From Astrochemistry to Astrobiology

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The logical beginning of this story goes back to Fred Hoyle's arguments of 1946 (ref. 1) that all the chemical elements in the world heavier than H and He are synthesised in nuclear reactions in stars. The synthesis of ^{12}C presented a problem at the outset because the only available route to its production (the triple-alpha reaction transforming ^{4}He to ^{12}C) required the existence of a hitherto undiscovered resonance in the carbon nucleus at E=7.162Mev, without which no carbon could be synthesised. Invoking the "anthropic principle" for the first time, Hoyle *predicted* the existence of this resonance in the nucleus of ^{12}C, which was later *discovered* in the laboratory by W.A. Fowler. Thereafter Hoyle, Burbidge, Burbidge and Fowler (ref.2) wrote their seminal paper on the production of chemical elements in stars, showing also how supernovae can scatter the products of nucleosynthesis into interstellar space.

Hoyle's work of the 1940's and 1950's and his espousal of the anthropic principle had a further important corollary. If life were to exist at all, not just on Earth but anywhere, the products of stellar nucleosynthesis had to be assembled into molecules that eventually led to life. We now know that the interstellar medium is indeed choc-a-bloc with organic molecules, but these contemporary developments were preceded by long history of denials that has a bearing on our thesis.

The first detection of diatomic molecules goes back to the identification of the methylidyne radical CH in stellar spectra in 1937 (refs 3-5). Although molecules such as H_2CO were not discovered until 1969, the existence of even larger and more complex molecules in interstellar space had been accumulating from earlier decades in the form of the so-called diffuse interstellar bands, the most prominent of which is centred on 4430A and has a half-width of 30A (ref.6). Fred Hoyle and a few others saw this data as evidence of exceedingly complex molecules in space, even perhaps a molecule as complex as chlorophyll (Johnson, ref.7). Whilst any publication of such statements in scientific journals was barred by peer review censorship, Fred Hoyle was so convinced by the force of evidence that he published these ideas in his classic "Frontiers of Astronomy" in 1955 (ref.8) and two years later fictionalised them in his famous novel "The Black Cloud" published in 1957 (ref.9).

Fred Hoyle's 1955 take on the extraterrestrial origin of life is summarised in the following quotation from his "Frontiers of Astronomy".

"Although this is a problem for the biologist and the biochemist rather than for an astronomer there is one feature that may be important and which might tend to be overlooked if the astronomer should keep himself entirely out of the problem.

The principle on which life is based seems to be fairly clear. Under the action of ultra-violet light from the Sun a mixture a of simple substances such as water, methane, ammonia can be *built into molecules of moderate complexity, molecules that contain up to perhaps 20 or 30 separate atoms, such as the amino acids. These molecules contain considerable stores of internal energy supplied to them by the ultra-violet light. Now it is a general rule that molecules with internal stores of energy tend to undergo chemical changes that get rid of the energy. Normally we should expect that a break-back into the original materials would occur, the stored energy being thereby released again. But owing to a chemical freak this does not happen in the present case provided the molecules are kept at the comparatively low temperature occurring on the Earth. It is on this freak that life is based. The lack of a straight-forward process of break-down forces the molecules to dispose of their energy by adding themselves together into more and more complex molecules, small quantities of energy being released at each step. It is to be noticed that ultra-violet light is not necessary to this adding process, only to the building up of the molecules with the energy reservoir.*

Ultimately the molecules become so large, and the aggregations of molecules develop to such a degree, that at last a collapse back to the primary substances becomes possible. In this way a chemical cycle based on the generating influence of ultra-violet light becomes set up. The cycle is illustrated in Fig. 1. The main interest in this cycle lies in the complex molecules and structures that precede the break-back into the primary chemicals. The nature of these structures probably depends rather sensitively on environmental factors such as the temperature, the intensity of ultra-violet light, the concentrations of the primary chemicals, and so on.

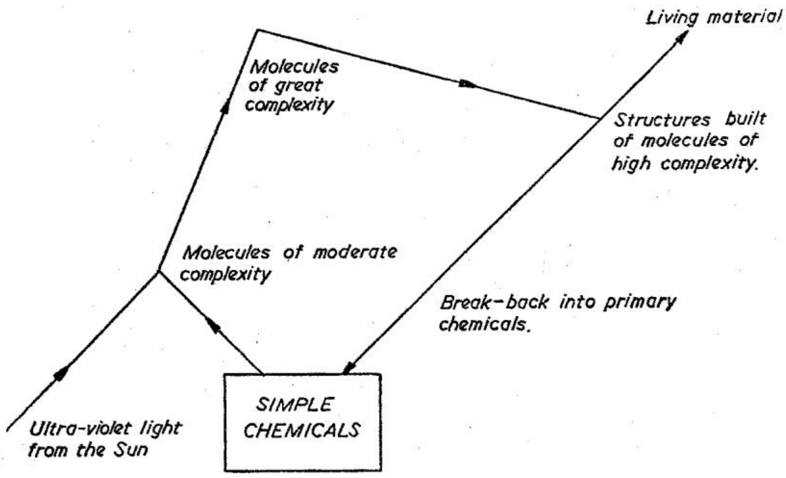

Fig.1 Origin of Life according to Hoyle (1955)

At what stage may life be said to appear? This depends on what we mean by life. As more becomes known about life it is increasingly clear that there is no hard and fast dividing line between what is alive and what is not alive. It is to a considerable extent a matter of choice where the line is drawn. This does not mean that the ordinary terminology whereby we say that a dog is alive and a stone is not alive loses its value. We can speak about rich men and poor men without implying that there is a sharp dividing line between wealth and poverty. We say that a dog is alive to denote the fact that the material of the dog is in a special condition, differing markedly from that of the material of the stone. But the properties of both the dog and the stone are different manifestations of the behaviour of matter.

Perhaps the most convenient definition of the origin of life is at the stage where some structure (built out of the highly complex molecules) becomes capable of using itself as a *blueprint for the building of similar structures. Even here subtleties arise. Sometimes a structure may be able to reproduce itself in the presence of certain other complex structures, but not in the presence of the molecules produced by the solar radiation alone. The virus is a case in point. A virus can only act as a blueprint in the presence of other complex structures. Is a virus alive? It all depends on what you mean by alive.*

The final break-back into the primary chemicals plays an important part in the processes of life. Certain structures have developed that possess the property of being able to break down other structures without being broken down themselves. These substances, known as enzymes, release the supplies of energy required by plants and animals.

But our present object is not to enter into a discussion of the chemistry of life, except in so far as our considerations may have an astronomical connotation. It has always been supposed that life originated on the Earth. The physical and chemical requirements must, however, have been far more favourable for the building of complex molecules before the Earth was aggregated. The Earth intercepts only a tiny fraction of the ultra-violet light emitted by the Sun, whereas the gases out of which the planets condensed intercepted a large fraction of the ultra-violet. The energy source was therefore much greater before the planets were aggregated than it was afterwards.

Another point in favour of a pre-planetary origin of life appears when we consider in a little more detail how the complex molecules were built up. This requires the addition together of many much smaller molecules. Now how did the smaller molecules manage to come in contact with each other? lf the molecules were dissolved in the sea, for instance, the chance of enough of the right kinds of molecules coming together would be negligible (this would seem to rule out the sea as the original source of life). Bernal has called attention to the necessity for solving this problem of association, and has suggested that favourable conditions would probably occur if the molecules were coated as a film on the surface of a solid particle. Such a condition would undoubtedly best be satisfied before the planets were aggregated, while the planetary material was still distributed as a swarm of small bodies.

An interplanetary origin of life would have seemed impossible in the days when it was believed that the Earth was formed in an entirely molten state, for the associated high temperature would have destroyed all complex molecules. Now that we realise that the Earth must have accumulated from a multitude of cold bodies it is no longer possible to be so sure of this. It is true that the temperature deep inside the Earth became high due to compression, but the temperature at, and near the surface probably was quite low especially during the last phases of the aggregation process. I do not see why already complicated chemical structures should not have been added to the Earth in this phase.

It is important to realise that all our present considerations refer to stages in the process of the origin of life that preceded the stages that are studied by the biologist. Evolution from amoeba to man is only a part of the story of life. From a chemical point of view amoeba is already an extremely complex structure. The crux of the origin of life had already been passed by the time that amoeba had evolved. It is to such earlier phases that all the above remarks apply. There is no suggestion that animals and plants as we know them originated in interplanetary space. But the vital steps on which life is based may have occurred there."

Carbonaceous Molecules Everywhere

Fig. 2 Interstellar dust turns out to be a vital clue pointing to carbonaceous grains

My own part in this exciting saga began when I joined Fred Hoyle in 1960 as his graduate student, setting out to review and reassess the observational data and theoretical arguments for the composition of interstellar dust. It was widely held at the time that this was a useless exercise, it being proved beyond doubt that the dust was made up of submicron-sized ice particles similar to the particles in the cumulous clouds of the terrestrial atmosphere. Very soon, however, our work showed clearly that the currently fashionable ice grain theory (Oort and van de Hulst[10]) was seriously flawed, and we argued instead for refractory grains comprised mainly of the element carbon – the element for the synthesis of which Fred Hoyle's predicted ^{12}C resonance was crucial. We first argued the case for carbon dust in the form of graphite (Hoyle and Wickramasinghe[11]). This model had a considerable measure of success, but with the passage of time and with the deployment of new techniques of astronomical spectroscopy and with instruments above the atmosphere, things developed rapidly – unerringly it would seem in the direction of *The Black Cloud*. In 1969 formaldehyde molecules as well as amino acid precursors were discovered in interstellar clouds, and in 1974 I argued that polymers based on H_2CO could make up the bulk of interstellar dust grains (Wickramasinghe[12]). Such grains accounted for the newly-discovered spectral features of interstellar dust at ~ 10 μm, features which were earlier attributed to mineral silicates.

At this time we proposed an identification of the 2200A interstellar absorption feature of dust on the basis of complex organic molecules including PAH type structures of the type that are being discussed widely in the present day[13]. Between 1974 and 1980 we began suggesting that prebiotic molecular evolution takes place in the interstellar medium and that the inclusion of such material in the outer regions of the solar nebula led to the origin of life – life originating in comets in the outer solar system[14].

Hoyle and I were constantly striving for better agreements with astronomical data, as such new data with higher degrees of precision came along. We first argued for H_2CO being assembled abiotically into cellulose chains[15] (cellulose being overwhelmingly the most abundant biomolecule on Earth). Not long afterwards in 1980 we presented for the first time the theory that a large fraction of the interstellar dust was in fact generated biologically[16]. The carbonaceous interstellar material contained biological (bacterial cells) in various stages of degradation. Only a minuscule surviving fraction (< 10^{-24} was required for panspermia to the dominant process of spreading and evolving life in the universe. In a lecture delivered in Cardiff on 15 April 1980 entitled "The relation of biology to astronomy" Fred Hoyle concluded thus:

"Microbiology may be said to have had its beginnings in the nineteen forties. A new world of the most astonishing complexity began then to be revealed. In retrospect I find it remarkable that microbiologists did not at once recognize that the world into which they had penetrated had of necessity to be of cosmic order. I suspect that the cosmic quality of microbiology will seem as obvious to future generations as the Sun being the centre of our solar system seems obvious to the present generation…."

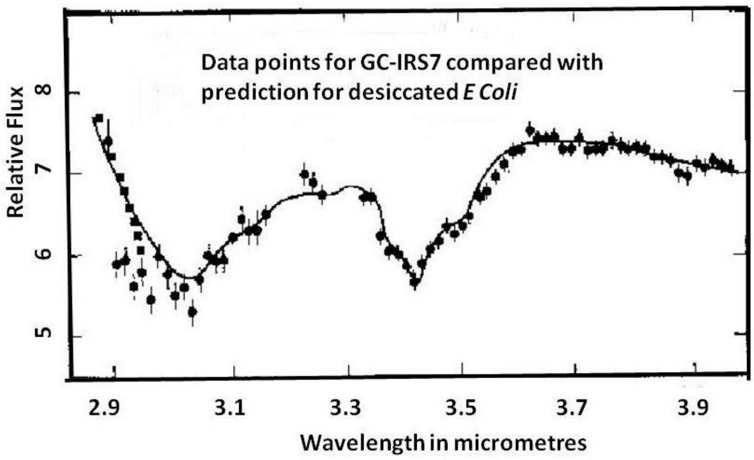

Fig. 3 Comparison of first GC-IRS7 spectrum with prediction for desiccated bacteria.

It was months after this declaration that D.A. Allen and D.T. Wickramasinghe (ref 17) obtained the first high resolution spectrum of the galactic centre infrared source GC-IRS7 over the 2.8 – 3.9µm waveband and obtained the stunning match with an earlier prediction for desiccated bacterial grains (Fig. 3). This result clinched the case for us: a precise prediction made ahead of an observation was matched to an amazing degree of precision (Hoyle *et al* [18]).

The period 1981-1991 following the discovery in Fig.3 were halcyon years for the Hoyle-Wickramasinghe collaboration, and for the theory of cometary panspermia. Correspondences between further predictions of the theory and new observations unfolded uncannily in a manner that should have convinced even the most hardened skeptic that we were on the right track. No "wrong theory" could produce unerringly such close correspondences with a wide range of predictions, as for instance the discovery in 1986 that the dust from Comet Halley had a spectrum that also matched the prediction of bacterial-type dust. Yet the entrenched geocentric position of most scientists remained stubbornly difficult to shift. We put out a stream of scientific papers and books, some of which were issued first as preprints in the infamous "blue" series lest they be rejected by publishers and journals. These preprints, in the days before the internet, constituted the only secure way of communicating our ideas to colleagues and the public. The Editor of *Nature*, Sir John Maddox, referred to these as "samizdat" publications, despite the fact that some of the key papers were in fact later published in *Nature*. In this volume we reprint a selection of papers in the form they originally appeared in preprint form, thereby avoiding any copyright restrictions. Fig.4 shows a sample of preprint covers in the Blue series, and Fig.5 is a photograph of Fred Hoyle and the author at the time.

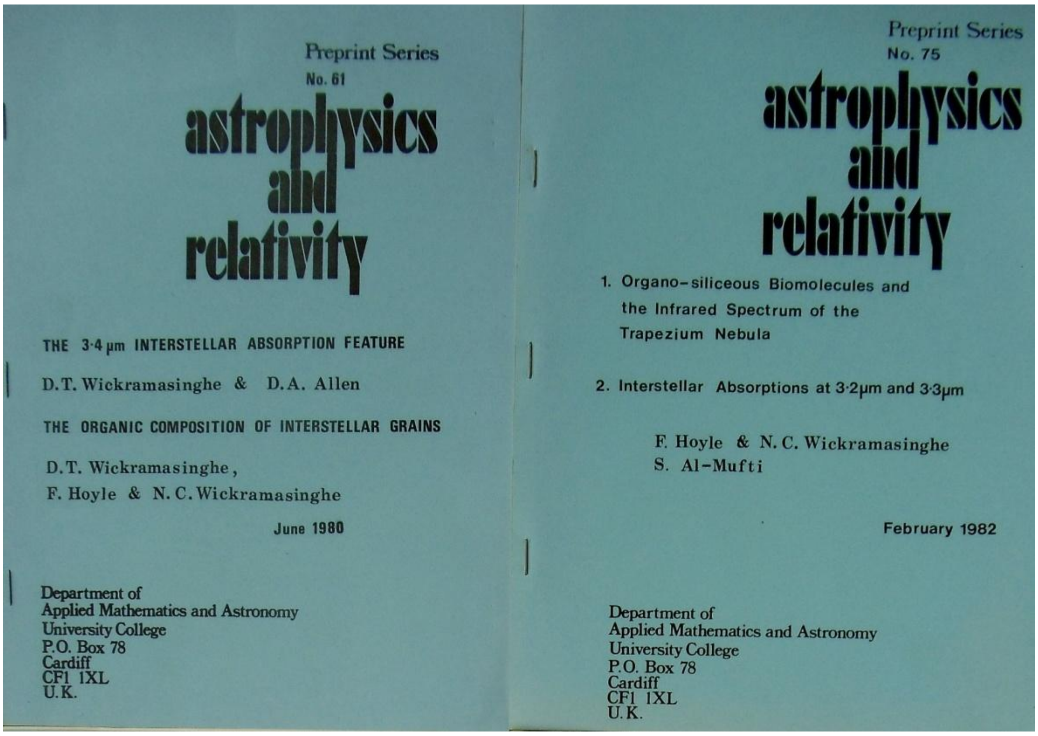

Fig. 4 Sample of covers of preprints


Fig. 5 The author and Fred Hoyle in 1982

We now also began to reassess the question of the improbability of life arising anywhere, and concluded that the problem of the superastronomical odds against the emergence of the first life had to be addressed. This matter was dealt with in our book "Evolution from Space" from which a crucial chapter is reproduced in this volume. We noted that life had to originate once and only once in the Universe, by any means whatsoever, but thereafter its survival and evolution is inevitable via the processes involved in panspersmia (see Wickramasinghe, J.T. et al.[19]).

In the first part of this special volume of the *Journal of Cosmology* we reprint key documents/quotations from our earlier published work leading up to the present position in relation to cometary panspermia and the origins of life.

I would like to end this introduction with the remark that our present position was not arrived at lightly or frivolously. Each step in our progression from inorganic carbonaceous dust to biology and biological dust was taken only after the most careful consideration of all the facts and with much trepidation. We would often hear in our imagination the laughter and ridicule in University common rooms (there were still common rooms in Universities then!). Now the laughter has faded to a large degree, but skepticism still prevails.

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