COSMOS AND COSMOLOGY

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Introduction

...ese objeto secreto y conjetural cuyo nombre
usurpan los hombres, pero que ningun hombre
ha mirado: el inconcebible universo.
Jorge Luis Borges

Perhaps science is not anything else than an attempt (inescapable) to elucidate our own relationship with nature. Seen in this way, the scientific treatment of our origins is vital to the understanding of ourselves. Cosmology, conceived as an effort to give coherence to the physical world at the largest scale using the methods and tools of physics and astronomy, has much to say about how the proper cosmic conditions for the emergence of life arrived.
As a matter of fact, perhaps the most important change in our view of the universe since the birth of modern science is the discovery by twentieth century cosmology that the universe is a dynamical entity, which evolves according to local laws that we can (and must) discover (or invent?). Cosmology is the ultimate historical science, that must understand the present universe as the result of the initial conditions that existed 15x(**diez a la nueve) years ago. The evolutionary process allowed to go from a hostile, hot and nearly uniform universe to another highly hospitable, cold, complex and finely structured at very diverse scales world, capable to develop variety, quasi-static structures out of equilibrium (thanks to the anti-entropic tendency of gravitation) and other conditions absolutely necessary for the emergence of any form of life.
Within the multidisciplinary approach of astrobiology, the view that cosmology offers is important. Specifically, we aim in this work to show in a non-technical way why this perspective is worth to be taken into account, that is to say, why we think that it has scientific value. Later we will present, again in a non-technical manner, the present paradigm and its supports. Finally, we shall comment briefly about the challenges posed by the paradigm, looking forward to the near future.

Scientific understanding of the universe.

`I do not pretend to understand the universe...
.it´s a great deal bigger than I am.

Thomas Carlyle

As cinema and jazz, cosmology was born in the twentieth century. The article which initiates scientific cosmology is by Einstein, published in 1917. Before that, the theoretical tools, the necessary observational technologies and a minimum understanding of the local astronomical phenomena were not available in order to develop an overview of the subject. At first sight we only distinguish our own galaxy, the Milky Way, which is only one of the 10(**elevado a la once) that exist in the observable universe. It was only sixty years ago that we understood the origin of the energy in the stars that allows them to shine for thousands of millions of years, while the heavy elements in the periodic table are formed in their interior. During the twentieth century the capacity to detect photons through the use of telescopes has been multiplied by a hundred thousand, and recently we can make observations not only in the optical range of the spectrum, but also in wavelengths corresponding to infrared and ultraviolet light, radio waves, microwaves, and up to 10 (**elevadoa la 12) e.v. We can avoid the distorting effect of the earth atmosphere putting telescopes in outer space. The experiments done in large accelerators have made it possible to invent (or discover?) the laws of the subatomic world. A great variety of equipments, observatories and accelerators throw up permanently a formidable quantity of high quality data about the physical world. This data is handled and analyzed swiftly through the use of modern computers. The combined effects of all these developments have taken cosmology from a conjectural and speculative stage, without solid data and in which prejudice had a lot of weight, to another much more precise, in which observational results and independent and crossed tests validate or not the proposed models and limit the freedom of theorists in their proposals. In these times of globalization, cosmology is, without doubt, big science, a mature science capable to deal with the real world, to correct itself, to lay off models and to convince us that that, at the largest of scales, the physical world is simple enough to be described in scientific terms.

Standard Cosmology

The universe is real but you can´t see it.
You have to imagine it
Alexander Calder

Cosmology is at the center of a square whose sides are Einstein´s gravitation theory, or general relativity, the standard model for elementary particles, statistical physics and some simplifying assumptions.
At great scale the universe is dominated by gravity. Consequently, we must resort to the best description of gravitational phenomena, that is to general relativity. The great moral of general relativity is that gravity is a manifestation of the curvature of space-time, which

turns them into main actors, at variance with their previous role as the stage in which matter and the physical fields `live´. The content of energy-matter determines the space geometry, and its evolution in time, according to Einstein´s equations, so that observations should make an inventory of the content of matter and energy in the universe. It is important to point out that general relativity has passed successfully all tests done through observations and experiments. It is one of the best corroborated physical theories.

On the other hand, the behaviour of matter and energy obeys the laws of the standard model for elementary particles. The standard model includes the quantum mechanical description of matter at different energy scales, from molecular physics to high energy physics, through atomic and nuclear physics. It is the physics that we were able to build through the use of great particle accelerators, and provides us with valuable information about the nature of the fundamental interactions. Its successes in the description of reality include the explanation of the structure and the properties of matter, the hierarchy in the periodic table, the nature of electromagnetic radiation, radioactivity, the nuclear reactions that make possible the shining of the stars as well as predict the results of any experiment done in the large particle accelerators.

With general relativity and the standard model in hand, cosmologists introduce some assumptions which they believe are valid in our universe, for instance that at very large scale, about 200 million light years, matter and energy are distributed uniformly, so that the geometry of space must reflect that homogeneity and isotropy. This assumption has been verified by measurements of the background radiation, of which we will say more below. The basic idea is, of course, to build models which try to replicate the salient features of the real universe. As is to be expected, the number of models consistent with theory is very large, so that one has to turn to observation to get input for the values of some parameters. Is through this interplay between theory and observation how it has been possible to design a coherent image, the big-bang model or standard cosmological model, with enough empirical successes (and, equally important, without contrary observations) that has established itself as the accepted paradigm for the community of cosmologists. It is important to remark that this does not mean that we understand every detail of the actual structure of the universe, nor that we can answer all questions (some of them very important). The big-bang model is the framework in which observations must be organized and interpreted and the context in which the details of the relevant cosmological processes that have taken place must be refined.

The history of a hot universe.

In the beginnings is the end.
Thomas Steam Elliot

The general scheme of the big-bang model assumes that the universe that we see today comes from a highly dense and hot stage which began to expand some thirteen billion of years ago. The expansion is gauged by the scale factor which measures the relative size of the universe. The model establishes that the temperature measured through the background radiation is inversely proportional to the scale factor, whose dynamics is ruled by the content of energy-matter that we observe, including the energy of the vacuum, and the curvature of space-time, through Einstein´s equations. So, the physical processes that take place depend on the temperature scale considered, which in turn depends on the time elapsed since the beginning of the expansion. The history of the universe is, then, the history of the processes that happen while the universe expands and gets colder.

Let us point out some of the relevant episodes of this history.

We will begin at 10 (**elevado a la menos 5) sec, time at which the energy that dominated the expansion of the universe was that of radiation and ultra-relativistic particles. The temperature of the environment was about 5x10 (** elevado a la doce) K and it was at this stage that protons and neutrons were constituted from quarks, through a process known as baryogenesis.

When t~1 sec-3 min, temperature goes down from **diez a la diez K to **diez a la nueve K, which are in the range typical in nuclear physics, the density is about **cinco por diez a la cinco gr. Cm **a la menos tres. Physics is now conventional and predictions can be made. In this period neutrinos decouple and nuclear reactions create light nuclei like deuterium, helium, helium 3 and some lithium (primordial nucleogenesis).

The process of creation of heavier nuclei does not continue because soon the temperature gets too low.

When t~ 300,000 years have elapsed matter density exceeds that of radiation and it begins to control the evolution of the scale factor. The temperature at this stage is about 4000K and photons do not have enough energy to impede the creation of hydrogen and helium atoms. The predominant physics is atomic physics. The universe ceases to be an opaque ionized plasma because radiation interacts very weakly with neutral matter and photons can travel freely, affected only by the expansion of the universe.

At t~**diez a la nueve-diez a la diez years, the dynamics of the universe begins to be ruled by the vacuum energy or the cosmological constant. This stage corresponds to long range gravitational physics, in which small fluctuations (ten parts per million) in the average density of matter, begin to collapse gravitationally amplifying the contrast in the density by a factor of **diez a la siete. It is the time of the formation of structures: galaxies, galaxy clusters and superclusters.

Finally, when **trece por diez a la nueve years have elapsed and the temperature is 3K, complex biochemical structures appear, originated from the heavy elements synthesized at the core of the stars and thrown out into space through supernovas.

For times less than **diez a la menos 5, the physics is more uncertain. At t~**diez a la menos 43, the so called Planck period, the quantum effects of gravity were the most important. Lacking a credible theory we can not say anything about it. It is believed that around **diez a la menos 35-diez a la menos 32 sec, an exponential inflation happened which gave the universe some of its most important features. Without this theory we could not be able to explain these characteristics, except by assuming bizarre initial conditions. As a result of the inflationary phase, the universe was made uniform, the curvature of space was annulled and, perhaps, the quantum fluctuations of the field that created the inflation also began the fluctuations which gave way to the formation of the cosmic structures.

Corpus delicti.

> It is a good rule not to push overmuch confidence
> In the observational results that are put forward until
> they are comfirmed by theory.
> Sir Arthur Eddington

What reasons can be put forward in favor of the big bang? Why cosmologists think that the big bang model is a good representation of the actual universe? Aside of the fact that it is supported by local theories with great solvency, the big bang model is solidly supported by recent observations, which have been made in recent years with increasing precision. Mainly these are related to the expansion of the universe, as shown by the red shift of the spectral lines of hundreds of thousands of distant galaxies. Measurements show that this expansion is larger by the same factor in which the distance of the galaxy is larger. The quantitative relation is v = H d, where the Hubble parameter is taken presently as H = 65 Km (**sec elevado a la menos uno. Mpc elevado a la menos uno), within an error of 10%. One Mpc = 3.2 millions light-years
The second observational support of the big bang is related to the synthesis of nuclei. The model allows the calculation of the abundance of light elements (helium 4, deuterium, helium 3 and lithium 7) relative to that of hydrogen. The proportion found (1:0.25, 3 (**por diez a la menoscinco):, 2 (** por diez a la menos cinco):, 2 (** por diea a la menos diez):) is consistent with what is found in primitive samples of the universe. Particularly, observations on the abundance of deuterium, measured with great precision using absorption lines from quasars, indicates that the present density of protons and neutrons (baryons) is about 3 (**por diez a la menos treintayuno).
The third observational basis for the big bang model is the detection of the cosmic microwave background radiation (CMBR) predicted in the forties by Gamow and collaborators and found by Penzias and Wilson in 1964. Its very existence tells us about a hot phase of the universe, but, moreover, the sophisticated study to which it has been submitted during the 90´s provides us with further evidence in favor of the big bang model, as well with valuable information about the universe when it only had 0.02% of its present age. CMBR is a residue from the last moment in which matter and radiation were in thermodynamical equilibrium, that ended when matter became neutral. Its present temperature is T = (2.725 (** mas o menos +-)0.002)K with a typical wavelength of about 2 mm, and with the most perfect black body spectrum found in nature (deviations are of three parts in 10000). Besides, CMBR has the same temperature for whichever direction of the sky that we are looking at, within a margin of 10 ppm. This isotropy is a consequence of the uniformity of the expansion and of the homogeneous and featureless quality of the universe when it was 300.000 years old and its temperature was 3000 K, and strongly supports the big bang model. Even more interesting is the finding in 1992, through more precise measurements, of changes in this background temperature for different directions (1 part in 100.000), which evidence the non-uniformity which generated the large structures seen today. Since then cosmic radiation has been examined in great detail, due to the fact that the precise form of the anisotropies or, technically, the power spectrum gives information about important cosmic parameters, as the density of matter, the cosmological constant and space curvature.

Solving the puzzle.

A place for every thing
And every thing into it´s place.
Anonymous

The kind of universe in which we live, its geometry and its special way to expand, depends, in every stage, of its content of energy-matter. These numbers, in turn, limit the possible models for structure formation. On the other hand, inflation in the first moments after the big bang imply some characteristics of our universe. Observations of the cosmic radiation, of the abundance of light elements and of the rate of expansion of distant objects give new data about the universe. In units of the critical density necessary for an Euclidean geometry of space, ordinary matter (baryons) contribute with 5%, cosmic radiation photons with 0.01%, neutrinos freed in the first fractions of a second with 3%, and dark matter detected through gravitational lenses, galaxy dynamics or great scale fluxes with 35% (so that the substance in which we are made is not the most abundant in the universe¡). Besides, the analysis of the fluctuations of cosmic radiation suggest that the total density must be unity, a result supported by inflation predictions, according to which the curvature of space is null and then the total density must have the critical value. The paradigm that begins to have the greater acceptance holds that the remaining 65% is provided by the vacuum energy, that is to say the cosmological constant. The effect of the vacuum energy is to produce a gravitational repulsion and that is what seem to indicate recent observations of distant supernovaes. Instead of diminishing, the expansion of the universe is accelerating due to the existence of a cosmological constant different from zero. Moreover, the more convincing models for the formation of structures are the ones that include non-relativistic dark matter, as well as a cosmological constant. So, it semms that

The challenges.

Physics is too complicated
To leave it to the physicists.

David Hilbert

There is no doubt that a healthy relationship between fundamental physics and valuable observations has played an important part in the great advances in cosmology during the last years. Thanks to it we now have a coherent picture of the evolution of the universe since fractions of seconds after the big bang to our days. However, there still remain a lot of loose ends and many unanswered questions. Some of them will be resolved in the near future, through more and better observations, many of which are been carried out already. But others will have to wait for new physical laws at a deeper level.

Specifically, the new measurements will allow to determine with greater accuracy the cosmological parameters (mass-energy densities, Hubble constant, radiation anisotropy, cosmological constant or its equivalent,…), which will allow to adjust the inflation models and those of structure formation. But it will be necessary to identify the composition of non-baryonic dark matter (neutralinos? axions?), without doubt the remains of an age whose physics we do not know well enough.

We do not understand why ordinary matter prevails over antimatter. The physics we know is symmetric with respect to particles and antiparticles. Fortunately for us, a few instants before baryogenesis a small asymmetry of one part in **diez a la menos 9 left a slight excess of particles, which are the ones that we now see.

The cosmological constant also creates enigmas related to the most fundamental physics. We must identify accurately the reason for the acceleration of the expansion of the universe if observations confirm its existence. Why theoretical calculations differ in 120 orders of magnitude with astronomical observations? The cosmological constant is a quantum originated term (the energy of virtual vacuum pairs) put into a classic equation. These great disagreements show that we are not using an appropriate description. It is possible that the much sought quantum theory of gravity, or some other `final theory´ will offer a better understanding of the problem of the cosmological constant. That presumed theory will also be needed to answer some fundamental questions as, for instance,

Which characteristics of the universe are fossils from the age of quantum gravity? Perhaps the number of dimensions of space and time?

What kind of dynamite propelled the expansion? What is the nature of the big bang?

Why the fundamental constants and the cosmological parameters have values that not only allow but favor the emergence of complexity? Are those values determined by basic principles or got in by the back door of chance through the break up of symmetries, for instance?

The history of science shows how foolhardy it is to dare to predict the way by which our understanding of the world will go. Nobody could have foreseen a few decades ago the giddy development of our understanding of the cosmos. Sometimes an unexpected observation or a new theory can alter the intended route. At this moment we can only assert that the turmoil in which cosmology finds itself promises advances which will elucidate our relation with nature. Is not that the aim of science?