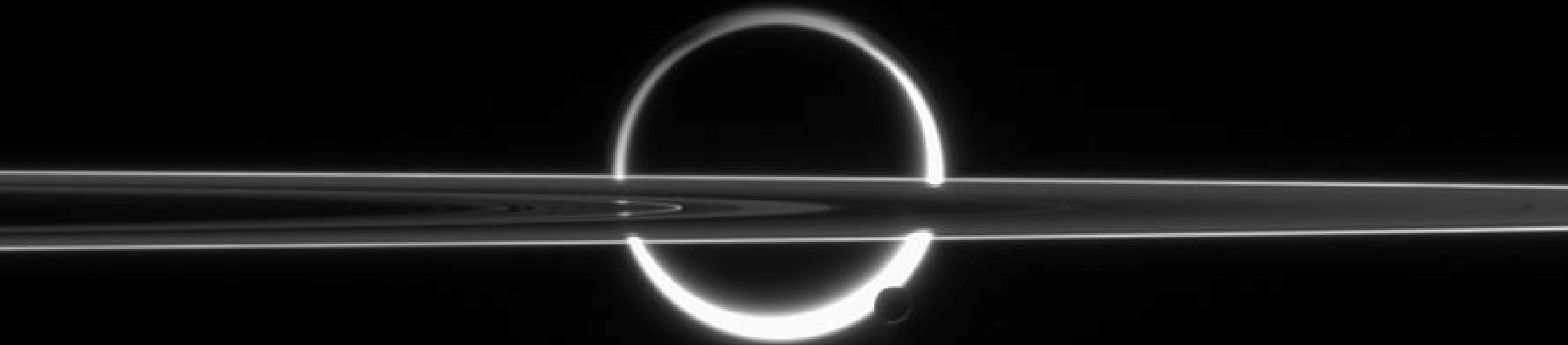
What’s Right for Life: Can Life Exist Without Water?



Morgan L. Cable, Jonathan Lunine, Jack Beauchamp and Christophe Sotin

31 October 2015

Jet Propulsion Laboratory
California Institute of Technology

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Don't Follow (Just) the Water: Does Life Occur in Non-Aqueous Media? - Part II

September 14-17, 2015
California Institute of Technology - Pasadena, CA 91125

Team Leads

Jack Beauchamp
California Institute of Technology

Christophe Sotin
Jet Propulsion Laboratory

Jonathan Lunine
Cornell University

Description

Workshop Overview:

The opening workshop in July 2015 addressed non-aqueous environments that meet the overall requirements for habitability (energy, organics, liquid). After some discussion the workshop settled on three such environments:

1. terrestrial petroleum deposits isolated from liquid water;
2. the methane-ethane seas of Titan, and
3. CO2 above and below the critical point.

With respect to (2), the team decided after much deliberation that the solubilities and reactivities in the Titan seas were too low for significant chemistry to occur, and so a broader range of environments - informed by Cassini data - were selected for consideration in the next workshop. Environment (1), the petroleum, is of interest provided samples not in intimate contact with water (or at least geologically pasteurized after exposure, followed by isolation). One such potential samples exists in the lab of a workshop participant (Prof. Orphan), but a careful protocol would need to be developed to open and test the sample. Further, there may be existing data from laboratories on petroleum samples that may shed some light on the question of contamination by aqueous organisms. Environment (3) was developed only after discussion about the extent to which planetary modelers needed to be specific about the T-P conditions and geologic settings.

WORKSHOP #1

LECTURE

MAP

WIKI

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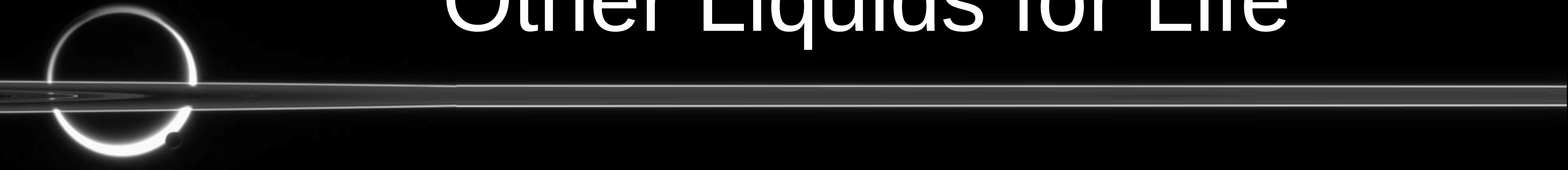
http://kiss.caltech.edu/new_website/workshops/life2.html

Other Liquids for Life



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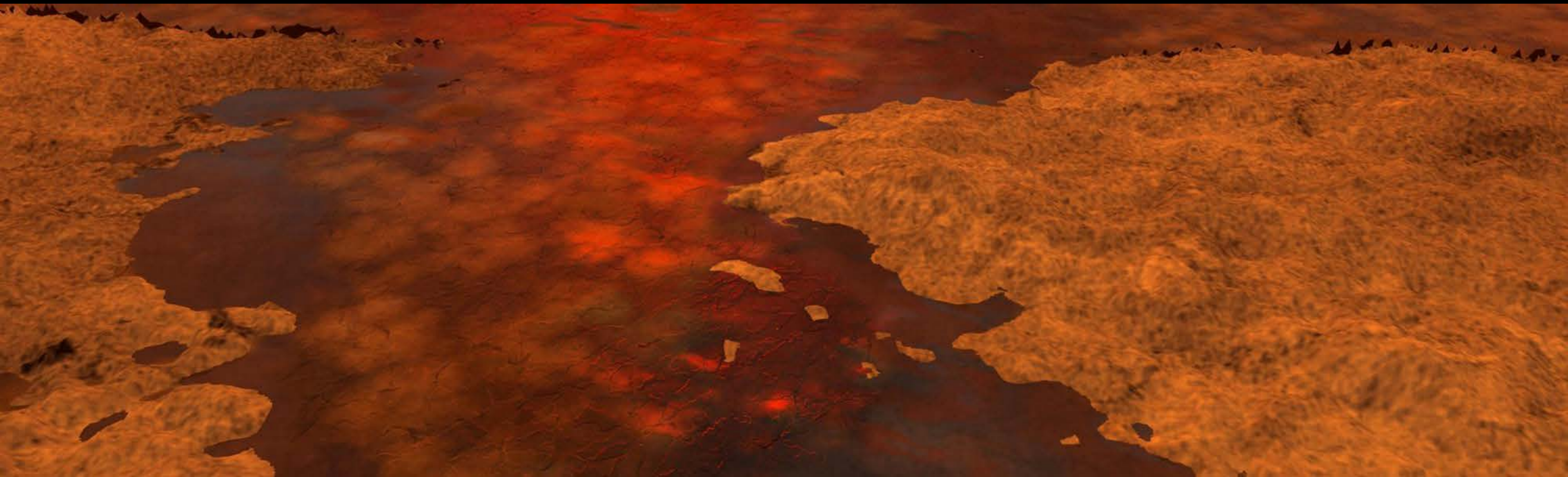

Focus on Carbon-Based Life

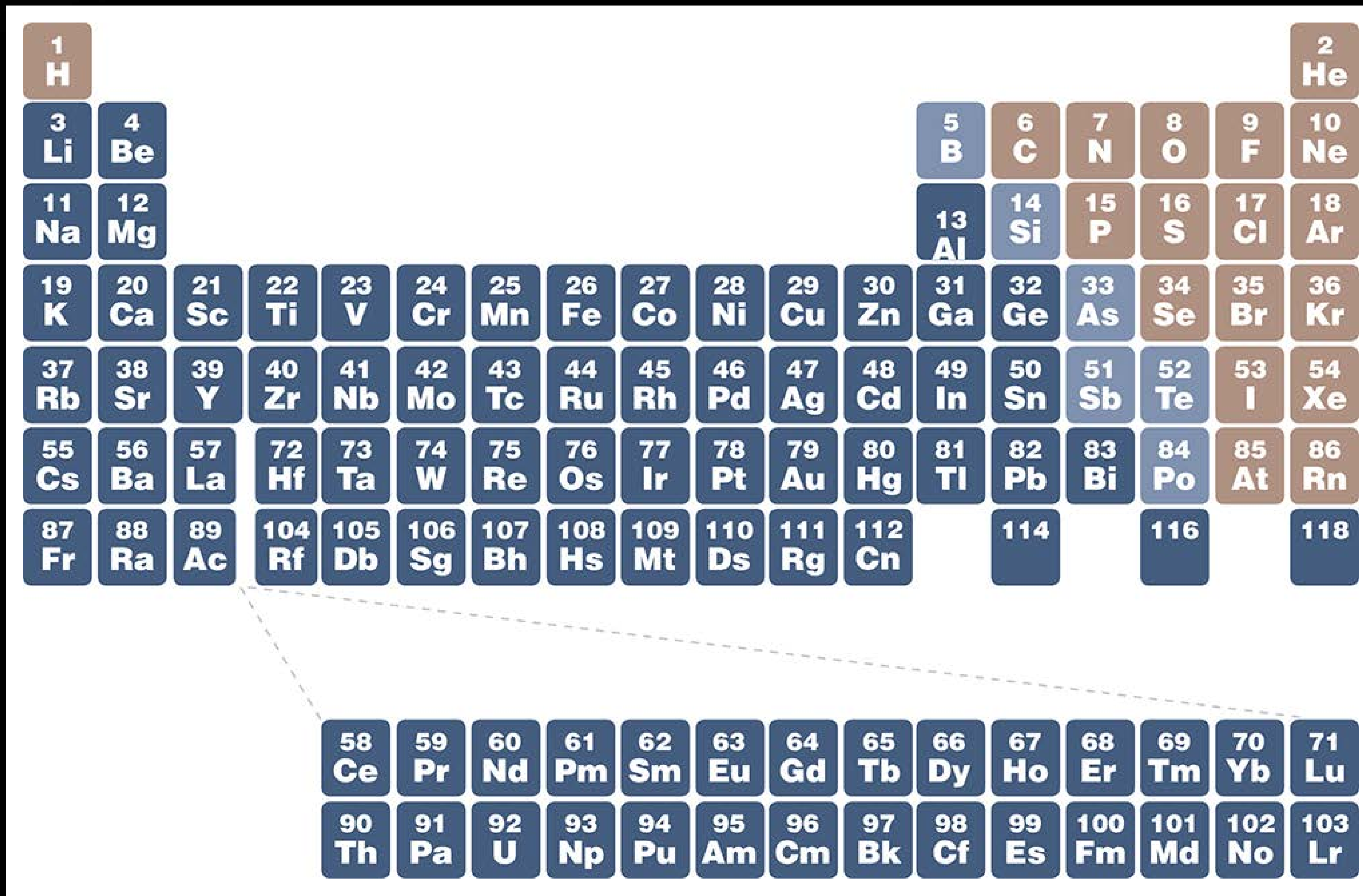

Image credit: NASA/CXC/M.Weiss)

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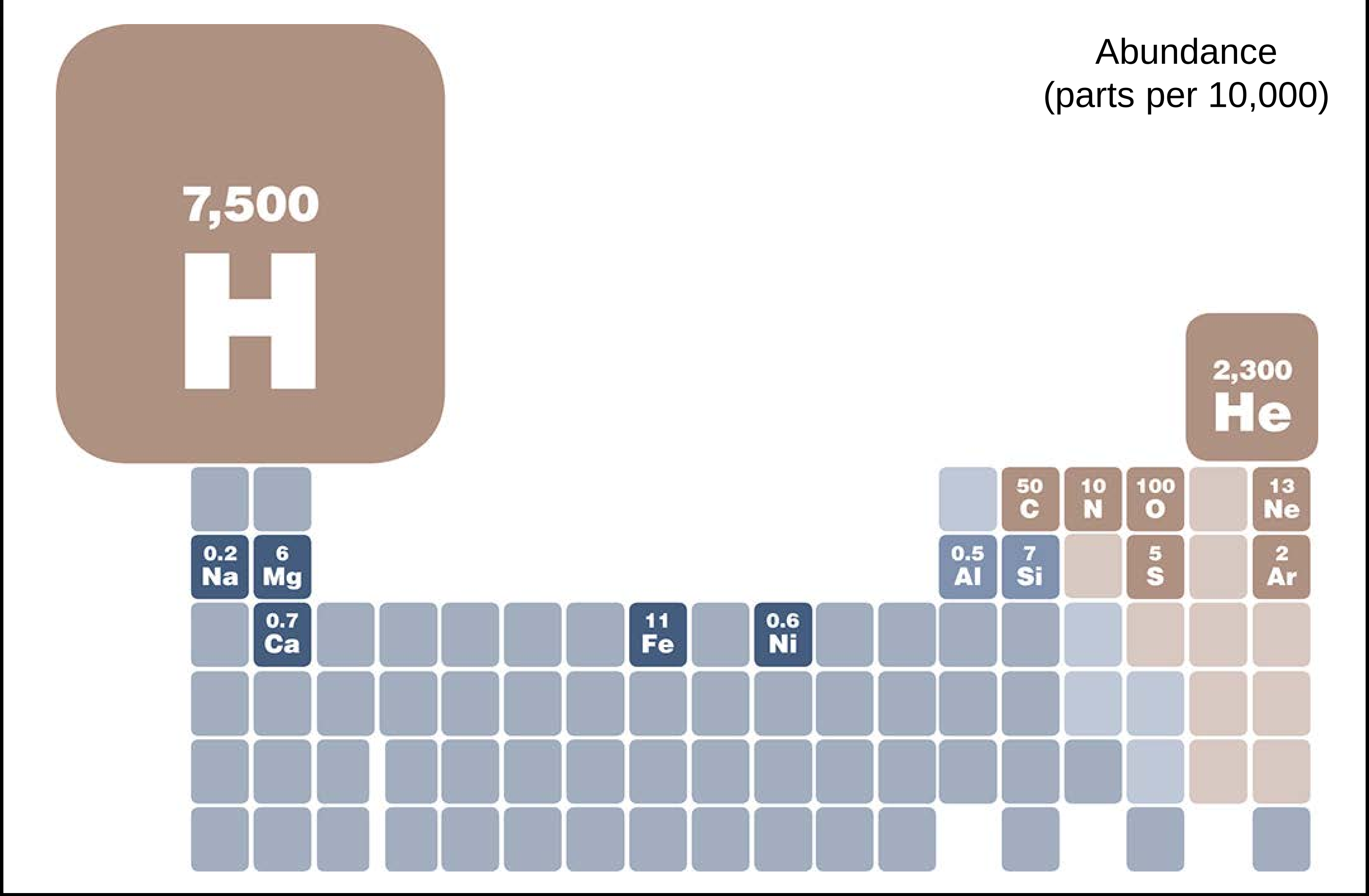


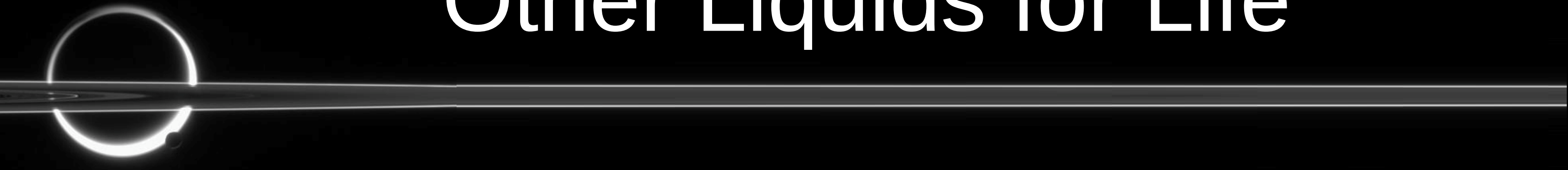
Image credit: NASA/CXC/M.Weiss)

Focus on Carbon-Based Life

The Horta: silicon-based life in the Star Trek universe

Image credit: NASA/CXC/M.Weiss)

Other Liquids for Life



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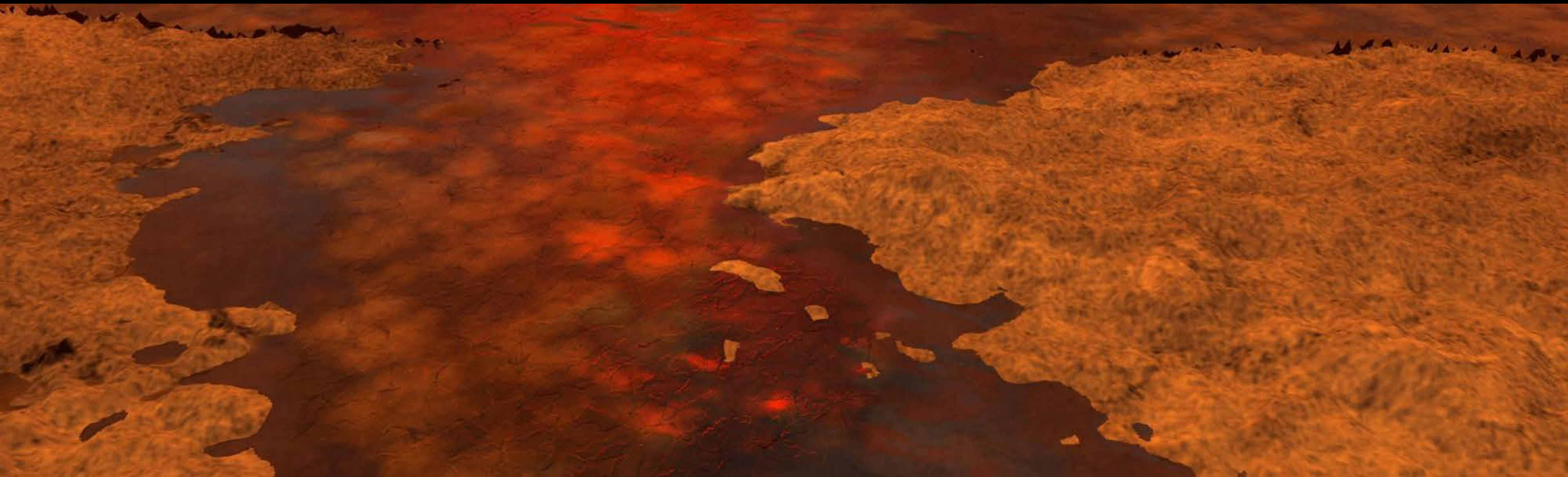

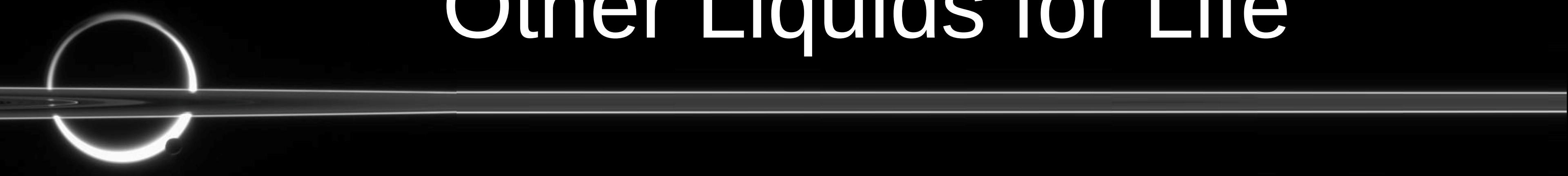

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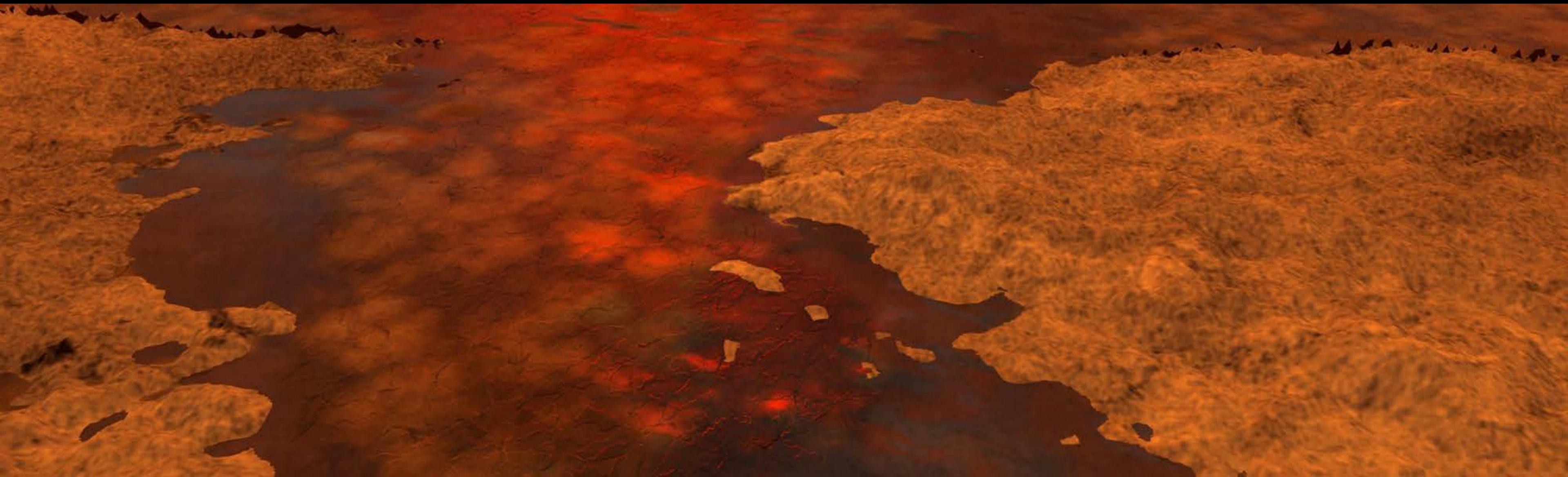
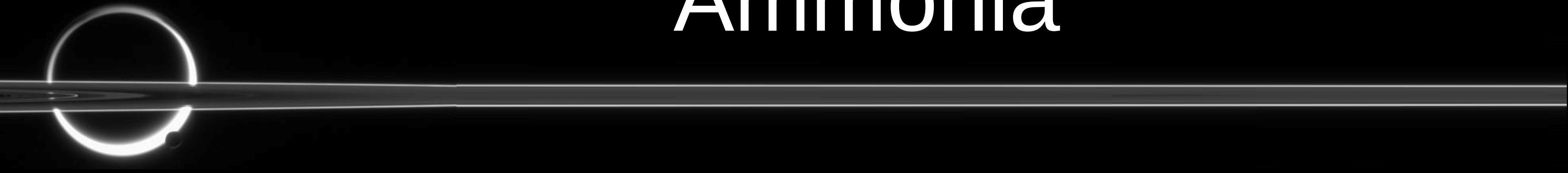
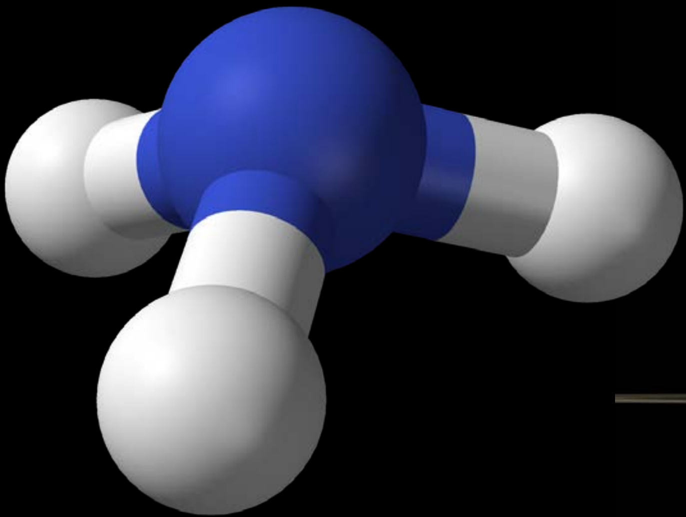


Ammonia





NH_3

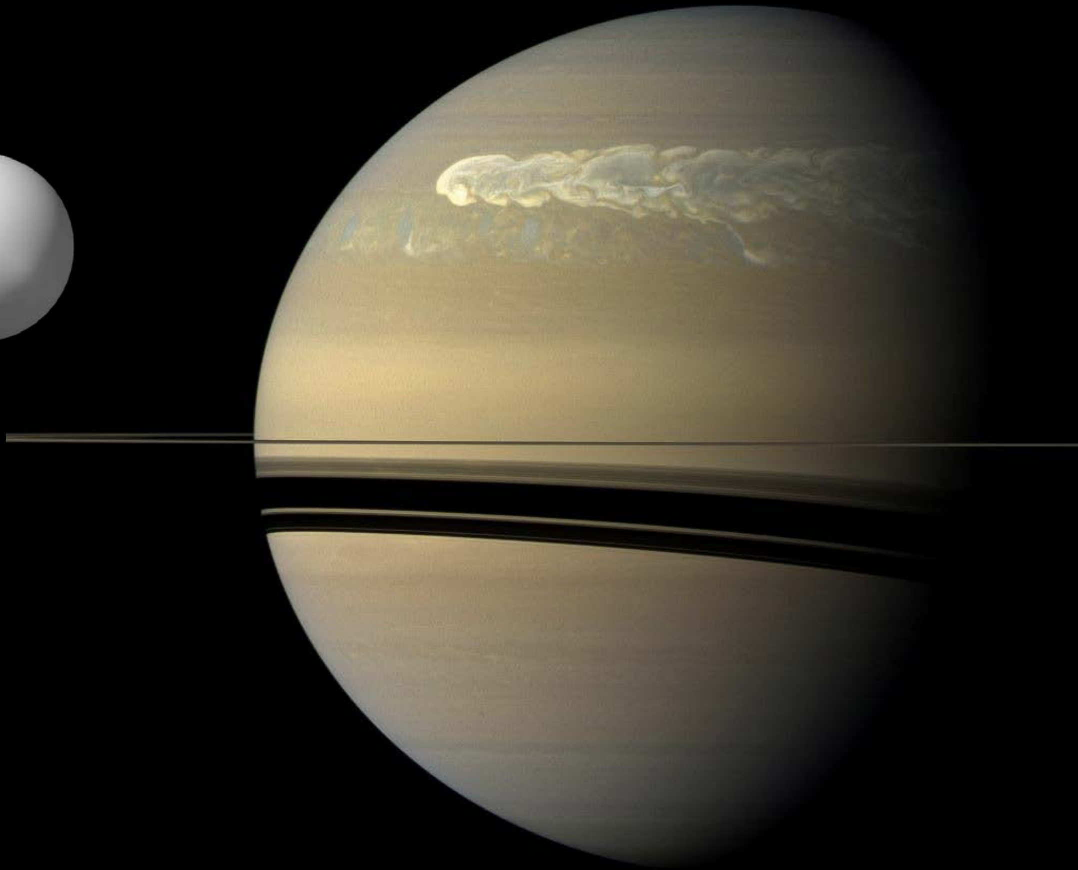


Image credit: NASA-JPL/Caltech

Ammonia

- Keeps things liquid down to 173 K
- Rare to find without H_2O
- Basically a subset of aqueous case

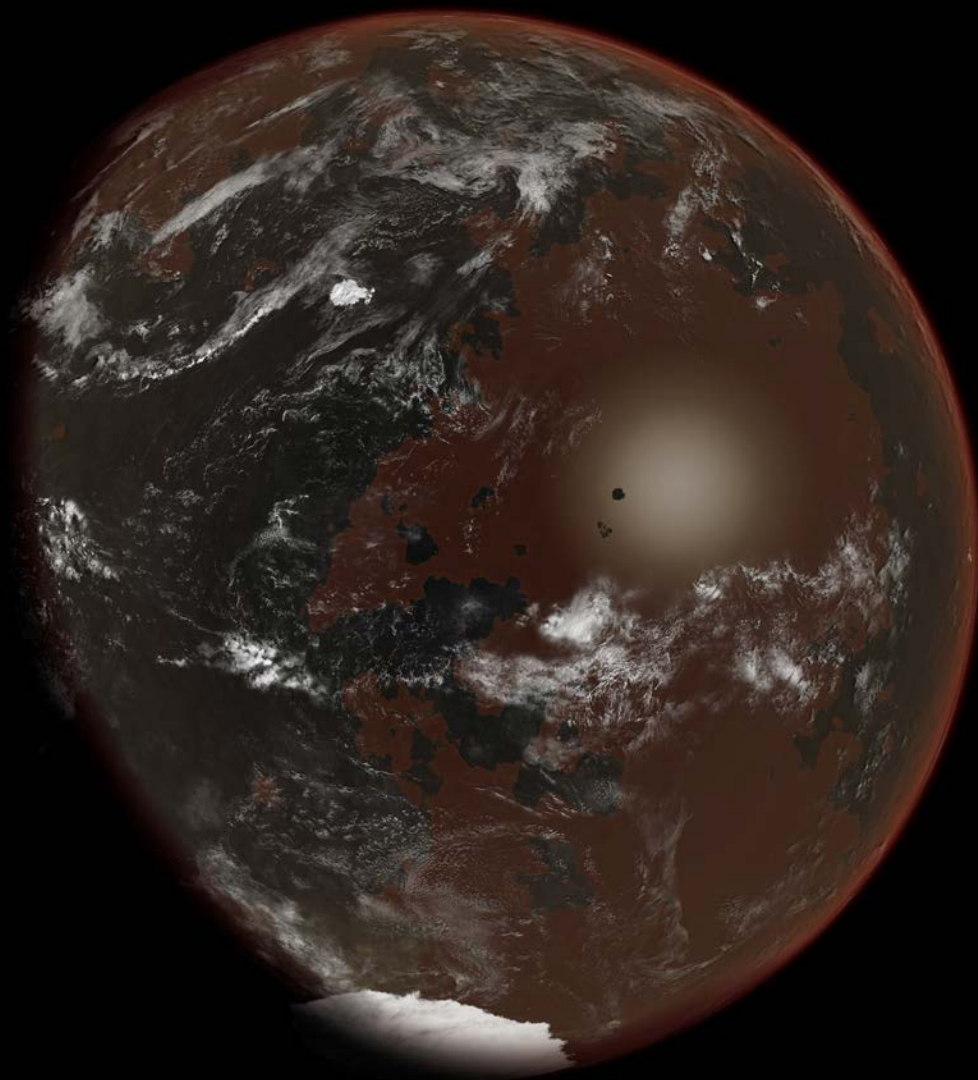


Image credit: Ittiz

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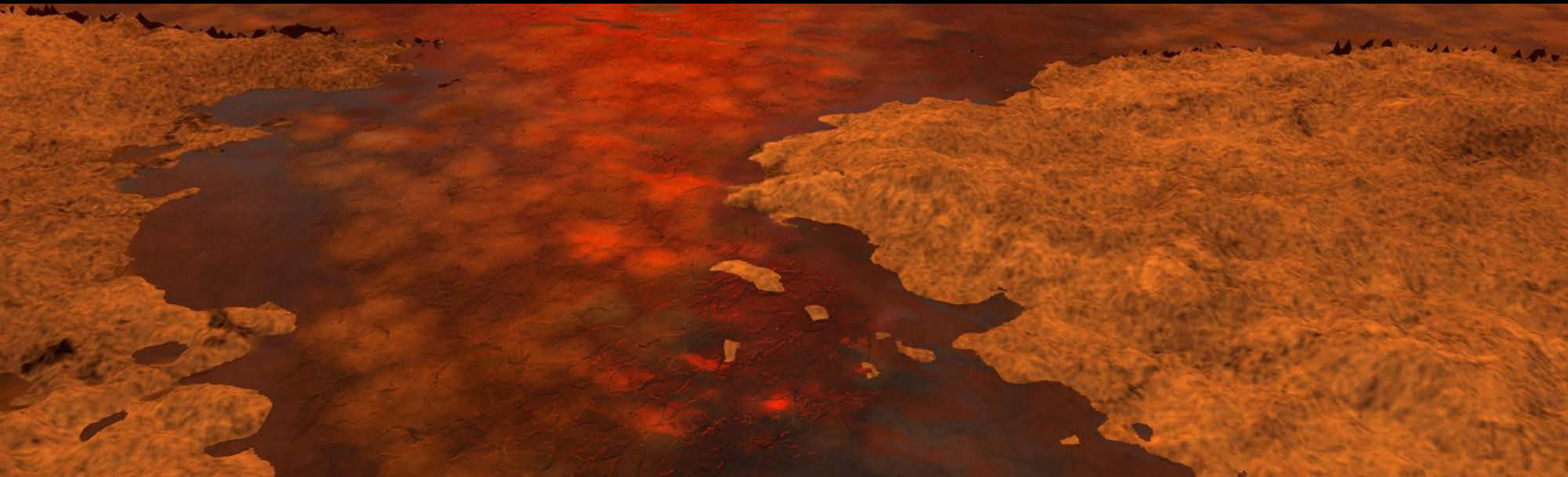

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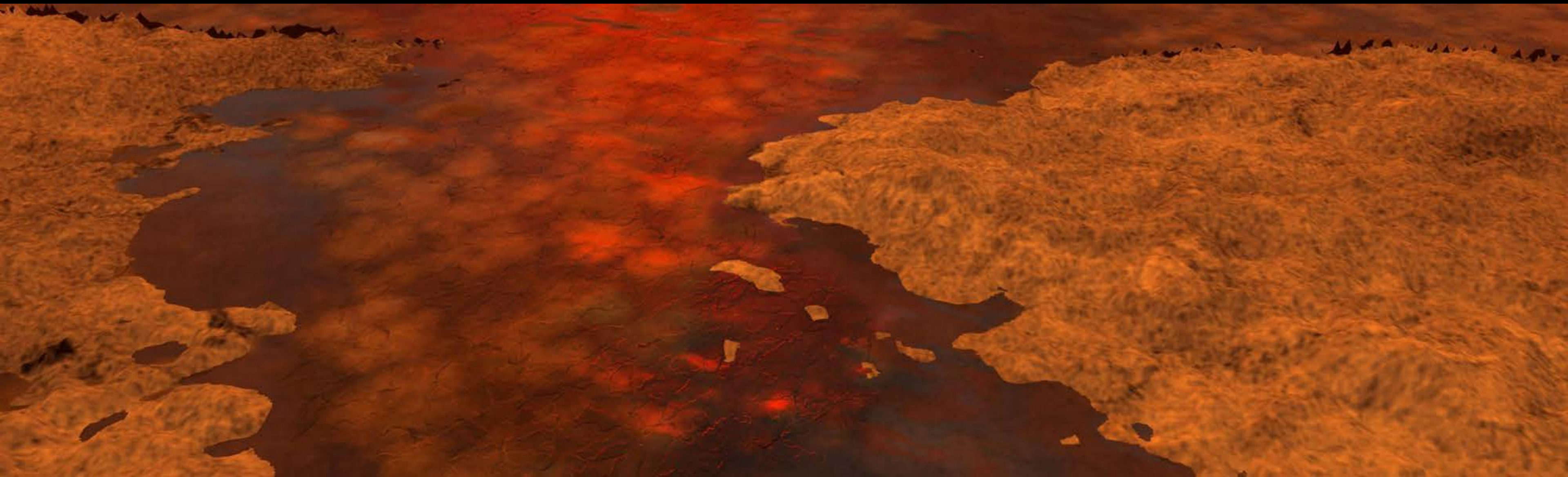
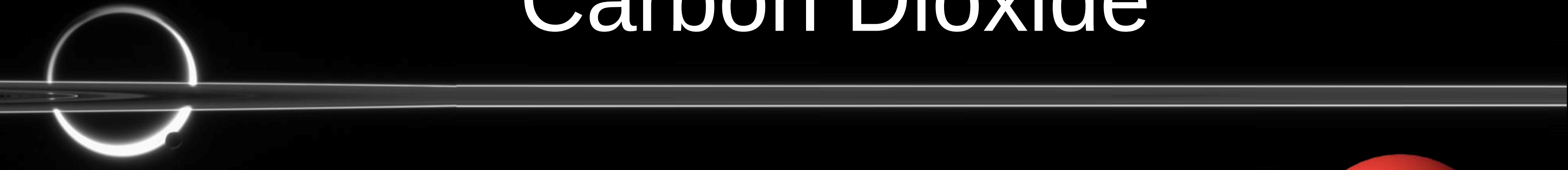
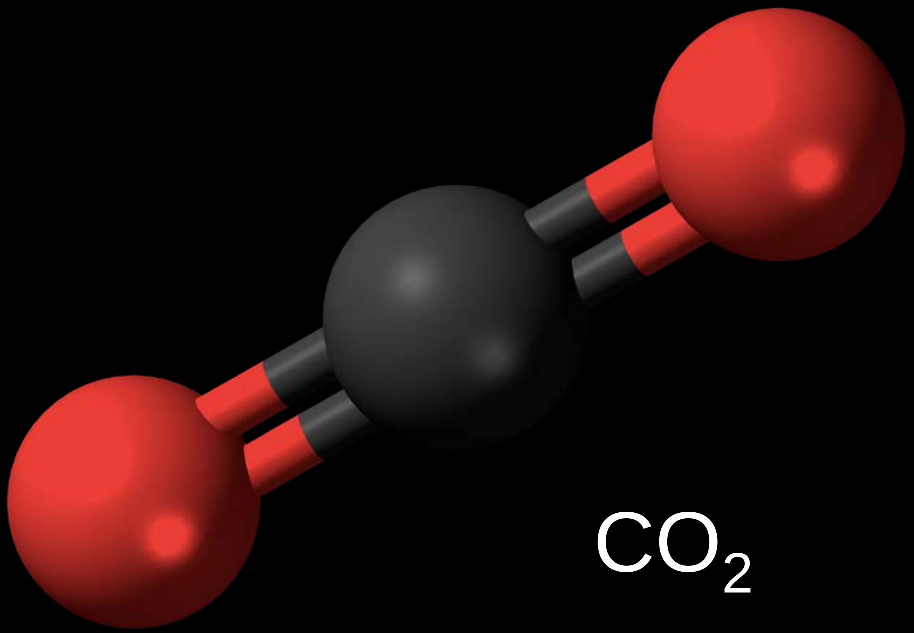


Carbon Dioxide



- Worlds to consider:
  - Venus
  - Earth (subsurface/ tectonic plates)
  - Mars (subsurface, ice caps, clathrates)
  - Niche environments (CO_2 bubbles, pockets)
  - Exoplanets with CO_2 oceans



CO_2

Carbon Dioxide

- Common in planetary atmospheres
- Comes in two liquid flavors:
  - Liquid CO_2
  - Supercritical CO_2

Image credit: NASA, ESA, & G. Bacon/STScI, STScI-PRC14-06

Supercritical Carbon Dioxide

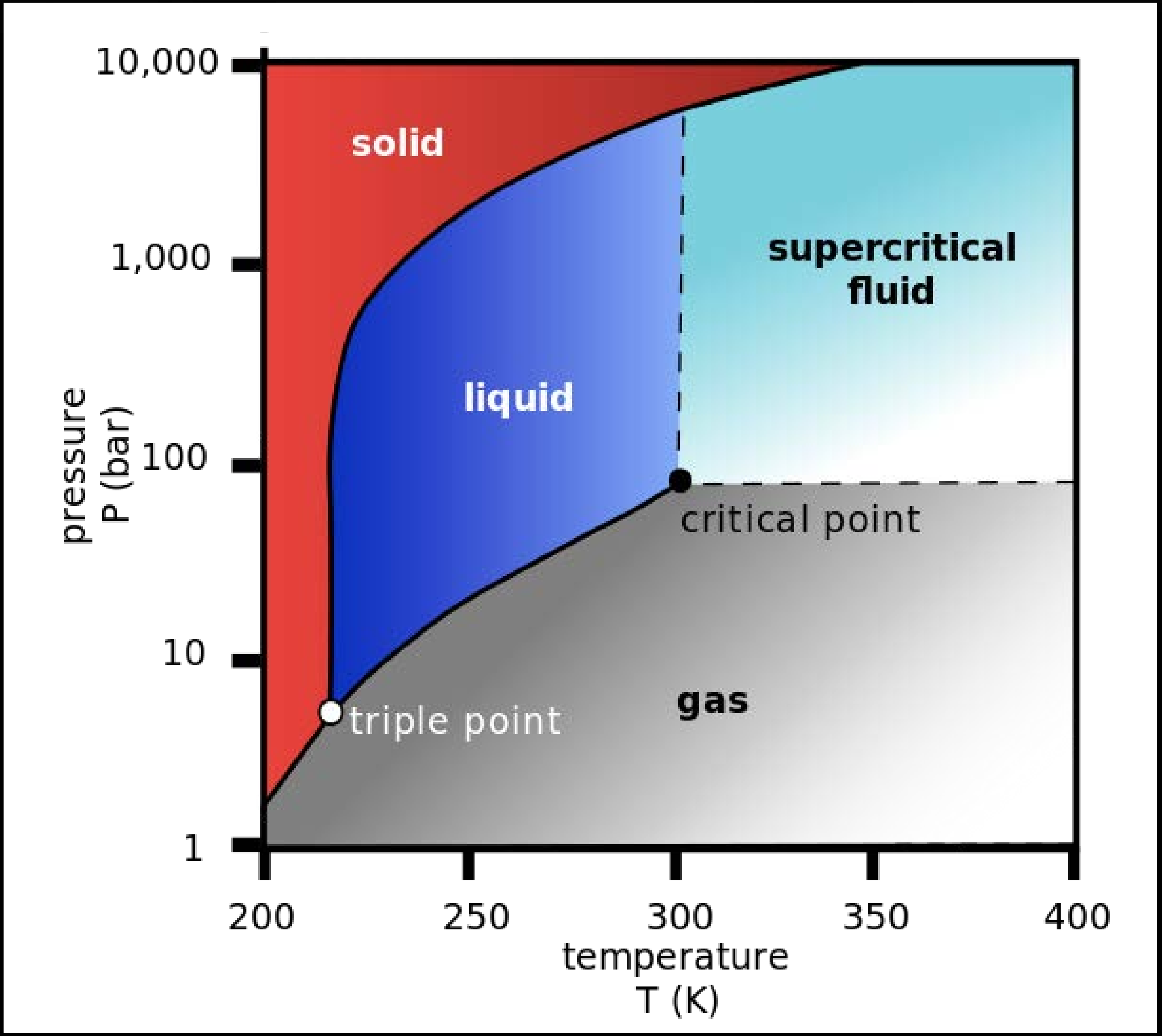
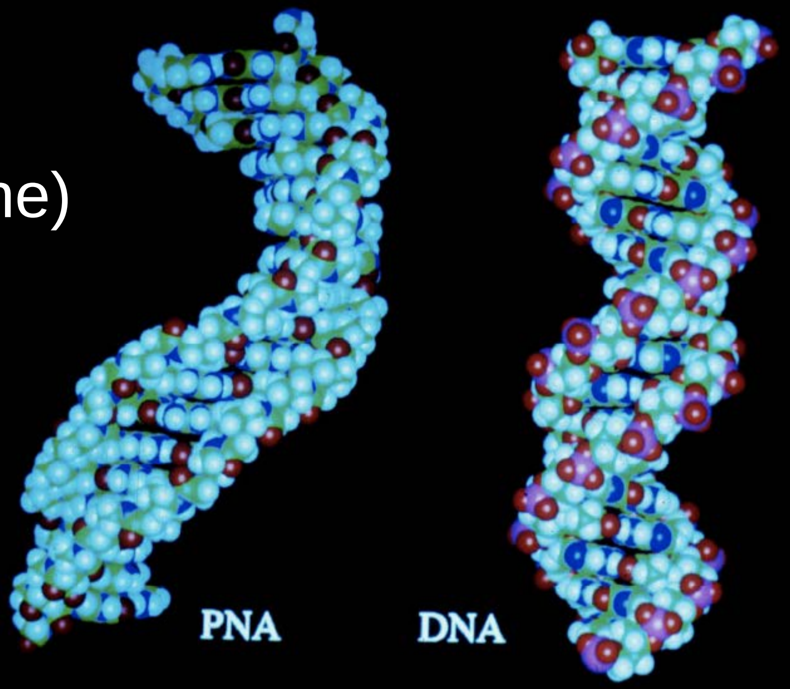


Image credit: Finney and Jacobs

Supercritical Carbon Dioxide

- Different from water
  - Nucleobases (purine, pyrimidine) aren't soluble
- But, many unique properties
  - Acetylated sugars show increased solubility in supercritical CO_2



  - Peptide nucleic acids (PNA) can act like DNA and serve as the information backbone in supercritical CO_2
  - Also polyethers are very soluble

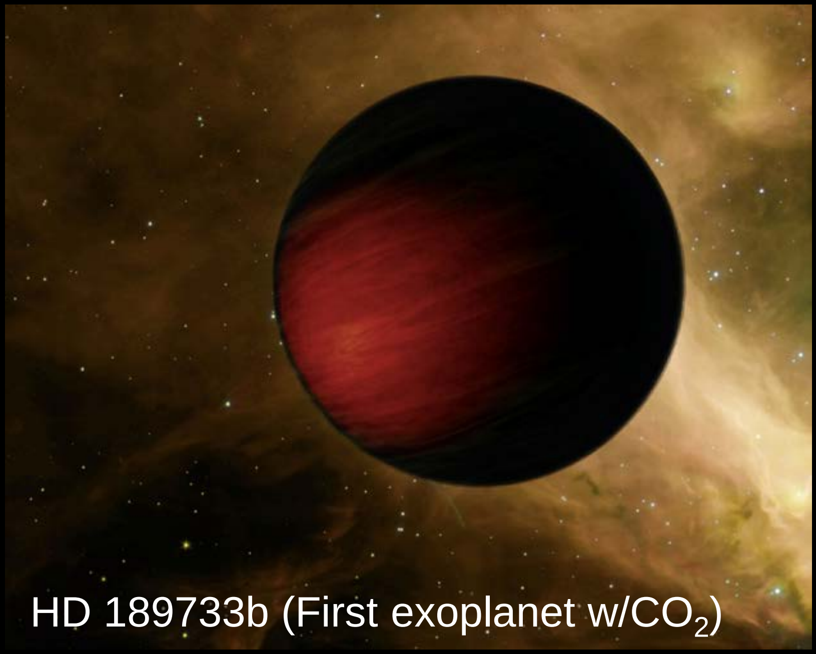
Avoiding Venus

- Challenging to prevent runaway Greenhouse effect
- Adding dissolved N_2, H_2 into the ocean might help stabilize
  - Allows atmosphere to lose heat to space better
  - H_2 atmospheres are stable for Earth-sized planets

Venus

Supercritical Carbon Dioxide

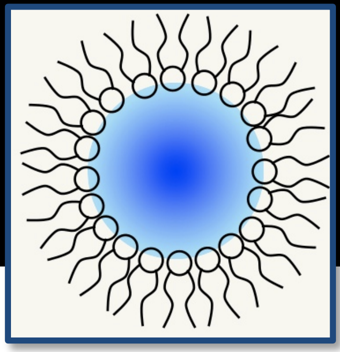
- More theoretical work is needed
  - Radiative convective calculations
  - 3 dimensional global circulation models (GCMs)
  - Include N_2, H_2
  - Trace species
  - Effect of CO_2 clouds
- Lab work is ongoing
  - Peptide backbones as a type of information carrying molecule

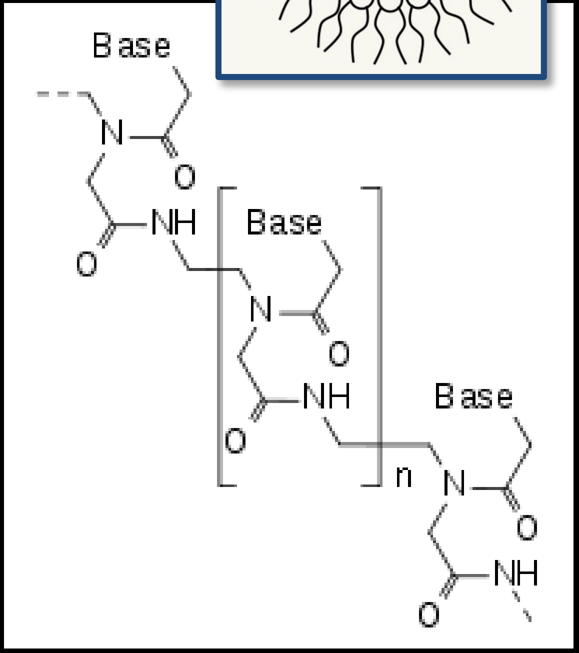


HD 189733b (First exoplanet w/CO_2)

Important Issues to Consider

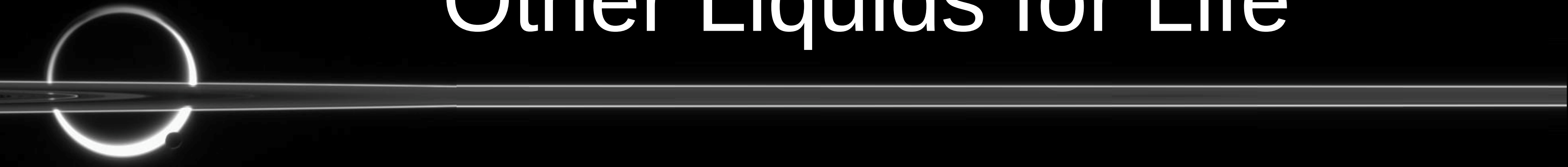
- Contact with/influx of prebiotic molecules as building blocks
- Solubilities of organics, catalytic species
- Unique reactivity of prebiotic molecules in CO_2 environments
- Formation of reverse micelles in supercritical CO_2
- Formation of CO_2 ‘bubbles’ in water
- Contact with minerals and/or catalytic surfaces in geological environments





Peptide Nucleic Acid (PNA)

Other Liquids for Life



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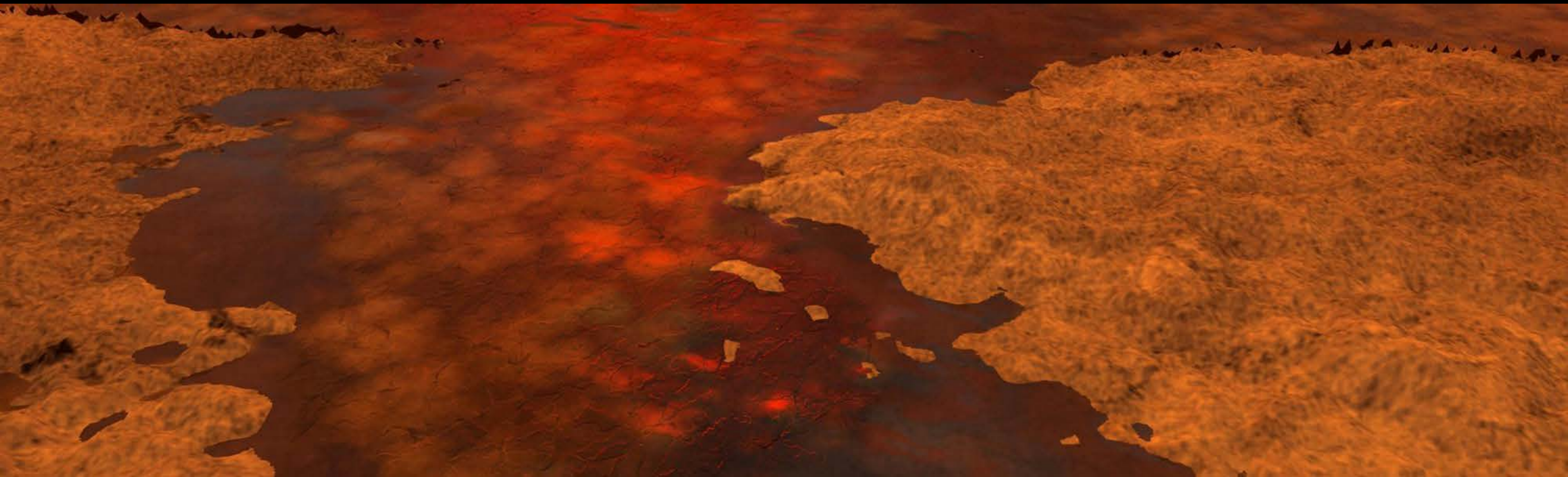

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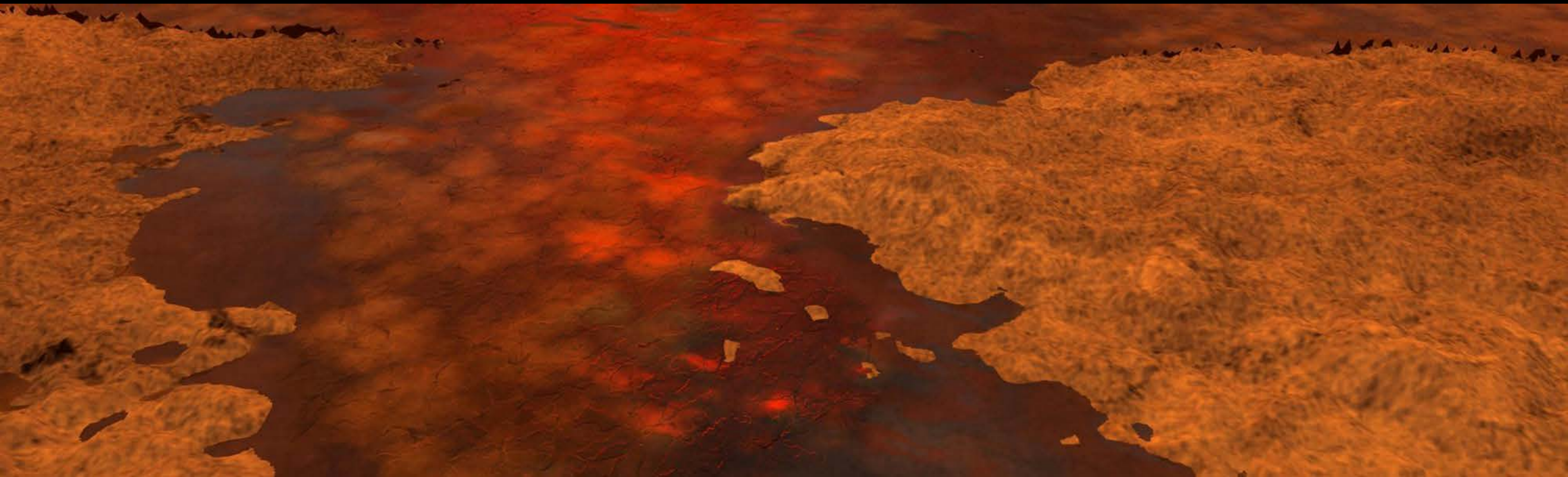
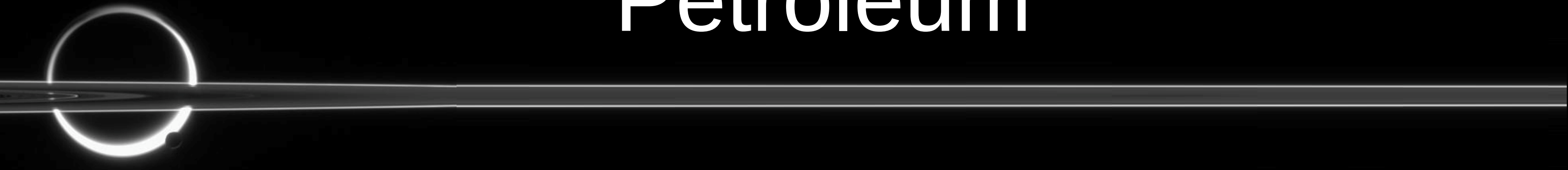
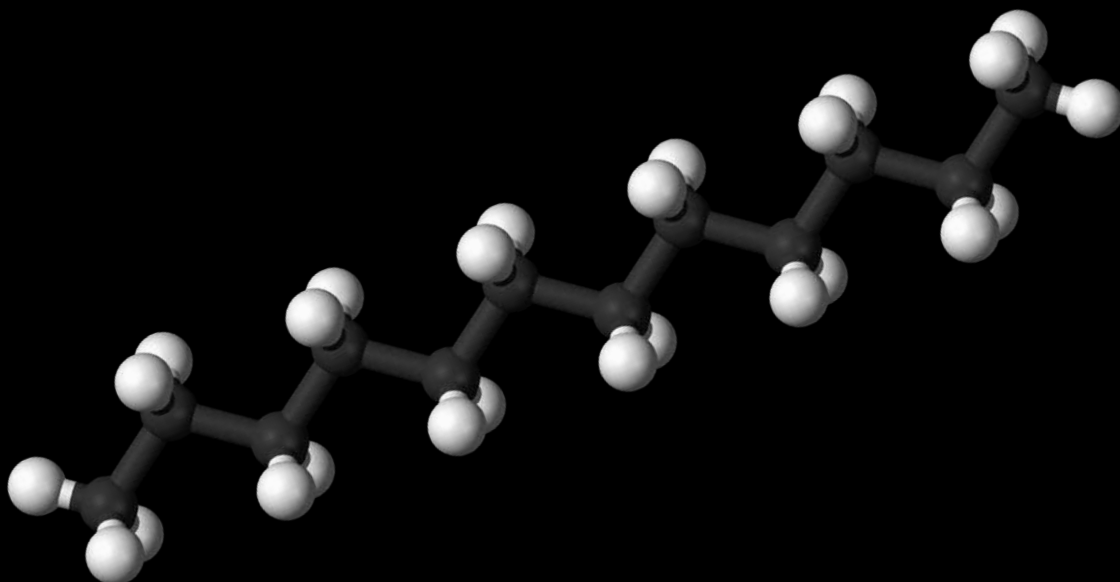
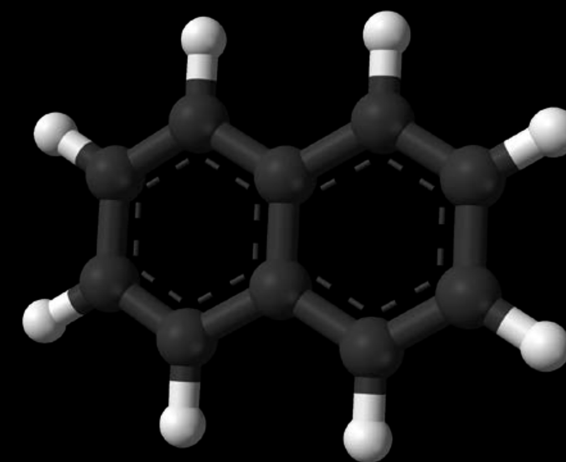


Petroleum

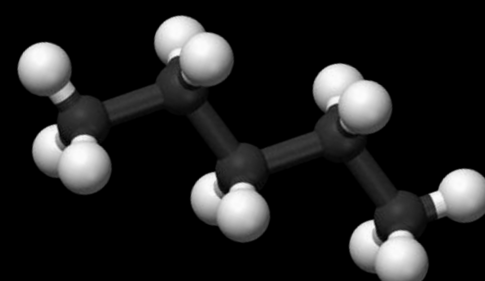




Dodecane



Napthalene

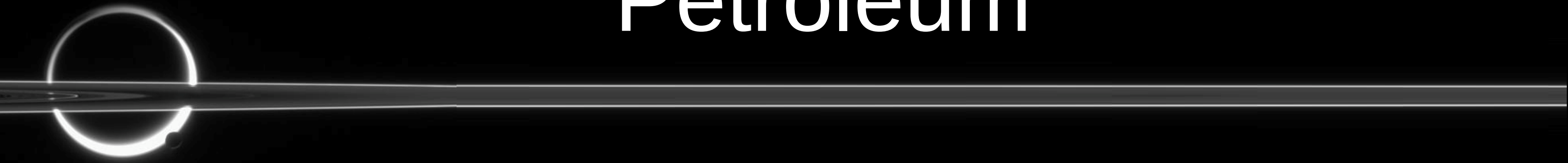


Pentane

Petroleum

- What could form the compounds of life in petroleum?
  - Isoprenoids
  - Long-chain fatty acids
  - Greasy amino acids (polyisoleucine, polyphenylalanine)
- Sample complexity is enormous
- Difficult to analyze
- Working to identify an environment where there is water-free petroleum
- Life as we know it might use petroleum at interfaces with water

Petroleum



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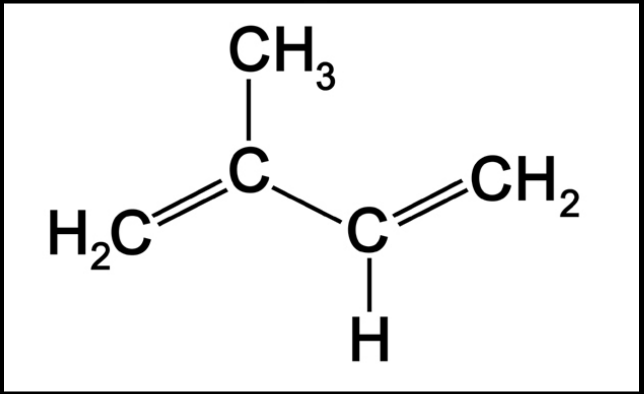
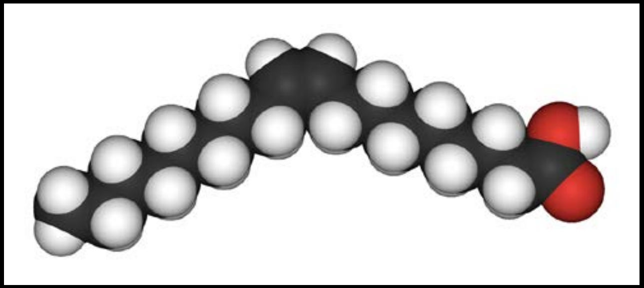


Isoprene

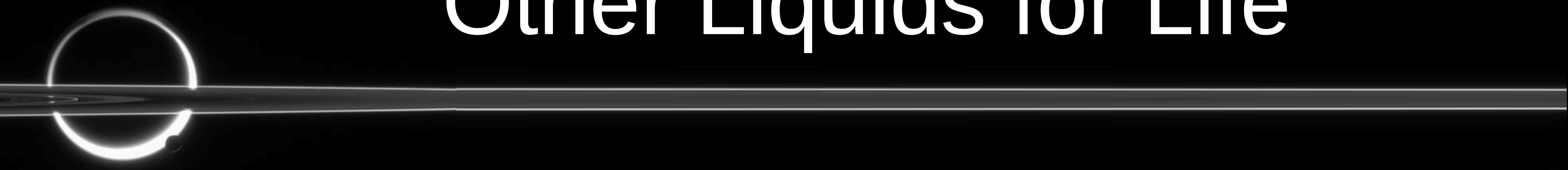


Oleic Acid (C18)

Petroleum

- There could be life in petroleum, but finding it will be challenging
- Look for petroleum deposits on Earth where contact with water has been broken for some amount of time
- Redox and metabolic experiments to identify:
  - Petroleum-associated water-based life as we know it
  - Hydrocarbon-based life as we don't know it
- Baseline abiotic processes in lab, then look at a biological process and see what the deviation is

Other Liquids for Life



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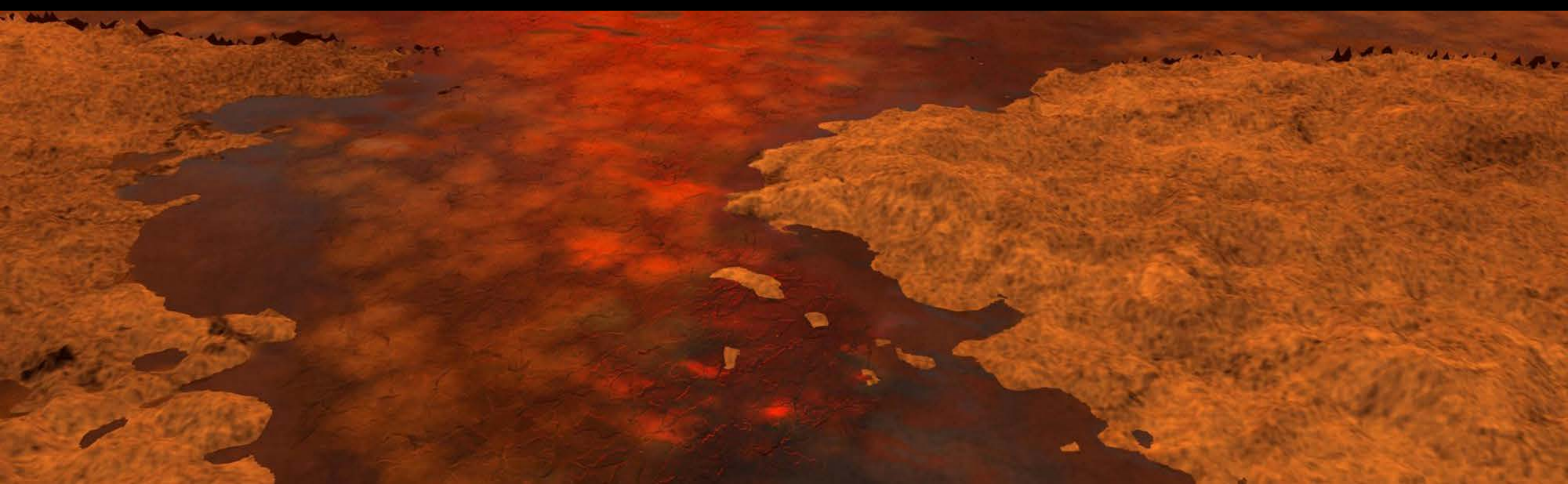

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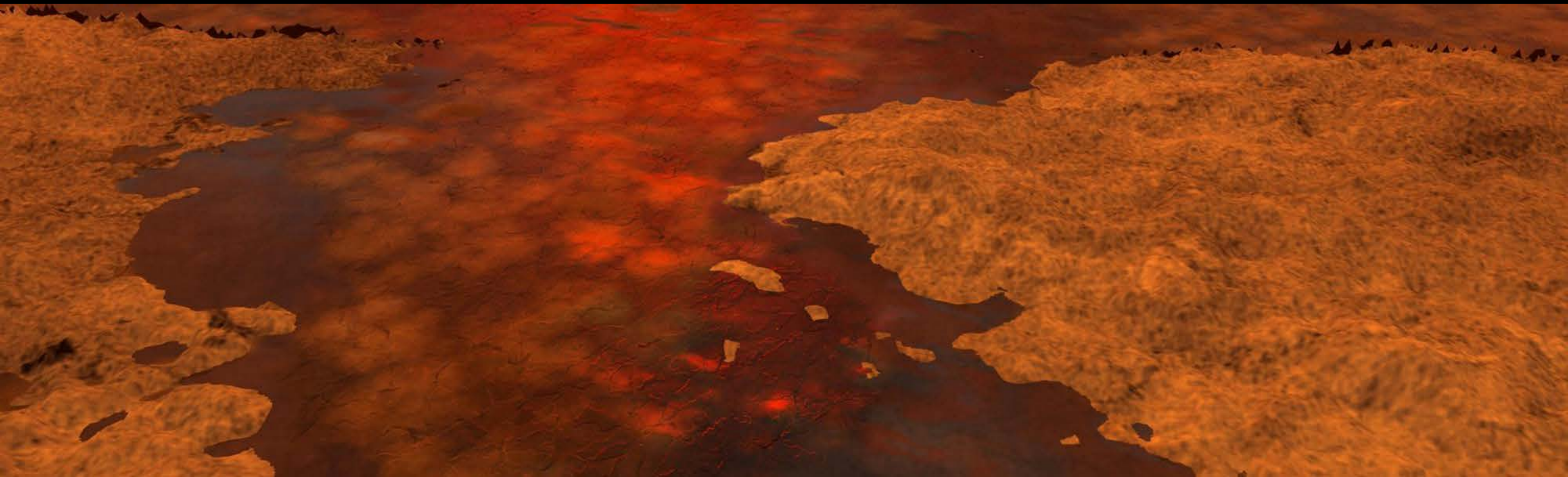
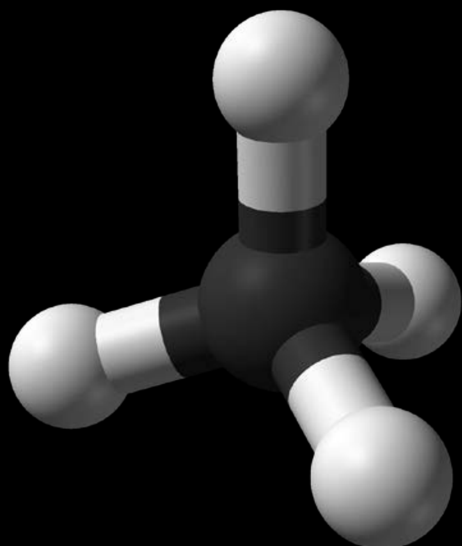
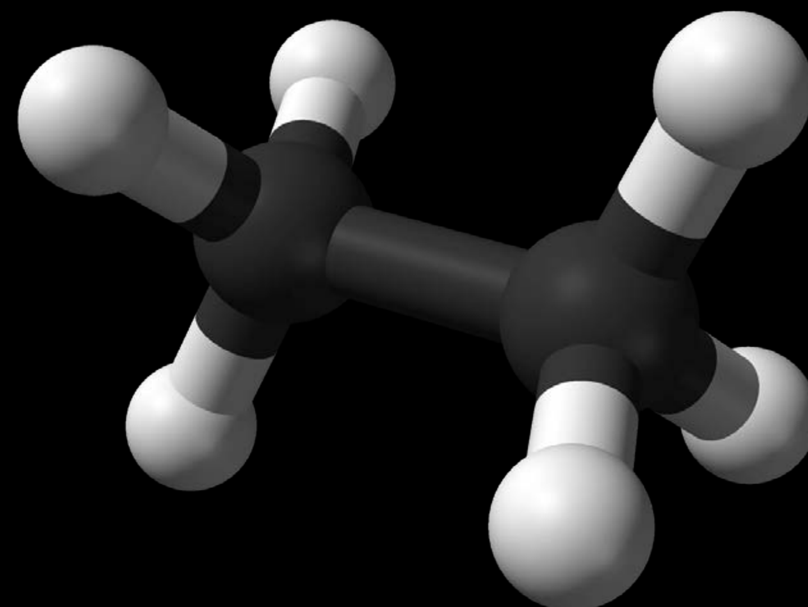


Liquid Methane, Ethane



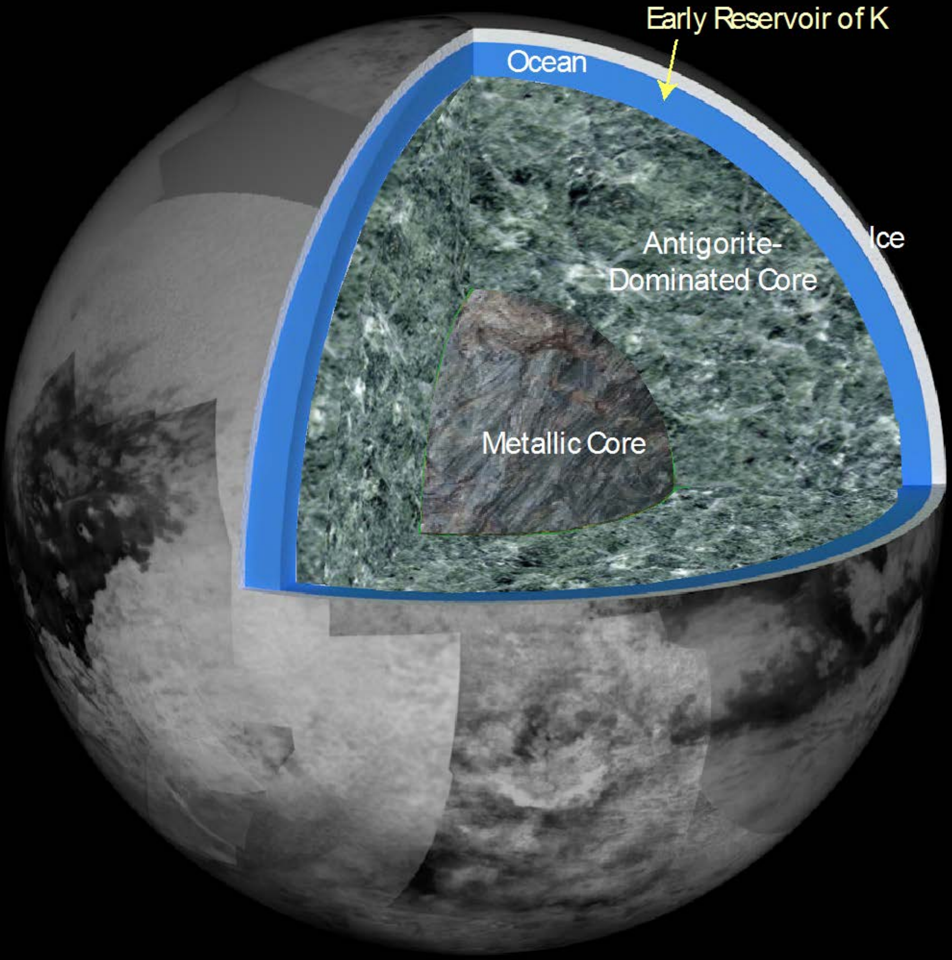
Methane (CH_4)



Ethane (C_2H_6)

Liquid Methane, Ethane

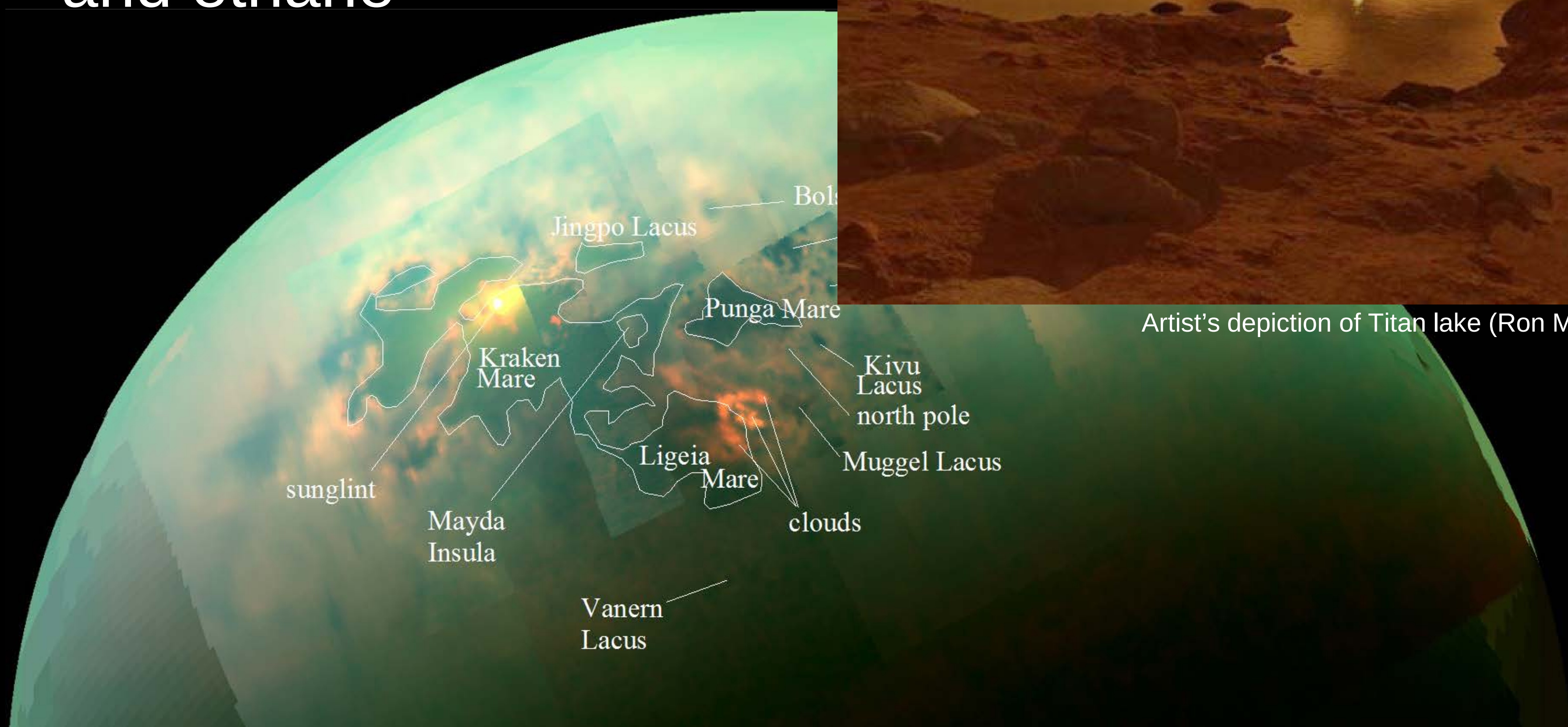
- Titan (moon of Saturn)



Liquid Methane, Ethane

- Titan (moon of Saturn)
- Lakes made of methane and ethane

Artist's depiction of Titan lake (Ron Miller)



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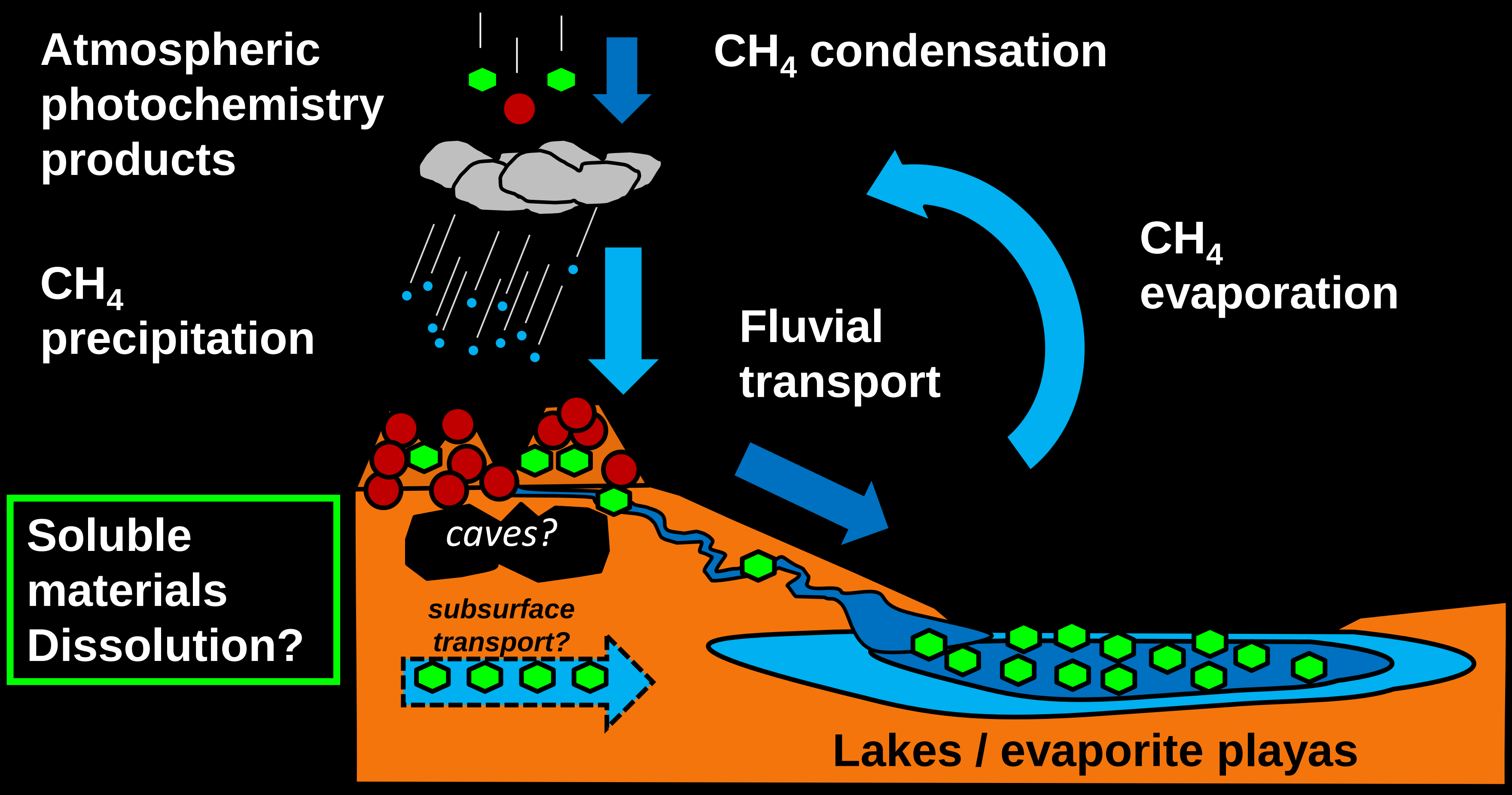
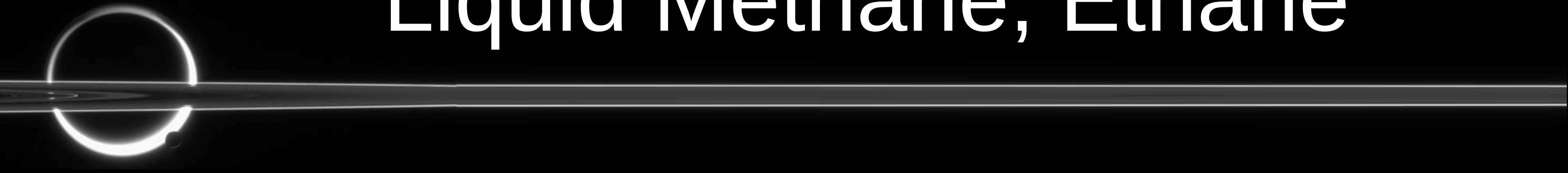
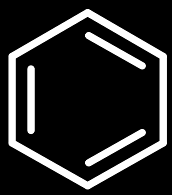


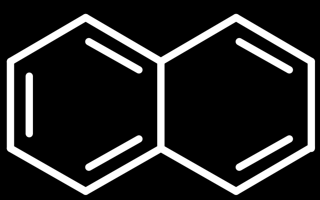
Malaska et al., Workshop on the Habitability of Icy Worlds (2014), Abstract 4020.

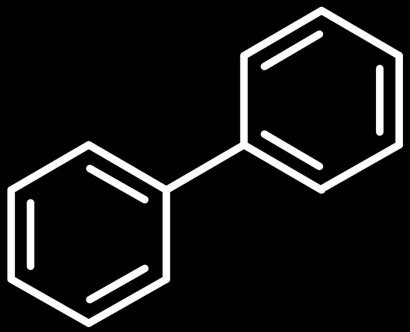
Liquid Methane, Ethane



- Solubility of most molecules in liquid methane and/or ethane is poor







Compound	Solubility in Liquid Ethane at 94 K (mg/L)
Benzene	18.5 ± 1.9
Napthalene	0.159 ± 0.003
Biphenyl	0.039 ± 0.006

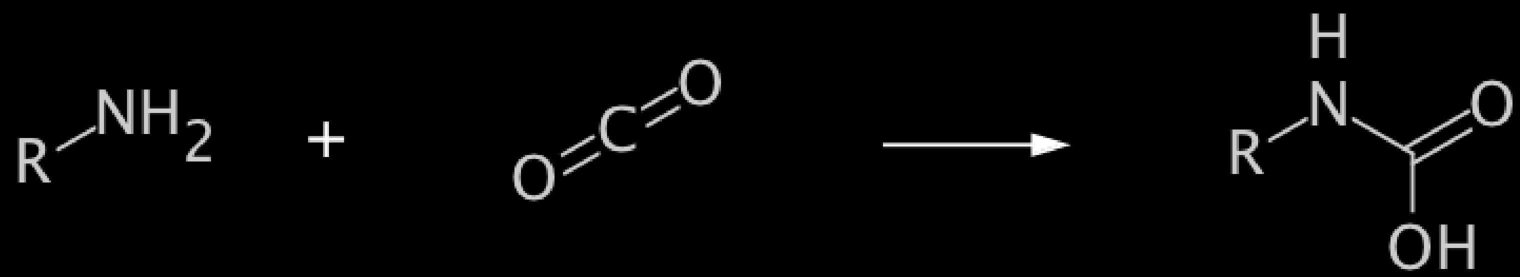
Sucrose in water (25 °C): 3,750,000 mg/L
Stearic acid (~olive oil): 3 mg/L

Malaska et al. Icarus 2014.

Looking to the Shorelines

Solid-Phase Chemistry

- Carbamation



Carbamic acid

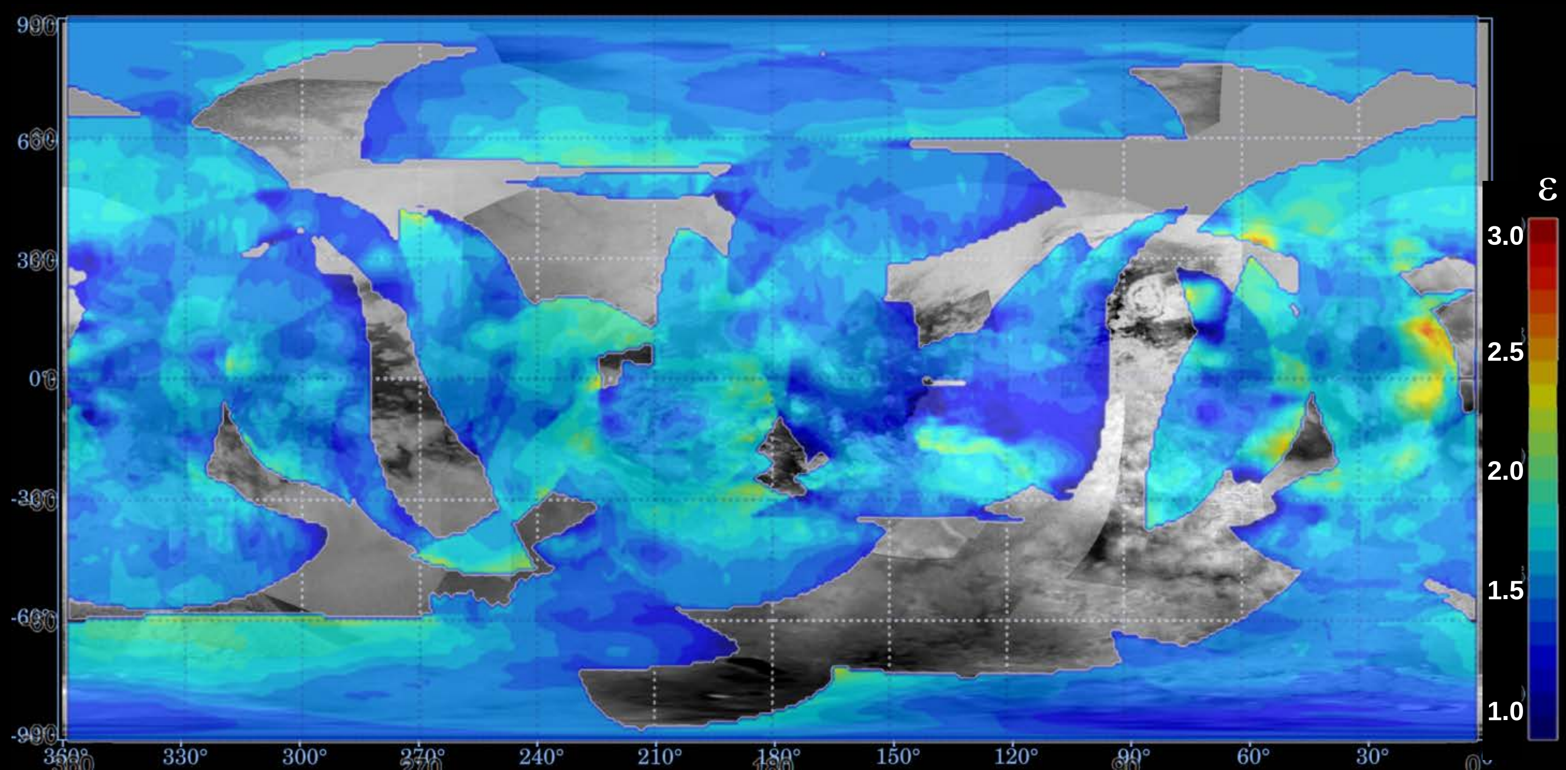
- Imine, ether formation
  - Polyimine could form a catalytic site

- Azide and alkyne polymerization
  - HCN polymerization

Looking for Organic/Ice Interfaces

RADAR – effective dielectric constant is low $\varepsilon = 1.6 - 2.0$ [1]
Consistent with organics with voids

H_2O ice	**$\varepsilon = 3.1$**
Hydrocarbon material	**$\varepsilon = 2.0 - 2.4$**
Avg. Titan surface	**$\varepsilon = 1.6 - 2.0$**



[1] Janssen et al., Icarus 200 (2009) 222-239.

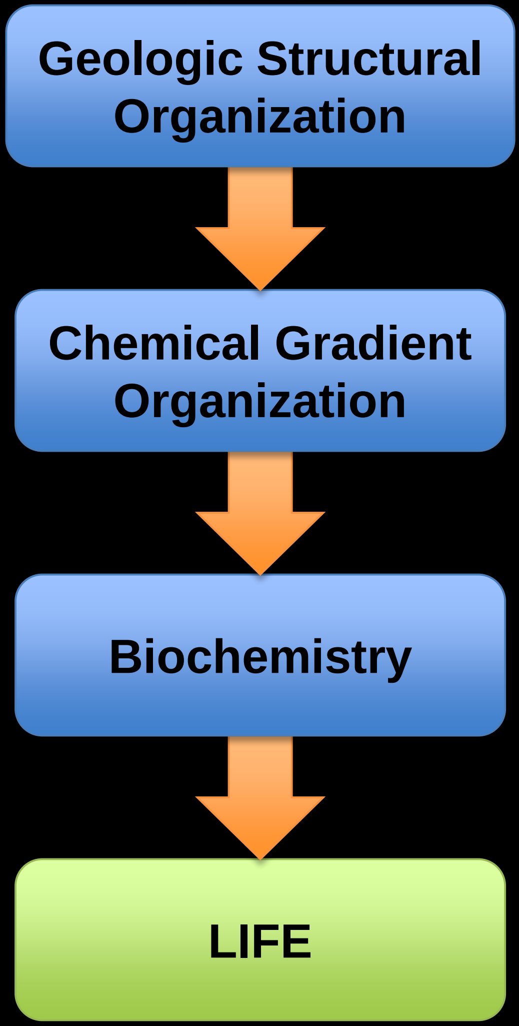
Low Temperature Considerations

- Weaker forces dominate
  – Noncovalent interactions
- We need to rethink our requirements for life

Earth	Titan	Interaction/Bond Strength
Ionic Bond	Covalent Bond	Permanent or semi-permanent
Covalent Bond	Hydrogen bonds, π-bonds	Can be made/broken on timescales relevant for life (ATP, proteins, etc.)
Hydrogen bonds, π-bonds	van der Waals forces	Loose associations that help hold together secondary structures

Prebiotic versus Protobiotic

- Instead of looking for life itself, target the mechanisms that lead to prebiotic chemistry (aka, Protobiotic chemistry)
  - Geologic patterning
  - Chemical gradients
  - On Earth, this led to more advanced chemistry, which eventually led to life
- How would we see this?
  - Look for differences in orientation and association of chemical subunits
  - Domination of one type of material on Titan (might change with seasons)



Overall Study Findings

- Mars’ charter is explicitly, “Follow the Water”
- Our conclusions have found that you may find interesting things apart from water
- Seek out the interfaces!
- Weak interactions may be the key

NASA shouldn’t just be looking for areas with liquid water

Happy Halloween from Cassini!

Image credit: NASA-JPL/Caltech

Acknowledgements

- Keck Institute for Space Studies (KISS)
- Office of the Chief Scientist, JPL