Theory Biosci. (2013) 132:133–137
DOI 10.1007/s12064-012-0172-1

SHORT COMMUNICATION

Non-terrestrial origin of life: a transformative research paradigm shift

N. Chandra Wickramasinghe · J. T. Trevors

Received: 4 July 2012 / Accepted: 26 November 2012 / Published online: 6 December 2012

Abstract Theories and hypotheses in science are continually subject to verification, critical re-evaluation, revision and indeed evolution, in response to new observations and discoveries. Theories of the origin of life have been more constrained than other scientific theories and hypotheses in this regard, through the force of social and cultural pressures. There has been a tendency to adhere too rigidly to a class of theory that demands a purely terrestrial origin of life. For nearly five decades evidence in favour of a non-terrestrial origin of life and panspermia has accumulated which has not been properly assessed. A point has now been reached that demands the serious attention of biologists to a possibly transformative paradigm shift of the question of the origin of life, with profound implications across many disciplines.

Keywords Transformative research · Scientific method · Galactic biosphere · Origins of life · Panspermia · Biology · Evolution · Sociology · Cosmic gene pool

Nature of transformative research

Almost every major scientific or technological breakthrough that has ever been made falls under the category of transformative research (TR) as defined by Trevors et al. (2012). The record arguably goes back to stone-age man and the discovery of fire and the use of tools (e.g. sharp stones, animal hides for clothes, thread and needle, spears, cooking pots, storage containers). In more recent times discoveries in atomic physics, atomic structure, the Hubble expansion of the universe, the unravelling of the human genome, the structure and function of DNA, to name but a few—all fall in the same category of transformative research, developments that led to fundamental revisions in our thinking about the world. It is upon discoveries and innovations of this kind that progress in modern civilization depends.

A case study

On a clear moonless night, far from the light of towns and cities, one can see a whitish band of light stretching across the sky. This is the Milky Way—our galaxy—comprising billions of stars seen edge-on. The whitish band of starlight is broken by dark irregular patches and striations which are gigantic clouds of dust obscuring the light of background stars. In the 1950s the consensus view amongst astronomers was that the dust in these clouds, cosmic dust, consisted of inorganic ice particles similar to the particles that exist in the cumulous clouds of the Earth's atmosphere. Icy dust grains were supposed to nucleate and grow to submicron sizes from interstellar atoms and molecules, and this theory became the holy grail of astronomy throughout the 1950s and early 1960s (Oort and van de Hulst 1946).

Together with Fred Hoyle, one of the present authors (C.W.) began to challenge the ice grain theory in 1962 (Hoyle and Wickramasinghe 1962; Wickramasinghe 2005). In a paper published in the Monthly Notices of the

N. C. Wickramasinghe (✉) · J. T. Trevors
Buckingham Centre for Astrobiology,
The University of Buckingham, Buckingham MK18 1EG, UK
e-mail: ncwick@gmail.com

J. T. Trevors
School of Environmental Sciences, University of Guelph,
50 Stone Road, East, Guelph, ON N1G 2W1, Canada
e-mail: jtrevors@uoguelph.ca

Royal Astronomical Society, we discussed evidence refuting the conventional ice grain theory and favouring instead a predominantly carbon composition for interstellar dust. As a result of our 1962 publication we came under intense criticism, which is of course expected in science. Critical discussions of theories, advancing different hypotheses and acquiring additional data sets are all necessary to maintain the vigorous progress of science.

The theory of carbon dust in interstellar space certainly merited discussion and examination for its own sake, and it did not appear initially to be obviously linked to any wider issues or paradigms in science (Wickramasinghe 1967). Critical examination of the carbon dust model eventually led to it being upheld in relation to the rival ice grain theory, but far bigger issues began to unfold (Wickramasinghe 1994). Such is the way of the scientific method. What we did not even remotely imagine at the time was that we were on the threshold of connecting a straightforward astronomical problem (the composition of interstellar dust) to the far bigger problem of the origin of life as we understand it. Carbon of course is the signature element of life.

Widening horizons

When it comes to challenging existing ideas in science, the bigger paradigms tend to be more firmly entrenched and understandably more difficult to shift. Perhaps the grandest suite of paradigms relates to questions of our own human origins—the origin of *Homo sapiens* and other species, and indeed the origin of the universe. From the early part of the twentieth century the widespread belief was that life in the form of the simplest prokaryotic cells originated on the Earth from processes that occurred in a "primordial soup" that was located on the Earth (Oparin 1953). This belief continued to be held by science long after astronomers had discovered the incredible vastness of the expanding universe in relation to our own planet, and biologists had gained a better understanding of the profoundly complex organization of even the simplest living cell.

Organic molecules that are life's chemical building blocks were originally thought to have been formed entirely in terrestrial clouds through the action of solar ultraviolet radiation and electrical discharges in the form of lightening. From the wholesale breakup of inorganic molecules that takes place under these conditions, it is not surprising that a trickle of organics would form in the cascade of recombination reactions that followed. The molecules thus formed rained down into the lakes and oceans of our planet forming a dilute primordial soup. This dilute soup was then hypothesized to become more concentrated near the edges of lakes and seas through evaporation, and after millions of years of a still imperfectly known chemistry, the first self-replicating living cell is posited to have formed.

Such evidence as existed for this theory in the 1960s was confined to laboratory work demonstrating the plausibility of a primordial organic soup forming in the lakes and oceans of the Earth. The now famous experiments of Harold Urey and Stanley Miller showed how mixtures of the gases H_2O, CH_4, HCN, NH_3 in a laboratory flask, when sparked with electric discharges produced traces of biological monomers including amino acids and sugars (Miller and Urey 1959). But the far more important second part of the theory, life arising from a soup of organics, still remains mostly in the realm of speculation and hypotheses. The primordial soup concept, however, soon acquired paradigm status and continues to be taught to students of biology as the mechanism involved in the origin of cellular life.

Panspermia versus primordial soup

An alternative to the primordial soup hypothesis is *panspermia*: life being transferred to the Earth from outside. This theory has its origins in classical Greece going back to Anaxoragas in the fifth century BC. The term panspermia has Greek roots: *pans* (everywhere) + *spermata* (seeds). This ancient idea was revived in a serious scientific context at the beginning of the twentieth century by Svante Arrhenius who argued that bacterial spores (which would contain genetic information) lifted off other planets could be propelled into interstellar space and reach Earth (Arrhenius 1908). Arrhenius' version of panspermia, however, was one that was intrinsically untestable because he maintained that the rate of ingress of extraterrestrial cells to the Earth at the present time would be too small to be detected. For this and other reasons Arrhenius' version of panspermia became unpopular, and the primordial soup theory consequently acquired the status of a favoured paradigm, one that continues even to the present day (Hoyle and Wickramasinghe 2000).

Resurgence of panspermia

The 1970s and 1980s saw the introduction of a new generation of telescopes and astronomical instruments that extended the wavelength range of observations into the infrared and ultraviolet. New data led to more stringent constraints being imposed on the nature of the carbon dust model that we had proposed in 1962. The dust grains in interstellar space, as well as in comets, had by now to include a large fraction that was not just native carbon or graphite but organic material—the molecules of which living systems are made (Hoyle et al. 1984; Hoyle and Wickramasinghe 1977a, b).

It was in attempting to characterise the precise nature of the organic dust that one of us (C.W.) experienced robust scientific criticism from astronomers as well as biologists. Fred Hoyle and one of the present authors (C.W.) had already published arguments, based on infrared observations of galactic sources, that cosmic dust had a striking resemblance to biomaterials. But attempts to obtain funding to pursue these arguments further were not possible at this time. The debate and controversy continued because attempts to correctly discover and explain the origin of life embraced several scientific disciplines, and for this reason peer review and the assessment of our proposed projects was not easy (Maddox 1986).

Challenge of the primordial soup

The hypothesis of the organic building blocks of life (chemicals) being delivered from comets to the Earth eventually came to be more accepted by the scientific community because it was perceived as adding value to the standard paradigm of the primordial soup on Earth. The crucial tipping point came, however, when we made the bold assertion that not only the chemical building blocks of life, but life itself, in its most primitive state may have been delivered to Earth from the expanding universe. Our thesis was that a far bigger setting than our singular planet was needed for the origin of life in the universe.

When we examined the arguments that were deployed to justify the origin of life in a "warm little pond" on Earth they began to look increasingly unsatisfactory. In Darwin's letter to Lyell, the reference to a "warm little pond with all sorts of phosphoric salts present" was admitted to be a speculation. Linking the idea to Charles Darwin ignores Darwin's own expressed agnosticism ("…if and Oh what a big if…") and his admission of a lack of understanding of the detailed processes by which the first life may have emerged.

The primordial soup theory (more correctly a hypothesis) was to some extent based upon an obsolete pre-Copernican world view. The end of the Copernican revolution half a millennium ago led to the Earth being removed from its privileged position of centrality in the physical universe; but the Earth continued to occupy a central position in regard to life. Throughout the twentieth century the vastness of the universe of galaxies, stars and planets was reaffirmed by every major astronomical breakthrough. And with the development of molecular biology and more advanced microbiology in the middle of the century, the immense complexity of molecular arrangements manifested in even the simplest living cell may have pointed to a cosmic rather than a singular terrestrial origin of life.

Cosmic life paradigm

In 1981 Hoyle and one of the present authors (C.W.) estimated that the random assembly of the simplest self-replicating bacterium from constituent organic molecules involved probabilities that were so incredibly miniscule they would not reasonably be thought to have happened in the context of an Earth-bound primordial soup (Hoyle and Wickramasinghe 1981).

Trevors and Pollack (2012) have hypothesized that the origin of life may have occurred in a gel pre-cytoplasm exposed to radiant energy resulting in a membrane-bound exclusion zone (EZ) with a charge differential (~100 to −200 mV). Such a system would serve as a possible location for the eventual organization of the first membrane and the first protocell. However, the near-insurmountable improbability for the transition from a membrane-bound pre-cytoplasm with prebiotic molecules to the simplest bacterium with a minimal genome still remains debatable. The situation is that the exact/correct mechanism for the origin of the first cell capable of growth and division is still being actively researched.

To overcome the vast improbability of arriving at the first life required the exploration of the biggest available system—the entire universe. We have recently argued that this is most likely to have happened early in the history of a Big Bang Universe, no sooner than the chemical elements needed for life were produced in the first generation of stars and supernovae, and when the universe was much smaller than it now is (Gibson et al. 2011).

A consequence of the cosmic life paradigm is that it leads to testable predictions (Hoyle and Wickramasinghe 2000). The hypothesis asserts that microbial life first arrived on Earth about 4 billion years ago through comets impacting its surface. We now know that the earliest evidence of microbial life at about 4 billion years ago (in the form of chemical signatures) coincides with an epoch of intense cometary bombardment of the Earth. Throughout the period when life evolved and diversified on Earth, comets have continued to bring a supply of new bacteria and genes that must have contributed to the evolutionary process (Hoyle and Wickramasinghe 1981). Moreover, the continuing process of comet and asteroid impacts—on average once every 50–100 million years—would have led not only to extinctions of species but also to the dispersal of genetic material splashed back into space from Earth to travel to millions of newly forming planetary systems in the galaxy (Wickramasinghe et al. 2010). In this way, genes of evolved life are readily mixed from one planetary abode to another and the biosphere in which Darwinian evolution takes place would be on a galactic rather than a planetary scale.

Recent discoveries of extremophilic bacteria that fit almost every conceivable niche, no matter how inhospitable it may appear, fits this new paradigm. The biospheres of Earth and other planets in the solar system may be interlinked and connected to a much wider galactic biosphere, with exchanges of genes taking place over long periods. The cosmic gene pool, with which we continue to be in contact, will therefore have the biggest possible genomic diversity. In such a situation habitats effectively select those genotypes that are best suited to local conditions from a vast cosmic mix.

The underlying assumption in the cosmic life theory is that the entire cosmic gene pool discussed here originated once and only once in the entire history of the universe. Since such cosmic genes will be packaged within solid particles of bacterial dimensions, the radiation pressure exerted by starlight would propel and disperse them across cosmic distances. Whilst bacteria in transit will suffer high rates of inactivation residual survival rates enormously outweigh the improbability of de novo origination of life at every habitable site in the universe (Hoyle and Wickramasinghe 1981; Wickramasinghe et al. 2010). A prediction of the cosmic life/panspermia hypothesis is that the genetic code for life will be invariant and universal. Independent origination events in multiple locations would lead to a diverse range of genetic codes, and it is interesting to think about observational tests to distinguish between these two options.

Tests of a paradigm

If comets brought the first life to the Earth, the process of cometary ingress of bacteria must still be operating today. We know that about 100 tonnes of cometary debris enter the Earth every day, and most of this burns up as meteors. However, a fraction survives and would be non-destructively added to our planet. The challenge is to detect this ongoing influx of microbial life, which is a prediction of the cometary panspermia theory. If samples of the upper stratosphere can be aseptically collected free from terrestrial contamination, such a detection might well be feasible; and the project will not entail an inordinately large budgetary burden.

From the mid-1980s Fred Hoyle and one of us (C.W.) had made informal approaches to various space and aerospace agencies, including ISRO (Indian Space Research Organisation) to ask whether high-altitude balloons can be deployed to collect such stratospheric samples. The answer was encouragingly positive in 1999 when ISRO, who had prior experience in stratospheric collections, declared an interest in participating with us in such a project. The ISRO–Cardiff–Sheffield cryogenic sampler experiment was carried out on January 20th 2001 and we successfully collected samples of stratospheric aerosols from heights of 41 km, heights to which terrestrial particles would not normally be lofted (Narlikar et al. 2003). The results turned out to provide possible proof of ongoing panspermia. New species of bacteria were discovered as well as evidence for viable but non-culturable (VBNC) microbes of unspecified kinds (Wainwright et al. 2003).

In 2005, the ISRO group carried out a second stratospheric sampling experiment from 41 km altitude and reported the isolation of three new species of bacteria including one that they named *Janibacter hoylei* sp.nov. in honour of the late Sir Fred Hoyle (Shivaji et al. 2009). Genetic similarities of the new species with their terrestrial counterparts can be interpreted as implying their terrestrial origin. However, such arguments are insecure: if a vast majority of bacteria on Earth had originated in a cosmic environment such genetic similarities are indeed to be expected (Hoyle and Wickramasinghe 1981). Samplings of the stratosphere have also been carried out by Yang et al. (2005, 2009) who isolated highly radiation-resistant strains of *Deinococci* from heights up to 35 km. These authors have even discussed the relevance of their discoveries explicitly to panspermia (Yang et al. 2009).

Wide-ranging implications

It is possible that humanity is on the threshold of another paradigm shift regarding the cosmic origins and prevalence of life (Wickramasinghe et al. 2010; Wickramasinghe 2010). The implications go beyond the narrow confines of astronomy and biology. Proving and eventually accepting the correct life-from-space paradigm will have far-reaching benefits for mankind. It would have a bearing on:

1. *Cosmology* Models of the Universe will be constrained to a subset in which life can exist.
2. *Star formation* Models of how stars and planets form, preserving the legacy of cosmic life.
3. *Evolution* Evolution that involves cosmically generated genes.
4. *Epidemiology* Certain bacterial and viral diseases may have had an external origin, and the recognition of such a fact would have a bearing on human health.
5. *Genomics and genetic engineering* Isolating bacteria from comets incident in the upper atmosphere could lead to isolation of exotic genes with potential biotechnology, public health and economic benefits.

6. *Psychology and sociology* The recognition that we have a cosmic ancestry would have a bearing on our psychology, religions and perceptions of ourselves.

This list is far from complete and provides only a few examples. Life may have originated in numerous micron-sized suitable microenvironments at numerous locations in the universe. The search for our origin(s) is one of the most profound questions we can explore. Intensive research, critical judgment … and patience might be required to ultimately obtain the correct answers. Transformative ideas, bold hypotheses and research are imperative as we explore our origins, whilst at the same time striving to manage our human population growth and our common biosphere in a sustainable manner. Obstacles to transformative research (e.g. lack of funding, faulty infrastructure, nontransformative thinking) should be removed as humanity is very much in need of a second renaissance. Rigidly managed and recycled stale old ideas are of minimal to zero value at the present time. Our common humanity needs to understand its origins, directed by a rigorous and impartial assessment of accurate observations and experimentation which are key components of the scientific method.

If the panspermia hypothesis is ultimately accepted as correct, with ample supporting evidence, there still remain important questions that need to be answered. The genetic code appears to be uniform and invariable across the entire spectrum of terrestrial life. Since this particular choice of code is arbitrary, the question arises whether other genetic codes may have arisen independently elsewhere in the universe. And could such different codes be incorporated into each other upon mutual contact in living cells and/or spores? Did the universal genetic code as we know it only originate once, or did only one code version amongst a vast number reach the Earth? If life on Mars, comets and other planetary bodies in the solar system turns out to have the same genetic code as in terrestrial life, a unique origin of life and panspermic transfers therefrom would be favoured.

Acknowledgments J.T.T. is supported by an NSERC (Canada) Discovery Grant.

References

Arrhenius S (1908) Worlds in the making. Harper, London

Gibson CH, Schild RE, Wickramasinghe NC (2011) The origin of life from primordial planets. Int J Astrobiol 10(2):83–98

Hoyle F, Wickramasinghe NC (1962) On graphite particles as interstellar grains. Mon Not Roy Astr Soc 124:417–433

Hoyle F, Wickramasinghe NC (1977a) Polysaccharides and the infrared spectra of galactic sources. Nature 268:610

Hoyle F, Wickramasinghe NC (1977b) Identification of the 2200A interstellar absorption feature. Nature 270:323

Hoyle F, Wickramasinghe NC (1981) Evolution from space. Dent, London

Hoyle F, Wickramasinghe NC (2000) Astronomical origins of life—steps towards panspermia. Kluwer, Dordrecht

Hoyle F, Wickramasinghe NC, Al-Mufti S (1984) The spectroscopic identification of interstellar grains. Astrophys Space Sci 98:343

Maddox J (1986) When reference means deference. Nature 321:723

Miller SL, Urey HC (1959) Organic compound synthesis on the primitive earth. Science 130:245

Narlikar JV, Wickramasinghe NC, Wainwright M, Rajaratnam P (2003) Detection of microorganisms at high altitudes. Curr Sci 85(1):29

Oort JH, van de Hulst HC (1946) Gas and smoke in interstellar space. Bull Astr Netherlands 376, 10:187

Oparin AI (1953) The origin of life (trans. S. Marguli). Dover, New York

Shivaji S, Chaturvedi P, Begum Z et al (2009) *Janibacter hoylei* sp.nov., *Bacillus isronensis* sp.nov. and *Bacillus aryabhattai* sp.nov. isolated from cryotubes used for collecting air from the upper atmosphere. Int J Syst Evol Microbiol 59:2977–2986

Trevors JT, Pollack GH (2012) Origin of life hypothesis: a gel cytoplasm lacking a bilayer membrane, with infrared radiation producing exclusion zone (EZ) water, hydrogen as an energy source and thermosynthesis for bioenergetics. Biochimie 94: 258–262

Trevors JT, Pollack GH, Saier MH Jr, Masson L (2012) Transformative research: definitions, approaches and consequences. Theor Biosci. doi:10.1007/s12064-012-0154-3

Wainwright M, Wickramasinghe NC, Narlikar JV, Rajaratnam P (2003) Microorganisms cultured from stratospheric air samples obtained at 41 km. FEMS Microbiol Lett 218:161

Wickramasinghe NC (1967) Interstellar grains. Chapman and Hall, London

Wickramasinghe NC (1994) Cosmic grains. In: Mampsaso A, Prieto M, Sanchez F (eds) Infrared astronomy. Proceedings of the 4th Canary Islands Winter School of Astrophysics, Cambridge University Press, Oxford, pp 275–299 (ISBN 0521 464625)

Wickramasinghe C (2005) A journey with Fred Hoyle. World Scientific Press, Singapore

Wickramasinghe C (2010) The astrobiological case for our cosmic ancestry. Int J Astrobiol 9(2):119–129

Wickramasinghe JT, Wickramasinghe NC, Napier WM (2010) Comets and the origin of life. World Scientific Press, Singapore

Yang Y, Yokobori S, Kawaguchi J et al (2005) Investigation of cultivable microorganisms in the stratosphere collected by using a balloon in 2005. JAXA Research Development Report, JAXA-RR-08-001, pp 35–42

Yang Y, Yokobori S, Yamagishi A (2009) Assessing panspermia hypothesis by microorganisms collected in the high altitude atmosphere. Biol Sci Space 23(3):151–163