Life in the Cosmos

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Life in the Cosmos

All Known Life Forms Require: **WATER**, **BIOGENIC ELEMENTS** (C, H, O, N, P, S)  
Minor Elements: (Na, K, Cl, Mg, Mn, Fe, Ca, Cu, Zn)  
Nitrogen Required in all DNA, RNA, Proteins & Enzymes

& **ENERGY**

Photoautotrophs – Energy from Light  
Organotrophs – Eat Organics (Sugars, Proteins, etc.)  
Chemotrophs – Energy from Chemicals  
Lithotrophs – Energy from Abiotic Elements/Rocks

Aerobes – Respire using Oxygen as Electron Acceptor  
Anaerobes – Use Other Acceptors (NO$_3^-$, SO$_4^{2-}$ or S)
Life in the Cosmos

Recent Discoveries Challenge the Long Held Paradigm that Liquid Water (and Life) Can Not Exist on Present-Day Mars and Comets

• Microbial Extremophiles Live in Glaciers and Grow at Sub-Zero Temperatures

• MRO & StarDust Data Show Liquid Water Exists Episodically on Mars and in Comets
Pingos and Double-Rimmed Polygons form only by Freeze-Thaw Cycles in Permafrost. N. Polar Cap of (Mars 1,200 km dia. X 3 km) Water Ice with Pingos & Polygons.
Sept. 22, 2005-HRSC on ESA Mars Express Spacecraft Discovers 3,500 M thick layer of Water Ice & Snow with Pingos at Promethei Planum
Life in the Cosmos
Evidence for Recent Water on Mars

Seasonal Flows on Warm Martian Slopes

MRO HiRISE Images of Recurring Slope Lineae
Hot, Black, Wet, Comet Nuclei
~ CI1 Carbonaceous Meteorites

Galileo Image of Comet Halley Nucleus (Albedo 0.03 ~ Orgueil 0.02)
Stardust Images Pinnacles, Cliffs & Jets of Comet 81P/Wild 2

"Mean elemental composition of this Wild 2 Material is consistent with the CI meteorite composition." Flynn et. al., Elemental Compositions of Comet 81P/Wild 2 Samples Collected by Stardust. Science, 314, 1731-35.
Water Ice on Comet Nucleus

Sunshine et al. Exposed Water Ice Deposits on the Surface of Comet 9P/Tempel 1 Science 311, 1453, 2006

Deep Impact Images of Water Ice on Nucleus of Comet 9P/Tempel 1
Spitzer IRS Data on Temple 1

*Spitzer IRS* Post-Impact data show at least 50% of Comet 9P/Temple 1 is Water Ice. Also detected were H-CN, Methanol, CO, CO$_2$, PAHs, Clays and Carbonates.

Rotation Period ~41 Hrs. changes with Jets and Comet Activity.
Feb. 14, 2011 Stardust NExT Images of Comet 9P/Temple 1
Extraterrestrial Glycine & Cubanite Found in Stardust Samples returned from Comet 81P/Wild 2

$\delta^{13}C = +29 \pm 6^{o/oo}$

Elsila, J. E., Glavin, D. P., and Dworkin, J. P.

Orthorhombic Cubanite ($CuFe_2S_3$) found in Comet Wild 2 & Orgueil CI1 Meteorite forms in Liquid Water at Temperature 20 – 150 °C; pH 7-10
Nitrogen in Biology

Nitrogen in DNA and Iron Hydrogenase
Chiral Biomarkers in Murchison Meteorite

L-Alanine, L-Glutamic Acid, L-Aspartic Acid, GLY, AIB, IVA
amino acids

Proprionic acid - Metabolism of Sugars and Fatty Acids by Propionyl Coenzyme-A
carboxylic acids

Lactic acid-Pyruvate Oxid. Stecker-Cyanohydrin Synth.
hydroxyacids

Polyols and Dihydroxyacetone DNA; RNA; Membranes; Energy
sugar-related compounds

17.8% L-Enantiomeric Excess of sec-butyl amine
amines

Amide linkage - Defining Molecular Feature of Proteins
amides

MISSING: Cytosine and Thymine
Cytosine => Uracil 17,000 yr. Half Life

**PURINES:** Adenine, Guanine, Xanthine, Hypoxanthine
**PYRIMIDINE:** Uracil

- Nitrogen heterocycles
- Sulphur heterocycles
- Aromatic hydrocarbons

- Cycloalkanes and Diverse Suite of C15-C30 Branched Mono, Di- and Tri-Cyclic Alkanes
- Polymers of Isoprenes (C5H8)n Major Building Blocks of All Life

- Over 30 Polynuclear Aromatic Hydrocarbons -- Kerogens

**legend**
- Hydrogen
- Carbon
- Nitrogen
- Oxygen
- Sulphur
Life in the Cosmos

Orgueil Trichomic Filament: O/C<0.1; N<0.5

Terminal Hair
Orgueil Trichomic Filament
Kerogenous Sheath
Branched Trichome
Branched Trichome

5 μm

Orgueil Trichomic Filament: O/C<0.1; N<0.5
Conclusions

Discoveries by NASA & ESA Spacecraft provide additional evidence for present day liquid water on Mars and water/ice jets on Comets & Enceladus. Stardust mineralogical data support the Hypothesis that water-rich Comets represent parent bodies for the CI1 Carbonaceous Meteorites. Undetectable Nitrogen & low O/C ratios in Filaments found in CI1 Orgueil meteorite rule out Modern Biological Contamination Hypothesis.