Observing Solar Far-Side Active Regions with Mastcam-Z on Mars Rover

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ABSTRACT

The Perseverance Rover has been on the Martian surface since February 2021. The rover has Mastcam-Z navigation stereo cameras, that can capture direct images of the Sun's surface. During periods of Mars's orbit, the rover has a unique view-point of the Sun's far-side (not visible from Earth at any given time). Solar scientists can use the rover's conveniently positioned cameras to monitor sunspots that we cannot otherwise observe. By collecting these data, we can verify helioseismic detections of the Sun's largest far-side active regions. In this project, solar far-side acoustic images obtained using time-distance helioseismology and SDO/HMI Dopplergrams are compared with white-light observations from the Perseverance Mastcam-Z cameras. By taking advantage of Mars' orbital positioning, our goal is to refine the acoustic "true/false positive" detections in the helioseismic maps. Ultimately, this can help improve the assimilated boundary conditions of coronal and solar wind models, which in turn can aid in more accurate space weather forecasting.

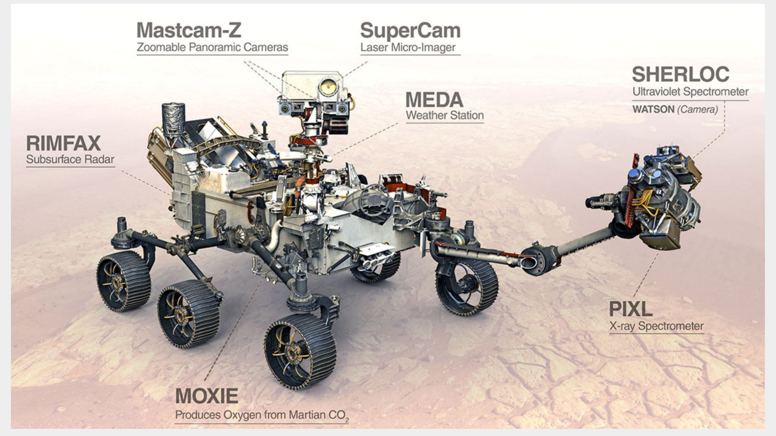
MOTIVATION

The lack of direct observations of the Sun's far side (which is not visible from Earth at any given time) poses a significant challenge to space weather forecasting. Predicting major solar features on the far side that will eventually rotate onto the near side (visible from Earth) is critical. These active regions can significantly influence space weather, including solar storms, and affect solar wind models. While far-side EUV data from STEREO observations is available, it spans only ~3 years and does not provide a direct comparison with continuum observations. Utilizing white-light observations from Mastcam-Z on Mars offers the opportunity for a direct comparison with sunspots.

Helioseismic phase shifts can be employed to indirectly detect perturbations on the solar far side (see, e.g., Lindsey & Braun 2000; González Hernández et al. 2007; Zhao et al. 2019). However, no method currently exists to distinguish active regions from other wave-induced perturbations for validation purposes.

During certain periods of Mars' orbit, the Perseverance Rover provides a unique vantage point of the Sun's far side. At such times, the rover's strategically positioned cameras can be used to monitor sunspots that are otherwise unobservable from Earth, offering a valuable resource for validating far-side helioseismology.

For this study, we are utilizing Mastcam-Z, a multispectral stereoscopic imaging instrument aboard the Perseverance Rover. Mastcam-Z's primary functions include capturing panoramic videos and 3D images of the Martian surface, along with atmospheric features and phenomena.



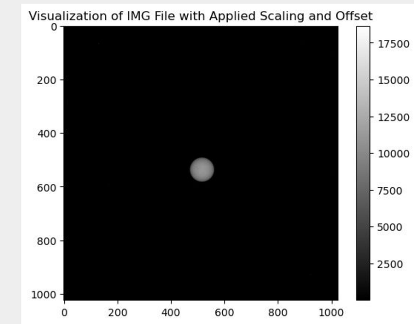
MastCam-Z Solar Data

Solar observations from Mastcam-Z onboard the rover are Radiance Calibrated (RAD) image products, available through Mars2020 PDS (Planetary Data System) Public Archive Bundles

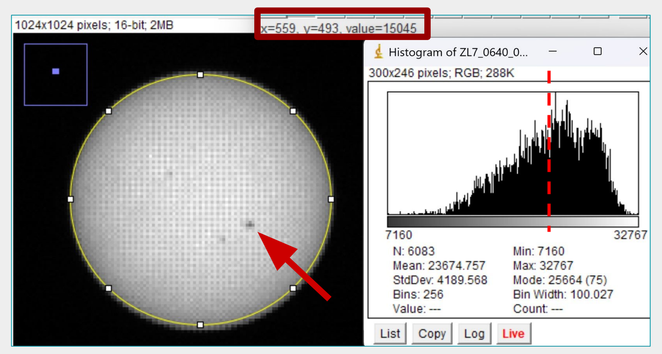
METHODOLOGY

DATA PROCESSING

The radiance calibrated data is available from the PDS repository in .IMG file format. The .odl header file included in the .IMG file has the required information to read the binary file.



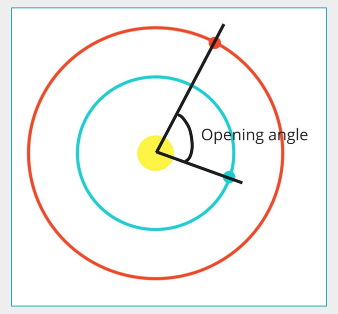
The values of coefficients & constants are used to translate the binary file into image. The matrix with solar disk in view is selected for analysis.



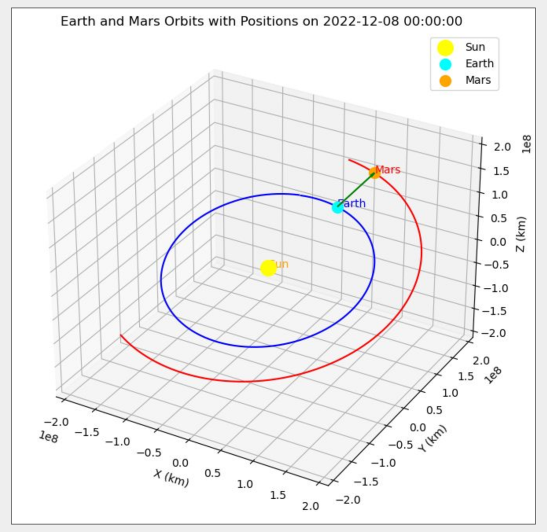
Histogram analysis shows that the value of sunspot fall outside the noise range (Value of 15045). The red dashed line on the histogram is where the pixel mean of around 23674 lies. Points to the left of the line are features of interest such as sunspots. Points on the right of the mean line constitute as noise.

NEAR-SIDE VALIDATION

Before we use the Mastcam-Z data to observe the solar far-side sunspots, it is preliminary to verify the data and derive the constraints. Earth and Mars shared the same view of the Sun during the month of December 2022. For the simplicity we have chosen the duration from 2nd December 2022 to 14th December 2022, during which the opening angle varies from -10^0 to 10^0.



The angular separation between the Sun-Earth vector and the Sun-Mars vector.



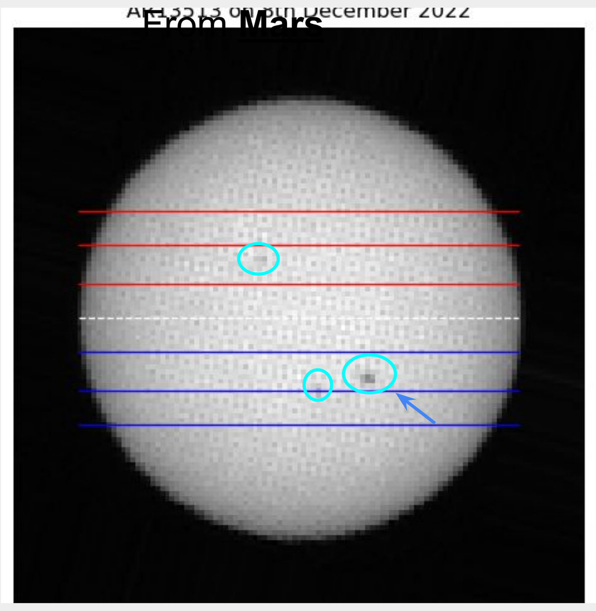
Orbital positioning of the Sun, Earth and Mars on 8th December 2022.

Solar surface captured by Mars camera on Perseverance on a specific date. Can see tentative sunspots in northern hemisphere.

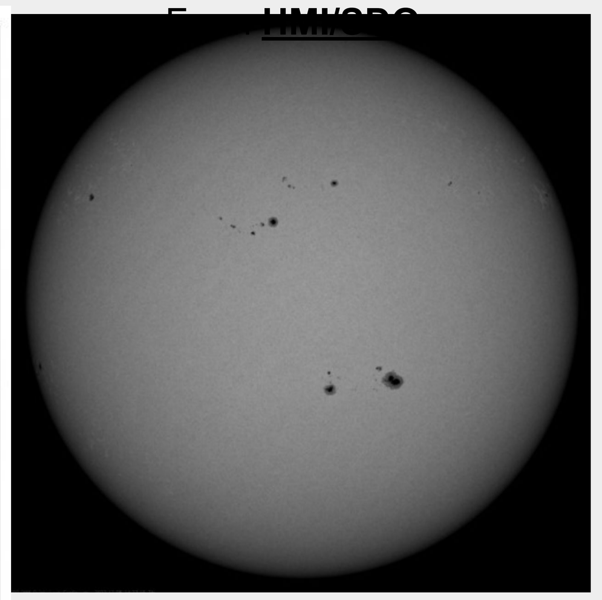
Can identify durations when Mars' position is opposite with respect to the Earth. Observations and validations done based on "**geocentric**" viewpoints.

To date, there have been no direct continuum observations of the solar far-side.

The active region AR13513 moved into the central region of solar disk on 8th December 2022. The opening angle was small such that both HMI on SDO and Mastcam-Z on Mars rover were looking at the same near side of the Sun. Three active regions were observed in the HMI continuum images, but only two of them were visible from Mars.

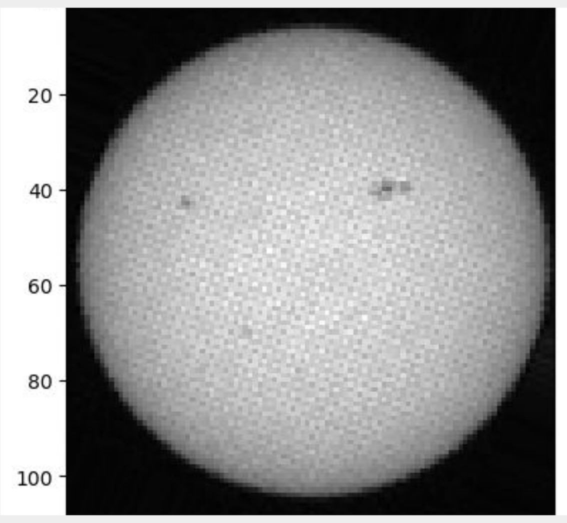


The Sun as seen from Mastcam-Z on Mars. The image is oriented along solar north & the AR13513 can be observed at the latitude near S20. Limitations are inferred by comparing the observations with HMI.

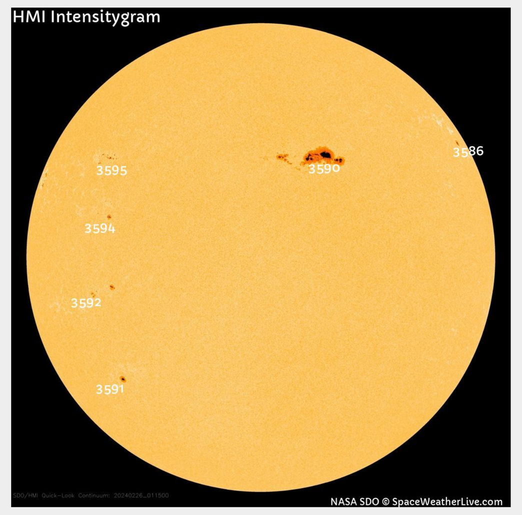


512x512 pixels of SDO Image of the Sun on 2022-12-08 using HMI Gray continuum images. AR13513 located at S17W20.

FAR-SIDE



AR13590 observed on far-side from Mars on March 7, 2024. This marks a significant milestone, showcasing the potential of data from Mastcam-Z. For the first time, we are able to obtain continuum observations of the solar far-side, providing new insights into solar activity from Mars.



AR13590 view from HMI/SDO on 26th February 2024. The active region went out of sight on March 1st.

ANALYSIS:

- **The solar disk view from Mastcam-Z is constrained within an array of size 92x92 pixels**: This resolution limits the scale and level of detail visible in the captured solar images, with the solar disk's entire extent fitting within this pixel grid.
- **The average resolution of the image taken from Mars is 13.5''/pixel**, allowing for the observation of large-scale solar features but limiting fine details.
- **The average size of each pixel is 15,000 km/pixel**
- **The threshold size of a sunspot to be seen from Mars is 100 Millionths of a Solar Hemisphere (MH):** ~ 304 million Square kilometers. Sunspots smaller than this threshold would not be visible at the current resolution, ensuring only larger, prominent sunspots are detected in the images.

Upcoming Results

Far-Side Data Validation

Once the threshold value for sunspot size and the acceptable error range for size and location are estimated from near-side observations, these findings will provide crucial insights into the limitations of the detection model. The constraints identified through near-side observations will help assess the model's accuracy and refine the ability to differentiate true sunspot signals from noise & other artifacts.

Furthermore, these limitations will shed light on the scope of the model's performance, particularly in identifying and reducing **false positive detections** in helioseismic maps. This evaluation is critical for ensuring that the model accurately validates solar features on the far side and reliably supports space weather forecasting efforts.

Machine Learning for Solar Far-Side Analysis

We aim to leverage established time-distance helioseismology data from near-side solar images to generate training data for a machine learning model. Radiation-calibrated images of the solar far side, captured by Mastcam-Z, will serve as testing data. The trained algorithm, capable of accurately identifying and categorizing solar features, will be applied to Mastcam-Z far-side images. This will help identify similar features, validate far-side acoustic measurements, and predict space weather as far-side features eventually rotate onto the near side, impacting the heliospheric environment.

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Database

- Mars 2020 Planetary Data System (PDS) - Public Archive Bundle
- Solar Dynamics Observatory Image Database

Software

- ImageJ is an open source image processing program designed for scientific multidimensional images.
- Planetary Data Reader (PDR) developed by Million Concepts, is used for a large variety of missions to read PDS products.
- Python Libraries : Astropy, Sunpy, Numpy, Skyfield, Matplotlib.

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