Astrobiology in the UK

Mark Burchell and Lewis Dartnell review the current standing of astrobiology research in the UK, and look to future success.

1: Traditional subject view of astrobiology starting with small scale (top) and progressing to larger scales to the bottom. In such a view each subject area is a distinct activity, with some overlap possible only at the boundaries. (CDC/James Gathany, NASA, ESA, NASA/Hubble Heritage Team and Univ. of Kent, S Beckwith [STScI] and the HUDF Team)

The growth of astrobiology – the study of the origin, evolution and distribution of life in the universe – worldwide has been mirrored in growing UK research. The focus of ESA's planetary missions on the Aurora theme leading to Mars (focusing on ExoMars in the near future and an eventual Mars sample return mission) has helped this, but in parallel a whole wide range of other activities in research and teaching are underway in the UK. The results of a recent survey of UK activities in astrobiology is about to be published in the journal *Astrobiology* (Dartnell and Burchell 2009) and reveals a wide ranging and deeply rooted UK community in the field. Here we present a sample.

In the UK, scientific research in the public sector is increasingly justified by reference to economic impact. But some topics are so fundamental, so potentially important, that it is hard to even begin to estimate their cash value. Nevertheless, a successful outcome from such research would potentially impact society so greatly and in so many ways that we cannot envisage not doing such work. Such is our view of the importance of the search for life and its origin, evolution and distribution both on Earth and beyond. This is a view shared by the public. For example, at the end of the 20th century, so-called "millennium fever" resulted, among other things, in top 10 lists of what the public expected scientists to discover in the 21st century; the origin of life was on most of those lists. Optimistic as this seems, something similar happened at the end of the 19th century, and searches for an answer to this question went unfulfilled then; we hope to do better this time.

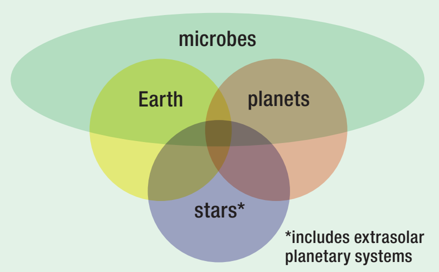
Panspermia and beyond

Progress has been made in the field during the 20th century. At the turn of the 19th century the question of how life started on Earth was related to space via the idea of panspermia: life came to the Earth from space as seeds or on meteorites (see Burchell 2004 for a recent review). This removes the need for an origin on Earth, and thus removes our need to see the Earth as special. The idea of life starting in space was suggested by, among others, Lord Kelvin in the late 1880s. Early in the 20th century the Swedish Nobel Prize winning scientist Svante Arrhenius popularized the idea further in a book (Arrhenius 1908). But improved knowledge of the conditions in the space environment seemed to preclude this, notably, for example, the deleterious effects on life of solar and galactic cosmic-ray radiation. Ideas of endogenous origins (rather than exogenous delivery) thus came to dominate and the primordial soup concept emerged in several countries in the 1920s and 1930s: the concept of proto-cells forming by making "bags" that acted as barriers, out of hydrophobic and hydrophilic molecules, became widespread in the science community and popular literature. Then, in the 1950s, in the famous Miller–Urey experiment, Miller showed that amino acids, complex molecules associated with life, could be synthesized in his model of the atmosphere of an early Earth via energy inputs from electrical discharges – lightning (Miller 1953). We now know that amino acids are commonly made by Nature in a wide variety of locations and are even found in meteorites (e.g. the Murchison meteorite was found to contain many amino acids, quite a few of which had no terrestrial counterpart, Cronin 1989). But none of these experiments led to creation of life itself.

Research then moved out into space, asking if Mars had life. But the Viking landers on Mars in the 1970s seemed to not only rule out this possibility, but also indicated that future Mars missions would be better focusing on geochemical measurements rather than pure life-science experiments, and any detailed biological experimentation should await a Mars sample return (MSR) mission (NRC 1977). While later Mars missions achieved mobility (via rovers) and have conducted extensive geochemical analyses on the surface, we still await MSR. Meteorites briefly came back in vogue when putative bacterial fossils were found in the Martian meteorite ALH 84001 (McKay *et al.* 1996), but this is discounted by most of the meteorite/Mars community who point to geochemical interpretations of the structures. On Earth, the argument of an exogenous vs endogenous origin of life has continued (e.g. Chyba and Sagan 1992). To try to better understand how life arose on Earth, searches for evidence of the earliest life on Earth are on-going (c.f. the controversy over the oldest fossils, 3.5 bya, Schopf *et al.* 2002 and Brasier *et al.* 2002).

In parallel to all this, throughout the 20th century astronomy continually revolutionized the way we see our universe and this has significant implications for astrobiology. The discovery of extrasolar planets is an obvious example. The discovery of Earth-type extrasolar planets (with Earth-like mass and orbit) is eagerly awaited. Equally eagerly awaited is the ability to then study the atmosphere of such a planet from its reflected sunlight, which will transform our understanding of planets and their potential for life (e.g. Cockell *et al.* 2009). Star formation and formation of planetary systems is also increasingly studied via both observations and modelling. Although still not fully understood, planet formation and solar-system architecture play a vital role in understanding how potentially life-bearing planets come about.

So what does the UK contribute to astrobiology? And how widespread is such work in this country? A recent paper (Dartnell and Burchell 2009) in the journal *Astrobiology* sets out to try to answer some of these questions. The paper contains the results of a survey of 286 UK researchers (based on 41 returns from 34 different research groups in UK university departments) and an analysis of abstracts submitted to a series of UK conferences on astrobiology. Activity was found in all four countries in the UK, with a large community of academics undertaking research and teaching in the field.



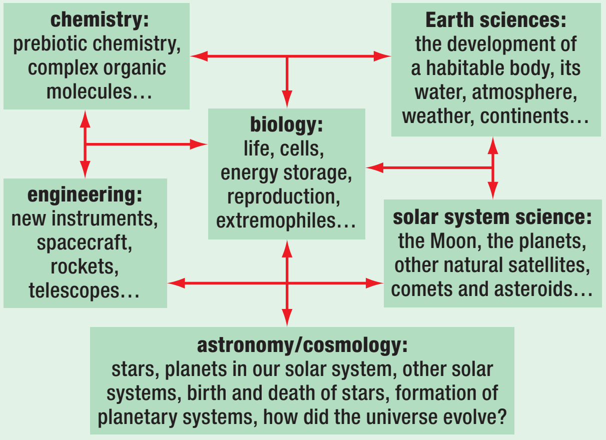
2: The inter-relationships between topics in astrobiology.

Key research areas

So what research does the UK community do in astrobiology? We have found that the UK astrobiology community is a broad church, with some relevant researchers even denying they are doing astrobiology at all. Work includes: understanding microbial life and its complexities; finding extremophiles here on Earth; searching for the origin of life on Earth via fossil evidence and non-equilibrium isotope ratios in old rocks; meteorite studies; lunar and martian science; searching for water on solar system bodies; characterizing the organic content of bodies in space; looking for organic molecules in interstellar space; and searching for terrestrial-type planets in other planetary systems. This work is carried out via experimentation, field-work, modelling, space missions, telescope observations and more. Details of this, along with who is doing what and where, are given in the Dartnell and Burchell paper.

In the traditional view, astrobiology is a series of almost disconnected specialisms, with distinct groups focusing on separate areas (see figure 1). However, in reality the work is inherently multidisciplinary. Some parts of it are carried out by single-subject specialists (after all, by definition, they are usually at the cutting edge of techniques in their fields), but other researchers need skills that span disciplines or combine in multidisciplinary teams. And the audience for the reporting of the results is often drawn from across discipline boundaries. This more holistic approach is reflected in figure 2 and is increasingly typical of how astrobiology works. The relationships between different branches of the field may not always be obvious at first glance; how, for example, do stars and microbes interact? But stars create the heavier elements without which life can't exist. The nature of individual stars defines the habitable zone around them in which liquid water

3: Possible inter-relationship between disciplines in astrobiology, illustrating the linkages between disciplines.



(necessary for life) can be sustained on a planet's surface, and so on.

Given this holistic approach, one might expect interplay between disciplines as shown in figure 3. Interestingly, however, in the survey by Dartnell and Burchell, physicists and astronomers dominate the field (54%) along with geologists/engineers (30%), while only 16% of respondents identify themselves as biologists (or related). This may reflect the now generation-old influence of the NASA Viking findings, and a focus on geochemistry and space missions. But here on Earth, the study of microbial life has advanced significantly over recent decades and it may now be time for this to be reflected in astrobiology, and as microbiologists peer back towards the origin of life they are perhaps evolving into astrobiologists. One area where microbiologists are heavily involved in astrobiology is in the study of extremophiles: microbial life that lives in environments here on Earth traditionally held untenable for life. The more we look on Earth, the more life we find, deep in the surface, high in the stratosphere, in salt environments, in radiation intense zones in nuclear plants, in regions of high UV flux and so on. Clearly there are limits, life can't exist in all environments, but the boundaries continually seem further away from the norms we are used to. And they move further away every few years.

Meanwhile, there is still no satisfactory definition of life itself. Many forms of the definition of life exist, but this very multiplicity suggests we still await a definitive statement on the subject. In chemistry, the old use of "organic" to label chemistry involved in life processes has been dead for a century now. But interestingly, progress is now being made in identifying complex compounds that seem to arise only as the result of life processes (e.g. see Parnell *et al.* 2007), and this opens up the possibility of detecting evidence for life via sensitive tests that can be almost based on a chip (i.e. life on a chip, see Sims *et al.* 2005).

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SETI vs SETL

One key decision UK academics seem to have reached almost by default is to favour the search for extraterrestrial life (SETL) over the search for extraterrestrial intelligence (SETI). The difference is obvious yet subtle. Here on Earth, life is billions of years old, but intelligence is a recent phenomenon. It therefore makes sense to focus on searches for life itself. Yet it is alien intelligence that so readily captures the public imagination. Moreover, searches for life are bedevilled by confusion over what life is, let alone how to recognize it elsewhere, especially if it is present in low concentrations. By definition, if intelligent life contacts us then the hard work has all been done: there will be a clear signal and we won't have to search too hard for it – it will come to us. This sort of logic is behind SETI searches that use radio-telescopes to look for modulated signals from elsewhere. Initially proposed by Cocconi and Morrison (1959) and separately proposed and translated into practice by Frank Drake in Project Ozma, these searches have so far proved fruitless. Apparent modulated signals have been reported but have not been repeated. The famous Drake Equation is a tool used to justify such searches, permitting an estimate of how many intelligent civilizations may exist out there, and hence how reasonable, or otherwise, it is for us to look for their handiwork. Unfortunately, as often pointed out, the Drake Equation is not really a scientific construct and the values assigned to its various terms are often so speculative as to preclude it yielding a firm prediction regarding the probability of contact (see for example Burchell 2006 for a discussion).

Radio signals are not the only means by which intelligence might communicate across space. The idea of self-repairing machines travelling at sub-light-speed across the galaxy is also one that grips the public mind. The RAS conducted a debate on this very topic in the old *Quarterly Journal* in the early 1980s (see Tipler 1980, 1981, Sagan and Newman 1983). Indeed, it could be argued man has taken the first steps on such a path via the Voyager spacecraft of the 1970s, which are now heading into interstellar space carrying the famous cultural artefacts chosen to represent mankind. As well as artefacts one can go further and contemplate spreading DNA across the galaxy (Crick and Orgel 1973). Indeed, at a more basic level the spread of DNA by natural means was the idea postulated by, among others, Sir Fred Hoyle and Prof. Chandra Wickramasinge in their frequent discussions relating to panspermia.

However, as stated above, the UK community has mostly avoided SETI and worked on SETL, although there is still interest in panspermia (i.e. natural migration through space). Perhaps this lack of interest in SETI is due to limited state-provided funding. In the US, the SETI institute has over the decades moved from state funding towards the private sector, with charitable donations helping it develop its work. It seems the public is willing to be more speculative in the ventures it supports directly than does peer-reviewed state funding.

Teaching

One way a subject embeds itself in the academic community is by the establishment of teaching programmes. This may seem odd, given that many academics seem keener on research than teaching, but it serves several purposes. One key issue is that it provides and enthuses a new generation of researchers. It also helps science departments attract more students by offering novel courses in a cutting-edge discipline with a high profile. Almost all research disciplines like to claim that they fit that bill, but astrobiology *is* photogenic, it makes the news and involves a readily understood big concept: life itself.

It should be no surprise that the recent survey found that 15 UK university departments were offering courses or modules involving astrobiology. This compares with just four identified in an earlier report (Cowan *et al.* 1999). One criticism of such surveys is always that they are based on sampling techniques and are hence incomplete; there may well be more courses out there. Nevertheless, the new results indicate that astrobiology teaching is now widespread in UK undergraduate science courses, particularly in physics and astronomy departments which account for 54% of the students on such courses (perhaps reflecting where the researchers are).

In parallel to this a wide range of astrobiology textbooks are now available. Where once there were just a few specialist books, typified by the excellent *The Search for Life on Other Planets* (Jakosky 1998), there are now many, and the UK academic community has generated several of its own, including the OU's very popular course textbook (Gilmour and Sephton 2004).

Outreach and public engagement

Astrobiology is doing well in public. People like to hear about astrobiology, from pre-school children (who like painting little green men), to adults – if you advertise a talk on astrobiology you will get an audience. Recently one of the authors of this article (Lewis Dartnell) spoke at the Cheltenham Science Festival, and at the other extreme the other author (Mark Burchell) took part in a hands-on "Little Green Men" activity morning at Whitstable Museum (finger painting, drawing and cutting out etc). This experience is shared by many researchers in astrobiology; if you offer a talk, there is an audience.

Organization and opportunities

In the UK, astrobiology is both an individual and an organized field of research. Individual researchers enter the field based on their interests. But to help push the growth of the discipline, a series of meetings at the Royal Society in London in 1996 and 1998 made several recommendations. These are summarized in Cowan *et al.* 1999 and included the suggestion that an ad-hoc committee should form and promote the discipline. This occurred, and the committee then organized a national conference in Cambridge in 2003, where the Astrobiology Society of Britain (ASB) was created by popular vote of the attendees. The ASB has since held further conferences, at Canterbury (2006) and Cardiff (2008). The next conference will be held at Royal Holloway College (London) in 2010. The ASB also runs a website where details of its activities and announcements concerning its conferences can be found. This site receives more than 3000 hits a week. One popular feature is the reviews of new astrobiology books (with more than 25 reviewed in the last two years).

In parallel to these national activities, other countries have similarly set up societies in this field, some predating and some postdating the ASB. At the European level, the European Astrobiology Network (EANA) has been holding annual pan-European conferences on astrobiology since 2000 (the 2009 meeting will be in Brussels in October). The UK has two representatives on the management committee of EANA. Above EANA and similar organizations is the FAO, the Federation of Astrobiology Organizations. While currently somewhat limited in its activities, this body tries to act to promote astrobiology and liaisons between its members.

Funding

It is a sad fact of modern life that any scientific discipline stands or falls by its ability to attract money. In this respect, in the US, NASA's decision to fund a National Astrobiology Institute (see NRC 2008) gives a strong focus to such work, and has helped the US to develop a healthy community in the field with a well defined roadmap (Des Marais *et al.* 2008). The UK relies on its Research Councils to back fields. Here, STFC responds to ideas-led research, and its solar-system exploration programme includes Aurora, which has as one of its key goals the search for evidence of life (past or present) on Mars. This is an inherently long-term activity, with participation in ESA's ExoMars lander mission in 2016 and participation in a Mars sample return mission in the 2020s. In the meantime STFC is encouraging a supply of trained scientists by investing in Aurora fellows (with two rounds of fellowships already awarded and the results of the third round to be announced shortly). In addition, STFC funded a postgraduate summer school on astrobiology in 2007 at the OU, and is funding a second such school in September 2009 at the University of Kent. In parallel to this, a series of STFC workshops are taking place to help educate the academic community on issues needed to fully participate in these long-term goals (e.g. in June 2009 a workshop on criteria for selection of Mars landing sites was held at the OU). Individual research grants, however, depend on the individual researcher submitting applications to a relevant funding agency. This, of course, is then dependent on how well the proposed work ties into the agency's objectives and how well it is received by its referees.

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The future

In some respects the future of astrobiology in the UK depends solely on academics and students: do they want it? The answer appears to be a strong yes. For example, the growth in undergraduate teaching found by Dartnell and Burchell (2009) suggests a fourfold increase in teaching provision in a decade. Such rates of growth cannot be sustained indefinitely of course, a slower growth rate and an increase in depth of provision in the existing institutions is the likely next step. In turn, a fraction of the students emerging from these undergraduate courses will want to undertake research degrees in the field. Already the Astrobiology Society of Britain reports increasing requests from graduates to help provide a PhD-place finding service. At the postgraduate level, the range of research topics covered by students is impressive, covering the whole field of astrobiology from microbiology through to astronomy. One perceived need is to translate this into greater visibility internationally. The UK hosts its own astrobiology conference series, and has also hosted the European astrobiology conference (EANA 2004 at the Open University), but participation at international meetings is patchy. For example, at EANA 2008 several papers were presented by senior UK academics but relatively few by the UK's early-career researchers.

In terms of published papers, the UK is successful. The Astrobiology Society of Britain's conference series has resulted in nearly 40 original papers in issues of the *International Journal of Astrobiology* (see volumes **3**(**2**), 2004, **5**(**3**) and **5**(**4**), 2006 and **8**(**1**), 2009). Work has also appeared in a variety of journals such as *Astrobiology, Biogeosciences, Icarus, the Journal of Geophysical Research, MNRAS* etc. But in addition to this broad spread of work the real test in the next decade will be whether the UK achieves notable leading breakthroughs in the field and in particular assumes key leadership roles in ESA's Aurora programme. ●

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Lewis Dartnell is a postdoctoral researcher at University College London and author of Life in the Universe: A Beginner's Guide.

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Further reading

Astrobiology Network (EANA)
http://www.astrobiologia.pl/eana/
Astrobiology Society of Britain
http://www.astrobiologysociety.org
Astrobiology summer school (September, University of Kent) http://astro.kent.ac.uk/astrobiologysummerschool2009
EANA conference (October, Brussels)
http://www.exobiologie.be/eana/index.htm
ESA's ExoMars lander mission http://www.esa.int/SPECIALS/Aurora/SEM1NVZKQAD_0.html
National Astrobiology Institute
http://astrobiology.nasa.gov/nai