LIFE FROM LIGHT, LIGHT FOR LIFE

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INTERNATIONAL YEAR OF LIGHT 2015

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The International Year of Light

The Earth in the early Archaean Eon (*ca.* 3500 Ma ago).

The United Nations has declared 2015 as the International Year of Light and Light-based technologies (IYL 2015). It is a proposal that attempts to highlight the great achievements that have been made on the knowledge and application of light and the importance of this scientific knowledge for the welfare of humanity. This event has the support of UNESCO, scientific societies and academic institutions of many countries, as well as technological platforms and private organisations that wish to promote and highlight the significance of light and its applications. The year 2015 also marks several anniversaries, including the publication, in 1015, of the first book on optics, written by Muslim astronomer and mathematician Ibn al-Haytham (latinized as Alhazen, Basra, 965–Cairo, 1040). This book has had a great influence on subsequent western thinkers such as Roger Bacon or Johannes Kepler.

The celebration of IYL 2015 by many scientific societies and the various activities undertaken during the year are related to the physical aspects of light, which is celebrated and studied from the physical point of view. Many different countries, including Spain and Portugal, have appointed committees in charge of the commemoration, committees that are integrated primarily by physicists and technologists.

Light and life

But light can be considered from many points of view. Light has an enormous influence on life, being the basic source of energy that maintains the ecosystems. And light has also a role in many aspects of culture and art (painting, photography, cinema, etc.). It is, therefore, necessary to consider that 2015 is also the celebration of what might be called the "International Year of Light and its effects on Life." Consequently, the Barcelona Knowledge Hub of the *Academia Europaea*, and the Portuguese Agency for Scientific and Technological Culture, *Ciência Viva*, are joining efforts in organising a conference in Lisbon, in which many different aspects of light, including its biological and cultural effects will be considered. The meeting will be held **(July 2-3, 2015)**, in the worldwide known Pavilhão do Conhecimento (Pavilion of Knowledge), one of the emblematic buildings made for the Lisbon World Fair of 1999, under the title **"Light, from the Earth to the Stars."**

Our planet is a tiny, blue dot lost in the vast space of the universe. A dot formed about 4550 million years ago by trapping atoms of the galaxy, but actually, a wonderful dot, a beautiful piece of stars' dust. What makes this planet so wonderful? Because planet Earth is not special in many aspects: it is not very large. It orbits the Sun, a medium star—both in size and age—, from which the planet receives all light and energy. And this star is within the Milky Way, one of the many galaxies in our cosmic region.

The answer is only one: Life. Life appeared on Earth when the planet was still very young, about 3850 million years ago. And life appeared in the same way as the Earth, by trapping molecules, by playing with atoms. Life and Earth evolve, or, in a better way, Life and Earth coevolve. And evolution connects life over time. Later organisms and systems cannot put aside the organisms and systems that have preceded them. The continuity and unity of life that we know today is evident in the uniformity of genetic systems and the molecular composition of living cells. During the first 2000 million years of evolution, prokaryotic microorganisms (bacteria and archaea) were the only inhabitants of the Earth, and the "inventors" of almost all metabolic strategies that are known today.

The evolution of life to the great diversity that we can see nowadays on Earth has been possible due to two amazing "mistakes". One was a "metabolic mistake," oxygen production, that originated aerobic life, and the other was a "strategic mistake", endosymbiosis, the origin of the eukaryotic cell. So, plants and animals emerged from a microbial world and, therefore, we all are star-dust, but also microorganisms-descendants.

From microbes to stars

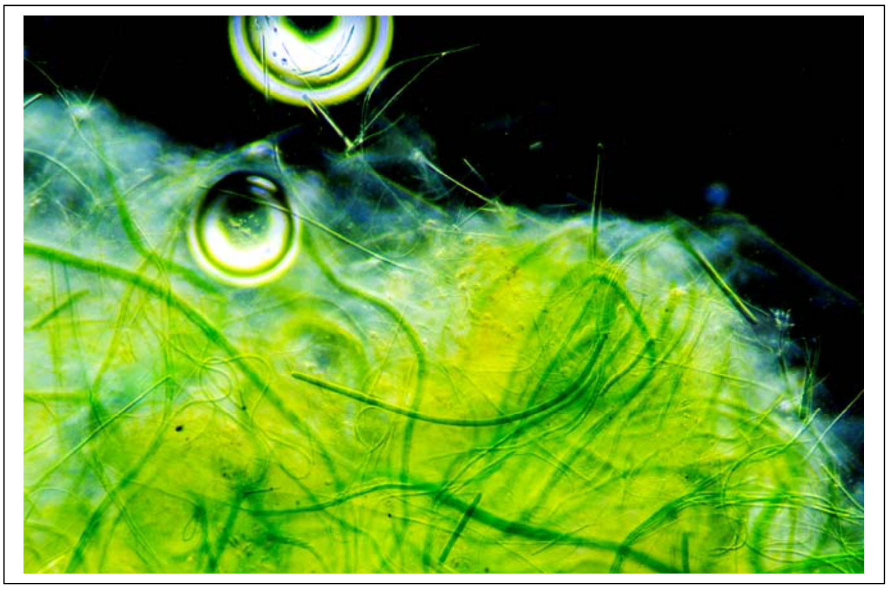
Microbes and stars could seem absolutely different things, but they share two distinctive characteristics. The first is quite obvious: to observe them, both huge stars and tiny microbes, we need instruments based on electromagnetic waves. Microbes can only be seen through microscopes, either those that use radiation from visible light (optical microscopes with a wavelength between 400 and 700 nm), or those using the electron radiation, with wavelengths much smaller. And although with the naked eye we can see a few hundred stars, to observe most of them we need visible-light telescopes and other types of instruments that detect a broad spectrum of radiation, from shorter as X-rays to the longest such as radio waves.

The second characteristic is that both, microbes and stars, have a huge number of individuals. Only in the Milky Way there may be over 100,000 million stars. And, surely the known universe has more than 100,000 million galaxies. But, even though this number is incredibly high (10^{22}, and surely we fall short in the calculation), the number of microbes on Earth is many orders of magnitude higher: it is estimated that it reaches more than 10^{30}.

Earth could be a tiny dot or a great rock in the space, but there is no doubt that is a special planet in the solar system. It is the only planet having its own light, and from different origins. All planets and other bodies from the solar system have no light; they can only reflect light received from the Sun. But Earth "produces" light: light coming from fires and volcanoes, but also from human lighting, and from several animals, plants and fungi that have luminescence.

Photosynthesis, the motor of life

Long time before bioluminescence appeared, light played a fundamental role in the evolution. Light brought energy to the first ecosystems through the process of photosynthesis. Light allowed organisms to fix CO_2 and reduce it with hydrogen to convert it into food, usually carbohydrates. Initially, hydrogen came from chemical reactions, mainly from hydrogen sulfide (H_2S), very abundant in the early Earth, due to the numerous volcanoes at that time. The first photosynthesis produced food like at present, but it did not give off oxygen, but sulfur, which was deposited into small granules.



Production of oxygen by cyanobacteria.

Life on Earth began *ca.* 3850 Ma ago. No later than three hundred million years afterwards, there was a phenomenon that caused a biological disaster and that became the cause of the first great extinction in the planet: bacteria now known as cyanobacteria (or "blue algae") invented a new system of photosynthesis. A system that instead of taking hydrogen from the sulfide molecule—or from other small molecules present in the medium—, broke water (H_2O, even more abundant that hydrogen sulfide), splitting it into hydrogen and oxygen. Hydrogen (protons) entered cells and combined with CO_2. With this, these cyanobacteria reached a desirable effect, a large facility to produce food (i.e. carbohydrates, compounds of CO_2 and hydrogen) since the supply protons was fully guaranteed. But they also get an undesirable effect (at first), the disappearance of most of the organisms living on Earth at that time. And, why is that? As a result of breaking the water molecule, was released a horribly toxic and poisonous gas for anaerobic life (life without oxygen), the only kind of life, at this time, on the planet.

This poisonous gas was oxygen. Most organisms became extinct at that early stage of life. Organisms were burned by oxygen, and only some who developed the enzymes to protect themselves, survived. And, slowly, this highly reactive gas was escaping into the atmosphere where, together with nitrogen gas, also produced by bacteria, formed the air and allowed the development of aerobic life and the great evolution erupted from this time. This behavior of microorganisms, maximal utilisation of energy and recycling of matter, assured the continuity and permanence of life on Earth. The activity of the first ecosystems determined the subsequent evolution of the planet that, until about 1800 million years ago, had the prokaryotes as its only inhabitants.

Evolution of the biosphere

Prokaryotes are essential members of the biosphere because they are essential components of the ecosystems that make possible the functioning of all biogeochemical cycles. The two key enzymes of the biosphere, the rubisco (which fixes CO_2 into a pentose, in the process of photosynthesis) and nitrogen synthase (enzymatic complex that converts N_2 from the air into organic nitrogen) are produced exclusively by prokaryotes. Rubisco is in most photosynthetic bacteria and chloroplasts (which are descendants of cyanobacteria). Nitrogen-synthetase is in several free-living bacteria, but especially in bacterial symbionts (*Rhizobium*, etc.) of legumes and some other plants. Microorganisms are responsible for the recycling of essential elements for life, carbon, nitrogen, sulfur, hydrogen and oxygen, etc. By recycling these elements in the soil, microorganisms regulate nutrient availability to plants, soil fertility, and the development of plants that sustain animal life, including humans.

Microorganisms are also able to use nutrients and other elements that other "superior" organisms cannot explode. So, often bacteria form the basis of the food networks in which the inert substances go into the biosphere. Microorganisms play a key role in recycling atmospheric gases, such as those responsible for the "greenhouse" effect which, paradoxically, on the one hand sustain life on our planet, but on the other, due to the overall increase temperature, threaten life (eukaryotic).

Microorganisms are the main, if not the only ones, responsible for the degradation of a great variety of organic compounds, such as cellulose, hemicellulose, lignin and chitin (the most abundant organic compounds on Earth). Without microbial degradation, all this organic matter would accumulate in forests and sediments. Furthermore, microorganisms are responsible for the degradation of toxic chemical compounds derived from anthropogenic activity, such as polychlorinated biphenyls (PCBs), dioxins, pesticides, etc. All living beings on Earth depend on prokaryotic life. Microorganisms are everywhere. The ubiquity of microorganisms is based on five main features: (i) their small size, which gives them a great dispersion capacity; (ii) their variability, from which they can occupy very different ecological niches; (iii) their metabolic flexibility, which allows them to tolerate and quickly adapt to unfavorable environmental conditions; (iv) their genetic plasticity (or large capacity for horizontal gene transfer), which allows them to recombine and collect favorable characters; and (v) their ability to enter in anabiosis or "be slumber" (not active forms), which allows them to persist for a long time adapting to changing environmental conditions.

"The eyes of Gaia"

All living beings depend on microbial life. Microbes are present in all those places where life can exist, in a wide variety of environmental conditions, from the "ideal" (ideal, obviously from the point of view of "macro-organisms") to extreme environments (unthinkable for animals and plants). Without the knowledge of microorganisms biology would be limited: we would not know that life can be extended to extreme conditions of temperature, salinity or pH; photosynthesis would only be oxygenic and aerobic (when, in fact, photosynthesis was originated in prokaryotes as anoxygenic and anaerobic); the longest-living macroscopic organisms (e.g., redwoods) do not exceed 1000 years (a "youngsters" compared with endospores of *Bacillus*).

In about 5000 Ma more, our Sun, just as his predecessor star, will become a red giant, expanding and burning all the planets around. Not even bacteria, that have inhabited our planet since the origin of life and have survived more than 30 mass extinctions, will escape the catastrophe. Or will they? Some scientists think that endospores, or other forms of bacterial resistance, have escaped from Earth in fragments given off by violent asteroid impacts. Since then, these microbial stowaways roam the outer space searching for new planets to inhabit and "conquer".

In the meantime, we humans will continue trying to interpret and explain the causes of evolution and the mechanisms and laws governing the universe in which we exist. Our species, at least to our knowledge, in the solar system, is the only one that asks itself for its past and tries to regulate its future. Without humans, Earth and the solar system will exist, yes, but nobody would interpret them, nobody would notice the wonders of nature. Nobody would see the forces and the logic of the universe. Not surprisingly, according to James Lovelock's fortunate phrase, "humans are the eyes of Gaia."

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Source of illustrations: Page 1: Official (Internet) and meeting's (M. Berlanga) logotypes of the IYL 2015, and painting by Carles Puche, made for *Mètode* magazine, University of Valencia. Page 3: Microphotography by R. Duro.