Lunar PAGES: Lunar Probes of the Ancient Galaxy, Sun and Earth. P. Saxena[1] and H. V. Graham[1], N.M.H.B. Curran[1,2], NASA Goddard[1], CRESST II/Catholic University[2] (prabal.saxena@nasa.gov).

Introduction: Lunar exploration in the next decade promises exciting reconnaissance of the lunar surface through international efforts such as the NASA-led Artemis program. In addition to establishing a sustainable human presence on the Moon, such efforts will enable the most persistent and in depth collection and analysis of lunar samples in a generation. This generational opportunity aligns with new and recent research in areas that suggest the Moon may hold key answers to questions in exciting topics related to the nature of the Ancient Galaxy, Sun and Earth. We discuss some of that recent research and potential that upcoming lunar exploration has in providing invaluable evidence on those topics. We discuss potential near term means of leveraging exploration to interrogate the record of the solar system the Moon holds.

Recent Advances in Understanding of the Ancient Sun, Earth and Galaxy: Recent research into the evolution of the Sun and Earth and the changing impact of our solar systems' galactic position has yielded both key insights into potential pathways of how they all evolved and also important questions that may have significant ramifications for both the past features and habitability of solar system bodies.

In the Sun's case, recent research that has leveraged observations of solar analogues of different ages has suggested the Sun has not been constant over time, but instead has likely experienced significant variation in UV, EUV, and X-ray flux [1, 2] as well as in magnetic activity driven phenomena such as the solar wind, coronal mass ejections and heliosphere morphology [3,4] during critical periods in the nascent solar systems' history. Constraining evolution of the Sun and these properties over time is key to understanding how it may have shaped the Earth and other planets [5-7].

Recent research on the state of the Early Earth's atmosphere, during periods that include when life is hypothesized to have first appeared, has also produced new and novel understanding of how the Early Earth may have evolved. A combination of new geological proxies and modeling has produced insight into atmospheres of the Hadean and Archean and water abundance on Earth over time [16], and how there may have been periods in the Early Earth's history that favored life despite having properties substantially different from the Earth's extant atmosphere [8-10]. Finally, variability in the interstellar boundary and heliosphere morphology over time has been examined recently, with the suggestion that such changes may influence the flux and Spectral Energy Distributions of Galactic Cosmic Rays (GCRs) on the Earth-Moon system over time [11-12].

The Moon as a Witness Plate: All of these changes may have left indelible records on the Moon that are awaiting discovery. While the influence of solar and galactic related variations may be intuitively understood, the Moon was also significantly closer to the Earth in these earlier periods in solar system history [13]. This may have facilitated the transfer of material from the Earth to the Moon in greater numbers than is expected today. This has been initially explored [14] with respect to the potential transfer of terrestrial meteorites to the Moon and should be updated with new understanding and advances in the frequency and ability of potential impacts on the Earth to produce such transfer. Recent research [15] has also shown that direct transfer of atmospheric constituents, such as biogenic oxygen, is also a plausible transfer mechanism to the lunar surface from Earth, with the implication being that such a process may have occurred in an enhanced manner during earlier periods. These are not necessarily the only two ways that the Moon may record early processes from the Earth, but all of these potential record pathways should be explored in greater detail to guide future science goals during exploration efforts. We will discuss potential pathways towards exploring what type of records may exist and the processes that may have produced them, including an overview of suggestions by recent and earlier research. Finally, we will discuss open questions the community may already have sufficient samples to answer or may be able to target diagnostic samples for in the future.

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