Space life holds its breath

Pressured by scepticism, budget cuts and the need to prove itself, astrobiology is coming to a crossroads

Research on alien life began as 'exobiology', a term first introduced in 1960 by Nobel laureate Joshua Lederberg to describe the study of life beyond Earth. This was then absorbed by astrobiology, a broader multidisciplinary field that, in addition to its extraterrestrial perspective, has some very Earth-bound objectives, including extremophile biology, molecular evolution, prebiotic chemistry, the origin of life on Earth, and the effect of gravity on organisms. According to Steven Dick, chief historian of the US National Aeronautics and Space Administration (NASA; Washington, DC, USA), "exobiology and astrobiology share the core concerns of origin-of-life research and the search for life beyond Earth. But astrobiology placed life in the context of its planetary history, encompassing the search for planetary systems, the study of biosignatures on other planets, and the past, present and future of life" (Dick, 2006).

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Despite its distant focus, astrobiology is by no means neglected. Shortly after its foundation in 1958, NASA inaugurated a robust research programme in the field, and money has generously flooded in ever since. Further augmenting the status of the discipline, NASA founded its Astrobiology Institute in 1997—with its headquarters at the Ames Research Center (Moffett Field, CA, USA) and nodes based at universities and research institutions around the USA—which is funded with a five-year budget. Europe has also jumped on the astrobiology bandwagon—albeit with an obvious delay. The European Space Agency (ESA; Paris, France) is working on life-seeking planetary missions, and the international Centro de Astrobiología, based in Madrid, Spain—the first non-US research centre to be associated with the NASA Astrobiology

Institute—coordinates much of these research activities in Europe.

Signs are accumulating, however, that astrobiology has finally reached the point at which its fate will be decided. Despite growing attention, the field is still haunted by the curse that evolutionary biologist George Gaylord Simpson voiced more than 40 years ago: "[T]his 'science' has yet to demonstrate that its subject matter exists!" (Simpson, 1964). By the same token, today's critics question whether astrobiology can really be considered a self-sufficient discipline or if it is just a trendy tag for biology and microbiology. They point to the key problem that experimental evidence—at least, for extraterrestrial life—is difficult, if not impossible, to obtain, thus making it a speculative rather than an observational science.

As Jeffrey Bada from the Scripps Institution of Oceanography (La Jolla, CA, USA) wrote, "[S]cientific curiosity alone cannot explain the explosive growth of astrobiology. After reading *The Living Universe: NASA and the Development of Astrobiology*, I came to the conclusion that one of the field's attractions was money—and lots of it" (Bada, 2005). Clearly, money will be a delicate issue for astrobiologists in the near future. NASA's total budget continues to shrink rapidly since its peak in 2005, and internal competition for funds is becoming tougher. After US President George W. Bush announced plans to "gain a new foothold on the moon" (Bush, 2004), NASA Administrator Michael Griffin proposed cutting astrobiology funding to half its 2005 level (Lawler, 2007). Consequently, astrobiologists are realizing how much their research needs political protection and scientific advocacy.

Dismissing these dark clouds on the horizon, many scientists continue to endeavour enthusiastically. "As to the future prospects

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for astrobiology, they are sunny! The search for life beyond the Earth is a major driving force behind many current space programmes of ESA and NASA and, who knows, maybe the Indian and the Chinese space agencies too," said Mark Brake, professor of science communication and Director of the Centre for Astronomy and Science Education at the University of Glamorgan, UK. "The recent excitement over the possibility of finding organic molecules on Titan [a moon of Saturn] will be nothing compared with the thrill of finding Earth-like planets in orbit around stars in our solar neighbourhood."

Luckily, astrobiology research does not necessarily require expensive satellites and planetary missions; it is firmly grounded on Earth because it often builds on research into terrestrial organisms and experiences. The Mars Simulation Laboratory, set up by the University of Aarhus, Denmark (Fig 1), for example, will carry out simulations under proxy Mars conditions with respect to temperature, pressure, atmospheric composition and light, according to Kai Finster, a microbiologist in the Mars group at the university. "We study the effect of simulated conditions on a complex microbial community from permafrost soil from Spitsbergen [a Norwegian island in the Arctic circle]. Permafrost soil was chosen because it has many properties in common with conditions on Mars, where permafrost areas are very extended," he explained.

In collaboration with other European groups, they are investigating the effects of reactive compounds—such as ozone or hydrogen peroxide—radiation and freeze-thaw cycles on selected microbes. "Our approach will contribute to getting a better understanding of the effects of Martian conditions on biological material," he said. "We can learn a lot about life on Mars by doing simulation experiments on Earth at very low costs."

Finster and fellow scientists who speculate on the existence and nature of alien life usually follow one of two lines of reasoning. Some are confident in the universal nature

of biochemistry, according to which chemical and physical constraints make it highly probable that life elsewhere in the universe follows the same general principles as terrestrial life and uses similar building blocks for macromolecules, although extraterrestrial life might have some biochemical peculiarities (Pace, 2001).

By contrast, fans of alternative biochemistry have shown much creativity in describing how life could have evolved in habitats very different from those on Earth, by using a combination of atoms other than carbon to build molecular structures, solvent systems besides water and a variety of energy sources (Bains, 2004; Benner *et al*, 2004; Schulze-Makuch & Irwin, 2006). Silicon-based polymers, liquid ammonia or ammonia–water mixtures, and geothermal energy or electromagnetic fields are some of the commonly proposed solutions for sustaining such truly alien life forms. “We propose that the only absolute requirements [for life] are a thermodynamic disequilibrium and temperatures consistent with chemical bonding,” stated Steven Benner and colleagues from the University of Florida at Gainesville, USA (Benner *et al*, 2004). “We must be careful [when equating] ‘water/ice’ and ‘life’,” remarked Philippe Blondel from the University of Bath, UK, who co-edited a book reviewing current knowledge of our solar system (Blondel & Mason, 2006). “The recent discoveries on Earth itself, like chemosynthetic life forms near hydrothermal vents in the deep oceans, or dormant microorganisms in the extremely low temperatures below Antarctica, have shown how adaptable life can be.”

But if life is possible in the absence of water, then the quest for living organisms in space rises to another level of complexity. Places such as Venus and Titan, where water is virtually absent, thus become possible habitats for life. Furthermore, if alien life diverges radically from terrestrial organisms, on which experimental basis will scientists recognize it? Conversely, if microbial organisms on, say, Mars share a substantial fraction of biochemical features with their Earth brethren, how will astrobiologists be able to distinguish them without any doubts about interplanetary contamination? To complicate matters, some astrobiologists also consider the possibility that life arose just once in our solar system—or even in the entire universe—and was then dispersed by meteorites, which would further reduce the ability to discriminate between alien

Fig 1 | Bio-chamber at the Mars Simulation Laboratory of the University of Aarhus, Denmark. This facility allows scientists to control abiotic parameters such as pressure, temperature, gas composition and radiation to simulate presumed Mars environmental conditions and study microbial responses. The chamber is about 40 cm in height and has a diameter of 36 cm, and can be refrigerated to about -60°C . Credit: University of Aarhus.

and terrestrial origins (Pace, 2001; Schulze-Makuch & Irwin, 2006).

For the time being, however, water is considered the source of life, and any planets and moons in our solar system that are likely to host water become obvious targets for exploration. At the forefront, owing to its proximity and similarity to Earth, is Mars. Next in line is Europa, one of the icy moons of Jupiter, where a

deep ocean could lie below the frozen surface (Figs 2,3). “Are Mars and Europa the more likely candidates to host ‘possible life’? Sadly, there is no answer at the moment, in the absence of past or present life or signatures of life to observe,” said Blondel. “However, the basic materials for water/carbon life forms are all there, distributed in many places around the solar system. The continuing discoveries of planetary exploration show us there are plenty

Fig 2 | Europa, a moon of Jupiter, appears as a thick crescent in this enhanced-colour image from NASA's Galileo spacecraft, which has been orbiting Jupiter since 1995. The view combines images taken in violet, green and near-infrared filters in 1998 and 1995. Reddish linear features are some of the cracks and ridges on the icy surface of Europa, which are caused by tides raised by the gravitational pull of Jupiter. Europa's surface has few craters, indicating that recent or current geological activity has removed the traces of older impacts. The paucity of craters, coupled with other evidence, has led scientists to surmise that there could be an ocean of liquid water beneath the moon's surface (Fig 3). Credit: NASA/JPL/University of Arizona.

Fig 3 | Two proposed models of the subsurface structure of Europa. Geological features on the surface, measured by the solid state imaging (SSI) system on NASA's Galileo spacecraft might be caused by the existence of a warm, convecting ice layer, located several kilometres below a cold, brittle surface ice crust (top model), or by a layer of liquid water with a possible depth of more than 100 km (bottom model). If a 100 km-deep ocean existed below the ice crust, it would be 10 times deeper than any ocean on Earth and would contain twice as much water as Earth's oceans and rivers combined. Data from various instruments on the Galileo spacecraft indicate that an ocean might exist, but no conclusive proof has yet been found. Credit: NASA/JPL-Caltech.

of opportunities for life to have evolved, or to evolve, in different places."

Europa is too far away—more than 600 million kilometres from Earth—to explore directly, but the Red Planet is near enough for ESA's new space exploration programme Aurora. Scheduled to launch in 2013, its flagship mission ExoMars is designed specifically to characterize the Martian biological environment. The mission will include a Mars orbiter carrying a descent module, which will contain a rover (Fig 4). The orbiter will put itself into orbit around the planet, while the module will deliver the rover to a specific location by using an inflatable braking device or a parachute system to ease impact. Powered by conventional solar

arrays, the rover will then be able to travel a few kilometres across the Martian surface, operating autonomously by using onboard software. Included in its approximately 40 kg 'Pasteur payload' will be a lightweight drilling system, a sampling device and a set of scientific instruments to search for signs of past or present life. ExoMars will also deploy the Geophysics/Environment Package to measure planetary parameters important for understanding the planet's evolution and habitability, identify possible surface hazards to future human missions and study the environment.

ExoMars' planners are well aware that providing convincing evidence for or against the existence of life on Mars is not an

easy task. Scientists still dispute the results of experiments conducted by the Viking Mars landers in the late 1970s (see sidebar); igniting another decades-long controversy might be detrimental for future astrobiology-focused missions. "To arrive at a clear and unambiguous conclusion on the existence of past or present life at the Rover sites, it is essential that the instrumentation can provide mutually reinforcing lines of evidence, while minimising the opportunities for alternative interpretations," wrote the members of the ExoMars working group when outlining the mission strategy (Vago *et al*, 2006). "The science strategy for the Pasteur payload is therefore to provide a self-consistent set of instruments to obtain reliable evidence,

for or against, the existence of a range of biosignatures at each search location."

Whatever the search for alien life uncovers, the research holds an enormous fascination for the public—if only to reveal whether we are alone in the universe. This public attention, according to Finster, should encourage the ESA to support students in astrobiology. "Compared with the USA, European countries have not realized the appeal that astrobiology has on new students. ESA should play a much more active role and learn from NASA's way of addressing people at all ages."

Brake, who leads the UK's first undergraduate degree in astrobiology, launched in September 2005, agrees with Finster over the importance of studying astrobiology. "I think it is probably the largest astrobiology outreach course in the world," said Brake. "I may be wrong, of course. But over the last three years over 500 people have joined up." The course reflects the multidisciplinary nature of astrobiology, coupling academic content to observational astronomy, he explained.

The lay public and students might become interested further in astrobiology's cause by the communication networks that astrobiologists have established. "For me, as a science communication specialist, the most interesting development in astrobiology recently has been the launch of a European edition of NASA's *Astrobiology Magazine*," said Brake. This quarterly web-based magazine will highlight European scientists who are studying the history of life on Earth and the possibility for life beyond. Besides this and other media—such as *Astrobiology Magazine*'s podcast service, Radio Astrobiology—aimed at a general audience, peer-reviewed scientific journals, such as *Astrobiology* and the *International Journal of Astrobiology*, report the results of research. Congresses are also regularly held and attended by an increasing number of practitioners.

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Fig 4 | ExoMars rover, the ESA's field biologist on the Red Planet, aims to characterize further the biological environment on Mars in preparation for robotic missions and human exploration. The ExoMars mission calls for the development of a Mars orbiter, a descent module and a Mars rover. Credit: ESA.

There is little doubt that the possibility of finding alien life—whether or not it resembles terrestrial life—exerts a tantalizing fascination. However, the lack of any proof so far remains a source of criticism, which should encourage scientists to adopt more rational guidelines. Many supporters of astrobiology maintain that without a good dose of irrational imagination—such as looking for something that might not exist—many a great leap in science would not have occurred. Research on extremophile organisms can help to clarify the problem of astrobiology's real meaning. The field is expanding rapidly, with intriguing microbial ecosystems having been found miles underground and surviving independently of solar energy. Astrobiologists consider this

a vital part of their science, together with space probes and astronomical observations to search for habitats where life could exist.

Yet, if the limits of life on Earth are still unknown, is it really worth the money and effort to look for life elsewhere? "We can learn more about life from terrestrial forms than we can from hypothetical extra-terrestrial forms," Simpson wrote (1964). The question then is whether it is worth repeating costly planetary missions every 20 to 30 years, to revise criteria for alien life detection based on progress in extremophile biology research. After all, ExoMars could be seen as an updated version of the 1970s Viking missions. "Finding evidence for life in another body in our solar system would give the field the justification it requires

LIFE? YES, NO, MAYBE

There is no firm evidence of life beyond Earth. However, several alien life ‘encounters’ have suggested such a possibility to both the scientific community and the lay public. In 1976, the Mars Viking programme was the first space mission to include experiments to detect metabolic activity in an extraterrestrial environment. The results of the three biological tests carried out by each of the two Viking crafts were controversial, and remained the subject of harsh debate for some time. Today, most—but not all—experts agree that they produced no conclusive proof of the existence of life on the Martian surface. However, Dirk Schulze-Makuch from Washington State University (Pullman, WA, USA) believes that the Viking results should be re-examined for biosignatures of hypothetical organisms that could not be imagined 30 years ago—such as microorganisms that use a water–hydrogen peroxide mixture as an internal solvent—and that our present knowledge of extremophiles allows at least to consider theoretically possible. The Viking instrumentation was not designed to detect the metabolic traces of this or other exotic life forms that could have been destroyed during biological testing, he claims. “If the hypothesis is true, it would mean that we killed the Martian microbes during our first extraterrestrial contact, by drowning—due to ignorance,” commented Schulze-Makuch (WSU, 2007). “We might be mistaken. But it’s a consistent explanation that would explain the Viking results.”

Meteorite fragment ALH84001. This photograph was taken during the initial processing of ALH84001. A dull, dark fusion crust covers about 80% of the sample. Credit: NASA.

Scanning electron microscope image showing tiny tubular structures on the surface of ALH84001. These structures, 20–100 nm in diameter, were interpreted as fossils of bacteria-like organisms, although they are much smaller than any cellular life form found so far. Credit: NASA.

If the Viking missions spurred hopes and disappointment, these were nothing compared with the impact of ALH84001. This 1.93 kg meteorite, recovered in 1984 in Antarctica, is one of the few rocks of certain Martian origin collected on Earth, and by far the oldest, with an estimated age of some 3.6 billion years. David McKay and colleagues from NASA (Washington, DC, USA) suggested that carbonate globules, organic molecules and some minerals observable on the meteorite surface could be “fossil remains of a past Martian biota” (McKay *et al*, 1996). NASA bought the life-on-Mars theory without hesitation, openly talking about a turning point in human history. General excitement grew so high that even former US President Bill Clinton marked the event in a formal television announcement. But all this was short-lived, as the scientific community swiftly dismissed every piece of evidence as the product of non-biological reactions or simply not compatible with life. The objects found on the meteorite are 20–100 nm long—several times smaller than the smallest bacteria or archaea ever found on Earth—which would not allow any free-living organisms to accommodate the entire molecular machinery needed for life, at least as we know it.

in order to remain an active, well-funded area of research,” noted Bada (2005). Thus, if ExoMars and other upcoming missions near to Earth fail to find life in space, further astrobiology research could be halted for an unpredictably long period, as politicians and the scientific community—not to mention society—decide whether the money is better spent on studying topics closer to home.

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doi:10.1038/sj.embor.7400966