Cosmology

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Summary

Although each individual celestial object has its particular charms, understanding the evolution of the universe is also a fascinating subject in its own right. Even though we are anchored to the neighborhood of the Earth, understanding that we know as much as we do -about so much- is captivating.

The last century was focused on knowing the properties of the observable universe and it was thought that this was all there was to our universe. However, we now speculate that our universe is part of a set of disconnected universes included in the megaverse of probable universes.

We will describe some properties of galaxies that are part of large structures in the universe. Later we will address what is known as the standard model of the Big Bang and the reasons which suggest that the evolution of the universe satisfies certain restrictions.

Goals

• Understand how the Universe has evolved since the Big Bang to today.
• Know how matter and energy are organized in the Universe.
• Analyze how astronomers can learn about the history of the Universe.
• Address concepts related to the possible existence of multiple universes.

The Galaxies

The stars are grouped into galaxies. The galaxy to which the Sun belongs has a hundred billion stars, gas, dust and dark matter (which will be described later). In the universe there are billions of such galaxies.

Our galaxy is a spiral galaxy and the Sun takes 200 million years to orbit its center, even when traveling at 250 kilometers per second. The solar system is immersed in the disk of the galaxy so we can not see it as a whole, like trying to see a forest from afar while being in it. The part of the galaxy that we see with the unaided eye from Earth is called the Milky Way and it is composed of an enormous number of stars and clouds of interstellar matter. The way the structure of our galaxy was discovered was by observing other galaxies. (If there were no mirrors, we could imagine how our own face looks by seeing other faces.) You can use radio waves to analyze our galaxy, since they can pass through clouds that are opaque to visible light, similar the way we can receive waves for mobile phones that, unlike visible light, can pass through walls.

Fig. 1a: Galaxy of Andromeda. Spiral galaxy very similar to our own Milky Way. The Sun is at the outer edge of one arm of our galaxy. (Photo: Bill Schoening, Vanessa Harvey / REU program / NOAO / AURA / NSF).Fig.1b: Large Magellanic Cloud. Irregular satellite galaxy of the Milky Way that can be seen with the unaided eye from the southern hemisphere. (Photo: ESA and Eckhard Slawik).

We classify galaxies into three types. Irregular galaxies are smaller and abundant and are usually rich in gas, i.e., with the ability to form new stars. Many of these galaxies are satellites of other galaxies. The Milky Way has 30 satellite galaxies, and the first of these discovered were the Magellanic Clouds, which are seen from the southern hemisphere.

Spiral galaxies, like our own, in general have two arms tightly or loosely twisted in spirals emanating from the central part called the bulge. The cores of galaxies like ours tend to have a black hole millions of times the mass of the Sun. The birth of new stars is mainly in the arms, since there is the greater density of interstellar matter whose contraction gives birth to stars.

When black holes in galactic nuclei attract clouds of gas or stars, matter is heated and before falling into the black hole, part of it emerges in jets of incandescent gas that move through space and heat the intergalactic medium. They are known as active galactic nuclei and a large number of spiral galaxies have them.

The largest galaxies are ellipticals (although there are also small ellipticals). It is believed that these, as well as the giant spirals, are formed at the expense of small galaxies by a process known as galactic cannibalism, during which galaxies merge. Some evidence for this comes from the diversity of ages and chemical composition of the various groups of stars in the merged galaxy.

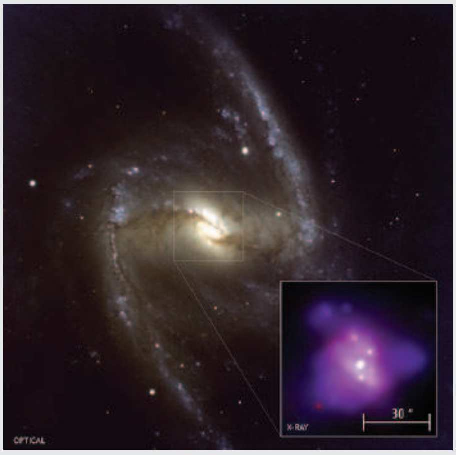

Fig. 2a: Optical image of the galaxy NGC 1365 taken with the ESO VLT and Chandra image of X-ray material close to the central black hole. (Photo: NASA, ESA, the Hubble Heritage (STScI / AURA) -ESA/Hubble Collaboration, and A. Evans). Fig. 2b: Samples of galactic cannibalism where two merging galaxies interact in a very spectacular process. University of Virginia, Charlottesville / NRAO / Stony Brook University).

Galaxies form clusters of galaxies, with thousands of components. Ellipticals are usually in the central regions, and some show two cores as a result of a recent merger of two galaxies.

Clusters and superclusters of galaxies are distributed in the universe in filamentous structures which surround immense holes devoid of galaxies. It is as if the universe on a large scale was a bubble bath where galaxies are on the surface of bubbles surrounding empty space.

Fig. 3: Abell 2218 cluster of galaxies. Arcs can be seen, caused by a gravitational lensing effect. (Photo: NASA, ESA, Richard Ellis (Caltech) and Jean-Paul Kneib (Observatoire Midi-Pyrenees, France).

Cosmology

We will describe some properties of the universe in which we live. The universe, which consists of matter, radiation, space and energy, evolves with time. Its temporal and spatial dimensions are much larger than we use in our daily lives.

Cosmology offers answers to fundamental questions about the universe: Where did we come from? Where will we go? Where are we? For how long?

It is worth mentioning that science does not pursue the truth. Research has shown that this is an unattainable goal because the more we know, the more we realize how much we do not know. A map is useful even if it is only is a representation of a site, just as science allows us to have a representation of nature, see some of its aspects and predict events, all based on reasonable assumptions that necessarily have to be supported with measurements and data.

The dimensions of the universe

The distances between stars are vast. The Earth is 150,000,000 km from the Sun and Pluto is 40 times farther away. The nearest star is 280,000 times more distant, and the nearest galaxy is ten billion times more. The filament structure of galaxies is ten trillion times greater than the distance from the Earth to the Sun.

The age of the universe

Our universe began its evolution 13.7 billion years ago. The solar system was formed much later at 4.6 billion years ago. Life on Earth emerged 3.8 billion years ago and the dinosaurs became extinct 65 million years ago. Modern humans arose as recently as 150,000 years.

We know that our universe had an origin because we observe that it is expanding rapidly. This means that all clusters of galaxies are moving away from each other and the more distant they are the faster they recede. If we measure the expansion rate we can estimate when the space was all together. This calculation gives an age of 13.7 billion years. This age does not contradict stellar evolution since we do not observe stars and galaxies older than 13.5 billion years. The event which started the expansion of the universe is known as Big Bang.

Speed measurement

You can measure the velocity of a star or galaxy by the Doppler effect. You can make an analogy if you place a ringing alarm clock in a bag with a long handle. If someone else spins the bag by the handle with their arm extended above their head, we can detect that the tone changes when the clock's moves toward or away from us. This change in tone is known as the Doppler effect. We could calculate the clock's speed by listening to the change of the tone, which is higher if the speed is greater.

Light sources also go through a frequency change or color change that can be measured depending on the speed with which they approach or depart. They become redder when moving away from us and blue when they move toward us.

The filament structure of the universe is the result of the expanding universe and the gaps between groups of galaxies increase in volume. When the universe was more compact, the sound waves passed through it and produced changes in density that are now reflected in the distribution of galaxies, since these are formed where the matter density was higher.

Sound waves

Sound travels through a medium such as air, water or wood. When we produce a sound we generate a wave that compresses the material around it. This compression travels through the material to reach our ear and compresses the eardrum which sends the sound to our sensitive nerve cells. We do not hear the explosions from the sun or the storms of Jupiter because the space between the celestial objects is almost empty and there is no way the sound compression can propogate.

The Megaverse

The fact that the universe we live in had an origin with the expansion of space and the formation of matter does not mean it could not have done so before or there weren't universes before ours. And there could be other universes existing in parallel with ours, i.e. a compound megaverse composed of different universes.

The expansion of the universe is necessary for its existence, since otherwise the force of gravity would dominate the cosmos. All objects attract each other. If galaxy clusters are not far apart, the cosmos would be in imminent danger of collapse, i.e., they would "fall" into themselves. This could have happened before the Big Bang, even in several cycles, before our present universe.

We can do the following thought experiment to clarify our ideas. If we throw a ball up, it falls after reaching a certain height; the greater its speed the higher it will go, but it will again eventually fall. This is because the Earth's mass is high and the speed of the ball is not enough to get it out of the Earth's gravitational influence.

In a possible universe, similar to ours but with relatively slow expansion and high density, clusters of galaxies reach a certain distance and then collapse and recombine. If we can throw the ball up with a speed exceeding 12 km/s it could escape from Earth's gravity. The speed of galaxy clusters is such that they will move away from each other forever because the gravity from the density of matter in our cosmos is not enough to prevent this expansion.

It is noteworthy that there is no center of the universe's expansion. Using a two-dimensional analogy, imagine we were in Paris at the offices of UNESCO and the Earth is expanding. We would observe that all cities would move away from us and each other, but we would have no reason to say that we are in the center of the expansion because all the inhabitants of other cities would observe the expansions the same way.

Now is the place to reflect on space. There is one space that can exist, and it is the one we observe.

Light travels at a speed that is very slow compared to the dimensions of the cosmos. Although from our point of view of 300,000 kilometers per second is unimaginable, to intergalactic distances it is minuscule. Starlight takes hundreds of years to reach Earth and the light from galaxies takes millions of years. That is, the only present we can see is that of the earth. All information from the rest of the cosmos takes so long to arrive that we always see the stars as they were in the past, not as they are now.

There are bodies so distant that their light has not had time to reach us from the moment they formed, so we cannot see them. It's not that they are not there, simply that were born after the radiation from that region of the sky has had time to catch up to us.

The finite speed of light has several implications for astronomy. Space affects the trajectories of light, so if we see a galaxy at a given place it may not actually be there, because the curvature of space changes its position. In addition, a star is no longer at the spot you observe it to be because the stars are moving. Nor are they like we see them now. We always see celestial objects as they were, and the more distant they are the further back in their past we see them. So analyzing similar objects at different distances is equivalent to seeing the same star at different times in its evolution. In other words we can see the history of the stars if we look at those we assume are simlar types, but at different distances.

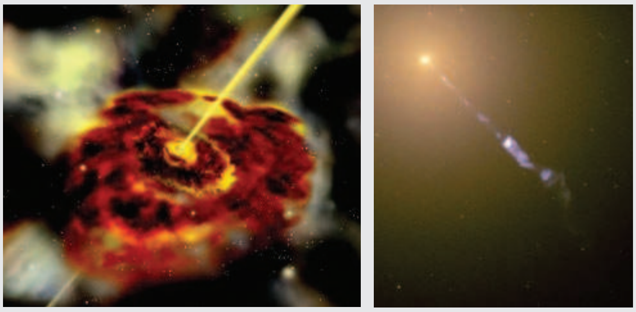

Fig. 4a: Artistic illustration of a black hole in the center with of a galaxy. (Photo: NASA E / PO - Sonoma State Univ.). Fig 4b: Galaxy M87, an example of real galaxy a jet. (Photo: NASA and Hubble Heritage Team).

We cannot see the edge of the universe because its light has not had time to reach Earth. If our universe is infinite, we only see a tiny section 13.7 billion light years in radius, i.e., the time that light has been traveling since the Big Bang. A light source emits radiation in all directions, so different parts of the cosmos are unaware of its existence at different times. The Earth is the only place where we can observe the present time: we see all the heavenly bodies as they were, because the light coming from them takes a finite time in coming to us. This does not mean we have some privileged position in the universe, any observer in any other galaxy would observe something equivalent to what we detect.

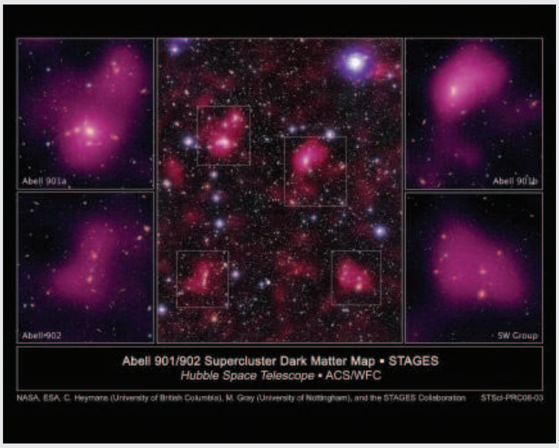

Fig. 5: To date, over 300 dark and dense clouds of dust and gas have been located, where star formation processes are occurring. Super Cluster Abell 90/902. (Photo: Hubble Space Telescope, NASA, ESA, C. Heymans (University of British Columbia) and M. Gray (University of Nottingham)).

As in any science, astronomy sees every day that the more we learn, the more our ignorance increases. Now we will discuss dark matter and dark energy, to give an idea of how much we still do not know about the universe.

Dark matter does not interact with electromagnetic radiation, meaning that it does not absorb or emit light. Ordinary matter can produce light, like a star, or absorb it, as does a cloud of interstellar dust. Dark matter is insensitive to any radiation. It was discovered because it affects the motion of visible matter. For example, if a galaxy has motion around apparently empty space, we are certain that something is attracting it. Just as the solar system holds together because the Sun's gravity forces the planets to stay in orbit, the galaxy in question has a rotation because something attracts it. It has been discovered that dark matter is the most common matter in the universe.

Our current knowledge of the universe has led us to measure that, of all the energy content of the universe, only 26 percent is matter, and only 4 percent is luminous matter (all the galaxies we see) and 22 percent is dark matter, with an unknown nature, but which can be measured by its gravitational effects. The remaining 74 percent of the energy content of the universe is in a form of energy which is responsible for the expansion, but whose nature we do not know and which we call dark energy.

The future of our universe depends on the distribution of visible matter, dark matter and the so-called dark energy. There are three possible scenarios for the end of the known universe. It may happen that the universe expands and then, if there is enough matter,

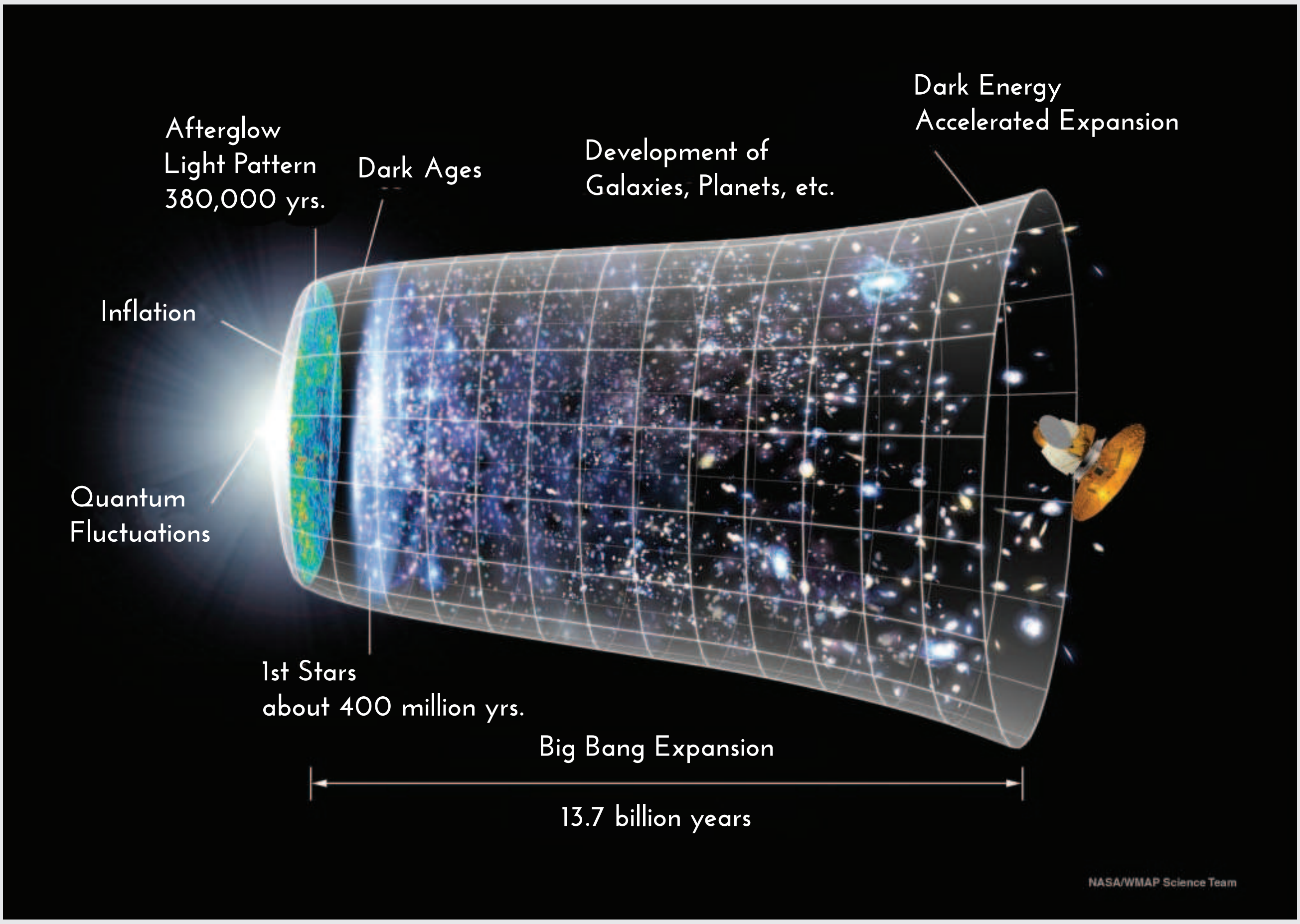

Fig. 6: Expansion of the Universe. (Photo: NASA).

gravity will reverse the expansion, and everything will return to the starting point in a process called the Big Crunch. In this case, the universe would undergo a process of birth, death and rebirth. But if, as current observations indicate, matter is only 24% of everything that exists in the cosmos, it could be that the expansion is stopped at infinity. There is still a third possibility. If, as current observations indicate may be the case, there is a repulsive force that is opposed to gravity and instead of stopping, the expansion of the universe is accelerating. Then what will happen is known as the Big Rip, a large space-time rip, leading to the disappearance of the universe.

While each individual celestial object has it own charms, to understand the evolution of the universe is usually a fascinating subject, because it encompasses everything. Realizing that while being anchored to the neighborhood of the Earth we know as much as we do -about so much- is captivating.

Bibliography

Fierro, J., *La Astronomía de México*, Lectorum, México, 2001.

Fierro, J, Montoya, L., "La esfera celeste en una pecera", El Correo del Maestro, México, 2000.

Fierro J, Domínguez, H, *Albert Einstein: un científico de nuestro tiempo*, Lectorum, México, 2005.

Fierro J, Domínguez, H, "La luz de las estrellas", Lectorum, El Correo del Maestro, México, 2006.

Fierro J, Sánchez Valenzuela, A, *Cartas Astrales, Un romance científico del tercer tipo*, Alfaguara, 2006.