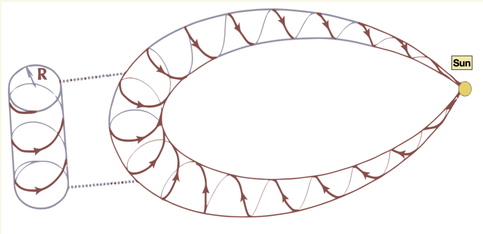
EXPLORING THE ROOT CAUSE OF CME ROTATION IN THE HELIOSPHERE

Motivation

Magnetic Flux Ropes (MFRs) are fundamental solar and heliospheric magnetic structures. They are often identified within Interplanetary Coronal Mass Ejections (ICMEs).



Adapted from Demoulin & Dasso (2009).

When the twist of the magnetic field lines in a MFR exceeds a critical threshold, a **plasma instability of the kink-type** can take place. This causes the MFR axis to become a helix itself, which would be seen as a **MFR rotation in the lower-middle corona**.

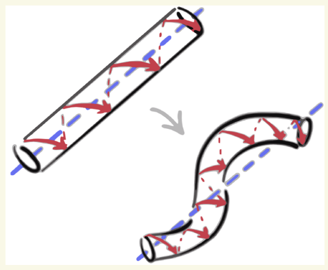
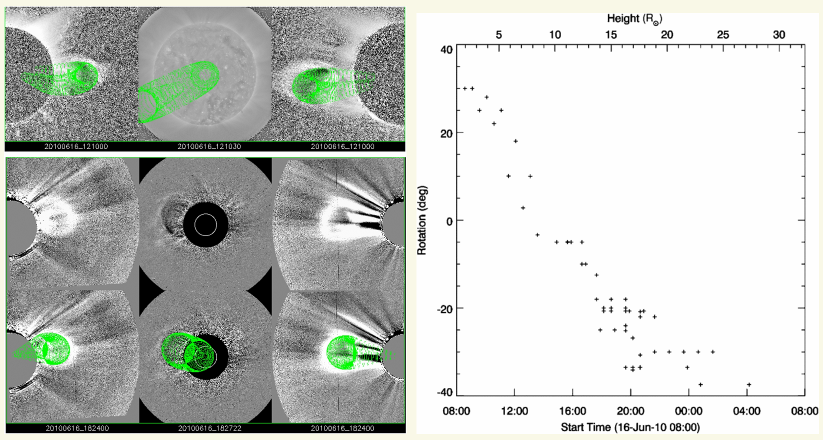


Illustration by M. Florido-Llinas.

Case Study: June 16-20, 2010 CME



The first direct detection of a rotating coronal mass ejection (CME) in the middle corona (5-15 R sun) by Vourlidas et al. (2011). The reported CME rotation rate is 60° day^{-1}.

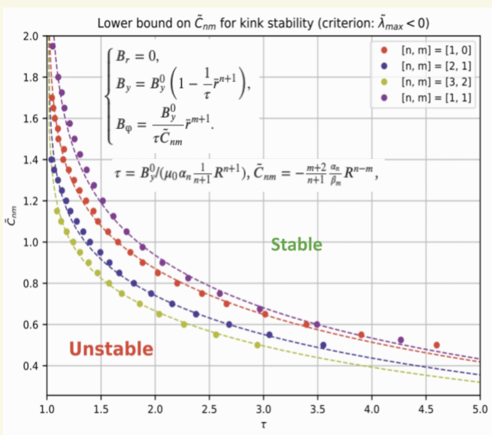
Methodology

Linear Stability Analysis (LSA) Linton et al. (1996):

- Cylindrical symmetry for the magnetic field, small displacement perturbation applied to the system that allows for linearized equations of motion
- Euler-Lagrange equation: gives the perturbation that minimizes the energy of the system

Stability criterion:

The system is kink stable if, and only if, the perturbations that solve the Euler-Lagrange equation and satisfy the boundary condition, do not grow exponentially with time, for any wavenumber.

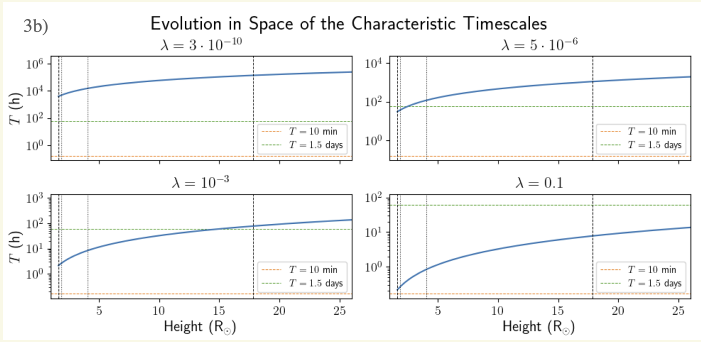


The LSA using the circular-cylindrical (CC) MFR model by Nieves-Chinchilla et al. (2016) allows us to determine if a MFR is stable/unstable. Colored lines are the boundary values of $C_{n,m}$ (internal force-freeness in the CC model) at fixed τ (twist in the CC model) between the stable and unstable regimes of the MFR. See: Florido-Llinas et al. 2020.

Results

From the LSA, the **growth rate** σ can be determined via the stationary points of the generalized energy $U(\xi) = W(\xi) + \lambda I(\xi)$, when one restricts the optimization to Fourier displacements $\xi(r,\theta,z) = [\xi_r(r), \xi_\theta(r), \xi_z(r)]\, e^{i(\theta+kz)}$. The relationship to the Lagrange multiplier is: $\lambda = \sigma^2$.

The **characteristic timescale of the instability**, T_c, indicates the time it takes for the instability to significantly affect the flux rope's macro-structure and is defined as $T_c = 1/\sigma$. For the CME under study, $\lambda = 3 \cdot 10^{-10} [s^{-2}]$, which falls in the stable regime.



T_c as a function of the distance from the Sun and different λ. The vertical lines indicate the time interval of the observed rotation.

Conclusions and Future Work

- Our analysis places the CME observed in June 16-21, 2010, in the improbable range for the onset of a kink-type instability throughout the interplanetary medium. Therefore, we can **reject the hypothesis that its rotation was due to an internal instability**.
- The rotation might be caused by external factors which will be addressed in a future study.
- We plan to investigate other events with visible rotations, especially at distances near the Sun (see also: Nieves-Chinchilla et al. (2022)).

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