Data Driven Modelling

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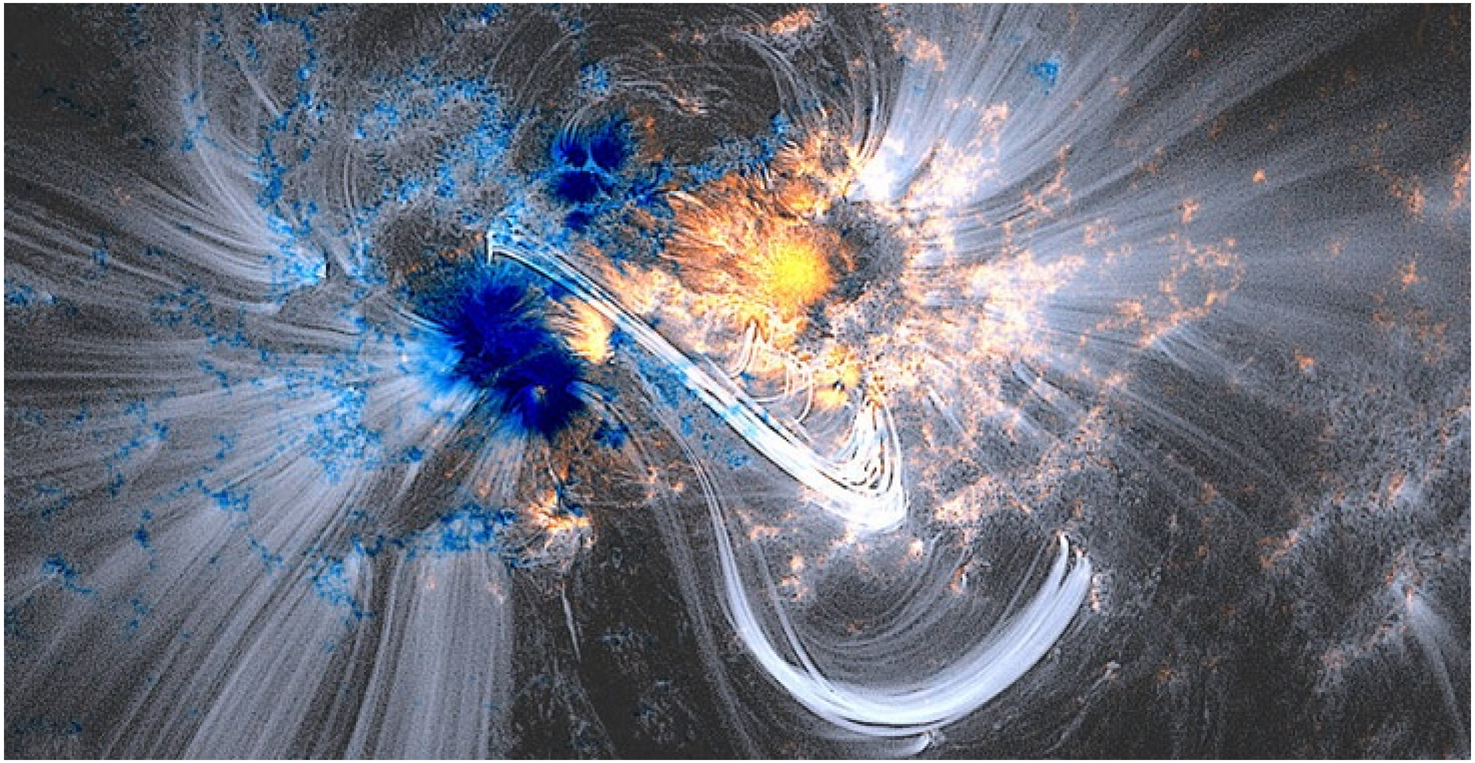
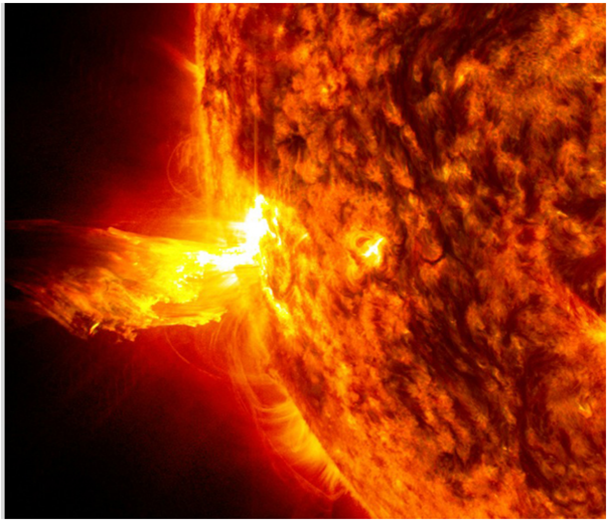


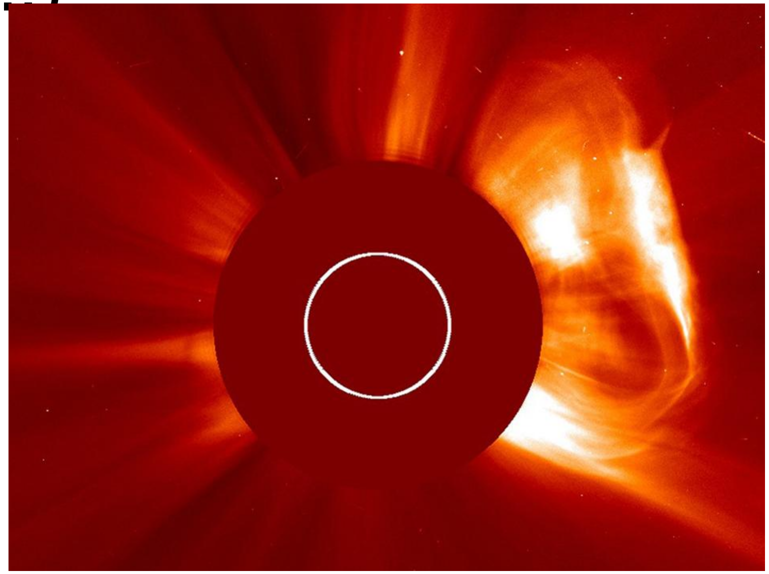
Content

- AR Modelling
- What does it takes to do it?
- Which methods/approaches to choose?
- An example

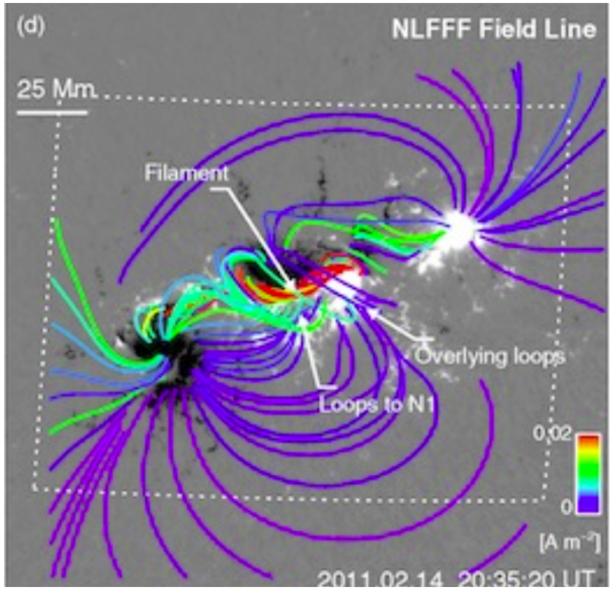
Introduction

- **Space Weather**
  - Need more *precise models* of the *initiation*
    - Flares and CMEs
  - Needed for realistic tracking further out in the system..... (Jens yesterday..)
  - How to do this?

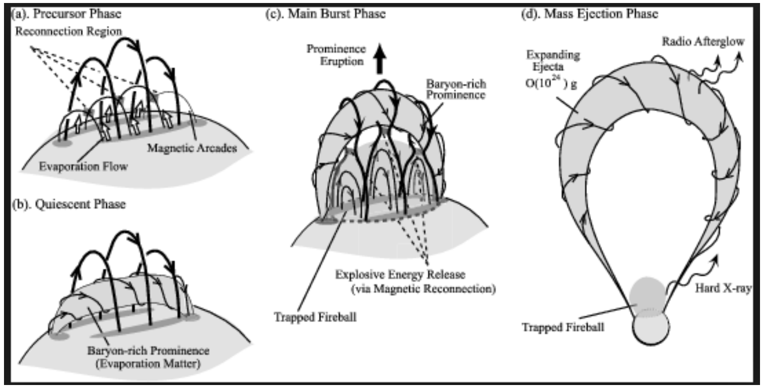




Realistic modelling of flares and CMEs



- Requirements:
  - **Realistic magnetic model**
    - Based on magnetic information – observations
  - **Realistic atmospheric model**
    - Energy equation
  - **Realistic driving of the system**
    - Based on observational data
  - **Realistic treatment of particles**
    - PIC or like



How to get these data?

- Observations of
  - **Surface magnetic field**
    - Various magnetic information, large scale
  - **Coronal structural information**
    - Large scale information, AIA observations at different wavelengths
  - **Boundary driving**
    - Emergence
    - Shearing
    - Various magnetic information, large scale, long time scales

Requirements for a magnetic model

- **Analytical models**
  - Simple models typically
  - Various large scale models
- **Relaxation**
  - Based on large scale modelling
    - Talk by Paolo PAGANO Wednesday
- **Extrapolations**
  - Potential, constant alpha, non linear force free
    - Thomas Weigelmann

NLFFF Limitations

- **Vector magnetic field**
  - Limited spacial, time and strength resolution
- **Flux balance of the region**
  - Only possible in active regions...
- **One current component**
  - Component perpendicular to the surface
- **No guarantee for a unique solution**

Atmospheric model

- **How complicated an energy equation?**
  - How important is the energy flow
    - Radiation, conduction, particles, spectral lines

- **Important for direct comparisons**
- **Important for real dynamics?**

Driving

- How do we get realistic information to stress the magnetic field system?
  - **Ball tracking**
    - Potts et al. A&A 424, 253-262 (2004)
  - **Local Correlation Tracking**
    - Walsch et al. ApJ, 610, 1148 (2004)
  - **Differential Affine Velocity Estimator** (DAVE)
    - Schuck, P. W. ApJ, 683, 1134-1152 (2008)
  - **PTD-Doppler-FLCT Ideal**
    - Kazachenko et al. ApJ, 795, 19 (2014)

Ball tracking

Potts et al. A&A 424, 253-262 (2004)

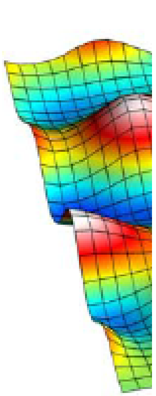
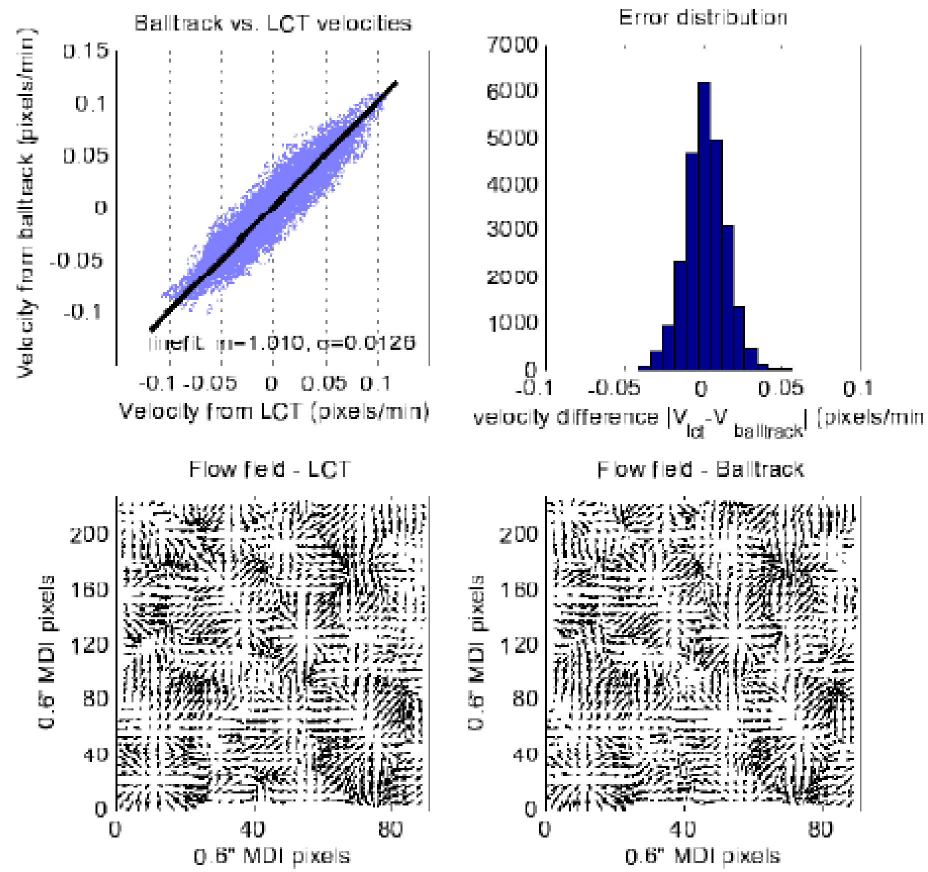
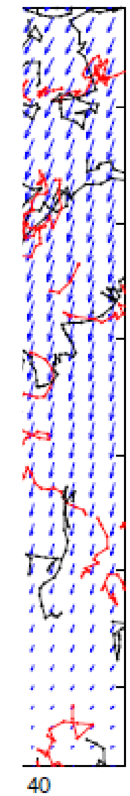
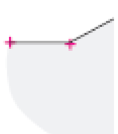


Fig. 1. One of
surface. As th
evolve, they pu







with under-
ig is to help

Fig. 3. Cross s
etrates the sur
proportional to the penetration distance.

Fig. 8. Comparison of Balltrack and LCT recovered velocity fields from real MDI data. The original data set consisted of 240 256 × 256 pixel (approx. 150 × 150″) frames taken at one minute intervals.

ILCT

Walsch et al. ApJ, 610, 1148 (2004)

- Combine the Induction equation with LCT
- Vector magnetograms
- LCT
  - Proper motion due to changes in intensity features
  - Gauss bell function with given sigma
  - FFT approach for deriving flow speed

Induction Equation

$$\frac{\partial \boldsymbol{B}}{\partial t} = \boldsymbol{\nabla}\, X\left(\boldsymbol{v}\; X\; \boldsymbol{B}\right)$$

→ normal component

$$\frac{\partial B_n}{\partial t} = \nabla_t \cdot \left(v_n \boldsymbol{B_t} - B_n \boldsymbol{v_t}\right)$$

LCT speed and normal component

$$\delta B_n / \delta t = -\nabla_t \left(\boldsymbol{u}\, \overline{B_n}\right) \approx -\nabla_t \cdot \left[\boldsymbol{u}^{\boldsymbol{LCT}}\, \overline{B_n}\right]$$

v parallel to ***B*** has no effect on **IE**

$$\boldsymbol{v} \cdot \boldsymbol{B} = 0$$

Corrected LCT flow speed:

$$\boldsymbol{v_t} = \boldsymbol{U}^{\boldsymbol{LCT}} - \frac{\boldsymbol{U}^{\boldsymbol{LCT}} \cdot \boldsymbol{B_t}}{\left|\boldsymbol{B}^2\right|} \boldsymbol{B_t}$$

$$v_n = -\frac{B_n}{\left|\boldsymbol{B}^2\right|} \left|\boldsymbol{U}^{\boldsymbol{LCT}} \cdot \boldsymbol{B_t}\right|$$

Ideal Ohms law

$$\boldsymbol{E} = -\boldsymbol{v}\; X\; \boldsymbol{B}$$

Boundary condition for MHD experiments

Dave/Dave4VM

Schuck, P. W. ApJ, 683, 1134-1152, (2008)

- Vector magnetograms
- Assumes a horizontal flow velocity
  - Solved for that together with the rest
  - Coordinate axis compared to some others that are field aligned.

Nomal component based models...

Welsch et al. (2007)

- In fact none of the pure line-of-sight methods—LMSAL’s LCT, FLCT, or the DAVE—estimated these fluxes reliably, reproducing (at best)
- respectively 11%, 9%, and 23% of the helicity rate
- respectively 6%, 11%, and 22% of the power injected through the surface.

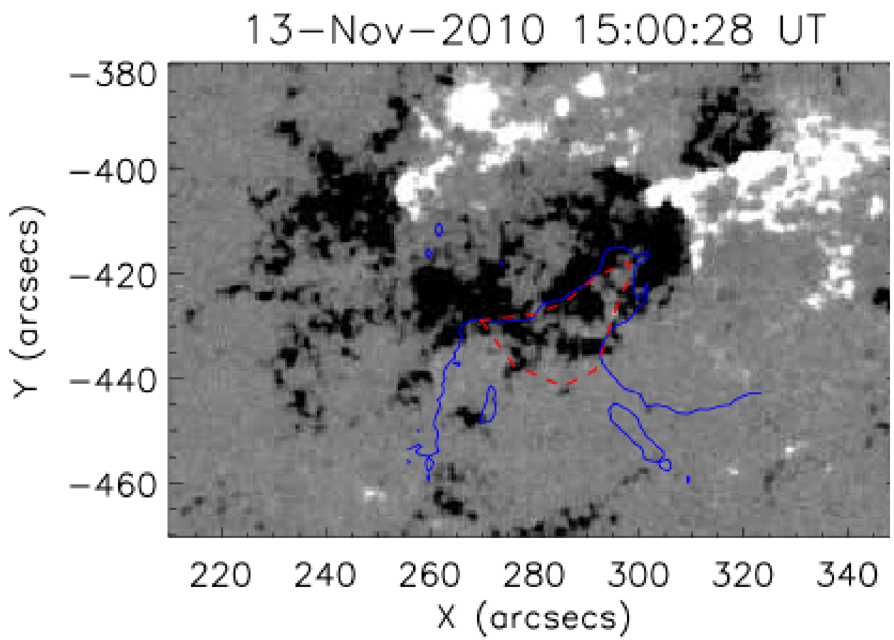
•*PTD-Doppler-FLCT Ideal*

Kazachenko et al. ApJ, 795, 19 (2014)

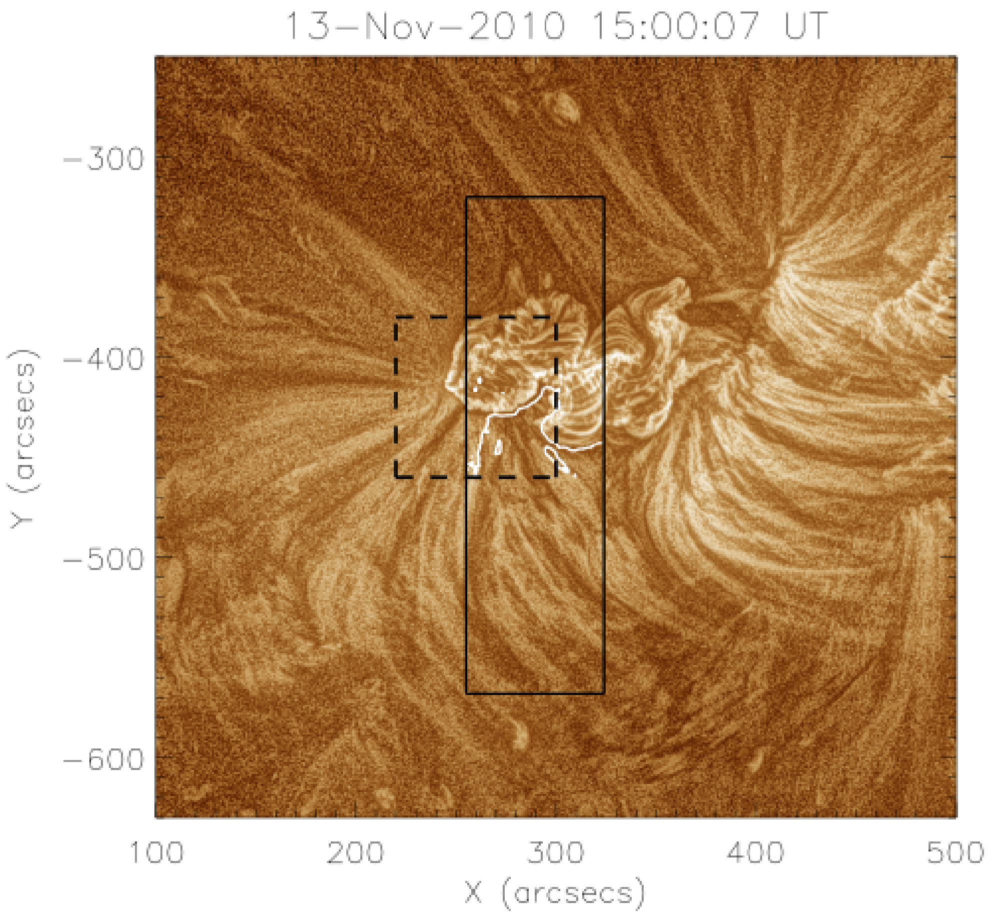
- Vector magnetograms
- Doubler velocity information
- Electric field vector at the boundary

- Strongly dependent on quality of observations

Observations

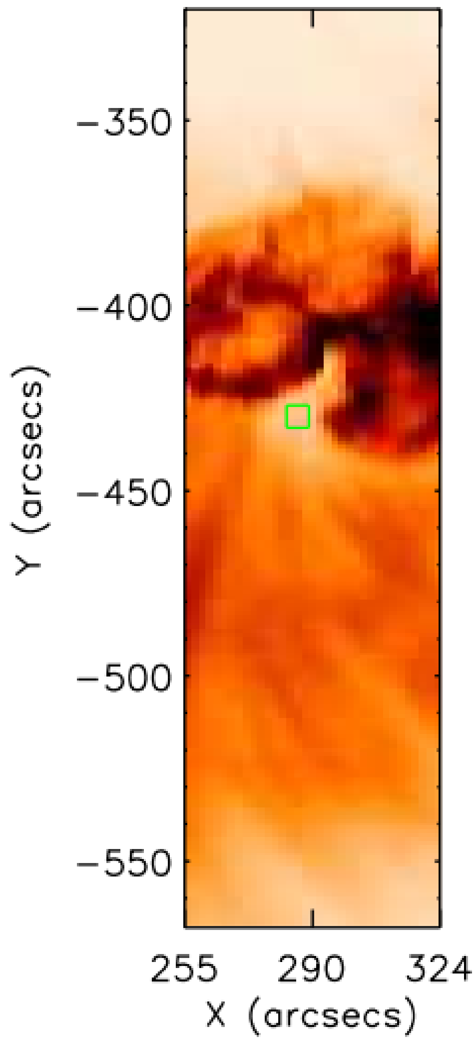


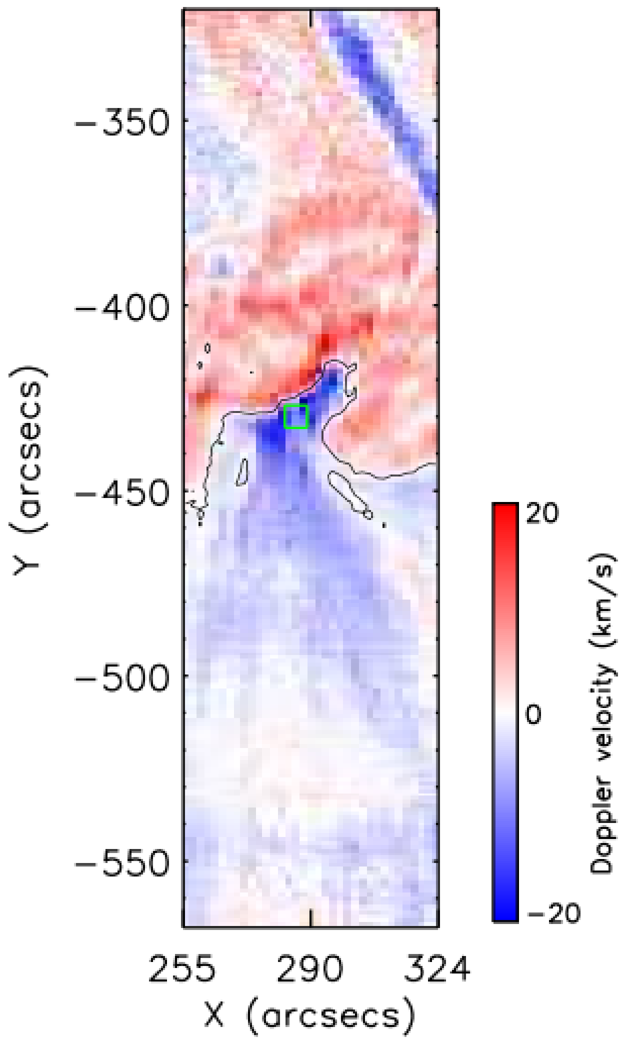
HMI magnatogram
Outflow region



AIA 198 Å MGN enhanced

Density and Flows





Left, EIS Fe XII 195.12 Å

Right Doppler velocity

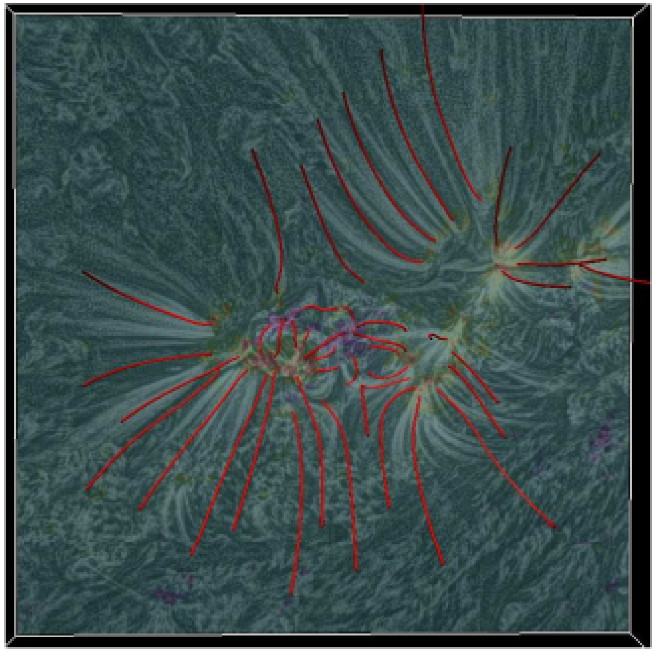
Two flow components
1-20 km/s president over
3.5 hours

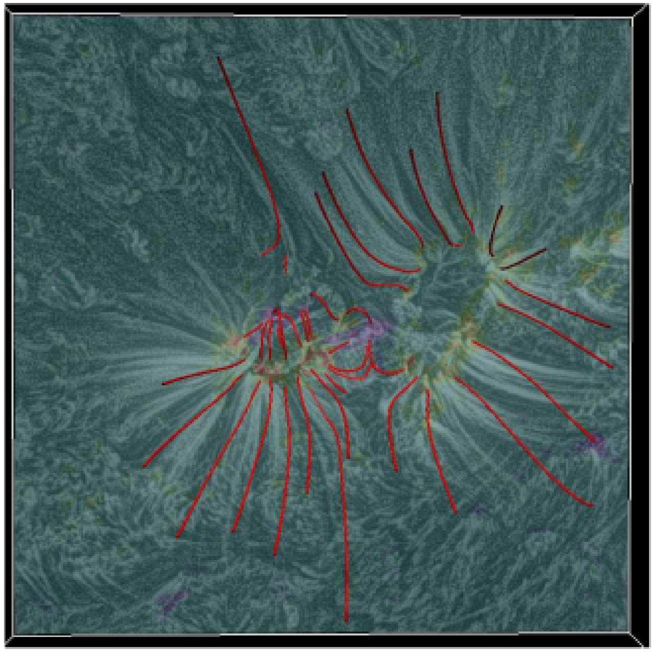
105 km/s contribution

Flows only observed above
Chromospheric
Temperatures

What drives these flows?

Field model



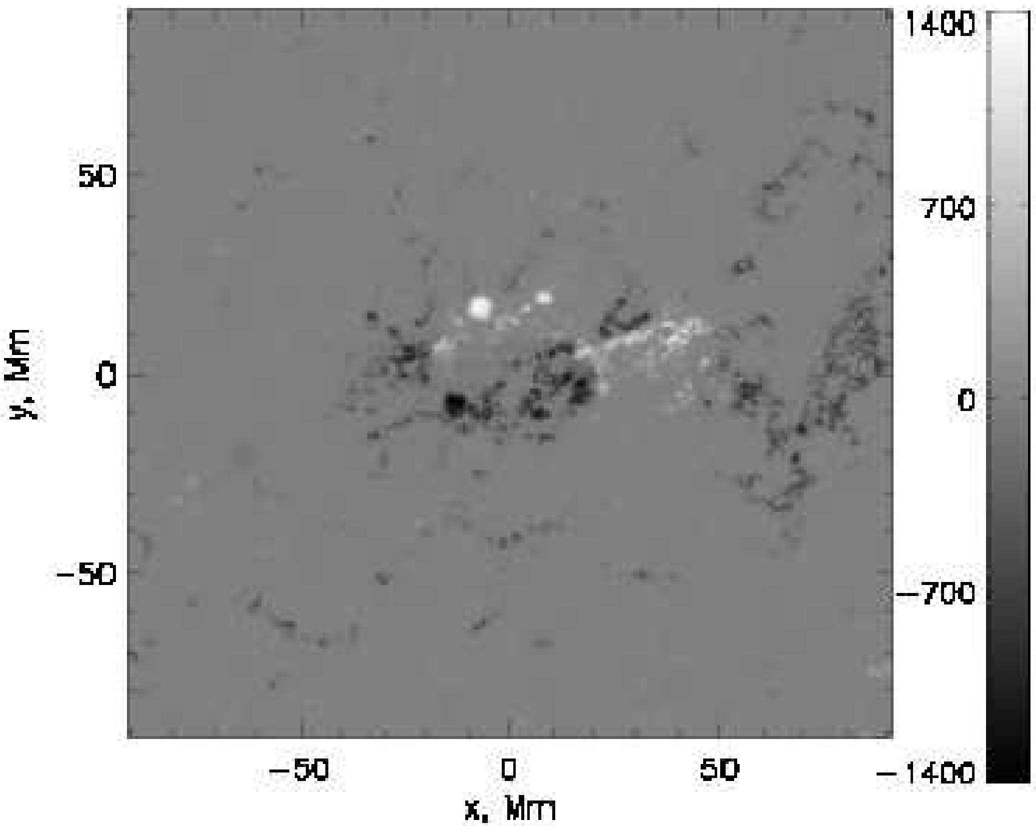


One day apart in time,

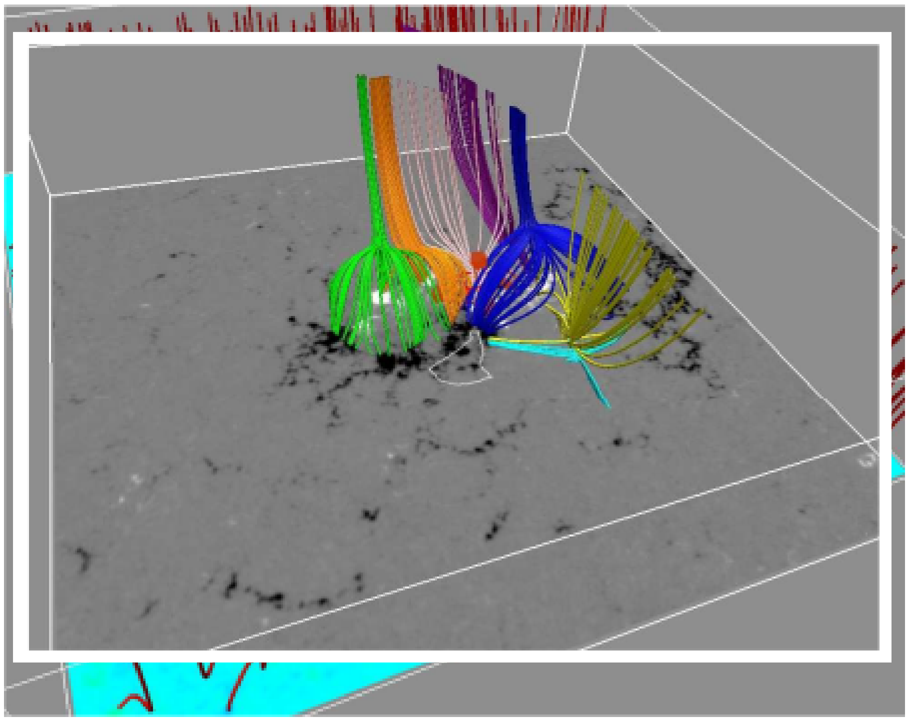
potential field model

Model example

Galsgaard et al. 2015 in press



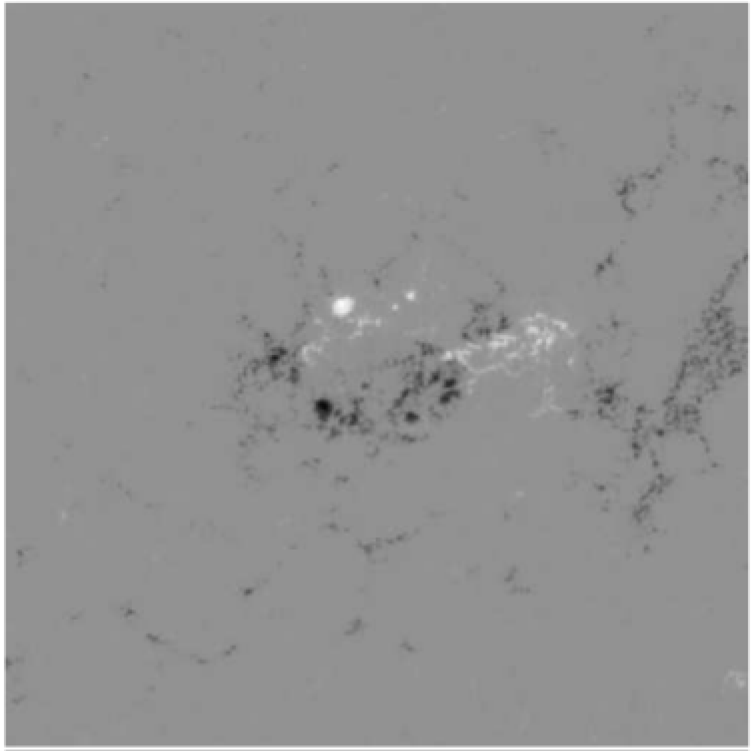
Magnetogram - HMI



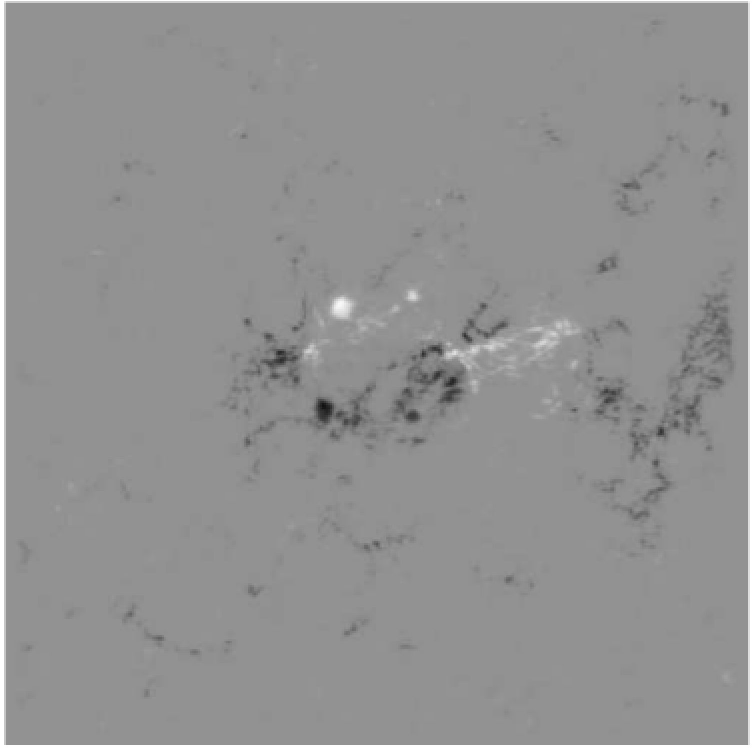
Potential extrapolation

Model driving

- LCT velocity field defined from 45 s HMI data
- After 193.5 min – Misses the fine details



Observations



LCT advanced B field

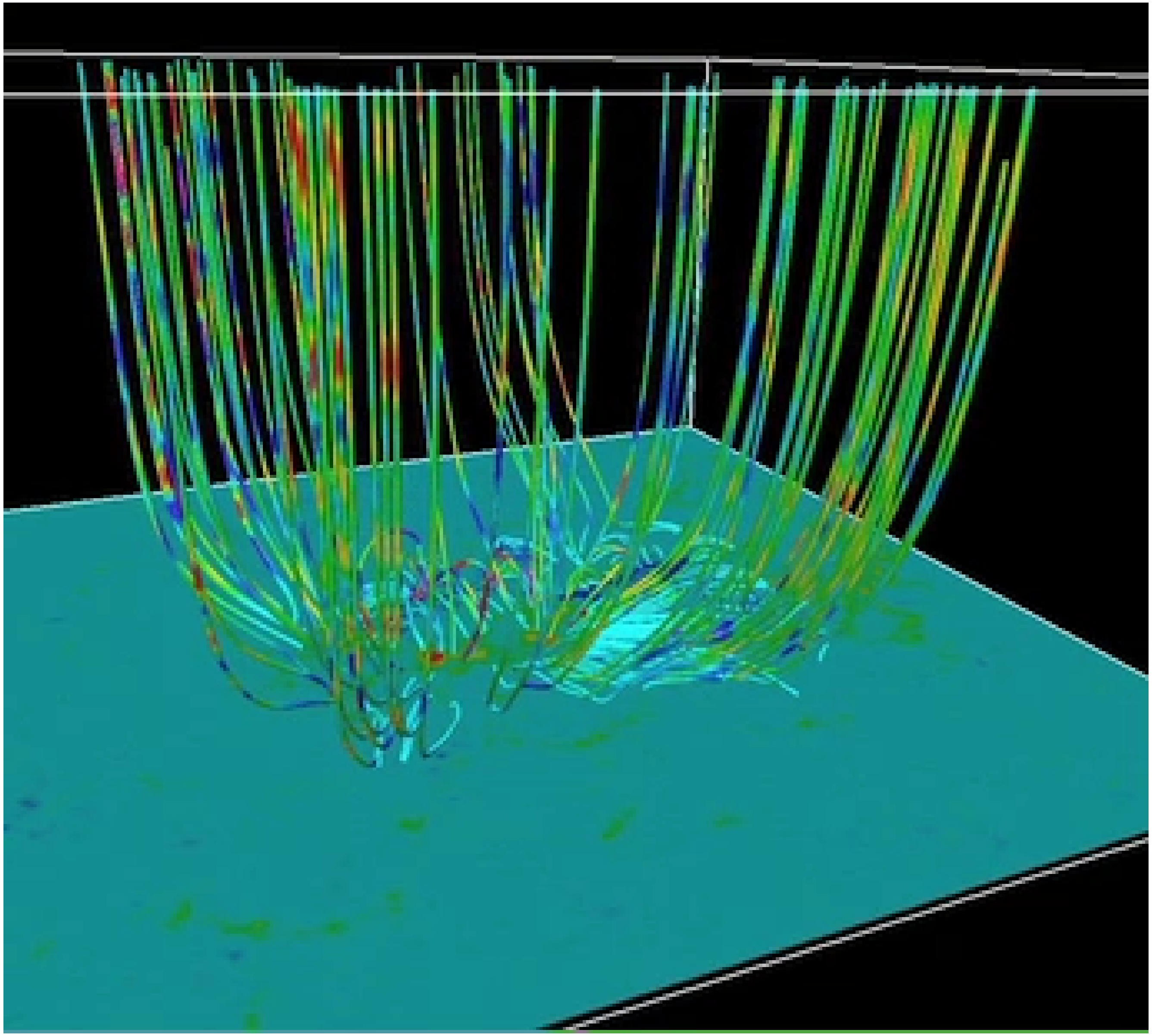
Model Induced flows

Wave propagation

Compression/
Decompression along
field lines

Imposed by the boundary
driving

Nothing interesting takes
place in this case...



Conclusion

- Not easy to make realistic data driven models
- Need GOOD observations
  - Calibrated, derotated, scaled,.....
  - Long time series
  - High resolution
  - Reliable methods to provide initial conditions
    - Extrapolations
    - Boundary driving
- Possible to use available data when carefull!