Can we drive coronal evolution models from magnetic maps?

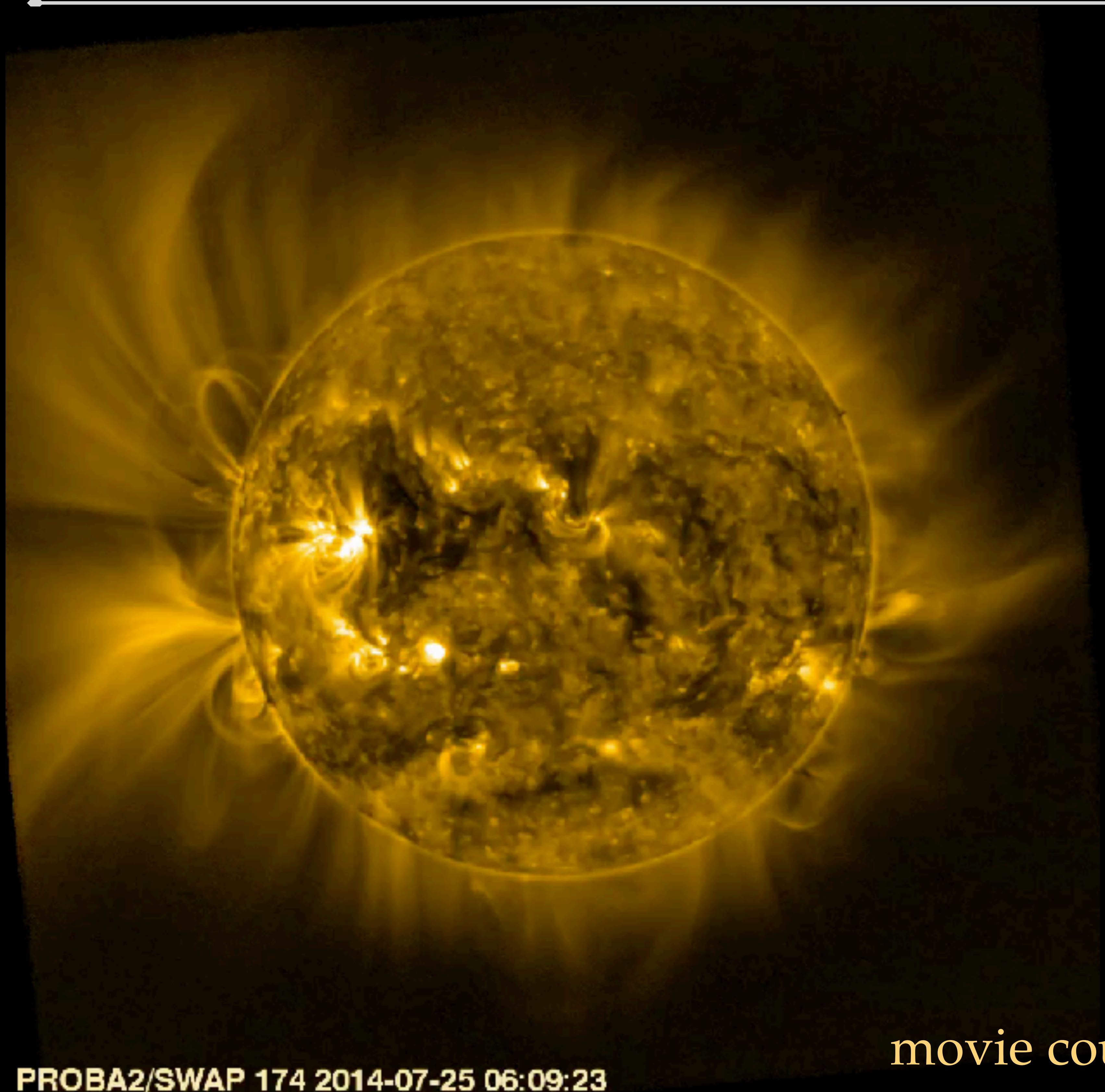
Durham University

Anthony Yeates

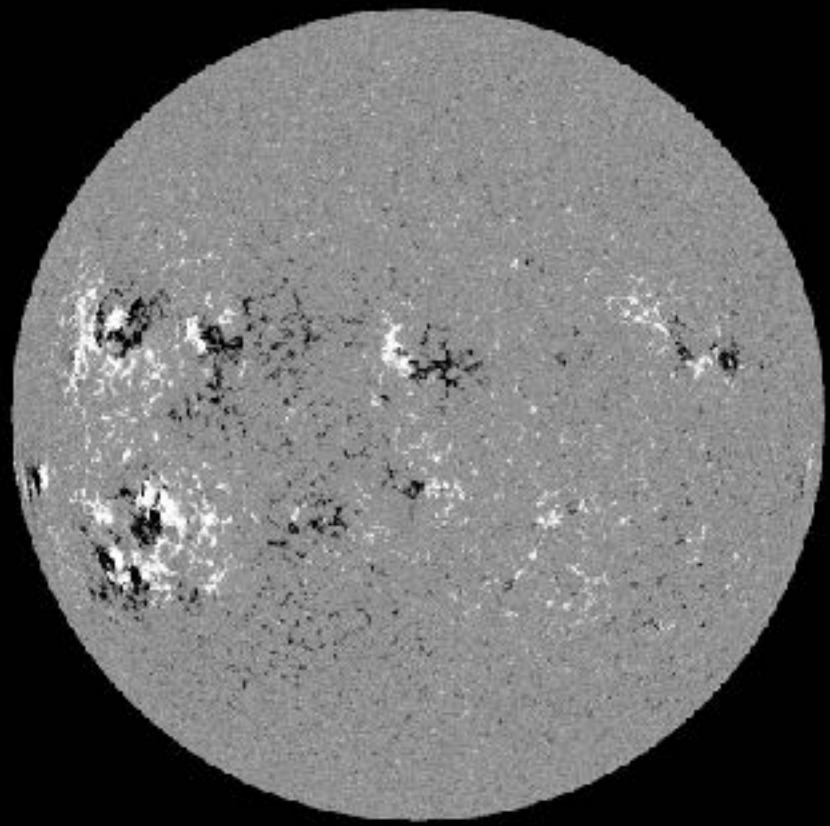
with thanks to
Lisa Upton (HAO), **Mark Cheung** (Lockheed-Martin)

National Astronomy Meeting, Hull, 04-Jul-2017

Why evolution?

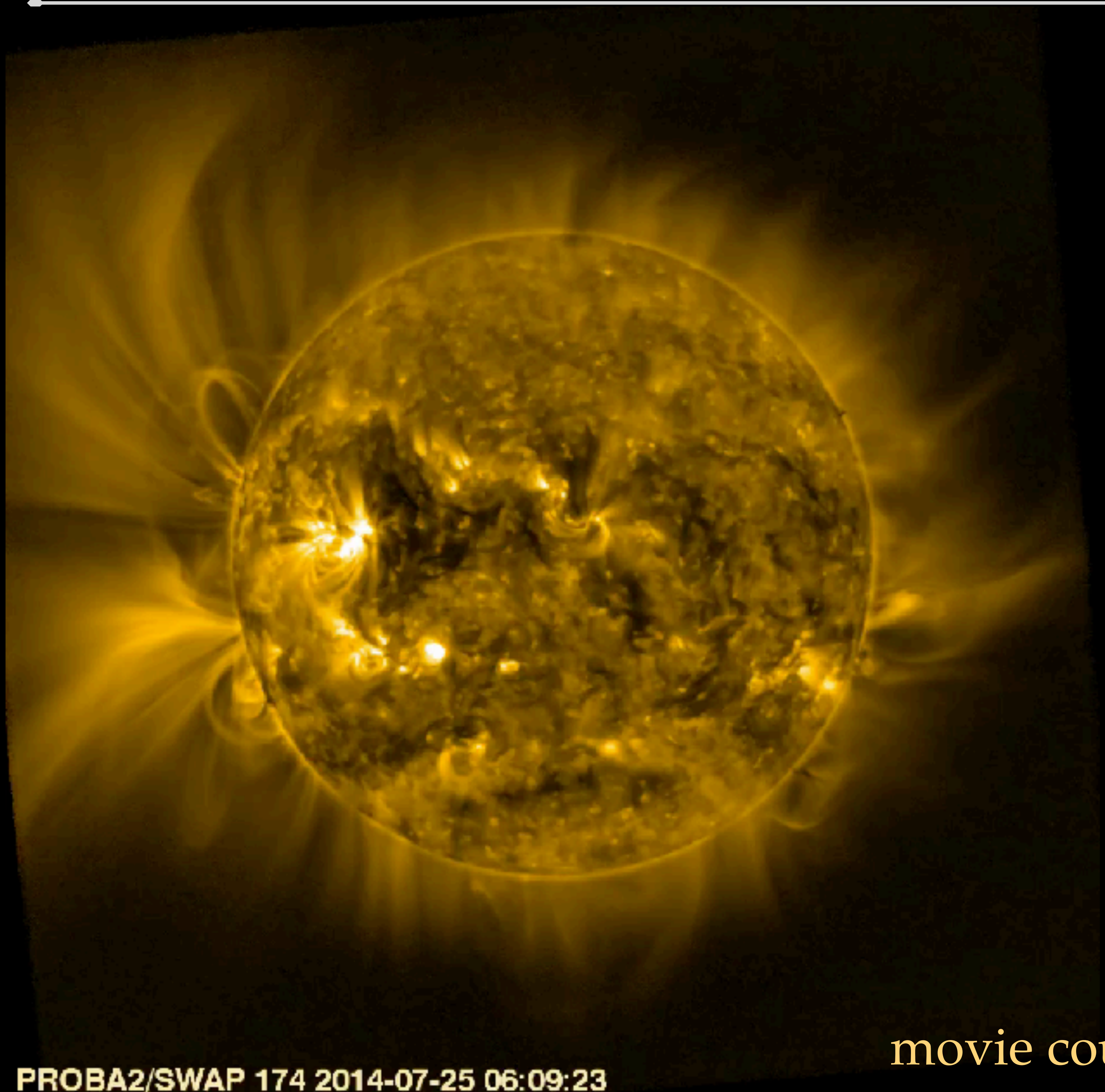


- Use sequence of photospheric magnetograms to build up stress gradually.

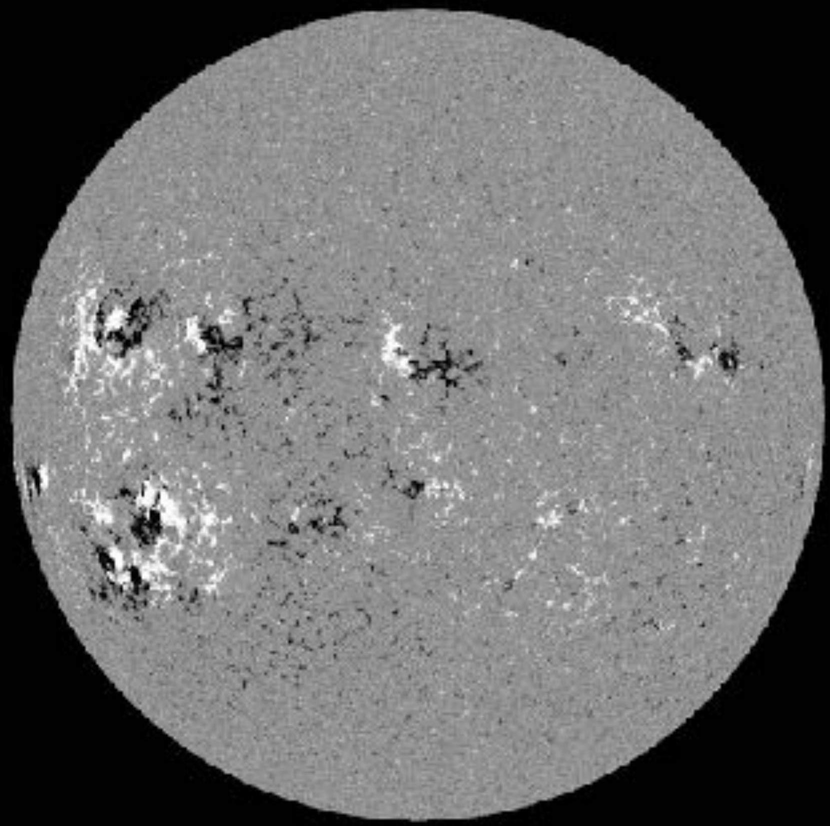


movie courtesy D. Seaton

Why evolution?



- Use sequence of photospheric magnetograms to build up stress gradually.

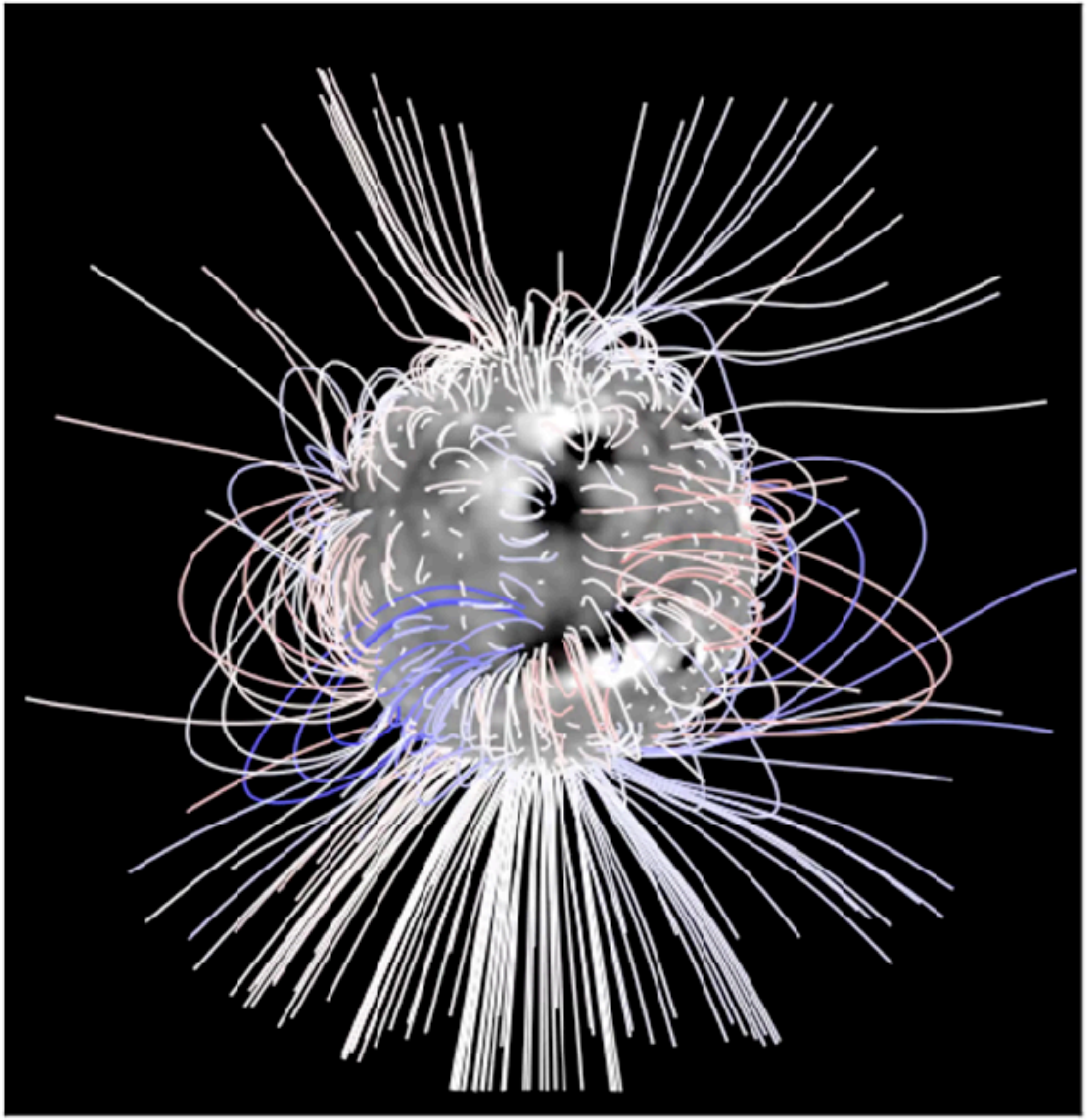


movie courtesy D. Seaton

How do currents build up?

- Flux emergence and photospheric footpoint motions.

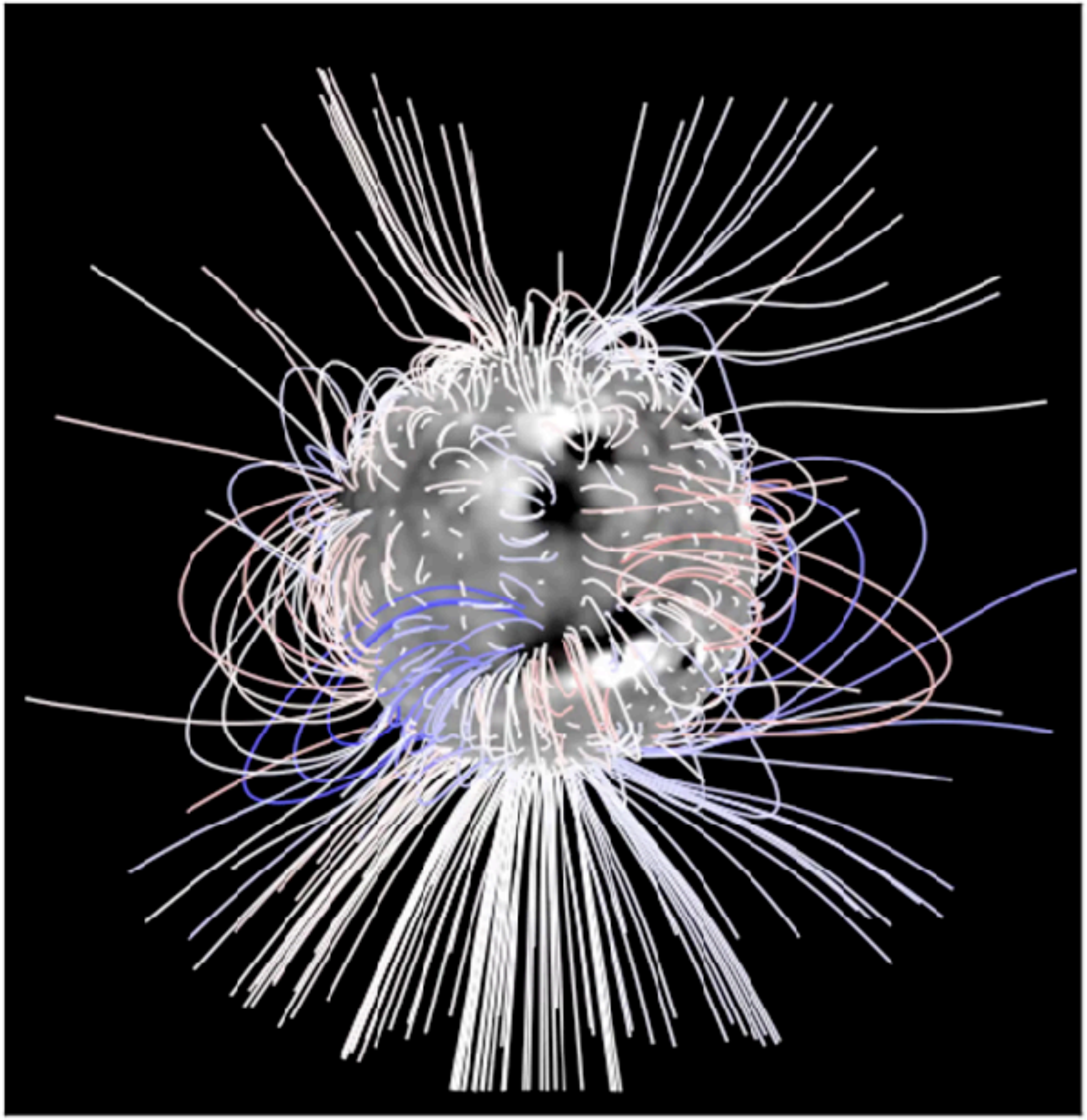
e.g. Yeates & Hornig, *A&A* (2016), coloured by field line helicity:



How do currents build up?

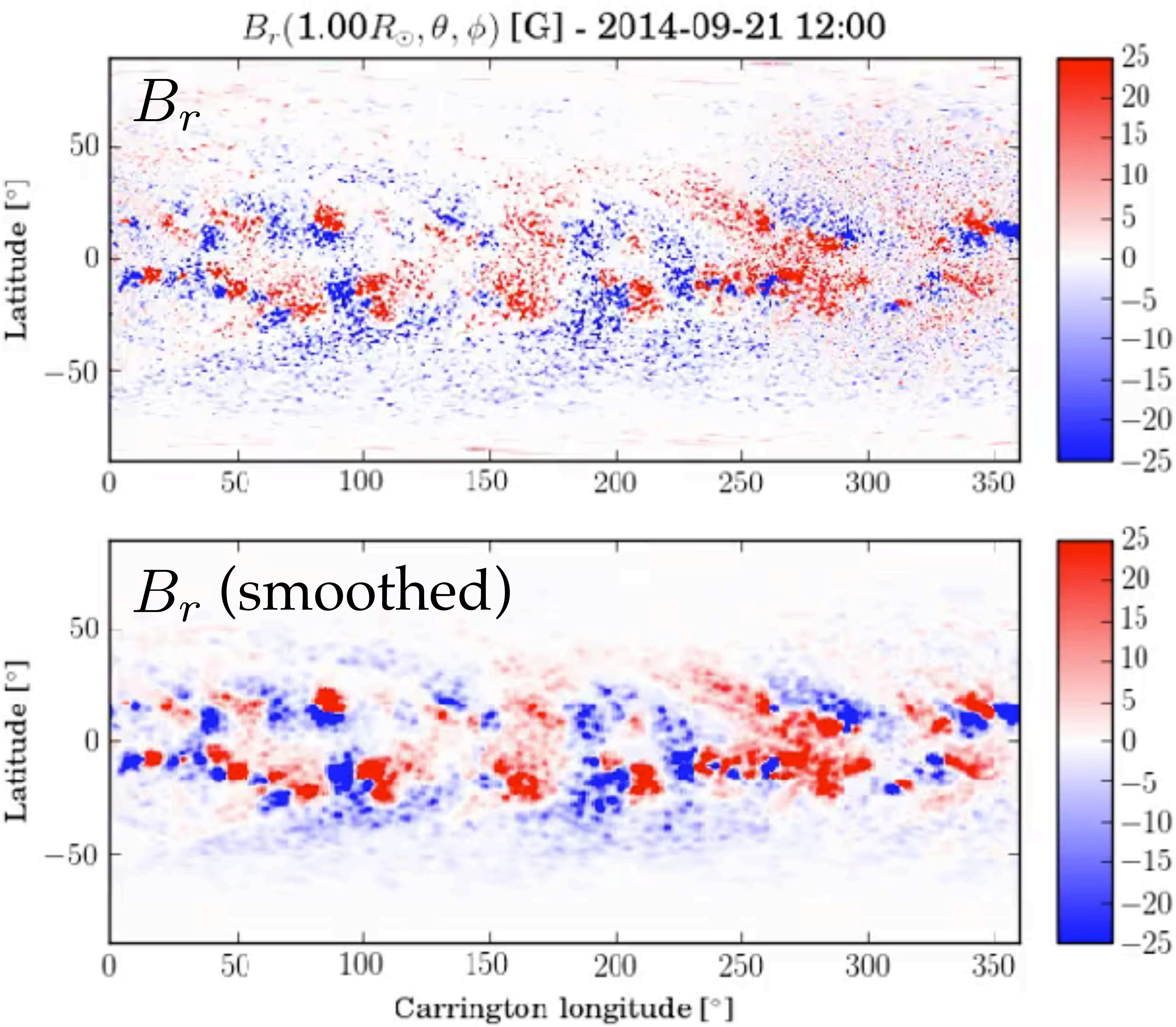
- Flux emergence and photospheric footpoint motions.

e.g. Yeates & Hornig, *A&A* (2016), coloured by field line helicity:



Example: Advective Flux Transport model

- Surface flux transport + magnetogram assimilation.

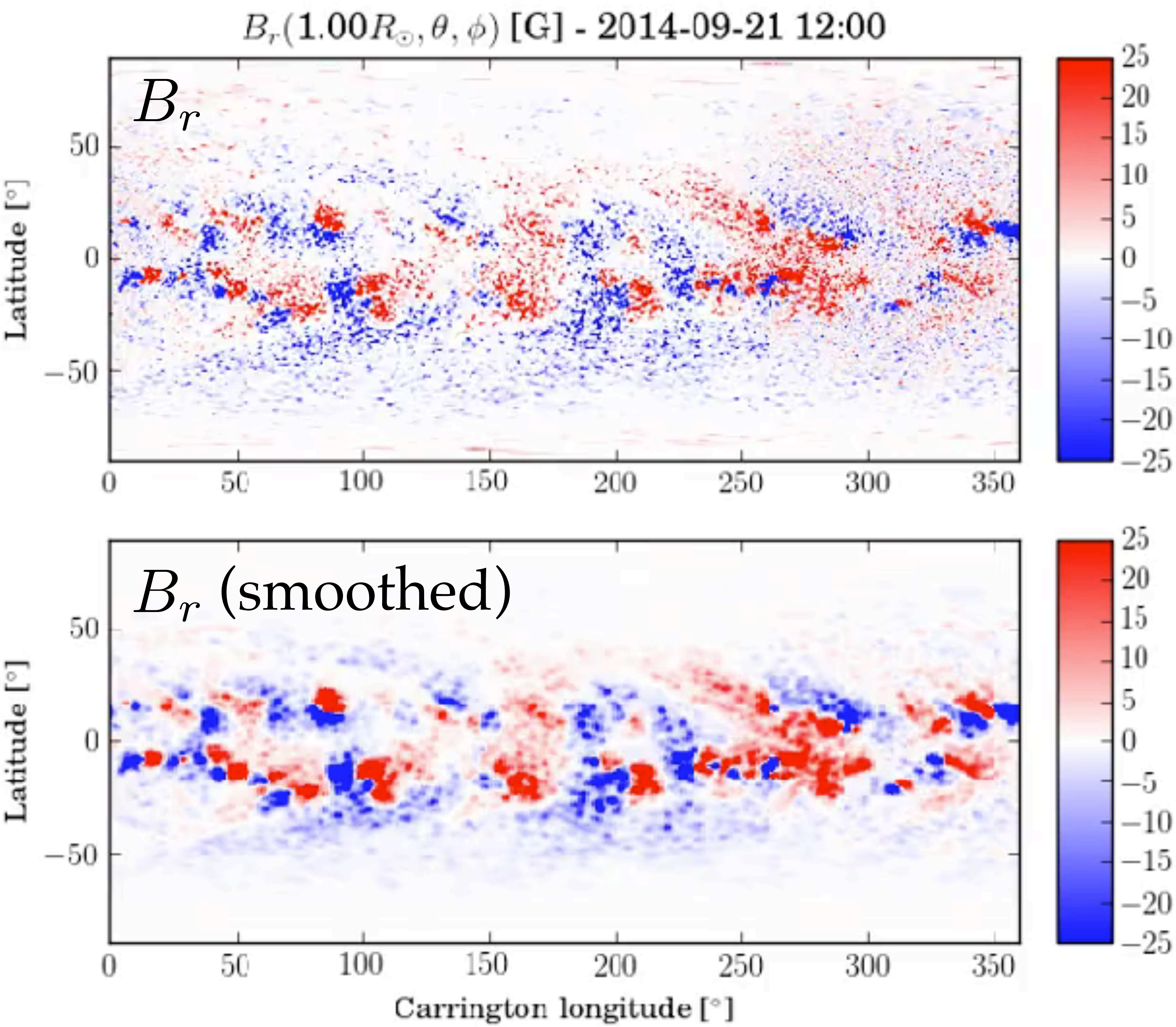


Upton & Hathaway, *ApJ* (2014)

- Imposed large-scale flows (from observational tracking).
- Explicit convective flows (not diffusion).

Example: Advective Flux Transport model

- Surface flux transport + magnetogram assimilation.



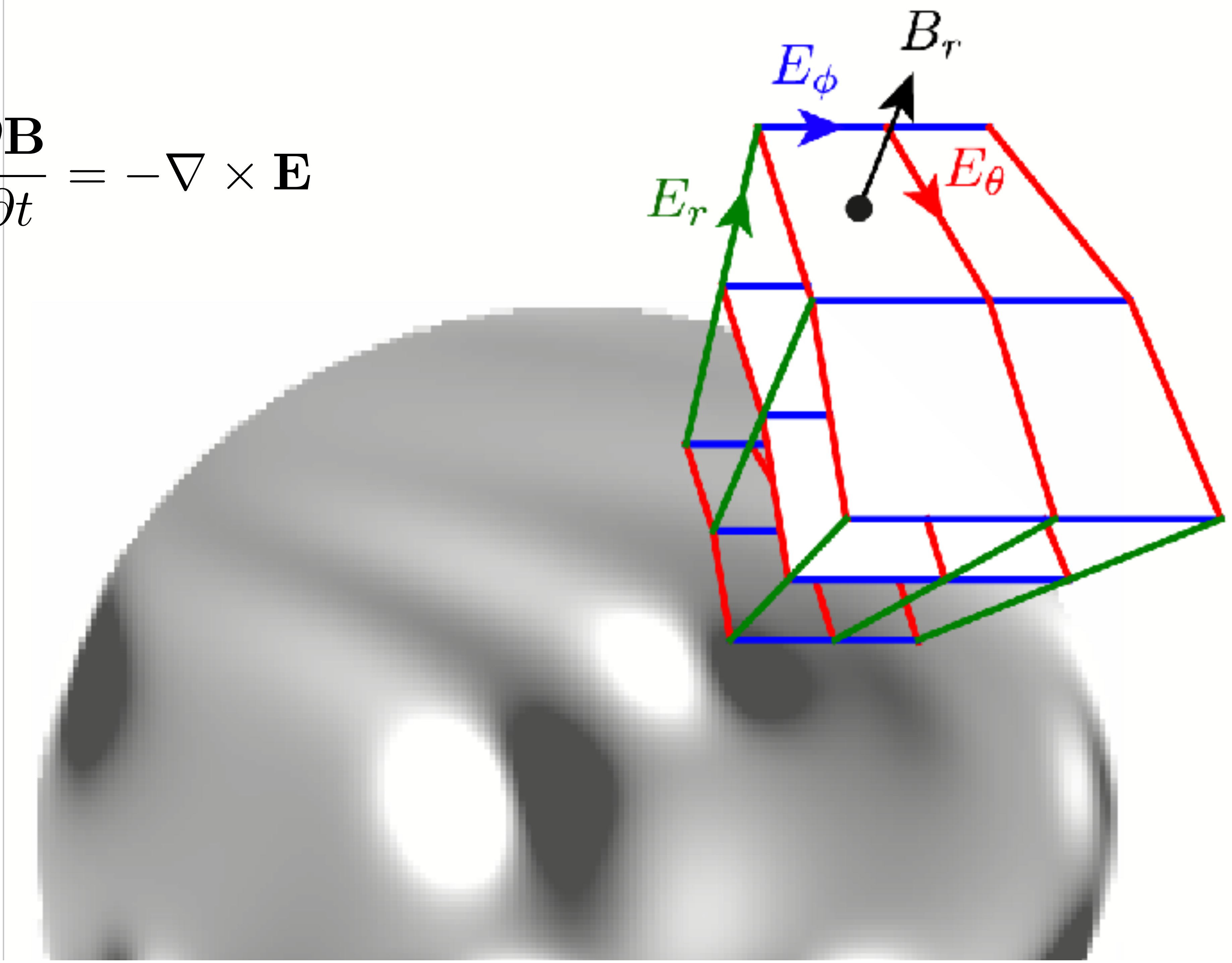
Upton & Hathaway, *ApJ* (2014)

- Imposed large-scale flows (from observational tracking).
- Explicit convective flows (not diffusion).

Required boundary conditions: E_θ, E_ϕ

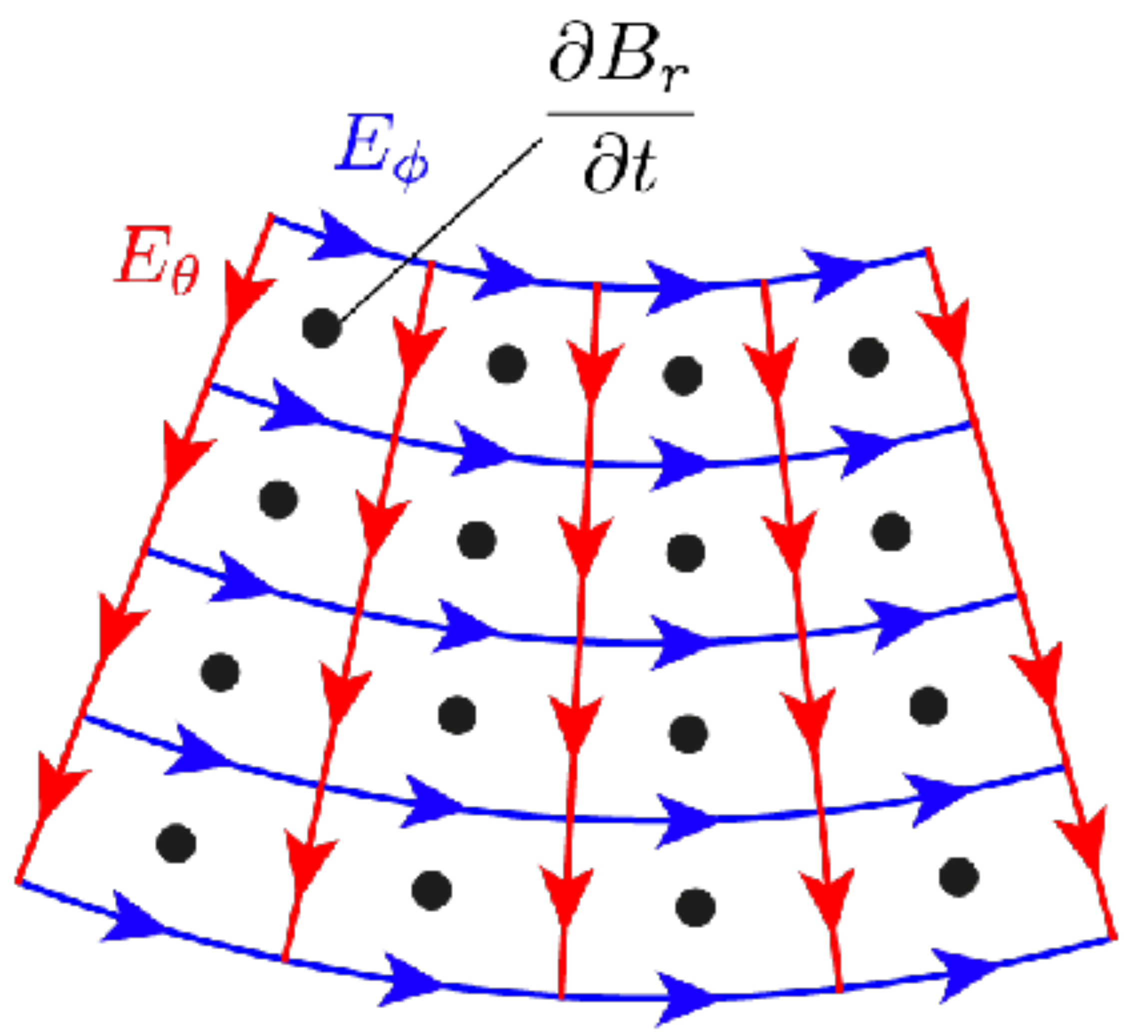
- Staggered grid (Yee, *IEEE Trans. Antenn. Prop.*, 1966).

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



Non-uniqueness of E

- For given $\frac{\partial B_r}{\partial t}$ the solution of $\mathbf{E}_\perp$ is not unique.
- i.e. we cannot uniquely invert Faraday's law: $\frac{\partial B_r}{\partial t} = -\hat{\mathbf{r}} \cdot \nabla \times \mathbf{E}_\perp$



The "inductive" solution

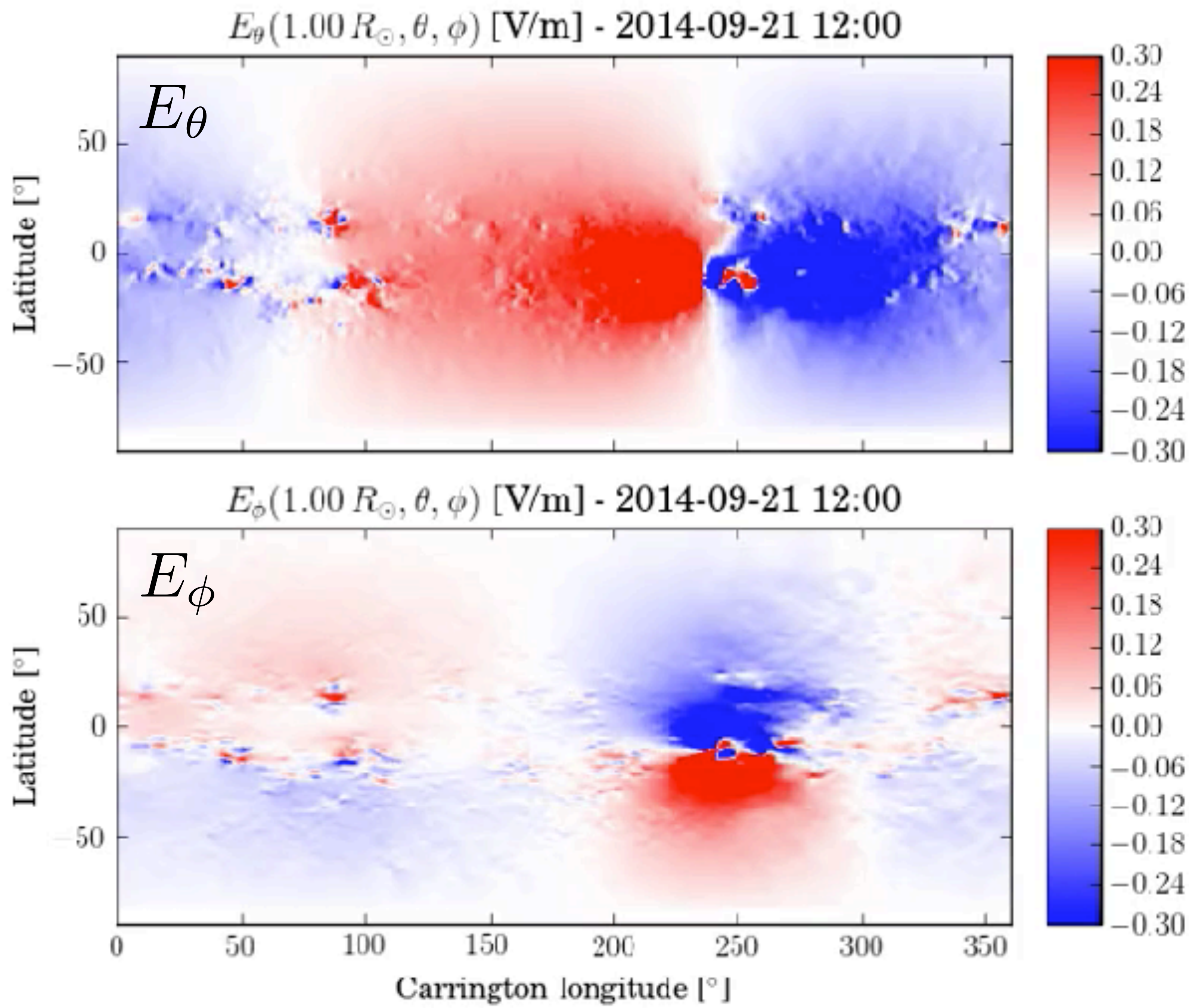
- Simplest solution: minimize $\|\mathbf{E}_\perp\|_2 := \left[\sum_{\theta,\phi}\left\{(\ell_\theta\,E_\theta)^2 + (\ell_\phi\,E_\phi)^2\right\}\right]^{1/2}$

  e.g. Mikić et al., *PoP* (1999);
  Amari et al., *ApJ* (2003);
  Mackay et al., *ApJ* (2011);
  Yang et al., *JGR* (2012)

The “inductive” solution

- Simplest solution: minimize $\|\mathbf{E}_\perp\|_2 := \left[\sum_{\theta,\phi}\left\{(\ell_\theta\, E_\theta)^2 + (\ell_\phi\, E_\phi)^2\right\}\right]^{1/2}$

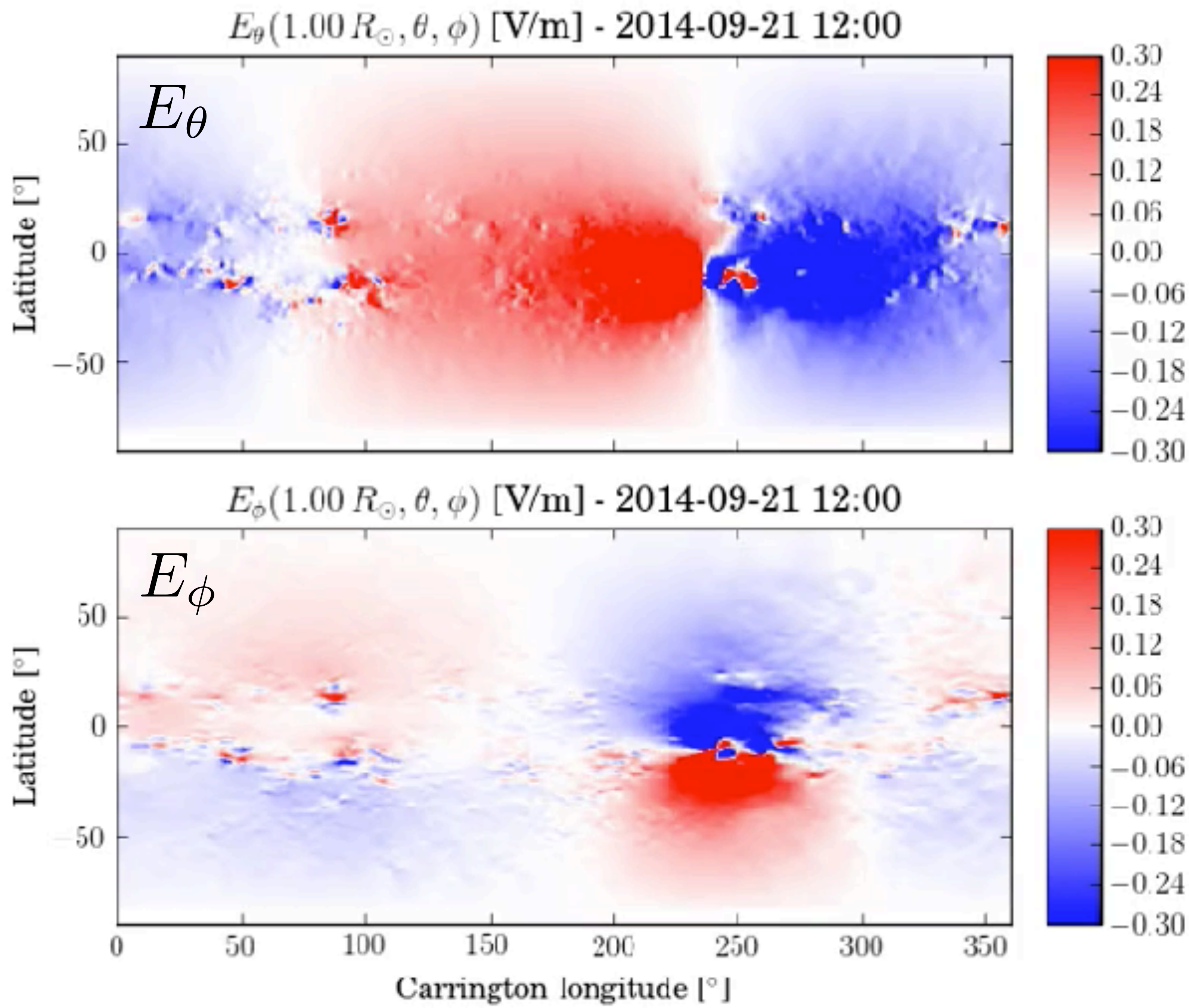
  e.g. Mikić et al., *PoP* (1999);
  Amari et al., *ApJ* (2003);
  Mackay et al., *ApJ* (2011);
  Yang et al., *JGR* (2012)



The “inductive” solution

- Simplest solution: minimize $\|\mathbf{E}_\perp\|_2 := \left[\sum_{\theta,\phi}\left\{(\ell_\theta\, E_\theta)^2 + (\ell_\phi\, E_\phi)^2\right\}\right]^{1/2}$

  e.g. Mikić et al., *PoP* (1999);
  Amari et al., *ApJ* (2003);
  Mackay et al., *ApJ* (2011);
  Yang et al., *JGR* (2012)

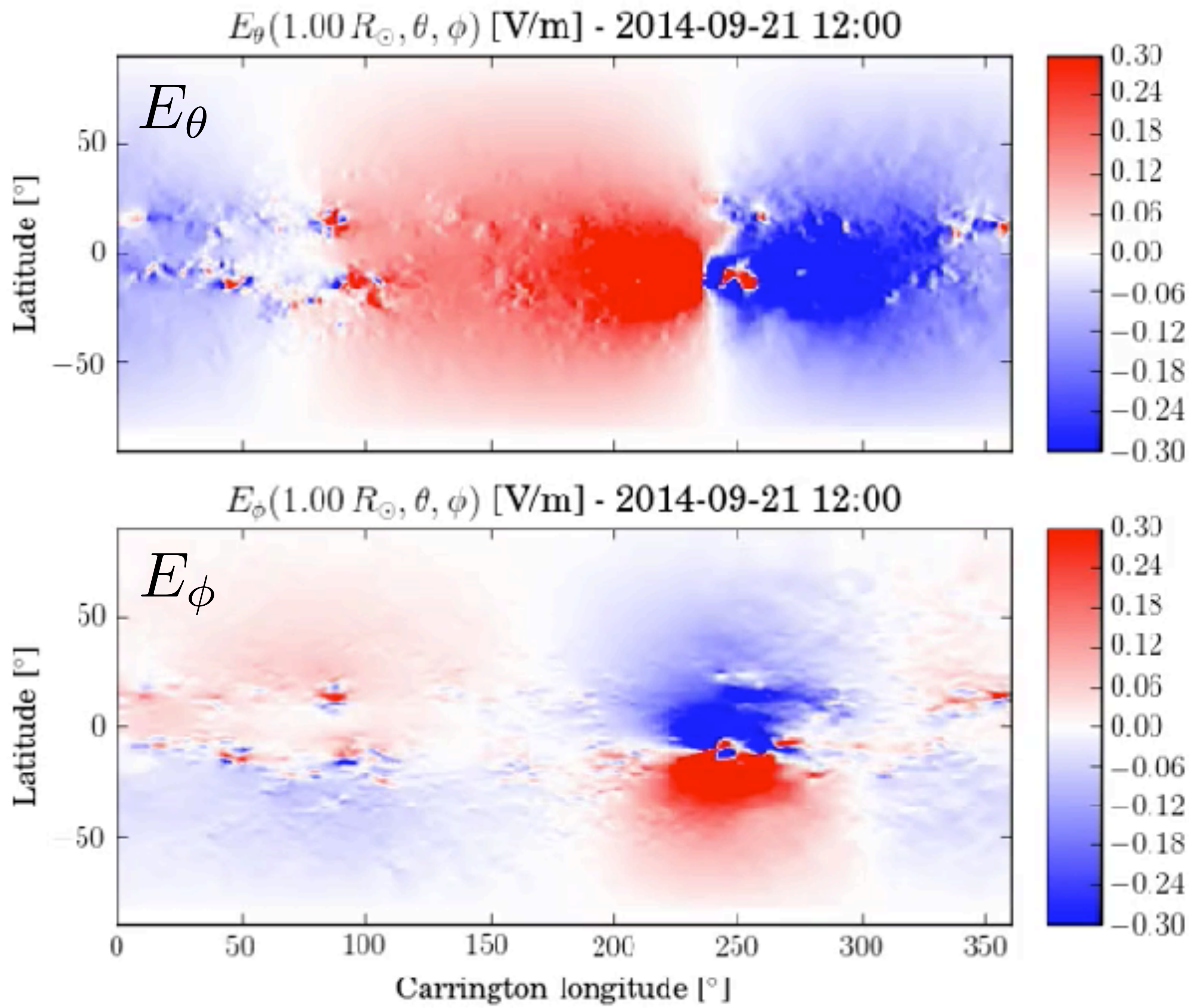


The "inductive" solution

- Simplest solution: minimize $\|\mathbf{E}_\perp\|_2 := \left[\sum_{\theta,\phi}\left\{(\ell_\theta\,E_\theta)^2 + (\ell_\phi\,E_\phi)^2\right\}\right]^{1/2}$

  e.g. Mikić et al., *PoP* (1999);
  Amari et al., *ApJ* (2003);
  Mackay et al., *ApJ* (2011);
  Yang et al., *JGR* (2012)

- Leads to "halos" (non localization).
  e.g. Fisher et al., *ApJ* (2010).



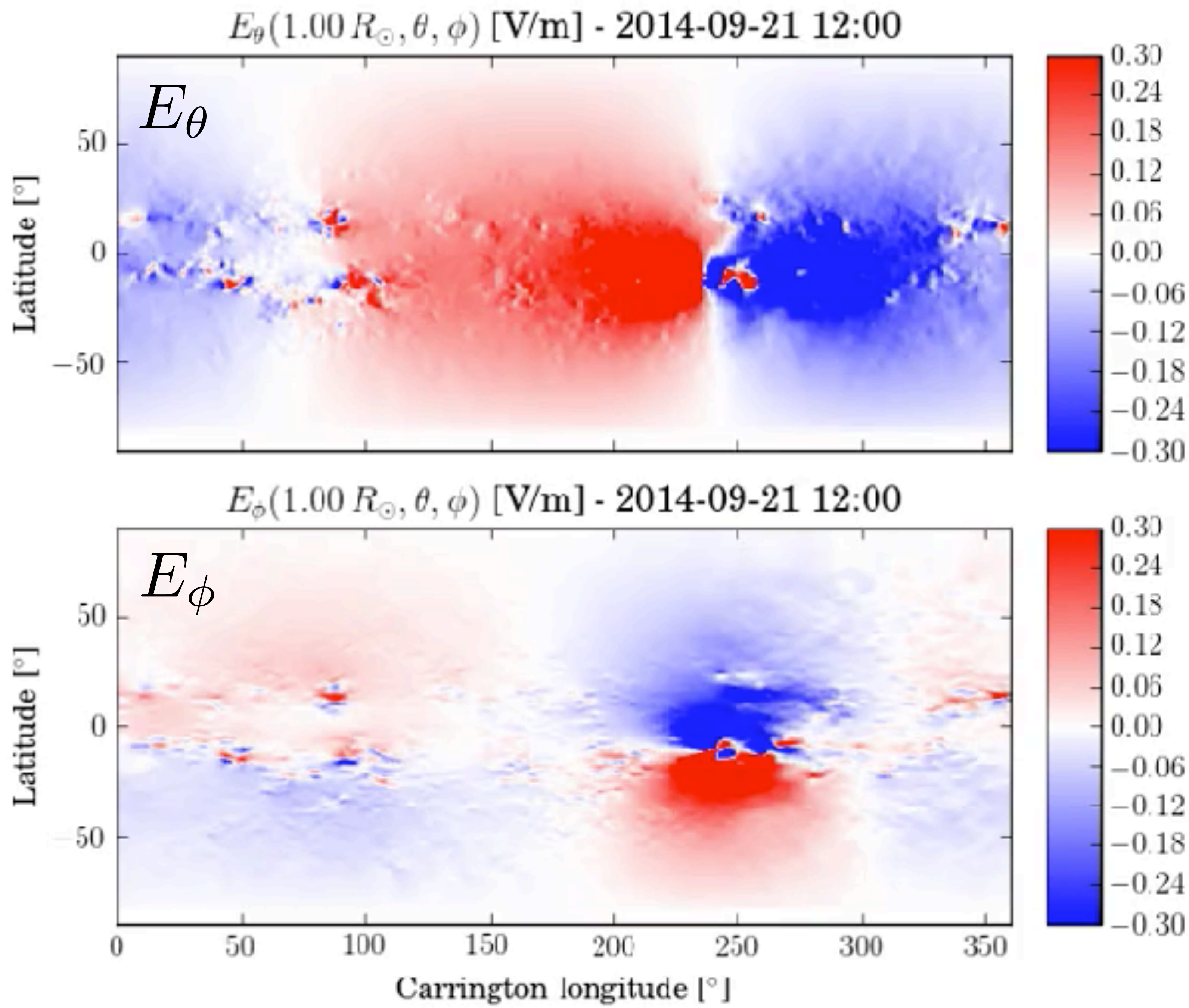
The "inductive" solution

- Simplest solution: minimize $\|\mathbf{E}_\perp\|_2 := \left[\sum_{\theta,\phi} \left\{ (\ell_\theta\, E_\theta)^2 + (\ell_\phi\, E_\phi)^2 \right\}\right]^{1/2}$

  e.g. Mikić et al., *PoP* (1999);
  Amari et al., *ApJ* (2003);
  Mackay et al., *ApJ* (2011);
  Yang et al., *JGR* (2012)

- Leads to "halos" (non localization).
  e.g. Fisher et al., *ApJ* (2010).

- Not consistent with Ohm's law.



Sparse solution

- Alternative approach: minimize $\|\mathbf{E}_\perp\|_1 := \sum_{\theta,\phi}\Big\{|\ell_\theta\, E_\theta| + |\ell_\phi\, E_\phi|\Big\}$

for details see Yeates, *ApJ* (2017)

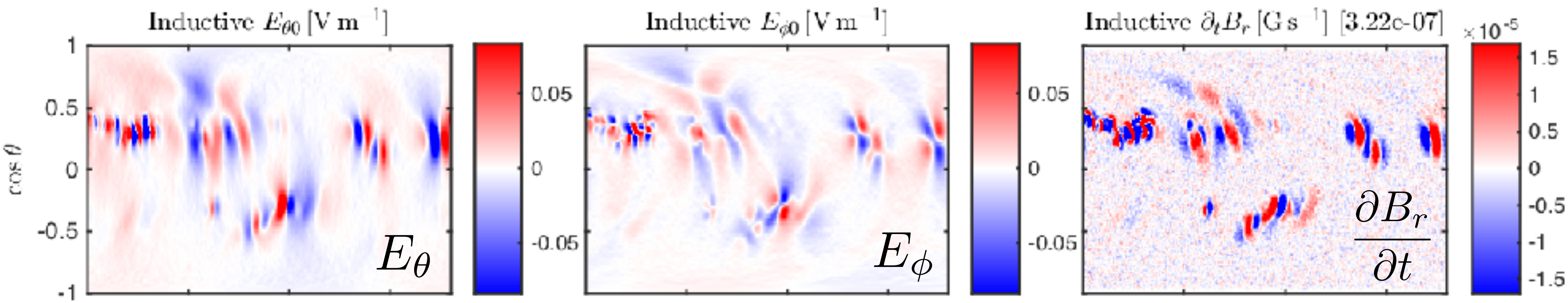
Sparse solution

- Alternative approach: minimize $\|\mathbf{E}_\perp\|_1 := \sum_{\theta,\phi}\left\{|\ell_\theta\, E_\theta| + |\ell_\phi\, E_\phi|\right\}$
- Use basis pursuit algorithm in SparseLab library (Chen et al., *SIAM Rev.*, 2001).

for details see Yeates, *ApJ* (2017)

Sparse solution

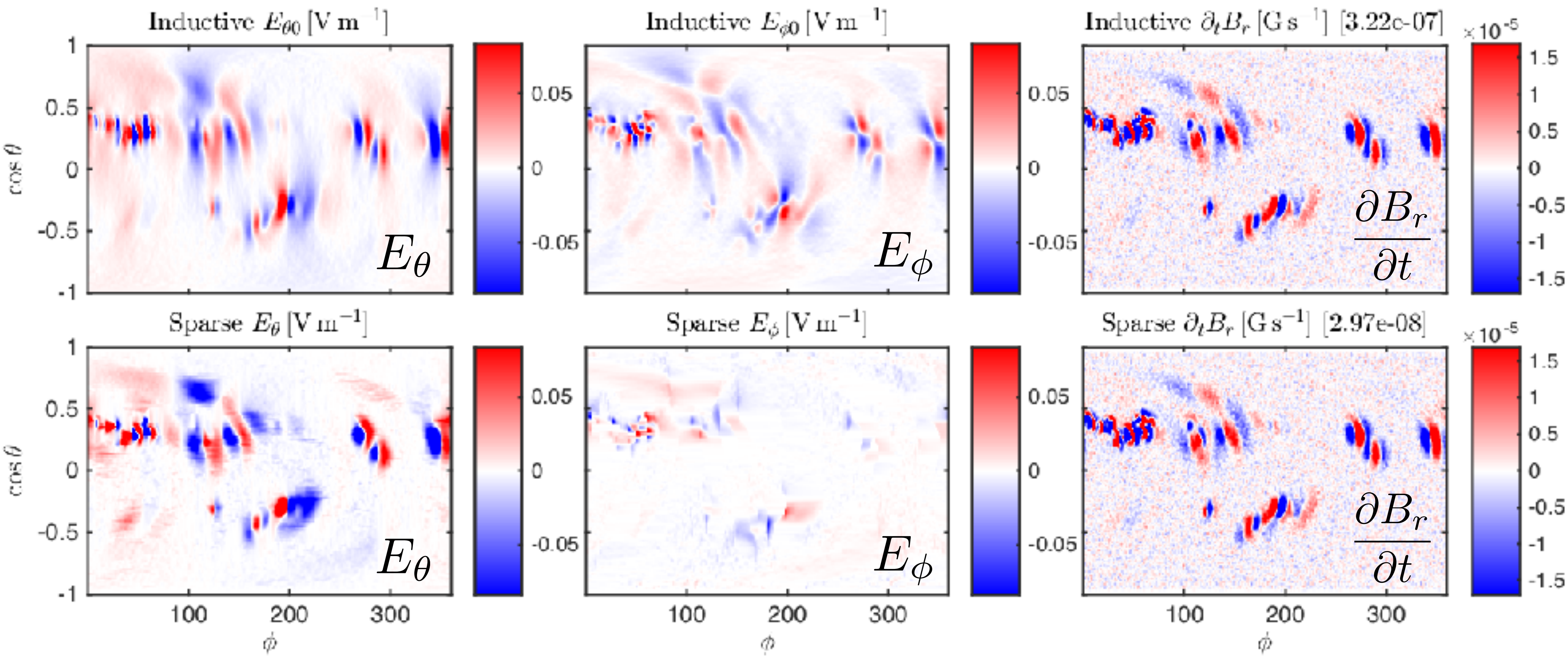
- Alternative approach: minimize $\|\mathbf{E}_\perp\|_1 := \sum_{\theta,\phi}\left\{|\ell_\theta\, E_\theta| + |\ell_\phi\, E_\phi|\right\}$
- Use basis pursuit algorithm in SparseLab library (Chen et al., *SIAM Rev.*, 2001).



for details see Yeates, *ApJ* (2017)

Sparse solution

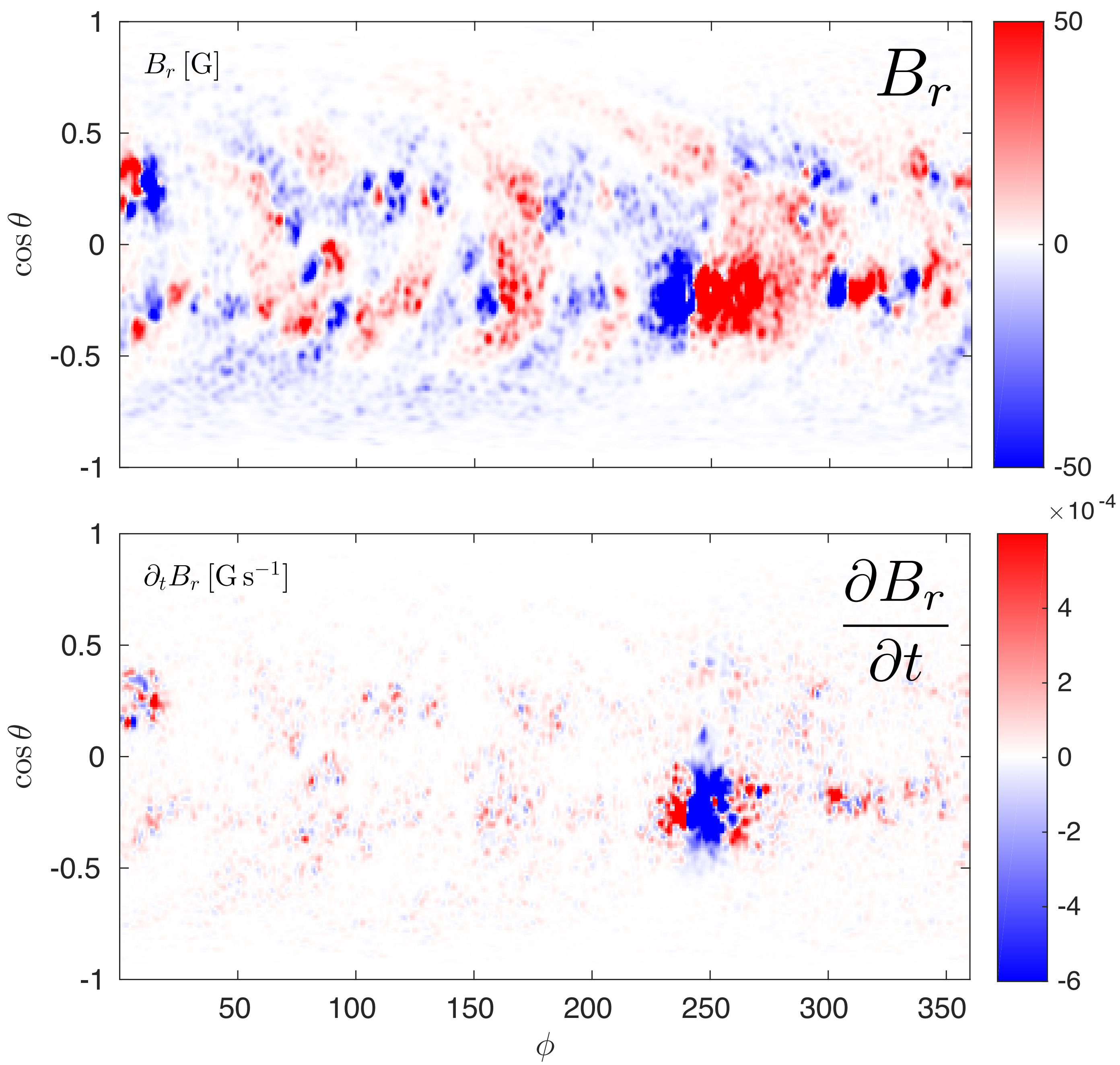
- Alternative approach: minimize $\|\mathbf{E}_\perp\|_1 := \sum_{\theta,\phi} \left\{ |\ell_\theta \, E_\theta| + |\ell_\phi \, E_\phi| \right\}$
- Use basis pursuit algorithm in SparseLab library (Chen et al., *SIAM Rev.*, 2001).



for details see Yeates, *ApJ* (2017)

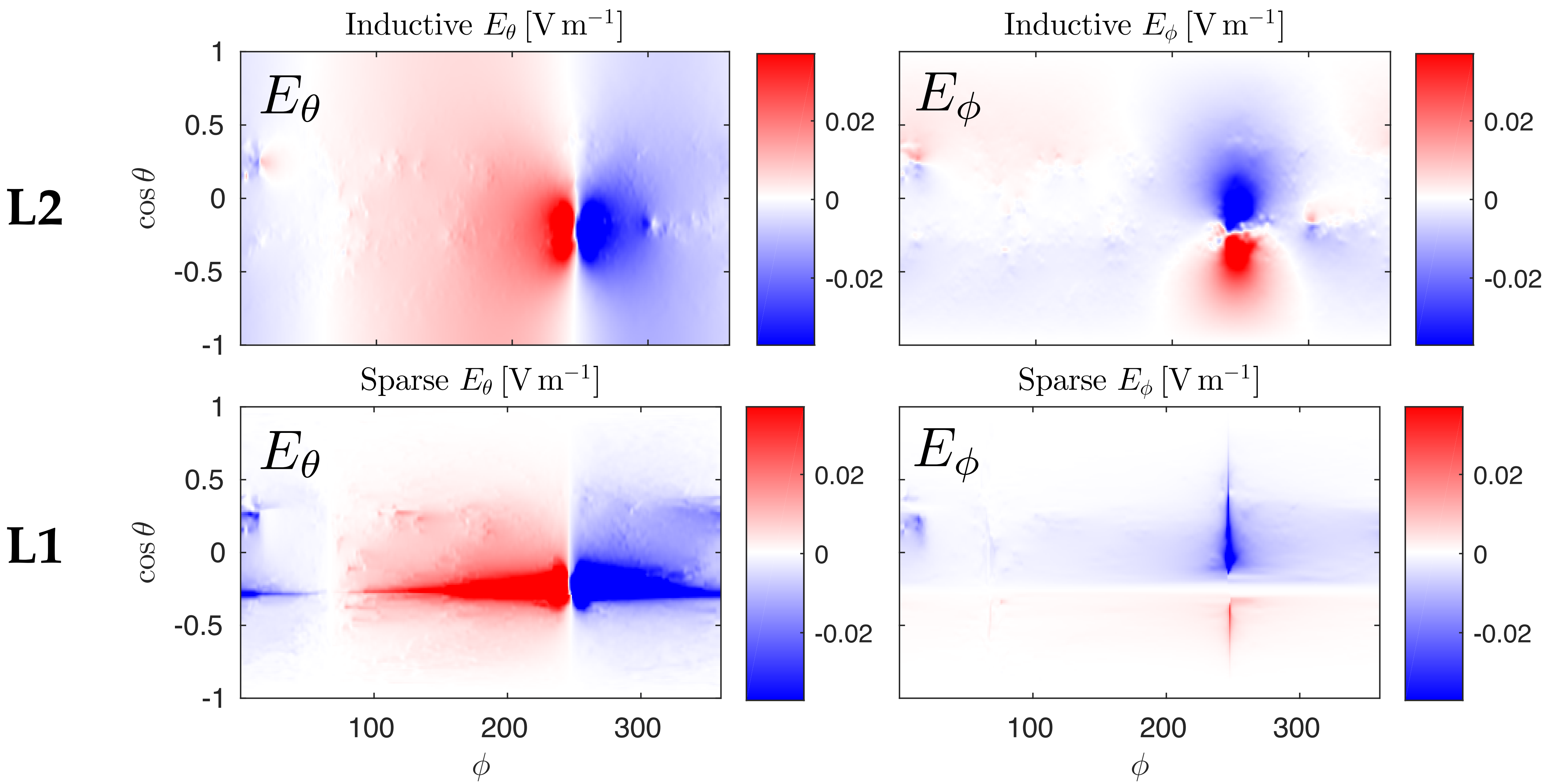
Problem: flux balance

- Example: 2014 November 15 in AFT model.



Problem: flux balance

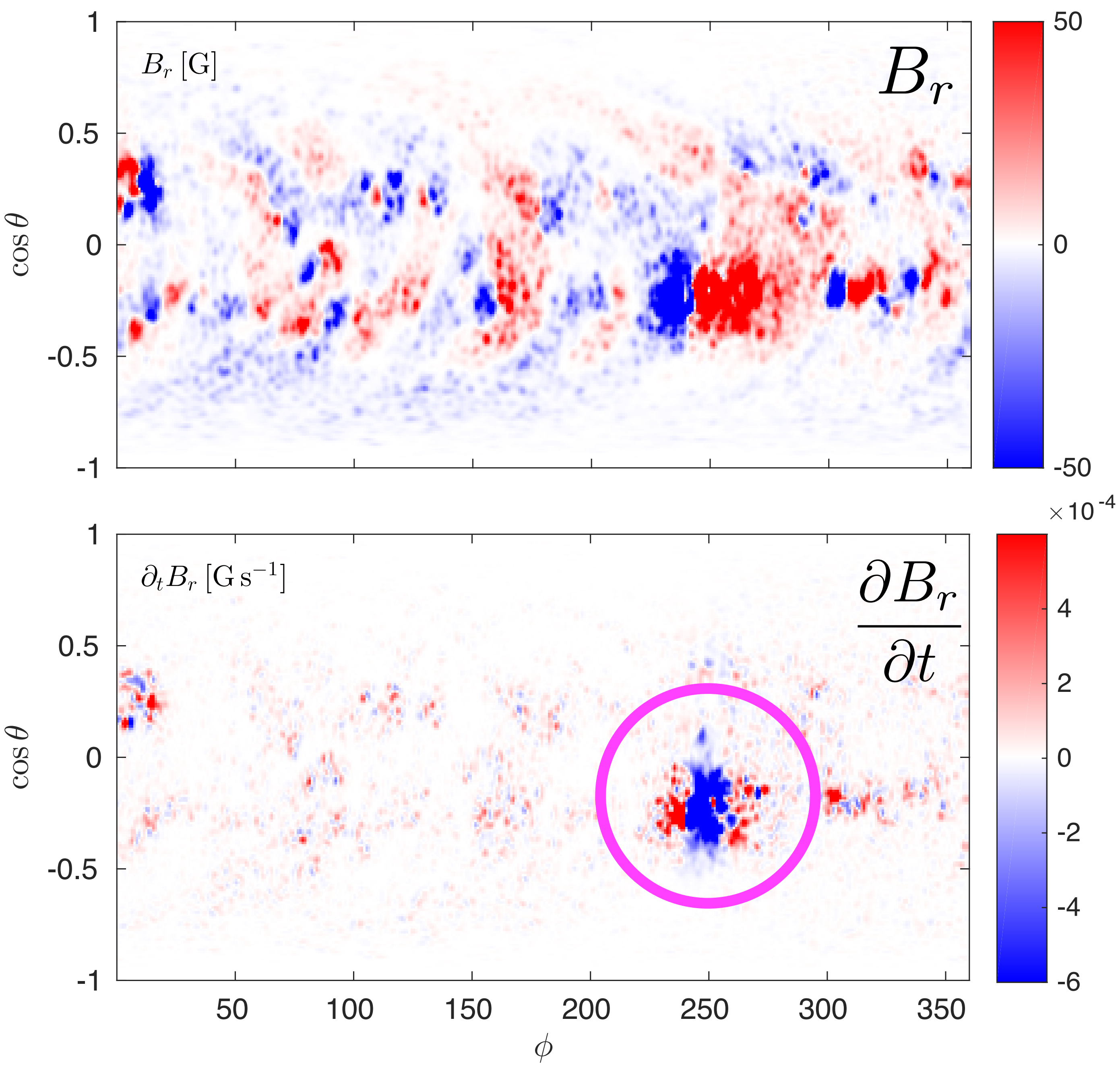
- Example: 2014 November 15 in AFT model.



- A localized solution is impossible due to imbalance.

Problem: flux balance

- Example: 2014 November 15 in AFT model.

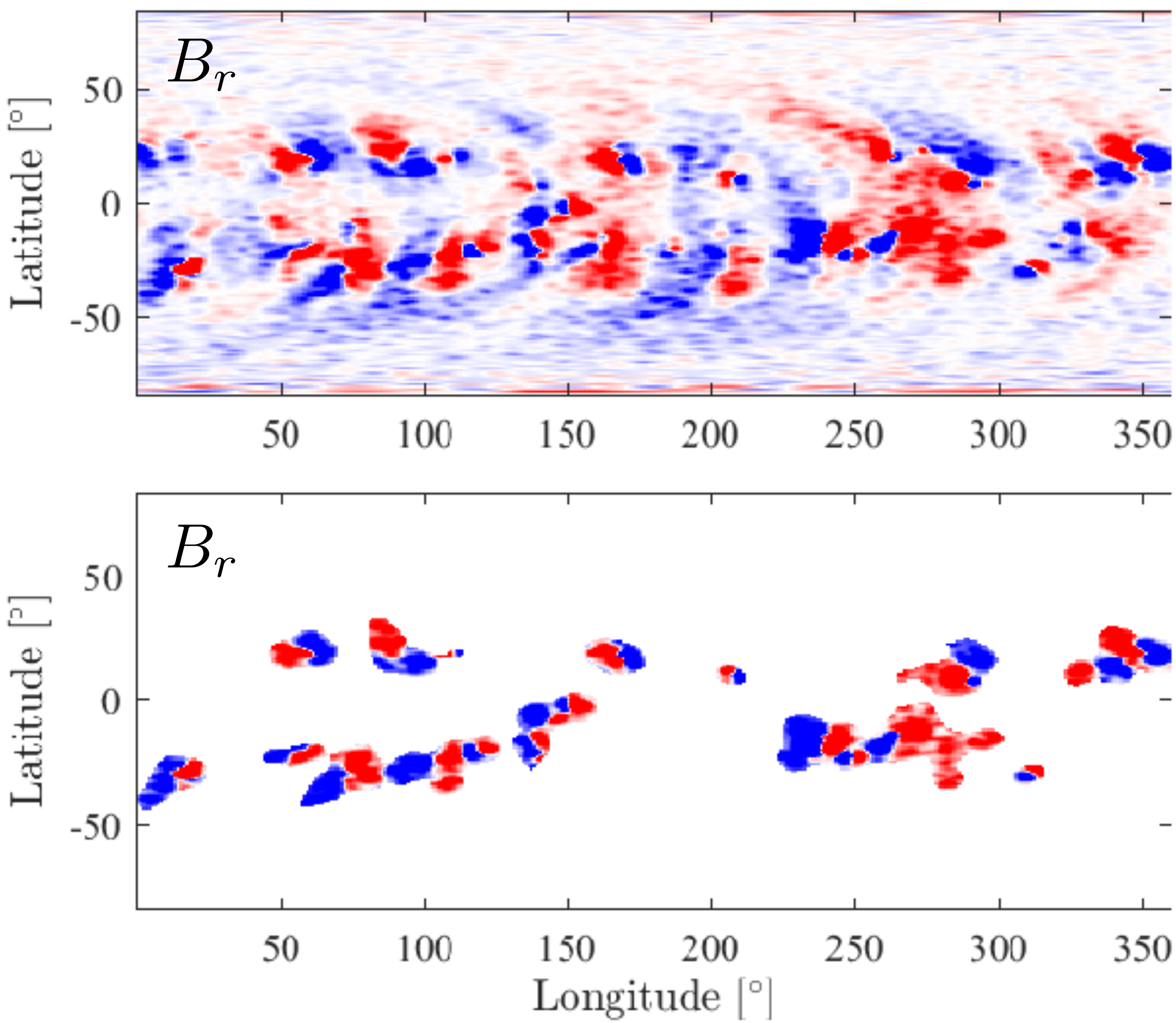


$$\int \frac{\partial B_r}{\partial t}\,\mathrm{d}x^2 = -\oint \mathbf{E}\cdot\,\mathrm{dl}$$

Alternative approach: local solution

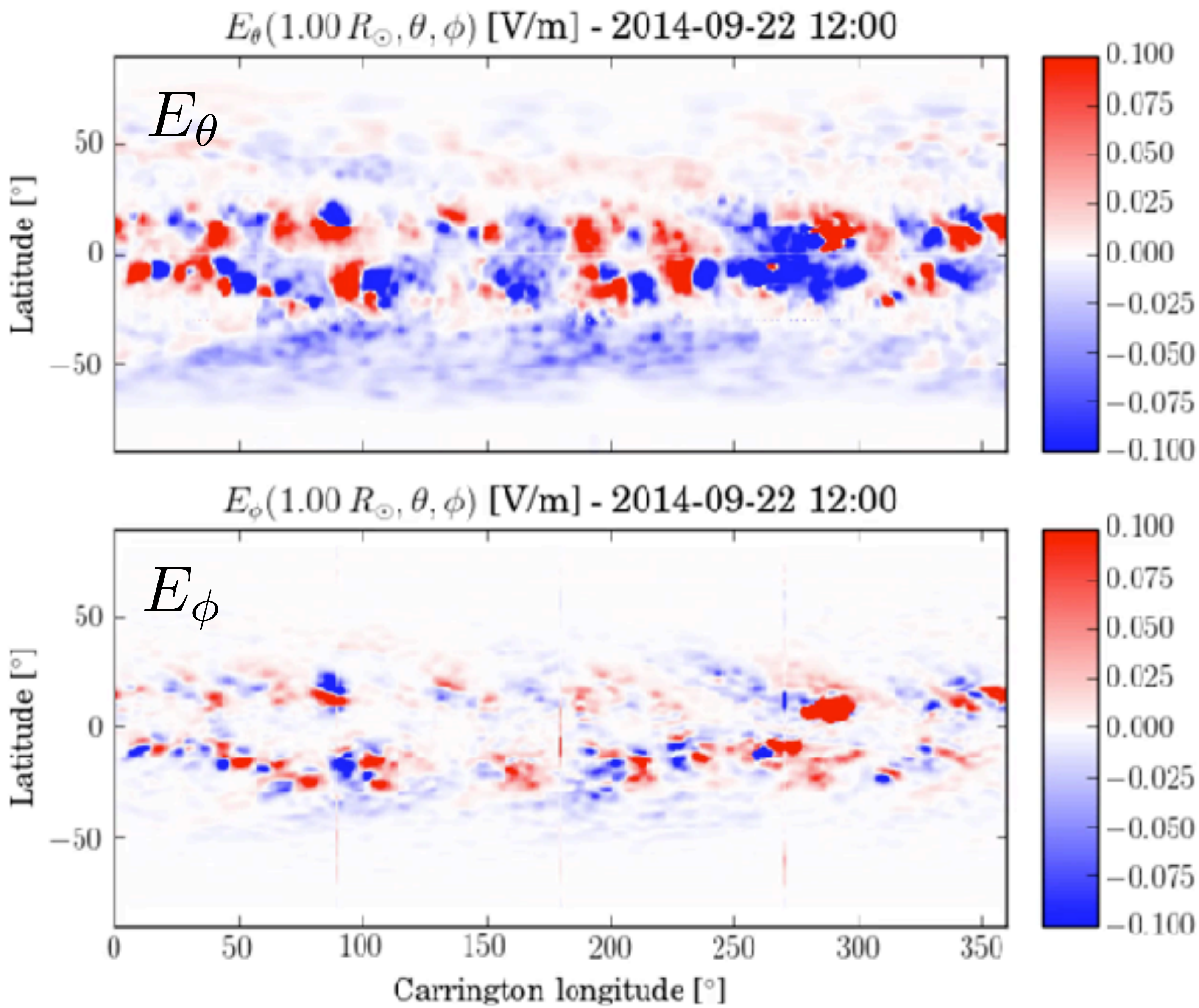
- **Step 1:** identify strong flux regions with local flux balance.

e.g.



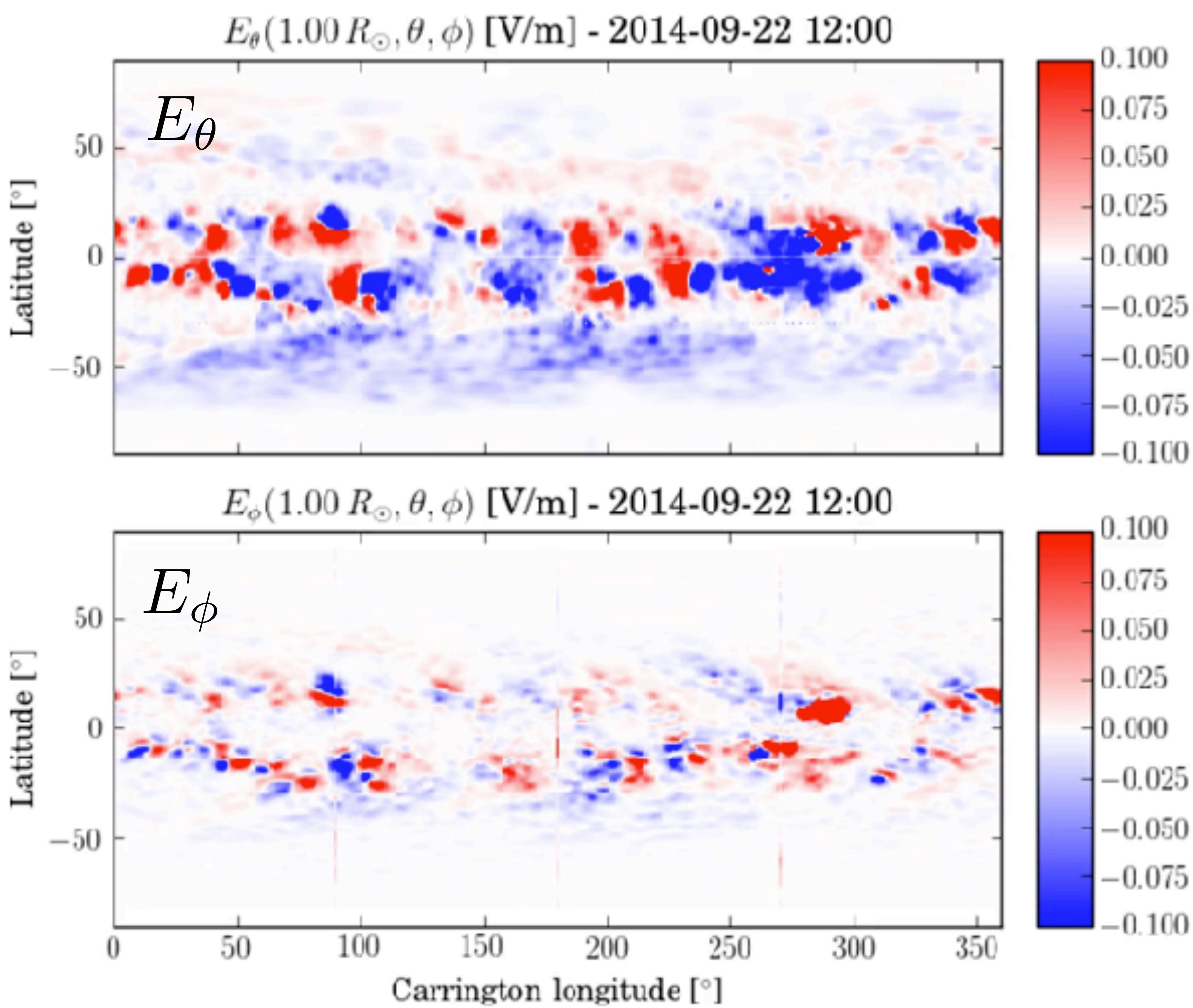
Alternative approach: local solution

- **Step 2:** compute local electric field (inductive or sparse).
  Add flux transport "background".



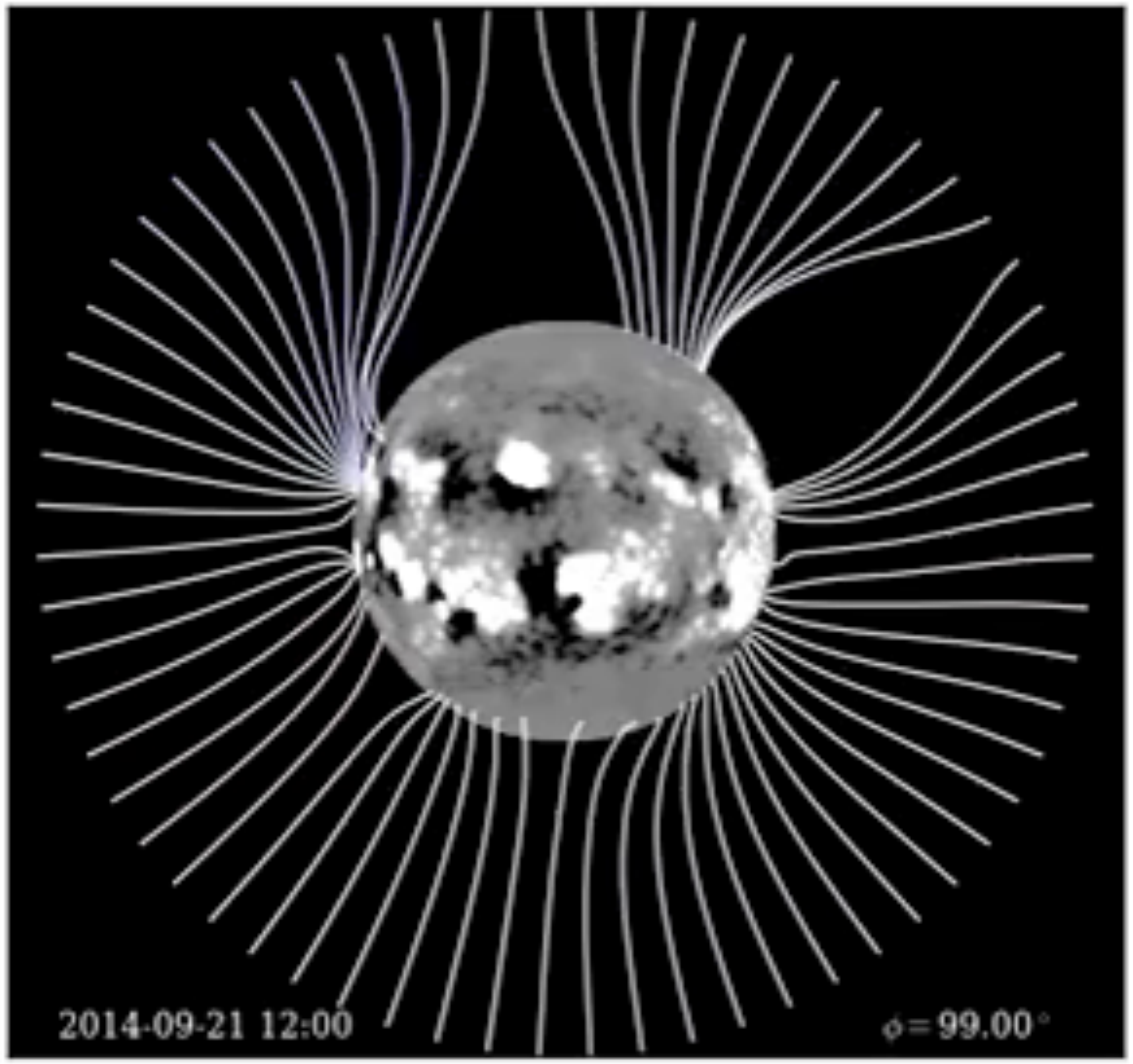
Alternative approach: local solution

- **Step 2:** compute local electric field (inductive or sparse).
  Add flux transport "background".

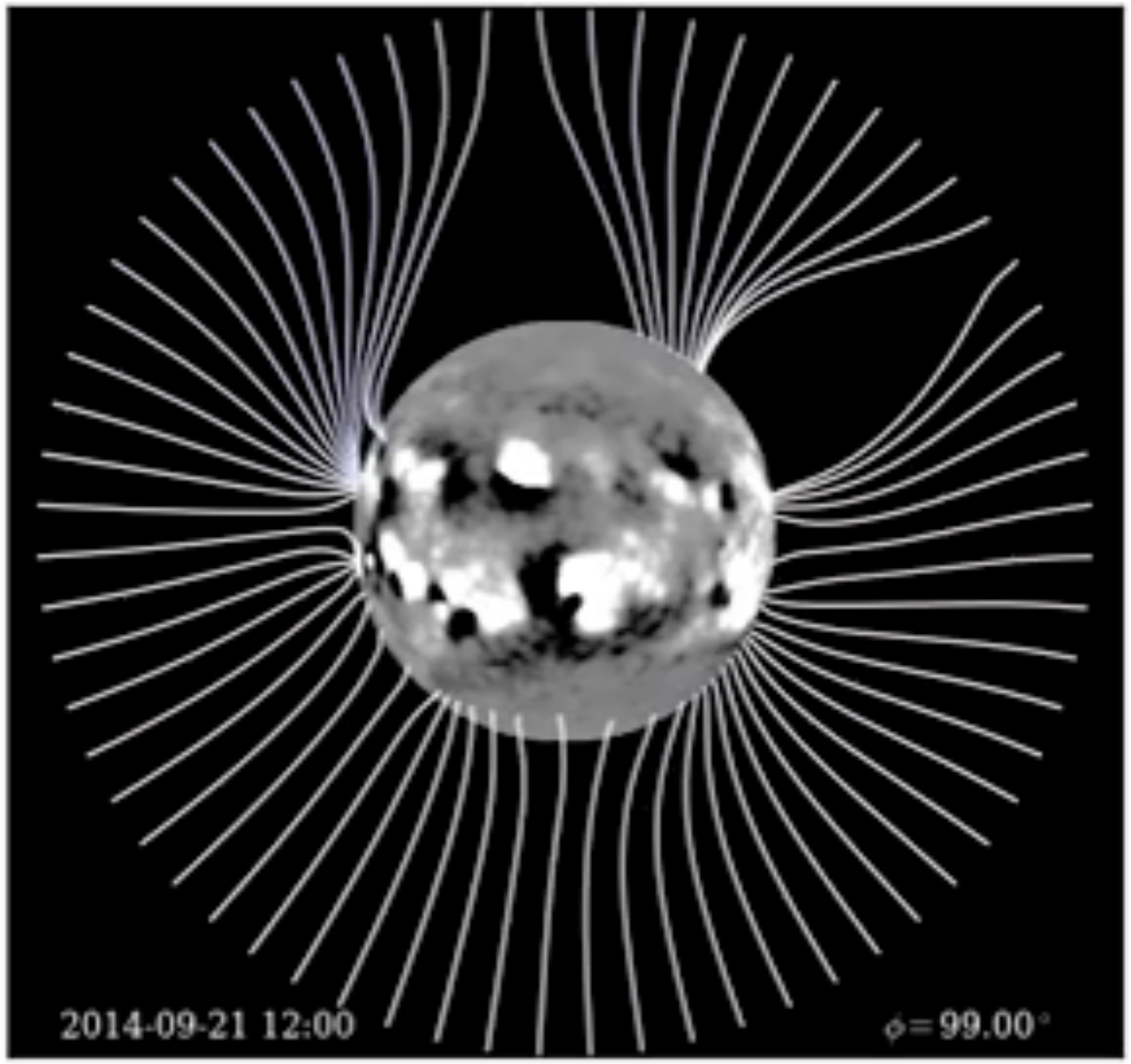


Impact on the corona

Global inductive

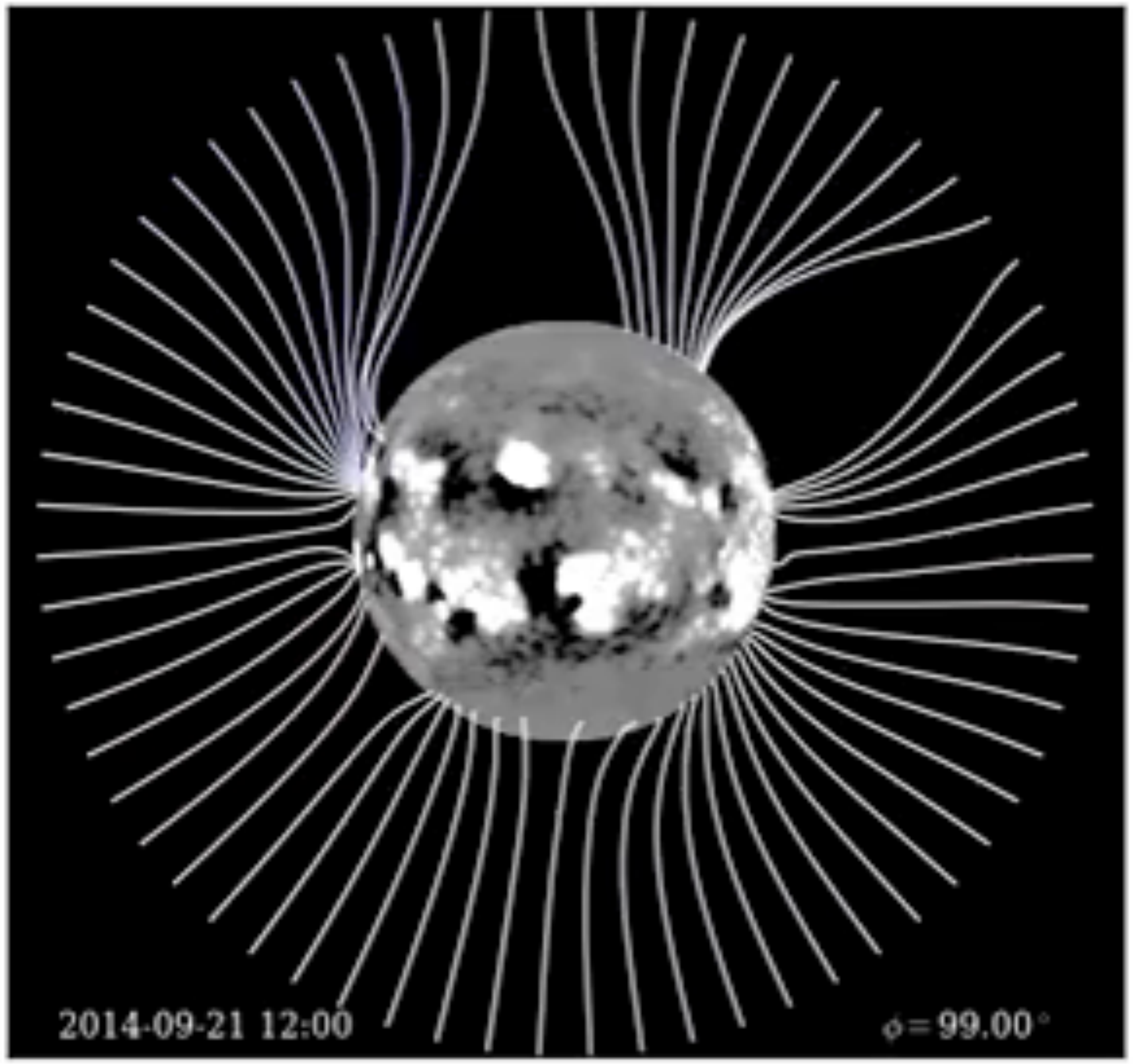


Local Inductive

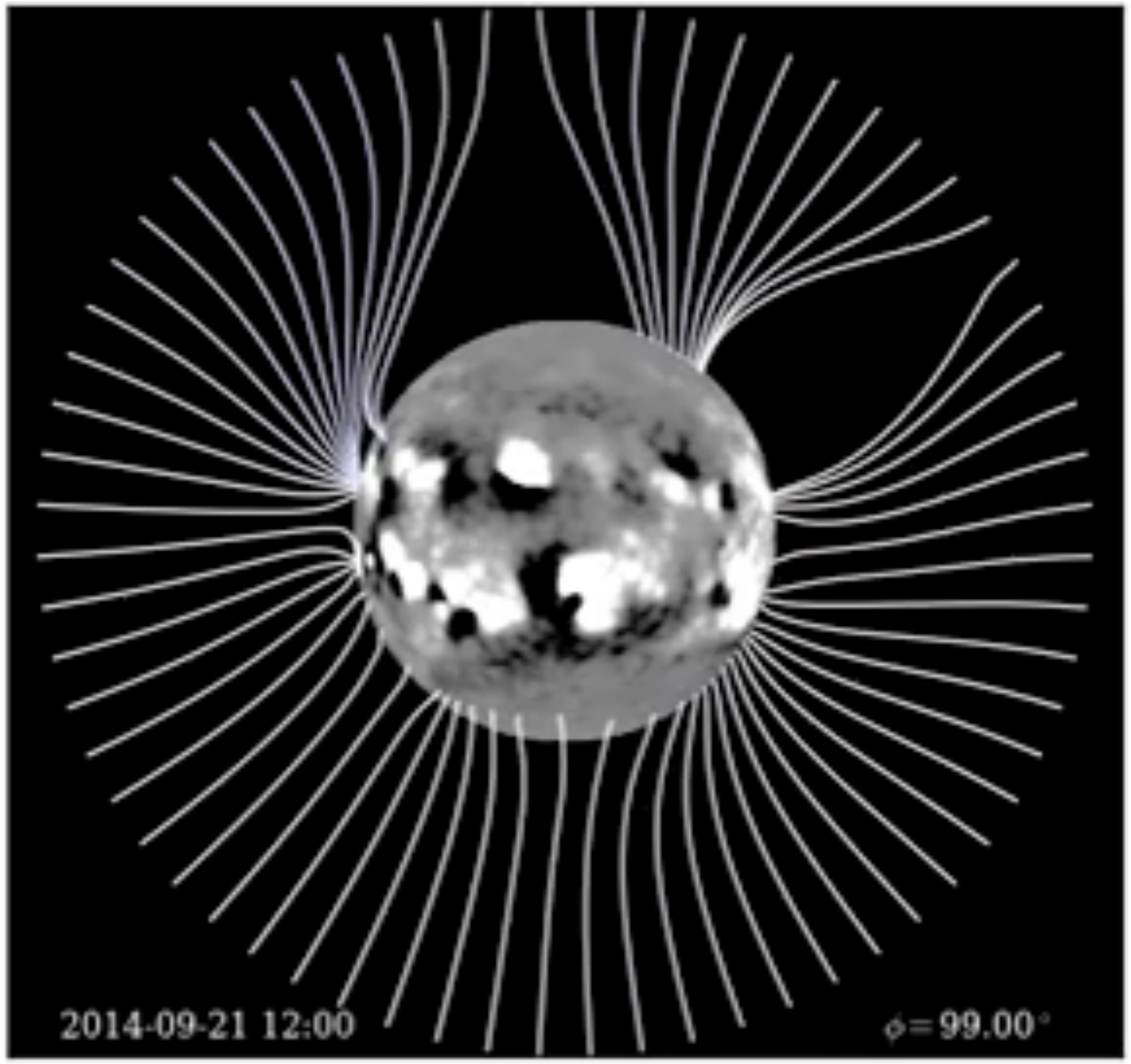


Impact on the corona

Global inductive

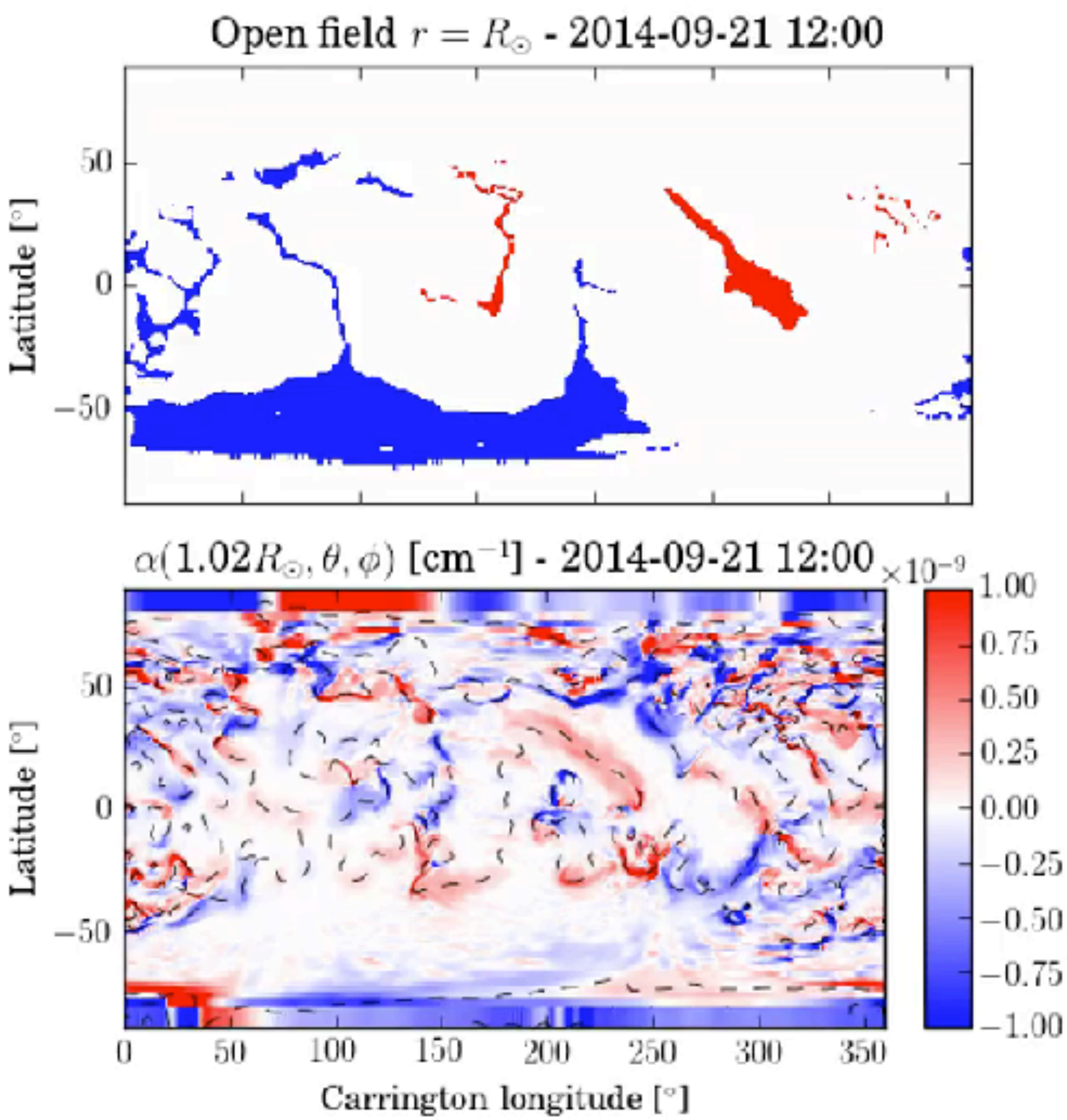


Local Inductive

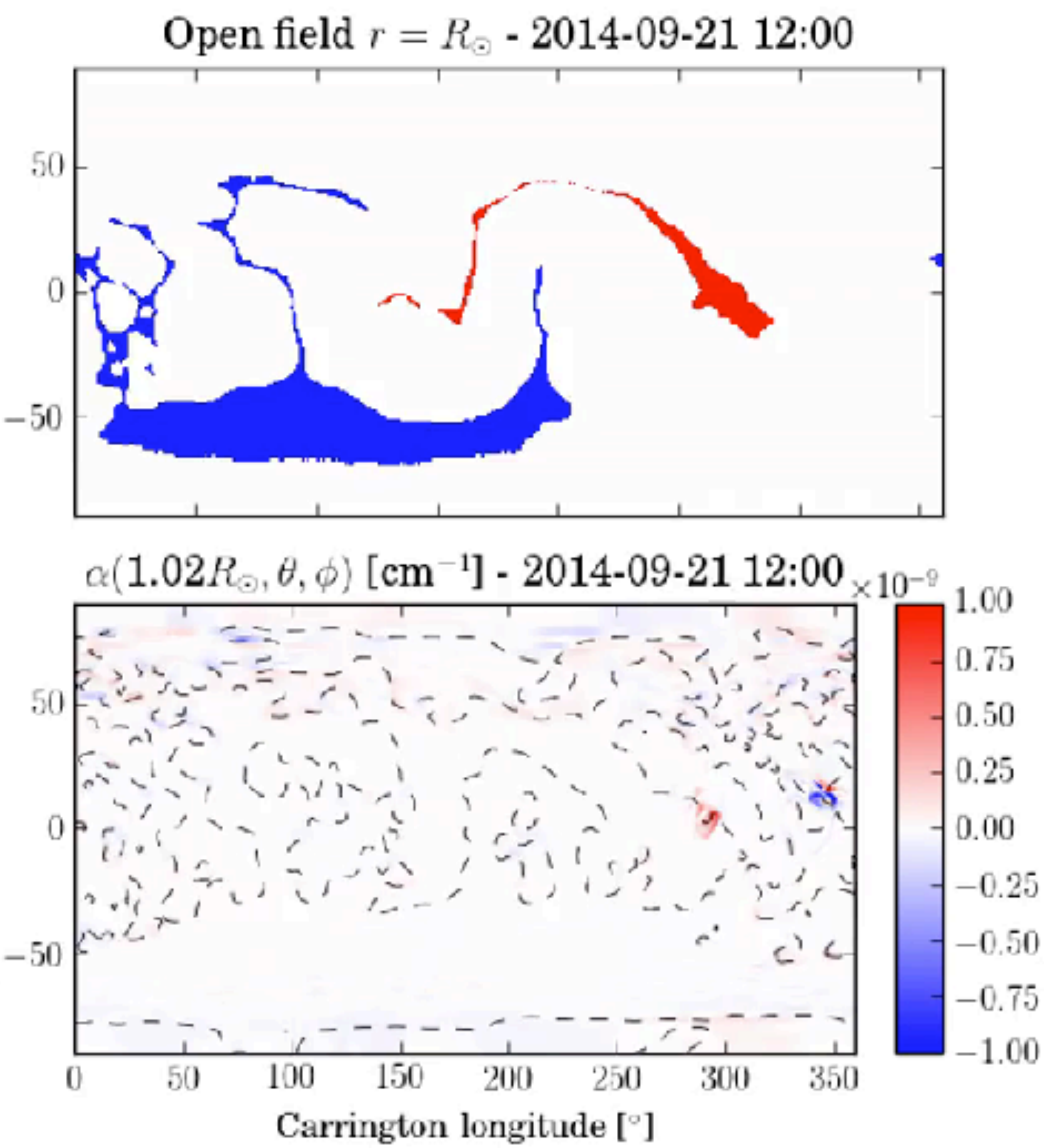


Impact on the corona

Global inductive

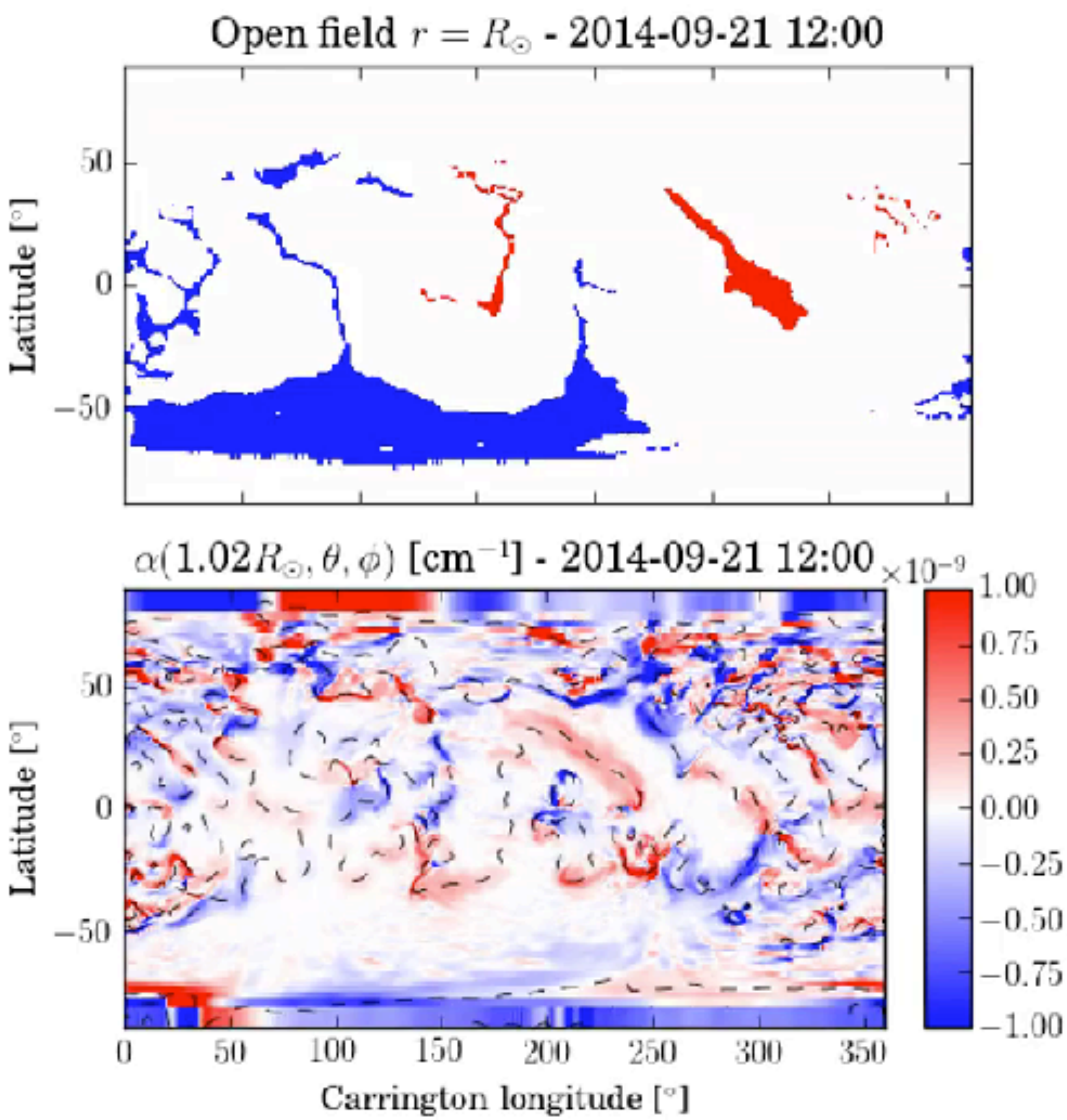


Local inductive

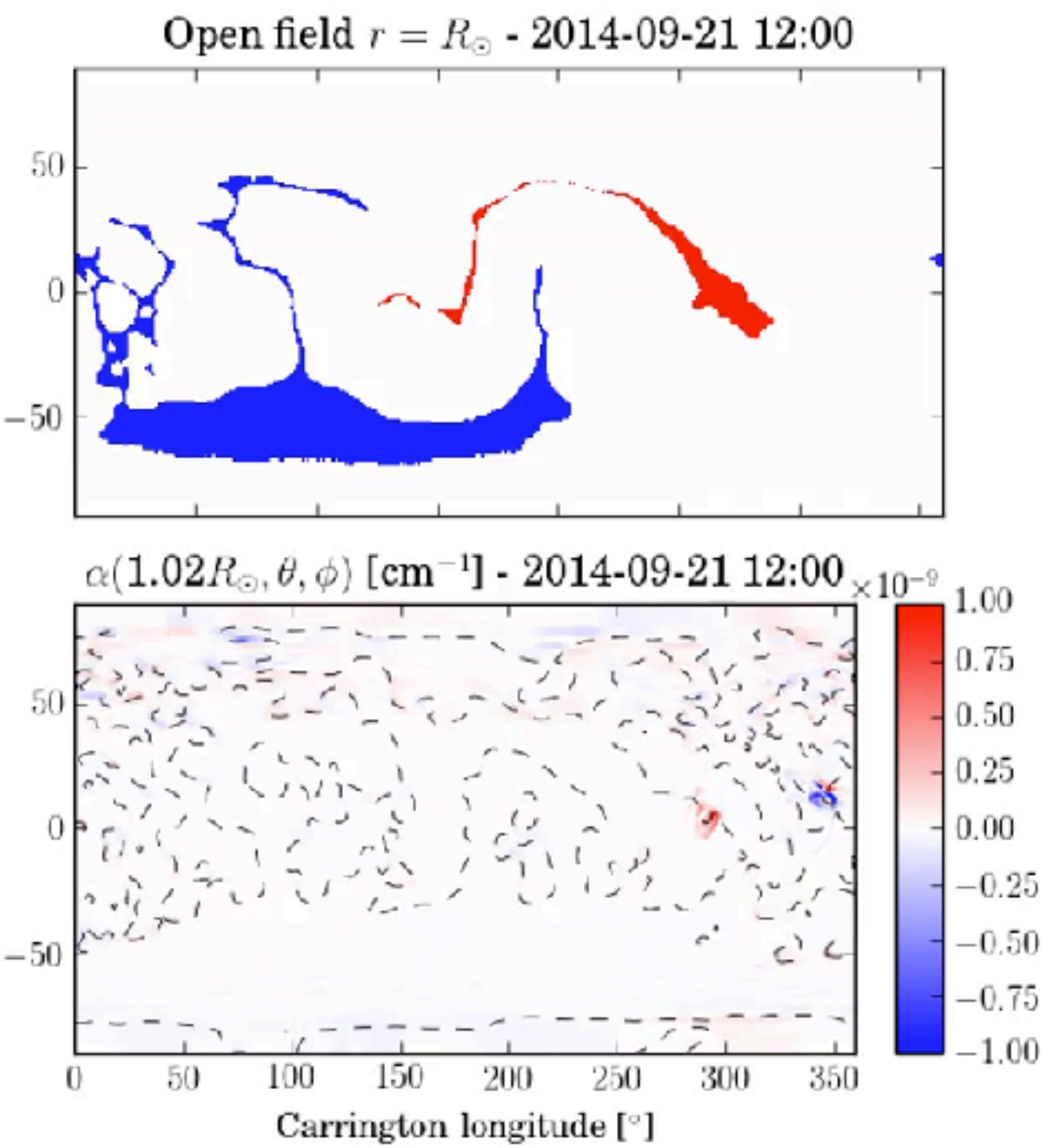


Impact on the corona

Global inductive



Local inductive



Conclusions

- **Yes!** We can drive coronal models from magnetic maps, but not directly.
- **Big issues:**
  - far-side coverage [need flux transport models]
  - local flux balance
- **Solutions:**
  - more observations: L5 magnetograph? far-side helioseismology?
  - sparse electric field reconstruction [Yeates, *ApJ* **836**, 131 (2017)]
  - "selective" assimilation [Yeates et al., *Sol. Phys.* **290**, 3189 (2015) + …]

http://www.maths.dur.ac.uk/~bmjg46/

Science & Technology Facilities Council
AFOSR AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Durham University