Lecture 17
Life on the Edge

Astronomy 141 – Winter 2012

This lecture is about the extremes of life on Earth.

Extremophiles are organisms adapted to extreme environments.

What are the limits of life on Earth?

Can there be life without liquid water?

Typical conditions on Earth today are comfortable for typical forms of life

Average Temperature
- −20 to 36°C (−4 to 97°F)

Pressure
- 1 atm (sea level) to 0.5 atm (5500m)

Salinity
- Oceans are 3.5% salt

Acidity
- Neutral (pure water) to slightly alkaline (sea water)

Radiation
- Low background: 0.003 Joules/kg/year

Location
- Land or Sea

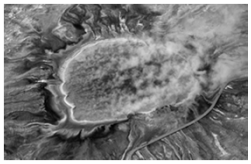
Extremophiles are organisms adapted to living in extreme environments.

Most are prokaryotes (bacteria and archaea)

Some are eukaryotes and simple animals (tube worms)

Overall they may constitute 1/3 to 1/2 of Earth's biomass

Could have been the first forms of life on Earth.

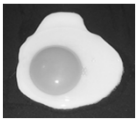


High temperatures are bad for most organisms

Heat degrades chlorophyll, stopping photosynthesis

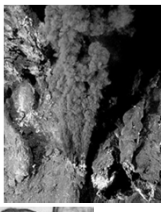
Heat decreases the solubility of CO_2 and O_2 in water

Heat denatures proteins, causing them to stop working



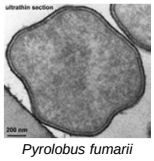
Thermophiles are organisms that thrive at high temperatures (>45°C)

Found in hot springs and deep-sea hydrothermal vents



Have proteins & enzymes that work at high temperatures

Chemoautotrophs
Chemosynthesis via oxidation of hydrogen sulfide or methane



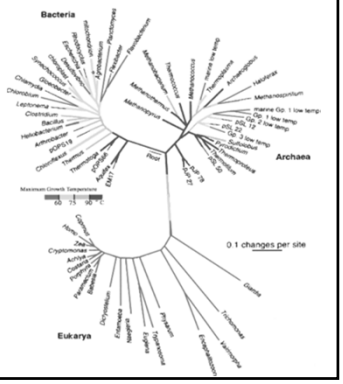
Pyrolobus fumarii

Were *Thermophiles* the first forms of life on Earth?

The earliest life was prokaryotic archaea

Prokaryotes tend to be more heat tolerant

Deep hydrothermal vents are isolated from the harsh surface of the young Earth

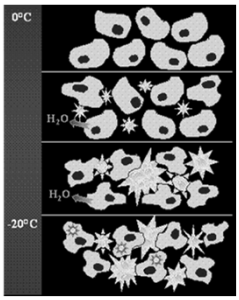


Cold temperatures are bad for most organisms

Freezing damages cells (superosmosis)

Cold increases viscosity, limiting mobility of nutrients & wastes

Cold proteins and enzymes get stiff, inhibiting their function

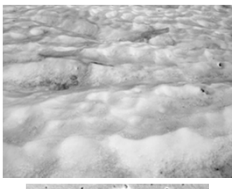


Psychrophiles are organisms that thrive at low temperatures (<15°C)

Found in glaciers, arctic ice, snow, & soil, and deep oceans

Have flexible enzymes and proteins that act like antifreeze

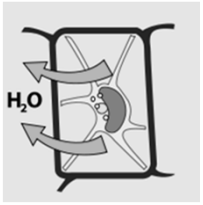
Some are eukaryotes that live by photosynthesis (snow algae)



Desulfofaba gelida

High salinity (too much salt) is bad for most organisms

High osmotic pressure desiccates (dries out) cells by drawing out water.



High salinity promotes protein aggregation (salting out), disrupting Function.

High Salinity limits the availability of oxygen for respiration.

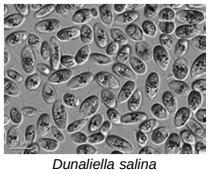
Halophiles are organisms that thrive in high concentrations of salt

Live in water with 10x the salinity of the oceans

Dead Sea & Great Salt Lake

Extra ions reduce osmotic pressure, stopping desiccation

Implications:
Salt seas on the early Mars & present-day Europa?



Dunaliella salina

The *Acidity* of an aqueous solution is measured by its *pH*

Low pH solutions are *acidic* (takes up electrons)

High pH solutions are *alkaline* (gives up electrons)

High acidity can destroy proteins and DNA or inhibit their function.

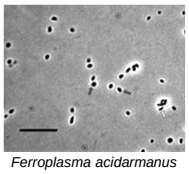
pH=0	Battery Acid
pH=1	Stomach Acid
pH=2	Lemon Juice
pH=3	Orange Juice
pH=4	Tomato Juice
pH=5	Black Coffee
pH=6	Urine, Saliva
pH=7	Pure Water
pH=8	Sea Water
pH=9	Baking Soda
pH=10	Great Salt Lake
pH=11	Windex
pH=12	Soapy Water
pH=13	Bleach
pH=14	Drano

Acidophiles are organisms that thrive in highly acidic environments

Survive in pH < 2
(lemon juice to battery acid)

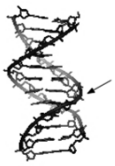
Some efficiently neutralize their cellular interiors

Other acidophiles have evolved acid-stable proteins.



Ferroplasma acidarmanus

Ionizing Radiation is hazardous to life

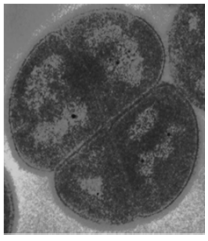


DNA is susceptible to radiation damage:
Minor Damage → self-repair
Lethal Damage → cell death
Non-Lethal Damage → mutation

Radiation Dose = Energy absorbed per kg
Medical X-ray: ~0.002 Joules/kg
10 Joules/kg is lethal to humans
60 Joules/kg kills *E. coli* bacteria

Radioresistant organisms can survive high doses of ionizing radiation

Deinococcus radiodurans can survive doses of 5000 Joules/kg



Can absorb up to 15,000 Joules/kg with 37% viability

Has very efficient DNA repair and carries 4 to 10 copies of its genome

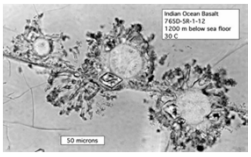
Deinococcus radiodurans

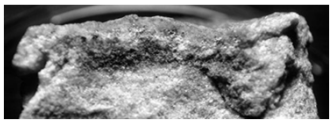
Endoliths are organisms that live inside rocks & between mineral grains

Found as deep as 3 km below the ground.

Most are chemoautotrophs

Reproduce maybe once per century





Total biomass in endoliths could exceed all surface life!

The Atacama Desert of northern Chile is the driest non-arctic place on Earth

Virtually sterile desert 100 times more arid than California's Death Valley.

In a double rain shadow from the Andes and coastal mountains.

No rainfall recorded in some regions for the past 400 years!

Free of glaciers for the past 1.8 Million years.

A 2003 study replicated the Viking 1 & 2 Mars life search experiments in the Atacama

No culturable bacteria were found down to 10cm

Two samples had *no* DNA

A later study found viable bacteria at 30 cm depth

Life can exist even in the driest environments as long as there is at least a little liquid water.

Studying the extremes of life informs our search for life elsewhere in the Universe.

The existence of extremophiles greatly extends the range of possible environments for life.

Extremophiles may have been the first life-forms on Earth.

No organisms are known that can survive without liquid water.