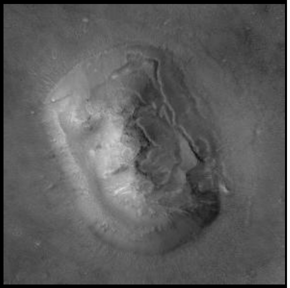
Today in Astronomy 106: life on Mars and possible habitats in the outer Solar system

- The ongoing search for life on Mars.
- Martian meteorites.
- Tidal heating, Europa and Enceladus, and their subsurface liquid-water oceans.
- Titan and its liquid-ethane lakes: a nonpolar-solvent habitat?



Unretouched picture of the "face on Mars," from Mars Global Surveyor (JPL/NASA). The modern version of Martian canals…

Prospects for life elsewhere in the solar system

While RNA World and alternative chemistries are fresh in our mind we should consider life elsewhere in the Solar system, where chances are it'd be primitive if it exists.

- Conditions are quite different in the inner and outer solar system: that is, between the classical "habitable zone" and places with sources of heating than other sunlight, or life based upon solvents other than water.

Phases of Venus (Wah!)

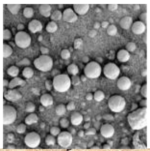
Water on Mars

Still, it is clear that Mars has a little bit of water on the surface (in the form of ice near the poles), and evidence is emerging that in the distant past (a few Gyr ago) it may have had liquid water oceans and a denser atmosphere:

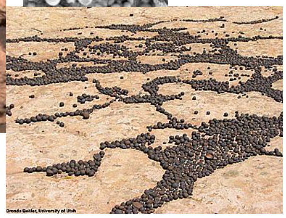
- Mars is remarkably free of impact craters, especially small ones and especially in the low plains, but even in the southern highlands. Thus the surface used to have more protection from impacts than it does now (Helfer 1990).
- Erosion features can be seen scattered over the planet (albeit rarely) that resemble terrestrial gullies and canyons in exact detail.
- Hematite – a mineral that forms in water on Earth – is *very* abundant on the Martian surface.

Martian "Blueberries"

Mars Exploration Rover Mission, JPL, NASA

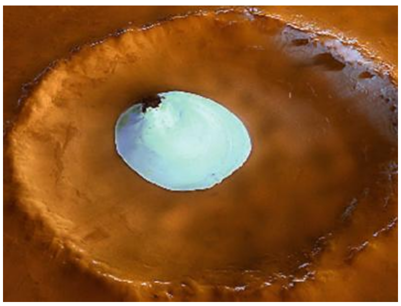


NASA/ JPL/U. Arizona

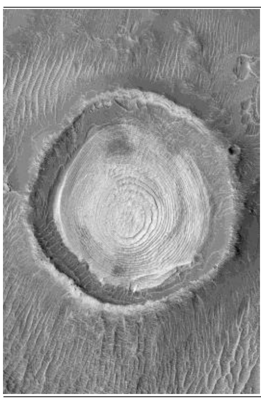


Hematite "Blueberries" in Utah

Water on Mars (continued)



Water ice on the floor of a deep, high-latitude, Martian crater (G. Neukum, Mars Express/ESA).



Water on Mars (continued)

Sedimentation (?) in Schiaparelli Crater, from Mars Global Surveyor (Malin Space Science Systems/ JPL/NASA)

Water on Mars (continued)

Canyons in Gorgonum Chaos, from [Mars Global Surveyor](#) (Malin Space Science Systems/ JPL/NASA)

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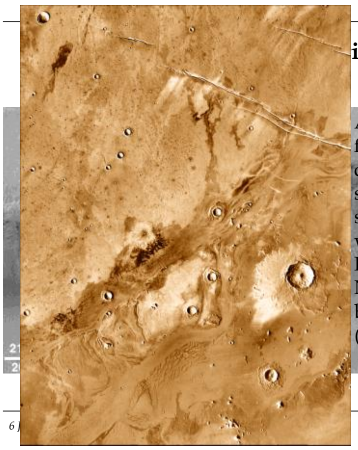


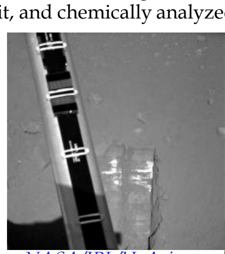
Athabasca Valles, the freshest outflow channel on Mars, with streamlined islands showing source of water, Cerberus Fossae and path from North to South. Taken by THEMIS (NASA/JPL/ASU)

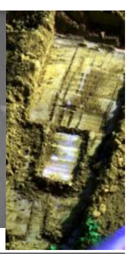
Crater walls in Terra Cimmeria from Mars Global Surveyor (Malin Space Science Systems/JPL/NASA)

Canyon walls in Gorgonum Chaos, from Mars Global Surveyor (Malin Space Science Systems/ JPL/NASA)

And, finally, water *under* the Martian surface

Long suspected, this was finally confirmed in summer 2008 by the NASA *Phoenix* lander, which dug several cm into the dirt, found ice, melted it, and chemically analyzed the results.





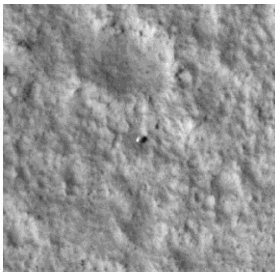
NASA/JPL/U. Arizona

Tests for Martian life by the NASA Viking probes

NASA landed two probes on Mars in 1976, to join in the US Bicentennial celebration: Vikings 1 and 2.

- ❑ Viking 1 went to Chryse Planitia (22° N).
- ❑ Viking 2 went further north, to Utopia Planitia (48° N).

Both had several experiments on board: cameras, organic-matter analysis, life detection, and a ditch digger.



Viking 1, as seen in 2006 from Mars Reconnaissance Observer in orbit.

Viking's organic matter analysis (GCMS)

Viking 1 self portrait (JPL/NASA)

Both Vikings had mass spectrometers and gas chromatographs to infer the presence of carbon bearing molecules thereby

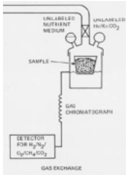
- ❑ Found: concentrations below a few parts per billion for organic molecules with more than two carbon atoms in them.
- ❑ This is 100-1000 times lower than terrestrial deserts. Pretty dead.

Viking's life searches

All were designed to detect organic/water microorganisms.

- ❑ Fairly near surface: within the few-cm range of their ditch diggers
- ❑ Either **heterotrophs**…
  - which would presumably produce metabolic products if they were fed: the probe could detect common metabolytes.
- ❑ … or **autotrophs**.
  - the probes could also detect photosynthetic products.
- ❑ If signs of life were found, a control experiment followed.
  - i.e. obtain another sample, sterilize it, and then feed or water it and look again for metabolytes, etc.

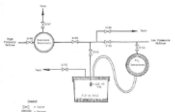
Life search 1: the Gas Exchange Experiment (GEX)



A.k.a. the Chicken Soup experiment.

- ❑ Sample dug up, sealed, pressurized, warmed to T = 10 C.
- ❑ First mode: humidify.
  - Immediately gases were released: N_2, Ar, CO_2, O_2. The O_2 apparently requires a chemical reaction between sample and water. Very encouraging.
- ❑ Second mode, a week later: add nutrients: very generic ones. Monitor for six months thereafter.
  - No sign of metabolizing, earth-like life activity.

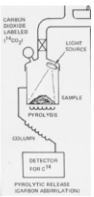
Life search 2: the Labelled Release (LR) experiment



Less Earth bias in this one:

- ❑ Prepare a soil sample as before, and treat with a mix of nutrients that's simpler than before, but in which some of the carbon is the radioactive version, ^{14}C.
- ❑ A metabolizing organism would produce $^{14}CO_2$; this could be detected in very small amounts.
- ❑ Results: immediate release of $^{14}CO_2$ from sample, but it didn't produce proportionally larger amounts of $^{14}CO_2$ when larger amounts of nutrients were added.
- ❑ Thus a chemical, not biological, reaction was suspected.

Life search 3: the Pyrolitic Release (PR) experiment

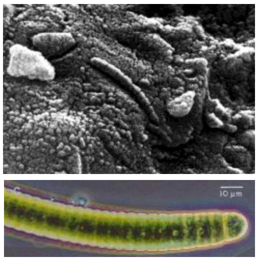


Prepare a sample and supply light and Martian atmosphere, but label some of the gases radioactively: $^{14}CO_2$ and ^{14}CO.

- ❑ Incubate for a few months as before, and then remove the gases and burn (pyrolize) the sample.
  - If any is produced in the burning, if would have to have been taken out of the gases, autotrophically (photosynthesis-like).
- ❑ And so it was: $^{14}CO_2$ was seen in the pyrolytic products.
- ❑ So they tried again with a sterilized sample: activity reduced but not eliminated. Most likely a non-biological chemical reaction again.

1st Mid-lecture Break

- Recitation tomorrow 12:30 in B&L 315.
- Homework #3 due Thursday by midnight.



Upper: putative Martian fossil bacteria from ALH84001 (McKay et al. 1996). Lower: a chain of live cyanobacteria (Alejandro Lopez-Cortes & Mark Schneegurt, Cyanosite). Too bad the lower is 100 times the size of the upper.

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Martian meteorites

Of course, one could perform much fancier experiments on Martian rocks and soils either by transporting bigger labs to Mars, or by transporting Martian samples here. Guess what's cheaper…

- The selection and return of samples is of course part of NASA's former "on to Mars" enterprise.
- But some samples have been delivered to us already, free of charge.

Rahe Crater (center); Mars Global Surveyor (JPL/NASA).

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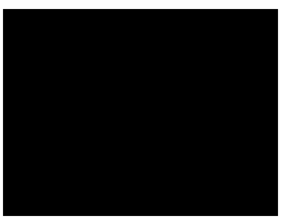
Ejection of rocks by collision between small Solar-system bodies

If small Solar-system bodies collide with sufficient relative speed and in a nearly grazing orientation, some of the debris may escape the pull of the larger body.



- Interacting with the gravity of other Solar-system bodies, the rocks get knocked from orbit to orbit til at last they are either ejected or swept up by planets.
- This results in debris from such bodies as Mars and the Moon reaching Earth.

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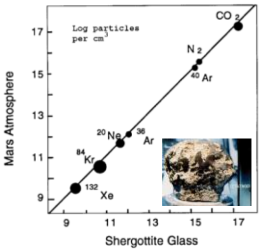
Martian meteorites (continued)

48 meteorites have been recovered, mostly from various deserts, that share the distinctive mineral content of parts of the Martian surface, and have trapped-rare-gas abundances different from Earth, but the same as the atmosphere of Mars.

- ❑ Thought to have been ejected from Mars in extremely oblique, grazing impacts, such as the one that created Rahe Crater.



Composition of trapped gases in EETA79001, compared to that of the Martian atmosphere (Pepin 1985).

Martian meteorites (continued)

We can measure several ages associated with these meteorites, including:

- ❑ formation age, as usual;
- ❑ time spent in space after ejection from Mars, from Solar-wind exposure of surface;
- ❑ time spent on Earth.

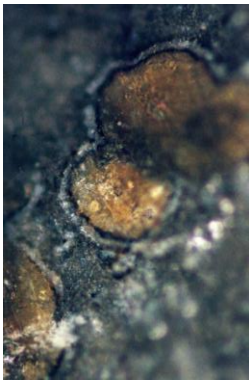
All but one of them formed less than 1.4 Gyr ago, by which time there was no liquid water on Mars's surface.

Los Angeles 002, a Martian meteorite found in the Mojave Desert around 1980, and at 175 Myr old the youngest found so far. (JPL/NASA)

Life in ALH84001?

The One is ALH84001:

- ❑ Solidified 4-4.5 Gyr ago.
- ❑ Ejected from Mars about 15 Myr ago…
- ❑ …probably from Eos Chasma (Hamilton 2005).
- ❑ Came to Earth about 15,000 years ago
- ❑ Found in December 1984 in icefields near Allan Hills, Antarctica.
- ❑ Identified as Martian in 1993



Life in ALH84001? (cont'd)

ALH84001 has been cracked, perhaps by meteoritic impact, a few times since 3.6-3.9 Gyr ago, during the time in which there could have been a good deal of liquid water on the Martian surface. Water gets in cracks…

- And indeed the cracks are full of carbonate inclusions (left). On Earth, carbonate minerals originate in bodies of liquid water.

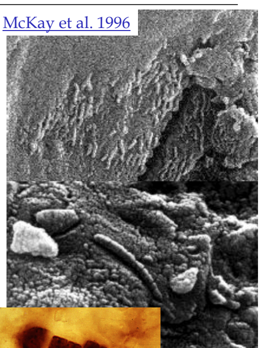
Romanek et al. 1994

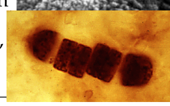
Life in ALH84001? (cont'd)

Electron-microscopic images of thin sections of the "cracked" parts reveal mineral deposits in shapes that resemble bacteria.

- Small, though: 30×130 nm and smaller. (Recall that a nucleobase pair is about 2 nm long!)
- Similar structures in rocks on Earth have often been considered to be fossil cyanobacteria , though these are all 10,000-nm size.
- Though the ALH84001 "bacteria" has no evidence for cell walls.

McKay et al. 1996





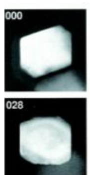
Schopf 1992

Life in ALH84001? (cont'd)

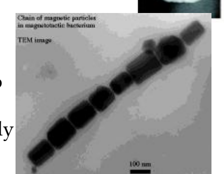
Along with the "fossil bacteria" and carbonate inclusions are compounds that can be associated with microbial systems:

- magnetite crystals, like those made by magnetotactic bacteria.
- PAH molecules (i.e. organics).

Unfortunately all of these features also have ready explanation by non-biotic processes, so ALH84001 is not generally considered to present compelling evidence for primitive life on Mars. However it has not been disproven.



Magnetite crystals from ALH84001 (35 nm in width). (Thomas-Keprta *et al.* 2000)



Magnetite crystals from Earth. (U. Western Australia)

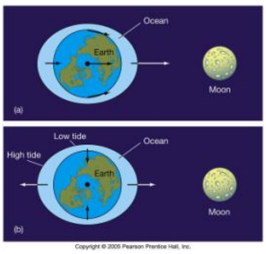
2nd Mid Lecture Break

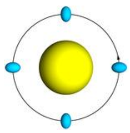
We'll continue our journey through the solar system after this short break…

- Reading for tomorrow & Wednesday pp. 84-100

Tidal Heating: Take 2

- Orbiting bodies seek a point where they experience no tidal forces.
- Tidal friction can slow rotation and move orbit out.





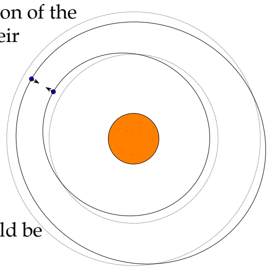
Tidal heating with synchronous rotation; if this were the whole story no tidal heating would occur U. Washington

Orbital resonances and tidal heating

When Jupiter and Saturn were formed, their moons were formed from the leftovers, in orbits smaller than they have now, rotating rapidly.

- Energy losses from tidal heating soon slowed their rotation; all are now tidally locked, rotating at the same rate they revolved. (Lecture notes, 11 February 2010.)
- And by the same token, they drifted away from their planets as their orbital spin increased.
- As they drifted outwards, they captured each other in orbital resonances: orbits with integer ratios of orbital periods.
  - For example, Io orbits Jupiter precisely twice for every orbit Europa makes.

Orbital resonances and tidal heating (continued)



- In resonant orbits, the attraction of the moons for each other keep their orbits slightly **elliptical** rather than circular.
  - …because their point of closest approach always occurs at the same point in the orbit. If this took place in random locations the long-term shapes would be close to circular.
- So the tides from the planet vary around the orbit, a never ending cycle of stretching/relaxing: tidal heating, again.

Orbital resonances and tidal heating (continued)

- The **low order resonances**, with periods close to the ratio of small **integers** like 2-1 or 3-2, are the most stable against getting perturbed further. Once the moons reach such a configuration they can stay in it essentially forever.
- Jupiter and Saturn are very massive, so the tidal forces are large for the nearby moons.
- Tidal forces drop off more rapidly with increasing distance than the gravitational force does, so tidal forces are much smaller for the more distant moons.
- Thus tidal heating should be greatest for inner moons in low-order orbital resonances. Are any warm enough for water to be liquid?

The large moons of Jupiter

All four, posing with the Moon (Galileo/JPL/NASA)

	Io	Europa	Ganymede	Callisto	
Orbital radius (10^{10} cm)	4.22	6.71	10.7	18.8	
Orbital eccentricity	0.004	0.010	0.002	0.007	
Orbital period in days	1.77	3.55	7.15	16.69	**Strong low-order orbital resonances**
Orbital period in Io orbits	1	2.01	4.04	9.43	
Mass (10^{26} gm)	0.893	0.480	1.48	1.08	
Albedo	0.62	0.68	0.44	0.19	**Icy surfaces**
Average density (gm cm^{-3})	3.53	3.01	1.94	1.83	**Rocky interiors**

The large moons of Saturn

(Cassini/JPL/NASA)

Strong low-order orbital resonances

Icy surfaces

Practically circular orbit (!?)

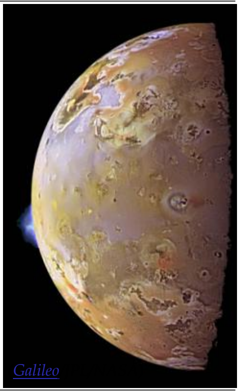
Orbital…	Mimas	Enceladus	Tethys	Dione	Rhea	Titan	Hyperion	Iapetus
radius (10^{10} cm)	1.86	2.38	2.95	3.77	5.27	12.2	14.8	35.6
eccentricity	0.020	0.005	0.000	0.002	0.001	0.029	0.104	0.028
period in days	0.942	1.37	1.89	2.74	4.52	15.9	21.3	79.3
period in half-Mimas orbits	2	2.91	4.01	5.81	9.59	33.8	45.2	168
Mass (10^{23} gm)	0.375	1.08	6.27	11	23.1	1345.5	0.2	15.9
Albedo	0.5	1.0	0.9	0.7	0.7	0.22	0.3	0.05/0.5
Density (gm cm^{-3})	1.14	1.61	1.0	1.5	1.24	1.88	0.5	1.02

Tidal heating (continued)

Considering this, and the fact that Jupiter is about three times as massive as Saturn, Io should suffer the largest tidal heating of them all.

- ❑ Sure enough, Io suffers enough tidal heating to melt the rock in its interior and to make it extremely volcanic.

Next on the tidal heating scale: Europa and Ganymede in the Jupiter system, Mimas, Enceladus and Dione in the Saturn system.

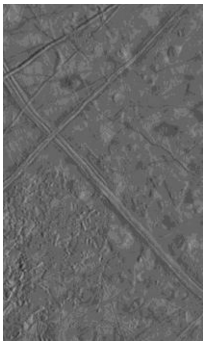


Galileo

Large bodies of liquid water on Europa

Europa is 100% covered in water ice.

- ❑ It has far fewer craters per acre than Ganymede and Callisto.
- ❑ Since it surely gets hit as often per acre as the other two, Europa must have a way to fill craters in.
- ❑ A clue: Europa's surface looks like terrestrial, oceanic pack ice, complete with places that look like the ice sheet repeatedly cracked and refilled with liquid water.

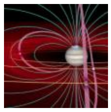


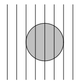
Closeup of Europa's surface Galileo/JPL/NASA)

Large bodies of liquid water on Europa (continued)

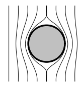
So can we sense an ocean under the ice? **Yes**.

- Jupiter has a strong bar-magnet-like magnetic field.
- Rocks and ice are electrical insulators, and they do not affect externally-applied magnetic fields. Most moons (like ours) behave this way in their planet's field.
- But close flybys have shown Europa to **repel** Jupiter's magnetic field, in the way an electrically-conducting surface would do.
- A salt-water ocean under the ice, covering most of the surface, would repel the field as observed.





Insulator

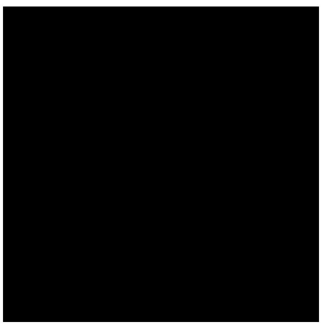


Conducting shell

Large bodies of liquid water on Enceladus

Enceladus has the highest albedo in the Solar system, very close to 1. So it must be covered in clean (water) ice, with a smooth surface.

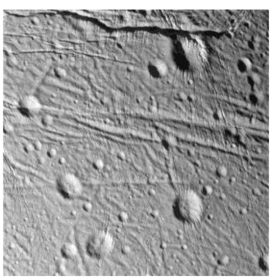
- Indeed, the surface is smooth: not many impact craters, lots of thin cracks and fissures. At close range it displays a Europa-like or pack ice-like appearance.



Large bodies of liquid water on Enceladus (continued)

- So the surface also gets recoated frequently. This requires heat sufficient melt water ice and a means to distribute it over the surface.
- Enceladus has also been identified as the major source of the ice particles in one of Saturn's outer rings: the one called the E ring.

Precisely how this happens was obscure until…

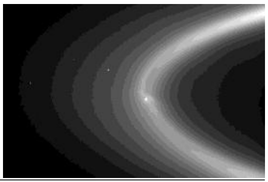


Cracked craters on Enceladus (*Cassini*/JPL/NASA).

Large bodies of liquid water on Enceladus (continued)

…the flybys by *Cassini* in 2005, in which water geysers were first seen.

- Thus Enceladus, too, has bodies of liquid water underneath the ice in at least some places, and has had them for quite some time.
- Only problem with the tidal-heating explanation now is that Mimas displays none of these features.



(*Cassini*/JPL/NASA)

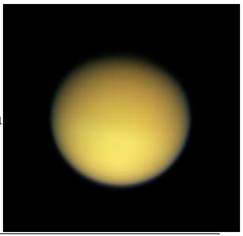
Saturn's Largest Moon: Titan

View of the surface of Titan, from the *Huygens* landing craft (ESA/ISA/NASA). The bigger rocks in the foreground are about six inches across. The haze is real and resembles ordinary smog.

Nonpolar-solvent-based habitats: Titan

Titan is the second largest satellite in the Solar system (slightly smaller than Ganymede), and the first one discovered after the Galilean satellites (by Huygens in 1665). It is unusual in many respects:

- It is the only moon in the solar system with a dense atmosphere: pressure about 1.6 Earth atmospheres at the surface, 95% nitrogen (most of the rest is ammonia), and so heavily laden with photochemical smog that the surface can't be seen at visible wavelengths. So *Cassini* packed infrared cameras and radars.

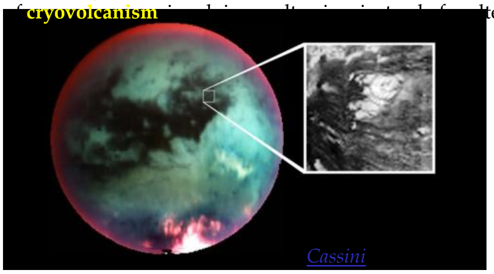


Nonpolar-solvent-based habitats: Titan (continued)

[Haze](#) in Titan's upper atmosphere (*Cassini*/ JPL/ NASA)

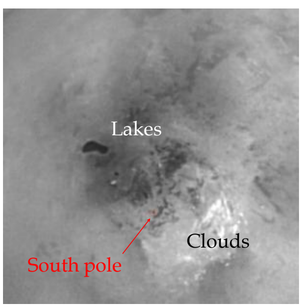
Nonpolar-solvent-based habitats: Titan (continued)

- There are few impact craters apparent (in infrared and radar images) on the surface of Titan, and some evidence



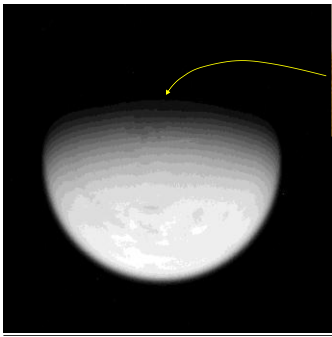
Nonpolar-solvent-based habitats: Titan (continued)

- Suspicions that Titan has liquid oceans and lakes were whetted by the observations (by *Cassini* and its probe/lander *Huygens*) of formations that look a lot like lakes, dry ocean beds and shorelines.
- All this surface erosion probably means that Titan has weather, including rain.



Hydrocarbon lake (Cassini/JPL/NASA)

Nonpolar-solvent-based habitats: Titan (continued)



Titan's North-Polar Great Lake (Cassini/ JPL/NASA), left, and its northern lobe on the same scale as Lake Superior, above.

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Nonpolar-solvent-based habitats: Titan (continued)

The surface temperature on Titan turns out to be about 94 K on the average; the atmosphere makes this more uniform than it would be on airless worlds. Thus

- water and most other polar solvents are frozen,
- it is too warm for liquid nitrogen to exist on the surface,
- but it would be just fine for methane (CH_4) and ethane (C_2H_6; see lecture notes for 2 March 2010, page 18). A few simple chemical considerations suggest that Titan's lakes are full of liquid ethane.

What would life be like at low temperature, in a nitrogen atmosphere with methane-ethane clouds and rain?

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Summary: the AST 106 habitability ratings

In order of likelihood of finding primitive life elsewhere in the Solar system:

- **Europa,** by far. A two-satellite, NASA/ESA mission called the Europa Jupiter System Mission (EJSM) is being planned for a 2020 launch.
- **Mars**. Many missions are already there and we would think about sending real geologists and biologists to help look, if we could keep them alive in space that long.
- **Titan**. Like Europa, NASA and ESA are planning two satellites as the Titan Saturn System Mission (TSSM). You may **not** suggest a natural-gas pipeline to Earth…
- **Enceladus**. Maybe TSSM can go there too.

Honorable mention: Ganymede.

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