Coronal flux rope eruptions triggered by Flux-feeding procedures

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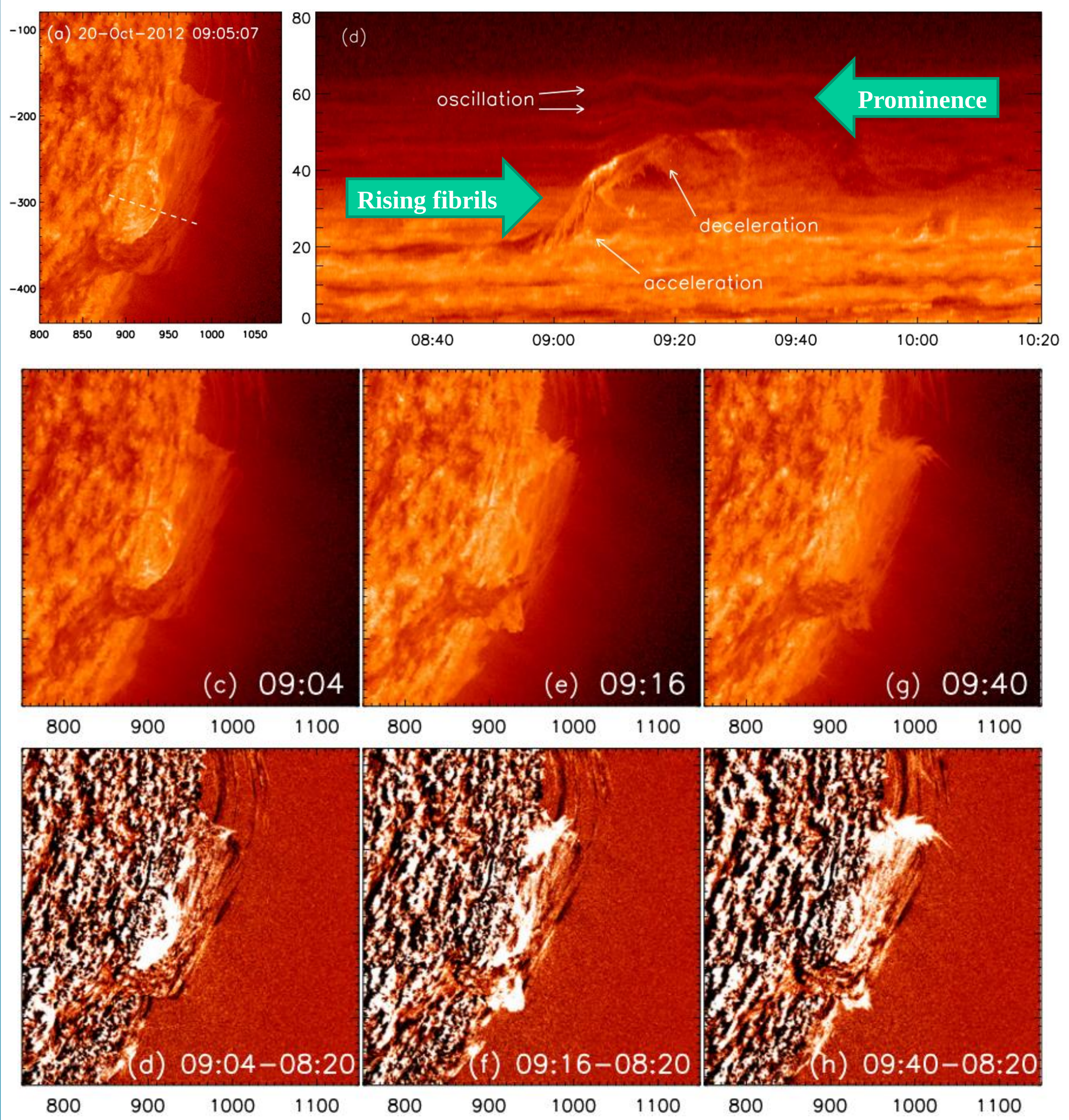
Abstract

Large-scale solar eruptive activities have close relationship with coronal magnetic flux ropes. Recent observation found that a flux rope system containing a prominence was triggered to erupt by the "flux-feeding" procedures, during which chromospheric fibrils rose upward and merged with the above prominence. In this paper, we carry out numerical simulations to investigate the influence of the flux-feeding procedures on flux rope systems. It is found that only axial magnetic flux is fed into the flux rope system by flux-feeding procedures, whereas the poloidal flux of the rope hardly changes. The simulation results demonstrate that flux-feeding procedures could trigger the flux rope system to erupt, provided that the total axial flux of the resultant flux rope reaches a critical value. Moreover, the cases, in which magnetic reconnection hardly occurs in the current sheet below the flux rope, also come to similar conclusions, indicating that an ideal process dominates the eruption. Therefore, we conclude that the flux rope eruption triggered by the flux-feeding procedure is, in essence, an upward catastrophe triggered by the increase of the axial magnetic flux of the rope.

What is Flux-feeding procedures?

- Chromospheric fibrils rose upward and merge with the prominence

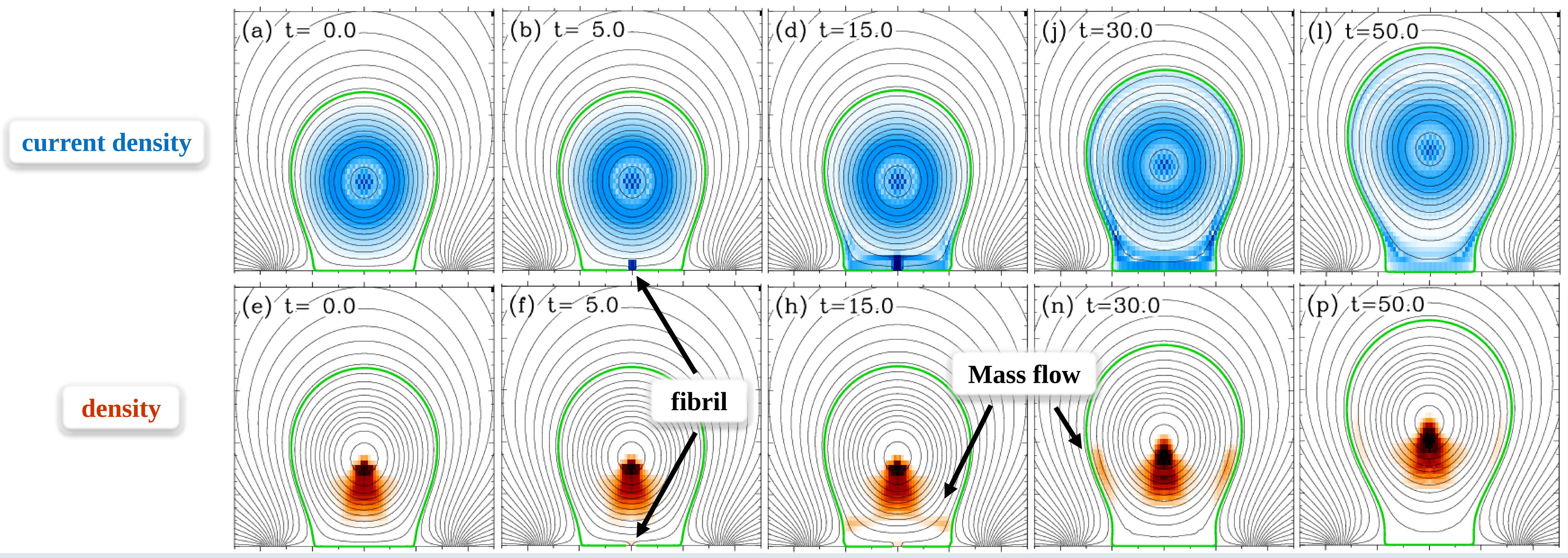


- Occur 3 times, finally the prominence erupted

(Zhang et al. ApJ, 2014)

Flux-feeding procedure in numerical simulations

- Simulation method: multi-step implicit scheme
- Initial state (t=0):
  - Bipolar background field
  - A flux rope (finite radius) sticks to the photosphere
- Flux-feeding procedure
  - A fibril emerges and rises upward from the lower boundary
  - The fibril is represented by a small flux rope in the simulation
  - Mass flows are triggered inside the major rope (counter-streaming flows)
- The fibril eventually merges with the target flux rope system, resulting in a new flux rope system



Influence of Flux-feeding procedures

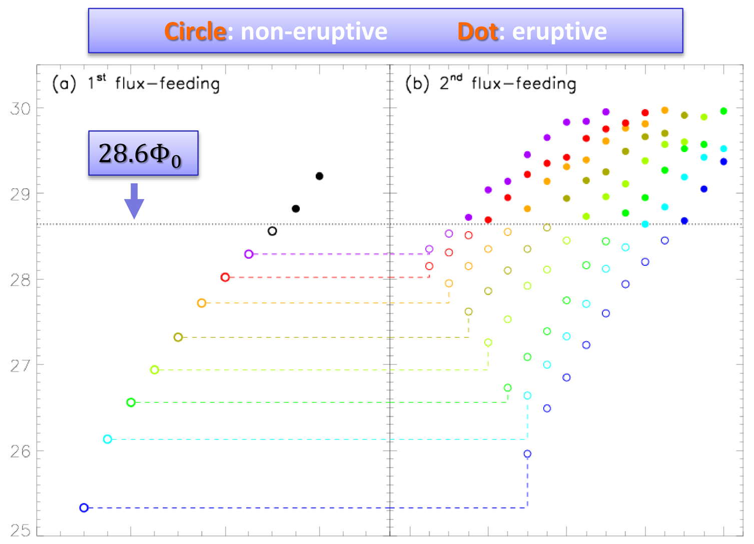
- The properties of the resultant flux rope after the flux-feeding procedures are tabulated here
  - The **poloidal** flux hardly changes
  - Flux-feeding procedures only feed **axial** flux into the flux rope system
- C_E: characterizes the fibril
  - Larger C_E, stronger magnetic field in the rising fibril, so that more axial flux is fed into the rope
  - Different C_E, different fibrils, different influence on the flux rope

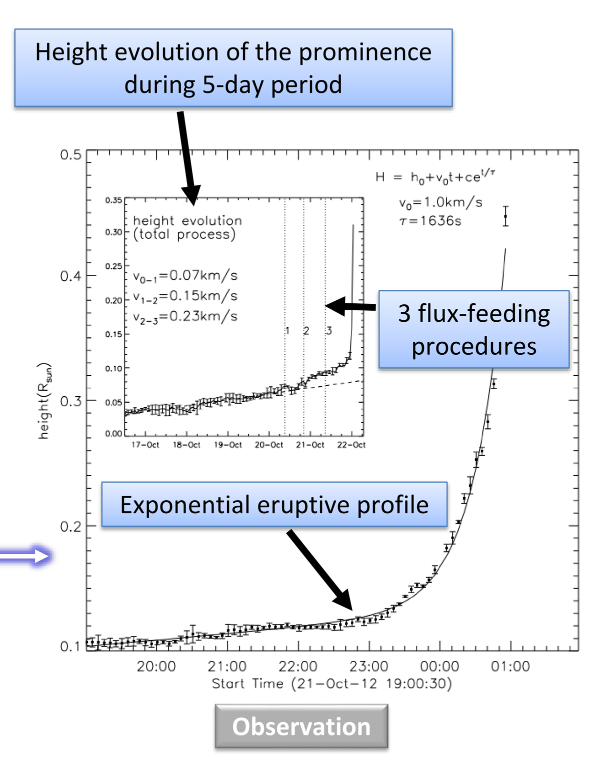
1st flux-feeding	Axial flux	Poloidal flux	Mass	Erupt?
Initial state	24.98	3.99	57.91	
C_E=1.20	26.56	4.00	63.18	N
C_E=1.35	27.72	3.99	65.01	N
C_E=1.51	28.60	3.99	67.28	N
C_E=1.52	28.64	3.99	67.75	Y
C_E=1.60	29.20	4.00	69.17	Y

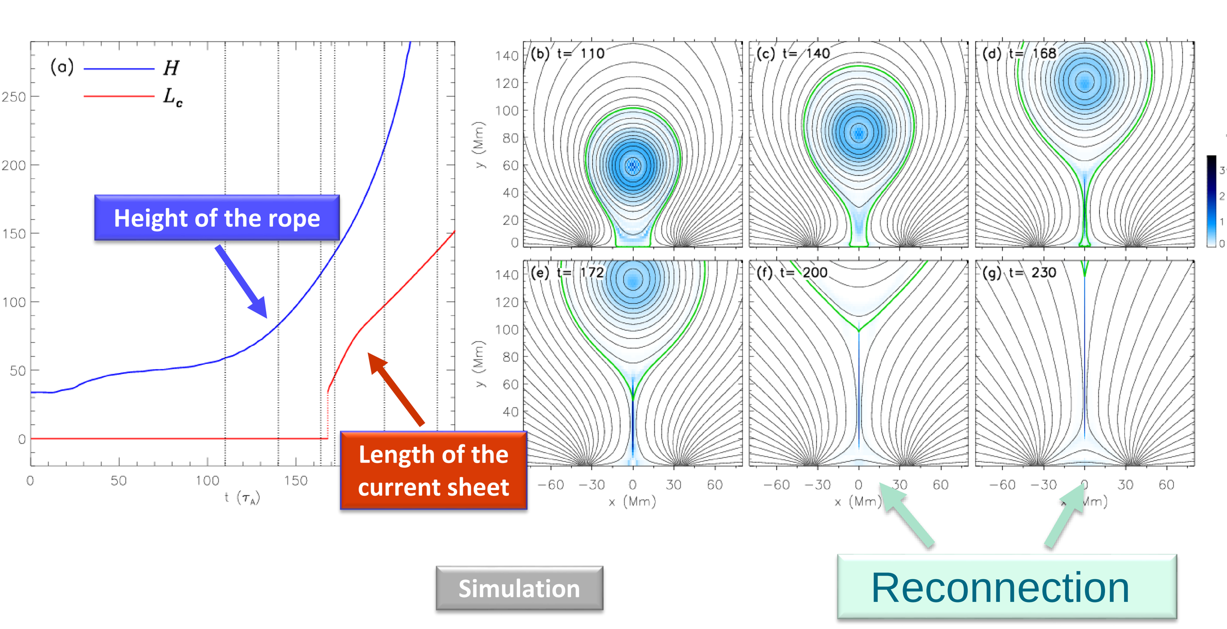
2nd flux-feeding	Axial flux	Poloidal flux	Mass	Erupt?
New initial state	26.56	4.00	63.18	
C_E=1.20	27.75	3.99	67.90	N
C_E=1.33	28.60	4.00	69.52	N
C_E=1.34	28.65	4.00	69.68	Y
C_E=1.40	28.95	3.99	70.74	Y

3rd flux-feeding	Axial flux	Poloidal flux	Mass	Erupt?
New Initial state	27.75	3.99	67.90	
C_E=1.00	28.52	3.99	72.07	N
C_E=1.01	28.58	3.99	72.40	Y

- Continuous flux-feeding procedures:
  - Select the non-eruptive state after 1st flux-feeding as new initial state
  - From the new initial state, emerges new fibrils, obtaining 2nd flux-feeding
  - Similarly, obtain 3rd flux-feeding
- Eruption triggered by flux-feeding procedures
  - No matter how many times flux-feeding procedures have occurred
  - Erupt when the axial flux reaches a critical value ($\approx 28.6\Phi_0 = 1.1 \times 10^{20}$Mx)
  - Exponential eruptive profile, consistent with observations







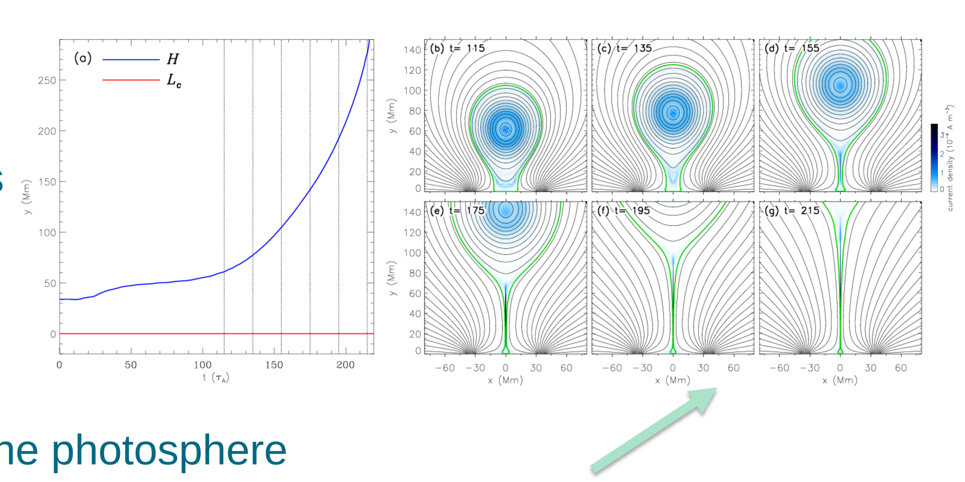
Cases without reconnection in the lower current sheet

- Prohibit reconnection in the lower current sheet below the rope
  - resistivity=0 → no physical reconnection
  - numerical treatment → no numerical reconnection

1st flux-feeding	Axial flux	Poloidal flux	Mass	Erupt?
Initial state	24.98	3.99	57.91	
C_E=1.20	26.56	4.00	63.18	N
C_E=1.52	28.64	3.99	67.74	Y

2nd flux-feeding	Axial flux	Poloidal flux	Mass	Erupt?
New initial state	26.56	4.00	63.18	
C_E=1.20	27.75	3.99	67.90	N
C_E=1.35	28.68	4.00	69.92	Y

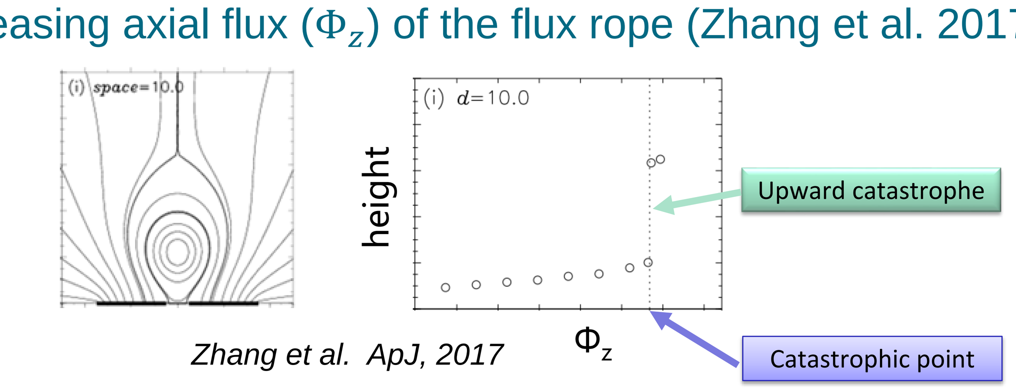
- Without reconnection, similar results
  - Flux-feeding procedures is recurrent
  - Eruption occurs if the axial flux excess a critical value ($\approx 1.1 \times 10^{20}$Mx)



- Eruption triggered by flux-feeding
  - Still exponential profile
  - Lower boundary of the rope sticks to the photosphere
  - Reconnection hardly occurs in the newly formed current sheet below the flux rope
- Therefore, the initiation of the flux rope eruption triggered by flux-feeding procedures should be dominated by an **ideal process**

Discussion and Conclusion

- Flux-feeding procedures
  - Hardly influence the background field but change the properties of the flux rope itself
  - Only feed **axial flux** into the target flux rope system
  - Could trigger the flux rope system to erupt
  - Eruption occurs if the **axial flux** excess a critical value, i.e. enough **axial flux** is fed into the flux rope system by flux-feeding procedures
  - The initiation of the eruption is dominated by an **ideal process**
- The eruption should be an upward catastrophe triggered by the increasing axial flux (Φ_z) of the flux rope (Zhang et al. 2017)



Zhang et al. ApJ, 2017