Interactions Between Coronal Mass Ejections

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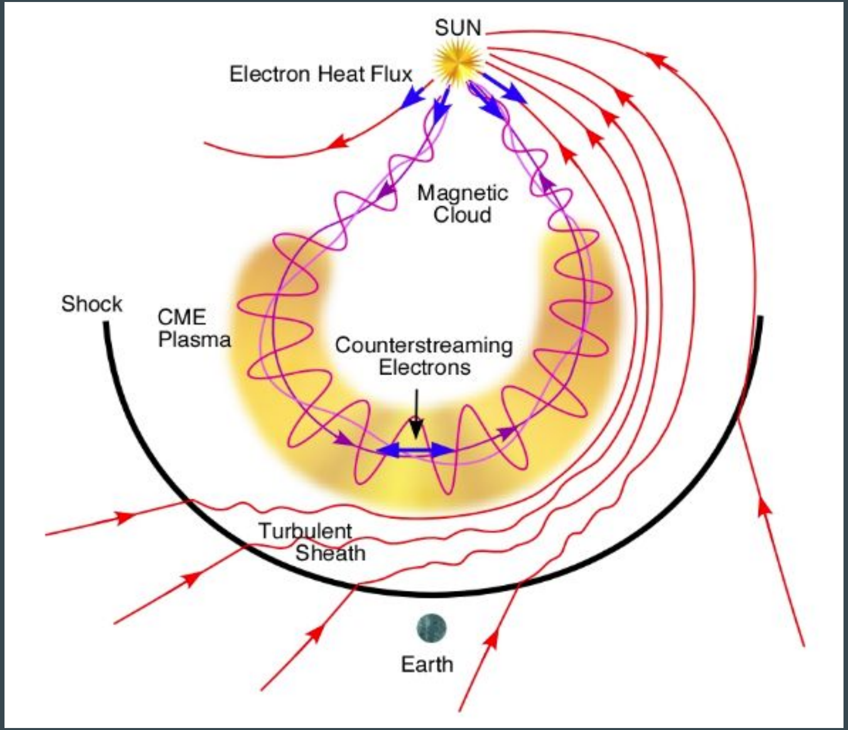
Outline

- Introduction to Coronal Mass Ejections
- The importance of studying interacting CMEs
- Our methods
- Example events
- Statistical Analysis
- Conclusions
- Future work
- Questions

What is a Coronal Mass Ejection?

- A cloud of magnetized solar material that erupts from the Corona
  - Mass of ~10^{16}g
  - Speed of 400 - 3000 km/s
  - Up to 0.5 AU wide
  - Becomes an ICME once it reaches the interplanetary medium
  - Takes 3.5 days on average to reach Earth
- Interactions between CMEs
  - Interaction must happen before 1 AU
  - The CME in front “clears the path” for the one behind it
- CMEs can interact within variable SW



Zurbuchen 2005

Why study interacting CMEs?

- CMEs are physically interesting
    - The largest structures produced by the Sun
    - CMEs can interact with Earth's magnetosphere
    - CMEs can interact with any other body in space
    - Plasma in space conditions
- CMEs are dangerous
    - Magnetic reconnection
    - Geomagnetic storms
    - Carrington Event
- Interacting CMEs are more dangerous
    - Following CMEs are faster (less interaction, magnetic field strength and bz are important)

Our Method

- Plot known ICMEs (1997 - 2015: 303 ICMEs)
  - Magnetic field, flow speed, proton density, temperature from the Wind spacecraft
  - Use the plots to determine candidates for interaction
  - Create a list of ICME data from the Wind and SOHO spacecraft
- Compute the “seesaw” parameter
  - Helped us detect significant changes in the data
  - Used to identify interactions in the solar wind, not to identify CMEs
- Perform wavelet analysis
  - Using the Morlet wavelet method to determine the complexity of the structures

The seesaw parameter

- Two sets of data: local and global
- Computing the local data

$$l = \frac{\sigma_{40}}{m_{15}}$$

- Computing the global data

$$g = \frac{\sigma_{40}}{m_1}$$

- Normalizing and joining them together

$$s = \sqrt{l^2 + g^2}$$

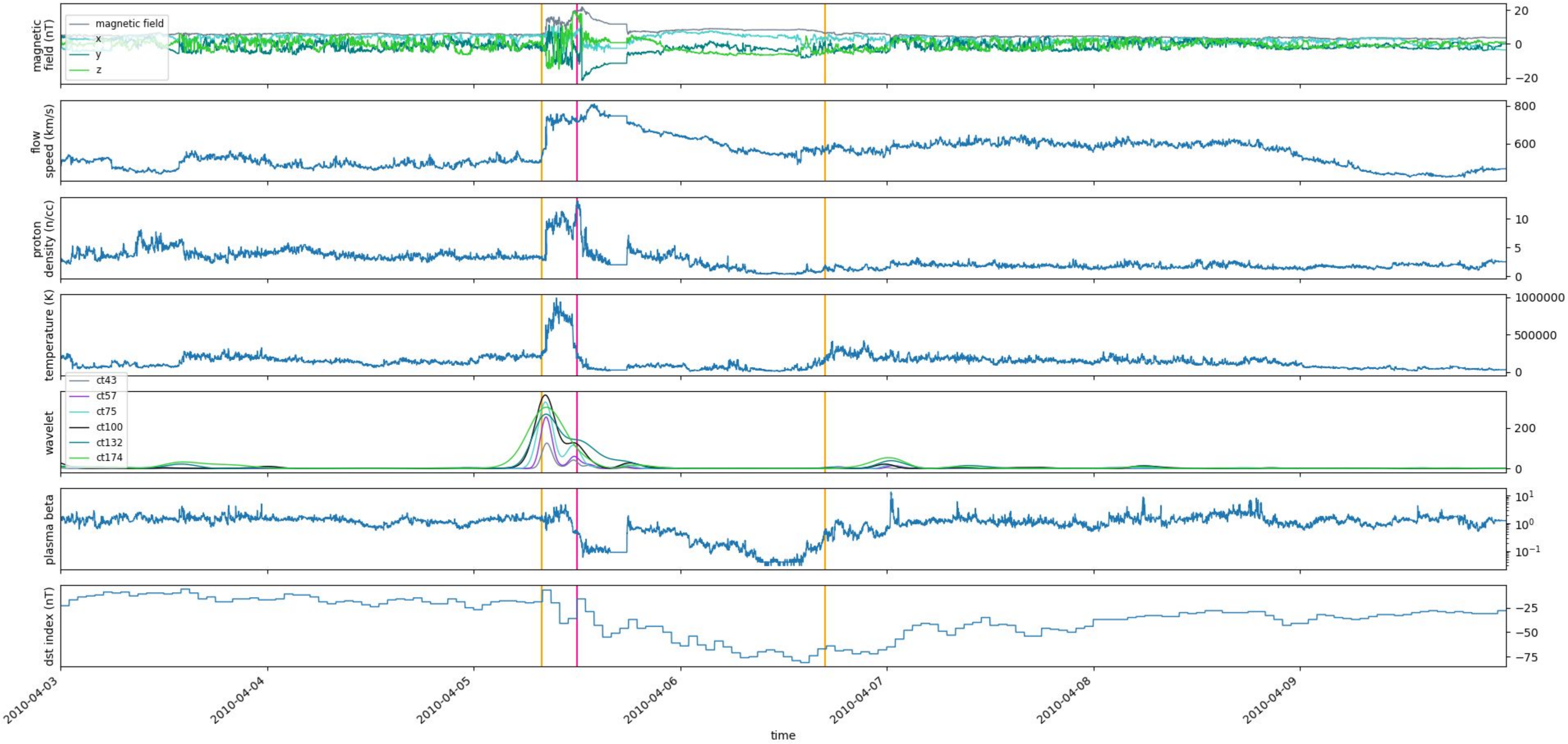
Applying the wavelet method

- Add the four seesaw parameters together

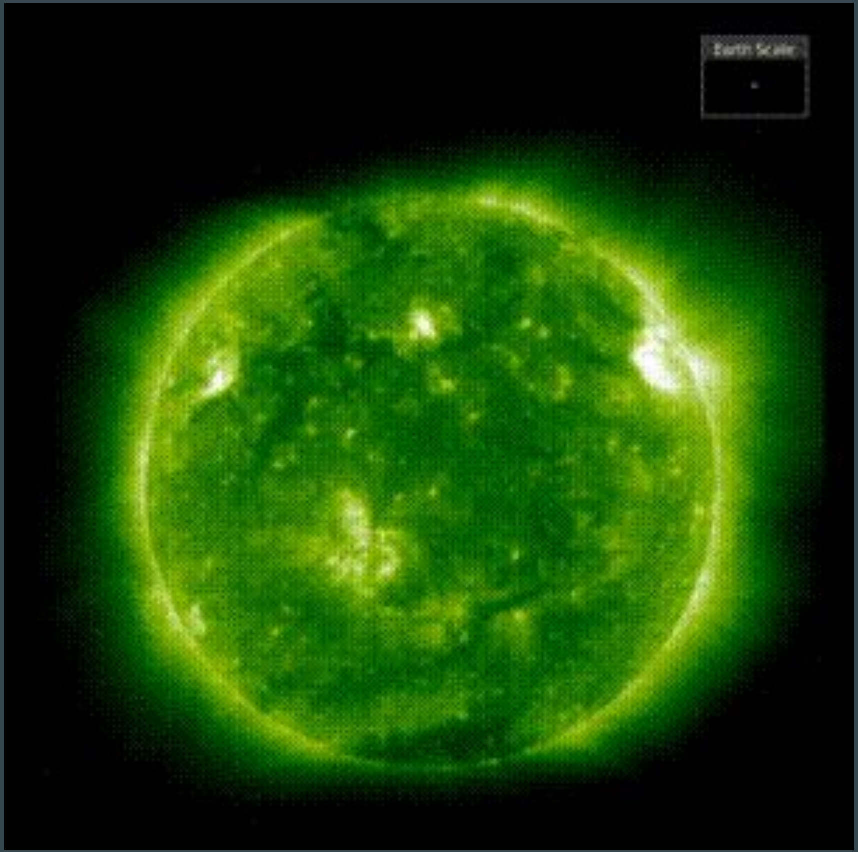
$$s_w = s_{mf} + s_v + s_d + s_t$$

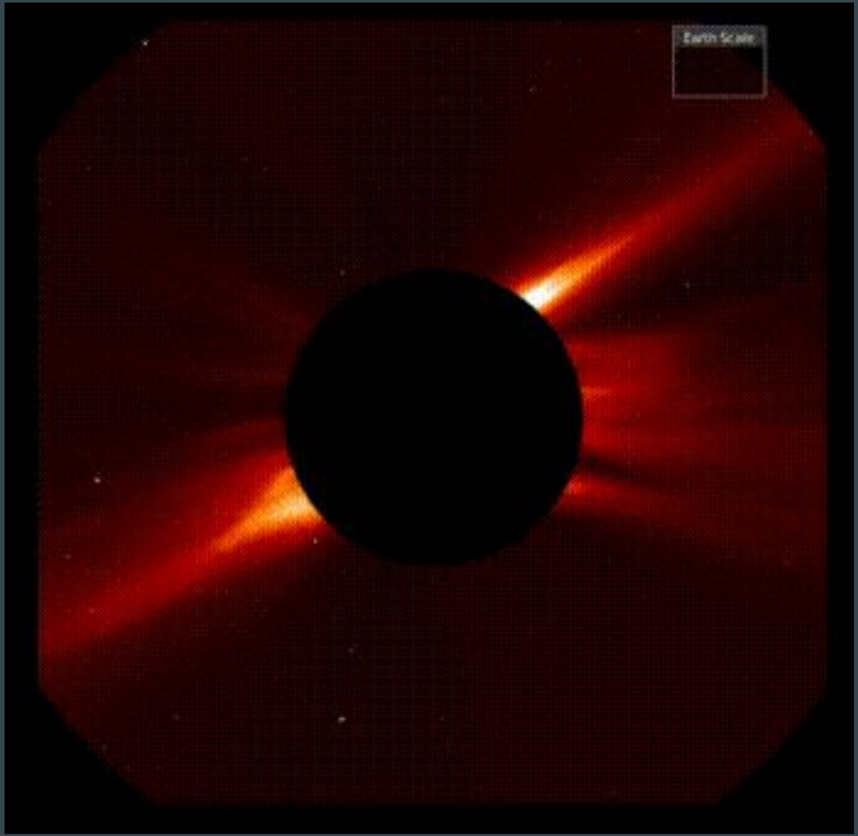
- Apply the Morlet wavelet method to the resulting curve

Single CME Example: April 4th, 2010



Remote sensing data: April 4th, 2010



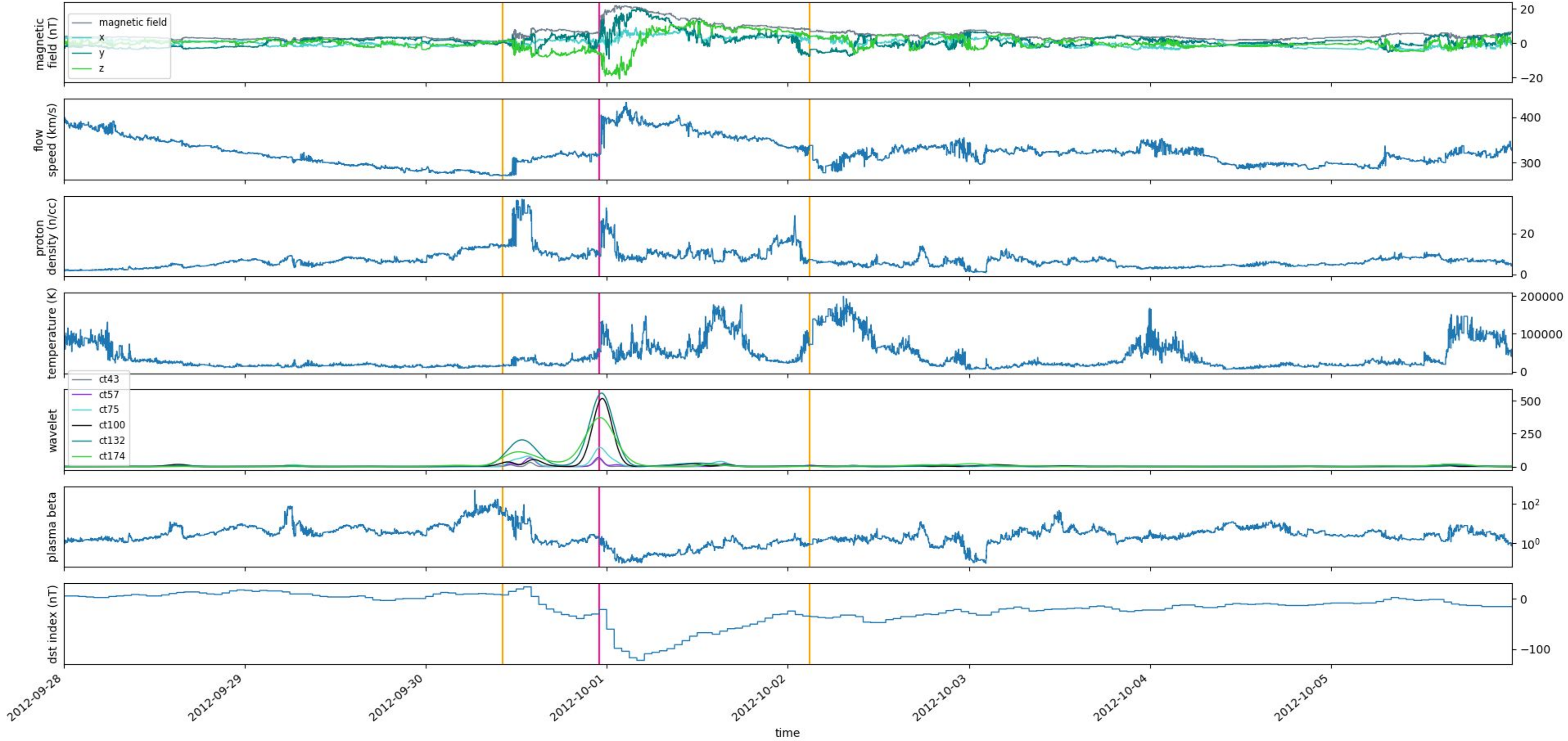


Complex events

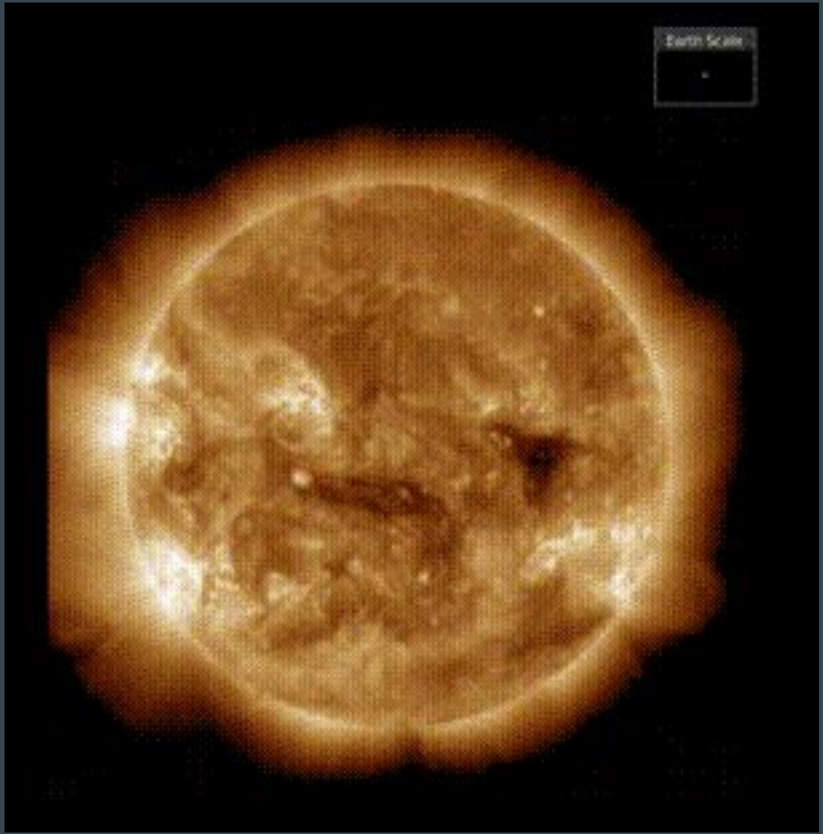
- Single CME with non-uniform solar wind
- Multiple CMEs with uniform solar wind
- Multiple CMEs with non-uniform solar wind

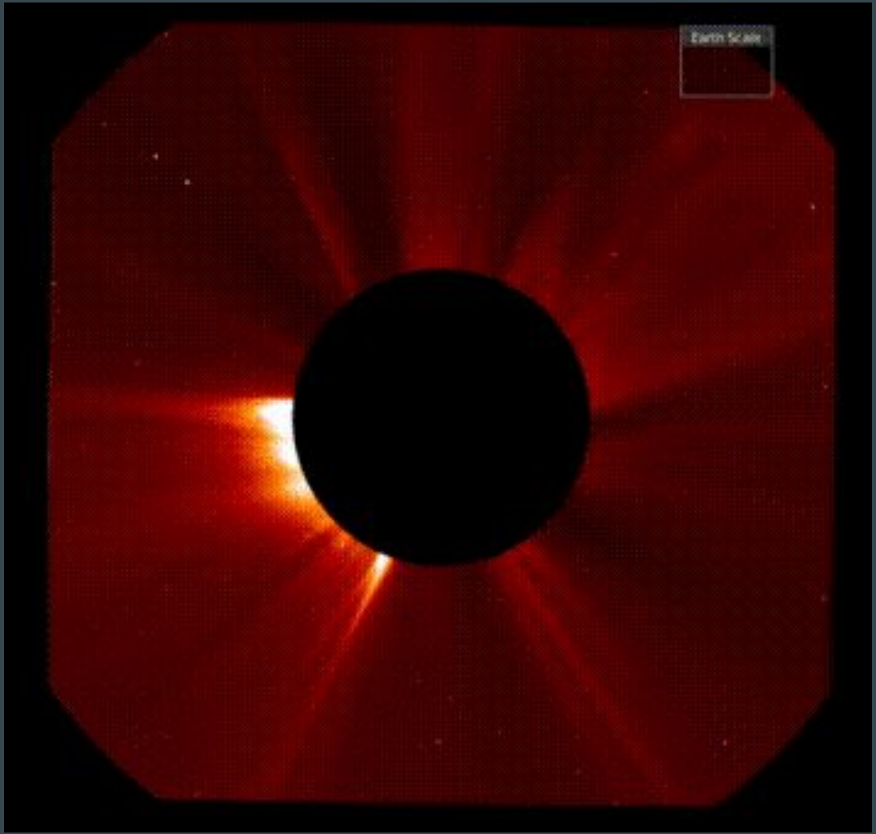
Note: An event can have two magnetic clouds within the same period of the reported event

Complex CME example: September 30th, 2012

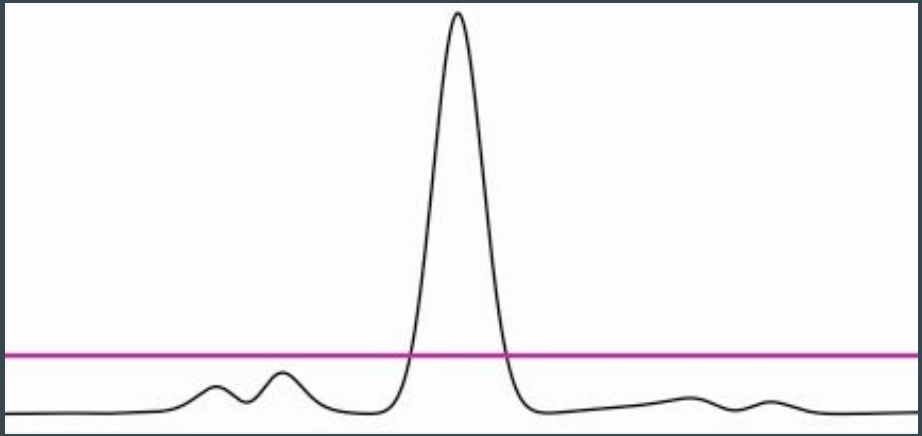


Remote sensing data: September 30th, 2012



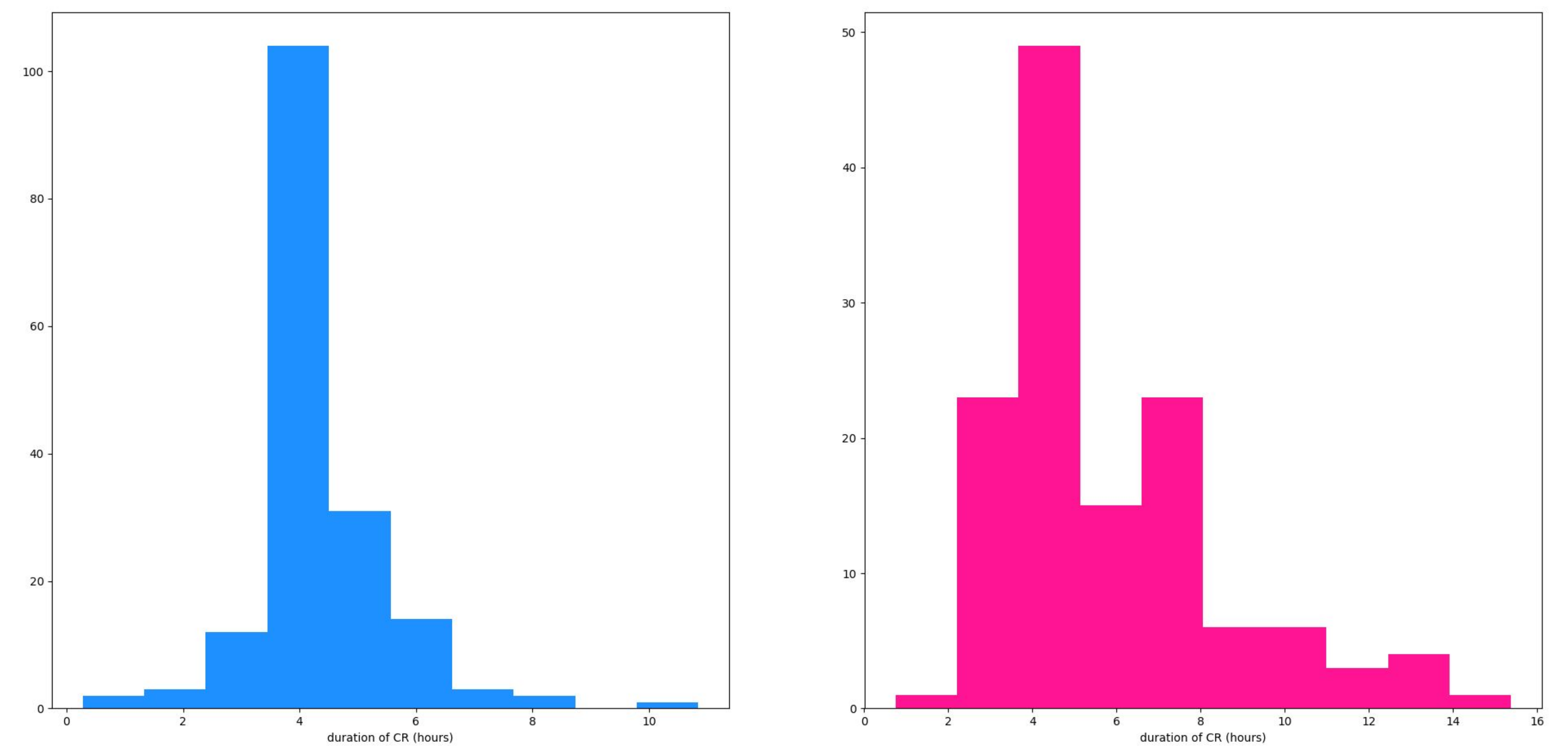


Statistical Analysis

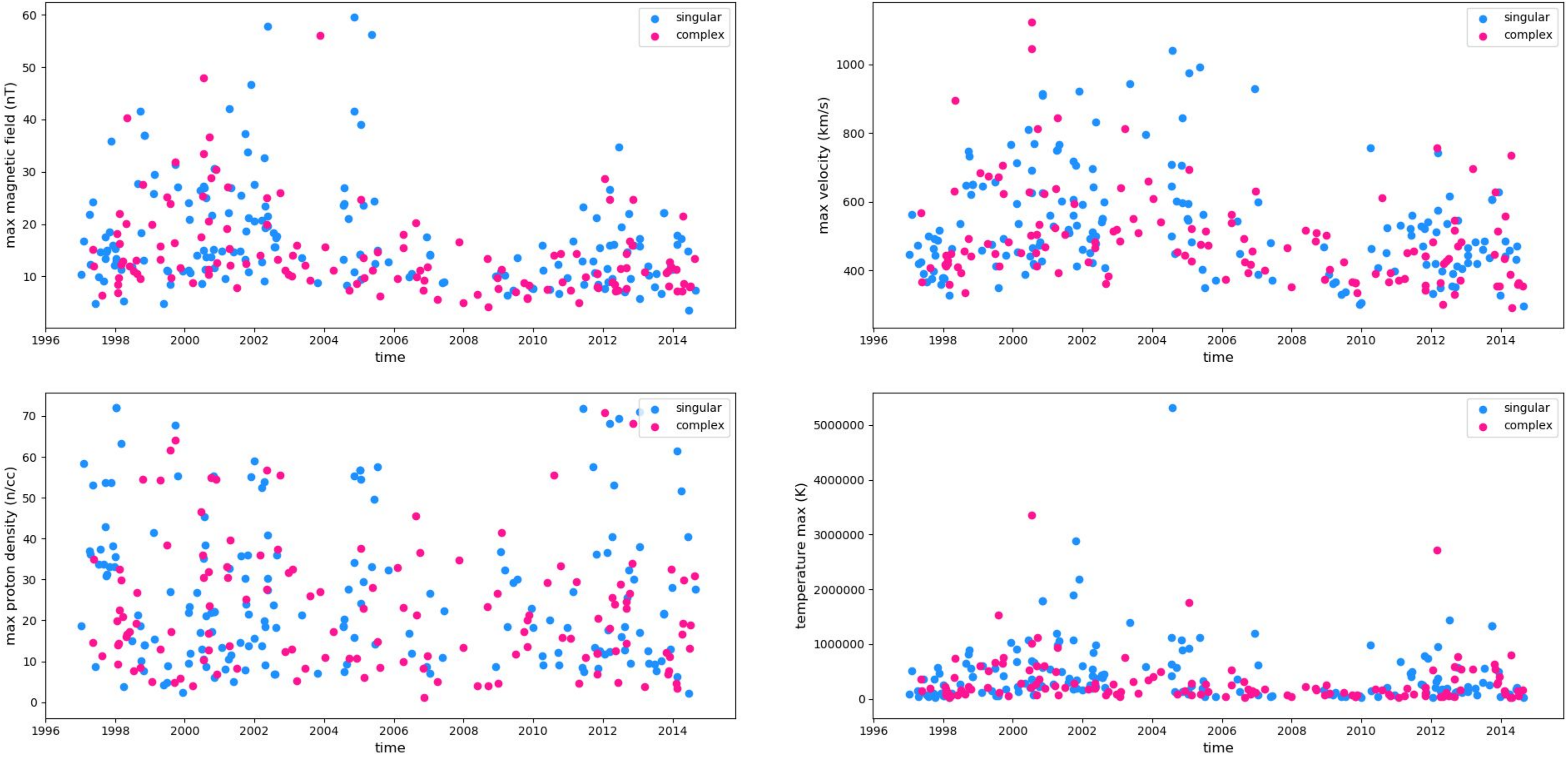


- Computing the compression region
  - maximum * 0.25 = threshold
- The number of wavelet peaks signifies complexity
- Out of the 303 events, 52 events had more than 2 peaks

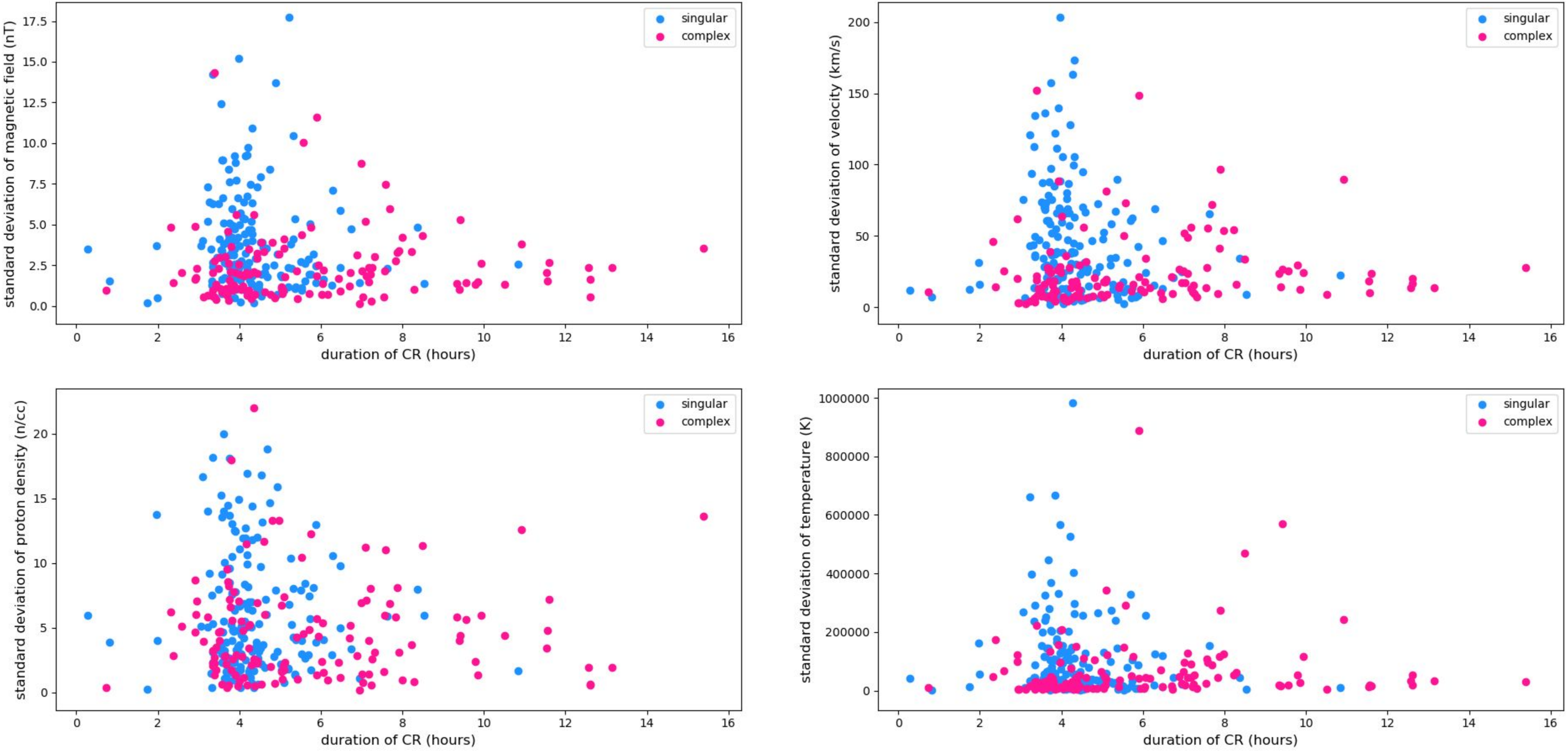
Duration of the compression region



Maximums over time



Standard deviations vs duration of the compression region



Conclusion

Using the wavelet method, we are characterizing the compression regions of the ICMEs identified by Wind spacecraft from 1997 - 2015 to determine their complexities.

Future work

- Making a hydrodynamical numerical model to prove the complexity of our events
- Presenting finalized lists of singular and complex structures for further analysis
- Based on our statistical analysis, we will attempt to identify events in which two or more ICMEs are involved

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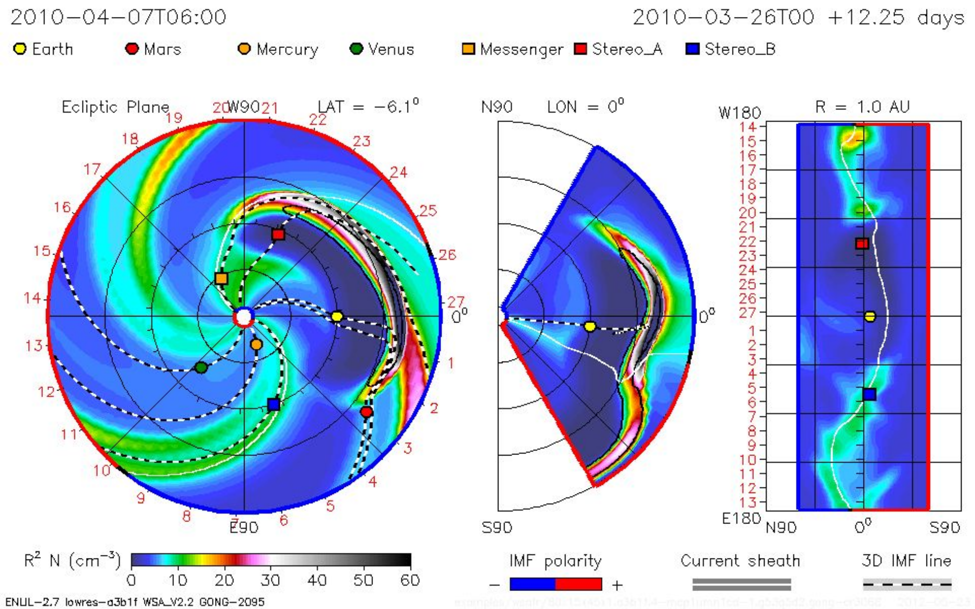
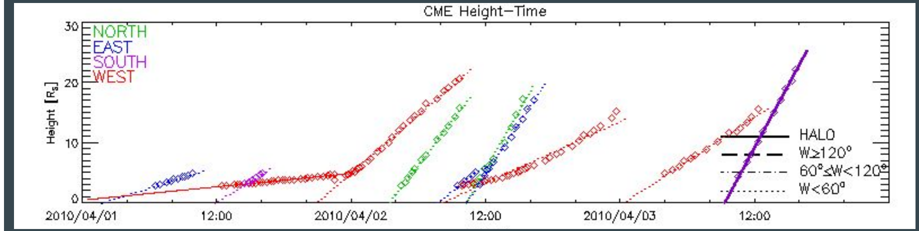
Questions?

Computing the seesaw parameter

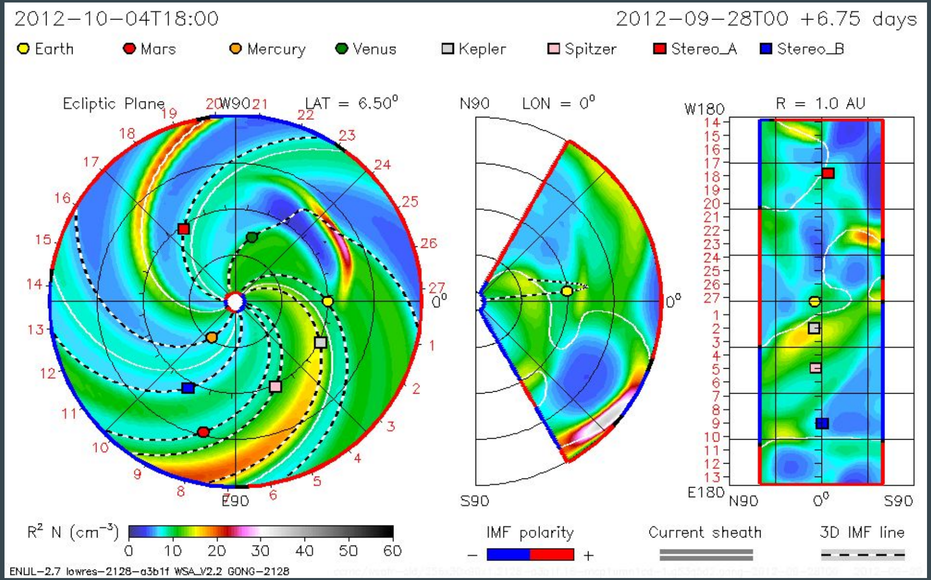
- We will have two sets of data: local and global
- Computing the local data
  - Create a 40-minute window around each data point and calculate the standard deviation
  - Create a 15-day window around each data point and calculate the mean
  - The local value for any given data point is the stdev / mean
- Computing the global data
  - Also uses a 40-minute window
  - Uses a 1-year window for the mean
  - Global values are calculated similarly
- Join the local and global data together using the distance formula to find the seesaw parameter

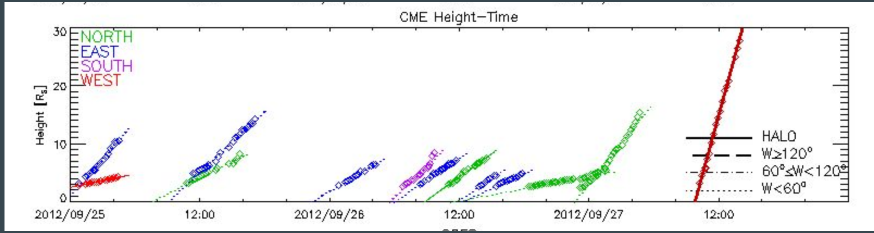
April 4th, 2010

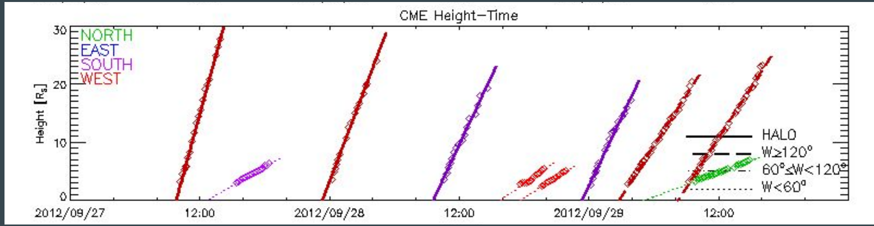


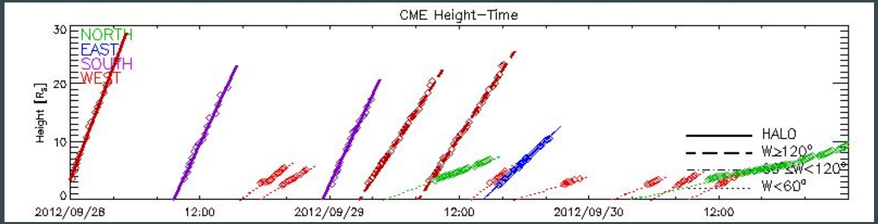


September 30th, 2012

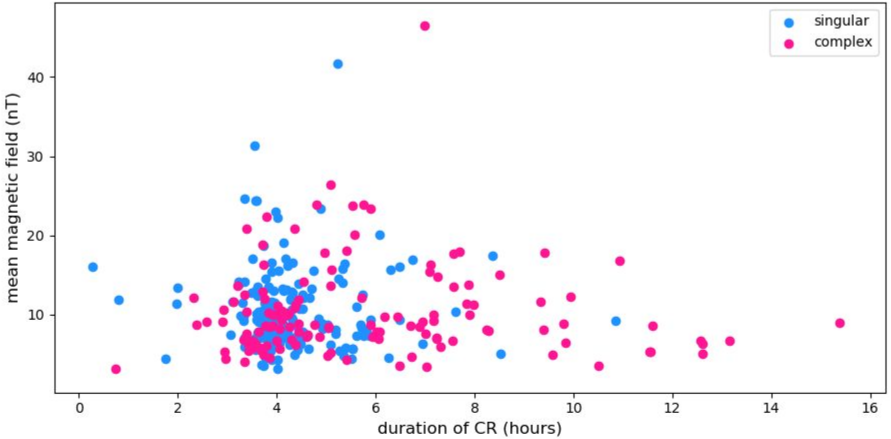


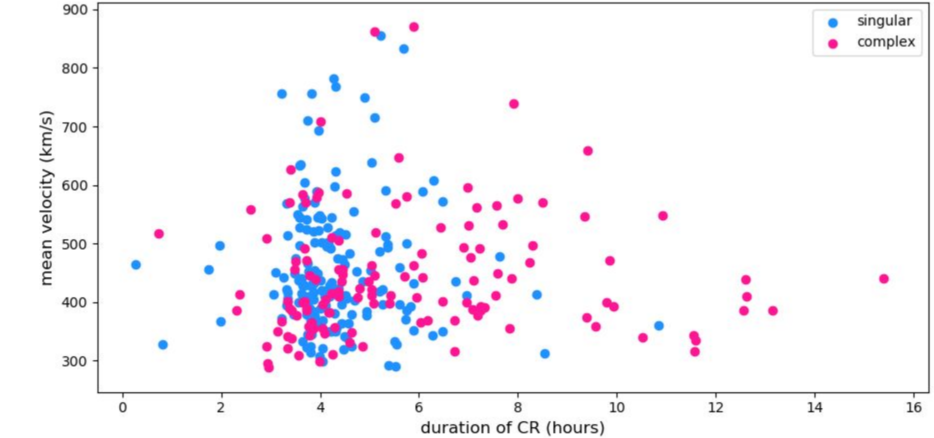


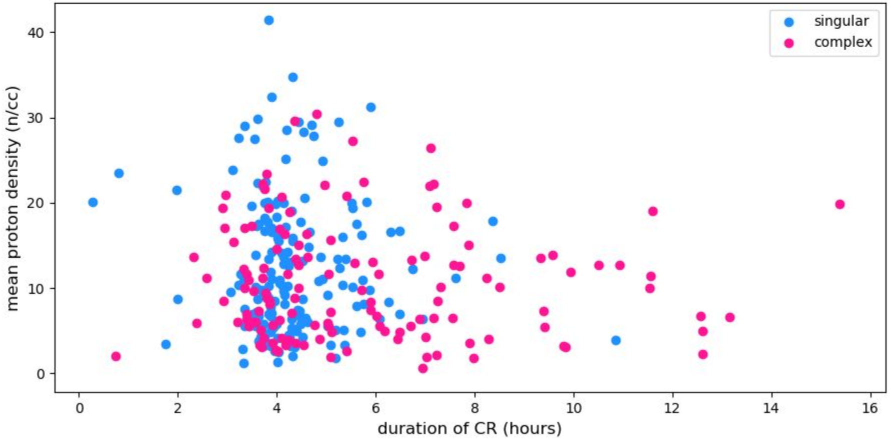


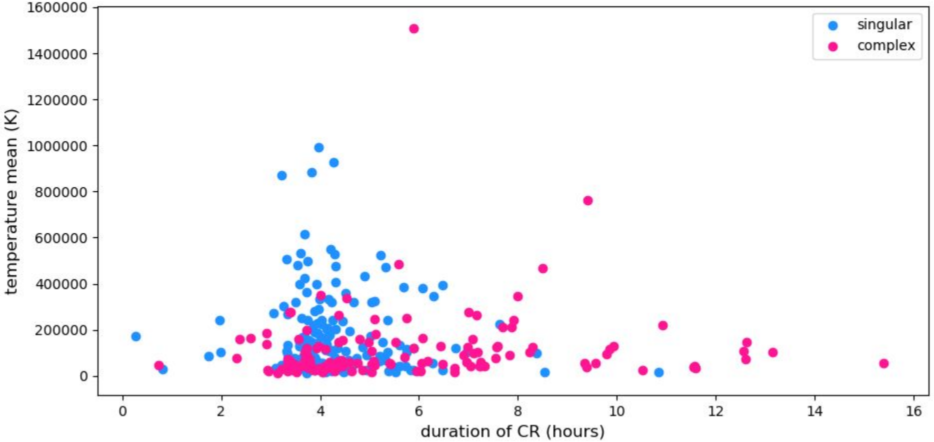


Means vs duration of the compression region









Maximums vs duration of the compression region