NASA HAUGHTON-MARS PROJECT (HMP), DEVON ISLAND, HIGH ARCTIC: LESSONS FOR MARS SCIENCE AND FUTURE HUMAN EXPLORATION OPERATIONS ON THE MOON AND MARS.

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Summary: Many lessons for Mars science and Moon/Mars exploration have been learned from 24 years of field research and operations at the NASA Haughton-Mars Project (HMP), Devon Island, Arctic.

Introduction: Devon Island in the High Arctic is the world's largest uninhabited island and the single largest continuous expanse of rocky polar desert. It is home to Haughton crater, a 23 Ma-old (Miocene), 20 km-diameter meteorite impact structure. Since 1997, Devon Island has been home to the NASA Haughton-Mars Project (HMP), an international field research project centered on science and exploration studies at Haughton crater and surrounding terrain across Devon Island. The HMP is supported by NASA and by the project's research partners among academia, non-profits, and industry. The HMP was also supported by the Canadian Space Agency (CSA) as part of its Canadian Analogue Research Network (CARN) for the duration of that program (2006-2011). HMP field deployments to Devon Island take place in Jul-Aug every year (COVID-permitting).

Mars Science. Important lessons for Mars science have been learned from the HMP, notably:

Early Mars Climate Was Cold. Only Its Ground Was Warm, Transiently and Locally. Based on field studies of *denudation* rates at Haughton Crater and of subglacial and ice-marginal meltwater channel networks across Devon Island, Lee et al. [1-12] showed that denudation rates on Early Mars must have been far lower than previously estimated, and that small valley networks on Mars likely formed not by rain followed by surface runoff under a warm climate (the classical interpretation which leads to the Faint Early Sun Paradox), but by subglacial meltwater flow under a cold climate and thin atmosphere. Transient ice covers would have occurred frequently on Early Mars, and the ground would have induced basal melting as it was warmer then due to impacts being more frequent, volcanism more active, Mars' geothermal gradient steeper, and thus the water cycle more dynamic. Early Mars' atmosphere and climate were likely like those prevailing at present: thin and frigid, thus resolving the Faint Early Sun Paradox.

Glaciations on Early Mars extended into Hesperian. Field studies at HMP also show that glacial trough valleys on Devon Island are unique morphologic, and probably genetic analogs for the late Noachian to Hesperian tributary canyons of Ius Chasma, bordering Sinai Planum, Mars [4,11,12]. A glaciation history for the region is consistent with episodic glaciations in Tharsis.

Moon/Mars Exploration.

Robotic Exploration. A range of autonomous systems and HMIs for Moon/Mars exploration have been tested at HMP: rovers, helicopters, airplanes, robotic arms, drills, astronaut smart glove [e.g., 5,6,12,13,14].

Human Exploration. HMP general field logistics and operations, and specific field tests, have resulted in a number of technological design advancements and the development of new concepts of operations for future human exploration of the Moon and Mars, particularly wrt EVA systems, pressurized and unpressurized mobility concepts, human exploration instruments and tools, communications and other information technologies, habitat design, and human factors. **Fig.1** provides an HMP field-developed concept of operations now proposed for the human exploration of the Moon *and* Mars.

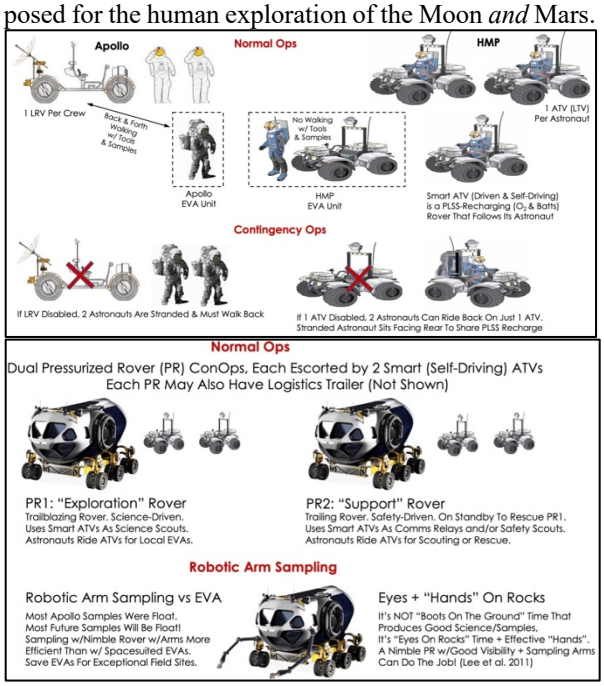

Figure: Top: Short-range (<2 km) & **Bottom:** long-range (>2 km to 100+ km) surface mobility con-ops.

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