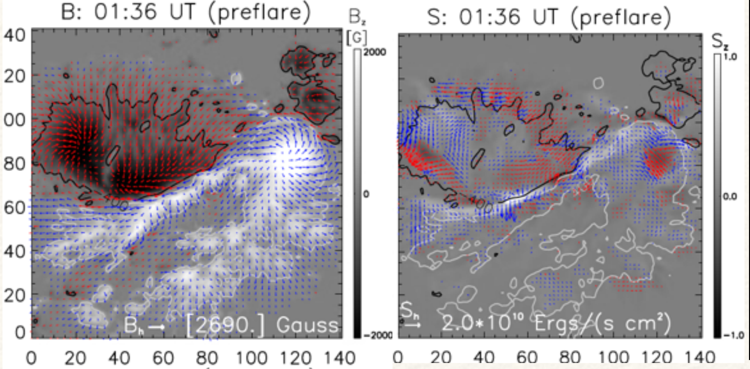
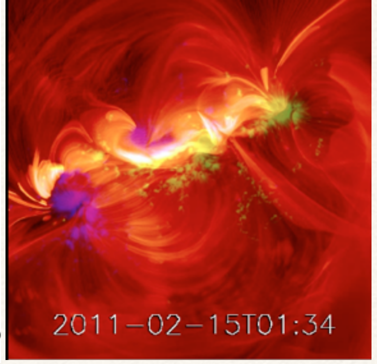


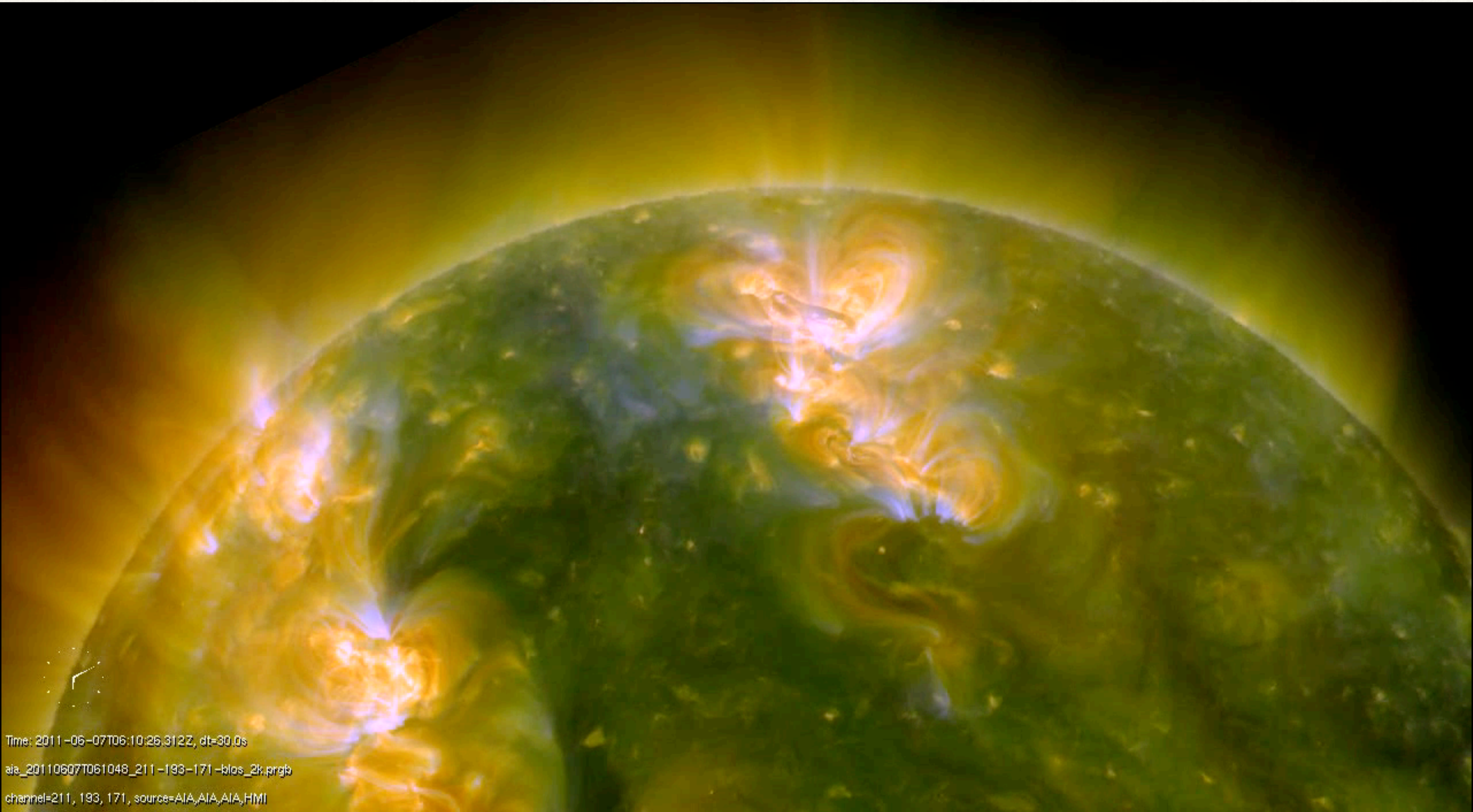


Электрические Поля на Поверхности Солнца: Как Их Искать и Зачем Они Нужны?

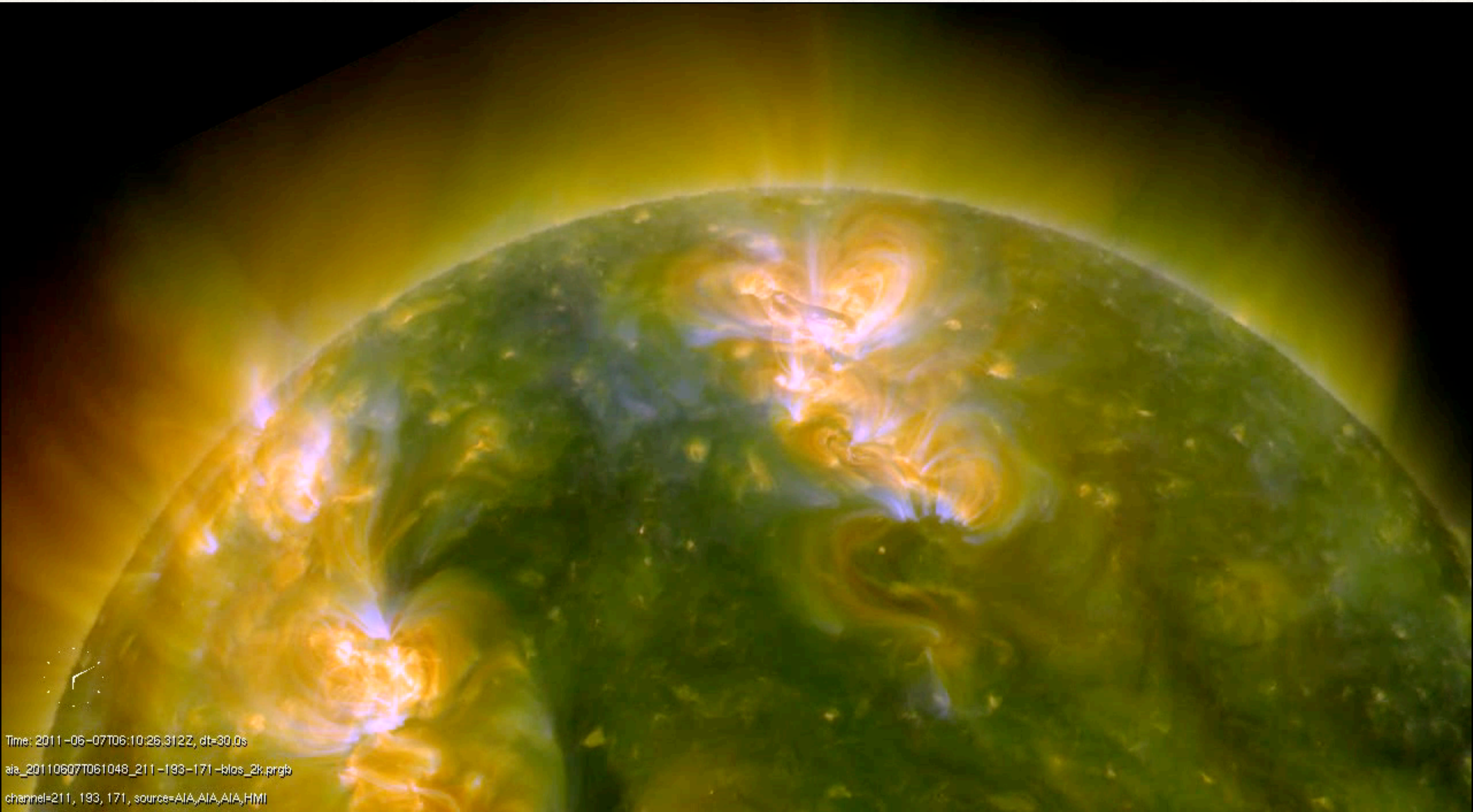
Мария Казаченко
Калифорнийский Университет Беркли

NJIT/Ioffe Online Seminar, May 3 2017

Самые мощные вспышки



Can We Use Observed Magnetic Fields in the Photosphere to Model Magnetic Energy Stored and Released in Solar Eruptions?



Outline

- **Introduction: coronal field models**
- **Electric fields inversions**
  - Our method
  - First E derived on the Sun
- **Driving coronal evolution with E and B**
  - Coronal Global Evolutionary Model (CGEM)

Finding Magnetic Fields in Solar Corona

- <u>Observations</u> - currently difficult
- <u>Models</u>
  - <u>Static Models</u>
    - Non-linear force free field
  - <u>Dynamic models</u>

?

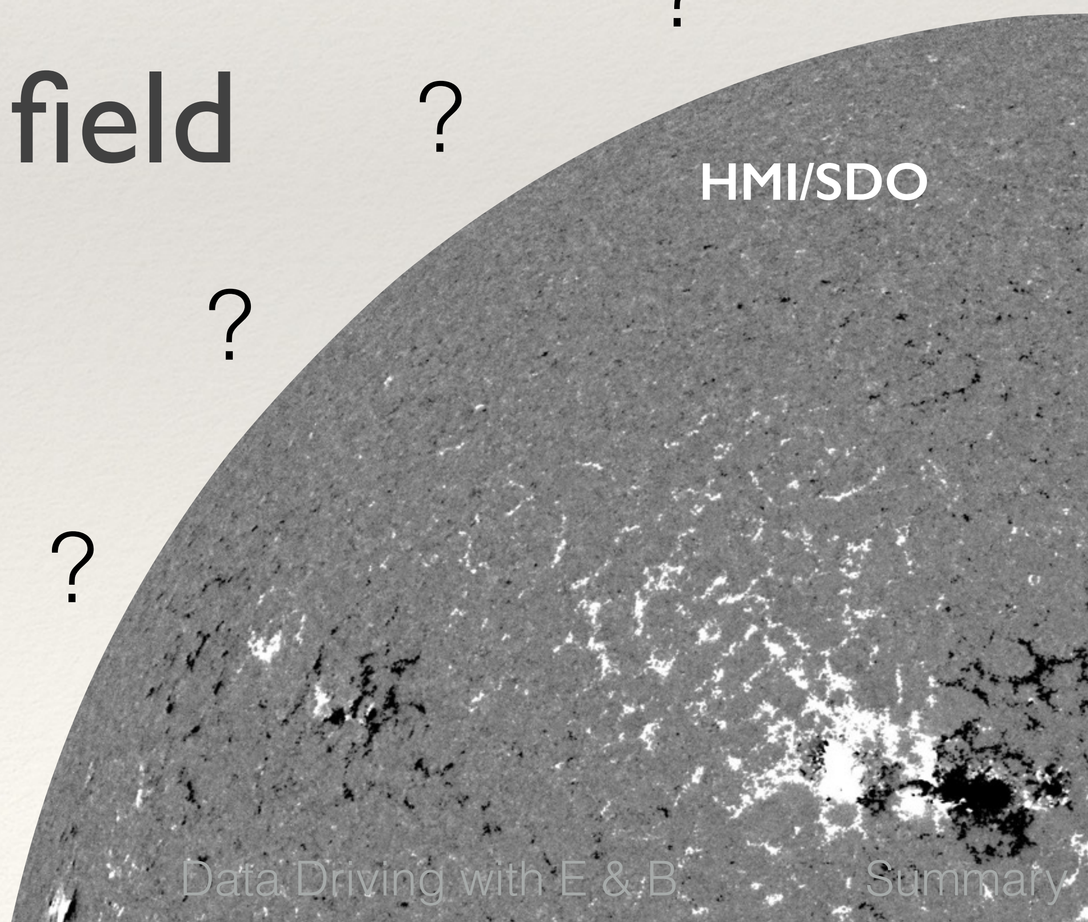
?

?

?

?

?



Dynamic Models

Data-inspired

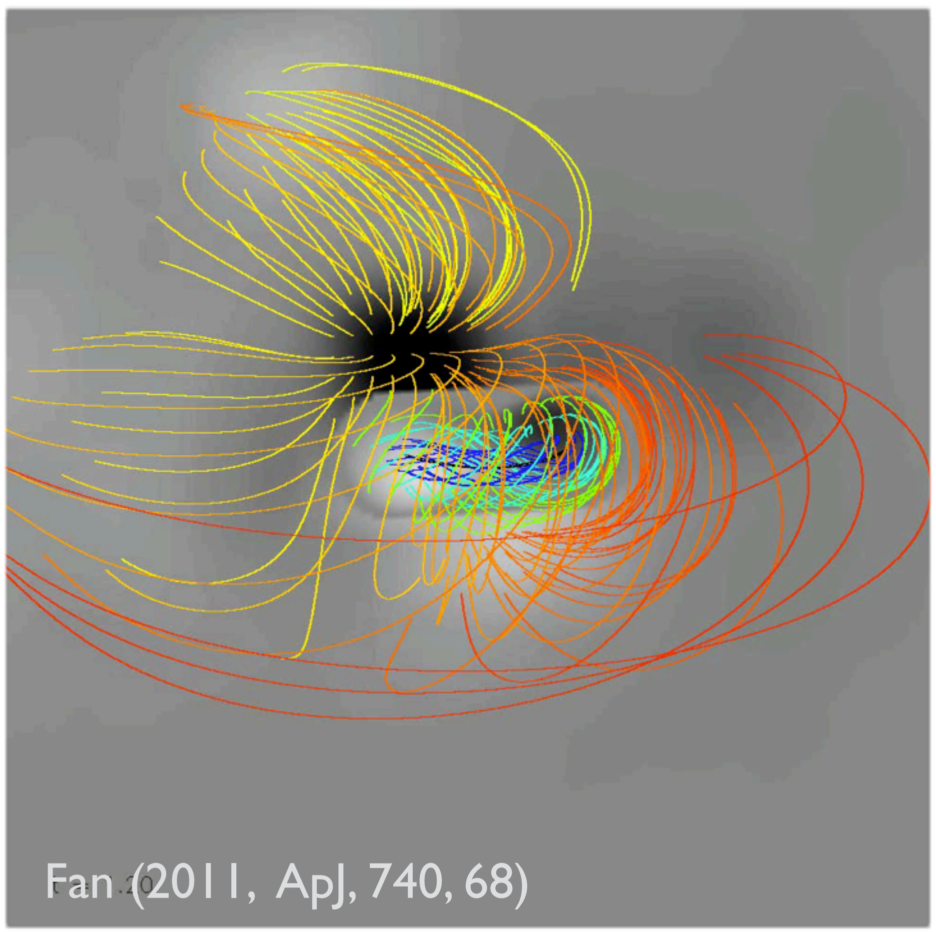
use simplified setups to mimic observed scenarios

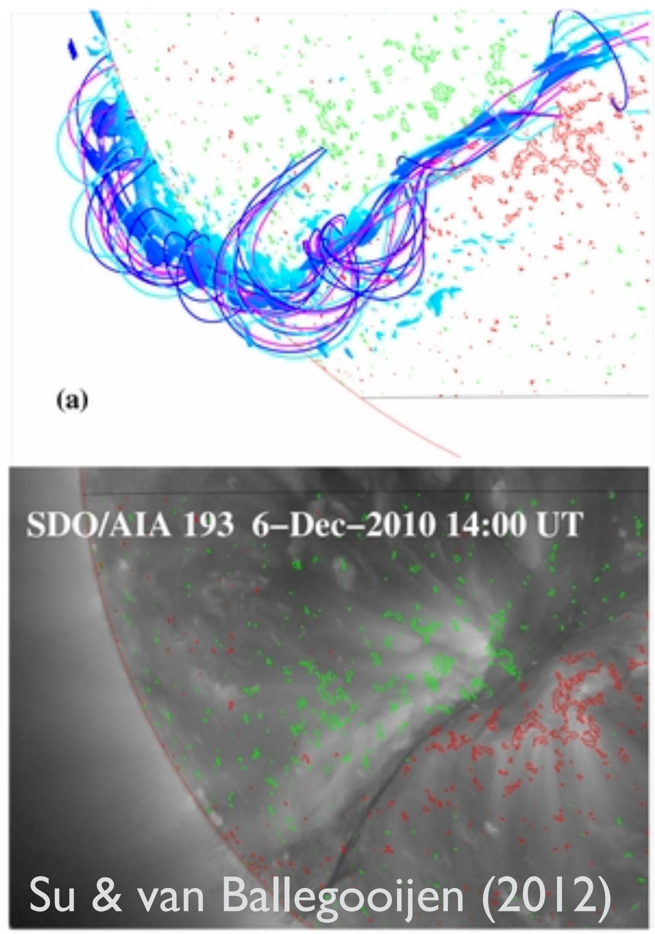
Data-constrained

satisfy observations at at an instant time

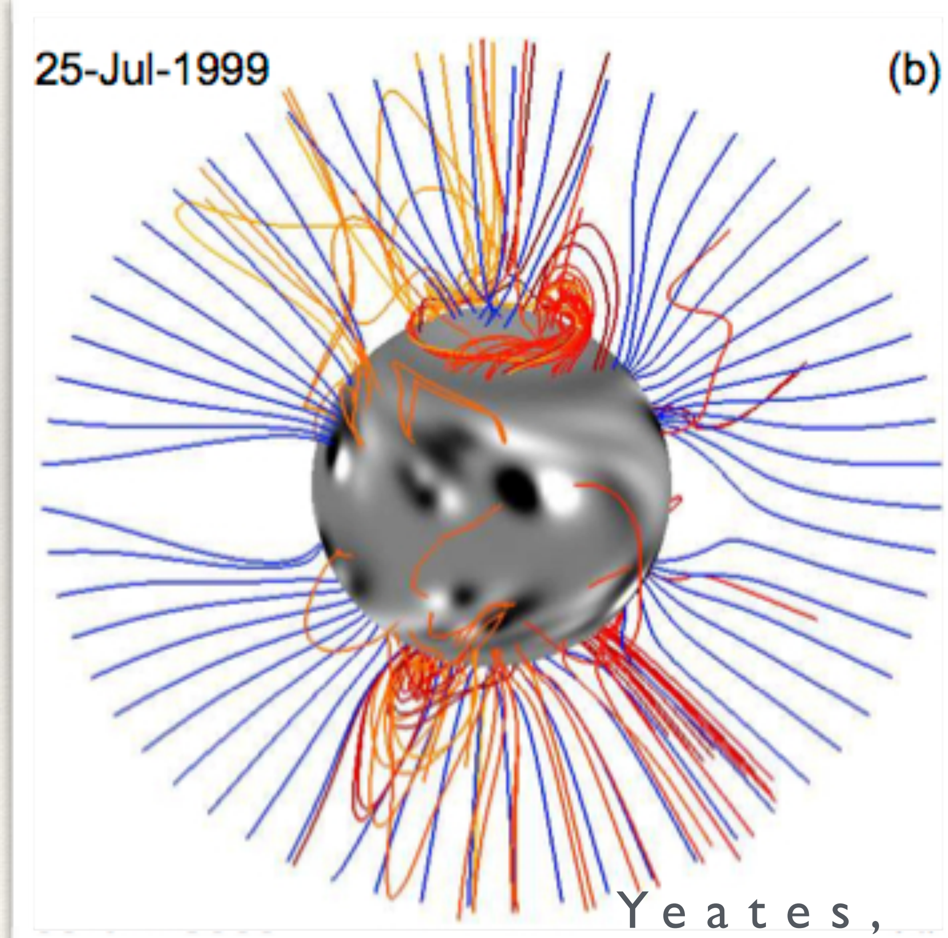
Data-driven

evolve in response to evolving boundary conditions


Fan (2011, ApJ, 740, 68)



Su & van Ballegooijen (2012)



Yeates, ...

Data-driven Models Need Electric Fields for Boundary Conditions!

<u>Follow the energy:</u> $S_z = (E \times B)_z$.

- Magnetic field **B** - from observations
- Electric field **E** - ?

Why Finding Electric Fields is Hard?

- Directly measure from Stark Effect? No.

  Wien(1916) … Foukal & Behr (1995).

- As $\mathbf{E} = -\mathbf{V} \times \mathbf{B}$, where **V** horizontal comes from velocity inversion methods.

  November & Simon 1988… Welsch et al. 2007… Schuck 2006, 2008

- From the Faraday's Law (our approach):

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

PDFI electric field inversion method: main idea

Poloidal-Toroidal Decomposition (PTD, Fisher et al. 2012):

$$\dot{\mathbf{B}} = \underbrace{\nabla \times \nabla \times \dot{\mathcal{B}}\hat{\mathbf{z}}}_{\text{poloidal}} + \underbrace{\nabla \times \dot{\mathcal{J}}\hat{\mathbf{z}}}_{\text{toroidal}} \overbrace{= -c\nabla \times \mathbf{E}}^{\text{Faraday's Law}}$$

Uncurling Faraday's law: $c\mathbf{E} = -\nabla \times \dot{\mathcal{B}}\hat{\mathbf{z}} - \dot{\mathcal{J}}\hat{\mathbf{z}} - \nabla\psi = c\mathbf{E}^{P} - \nabla\psi$

$\mathbf{E}^{P}$ is inductive PTD electric field

$\nabla\psi$ - non-inductive electric field

To find $\mathbf{E}^{P}$

$$\nabla_h^2 \dot{\mathcal{B}} = -\dot{B}_z$$

$$\nabla_h^2 \dot{\mathcal{J}} = -\frac{4\pi}{c}\dot{j}_z = -\mathbf{z} \cdot \left(\nabla \times \dot{\mathbf{B}}_h\right)$$

$$\nabla_h^2 \frac{\partial \dot{\mathcal{B}}}{\partial z} = \nabla_h \cdot \dot{\mathbf{B}}_h \Rightarrow \dot{\mathcal{B}}, \dot{\mathcal{J}} \Rightarrow c\mathbf{E}^{\mathbf{P}}$$

PDFI electric field inversion method: main idea

Faraday's Law

Poloidal-Toroidal Decomposition (PTD,

$$\dot{\mathbf{B}} = \nabla\times\nabla\times\dot{\mathcal{B}}\hat{\mathbf{z}} + \nabla\times\dot{\mathcal{J}}\hat{\mathbf{z}} = -c\nabla\times\mathbf{E}$$

Uncurling

c field

To find E

field

$\nabla_h^2\dot{\mathcal{B}}$

$\nabla_h^2\dot{\mathcal{J}}$

$$\nabla_h^2\frac{\partial\dot{\mathcal{B}}}{\partial z} = \nabla_h\cdot\dot{\mathbf{B}}_h \Rightarrow \dot{\mathcal{B}},\dot{\mathcal{J}} \Rightarrow c\mathbf{E}^{\mathbf{P}}$$

The final electric field

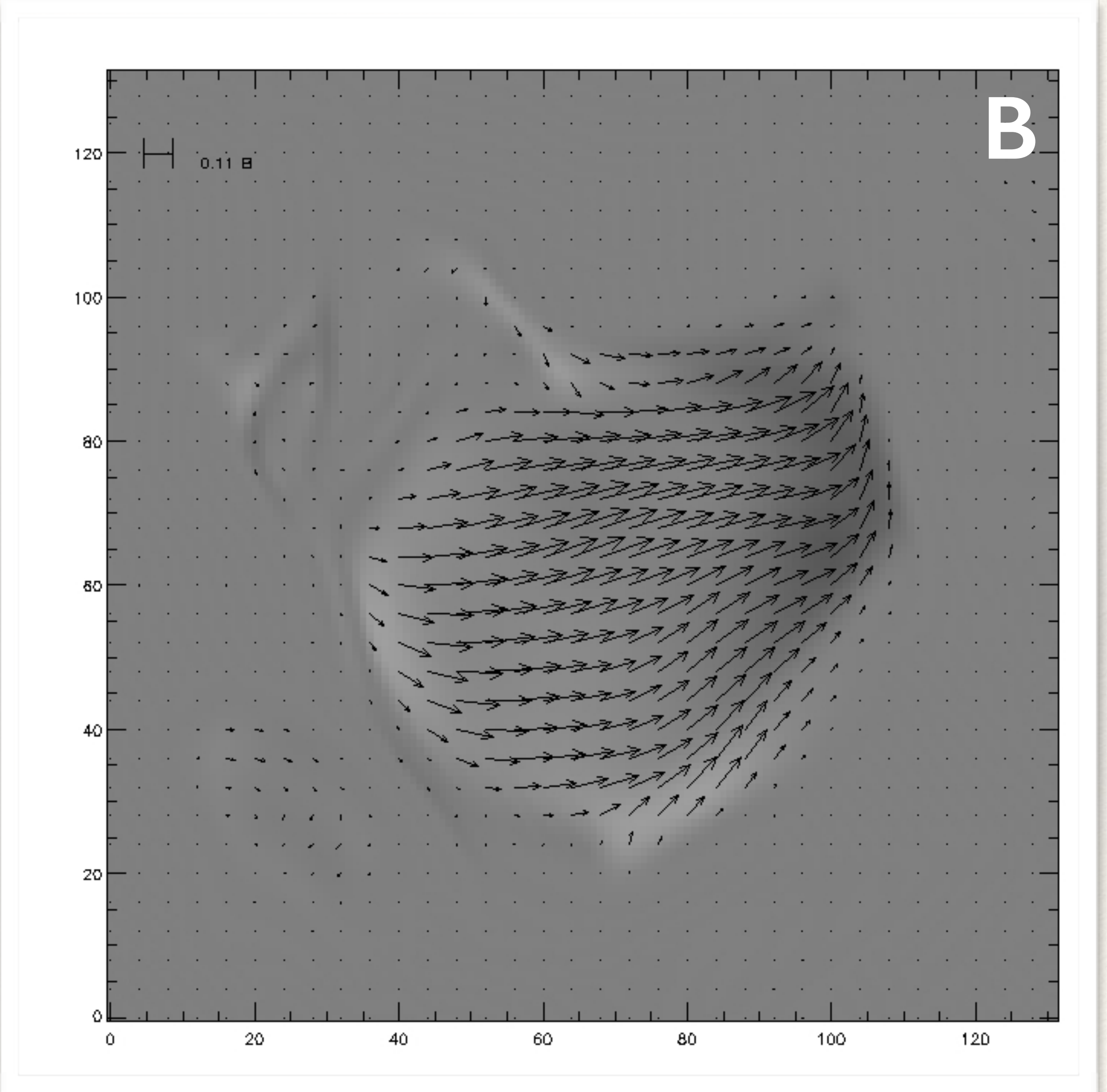
$$E = E_{PTD} + E_{Doppler} + E_{Horizontal\ flows} + \ldots$$

is called PDFI electric field.

Kazachenko et al. 2014

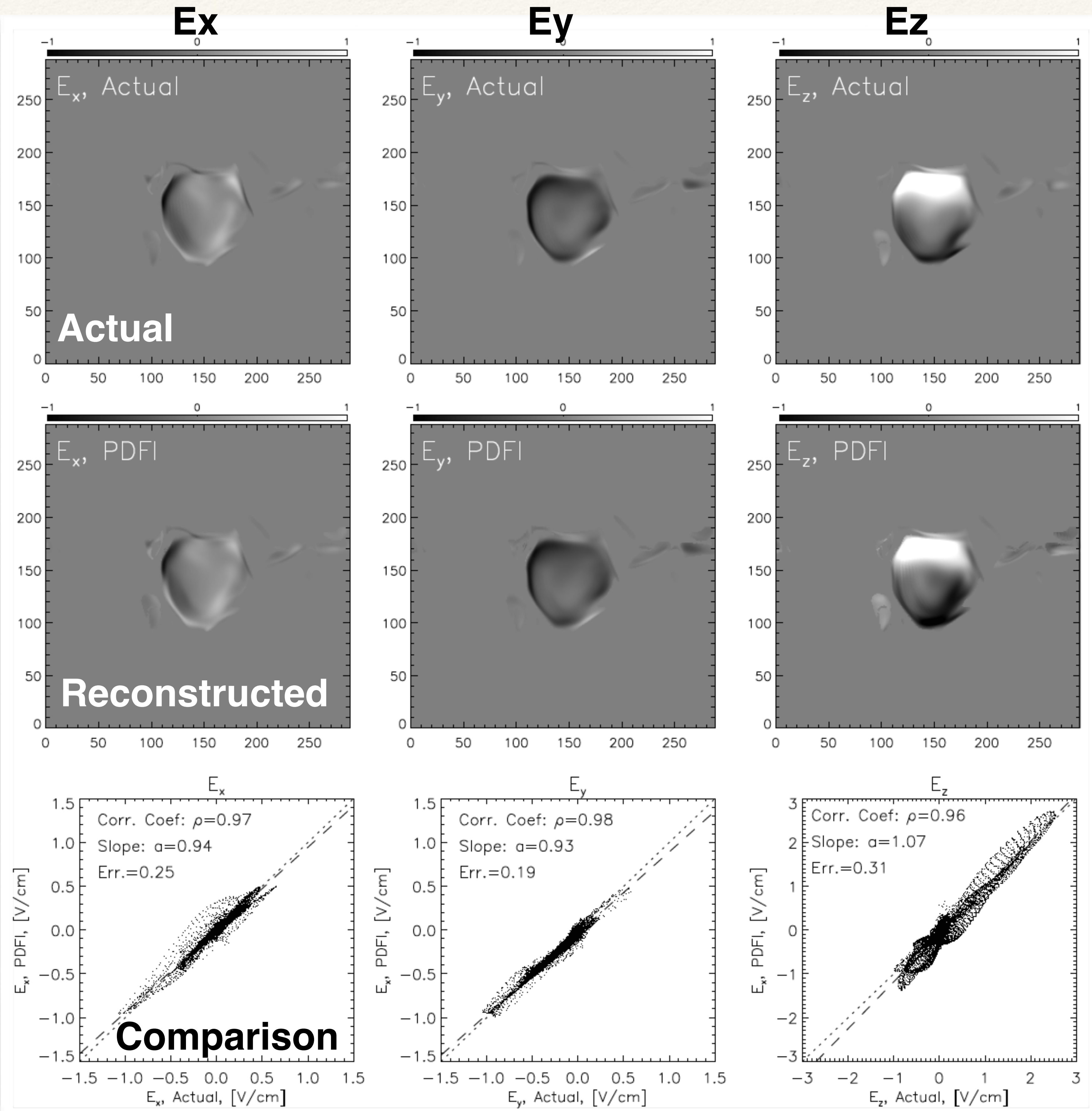
PDFI validation using MHD simulations

- Evolution of vector magnetic field in small "sunspot" emerging through convective zone
- Both **V** & **B** are known
- Common test case for validation of velocity inversions



Abbett, 2007

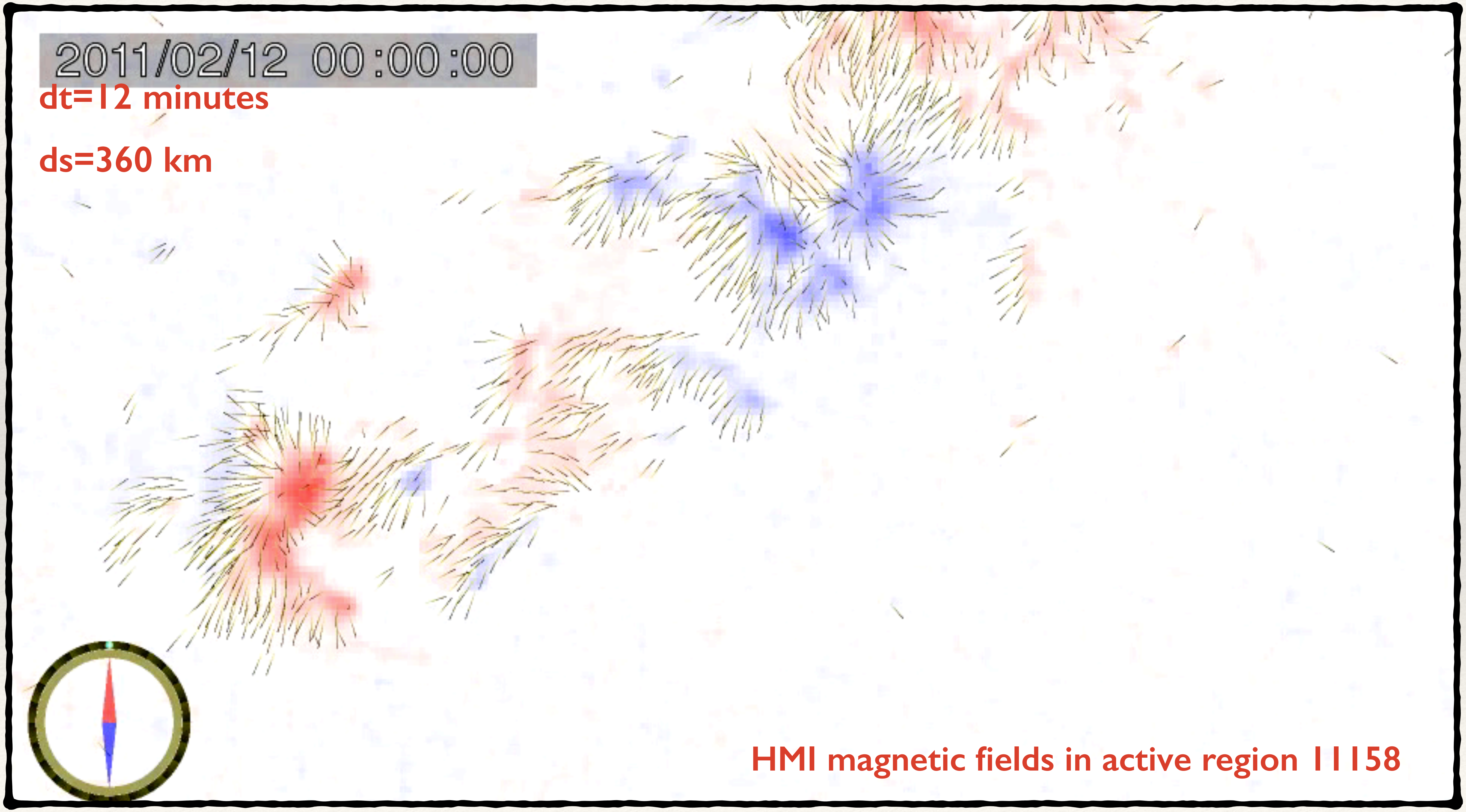
Electric field validation



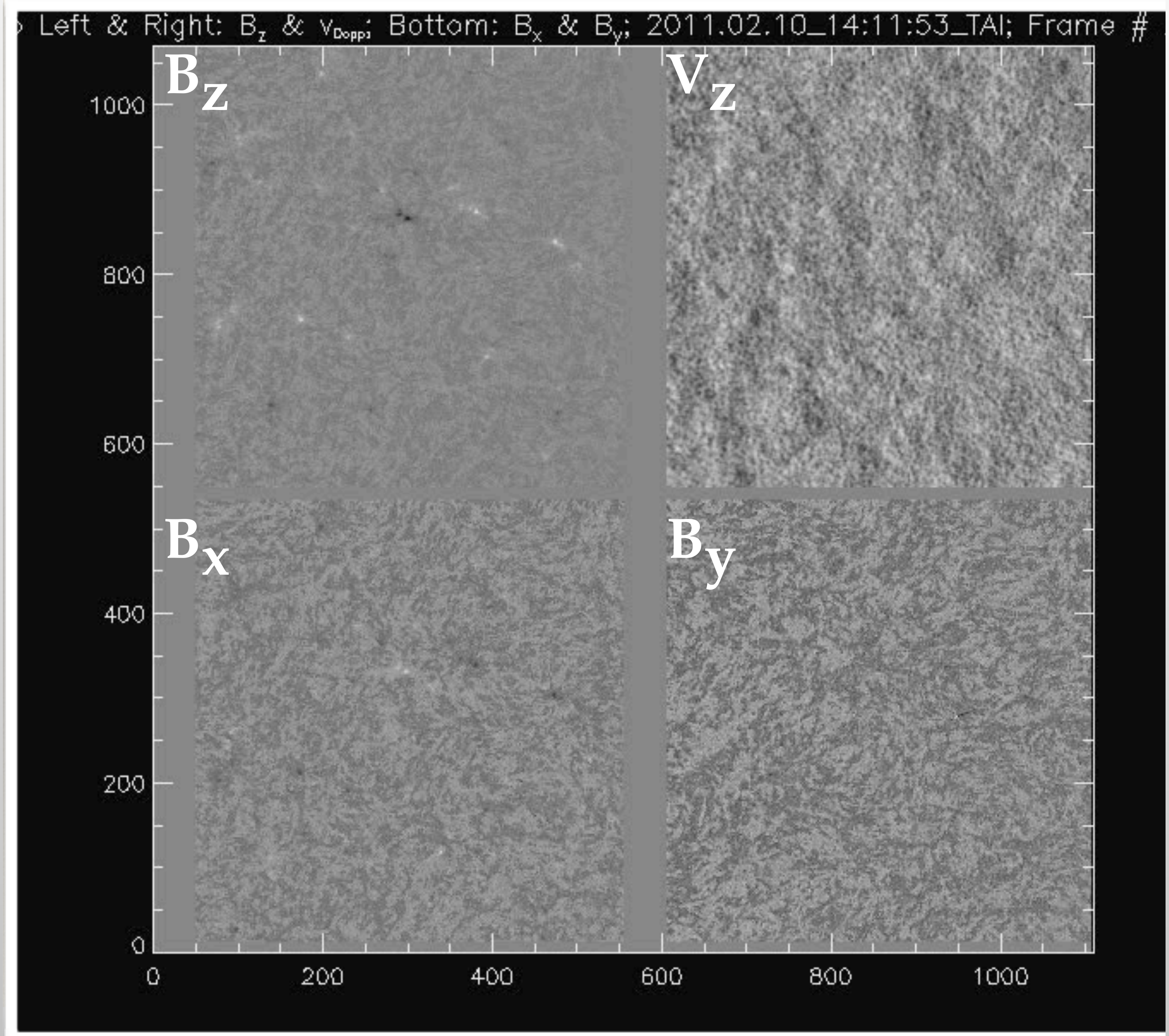
- Actual electric fields [Ex, Ey, Ez] from ANMHD test simulation
- Reconstructed [Ex, Ey, Ez] from the PDFI method
- Scatter plots of inverted versus actual electric field components

Kazachenko, Fisher, Welsch (2014)

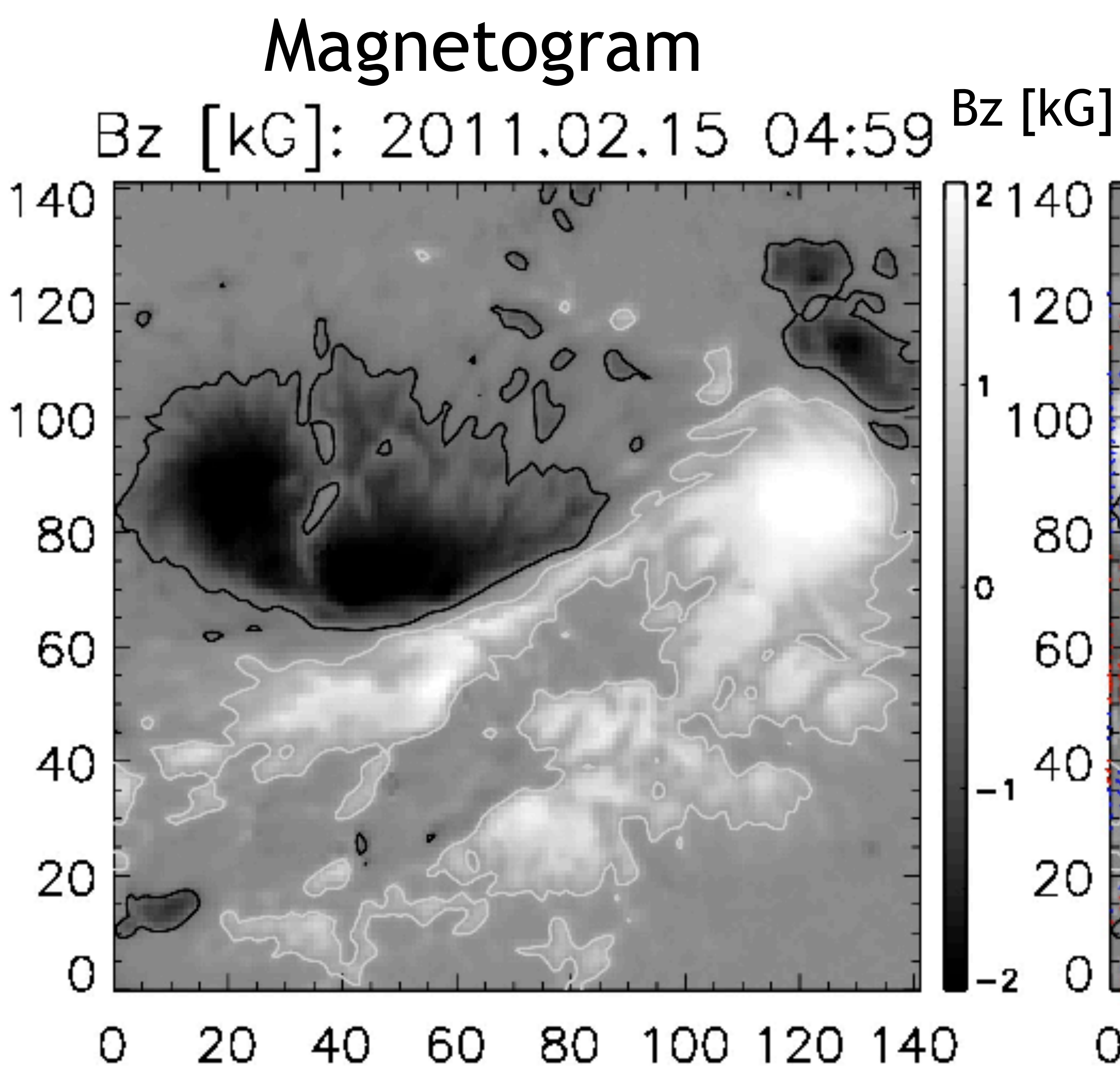
Solar Dynamics Observatory (SDO)
Vector Magnetic Fields

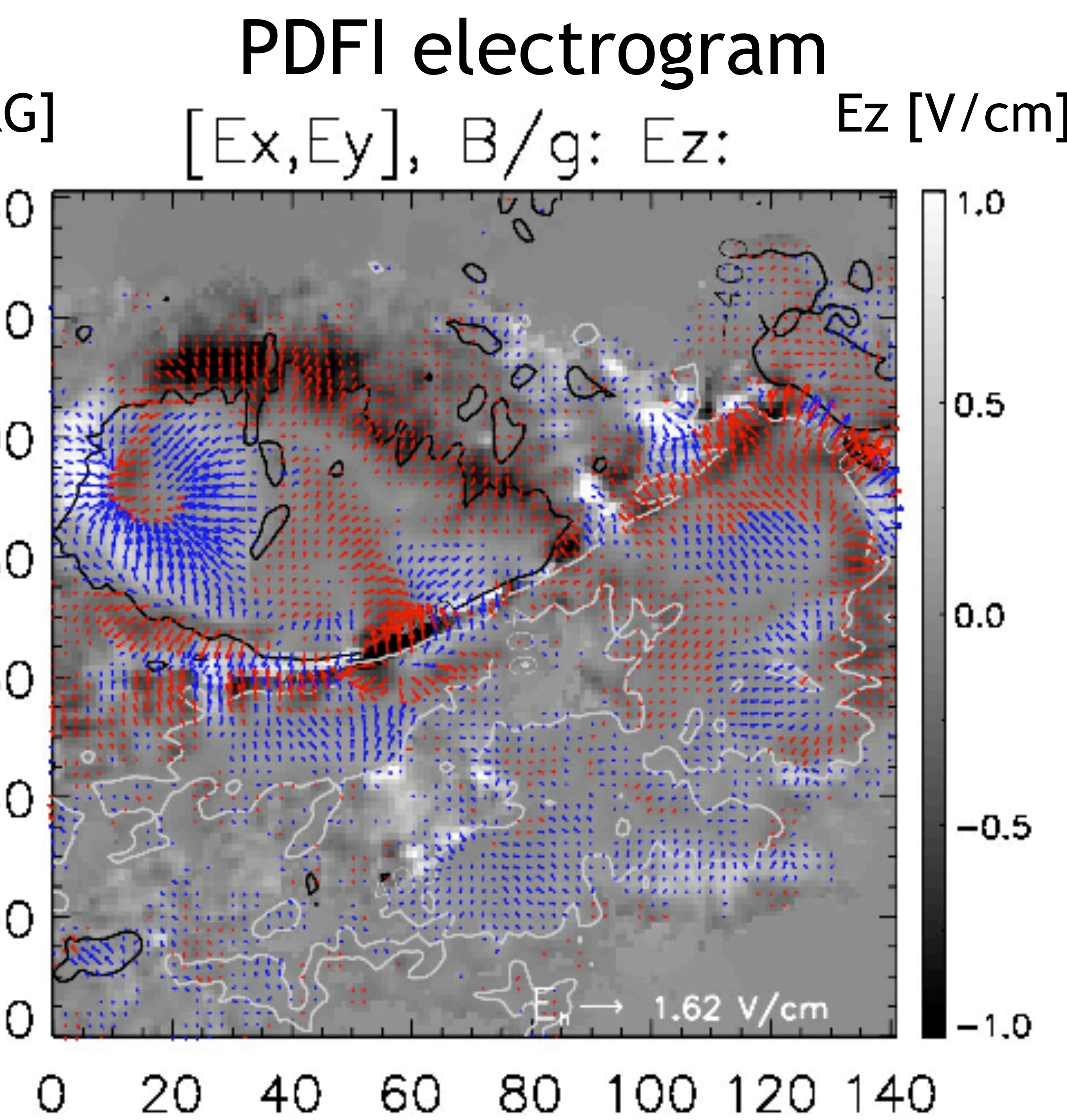


We Used B and Vz in AR11158 To Find First High Cadence Electric Fields



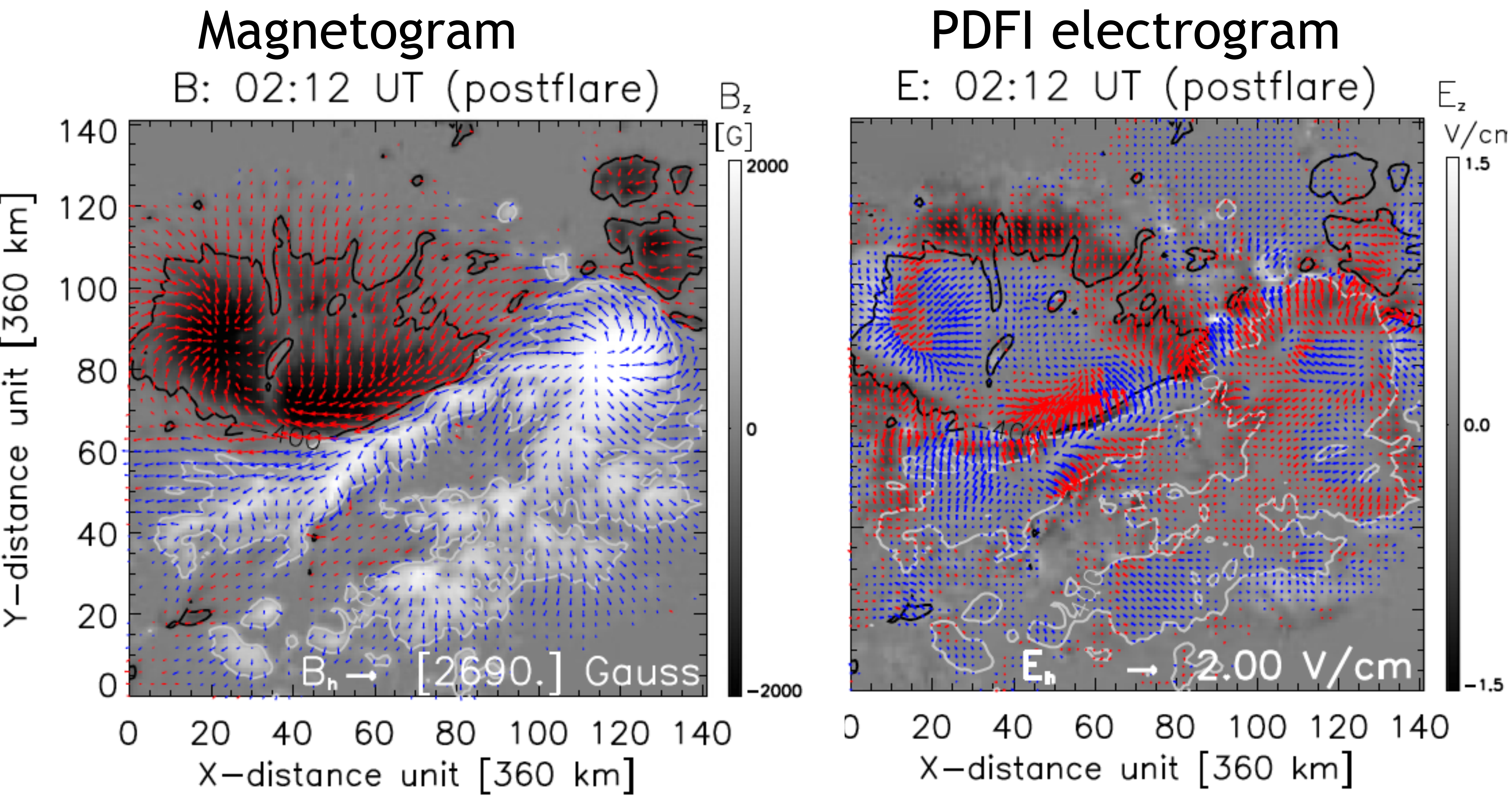
Observed Magnetogram and Derived Electrogram





Kazachenko et al. 2015

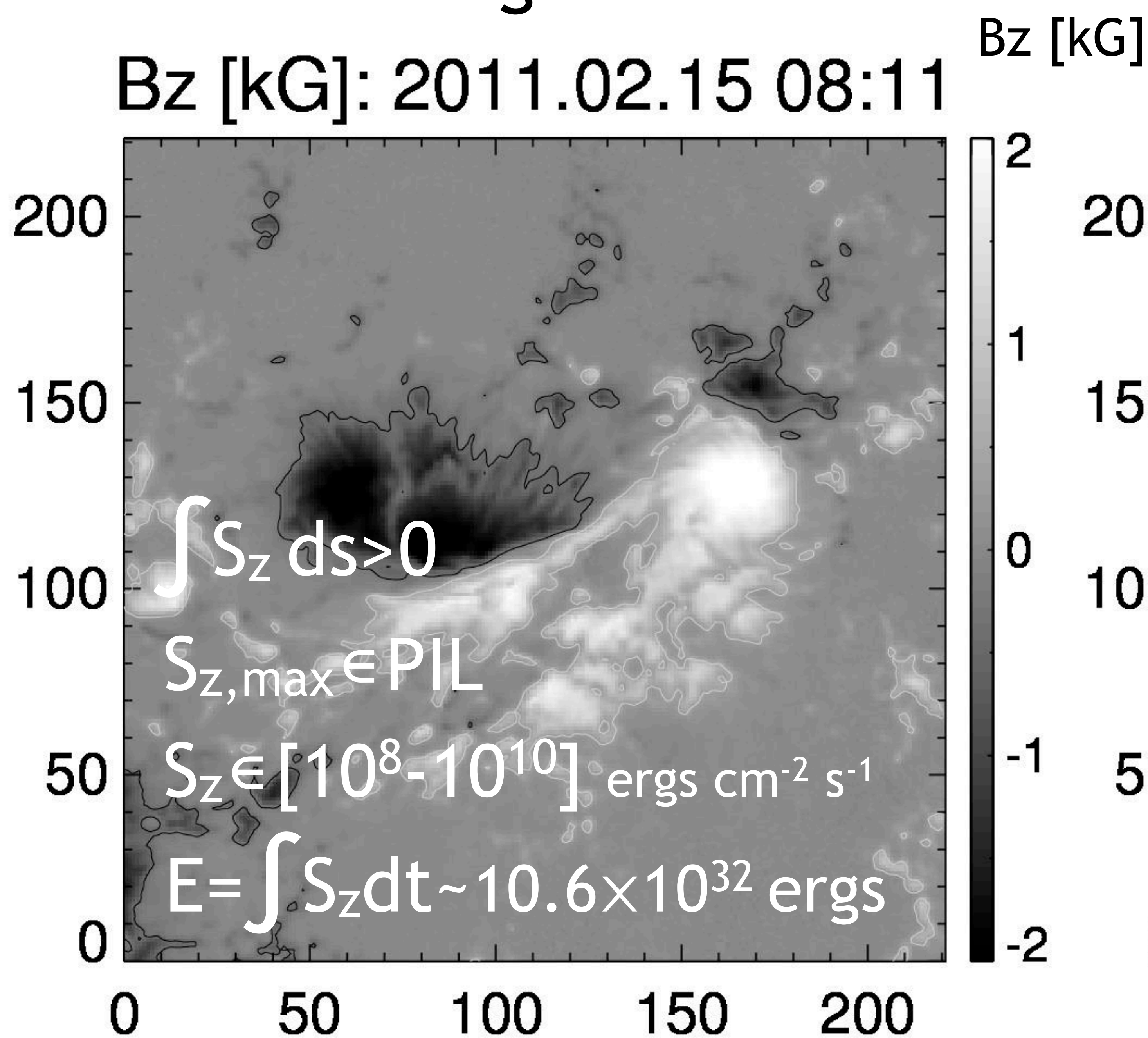
Single Snapshot of B and E



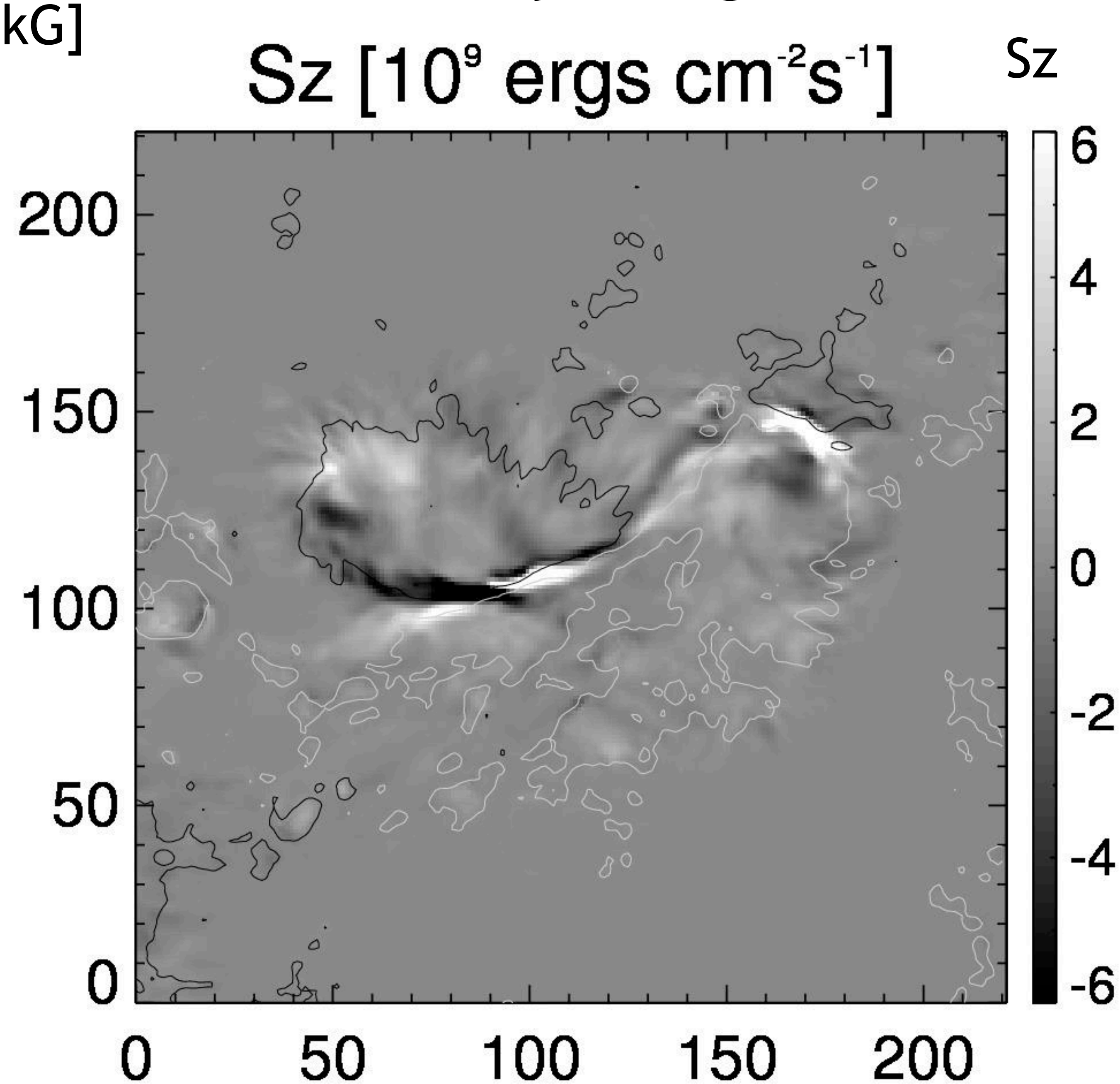
Kazachenko et al. 2015

Observed Magnetogram and Derived Energy Flux

Vertical magnetic field

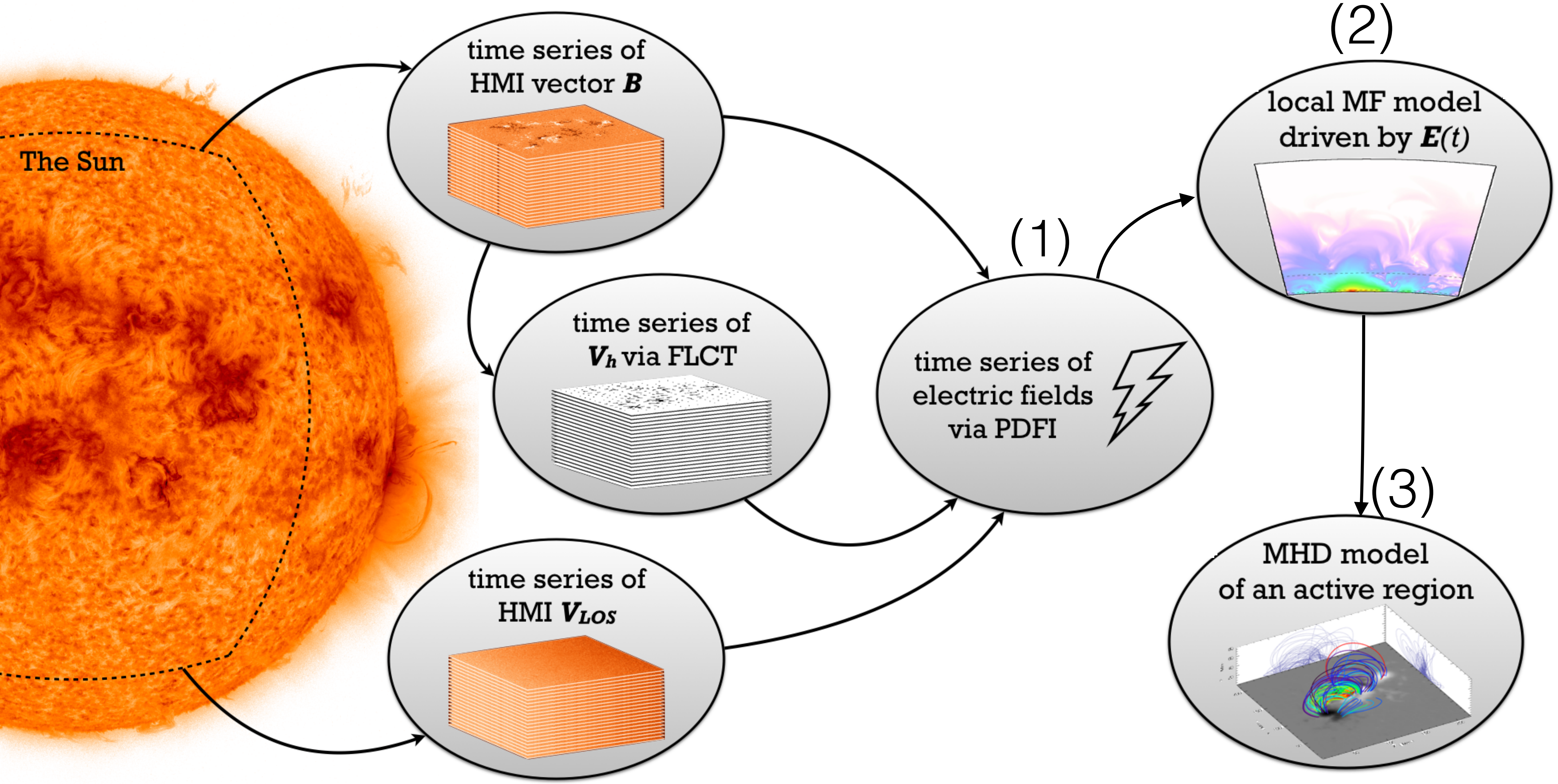


Vertical Poynting flux



Kazachenko et al. 2015

Driving Coronal Evolution With E and B: Coronal Global Evolutionary Model



Magnetofrictional Model: Main Idea

1. Evolve coronal field using induction equation:

$$\partial A/\partial t = V \times B - \eta J,$$

where $B = \nabla x A$, η — magnetic diffusivity,

V - plasma velocity

$J = \nabla x B$ — current density

2. Set velocity proportional to Lorentz force:

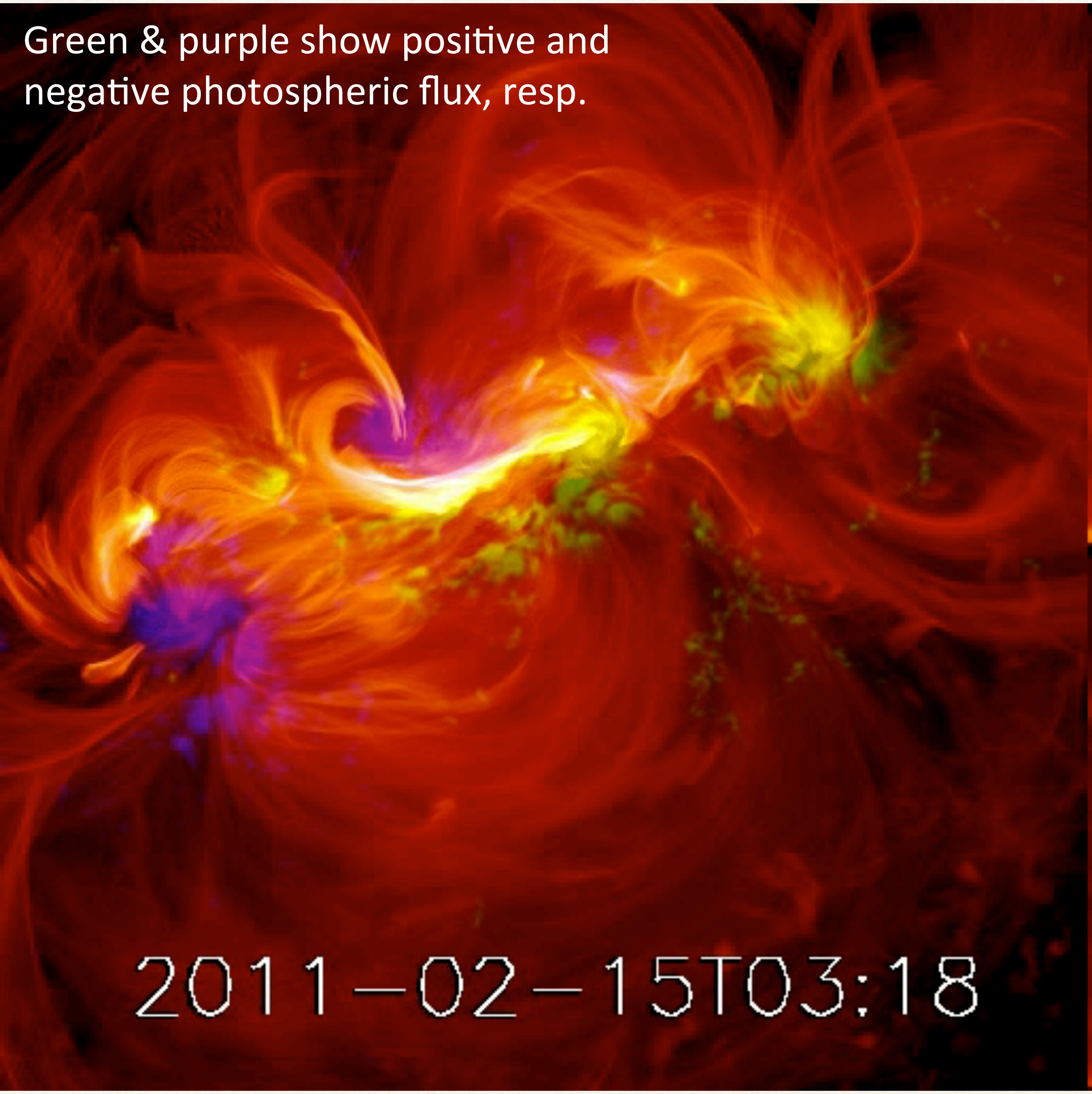
$$V = J \times B/\nu_0,$$

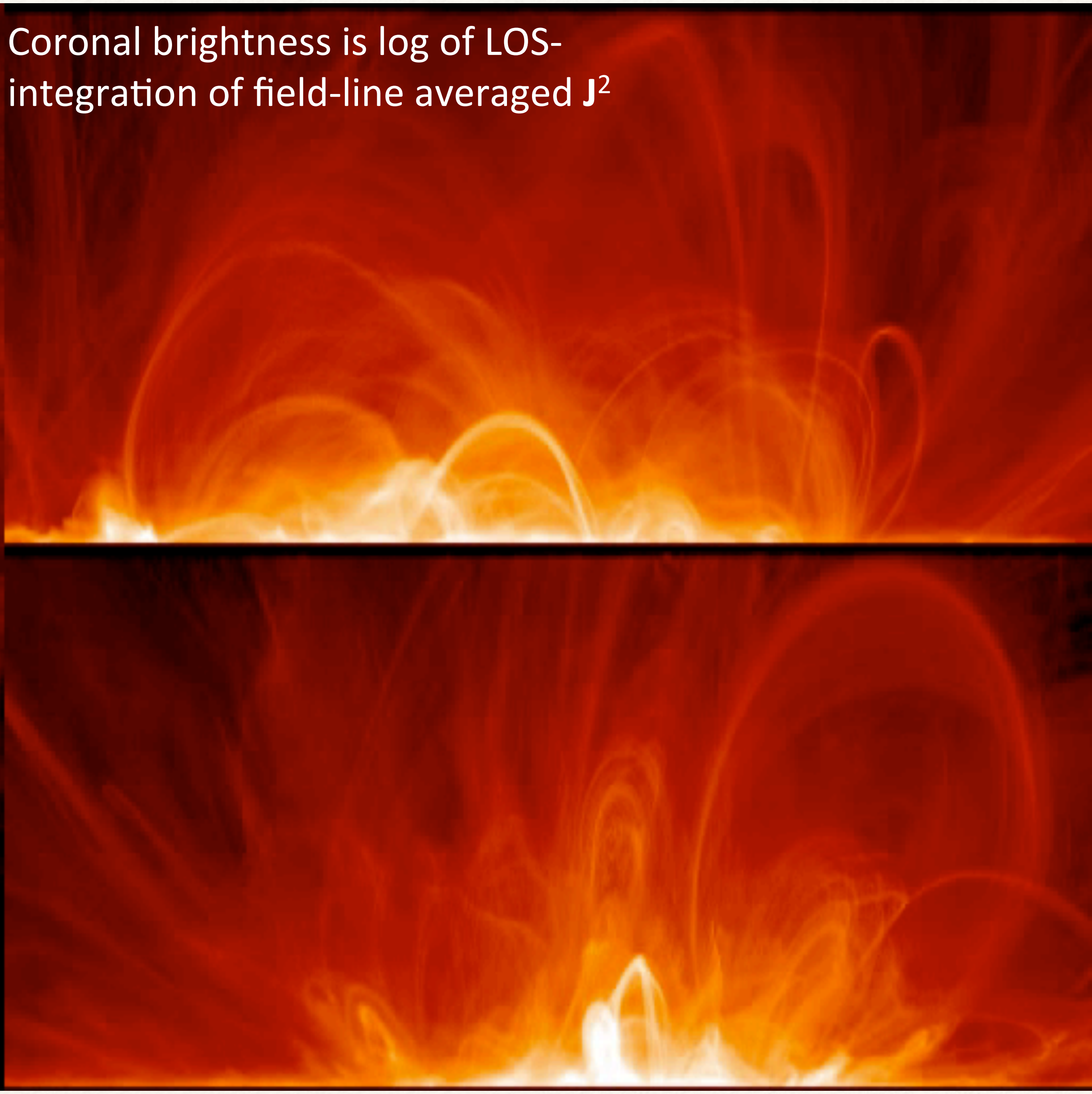
where ν_0 — magnetofrictional coefficient

3. For boundary conditions use $Eh = \partial A_h/\partial t$ from PDFI

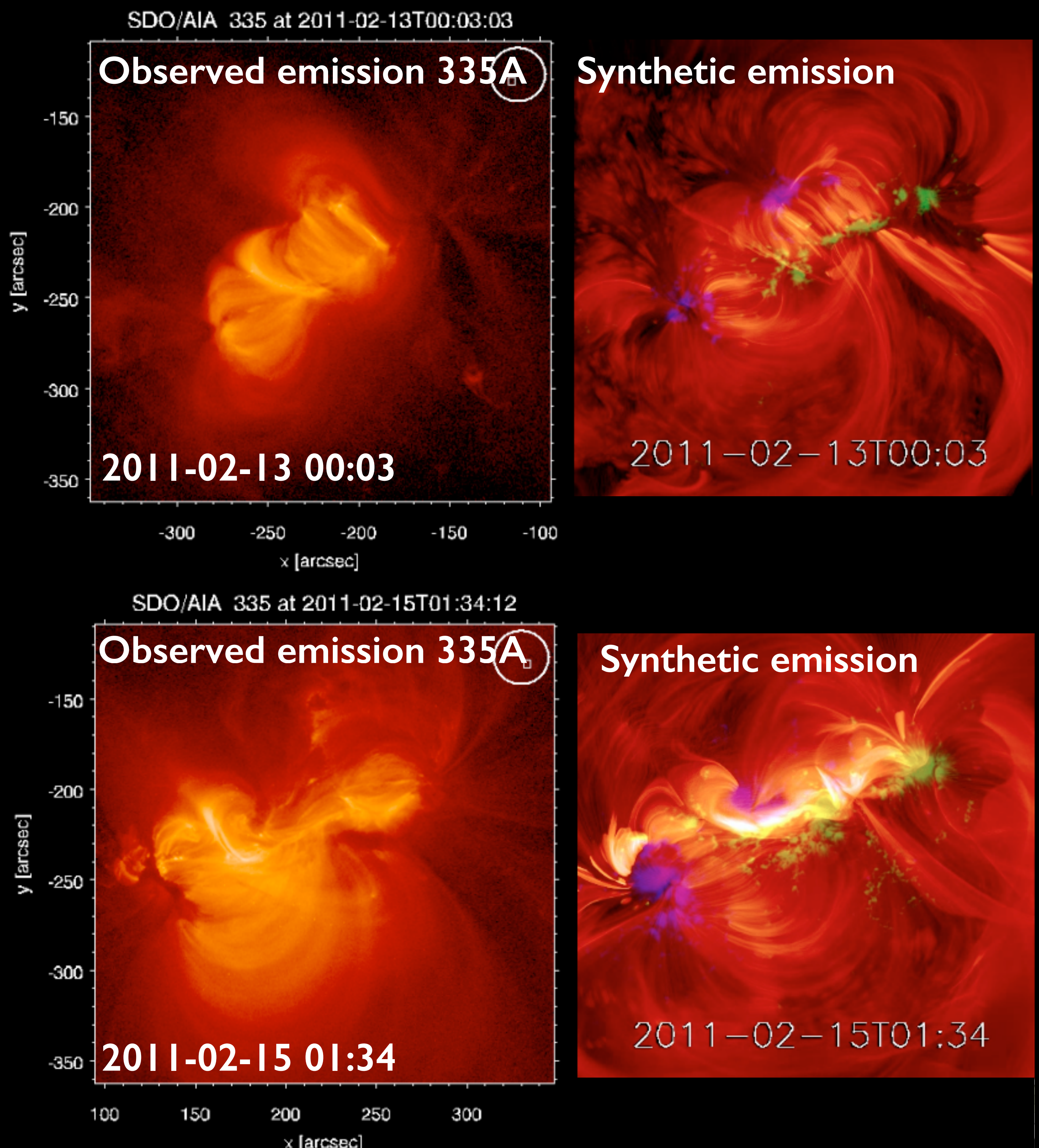
Cheung & DeRosa 2012

Coronal Field Model of AR 11158 Driven by Photospheric B and E

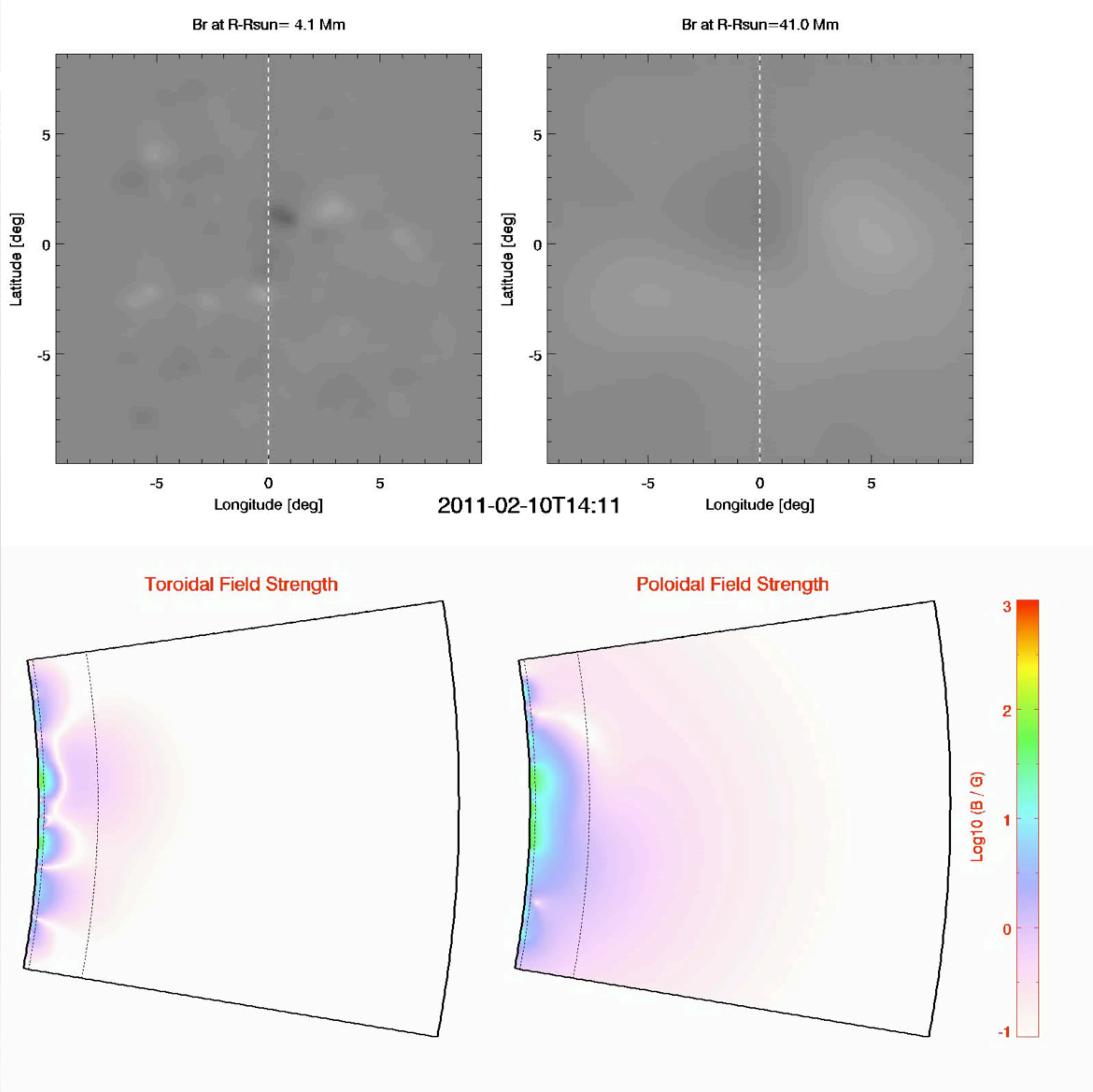




Validation: Observed Versus Synthetic Intensities



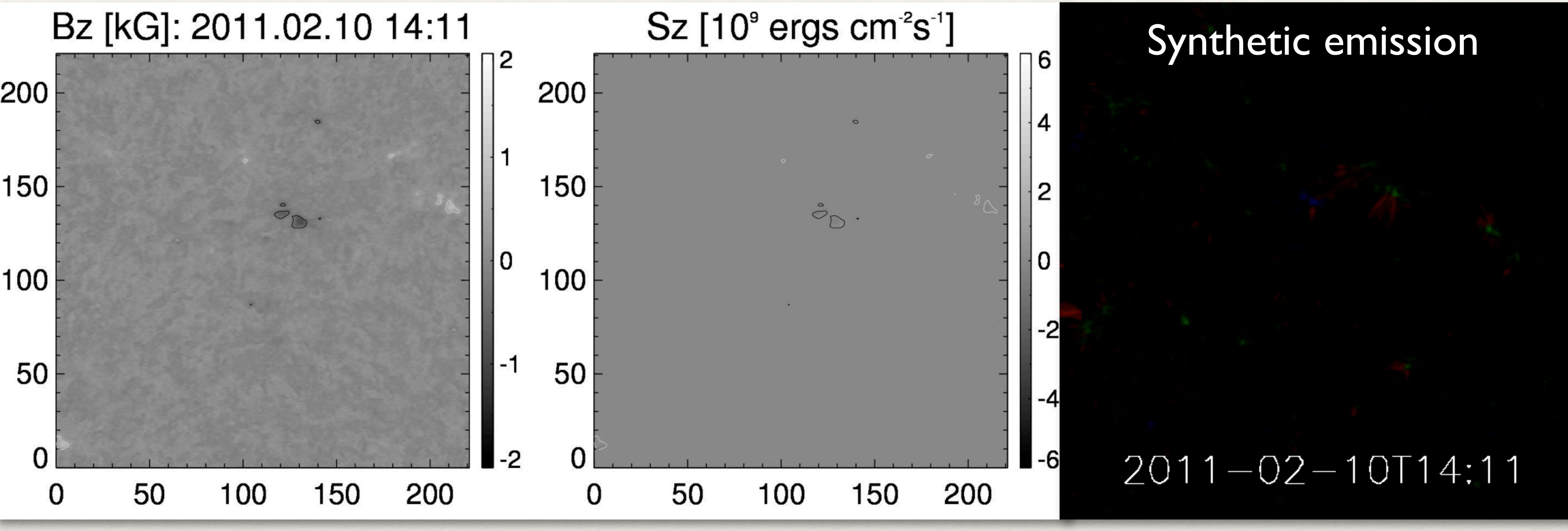
Coronal Field Model In Spherical Coordinates



- Global J
- Better condition for local-scale simulations.
- Improve accuracy of solar wind prediction

cgem.ssl.berkeley.edu,

Main Ideas



PDFI - new method for deriving electric fields.

PDFI allowed us to:

- Estimate E(x,y,t), S(x,y,t)
- Do data-driven simulations of coronal B and build-up currents.

Спасибо!