EPISODES OF XX CENTURY COSMOLOGY: A HISTORICAL APPROACH

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Contents

Summary

A broad panorama of the history of some important episodes in modern cosmology is given. Beginning with some considerations about the state of stellar astronomy in earlier times, the evolution of the concept of nebulae is associated to the developments of astrophysics in the 19th century and the first decades of the 20th. The emergence of the concept of galaxy and the birth of extragalactic astronomy is associated to early research on the expansion of the universe. The classical relativistic cosmological models are contrasted with steady-state theory. Theoretical cosmology is confronted with observational cosmic background radiation and with the discovery of its fluctuations, via the COBE satellite. Later, some considerations about the epistemological changes in cosmology due to precision measurements and the influence of these new perspectives in the field are made. General remarks are added about the relations between cosmology and other scientific disciplines, such as physics. Epistemological and methodological aspects are taken into account and commented on when considered appropriate.

1. Introduction

The history of cosmology is a fascinating subject. It is common belief that scientific cosmology is a twentieth century discipline. Although this is not entirely valid, there are some good arguments to sustain this epistemological view. One of the purposes of this article is to elucidate this perspective, focusing on the principal results in the field during the last century. Although astronomy is the chief player in the cosmological scenario, in most cultures, especially in the west, it has been related to images of the world throughout the course of history: the two are in fact closely linked. This article deals primarily with relatively recent scientific activity. It is part of the general culture of the educated to have an idea of the transition from the Ptolemaic to the Copernican view of the world, even though the details of these conceptual changes are far from easy to follow. Historians of science have expressed each in their own way that in the West, over time, the ancient view of a closed cosmos was to suffer a drastic metamorphosis: the picture of an open, even infinite, universe was to make its appearance, one that was populated by a veritable “zoo” of entities which we today consider integral parts of our cosmovision. For centuries planets were thought to have a background scenario of fixed stars; later these stars were seen as no longer belonging to rigid spheres, but rather dispersed throughout space. Over time, generations of powerful telescopes were to reveal the presence of nebulae, along with many small bodies near the solar system, such as comets; finally, whole galaxies were to make their appearance, drastically changing the image of the universe: simultaneously hundreds of new astronomical entities emerged, with different and changing roles in cosmology. The difficulty of classifying these entities has been one of the main issues throughout the history of astronomy. Naturally this has influenced the scientific image of the universe in a number of ways. During the second half of the nineteenth century, physics and chemistry also began to participate actively in astronomy, with a notable by-product: astrophysics. Till then, physics had contributed to cosmology and astronomy mainly through gravitation and classical optics.

Given the amount of information obtained by astronomers and contextualized by historians of astronomy in the last two centuries, it is necessary to make a rigorous selection of the salient facts, both theoretical and observational, so as to provide a clear outline of the principal historical changes in recent cosmology. We propose to give an account of some of the most important historical features of the discipline that have led to present views in the field. It will be seen that consensus among the scientific community is far from having been reached: the tapestry of images, arising from different sources of the observational portion of the universe, provides astronomers with only a partially integrated environment. This guides research heuristically through the appearance of new theories and scientific instruments.

Here, priority will be given to the emergence of new phenomena and to their impact on the models of the universe, but some aspects of the scientific practice related to these topics will also be mentioned. The development of physics and the detection of new astronomical sources have both given rise to an inextricable network of practices in the field of astronomy, especially in relation to the electromagnetic field and the consequent construction of new instruments for taking measurements. We intend to describe the close interaction between these two aspects, illustrating how it shapes our image of the universe today.

On the theoretical side, the changes in the geometrical views of space and the emergence of the concept of space-time opened the door to a completely original framework for physical cosmology, particularly in the distribution and dynamics of matter in the universe. The development of mathematical ideas involved in cosmological models illustrates the difficulties of restricting cosmology merely to a limited set of empirical disciplines. Quite the contrary, mathematics, physics and astronomy have all contributed, and continue to contribute, in their own specific - albeit interconnected - ways to the building of the cosmological environment.

Thus we see cosmology today as a blend of trans-disciplinary and interdisciplinary research. History helps us to see these interactions in a dynamic context. We propose to focus primarily on conceptual changes whilst also drawing on history. We will however avoid any attempt at any detailed historical chronology of episodes and results. Hence, the topics we have selected: the development of thought and the reception of new signals from the sky. The historical approach taken here is sensitive epistemology and methodology, scientific activity involving as it does a plurality of methods and epistemological criteria. There is an additional epistemological point that deserves special mention. Cosmology is a discipline about the universe as a whole, and in this regard it contains concepts of a particular type, especially from a methodological point of view. Usually scientific disciplines allow the repetition of experimental procedures, or are intended to predict and explain regularities of the phenomena. A science of a unique object, namely, the universe, must always be something very peculiar. In this sense, philosophical and epistemological questions constantly accompany scientific activity in the area. Epistemological perspectives are usually present, in an explicit or implicit way, in theoretical cosmological frameworks. We can simulate physical situations occurring in space-time on a large scale, but we cannot experiment with these phenomena. Indeed, as in ancient classical astronomy, we can merely save appearances. Philosophy of science has shown several epistemological problems concerning the realistic attitudes taken by scientists towards different phenomena, especially when they are only in a position of being able to explain nature, but not control it. In the case of cosmology, scientists will always be in the epistemological position of having many possible explanations for each astrophysical phenomenon, and indeed for the global properties of the universe as a whole.

Given therefore that cosmology is a heavily dependent observational activity, it is also important to remember that observational astronomers work most of the time with different levels of theories, at least as they are incorporated into the instruments they use. Besides a set of theories of the sources, theories of the transmission of information, and a theory of the receptor, there must be a good functional framework allowing an adequate relation between them, according to state-of-the-art observational techniques. For cosmology, the main medium for transmission has been the electromagnetic spectrum, and in a more indirect way, gravitational interaction. Today cosmology is trying to improve the detection of gravitational signals through the search for gravitational waves, even though research has only just begun to show an interesting prospective for cosmological purposes. But both the strong and the weak fundamental interactions are also an important part of our image of the world today and they have grown considerably as basic frameworks for cosmological models in the last decades. In the light of this development, the convergence of cosmological ideas with the contemporary and future programs for the unification of physics seems inevitable. To date however, no such unified theory which is universally accepted exists. The current programs of research in the field show few viable alternatives as candidates for a grand unified theory: from the theoretical point of view, they exhibit visible lacunae and inconsistencies, besides a considerable lack of experimental confirmation. For those scientists that are optimistic, physics may be near to such an optimal goal. But skeptical scientists think very differently about the panorama. On many occasions history has shown that it is premature to extract definitive conclusions from uncertain domains of knowledge about nature. This lesson is the principal reason for our decision to root cosmology within a historical framework. We intend to illustrate how the dynamics of change point to the fragility of our theories of the universe, whilst at the same time showing how scientific knowledge has been and continues to be accreted.

It is likewise important to consider cosmology as a source of inspiration for people interested both in science and the humanities. The place of humankind in the cosmos is always relevant for the relation between science and values and, in different ways, for everyday life. Traditionally, the views of the cosmos have been meaningfully associated with anthropological questions. The fact that human beings live in a universe and that in many ways they are constrained by the same physical laws, has a subtle effect on how the universe is perceived. This interaction undoubtedly conditions cosmological thought, although we do not know precisely how profound this influence is. Astronomers are continually identifying new cosmological phenomena, distinguishing between observers on the one hand, and on the other, the objects, events and processes observed. At present, the amount of registered data from the universe is incredibly large. New windows are opening every year, and old windows still continue to collect huge sets of data awaiting analysis. It is probably the most dramatic area of research, considering the tensions that exist between theory and observational techniques.

In the light of the above, in this article we intend therefore to briefly present a series of representative landscapes of some cosmological research that has changed the understanding of the universe as a whole. The selection of topics does not mean that there are no other key areas of research that might have been included here. A complete history of cosmology in the twentieth century would encompass many volumes, and would probably have to include contributions from a team of experts from the respective disciplines it involves.

2. Cosmological Lessons from Earlier Centuries

The first important transition in astronomy in modern times was indisputably the shift of the focus of attention from the planets to the stars. The universe virtually “exploded” into stars, and this new view eclipsed the remarkable results of Copernicus and Kepler. In many senses, Newton was a special case. Without doubt, he was one of the most important contributors to science in history, showing extraordinary talent. His law of gravitation guided research on celestial mechanics through several European scientific traditions. It must be remembered that the reach of gravitational effects on the universe as a whole was not properly understood in his day. Newton considered that in an infinite universe filled with an infinite number of stars with a fixed spatial distribution, the force between them would be balanced. In time, he was shown to be wrong: it was proved that gravity is not consistent with a static infinite universe. It has been shown that Newton could have predicted the expansion of the universe. Later we will discuss how Einstein pondered on this issue.

Among other eighteenth century philosophers, I. Kant developed another important feature of the Newtonian program in a qualitative way. For him it was reasonable to make conjectures about systems dispersed throughout the universe, which were moving as a consequence of the same universal gravitational force. Kant was a very special and talented Newtonian on cosmological matters. He seriously considered the possibility of hierarchical systems, each of them acting under the influence of the same law of gravitation. This extrapolation was a remarkable anticipation of the main- stream studies on extragalactic objects to be carried out in later centuries.

Observation was moving in the same direction, offering diffuse objects as plausible candidates for island-universes. The solar system continued to resign its privileged status in the structure of the cosmos, not only due to the multiplication of the stars, in the style of Giordano Bruno. Likewise, the extrapolation of a dynamical system to the whole universe using the law of gravitation contributed to the displacement of a planetary cosmos, giving place to an open universe incredibly greater than previously comprehended.

From the perspective of observational stellar astronomy, it is clear even to the naked eye that the sky does not exhibit a homogeneous distribution of brilliant objects. The Milky Way has a long history of descriptions and speculations. In 1750, Wright of Durham presented two theories about the possible reasons for this structure. One of them expresses the hypothesis of a hollow spherical shell of stars. The other theory puts the Earth into a circular ring of stars. Today, these models sound exceedingly naïve and far-fetched, but it is important to acknowledge the effort to obtain a structural description of the irregularities in the distribution of stars and other celestial bodies. Eventually, Kant was to come to recognize the influence of Wright of Durham on his thought. It is interesting to note the place that a plane has in Wright's model, accounting as it does for the apparently elliptical figure that is seen from the Earth. Another important issue worthy of comment in these early cosmological images is the growing difficulty in distinguishing between stars as points of light and nebulae. Numerous objects were observed at the limits of the scope of the sensitivity of the instruments available at the time. Some of them were resolved into stars through the most powerful telescopes of the epoch, but others were not. Finally it must be mentioned that a number of present–day cosmological enigmas, such as Olber's paradox, take their origins in the observation of the stars. Olber posed the question of why the sky is dark at night if the universe has an infinite number of stars. Such questionings stimulated a variety of points of view on the cosmological environment at the time.

The number of observed nebulae also grew considerably over the years. The catalogues bear testimony to this increase in the number of entities recorded. Since the Durham catalogue with its record of 21 nebulae in the year 1733, to William Herschel's register of 2500 at the beginning of the nineteenth century, observational activity shows a correlation between the quantitative and qualitative aspects of nebulae. Two different kinds of models constructed for them produced growing tension among the scientific community. The first interpretation was that nebulae could be sets of stars, situated very far from the Earth, beyond the scope of resolution of the best telescopes at the time, or that they could be homogeneous objects composed of a kind of brilliant fluid. The second hypothesis was that the new entities had a discrete or continuous structure. In 1784, Messier published his famous list of 103 nebulae. Herschel, arguing on the basis of this material, broadened the debate on the nature of these objects. The nebulae in

Orion were observed to have changed their form, which meant that it could not be sufficiently distant to compose a set of stars. It was reasonable to think of a near object reached in a detailed form by the instruments available at the time. Another important lesson to be learned from this episode is the consideration of the dynamic evolution of these objects. Gradually the notion that the stars had been formed from nebulae through a process of slow condensation began to be gain credence. This idea was associated to different events in the cosmos, from the planetary nebulae, like that of P. Laplace related to the origin of the solar system, to objects of a size equivalent to the Milky Way. The observations made by W. Herschel led him to estimate that from the several hundreds of nebular objects that he had analyzed, there were many that could be as big as the Milky Way

In a parallel line of observation, at the end of the eighteenth century the first stars with an atmosphere made their appearance: a weak, diffuse light around the main object. All this reinforced the idea of new entities in the universe. The sheer number of new entities stimulated the exercise of taxonomies of diverse types, due to the irregularities of those entities: tails of comets, rings around objects, luminous objects not resolved into points, and so forth. Even though surrounded by obscurities, there was an emerging new image of the universe, one which contained a new set of patterns to be analyzed. It is possible to see in the peculiarities of the observations of this epoch that the concept of the universe also grew in size, and the eventual existence of giant structures relatively separated one from the other began to be considered a plausible proposition. J. Herschel's catalogue of 1865, with more than 5000 nebulae, shows a sample of the variety of astronomical objects that nineteenth century astronomers were familiar with. This astronomer introduced another interesting topic related to the nature of these entities. He considered that the irregular distribution of nebulae, relative to the plane of the Milky Way and their perpendicular axis, showed that many of them could not be very far from our system and that dependence on the structure of the Milky Way was not a reasonable cosmological hypothesis. The second half of the nineteenth century shows nebulae as being very active protagonists in the image of the universe. New telescopes helped to place them in the centre of the scene. The nebulae of Andromeda, for instance, exhibited a spiral structure, and it was conjectured that it was similar to the Milky Way, even as to its arms. Structures grew also in complexity with the evolution of observational techniques, structures also grew in complexity. A final ingredient of this complex panorama was the dynamics of some of these objects. Some nebulae showed rapid changes, a phenomenon that was difficult to reconcile with the slow movements of the stars close to the Earth.

A totally new chapter of research in astronomy appeared with the emergence of astrophysics in the nineteenth century. Light, magnetism and electricity, on the one hand, and chemistry on the other were to irreversibly change the mode of research in astronomy, opening as they did the doors to the investigation of the physical nature of stars. In spite of some skepticism about the possibility of knowing them internally, spectroscopy with its laws obtained in terrestrial physics was to produce cutting-edge progress. The Sun began to exhibit its spectral features. The association of spectra with chemical elements raised some fundamental questions, such as unequivocally correlating the spectral lines with the chemical elements. Among other consequences, it allowed astronomers to infer the existence of new elements. One of the major results of this new area of research was the discovery of the differences between the continuous spectrum of a luminous liquid or solid, on the one hand, and a hot gas which produces a bright line spectrum on the other. This, together with prisms and diffraction ratings adapted to the telescope, improved the quality of the observations and the theoretical meaning of astrophysical processes. All these instrumental changes were accompanied by the evolution of the telescopes. It is necessary recall the growing transition from refractor to reflector telescopes. The complex technical evolution of optics associated to astronomical instruments influenced the role of spectroscopy as a fundamental tool for astronomy. The spectroscope connected to the telescope shifted the focus of astronomical researches. Under this new style of research, nebulae appeared with new faces. It was shown that some of them were composed of luminous gas; that meant that they were not a set of stars. Additionally, the observational activity grew in such a way that by the end of the Nineteenth Century many thousands of stars had been analyzed in spectral types.

A natural next step was to incorporate photography into the observational domain. Spectrographs came into the field. Since the 1840s, astronomers tried to use daguerreotype process, but these earlier intends suffered from serious constraints. The evolution of photography and its detailed use in astronomy is out of the goals of this article, but it must be said that it permitted to clarify several important questions. Photography also began to be a very relevant astronomical tool. Stars were waiting for photographical registration, and particularly, the study of the most neighbor star, the Sun, contributed in a significant manner to the development of astrophysics. By the end of Nineteenth Century, the *Cape Photographic Durchmusterung* showed a number near to five hundred thousands stars, exhibiting the positions and intensities of them. Stellar photometry deserves a special consideration because it was also a central component of the new styles of research in that epoch. Firstly, it was suggested that a detailed study of all the visible stars should be carried out. Very soon this was extended to weaker stars, in accordance with the developments of photometrical techniques. Returning to nebulae, all this activity contributed in different ways to enlarge the amount of objects to study. The beginning of Twentieth Century exhibited more than one hundred thousand nebulae at the access of the astronomers, but it was lacking a general agreement about the nature of them.

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Biographical Sketch

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