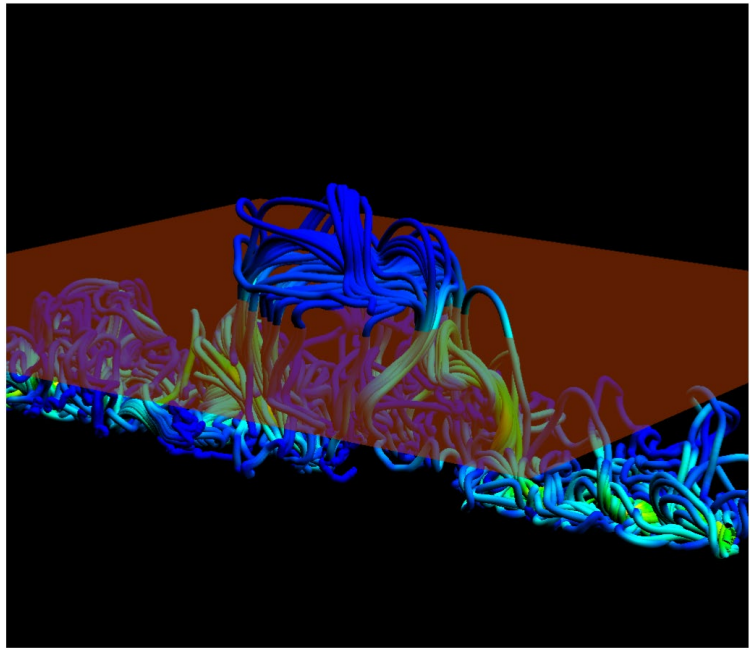
Direct evidence of a pre-twisted magnetic flux rope emerging into the solar corona.



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Understanding the topology of emerging magnetic field is of fundamental importance.

Dynamo constraint

AR evolution, flares, CMEs

For the latter, many proxies have been developed that indicate the emergence of *pre-twisted* magnetic field.

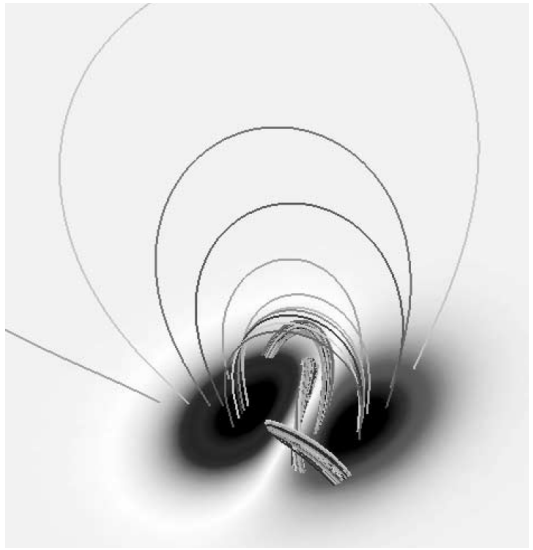
Without a *direct* measure of emerging field line topology, however, the problem remains open. Why?

Many important signatures can potentially be produced by means other than emerging twisted flux tubes.

Magnetic tongues created by *braided* rather than twisted tubes

Prior and MacTaggart 2016, GAFD, 110, 432

Sigmoids created by photospheric motions

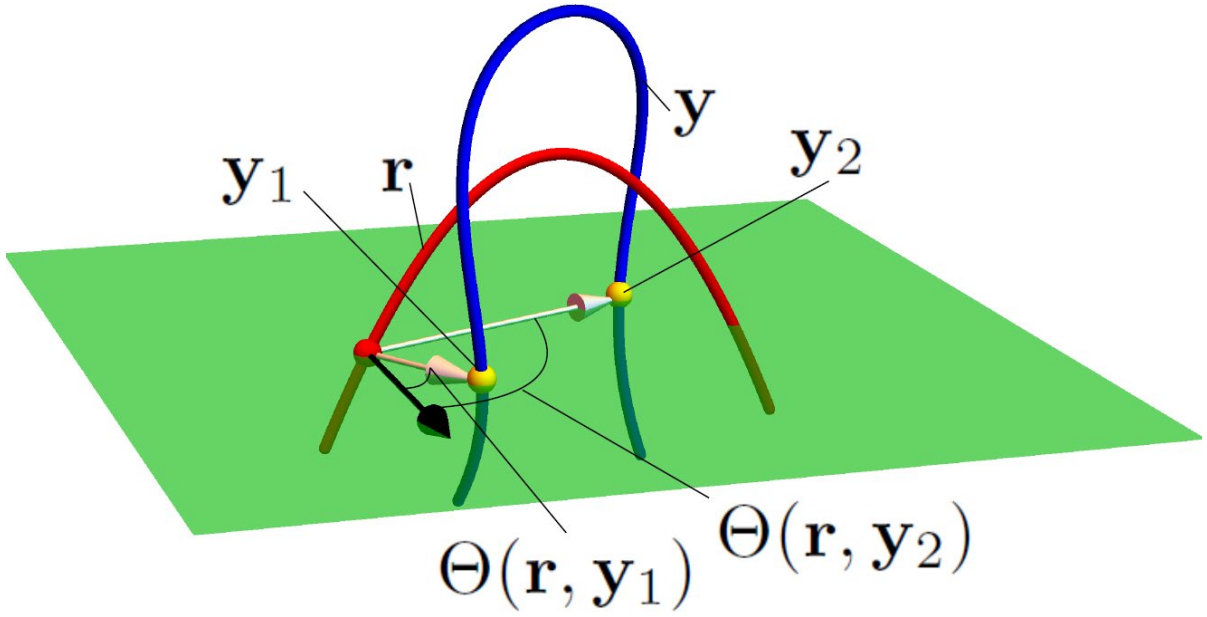


Amari et al. 2003, ApJ, 585, 1073

What we need is a *direct* measure of the field line topology.

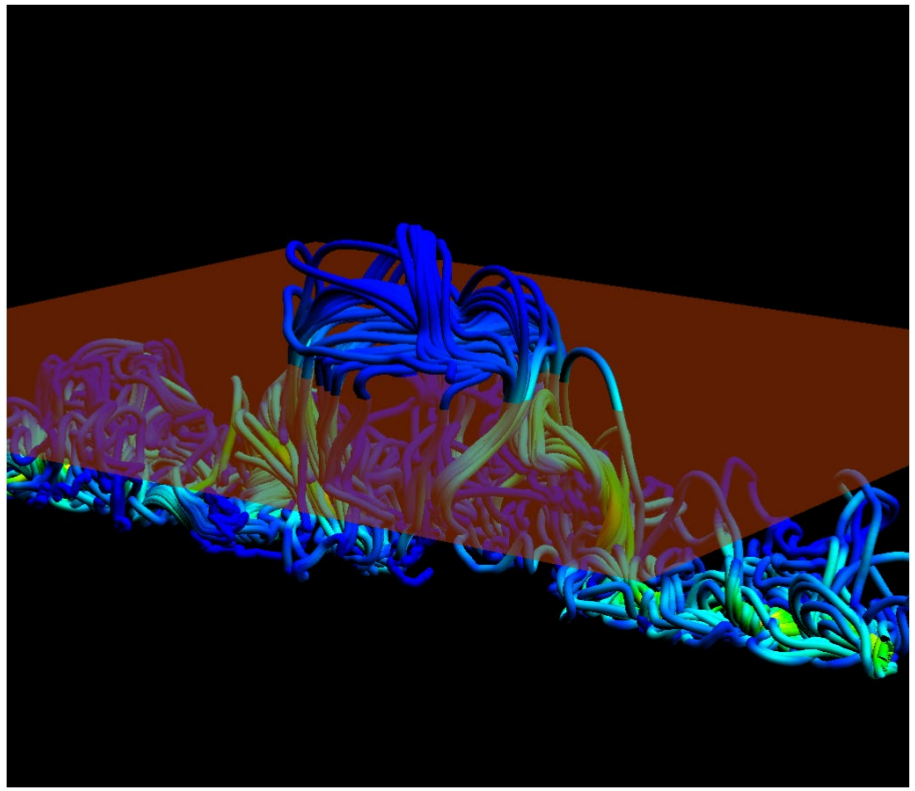
Magnetic winding

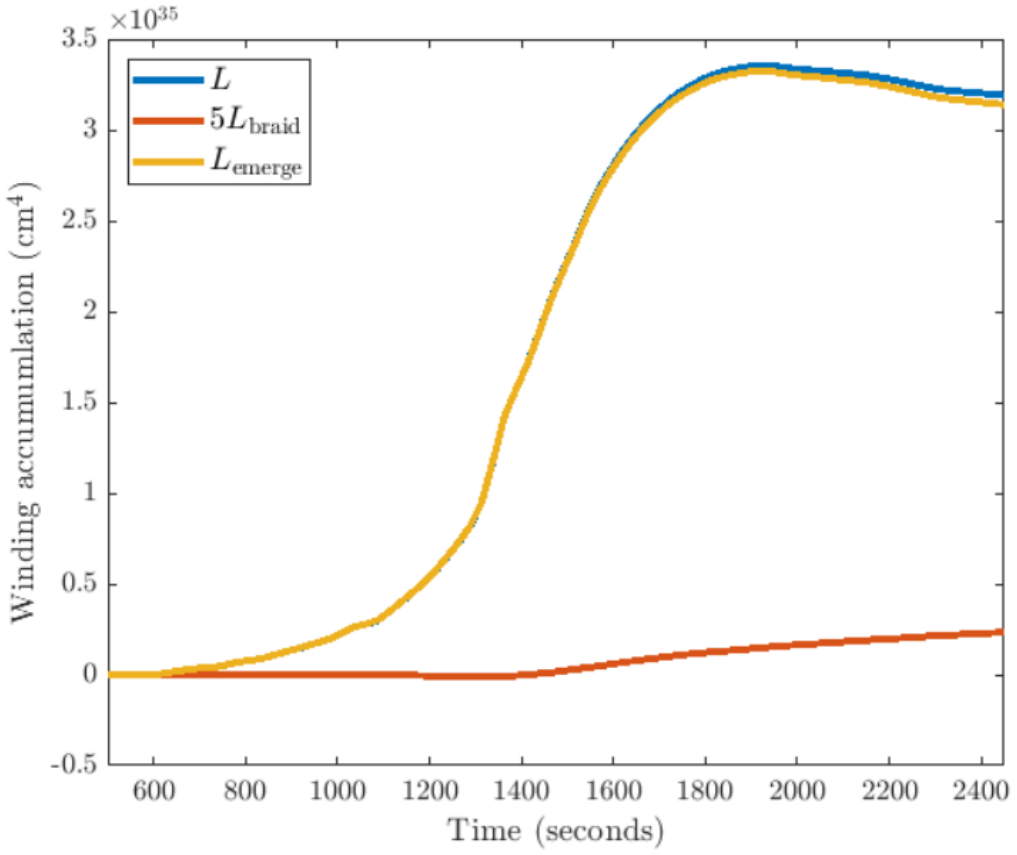
$$\frac{\mathrm{d}L}{\mathrm{d}t} = -\frac{1}{2\pi}\int_{P'}\int_{P}\sigma(\mathbf{y}')\sigma(\mathbf{y})\frac{\mathrm{d}\theta}{\mathrm{d}t}\,\mathrm{d}^2y\,\mathrm{d}^2y' = -\frac{1}{2\pi}\int_{P'}\int_{P}\sigma(\mathbf{y}')\sigma(\mathbf{y})\hat{z}\cdot\frac{(\mathbf{u}(\mathbf{y}')-\mathbf{u}(\mathbf{y}))\times\mathbf{r}}{r^2}\mathrm{d}^2y\mathrm{d}^2y'$$



$$\mathbf{u} = \mathbf{v}_\perp - v_z\frac{\mathrm{d}\mathbf{y}}{\mathrm{d}z} = \underbrace{\mathbf{v}_\perp}_{\text{braiding motion}} \quad \underbrace{-\frac{v_z}{B_z}\mathbf{B}_\perp}_{\text{emergence motion}}$$

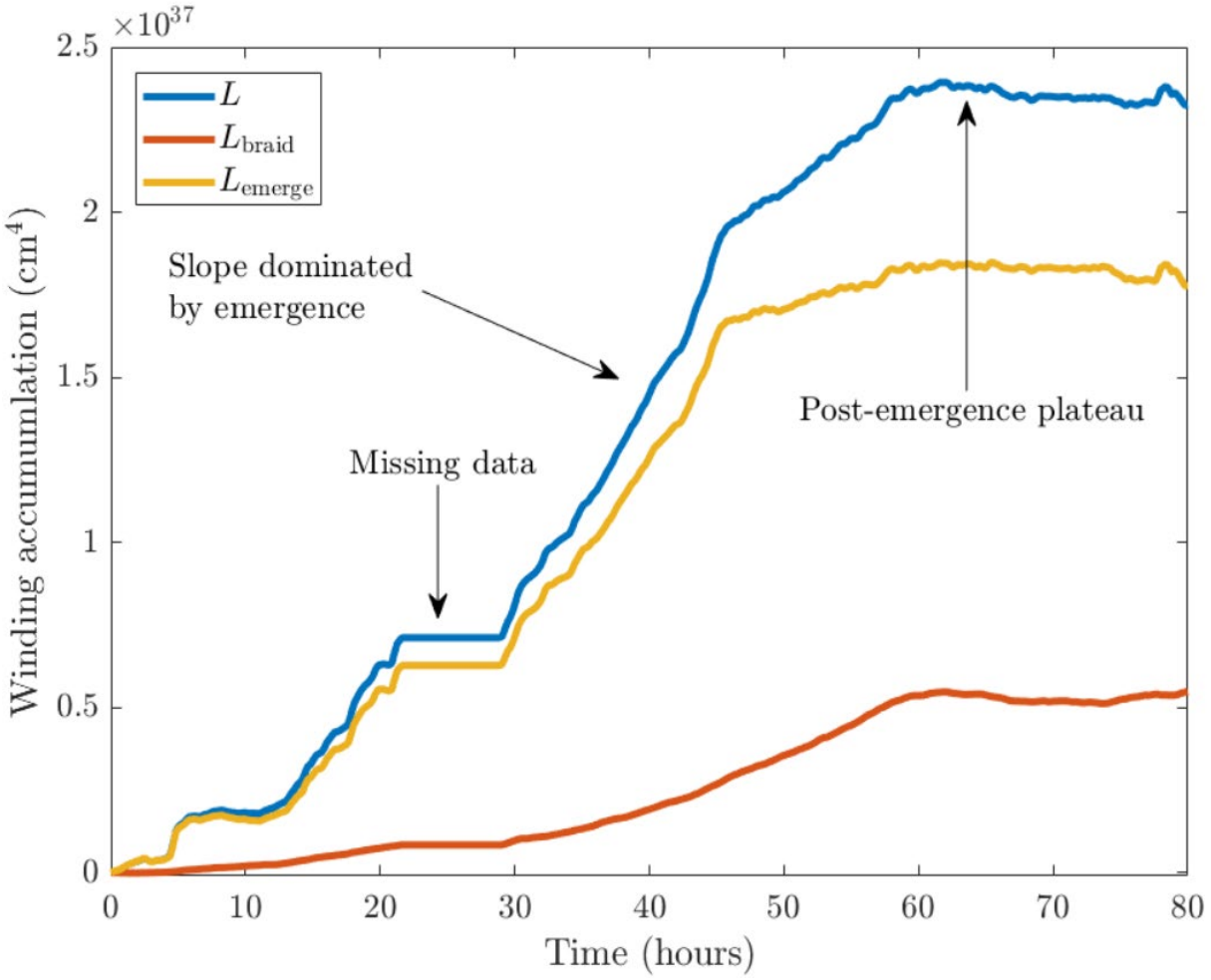
Simulation example



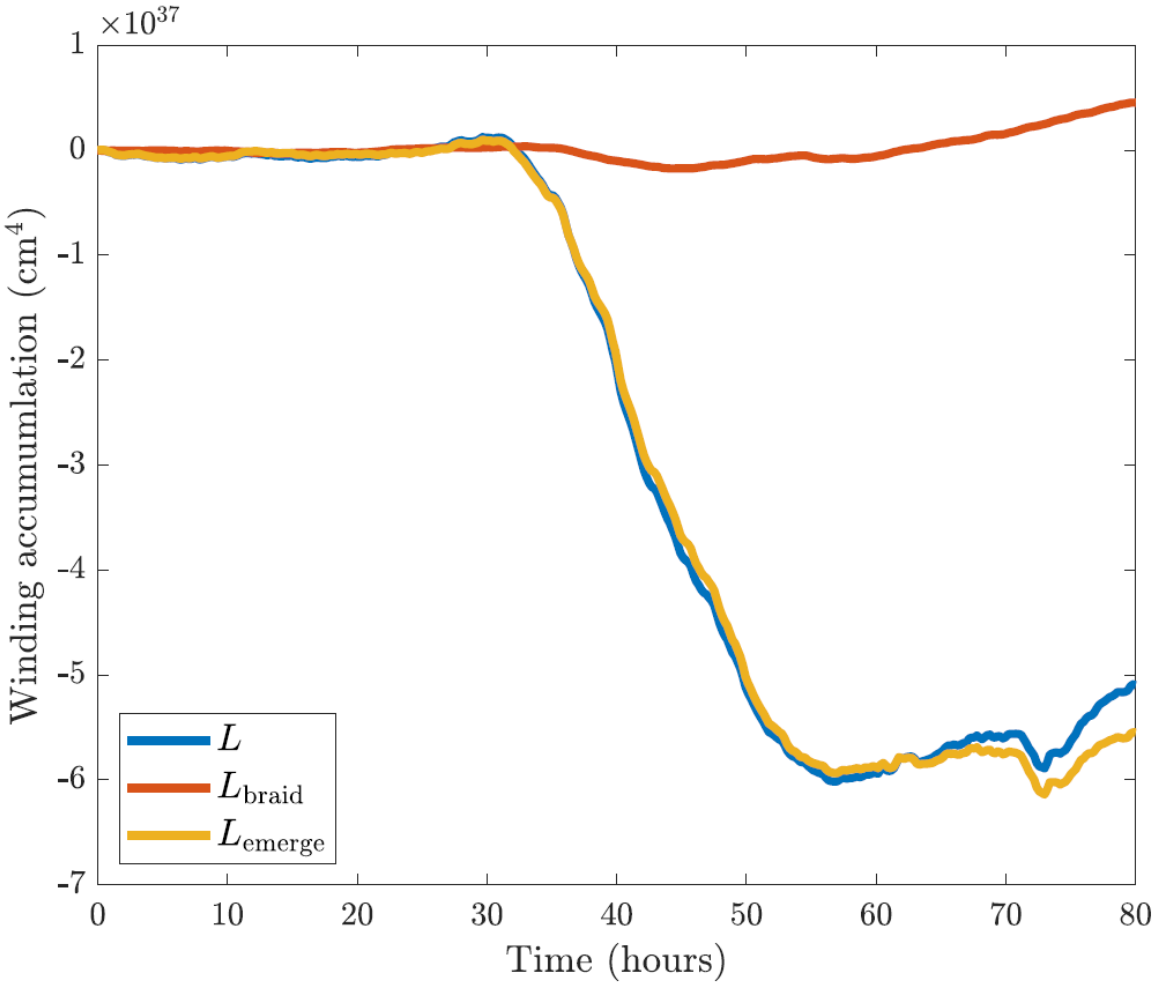


Observational example

AR11318



AR12203



Further reading:

Theoretical descriptions:

Prior, C., MacTaggart, D., Magnetic winding: what is it and what is it good for? 2020, Proceedings of the Royal Society A, 476, 20200483

MacTaggart, D., Prior, C., Magnetic winding – a key to unlocking topological complexity in flux emergence 2020, Journal of Physics: Conference Series, 1730

Simulations:

Prior, C., MacTaggart, D., Interpreting magnetic helicity flux in solar flux emergence 2019, Journal of Plasma Physics, 85, 775850201

MacTaggart, D., Prior, C., Helicity and winding fluxes as indicators of twisted flux emergence 2021, Geophysical and Astrophysical Fluid Dynamics, 115, 85

Observations:

MacTaggart, D., Prior, C., Raphaldini, B., Romano, P., Guglielmino, S. 2021, Direct evidence: twisted flux tube emergence creates solar active regions, https://arxiv.org/abs/2106.11638 (currently under revision)