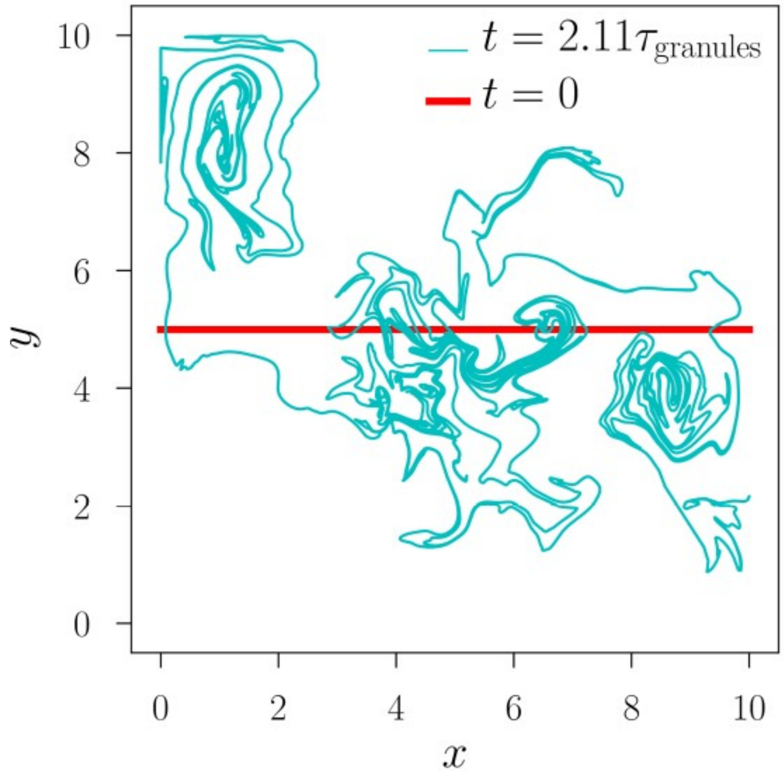
Field line braiding in the solar corona by photospheric flows.

Simon Candelaresi, David Pontin,
Anthony Yeates, Gunnar Hornig, Paul Bushby



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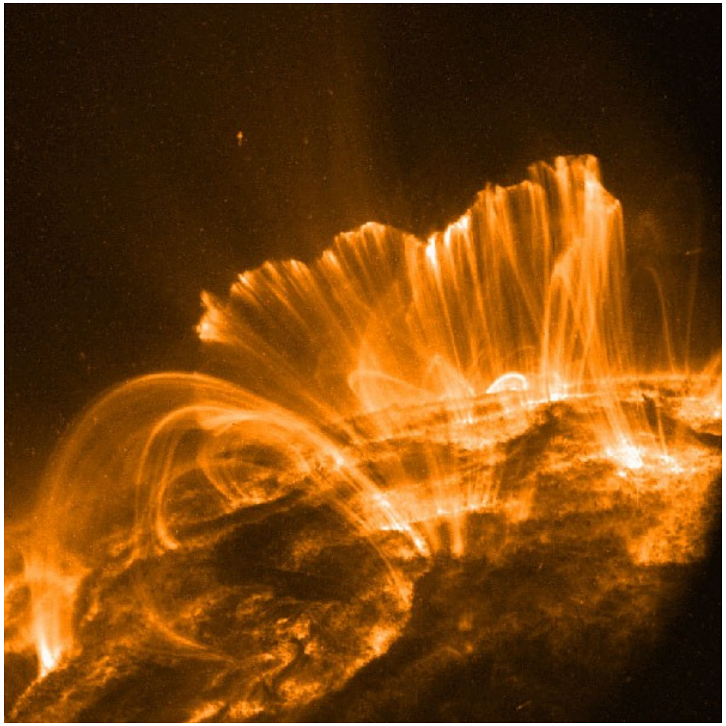
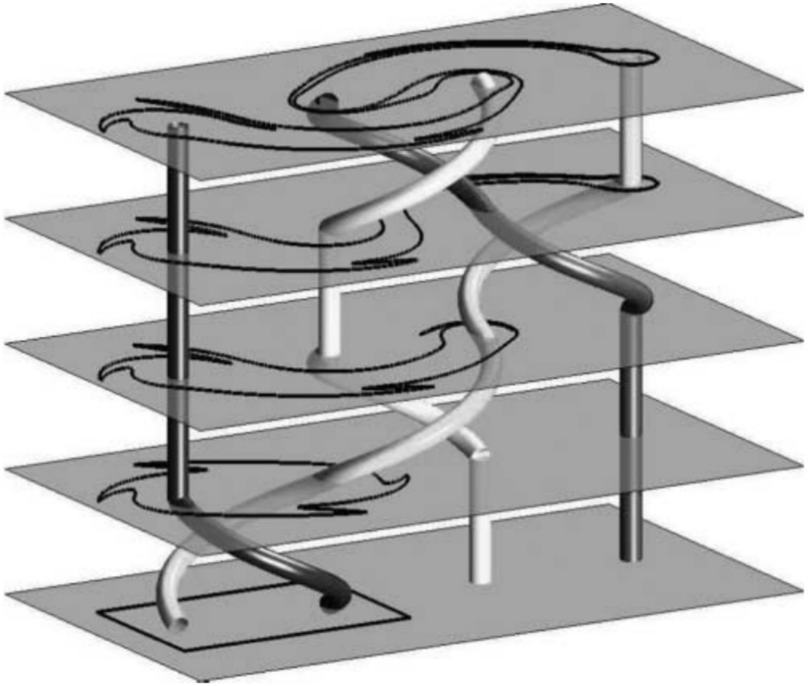
Coronal Magnetic Fields

NASA

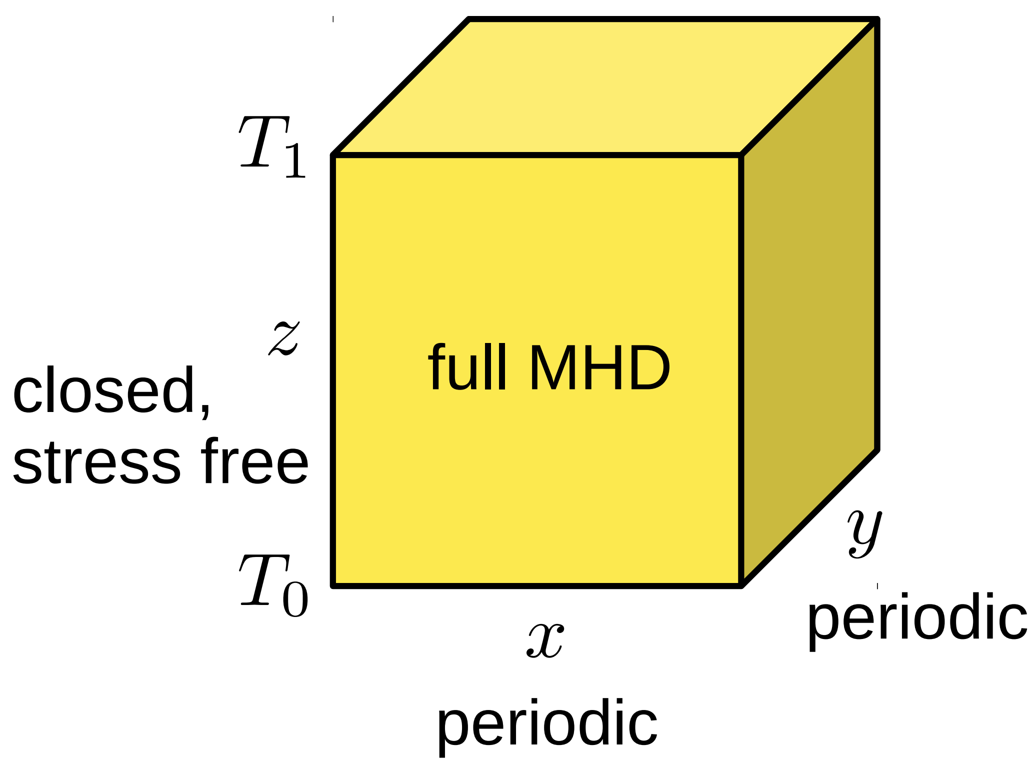


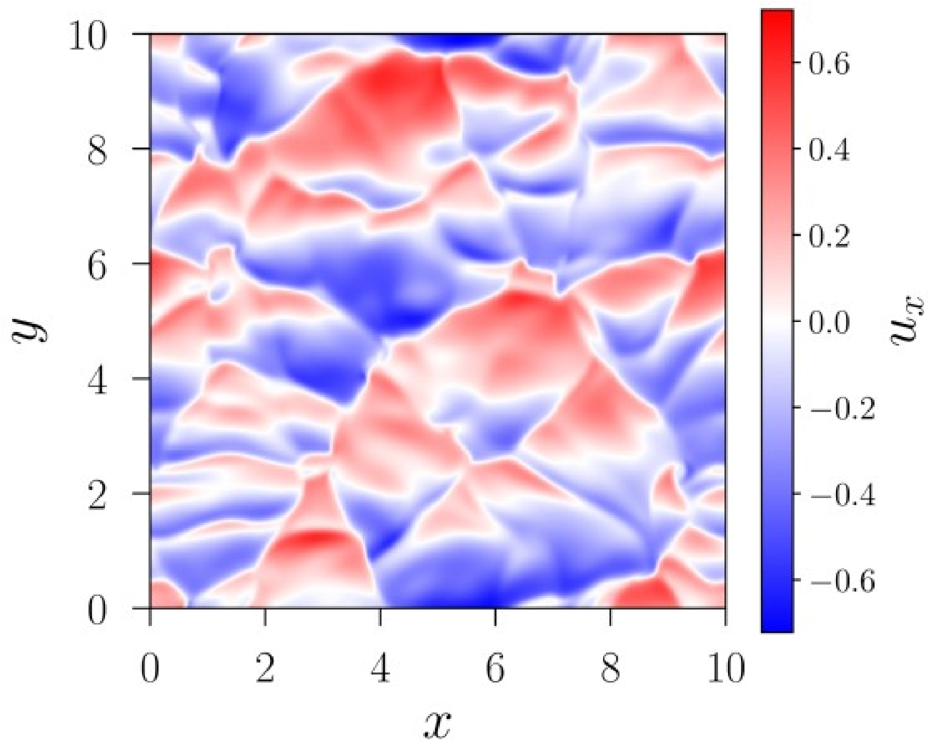


(Thiffeault et al. 2006)

- Field line tangling in solar magnetic fields.
- Study the tangling of solar magnetic field lines.

Magneto-Convection Simulations





(Bushby et al. 2012)

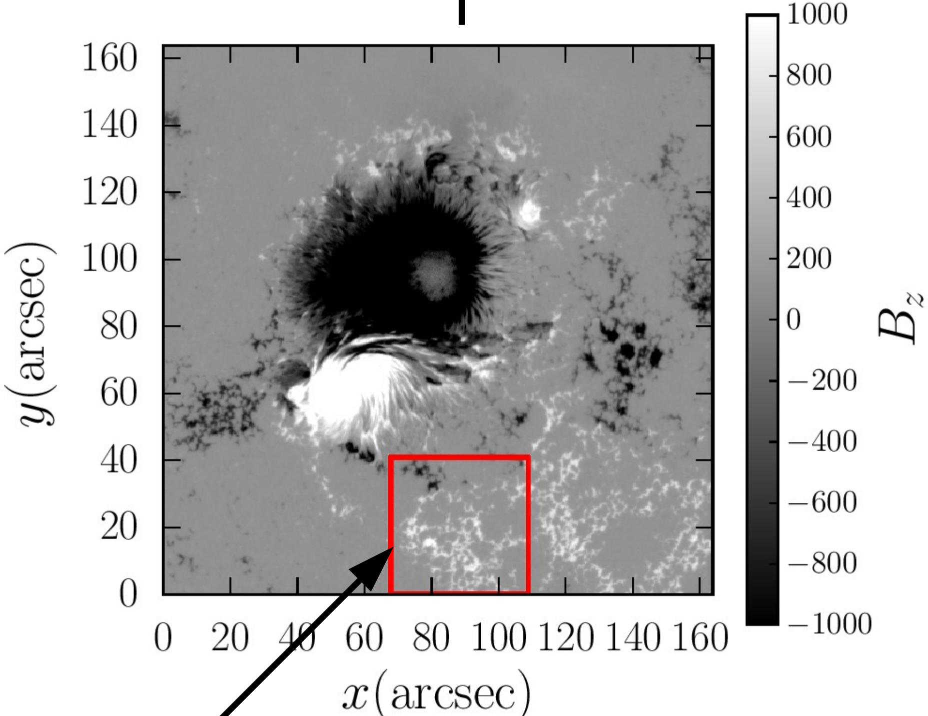
Helmholtz-Hodge Decomposition: $\mathbf{u} = \mathbf{u}_\mathrm{i} + \mathbf{u}_\mathrm{c} + \mathbf{u}_\mathrm{h}$

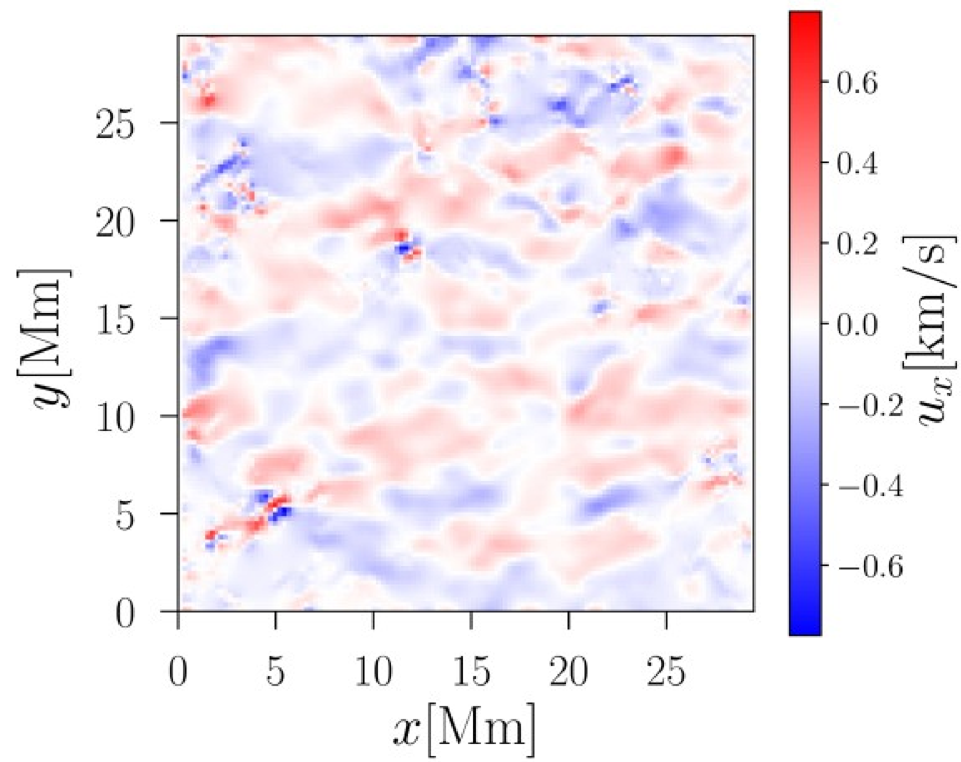
$$\mathbf{u}_\mathrm{i} = \nabla \times (\psi_z), \quad \mathbf{u}_\mathrm{c} = \nabla\phi, \quad \mathbf{u}_\mathrm{h} = \nabla\chi,$$

Active Region 10930

Helmholtz-Hodge Decomposition

FLCT

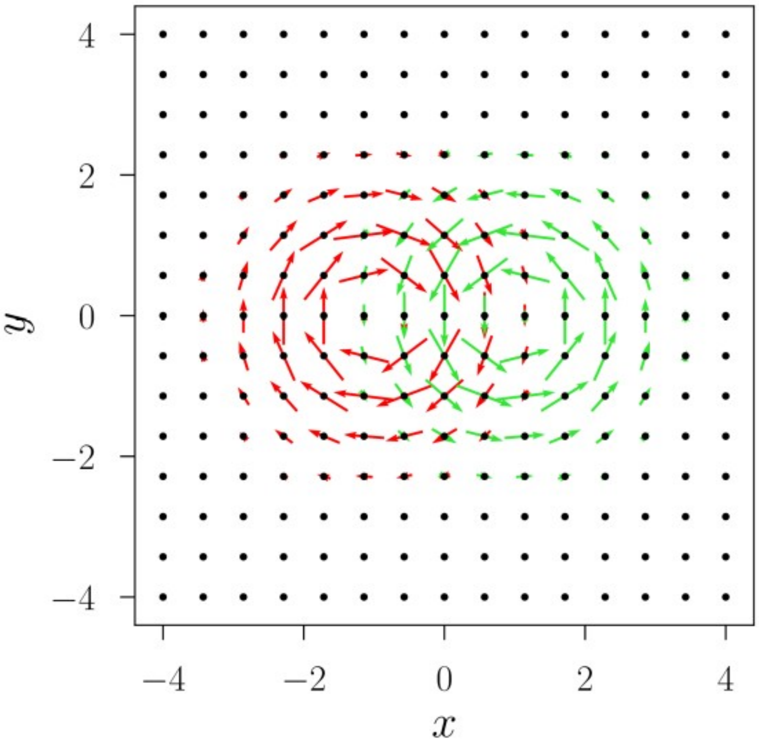


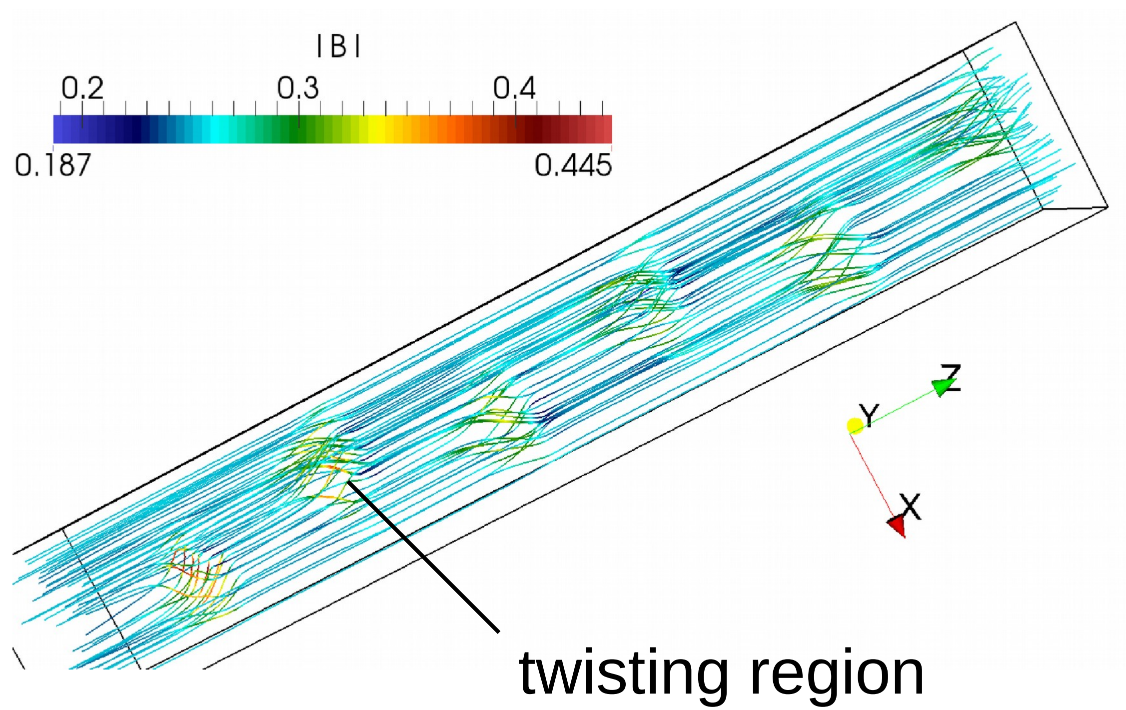


Consider this region.

12th of December 2006, 14:04 UT,
(Tsuneta et al. 2008, Fisher & Welsch 2008)

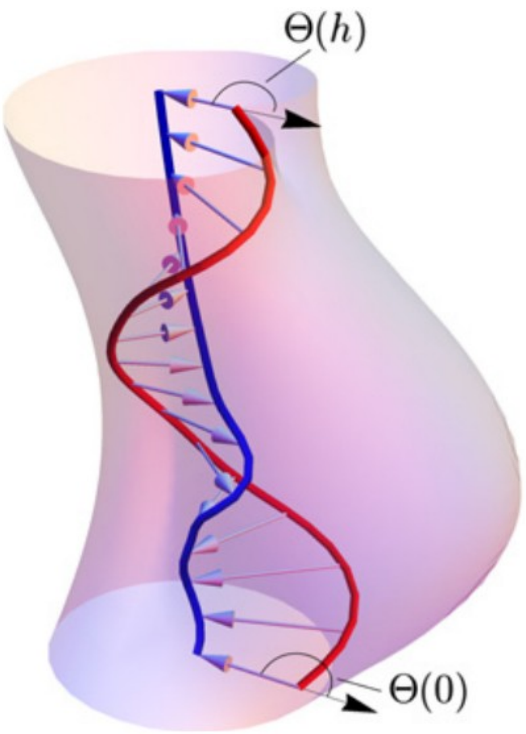
Blinking Vortex Benchmark





- Repeated applications of the blinking vortex motion.
- World lines correspond to 3d braided magnetic field (pig tail, E3).

Winding Number



(Prior & Yeates 2014)

$$\frac{\mathrm{d}\mathbf{r}_1(t)}{\mathrm{d}t} = \mathbf{u}(\mathbf{r}_1(t), t) \qquad \frac{\mathrm{d}\mathbf{r}_2(t)}{\mathrm{d}t} = \mathbf{u}(\mathbf{r}_2(t), t)$$

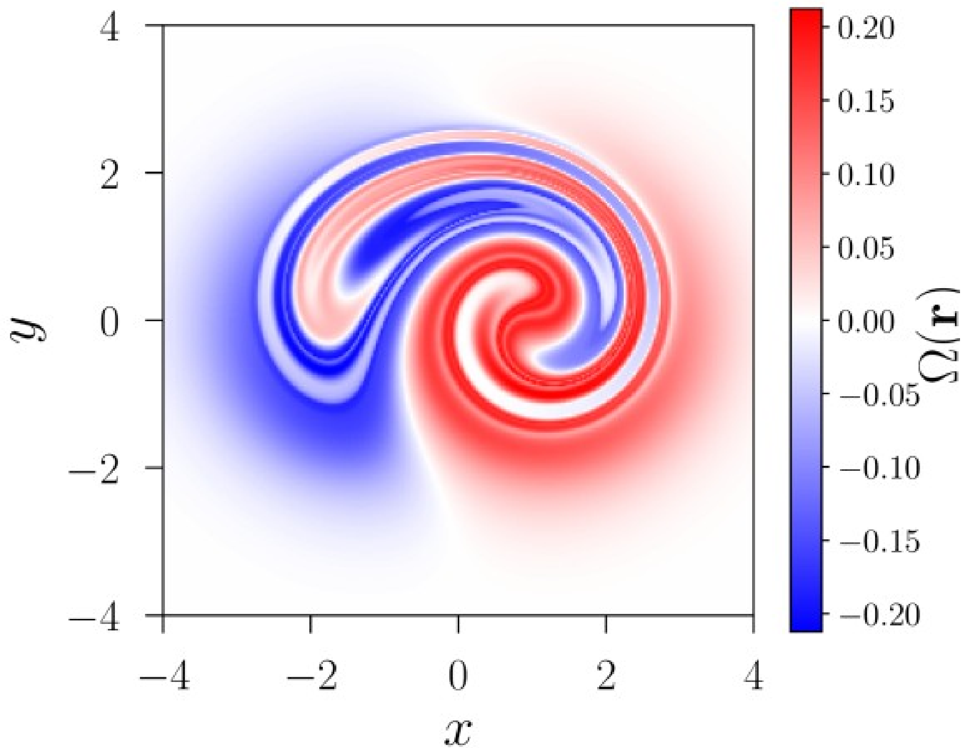
$$\Theta(\mathbf{r}_1, \mathbf{r}_2, t) = \arctan\left(\frac{y_2(t) - y_1(t)}{x_2(t) - x_1(t)}\right)$$

$$\Theta(\mathbf{r}_1, T) = \frac{1}{L_x L_y} \int_0^T \int_{(0,0)}^{(L_x, L_y)} \frac{\mathrm{d}\Theta(\mathbf{r}_1, \mathbf{r}_2, t)}{\mathrm{d}t} \, \mathrm{d}\mathbf{r}_2 \, \mathrm{d}t$$

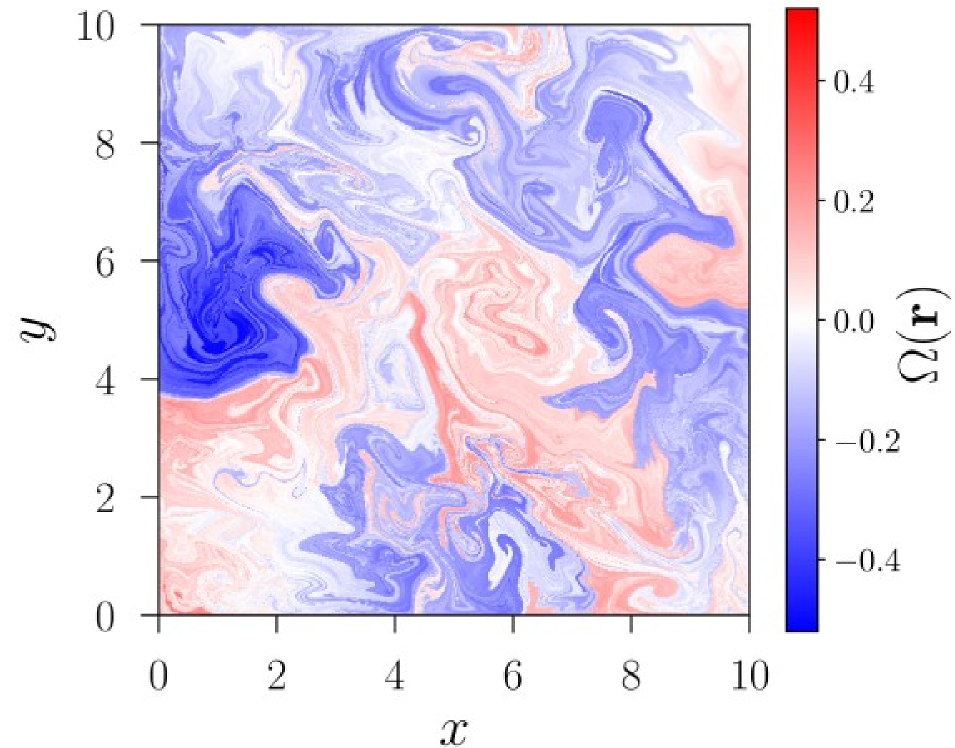
normalized averaged winding number:

$$\Omega(\mathbf{r}_1, T) = \frac{\Theta(\mathbf{r}_1, T)}{q(T)}$$

Winding Number

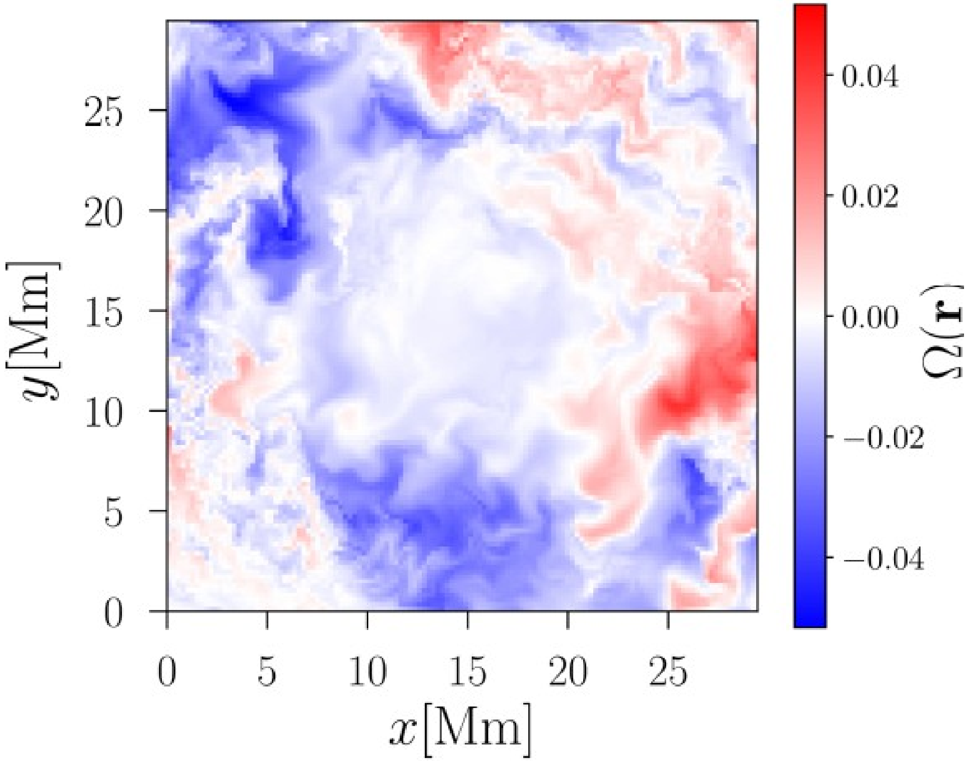


blinking vortex



simulation

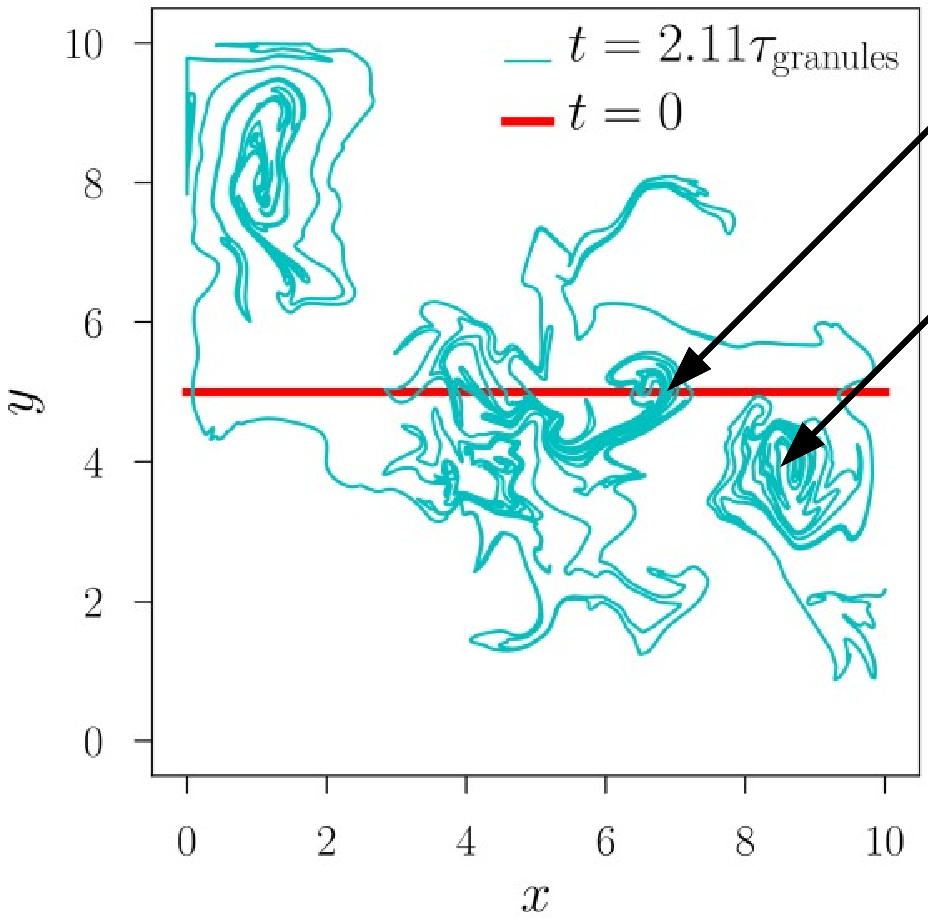
Winding Number



observations

- High winding for simulations.
- Low winding for observations.

Finite Time Topological Entropy



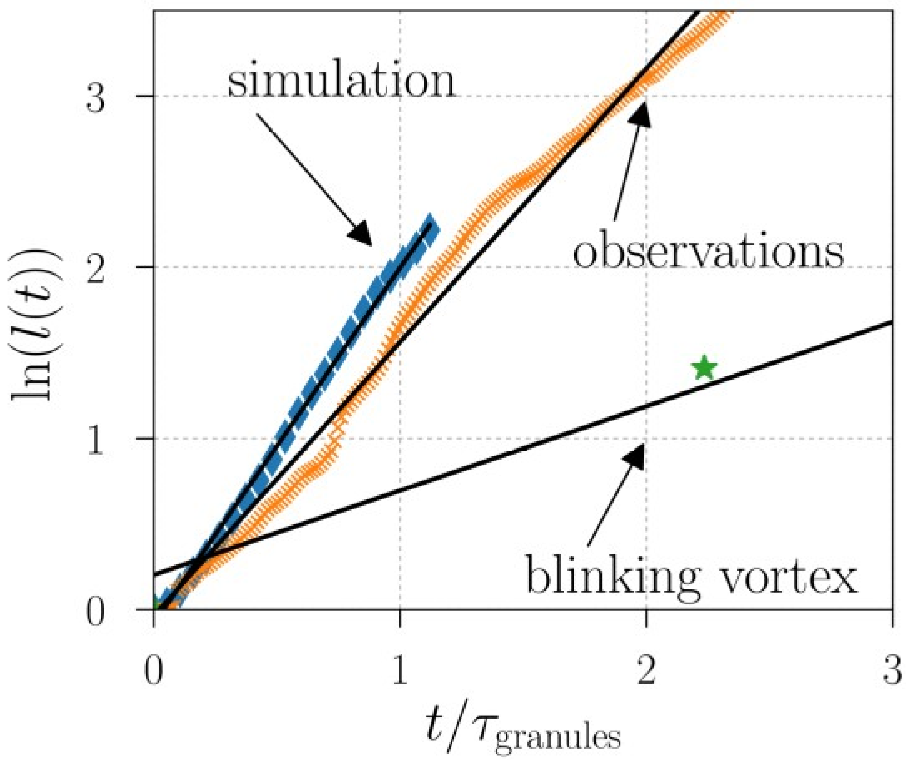
material line γ

advected material line $F(\gamma)$

FTTE:

$$h(F,\gamma,t) = \frac{1}{t}\ln\left(\frac{l(t)}{l_0}\right)$$

Finite Time Topological Entropy



- High tangling for simulations and observations.
- It takes 3.059h for the photosphere to get as tangled as during for one cycle of the blinking vortex motion.

Conclusions

- High degree of winding possible.
- High degree of entanglement
- Tangled magnetic field stores free energy to be released in reconnection events.
- Resolution less important than velocity extraction method (Welsch 2007).

arXiv: 1807.10188

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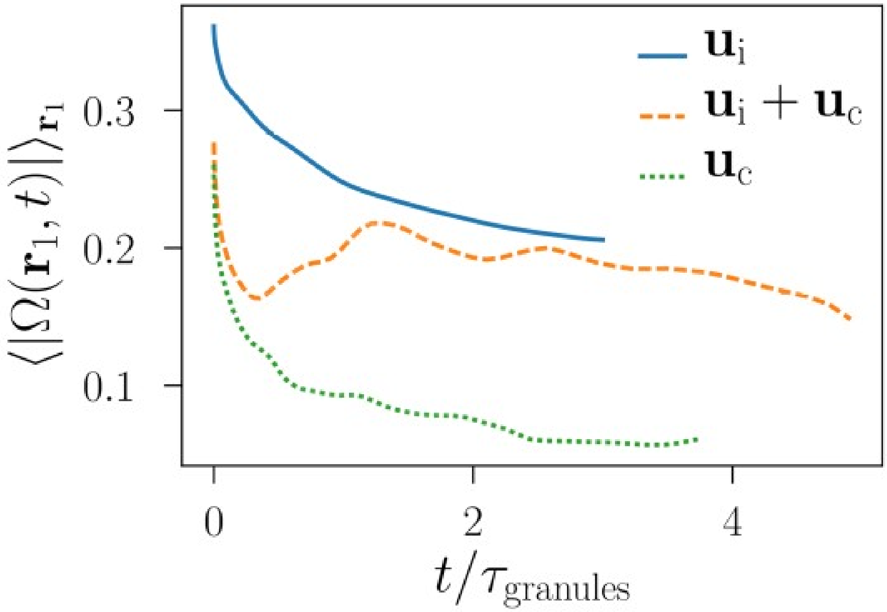
Winding Number

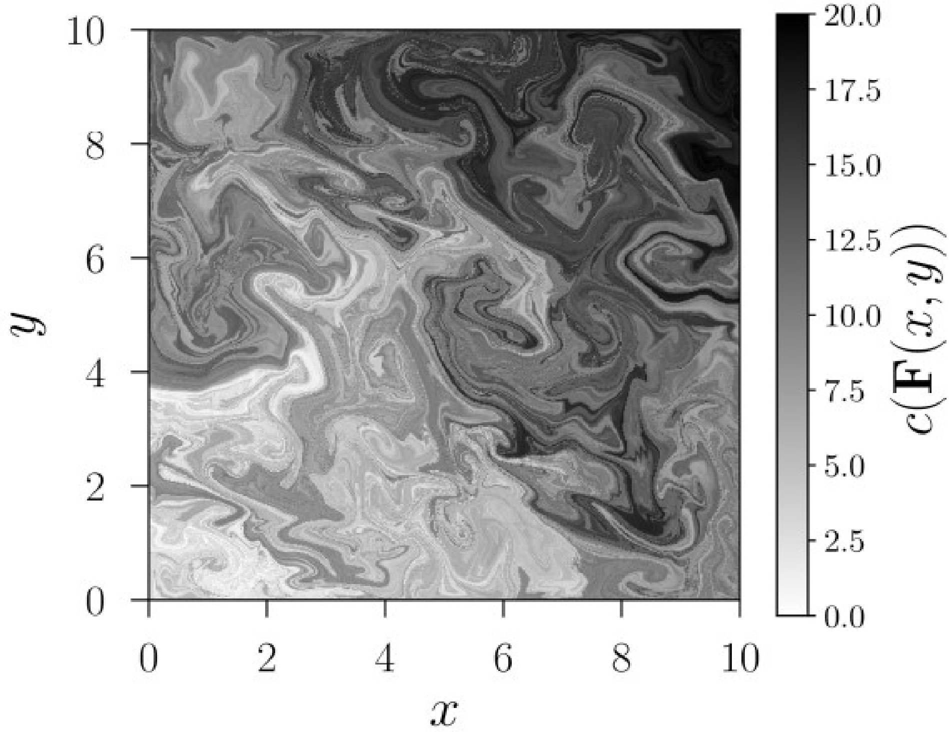
normalization: $$q(T) = \frac{1}{l_{\text{granules}} L_x L_y} \int_0^T |\mathbf{u}| \, \mathrm{d}x \, \mathrm{d}y \, \mathrm{d}t.$$

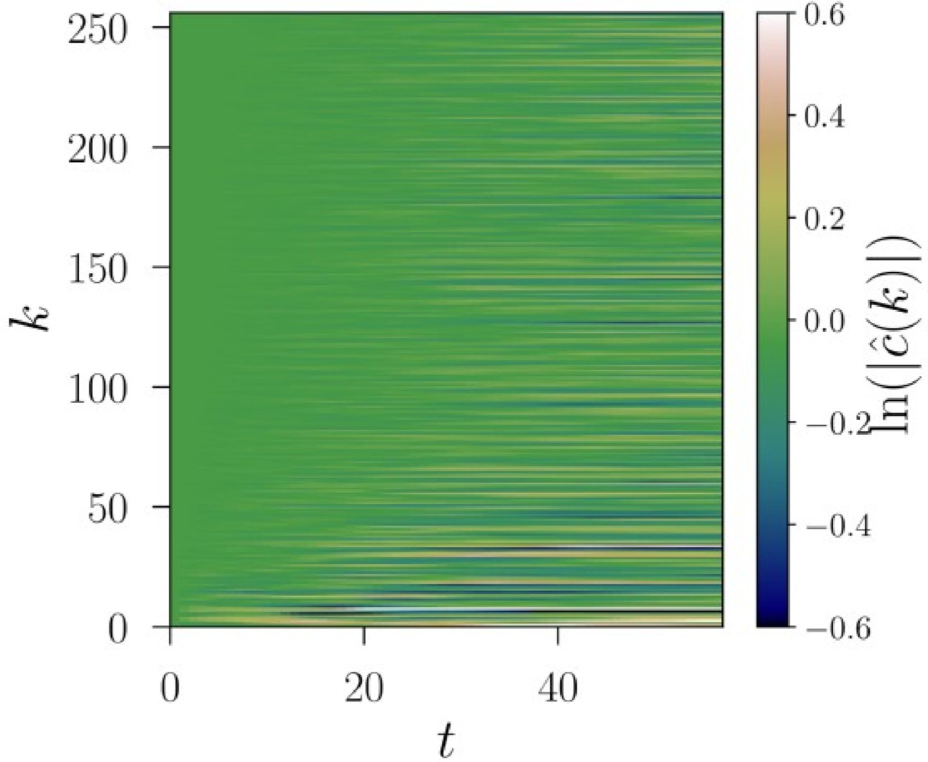


$$\mathbf{u} = \mathbf{u}_{\text{i}} + \mathbf{u}_{\text{c}} + \mathbf{u}_{\text{h}}$$

Compressional part does not significantly contribute to the winding.

Passive Scalar





initial profile: $c(x, y) = x + y$

- High mixing of passive scalar.
- No clear scale due to turbulent motions.