The case for life as a cosmic phenomenon

from F. Hoyle and N.C. Wickramasinghe

The arguments in support of life as a cosmic phenomenon are not readily accepted by a culture in which a geocentric theory of biology is seen as the norm.

A LEADING article in a recent issue of *Nature* explained that we had ourselves to blame for experiencing difficulties of an unusual kind in the publication of referencing of our work[1]. Our fault was that we had become caught up in the eccentric doctrine of panspermiology, a doctrine for which there was said to be little or no evidence. We have now been invited by the editor of *Nature* to explain why we differ from his judgement and why in our opinion there is indeed evidence in favour of our position. In our experience, people who become eccentric usually do so through a mental discontinuity, whereas we would claim to have progressed by a series of comparatively small steps over many years, with each step rather cautiously tested by either observation, experiment or calculation using generally accepted methods of deductive science.

Our ideas began in the middle 1950s with qualitative considerations on the nature of interstellar grains and with a straightforward generalization to interplanetary conditions of the well-known Urey–Miller prebiotic experiment[2]. By the early 1960s we had added a refractory carbonaceous component to the ice-grain model of van de Hulst[3] and had begun to calculate the extinction of starlight to be expected from complex mixtures of ice and carbonaceous particles[4–6]. The correspondence between our results and the observed interstellar extinction of visible starlight was tolerable but not really good in view of the many adjustable parameters that were present in the calculations.

Eventually we discovered that appreciably better agreement could be obtained between observation and calculation provided the real part of the refractive index of interstellar grains was low, say 1.15, instead of being 1.3 as for ice or ~2.4 as for carbonaceous particles. A low refractive index turned out to be much better than the many-parameter adjustments we had formerly used. But what material could have a refractive index as low as 1.15? In seeking an answer to this question it was important that the grains be largely made up of cosmically abundant elements, because the amount of the observed extinction is so considerable that only abundant elements will suffice to give the necessary quantity of grains. Of materials based on common elements only solid hydrogen would have the required low refractive index it seemed. So for a while we investigated this possibility and became enthusiastic about it[7–9]. The trouble, however, turned out to be that solid hydrogen was too volatile and would evaporate away[10]. So it came about that we were left with an unsolved problem, and we had to put it aside for a decade until quite new ideas suggested themselves.

Organic polymers

From calculations made in 1968 of condensations occurring in large mass flows from astronomical objects we suggested that interstellar grains might contain a magnesium oxide–silicon oxide component[11] and when a so-called silicate emission-band near 10 μm in the infrared was observationally discovered the following year we had a new topic to become enthusiastic about[12–16]. Unfortunately as it seemed at the time, our former disappointing experience repeated itself. Following an initial approximate success in matching the laboratory absorption properties of mineral silicate particles to the infrared observations[16], the situation did not improve as better laboratory measurements and better observations were made. Discrepancies that were unsatisfactory remained, as they do to this day. It was with mounting frustration that we began to look through mountains of chemical literature, searching for a substance made-up of common atoms with infrared properties similar around 10 μm to the astronomical observations. It was from this intensive literature search that the idea at last dawned on us that organic materials in the form of polymeric structures might make up a major fraction of the interstellar grains[17], and moreover that similar structures might be present in cometary dust[18].

The step from inorganic to organic grains did not seem particularly revolutionary. Organic molecules in the gaseous interstellar medium had been discovered already by radioastronomers, although in nothing like the quantity of the grains, while as long ago as 1956 Platt had suggested the widespread presence of very tiny organic grains[19]. Still pursuing the infrared problem, we eventually found that among organic materials polysaccharides gave the best correspondence to the astronomical data[20,21], and it was at exactly this point in our work that we began to experience hostility from the referees of journals and from the assessors of grant applications at what was then the Science Research Council. We realize now that because polysaccharides on the Earth are a biological product we had unwittingly made a contact that is deeply forbidden in our scientific culture, a contact between biology and astronomy. We did not see that we had sinned mortally and were deeply mystified since at first, we thought of polysaccharides as being produced abiologically. Nor did we realize that the cultural taboo that confronted us had already surfaced in 1870, only one year after the inception of this journal[21].

Only gradually did we come to understand the difficulties of producing very large quantities of organic material by abiological processes[22]. The Fischer–Tropsch reaction, for example, which produces hydrocarbons from hydrogen and carbon monoxide depends on the use of carefully controlled catalytic surfaces, which would almost surely be quickly poisoned by corrosive sulphur compounds under cosmic conditions (it may be noted that the Fischer–Tropsch process could not be operated profitably to complete with natural oil at $30 per barrel, even under the most expertly managed terrestrial conditions).

Biological solution

We are not sure of exactly what it was that caused biology to enter our perceptions, but we think it was noticing a series of drawings of a bacterium from which the internal water was progressively dried out. The cell wall remained in place as cavities developed in the interior, eventually yielding a particle of typically the size of an interstellar grain that was hollow. We realized at once that such a particle would behave with respect to visual light, to a close approximation like a particle of low refractive index, just the situation we had been seeking more than ten years earlier in the 1960s. We obtained an experimentally-determined size distribution of bacteria from a standard manual and were quickly able to calculate how such a size distribution of hollow particles would behave with respect to the extinction of starlight. The result was a truly excellent fit to the astronomical data, the data we had attempted to fit without real success by our many-parameter models in the 1960s[23].

On the strength of this result, Dr Shirwan Al-Mufti began to measure the infrared properties of a number of species of bacteria, finding to his and our surprise a remarkable constancy of absorption for the wavelength range 3.3 to 3.5 μm, and a general constancy for the whole range from 3 to 4 μm (ref 24). If bacteria made up an appreciable fraction of the interstellar grains, as the observed extinction of visible starlight seemed to suggest, it was necessary therefore that the grains must possess the characteristic absorption pattern which Al-Mufti had measured in the laboratory. It happened not long after these experiments that the average absorption properties of grains along the whole path length from the galactic centre to the Earth was measured to a high degree of accuracy by Allen and D.T. Wickramasinghe[28]. The results, made at no less than 60 wavelengths between 3 and 4 μm, agreed with the bacterial experiments to within an accuracy of typically about one small graticule division on a standard Perkin-Elmer pen chart, an accuracy that we, who had hoped for accuracy, found impressive[26].

We are aware that astronomers and chemists can be found who will claim that these results are not impressive, because equally good results could be obtained using plausible non-biological materials. Our answer is that equally good results have not been obtained using plausible non-biological materials. Such claims are advanced and listened to only because they are designed to be culturally acceptable, whereas our results, although based on careful observations, experiments and calculations are not culturally acceptable. In such a situation the critic is permitted to say anything at all without being weighed in the balance and found wanting.

Stellar replication

An attempt is often made to saddle us with the criticism that bacteria could not replicate in interstellar space. We have never said that they did. Our model is a cyclic one, with bacteria replicating as a by-product of star formation in environments where replication *can* occur[27–29]. Following star formation, a fraction of the bacteria produced are expelled into the interstellar medium. Some die, some survive — quite likely only a minority survive — to become incorporated in further star formation processes, and so on around the cycle. Biological replication is an exponential process that can immensely outstrip all abiological processes. Granted sustained conditions for the growth of a bacterial culture, a single viable bacterium could grow to a mass of bacteria equal to the Earth in about nine days, a mass equal to the galaxy in about fifteen days, and a mass equal to the whole visible universe in about twenty days.

It is a necessary corollary that bacteria must be space-hardy, unless after arriving here on Earth mutations have destroyed properties which they possess intially[29,30] A viable strain of *Streptococcus mitis* was recovered after two years of exposure to conditions on the surface of the Moon[31]. Bacteria can be taken down to near zero pressure and temperature without loss of viability, provided suitable care is exercised in the experimental conditions[32,33]. Bacteria can survive after exposure to pressures as high as 10 tonnes cm^{-2} (ref. 34) and after flash heating under dry conditions at temperatures up to 1,000 K (ref. 35). Viable bacteria have been recovered from the interior of an operating nuclear reactor[36]. A fraction of bacteria remain viable even after extremely heavy flash doses of high energy radiation, upwards of a megarad, while it seems that bacteria can repair themselves continuously in a maintained environment of high radiation intensity, to the extent of repairing tens of thousands of breaks in their nucleic acid stucture[37,38]. These are not properties one would have expected to evolve on the Earth, but they are all properties necessary for survival in space. Damage from ultraviolet light, which is often raised as a problem is actually no problem, because ultraviolet light is easily shielded against[29,39].

An individual comet has only a small mass, but if one considers all the comets that are believed to exist in the present-day Oort cloud, and to have existed over the whole history of the Solar System, their combined mass could well be comparable to that of the outer planets Uranus and Neptune, about 10^{29} grams. If the $\sim 10^{11}$ stars of our Galaxy are typically endowed with similar quantities of cometary material, the total cometary mass for the whole Galaxy would be $\sim 10^{40}$ grams, very close to the mass of the interstellar grains.

We were led from this consideration to think of a swarm of comet-like bodies, present towards the outer regions of the Solar System in its early history, and being made warm in their interiors by radioactive heat, as the likely sites for early biological replication[40–42]. As we put it on one occasion, such an individual cometary interior would be like a vast laboratory with a floor area of some thousand square kilometres and with a height comparable to that of the Empire State Building. If other dwarf stars are mostly like the Solar System, there could be more than 10^{20} such laboratories in the Galaxy, which makes it only a matter of commonsense we believe to regard such bodies as a more favourable venue for the development of life than the initiallly sterile surface of a small planet like the Earth, which even today has a biosphere with a mass of not more than $10^{18}-10^{19}$ grams.

Holding these views, it was easy for us to predict that an important fraction of the dust expelled from comet Halley would be organic in composition, that bacteria in the dust would become hollow as water within them dried out, thereby yielding particles with an average mass density less than 1 gm cm , and that organic material at the surface of comet Halley would be dark[43]. We have heard astronomers speaking of the surface material of comet Halley as being dark like tar, perhaps without realizing that tar is itself a biological product.

It has often been suggested to us that our views might be tested by a suitable satellite experiment. Such an experiment would be expensive and difficult because of high impact speeds, as we saw in the recent Giotto encounter. Another suggestion often made is to send balloons or rockets into the high atmosphere with the aim of recovering viable bacteria from space. This has actually been done, repeatedly. On every occasion viable bacteria were obtained[44–48], and on every occasion the result was discounted because of the possibility, admittedly serious in some cases, of terrestrial contamination. When a result is culturally unacceptable it will always be discounted on some excuse or other. One cannot win that way.

The Earth is perpetually embedded in a halo of cometary material, of which some 1,000 tonnes enter the terrestrial atmosphere each year. Because of the low density of the upper atmosphere, incident small particles of the sizes of bacteria and viruses could land 'soft' without viability being destroyed by flash heating. After intervals ranging from months to years such particles eventually settle to ground level, where they would be added to the already-existing reservoir of bacteria and viruses. It is to the potential interaction of such incoming particles with plants and animals that one can best look for a direct verification of these ideas. For some years we have been much concerned with this interesting and informative mode of verification[22,41]. It is our opinion that a large body of facts exists to prove the correctness of the general picture outlined above. The topics themselves being in the medical field of epidemiology, would take us far away from the rest of the present article. Besides which, we are about to run out of the space the Editor has kindly allotted us, and so must refer the reader, if any should be interested, to a recent publication entitled: *Viruses from Space*[49]. We have found it not a little odd to find our views taken more seriously, or at least received more politely, by the medical profession than they have been by astronomers and chemists, for whom we retain not a few rods in pickle. ☐

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ARTICLES

Detection of an X-ray-ionized nebula around the black hole candidate binary LMC X-1

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Optical spectra of the black hole candidate X-ray binary LMC X-1 reveal that the system is surrounded by an extended, highly ionized He III region, N159F, which appears to be the long-sought-for example of an X-ray-photoionized nebula. The spatially resolved temperature and ionization structure allows us to measure the previously unobservable extreme ultraviolet (EUV) luminosity of an accreting compact object.

DESPITE a fairly accurate (±3 arc s) Einstein HRI (high-resolution imager) position for the bright (X-ray luminosity $L_X = 2\times10^{38}$ erg s^{-1}) variable X-ray source LMC (Large Magellanic Cloud) X-1 (ref. 1), neither of the previously suggested optical counterparts[2–4] can be excluded on positional ground alone (Fig. 1). The optical properties of the B5 I star R148 (V = 12.2 mag) appear normal for its spectral type, including the slight radial velocity and photometric variations[5,6] which are observed in most supergiants. More promising for an optical identification is the fainter (V = 14.5) O7 III-type star '32', which reveals the variable He II λ4,686 and $\lambda\lambda$4,640–4,650 emission[4–6] generally considered to be the hallmark of high-luminosity massive X-ray binary (MXRB) optical counterparts. Hutchings *et al.*[6] have suggested that part of the 4,686-Å emission stems from the surrounding H II region N159F (refs 7, 8; see also Fig. 1); but these authors did not elaborate on this potentially important result.

In order to study the reported radial velocity variations[6] in star 32 which suggest that LMC X-1 might be a black hole (a conjecture which is supported by the interpretation of its extremely soft X-ray spectrum[9]), and to investigate possible X-ray heating effects on the H II region N159F, we have obtained long-slit spectra of this region. Our observations reveal a remarkable ionization structure, suggesting that we have observed the first example of a spatially resolved X-ray-ionized nebula.

Observations

We carried out two-dimensional charge-coupled device (CCD) spectrophotometry 4 nights in December 1984, using the B&C spectrograph attached to the 3.6-m ESO telescope at La Silla, Chile. Here we are concerned mainly with the results of our observations on 21 December, which were obtained with a reciprocal dispersion of 114 Å mm^{-1}, resulting in a full width at half-maximum (FWHM) resolution of 5 Å in the wavelength range 3,600–5,200 Å. The relatively large width of the slit (2 arc s) made this configuration most suitable for the study of nebular emission from the surrounding H II region N159F. The slit orientations were chosen as shown in Fig. 1*b*: A, including both candidates R148 and star 32 and B, roughly perpendicular to the former orientation, including star 32. Two longer-wavelength CCD spectra which also include the 5,000–6,700 Å region, at a lower resolution of 8 Å, were obtained in May 1985.

The images were flat-field- and extinction-corrected and calibrated in wavelength and flux from the observation of a He–Ar lamp and the spectrophotometric standard stars LLT1020, EG21 and L745-46A, respectively[10], using the image processing facilities IHAP and MIDAS at ESO, Garching.