BBSRC research into the physical limits of life on Earth is being used by the international space community to define regions on Mars where life could exist.

The findings have been incorporated into a report from the NASA Special Regions Science Analysis Group, which is now being reviewed by COSPAR, the Committee on Space Research. Once approved, the final report will form the basis of international planetary protection policy, which aims to prevent contamination of planetary biospheres (both the Earth and elsewhere) with alien life by providing guidance for the development of future space missions.

The research, led by Dr John Hallsworth, Lecturer in Environmental Microbiology at Institute for Global Food Security (Queen’s University Belfast), found that substances known as ‘chaotropes’ can lower the minimum temperature microbes require for growth by as much as 10°C. As chaotropic salts are present in the Mars regolith, or soil, the findings suggested that minimum temperature limits used to define Special Regions – i.e. areas with the potential to harbour Martian life, or where terrestrial microorganisms could replicate – may need to be revised to avoid potentially contaminating Mars with terrestrial microorganisms.

Everything is stressed
“There’s no such thing, really, as stress-free conditions,” explains Hallsworth. “The whole of life is played out in that grey zone between destruction and some hypothetical perfection. Everything is stressed.”

Those stresses set the limits on where life can exist: extremes of temperature, water availability, radiation, pressure, or pH (among others) can all limit where microbes can grow. In earlier research Hallsworth had shown that solutes called chaotropes could lower the minimum temperature microbes require for growth.

The research arose from a £132K BBSRC responsive mode grant.

IMPACT SUMMARY
BBSRC-funded microbiology research into the limits of life on Earth is being used by the international space community to help define planetary protection policy.

Based on results from a BBSRC project, Dr John Hallsworth from Queen’s University Belfast was invited to join the Special Region Science Analysis Group of NASA’s Mars Exploration Program Analysis Group.

Hallsworth’s research was used by the group to help define ‘Special Regions’ on Mars; areas where life may be possible and where there is a risk of contaminating Mars with terrestrial microbes carried by spacecraft and landers or rovers.

The findings were incorporated into the Group’s published report. Following review by the international Committee on Space Research, the findings will form the basis of international planetary protection policy used by space agencies around the world to design future space missions.

Hallsworth also contributed to a NASA special analysis group on life detection, which is informing the development of a NASA/ESA mission to return samples from Mars for analysis, and a NASA–Princeton University analysis group on the bioethics of searching for life.

The research arose from a £132K BBSRC responsive mode grant.

From soil to the stars: microbiology informs international space policy

A self-portrait of NASA’s Mars Curiosity Rover on Mount Sharp, Mars. Rovers can carry hardy terrestrial microbes, which could colonise Martian sites. Image: NASA.
‘chaotropes’ can limit life on Earth. Chaotropes destabilise the double-layer membrane made of lipid macromolecules that surrounds every cell. This makes the membrane more fluid and more permeable and, ultimately, can lead to it rupturing, killing the cell.

“The science within the BBSRC project, and my main interest, is what happens within the cell at the macromolecular level?” Hallsworth adds. “How much, in terms of biophysical stresses caused by solutes or temperature, can macromolecular systems take, and what can the cell do about it?”

BBSRC funding enabled Hallsworth to examine how the soil bacterium Pseudomonas putida and other microbes responded to stress caused by low temperatures in the presence of chaotropes – solutes such as ethanol or urea that can destabilise the cell membrane and ultimately cause it to rupture, killing the cell.

The results showed that at low temperatures, the destabilisation caused by chaotropes enabled microbial cells to replicate at substantially lower temperatures; reducing the minimum temperature required for growth by 5-10°C. The researchers also found that cells could selectively accumulate chaotropes to manipulate the temperature range in which they could grow. The results were published in 2010.

“That’s when NASA became interested in my work,” says Hallsworth.

**First contact and planetary protection**

Hallsworth’s first contact with NASA came in 2011 when he was invited by the Director of the Astrobiology Program at NASA to speak at an American Society for Microbiology conference on the topic of low temperature biology, based on his 2010 paper from the BBSRC-funded project. Later that year, Hallsworth was invited by NASA to join a scientific analysis group in San Diego looking at life detection. “Specifically for the next mission between NASA and the ESA when a rover will be sent to Mars,” says Hallsworth. “What apparatus needs to be to there, what methods will be used to retrieve samples, how they will be contained, what samples will be required? All based on how they will be analysed when they are brought back to Earth. It will be the first samples to be brought back from Mars.”

Following that, in 2014 Hallsworth was asked to join NASA’s Mars Exploration Program Analysis Group (MEPAG) Special Regions Science Analysis Group, which was reviewing science pertinent to COSPAR’s planetary protection policy, first published in 2010, and in 2015 he contributed to a NASA - Princeton University analysis group on the bioethics of searching for life.

The MEPAG Special Regions Science Analysis Group focussed on defining ‘Special Regions’ of Mars; areas where terrestrial life could survive and grow, or where there is a chance of finding evidence of living Martian organisms.

**PLANETARY PROTECTION POLICY**

International planetary protection policy provides guidance for space missions to reduce the risk of contaminating their destinations. As all spacecraft carry some terrestrial microbes, space-exploration missions cannot land at destinations that where terrestrial life could multiply and contaminate otherwise pristine environments which may provide resources of future human habitation, may contain evidence of extant extra-terrestrial life, or could be of interest in the study of chemical evolution or the origins of life. It also addresses the need to ensure Earth is not contaminated by any samples returned from elsewhere.

There are two main parameters that determine Special Regions of Mars; temperature, and ‘water activity’ – which is similar to relative humidity. “In terms of temperature, our 2010 paper showed that if chaotropes are present they can potentially reduce growth windows of microbes by five or ten degrees centigrade,” says Hallsworth. “All sorts of salts in the Mars regolith are chaotropic, such as magnesium chloride, [so our results] put a question mark on the safety limits.” He adds, “The lowest temperature in which a microbe has been known to divide in experiments on Earth is -18°C. Do we take that value as an absolute, or, given there are chaotropes all over Mars, do we need to build in a bigger safety margin?”

Hallsworth also influenced discussions around the second parameter, water activity, and the report now considers the concept of water availability at the micrometre scale. Water availability on Mars is determined by detecting humidity from orbiting spacecraft, which suggested that much of Mars has too little water to support life. However, this assumes water is in equilibrium between potential habitats for terrestrial microbes in surface and subsurface locations, and the Martian atmosphere. Hallsworth revealed that this is not necessarily true, and that planetary protection policy must account for high water activity at much smaller, microbial cell-relevant scales. These could include, for instance, the spontaneous formation of a thin film of liquid water around soil or dust particles, which could support life.

Late in 2014 the Special Region Science Analysis Group published a report that incorporates Hallsworth’s findings, and the science it contains is now being reviewed by COSPAR. Once that process is complete, the findings will form the basis of international planetary protection policy.
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ASTROBIOLOGY

Astrobiology is the study of the origins, evolution and distribution of life on Earth and elsewhere. It includes understanding the limits to life, as well as looking at where in the Solar System there could be habitable environments: current possibilities include Mars, Jupiter’s moon Europa, and Saturn’s moon Enceladus.

The nature of Hallsworth’s research on terrestrial microbes means that it has implications for astrobiology and he is continuing to work with senior researchers from NASA, ESA, the UK Centre for Astrobiology, and COSPAR. However, involvement with the astrobiology community is also providing novel science for research into terrestrial systems such as fermentation microbiology, food spoilage and preservation, biological control of agricultural pests and pathogens, and the microbiology of soils in arid regions.

REFERENCES

1. COSPAR: https://cosparhq.cnes.fr/
2. Dr John Hallsworth: http://www.qub.ac.uk/schools/SchoolofBiologicalSciences/People/IDJEHallsworth/
5. NASA MEPAG

Bacteria that can survive in extreme environments on Earth enable scientists to understand the limits of life elsewhere in the Solar system. Image: Steve Jurvetson/Flickr. CC BY 2.0.