Do All CMEs have Flux Rope Structure?
A (Biased) Perspective from an MHD Modeler

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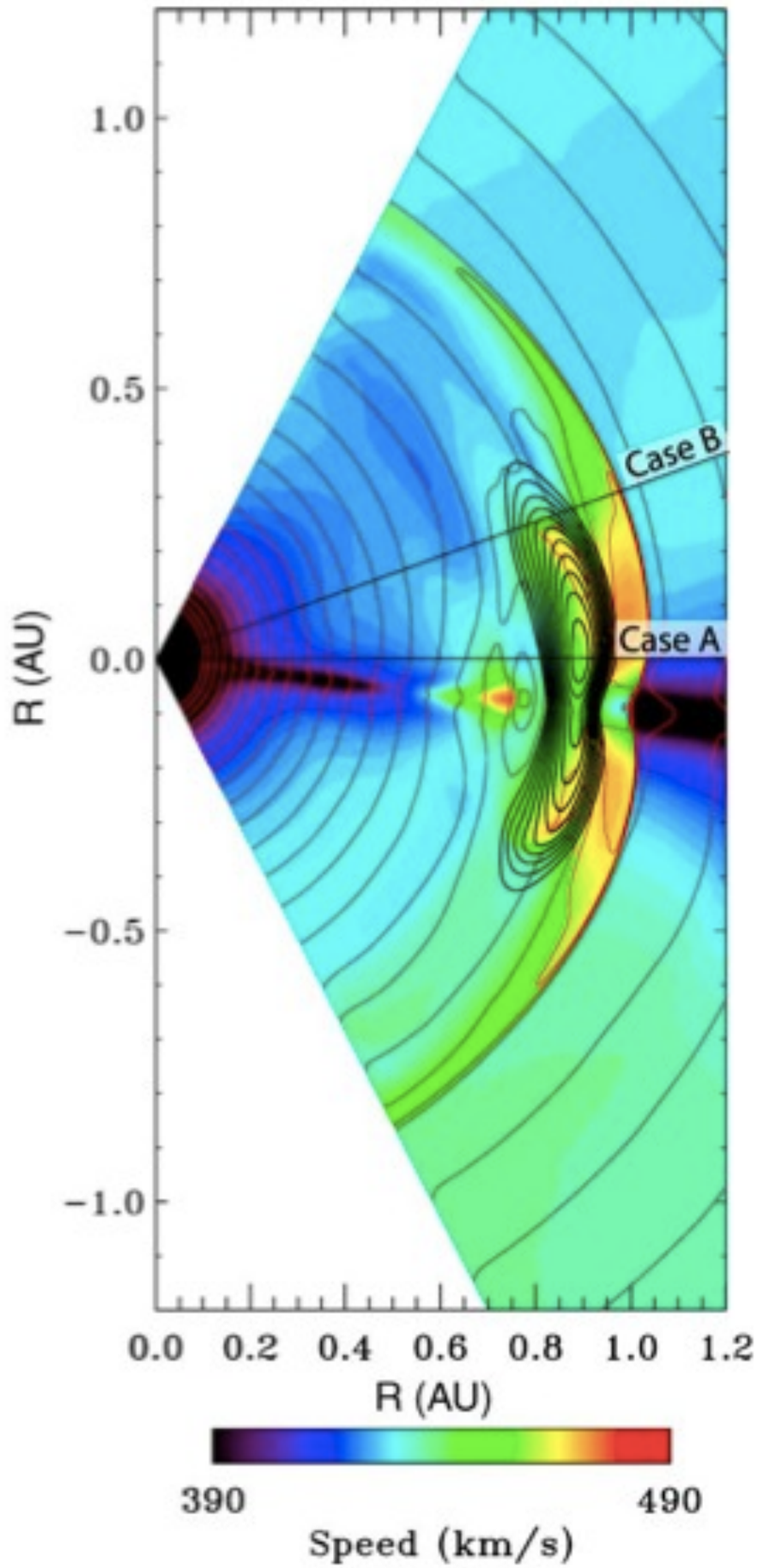
Outline

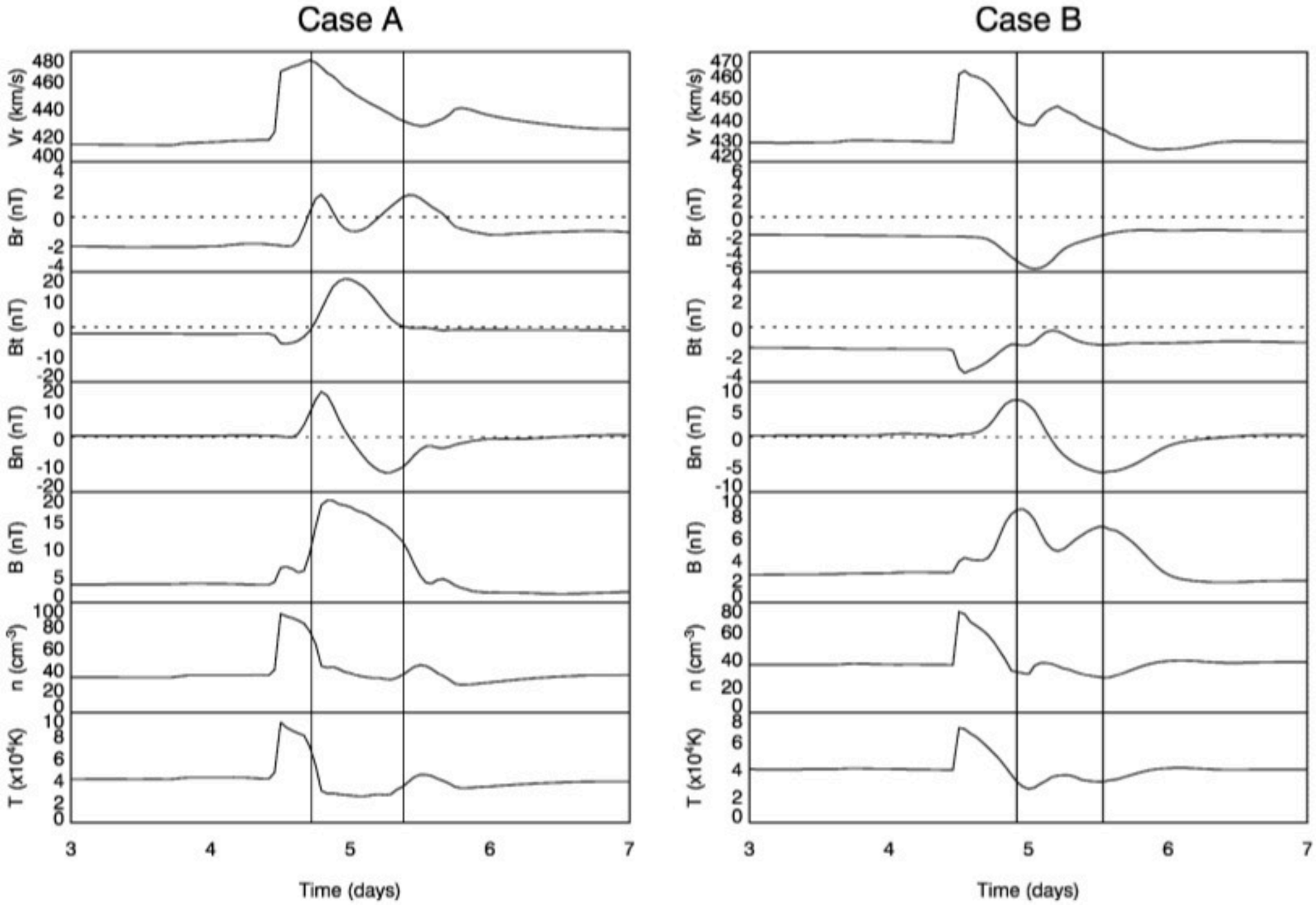
- Flux rope fitting games;
- Global MHD solutions of specific events;
- Possible explanations for the relationship between flux ropes and CMEs.

Flux Rope Fitting Techniques:

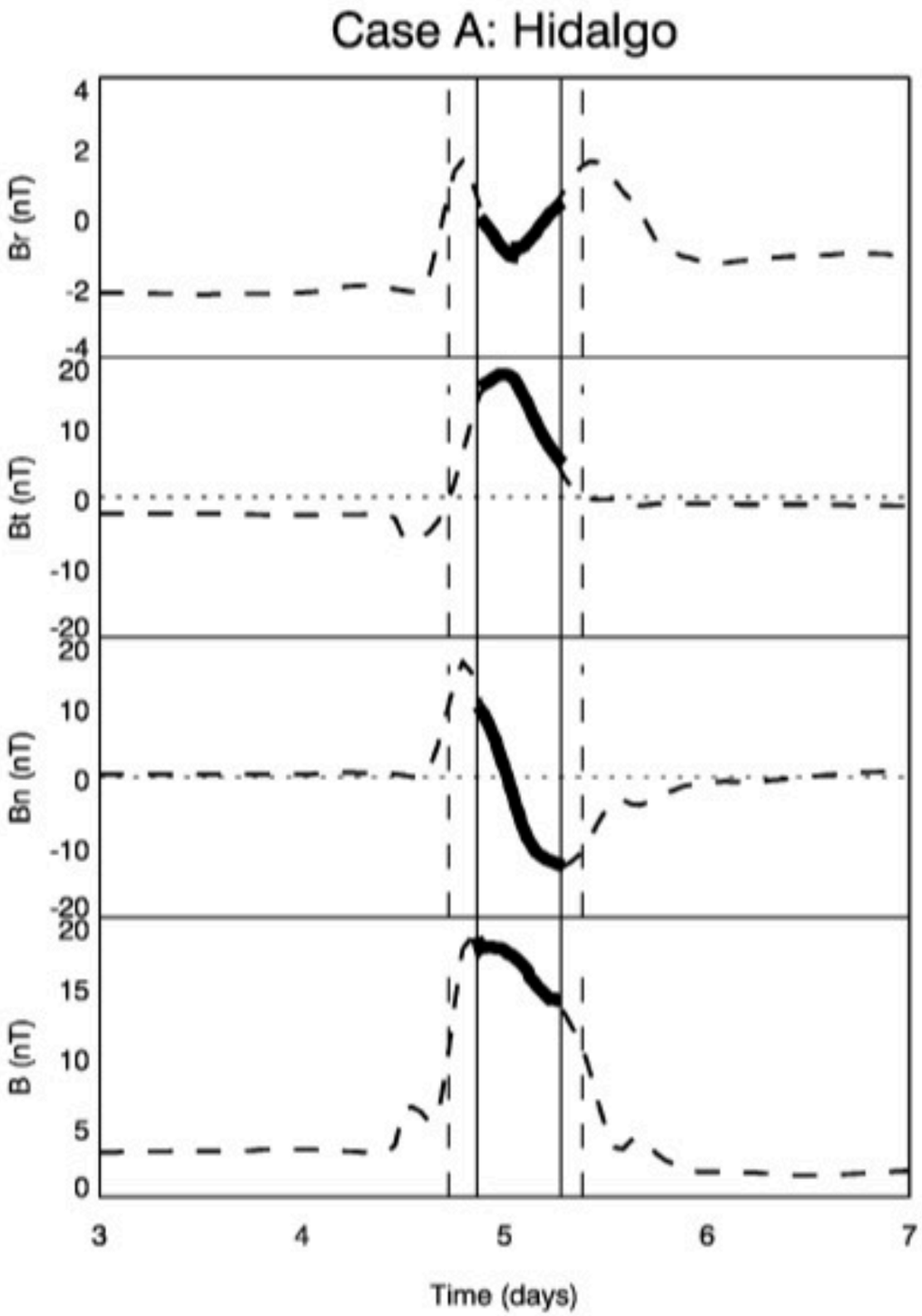
Using Global MHD Results to test fitting procedures

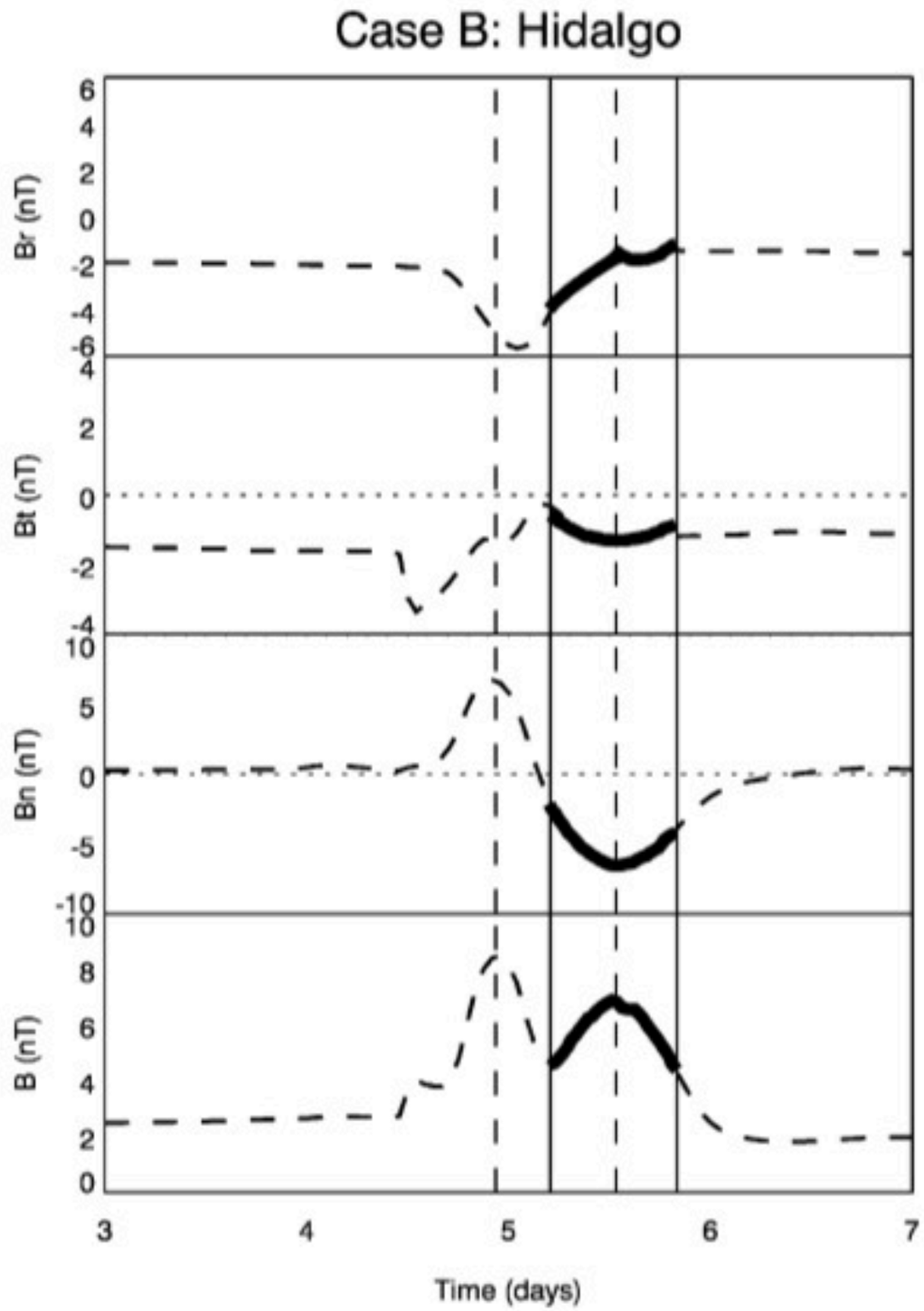


Simulated Time Series for the fitting techniques

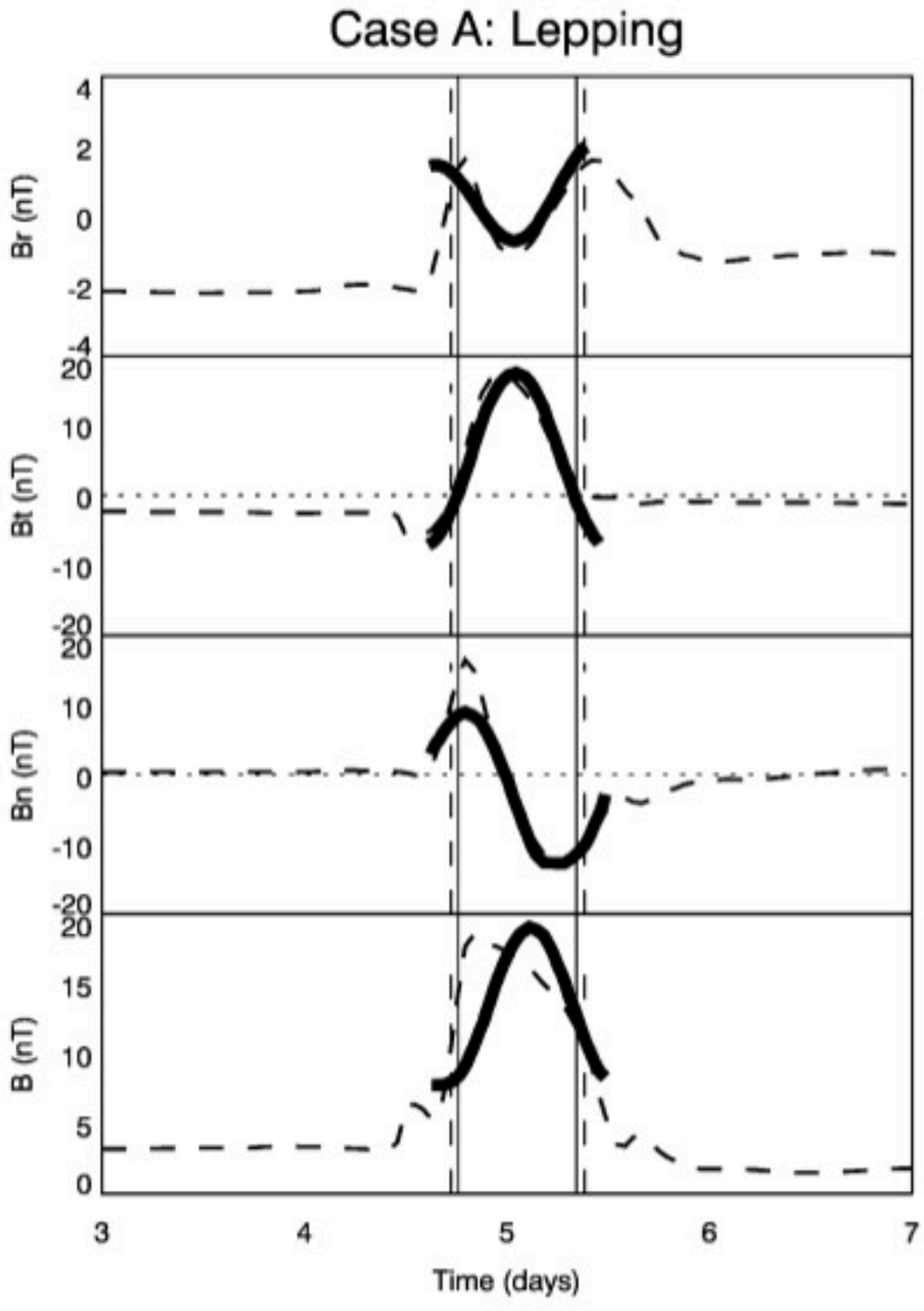


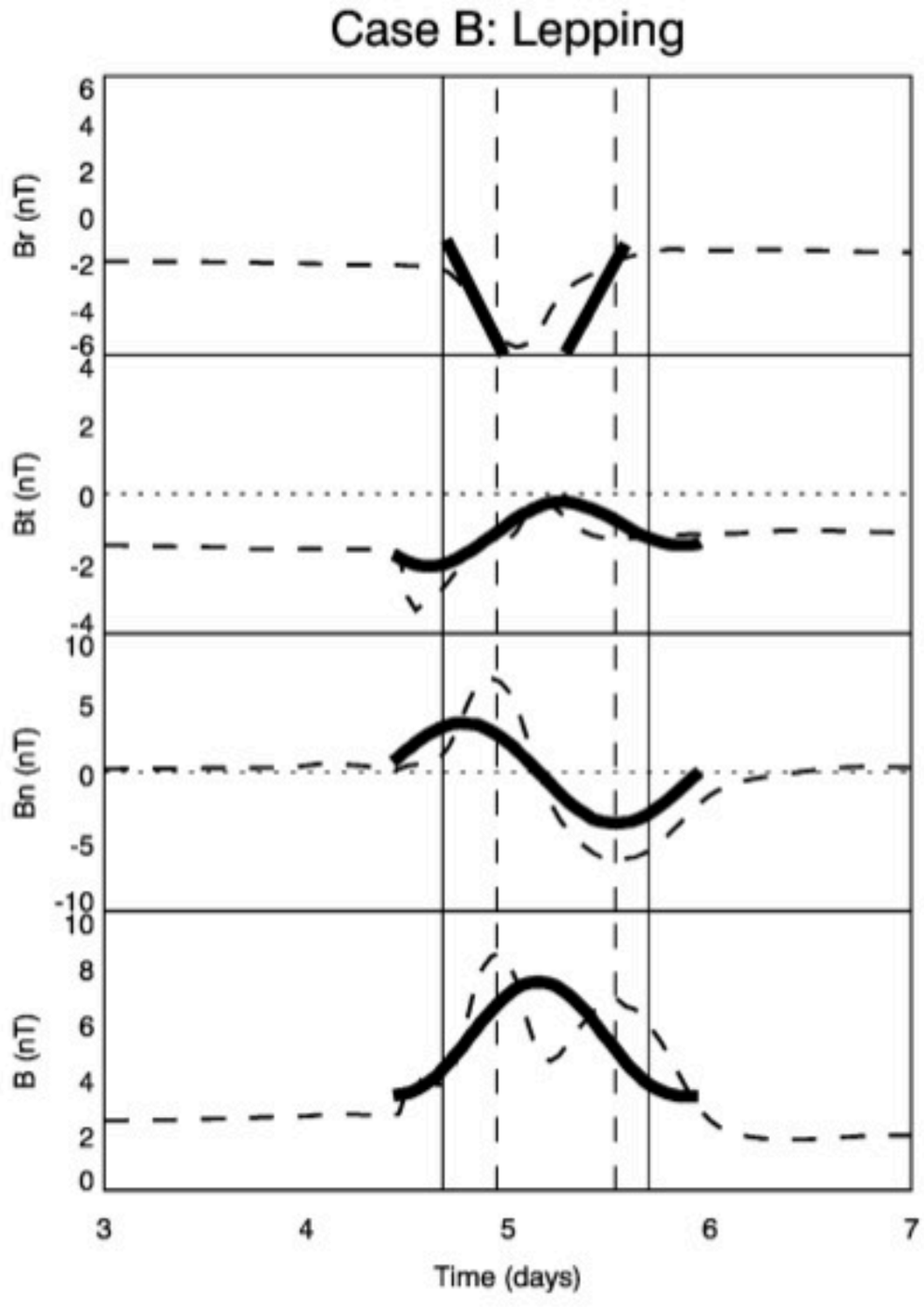
Miguel Hidalgo's Fit



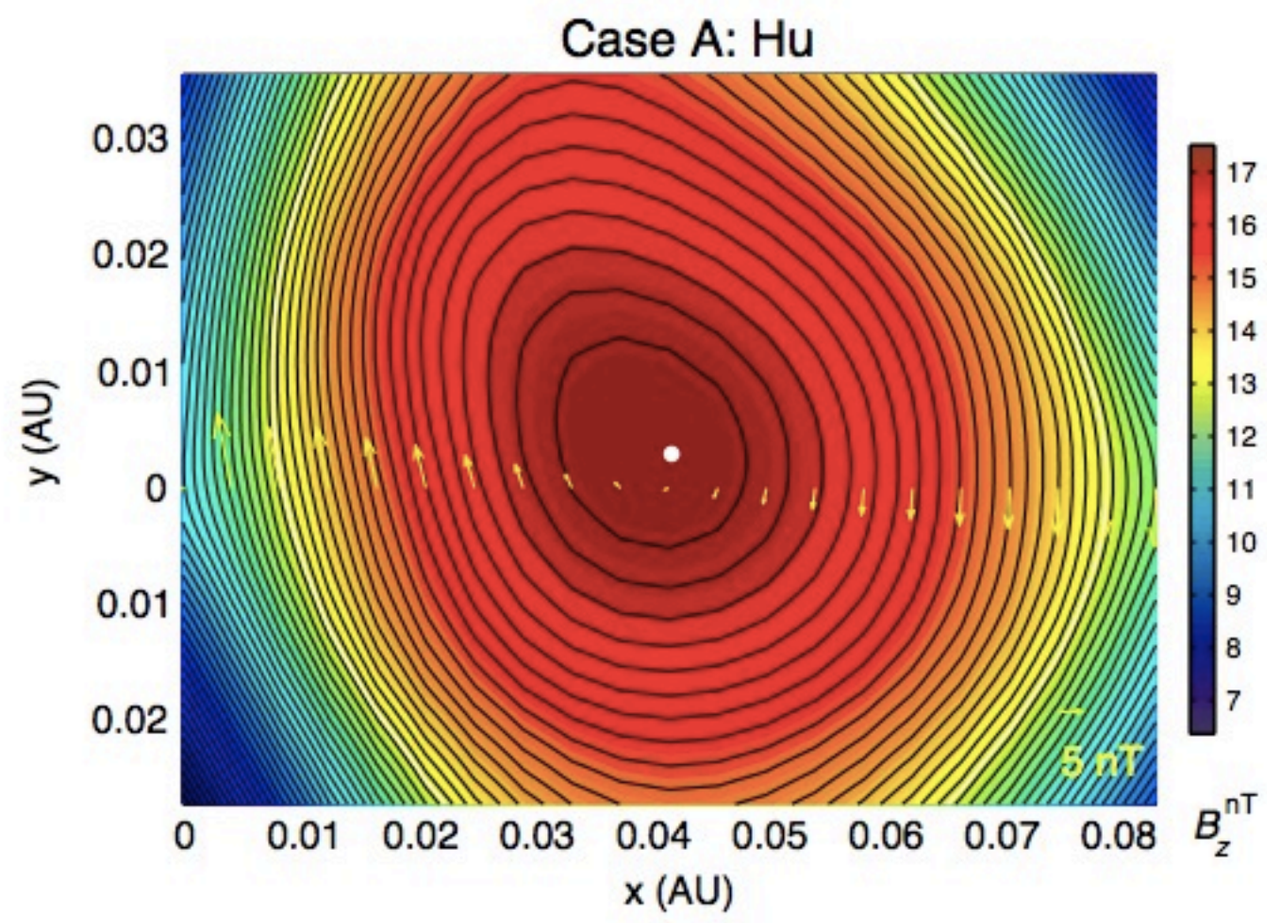


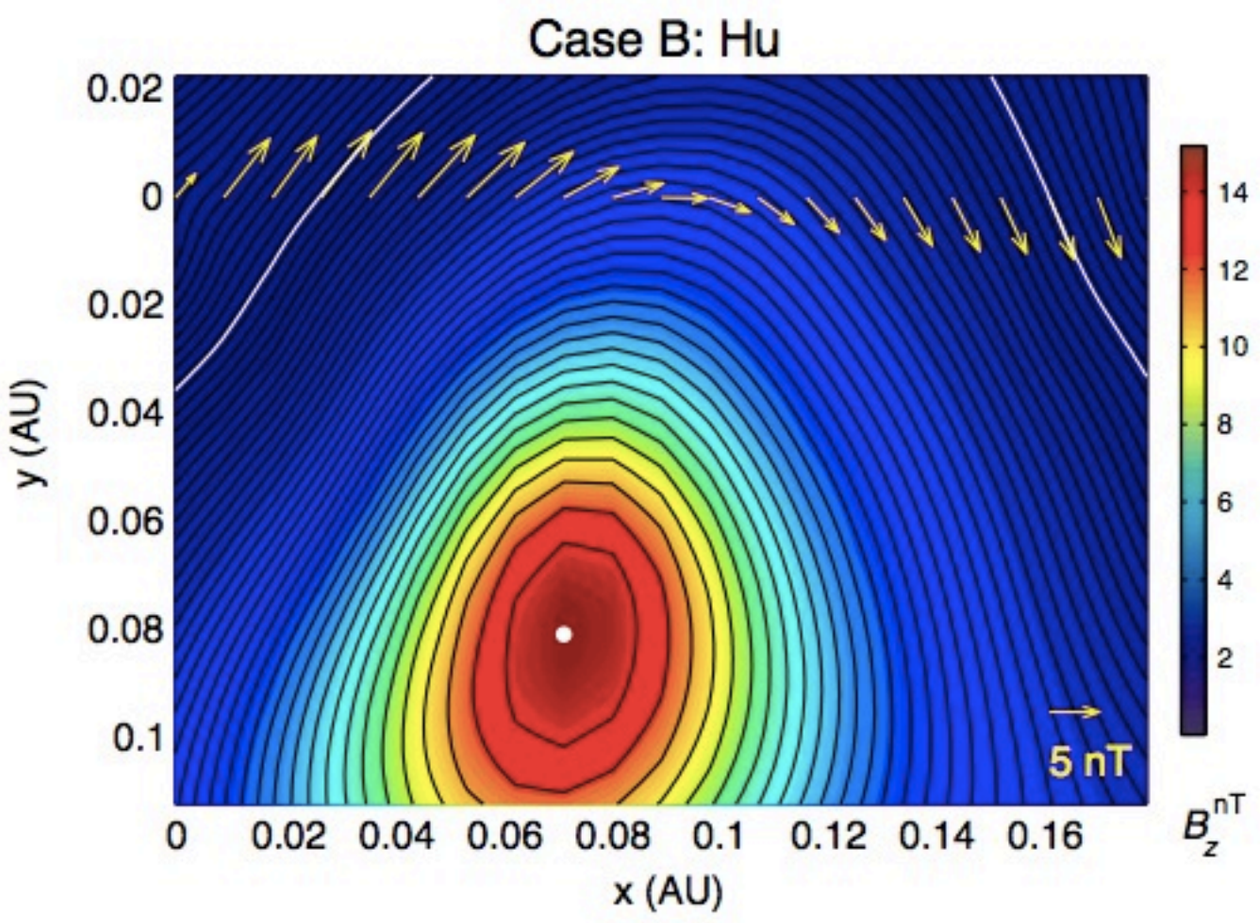
Ron Lepping's Fit





Qian Hu's Fit

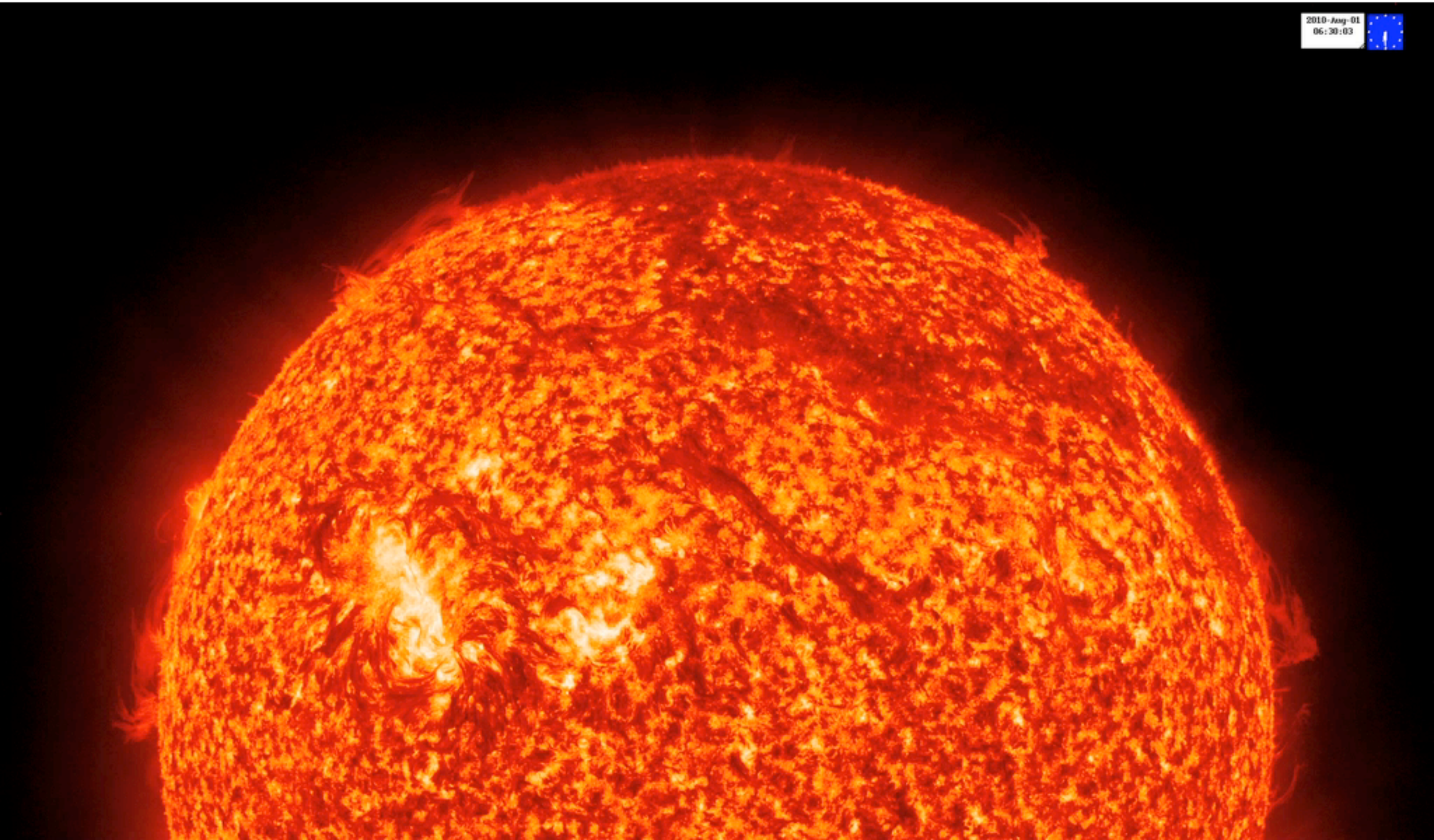

Case A: Hu
0.03
0.02
0.01
0
0.01
0.02
y (AU)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
x (AU)
5 nT
17
16
15
14
13
12
11
10
9
8
7
B_z^{nT}


Case B: Hu
0.02
0
0.02
0.04
0.06
0.08
0.1
y (AU)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
x (AU)
5 nT
14
12
10
8
6
4
2
B_z^{nT}

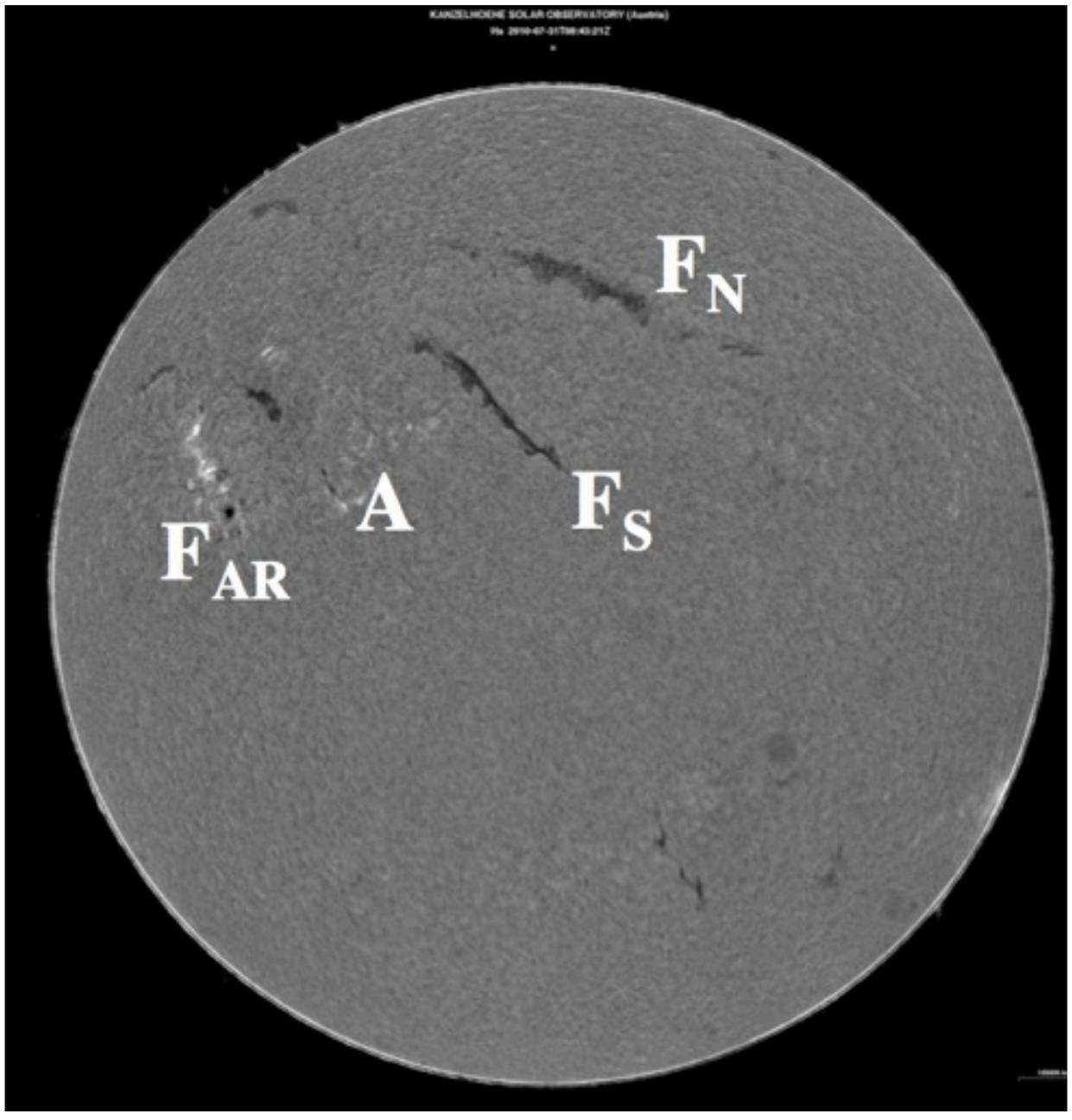
Modeling specific events

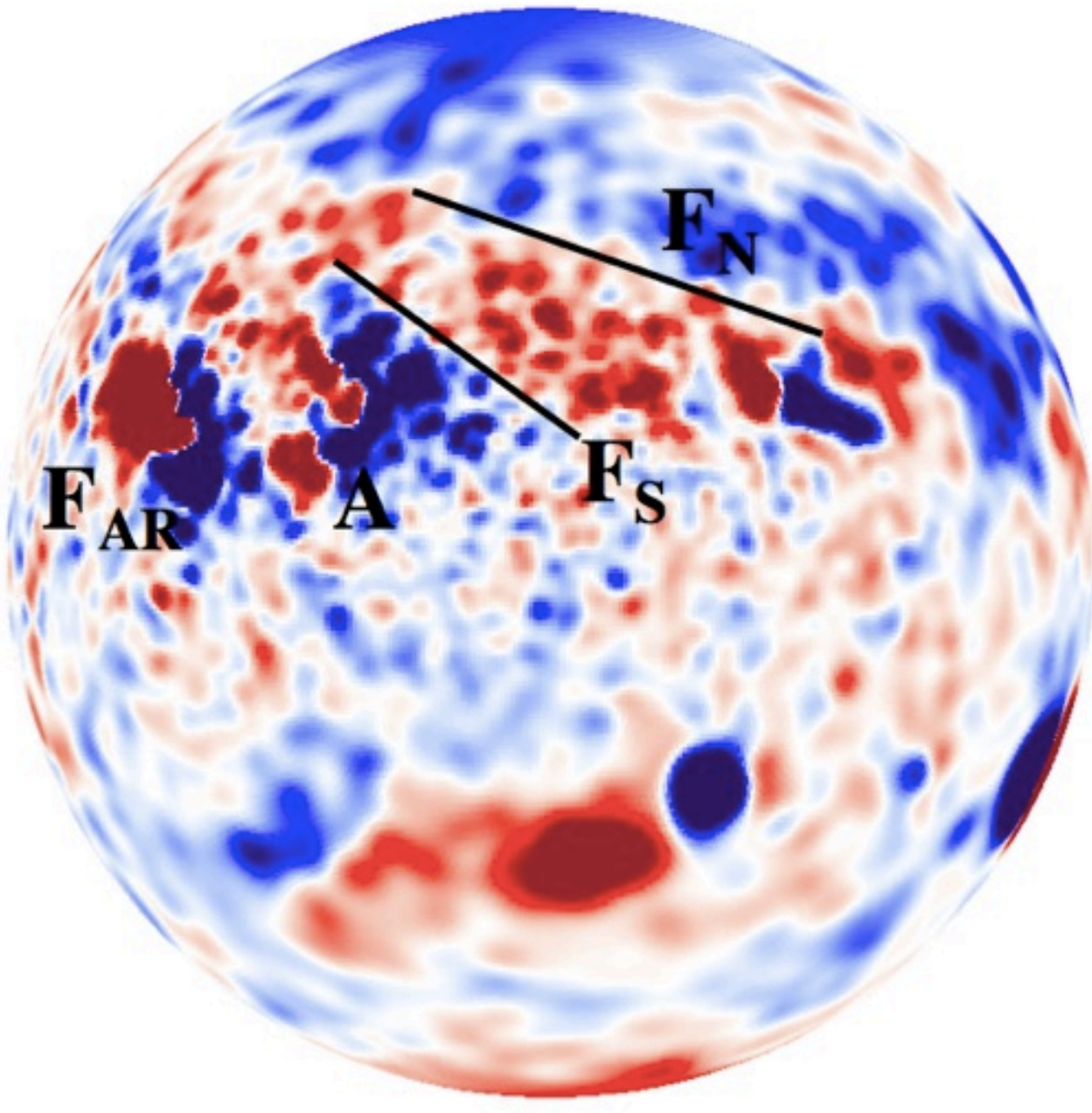
- August 1, 2010 CMEs;
- December 12, 2008 CME;
- May 2005;
- August 1997;
- Others?

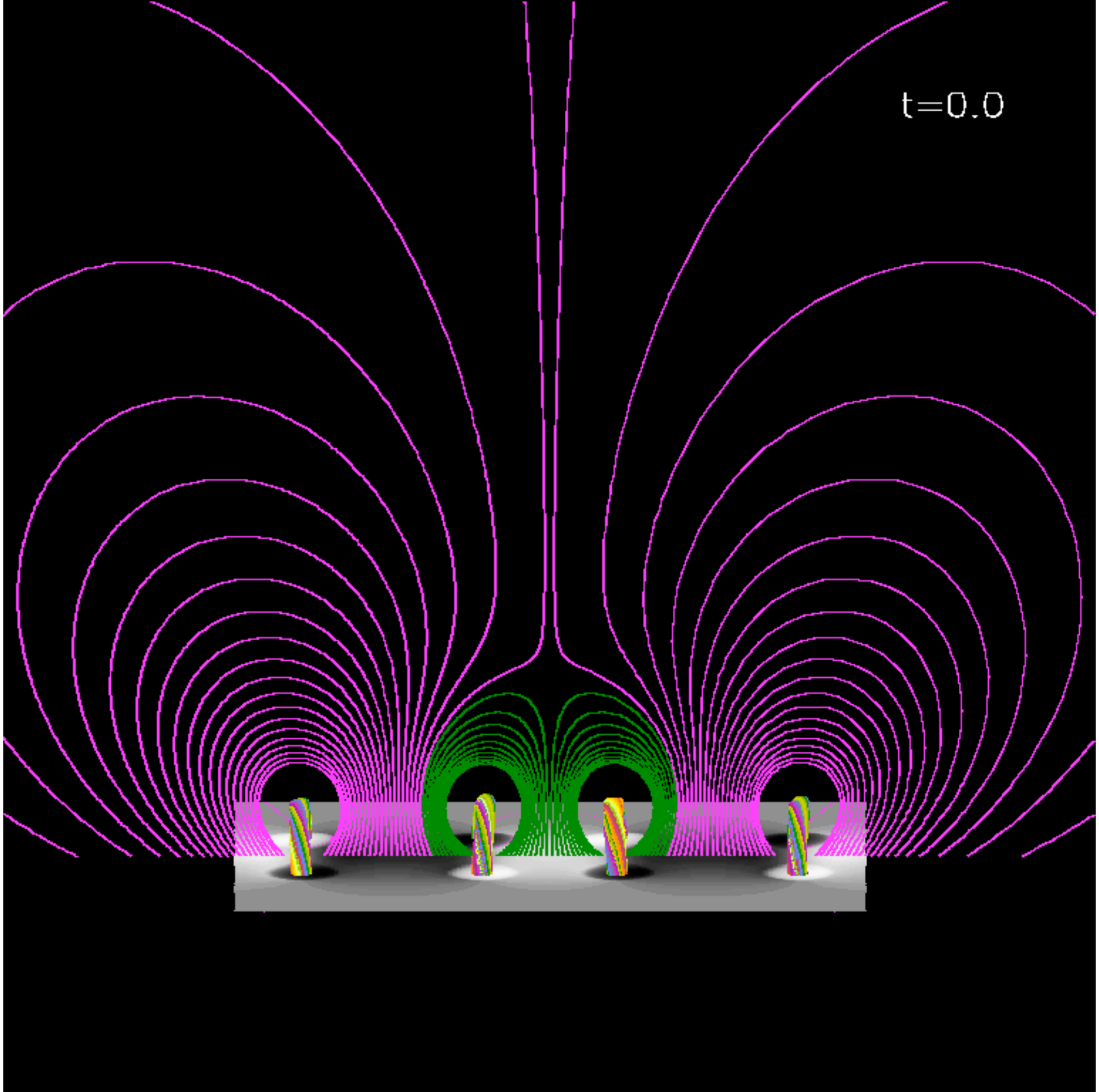
August 1, 2010 CMEs



Modeling Procedure



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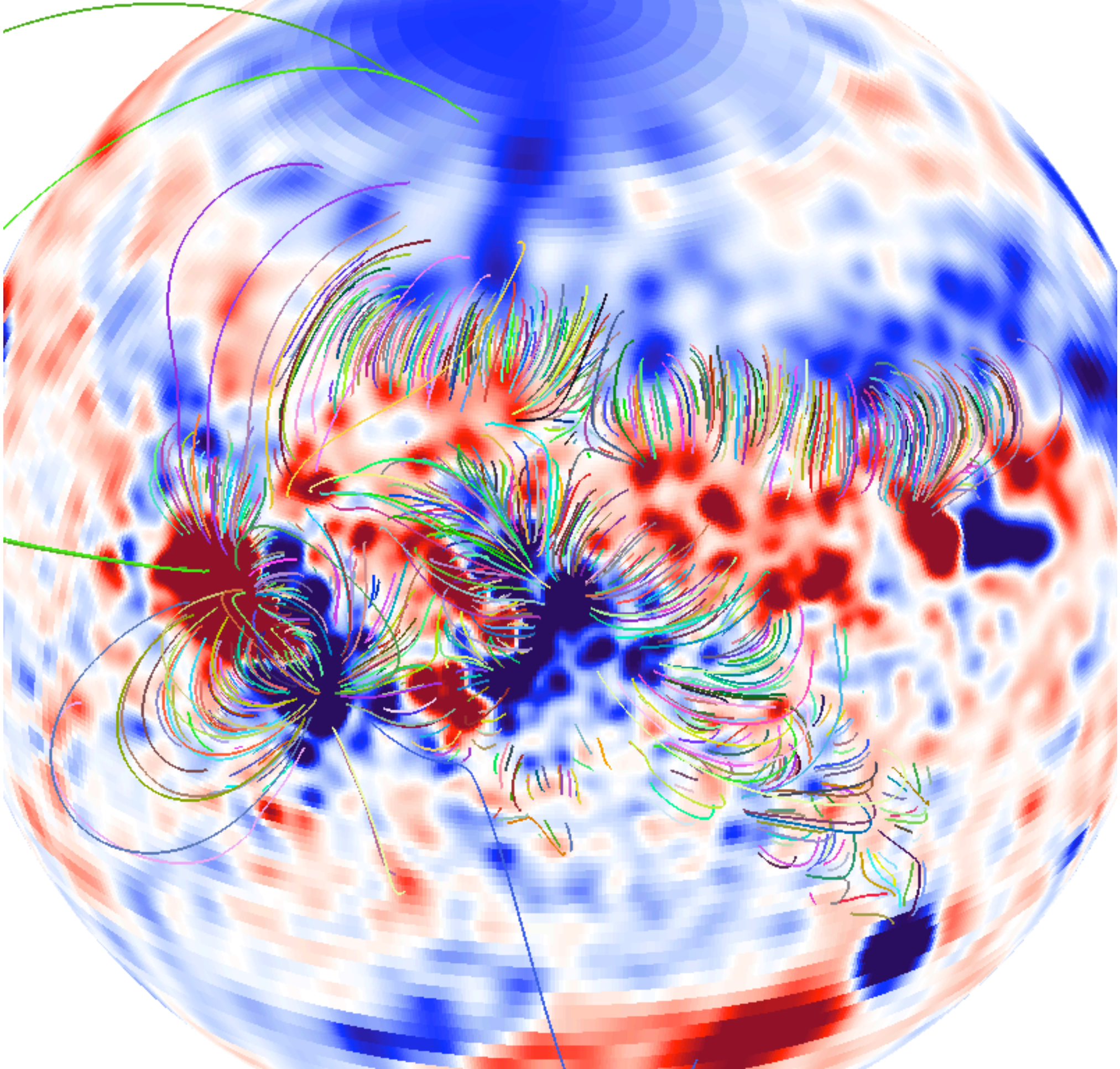
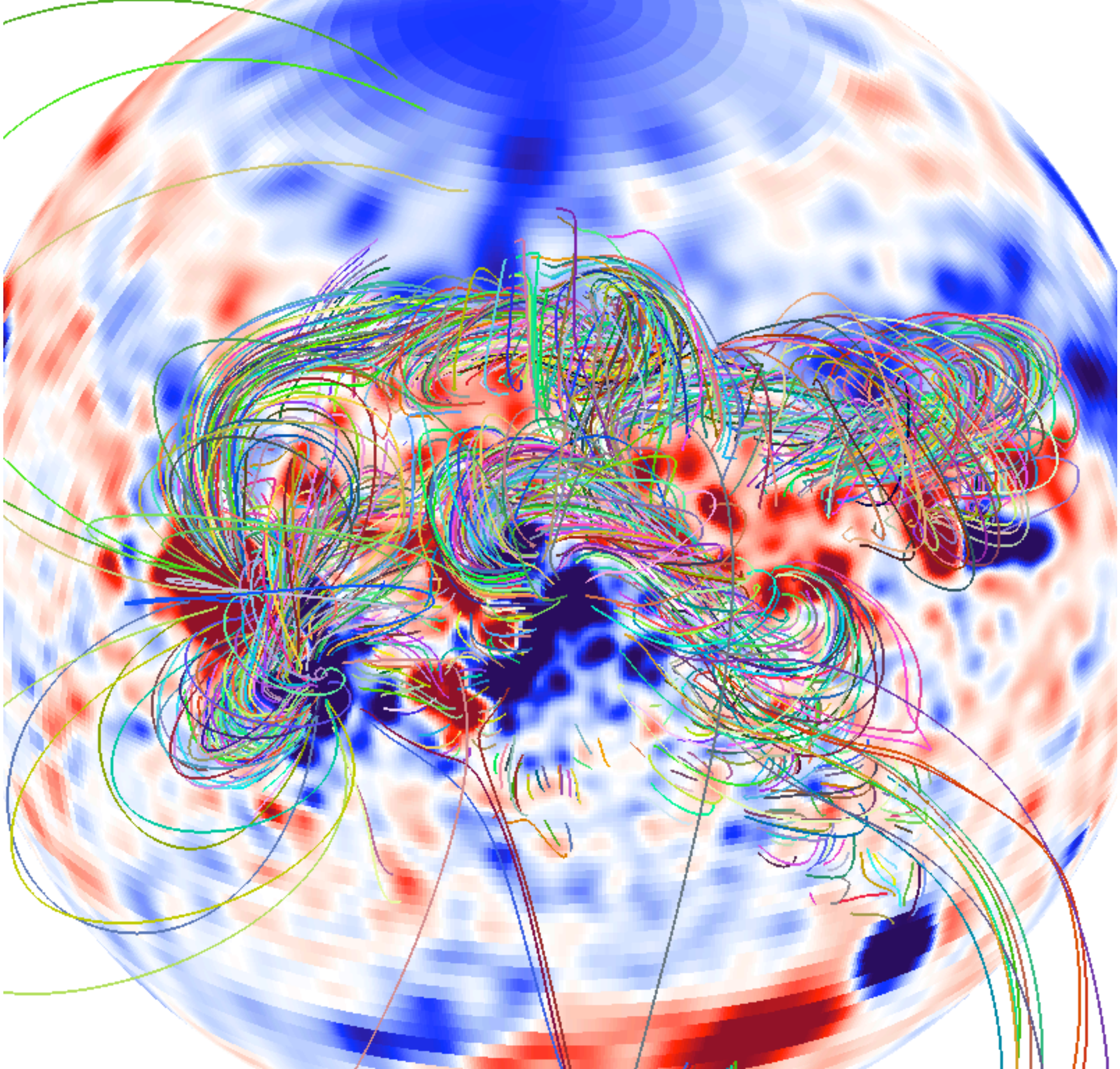




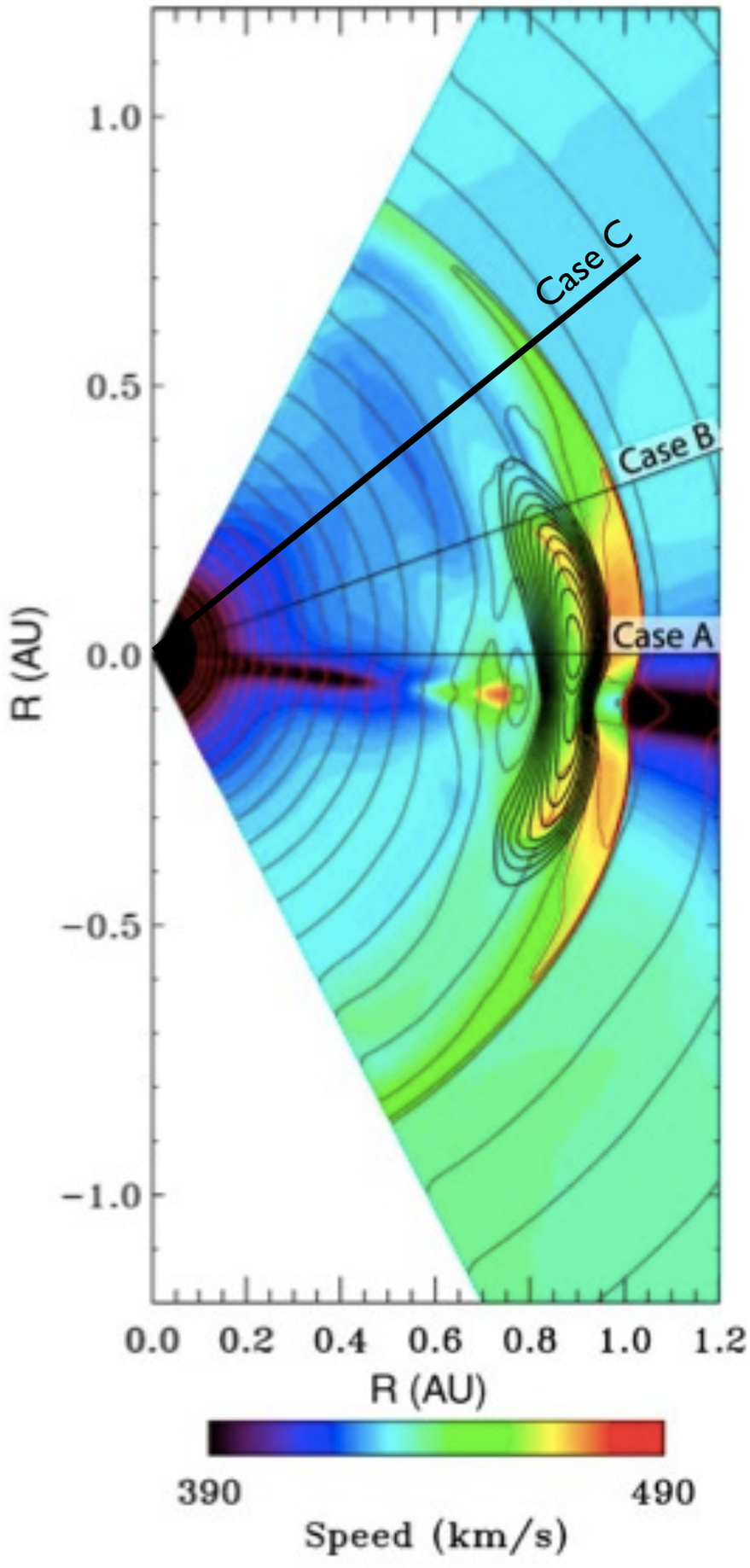
Do all CMEs have Flux Rope Structure? ....Some Possible Answers

- Yes, it an observational selection effect.
- No, interactions of an erupting flux rope with itself or between neighboring flux ropes create non-FR CMEs.
- No, it's an evolutionary process.
- No, there exist two (or more) intrinsic mechanisms for producing CMEs, some with FRs and some without.
- Other alternatives?

(1) An Observational Selection Effect

- All CMEs do in fact contain flux ropes;
- The trajectory of the spacecraft through the event is what determines whether a flux rope is also encountered;
- Near axis => Flux rope CME;
- Near flanks => non-Flux rope CME;
- Field rotations do not necessary imply flux rope; field-line draping can also cause rotations.

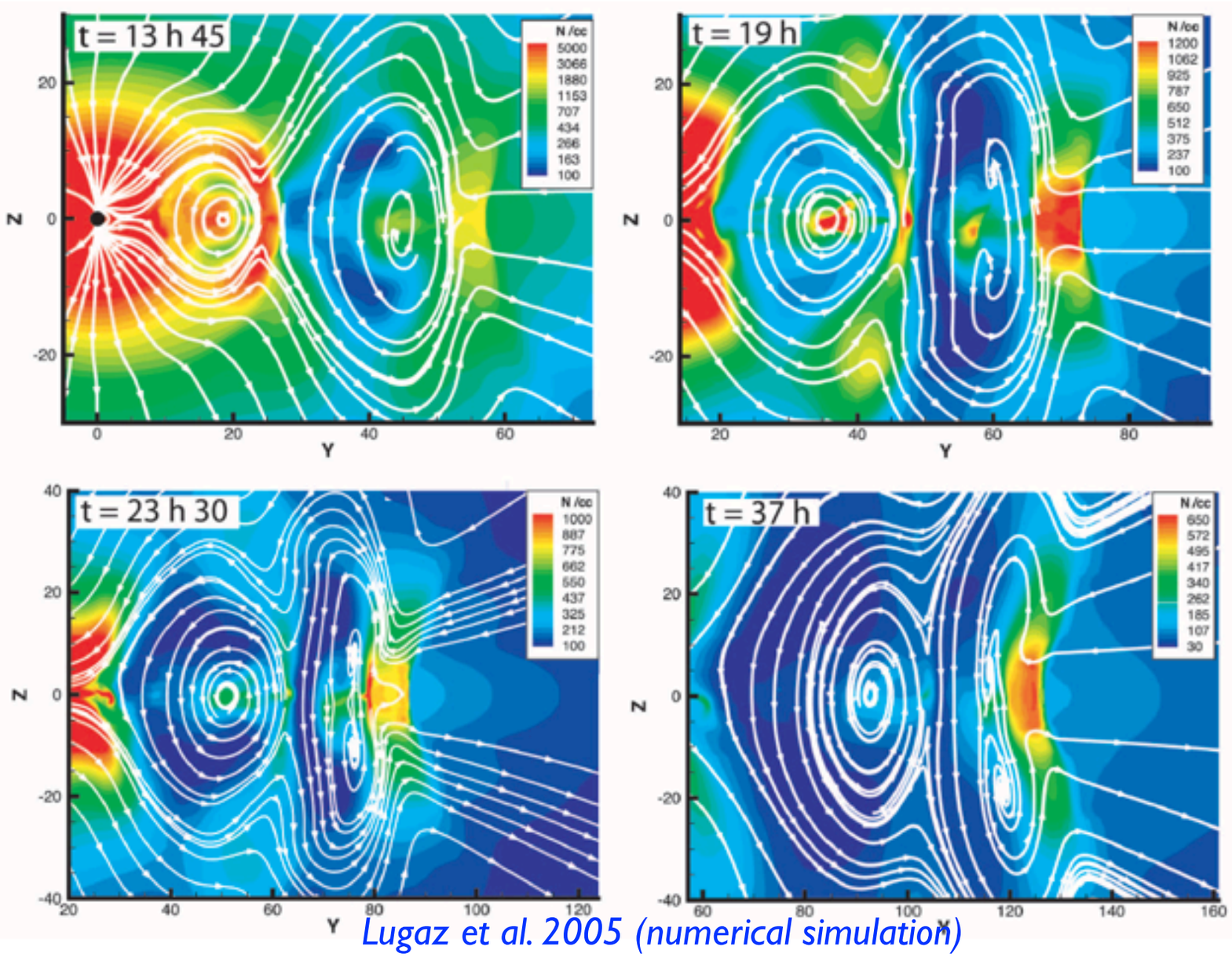
The presence, or absence of a flux rope is sensitive to the trajectory of the spacecraft through the event.



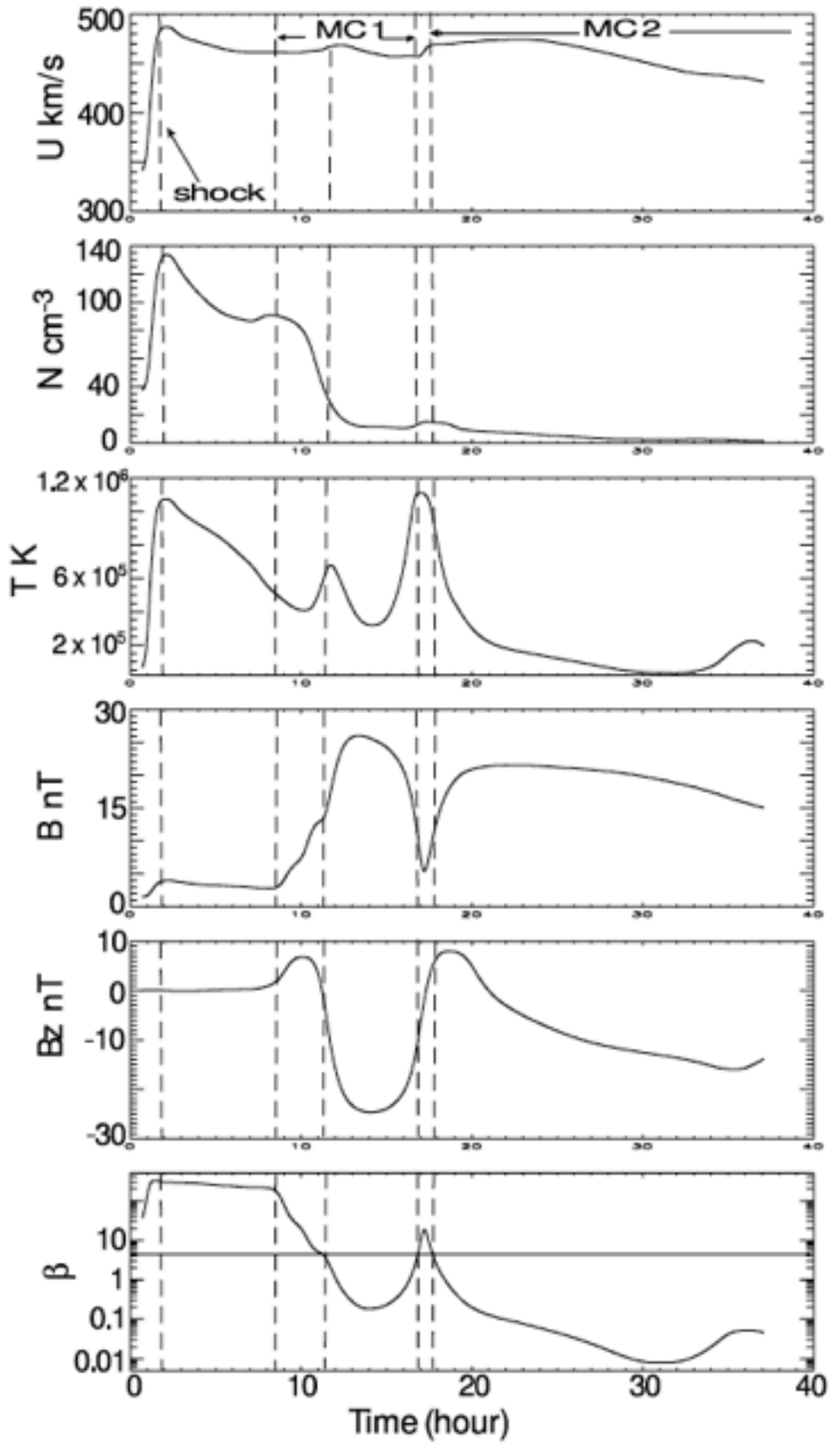
(2) CME-CME Interactions Destroy Flux Ropes

- Len Burlaga's concept of "complex ICMEs" produced by two (or more) ICMEs colliding and interacting;
- Complex (i.e., non-flux rope CMEs) are typically longer duration (bigger) than simple flux rope CMEs;
- As CME rate increases, should see more non-flux rope CMEs due to higher probability of interaction.

Magnetic signatures of interacting CMEs

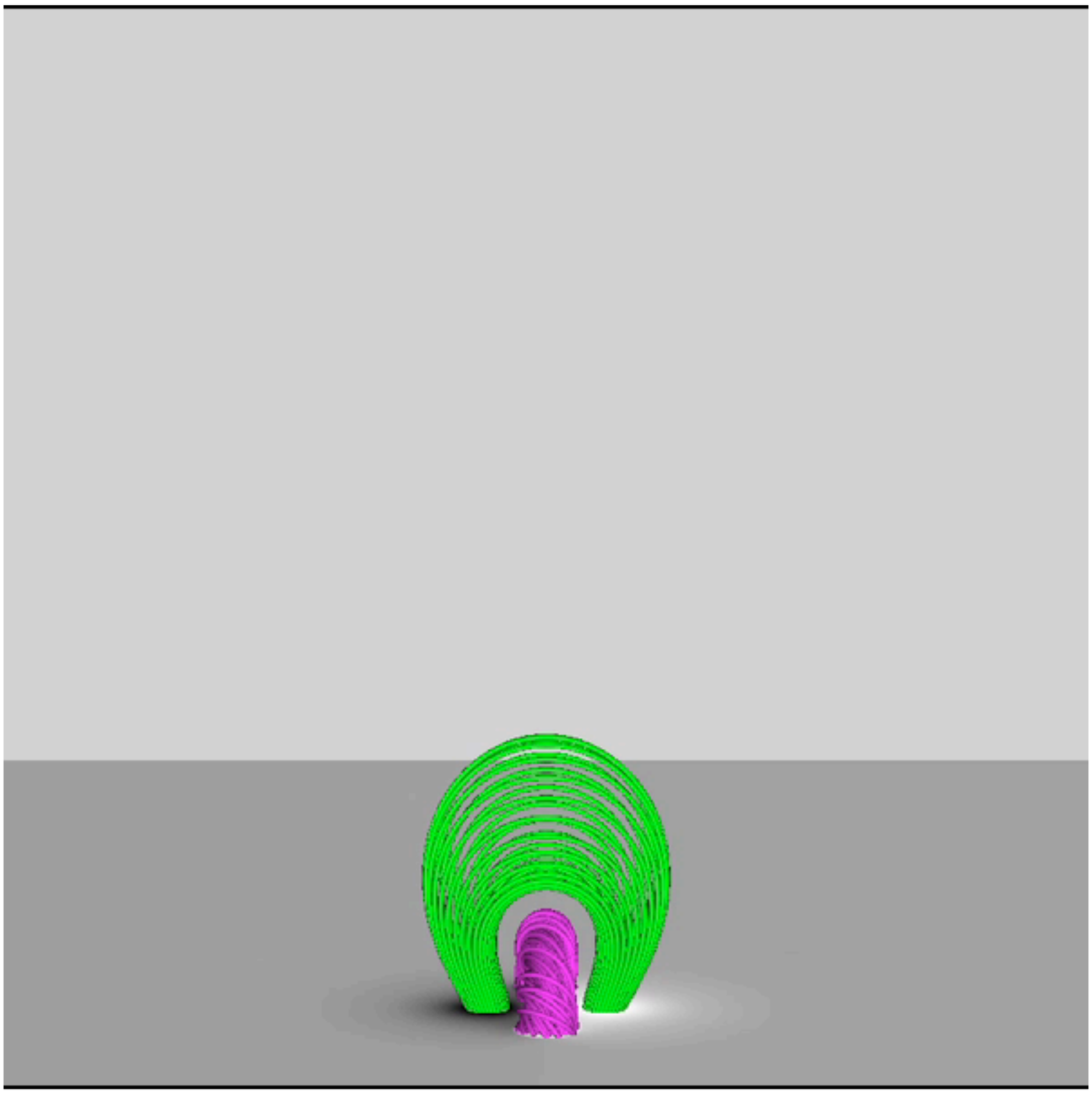


Lugaz et al. 2005 (numerical simulation)



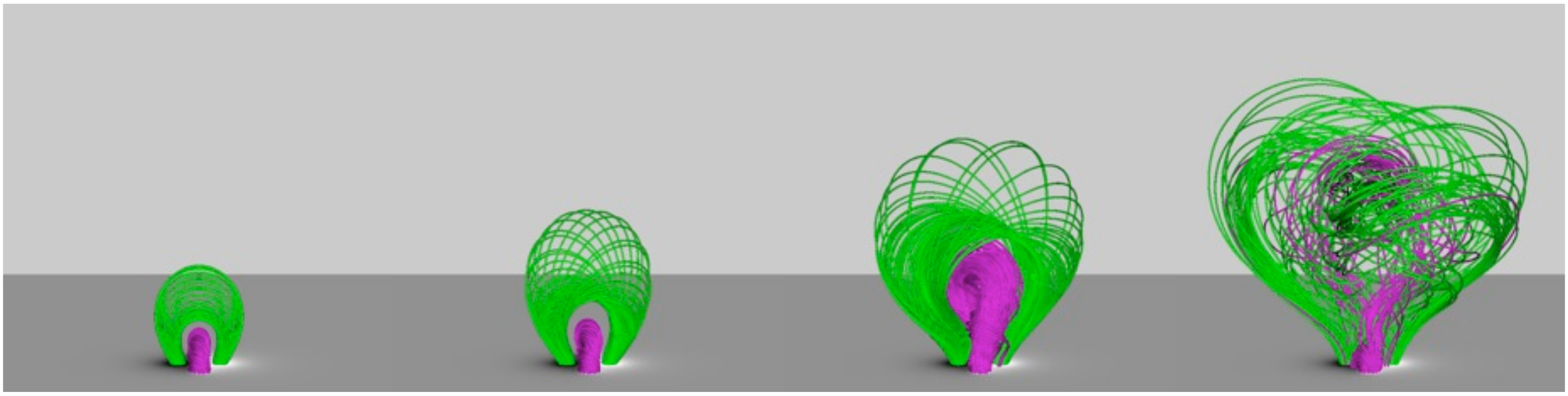
- CMEs occasionally collide before hitting the Earth *(e.g., Gopalswamy et al. 2001; Wang et al. 2003)*
- Interaction has been studied in numerical simulations *(e.g., Lugaz et al. 2005)*

Simulation: twisting up potential field above TD flux rope



Simple setup: ideal MHD equations & zero beta (only Lorentz-force)

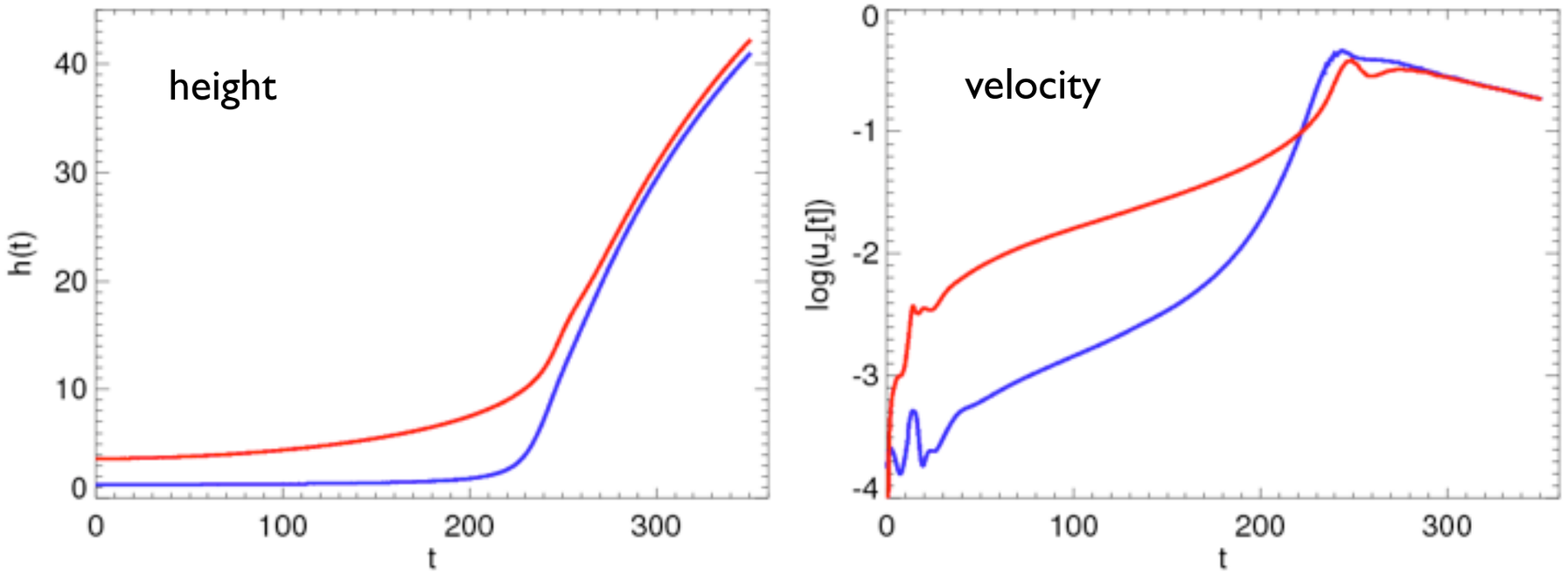
Simulation: twisting up potential field above TD flux rope



initial state | flux tube rises | TD rope follows | ropes collide & reconnect

- Photospheric vortex motions produce twisted flux tube (green) that expands and rises
  - → stabilizing tension above TD rope (magenta) successively weakened
  - → TD rope becomes (torus-) unstable and erupts
  - → flux ropes collide and reconnect
- Handedness of both flux tube and TD rope can be chosen freely (above: both left-handed)
- Moment of collision can be adjusted by changing stability properties of TD rope

Rise profile



red: twisted flux tube axis

blue: TD flux rope axis

- Plots show height of fluid elements initially located at apex of axes;
- TD rope rises faster than twisted flux tube → collision;
- Flux ropes continue eruption as joint structure;
- Reconnection and geometry of resulting structure (flux rope?) remain to be studied.

(3) Evolutionary/ Relaxation Processes

- For example, high-beta CMEs near the Sun may evolve into lower beta ejecta farther out in the solar wind;
- Low-beta ejecta, where field has relaxed to some kind of equilibrium more likely to be flux ropes;
- Does the rate of flux-rope CMEs to non-flux rope CMEs change in a systematic way with heliocentric distance?
- Other evolutionary possibilities?

(4) Existence of two or more intrinsic mechanisms

- All "self-consistent" CME models produce ejecta with flux ropes embedded;
- The only way to produce non-flux rope CMEs is from "*ad hoc*" boundary conditions, such as cone-model CMEs;
- Is there a physical process that could produce ejecta that doesn't have helical fields?;
- Could such a process be modeled self-consistently with MHD codes?

Summary

- MHD models, by design, necessarily produce CMEs with flux ropes embedded. But is this correct?
- Other ideas should have testable predictions:
  - If non-flux rope CMEs are complex CMEs (i.e., from CME-CME interactions), then they should: (1) be modulated by CME rates and non-flux rope CMEs; and (2) show a propensity to be wider.
  - Evolutionary ideas should show trends with heliocentric distance.
  - If another physical mechanism produces non-flux rope CMEs, what is it and what signatures does it predict?