Mini-Eruptions driven by magnetic flux emergence in a coronal hole environment

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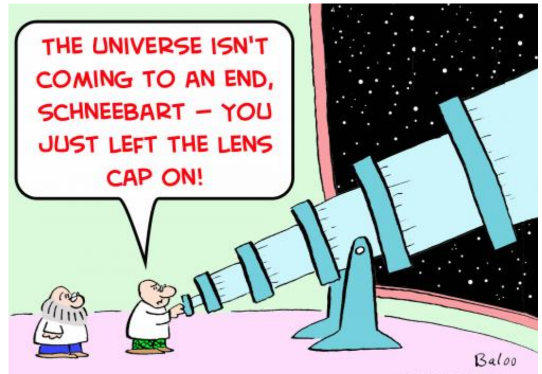
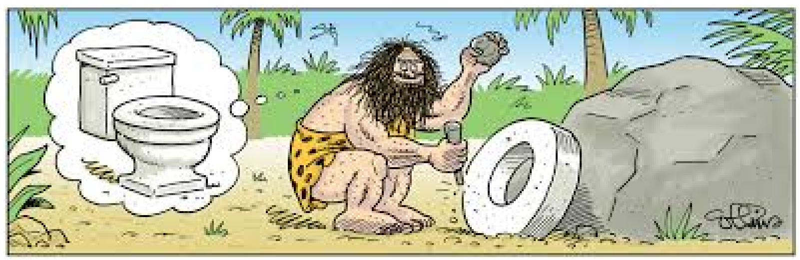
Content

- Observations



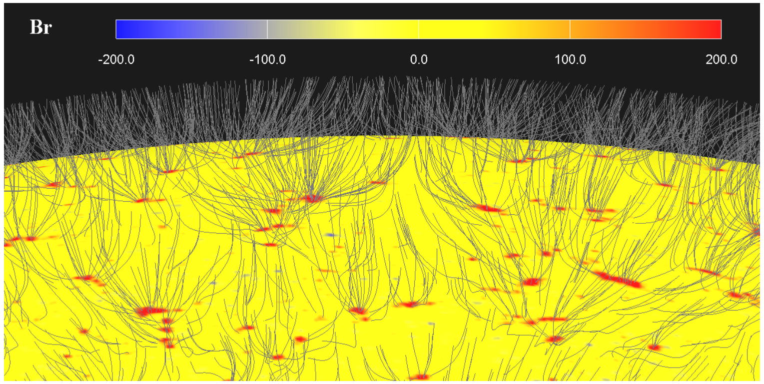
- Model

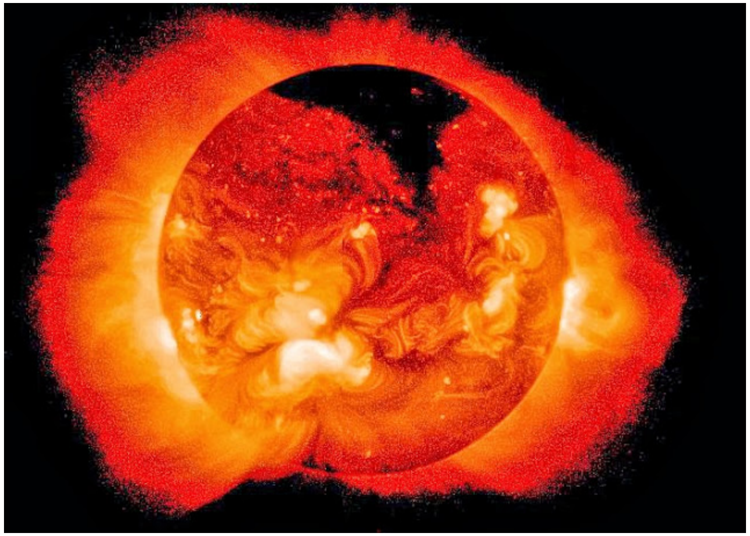


- Results

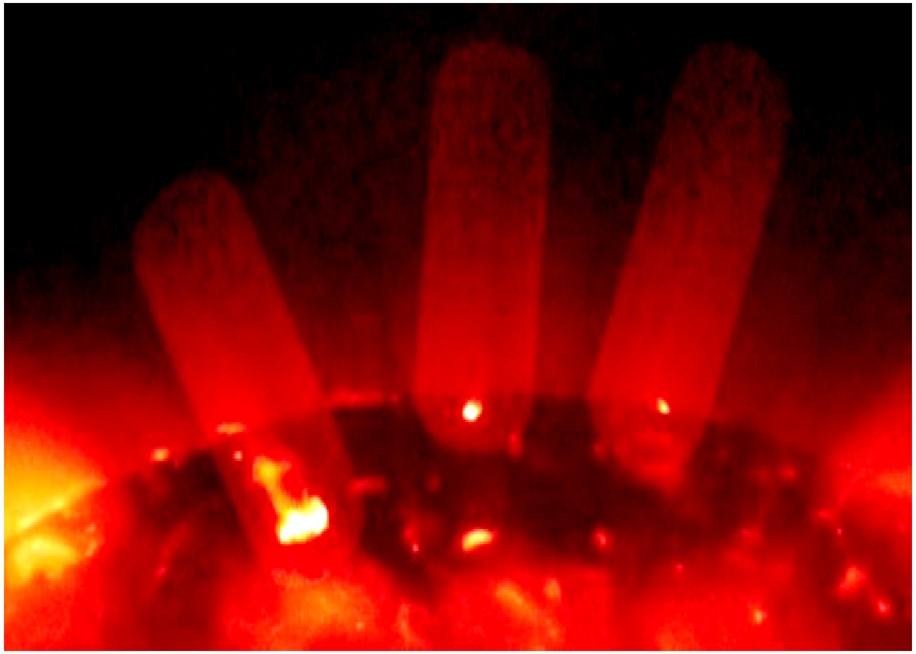
Observations

Model extrapolation





Hinode obs of CH, January 10, 2007



Standart jet – Eiffel-tower jet

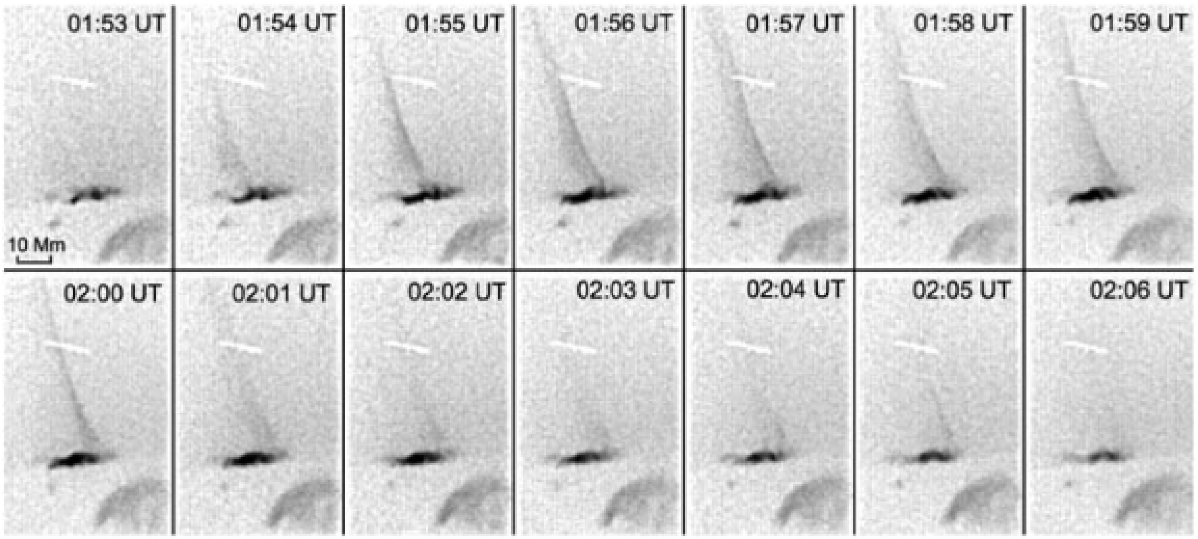


Figure 2 Negative X-ray images showing the small jet evolution between 01:53 UT and 02:06 UT on 23 November 2006. This jet is visible in Figure 1, labeled A. The white segment at the top of each image is produced by a speck of dust in front of the CCD detector.

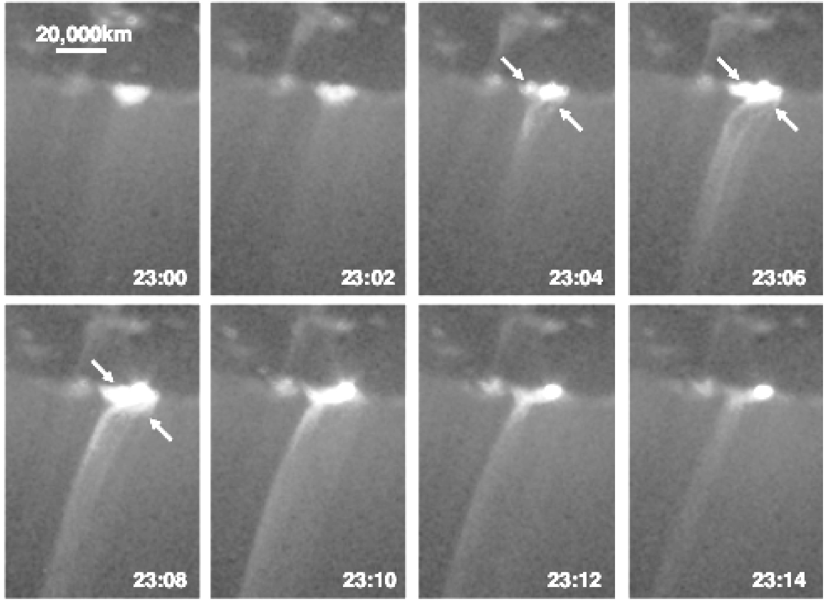
Moore et al. 2010

- Order 13 minutes duration
- Bright point, Jet axis, position change of jet with time
- Flow speed of few 100 km/s
- Temp 3-8 Mill K
- Densities 7 10^8 - 4 10^9 par/cm^3

Savcheva et al. 2007, Cirtain et al. 2007, ...

”Blowout” jets

- Typically follows an Eiffel-tower jet period
- Mini-CME eruption of the lower regions
- Hot and cold plasma observed simultaneous



Moore et al. 2010

Mini-eruptions found to occur several times from the same region.

Madjarska 2011 found 4 eruptions within 30 minutes

Innes et al. 2010 – *Mini CME*
Morre et al. 2010 – *jets*
….

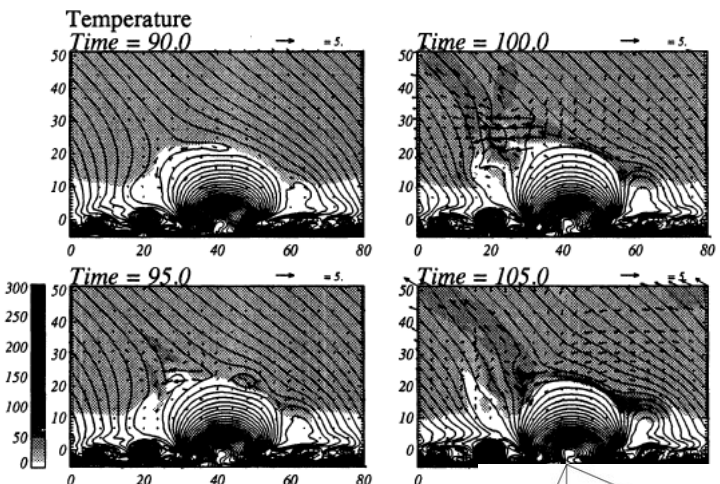
Models:
Pariat et al. 2009, 10,
Moreno-Insertis et al. 2010, 13
Archontis et al. 2013
Fang et al. 2015
Jui Lee et al. 2015
...

Basic for modelling

- Eruptions are found in many situations in the solar magnetic field
  - *Flares, CME, Jets* of various sizes,duration,..
- Typically assumed the magnetic field is responsible for the event
  - *Zero beta* approximation
- Instabilities in flux tubes/loops may be
  - *Kink instability* – high twist
  - *Ballooning instability* – sufficient gradient in the magnetic pressure
  - *Shear instability* – large shear distances

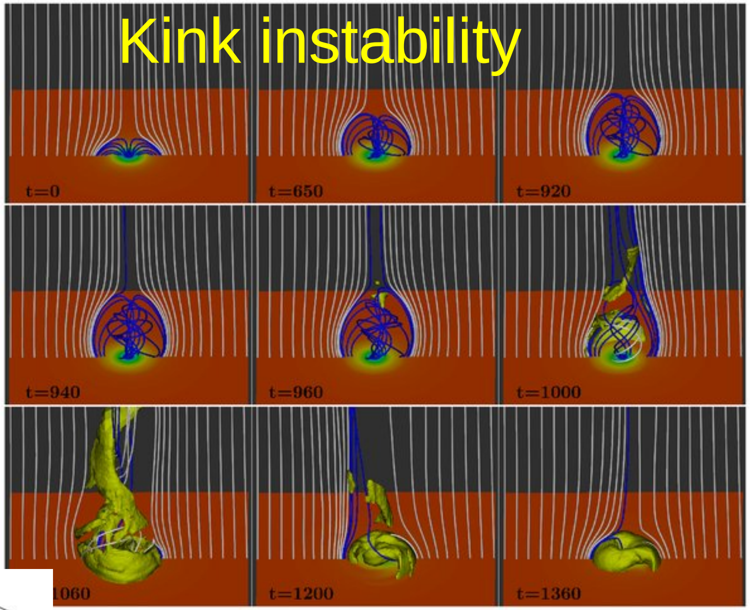
- **What happens in a no-zero beta?**

Characteristics for models



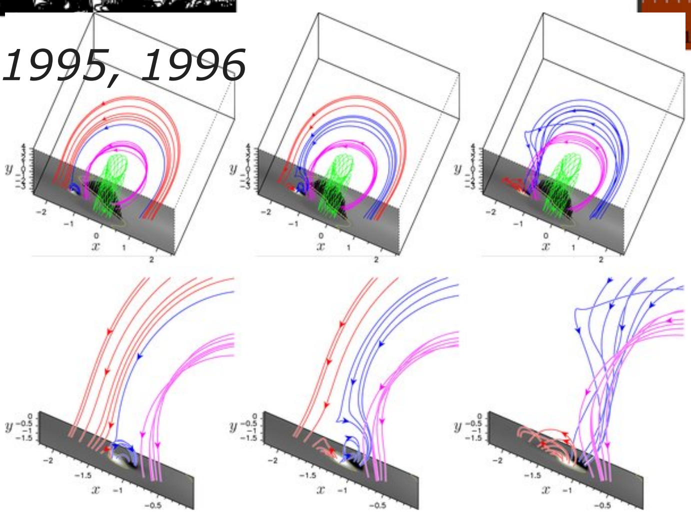
Yokoyama & Shibata 1995, 1996

Emergence models



Pariat et al. 2009, 2010

Boundary driving

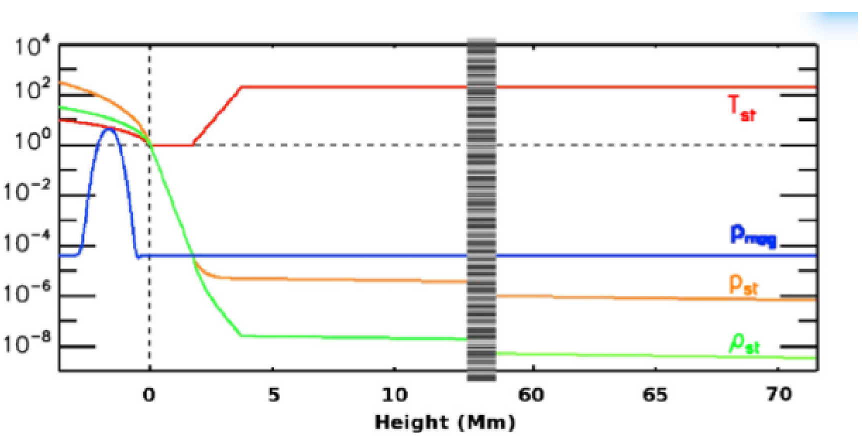


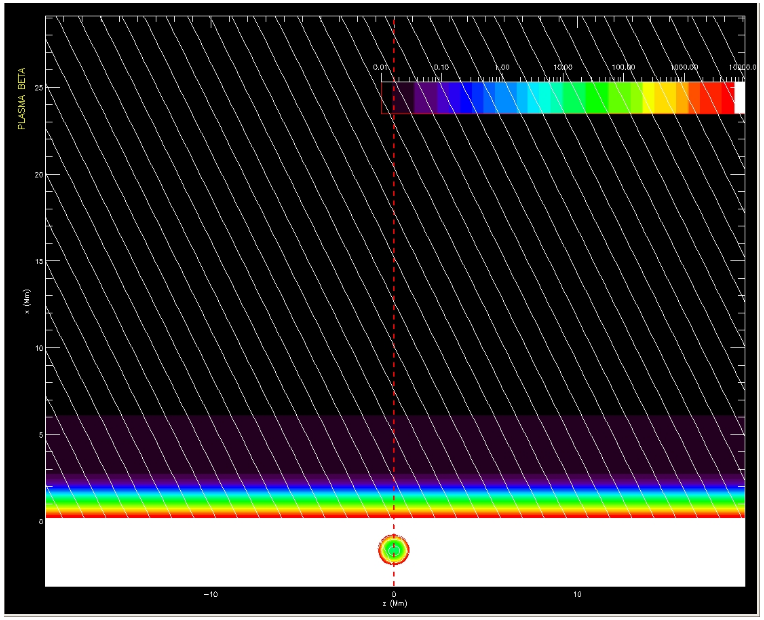
Torok et al. 2009

”Standard” 3D cartoon emergence model

- Twisted flux loop inside the convection zone
- Tilted uniform background magnetic field
- Stratified hydrostatic model atmosphere

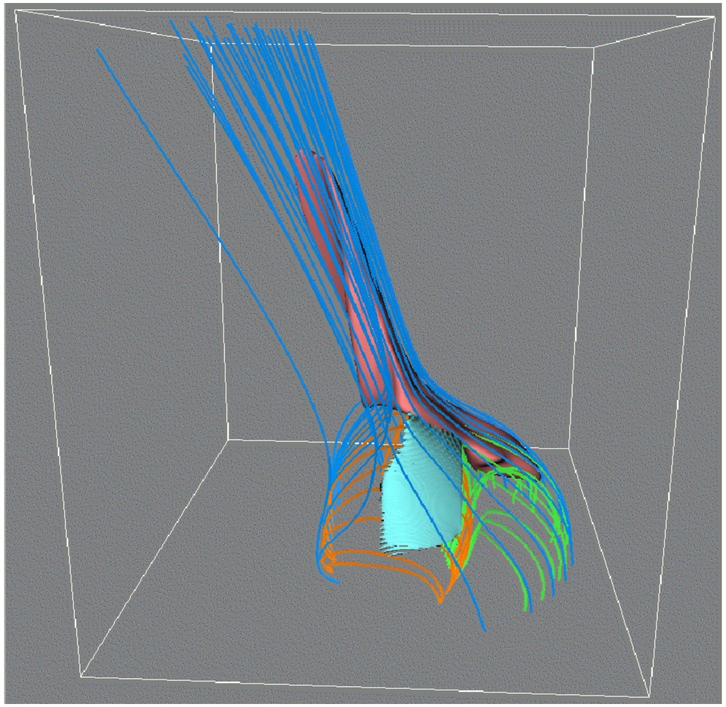
Shibata et al. , Fan et al. Manchester et al., Archontis et al. ,Magara et al., Moreno-Insertis et al., ...





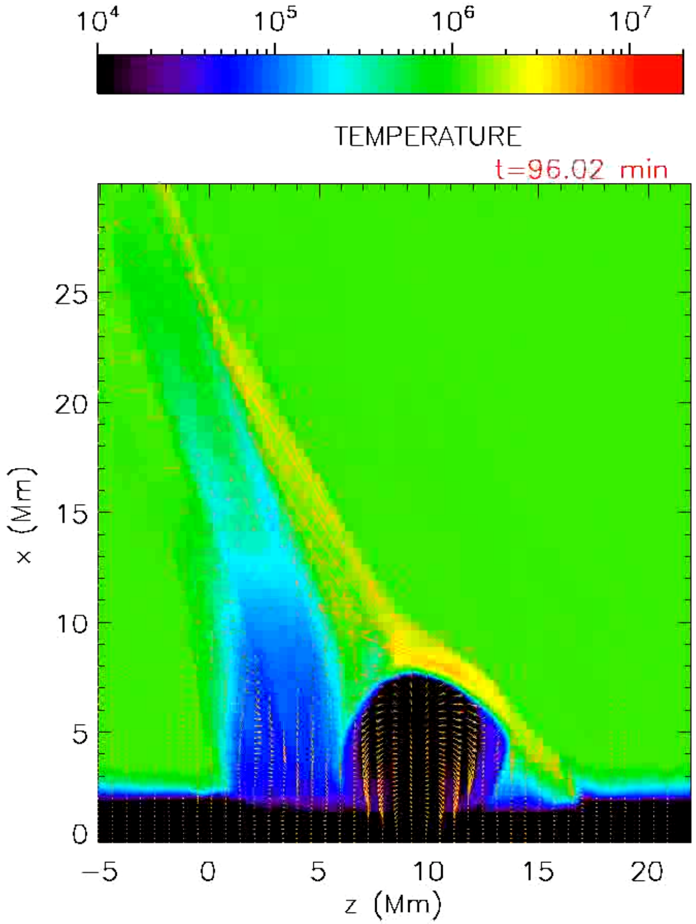
Jet models 2D slice time view

Relevant fraction of the domain



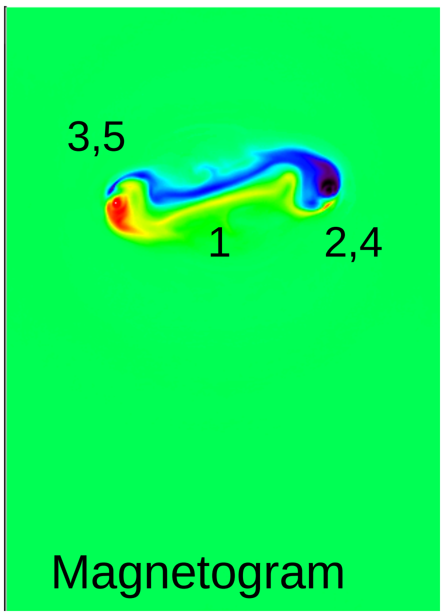
Second eruption around t=180

Later ones are not as clearly observed in this 2D plane

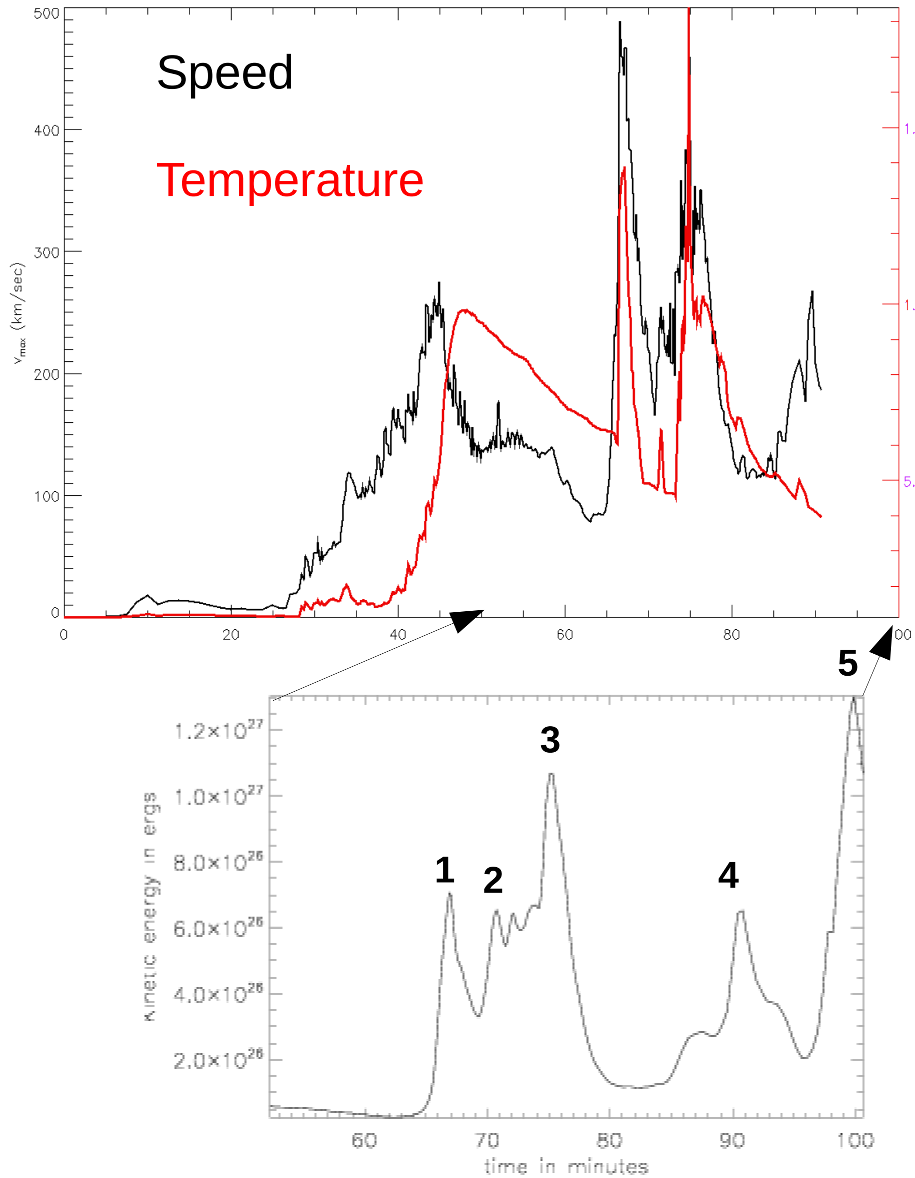


Moreno−Insertis & Galsgaard 2013

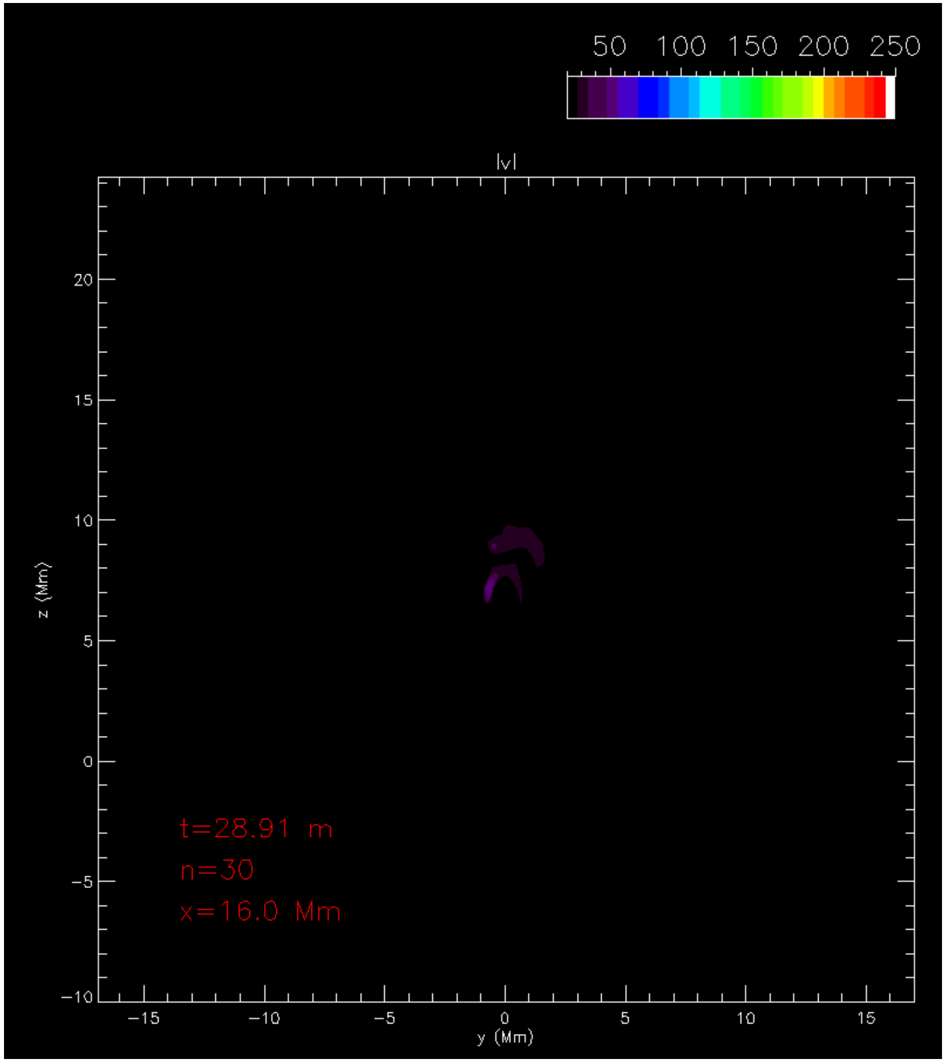
5 Mini-CME eruptions in 35 minutes

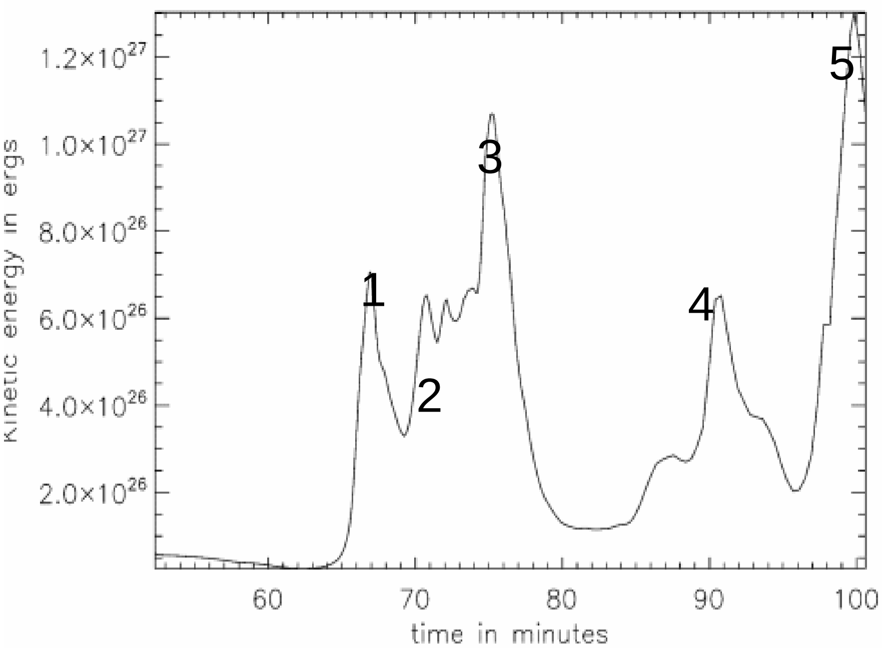


Location of Mini-ERs



Velocity profile and kinetic energy

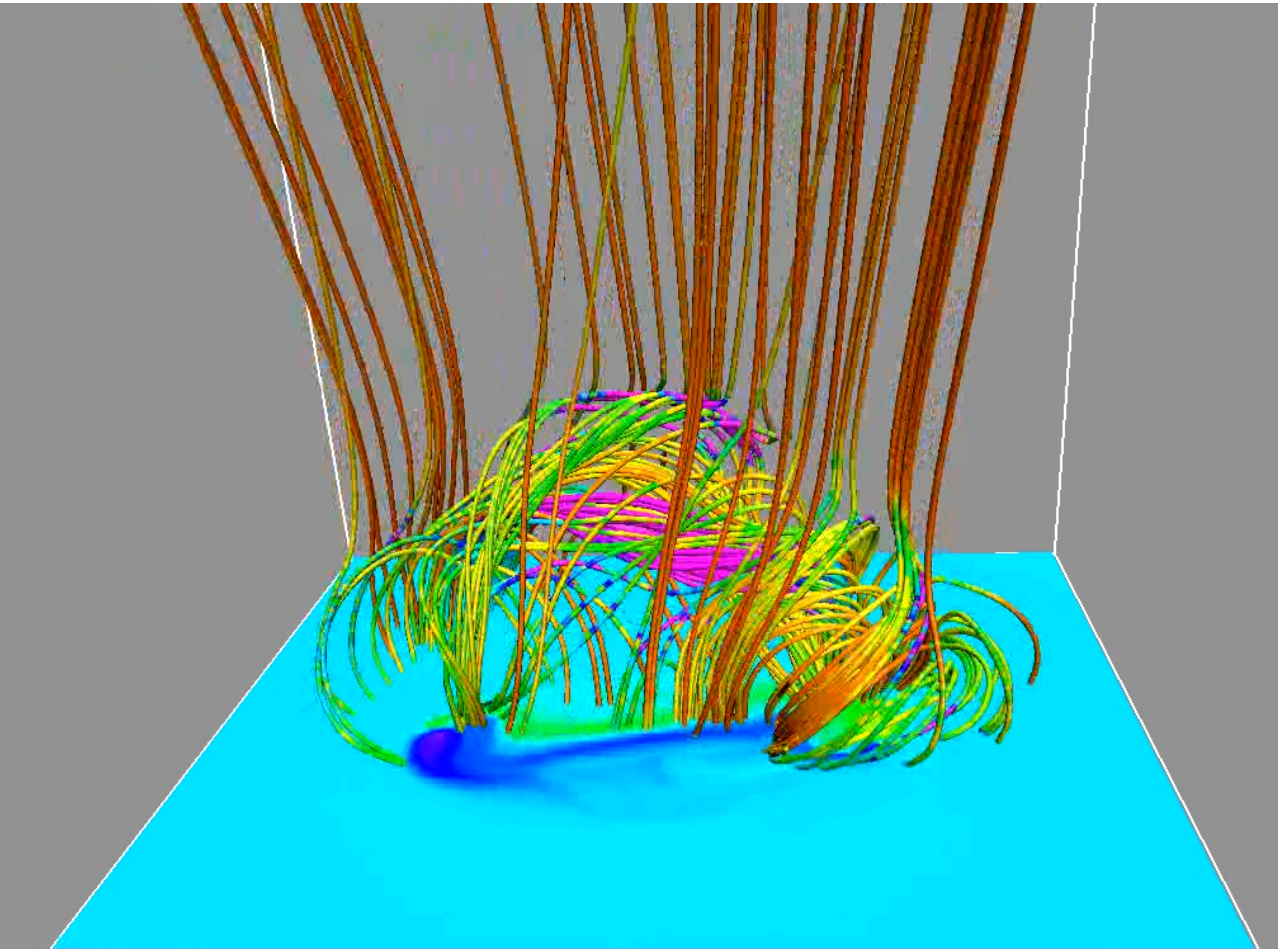




Left: the velocity magnitude at a fixed height. Eruptions are clearly seen.

Right: the amount of kinetic energy in a small volume as a function of time

Example of the field line evolution



Field lines traced from fixed positions in space

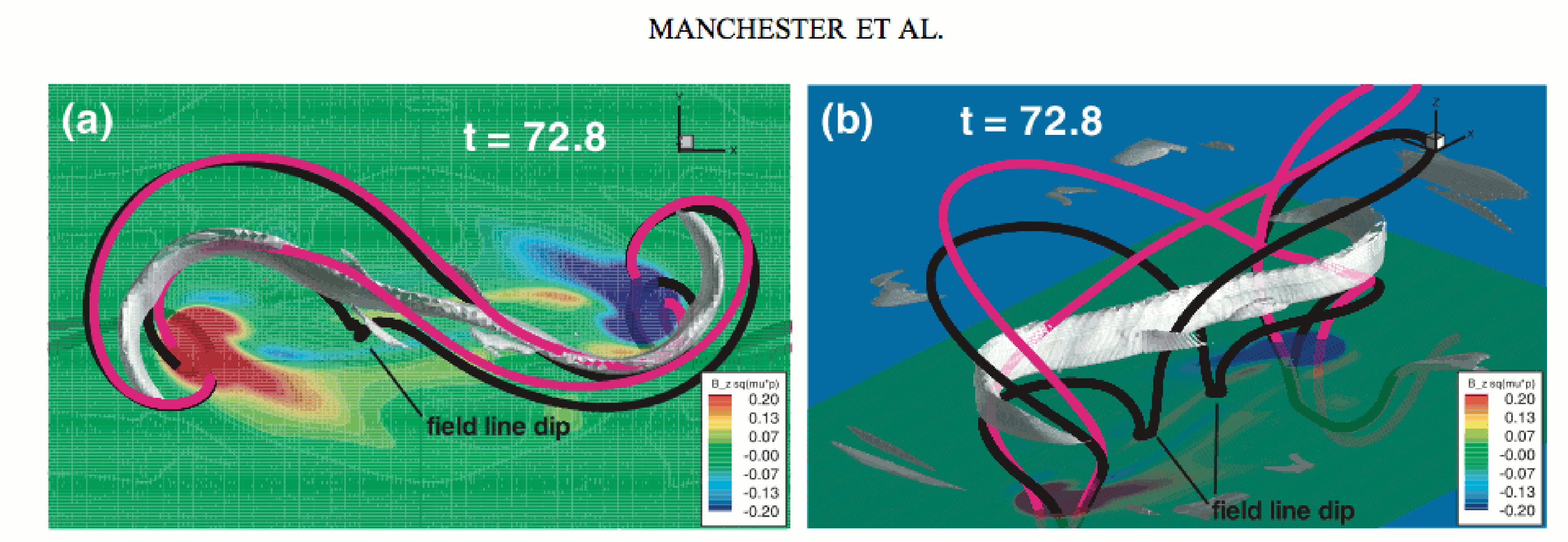
Colour coded field lines: upflow speeds

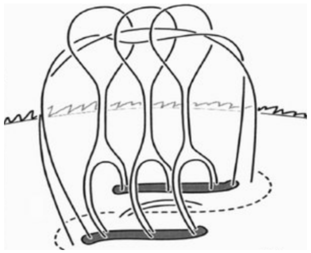
0 50

Magnetogram at the base

5 eruptions

Eruption 1: Tether cutting of emerging loop system

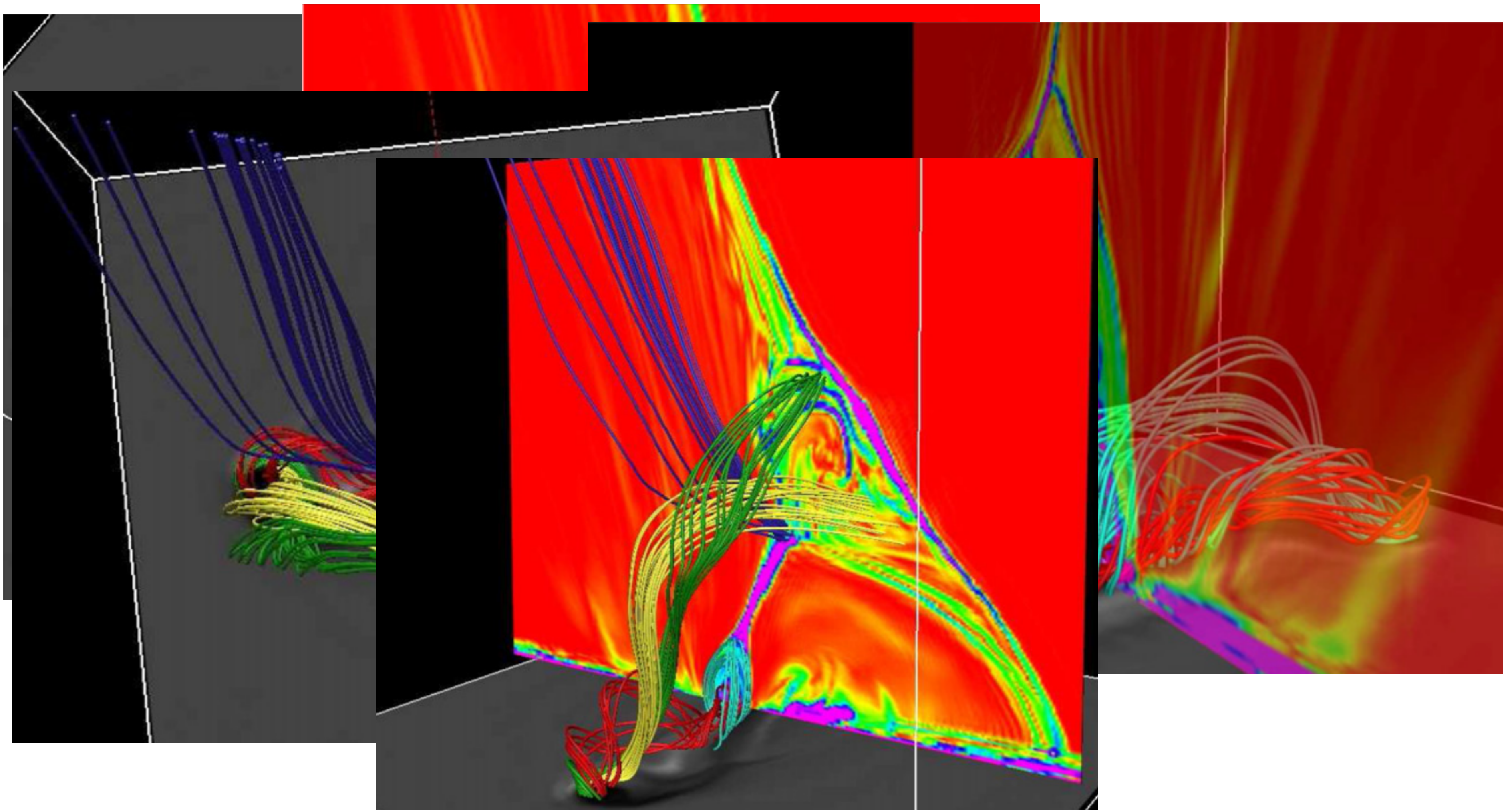




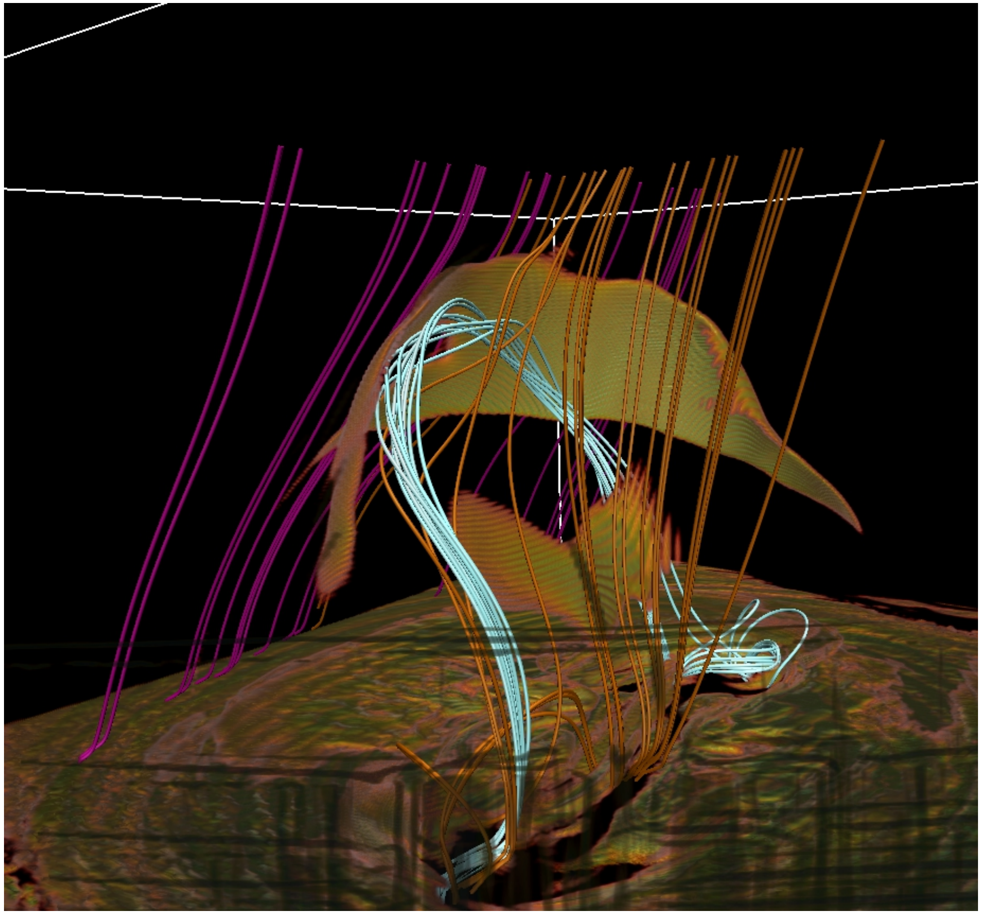
Yan Xu et al 2010

Creates a twisted flux rope above the rec site
Near potential loop system below the rec site
Increases the twist of the remaining loop system

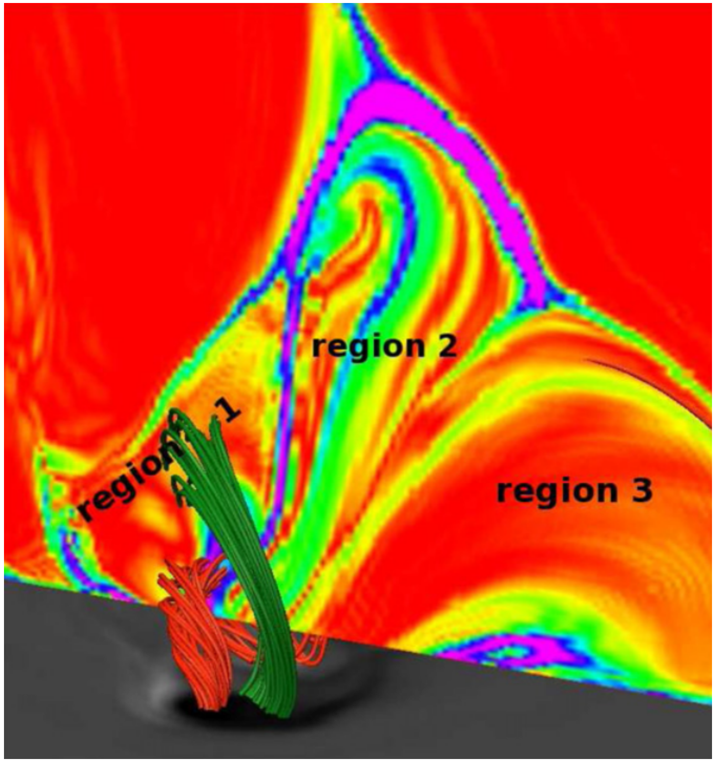
Eruption 1: Field line structures - Domains



Destruction of the rising flux robe



Mini CME Eruption 2.: "Domain decomposition"



Located above the negative polarity flux concentration

Loop system partly grown by eruption 1

Region 1: origin of 2nd eruption
Region 2: perturbed flux after 1st eruption
Region 3: hot loop system after the steady state jet phase

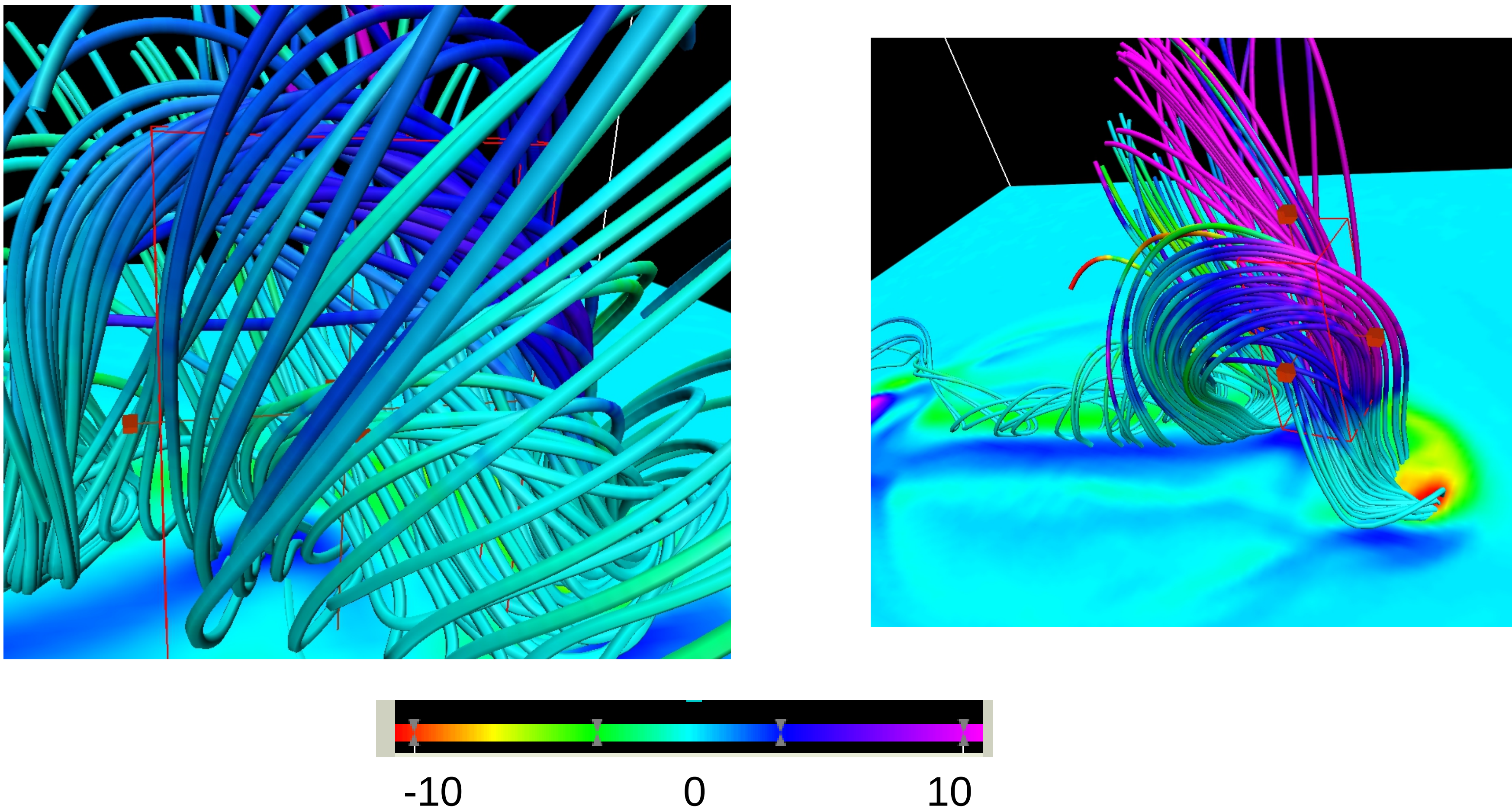
|J|/|B| surface

Flux into the area from above
Twisted rope low down (red)

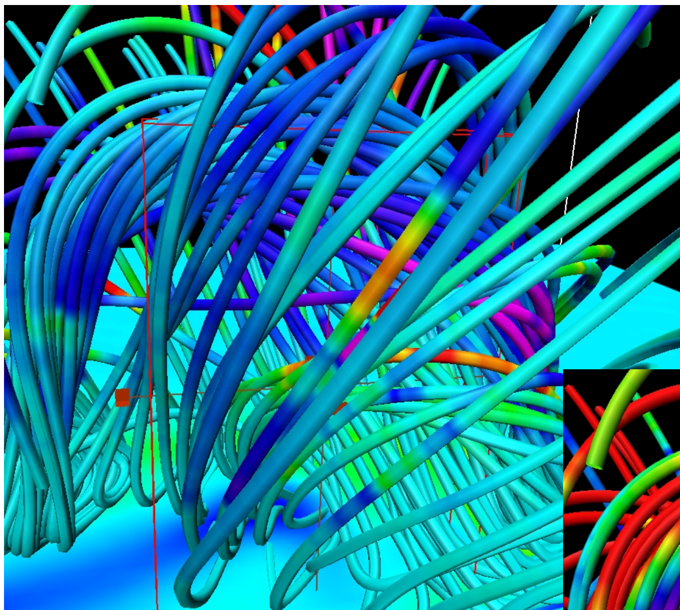
Magnetogram at the base

Region closely related to the negative flux concentration

Eruption 2: Vertical flow speed

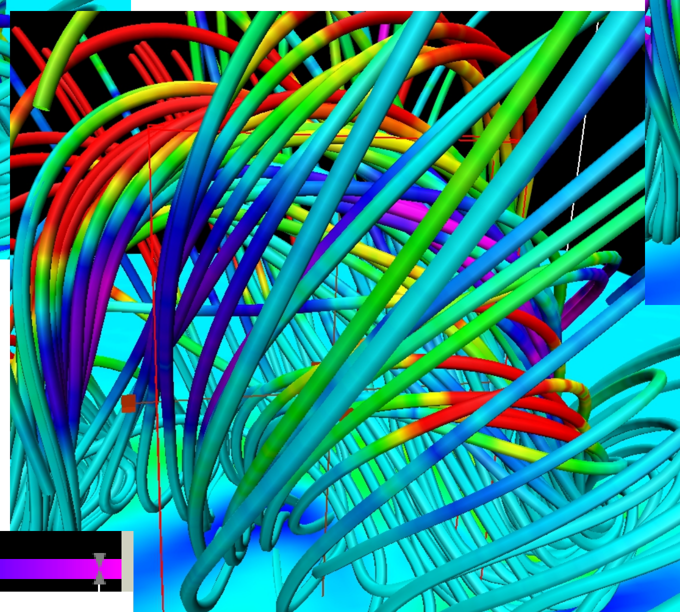


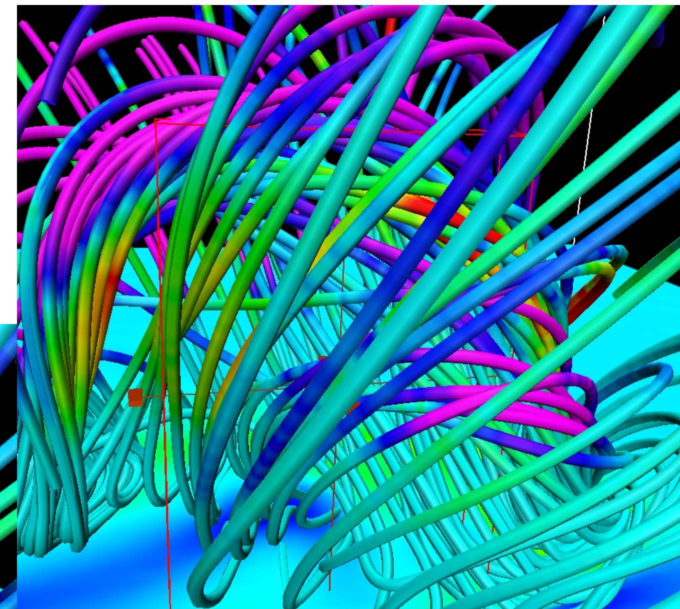
Eruption 2: Acceleration terms



Total acceleration

Lorentz force



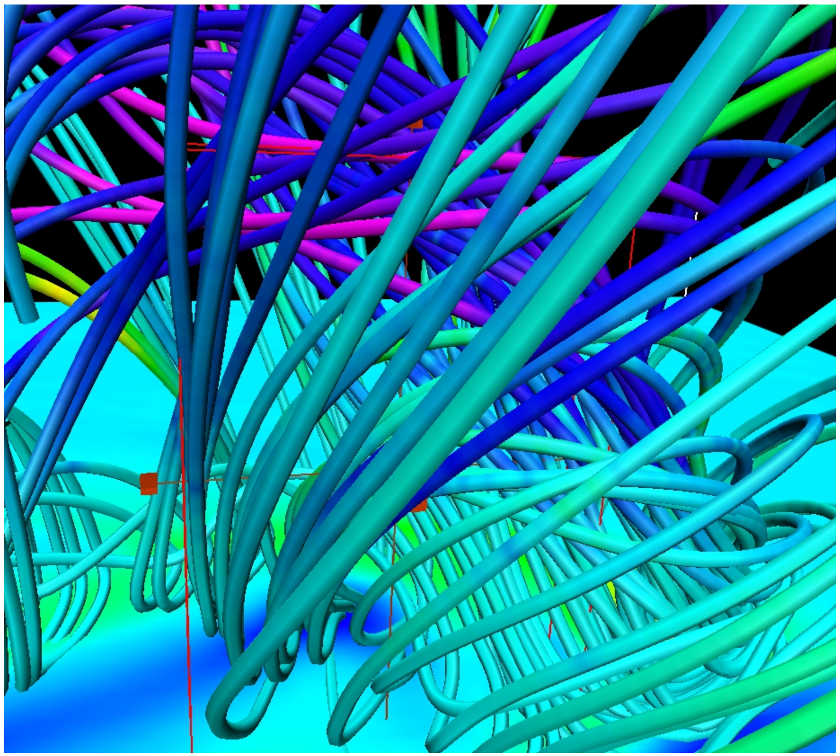


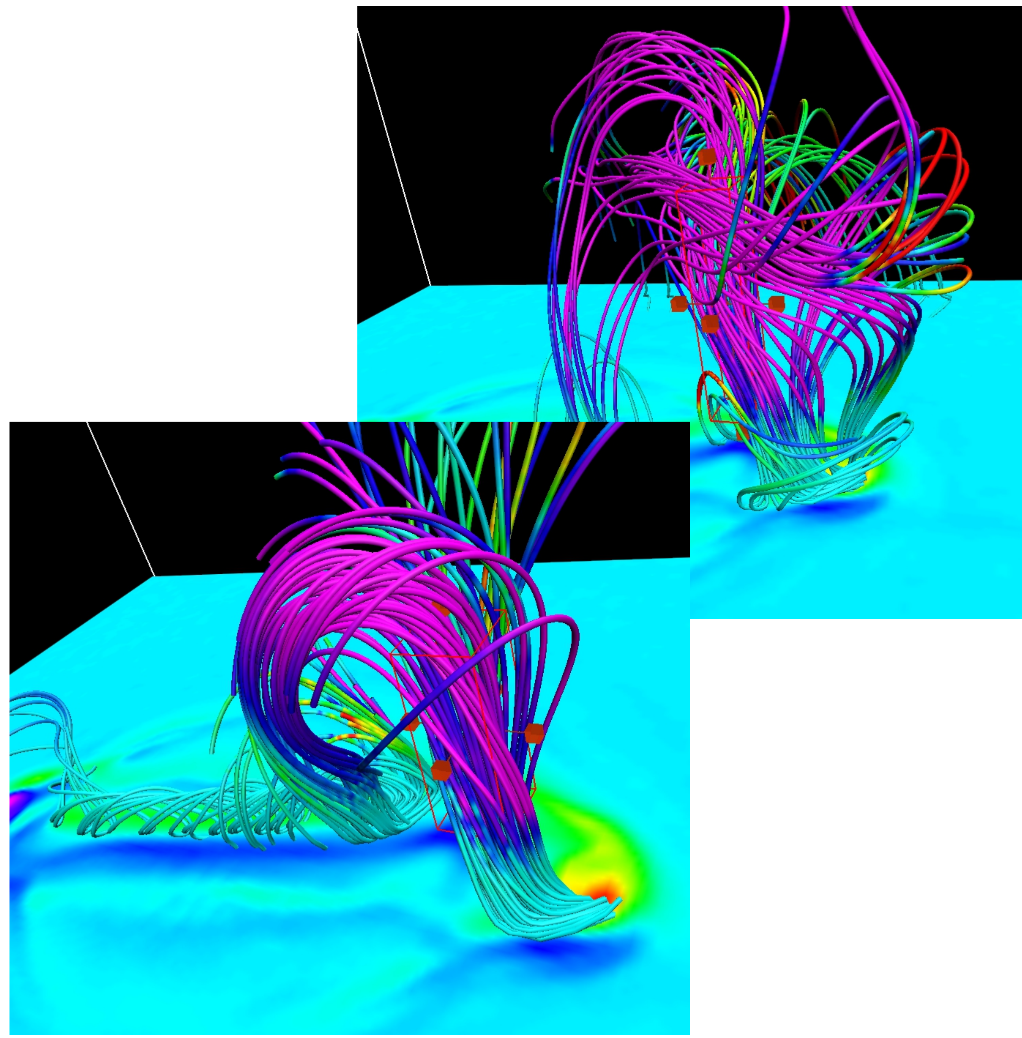
Pressure gradient

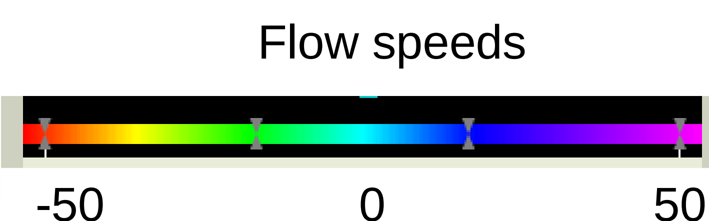
Corrected for the hydrostatic contribution

- 0 +

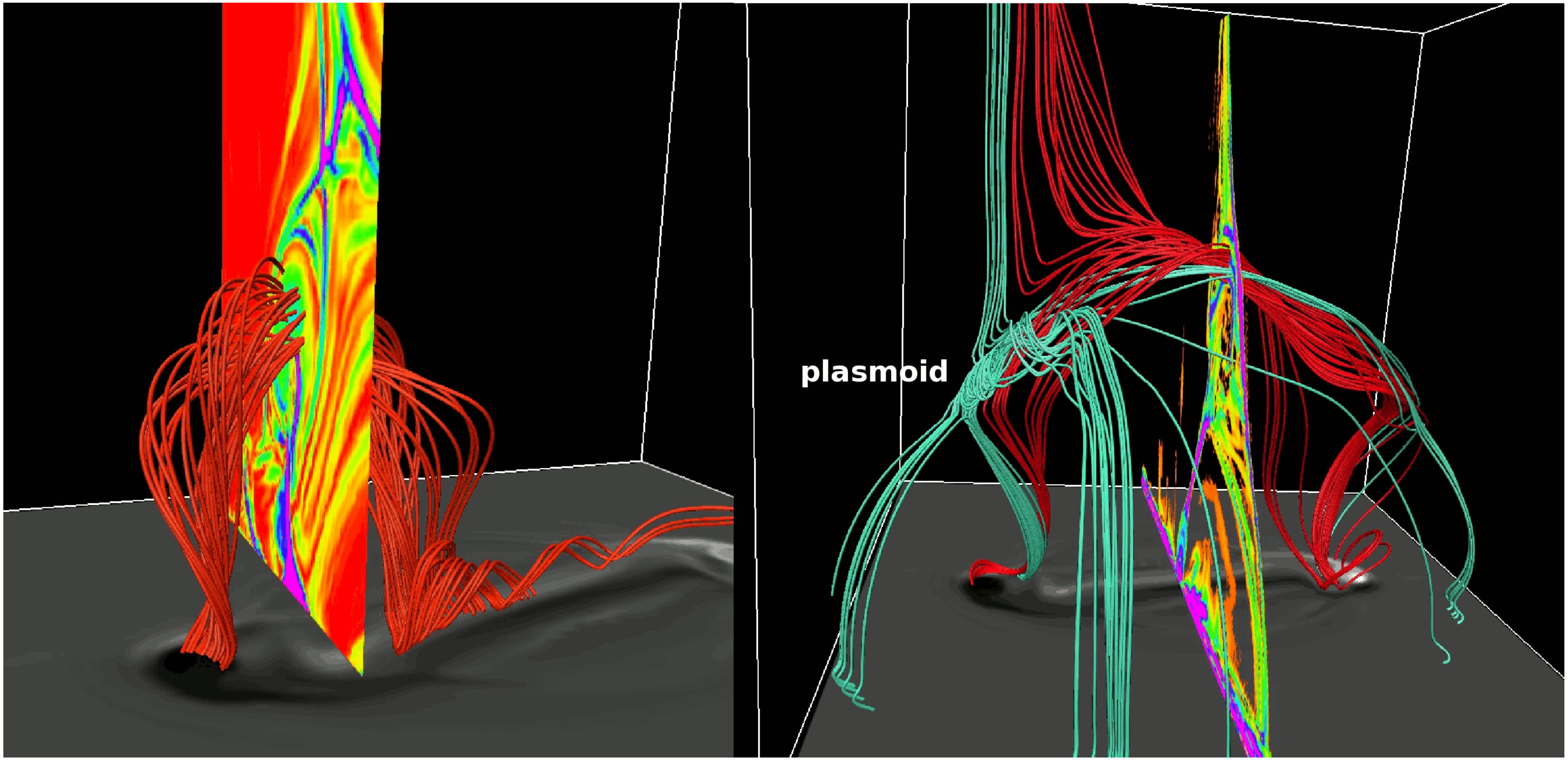
Eruption 2: Onset of the eruption







Evolution of the 2nd eruption

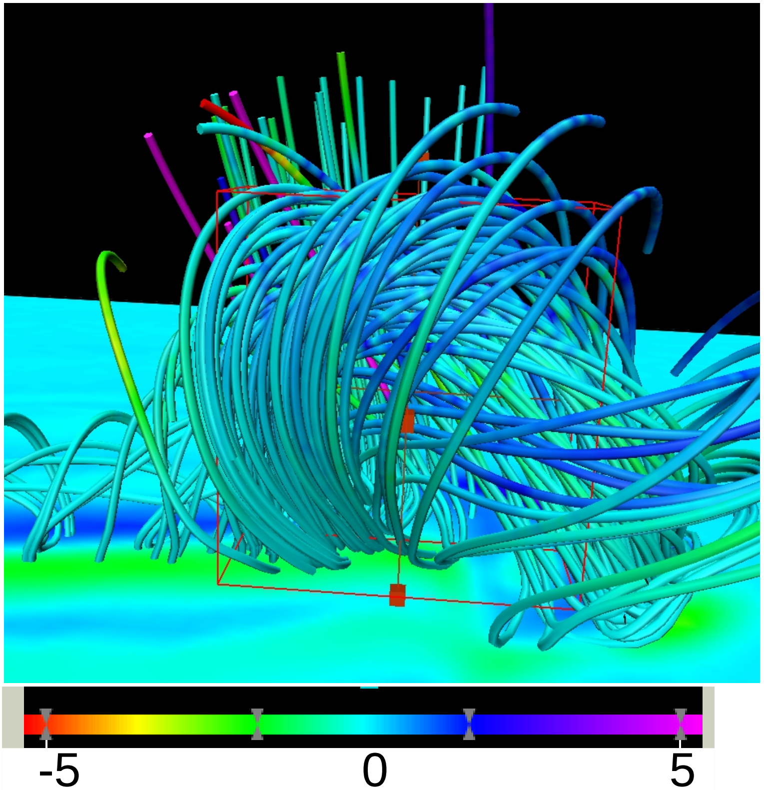


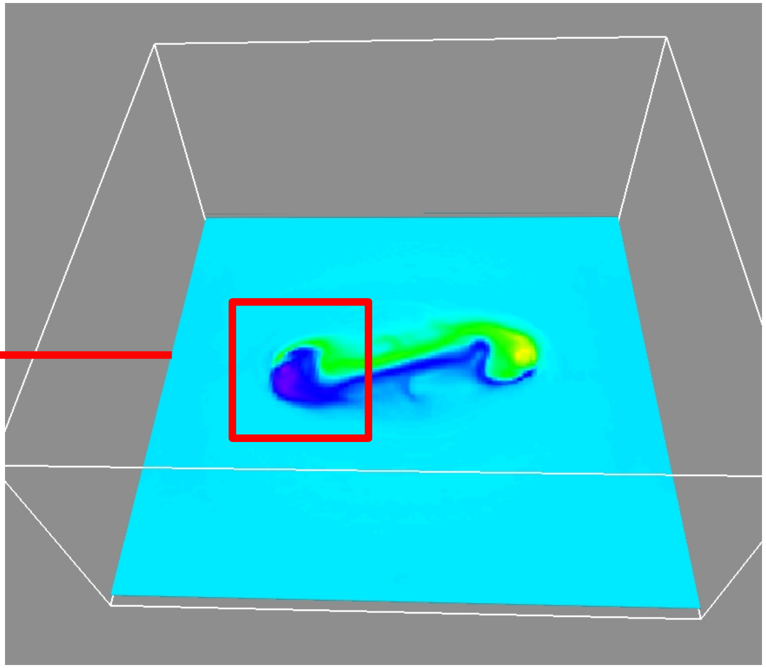
Eruption 2: Summary

- **Delicate force balance** between the Lorentz force and the gas pressure gradient (corrected for the hydrostatic contribution)
- Driven by the local ***magnetic pressure gradient*** from the strong field footpoint of the loop system.
- Initiates upflows along the **one side of the loop** – expansion of the loop in height
- Stretches the field below it and generate a current sheet → **tether cutting** as in eruption 1 → releases the twisted loop system upwards very fast
- The loop hits the flux interface which is defined by the fan plane of a **single null point**
  - **Spine–fan reconnection** involved in reopening the loop system and spread the free energy and cold plasma into the open/closed field domains

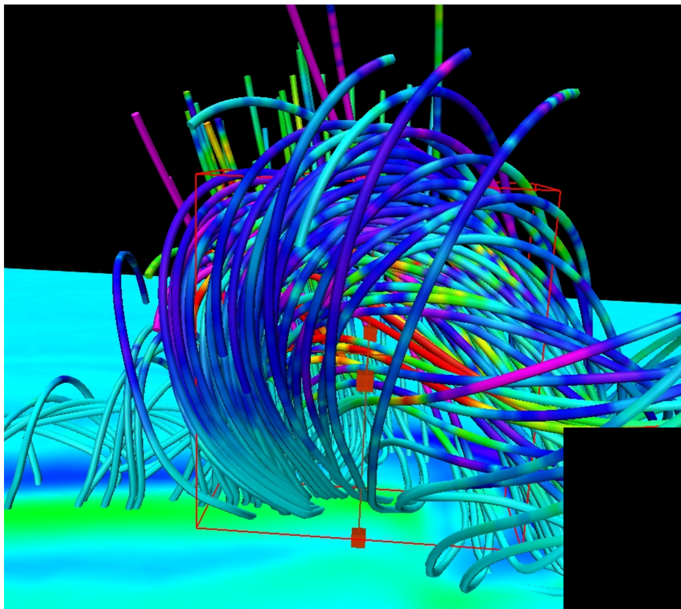
Eruption 3: Initial setup

- Located over the positive flux concentration
- Field line structure + vertical flow speed



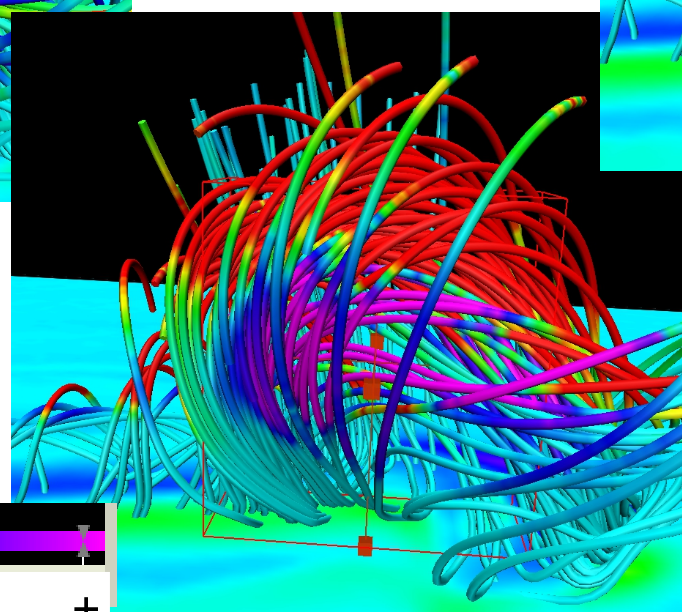


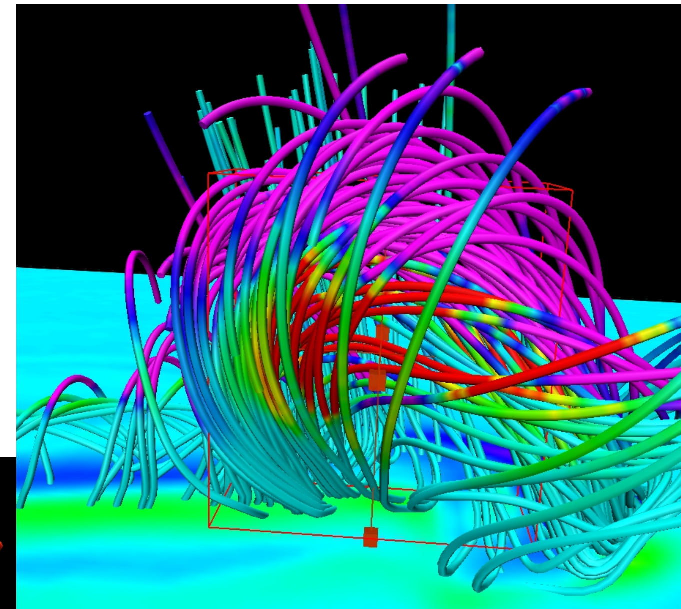
Eruption 3: Acceleration contributions



Total acceleration

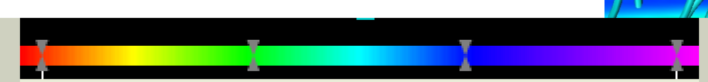
Lorentz force





Pressure gradient

Corrected for hydrostatic contribution

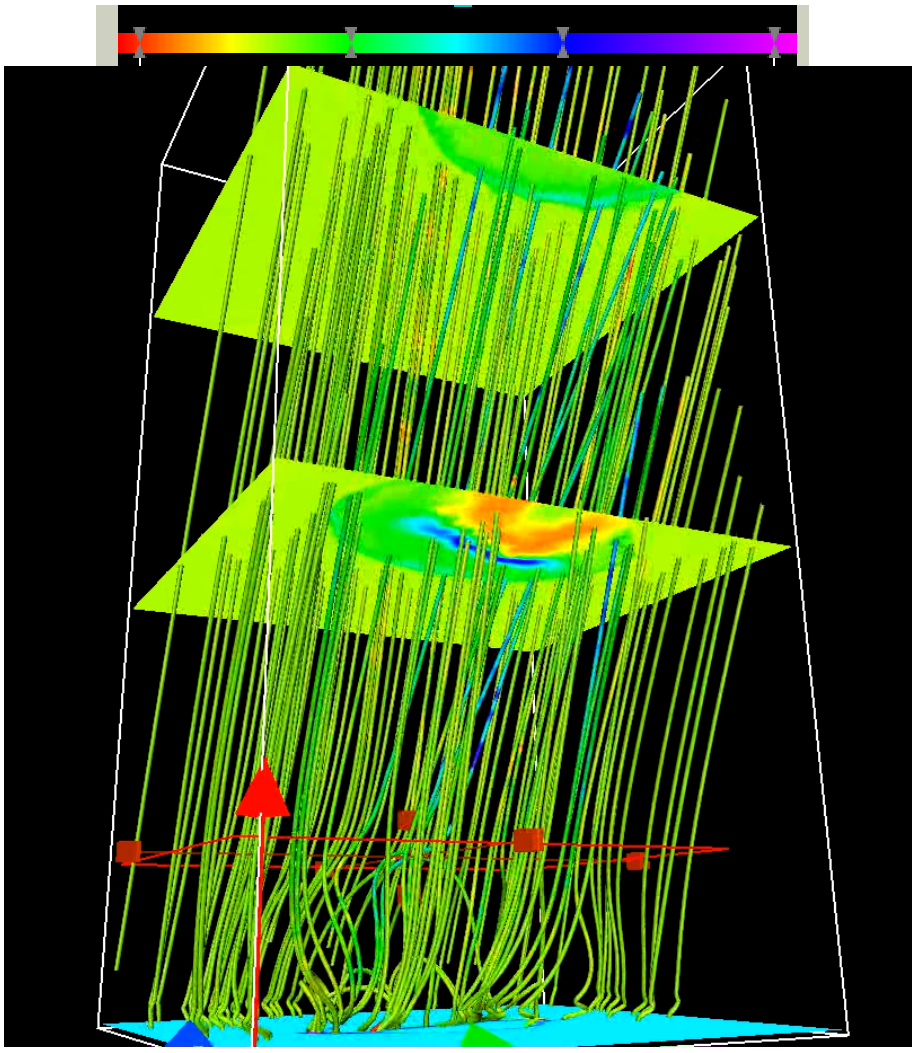


- 0 +

Eruption 3: Summary

- Twisted loop system becomes unstable near the positive flux concentration of the emerged flux
- The **centre of the loop rises in time** in a ”homogeneous” way compared to eruption 2
- Driven by ***gas pressure* at the summit and *magnetic pressure* at the foot points** !!
  - **Very different from traditional models…**
- Creates a current sheet below the rising tube
  - **Tether cutting** again!!
- No null directly above the rising loop system, but to ons side
  - **Interacts with both the open field and the null**
    - A combination of eruption 1. and 2. With ”1.” type dominating
  - **Totally reopens the twisted loop system**

Coronal impact of the eruptions



Field lines coloured with vertical flow speed (purple is high speed up flows)

Two planes representing plasma temperature. Blue is being hotter and red is colder

Generally hot plasma is ejected upwards spreads over a large horizontal surface.

These regions are over dense compared to the bg. plasma

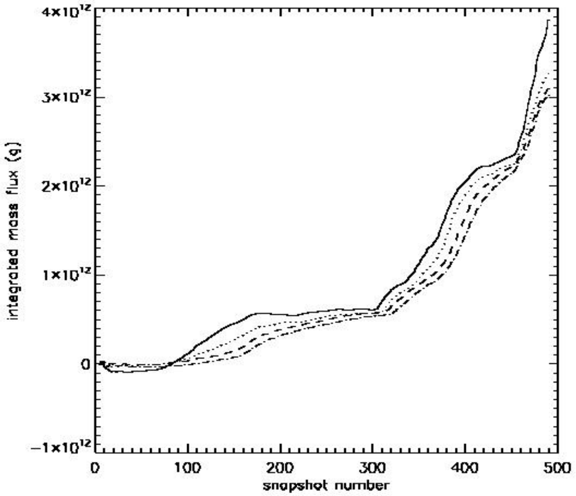
The mini-CMEs are not seen directly!!

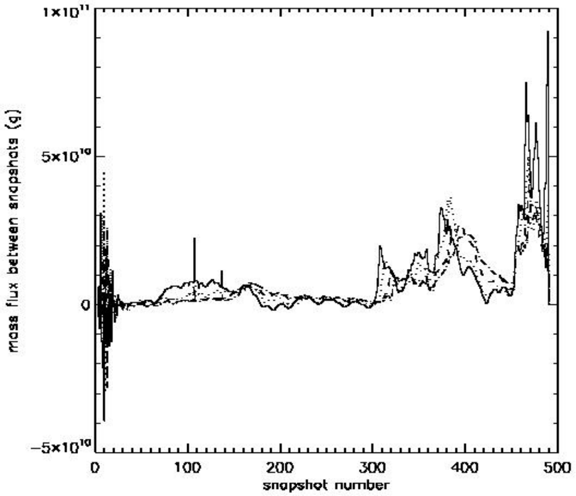
Just for fun mass loss...

- **Do jets/mini-CMEs contribute to the solar wind?**

- Sum up mass loss at different heights
- Gives a mass loss with time (top)
- Rates (bottom)

- **Needs on the order of 500 jets per day**..... (very rough number!!!)
  - only sees order 60 from coronal hols
    - Innes et al. 2009





Summary

- **Simple initial magnetic model → Complicated dynamical evolution**
- **5 eruptions** from the flux emergence regions
- **3 key locations** → Centre and over the two flux concentrations
- **Different mechanisms drives the local flux systems** into the instability
  - Central shear due to emergence where the central part of the tube will not emerge → tether cutting
  - Loop rise driven by magnetic pressure gradient in one footpoint
  - Dominating pressure gradient at the summit of the loop
  - "Shear across the PIL near one flux concentration"
- Typically **high density, low temperature plasma** (transition region values) **is lifted and ejected upwards**
- The **mini-CME is destroyed on impact with the ambient field**