Realtime Monitoring of Ionizing Radiation on the Lunar Surface in the Worsening Space Environment. F. Rahmanifard[1], N. A. Schwadron[1], J. K. Wilson[1], A. P. Jordan[1], H. E. Spence[1], W. C. de Wet[1], [1]University of New Hampshire (Morse Hall 245, 8 College Road, Durham, NH 03824, USA, F.Rahmanifard@unh.edu)

Abstract: The trend of weakening peak sunspot number associated with the solar maxima has persisted over the last 60 years. More importantly, the proloned solar minimum of cycle 23, the mini solar maximum of cycle 24, followed by the current phase of solar minimum, which has already been deeper and longer than previous predictions indicate that we could be moving into another secular (grand) minimum scenario.

The declining solar activity has caused a 20% increase in the dose rates on the lunar surface from one solar minimum to the next since mid-1990s [1]. As a result, a permanent presence in deep space including the lunar surface will expose astronauts and equipment to a different radiation dose environment than previously experienced. Here we report on observations from CRaTER (the Cosmic Radiation Telescope for the Effects of Radiation) on Lunar Reconnaissance Orbiter (LRO). We used the evolution of the interplanetary magnetic field from [2] to project dose rates from galactic cosmic rays on the lunar and show that the radiation environment is worsening even more rapidly than previously estimated [1, 3, and 4] .

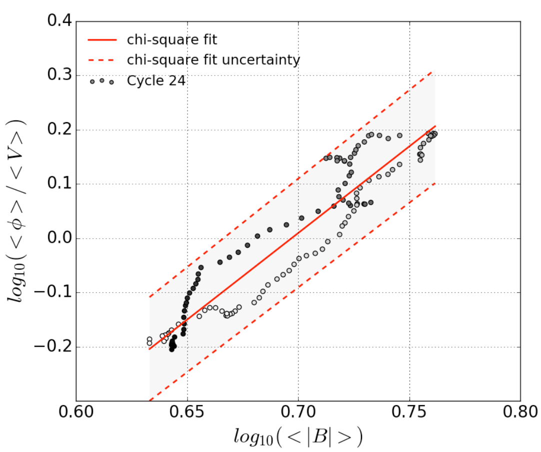

Figure 1. *We have used the modulation potential from CRaTER measurements to show the correlation between the modulation potential and the HMF strength. This correlation reveals trends very similar to the past solar grand minima conditions.*

Re-examining the correlation between the interplanetary magnetic field and the modulation of the GCRs found by[1], with a recent reconstruction of the interplanetary magnetic field from [2] and modulation potential data from CRaTER [5], not only shows that correlation persists but also reveals trends very similar to the past solar grand minima conditions [6]. Therefore, we consider and the Dalton minimum (1790-1830) and the Gleissberg minimum (1890-1920) as possible scenarios to predict the dose rates of galactic cosmic rays throughout the next solar cycle [4]. We use these results to predict the most conservative permissible mission durations based on 3% risk of exposure-induced death (REID) at 95% confidence level on the lunar surface.

Despite the persistent paucity of solar activity, the solar energetic particle event of September 2017 was extremely hard with the largest dose rates in D3/D4 (the most shielded detectors of CRaTER). It occurred as the result of successive fast coronal mass ejections. The occurrence of the September 2017 event after more than a year of very few solar particle events shows that besides the high galactic cosmic radiation, discrete solar energetic particle events remain a significant hazard [3].

We suggest that in order to create a sustained human presence on the lunar surface instruments such as CRaTER or DoSEN (Dose Spectra from Energetic Particles and Neutrons) would be essential to provide realtime knowledge of ionizing radiation. CRaTER is a successful radiation detector, and DoSEN, which is a natural extension of CRaTER are ready to be utilized in new missions such as Artemis. CRaTER (and DoSEN) measure the energy of energetic particles that affect human (and robotic) health. They provide a direct measurement of the Lineal Energy Transfer (LET) spectra behind shielding material. For LET measurements, they contain stacks of thin-thick Si detectors. With the help of risk models such as [5] dose rate data from these instruments can be translated to permissible mission durations for astronauts on the lunar surface.

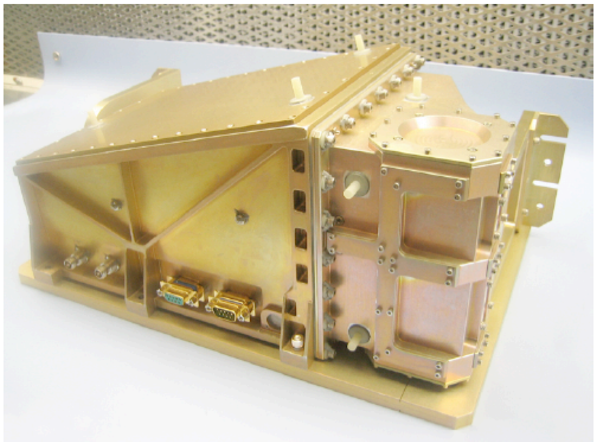

Figure 2. *A photograph of the CRaTER instrument.*

References: [1] Schwadron, N. A. et al. (2014) *Space Weather*, *11,* doi:10.1002/2014SW001084. [2] Rahmanifard F. (2017) *APJ,* 837, 2, doi:10.3847/1538-4357/aa6191. [3] Schwadron, N. A., (2018) *Space Weather,* 16, doi:10.1002/2017SW001803 [4] Rahmanifard F. (2020) *Space Weather,* Under revision [5] de Wet W. (2020), Life Sciences in Space Research, Under revision [6] Rahmanifard F. (2020), In Work.