

Radioactivity

Lecture 15

The Origin of Life

The origin of life

through building of complex molecules



The scientist definition:

Life is a complex, self-organizing, adaptive chemical system!

The adaptive chemical system is an extensive network of interactions and feedback mechanisms between its different components. The feed-back component allows to adapt to changing environmental situations.

Self-organization means that collective patterns evolve out of simple basic rules operating at the local level. No single molecule has the master-plan the dynamic pattern defines the ensemble.

The simple rules are the chemical (an physical) laws, that each complex molecule desires to be in the lowest energy configuration, which is facilitated through chemical reactions forming more complex systems.

Life and Energy

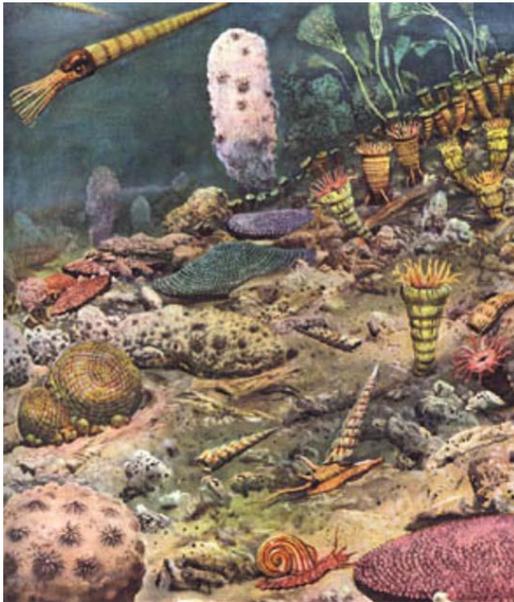
- Life requires energy to maintain the physiological functions of the bodies.
- The main energy source of the biological system of animals (includes us) is chemical energy that is generated by the chemical conversion of food in the gastro-intestinal system.
- The main energy source of the biological system of plants is solar energy that is converted through photosynthesis in nutrient plant food.
- The energy source of less developed microbiological systems are also different chemical mechanisms.
- **Three ingredients of life, Water, Organic Molecules (Carbon), Energy!**
- The question is, what is the energy source for generating the first self-sustaining biological systems that can be identified as life. Options, solar light, heat and fire in Hadean period, electrical discharges (lightening) in a methane atmosphere during the first two billions years of Earth?

The First Two Billion Years



Water
Energy
Organic
Molecules

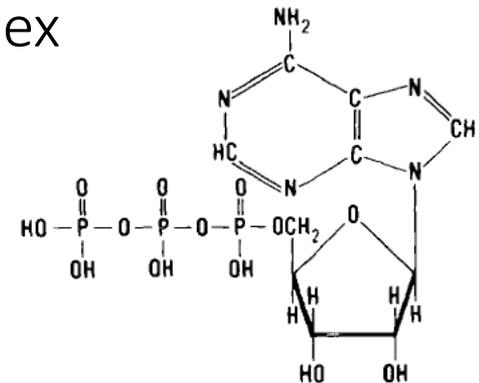
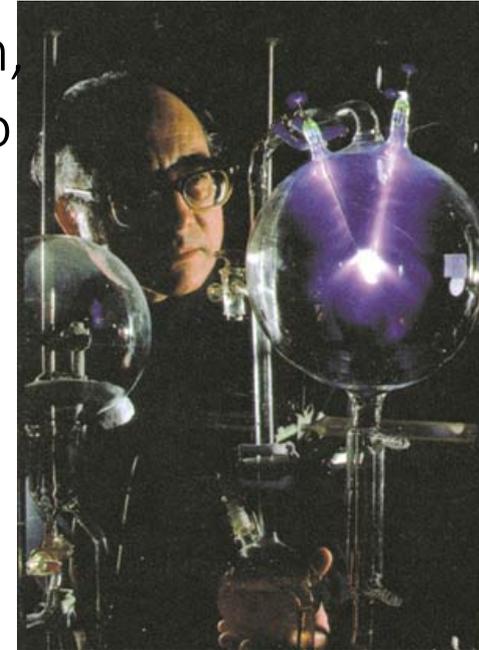
How did
that come
about???



Early Experiments

- Urey-Miller experiment with artificial ammonium, methane, and hydrogen atmospheres exposed to **electrical discharges**, generates amino-acids as base for complex molecules
- Carl Sagan took a similar experimental approach that produced by phosphorus enrichment Adenosin-Tri-Phosphat (ATP), an important building block of protein, RNA and DNA.
- A challenge remains the building of more complex chemical molecules that requires long time and sustained chemical conditions.
- Two theories are presently being discussed:

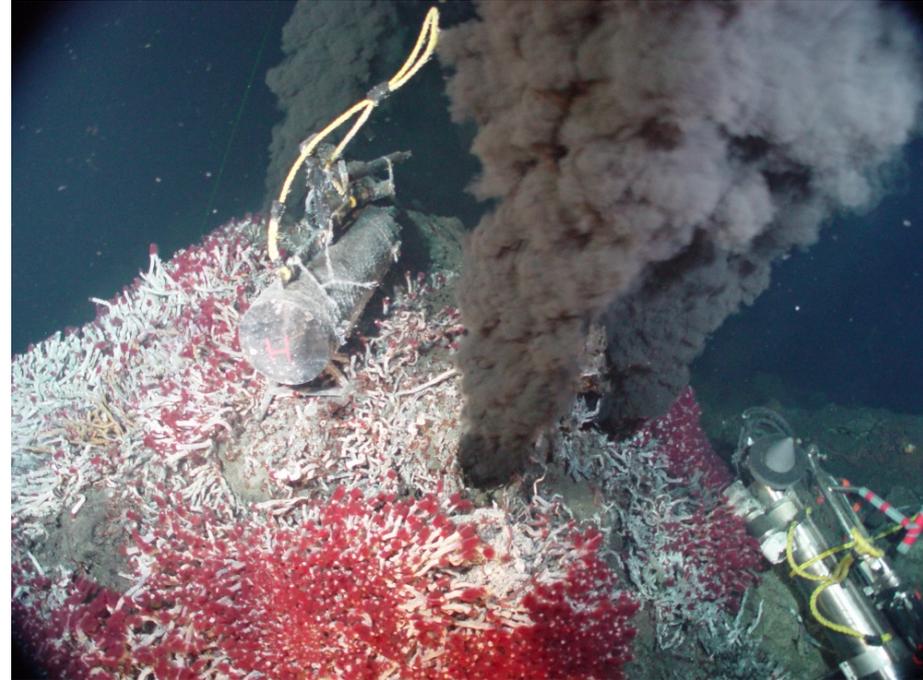
Heaven and Hell!



Heaven and Hell



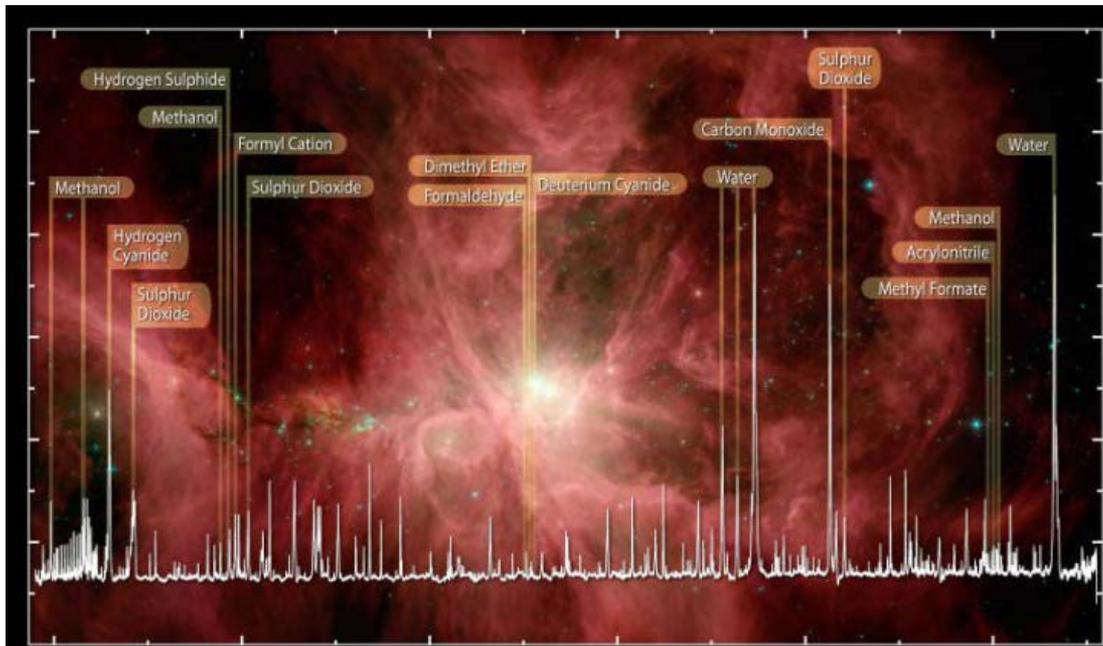
Astrobiology: formation of complex molecules in carbon enriched ices in comets, asteroids, planets through constant bombardment by intense cosmic radiation that provides the energy. The molecules are deposited on earth at more moderate conditions for further development.



Deep ocean vents: volcano heated deep sea vents that pump hot mineral rich material into ocean water at conditions that allow catalytic building of more complex Sulphur and phosphate rich organic molecules. Possible source of mineral component in biological systems.

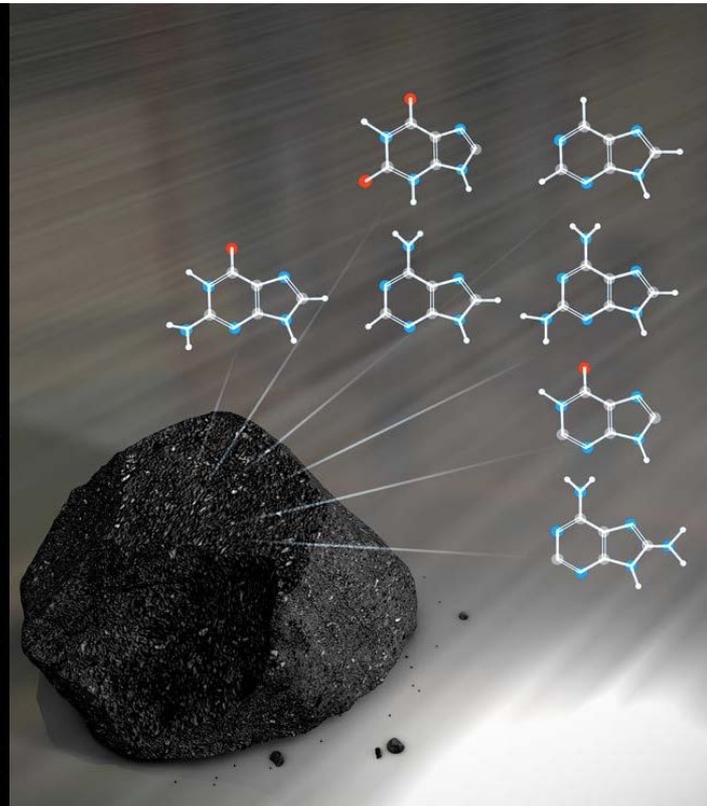
Astrobiology

Space is not only an active nuclear laboratory, breeding new elements, but it is also an active chemistry laboratory breeding new molecules with ever increasing complexity. These molecules can clearly be observed and identified by molecular spectroscopy in the infra-red radiation range. Complex molecules as building blocks of life are also found in meteoritic inclusions.



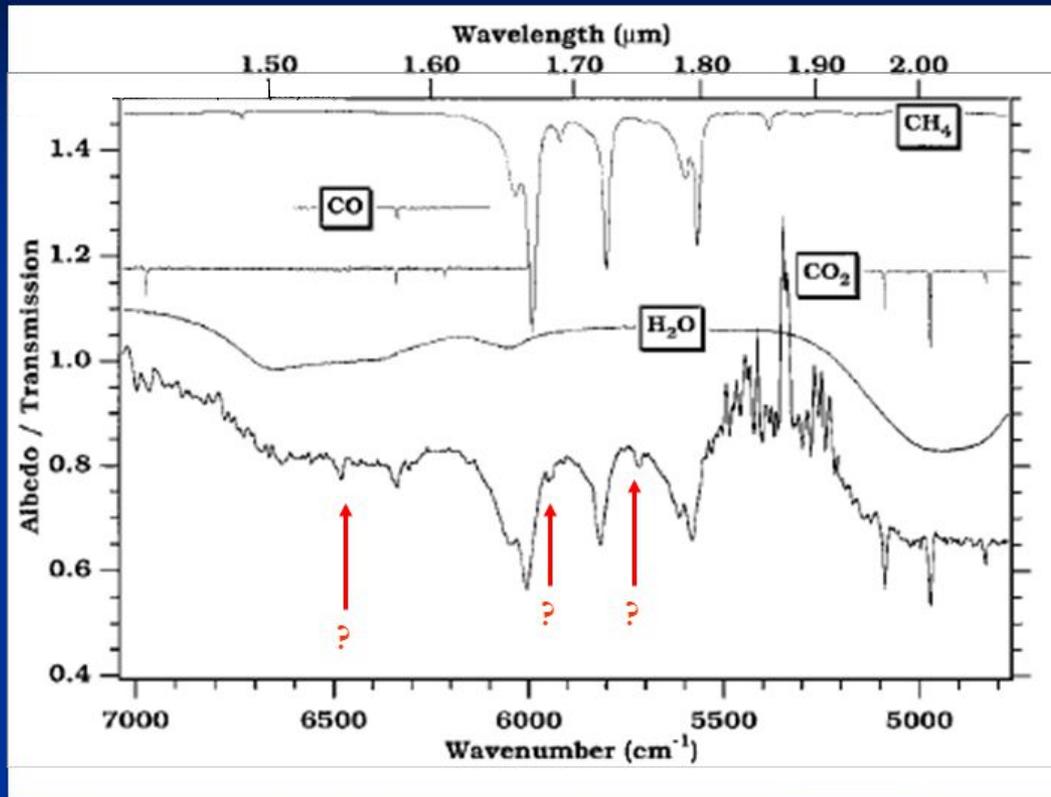
HIFI Spectrum of Water and Organics in the Orion Nebula

© ESA, HEXOS and the HIFI consortium
E. Bergin



Cosmic ice composition

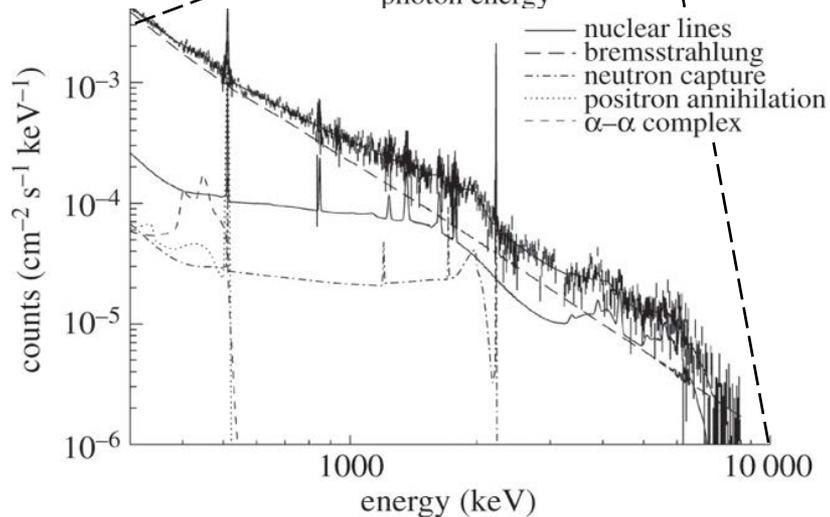
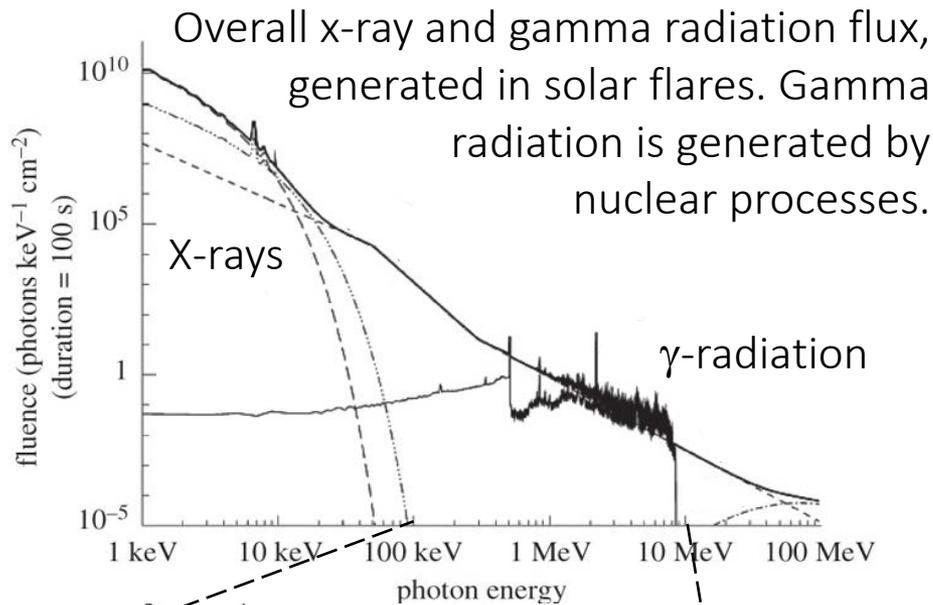
Ices Matching the Observed Spectra



- Carbon
- Carbon dioxide
- Carbon monoxide
- Methane
- Ammonia plus
- Water components make a perfect mix for further synthesis if energy is supplied.

Ice templates used: C_2H_2 , C_2H_4 , C_2H_6 , C_3H_8 , NH_3 , NO , NO_2 , SO_2 , CH_3OH , CH_4 , CO , CO_2 , H_2O , N_2 .

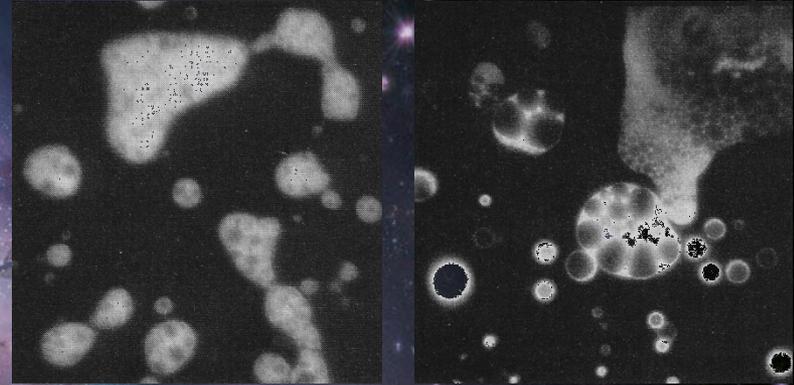
Energy Distribution in Solar Flare



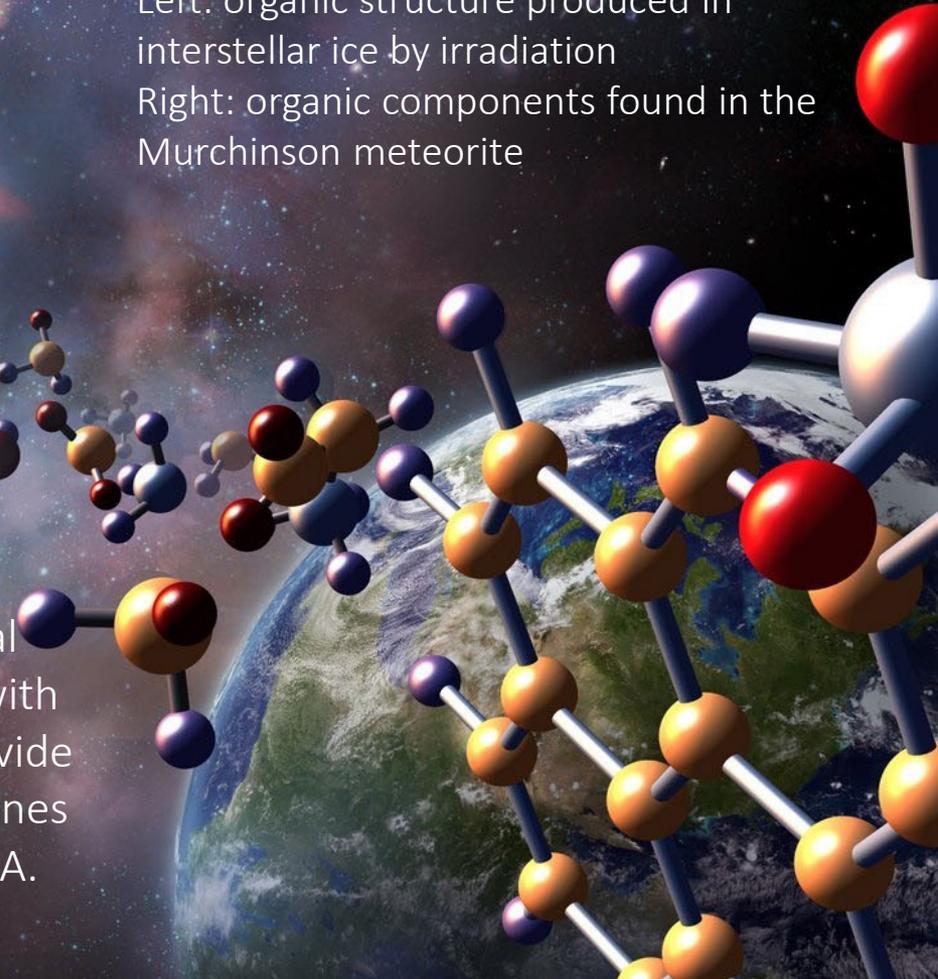
Molecule Synthesis

Either direct radiation, or decay heat from deposited radioactive isotopes can provide the energy for the molecule synthesis, unlike sudden lightening with sporadic powerful electrical discharges, the continuous flow of decay heat as a likely energy source. This would prevent the dissociation of complex molecules.

Synthesis is most likely facilitated through gradual build-up of molecules with growing complexity with numerous catalytic and intermediate step to provide intermittent stability of molecules as building stones of organic macro-molecules such as RNA and DNA.

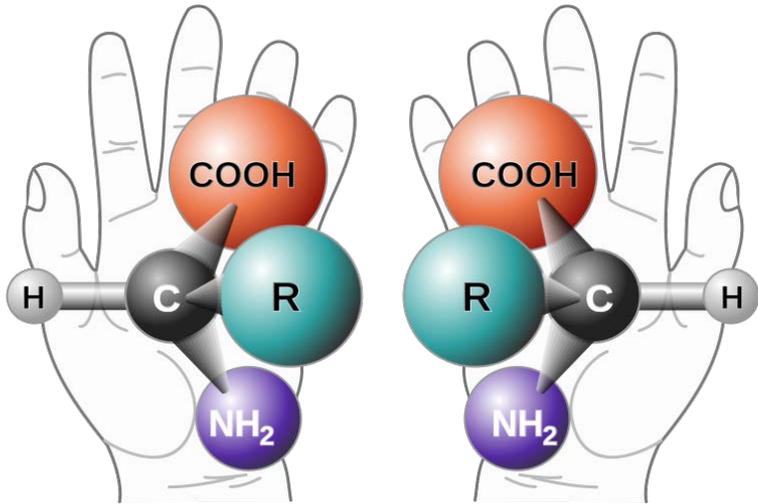


Left: organic structure produced in interstellar ice by irradiation
Right: organic components found in the Murchinson meteorite

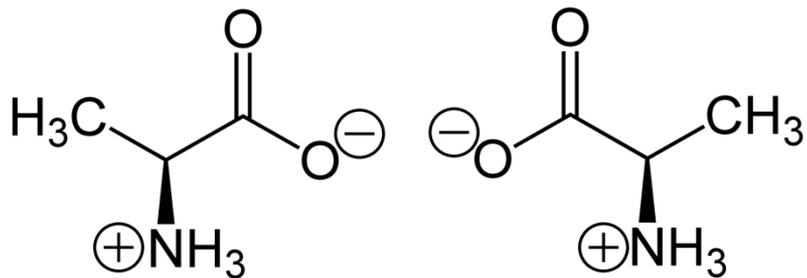


Chirality in Amino Acids, a Cosmic Signature?

Left handed Right handed
versions of a generic amino acid



While both chirality options can be made in the chemical laboratory, biological proteins are nearly exclusively made of L amino acids, known as *left-handed proteins*. D-amino acids are very rare in nature and have only been found in small peptides attached to bacteria cell walls. This phenomenon is called Enantiomerism.

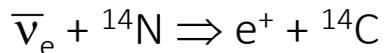


(S)-Alanine (left) and (R)-alanine (right)
or levorotatory (L) and dextrorotatory (D).

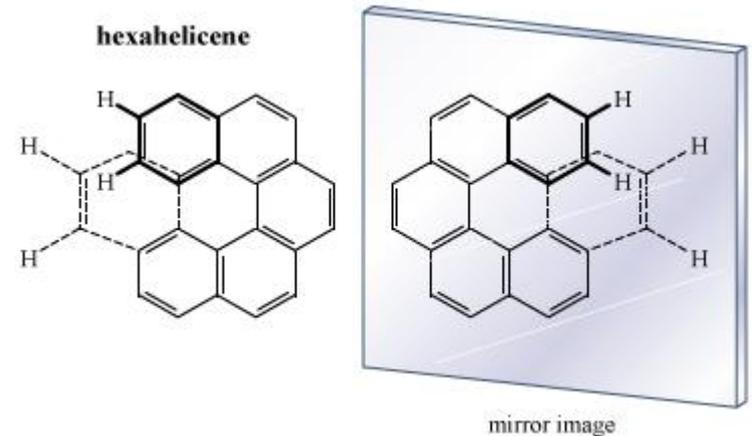
The Supernova Explanation?

Possible explanation is the large neutrino flux from supernova a nearby supernova triggering the formation of the solar system and the magnetic field of the remaining neutron star.

- the spin of the ^{14}N in the amino acids, or in precursor molecules from which amino acids might be formed are coupled to the chirality of the molecules
- The ^{14}N nuclei align in the magnetic field and the high anti-neutrino flux cause the right handed ^{14}N to be converted to ^{14}C destroying the dextrorotatory version of the molecule:

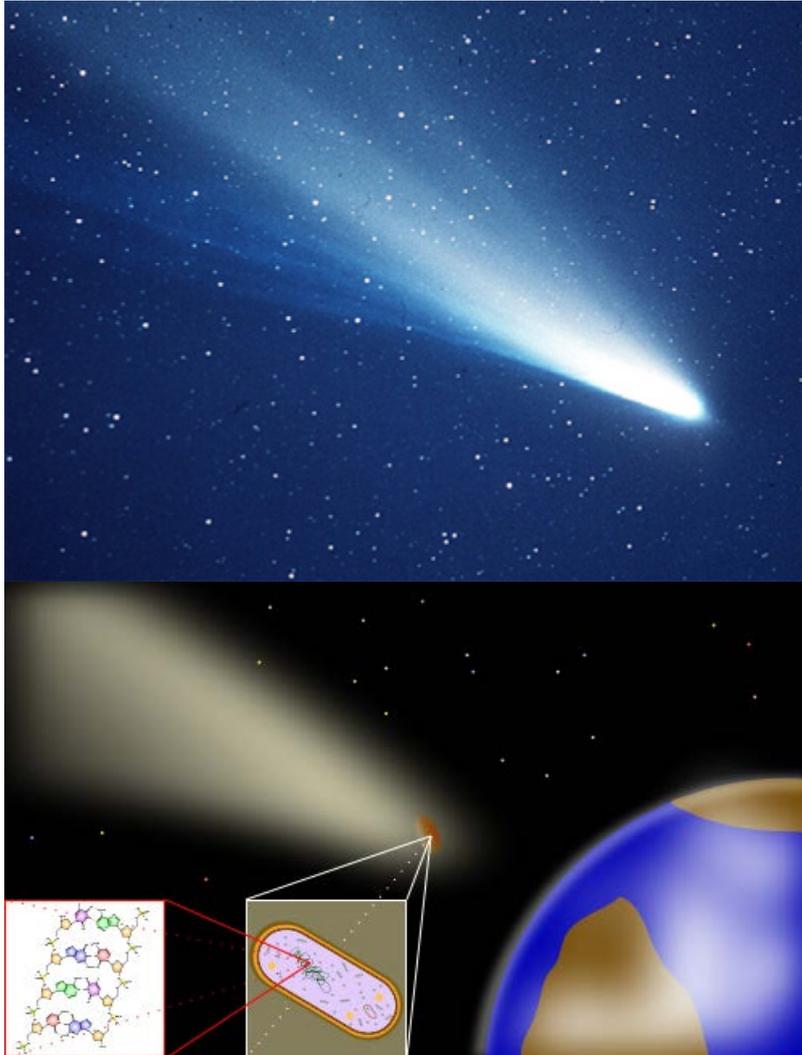


- Chemical evolution transfers dexterity to more complex organic molecules.
- The mechanism might be universal for life origins in our universe.



If this model is correct, molecules of life would appear to have been created in the molecular clouds of the galaxy, with their Enantiomerism determined by processes induced by a near-by supernovae, and subsequently either transported to Earth in meteorites, swept up as the Earth passed through molecular clouds, or included in the mixture that formed Earth when the planets were created.

Seeding Earth



Enormous flow of meteoritic material during the Hadean period of the solar system. Probably not enough time for having formed complex molecules by early cool sun. Seeding within first Billion of years or long-term seeding according to Panspermia Theory

Present Frequency of Impactors:

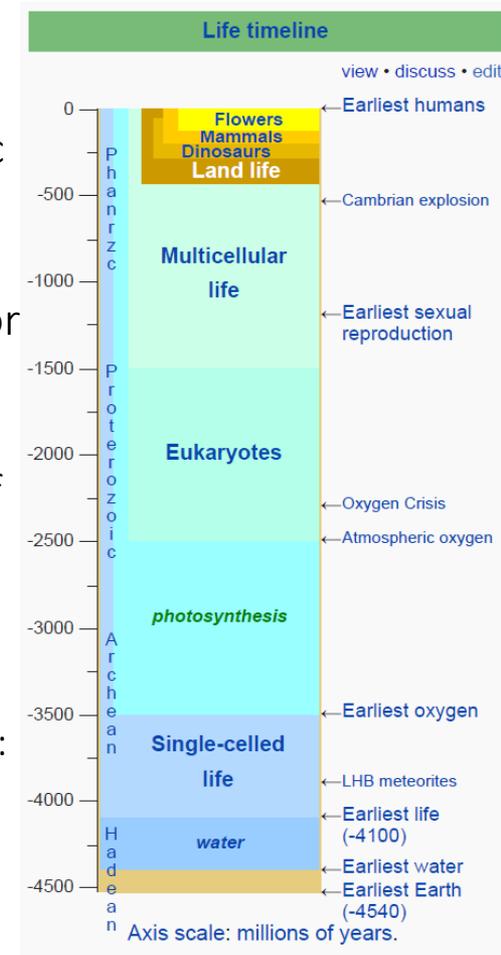
- Pea-size meteoroids - 10 per hour
- Walnut-size - 1 per hour
- Grapefruit-size - 1 every 10 hours
- Basketball-size - 1 per month

50-m rock that would destroy an area the size of New Jersey - 1 per 100 years

1-km asteroid - 1 per 100,000 years

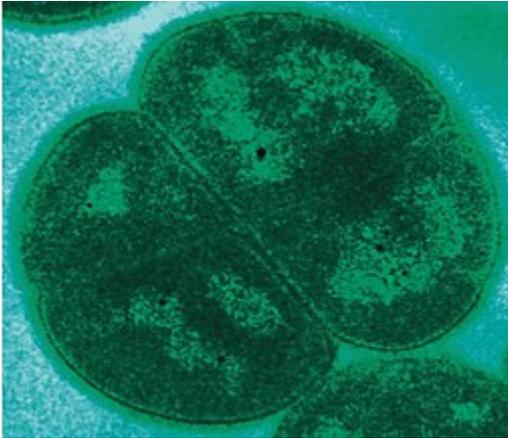
2-km asteroid - 1 per 500,000 years

A "nemesis" comet impactor would give us only a 6-month warning.



Conan the Bacterium

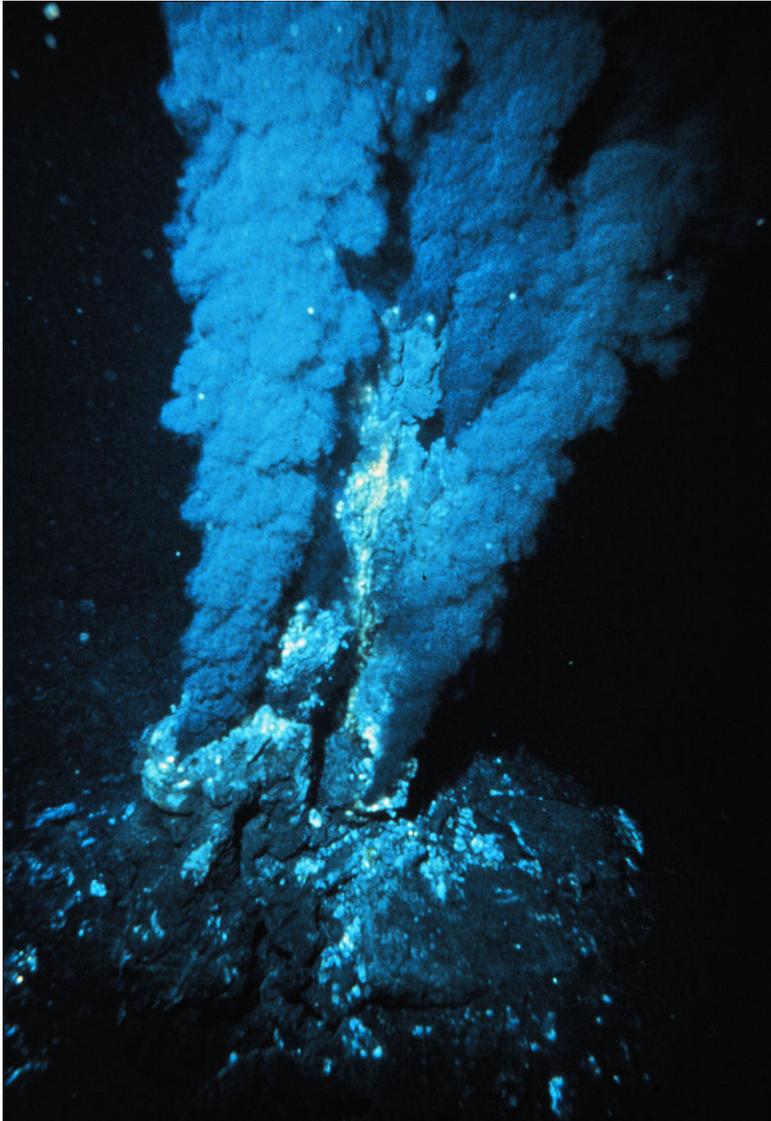
Arguments against panspermia or any other theses suggesting life is from space are the exceedingly cold temperatures in interstellar environments and the extremely high level of radiation near stars.



Deinococcus radiodurans is one of the most radiation-resistant organisms known. It can survive cold, dehydration, vacuum, and acid, and is therefore listed as the world's toughest bacterium in *The Guinness Book of Records!* It can survive a radiation level of 1.5 million rads. It will survive into a post-nuclear world.

Deinococcus accomplishes its resistance to radiation by having multiple copies of its genome and rapid DNA repair mechanisms. It usually repairs breaks in its chromosomes within 24 hours by a 2-step process. First, *D. radiodurans* reconnects chromosome fragments by a process called single-stranded annealing. In the second step, multiple proteins mend double-strand breaks through homologous recombination. This process does not introduce any more mutations than a normal round of replication would, but could lead to less radiation safe DNA and chromosome composition in a less radiation prone environment.

Alternative Origin or further Processing?



Hydrothermal vents are the result of seawater percolating down through fissures in the ocean crust in the vicinity of spreading centers or subduction zones (places on Earth where two tectonic plates move away or towards one another). The cold seawater is heated by hot magma and reemerges to form the vents. Seawater in hydrothermal vents may reach temperatures of over 700° Fahrenheit. Hot seawater in hydrothermal vents does not boil because of the extreme pressure (~300 atm) at the depths where the vents are formed.

When the fluid rises up through the seafloor, it carries many new chemicals with it, such as copper and zinc. These chemical reactions also remove chemicals from the seawater, such as oxygen and magnesium. These elements are important catalysts and ingredients for building complex organic molecule systems.

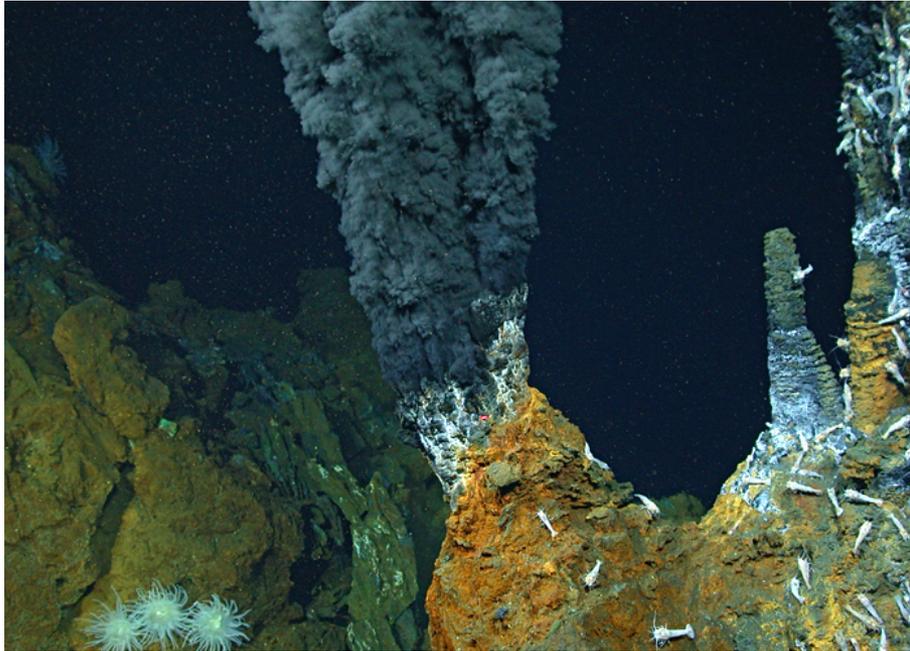
Chemical Ingredients Steaming from Vent

Composition is mm = mmol/kg fluid.

Vent Site	Tem °C	Cl, mm	H ₂ , mm	H ₂ S, mm	Br, mm	Na, mm	K, mm	Ca, mm	SiO ₂ , mm	Sr, μm	Fe, μm	Mn, μm	Cu, μm	Zn, μm	Rb, μm	Al, μm	B, μm	Li, μm	Ni, μm	Co, μm	Cd, nm	Cs, nm	Pb, nm	Be, nm	Ag, nm	Mo, nm
#1	347° C	426	0.33	7.4	0.71	352	24.6	33	14	135	900	300	10	42	28.0	8.5	810	375	2.3	0.14	110	345	275	52	15	101
#2	350° C	418	0.52	13	0.67	333	22.8	27.5	13.9	125	2000	475	15	35	26.0	8.4	825	315	1.6	0.20	30	320	60	85	6	78
#3	368° C	208	0.62	22	0.34	166	10.0	12	9.2	63	2200	550	25	32	11.0	4	800	160	0.8	0.14	65	115	100	100	9	68
#4	375° C	32	0.70	25	0.08	27.2	1.42	0.88	3.8	5	350	70	10	155	1.5	1.2	960	25	0.2	0.04	225	15	525	75	12	37
#5	379° C	39	0.96	20	0.05	31.1	1.94	1.85	2.9	10	400	90	12	18	2.0	1.3	980	30	2.0	0.10	25	25	100	72	4	38
Sea-water	25°C	550			0.84	470	10.2	10.3	0.10	87	0.01															

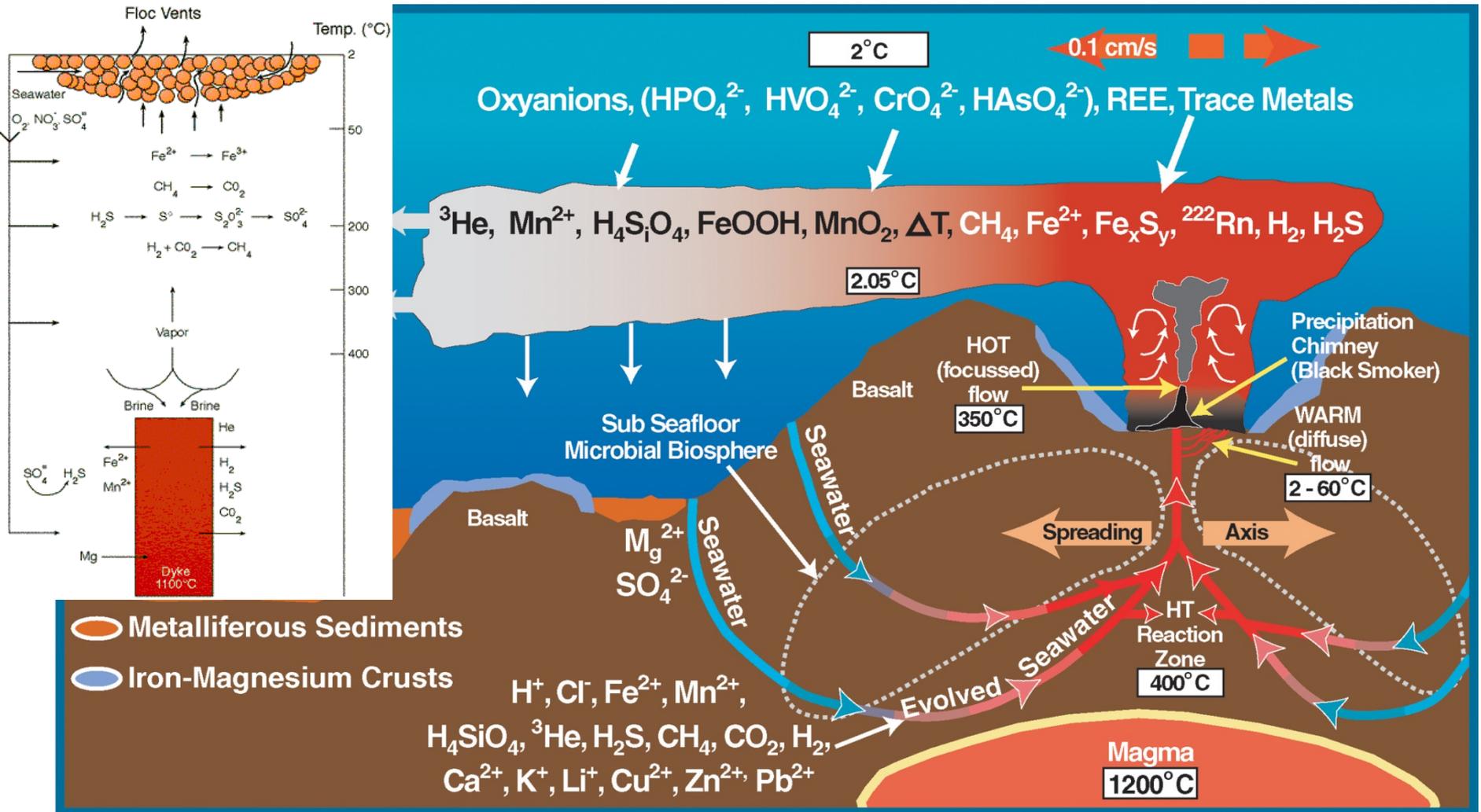
Admixtures also contain radioactive elements, but most of the energy comes as thermal energy from the hot (magma heated) vents. In this hot mineral rich environment lots of chemical reactions can occur that may serve either as first steps to life or as a breeding ground for Conan the bacterium and his descendants.

Black Smoker – White Smoker

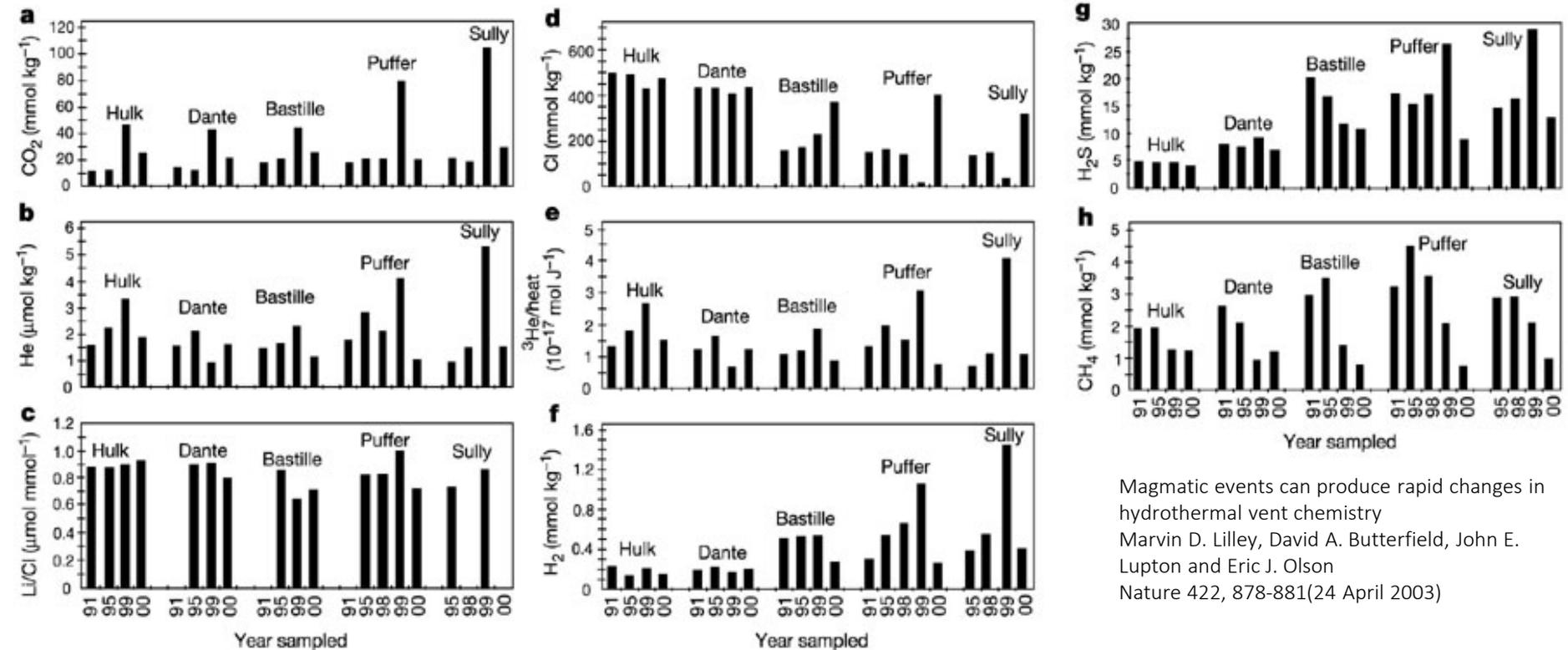


A venting black smoker emits jets of particle-laden fluids. The particles are predominantly fine-grained sulfide minerals formed when the hot hydrothermal fluids mix with near-freezing seawater. These minerals solidify as they cool, forming chimney-like structures. “Black smokers” are chimneys formed from deposits of iron sulfide, which is black. “White smokers” are chimneys formed from deposits of barium, calcium, and silicon, which are white.

The Chemistry of Hydrothermal Vents



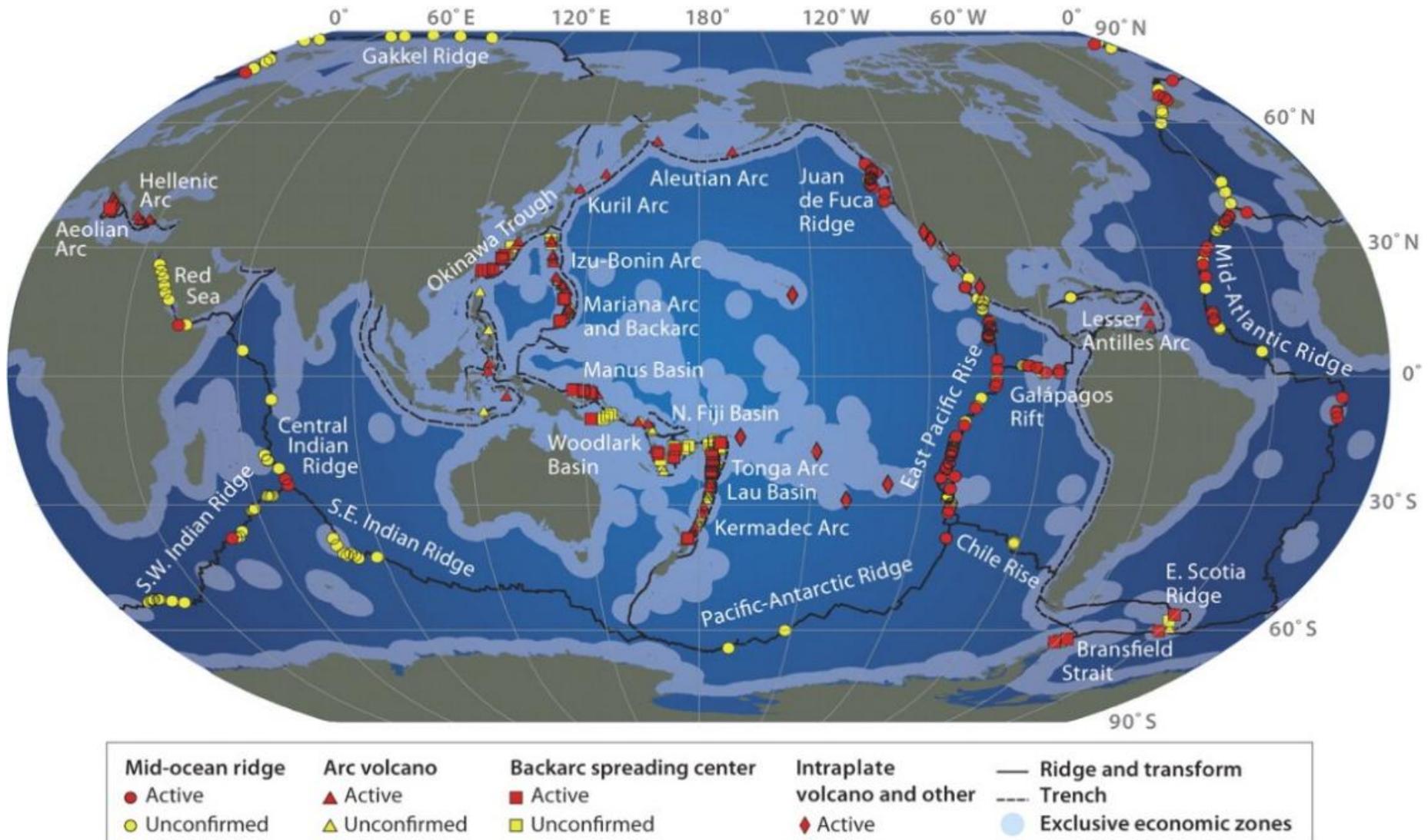
Concentrations of main molecules in vent gases



Magmatic events can produce rapid changes in hydrothermal vent chemistry
 Marvin D. Lilley, David A. Butterfield, John E. Lupton and Eric J. Olson
 Nature 422, 878-881(24 April 2003)

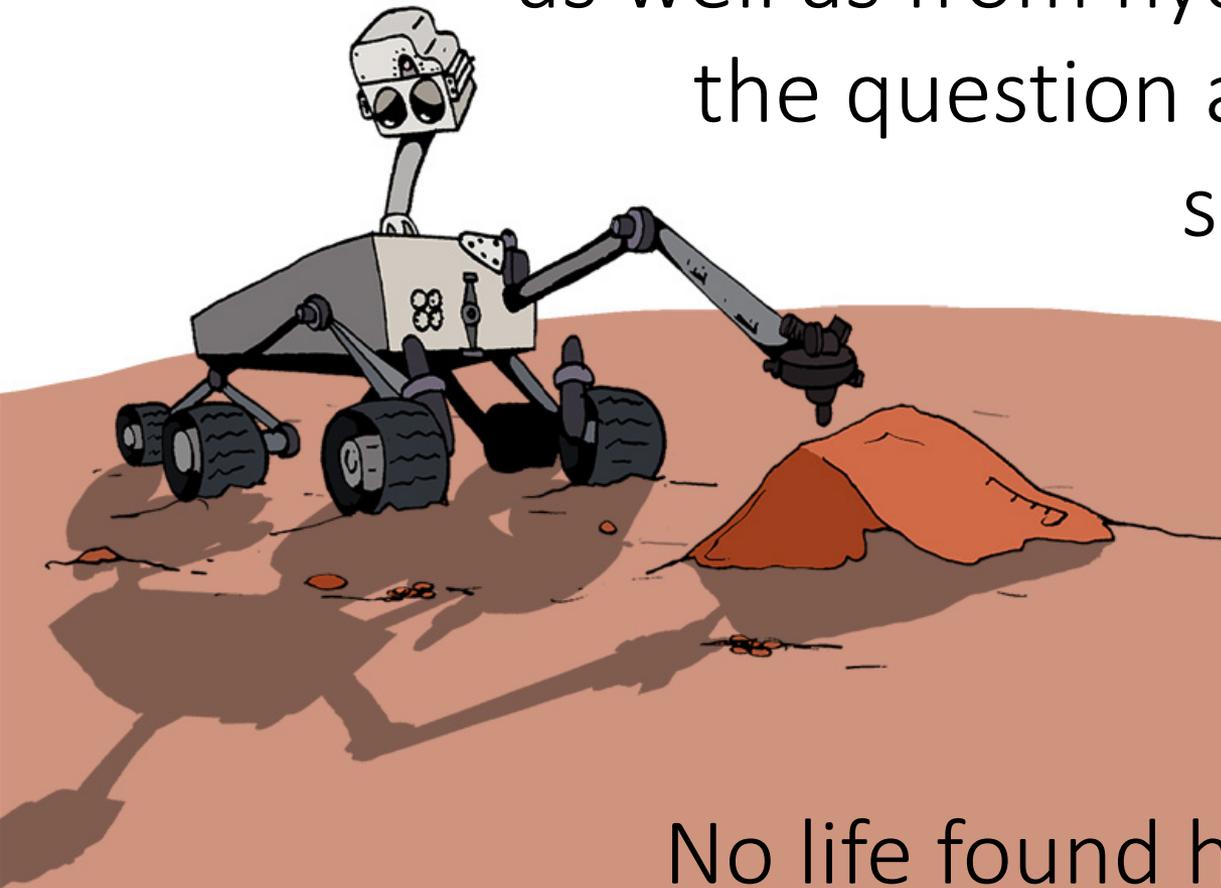
Shown are the concentrations of CO_2 (a), He (b), Cl (d), H_2 (f), H_2S (g) and CH_4 (h); also shown are the ratios Li/Cl (c) and $^3\text{He}/\text{heat}$ (e).

The Locations of Hydrothermal Vents



Newly formed organic materials will become part of the freshly formed deep-sea crust

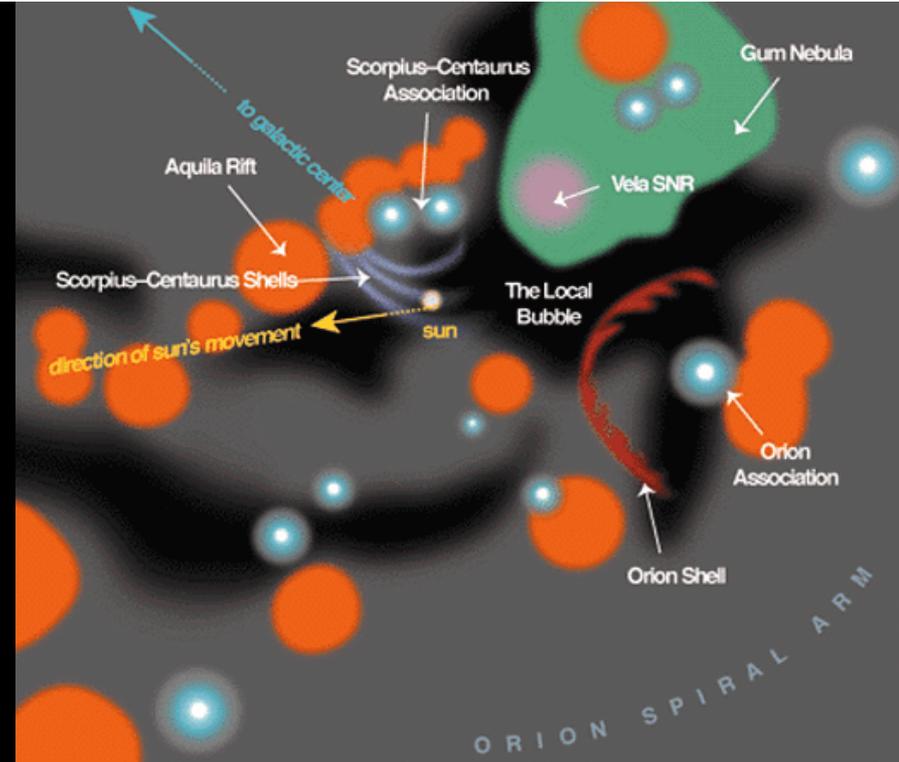
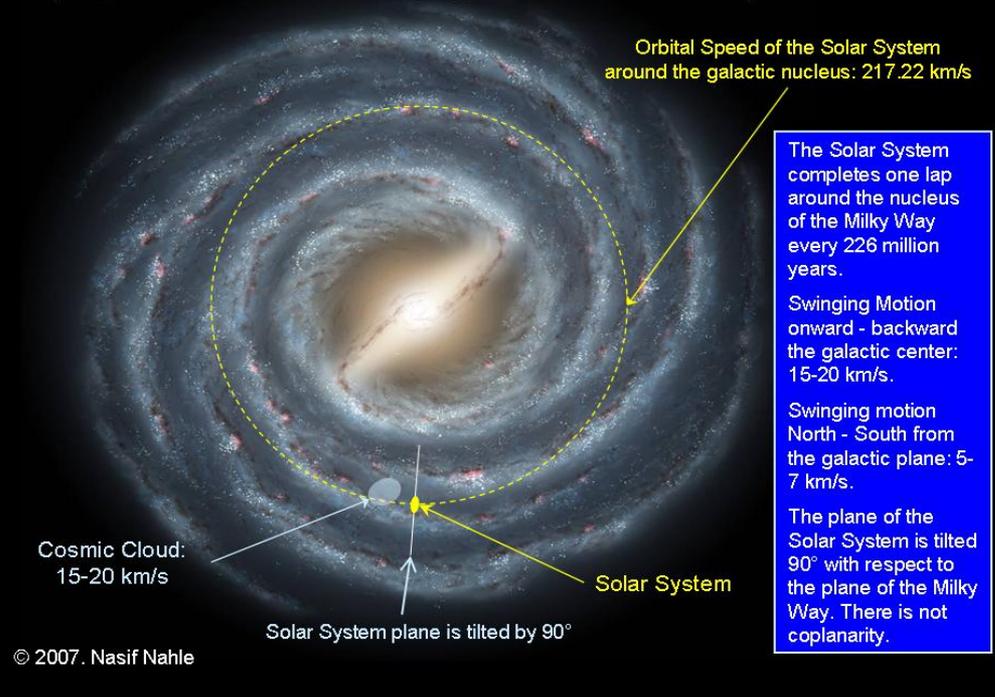
Multiple probes have been taken from asteroid and meteorite space samples as well as from hydrothermal vents, the question about the original site remains open.



No life found here. The search for the origin of life is still on!

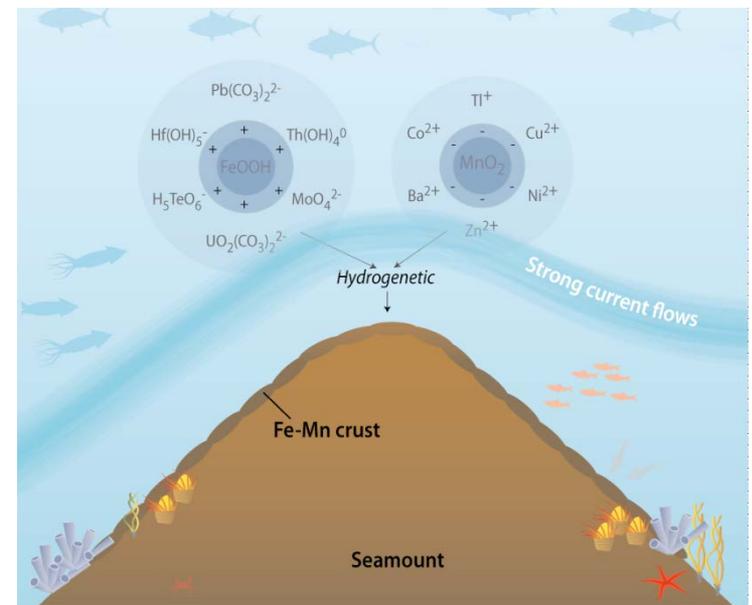
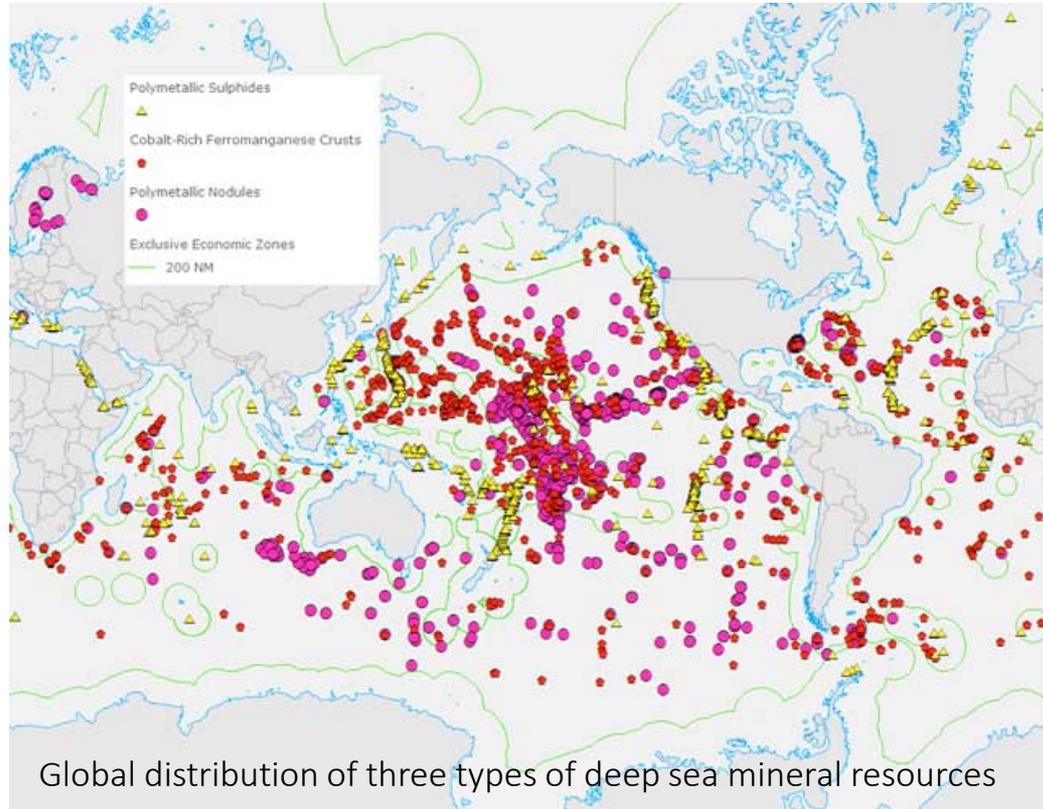
Cosmic Impacts

Milky Way Illustration Credit: © R. Hurt (SSC), JPL-Caltech, NASA. Survey Credit: GLIMPSE Team

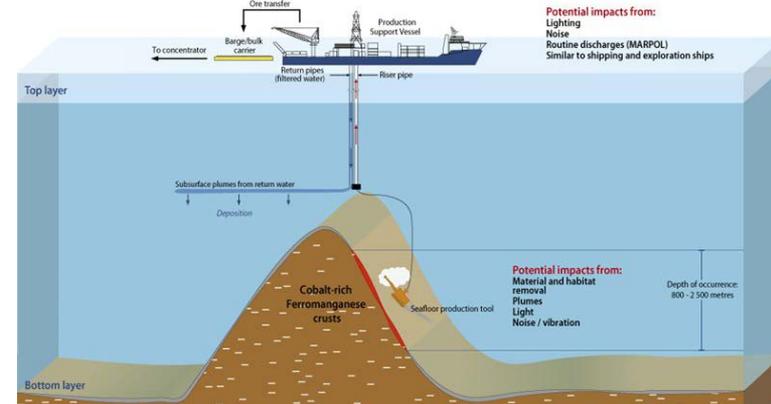
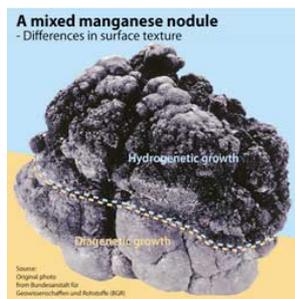


The solar system circles around the galactic center once every 226 Million years on a tilted orbital plane in a swinging motion. On its trajectory it passes through different regions of density and activity, regions of star formation and star death. Presently it moves through the so-called local bubble, an area of low activity. There was nearby supernova activity in the past and there will be areas of supernova activity in the future.

Finding the Evidence

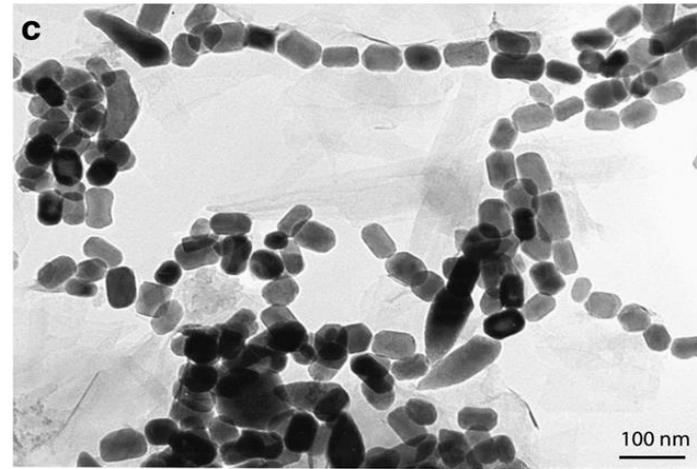


Cobalt-rich ferromanganese crusts are solid layers that form when manganese and iron precipitate out of cold seawater. They may contain cobalt, nickel, and some rare earth elements and could provide up to 20% of the global cobalt demand.

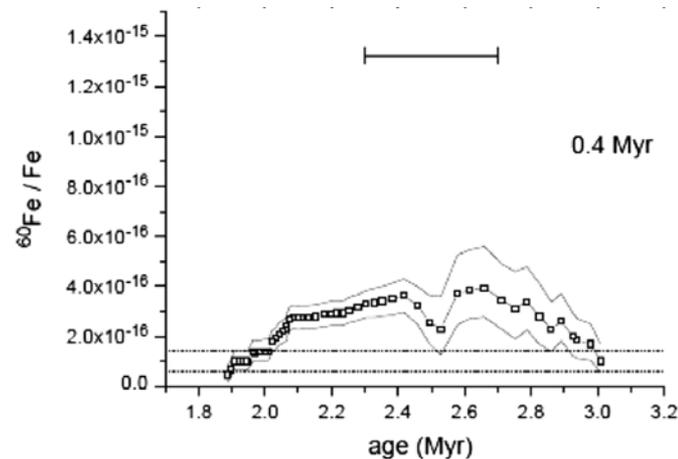
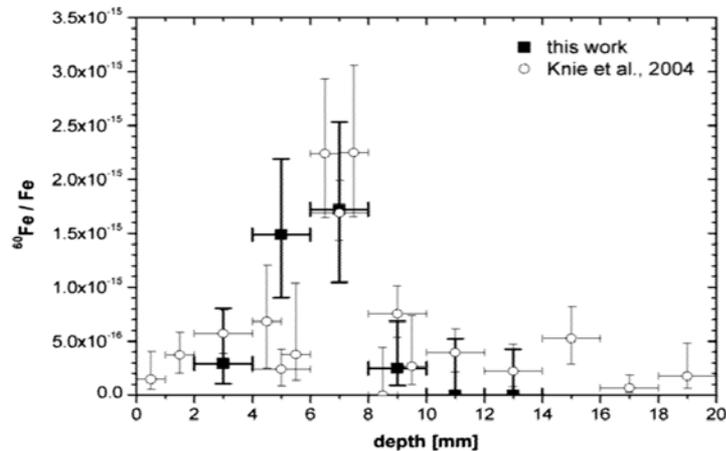


Deep sea mining of manganese nodules and cobalt-rich ferromanganese crusts

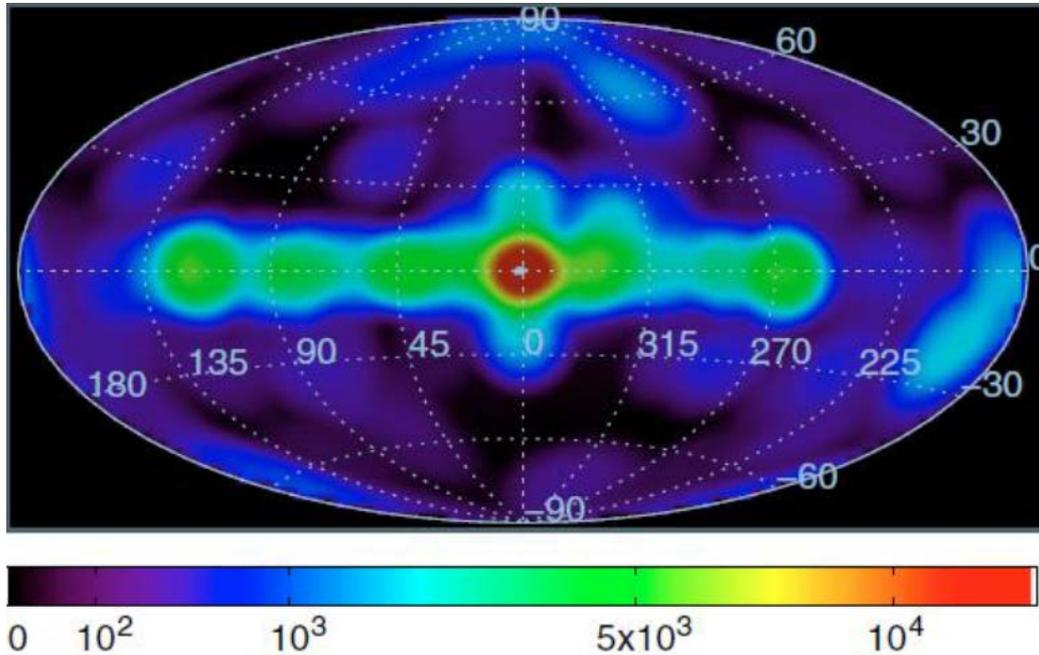
The evidence of near-by supernovae



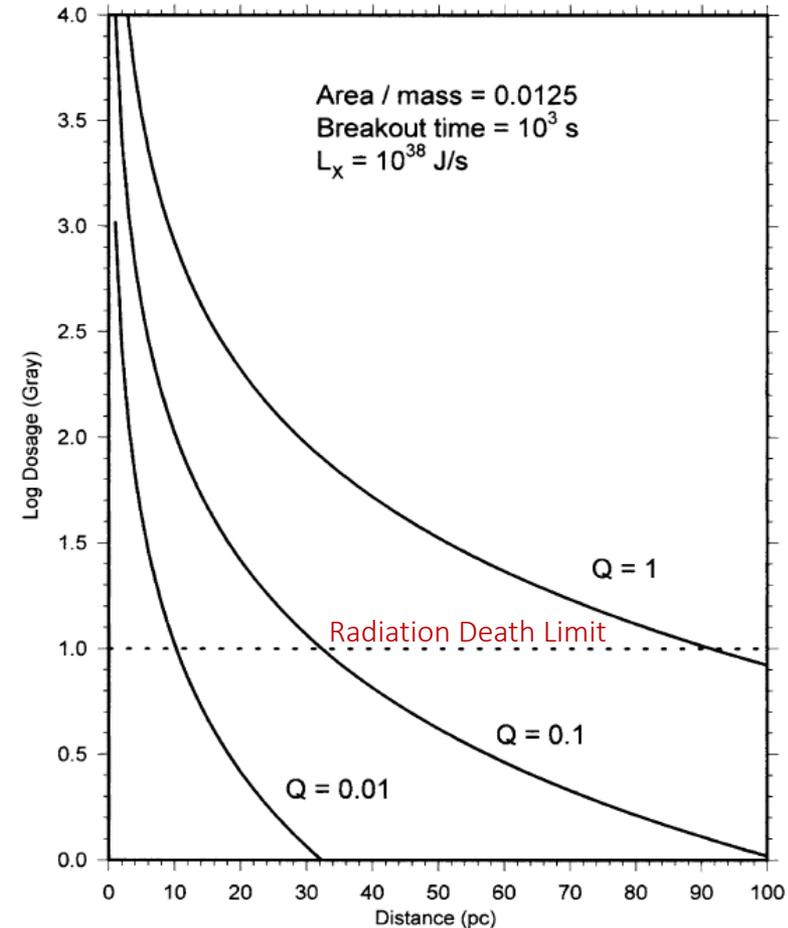
Measurements of isotope distribution as a function of depth in the ferro-manganese crust as well as in magnetotactic bacterial found in deep sediments indicates an enrichment in ^{60}Fe ($T_{1/2} = 2$ million years) at a depth level that corresponds to a deposition time between 2 and 3 Million years ago. 1 Million years of crossing a supernova remnant.



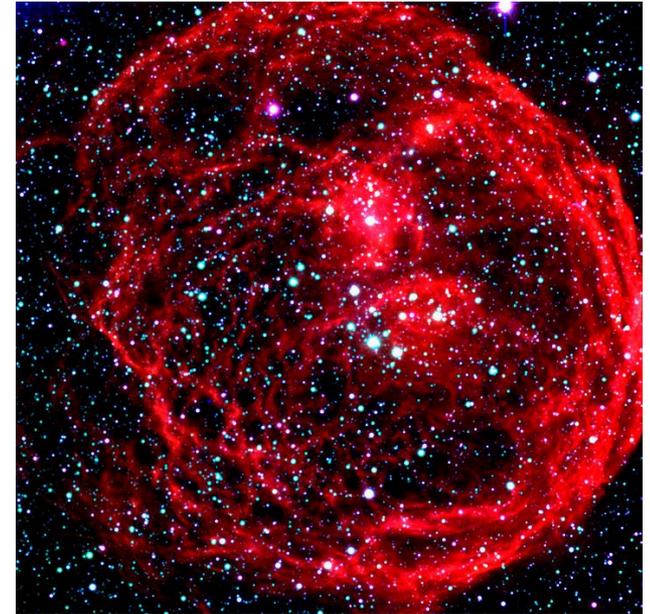
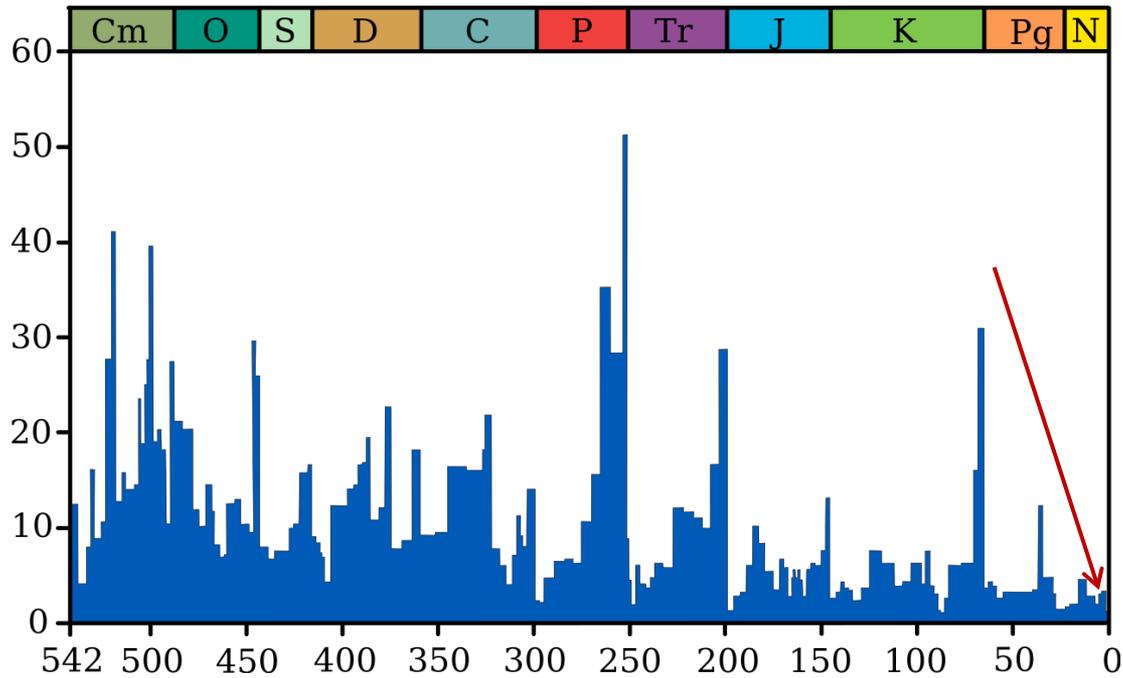
Galactic distribution of ^{60}Fe



The radiation flux from supernova on earth surface depends on the shielding power of atmosphere is typically 99% , $Q=1\%$ reaches the surface. However high radiation intensity breaks-up the protective Ozone layer and transmission increases transmission to $Q=10\%=0.1$. In that case a supernova closer than 35pc would generate more than 10Gy in dosage, deadly for the normal human being. In distances between 35 and 100 pc, the average dose varies between 10 and 1 Gy, causing considerably enhanced mutation rates in biological systems. There is no strong evidence for large extinction between 2 and 3 Million years, but possibly some evidence for mutational change in pre-hominide creatures.



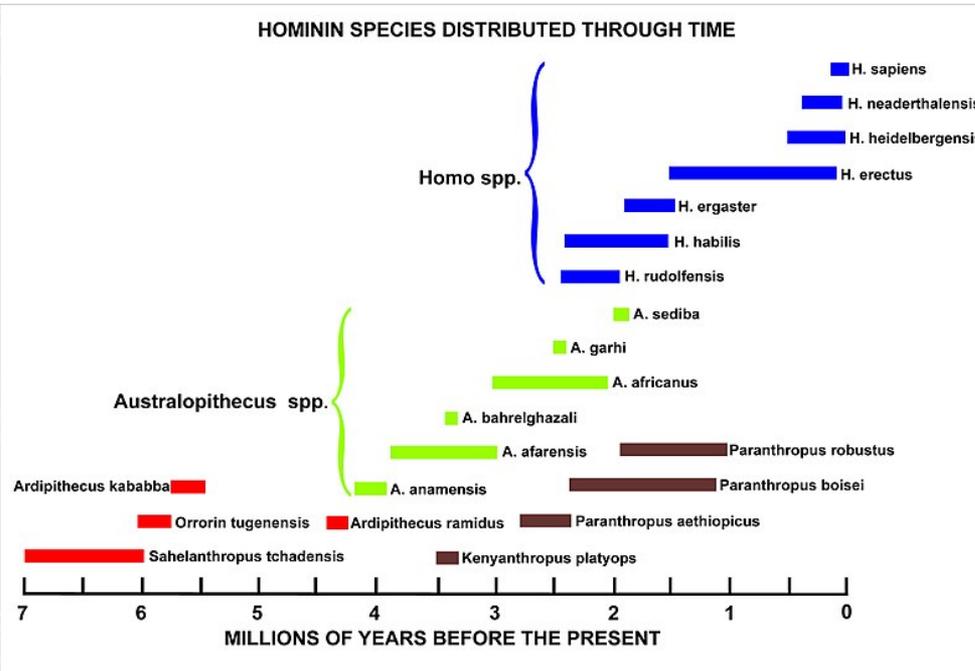
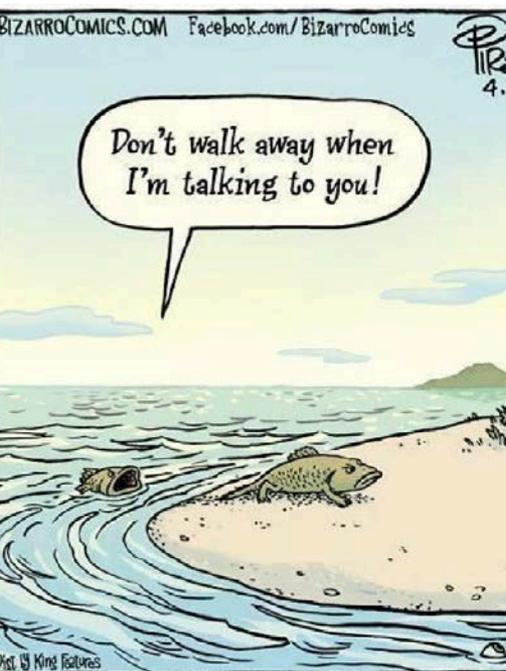
Any Global Evidence in Extinction Record?



2.6 Million years ago is the transition from Pliocene to Pleistocene, characterized by the decline of ocean species. Temperatures had suddenly dropped and a cooling period caused expansion of arctic zones. The shift of ocean currents was assumed to provide the explanation, but a cataclysmic supernova event near-by might offer a different cause. Nearby stellar systems at a distance between 50-100 pc was the Scorpion Centaurus association near the star Antares, with high supernova activity rate.

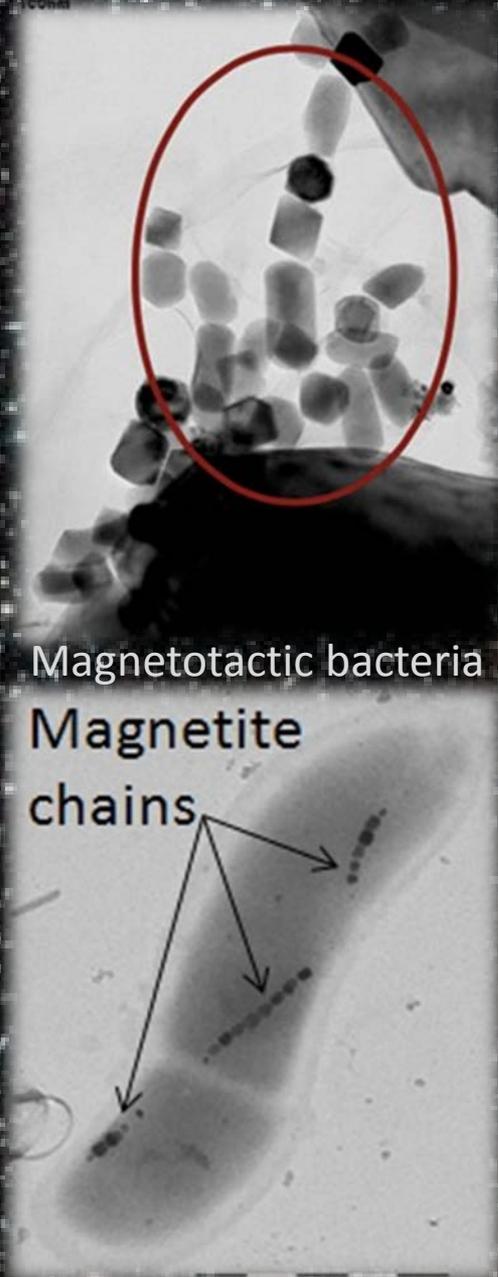
2.5 M years ago?

Could be the sudden development of bi-pedalism, talking ability, and language a reflection of an enhanced mutation rate 2.5 Million years ago?



This is a speculation like the speculation about an extinction event. More research is needed

Biological evidence?



Fine-grained debris from a supernova explosion could pass through Earth's atmosphere, rapidly oxidizing in the process. The nano-particles would rapidly dissolve in oxygen, form rust, and eventually settle in the sediment along the ocean floor, where the bacteria would suck them up for their crystal chains.

When the bacteria eventually die, those chains remain behind in the sediment, and ^{60}Fe would be locked inside. So any traces of ^{60}Fe found in that sediment would constitute a kind of biogenic signature of a supernova event, preserved in the fossil record.

The path to the bottom

