Which parts of Mars are the safest from cosmic radiation?

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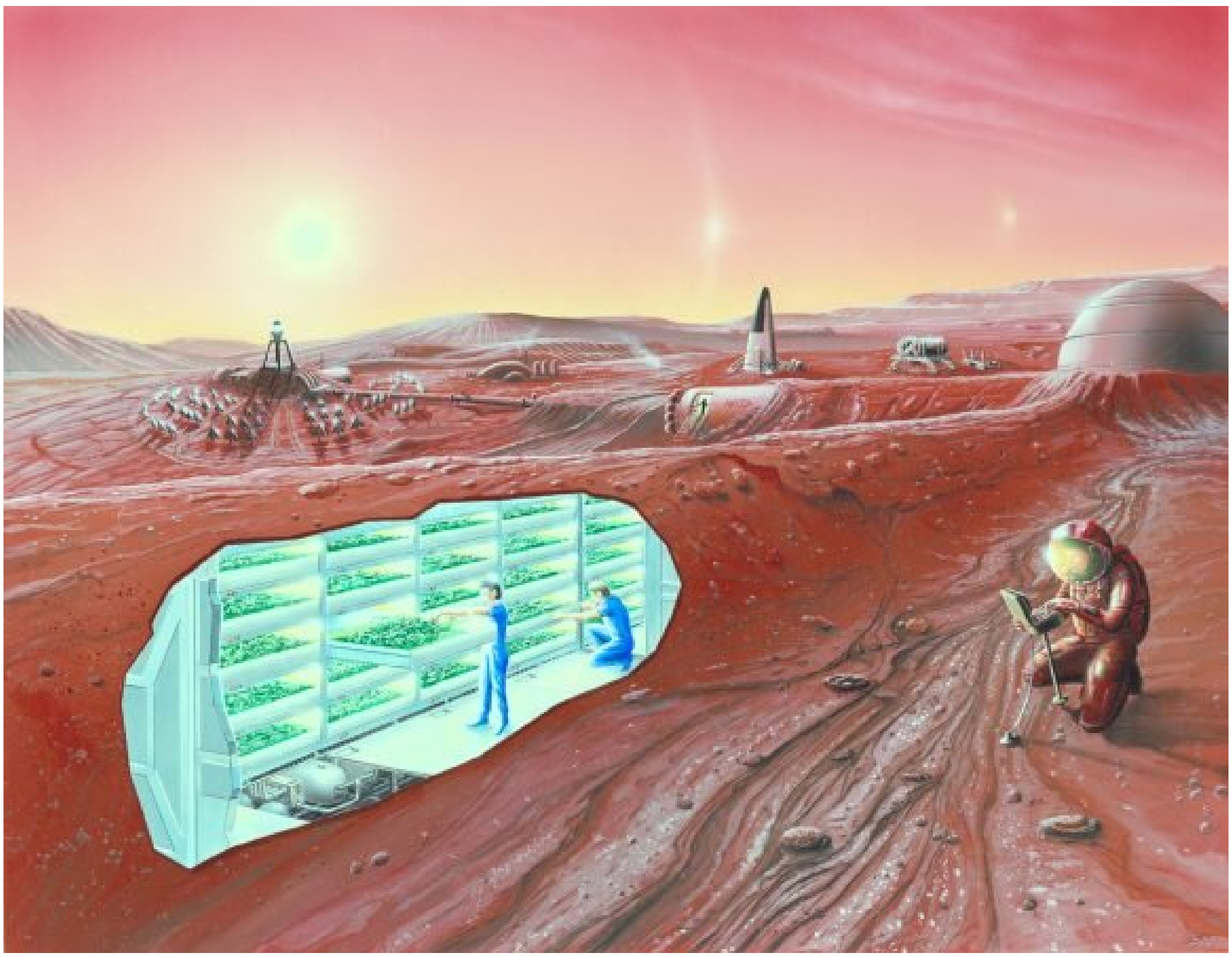

Artist impression of a Mars settlement with cutaway view. Credit: NASA Ames Research Center

In the coming decade, NASA and China plan to send the first crewed missions to Mars. This will consist of both agencies sending spacecraft in 2033, 2035, 2037, and every 26 months after that to coincide with Mars opposition (i.e., when Earth and Mars are closest in their orbits). The long-term aim of these programs is to establish a base on Mars that will serve as a hub that accommodates future missions, though the Chinese have stated that they intend for their base to be a permanent one.

The prospect of sending astronauts on the six- to nine-month journey to Mars presents several challenges, to say nothing of the hazards they'll face while conducting scientific operations on the surface. In a recent study, an international team of scientists conducted a survey of the Martian environment—from the peaks of Mount Olympus to its underground recesses—to find where radiation is the lowest. Their findings could inform future missions to Mars and the creation of Martian habitats.

The team was led by Jian Zhang, an assistant professor from the School of Earth and Space Sciences (ESS) at the University of Science and Technology of China. He was joined by colleagues from the ESS and the CAS Center for Excellence in Comparative Planetology in China, the Institute of Experimental and Applied Physics (IEAP) in Kiel, Germany, and the Russian Academy of Science's (RAS) Institute of BioMedical Problems and the Skobeltsyn Institute of Nuclear Physics (SINP) in Moscow. The paper that describes their findings recently appeared in the *Journal of Geophysical Research: Planets*.

When it comes to missions to Mars and other locations beyond low Earth orbit (LEO), radiation is always a going concern. Compared to Earth, Mars has a tenuous atmosphere (less than 1% of the air pressure), and there is no protective magnetosphere to shield the surface from solar and cosmic radiation. As a result, scientists theorize that harmful particles, particularly galactic cosmic rays (GCRs), could propagate and interact directly with the atmosphere and even reach the subsurface of Mars.

However, the level of radiation exposure depends on just how thick the atmosphere is, which changes due to altitude. Within low-lying areas like Mars' famous canyon system (Valles Marineris) and its largest crater (Hellas Planitia), atmospheric pressure is estimated at over 1.2 and 1.24 kPa, respectively. This is about twice the average of 0.636 kPa and up to 10 times the atmospheric pressure at high-elevation locations like Olympus Mons (the largest mountain in the solar system).

Dr. Jingnan Guo, an esteemed professor with the IEAP at Christian-Albrechts-University and a member of the Chinese Academy of Sciences (CAS), was Prof. Jian Zhang's Ph.D. supervisor and a co-author on the paper. As she explained to Universe Today via email:

"Different elevation means different atmospheric thickness. High-altitude places generally have a thinner atmosphere on top. High energetic particle radiation needs to traverse through the atmosphere to reach the surface of Mars. If the atmospheric thickness changes, the surface radiation may also change. Thus elevation could influence the surface radiation of Mars."

To this end, the team considered the influence of atmospheric depths on Martian radiation levels. This included the absorbed dose measured in rads; the dose equivalent, measured in rems and sieverts (Sv); and the body effective dose rates induced by GCRs. This consisted of modeling the radiation environment using a state-of-the-art simulator based on the GEometry And Tracking (GEANT4) software developed by CERN.

Known as Atmospheric Radiation Interaction Simulator (AtRIS), this software employs Monte Carlo probability algorithms to simulate particle interactions with the Martian atmosphere and terrain. As Dr. Guo illustrated:

"We use a Monte Carlo approach called 'GEANT4' to model the transport and interaction of energetic particles with the Martian atmosphere and regolith. The Mars environment is set up considering the Mars atmospheric composition and structure and regolith properties.

"The input particle spectra on top of the Mars' atmosphere are obtained also from data-calibrated models which describe the omnipresent particle radiation environment in the interplanetary space that includes charged particles of different species which are mainly protons(~87%), helium ions(12%) and also small traces of heavier ions such as carbon, oxygen and irons."

They found that higher surface pressures can effectively reduce the amount of heavy-ion radiation (GCRs) but that additional shielding is still needed. Unfortunately, the presence of this shielding can lead to "cosmic ray showers," where the impact of GCRs against shielding creates secondary particles that can flood a habitat's interior with varying levels of neutron radiation (aka. neutron flux). These can contribute significantly to the effective dose of radiation astronauts will absorb.

They determined that both the neutron flux and effective dose peak at around 30 cm (1 foot) below the surface. Luckily, these findings offer solutions as far as using Martian regolith for shielding is concerned. Said Dr. Guo:

"For a given threshold of the annual biologically-weighted radiation effective dose, e.g., 100 mSv (a quantity often considered as the threshold below which radiation-induced cancer risk is negligible), the required regolith depth ranges between about 1 m and 1.6 m. Within this range, at a deep crater where the surface pressure is higher, the needed extra regolith shielding is slightly smaller. While on top of Mount Olympus, the needed extra regolith shielding is higher."

Based on their findings, the best sites for future habitats on Mars would be located in low-lying areas and at depths of 1 m and 1.6 m (3.28 to 5.25 ft) beneath the surface. Therefore, the Northern Lowlands, which make up most of the northern hemisphere (aka. Vastitas Borealis), and Valles Marineris would be very suitable locations. In addition to having thicker atmospheric pressure, these regions also have abundant water ice just beneath the surface.

If all goes according to plan, astronauts will be setting foot on the Martian surface in just over a decade. This will consist of transits lasting six to nine months (barring the development of more advanced propulsion technology) and surface operations of up to 18 months. In short, astronauts will have to contend with the threat of elevated radiation for up to three years. As such, detailed mitigation strategies need to be developed well in advance.

NASA and other space agencies have invested considerable time, energy, and resources to develop habitat designs that leverage 3D printing, In-Situ Resource Utilization (ISRU), and even electromagnetic shielding to ensure astronaut health and safety. However, there are still unanswered questions about how effective these strategies will be in practice, especially when considering the amount of time crews will be spending on the Martian surface.

"Our study may serve for mitigating radiation risks when designing future Martian habitats using natural surface material as shielding protection," said Dr. Guo. "Research like this will therefore be of considerable value when mission planners begin considering designs for future Martian habitats that rely on natural surface material to provide radiation protection."

More information: Jian Zhang et al, From the Top of Martian Olympus to Deep Craters and Beneath: Mars Radiation Environment

Under Different Atmospheric and Regolith Depths, *Journal of Geophysical Research: Planets* (2022). DOI: 10.1029/2021JE007157

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