Cosmology

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Summary

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

Astronomy in the 19th century was focused on cataloguing the properties of individual celestial objects: planets, stars, nebulae, and galaxies. By the end of the 20th century the focus changed tounderstanding the properties of categories of objects: clusters of stars, formation of galaxies, and structure of the Universe. We now know the age and the history of the Universe, and that its expansion is accelerating, we do not yet know the nature of dark mater. And new discoveries continue to be made.

We will first 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 evidence that supports the model

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 learn about the history of the Universe.

The Galaxies

Galaxies are composed of stars, gas, dust, and dark matter, and they can be very large, more than 300 000 light years in diameter. The galaxy to which the Sun belongs, has a hundred billion (100 000 000 000) stars. In the universe there are billions of such galaxies.

Our galaxy is a large spiral galaxy, similar to the Andromeda galaxy (figure 1a). The Sun takes 200 million years to orbit its center, traveling at 250 kilometers per second. Because our solar system is immersed in the disk of the galaxy, we cannot see the whole galaxy, much like trying to picture a forest when you are in the middle of it. Our galaxy is called the Milky Way. With the unaided eye from Earth, we can see many single stars and a wide belt composed of an enormous number of stars and interstellar clouds of gas and dust. Our galaxy's structure was discovered through observations with visible and radio telescopes, and by observing other galaxies. (If there were no mirrors, we could imagine what our own face is like by looking at other faces.) We use radio waves since they can pass through clouds that are opaque to visible light, similar to the way we can receive calls on mobile phones inside a building.

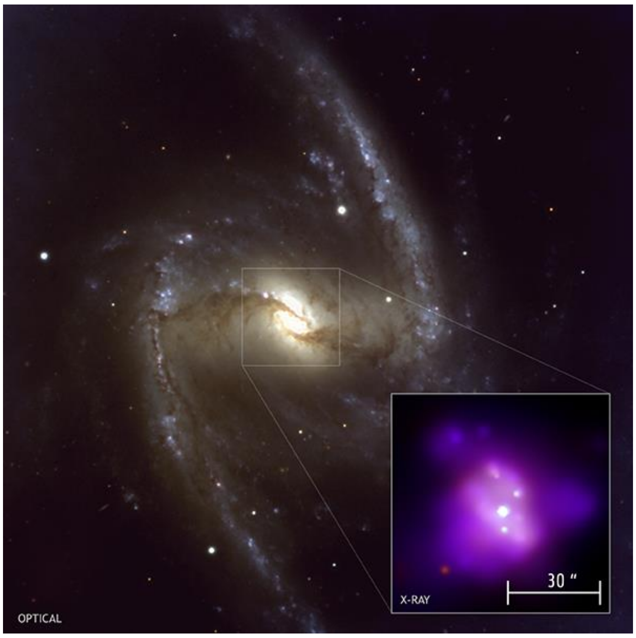
Fig. 1a: Galaxy of Andromeda. Spiral galaxy very similar to our own Milky Way. The Sun is at the outer edge of one arm of our galaxy. (Photo: Bill Schoening, Vanessa Harvey / REU program / NOAO / AURA / NSF).Fig.1b: Large Magellanic Cloud. Irregular satellite galaxy of the Milky Way that can be seen 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, and 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. New stars are born mainly in the arms, because of 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 the ellipticals (although there are also small ellipticals). It is thought that these, as well as the giant spirals, are formed when smaller galaxies merge together. Some evidence for this comes from the diversity of ages and chemical composition of the various groups of stars in the merged galaxy.



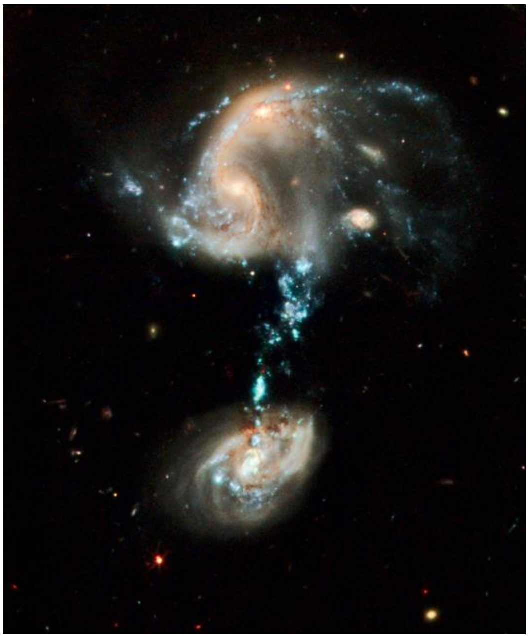


Fig. 2a: Optical image of the galaxy NGC 1365 taken with the ESO VLT and Chandra image of X-ray material close to the central black hole. (Photo: NASA, ESA, the Hubble Heritage (STScI / AURA) -ESA/Hubble Collaboration, and A. Evans). Fig. 2b: Arp 194 – a system of two galaxies interact in a very spectacular process. The cores are merging, and a blue tail is released (credit: NASE,ESA and the hubble Heritage Team (STScl))

Galaxies form clusters of galaxies, with thousands of components. Giant ellipticals are usually found in the cluster centers, and, some of them have two cores as a result of a recent merger of two galaxies.

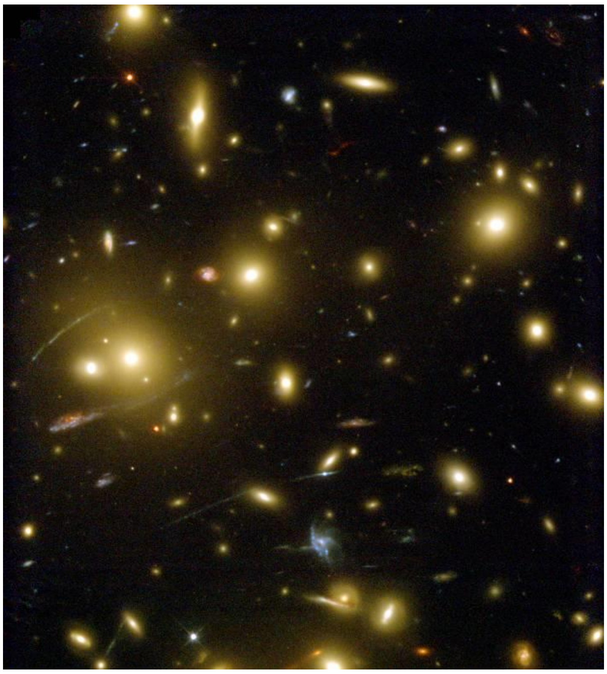


Fig. 3: Abell 2218 cluster of galaxies. Arcs can be seen, caused by a gravitational lensing effect. (Photo: NASA, ESA, Richard Ellis (Caltech) and Jean-Paul Kneib (Observatoire Midi-Pyrenees, France)).

Clusters and superclusters of galaxies are distributed in the universe in filamentary structures surrounding immense regions devoid of galaxies. It is as if the universe on a large scale was a bubble bath where galaxies are on the bubble surface.

Cosmology

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

Cosmology tries to answer to fundamental questions about the universe: Where did we come from? What is the future of the Universe? Where are we? How old is the Universe?

It is worth mentioning that science evolves. 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 reason able 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, Pluto is 40 times farther away. The nearest star is 280 000 times more distant, and the nearest galaxy is ten billion (10 000 000 000) times more. The filament structure of galaxies is ten trillion (a one followed by 12 zeros) times greater than the distance from the Earth to the Sun.

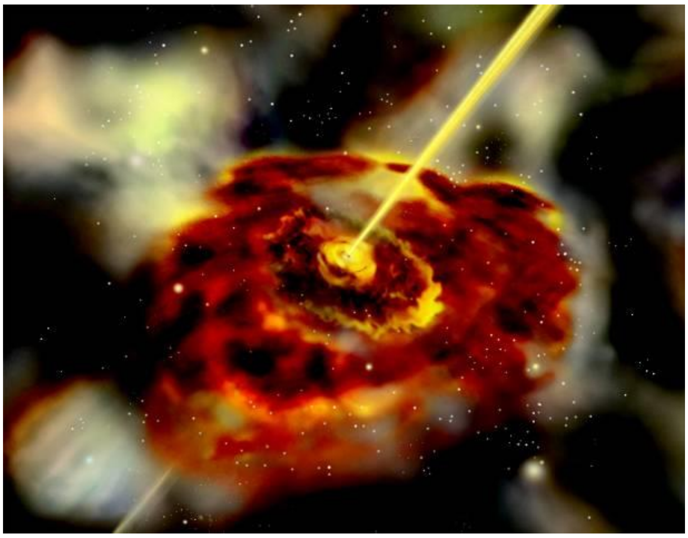
The age of the universe

Our universe began 13.7 billion (13 700 000 000) years ago. The solar system formed much later at 4.6 billion (4 600 000 000) years ago. Life on Earth emerged 3.8 billion (3 800 000 000) years ago and the dinosaurs became extinct 6 5 million years ago. Modern humans have only been around a mer e 150,000 years.

We reason that our universe had an origin in time 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 all of space was 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 that started the expansion of the universe is known as Big Bang.

Measuring Speed

You can measure the velocity of a star or galaxy using the Doppler effect. In everyday life we experience the Doppler effect when we hear the change in tone of an ambulance or police siren as it approaches and then passes by. A simple experiment is to 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. We could calculate the clock's speed by listening to the change of the tone, which is higher if the speed is greater.



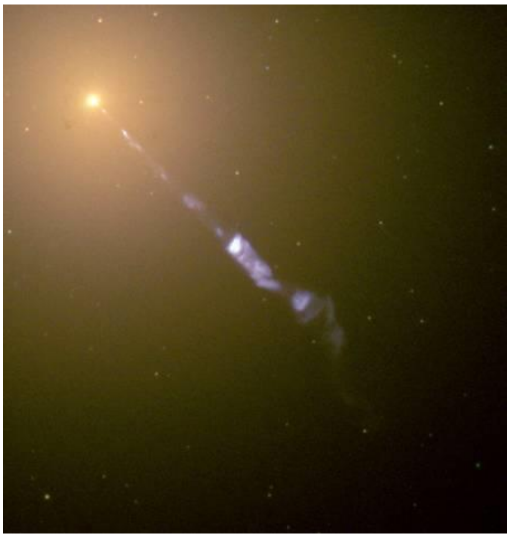


Fig. 4a: Artistic illustration of a black hole in the center with of a galaxy. (Photo: NASA E / PO - Sonoma State Univ.). Fig 4b: Galaxy M87, an example of real galaxy a jet. (Photo: NASA and Hubble Heritage Team).

Light emitted by celestial objects also goes through a frequency change or color change that can be measured depending on the speed with which they approach or depart. The wavelength becomes longer (redder) when moving away from us and shorter (blue) when they move toward us.

When the universe was more compact, sound waves passing through it produced regions of higher and lower density. Superclusters of galaxies formed where the matter density was highest. As the universe expanded, the space between the regions of high density increased in size and volume. The filament structure of the universe is the result of the expanding universe.

Sound waves

Sound travels through a medium such as air, water o r wood. When we produce a sound we generate a wave that compresses the material around it. This compression wave travels through the material to 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 therefore sound compression cannot propagate.

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 each other, and us but we would have no reason to say that w e are in the center of the expansion because all the inhabitants of other cities would observe the expansions the same way.

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)).

Although from our point of view, the speed of light of 300 000 kilometers per second is extremely fast, it is not infinitely fast. Starlight takes hundreds of years to reach Earth and the light from galaxies takes millions of years. All information from cosmos takes a very long time to arrive so that we always see the stars as they were in the past, not as they are now.

There are objects so distant that their light has not had time to reach us yet so we cannot see them. It is not that they are not there, simply that they were formed after the radiation from that region of the sky has caught up to us.

The finite speed of light has several implications for astronomy. Distortions in space affect the trajectory of light, so if we see a galaxy at a given place it may not actually be there now, 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 object 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 similar types, but at different distances.

We cannot see the edge of the universe because its light has not had time to reach Earth. Our universe is infinite in size, so we only see a section, 13.7 billion light years in radius, i.e., where the light has had time to reach us since the Big Bang. A source emits light in all directions, so different parts of the universe become are of its existence at different times.

We see all the celestial objects as they were at the time they emitted the light we now observe, because it takes a finite time for the light to reach 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.

Just like all the sciences, in astronomy and astrophysics the more we learn about our universe, the more questions we uncover. Now we will discuss dark matter and dark energy, to g ive an idea of how much we still do not know about the universe.

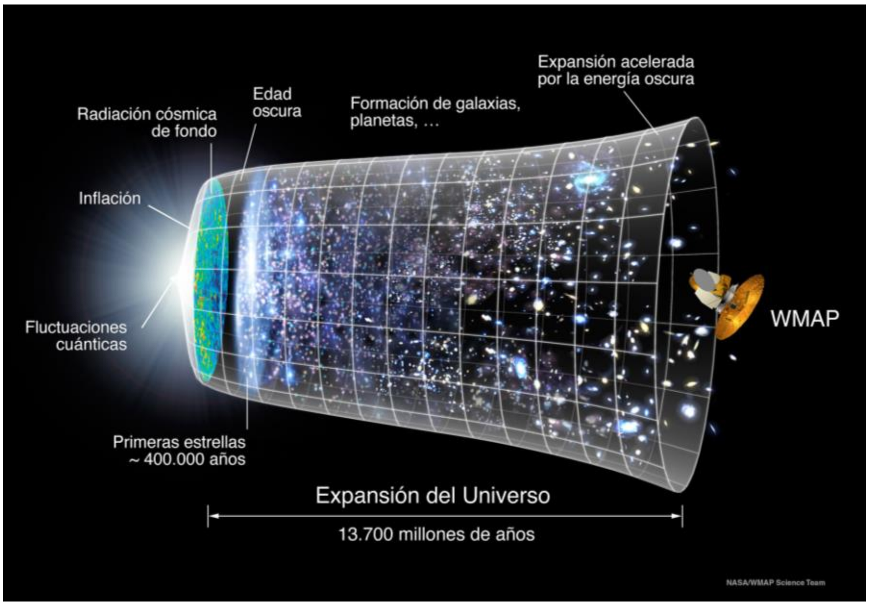


Fig. 6: Expansion of the Universe. (Photo: NASA).

Dark matter does not interact with electromagnetic radiation, so it does not absorb or emit light. Ordinary matter, like that in a star, can produce light, or absorb it, as does a cloud of interstellar dust. Dark matter is insensitive to any radiation, has mass, and therefore has gravitational attraction. It was discovered through its effects on the motion of visible matter. For example, if a galaxy moves in an orbit around apparently empty space, we are certain that something is attracting it. Just as the solar sy stem is held together by the Sun's gravitational force, which keeps the planets in their orbits, the galaxy in question has an orbit be cause something attracts it. We now know that dark matter is present in individual galaxies, it is present in clusters of galaxies, and it appears to be the foundation of the filamentary struc ture of the universe. Dark matter is the most common type of matter in the universe.

We also now know that the expansion of the universe is accelerating. This means that there is a force that counteracts the effect of gravity. Dark energy is the name given by astronomers to this recently discovered phenomenon. In the absence o f dark energy, the expansion of the universe would be slowing down.

Our current knowledge of the matter-energy content of the universe is that 74 percent is dark energy, 22 percent is dark matter and only 4 percent is normal, luminous matter (all the galaxies, stars, planets, gas, dust) Basically, the nature and properties of 96 percent of the universe remain to be discovered.

The future of our universe depends on the amounts of visible matter, dark matter and dark energy. Before the discovery of dark matter and dark energy, it was thought that the expansion would cease, and gravity would reverse the expansion resulting in Big Crunch, where everything would return to a single point. But once the existence of dark matter was established, the theory was modified. Now, the expansion would reach a constant value at an infinite time in the future. But now that we know of dark energy, the expected future is that the expansion accelerates, as does the volume of the universe. The end of the universe is very cold and very dark at an infinite time.

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