Numerical Modeling of Fast CMEs

Predictive Science, Inc.

Tibor Török (PSI)

Bernhard Kliem (Potsdam/MSSL)

Cooper Downs (PSI)

Slava Titov (PSI)

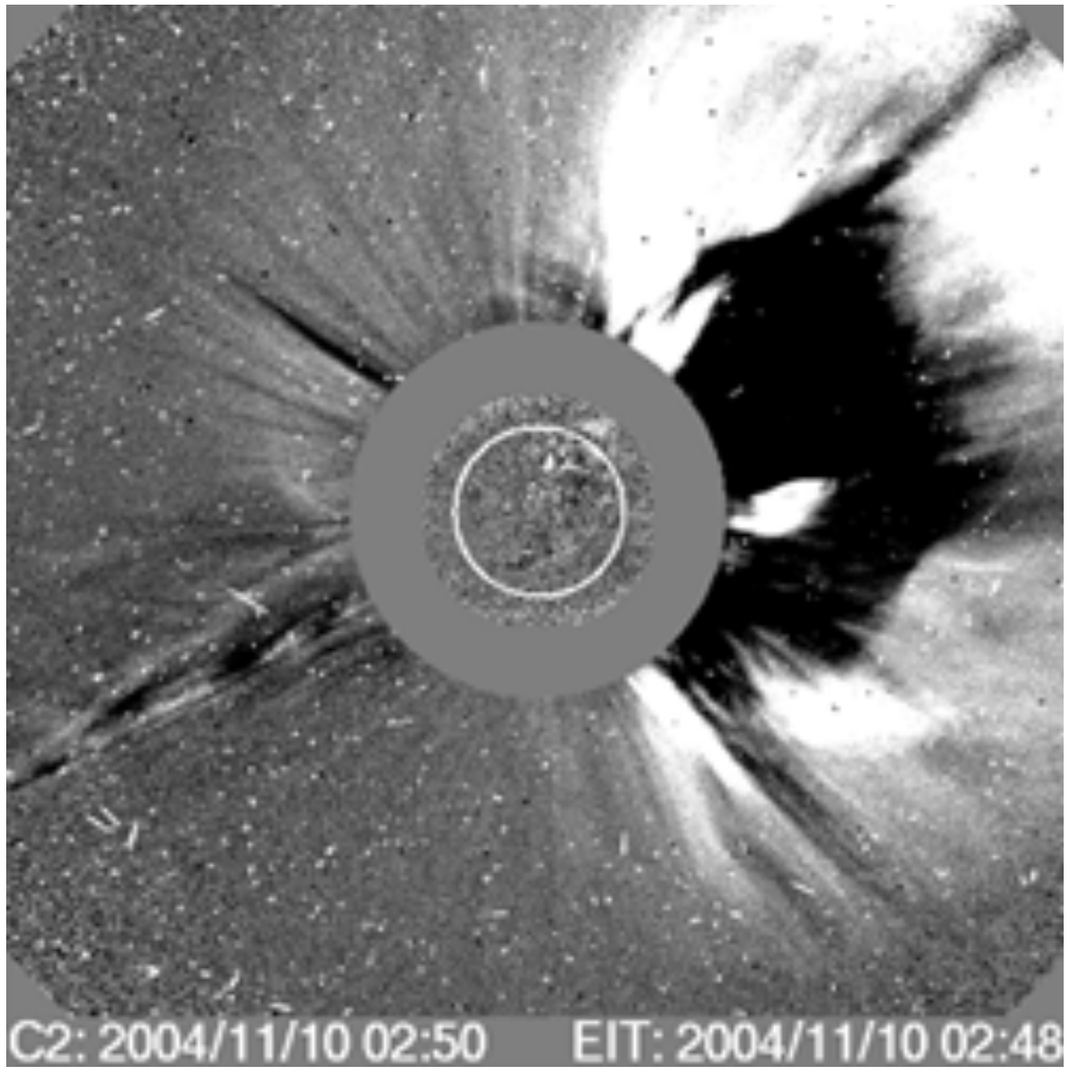
Zoran Mikić (PSI)

Jon Linker (PSI)

Jie Zhang (GMU)

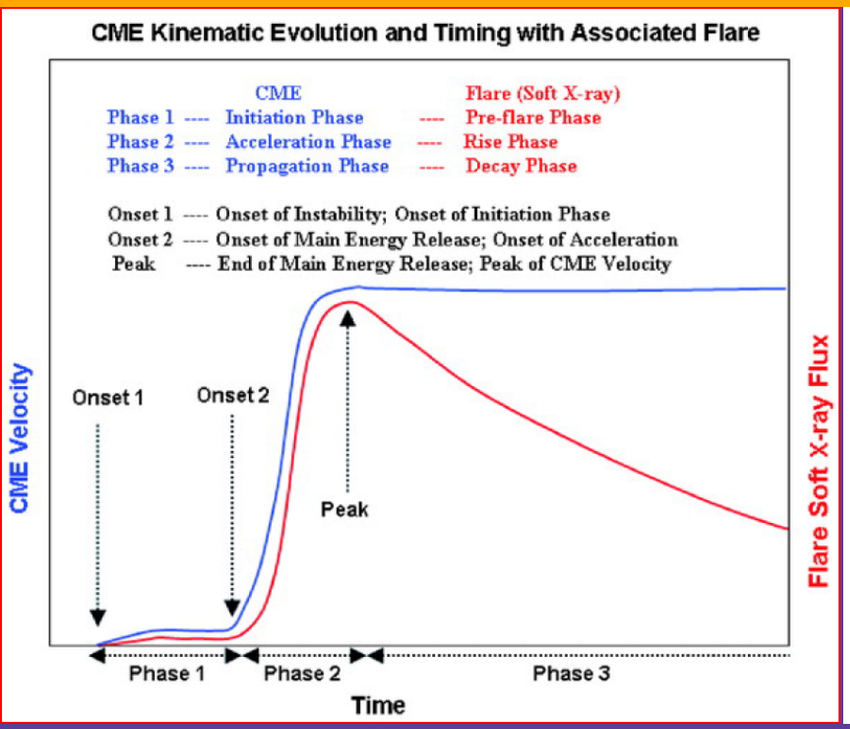
Roberto Lionello (PSI)

Pete Riley (PSI)

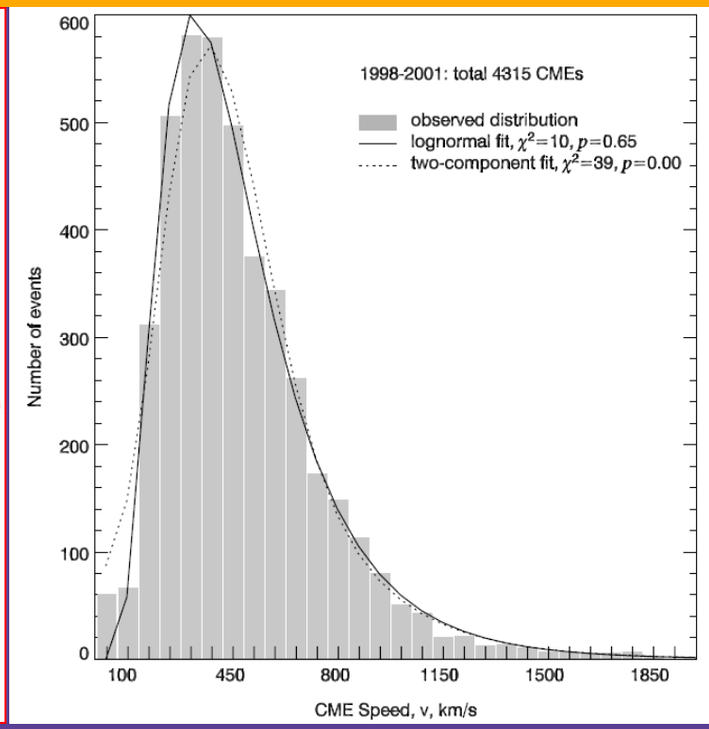


Hinode 6 meeting, 2012, August 14-17, St. Andrews

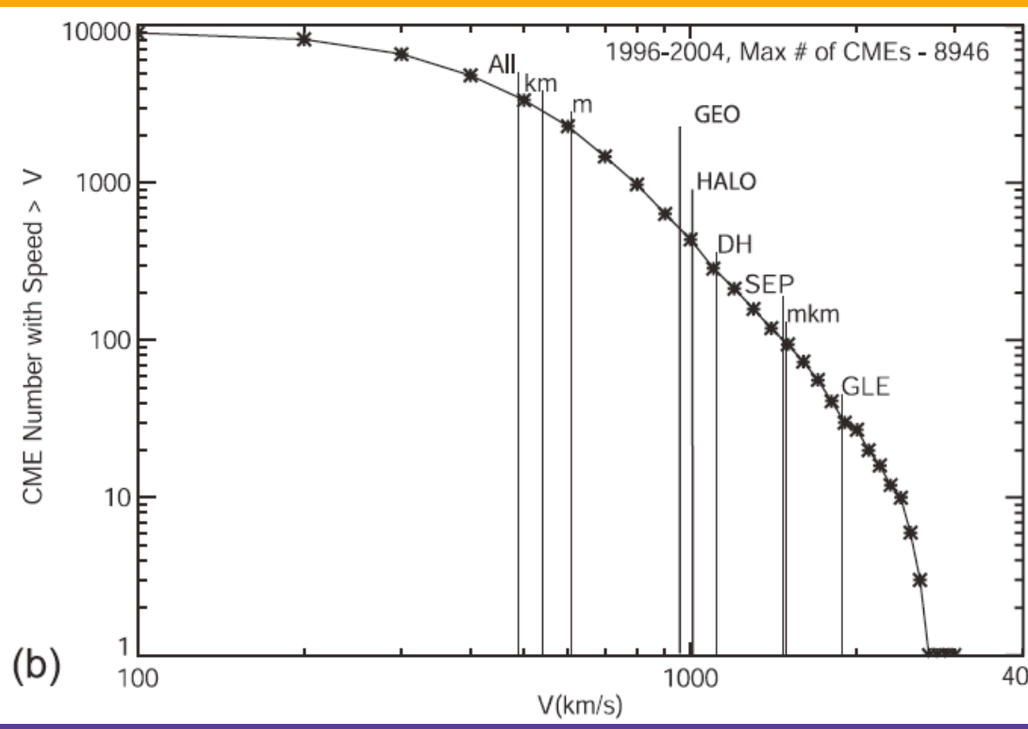
CME velocities: observations



Zhang & Dere (2006)



Yurchyshyn et al. (2005)



Gopalswamy (2006)

- CMEs: rapid acceleration in low corona & propagation with approx. const. speed
- CMEs show wide range of (coronal) propagation velocities (few 100 to >3400 km/s)
- Fast CMEs more geo-effective than slow ones (shock; larger ram pressure)

What determines the speed of CMEs?

- CME accelerated by ideal instability (jxB) + flare reconnection (“feedback”)

- Major events (strong, sheared source regions & flares) tend to produce fast CMEs

- Source region properties: positive, but weak correlations with CME speed:

  - (free) magnetic energy and helicity; photospheric flux, area, and ave. field strength; number, length and of PILs (complexity); shear across PILs; distance of main polarities (e.g., Venkatakrishnan & Ravindra 2003; Liu 2007; Su et al. 2007; Wang & Zhang 2008; Guo et al. 2006)

  - large scatter, significant number of exceptions, and some contradictory results (e.g., Feynman & Ruzmaikin 2004; Wang & Zhang 2007; Gopalswamy 2010; Chen et al. 2011)

  → CME speed must be controlled by several effects and parameters

- Reconnection in associated flare: quite different degrees of correlation:

  - peak soft X-ray flux, reconnected flux & flare plasma temperature (e.g., Moon et al. 2002, 2003; Qiu & Yurchyshyn 2005; Jain et al. 2010; Bein et al. 2012)

  → relationship complex, difficult to disentangle by statistical means

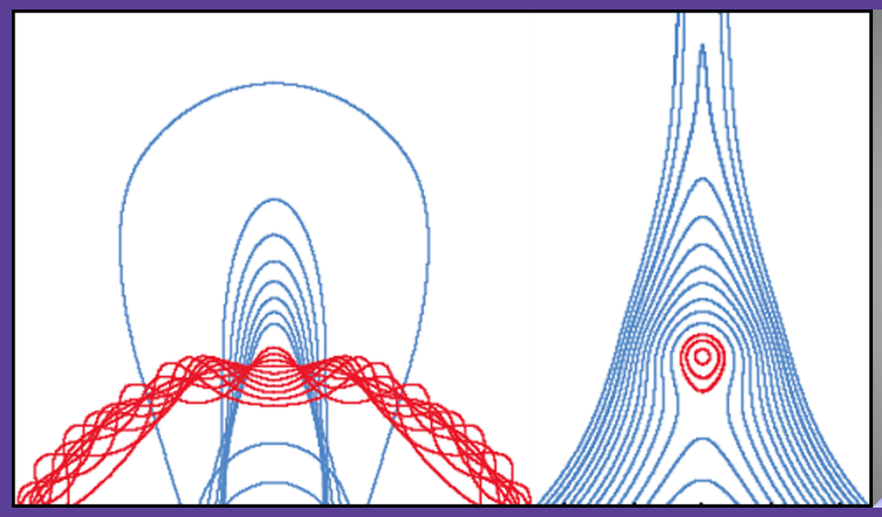
Role of the “overlying” coronal field ?

TABLE 1

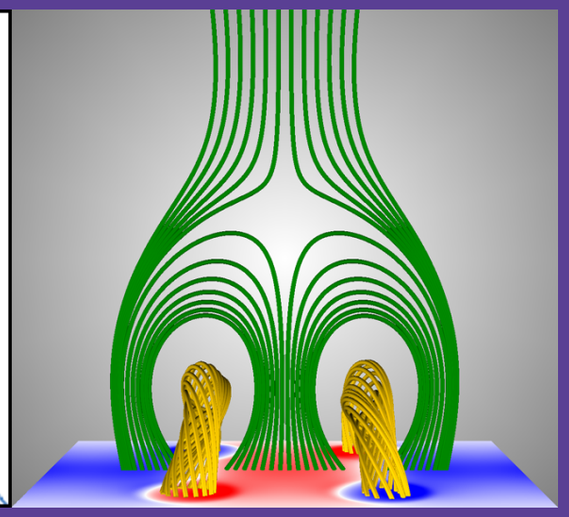
STATISTICAL PROPERTIES OF THE 99 HALO CMEs FROM 2000 TO 2004

Parameter	Type 1	Type 2	Type 3
Number	39	46	14
Percentage	39%	47%	14%
Median speed (km s^{-1})	728	1208	1443
Mean speed (km s^{-1})	883 ± 403	1345 ± 596	1530 ± 736

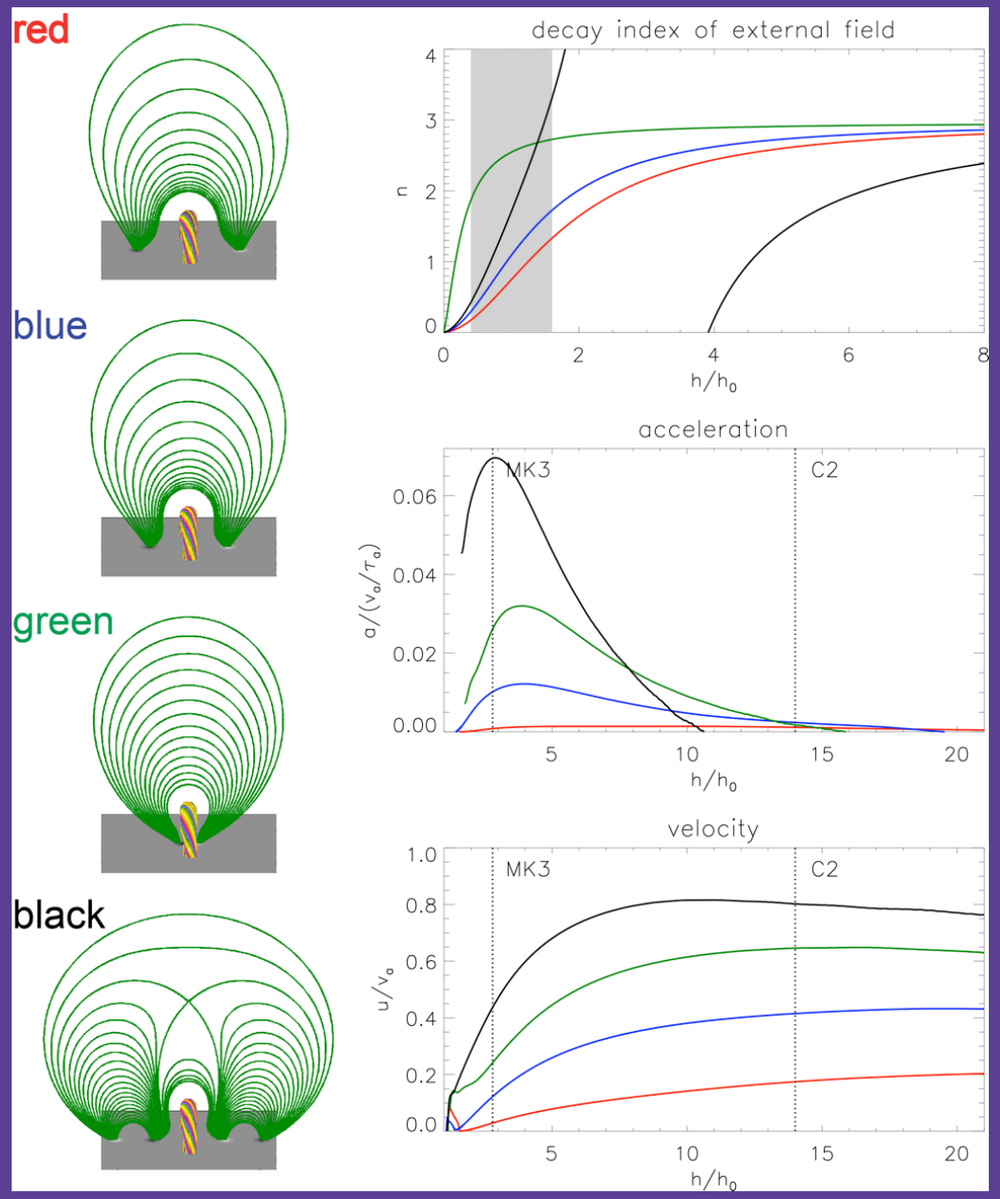
Liu Y. (2007)



Streamer



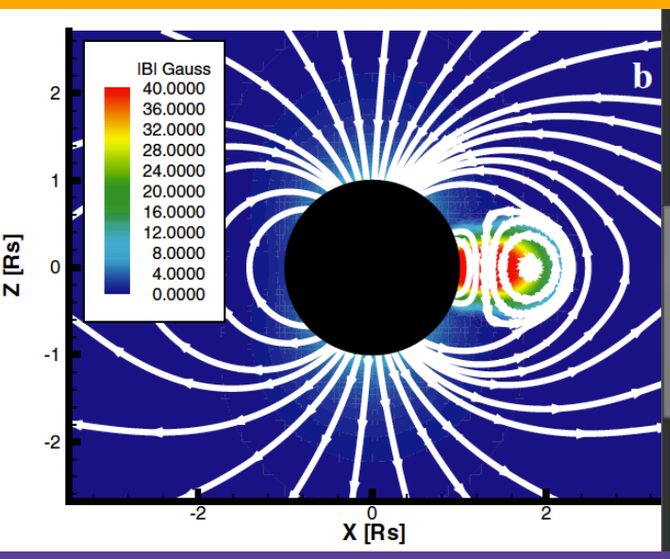
Pseudo-streamer



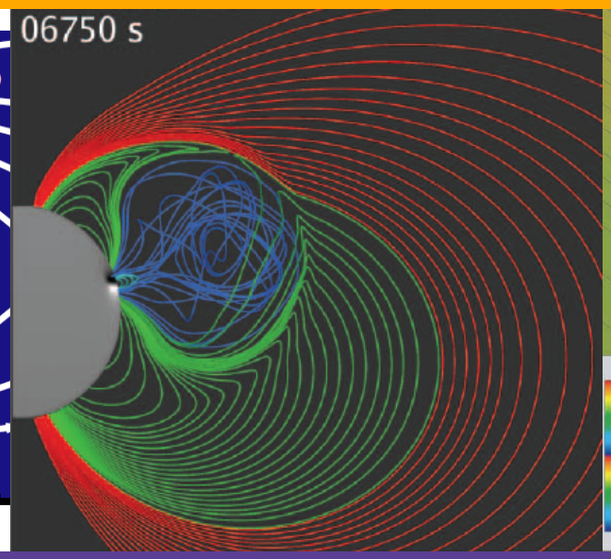
Török & Kliem (2007)

- CME faster if originating close to open field or pseudo-streamer
- CME faster if “overlying” field drops faster with height
- CME faster if there was a preceding CME? (Carrington 1859, Halloween 2003, 2004 Nov 10, ...)

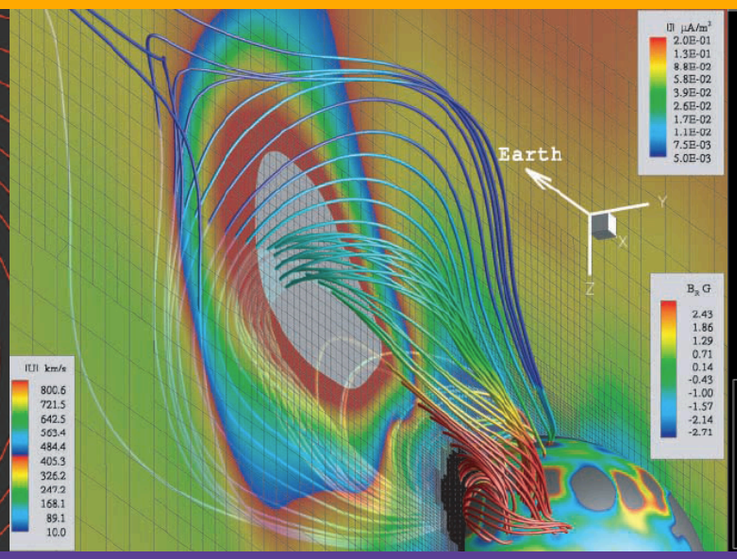
Simulations of fast CMEs



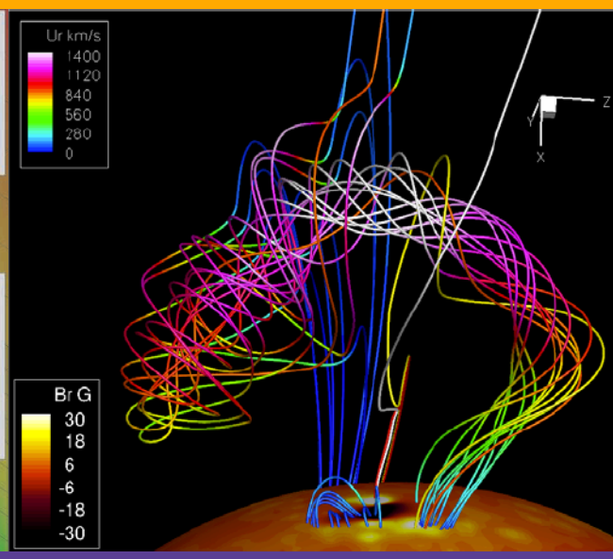
Manchester (2006)



Lynch et al. (2008)



Roussev et al. (2004)

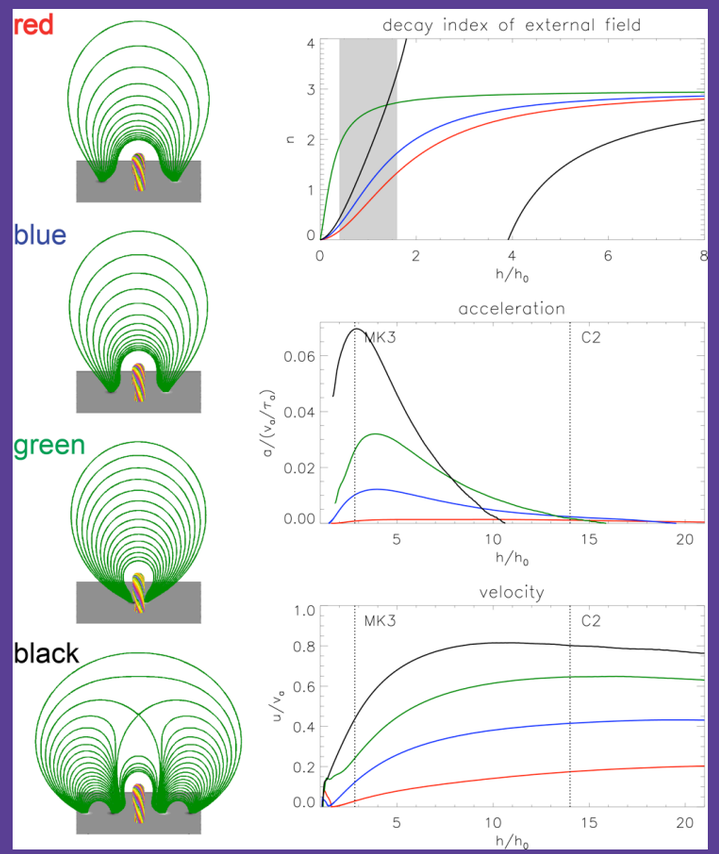


Lugaz et al. (2011)

- Both idealized and case-study simulations produce fast CMEs
- “Single” simulations; no systematic study of factors that control CME speed
- Often: CME produced by (GL or TD) flux rope out of equilibrium
- Partly unrealistic field strengths required to get fast CME

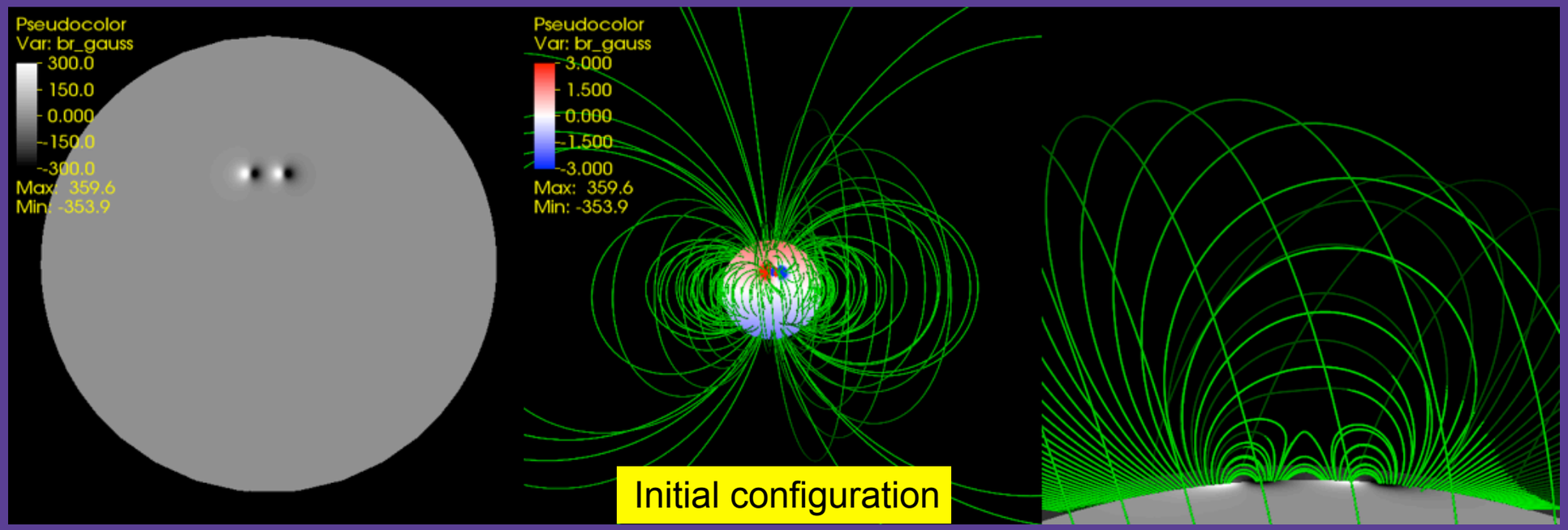
Our goals

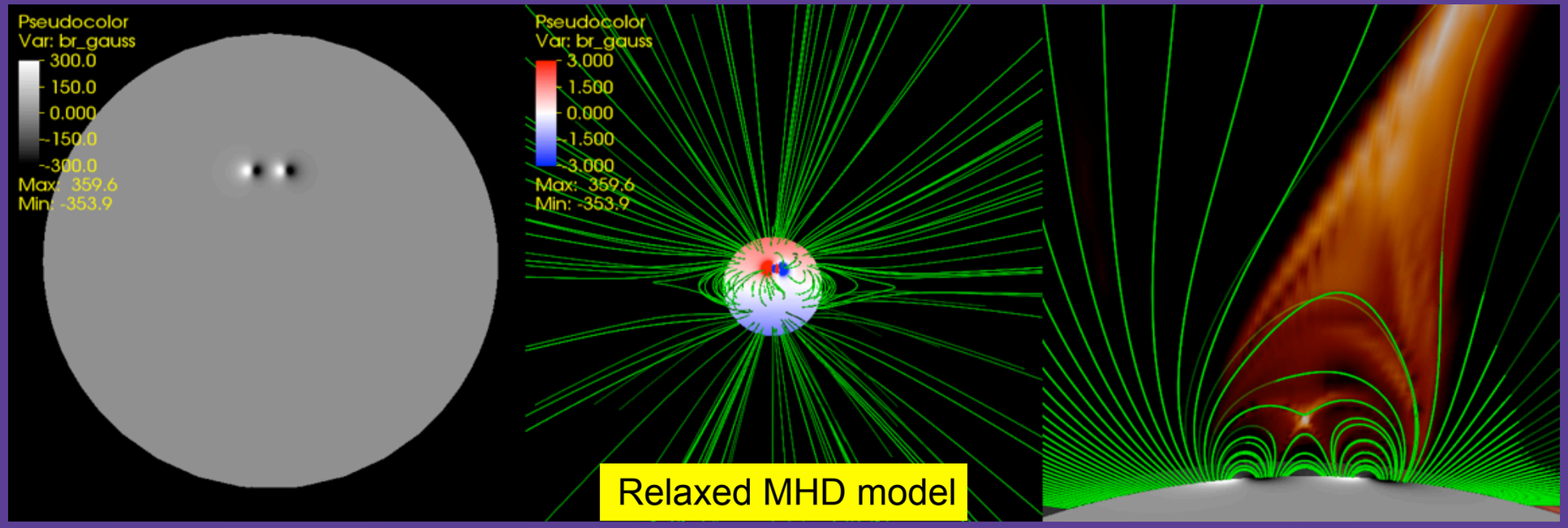
- Systematic (parametric) studies of factors that control CME speed



- Improve “realistic” simulations of (fast) CMEs:
  - Pre-eruption flux rope in equilibrium
  - Realistic source region fields
  - Case studies: preserve observed magnetogram

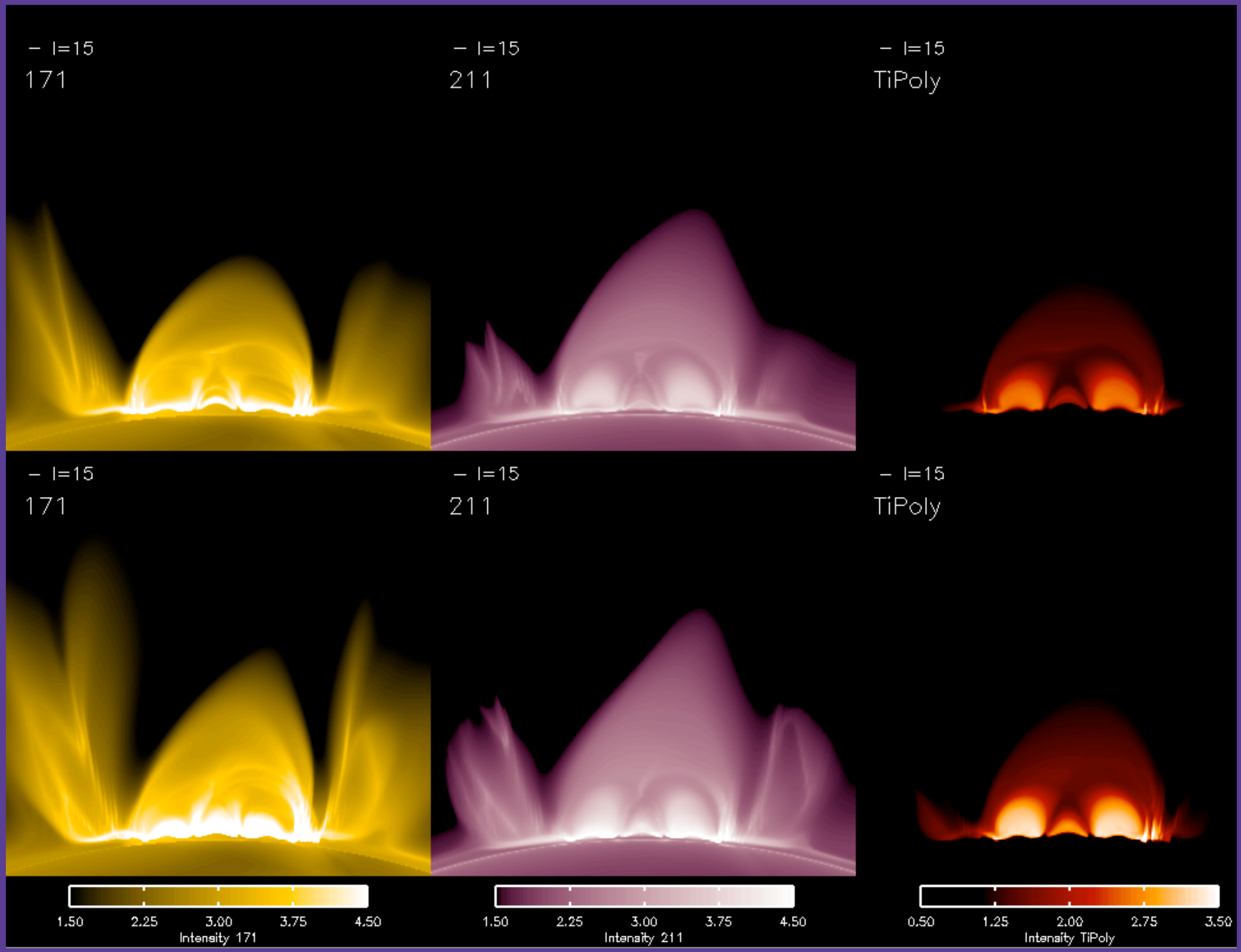
Global model setup



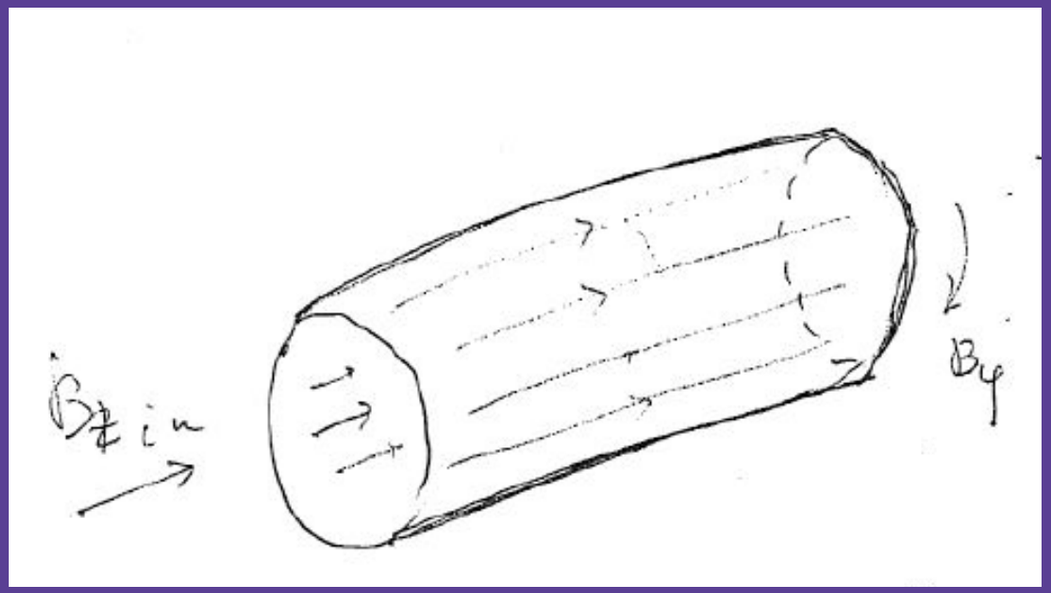


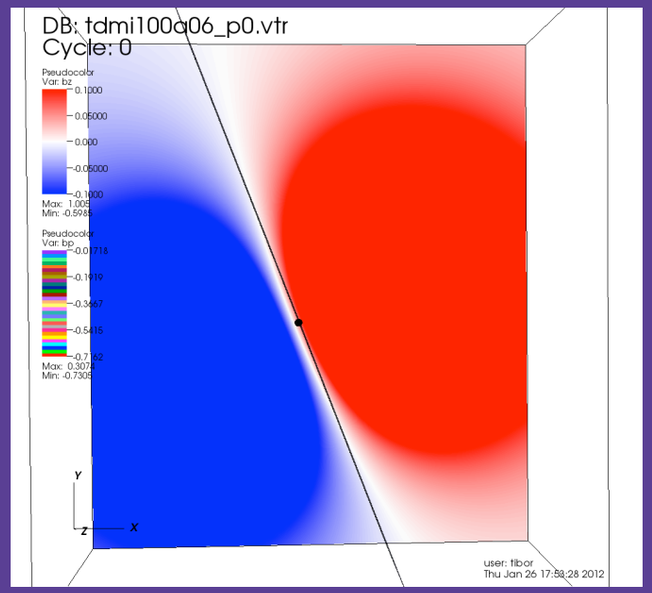
- global dipole + quadrupolar active region (large decay index)
- AR flux ≈ 2 * 10^{22} Mx; B_{max} = 360 G

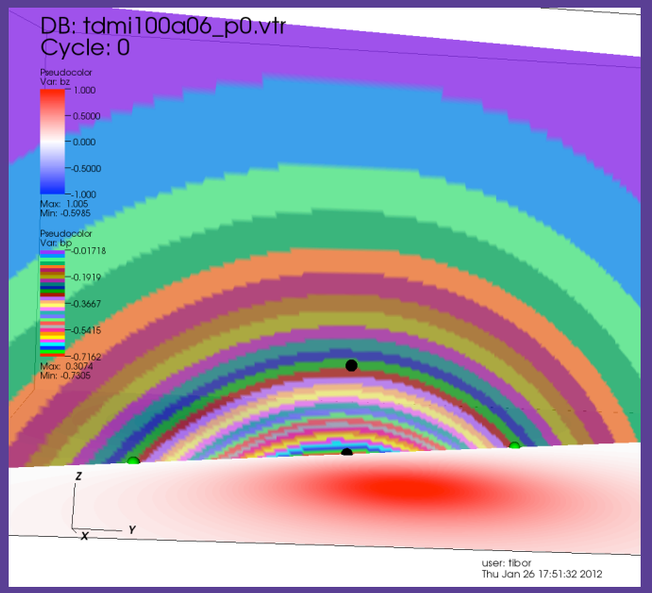
Testing heating parameters

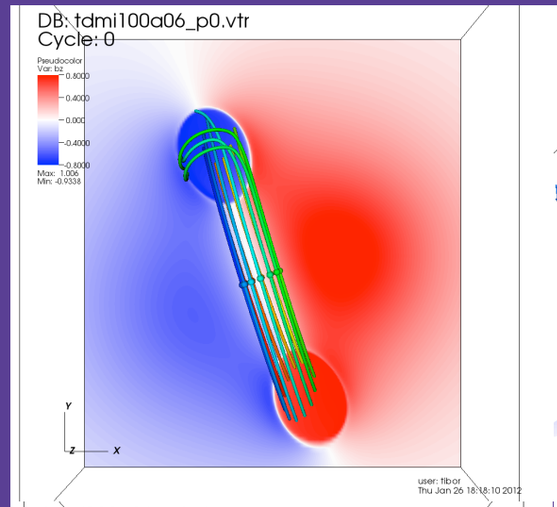


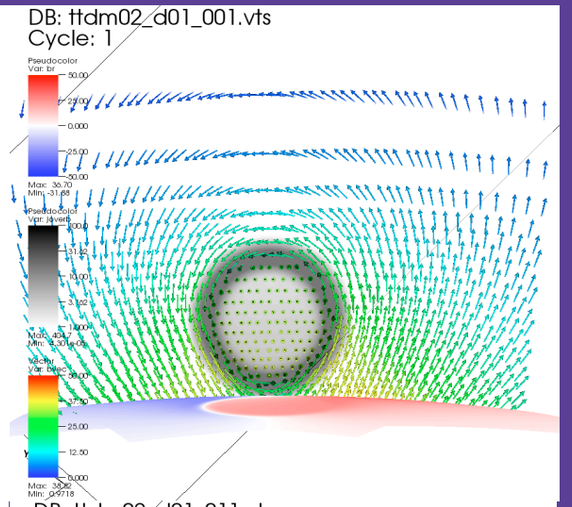
Construct flux rope in magnetic equilibrium

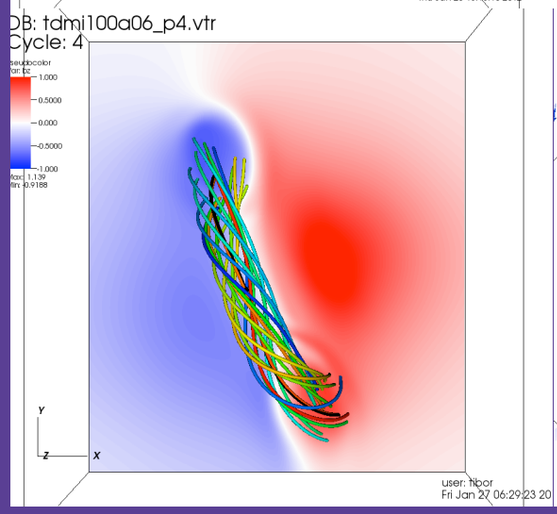


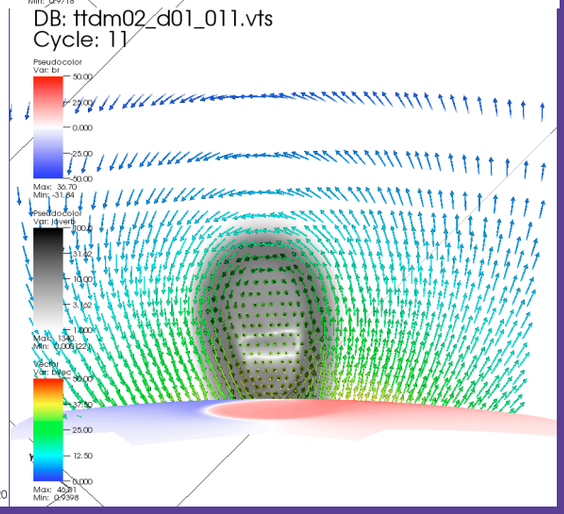




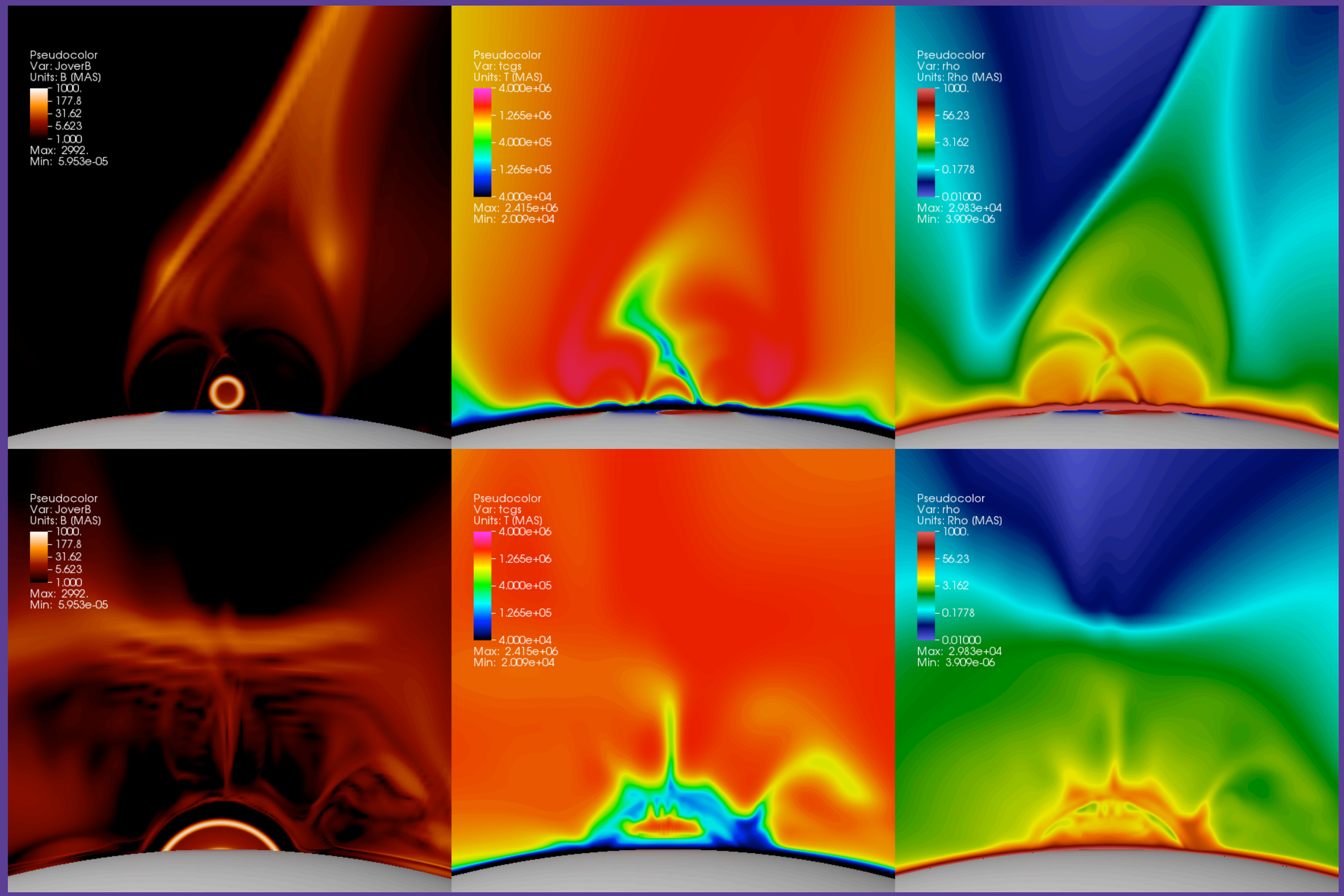






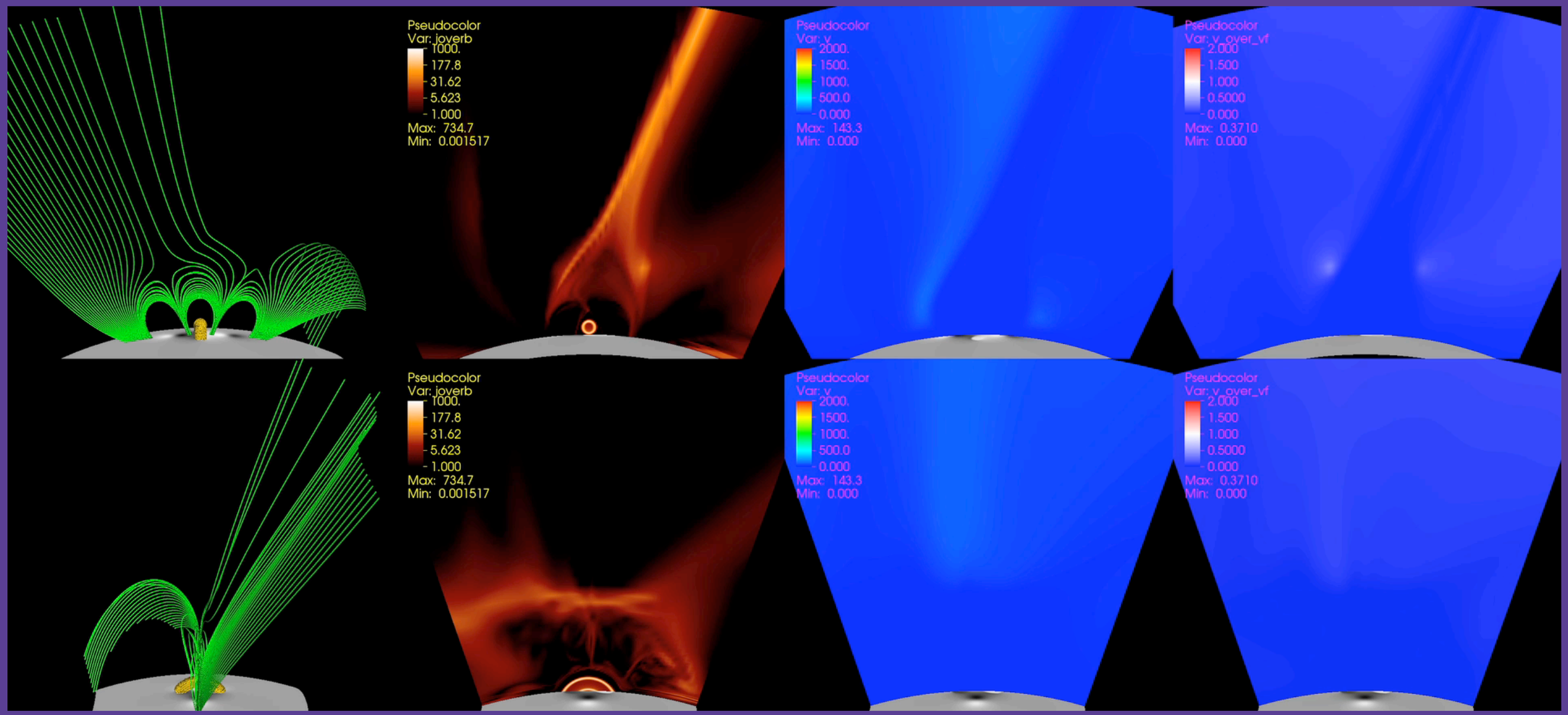


Insertion of flux rope & relaxation



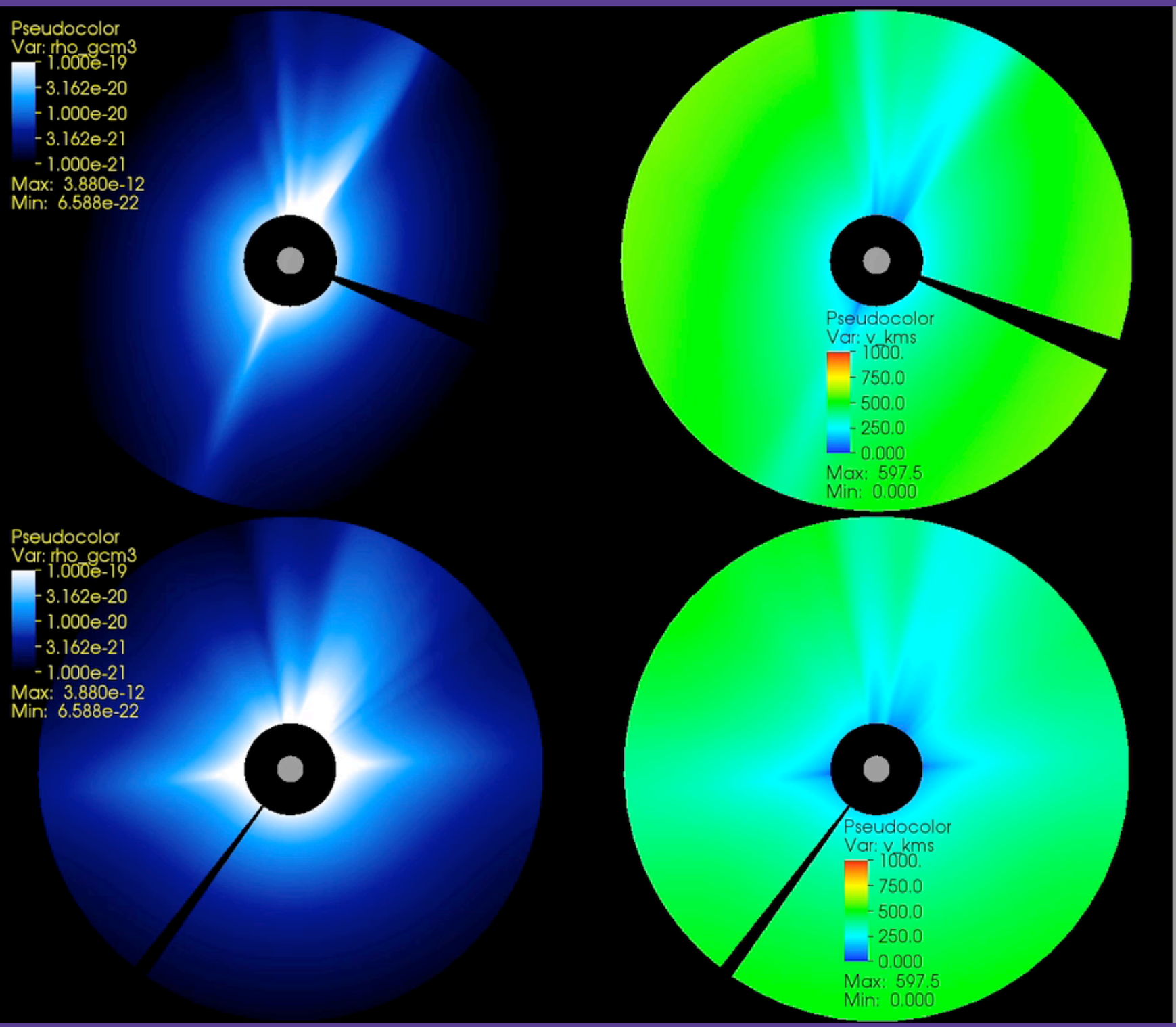
→ Goal: trigger eruption by converging flows toward PIL

Eruption with flux rope slightly out of equilibrium



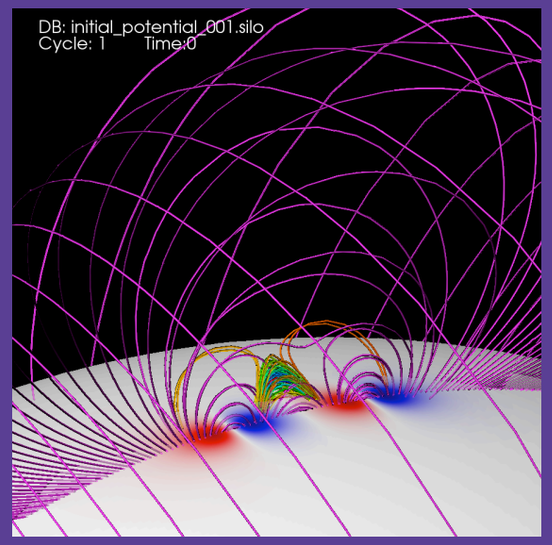
- fast CME, produces shock (but also strong initial wave!)
- max. CME speed 2000 km/s, but CME slows down more than observed
- released magnetic energy ≈ 1.6 * 10^{32} erg
- stronger FR fields yield faster CMEs (>4000 km/s), but out of equilibrium

Eruption with flux rope strongly out of equilibrium

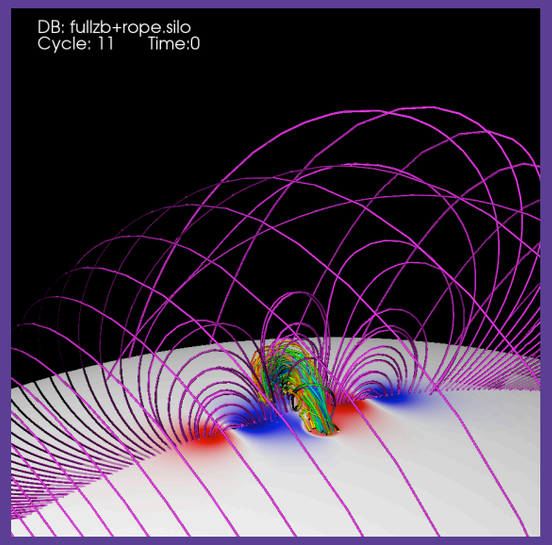


Next improvements

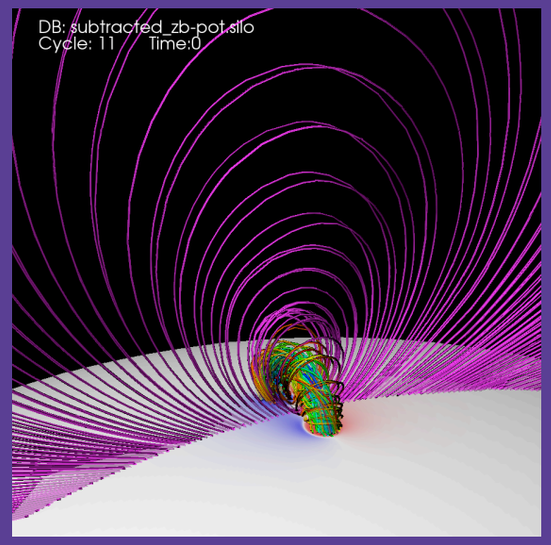
- Insert pre-relaxed flux rope (to avoid strong initial wave):



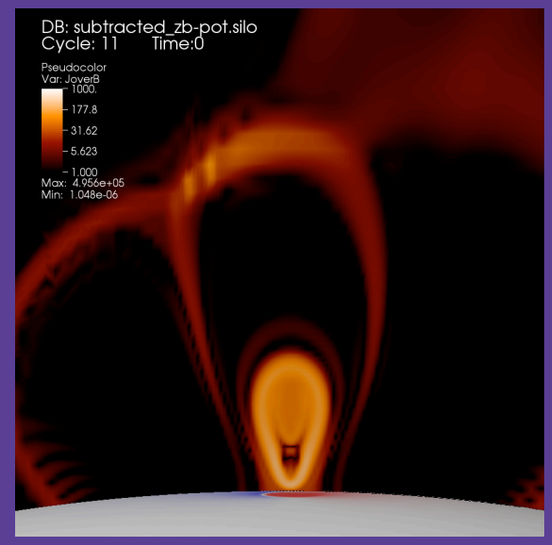
potential



total (relaxed)



subtracted rope



subracted j/B

- Preserve magnetogram: