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SAMPLE RETURN MISSIONS TO HYGIEA: A STRATEGIC RESOURCE HUB FOR DEEP SPACE EXPLORATION AND HUMAN PRESENCE BEYOND EARTH

Abstract

Hygiea, the fourth-largest asteroid in the asteroid belt, represents an exceptional opportunity for both scientific exploration and the future of deep space missions. With an estimated diameter of 430 kilometers, Hygiea is thought to contain a wealth of carbonaceous materials, water ice, silicate minerals, and metals such as iron, nickel, and platinum group metals. These resources could play a critical role in supporting sustainable in-situ resource utilization (ISRU), powering future missions, and enabling human exploration beyond the asteroid belt.

The carbonaceous materials on Hygiea are likely to include organic molecules like ammonia, carbonates, and complex carbon compounds, which are important for astrobiological studies and life support systems. Its silicate composition may include olivine, pyroxenes, and feldspar, materials useful for construction and manufacturing technologies. The presence of water ice could be vital for producing water, oxygen, and fuel, laying the foundation for deep space travel and interplanetary missions.

This paper explores the concept of a sample return mission to Hygiea, focusing on its potential to provide valuable data on the composition, evolution, and early formation of planetary bodies in the asteroid belt. In addition to its resource potential, Hygiea offers unique scientific insights into the early solar system, serving as a valuable target for studying planetary formation and the role of volatiles in the development of celestial bodies.

To harness Hygiea's potential, specialized landing and drilling mechanisms have been proposed due to its low gravity and nearly spherical shape. The lack of an atmosphere presents unique challenges for surface exploration, but technologies like robotic landers equipped with advanced drilling systems capable of penetrating the asteroid's loose regolith are essential. Autonomous navigation systems would also allow landers to adjust in real-time to environmental conditions, ensuring successful deployment and operation. These innovations will enable future missions to harness Hygiea's rich resources while advancing space exploration technologies.

As a potential site for a space station or refueling hub, Hygiea's carbon-rich and metal-rich composition could support a sustainable human presence in deep space, providing a strategic resource base for long-duration space missions and the expansion of humanity's reach beyond the asteroid belt. The study of Hygiea also aligns with current goals in space exploration and resource management, potentially accelerating our ability to establish a permanent human presence off-Earth.