UNLOCKING THE MYSTERIES OF THE MOON'S SHADOWED REGIONS

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Abstract: The Moon poles host large quantities of water-ice deposits in the permanently shadowed regions (PSRs), which are vital for enabling sustainable human space exploration, making these regions high-priority targets for upcoming Artemis missions [1]. Unfortunately, today, the best available orbital lunar imagery [2, 3] lacks the meter-scale resolution and signal needed to understand the geomorphology and trafficability of PSRs, complicating the planning and execution of future missions seeking to explore PSRs.

We have developed an image enhancement tool called HORUS (Hyper-effective nOise Removal Unet Software) [4, 5], designed to enhance LRO Narrow-Angle Camera (NAC) optical low-light imagery of permanently shadowed regions by effectively removing the CCD-related, photon, and other residual noises that corrupt the images. The tool is composed of two deep learning neural networks trained on environmental metadata and real and synthetic imagery, the latter generated by a physical noise model (LROC). We demonstrated that HORUS effectively produces low-noise, high-resolution images (~1.5m/px), achieving a 5 to 10x improvement over existing long-exposure images of PSRs. HORUS allows scientists and engineers to identify geomorphic features (e.g., craters and boulders) in shadowed regions as small as 3 meters across as well as to peek inside of small shadowed regions, for the first time.

The tool was deployed and thoroughly validated for NASA's VIPER mission [6], where it was applied to 20 candidate target regions across the lunar South Pole. Additionally, we conducted different approaches to validate the resulting HORUS-processed images.

With HORUS denoised images, VIPER scientists can increase their confidence on what surface features (previously unseen) exist in the shadowed regions, helping them plan rover traverses more safely and efficiently (e.g., Fig. 1)

In this manuscript, we will describe how VIPER scientists are utilizing HORUS denoised images to extract new information from the terrain and increase their confidence in what surface features exist in the shadowed regions. In combination with other high-resolution images and digital elevation maps, HORUS images are helping the team analyze potential lading and science sites, as well as planning traverses more safely and efficiently (e.g., Fig. 1).

Additionally, we will describe how HORUS tool unlocks a broad range of scientific and exploration applications to other Artemis and CPLS missions to the lunar poles, including (but not limited to) geomorphic analysis, change detection, surface hazard detection, and terrain relative navigation.

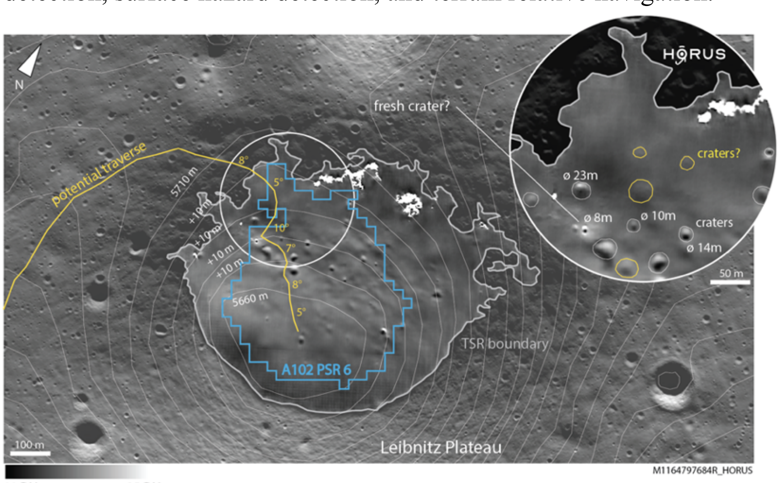

Fig. 1: HORUS image of a potential Artemis candidate PSR on the Leibnitz plateau, embedded into a regular NAC (Narrow Angle Camera) image. Topography is indicated with white contour lines; the extent of the PSR is indicated in blue; the boundary of the NAC-observed TSR (transiently shadowed region) is indicated in gray; a potential access traverse is shown in yellow [5]. Raw image credits: NASA /ASU.

References: [1] NASA (2020). Artemis Plan. NASA's Lunar Exploration Program Overview. NP-2020-05-2853-HQ. [2] Robinson et al. (2010) *Space Sci Rev*. [3] KAGUYA Project Site http://www.kaguya.jaxa.jp/ [4] Moseley et al. (2021) *IEEE CVPR*. [5] Bickel et al. (2021) *Nature Comms.* [6] Colaprete et al. (2021) 52nd *LPSC*.