The Universe: Past and Present Reflections

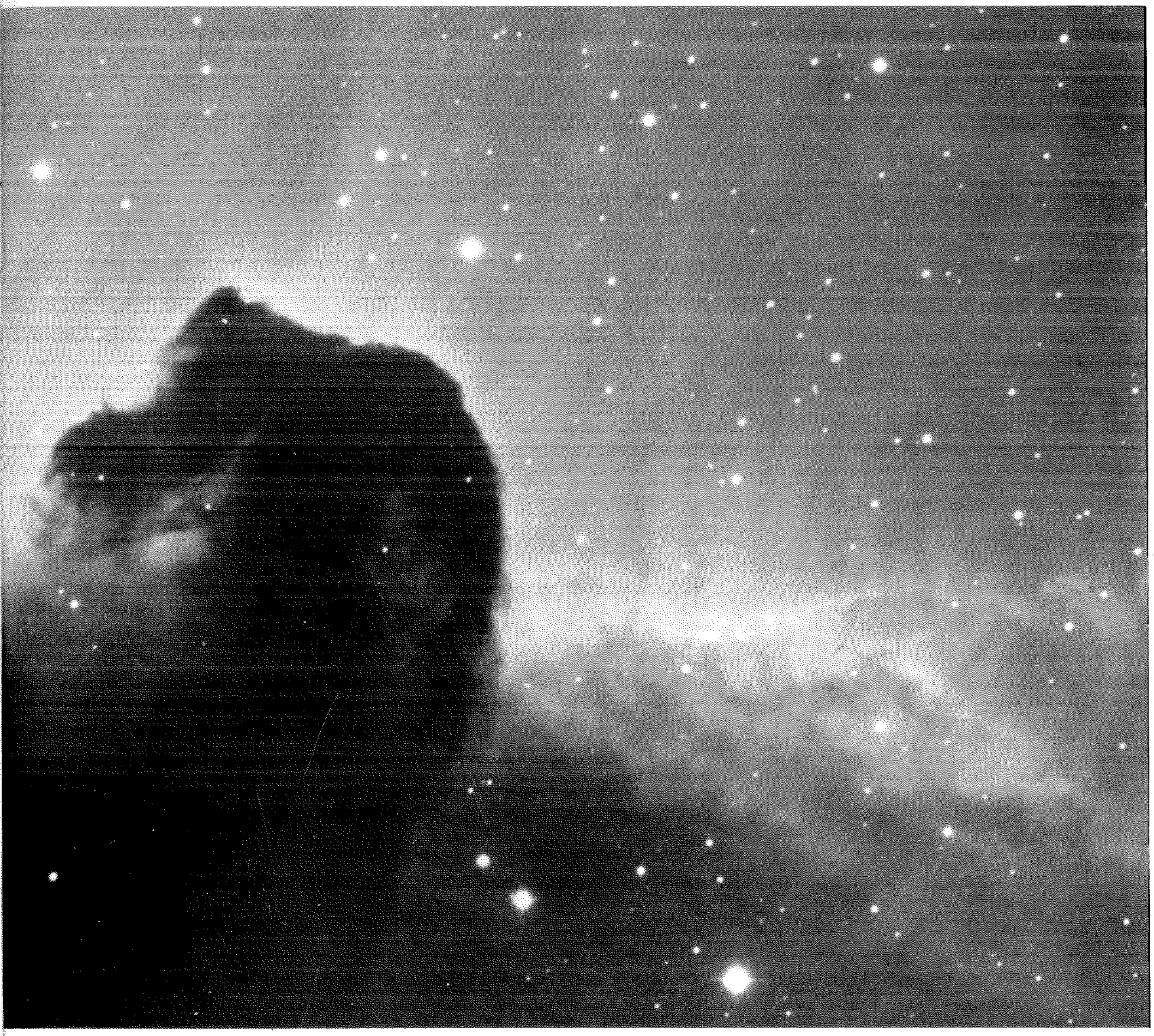
by Sir Fred Hoyle

DEFINING the universe to be everything there is, manifestly we cannot be expected to understand it exactly, since to do so we would need both a complete command of the laws of physics and the fantastic calculating power to work through the detailed properties of assemblies containing very large numbers of particles. What then are astronomers doing in their studies of cosmology? Obviously, we are beavering away to give an imperfect answer to an imperfectly defined problem. The issue is the quality or otherwise of our approximations. I suppose nine astronomers out of ten work on the presumption that our approximations are quite meritoriously good. In this essay I shall presume to hint that it may be otherwise.

The nebulosity of nebulae, for example, is due to small particles, or grains, which act to produce a fogging of the distant light. In fact, sometimes the fogging is so extreme that we don't see the stars that lie behind the nebulosity. Sometimes this fogging effect produces apparent rifts that are really due to the material of the grains blocking out the light of the stars that lie behind. Measurements of the properties of the grains indicate that they are remarkably similar in their physical properties, in their sizes. Whatever observations are being made, they always seem to turn out the same.

The problem of the nature of these grains began for me in a very innocent way but ended in unexpected results. In the 1950s, when I was much of the time here at Caltech, astronomers believed the interstellar grains to be water ice. Nothing at all was riding on this issue for me, and I would gladly have accepted the conventional point of view if calculation had shown it to be viable. The trouble was that interstellar grains are constantly changing their positions in relation to the stars. Even the briefest exposure of a water-ice grain to a temperature no higher than $-150°$ C will cause it to evaporate. I didn't find in my calculations that, once evaporated, water-ice grains would recondense by themselves under any conditions that seemed plausible. I chanced on this difficulty as long ago as 1955 thinking then that the grains must consist of some more refractory substance than ice as, for instance, graphite. But the matter rested so lightly with me that I did nothing more about it until some five years later when I had a graduate student, named Chandra Wickramasinghe, in need of a problem.

It was an encouraging indication that there might be something right about the idea when it turned out that the physical properties of graphite happened to be such as would give a reasonable approximation to the observed fogging that the grains produce in the visual light of distant stars. Furthermore, the behavior of the physical properties with respect to frequency, to wavelength, enabled us to predict that graphite would produce enormous fogging in an ultraviolet waveband cen-



The fogging effect in nebulae – as shown in this photograph of the Horsehead Nebula in Orion in our own galaxy – is due to small particles, or grains. On the following page the same effect can be seen in the central region of the galaxy M33, much farther away. Measurements of interstellar grains show them to be remarkably similar in physical properties regardless of where they are observed. Both of these photographs are from the 200-inch Hale telescope at Caltech's Palomar Observatory.

tered at about 2000 angstroms. When this predicted large extinction was actually discovered about a year later from rocket firings, it seemed certain that there really must be something right with the graphite idea. However, it's one of the incorrigible features of science that, whenever you have a theory that appears at first to be correct, you eventually find trouble in fitting all the other details that come along subsequently. And so it was with our graphite particles.

By 1965 enough was known of the reflectivity of interstellar grains for us to see that the reflectivity of graphite was too low. Graphite was too absorptive, too black. It seemed therefore that, while there was something right about graphite, the graphite theory could not be all right.

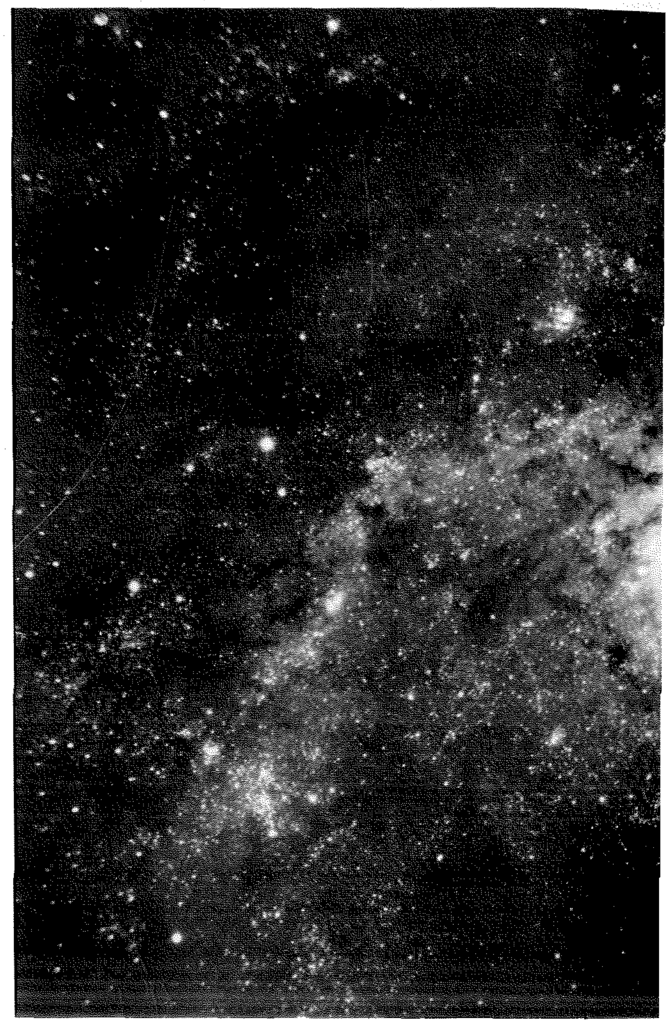
The next step was to try a composite model for the particles, a model with graphite cores and water-ice mantles. This composite core-mantle theory was a parameter-fitting enthusiast's delight. The shapes and sizes of the particles could be varied, as well as the relative proportions of graphite and ice. With so many parameters available, a moderate correspondence with all the data was inevitable and could not therefore be considered much of an achievement. The important thing was to obtain a really good correspondence with the data, and this holy grail eluded us with maddening persistence. Starting from a moderate agreement with all the data, we would tune up the parameters to get some particular feature almost exactly right, only to find the correspondence with the rest of the data had become worse. Gradually it was borne in on us that we had a wrong theory on our hands.

So it came about that in the later 1960s we began thinking of what other kinds of particle there might be. We tried metals and silicates as well as graphite. However, by 1970 the total quantity of interstellar gas had become quite accurately known. Supposing all the refractory material, such as magnesium oxide, silica, calcium oxide, and iron to become condensed out of the gas into grains, one could calculate that the amount of the grains was insufficient to explain the observed degree of fogging of starlight by a factor of about three. And then only if the sizes of the grains were chosen to give maximum opacity. Because this maximum opacity condition was quite unlikely to be satisfied everywhere throughout our galaxy, the prudent conclusion was that the amount of metals and of magnesium aluminum silicates was in deficit by a factor of at least five.

This result forced the conclusion that the grains have to be composed of elements with cosmic abundances an order of magnitude greater than magnesium, aluminum, silicon, and iron. It forced the conclusion that the mass of the grains had to come largely from carbon, nitrogen, and oxygen. But since by now we were fully convinced that the graphite-water ice mixture couldn't be correct, what otherwise could the grains be? All inorganic solids built from carbon, nitrogen, and oxygen, perhaps together with hydrogen, could easily be seen to evaporate much too readily. So with an initial sense of bewilderment, Wickramasinghe and I reached the conclusion that the grains had to be made up largely of organic material.

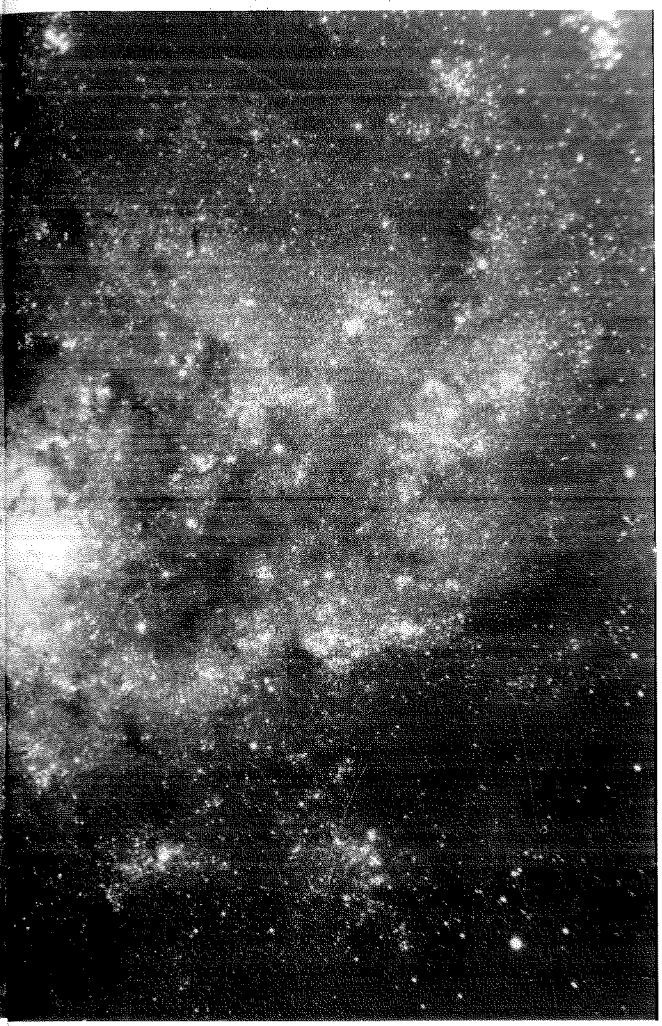
An interesting question forced itself on our attention. With the realization that the interstellar grains are largely organic, one sees that the material of the early solar system must have contained an enormous quantity of organics, at least 3000 earth masses of it. Much organic material would be destroyed by the heat of the solar nebula, but much would survive in the comparatively cool outer regions of the solar system, especially in the regions of the distant comets. And since at subsequent times a fraction of comets have developed orbits of high eccentricity, bringing them to the inner regions of the solar system with a part of the material that is constantly evaporating from them enmeshing the terrestrial atmosphere, there was a known process for transferring organic materials from the outer distant regions of the solar system to the earth. Could this potentially very large and still continuing source of organic material have formed the basis for the origin of life rather than the comparatively tiny quantity of organics generated in terrestrial thunderstorms and other purely local events?

Wickramasinghe and I answered this question affirmatively, and so we arrived at a temporary equilibrium point in our thinking: The organic basis of life was interstellar, a position that some others I think are favoring nowadays. It was at



this stage that we began our technical readings in biology, fully expecting the usual picture of the terrestrial origin and evolution of life to be amply confirmed by the facts.

But this first resting point did not survive those early readings, as it was quickly apparent that the facts point overwhelmingly against life being of terrestrial origin. Although we were quite released from what I now regard as a conceptual millstone, my own brain made no profound leap toward freedom. It just plodded its way, small step by small step, first to the comets. Because comets must have experienced break-up and reformation with material interchanged between them, and because the material would be organic, in our view, it was possible to think of the whole ensemble of comets, many billions of them, as a life-generating unit. And because a few comets are breaking up and scattering their contents all the time, the process was not relegated to the remote past. This was a big plus mark, since theories that relate to current events stand in my view much above those that are concerned only with situations that are long dead and done



with. There was therefore much of interest to be worked through in this first shift from the earth to comets, and the investigation of a number of side issues deluded us for a while into thinking that the main problem — the origin of life — had been faced.

The big problem in biology, as I see it, is to understand the origin of the information carried by the explicit structures of biomolecules. The issue isn't so much the rather crude fact that a protein consists of a chain of amino acids linked together in a certain way, but that the explicit ordering of the amino acids endows the chain with remarkable properties, which other orderings wouldn't give. The case of the enzymes is well known. Enzymes act as catalysts in speeding up chemical reactions that would otherwise go far too slowly, as in the breakdown, for example, of starch into sugar. If amino acids were linked at random, there would be a vast number of arrangements that would be useless in serving the purposes of a living cell. When you consider that a typical enzyme has a chain of perhaps 200 links and that there are 20 possibilities for each link, it's easy to see that the number of useless arrangements is enormous, more than the number of atoms in all the galaxies visible in the largest telescopes. This is for one enzyme, and there are upwards of 2000 of them, mainly serving very different purposes. So how did the situation get to where we find it to be? This is, as I see it, the biological problem — the information problem.

It's easy to frame a deceitful answer to it. Start with much simpler, much smaller enzymes, which are sufficiently elementary to be discoverable by chance; then let evolution in some chemical environment cause the simple enzymes to change gradually into the complex ones we have today. The deceit here comes from omitting to explain what is in the environment that causes such an evolution. The improbability of finding the appropriate orderings of amino acids is simply being concealed in the behavior of the environment if one uses that style of argument.

As this enormous problem gradually dawned on us, we thought to transfer the origin of life from the comets of our own solar system to all the other star systems of our galaxy. In going from the earth to the comets we gained in scope by perhaps a factor of a million. And in going from the comets to the whole galaxy we gained a further factor of 100,000 million — which satisfied us for awhile. This was a transposition into biology of a diagram that William Fowler [Institute Professor of Physics] and I drew together many years ago to illustrate the origin and evolution of the chemical elements.

Returning to the problem of the organic nature of the interstellar grains, the question now suggested itself — could the grains be living cells together with the decay products of living cells? An entirely preposterous question on the face of it, but one that could be tested immediately. Apart from graphite particles, which are known from observations to have sizes of a few hundred angstroms, the other interstellar grains must have sizes mainly centered at about .7 of a micron. This again is a requirement demanded by the astronomical observations. And this is precisely the size of the most numerous kind of living cell — bacteria. Moreover, the grains are known to be remarkably similar over the whole galaxy, and it's the outstanding property of biological systems that they are reproducible. Inorganic grains are without any strong size-determining property.

In calculating the fogging effect that would be produced by the normal size distribution of bacteria and degradation products, the correspondence to observations is remarkable. Unlike the complex and unsatisfactory calculations we made in the 1960s, we obtained an almost perfect result in only a couple of days. Einstein is reported to have remarked that while God may be subtle, he is not malicious. If grains aren't organic with connections to living cells, it would certainly be incorrigibly malicious to have given us this excellent result with a wrong theory coming after a long history of poor results with the right theory.

The potentiality of a cosmic system of life was so enormous compared to an earth-bound system that it was possible to rest content with the situation for awhile. But eventually I came to wonder if the potentiality of even a cosmic system was really big enough. In thinking about this question I was constantly plagued by the thought that the number of ways in which even a single enzyme could be wrongly constructed was greater than the number of all the atoms in the universe. So try as I would, I couldn't convince myself that even the whole universe would be sufficient to find life by random processes — by what are called the blind forces of nature. The thought occurred to me one day that the human chemical industry doesn't chance on its products by throwing chemicals at random into a stewpot. To suggest to the research department at DuPont that it should proceed in such a fashion would be thought ridiculous.

Wasn't it even more ridiculous to suppose that the vastly more complicated systems of biology had been obtained by throwing chemicals at random into a wildly chaotic astronomical stewpot? By far the simplest way to arrive at the correct sequences of amino acids in the enzymes would be by thought, not by random processes. And given a knowledge of the appropriate ordering of amino acids, it would need only a slightly superhuman chemist to construct the enzymes with 100 percent accuracy. It would need a somewhat more superhuman scientist, again given the appropriate instructions, to assemble it himself, but not a level of scale outside our comprehension. Rather than accept the fantastically small probability of life having arisen through the blind forces of nature, it seemed better to suppose that the origin of life was a deliberate intellectual act. By "better" I mean less likely to be wrong.

Suppose a spaceship approaches the earth, but not close enough for the spaceship's imaginary inhabitants to distinguish individual terrestrial animals. They do see growing crops, roads, bridges, however, and a debate ensues. Are these chance formations or are they the products of an intelligence?

Taking the view, palatable to most ordinary folk but exceedingly unpalatable to scientists, that there is an enormous intelligence abroad in the universe, it becomes necessary to write blind forces out of astronomy. Interstellar grains, living cells, are to be regarded as purposeful tools, every bit as purposeful, if you like, as a garden spade. We know from astronomical studies that the grains are mysteriously connected with a whole range of phenomena: the rate of condensation of stars; the mass function of stars; magnetic fields; spiral arms of galaxies; and quite probably with the formation of planetary systems. Not one of these phenomena has been explained by astronomers in better than fuzzy terms, just as the views of the imaginary travelers in the spaceship would be fuzzy if they attempted to explain terrestrial fields, walls, and ditches as products of the blind forces of nature.

It would be necessary to calculate in full detail the properties of complex biopolymers in order to obtain the information required for the construction of a living cell. Such a project would be quite beyond our practical ability, but not beyond our comprehension. Indeed we are nearer to understanding what would be involved in it than a dog is to understanding the construction of a power station.

Now imagine yourself as a superintellect working through possibilities in polymer chemistry. Would you not be astonished that polymers based on the carbon atom turned out in your calculations to have the remarkable properties of the enzymes and other biomolecules? Would you not be bowled over in surprise to find that a living cell was a feasible construct? Would you not say to yourself, in whatever language supercalculating intellects use: Some supercalculating intellect must have designed the properties of the carbon atom, otherwise the chance of my finding such an atom through the blind forces of nature would be utterly minuscule. Of course you would, and if you were a sensible superintellect you would conclude that the carbon atom is a fix.

From 1953 onward, Fowler and I have been intrigued by the remarkable relation of the 7.65 MeV energy level in the nucleus of ^{12}C to the 7.12 MeV level in ^{16}O. If you wanted to produce carbon and oxygen in roughly equal quantities by stellar nucleosynthesis, these are just the two levels you would have to fix, and your fixing would have to be just about where these levels are actually found to be. Is that another put-up, artificial job? Following the above argument, I am inclined to think so. A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question. □