Northumbria University NEWCASTLE

Seray Sahin (PhD Student)

Northumbria University, Department of Mathematics, Physics and Electrical Engineering

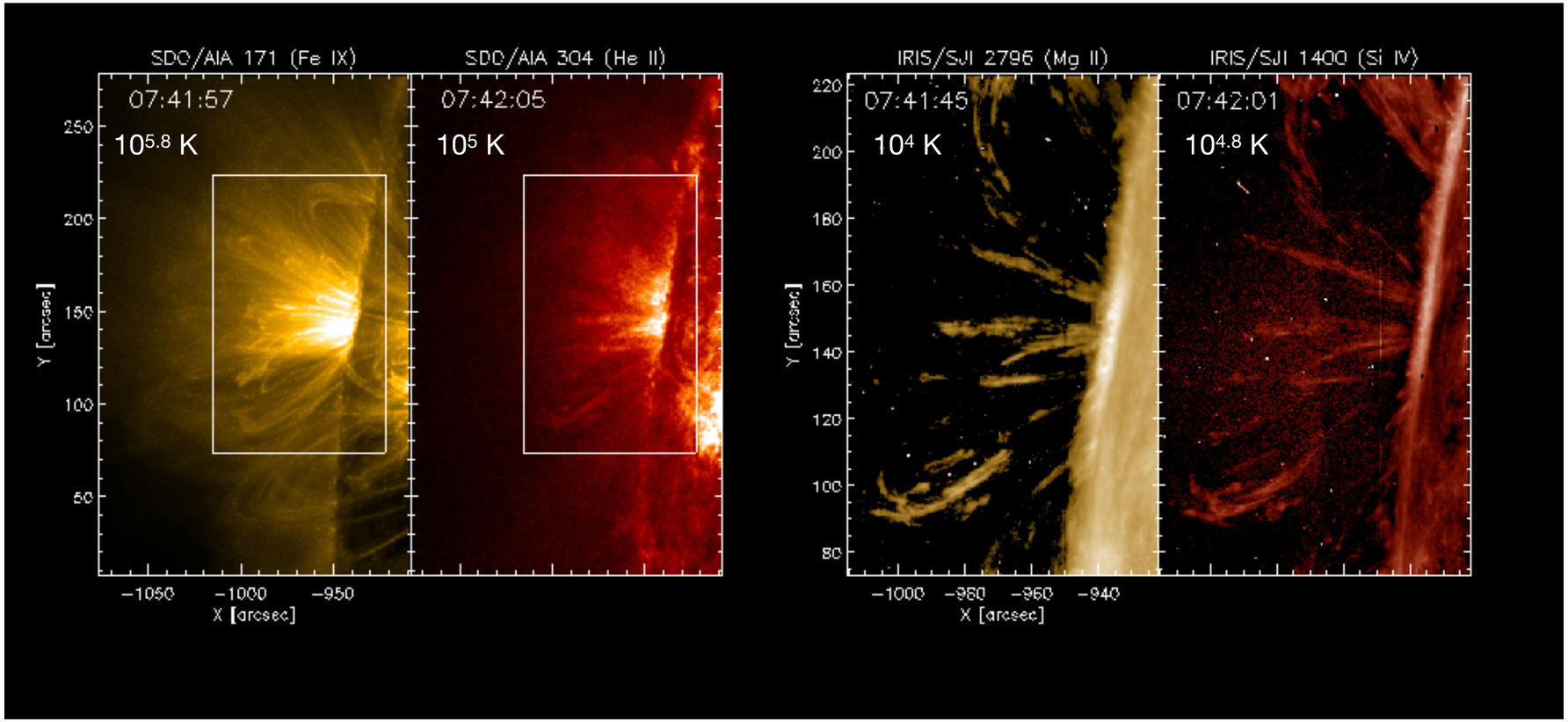
seray.sahin@northumbria.ac.uk

Supervisor: Patrick Antolin

ESPM-16

16th European Solar Physics Meeting

Prevalence of thermal non-equilibrium (TNE) over an active region



Scan the QR code for a movie of our coronal rain observation

16th European Solar Physics Meeting (Sep 6 - Sep 10, 2021 - Rome, Italy)

Introduction

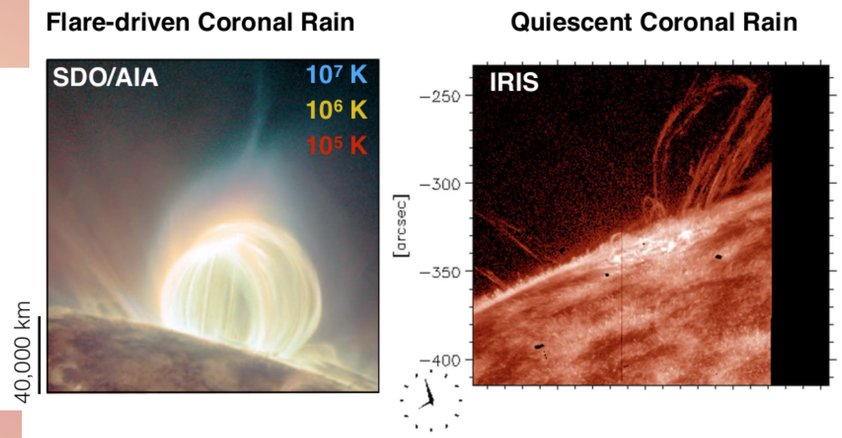
Coronal Rain

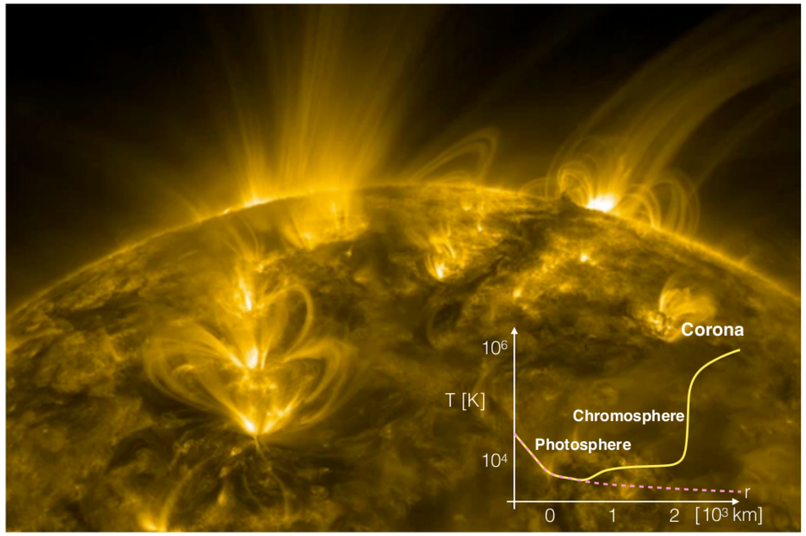
- Cool (10^3-10^5 K) & Dense
- Small clumps falling along loops
- Flare-driven or Quiescent

Why Coronal Rain?

- Strongly related to coronal heating
- Formation, dynamics and morphology still hotly debated.
- Unclear how widespread this phenomenon is over an AR.

Patrick Antolin, July 2021 (SoLO Atmospheric Heating)





Data - Method

Date	: 6/2/2017
Instrument	: IRIS SJI 1400 & 2796 Å
Time sequence	: 07:28 UT - 12:55 UT
Cadence	: 43.1 s (1400 Å) 32.2 s (2796 Å)
Spatial Sampling	: 0.3327 “/pixel
FOV	: 232” x 182”
Raster Step	: 64 (dense raster mode)

- Automatic detection with Rolling Hough Transform Technique

Schad, 2017

Results

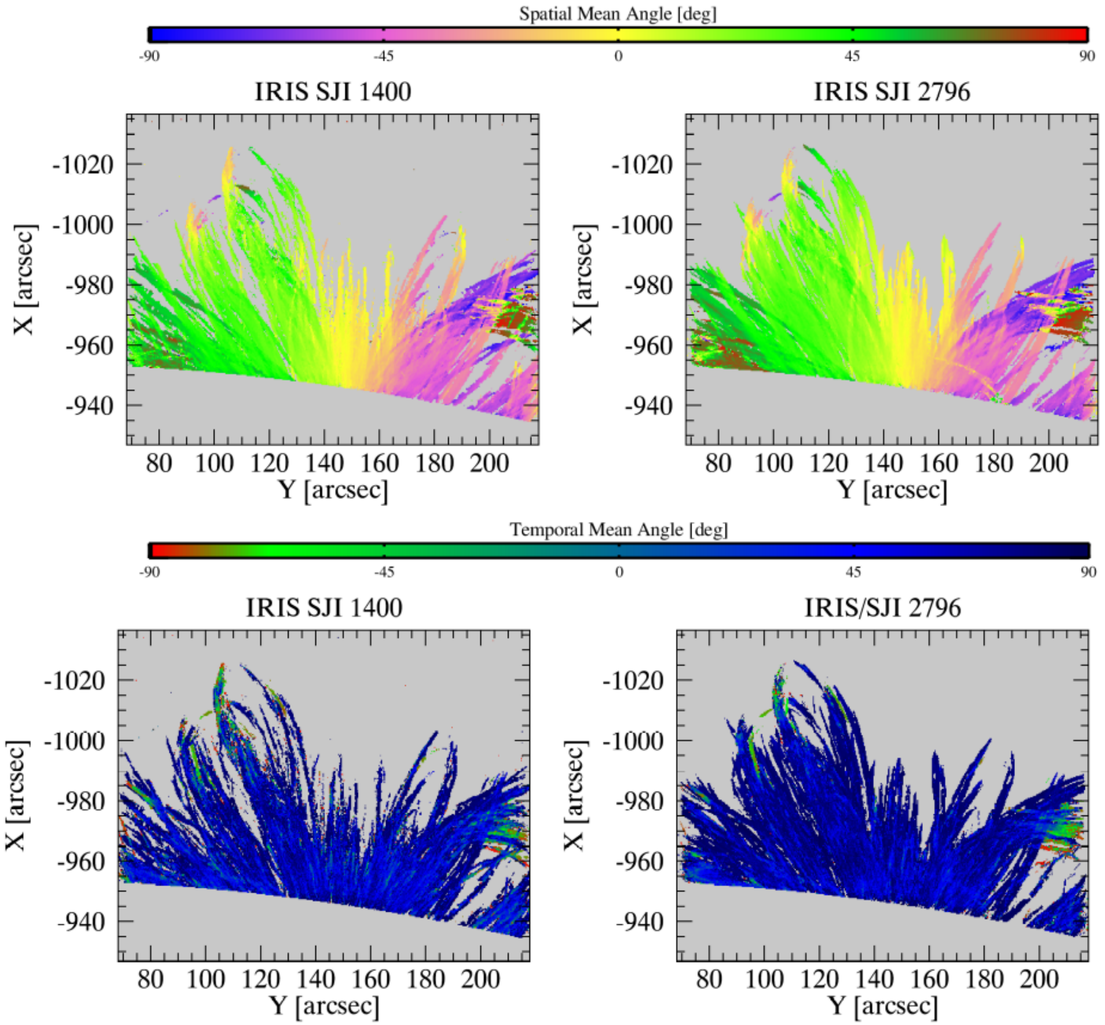


Figure 3. Average spatial (top) and temporal mean angle (bottom) maps

Spatial mean angle (θ_{xy}) = inclination of the rain with respect to the vertical direction. Temporal mean angle (θ_t) = dynamical change along a trajectory.

- Coronal rain is widespread over the active region.
- Coronal rain in chromospheric conditions is more extended.
- Downward motion is dominant.

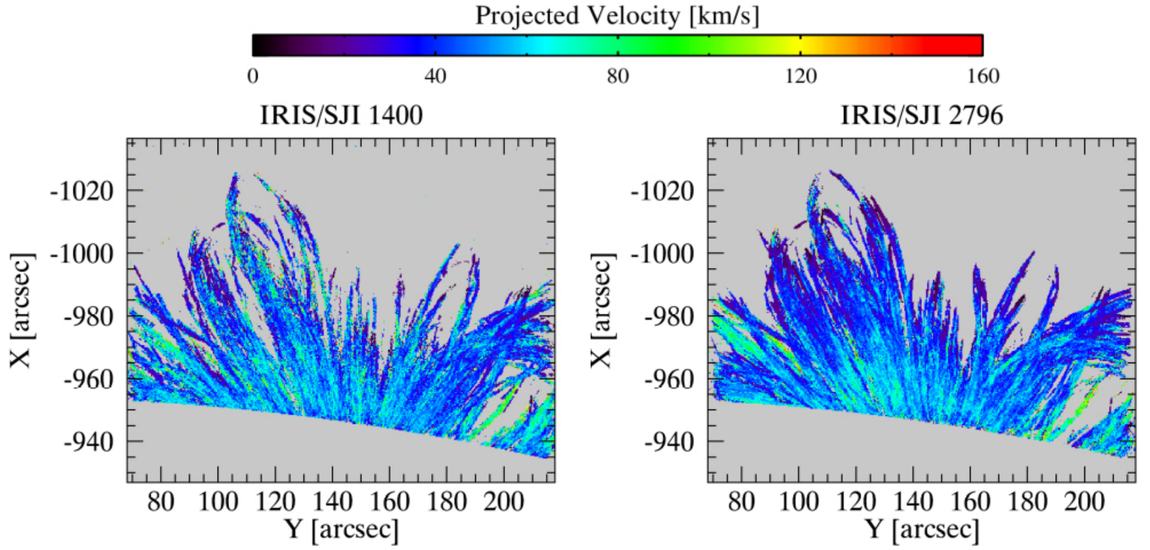


Figure 4. Average projected velocity maps

- Tangential and radial velocity maps are obtained from the temporal and spatial mean angles, which in turn provides the projected velocity:

$$v_p = \sqrt{v_{tan}^2 + v_{rad}^2}$$

- Higher velocity values are found towards the active region centre.

Results

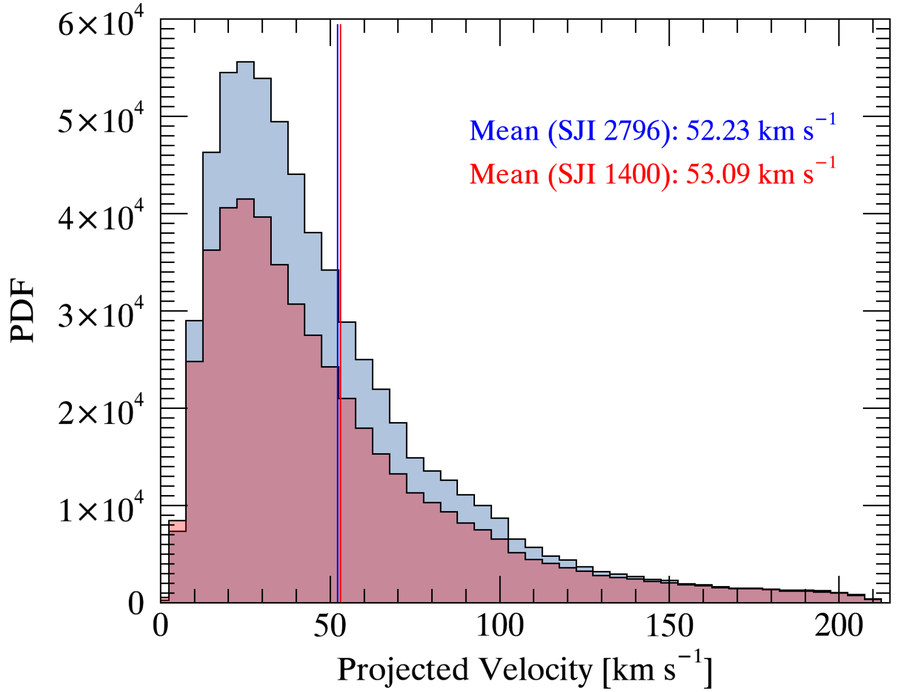


Figure 5. 1D histogram distribution of projected velocity for SJI 1400 (red) and SJI 2796 (blue)

✦ High velocity tails with peaks below 50 km/s, broadly consistent with previous results *(Antolin et al. 2012, Froment et al. 2020).*

✦ The 1400 Å velocity values appear slightly larger than the 2796 Å velocity values at all heights.

✦ On average, a linear increase in velocity for both 2796 Å and 1400 Å is observed between 10 and 50 Mm, with 1400 Å clumps being steadily 5-10 km/s faster.

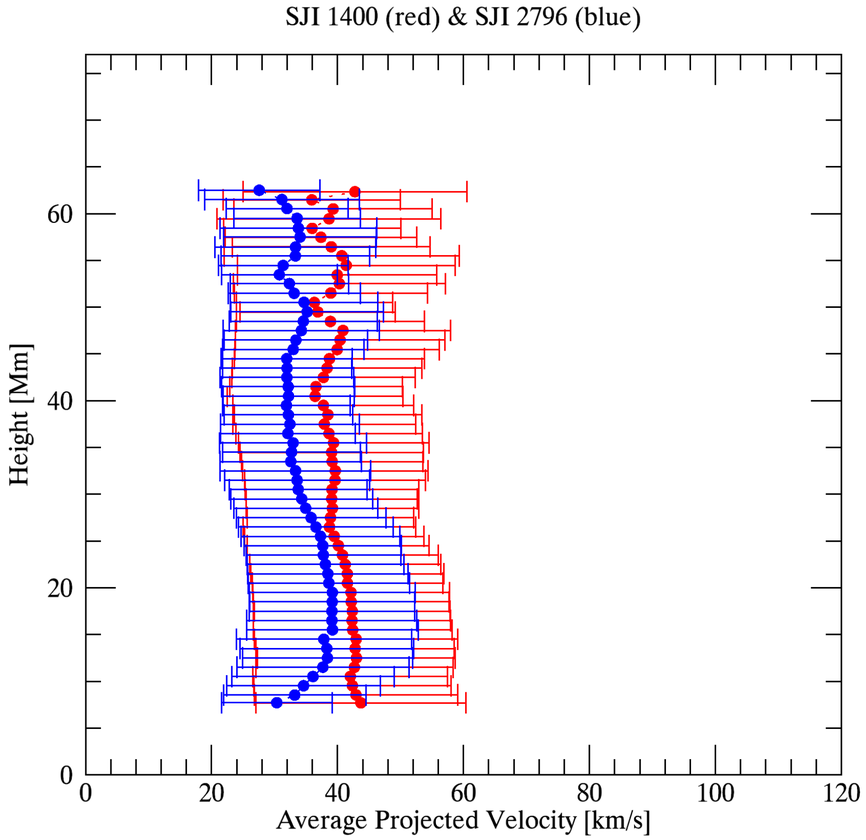


Figure 6. Average projected velocity at several heights, with 1 Mm binning

Results

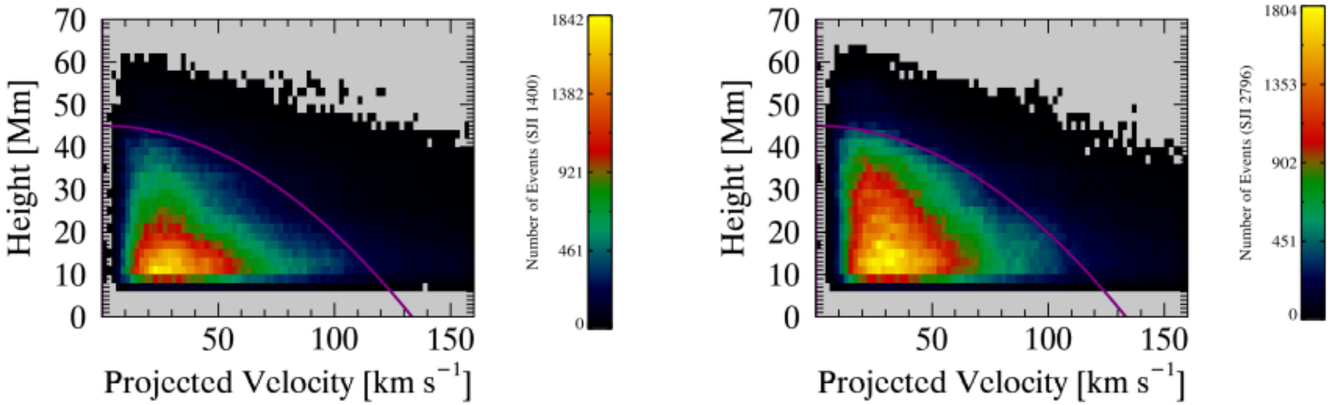


Figure 7. Two-dimensional probability distribution functions (PDFs) of the projected velocity

✦ Downward velocities are consistently lower than the free-fall velocity limit.

✦ On average, the heavier material (2796 Å) is not observed to fall faster than the lighter material (1400 Å), contrary to theoretical predictions (Oliver et al. 2014).

✦ The acceleration of the rain downwards for each event is clearly observed.

✦ Rain is continuously observed over the active region

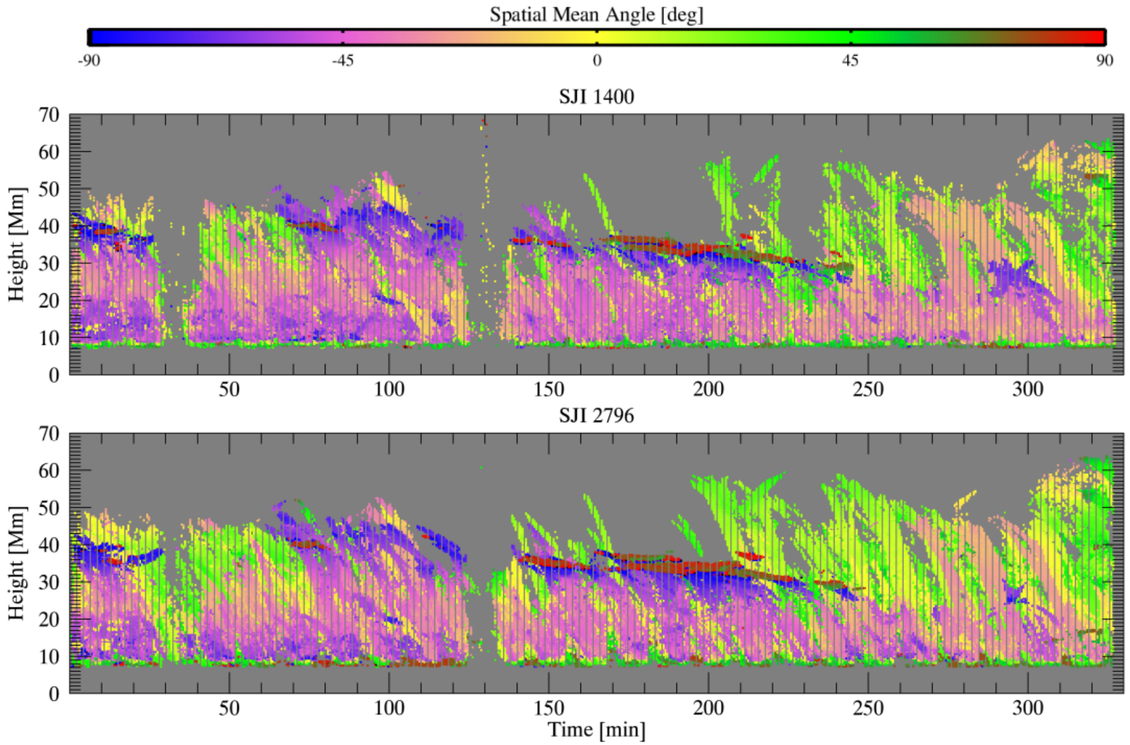


Figure 8. Space-time diagram of spatial mean angle

Results

- Average clumps width is found 800±300 km.

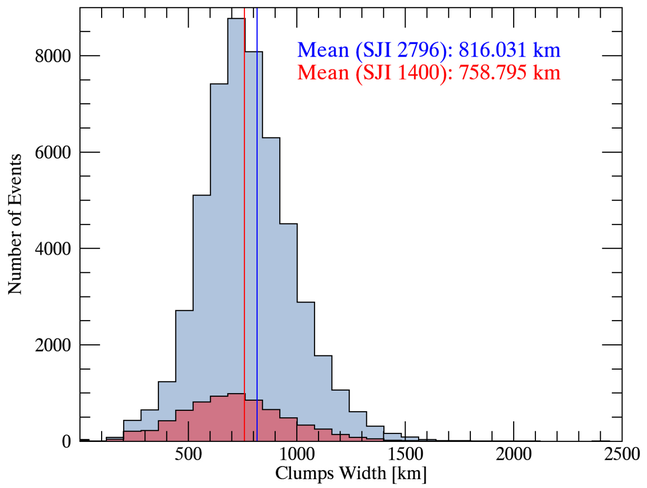


Figure 9. 1D histogram distribution of individual rain clumps width

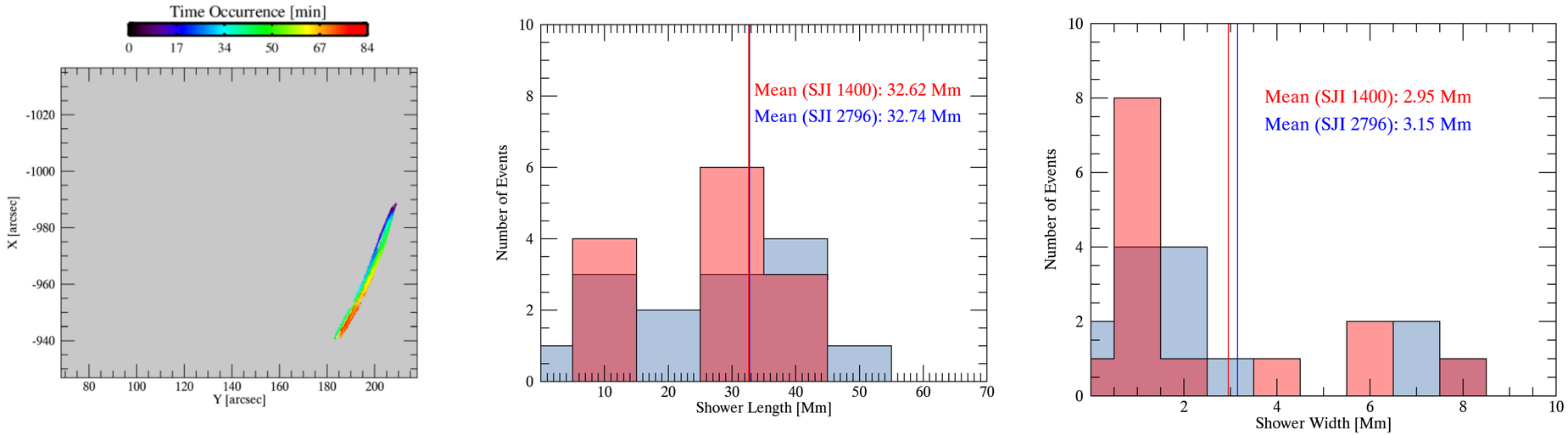


Figure 10. An example of shower event (#Shower 9) (first left panel) and 1D histogram distribution of shower events width and length

- 14 shower events are detected manually through ‘region_grow’ technique *(IDL Library)*.
- The length of shower events ranging from a few Mm to 55 Mm, with peak number values around 30 Mm.
- The width of shower events ranging from a few Mm to 9 Mm, with peak number values around 1 Mm.
- Shower events may provide a better definition of what is a coronal loop.

Discussions and Conclusions

✦ **First high-resolution statistical study of coronal rain over an entire AR and over a significant time duration (4.5 hours).**

✦Coronal rain properties consistent with previous findings (Antolin et al., 2012; Froment et al., 2020):

- Dynamics : peaks at 25 km/s, high velocity tails up to 200 km/s)
- Morphology: widths of 0.8±0.3 Mm

✦ Linear increase with lower height in velocity: combination of effective gravity and pressure restructuring ? (Oliver et al., 2014)

✦ Rain in 1400 is observed to fall slightly faster (5-10 km/s) than that in 2796, contrary to theory.

✦ Showers occur periodically (10 min), but further analysis needed to confirm periodicity.

✦ **Prevalence of thermal non-equilibrium (TNE) over this active region.**

✦ **Shower events may provide a better definition of what is a coronal loop.**