Introduction to Planetary Protection and Biological Contamination

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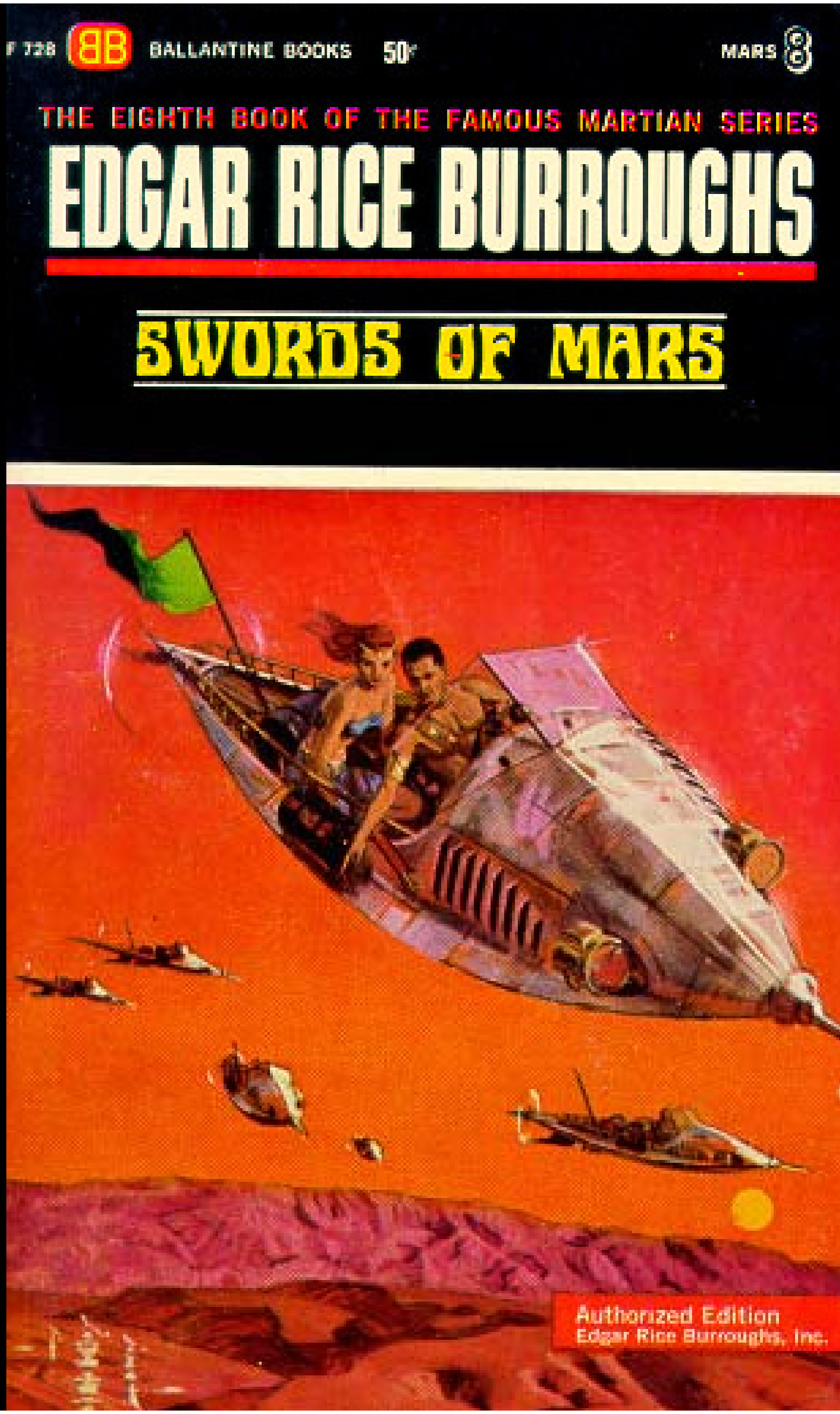
EJSM Short Course on Planetary Protection
29 July 2010



On Earth, life is everywhere:

How do we ensure that we don’t find what we brought with us, when we go to explore somewhere else?

Planetary Protection Policy:
Protect Science, Protect the Earth

- "The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized."
  - *avoid forward contamination: don't "discover" life we brought with us*
- "In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet or other extraterrestrial sources."
  - *avoid backward contamination: don't contaminate the Earth*
- "Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed in accordance with directives implementing this policy."
  - *tailor requirements by target location and mission type: don't require unnecessary measures*

27 June 1958, Volume 127, Number 3313

SCIENCE

Moondust

The study of this covering layer by space vehicles may offer clues to the biochemical origin of life.

Joshua Lederberg and Dean B. Cowie

tions are very small, they are perhaps large enough to initiate the condensation. If this point is granted, it would then be necessary to examine the capture of a second atom of hydrogen or of carbon by the CH molecule. Because of the abundance of hydrogen, the first is more probable but the calculation of the probability of formation of the CH_2 molecule is very difficult. It is possible that some more hydrogen atoms attach themselves to the CH_2 molecule (CH_2 CH_3 CH_4 ?) but before long it is mainly atoms of much larger mass (C, N, O, . . .) which are captured because the large molecule

"…we urgently need to give some thought to the conservative measure needed to protect future scientific objectives on the moon and the planets"

An International Endevour

- The Outer Space Treaty of 1967
  - Proposed to the UN in 1966; Signed in January 1967
  - Ratified by the US Senate on April 25th, 1967
  - Article IX of the Treaty states that:

    "...parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose..."

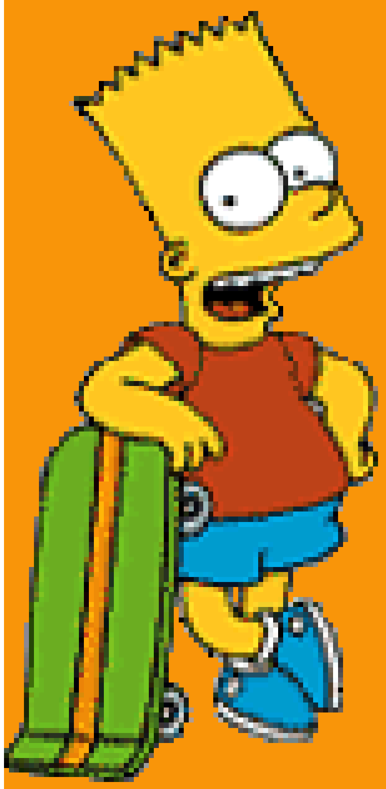
- The Committee on Space Research of the International Council for Science maintains the international consensus policy on planetary protection
  - COSPAR policy represents an international scientific consensus, based on advice from national scientific members, including the US Space Studies Board
  - COSPAR advises the UN (through UN COPUOS and the Office of Outer Space Affairs) on measures to avoid contamination and protect the Earth under the Treaty
  - NASA and ESA policies specify that international robotic missions with agency participation must follow COSPAR policy, providing a consensus basis for requirements
  - COSPAR policy requires an inventory of microbial diversity carried on spacecraft

Planetary Protection Requirements

- Assignment of categories for each specific mission/body will "take into account current scientific knowledge" via recommendations from scientific advisory groups.
- Categorization depends on the nature of the mission and on the target planet
- Examples of specific constraints include:
  - Limitations on spacecraft operating procedures
  - Inventory of spacecraft hardware and materials
  - Documentation of spacecraft trajectories and material archiving
  - Reduction of spacecraft biological contamination
  - Restrictions on the handling of returned samples
- Probabilistic requirements allow derivation of numerical limits on microbial contamination pre-launch

The Basic Rationale for Planetary Protection Precautions

(as written by Bart Simpson, Dec. 17, 2000, “Skinner’s Sense of Snow”)



Science class should not end in tragedy....
Science class should not end in tragedy....
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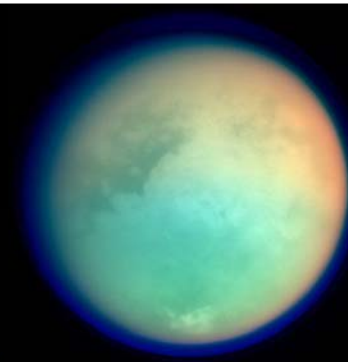
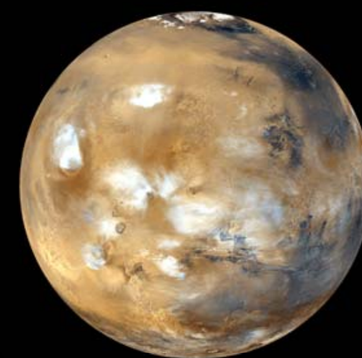
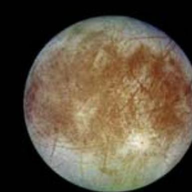
Science class should not end in tragedy....
Science class should not

What can we learn about searching for life, by studying life on Earth?



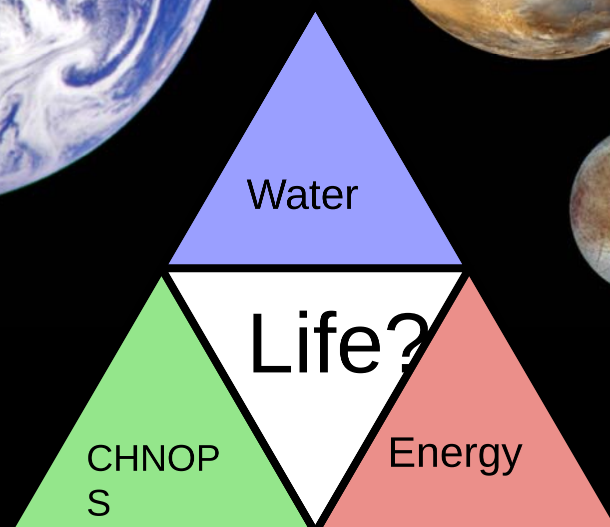




1. Life is tough
   (extremophiles)

2. Life is tenacious
   (long survival times)

3. Life is metabolically diverse
   (eats anything, breaths anything)

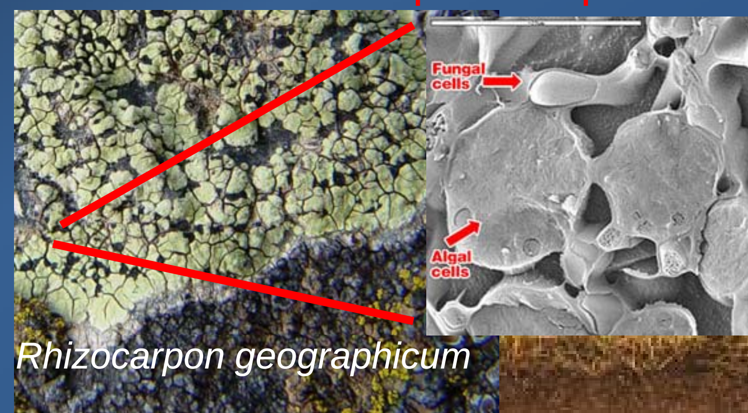


4. When conditions get tough, life moves inside the rocks

Earth Organisms Survive in Communities

Most organisms live in fairly complex communities, in which members share resources and improve community survival

Lichen survives space exposure

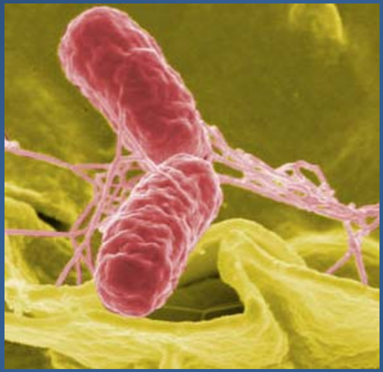


Some communities are made up of small numbers of species: frequently found in more ‘extreme’ environments

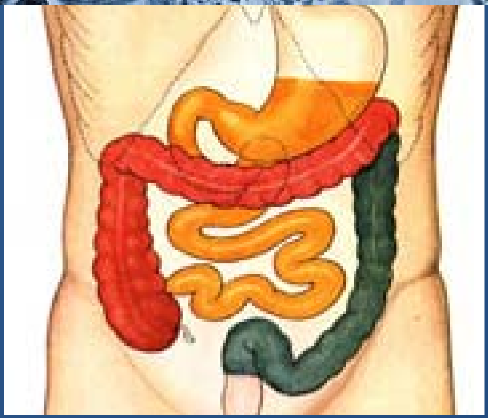
Ecological Impact of Introduced Organisms

Most stable communities are resistant to invasion by novel species

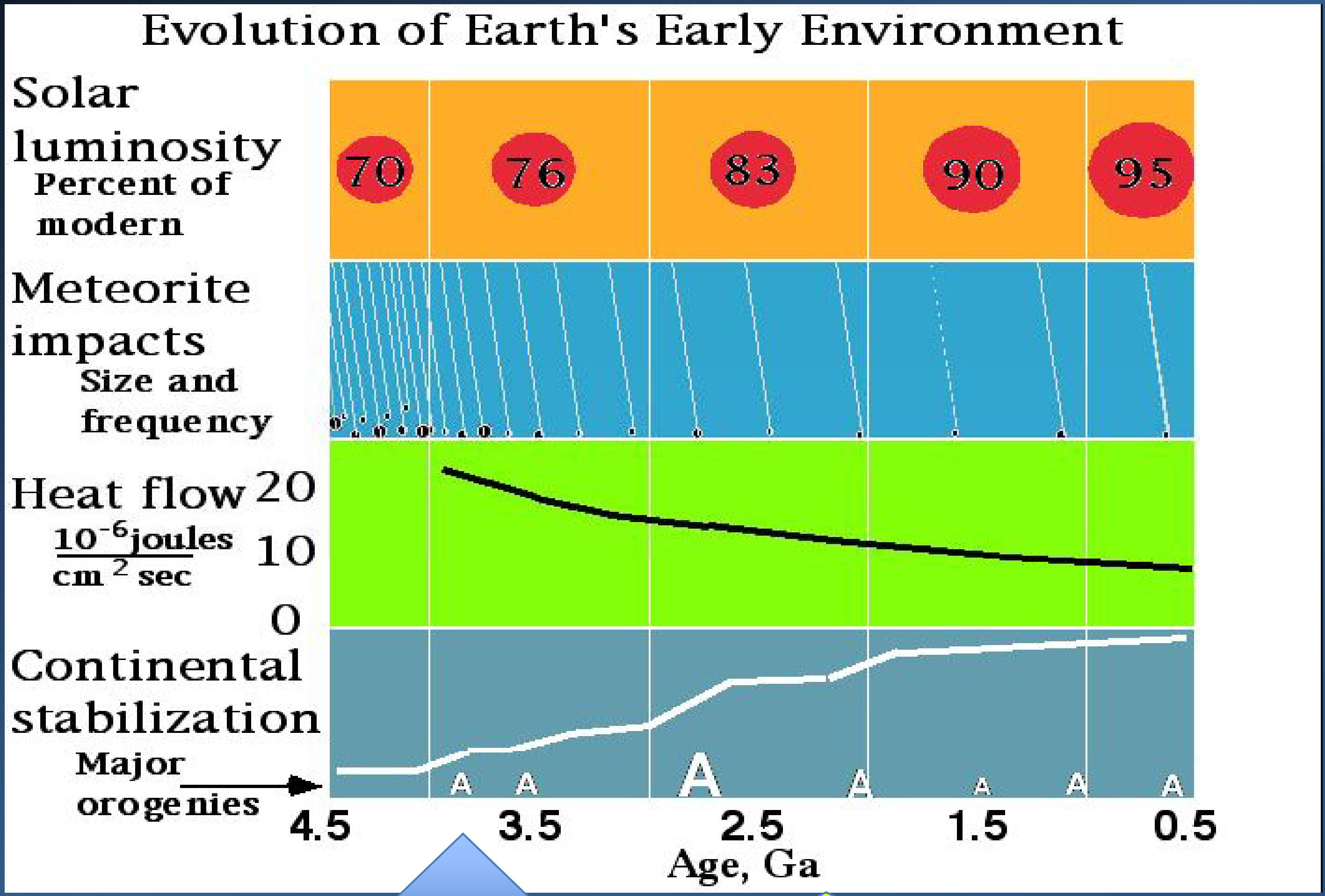
Salmonella typhimurium is more virulent after culture growth in space



However, sometimes organisms with novel capabilities can sweep through a community



Life's Effect on Earth



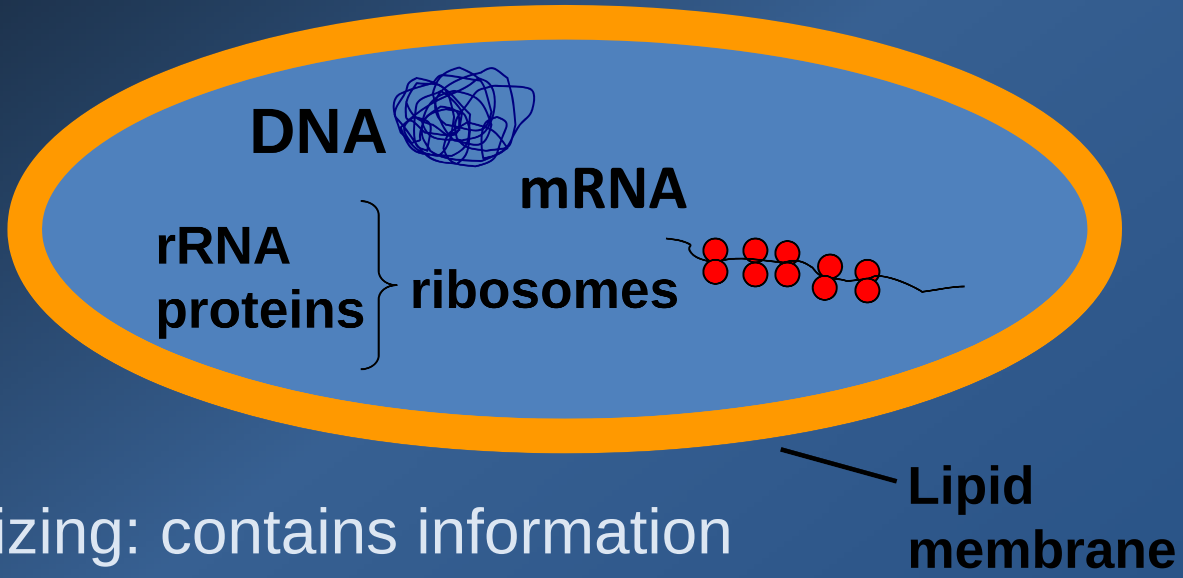
Origin of Life

Oxygen Atmosphere

What is life?

May include elements of the following...

Life Has Structure

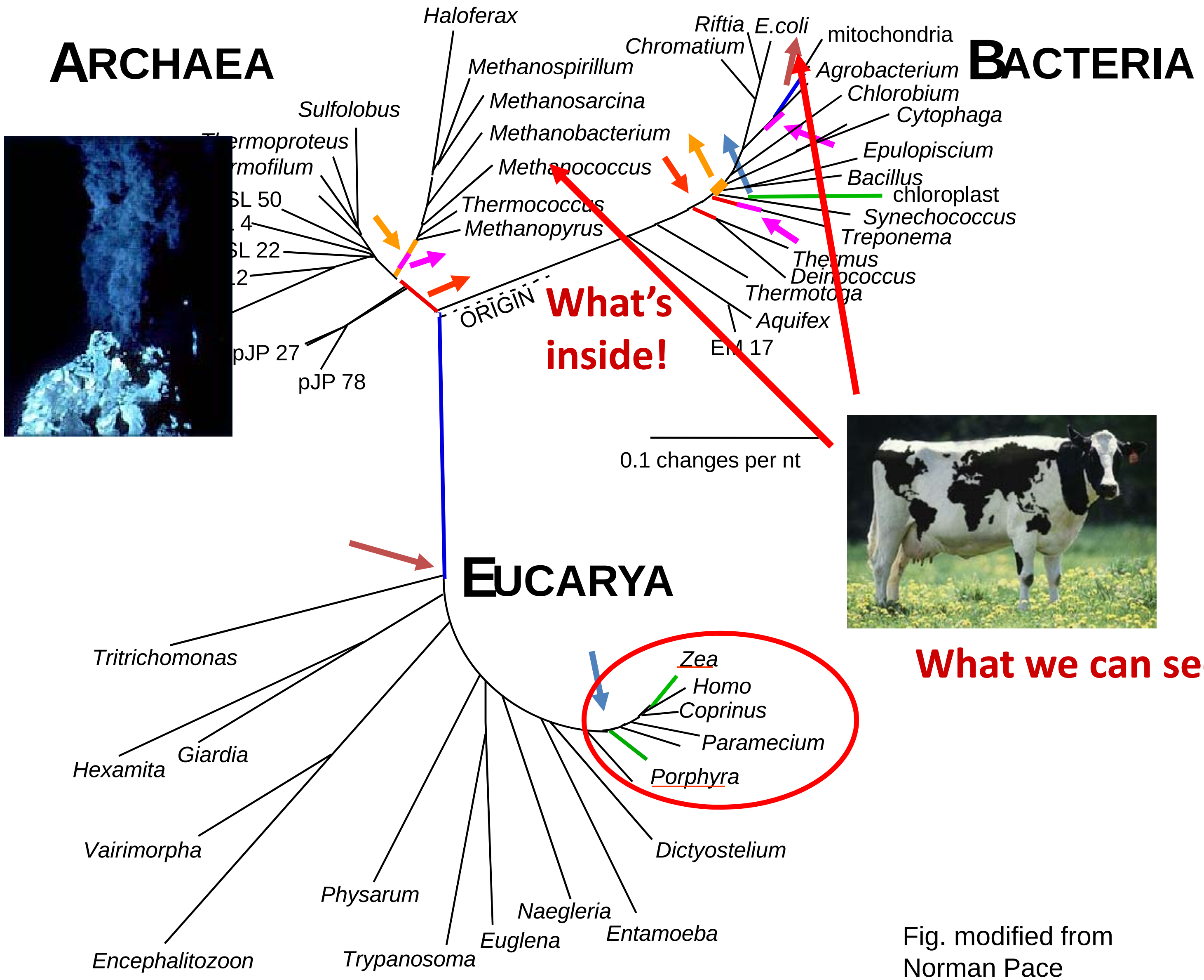


Self-organizing: contains information

Self-maintaining: can replicate (at least some of them)

Energy Flows: takes in energy and matter to maintain, grow and reproduce

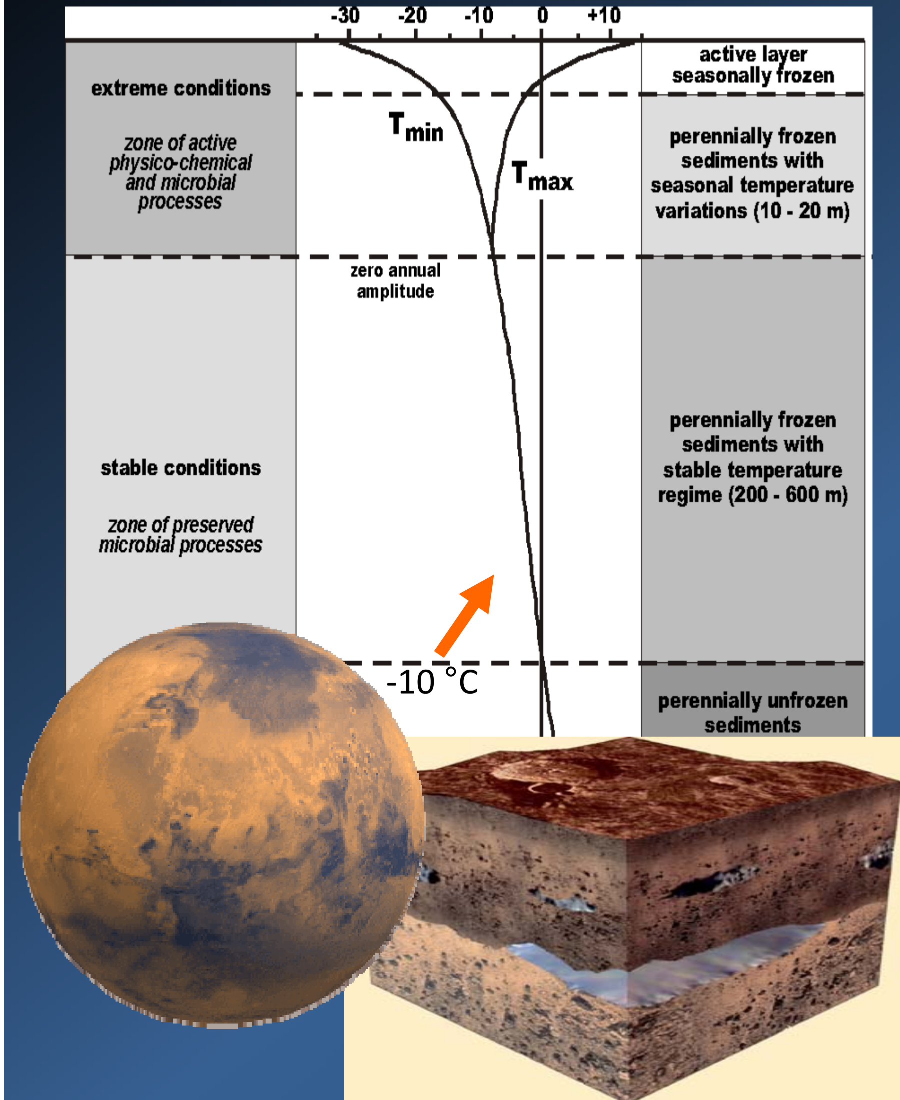
SSU-rRNA Tree of Life

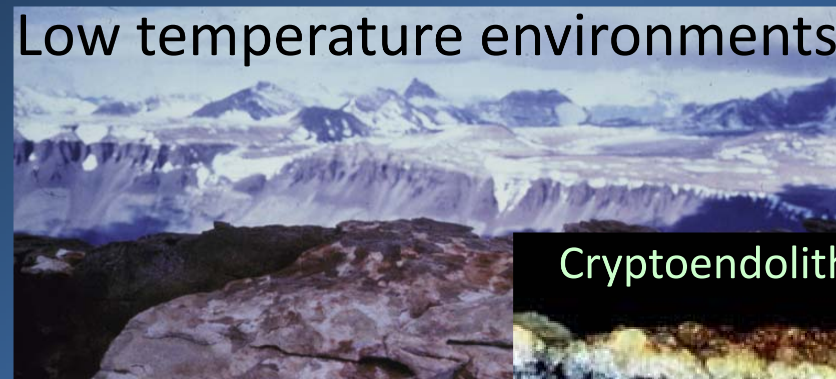


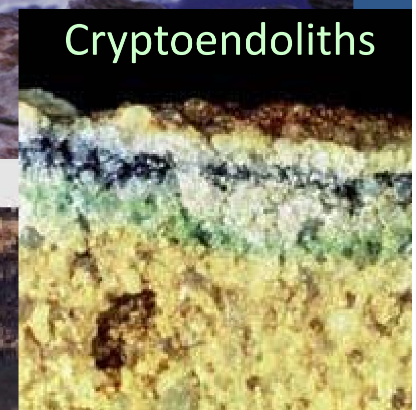
What we can see...

Fig. modified from
Norman Pace

Microorganisms Seem to Live Everywhere







Up to 10^7 cells/g in 60m depth, with metabolic activity down to -20°C

Really, Everywhere...

Ocean Vent Communities:

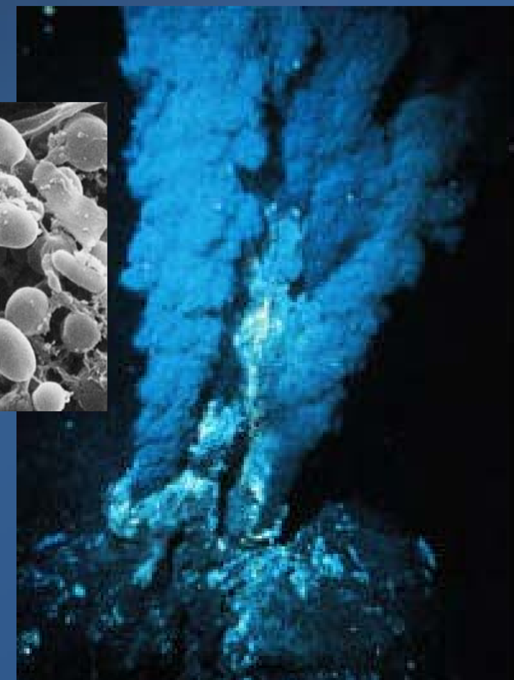
110-360°C (230-660°F) water

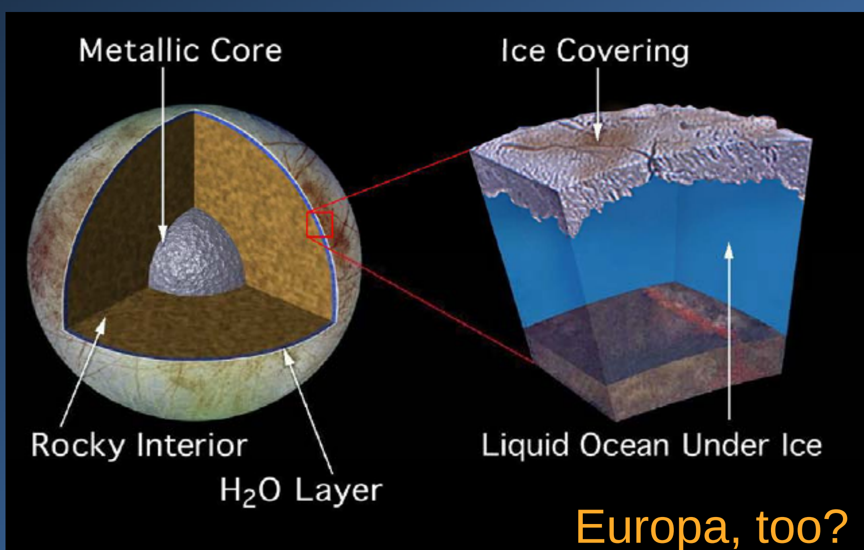
1000s of meters depth

Sulfur-oxidizing Bacteria

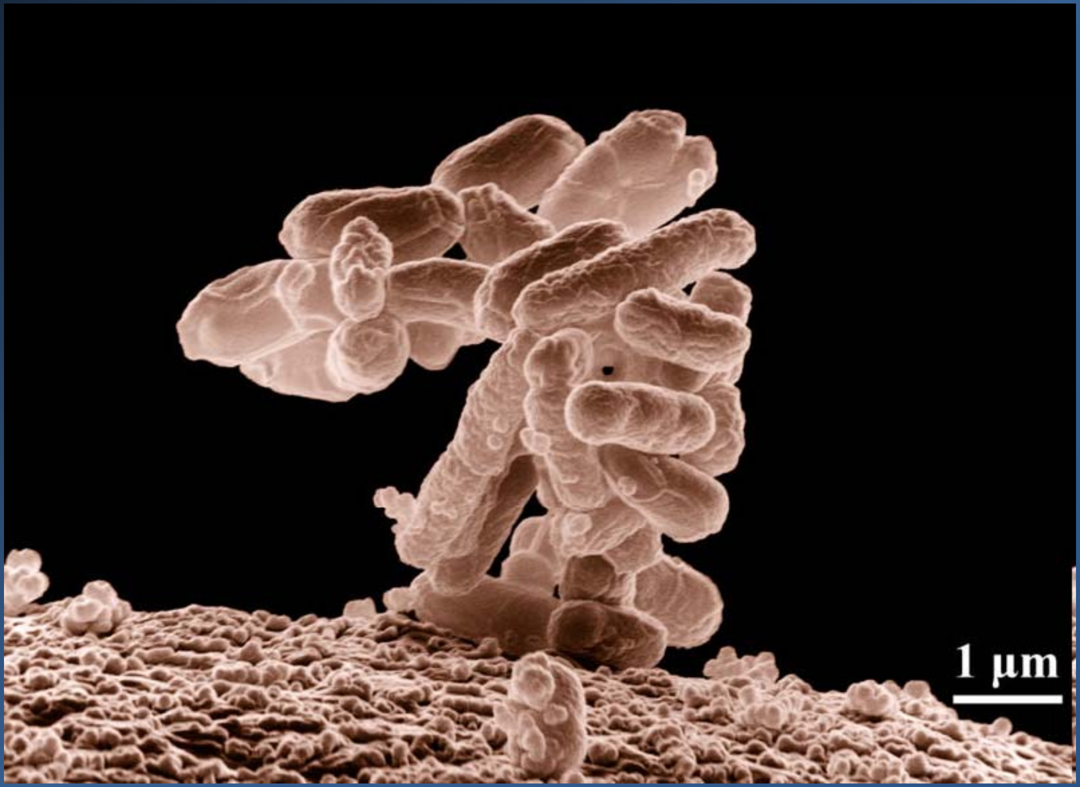
No light input from the surface

Bacteria, maybe, but...



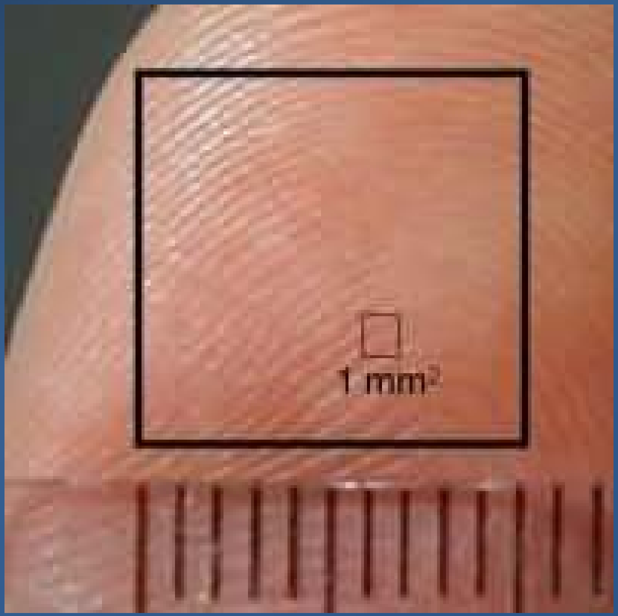


How Big Are They?



A cluster of *Escherichia coli* bacteria magnified over 10,000 times

How Many Microbes On Your Fingers?

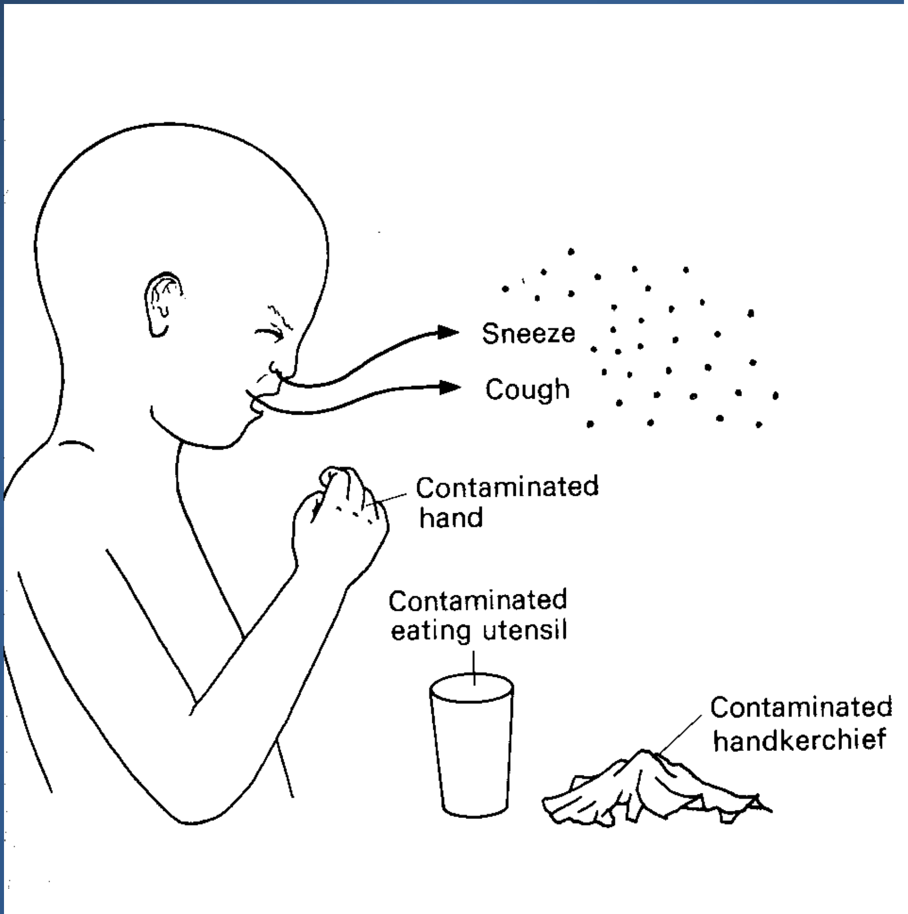


- Up to 10 000 microbes on 1 cm^2 of skin
- Up to 100 microbes on 1 mm^2 of skin
- At 1 micron, you need a microscope to see them

Remember Everywhere?

Occurrence of microorganisms:

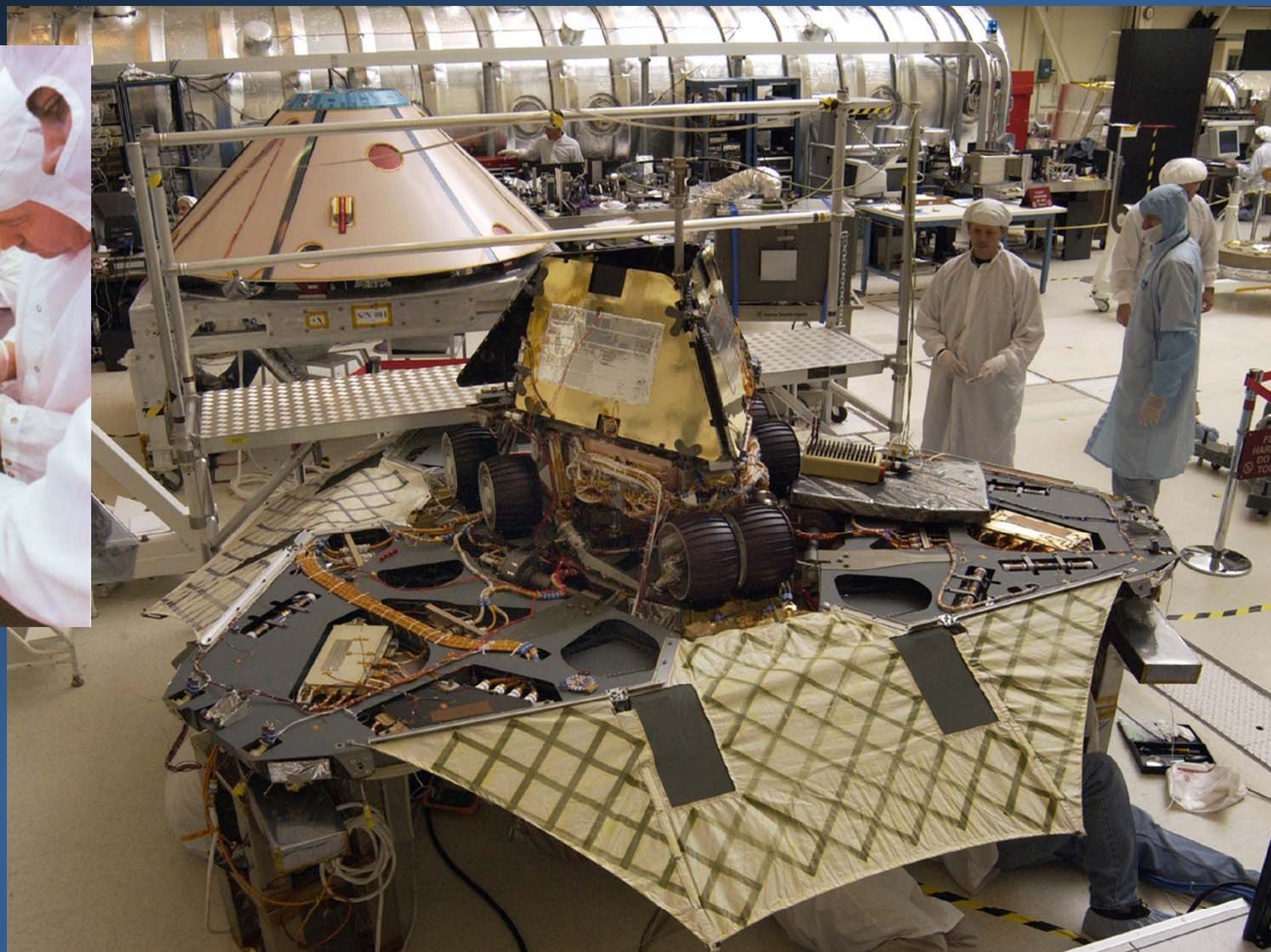
- Total: 10^{30} cells à 5×10^{-13}g ~10^{11} tons
- In air: desiccation resistant species
- In drinking water: < 100cells/ml
- In soil: up to 10^{8} cells/g soil
- On human skin: 10^{12} cells
- In human mouth: 10^{10} cells
- In gastrointestinal tract: 10^{14} cells



Total human microflora:
Orders of magnitude more microbial cells than human cells!

This Means Also In Spacecraft Cleanrooms!

Viking
Life
Detection
Package



MER-1 in SAF

Where Do Contaminants Come From?

Sky  *B. stratosphericus* (above 24 km)

Soil 

B. thermoterrestis
(egypt. soil, 55°C)

Hay 

B. subtilis
(the „hay“-*Bacillus*)

Desert 

B. sonorensis
(Sonoran Desert, Arizona)

Rocks 

B. simplex
(500 spores/g rock)

Deep surface  *B. infernus*

SAF  *B. pumilus SAFR*

Food 

B. cereus

Pathogens 

B. anthracis
(the bioterrorist)

Insects 

B. thuringiensis
(the exterminator)

What Organisms Do We Worry About?

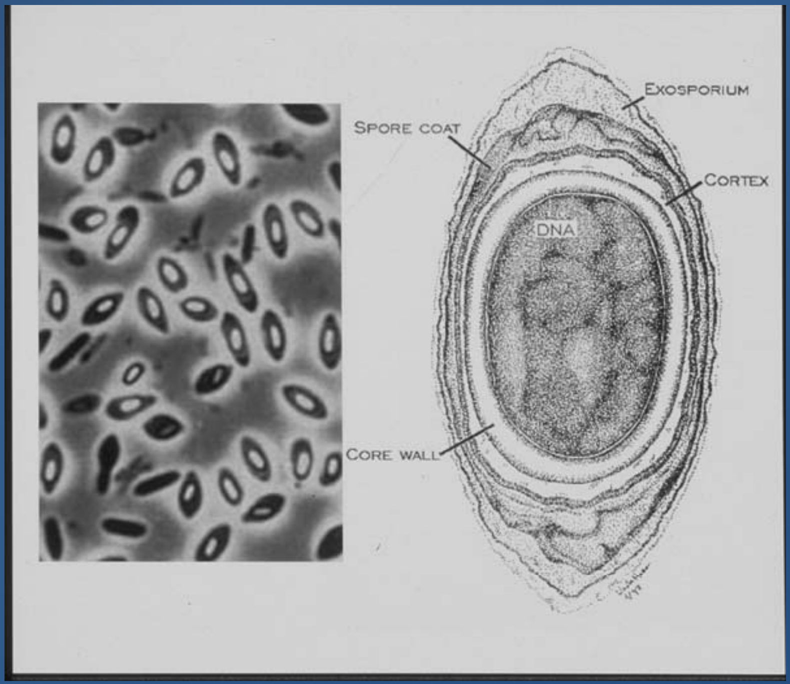
Bacterial Endospores (Spores) are among the most resistant organisms to heat sterilization

Subcellular body formed when conditions not favorable for growth

Resistant to harsh conditions (temperature, heat, drying, radiation, acids, disinfectants etc)

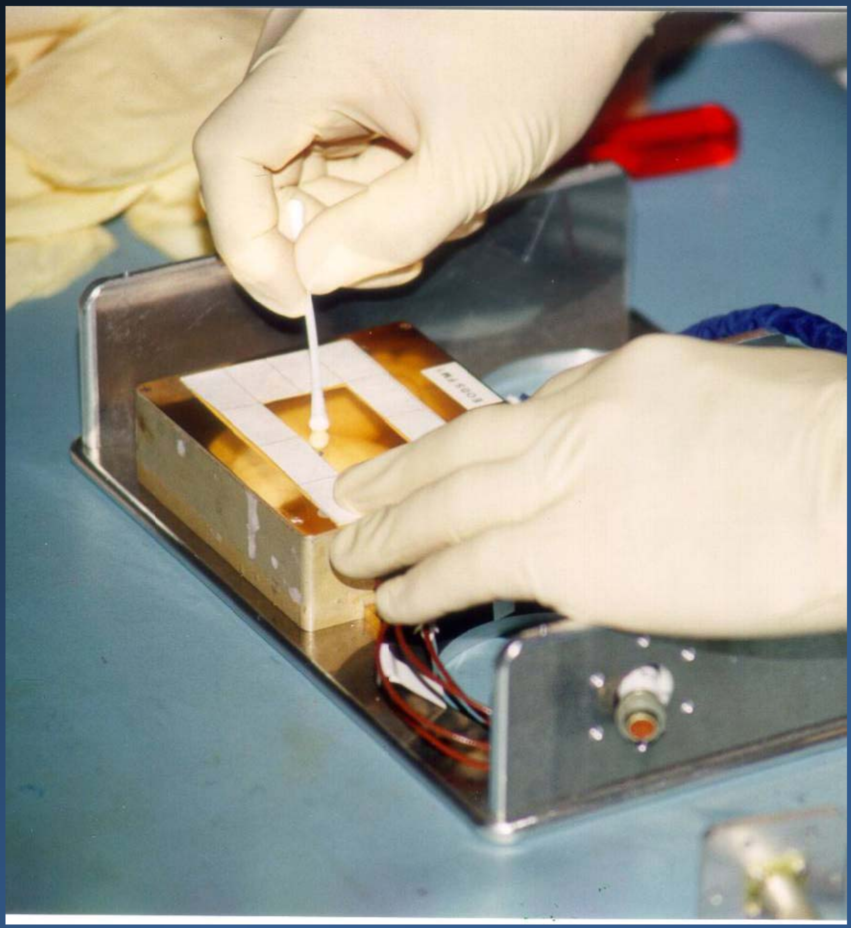
Can remain dormant for $>10^7$ years

Convert back to vegetative cells quickly



Bacillus spores

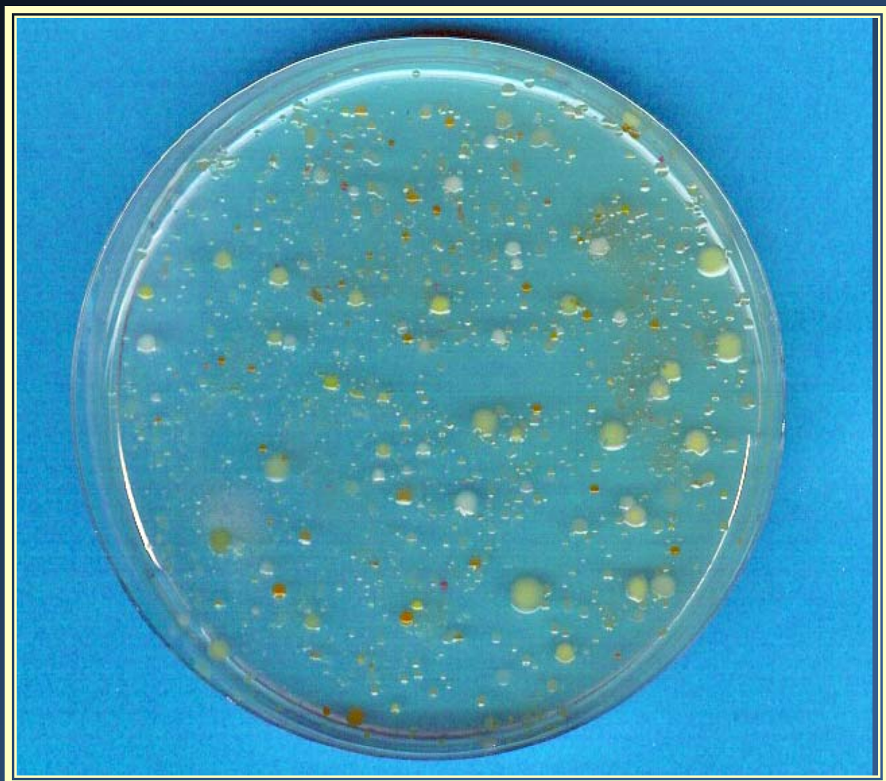
How Do We Find Out What's There?



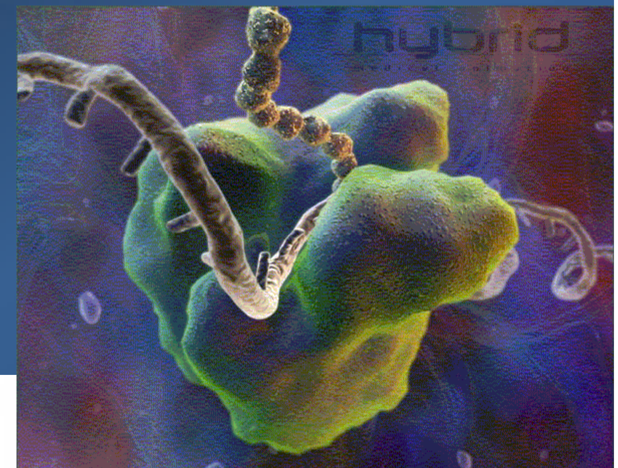
Collect samples...

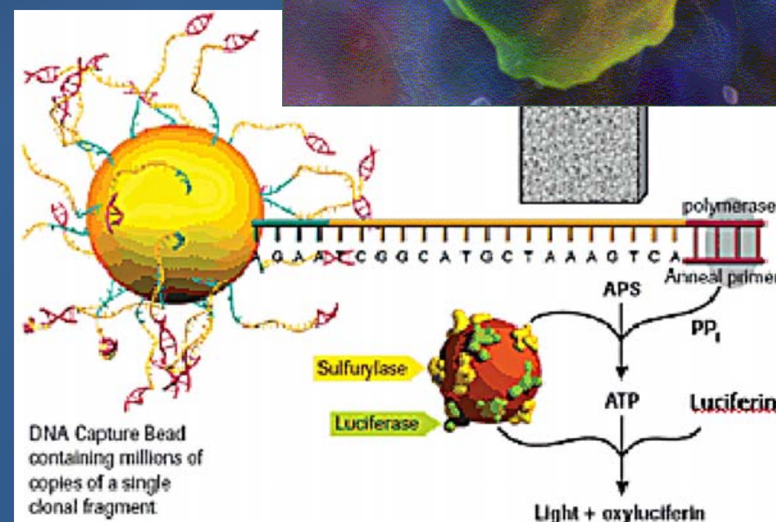
- Directly from components
- From assembly environments
- Use specification values

Evaluation Methods:



Culture studies identify or count some organisms in samples taken from spacecraft



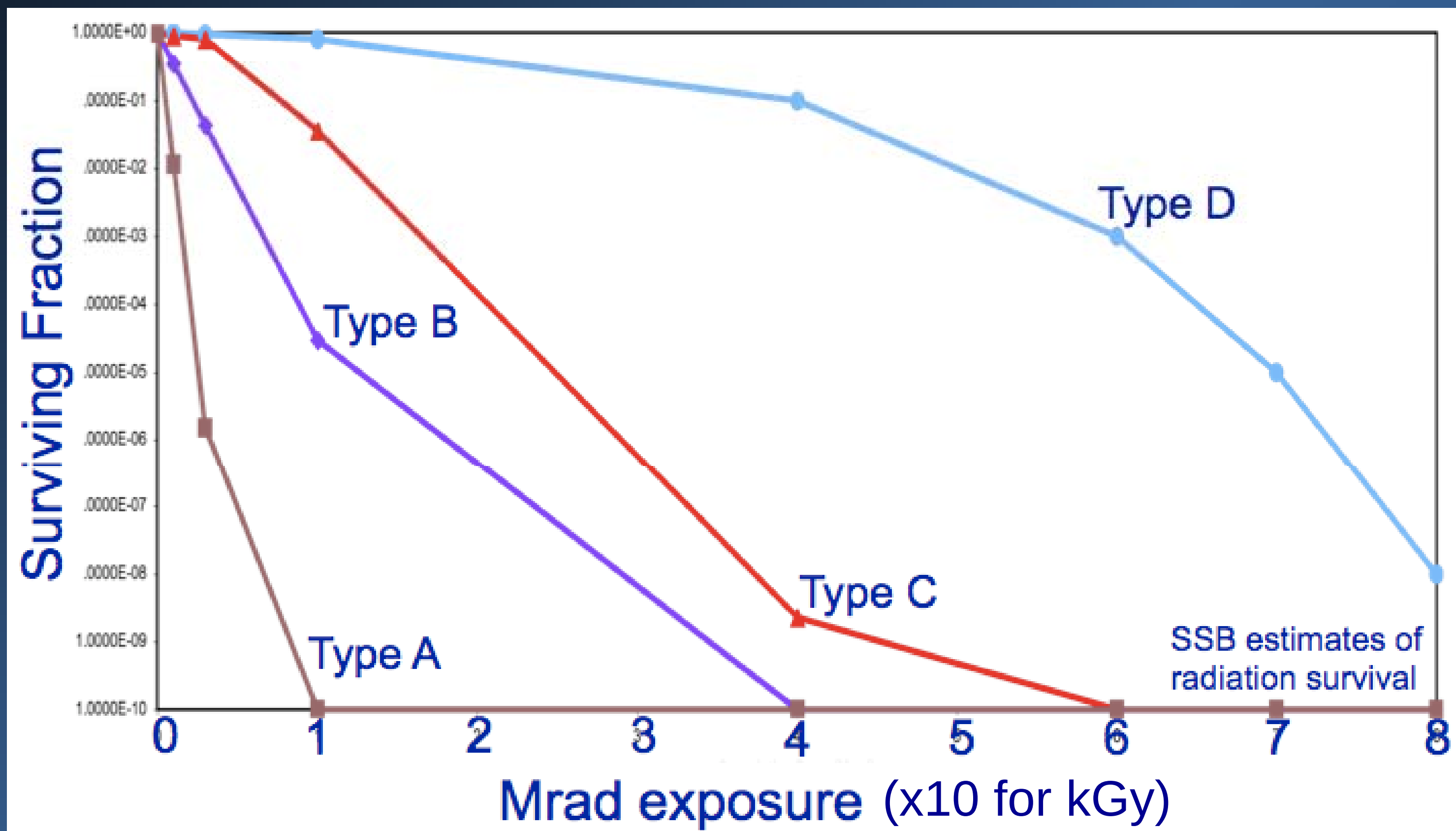


Molecular biology can be used to identify more organisms, but counting is challenging

Sterilization Options

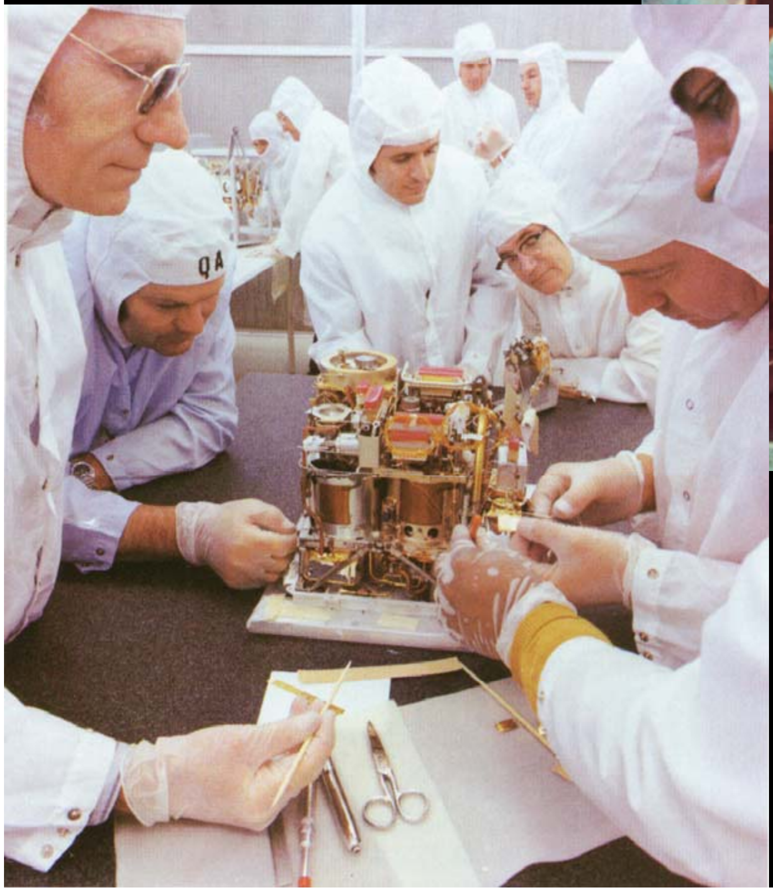
- Dry Heat Microbial Reduction: approved method
- Other ‘penetrating’ technologies include hard radiation, or combinations with heat
- Surface sterilization might involve gas treatment (Vapor Hydrogen Peroxide, cold plasma); radiation (UV, e- beam); or cleaning to sterility (mechanical removal by solvents, CO_2 snow)
- Protect from recontamination during subsequent assembly and launch

Microbes are More Radiation Resistant than Electronics...



Type A: Typical, common microbes Type B: Spores of typical microbes
Type C: Dormant microbesthat are especially radiation-resistant;
Type D: Rare but highly radiation resistant non-spore microbes (e.g., *Deinococcus radiodurans*).

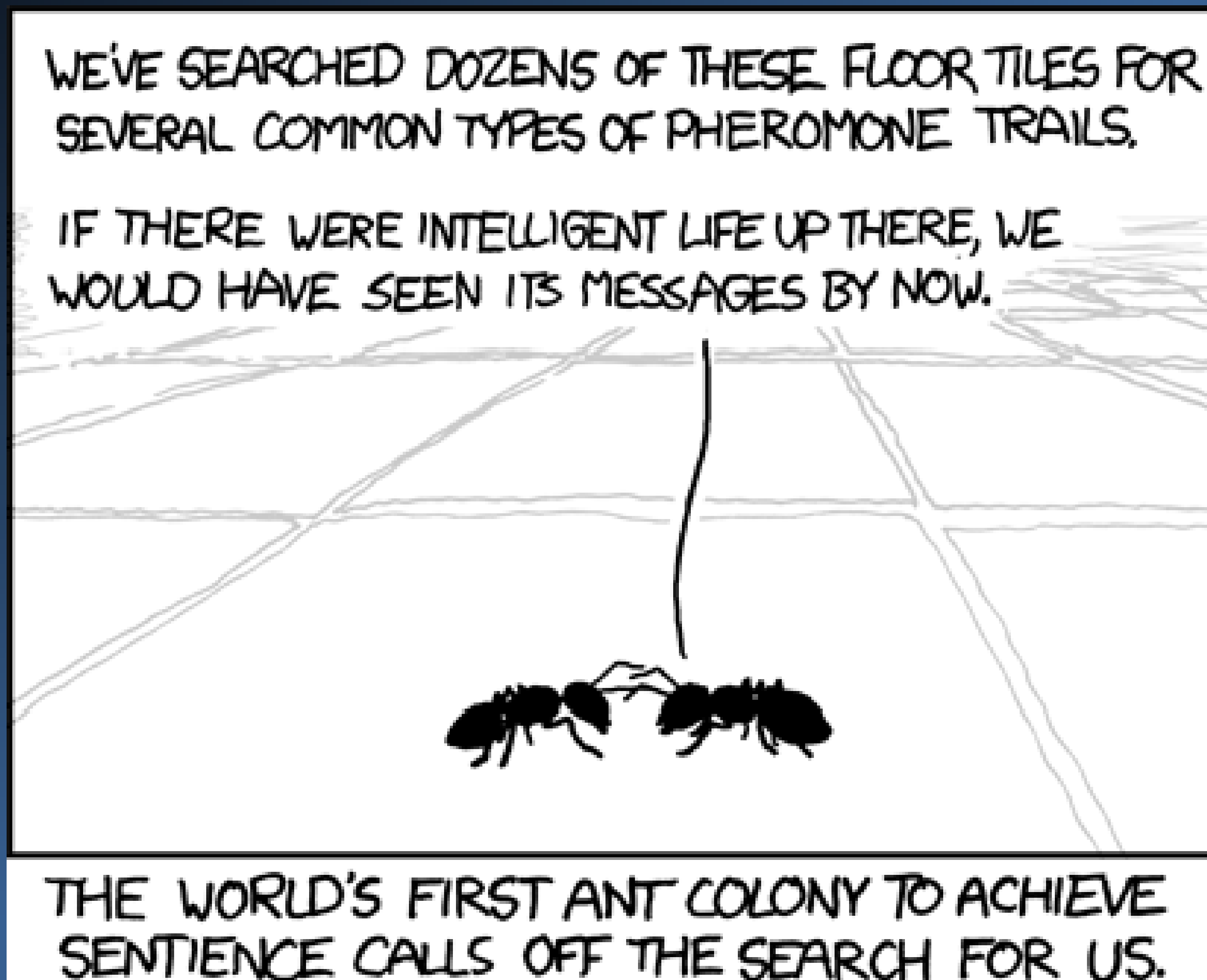
The Torquemada Approach



Viking
Life Detection
Package

Full-System
Sterilization
Works

Searching for Life...



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