Kinking & Flaring – any relation?

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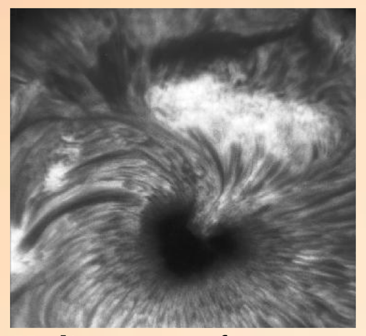
Why Consider the Kink Instability

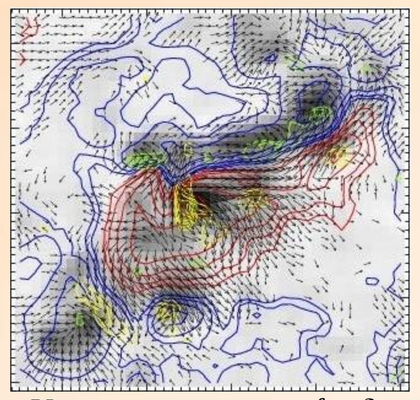
Observations

There is long-standing evidence of "twisty", "whirling" fibrils current-carrying magnetic fields.

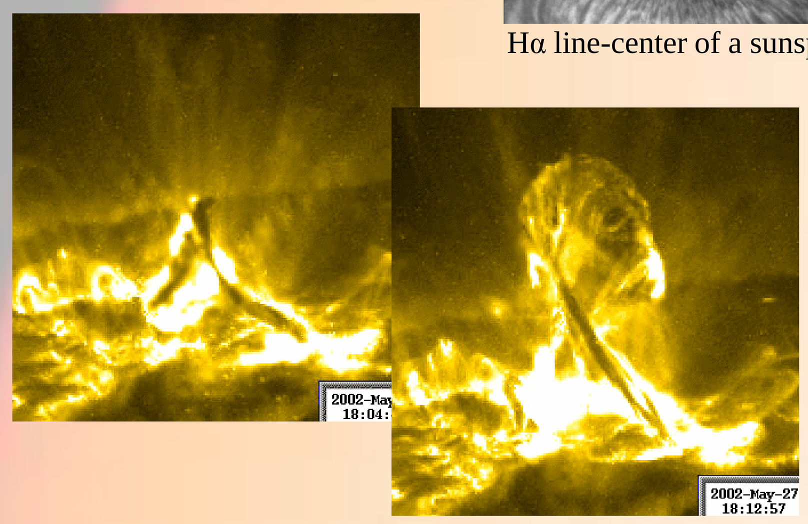
Twist is seen in erupting filaments in Dopplergrams:



Hα line-center of a sunspot



Vector magnetogram of a δ-spot with fields (blue/red contours, arrow) and vertical current (yellow/green) contours.



TRACE 195 of post-flare activity

Occasionally, plasma seems to writhe as it erupts.

Is this a cause or an effect?

Theory

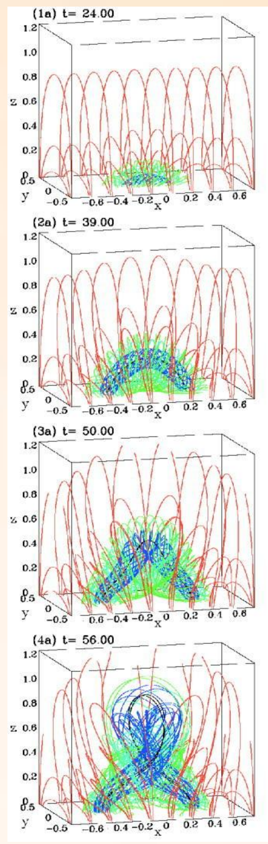
Hypothesis: If a flux tube within a solar active region contains sufficient magnetic twist, the m=1 mode "kink" instability could trigger magnetic reconnection and an energetic event.

Kink instability: rapid conversion of twist (field lines wrapping around an axis) to writhe (the axis itself deforms).

Instability is needed for the rapid change required by the short time scales relevant to flare events.

Twist helicity can be related to number of times field lines wind around the axis: $H_{twist} = T/2\pi * \Phi^2$ (number of winds times magnetic flux squared), for constant winding rate.

Instability can be triggered at $T/2\pi \geq 1.0$, but this threshold is sensitive to context. (see, e.g., Hood & Priest 1979)



Fan & Gibson, 2004

Measuring Wind Number

(following Leka, Fan & Barnes 2005)

For a *thin flux tube* (radius << all other relevant size scales) of *constant winding rate q(r)*, the wind number is:

$$\frac{T}{2\pi} = \frac{lq}{2\pi} = \frac{l}{2\pi}\frac{\alpha_{peak}}{2}$$

where l is the length of the axis field line of the flux tube, and α_{peak} is the maximum $|\alpha| = |J_z/B_z|$, corresponding to that axis (*the only place* it can be directly related to the winding rate q).

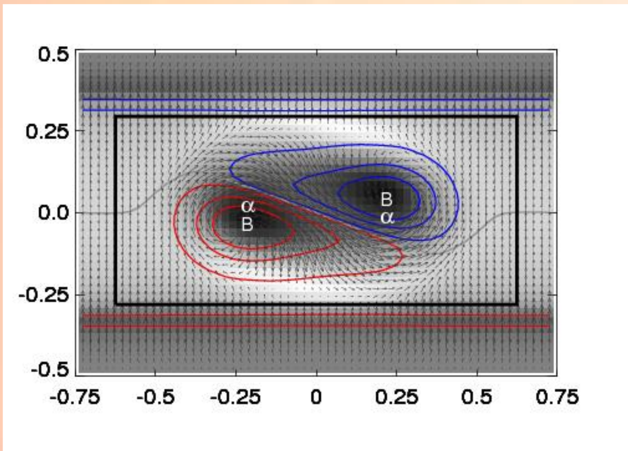
Assumptions:

- Thin flux tube
- Axis of flux tube is above the observed plane
- Constant winding rate q
- No writhe present
- If the axis length is indeterminant, two reasonable approximations for the minimum and maximum values of l are: a straight line between α_{peak} locations ($l = d$) and a semicircle between α_{peak} locations ($l = \pi d/2$)

Observational requirements:

- Young Emerging Flux Region (known connectivity, no reconnection, thin)
- Bald patch (magnetic field directed the "wrong way" across the local magnetic neutral line), indicating that the axis has emerged
- No writhe apparent

Model Data: Fan & Gibson 2004 simulation



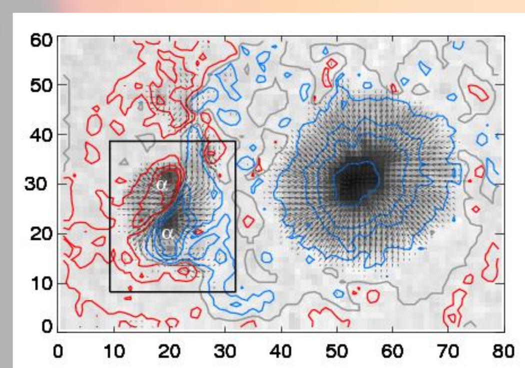
Vector magnetic field at timestep 30. **Positive**/**negative** vertical magnetic flux (at 100, 500, 1000, 2000 G) and the **magnetic neutral lines** are contoured; horizontal field is plotted at every 4th pixel. Tickmarks are in units of *L*. The black box outlines the fluxrope sub-area. The peak B_z locations are marked ***B***, the locations of peak $\boldsymbol{\alpha}$ are similarly marked. The locations of $\boldsymbol{\alpha}_{peak}$ coincide with the known fluxrope axis locations.

Eruption?	yes	
Timestep	30	45
Axis emerged?	barely	yes
α_{peak}, $\lvert B\rvert_{peak}$ coincident?	no	no
$l = \pi d/2$	0.72	1.13
α_{peak}	-18.2	-17.5
T/2π	**1.04**	**1.57**
True Model	0.77	1.6

The discrepancy in the inferred twist helicity at timestep 30 is due to a very inclined axis, much different from the assumed semi-circle.

With the correct axis length, the α_{peak} method does recover wind number given by the model.

Data Example 1: AR7201 δ-spot

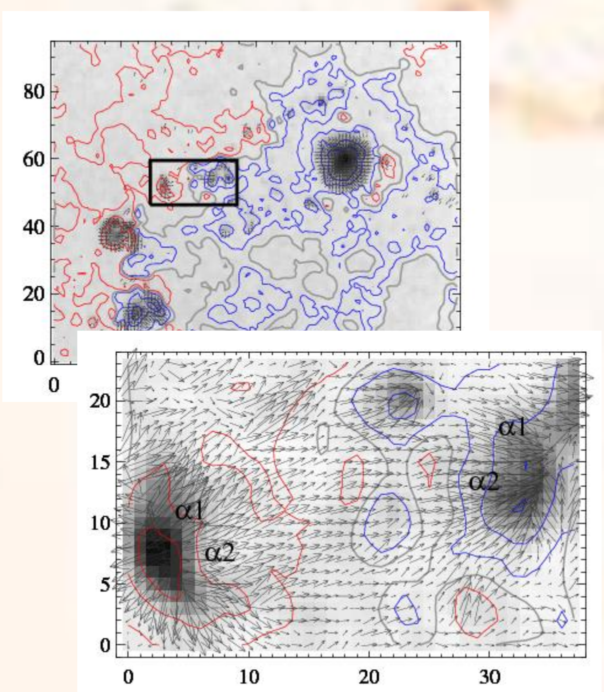


NOAA AR7201, 1992 June 19, from the NSO/HAO Advanced Stokes Polarimeter; same format as the model figure above. Tick marks are approximately in Mm. Black box outlines the δ-region sub-area, "α"s indicate the locations of α_{peak}.

Eruption?	possibly, next day
Axis emerged?	yes
α_{peak}, $\lvert B\rvert_{peak}$ coincident?	no
$l = \pi d/2$ (Mm)	16.5 ± 0.78
α_{peak} (Mm^{-1})	-0.72 ± 0.3
T/2π	**0.94 ± 0.41**

This is consistent with $T/2\pi \geq 1.0$, but there is a large uncertainty from the ***B*** observations. No flare occurred close to this time.

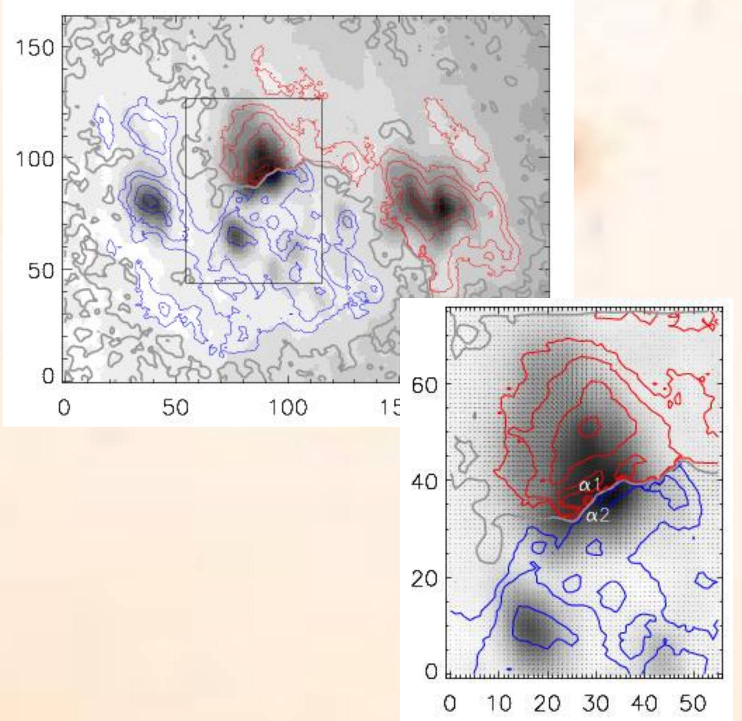
AR 09767, 2002 January 04: *B* at 17:52UT, C7.2 at 22:53UT



Emerging flux?	yes	
Axis emerged?	maybe	
Two α_{peak} concentrations	α1	α2
α_{peak}, $\lvert B\rvert_{peak}$ coincident?	no	no
$l = d$ (Mm)	22.6	16.3
$l = \pi d/2$ (Mm)	35.6	25.6
α_{peak} (Mm^{-1})	-0.75 ± 0.19	-1.06 ± 0.65
T/2π	**1.0 – 2.6**	**0.5 – 3.5**

Range in $T/2\pi$ is due to range in values of l used, plus errors.
Note: two α_{peak} locales within EFR give similar winding numbers.

AR 10646, 2004 July 13: *B* at 17:50UT, M6.2 at 19:24UT

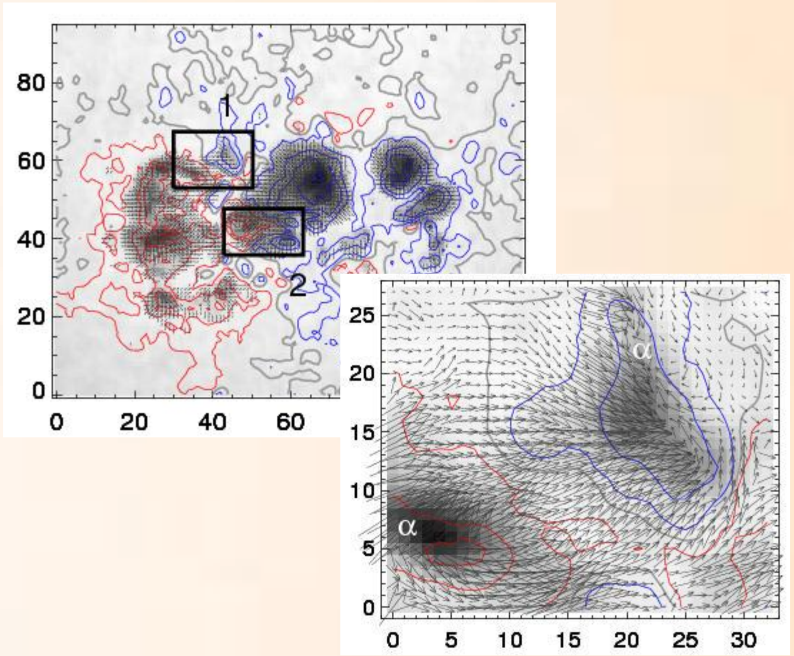


Emerging flux?	maybe
Axis emerged?	maybe
α_{peak}, $\lvert B\rvert_{peak}$ coincident?	no
$l = d$ (Mm)	5.1
$l = \pi d/2$ (Mm)	8.0
α_{peak} (Mm^{-1})	0.7 ± 0.12
T/2π	**0.28 – 0.45**

Note: for the two locales, α_{peak} differs significantly. Above is an average of the two.

This region is at W60; there is significant noise, and interpretation is difficult.

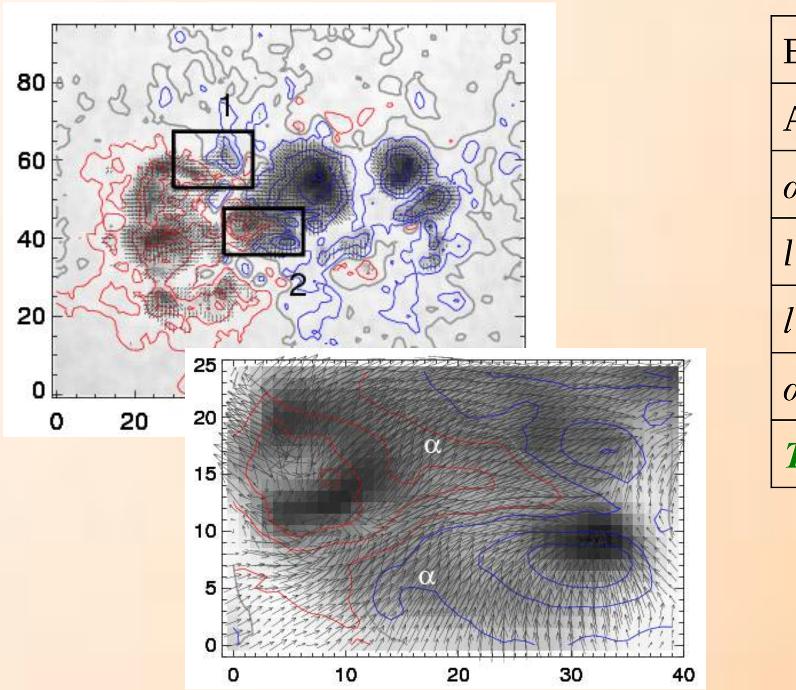
AR 10656, 2004 August 10: *B* at 17:09 UT, C1.0 at 17:25UT Emerging Bipole #1



Emerging flux?	yes
Axis emerged?	yes
α_{peak}, $\lvert B\rvert_{peak}$ coincident?	no
$l = d$ (Mm)	21.7
$l = \pi d/2$ (Mm)	34.1
α_{peak} (Mm^{-1})	-0.9 ± 0.1
T/2π	**1.4 – 2.7**

$T/2\pi$ is definitely greater than 1.0.

AR 10656, 2004 August 10 Emerging Bipole #2



Emerging flux?	yes
Axis emerged?	yes
α_{peak}, $\lvert B\rvert_{peak}$ coincident?	no
$l = d$ (Mm)	11.0
$l = \pi d/2$ (Mm)	17.3
α_{peak} (Mm^{-1})	-0.95 ± 0.49
T/2π	**0.40 –1.98**

This wind number is different from that of bipole #1.

Conclusions

Are all energetic events initiated by the kink instability? No.

- There exist definite cases of flares in active regions with arguably *insufficient* twist for the kink instability to occur.
- There are emerging bipoles which clearly:
  - have significant twist helicity.
  - depending on context, are good candidates for being kink-unstable.

The uncertainties are dominated by the unknown length of the axis, in addition to uncertainties in magnetogram data.

- This can be mitigated by including the field inclination at the axis.
- Extrapolations are to be used sparingly in this context.

Do we have more work to do? Most definitely.

All examples here produced energetic events. What is the wind number in otherwise similar emerging bipoles but in flare-quiet active regions?

References

Fan , Y. & Gibson, S.E. 2004, ApJ, 609,1123
Hood, A.W., & Priest, E.R. 1979, SolPhys, 64, 303
Leka, K.D., Fan, Y., & Barnes, G. 2005, ApJ, 626, 1091

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