A Conceptual Introduction to Cosmology

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Abstract. The present study had the objective of introducing the main concepts inherent to the physics' field of cosmology, wherein its beginning with humankind's first civilizations, passing through the cosmic microwave background's discovery and how it evidences the cosmological principle, also defining the concept of redshift and its relation to the Universe's expansion, and finally coming to the topic of how large-scale structures are formed.

Keywords. Cosmic microwave background, cosmological principle, redshift, Universe's expansion, large-scale structures formation.

1. Introduction

The stars and sky have been entities that intrigue humankind since its ancient civilizations, these being important not only for admiration but also for temporal and spatial purposes. Such curiosity regarding those celestial bodies was responsible for the development of religions and, afterwards, of scientific theories, hence providing answers that would inspire and comfort people worldwide.

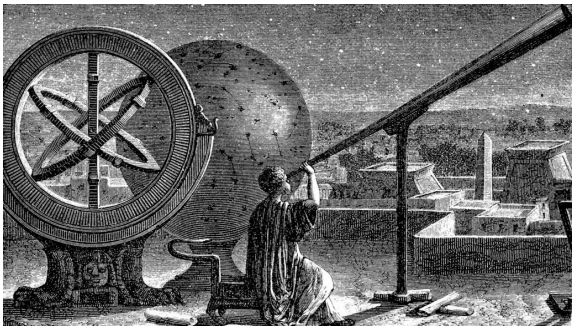

Fig. 1 - Ancient man mapping the night sky.

In the ancient past of human civilizations, the absence of compasses and clocks did not prevent humans to geolocate themselves and keep track of long periods of time, because people would make use of stars and the moon, given that they knew where a given star should be in the night sky for them to be going in a given direction, meanwhile the phases of the moon were used for determining the season of the year. Therefore, a basic understanding of these entities was already enough to facilitate travelling and keeping up an agenda.

Although a basic understanding of the cosmos was enough for ancient societies, as human civilizations developed intrinsically to it came the necessity of more precise understandings of natural phenomena, however, it was only with the advance of scientific areas such as physics and mathematics that a precise comprehension of celestial bodies became possible, and consequently of more complex phenomena, e.g., the existence and movement of planets, stars, solar systems, galaxies and clusters. Therefore, the physics field responsible for the comprehension of the large scale Universe was born, *Cosmology*.

2. Cosmic Microwave Background

In the middle of the 20th century, the use of antennas was becoming more and more relevant around the globe, and it was during studies using one of these that a microwave signal was detected in all directions from Earth.

Initially, the scientists who first observed this signal thought it was a malfunction of the antenna, however, independently of what they did to try and their data, they ended up arriving at the same result. After numerous attempts, they had to accept that there was not any problem in their device, they were actually measuring an entity that permeates the Universe itself, what would later be called *Cosmic Microwave Background* (CMB).

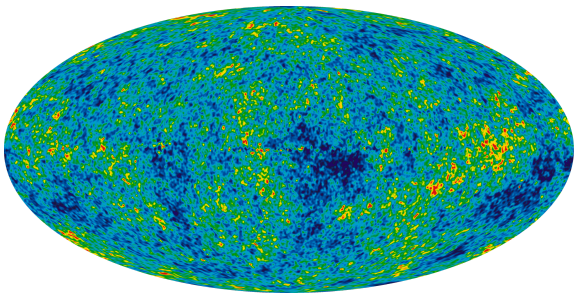

Fig. 2 - Map of the cosmic microwave background.

Nowadays, evidences confirm the presence of this microwave in all directions, presenting only fluctuations in its magnitude depending on the direction observed, a fact that is helpful for mapping the Universe itself and understanding its beginning.

2.1 Cosmological Principle

One of the main affirmations that guide cosmology is the *cosmological principle*, which states that the Universe in large scales (>100Mpc) is homogeneous and isotropic, i.e., from a large enough reference frame there are no privileged positions nor directions.

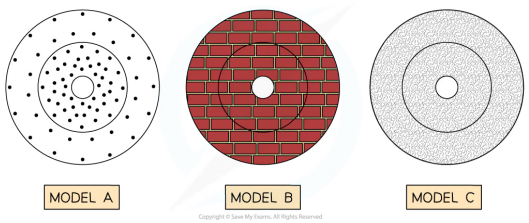

Fig. 3 - Model A: Only isotropic; Model B: Only homogeneous; Model C: Both isotropic and homogeneous.

This principle, although initially stated by Newton in 1687, was not to be proven right by concrete evidence until the discovery of the CMB, which made the construction of a "heat" map for the Universe possible and consequently proved the properties pointed out by the cosmological principle.

3. Redshift

In physics, there exists a phenomenon called Doppler effect, which enunciates that sound waves emitted from a moving source or received by a moving observer will change wavelengths according to the direction of movement. But why is this important in the context of cosmology? So, it happens that light is also a wave and associated to it one will find a relativistic Doppler effect, which will cause light to shift to red when the objects are getting further apart, *redshift*, or to blue when they are getting closer, *blueshift.*

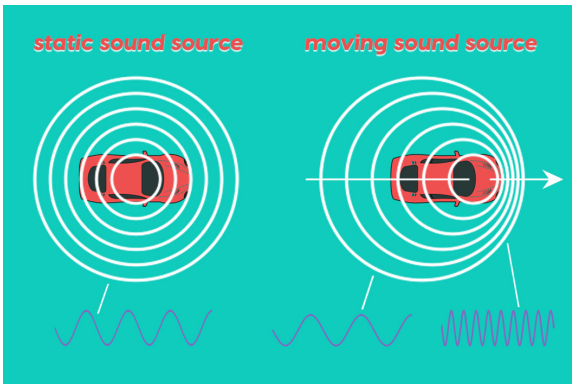

Fig. 4 - Doppler Effect.

It is interesting to note that, nowadays, it is only possible for humanity to observe the sky and make fair predictions about its distance to cosmological entities due understanding of the redshift phenomenon, and not only that, given the comprehension of redshift, it became clear that objects are getting farther away from us in all directions, but what does that mean? It means that, at the moment, the Universe is expanding. And besides discovering that the Universe is expanding, it was also determined that structures were being formed in a different manner than expected, implying the existence of another entity called the *cosmological constant* also known as *dark energy* and *dark matter*, whose true nature remains unknown to this day but composes most of the observable Universe.

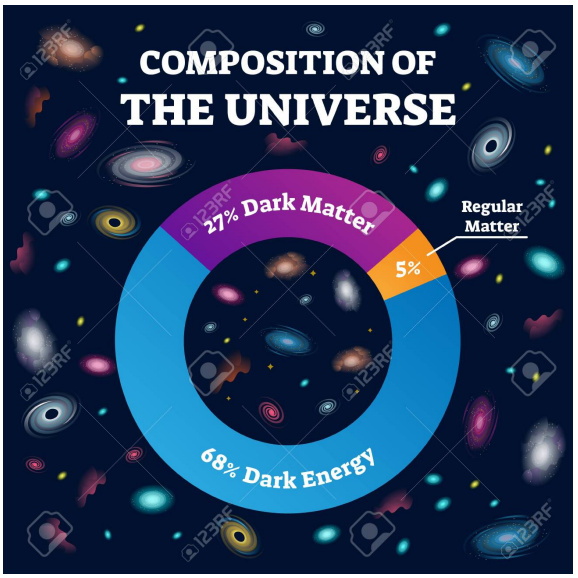

Fig. 5 - Composition of the Universe.

In conclusion, knowledge of light's wave nature made it possible for mankind to observe that entities all around Earth's reference frame are getting farther, which implies the Universe's expansion, furthermore, also from understanding redshift, the existence of a new component of the Universe was determined, the cosmological constant.

4. Universe Expansion

During the 20th century humankind lived an age of great developments not only scientifically but also technologically, these advancements leading to new discoveries, such as that the Universe seems to be expanding.

Based on data regarding large-scale structures and application of physical formulations to analyse them, evidence was found that celestial bodies in all directions are distancing themselves from us, hence the well-founded fact of the Universe's expansion (see Fig. 1).

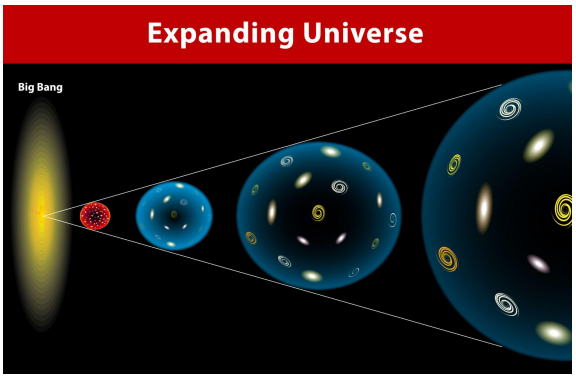

Fig. 6 - Illustration of the Universe's expansion.

Although the expansion of the Universe is a fact, its cause and behaviour through time is still a theory being developed to this day, since it is not an easy task to describe a physical phenomenon that started so long in the past and may not be reproduced. However, one not being able to know for sure which model is correct does not prevent the existence of models themselves, from there rises theories as the Inflationary Universe and Bouncing Cosmology, which attempt to explain such phenomenon.

Therefore, with the advancement of technology and physics, it became known that the Universe around us is expanding, however, describing its cause and behaviour is still an ongoing task for humankind.

5. Large-Scale Structures Formation

Nowadays, through redshift surveys and mappings of the Universe using the CMB, mankind has acquainted itself to the existence of large scale structures, e.g., galaxies and clusters of galaxies, and with this familiarity, theories to describe how such structures were formed were developed, one of these being *Jeans Theory.*

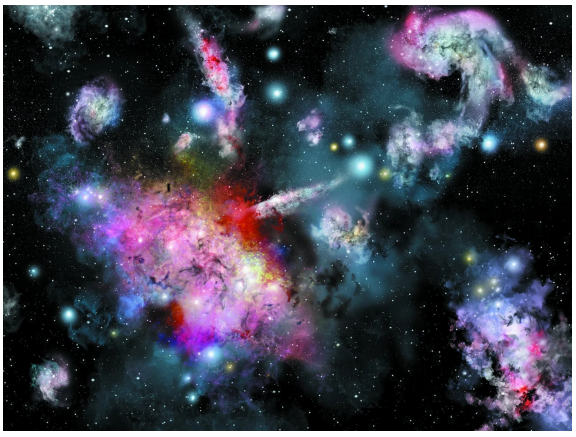

Fig. 7 - Illustration of galaxy clusters.

Therefore, based on the cosmological principle and Universe expansion, it became possible to understand the formation of large scale structures through Jeans theory.

5.1 Jeans Fluid Theory

It is interesting to note that Jean's theory is responsible for describing a complex phenomenon and consequently it is also a complex theory, hence as such it may take different forms according to the model being studied.

Now, in order to better understand how powerful this theory is, one may consider the case where the Universe is not only expanding, but also comparable to an ideal fluid, *Jeans Fluid Theory*.

For such an Universe, it is possible to determine a wave equation that will dictate the distribution of matter, i.e., its density, and by reformulating the equation for the density in terms of an homogeneous density plus a perturbation on it, it became possible to determine a wave equation for these perturbations that depends on a wavelength term, such wavelength being called *jeans wavelength* and sets a limit to which structures are formed.

In conclusion, through the formulae provided by Jeans fluid theory, it is possible to understand how perturbations of density in a plane expanding Universe may cause formation of structures.

6. Conclusions

In this work, a brief introduction to the main concepts and results from modern cosmology was conducted, starting from humankind's curiosity regarding the sky and its entities going until the study of large-scale structures formation, passing through the cosmic microwave background, cosmological principle, redshift and also the Universe's expansion.

During this journey through the physics' field of cosmology, one probably noticed how the cosmos is a complex entity and, although humanity has a good understanding of it nowadays, there are still intriguing phenomena, such as the nature of the so-called cosmological constant and the Universe's expansion behaviour.

Finally, based on this work, one is capable of understanding cosmology's state of the art, that being the certainty of the Universe's at the moment expansion, how the study of cosmological structures is performed and the disposition of the Universe's components.

7. References

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