Complexity analysis of a Compact Torus injection experiment on BRB

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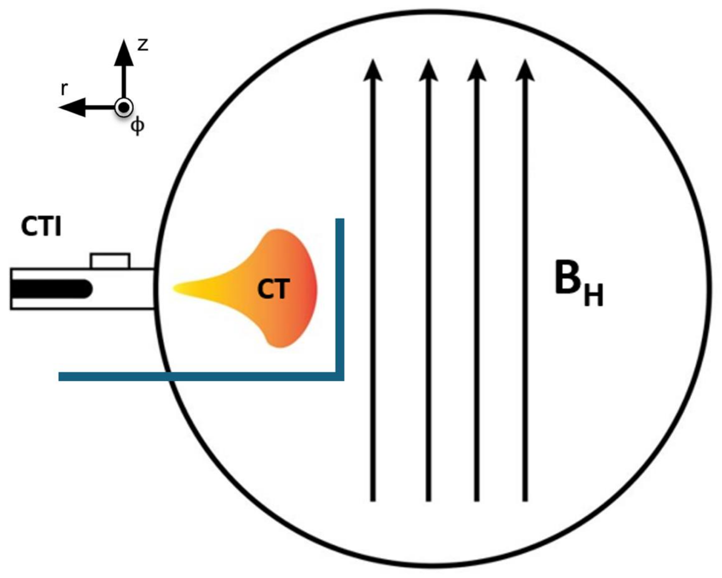
Motivation

Compact Torus injection experiments at the Big Red Ball (BRB) facility at the University of Wisconsin – Madison were conducted to create repeatable, scaled interplanetary coronal mass ejections (ICMEs) in the lab. ICMEs are the source of geomagnetic storms and can cause damage to satellites and electrical systems. Creating accurate scaled ICMEs increases the wealth of data that can be used to increase predictive power of space weather models. This research is to further investigate the parity between the experimental plasma and the space plasma.

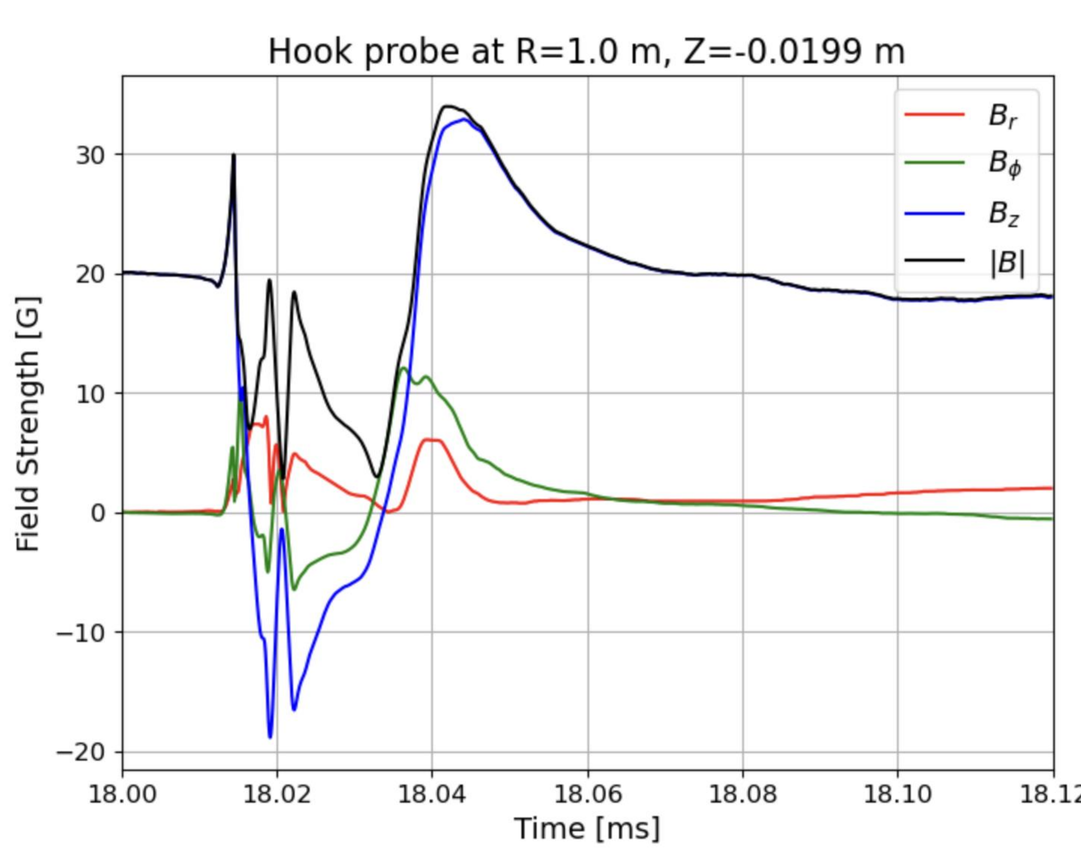
Experiment

Experiment was in creating a scaled analog to an ICME event



- The experiment was conducted by injecting a compact torus of plasma into a magnetized background plasma
- The experiment was diagnosed using a Bdot probe array and Langmuir probe

We analyzed the data from 30 shots in the experiment



- We gather the three components of magnetic field and magnitude as functions of time

Entropy and Complexity

- *n* consecutive elements in time series are noted in ascending order to make ordinal patterns
- Counting the occurrences of each pattern makes a probability distribution that is used to calculate entropy
- Jensen-Shannon Complexity is formulated using entropy and the probability distribution

X = {2,7,3,5,1,8,4}
n = 3

grouped elements = (2,7,3), (7,3,5), (3,5,1), (5,1,8), (1,8,4)

ordinal patterns = (0,2,1), (2,0,1), (1,2,0), (1,0,2), (0,2,1)

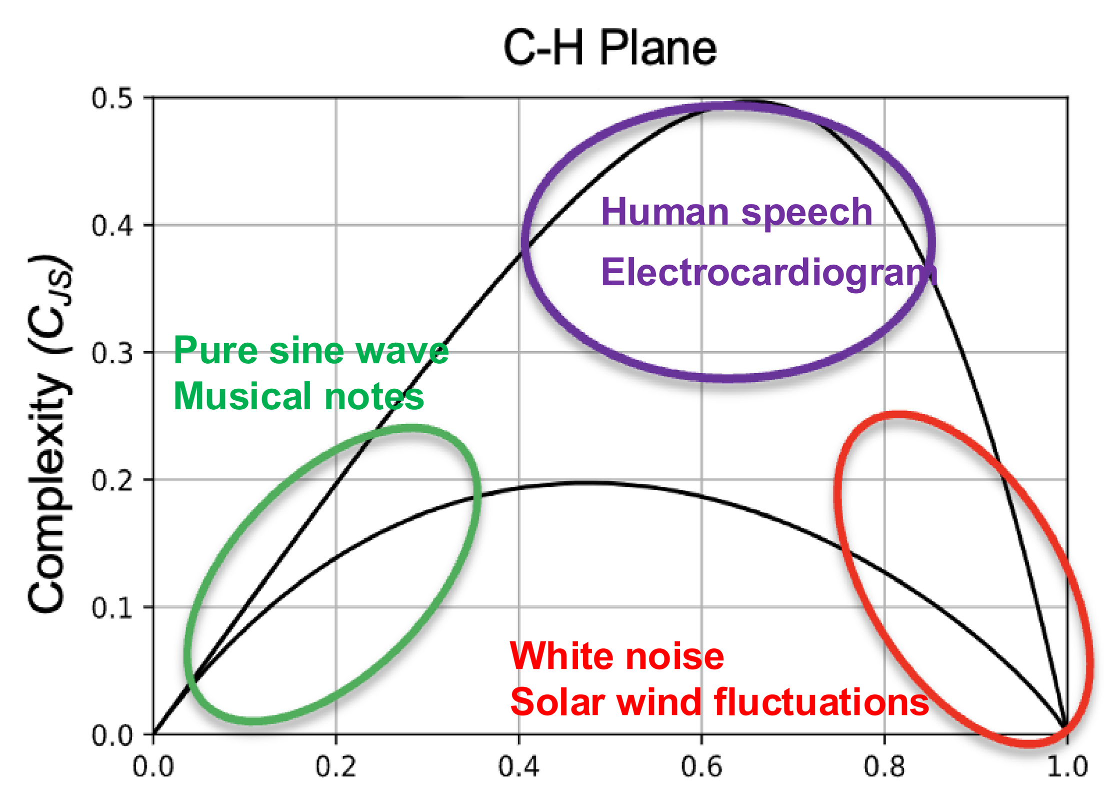
$$S = -\sum_{\pi}^{N} p(\pi)\, log_2\, p(\pi)$$

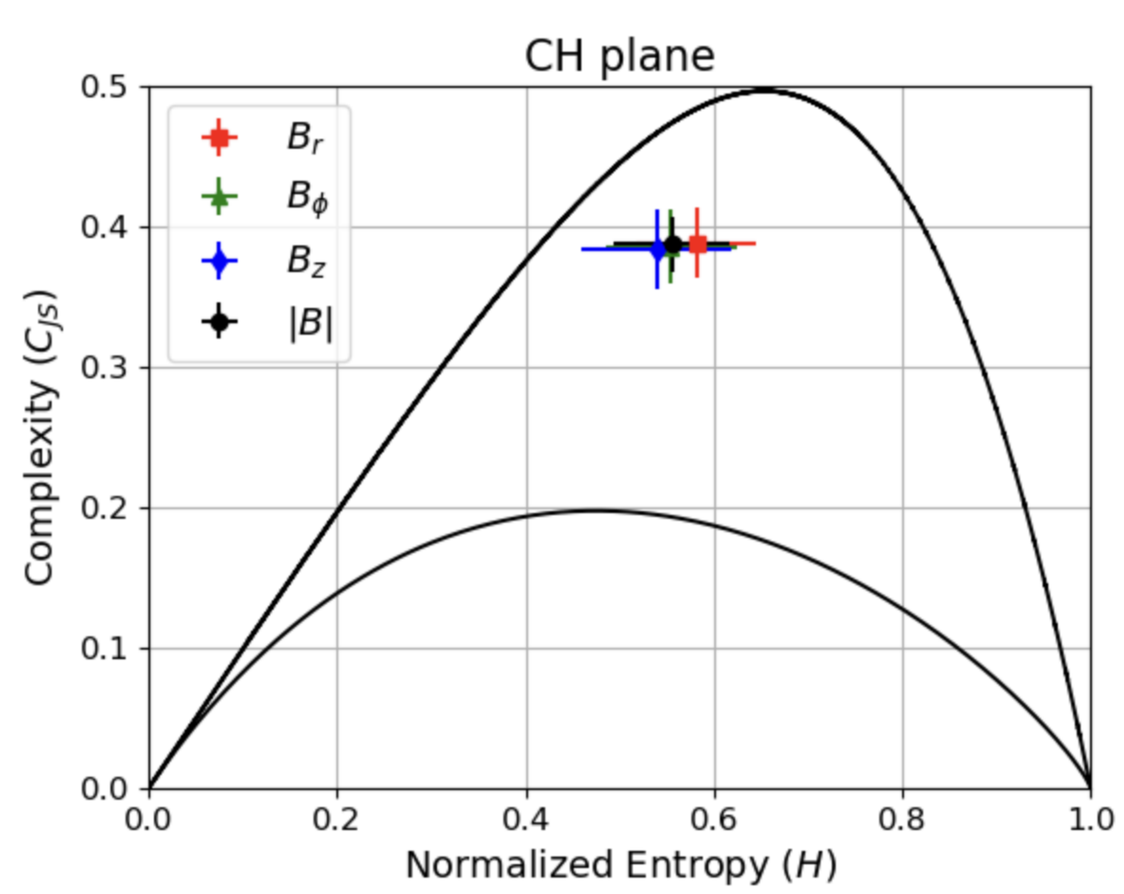
$$P = p(\pi) \qquad H[P] = \frac{S[P]}{\log_2 N}$$

$$P_e = \left\{\frac{1}{N}, \ldots, \frac{1}{N}\right\}$$

$$C_{JS}[P] = -2H[P]\left(\frac{S\left[\frac{P+P_e}{2}\right] - \frac{1}{2}S[P] - \frac{1}{2}S[P_e]}{\frac{N+1}{N}log_2(N+1) - 2\,log_2(2N) + log_2(N)}\right)$$

- The Complexity – Entropy (C–H) plane is used to determine whether a time series is periodic, stochastic, or chaotic.





Complexity Delay

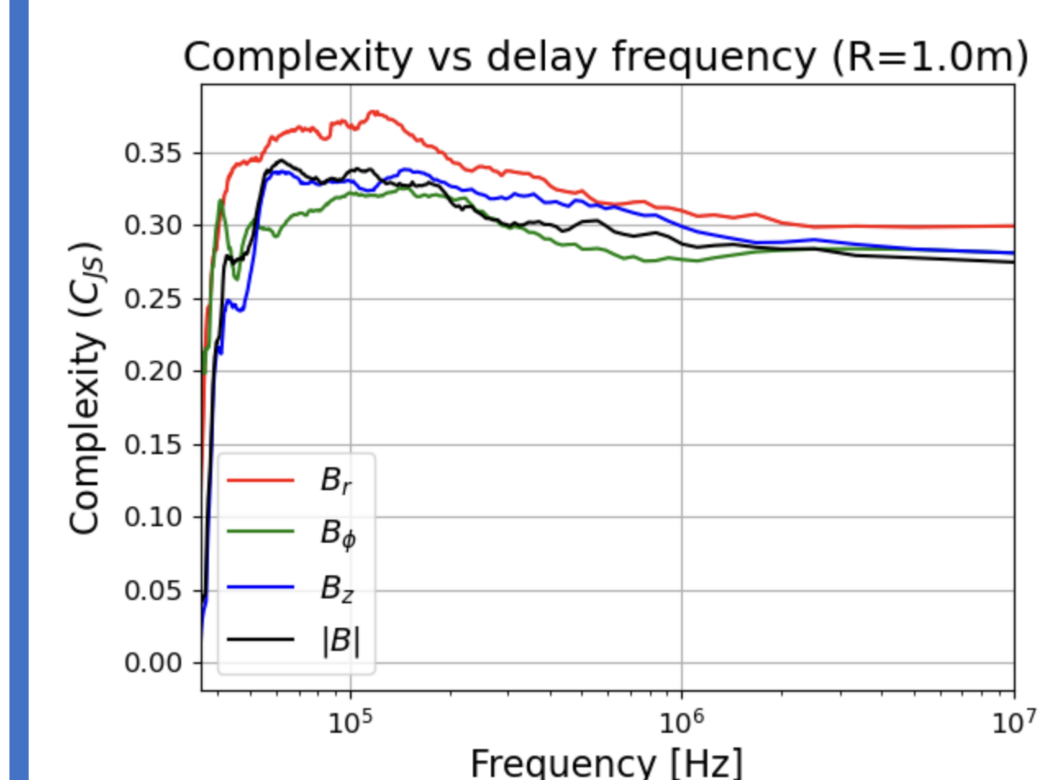
- The plots show that our experimental plasma is very chaotic
- We set out to find out why the complexity is so high in contrast to the solar wind that is very stochastic

How do we get complexity as a function of frequency?

- Instead of using consecutive elements in the time series to find entropy/complexity, skip every other element, every 2 elements, etc.
- The skipping results in a "delayed" sampling frequency
- We calculate the complexity with each "frequency" for every time series

X = {2,7,3,5,1,8,4}
n = 2, delay=1

grouped elements = (2,3), (7,5), (3,1), (5,8), (1,4)



- The complexity has a broad peak at around 100KHz
- We investigated frequencies that we calculated from measured parameters in the experiment

Frequency	Background	CT
Electron collision	$(3.05\times10^2)\pm5.23$ kHz	$(4.03\times10^2)\pm6.09$ kHz
Ion collision	$5.03\pm(8.62\times10^{-2})$ kHz	$6.21\pm(7.55\times10^{-2})$ kHz

Gyrofrequency	lower limit	upper limit
Electron	1.76×10^5 kHz	7.03×10^5 kHz
Ion	3.84×10^2 kHz	9.60×10^2 kHz

Conclusion

Collisional and gyrofrequencies do not correspond to the frequencies of maximized complexity, implying that something else may be causing the high complexity in the experimental plasma

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