Exploration of the Physical and Spectroscopic Characteristics of Coronal Rain

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Abstract

The correlation between the phenomenon known as coronal rain and the origin of the Sun's heating and cooling mechanisms has become a popular area for exploration in recent years. In this study, we explored the specifics of how plasma flows are triggered and how material moves along closed magnetic field entities. Using spectroscopic data from the Interface Region Imaging Spectrograph (IRIS), we analyzed the Mg II, Si IV and C II emission lines in relation to the different magnetic structures, allowing us to study plasma under different emitting regimes. We have extracted spectroscopic characteristics of these emission lines for an off-limb prolonged coronal rain event taking place above a quiescent active region system. Additionally, we augmented our dataset with SDO/AIA coronal observations, highlighting corresponding higher temperature structures. We report a case where recurring coronal rain episodes occur over timescales of several hours. Our work reveals a multitude of complex, differently oriented, and turbulent, structures under what appeared to be a standard coronal rain event.

Introduction

What is coronal rain?

- Coronal rain typically occurs after destabilization of a filament/prominence or as a result of eruptive events in the solar corona where (relatively) cool and dense clumps of plasma is kicked up from the solar surface and the "rain" is due to the plasma falling back down along the closed magnetic field entities, otherwise known as loops.

Our Goals:

➔ Under quiet active region conditions:
  - Understanding how plasma flows work and how they move along closed magnetic field entities.
  - Following the evolution of solar structures in detail.
  - Specifically analyzing the Mg II spectroscopic emission lines from a coronal rain event.
  - Exploring emission line characteristics.

How do we obtain the data and imagery?
- Interface Region Imaging Spectrograph (IRIS) provides spectroscopic data
- SDO/AIA observations showing the large scale context

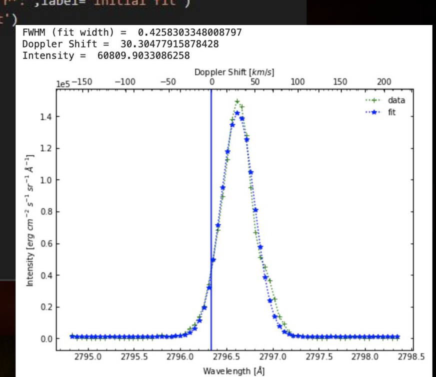
Methodology

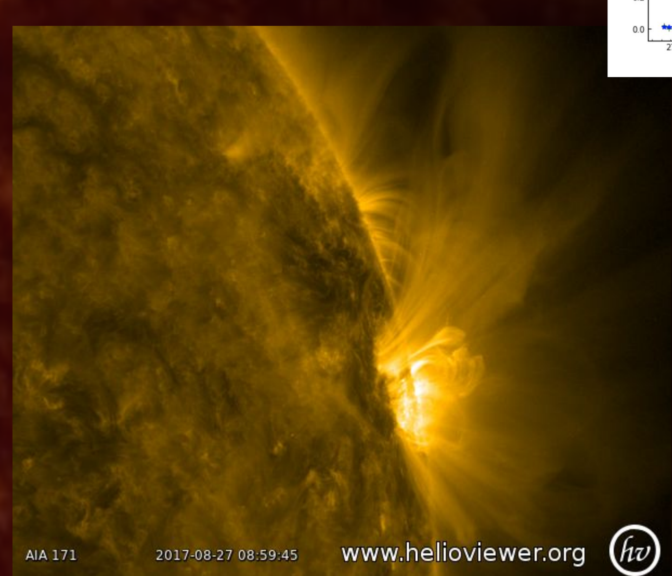
Level-2 data were acquired from IRIS and were first calibrated to physical units.

➔ Data analysis using Python
  - Code packages
    - Matplotlib
    - Numpy
    - Scipy
    - Glob
    - Astropy
  - IRIS data analysis of the Mg II emission lines
  - Creating functions and using them to simplify the coding process
  - Gaussian fitting captures the off-limb spectral line shape of the Mg II lines reliably well, even if the data is noisy.
  - SDO/AIA observations reveal higher temperature structures

➔ Other tools:
  - SAOImageDS9
  - Helioviewer

```python
# Fitting k line
def new_function_k(x,y):

# Initial guesses of the properties of the distribution
  n=sum(y)
  mean = sum(x*y)/n
  sigma=math.sqrt(sum(y*(x-mean)**2)/n)
  ymax=np.max(y)
  print('Mean = ', mean,' Sigma = ',sigma,'  ymax = ',ymax)


# Fitting the curve
  popt,pcov = curve_fit(gaus,x,y,p0=[ymax,mean,sigma, 0.0],maxfev=10000)
  print('Max_of_fit','\t   Max location','      fit_sigma ')
  print(popt)


# Plotting the result
  fig=plt.figure(figsize=(8,4))
  plt.plot(x,y,'g+:',label='data')
  plt.plot(x,gaus(x,ymax,mean,sigma, 0.0),'r*:',label='initial fit')
  plt.plot(x,gaus(x,*popt),'b*:',label='fit')
  plt.axvline(x=2796.34,color='blue')
  plt.legend()
  plt.xlabel('Wavelength')
  plt.ylabel('Intensity')


# Finding line properties
  totint = intensity(x,y,popt[2],popt[1])
  print('Line intensity) = ',totint)
  dopp1 = dopp (popt [1])
  print('Doppler Shift) = ',dopp1)
  fwhm = line_width(popt [2])
  print('FWHM (fit width) = ',fwhm)
```

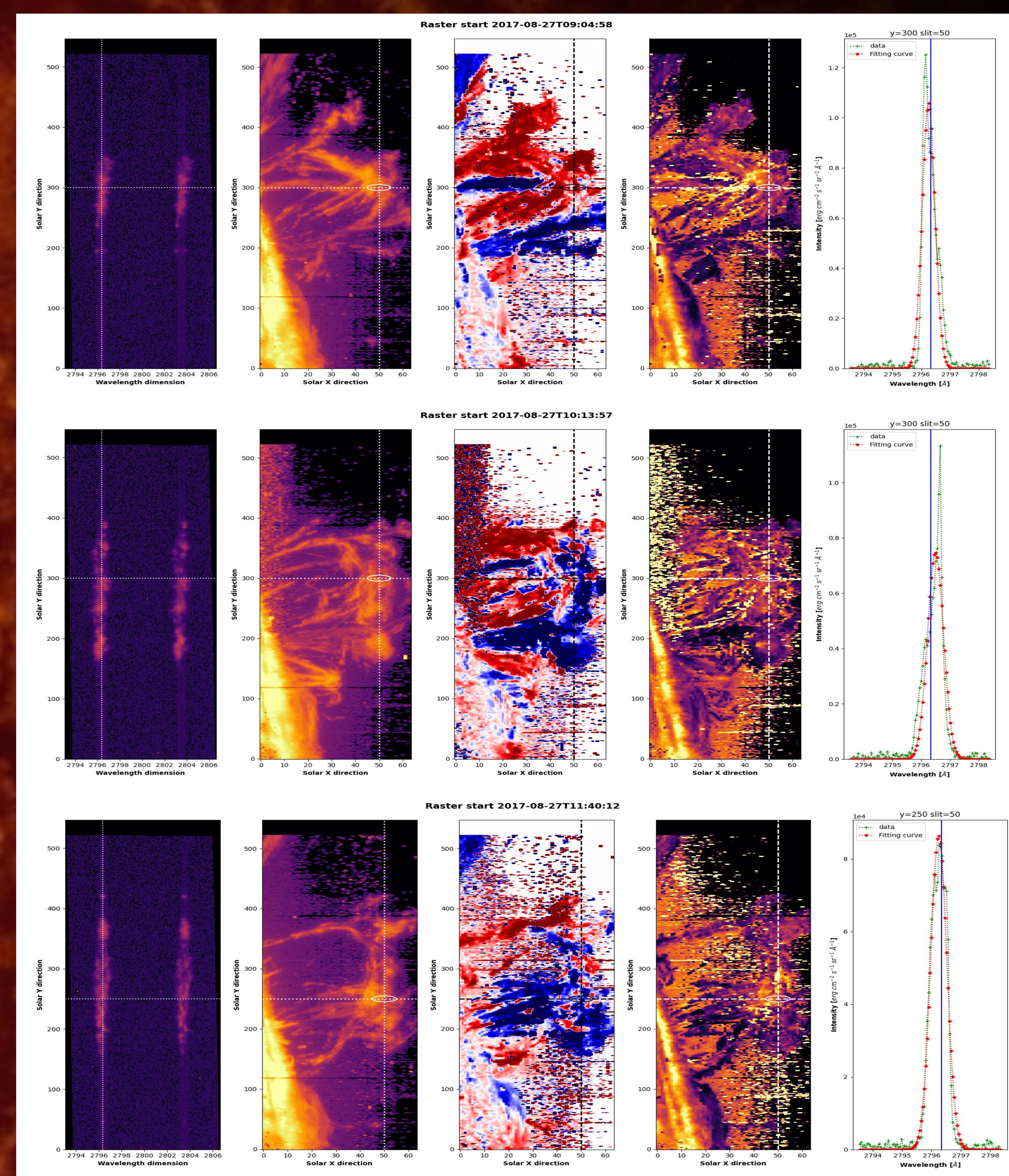




Results

➔ What does the data and imagery tell us?
  - Evolving structures: The structure shows important dynamics and morphological changes
  - Timescales: Individual flows are short lived, but recurring flows happen over a 10-hour period

➔ Using the fit parameters for the Mg II emission lines we constructed maps of Integrated intensity, Doppler Shift, and Line width for all sets of scans in the dataset
  - Intensity variation in the integrated intensity maps in regions of plasma concentrations
  - Doppler shift maps highlight the different flow systems within the larger structure
  - The flows highlight the magnetic structures within the active region loop system.



Conclusions

➔ What appeared from emission to be a very simple event, actually:
  - revealed a multitude of complex, differently oriented and turbulent structures under what appeared to be a standard coronal rain event.
  - had different flow structures within the event as highlighted by the Doppler shift maps.
  - showed substructure flows with various strands being active at different times during its lifetime
  - evolved continuously for approximately 10 hours.

Future Work

➔ In the future, we will:
  - expand our research to include the C II and Si IV lines and use similar methods to examine the coronal rain regime
  - explore the coronal counterpart to our event using SDO/AIA data in order to explore the temperature structure.
  - compare the evolution of the structures as recovered from the different analysis techniques
  - identify possible precursors of the observed activity

References

Antolin, P. and Rouppe van der Voort, L., *Astrophysical Journal*, 745(2): 152 (2012).
Ishikawa, R. T., Katsukawa, Y., Antolin, P. and Toriumi, S., *Solar Physics*, 295(4): 53 (2020).
Kohutova, P. and Verwichte, E., *Astrophysical Journal*, 827(1): 39 (2016).
Kriginsky, M., Oliver, R., Antolin, P., Kuridze, D. and Freij, N., *Astronomy and Astrophysics*, 650: A71 (2021).
Li, L., Peter, H., Chitta, L. P. and Song, H., *Astrophysical Journal*, 905(1): 26 (2020).

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