Numerical modelling of stealth solar eruptions; Initiation and Signatures at 1AU

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1. Coronal mass ejections

- huge expulsions of magnetized plasma from the Sun into the interplanetary medium
- associated with solar features (e.g. filament eruption, jet, flare, post-eruptive arcade, coronal dimming, coronal wave)
2.1 Stealth CMEs

- No distinct low coronal signature
- D’Huys et al. (2014) - 40 stealth events
- Some characteristics: slow, gradual, narrow events; preceding eruptions

Date CME: 2 June 2008

(Robbrecht et al. 2009)
2.2 Research background

- 2 sympathetic events
- Zuccarello et al. (2012)
- Bemporad et al. (2012)
Bemporad et al. (2012)
Steps

• MHD code: MPI-AMRVAC (parallelized Adaptive Mesh Refinement Versatile Advection Code)

• Parameter study => range of values

• Real parameters of the stealth CMEs found by D’Huys et al. (2014)

• Model results <-> observationally identified events

• MHD model for sympathetic stealth events
Code info

- Domain specs:
  - 2.5D
  - spherical
  - axisymmetric
  - non-equidistant
- Grid size used so far: 480x240 cells
- Numerical scheme: TVDLF
- CFL number: 0.5
- Limiter: minmod
- Method of keeping $\nabla \cdot \vec{B} = 0$: GLM
- 3 levels of refinement
3.1 Results from the parametric study

- transition VAC -> AMRVAC
- initial conditions: dipole + triple arcade
- parametric study => similar configuration
- parameters varied:
  - strength of the dipole and of the multipole;
  - the shift and width of the arcades;
  - shearing speed
- results in accordance with those of Zuccarello and Bemporad (sympathetic event obtained)
Initial conditions

Global dipole field + :

- VAC: $A_\phi = \frac{A_0}{r^4 \sin \theta} \cos^2 \left( \frac{\pi (\lambda + \text{shift})}{2 * \Delta \theta} \right)$

- MPI-AMRVAC:
  
  \[
  \begin{align*}
  B_r &= \frac{A_0}{r^5 \sin \theta \Delta \theta} \frac{\pi}{\cos \left( \frac{\pi (\lambda + \text{shift})}{2 * \Delta \theta} \right)} \sin \left( \frac{\pi (\lambda + \text{shift})}{2 * \Delta \theta} \right) \\
  B_{\theta} &= \frac{3A_0}{r^5 \sin \theta} \cos^2 \left( \frac{\pi (\lambda + \text{shift})}{2 * \Delta \theta} \right)
  \end{align*}
  \]
• VAC
  (Zuccarello et al. 2012, Bemporad et al. 2012)

• AMRVAC
  (current simulations)
Shearing profile

\[ v_\phi = v_0 (\alpha^2 - \Delta \theta^2)^2 \sin \alpha \sin \frac{\pi (t-t_0)}{\Delta t}, \]

\[ \alpha = \frac{\pi}{2} - \theta_0 - \theta, \quad \theta = \text{colatitude}, \]

\[ \theta_0 = -0.7 \text{ rad}, \quad \text{(latitude of the southernmost polarity inversion line)} \]
Propagation to 1AU

32h after the start of the shearing motions at the equator

24.3° N of the equator
48h after the start of the shearing motions at the equator

24,3° N of the equator
61h after the start of the shearing motions at the equator

24.3° N of the equator
3.2 Results from the propagation to 1 AU

- stealth CME faster than the first one
- same magnetic field orientation

⇒ reconnection at the interface between the 2 flux ropes; at approx. 110 solar radii (45h after the start of the shearing motions), the second flux rope completely reconnects

- arrival of the CME at Earth: at approx. 45h after the eruption of the first CME
- deceleration and flattening of the resulting CME/flux rope
3.3 Future work

• Compare current results with observed signatures at 1AU
• Improve current simulations
• Deeper parameter study – apply the shearing on different magnetic configurations
• Comparison numerical simulations ↔ observational data (events identified by D’Huys et al. 2014)
• Develop MHD model for individual stealth events
4. Conclusions

• What?
  ➢ processes that cause and drive stealth CMEs
  ➢ difference from the typical solar eruptions
  ➢ a stealth CME model

• How?
  ➢ observations and model predictions
  ➢ physical properties of these events (observational and model results)

• Results
  ➢ transition from VAC to AMRVAC
  ➢ parameter study => configurations and sympathetic CMEs similar to those of Bemporad et al. (2012) and Zuccarello et al. (2012)
  ➢ shearing speed, magnetic field strength -> decisive for stealth CME appearance
    • lower speed: only one CME, or no eruption at all
    • higher speed: multiple CMEs
  ➢ reconnection at the interface between the 2 flux ropes, at approx. 110 Rs
  ➢ arrival of the CME at Earth: at approx. 45h after the eruption of the first CME
  ➢ deceleration and flattening of the resulting CME/flux rope
Thank you for your attention!