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Imaging the Subsurface with Upgoing Muons

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We assess the feasibility of imaging the subsurface using upgoing muons. Traditional muon imaging focuses on more-prevalent downgoing muons. Muons are subatomic particles capable of penetrating the earth's crust several kilometers. Downgoing muons have been used to image the Pyramid of Khafre of Giza, various volcanoes, and smaller targets like cargo. Unfortunately, utilizing downgoing muons requires below-target detectors. For aboveground objects like a volcano, the detector is placed at the volcano's base and the top portion of the volcano is imaged. For underground targets like tunnels, the detector would have to be placed below the tunnel in a deeper tunnel or adjacent borehole, which can be costly and impractical for some locations. Additionally, detecting and characterizing subsurface features like voids from tunnels can be difficult. Typical characterization methods like sonar, seismic, and ground penetrating radar have shown mixed success. Voids have a marked density contrast with surrounding materials, so using methods sensitive to density variations would be ideal. High-energy cosmic ray muons are more sensitive to density variation than other phenomena, including gravity. Their absorption rate depends on the density of the materials through which they pass. Measurements of muon flux rate at differing directions provide density variations of the materials between the muon source (cosmic rays and neutrino interactions) and detector, much like a CAT scan. Currently, tomography using downgoing muons can resolve features to the sub-meter scale. We present results of exploratory work, which demonstrates that upgoing muon fluxes appear sufficient to achieve target detection within a few months.

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