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High-energy Photons and Particles in Space Environment

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Space is full of energetic events emitting high-energy radiations which may be fatal to all living things unless protected. The present paper briefly describes high-energy photons and particles incident on Earth surface and their common properties toward living things. Role of radiation played in evolution of life and earth environment will be presented.

Key words: cosmic rays, solar wind, chemical evolution, radiation belts, life, earth environment

INTRODUCTION

In the Universe a variety of energetic events are known to take place releasing enormous energy originally due to gravitation. Typical examples are supernova and gamma-ray burster (GRB). This energy, if concentrated on a few fraction of constituent particles making matter, results in the production of fast moving charged particles, and also simultaneously formed magnetic fields and electromagnetic waves. So space is full of energetic photons and cosmic radiation of all kind [1], and it provides, beside the temperatures approaching absolute zero and a vacuum, a very severe environment for all living things. High-energy radiation may be fatal to all living things unless protected. As an introduction of Symposium on Photobiology in Space Age, the present paper briefly describes on radiation environment near Earth surface, followed by discussion on their common properties toward living things. Finally, a comment will be presented about the role of radiation played in evolution of life and earth environment.

INTERSTELLER MEDIUM WHERE HIGH-ENERGY PARTICLES EXIST

The Universe may be considered on a very large diversity of physical scales [1], in factors of 10^5. The solar system is of order 10^{-5} pc (parsec) in which 1 pc = 3.1×10^{16} m. The interstellar scale is of order 1 pc. The galactic scale is of order 10^5 pc. A typical galaxy contains about 10^{11} stars of varying masses between 0.08 and ~100 $M_\odot$ (1 $M_\odot$ = one solar mass = 2×10^{30} kg).

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Furthermore, there are an enormous number ($\sim 10^{11}$) of such galaxies on cosmological scale of order 10^{10} pc.

It is important to remember that in space surrounding the Earth and the Sun there exist magnetic field [2]. Field strength at Earth surface is 0.3 G, while that at the surface of the Sun 1 G and at the sunspots 10^3 G. The magnetic field strength of interstellar medium is estimated to be 10^{-5} G. The stars of a galaxy are embedded in an extremely rarefied medium, which contains plasma (ionized gases and dusts not so dense), cosmic radiations (relativistic charged particles), and magnetic fields. These three constituents are bound together by electromagnetic forces [2]. The masses of the dusts and gases confines magnetic fields and cosmic radiations to the galaxy, and the turbulent motions of the galaxy can amplify the magnetic fields and accelerate the cosmic radiations. The energy necessary to maintain these confinements may be provided by supernova explosions explained later which occur every 20 or 30 years in a galaxy.

CHEMICAL EVOLUTION

It is also known that more massive stars are much short-lived than less-massive stars. The "life" of a star is the time they spend while nuclear fusion reactions continue to synthesize chemical elements in the central part of the star. *Supernova* is the result of a massive star (>8 $M_{\odot}$) exploding at the final stage of evolution [1,2]. It releases some 10^{44} joules in the forms of photons, neutrinos, and kinetic energy of ejected matter, mainly protons, helium, and other heavier elements which has been synthesized in the star. Supernova explosion leaves behind a compact object, e.g., a *neutron star* or a *black hole* depending on the mass of the original star. Of particular interest is a *binary-star system* in which, after a supernova explosion, the mass of the companion star falls on a compact object, say a neutron star which is rapidly rotating and strongly magnetized at birth, forming a pulsar possibly emitting synchrotron radiation and/or an X-ray or γ-ray. *Gamma-ray burster* (GRB) is known to release 10^{46} joules in the form of γ-rays alone [1,2].

These energetic photons and particles may well induce ionization and excitations of atoms and molecules irrespective of the phase and temperature. They are considered to have accelerated chemical reactions to produce methane, ammonia, water, and many other molecules (*chemical evolution*) in interstellar clouds (gases and dusts) [5-9] from which our solar system was made some 4.6 billion years ago.

RADIATION FROM THE SUN

Turning now to our solar system [3], the Sun releases about 4×10^{26} joules/s as a black body emitting at 6,000 K most strongly in the visible part of photon spectrum. Because of its proximity to the earth, the Sun furnishes all of the energy supporting life on earth. This energy output is generated in the center of the Sun where the temperature is 16,000,000 K and the protons undergo nuclear fusion releasing energy in the form of gamma radiation. The energy thus produced is transported toward the solar surface by radiation scattering, thermal conduction, and thermal convection. Thermal convection is thought to result in the production of magnetic fields. Along the magnetic field lines extending above the surface of the Sun outflow charged particles (mainly electron, protons, and helium nuclei with X-rays) forming the corona and the hot coronal component escapes the Sun to flow outward into space as the solar wind.

As to the energy spectrum of the energetic particles existing in space, there are two kinds of energy distribution originating from different sources [7].

(1) *Thermal emission* having specific temperature (e.g., black-body emission from stars including Sun) : $N(E) \propto \exp(-E / k_B T)$

(2) *Non-thermal emission* (e.g., due to gravitation, or accelerated in interstellar medium):

$$N(E) \propto E^{-\mu}$$

RADIATIONS INCIDENT ON THE EARTH

Photons and charged particles coming from the Sun and galaxies fall on Earth's surface. Charged particles are greatly influenced by Earth's magnetic field. Thus, charged particles of which the energy is less than 60 GeV/n may not enter Earth's surface, instead may be trapped by Earth's magnetic field in two doughnut-shaped region called radiation belts, one located about 3,600 km and the other 20,000 km above Earth's surface. The charged particles are in spiraling motion around the magnetic field lines by the Lorentz force. As the magnetic field is stronger near the poles of the earth, the particles are reflected and travel back and forth on spiraling paths.

Earth's atmosphere also plays an important role in attenuating the incident high-energy photons as well as cosmic rays (energetic protons), thus protecting all living things from radiation damage. Atmospheric density decreases with increasing altitude. Therefore, any biological material located at different height above the surface of the Earth receives a different radiation dose (J/kg) from photons and charged particles.

Apart from the effect of high-energy radiation, the atmospheric constituents, such as oxygen, ozone, carbon dioxide, and water, each absorbing different part of optical spectrum, is relevant to the environment for living things.

PROPERTIES OF HIGH-ENERGY PHOTONS AND PARTICLES HAVING IN COMMON TOWARD LIVING THINGS

The primary actions of high-energy photons and particles toward all living things are rather simple. They all penetrate the materials without destroying or changing the shape and form of the materials, and thereby eject some electrons from the atoms and molecules resulting in ionization or excitations along the path in the materials they traverse. Some of the molecules ionized or excited may enter chemical reactions. The chemical reactions take place irrespective of temperature and phases. Moreover, the mechanisms by which molecules undergo chemical and biological reactions are almost the same for all different radiations. Only difference is the spatial distribution of the sites where energy deposition occurs. Different chemical and biological effects due to different high-energy photons and particles may be attributed to different distribution of energy-deposition sites.

ROLE OF HIGH-ENERGY RADIATION PLAYED IN THE EVOLUTION OF LIFE

Earth was born 4.6 billion years ago and first life some 4 billion years ago on Earth. Before the birth of life many bio-molecules must have been provided. UV and X radiation, synchrotron radiation, and other cosmic rays are thought to play important roles in preparing such fundamental molecules as water, methane, and ammonia, as well as amino acids and other organic molecules before the birth of the solar system. This stage is called *chemical evolution* [4-7,9]. During the first stage of Earth evolution, impacts of meteorites and comets continued to make the Earth hot to produce magma-ocean precipitating metallic iron and evaporating water vapor, carbon dioxide, and nitrogen to form earth's atmosphere. As the earth cooled, water condensed to form ocean. The first life was born most probably deep in the ocean where they were protected against high-energy photons and particles. Next step was the formation of magnetic fields on the earth, originating from also cooling down of the temperature of the iron-core of the Earth. It is believed that convection currents of charged, molten metal circulating in the earth's core are the source of earth's magnetic field. A powerful magnetic field became surrounding the earth. This enabled life to extend its activity area up to shallow seas where solar energy was available. In particular, photosynthesis (due to *cyanobacteria*) gradually added *oxygen* to the ocean and then atmosphere. This must have accelerated the generation of eukaryotes. Finally, sufficient oxygen to produce *ozone layer* by UV-radiation stimulated life go ashore. Thus, the environment of the Earth in which living things exist has been changing through the interactions with high-energy photons and particles. In conclusion, without the atmosphere and magnetic field of the earth, there would be no life on earth. They support life and provide protection of DNA in particular from harmful radiation. We must always remember this fact in facing the so-called space age and repeatedly ask ourselves where we came from and where we are going.

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