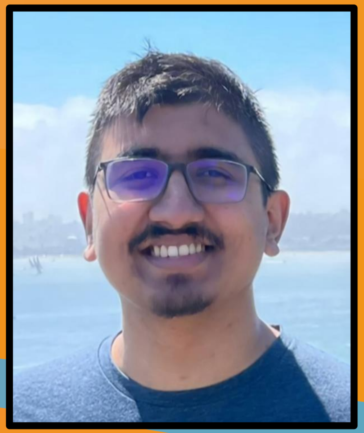
Flare Precursors in Acoustic Waves

Varun Chaturmutha[1], Bernhard Fleck[2], Stuart Jefferies[1,3]

[1] Georgia State University, [2] European Space Agency, [3] University of Hawaii

varun@astro.gsu.edu

Waves in the Lower Solar Atmosphere



WHY CARE WHAT THE SUN DOES?

Solar Flares

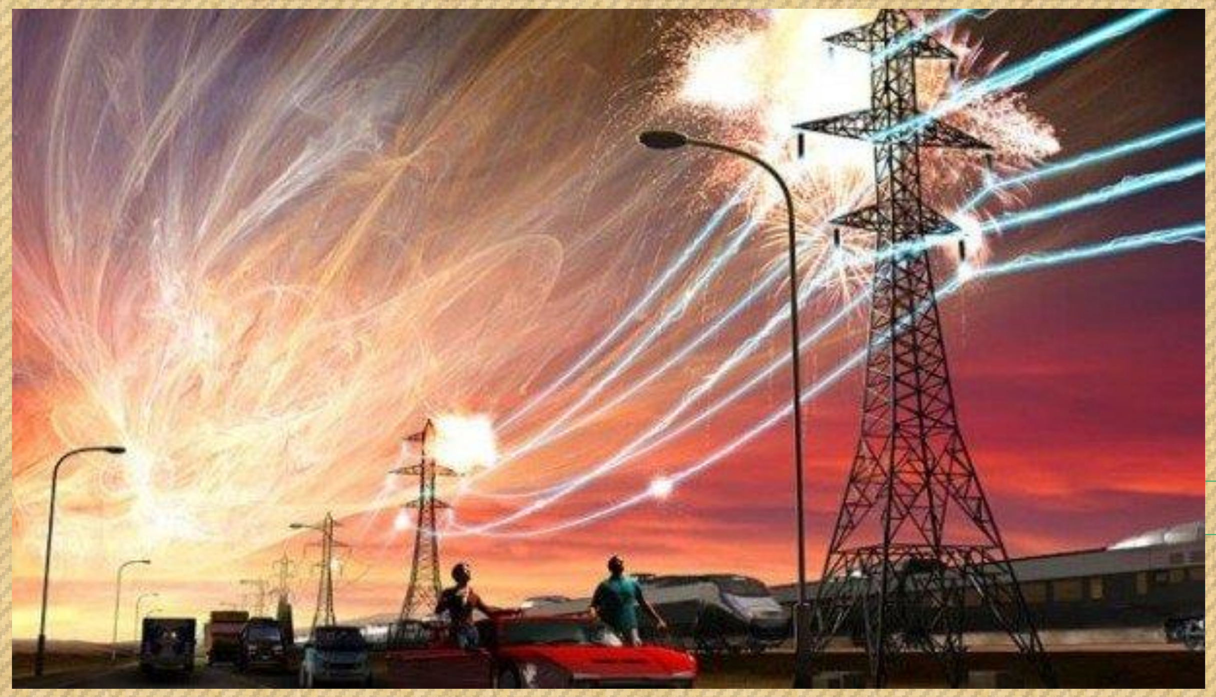


Figure 1: Sparks in electrical grids due to a geomagnetic storm

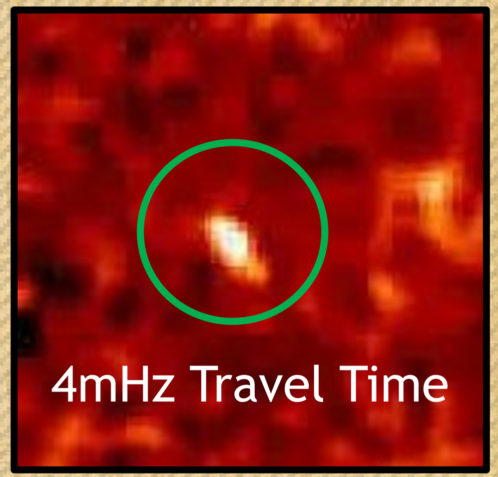
The sun is home to constant energetic eruptive events. Such events can destroy power grids, disrupt communication satellites, and pose health hazards to astronauts in space. In the modern age, predicting solar events is paramount for the survival and functioning of our civilization.

Current methods → ML (Deep Flare Net and Flarecast)

→ Susceptible to false positives and false negatives

WHAT IS MY NEW APPROACH?

Figure 2: 4mHz travel time map [1]. Courtesy: Stuart Jefferies



1. *Acoustic Cutoff Frequency (ACF):* 2-3 hours before a flare erupted on Jan 17, 2003, 4mHz waves escaped into the upper atmosphere. This suggest that the acoustic cutoff frequency (ACF), the frequency below which waves become evanescent, must have changed pre-flare. Therefore, ACF could act as a strong flare precursor!

2. *Travel time variation:* Figure below shows the temporal evolution of travel-times for the 6.5 mHz wave prior to a flare (red). The travel-time for the flaring region (green) shows instabilities ~8 hours before (yellow highlight) the flare erupts. The dashed line represents the timestamp before which travel-time measurements are not affected by the flare. Travel times are calculated using MOTH Na and K Doppler velocity data. This was observed in 11 out of the 13 flares under study.

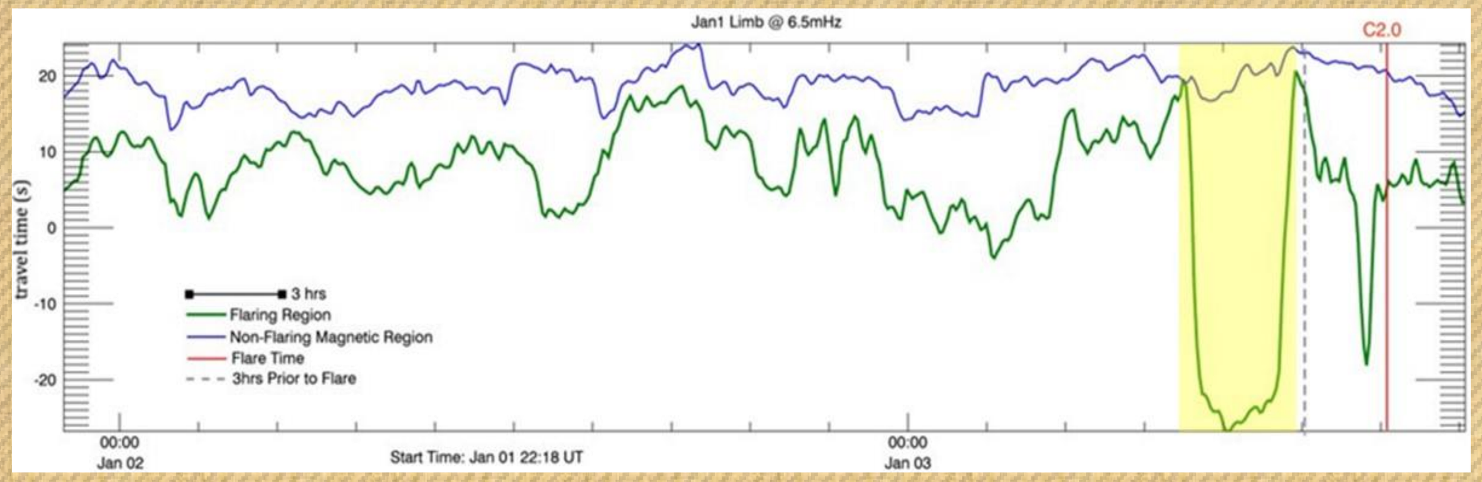


Figure 3: 6.5 mHz travel time evolution (Venkataramanasastry, PhD Thesis, 2022)

ANALYSIS

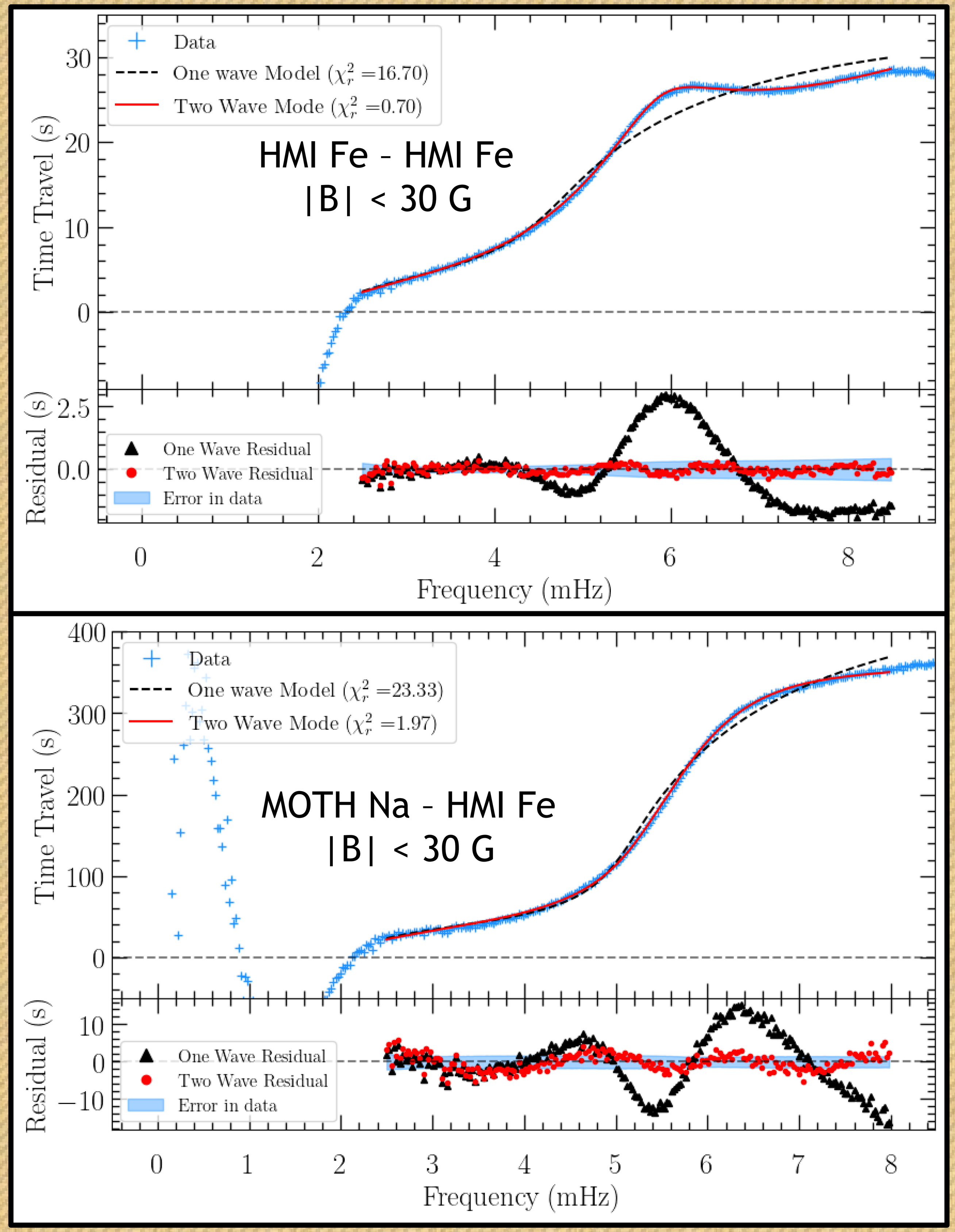


Figure 4.: Observed travel times (blue) measured using (a) HMI Fe - HMI Fe Doppler velocity data and (b) MOTH Na - HMI Fe. Black lines shows a fit for two different wave propagation model. (Chaturmutha et al. 2023 (*in prep*))

1. The observed travel time between two different heights in the solar atmosphere can be modeled to extract the acoustic cutoff frequency [2].
2. Figure 4. shows observed travel times. They are modeled using a single wave traveling upward (shown in black; [3,4]).
3. Upon including a downward traveling wave in addition to an upward traveling wave, we achieve a more accurate wave propagation model (red).

RESULTS

1. The acoustic cutoff frequency for the HMI Fe - HMI Fe data set was measured to be 6.1mHz whereas that for MOTH Na - HMI Fe was 5.5 mHz. Magnetic fields undergo fluctuations before a flaring event that induces changes in the ACF. Thus, ACF can be a sensitive flare precursor and we have a tool to measure that on the Sun.
2. We measure a reflection coefficient of ~20%. This has implications to the energy budget of atmospheric heating.

FUTURE WORK

1. Extend wave propagation analysis to high magnetic field regions.
2. Monitor the temporal evolution of ACF in flaring and non-flaring datasets.
3. Analyze the temporal evolution of 6.5 mHz trave times in flaring and non-flaring datasets to verify Venkataramanasastry, PhD Thesis, 2022 preliminary analysis.
4. SDO/HMI has recorded over 8000 flares since 2010. We aim to acquire SDO/HMI filtergrams to extract multi-height Doppler velocity data in flaring and non-flaring regions.
5. Use SDO/HMI decade+ data to measure monitor ACF variation in pre-flaring regions and travel times of 6.5 mHz waves.

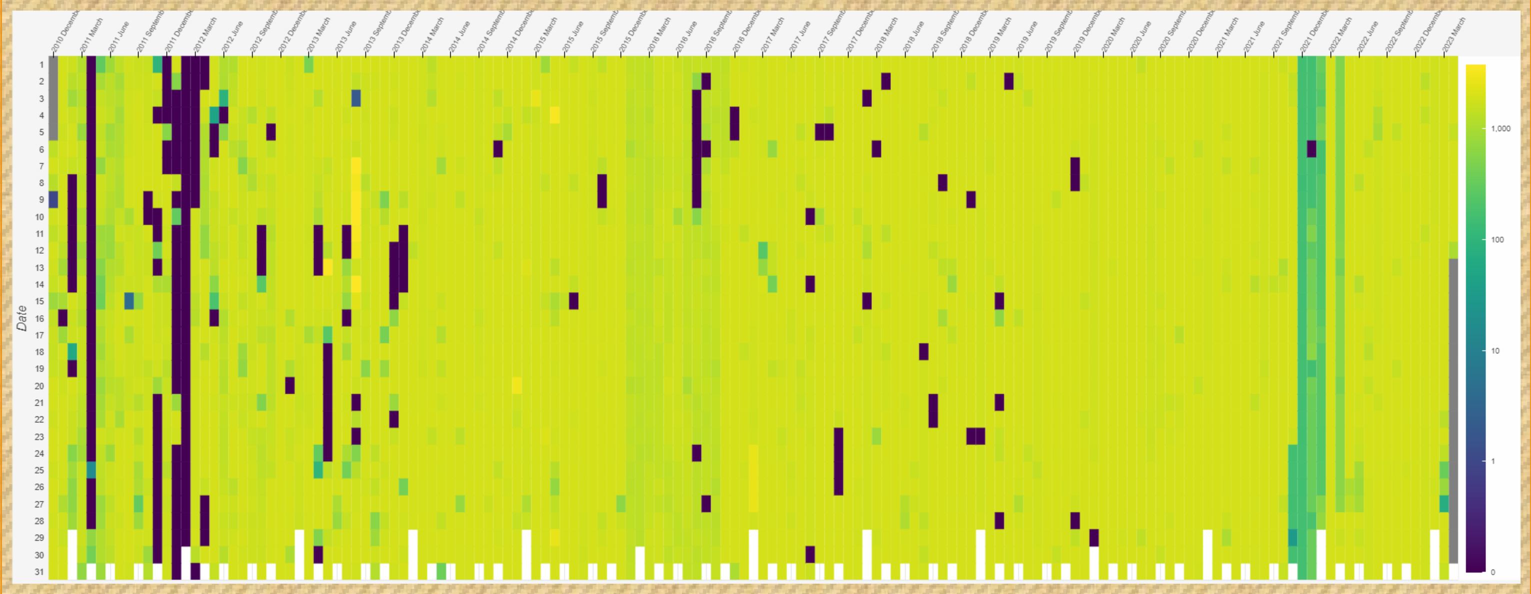


Figure 5: Coverage map of SDO/HMI instrument from 2010-2023. (Courtesy: Varun Chaturmutha, The Helioviewer Project https://api.helioviewer.org/statistics/bokeh)

REFERENCES

[1] Finsterle, W., Jefferies, S. M., Cacciani, A., Rapex, P., & McIntosh, S. W. 2004, ApJL, 613, L185
[2] Jefferies, S. M., Fleck, B., Murphy, N., & Berrilli, F. 2019, ApJL, 884, L8
[3] Mihalas, B. W., & Toomre, J. 1982, ApJ, 263, 386
[4] Souffrin, P. 1972, A&A, 17, 458

ACKNOWLEDGEMENTS

I'd like to thank the Department of Physics and Astronomy at Georgia State University for funding my graduate studies. The department has also provided support for my travel to the AGU Fall 2022 meeting. Special thanks to my advisors: Dr. Stuart Jefferies and Dr. Bernhard Fleck.

Website: astro.gsu.edu/~varun

Linkedin: vchaturmutha

Email: varun@astro.gsu.edu