# The Cosmological Principles

by

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# Foreword

Cosmology deals with the whole universe, both observable and unobservable, while astronomy deals with the observable part. Cosmological principles are the assumptions which allow us to deduce the nature of the whole on the basis of the observable. Not surprisingly, any study of cosmological principles must combine elements of astronomy, physics, and philosophy. Therein lies not only a fascinating challenge but also a problem for the author of a book on this subject. For astronomers usually do not know philosophy very well; physicists often do not know much of astronomy and philosophy, and most philosophers are not adept in astronomy and physics.

In writing a book to be read by all three groups of scholars - as well as by serious amateurs in these fields - I have attempted to avoid mathematical formulae and sophisticated terms. Instead, I have referred to original papers and professional books when appropriate. I presume the reader to be familiar with at least one of these three areas and to be acquainted with at least the basic facts and notions from the others.

A book about the development of the human approach to so basic a scientific and philosophical problem as the structure of the Universe has to deal with yet another domain of human knowledge: the history of science. History is not the subject of this book, so I have taken the liberty to simplify, even to schematize, my account of various historical epochs and the outlooks of various scholars and philosophers. I beg my historian colleagues to pardon me for all these simplifications which were necessary to prevent the book from growing too large. It was not my primary intent to write a popular book on science, but I will be glad if it turns out that for the most part it can be also read and comprehended by amateurs of astronomy, physics, or philosophy.

I completed the manuscript at my home in Cracow, but the main conceptual work was done earlier, in 1988/89, during my sabbatical year at the Department of Space Physics and Astronomy of Rice University in Houston, Texas. I owe cordial thanks to the people who invited me and made my stay there possible, particularly to Professor Alexander Dessler and to the late Professor Konstantin Kolenda, as well as to my son Anthony and his wife María. Furthermore, I am indebted to Rev. Professor Michael Heller for his systematic reading of the text and for his valuable comments. My friends Marek Krosniak and Andrea Karpoff have corrected my English and contributed greatly to its readability. Clopper Almon assisted on the American end of invaluable email communication between America and Poland.

During my visit to Tucson, Arizona in 1989, I discussed some philosophical matters with Professor Andrzej Pacholczyk; this conversation was an important turning point in my work. It was he who drew my attention to the fact that there was no book devoted specifically to the issue of cosmological principles. Thus, instead of taking up some particular problems in the form of contributions to professional journals, I made up my mind to prepare such a book. I am aware that this is but a first attempt to discuss in depth this rather peculiar field of human activity. Future authors will surely find many ways to improve on it.

**Cracow, October 1992** **Konrad Rudnicki**

**About the author**

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# Introduction

## 0.01. Astronomy and cosmology

Cosmology is a science concerned with the Universe as a whole, while astronomy deals with celestial bodies, their systems and all related phenomena. If the entire Universe were observable, cosmology could be considered as just the most general section of astronomy. But it may well be that the entire Universe is not observable. If so, then we may well ask if its possible to extrapolate from the observable to the unobservable. Simple philosophical statements that make it possible to make this step are called *cosmological principles* and are the subject of this book.

There are cosmological theories and even strict mathematical models, so-called *small universe models* (Dyer 1987, Ellis 1987a), which represent the Universe as fully accessible to our observations. But most cosmologists and astronomers do not believe in their validity. Moreover, they would be rather difficult to verify and do not belong to the mainstream of contemporary cosmology. Were it to be proved at some future time that the Universe is ultimately observable, then this book will lose its point. But as long as this is not the case, the profound question of bringing the unobservable parts of the Universe under investigation remains a central problem in contemporary cosmology.

While the ancient thinkers believed in the existence of non-observable parts of our universe consisting of imponderable, sublime, and invisible matter, according to most contemporary astronomers and cosmologists there is a surface called the "cosmological horizon." No physical signal, no information can reach us from beyond this horizon. Thus there are two possibilities. One is to consider cosmology as not belonging to the exact sciences but rather as a domain of metaphysics1. One can say: it is not a task of any experimental or observational science to form statements about the Universe in general, i.e. referring also to its parts that cannot be observed. After all, the unobservable belongs to the domain of metaphysics[1]. But again it might be said that any exact science involves statements that are not directly related to observations. In mathematics, for example, no geometrical figure can be seen or measured by physical devices. All that can be constructed in the physical world can be but a representation of mathematical entities; yet mathematical reality in itself can be accessed only through our minds. The laws of physics as such are also not observable; only their consequences can be observed. Should this mean that they belong to the realm of metaphysics? Accordingly, nobody has any right to demand that everything has to be observable in cosmology. In that domain also, the human mind can supplement what cannot be accessed by sensory perception or physical instruments. Sometimes cosmology, along with its cosmological principles, is considered to be not metaphysics but metascience (e.g. Kaz-yutinskiy 1981), which amounts to the same thing but sounds better.

The above considerations are based on a specific concept of the Universe, which will be explicitly explained and used further in this book. But this understanding is not the only one possible. For one, George W. Collins II (1988) defines the Universe in following way 'The Universe is all what was, is, and will be accessible to observation". In such a sense only those regions situated beyond the horizon belong to the Universe which in future (or past) cosmological epochs will (did) cross the horizon surface and enter (leave) "the observable part of the Universe." Another plausible concept of the Universe, exploiting the difference between the notions "Universe" and "Cosmos" is brought up in Section 6.12.

The problem consists in how to augment the existing body of evidence about the observable parts of the Universe so as to encompass its unobservable parts too. One possible way of doing this, perhaps the simplest one, consists in extrapolating the avail-able results of astronomy to the whole of the Universe. As we have noted, simple philosophical statements instrumental in accomplishing such an extrapolation are now called cosmological principles General propositions stating the impossibility of such an extrapolation should also be included among cosmological principles, if they include some idea about the overall structure of the Universe.

## 0.02. Philosophy, physics, astronomy and cosmology

Cosmology, if we do accept it as a science and not as metaphysics, is a discipline standing right at the meeting point of three areas of human knowledge: astronomy, theoretical physics, and philosophy. All the three are of equal significance for cosmology. Astronomy determines which kind of celestial bodies or their aggregates are the "building stones," basic elements in the construction of the Universe. Theoretical physics shows us what laws govern or may govern in various parts of the Universe and in various times past, contemporary, and future. Philosophy (particularly the branch called methodology of science or theory of knowledge) instructs us how to use our mental capacity to grasp the entire Universe, even though we do observe just a part of it and can experiment only within a very limited range of conditions, the Earth and its immediate environment (not possibly further than within in the Solar system).

## 0.03. Philosophy in cosmology

The role of philosophy in cosmology is sometimes underestimated. It is said that the impact of an overall manner of thinking, specific individual philosophy, is to be found in every science. This causes the same data to be interpreted quite differently by various researchers according to their respective world views. Certainly cosmology should be not considered as an exception in this respect In most fields of science the interpretation but not the results themselves depend on philosophical assumptions; cosmological results, however, are strongly conditioned by personal way thinking. Cosmology is a perfect example, showing in a clear way how substantial the influence of the accepted world view on the output of scientific activity may be. It is cosmology's strong dependance for its results on philosophy that causes doubts to emerge as to whether cosmology should count as an exact science at all.

The awareness of this fact was born relatively late. When, in 1917, Albert Einstein calculated his first model of the Universe, he made a simplifying assumption that the Universe is self-similar in all his parts. In effect, his model had the particular feature that the only systematic motion should be an overall expansion or contraction; the relative velocity of any two points in the space being proportional to the distance between them. Any other systematic motions in the Universe were excluded. Only relative radial motions with positive or negative velocity, and as an intermediate zero case, total absence of any systematic motions, were allowed[2]. Einstein and his followers first considered this result an implication of general relativity. The additional assumption about self-similarity of the Universe seemed for them to be an innocent, simplifying formal trick to facilitate solving the mathematically complicated tensor equations. Only later, it turned out that models of the Universe based on quite different physical theories but involving the self-similarity assumption led to the same restriction about systematic motions in the Universe. Such was, for one, the model of Edward Milne and William McCrea (1934) based on Newtonian mechanics[3]. On the other hand, models based on general relativity but rejecting the assumption of self-similarity gave quite different results. When the issue was studied in more detail, one arrived at the conclusion that excluding all but radial velocities is a mathematical consequence of the self-similarity assumption (Bondi 1961) and is not related with any particular physical theory.

## 0.04. A possible misunderstanding

The problem I want to bring up here will be further discussed in Chapter 4. I mention it here to avoid misunderstanding that may affect proper comprehension of these earlier chapters or introductory passages.

The proposition that the only systematic motions in the Universe are those with radial velocities proportional to the distance between two points was first considered by Friedman, Lemaitre, and his contemporaries as a consequence of general relativity. Subsequently, as mentioned above, it became clear that this feature was due to the assumption of self-similarity of the Universe in all its points, irrespective of the underlying physical theory. The systematic expansion or contraction (or, as an intermediate state, a general immobility (i.e. the radial motion with zero velocity) of the Universe, related to this feature, provided a foundation for the hypotheses of initial and final singularities and the Big Bang Hypothesis. Later, a number of contributions, summarized in the paper by Roger Penrose and Stephen W. Hawking (1970), proved that from very general mathematical and physical assumptions which every realistic universe model must fulfill it follows that the Universe should have at least one singularity.

These two separate facts are sometimes confused. At first the linear expansion of the Universe was proclaimed to be an implication of General Relativity and then it was proved that linear expansion could be deduced out of the assumption of the homogeneity of the Universe alone. But in turn, Penrose and Hawking proved that it follows from General Relativity alone, thus showing that the original opinion was right. In fact, the Penrose-Hawking theorem has nothing to do with the linear expansion (or contraction) of the Universe. "The theorem implies that space-time singularities are to be expected if the Universe is spatially closed, if there is an 'object' undergoing relativistic gravitational collapse (Existence of a trapped surface), or if there is a point p whose part null cone encounters sufficient matter that the divergence of the null rays through p changes sign somewhere to the past of p." But it is not specified here whether this is a universal initial or final singularity involving all the world lines of the Universe, or just a local one. Furthermore, even if we assume it to be the initial singularity, it does not amount to the linear velocity law. So, though it is right that general relativity implies singularities in models of the Universe, in order to obtain the Big Bang scenario with its radial systematic motions, the additional assumption of cosmic self-similarity has to be introduced.

### 0.05. A cosmological principle

In this way it began to be evident that the very significant scientific claim, the assertion that only radial systematic motions are allowed in the Universe, which in the meanwhile was widely acknowledged by astronomers and cosmologists as a fundamental law of cosmology, follows neither from astronomical observations nor from physical experiments or theories but results from an unfounded assumption that the Universe looks much alike in every direction from every point. However, this assumption can be regarded as warranted only from a very particular point of view, the standpoint of a specific philosophy dominating the first half of our century. Thus, the attention was focused on the decisive impact of philosophy not only on interpretation but also on the cosmological results themselves. The self-similarity assumption, in its strict formulation that "the Universe is homogeneous and isotropic" was designated a cosmological principle and acclaimed to be unique. Its subsequent modifications led to distinguishing two different cosmological principles. Still later, historical research discovered ancient cosmological principles from the past epochs of human evolution and based on all together different modes of thinking and reasoning. In recent decades, some contemporary philosophical assumptions and ideas concerning the fundamental structure of the Universe seem to have acquired the rank of cosmological principles. If we rummage deeply through the cosmological literature, a dozen or so of such principles may be discriminated.

In the following I would like to present the most important, by my estimation, cosmological principles in their historical order but with contemporary interpretation and then discuss some of the less known ones.

### 0.06. Cosmological model and physical theories

A cosmological principle alone can sometimes produce a cosmological model. The way to constructing such models was shown, for instance, by H. P. Robertson (1935) and A. G. Walker'(1936). But contemporary models usually involve some physical theories. Most often it is general relativity, but other theories, mainly theories of elementary/ particles, are exploited, too. Sometimes very exotic physical constructions are applied just to see what kinds of results it is possible to obtain with their help. Or, for that matter, one introduces some of the classical theories, as when with calculating models based on the good old Newtonian mechanics. It is difficult to tell which models are calculated in order to extend knowledge of our real Universe and which just as exercises in model calculating or for methodological purposes (i.e. to investigate the influence of particular assumptions on the resultant model). This book is not devoted to models but to cosmological principles. Models as such will be mentioned here only for illustration. Any problems arising in connection with various physical theories will be brought up only in exceptional cases.

## 0.07. Cosmological models and constituents of the Universe

There are abstract models of the Universe where matter to fill cosmic space does not appear at all. Such is the famous model of empty Universe of Willem de Sitter (1917a, b, c, d). But usually models are constructed (i.e. calculated or just conceived) as involving some kind of "substance." One has in mind celestial bodies or agglomerations of matter, some "building stones," of which the Universe should ultimately consist. The presumed nature of those constituents changes in the course of human evolution as often, if more frequently, than cosmological principles themselves. Essential as they may be for understanding the development of scientific theories, they are still of rather minor importance for discussing general views about the Universe.

Let me show this through an example. The construction of relativistic models of the Universe based on the self-similarity assumption, practiced by Einstein himself, and then by Friedmann and others, has continued, with some modifications, up to the present day. Einstein himself considered the Universe to consist of stars. By the time of the Second World War, galaxies were introduced as the basic stuff for constructing universe models. Soon afterward, extragalactic research revealed that not individual galaxies but rather their clusters should be considered as the main constituents. At present, it looks as if the clustering pattern of galaxies is but a superficial structure covering empty spaces, cells of sorts (designated "bubbles of Voronoy foam") which should be the very fundamental stuff of the Universe. Maybe, some concepts will get into circulation when -this book reaches the readers. But all those changes in no way affect results of calculations of relativistic models. The oldest and newest ones can be readily compared with each other, notwithstanding which constituents of the universe one or another scholar had actually in mind.

This comparability is due to the fact that cosmologists working on general models of the Universe very often disregard local structures and deal only with the mean properties of matter filling the Universe. Such a "mean content" of the Universe even has a separate name, "substratum." The "local heterogeneities" introduced by cosmologists working on the evolution of matter, stars, and galaxies have only refined - not invalidated - the previous general models of the universe based on homogeneously distributed matter.

The problem of constituents of the Universe is, of course, fundamental for cosmology as such; but it is, in fact, quite independent! from the issue of cosmological principles This book intends to bring to the light, above all, the widely known as well as some of the less familiar properties and implications of these principles Problems related to ideas on the kinds of celestial bodies or physical theories to be considered in connection with one or another cosmological principle are mentioned only occasionally.

### 0.08. Spacetíme

Apart from celestial bodies, the structure of spacetime also belongs to the "building materials" for models of the Universe. That the geometry of the Universe need not necessarily be Euclidean, was realized already by Cari Friedrich Gauss, who made the first attempts to establish through observation the Universe's actual geometry (cf. Helleret aal. 1989).But the scientific treatment of physical space as something that can possess properties of cosmological interest began first with General Relativity in the beginning of 20th century. With relativistic physics not only properties of our three-dimensional space but also the concept of four-dimensional spacetime entered cosmological investigations, and so began the era of modern cosmology. A few decades later, there appeared some different theories of spacetime, and among them, the remarkable theory of covariant chronogeometry (Segal 1972), Stanislaw Bellert's theory (1969, 1970), and a number of others. Thus thinking about modern Universe models, we would consider "empty" space as possessing some non-trivial properties as well as consider the origin of time and related questions, whereas, thinking of ancient conceptions of the Universe we bring to mind three dimensional Euclidean space and time as separate entities. This has important historical, but not only historical, reasons. In fact, the so called Newtonian Cosmology, based on the classic concept of space and time but involving the Copernican Cosmological Principle, reveals still interesting problems (e.g. Bondi 1961). On the other hand, Schwarzschild's solution of the equations of relativity (see any classic book on general relativity. E.g. Bergman 1942) reveals an obvious outward similarity to ancient heliocentric or geocentric models based on cosmological principles of past cultural epochs.

Cosmological principles are little dependent on either observed or imagined celestial bodies or properties of spacetime, but they do influence some particular geometrical or topological properties of spacetime.

1 There was once a paper under the provocative title Has cosmology become metaphysical? (Rothman and

Ellis 1987).

2 Einstein had some problems with the intermediate case, which he took at first to be the most realistic one. This variant of a static Universe model is considered not stable by most cosmologists, any smallest disturbance triggering a contraction or expansion.

3 It was shown later that this model was not really self-consistent, but this is irrelevant for the problem of the linear law of velocity.

# Chapter 1

# The Cosmological Principle of Ancient India

## 1.01. The discovery of ancient civilizations

With time, we are increasingly aware of the existence of ever older cultures. As recently as the 18th century, it was believed that human culture was something very recent - that the first roots of it are to be found only in the social and scholarly institutions of ancient Greece and Rome. The Europeans of that time thought that prior to ancient Greece there were only uncivilized customs and barbaric art and therefore ideas about nature, and particularly about the Universe, must have been quite primitive, too. Furthermore, it was commonly thought that though, to be sure, the Greeks had laid the foundations for modern science, true scientific research had actually begun only in the Renaissance era.

There was something known about the ancient Egyptian knowledge of nature, but in fact genuine interest into the culture and civilization of Egypt began in Europe only with Napoleon's Egyptian campaign. The Europeans discovered the surprising fact that Egyptian culture, though a few thousands years older than the culture of the ancient Greeks, had apparently been much more advanced scientifically. The first Egyptologists were enchanted by the mathematical proportions of the astronomically oriented pyramids. In the 19th century, ancient Egypt and its culture became fashionable in Europe.

But all developments of ancient Egypt were still considered an exception to the universal uncouthness that was believed to dominate throughout the ancient world.

In the course of time, ever more such exceptions were discovered. Historians digging into documents, but above all archaeologists excavating old settlements, palaces, tombs and shrines, found more and more evidence of great advanced civilizations in the remote past. At first they were civilizations rather close to those of ancient Egypt and Greece: Babylon, Chaldea, Persia. But later on, traces of fairly developed civilizations were found also in the Caucasus, Central Asia, India, China, the Americas, Oceania and the Central Africa. It seemed as if the entire Earth had consisted of such "exceptional" regions where one or another past civilization once used to be.

The development of human culture and civilization seems not to have proceeded by straight lines. Rather there was an advanced civilization somewhere in the world in almost every millennium. It is also evident that every civilization after its efflorescence falls into decay and degeneracy. What do present-day Egyptians have in common with the ancient Egyptian culture? And inhabitants of Polynesia - with the monuments of Easter Island? And the contemporary British - with the master-builders of Stonehenge?

It is not my aim to determine how long some particular culture persisted, or how long humanity fostered some particular ideas concerning the Universe as a whole. With more discoveries, the history of human culture seemed to reach further into the past. I would not like to affirm or reject here any old stories about missing continents and civilizations such as Lemuria and Atlantis. As long as no records are available about attitudes of their inhabitants toward the Cosmos as such, the issue of their existence is of no significance for our considerations.

## 1.02. Culture of Ancient India

The first culture of which we have definite information concerning its cosmological ideas is ancient India, meaning the period of India's history prior to that of the wars in the south of the Indian Peninsula. That was an epoch of efflorescence of the Hindu spirit when the Indian nation lived peacefully in the northern part of what is now India. This epoch carne to an end as early as about six thousand years before Christ. It is sometimes called the epoch of great Rishis - great teachers of India. There is no consensus among Indologists in which millennium those general beliefs about the Universe arose.
Some scholars place them even before the 9th millennium B.C. We can reproduce the natural environment of this nation as abundant and favorable to people who lived in rather small communities scattered all over the country. The soul mood of ancient Indians was very different from our own. That difference has to be grasped if we are to understand what is today called the **Cosmological Principle of Ancient India**.
Ancient Indians considered all that is perceived by the physical senses as an illusion or "maya". They felt it discomforting to have to live within that maya. Instead, they strove toward spiritual reality, which they wanted to grasp and experience, not by conceptual and logical thinking (logic as such did not exist yet!) but through ardent fee1ings.
It is true that this epoch left no direct written records behind, but it did leave a great oral tradition. The Indians up to the present day, living in the echoes of that culture, inherited traditions richer and stronger than other nations, and the extraordinary collective memory, cultivated by appropriate exercises, preserved many ancient oral works for posterity. Most of those works were written only in post-Christian times. But their content as well as the fact that they are in Sanskrit, a language that has not been spoken for thousands of years, is taken by Indologists as evidence that they go back to ancient times (cf. Radhakrishnan 1951). In any case, the roots of a meditative attitude towards the world, so characteristic for India, had formed very early, thousands of years before the strictly historic era of India began.

## 1.03. World view of Ancient India

The content of most ancient works preserved to date is varied: some are

completely incomprehensible for a contemporary researcher used to logical thinking; some were meant for educated people, others for the ordinary public -like today's popularization of science.
The first attempt at reconstructing the Ancient Indian Cosmological Principle was made in 1972 (Heller and Rudnicki, 1972), but its more correct formulation was presented only ten years later (Rudnicki 1982, 1989). In investigating the ancient Indian mode of thinking, it must be kept in mind that there was no philosophy in the modem sense then. Issues which belong today to philosophy were previously approached through artistic activity. Philosophy was still immersed in poetry or, rather, poetry was the way of expressing what we would call now philosophical beliefs. To c1arify, to talk about primeval Indian philosophy, meaning "philosophy" as it is understood today, would lead to conceptual confusion. Most ancient Indian texts were supposed to be experienced, not argued about logically or discussed. Indian philosophy as such carne about only much later, arising in its more or less contemporary form a few centuries before Christ, at approximately the same time that Greek philosophy was born. In those times, there was no philosophy and no science in today's sense. But if we are to find, through the ancient Hindus, the roots of modem science, then we can say that what is natural science today was in those days elaborated on the one hand with the highest principles of universal existence, and on the other with the finest sensory perceptions.
Spiritual, like physical perceptions, were felt to be revelations. Nobody thought of proving truths about the world; they were true by intuition.

**1.04. Documents about the cosmological views of Ancient India**

The highly spiritual Vedic cosmological texts are now incomprehensible to us. Myths about the Earth, the Sun, and the planets, in the form they reach us, belong rather lo the "popularization of science;" and they refer only to the immediate vicinity of the Earth. The most distinct source of the ancient Hindu outlook of the Cosmos is the eleventh chapter of the Bhagavad-Gita. The poem itself was created in relatively modern times, just a few centuries - maybe two, no more than six - before Christ, but that chapter contains the oldest cosmological concepts available to us, expressed in a language comprehensible to us without resorting to precarious interpretations. One might say that here we encounter the old Vedic contents in a form elaborated for our purposes in later times. These are some excerpts from the eleventh chapter of Bhagavad-Gita in translation by Michael Lipson (quoted from Rudnicki 1991) - a dialogue between Krishna and Arjuna:

"Krishna: See me then, O son of Earth,
As one in the plurality of forms
As a more heavenly Nature, various
And countless as the stars of heaven are...

Regard as a unitary Whole

The whole world, with all its forms.
It is my body. I myself its spirit:
And everything that is, is all in me...

Now, when the Lord of worlds had spoken thus,
He revealed to the son of earth
Himself, in his own true form,
As the Ruler who contains the entire world.

With countless faces, countless
Forms of consciousness, regal, multiform,
Arrayed with every glory of heaven,
And steeped in every heavenly power.

Even if a thousand suns at once
Rose on the horizon, yet the light
Would not compare to that glory
Which Arjuna's spirit-eye beheld.

Pandava saw the whole of the Universe
And everything within it that moves
Or does not move, as multiple in appearance
Yet in truth as only One.

Shocked with wonder Arjuna sank down,
Shivering; then with devotion
Bowing his head, he folded his hands,
And spoke thus to the Lord of the Universe:..

I see you now: with many arms,
With countless breasts to nourish
Everything in the world, and many eyes;
With no beginning, middle, or end...
Without beginning, middle, or end,
Infinite in power and in activity...

### 1.05. A Contemporary formulation of the Ancient Indian Cosmological Principle

According to the oldest Indian traditions, the Universe is understood to be the body of the highest, infinite spiritual being and thus has some of his properties. If we attempt to render this into the language of contemporary science, we arrive at the following formulation:
*The Universe is infinite in space and time and is infinitely heterogeneous.*
This means also: our Earth is not a unique, exceptional, celestial body. It does not

have any favored position in time or in space. Many such "earths" (those oldest cosmological considerations do not refer to any specific kind of celestial bodies) preceded and many will follow our Earth in time. Also, in present time there are many other "earths" of the same significance for the Universe as that of ours. On the other hand, the Earth is not something average either in its location in space or time or in respect to its inner qualities. No average values can be arrived at when differences between objects tend to infinity.
The ancient Indians left some concepts about the structure of the neighborhood of the Earth (e.g. the familiar picture of the Earth resting on a great turtle), but they left no overall system of the Universe as such. In ancient Indian documents nothing can be found that could be called a model of the Universe as a whole. When we grasp the content of their cosmological principle, we can see that it is not incidental. No mathematical model of the Universe involving the Ancient Indian Principle can be constructed even now, since mathematics have not yet developed any tools to deal with the notion of infinite heterogeneity. The development of the newly elaborated theory of fractals tends to this direction, but the heterogeneity that theory is able to deal with is still too limited. Cosmology based on fractal structure of the Universe (cf. e.g. Mandelbrot 1977) is still far from the ancient Indian outlook. An Indian sage from many thousands years ago would say to the contemporary cosmologist: the Universe is much too complicated to be put into those primitive mathematical formulae of yours. Perhaps further developments in mathematics will make it possible to calculate a model of the Universe concordant with the Cosmological Principle of Ancient India. But at present, without resorting to models and strict calculations, we can imagine a picture, or rather a number of different pictures of such a Universe, infinitely self-different at every point. Everything that is plausible comes to be realized somewhere in it. But still it is Cosmos, not Chaos, and the highest order and beauty govern it.
Of course, this is just one of many historical cosmological principles. It has few adherents nowadays (e.g. in connection with the Anthropic Principle, see Chapter 6), but its importance in the development of cosmological ideas is considerable. One can at 1east suspect, if not prove, that it influenced the cosmological ideas of some philosophers of ancient Greece. And when Nicolas of Cusa (Nicolaus Krebs 1401-1464 A.D.) revealed his view that the fabric of the world has its center everywhere and its circumference nowhere, we cannot be sure if this was a far echo of the Indian Principle or a precursor of the modern, Copernican, mode of thinking about the Universe or, perhaps, both. The comparison of this oldest known cosmological principle with contemporary principles shows major differences but some close similarities as well.

### 1.06. Ancient Indian "Scientific method" today

The content of the Cosmological Principle of Ancient India, as expressed in contemporary terms, is still of use in contemporary cosmology. This brings some people to the conclusion that the method used in those times can find an application nowadays. The great sages of ancient India did not think about the world in logical terms nor was their approach to reality based on "pure feelings," if we are to understand the term feelings in its contemporary sense. We could rather say that they "participated in the world through internal and external experiences." After this most remote style of world perception, many others followed, each connected with another epoch of human evolution.

The contemporary way of approaching reality, called *science*, has its roots in the works of Greek mathematicians like Euclid (306-283 B.C.) but developed only in the Renaissance era. Galileo Galilei (1564-1642 A.D.) is usually considered the founder of science. Gradually people learned to perceive the world with logical thinking and with full control of their self-consciousness. (That was the overall tendency but many scholars did not reach that stage.) Every epoch has its own manner of approaching reality and contributes its achievements to the overall development of humanity and general knowledge. We would not have science in its contemporary form if the ancient Rishis in India did not exist once upon a time, if the Persian, Egyptian, Chaldean, Greek and Medieval scholars did not make their contributions.

The results stay; the styles of epochs change. Of course it is still possible, with great endeavor, not only to understand an approach to the reality of great personalities of past epochs, but even to follow their footsteps, to imitate their inner spiritual mode and their ways of striving for truth. Such attempts are quite popular at present, and the epoch of ancient India is the favorite one for such experiments. Whoever does this is, at best, reproducing old results but in no way contributing anything new to science.

It is useless to discuss which epoch of human development was better or which comprehended reality in the most intrinsic way. I am far from claiming that the contemporary scientific world view reveals to us more important aspects of existence than that of ancient India. I do not maintain either that this world view is the final one and that it will remain up to the very end of human evolution. I would like to affirm only that it is not possible to obtain any results of importance in contemporary science by making use of ancient Indian or Egyptian methods. Whoever is not too fond of contemporary ideas has the full right to revive ancient outlooks but should not pretend to be a scientist in the true sense.

These remarks are certainly trivial but by no means superfluous. Some amateur astronomers and other laymen practicing science send letters to observatories and scientific societies with results of their investigations that are based or most often appear to be based on beliefs and concepts proceeding along the same lines of those prevailing in ancient times. I myself have received for reviewing no less than a hundred "scientific" papers of that sort. In most cases, no other objections could be raised against them except for that they were late by several thousands of years.

Chapter 2

# The Ancient Greek Cosmological Principle

## 2.01. **Cosmology after the epoch of Ancient India**

Several cultures arose, reaching their prime and then gradually declining, between the oldest known, the culture of ancient India, and the culture we want to refer now. One can mention here the cultures of ancient Iran, Egypt, Chaldea, and Babylon. All of them had quite definite views on celestial phenomena. Some nations, Chaldeans in particular, contributed much to astronomy but no account was left of their ideas about the Universe as a whole. Much is known about their views concerning the relationships between the Earth and the Moon, the Earth and the Sun, Venus or other particular celestial bodies, but neither contemporary records from those cultures nor documents written in later centuries but reflecting earlier views on the entire Cosmos (as was the case with the *Bhagavad-Gita* in respect to the outlook of ancient India) have yet been found by historians and archaeologists.

Taking into account the highly developed spirituality of ancient Egyptians, it seems very unlikely for them not to have any definite ideas about the Cosmos as such. The ancient Egyptian priest-astronomers developed the concepts of the Sidereal Zodiac (cf. Powell and Treagold 1979), which reveals that a certain view of the overall structure of the Universe must have existed in ancient Egyptian culture. This view, however, remains unknown to date. It was customary in those times that the highest wisdom should be preserved and passed solely to initiated persons orally or written in such a form that strangers should not understand it. Therefore it is very probable that any written records from that epoch concerning cosmological ideas, which would be of so much interest to us, never existed. Of course, it cannot be excluded that another collection of c1ay tablets or papyrus rolls will be discovered some day, delivering us information about Persian, Chaldean, Babylonian or Egyptian cosmological ideas. But as this has not happened yet, we have to skip those remarkable historical cultures and pass directly to ancient Greece. Here we have enough contemporary documents to reconstruct the general philosophical assumption, on which a number of mathematical models of the Universe were based, called the Ancient Greek Cosmological Principle or Cosmological Principle of the Ancients. This principle was reconstructed in 1972 by Michal Heller (Heller and Rudnicki 1972).

## 2.02. **Greco-Roman culture**

Classical western culture is not merely Greek culture. Its other major constituent is the Roman element. Therefore it is usually called, with reason, Greco-Roman culture. Yet I will be concerned with the Greek component only, because the Romans contributed

mainly to the development of legal and political ideas, rather than to scientific or philosophical ones. In these latter areas they took over the achievements of Greeks.
Of course, that Greco-Roman culture was not detached from neighboring cultures and civilizations. Those connections as such, as well as their relation to cosmological ideas, may be of interest for the history of these times. For our aim, however, for the description of the evolution of cosmological principles, I will limit myself to a slightly simplified depiction of the Greek ideas.
When speaking about ideas of the ancient Greeks, it has to be said that it is impossible to find one consistent attitude towards the entire Universe; there were quite a variety of cosmological ideas instead. Traces of ancient Indian ideas are to be found there, as well as some original ideas, possibly cognate to some Chaldean or Egyptian views unknown to us. Some researchers presume that traces of anticipated elements of cosmological principles of our epoch could be found in ideas of some Greek philosophers. I will return to this problem in later chapters. Here I want to describe the main stream of Greek cosmology, which prevailed through at least two millennia and led to mathematical calculations of many historically and methodologically important and remarkable models of the Universe.

### 2.03. **Logical Thinking - Philosophy**

The particular intellectual atmosphere of Greek culture is strictly connected with the evolution of the human attitude towards cognition. For a priest in ancient Egypt, who was a scientist par excellence of that time, science was secret in the sense that its source was not research but revelation. The Egyptians knew a number of mathematical theorems, but they did not prove them logically. Rather, these theorems were revealed, in the sense that somebody first had the privilege to "perceive," to "see" a theorem in the realm of ideas, after which he could share his "revelation" with those worthy of it. Such a theorem was treated as something given from above to the chosen, to the initiated only. Nobody could arrive at such knowledge by an effort of his own. Revelation, not logical thinking could be of assistance in the cognitive process. Of course it was connected with thinking but with a thoroughly different manner of thinking than our contemporary, logical thinking.
Beginning from about the sixth century before Christ, another approach toward cognition was born. That was philosophy, which consisted of clear, logical thinking. The knowledge of the world gradually lost its occult character. One did not need to be previously initiated. Whoever could think was able to get knowledge. Mathematical truths were no longer valid by revelation, but rather by logical proof, as was the case with the formulation of classic geometrical theorems by Euclid. Personal, individual thinking was discovered as a new human capacity. And as with everything new, here also the power of the new - of thinking - was overestimated. People hoped to understand and explain everything by means of mere thinking. At the beginning, however, there were only a few people who had really developed the thinking abilities to a sufficient degree. Therefore, with the epoch of philosophy an epoch of human authorities also

began. There began a period of reverence for people who could think by themselves. Those individuals were now admired in a somewhat similar way that revealed truths as such had been admired before. In the late Middle Ages, when the period of mental enlivening was in decline, this reverence for authority grew exuberantly, like weeds. In certain academic circles, adducing an authority counted for more than any independent observation and independent thinking. But we are concerned now with the first, positive, ascending branch of that cultural and scholarly trend.

### 2.04. **Respect for the sensory world**

In the ancient Indian manner of thinking, only spirit was of any importance. The world accessible to our senses was taken as a gross illusion, as *maya*. In the realm of spirit everything was in its real shape, and this meant also that everything was good. Even something which in the material, sensual world seemed to be evil was understood as good in the spiritual world of true reality. Thus evil was *maya* - merely an illusion. In the ancient Iranian culture, the material world obtained the same level of reality as the spiritual one. To transform, to elaborate this material world according to norms of spirit, was considered to be the primary goal of humans. Evil became reality, and opposing it was the highest human obligation. The eternal struggle between the principles of Good and Evil must end eventually in the victory of the former, but presently both possess about equal power. In the same manner, matter and spirit were considered as staying in a kind of equilibrium.
The material world was considered even more seriously in the three cultures that developed on the adjoining territories of Asia and Africa: Egyptian, Chaldean, and Babylonian. To be sure, they considered the spiritual world as the foundation of all existence, and their attitude towards it was that of high esteem. However, except for some highly initiated individuals, exploring contacts with heavenly beings served them first of all for more conveniently arranging earthly life, which was considered the most important one for human beings. And so it was for the Egyptians; they preserved earthly human bodies after death as mummies. And so for the Chaldeans, who developed astrology to be able to interpret the intentions of deities and thus to carry out their worldly affairs in a more effective way. And so for the Babylonians who developed systems of magic to harness spiritual energies for mundane purposes. Some elements of preserving bodily remains of the dead, of reading the stars, and of magical ceremonies were known in almost all previous cultures as well. But only these three brought them to perfection in their efflorescence.
A still deeper stage of the process of "materialization" is to be seen in the period of Greek culture which began some centuries before Alexander the Great. Obviously, an ancient Greek was by no means an atheist. He worshipped gods and believed in his own life after death. The average member of the middle or upper class of that time, was convinced that the gods themselves are concerned mainly with earthly problems. A Greek foresaw his future spiritual life after death as a very miserable one indeed. [1] One can put it this way: they believed in gods but did not believe in God; they believed in

spirits but not in the Spirit.

## 2.05. **Two ways to atheism**

Some prominent personalities of that epoch did not share those prevailing beliefs. Just in this cultural environment some philosophers developed highly spiritualized notions like the *logos* of Heraclites of Ephesus (540-480 B.C.) or the *nuos* of Anaxagoras of Klazomenae (ca. 500-428 B.C.). They acknowledged that there were either some high spiritual principles of existence or just one highest Spiritual Principle and were not ready to accept the widespread concept of small gods concerned mainly with earthly affairs. So did, for example, Euhemer, who lived at the turn of the 4th century B.C. He considered all the deities worshipped by people to come from among people themselves but to be venerated and deified by the others.

There are two positive ways towards atheism. In the first, one does not accept the existence of the highest creator and ruler of the world, accepting only lower hierarchies of spirits (one "believes in saints and angels but not in God"). This way usually leads through superstitious belief in spirits of nature, and, in its eventual stage, brings one to accept the notion of inanimate laws of nature. The other way consists in accepting the existence of the highest creator or the highest principle of all being but denying the existence of lower spiritual hierarchies, especially those having any contact with the earth and individuals dwelling on it (one "believes in God but not in angels"). This leads through sublime but usually dry considerations and adoration of the Creator towards searching for a philosophical principle of the highest necessity. Euhemer is considered to be the precursor of atheism though he did accept the Supreme Being. In present times this other tendency reappears as an attempt at reducing all spiritual phenomena to intellectual ones, all intellectual to mental, all mental to biological, all biological to chemical, all chemical to physical, and all physical to the unified theory of all interactions. The entire content of the Universe thus is comprised in one set of mathematical equations - what a lofty goal! It makes men gods, knowing everything good and evil.

Both those opposite trends can be seen in the classical Greek culture. Each of them tended from a different side to the same point: atheism.

## 2.06. **Halfway cosmological principle**

As already stated, classical culture was not atheistic, but was on the way to atheism. At that intermediate stage, the attitude of Greeks toward the world was quite particular. On the one hand, they looked upon their physical, worldly environment in the same way as average people of our 20th century. To be sure, there could still be a nymph immersed in a stream; there could be a satyr hiding behind a tree, and one could meet a goddess when traveling. But any physical object was not a mask or external disguise, not *maya*, not just a symbol of some higher entity, but it was exactly as perceived by the human senses and a reality in itself. Something was beautiful or ugly exactly as much as it presented itself to one's senses. Greek and Roman sculptures and paintings represent the beauty and importance of prominent persons not by furnishing them with a nimbus or symbolic vestments but by realistically reproducing those features of one's inner constitution that manifest themselves externally. The Greeks were, in fact, masters of realistic plastic art. But on the other hand, the Greeks did not look upon celestial bodies as physical objects. They could not be either touched or smelled or even heard (not everybody can listen to the harmony of spheres). One could only see them, and that was not sufficient for considering them as consisting of physical matter. Therefore the attitude of Greeks towards celestial bodies much resembled the attitude of ancient Indians towards any things. Celestial bodies were for them but tokens of workings of higher worlds; they were a sort of *maya*. Even when a Greek actually did say that celestial bodies consisted of matter, he had in mind another, sublime kind of matter.

Only physical existence was regarded as truly important. The only place of physical existence was our Earth. Even the deities concentrated their activities on earthly affairs. Thus the Earth was the natural center of all. Every reasonable description of astronomical reality had to be geocentric. The Cosmological Principle of the Ancients reflecting the Greek common outlook can be put today in a following way:

*Our Earth is the natural center of the Universe.*

In other words: the structure of the Universe must reveal a symmetry or quasi-symmetry in respect to the Earth. This principle was never formulated exactly so, at least no such c1assical texts are available, but for about two thousand years all the known models of the Universe involved this assumption. The symmetry was understood in a geometric, not kinematic, sense and concerned positions of celestial circ1es or spheres. On the other hand, the presence of privileged axes of rotations, even a number of them, inc1ined to one another in various ways, were not considered to break that quasi-symmetry.

This idea of spherical symmetry of the Universe is necessarily connected with the hypothesis (or discovery) that the Earth is a sphere. Presumably Pythagoras (ca. 572-497 B.C.) first stated that the Earth had a spherical shape. Some believe that it must have been Parmenides of Elea (ca. 540-470 B.C.) or even Hesiod (7th century B.C.) to arrive first at this conc1usion (cf. Ley 1963). Regardless, it was Eudoxos of Knidos who made the idea widely accepted. The conviction of the spherical shape of the Earth, born at about the same time as the new cosmological principle, was probably the departure point for the belief that the entire Universe had a spherical shape. But even if we suppose that the spherical shape of the sky[2] was the first and foremost argument for representing the Universe as a set of spheres, the spherical form of the Earth was an important fact in support of that view.

## 2.07. **The sublunary and superlunary world; circular motions**

Another idea was that the entire Universe was divided in two main parts: the sublunary and superlunary one. To the sublunary one belonged the solid Earth and atmosphere with clouds and a11 its phenomena. In contrast to superlunary planets, they were still considered physical.

Another important assumption was that the only movements admitted in the superlunary world were uniform circular motions. All known models of the Universe involving the Ancient Greek Cosmological Principle rely also on this assumption. But it is not as fundamental as the assumption of spherical symmetry; it does not constitute a part of the cosmological principle. The latter assumption is valid only for the observable parts of the Universe. Constructing models based on the Ancient Greek Cosmological Principle did not lead to the concept of a cosmological horizon in the contemporary sense. They provided, however, in their geometrica11y understood space, a concentric region reserved for the physica11y unobservable, purely spiritual world. This was the outermost part of the Universe. No systematic motions were possible there. Thus the assumption of exclusive1y circular, uniform motions, although very characteristic for those models, did not hold for the entire Universe. Different laws of motion governed in the innermost, sublunary sphere and in the outermost, invisible regions. Thus the circular uniform motion principle should be treated not as a cosmological principle or some part of such, but as a separate, additional assumption. The connection between the point symmetry and the circular motions around that point is obvious. It is remarkable that in fact also radial systematic motions do conform to the same symmetry, but such kind of motions was not regarded by the ancients as suitable for the Universe. Only in the 20th century did the Hubble law admit such kinds of movements in the Cosmos.

## 2.08. **Systems of spheres**

Two main kinds of mode1s involving the Ancient Greek Cosmological Principle, i.e. geocentric models, were developed. The first was constructed solely of concentric rotating spheres. This kind of model fulfi11s the condition of exact point symmetry. Models of the second kind, besides a sphere or system of spheres, also inc1uded hierarchical circ1es. The circ1es were not necessarily concentric and some minor ones (epicyc1es) were situated so that they did not encirc1e the center of the Universe, i.e. the Earth, at a11. The point symmetry was nearly preserved, in the sense that the Earth remained the central body of the entire model. Planets, which inc1uded the Moon and the Sun, were considered in those models as basic constituents of the Universe. The stars were also taken into consideration, but only as a far-off background for the apparent planetary movements.

The construction of the first geocentric model of the first kind is attributed to Anaximander of Miletus, (611-546 B.C.). This model consisted of less than twenty spheres. The most famous model was constructed by Eudoxos from Knidos (ca. 408-355 B.C.). In Eudoxos' model, each sphere except for the outermost one which was at rest, rotated about its axis, which was fixed at the next, larger sphere. The axes had various inclinations. The first moving sphere here was the sphere of fixed stars. Its axis

was the straight line connecting the celestial poles and was considered the most important axis in the Universe, [3] its rotation is the daily rotation of the celestial sphere. Several spheres, several axial inclinations, several periods of (uniform!) rotations had to be applied to account for the motion of a planet, to imitate its apparent wanderings over the sky, involving deviations from the ecliptic plane, deviations from a constant velocity, and loops. Another difficulty in that construction was that every sphere's movement included all the other spheres within it. Thus, spherical motions corresponding to individual planets were not independent from each other.
Luckily enough, the knowledge of planetary motions was not yet very accurate by Eudoxos' times; he succeeded in constructing a model of the Universe using no more than 27 spheres. Another model of this kind was described by Plato (ca. 427-347 B.C.) in the final chapter of his *Republic*. An even more widely known model was that of Aristotle (384-322 B.C.), consisting of 56 spheres. These kinds of models, although used in later times, as the accuracy of astronomical observations improved, became too intricate for practical construction and gradually gave way to developing models of the second type.

2.09. **Systems of circles**

The first model of the second kind is attributed sometimes to Anaximander of Miletus (611-546 RC.), sometimes to Heraclites of Ephesus (540-480 B.C.) or even to Seleukus (a Babylonian, living probably in the 3rd century B.C.). The scheme is here less complicated. The sphere of fixed stars, rotating with the period of one sidereal day, is the same as that of Eudoxos, but, for reproducing planetary motions, flat circles surrounding the Earth are used instead of spheres. They are located within the sphere of stars according to inclinations of their orbits. The circles are independent of each other. The motion of one planet does not influence the others. Thus it is possible to obtain a good agreement from observations of each planet separately, without regarding the motions of others.
The motions along those circles had to have constant angular velocity. A circle surrounding the Earth, the center of the system, is a great circle projected on the celestial sphere. To account for all the departures from great circles and from constant velocities in planetary motions, several auxiliary circles were introduced by Hipparchus (190-125 RC.). The main, large circles corresponding to the basic position of a planetary orbit are called deferenses. A small circle, called epicycle, moves along each deferens. Planets were situated on epicyc1es and so were capable of performing quite complicated movements. It was presumably Hipparchus who noticed that it is better not to set the Earth in the very center of the main circ1e but a little off it. This disposes of one epicyc1e. Thus, it is quite plausible that Hipparchus displaced the Earth from its central position (but one cannot be quite sure whether it was he who invented the eccentric circ1e in cosmological mode1s); indeed, if it was not he, then it must have been Ptolemy. I am not going to describe such models in detail here. This can be found in any book on history of astronomy (e.g. Ley 1963).

As astronomy progressed, with the collection of more astronomical data, the planetary movements appeared more and more complicated. Accordingly, over time, the mode1s became more accurate, but they also became more complicated. The epicyc1es of higher order, moving along other epicyc1es were introduced. The number of epicyc1es with different inc1inations from one to another can be increased following accuracy requirements, reflecting the increasing precision of astronomical measurements. The planet itself was always located on the last epicyc1e.
Such a system of epicyc1es is equivalent to the Fourier analysis and every quasi periodical motion can be thus decomposed into a finite number of strict periodic motions within the required degree of accuracy. Any motion can be expressed in terms of a Fourier series and thus be reproduced by a complex system of epicyc1es. Nevertheless, with the purpose of reducing the number of epicyc1es, some other constructions were also introduced. Beginning with Ptolemy, the angular velocity along the deferenses was no longer assumed to be constant even though it seems to be so when viewed from the center of another circ1e, the aequant. This was a way to preserve the principle of constant velocity, albeit in a very abstract sense indeed.

## 2.10. **Various geocentric models**

Besides those two major types of models, there were some less typical ones. Such was, for one, the late mode1 of Jan of Glogów (16th century) that involved no spheres and no circ1es but a sort of space tunnel instead. The sufficiently large diameters of these tunnels in respect to diameters of planets allowed for departures from the strictly uniform motions.
The number of known models based on the Cosmological Principle of Ancients is enormous. The best known ones have already been mentioned. The last model of considerable importance for history and astronomy based on the Ancient Greek Principle is the model of Tycho Brahe (1546-1601). It is remarkable in that it conforms to two cosmological principles at the same time. I will return to it in a later chapter.
By all means the most famous of all those mode1s is the model of Claudius Ptolemy constructed in the second century after Christ. This is described in Ptolemy's work entitled in Greek *E Megale Syntaxis* or *E Megiste Syntaxis* but more often going under its Latinized Arabic name *Almagestum*. Ptolemy's model, with its numerous later corrections (i.e. provision of additional epicycles for obtaining a better agreement with the even more accurate knowledge of actual movements of planets over the celestial sphere), was widely accepted by the scholarly community and was dominant for about thirteen centuries. For many people, a geocentric model, a geocentric system of the Universe, remains to date synonymous to Ptolemy's.

## 2.11. **Unobservable regions of the Universe**

The Greeks' division of the Universe into two parts, the sublunary and the superlunary, was, as I mentioned above, equivalent to the division into the physically existing part of the Universe and the part with a sublime, superphysical existence. Only first regions of that second part were accessible to the human eye through manifestations as celestial phenomena. The rotating sphere of fixed stars was considered to be the ultimate constituent of the Cosmos still able to be perceived by humans. That sphere or the next one, enclosing it, was widely known under the Latin name given to it in much later, in the Middle Ages by Nicolas of Cusa (1401-1464): *primum mobile*. This was the border between the observable and unobservable parts of the Universe. No physical signal could be obtained from beyond it, where unmoving and invisible spheres were located. It was the world of the heavens, called in later centuries Empyrean, a region filled with heavenly fire and brilliance, which in the conception of ancient pre-Christian philosophers (e.g. Aristotle), and in the opinion of Christian thinkers was the abode of God himself, his angels and saints. From the general considerations (based on the cosmological principle adopted), it was known that it surrounds the Earth and the other celestial circles and spheres. Any other, more detailed knowledge about the Empyrean could be obtained only through supernatural revelation.

This was a specific kind of thinking indeed, establishing for spiritual, not physical, beings an appropriate location in space. It is paradoxical enough to provide room in a geometrically conceived model of the Universe for imponderable, sublime beings. This is, of course, related to a certain inconsistency of the ancient Greek world view which stopped halfway between the spiritual Indian philosophy and the modern materialistic one. The spiritual nature of the immediate human environment, of minerals, plants, and animals, was no longer accepted, at least not in daily life. But still, it was believed that physical matter is not the sole constituent of reality. Thus, for all that was not physical one had to assign a particular region, sufficiently removed from the human abode. For the ancient Indians, all that existed had two aspects, two sides. One spiritual, the fundamental one, and the other the physical, not quite real one, the *maya*. The dividing line did not lead through geometric space. In models based on the Ancient Greek Cosmological Principle, the physical world that could be observed through our senses was geometrically separated from the higher worlds.

It may be proper to add here that the rise of geocentric models based on the Ancient Greek Cosmological Principle took place in the last centuries before and the first centuries after Christ. Medieval European astronomy lived only with the echoes of ancient Greek and Arabian astronomies. The cosmological model prevailing at those times was a vulgarized model of Eudoxos. Thus the geometric, philosophic, and theological interpretation of that time concerning the observable and unobservable parts of the Universe did not have any reliable cosmological base. So it is not easy for the contemporary mode of thinking to grasp medieval consideration and compare them to the original ancient or later ones of the Renaissance. But for our purposes, exact delimiting of epochs is not necessary here.

In general, it can be stated that in all the known geocentric models the same outermost space was assigned for the part of the Universe not accessible to observation. Not too much could be said about these parts. Their sole property resulting directly from the accepted cosmological principle was that they have a certain (quasi)symmetry in respect

to the Earth. One could say that the Cosmological Principle of the Ancients was a very "weak" one. It set little constraints on models in respect of unobservable regions of the Universe; nonetheless that is still enough to include it to the family of cosmological principles.
There is a subtle difference between the old Greek and our contemporary idea of the unobservable. At present the cosmologists believe that the regions of the Universe situated beyond the cosmological horizon are not connected with us in any causal sense. No event occurring in those distant regions can in any way influence us; no signal, no information can reach us from "out there." And vice versa, we cannot have any influence on anything that happens there. Such a strong separation did not exist in relation to the highest spheres in the ancient models of the Universe. The spiritual entities abiding there could come down even to the very Earth and human prayers were able to reach those highest invisible spheres. The separation was understood only in a physical sense, only for sensual perception. In that epoch the Universe was still considered both physical and spiritual. Its physical component was but one part of it. However, when those ancient models of the World are expressed using notions of contemporary cosmology, the difference disappears. The unobservable parts of the Universe were in a physical sense as little connected causa11y with us as is the case in the contemporary models with the regions beyond the cosmological horizon.

### 2.12. **The Geocentric system in contemporary astronomy**

Geocentric observation of the Universe brought about major developments in the knowledge of the sky. Such words as "astronomy," "planet," "comet," all of Greek origin, testify to that fact and provide evidence that the geocentric view really had its point.
Not all astronomers, not to mention the general public, are aware that the Ancient Greek Cosmological Principle is sti11 alive today. To be sure, it hardly underlies any mainstream cosmological research; nevertheless, it is used in many astronomical ephemeredes and tables in astronomical yearbooks and almanacs, since astronomical data quite often are given in the geocentric coordinate system. Although the belief that our Earth is the natural center of the Universe is no longer accepted, in our astrometry measurements the geocentric system is applied as the most comfortable one. It is more objective than the topocentric system in which our measurements are actua11y performed and much easier for reduction than the other systems used in today's astronomy. Besides, since we consider (like the ancient Indians did) that there is no favored point in the Universe, all its points being of equal importance, our Earth can be freely adopted as a conventional center of the Universe as can any other celestial body or individual point in the Universe.

### 2.13. The Generalized Ancient Greek Cosmological Principle

As was said, the Ancient Greek Cosmological Principle divided the Universe geometrically into two parts; one is our ordinary physical world, and the other is where the visible celestial bodies perform their movements and the beings and phenomena are neither physical nor purely spiritual. By implication, this view led to accepting the Earth as the center of the universe. But we can say laconically that the content of this principle is: the Universe does possess a distinguished center, the Earth. It is easy to generalize this statement by simply dropping its last words after the comma. We obtain then a simple proposition: the Universe does possess a distinguished center. This generalized assumption is fulfilled not only by all the ancient models with spheres or circ1es but also by the models of Copernicus and Kepler (with the Sun as the center).

In such a generalized form, that cosmological principle reappears time and again in contemporary cosmology. For example, Ellis, Maartens and Nel (1978) put forward a model of a spherically symmetrical Universe with our Galaxy in the center. It is considered to be a methodological exercise rather than an actual model. The intention of its authors was to show that even such an exotic model did not contradict observations.

Sometimes the relativistic point solution of Karl Schwarzschild (cf. 0.08 and 9.07) is considered a cosmological model. It also fulfills the Generalized Ancient Greek Cosmological Principle.

**Notes**

1. Homer says in his *Odyssey*: "Better a most poor herdsman on the earth than a king in the kingdom of shadows" (realm of souls of the dead).

2. In fact, the shape of the firmament, as it presents itself to our perception, is not strictly spherical. The "canopy of heaven" has rather an ovaloid shape, that of a two-axial ellipsoid. The actual shape is contingent on landscape, weather, time of day, placement and temper of the observer. The distance to its highest point (zenith) always seems to be smaller than the distance to the horizon.

3 The term world axis taken from that model is still in use in many languages and sometimes even in English in modern spherical astronomy.

# Chapter 3

## The Genuine Copernican Cosmological Principle

### 3.01. **Copernicus as the constructor of a model of the Universe**

The question of what the Universe looks like when observed from a planet has excited human minds for a long time. Cicero (10-3 B.C.) in his *Republic* describes "Scipio's dream" (*Somnium Scipionis*) where, according to the general beliefs of that epoch, the Universe seen from other planets was completely different than when seen from the terrestrial perspective. Nicolaus Copernicus (1473-1543), however, provided an answer completely contradicting the ancient outlook. He came to the opinion that the Universe seen from any planet would look much the same as when seen from the Earth. He considered the Earth to be just one of the planets.

In historical and astronomical books, Copernicus is often presented as a founder of a new model of the Universe. This is correct in that he did construct such a model. The Sun was at the center; our Earth and other planets circled it, moving along epicycles and deferenses. This is called the Copernican Model of the Universe (or of the world). And this Copernican, heliocentric model with circular deferenses and epicycles orbiting around the Sun (not around the Earth as with Ptolemaic), was, as early as about a hundred years later, replaced by Kepler's model with elliptical orbits. Of course, a scientific idea which survives for a century is certainly of historical importance. But the actual value of Copernicus' discovery did not consist merely in constructing a model of the Universe.

Sometimes Copernicus is honored as having substituted the old geocentric system with the new, heliocentric one, as having regarded the Sun, instead of the Earth, as the unmoving center of the Universe. This view, while quite correct, does not render the actual significance of Copernicus's work. Giordano Bruno, born five years after Copernicus' death, proclaimed that other stars are other suns with their own planetary systems. Thus the Sun was no longer the center of the Universe. As it has been known for several centuries, the Sun is not stationary; it does move in relation to the neighboring stars at a velocity of 20 kilometers per second towards the Hercules constellation and, furthermore, along with the neighboring stars, it circles the galactic center at a velocity of about 250 kilometers per second. Besides, it is suspected that, together with the Galaxy, the Sun circles our Supergalaxy (sometimes called Local Supercluster) at a velocity of several hundred kilometers per second. Thus, in that respect, the work of Copernicus is of important historical value, but only historical.

### 3.02. **The Copernican Cosmological Principle**

In fact, Copernicus accomplished something more. His model of the Universe, his

opinions about positions of various celestial bodies in the Cosmos, in fact, all his work involved a new cosmological principle originated by him. It is today called the Genuine Copernican Cosmological Principle and says:
***The Universe as observed from any planet looks much the same.***
This means that from every planet we would observe the same starry sky, and the qualitatively similar motion of the Sun, as well as the motions of other planets with their characteristic loops.
Of course, the Copernican model ("the Copernican system of the world") is based on this principle, but one has to distinguish between cosmological principles and models based on them. The significance of Copernicus's achievement can be properly assessed only when we realize that not only did he formulate a new, primitive, cosmological model, but he also established a quite novel cosmological principle that was to underlie the modern world view.
Three models, historically important for the development of cosmology, were based on the Genuine Copernican Cosmological Principle. The first one was the indeed very primitive (deferenses, epicycles, uniform circular motions) original model of Copernicus. The best known one is certainly the model of Johann Kepler with elliptical orbits and velocities following the three familiar Keplerian laws. But the less known model of Tycho Brahe also belongs here. This last one is of special interest to us, as it is based on two cosmological principles at the same time. The central place in the model is occupied by the Earth (according to the Cosmological Principle of the Ancients), but the Universe observed from any planet looks much alike (Copernican Principle).

### 3.03. **Some properties of the Copernican Principle**

The story of Tycho Brahe's model is very informative for understanding the origin of the Copernican Cosmological Principle itself; therefore, I want to discuss some issues concerning that particular model, although presenting models as such is not the purpose of this book. Time and again, there are opinions that the Copernican idea of the planets having the same status as our Earth was corroborated by observations from the very beginning. In fact, this was by no means the case. The Ptolemaic model of the Universe was very flexible indeed. With any new observations, with any development in the knowledge of planetary motions, it could be extended and made even more accurate by supplementing it with further epicycles, and Copernicus was well aware of that. The original model of Copernicus was essentially the same as Ptolemy's. Certainly, it was a little bit simpler, involving a smaller number of epicycles. Both were accurate to the same extent and able to reproduce celestial phenomena to even higher accuracy by increasing the number of epicycles.
One can say that a simplification of his model was for Copernicus only a pretext to promote his world view; nowadays we would say: to promote his cosmological principle. The agreement of a model with observations and the number of epicycles made just a quantitative difference. However, there was another difference, much more fundamental. In the Ptolemaic or any other model before Copernicus, the planets described loops not

only in the celestial sphere but also in the geometric system of reference, in the geometric system of coordinates. In the Copernican system, the loops were apparent phenomena observed in the celestial sphere; but in the spatial sense the planetary motions, composed out of epicyclical circuits, though still very complicated, involved no effective retrograde motions. This introduced more order into the Copernican idea of the world. Besides, Copernicus disliked the idea that the refulgent Sun should be of the same status as the other planets. It was planets that ought to be subordinated to the Sun. Those two "mental simplifications" were regarded as the most important arguments in favor of Copernicus' ideas. Tycho Brahe was also enthusiastic about them. Yet he was a serious scholar and wanted to obtain some observational evidence in support of the new system of the world. That is, he expected to observe the yearly parallax of stars.

### 3.04. **Tycho Brahe's model**

If the Earth is in motion, then the optical perspective of remote immovable objects, that is fixed stars, should change with time. The yearly movement of the earth should be reflected by an apparent yearly displacement of stars, called parallactic motion or simply parallax. Tycho, being an excellent observer, looked for the parallaxes and failed to find any. Today we know only too well that the so-called fixed stars are much more distant than it was believed by Tycho and, with the instruments at his disposal, he was not in the position to measure them. Stellar parallaxes were actually measured only more than two hundred years after his death with the use of more modem astronomical devices. But for Tycho Brahe the failure of his observations was an argument against the Copernican model of the Universe with a moving Earth.

Tycho could not accept the model of Copernicus yet he believed that what is today called the genuine Copernican Cosmological Principle is true. He was deeply convinced that the Universe as seen from each planet looks much alike, that the planets, considered in some system of coordinates, do not describe any loops in cosmic space and are subordinate to the Sun. He developed his own model of the Universe in which the Genuine Copernican Cosmological Principle holds, but the Earth is immovable, constituting the center of the Universe. Thus, his model conforms to two cosmological principles at the same time. It was obtained in a simple way by changing the coordinate system. Tycho took the model of Copernicus and, preserving all its relative motions, displaced its center to the center of the Earth. To put it figuratively, he took over the model of Copernicus as it was, with all its moving "wheels," but "pinned" the Earth at the origin of the coordinate system, allowing all the other bodies to continue their previous, relative, "Copernican" motions. In his model the Sun and the Moon revolve around the Earth, but all the other planets orbit around the Sun.

Tycho's example gives rise to a few reflections. First, the scientist has the right to maintain some ideas even though observational (experimental) evidence contradicts them (here, absence of stellar parallaxes). Second, an absence of evidence should never be taken as equivalent to an evidence of absence (the parallaxes were discovered later). Third, one fundamental cosmological idea does not necessarily exclude other ones; two

cosmological principles can be reconciled.
There has been a prolonged discussion whether one feature of the Tychonian model was not known already to ancient Egyptians or to other ancient astronomers, namely that of Mercury and Venus circling the Sun, whereas the Sun itse1f and the other planets orbit around the Earth (cf. Dreyer 1953). Robert Powell (1987) presented a hypothesis that the entire Tychonian system was known already to the ancient Egyptians. If that hypothesis were to survive, it could be used as an argument that some ideas identical or similar to the Genuine Copernican Cosmological Principle were known already in the Egyptian epoch.

### 3.05. **Copernicus and the Renaissance**

Nicolaus Copernicus was born in 1473, several decades after the new cultural epoch inaugurated with the novel trend called the Renaissance began. The prime years of Copernicus's life occurred when the Renaissance was at its full development. At that time the study of nature took a new turn. Scientific truth began to be seen not as something to be acquired by intuition, to be felt or experienced internally (like in the ancient Indian or even the ancient Egyptian epoch), or even to be based on authority or merely construed logically (as it came down from the classical Greek culture until medieval times), but rather as something to be based on external observations and experiments.
Aristotle attached no importance to experiments in testing his physical views, he carne to them by mere1y thinking. Now scholars, instead of studying books of famous philosophers and thinking about them, set to observing and experimenting. Gradually people learned to form scientific hypotheses, which could be proved by experiments and observations. These were new trends in biology, in medicine....
From the formal point of view, Copernicus was just a lawyer; he was a doctor in church law. But in his student days, which he spent at the universities of Cracow, Bologna, Padua and Ferrara, he attended courses in medicine and astronomy as well.
The old geocentric world model developed in the second century after Christ by Claudius Ptolemy according to the Ancient Greek Cosmological Principle was generally accepted at that time. Let us turn again to that model. By Copernicus's time it had become quite complicated. Astronomical observations developed much since Ptolemy. The original model of Ptolemy was no longer in good agreement with observations. One had to supplement it with new epicycles to obtain a better approximation. But every next approximation proved to be inadequate for improving astronomical knowledge. Thus, the adherents of Ptolemy had to add even farther circles, epicycles of still higher orders. In effect, Ptolemy's model of the Universe grew quite complicated indeed. Notwithstanding, the yet newer observations failed once and again to conform to the model.

### 3.06. **Corrections lo Ptolemy's model**

In fact, a generic characteristic of quantitative mathematical models of reality is that they are only of limited accuracy. The Ptolemaic model was able to be adjusted to any observational data, because it made use, as it was already said in a former chapter, of what is nowadays called Fourier's approximating process. Nevertheless, people in those days would regard the Ptolemaic system as an absolute one. For instance, Wojciech of Brudzewo (Adalbert/Albert Brudzewski, 1446-1495), a professor at the Jagiellonian University in Cracow, considered just that inexactitude to be a drawback of the Ptolemaic model. He criticized it on this point, yet, since he could not break up with the ancient Greek legacy of cosmological thinking, he was not able to propose any positive solution. He, like other scholars of the early Renaissance, still clung to the world view of the ancients which sets the sky in opposition to the Earth. It cannot be proved that Copernicus did attend talks of Albert Brudzewski,[1] but his later ideas show that during his student days in Cracow he must have gotten acquainted, in a direct or indirect way, with Brudzewski's anti-Ptolemaic attitude.
However, Copernicus was more individual in his thinking. He preferred rather idealistic thinking in a Platonic manner instead of Aristotelian one. Thus, he was more ready to overcome the barrier of scholarly superstitions. Albert of Brudzewo and other scholars of those times endeavored just to further modify the Ptolemaic model. Copernicus was the first to have sufficient courage to propose changing its very philosophical assumptions, to attack what is nowadays called the Ancient Greek Cosmological Principle. Instead, he introduced an assumption of his own, which is known now' as the Copernican principle.
Copernicus did not try to reject the Ptolemaic geometrical construction altogether. One could say today that he knew the point consisted of something different. In his model he still used deferenses and epicycles, yet it was by introducing a new cosmological principle that he opened up a novel perspective in philosophy and natural research.

## 3.07. **The issue of the Aristarchean Cosmological Principle**

Let us draw our attention for a while to the problem of whether the Copernican principle was actually new. This principle does not force but just allows one to consider the Earth not the center of the Universe, and this idea by itself is, of course, nothing new in the history of thought. It could be regarded as a far-off echo of the ancient Indian philosophy where the Earth was considered as one of many similar and dissimilar "earths."
Edward R. Harrison (1981) attributes this assumption to Aristarchos of Sarnos (ca. 320-250 B.C.) rather than Copernicus, even calling it the Aristarchean Cosmological Principle; presumably it was Aristarchos who stated first that the Earth circles about the Sun and not the other way around. Certainly, there is too little evidence for maintaining that he did formulate another cosmological principle. In fact, all but one of Aristarchos writings is lost. His statement about the movement of the Earth around the Sun can be considered a precursor of the Copernican model of the Universe rather than of the Copernican Principle. But that is not sure either. There are no documents available of

his views about the motions of other planets. Did he calculate or outline any definite model of the world? If so, did he consider all the planets as circling round the Sun? If so, did he take any notice that the Moon should not belong to them, that its status is different? Or did he accept the orbit of the Moon as surrounding the Earth but also consider all the planets to revolve around the Earth as well? In fact, we have no account of the Aristarchean idea of the Universe to compare with the models of Copernicus or Kepler. Until new sources, possibly the missing writings of Aristarchos himself, are found, we are not in the position even to guess what his model was like. We can be assured only that he considered the Earth not to be the center of the Universe and rotating about its axis and circling the Sun.

Not much more can be said about the views of Aristarchos of Samos on the Universe as a whole than that he believed the fixed stars to be so distant that the dimensions of the Earth's orbit were quite negligible in comparison; thus he claimed that the dimensions of the Universe were several times larger than had been thought before. And, as a consequence of accepting the rotation of the Earth, he considered that the Sun and the fixed stars were at rest. But did he consider also that the Universe looks alike from every planet? Or did he accept some general principle about the structure of the Universe as whole? It is not known whether he did express any opinions in that matter. Did he consider the problem to be of importance at all? Did he go even further than Copernicus and consider that the Universe looks much alike when observed from any its point, for example, from a fixed star? Or did he perhaps consider the Universe as infinitely heterogeneous in its various aspects? Each of these possibilities may, of course, be true. But lacking relevant evidence, we have no ground to maintain either that Aristarchos introduced the principle which now goes by the name of Genuine Copernican Cosmological Principle or that he conceived any other cosmological idea concerning the general structure of the Universe.

Neither the isolated statement of Aristarchos that the Earth moves around the Sun nor his outright negative statement that the Earth is not the center of the Universe can be regarded as a cosmological principle. We notice that no idea concerning unobservable parts of the Universe can be deduced from what we know of Aristarchos.

Józef Misiek drew my attention to the fact that it is sheer nonsense to maintain that the essence of the Copernican revolution consisted in removing the Earth from the very center of the Universe, because it was as early as the time of Ptolemy, if not Hipparchus, that the Earth, with the introduction of the eccentric deferens, definitely lost its geometrically distinguished position. And this did not bring about any philosophical revolution. On the other hand, in the Copernican model, the Earth remained still pretty close to the center. In both cases a certain quasi symmetry remains. The difference in this respect was quantitative only, not qualitative.

### 3.08. **Celestial bodies as physical bodies**

Copernicus considered the Earth and all the planets similarly. In his considerations about the apparent motions of planets in the 26th and 27th Chapter of the 5th book of his *De*

*Revolutionibus*, he used a complicated geometrical construction where the same line represented both the orbit of the Earth and the orbit of a planet. That construction showed his inherent conviction that the Universe looks from every planet just as it does from the Earth. For him, the status of the planets is the same as that of our Earth. Copernicus did not go as far as to maintain that all celestial bodies had the same status, that of physical bodies. He stated that only for planets, but this was enough to raise the question of the border between the sublunar and superlunar regions of the Universe. This had immense consequences not only for cosmology and science in general but also for the entirety of culture and civilization. Our present commonsense awareness still rests on the statement of Copernicus that the planets are bodies similar to the Earth.

All the other cosmological principles are direct implications of some world views, conclusions of some philosophical outlook. With the Copernican Principle, the case is different. Its formulation shaped the so-called modern world view. Of course, one cannot deny that Copernicus's way of thinking was based on his predecessors' ideas. For several decades, the Renaissance attitude toward the sensual experience had dominated in the cultural life of Europe. Without it, Copernicus would probably not have formulated his cosmological views or at least would not have had enough courage to communicate them to others. However, the impact of his ideas on the further development of culture is much stronger than the impact of the culture of his times on him. In any case, his cosmological principle is the most important of the several cosmological principles named after their inventors.

It is sometimes said that the Copernican principle is nothing new, because the ancient Indians already claimed that the Earth was not alone, was not the center of the Universe, or distinguished in any way. When we put it this way, some similarities are obvious. But it is not true that after the period of paradoxical Greek opinion that the Cosmos is divided geometrically into the physical and non-physical regions, Copernicus reintroduced the ancient Indian idea of a uniform Universe. He was rather still developing the ideas of ancient Greeks. The ancient Indians beheld a spiritual unity. The later Greeks promoted the inconsistent view of the Universe as both material (sublunar region) and spiritual. Copernicus, in contrast to the Indian view, regarded the other celestial bodies as similar to the Earth and therefore as material ones.

### 3.09. **Methodological and ontological materialism**

The Copernican ideas were strongly opposed by the official scholarly circles of the time as well as by some churches. The semi-materialistic world view of medieval Europe ascribed the material existence to the Earth and the spiritual one to the heavens, in the manner of the Greeks. By then, the Earth was no longer a mere symbol for the material, and the sky no longer a symbol for the spiritual, as it was in ancient times or for that matter, in the Bible. Instead, they were seen as actually material or actually spiritual! To be sure, one could find in the writings of the church fathers a clear distinction between the heaven of theology and the sky of astronomy, but for most preachers and the faithful, there was really no difference between the two. As it was already stated, the

Middle Ages assigned an invisible place in the Universe (the Empyrean) solely for the highest spirituality. However, it was located in space - beyond the fixed stars. The Western church of that time did take over the common view: the "materialization" of the Earth that contained in its interior the devil and hell. But the church wanted to protect the heavens, its greatest treasure from such a materialization. And Copernicus's ideas led directly toward materialism. Copernicus himself was not only a canon of the Roman Catholic Diocese of Varmia, but also a truly devout, spiritually minded man. His followers, Bruno, Kepler, and Newton, were also devout. They had no intention of promoting atheism. In contemporary philosophy one distinguishes two different concepts of materialism. One is methodological materialism (called also methodological positivism) which demands that material should be grasped through "material concepts." To put it in a striking way, when we study the movements of billiard balls, we should not try to explain them as actions of Seraphim. The other is ontological materialism, which regards matter alone as truly existent, and when it admits any spiritual existence, it considers it secondary to matter. The former does not oppose a spiritual viewpoint; the latter is in sharp contrast to it. The materialism for which Copernicus and his immediate followers opened the way was the methodological one. No one could predict that the other one would also creep in somewhere along the way. But the distinction between the two types of materialism, even today by no means clear to everyone, was completely unknown at the time.

If Copernicus had lived in ancient India, his views would not have been regarded as affecting the spiritual world view in an adverse way. His hypothesis, after all, concerned only the *maya* of the physical world, and it would have been considered in that light alone. The situation in the Middle Ages was quite different. The churches felt that Copernican ideas would deprive the simple people of the last bulwark of the spirit, the heavens, as identified with the sky. The Western churches wanted to prevent this. Yet the kind of defense to which they resorted was an immoral one. Instead of looking for deeper spiritual truths, instead of teaching their faithful that the material sky is something completely different from the spiritual heavens, the churches struggled against both methodological materialism and the material truth of the Copernican world view. They could never succeed in this. The western churches were certainly right in regarding the rise of Copernicanism as a call to arms. But the direction and methods of their battle were fundamentally wrong. A struggle against truth cannot but be ever lost.

### 3.10. **The attitude of the Protestant Church toward Copernicanism**

We should note, however, that the relationships of different churches to Copernicanism were varied. The more materialistic a church's doctrine, the more fiercely it condemned Copernicanism.

The Lutheran church emerged as the first to openly condemn Copernicanism.

Martin Luther himself called Copernicus *a Sarmatic fool*[2] who "wants to turn the whole art of astronomy upside down," and quoted the appropriate biblical verses from the Book of Joshua (Jos. 10, 12-13):

"Then spoke Joshua to the Lord in the day when the Lord gave the Amorites over to the men of Israel; and he said in the sight of Israel, 'Sun, stand thou still at Gibeon and thou Moon in the valley of Ai'jalon.' And the Sun stood still, and the Moon stayed, until the nation took vengeance on their enemies. Is this not written in the Book of Jashar? The Sun stayed in the midst of heaven, and did not hasten to go down for about a whole day" (Bible, Revised Standard Version).

If we try to render this biblical description into modern astronomical language, we come to conclusion that a celestial phenomenon is here described in the terms of one of the possible systems of astronomical coordinates. To make the issue even more diversified, this is not the geocentric system but the topocentric one. The phrase "the Sun stayed in the midst of heaven" could be accounted more strictly in astronomical language as "The Sun stayed near the meridian," and the notion of meridian originates from and is truly meaningful in the topocentric system. Of course, it was difficult for the people of that time not only to accept a possibility of describing the same event using various coordinate systems but even to think about motions other than absolute ones.
Melanchthon, the second to Luther in leadership of the Protestant Church, also considered the Copernican ideas to be "a spiritual licentiousness." From the statements of those both great reformers, we can clearly see how they confused spiritual and material facts, projecting spiritual truths into the physical plane. Therefore, they could not tolerate the actual material truth. We should not underestimate the Protestant Augsburgian Church either. It was, in fact, the most advanced church, since it had previously recognized problems now experienced by the majority of humanity. Contemporary people are not willing to refute Copernicanism, and since they wish to remain materialistic, they instead refute God.

### 3.11. **The Roman Catholic Church and Index Librorum Prohibitorum**

The attitude of the Roman Catholic Church was different. For a long time it had not expressed any definite opinion about Copernicus' ideas, considering the matter to be of scientific, not theological, significance. Only when the Copernican ideas began to spread to the general public in a vulgarized, that is much simplified, most often distorted, form[3], the Roman Church felt urged to counteract. In 1543 Copernicus died, and in the same year his main book, *De Revolutionibus*, appeared. Only 73 years later the official judgment on his work from the Roman Catholic Church was announced. On February 23, 1616, the so- called Holy Office proclaimed the book *De Revolutionibus Orbium*... to be suspended (only suspended!) "until corrected." And it was with those remarks about suspension and the need for correction that *De Revolutionibus* got into the Index Librorum Prohibitorum. On the same day, the Vatican outrightly condemned another book, by Paolo Antonio Foscarini, which sought to prove that the Copernican teaching did not contradict Holy Scripture. The Roman Church found it not possible at all to reconcile Copernican ideas with the Bible. Anyone who, like Foscarini, tried to prove the

opposite was a heretic. However, since the truths of science concern a plane different from that of the Bible, they could be published as long as they made no c1aim to interfere with the biblical, spiritual truths. In *De Revolutionibus*, only those fragments which pretended to claim the absolute (i.e. spiritual) validity of Copernicus' ideas needed correction. After correction, the book and its ideas could be spread to the public. The Roman church of that time was still capable of keeping to the old spiritual traditions, even if in everyday practice the Roman Catholic and Lutheran priests did not differ too much in their attitudes toward Copernicus.
Owing to that relatively gentle suspension verdict, the book was actually destroyed in only a few libraries. In most cases it was merely put away in a locked bookcase "until corrected." Therefore, more than a hundred copies of the first edition of *De Revolutionibus* survived in Catholic libraries throughout the world. Some of them show signs of attempts at "correction."

### 3.12. **Copernicanism and the Orthodox Church**

Even today the Eastern Orthodox Church still attaches greater weight to the utterances of devout monks than to those of learned theologians. Not only monks and nuns in monasteries, nunneries and hermitages, but even ordinary church members have performed mystical exercises. It is no wonder that this church never condemned Copernicus. The view is at times encountered that the Orthodox Church of that time had other, greater preoccupations or even that the Copernican ideas never really penetrated to that church. This might well be true of the Constantinople Patriarchate, whose greatest worry was how to survive the Turkish persecution. However, this cannot be the case for the church in Russia and even less so for the Church in Copernicus's native land, the Polish-Lithuanian Commonwealth, where the Orthodox church flourished throughout the Renaissance and where its members (about fifty percent of the population) could not isolate themselves from Copernican ideas, which were avidly disputed in Lithuanian and Polish scholarly centers. The fact is that the Orthodox Church did not see itself endangered by any scientific ideas. Anyone who could perceive or even dimly sense the spiritual reality did know that the Earth is surrounded by spiritual beings. Therefore it did not matter whether one thought that the physical Earth moved or was at rest. Within the Orthodox Church, it was conceivable to argue about true mantras for prayer, best finger placements, or the proper inclination of the body during mystical practices (e.g. the Old Believers movement of 18th century) but not about astronomical problems. To be sure, also for the Orthodox Church the visible sky was no longer regarded as *maya*, but it was still not the church's domain of interest. The Orthodox Church considered Copernicanism to be thoroughly irrelevant.

### 3.13. **Roots of contemporary materialism**

Ontological materialism, agnosticism, and atheism are not logical consequences of the methodological materialism implied by Copernicanism. The cause here is not of a logical

but of an emotional nature.
When Galileo Galilei (1564-1642) discovered, with his telescope, mountains on the Moon as well as the phases and satellites of planets, when the civilized world accepted Copernicus' opinion that the planets are material bodies, it was just one further step to regard all the other celestial bodies and all the celestial phenomena as physical phenomena. Thus Man began to feel himself surrounded by the physical world alone. Any contact with spirits needed some inner effort, while physical reality could be grasped without any difficulty. Humans are rather lazy as a rule, so they appreciated the physical world much more. There began the eventful epoch of developments in physics and chemistry as well as in technology based on these two and other disciplines(The progress of materialist knowledge brought about the situation of modern humanity which has to make use of many, sharply distinct theoretical ideas in the fields of science and technology; these are its objects of everyday contemplation. The feelings and interests of humanity are at present connected almost exclusively with matter, not with any higher planes of existence. And so it happened that with Copernicus ontological materialism, which was first introduced as long ago as in the Greco-Roman period, penetrated not only into cosmology, but also throughout all science and even into the tenor of everyday life.[4]

## 3.14. **Isotropy of the Universe**

What can we conclude from the Genuine Copernican Cosmological Principle about the unobservable parts of the Universe? If all the planets are in motion and the Universe should look alike from every planet, than it must be to some degree isotropic. Copernicus himself did not arrive at that conclusion or at least did not communicate it to anybody. But for his followers it became more and more clear that in all directions of the Universe we should meet much the same pattern, for instance, other suns with their planetary systems. This was the opinion of Giordano Bruno (1548-1600), born five years after Copernicus' death. But this relates to the next cosmological principle.

[1] Brudzewski no longer had astronomy-related classes by the time Copernicus began his studies in Cracow but probably was still active in astronomical disputes.

[2] Copernicus' father was a Pole, his mother a German woman. He was born in the territory of Poland in a town with a predominantly German population. It has long been debated whether Nicolaus Copernicus was really Polish or German. This discussion became a fierce scholarly quarrel in the times of nationalism (second half of 19th century up to the Second World War). Luther's statement was often cited then as an argument that Copernicus had been considered Polish, at least by his contemporary Germans. (The adjective "Sarmatic" was used as equivalent to Polish.)

[3] Among others, this was the case with Galileo's writings published in Italian. The

ambivalent role of Galileo Galilei in the propagation of Copernican ideas can also be instructive for many aspects of today's popularization of science, but the problem of Galileo is too complex (cf. Coyne et al. 1985) to be discussed in this book.

[4] There are various concepts and definitions of ontological materialism. There is an opinion that the modern scientific outlook is by no means materialistic because contemporary physics does not involve any definite concept of matter (in science one uses units of mass, of gravitational or magnetic fields, etc., but no unit of matter as such), that elementary particles are to be considered as some condensation of energy, that instead of strict causality probabilistic laws are introduced, etc., etc. For me, materialism in contemporary physics consists in the opinion that everything in the world can be deduced out of some inanimate physical principles, which are formulated using mathematical equations. It is in this sense that I use the term materialism and materialistic throughout this book. The reader can substitute some other term if mine does not suit him.

**Chapter 4**

# The Generalized Copernican Cosmological Principle

## 4.01. Simple generalization

The generalization of the Genuine Copernican Cosmological Principle was an obvious step to take. It required only two small changes in its formulation to turn into another, more general principle. Copernicus was of the opinion that the Universe observed from every planet looks roughly the same. It is enough to replace the word *planet* with *point* and to add *in every direction* to get the Generalized Copernican Cosmological Principle, which is also called the *Ordinary, Narrow, or Weak* Cosmological Principle: *The Universe observed from every point and in every direction looks roughly the same*.
Another, more exact, formulation is: *the Universe is roughly homogeneous and isotropic*. Still another, not quite equivalent formulation is: *the Universe possesses spatial homogeneity*. Due to that last formulation, the Copernican Cosmological Principle is sometimes called *Spatial Homogeneity Principle*.

## 4.02. Other forms of the Generalized Copernican Principle. Principles of Neyman-Scoff, Mandelbrot and Einstein

There are many other formulations of the Copernican Principle. For example, Jerzy Neyman and Elisabeth Scott (1959) give the following probabilistic definition: "*the... Universe is a single realization of a stochastic process which is stationary with respect to displacement in space but, probably, not stationary in time*" but they restrict its validity to the "*observable Universe*" and thus arouse some doubts whether it can actually be regarded as a *cosmological* principle. Furthermore, this formulation can be accepted only when one shares Neyman's probabilistic world view; then this formulation becomes essentially identical to the versions given above, and even explains in what sense the Universe is only *roughly* homogeneous - namely in the probabilistic sense. So it is the matter of additional assumptions and personal predi1ections whether to consider it as another version of the Generalized Copernican Principle, or maybe as a separate *Probabilistic Cosmological Principle* or *Cosmological Principle of Neyman-Scott*. Yet another probabilistic version of the Copernican Principle (*the matter distribution in the Universe satisfies the same statistical laws, irrespective of the reference system from which the Universe is observed*) was proposed by Mandelbrot (1977). But this form of the principle is not consistent with most of its other formulations, as it was shown by Zabierowski (1988a). It can be, however, considered as a separate *Fractal Cosmological Principle*.

When Einstein used the Copernican Principle for the first time, he postulated that *no average property of the cosmic medium defines a preferred place or preferred direction in space*. He assumed, in fact, that all the observers connected with the typical partic1es of the Universe (*fundamental particles* in the sense of 4.14; see below) are equivalent to each other. This formulation of the principle was sometimes called the *Cosmological Principle of Einstein*. Milne (1935b) was of the opinion that this principle is more general than the theory of General Relativity, which is just one of a number of its possible realizations. However, in fact, it proved not to be so. The theory of General Relativity can be applied to cosmology without acceptance of this principle (cf. 4.07). The form of the Copernican Principle used by Einstein can also be helpful today for understanding some properties of the Universe. But the name the *Cosmological Principle of Einstein* is rather seldom used.

### 4.03. Genuine and Generalized Copernican Principles

In early considerations of cosmological principles the genuine and the generalized Copernican principles were usually considered as the same principle. The difference was seen only in the fact that Copernicus, Tycho Brahe, Kepler and their contemporaries constructed their universe models using planets, whereas today we construct them using extragalactic objects. It was Edmund Skariynski (1970a, 1970b) who showed that the difference between those two formulations is a much deeper one. I am not going to relate Skarzynski's papers here. It is enough to say that models of the Universe having definite, favored centers are allowed in the genuine formulation (the genuine model of Copernicus has also its center - the Sun) but not allowed in the generalized one. Thus, the two cosmological principles have to be investigated separately, even though they have a number of common attributes.

The Generalized Principle is a special case of the Genuine Copernican Principle, and not the other way around. If a model is homogeneous and isotropic, if it looks roughly the same from every point, then, of course, it looks roughly the same when seen from each planet. But it can happen that it looks the same from every planet but not from every point in general. For example, the Tychonian model fulfills the conditions of Genuine Copernican Principle but not those of Generalized Copernican Principle, since it has a distinguished, central point. The kind of generalization applied in the Generalized Copernican Principle yields not a wider but a narrower c1ass of models.

The question is whether the generalization of the Genuine Copernican Principle could be made in just a one way. Is it not possible that a different generalization could have been made, perhaps even still can be made today? If we consider this principle as a geometrical rule, from which the spatial, mechanical models can be constructed, then the generalization involved in the Generalized Copernican Principle is the most straightforward one. But when we consider that in the statements of Copernicus the idea that *planets are bodies similar to our Earth* is also inherent, then a generalization tending toward accepting physical life on other planets and, in consequence, in the entire Universe, would also be possible. Some philosophical considerations of that kind after Copernicus are actually known. However, they were of no significance for cosmology. Only recently, the Anthropic Principle refers to this latter meaning of the Copernican

Principle (See Chapter 6). Still another direction of generalization is possibly realized in the Uniformity Principle (cf. 7.5).
When in the literature, the name *Copernican Cosmological Principle* or just *Copernican Principle* is used, without the term genuine or generalized, usually the Generalized Principle is understood. Also in this book, I will use this shorter designation for Generalized Principle wherever there is no danger of misunderstanding.

## 4.04. Precursors of Generalization

The Generalized Copernican Cosmological Principle was formulated in its strict form only in the 20th century, but existed much earlier as a vague idea concerning the structure of the Universe. Some scholars trace it back to the beliefs of Anaximenes of Miletus (ea. 585-525 B.C.), who maintained that there were earthlike bodies that circle "with stars." However, according to the same Anaximenes, the stars were like nails in the celestial sphere. Thus it seems that he considered those earthlike bodies to move together "with stars" around the Earth rather than to move "around stars." Whether elevating "earthlike bodies" (material bodies?) under the celestial sphere was a step towards Copernicanism or just a reverberation of ancient Indian views that there were many "earths" (not necessarily material ones) in the Cosmos, remains quite unknown, since we know Anaximenes only from scarce quotations by later Greek writers.
Demokritus (ca. 460-370 B.C.) is regarded sometimes as an early adherent of the opinion that the Universe is roughly homogeneous. He maintained that the Milky Way consisted of "many small" stars. However, since it is not known what his views on the nature of stars were, the question cannot be answered whether his cosmic outlook can be considered as a step towards Copernicanism.

But it is clear that when Giordano Bruno claimed that the fixed stars seen in all directions are remote Suns with their own planetary systems, he had in mind the idea that everywhere in the Universe much the same can be encountered (cf. Michel 1973). Also the famous cosmological paradoxes, photometric (the sky should shine in every point with the mean stellar surface brightness), gravitational (the force of gravity from all directions of the sky should be infinitely large), had among their premises that the Universe in all directions is roughly homogeneous.

This kind of thinking about the Universe is strictly related to the materialism developed by and after Copernicus. When the physical, material world is to be taken as a self-dependent entity, then it has to possess some stateliness formerly attributed to God; its laws should be universal and grandiose [1]. In the beginning of the 20th century this opinion began to be considered as a self-evident and often even unmotivated one. Only a few scientists considered it as just one of many possible cases.

## 4.05. Einstein's excuse

In any case, when Einstein (1917) used the homogeneity of the Universe as one of the assumptions in the mathematical construction of his first relativistic model of the

Universe, he justified it in a rather primitive way. He said that as long as we are concerned with large scale structures, we can imagine that matter is distributed over immense regions of space. The density of matter varies, but that variability is very slow, so his simplifying procedure is similar to accepting the ellipsoidal shape of the Earth instead of the very complicated (in small scale), real shape of the Earth. Another fact important for Einstein was that the velocities of stars (sic!) are very low in comparison with the velocity of light. Thus he based his cosmological investigations on the following approximating assumptions: 1: there is a frame of reference in which matter can be considered as remaining at rest. 2: the scalar of the mean density of matter can be accepted as constant. Of course, a priori this scalar may be (sic!) a function of coordinates, but if we accept that the Universe is finite, then one can incline to the hypothesis that it does not depend on its location in space.

This kind of explanation shows most clearly that Einstein did not realize how serious an impact that "modest" assumption could have on the results of calculations. Besides, he had in mind rather a small, closed Universe, where an observer could see "around the world", filled with individual stars. He did not admit the possibility that celestial bodies (e.g. galaxies) can have large velocities (cosmological or peculiar); he had no idea about gross irregularities in distribution of stars throughout the Universe. Initially he regarded both as small and preserved the same assumptions even when he already knew of galaxies and their large redshifts. He made only one exception in his later works, assuming that matter remains in rest only in the local frame of reference. But he retained the assumption of constant matter density (homogeneity and isotropy) in its initial form. In fact, the assumption of homogeneity and isotropy puts strong constraints on the possibility of motion in space. Only radial movements with velocity proportional to the relative distance of two points in space are permitted. When the impact of that "simple" assumption was later discovered, it was designated a *Cosmological Principle*, for the first time in the history of cosmology. After admitting the possibility of other cosmological principles, it was called *Ordinary Cosmological Principle*, *Narrow Cosmological Principle* or *Weak Cosmological Principle*. The last name shows that, for a long time, it was not realized how strong the assumption in fact is, how much it constrains the models. Bondi (1948) was the first one to grasp the connection of this cosmological principle with the Copernican ideas and to use the name of *Copernican Cosmological Principle*. After Skarzynski's paper, the name *Generalized Copernican Cosmological Principle* won wide acceptance.

### 4.06. The Copernican Principle and Hubble's Law

The Copernican Cosmological principle is closely connected with the so-called Hubble's law. There are many false opinions and deep-rooted superstitions in this matter.

The positive correlation between the distance of a galaxy and its redshift was actually known before Hubble, i.e. before the scale of extragalactic distances was established. Stellar magnitudes of what were then called *extragalactic nebulae*, or their angular sizes, were used as indicators of relative distances. Edwin Hubble, in his very early papers on redshifts, did not discuss any deeper regularities at all. And later, in his first paper devoted to wider problems of redshifts of galaxies (Hubble 1929), the relation between distance and redshift was presented as a linear dependence; in this form it became known as Hubble's Law. Here its history begins. Only a few people actually witnessed the "prehistory" of the law's formulation.

In fact, like his predecessors, Hubble first tried to find a polynomial form fitting a regression curve of redshifts on the distance axis. Only after acquainting himself with the first relativistic models of the Universe did he drop the terms involving higher powers of distance and adopted the linear form (Gates 1962, cf. also: Rudnicki 1991). Of course, any correlation and any empirical function can be represented in a linear form as a first approximation. In this case, accepting a linear form was quite natural. For nearby galaxies, the numerical value of the coefficient by the linear term in the polynomial form considered was much larger than by the higher terms.

It may be of interest to know that not only Einstein's method of modeling the Universe influenced Hubble's investigations, but Hubble's method also affected Einstein's theory. Einstein felt at first quite unhappy with a Universe which evolved by either expansion or contraction. He introduced the famous cosmological constant to the General Relativity equations. The aim of this constant was to secure the stabilization of the static Universe. Only after getting acquainted with Hubble's correlation between redshifts and distances did he accept the expanding model of the Universe, dropping the cosmological constant. It is said that R.C. Tolman, who collaborated first with Einstein and then with Hubble, contributed much to this interaction between the famous theorist and the famous observer.

### 4.07. Hubble's Law and the expansion of the Universe

In its early years, Hubble's Law was viewed by many as an observational corroboration of the theory of General Relativity. Today, second-rate popular treatments often make this claim. Even in a very interesting book written by a known scientist in 1986, I found a statement: the Big Bang cosmological model is a prediction of Einstein s general theory of relativity, which of course is not altogether true. It became clear that the linear expansion in most relativistic models (e.g. models of Alexander Alexandrowich Friedman (1922, 1924)) results not from General Relativity but from the mathematical assumption of homogeneity and isotropy (i.e. from the Copernican Cosmological Principle). The principle can be reconciled with radial motions only, the observed velocity of this movement being proportional to the distance from the observed body.

The factor of proportionality may be positive (general expansion), negative (contraction) or zero value (a static Universe, with no systematic motions). In fact, these three possibilities can be all considered as expansion when considering contraction as negative expansion and the static state as the intermediate (zero) case. Every model of the Universe based on this assumption, independently of accepted physical theories, obeys Hubble's law of proportionality. That it is necessarily so was proved by Bondi

(1961). On the other hand, relativistic models constructed without assumption of this cosmological principle do not necessarily fulfill Hubble's Law, as for example Kurt Goedel's model (1949). This shows that Hubble's Law is not related to General Relativity or to any other physical theory but to a cosmological principle, a mathematical assumption based on philosophical conviction.

The implication here goes in one direction only. The Generalized Copernican Principle results in Hubble's Law, but Hubble's Law can also be valid when this principle is not fulfilled.

The actual strength of the Copernican Cosmological Principle was not recognized for a long time. This fact is also 'reflected in one of its alternate names: *Weak Cosmological Principle*. Contrary to that unassuming name, it requires a very specific property of its models; it allows only relative systematic radial motions with velocity proportional to distance, as seen by any (actual or imagined) observer located in any part of the Universe. The proportionality constant, called Hubble's Constant, may take, in theory, any possible finite value, i.e. it may also be zero. This value, which in general is a function of time, depended on the initial conditions and the course of evolution (by fixed initial conditions - on the age) of the modeled Universe. If Hubble's Law is accepted, the numeral value of the constant can be established from observation.

It must be said to Hubble and his collaborators' credit that even as they formally adjusted the redshift-distance relation to a relativistic, expanding model, they were aware that the observational data did not necessarily have to be regarded as confirmation of the expansion of the Universe. They merely regarded expansion as the simplest of many possible hypotheses.

In one of the first papers devoted to this problem, Milton L. Humason (1931) writes:

> *It is not at all certain that the large red-shifts observed in the spectra are to be interpreted as a Doppler effect, but for convenience they are expressed in terms of velocity and referred to as apparent velocities.*

Edwin Hubble and Richard C. Tolman (1935) wrote the following about the redshift-distance relation:

*The most obvious explanation of this finding is to regard it as directly correlated with a recessional motion of the nebulae, and this assumption has been commonly adopted in the extensive treatments of nebular motion that have been made with the help of the relativistic theory of gravitation and also in the more purely kinematic treatment proposed by Milne. Nevertheless, the possibility that the redshift may be due to some other cause, connected with the long time or distance involved in the passage of light from nebula to observer, should not be prematurely neglected, and several investigators have indeed suggested such other cases, although without as yet giving an entirely satisfactory detailed account of their mechanism. Until further evidence is available, both the present writers wish to express an open mind with respect to the ultimately most satisfactory explanation of the nebular red-shift and, in presentation of purely observational findings, to continue to use the phrase »apparent« velocity of recession. They both incline to the opinion however, that if the red-shift is not due to recessional motion,* *its explanation will probably involve some quite new physical principles.*

In the above statement, not only the nature of redshifts is considered to be uncertain, but, even assuming the Doppler interpretation to be correct, the authors do not see any need to connect it with General Relativity. They refer to a very general kinematic theory put forward by E.A. Milne (1935a). Moreover, in the same paper they propose tests of the nature of galactic redshifts that might be performed by future investigators. These tests are today considered too primitive, but no better tests have been proposed till now.

The last sentence of the paper contains the following statement:

*It...seemed desirable to express an open-minded position as to the true cause of the nebular redshift....*

It is appropriate to add here that Milne's theory and its formulae were developed from purely kinematic considerations, without recourse to the assumption of the existence of "laws of nature" or appealing to any specific theory of gravitation (Milne 1935a). Milne was one of the first scientists (Milne 1932) who was courageous enough to raise doubts as to the validity of relativistic cosmology; he set forth his reasons in detail a few years later (Milne 1935b).

Both Hubble himself and Humason, who was still active in the 1960's, up to their deaths hesitated to accept the "simplest interpretation" of the Hubble Law. Hubble was even urged by some physicists to accept such an interpretation, but he never gave in (Arp 1991). There is no need to quote all the scientists who entertained doubts about this interpretation of the correlation of redshift and distance. I want, however, to mention Fritz Zwicky, who several decades later, up to his death, continued to use the symbol Vs (i.e. symbolic velocity expressed in $km.s^{-1}$) instead of Vr (radial velocity expressed in the same units).

These examples show that from the time the Hubble Law was enunciated its interpretation as a confirmation of Friedman-type models of the Universe was readily accepted by people less familiar with astronomy but certainly not by some of the more reputable scientists.

## 4.08. Hubble's Law, Doppler Effect, relativistic models

There are two different aspects of Hubble's Law that have to be distinguished: the observational, linear correlation between redshift and distance, and the law of linear expansion or contraction of the Universe. In fact, they are two different statements called by the same name. To avoid misunderstanding, I propose to call them the spectral Hubble Law and the kinematic Hubble Law, respectively.

Before the spectral Hubble Law can be accepted as an observational confirmation of any relativistic model of the Universe, or more generally, as the overall expansion implied by the Copernican Cosmological Principle (homogeneity and isotropy), the following independent evidence is required:

l. Proof that the redshift-distance relation is (in a fixed moment of time!) linear not only in the first approximation but also in its intrinsic sense. This does not mean that the observed redshifts are strictly linear with distance. The light from various objects takes different times to reach the observer, who contemplates those objects as they were in various epochs of the evolution of the Universe. This departure of observed dependence of redshifts on distance due to the variability of the Hubble constant with time (it is supposed to be constant only in spatial coordinates) has to be allowed. Of course, some dispersion due, for example, to the peculiar motions of galaxies, to certain accidental error dispersion, or to some systematic deviations, also has to be taken into account. This poses no serious problems for practical calculations. The redshift of extragalactic objects can be measured to great accuracy today, in sharp contrast to the imprecision of contemporary methods in establishing distances. Distances to only a few nearby galaxies were established with good reliability, i.e. using several different, independent methods applied to the same objects. These few objects are not enough to deduce a strict functional dependence between redshifts and distance. Some observations originated by Halton Arp (1987) seem to show that objects obviously located at the same distance may have quite different redshifts. Also, the so-called Rubin-Ford effect alone (cf. Rubin 1986) causes some doubts about the fundamental linear character of this law. This effect consists in small but real dependence of the Hubble constant on direction and distance. Some not fully explored phenomena like the so-called Great Attractor make the situation even more complicated. Undoubtedly, there is a correlation between distance and redshift. But how strict this correlation is and how precise it can be approximated with a linear function is still a matter of further investigations. It may also be mentioned here that, according to a space-time theory originated by A.A. Robb (1936) and developed by Le. Segal (1972), the redshifts should be proportional to the square of distance and only in small distance intervals can be approximated by linear functions. It is known to every student of mathematics that every three points can be connected with a straight line, provided the line is thick enough.

2. Proof that the observed redshifts are to be accounted for predominantly by the Doppler Effect, the other causes remaining insignificant for large distances. Such a proof is very difficult because nobody can be sure that we already know all the possible causes underlying the shifting of spectral lines. Especially in last decades the discovered phenomenon of periodicity (or quantization) of redshifts (I do not refer to any specific paper because the problem belongs to the forefront of astronomy, and by the time this book becomes available to readers, any paper of today will be out of date) shows that the Doppler effect cannot explain at least some features of extragalactic redshifts.

3. Furthermore, a separate proof is needed that the Universe conforms to an expanding model based on the assumptions of homogeneity and isotropy, for example to a model of the Friedman type. Such proof is possible, if at all, only in an observational way - only for the observable part of the Universe.

Accomplishing the first of these proofs would be of great importance in and of itself; it would qualify redshift as a simple, secure indicator of extragalactic distances and not just in a statistical sense. This would have an enormous practical significance. A large

part of the modem debate about Hubble's Law is devoted to this practical problem. But the proof would also be very important for the physical understanding of the Universe. If it turns out that the effect is strictly proportional to the distance independent of the nature of the objects, we can conclude that the phenomenon is due to the structure of space-time alone. Or, if we do not like to accept the notion of space-time, we can conclude it is due either to space or to time by itself. If, for example, we decide to attribute the redshift effect to some particular kind of intergalactic matter, we should conclude that this matter is distributed completely homogeneously over the entire Universe accessible to our observations. (It is worth noting that this implication is not valid in reverse. The redshift may be caused by space or time alone, even if it is not strictly proportional to distance, provided space-time is not homogeneous.) The problem whether some component of redshift may depend on the nature of the object observed is now under vivid discussion (Arp 1987), so let us wait until the discussion ends.
It may be very difficult to carry out a positive Proof No. 2, provided Proof No.1 turns out negative, but such a possibility cannot be rejected a priori. It is possible that redshifts are Dopplerian in origin but related to the nature and/or history of bodies, not space or time. For example, there could be some (unknown) effects which make bodies moving toward us invisible. Then even out of completely accidental movements, without any privileged directions, only shifts toward the red end of the spectrum could be observed. Another possibility would be a real but irregular expansion of the Universe. It may be mentioned here that Milne (1935a) showed that a phenomenon of general expansion observed in terms of radial velocities is not equivalent to a purely physical expansion of a system of celestial bodies. Out of formulae derived by him it became clear that most kinds of systematic motions of a system of points, observed from one of these points, also cause observed systematic radial motions. Milne's formulae linking observed radial velocities with spatial motions of celestial bodies are quite complicated even with the assumption that there are no peculiar motions within the system. The observed general expansion (or contraction) can be due to quite complicated spatial motion conditions. In this case, however, one should bear in mind that no actual Universe showing systematic velocities with distance but revealing no linear proportionality could ever be reconciled with the Copernican Cosmological Principle.

Sometimes in the definition of redshifts the Doppler Effect is involved. So, for example, Hawking (1988) provides the following popular scientific definition: *Redshift - the reddening of light from a star that is moving away from us, due to the Doppler effect*. If this definition is accepted, then the proof must be given whether the shifts of galaxy and quasar spectra towards the red end is the "redshift" in sense of the above definition.

Proof No. 3 can be positive without No.1 and No.2 in only one case, namely, when we suppose a static relativistic model of the Universe. Under these circumstances, a Universe model may be constructed according to General Relativity even if the redshifts are neither Dopplerian in origin nor strictly proportional to distance. Of course, other physical theories must be involved in explaining the nature of redshifts in this case.

Summing up, the spectral Hubble Law, with its simplest Dopplerian explanation as a confirmation of a Friedman-type relativistic model or any other model based on the Copernican Cosmological Principle, is not a monolithic statement. Its three main components - the phenomenological part, the Doppler explanation, and its application as an argument confirming the homogeneity and isotropy of the Universe - are logicalIy independent, and may be verified or falsified, accepted or rejected, independently of one another.

### 4.09. Can the Copernican Principle be proved observationally?

The Copernican Cosmological Principle can be proved at most in the observable parts of the Universe. Even if such a proof could be provided positively in the future, we cannot exclude the possibility that only our part of the Universe has this particular property of homogeneity and isotropy, whereas the Universe at large does not reveal this property. On the other hand, even if it turned out that our parts of the Universe are altogether neither homogeneous nor isotropic, the possibility is not excluded that this feature is local, typical only for this particular region of space accessible to our observation. The Universe considered as a whole (infinitely large or only much larger) may still be roughly homogeneous and isotropic - in principle.

If there was a good reason to accept the Copernican Principle for the entire Universe, any observational fact concerning the observable part of it could not be accepted as an argument against the Copernican Principle. Again, if there was a good reason to reject the principle, no observational arguments could force us to keep it. This, along with the fact that the nature of the redshift of extragalactic objects remains unknown, makes it a not insignificant minority of astronomers unconvinced that the Universe actually expands. Before they accept the expansion of the Universe, they want first to scrutinize all the other possibilities (e.g. Vigier, Festschrift, Keys el al. 1991). I will not repeat this again when, in later chapters, the possibility of a negative Hubble Constant etc. is mentioned. It does not mean that such a group believes that the Universe does not expand. Most of them are just waiting for more c1ear evidence for or against.

### 4.10. Radial versus circular motions

Whatever we think about radial movements as the only systematic movements allowed in the Universe, it may be of interest to notice that this view is the opposite of the conviction of the ancient Greeks that only circular motions are allowed in the Universe.

### 4.11. Actual but unobservable regions of the Universe

The Generalized Copernican Principle in its most common form - the kinematic Hubble Law and the expansion of the Universe - has produced the notion of a cosmological horizon: a surface surrounding every observer and situated at such a distance from him that the velocity of recession is equal to the velocity of the fastest physical signal, to the upper limit of physical velocities. (The velocity of light is considered today to be just that limiting value). No physical signal can reach the observer from the regions of the Universe located beyond the cosmological horizon. In the ancient models of the Universe, only the non-physical, purely spiritual regions were not accessible to sensual observations. Now, for the first time, some parts of the physical Universe have become unobservable. But the same Copernican Principle underlying the Hubble Law also gives one the means of forming a judgment about those unobservable regions, of overcoming the cosmological horizon mentally. According to this principle, beyond the cosmological horizon there is, in every direction, much the same as what we observe here in the neighborhood of our native Earth.

### 4.12. Models based on the Generalized Copernican Principle

There are many models consistent with the Copernican Principle. Most of them are relativistic ones. But there are also models of the Robertson-Walker type (H.P. Robertson 1935, A.G. Walker 1936) where the Cosmological Principle alone, without invoking any physical theory, is sufficient for producing a model. The prevailing number of models based on the Copernican Principle begins in time from a kind of primordial explosion called the *Big Bang*. Some of them end in time with a general squeeze called the *Big Crunch*. In this case, the Universe exists only during a finite interval of time.
Some Universe models are infinite in space, some are finite (finite but not limited space, due to its curvature). The infinity in space always corresponds to that of time. Reviews of such models were given in many books, beginning from the third decade of this century (e.g. Rindler 1924, 1967).

On the other hand, all contemporary models (even non-relativistic ones) of the Universe which have a beginning, or a beginning and an end, are based on the Copernican Principle. It is remarkable that there is no known model which has no beginning but possesses an end in time. The Copernican Principle allows such models. Thus it is rather a matter of philosophical convictions that models of this kind are not constructed. Are these models too pessimistic, or is it simply that those cosmologists who do not accept redshifts as an argument for expansion of the (entire) Universe do not accept the Copernican Principle either?

### 4.13. The Copernican Cosmological Principle for space

Einstein was sure that his General Relativity theory fulfilled a principle called, by Einstein himself, Mach's Principle. This principle, based on the philosophical considerations of Ernst Mach (1838-1916), claims that local physical conditions are unambiguously determined by the entire Universe. For cosmology this meant that local physical properties, revealed in the curvature of space, are univocally determined by the distribution of matter in the entire Universe and vice versa. Derek J. Raine and Michael Heller (1981) proved that this is not true. For example, the relativistic model of the Universe constructed by Wilhelm de Sitter (1917a,b,c,d) yields zero density of matter (i.e.

empty) and has the same curvature of space as Einstein's model which consists of a finite amount of matter. Similarly, in those models by Friedmann which expand to infinity, the mean density of matter drops, with time, to zero, but the expansion rate remains positive; it means that the expansion of space is (with time tending to infinity) independent of matter.

All this showed that when discussing relativistic models of the Universe or any models based on theories involving curvature (or any other structure) of space, the distribution of matter and the features of space have to be treated separately. It follows logically from this that there can be a Universe model fulfilling a cosmological principle in respect to distribution of matter but not in respect to structure (e.g. curvature) of space, or vice versa. In principle, this can be stated about every cosmological principle in connection with every physical theory including a developed theory of space. In practice, this revealed itself as a problem only in discussing the Copernican Principle in connection with General Relativity.

Since properties of space and those of distribution of matter are, as we saw, more of less independent, Heller maintains that two kind of cosmological principles have to be taken into consideration, one cosmological principle for space and another for matter. It is relatively easy to formulate a cosmological principle for space, because a mathematical formulation is sufficient here. For the Generalized Copernican Cosmological Principle, it is enough to require that space have a constant and isotropic curvature (constant in spatial coordinates, not necessarily in time).

### 4.14. The Copernican Cosmological Principle for matter

More complicated is the issue of a cosmological principle for matter. The Ancient Indian Principle had produced no definite model, at least up to the present. For the construction of cosmological models based on the other two historical cosmological principles (Ancient Greek and Genuine Copernican), individual celestial bodies and their trajectories were used. This was possible because these principles proclaimed only some privileged positions (the Earth by Ancient Greek) or equipollence (planets by Copernicus) of certain celestial bodies.

It is not so with the Generalized Copernican Principle. It states some property (self similarity in every point and in every direction) of the Universe as such, not of any particular kind of objects. Any celestial objects can be considered here. Whichever "constructing material" one chooses can be useful, provided it fulfills the accepted cosmological principle. Einstein, who was a physicist rather than an astronomer, applied stars. It was already known in Einstein's time that the spatial distribution of stars is not homogeneous. Since Hubble, it has been clear that stars which are aggregated into stellar systems (*islands*, as Immanuel Kant (1724-1804) called them, galaxies, as we call them now) are of no use for the purpose. The spatial distribution of stars cannot be considered as obeying, even in a very gross approximation, the law of homogeneity. In the course of time galaxies also turned out not to be good enough because Fritz Zwicky (1938) showed that all the galaxies participated in clustering. Clusters of galaxies also revealed themselves as not good "bricks" for constructing a homogeneous Universe. But there is a quite common belief among cosmologists that some celestial bodies (or agglomerations of celestial bodies) must exist whose spatial distribution obeys the Copernican Principle. Whatever their nature, they can be called *fundamental bodies*.

With the development of extragalactic astronomy, irregularities of ever higher order were discovered. Of course, statements of homogeneity in the observable part cannot be taken as an argument for universal homogeneity over the entire Universe, but even proving this for the regions accessible to physical perception would be of great importance. Suggestions of such proofs are sometimes given (Stoeger, Ellis and Helaby 1987), but have not been conclusively accomplished to date. Most contemporary observations contradict homogeneity over any scale of dimensions. Some adherents of easy cosmology say that this is of no importance because the contrast between density of matter in large galaxy clustering structures and in intervening voids is very low. This could be valid by assuming that the density in voids is still considerable. If we assume that it is close to zero, then it produces an enormous contrast in proportion to any finite density. It has to be noted that all the considerations about spatial distribution of extragalactic objects rely on the validity of the spectral Hubble Law, which is still disputable.

In most cases when an assumption turns out not to correspond to reality, as here, there are two ways out. The first is to reject the perplexing assumption. The second is to assume that the assumption is fulfilled in some other realm, e.g. in a different dimension range. Since this chapter is devoted to the Generalized Copernican Principle, I wil1 consider only the second case, which does not require rejecting it.

Instead of real celestial bodies and their agglomerations, some abstract *substratum* can be used which *ex definitione* satisfies the needed criterion. One can consider the substratum to consist of such large agglomerations of matter that, in the corresponding scale, fulfill the conditions of homogeneity and isotropy. Or, one can say that the substratum is an abstract notion of homogeneously distributed matter. This matter has its density equal to the mean density of the matter actually existing within the Universe. One can also say, in a picturesque way, that the notion of substratum is that of the real matter of the Universe ground finely and then dispersed in a strictly homogeneous way throughout the Universe.

This notion is a highly abstract one, and to make a bridge between it and the actual celestial bodies requires some mental endeavor. Michael Heller (Heller 1975, Heller et al. 1974) proposes for this purpose a procedure which can be described in a slightly simplified form as follows.

I. description of theoretical concepts.

Definition 1: A substratum is a set of material points obeying the Cosmological Principle.

Definition 2: Material points which are the elements of the substratum are called fundamental particles.

II. description of empirical reality.

Definition 3: A fundamental body is the matter included in a fundamental region.

Definition 4: A fundamental region is the part of the momentary (t = constant) space resulting from the following procedure:

A) We divide the (three-dimensional) space in as many ways as possible into relatively compact parts, i.e., parts bounded gravitationally so that the ratio of inner to outer gravity forces is rather high). Furthermore, these parts ought to have equal volumes, limited diameters, and limited differences of contained mass.

B) We choose from all possible partitions described under A the one which shows the smallest differences of contained masses and highest ratio of inner to outer gravity forces.

III. Postulate connecting the theoretical and empirical part: The fundamental particles defined in 2 can be identified with the centers of fundamental bodies defined in 3.

Heller said about the last postulate that at the present level of our cosmological knowledge (it) remains wishful thinking.

All this looks to be complicated indeed, and nobody has performed this procedure to date. But any other attempts at identifying the theoretical substratum with any individual fundamental bodies have also failed. Up to now, no scale is known in which the distribution of matter could be regarded as homogeneous and isotropic; but the Copernican Cosmological Principle is still preferred among other cosmological principles, and most contemporary cosmological considerations rely on it. One can yet hope that a scale will be discovered in which the principle will appear to correspond strictly to reality.

### 4.15. Hierarchical Universe

We can examine a case where no scale homogeneity is obtained but the aggregates of matter (clusters of higher order) still form an infinite sequence. Such a model of the Universe was proposed first by Johann H. Lambert (1728-1777) and was made more popular in the beginning of our century by C.V.L. Charlier (1908a, 1908b). There are two possibilities for a hierarchical Universe: the first, that the mean density tends to zero as scale increases, and the second, that the mean density tends to a constant non zero value but the distribution of matter tends to total homogeneity as the scale increases (the density contrast between consecutive agglomerations tends to zero; cf. Maciejewski 1991).

The hierarchical models of the Universe are infinite in their spatial extensions. In the latter case (the mean density contrast tending to zero) they fulfill the Copernican Principle not in a finite scale but only as the limit in infinity. If our Universe is similar to those models, then the Copernican Principle can be legitimately accepted, but the observable part of the Universe, as well as any finite region of the Universe, must be considered as filled with matter in a non-homogeneous way. Of course, in the case of a hierarchical Universe, the procedure proposed by Heller cannot work.

### 4.16. Frame of absolute rest. Neoether

The Generalized Copernican Cosmological Principle was introduced into cosmology during the elaboration of relativistic models of the Universe. As stated above, it is not related to General Relativity in any logical way, but its history is, nonetheless, strictly connected with that of General Relativity. Even more astonishingly, any model based on the Copernican Principle and thus accepting the kinematic Hubble Law is, in a certain sense, antirelativistic or, to put it in a less extreme way, involves the conception of an absolute frame of reference. Such concepts are quite opposite to the concept of relativity of all motions.

There exists in astronomy the phenomenon of *astronomical aberration* (see any book on general astronomy). Its essence consists in superposing the velocity of the observer and the velocity of light. The strict theory of aberration is very complicated because every mixture of the velocity of light with another velocity needs a very exact treatment; simple vector addition is not adequate here. Thus, even in some scientific books the similitude of falling rain is given instead of exact formulae [2]. The phenomenon causes the line of sight of every observer to any celestial body to change its direction, inclining itself towards the direction of the observer's velocity. In effect, due to the aberration, more objects are seen on the hemisphere towards which the observer moves.

This phenomenon is observationally proved in connection with the annual movement of the Earth, with the orbital movement of the Sun within our Galaxy, and probably (the interpretation is not certain!) with the velocity of our Galaxy or systems of galaxies. It reveals itself in the positions of celestial bodies. However, the most distinct effect can be noticed by observing the 3-Kelvin background radiation. Out of observations of aberrational effects, an absolute frame of reference, an absolute rest system can be derived; it is the only one in which the Universe is isotropic and homogeneous, manifesting the same mean density of objects in all directions and in all its points. The theory of General Relativity claims that there are no absolute, no preferred frames of reference, but when combined with the Copernican Principle, it does provide such an absolute frame of reference locally. Heller (Heller et al. 1974) calls it *Neoether*. The existence of some absolute frame of reference does not logically contradict the theory of General Relativity. It can be said that the relativistic theory provides the possibility of describing motion and gravity phenomena in any coordinate systems, and thus deals with relative motions only and that the Copernican Principle selects out of many possibilities the coordinates connected with the neoether as a preferred frame of reference. The Copernican Principle destroys the idea of equipollence of all frames of reference. Thus it is in opposition not only to General Relativity, not only to Einstein's Special Relativity, but even to the basic relativity principle of Galileo. Galileo promoted the idea that a motion with constant velocity is strictly equivalent to being at rest. The frame of reference connected with the neoether distinguishes not only between motions with a constant and non-constant velocity but also distinguishes absolute rest from all other constant velocities. In this way, the Copernican Principle brings us to the old view of Aristotle that the natural state for a body is (absolute) rest. The Copernican cosmology does not state that it is the *natural* state, but only that it is a favored one.

## 4.17. Absolute time

Apart from the absolute rest frame, all the Copernican Principle models, except for the models with a Hubble Constant equal to zero, also produce an absolute time called *cosmic time*. Due to the kinematic Hubble Law (the Hubble constant not equal to zero), the density of matter in the Universe changes constantly. Thus, the momentary density of the Universe univocally determines time, a time which is the same for all points in the Universe. The same fact may be formulated in a more strict way as follows. In the four-dimensional space-time of these models, a family of three-dimensional surfaces can be distinguished in a unique way; the averaged density of matter is constant. The vector perpendicular to these three-dimensional surfaces shows in every spatial-temporal point the direction of absolute time.

If the substratum is to possess the basic properties of homogeneity and isotropy, it has to be considered in the coordinate system connected with the neoether. In other words, the substratum complying with the Copernican Cosmological Principle implies the neoether frame of reference, which is a preferred one.

According to General Relativity, each observer has his own time which depends on the local value of his gravity field as well as his velocity in respect to other bodies. This time can be used in all scientific considerations with the same validity as the individual time of any other observer. But such an observer can see the Universe in a very complicated way, in various stages of overall evolution, with various densities of matter, in various directions and space points. However, he can transform his picture of the Universe to a reference frame in which the Universe agrees with the Copernican Cosmological Principle, and then he sees the Universe as possessing (roughly) equal overall density. Thus, he now considers everything in the neoether frame of reference, and his time becomes cosmic time. Such an observer, connected with a substratum and thus with the absolute frame of reference, is called a *basic observer*.

## 4.18. Copernicanism versus General Relatively

From these considerations, it is clear that General Relativity is not responsible for producing Hubble's Law (and thus the Big bang hypothesis); on the contrary, it is rather difficult to reconcile the basic "world view" of General Relativity with the conclusions of Hubble's Law which result from the Generalized Copernican Cosmological Principle alone. In fact, General Relativity and the Copernican Principle tend to quite opposite directions, relativity towards making all more and more diversified, more "individual", and "Copernican" towards making everything as homogeneous as possible.

This peculiar misalliance of the highly intellectual, sophisticated and "democratically oriented" (every coordinate system has equal rights) General Relativity with the "common, rough", so to say "Communistic" (there is only one pertinent system), Copernican Principle conceived in 1917 by the very father of the former, Albert Einstein, created a tightly married couple remaining together in the common cosmological life for more than 75 years in spite of difficulties and inner controversies which it causes in trying to understand the Universe. Was this actually another great invention of Einstein, greater than either he, his contemporaries, or even we, now realize? Or was it just another great mistake he made, leading cosmology altogether astray? The problem of combining these two ideas was never fully analyzed from a methodological, philosophic, or even historical point of view. Of course, the question - what if Einstein did apply some other cosmological principle in his first relativistic model of the Universe is not a scientific one either from a cosmological or from any other standpoint. However, it will be of interest to see, when the future development of mathematics permits, what kind of Universe models could be obtained by combining General Relativity with, for example, the Ancient Indian Cosmological principle.

### 4.19. Zero case of the Hubble Constant

Most of the above conclusions were based on the assumption that the Hubble Constant does not equal zero. The zero case can be analyzed as a particular case in the frame of the Generalized Copernican Principle. But it may also be considered as a special case of the Perfect Cosmological Principle, and so it will be discussed in the next chapter.

### 4.20. The Copernican Principle and Kaluza-Klein type models

Relativistic models of the Universe are constructed not only in 3+1 space-time but also in spaces with a higher number of spatial dimensions. This involves theories of the Kaluza-Klein type where the non-gravitational interactions are combined with additional space dimensions. Most known models of this type operate with a 10+1 dimensional space-time (ten space dimensions and time). Those models usually accept the Copernican Cosmological Principle as the initial condition (for the first stage after the Big Bang) for all the space dimensions. In the course of the evolution of the Universe, only three dimensions (the "normal" space dimensions that we perceive with our senses) keep fulfilling the Copernican Principle while other dimensions contract (the so called spontaneous reduction of dimensions). But among these others dimensions, some symmetries are preserved as well.

It remains problematic whether the cosmological principle assumed here for many dimensions in the beginning of evolution is the same Generalized Copernican Cosmological Principle formulated for 3 space dimensions or whether it is a modification. Another problem is how to comprehend symmetries remaining in the further course of evolution. Such symmetries are connected with general simplifying assumptions involved in the model. These assumptions are, in fact, strictly equivalent to the cosmological principles of the "ordinary" 3-dimensional models.

At present, no terminology for such multidimensional cosmological principles is created yet. Sometimes one wonders if the authors of Kaluza-Klein type models are aware that their work involves cosmological principles of a new kind, or, at least, new versions of the old ones.

### 4.21. 3-Kelvin background radiation

The presence of the 3-Kelvin background radiation is sometimes considered an important argument for the reality of the Big Bang. Specifically, after improving observational methods to such sensitivity that local differences of temperature became measurable, many cosmologists claimed that this is a direct confirmation of the hypothesis. I do not want to enter into discussion about this problem here. But it should be noticed that no matter to what extent the temperature and the differences in intensity and spectral characteristics in various directions are or are not in agreement with this or that Big Bang model, some other hypotheses can explain all those properties (e.g. Davies 1972, Skarzyóski 1975, Rana 1979, 980a, 1980b).

When we want to stay within our main area of interest, namely within the issue of cosmological principles, not of particular cosmological models, the most important conclusions concerning the existence and characteristics of background radiation are the following. It is impossible to test any cosmological principle in a general way without any additional assumptions. And we can add the supplementary assumption that the observable part of the Universe is so large that any given cosmological principle can be applicable for what can be observed. So, when the Generalized Copernican principle is under consideration, we can expect to observe something that is homogeneous. Cosmologists, from the very birth of cosmology, have looked for celestial bodies or phenomena which are distributed in this way. Einstein supposed that such homogeneity is found in the distribution of stars. Hubble presumed that this condition is fulfilled by galaxies. In the middle of 20th century, the hope was to find homogeneity in the distribution of clusters of galaxies. All those hopes proved to be futile.

Only background radiation revealed a high degree of isotropy, and if we assume that this isotropy is preserved in all other points of the observed part of the Universe, then we can conclude that the sources which emitted (or, in some hypotheses, still emit) this radiation were (are) distributed homogeneously. Thus, to date, background radiation can and does serve as the best observational support for the Generalized Copernican Principle.

### 4.22. The Softened Copernican Principle

The Copernican Principle consists of two independent assumptions: homogeneity and isotropy. Andrzej Zieba (1975) discussed a remarkable kind of relativistic model where only the former condition is satisfied. His models, called the models of the *Zone-Universe*, consist of concentric spherical shells of equal thickness possessing alternately finite and zero density and filling in this way the entire (finite or infinite) space of the Universe. The *mean* density in regions sufficiently thicker than individual shells is obviously constant here. But in every region, a certain direction (perpendicular to the shell surface) is distinguished. Zieba himself claimed that his models fulfilled the Copernican Principle globally but not locally. He had in mind here that the favored directions are various in various regions and thus, *overall*, there is no preferred direction. However, the mean density is attained here by a very simple procedure, whereas, in order to obtain an average mixture of directions, the fields must be selected in a rather particular way. Thus, it seems more accurate to say that only a Softened Copernican Principle, or a softened version of the Generalized Copernican Principle, can be applied locally as well as globally, because, in fact, only the approximate homogeneity of distribution of matter is preserved here.

The Zone-Universe models have a number of remarkable features, some of them elaborated by Zbigniew Dulewicz (1971). The Softened Cosmological Principle allows that a model might be infinite in space but finite in time.

The cosmological model of Kurt Goedel (1949) also fulfills that softened version of the Copernican Principle. Here the assumption of homogeneity is fulfilled, but all over the Universe there is a preferred direction which can be interpreted as a rotation axis. Goedel's Universe has no center but is not isotropic. This model contains world lines which form loops; it means that the same point of space-time may appear several times in the history of a particle, thus violating the causal order of events.

Nobody knows how many other remarkable features the models based on that softened version of the Copernican Principle may have. This version of the principle and the cosmological consequences of its models seem to be of interest at least methodologically. But this version could be particularly worth remembering if any large-scale anisotropies are subsequently discovered in the observed region of the Universe.

Similar anisotropies can be expected if the topology of the Universe is not too simple. In thinking about the Universe, which is finite but not limited, one has usually in mind a three-dimensional closed space immersed in a four-dimensional Euclidean space. When we think of the space of the Universe, we often think of a sphere or a Moebius Band as an adequate model. In fact, a finite, unlimited three dimensional space can possess a much more complicated structure, involving not only different geometries but also different topologies. Such topologies can allow quite complicated local inhomogeneities while preserving mean (!) constant density of matter over sufficiently large regions. These possibilities, based on the so called *Clifford-Klein spatial forms*, were elaborated in the last decades by George F.R. Ellis (1971). Some cases go beyond any Copernican way of thinking, but some could be considered as further examples of models satisfying the Softened Copernican Principle. Models of the Universe based on that (as yet almost unexplored) principle could give some interesting results and shed new light on some methodological issues. It is also possible that some of the results could somehow correspond to our actual Universe.

### 4.23. Isotropy without homogeneity

Another way of reducing the Copernican Principle, that is, accepting isotropy but rejecting homogeneity (Cosmological Principle of Isotropy), leads to highly sophisticated geometrical and topological models if isotropy has to be fulfilled all over the Universe. The Schur's theorem states that if isotropy is preserved in every point of some space in which the concept of parallel lines has any sense, then this space must be a homogeneous one. To construct a Universe model where isotropy is preserved but homogeneity not, we have to turn to some highly sophisticated space constructions where the usual concept of parallel lines can no longer be applied. Thus the notion of 'direction' must be defined in an unusual way. Universe models obtained using such procedures are rather far from reality, or at least from the kind of reality that we can imagine today.

If, however, we admit that this isotropy has to be kept only in a specific, distinguished point of the Universe, then we, accepting our Earth as this point, arrive at the Ancient Greek Cosmological Principle or to its generalized form if we accept other points (other centers of the Universe, cf.2.13).

From the last discussion we can see that when we restrict ourselves to mathematically trivial topologies and geometries of space (e.g. to manifolds only), the assumption of isotropy observed from every point in the Universe produces by itself the homogeneity of the Universe. With such a restriction, one can shorten the definition of the Generalized Copernican Principle to the following formulation: *The Universe is isotropic when seen from every point*. For a practical use in constructing cosmological models this form seems to be sufficient. Nevertheless in most cosmological papers and books, homogeneity is considered an independent assumption; this is completely correct if we have in mind not just practical purposes but all the possible exotic topologies of the Cosmos. The assumption of isotropy in every point is stronger than the assumption of homogeneity. As can be seen from the Zone-Model, even on all types of manifolds the latter assumption can stand alone. It does not imply the former one. One could question whether each kind of existing symmetries (e.g. the 9 Bianchi types) should be considered to be another version of some cosmological principle or an independent cosmological principle.

[1] I leave it to the reader to think over why as long as the Universe was considered to be the body of a supreme spiritual being (ancient India), it was considered as infinitely heterogeneous, but when considered to be a supreme being in itself it is considered as infinitely homogeneous.

[2] When drops of rain fall freely towards the earth in the absence of any wind, a standing person sees, on average, the same number of rain drops in all directions. However, if she (or he) starts to run, she encounters more drops from the direction in which she moves. If she has an umbrella, she has to tilt it forward when running.

# Chapter 5
# The Perfect Cosmological Principle

## 5.01. Time horizon

The Generalized Copernican Cosmological Principle produces the kinematic Hubble Law. The simplest interpretation of redshifts of extragalactic objects is that of the Doppler effect. If we combine them both, we come to the conclusion that the Universe is in a state of expansion. Again, the simplest interpretation of that expansion is the diminishing of mean density. A decrease of density with time (toward the future) is equivalent to an increase against time (in direction toward the past). The models based on General Relativity claim that this increase will go to infinity, so going back into the past far enough we reach a stage of infinitely high density. The time when the density was infinite is called the initial singularity and, at first, was considered to be singular in a mathematical sense only. Mathematics is, after all, only an approximation of reality. Georges E. Lemaitre (1927, 1946) came early to the conclusion that the initial singularity can be interpreted as a violent origin of the Universe. The first not only to consider that singularity to be of physical significance, but also to realize how to draw physical conclusions from it, was a student of Alexander Friedman, George Gamoff, who, in the middle of 20th century, showed how important conclusions can be made about the stages of evolution close to the singularity involved in Friedman-type models. This line of research was very fruitful and was continued by followers of Gamoff (cf. Melchiorri and Ruffini 1986).

Earlier cosmological theories were concerned only with mean mass density in cosmic space. Other features of matter -like chemical composition, types and dimensions of aggregates of matter in consecutive epochs of cosmic evolution, or forces other than the gravitational one - were irrelevant for them. Only after Gamoff did cosmology come into contact with almost all areas of physics and chemistry. This line of research is still alive, and some of its results became classic long ago (cf. Weinberg 1977). In this way one could explain the mean abundance of chemical elements in the Universe. It is possible even to propose some scenarios of formation of galaxies, and - what is most striking - the origin of physical constants or even the origin of physical laws as such (cf.: e.g. Reeves 1986). There are, in fact, immense possibilities yet to be explored. Nevertheless, the fact remains that present day physics cannot grasp states of matter with densities of arbitrary high value. For very high densities beyond a certain limit (today this limit is considered to be about $10^{100}$ $g.m^{-3}$), physics is completely incapable of producing even a single physical formula since any physical interactions no longer have any meaning and relationship to space and time. As long as the explanations of physical phenomena consist of deriving physical equations, it is very unlikely that this limit of density (called Planck density) could be overcome by physical consideration. And no other style of physics can be proposed, or, at least, has been proposed yet. This situation created another limitation for our knowledge: time horizon. The limiting density $10^{100}$ $g.m^{-3}$) was achieved, according to contemporary theories, in $10^{-4}$ of a second after the singularity.

Whether or not there was the Planck density long ago or even the singularity itself, most contemporary cosmologists are convinced that the history of our Universe is, beyond some point in its earlier past, impenetrable for scientific investigation. Thus, the problem of how to approach the question of the time horizon has been considered to be one of the most fundamental.

## 5.02. Overcoming horizons with a suitable cosmological principle

The difficulties with the spatial cosmological horizon can be removed using the Generalized Copernican Principle. This principle, once adopted, automatically overcomes all the difficulties which the spatial horizon itself created. The horizon is still there, but it no longer delimits our knowledge about the Universe; it vanishes, as it were, at least when considering the most general aspects of the Universe. But what to do with the cosmological time horizon? In order to remove it two cosmologists, Herman Bondi and Thomas Gold (1948), proposed a new cosmological principle called the *Perfect Cosmological Principle* or *Strong Cosmological Principle*. It states:

*The Universe observed from every point, in every direction, and at every time looks roughly the same.*

Or using other words:

*The universe is (roughly) homogeneous in space and time and isotropic in space.*

As is easy to see, this principle removes the problems of both cosmological horizons. It retains the assumptions belonging to the Copernican Principle and adds another one: homogeneity in time. Of course the Hubble Law must still be fulfilled: it does follow from spatial homogeneity and isotropy. It could be said that the Perfect Principle is merely one particular case of the Generalized Copernican Principle, just as the Generalized one is merely one particular case of the Genuine Copernican Principle. The Perfect Principle puts more constraints on the models of the Universe.

## 5.03. Spatial infinity of the Universe

To the assumptions of Generalized Copernican Principle, the Perfect Principle adds only one more assumption, that of the invariability in time. But, just as the Hubble Law follows from the assumptions of the Copernican Principle, so, too, from this additional assumption follows infinity not only of time but, in most cases, also of space. Since the Perfect Principle is one special case of the Copernican Principle, one could deduce this spatial infinity of the Universe from the General Relativity models. Since invariability in time also means infinite time duration, an everlasting expansion or contraction with constant velocity needs unlimited space; otherwise, the Universe would, in time, be either larger or smaller. Only infinity has the property that its dimensions remain the same even when multiplied or divided by some finite factor.

In the so-called *Steady State model* based on the Perfect Principle, the infinity of space is derived from relativistic equations. But the problem is a more general one. Not only relativistic models of the Universe can be constructed. The Copernican Principle produces the Hubble Principle. Regardless of whether the Hubble Constant is positive or negative, with the new assumption, this parameter must also be constant in time (no time changes are allowed!). If the Universe expands or contracts with constant speed and is nonetheless everlasting, its spatial dimensions must be infinite, whatever physical theories we accept.

There remains, however, the zero case of the Hubble Constant. There is no mathematical necessity to accept the spatial infiniteness of the Universe. One could imagine a finite but not limited cosmic space lasting from eternity to eternity. However, the Universe consists not only of space which can be considered mathematically, but it also has to contain some matter. Sir Isaac Newton, who was an adherent of the Static Universe model, was of the opinion that a finite Universe would shrink to one great lump of matter due to gravity alone. He had in mind a finite material Universe immersed in infinite Euclidean space. The concept of the curvature of space was not yet known at the time. Besides, he was not aware that an infinite but static Universe would be inherently unstable as long as we applied classic (or relativistic) mechanics to it; that instability would lead to systematic changes. Anyway, it is easier to imagine an infinite than a finite static Universe, and all the adherents of zero Hubble Constant are of the opinion that in a finite Universe some overall variability would be unavoidable. All the matter would contract to one point or all the celestial bodies would evolve in one direction (thus there would be a global evolution of the Universe). The problem of the stabilization of an infinite static Universe remains still under discussion. In any case, if we accept as a reality a Universe model with the Hubble Constant equal to zero, we also have to consider this Universe as infinite in space. The opposite case, an invariable Universe infinite in time but finite in space, remains still as a logical but completely abstract possibility without any theoretical elaboration.

As we showed above, in the case of a finite, positive, or negative value of Hubble Constant and within the Perfect Cosmological Principle, spatial infinity of the Universe can be mathematically proved. The zero case is the limiting case from both sides. When the mathematical functions are not too exotic (and most of the macrocosmic physical functions are not) we should have the same result for both limiting cases. Is this pseudo-mathematical proof more convincing, or the fact that all adherents of zero case claim so? Whichever is the case, all considerations known to me which are based on the Perfect Principle always involve infinite space.

### 5.04. Metagalaxy

(This Principle allows for the evolution of particular celestial bodies, their systems, and their supersystems. Any global evolution of the Universe is, however, excluded. According to Jaakkola (1989), systems do evolve and have centers. But the Universe is neither a system nor a supersystem. It is totality, it is infinity and as such without a center and in all its history ever self-similar. In order to emphasize the fact that all we can observe is just an inconspicuous speck in comparison to the infinite Universe, the term *Metagalaxy* was introduced for the observable part of the Universe. Of course knowledge of the Metagalaxy belongs to astronomy. Cosmology can only make use of astronomical facts concerning the Metagalaxy. If we accept the Perfect Principle, no observational evidence can convince us of the evolution of the entire Universe. Thus, there exists no possibility to convince (by logical argumentation) the adherents of the Perfect Principle that they are not right.

The notion of the Metagalaxy proved very useful during the Stalinist period as well as during the first years of the post-Stalinist period in the Soviet Union and other countries under Soviet domination. At that time, it was considered an ideological crime to support the hypothesis of an expanding Universe. But it was permitted to speak and even lo publish papers on the expansion of the Metagalaxy. Thus, Metagalaxy became for many cosmologists from the Soviet block the cryptonym for Universe. The censors, happily enough, took no notice. In many Russian, Ukrainian, Estonian, Czech, Slovak and other papers from that epoch, the secret name 'Metagalaxy' should be replaced with the proper one by a present-day reader.

Of course the term 'Metagalaxy' is meaningful in cosmology not only as a cryptonym. It reminds us constantly of the necessity of distinguishing between astronomy and cosmology.

### 5.05. The only possibility of knowing everything

The Perfect Principle, when accepted, gives the feeling of knowing all. I can look in any direction of space; I can think about regions of the Universe located as far beyond the cosmological horizon as I wish; I can imagine epochs as faraway as I wish and know exactly how it was then. Literally everything, everywhere, and in any time is such as it is here and now. In a scientific sense, it means that I do not need to investigate any exotic stages of matter or strange geometries of space. The best thing I can do is to become acquainted in ever greater detail with those parts of the Universe which are easily accessible to my sensual perception and to the reach of my instruments.

In the times when the Perfect Principle used to be fashionable, it was said that this principle is like a lonely street lamp on an otherwise dark street. If a man walking home at night loses his house key, he has to search for it where the lamp sheds some light. If the key dropped from his pocket into the light, then he may be lucky and find it. If, however, the key was lost somewhere else, then he has no chance. Similarly if the Perfect Principle is not true, then we have no other possibility of knowing what is beyond the time horizon. Due to progress in physics, that time horizon may be shifted still further, but some initial stages of the Universe will always be altogether inaccessible to us. The horizons would be impenetrable for us. And thus, humanity would have to abandon its pretensions of knowing everything. The Universe would always remain only partially known. So we had better hope that the Perfect Principle is true...

**5.06. Creation of matter**

But when we accept the Perfect Principle, which is just a narrowed version (involving an additional assumption) of the Copernican Principle, and, as a consequence of this fact, we accept the Hubble Law, then, due to this law alone, the density of matter must change with time, which would contradict homogeneity over time. Only three possibilities remain to fulfill simultaneously the old requirements and the new demand of homogeneity in time: to compensate these changes in the density of matter with the creation of matter by a positive value of the Hubble constant, to compensate through the vanishing of matter in the case of a negative value, or to ascribe a zero value for the constant.

The first possibility is realized in the *Steady State* model, postulated in 1948 by Herman Bondi and Thomas Gold as well by Sir Fred Hoyle (1948, 1949). This model accepts the expansion of the Universe as a fact and considers the rate of that expansion (the Hubble constant) to be constant not only in space but, in accordance with the additional assumption, also in time. Thus, the creation of matter has to be assumed in order to make the mean density of the Universe invariable. Such a creation may be regarded as some fundamental law of nature. As a matter of fact, to keep the density constant, the creation of one hydrogen atom per year in a volume of about one cubic kilometer proved to be sufficient if a Hubble constant of 100 $km.s^{-1}.Mpc^{-1}$ is accepted. Such a tiny process cannot be discovered with today's measuring instruments. The creation would have had to be roughly homogeneous (i.e. the newly created elementary partic1es or atoms should be distributed homogeneously over very large areas of space), but some places can be locally distinguished. For example, matter can be created just in maximal distances from the existing galaxies and aggregate into protogalaxies. Or, it can be created just in the nuc1ei of galaxies and then be sent off as protogalaxies. This can make the possibility of observational or laboratory confirmation of the creation process even more difficult.

The Perfect Cosmological Principle originated from an extremely materialistic world-view. The attitude of its adherents can be described in a simplified way as follows: if one accepts that all knowledge must be attained through physical means only, if one accepts that the human mind is the highest intelligence throughout the Universe, and if one accepts that the truth about all the Universe should be attainable for humanity, then all the physically construed cosmological horizons have to be overcome. The Perfect Principle is considered as a method of overcoming those horizons. But when we adopt the Steady-State model, the creation of matter must be also acknowledged. Could such a creation be reconciled with the materialistic world view? Some people (cf. Rudnicki 1982) are of the opinion that the materialistic world view is self-destructive.

For the benefit of that model, it can be said that it does remove the photometric cosmological paradox x in the most straightforward way by not involving any additional assumptions.

**5.07. Static Universe**

Another possibility of materialistic thinking is the homogeneously populated everlasting Universe with no expansion (the Hubble constant equals zero). It is usually called the *static* or *quasistatic* model of the Universe. The prefix 'quasi' means that over detached, even immensely vast areas of such a Universe non-static processes are going on, but the Universe at large remains ever the same. This model had many advocates in the epoch of classic materialism, especially in the 19th century when the Perfect Principle and the Hubble Law had not yet been formulated. Also, the official Soviet cosmology in Stalin's time, supported by the Communist Party, proclaimed that model as the only one corresponding to the actual Universe. Propagation of other models was prohibited by Soviet law [1]. At present it has little appeal; notwithstanding that a modern version of it was presented by Toivo Jaakkola (1989).

There are two very difficult questions to be addressed. The first one is: how to limit the action of gravitational forces in such a way that they do not cause ever increasing condensations of matter in the Universe. And the second: how to reconcile the evolution of celestial bodies with the assumed globally constant composition of chemical elements in the Universe. Jaakkola (1989) proposes some ways of doing this using some remarkable ad hoc assumptions.

The models based on the Perfect Principle differ from those based on the Copernican Principle in the necessity of securing their (rough) invariability in time; one must, so to speak, neutralize the Hubble Law. But in the zero case, the Hubble Law turns into a stationary state by itself. This zero case for the Perfect Principle is thus identical with that of the Generalized Copernican Principle. I discuss it here because it is more closely related to the Perfect Principle in philosophy.

Sometimes the Copernican or the Perfect Principle with the Hubble constant equal to zero is considered as a separate cosmological principle and goes by the name of the *Lucretian Principle* (cf. 7.2).

### 5.08. Vanishing of matter

The case of a Universe fulfilling the Perfect Principle with a negative value of the Hubble constant is for cosmologists a matter of coffee-break talks rather than of scientific publications. The advocates of the Perfect Principle usually accept the Dopplerian interpretation of redshifts and thus the positive value of Hubble's constant. No model
with vanishing matter is known. But constructing one could be instructive, just as a methodological exercise. Some ideas as to where the excess mass vanishes (within all existing galaxies? or in only some of them?) have to be developed in order to secure the overall invariability of the Universe. Certainly it will not be merely a Steady-State model with reversed time.

### 5.09. The Perfect Principle and absolute frame of reference

In all models based on the Perfect Principle, the evolution of individual celestial bodies is possible and even inevitable, but any evolution of the Universe at large is excluded. In the models based on the Copernican Principle, the overall state of the Universe is a kind of clock measuring cosmic time. All the models based on the Perfect Principle involve no cosmic time in this sense. However, they do possess an absolute frame of reference. In order to be able to see the Universe as (roughly) the same in any direction, only one relative velocity must be chosen (different from point to point in space) and, in fact, this velocity may even be absolute rest as well. Thus, the neoether is admissible also in this class of models. Due to the aberration effect, the Universe will be seen as having various densities in various directions during any movement relative to this state of rest.

When there is a preferred absolute frame of reference, there is also a preferred time direction in space-time, and it may be designated cosmic time. In four-dimensional space-time it is a direction perpendicular to the three-dimensional surfaces connected with neoether. It differs from the case based on the Copernican Principle only in that there are no global zero points in time. The different fundamental observers have to synchronize their docks in an arbitrary way, but their times run para11el. The duration of a time unit and simultaneity can be established in the same way for all observers.

### 5.10. Possible generalizations of the Perfect Principle

The premises of the Generalized Copernican Principle were deliberately determined and discussed for the needs of a relativistic outlook on the Universe. In fact, this cosmological principle is not based on relativistic concepts. It proclaims only some properties of space, not of time, whereas relativity employs in its considerations a unified concept - space-time. Thus, any assumption which does not concern all four dimensions of space-time spoils the elegant generality and symmetry of the relativistic picture of the world.

In this sense, the Perfect Principle is much more relativistic because it puts similar conditions on space and on time. According to this principle, the Universe should be homogeneous in respect to space and time. However, some asymmetry still remained. The Perfect Cosmological Principle requires the homogeneity of both, but it limits the requirement of isotropy to space only; it does not require such from time.

At first glance, the requirement of isotropy in time seems to be impossible of realization in the actual Cosmos. Even in the stationary Universe of Jaakkola, the isotropy in time can be construed only in a metaphorical sense. To be sure, the overall view of the universe is the same when we move in time to the positive or to the negative direction, but the local phenomena are not reversible. Gravitation, the pulling forces and the explosive, dispersing forces, all act in opposite directions in time and produce, in Jaakkola's Universe as well, phenomena by no means the same but merely directed the opposite way in time. The same is the case with electromagnetic radiation. The time arrow does still exist.

Nevertheless, one cannot exclude the possibility that, in the course of the further search for similarities and identities in various physical interactions, theories will emerge involving phenomena perfectly symmetrical in time. Then a model of a completely static universe, fulfilling what could be called the *Generalized Perfect Cosmological Principle* would be possible. Of course, a model does not necessarily correspond to reality. One can think over how it would be to live in a Universe with no arrow of time or, rather, with equal arrows in two opposite directions.

But even such a generalized principle is not fully equitable in respect to the space-time concept. It sets the same requirements for space as for time but still does so separately for space and for time. The Fully Perfect Cosmological Principle should set one unitary requirement for space-time as such. At first glance such a total isotropy is not possible, at least as long as we retain the ordinary notion of relativistic space-time, because the metric signature of space-time itself distinguishes the time with the sign opposite to the signs of spatial dimensions. But there is a mathematical trick of using imaginary time. Then the metrics of space-time becomes fully symmetrical in respect to all four dimensions, and the Fu11y Perfect Principle can be introduced. This possibility is explored in the Hartle-Hawking model of the Universe. Besides, there are other space-time theories (e.g. the theory of Segal 1972). Thus, the Fully Perfect Principle can be used for constructing models in many ways.

I hope the reader has already noticed that the last versions of cosmological principles make no claims to be fulfilled in reality. Rather, they are formulated here to draw our attention to the fact that the more elegant, symmetrical, and simple a principle, the narrower and the further from reality it is.

This is the property of all theoretical considerations. The simpler, the more elegant a theory, the less is it concerned with reality. Without any idealization and simplification, reality would be utterly incomprehensible for us, but if the idealization and simplification proceed too far, then, though the theory can be readily grasped, it hardly fits reality.

Keeping a balance between idealization and complexity is the task of the theoretician and not just in cosmology.

[1] Alexander Friedman with his relativistic models had good luck. He died early enough, just before the persecutions began. His disciples, however, were less lucky.

# Chapter 6
# The Anthropic Cosmological Principle

## 6.01. Ecological correction to the Copernican Principle

The Anthropic Principle (not Anthropic Cosmological Principle yet) emerged, in fact, in 1973 in connection with the solemn celebration of 500th anniversary of Copernicus's birth. The first publications about it appeared only one year later. Some ideas, very similar to this principle, can be traced back even to the ancient philosophers. If one accepts that any idea of our Universe having some special properties necessary for the existence of human beings is a precursor of the Anthropic Principle, then one can find some elements of it in every religion which states that the Universe or part of it was created for people. Thus, the Anthropic Principle could be regarded as very old indeed, since such statements are involved in many religions. Therefore, according to Oddone Longo (1989), we have to be very careful in comparing the contemporary Anthropic Principle to any old religious or philosophical views. There are many different versions of the Anthropic Principle. They differ not only in formulation but also in content. Thus it is truly difficult to determine when and where the idea of the principle in its contemporary sense first emerged. Probably a group of American, English, French, and German Christian philosophers and scholars active in the 17th century, called "natural theologians", should be regarded as forerunners of this trend. They noticed, for example, the particular property of water, the density of which increases with rising temperature near its freezing point, and they showed that this is of great importance for living organisms. Again, they pointed out the special chemical properties of carbon and a number of other particular facts concerning the human environment which are exploited even today by adherents of the Anthropic Principle. However, statements of the kind can be found much earlier, too. Barrow and Tipler (1987), in their fundamental book on this principle, date its first scholarly antecedents to as early as 500 B.C.

As the first contemporary and fully purposeful publications about this idea, the papers of Whitrow (1955), Idlis (1958) and Dicke (1961) are usually cited. Dicke stated that in many respects human placement within the Universe (in the sense of location in time and space, mean density of matter, degree of isotropy, etc.) is a favorable one and cannot be considered as incidental. Nevertheless, the very idea of an anthropic principle gained popularity only when two scientists preparing independently of each other, on the occasion of celebrating the Great Anniversary of Copernicus, presented their contributions with some modification or supplementation to the Copernican Cosmological Principle.

Igor Karachentsev (1974, 1975) accepted the validity of the Copernican Principle but stated that 'the confrontation of the observational data with the Copernican Principle needs an ecological correction'. This ecological correction consists in the statement that, in fact, the a priori probability of our actual location in the Universe is very, very low. I would like to interpret Karachentsev's mathematical considerations in a following way. The most probable a priori location of an observer in the Universe would be somewhere in a galaxy cluster structure (today one could say - within some Voronoy foam bubble, or in a more general way - within some intergalactic void). However, we are not located between galaxies. We live within a small, loose, local group of galaxies, and this makes it possible for us to live in a spiral galaxy (the large, compact clusters consist of ellipsoidal galaxies). Only because we are in a spiral galaxy (there are many more elliptical than spiral galaxies in the Universe) our star, the Sun, can belong to a disk subsystem of stars (ellipsoidal galaxies have no disk). Only because we do belong to a disk subsystem (most stars in the Galaxy belong to spherical subsystems) can we have at our disposal so much carbon and water (the presence of heavy elements in a spherical subsystem of stars is very low). Furthermore, we can avoid close encounters with other stars which would be quite tragic events for us. Only because our Sun is a single star (most disk stars are double or multiple systems) can the planetary orbits around it be roughly circular and stable, and thus, the thermic condition can stay more or less the same throughout long epochs.

Only because our Earth revolves around the Sun not too far from and not too close to it (most planetary orbits are located too far or too close) can we have water in a liquid state, which is indispensable for life. Only because our Planet has an relatively massive satellite - our Moon - which causes tides, did life on Earth have the opportunity to go ashore from the sea where it originated; and, according to Karachentsev, this is the condition necessary not only for life but also for civilization to arise here.

To summarize: only this very particular location of our Earth allows for the existence of man, a being which can observe the Universe and explore it. In average, the Universe may look a certain way, but we see it from a very particular place. From our Earth we can see our Moon, planets, the shining Sun, the Milky Way.... In an average place in the Universe, such objects would not be visible at all; in such an average place, we ourselves could not have existed. The location of a conscious observer of the Universe is, necessarily, a rather special one, due to this 'ecological correction' to the Copernican Principle. It was Copernicus who first said: we can observe planetary loops because we ourselves are on a planet. Can he also be counted as one of forerunners of the Anthropic Principle?

Thus the notion of consciousness, which before was consciously avoided in any astronomical, physical or other investigation in the realm of the strict sciences, entered cosmology. It could be said that the Copernican Principle removed man from cosmological considerations. The ecological correction brought man as a conscious being back into the focus of matter.

## 6.02. Relativistic observer and actual observer

At the same time, Brandon Carter (1974) arrived at conc1usions that our location within space-time is a very particular one; also, there are particular laws of nature governing us. He invoked for the first time the very name of the Anthropic Principle, distinguishing two versions of it: the Weak Anthropic Principle and the Strong Anthropic Principle.

It is not only because of this preferred location in space but also because of particular properties of our cosmic environment that something like human beings can subsist. In order to produce a being not necessarily human, but conscious, striving towards knowledge, and having a physical body (for the angelic beings are not subject to natural scientific investigations), some very special conditions must be fulfilled. In the course of time, more and more of these conditions were found.

Einstein's General Relativity, and thus relativistic cosmology, often makes use of the term 'observer'. This is an imaginary being capable of perceiving certain domains of the Universe. These 'observers' not only play an important role in many relativistic, ‘mental experiments’, leading to a better understanding of the investigated phenomena, but they even appear as legitimate elements of the theory. When we are expressing the Generalized Copernican Cosmological Principle that the Universe looks from every point thus or so, we have in mind an abstract observer located in an arbitrary point of cosmic space (e.g. on a star or on an intergalactic dust partic1e). G. Whitrow (1955) said that this Einsteinian approach misses the point, that the "great" Universe is an abode of many living organisms, and only as such can it be understood in the right way. The anthropic principle brought to our attention that in cosmology an important role is assigned to the real observers, i.e. physical, conscious beings, striving for knowledge.

## 6.03. Conditions for the existence of actual observers

If such a real observer exists, he is necessarily endowed with a physical body of a rather complicated structure (something similar to human senses, something resembling the human brain). This can be realized, to the best of our knowledge, only in the realm of chemical compounds of carbon. But carbon as a chemical element can have its very special properties only within a very limited interval of physical constants. Any small variation in Planck's constant or in the electric charge of the electron would result in a radical change of the properties of carbon and prec1ude the life of beings complicated enough to be real observers. Likewise, if the gravitational constant had been only slightly different, stars (according to the Universe models with expansion) either would have been unable to produce carbon at all or would have produced but not ejected it into cosmic space; then, carbon could not have constituted the bodies of living beings. Besides carbon, another substance necessary for life is water. Water can have its beneficial properties only within the existing set of values of physical constants. In the course of time, it became c1ear that all physical laws, all physical constants, all initial conditions of the Universe, as well as its age (cf. e.g. Carr 1982) can be deduced from the assumption that "real observers" (i.e. physical, conscious beings striving for knowledge) do exist in the Universe.

Hawking (1988) provides the following simple formulation: The Anthropic Principle: We see the universe the way it is because if it were different, we would not be here to observe it. John Maddox (1984) formulates this as a paradox: we can derive the values of physical constants from the fact that we know these values. It should be noticed that Carter (1984), who was first to call this complex of facts and problems the Anthropic Principle, confessed later that this very name brought some wrong associations. If he could change the name, he would have called it the 'cognition principle' or the 'self-selection principle'.

### 6.04. The Anthropic Principle and the arrow of time

If an observer of the Universe is to be humanlike, he has to have a sense of time. His psychological arrow of time must be there, clearly dividing the past from the future. If this observer is a physical being (contemporary cosmologists are not fond of dealing with ange1s), his arrow of time has to be based on some physical time arrow, first and foremost on the thermodynamic one. The discussion whether the increase of entropy, and thus the existence of an arrow of time, is a general property of the physical world, initiated by scientists like Ernest Dermal (1896) and Ludwig Eduard Boltzmann (1897), has not been finished to this day. In the light of the Anthropic Principle, the problem cannot be solved in either an observational or experimental way. We, with our psychology based on time consciousness, can exist only in those regions of the Universe where there is an arrow of time. Thus, everything we perceive around us has a definite direction in time. The substratum can be conceived as ideally homogeneous in respect to space and time but 'deviations from this ideal from symmetry of substrate continuum... or from the symmetry with regard to time direction... make it possible to introduce the observer in a natural way' (Zabierowski 1988a).

### 6.05. Must every actual observer be humanlike?

One can have objections as to whether the bodily structure of every real observer necessarily requires the same conditions as earthly man. Of course, no physical, intelligent being could live in a world where a universal levitation instead of universal gravitation were the basic physical reality. In such a Universe, all particles would tend to get dispersed, and a body of a being could not have been formed. However, we can conceive a physical being based on another intelligence principle, and then the limits of allowed variation of physical constants might be substantially larger than those usually provided by the adherents of the Anthropic Principle. For one, there is a widespread opinion that a hive (understood as a family of bees not the place where they live) possesses much greater intelligence than the sum of the combined intelligences of the individual bees. One can imagine an intelligent, conscious being striving for knowledge which exists not as one body but as a swarm of small, primitive particles of some sort of dust. Each particle alone would have too primitive a structure to be intelligent by itself, but the swarm as a whole could have a high combined intelligence. Much simpler conditions would have to be fulfilled to sustain the existence of such particles than the existence of one body possessing this required degree of intelligence and consciousness.

Another objection may result from the fact that nobody, up to now, has performed a profound analysis of possible properties of chemical elements which could be formed by various values of physical constants. It is true that by changing any of the physical constants in any way, carbon and hydrogen would lose their properties which are necessary for sustaining life. But, would some other elements then acquire favorable properties? The adherents of the Anthropic Principle usually maintain that, even if there could be life based on other chemical elements and other physical phenomena, it would not have been capable of evolution, that is, it could not have risen above the most primitive level, even if it could have originated in such conditions at all. The opinion that, besides carbon life, there could also be silicon life undergoing evolution, is usually disproved by indicating that carbon dioxide, the gas which makes possible the metabolic processes in plants and animals, is of essential importance for carbon life. Compounds of silicon could be, in principle, useful for living beings, but silicon dioxide is just a solid mineral, in no way suitable for any respiration process. That is true, but nobody can say if the silicon dioxide or another silicon compound would not have been suitable for a metabolism with other values of physical constants.

The objections can go even further. One can ask whether life and intelligence must be based on chemical phenomena at all, for which (according to up-to-date theories) the underlying forces are electromagnetic. We could conceive of gravitational life or life based on nuclear forces. It is usually contended that these interactions are either too "lazy" (gravitation) or too simple (nuclear forces: a nucleus of an atom cannot contain more than 200 elementary particles). Paul Davies (1981) comes to the conclusion that there cannot possibly be gravitational or nuclear life. But do we really know everything about gravitation? Besides, can one be sure that all the existing physical interactions are already known? Michael Friedjung (1987) considers the conditions of life usually alleged by the adherents of the Anthropic Principle to be just not true.

Those who raise these kinds of objections say that, in fact, the Anthropic Principle states nothing more than: 'Man, as he is, can exist only in the Universe as it is', which implies that in other existing or possible universes there can or could exist some other kind of "men." It may be said here that all the physical laws and other properties of the Universe can be deduced not only from the existence of men, but also from the existence of anything that is there as well. A profound analysis and discussion of a grain of sand must lead to the conclusion that such grains of sand can exist only in such a Universe as it is. This kind of opinion can be formulated crassly by stating that the Anthropic Principle is but a tautological statement: 'The Universe with humanity is such as it is'.

However, until either "non electromagnetic" (non chemical) life or a definite set of physical laws or physical constants completely different from those at work in our Universe but still supporting the existence of physical, conscious, intelligent beings is described in detail, the Anthropic Principle has to be accepted, at least as a stimulating suggestion.

## 6.06. The Principle of Mach as a cosmological principle

The proposition that the Universe, or any arbitrary fragment of it (e.g. humanity), is such as it is, is not as trivial as it looks at first glance. If it only could be true that one fragment can reveal the structure of all the remaining parts! In this case, if the properties of the All can be deduced from any part, it would be the same whether one is concerned with the existence of a scientist or that of a grain of sand. As we stated before (cf. 4.13), Einstein set about creating a theory which should fulfill the Principle of Mach (i.e. a theory which would admit a possibility of reconstructing the structure of all being out of just one of its fragments). Neither Special nor General Relativity does fulfill the Principle of Mach, but this is no proof that Mach's principle as such cannot still be valid.

The aspiration of understanding the total structure of the Universe from one fragment of it involves the conviction that Mach's Principle is valid. If it is, then the Anthropic Principle in its strong version would be just one of many ways of putting the principle to practical use. The Anthropic Principle can be considered as a particular variant of the much broader Principle of Mach (cf. Ellis 1987b). Why then is the Principle of Mach hardly ever called a cosmological principle? Is this only because Einstein eventually failed in his attempts?

When we attempt to construct an adequate model of the Universe based on the phenomena as perceived in its observable region, which is but one fragment of the totality, no matter what physical theories we do apply and what philosophical views we adopt, we are making use, consciously or not, of Mach's Principle. We are inwardly convinced of this principle; we believe in it.

## 6.07. Weak and strong versions of the Anthropic Principle

For the sake of further discussion, let us formulate the main versions of the Anthropic Principle so that they are representative of its subsidiary formulations.

The Weak Anthropic Principle: The physical properties of the observable part of the Universe have to be taken as a logical conclusion from the premise that the human being observes it. Carter (1984) proposes a simpler definition: Our existence implies restrictions for our location in the Universe. By location we are to understand a location in space-time. Not every cosmic epoch allows our existence. The words here are much more modest; they convey roughly the same sense, but they need more explanation.

By skipping the words "of the observable part" and changing the "human being" to "real observers" in the former definition, one obtains the Strong Anthropic Principle: The physical properties of the Universe have to be taken as a logical conclusion from the premise that real observers exist in some parts of the Universe's space-time. This can be formulated also: Our existence implies restrictions for properties of the Universe.

Carter admits that he cannot defend the Strong Anthropic Principle with the same conviction as the weak one. John D. Barrow and Frank J. Tippler (1986) consider the Weak Anthropic Principle...a culmination of the Copernican Principle (...) that a man can observe only from the point where a man can stand because the former [the Copernican Principle] shows how to separate the features of the Universe whose appearance depends on anthropocentric selection, from those features which are genuinely determined by the action of physical laws (...) The Copernican Revolution was initiated by the application of the Weak Anthropic Principle (...) We observe the retrograde motion (of planets) because we are on a planet.

Thus Barrow and Tipler gave a positive answer to the problem formulated first by Karachentsev. Copernicus should be considered as one of the forerunners of anthropic kind of thinking. But, according to them, this concerns only the Weak Anthropic Principle.

### 6.08. Purposeful Creation

The Anthropic Principle presents a logical implication only. Various philosophical, and even more diversified cosmological, astronomical, and physical interpretations may be drawn from it. These can be divided into three classes.

Some religiously minded people conclude that here is the proof that the Universe was created in order to make human existence possible. Out of an infinite number of possibilities, the Supreme Creator took one which is conducive to developing life, intelligence, consciousness, and culture. He "had in mind" future humanity when creating the laws of logic and space-time and establishing the initial conditions for the Universe. The logical implication involved in the anthropic principle is considered here as a causal implication. This is the simplest interpretation of the principle, but it is too simple to win wide acceptance. The difference between these two kinds of implications (logical and causal) is assumed here on no basis other than religious conviction, very important, indeed, as such, but by no means equivalent to scientific convictions. In fact, if somebody believes in the teleological order of the Universe, he needs no scientific affirmation of it. At most, he can find some sublime pleasure in the fact that the anthropic principle confirms his beliefs. In his interpretation, purposeful creation belongs to the premise, not to the conclusion of his reasoning. On the other hand, one who believes in the accidental structure of the world has other interpretations of the anthropic principle.

The kind of interpretation presented above is sometimes called the teleological version of the Anthropic Principle. Its adherents usually claim that such a Universe is unique. In fact, one can well argue that the Creator created several universes for a purpose, or, perhaps, for various purposes.

### 6.09. Is the probability of our existence so low?

Another type of interpretation is the following one. The Universe could have had not only different initial conditions and different physical laws but also a completely different structure of space and time, even a different number of space-time dimensions. Most of these possibilities would exclude the possibility of human existence, and certain ones would exclude even the possibility of any physical causal order. Out of manifold possibilities, one is realized. The probability of the realization of just one out of an infinite number of possibilities is infinitely low. In a mathematical sense, the probability of any realization is close to, or even strictly equal to zero. It is quite improbable that our Universe provides the possibility of human existence, but any other structure of the Universe is equally improbable. The situation bears some resemblance to that situation whereby, out of a mathematical linear segment containing an infinite number of points, one point has to be selected by chance. The a priori probability of selecting any one point is zero, but still, one point is selected. So it is here. If one assumes that, out of innumerable possibilities, something had to become reality, then our quite improbable Universe is no less probable than any other. lf our Universe had not happened to produce any physical intelligent being striving for knowledge, then nobody would have been there to formulate problems and ask questions about the Universe. Because, by chance, the Universe does make our existence possible, we can propose problems; we can ask questions.

As is clearly seen, this view explains the anthropic properties of the Universe in a strictly scientific way, without resorting to any religious beliefs. However, it is based on the assumption that one of the many possibilities had to become a reality; in other words, it assumes that it is necessary that something exist. Without this assumption, the above argument is not complete. The assumption of God's free will, inherent in the religious interpretation, is here replaced with the assumption of the necessity for the existence of something.

But what is real existence? Can an entity that is not aware of its own existence actually be said to exist? Among some physicists there appears the opinion that elementary particles exist only when they are observed (cf. Hibner 1987). Is it not the same with macrocosmic and megacosmic existence? According to Miroslaw Zabierowski (1988), the Anthropic Principle is a direct consequence of modern quantum considerations. It is believed that John Wheeler said for the first time: an observer is necessary for bringing the Universe into existence. It is called the Participatory Version of the Anthropic Principle, but some also call it the strong formulation of the Strong Anthropic Principle.

However, in fact, all our observations are biased because we perform them. The Anthropic Principle states that this bias is so considerable that we are not able to tell whether our existence is an exception or just a common phenomenon (Maddox 1984).

Karol Zieleznik (1991) noticed that the teleological and the participatory versions are not mutually exclusive, and neither follows from the other in a logical way. It means that they are logically independent.

### 6.10. Existence of many universes

The third possibility is to accept the existence of many universes. The old idea of Everett (1957), introduced to explain some quantum phenomena, is employed to explain a macrocosmic phenomenon - to account for the existence of our Universe with all its peculiar properties. Also, Yakov Borisovich Zeldovich (1981) relates the idea of quantum indeterminism to the concept of many universes. However, the concept can also be discussed without such connections. One can assume all that is possible exists somewhere (in its own space) or that only certain possibilities are actualized. In any case, one can assume that our Universe is not unique. There can be universes with a different number of dimensions, with different signatures of these dimensions, with various laws of physics. If there is an infinite variety of Universes, everything we could have wished could be found among them. The ranges of conditions providing for the existence of intelligent beings are small but finite. Thus, in some of these Universes, conscious beings striving for knowledge could exist, but not in most of them. In the universes where such beings do exist (e.g. in the Universe where we live), we can ask how is it that the existence of life and consciousness is possible. These universes, so to say, know of their existence. In the others, nobody can know anything; there is no intelligence to grasp them. It is no wonder that in just such a peculiar universe as ours all those questions have arisen. They could only have arisen here. According to Davies (1981), in the case of an infinite number of universes, we can only ascertain that our Universe is such as it is, whereas if the Universe were unique, we could exclaim with joy what lucky fellows we are.

The adherents of this interpretation maintain that as it is with universe so it is with almost everything in nature. Nature makes plants produce many seeds, but only few of them actually have an opportunity to germinate. Nature has initiated nuclear reactions in many stars, but heavy elements have been produced in only a few of them. Likewise, nature has created many universes, but only few of them can be aware of their own existence.

The multitude of Universes can most easily be understood by considering that there is a super-space-time in which the space-time of individual universes are somehow located; but one can also conceive of one Universe oscillating through an infinite number of cycles and only once in a while producing conditions conducive to life (Wheeler 1977). Or, one can follow Sacharov's (1980) idea of "multileaf' models of the Universe. Another possibility is that "our Universe" is unique, but it is infinite in time and space, containing space-time domains of an infinite variety of physical conditions. Hoyle called such a universe model the domain universe (Hoyle 1965, 1975; Ellis 1978, 1979). The last possibility creates a bridge between the Anthropic and the Ancient Indian Principles. There are still other variants of understanding a multitude of Universes, some of them connected with the idea of inflationary Universe (cf. Zabierowski 1990).

According to Hawking (1988), the idea of multiple universes or many different domains within our Universe is not consistent with the Strong Anthropic Principle.
He writes:

There are a number of objections that one can raise to the strong anthropic principle as an explanation of the observed state of the universe. First in what sense can all these different universes be said to exist? If they are really separate from each other, what happens in another universe can have no observable consequences in our own universe. We should therefore use the principle of economy and cut them out of the theory. If on the other hand, they are just different domains of a single universe, the laws of science would have to be the same in each domain, because otherwise one could not move continuously from one domain to another. In this case the only difference between the domains would be their initial configurations and so the strong anthropic principle would reduce to the weak one.

Hawking sees no possibility of fluent transition between two domains of completely different structures.

It is possible to provide further philosophical and fantastic conceptions involving the idea of multiple universes. Some arguments based on the mathematical set theory can lead (using certain assumptions and certain interpretations) to the result that among an infinite number of universes there is also an infinite number of exactly the same universe. If any event (for example, you reading this book) exists within some universe, it must exist in innumerable other universes as wel1 (Barrow and Tipler 1986).

In interpreting the Anthropic Principle using the concept of many universes or many different domains within one universe, the assumption of God's Will or that of necessary existence is replaced with the hypothesis that everything (or at least some kind of everything) possib1e does exist. Perhaps another notion of possibility or of existence should be involved here. Both notions give rise to some basic difficulties but discussing them here would lead us too far afield. It is worthwhile, however, to notice again that it is simply impossible to avoid philosophical issues, even those apparently not related to astronomy or physics, when dealing with cosmological principles....

In the series of considerations presented above (arguments about the exceptional or common character of our Universe, incidental origin or purposeful creation), we not only stand on the frontier of science and metaphysics but also go over to theology. Similar problems were discussed already by Baruch Spinoza (1637-1677) and he eventual1y concluded that to understand God means to understand the Universe and vice versa. However, I wish to comfort all the atheists and agnostics: the God of Spinoza was comprehended in a very abstract or, if you wish to call it so, materialistic way. No minister of any traditional religious organization either in Spinoza's times or at present could accept Spinoza's concept of God.

### 6.11. Universe and universes

If we want to talk about multiple universes, the question of what a universe (1ower case u) actual1y is must be addressed. As long as we are confronted with just one Universe, we can keep to the definition that the physical Universe is a system inc1uding everything which physical1y exists. If we allow the existence of many various universes, this definition wil1 no longer be sufficient.

In order to obtain a clear notion of a universe and to be able to distinguish our Universe (capital U) from the others, a fol1owing set of definitions may be used (cf. Rudnicki 1990).

l. universes (small u): sets of domains, each set consisting of all domains of physical existence connected causally to one another in a direct or indirect (e.g. through consecutive partial overlapping) way.

2. Universe (capital 'U'): the universe containing the observable realm of existence.

3. observable realm of existence: the domain causal1y connected directly with human beings.

Definition 3. simply states that to be observable means to be in a causal connection - to be able to exert an influence and to be subject to such influences. This observable realm of existence is the same which was called in the previous parts of this book the observable part of the Universe. The first definition demands that a universe include all domains which are, even in the most indirect sense (consecutive overlapping), connected with one another. Thus the definition rejects any possibility of interaction between two different universes; in other words, it proclaims that two different universes are unobservable by each other. Definition 2 distinguishes our Universe from all the others. These definitions make a distinction between two kinds of unobservability. The parts of our Universe located behind the cosmological horizon are unobservable for us, but a real or imaginary observer located close to our horizon is still able to observe us and those parts simultaneously. He cannot send us any message about the parts unobservable to us or transfer our message to them, but nevertheless he is, in a sense, a connecting link between us and them. A completely different situation exists between two universes. According to Definition l., there could be no such link. If it does exist, then ex definitione the two universes are in fact one universe.

### 6.12. Can we know anything about other universes?

We come here, in fact, to the limits of logical thinking. This revealed itself fully in a heated argument during the conference "Cosmos" in Venice in May of 1987. D.W. Sciama proposed a proof of the existence of other universes. He said that if our Universe was the only one existing and fulfilled the anthropic principle of purposeful creation, then the numerical values of the physical constants should be optimal (i.e. should be right in the middle of the small range permitted by the anthropic principle). However, if there are many universes with incidental actualization of physical conditions, then, in his opinion, the values of physical constants in our Universe should be dispersed at random within their allowed limits respectively. For the time being, we are not able either to calculate exactly either the limiting values of these intervals or to establish very accurate values of physical constants, but in the future this should be possible. Thus, this is a scientific proposal for the future. The other universes, if they exist, will reveal themselves. We have the experimental (not the observational, just the experimental!) possibility to get information about their existence.

One participant, however, expressed his doubts whether something investigated in our laboratories could be legitimately called another universe because anything that can exert any impact on us belongs ex definitione to our Universe. Another disputant tried to overcome the problem by introducing two separate notions of Universe and Cosmos to distinguish between 'everything that exists and therefore can be investigated in some way' and 'belonging to the same space-time.' Nevertheless, the discussion (or rather both discussions, the official one in the conference room and the other one during the coffee-break) came to a dead end as nobody was able to explain what kind of space-time may be called a universe. The Kaluza-Klein and other models in multidimensional space-time make the problem a rather tricky one. A further question asked in what sense an entity limited to one space-time can or cannot coexist with other similar entities in a super-space-time. The issue of the existence or non-existence of limits of knowledge came out fully (cf. Appendix: Goetheanism in science).

### 6.13. The Final Anthropic Principle

There are many geometric and physical propositions which are instrumental in understanding the world. Some of them, considered to be more important, go under the name of principles. These include Archimedes' principle, the exclusion principle, the uncertainty principle, the principles of conservation, etc. The Anthropic Principle first used to be included among such general principles also. It was not until the 1980s that one began to talk of the Cosmological Anthropic Principle.

In the book of Barrow and Tipler (1986) discussing this principle as a cosmological one, three versions of the anthropic principle are distinguished. Besides the weak and strong versions, there is a third one, the Final Anthropic Principle. It is provided in the form of a hypothesis which can be briefly expressed as follows: Every civilization is able to attain a point from where it can not only defend itself from outer and inner perils but can also create (construct) other beings more intelligent and more resistant to the physical condition of the Universe than the members of the civilization themselves (computer construction, genetic engineering. etc.). Technological products such as computers count as intelligent beings since, as the authors put it, in the behavioristic sense they do act as living, intelligent beings. Such a civilization is capable of conquering ever larger parts of the Universe and in favorable circumstances can get in contact with other civilizations. It can survive up to the moment of the Big Crunch (final singularity) or, if the Universe is to expand forever, survive over enormous cosmic epochs.

### 6.14. Automata as descendants of men

Here the entire argument is based on the Hubble Law and the Big Bang model. Therefore, since the Big Bang models fall into two classes, there are two possibilities. Either the Universe expands forever and with time tending to infinity the mean density tends to zero; or the total age of the Universe is finite and, after the period of expansion, there is a contraction era terminating in the Big Crunch. In either case, life conditions will change considerably over large cosmic epochs, and today's people or their natural offspring are not likely to persist, even if strong natural evolutionary processes were at work. However, the intelligent beings will be capable of constructing artificial descendants which can live on (i.e. perform purposeful work and construct the next generations of ever more sophisticated automata) in adverse environmental conditions, such as extremely low density of matter (perpetual expansion) or density tending to infinity (Big Crunch).

For a better understanding of the picture presented by the Final Anthropic Principle, let us take into consideration the following. Scholars of the past had a detailed knowledge of their results as well as all the calculations and arguments leading up to them. A scientist of today is an expert in the results obtained and the underlying line of argumentation, but he delegates the burden of arduous calculations to his computer, and, if he uses "library programs," he may well not even understand how those calculations are actually performed. In not too distant future, a scientist will be able to delegate the task of logical argumentation to his computer as well. At some next stage of development, there will be no necessity of scientists knowing the results of investigations, as the computer will produce, record and put them to use by itself when needed. It (he?) will then be wise. The ideal stage will be attained when the computers not only elaborate the results of research but also do scientific research on their own. When we take all this into consideration, the brilliant future predicted by Barrow and Tipler begins to be understandable.

Even if the Universe is to expand forever, generations of more and more sophisticated automata will pass on culture and civilization in the Universe. The only plausible peril could arise if it happens that elementary particles (also protons) have a finite life time.

More promising is a situation when, after the expansion era, there is a period of universal contraction. This would enable neighboring civilizations to come in contact more easily and have an opportunity of exchanging their mutual accumulated experiences, thus increasing their abilities and knowledge enormously. When the Big Crunch, the final singularity, becomes imminent, the civilized and intelligent automata will have unlimited knowledge of everything, possibly even of other universes. And that will be the happy (?) end of human (?) culture and civilization.

The authors of the Final Anthropoid Principle agree with others that the natural evolutionary processes that can produce real observers involve carbon compounds and many other very special circumstances, but they are of the opinion that once human or humanlike beings come into existence and attain a sufficiently high stage of development they are able artificially to construct living and conscious beings from a completely different chemical and physical basis. Those next generations of "scientists" will be, to a large extent, independent of the conditions demanded from the Universe by the first two (weak and strong) versions of the Anthropic Principle.

## 6.15. Notions of life and consciousness

The promoters of Final Anthropic Principle use the notions of life and consciousness in a sense quite remote from the sense commonly attributed to them. The behaviorist interpretation (definition) given by the authors of Final Principle is utterly materialistic (in the sense of "materialism" that I explained in 3.14). The difficult problem of the nature of life and consciousness, fundamental in most issues related to the Anthropic Principle, is too broad and too serious to be addressed merely as part of the present cosmological considerations. Its essential character should be, nevertheless, stressed here. A few remarks on it will be further provided in the appendix (a.08). Barrow and Tipler propose treating men and automata equally by remarking that every living being, and so every intelligent one, is limited by the laws of physics in the same way that computers are. They do not even refrain from using such notions as soul and eschatology. The software of a computer should be its soul. The issue of eschatology consists of a number of technological problems of existence (of automata) in the exotic physical conditions close to the final singularity.

## 6.16. The Weak Anthropic Principle as cosmological principle

Let us now discuss what the properties of the three versions of the Anthropic Principle are when accepted as cosmological principles.
The Weak Anthropoid Principle as formulated by its early advocates, Dicke (1961), Karachentsev (1974, 1975), and Carter (1979), was at first conceived not as a cosmological principle but rather as an explanation of why a real observer is necessarily located in a particular place in the Universe (i.e. the terrestrial globe) even though the Copernican Principle remains valid. This purpose, "ecological correction," is particularly distinct in both papers of Karachentsev.

In later formulations, the Weak Anthropic Principle proclaims something concerning solely the observable part of the Universe: its properties can be deduced from the sole fact that Man is there to observe it and that Man could have formed only in this part of the Universe.

As to the unobservable parts of the Universe, the Weak Anthropic Principle requires that they not prevent, in the Earth's vicinity, the development of such laws of nature, numerical values of physical constants, and initial conditions that human beings could come into existence. Apparently, it looks like a negative requirement of the Genuine Copernican Principle, a requirement of not standing in the way of Man's development. However, since "to be unobservable" in contemporary science means "to have no possibility to exert any influence," even a disturbing one, the condition is fulfilled *ex definitione* by all the unobservable parts of the Universe. It does not describe any additional property of these parts, even in a minimal way, as some of the historical cosmological principles do. So the Weak Anthropic Principle, for all its importance for contemporary astronomy, cannot go by the name of a cosmological principle unless the term cosmological principle is understood as something completely different than it has been to date.

## 6.17. The Strong Anthropic Principle and the Copernican Principle

The Strong Anthropic Principle refers to the entire Universe and, as such, is a cosmological principle par excellence. The only question is how many properties of the Universe it can predict. The requirement that there be real observers somewhere in the Universe's space-time can be considered fulfilled because the Earth is populated by such observers - us. However, in such an interpretation the Strong Anthropoid Principle turns out to be identical in content to the weak one. Therefore, the Strong Principle is usually understood in that the plural notion of real observers should mean many different "physical conscious beings striving for knowledge" distributed more or less all over the Universe. Only by such an interpretation can this principle be considered to be a cosmological principle at all.

In such a case, it can also be considered as an ecological addition, or, better still, an ecological correction to the Generalized Copernican Principle. Combined, they can be formulated as follows:

The Universe looks (roughly) the same in any direction to an observer located at any point, and in any (large enough) spatial area some real observers can be found in some epoch of its existence.

In fact, if we accept the Copernican Principle, we would have (roughly) the same situation everywhere. If we do not neglect the presence of human or humanlike beings, then the requirement that such beings should not be exceptional in the Universe but should occur throughout it seems quite natural.

## 6.18. The Strong Anthropic Principle and the Ancient Indian Principle

When discussing the implementation of the Anthropic Principle and the idea of multiple universes, we noted that, in fact, instead of many universes, it would be sufficient to have a unique universe comprised of various domains with random distributions of density of matter, physical constants, physical laws, or even metrics of space-time and number of dimensions. Of course, such domains generally should be large enough to allow the existence of homogeneous sub- domains like the observable region in which we live. There are differing views as to the possibility of the existence of such a universe. We saw already that Hawking argued that if two domains had a different number of dimensions a smooth transition between them would be impossible. However, non-trivial mathematical models involving a gradual change of dimensions are possible. Still easier is to gradually alter signatures of space-time. And, in fact, a gradual transition between different laws of physics is proposed in all theories of unification, like the Grand Unified Theory or Super gravity. Thus, that is not the point. The encountered difficulties are of a different kind.

In the multiple-universe interpretation an infinite number of universes are assumed. *Mutatis mutandis*, in the one-heterogeneous-universe interpretation we have to provide for an infinite number of domains. Some should be in expansion, some static, and some collapsing. Only in an infinite number of domains can everything be produced by random variations. Thus, also, humanlike beings can arise by chance. Otherwise, we could still ask why circumstances are so favorable for life and intelligence as they are. The advocates of this interpretation usually have in mind (deliberately or not) a universe fulfilling the Copernican Principle at large. However, in this case it should fulfill three cosmological principles at the same time: Anthropic, Copernican, and Ancient Indian. In principle, a model of a universe can involve any number of cosmological principles, if they do not contradict each other. Here, however, this last condition is not fulfilled. The Indian Principle requires that variability, diversity, and heterogeneity exist in space and in time, in every dimension scale, and also as a mathematical limit in infinity. The Copernican one demands that the Universe should be more and more homogeneous at least when tending to infinity. Therefore a Copernican Universe must either be static in time or originate or end in a singularity. And this property has to be common all over it. Otherwise, the Copernican Principle would be violated. However, it is impossible to reconcile Hubble's Law, for example, with infinite heterogeneity.

The only possibility is to base a model on two principles only: Anthropic and Ancient Indian. Such a model cannot be computed mathematically even using state-of-the-art mathematics, but it still can be perceived mentally as a dim picture. And, in fact, the idea of a universe containing everything is sometimes presented as a picture, although usually an unclear one.

### 6.19. The Strong Anthropic Principle as cosmological principle

Of course, there is no logical necessity to combine two principles. Let the Copernican and Ancient Indian principles be understood as dealing with large-scale physical objects, celestial bodies, whereas the Anthropic Principle deals with observers of these bodies. This is a reasonable distinction to be made. As was said above, only the Strong Anthropic Principle can be considered a cosmological principle. However, it is not able to produce any mathematical model of the Universe. The logical way from a statement about the existence of conscious beings to the production of a mathematical model of space-time and the properties of matter contained in it is by no means direct, straightforward or short. Nevertheless, this is not an objection to regarding it as a cosmological principle. The Ancient Indian Principle has not produced any mathematical model of the Universe either....

In fact, all the adherents I know of the Anthropic Principle (Strong or Weak) also accept the Generalized Copernican Principle. Only after taking into account the conclusions of the latter (i.e. Hubble's Law and the Big Bang Hypothesis) can some fruitfu1 further conclusions can reached. The formation of chemical elements or physical constants can be deduced, or at least there is a hope of deducing them, after solving the problem of unifying all physical interactions. Barrow and Tipler (1986) confirm this fact in their book, stating frankly (p.368): The 'Big Bang' Theory of the 'origin' and evolution of the Universe is the paradigm of modern cosmology. Sometimes (e.g. Davies 1981) argumentation is provided that Hubble's Law can be derived not only from the Copernican Principle but also directly from the Anthropic Principle, but it can always be shown that these kinds of "proofs" are actually based on assumptions equivalent to the Copernican Principle or Hubble's Law as such; they involve the error of petitio principio.

There are cases in the history of cosmology when two cosmological principles have been applied simultaneously. The world model of Tycho Brahe followed from both the Ancient Greek and the Genuine Copernican Principles and was not easily derived from either one alone. The Strong Anthropic Principle cannot replace all the other principles but can be of interest as a supplement to at least one of them. Of course, it is still too early to assess how important this "ecological correction" is or how permanent the conclusions deduced from it will be. So far, the Strong Anthropic Principle makes us think of a novel interpretation of previously known facts, and this alone provides for its importance, regardless of whether it should be given the status of "cosmological principle" or just "principle," or even that of a logical tautology.

### 6.20. The Final Anthropic Principle as cosmological principle

As opposed to the other principles, the Final Anthropic Principle is formulated as a hypothesis; at a first glance, it seems hardly possible for it to count as a cosmological principle at all. It claims that there are civilizations perpetually arising, developing, and expanding within the Universe. With increasing age, the Universe should become more and more populated with civilizations. Accepting this principle means an outright refutation of the Steady State Model, according to which the Universe, being infinitely old and always the same, civilizations would have had enough time to develop very highly. However, in fact, our civilization is still in a quite primitive stage, and no contact with any other civilization has been established yet.

I would not like to go here into the detail of proving whether or not our civilization is indeed primitive, arguing whether we can be sure that we are not observed by another civilization, etc. I will even avoid the most important point, whether in the Steady State Model the density of the oldest civilizations should actually be so high, or what the average age of a civilization should be. The Steady State Universe expands, and there are no data enabling one to calculate what precedes faster, the expansion of the Universe or the development of an average civilization. These questions, however remarkable, are rather detailed ones.

Even if the Final Anthropic Principle (when accepted) does not exclude the Steady State model in general, it does exclude certain versions of it. And this states something about the unobservable parts of the Universe. Thus there is no good reason for rejecting the Final Anthropic Principle as a cosmological principle....

### 6.21. Is every hypothesis a cosmological principle?

Any reasonable, even if completely fanciful, hypothesis concerning the entire

Cosmos is consistent with some models of the Universe and inconsistent with others. Thus, a hypothesis, when accepted, discriminates between models, and so says something about the unobservable regions of the Universe as well. To put it in a paradoxical way: if I accept the hypothesis that all stars contain some dragons in their nuclei, then I cannot accept any model which states that in the unobservable regions of the Universe there are stars with no dragons. Can it rightly be claimed that the assumption that stars contain dragons in their nuclei is a cosmological principle? What conditions should a statement satisfy to count as a cosmological principle? What is the difference between a cosmological hypothesis and a cosmological principle...?

### 6.22. Limitations of our knowledge due to the Anthropic Principle

The Perfect Cosmological Principle is full of optimism. By accepting it we are capable of knowing everything. Just opposite is the case with the Anthropic Principle. Our location in space-time is not an average one. We reside in a specific spatial domain and in a specific epoch of cosmic evolution. Thus, we can observe solely phenomena characteristic of that particular stage of evolution which provides for life and, moreover, only those which can to be observed from the particular environment supporting our existence. We may have no idea what remarkable celestial bodies and phenomena exist in other parts of the Universe (where no intelligent beings to observe them can abide) or in remote epochs in the past from which no traces have been found to date. The fact that one has to exist physically prior to perceiving anything imposes limits on our perceptional ability. Barrow and Tipler (1986) see some analogy between this fact and the theorems of Gödel and Türing-Halton.

Gödel's theorem, which concerns mathematical theories, can be expressed in terms of everyday language: In any more developed mathematical theory one can formulate sentences belonging to the theory but whose veracity cannot be either proved or disproved on the basis of the theory's axioms. That is to say, no more developed mathematical theory gives the possibility of deriving all possible theorems belonging to its domain using strict mathematics (formal logical). Gödel's theorem (the validity of which was proved in a strict mathematical way!) frustrated those who had set to formalizing the entirety of mathematics.

The Türing-Halton theorem states that the construction of a particular computer cannot be fully analyzed using this very computer.

The Anthropic Principle can be put into a form along the same lines: the Universe cannot be grasped in a sensory way in its space-time totality by any physical intelligent beings produced by this very Universe.

This line of argumentation involves the kind of thinking developed in recent centuries and used now in science as the only admissible one. In fact, the knowledge of the full potential of human thought is still rudimentary. The Anthropic Principle seems to impose more absolute limits on human understanding than the "classic" cosmological horizons did. And nevertheless, if we are able to think of the entire Universe, even using that restricted contemporary variety of scientific thinking, we do know something about it. Georg Unger (1991), after discussing the problem from the Goethean standpoint, considers the Anthropic Principle to be nothing more than idle musing of frustrated scientists.

John A. Wheeler in his foreword to Barrow and Tipler's book (1986) writes:

What is the status of the anthropic principle? Is it a theorem? No. Is it a mere tautology, equivalent to the trivial statement 'The universe has to be such as to admit life, somewhere, at some point in its history, because we are here?' No. Is it a proposition testable by its predictions? Perhaps. Then what is the status of the anthropic principle?

And he urges the reader to make his own judgment about this principle.

# Chapter 7

# Other cosmological principles

## 7.01. How many cosmological principles are known?

In the first six chapters of this book, the six major cosmological principles were presented; some of them have many different formulations, and sometimes substantially different, even separately designated, versions. Thus, along with the six main principles, several minor ones were presented too, but only those closely related to them. In this short chapter I would like to introduce some of the other, less known principles. There have been many attempts to classify all the known or even all the plausible cosmological principles (e.g. Ellis 1975, 1984; Ellis, Harrison 1974). In this book I made use of the systematic review by Tadeusz Sierotowicz (1990) as a check list for ascertaining that any principle of interest had not been omitted. However, the order of the following presentation is not too systematic, just starting from the most particular and ending with the most general. Of course, it is debatable what is more and what less general.

## 7.02. The Lucretian Cosmological Principle

Titus Lucretius Carus (95-ca. 55 B.C.) was a poet rather than a philosopher or astronomer, but in his poetic works, particularly in his poem De Rerum Natura, he recapitulated and popularized the views of the Greek philosopher Epicurus (341-270 B.C.), providing a general view of the Universe, which is as follows.

*The Universe then is not limited along its paths...Nor does it matter in which of its quarters you stand: so true is that, whatever place anyone occupies, he leaves the whole equally infinite in every direction....unless matter had been everlasting, before this all things would have returned utterly to nothing....Nor can any power change the sum total of things; for there is no place without into which any kind of matter could flee away from the all; and there is no place whence a new power could arise to burst into the all, and to change the whole nature of things and turn their motions.* (Translation: W.D.H. Rouse, Lucretius 1975, quoted after Jaakkola 1989).

In this and similar statements Lucretius maintains that the Universe is infinite in space and time and that there is no center of the Universe. All this is concordant with the Ancient Indian Cosmological Principle, but there is a new element, the proposition that the total amount of matter as well as of energy within the Universe does not change with time. The Ancient Indians believed that everything is subject to permanent change. Some cosmologists consider Lucretius a precursor of Copernicus (cf.: Jaakkola 1989) and his theses an anticipation of the Perfect Cosmological Principle, while others give his propositions the rank of an independent principle, the Lucretian Cosmological

Principle.

It should be left to historians to clear up to what extent the propositions of Lucretius were original, what he had just repeated from Epicurus and his other predecessors, and what impact he had on his successors. From the point of view of cosmological principles, his is a variant of the Perfect Cosmological Principle with Hubble's constant equal to zero, as discussed in 5.7. As a matter of fact, the Perfect Principle produces only one model with three variants (according to the respective values of Hubble's constant: positive, zero, or negative). Since the Lucretian Principle corresponds to just one of the variants, it is a matter of individual opinion whether it is more proper to call it the Lucretian Cosmological Principle or the cosmological model of Lucretius, which happens to fit into the frames of one of the modern cosmological principles.

There can be found in historical treatises as well as in modern non-professional publications of astronomy some other pictures (models) of the “world system” (Universe) built upon personal views. Hardly ever are such philosophical views regarded as cosmological principles and named after their authors. This fact should not be taken as a depreciation of their work. I do not want to underestimate the impact of non-astronomers on the development of astronomy.

**7.03. Weyl's postulate as a cosmological principle**

Weyl's postulate concerns a particular geometric property of space-time noted in General Relativity, that the world lines of the substratum form a normal congruence of time geodetics. To express the same idea in non-mathematical terms: the lines representing individual histories of substratum particles in four-dimensional space-time look, in three-dimensional space, like hair that has just been brushed. Though the postulate can be applied in other theories using the concept of space-time, it is used primarily in relativistic models.

As a cosmological principle, it is broader than the Copernican Principle when applied to constructing relativistic models but narrower when considered in general, since it cannot be applied to theories not involving the notion of world lines (e.g. to some quantum theories). In fact, the majority of relativistic models conform to Weyl's postulate, but it is rather seldom referred to as a cosmological principle.

**7.04. Principle of Verification**

Sometimes it is required that a model of the Universe be verified in the observable part of the Universe (in the local environment of the human abode). This requirement as a categorical demand is, of course, contradictory to the very essence of a cosmological principle. A cosmological principle is by no means to be verified by astronomical observations. If it were possible, then instead of forming theories or constructing models of the Universe, we could just describe what it looks like. Of course, one can assume that the Universe is the same in every place as it is around us (this is the meaning of the Copernican Principle), but this assumption cannot be tested observationally in the observable region.

Thus, if we understand this principle to mean that the entire Universe should look like our environment, it would become tantamount to the Copernican Principle. If, however, the Principle of Verification is to have any cosmological meaning different from the above, it has to be interpreted that cosmological models should describe the observable (as well as the unobservable) region of the Universe, and this description should be consistent with the observations. It requires very little indeed. All cosmological models constructed not just for their own sakes or for methodological purposes conform to this principle. Otherwise they would not have been taken seriously. Even the models which presume various physical laws and various dimensionalities in different parts of the Universe describe exactly what we do observe within the observable part.

So indeed this postulate (principle) as a cosmological principle is either contradictory or equipollent to the Copernican Principle, or it can be meant as an appeal: "You should not construct cosmological models just for their own sake." Models constructed only for methodological purposes often, contrary to the Verification Principle, do not depict reality as observed around us and thus can be readily discriminated from the “actual” models.

### 7.05. The Uniformity Principle

This principle requires that the laws of physics be the same all over the Universe (i.e. the same as those valid in terrestrial laboratories). This requirement amounts to less than the Generalized Copernican Principle. Copernicus considered the planets as physical bodies. He said expressis verbis that other planets produce gravity[1] like our Earth. If, instead of the laws of gravity, we take the laws underlying all physical interactions and, instead of the planetary bodies, all matter contained in the Universe, then we obtain another generalization of the Genuine Copernican Principle: the Universe at every point is governed by the same physical laws. Thus we have obtained a universe which can be very much diversified, but still the same physics is valid everywhere. The Generalized Copernican Principle is a special case of the Homogeneity Principle. All models based on the former must necessarily conform also to the latter. Hierarchical models of the Universe (cf.: 4.15) satisfy the latter only.

### 7.06. The Probability Principle

This principle makes us choose from all plausible cosmological models those which are most probable in the sense of probability calculus. This criterion of selection is in fact used by many cosmologists as an auxiliary principle. For example, in contemporary relativistic models one looks for a development of the Universe that is independent as much as possible from the initial conditions. The probability of such an evolutionary line is greater than that of a line involving some specific initial conditions.

This principle cannot be reconciled with the Anthropic Principle in most of its versions. The Anthropic Principle does not claim that the Universe should be the most probable one but, rather, calls for an explanation of why it is so improbable.

**7.07. The Stability Principle**

This principle advises the selection of such models which are, as much as possible, not sensitive to perturbations. In fact, all models conforming to the Probability Principle also satisfy the Stability Principle and the other way around. The difference is that the former is formulated in mathematical terms, while the latter rather in physical ones.

**7.08. The Uncertainty Principle**

Heisenberg's quantum principle of uncertainty is nowadays almost always assumed in all cosmological discussions. However, cosmology can also have an uncertainty principle of its own. When we claim something about the unobservable parts of the Universe, even "nearby" regions placed just beyond the horizon, then our claim is uncertain. The same is the case when we express any opinion or make any calculations concerning distant cosmological epochs.
It is rather difficult to count this principle as a cosmological one. It does belong to cosmology, but it does not tell how to imagine the physically unperceivable parts of the Universe. Rather, it prevents us from making hasty conclusions about them.

**7.09. The Simplicity Principle and the Principle of Aesthetic Appeal**

In fact, the Simplicity Principle was conceived after the old and good rule of Ockham's razor; it claims that one should avoid superfluous entities. This principle had already caused much harm in astronomy (cf.: Rudnicki 1984). At the turn of the 19th century, astronomers were at the point of accepting the "elliptical and spiral nebulae" as other galaxies. But the zone of avoidance along the Milky Way was discovered. To avoid the anti-Copernican conclusion that our Galaxy is situated in the center of the Universe, it was natural to assume the existence of galaxies also in the zone of avoidance, as well as the existence of dark matter of some kind, screening them from us. However, the invisible galaxies and (also invisible) screening matter were considered, following Ockham's razor rule, to be merely "superfluous entities." Therefore, for about 100 years, the preferred interpretation was that those "elliptical and spiral nebulae" are but dusty or gaseous nebulae situated within the Galaxy; the central position of our Galaxy could not be accepted without violating Copernican views (the term 'Copernican Cosmological Principle' was not in use yet). Extragalactic astronomy was thus brought to a standstill for a century, until eventually everyone became convinced that the two "superfluous entities" actually exist. Thus, in a science like cosmology, appealing to a principle like Ockham's razor would be outright indecent.

However, simplicity can be also understood as something that is modest and aesthetic. Since we know very little about the unobservable parts of the Universe, the appeal that we should represent them in as simple and as smooth a way as possible is certainly reasonable. A hypothesis or a picture of the Universe should not avoid multiplying entities when needed, but should be simple in the aesthetic sense of the word. Usually the Principle of Aesthetic Appeal is considered a separate one. 'Cosmos' is a Greek word for something ordered, that is, something beautiful, aesthetic and not too complicated. When we comprehend the etymology of the word "cosmos", then the principle of aesthetic appeal is inherent in the very name "cosmological principle". One should keep it in mind.

### 7.10. The Principle of Unity

This principle can be formulated as follows: cosmology must be concordant with physics. When taken in the most primitive sense, this principle is, in fact, always fulfilled. More sophisticated cosmological models involve more sophisticated physical theories, more fantastic models more fantastic theories. No individual physical theory is accepted by all physicists or by all cosmologists. Every, even the most exotic cosmological idea bases itself on some physical considerations.

This principle should not be wrongly connected to the Homogeneity Principle. Here the laws of physics may be different in various domains of the Universe, but every domain must be based on solid physical principles. The only question remains - what is and what is not a solid physical principle?

This principle can be regarded as an appeal for a closer collaboration of physicists with cosmologists. In this form, it is the most general principle, requiring that any considerations concerning the unobservable parts of the Universe be performed only by people with a background in physics. As a cosmological principle it requires very little indeed. Therefore, I have mentioned it last.

[1] The laws of gravity were not known in Copernicus's times. Copernicus laid here the first foundations of the concept of general gravitation.

# Chapter 8

# Comparison of various cosmological principles

## 8.01. Families of cosmological principles

Some cosmological principles can be grouped into families. The most influential in the history of cosmology is the family based on the Copernican Principle. As we have seen (cf. 4.03), the models fulfilling the Generalized Copernican Principle are a subset of the models fulfilling the Genuine Cosmological Principle. Thus, the area of validity of the former is contained in the area of the latter. Some models fulfilling the Generalized Principle meet the stricter requirements of the Perfect Principle, which possesses a still smaller area of validity. In the same relation of subordination is the Lucretian Principle (5.07) to the Perfect one, and - if one would accept them - the Generalized Perfect one (5.10) to the Lucretian one, and the Fully Perfect one to the Generalized Perfect one. Of course, the entire family falls into the area of validity of Mach's Principle (6.06). Here we can also add the Homogeneity Principle, which is situated between the Genuine and the Generalized Copernican principles.

Analogously, the area of Mach's Principle includes the Generalized Ancient Greek Principle and, as a part of the last one, the Ancient Greek Principle (here the generalization makes the requirements less strict, cf.: 2.13).

The Ancient Indian Principle remains beyond the scope of Mach's principle. It leaves no possibility of extrapolation and forms a separate area of validity.

The Strong Anthropic Principle can be reconciled with Mach's as well as with the Ancient Indian principles. The Final Anthropic Principle, however, contradicts the Ancient Indian one.

Mutual relations of the above mentioned principles are presented in the following figure:

## 8.02. Infinity of the Universe. Space symmetries

First I would like to compare some of specifications of the six main principles described in Chapters 1 through 6. The first is the possibility of considering the Universe as spatially finite or infinite. Some of principles involve, in an explicit or implicit way, the conviction that the dimensions of the Universe are infinite (Ancient Indian and Perfect principles). Others allow for conceiving the Universe as finite as well. Two historical principles (the Ancient Greek and the Genuine Copernican) do not touch upon this issue. We could study the views of the Ancients on the infinity of space, but they are of no concern for cosmological principles. Of course, one can state that Aristotle considered the Universe to be finite and provided some philosophical arguments to support that statement. However, the opinion that his model of the Universe was finite is not implied by the accepter cosmological principle. Analogously, one may ask whether, for example, the Empyrean was imagined as finite or not, but this will be a question concerning some feature of a certain model, not the Cosmological Principle of Ancient Greeks as such. These two historical principles, when submitted to logical analysis, yield no requirements about the size of the Universe. So we have to consider them as allowing both finite and infinite size. It is remarkable that there are cosmological principles permitting finite dimensions of the Universe and those permitting infinite ones. There are cosmological principles requiring the infinity of the Universe (the Ancient Indian and the Perfect ones), but none is known which would require its finiteness. Does this mean that the human mind is always more inclined to see the Universe as infinite rather than finite?

No strict space symmetry is demanded by the Ancient Indian Principle, but the Universe is regarded as spatially infinite in all directions. For the Anthropic Principle, when considered independently from the Copernican Principle (without assuming

Hubble's Law), the problem of symmetry in various space directions is irrelevant. This principle can allow the existence of torus-like spaces with some dimensions finite and some infinite. It is worthwhile to note that assumptions equivalent to cosmological principles, which are used in discussing Kaluza-Klein type universes, usually require either that the Universe be infinite in three dimensions (the "ordinary" spatial dimensions accessible to our senses) and finite in the seven others, or, more often, that it be finite in all 10 spatial dimensions. The three "ordinary" dimensions differ from the other seven only in space curvature. However, this does not belong to any of the six main cosmological principles.

### Origin and end of the Universe

Another fundamental specification relates to the beginning and the end of the Universe, or, in other words, the issue of its finite and infinite duration in time. Again, we find some similarities. There are principles requiring infinity in time (the Ancient Indian and the Perfect) but none requiring finiteness. This is the case even in the Generalized Copernican Principle. It produces Hubble's Law, but Hubble's constant can be, in theory, equal to zero. The Big Bang theory is not a necessary implication of this principle but just one (certainly the most remarkable!) of the possibilities. Thus even this principle, which undoubtedly favors most the finite duration of the Universe, does not necessarily require it.

All that can be said about the age of the Universe on the basis of the Strong Anthropic Principle can be deduced only by accepting the Copernican Principle. The Strong Anthropic Principle as such states nothing about the beginning or the end of the Universe. The Final Anthropic Principle, when considered as a cosmological principle, demands that there has been a beginning of the Universe (cf. 6.20).

Time can be finite in one direction but infinite in another. No principle which allows finite time demands any symmetry.

## 8.04. Center of the Universe

The third important specification of cosmological principles is the existence of any center of the Universe. Only the Genuine Copernican and the Anthropic principles are liberal enough to allow both existence and non-existence of some central body or central point of the Cosmos. All the other ones do not allow any center, except for the Ancient Greek Principle which does demand a center and is thus in extreme opposition to them.

# Chapter 9

# Some final remarks

### 9.01. Cosmology and calculating models

Cosmology, the science of the entire physical Universe, from the beginning of its contemporary development, that is from the time when Albert Einstein wrote down a single set of mathematical equations and suggested that it represent the entire material world, has employed models for presenting its results. Models, in the sense used in cosmology, are strict mathematical conclusions drawn from simplified but distinctly formulated assumptions. Other branches of astronomy and physics also used models. There were models of atoms, models of stellar interiors, models of the Earth's core....Models were first used for understanding structures and processes not accessible to direct observation. The atoms were too small to be observed; the stellar and terrestrial interiors were screened by the outer shells of those bodies. Similarly, the regions of the Universe situated beyond the cosmological horizon were unobservable and thus needed to be represented through models.

However, the difference is that in other sciences those processes, though unobservable directly, have some impact on the phenomena accessible to human experience and so can be indirectly compared with the observations. Thus, models can be somehow checked, compared with reality in the same way as any other hypotheses. So it is the case with, for example, quantum mechanical models. Even the quark models of elementary particles yield some observable consequences. Yet the matter looked otherwise, from the very beginning, for cosmological models. When the cosmological horizon appeared in the first model calculation of the Universe in the 20th century, it was obvious that all occurrences beyond the horizon can have no influence on the observable part of the Universe; they never cause any observable phenomenon. Thus, one has a limited possibility of comparing the properties of calculated cosmological models with reality; it can be done only locally, in an exceedingly small part of the Universe. All the global features of models must, however, remain forever unchecked in any direct way. Thus, in other branches of human knowledge, models served as supplementary tools for investigating reality. In cosmology, they were rightly considered the only method possible. Constructing models became something characteristic of cosmology. Those first models appeared in times when numerical calculations had to be performed with the help of arithmometers, mechanical calculating machines, when the obvious tools of theorists were the analytical, mathematical deduction and transformations of formulae. This changed diametrically with the invention of computers. Making models became easier. At present, thinking in terms of models is standard in almost all branches of the sciences and even in the humanities. Sometimes constructing models is considered theoretical work. Some people do not discriminate between the basic significance of theoretical considerations and the secondary significance of numerical calculations based on them. Models are also provided in disciplines where reality can be observed without difficulty. In such situations, models serve as a simplified way of depicting reality. Such simplified models, simplified pictures of reality, can be used for easily predicting events in any possible domain of interest. In this respect, cosmology with its numerous models of the Universe does not seem to be so different from other sciences. There is little understanding of the difference between cosmological models and other types of models widely used today.

### 9.02. Cosmology without models

Question (1) may be put thus: *is constructing models the only possible way of getting knowledge of the Universe as a whole?* However, before we start to discuss this question, a more precise notion of the scientific model has to be introduced. In principle, any case of simplification in science may be called a model. One could say that even in the simple situation when we explain the motion of a thrown stone by using notions of free fall and inertia, we use a model. And, in fact, the transition between applying such straightforward concepts like *inclined plane* and very sophisticated ones like *steady state Universe* is a continuous one. Nevertheless, some line of division, even when not a sharp one, can be drawn here.

Even in our daily life, we distinguish between 'notion' [concept – Ed.], which the Germans call "Begriff," and 'mental picture,' or 'representation' (German: "Vorstellung"). One could say that it corresponds more or less to the difference between 'concept' and 'conception.' To communicate our thoughts to other people, or even to comprehend our own thoughts better, we have to use some 'notions', some 'concepts,' some logical units which are either so simple and need no definition (we call them *elementary notions*), or which can be defined with the help of other notions. Even though such concepts can be used for emotional descriptions, they remain inherently objective. When a human being wants to comprehend some sensual perceptions, to describe them in an impersonal way, he uses concepts. We make efforts to put our feelings aside when creating concepts. However, our life, even our scientific life, would be completely impossible if we were to restrain from any feelings and emotions. Therefore an important ingredient of our activity is the power of imagination. When we personally experience a single notion (concept) or a complex one, when we supplement them with our feelings, our personal propensities, we create mental pictures, conceptions. When such a conception gives rise to a more or less compact picture of some physical reality, it can be called a "model" for this reality. Cosmological models are special examples.

A theory, as regarded in this book, in opposition to models, is a logical structure consisting solely of concepts in the given sense. As (1) stated above, there is no sharply limiting line between theories and models. Nevertheless, there is an obvious difference between such constructions from various epochs like the Theory of Four Elements, the Theory of Flogiston, the Theory of Evolution, the Theory of Sets or General Relativity on the one hand, and, on the other hand, such model descriptions as the Cosmological

Model of Eudoxos, the Model of Jupiter's interior, or models of economical growth.

So understood, modeling is of long standing in cosmology. Mathematically calculated cosmological models were used even in antiquity. Geometrically conceived "systems of worlds" were constructed in times when constructions of such a type were completely unknown in other disciplines. However, this tradition of modeling in cosmology is not the only one. If we choose to take a closer look at antiquity we find not only Eudoxos with his model, but also, for example, Epicurus with his general, philosophical considerations of the Universe. At that time, philosophical argumentation was a received style of working in the domain that is now called science.

In more recent times, a classic example of the non-model kind of cosmological research was the cosmological paradoxes. Let us analyze the Photometric Paradox, called also Olbers' Paradox. There is a combination of assumptions. The mathematical assumption: (i) our space is Euclidean. The physical assumptions: (ii) the surface brightness of a body is independent from its distance from the observer, (iii) the principles of propagation of light are valid in space up to infinity. The astronomical assumption: (iv) there is no obscuring matter in astronomical space. And, the philosophical assumptions: (v) the Universe is homogeneous and isotropic, (vi) the Universe is infinite, (vii) there is no general evolution of and in the Universe. In fact, some other assumptions were involved here too, but they seemed at that time and to date, so obvious that as long as nobody introduces any assumptions contradicting them, they are not worthy of mention. Such hidden assumptions include, for example: the validity of ordinary arithmetic, the linear character of time, the validity of our logic in all times, etc., etc. An elementary calculation made under those assumptions shows that the line of sight, in every direction, within a certain distance must intersect the surface of some star. Thus, one can draw a conclusion that in every direction the celestial sphere should shine with the surface brightness equal to that of an average star. The "paradox" carne about because all the assumptions were considered at that time as the most obvious ones, and still the conclusion did not agree with the elementary observation that the night sky is quite dark.

No model is constructed here in the sense given above. Out of some general assumption, a simple but general conclusion is drawn. And the fact that this conclusion did not agree with observations showed that at least one of the assumptions was wrong. Thus, out of this argument we can learn something about the entire Universe: one or more among the accepted properties are not valid over all of it. This is certainly a negative kind of knowledge, but by eliminating some possibilities we do approach the true idea of the Universe. Most of today's cosmologists are convinced that out of the 7 main assumptions, only two (v - homogeneity, and vi - infinity of space) remain (approximately) valid. All the other ones are wrong. In fact, this last statement is founded on the knowledge of only the observable part of the Universe. The Universe at large may be, for example, Euclidean, and perhaps there is no general evolution (e.g. model of Jaakkola). Thus we cannot be sure which ones among the assumed properties are actually wrong. However, we can be absolutely sure that some of them (at least one) are unfulfilled in the Universe at large. The cosmological paradoxes are usually underestimated. In fact, they demonstrate clearly the power of thinking, which is able to make up for an absence of other types of perception and penetrate otherwise inaccessible regions.

We have arrived here at an answer to Question (1). This answer is negative, although few examples of non-model cosmological results can be cited to date.

**9.03. Cosmological principles and the evolution of world views**

The premises of cosmological paradoxes are of the same type as general assumptions formulated as cosmological principles. The very foundation of the Generalized Copernican Principle, the assumption of homogeneity and isotropy, can easily be found among the assumptions used for formulating the photometric paradox. Question (2) can be stated thus: are assumptions in the form of cosmological principles necessary for cosmological research at all? (cf.: Klotz 1979) To address that question, let us once more make a short review of the basic cosmological principles. The first known cosmological principle was conceived by the ancient Indian culture, where spiritual existence was considered the only important mode of being. This principle is so sublime in content that it is still impossible, even applying modern mathematics, to construct any specific model based on this principle. The cosmological principle based on the half-materialistic world view of the ancient Greeks is also half-materialistic and looks, from today's standpoint, like a mockery of reality. It is neither truly spiritual, nor strictly materialistic, trying to reconcile two, in fact contradictory, tenets. Copernicus furthered this process of considering the sensual world an agglomeration of material bodies. His cosmological principle, in contrast to their predecessors, regards also planets (i.e. a certain kind of celestial bodies) as physical bodies. A generalization of his principle leads us to consider all that we can perceive with our senses - all the Universe - a physical entity. In the course of this process, the Universe becomes, in the minds of scientists, more and more homogeneous.

The generalization of Copernican views seems to be self-evident for cosmologists. Sometimes they even do not take notice of what they assume (Einstein). However, here an important fact is involved. There was increasing awareness in the first half of the 20th century that there is something like a *cosmological principle* and that it is not given from above but rather assumed by cosmologists by choice. The period of purposefully creating cosmological principles began. One can find attempts to weaken the Copernican Cosmological Principle (the Softened Copernican Principle of Zieba, see 4.22). However, these attempts are not very typical. Better known and more characteristic of this epoch is the attempt to make the Copernican Principle stronger and narrower, the Perfect Principle. From a certain point of view, the birth of the Perfect Principle can be regarded as a final move towards a thoroughly materialistic view of the Universe, as it is indeed viewed by some conscious and dedicated materialists. For example, Jaakkola (1989) considers the Perfect Cosmological Principle as the only one satisfying the requirements of strict scientific thinking free from any metaphysical ideas. Therefore, he proposes to call it simply "the Cosmological Principle" without any other adjective. Can one proceed further in this direction? In an abstract way, yes; in any relation to reality, no (cf.: 5.10).

In the middle of the 20th century there began a peculiar process. Some considered it a new trend towards a spiritual comprehension of the world, some - just the opposite - as a tendency to reduce everything (including life) to a sub-physical reality, and still others considered it a complex mixture of both. Whatever it is and however it will be called by posterity, this trend marked a distinct departure from the classical form of materialistic science of the 19th century. Carter (1984) maintains that the Copernican standpoint (that the Earth is an average celestial body) was merely an unfounded reaction to the ancient Greeks' endowing a privileged position to the Earth as the center of the Universe. It seems that there exists a general trend today at least to bring together, if not to reconcile, many old and new convictions and principles, not only the cosmological ones. What are the main symptoms? The strict causal relations in physics are replaced with probabilistic causality for microcosmic phenomena and in certain sense also for macrocosmic ones (cf.: Neyman and Scott 1959). Some practices of folk medicine, rejected before as sheer superstitions, are generally accepted and practiced by certified physicians (acupuncture, acupressure etc.). The same pertains to some systems of esoteric medicine (homeopathy). Some astronomers do believe that the entire Universe is a living being (cf.: Hoyle 1988). Some beliefs of astrology are tested in scientific ways and accepted as scientific reality (cf.: Culver and Philip. 1977). Telepathy, the ability of foreseeing the future, telekinesis, and similar phenomena are being examined in official scientific institutes. Certainly this is a period of some scientific turmoil. It is too difficult to evaluate it at present and predict in which direction it will eventually go. In any case, a new cosmological principle - the Anthropic Principle - arose just in this period. Is this a spiritual principle which brings us closer to the idea of purposeful creation of the world, or is it, rather, a mechanistic perspective of seeing the Universe, which make it possible to claim that automata (intelligent and feeling) will replace humanity? The matter here is much confused. This particular cosmological principle is a true child of its scientific time.

### 9.04. Cosmology and the Gaia Hypothesis

It seems to be not incidental that more or less simultaneously with the Anthropic Principle, another scientific conjecture which also attempts to unite physical existence with elements of life and consciousness appeared. It is the Gaia hypothesis (Lovelock 1979). The hypothesis (which in its original formulation and in the opinion of other scientists, considers the Earth as a more or less "self-aware" organism capable of exploiting other beings for its own good and capable of defending itself but also endowed with some kind of "feelings" toward earthly mankind) belongs - from the formal standpoint - to geophysics but is closely related to cosmology as well (cf.: Follgett 1988). If the Earth is an "organic" being, then what about the other planets? What about all the celestial bodies, what about the entire Universe? One could even think that this hypothesis says more than the Anthropic Principle in its three versions. The Anthropic

Principle states that the Universe is capable of producing and maintaining intelligent beings.

If we extend the Gaia Hypothesis to all celestial bodies and their agglomerations, then we obtain a Universe which is not only able to produce and maintain intelligent beings but is also intelligent in itself.

This opinion is close to the old Indian views that the Universe is a Body of some spiritual being (possibly even of the Highest Spiritual Being). However, the basic difference is that the Indians considered only spirit of importance, whereas in the Anthropic Principle and the Gaia Hypothesis such properties as life, intelligence, and consciousness are all closely related to or even (in some interpretations) deduced from material existence. It may be said that in the old Indian times the spiritual aspect of existence was overestimated, and only the later evolution of scientific views led to ascribing more significance to the material aspect of life. Ideas of that kind reached their climax in the Perfect Cosmological Principle. And now it tends towards equilibrium of some sort: acceptance of the physical and the spiritual aspects of the Universe as equally valuable. The spiritual side is sometimes understood as autonomic or even as primary - that which brought the sensory world to existence. Sometimes it is considered secondary, something descending from physical reality. Both these versions do somehow coexist in science. In this new approach to the Universe and to its spiritual-physical existence the modern tendency to attain a certain kind of balance between spiritual and materialistic world views manifests itself.

One can say that the Gaia Hypothesis supports the Anthropic Principle. In fact, the situation is not so simple. The Anthropic Principle provides the argument that the size of a physical and intelligent being striving to knowledge must be approximately the size of a man. If we, following the Gaia Hypothesis, allow the physical intelligent beings to be as large as the earthly globe (if not the stars), then some important arguments usually used in support of the Anthropic Principle have to be rejected. Both the hypothesis and the principle arose out of the same philosophical attitude. However, they do possess some features which are mutually contradictory.

**9.05. Future cosmological principles**

Can we expect some further cosmological principles? What kinds will appear in the future? That strictly depends on the evolution of scientific world views. So far, we can see an enormous proliferation of models in all the fields of science. This is an obvious consequence of the proliferation of computers. And understandable, too. When there are new tools available it is profitable to see what can be obtained using them. As long as this development proceeds, mathematical modeling will not ebb. Such models must be calculated from well-defined assumptions. For cosmology it means that cosmological principles (old or new) will remain fundamental for cosmological research as long as constructing mathematical models dominates scientific research.

This demand for strictly and consciously formulated assumptions for the purpose of ca1culating models brought about the formulation of the "minor" cosmological principles discussed in the Chapter 7.

However, no scientific style of research has lasted forever. Today we can see the development of some quite novel approaches to scientific investigations, methods which are likely to replace the old ones. Almost all of present day science has developed in the following manner: one makes a hypothesis and then tests whether or not observations and experiments confirm it. Fritz Zwicky (1957, 1959) developed another approach to reality. He proposed not to form individual hypotheses but to take into account all plausible hypotheses and then exc1ude those that have not withstood verification. One thinks here in a rather deductional way, and the research is done using as few assumptions as possible. Zwicky's method has been developed within the general stream of Goetheanism (see. Appendix), which in the last decades has spread among some scientific circ1es. Is this a trend to deliver cosmology from accepting *a priori* philosophical assumptions, from using cosmological principles?

After the epoch of direct, mental seeing of the truth (Ancient India), after the epoch of coming upon intellectual truths through revelation (Egypt, Chaldea, Babylon), after the epoch of deriving all truths from logical thinking (Greece, Rome, up to the Middle Ages) comes an epoch which tries to found all logical thinking on physical experiment. In its contemporary stage it attempts to calculate models of everything or states hypotheses which have to be checked *afterwards* by comparing them to reality. In all these epochs the power of thinking was used - but differently in each one.

Should we be so self-satisfied and arrogant as to think that our approach to thinking as a scientific tool is the superior and concluding one? Are we to believe that human thinking cannot be used for scientific purposes in a still better way?

Fritz Zwicky used to say that the most important scientific instrument is the scientist himself and that this instrument must be well set, well adjusted. Do we really think that the scientific attitude most common today is the best possible?

### 9.06. Is any simplification a shortcoming?

The above considerations were stated with the *implicit* assumption that the cosmological principles' simplification of the structure of the Universe is their weak point. We want to obtain a true picture of the Universe and so look for a possibility to bypass cosmological principles. This is not the only stance possible. Stanislaw Zieba (1991) maintains that cognition of the actual structure of the Universe cannot be regarded as the true aim of cosmology. The Universe is too complicated, even in its most general outline, to be comprehensible for us. We simplify its picture using cosmological principles because we want to do so.

The principal aim of science is to provide simplified pictures of reality: Even the logic we use as the basis of every scientific argumentation is - according to Zieba - not the way we actually think, not the way we distinguish truth from falsehood, but just a model of our thinking, a simplified model of human cognition of reality. Woe betides him who trusts the received laws of logic as absolute ones. The same situation exists in other disciplines of knowledge. And so it must be in cosmology. The physical Universe is *ex definitione* the largest object of sensory investigations, and it is enormously complicated, even in the regions accessible by observation. When we want to describe the distribution of extragalactic objects in neighboring regions of our Galaxy, we do not give spatial coordinates of all extragalactic objects, even if they are determined. Such a true picture of the distribution of objects is just incomprehensible and thus useless for us. Also, in cosmology we have to look for the most basic features of the structure of the Universe in order to understand it. In this sense, cosmological principles will be always needed and useful. There can even be a number of cosmological principles, not necessarily consistent with each other, each one revealing a different feature of the Universe. The problem consists in remaining aware of the extent to which each of the principles accepted approximates reality.

One cannot object to this idea, but a remark should be made that in Zieba's view the cosmological principle is regarded more as a result than as a tool of cosmological research.

**9.07. Models without principles**

We have .arrived at the conc1usion that it is possible to use cosmological principles without constructing models and also that one can practice cosmology without involving cosmological principles. The question still remains if it is possible to create models without resorting to cosmological principles. Ellis wrote that "...we are unable to obtain a model of the universe without some specifically cosmological assumptions which are completely unverifiable," - but what sort of unverifiable assumptions did he have in mind?

This question can be understood in various ways. If we ask whether one has to consciously accept some philosophical assumption as a cosmological principle, then obviously the answer is negative. Neither Eudoxos nor Hipparchus was aware of the Ancient Greek Cosmological Principle as such. Einstein, when introducing the assumption of homogeneity of the Universe, considered this just a simplifying mathematical assumption and did not expect that in the future it would be ranked as a cosmological principle. A cosmological principle has to be used first - explicitly or implicitly - by a certain number of scientists and only later acknowledged as such. Even the deliberately created Perfect Principle, which was so named right after its conception, does not breach this rule. However, it may be asked whether one can construct a model involving no philosophical assumptions, only mathematical and physical ones. Of course we do not like to ask silly questions. We are aware that philosophical assumptions are involved in all mathematics and physics and many of them are unverifiable. Thus perhaps the question should be so formulated: is it possible to create a model of a Universe without introducing any assumptions not commonly used in mathematics and physics? This was done several times. It was the case with the model called Schwarzschild's solution in general relativity (cf.: 2.12). This solution was found by Schwarzschild in 1917, when Einstein constructed his first model. It describes the case of all mass concentrated in one point in empty curved space. This was considered at first by all the physicists and by Schwarzschild himself as a solution useful only for celestial mechanics and not relevant to cosmology. Only many years later was it realized that this is a kind of Universe model, remarkable from a methodological point of view. Schwarzschild's solution found an application in the theory of black holes, which are sometimes considered as little universes. Thus it obtained the status of a cosmological model, even if not corresponding to the actual Universe.

Apparently the model of Gödel (1949) was also constructed without any particular cosmological principle. However, in fact, it fulfills an assumption very similar to that of the Zone-Model of Zieba. The mean density of mass in both models is constant all over space. There is a preferred direction in any space point. It is the rotation axis direction for Gödel; it is the direction perpendicular to local density layers in the Zone-Model. The anisotropy distinguishes it from the Generalized Copernican Principle. The model of Gödel also fulfills the Softened Copernican Principle (4.22).

Ellis and his collaborators (1978) proposed the so-called *Static Spherically Symmetrical (SSS) Universe Model* with our Galaxy in the center of the Universe. Instead of any cosmological principle, two features were assumed, static character and spherical symmetry. One can say that this was a particular philosophical assumption, not a cosmological principle. However, if there were a number of models based on that assumption of spherical symmetry, it would certainly deserve to be ranked among the cosmological principles. In 2.13, I called it the *Generalized Ancient Greek Principle*.

### 9.08. What is a cosmological principle?

Up to now, we have considered more than thirty cosmological principles, most of them known only to a small number of specialists. As we have seen, six of them exerted a considerable effect on cosmology. Out of those six, three are often used and discussed in contemporary cosmology. We reviewed specifications of a number of cosmological principles and found that most of them are useful in extrapolating the properties of the observable parts of the Universe to the unobservable ones. We saw also that not all statements, not all hypotheses, proclaiming something about those unobservable parts, can count as cosmological principles. However, we did not come to any general definition;
we still do not know what is a cosmological principle and what is not.

Exact definitions are usually not easy. We had trouble defining what a theory is and what a model is. The same is true for most other areas. Can we strictly define what is (and what is not) a philosophical idea, what is (and what is not) a law of nature, what is (and what is not) science? We have some ideas about them but there are no strict definitions which would be acceptable to everybody.

It cannot be strictly delimited what is a cosmological principle and which, even remarkable and general, statements about the Universe are to be considered as cosmological hypotheses but not as cosmological principles. However, allowing myself to present my rather lenient demands in this area, I propose that a cosmological principle is a statement fulfilling the three following conditions:

a. it states something about important features and properties of the Universe as a whole;

b. it indicates how to extrapolate our local scientific results to the entire Universe, or it explains why such an extrapolation is not possible;

c. it is embedded in some general attitude concerning human knowledge.

Of course any group of cosmologists, or even an individual cosmologist, can have their own judgment regarding what is an "important" and what is an "unimportant" property of the Universe. And naturally everyone will have his own general attitude concerning human knowledge.

# Goetheanism in science

By Konrad Rudnicki

Appendix to “The Cosmological Principles”

a.0l. The inconsistencies of some theories of knowledge

There is a widespread belief that a sharp distinction must be made between thinking (something entirely subjective) and perception (something having an objective origin but thoroughly contingent upon man's physiological and psychological constitution). It is through the interaction of perception and thinking that a gradual development of the process of the cognition of reality (Immanuel Kant called this a thing-in-itself) inaccessible in any direct way comes about. The subjective character of thinking is usually taken as an axiom. The conditioning of perception by physiology (it is electromagnetic waves that are really there, and we perceive them as colors, heat etc.) is supported with evidence from the natural sciences. Various theories of knowledge lead to various, even diametrically opposed conclusions - from the belief that the thing-in-itself is absolutely beyond any cognition to the assumption that there are ways of obtaining some knowledge of it.

Theories of knowledge thus rely on particular research disciplines (neuropsychology, electromagnetism, acoustics etc.) while it should be the other way round. Any particular research discipline should be first verified by the theory of knowledge. So here is a vicious circle. This poses considerable difficulties in constructing a self-consistent and reliable theory. Due to this, even the very term “theory of knowledge” is seldom used nowadays. The methodologists prefer to use the term paradigm (i.e. some pattern of scientific procedure), leaving aside the question of its justification. If a given procedure proved successful in the past, then we too hope to succeed using it. It is the pragmatic criterion of usefulness that is at work here, not that of truth. Furthermore, it is not possible to define "what is truth" (cf.: John 19,38).

**a.02. The Goethean theory of knowledge**

Johann Wolfgang von Goethe achieved recognition primarily as a poet who during his life had also published some papers on science. However, Goethe himse1f claimed to be a scholar who had written some poetry at his leisure. Goethe's papers are mostly small contributions to science. However, it is not the results of Goethe's research, but his specific method of thinking and research which is of special interest to those scientists who call themselves Goetheanists and who apply in their verification of truth the Goethean ideas based on an alternative theory of knowledge.

A theory of knowledge should not rely on data of any particular research discipline. A theory of knowledge must logically be prior even to logic; it cannot depend on any logical or scientific assumptions. To construct such a theory, the Goetheanists propose a picture of the process of cognition, which can be taken for granted as obvious or rejected outright. This is a matter of personal attitude. One who is not ready to accept the Goethean view is just not a Goetheanist, and there is nothing to argue about.

### a.03. Pre-scientific base; mental experiment

The foundations of a theory of knowledge must be of a pre-scientific character. A description of the process of cognition can be obtained by the following thought-experiment. Make an effort to forget for a while that you know anything, and scrutinize your cognitive process. One should not pretend to have become a child or a primitive man. We want to have a theory of knowledge for a civilized, adult person of the current century. Thus, let us look upon ourselves such as we really are, leaving aside all the stock of accumulated knowledge, and observe a small interval of our own life. An aid for such an experiment may be found in Johannes Volkelt (1879), a philosopher who described a few minutes of his own life as follows:

"*Now, for instance, the content of my mind is that I have done a good deal of work today; and with that goes the idea that now I should have a well-deserved walk; in this very moment I have the perception of the door opening and a postman coming in; the postman's image undergoes changes; once he holds out his hand, once he opens up his mouth, once he does the opposite; the perception of opening mouth is accompanied by various sound perceptions including that it has just begun raining outside; the postman's image disappears from my consciousness, and in turn come the following ideas; seizing scissors, cutting the envelope open, objection to the illegible hand, shapes of particular letters and words, and various thought and mental images connected with them. As soon as this series is over, back is the idea that I have done much work and the perception that it is still raining accompanied by the feeling of dissatisfaction; then both vanish from my mind and there appears the idea that one problem which I believed to have solved during today's work has not been solved at all; in fact, there are other ideas: freedom of will, empirical necessity, responsibility, the value of virtue, pure chance, incomprehensibility, etc.; all the ideas associate with one another in various, most complex ways. And it goes further like that*."

### a.04. Thoughts as perceptions

I cite this passage by Rudolf Steiner (1886), who first presented the Goethean Theory of Knowledge in an easily understandable form. From those few sentences from Volkelt we can see that in the field of our consciousness we find, originally on equal footing, perceptions of various kinds such as sensations, reminiscences of the past, feelings, acts of will, and thoughts. Initially none is more important than any other; none is better explained or accounted for than any other. Yet we immediately feel the need for providing some explanation, associating and grouping details of this much diversified, but quite flat, field of conscious perceptions. A more detailed description of the Goethean cognitive process can be found in the work of Steiner cited above. The most important thing for us is that in this approach *thoughts* are treated as *perceptions*; they are not placed in opposition to perceptions. Our thinking may and does have particular qualities not shared with other kinds of perception, but we perceive our acts of thinking in a way similar to how we perceive our sensory impressions, our feelings, our acts of will, our reminiscences....

We'll feel a sort of anxiety when a new perception appears within the field of our consciousness. And then we feel satisfaction when we succeed in associating a particular perception (which is not perception of a thought) with the relevant thought. This is a basic act of cognition. Only in exceptional cases can such an act be followed as it proceeds in time. For example, I see some blue thing on a distant tree in my garden; I wonder what it could be: a bird, an empty can, the cover of a book, a piece of plastic, or just my son's pants; and then I recognize it: my wife's cap; now I have found cognitive satisfaction. An elementary cognitive act of this kind is usually too momentary to follow or (in the case of some scientific research) too extended over time to grasp as a single unity. However, this is the picture which appears (to some persons) as a result of the proposed mental experiment. Whoever accepts this picture can follow the further paragraphs. Whoever considers the picture to be not true may stop reading here.

### a.05. Particular properties of thoughts

A detailed inner inspection of cognitive acts shows that, in general, every perception has, symbolically speaking, a kind of shell, which can be penetrated to the core by another perception, (i.e. by adequate thought). Thoughts differ from other kinds of perceptions in that they have no shell, or, rather, their shell is identical with their core. Every thought is accounted for by itself; there is nothing concealed in it. If the thoughts' triangle, cause, effect appear within the field of my consciousness, they need no external explanation. Of course thoughts can be associated with each other. The thoughts equidistant from a point and homogeneous curvature can be associated with the thought plane figure, and it can be considered that they are all inherently associated with the thought circle. We feel cognitive anxiety when contemplating whether and how a certain set of given thoughts can be associated in a natural way, and we are satisfied when we combine thoughts properly. However, a single thought, unlike the other kinds of perception, does not cause such anxiety. A thought gets to the very essence, to the foundation of things; there is nothing beyond.

### a.06. Subjectivity and objectivity of thinking

Thoughts are subjective in that they can be freely moved around within the field of our consciousness. They are objective in that they cannot be associated in a manner other than that determined by their proper nature. One can think of anything one wishes, but having chosen some particular set of thoughts, one is unable to influence the result of the thinking process. Of course we are concerned here with .actual thinking, with perceiving and putting together thoughts (i.e. notions and ideas), not with dreams or dreamlike imaginations. The thought “My football team must win” belongs rather to the domain of imagination or feelings. Wishful thinking is no thinking at all. It is an objective fact that two times two makes four, and it is accepted by everyone, whatever imaginings he may have, when he is able to perceive the notions: two, times, makes and four. It is true that in some systems of formal arithmetic there is, for example, 2 x 2 = 5. However, here thoughts quite different from the common two, times, makes, and five are associated with the symbols 2, x, =, and 5.

**a.07. Cognition as revelation**

The process of cognition (i.e. association of some perception with the perception of a thought (in particular cases, the association of two thoughts) is a kind of "revelation." Goetheanism sees no fundamental difference between research done in mathematics, physics, humanities, or theology, provided we mean actual research, not just the construction of arbitrary images. However, this does not mean that there are no differences at all.

**a.08. Various levels of thinking**

It follows from a detailed observation of the cognitive process that thoughts of the simplest kind, notions (i.e. thoughts subject to propositional calculus and the theory of quantifiers), are able to explain the perceptions in the domain of physical and chemical phenomena. If we proceed to the domain of the simplest living beings, plants, we must pass to a higher level of thinking - that of ideas. Ideas are complex associations of notions in constant movement and include whole classes of concepts subject to inner metamorphoses. The difference between a notion and an idea is like that between an individual house and a town. The problems of planning a house are far different from those of planning a town, though a town consists mainly of houses. However, in both cases there are objective rules to be followed. A higher level of thinking must be applied when we want to investigate feeling creatures - animals, and still higher ones when studying self-conscious creatures - human beings. Of course one may be interested only in the physical and chemical structure of man, and then the first level of thinking is sufficient. In a similar way, one may take interest in the animal nature of man, or in the vegetative nature of animals; then the respective lower level of thinking is sufficient. In physical cosmology, in fact, we do not go beyond the physical phenomena. Even the Anthropic Cosmological Principle has so far been applied only to the physical shape of the Universe. Therefore, I will not discuss here the problems related to those higher levels of mental activity. However, when we want to comprehend the Universe with its life and consciousness beyond the abstract, formal way as proposed by the Anthropic Principle, then we have to develop these higher levels of thinking - which are by no means to be confused with vague, or worse, self-delusionary kinds of comprehension.

**a.09. Reality constituted of perceptions**

Our perception of the moon's shape is qualitatively equal to our thoughts of the moon. A thought concerning the moon is not less objective than any other perception of it. If I am able to think anything about some object - truly think - not just form some arbitrary image - then I already know something of it. Hence there is no thing-in-itself which is unknown in any aspect. If we were to think that the thing-in-itself is a thing that cannot be thought about, we would have to admit that our thinking is inherently contradictory; it would be no thinking at all.

Reality is constituted solely of perceptions. Indications of measuring devices and the output of computer calculations are perceptions, too. And thinking enables us to obtain knowledge of objective reality out of that immense variety of perceptions. No limits of human understanding can be set, though there are individual limits to the knowledge of a particular person or temporarily limits to the knowledge of humanity as such. Beyond these limits, there are perceptions not penetrated by thought and perceptions not yet made. Goetheanism sees no limit to knowledge. Thus, a cosmological horizon cannot be accepted as such a limit.

Everything around us is constituted of various perceptions. Therefore, there is neither the need nor the possibility of distrusting them by raising objections that they distort reality. The perception of a red light is as correct as the perceptions connected with studying the corpuscular or undulatory nature of that red light. The fact that the redness can be perceived in a different way by a normal man, a partial daltonist, and an absolute daltonist or that light involves both undular or corpuscular phenomena can be ordered by appropriate thinking and relevant associations. Thinking is able to overcome illusions of the senses as well as logical errors by recognizing and explaining them.

After all, the illusions are real illusions, and the errors are actual errors; in other words, they too belong to reality. The phenomenon of the Sun moving around the Earth is commonly perceived and as real as that of the Earth moving around the Sun, which is established by mental ordering of other perceptions. By thinking we decide which way of looking at things is the most suitable one for a particular problem. Thus it does not surprise a Goetheanist that geocentric coordinates are still used for some astronomical purposes (cf.: 2.12).

**a.10. Basic phenomena**

For a thinking person the pitfall of misinterpreted phenomena seems to be a much lesser threat than that of considering the phenomena as non-real (as opposed to any "objective reality" or, as Kant puts it, to the "thing-in-itself"). Scientific research in the Goethean sense consists of reducing complex perceptions, observational phenomena, to basic (or fundamental) phenomena, which may, but do not have to, belong to the domain of sensory perceptions. Looking for simple phenomena and simplifying other, more complex, phenomena constitutes the very essence of research work for a Goetheanist.

A thrown stone is the classic example used when reducing complex phenomena into basic ones. Steiner in his book on Goetheanism (1886) uses it, too. A thrown stone traces a complicated trajectory and falls back to the earth. We can divide this phenomenon into the following basic ones. First, we have the free fall component. If nothing else were involved, this motion would occur along a vertical straight line with velocity changes described by the familiar physical law. Yet we also have a horizontal component. If only this were to govern the trajectory, the stone would move along a different straight line with a constant velocity. Air resistance is also at work here. The first two basic components govern the main properties of the stone's motion. The third one only modifies them, not changing it in any qualitative manner. One can find still other modifying factors such as the motion of air (wind), the shape of the stone itself, etc. One can describe the motion of the stone without dividing it by providing a ready mathematical equation of motion. But then the trajectory would remain not accounted for. Thus in almost all physics textbooks this division is performed.

There are much more complicated phenomena than that of a thrown stone. Many phenomena in astronomy, physics, chemistry as well as some in botany are already considered in a Goethean sense. This work has not been accomplished yet in cosmology. Only some first attempts have been published (ef. Rudnicki 1992), but they do show us clearly that it is possible to think about the Universe as a whole without the help of philosophical assumptions - without cosmological principles. Some cosmologists think that work with cosmological principles, though fruitful, will be replaced by grasping the universe with the help of basic phenomena belonging to the realm of perceptions, but not necessarily physical perceptions. [1]

### a.11. One hypothesis versus a totality of hypotheses

Another important feature of the Goethean approach consists of dealing not with just one individual hypothesis concerning a given problem but with a number of hypotheses, all the plausible hypotheses, if possible. The general custom in science is just the opposite. One usually sticks to one hypothesis and looks for positive arguments supporting it. This brings science to the situation which the great Goetheanist Fritz Zwicky (1957) described as follows:

*"If rain begins to fall on previously dry areas on the earth, the water on the ground will make its way from high levels to low levels in a variety of ways. Some of these ways will be more or less obvious, predetermined by pronounced mountain formations and valleys, while others will appear more or less at random. Whatever courses are being followed by the first waters, their existence will largely prejudice those chosen by later floods. A system of ruts will consequently be established which has a high degree of permanence. The water rushing to the sea will sift the earth in these ruts and leave the extended layers of earth outside essentially unexplored. Just as the rains open up the earth here and there, ideas unlock the doors to various aspects of life, fixing the attention of men on some aspects while partly or entirely ignoring others. Once man is in a rut he seems to have the urge to dig even deeper, and what often is most unfortunate, he does not take the excavated debris*

*with him like the waters, but throws it over the edge, thus covering up the unexplored territory and making it impossible for him to see outside his rut. The mud he is throwing may even hit his neighbors in the eyes, intentionally or unintentionally, and prevent them from seeing anything at all."*

**a.12. The shape of a problem**

Zwicky and other Goetheanists propose the following: When a scientist approaches a new problem, he should first establish the shape of it (from the Greek word for shape - morphe - Zwicky called this approach the morphological approach; cf. Zwicky 1959, 1969). The limits of the investigation must be clearly established. In the real world everything is related to everything, but we are not able to investigate all the complex interconnections at once. For instance, if one is to study the perihelion shift of a planetary orbit, one must decide whether to take into account all plausible gravitation theories, all gravitation theories known, or just one of them, whether to consider only the known masses, or to acknowledge the presence of hidden ones, etc. Such a well-defined, limited domain of investigation should be put to closer scrutiny in selected places (since we cannot look at everything at once). Thus, even prior to any actual investigation, we can perceive the shape of the problem within the limits we have established for ourselves. It is good to study every problem from the beginning in order not to be led astray by existing views, artificial constructions and hypotheses. Only the proper performance of this step can lead to the right result in the next steps, which vary in different research disciplines.

**a.13. Morphological box**

In exact sciences - and we want to develop cosmology as such - one has to divide the total problem into individual elements, which may be continuous (e.g. the variability range of some physical constant) or discrete ones (e.g. number and kind of symmetries of hidden space-time dimensions in Kaluza-Klein cosmology). Of course any problem can be represented parametrically in an infinite number of ways. The choice of relevant parameters is crucial. If our perception of the problem's shape has not been clear enough - if we have selected the wrong parameters - we cannot hope to obtain anything significant. Unfortunately, there are no ready specifications of how to select parameters. Important research cannot be done by merely following ready prescriptions.

After that, a morphological box may be constructed. It is a multidimensional parametric space, whose particular dimensions may be continuous or not, infinite or finite, according to the nature of the parameters chosen by us. Each point represents a possible solution of the problem, a set of values of our parameters. Every point is an explanation of the complex phenomenon under investigation, a hypothesis. If we assume that there is just one reality, then only one hypothesis can be true.

A morphological box in the form of discrete points is rather rare. In most cases, at least some of the parameters are continuous ones. Accordingly, we obtain a continuum of hypotheses and have to deal with many possible classes of them at once. Now we remove from the box the areas corresponding to the classes of hypotheses which are to be excluded within the given formulation of the problem because they do not agree with the observational experimental evidence available. In the ideal case, the procedure would yield a unique point, corresponding to the correct theory of the investigated fragment of reality. Such an ideal situation is exceptional. In most cases one obtains a number of detached domains or, at best, one large domain including an entire class, a continuum of hypotheses. Thus we have a qualitative result, delimiting the domain where the truth is, yet we still are not able to determine the truth unequivocally. The antagonists of Goetheanism find this situation unacceptable. The Goetheanists reply that it is better to know the truth in an approximate way (the broad domain within the box) than aspiring to the unequivocal truth, to investigate just one hypothesis (an individual point within this domain), which may actually correspond to the truth but most often does not.

**a. 14. Theory and reality**

Even if the morphological box yielded a unique theory, we could hardly claim to know all the truth. Any theory is no more than a representation of reality as determined by the particular formulation of the problem. If, for example, we solved in an unequivocal way the problem of galaxy formation based on Newtonian mechanics, then we can broaden our perspective by using other theories (General Relativity, Dicke-Brans, Milgrom etc.). If we solved it assuming the Generalized Copernican Principle, we can then extend our investigations to other principles. A theory is always only an approximation, which may be better or worse but never completely exact. A theory can fit only some fragment of reality. Reality is ever much more complex, rich, and fascinating. In the best of cases, we can obtain an iterative sequence of theories, of which none is the conclusive one: A theory can be the object of interest for a methodologist or philosopher. For a scientist, a theory is but a tool, not the object to be investigated. In one of his famous aphorisms Goethe said: *Whoever cannot distinguish theory from reality is like someone who cannot distinguish between the scaffolding and the building itself*. A Goetheanist working in cosmology hopes to obtain a new perspective on the construction of the Universe as a whole; ideally, he does this with the help of basic cosmological phenomena and without any cosmological principles. However, he knows that this task is not an easy one. But even when he works in a "traditional way" (i.e. with cosmological principles) he tries not to stick to one of them but to consider all of them as various values of one parameter within the morphological box used.

[1] To avoid misunderstanding: under "not physical” perceptions are here understood not vague "mystical" feelings but conscious products of a "daylight" thinking process (laws of nature are not physical objects; we perceive them mentally). For details, see Steiner (1886).

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