Formation and evolution of coronal rain observed by SDO/AIA on February 22, 2012

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Outline

- Motivation
- Formation and evolution of coronal rain
- Conclusion

Motivation

- Coronal rain is probably connected to coronal heating, therefore it is important to answer two major questions:

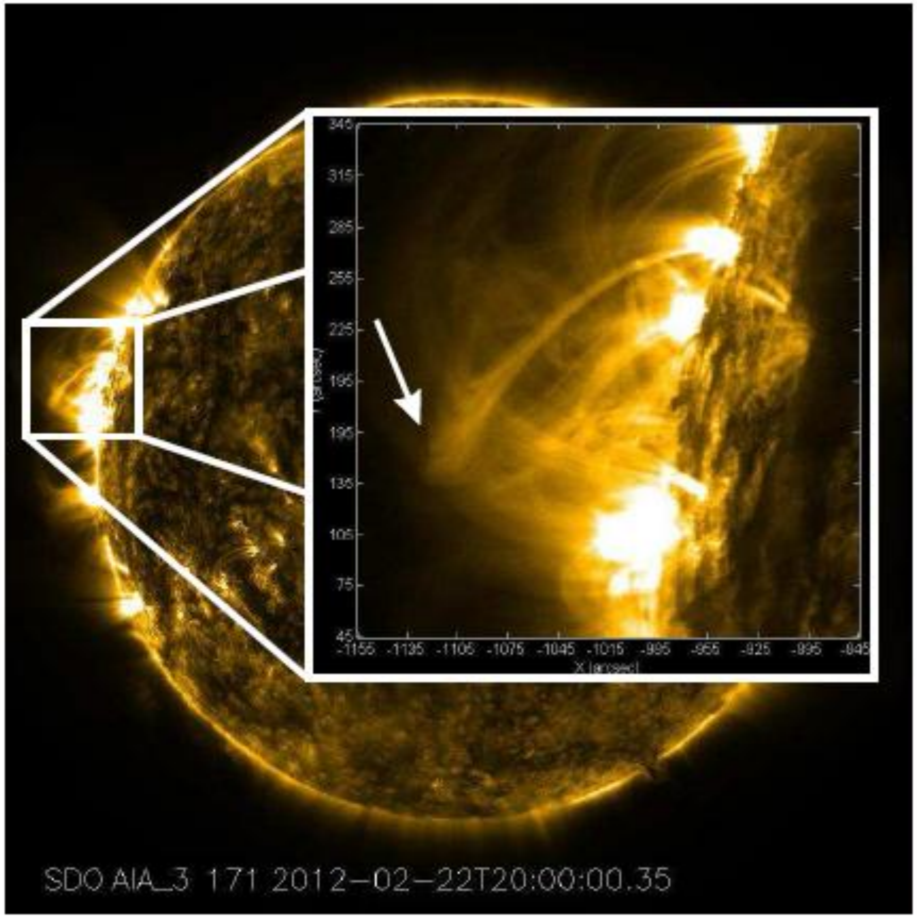
- 1. How does the coronal rain form?

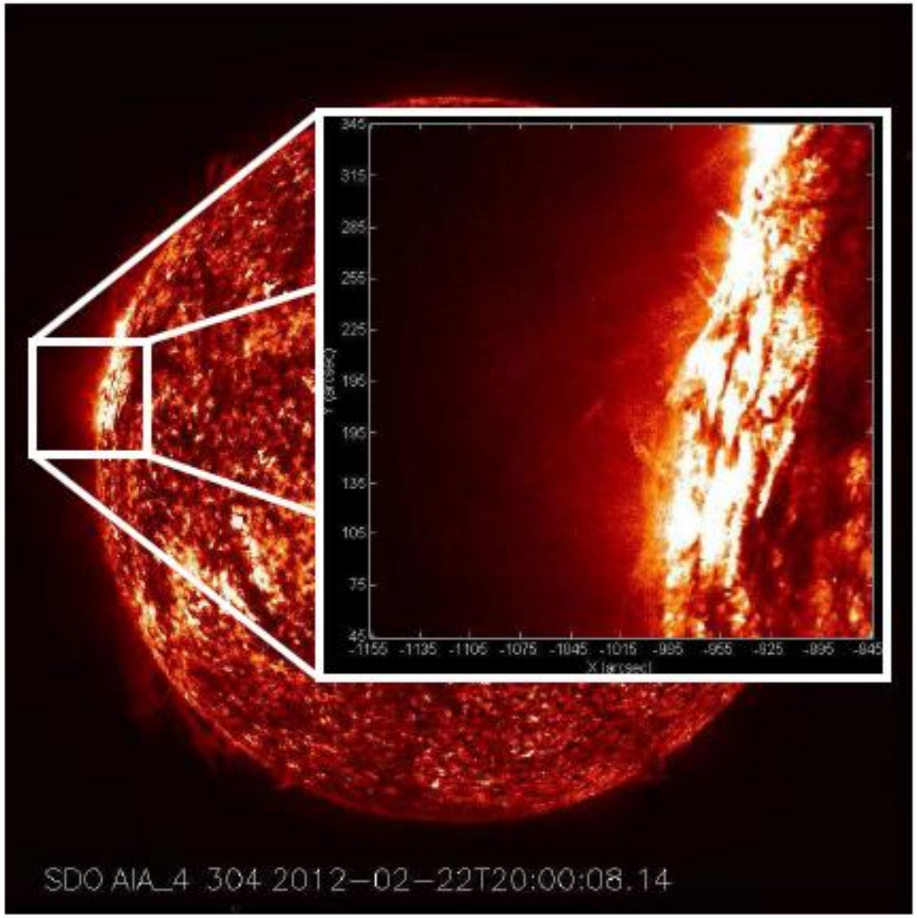
- 2. Why acceleration of coronal rain is less than gravitational free fall?

Observations

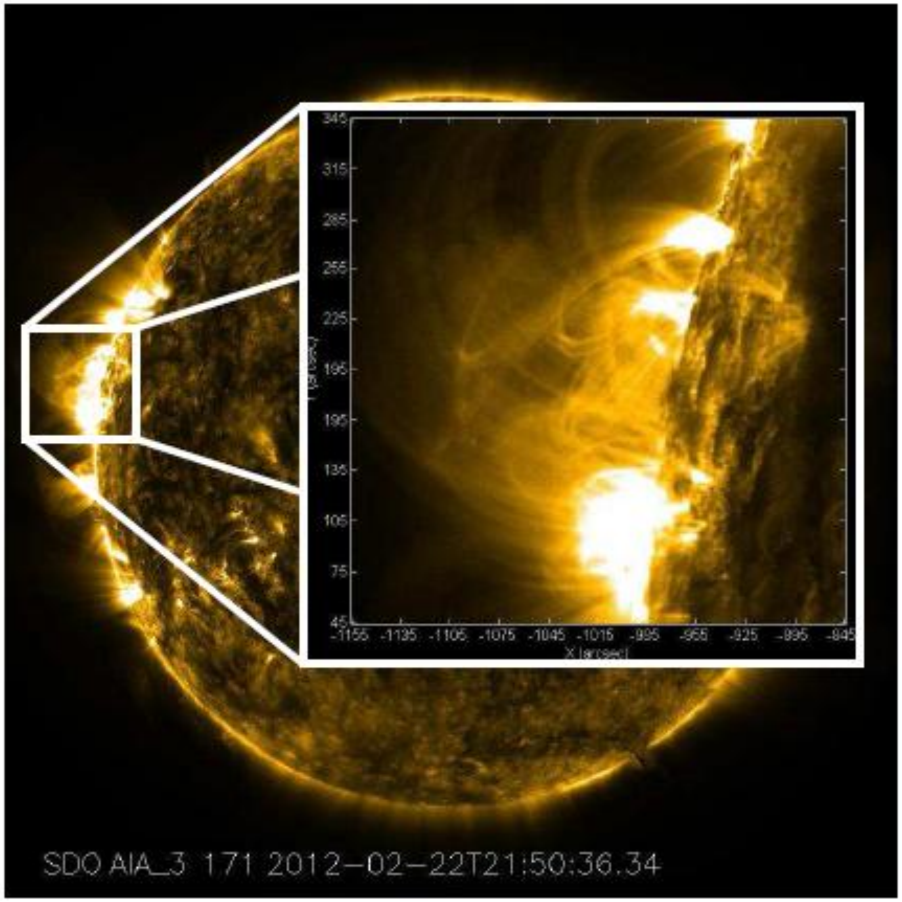
- We used AIA/SDO time series in 304 Å and 171 Å spectral lines.
- Coronal rain was observed in the 304 Å line above active region AR 11420 on 22 February, 2012.
- Event started at UT 19:16 and continued until UT 24:00.
- The formation of the coronal rain was connected to a coronal loop system in the overlying corona.
- The coronal loop (or loop system) was first seen in 171 Å line.
- During the next 1 hour the loop has permanently disappeared in 171 Å and appeared in the 304 Å line.
- The loop has cooled from $\sim 10^6$ to $\sim 10^{4.7}$ K.
- The cooling was accompanied by coronal rain events.
- We study two different sequences of coronal rain blobs in the 304 Å line.

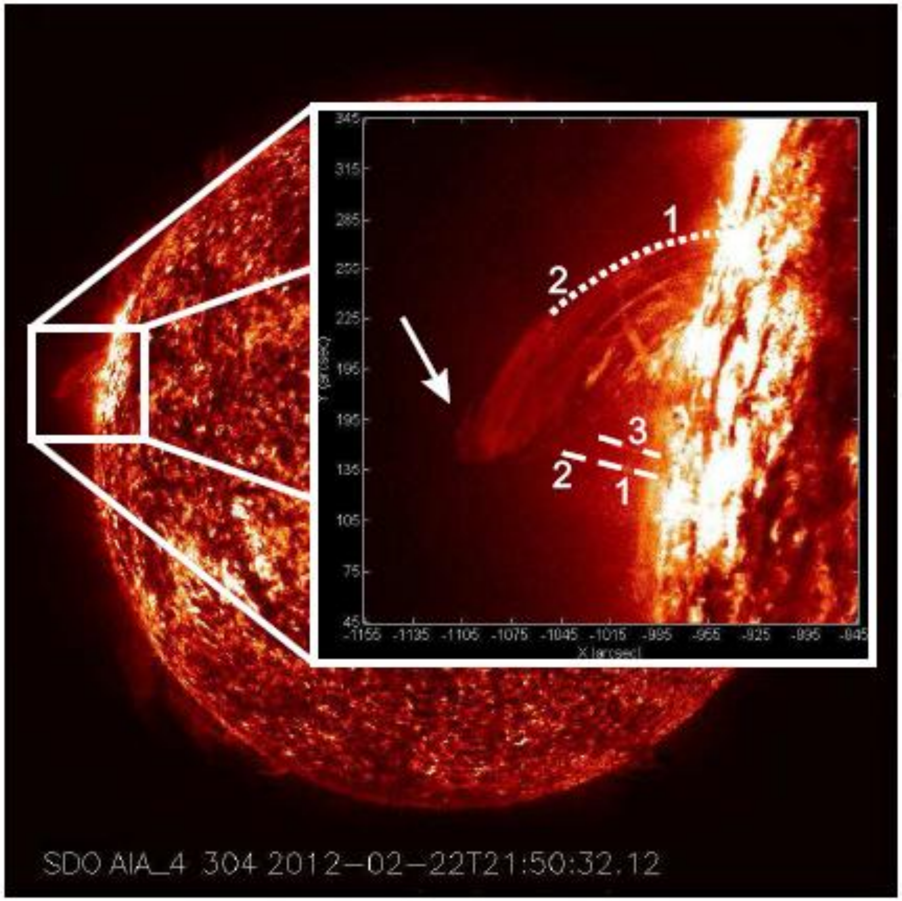
Active region at UT 20:00 in 171 and 304 lines



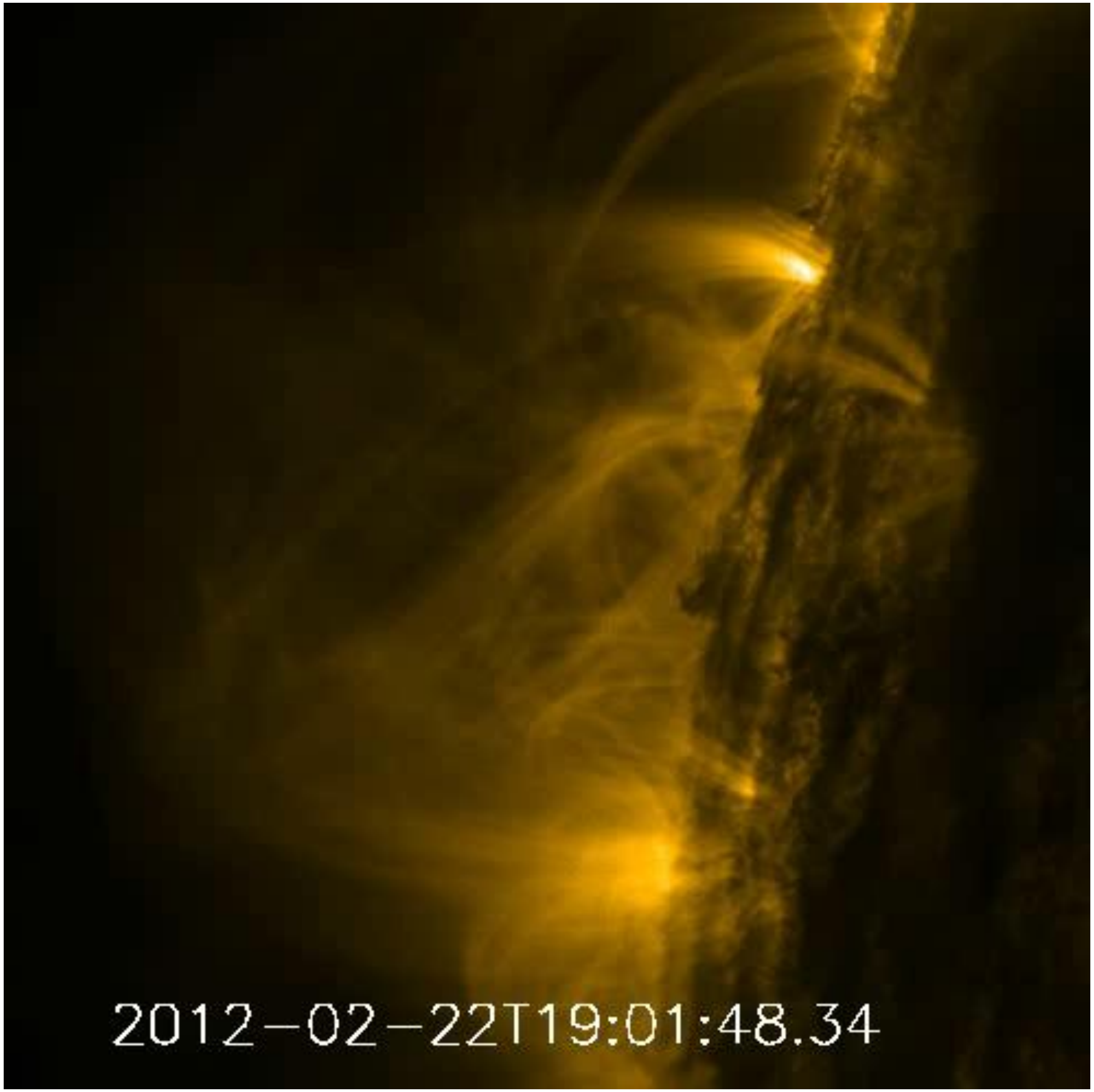


Active region at UT 21:50 in 171 and 304 lines





Active region dynamics in 171 line



Active region dynamics in 304 line

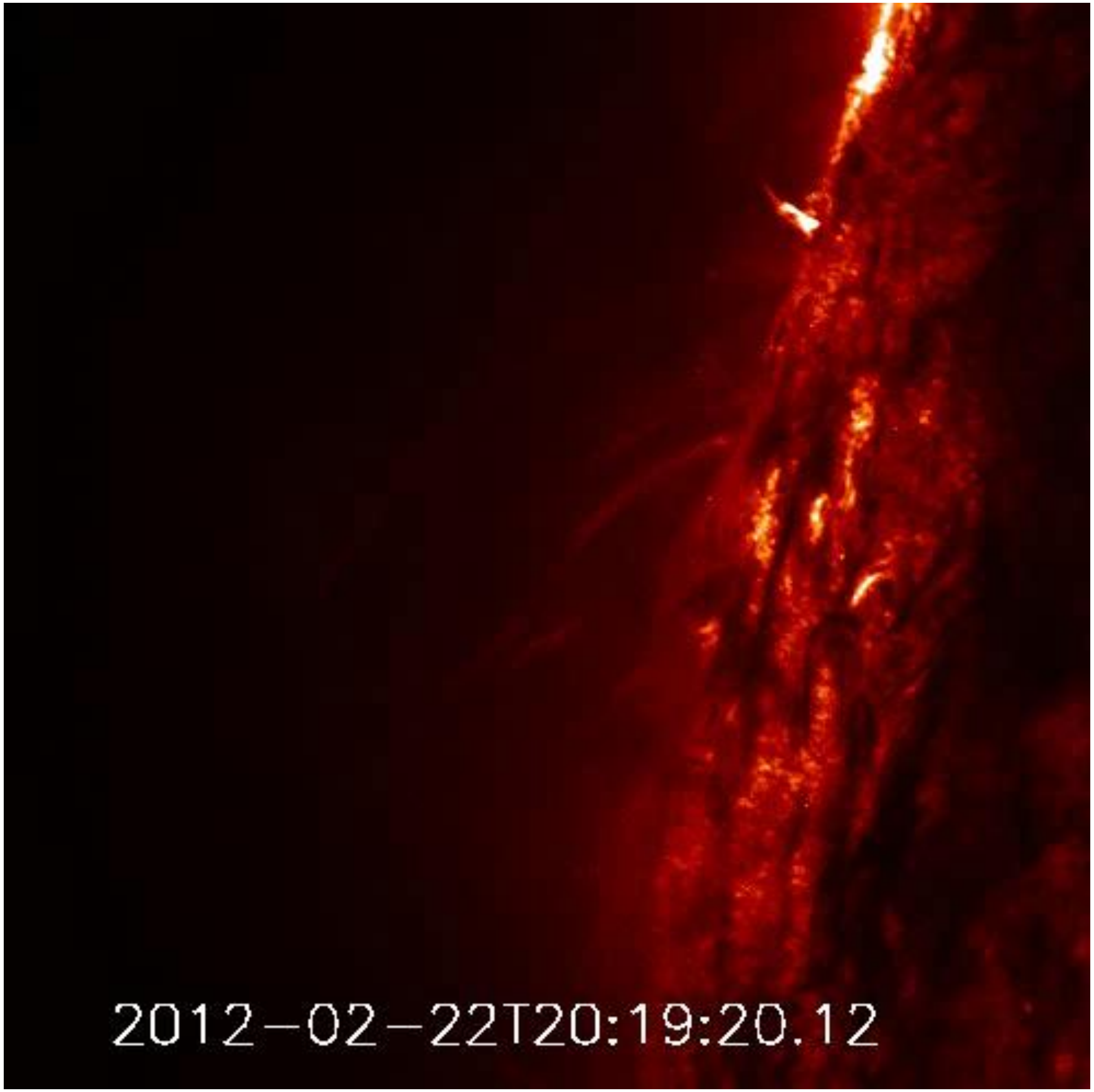
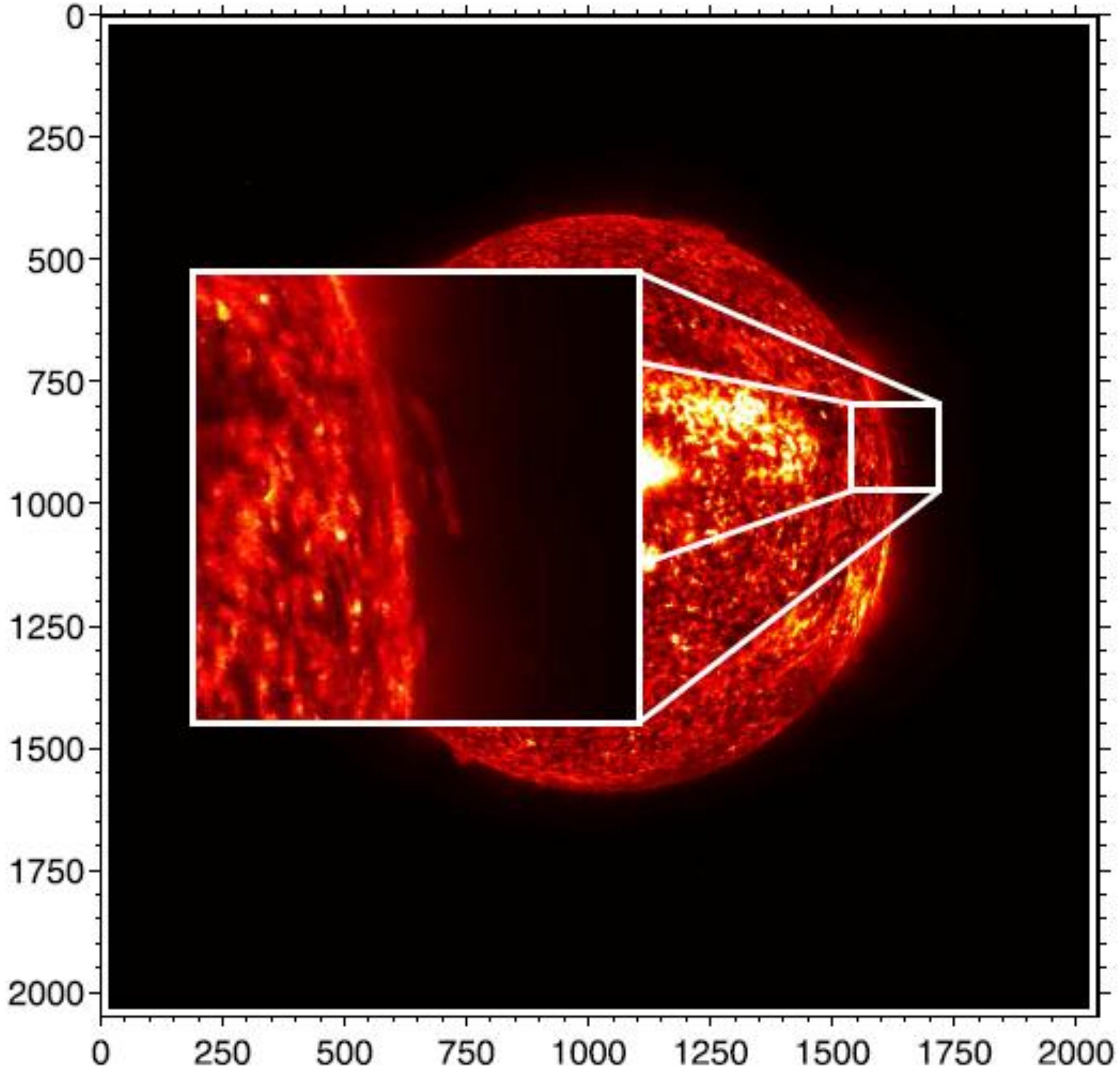
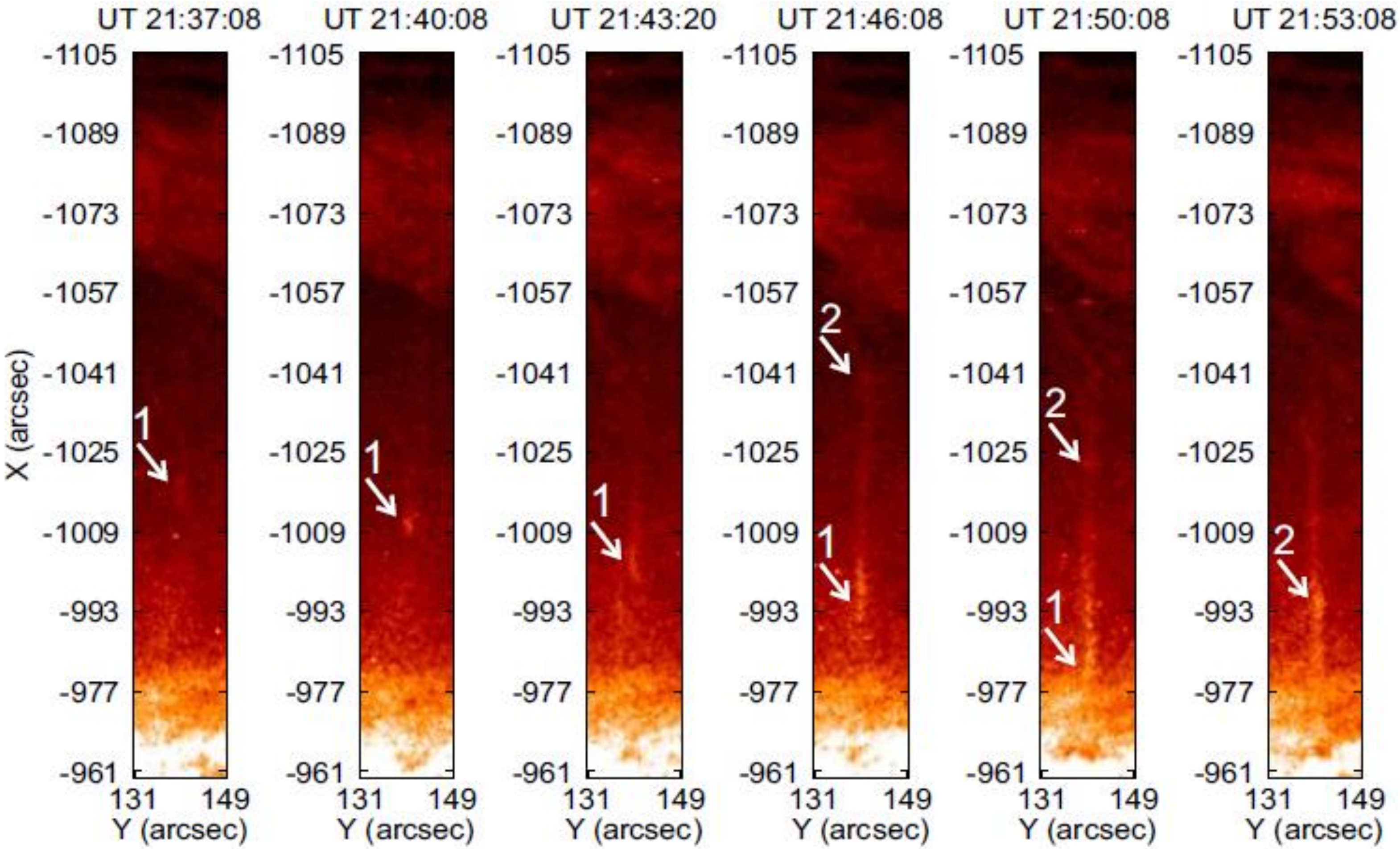


Image taken by STEREO B in the 304 Å line at UT 21:56.



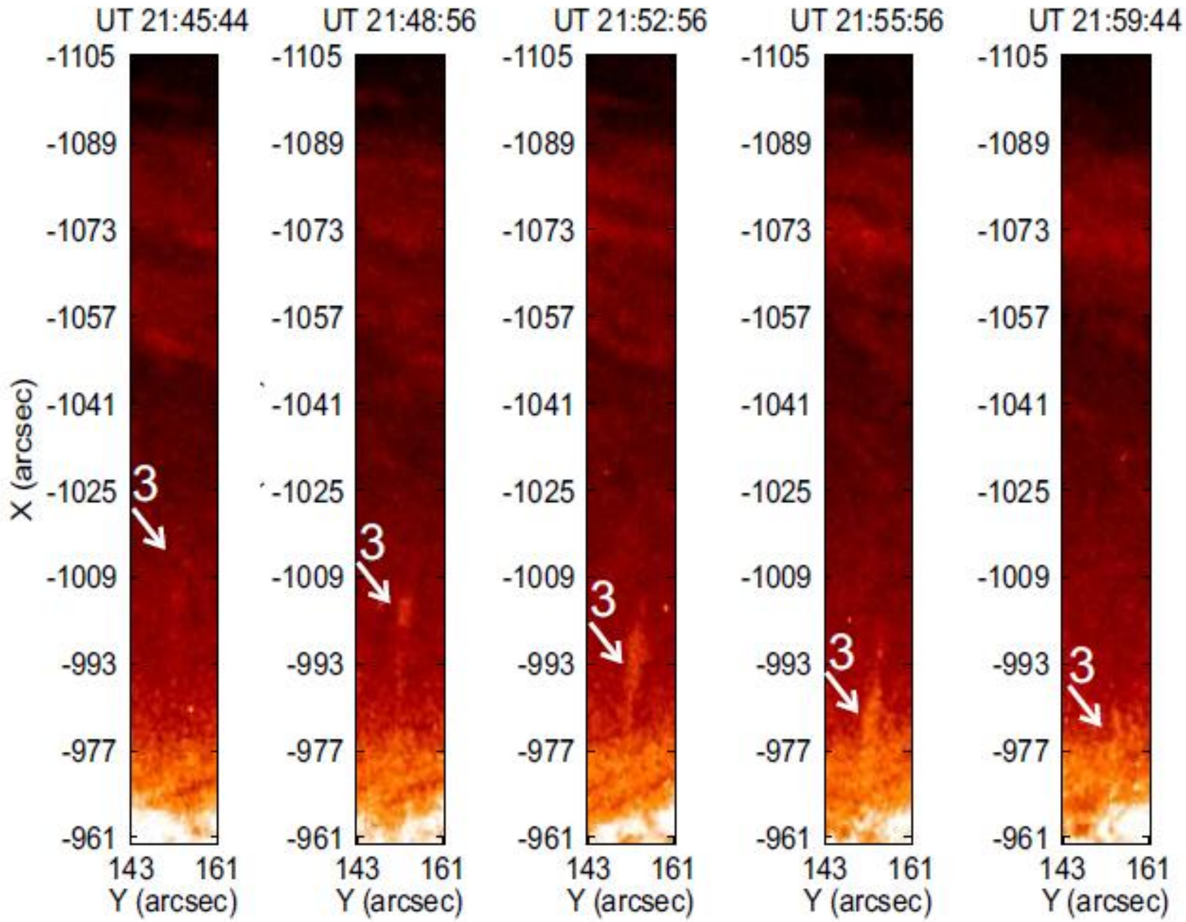
Two blobs falling allong the same path

- The first blob appears at UT 21:37 at a height of ~ 4×10^4 km and reaches the surface in ~ 13 min with a mean speed of ~ 50 km s^{-1} . The second blob appears at UT 21:50 at a height of ~ 6×10^4 km and reaches the surface in ~ 17 min with a mean speed of ~ 60 km s^{-1}.

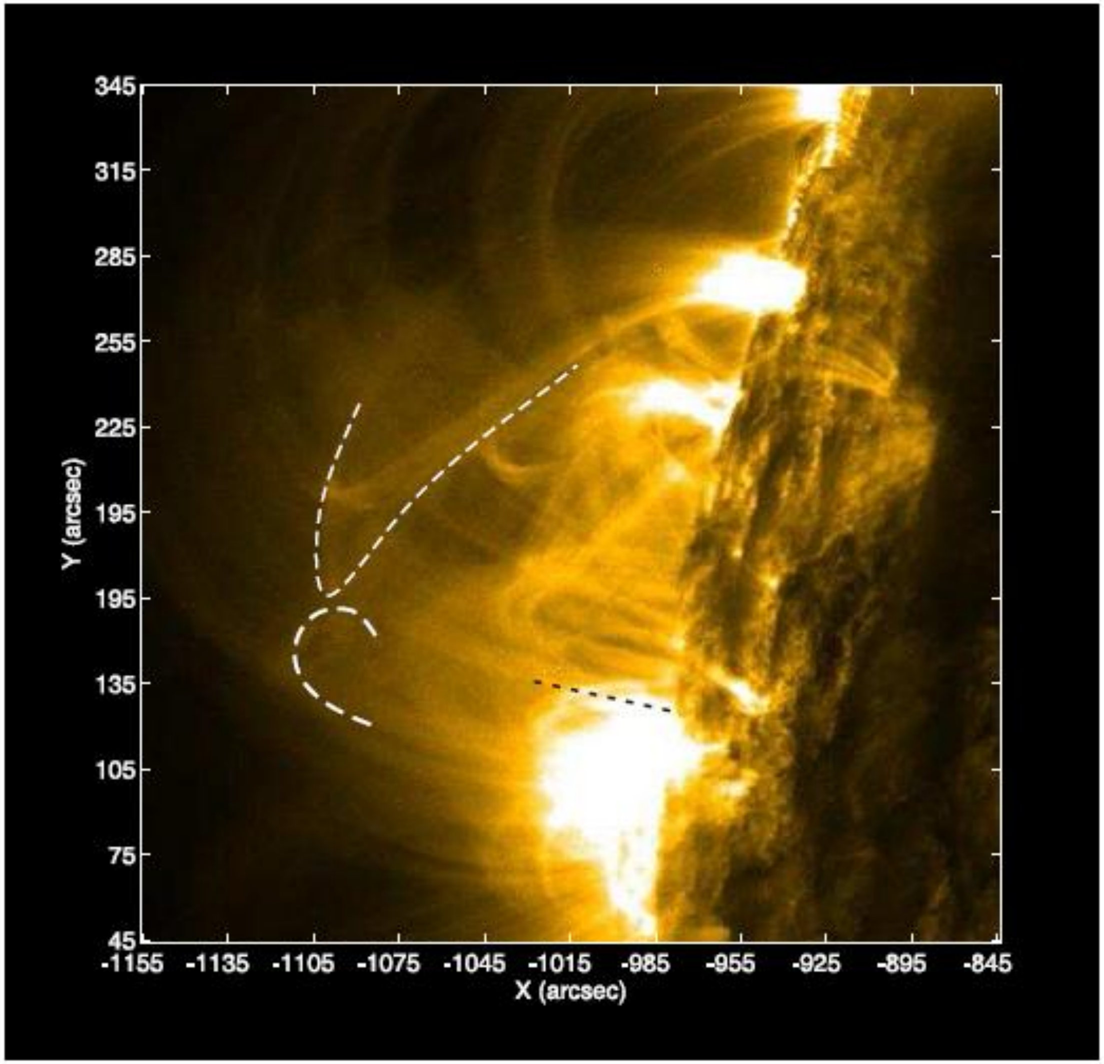


Third blob falling along the different path

- The third blob appears simultaneously with the second blob, i.e. at UT 21:50, at a height of ~ 3×10^4 km and reaches the surface in ~ 12 min with a mean speed of ~ 40 km s^{-1}.

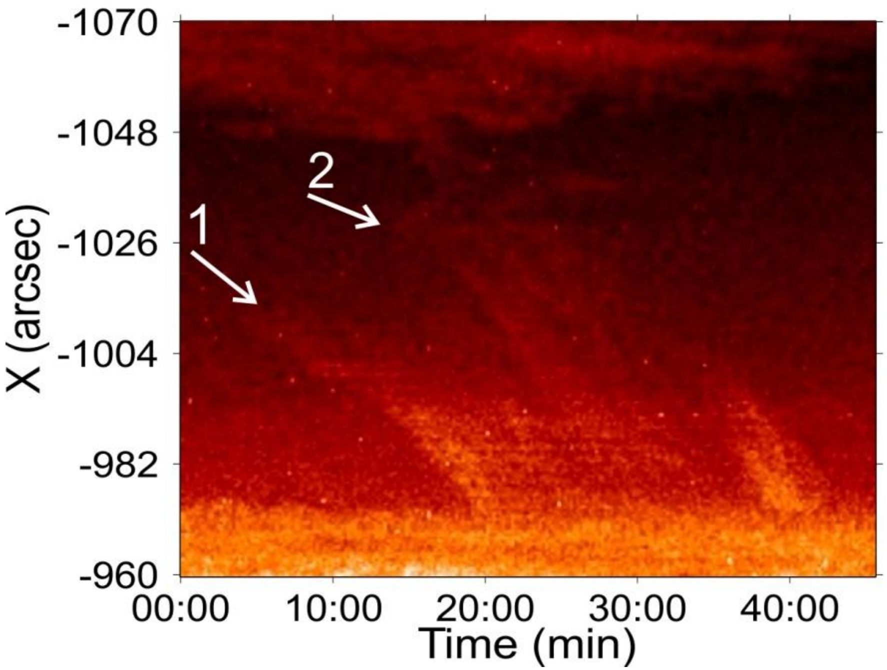


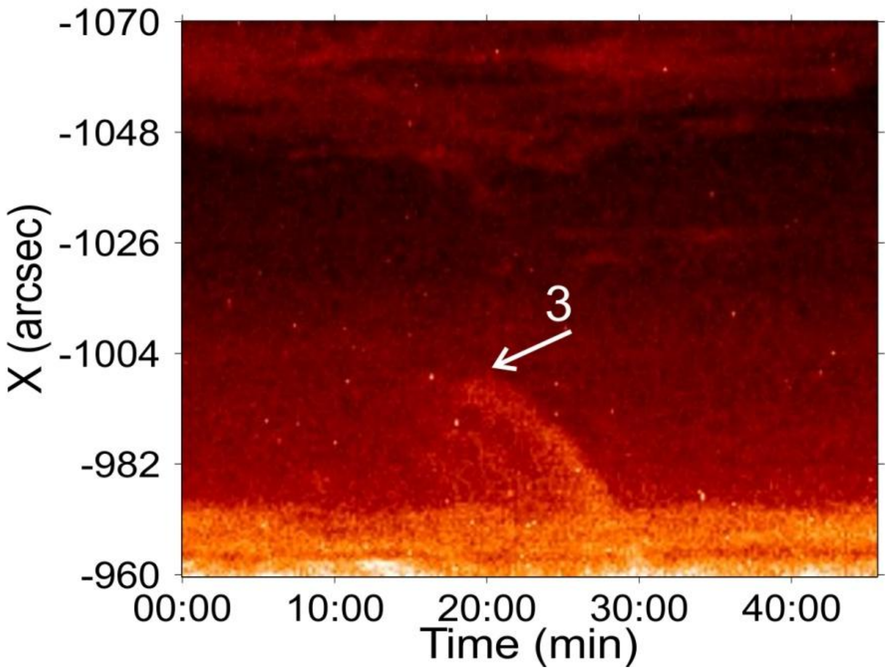
Coronal loops at UT 21:00, which could reconnect and reconstruct the active region.



X-t cuts

- x-t cut during the time interval UT 21:30-22:15.

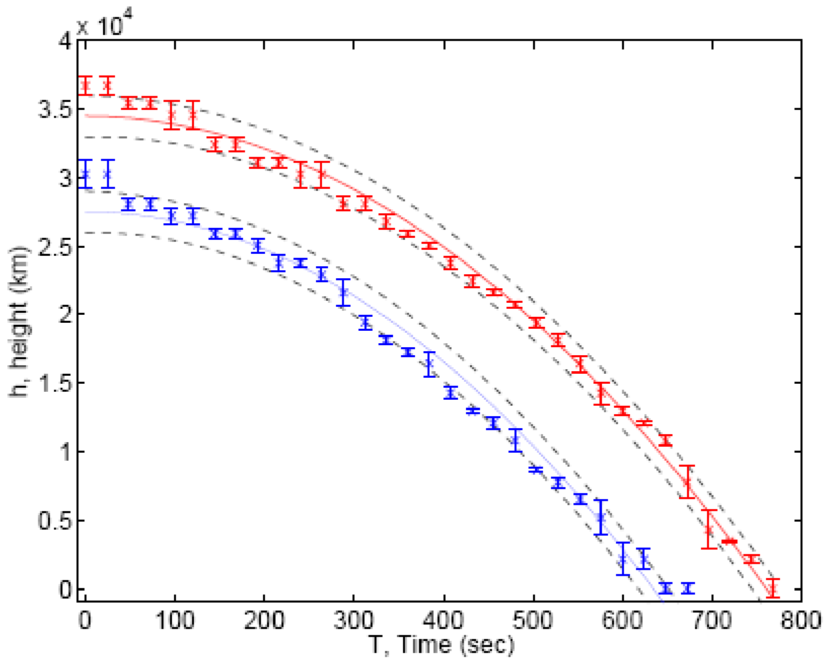




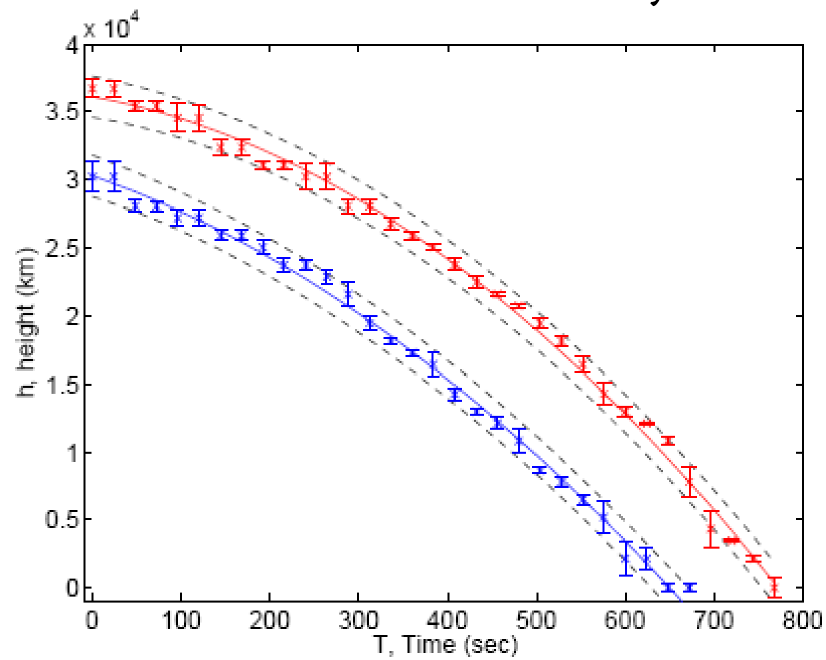
Acceleration

- We made plots of height vs time for the first and the third blobs and fit with a quadratic polynomial $h = h_0 - V_0 t - a t^2/2,$

Zero initial velocity



Non-zero initial velocity

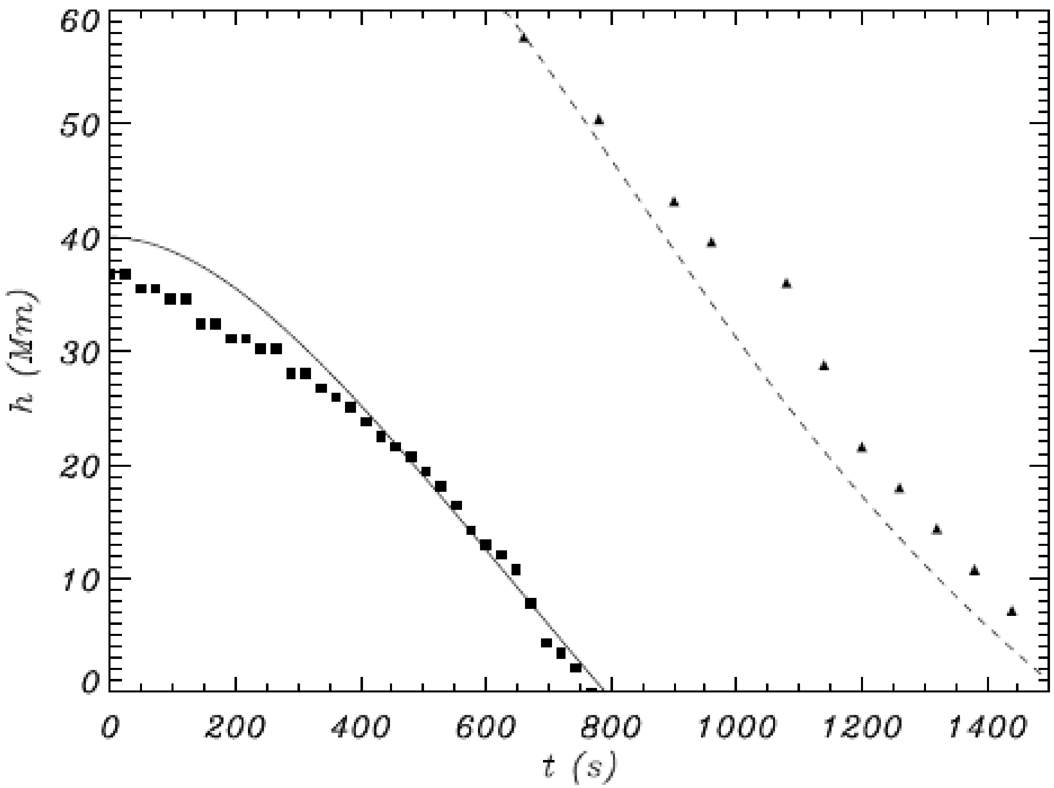


- The estimated acceleration without initial velocity is 120 m s^{-2} for the first and 136 m s^{-2} for the second blob.
- The fitting with non-zero velocity gives 12 km s^{-1} and 92 m s^{-2} for the first blob and 22 km s^{-1} and 74 m s^{-2} for the third blob.

Some numerics

- The acceleration of the second blob, which follows the same path (or the same loop) as the first blob, is almost zero.

- To try to understand the different behaviour of the two blobs falling along the same magnetic flux tube, we have done a few numerical simulations based on the work of Oliver et al. (2014).



- solid and dashed lines show the dynamics of the two blobs after numerical simulation.

- Squares and triangles show the observed points.

Second sequence

- Besides the above mentioned blobs, there is more powerful coronal rain event after the cooling of coronal loop: cool plasma starts to move along inclined trajectory, probably along inclined magnetic field of coronal loop system.

- This is a flow-like event of coronal rain, which maybe consists of many smaller blobs, but we could not see them owing to the resolution limit.

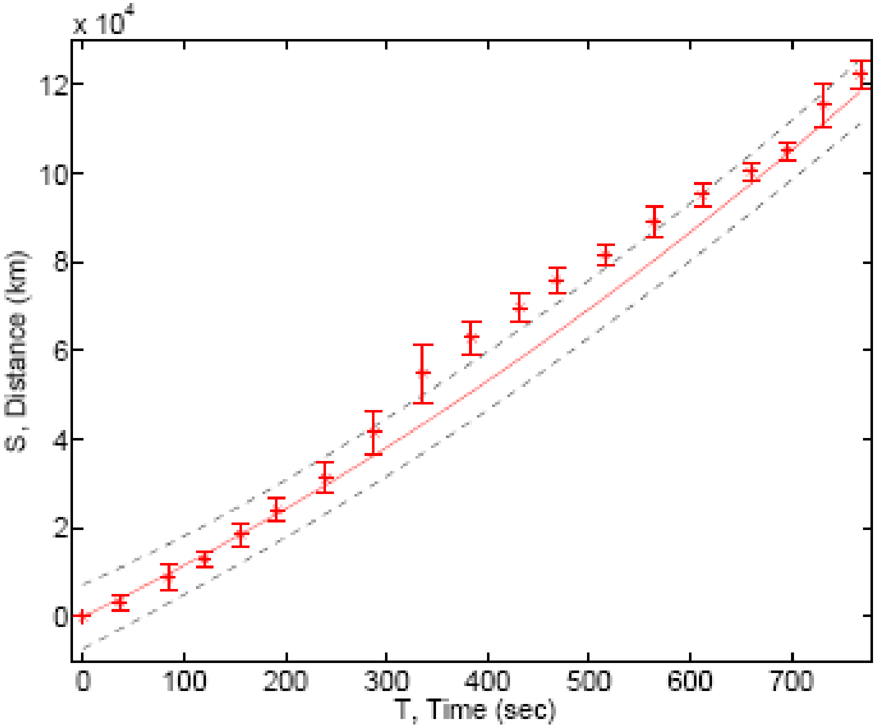
- We could identify only two different blobs

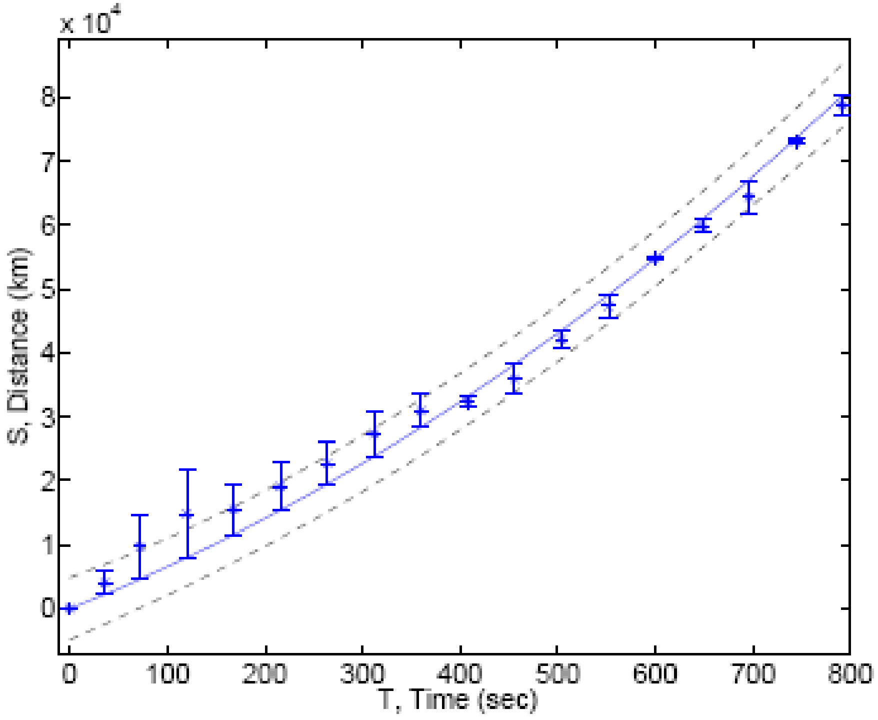
- The first blob appears at UT 21:41 at a height of **9×10^4 km** and reaches the surface in 13 min.

- The second blob appears at UT 21:57 at a height of **8.6×10^4 km** and reaches the surface in 13 min.

Accelerations

- The acceleration of the first blob along the inclined loop is estimated as 130 m s^{-2} with initial velocity of 80 km s^{-1}. The acceleration of the second blob is 100 m s^{-2} with initial velocity of 60 km s^{-1}.





Energy balance

- The coronal loop completely disappeared in the 171 Å line and simultaneously appeared in the 304 Å line for over ~ 1 hour.
- Energy balance during the cooling:

$$\frac{n_e k_B}{\gamma - 1}\frac{\partial T}{\partial t} = E_H - E_R - \nabla F_c$$

- Electron number density 3×10^{9} cm^{-3},
- Radiative loss function $\Lambda(T) = 10^{-22}$ erg cm^{3} s^{-1}
- Loop half length 110 Mm
- $E_R \approx n_e^2 \Lambda(T) = 9 \times 10^{-4}$ erg cm^{-3} s^{-1}
- $\nabla F_c \approx 10^{-6} \frac{T^{7/2}}{L^2} \approx 8 \times 10^{-6}$ erg cm^{-3} s^{-1}

- Heating function for uniform heating (Rosner et al. 1978) for 1 MK

- $E_H = 3.37 \times 10^{-4}$ erg cm^{-3} s^{-1}

- Heating function for nonuniform heating (Aschwanden and Schrijver 2002)

- $E_H = 10^{-6}$ erg cm^{-3} s^{-1} (for the scale height of 110 Mm)

- Energy balance is violated as the radiation losses overcome the heat input in both uniform and nonuniform heating!

- Therefore, the "catastrophic cooling" probably leads to the cooling of our loop and consequently the formation of coronal rain.

Conclusions

- The process of ”catastrophic cooling” is responsible for the formation of the coronal rain.

- All blobs leave trails behind, which could be a result of continuous cooling in the tail (Fang et al. 2013).

- The acceleration of the blobs does not depend on local loop parameters, but could depend on blob to coronal density ratio (Oliver et al. 2014).

- Blobs following a previous blob along the same path have smaller acceleration, which could be a result of changing environment (Oliver et al. 2014).