Solar Activity Signatures in Lunar Samples: Exploring Past Space Weather Using Multiple Lines of Evidence. P. Saxena1,2, N. Curran2,3, R. Killen2 and V. Airapetian2,4, 1UMD-CP/CRESST II (prabal.saxena@nasa.gov), 2NASA GSFC, 3USRA, 4Catholic University of America

Abstract: The Moon provides a remarkably well-preserved record of past solar system processes and events. This is particularly true for the Sun, as the Moon can provide insight to the evolution of solar activity over time. Constraining the history of solar activity is incredibly important to understanding the evolution of terrestrial planets in the solar system due to space weather’s ability to modify the atmospheres, surfaces and habitability of these worlds. We will discuss some of the ways in which lunar samples may contain signatures of past space weather and how these signatures may be extracted to put constraints on the evolution of solar activity.

Introduction: Recent research [1] suggests that the Moon experienced a violent space weather environment in the first billion years of the Solar Systems’ history, when the Sun was rotating faster and consequently, more active. Additionally, moderate volatile abundances on the Moon’s surface suggest that the sun was a slow rotator star based upon the relative loss of elements from the lunar surface. However, a considerable uncertainty in the level of space weather activity remains, with a range of plausible rotation states of the Sun that lead to an uncertainty in the frequency of powerful coronal mass ejections which ranges over an order of magnitude. Constraining this space weather activity is critical given its’ ability to impact the atmospheres and surfaces of all the planets in the inner solar system. Due to the relatively well-preserved surface environment of the Moon over time and the ability to access samples from the lunar crust, this evolution of the Sun’s activity may also be recorded in lunar regolith and would be an important well-preserved and relatively accessible record of past Solar System processes.

This is especially important since Earth, Mars and Venus’ atmospheres may all have been shaped by solar activity and because there remain open questions not only regarding the space weather environment early in the solar system’s history, but also during much more recent times (see [2][3] for the dramatically different frequency predictions for Earth-incident extreme CMEs in the recent past). Given the impending analysis of newly opened Apollo samples and plans to return to the Moon with the prospect of additional samples, it is important to understand how exactly to leverage the information from these samples to probe these questions.

Potential Signatures of Solar Activity in Lunar Samples: Constraining this past space weather environment using samples requires an understanding of the different lines of evidence and proxies that may exist in samples due to the repeated interaction with past space weather. These lines of evidence and proxies include net deposition of exogenous elements and depletion of endogenous elements, fractionation of endogenous elements on the lunar surface and the potential for fission tracks in samples due to solar energetic particles. All of these signatures are potentially extractable from samples, and have been explored in the past for many samples, but will require new modeling that would enable an accurate interpretation of what these signatures may imply about past space weather environments. This is particularly true given the growing understanding that Sun-like stars appear to have had considerably different early stellar activity frequencies and intensities. We will discuss how such models may be constructed in ways which trace potential sample signatures, and consequently how they may be leveraged in future sample analysis efforts.

Finally, we will also discuss initial work trying to examine evidence from chemical abundances from lunar samples which can provide additional understanding into the current frequency of Earth-incident extreme CMEs. There is debate regarding the current frequency of extremely energetic CME events that impact the earth (see [2][3]), which has important implications for planning for the potential human impacts. Past research has attempted to look for recent records of averaged SEP activity in lunar samples, but signatures of the frequency of particularly energetic events may be constrainable through abundance measurements and fission track analysis. These lines of evidence in lunar samples may be immune to the same level of degenerate alternate mechanisms that complicate analysis of certain Earth-based signatures of the frequency of recent extremely energetic CMEs (see [4]).

References: