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

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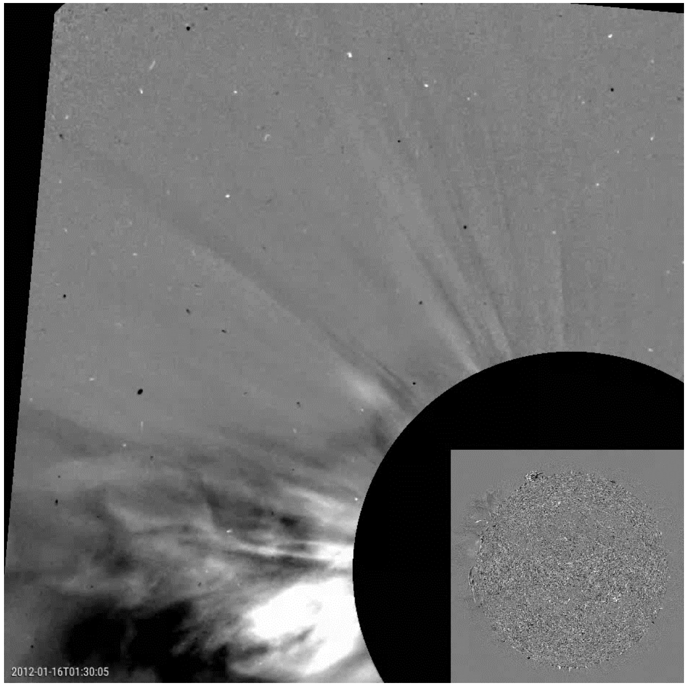
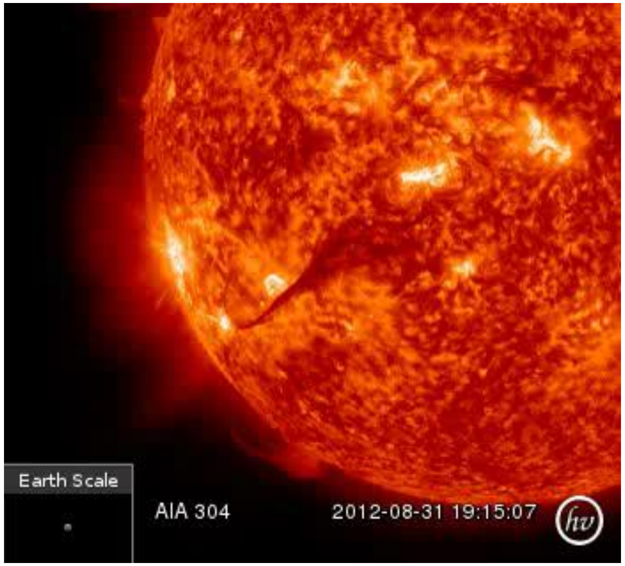
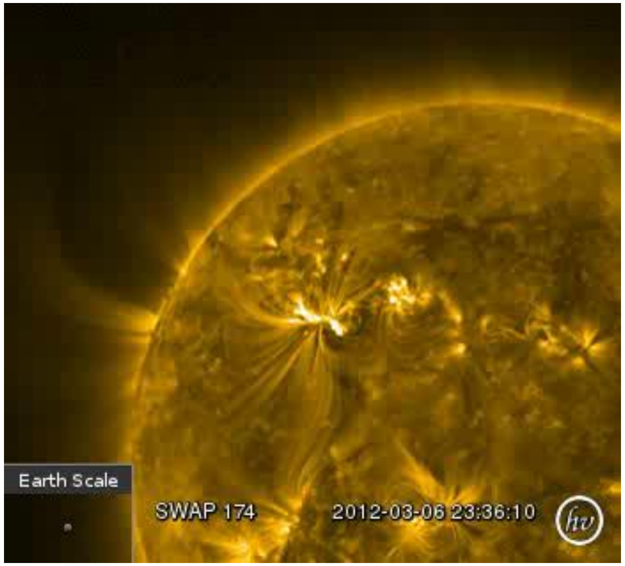
1. Coronal mass ejections

- 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)





Filament eruption



Flare, post-eruptive arcade, coronal dimming

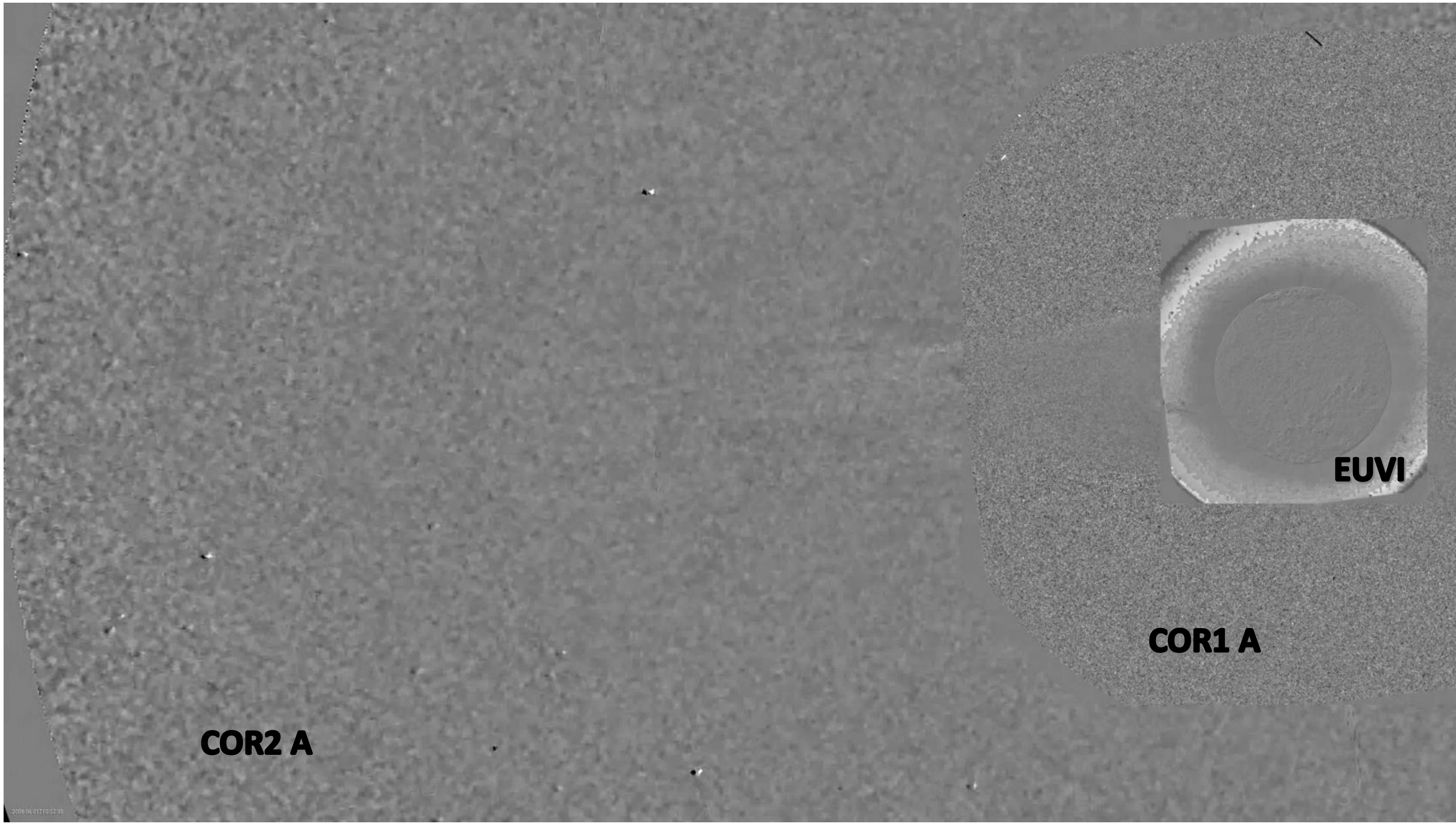
Coronal wave

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

(Robbrecht et al. 2009)

Date CME:
2 June 2008

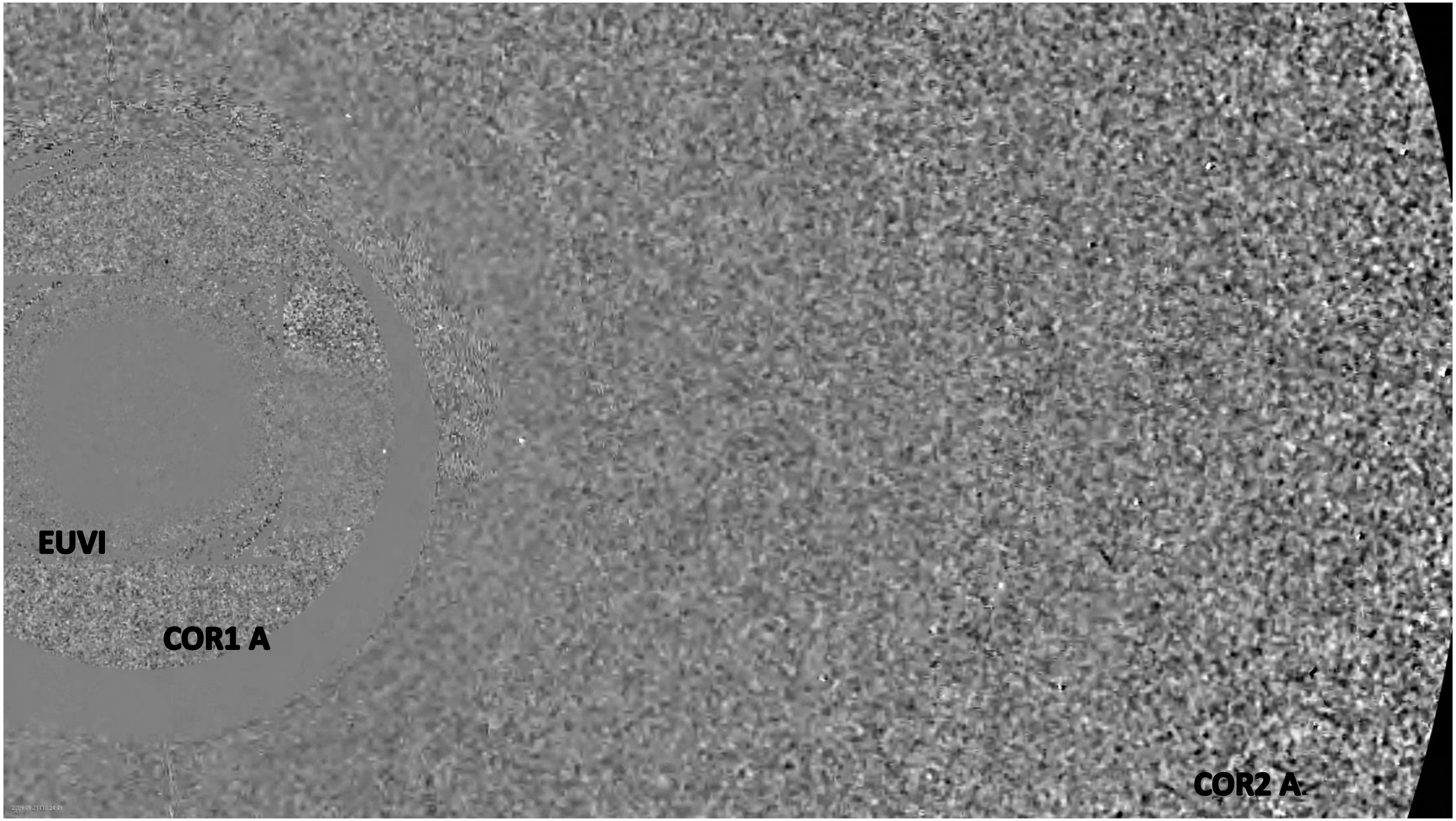


2.2 Research background

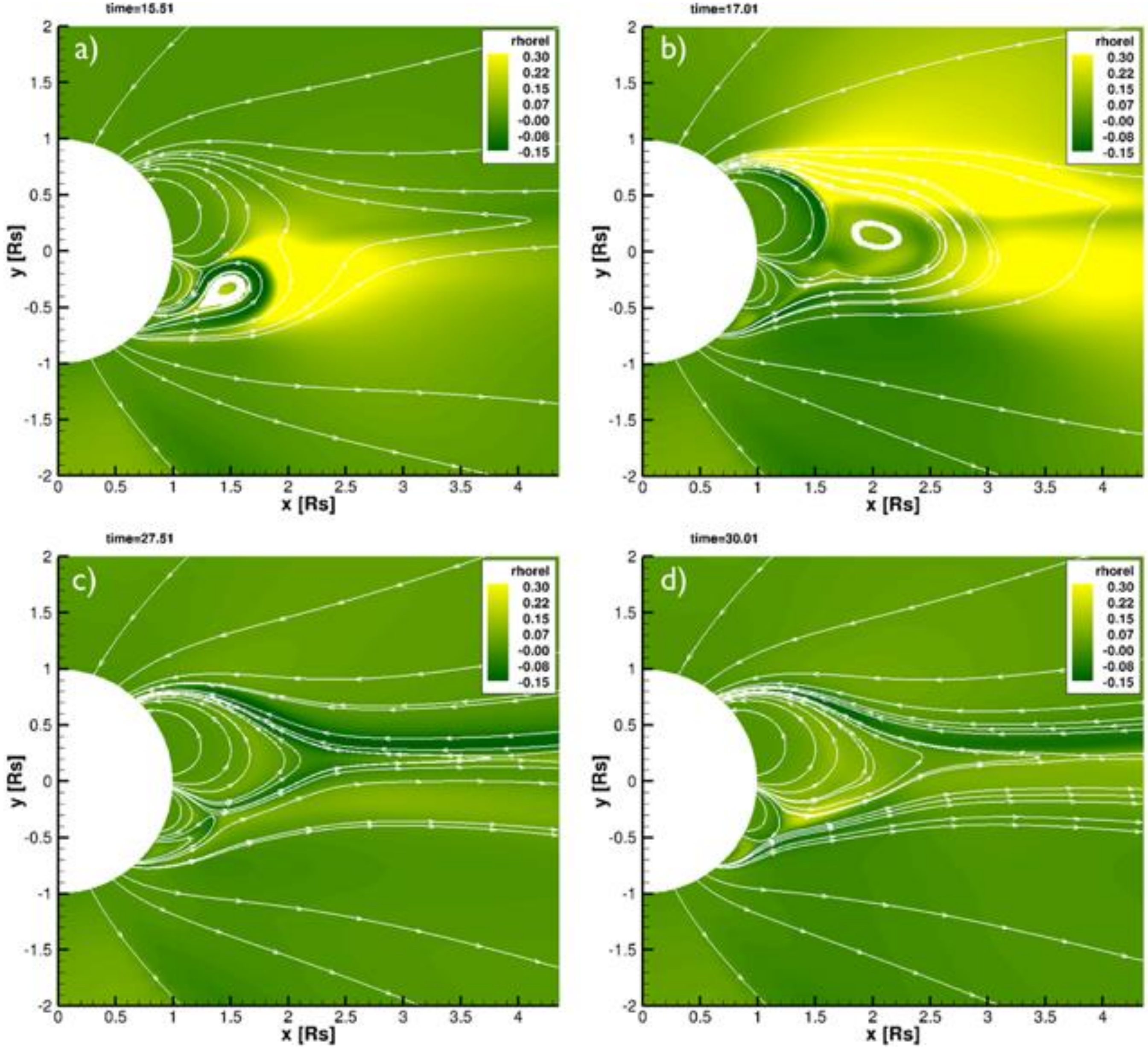
- 2 sympathetic events

- Zuccarello et al. (2012)
- Bemporad et al. (2012)

Date CME: 21 September 2009



Bemporad et al. (2012)

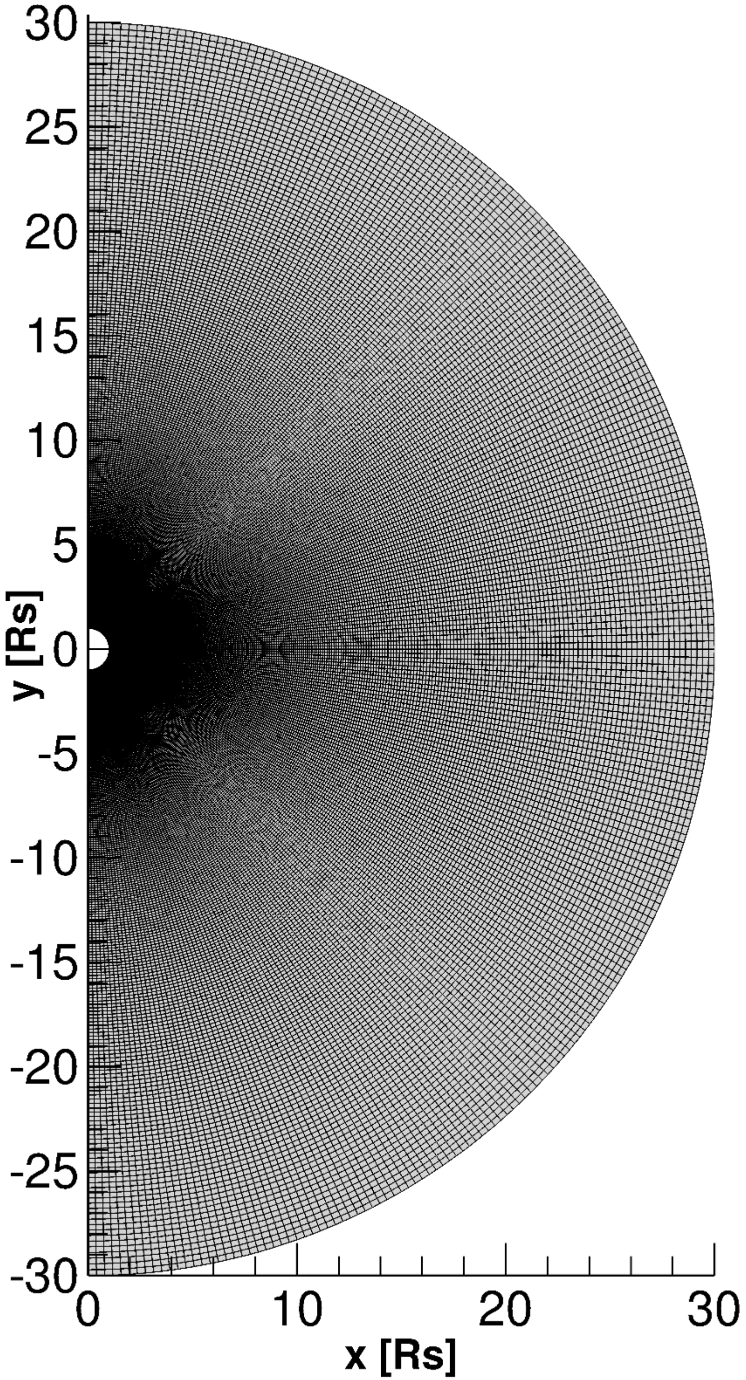


Steps

- 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

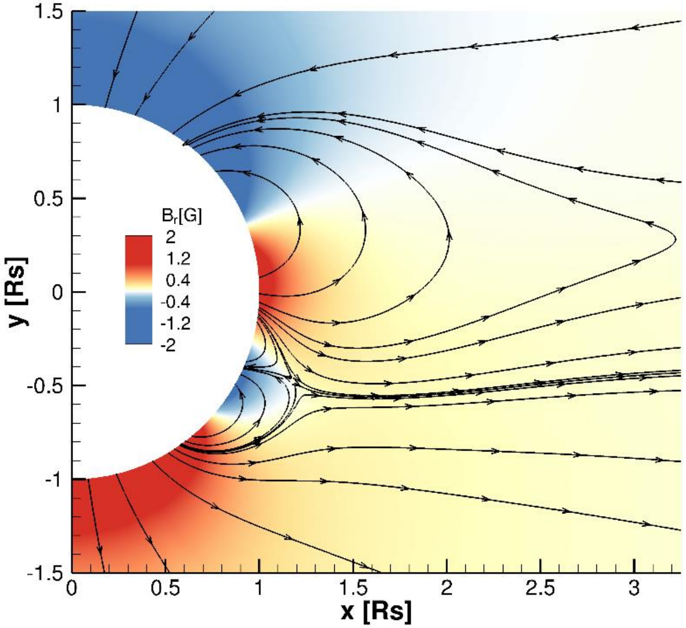
Code info

- 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

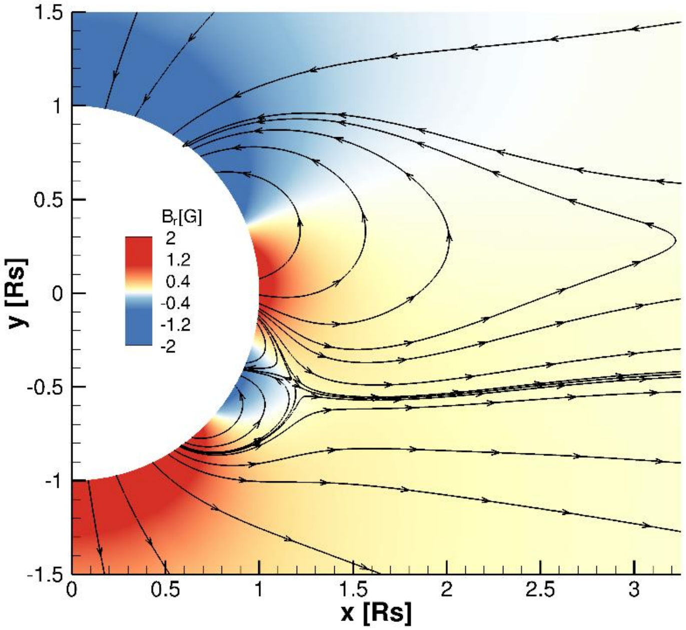


3.1 Results from the parametric study

- 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

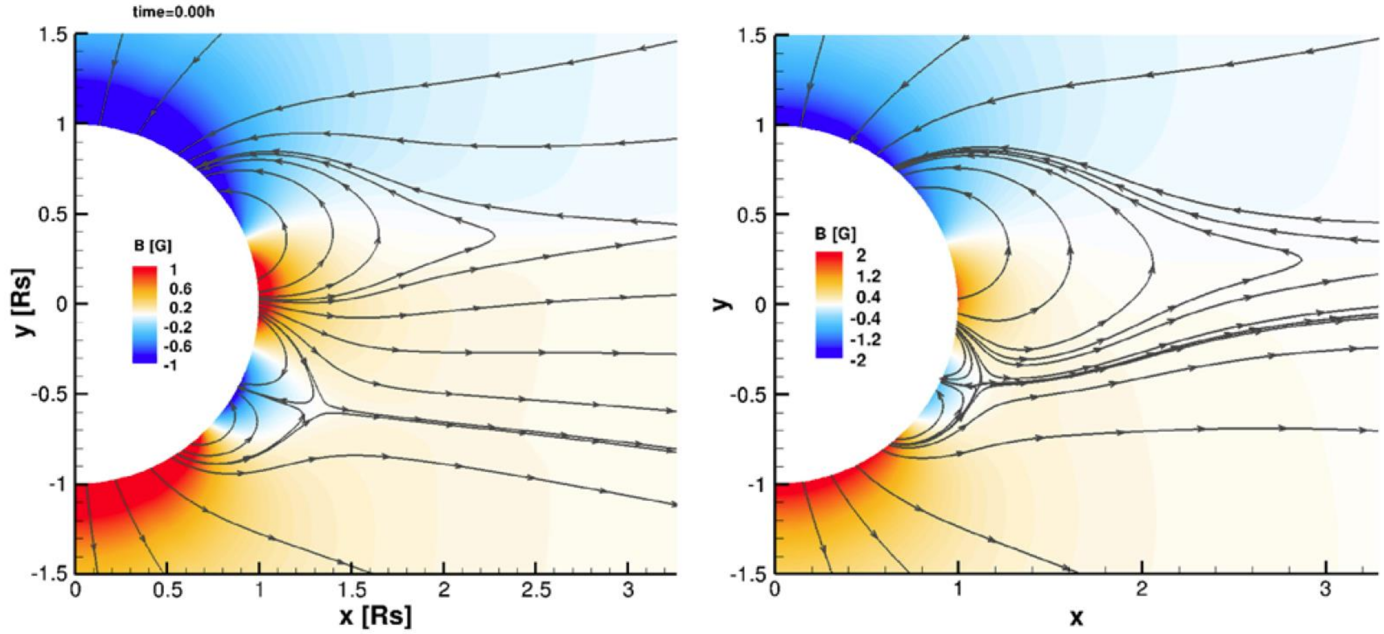


Global dipole field + :

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

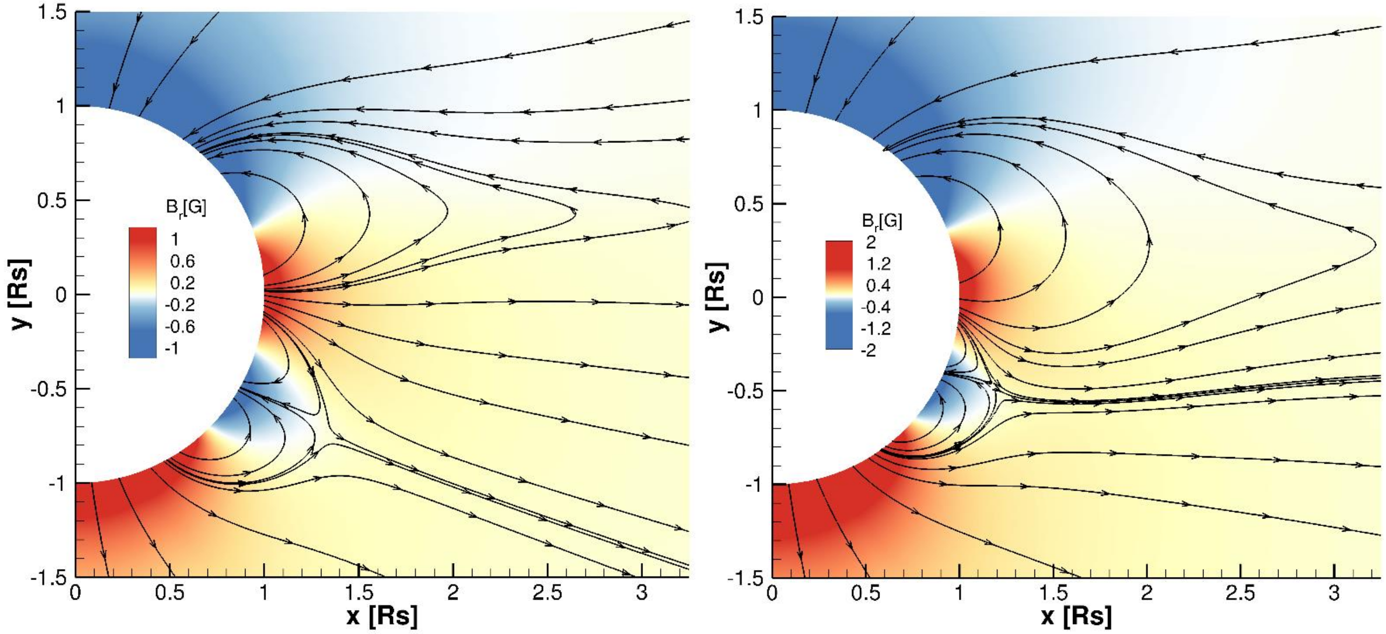
- MPI-AMRVAC:

$$\begin{cases} B_r = \frac{A_0}{r^5 \sin\theta}\frac{\pi}{\Delta\theta}\cos\left(\frac{\pi(\lambda+shift)}{2*\Delta\theta}\right)\sin\left(\frac{\pi(\lambda+shift)}{2*\Delta\theta}\right) \\ B_\theta = \frac{3A_0}{r^5 \sin\theta}\cos^2\left(\frac{\pi(\lambda+shift)}{2*\Delta\theta}\right) \end{cases}$$



- VAC

(Zuccarello et al. 2012, Bemporad et al. 2012)



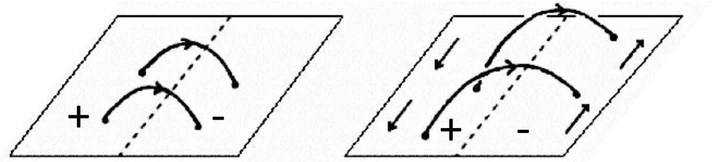
- AMRVAC

(current simulations)

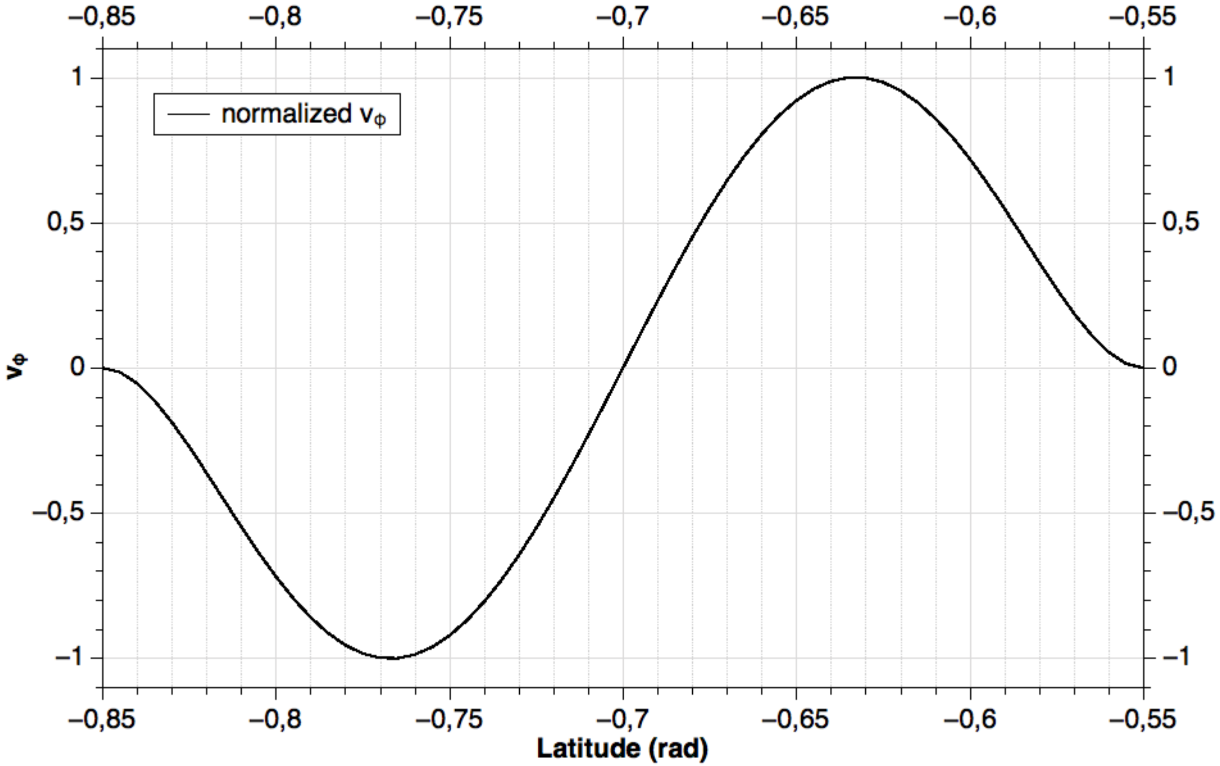
Shearing profile

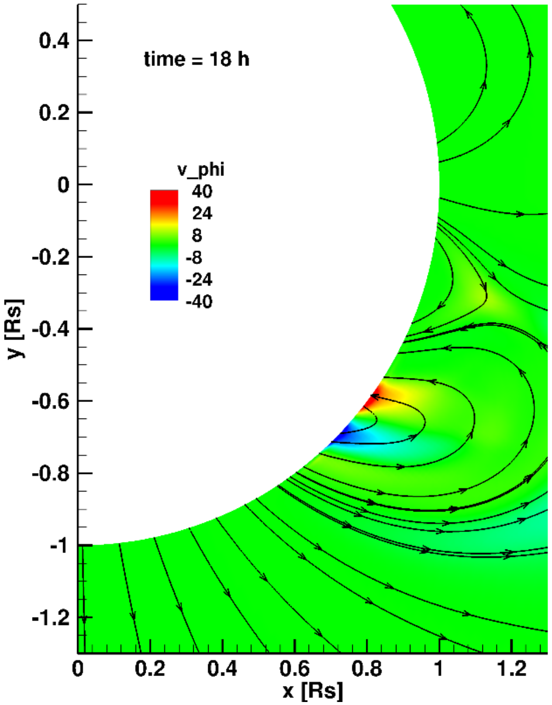
- $v_\phi = v_0(\alpha^2 - \Delta\theta^2)^2 \sin\alpha \sin\frac{\pi(t-t_0)}{\Delta t}$,

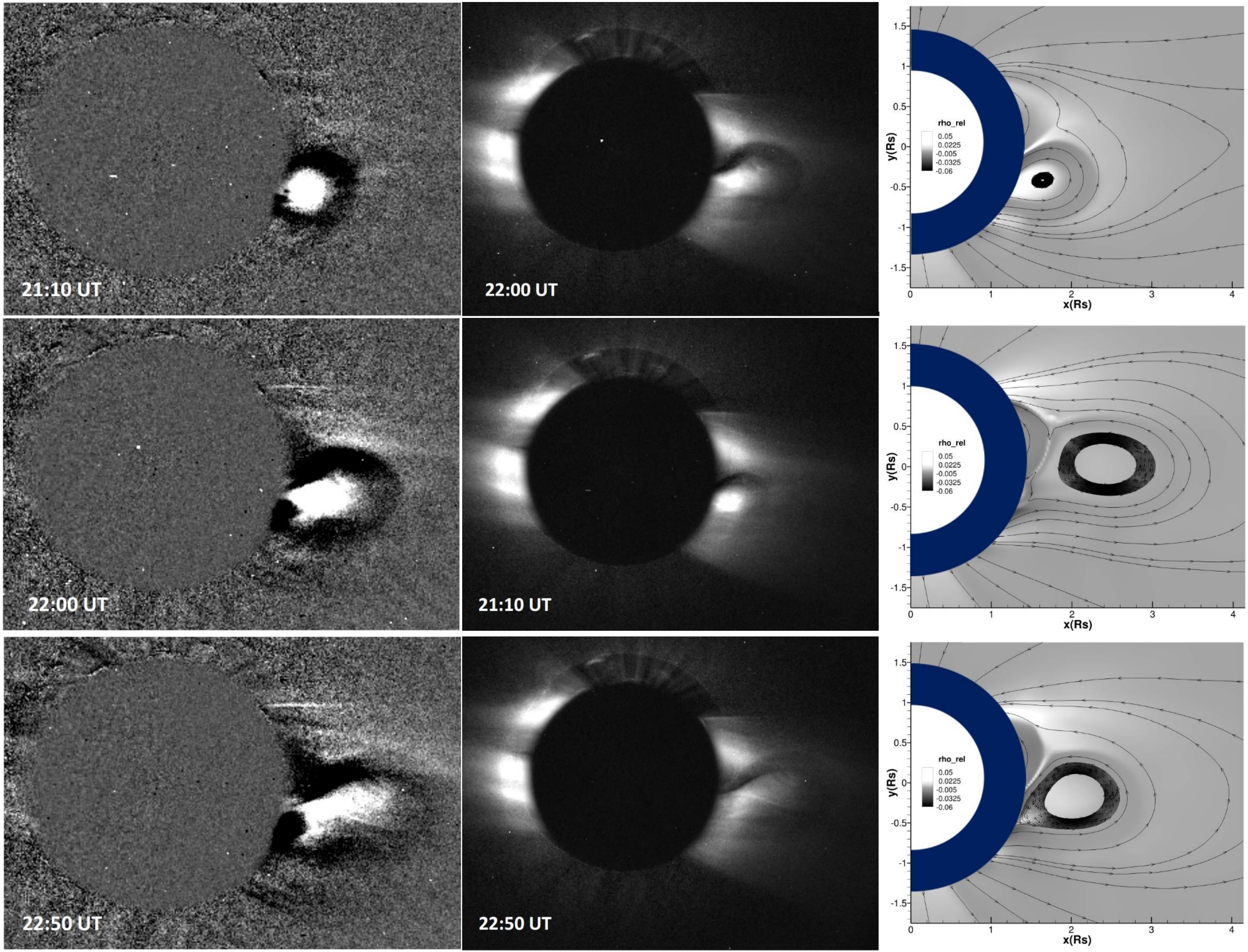
  $\alpha = \frac{\pi}{2} - \theta_0 - \theta$, $\theta = colatitude$,
  $\theta_0 = -0.7\, rad$, (latitude of the southernmost polarity inversion line)



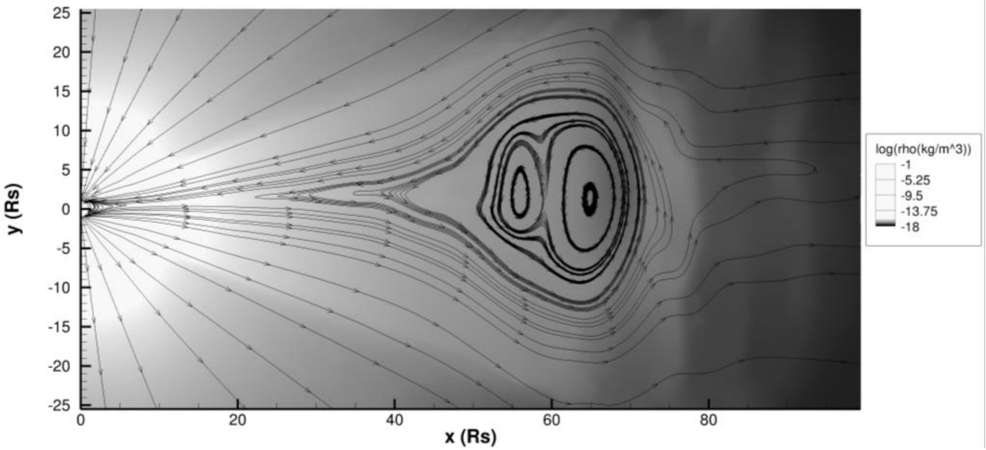
Ballegooijen & Martens (1989)



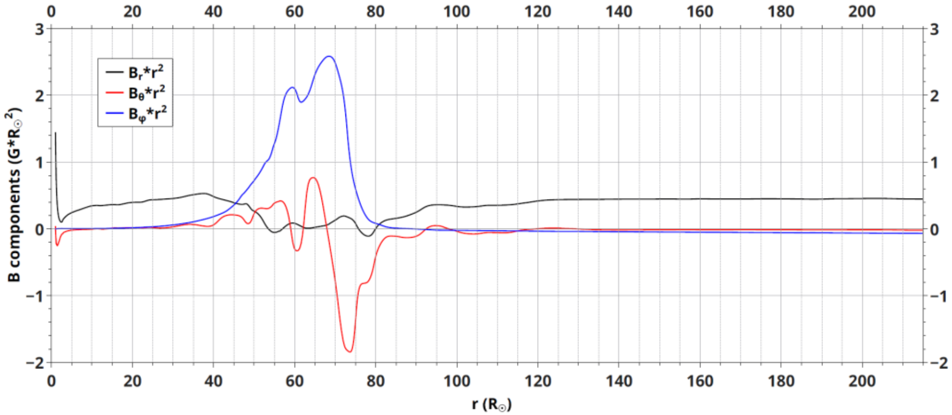



21:10 UT
22:00 UT
22:00 UT
21:10 UT
22:50 UT
22:50 UT
rho_rel
0.05
0.0225
-0.005
-0.0325
-0.06
y(Rs)
x(Rs)
1.5
1
0.5
0
-0.5
-1
-1.5
0
1
2
3
4

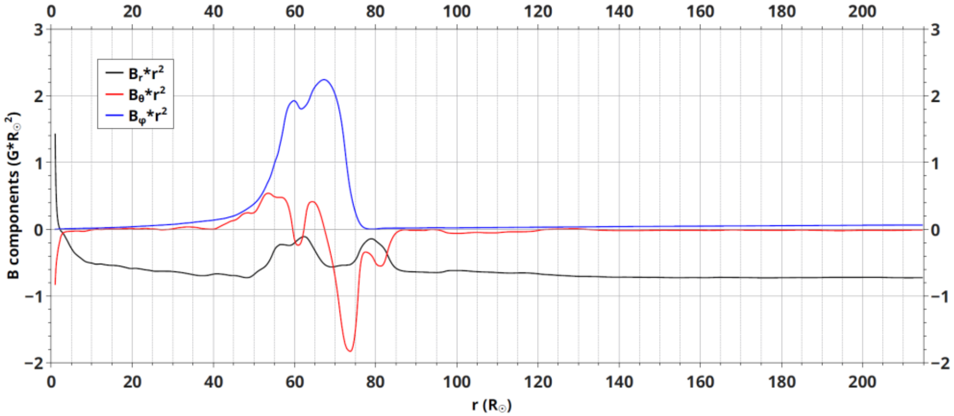
Propagation to 1AU



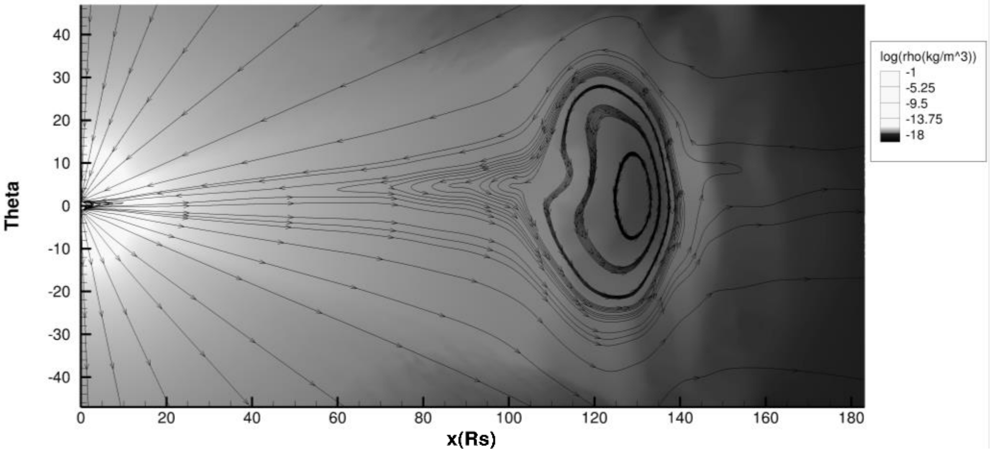
32h after the start of the shearing motions



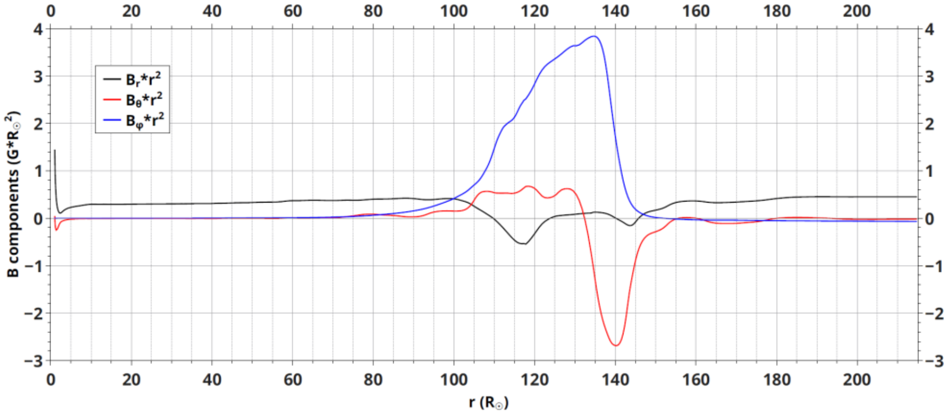
at the equator



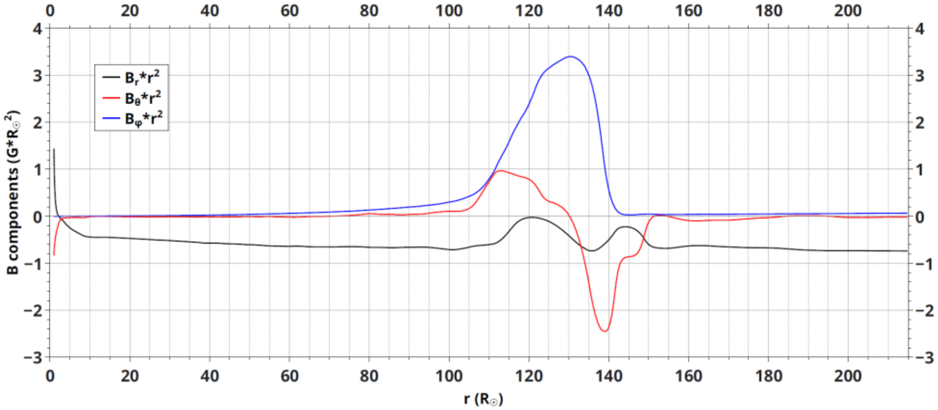
24,3˚ N of the equator



48h after the start of the shearing motions

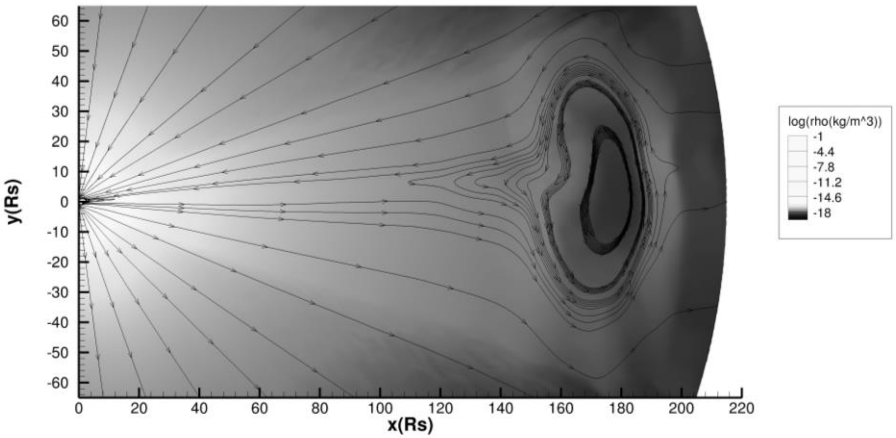


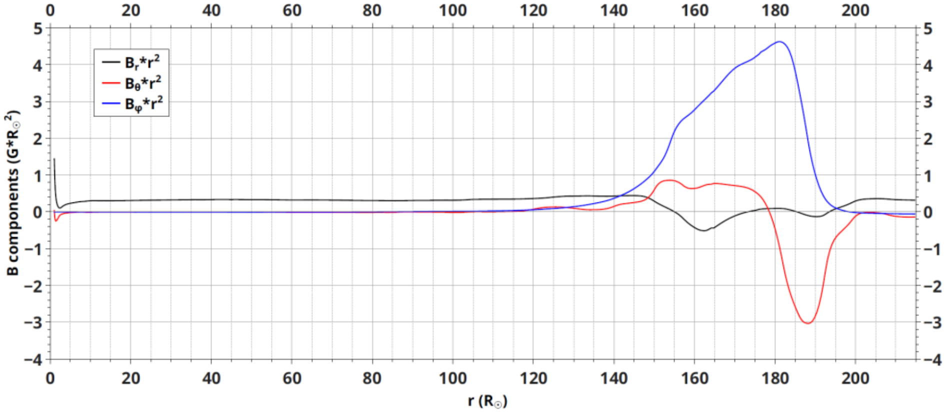
at the equator



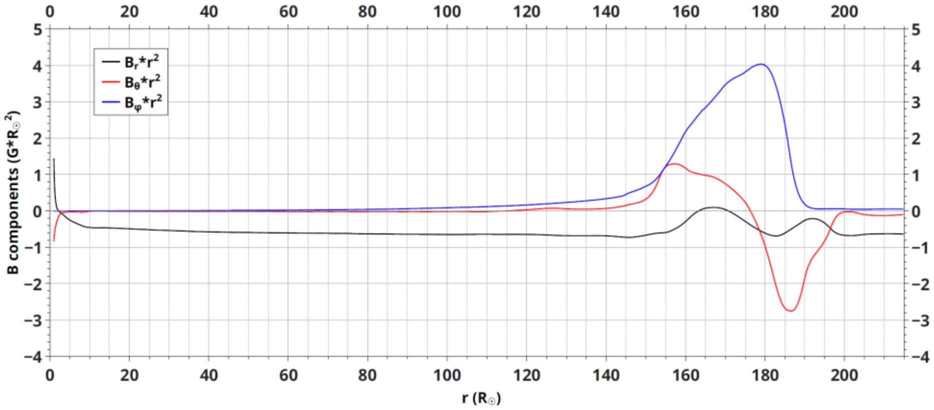
24,3˚ N of the equator

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!