ISEST June 17 – 20, 2013 Hvar, Croatia

Eruptive Flux Rope Model for ICME Evolution

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Goal

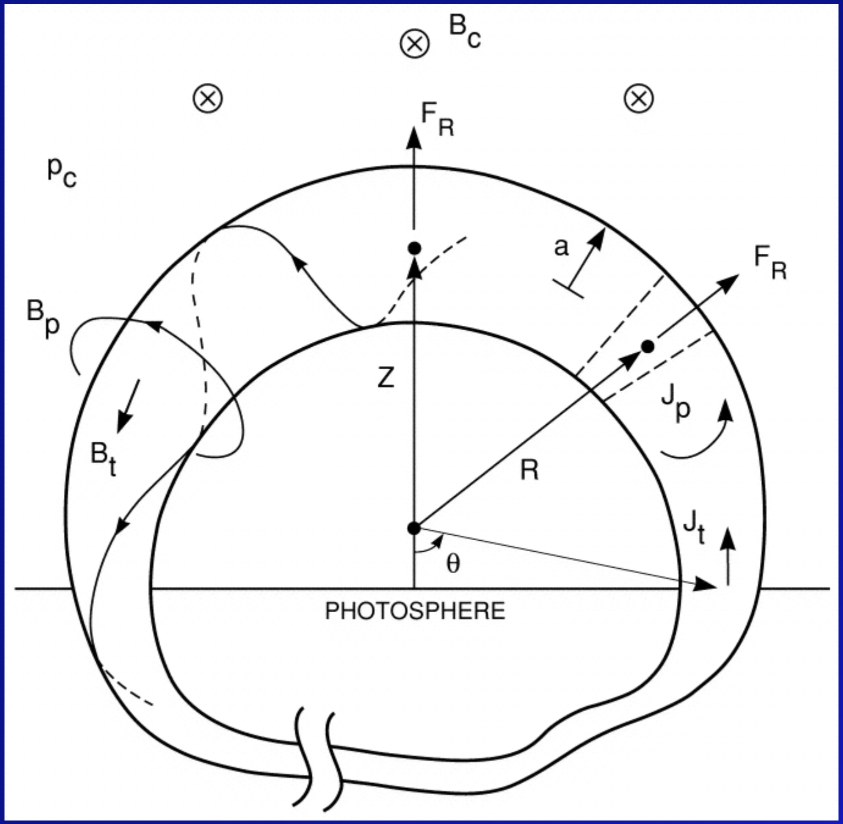
Understand the physical mechanism that controls the (1) initiation and (2) evolution of CMEs, using a unified flux rope model

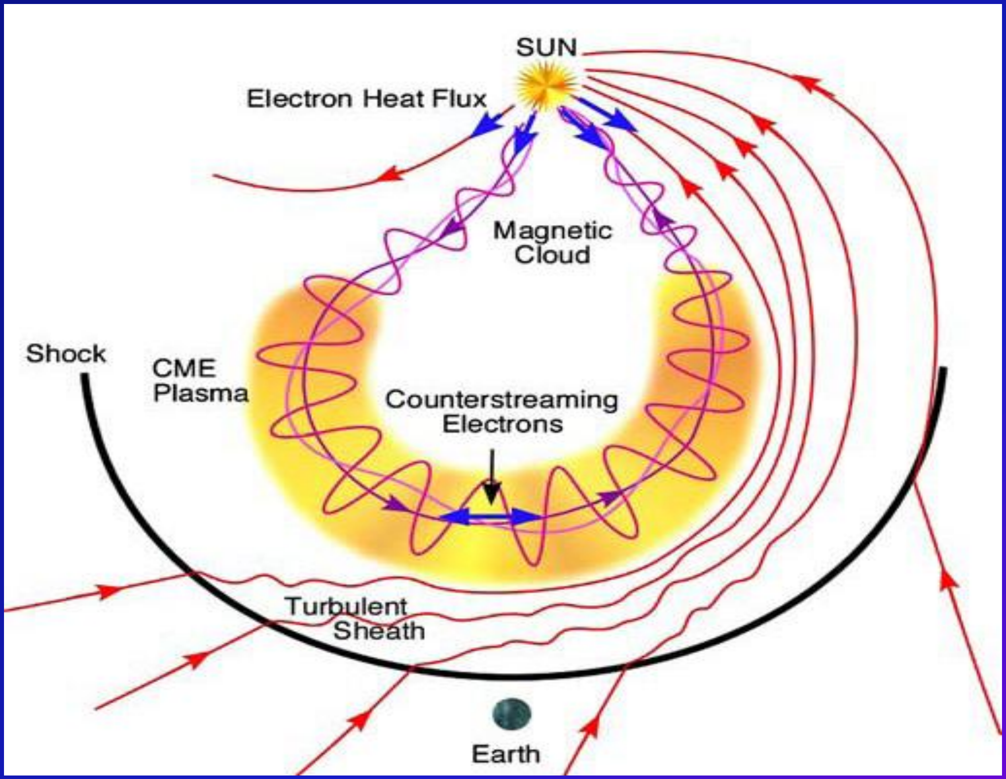
Advantages:

1. **A unified model for both initiation and evolution**
2. **Analytic approach allows the examination of multiple relevant physical forces acting on flux ropes**
3. **Useful for understanding**

Eruptive Flux Rope Model

- Eruptive flux rope model





In the Corona (Chen 1989); Analytical

In the Interplanetary Space (Zurbuchen & Richardson 2006); Conceptual

Forces

- **Forces on the major axis (Chen 1996)**

$$F_R = \frac{I_t}{C^2 R}\left[\ln\left(\frac{8R}{a}\right) + \frac{1}{2}\beta_p - \frac{1}{2}\frac{B_t^2}{B_{pa}} - 1 + \frac{\xi_i}{2} + 2\frac{R}{a}\frac{B_s}{B_{pa}}\right] + F_g + F_d$$

1. Lorentz Self - force
2. External Lorentz Force
3. Gravity Force
4. $F_d = \rho_e \pi a C_d (V - V_{sw})|V - V_{sw}|$; SW aerodynamic drag force

- **Forces on the minor axis**

$$F_a = M\frac{dw}{dt} = \frac{I_t}{c^2 a}\left(\frac{B_t^2}{B_{pa}^2} - 1 + \beta_p\right)$$

magnetic pressure
plasma pressure

Forces: modified Bs

When ambient solar wind exists in the outer coronal and heliosphere, the external magnetic force should be modified as

$$B_s \rightarrow B_s \cdot (V - V_{sw}) / V_{sw}$$

Can we call it magnetic drag force or something else?

Morphology Reconstruction

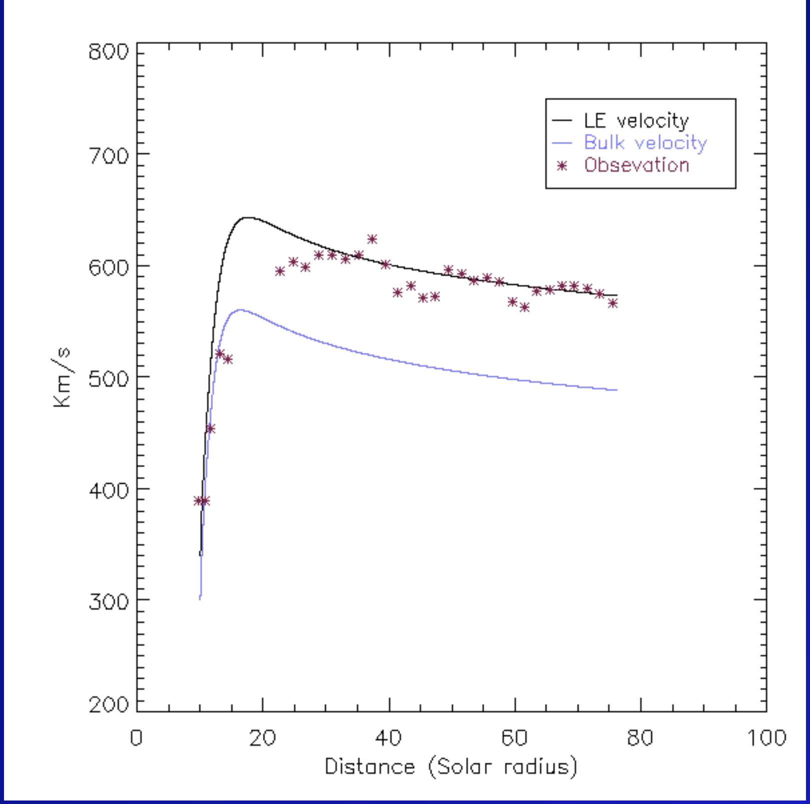
Forward modeling is effective, since the overall morphology persists; near-self-similar

GCS model: six free parameters characterizing a semi-circular flux rope on the top of cone-shaped legs.

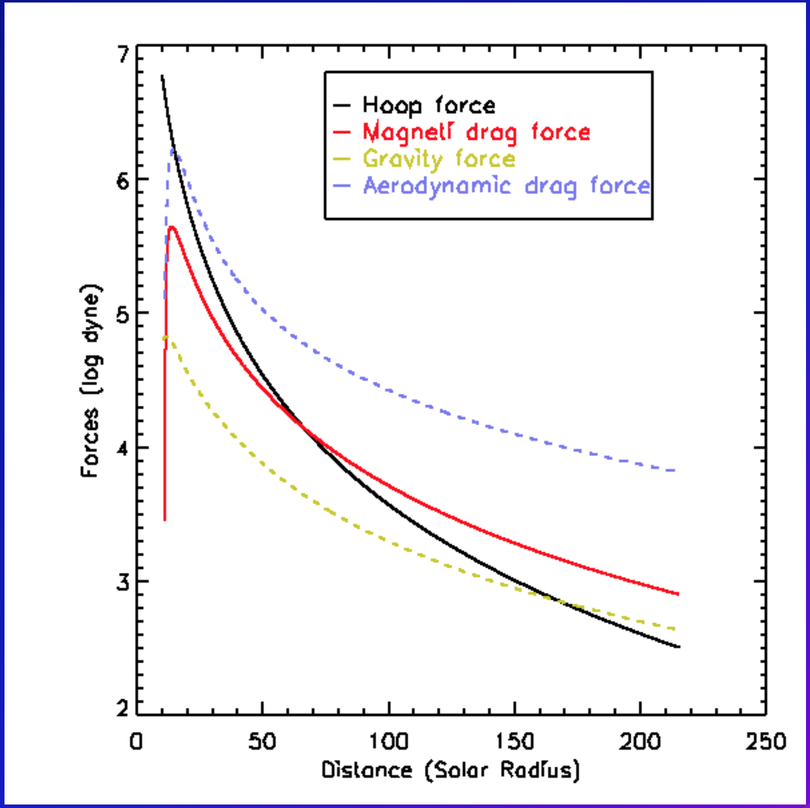
GCS model (Thernisien et al. 2006)

Observational Test

- 2008/12/12 CME event
- Aerodynamic drag force dominates others at > 10s Rsun
- (Poomvises 2011; Ph.D. Thesis)

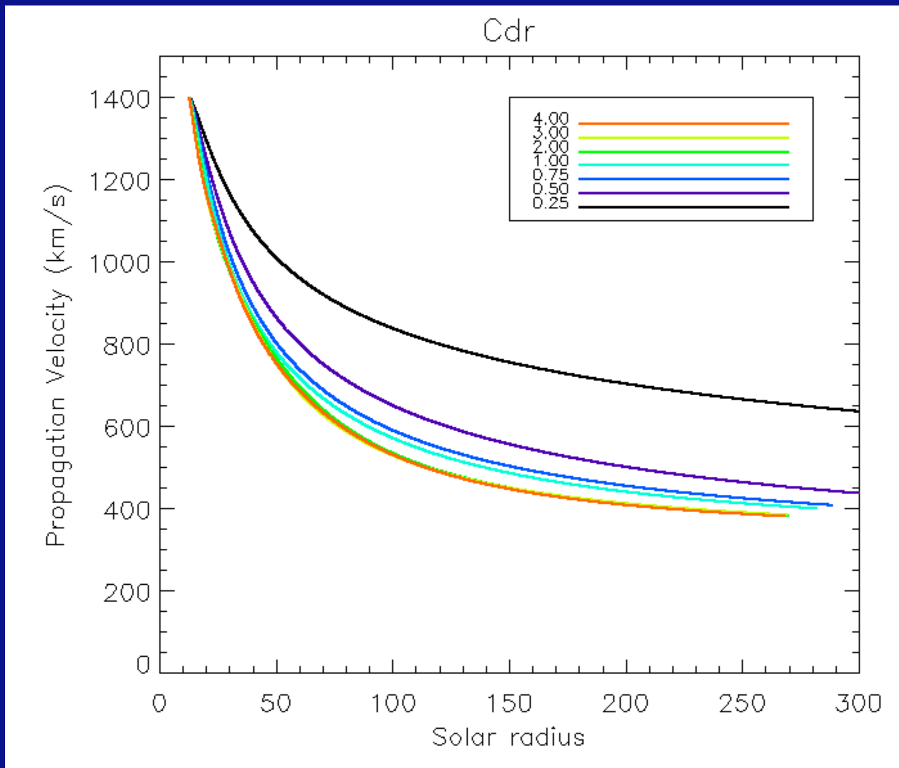


Kinematic Evolution: Observation and Fitting



Physical Forces Acting on CME Flux Rope Major Axis

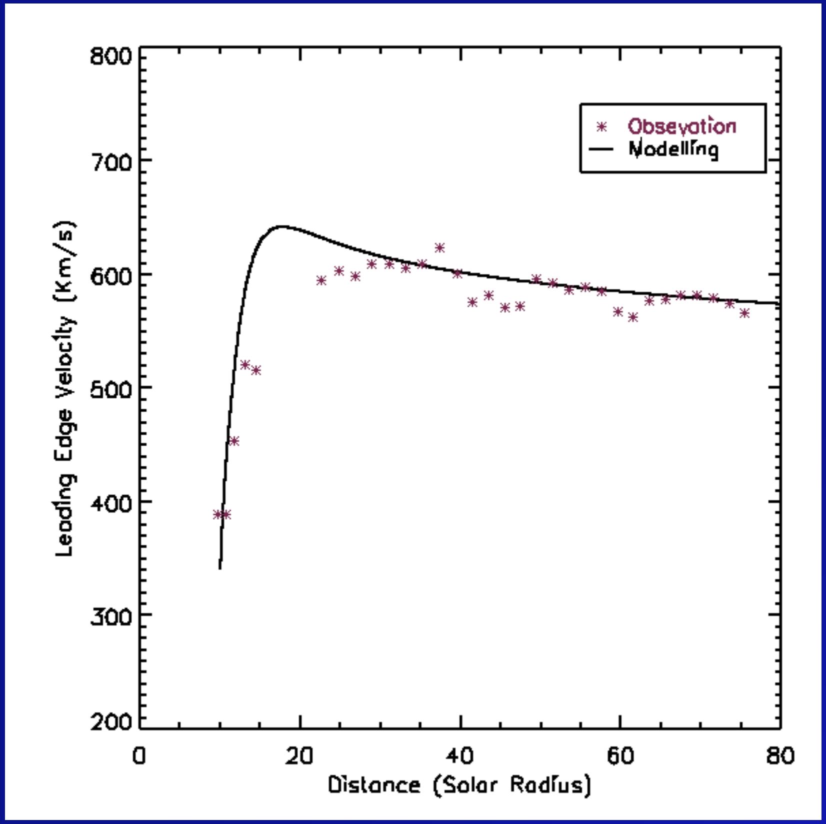
Drag Coefficient C_d



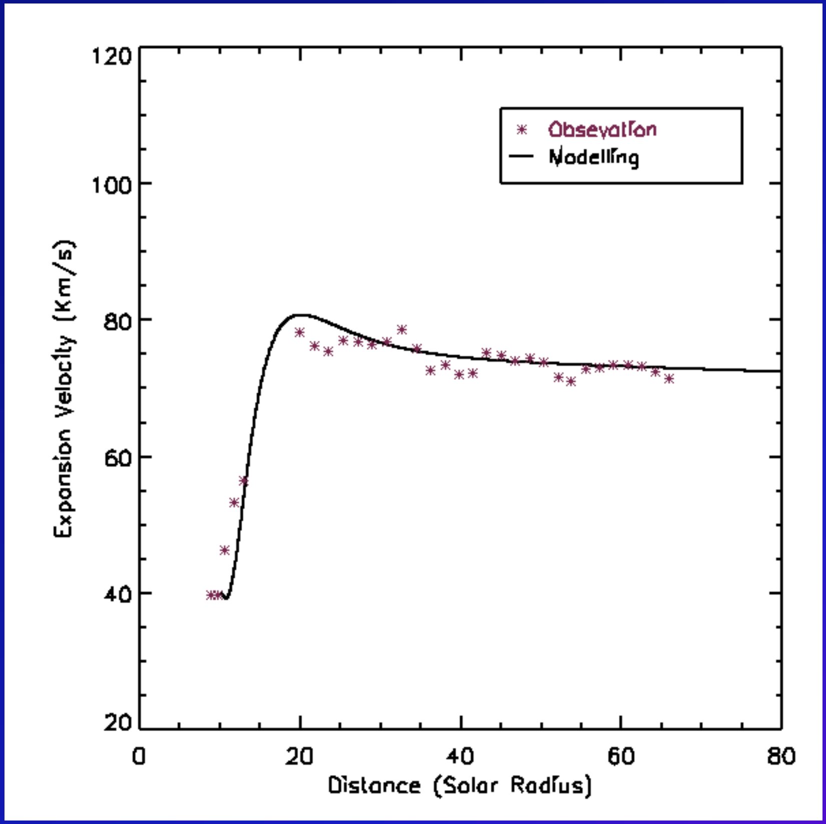
Parametric Space Study of C_d

- **C_d could be from 1 to 10 from MHD simulation (Cargill 2004).**
- **However, STEREO observations indicate a much narrower range between 2 and 3.**
- **Thus, CMEs experience strong drag (C_d >1)**
- **It implies that most velocity changes within ~ 80 $R_{\odot}$.**
- **It implies that the propagation couples with expansion.**

Do not forget EXPANSION - 3D



LE Velocity



Expansion Velocity

- **A "good" model needs to explain not only (1) the propagation, but also (2) the expansion**
- **Expansion needs the knowledge of polytropic index, which regulates the internal pressure**

Conclusion

Very useful for understanding the physical mechanism that controls the (1) initiation and (2) evolution of CMEs.

Advantages:

(1) A unified model for both initiation and evolution (not extensively discussed here)

(2) Analytic approach allows the examination of multiple relevant physical forces acting on flux ropes

Caveats of this approach

1. Does not include the effect of magnetic reconnection in the initiation model
2. Ignore the shock and shock sheath
3. There is no explicit treatment of the 3-D structure

Thus, very useful in understanding, but limited in prediction, because of the lack of the true 3D context; need help from 3D numerical simulation

The End