the structure and evolution of the universe

FRANCISCO SÁNCHEZ MARTÍNEZ

Previous page:

Figure 1. In this image, two spiral galaxies—NGC2207 and IC2163—meet in their initial phase of interaction. Over time, the two galaxies will merge to form just one. The forces of NGC2207's gravitational tide have twisted the shape of IC2163, which expulses stars and spills gasses in long snake-like shapes one hundred thousand light-years long (on the right side of the image). That is how the large spiral galaxies were formed. Our own galaxy, the Milky Way, has absorbed smaller galaxies in the past and is currently swallowing up another. In the future, we will collide with M31, the largest spiral galaxy in our Local Group. NASA.

The Great Adventure

Ever since man became "sapiens," he has looked questioningly to the heavens with great interest and awe. And that is quite natural, for what happens over our heads has a great effect on us. Primitive man had a direct sense of the influence of the heavens on our lives, for he was in permanent contact with nature and totally dependant on the birth and death of the Sun, Moon, and stars that marked the rhythm of day and night, and of the seasons. He learned prediction by looking at the situation of the heavenly bodies, as he needed to know what was going to happen in order to find food, not to mention avoiding being eaten himself by other predators. Moreover, we can imagine the stupor and fear our ancestors must have felt in the face of the unforeseen and dramatic phenomena they could observe in the sky: lightening, thunder, the polar auroras, shooting stars, meteorites, comets, and solar or lunar eclipses. How could they not see them as signs of far superior beings? It is thus logical that they would consider the heavens to be where their gods dwelled. Some quickly realized that knowing the secrets of such phenomena and making others believe in their capacity to use them to help or harm each other would bring them great power and stature as divine mediators. That is why even the most archaic civilizations had celestial myths, rites, and omens, which were kept by their priesthoods. And even today, in the twenty-first century's most developed and technological societies, these primitivisms emerge in the form of astrology, astral sects, and other such trickery. And the most complex and speculative scientific theories and cosmological models are today defended by many of our world's must erudite people with a fanaticism that borders on the religious. All of this must be kept in mind when trying, as I now am, to offer a necessarily condensed and accessible overview of what we know today about the structure and evolution of the immense Universe to which we belong.

We must start by remembering and emphasizing something that will put the following observations in context: all scientific knowledge is provisional, and completely subject to revision. Moreover, what I am going to explain below are speculations based on rigorous science—but speculations all the same—that try to explain what we have been able to observe with the most advanced telescopes and instruments of our time. The real and complete reality of the vast Cosmos cannot be grasped by us, due to our own finitude. In sum, while we have learned a huge amount, there is a much larger amount that we still do not know. And, in writing this overview, I have been sorely tempted to accompany each statement with the cluster of unanswered questions that envelop it. But such detail must be left for specialized books.

That being said, it is even more thrilling to contemplate the beautiful and unfinished adventure of humans moving blindly but decisively forward in search of the infinite mysteries, driven by their curiosity and innate desire to learn. Such are the characteristics that have made us able to surpass our own strong limitations, reaching previously inconceivable heights. For example, in the concrete case of the sense of sight—we are, after all, practically blind, incapable of making out distant objects, and only capable of seeing an extremely limited band of wavelengths of the electromagnetic spectrum—we have been able to invent marvelous "prosthetic devices", that is, telescopes. So we can now "see" celestial objects that are at such enormous distances that we have to measure them in thousands of millions of light years.

As our capacity to "see" farther and in more detail has grown, our idea of the Cosmos has changed, and that change has been dramatic in recent times (fig. 2). If we look back only as far as the Renaissance, we find the "Copernican Revolution," which removed the Earth from the center of the Universe, reducing it to a mere satellite of the Sun and showing us that heavenly matter was of the same nature as us—no more divine than the Earth's own dust. For a time, we were thrilled by such unexpected and fantastic things, and entertained by the precise mechanics of the heavens, studying the movement of the bodies that make up our Solar System. As a result, we believed in the perfection of the cosmic clock and the unchanging nature of the Universe.

It was less than a century ago when this perfection and serenity came crashing down. First, science confirmed the existence of many other "island universes" located outside our Milky Way—until then, we considered it a unique cluster of stars and nebulae surrounded by infinite emptiness. Then we discovered that, the farther away they were, the faster they were separating from each other. So finally, we had to accept that the Universe was expanding, that it was growing larger, and colder. It was enough to posit this expansion in reverse in order to arrive at the original singular moment, and from there to the idea of the "Big Bang" that was the origin of everything. Alongside this, there was the discovery of the energy that makes the stars shine, which forced us to accept that the Universe is in permanent evolution. It is neither static nor eternal, and everything it contains is "alive," including stars and galaxies. Thus, we can observe the birth and death of celestial objects in all parts of the Universe, in perpetual processes of transformation and recycling.

And suddenly, we are surprised to discover that the Universe's expansion is *accelerating!* So once again, our cosmology is in upheaval. This global acceleration forces us to rebuild the edifice of cosmic physics from the ground up, conceiving of some sort of mysterious energy linked to what we call the vacuum, which fills, and pushes, everything. An energy that produces anti-gravitational forces capable of resisting the foreseeable implosion, and with such enormous strength that it can accelerate the expansion of space.

So now, dear reader, let us explore the narrow trail blazed by science in search of the structure and evolution of the Universe to which we belong.

The Universe is accelerating

One of the great practical problems involved in exploring the edges of the Universe is the precise determination of distances. Without getting too technical, we can say that we use "type 1a" supernovas (terminal stars, all of which have practically the same intrinsic brightness) as marker beacons, allowing us to determine the distance of extremely faraway galaxies. The concept is simple: if all such stars are equally bright at their point of origin, then a given supernova's degree of brightness when observed from the Earth will reveal its distance, and consequently, that of the galaxy to which it belongs.

Using this technique, research groups directed by Saul Perlmutter and Adam Riess were able to independently determine the distance of galaxies in which these type of supernova explosions occurred. When they compared the data they obtained with those galaxies' red shift—which measures the expansion of the Universe—they were surprised to discover that, the further away the galaxies, the slower the rate of expansion. In other words, in the past, the Universe was expanding more slowly than it is today. So the Universe is now governed by an accelerated expansion.

These observations by Perlmutter's and Riess' groups constitute the first observational data that the Universe's expansion rate has not been uniform throughout its very long history. That fact is enormously important, as we will see later on.

But before that, let us think for a moment about the idea of the Universe's expansion. This is one of the fundamental concepts of modern science, but it is still one of the most poorly understood. Most people imagine the Big Bang as some sort of enormous bomb that exploded at some point in space, pushing matter outwards because of pressure differences caused by that explosion. But for astrophysicists, the Big Bang was not an explosion "in space" but rather, an explosion "of space," and that is a truly important nuance. In this type of peculiar explosion, density, and pressure are maintained constant in space, although they decrease over time.

The visual metaphor for this explosion is generally a balloon. As it is inflated, any details printed on the surface grow farther apart, so that everything gets farther away from everything else. This two-dimensional idea is very graphic, but it has a problem: it can lead us to believe that, like a balloon, the Big Bang also had a center, a single point from which it expanded. In fact,

Figure 2. This is how we see the distant universe through a "gravitational lens." The galaxy cumulus, Abell 2218, is so massive that it is able to curve light rays, creating images the way a lens would. The arcs we can see are distorted images of galaxies much farther away than the cumulus. This amplifying effect makes it possible to penetrate even more deeply into the cosmos, seeing farther. NASA.

the Big Bang happened at all points in space at the same time, not in any specific one, which is in keeping with Einstein's General Theory of Relativity. According to the most accepted models, the Universe needs neither a center from which to expand, nor empty space *into which* it can expand. Those models do not even call for more than three dimensions, despite the fact that some theories, such as "string theory," call for a few more. Their theoretical base is Relativity, which establishes that space needs only three dimensions to expand, contract, and curve. Moreover, we should not imagine that the singular event at the origin of the Big Bang was something small, an "initial atom," as is sometimes said. Because this is generated no matter what size the Universe may have, be it finite or infinite.

Let us now recall that atoms emit and absorb light at very specific wavelengths, no matter whether they are in a laboratory or in a faraway galaxy. But in the latter case, what we see is a shift towards longer wavelengths ("red shift"). This is because, as space expands, electromagnetic waves stretch, becoming redder. This effect makes it possible to measure the speed with which galaxies are separating from each other, called recession speed. We should emphasize that cosmological red shift is not the normal Doppler effect that happens in space, and its formulae are also different.

Despite the overall expansion of space, there are galaxies, such as our neighbor Andromeda, that are drawing closer and seem not to obey the law of expansion. These are apparent exceptions caused by the fact that, near large accumulations of matter, gravitational energy becomes preponderate, leading those giant swarms of stars to turn around each other. Distant galaxies also present those local dynamic effects, but from our enormously distant perspective, they are overshadowed by their great recession speeds.

To make matters even more complex, the Universe is not only expanding, it is also doing so at an ever-faster rate. That situation has led scientists to recover the constant that Einstein introduced in his General Theory of Relativity to maintain the paradigm of a stationary Universe. When we thought we were living in a decelerating Universe, it was logical to think that, as time passed, we would be able to see more and more galaxies, but in an accelerating Universe, the opposite should be true. The cosmic horizon of events, determined by the finite velocity of light and space's increasing recession speed, marks a border beyond which the events that occur will never be seen by us, because the information they emit cannot reach us. As space's rate of expansion increases, we will gradually lose site of one galaxy after another, beginning with the most distant ones.

Dark energy

The fact that the Universe is accelerating has caught astronomers and physicists off guard and they are brimming with scientific speculations to explain it. The human imagination is capable of inventing many truly ingenious theories, but only those that can explain all of our observations will last. Astronomic observation continues to be the touchstone of any theory, and no matter how elegant it may be, it will have to be validated by observation. That is what makes scientists seem slow and conservative, moving extremely cautiously as they change well-established theories and paradigms.

One immediate form of interpreting accelerated expansion would be to consider that gravity does not follow the same laws in our nearby surroundings as on a super-galactic scale, and that such distances cannot brake expansion because gravity's power of attraction does not extend to an infinite distance. Another proposal that has already been formulated is that the acceleration observed is actually caused by time itself, which is gradually slowing down. But cosmologists prefer to maintain the universality of the physical laws established on planet Earth and its surroundings, and they have begun postulating the existence of a sort of cosmic fluid with contradictory properties that fills everything and appears in the form of an unknown energy—called "dark energy"—that repels, rather than attracts. Its power would be so great that it very efficiently overcomes the gravitational attraction of the enormous masses of galactic cumuli and supercumuli.

For the time being, available observations seem to favor this dark energy. As we mentioned above, the first observations were those made using photometry of type 1a supernovas, which showed that the oldest galaxies are expanding at a slower rate than at present. But measurements of radiation from the Cosmic Microwave Background (or "background radiation") point to the same conclusion.

Discovered in 1965 by Penzias and Wilson, this radiation is a background noise that fills everything and its discovery served to reinforce Big Bang models. Much later, it became possible to detect anisotropies (directional dependence) in the Cosmic Microwave Background, and even though they are extremely small—around 0.00001%—they are full of information about the origins of the structure of the gigantic Cosmos that we see. So now, the contribution of dark energy seems necessary to complete the density of the Universe as measured by the Cosmic Microwave Background. Since the sizes of irregularities in background radiation are a reflection of the global geometry of space, they serve to quantify the density of the Universe, and that density is considerably greater than the simple sum of ordinary and exotic matter. Moreover, the modifications that the gravitational fields of large cosmic structures cause in this radiation depend on how the rate of expansion has changed. And that rate agrees with the predictions made by dark energy models.

The distribution of galaxy swarms follows certain patterns that are in keeping with "stains" observed in background radiation and those stains can be used to estimate the Universe's total mass (fig. 3). It turns out that those models, too, require dark energy. And studies of the distribution of gravitational lenses (remember that very massive objects behave as lenses, curving the trajectories of light) seem to need dark energy to explain the growth over time of agglomerations of matter. But not everything confirms its existence. There are observations that cannot be explained by these models, including the abundance of the most distant galaxy cumuli.

Many researchers are trying to posit dark energy as the cause of aspects unexplained by previous models. Data is accumulating, and models are ever more refined, and more indications, and even proof, will undoubtedly

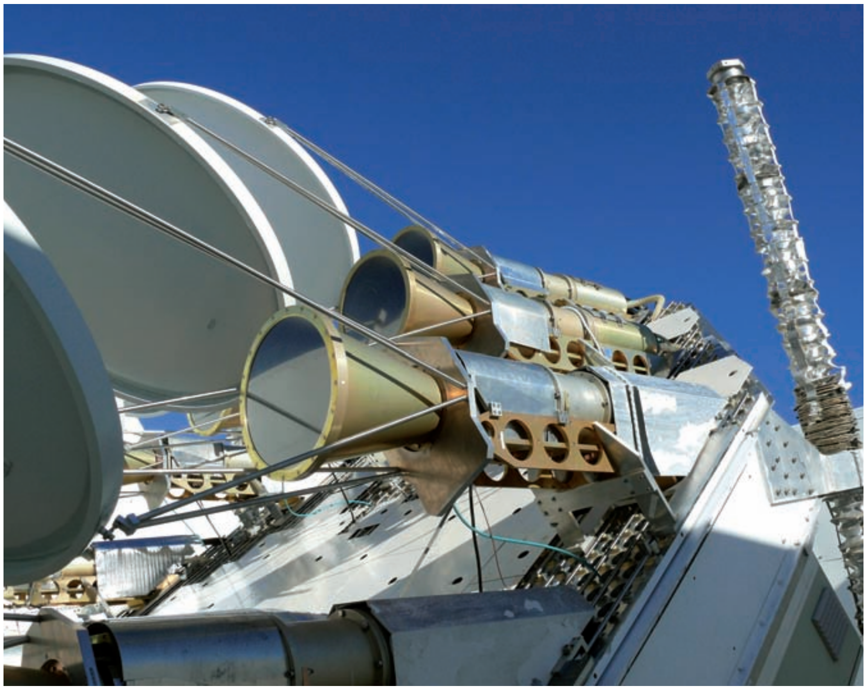

Figure 3. The Very Small Array, which belongs to the IAC and the Universities of Cambridge and Manchester, is one of the instruments installed at the Canary Islands' Astrophysical Institute's Teide Observatory for measuring anisotropies in the Cosmic Microwave Background. The observatory has been systematically measuring this primeval radiation with different instruments and techniques for over twenty years. IAC.

be added, given the feverish activity this surprising acceleration of the Universe has caused among scientists.

The omnipresence of dark energy is so subtle that, even though it fills everything, it has gone unnoticed until now. It is very diluted, and does not accumulate in "lumps" as matter does. In order for its effects to be noticeable, very large amounts of space and time are necessary, even though it is the most powerful energy in the Cosmos. Let me add that, in this energy, which acts as a repulsive force and thus has negative pressure, there are two possibilities: the so-called "phantom energy" and what has been dubbed as the "quintessence." All of this is very evocative, but difficult to digest from a scientific standpoint, as these are forces we do not understand and cannot observe.

It is totally logical to think that if such energy represents more than three quarters of our Universe, it must have had an enormous influence on the latter's entire evolution, determining its large-scale structure and the formation of galaxy cumuli. The very evolution of galaxies themselves must be marked by its omnipresence. We know that the formation of galaxies and their grouping in cumuli is determined by their own interactions, collisions, and merging—our own Milky Way is thought to be the result of the coalescence of perhaps a million dwarf galaxies—so dark energy must have played a significant role in all of this. Nevertheless, clear confirmation will come when we are able to determine whether the beginning of the predominance of accelerated expansion coincides in time with the end of the formation of large galaxies and supercumuli.

The Universe in four dimensions

I have thought a lot about how to illustrate what we know today about our Universe's structure. It is not at all easy for many reasons, and not only because of the difficulty of simplifying things for non-specialists without leaving any loose ends that we take for granted.

If we consider the Universe to be everything that exists, from the smallest to the most gigantic entities, one way of showing their structure would be to make an inventory of all such elements and order them hierarchically in space. But this would be incomplete unless we also listed their interconnections and interrelations. Moreover, none of this—neither the elements nor their interconnections—is static, all of it is interacting and changing on a permanent basis. We must realize that, as such, we cannot have a "snapshot" of what is in the Universe at the present time, because when we look in one direction with a telescope, the deeper our gaze looks, the farther back in time we go. Thus, we are looking at a wedge of the Universe's history, rather than a snapshot. Nevertheless, inasmuch as all directions in the Universe are statistically identical, what we see in any direction at a distance of thousands of millions of light-years must be a representation of how our own, or any other, region of space was, thousands of millions of years ago.

Let us take it a step at a time. First we should remember that, in keeping with what we have already said, more than three quarters of our Cosmos is now a form of that mysterious entity we call dark energy, and more than 85% of the rest is what is called "dark matter," which we cannot see because, though it interacts with gravity, it does not interact with radiation. In other words, not much more than three percent of the entire Universe is "ordinary matter." And we only manage to see a tiny part of the latter, concentrated in stars and galaxies. What we call ordinary matter is actually the baryonic matter—protons, neutrons, and so on—of which we ourselves are made. Most of such matter takes the form of ionized gas plasma, while only a tiny part of it is in solid or liquid state. How difficult it is to grasp that the immense oceans and solid ground of the Earth's surface, on which we so confidently tread, are incredibly rare in our Universe! But science has taught us to accept that we live in a very exotic place in an everyday part of the Cosmos.

On the other hand, the panorama could not be any more disheartening: despite our elegant scientific speculation, we do not have the slightest idea about the nature of 97% of what constitutes our Universe! Of course, just knowing that is already a great triumph for the grand human adventure in search of knowledge.

Our own nature leads us to move and understand things in three spatial dimensions plus time. And this space-time is the context in which most relativist models are developed. That is why I am going to describe the structure of the Universe in four dimensions. But first, I must at least mention models of "multiverses" derived from superstring theory. These are elegant physical-mathematical speculations about multiple universes in which our three-dimensional Universe would be just one projection of three dimensions installed in a global space of nine.

Below, I will try to offer an accessible description of how astronomers currently imagine the Universe to be at the present time in its history. Afterwards, I will focus on some of the most significant stages of its evolution.

On a large scale, the Universe we can now contemplate with our telescopes appears to be a little more that 13,000 million years old, and enormously empty. Matter appears to be very concentrated and hierarchically organized around the gravitational fields of the stars, with their planetary systems, of galaxies, galactic cumuli, and supercumuli (fig. 4). The enormous planetary, interstellar, and intergalactic voids are filled with very diluted matter, which actually adds up to the greater part of ordinary matter. Dark matter also accumulates, and is ordered in analogous fashion, for it, too, is ruled by gravity. Dark

Previous page:

Figure 4. The galaxy known as Triangle or M33. This extraordinary image obtained with the INT at the Canary Islands' Astrophysical Institute shows the smallest of the three spiral galaxies that make up the Local Group, which also includes Andromeda, the Milky Way and a few other smaller galaxies. Also visible are innumerable other components, from various sorts of interstellar clouds to stars in every phase of life, beautiful planetary nebulae and the remains of supernovas. IAC.

energy, however, does quite the opposite: it is uniformly spread throughout the Universe.

Were we to zoom in, drawing close to each part of our own galaxy—the Milky Way—we would find brilliant planetary systems with one or more suns, with their planets, satellites, comets, and myriad smaller objects orbiting around each other, and all around their respective centers of mass. And as there can be hundreds of thousands of millions of them in any galaxy, some will be new, emerging from clouds of interstellar dust and gas, among convulsions and readjustments, while others are in their final stages, imploding and exploding, expulsing incandescent matter, particles, and radiation in a very beautiful but nightmarish spectacle. Most galactic objects, of course, will be in the intermediate stages of their lives. A description of the lives and miracles of such multifaceted and variegated galactic "fauna" would exceed the scope of the present article, though it would be full of color, beauty, and drama. Another question that is very much more important to us here is that of the existence of life outside our planet. If there were life in different parts of the Universe, it would have to have an influence—though we do not yet know what that might be—on its structure. This might well lead to readjustments of our concept of the Cosmos even greater than those we now have to make as a consequence of the Universe's acceleration.

The enormous swarms of stars, gas, dust, and much dark material that make up the galaxies are not isolated in space. On the contrary, we can see that they are strongly linked to each other by gravity. And those links lead to groups, called galactic cumuli, which are, in turn, linked to form galactic supercumuli. Such enormous accumulations of material appear to be organized in meshes similar to spider webs, favoring filament-like directions of tens of millions of light-years. And all of it floats in enormous voids.

We must not forget that all this enormity is fully active and that all the celestial objects are moving at incredible speeds. Thus, to imagine a Universe that is mechanically regulated like some sort of perfect clock is the farthest thing from reality. Interactions are multiple, and collisions frequent. Those collisions—of external layers of stars with their surroundings, or interstellar clouds and super-clouds, or even between galaxies—turn out to be the most efficient mechanisms for fine-tuning the galaxies and mobilizing cosmic surroundings (fig.1). Energy seems to be unleashed in incredibly violent phenomena that we can observe all over the Universe, producing new celestial objects.

And every bit of this superstructure is also steeped in dark energy, which efficiently counteracts gravity, expanding space at an accelerating rate and undoubtedly generating direct or indirect activity at all levels of the cosmic structure. The fact that we do not yet know about it does not mean that it is not occurring.

We can retain this simplified image of a gigantic, violent Universe in accelerated expansion, with its matter—the ordinary matter of which we ourselves are made, and the dark matter—concentrated in islands full of action, pushed by gravity, uniformly steeped in dark energy, and bathed in electromagnetic radiation. And in one tiny spot, our miniscule Earth, filled with life, dancing in space.

Following this semi-cinematic portrayal of how we understand what must be the current structure of the Universe, we must say a little about the main stages of its life. Because what we see today, including the life that thrives on planet Earth, is a consequence of its general evolution, which is determined by laws we are trying to discover. In fact, the quest for knowledge about the birth and evolution of each and every part of the Cosmos is what presently underlies all astronomical research.

The evolution of the Universe

Much has been written about time's arrow, trying to discover where the evolution of our Universe is headed and, since it had a beginning, finding out what its end will be. Let us see what can be said about all this in an intelligible way, and with both feet on the ground.

Ever since the Universe stopped seeming immutable at the beginning of the past century, we have sought knowledge of its history and, most of all, its evolution. For that is the key to the origin of our own history, and of intelligent life on other planets in other star systems. But history is the story of events in time, and it seems that time, our time, began with the very Universe to which we belong. And we do not yet know with any certainty what the real essence of this physical parameter might be. Without entering into profound disquisitions, we can consider time to be the way we intuitively imagine it: a uniform continuity reaching from the Big Bang towards a distant future.

Almost all the information we received from outer space comes in the form of electromagnetic radiation, and the first retrospective snapshot of the Universe comes from the Cosmic Microwave Background. By then, the Universe was about 400,000 years old, and many things of enormous importance had already happened. We can infer what those things were using our cosmogonic models, the most accepted of which is known as the Standard Model. We must not forget that this model describes what happened after the Big Bang, but it does not offer information about that event, itself. We should also remember that the model was developed before the discovery of accelerated expansion, and the three pillars on which it stands are: decelerating expansion, the Cosmic Microwave Background, and primordial nucleogenesis, which produced the first light elements that continue to dominate matter. The key to this model is that, at the beginning, the Universe was very hot and very dense, becoming cooler and less dense as it expands.

Abundant new and highly speculative models continue to appear in order to explain the nature and birth of matter and its interactions, and they are so complex that they are only understood by those who work in that field. Their empirical underpinnings, however, are astronomic observations and experiments with large particle accelerators, all of which are still not sufficient to shed light in the midst of so much physical-mathematical speculation. I say all this in order to avoid the misconception that most of the disconcerting things being said about the Universe's first moments—including what I am going to say—are scientific fact.

Immediately following the Big Bang that started everything, in just the first 10^{35} seconds, when all the fundamental forces were still unified, space underwent a prodigious exponential expansion. It grew by a factor of 10^{26} in just 10^{33} seconds. That is what inflationary models suggest, and they rely on data from background radiation. That accelerated expansion rarified everything that preexisted, smoothing out possible variations in its density. This, then, is the first accelerated expansion, implying something as inconceivable as the idea that energy must be positive and remain almost constant—the "almost" is very important, here—while pressure is negative (fig. 5). This ends with a sudden drop in density. Obviously, we do not know how, nor why this inflation started and stopped.

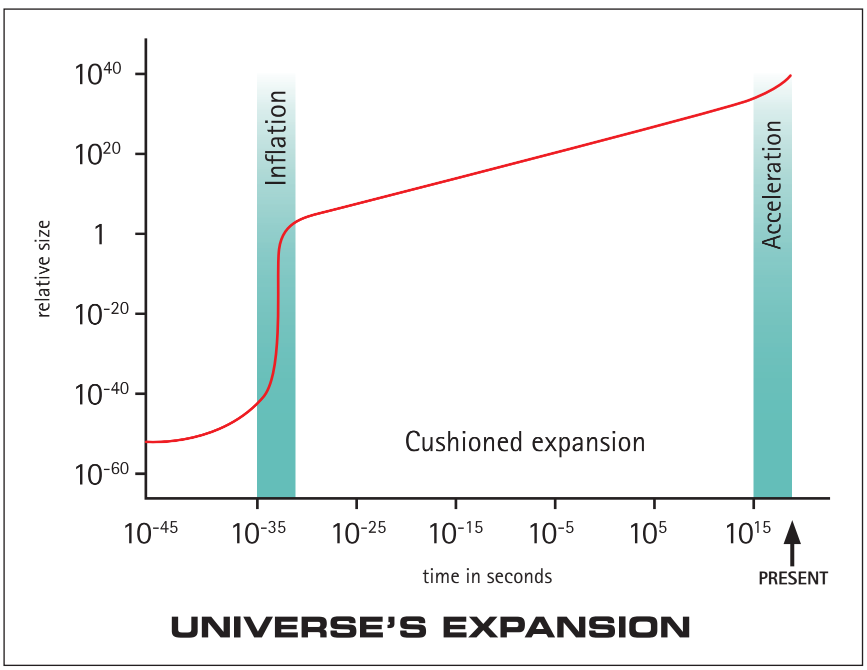

Figure 5. While it is not possible to realistically represent the expansion of space, much less its extraordinary "inflation," we can get a preliminary, though greatly simplified, idea of its expansion over time using the graph shown above. It uses logarithmic scales to make details visible. Both "inflation" and "accelerated expansion" share a negative pressure that opposes gravitational attraction. We have yet to discover the nature of these phenomena. IAC.

During the inflationary period, the density of space fluctuated minimally, due to the statistical nature of quantum laws that hold at subatomic levels. But those irregularities were exponentially expanded by inflation, leading to the anisotropies in the Cosmic Microwave Background. These are the seeds that mark the grandiose destiny of the Universe; they are the embryos of the macrostructures of galaxies and galactic cumuli we see today. The Universe emerged from this period in a heated state, with the potential energy of the void converted into hot particles.

To continue with this succinct description of the Universe's evolution based on the most accepted models; the different particles and antiparticles, along with their interactions, created themselves, as this was permitted by the Universe's ongoing expansion and cooling. Just 10^{5} seconds after the Big Bang, baryons already existed. This "soup" of particles in continuous birth and death continued to cool and almost all particles of matter and antimatter annihilated each other. But for unknown reasons, there was a slight excess of baryons that did not find particles of antimatter against which to annihilate themselves, and thus they survived extinction.

When the temperature fell to around 3,000 degrees, protons and electrons became able to combine and form electrically neutral hydrogen atoms. Matter thus stopped being linked to radiation, as photons stopped interacting with matter in such an intense way, and light spread all over. Those very first photons are what make up the radiation of the Microwave Background. By then, the Universe was about 400,000 years old and, as we have seen, some very important things had happened. One of these was the "primordial nucleosynthesis" that determined the absolute preponderance of hydrogen and helium in the Universe. That process, governed by expansion, must have happened in only a few minutes, which is why nucleosynthesis only generated the lightest elements.

This was followed by a grey period stretching from the freeing of the radiation that makes up the Cosmic Microwave Background to the re-emergence of light as the first galaxies and stars were born. We know very little about that period of the Universe because there are no radiations to be observed. Still, it was decisive, because that is when gravity began to assemble the objects that now inhabit the Cosmos. It ended in the first millions of years, when starlight became strong enough that its ultraviolet radiation could ionize the gas that now dominates intergalactic space. The stars that made that light were very peculiar—super-massive stars of one hundred solar masses or more, made up exclusively of hydrogen and helium. All of this is corroborated by observations of the spectra of the most remote quasars, galaxies, and explosions of gamma rays, as well as the discovery of distant galaxies less than one thousand million years after the Big Bang.

It is believed that galaxies and stars begin to form when a region of space with greater density than its surroundings begins to contract upon itself, as a result of its own gravity. Let us not forget that galaxies are made mostly of dark material, which cannot be directly observed. Even though such a region is subject to overall expansion, the excess of matter leads it to contract, creating a linked object, which may be a star, a stellar cumulus, or a galaxy. Of course many additions and nuances would have to be brought in to explain what we know about all this, which is quite a bit. And there are innumerable research projects underway to study the origin and evolution of stars and galaxies. Here, I can only indicate the basic mechanism that generated most of the objects we observe.

By all indications, during the Universe's first few thousand million years, there were frequent collisions among galaxies, gigantic outbreaks of star making inside them, and the generation of black holes of more that a thousand million solar masses. This, then, was an extraordinarily energetic and agitated period. That disorderly activity seems to be declining now, perhaps as a result of the accelerated expansion. In the nearest parts of the Universe, we only find such prodigious activity in the smaller galaxies. The larger ones, such as the Milky Way or Andromeda, are calmer and seem to have entered a mature stage.

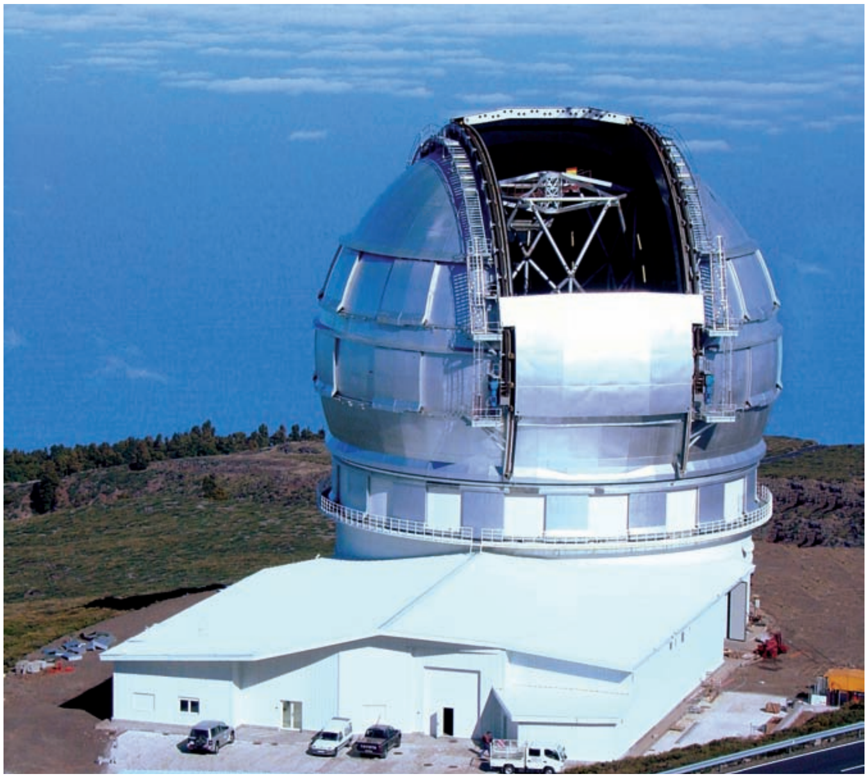

Figure 6. An outside view of the Gran Telescopio CANARIAS (GTC) at the Roque de los Muchachos Observatory of the Canary Islands' Astrophysical Institute. This is the largest and most advanced optical-infrared telescope in the world, with a segmented primary mirror of 10.4 meters in diameter. The low incidence of clouds—the ones visible in this image are actually below the telescope, although the photo's perspective does not make this clear—along with the transparence and stability of its atmosphere make this one of the extremely rare places on Earth where such an advanced telescope can be profitably installed. A large lens, excellent optics and powerful focal instrumentation, as well as the extraordinary astronomic quality of the sky over La Palma, make the GTC an extremely powerful tool for penetrating the secrets of the universe. IAC.

We cannot yet say when acceleration began to predominate over deceleration, although it has been pointed out that this must have happened when the Universe was around eight thousand million years old. Earlier, we mentioned the degree to which scientists speculate about the effects of dark energy. Undoubtedly, once the reality of the two competing energies is confirmed—gravity, which tries to bring material together; and dark energy, which tries to separate it—there will have to be new models to explain all our observations. But we will have to wait until the new telescopes on Earth and in space begin producing significant data before we can consider them trustworthy. In that sense, we have high hopes for the Gran Telescopio CANARIAS, which will be fully operational in 2009 (fig. 6). Telescopes are the only time machines, and the larger their mirrors, the more deeply they can look into the Cosmos, and the further back in time we can see. With them, we seek to observe the birth and evolution of the earliest objects.

Because of their importance to us, we should add that our Sun and its Solar System were born when the Universe must have been around nine thousand million years old. They stem from a cloud of recycled matter produced inside previous stars, and cast out into the interstellar void. The chemical elements of organic molecules that sustain all forms of life on our planet, could not have been created *in situ,* and must have already been in the protoplanetary disc, which allows us to say, with certainty, that "we are stardust." And this is much more than a pretty bit of poetry.

Until a very short time ago, the future of the Universe was predicted on the basis of gravitational energy and thermodynamics, as a function of the quantity of material it contained. If its mass was greater than the critical value calculated in keeping with common models, it was predicted that its expansion would grow slower until it imploded, as part of an oscillating process of Big Bangs and their posterior implosions. If that were not the case, we would continue to expand indefinitely. Now, we have to take into account the Universe's acceleration, and that leads us to imagine a different future.

The End

If accelerated expansion continues, the galaxies will begin disappearing from view as they cross the horizon of events, beginning with the most distant ones. In a few thousand million years, the nearby galaxies will have fused, forming a gigantic group of stars linked by gravity, a mega-super galaxy or "mesuga," enveloped in a dark, empty space. Radiation from the Microwave Background will be so diluted that it will be undetectable. Long before everything grows cold and ends, we will be isolated in space and our accessible Universe will be only our own "mesuga".

A bleak ending for our physical world. But is it really the end? What will the internal evolution of the myriad millions of "mesugas" be when they become isolated? Will there be a mechanism that connects them in some way, even though the separation between them continues to grow at an accelerating rate?

Clearly, we never lose hope, nor do we lose our will to be eternal! For that is how we are. Moreover, we are designed to be curious. We have a will to know, and in Sapiens-Sapiens, that drive seems as basic as the one to reproduce. Could this have something to do with the expansion of the Universe?

As things stand today, the joint existence of two opposite energies—gravity and dark energy—seems to have been necessary for the formation of the Universe, and of our Sun and Earth within it, so that, following a laborious process of evolution, our own parents could begat each of us. If dark energy had been just a little weaker, or a little more powerful, you would not be reading this book now, nor would I have been here to write it. Whether we descend to the minimum level of the most recently discovered sub-nuclear particles, or lose ourselves in the immensity of the Cosmos, we find everything in constant activity, moved by powerful forces. And the same can be said of life in all its facets, be they unicellular organisms or impenetrable forests—there, too, activity is incessant. This must be something consubstantial with our Universe: nothing is static, everything is action and evolution. Energy is abundant and seems to be wasted: cataclysmic episodes of immense power are frequent in galaxies and stars. This constant and often catastrophic agitation is the manifestation of what we could call "Cosmic impetus," which fills and pushes everything. That impetus is expressed as energies that we could try to systemize by cataloguing them in two large groups: "physical energies" and "life energies." At some point, it will be necessary to conceptualize all of this in mathematical form.

Anyone who has enjoyed the starry nights of the wilderness, far from the polluted hustle and bustle of our cities, and has let himself be carried away by his sensations, feelings and imagination in this state of grace, will have felt the profound force of the fundamental questions. Even if none of them has been answered in the previous pages, the careful reader will have sensed the brilliant spark of human intelligence successfully confronting the immensity of the Universe and its attractive mysteries. The truth is: even though our ignorance borders on the infinite, what we already know is considerable, and constitutes a notable triumph that dignifies all of humanity. While this incredible, evil, and stubborn, yet loving and intelligent species continues to exist, it will continue to look questioningly at the heavens.

Bibliography

Adams, Fred C. and Greg Laughlin. *The five ages of the universe: inside the physics of eternity.* Free Press, 2000.

Caldwell, Robert R. "Dark energy." *Physics World,* l.17/5, 2004, 37–42.

Caldwell, Robert R., M. Hamionkowski, and N. N. Weinberg. "The phantom energy and cosmic doomsday." *Physical Review Letters*, 91/071301, 2003.

Dine, M. and A. Kusenko. "Origin of the matter antimatter asymmetry." *Reviews of Modern Physics*, 76, 2004, 1–30.

Freedman, W. L. and Michael Turner. "Measuring and understanding the universe." *Review of Modern Physics,* 75, 2003, 1433–1447.

Harrison, Edward R. *Cosmology: the science of the universe.* Cambridge University Press, 2000.

Hertzberg, Mark, R. Tegmark, Max Shamit Kachru, Jessie Shelton, and Onur Ozcan. "Searching for inflation in simple string theory models: an astrophysical perspective." *Physical Review*, 76/103521, 2007, 37–45.

Kirshner, Robert P. *The extravagant universe: exploding stars, dark energy, and accelerating cosmos.* Princeton University Press, 2004.

Krauss, Lawrence and Glenn Starkman. "Life, the universe and nothing: life and death in an ever-expanding universe." *Astrophysical Journal,* 531/22, 2000, 22–30.

Peebles, P. J. E. and B. Ratra. "The cosmological constant and dark energy." *Review of Modern Physics,* 75, 2003, 559–606.

Primack, Joel and Nancy Ellen Abrams. *The View from the Centre of the Universe: Discovering Our Extraordinary Place in the Cosmos.* Riverhead, 2006.

Silk, Joseph. *The infinite cosmos: questions from the frontiers of cosmology.* Oxford University Press, 2006.

Srianand, T. A., P. Petitjean, and C. Ledoux. "The cosmic microwave background radiation temperature at a redshift of 2.34." *Nature*, 408/6815, 2000, 93–935.

Wilson, Gillian et al. "Star formation history since z = 1 as inferred from rest-frame ultraviolet luminosity density evolution." *Astronomical Journal*, 124, 2002, 1258–1265.