

Extraterrestrial Life

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- *How did life originate?*
- *Is there life elsewhere in the Universe?*

Scientific study of the (many) issues related to these grand questions: **astrobiology**

How did life originate?

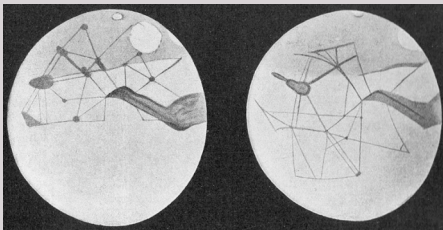
Until surprisingly recently - common theory was that of *spontaneous generation*... life arises from non-living matter whenever conditions are favorable.

Disproved by experiments by Pasteur (1864): life does not arise spontaneously in closed, sterilized containers.

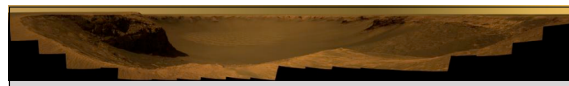
Life arises from pre-existing life - question of its ultimate origin is meaningful.

Is there life elsewhere in the Universe?

Habitability of Mars was discussed in late 19th century:



Martian canals - proven not to exist in 1965 with first flybys of Mars



Opportunity rover image

First *in situ* Mars landers: 1976 (Viking)

First extrasolar planet around a Solar-like star found: 1995

Today 221 planets (mostly massive) known outside the Solar System

Overview

How can we define "life"?

"The quality which people, animals and plants have when they are not dead..." (Collins English dictionary)

*"Dead: A person, animal or plant that is **dead** is no longer living..."*

NASA Exobiology program definition:

"Life is a self-sustaining chemical system capable of undergoing Darwinian evolution"

What is extraterrestrial life?

Life (extant or fossil) beyond the Earth

In the case of Mars / Earth, extraterrestrial life could (in principle) have single point of origin

Discovering life that had an *independent* origin would be most exciting

Extraterrestrial life may or may not resemble life on Earth, certainly need not be intelligent

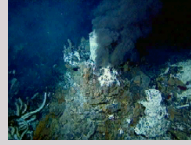
Properties of life on Earth

As sole example, life on Earth is template for understanding

- requires water, energy and source of nutrients
 - working definition of "habitability"
- probably arose very early in Earth's history (3 - 3.8 billion years ago vs Earth age of 4.6 billion yr)
- has evolved via natural selection
- now appears very diverse (plants, microbes, humans) and permeates almost all terrestrial environments

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Undersea vents



Thermal pools (Yellowstone)



Examples of *extremophiles*

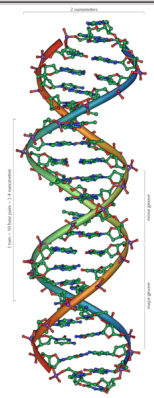
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But... all life on Earth is amazingly *similar*:

- based on same set of chemicals:
 - DNA, RNA, proteins...
- transmits genetic information
- occurs within structures - *cells*

All existing life on Earth had a common ancestor

+ viruses, prions...



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Problem of the origin of life

Simple organic molecules involved in life can be formed from known physical processes

???

Simplest living organism with current life chemistry has ~100 genes

Evolution



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Problem of the origin of life

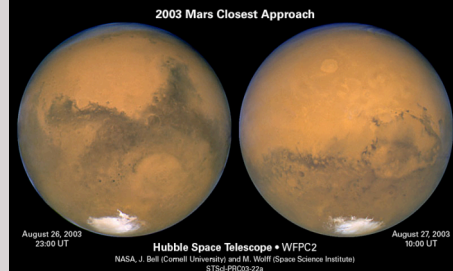
Hypothesis: origin of life must have involved "living" organisms with a simpler biochemistry than any present (identified?) on Earth today

What were they?

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Extraterrestrial life in the Solar System

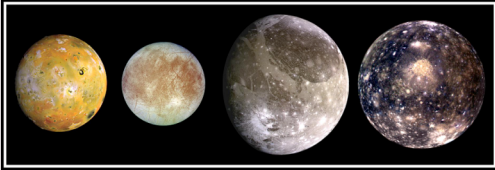
2003 Mars Closest Approach



Mars: liquid water likely to have been present for an undetermined period in Martian history, and possibly is present today

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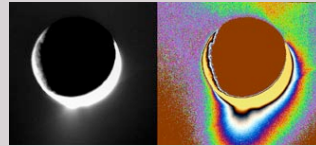
Extraterrestrial life in the Solar System



Jupiter's moon Europa may possess a subsurface ocean

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Extraterrestrial life in the Solar System



Plumes of water ice from Enceladus, possibly indicating liquid subsurface water?

Liquid water is unlikely to exist on any other bodies in the Solar System

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Life on extrasolar planets?

Sun is one of ~100 billion (10^{11}) stars in the Milky Way galaxy



Around 10^{11} galaxies in the Universe - enormous number of stars that might host habitable worlds

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Life on extrasolar planets?

Surveys of nearby stars show 5-10% host detectable planets - mostly massive planets due to observational limitations

Abundance of Earth-like, potentially habitable planets is unknown - probably these are very common too

- How can we detect these planets?
- How to search for life on them?

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Is intelligent extraterrestrial life common?

Fermi paradox:

- Sun is 4.6 billion years old - much *younger* than many other stars in the Milky Way (~10 billion years old)
- After ~few thousand years of modern civilization, we can communicate with other stars, and can conceive of sending a probe to nearby systems
- If intelligent life is common, many civilizations must be millions (billions!) of years more advanced than us, so why aren't they here already?

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