



SIMULATIONS OF THE SOLAR ATMOSPHERE

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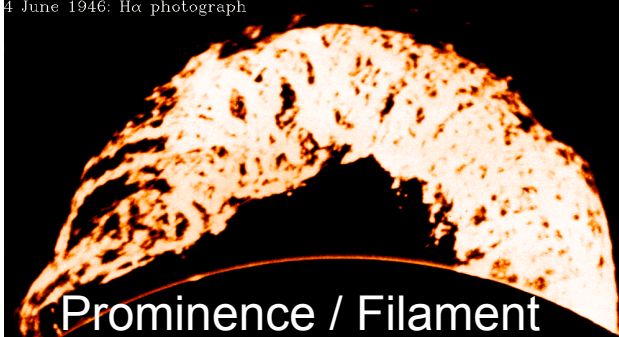
University of Oslo



A CODE COMPARISON EXERCISE

- Simulations of Coronal Mass Ejection (CME) initiation in solar corona
- Pencil Code Vs Magnetic Flux Emergence (MFE) code

4 June 1946: H α photograph

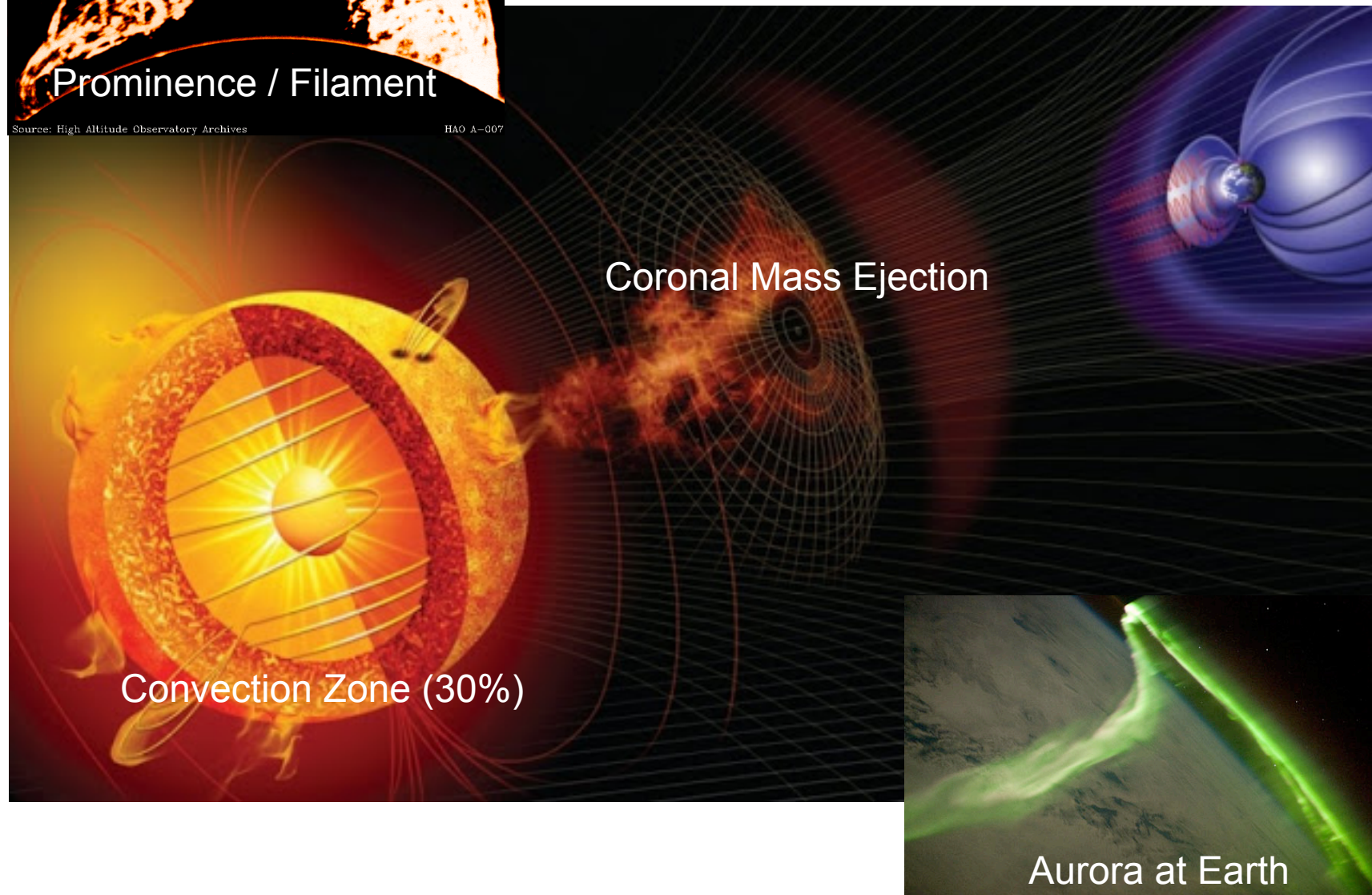


Prominence / Filament

Source: High Altitude Observatory Archives

HAO A-007

The Sun-Earth Connection



Coronal Mass Ejection

Convection Zone (30%)

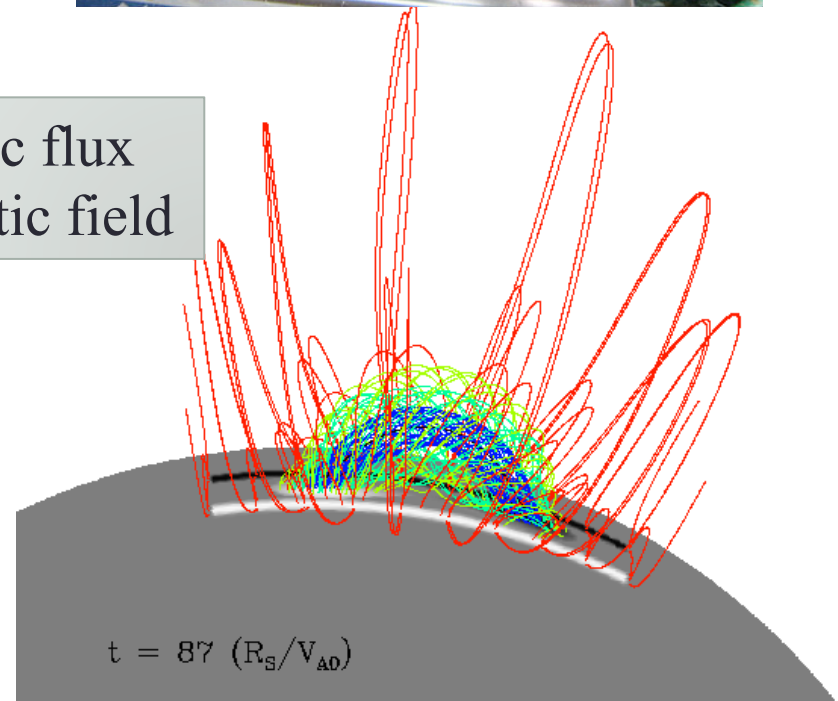
Aurora at Earth

Coronal Mass Ejections: storage and release of energy

CMEs erupt as a result of **Plasma Instabilities**, when magnetic field system cannot contain itself just like in a **pressure cooker**.

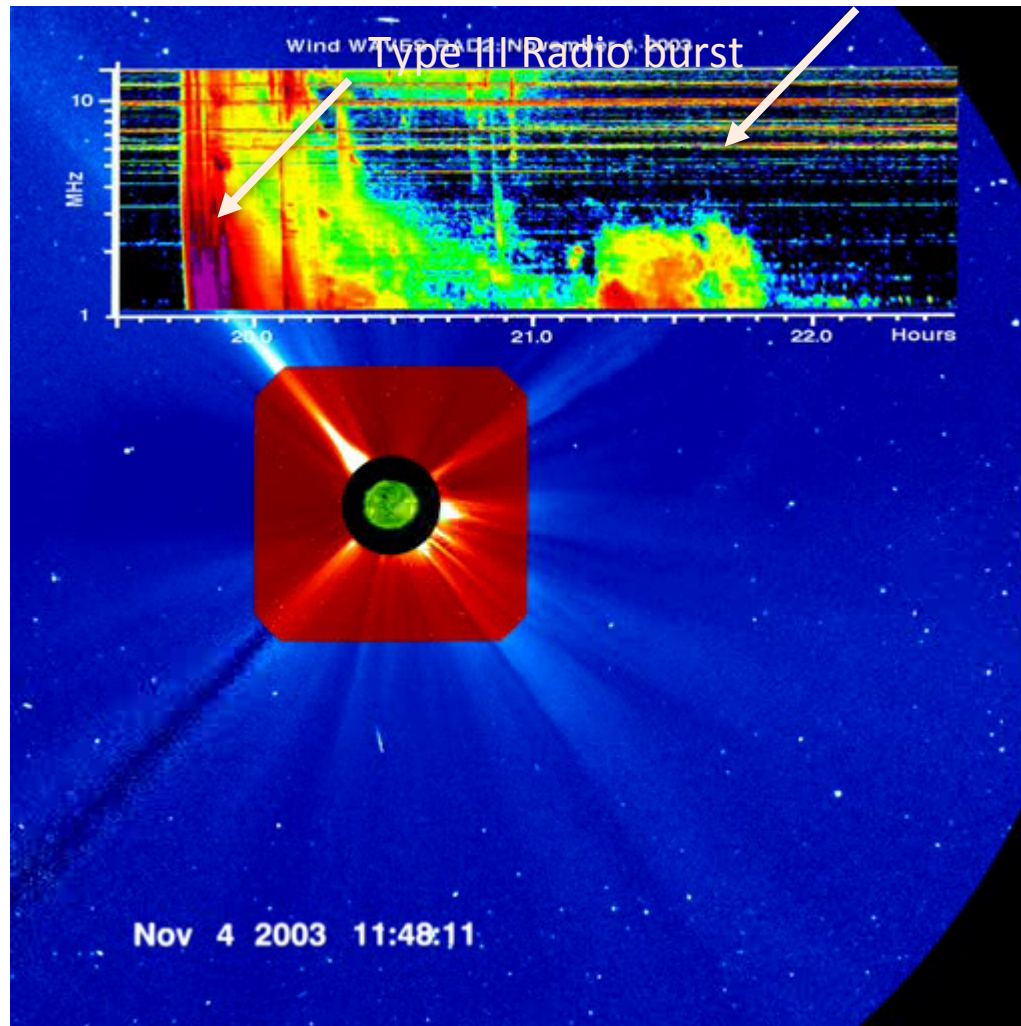


Heating = Emergence of twisted magnetic flux
The pressure valve = Pre existing magnetic field



Cannibalism from Homologous CME

Enhancement



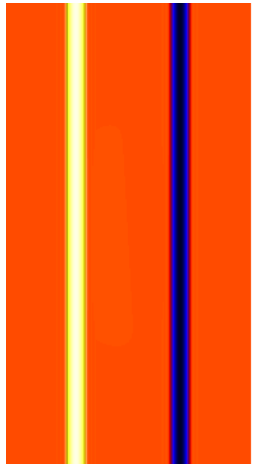
Halloween Storm of Nov, 2003:

Fastest CME (~ 2700 km/s)

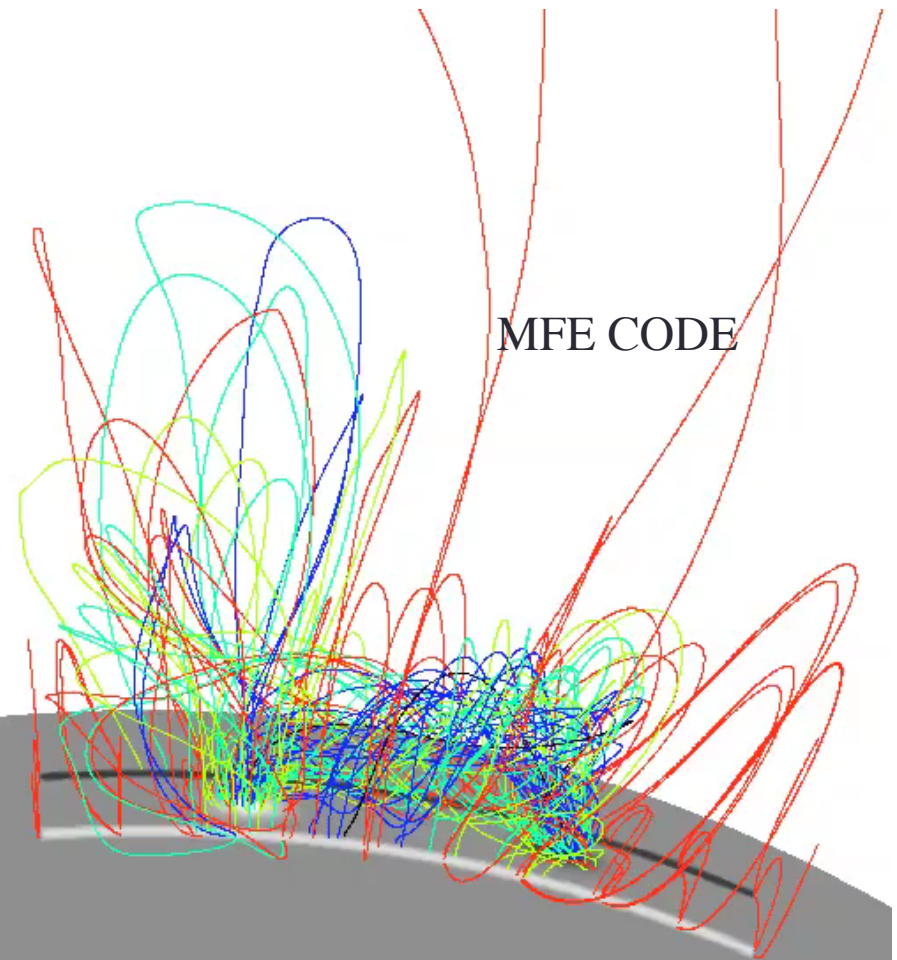
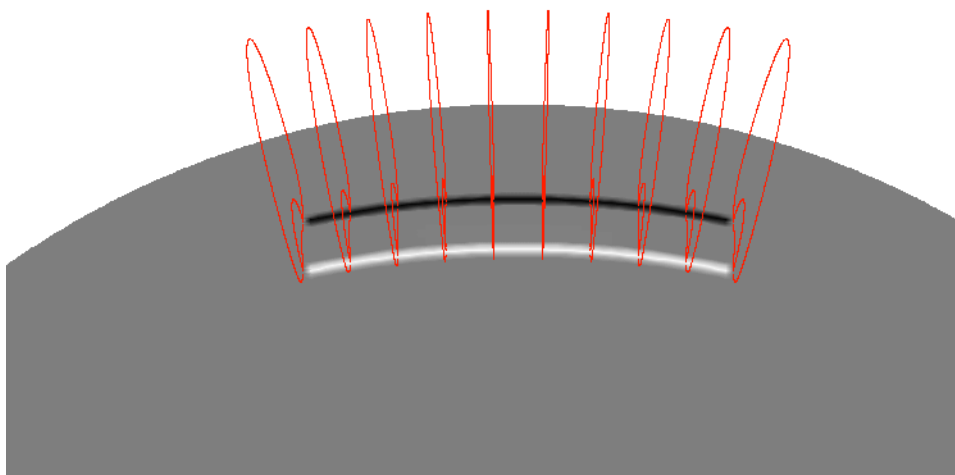
Radio detected by Wind, Ulysses and Cassini spacecrafts.

Fast CME > 400 km s $^{-1}$

CME initiation: Magnetic field line evolution



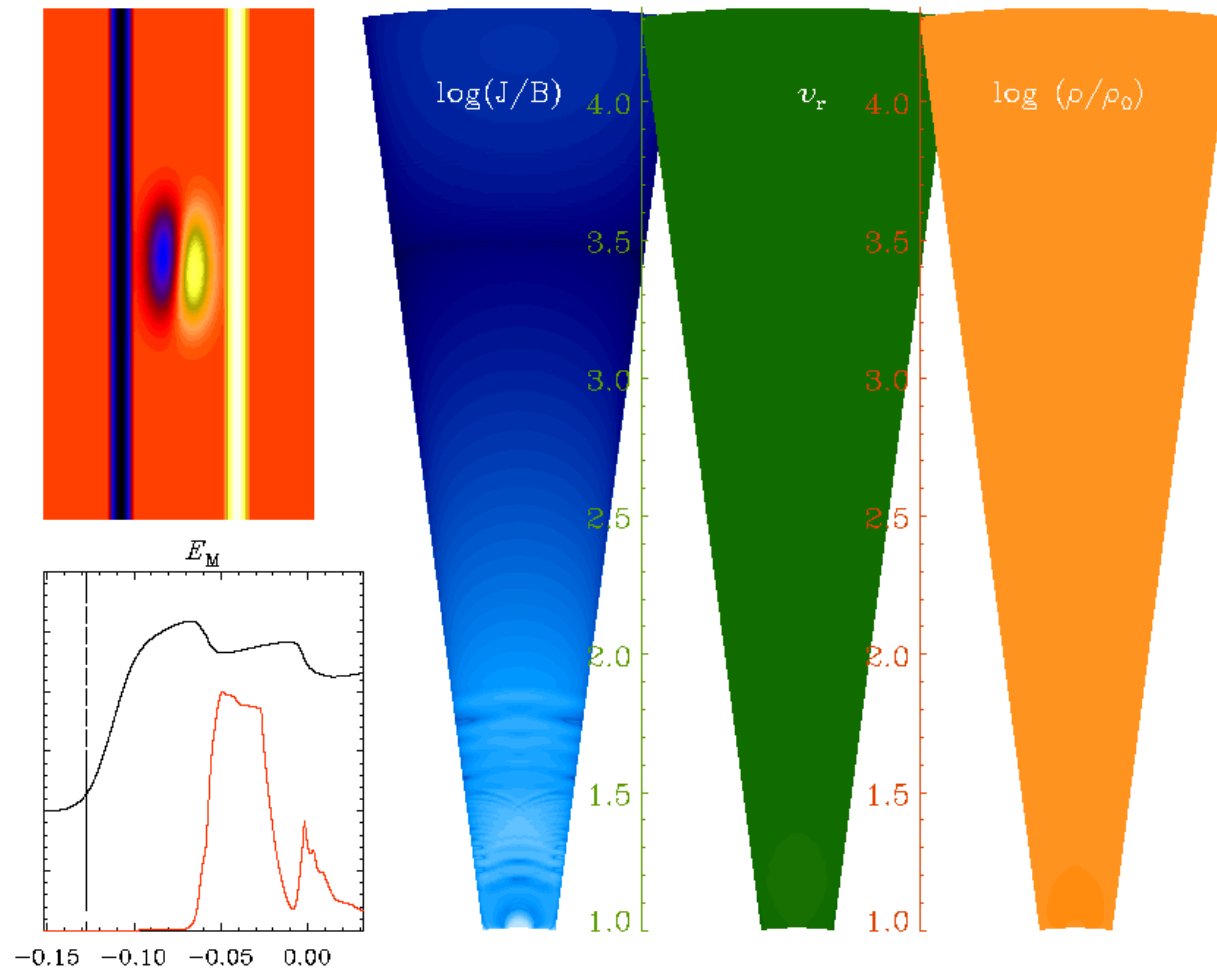
PENCIL CODE



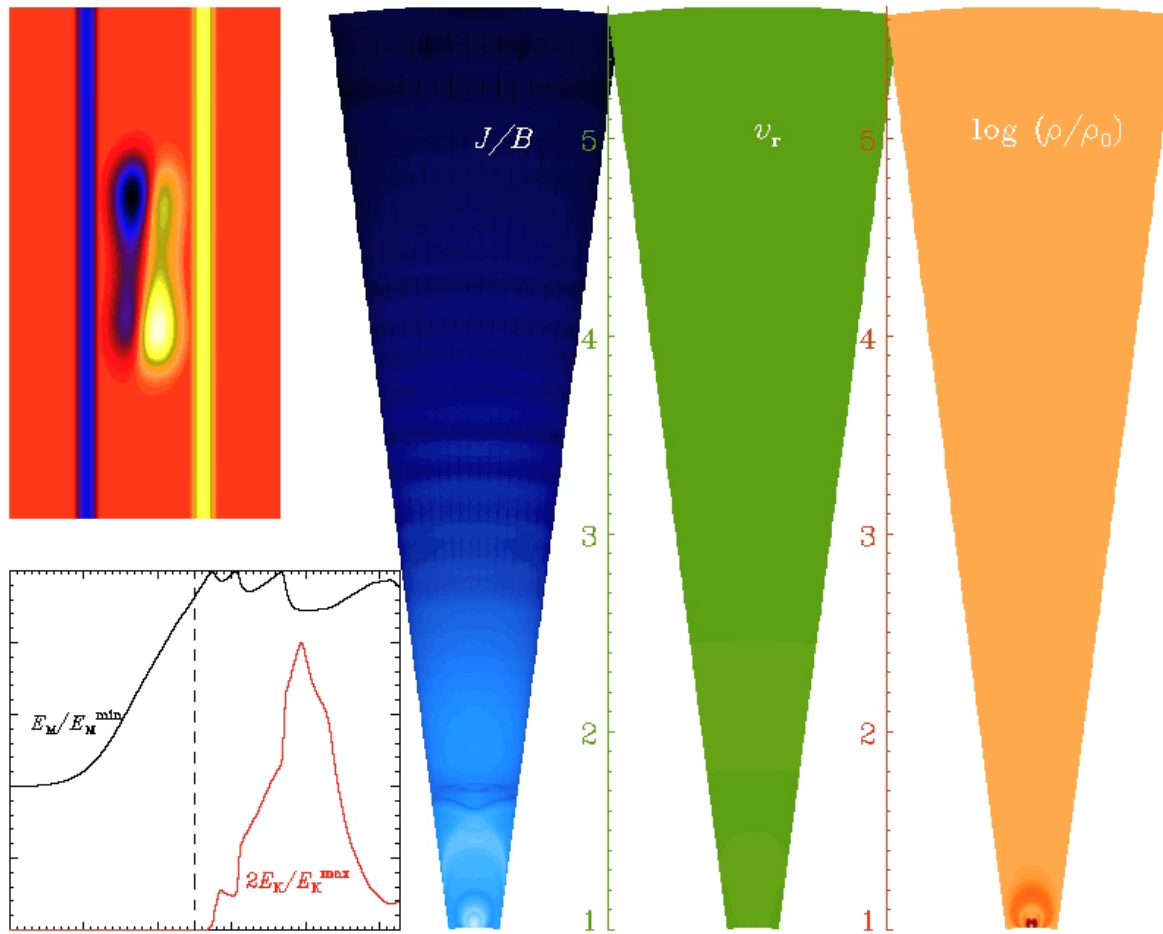
MFE CODE

t = 5.228 hour

PENCIL CODE: homologous CMEs



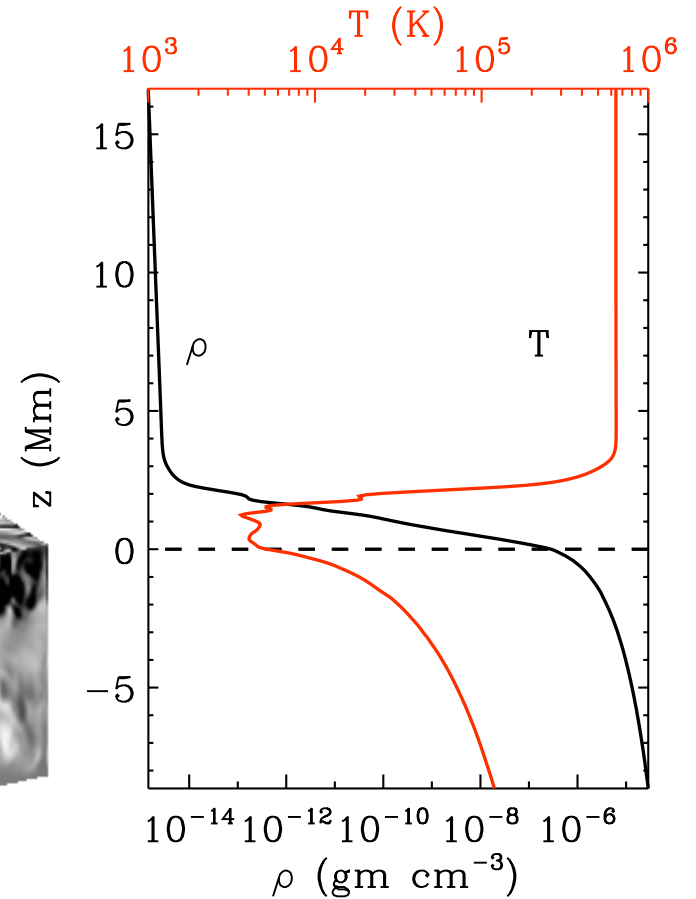
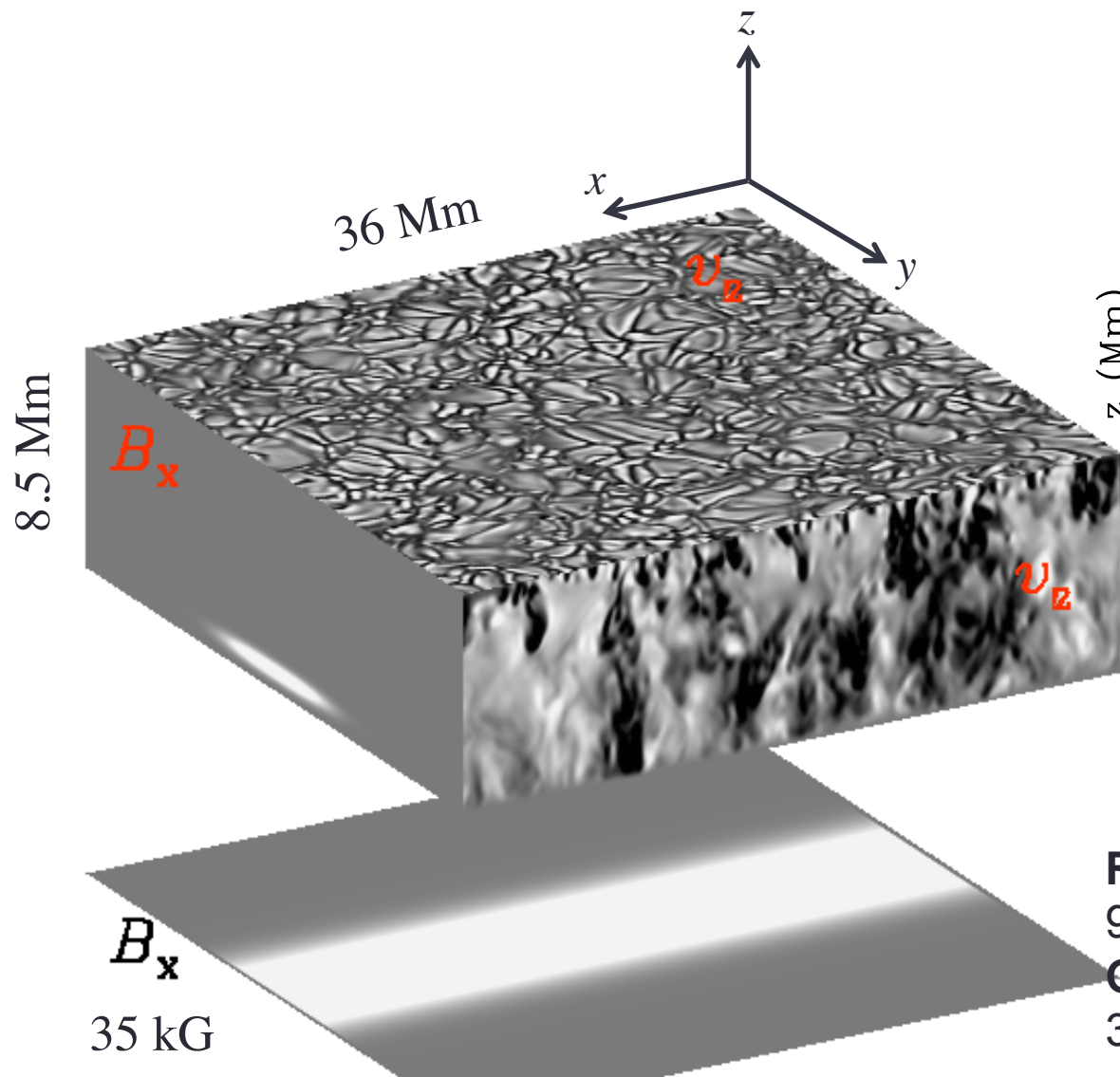
MFE CODE: homologous CMEs



Likely causes of differences

- Successive eruptions less energetic with PC where as successive eruptions more energetic with MFE
- Density diffusion possible culprit
- Incorporated slope limited density diffusion from Rempel et. al (2009) as a special module (works for spherical domains but commented now)
- Still density deficit in the flux rope is small with PC than with MFE
- The successive eruptions with PC lose steam and are confined eruptions rather than ejective
- Now, confined eruptions also exist as do ejective eruptions.

FLUX EMERGENCE SET UP



Resolution:

93.75 km x 93.75 km x 48.9 km

Grid points:

384 x 384 x 512

Set-up details

Fully compressible MHD equations
With heat conduction along field lines and radiative cooling

Grid size: $384 \times 384 \times 512$

Box size: $36\text{Mm} \times 36\text{ Mm} \times 25\text{ Mm}$

Resolution: $92\text{km} \times 92\text{km} \times 48\text{ km}$

8.5 Mm is the size of the convective layer.

The entropy, s driven to have coronal temperature of 10^6 K

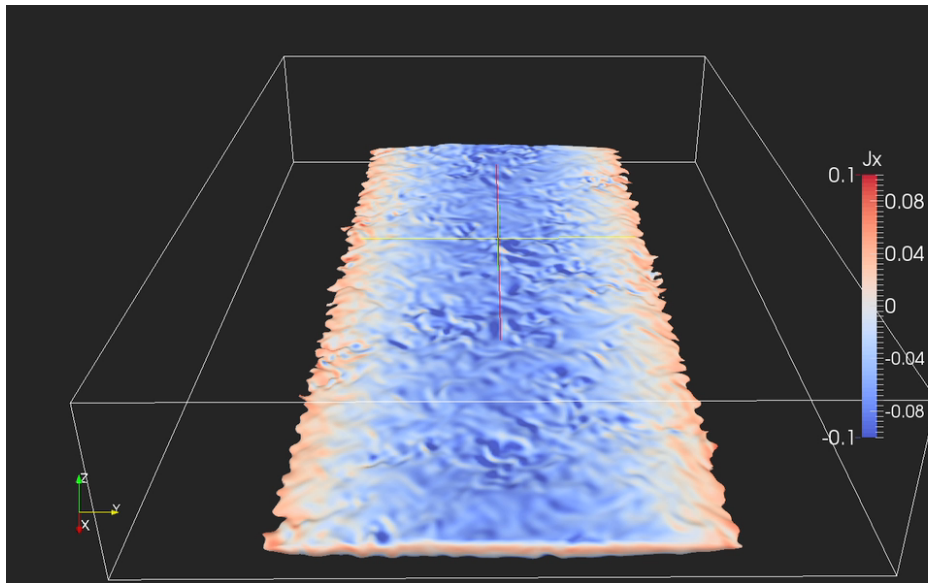
Start with a *convectively relaxed* solution in which we embed a Flux sheet 8 Mm below photosphere

$B_0 = 35\text{KG}$ in the sheet

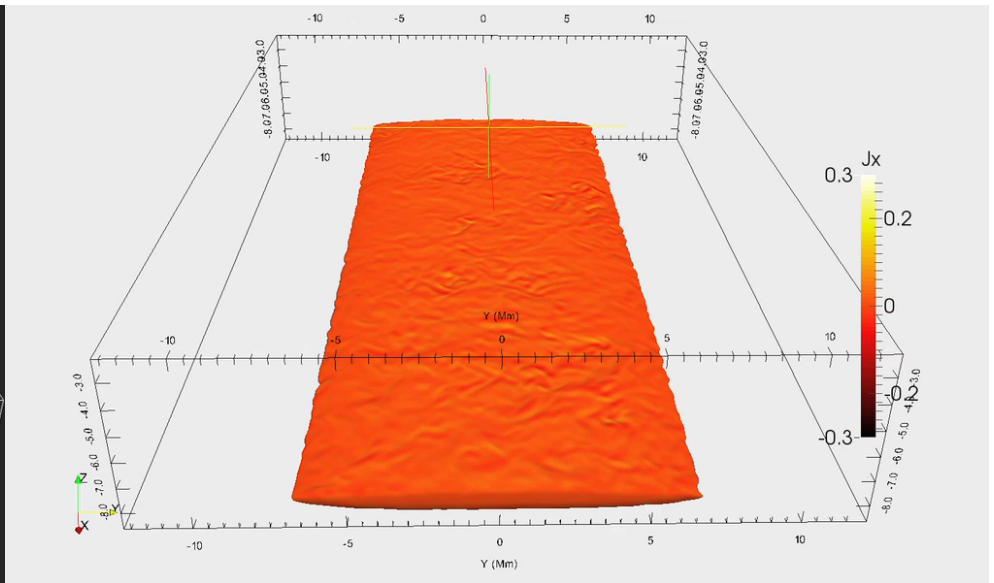
Weak ambient fields

* <http://pencil-code.googlecode.com>

Evolution of the initial (pressure balanced) magnetic sheet



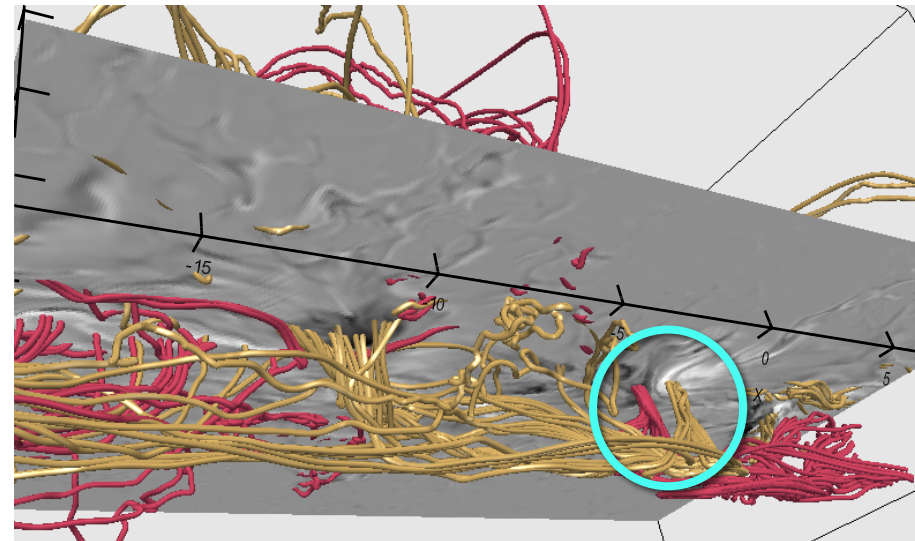
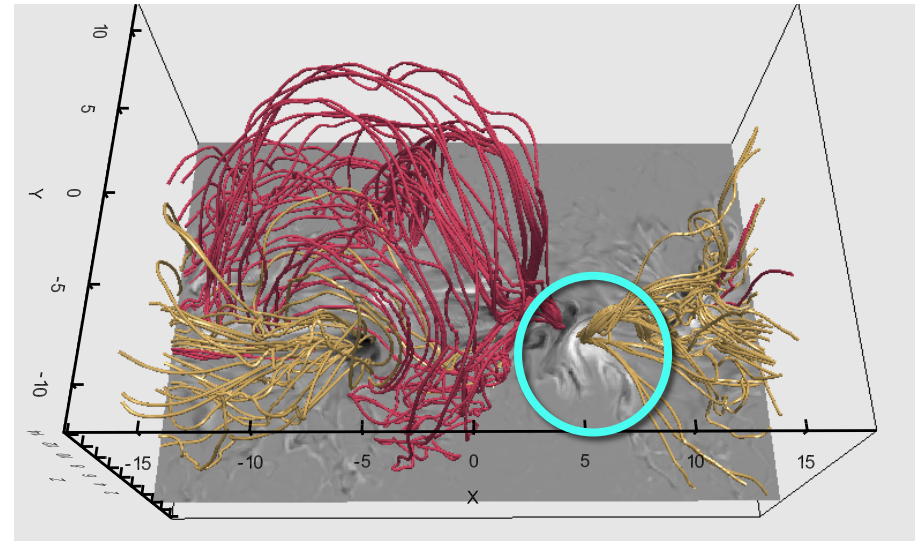
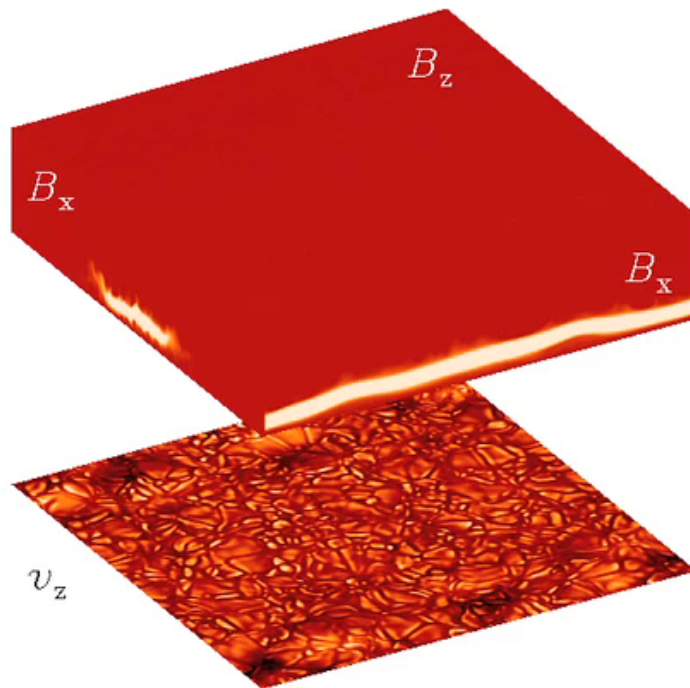
Large Initial J_x



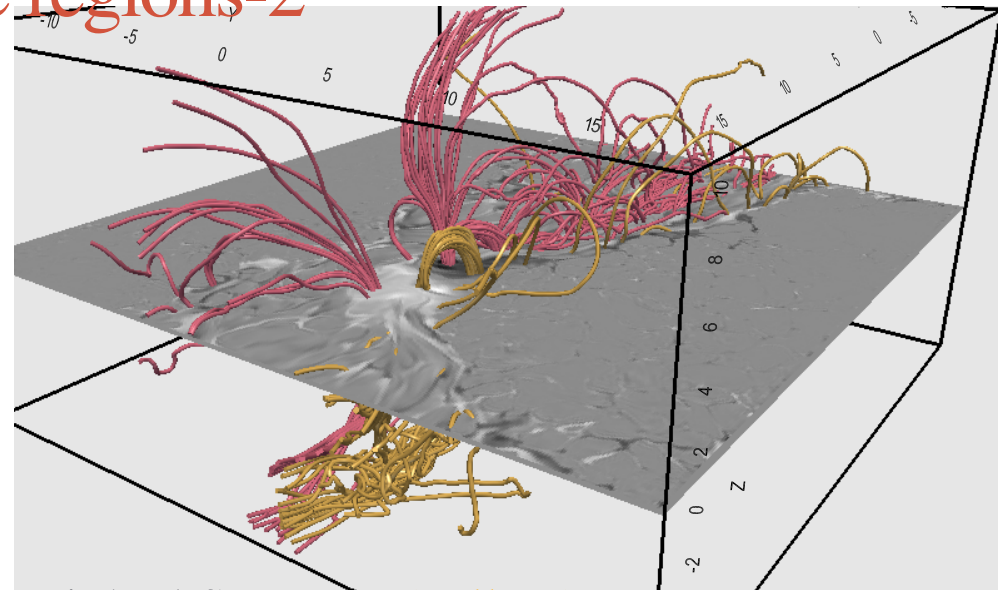
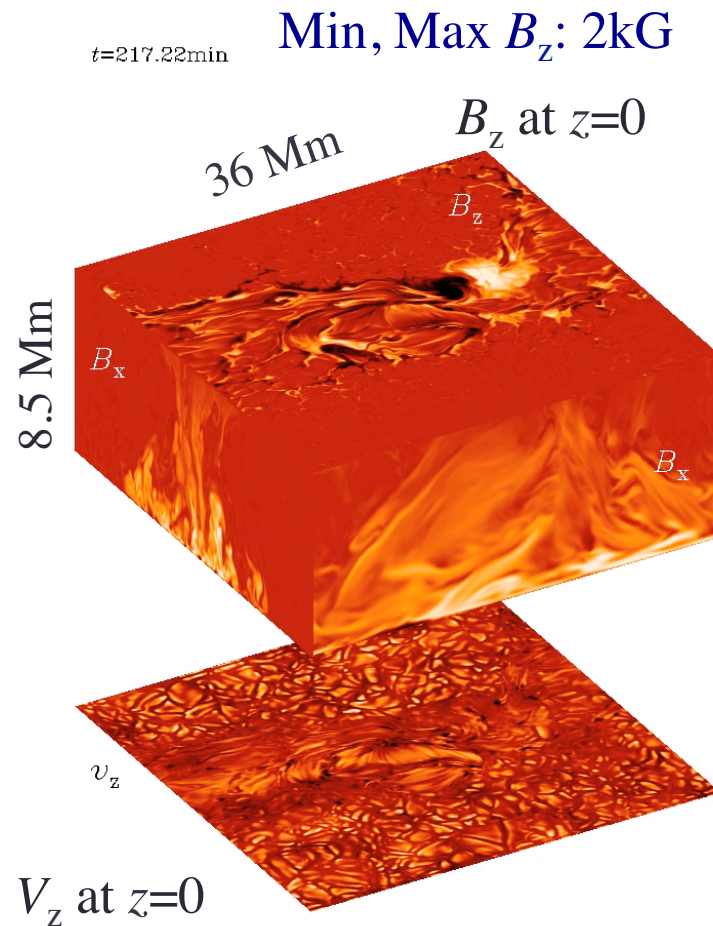
Small Initial J_x

Formation of complex active regions-1

$t = 8.33\text{min}$

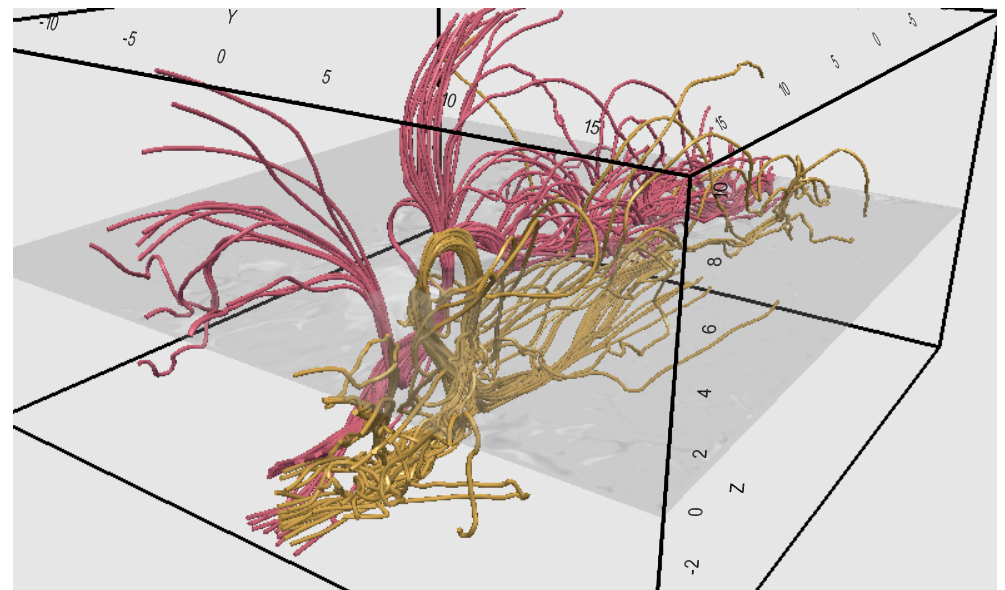


Formation of complex active regions-2

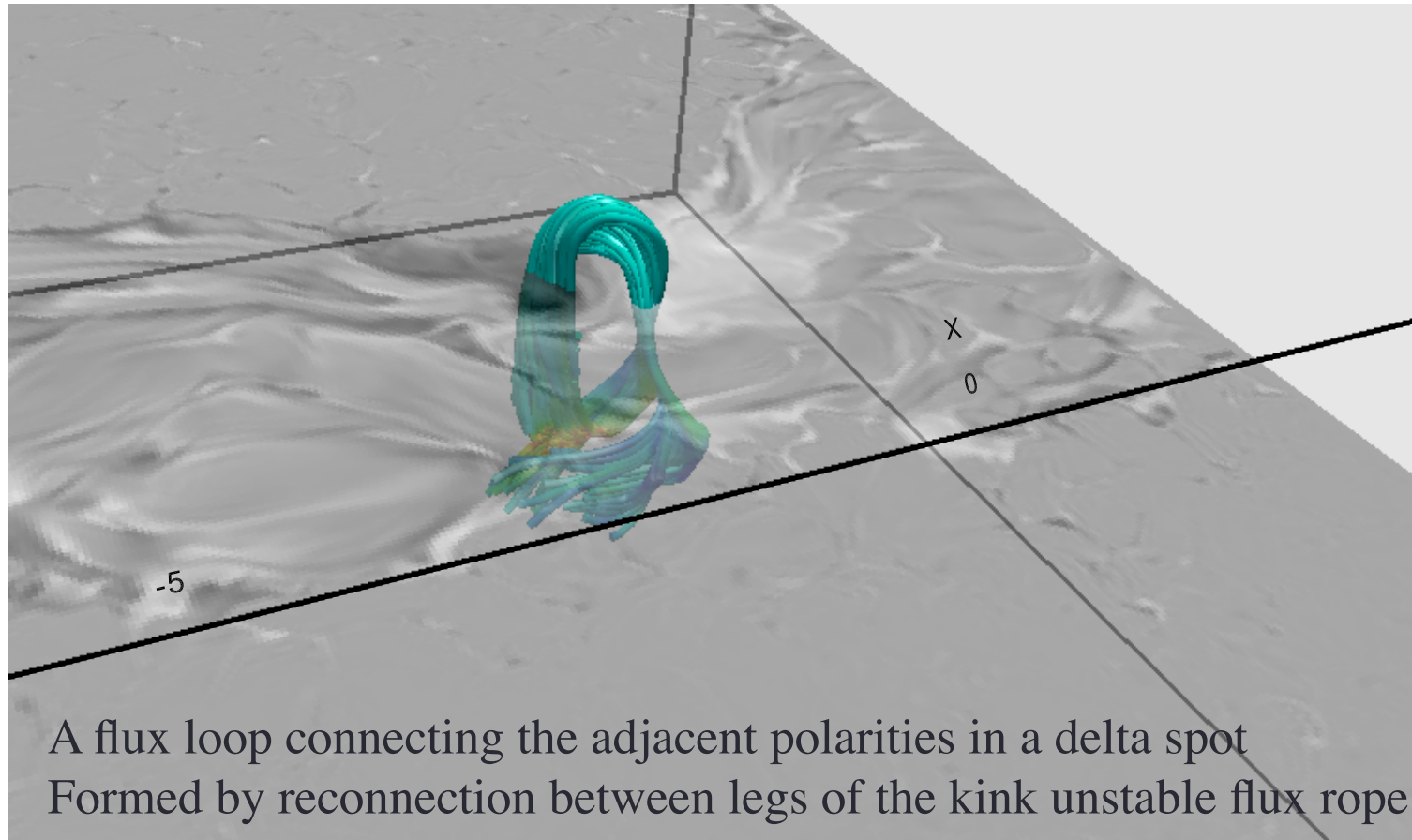


Kinked flux rope (yellow)

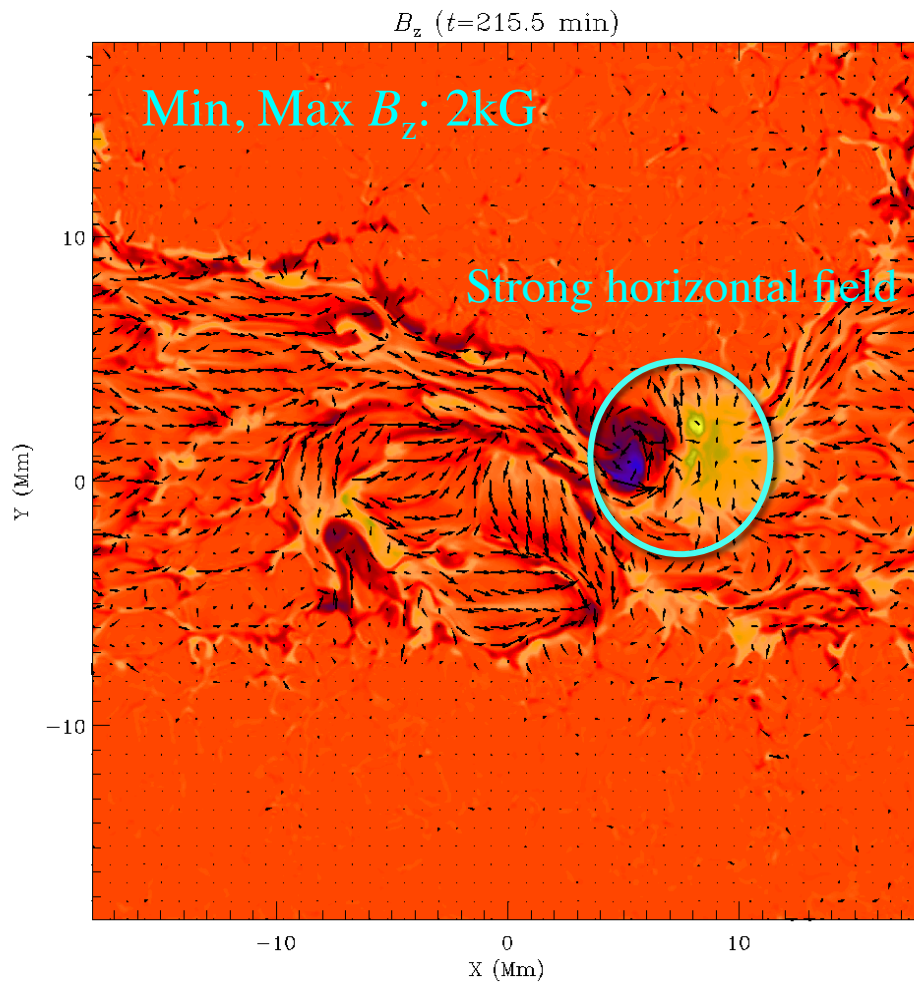
Legs of same flux rope colliding (magenta)



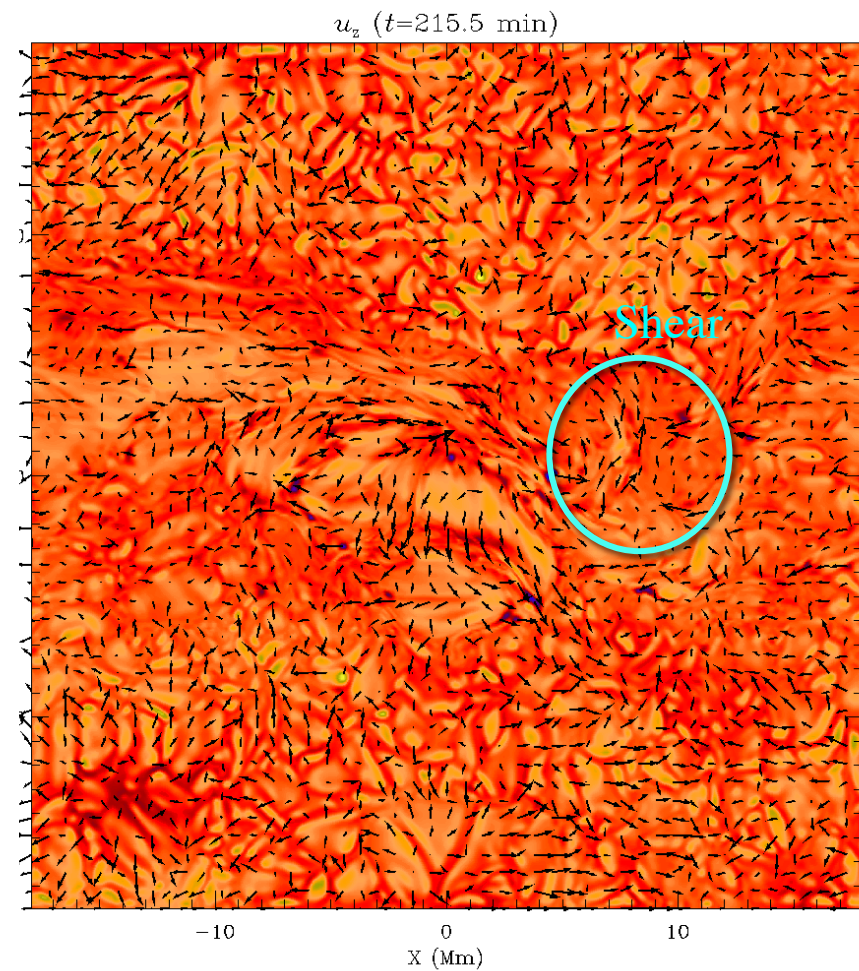
Field lines connecting the delta spot



Photospheric magnetic field and flows



B_z (color) and B_x, B_y (arrows) at $z=0$



u_z (color) and u_x, u_y (arrows) at $z=0$

Present road blocks and future plans: Help! Anyone?

- Processors writing to single file in allprocs. IO=io_collect, io_mpi2? Error in MPI_ALLReduce when trying these options in Makefile.local
- Radiation (LTE) and realistic equation of state. Anyone currently working with these modules? Sample (solar-atmosphere-magnetic) doesn't work for me.