Complexity and Analogy in Science
Pontifical Academy of Sciences, *Acta* 22, Vatican City 2014
www.pas.va/content/dam/accademia/pdf/acta22/acta22-funes.pdf

A Cosmic End: From the Earth to the Universe

José G. Funes, S.J.

> *"Human curiosity is the driving force for scientific development, in which belief systems and philosophy still have their valid place"*.[1]

> *"To the scientist, and especially to the Christian scientist, corresponds the attitude to examine the future of humanity and the Earth"*.[2]

Attracted by curiosity about the end of the universe, and encouraged by the words of Pope Francis about the the importance of examing the future, I have tried to consider the cosmic end at different scales.

There is a painting by Paul Gauguin with the title: *Where are we? Where did we come from? Where are we going?*[3] These are the big questions which cut across human culture. The question of the end of the universe is one of those big questions.

To address these questions the scientific method is not the only approach but certainly an important one. Scientific knowledge seeks the explanation of the observed phenomena based on natural causes. It should be able to explain the observed data postulating a new model to predict results that

[1] Preface of the booklet the Plenary Session of the Pontifical Academy of Sciences on *Evolving Concepts of Nature,* 24-28 October 2014.

[2] Address of Pope Francis to the Plenary Session of the Pontifical Academy of Sciences on the occasion of the inauguration of the bust in honor of Pope Benedict XVI, 27 October 2014.

[3] Gauguin had been a student at the Petit Séminaire de La Chapelle-Saint-Mesmin. His subjects there included a class in Catholic liturgy; the teacher for this class was the Bishop of Orléans, Félix-Antoine-Philibert Dupanloup. Dupanloup had devised his own catechism to be lodged in the minds of the young schoolboys, and to lead them towards proper spiritual reflections on the nature of life. The three fundamental questions in this catechism were: "Where does humanity come from?" "Where is it going to?" "How does humanity proceed?" Although later in life Gauguin was vociferously anticlerical, these questions from Dupanloup's catechism obviously had lodged in his mind (cfr. Wikipedia contributors, *Where Do We Come From? What Are We? Where Are We Going?* Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/wiki/Where_Do_We_Come_From%3F_What_Are_We%3F_Where_Are_We_Going%3F, accessed December 17, 2014).

must be verified with further observations. As Chris Impey has written "Science mostly answers the question of how things got to be the way they are. Yet if we stop at the present day, the job is only half done, as every good story needs an ending".[4]

We can only think the past and the future of the universe from its present, that is, from the local universe and from the data we have collected and interpreted in a theoretical framework. We verify our ideas about the beginning and the end of the universe with a reality check, *id est*, confronting them with experimental data. To survey the local universe we have used telescopes for centuries. I like to think that we are a species with long eyes and that Galileo Galilei is the forefather of this people with long eyes.[5]

We have a good picture of the early universe. As T.S. Elliot said, "*In my beginning is my end*"; in the initial conditions of the Universe is written somehow its end. Though there are many unknowns, our current understanding of Physics allows us to reconstruct the history of the universe since the universe was 10^{-43} seconds old. We cannot go beyond this limit in our look-back time; there we arrive to the present limit of human knowledge.

It is uncertain to predict scientifically the future. Our predictions will depend on the different time scales that we take into account. Thus we can consider the end of Earth, of the Sun, of our galaxy and of the whole universe. In this paper I won't discuss any biological evolution or technical development that would exceed the goal of these considerations.

The Beginning

If we ponder the cosmic end from the Earth to the universe, we should discuss the beginning and evolution of planets, stars, and galaxies. Clearly this would be a gigantic effort, much beyond my abilities. Allow me to say that we have a good comprehension of the formation and evolution of planets, stars and galaxies.

In the last decades we have achieved a very solid foundation for the Big Bang theory, gathering observational, experimental and theoretical evidence to support the case for the standard Big Bang model, which is the best up-to-date explanation of the origin, evolution and current state of the universe. A key component of the standard Big Bang model is the hypothesis of infla-

[4] C. Impey, *How it ends: From you to the universe*, 2010, W.W. Norton & Company, Inc., New York, p. 11.

[5] Cfr. J.G. Funes, *Preface* in *ASTRUM 2009, Astronomy and Instruments, Italian Heritage Four Hundred Years After Galileo*, edited by Ileana Chinnici, 2009, Edizioni Musei Vaticani and Sillabe, Livorno, p. 19.

tion, an extremely rapid expansion of the early universe, introduced by Alan Guth and Andrei Linde, that is supported by observational evidence.

A good amount of experimental data has been collected to confirm the case for the standard hot Big Bang that I briefly summarize here:

- The expansion of the universe. All galaxies are receding from us with a velocity which is proportional to their distance. This observational evidence was discovered by Edwin Hubble and it is known as Hubble's law. Saul Perlmutter (Supernova Cosmology Project), Brian P. Schmidt and Adam G. Riess (High-Z Supernova Search Team) in 1998 discovered the accelerating expansion of the universe through observations of distant supernovae.
- The Cosmic Microwave Background Radiation. It is the radiation released when the universe was about 380,000 years old. It was detected by Arno Penzias and Robert Wilson in 1965 and observed by NASA's satellites COBE and WMAP, and recently by ESA's Planck mission.
- The Big Bang model predicts the ratio of protons and neutrons during the period of nucleosynthesis. The chemical composition of the universe should be 75% hydrogen, 25% helium and a trace amount of other light elements. This prediction corresponds to observations of cosmic abundances.

According to the current observational evidence the universe is composed 26.8% of dark matter, 4.9% of ordinary matter, and 68.3% of dark energy and has an age of 13.8 billion years.

Taking into account the current knowledge of the beginning and the present of the universe, we expect that, in a very distant future, the universe will continue to expand going toward a final state of cold and darkness. But before discussing the future of the universe, I briefly discuss the cosmic future at different scales.[6]

The Future Earth: A Declining World

It is very challenging to predict the future of Earth since there are many factors that play an important role in its evolution. The Earth has been and will be affected by geological processes. The four geological processes

[6] In the presentation of the future at different scales I follow A.J. Meadows, *The Future of the Universe*, 2007, Springer-Verlag London Limited, iBook, https://itun.es/us/-MuvB.l; C. Impey, *How it ends: From you to the universe*, 2010, W.W. Norton & Company, Inc., New York; J.O. Bennett, M.O. Donahue, N. Schneider, M. Voit, *The Cosmic Perspective (7th Edition)*, 2014, Pearson Education, Inc., San Francisco.

determine the shape of the surface of the Earth are impact cratering, volcanism, tectonics, and erosion.

Geological activity depends on the fundamental properties of the planet, especially the size. Earthquakes release energy from the earth's crust through seismic waves. The core and mantle are changing continuously. In its final state, about 3 billion years from now, the Earth will be a cold solid body. At this point, there will be no earthquakes on the surface.

Another factor to be taken into account is the change in the atmosphere and in the oceans. The Earth's surface has gone through periods of warmer and colder climates. The timescale on which major ice ages have occurred corresponds with the timescale for continental drift (about 400 million years).

We also need to consider the dynamical evolution of the Earth-Moon system. Some calculations suggest that, within the next 4.5 billion years, the Sun would be overhead at the poles rather than the equator. Changes of this sort will alter considerably the distribution of temperature across the terrestrial surface.

Prolonged periods of high volcanic activity can act as a trigger for climatic change. Also, the world will be warmer or colder depending on how freely equatorial currents can flow as the final layout of continents is approached. The winds too will adapt to the final continental pattern.

If the level of carbon dioxide in the atmosphere continues to rise, as at present, the average temperature in 2100 could be between 2 and 5°C above its current value. Cities around the globe that currently have moderate summer temperatures would be substantially hotter. At the same time, the higher temperatures could well lead to more violent hurricanes. As a consequence in 2-3 billion years the Earth would be a declining world.

In this timescale the Sun will considerably grow in size turning into a red giant (200 times bigger than its current size). The Sun will expand out as far as the Earth's present orbit. This will happen some 8 billion years from now. In its expansion, the Sun will blow off a considerable part of its mass into space. As a result the Earth will move into a more distant orbit. By the time the Sun expands to the Earth's present orbit, the Earth itself will have moved out to nearly twice its current distance from the Sun.

In this very rough description of the Earth's future, I have not taken into account the magnetic fields of the Earth and the Sun.

Impacts on the Earth

Geological data shows that large impacts that happened in the past caused mass extinctions. More recently, Earth experienced the smaller but well-documented entrance of the Chelyabinsk meteor in Earth's atmosphere over Russia on February 15, 2013. This kind of event may occur every couple of years though the probability of major impact is very low in our lifetime.

The range of impactor size could go from small bodies to large objects like asteroids and comets. At the moment no one knows for sure if with the current technology we would be able to destroy or divert a potential large object such as an asteroid or comet.

The Solar Neighborhood

The next step is to consider nearby stars and how they could affect life on Earth. Taking into account the solar neighborhood, a star would wander to within a distance of 3 light-years from the Sun every 100,000 years on average, and a nearby star could pass by about a light-year from the Sun. This is far away enough to have little effect on the Sun and planets. The closest approach to the Sun by any other star over the next few billion years is likely to be at a distance of about 10,000 AU.[7] The gravitational pull of the star would disturb comets, especially the outermost ones. The shower of comets that would result may well increase the impact rate on the planets for a prolonged period after the encounter with the passing star.

A galaxy is a system of stars, gas, dust and dark matter gravitationally bound together with a total mass ranging from 10 million to 1000 billion times that of the sun. Gas and dust are the material between stars and it is called interstellar medium. This is the material from which new stars form.

Collisions between stars may be unlikely in the solar neighborhood but collisions between stars and interstellar clouds are possible. The Sun is likely to encounter a molecular cloud once or twice every billion years. The gravitational pull of the cloud as the Sun moves through it would disturb comets, causing a major shower of comets into the inner regions of the solar system.

In addition, within a molecular cloud, the solar wind will be almost entirely suppressed, and the Earth will be surrounded by interstellar material. This may affect the upper atmosphere, and also what happens at the Earth's surface. It could affect the ozone layer and the amount of sunlight that the Earth receives. Encounters with dense clouds could affect the longer-term future of the Earth.

Any supernova that occurs within 150-200 light-years of the Sun is likely to have a noticeable effect on the solar system. The particles and ra-

[7] 1 AU (astronomical unit) = distance from the Earth to the Sun, or approximately 150 million km.

diation from a nearby supernova could produce significant, though temporary, changes in the Earth's atmosphere. Examination of the radioactivity in meteorites suggests that cosmic-ray bombardment of the solar system originated by a supernova becomes stronger every 100-200 million years.

In the present the atmosphere and the magnetic field of the Earth protect us from the direct effects of cosmic rays. Cosmic rays can interact with the Earth's upper atmosphere, altering the ozone layer and letting through a flood of ultraviolet light. It also seems that an abundance of cosmic rays could affect the greenhouse effect lowering temperatures at the terrestrial surface.

A supernova also produces gamma rays that would cause cellular damage to all land creatures within thirty light-years and inflict destruction on the food web. An even more dramatic stellar cataclysm could disrupt genetic material at a distance of a thousand light-years. Luckily, violent star death is rare.[8]

Galaxy Future

Galaxy formation and evolution is a complex combination of hierarchical clustering, gas dissipation, merging, and secular evolution. Galaxies are tracers of cosmic evolution over the last 13 billion years. Galactic time scale is the combination of two clocks. One time scale is the cosmological one (the Hubble time, i.e. basically the age of the universe) and the other scale is related to stellar evolution. The combination of both gives rise to galaxy evolution.

Our knowledge of galaxy evolution showcases our understanding of cosmology, stellar evolution, and galaxy dynamics. It is an excellent example of how scientific knowledge achieved independently can be put together to shed light on a complex process that involves other physical processes at different scales.

As we know from Hubble's law, galaxies move farther apart over time, and within them stars are born and die. Meanwhile stars are born and die within the galaxies. They are born from the gravitational collapse of gas clumps in molecular clouds. Massive stars, when they die, enrich the gaseous environment with new and heavier elements. Eventually this gas cools off in molecular clouds completing the star-gas-star cycle. Looking to the far future, in a trillion years, the cycle will be broken as more gas is trapped in stellar corpses (white dwarfs, neutron stars, and black holes) and less is left over to form new stars.

In each and every galaxy, the lights will gradually go out. In 10^{100} years (10^{90} times the age of the universe) clusters of galaxies will become clusters

[8] Cfr. C. Impey. "Humble before the Void." iBooks. https://itun.es/us/XUKw0.l, chapter 3.

of black holes; finally black holes will evaporate. The Milky Way will be one of those galaxies fading into darkness.

The Fate of the Universe

According to our current comprehension of the universe, dark energy seems to be the driving force for the accelerated expansion of it. If this is the case and dark energy does not change with time and there are no other factors, in the very distant future the universe eventually will be shredded. This final stage of the universe is known as the *Big Rip*. Some cosmologists propose that the universe could not have a single final end but even multi-ends.

Thus the universe is going toward a final state of cold and darkness, thermal death, which says that the universe will go toward a state of maximum entropy (*Big Freeze*). The long-term scenario, with everything in the universe gradually dying, is obviously hostile to life.

Emptiness and Questions

Using the poetic language of T.S. Eliot, the end of the universe can be metaphorically described as follows:

> *"This is the way the world ends*
> *This is the way the world ends*
> *This is the way the world ends*
> *Not with a bang but a whimper"*

Our scientific journey to the end of the universe is also a spiritual one to the last frontier, to our existence in this cosmos. Looking at a not very bright perspective for life we may experience what Friedrich Nietzsche sums up effectively in few words: *"When you look long into an abyss, the abyss looks into you"*. Similarly we could feel emptiness in front of the vastness of the cold and dark universe in its final stage as the sacred author of the book of Ecclesiastes sees the fragility and contingency of this world: *"A vast emptiness – Qoheleth says – an immense void, everything is empty"*.[9]

In the previous sections I have tried to summarize what is possible to say about the future of the universe from the scientific point of view. This perspective poses many questions regarding life in the universe:

– If our location in the universe is crucial for life, will all life end with Earth?

[9] Ecclesiastes 1:2.

– Is life a common phenomenon?
– What will happen with life in trillions and trillions of years when the universe fades?
– If there are other universes will life survive in those places?
– What is the Christian perspective on the end of the Universe?
– What can we say about the *Last Day*?

At this point I would like to quote Martin Rees who put in evidence our crucial position regarding the future:

> "*The most crucial location in space and time (apart from the big bang itself) could be here and now*".[10]

> "*The wider cosmos has a potential future that could even be infinite. But will these vast expanses of time be filled with life, or as empty as the Earth's first sterile seas? The choice may depend on us, this century*".[11]

Christian Realism

It is very difficult to dare to make any statement or hypothesis about the future of life in the universe. However we know from direct observation on Earth that life is resilient, it has an extraordinary capacity to adapt and evolve in hostile conditions. Life could have spread elsewhere in the universe or in other universes if the idea of the multiverse were confirmed.

The good scientist should remain open to the interpretation of reality being aware that the scientific knowledge is incomplete, as Pope Francis pointed out for theologians and philosophers:

> *"The theologian who is satisfied with his complete and conclusive thought is mediocre. The good theologian and philosopher has an open, that is, an incomplete, thought, always open to the maius of God and of the truth, always in development…"*.[12]

There are many incomplete issues in science and this paper is incomplete in many aspects, however I would like to conclude with the Christian ap-

[10] *M. Rees, Our Final Hour,* 2003, iBooks*, https://itun.es/us/X9EXw.l,* Basic Books, New York, Chapter 1.

[11] *Ibid*. Chapter 14.

[12] Address of Pope Francis to the Community of the Pontifical Gregorian University, 10 April 2014.

proach to the *Last Day*. I find Joseph Ratzinger's words very illuminating in this regard:

> *"Christian realism goes beyond the physical, as realism of the Holy Spirit".*
>
> *"If the cosmos is history and if matter represents a moment in the history of the spirit, then matter and spirit are not forever next to each other in a neutral manner, it is necessary to consider one last "complexity" in which the world finds its Omega and unity. Then there is one last link between matter and spirit in which the destiny of man and the world finds compliance, even if today we cannot define the type of such a connection. Then the "last day" is one in which the fate of each man will be fulfilled because the fate of humanity* (... and of the universe I would add) *has found fulfillment".*[13]

[13] J. Ratzinger, *Introduzione al Cristianesimo*, 2010, Queriniana, Brescia, 347-348.