

## DEEP LEARNING OBJECT DETECTION FOR MAPPING CAVE CANDIDATES ON MARS: BUILDING UP THE MARS GLOBAL CAVE CANDIDATE CATALOG (MGC<sup>3</sup>).

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**Introduction:** The Mars Global Cave Candidate Catalog (MGC<sup>3</sup>) v1, published by Cushing et al. [1] in 2017 contains the locations and a short description of more than 1000 possible cave-entrances on Mars that have been identified by manually surveying images acquired by Mars Odyssey's (MO) Thermal Emission Imaging System (THEMIS) and Mars Reconnaissance Orbiter's (MRO) Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) cameras. Authors analysed all images that covers the area north of Arsia Mons (235° to 243° E, 28° to 2° N). The Arsia Mons is a shield volcano, located in the southern area of the large Tharsis Region, on whose flanks have been identified at least 7 possible cave entrances in a previous work [2] and thus selected by the authors for creating the MGC<sup>3</sup>. Since cavities are among the most interesting and valuable targets for space exploration [3][4], extending the investigated area to the whole planet could advance the state of the art and provide potential targets for future mission. Since the datasets involved are very large, with approx. products of 115,897 for CTX and 1,775,440 for HiRISE [5] a manual approach is not feasible. In this respect, computer-assisted techniques that rely mainly on Machine Learning and Deep Learning algorithms are extremely valuable, providing robust, standardized and highly customizable pipelines and tools for analysing automatically large datasets. Deep Learning Object Detection algorithms such [6] were used in this study, with proper training, can detect virtually all pit and cave entrance occurrences.

**Data and Methods:** Data used consists of CTX and HiRISE imagery, accessed from the PDS Geosciences Node Mars Orbital Data Explorer portal and divided into train and test datasets.

**Training:** For training the Deep Learning Object Detection algorithm, have been used 130 HiRISE red channel images. These images have been divided into training, test, and validation sub-datasets, then the training and testing images have been scaled to approx. 1/3 of the original resolution and then tiled into 900x900 pixels image with black border removed. Then all images have been randomly flipped, rotated, and mirrored to increase the training dataset. Object labels have been created in all resulting images. The labels have been created ex-novo, according to literature description of features and feature's characteristics

clearly visible in the used images Table 1. The model has been trained for approx. 24h.

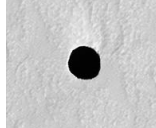
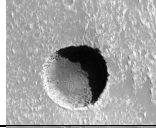
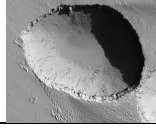
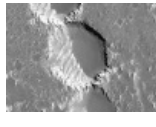

Image	ID	Description
	1	Type 1 – Skylight with possible cave entrance, flat rim, no ejecta blankets, almost perfect circular shape and no visible bottom. Best candidate
	2	Type 2 – Pit crater with possible relation to lava tube, flat rim, no ejecta blankets, almost circular shape and visible bottom.
	3	Type 3 – Depression with flat rim, no ejecta blankets, elongated shape and visible bottom. Possible connection to lava tubes.
	4	Type 4 – Depressions with flat rim, no ejecta blankets, shallow to very shallow depth. Circular to elongated shapes and usually aligned with other similar shapes. May be related to lava tube collapse [4], secondary impacts or geomorphological evolution of other types due to other processes such wind erosion.
	5	Type 5 - Impact crater with always visible non-flat rim. Often visible ejecta blankets or remnants.

Table 1 – Classes used for label training dataset.

**Testing:** validating images, have been used to check the quality of the training sessions.

**Tools:** All the above processing have been made using open-source tool developed in python [7][8]. YOLOv5 algorithm has been modified and integrated into Python scripts and notebooks.

**Results:** Trained model has been used to inference 900 HiRISE images and 50 CTX images mainly of Tharsis region. Detection have been georeferenced, and a shapefile has been created. In figure 1 is shown an example of HiRISE image (with bounding boxes of detected objects. For each box is shown the ID of the

detection and a confidence score (0 to 1). In figure 2 is shown a comparison between MGC<sup>3</sup> and results of the inference in the Tharsis region. Even if the dataset used for the test is not the same of the one used for MGC<sup>3</sup>, there is a high correspondence between MGC<sup>3</sup> and obtained results as shown in Figure 2 and Figure 3.

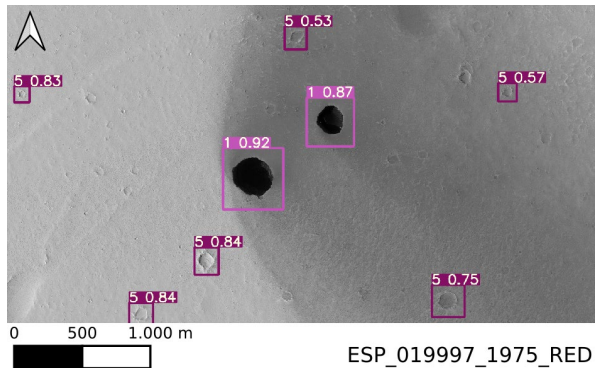


Figure 1 - Example of detections obtained on HiRISE images. For each detection, the first number represent the type and the second represent the confidence level.

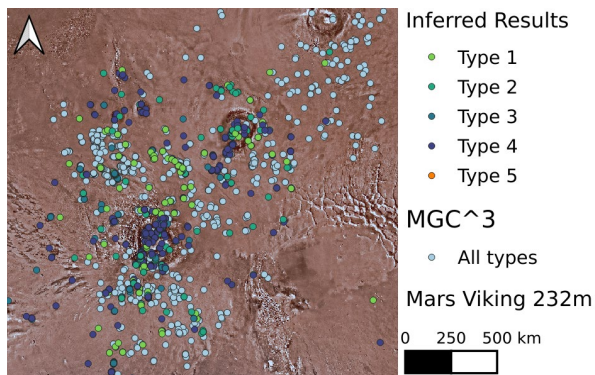


Figure 2 - Comparison between MGC<sup>3</sup> and obtained results over Tharsis Region.

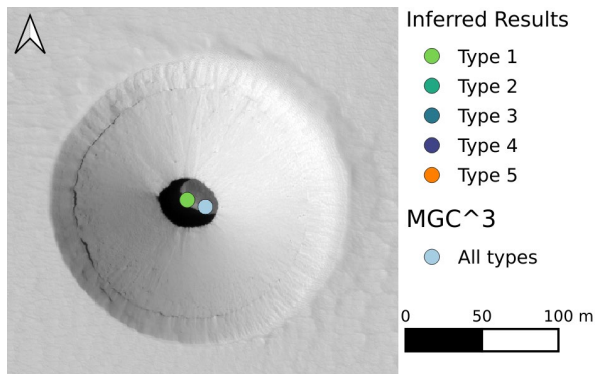


Figure 3 - Detail of comparison between MGC<sup>3</sup> and obtained results on HiRISE ESP\_023523\_3840\_RED.

The most promising results are potential new detections not present in the MGC<sup>3</sup>, that still needs to be manually validated (Figure 4).

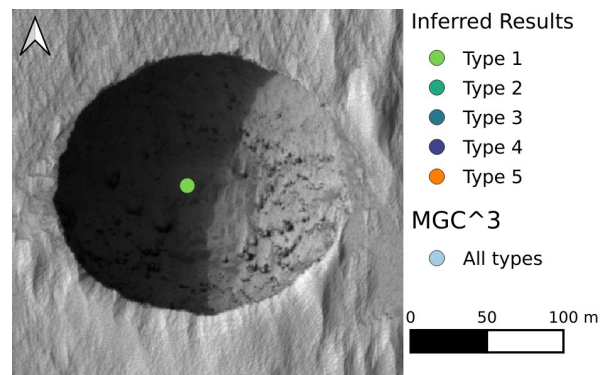


Figure 4 - Example of possible new cave candidate on HiRISE ESP\_028793\_1655\_RED.

**Conclusions:** Preliminary results obtained using a Deep Learning object detection algorithm provided promising results, since there are: a high correspondence with the MGC<sup>3</sup> candidates, new detections of cave candidates and detections of craters. At this stage of work, manual validation is fundamental since there are several false positive and the training dataset is fairly small but further studies, including the increase of training dataset could lead to optimizations of the trained model and provide a reliable tool to be used to build up the MGC<sup>3</sup> using the full datasets of HiRISE and CTX.

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**References:** [1] Cushing G.E. (2017) *Mars Global Cave Candidate Catalog (MGC<sup>3</sup>)*. [2] Cushing et al. (2007) *Themis observes possible cave skylights on Mars*. [3] Cushing G.E. (2012) *Candidate cave entrances on Mars*. [4] Sauro R. et al. (2020) *Lava tubes on Earth, Moon and Mars: A review on their size and morphology revealed*. [5] PDS Geosciences Node Orbital Data Explorer (ODE). [6] Redmon J. et al. (2016) *You Only Look Once: Unified, Real-Time Object Detection*. [7] Nodjoumi G. (2020) *ImageProcessingUtils* (<https://zenodo.org/record/4396191>). [8] Nodjoumi G. (2020) *DeepLandforms-YOLOv5* (<http://doi.org/10.5281/zenodo.4430015>)