Biological Research and Space Health Enabled by Machine Learning to Support Deep Space Missions

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A key science goal of the NASA "Moon to Mars" campaign is to understand how biology responds to the Lunar, Martian, and deep space environments in order to advance fundamental knowledge and support human space missions. Through artificial intelligence (AI) and machine learning (ML), a paradigm shift has begun in space biosciences and engineered astronaut health systems, to enable Earth-independence and mission operations autonomy. We describe current AI/ML methods to support 1) fundamental biology, 2) *in situ* analytics, 3) high performance computing, 4) automated science, 5) self-driving labs, 6) remote data management, 7) integrated mission biomonitoring, and 8) a Precision Space Health system. AI/ML approaches that can be integrated to support these domains include active learning, explainable AI, adaptive learning, causal inference, knowledge graphs, federated learning, transfer learning, and large language models. Finally, we present results from several current ML projects that are underway in the space biology field to address key challenges of small sample n, high feature count, heterogeneity, and sparse data. These include 1) connecting omics to phenotypic data using an ensemble model to infer causality of rodent liver health disruption, 2) usage of explainable ML to interrogate muscular underpinnings of muscle atrophy, 3) ML models analyzing and determining directed acyclic graphs of human health risk leveraging rodent bone datasets, 4) usage of large pre-trained models connecting biomedical knowledgebases with small spaceflight datasets to understand gene-to-gene interactions, and 5) a suite of benchmarked open science datasets enabling programmers to identify best algorithms to answer space biology questions.