

Sunspot classification using artificial intelligence

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Abstract

Sunspots, visible through telescopes or with the naked eye at sunset, are caused by the Sun's magnetic field. Studying these phenomena is crucial for predicting solar activity and understanding the Sun's cycle. My research focuses on automating the recognition, classification, and analysis of sunspots using hand-drawn observations from the Astronomical Institute of the Czech Academy of Sciences. I trained a convolutional neural network to label sunspots based on the McIntosh classification system, aiming to bridge deep learning with solar astronomy.

Methods

The preprocessing and classification of sunspot data were automated using Python. The initial dataset consisted of hand-drawn sunspot observations, which were prepared for machine learning through a series of adjustments. The processed images were then labeled according to the McIntosh classification system, providing key information on sunspot size, structure, and distribution.

For model training, the dataset was divided into training, validation, and test sets in an 80-10-10 ratio. I used a Convolutional Neural Network (CNN) to classify the sunspots, utilizing libraries such as Keras and TensorFlow. Model selection was based on the validation loss function, choosing the model that minimized the loss. After training, predictions were run on the test set, and the results were evaluated using accuracy metrics and a confusion matrix.

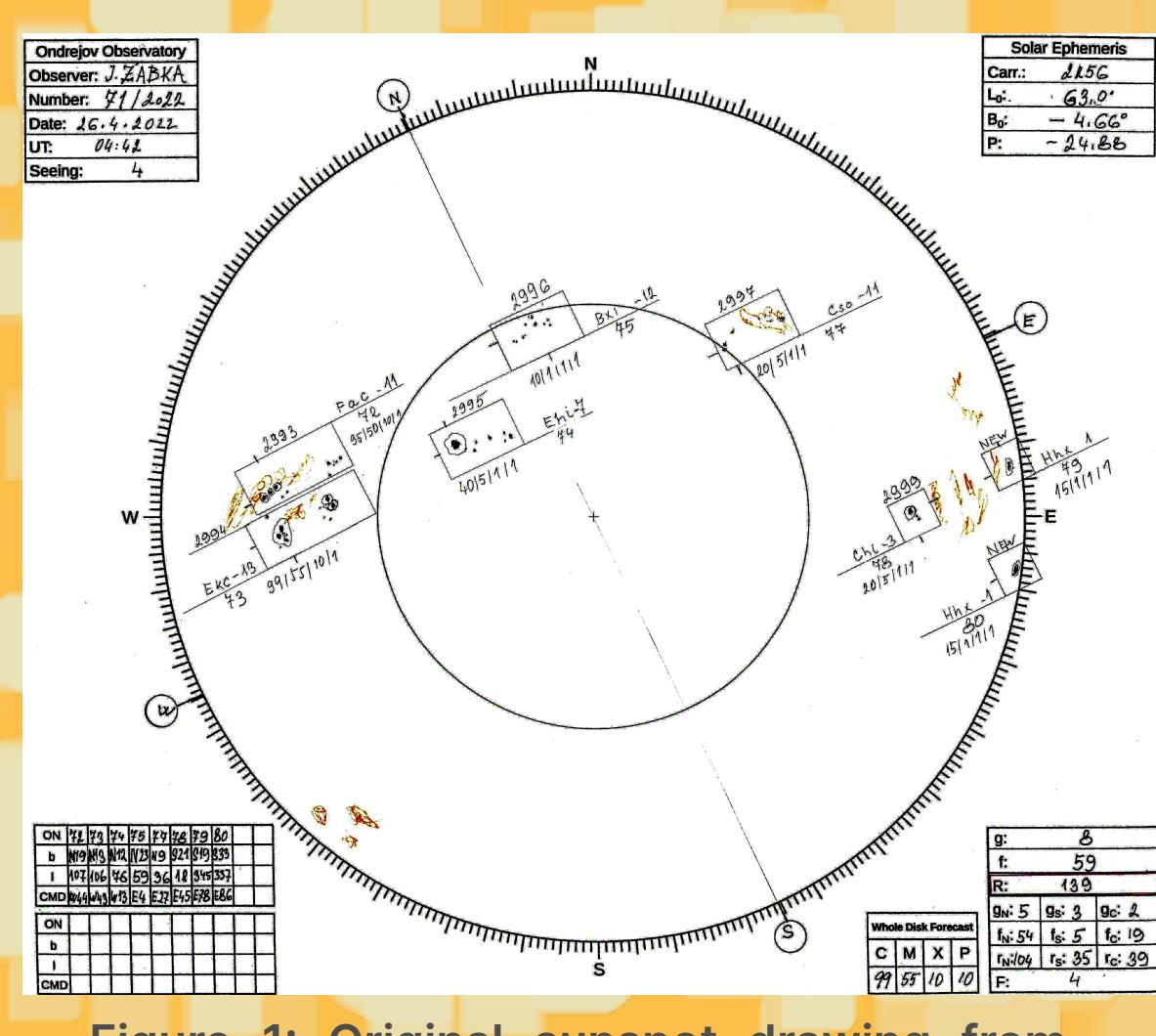


Figure 1: Original sunspot drawing from 26.04.2022 drawn on the Astronomical Institute of the Czech Academy of Sciences

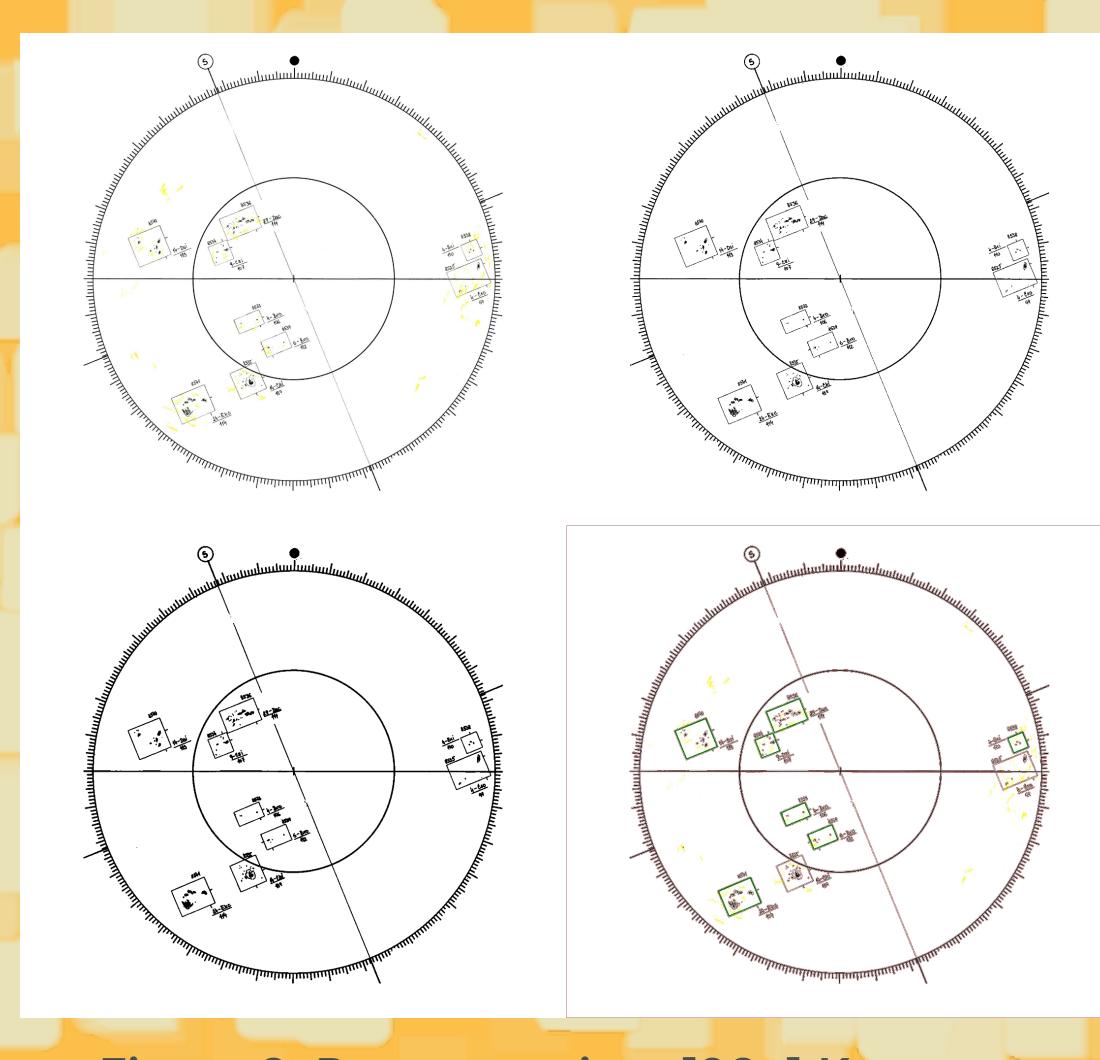


Figure 2: Preprocessing: [02a] Key area of drawing [02b] Removed yellow filaments [02c] Enhanced contours with blur and black-white conversion [02d] Highlighted detected contours in green.

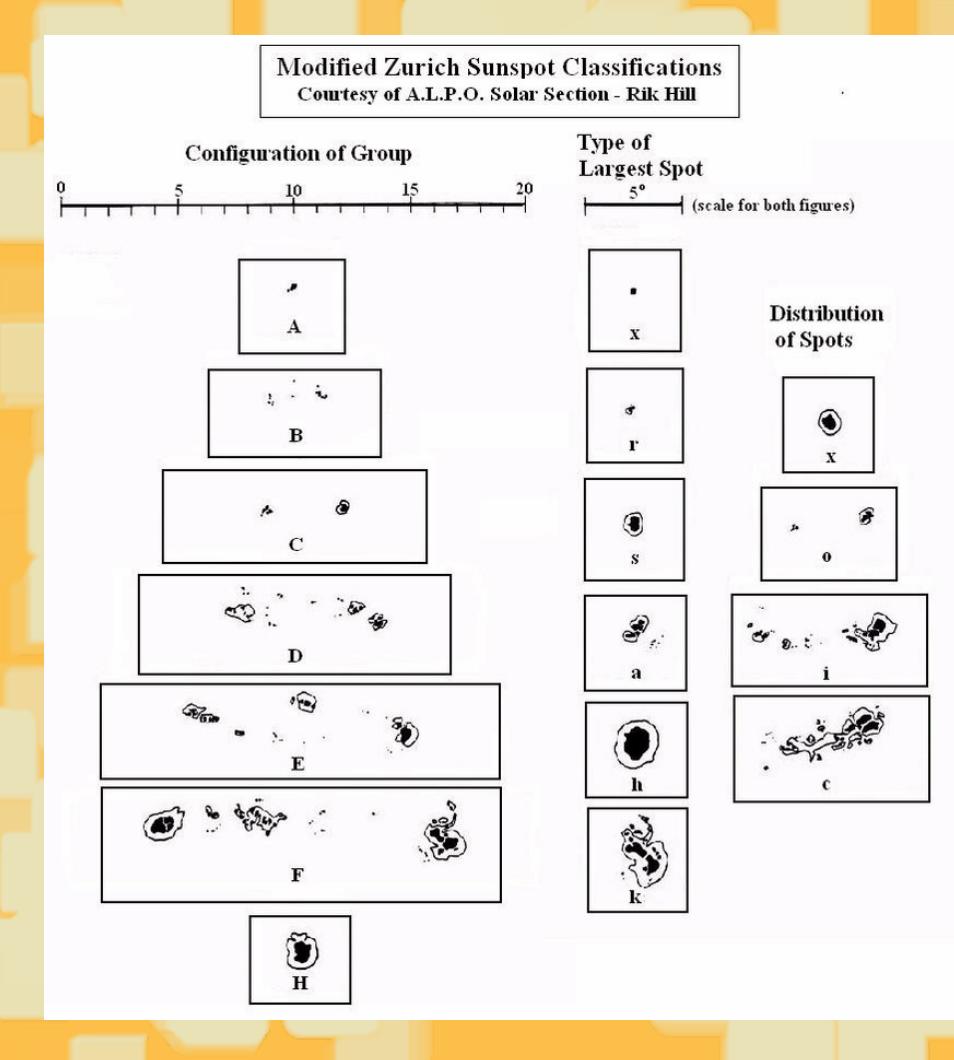


Figure 3: Visualisation of each group of McIntosh classification system. McIntosh system classifies sunspots using three letters to indicate size, the largest sunspot's properties, and group distribution



Figure 4: Preprocess of individual sunspot groups. [06a] Extracted the square area containing the sunspot. [06b] Removed surrounding areas based on the detected rectangle. [06c] Inverted the colors to enhance machine learning performance. [06d] Visualisation of labeling for supervised machine learning.



Figure 5: Visualization of dataset split into training, validation, and test groups.

Sources

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- [2] PROJEKCE - ZÁKRES SLUNEČNÍ FOTOSFÉRY. Astronomický ústav AV ČR [online]. [cit. 2024-03-14]. Dostupné z: <https://wwwasu.cas.cz/~sunwatch/cs/stranka/kresba>
- [3] Sunspot SST 05Sep2016. Online. In: Wikipedia: the free encyclopedia. San Francisco (CA): Wikimedia Foundation, 2001-. Dostupné z: https://upload.wikimedia.org/wikipedia/commons/e/eb/Sunspot_SST_05Sep2016.png. [cit. 2024-10-06].
- [4] Astronomický ústav Akademie věd České republiky [online]. c2024 [cit. 2024-10-06]. Dostupné z: <https://wwwasu.cas.cz/>
- [5] nějaký článek/bakalarska s AI?

Results

I've trained several convolutional neural network (CNN) models capable of detecting sunspots at varying levels of complexity, showcasing the potential applications of AI in solar astronomy. Additionally, I have outlined several pathways for future research in this field.

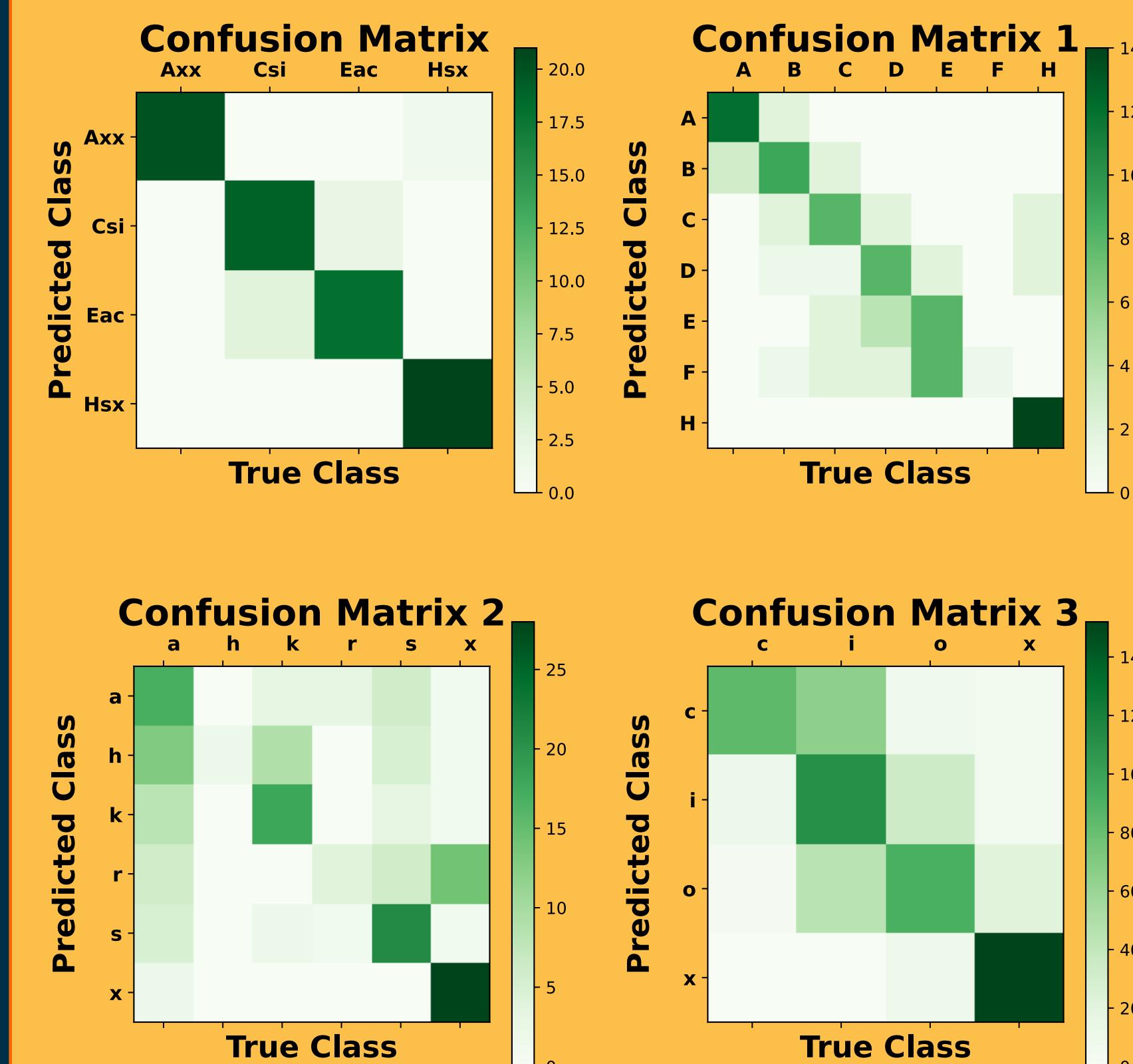


Figure 6: Confusion matrices of selected models. [09a] Model for classification between 4 groups, with 93% accuracy. [09b] Model for predicting the first letter of the McIntosh classification, with 61% accuracy. [09c] Model for predicting the second letter of the McIntosh classification, with 50% accuracy. [09d] Model for predicting the third letter of the McIntosh classification, with 68% accuracy.

Future possibilities

Future work could focus on developing more accurate models, improving spot detection, or incorporating data from additional observatories. Expanding model complexity with deeper layers and more neurons could also enhance precision. Another direction is creating a tool for automatic sunspot classification, aiding observatories in verifying manual classifications.

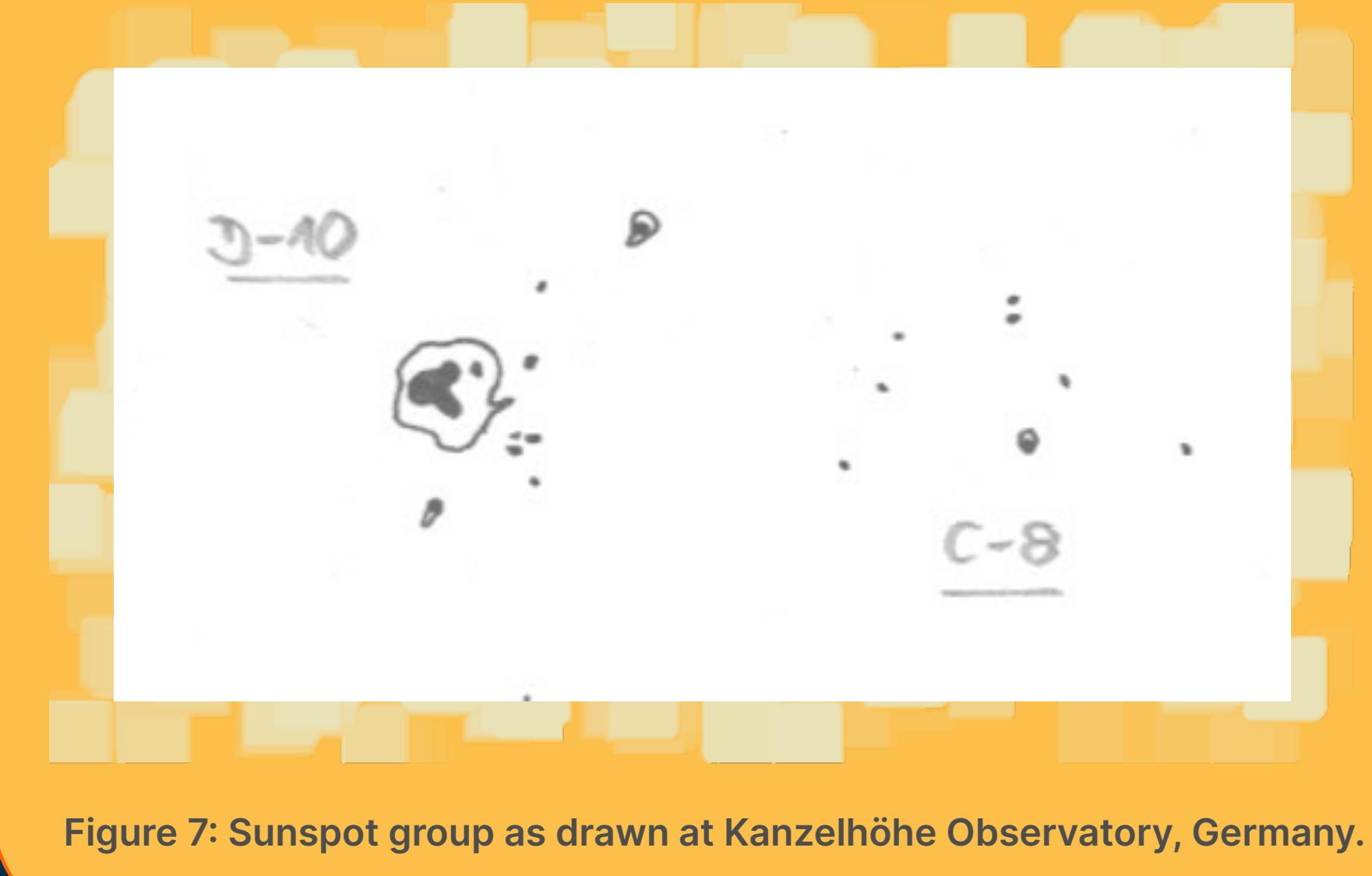


Figure 7: Sunspot group as drawn at Kanzelhöhe Observatory, Germany.