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Deep learning map of fresh crater ejecta on Mercury: a resource for space weathering studies

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Space weathering (SpWe), the physical and chemical alteration of planetary surfaces due to exposure to the space environment, and namely to micrometeorite impacts and solar wind particles, is the primary process that continues nowadays to modify the surface of Mercury. The effects of SpWe include the amorphization of regolith grains, the chemical reduction of the surface leading namely to the transformation of ferrous oxide (FeO) into nanophase particles of elemental iron, and the darkening and reddening of the surface's visible and near-infrared reflectance spectrum (Domingue et al. 2014).

These effects have however been ascertained primarily through the study of lunar samples and it is unclear to what degree they can be generalized to Mercury. The planet's proximity to the Sun suggests that SpWe should be more intense, an assumption borne out by the absence of the FeO 1 μm absorption band, which implies that most FeO has already been converted to nanophase iron (Izenberg et al. 2014). If that were so, however, SpWe should have reached saturation across the planet (Leon-Dasi et al. 2025). This is clearly not the case, as demonstrated by the prominent presence of high-albedo terrains with a low degree of weathering, mostly associated with recent impact craters and their ejecta. Furthermore, intense SpWe is supposed to deplete volatile elements in the planetary surface, but these have been observed to persist on Mercury (Weider et al. 2012). Mercury's magnetic field, finally, might influence SpWe by regulating the solar wind particle flux to the surface (Lavorenti et al. 2023). However, no correspondence has so far been found between the expected particle fluxes and the surface's spectral properties.

In order to investigate these questions, we have focused on the ejecta of recent impact craters. Distinguished by their higher albedo, these are the most widespread surfaces where SpWe can be confidently said not to have reached saturation. A comparison between their spectra and those of more weathered terrains could thus provide information on the effect of SpWe and make it possible to develop a reliable quantitative SpWe spectral indicator. Furthermore, comparing ejecta spectra from the same crater, which have the same age, but in different locations could reveal SpWe spatial patterns across Mercury. Finally, comparing ejecta spectra from different craters could provide information on the age of said craters.

Unfortunately, crater ejecta on Mercury have not so far been systematically mapped. Mercury quadrangle maps (Galluzzi et al. 2016) contain a partial map, but they are not yet complete and crater ejecta have been mapped unevenly across them. We have thus created a more complete map through deep learning. We trained a convolutional neural network model for semantic segmentation on multi-band images of Mercury's surface produced by the MDIS/WAC instrument of the MESSENGER mission, having classified the crater ejecta in these images either manually or by using the quadrangle maps. We then used this neural network to produce a planet-wide map of crater ejecta. We then built a second deep learning tool that assigned the ejecta to their progenitor crater, on the basis of the ejecta shape and orientation.

We present the resulting ejecta map, a valuable resource for SpWe studies. It will now be possible to systematically retrieve the spectra of ejecta measured by the MESSENGER MASCS/VIRS hyperspectral instrument. The ejecta map could also prove useful to reconstruct the dynamics of the progenitor impacts and perhaps even the characteristics of the impactors. The deep learning tools we have developed could furthermore help map crater ejecta on the Moon or on other bodies.

References

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