The CHASM-SWPC Dataset for Coronal Hole Detection & Analysis

Cutter Beck*, Evan Smith*, Rudra Kafle*, Jacob Whitehill* and Khagendra Katuwal**
*Worcester Polytechnic Institute and **New Mexico State University

Coronal holes (CHs) are low-activity, low-density solar coronal regions with open magnetic field lines. In the extreme ultraviolet (EUV) spectrum, CHs appear as dark patches. Using daily hand-drawn maps from the Space Weather Prediction Center (SWPC), we developed a semi-automated pipeline to digitize the SWPC maps into binary segmentation masks. The resulting masks constitute the CHASM-SWPC dataset, a high-quality dataset to train and test automated CH detection models. We developed CHASM (Coronal Hole Annotation using Semi-automatic Methods), a software tool for semi-automatic annotation that enables users to rapidly and accurately annotate SWPC maps. The CHASM tool enabled us to annotate 1,111 CH masks, comprising the CHASM-SWPC-1111 dataset. We then trained multiple CHRONNOS (Coronal Hole RecOgnition Neural Network Over multi-Spectral-data) architecture neural networks using the CHASM-SWPC dataset and compared their performance. Training the CHRONNOS neural network on these data achieved an accuracy of 0.9805, a True Skill Statistic (TSS) of 0.6807, and an intersection-over-union (IoU) of 0.5668, which is higher than the original pretrained CHRONNOS model Jarolim et al. (2021) achieved an accuracy of 0.9708, a TSS of 0.6749, and an IoU of 0.4805, when evaluated on the CHASM-SWPC-1111 test set.

Overview: What are Coronal Holes (CHs)?

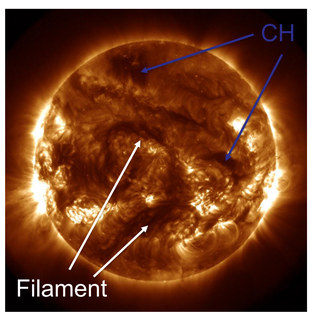
- CHs are low-activity, magnetically unipolar regions in the solar atmosphere, the corona, which appear dark in extreme ultraviolet (EUV) imagery of the sun due to their low density[1].
- CHs are correlated with fast solar wind[1] which can lead to geomagnetic storms, affecting satellites and power grids on Earth[2,3].
- CHs are drawn daily, by hand, at the NOAA Space Weather Prediction Center (SWPC).

Our Contributions

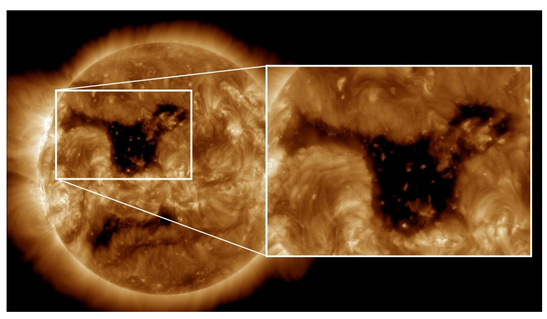
- An open-source tool to digitize expert-drawn SWPC synoptic maps.
- A dataset of digitized and labeled SWPC CH segmentation masks with 7 SDO AIA EUV wavelength images and 1 HMI magnetogram.
- Neural network models trained on this data.

[1] S. R. Cranmer, "Coronal Holes," en, Living Reviews in Solar Physics, vol. 6, no. 1, p. 3, Sep. 2009, issn: 1614-4961. doi: 10.12942/lrsp-2009-3. [Online]. Available: https://doi.org/10.12942/lrsp-2009-3.
[2] R. Schwenn, "Space Weather: The Solar Perspective," en, Living Reviews in Solar Physics, vol. 3, no. 1, p. 2, Dec. 2006, issn: 1614-4961. doi: 10.12942/lrsp-2006-2. [Online]. Available: https://doi.org/10.12942/lrsp-2006-2.
[3] NOAA Space Weather Scales | NOAA / NWS Space Weather Prediction Center. [Online]. Available: https://www.swpc.noaa.gov/noaa-scales-explanation.

Solar Dynamics Observatory (SDO)



193Å Atmospheric Imaging Assembly (AIA) image September 24, 2024 (SDO[4])



January 28, 2025 SDO AIA 193Å with CH inset (Space[5])

[4] "SDO | Solar Dynamics Observatory." Available: https://sdo.gsfc.nasa.gov/.
[5] D. D. last updated, "Aurora alert! Gigantic 500,000-mile 'hole' in the sun's atmosphere could spark impressive northern lights tonight and tomorrow (photo)," Space. [Online]. Available: https://www.space.com/the-universe/sun/gigantic-500-000-mile-hole-in-the-suns-atmosphere-aims-aurora-sparking-solar-wind-at-earth-photo

Automatic CH Detection Methods

1. He I 10830Å and Magnetogram Thresholding[6] (2007)
   1. Uses intensity and magnetic unipolarity thresholds.
2. SPoCA[7] (2013)
   1. Fuzzy clustering of 2 EUV images, can remove filaments.
3. CHIMERA[8] (2017)
   1. Thresholding across 3 EUV images and a magnetogram, optimized to detect on- and off-disk CHs.
4. CNN-193[9] (2018)
   1. U-Net trained with 1 EUV image and thresholded, human-curated ground truth (GT) masks.
5. CHRONNOS[10] (2021)
   1. Multi-channel U-Net trained on 7 EUV images and 1 magnetogram. Current State of the Art in automatic CH detection.

CH Labels

- CNN193 ObserveTheSun[11]: Uses intensity thresholding with human intervention.
- CATCH[10,12]: Uses an intensity gradient to threshold 193Å EUV images.
- SPoCA-CH[10]: A modified version of SPoCA[7] that uses thresholding and removes filament channels.
- SWPC: Daily hand-drawn maps of the sun since June 2, 1972[13].

[6] C. J. Henney and J. W. Harvey, "Automated Coronal Hole Detection using He I 1083 nm Spectroheliograms and Photospheric Magnetograms," Jan. 04, 2007, *arXiv*: arXiv:astro-ph/0701122. doi: 10.48550/arXiv.astro-ph/0701122.
[7] C. Verbeeck, V. Delouille, B. Mampaey, and R. D. Visscher, "The SPoCA-suite: Software for extraction, characterization, and tracking of active regions and coronal holes on EUV images," *A&A*, vol. 561, p. A29, Aug. 2013, doi: 10.1051/0004-6361/201321243.
[8] T. M. Garton, P. T. Gallagher, and S. A. Murray, "Automated coronal hole identification via multi-thermal intensity segmentation," *J. Space Weather Space Clim.*, vol. 8, p. A02, Nov. 2017, doi: 10.1051/swsc/2017039.
[9] E. A. Illarionov and A. G. Tlatov, "Segmentation of coronal holes in solar disc images with a convolutional neural network," *Monthly Notices of the Royal Astronomical Society*, vol. 481, no. 4, pp. 5014–5021, Sep. 2018, doi: 10.1093/mnras/sty2628.
[10] R. Jarolim *et al.*, "Multi-channel coronal hole detection with convolutional neural networks," *A&A*, vol. 652, p. A13, Apr. 2021, doi: 10.1051/0004-6361/202140640.
[11] "Observe the Sun." [Online]. Available: https://www.observethesun.com/?current=2025-04-17&objects=3f&past=2024-04-18
[12] S. G. Heinemann *et al.*, "Statistical Analysis and Catalog of Non-polar Coronal Holes Covering the SDO-Era Using CATCH," *Sol Phys*, vol. 294, no. 10, p. 144, Oct. 2019, doi: 10.1007/s11207-019-1539-y.
[13] "Solar Synoptic Map | NOAA / NWS Space Weather Prediction Center." Accessed: Sep. 24, 2024. [Online]. Available: https://www.swpc.noaa.gov/products/solar-synoptic-map.

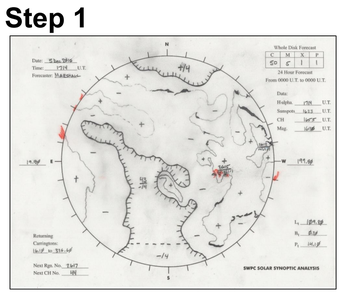
Efficiently Labeling Hand Drawings

Step 1: Download the SWPC synoptic map.
Step 2: Pre-process with Meta's Segment Anything Model (SAM)[14].
Step 3: Utilize the CHASM tool to select CHs and refine the selections.
Step 4: Save the CH selections as segmentation masks with metadata.
Step 5: Post-process the CH segmentation masks into one scaled mask.

[14] A. Kirillov *et al.*, "Segment Anything," Apr. 05, 2023, *arXiv*: arXiv:2304.02643. Accessed: Sep. 17, 2024. [Online]. Available: http://arxiv.org/abs/2304.02643

CHASM Labeling Pipeline

Step 1



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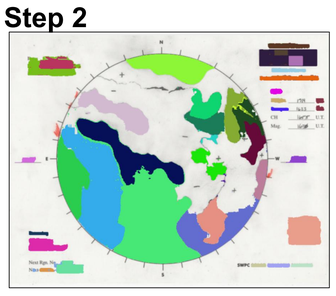
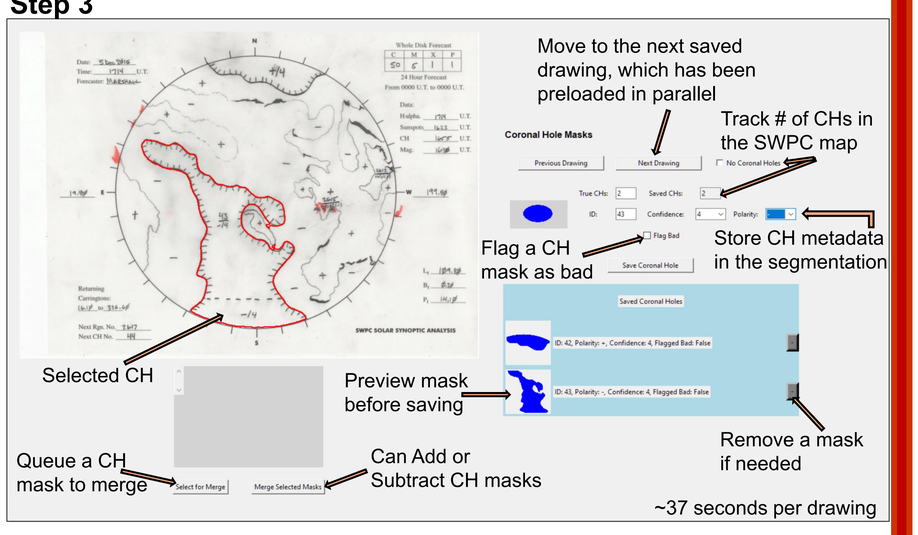


Step 3



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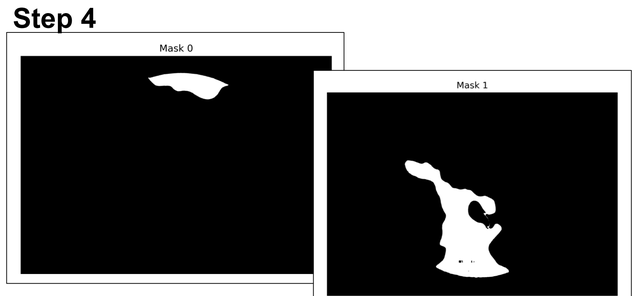
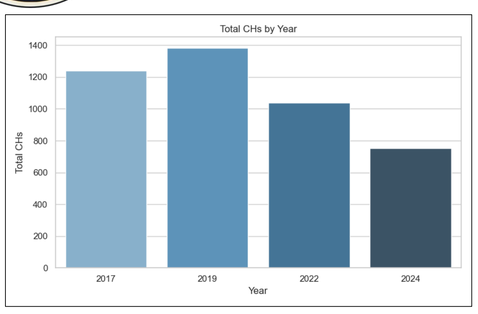
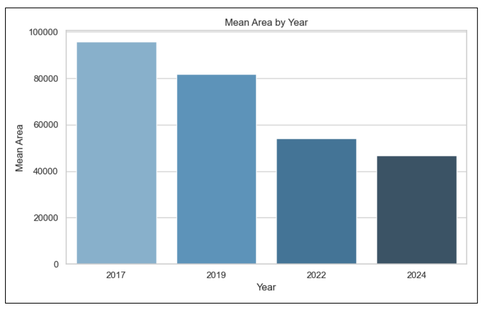


Step 5

CHASM: Digitized SWPC Maps

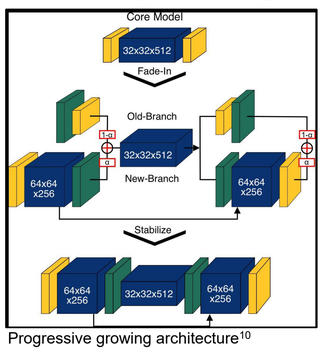
- First known digitized set of SWPC maps
- High inter-annotator agreement
- 4 years of SWPC synoptic maps collected
- 1,446 total SWPC synoptic maps labeled
- 4,411 total coronal holes labeled
- Average CH size of 69,543.7 pixels^2
- 1,111 high quality SDO image-mask sets





CH Detection Neural Networks

- Using the CHRONNOS architecture, models were trained on CHASM data.
- A model was developed by finetuning (FT) the pretrained CHRONNOS model (PT-CHR) with CHASM data.
- CHASM-based models can accurately produce SWPC-style CH segmentations.



Progressive growing architecture[10]

Results

Model	Acc.	TSS	IoU
CHASM-1111	**0.9805**	**0.8253**	**0.5810**
CHASM-1407	0.9791	0.8184	0.5542
FT CHASM-1111 lr=1e-5	0.9786	0.8003	0.5470
SPoCA-CH	0.9767	0.7000	0.5022

Conclusions

- Developed the CHASM tool which can be used to label CHs in hand drawings.
- Produced a high-quality dataset of labeled CHs based on expert drawings.
- Produced the first automatic CH detection model which does not rely on thresholded GT.
- Our model trained on CHASM masks produces more accurate images inline with SWPC than PT-CHR trained on SPoCA-CH, making it suitable for CH detection.

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