# Magnetic erosion and kinematics of Coronal Mass Ejections

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# Motivation of our study

- The strong impact of magnetic reconnection on the basic parameters and geometrical features of the structure affects its dynamic evolution and geo-effectiveness.

- The addition of the erosion process enriches Drag-based modeling. The difference in the Time of Arrival might lead to lower MAE (see Vourlidas et al. 2019)

| | Accuracy (h) | MAE (h) |
|---|---|---|
| Vršnak et al. 2014 | +1.1 | 14.6 |
| Dumbović et al. 2018 | - 9.7 | 14.3 |
| Shi et al. 2015 | - 9.9 | 13.2 |

# drag force

## ICME ← interaction → Solar Wind

Bothmer and Schwenn et al. 1998, Forsyth et al. 2006, Liu et al. 2005, Wang et al. 2005, Leitner et al. 2007

$$\boldsymbol{R} = 0.138 * \mathrm{R}^{0.69}\,(AU)$$

$$\boldsymbol{n} = 6.59 * \mathrm{R}^{-2.384}\,(AU)$$

$$n_{sw}(R) = \frac{8.0 * 10^7}{R^6} + \frac{4.1 * 10^6}{R^4} + \frac{3.3 * 10^5}{R^2}$$

LeBlanc et al. 1998

$$V_{sw}(R) = V_{sw\,(1\,AU)} \frac{n_{(1\,AU)} R_{(1\,AU)}{}^2}{n(R) R^2}$$

Cargill et al. 2004 → **Cylindrical flux rope**

$$\frac{dV_i}{dt} = -\gamma C_D |V_{ICME} - V_{sw}|(V_{ICME} - V_{sw})$$

$$\gamma = \frac{\rho_e A}{\tau(\rho_{ICME} + \rho_{sw}/2)}$$

Subramanian et al. 2012

$$R_e = \frac{(V_{ICME} - V_{sw}) * R_{ICME}}{\eta}$$

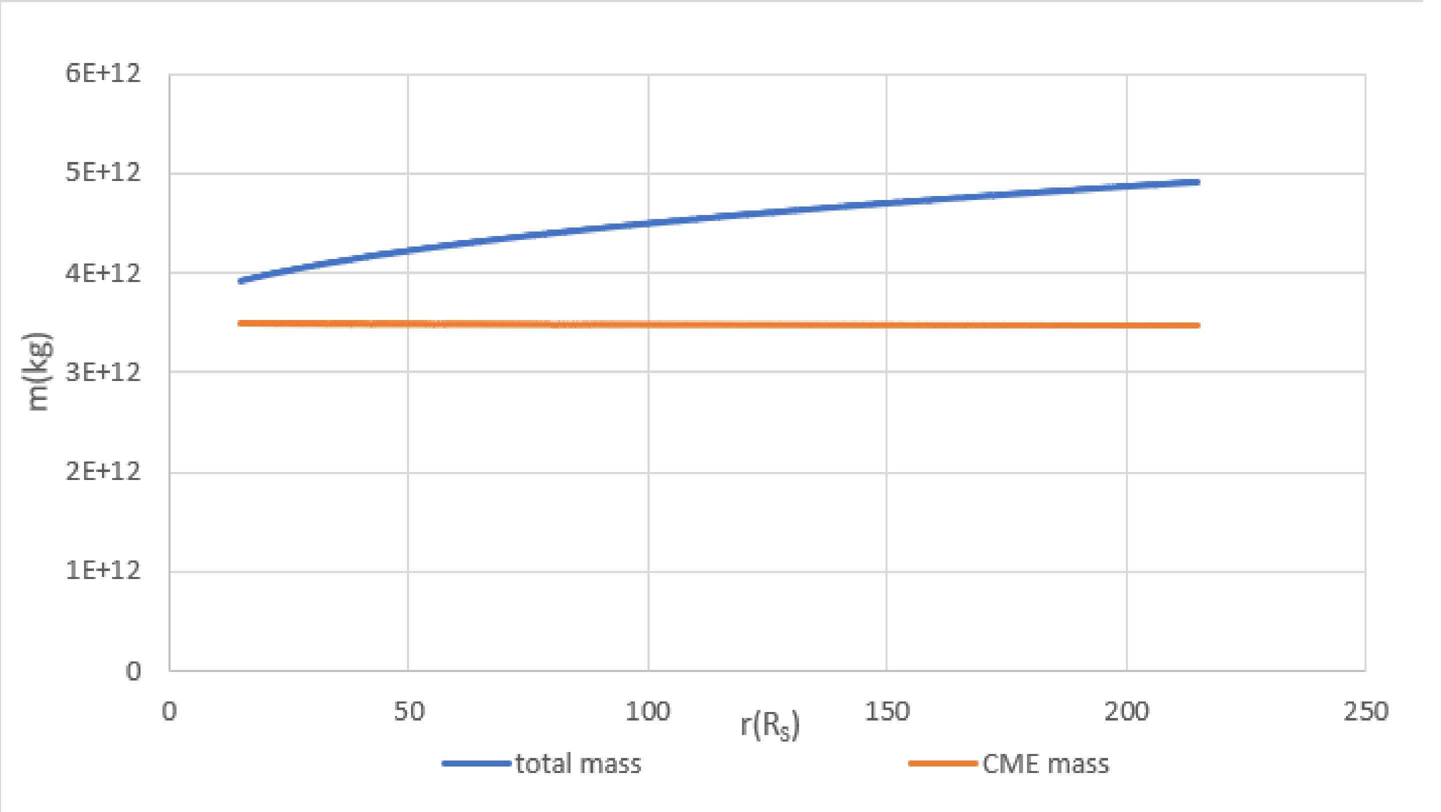
$$C_D = 0.1478 - \frac{42834}{R_e} + 9.8 \times 10^{-9} R_e$$

# CME pile-up and virtual mass system

- pile-up due to solar wind interactions (sheath)
- virtual mass = added mass

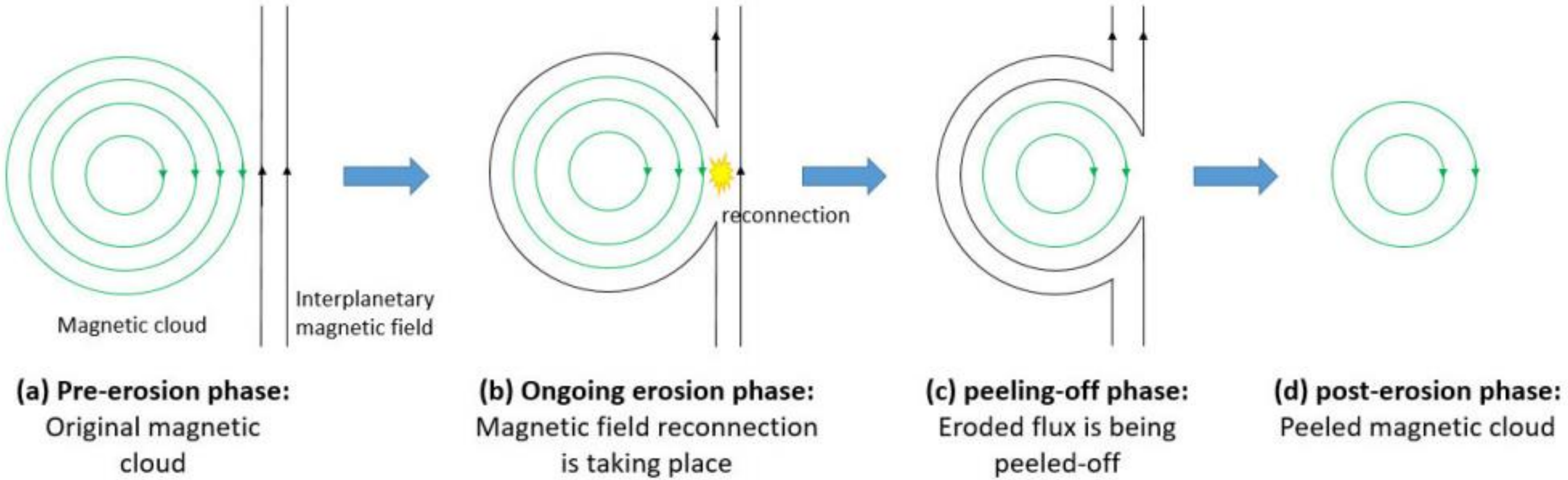
  $M_{virtual} = \frac{1}{2} \rho_e \pi R^2 L$

  Total mass = CME mass + virtual mass
- total mass isn't constant
- Variable mass system solution




$$F_D = \frac{dP}{dt} = M_{total}\frac{dU_{CME}}{dt} + \frac{dM_{total}}{dt}(U_{CME} + U_{ex} - u_{sw})$$

# Magnetic reconnection and erosion process




Wang et al. 2018

# Magnetic reconnection and erosion process

"The results suggest that Magnetic Clouds may be eroded at the front or at rear and in similar proportions, with a significant average erosion of about 40% of the total azimuthal magnetic flux. For Magnetic Clouds with well-determined boundaries, we note the frequent observation of local magnetic reconnection signatures in the range 20 to 50% depending on spacecraft and criteria."
**Ruffenach et al. 2015**

## ICME

Forsyth et al. 2006, Liu et al. 2005, Wang et al. 2005, Leitner et al. 2007

$$B = 11.4 * \mathrm{r}^{-1.383}\ (AU)$$

Cassak and Shay et al. 2007

$$\Re = 0.1(B_1 \times B_2)^{3/2}(\mu_0\rho_1 B_2 + \mu_0\rho_2 B_1)^{-1/2}(B_1 + B_2)^{-1/2} \longrightarrow$$

## Solar Wind

Interplanetary magnetic field:

$$B_\varphi = \frac{B_0 \mathrm{r}_0{}^2}{\mathrm{r}} \frac{\Omega}{V_\mathrm{r}}$$

$$R_i = R_{i-1} * (1 - h * \Re^\alpha)$$

$\Re$ : magnetic reconnection rate
**h** : integration step
**α** : gives the impact of the erosion process

$$\alpha = 0.747\ (50\%\ magnetic\ flux\ reduction)$$

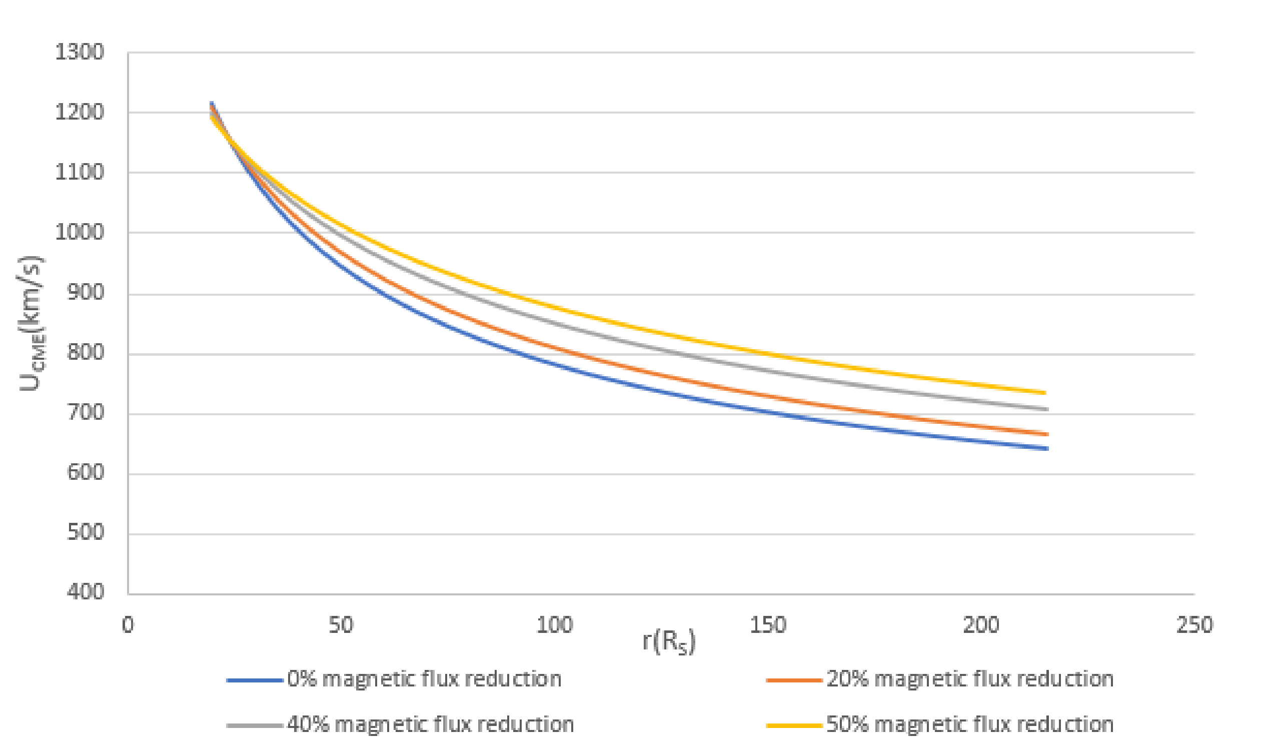
$$\alpha = 0.786\ (40\%\ magnetic\ flux\ reduction)$$

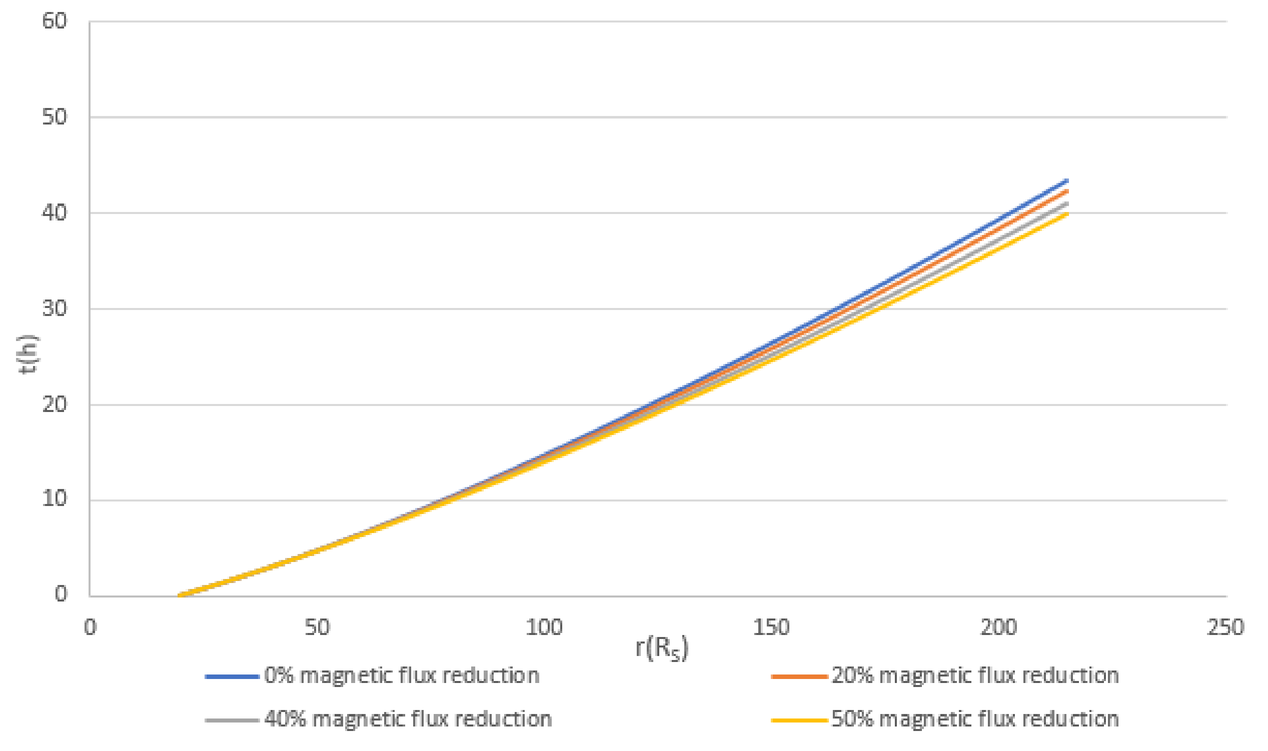
$$\alpha = 0.889\ (20\%\ magnetic\ flux\ reduction\ )$$

$$F_D = M_{total}\frac{dU_{CME}}{dt} + (U_{CME} + U_{exp} - u_{sw})\frac{dM_{total}}{dt}$$

$$\frac{dM_{total}}{dt} = \frac{dm_{added}}{dt} + \frac{dM_{erosion}}{dt}$$

# Results

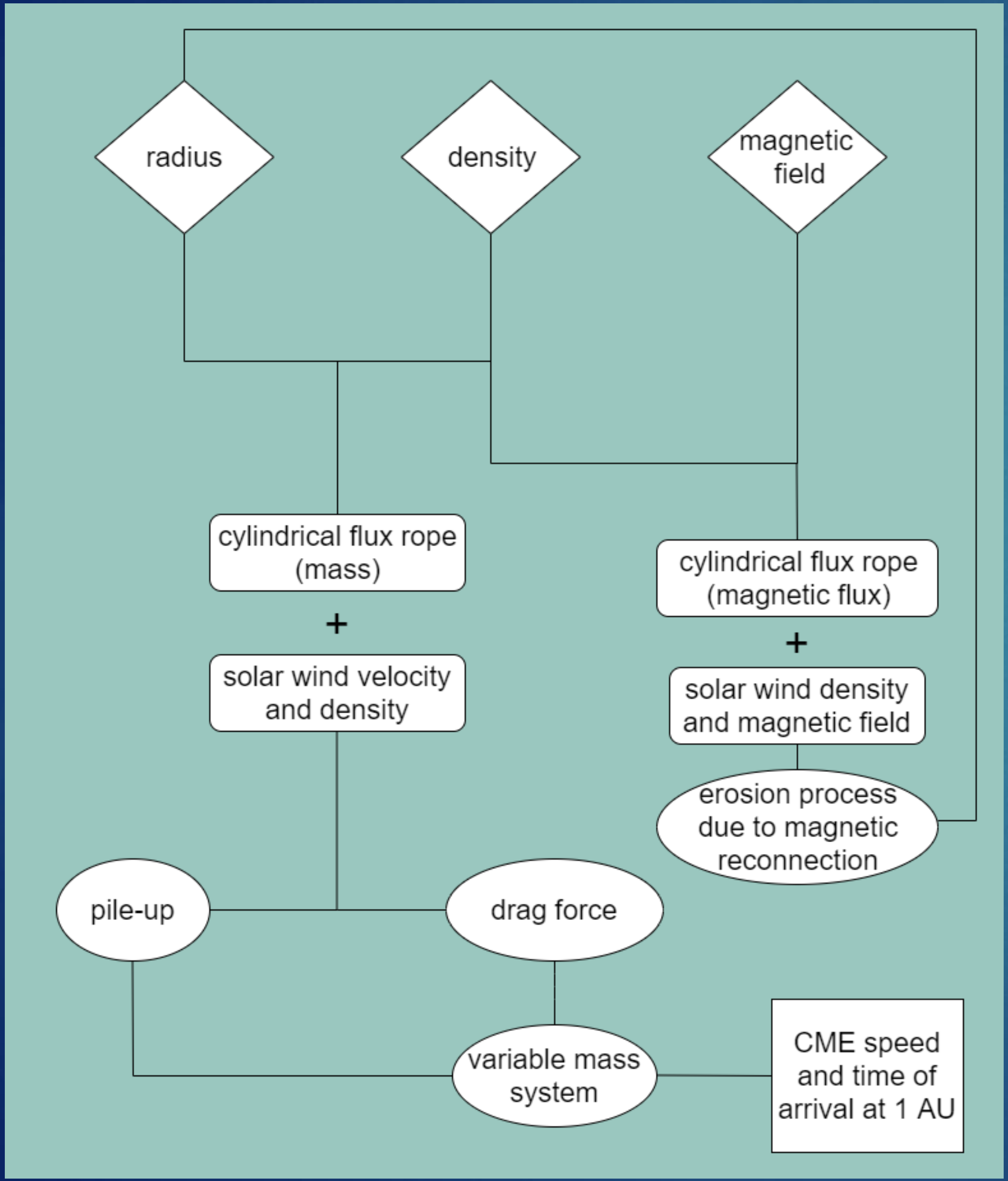



Speed of arrival: 25 – 95 km/s faster

Time of arrival: 1 – 3.5 hours earlier

# What we did




- We studied the effect of magnetic erosion on the drag force acting on Coronal Mass Ejections

- Depending on the magnetic flux reduction, and as a consequence, the outer shell mass erosion, the leading edge of the ICME arrives at 1 AU, 1-3.5 hours earlier than expected

# What needs to be done

- Understand how the CME radius, density and inner magnetic field change over time
- Use data from Parker Solar Probe and Solar Orbiter missions
- Test our results on real events with observed magnetic erosion signatures

# Thank you