

# SOLAR ERUPTIONS:

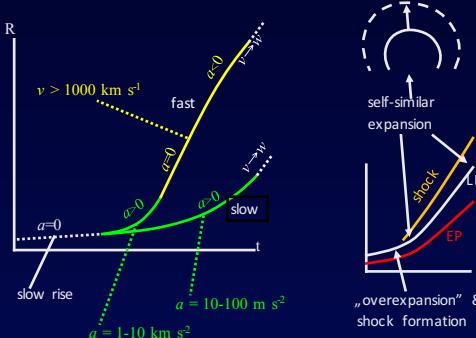
Physical mechanisms and processes  
governing initiation and propagation of CMEs  
and shocks

Bojan Vršnak

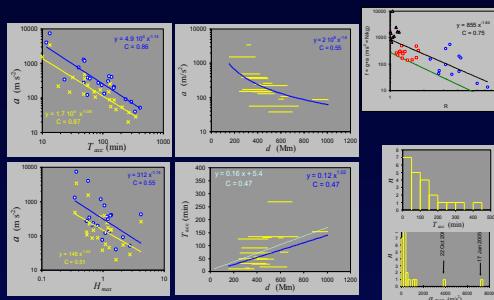
Hvar Observatory,

Faculty of Geodesy, Kačićeva 26, HR-10000  
Zagreb, Croatia

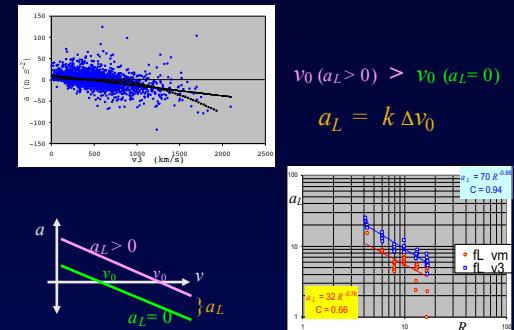
## Observations: a) kinematics



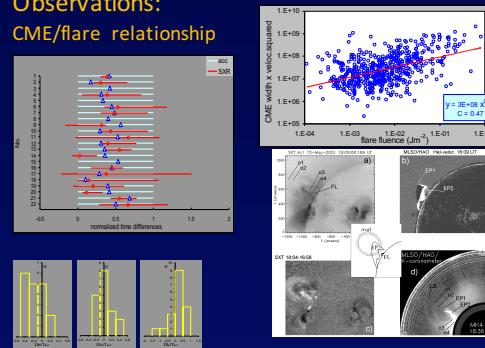
## Observations: b) acceleration scaling



## Observations: c) propagation phase

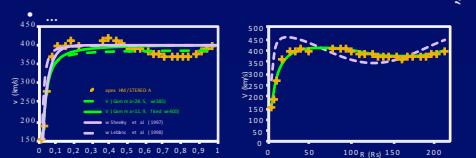


## Observations: CME/flare relationship

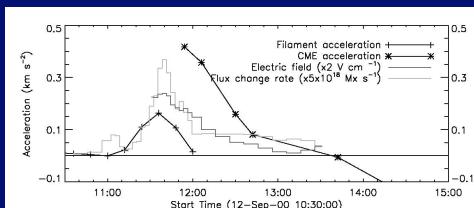


## IP propagation

- fast CMEs decelerate, slow CMEs accelerate
- deceleration of massive CMEs is weaker than in case of light CMEs
- deceleration is weaker when a CME propagates in high-speed solar wind
- CME cross section deforms ("pancaking", deformations related to high-stream streams)



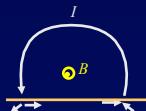
## CME acceleration and $v \times B$ proxy



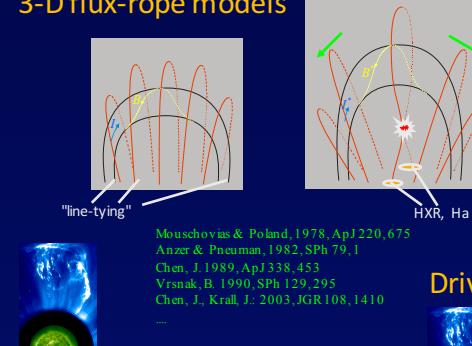
## General concept

### Forces & Energies

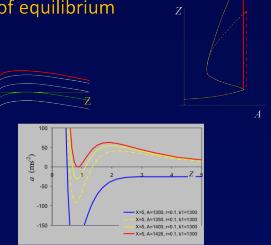
$$\begin{aligned} \text{Free energy of non-potential magnetic field} &\rightarrow \text{Electric current, } I \\ E_{\text{mag}} = L I^2 / 2 & \\ \Phi = L I \quad \left\{ \begin{array}{l} \Phi \approx \text{const.} \\ L \propto R \end{array} \right\} &\Rightarrow I \propto L^{-1} \\ \Delta I / \Delta R < 0, \quad \Rightarrow \Delta F_I / \Delta R < 0 & \\ \Delta W / \Delta R < 0 & \\ \Delta E_{\text{mag}} = \Delta E_{\text{kin}} + \Delta E_{\text{pot}} + W_{\text{drag}} & \end{aligned}$$



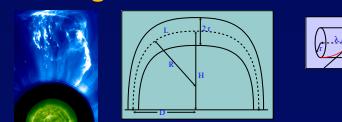
## 3-D flux-rope models



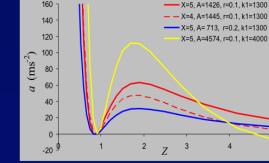
## Loss of equilibrium



## Driving force



## Eruption without reconnection



in the absence of reconnection:

$$\Phi_c = \text{const.} \propto l / [l \ln(8R/r) - 2] \Rightarrow I \propto l^{-1}, \quad r \propto R, \quad X \propto r/l$$

## Shock formation & propagation



**Formation:**  
3D piston („explosion phase“;  
„overexpansion“)

**Coronal propagation:**  
- lateral (piston-driven) → freely propagating  
- upward (driven:piston/bow)

