Autonomous detection of whistler-mode chorus elements in the Van Allen radiation belts using morphological signal processing and pattern recognition techniques

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November 21, 2022

Abstract

Autonomous large-scale detection of whistler-ode chorus elements in the Van Allen radiation belts has been an open computational challenge. This is primarily due to: (i) Variability of the spectral morphology of chorus elements, and (ii) Structured background interference from hiss-like chorus that can make elements difficult to detect using traditional signal processing and pattern recognition techniques. We will present computational techniques drawing on pixel connectivity, signal-to-noise (SNR) considerations as well as supervised and unsupervised pattern recognition techniques. Specifically, we will explore the efficacy of popular machine learning techniques trained on unfiltered spectral images versus those trained on culled features generated by unsupervised feature extraction techniques. Representative results will be presented based on magnetic field measurements taken by the EMFISIS instrument suite in the Van Allen probes mission.

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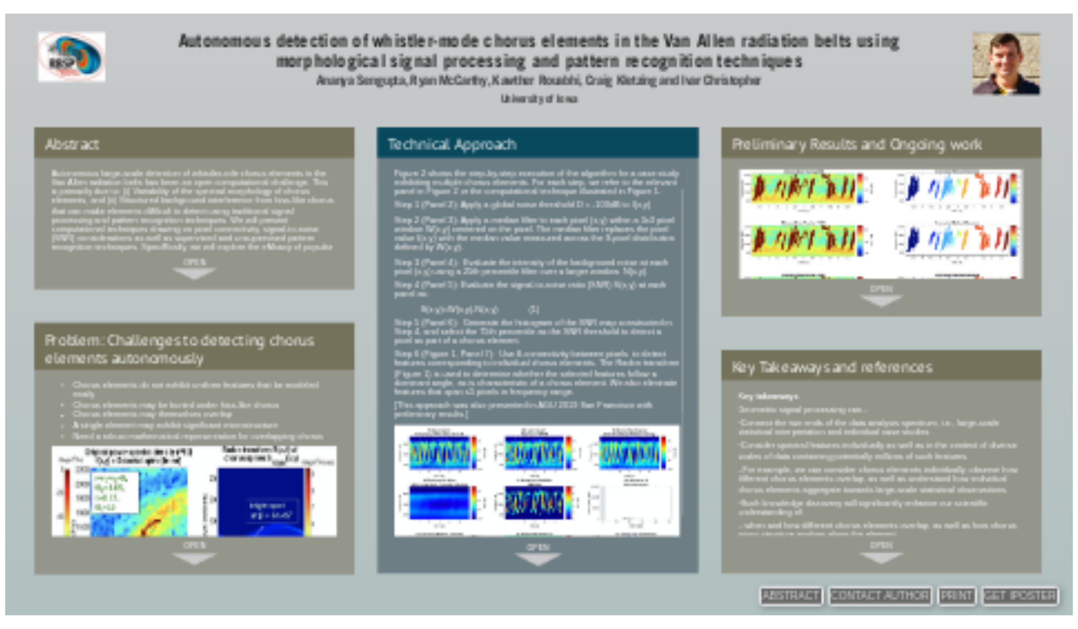

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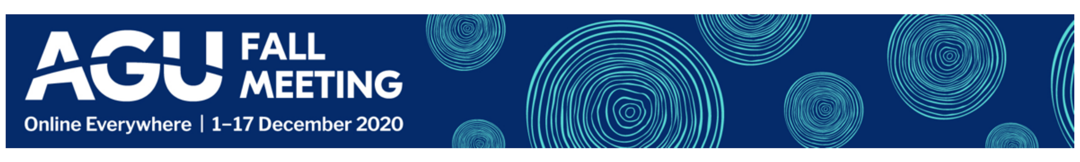

ABSTRACT

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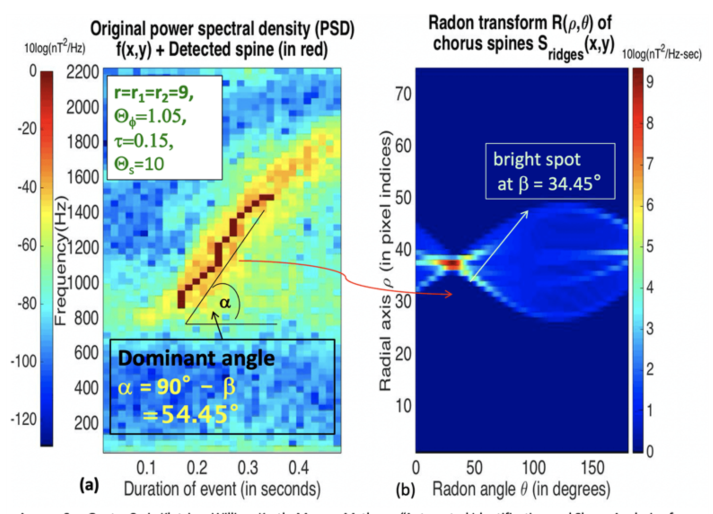
PROBLEM: CHALLENGES TO DETECTING CHORUS ELEMENTS AUTONOMOUSLY

- Chorus elements do not exhibit uniform features that be modeled easily
- Chorus elements may be buried under hiss-like chorus
- Chorus elements may themselves overlap
- A single element may exhibit significant microstructure
- Need a robust mathematical representation for overlapping chorus



Ananya Sen Gupta, Craig Kletzing, William Kurth, Morgan Matheny, "Automated Identification and Shape Analysis of Chorus Elements in the Van Allen Radiation Belts", AGU Journal of Geophysical Research – Space Physics, January 2018.

TECHNICAL APPROACH

Figure 2 shows the step-by-step execution of the algorithm for a case study exhibiting multiple chorus elements. For each step, we refer to the relevant panel in Figure 2 or the computational technique illustrated in Figure 1.

Step 1 (Panel 2): Apply a global noise threshold D = -100dB 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 (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:

$$S(x,y)=W(x,y)-N(x,y) \qquad (1)$$

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 a chorus element.

Step 6 (Figure 1, Panel 7): Use 8-connectivity between pixels to detect features corresponding to individual chorus elements. The Radon transform (Figure 1) is used to determine whether the selected features follow a dominant angle, as is characteristic of a chorus element. We also eliminate features that span ≤5 pixels in frequency range.

[This approach was also presented in AGU 2019 San Francisco with preliminary results.]

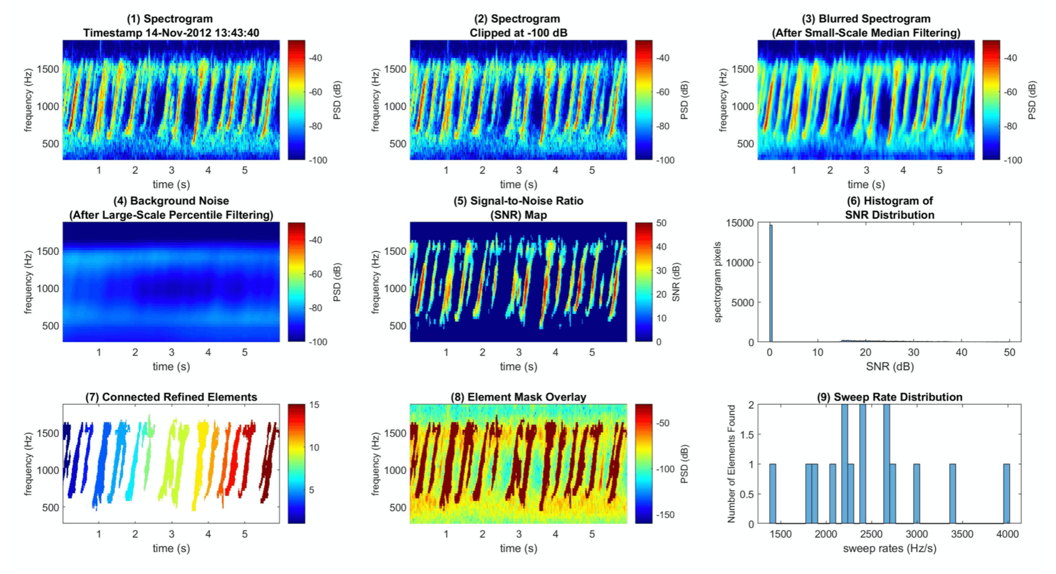


Figure 2. Panel showing algorithm run over a specific case study and histogram of sweep rates computed based on identified chorus elements.

Conclusions and Future Work

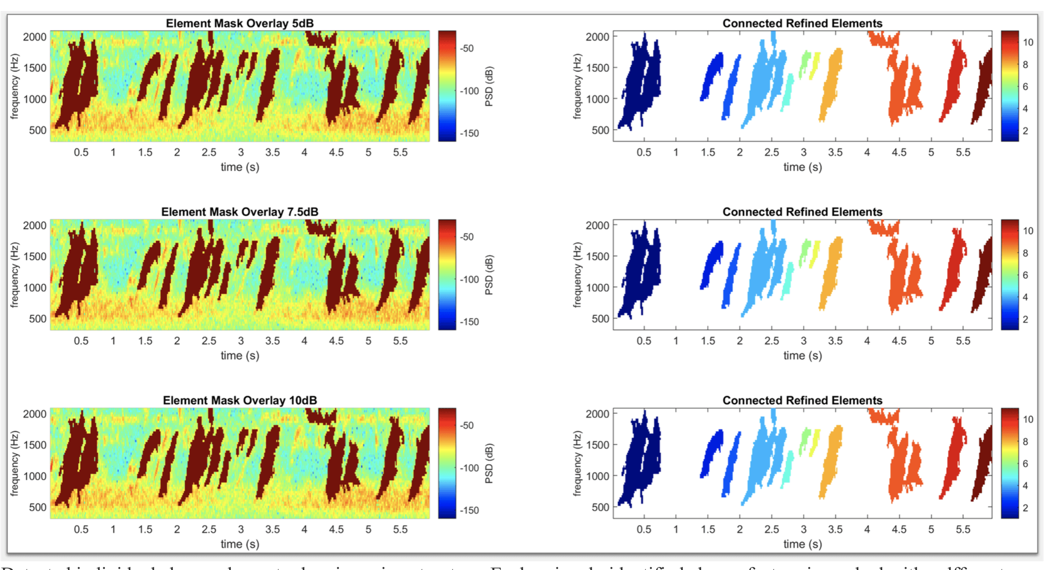
•Automated chorus element detection algorithm allows new types of studies of chorus

•Consistent identification of individual chorus elements, even in the presence of background hiss-like chorus

•Few false detects (No chorus detected where no chorus was present)

•Next steps: Validate algorithm performance across a larger portfolio of case studies

PRELIMINARY RESULTS AND ONGOING WORK



Detected individual chorus elements showing microstructure. Each uniquely identified chorus feature is marked with a dfferent color. We note that some overlapped chorus features are identified with the same color label as they are not separable given the data. [Sen Gupta, et al (under prep) to JGR 2020]

KEY TAKEAWAYS AND REFERENCES

Key takeaways

Geometric signal processing can...

•Connect the two ends of the data analysis spectrum, i.e., large-scale statistical interpretation and individual case studies

•Consider spectral features individually as well as in the context of diverse scales of data containing potentially millions of such features.

–For example, we can consider chorus elements individually, observe how different chorus elements overlap, as well as understand how individual chorus elements aggregate towards large-scale statistical observations.

•Such knowledge discovery will significantly enhance our scientific understanding of:

– when and how different chorus elements overlap, as well as how chorus micro-structure evolves along the element

– Bridge the ga between individual case studies of epochs containing chorus elements and large-scale statistical observations

References

[1] Ananya Sen Gupta, Craig Kletzing, William Kurth, Morgan Matheny, "Automated Identification and Shape Analysis of Chorus Elements in the Van Allen Radiation Belts", AGU Journal of Geophysical Research – Space Physics, January 2018.

[2] Sen Gupta, Ananya, Craig Kletzing, Ivar Christopher, and Kawther Rouabhi. "Autonomous Identification of the Morphology of Chorus Elements in The Van Allen Radiation Belts." AGUFM 2019 (2019): IN31C-0814.

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[4] Claudepierre, Seth, Joseph Fennell, Ananya Sengupta, and Craig Kletzing. "Automated Identification of Electron Microinjections in MMS/FEEPS Measurements: Initial Results." AGU (2019).

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