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Cosmology: Myth or Science?

For the Golden Jubilee of the Indian Academy of Sciences, representing a culture which has investigated cosmology for four millennia

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1. Pre-Galilean cosmologies

1.1 *Ancient Cosmological Myths*

Cosmology began when man began to ask: What is beyond the horizon and what happened before the earliest event I can remember? The method of finding out was to ask those who had travelled very far; they reported what they had seen, and also what people they had met far away had told them about still more remote regions. Similarly, grandfather told about his young days and what his grandfather had told him and so on. But the information was always increasingly uncertain the more remote the regions and the times.

The increasing demand for knowledge about very remote regions and very early times was met by people who claimed they could give accurate information about the most distant regions and the earliest times. When asked how they could know all this they often answered that they had direct contact with the gods, and got revelations about the structure of the whole universe and how it was created. And some of these prophets were believed by large groups of people. Myths about the creation and structure of the universe were incorporated as essential parts of religious traditions.

In different cultures, the mythologies became drastically different, depending on the way the philosophical thinking developed and on the personalities of great prophets.In several of the world religions, both the universe and the gods were believed to the eternal; in others, the gods or one God created the universe. In some religions, there is no conflict between these views; initially the universe was identical with a god and the different members of his body developed into the different parts of the universe. In India during the Vedic period, the god Purusa was initially identical in the whole world, and part of his body became the Earth, other parts the Heaven; the Sun formed from his eyes and the Moon from his soul. In other philosophical-mythological schools, both Heaven and Earth are regarded as gods and as parents of gods. Sometimes one god—in India, Agni or Soma or Rudra—and sometimes all gods together are said to have generated or created the whole universe.

In Rigveda, there is a remarkable poem telling that originally

> “There was neither Aught nor Naught, no air nor sky beyond”.

There was only

> “A self-supporting mass beneath, and energy above.
> Who knows, who ever told, from whence this vast creation rose?
> No gods had yet been born – who then can e’er the truth disclose?”

During the more than three millennia which have passed since the Vedic period, Indian mythology has developed a jungle of co-existing creeds, in part absorbed from neighbours, and in part from earlier cultures which had collapsed. The sophisticated mythological philosophy is, perhaps, somewhat less chaotic. There is a general tendency to consider the evolution of the universe as well as the human society to be periodic. Indeed, there is a hierarchy of periods. A golden age, followed by a silver, a bronze and the present iron age (Kaliyuga) forms a Mahayuga of 54,000 years. A number of Mahayugas forms a larger period, and so on in steps up to the Kalpa or the day of Brahma, which is 4×10^9 years. This is only half an order of magnitude smaller than what according to the Big-Bang hypothesis should be the 'age of the universe'. However, there are 365 Brahma days in one Brahma year, and Brahma lives for 100 years, so the ancient Indians used time units which were four orders of magnitude longer than in the Big Bang. (Of course, when Brahma dies after his 100 years, he is immediately reborn). Indian estimates of the size of the world were not so fantastic. Sometimes the figure10,000 yojanas is given, which means less than half the distance to the Moon.

The Mediterranean-Middle East thinking was initially as closely related to the Indian mythologies as Greek, Latin, and Persian are related to Sanskrit. The way of life of the people speaking these languages was also similar. The battle of Kuruksetra and the battle before the walls of Ilion took place at about the same epoch and were fought in a similar way. The heroes spent day after day fighting, and at dusk they went back to their camps, drinking and bragging. Their gods took a decisive part in the fight. (By the way, in Scandinavian mythology, the Vikings who fell in battle came immediately to Valhalla, where they enjoyed the same type of daily life).

In the same way, the Mediterranean mythology was initially similar with a golden, silver, bronze and iron age in sequence. However, the Greek cosmological philosophy which took the lead at the Greek cultural explosion around 500 B.C. did not develop like the Indian. First of all, the world remained very limited in time. Indeed, the guesses of the age of the world considered periods of some thousand years, which is only one micro-kalpa. On the other hand, the estimates of the size of the universe were not so different.

Not all the early cosmologies were so intimately connected with religion. The sages of China had no preconceived theories, and seem to have based their cosmological thinking more on phenomena which they observed. But the observations they could make did not suffice for any certain conclusions, and any more elaborate scenarios were no less speculative than those which originated from divine revelation to prophets.

1.2 *Buddhist Cosmology*

Buddhism developed views on cosmology which were drastically different from the other Indian cosmologies. As Buddhism is basically an agnostic religion, it does not deny the possible existence of gods, but it does not claim that there are any. The existence of gods is irrelevant to the aim of Buddhism, which is to find the right way to salvation, to the annihilation of desire, to the state of Nirvana.

As a logical consequence of this, when the Buddha was asked whether the universe was eternal or created he is reported to have answered in his characteristic style:

It is wrong to say that it is eternal.
It is wrong to say that it is created.
It is wrong to say that it is both eternal and created.
It is wrong to say that it is neither eternal nor created.

Perhaps this is an echo from the quoted Rigveda poem which probably derives from one millenium earlier: As man got his knowledge about the early states of the universe from prophets who got their knowledge directly from the gods, then no information could be gained about the epoch when the gods had not yet been born. Similarly, as the Buddha did not believe in gods—or in any case, did not care much about them—there was no possibility to get information about early cosmology.

Perhaps one could also find an echo two millenia later, when Descartes proclaimed: *De omnibus est dubitandum* (We should question everything). However, this is not altogether correct because Descartes had also inherited the Galilean scientific tradition according to which controversial issues should be settled by reference to experiment and observation. But there does not seem to be any basic logical conflict between Descartes and the agnosticism of Rigveda and the Buddha.

1.3 *Rise of Mathematics*

1.3.1 *The Pythagoreans*

A new element in the cosmological discussion was introduced by the rise of science and natural philosophy in Greece as a part of the cultural explosion around 500 B.C. The Greeks had absorbed astronomical knowledge both from the Mesopotamian and Egyptian cultures, and, as we have mentioned already, their mythology was genetically related to the Indian.

The new element consisted of the rise of geometry, which to a large extent derived from Egypt, where it was of practical importance for land surveying. The Greeks developed this to the still unsurpassed masterpiece of logically stringent structure which we know as Euclidean geometry. It is questionable whether the beauty of the theorem of the regular polyhedrons will ever be surpassed. By a simple discussion which anyone can understand in a few minutes, the *a priori* surprising conclusion is reached that there are five and only five such bodies.

Strongly connected with this, a much wider breakthrough of new thinking was achieved by the Pythagoreans. They demonstrated that the basis of musical harmony was simple ratios of integers. It is quite understandable that this led to a philosophical optimism. The Pythagoreans tried to incorporate astronomy and cosmology as well into their philosophy. They claimed that astronomy should be to the eye what musical harmony was to the ear.

This was indeed a revolutionary idea. It was the first attempt to construct a comprehensive mathematical scheme of cosmology and to work out a synoptic view of the universe as a whole.

One may say that its basic principle is that because the world was created by the gods, there must be a sublime order in its basic structure – even if many regrettable local disorders were obvious. According to the Pythagoreans, the most 'perfect' geometrical figure is the circle, and the most 'perfect' of all solid bodies is the sphere. *Ergo* the Earth must be a circular disk or a sphere, surrounded by a number of crystal spheres, on which the planets and the stars were located. Further, the most perfect motion was uniform motion. *Ergo* the crystal spheres must rotate with uniform velocity. This was necessary for the 'harmony of the spheres.'

1.4 *Relation between Theory and Observation*

Neither the Pythagoreans nor Plato cared very much for a comparison with observations. The Pythagoreans formed a secret society with no real contact with the rest of Greek society. Indeed, traitors were severely punished. The rules of Plato's Academy included: "Let none who has not learnt geometry enter here," and he advised all scholars to "concentrate on the theoretical side of their subject and not spend endless trouble over physical measurements to the neglect of theoretical problems."

This was in conformity with the general attitude of the intellectual aristocracy in Greece. The belief was that technology,including technological innovation, ought to be largely relegated to the lower classes, especially to slaves. It was degrading for a philosopher to get his hands dirty.

It has been suggested that this cleft between sophisticated theoretical thinking and practical work, including experiments, was the basic reason why the highly advanced science in ancient Greece never led to the scientific breakthrough which took place in Europe two millenia later.

1.4.1 *The Ptolemaic System*

When, in spite of Plato, observations began to attract interest, the Pythagorean cosmology seemed to be confirmed by observations in one respect: the outermost crystal sphere, the one on which the stars were fixed, did apparently move with a constant speed. This was just what could be expected because this sphere was the outermost one, closest to where the gods lived, and hence most divine. Unfortunately, the theory did not agree so well with observational results when applied to the planets, including the Sun and Moon. The Sun and the Moon sometimes moved more to the north, sometimes to the south, and a planet like Jupiter sometimes reversed its motion in relation to the stars.

It was obvious that something was wrong. But the basic principles—uniform motion and perfect geometrical figures—were sacrosanct and could not be given up even if they were in conflict with observations. Instead, very ingenious auxiliary ideas were forwarded. Planets are not directly fixed on the crystal spheres, but each is fixed on a small circle, an epicycle, which moved with a constant velocity with its centre fixed on the crystal sphere. For a time such theories looked promising, but better observations demonstrated that they were not accurate. The reaction of the scientists was to try to patch up an old fiction instead of asking themselves whether, after all, its basis was laid in truth. They tinkered instead of recreating. Hence, increasingly complicated additions to the system were made.

The result of this was the Ptolemaic system, which was worked out in the third century A.D. No less than 54 epicycles, eccentrics, *etc*., had been introduced. But at the same time, as it became more complicated, it became more sacrosanct. When an avalanche of religious fanaticism put the classical culture into a deep freeze for more than a millenium, it did not develop very much, and age made it still more sacrosanct. Criticism was dangerous, and it was a rare exception when the famous astronomer, King Alphonse X of Castile, complained about its degree of complexity: "Had I been present at the creation, I could have rendered profound advice."

1.4.2 *Astronomy*, *Astrology*, *and Myth*

This mathematically based cosmology did not come into serious conflict with the ancient myths. They became to a certain extent incorporated, and a jungle grew up of mathematics, astronomy, astrology, and myths from many earlier cultures. Gods and spirits of all kinds began to settle on the crystal spheres, soon causing a population explosion. For example, one group of constellations depicts how Perseus saved Andromeda from Medusa, whose terrible head is represented by a variable star. Still more dramatic is the giant hunter Orion, who, followed by the Big Dog and the Small Dog, lifts his club against the red-eyed Bull.

The early motion of the Sun along the ecliptic was illustrated by a number of sun-myths. For example, when Heracles fought a bull and later a lion, this is thought to represent the Sun's entry—on its walk along the zodiac—into the constellations Taurus and Leo. Another sun myth, in which Delilah cuts Samson's hair from which his strength derives, tells us that in the fall, when the Sun enters the constellation Virgo, its rays lose their heating power and he becomes a captive for half a year, until spring, when he has regained his force.

This chaotic conglomeration of mathematics, astronomy (including cosmology), and myths from many religions has turned out to be a permanent ingredient in our culture. Today, after more than 2000 years, it has as much vitality as ever. Newspapers and periodicals usually have astrological columns; every jeweller sells pendants and pins with signs of the zodiac. From the point of view of our commercialized society, there are many more dollars in astrology than in astronomy.

1.5 *Creation Ex Nihilo Versus Ungenerated Universe*

The rise of the monotheistic religions meant that one of the gods became more important than the others; He became the Pharaoh, the dictator of the Heavens, God with capital 'G'. He also became more important than the material world. He alone was eternal. He was not a product of the evolution of the universe, as in Rigveda. On the contrary, the whole world was a secondary structure created by Him. In the Bible the creation takes six days. It still has the character of bringing order into a pre-existing chaos. It was not until the first few centuries A.D. that creation was thought of as the production of the world *ex nihilo* (but this is never taught in the Bible). God had now become powerful enough to create the whole world by just pronouncing some magic words, or by his will-power.

Monotheistic religions have often a tendency to become fanatic. Certainly Christendom did so, at least during some periods. Tertullian said *Credo quia absurdum* (I believe because it is absurd). Hence there should be no serious attempt to reconcile religion and science.

In the Aristotelian philosophy the material world was 'ungenerated and indestructible', a view which is not in conflict with some of the Rigvedic views. It was not until medieval times that Aristotle's views were accommodated to the idea of creation *ex nihilo* essentially by Saint Thomas, who remodelled the Aristotelian philosophy in accordance with the requirements of ecclesiastical doctrine.

It is of interest to remember that even Saint Thomas confessed that *reason* could only be satisfied with the assumption that the world had no.beginning. “The doctrine of a beginning or the non-eternity of the world is to be received *sola fide*, as an act of pure faith in deference to authority.”

Not even the monotheistic religions were fatal to the old myths. The ‘pagan’ gods changed their names—some became devils, others became saints. In Italy, one pays homage to saints in the same places in the woods where earlier a nymph or a dryad used to live. They have only acquired more modern dress. Midwinter solstice was in ‘pagan’ times the festival of the Sun-god, and a fertility Moon-goddess was worshipped at the first full moon after the vernal equinox. These nice old traditions remain, even today, although with a modified meaning.

The ancient belief that the wandering stars governed the life of men was conserved and developed further. Astrology, mythology and religion formed an increasingly complicated, fascinating structure. The basic conflict between an omnipotent God and the old belief that our destiny is governed by the stars was patched over by the formula:

Astra regunt hominem, *sed regit astra Deus*
(Stars rule men, but God rules the stars)

The scientific basis of the Ptolemaic system, *viz*., that the stars move according to certain mathematical laws, was forgotten.

1.6 *Myth Versus Science; Mathematical Myths*

The Ptolemaic system was initially a quite attractive theory but, during the centuries, it developed into a sacred and rigid structure increasingly impotent in incorporating new discoveries. The reason for this was that fundamentally the approach was not scientific but mythological.* The basic ideas were the perfect geometrical figures and uniform motion. The idea of building a world system on such general principles represented great progress, because earlier it had been generally believed that events in the world were governed by the will or the whimsies of gods. The Ptolemaic system did not necessarily question that the celestial system was created by the gods, but it claimed that they must have acted according to certain philosophical or mathematical principles which it was possible to analyze and understand. A sufficiently sophisticated mathematician might find out what the divine mathematic principles were.

The Ptolemaic system originated from what we may call a *mathematical myth.*

The Pythagorean philosophy had a logical beauty which could well be called ‘divine.’ By pure abstract thinking the theoreticians claimed to have discovered the principles according to which the gods acted when they created the world. And when these principles were found, it was held that the world must be structured according to them. In a way, the demiurges had no choice; it was not even necessary that they existed. But not even observations of physical reality were necessary. The system was based on divine inspiration or logical-mathematical necessity. If Galileo claimed that in his telescope he saw celestial bodies or sunspots which *a priori* do not exist, it was his telescope and not the theoretical system which was wrong.

* It is a semantic question whether a model initially deriving from ‘divine inspiration’ should be called a myth even if it includes philosophical and mathematical elements. Some would no doubt prefer to call it, for example, ‘*a priori* metaphysics’.

But long before Galileo, new ideas had appeared in Islamic culture, which took the lead in science less than 100 years after the Hegira. In the twelfth century, Avaroës from Cordova claimed that the world is eternal—not created, but in a state of evolution (Singer 1959), a view which is similar to the hierarchical cosmology of today. In his impressive treatise Mugadema Ibn Khaldun (around 1400 AD) dared to oppose Plato's view that the world could be explored by logical thinking alone. Indeed, he said that "logic is not a safe way of thinking, because of its tendency towards abstraction and its remoteness from the tangible world" (Baali & Ward 1981). This is similar to Bertrand Russell's warning half a millenium later against 'unaided reason'. Ibn Khaldun claimed explicitly that *cosmology must be based on observations.*

1.7 *The Copernican System*

The Ibn Khaldun idea had to hibernate for two hundred years until it reappeared in Europe, where it led to the well-known crisis which resulted in the victory of the Copernican heliocentric system (but after some time the latter had to abdicate in favour of a 'galactocentric' system).

1.8 *The Tycho-Brahe Compromise*

During the fight between the geocentric and the heliocentric cosmologies, an ingenious compromise was proposed by Tycho Brahe. His cosmology accepted that all the planets moved around the Sun, but the Sun (together with all the planets) moved around the Earth. (The Moon also moved around the Earth.) In this way he satisfied the observations which indicated that the planets moved around the Sun, but he conserved the sacrosanct geocentric cosmology. The Tycho-Brahe cosmology agreed with observations about as well as the Copernican cosmology. But it soon turned out that the basic issue was another. It was the survival or defeat of a sacrosanct myth. The myth had been sterile. It had not been able to predict a single new phenomenon which later was confirmed by observation.

2. The introduction of the telescope

2.1 *Empirical Approach; Newton*

The real importance of the Copernican revolution was not that a geocentric cosmology was replaced by a heliocentric one, but that the new approach to cosmology was based on observations, not on mathematical-philosophical principles. The Ptolemaeans had never clearly understood that—as Bertrand Russell puts it—"mathematics is the science in which you never know what you are talking about, if what you are saying is true". Indeed, "it deals with hypothetical entities and it is only concerned with their relationships to each other, being indifferent to whether anything in the real world corresponds". This means that mathematics is suitable to give prestige to any idea, but if the idea is a myth, mathematics can turn it into a 'mathematical myth', but not guarantee that it has anything to do with reality.

The observational approach was essential because Galileo's introduction of the telescope led to a rapidly increasing avalanche of observational facts. Galileo, Kepler and Newton established new laws of nature which accounted for the observational facts with a surprising accuracy. From them it was possible to predict several phenomena which later were observed. At the same time they had a mathematical ‘beauty’ which perhaps even surpassed that of the old laws. But it was clearly understood that they were not sacrosanct. Newton said: ‘*Hypotheses non fingo*’ (I do not make any hypothesis.) However, they remained unchallenged until the beginning of this century. The transition from a heliocentric cosmology to a galacto-centric cosmology and later to cosmologies with the centre in our cluster of galaxies, *etc*., did not lead to any crises. Indeed this transition was predicted by the Newtonian theory.

An important result of the new approach to cosmology was the abolishment of the old division of physics into ‘mundane physics’ and ‘celestial physics’. According to Aristotle, all phenomena ‘*sub luna*’ (below the Moon) were ruled by the former, whereas the latter ruled events at or above the lunar orbit. The only one who earlier had questioned this was Giordano Bruno, but it was proved to be true by Galileo and Newton. It was the falling apple in Newton’s garden which smashed the sphere which separated the two disciplines of physics.

Let us now return to the difference between myth and science. This is the difference between divine inspiration or ‘unaided reason’ (as Bertrand Russell put it) on the one hand and theories in intimate contact with observation on the other. The enormous inflow of observational material caused by the introduction of the telescope could not be accommodated within the crystal spheres. They were blown up by the injection of so many new observational facts. It is fair to say that *the ‘Copernican revolution’ was caused more by Galileo’s introduction of the telescope than by the Copernican theory.* In fact, Aristarchos had proposed the same theory 2000 years earlier, but because there were no telescopes it could not be proved.

2.2 *Limitations of Newtonian Theory*

At the beginning of this century the Newtonian formalism was challenged in four different respects:

1. It was obvious that it was not applicable to atoms, where it had to be replaced by quantum mechanics.
2. Motions with velocities which were not negligible in comparison to the velocity of light must be treated by the special theory of relativity.
3. The general theory of relativity required that the three-dimensional Euclidean space of Newton be replaced by a four-dimensional curved space.
4. It became obvious that electromagnetic phenomena were of decisive importance for the motion of ionized diffuse media. It was necessary to introduce magneto-hydrodynamics and plasma physics into cosmic physics.

While the consequences of (1) and (2) are non-controversial, we shall discuss (3) and (4) later in Sections 3 and 4.

2.3 *Science and Old Myths*

How did the scientific breakthrough affect the old myths? To several of the pioneers it seems not to have been a real conflict. Tycho Brahe and Kepler, for example, were not only prominent scientists but also prominent astrologers. (Even in present times, when a day has been extremely unlucky, Scandinavians often exclaim: “Today is a real Tycho-Brahe day!” The reason for this is that he published a calender of those days when the constellations were very unfavourable.) With regard to some of the pioneers, this lack of conflict may have been because it was dangerous to oppose the existing beliefs, or because some earned their living as royal astrologers. But it seems obvious that such an explanation does not suffice. In his letter to Bishop Bently, Newton himself wrote that his celestial mechanics proved the existence of God, and he spent his old age in calculating how many angels there were according to the Apocalypse.

2.4 *Science and New Myths*

The victory of science over myth in the field of celestial mechanics spread slowly to other fields. It took more than two centuries before it seriously invaded biology. In our century the scientific approach has embraced other areas which earlier were alien to it, such as the origin of life and the functioning of the human brain.

However, this does not mean a complete and definite victory of common sense and science over myth. In reality we witness today an antiscientific attitude and a revival of myth. This tendency has at least two causes. The popular creationism in the South in the United States derives from religious fanaticism. But in a way, the most interesting and also most dangerous threat comes from science itself. In a true dialectic sense it is the triumph of science which has released the forces which now once again seem to make myths more powerful than science and causes a ‘scientific creationism’ inside academia itself.

2.5 *Special Relativity*

One of the most beautiful results of science was the *special* theory of relativity. It was essentially based on the Michelson-Morley experiment and on Maxwell’s theory of electromagnetism, which in an elegant way described all the results of the study of electric, magnetic, and optical phenomena. Already when expressed in an ordinary three-dimensional Cartesian coordinate system, the special theory of relativity is a beautiful theory, but its mathematical beauty is definitely increased somewhat if it is expressed in four-dimensional space.

This fact was given an enormous importance. It was claimed that “Einstein has discovered that space is four-dimensional”, a statement which is incorrect. In fact, H. G. Wells (1894) has based his ingenious novel, *The Time Machine,* on the ‘generally accepted idea’ that space was four-dimensional, with time as the fourth coordinate. This novel was published when Einstein was fifteen years old.

However, the fourth coordinate which Einstein introduced was not time, but time multiplied by $\sqrt{-1}$. From a *mathematical* point of view this is elegant, because it meant that the Lorentz transformation can be depicted as a turning of a coordinate system in four-dimensional space. However, from a *physical* point of view it does not give any new information.

Many people probably felt relieved by being told that the true nature of the physical world could not be understood except by Einstein and a few other geniuses who were able to think in four dimensions. They had tried hard to understand science, but now it was evident that science was something to *believe* in, not something which should be understood. Soon the bestsellers among the popular science books became those that presented scientific results as insults to common sense. The more abstruse the better! The readers liked to be shocked, and science writers had no difficulty in presenting science in a mystical and incomprehensible way. Contrary to Bertrand Russell, science became increasingly presented as the *negation of common sense.* One of the consequences was that the limit between science and pseudoscience tended to be erased. To most people it was increasingly difficult to find any difference between science and science fiction, except that science fiction was more fun.

But let us return to the theory of relativity and its direct impact on scientists. The four-dimensional presentation of the *special* theory of relativity was rather innocent. This theory is used every day in laboratories for calculating the behaviour of high-energy particles, *etc.* As experimental physicists have a strong feeling that their laboratories are three-dimensional, firmly located in a three-dimensional world, the four-dimensional formulation is taken for what it is: a nice little decoration comparable to a cartoon or a calendar pinup on the wall.

3. General relativity and the universe

3.1 *Revival of Pythagorean Philosophy*

On the other hand, in the *general* theory of relativity the four-dimensional formulation is more important. The theory is also more dangerous,because it came into the hands of mathematicians and cosmologists, who had very little contact with empirical reality. Furthermore, they applied it to regions which are very distant, and counting dimensions far away is not very easy. Many of these scientists had never visited a laboratory or looked through a telescope, and even if they had, it was below their dignity to get their hands dirty. They accepted Plato's advice to "concentrate on the theoretical side of their subject and not spend endless trouble over physical measurements". They looked down on observers and experimental physicists whose only job was to confirm their highbrow conclusions. Those who were not able to confirm them were thought to be incompetent. Observing astronomers came under heavy pressure from prestigious theoreticians.

The general theory of relativity opened an extremely fascinating possibility. Similar to the Earth's surface, which is without borders but is still finite, one can in a four-dimensional space have a hypersphere without any limits and still with a finite volume. This idea was certainly worthwhile investigating.

General relativity paved the way for a revival of Pythagorean thinking. Once again it was believed possible to explore the universe by pure mathematics. All the arguments against this, which had caused the downfall of Ptolemaean cosmology, were wiped away. The sign at the entrance to Plato's Academy, "Let none who has not learnt (Euclidean) geometry enter here", was modernized to "Let none who has not learnt Minskowskian geometry enter here". The cosmological discussion became monopolized by Big-Bang believers who had studied general relativity for years. No one else is allowed to have any views about cosmology. Textbooks on 'modern cosmology' start with general relativity and often, do not even mention the existence of heretical views.

Still more serious is the fact that only those observations which by any stretch of imagination could be interpreted as supporting the Big Bang are mentioned. The increasing number of observations which prove the Big-Bang hypothesis to be wrong are swept under the rug.

Also, the Pythagorean idea of correspondence between microcosmos and macrocosmos attracted new interest.

3.2 *Eddington's Cosmology*

One of the most interesting attempts to apply general relativity to cosmology was due to Eddington. With general relativity as background, he derived mathematical relations between the fine structure constant, the ratio between the gravitational and the electrical attraction, the age of the universe expressed in atomic time units, and the number of particles in the universe. The latter was found to be $2.36216\ldots \times 10^{79}$. It was not really necessary to take the trouble of going out to count them all. He knew that at his writing desk he had counted every single one! Indeed, he followed Plato's advice to "concentrate on the theoretical side of the subject" and did "not spend endless trouble over physical measurements to the neglect of theoretical problems".

Eddington's cosmology was no doubt an intellectual masterpiece of the scientist whom Chandrasekhar calls " the most distinguished astronomer of his time". In a way it is a pity that it did not survive confrontation with fact. Eddington had good reason to say—like King Alphonse—"had I been present at the creation, I would have rendered profound advice".

3.3 *Big-Bang Hypothesis*

But the main stem of general relativity carries several other branches. If Eddington's cosmology is the most ingenious one, the most popular one is the Big-Bang cosmology. It is based on Friedman's solution of Einstein's equations. This solution has a *singular point.* To a mathematician a singular point is nothing very remarkable, but to a physicist it had *earlier* meant that something had gone wrong, a warning that the theory could not be applied to a real problem. However, without any serious discussion, this old tradition in physics was suddenly neglected. Instead, it was generally accepted that the singular point represented reality, and meant that at a certain time the whole universe consisted of one single point only. From this singular point the universe began to expand, so that all parts of it rush away from each other with velocities which are proportional to the distance between them.

These types of mathematical solutions seemed to be applicable to the 'expanding universe' which Hubble's famous empirical law describes. The way was now open for a grand new cosmology.

One of the originators of this was Abbé Lemaître, who called the universe when it was at the singular point '1' Atome Primitive'. Its great propagandist was Gamow. Neither Lemaitre nor Gamow went to the extreme in postulating that the whole universe ever was a mathematical *point.* The 'initial state' was supposed to be a concentration of 'all mass in the universe' in a very small sphere. This mass is heated to a temperature of several billion degrees. When this 'atomic bomb explodes', its parts are thrown out with relative velocities which are sometimes close to the velocity of light. (As there is no pressure gradient, the analogy with an exploding bomb is misleading.)

This model, which at least from certain points of view was fascinating, was believed to explain the main evolution and the present structure of the universe. A number of consequences were claimed to derive from it: in less than half an hour after the explosion the elements we find now were formed by nuclear reactions in the very hot and very dense matter. At an early time a heat radiation was produced which, on further expansion, cooled down and should be now observed as a blackbody radiation with a temperature of 50 K. At a later stage the expanding matter condensed to form the galaxies we observe today. The average density in the universe must be at least 10^{-29} g cm $^{-3}$ in order to close it.

3.4 *Big Bang and Observations*

There is not a single one of these early agreements with observations which have not proved to be wrong. In fact, the Big Bang believers of today claim only two observational supports of their hypothesis.

One is the '3 K blackbody radiation' which obviously has a very high isotropy. Compared to the early prediction of a 50 K isotropic radiation, this represents a discrepancy of 10^4 in energy (because the energy is proportional to T^4), but with 'generally accepted' modifications of the scenario the claim that it supports the hypothesis must be taken seriously.

The other support is that the observed abundance of some light elements is too large to be explained by the nucleosynthesis in stars, which is accepted to explain the abundance of the other ~ 90 elements, (the Big-Bang believers claimed initially that they could account for the production of all elements, but now they admit that this is untenable). Because both the observational values of the cosmical abundances and the theory of nucleosynthesis in stars may very well be uncertain by a considerably larger factor, this is not a very strong support.

On the other hand, there are an increasing number of observational facts which are difficult to reconcile in the Big-Bang hypothesis. The Big-Bang establishment very seldom mentions these, and when non-believers try to draw attention to them, the powerful establishment refuses to discuss them in a fair way. A collection of objections has recently been published by Oldershaw (1983). Other critical arguments are summarized by Alfvén (1981).

The present situation is characterized by rather desperate attempts to reconcile observations with the hypothesis to 'save the phenomena'. One cannot avoid thinking of the state under the Ptolemaean epoch. An increasing number of *ad hoc* assumptions are made, which in a way correspond to the Ptolemaean introduction of more and more epicycles and eccentrics. Without caring very much for logical stringency, the agreement between these *ad hoc* assumptions with the Big-Bang hypothesis is often claimed to support the theory.

In reality, with the possible exception of the microwave background condition, there is not a single prediction which has been confirmed. The Big-Bang era has seen the discovery of quasars which have a fantastic release of energy. Unpredicted and explainable only by a precarious mechanism. X-ray astronomy and gamma-ray astronomy have introduced a new era with discoveries of incredibly rapid enormous energy explosions (time constant of a fraction of a second!). Unpredicted again and even *post facto* difficult to reconcile in the Big-Bang cosmology.

The Big Bang is indeed a cosmology of the same character as the Ptolemaean: absolutely sterile. Will it have the same life-expectancy?

3.5 *Cosmic Black-Body Radiation*

It is increasingly evident that there is only *one* phenomenon which the Big-Bang believers seriously claim to prove their cosmology; the 3 K radiation. Schramm & Wagoner (1977) write "the primary reason for believing that our universe did emerge from a Big Bang remains the 3 K background radiation" and Weiss exclaims enthusiastically that the background radiation "satisfies almost beyond expectations the simple hypothesis that it is a remnant of a primeval explosion".

However, if we look at the background radiation without any preconceived ideas, how convincing is it? We measure an extremely cold radiation in a 'universe' which is 10^{10} light years or 10^{26} m, and conclude that this must derive from a state which was billions of degrees hot. Indeed, the expansion from, say, a millimeter-sized universe to the present 10^{10} light year size is by a factor 10^{29}. Is there any other field of science where such an extrapolation in one jump is accepted without very strong proof ? One seems never to have asked seriously whether at intermediate states there could not have been other mechanisms for isotropisation of the background radiation. As we have seen above, the Big-Bang universe contains so many phenomena which this cosmology cannot explain, so it would not be surprising if we discovered such a mechanism.

Indeed one such mechanism may already have been discovered. According to Wright (1981), it is quite reasonable that "needle-shaped conducting grains can provide sufficient capacity to produce the observed spectrum".

It will probably be objected that no one has observed the existence of such grains. However, long ago Spitzer had already shown that the existence of such grains were required in order to account for the interstellar polarization of light. If the choice is either to postulate the existence of such grains or accept the Big-Bang cosmology—which according to its believers has no other certain support—the needles may be preferred by all who are not fanatical believers.

3.6 *Creation ex Nihilo*

A very important conclusion from the Big-Bang cosmology, which is seldom drawn explicitly, is that the state at the singular point necessarily presupposes a divine creation.

To Abbé Lemaître this was very attractive, because it gave a justification to the creation *ex nihilo*, which Saint Thomas had helped establish as a credo. To many other scientists it was more of an embarrassment because God is very seldom mentioned in ordinary scientific literature. There seem to be rather few scientists (but among them Whittaker and Milne) who, like Jastrow (1978) in his book *God and the Astronomers*, explicitly draw what seems to be the logical conclusion of the Big-Bang cosmology, *viz*., that the universe was created *ex nihilo* by God. "When the scientist has scaled the mountains of ignorance, he is about to conquer the highest peak; as he pulls himself over the final rock, he is greeted by a band of theologians who have been sitting there for centuries." However, most of the Big-Bang believers prefer to sweep creation under the rug. In fact, they fight *against* popular creationism, but at the same time they fight fanatically *for* their own creationism. Peratt (1983) suggests that the creationism *extra muros* is inspired by the Big-Bang creationism *intra muros.*

3.7 *Hierarchical Cosmology*

Are there any alternatives to the Big Bang? Indeed there are, although the Big-Bang believers very seldom mention this. Like in the good old days, even mentioning of the existence of a heresy is a crime. One of the mostinteresting alternatives is the hierachical cosmology,which envisages an *infinite universe with a hierarchical organization.* It is based on an approach which attracted considerable interest in the beginning of this century, long before the Big Bang, indeed even before the general theory of relativity.

Inspired by Fournier-d'Albe, Charlier demonstrated that in order to avoid the Olbers and Seeliger objections to a Euclidean infinite universe, it is necessary that the universe is 'clumpy', with a hierarchical matter distribution. This means that stars should be organized in galaxies G_1, a large number of these galaxies form a larger 'galaxy of type G_2'—we would today prefer to speak of a 'cluster'—, a large number of these a still larger structure G_3, and so on into infinity. Charlier showed that the mean density of a structure of size *R* must obey

$$\sigma \sim R^{-a} \qquad (1)$$

with $a > 2$. This leads to an *infinite universe with infinite mass but with average density zero.* It satisfies both the Olbers and the Seeliger objection.

The Charlier school speculated whether our *metagalaxy* (a synonym for what is the Big Bang formalism is considered as the whole 'universe') may have sisters which together form a still larger structure (a 'teragalaxy'), thus continuing one step further in the hierarchy. (This is, of course, against the Big-Bang view).

With the arrival of the Big-Bang cosmology,the Charlier model was considered to be of historical interest only. However, in a classical paper, de Vaucouleurs (1970) revived that model by demonstrating that within wide limits, the maximum *observed density distribution* satisfies Equation (1), but with $a = 1.7$.

In his theoretical interpretation of the observations deVaucouleurs (1970) must take into account the Hubble expansion, which means that his hierarchical model is not identical with Charlier's.

Peebles and collaborators (*cf.* Peebles 1980) have treated the observational data with advanced statistical methods, and have essentially confirmed the de Vaucouleurs hierarchical model. (See survey article by Groth *et al.* 1977. However, they find a value of a which is somewhat higher: $a = 1.77$.)

3.8 *A Tycho-Brahe-Type Compromise*

The hierarchical structure does not necessarily come into conflict with the Big Bang. A number of scientists (including even de Vaucouleurs and Peebles) prefer a Tycho-Brahe compromise: Certainly observations demonstrate that the universe has not at all the homogeneity which it should have according to the Big Bang, but the inhomogeneities may be explained by secondary effects, *e.g.*, instabilities. In this way, an open conflict with the sacrosanct Big Bang is avoided. However,even if a hierarchical structure could be derived from the Big Bang, *this does not prove that the Big Bang can be derived from the observed hierarchical structure*! Moreover, the real advantage with the hierarchical structure is that it saves us from the *singular point and creationism.* So this compromise seems to be just as superficial as Tycho Brahe's.

Neither Charlier nor anyone else has given any reason *why* matter has this structure and is distributed in this way. Only by implication do they claim that there must be *some law of physics* which produces a hierarchical structure.

In any case, it seems legitimate to look for alternatives to the Big Bang. However, it is beyond the scope of this paper to discuss these (see Alfvén 1981, Chapter VI; Alfvén 1982a).

4. Introduction of spacecraft

4.1 *Importance of Electromagnetic Forces*

Independent of the introduction of the General Theory of Relativity into the cosmological discussion, there was another drastic change in our approach to cosmical physics, namely, the realization of the importance of *electrodynamic effects* to the motion of dispersed media. Because the ratio of Coulomb attraction to Newtonian attraction between elementary particles is 10^{39}, electromagnetic effects are decisive to the dynamics in all cases when the number of positive charges are not almost exactly compensated by the same number of negative charges. This is the case for all massive celestial bodies down to grains of the size of the order of microns, but very seldom for the diffuse media in interplanetary, interstellar and intergalactic space. In fact, hydromagnetic and plasma phenomena dominate most of those regions which (by volume) constitute more than 99.999 . . . per cent of the universe.

In the following, we shall see that it is not only Newton and Einstein, but also Maxwell who are important to cosmology.

4.2 *Space Research and the Paradigm Transition in Cosmic Physics*

Scientific progress depends on the development of new instruments. The change from Ptolemaic to Copernican cosmology was to a large extent caused by the introduction of telescopes. Similarly, space research has changed our possibilities to explore our large-scale environment so drastically that a thorough revision of cosmic physics is now taking place.

First of all, *space observations* have made almost the whole electromagnetic spectrum available to observation. Earlier, less than one-third of the octaves (visual and a region of the radio frequencies) supplied us with information.

The new regions include X-ray and gamma-ray astronomy, and most of the new phenomena discovered in these regions are obviously due to plasma effects. This means that the decisive importance of hydromagnetics and plasma physics has now become increasingly obvious.

the solar wind region ('solar magnetosphere') drastically changed our understanding of the properties of cosmic media. Further, we have learned how to generalize results from plasma investigations in one region to other regions. This means that laboratory investigations of plasmas of the size of, say, 10 cm can be used to achieve better understanding of cosmic plasmas of magnetospheric dimensions; say, 10^{10} cm. By another step of 10^9 we can transfer laboratory and magnetospheric results to galactic plasmas of, say, 10^{19}cm. A third jump of 10^9 brings us up to the Hubble distance 10^{28} cm and hence to cosmological problems.

All this has led or is leading to a revision of our concept of cosmic plasma, which in many respects is so drastic that it is appropriate to speak of a *change in paradigm.*

As our cosmic environment consists of plasma to more than 99.999 . . . per cent (by volume), this means a revision of a large part of cosmic physics.

A list of fourteen fields of astrophysics which must be revised has been given (Alfvén 1981, 1982b, 1983). Those of most interest in this connection are:

(a) Electric double layers, which did not attract very much interest until five or ten years ago. They are now known to accelerate charged particles to kilovolt energies in the terrestrial magnetosphere. Double layers may also exist elsewhere and accelerate particles to even higher energies. Carlqvist (1982) has treated relativistic double layers which may accelerate particles to cosmic ray energies. The breakthrough in the acceptance of electric double layers came with the Risø Symposium (Michelsen & Rasmussen 1982). In a cosmological connection, the rapid release of magnetically stored energy in exploding double layers is of considerable interest.

(b) Cosmic plasmas are often not homogeneous, but exhibit *filamentary structures*, which in accessible regions are known to be associated with currents parallel to the magnetic field. It is likely that filamentary structures in interstellar clouds as well as further out are also produced by filamentary currents.

(c) In the magnetospheres there are thin, rather stable *current layers* which separate regions of different magnetization, density, temperature, *etc*

(d) It is difficult to avoid the conclusion that similar phenomena exist also in more distant regions. This is bound to give space a general *cellular structure* (or more correctly, a cell-wall structure).

(e) The arguments for the non existence of antimatter in the cosmos are not valid (Rogers & Thompson 1980). There are sound arguments for the existence of antimatter, which means that *annihilation* should be considered an important source of energy. In fact, annihilation seems to be the only reasonable energy source for those celestial objects which emit very large amounts of energy (*e.g.*, quasars).

(f) Radio, X-ray, and gamma-ray emissions and cosmic-ray acceleration are largely due to plasma processes. Theories of, for example, double radio sources, the formation of stars and planetary systems from interstellar clouds, energy release in quasars and acceleration of cosmic radiation upto 10^{19} must be based on plasma physics.Hence the paradigm transition implies a revision of considerable parts of radio, X-ray and gamma-ray astronomy, the theory of cosmic rays, and also of cosmology. These sciences must ultimately be based on the observed properties of laboratory and magnetosphere plasmas.

Hence, in conclusion, there is not very much left of the observational support for Big Bang. Indeed, *the space age gives a picture of space as essentially three-dimensional and highly inhomogeneous, because of the dominance of hydrodynamics and plasma physics.* In contrast, *the Big-Bang scenario is a four-dimensional and basically homogeneous space.*

4.3 *Mundane and Celestial Mechanics*

At present, it is agreed at least in principle that up to a distance of some per cent of the Hubble distance, Newtonian mechanics and a Euclidean space should normally be used. Of course, special relativity must be applied for all motions and velocities comparable with the velocity of light. Further, hydromagnetics and plasma physics are often of decisive importance. Even if it is admitted that *in principle* general relativity is valid, the difference between this and Newtonian mechanics is negligible except in a few special cases. In fact, for calculations of planetary orbits, and also the orbits of spacecraft, Newtonian mechanics is used, because the relativity correction is only of the order of 10^{-8}. Similarly, for the large-scale dynamics, we expect the relativity correction for galaxies to be, say, 10^{-6} and for galactic clusters and superclusters, perhaps 10^{-5}. Exceptions are special cases like neutron stars and black holes (if there are any!). If, using the empirical formula of de Vaucouleurs, we extrapolate to a hierarchical order of the whole metagalaxy (to the Hubble distance), we get a relativity correction of about 10^{-4}. This is also negligible considering the accuracy which at present is useful in treating large-scale phenomena in regions so distant.

It goes without saying that in all these regions, hydromagnetics and plasma effects are, in general, much more important.

The exploration of increasingly distant regions have demonstrated that the strong inhomogeneity characteristic of a hierarchical structure is valid out to at least some per cent of the Hubble distance. Indeed, very large void regions of dimensions 10^{20}–10^{25} m have been discovered and also massive regions of different structures out to similar distances. If we use the Charlier-de Vaucouleurs relation between average density and size of the hierarchical structures we obtain an average density which is four orders of magnitude less than what is required for closure. Hence, those who want to close the ‘universe’ at the Hubble distance have to assume a drastic change in average density to take place within the last order of magnitude out to this limit.*

Hence, there is a reasonably well-defined limit between strongly inhomogeneous and essentially Euclidean space which is extrapolated from space research results and the homogeneous four-dimensional space which is postulated by Big-Bang believers. This limit is given by the present reach of reliable observations. The limit has been retreating with the advances in observational technique. But, of course, we cannot be absolutely sure that it will retreat still further.

This limit may be compared with the limit in the Aristotelian cosmology between mundane laws, valid below the lunar orbit, and celestial laws, valid above. For example, according to mundane mechanics heavy bodies fall down, but the Moon, the planets, the Sun and the stars do not fall down because they obey celestial laws. Similarly, out to several per cent of the Hubble distance, we are confident that the ‘mundane’ laws of laboratory and near space hold. But the Big-Bang believers claim that their ‘celestial’ laws hold outside the limit.

Allowing for the uncertainty which is inherent in all cosmologies, it seems that the present cosmological situation is similar to what it was at the time of Saint Thomas: “Reason can only be satisfied with the assumption that the world has no beginning. The

* What is said should not be interpreted as a questioning of the general theory of relativity. It is only an attempt to clarify to what extent it is applicable to cosmology. Einstein expressed himself in a much more careful way than many of his epigones.

doctrine of a beginning or the non-eternity of the world is to be received *sola fide* as an act of pure faith in deference to authority".

5. The cosmological pendulum

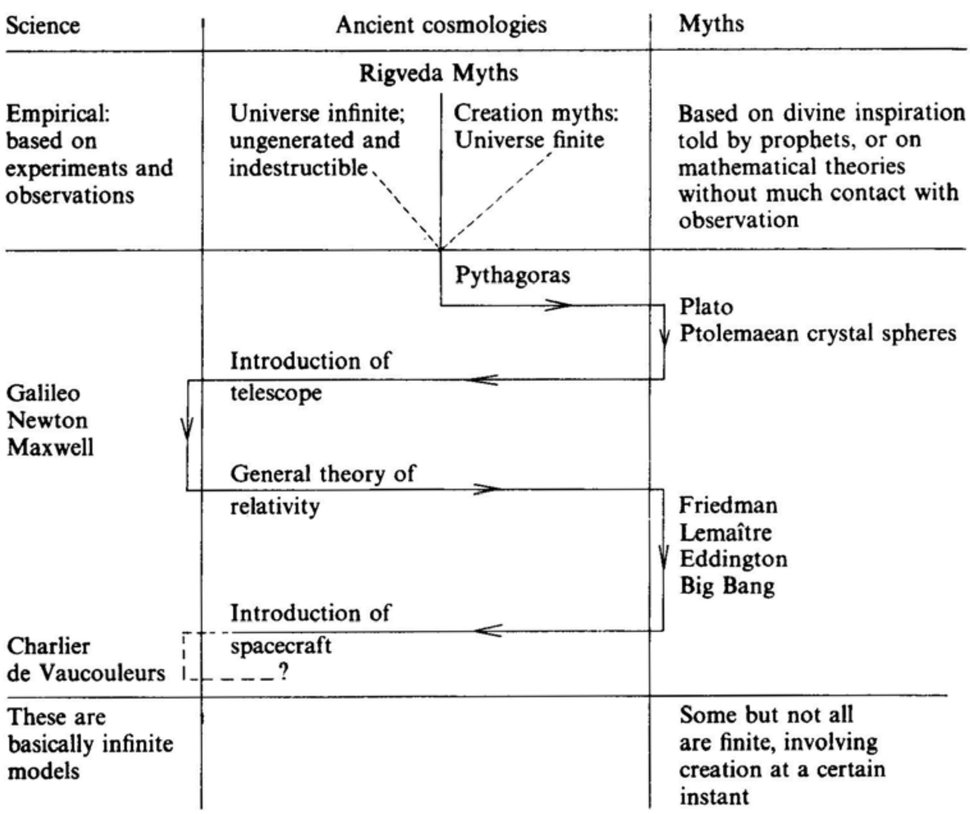
Three or four millenia of cosmological speculation has resulted in essentially three different types of approaches to cosmology:

1. The scientific approach. As science is basically *empirical*, this means that cosmology should be based on observations with experimental results (from laboratory or nowadays also space experiments) as a background.

The *Newtonian* theory was largely based on accurate observation of planetary motion. It turned out to be applicable—at least to a good first approximation—to motions of galaxies,'and clusters of galaxies.

Today, especially after *in situ* magnetospheric measurements and the birth of X-ray and gamma-ray astronomy, it must be fused with *Maxwellian* theory, which leads to hydro-magnetics and plasma physics as basic to the study of our cosmic environment. Maxwell's theory is a summary of the results of electromagnetic investigations, and—like Newton's theory—it turned out to be applicable to a number of problems in other fields.

Evolution of cosmology



2. *The agnostic attitude.* This is the Rigvedic and Buddhist approach: How can we know about or why should we care about problems so distant?
3. *The mythological approach.* If venerable prophets have told us that by divine inspiration they know that the universe was created, and how it was created, how can we doubt what they tell us? This approach is closely related to the *mathematical myths*: It is possible to explore the structure and evolutionary history of the universe by pure theoretical thinking without very much contact with observations. Typical examples are the Pythagoras-Plato-Ptolemaean cosmology, or in our day, the Eddington cosmology, but also the Big Bang.

There has been—and will perhaps always be—an oscillation between mythological and scientific approaches. This is summarized here in the diagram called the *Cosmological Pendulum* which is a summary of what has been said in this paper.

It is interesting to ask whether the pendulum could come to rest in an intermediate position. Eddington himself has given the answer: "In one sense, deductive theory is the enemy of experimental physics." Since the birth of science, there has never been a time when there could be a compromise between myth and empirical science.

Will there—in a still more distant future—again be a swing back to created cosmologies? Perhaps. However, we cannot expect such a future model to resemble the Big Bang any more than Big Bang does the crystal spheres. Its size and timescale will be much larger. In fact, the age of the Big Bang is just a few *Kalpas*, and the life expectancy of Brahmais ten thousand times this. Perhaps this future model will be of a scale which only the Vedic cosmologists dared to imagine.

Philosophizing over the swings of the cosmological pendulum we may remember the words of the Buddha:

> "It is wrong to say that the world is infinite and eternal."
> Yes, at least during some periods it has been.
> "It is wrong to say that the world is finite and created."
> Yes, at least during some periods it has been.

In this sense the Buddha was correct. But of course what he meant was something else, much deeper and more sophisticated.

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