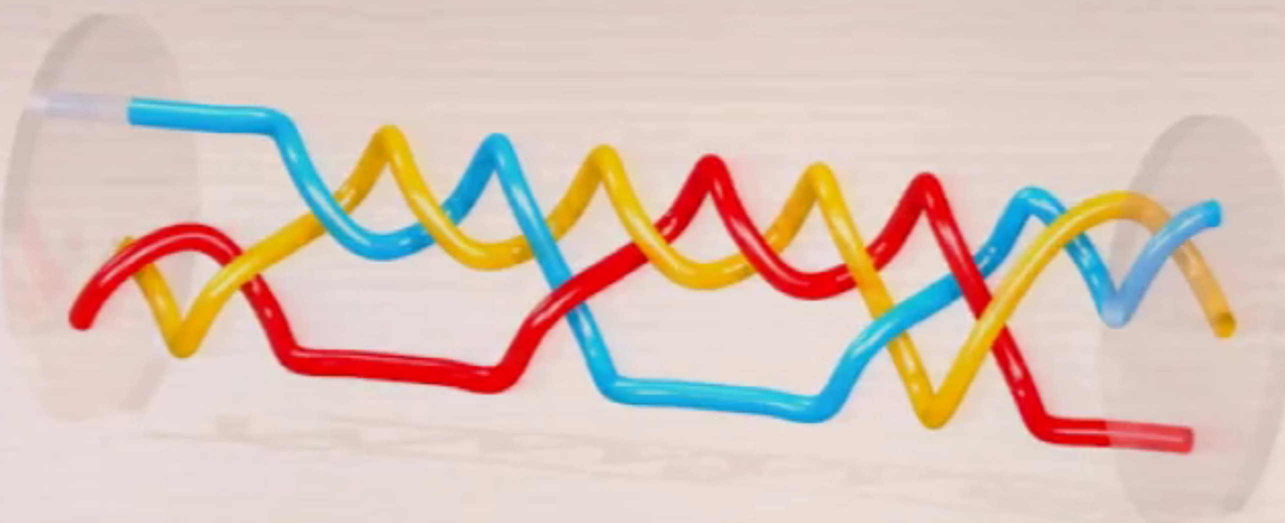
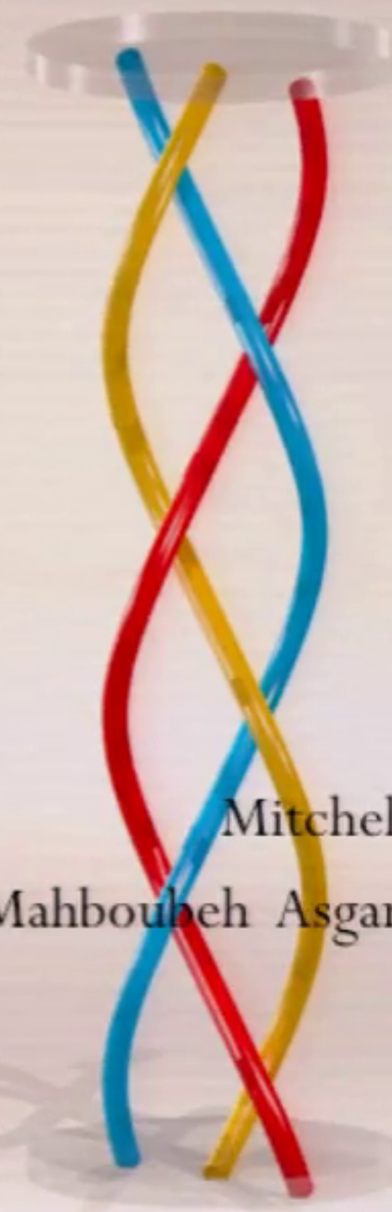
Self Organized Braiding of Coronal Loops

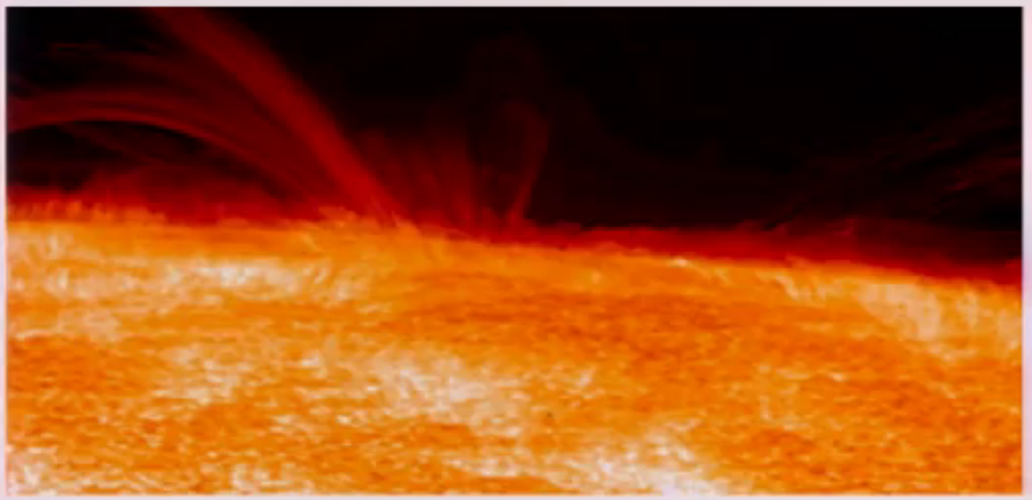




Mitchell Berger

Mahboubeh Asgari-Targhi

Coronal Heating and Nanoflares



Hinode EIS (Extreme Ultra Violet Imaging spectrometer) image

Trace image

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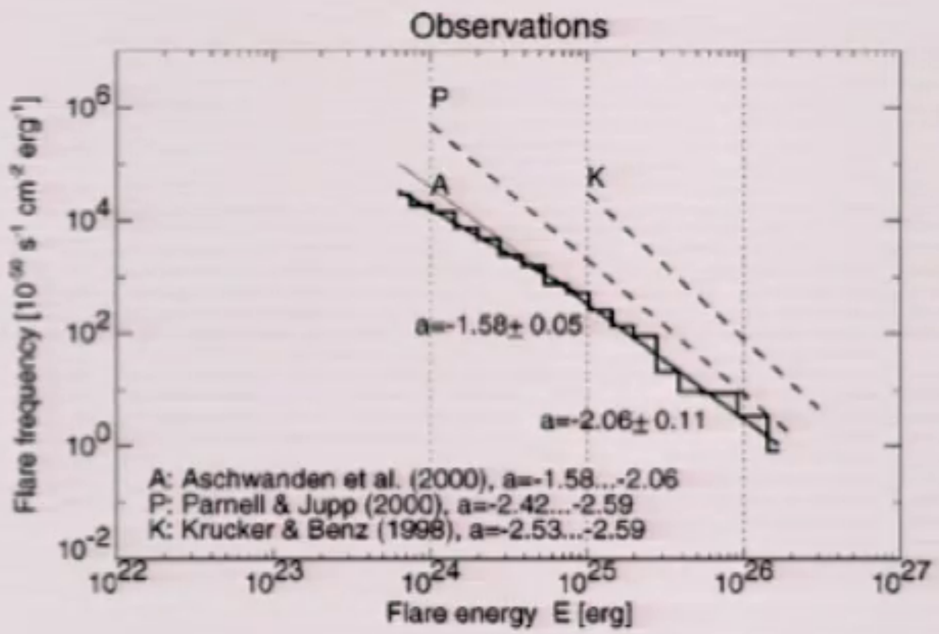
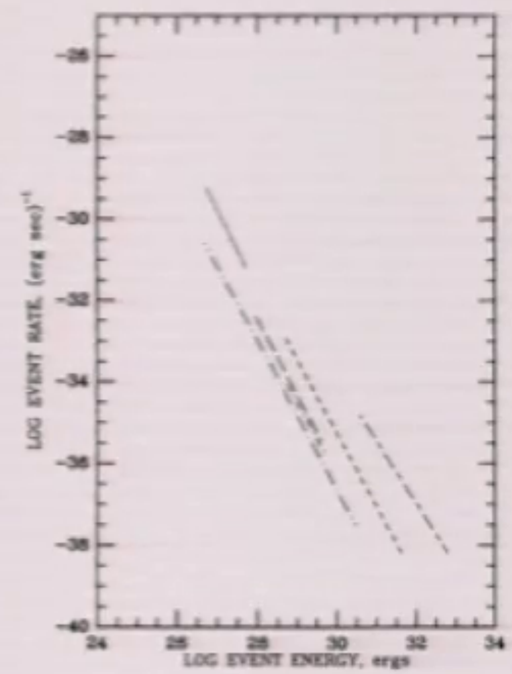
- Why is the corona heated to 1 − 2 million degrees?
- What causes flares, μflares, and [illegible]flares? Why do they have a power law energy distribution?





Hudson 1993

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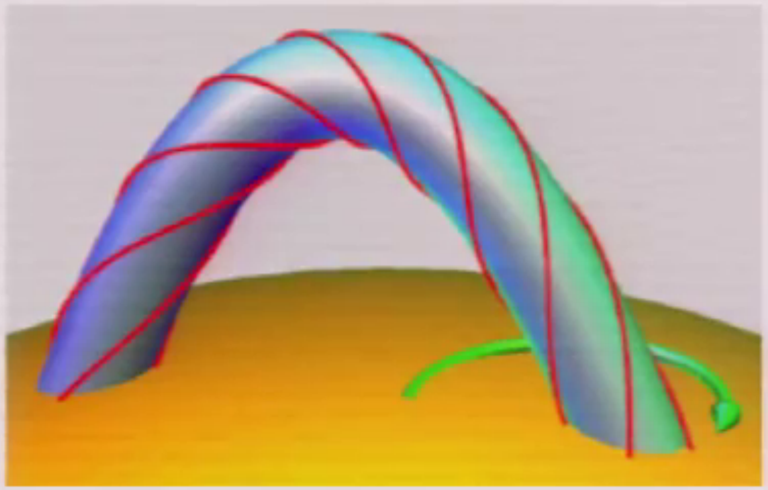
Sturrock-Uchida 1981

- Random twisting of one tube



Energy is quadratic in twist, but mean square twist grows only linearly in time.

Power = dE/dt independent of saturation time.

Parker 1983

- Braiding of many tubes

412 E. N. PARKER: LOW

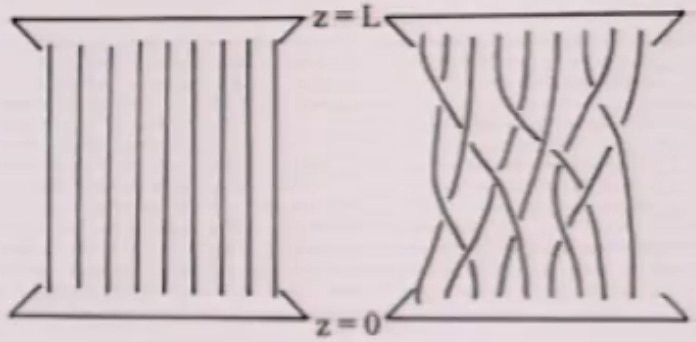


Fig. 1. A sketch of the arbitrary interlace field created by the arbitrary stream function ψ throughout $0 < z < L$.

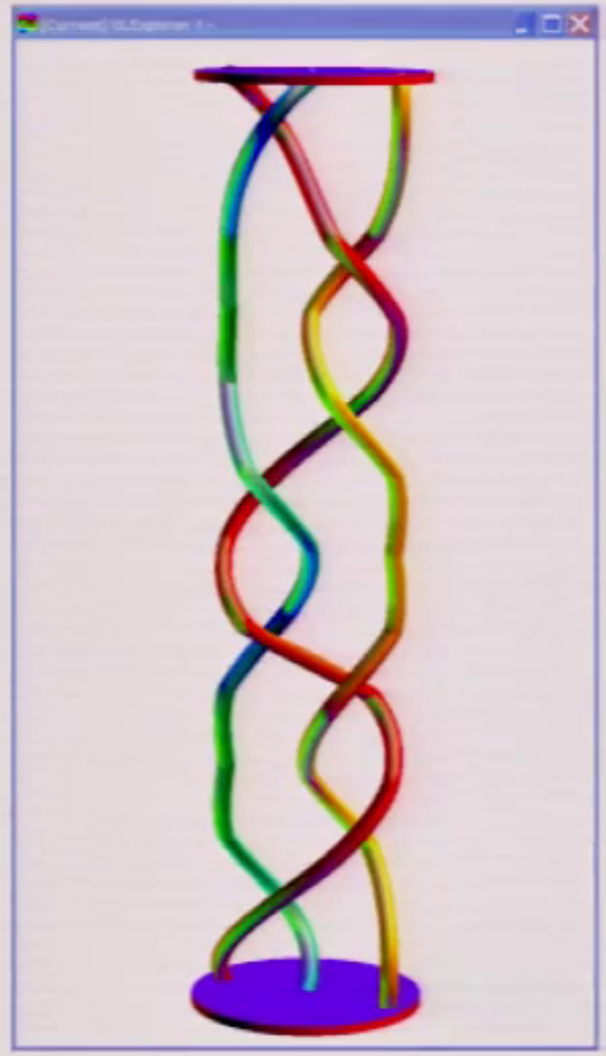
Energy grows as t^2 .

Power grows linearly with saturation time.

Twisting is faster, but braiding is more efficient!

A braid is a collection of curves extending between two planes (sometimes other surfaces). The curves must always travel upwards. If the endpoints are fixed, the *topological braid* is invariant, although the *geometric braid* may change.

Example: A pigtail braid relaxing to its minimum energy state



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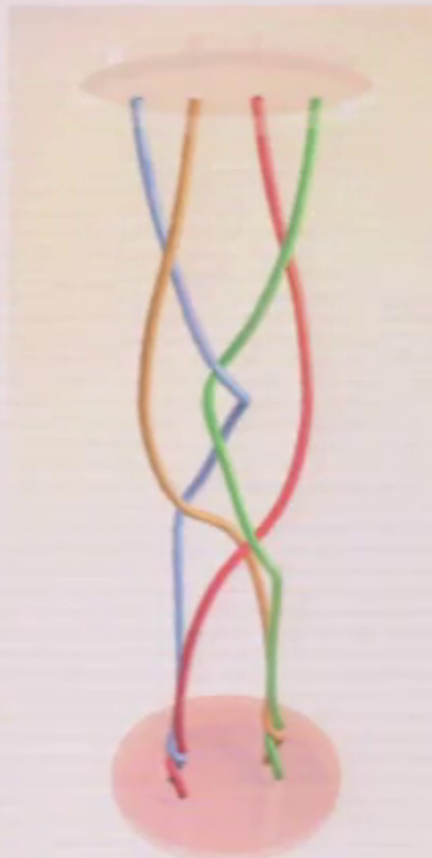
Classification of Braids

Periodic
(uniform twist)

reducible



Pseudo-Anosov
(anything else)

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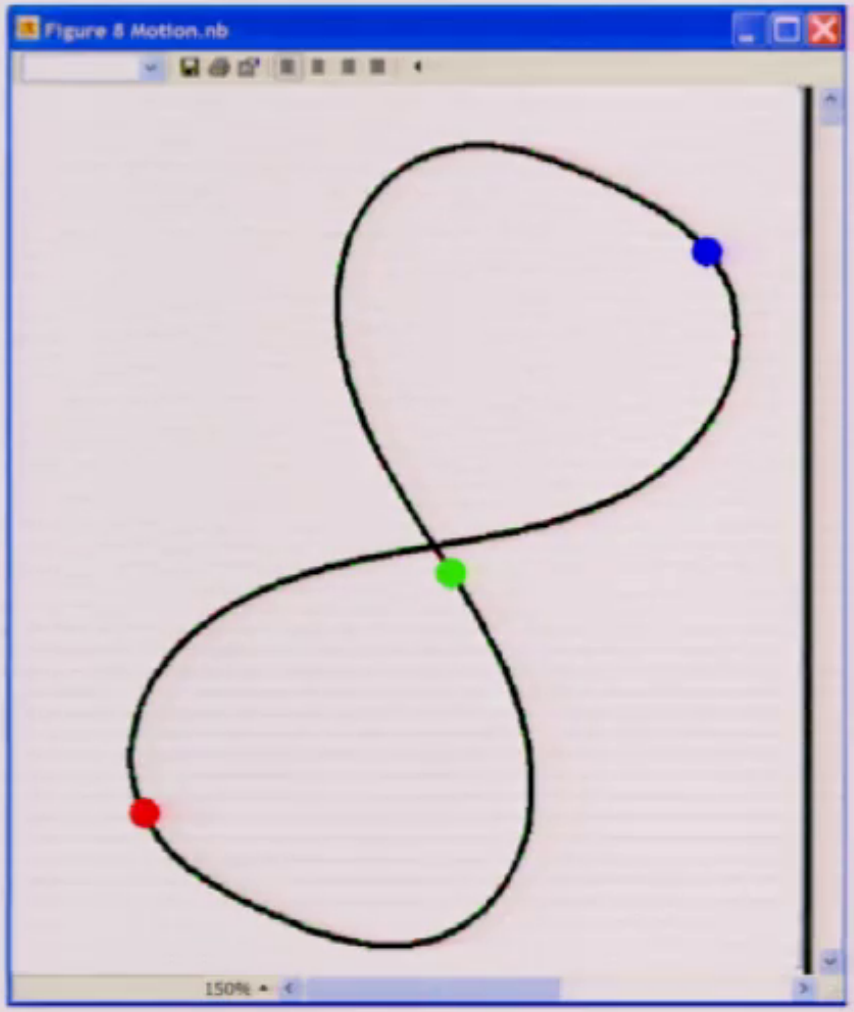
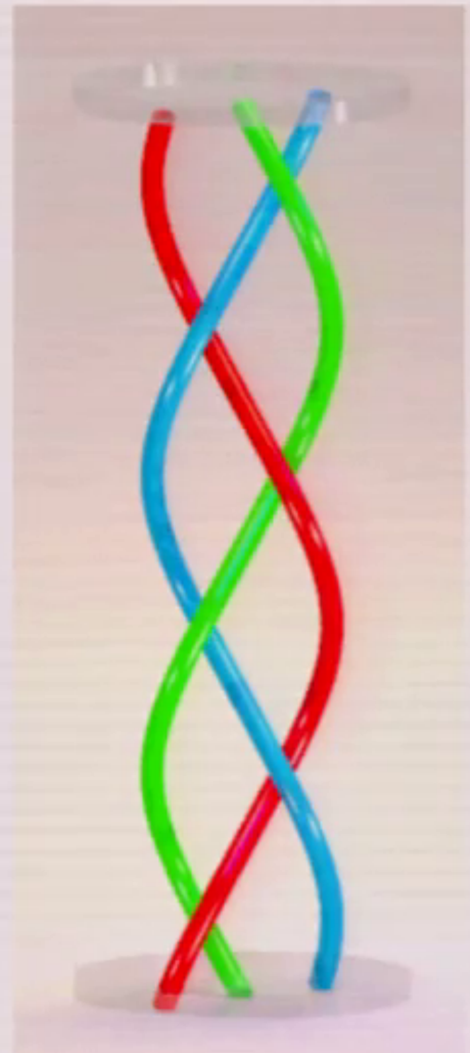
Braids as space-time diagrams of motion in 2D





Braided Magnetic Fields

- Braided Continuous Fields

  Choose sets of field lines within the field; each set will exhibit a different amount of braiding Wilmot-Smith, Hornig, & Pontin

- Braided Discrete Fields

  Well-defined flux loops may exist in the solar corona:

  1. The flux at the photosphere is highly localised
  2. Trace and Hinode pictures show discrete loops
  3. Coronal Loops split near their feet
  4. Reconnection will fragment the flux

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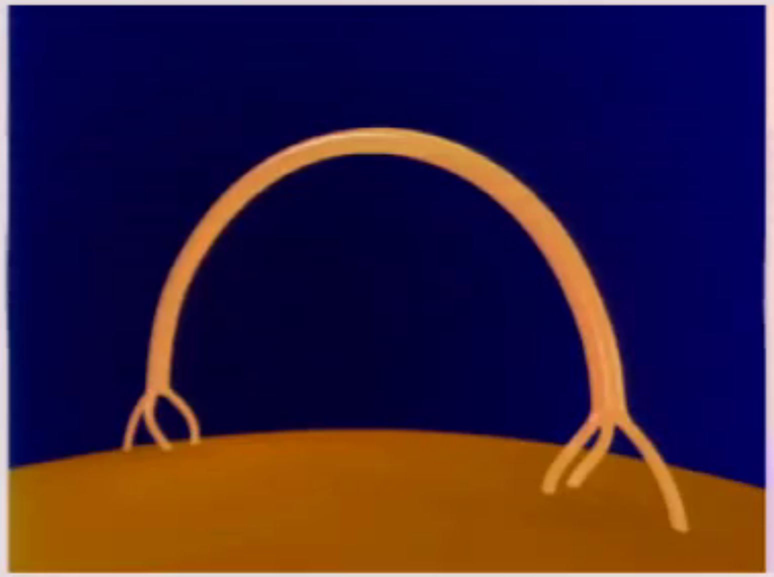
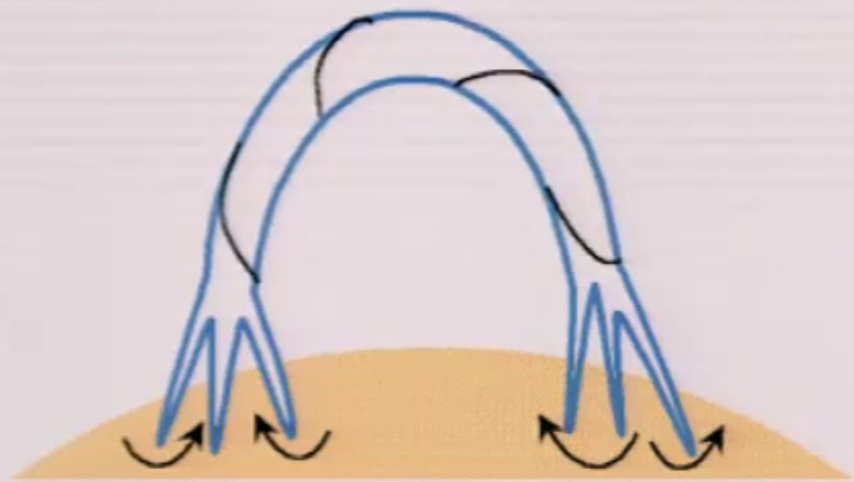
Flux Tube Splitting

More recent models add interactions with small low lying loops

Ruzmaikin & Berger 98, Schriver et al 1998, Priest et al 2002





Flux tube endpoints constantly split up and gather together again, but in new combinations. This locks positive twist away from negative twist.

Berger 94

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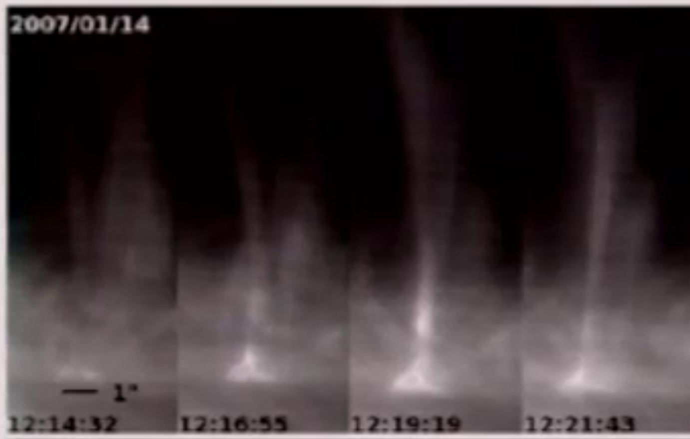
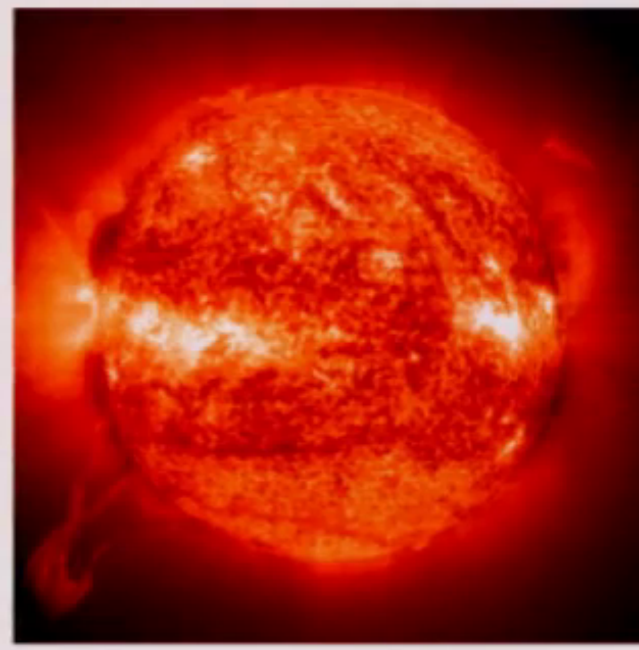


Fig. 2. Time evolution of typical Ca jets observed in Ca II H broadband filter of Hinode/SOT. Times are shown in UT.

Shibata et al 2007 Hinode "Anemone jets"

Parker's topological dissipation scenario:

1. Corona evolves quasi-statically due to footpoint motions (Alfvén travel time 10-100 secs for loop, photospheric motion timescale ~2000 seconds)
2. Smooth equilibria scarce or nonexistent for non-trivial topologies – current sheets must form
3. Slow burn while stresses buildup
4. Eventually something triggers fast reconnection



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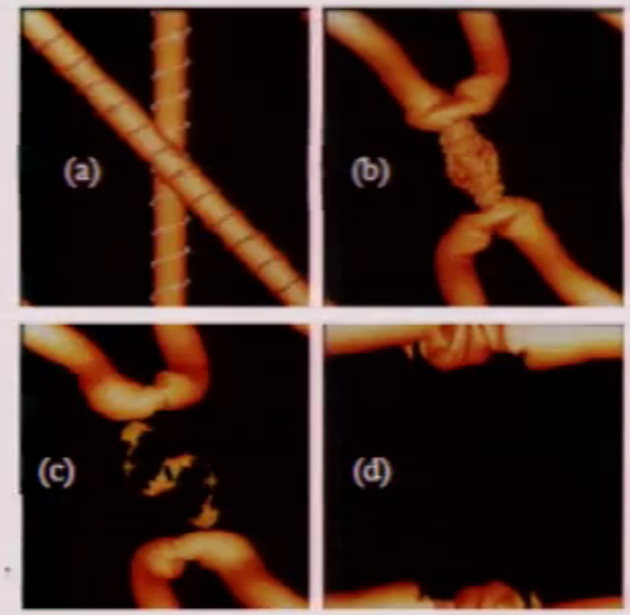
Reconnection

Klimchuck and co.: Secondary Instabilities

When neighbouring tubes are misaligned by ~ 30 degrees, a fast reconnection may be triggered. This removes a crossing, releasing magnetic energy into heat – a nanoflare.



Linton, Dahlburg and Antiochos 2001
Dahlburg, Klimchuck & Antiochos 2005

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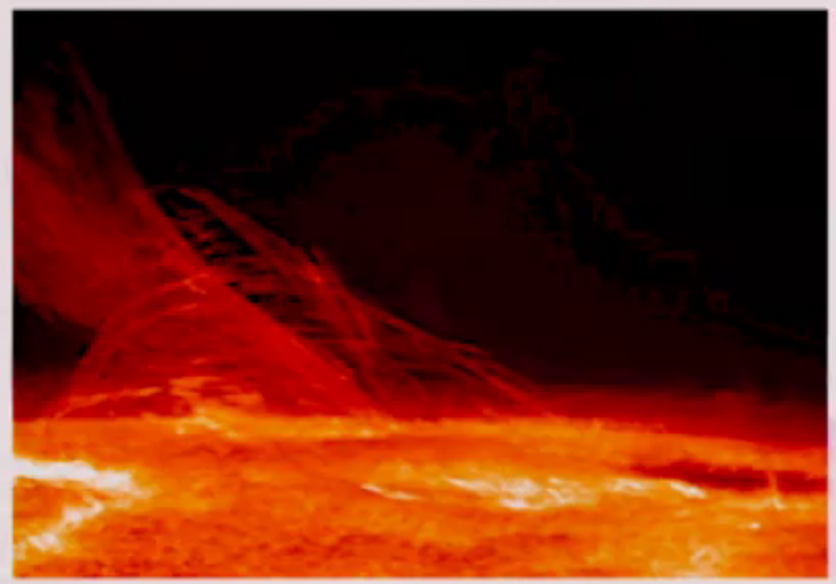
Will we be able to see braids on the sun?



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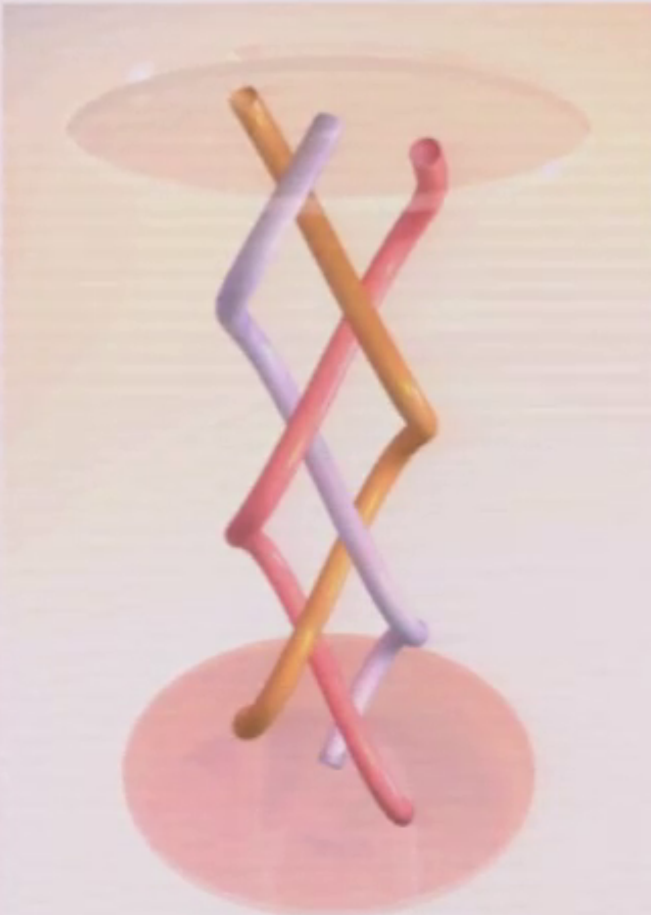
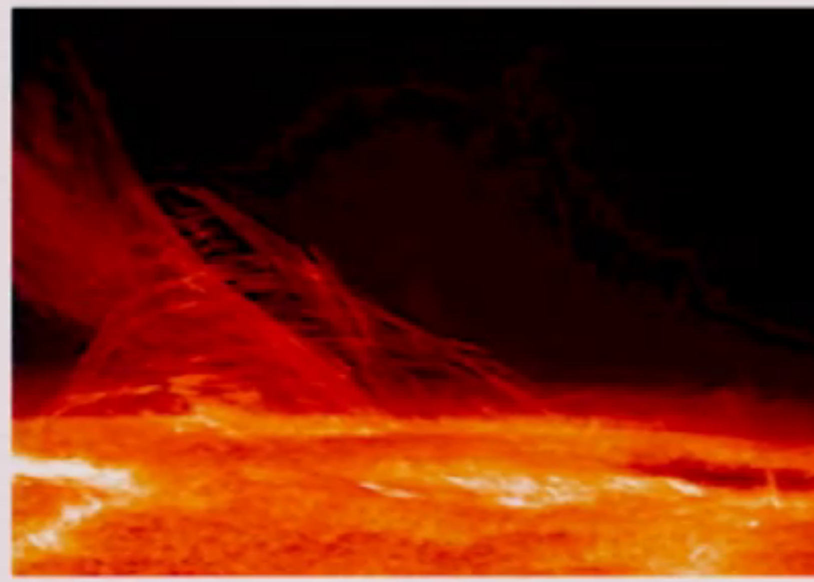
Will we be able to see braids on the sun?





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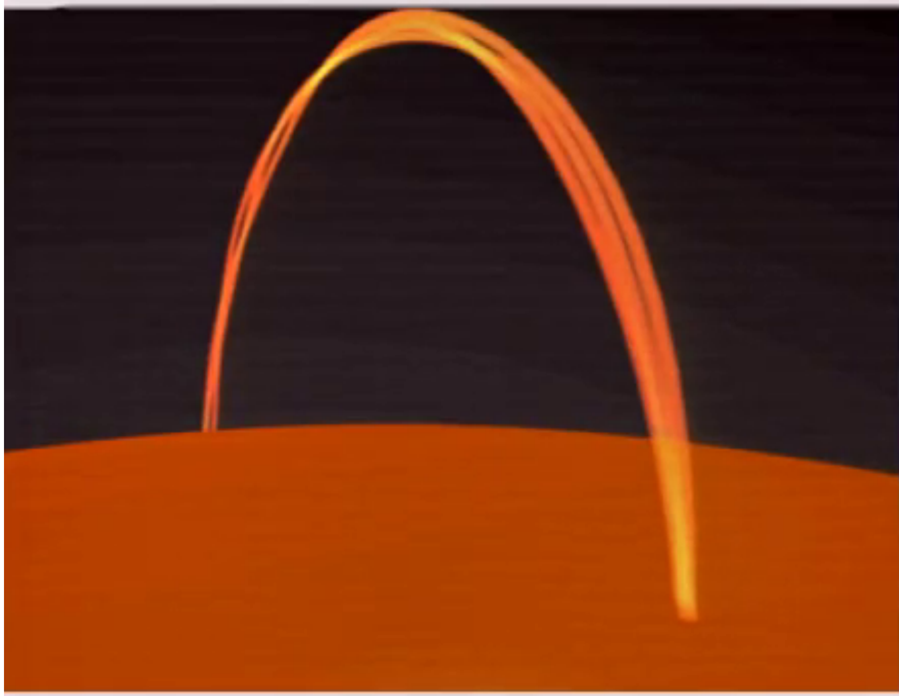
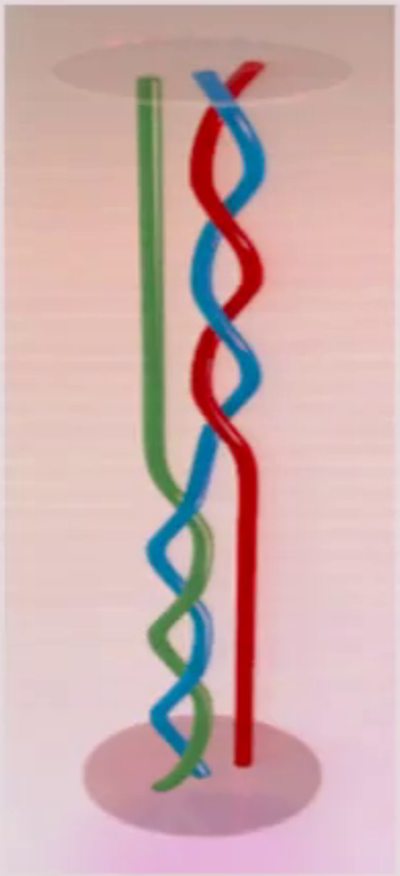
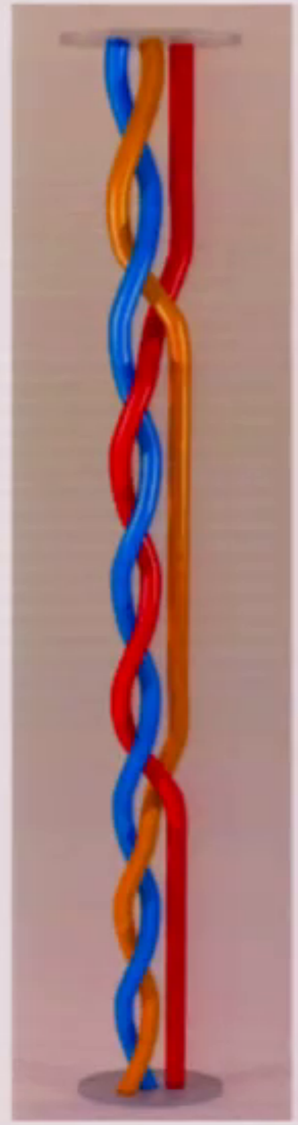


Difficulty: x-ray loops appear to have near constant diameters

- Galloway et al 2006: random transverse field would lead to loops which are fat on top.

Braids with some amount of coherence





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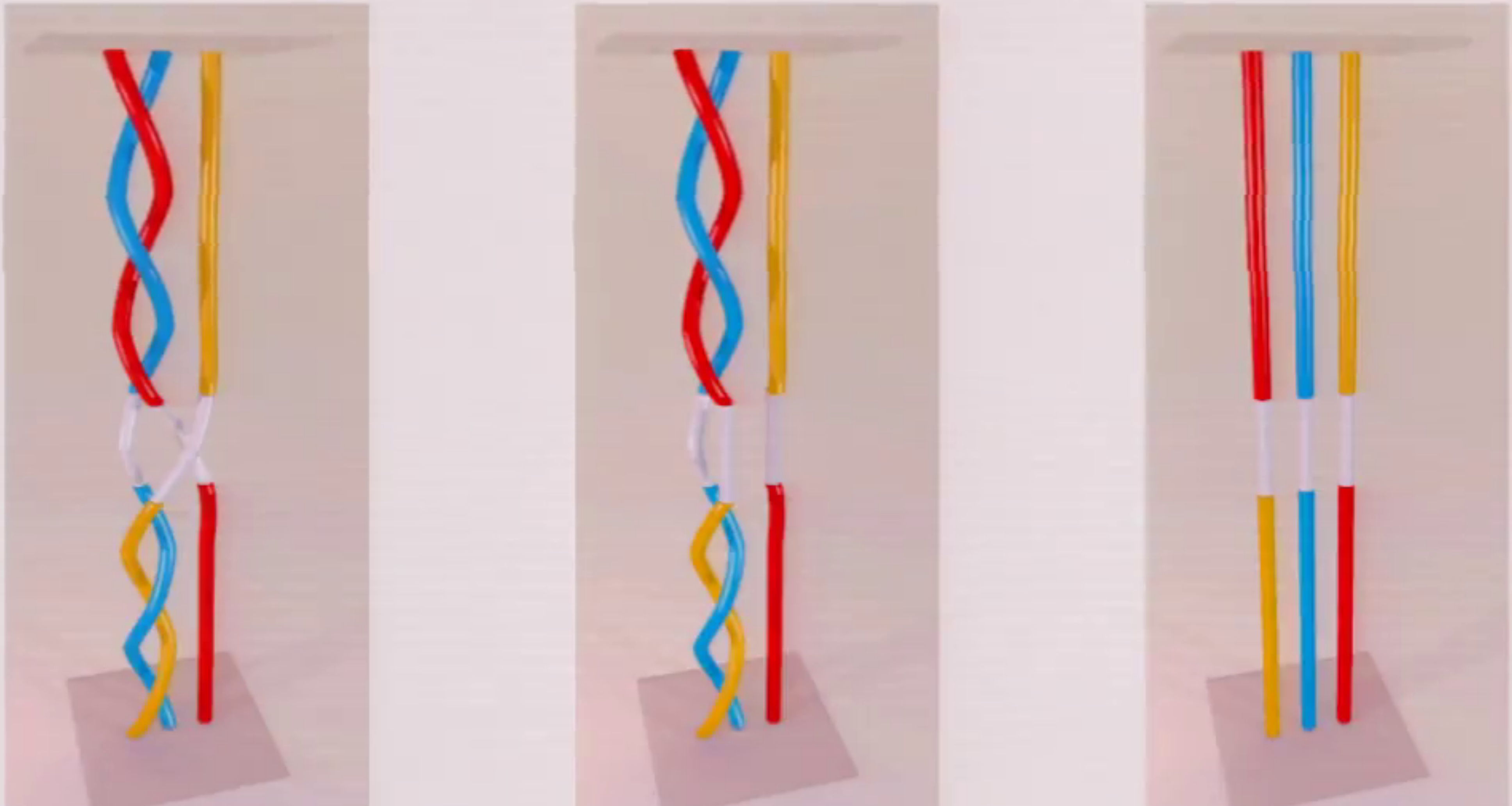
Reconnection in a coherent braid can release a large amount of energy…



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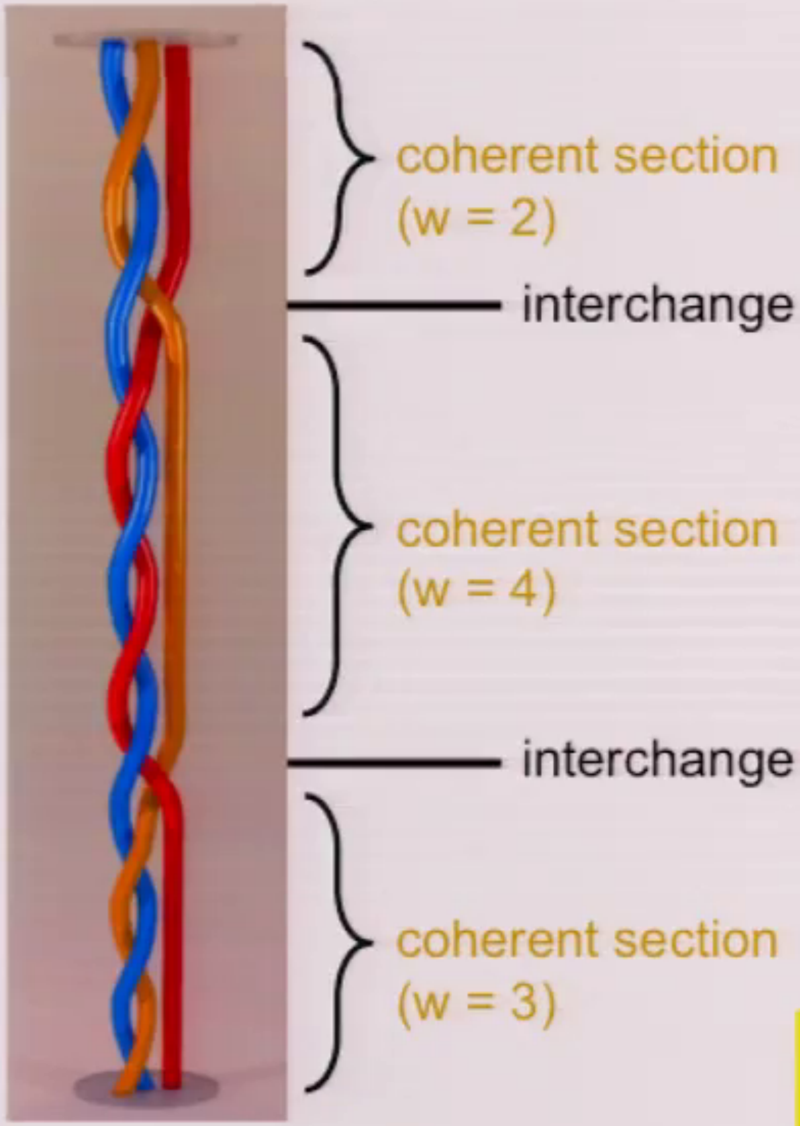
A simple model for producing coherent braids



At each time step:

1. Create one new “coherent section
2. Remove one randomly chosen interchange. *The neighbouring sections merge.*

What is the steady state probability distribution *f(w) of coherent sections with twist w?*

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Analysis

Let *p(w)* be the probability that the new coherent section has length *w. Then at each time step,*

$$
\begin{aligned}
m\delta f(w) &= p(w) - 2f(w) + \int_{-\infty}^{\infty} f(w_1)\mathrm{d}w_1 \int_{-\infty}^{\infty} f(w_2)\mathrm{d}(w_2)\delta(w-(w_2+w_1)), \\
&= p(w) - 2f(w) + \int_{-\infty}^{\infty} f(w_1)f(w-w_1)\mathrm{d}w_1.
\end{aligned}
$$

In a steady state, the left–hand side vanishes. Thus

$$p(w) - 2f(C) + (f * f)(w) = 0,$$

where $f * g$ is the Fourier convolution. To solve this, we take the Fourier transform,

$$\tilde{p}(k) - 2\,\tilde{f}(k) + \tilde{f}^2(k) = 0.$$

This has solution

$$\tilde{f}(k) = \left(1 \pm \sqrt{1-\tilde{p}(k)}\right).$$

(Take negative square root for good behaviour at infinity).

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Input as a Poisson process:

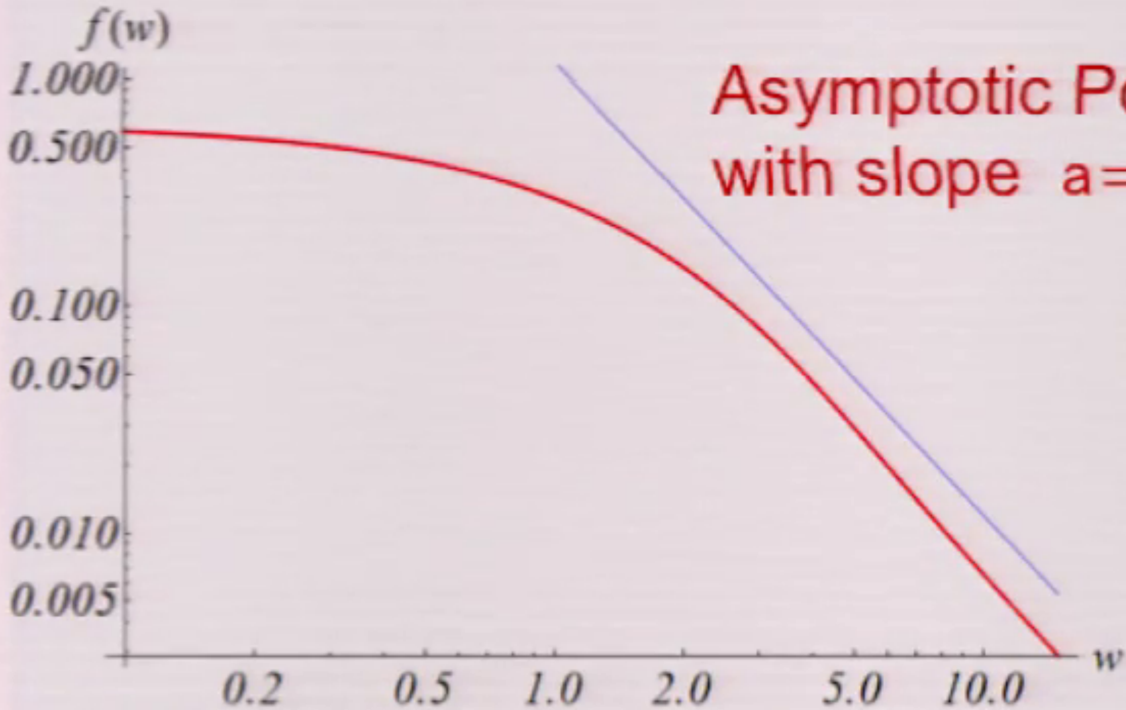
$$p(w) = \frac{\lambda}{2} e^{-\lambda|w|}$$

$$\tilde{p}(k) = \frac{\lambda^2}{\lambda^2 + k^2}$$

Solution:

$$f(w) = \frac{\lambda}{2} (I_1(\lambda w) - L_{-1}(\lambda w))$$

where L_{-1} is a Struve L function, and I_1 is a Bessel I function.



Asymptotic Power law with slope a= -2.

Flare energies should be a power law with slope 2a+1 = -3.

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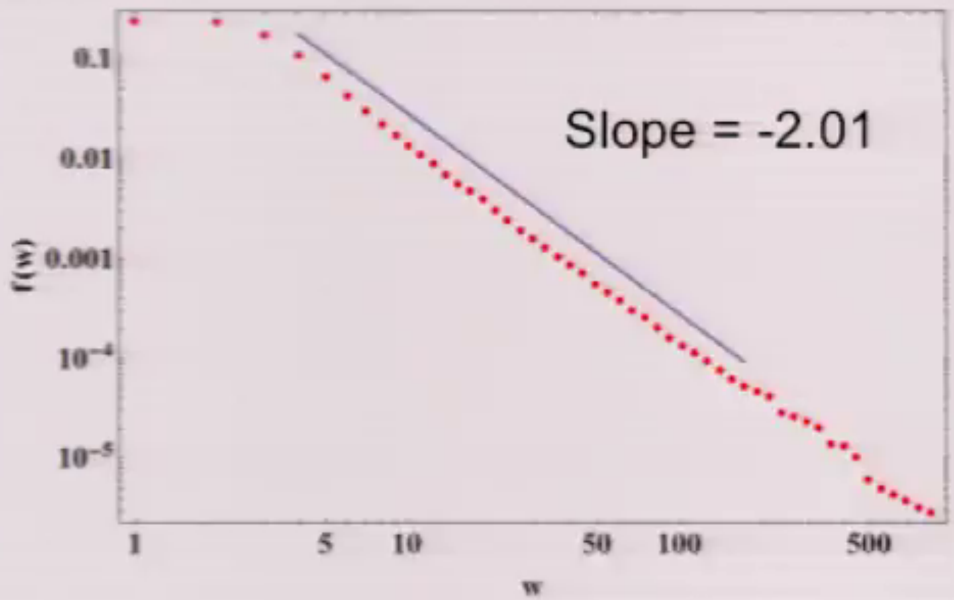
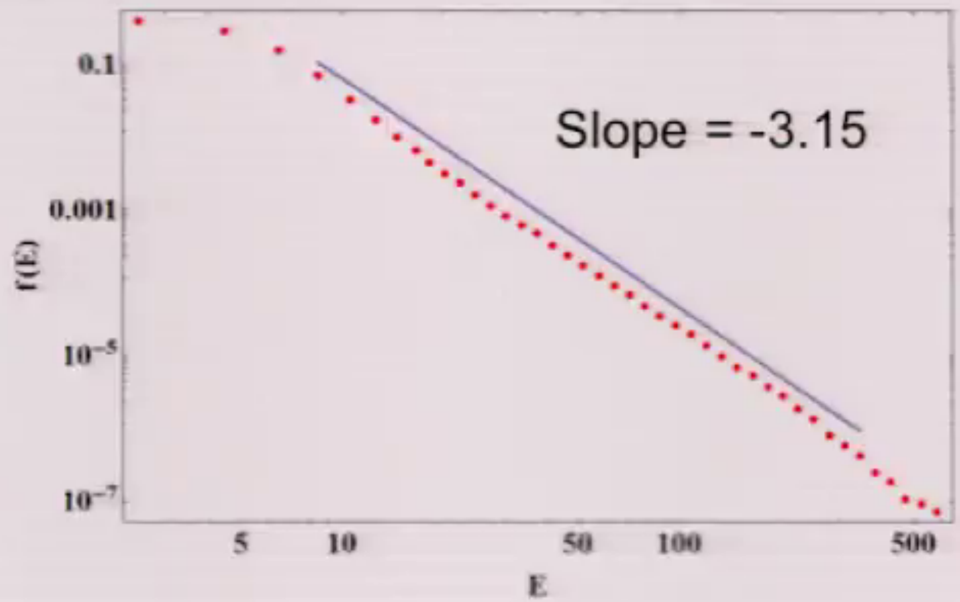
Monte Carlo simulation – no boundaries



Coherent sequence sizes



Energy releases

- Periodic boundary, nsequences = 100, nflares = 16000, nruns = 4000

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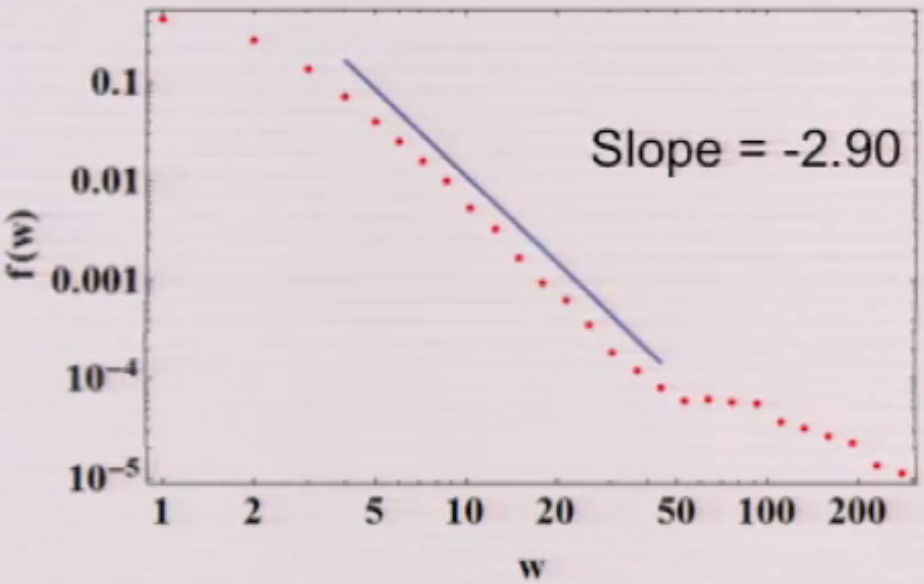
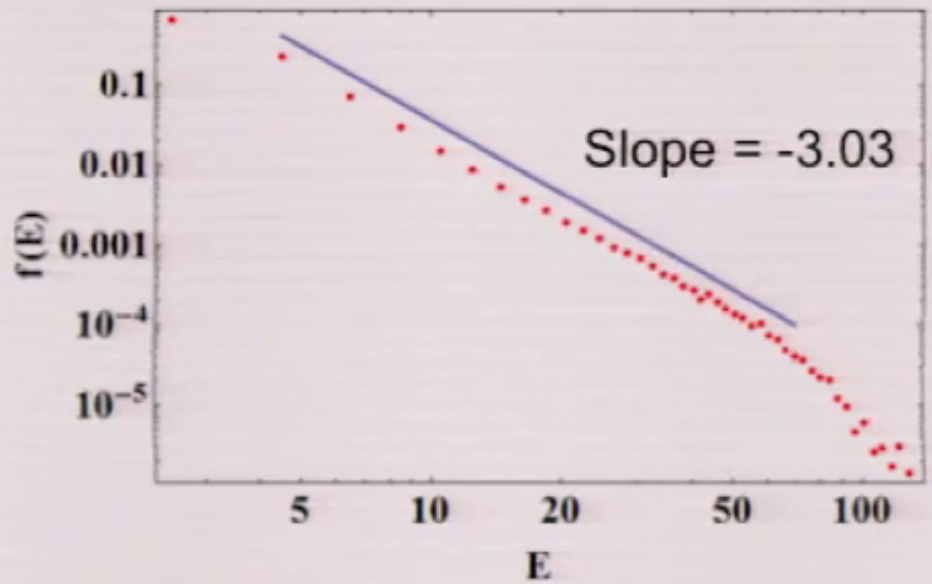
With input only at boundaries



Coherent sequence sizes



Energy releases

- Fixed boundary, nsequences = 100, nflares = 4000, nruns = 1000

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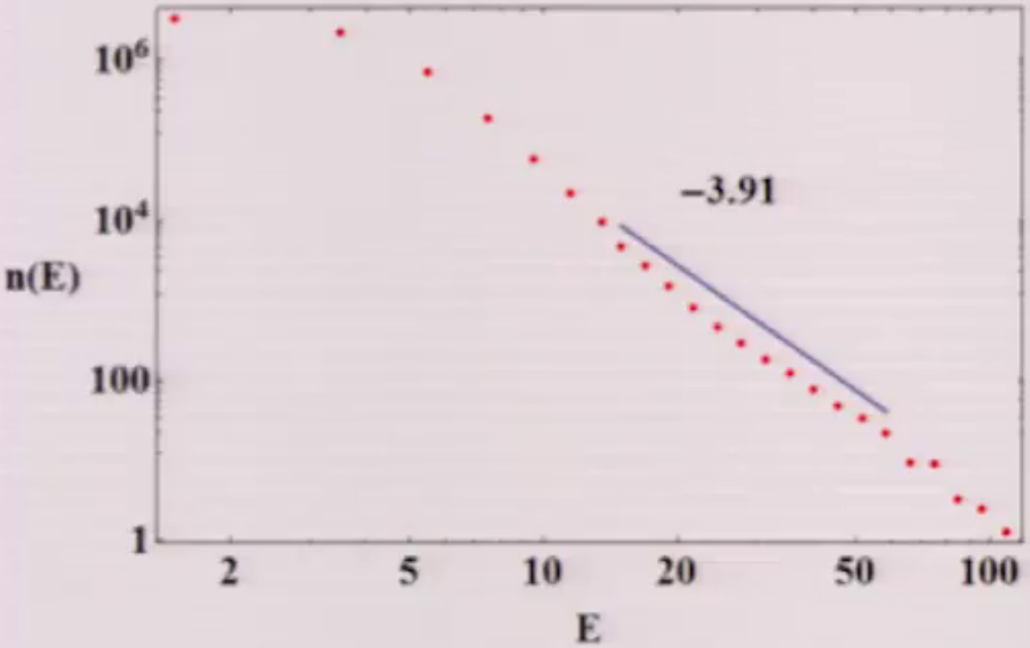
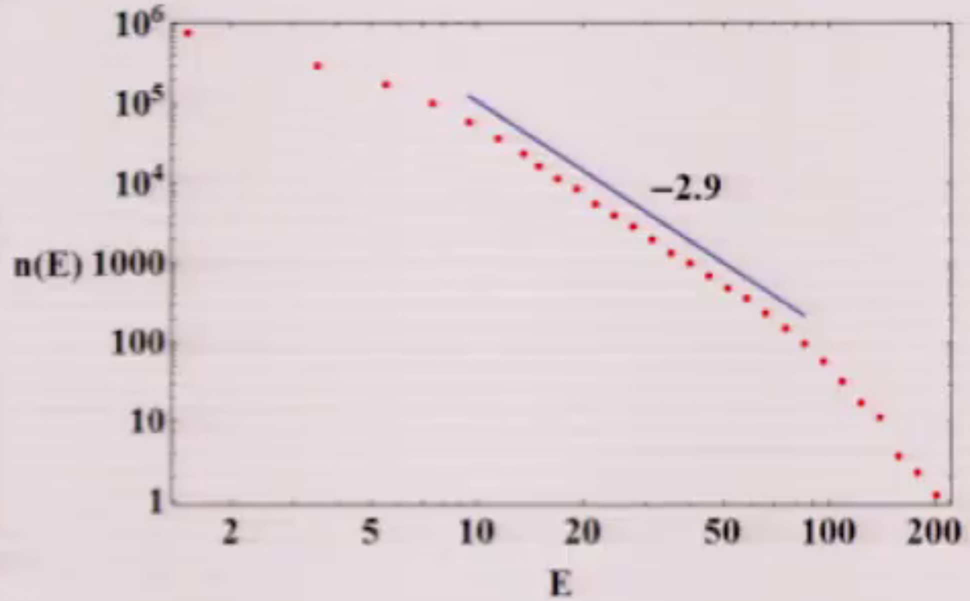


Flares near loop ends



Flares near loop middle

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