UNIVERSE

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Introduction

Do you want a galaxy, ready to be served? Here is the recipe you need: take at least 100 billion stars and interstellar gas you desire. Add interstellar dust and dark matter, as required. Cook the mixture at a temperature of 1032K and do not forget the fundamental ingredient: gravity!
Leave it all to cool for at least a billion years… and ready! you have a galaxy that you can serve! It seems easy to create a new galaxy, but really we did not know what a galaxy was, until a very few time ago. In the past, we didn't have powerful observation instruments as today, so galaxies seemed small regions, placed everywhere in the skies and featured by a bright vagueness, called, exactly, nebulas.

Galaxies

Have you been invited to an astronomical dinner, and you don't want to come hempty-handed? Here we have the perfect recipe for you!
Let's take at least 100 billions of stars and all the interstellar gas as much as you like. Then add enough interstellar dust and dark matter. Cook your mixture at least at 1032 K and do not forget the fundamental ingredient: the gravity! Let's make all cold for a billion of years and… voilà! You will have a new galaxy, ready to be waited on!
It seems easy to create a new galaxy, but really we did not know what a galaxy was, until a very few time ago. In the past, we didn't have powerful observation instruments as today, so galaxies seemed small regions, placed everywhere in the skies and featured by a bright vagueness, called, exactly, nebulas.
Until the Twenties of the last century, scientists supposed that these nebulas were parts of our galaxy, whose real dimensions were still mysterious. In 1924, astronomer Edwin Hubble, thanks to one of the most powerful telescope of his time, had been able to see some regions of the nebula of Andromeda, confirming that it was a single galaxy, external to ours. Already around 1929, Hubble discovered 18 galaxies, each one containing billions of stars. But are all these galaxies equal?

Galactic morphology

We can see several types of galaxies, differring for example for their form, dimensions, brightness, mass, stellar contents and, in the end, for the energy emission distribution in the different bands of the electromagnetic spectrum. The principal classification, called Hubble Sequency, is based on the form and it divides the galaxies between elliptical, spiral and irregular ones.
Elliptical galaxies. They show regular systems, approximately with a spherical form, with just few dust and interstellar gas, fitted with a really dense nucleus, whose superficial brightness decreases from the centre towards the periphery. Their structure may change from the circular form, called E0, to the extremely crushed one, described like E7. The elliptical galaxies are made, above all, by red stars (or Population II) that, according to the theory of the stellar evolution, are very ancient.

Stars are in fact used to change their color becoming old. In the first part of their life they show a blue color, becoming then more yellow-red.

Spiral galaxies. They appear like systems full of interstellar gas and dusts, based on a central bulge surrounded by a disc, from where run bright spiral filaments, called arms, site of an intense stellar formation. We can also divide these spiral galaxies into two classes: normal ones (S), with a central and at least perfectly spherical central nucleus and spiral arms, and barred spirals (SB), different from the normal ones because of a central structure placed through the nucleus, a so-called bar-shaped structure.

Irregular galaxies. They appear like systems full of interstellar gas and dusts, usually being inferior, for their mass, to the spiral and elliptical galaxies. They are usually called “irregular” because their aspect has no simmetry. They typically host young stars, or stars from the population I.

The Milky Way

At night, glancing up to the sky, it is possible to admire a milky white stripe through the vault of heaven. It really seems made with milk, causing the ancient Greek definition “Galaxia”, that exactly means “made with milk”. The Galaxy or Milky way is a large, barred spiral galaxy with arms surrounding its bulge, a central swelling with a depth of about 16.000 light years. This bulge is placed in the middle of a disc that, in turn, contains the spiral arms, the gas filaments and stars extended from the centre of the disc, wrapping themselves up it. The disc is surrounded by an almost spherical halo extended until a 150.000 light years diameter, hosting about 200 globular clusters. They are spherical groups, extended for few hundreds of light years, able to contain a million of stars. In our galaxy, we found three arms: the Orion one, that contains the Sun (placed at about 28.000 light years from the centre), the Perseus and Sagittarius ones. In the middle of the bulge we have the nucleus, made of stars and stellar clusters, whose birth seems to date back to the formation of our galaxy.

The disc is largely composed by dust, interstellar gas and bright blue stars, recently born. These stars are placed, starting from the nucleus, along a spiral trajectory.

Our galaxy is not fixed in the Universe. Its spiral arms, in fact, orbit around the nucleus with different velocities. All the stars are trailed from this movement, like the Sun with all the Solar System, on an elliptical trajectory around the galactic centre, with a period of 250 millions of years and a speed of about 250 km/sec.

The birth of galaxies

If the universe shows us an expansive motion, it is natural to suppose that, if we would be able to rewind at the same speed the tape of this expansion, all the matter that composes the Universe would come back to form the first cluster, very dense and really hot. This experiment of thought encouraged, in the Forties, the physicist G. Gamow to elaborate the Big Bang or standard model theory. According to his theory, about 15-20 billions of years ago, the Universe was characterized by an incredibly high temperature and density state, concentrated in a very small place.

In an infinitesimal time, it started to expand itself to an enormous speed, decreasing temperature and density, until it reached the current dimensions and aspect.
This model allows to explain several observations, like the universal abundance of lighter atomic nuclei (hydrogen, helium, deuterium, lithium) and the existence of a cosmic microwave background radiation. But let's try to examine the evolution of our Universe dividing it into phases, to make easier our comprehension of this phenomenon.
Phase 1. This first phase is extended from the instant t=0 to the instant t=5,39 x 10^{-44} (also called Time of Planck). In this phase, probably, the four interactions of the physics, strong and weak nuclear, electromagnetic and gravitational, were probably unified. In this instant, temperature was incredibly elevated (T= 10^{32} K) while the Universe itself was just a mathematical singularity.
Phase 2. The gravitational interaction breaks apart from the other three fundamental interactions, still unified according to the Great Unification Theory or GUT. In the present moment, the Universe is full of radiation of mutual interaction, that means in thermal balance, with electrons and neutrinos.
Phase 3. Little by little, with the decreasing of temperature (T=10^{27} K), the bariogenesis process starts, which causes the prevail of the matter on the antimatter. The Universe is made of quarks, leptons and corresponding particles, gluons and bosons.
Phase 4. We observe the separation of the electroweak interaction in weak and electromagnetic. The Universe is dominated by quarks, leptons, photons, neutrinos and dark matter.
Phase 5. Only at 10^{-4} s after the Big Bang, protons and neutrons are generated, which remain in thermodynamic balance with electrones and neutrinos.
Phase 6. About 0,7 s after the Big Bang, neutrinos separate from the remaining part of the matter, creating a neutrinos fossil reaction that we still can see.
Phase 7. When the Universe has got about 3 minutes of life, the formation of light nuclei, like 2H, 3He, 4He and 7Li is completed. At the end of these first three minutes, the Universe is dominated by the presence of protons, neutrons, light nuclei, neutrinos and dark matter.
Phase 8. When the Universe was 300.000 years old, the radiation separated from the matter. This radiation arrived till us, actually named cosmic microwave background radiation. From this moment, it is possible to make direct observations, because the Universe becomes transparent to this radiation.
Phase 9. After some hundreds billions of years, temperature decreases until 4000 K. Small fluctuations of density may start to attract gravitationally the surrounding matter, creating protogalaxies (giant clouds of extremely cold gas), and then of galaxies and cluster of galaxies. After 4 billions years, the first stars appeared.

Cluster and supercluster of galaxies

The structure of our Universe seems like a kind of sponge. As a matter of fact, the measurement of the placements of thousands of galaxies showed us that they are not equally arranged. On large-scale, the Universe is composed by groups of galaxies, called clusters, creating all together giant and flat thickenings. They are divided by immense and empty regions.

Moreover, many galaxy clusters are involved in overall motions towards other large clusters, called attractors, because of their gravitational force.
The birthplace of this large-scale structure seems to be hidden in very small unhomogenities in the initial matter distribution. After the Big Bang, on a chronological time of billions of years, the gravitational forces would have condensed the matter, creating at first the galaxies, then clusters and superclusters, and in the end the larger structures, like the attractors.
Before 1989, scientists supposed that supercluster represented the largest structures in the whole Universe, equally placed everywhere in the Universe. Instead, in 1989, Margaret Geller and John Huchra discovered a real wall of galaxies, extended for more than 500 millions of light years, large 200 millions, with a thickness of 15 millions. They called it “Great Wall”.

The Hubble’s Law

In 1929, Hubble saw 18 galaxies, also estimating their distance. He also discovered that all the galaxies seem to move away from us. In fact, the radiation emitted by these galaxies moved towards the red, in the electromagnetic spectrum: this is called redshift. This phenomenon has a simple explanation: whenever a source moves away from us, the number of oscillation per second decreases, so the wavelength seems to raise and we are used to say that the light turns to red. While a source comes towards us, the number of oscillations per seconds increases, and so the wavelength decreases and the light seems moved to the blue (**blueshift**). Hubble also showed that the movement was directly proportional to the speed of the bright source; he found a precise correlation between the distance of the galaxies and their recession speed, then called the Hubble’s Law, based on this formula: **v = H d** where **H** is the **Constant of Hubble, v** is the **galaxies departure speed** and **d** their **distance**. The Universe, as matter of fact, is subject to an expansion movement and the Earth takes part to this inexorable motion, without being its centre.
In conclusion, it does not exist a privileged observer: the speed with the galaxies are moving away increases with the distance, from every place we can be. Another observer, placed in whatever point of a different galaxy, would exactly find the same law achieved by Hubble.

Quasar

The Quasars (Quasi-stellar Radio Source) are really far galaxies, the furthest we saw, able to emit an enormous quantity of energy, above all on the radio frequencies.
Looking with a telescope, they appear like bright dots, with a stellar aspect (from which it derives the definition, Quasi-stellar Radio Sources), while their spectrum shows bands considerably inclined to the red color (redshift).
If we suppose that this redshift is due to the Doppler effect, this would mean that these objects are coming away from us with high speeds, superior than 35000 km/s, too elevated for a normal star. In conclusion, we are talking about really far extragalactic sources.
Considering their distance and their apparent brightness, we can also find the enormous power radiated by these objects, hundreds times more than the most sparkling galaxies.

The engine of these quasars is not the nuclear reactions inside the single stars: the power we observed is not the addition of the energy contribution of all the stars of this galaxy. Scientists are almost sure that this powerful engine is powered by a giant black hole placed in the galactic nucleus. Around this black hole there is an accretion disc of gas and stars in extremely quick rotation. The matter, falling on this black hole, creates an enormous power of radiation.

Energy and matter

At present, we still don't know the real composition of our Universe! Researchers found several evidences about the existence of an invisible matter, able to connect with its gravitational attaction galaxies and cluster of galaxies. It constitutes about the 90% of the whole universal matter. Its secret nature is still mysterious, anyway its presence is revealed by some indirect effects in the surrounding space:

Spiral galaxies rotation. If we observe the trend of rotation speed in a spiral galaxy, in operation to the distance of the galactic centre, we will discover that, in large distances, this speed remains elevated, instead to decrease. We can explicate this phenomenon just admitting the existence of other matter, not visible, able to produce a strong gravitational field, increasing the speed.

Speed distribution in the galactic clusters. A single cluster is stable if it owns mass enough to connect all the included galaxies. These galaxies should have an inferior speed, in comparison to a precise stability limit. Scientists discovered that in many galactic clusters, the galaxies are able to reach speeds really superior to this limit of stability, but they still maintain a stable structure. This implies the presence of a really intense gravitational field, able to tie together these galaxies. We are not able to explain this field with the visible matter. The cluster should be tied together by an invisible matter, really more abundant than the bright one.

Gravitational lenses. The gravitational lenses are objects, or groups of objects, endowed of an extremely large mass, whose gravitational field is intense enough to deflect the course of the nearest beams. As a result, if one of these "lenses" would be placed between us and a far light source (for instance, a quasar), we will be able to admire more images for the same object.

This kind of optical illusion allows us to discover the potential dark object which deviated the light. Anyway, which is the composition of this dark matter? It may be normal matter, for instance, planets or "brown dwarfs", so small that they are unable to trigger the nuclear fusion reactions on their inside. Nevertheless, these small objects are really too few to be the real cause of the effects observed in the dark matter.

A different hypothesis concerns mass-fitted neutrinos. Scientists believe, in fact, that neutrinos are particles without mass, but recent experiments seem to indicate that they hidden a mass, even if very small (1/5000 of an electron mass). Being very diffused in the Universe, neutrinos would be enough to justify all the observed effects of the dark matter. Another type of possible obscure matter is made of particles, whose existence has still not been proved, called WIMPS (Weakly Interacting Massive Particles).

Dark energy

Recent observations indicate that the Universe, contrary to what we supposed, is not braking like we would imagine in the case of a Universe full of matter. Instead, it is accelerating. Scientists tried to explain these observations supposing a new type of energy, with negative pressure, the so-called dark energy. According to the theory of relativity, this negative pressure produces an antigravitational force (push) on a large scale, allowing to bridge the important portion of missing mass. We have two possible candidates for the role of dark energy: the cosmological constant, a constant energy density able to fill all the space, and the quintessence, a field whose energy density is able to change in space and time.

The inflationary model

Two distant objects are causally connected when they are able to communicate with a signal, provoking an effect the one to the other. The effects of this signal won't be perceived immediately, but after some times, the higher the more distant they are because the speed of these signals, in the space, is finished. The causal horizon exactly represents the spacetime region where the two objects are connected in cause and effect.

Our Universe is made of galaxies thickenings and relatively empty regions, but in the main it appears homogeneous and isotropic isotrope (equal in every direction). How is it possible that regions so far from each other, out of the causal horizon, own such properties?

Not even the light, able to reach the highest speed, would have been able to connect casually these regions. To this question answered, since the first '80s, the US physicist and cosmologist Alan Guth. He suggested to modify the classic Big Bang model, adding the inflation phenomenon (inflationary model). During the first instants after the Big Bang, our Universe was so narrow than its galaxies could find themselves in a cause-and-effect contact. In the instant t= 10-35 s it started to expand suddenly and very quickly, then, just in 10-32 seconds, it increased its dimensions of a 1050 factor. Then this expansion continued, like it had previously been described by the Big Bang standard model.

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