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MODERN COSMOLOGY AND LIFE'S MEANING

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Introduction

Modern cosmology, as well as ancient mythologies, cosmologies and cosmogonies, bear witness to the immense power which drives us humans in our continuous search for a deeper understanding of the universe and our place in it. They also bear witness to the insufficiency of our search for understanding, of the need for something or someone out there, beyond oneself. From time immemorial we have always sought this further understanding in a person with whom we could converse, someone who shared our capacity to love and be loved and our desire to understand and to accomplish.

Our attempts, therefore, to understand the universe have as much to say about ourselves as they do about the universe. In fact, in us the universe can reflect upon itself and from our reflections there grows the conviction that we are part of that upon which we are reflecting. As soon as we set out with the powerful instruments for telescopic observations, together with those of mathematics and physics, to understand the universe and our place in it, we are made aware that we are standing on the shoulders of giants and that the path which has led to what we know today has been, with respect to a human lifetime, a long and arduous one and that many have gone before us. But, in comparison to the age of the universe, it has really been quite a short trek. Let us review some of the important things we have learned about the universe during that trek.

The Universe of Modern Science

If we look in infrared light at the center of Orion we see boiling gas and dust. If we look even closer up we see incandescent regions buried in

that gas and with the Hubble Space Telescope we see the fine separation of blue gas and red gas in the midst of a rather chaotic structure. The fact is that stars are being born in this gas. And where the hottest, most massive and, therefore, brightest stars are already born, they are irradiating the gas, and it is giving off hydrogen alpha radiation. In this way we can identify star birth regions.

The region of star birth in Orion is just a little part of our Milky Way. Our Milky Way, like most other spiral galaxies, measures 100,000 light years across and it contains about a hundred billion stars. It has several beautiful spiral arms and the sun is located in one of the outer arms, about 2/3 of the distance from the nucleus of our galaxy.

We have reconstructed the plane of our galaxy the Milky Way with a mosaic taken by an infrared satellite. We see myriads of stars but we also see dark areas where there are none or very few stars. It is precisely this dark stuff out of which stars are born. These dark areas are really veils of gas and dust hanging down and hiding the stars that are embedded in them.

How is a star born? It happens by the laws of physics. A cloud of gas and dust, containing about 100 to 1,000 times the mass of our sun, gets shocked by a supernova explosion or something similar and this causes an interplay between the magnetic and gravity field. The cloud begins to break up and chunks of the cloud begin to collapse. And as any gas collapses, it begins to heat up. In this case the mass is so great that the internal temperature reaches millions of degrees and thus turns on a thermonuclear furnace. A star is born. Thermonuclear energy is the source whereby a star radiates to the universe.

Stars also die. A star at the end of its life can no longer sustain a thermonuclear furnace and so it can no longer resist against gravity. It collapses for a final time, explodes and expels its outer atmosphere to the universe. This may happen nice and peacefully or it may happen in a violent cataclysmic explosion, called a supernova. The most famous of these is the Crab Nebula which has a pulsar at the middle as its dead star.

So stars are born and stars die. And as they die they spew leftover star matter out to the universe. The birth and death of stars is very important. If it were not happening, you and I would not be here. In order to get the chemical elements to make the human body, we had to have three generations of stars. A succeeding generation of stars is born out of the material that is spewed out by a previous generation. But now notice that the second generation of stars is born out of material that was made in a thermonuclear furnace. The star lived by converting hydrogen to helium, heli-

um to carbon, and if it were massive enough, carbon to oxygen, to nitrogen, all the way up to iron. As a star lives, it converts the lighter elements into the heavier elements. That is the way we get carbon and silicon and the other elements to make human hair and toe nails and all of those things. To get the chemistry to make amoebas we had to have the stars regurgitating material to the universe.

Humans Come on Stage

Obviously this story of star birth and death is very important for us. Out of this whole process around one star, which we call the sun, a group of planets came to be, among them the little grain of sand we call the Earth. An amazing thing happened with that little grain of sand. We know it happened and we deal with it every day, but we should still pause to think about the amazing occurrence in the 16th and 17th centuries with the birth of modern science. We developed the capacity to put the universe in our heads. We do that by using mathematics and the laws of physics, of chemistry and of biology.

How is it that I can claim without hesitation, as I did above, that there are a hundred billion stars in our galaxy and that the galaxy is 100,000 light years across? I obviously could not go out there and measure those quantities directly. And yet I claim that those measurements are as accurate as the measure of my height and weight. I can have the same certainty because I have been able to use the laws of physics and mathematics and chemistry and biology to put a galaxy, the universe, in my head and work with it. Of course some measurements in cosmology are more certain than others, but we really are certain about the mass of our galaxy. Because it rotates we can use the law of gravity to measure the mass of the galaxy in the same way as I measure the mass of the earth and the other planets going about the sun. The law of gravity will give you the total mass of the galaxy.

The Questioning Human Brain

Once we developed this capacity to put the universe in our heads, we became passionately interested in asking all kinds of questions. I would like to ask a few. Did our planetary system come about by a miracle? Absolutely not. Although we do not know everything about how it came about, we know that it happened in conjunction with the formation of the sun. Gas and dust were left over from the birth of the sun, and this gas

and dust had to form into a disk by the law of physics to conserve angular momentum. Once all of this mass is concentrated into a disk, there is a much greater chance that the particles of gas and dust will collide and, in some cases, stick together. And, just like the rolling snowball effect, planetesimals, about 100 kilometers in diameter, are built up through accretion and finally planets are accreted from the planetesimals. We do not know everything about this process, but we know enough about it to know that it did not happen by a miracle. It happened by ordinary physical and chemical processes.

So, a further question arises: Did what we have just described happen elsewhere? First of all we look at those nearby stars that we suspect may be something like the sun. We have detected thus far more than 100 planets about other stars due to the center of mass motion of the star. That is an indirect way but a very solid one of detecting planets. We detect a wobble in the star due to the fact that there is mass outside of it so that the center of mass of the system is not at the geometrical center of the star. Furthermore, with the Hubble Space Telescope we have discovered disks around very young stars. We know for certain that they are very young stars by their spectra. We call the disks proto planetary because we have indirect evidence that the first planets have begun to form in the inner regions of the disk. We are beginning to see about other stars the process that we think formed the planets about the sun.

Since we have the capacity to put the universe in our heads, a further question comes to us. Where did galaxies come from? Galaxies are the building blocks of the universe. Hubble Space Telescope has been able to photograph some of the most distant objects we have ever seen in the universe. They are at a distance of about ten billion light years from us. So we are seeing these objects as they were ten billion years ago.

We think that Hubble is seeing proto galaxies. We see, for instance, a case of two blobs which seem to be merging and perhaps building up a galaxy. However, this is very controversial. We are uncertain about galaxy formation, whether it is bottom up with small units that build into a galaxy, or top down with a big cloud that collapses to form a galaxy, and then the stars form within it. Nevertheless, when we compare distant galaxies to nearby galaxies, we see clear differences in the stellar populations. Galaxies as they are born and age go through an evolutionary process. Galaxies are participating in the expansion of the universe. When we look at them on a large scale we see that they are not distributed homogeneously. There are large empty spaces and many dense alignments.

Origins of Intelligent Life

How did we humans come to be in this evolving universe? It is quite clear that we do not know everything about this process. But it would be scientifically absurd to deny that the human brain is a result of a process of chemical complexification in an evolving universe. After the universe became rich in certain basic chemicals, those chemicals got together in successive steps to make ever more complex molecules.

Finally in some extraordinary chemical process the human brain came to be, the most complicated machine that we know. I should make it clear that, when I speak about the human brain as a machine, I am not excluding the spiritual dimension of the human being. I am simply prescinding from it and talking about the human brain as a biological, chemical mechanism, evolving out of the universe.

Did this happen by chance or by necessity in this evolving universe? The first thing to be said is that the problem is not formulated correctly. It is not just a question of chance or necessity because, first of all, it is both. Furthermore, there is a third element here that is very important. It is what I call 'opportunity'. What this means is that the universe is so prolific in offering the opportunity for the success of both chance and necessary processes that such a character of the universe must be included in the discussion. The universe is 15 billion years old, it contains about 100 billion galaxies each of which contains 100 billion stars of an immense variety.

We might illustrate what opportunity means in the following way. Einstein said that God does not play at dice. He was referring specifically to quantum mechanics, but it can be applied in general to his view of the universe. For him God made a universe to work according to established laws. This is referred to as a Newtonian Universe. It is like a clock that just keeps ticking away once you supply it energy. Today we might be permitted to challenge this point of view. We could claim that God does play at dice because he is certain to win. The point being made is that God made a universe that is so prolific with the possibilities for these processes to have success that we have to take the nature of the universe into consideration when we talk about how we came to be.

For 15 billion years the universe has been playing at the lottery. What do I mean by the lottery? When we speak about chance we mean that it is very unlikely that a certain event would happen. The 'very unlikely' can be calculated in mathematical terms. Such a calculation takes into account how big the universe is, how many stars there are, how many stars would

have developed planets, etc. In other words, it is not just guesswork. There is a foundation in fact for making each successive calculation.

A good example of a chance event would be two very simple molecules wandering about in the universe. They happen to meet one another and, when they do, they would love to make a more complex molecule because that is the nature of these molecules. But the temperature and pressure conditions are such that the chemical bonding to make a more complex molecule cannot happen. So they wander off, but they or identical molecules meet billions and billions of times, trillions if you wish, in this universe, and finally they meet and the temperature and pressure conditions are correct. This could happen more easily around certain types of stars than other types of stars, so we can throw in all kinds of other factors.

The point is that from a strictly mathematical analysis of this, called the mathematics of nonlinear dynamics, one can say that as this process goes on and more complex molecules develop, there is more and more direction to this process. As the complexity increases, the future complexity becomes more and more predetermined. In such ways did the human brain come to be and it is still evolving.

Summary

It makes us dizzy to contemplate billions of years in the evolving universe and then to think that we are on a little planet orbiting a quite normal star, one of the 200 billion stars in the Milky Way. And the Milky Way is just one galaxy and not anything special among the billions of galaxies which populate the visible universe.

Cosmology today is ever more human; it stimulates, provokes, questions us in ways that drive us beyond science in the search for satisfaction, while at the same time scientific data furnish the stimuli. In this context the best cosmology, to its great merit, does not pretend nor presume to have the ultimate answers. It simply suggests and urges us on, well aware that not all is within its ken. Freedom to seek understanding and not dogmatism in what is understood characterize the best of cosmology. It is, in fact, a field where certainties lie always in the future; thus it is vital, dynamic and very demanding of those who seek to discover the secrets of the universe.

DISCUSSION ON THE PAPER BY COYNE

RAO: Professor Coyne, I don't think that the neural networks, or whatever those networks are, generate heat, as is the case in large integrated circuits. I do not know about thermal energy and the way it is released. Are you sure the situation is like that: as you increase the surface area you would expect heat to be generated? I just wonder, because it is important to know whether heat is generated because of our neural network functioning. I am not sure that this is known.

SINGER: The cooling problem is not the central problem of brain science. There is a very efficient way to cool down the brain by blood circulation, and there are much bigger brains than our brains, such as the elephant brain or the whale brain. What seems to limit brains ultimately is that the conduction time of the nerve fibre is finite and if you want to establish coherence in time you cannot go too far, otherwise you lose coherence, but there may be other reasons as well.

MURADIAN: I have a small, but I think important, remark about life in the universe, about the transformation of inorganic matter into organic matter. Let us suppose that the rate of the transformation, of the augmentation of humanity, human mass, is 1% per year, and that over the past five thousand years the mass of the earth has become a mass of humans. This is a historical time, not a cosmological time. Over these five thousand years all the mass of the universe will transform into organic or human mass. It seems that the arithmetic here is very simple. There is no doubt: it is Malthusian arithmetic. And what do you think will prevent such a catastrophe? The meaning of life is the transformation of inorganic matter into organic form, and we see that this transformation occurs in a very short time-scale. Is there a contradiction from the point of view of religion or science to this?

COYNE: If I have understood, I do not see any contradiction. Religion has nothing to say to the transformations to which you refer. From our sci-

entific knowledge we know that there is a constant replenishment of inorganic materials to the universe through the process of stellar evolution. But, in my paper I did not address the percentage of living matter in the total matter of the universe. It must be very small. I assume, for instance, that life could not exist in, or even near, black holes of which the universe is abundant. Actually, I referred in my paper only to the distribution of living matter on the Earth, 98% in plants, 2% in animals.

LÉNA: Yes, this is more a comment than a question, and it's about strategies to look for life in the universe. You mentioned the SETI, the search for extraterrestrial intelligence with radio signals, which is one approach. This is a top to bottom approach: we search for the most elaborate forms of life that we know about through the detection of intelligent signals. Now, the other method is of course bottom up, namely looking for signs of life which are vegetation, for instance, or any other sign such as the presence of ozone around the terrestrial planet which in our view is related to organic chemistry and life production because of the balance of thermodynamic equilibrium. Now, both approaches are extremely interesting. The first one is a somewhat fishing approach, I mean, either you succeed, and you get a signal, or you get nothing and you know nothing. The other one seems to me more scientific in the sense that it can go gradually, you get an image and this is within reach. We know that, ten or fifteen years from now we will have images of the surface of planets such as the earth at distances of a few light-years, and then we can look on those for signs of changing vegetation with time, which is perhaps not as conclusive as the first approach, but it is less of a fishing approach. I think one has to have both. I suppose you agree with that point.

COYNE: Yes, I agree. I agree completely that there are two ways of doing this. The limitation today is that looking out from the Sun, there are only a few solar-like stars within a few thousand light years of the Sun. To look all the way across our galaxy is going to take two hundred thousand light years to send the signal and receive it back so the chances, if you put all the well-known statistics on the distribution of stars, the chances of getting an intelligent signal are minimal.

But the point is, it's a less scientific way to do it, but it would be an immense achievement if we received what could really be interpreted as an intelligent signal. There are all kinds of implications. I agree absolutely. Our observing technology is improving all the time. In the past decade

we have discovered more than one hundred planets about other stars. We have also discovered planetary systems. Furthermore, we have discovered disks of matter about extra-solar stars which are very much like the disk of material about the Sun out of which our planetary system was formed. We are developing techniques to sample the chemical composition of extra-solar planets in an attempt to detect such constituents as oxygen, ozone, nitrogen, etc., possible signatures of life.

SINGER: I think I have to cut the discussion here. We could go on for long, talking about the possibility of extraterrestrial life and the limits of the universe and why we apply a Cartesian system in order to describe something which is probably not Cartesian, and so forth.