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Space missions out of this world with AI

In the next phase of space exploration, human crews will be sent on missions beyond the low Earth orbit. Artificial intelligence (AI) is expected to play a main role in autonomous biomonitoring, research and Earth-independent healthcare.

Space travel poses a wide range of dangers to astronaut health. Risks include exposure to ionizing radiation and microgravity, prolonged isolation and confinement, accelerated day–night cycles, extreme temperatures and other harsh environmental conditions. Beyond the low Earth orbit (LEO), medical supplies and equipment can not be restocked, and communications with ground-based mission control centres face delays. Many of the environmental hazards also apply to other living organisms, which are needed for sustainable habitats in space.

Scientific research is underway to better understand these challenges, with ground-based as well as space-based experiments, including at the International Space Station (ISS). At the beginning of this month, NASA's SpaceX Crew-6 successfully launched and arrived at the ISS, beginning over 200 science experiments. The hope is that the findings will inform future space missions. For example, the Cardinal Heart 2.0 project will test whether clinically approved drugs reduce microgravity-induced changes in heart-cell function as previously observed with tissue chips. Another experiment involves the collection of samples outside life-support vents of the ISS to examine whether microorganisms are released and if so how far they travel. Last year saw the deployment of NASA's Biosentinel experiment, which sent yeast cells into heliocentric orbit in an automated microfluidic culturing device aboard a CubeSat. The platform gathers data to study the effects of deep space radiation on biological systems.

Biosentinel is the first study to observe biological effects in deep space in almost 50 years. To extend research to more experiments and missions beyond LEO, including manned ones such as to the Moon and Mars, maximally automated approaches are needed. AI and machine learning are expected to play a key role in these efforts. In 2021, NASA organized a workshop gathering biologists, clinicians and machine learning experts to envision how AI technologies will enable space biology research and personalized healthcare on board space missions.

In this issue of *Nature Machine Intelligence*, Sanders et al. and Scott et al. present the key outcomes of the workshop in two parallel Review articles entitled Biomonitoring and precision health in deep space supported by artificial intelligence and Biological research and self-driving labs in deep space supported by artificial intelligence. The articles describe a broad vision for the next decade regarding what capabilities need to be developed, how current machine learning approaches should be adapted to space and where technology and knowledge gaps exist.

In the first of these two Review articles, the workshop participants identify various broad areas for setting up a precision space health framework for space travellers. Special emphasis is put on integrating software with on-board hardware for data collection, data analysis and in-situ computation and inference, with the goal of building autonomous and Earth-independent systems, whose output can be accessed and analysed by the crew and Crew Medical Officer. The authors envision that longitudinal and continuous data are collected from three different layers: environmental sensors, non-invasive wearables and point-of-care devices, and from invasive measurements, such as from blood samples but also smart toilets and showers for microbiome profiling.

Advanced machine learning methods will be needed to process such multi-layered, multimodal data. Another challenge for a precision space health system is making useful predictions based on out-of-distribution data, given that representative training data is lacking. Methods are needed that, when initially pre-trained on Earth-based datasets, can adapt to data that are acquired in space flight.

The second article reviews existing capabilities in AI-assisted biology experiments, both Earth and space-based, and discusses what is needed for further automation in deep space missions. This leads to a focus on 'self-driving labs', where, in a closed-loop system, a machine learning model can choose the experimental design and parameters for testing a particular hypothesis, producing data that, in turn, informs the machine learning model.

An overarching challenge mentioned in both articles is the collection and maintenance of large amounts of data of various types, from omics datasets to behavioural observations. The authors emphasize the need for standardization of space data and metadata, advocating the development of an open science approach building on 'FAIR' principles[1] for data management (findable, accessible, interoperable and reusable).

There is a revival of interest in deep space exploration with manned missions, as well as a growing interest in commercial space travel. AI-enabled autonomous monitoring, research and precision healthcare will be key technologies. There are already strong converging developments in this area, such as in efficient and robust computing hardware for AI, wearable devices, automated biological experimental platforms, advanced machine learning models and more. The launch of crewed deep space missions may be some years off, but there could soon be spin-off applications for Earth-based healthcare, in providing reliable medical care, screening and treatment for remote and isolated areas.

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References

1. Wilkinson, M. D. et al. *Sci. Data* **3**, 160018 (2016).