EXOBIOLOGY
OF
TITAN

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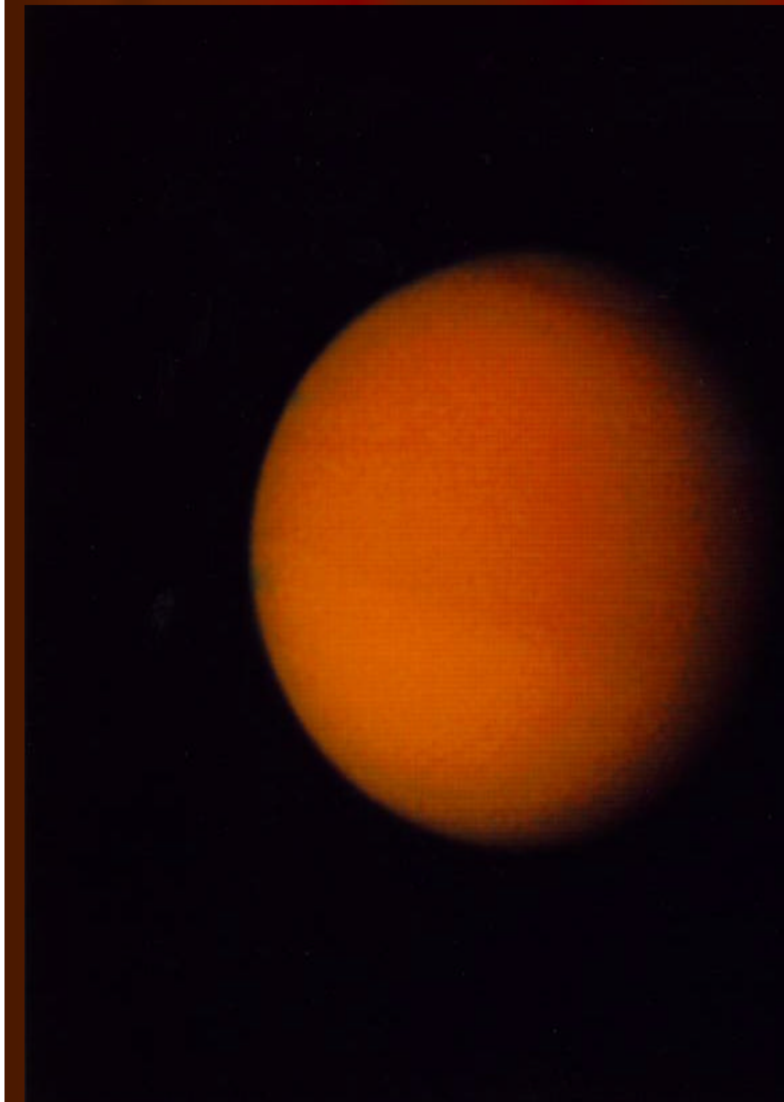
Titan – mysterious moon



- Titan is the largest satellite of Saturn, and unique in the solar system in that it is the only satellite with a substantial atmosphere.

Some satellite's properties

- radius - 2575 km
- mass – 1.35×10^{26} g
- density - 1880 kg/m^3 – suggesting a roughly 50:50 mix of rock and ice.
- surface gravity – 135 cm/s^2
- surface temperature ~95 K
- surface pressure – 1496 mbar

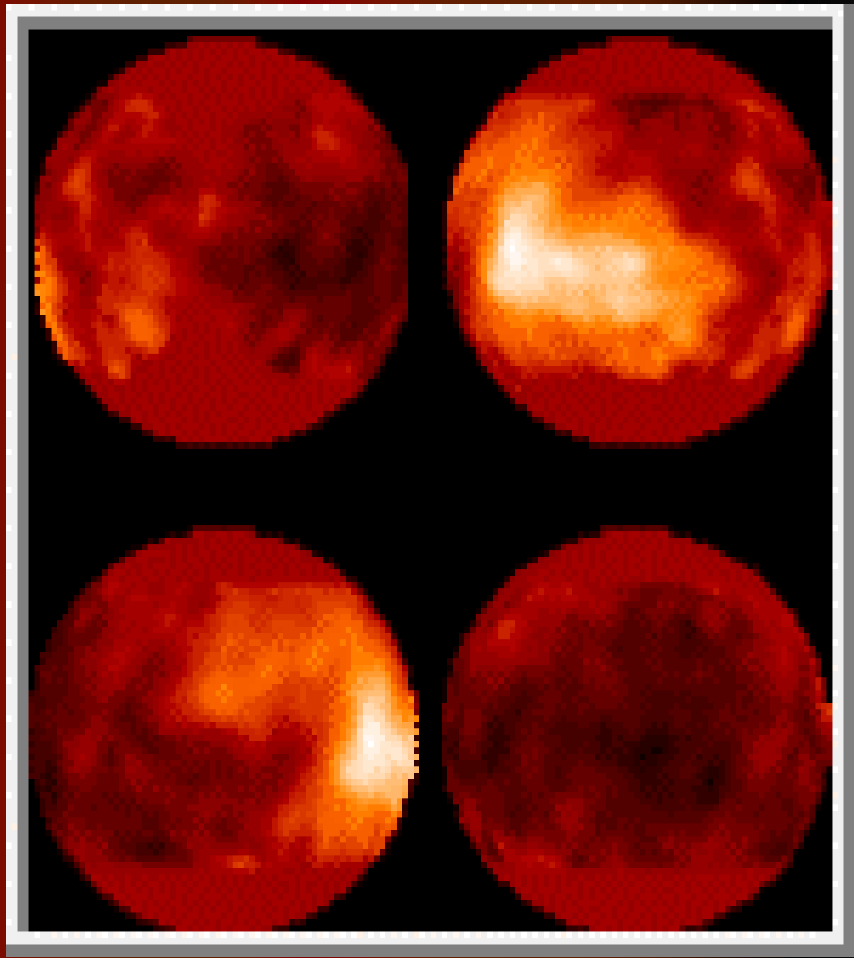
- distance fron the Sun – 9.546 AU
- solar flax 1.1% of Earth

ATMOSPHERE

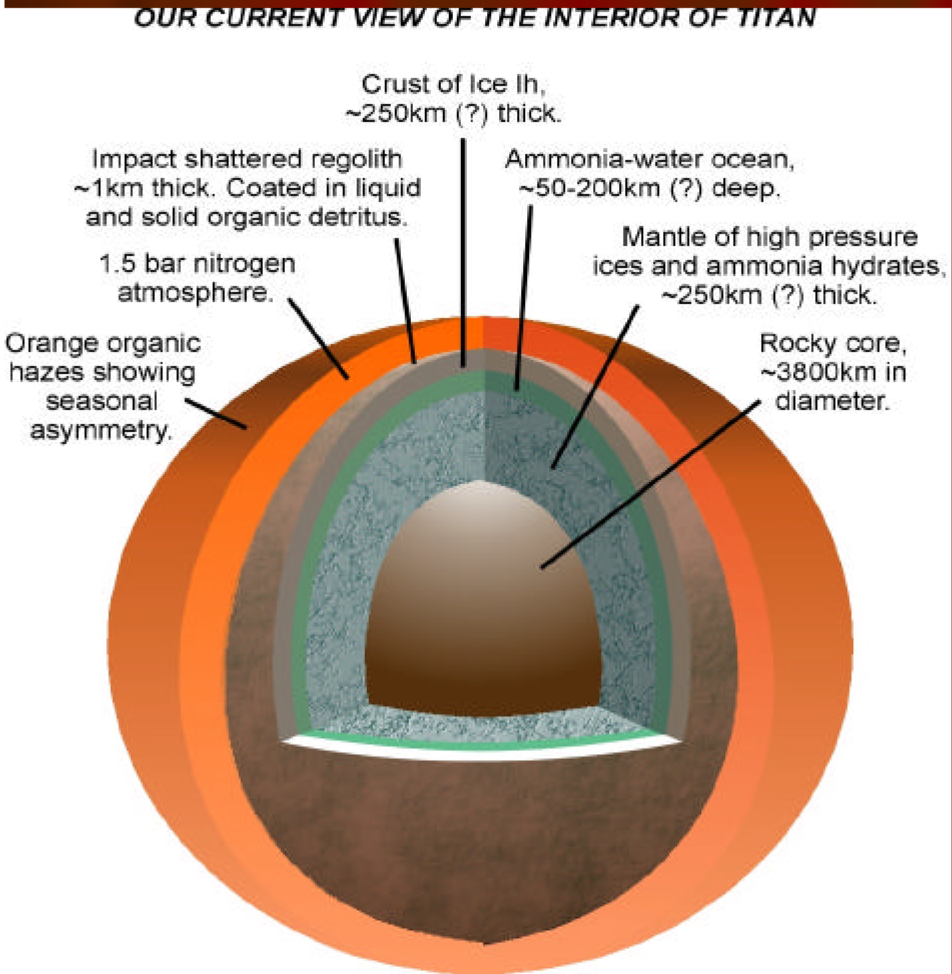
- Pressure 1.5 Bar
- Main components:
  - N_2 (90%)
  - CH_4 (~9%)
- Very complex atmospheric photochemistry (nitriles, hydrocarbons and more complicated organics)
- Haze layers (*The haze production rate is ~10-14 g/cm²s. A complex organic mixture of simple alkanes, aromatic compounds, heteropolymers and amino acids precursors forms tholins - the solid organic product with very poorly known molecular composition*)
- Complex meteorology

SURFACE

- Titan's surface should be mostly of light materials – ice and organics.
- It was expected to be covered, at least partially, by liquid hydrocarbons in form of lakes or even a global ocean.
- The solid organic products with very poorly known molecular composition could also cover the surface of Titan (up to 100 m thick).



INTERNAL STRUCTURE



- The most recent models of the Titan's interior lead to the conclusion that a substantial liquid layer exists today under relatively thin ice cover inside Titan (Lunine and Stevenson, 1987; Grasset and Sotin, 1996; Grasset et al., 2000);

- Lunin (1993) has shown that the underground ocean is the only structure that is consistent with all of the known constraints (chemical, tidal, ground-base radar and near-infrared observation);

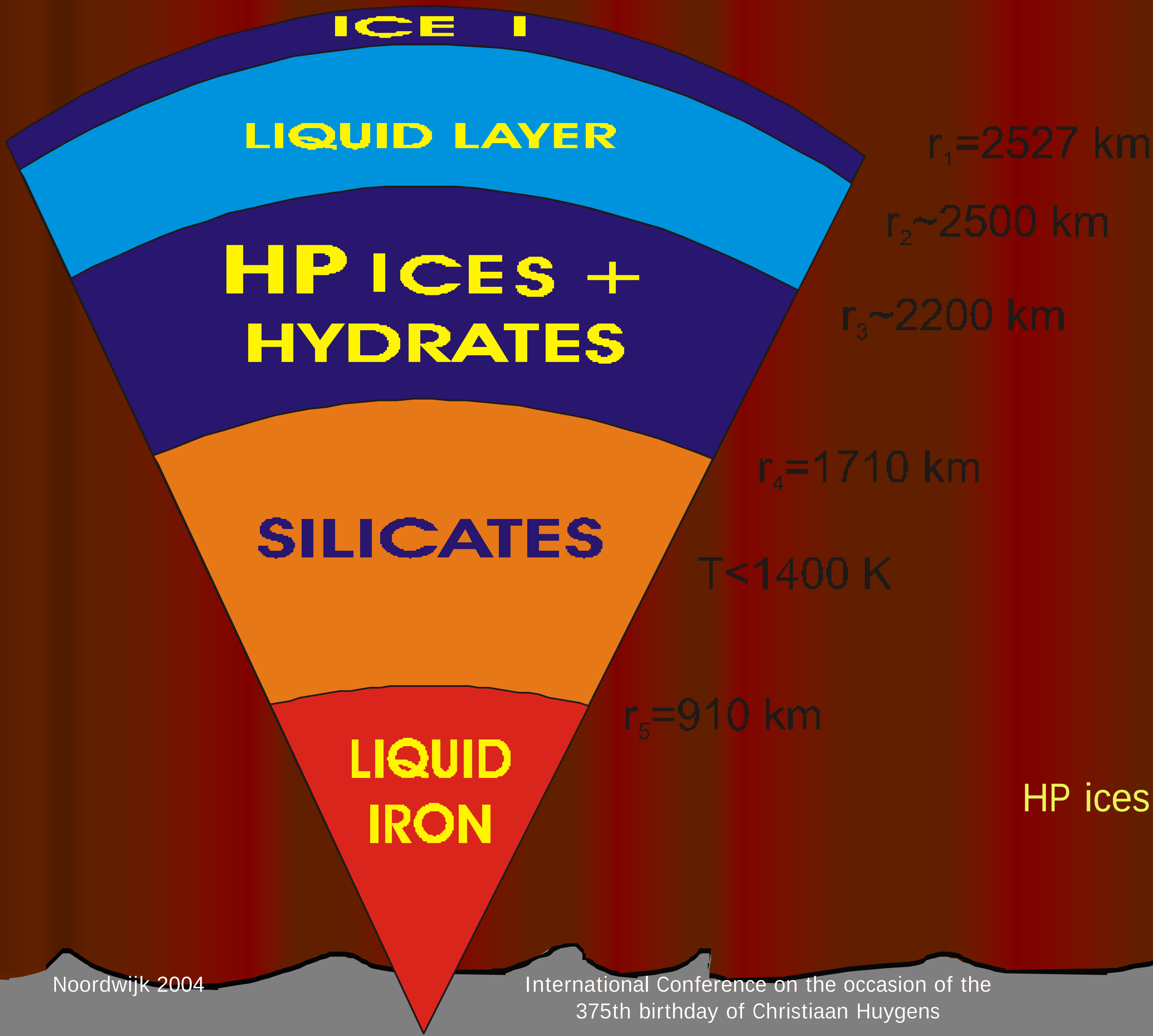
- Lorenz (2001) has found that internal oceans are mandated for the large icy satellites.

- Thermal evolution models also predict the existence of thick (~300 km) liquid layer with relatively thin (~80 km) ice cover (Grasset et al., 2000).

- Spohn and Schubert (2002) have shown that even radiogenic heating in a chondritic core may suffice to keep a water ocean inside large icy satellites.

INTERNAL STRUCTURE

Grasset *et al.*, 2000



ice I	~27 km
liquid layer	~300 km
HP ices + hydrates	~490 km
silicates	~800 km
liquid core	~910 km

THE CHEMICAL COMPOSITION

- The present composition of the putative liquid layers of the ice satellites is probably very complex.

  Mass balance calculations that model extraction of elements into the aqueous phase from chondritic material show that Titan's extensive subsurface ocean likely contains dissolved salts from endogenic materials resembling to carbonaceous chondrite rocks incorporated into the satellite during its formation and released at time of planetary differentiation.

- The low and high-temperature alteration of primitive accreted material leads to form of a complex water solution of such cations as **K, Na, Mg, Ca, Mn, Fe** and anions as $\mathbf{SO_4^{2-}}$, $\mathbf{NO_3^-}$, $\mathbf{Cl^-}$, $\mathbf{Br^-}$, $\mathbf{CO_3^{2-}}$, $\mathbf{HCO_3^-}$ and others (Fanale *et al.*, 2001).

THE BASIC REACTION FOR METABOLISM

- So, the initial components, such as NO_3^-, SO_4^{2-}, CO_3^{2-} for the origin of lithoautotrophic metabolic processes could exist in the Titan's putative ocean from the earlier stages of the satellite's evolution and provide biologically useful electron donor-acceptor pairs. Electron acceptors such as NO_3^-, SO_4^{2-}, Fe^{3+}, Mn^{4+}, or CO_2 have to be coupled with the electron donors constructng a Basic Reaction (**BR**). Electron donors that may be important in such process include H_2, CO, CH_4, Fe(II), Mn(II), pyrite, sulfur compounds and organic material (Ottley *et al.*, 1997).
- There are some candidates on the role of the BR.
- The reaction of nitrate reduction $NO_3^- \Rightarrow N_2$ is a more thermodynamically favorable in the row of different inorganic substrates (Gaidos *et al.*, 1999). The all gaseous nitrogen in the contemporary Titan's atmosphere can be the product of this reaction (Simakov, 2000).

Other possible BRs are:

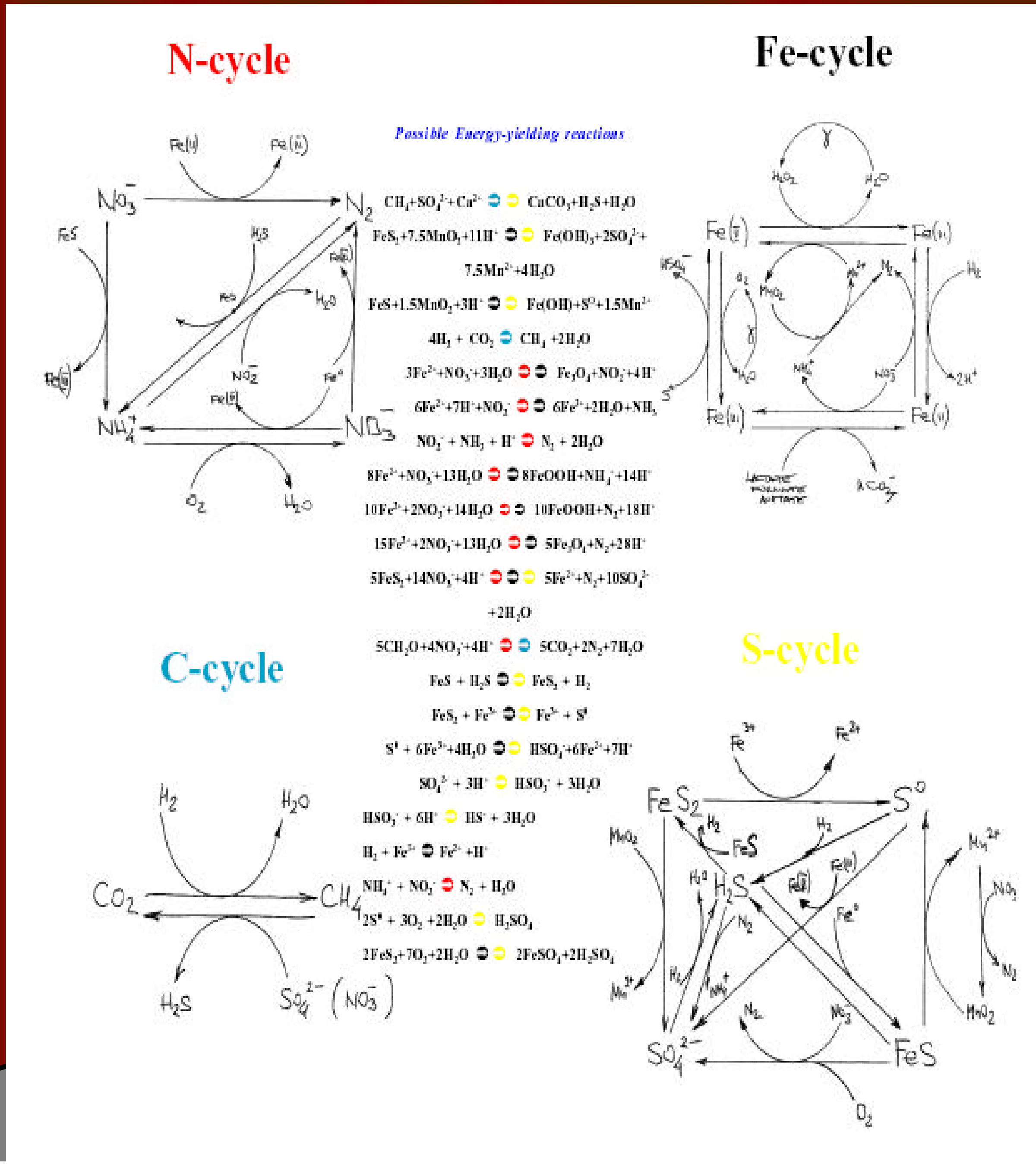
- $Fe(III) \Rightarrow Fe(II)$
- $Fe(II) \Rightarrow Fe(III)$
- $SO_4^{2-} \Rightarrow S_0$
- $CO_2 \Rightarrow CH_4$
- $CH_4 \Rightarrow CO_2$

POSSIBLE BIOGEOCHEMICAL CYCLES

- **Nitrogen cycling (N-cycle)**
- **Sulfur cycling (S-cycle)**
- **Iron cycling (Fe-cycle)**
- **Methane cycling (C-cycle)**

which are connected with each other

possible biogeochemical cycles



bacteria using rocket fuel

A very interesting bacteria have been discovered recently which use ammonium as an inorganic electron donor for denitrification :

$$NH_4^+ + NO_3^- ?\ \ N_2 + 2H_2O$$

This reaction has a very favorable energetic (-357 kJ/mol) and presents a good source of free energy for the metabolism.

Hydroxylamine (NH_2OH) and hydrazine (N_2H_4) are formed as intermediates.

This is the first case when hydrazine, a rocket fuel, is a free intermediate in any biological system. Both these components could be widespread in the Titan's environments

It is possible to hypothesize a start reaction as:

$$N_2H_4 ?\ \ N_2$$

which can evolve through:

$$NH_2OH ?\ \ N_2H_4 ?\ \ N_2$$

to

$$NO_3^- ?\ \ NH_2OH ?\ \ N_2H_4 ?\ \ N_2$$

at the rout of microbial evolution.

(Jetten *et al.*, 1999)

HISTORY

- time after accretion

~10^8 years
there were both warm atmosphere and ocean on the surface, abundant energy sources;

- present time

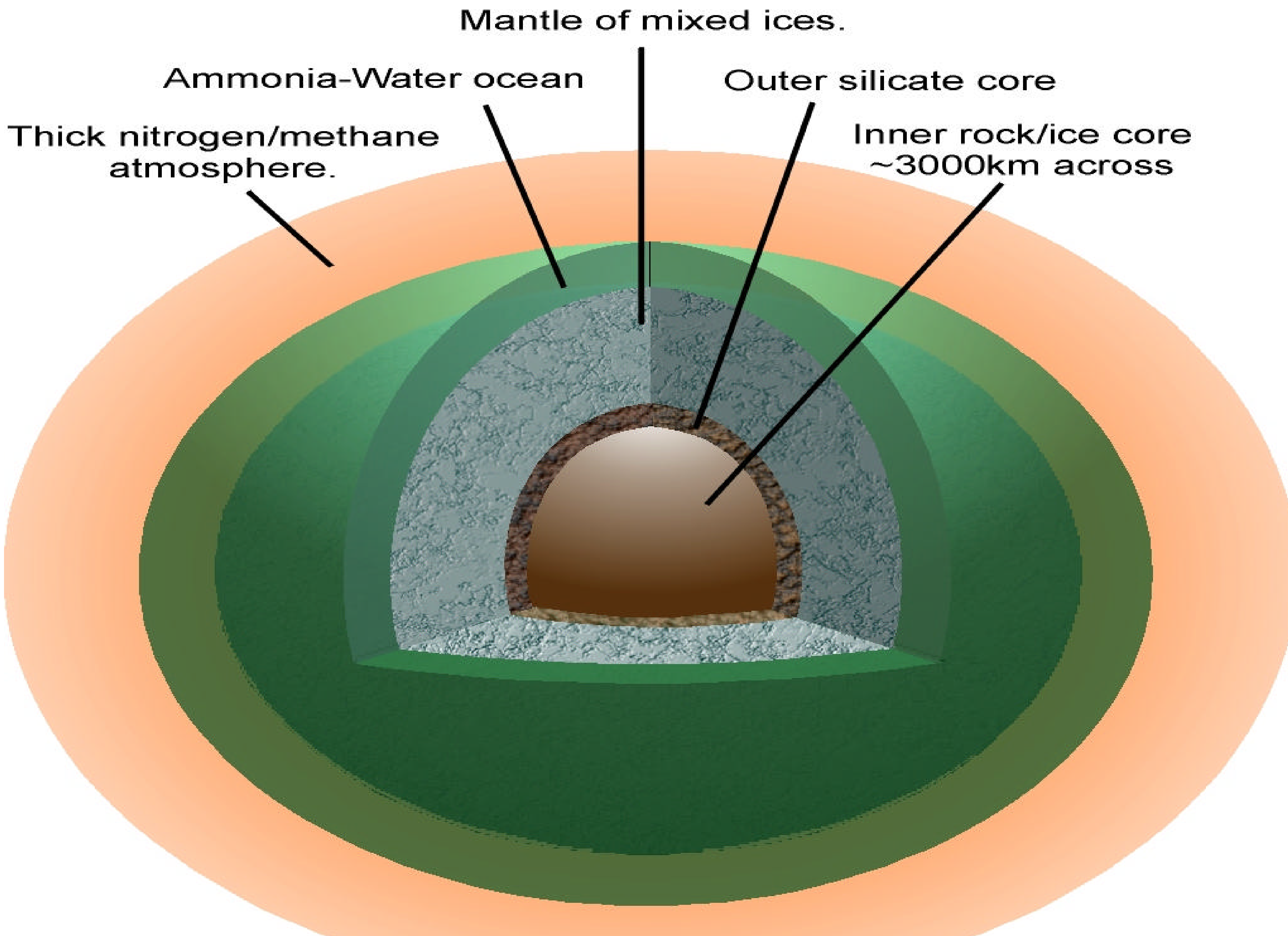
- future

Sun as a Red Giant star (Lorenz and Lunine, 1997)

POSTACCRETIONAL PERIOD

- Titan is large enough that the energy of accretion should have softened and melted the outer layers of ice, allowing the rock component to settle into the interior forming a rocky core
- if life had originated then it could continue to the present day (Fortes, 2000)

On Earth microbial life exists in ALL locations where microbes can survive

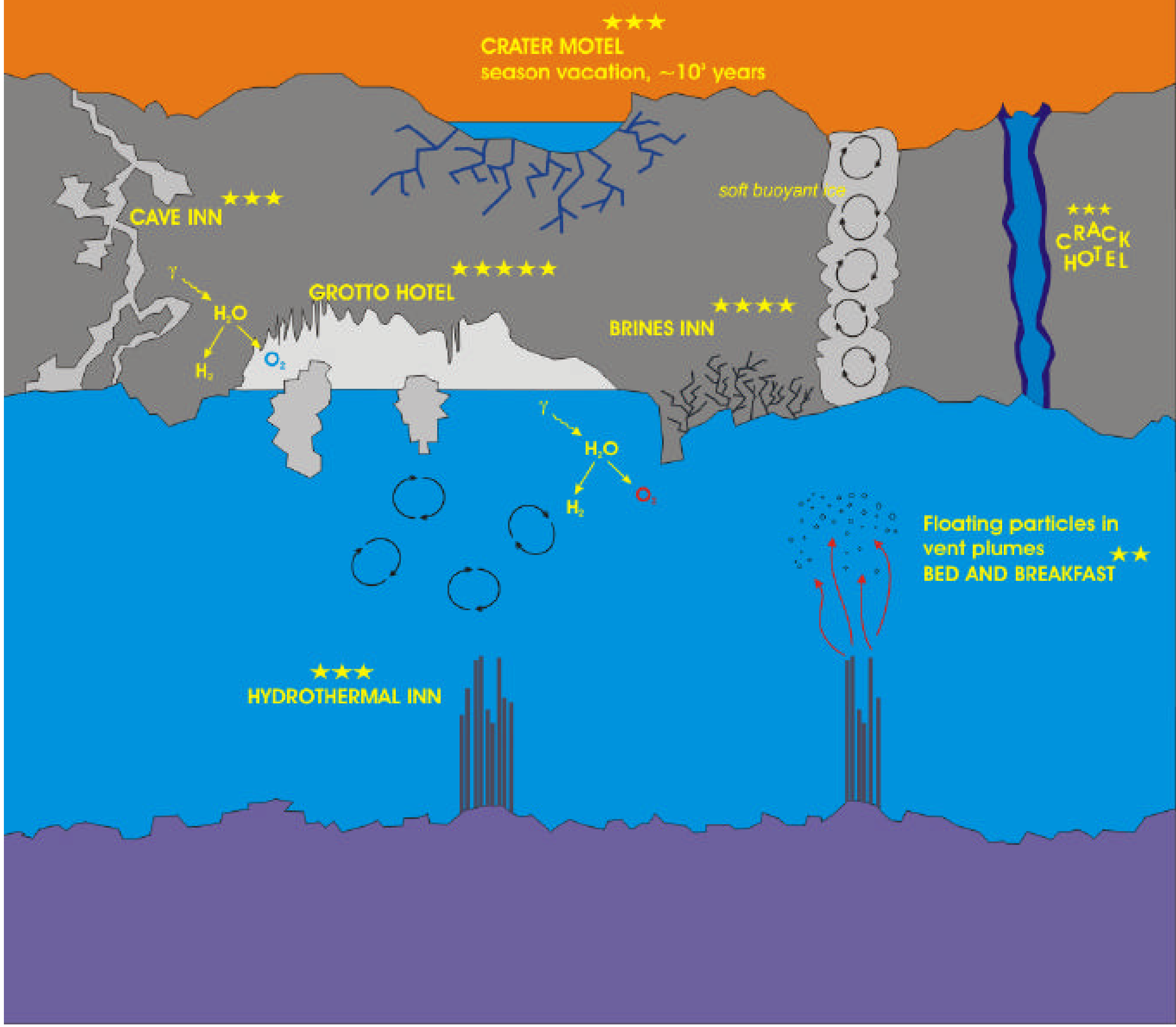


Mantle of mixed ices.
Ammonia-Water ocean
Outer silicate core
Thick nitrogen/methane atmosphere.
Inner rock/ice core ~3000km across

energy sources

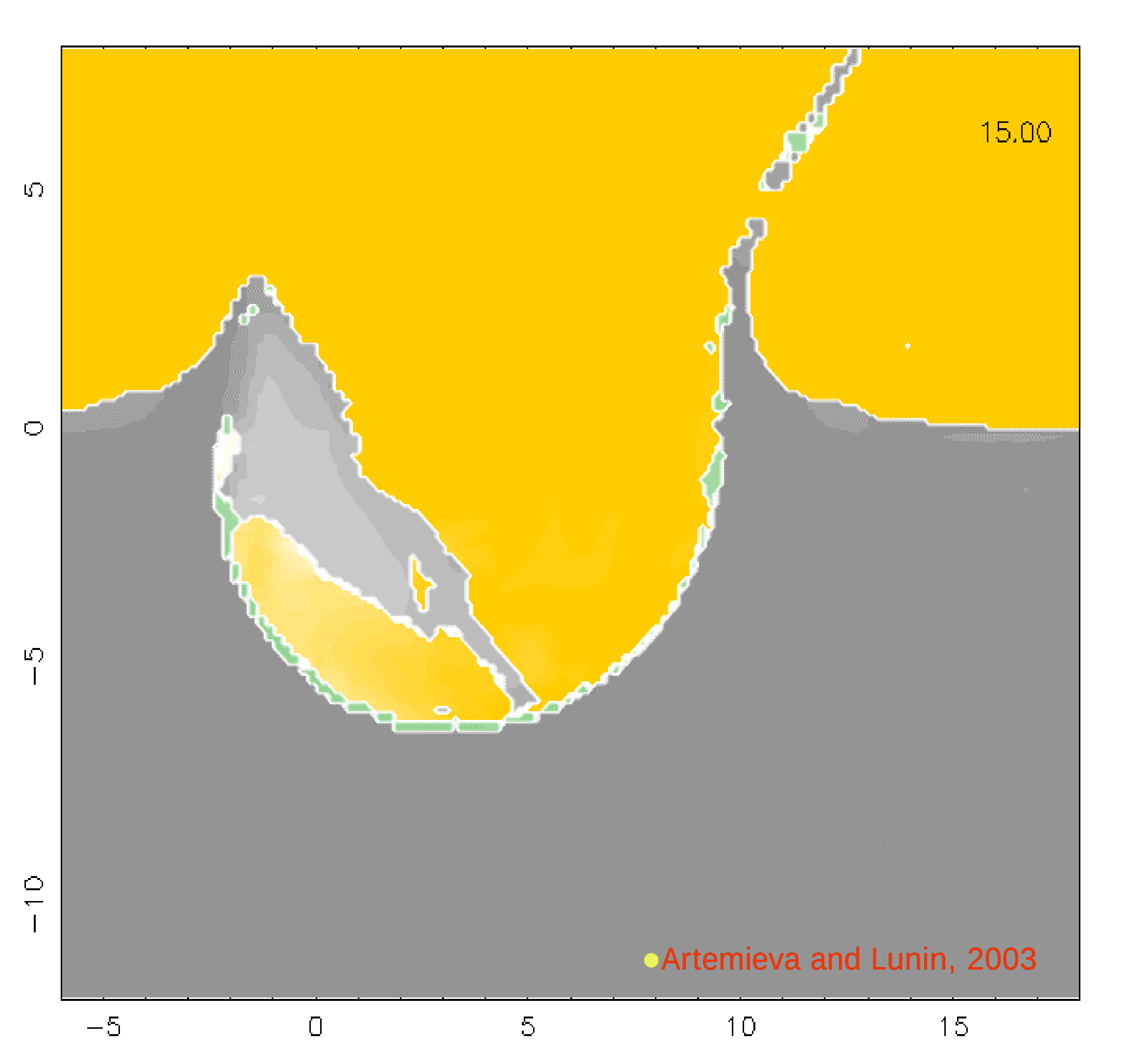
- UV-LIGHT FROM SUN
- GALACTIC COSMIC RAYS
- ELECTRONS FROM SATURN'S MAGNETOSPHERE
- ELECTRIC DISCHARGES IN THE ATMOSPHERE
- METEORITIC STRIKES
- REDIOGENIC HEAT

POSSIBLE HABITATS



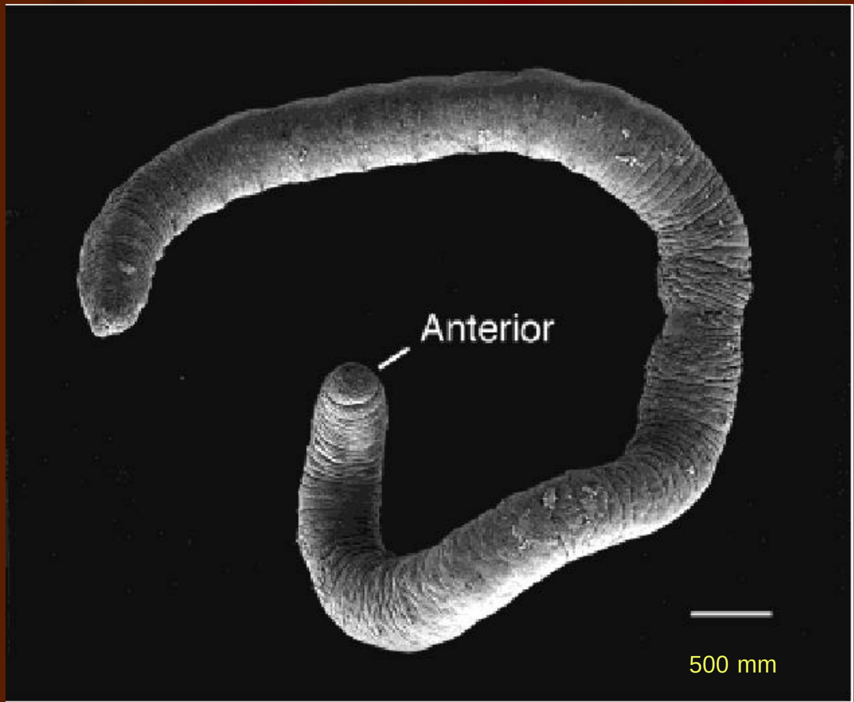
- an upper water layer;
- a water surface and icy walls in the groote features;
- water pockets and liquid veins inside icy layer;
- the places of cryogenic volcanism;
- caves into icy layer;
- the brine-filled cracks;
- liquid water pools on the surface originated from meteoritic strikes;
- the sites of the hydrothermal activity

METEORITIC STRIKES



- 10% of the Titan's surface might be with impact crates large enough to create transient but prolonged liquid water layers (Thompson and Sagan, 1992)
- The large fraction of Titan's organic deposits might have been exposed to liquid water to allow for a number of oxygen-containing compounds (including amino acids, purines and pyrimidines)
- ~70% of organic inventory has been exposed to impact melted water for mean period of around 10^3 years
- There are different mechanisms for delivering of these components into internal ocean

POSSIBLE ICE CREATURE



- Ice worms *Mesenchytraeus solifugus* which occupy an unique niche as they completes its life cycle in ice
- Ice worms spend their life in glacial ice, an environment that does not deviate significantly from 0°C. Strikingly active at 0°C, they become lethargic as temperatures rise, and "melt" at room temperature, presumably because of liquefaction of their membranes.
- Among the curious behaviors of ice worms is their ability to penetrate hard glacial ice, possibly by navigating along irregularities caused by differential melting at ice crystal boundaries.
  - Shain *el al.*, 2000

THE CONDITIONS FOR LIFE ON TITAN

- Liquid water which exists within long geological period
- Existence of wide range of inorganic and organic chemical substances both in the atmosphere and in the ocean
- Energy sources:

  radiogenic heat flow from the core;
  heat flow due to tidal dissipation;
  heat flow due to some kind of volcanic activity;
  meteoritic strikes;
  solar energy for rich atmospheric photochemistry;
  lightning (?) in the atmosphere;
  cosmic rays;
  energetic electrons from Saturn's magnetosphere;
  chemical potentials of different red-ox reaction