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ALFRED WATSON MEMORIAL LECTURE

THE NATURE OF THE UNIVERSE

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I WANT to talk to you this evening about our present knowledge of the universe. This knowledge has been revolutionized during my own lifetime, by the use of two new techniques for exploring the universe—the radio telescope and the space probe. It is remarkable that for three hundred years after Galileo first used his small telescope to look at the heavens at the beginning of the 17th century and produced the observational proof that the Earth was in motion around the Sun, man has depended entirely on his own eyes for gaining knowledge of the stars, the galaxies and the universe. In my student days it was still believed that the Sun, with its family of Earth and planets, was fixed at the centre of the universe. At that time—between 1920 and 1930—man's concept of the universe was an extremely localized one. Astronomers were then primarily concerned with the dynamics of the system, but on the general cosmological problem which now concerns us so much—that is, the nature of the universe; its total extent; whether it is finite or infinite; whether it is bounded or boundless in space and time—there was little enquiry. It was believed that the stars which could be seen with the telescopes in the sky at night were nearly symmetrically distributed around the Sun out to a distance of a few thousand light years.

Now, as I hope to describe to you, our concept of space and time and of the universe has changed in a most dramatic fashion. The first significant change in our understanding of the nature of the universe came before the invention of the radio telescope and the space probe, at the time when American astronomers were first able to use a large optical telescope on Mount Wilson in California. There, through skies which were, at that time, clear, they obtained the first indication of the true immensity of space, and of the enormous numbers of stars and galaxies which constitute the universe observable today.

The first of the great discoveries was made by the American astronomer, Harlow Shapley. He was interested in the distribution of groups of stars which we call globular clusters. He expected to find that these globular clusters were symmetrically distributed around the Solar System. When he studied the photographs taken by this new telescope he found that this was not the case, but that the clusters were asymmetrically placed with respect to the Solar System. It was from this work that astronomers first developed the concept of the asymmetrical structure of the Milky Way, and realized that the Sun—which is an ordinary star in the Milky Way—was not at the centre of the system. Harlow Shapley deduced dimensions for the Milky Way system which have since been modified. Today, we believe that in the hierarchy of the evolution of the stars the Sun is a fairly average member, and that, in the system which we can see with our telescopes, there are about a hundred thousand million stars. These hundred thousand million stars are not distributed in a sphere with the Sun at the centre, but in a highly flattened ellipsoid, which is about twenty thousand light years thick at the centre, and whose total dimension along the major axis is about one hundred thousand light years. This means that the light from a star at one end of the disc would take a hundred thousand years to travel across the volume which contains this immense number of stars.

The Sun is not near the centre of this system, but right out in one of the extremities—about twenty or thirty thousand light years from the nucleus of the galaxy. Furthermore the stars in this flattened ellipsoid are not distributed uniformly. There is a heavy concentration in the central regions, and from this nucleus the stars radiate in a series of spiral arms. This whole system is itself rotating. It may be likened to a giant octopus which is rotating, with the whole behaving like a viscous fluid, so that the speed of rotation differs as the distance from the centre varies. The Sun is in one of the spiral arms at a distance such that we are undergoing a cosmological rotation in about two hundred and fifty million years.

There is no complete understanding today as to how this Milky Way system came into existence. Until recently it was believed that this dense central region and the spiral arms came into existence at the same time. The difficulty with this idea is that the nature of the stars in the two parts of the Milky Way is entirely different. The stars which pack the central region are old stars. In this region there is little gas and dust and star formation has ceased. Around us, in the neighbourhood of the Sun and in the spiral arms, we have young stars that are in processes of birth from the mass of interstellar gas and dust which still exists and which, incidentally, obscures our view of the central regions. The estimate of the fraction of the total mass of the galaxy which is condensed into stars compared with that which is still in the form of gas and dust is imprecise. Probably about half of the total mass is concentrated in the form of stars in various stages of evolution.

Shapley's work on the shape and size of the Milky Way was followed immediately by the discoveries of Edwin Hubble, using the 100-inch telescope at Mount Wilson. For centuries astronomers had been aware that amongst the stars in the Milky Way there were regions in which diffuse patches of luminous gaseous material could be seen; they were called nebulae. The history of astronomy reveals that in the first part of the 19th century astronomers—particularly Sir William Herschel—came close to understanding the true nature of these nebulae. Herschel speculated that many of these nebulosities were not gaseous but were star systems in their own right, like the Milky Way. His telescope was not adequate to produce the decisive observational evidence. Subsequently we were to find that the situation is confusing and that many of these nebulae are indeed gaseous domains within the system of stars in the Milky Way. It was Hubble who first found the proof that at least some of these nebulosities were separate entities remote from the Milky Way.

Astronomers using the spectroscope with the 100-inch telescope had already studied the spectrum from some of these nebulae, and in many cases they had found that the spectral lines were shifted towards the red end of the spectrum. Spectral lines characteristic of common elements like hydrogen can be identified in these distant bodies, and when their actual wavelengths are compared with comparison sources in the observatory, it is found that the lines are shifted to the red end of the spectrum. Hubble found the explanation for the shift, and also obtained the proof of the extragalactic nature of nebulae. Hubble's work is fundamental to our understanding of the universe today. He obtained evidence that many of these gaseous nebulosities contained certain types of variable stars. Miss Leavitt, at Harvard, had already observed a strange relationship between the absolute luminosity of these variables and their rate of variation. Hubble measured the rate of variation of these Cepheid variables which he identified in the nebulae. He knew that a certain rate of change corresponded to a star of a given absolute magnitude, he was able to measure the apparent magnitude and hence he could estimate the distance of the stars. He found, for example, that the nebulosity in Andromeda was not within the confines of the Milky Way but was so far away that the light from it was taking two million years on its journey towards us. In other words, this nebula was two million light years away. Subsequently photographs taken with the large optical telescopes revealed that this nebula was a great spiral galaxy similar to our own Milky Way. We believe that if we could reach this M31 galaxy in Andromeda we would find that it was almost identical to our own system, that it contains about one hundred thousand million stars, and that they also are in a flattened spiral structure with the old stars concentrated in the nucleus of the galaxy.

Subsequently Hubble investigated the Cepheid variables in a considerable number of these nebulae and found that extragalactic star systems were a common feature of the universe. Simultaneously he found the correct explanation for the red shift of the spectral lines. He observed that the amount of the shift in wavelength increased linearly with the distance of the object he was observing. However far we penetrate into the universe today we can find no departure from this law first established by Hubble in 1927.

Today we recognize that these extragalactic nebulae observed by Hubble are merely a small number of the galaxies which lie within the field of view of our modern telescopes and which seem to be distributed with a high degree of uniformity throughout time and space. If we could travel away from the solar system with the speed of light—186,000 miles a second—we would travel for a hundred thousand years and then we would begin to move out of our own star system. The stars would begin to thin out, and eventually we would travel in intergalactic space, for about two million years, and then we would reach Andromeda. We could continue this journey for many thousands of millions of years through a universe populated with great numbers of star systems similar to our Milky Way and Andromeda.

The central problem about the universe is that of the origin of these galaxies which populate space in such great numbers. The number is not known with any precision but we can say that to the limits of our present observation there must be something like one hundred thousand million galaxies, and that each of these galaxies contains something like one hundred thousand million stars, so that the total number of stars and galaxies in the universe is inconceivably large. Further, it is probable that this is only a limit which we set because of the present insensitivity of telescopes. Every time there is a new accession of sensitivity we find that the number of objects we can see continues to increase by about two and a half times for every magnitude. Therefore, if you ask how many galaxies the universe contains, the answer cannot be given; it can only be approximate in terms of the numbers which are visible in the contemporary telescopes.

Was there an epoch in history when the material which forms this universe can be said to have been created or came into existence? What is going to happen in the future? Do we exist in an evolutionary universe in which there is a beginning and an end, or in a universe which has always existed and in which processes of continuous creation are taking place? Is the enquiry into the beginning and the end meaningless because there was never a beginning and never will be an end?

In any discussion of this problem the Hubble law relating to the red shift and the implications regarding the expansion of the universe is of prime importance. As we penetrate into space with the telescopes we find that the red shift increases with distance. This implies that the objects are moving away faster and faster as we move out into space, and today we are apparently studying objects which are receding with speeds which are a significant fraction of the velocity of light. In observatories like Jodrell Bank it is a common occurrence to receive signals which started out on their journey through space many thousands of million years ago. If our present interpretation of the nature of the universe is correct, the object which emitted those signals is itself moving away from us with a speed which may be more than half the velocity of light—more than ninety thousand miles a second. We are therefore forced to the conclusion that since we have been here this evening the objects which we can easily study with our modern instruments have separated further by millions of miles. If we imagine the situation in reverse we obtain an interesting concept, that is if we move back in time the whole of the material of the universe must have been much closer together in an earlier epoch. Indeed, if we accept the slope of the Hubble line relating red shift to distance, and if we extrapolate back to the point where it meets the origin, we find that the time of origin is ten thousand million years ago.

It is natural to enquire if this implies that the universe itself came into existence at this time. Indeed there is one popular theory, well known as the big bang theory, which maintains that this is precisely what happened ten thousand million years ago—that the universe was then a concentrate of primeval hydrogen of enormous density which became unstable and disintegrated. This theory maintains that in the course of time this primeval hydrogen condensed into the stars and galaxies, and the reason we live in an expanding universe today is because we are witnessing the remaining impetus of that initial explosion. Unfortunately, when we search for direct observational proof of this primeval event we meet imponderable difficulties. It might appear impudent to maintain that a human being on this earth could even speculate or attempt to measure anything which happened ten thousand million years ago. But in astronomy we have no knowledge of the present time; all our knowledge is of time past, and this is the fundamental feature which enables us to explore the remote past history of the universe. The Sun is ninety-three million miles away, and light takes eight minutes to travel that distance. If the Sun disappeared, it would be eight minutes before we knew anything about it. Our knowledge of the most distant planet—Neptune—is about thirty minutes old. We see the nearest star tonight as it was in 1966. We see the spiral galaxy in Andromeda as it was two million years ago, when light from it which is now reaching earth started out on its journey through space. With our modern optical and radio telescopes we receive signals from objects far away in the universe which are thousands of millions of light years distant. In this work we penetrate into the remote past history of the cosmos.

If you reflect on this you will realize that if the universe was in a highly condensed state ten thousand million years ago, and if we are penetrating many thousands of millions of years into the past history of the universe, then we ought to find some sign of the early evolutionary state of the material of the universe. For example, if we measured the total number of galaxies per unit volume of space we might expect to find that, at these great distances, where we now view past epochs, they are more densely packed together than in the regions of space-time nearer to ourselves now. Evidence has been obtained from the counts of radio sources that the numbers of galaxies increase as we penetrate to greater distances, but this evidence is subject to some controversy. In fact, it does not seem that there is any generally agreed decisive evidence at this moment that the material which we observe in these remote regions of space-time is in an earlier evolutionary state compared with the objects closer to us in the universe.

At this stage it is important to consider the observations in relation to the predictions of cosmological theory. The mathematical theory of contemporary cosmology is based on the General Theory of Relativity. Einstein's application of his General Theory of Relativity to the problem of the universe revealed a fascinating situation. Einstein believed in 1917 that he had found a unique solution of the cosmological problem in the form of a closed universe with certain distributions of matter. Shortly afterwards however, de Sitter showed that the Einstein solution was only stable if it was completely empty of matter, and that as soon as matter was placed in the universe an expansion would occur. This theoretical prediction was made ten years before Hubble produced the observational proof of the expansion of the universe. Naturally, the observations of Hubble ten years later, that the universe was in a state of expansion, were widely held to be a great triumph for the Theory of Relativity. However, in the meantime, other solutions of the equations predicting different world models for the universe had been found.

In fact, until the observations of the universe can define certain characteristics of space-time, there can be no singular solution of the equations. The constant of integration in the equations, commonly known as the lambda term or the cosmological constant, can be negative, zero or positive. There has been much dispute about the significance and meaning of this cosmological constant. With the constant zero we are led to the concept of a singular beginning—popularly known as the big bang universe. According to the currently accepted slope of the Hubble line connecting red shift and distance, the singularity existed ten thousand million years ago. In the initial moment of time the supercondensate of primeval hydrogen exploded. In this model there is no reprieve for the universe and the galaxies will continue to move apart at great speed until everything moves to its ultimate death with zero energy. However, the observations of the universe do not confirm that this concept of the expansion of the universe from the super-dense state with the lambda term zero is unique. If the term is negative the theory predicts that the universe, starting from a condensed condition in the past, will expand to a maximum radius and will then contract again to a highly condensed condition. Thus our descendants in the remote future would observe blue shifts when they study the distant regions of space-time. Depending on the value assigned to the negative cosmological constant the universe might either move through one cycle or continue endlessly with the successive expansions and contractions. At least some cosmologists have interpreted recent observations in favour of a cyclical universe of this type.

In a universe of this cyclical nature the problem of time's arrow is intriguing. For us time moves forward; time's arrow is well defined. This evening is later than this morning, today is earlier than tomorrow. But when the universe moves over the hump through the state of maximum expansion with the lambda term negative, and then begins to contract, it does not seem to be clear that time's arrow is well defined in this positive manner. As far as I am aware there is no observation which can be made on the universe as a whole which defines, on the cosmic scale, the direction of time's arrow. Indeed one of the fundamental laws of thermodynamics (relating to increase of entropy) would seem to imply that time's arrow must be reversed when the universe begins to contract otherwise the entropy of the universe, instead of increasing, would begin to decrease. It seems to be fundamental on the macroscopic scale that the entropy of a system is always increasing, so I think there is a very deep physical and philosophical problem in some of the cosmological theories with the negative cosmological constant.

The other condition, with the cosmological constant positive, has been thoroughly explored by the Belgian Jesuit astronomer, Abbé Lemaître. Lemaître's theory with the positive cosmological constant predicts a singular state for the origin of the universe. But this singular state existed fifty thousand million years ago, not ten thousand million as on the big bang theory. Furthermore, the subsequent history is different from that of the big bang model. The singular condition, which Lemaître calls the primeval atom, disintegrated. After about fifty thousand million years, the whole of the primeval gas had expanded so that the initial impetus of the explosion was exhausted and a state of near stability was reached. At that epoch—about ten thousand million years ago—the universe must have settled down into a nearly uniform condition of gaseous hydrogen, distributed throughout a sphere of about ten million light years in diameter. Then some disturbance occurred and the condensation into the stars and galaxies began. Since the impetus of the initial explosion has been lost it is still necessary to explain why we live in an expanding universe. According to Lemaître, the positive cosmological constant implies that there must be some other force in the universe which works in opposition to that of Newtonian attraction. It is known as cosmical repulsion. In this case, bodies on the large scale repel one another with a force which increases with the distance apart of the bodies (not varying as the inverse square of the distance as in Newtonian attraction). So with the cosmological constant positive there is a strange geometry about the universe which produces a force observable only on the cosmological scale at great distances, and which overcomes the Newtonian attraction between the galaxies and leads to the expansion of the universe.

At this moment there does not appear to be any conclusive evidence which might lead to a decision between these possible theories. About 25 years ago the position was complicated even further because of a difficulty about the age of the earth compared with what was then believed to be the age of the universe. At that time the available information about the age of the universe was that it could not be more than five thousand million years—not significantly older than the age of the earth. The theory of continuous creation was then proposed to overcome this conflict. On this theory there never was a singular condition such as is demanded by the evolutionary theories derived from General Relativity, but the basic material of the universe (hydrogen) is being created continuously throughout all time and space. The creation of the hydrogen is occurring at just the right rate to form into galaxies which take the place of the galaxies moving out of our field of view because of the expansion of the universe. On this theory, the expansion of the universe occurs because of the pressure of the created hydrogen which forces the galaxies apart.

On the whole, I think it would be true to say that the balance of the observational evidence at the present time is against the Steady State or Continuous Creation Theory, at least in this simple form just stated. Insofar as one is able to make any conclusions from the conflicting evidence available, the indications are that the universe must be in some form of evolutionary condition. The task which faces us now is to extend our observations of the universe beyond the present limits in order to find out if we can detect any signs of change as we move back into its past history.

I want to say a few words about the present condition of these observations. The large optical telescopes—the 100-inch telescope on Mount Wilson which commenced observations in 1917, followed by the 200-inch telescope on Palomar 30 years later—succeeded in penetrating the universe only a few thousand million light years. Then work began with the recently developed radio telescopes which enabled us to detect the radio waves coming from the universe. It is still our major problem to find out the nature of many of the objects in the universe which are responsible for the emission of these radio waves. A large radio telescope, such as the one at Jodrell Bank, can be used to make a survey of the sky. A record can be made of the intensity of the radio signals either on a chart recorder, or by punched tape in a computer. This radio map reveals that the heavens are packed with many, many thousands of intense sources of radio waves. It is natural to attempt to relate these intense radio sources to visible objects on an ordinary star map. If we attempt this correlation there are many surprises because we find that the strongest radio sources do not seem to be related to any of the common objects, such as the stars or galaxies, which we find on the photographs of the sky taken with the large optical telescopes. It is the investigation of this anomaly which has extended our view of the universe far into space and into its past history.

Ten years ago radio-astronomers succeeded in finding an accurate position for some of the strongest radio sources in the sky. These positions were good enough for long exposures to be made with the 200-inch optical telescope with the certainty that the photographs would cover the regions of the sky containing the radio-emitting objects. The American astronomers concerned found an image on the plate in the position of the radio source which was of a type not previously recognized. It was interpreted as two galaxies, apparently interacting. Originally it was believed that this was a photograph of the collision of two galaxies—for example, as though the Milky Way and M31 had collided with one another. The remarkable fact was that the object, whatever its nature, was extremely distant—about seven hundred and fifty million light years away. Another surprising feature was that although these galaxies were so distant and faint that they could only be photographed after an exposure of many hours with the world's largest optical telescopes the radio signals were prominent. In fact a simple television aerial is adequate, as a radio telescope, to receive these signals. In other words these remote and hitherto unrecognized galaxies were powerful emitters of radio waves, but extremely faint optically. This immediately led to the view that our failure to identify the many thousands of radio sources arose because we were dealing with hitherto unrecognized objects far away in the universe which could be revealed more readily with the radio telescopes than with the optical telescopes.

The pursuit of this concept, and the successive identification of special types of radio-emitting sources with the 200-inch telescope, rapidly extended our knowledge of the universe to about four and a half thousand million light years. In 1959 a radio source was identified in the constellation of Boötes which was receding with a speed of nearly half the velocity of light. By that time these newly discovered objects had become known as radio galaxies. Then a remarkable situation developed. A group of radio astronomers at Jodrell Bank were concerned with the measurement of the angular diameters of these radio galaxies. It had been found that the more distant the radio galaxy, the smaller its angular diameter. Indeed it was the small value of the angular diameter measured for the radio galaxy in Boötes which led to the concentration of the optical telescopes on it. In view of the desire to penetrate further into time and space to obtain more decisive information about the cosmological problem, the next stage in the investigations seemed clear. That is more of the radio galaxies of even small angular diameters must be sought and identified optically. The existing evidence suggested that they would be more distant than the Boötes radio galaxy.

These researches were pursued and in 1960 the radio astronomers at Jodrell Bank found a few objects which had significantly smaller angular diameters than the radio galaxy in Boötes—only about a second of an arc in diameter. The precise positions of these sources were known from measurements made by radio astronomers in Cambridge and in California. They were photographed by the 200-inch optical telescope and at a meeting in New York at the end of 1961 Dr Allan Sandage announced that he had succeeded in identifying these objects. He said that they were not radio galaxies far away in the universe, but blue objects with star-like images of a type which had not previously been known. Since no red shift could be measured there was a presumption that these must be blue stars in the

Milky Way. The astronomical world was astonished by this announcement because all the evidence led to the expectation that these objects would be remote in the universe. No one was happy about this relation with the stars, but only another year elapsed before the true answer was found by a young Dutch astronomer then working at Palomar, Maarten Schmidt. He made one of the most startling astronomical discoveries of modern times. So far no one had been able to make sense of the spectrum of these blue objects. Schmidt succeeded. He found that the spectrum of these blue objects was red-shifted so much that the lines which ought to be in the invisible ultraviolet region of the spectrum had been shifted so far that they were in the visible region. That is, the lines which were visible would have been in the invisible ultraviolet part of the spectrum for an object in a stationary condition. In other words Schmidt found that these blue objects were not stars in the Milky Way but were, indeed, objects at a very great distance with red shifts far in excess of any that had been measured previously.

For the last decade many observational and theoretical astronomers, radio and optical, have wrestled with the problem of these objects which became known as quasars (quasi-stellar radio sources). So far about 300 have been identified, but we believe that the quasars probably constitute only a quarter of the total population of the universe. It is a salutary thought to those who claim to understand the nature of the universe that today we believe that the quasars are such a prominent constituent of the observable regions of space-time and yet they were discovered only a decade ago. The red shifts which have been measured for the identified quasars are very high indeed. The indicated velocity of recession of the most distant ones seems to be between 80 and 90% of the velocity of light.

If this interpretation of the red shifts is correct then we must nearly have reached the limit of possible penetration into space, because we are observing objects which are already receding with velocities close to the velocity of light. We are close to the possible observational horizon set by the velocity of light and radio waves in space. The red shift of the spectral lines is the measured parameter, the velocity is derived on the assumption that the red shift is a Doppler effect arising because of the expansion of the universe. What further information can this give us about the distance of these quasars, and what is the 'look-back' time into the past history of the universe? These answers cannot be given until we know which cosmological model applies to the universe of our observation. Tentative answers can be given if assumptions are made about the value of the cosmological constant and the Hubble constant. If the cosmological constant is zero, and the Hubble constant 100 km. per sec. per megaparsec., then the distance of these quasars having recessional velocities of about 80% of the velocity of light must be of the order of six thousand million light years or more, and we must be looking back six thousand million years into the past history of the universe. On the basis of any of these theories, we must now be penetrating into the regions of time and space where the answers to the cosmological problem must be contained. Ten years ago it would have been rational to believe that under these circumstances a definite answer to the cosmological problem would be at hand. Unfortunately, if we place the red shifts of these objects on to the extrapolation of the Hubble line we find that the scatter is so much that all possible cosmologies remain possible. There is too great a dispersion in the results to enable us to define the critical deceleration parameter and we cannot say decisively that the universe was in a singular condition of high density ten thousand million years ago. It might have been.

There is another problem which hinders our assessment of these distant radio galaxies and quasars. Normally, when we enquire about the energy of the universe we are accustomed to dealing with the energy of bodies like the Sun and the stars. The Sun and the stars generate their energy by thermonuclear processes in their deep interiors during the main sequence phase, by the conversion of hydrogen into helium. In these processes about 1% of the mass is lost to radiation which appears as the enormous energy of the star. But the process is rather inefficient in the amount of matter which is converted to energy. Conversion efficiencies of about 1% are common in the thermonuclear reactions in the universe. If we apply these concepts to the quasars and radio galaxies we find that they are quite inadequate to explain the great amount of energy which is involved. The total energy emitted in the radio and optical regions of the spectrum from these quasars may be 10^{60} to 10^{62} ergs. Furthermore, the output of this energy is not constant. Normally we think of long-term stability in the universe, yet if we measure some of the quasars we find that they exhibit short-term variations—detectable in some cases from day to day. Some of the radio galaxies and quasars are not only pouring out enormous amounts of energy, but also have variable emission processes.

In itself this would be a difficult problem but the possible explanations are further constricted by the angular diameter measurements. These angular diameter measurements have been pursued by using two radio telescopes to observe the quasars simultaneously. The greater the separation, the smaller the angular diameter which can be measured. For many years our own measurements used a remote telescope which was installed at various distances from the large telescope at Jodrell Bank. When all reasonable baselines had been explored we still found that there were a number of the quasars which were not resolved, indicating that their diameters were less than about a tenth of a second of arc. Then the Canadians devised a new type of equipment which enabled them to have one radio-telescope in Canada and another elsewhere in the world. Recently we have, ourselves, linked Jodrell Bank with radio telescopes in Arecibo (Puerto Rico). The resolving power of these combinations is now reduced to one thousandth of a second of arc, and still we find that some of the quasars remain unresolved. On the basis of the observed red shifts to which I have referred we can estimate the physical dimensions of the quasars. We then reach the astonishing conclusion that this vast amount of energy is being generated, not over the dimensions of the galaxy as one might expect from the nature of the universe around us, but in a volume of space only a few light years across. Imagine a volume of space similar to that containing the Sun and the nearest star for example. Then, in order to account for the energy we would have to envisage one hundred million suns packed into this small volume of space. Moreover, these hundred million suns would not simply be generating energy with the normal 1% efficiency of the hydrogen-helium transmutation. They would be converting almost their entire rest mass into energy. This illustration may give you some idea of the tremendous problem we face today in explaining the processes at work in these remote regions of the universe.

Needless to say many theories have been developed in an attempt to explain these observations. It has been suggested, for example, that we are witnessing the release of the whole gravitational energy due to the implosion of this great mass of material. It is a problem which, at the present time, can be described but which has no known solution. It is even conceivable that in these observations, we are dealing with the very early state of the universe in which we are concerned with matter, and with anti-matter. In the beginning the universe may have consisted of an ambi-plasma of matter and anti-matter. The consequent interaction would give total annihilation. The least satisfactory escape may be to say that the laws of physics which concern us on earth are local and do not apply to the universe as a whole but that entirely different laws of nature apply in these remote parts of time and space. This is an escape, and not a solution to be recommended until we are absolutely certain that the observations with which we are dealing cannot be explained in terms of the common laws of nature of our daily experience. So I regret to have to remark at the end of my talk on the nature of the universe that I have presented you with many new problems and few solutions. In recent years our observations seem to me to have increased the complex problems about the nature of the universe. The marvellous scientific devices of our age undoubtedly penetrate to the regions of space-time which on any rational theoretical basis should enable us to define the limits of the cosmological problem more precisely than at any previous time in history. It is a puzzling and haunting feature of our time that the observations which seem destined to settle the cosmological issue serve again and again to uncover a whole new range of apparently intractable problems.