Autonomous Feature Detection of Solar Wind Ion Trails in Martian Ionosphere

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Abstract

We present a computational application of geometric feature extraction that autonomously detects and tracks charged particle trails in the Martian ionosphere. Using solar wind ion analyzer (SWIA) data from NASA's MAVEN mission, our technique involves algorithmic analysis of energy spectrograms to extract ion trails that exhibit high signal-to-noise ratio (SNR) levels. Specifically, we utilize various signal processing methods to unite connected particles and isolate individual trails from surroundings. We provide results of our algorithm's extraction process over energy spectrograms.

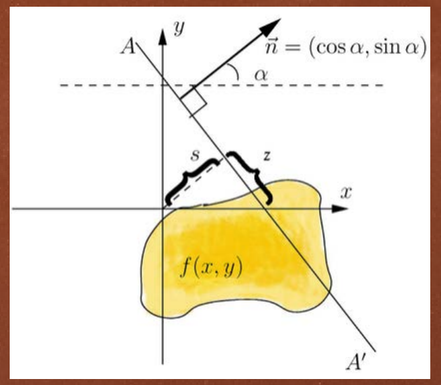

*Figure 1. Applying **Radon Transform** reveals whether a detected ion trail has a dominant angle*

Challenges of Detection

- Isolating individual ion trails that may overlap other trails
- Algorithm being flexible to identify trails of various shapes and sizes
- Connecting charged particles of varying energy levels

Technical Approach

Our technique is a direct application of recent work on autonomous detection of chorus elements presented in [1] to Martian ion trails. We apply the following step-by-step approach to the spectrogram of the magnetic field, treating the spectrogram as an image I(x,y). For each step, we refer to the relevant panel in Figure 3 or the computational technique illustrated in Figure 1.

Step 1 (Panel 2): Apply a global noise threshold to I(x,y).

Step 2 (Panel 3): Apply a median filter to each pixel (x,y) within a 3x3 pixel window W(x,y) centered on the pixel. The median filter replaces the pixel value I(x,y) with the median value measured across the 9-pixel distribution defined by W(x,y).

Step 3 (Panel 4): Evaluate the intensity of the background noise at each pixel I(x,y) using a 25th percentile filter over a larger window N(x,y).

Step 4 (Panel 5): Evaluate the signal-to-noise ratio (SNR) S(x,y) at each panel as:

$$S(x,y) = W(x,y) - N(x,y) \qquad [3]$$

Step 5 (Panel 6): Generate the histogram of the SNR map constructed in Step 4, and select the 75th percentile as the SNR threshold to detect a pixel as part of an ion trail.

Step 6 (Figure 1, Panel 7): Use 8-connectivity between pixels to detect features corresponding to individual ion trails. The Radon transform (Figure 1) is used to determine whether the selected features follow a dominant angle, as is characteristic of a charged particle trails.

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References

[1] Sen Gupta, Ananya, Craig Kletzing, Kawther Rouabhi, and Ivar Christopher. "Autonomous Identification of the Morphology of Chorus Elements in The Van Allen Radiation Belts." Presented at American Geophysical Union Fall Meeting, December 2019.

[2] Jin, Qiutong, Ananya Sen Gupta, Mirela Kapo, Emma Hawk, and Jasper S. Halekas. "Autonomous Detection and Disambiguation of Martian Ion Trails Using Geometric Signal Processing Techniques." In ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), pp. 2312-2316. IEEE, 2019.

[3] Sen Gupta, Ananya, Craig Kletzing, Robin Howk, William Kurth, and Morgan Matheny. "Automated identification and shape analysis of chorus elements in the Van Allen radiation belts." Journal of Geophysical Research: Space Physics 122, no. 12 (2017): 12-353.

Results

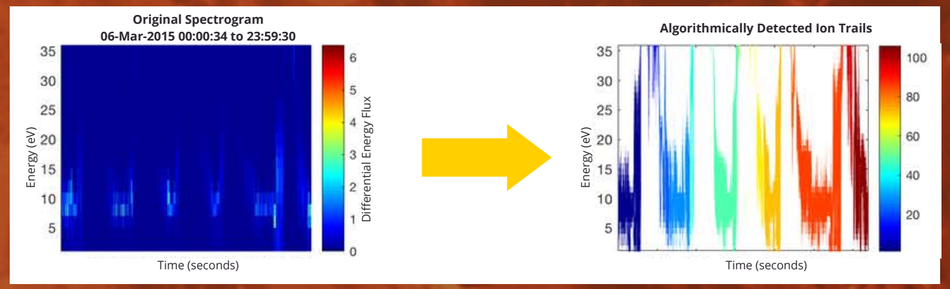

Figure 2. Algorithm performance detecting Martian ion trail

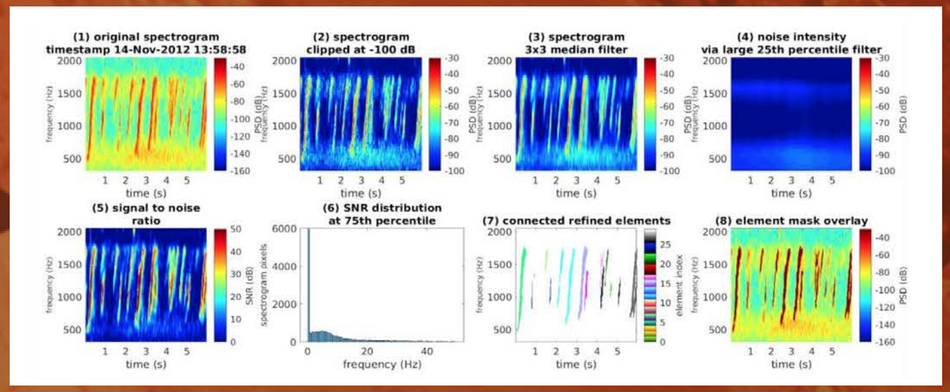

Figure 3. Steps of feature detection process demonstrated on a spectrogram of chorus elements in the Van Allen Radiation Belts

Conclusions

- Consistent identification of charged particle trails and low false detection rate (No trails detected where no trails were present)
- Next steps: Evaluating algorithm performance across larger collection of energy spectrograms
- Similar autonomous detection by method of geometric feature extraction can be applied to other NASA missions, as we see in *Figure 3* with EMFISIS data from the Van Allen Probes mission