Search for Life in the Solar System

Where could they be hiding?

http://dps.aas.org/education/dpsdisc/

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Look for Habitable Environments

- In looking around our solar system we are looking for habitable environments
- These are environments that will have
  - Energy source
  - Chemicals of life
  - Liquid water (or possibly other liquids as a solvent)

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What creates Habitability

- The main energy source on Earth is the sun, but this won't be strong enough much past the orbit of Mars
- But only at certain distances from the sun will water be in the liquid state
- We refer to this as the habitable zone of a star
- Further out we have to look at other energy sources

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Other sources of energy

- Although we tend to focus on stars as our main source of energy others are also possible
  - Radioactivity
  - Internal heat
  - Chemical reactions

Radioactivity

- If the star is too far to provide sufficient energy radioactive decay may also provide energy
- Many nuclei, particularly larger ones like Uranium or Thorium occur naturally, but are unstable and will decay into smaller atoms
- During this process they release energy
- As some decay can proceed slowly over billions of years this can provide a long term energy source.

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Internal Heat

- Internal heat can come from two sources
  - Gravitational tidal heating (which I will touch on agwith outer moons)
  - During the formation of a planet
- Most of Earth's internal heat comes from the heat accumulated during the formation of the planet (radioactivity is the other major contributor)
- With a thick hydrogen atmosphere in theory Earth's internal heat alone might be able to produce a habitable surface

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Chemical Reactions

- Life on Earth depends on chemical reactions
- Under certain conditions reactions can also be used to power life
- One such example here on Earth is *Thiobacillus ferrooxidans* which lives in highly acidic conditions
- This organism obtains its energy from oxidizing iron
- Other reactions using hydrogen and sulphur are also possible and are used by some organisms at deep sea vents

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Surface or Underground

- Another key issue is whether an object is surface habitable (like Earth) or whether life exists under a thick layer of material (like ice on Europa)
- Surface life would be much easier to find as it would probably affect the composition of an atmosphere which we could detect even on worlds around other stars (i.e. oxygen in Earth's atmosphere)
- Many more environments may exist beneath a surface but they would leave very little evidence of their existence so would be very hard to find even in our own solar system

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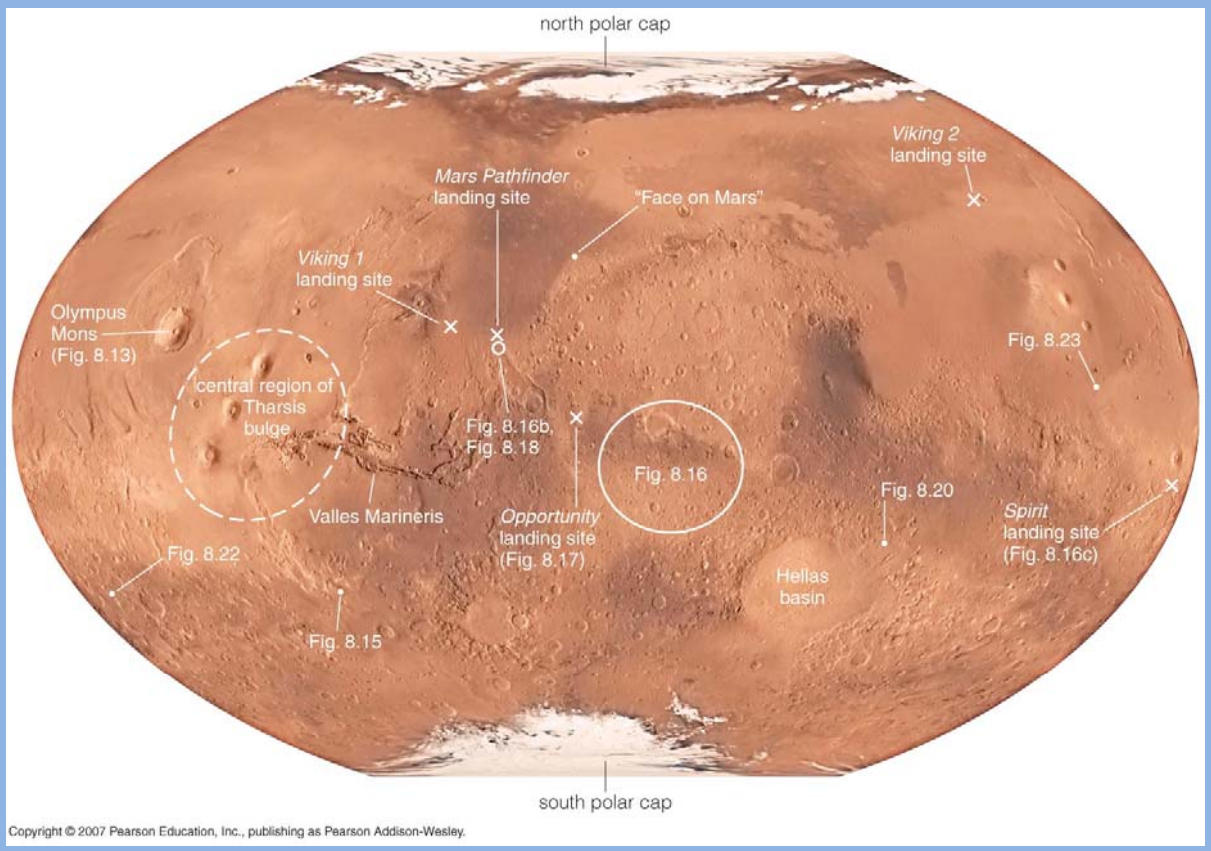
Water on Mars



WATER?!

- The marathon rovers operating on Mars - Spirit and Opportunity have found evidence in rock of mineral deposits and other water deposition features that most accept as conclusive proof that water once flowed on the surface of this planet.

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Water Today

- Today it is thought most of the water is frozen as permafrost meters below the surface, and may extend down 100's of metres. Some water is probably also frozen at the polar caps, though the part of the cap that melts in carbon dioxide- it never gets warm enough at Mars' poles to melt ice.
- The recent Phoenix mission in particular found strong evidence of water both in the ice and liquid state (containing salts)

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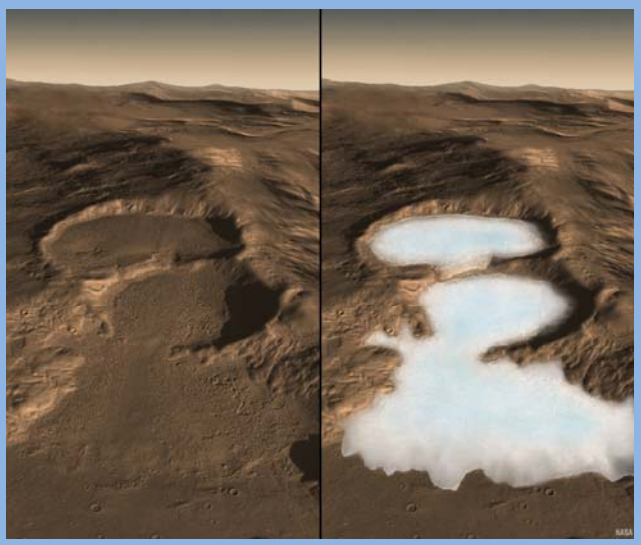
Buried Glaciers at Mars

- Radar observations made from orbit reveal that nearly pure ice "glaciers" covered by rock are common at mid-latitudes on Mars
- Previous spacecraft images indicated glacier-like features next to steep slopes and filling some craters, but could not see through the overlying rock to confirm their presence
- The layer of rock protects the ice from subliming (evaporating) in Mars' cold dry climate



(Left) Perspective image of craters in the southern hemisphere of Mars, created using NASA Mars Reconnaissance Orbiter images; (Right) Artist conception of ice underlying a surface layer, based on radar observations.

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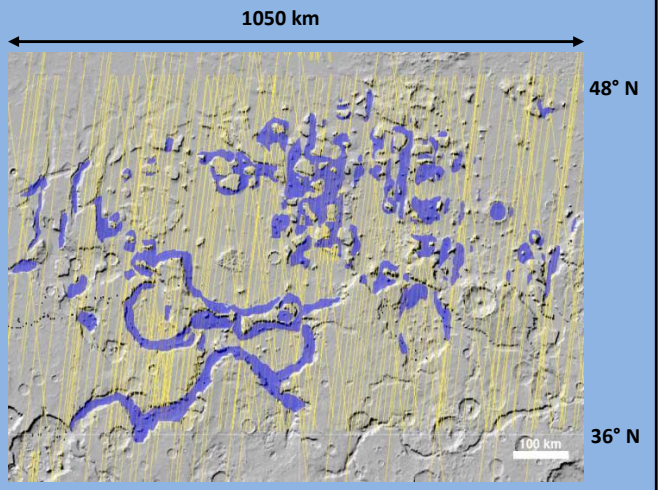
Forming Protected Ice Reservoirs

- The tilt of Mars' rotation axis was likely much greater (~45°) millions of years ago
- During that epoch glaciers could form more easily at mid-latitudes on Mars
- Overlying debris transported from nearby steep slopes would prevent some glaciers from subliming, even after Mars' tilt changed



Topography map from Mars Global Surveyor showing the locations of buried glaciers (blue) in a northern hemisphere region of Mars, inferred from many radar observations obtained by Mars Reconnaissance Orbiter (yellow). Buried glaciers are always found near steep slopes.

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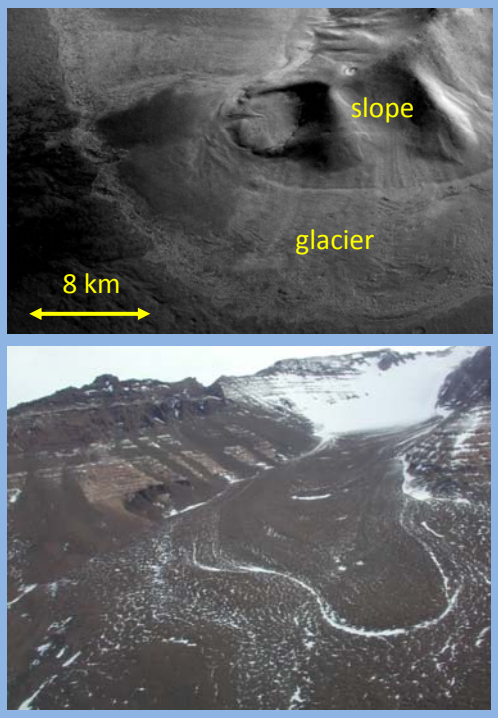
The Big Picture

- Debris-covered glaciers at mid-latitudes on Mars may contain enough ice to cover the entire planet in 20 cm of water
- These ice reservoirs are covered by only a few meters of material - easily accessible for future human and scientific exploration
- Buried ice may record the history of Mars' climate, as ice cores from Earth's glaciers do



Debris covered glaciers on Mars (top, imaged by the Mars Express spacecraft) and in Beacon Valley, Antarctica (bottom, photo courtesy Jack Holt)

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Opportunity

- Continues to operate
- Recent finding of a mineral rich in calcium and sulfate (possibly gypsum)
- Strong evidence water flowed in the location it is sampling.

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Curiosity

- Launched Nov. 26th.
- Significantly larger than Spirit and Opportunity
- At Gale Crater will look if the conditions for life every existed at that location.

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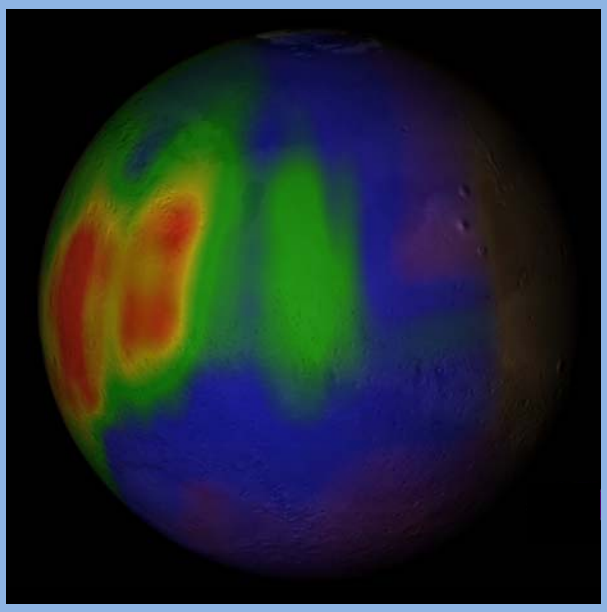
Methane in the Martian Atmosphere

- Methane gas was recently detected in Mars' atmosphere using groundbased telescopes
- The methane gas distribution is patchy and changes with time
- Most methane in Earth's atmosphere is produced by life, raising questions about its origin on Mars



View of Mars colored according to the methane concentration observed in the atmosphere. Warm colors depict high concentrations.

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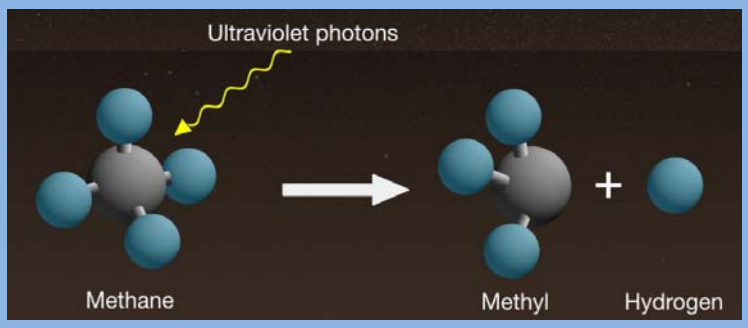
Recent Release of Methane

- Methane in the atmosphere should be destroyed by UV light within a few hundred years or by the electrical activity in dust storms even more rapidsly
- Methane observed now must therefore have been produced recently
- Variations in space and time suggest that it was recently released from the subsurface in localized areas



UV photons have enough energy to break molecules apart

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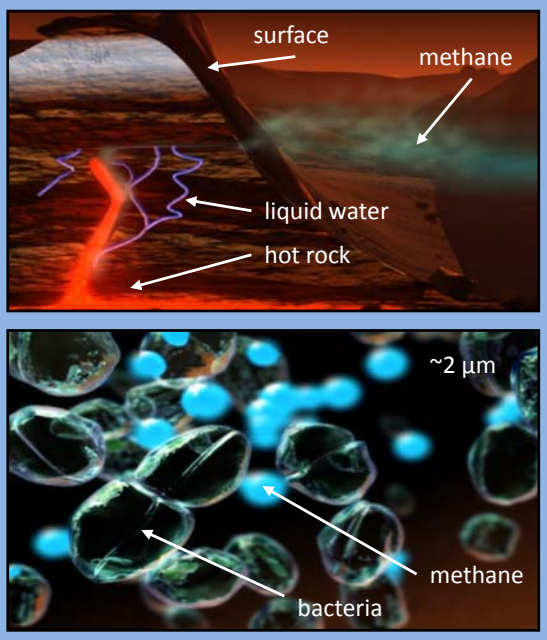
The Big Picture

- Where can the methane come from? From analogy with Earth, there are two leading theories for the origin of recent subsurface methane at Mars:
  1. Methane is produced by water-rock interactions
  2. Methane is produced by bacteria, in regions where liquid water is found

  Either theory implies that the Martian subsurface is dynamic
- Future observations can test for trace chemicals associated with each process



Methane on Mars could be produced chemically through liquid/rock interactions (top) or biologically (bottom)

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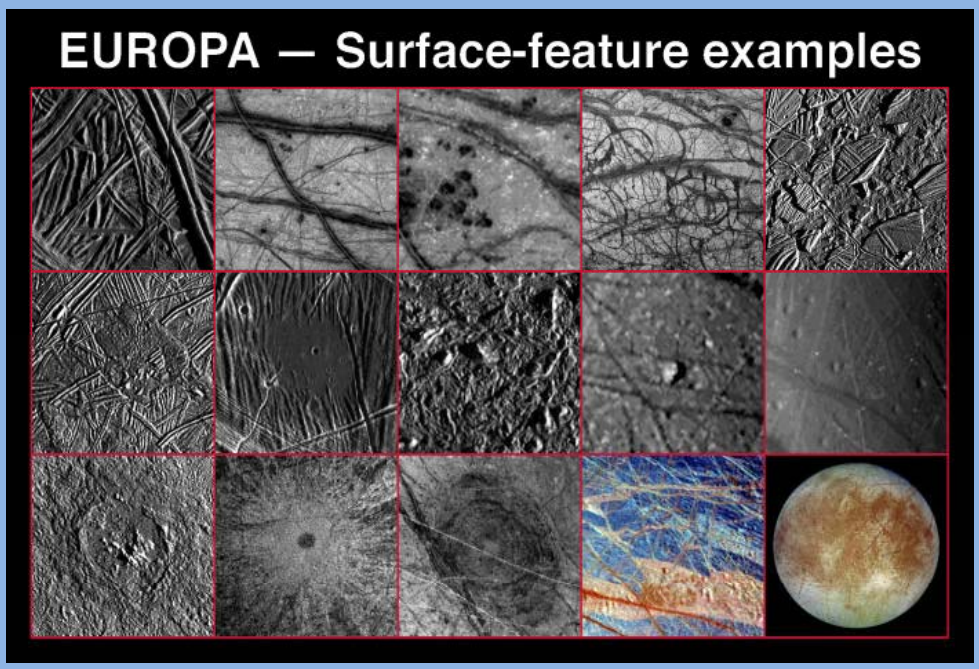
- If the methane were being produced geologically, other gasses would also likely be produced. There is no evidence to date of these gasses being present so a liquid subsurface source seems more likely

Europa

Europa

- after Mars this is one of the most likely locations for life to have arisen in our solar system.
- The surface of most of Europa is made of ice sheets. These sheets clearly show signs that the ice is moving. There are features that suggest that the ice breaks up, and liquid water flows up and refreezes at the surface.


EUROPA — Surface-feature examples

Recent Discoveries

- Recently analysis of Galileo data suggests there are pockets of water in the ice
- http://science.nasa.gov/science-news/science-at-nasa/2011/16nov_europa/
- Specifically they have found one that appears to be the size of the Great Lakes, but several kilometers below the surface.

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Young Surface

- The relatively small number of craters also tells us the surface is relatively young, as little as a few 10 millions of years so some mechanism is changing it

Energy

- Europa could have a liquid ocean under a thick layer of ice. Jupiter's tidal heating, could be driving volcanic activity at the rock surface, but deep under the ice and water. These volcanoes could provide enough energy to keep the water liquid, and to provide an energy source for life, though additional sources may also be necessary (like UV, high energy particles trapped in Jupiter's magnetic field)

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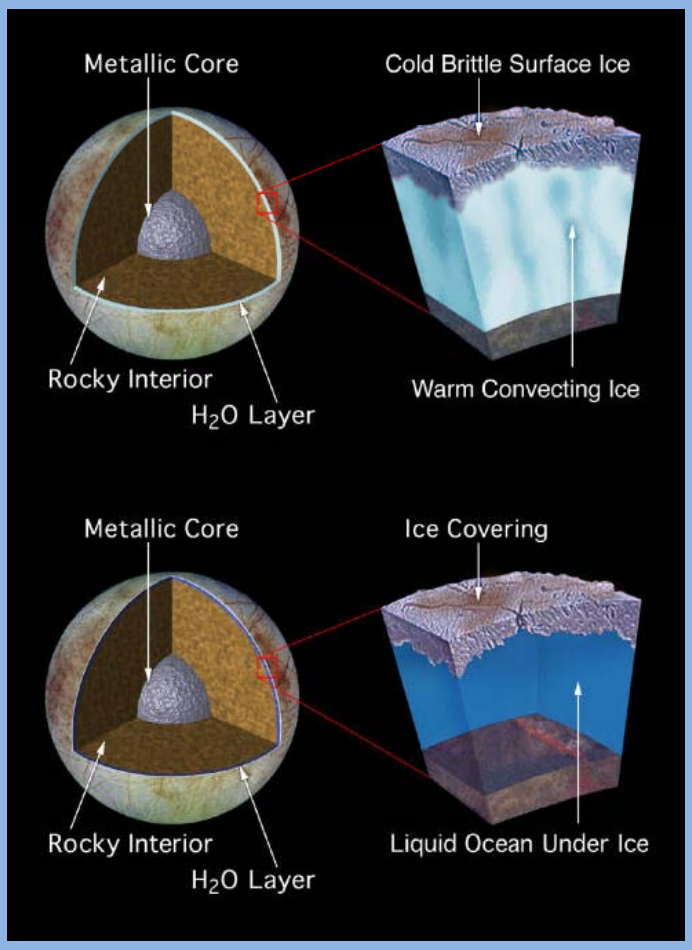
Metallic Core
Cold Brittle Surface Ice
Rocky Interior
H_2O Layer
Warm Convecting Ice
Metallic Core
Ice Covering
Rocky Interior
H_2O Layer
Liquid Ocean Under Ice

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Magnetic Field

- Europa does also have a weak magnetic field which could be due to the motion of a salt water ocean as it is affected by Jupiter's magnetic field (but it is not generated solely by the moon the way Earth's generates it's field)

- On Earth we do see ecosystems at the deep ocean volcanic vents that rely on the volcanoes as their source of energy instead of sunlight. Results from the Galileo space probe also suggest that the chemicals needed for life are present in the ice.

Europa Mission

- A dedicated mission to Europa is in the planning stages, but there are a couple of significant obstacles (Other than money)
- Any search for life will be required to search under the ice.. This requires significant technology to be able to bore through possibly kilometres of ice remotely

(though a lander may also just analyze the surface for evidence of chemicals like amino acids)

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Europa mission

- Another important consideration is contamination
- There are Earth organisms that could survive in the Europan environment, one worry is that they could contaminate the system and cause the extinction of Europan life
- This is the main reason the Galileo probe was crashed into Jupiter in 2003

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Saturn's Moons

Titan

- http://www.esa.int/SPECIALS/Cassini-Huygens/SEMHB881Y3E_0.html
- Titan is the largest of Saturn's moons. It is the second largest moon in the solar system (only Ganymede is larger), and is larger than the planet mercury.
- Because Saturn is quite far from the sun, it is much colder as it receives far less sunlight. For this reason, molecules have less energy and move slower, so Titan can hold onto a significant atmosphere.

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- Its atmosphere is 1.5 thicker than Earth's.
- It is also made up of 90% nitrogen, with significant amounts methane, argon, ethane and traces of many other carbon compounds
- This mix is related to Titan's distance from the sun.
- Where this moon and it's planet formed ammonia and methane could be ice (whereas near Jupiter for Ganymede that would not be the case)

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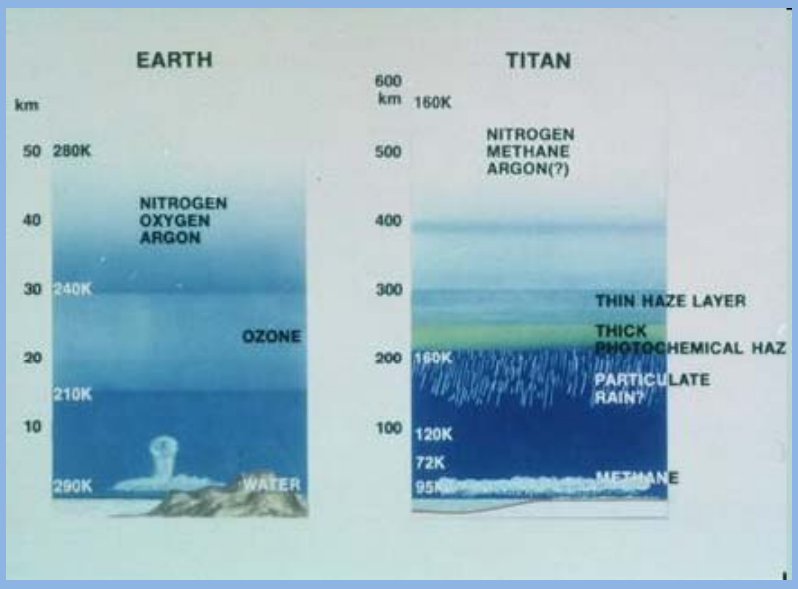

From NASA/JPL multimedia

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- Significant amounts of these materials could be trapped in Titan's interior and be outgassed over time
- UV hitting the atmosphere would breakdown the methane and create other organic molecules
- Titan is essentially covered in a thick smog, and the surface is never visible in the optical due to this thick haze

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- It is too cold for liquid or vapour water to exist, but it is probably made of a significant percentage of water ice (up to 50% of the moon).
- At the cold temperatures on the surface of around 100K, methane and ethane can exist in a liquid state.
- At these low temperatures although these substances are liquid and could act as a solvent for life, it would be difficult as the rate of chemical reactions would be much slower due to the low temperatures..

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- Cassini evidence clearly shows us features that may have been carved by flowing liquid methane
- Titan could also have liquid water deep under the surface possibly either due to tidal heating from Saturn or possibly from radioactive decay. With a source of heat, and the abundant organic material this also could provide a haven for life.

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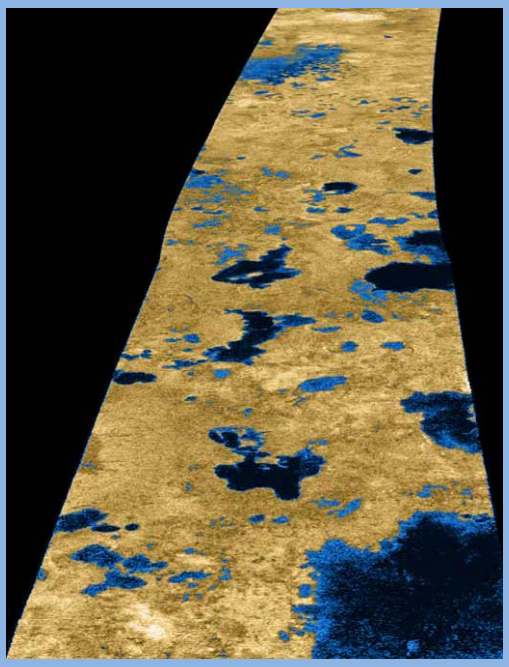
Lakes without Water

- Titan is 94 K - too cold for liquid surface water, but not too cold for liquid methane and ethane
- Sunlight should rapidly convert atmospheric methane to ethane and other species. But methane is abundant, so must be replenished.
- Methane and ethane should be exchanged between the atmosphere and lakes through evaporation and precipitation (similar to water on Earth)
- These processes can help maintain the high atmospheric methane abundance and contribute to observed seasonal variations in the lakes



False color Cassini image showing the amount of radar signal reflected from a region of Titan's northern hemisphere. Dark regions are likely lakes.

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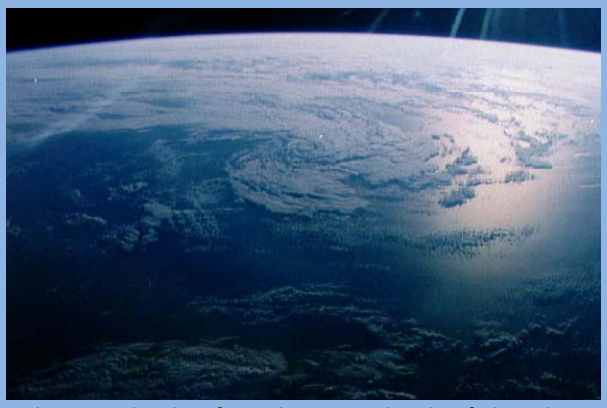
The Big Picture

- Earth and Titan are the only two objects in the solar system that have stable bodies of liquid at the surface
- Similar processes help maintain surface liquids and atmospheric compositions, despite very different temperatures and materials at each body
- Surface liquids facilitate erosion, and can create 'Earth-like' landscapes (e.g. sedimentary layers, river beds, …)
- Surface liquids may exist on a variety of bodies orbiting other stars, and not be restricted to 'Earth-like' bodies



Photograph taken from the space shuttle of glinted sunlight from Earth's oceans.

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- Even if there is no life on Titan, it is interesting to study as the composition and chemical reactions occurring in its atmosphere must be similar to what happened on Earth early in Earth's evolution.

An Ocean Below Enceladus' Icy Crust?

- NASA's Cassini spacecraft has observed plumes of material escaping from Saturn's small icy moon, Enceladus
- The plume is mostly water vapor, with tiny ice particles and other gaseous molecules mixed in (e.g. CO_2, CH_4, C_2H_6)
- The plume supplies ice particles to one of Saturn's rings
- Some ice particles contain salt, which may indicate they originate in an ocean deep below the icy crust

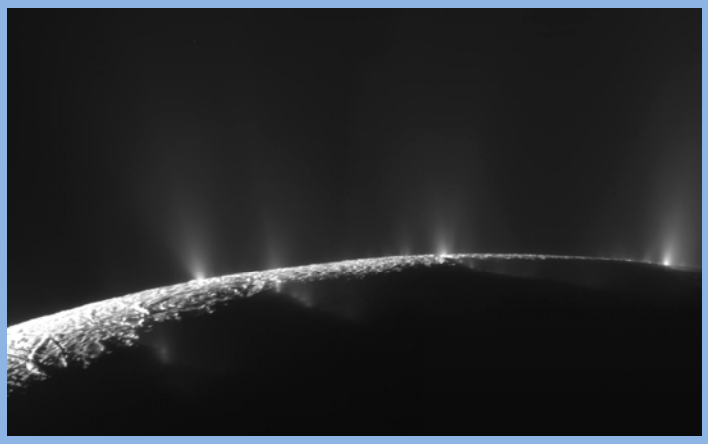

Image mosaic of Enceladus taken by Cassini, showing individual plumes of gas and ice escaping from the surface. The plumes extend 100's of km into space from the ~500 km diameter moon.

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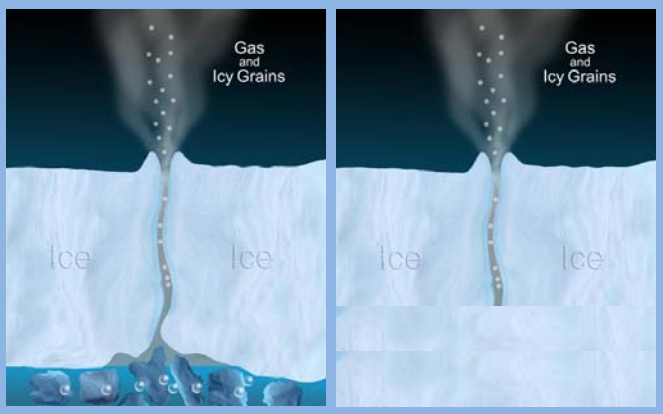
What Process Creates the Plume?

- Plumes may be material escaping through surface cracks from an internal salty ocean or lake
- Alternatively, ice along cracks may sublime or melt, followed by escape of water vapor and icy particles
- Many scientists find the salty ocean model most convincing, but others favor combinations of alternative explanations



Left: Enceladus may have a salty subsurface ocean that releases material to space through cracks in the moon's icy shell. Right: The walls of icy cracks in the surface may melt or sublime, venting gas and icy particles to space.

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- Another theory is that gasses become dissolved in the water which lowers the density so it flows upward through the pores in the ice.
- In some places this water collects, and spews out when the pressure rises high enough.
- Over the rest of the ice sheet it warms to surface to as high as 190 Kelvin.

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The Big Picture

- Enceladus is surprisingly active for such a small body - likely a consequence of tidal heating
- If Enceladus has an ocean, then it contains all of the 'ingredients' known to be important for life: liquid water, molecular building blocks, and energy

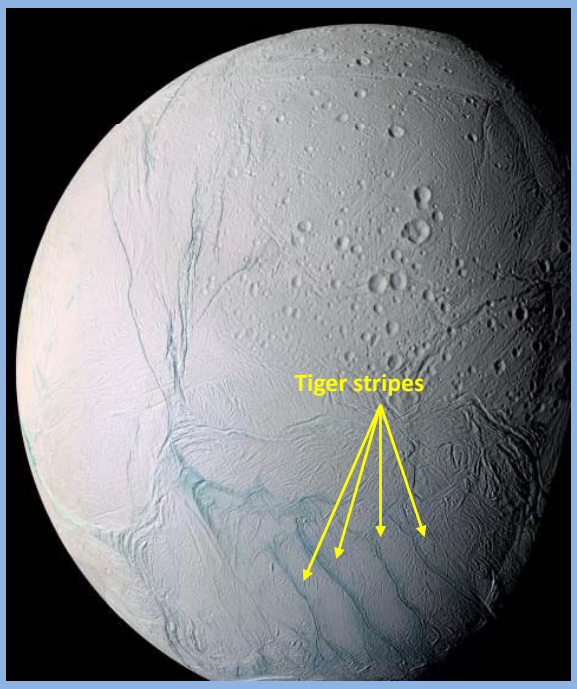

Image of Enceladus showing the 'tiger stripes' region in the southern hemisphere, where the plumes originate

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