Influence of photospheric magnetic conditions on the catastrophic behaviors of flux ropes in active regions

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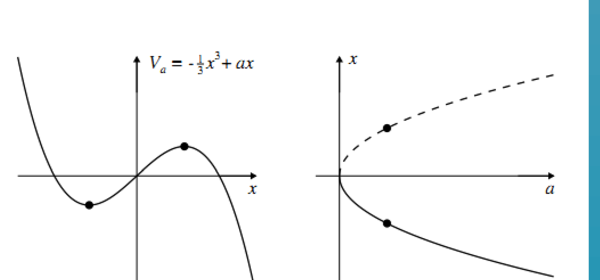
Abstract

Since only the magnetic conditions at the photosphere can be routinely observed in current observations, it is of great significance to find out the influences of photospheric magnetic conditions on solar eruptive activities. Previous studies about catastrophe indicated that the magnetic system consisting of a flux rope in a partially open bipolar field is subject to catastrophe, but not if the bipolar field is completely closed under the same specified photospheric conditions. In order to investigate the influence of the photospheric magnetic conditions on the catastrophic behavior of this system, we expand upon the 2.5 dimensional ideal magnetohydrodynamic (MHD) model in Cartesian coordinates to simulate the evolution of the equilibrium states of the system under different photospheric flux distributions. Our simulation results reveal that a catastrophe occurs only when the photospheric flux is not concentrated too much toward the polarity inversion line and the source regions of the bipolar field are not too weak; otherwise no catastrophe occurs. As a result, under certain photospheric conditions, a catastrophe could take place in a completely closed configuration whereas it ceases to exist in a partially open configuration. This indicates that whether the background field is completely closed or partially open is not the only necessary condition for the existence of catastrophe, and that the photospheric conditions also play a crucial role in the catastrophic behavior of the flux rope system.

What is catastrophe?

- Equilibrium states
  - Solutions of the force balance equation $F = 0$, vary with the control parameters (**CP**)
  - Might vanish for certain **CP** under certain magnetic configurations
- If there exists catastrophe:
  - After **CP** reaches a critical value, equilibrium states of the system will cease to exist in current configuration
  - The system will quickly evolves to a new magnetic configuration where exists equilibrium states, usually manifested as a sudden jump of **GP**
- A simple example (Kliem et al. 2014)

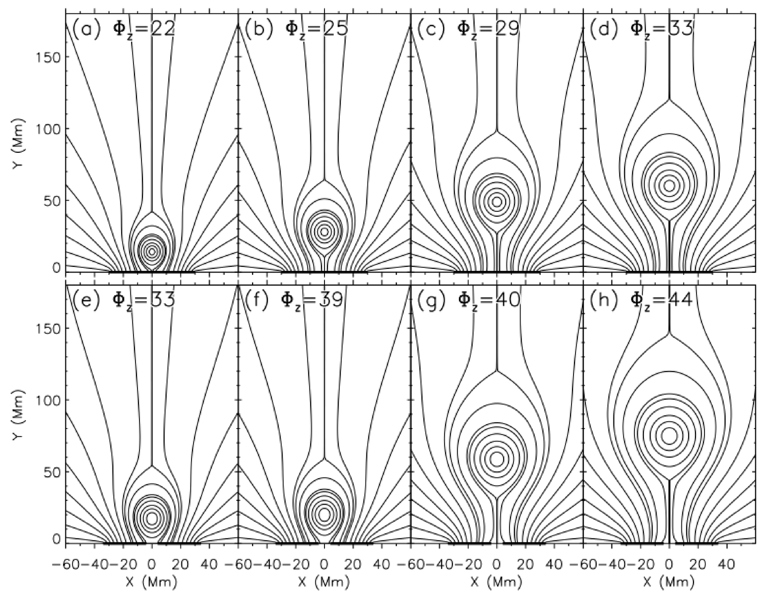


Previous studies

- Finite radius of the flux rope
- Bipolar background field
  - Fully closed: non-catastrophic (Forbes et al. 1991, Hu et al. 2000)
  - Partially open: catastrophic (Hu et al. 2001)
- Question: Is this the only determinant?
- Photospheric magnetic conditions are what we can observe currently
  What is the influence of photospheric conditions on catastrophe?

Example

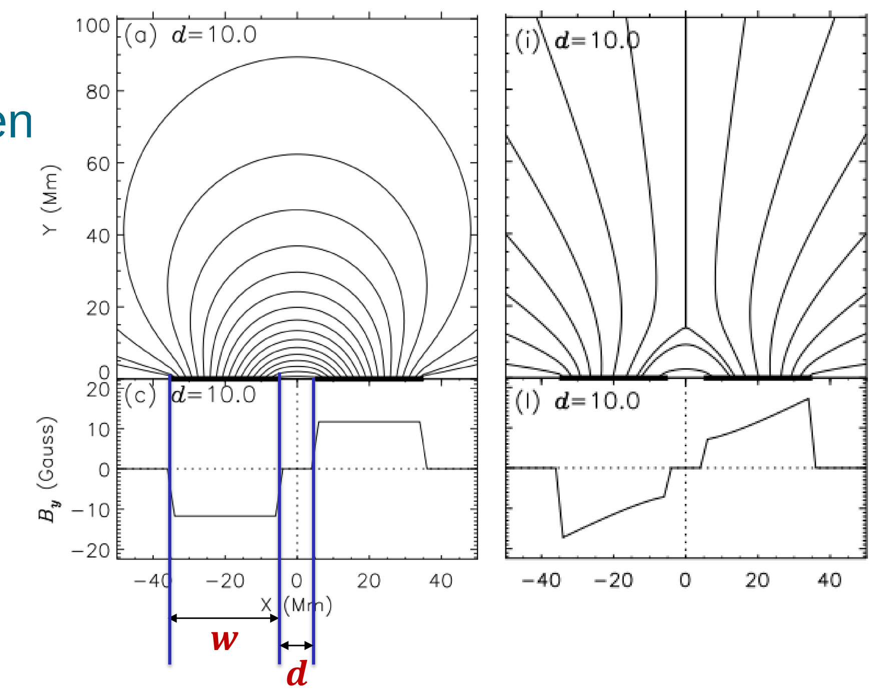
Top panels: a non-catastrophic case



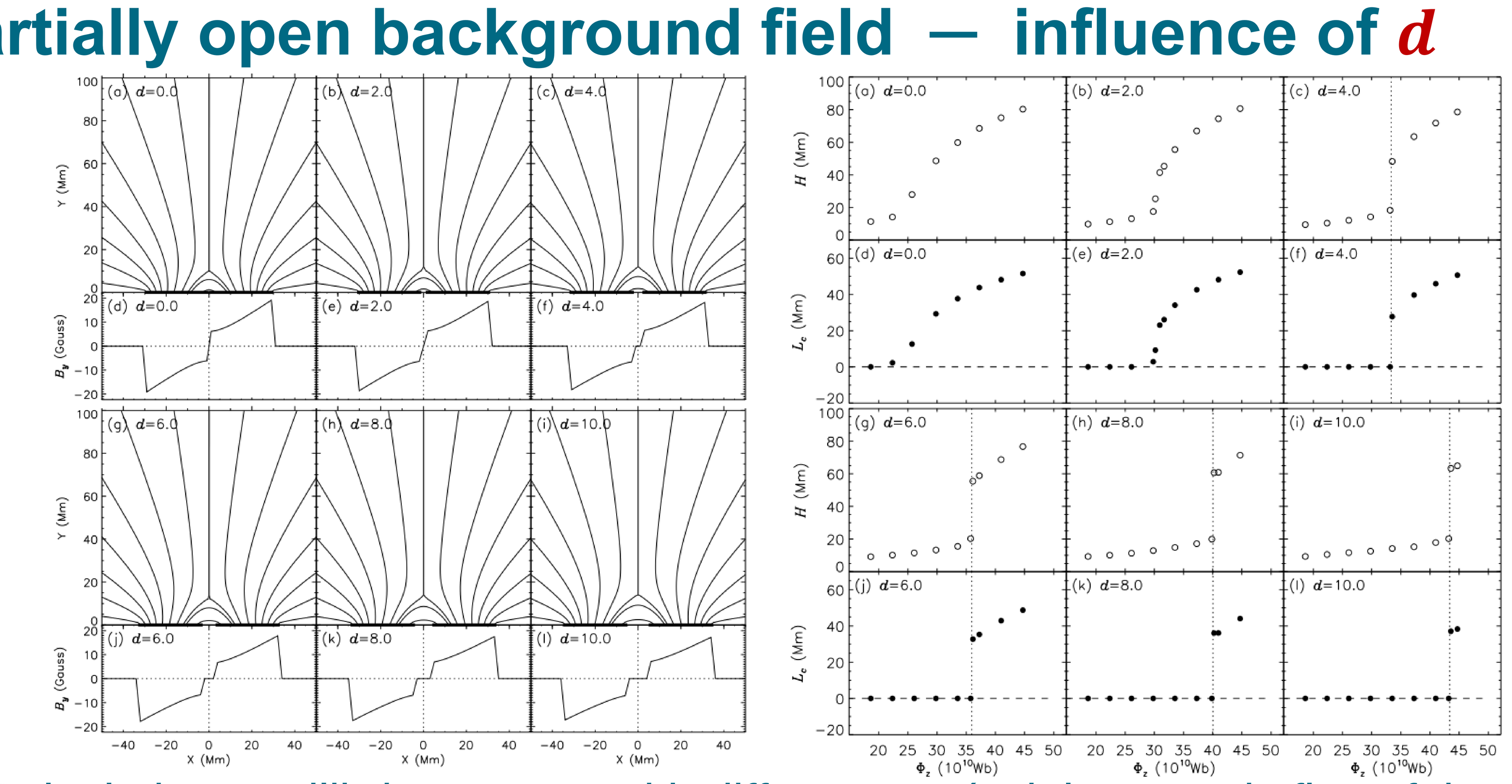
Bottom panels: a catastrophic case

Model

- Bipolar field: fully closed or partially open
- Photospheric magnetic conditions:
  - ***d*** : the distance between the inner edge of the two magnetic charges
  - ***w*** : the width of the charges
- Different ***d*** and ***w*** result in different magnetic systems
- We investigate under what ***d*** and ***w*** the magnetic system are catastrophic



Partially open background field — influence of *d*



- Calculating equilibrium states with different Φ_z (axial magnetic flux of the rope)
- H : height of the rope axis L_c : length of the current sheet below the rope
- For different systems: ***w*** is fixed as 30 Mm, $d = 0, 2, 4, 6, 8, 10$ Mm
  - $d = 0$: the evolution is continuous
  - $d = 2$: although the evolution is steeper, it is still continuous
  - $d \geq 4$: the evolution is catastrophic
- The system with partially open bipolar field is not always catastrophic
- The distance ***d*** also influences the existence of catastrophe

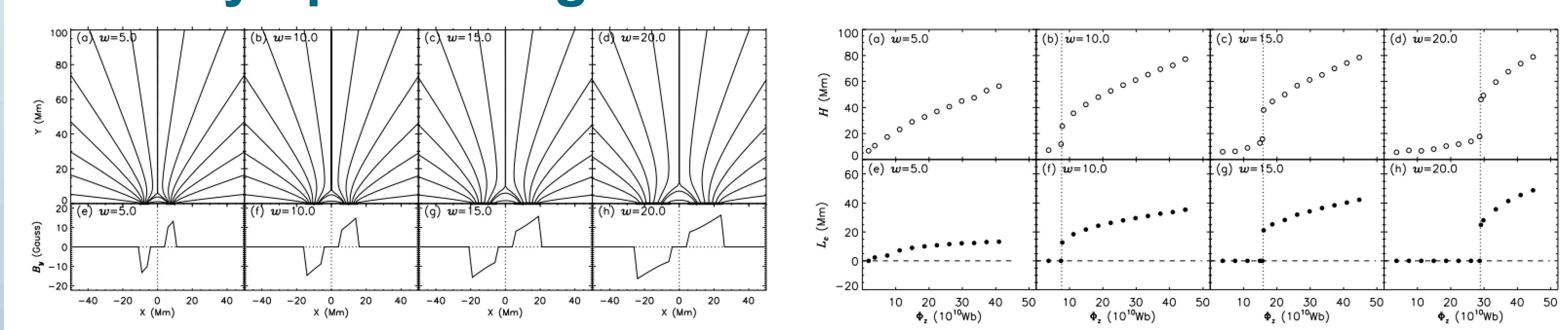
Partially open background field — influence of *d*

- ***d*** affects both the existence and the properties of the catastrophe
- Larger ***d*** results in:
  - Higher catastrophic point (Φ_z^c)
  - Larger amplitude (ΔL_c)
  - More released magnetic energy ($\Delta E/E$)

d(Mm)	$\Phi_z^c(10^{10}$ Wb)	ΔL_c(Mm)	ΔE(J m^{-1})	E(J m^{-1})	$\Delta E/E$
4.0	33.5	27.7	5.98×10^{13}	1.96×10^{15}	3.04%
6.0	36.1	32.7	7.64×10^{13}	1.99×10^{15}	3.84%
8.0	40.2	36.1	8.15×10^{13}	2.00×10^{15}	4.08%
10.0	43.6	37.1	9.24×10^{13}	2.03×10^{15}	4.55%

- The catastrophic evolution with larger ***d*** is more drastic

Partially open background field — influence of *w*

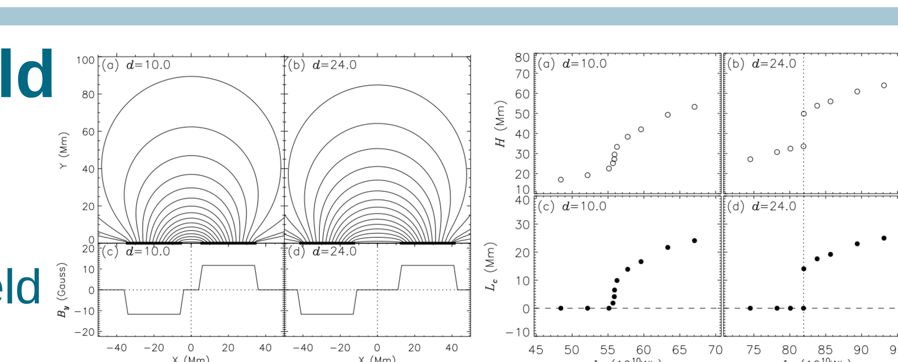


- Influence of ***w*** is similar (***d*** is always 30 Mm):
  - Non-catastrophic with small enough ***w***
  - More drastic evolution for larger ***w***

w(Mm)	$\Phi_z^c(10^{10}$ Wb)	ΔL_c(Mm)	ΔE(J m^{-1})	E(J m^{-1})	$\Delta E/E$
10.0	7.8	12.7	0.66×10^{13}	0.32×10^{15}	2.10%
15.0	16.0	21.1	2.14×10^{13}	0.58×10^{15}	3.69%
20.0	29.1	24.9	3.87×10^{13}	0.95×10^{15}	4.06%

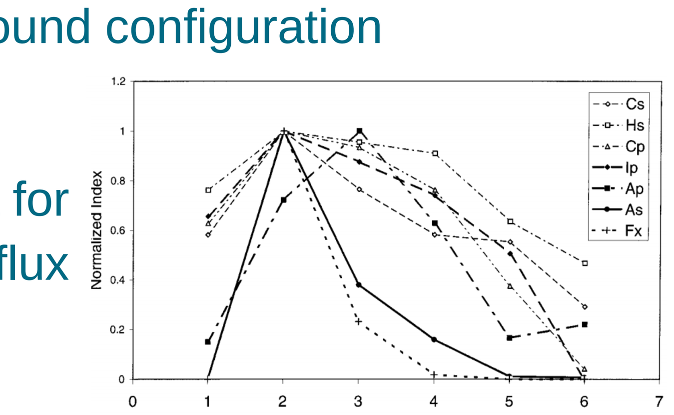
Fully closed background field

- Similarly, larger ***d*** also favors the existence of catastrophe
- The system with fully closed bipolar field is not always non-catastrophic



Discussion and Conclusion

- Whether the background field is completely closed or partially open is not the necessary condition for the existence of catastrophe
- Photospheric magnetic conditions also influence both the existence and properties of the catastrophe
  - Catastrophe exists when:
    Photospheric flux is not concentrated too much toward the polarity inversion line (***d*** is not too small)
    Source regions of the background field are not too weak (***w*** is not too small)
  - Larger ***d*** and ***w*** results in more drastic catastrophic evolutions
- We may infer that the determinant is the background configuration
- Our simulation results about the influence of the photospheric magnetic conditions might account for the evolution of active regions during their early flux emergence phase



Tapping et al. 2001