Friction, flux ropes and field line helicity

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with thanks to
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Gunnar Hornig (Dundee)

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Goals

- **How can we better utilise remote-sensing observations for space-weather forecasting?**

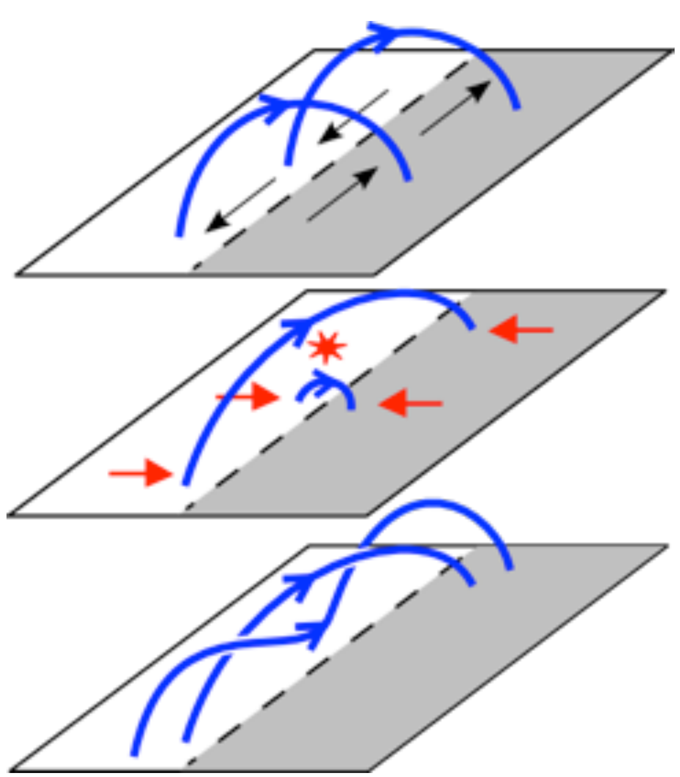
- **<u>This work</u>: study flux ropes predicted by a global coronal evolution model.**
  - **Where/when on the Sun will CME eruptions occur?**
  - **Can we predict the properties of individual (I)CMEs?**

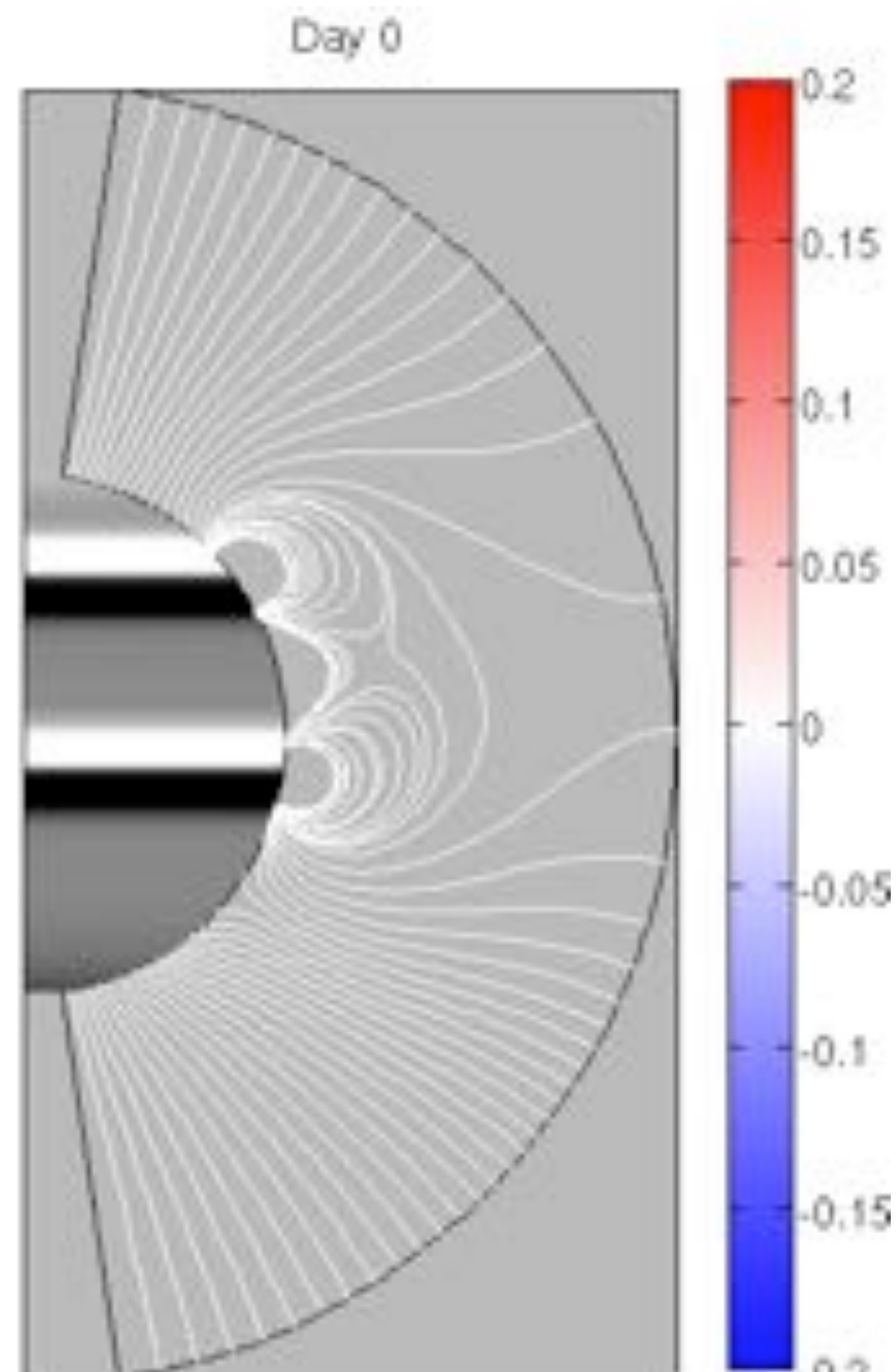
Modelling approach

- **Magneto-friction:** Build up coronal currents over time by footpoint shearing.
- Only require B_r + **v** on solar surface.

- Large-scale footpoint motions + flux cancellation leads to formation and eruption of flux ropes.

  van Ballegooijen & Martens, *ApJ* (1989)
  Mackay & van Ballegooijen, *ApJL* (2005)
  Mackay & van Ballegooijen, *ApJ* (2006)

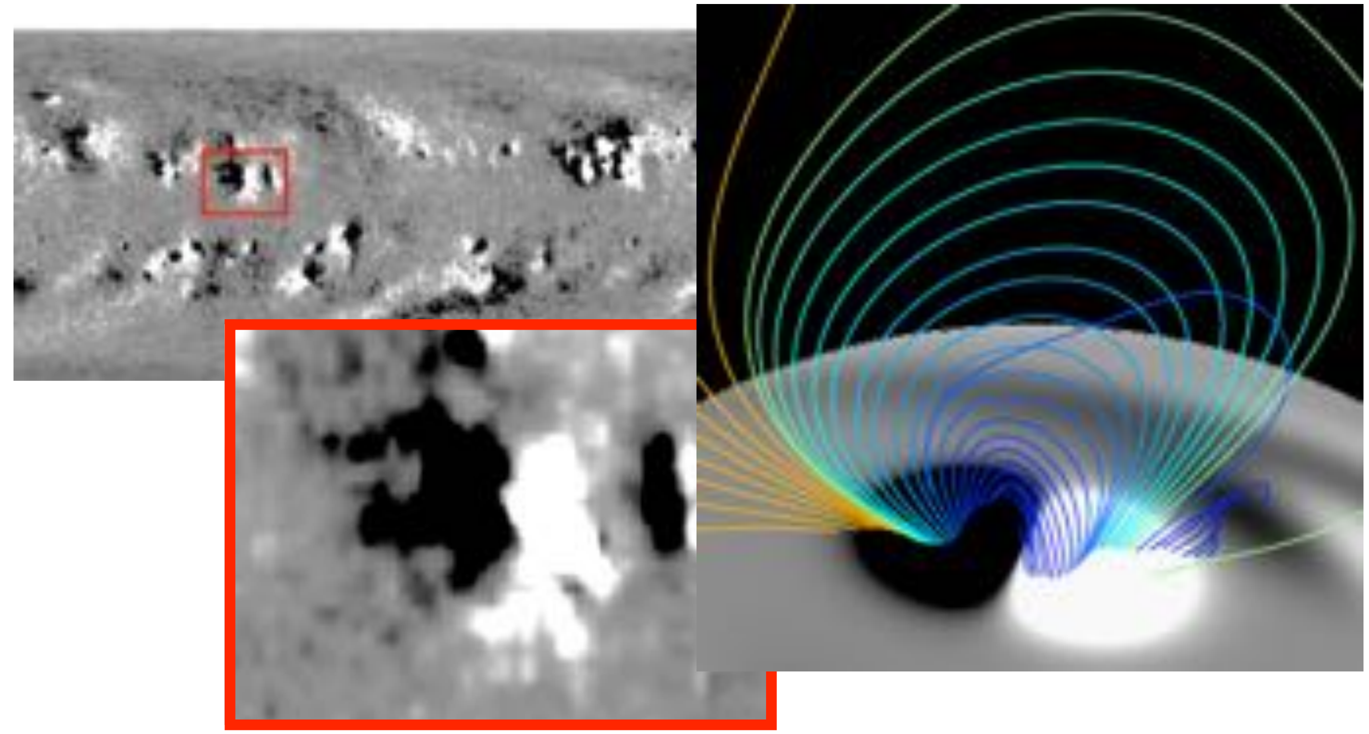


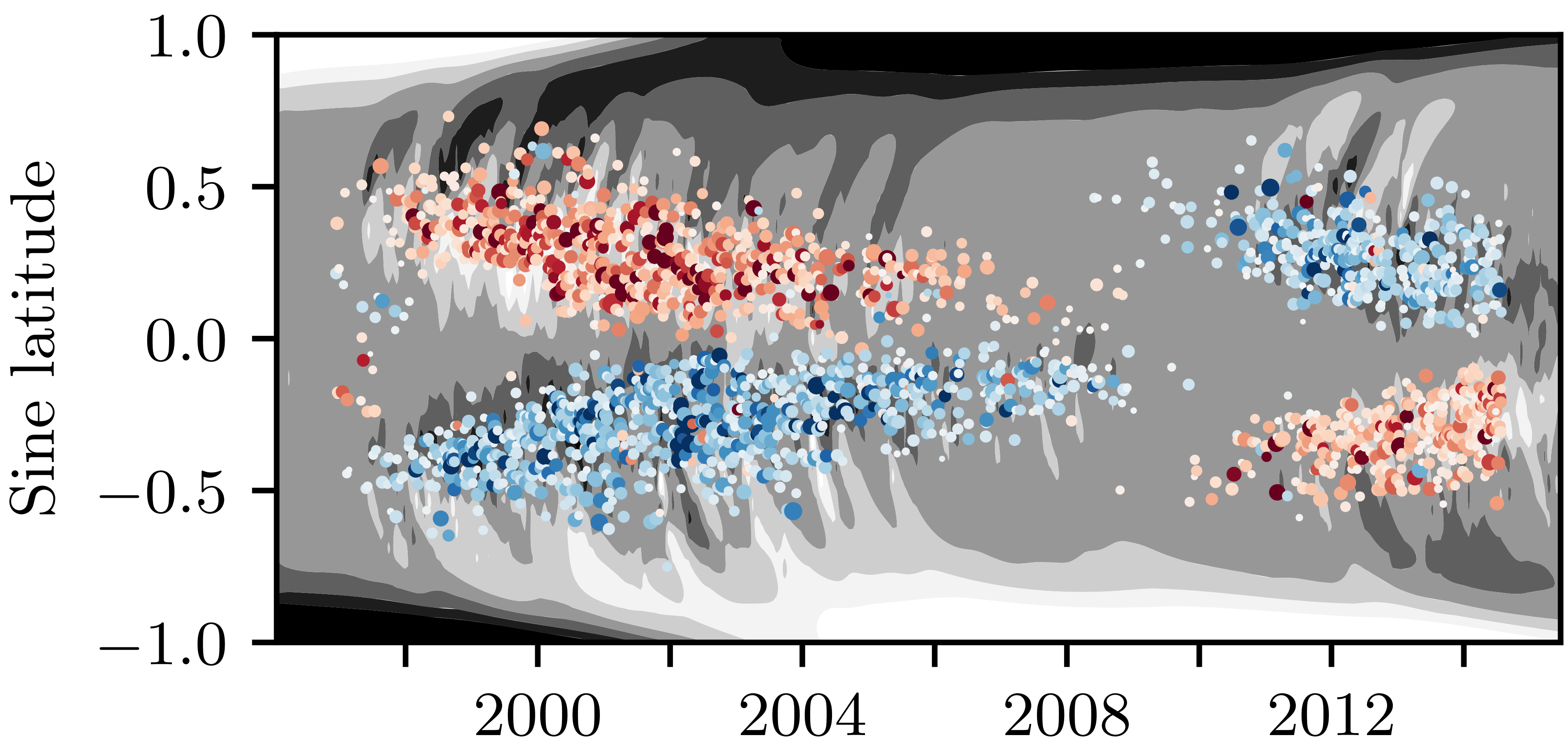


Full solar cycle simulation

- Individual bipolar magnetic regions determined from NSO synoptic magnetograms.
- Inserted with idealised 3D form.

Yeates & Mackay, *ApJL* (2012)
Yeates, *Solar Phys.* (2014)



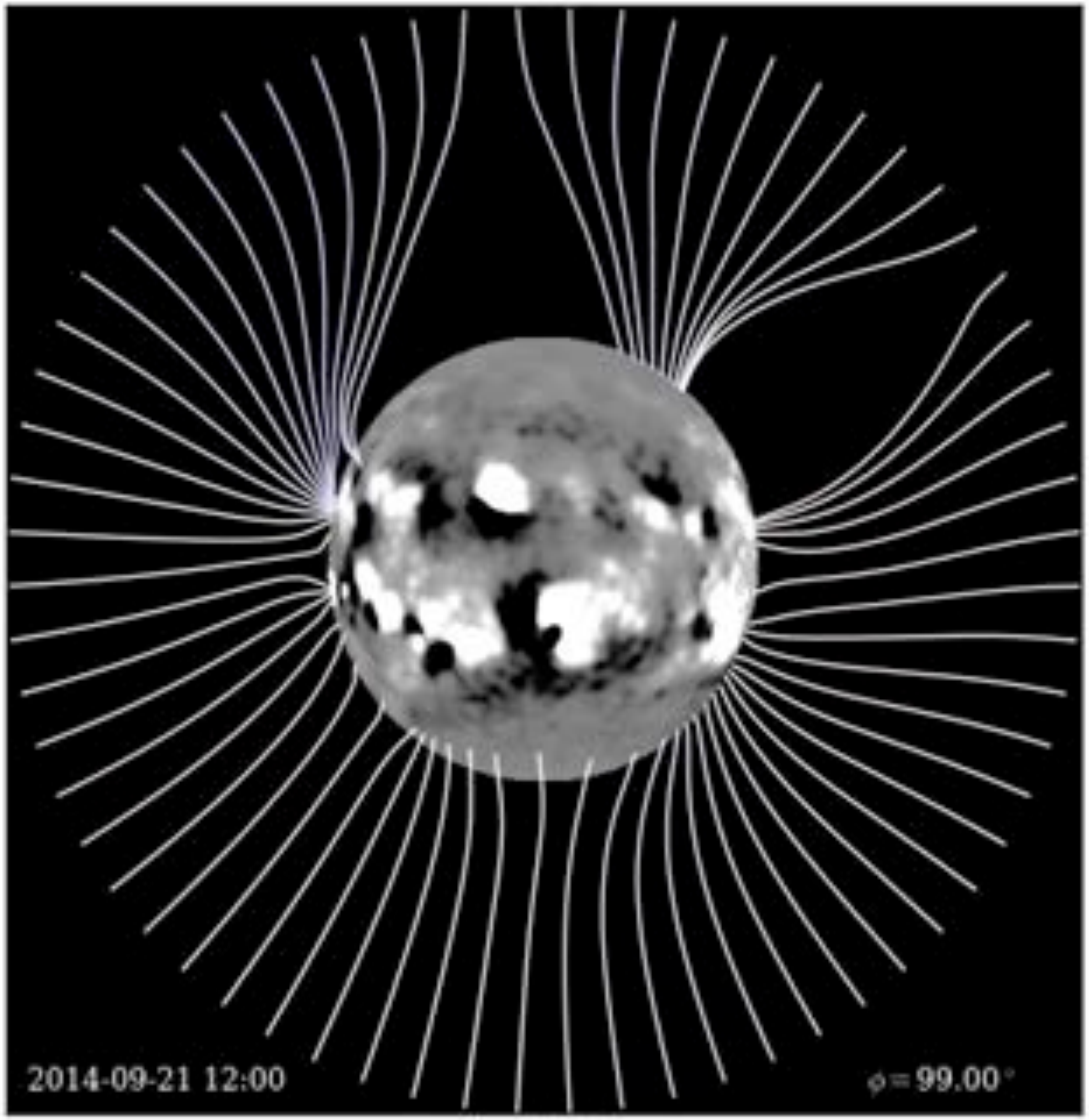


June 1996 — Feb 2014

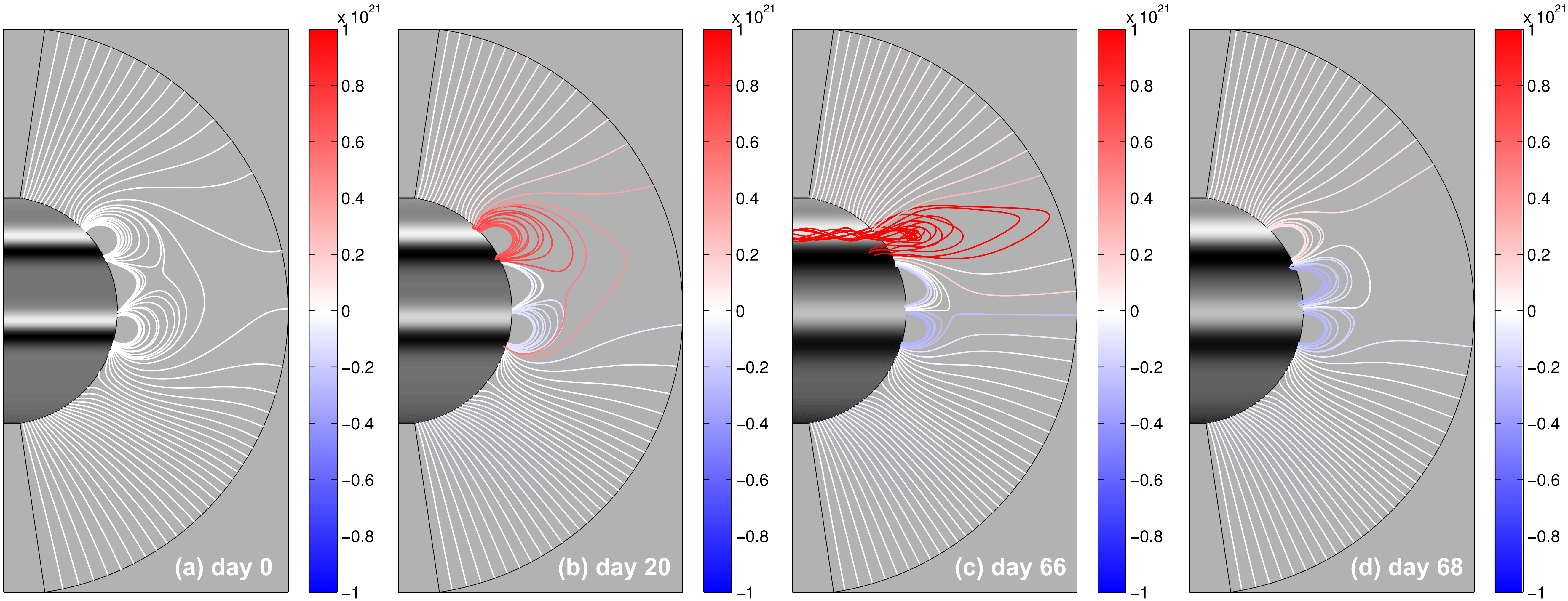
$R_\odot \leq r \leq 2.5\,R_\odot$

1.875° resolution at equator

Global evolution



Field line helicity

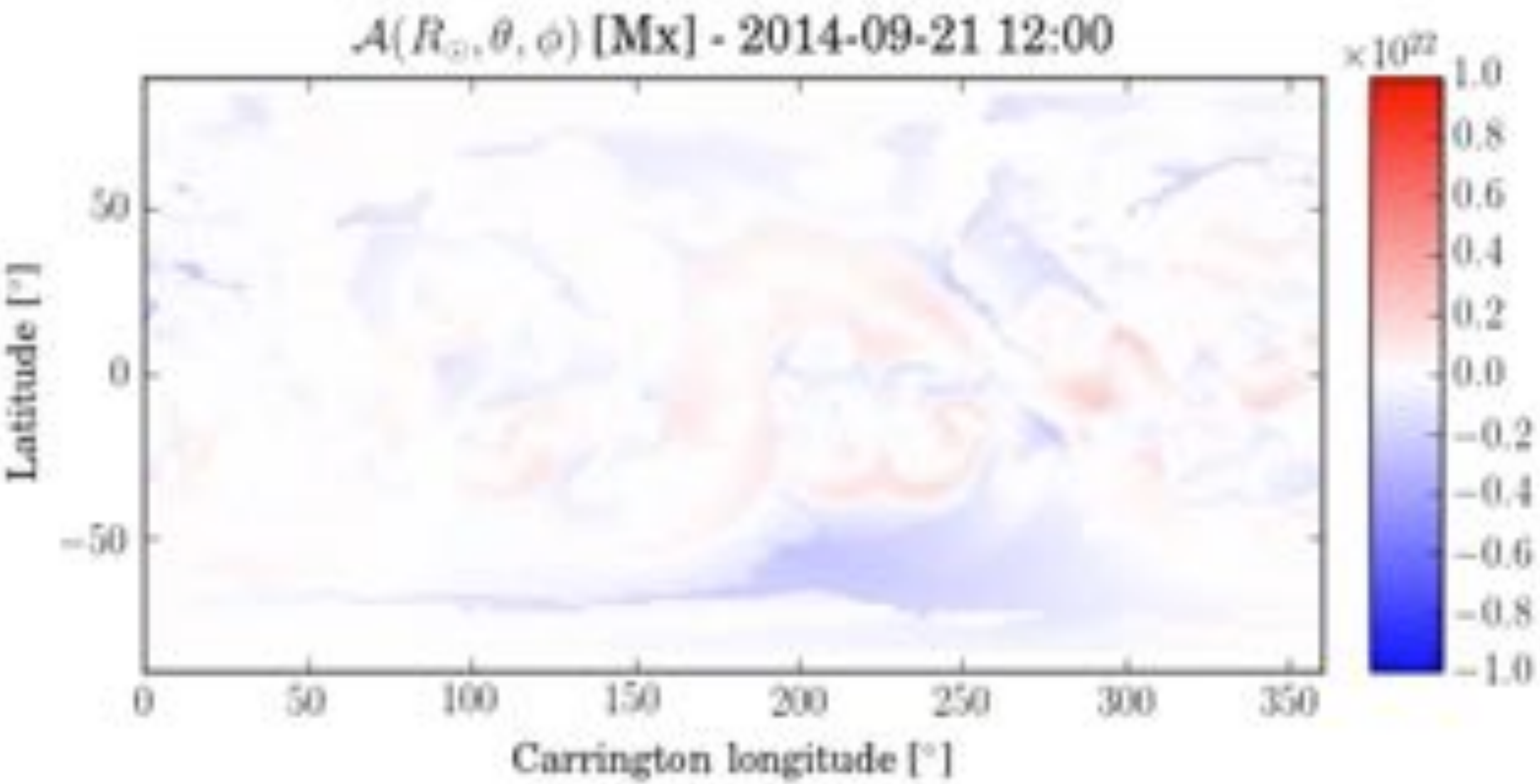


$$\mathcal{A}(L) = \int_L \boldsymbol{A} \cdot \mathrm{d}\boldsymbol{l}$$

- We compute **field line helicity** to reveal the distribution of magnetic helicity.
- Helicity is stored in the flux rope and suddenly released through eruption.

Global simulation

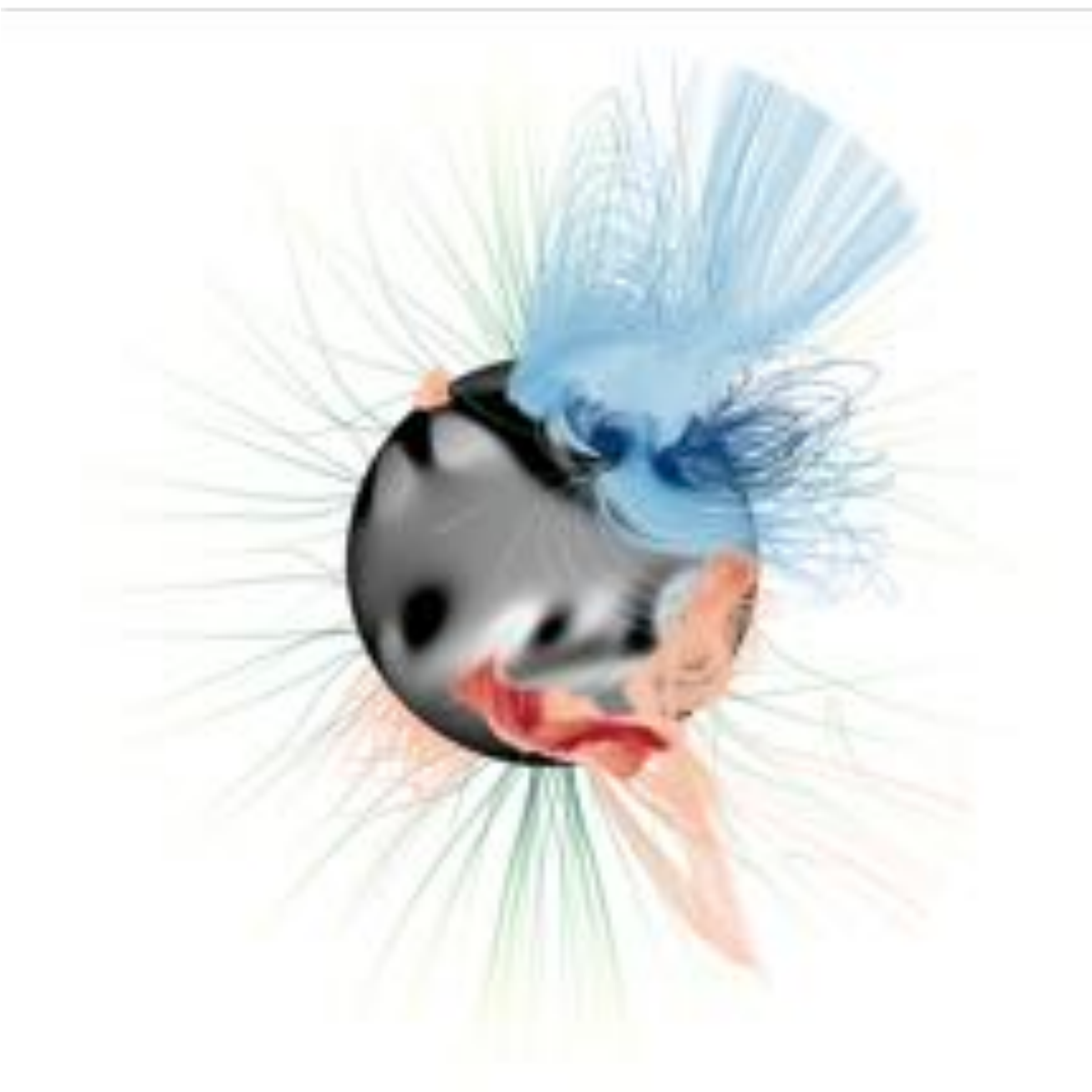
- Field line helicity builds up in a non-uniform way, indicating that "tangling" is stored at particular locations.

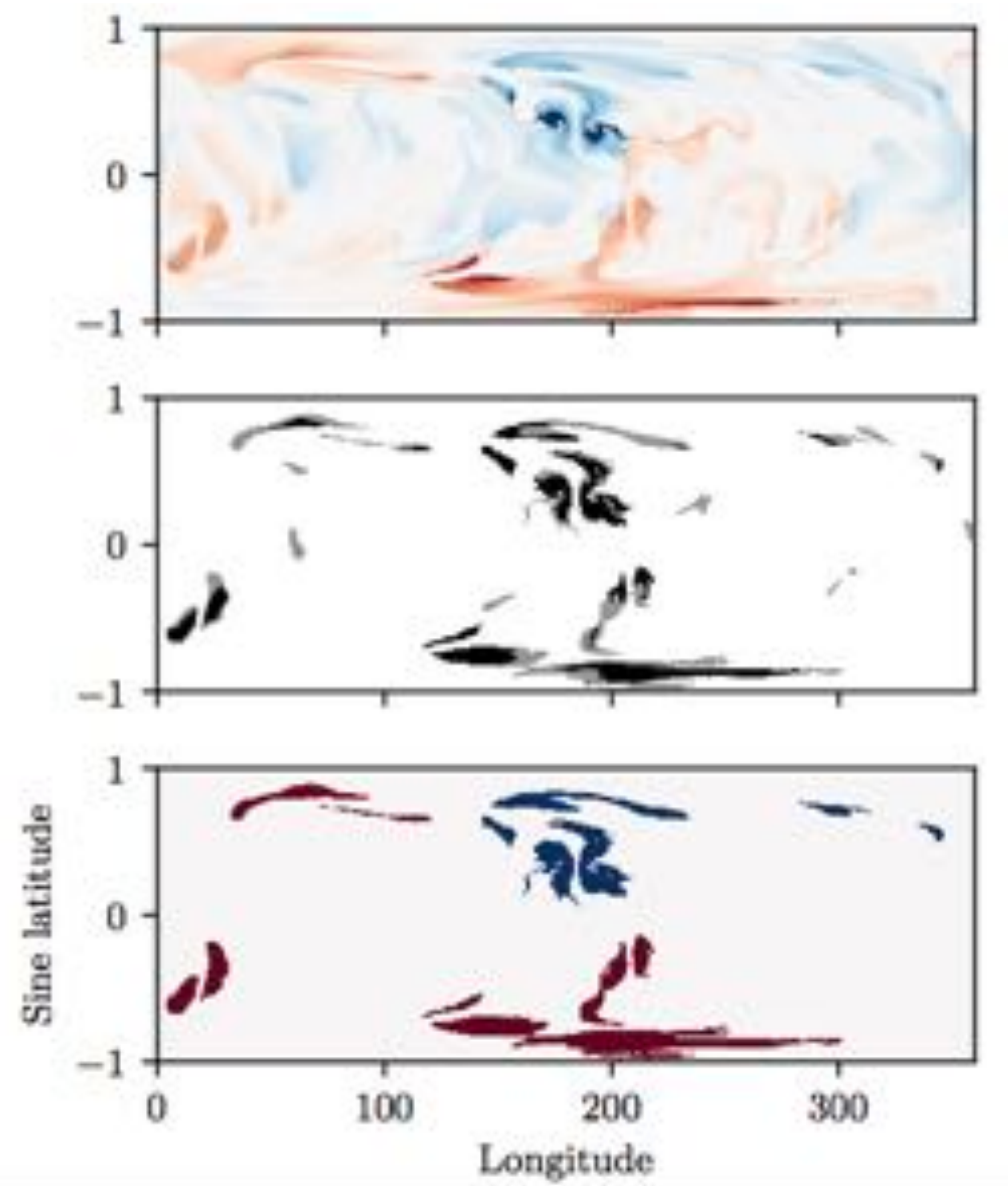


Flux rope detection/definition

Lowder & Yeates (*ApJ*, 2017)

- Identify *core* field lines with $|\mathcal{A}| > \mathcal{A}_{\text{core}}$.
- Grow to an *extent* threshold $|\mathcal{A}| > \mathcal{A}_{\text{extent}}$.
- Minimum footprint size 10 pixels.



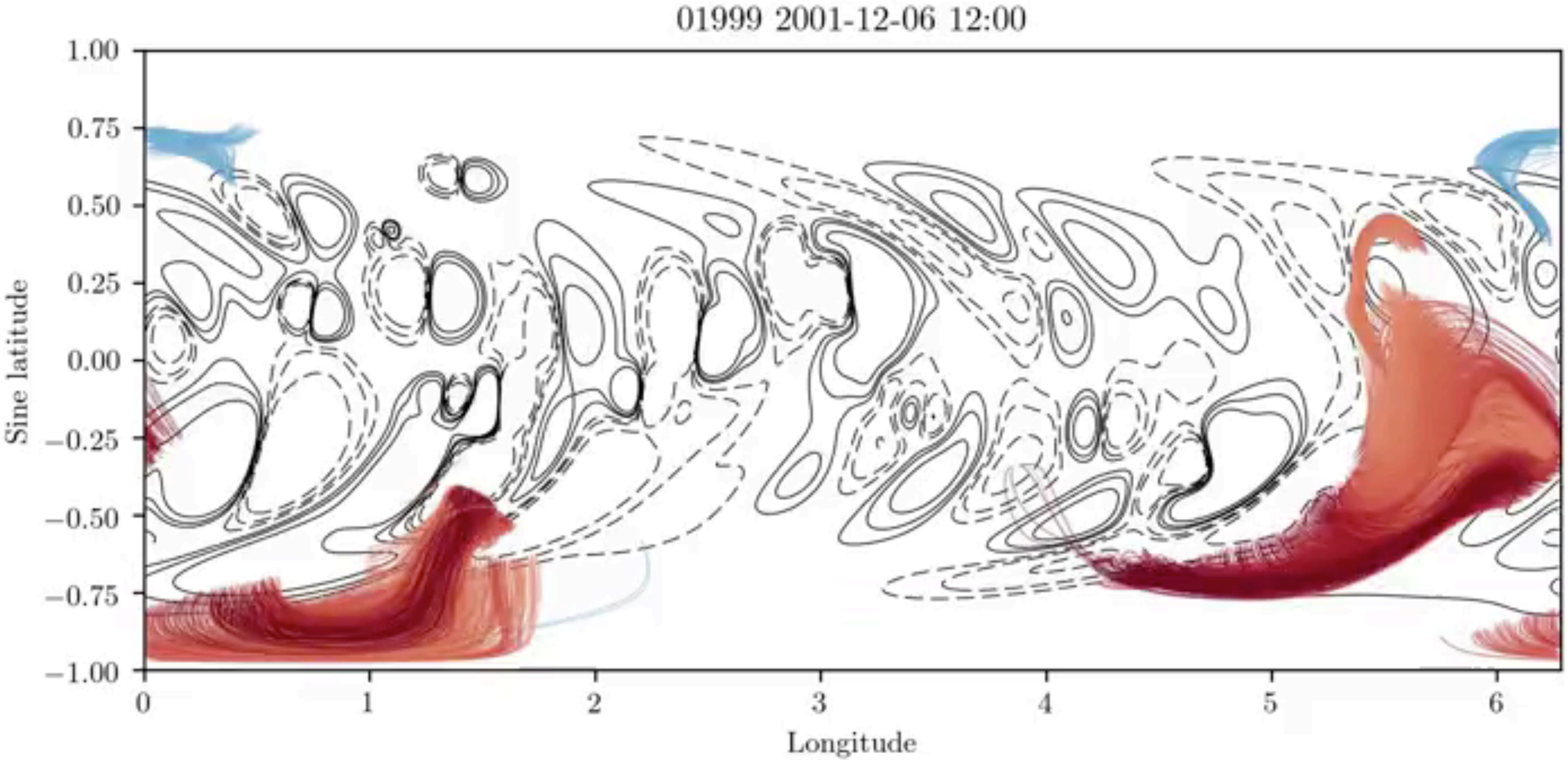


Flux ropes

Lowder & Yeates (*ApJ*, 2017)

- Built database over full 18-year model run (daily cadence).
- Tracked flux ropes over time ($> 50\%$ area overlap).
- Removed structures spending more than half of lifetime above 1.25 Rsun.

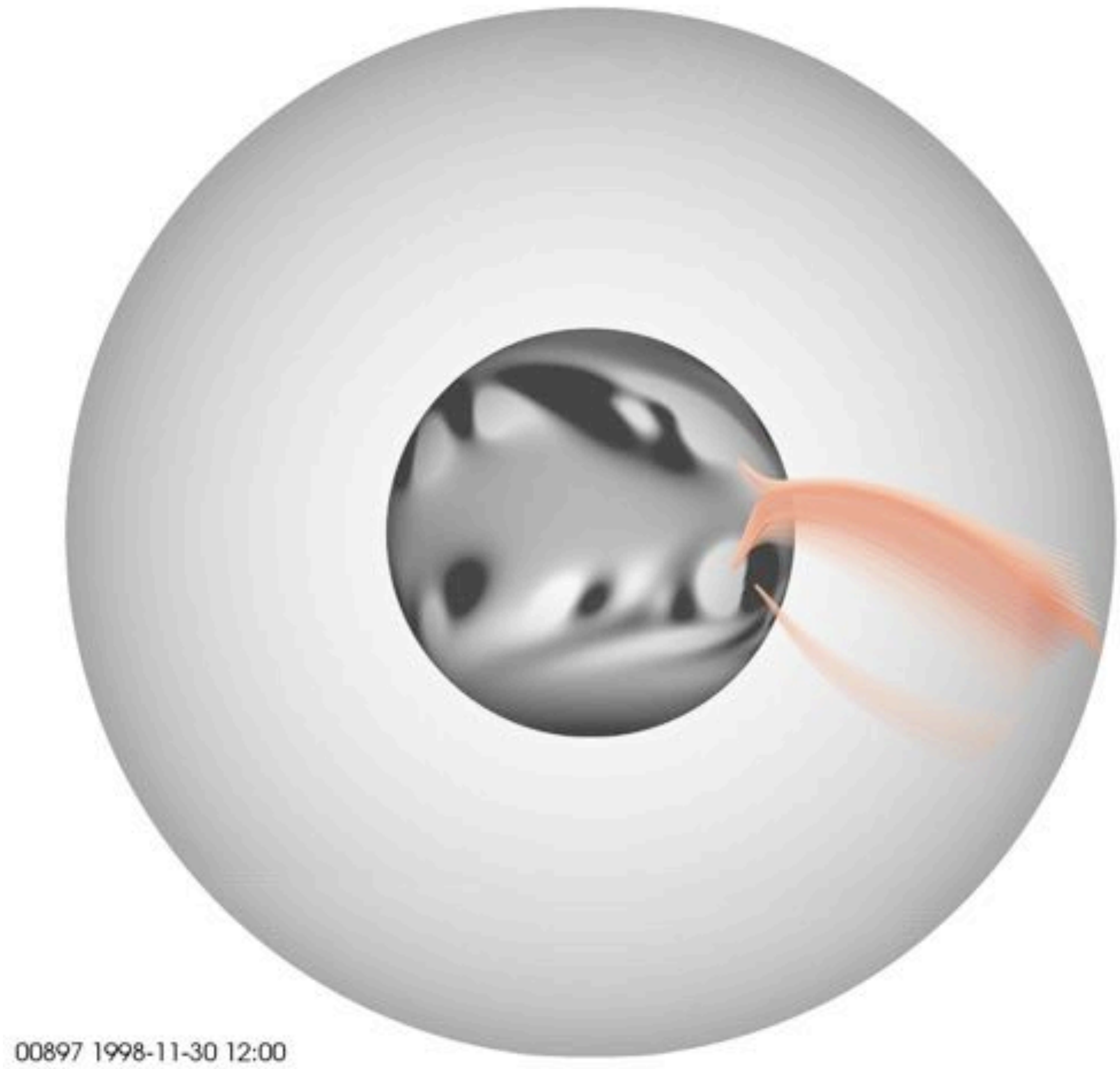
- Movie shows flux rope cores for part of run (coloured by $\mathcal{A}$):



Eruption detection

Lowder & Yeates (*ApJ*, 2017)

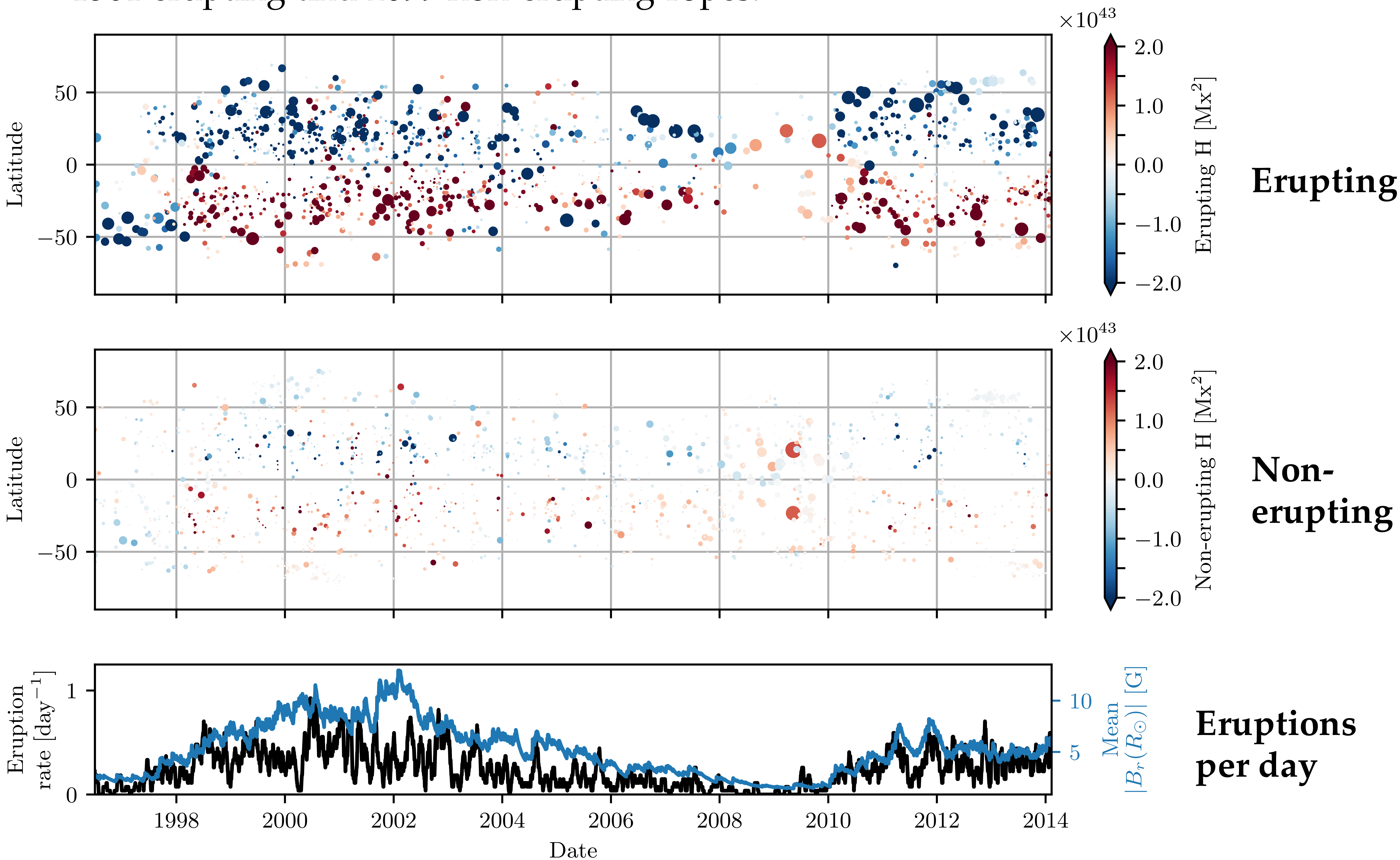
- Detect eruptions with thresholds on both $|\mathbf{B} \times \mathbf{e}_r|$ and $|\mathcal{A}|$ at upper boundary.
- Trace down to photosphere and link to pre-eruption database.



Results

Lowder & Yeates (*ApJ*, 2017)

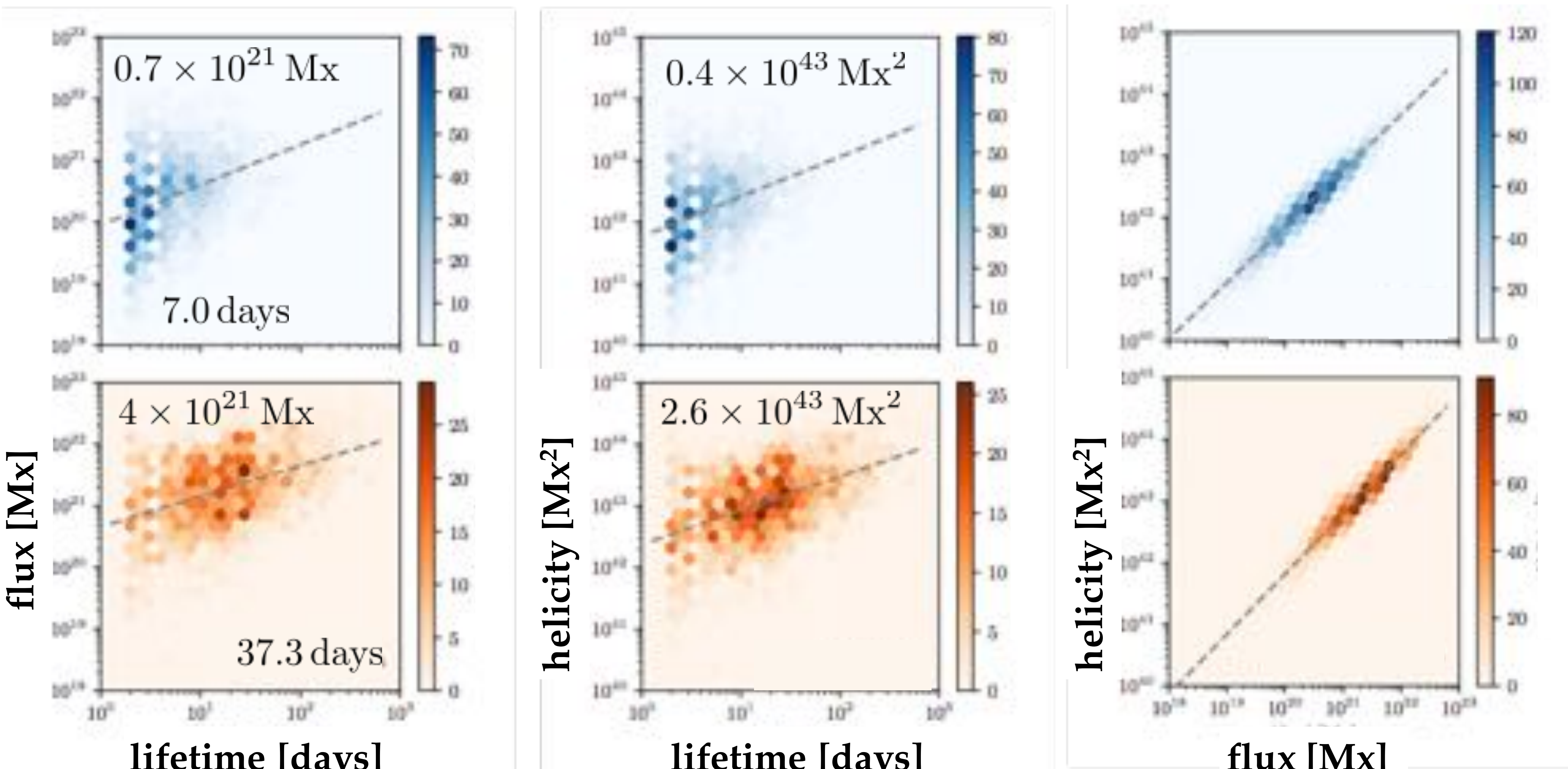
- 1561 erupting and 2099 non-erupting ropes.



Erupting vs. non-erupting

Lowder & Yeates (*ApJ*, 2017)

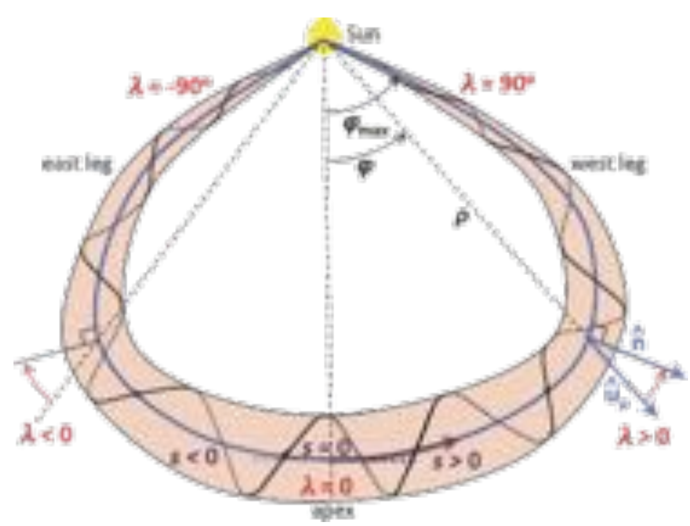
- Erupting ropes are longer lasting, with greater flux and helicity than non-erupting.



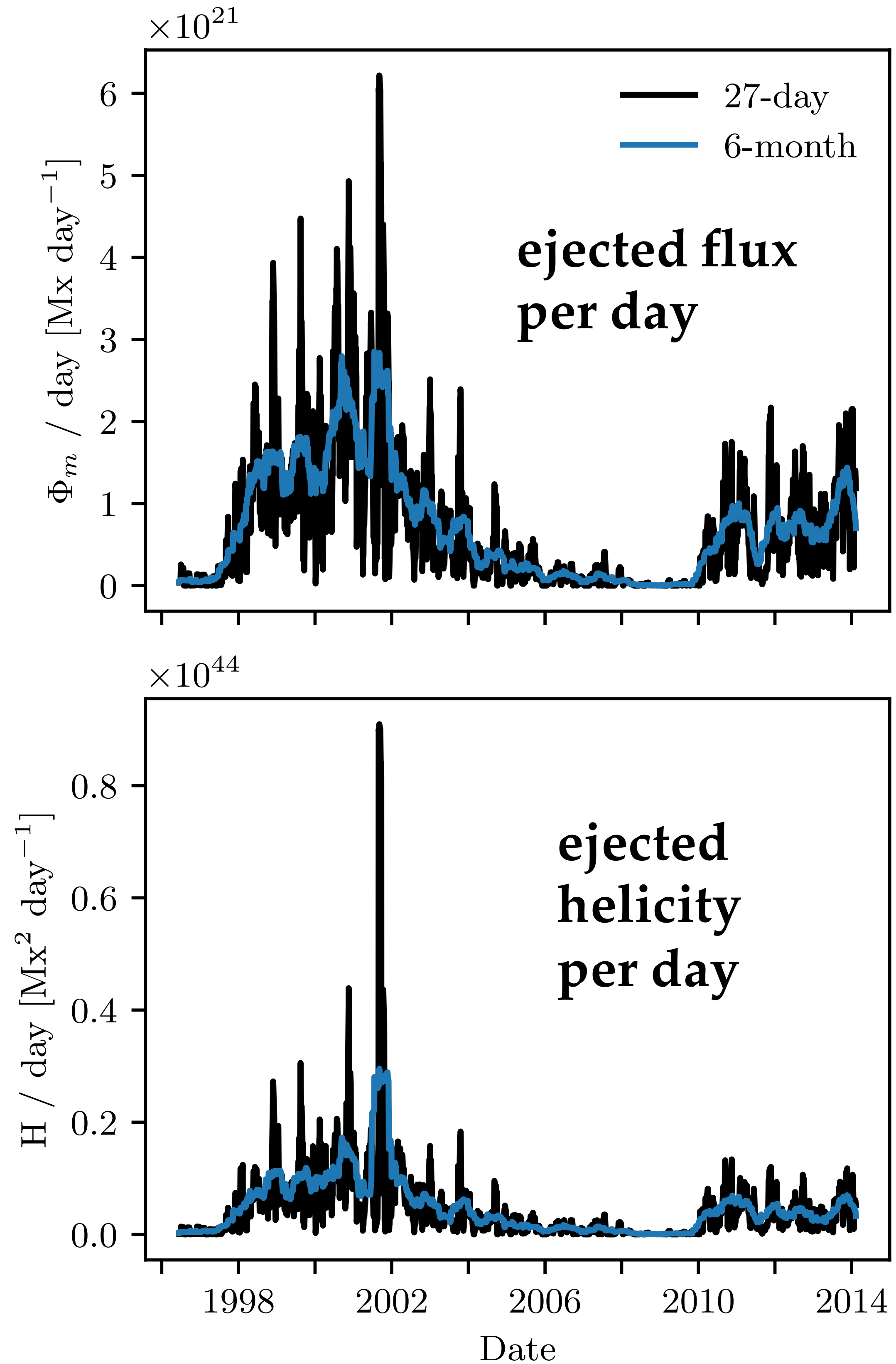
Estimated ejection rates

Lowder & Yeates (*ApJ*, 2017)

- At peak strength of *pre-erupting* rope.
- Totals ejected over Solar Cycle 23:
  - 3.5×10^{24} Mx magnetic flux
  - 2.4×10^{46} Mx^2 magnetic helicity
- Similar to magnetic cloud estimates by Démoulin et al., *Solar Phys.* (2016) ~ 3×10^{24} Mx, ~ 2.5×10^{46} Mx^2.



- But our ejection rate of **0.24 per day** is lower than LASCO CME rate.



Conclusions

- Time-dependent modelling of non-potential magnetic field in the solar corona.
- Definition/identification of magnetic flux ropes using field line helicity.
- Active regions + large-scale motions lead to ejected flux and helicity comparable to observational estimates, but too few CME eruptions.
- **FRoDO** Python code for flux rope tracking — https://doi.org/10.5281/zenodo.825186
- Future plans: study model dependence.

References

- Yeates & Mackay, *ApJL* **753**, L34 (2012).
- Yeates, *Solar Phys.* **289**, 631 (2014).
- Yeates & Hornig, *A&A* **594**, A98 (2016).
- Lowder & Yeates, *ApJ* **846**, 106 (2017).

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

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