The Mercury HORNET: Deep learning-driven mapping of hermian hollows

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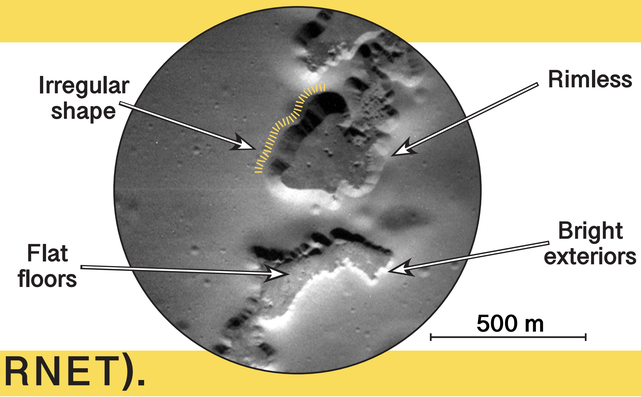
ABSTRACT #6017

Hollows on Mercury.

Hollows are some of the most interesting features on Mercury. These small, shallow depressions likely formed via volatile loss, and appear to be very geologically young[1–6].

Today, important questions remain about the origin and evolution of hollows, and a detailed understanding of their distribution (both globally and locally) can help address these questions.

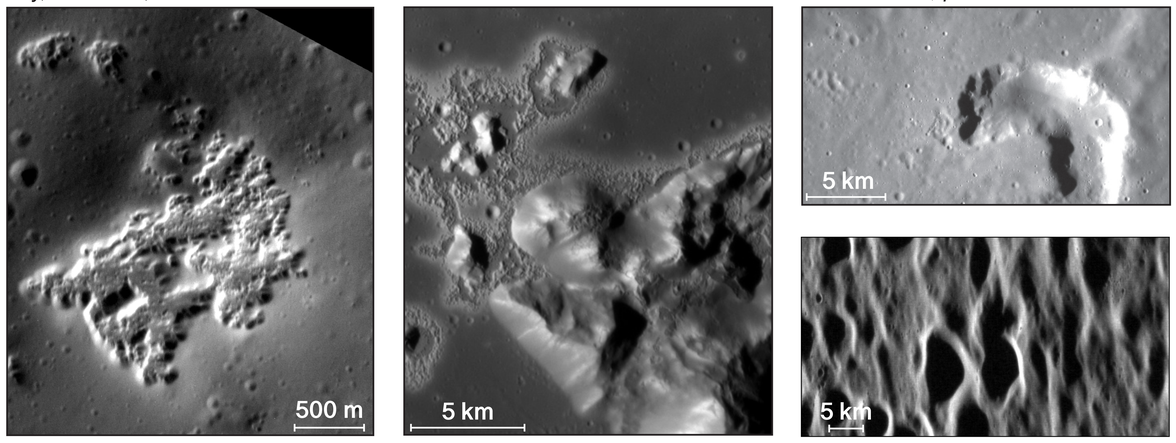
We are taking an automated approach to identifying hollows by training a convolutional neural network based on the RetinaNet architecture[7], using a ResNet 50 backbone.



Training the Mercury HOllows Retrieval NETwork (HORNET).

INPUT: We are training the Mercury HORNET to automatically detect hollows in MESSENGER NAC images. Training sets include images of hollows and images of features that may look similar to hollows - like vents, pits, or small craters - but aren't.

Hey, HORNET, label features like these as "hollows." *Or these.* *But not these, please.*

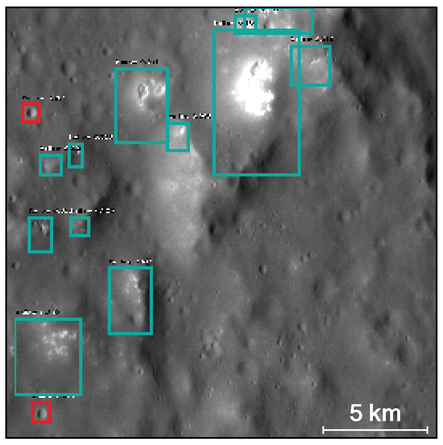


So far, HORNET has been trained on 69 NAC images and 1,012 labels. We used image augmentation during training to generate a total of 50,600 labels over 50 epochs* by varying:

- Rotation up to 90°
- Shear up to ±20%
- Scaling up to ±20%
- Chance of X & Y flip of 50%
- Contrast up to ±10%
- Brightness up to ±30%
- Hue up to ±3%
- Saturation up to ±5%

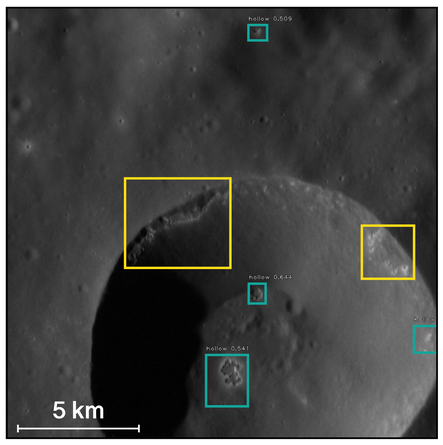
*In 50 epochs, the entire training dataset is passed through the neural network 50 times.

OUTPUT: Promising preliminary results yield detections of hollows at a range of spatial scales (~10–100 mpp) and illumination conditions. Future versions will include a segmentation capability for more accurate tracing and geometric measurements.



- A True Positive (TP) is where HORNET correctly identified a hollow.
- A False Positive (FP) is where HORNET labeled something else a hollow.
- A False Negative (FN) is where HORNET missed a hollow.

It's still learning.



An example output at Confidence Threshold (CT) = 0.2.
- Recall = 0.85
- Precision = 0.81

At lower confidence levels, more features are identified - including both hollows (TPs) and non-hollows (FPs). Recall goes up, precision goes down.

Outputs are evaluated by:

- Recall: The proportion of actual hollows that was identified (1.0 is optimum).
- Precision: The proportion of positive IDs that was actually hollows (1.0 is optimum).

An example output at Confidence Threshold (CT) = 0.5.
- Recall = 0.58
- Precision = 0.90

At higher confidence levels, HORNET is stricter in what it labels as hollows, so tends to miss some (FNs). Recall goes down, precision goes up.

Applying the HORNET to MESSENGER and BepiColombo.

We will apply the HORNET to the entire MDIS dataset to scan globally for hollows. We will also be ready to infuse the Mercury HORNET with BepiColombo data by applying transfer learning principles, allowing for immediate and optimized progress in the global identification of hollows.

The automated identification of hollows has wide-reaching scientific applications:

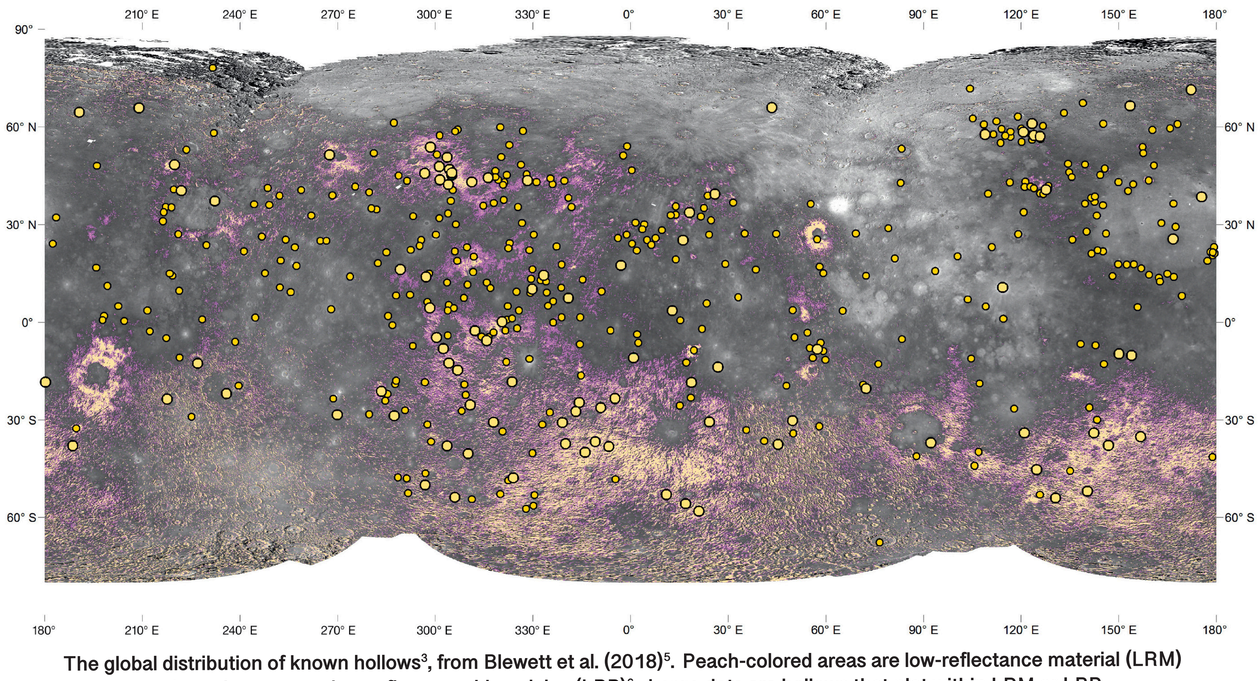
Mapping, to understand processes driving volatile loss and hollow formation.

GLOBALLY:

- What is the extent of the volatile-bearing layer?
- What is the extent of the proposed lag deposit that could limit volatile loss?

LOCALLY:

- Do hollows favor specific formation locations (e.g., Sun-facing slopes)?

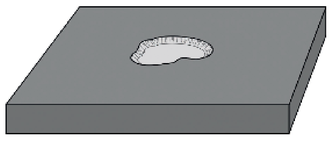


The global distribution of known hollows[3], from Blewett et al. (2018)[5]. Peach-colored areas are low-reflectance material (LRM) and purple areas are low-reflectance blue plains (LBP)[6]. Large dots are hollows that plot within LRM or LBP and small dots are hollows located in neither LRM nor LBP at the scale of the global color images used for mapping.

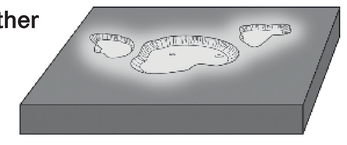
Change detection, to understand growth sequences and rates of hollow formation.

- What is the timescale of hollow development?
- Is hollow formation an active process on Mercury?

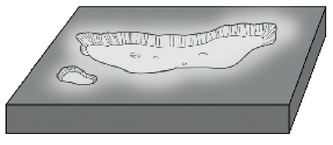
1. A small hollow forms.



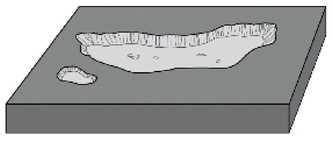
2. The hollow enlarges and other hollows begin to form. Their interiors are halos are bright.



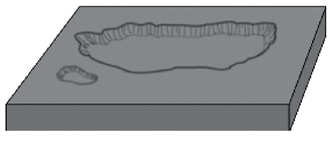
3. Small hollows continue to grow and merge. Another small hollow begins to grow.



4. Activity slows down and bright halos fade.



5. Activity stops. Hollows have the same reflectance as their surroundings. Impact erosion begins to modify the features.



Inferred sequence of hollow development, from Blewett et al. (2018)[5].

REFERENCES. [1]Blewett D. T. et al. (2011) *Science, 333,* 1856–1859. [2]Blewett D. T. et al. (2013) *J. Geophys. Res. Planets, 118,* 1013–1032. [3]Thomas R. J. et al. (2014) *Icarus, 229,* 221–235. [4]Blewett D. T. et al. (2016) *J. Geophys. Res. Planets, 121,* 1798–1813. [5]Blewett D. T. et al. (2018), ed. by Solomon S. C. et al., *Cambridge Univ. Press, pp.* 324–345. [6]Klima R. L. et al. (2016) *Lunar Plant. Sci. Conf., 47,* abstract 1195. [7]Lin T.-Y. et al. (2017) *Proc. of IEEE Int. Conf. on Comp. Vision., 118,* 2980–2988.