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ASTRONOMICAL PROBLEMS OF TO-DAY[1]

By Sir JAMES JEANS, F.R.S.

PROFESSOR OF ASTRONOMY, THE ROYAL INSTITUTION

THIS evening I propose to discuss a group of problems relating to the central problem of the structure of the universe. No final or definite answers have yet been found for these, so that we shall be discussing questions rather than answers.

The earliest astronomy was geocentric, the earth being supposed to be the center of the whole universe. This view was not based on astronomical evidence but had its roots in man's self-esteem, in his want of imagination and in the meagerness of his scientific knowledge. It met its end in the arguments of Copernicus and in the observations of Galileo.

It was succeeded by what we may call a heliocentric astronomy, in which the sun was supposed to be at or near the center of the galactic system and possibly also of the whole universe. This view did not result from any human frailty; there seemed to be good scientific evidence for it.

For a superficial study of the sky shows that those stars that appear brightest to us, and so are presumably nearest to us, are scattered fairly uniformly in the different directions of space, while the Milky Way divides the sky into exactly equal halves and itself looks about equally bright in all its parts. All this seemed to indicate a disc-shaped system of stars, with the sun lying in the central plane of the disc and fairly close to its center. Such a view of the structure of the galaxy appeared to find confirmation in the pioneer researches of the two Herschels and in the later investigations of Kapteyn, Seares and others.

We know now that it was entirely wrong. It was wrong because these investigators had assumed that space was entirely transparent to light. We know now that the whole galactic system is permeated by a patchy fog of obscuring matter, which is not dense enough to affect the light of the nearer stars appreciably but blots out the more distant stars entirely. This fog makes the greater part of the galactic system

[1] Abstract of lecture before the Royal Institution of Great Britain, March 26, 1943.

invisible to us; if our predecessors thought they were at the center of the galactic system, it was as a man who is in a forest in a thick fog may think he is at the center of the forest, although in truth he is only at the center of the small group of trees he can see through the fog.

We know now that the center of the galaxy is far removed from the sun and that the sun, like all the rest of the galaxy, is revolving round this distant center. Observation shows that the sun's period of rotation is about 250 million years and that its orbital speed is of the order of 270 kms. a second. These purely observational data show that the galactic center must be at a distance of about 36,000 light-years from the sun.

It used to be thought that our own particular galaxy was far larger than any other in the sky, but it is now clear that all galaxies are very similar in size and also very similar in mass. Our own galactic system can be weighed by calculating the gravitational force it exerts on the sun to keep this moving in the orbit already described; the requisite mass comes out at about 150,000 million suns. It is also possible to weigh a close pair or cluster of galaxies by calculating the gravitational force they must exert on one another so as to prevent the more rapidly moving members running away into space. The average mass needed usually comes out at about that just mentioned for our own galaxy, most estimates ranging from 95,000 million to 200,000 million suns. On the evidence at present available the galaxies seem likely to differ far less one from another than the stars of which they are composed, and we are led to picture the astronomical universe as consisting of a number of similar units—our own galaxy and the other galaxies—rather like the molecules of a gas.

On pointing a telescope in different directions in space we see fields of stars which differ greatly from one another, a consequence of the finite size and definite structure of the galaxy. No comparable variations are to be found in the fields of galaxies seen in different directions in space. Clusters may be seen here and there, also bare patches in places, but broadly speaking the galaxies seem to be scattered fairly evenly through space, the average distance of neighbors being something over a million light-years. We do not know whether this uniformity of distribution persists through the whole space or not, for the galaxies that we can see may perhaps form only a small part of some grander system, built on such a scale that no appreciable difference of structure occurs within the distances accessible to our telescopes.

If, however, the distribution is uniform through the whole of space, then space must be finite; otherwise it would contain an infinite amount of matter and the gravitational force from this would be infinite, which is contrary to the fact. This alternative, then, brings us to the type of universe which Einstein contemplated in his original relativity theory. Space is curved with a positive curvature—like the surface of the earth—and is filled with matter of which the average density is everywhere the same. On this theory the size of space is determined uniquely by the average density of matter, much as the size of an expanded balloon depends on the density, and so on the pressure, of the gas inside it. From the data already mentioned, we can deduce that the average density of matter in space must be of the order to 10^{-28} gms. per cu.cm., or about one atom to the cubic yard. With this density the radius of space must be about 3,300 million light-years—at least if the whole structure is at rest in a configuration of equilibrium. Thus the whole range of our biggest telescopes would be only a minute fraction of the size of space.

This seemed to provide a possible and consistent scheme until Friedmann and Lemaître showed that such a universe could not stand at rest in equilibrium. It would be unstable in the sense that space itself would have to start either expanding or contracting. Some time after this, Hubble and Humason found displacements in the spectra of distant nebulae which, if interpreted in the simplest way as Doppler effects, showed that the distant nebulae were all receding from us and suggested that space might actually be expanding just as Friedmann and Lamaître had predicted. Observation showed that the rate of expansion would be the same everywhere and such that, if it were maintained at its present value, the linear dimensions of space would be doubled in about 1,800 million years.

This in turn suggested that the universe might have started as an Einstein universe of the kind already described and that the inherent instability of such a configuration had caused it to expand to its present dimensions. But the theory of relativity could not deduce the present dimensions, either from the present density of matter or otherwise, Einstein's relation between size and density referring only to a universe at rest in equilibrium.

Eddington has claimed to solve the problem by quite different methods. In brief he believes that the total number of protons in the universe must be 136×2^{256}, there being also an equal number of electrons; he has produced arguments to show that there can not, from the nature of things, be anything other than this.

Knowing the number of particles in the universe and the mass of each, it is easy to calculate the total mass of the universe, and hence the dimensions, since we already know the average density to be about 10^{-28};

the radius of curvature comes out at some 2,000 or 3,000 millions of light-years. But if the universe started as an Einstein universe in equilibrium, then the total mass it contained—the known total mass of all Eddington's particles—would fix its curvature definitely and precisely. Eddington calculates that the radius of curvature would then be 1,068 millions of light-years. Thus the expansion of the universe up to the present can only have increased its dimensions some two or three fold, a process which would occupy only a few thousands of millions of years. This agrees well enough with what we know as to the age of the earth, for it seems probable that the earth came into existence between 2,000 and 3,000 millions of years ago, the sun then being at the very beginnings of its existences as a star. It also agrees with what we know as to the ages of the stars; if present conjectures as to the mechanism of stellar radiation are right, the stars can hardly have contained available energy to provide radiation for more than a very few thousands of millions of years.

The problem has been attacked on different lines by Milne, Dirac and others. After the geocentric and the heliocentric universes had been banished from astronomy, the apparent recessions of the nebulae seemed to suggest a galacto-centric universe, with our own galaxy as the center from which all others were moving radially away. Milne based his theory on what he described as the "cosmological principle"—the universe is not in any way centered in our galaxy; this occupies no specially favored position, so that the picture which an inhabitant of our galaxy draws of the large-scale features of the universe would be equally valid for any other galaxy.

With the help of this principle Milne draws a picture which seems at first sight to describe something totally different from the expanding universe of Friedmann and Lamaître. But Kermack and McCrea claim to have shown that the two pictures differ only in the way in which two maps of the same country differ when they are drawn on different projections—if we compare the relativity picture to a spherical projection, then Milne's picture may be compared to a Mercator projection. McVittie has recently claimed that Milne's results do not really depend on the cosmological principle at all, but can all be deduced from assumptions which Milne has unwittingly introduced under an erroneous impression that they are axiomatic. But all this is still under discussion.

Another line of investigation was opened by Dirac, possibly under the influence of a remark which Eddington made as far back as 1923.

Physics provides a natural unit of force, namely, the attraction between the nucleus and the electron in the hydrogen atom. Astronomy also provides a natural unit of force—the force with which the same two particles attract one another gravitationally. This latter unit is very small in comparison with the physical unit, the two standing in the ratio of 1 to 2.3×10^{39}. This is of course a pure number and so is independent of the particular units we use for our measurements. We have already mentioned another large number—the number of protons in the universe, which Eddington claims must be 1.57×10^{79}. The square root of this number is 3.9×10^{39} and so is very close to the ratio of the electric and gravitational forces just mentioned. Eddington and Dirac have both suggested that the agreement is too good to be the result of a mere coincidence; they prefer to think that it must result from some fundamental property of the universe.

Again physics provides a natural unit of time. It can be expressed in a variety of forms, the simplest being that it is the time light takes to travel across the diameter of an electron, about 1.25×10^{-23} secs. Astronomy also provides a natural unit of time; it is the fictitious time that the various galaxies would take to reach their present positions if they had all started simultaneously from a point and traveled uniformly at their present speeds of motion. This time is the same for all galaxies, being the 1,800 million years just mentioned. Again the ratio of these two units is a very large number; this time it is 4.5×10^{39}, which is very near to the large numbers already mentioned. Again we must assume that the agreement is not a mere accident but must represent something in the order of nature.

We do not know what is the explanation of these apparent coincidences, but they seem to conceal something which has not yet been fully explained and which, when fully understood, may prove to be of outstanding importance. It is true that Eddington's researches provide an explanation but only in a rather special and very recondite form; it looks as though this explanation is only a special case of something simpler and far wider.

Some investigators have gone further than this and traverse, as it seems to me, very dangerous ground. The age of the universe, expressed in terms of the natural physical unit of time, proves once again to be of the order of 10^{39} and the suggestion is made that this also can be no mere accident, but it must express something in the fixed order of nature. The weakness in this argument is, as it seems to me, that the basic fact on which it rests can be put in the simpler form that the age of the universe is some one, two or three times the time in which space doubles its dimensions and that, when it is so expressed, it is difficult to find any "coincidence," either real or apparent. The supposed coincidence is seen to be merely a simple transformation of one which has already been dealt with and we must not, so to speak, try to cash in on the same coincidence twice over.

Let us, however, waive the objection and accept the suggestion made. We have then to suppose that all the numbers of the order of 10^{39}, including the age of the universe, owe their approximate equality to something in the fixed order of nature. When the universe attains to 10 times its present age, the 10^{39} which measures its age will have increased to 10^{40} and all the other big numbers will have done likewise. Thus while the ratio of electrical to gravitational attraction will be ten times what it now is and so on, the number of particles in the universe will have increased 100-fold, so that creation must still be in progress. In brief, some or all of the quantities that we used to regard as unalterable constants of nature lose their quality of constancy and must change continually with the time. Milne was led to the same conclusion by a very different road; he reached it from a study of his cosmological principle. By whatever road we arrive, we come into a fantastic new world.

We may avoid the need for a continual creation of matter by supposing that the natural physical unit of time changes *pari passu* with the age of the universe. Then the measure of the age of the universe stays always the same as does also the number of particles in the universe. But now we find that either the mass or the charge of an electron must continually change.

All these seem strange to old-fashioned physics, but it simplifies some things and removes some difficulties. When, for instance, we study the spectrum of a nebula at 250 million light-years distance, we are in effect watching the emission of light from atoms as they were 250 million years ago. And a simple interpretation of what we see is that the atoms of those days were not the same as the atoms of to-day. Hydrogen atoms seem to have given out radiation of longer wavelength than they do now, and so were apparently larger—or perhaps their electrons moved more slowly in their orbits and so took longer to complete their revolutions, possibly because the electric attraction on them was less intense. There are many possibilities, each with its merits but also with many demerits.

Whatever the final solution of this vast problem may prove to be, it is already clear that there is no solution on the lines of the kind of dynamics that we learned at school. The mechanical interpretation of the universe fails as completely in the large-scale world of astronomy as it has already failed in the small-scale world of atomic physics. The quantum-theory has replaced mechanics in the physical world; we still do not know what is destined to replace it in the world of astronomy.

SCIENCE IN CHINA

By CHUNG YU WANG

COUNSELLOR, ACADEMIA SINICA; TECHNICAL EXPERT, MINISTRY OF ECONOMIC AFFAIRS

CHINA is, paradoxical as it may seem, the youngest and the oldest in science among the family of nations. The remark of Gore about Western civilization, that "the origin of many important discoveries lies buried in the obscurity of past ages," is none the less true of Chinese inventions and discoveries. It may be recalled that compass, paper, printing, glass, porcelain, gun-powder, etc., were discovered in China long before the time of Galileo, Bacon and Newton. In the realm of physical and biological sciences, some fundamental conceptions may be found buried in some Chinese ancient classics.

In the twelfth and thirteenth centuries, as a reaction against the "Subjective Philosophy" of Zennism, the "Rational Philosophy" of the Neo-Confucian philosophers was heralded in with the slogan "go to the things and investigate their reasons," a phrase as if taken out of Bacon's "Novum Organum." The greatest leaders of this movement were Chang I (1022 to 1107 A.D.) and Chu Hsi (1129 to 1200 A.D.). Chu Hsi wrote: "In every human mind, there is the knowing faculty; and in everything there is its reason. The incompleteness of our knowledge is due to our insufficiency in investigating the reason of things. The student must go to all things under heaven, beginning with the known principles, and seeking to reach the utmost. After sufficient labour has been devoted to it, the day will come when all things will suddenly become clear and intelligible" (translation by Dr. Hu Shih). This statement sounds quite modern in the sense that it may be construed to indicate the problem and procedure of what is now called science. Unfortunately, in the ensuing centuries, this movement, due to the introverted mentality of its leaders, had degenerated into a mere study of the classics of the ancients, and through centuries of classical education, by which, as Carlyle pertinently remarks, "they do attempt to make their Men of Letters their governors," the study of science was muffled and stifled.

The real awakening of China to the spirit and character of science, due undoubtedly to the impact of the return of Chinese students, trained both in