Coronal Response to New Magnetic Flux Emergence

In Relation to Global Coronal Magnetic Field Reversal and Coronal Mass Ejections

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Coronal Response to New Flux Emergence

- In relation to the global coronal magnetic field reversal
- In relation to the two kinds of prominences and two kinds of CMEs
- The role of helicity conservation

Part One:

Global Coronal Magnetic Field Reversal

Motivation

- We know the global magnetic field on the solar surface reverses itself once approximately every 11 years.
- How coronal magnetic field reverses its polarity accordingly?

The General Idea

- A magnetic field is always seeking a lower energy state, so a magnetic field will finally reach a potential state as the end state.
- However, because the corona is of high electrical conductivity, when a new flux emerges into the corona, it cannot immediately mix with the old flux to reach a potential state.

What We Do

- We *examine* a family of possible equilibrium states, and are interested in *demonstrating* that the possibility of an expulsion of magnetic flux to infinity is implied when the atmospheric magnetic field makes a *transition* between two equilibrium states.

What We Assume

1. A magnetic field emerges from the base of a stellar atmosphere, with a polarity different from the preexisting one.
2. The stellar atmosphere is the unbounded space outside a unit sphere.
3. The atmosphere is a perfect electrical conductor.
4. We neglect the presence of a stellar wind.
5. The magnetic field is force free.
6. The magnetic field is poloidal.

What We Calculate

- *Nine different cases*:

  Each is distinguished by the ratio of new emerged flux (Fe) to preexisting dipolar flux (Fo).

Cases	A	B	C	D	E	F	G	H	I
Fe/Fo	0.18	0.29	0.44	0.67	1.0	1.5	2.25	3.4	5.4

What We Calculate

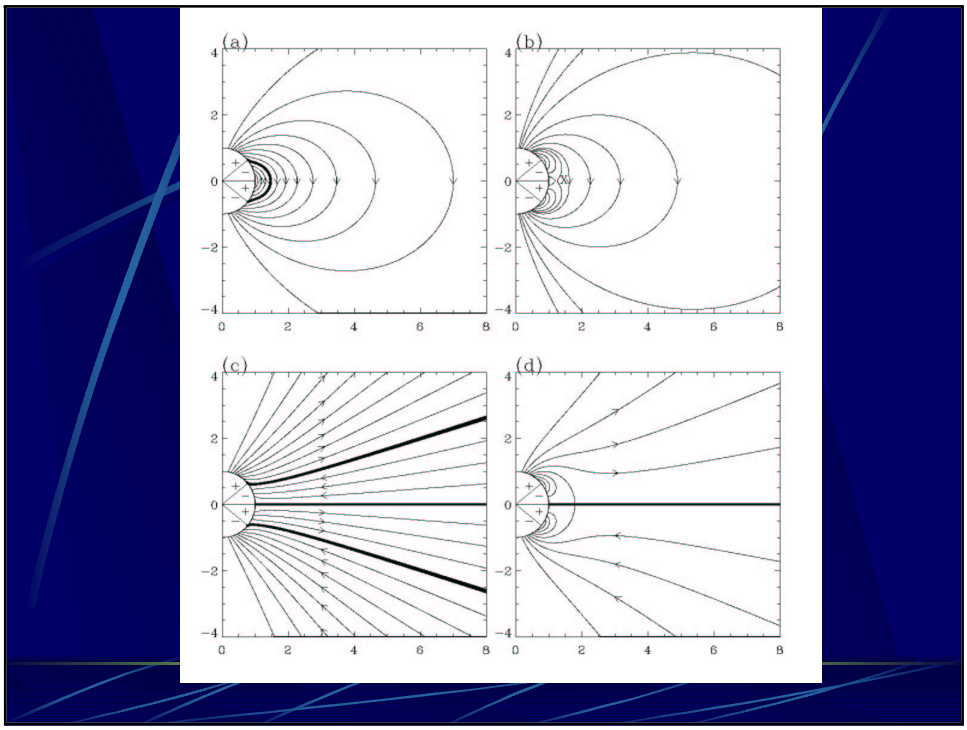
- *Four different kinds of equilibrium fields* for each case:

1. *Current Sheet Fields*: Treated as the initial states.
2. *Potential Fields*: Treated as the end state fields.
3. *Fully open Aly Fields*: A possible intermediate state.
4. *Partially open Fields*: Another possible intermediate state.

Above all have the same boundary flux distribution for each case.

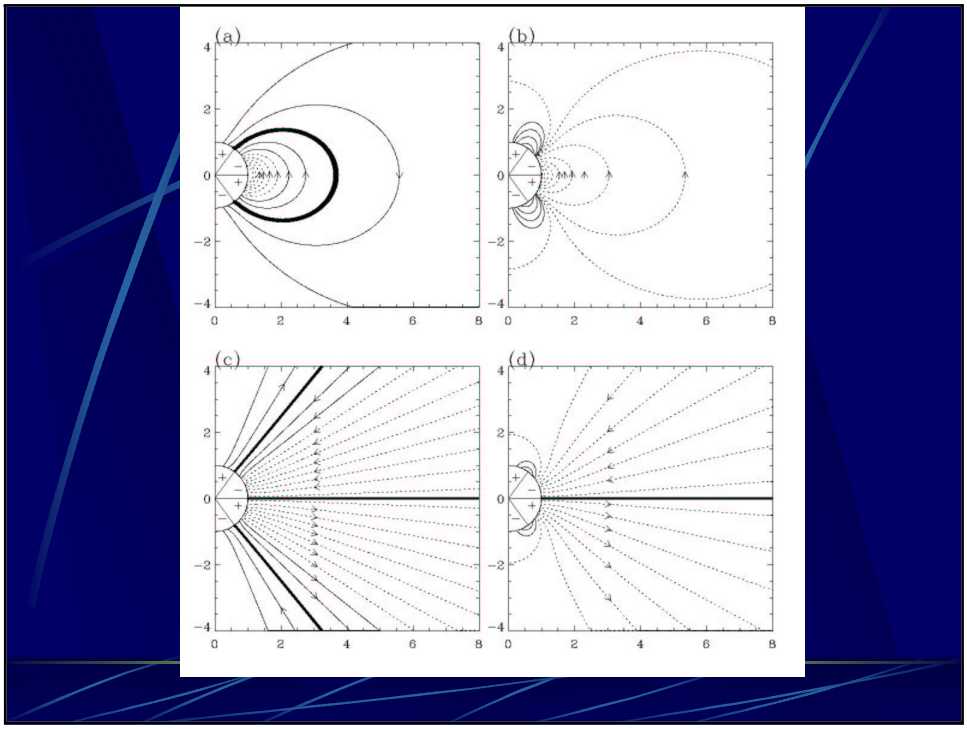
Two Distinguishing Cases (I)

- Case C, with a small Fe/Fo (= 0.44)
- The far field has not reversed yet despite the emergence of new magnetic flux of the opposite polarity at the surface.
- In this case, the partially open field is open at high latitudes.

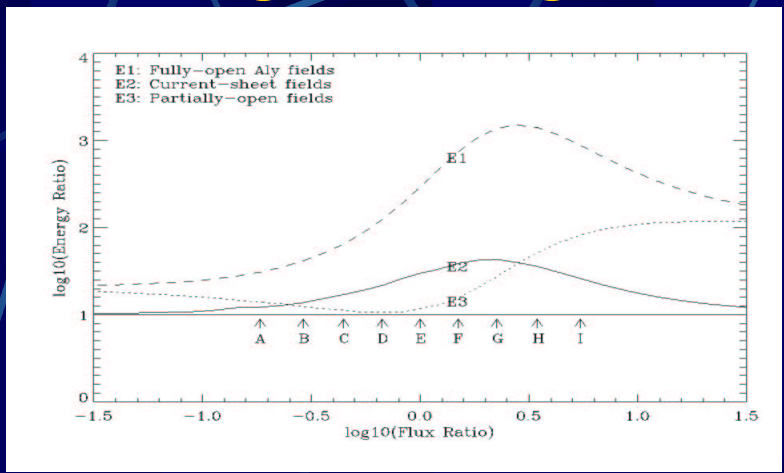


Two Distinguishing Cases (II)

- Case H, with a large Fe/ Fo (= 3.4)
- This is a case where there is a reversal of magnetic polarity in the far field.
- In this case, the partially open field is open near the equator .



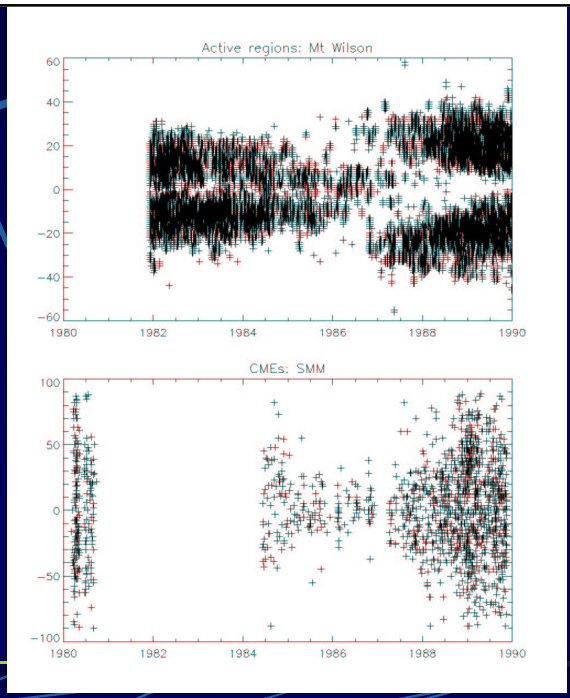
Magnetic Energies



Relating each field: from high-energy states to low-energy states
(for cases: E2>E3)

An Interesting Implication

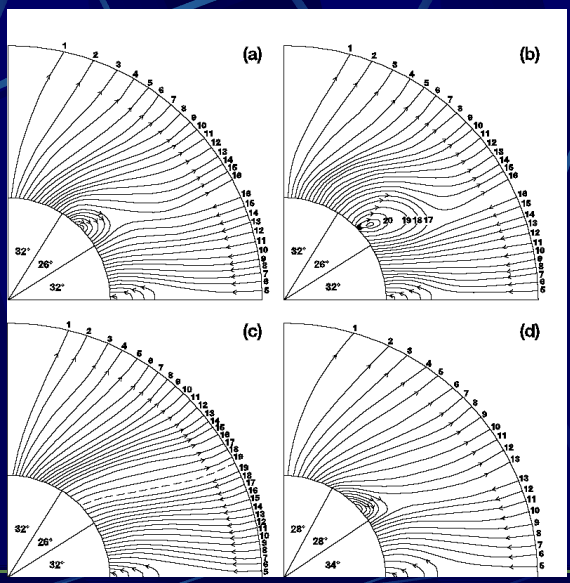
Hundhausen (1993)



Conclusion

1. When the emerged flux exceeds the preexisting flux by a certain threshold (say, Fe/Fo>2.25 here), the corona will reverse its large scale magnetic polarity.
2. For some cases, the initial global field with the new emerged flux has enough magnetic energy to be partially open, that is, to let one or two parts of its multipolar field to become open.
3. The partially open field will be open at high latitudes near the stellar poles when the flux ratio Fe/Fo is less than 1.0, and the partially open field will be open near the equator when the flux ratio Fe/Fo is higher than 1.0, even though in all cases the new flux, as the drivers of the evolution, is emerging in the equator.

CME taking off flux



Global Coronal Magnetic Field Reversal Story

- At the beginning stage:

  Fe/Fo is small

  Not reverse yet.

  However, the field may have enough magnetic energy to be partially open and will open at locations other than where the new flux has emerged. This may shed the preexisting flux in steps and systematically increase Fe/Fo.

Global Coronal Magnetic Field Reversal Story

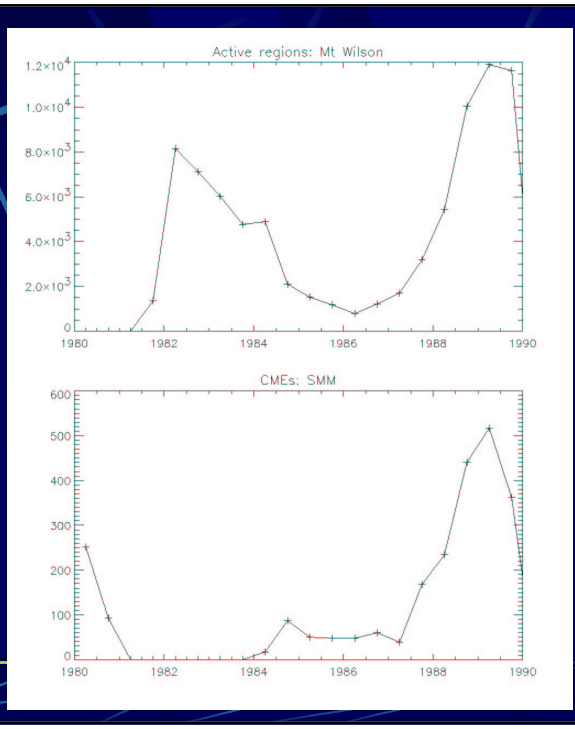
- As more and more new flux emerges, and as more preexisting flux is removed, the net emerged flux to preexisting flux ratio will eventually exceed its critical threshold. At this point, the corona may finally reverse its large scale magnetic polarity.

What are the Global Parameters That Control the Relationship of Active Regions and CMEs?

Observations

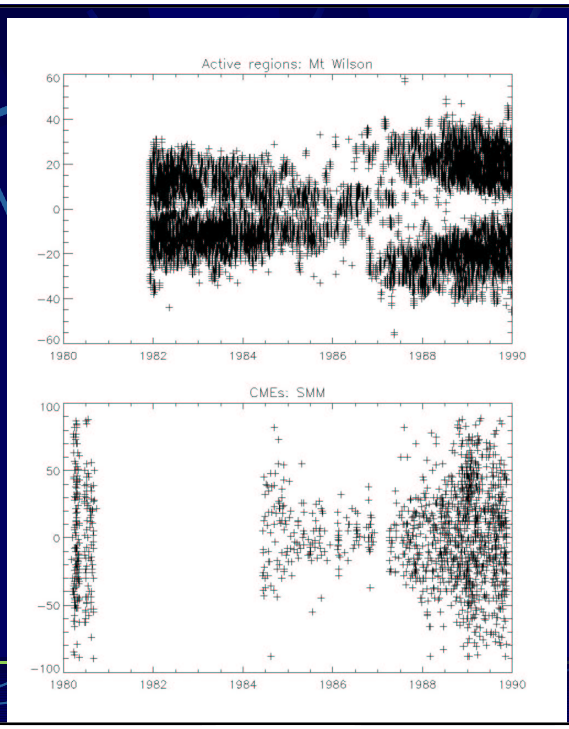
Number of active regions

Number of CMEs



Observations

Hundhausen (1993)



Explanation

- *First parameter*: The happening of CMEs is related to new flux emergence.
- *Second parameter*: The position of CMEs is related to new flux to preexisting flux ratio.
- Or *a third parameter*?

Part Two:

The Two Dynamical Types of Coronal Mass Ejections

Two Kinds of CMEs

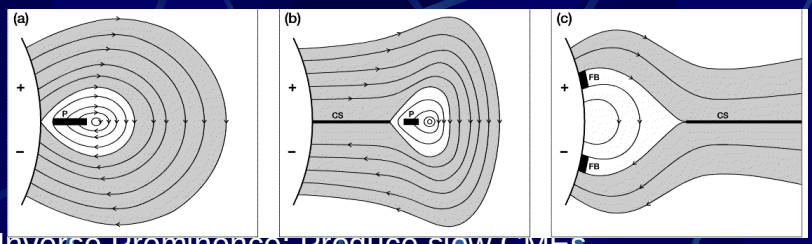
- Fast CMEs:
  - Usually from active regions, with flares.
  - Have speed already high in the low corona.
- Slow CMEs:
  - Show gradual accelerations.
  - Starting at or below median CME speed (400 km/s).

Two Kinds of Prominences

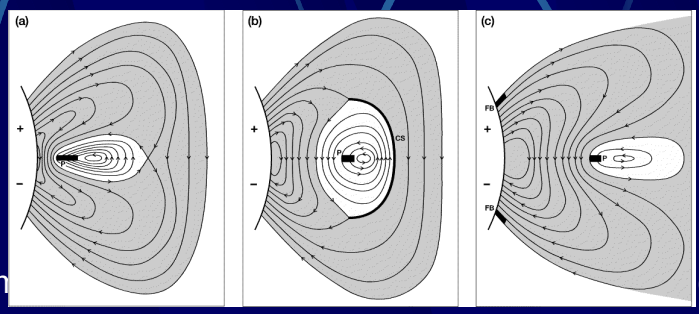
(Leroy, 1989)

- Inverse Prominences:
  - The horizontal field in the prominence is in the opposite direction relative to the underlying photospheric field.
  - Major class (75%)
- Normal Prominences:
  - The same direction
  - Minor class (25%)

Our Model



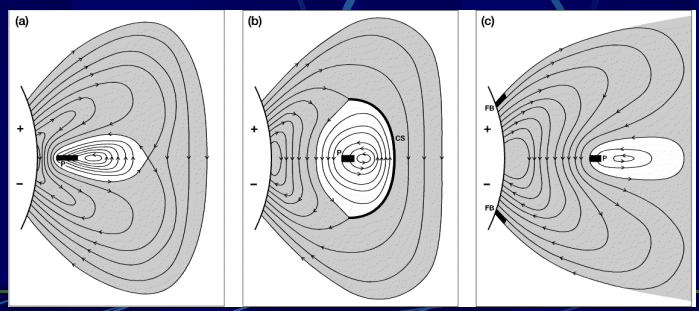
- Inverse Prominence: Produce slow CMEs



- Norn on)

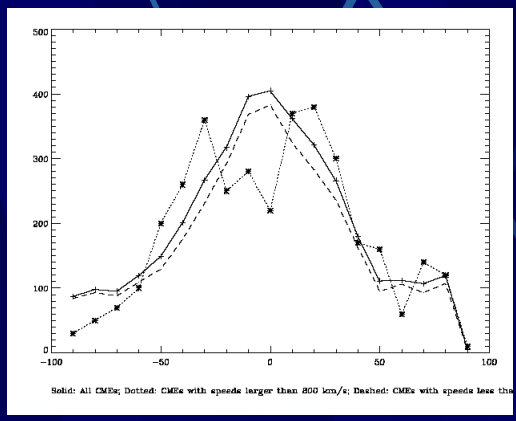
New Flux Emergences and Fast CMEs

- New flux emergence
  - --- opposite sense (Normal Prominence)
  - ---- Fast CME
  - --- Active regions
  - --- solar cycle dependence
  - --- ratio of fast CMEs to slow CMEs
  - --- ratio of normal prominences to inverse prominences



Observational Indication

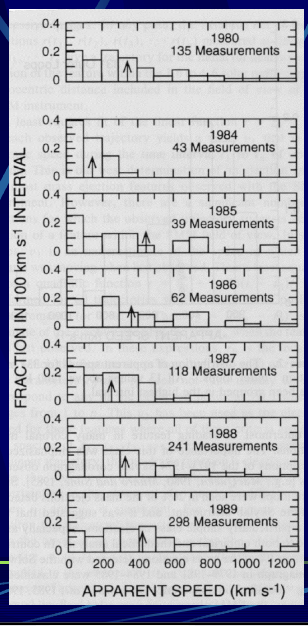
- CME latitude distributions (LASCO)



Observational Indication

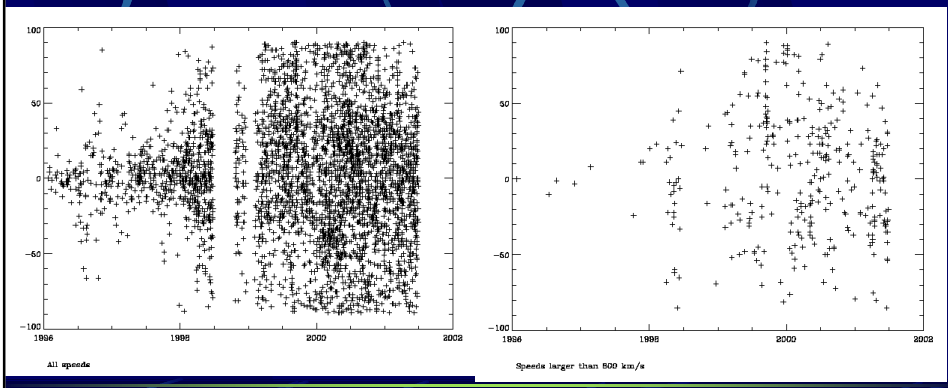
- Fast CMEs at the solar minimum (SMM)

Hundhausen et al. (1994)



Observational Indication

- Fast CMEs at the solar minimum (LASCO)



Part Three:

The Role of Helicity Conservation

(on going)

The Model

- Domain: $r=r_1=1.0$, $r=r_2=4.0$
- Constant α force-free field

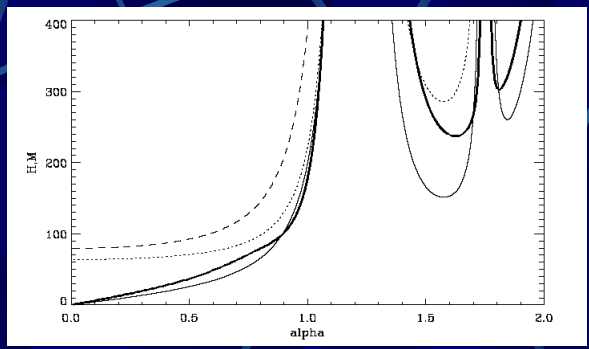
$$\mathbf{B} = \frac{1}{r\sin\theta}\left(\frac{1}{r}\frac{\partial A}{\partial \theta}\hat{\mathbf{r}} - \frac{\partial A}{\partial r}\hat{\theta} + \alpha A\hat{\varphi}\right)$$

  - Solution:

$$A = (a_n J_{n+1/2}(\alpha r) + b_n J_{-(n+1/2)}(\alpha r))\sqrt{\alpha r}\sin\theta P_n^1(\cos\theta)$$

  - a_n and b_n determined by the boundary condition
  - with or without a current sheet
- Boundary condition:
  - at $r=r_1$, any prescribed A, taken same as in Paper 1.
  - at $r=r_2$, A=0.

The Model

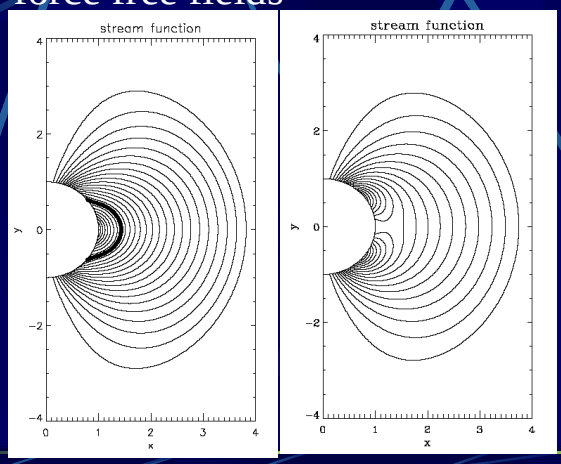


- Assumption: *Total Helicity Conservation*

  Reconnection happens to change the topology and make the field reach a lower magnetic energy state, but the total helicity is conserved.

Interesting Implications

- The relaxation from current sheet fields to force free fields

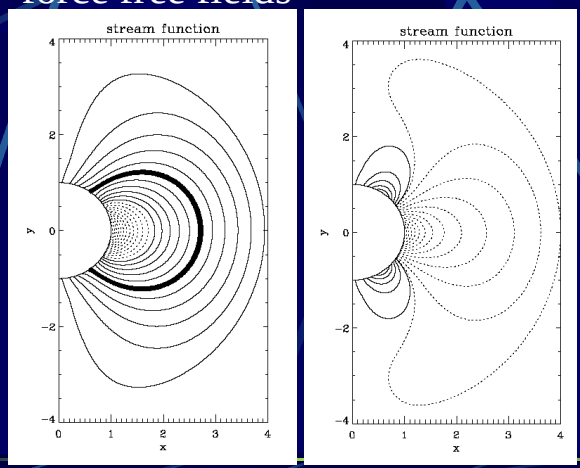


Fe/Fo=0.44

H=12.67

Interesting Implications

- The relaxation from current sheet fields to force free fields

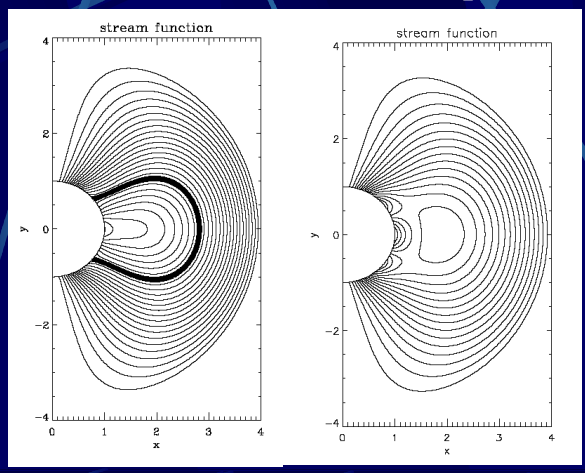


Fe/Fo=3.4

H=5.91

Interesting Implications

- The formation of flux ropes

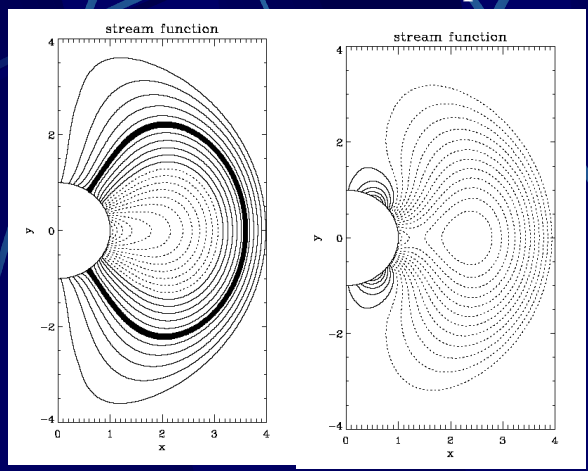


Fe/Fo=0.44

H=88.3

Interesting Implications

- The formation of flux ropes

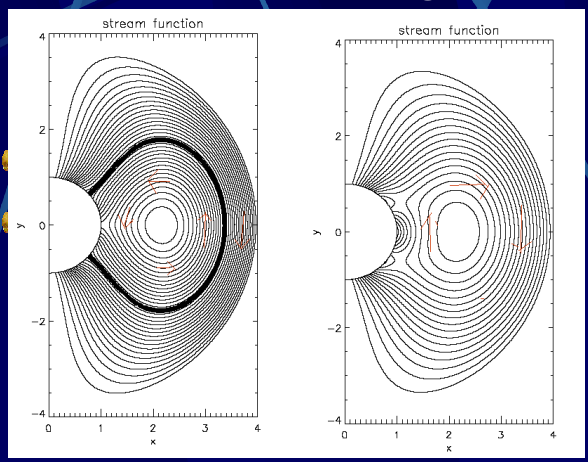


Fe/Fo=3.4

H=76.0

Interesting Implications

- The evolution of emerged flux ropes

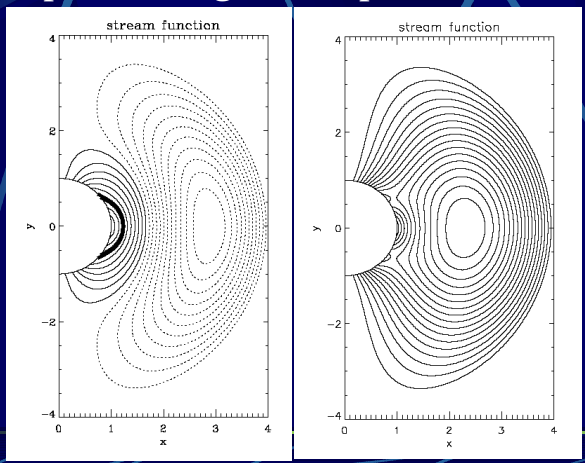


Fe/Fo=0.44

H=178.5

Interesting Implications

- The role of magnetic flux emergences to the preexisting flux ropes

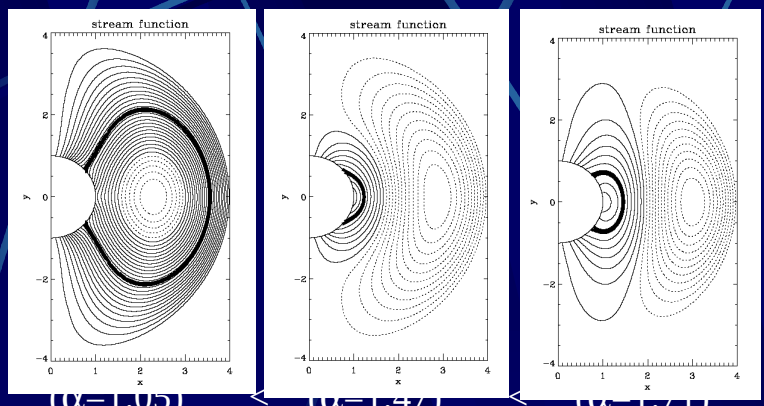


Fe/Fo=0.44

H=178.5

Interesting Implications

- The minimum energy α value for a given helicity



(α=1.05) < (α=1.47) < (α=1.71)

M1 > M2 > M3

Concluding Points …

- New Flux Emergence brings new flux, new helicity (internal + mutual), forming current sheet, storing magnetic energy …
- Reconnection changes the topology and makes the releasing of magnetic energy and redistribution of magnetic helicity possible.
- And all these are related to the coronal phenomena and activities, such as the reversal of global magnetic field, coronal mass ejections, two kinds of prominences ---