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The chemical evolution in open space: An experimental approach

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dust is the flesh of time

J.Brodsky

silicate dust (olivine, pyroxene) is common in many astrophysical settings
circumstellar, interstellar, and interplanetary environments

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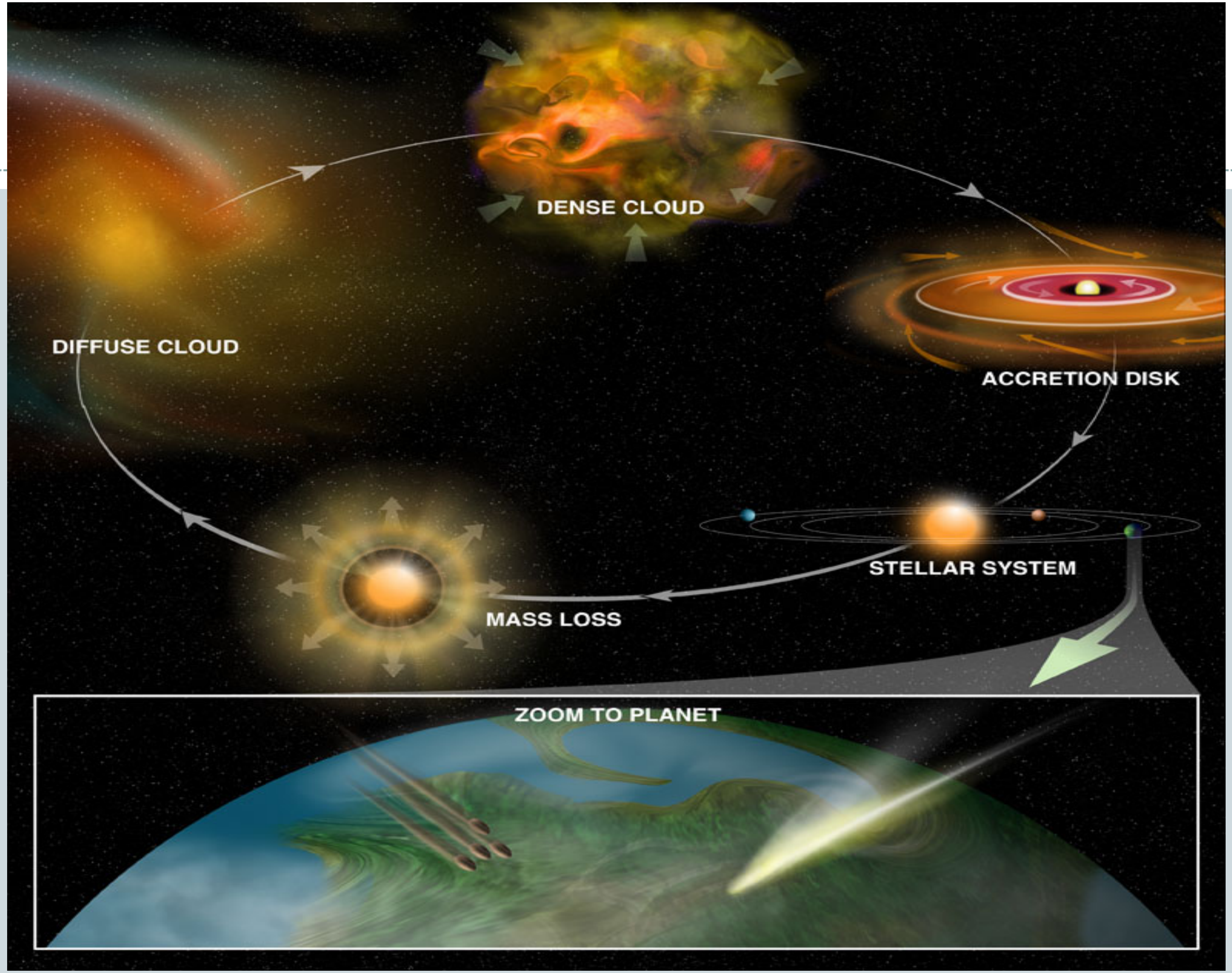
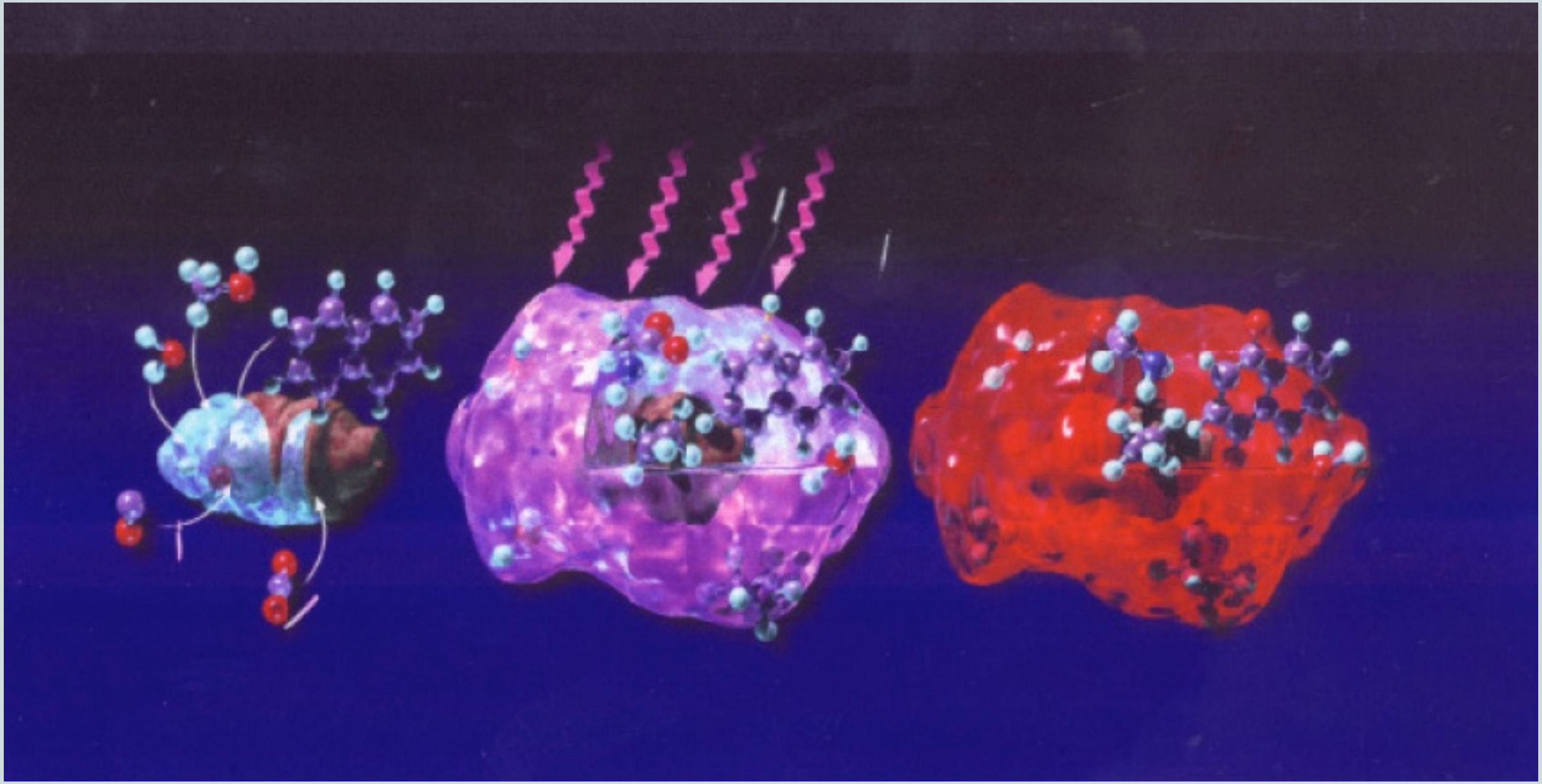

DENSE CLOUD
ACCRETION DISK
DIFFUSE CLOUD
STELLAR SYSTEM
MASS LOSS
ZOOM TO PLANET

the main place of interstellar chemistry – icy mantles on interstellar dust particles



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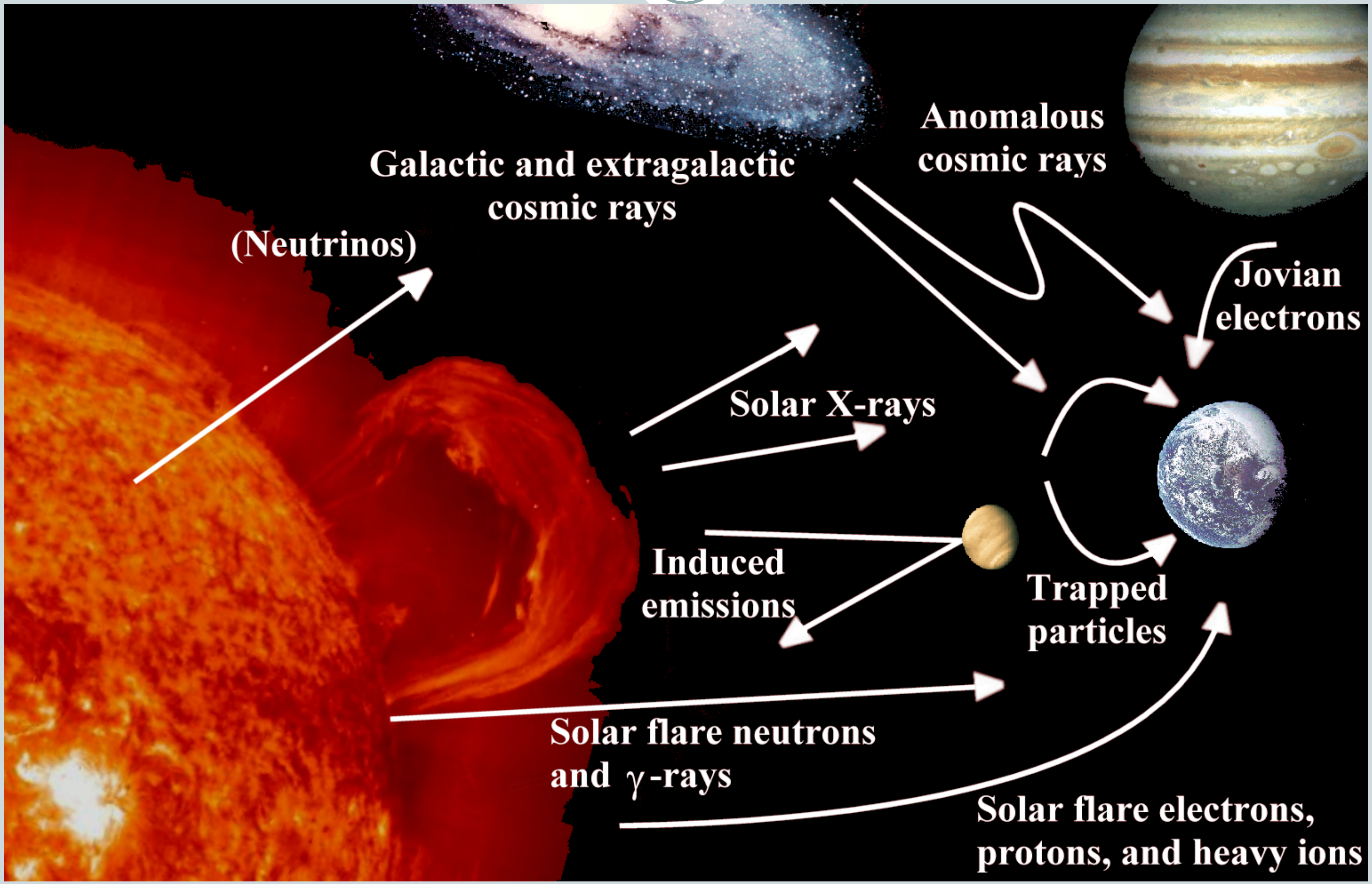
energy fluxes in the interstellar medium

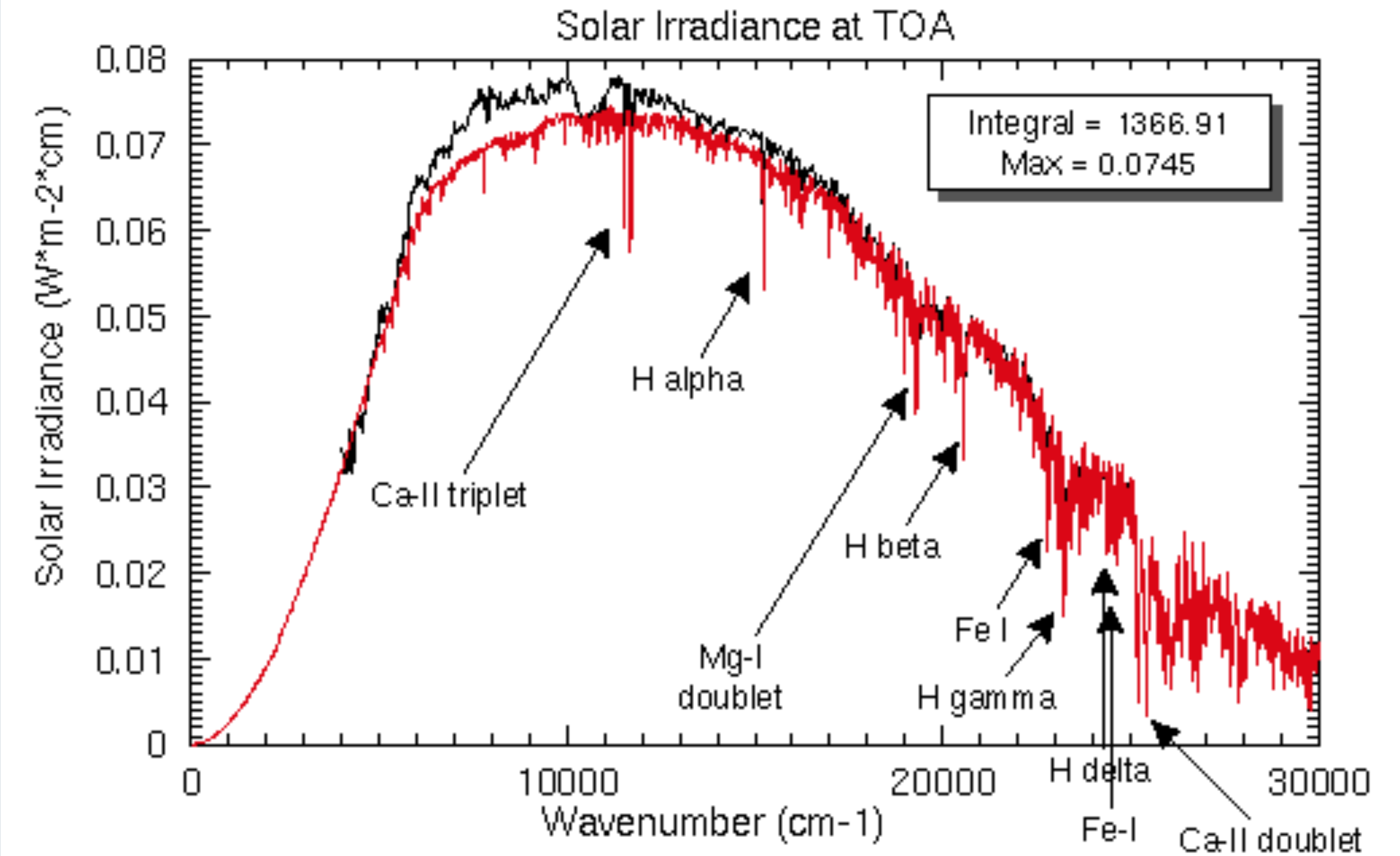
Environment (ice residence time in years)	Ion Processing			Photon Processing		
	Flux, 1 MeV p^+ (eV cm^{-2} s^{-1})	Energy absorbed (eV cm^{-2} s^{-1})*	Dose (eV $molecule^{-1}$)	Flux (eV cm^{-2} s^{-1})	Energy absorbed (eV cm^{-2} s^{-1})	Dose (eV $molecule^{-1}$)
Diffuse ISM (10^5–10^7)†	1×10^7	1.2×10^4	<1–30	9.6×10^8 at 10 eV†	5×10^8 0.02 μm ice	10^4–10^6
Dense cloud (10^5–10^7)†	1×10^6	1.2×10^3 0.02-μm ice	≪1–3	1.4×10^4 at 10 eV	1.7×10^3 0.02 μm ice	<1–4
Protoplanetary nebula (10^5–10^7)‡	1×10^6	1.2×10^3 0.02-μm ice	≪1–3	2×10^5 at 1–10 keV	§5×10^4 0.02 μm ice	2–240
Oort cloud (4.6×10^9)	φ(E)**	**	~150 (0.1 m) ~55–5 (1–5 m) <10 (5–15 m)	9.6×10^8 at 10 eV	9.6×10^8 0.1 μm ice	2.7×10^8
Laboratory (4.6×10^{-4})††	8×10^{16}	2×10^{15} 1-μm ice	10	2.2×10^{15} at 7.4 eV	2.2×10^{15} 1 μm ice	10

Colangeli et al., 2005

radiation environment affecting the surface of the solar system bodies



solar radiation



45% - IR
47% - visible
7% - UV

1.371 kW/m² - the solar constant at 1AU

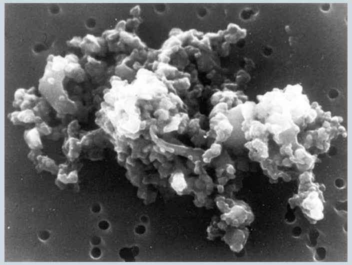
classification of delivering vehicles

Extraterrestrial matter is broadly divisible into three groups by size:

large impactors (comets and large asteroids),

meteorites,

interplanetary dust particles.



The total flux of extraterrestrial material to the surface of the early earth is estimated as being between 2×10^{20} kg (Marty and Yokochi, 2006) and 5×10^{22} kg (Owen 1998).

CARBON IN METEORITES

	%
organic matter	2.0
carbonate	0.2
diamonds	0.04
graphite	0.005
silicon carbide	0.009

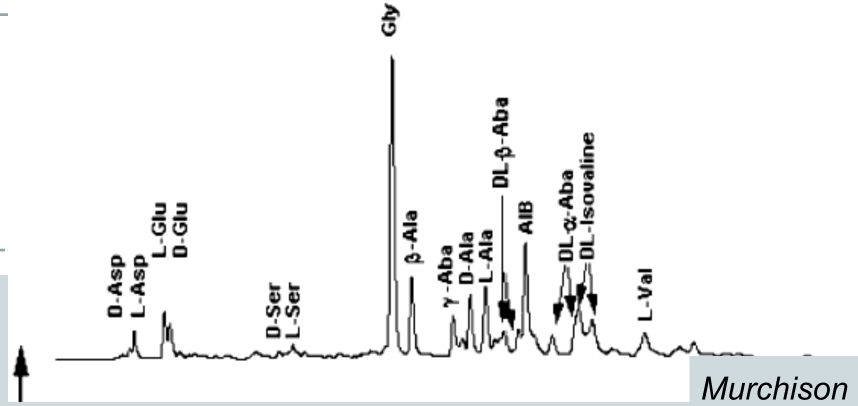
carbonaceous chondrites

Murchison **(CM)**

Orguel **(CI)**

Allende **(CV3)**

amino acids in meteorites



from **883** ppb (Tagish Lake) up to **12270** ppb (Murchison)

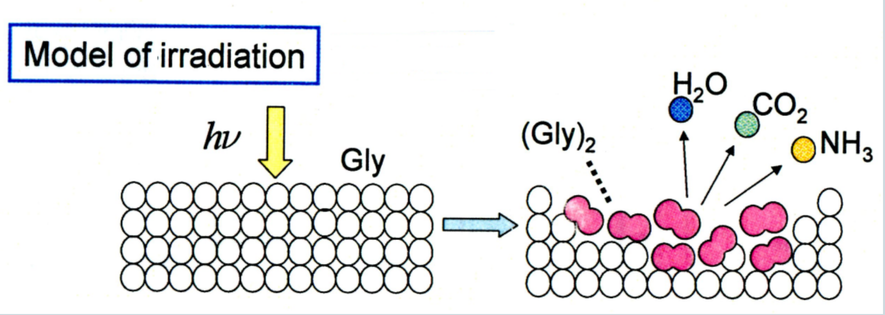
- 78 amino acids (including 7 ones from peptides and 11 ones from earth biosphere;
- length of carbon chains from 2 to 9 atoms;
- there are all possible isomers, the branched ones are predominate;
- α-amino acids more spread (α>γ>β)
- concentration diminish along with chain increasing;
- all amino acids display σD values that are much higher than those of terrestrial compounds

some interesting amino acids from CCs

glycine	α-amino-*n*-butyric acid (ABA)
alanine	β-aminoisobutyric acid (AIB)
glutamic acid	norvaline
valine	pipecolic acid
proline	isovaline
aspartic acid	*N*-methylalanine
leucine	β-amino-*n*-butyric acid
	N-methylglycine (sarcosine)
	β-alanine
	N-ethylglycine
	α-aminoisobutyric acid (2-methylalanine)
	γ-amino-*n*-butyric acid

in our experiments the solid mixtures of amino acids were exposed to different energy sources available in open space:

- vacuum ultraviolet photons (VUV);
- ultraviolet photons (UV);
- protons;
- space exposure



it was important to test experimentally how far the process of chemical evolution could take place on the surface of space bodies under action of energy sources available at that period and evaluate a possible role of mineral components in such processes.

amino acids

Character of Amino Acid

Zwitterion at solid phase. (pH vary in aqueous solution.)

→Vapor pressure is very low.

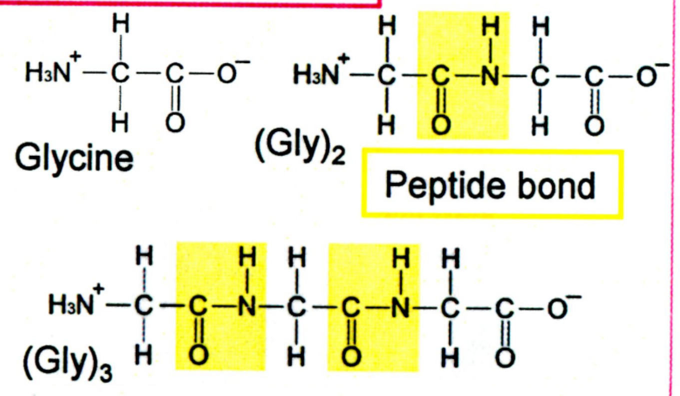
・Stable existence at solid phase in space.

Gly→$(Gly)_2$

Kanako (2005)

Energy (eV)	Resonance	Quantum efficiency ϕ
8.5 (146 nm)	$\pi \rightarrow \pi^*$	0.0060±0.0004
400	N pre-edge	0.12±0.02
407	N 1s → σ^*	0.015±0.003
413	N ionization	0.13±0.01
530	O pre-edge	0.07±0.08
533	O 1s → π^*	–
539	O 1s → σ_1^*	0.020±0.001
860	–	0.032±0.015

Structural formula



abiogenic synthesis of oligopeptides

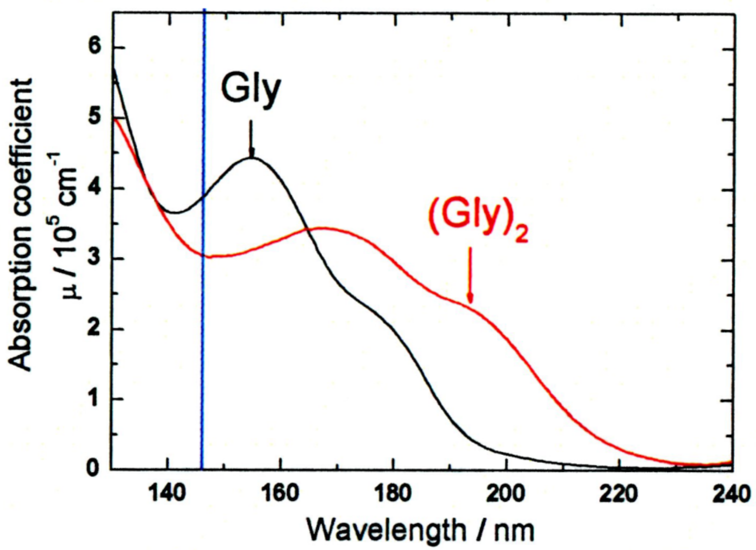
Irradiation of VUV

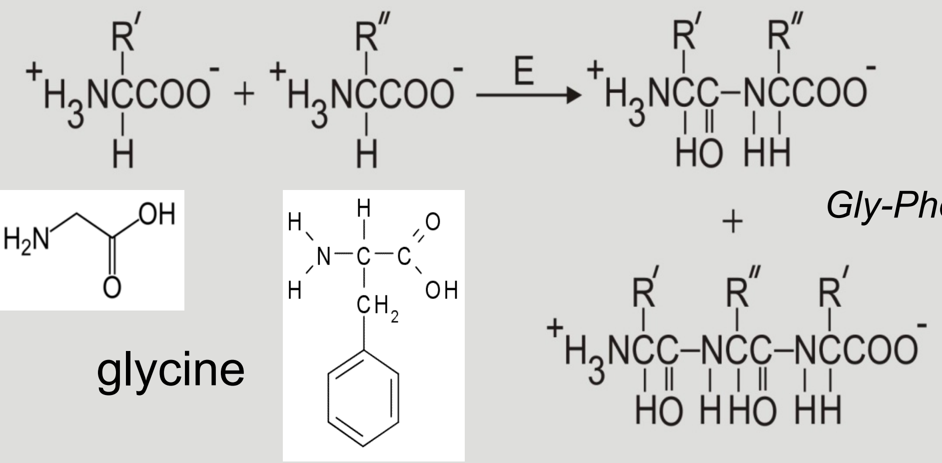
Light source: Kr_2 lamp

Irradiated energy: 8.5 eV (145 nm) → **Excited $\pi \rightarrow \pi^*$ resonance of COO^-**

Light intensity:
6.9×10^{15} (photons/sec·cm^2)

Absorption spectra





glycine

phenylalanine

abiogenic synthesis of Trp-Trp under action of different energy sources

energy source	dose	yield (%)	G
p^+	5.0×10^{11} p^+/cm^2	2.43	1.2×10^{-6}
VUV	3.8×10^{3} J/m^2	1.87	6.0×10^{-8}
$\gamma(Cs^{137})$	3.0×10^{9} J/g	0.41	3.8×10^{-9}

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minerals

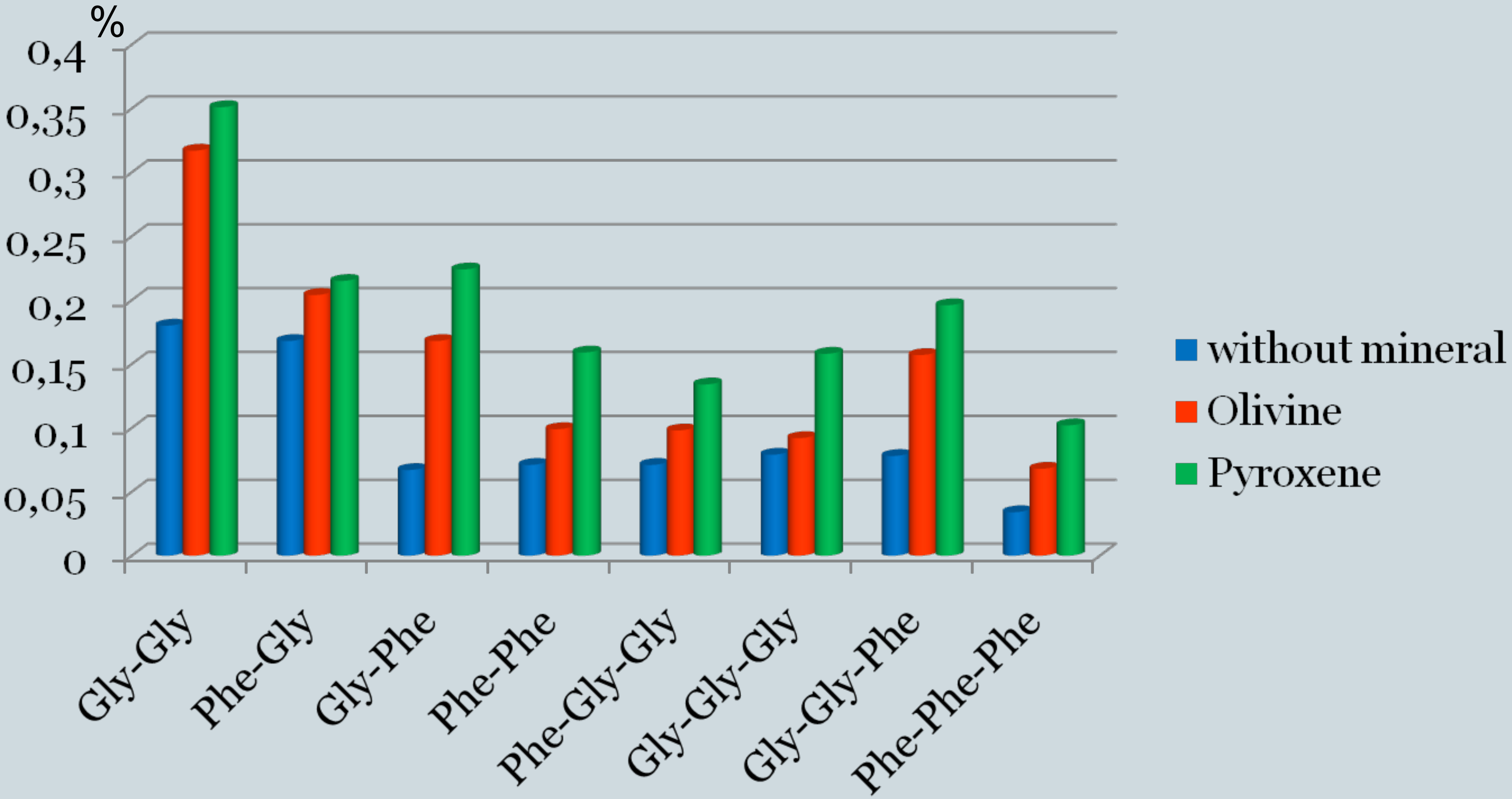
olivine $(Mg_xFe_{1-x})_2SiO_4$

pyroxene $(Mg_xFe_{1-x})SiO_3$

SiO_2

yields of oligopeptides

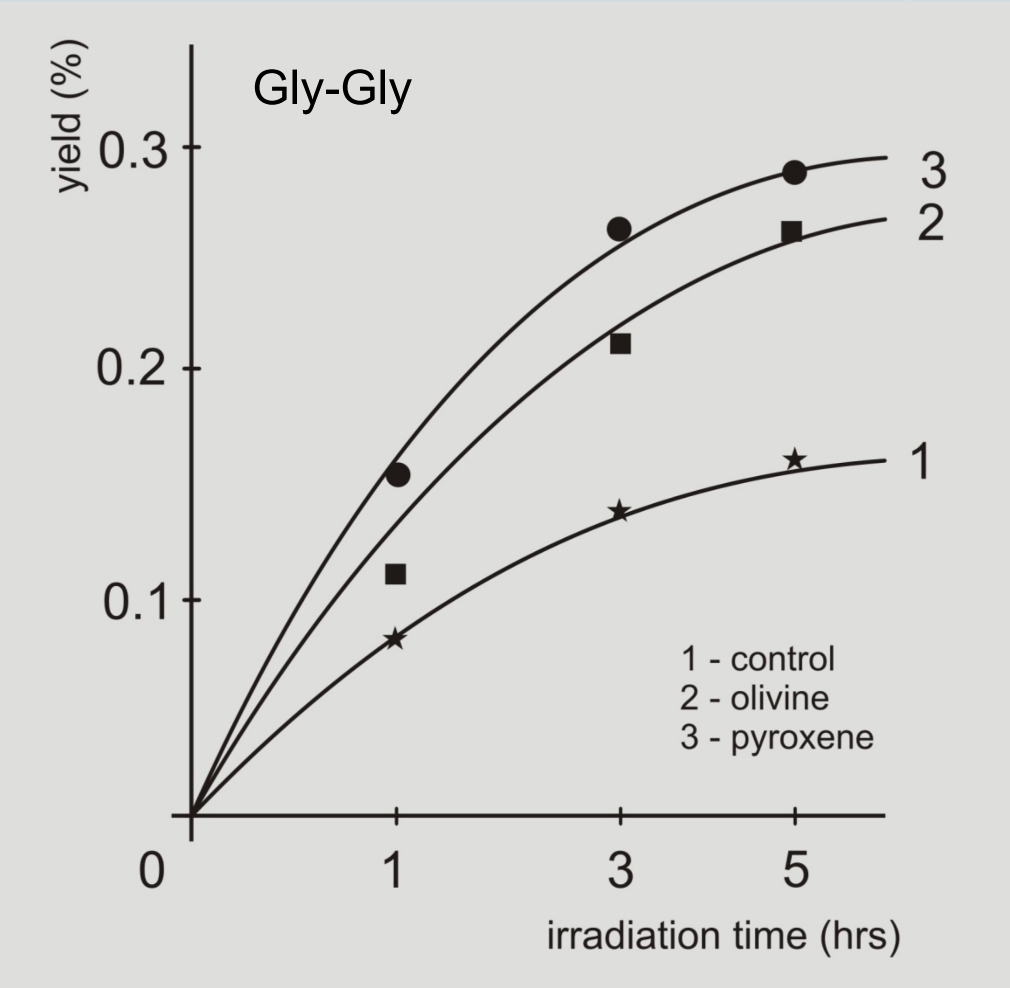
VUV
Gly+Phe

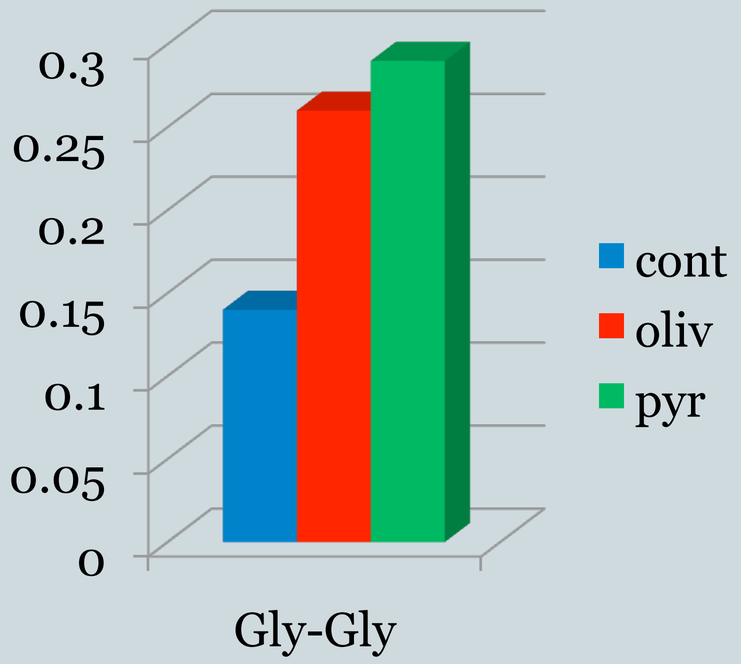


VUV (145 nm), dose 2.1 × 10^5 J/m^2

abiogenic synthesis of Gly-Gly

VUV
Gly+Phe





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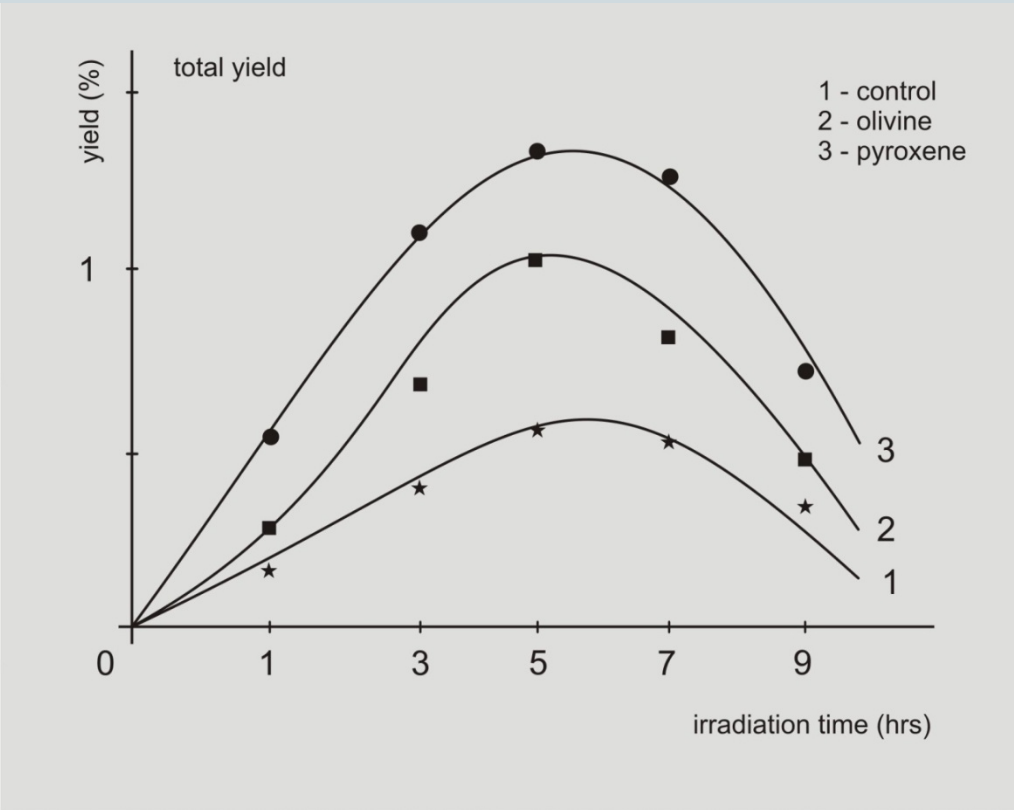
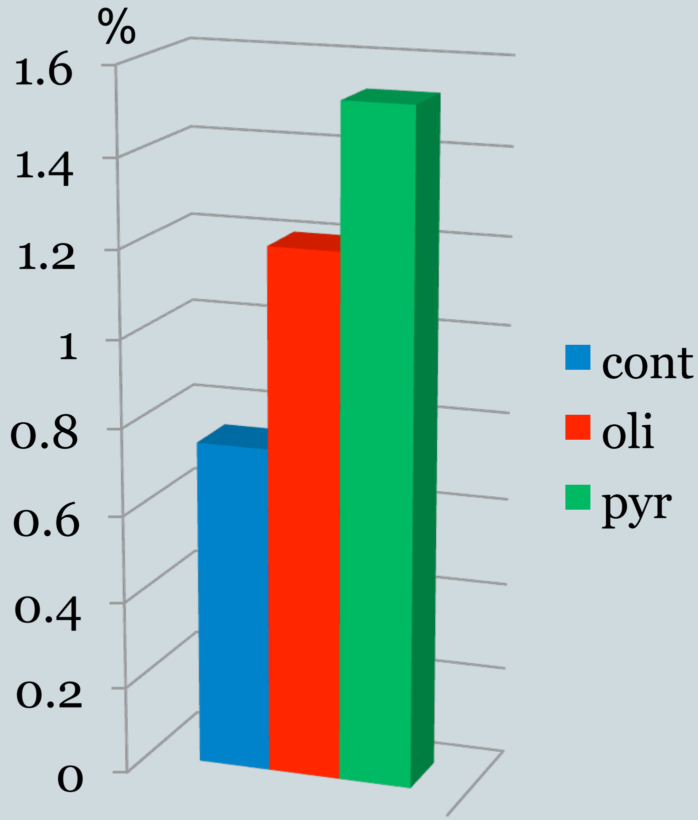
total yields of oligopeptides

VUV
Gly+Phe





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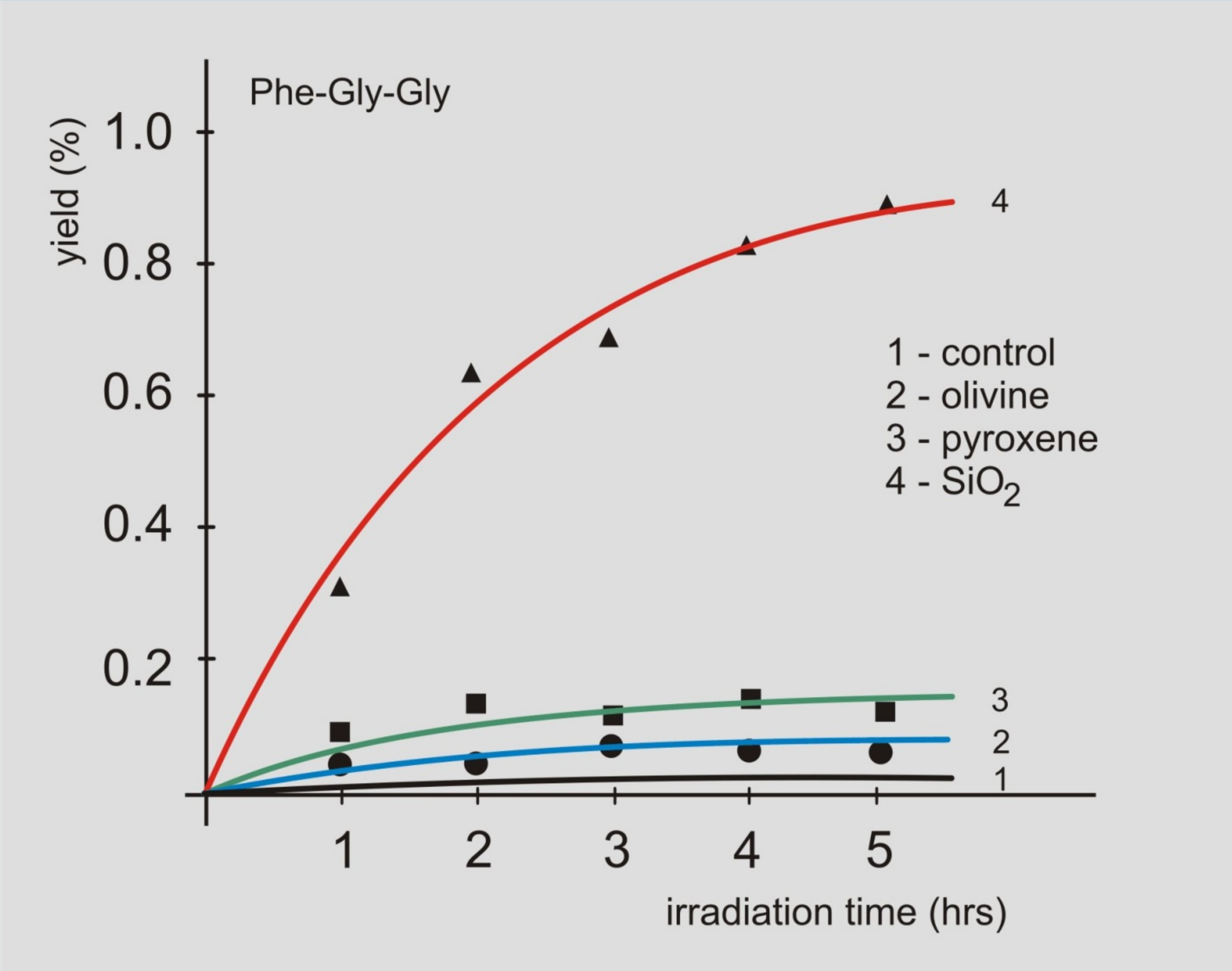
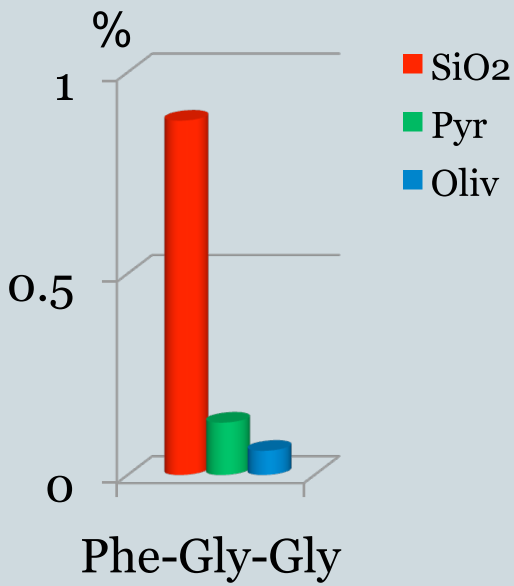
abiogenic synthesis of Phe-Gly-Gly

VUV
Gly+Phe





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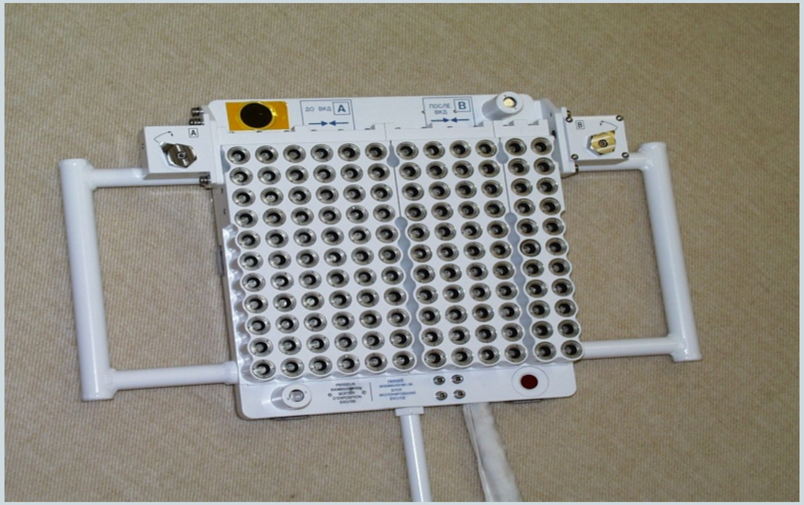
abiogenic synthesis in open space «Perseus-Exobiology»

- in all cases solid films were obtained from similar basic solution of 10 μM Gly and Trp amino acids;
- flight data were calculated as a result of 115-days long exposure on the outside core of MIR space station;
- heating at the temperatures exceeding 60°C triggered formation of dipeptides;
- presence of minerals promoted higher yield.

PERSEUS hardware mounting on the outer shell of Mir core module



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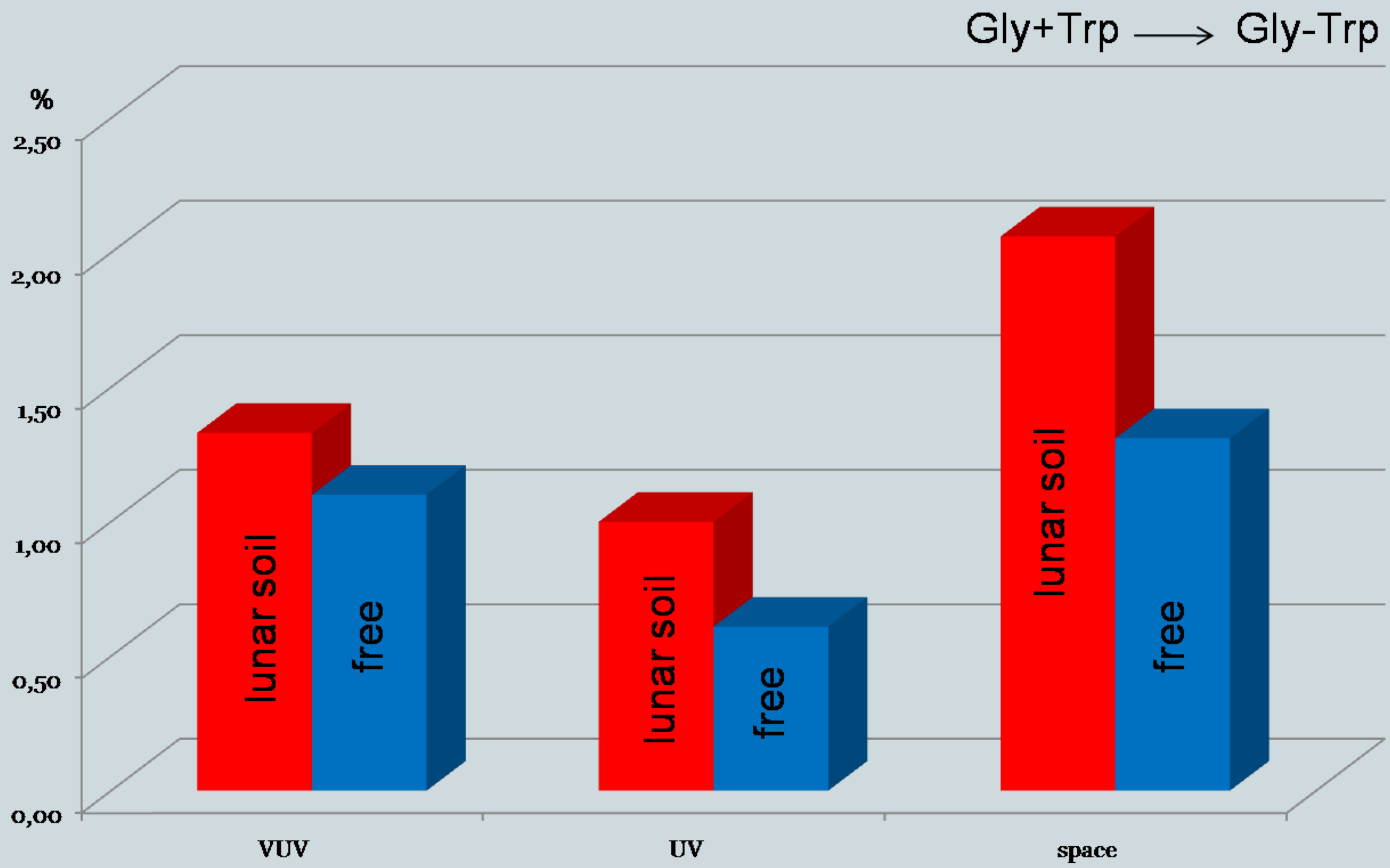
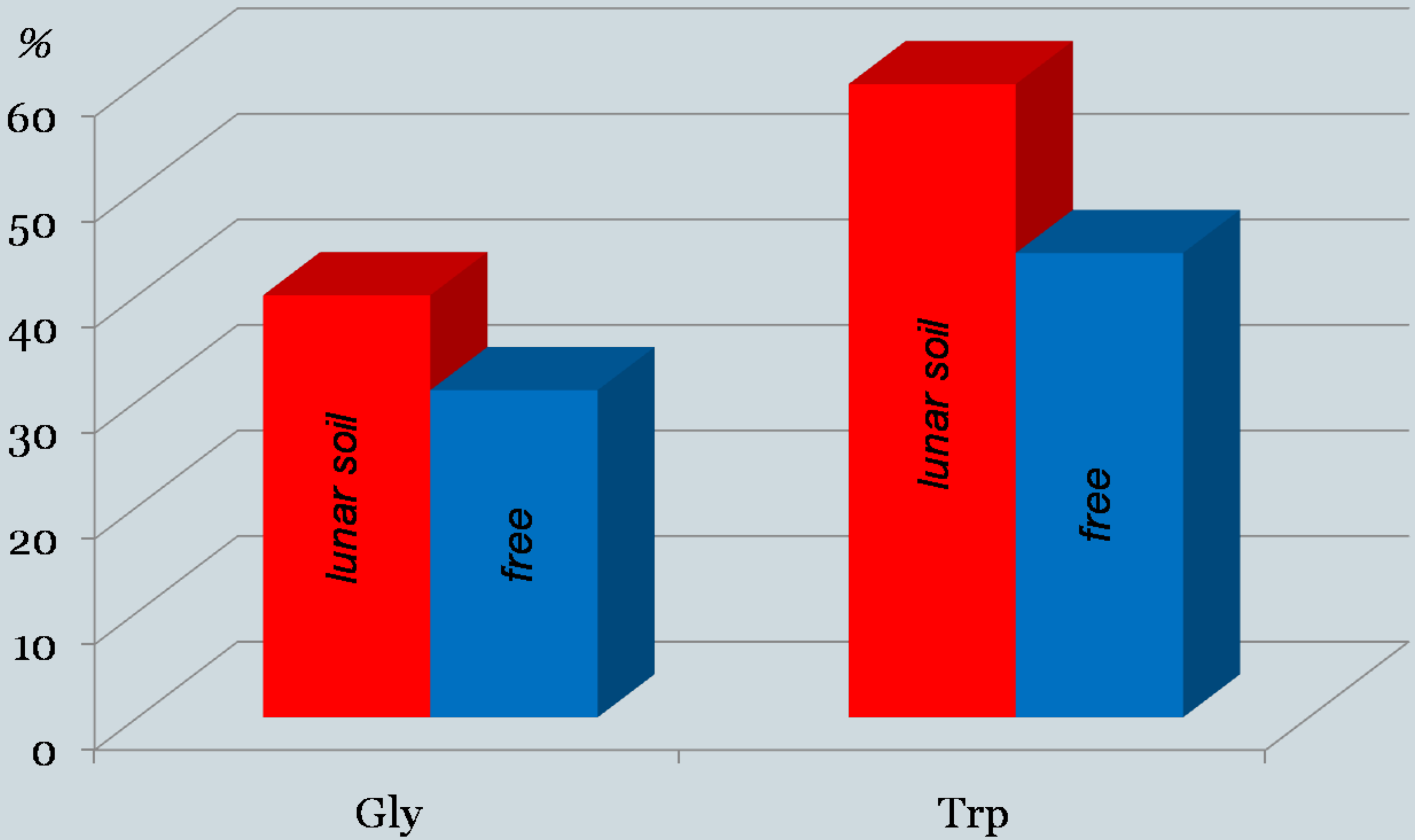
synthesis of oligopeptides in presence of lunar soil

space

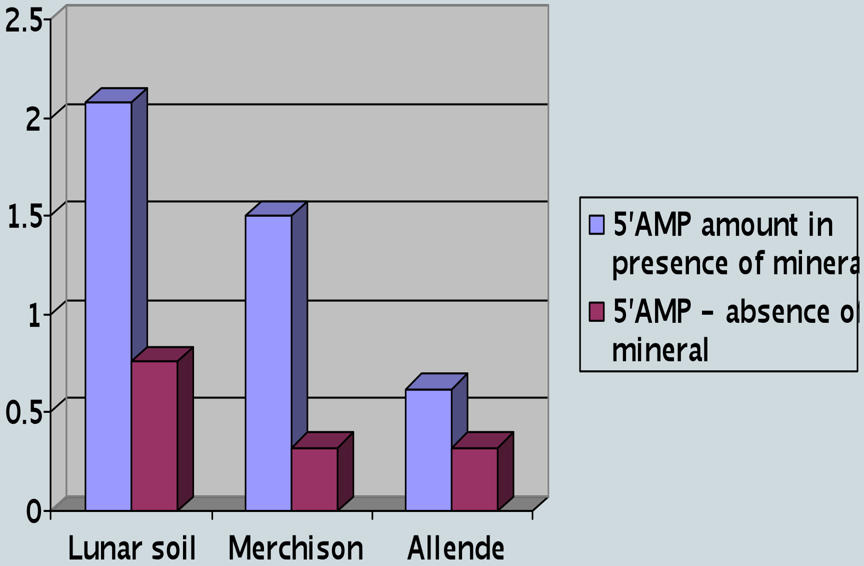


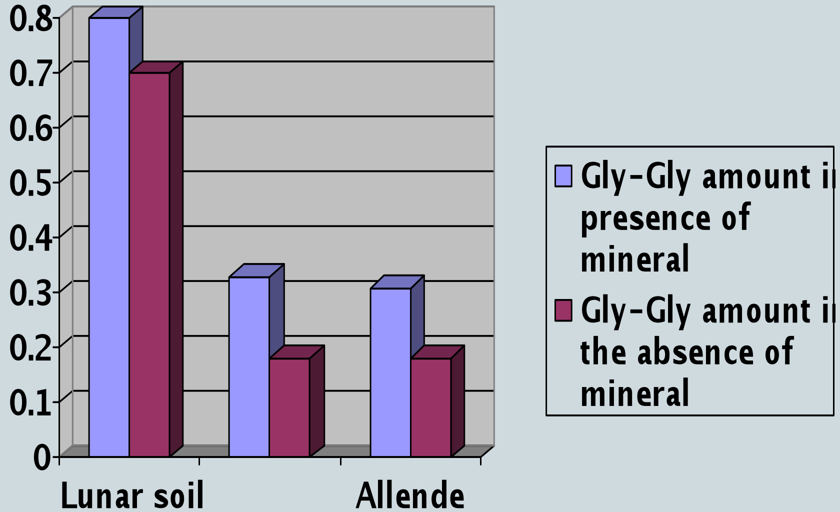
survival of the initial amino acids

space



formation of biomolecules in presence of extraterrestrial minerals





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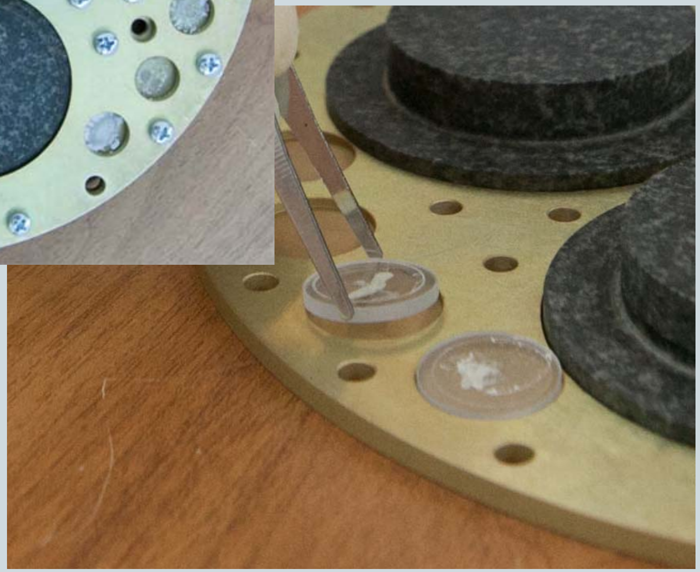
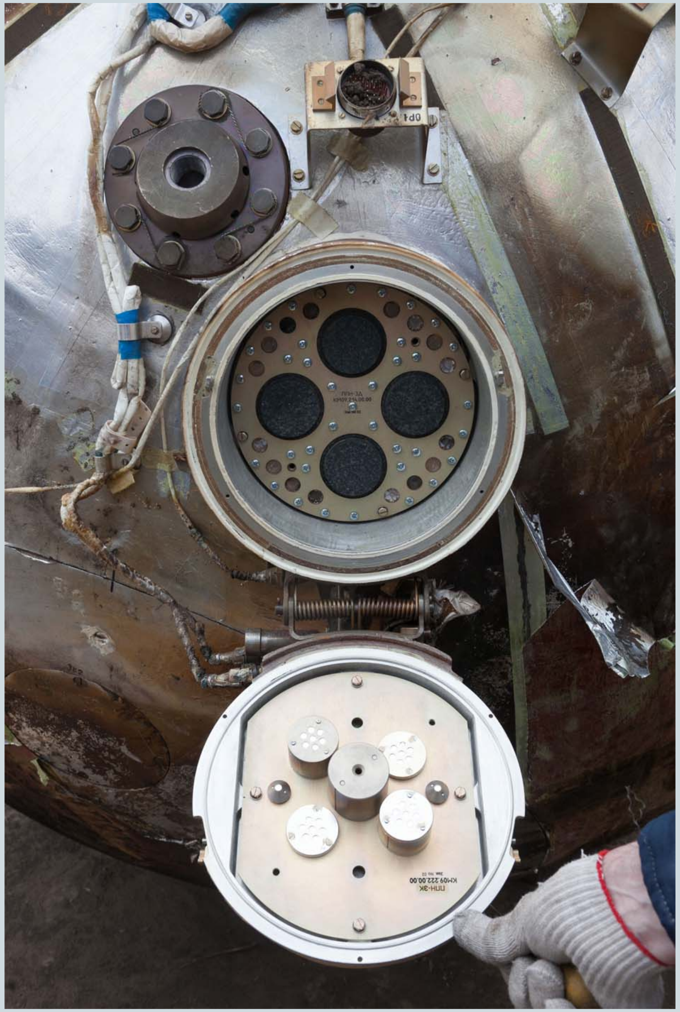
BION-M hardware





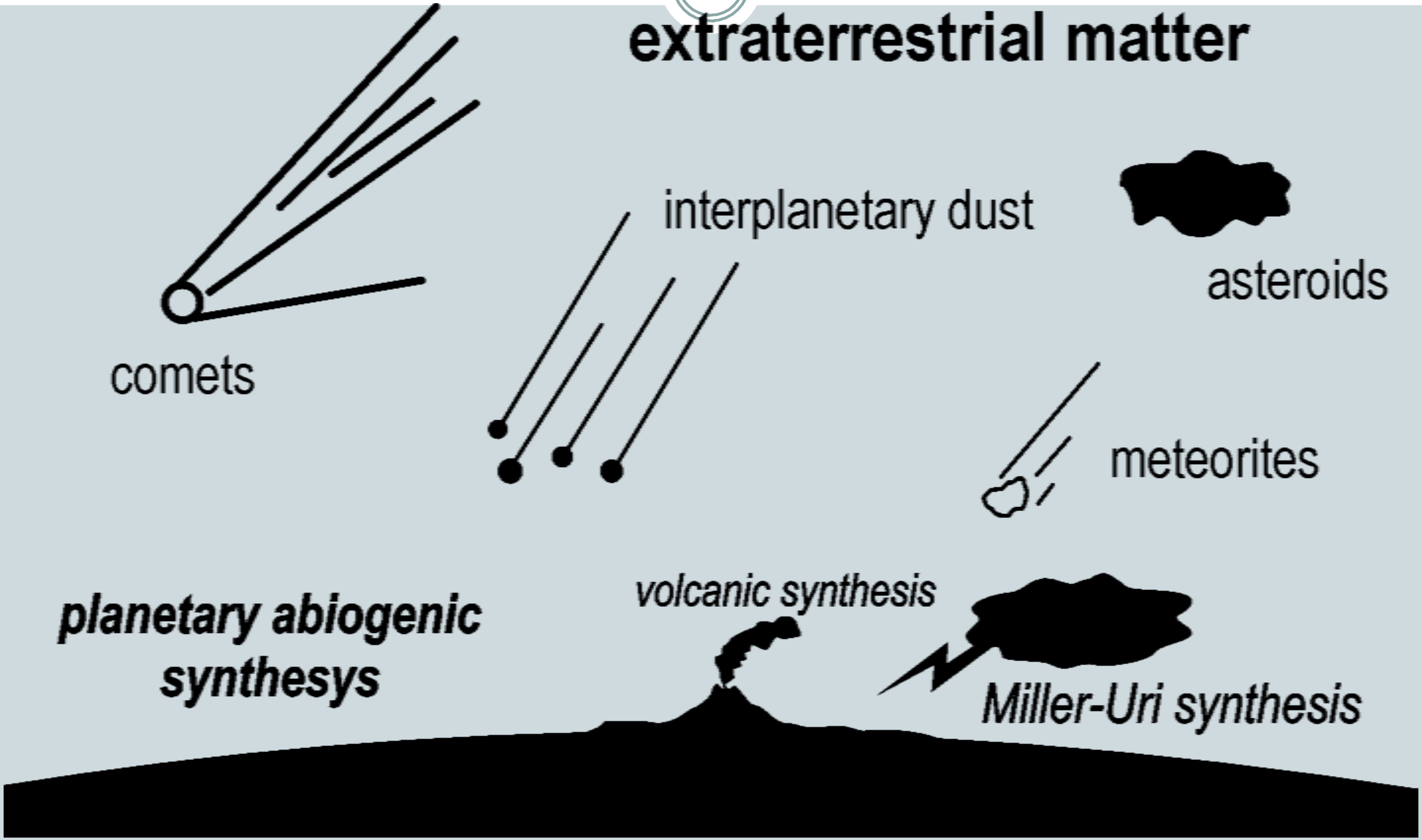
the mineral matrices could acted as:

- matrices for concentration of organics;
- catalysts for abiogenic reactions (including polymerization);
- shield for initial and newly synthesized compounds from harsh radiation environments.

- so, we can propose that a large reservoir of complex organic molecules was synthesized in the warm, inner Solar nebula via reaction on the surface of silicate and oxide dust grains.

- and these materials could be delivered by different vesicles to the primordial Earth.

sources of organic compounds on prebiotic Earth



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