A New Hope Against the Invisible Threat of Space Radiation

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Space exploration missions face numerous challenges. However, cosmic radiation – which damages human cells and causes mutations in DNA – is one of the biggest problems that scientists are striving to address. How are they approaching it? **THINK** *talks to researchers from the* ***DeepAFQ*** *project, whose work will help in understanding the impact of radiation on human health and to developing strategies that protect both astronauts in space, and patients undergoing radiation-based treatments on Earth.*

Imagine you are an astronaut in space, on a mission to explore new parts of our solar system. The idea sounds exciting, doesn't it? But what challenges would you face during the mission?

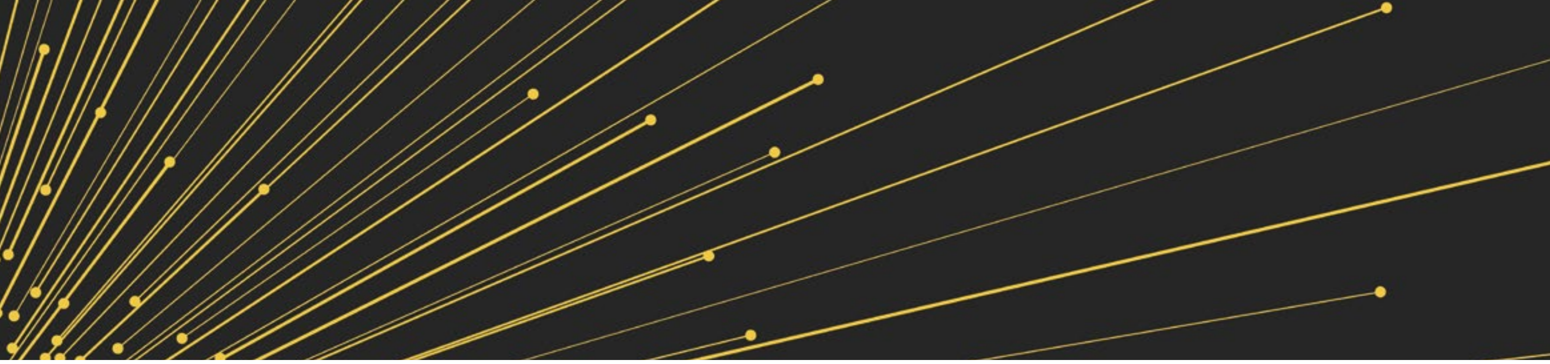
One of the biggest challenges for long-term space missions is radiation exposure, which poses a serious risk to all living cells and threatens the health of astronauts. When radiation penetrates the body, it can damage our DNA (the molecule that carries the genetic information in our cells) by causing lesions that may lead to mutations. These mutations can disrupt normal cell function and, in some cases, trigger cancer, making radiation a serious threat. Therefore, research into the effects of radiation on our DNA is not only important for those venturing beyond our planet's atmosphere, but also has vital implications for medicine and healthcare here on Earth.

The DeepAFQ (Deep learning for Automatic Foci Quantification) project, an international collaboration between researchers from the University of Malta and NASA Ames Research Center, aims to revolutionise how scientists detect and analyse radiation-induced DNA damage. By using artificial intelligence (AI) techniques, the project automates the identification of DNA lesions in cells, making it easier and faster to quantify radiation-induced damage. This is a crucial step in understanding the extent of cellular harm and evaluating protective measures or treatments. But why are astronauts exposed to the risk of radiation damage in the first place?

When we look up at the sky, we don't see them, but Earth's atmosphere and magnetic field protect us from dangerous particles, such as cosmic rays and solar storms. In space, astronauts are exposed to these particles, which can penetrate their cells, alter their DNA, and increase the risk of cancer and other diseases, including cardiovascular problems. Understanding how cells respond to radiation is crucial for developing protective measures for astronauts, whether on the International Space Station (ISS) or on future missions.

DEEPAFQ: AUTOMATING THE ANALYSIS OF DNA DAMAGE

To study radiation damage at the cellular level, scientists rely on specialised imaging techniques to capture irradiated cells – microscopic



images of cells that have been exposed to radiation. These cell images reveal DNA lesions as darker areas where the cell's genetic material has been damaged. These darker areas appear because the DNA in these regions has been altered due to radiation exposure, highlighting the spots where the cell's DNA is most affected. Although identifying and quantifying these lesions is essential, the analysis of those images is still carried out manually, making it both time-consuming and prone to human error. This is where AI comes in.

The DeepAFQ project is developing a state-of-the-art AI algorithm that can automatically identify DNA damage in images of irradiated cells. Its main innovation is automating the identification of DNA damage based on cell images. However, since these darker areas, called foci, can vary in shape, size and intensity, they are difficult to detect with simple image-processing tools. By using machine learning, DeepAFQ can quickly analyse large datasets, providing a more consistent and efficient alternative to manual counting methods. To advance this, postdoctoral researcher Dr Saeed Ullah (Department of Communications and Computer Engineering) uses deep learning models trained on thousands of images with identified foci to detect these patterns with high accuracy. This allows researchers to process and analyse the data much faster than ever before.

According to Prof. Ing. Gianluca Valentino (Department of Communications and Computer Engineering), the project's principal investigator, 'The main challenge of the project has been the availability of ground truth data (the previously existing, manually labelled images) to serve as reference points for training AI models.' To overcome this, the team developed algorithms to generate synthetic datasets that mimic real images of irradiated cells. By training the AI on both real and synthetic data, 'we were able to get very good results; the model is doing a good job,' adds Valentino.

AUTONOMOUS LABORATORIES: THE FUTURE OF DEEP SPACE MISSIONS

One of the long-term applications of DeepAFQ is its potential contribution to the development of self-sufficient research platforms that can operate with minimal human intervention – so-called autonomous laboratories. These systems could be installed on space stations or deep space missions to continuously monitor how biological samples respond to radiation and other environmental factors.

Maltese researchers have already made progress in this area. The space programmes Maleth I, II, and III – led by Prof. Joseph Borg (Department of Applied Biomedical Science) – sent biological samples into space to evaluate the effect of radiation on human tissue, such as by monitoring the growth of bacterial cultures. In future space missions, these biological samples could also be sourced from astronauts themselves, helping to assess the direct impact of radiation exposure during long-term space missions.

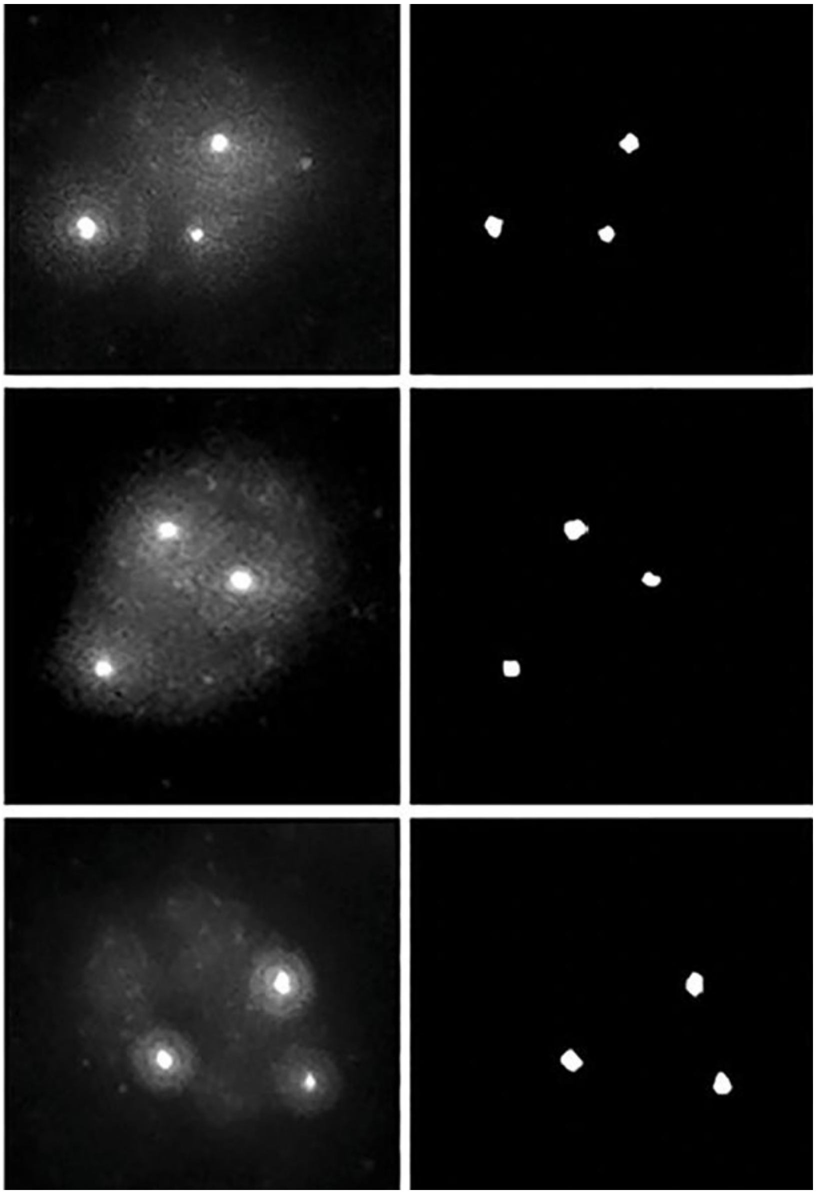
'Autonomous laboratories will have to be present on future missions – especially long-term missions, for instance, to Mars and other planets – as astronauts will be exposed to much higher levels of radiation,' says Valentino. Automating some laboratory analyses would free astronauts from time-consuming manual tasks, allowing them to focus on mission-critical activities. These laboratories could analyse biological samples in real time and send the data back to Earth for further study.

A WIDE RANGE OF COLLABORATIONS AND IMPACTS

The DeepAFQ project forms part of a broader collaboration involving the NASA Ames Research Center. Known for its expertise in life and space biosciences, NASA Ames has played a key role in developing methods to study the effects of radiation on biological systems. DeepAFQ researchers are members of an international, multidisciplinary working group called the Artificial Intelligence and Machine Learning Analysis Working Group (AI-ML AWG), which applies its expertise to addressing problems posed by space exploration.

Beyond space exploration, DeepAFQ has significant implications for medicine. Dr Anu Rasalam Iris (Department of Applied Biomedical Sciences) notes, 'Radiotherapy, a common method of cancer treatment, works by targeting and damaging tumour cells. However, accurate assessment of DNA damage is essential to optimise treatment plans and minimise harm to healthy cells.' Dr Josef Borg (Department of Applied Biomedical Sciences), who is developing the synthetic dataset, adds, 'The whole point of creating such models is to be able to apply them to different datasets.'

Whether the damage is caused by space radiation, medical radiation or other sources, the underlying biological processes remain similar. This means that DeepAFQ has the potential to be used in a range of research and clinical settings, making it a valuable tool beyond the space sector.



Examples of three irradiated cellular nuclei images (left), with their corresponding masks (right) for foci detected by the deep learning model
Images courtesy of the DeepAFQ Team

WHAT'S NEXT FOR DEEPAFQ?

As the project enters its final stage, the team is also trying to extend the applicability of its AI model. By refining its algorithms, DeepAFQ aims to create a flexible tool that can adapt to different research needs. 'The applicability of the tool to other datasets should be a reality. In the future, when we have access to different datasets, I think we will be able to prove that,' says Dr Borg.

'This is very recent, but we are getting interest from local scientists working in radiography and radiology – so-called nuclear medicine,' co-investigator Prof. Borg continues. 'With DeepAFQ, we are one step closer to having the tools available to quantify the DNA damage caused by radiation treatments.'

By creating a link between space science and medical research applications, the project is encouraging new collaborations that could improve healthcare outcomes. In future, the DeepAFQ model could be used in hospitals to help radiologists and oncologists analyse cellular responses to radiotherapy with greater precision.

The future of human space exploration depends on our ability to manage and mitigate health risks – and DeepAFQ provides a critical piece of the puzzle. At the same time, its innovations have the potential to transform radiation medicine, proving that space exploration is not just about venturing into the cosmos – it is also about improving life here on Earth. 'The project is not developing a very exclusive tool. It can be used for everything else!' emphasises Prof. Borg.