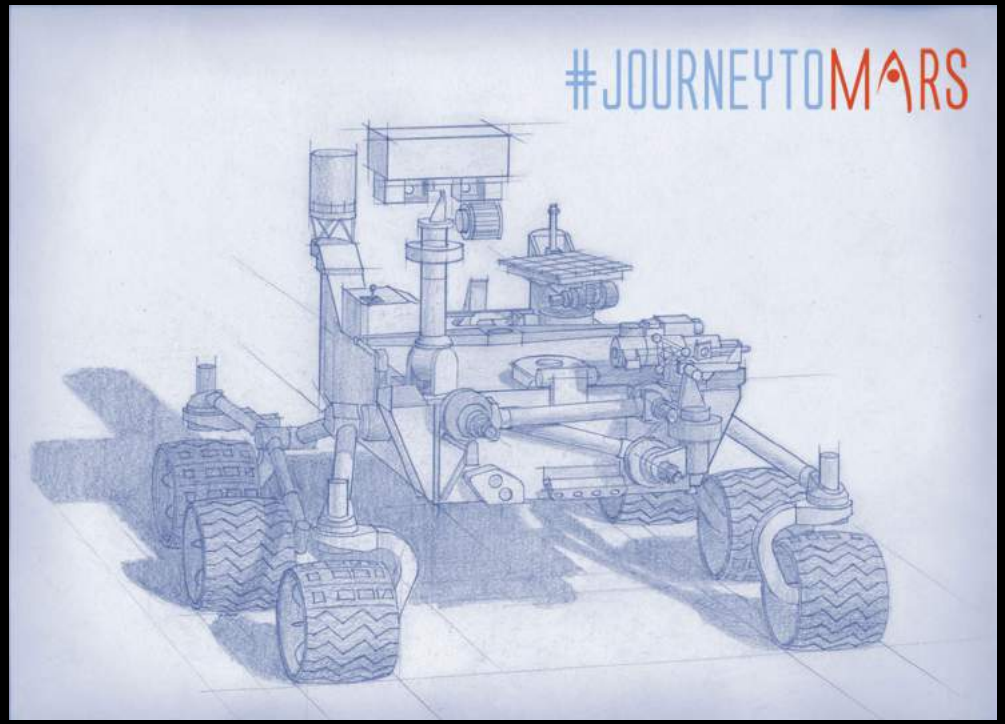

Image: NASA/JPL-Caltech

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Photos: M. Cable

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Photos: A. Stevens

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Photos: M. Cable

Analogue Environments

The next best thing to actually being there

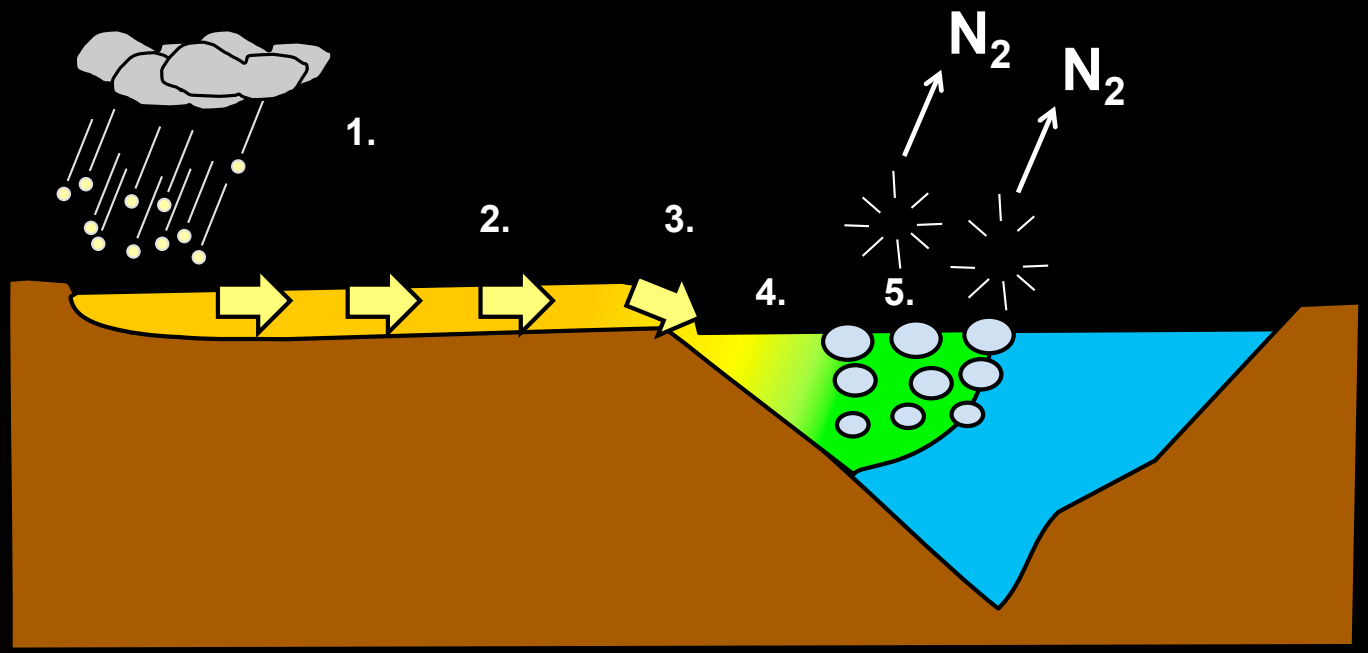
Analogue /Analog *(ān'ə-lôg′) n.*

A physical object or quantity used to measure or represent another quantity.

Image: Flickr/J. Jensen

Titan Laboratory Experiments: How Things Dissolve

May explain Titan's Magic Island



Malaska et al., in preparation.

Image: M. Malaska

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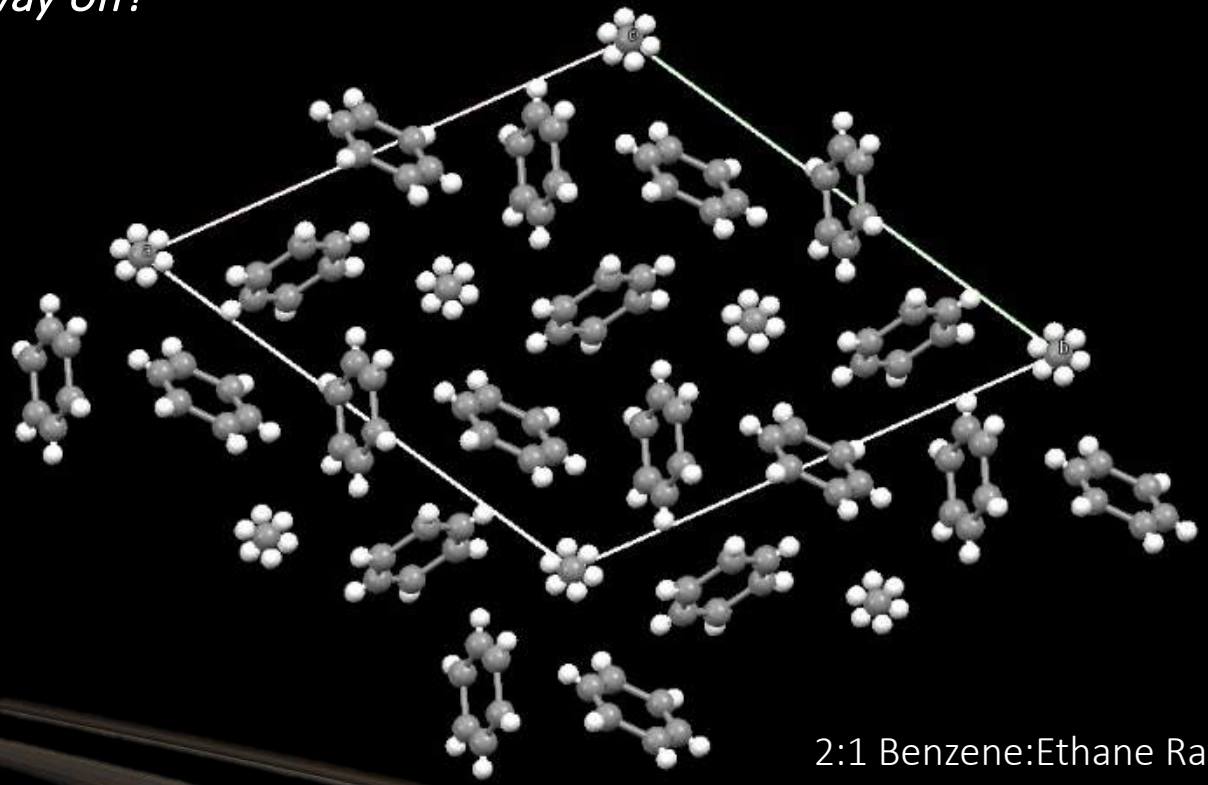


2:1 Benzene:Ethane Ratio

Titan Laboratory Experiments: Conclusions

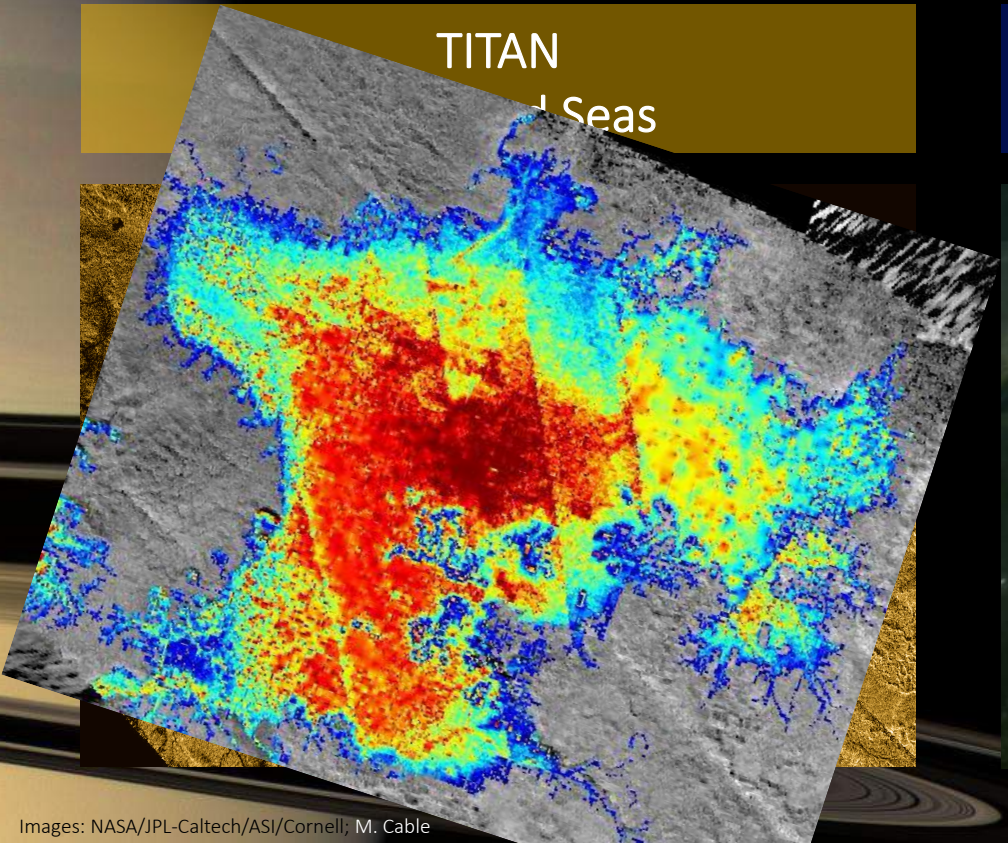
Storage and transport of organics on Titan

- Benzene and ethane form a co-crystal at Titan surface temperatures, similar to hydrated minerals on Earth.
- There may be a surface process on Titan capable of selectively sequestering and storing ethane in surface materials.
- Other important Titan surface materials (hydrogen cyanide, acetylene) have the potential to be co-crystal formers also.

TITAN

Familiar, yet alien

TITAN
Lakes and Seas



EARTH
Lakes and Seas

Vu, T. et al., **2014**, *J. Phys. Chem. A*, 118, 4087–4094.

Images: NASA/JPL-Caltech/ASI/Cornell; M. Cable