Astrobiology, bio-mass-extinctions, and all that

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Introduction. It is generally accepted now that AstroBiology is “a branch of astrophysics on the base of a multidisciplinary study of subjects related to the origin, evolution, distribution and extinction of life as well as to its detection in the universe”. The question is how reasonably astrobiology’s subjects relate with origin of terrestrial life as we know it because some people from the scientific community like biologists (e.g. Campbell et al. 2010) and geologists cannot make out what is it to astrophysics ? They strongly believe that life on Earth clearly originated in the same way that everything (including complex natural systems) originated, step by step from subunits of only terrestrial origin. But thanks to modern observational and theoretical data we know that it is not the case, a surface of the newborn protoEarth was too hot (T~ 800 K) and a following scenario for the origin of the mentioned subunits should be proposed, establishing a bridge between Astrophysics and Astrobiology (Ehrenfreund et al. 2002).

A. Water for terrestrial oceans was delivered by comets and interplanetary dust particles between 4.5-3.8 Gyr ago (D/H is well agreed).

B. The terrestrial primordial atmosphere which was also created by such a way was neutral ($CO_2 + N_2$).

C. Organics delivered on the Earth by comets and interplanetary dust particles must already have contained heavy hydrocarbons and amino acids including chiral species because molecular symmetry could not be broken under terrestrial conditions.

D. Comets impacting the Earth with grazing trajectories (with $\alpha \leq 5^0$, 2-3 % of all impacts) created first biochemical reactors or „little warm ponds“ .

E. Life (on Earth) has originated 3.8 Gyr ago immediately after cessation of the „heavy bombardment“ period when over 100 million comets collided with the Earth between 4.5-3.8 Gyr ago.

Comets have originated beyond a so called "snow line" in the protosolar disk consisted of unchanged matter coming from a protosolar cloud. Thus any question concerning to what extent complex organic molecules were presented on the primordial Earths' surface should focus on compounds which were readily synthesized under plausible conditions of star birthplaces that is interstellar molecular clouds (MC) and played an essential role in chemical (and/or prebiotic) evolution as we know it. This is the bridge connecting classical problems of astrophysics with that of origin of life. We have tried to reveal some of them in our study during last 10 years. In this short communication we present some results.

Some results. A basic idea is that complex species are more easily generated in solid state of ice mantles of dust grains inside MC if ultraviolet (UV, 6-13.6 eV) and cosmic ray (CR, > 1 MeV) radiation fields are available.

1. We have theoretically studied the composition of icy mantles deposited in cold dense contracting cores of interstellar MC (Yeghikyan et al., 2001; Yeghikyan, 2003; Keheyan, Cataldo, Yeghikyan, 2004) and have shown that the grain mantle initially was methane-rich but then if about 1 Myr is available for the ice deposition time the methane fraction reduces to around 10-40% (both for the atomic and molecular gas-form initial states), and remains level at this value until late times when its conversion to other species e.g. CH_3OH, should be taken into account. Using experimental results regarding the chemical transformation of carbon-containing molecular solids (CH_4 etc.) to heavy hydrocarbons (alkanes, alkenes and PAH) due to irradiation by energetic ions we have also shown that 1-5 % of the total abundance of the ice mantles may be converted to aliphatic olygomer species containing up to 30 carbon atoms during the total ice processing time of about 1.2 Myr and should dominate over aromatic hydrocarbons in stable cool environments. Last Spitzer Space IR observatory data have confirmed that fact by sensing many predecessors of PAHs molecules with relatively fragile aliphatic bonds in cool and tranquil regions (Sloan, 2007, 2008). Observations regard to circumstellar disks but clearly demonstrate a possibility of aliphatic bonds to survive in the densest cool regions of the clouds. If so, it is worthy to search

corresponding lines of solid polyisoprenoid hydrocarbons in the IR spectra of MC and circumstellar disks. It is important from the point of view of prebiotic evolution of matter as it was highlighted earlier (McCarthy, Calvin, 1967) but the question up to now is not investigated. From observational point of view it has to do with vibrational lines of dienic molecules in the range of 3.23-13.7 μm (Sverdlov et al., 1970). Possible identification of such species would localize regions of their formation which in turn would permit putting essential constraints on astrochemical scenarios of their origin. Finally all that would permit to clarify details in the transition from the chemical evolution to the biological one.

2. Space ices containing water, carbon- and nitrogen-rich structures are important in certain chemical and radiation induced processes in interstellar MC dust systems, in cold circumstellar outflow reactions and protosolar nebula chemical processes. Until now there is no detailed investigation on a combined energetic processing of various ices by ions and electrons, modeling the CR irradiation over the whole energy range from eV to GeV, and by UV photons longer than 912 Å. It should be noted that our studies on the proton induced conversion of ices include an examination of the linear energy transfer due to stopping processes by which the input projectile loses its original energy to particles in the target. This deposited energy rate has been calculated under circumsolar radiation field environment for various species (Yeghikyan, 2008). The results can be used to predict a radiation induced chemical conversion rate of simple chemical species to complex ones by means of existing and forthcoming experimental data.

3. Cosmic ray and UV irradiation doses up to the extinction value A_V = 50 caused respectively by the galactic proton spectrum and the nearby A class star and the average isotropic interstellar radiation field have been also calculated and discussed in our works (Yeghikyan, 2009, 2011a, 2011b). We investigated theoretically the transformation of the energy dependence of the CR proton flux in the MeV to GeV region when penetrating inside molecular clouds (A_V > 3 mag) and have shown that particles with energies less than 1 MeV are being absorbed in outer layers where ices are absent. A cut-off of the CR spectrum inside clouds by their magnetic fields has been phenomenologically also taken into account at the energies 1 MeV – 10 GeV. The computations suggest that energy losses of the CR particles by interaction with the matter of the molecular cloud are principally caused by the inelastic (electronic) interaction potential; the transformed energy distribution of energetic protons is determined mainly by the column density of the absorbing medium. This procedure allows a determination of environment-dependent ionization rates of MC. Mentioned energy sources like UV and CR radiation have caused irradiation doses over experimental threshold values of 0.4 eV/a.m.u. and 1.4 eV/a.m.u., respectively, during clouds lifetime about 10-50 Myr, which is enough to arrange the heavy hydrocarbons and amino acids syntheses from simple and mixture ices.

4. Any MC should collide with intermediate and cold dwarf stars every few kiloyears (Yeghikyan, 2013a). Radiation fluxes caused by moving through MCs A, F, G stars are calculated. It is shown that photons in the spectral range $912 < \lambda < 2067$ Å penetrate deeply into the clouds to such an extent to arrange enough irradiation doses to initiate chemical reactions in icy mantles of dust grains during the stars passage time. A possibility to use these data to interpret known laboratory results from the UV photolysis of realistic ice analogues like $H_2O:CH_3OH:NH_3:CO$ producing heavy hydrocarbons and aminoacids has been discussed (Yeghikyan, 2013a).

5. Anomalous cosmic ray fluxes inside molecular clouds originated during collisions of solar-like GV stars with clouds have been calculated. Charged particles originating in clouds in star's neighbourhood are accelerated at the astrosphere's shock up to energies of a few 100 MeV. It is shown that protons and α-particles in the energy range 1 keV $< E <$ 10 GeV penetrate deeply into the clouds to such a degree to arrange irradiation doses of various ices with a cumulative effect over a threshold value of 0.1-1 eV/a.m.u. during the star passing time through the cloud of 1-5 kiloyears and from 10 to 100 collisions of stars with a given cloud. A possibility to use these data to interpret known laboratory results from the ion processing of realistic ice analogues like $H_2O:CH_3OH:NH_3:CO$ producing potentially important pre-biological complex molecules has been discussed (Yeghikyan, Barsamyan, 2013).

6. The solar system must have passed through interstellar MCs many times in the past. These events would have pushed the heliosphere inward to the region of the terrestrial planets bringing the Earth into immediate contact with the clouds' matter, provided that the number density of that was the order of, or greater than, 10^3 cm^{-3}, and that relative velocities of about 20 km/s prevailed. A simple two-fluids treatment of the incoming flow of the clouds' material is proposed here. We consider flow matter that is ionized only by the solar UV and then assess the amount of neutral hydrogen that is accreted by the Earths' atmosphere during a single passage through a dense cloud. The behavior of the flow variables has been investigated by a 2D-hydrodynamic approach to model the interaction processes, taking into account both the photoionization and the gravity of the Sun. As we have shown, the resulting strongly increased neutral hydrogen fluxes, ranging from 10^9 to 10^{11} atoms·cm^{-2} s^{-1}, cause substantial changes in the terrestrial atmosphere. In that case hydrogen acts as a chemical agent to remove oxygen atoms and to cause ozone concentration reductions above 50 km by a factor of 1.5 at the stratopause, to about a factor of 1000 and more at the mesopause (~100 km). Thus, depending on the specific encounter parameters, the high mixing ratio of hydrogen in the Earths' atmosphere may substantially decrease the ozone concentration in the mesosphere and may trigger an essential climatic change of relatively long duration, probably causing the bio-mass extinction (Yeghikyan, Fahr, 2003, 2004, 2006; Yeghikyan, 2013b).

Conclusion. It was claimed that at least certain stages of the process by which life originated occurred in space, hence there is a strong interest in the range of organics in ice-rich structures in dense MCs that may have contributed the precursors of life.

The combination of the astronomical data regarding star-forming regions with published experimental results of energetic particle and UV processing of ices with our theoretical modeling will help estimating the contribution of the CR and UV irradiation to the changes in dust grains in the dense MC. From astrobiology's point of view, an area of rapidly growing interest, it seems important to understand the mechanisms by which large molecules, possibly of pre-biotic interest like heavy hydrocarbons and amino acids could be formed by UV and CR processing of chemically simpler solids in the environment of the clouds. If it turned out that such conversions depended, for example, on star formation efficiency in clouds, stellar masses etc., then these results would have interesting implications for astrochemistry and astrobiology.

REFERENCES

Campbell, N., Rees, J., Urry, L. et al., 2010, Biology, Pearson Education, Inc., SF, pp.507-511.

Ehrenfreund, P., Irvine, W., Becker L.et al., Astrophysical and astrochemical insights into the origin of life, Rep. Prog. Phys., **65**, 1427, 2002.

Keheyan, Y., Cataldo, F., Yeghikyan, A. 2004, Cosmic ray-induced polycondensate hydrocarbons in giant molecular clouds, Astrophysics, **47**, 422-431.

McCarthy, E., Calvin, M., 1967, Organic Geochemical Studies . I. Molecular Criteria For Hydrocarbon Genesis, Nature, **216**, 642-647.

Sloan, G.C. et al., 2007, The Unusual Hydrocarbon Emission from the Early Carbon Star HD 100764: The Connection between Aromatics and Aliphatics, Astrophys. J., **664**, 1144.

Sloan, G.C., 2008, Spitzer spectroscopy of unusual hydrocarbons in cool radiative environments, Proceedings of the IAU. 4, 191.

Sverdlov, L.M., Kovner, M.A., Kraynov, E.P. Vibrational spectra of polyatomic molecules, Nauka, M., in Russian, 1979.

Yeghikyan, A., Barsamyan, L., 2013, On dust irradiation in molecular clouds. IV. ACR doses, Astrophysics, 56, № 3, in press.

Yeghikyan, A., 2013a, On dust irradiation in molecular clouds. III. Internal sources of stellar UV photons from A-F-G dwarf stars, Astrophysics, **56**, 142-151.

Yeghikyan, A., 2013b, On astrospheres radii, Astrophysics, **56**, 246-254.

Yeghikyan, A., 2011a, On dust irradiation in molecular clouds. II. CR doses, Astrophysics, **54**, 103.

Yeghikyan, A., 2011b, On the cosmic ray induced ionization rates in molecular clouds, Inter. Schol. Res. Net. Astronomy and Astrophysics, vol.2011, 1-10.

Yeghikyan, A., 2009, On dust irradiation in molecular clouds. I. UV doses, Astrophysics, 52, 289.

Yeghikyan, A., 2008, Theoretical investigation of cosmic ray processing of solar system ices, Astrophysics and Space Sciences Transactions, 5, 1, 2008.

Yeghikyan, A., Fahr, H. 2006. Accretion of interstellar material into the heliosphere and Onto Earth, in: Solar Journey: The Significance of our Galactic Environment for the Heliosphere and Earth, P.Frisch (ed.), Astrophysics and Space Science Library, **338**, Ch.11, p.317-348, Kluwer AP.

Yeghikyan, A., Fahr, H. 2004. Terrestrial atmospheric effects induced by counterstreaming dense nterstellar cloud material, Astron. Astrophys. 2004, **425,** 1113-1118.

Yeghikyan, A., Fahr, H. 2004. Effects induced by the passage of the Sun through dense interstellar clouds. I. Flow outside of the compressed heliosphere, Astron. Astrophys. **415**, 763-770.

Yeghikyan, A., Fahr, H. 2003, Consequences of the Solar System passage through dense interstellar louds, Annales Geophysicae, **21**, 1263-1273.

Yeghikyan, A., 2003, On accretion of hydrocarbon content of interstellar clouds by the Earth, L.M.Celnikier, J.Tran Thanh Van (eds.). Frontiers of Life, Proc. 12emes Rencontres de Blois, Gioi Publ., 59-63.

Yeghikyan, A., Viti, S., Williams, D. 2001, The formation of heavy hydrocarbons in molecular clouds, Mon. Not. R. Astron. Soc. **326**, 313-316.