

Does the magnetic kink instability trigger solar energetic events?

Peter Ashton & Rachel MacDonald
Mentors: K.D. Leka & Graham Barnes



Overview

- What is the kink instability?
- Determining twist from observables
- Data requirements & target selection
- Analysis process
- Results
- The future

“What is the Kink Instability?”

- The “Helicity” of a magnetic field in some volume is defined as $\int \mathbf{A} \cdot \mathbf{B} \, dx^3$, where \mathbf{B} is the magnetic field and \mathbf{A} is the vector potential ($\mathbf{B} = \nabla \times \mathbf{A}$) both defined on some volume.
- Qualitatively, helicity is a measure of how much a magnetic field is wrapped around itself.
- In the approximation of ideal magnetohydrodynamics (MHD), helicity is a conserved quantity.

“What is the Kink Instability?” II

- Helicity can be decomposed into two components: “twist” and “writhe”
- “Twist” means that field lines are wrapped around an axis.
- “Writhe” is the warping of the axis itself.
- “Twist Helicity”: $H_T = T/2\pi * \Phi^2$, where $T/2\pi$ is the number of times the field lines wrap around the axis (the winding number), and Φ is the magnetic flux.

“What is the Kink Instability?” III

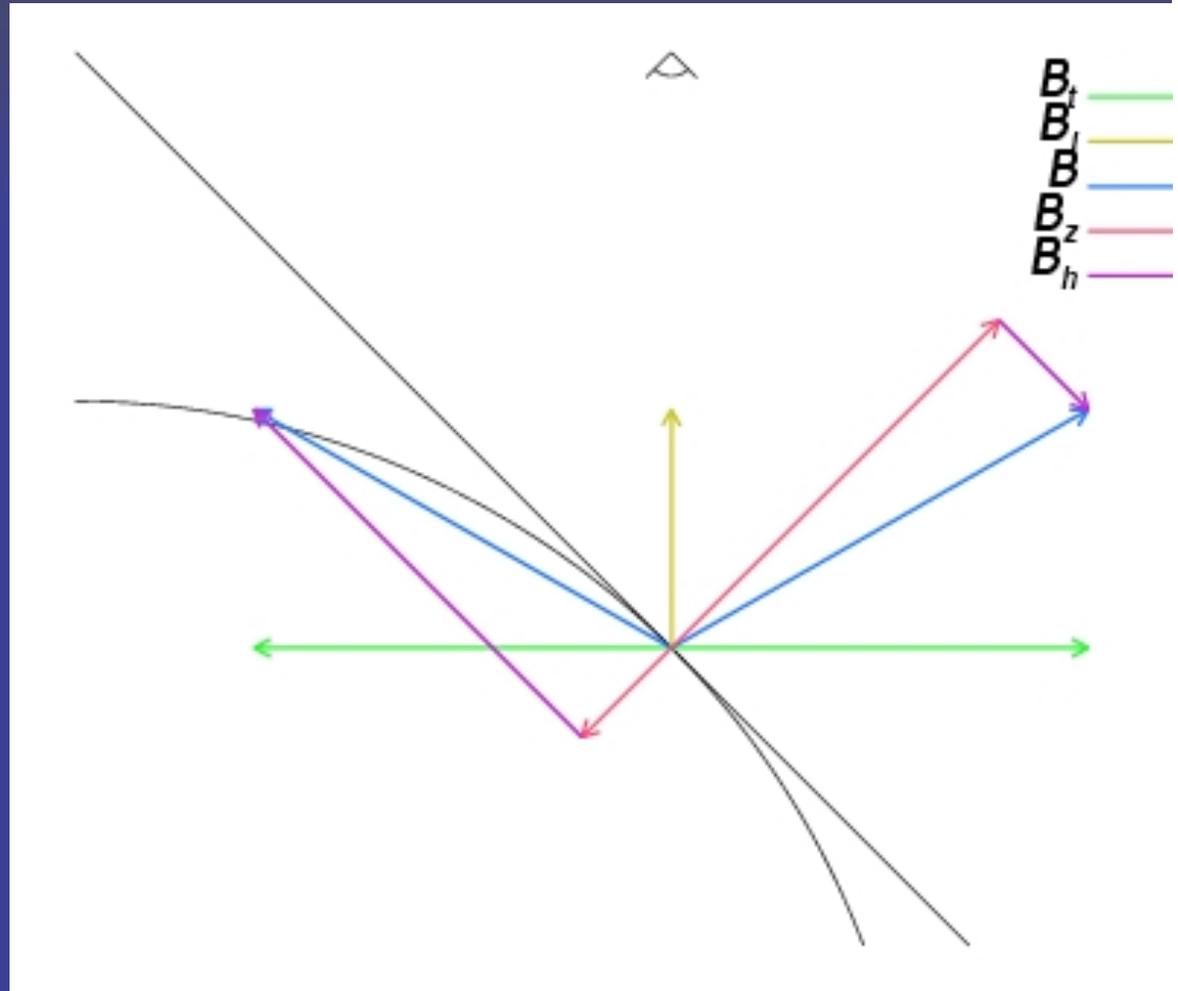
- The kink instability is the process of twist converting into writhe over short timescales (~minutes) when the winding number goes above some critical value.
- $T_{crit.}/2\pi \approx 1.0$ (but variable, especially depending on overlying magnetic field)
- We investigate whether this instability is a possible trigger for energetic events (flares and coronal mass ejections) by determining if it is a necessary condition.

How to Determine Twist from Observables

- Data come from Imaging Vector Magnetograph (IVM) at Mees Solar Observatory, University of Hawaii.
- In the presence of a magnetic field, spectral lines will be split into different wavelengths as a function of field strength. → “Zeeman Effect”
- By observing polarization and Zeeman splitting of magnetically sensitive spectral lines, three components of the magnetic field can be inferred on the photosphere (spectral polarimetry).

Well.... Sort of.

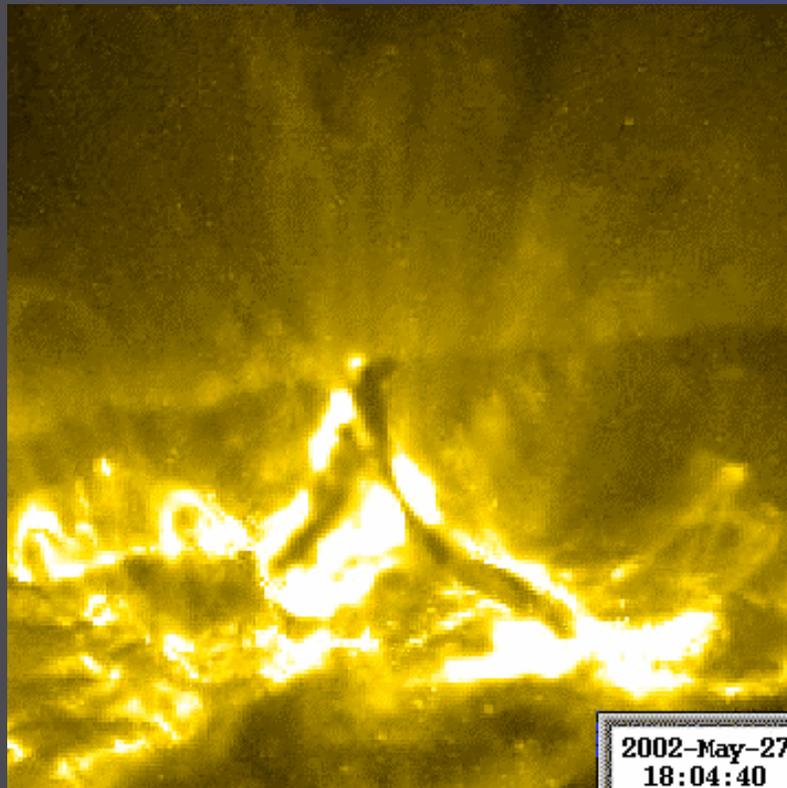
- Magnetic field perpendicular to the line of sight is 180° ambiguous.
- Leads to two distinct resultant field possibilities.
- Choose the field that is closer to potential ($J = 0$)



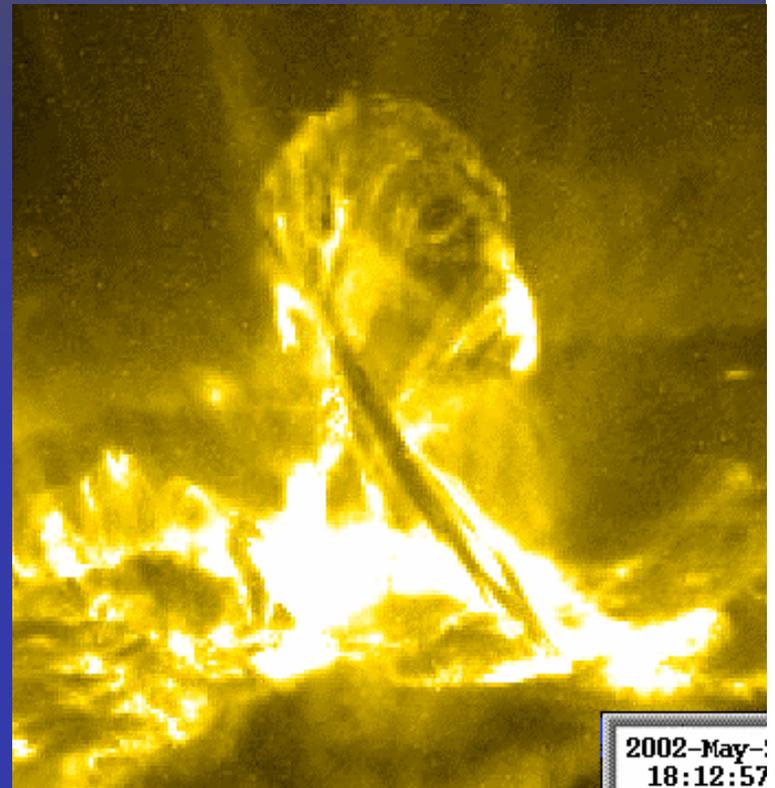
Calculating and using the force-free parameter α

- α is defined by the equation $\mathbf{B}\alpha = \nabla \times \mathbf{B}$
- However, we only have spatial derivatives of \mathbf{B} in x and $y \rightarrow \nabla \times \mathbf{B}_{Hor.} = J_z$
- $\alpha = J_z / B_z$
- For a constant winding rate, q , $T = Lq$
- $q = \alpha/2$ in thin flux-tube approximation (If not a thin flux-tube, q and α aren't simply related.)
- winding number, $T/2\pi = L\alpha/4\pi$

Is it a kink instability?



2002/05/27
18:04:40 UT



2002/05/27
18:12:57 UT

Is it a kink instability?

- Short Answer: Maybe...
- Long Answer: We can't really be sure without plasma velocity data, since this is a 2-D projection of a 3-D structure. Even though it looks like a kink, it could be other things. You really can't tell just by looking at pictures of coronal loops.

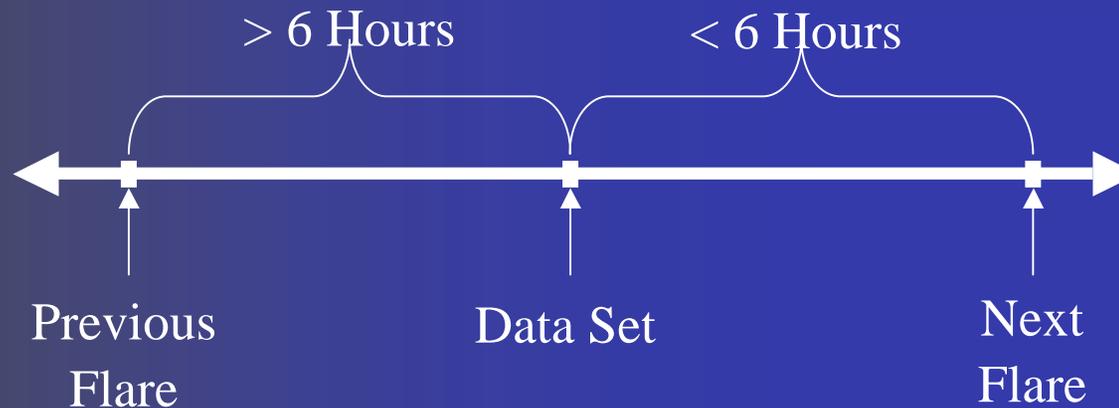
Data Requirements

To use α_{peak} to get the winding number ($T/2\pi$):

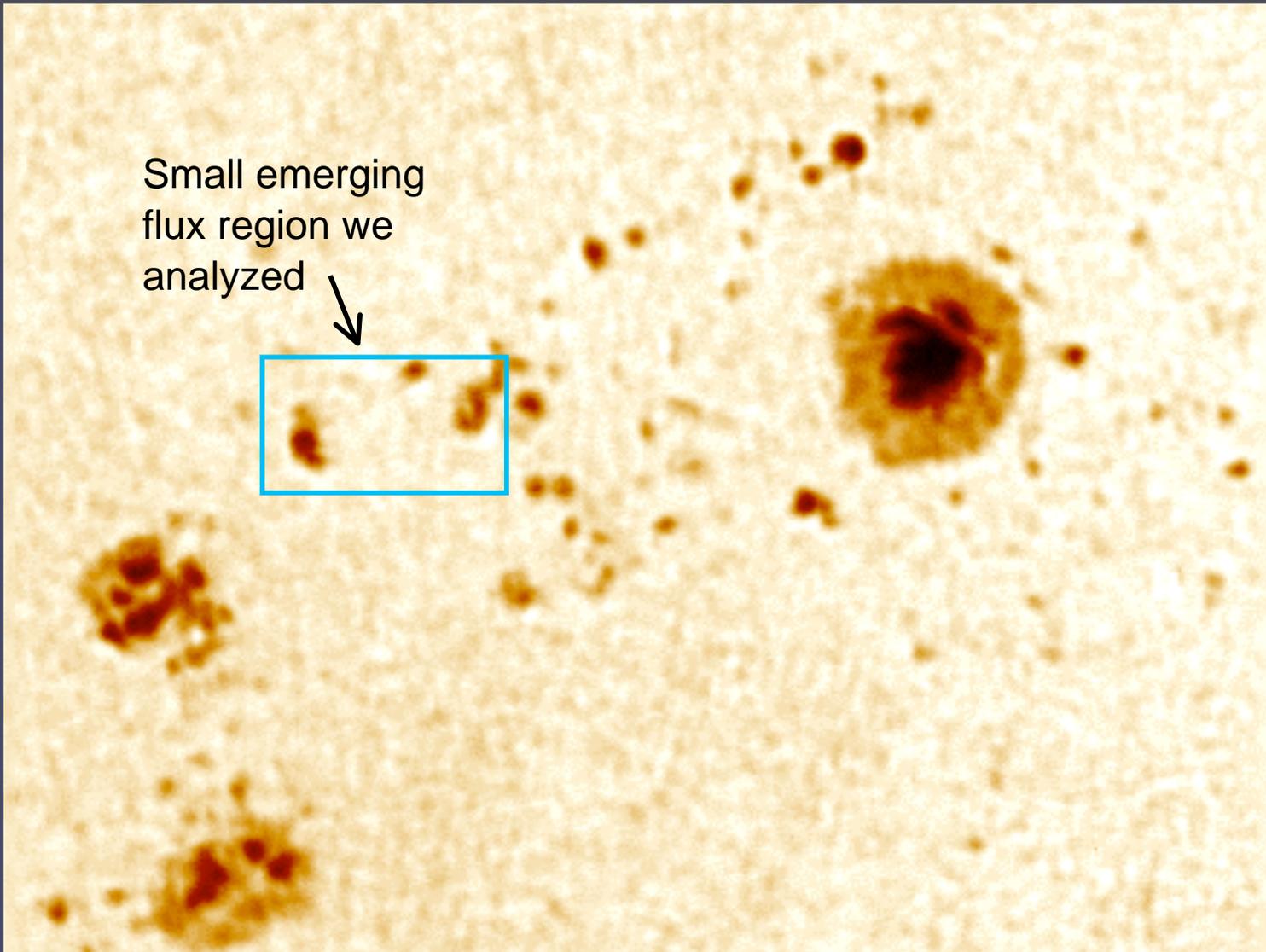
- Thin flux tube
- Axis of flux tube is above observed plane (Look for “bald patches” where $B_{Hor.}$ points in “wrong” direction”)
- Area is not complex (in specific ways):
 - No writhe present
 - Two pores or spots only magnetically connected to each other (not to other spots or regions)
- Assume a constant winding rate (q)

Data Requirements

- Translation to finding candidate active regions:
 - Need vector magnetograms
 - Want active regions that flared within 6 hours after 'gram was taken
 - No flares within 6 hours before 'gram was taken



- Look for small emerging flux region within larger active region



Small emerging
flux region we
analyzed

NOAA Active Region 9767, Jan. 4, 2002

Imaging Vector Magnetograph, Mees Solar Observatory,
Haleakala, Maui, Hawai'i

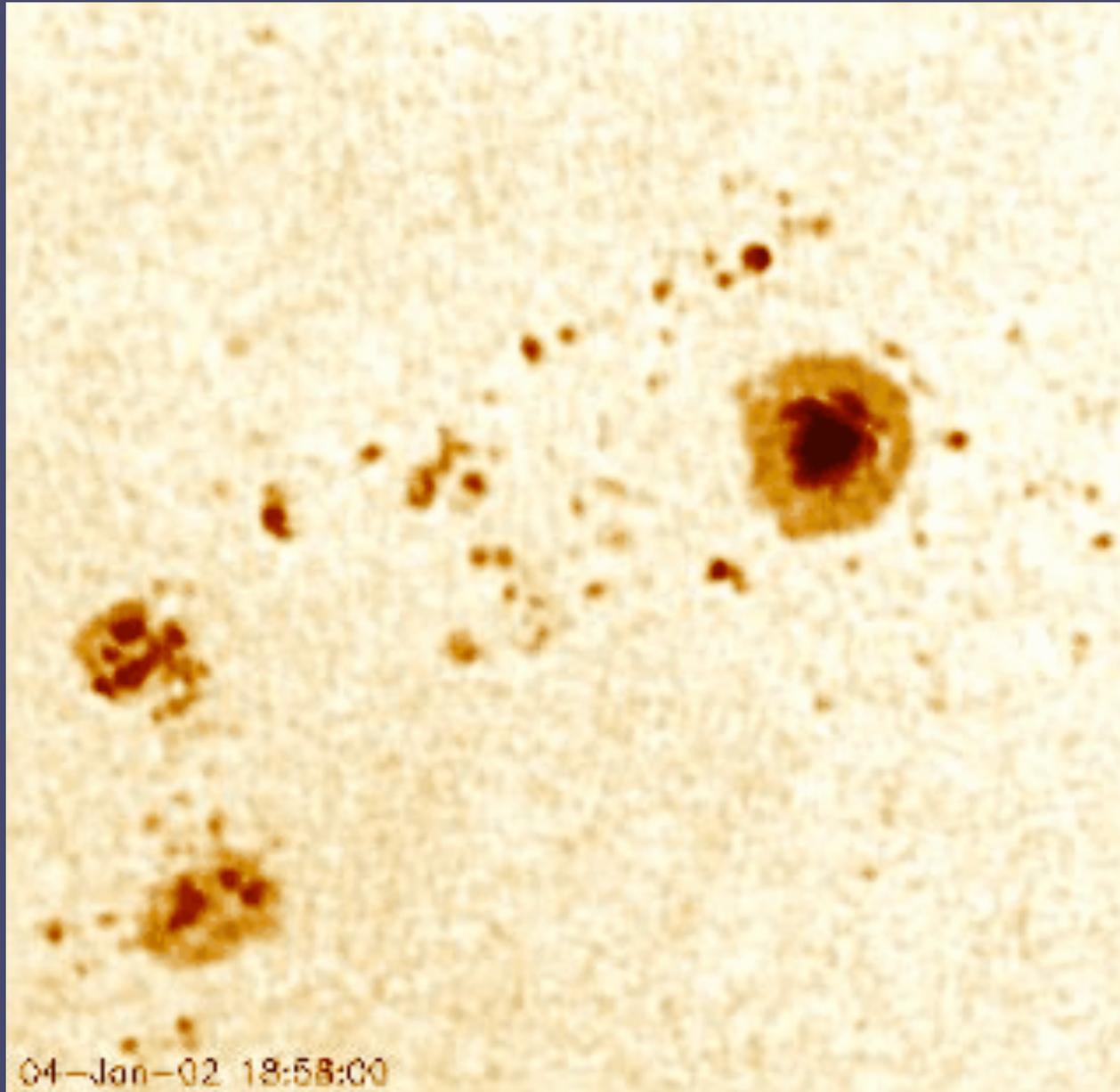
Data Requirements

- Good seeing
 - Ground-based instrument
- Good instrument performance
 - No double images or other issues
- Get raw data quickly
 - Older data on tapes, newer data on DVDs

Target Selection

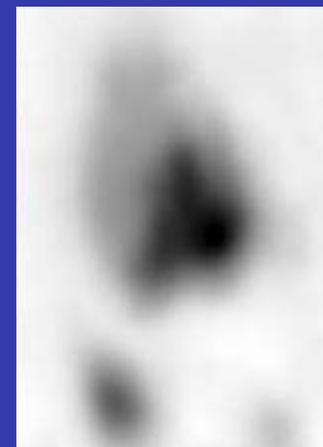
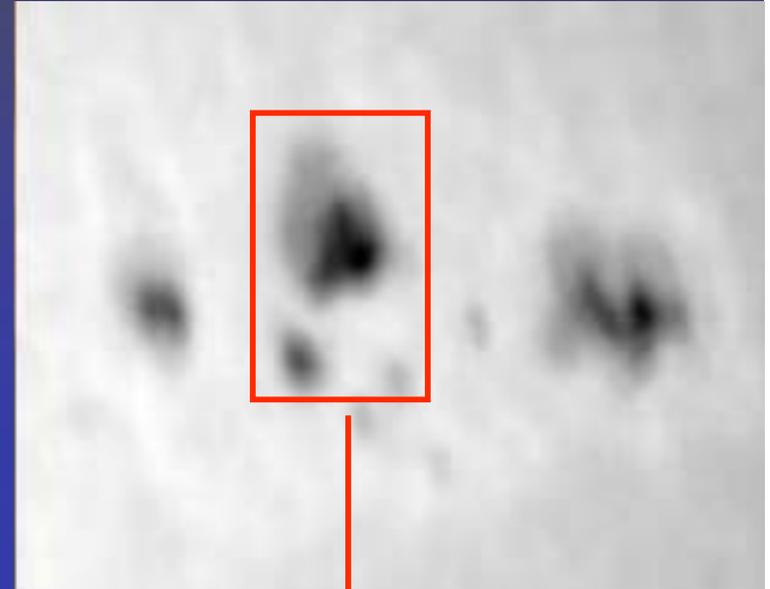
- Began with a list of flares associated with active regions from 1999-2004.
- Cross-reference with IVM data logs (~2000 regions)
- Remove regions without flare within 6 hours after → little evolution before flare (195 remain).
- Remove regions with a flare within 6 hours before → few effects of reconnection (~100 remain).
- Identify those with emerging flux regions (12-16)
- Identify data sets that we have on hand or can get easily from Hawaii (4 or 5 final targets)

Emerging Flux



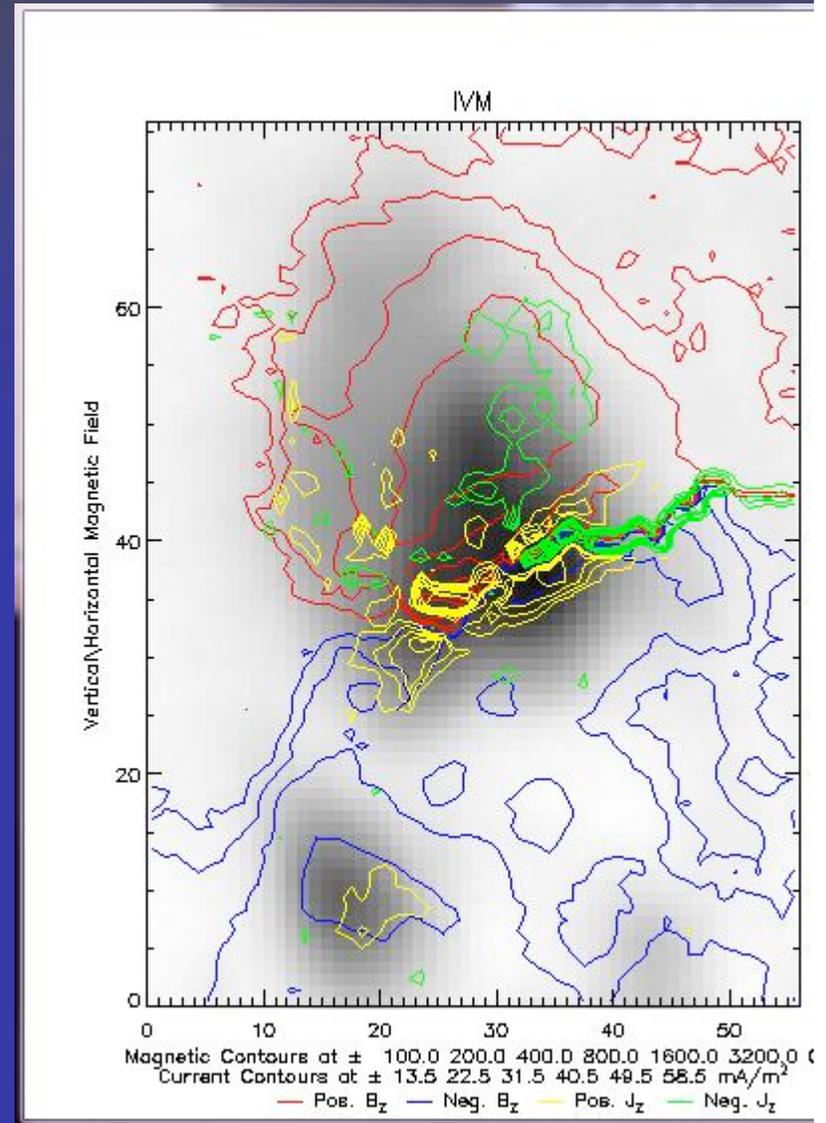
Analysis Process

- Choose subregion



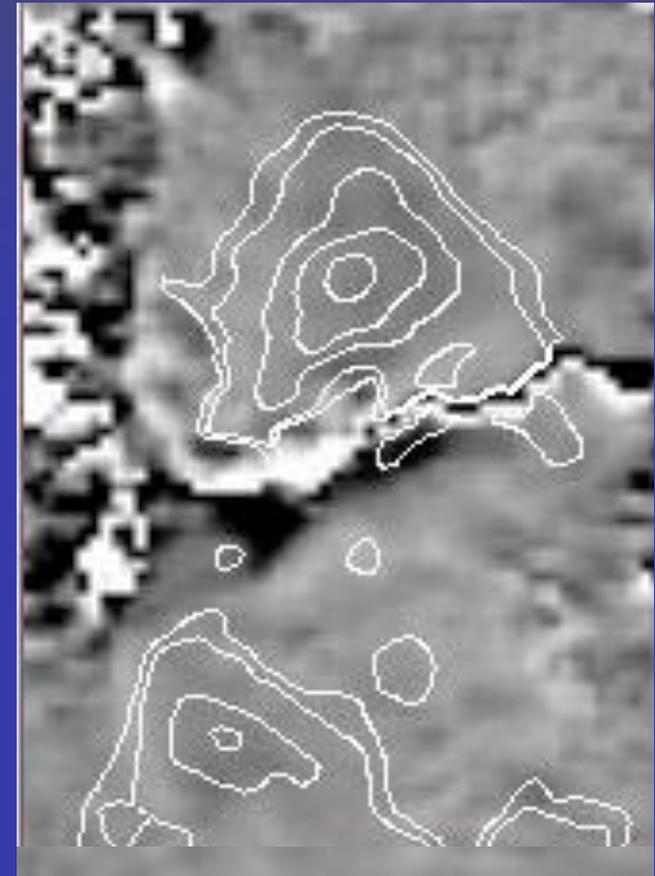
Analysis Process

- Choose subregion
- Map magnetic field
- Identify location of peaks in B field strength
- Calculate current in the area ($J_z = \nabla \times B_{Hor}$)
- Calculate $\alpha = J_z / B_z$



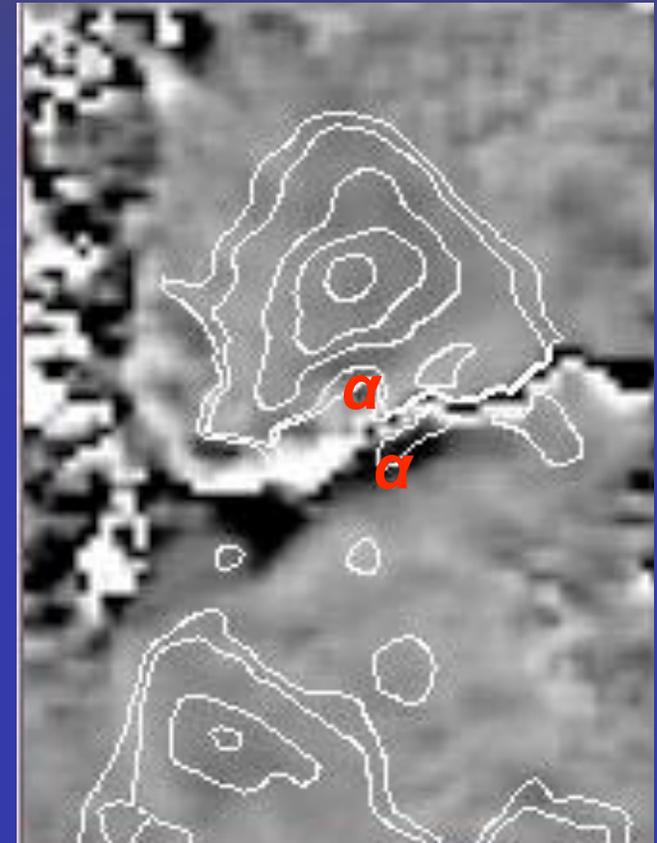
Analysis Process

- Map α
- Find location of peaks in α
- Use B field contours to help – but α_{peak} is not usually coincident with B_{peak}



Analysis Process

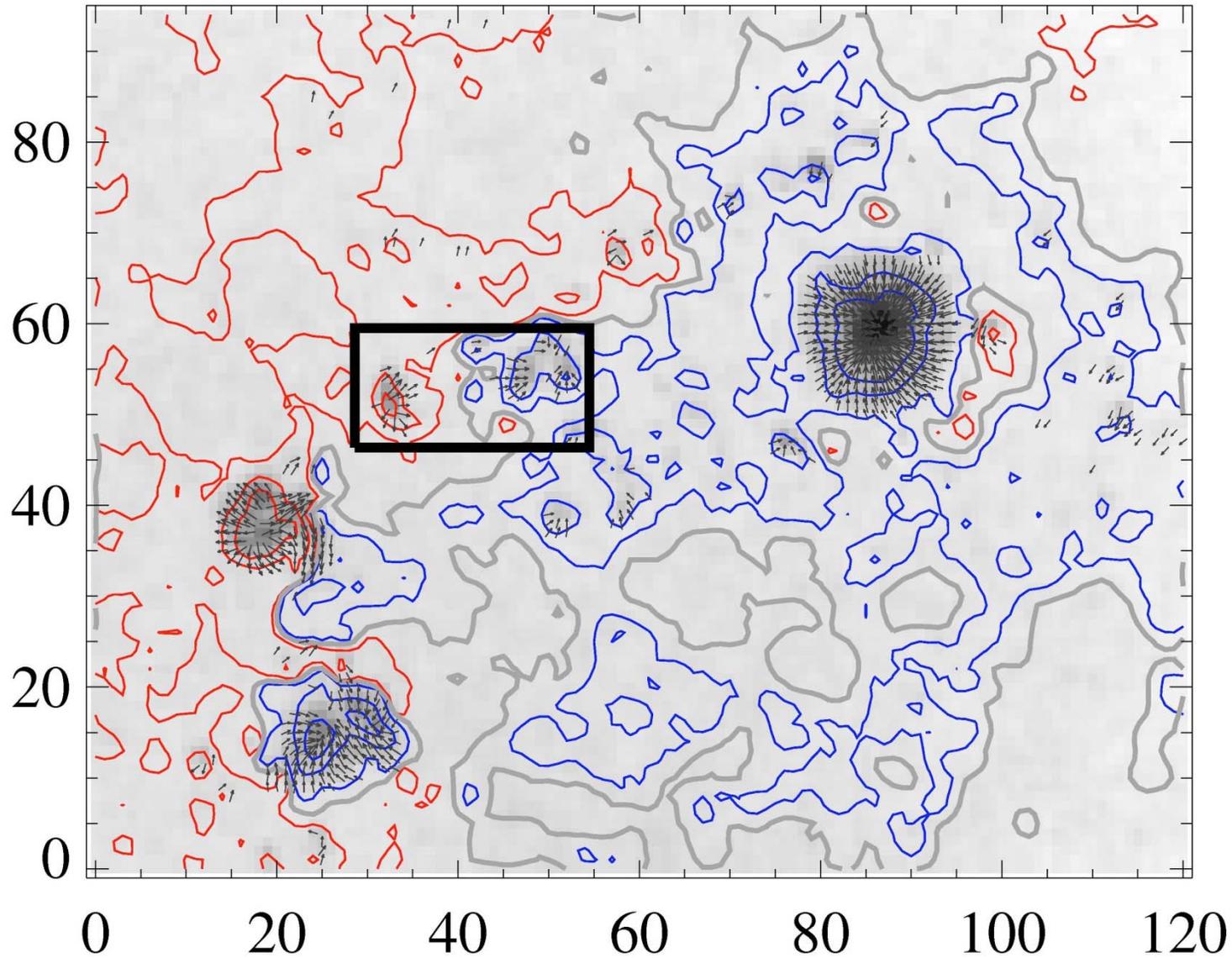
- Calculate distance d between two α_{peak} values
- Calculate range for winding number
 - $T/2\pi = d\alpha_{peak}/4\pi$ (*straight line*)
 - $T/2\pi = d\alpha_{peak}/8$ (*semicircle*)
 - Critical value: $T/2\pi \approx 1$
- Calculate errors for α_{peak}



Results

- We analyzed 3 active regions that flared:
 - AR09767 on 2002/01/04, 17:52 UT
 - AR10646 on 2004/07/13, 17:50 UT
 - AR10656 on 2004/08/10, 17:09 UT
- The following images are of the continuum overlaid with contours of B_z (red positive, blue negative) and vectors indicating B_{Hor}
- For each α_{peak} pair, a range of winding numbers is given, minimum using $L = d$ (tangent to surface), maximum using $L = \pi d/2$ (assuming a semicircle loop)

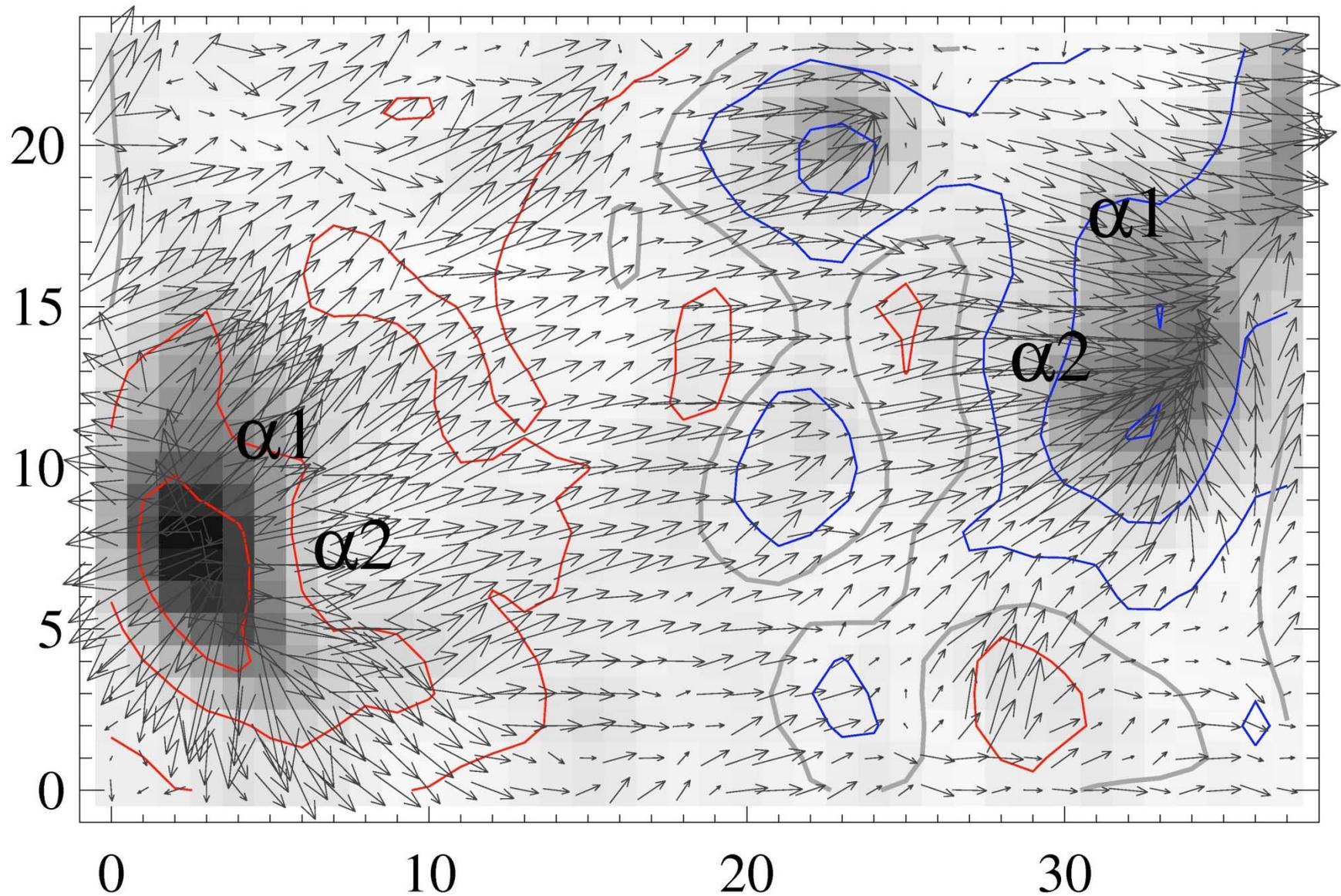
AR 09767: 2002/01/04



B @
17:52 UT

C7.2 Flare
22:53 UT

Emerging Bipole



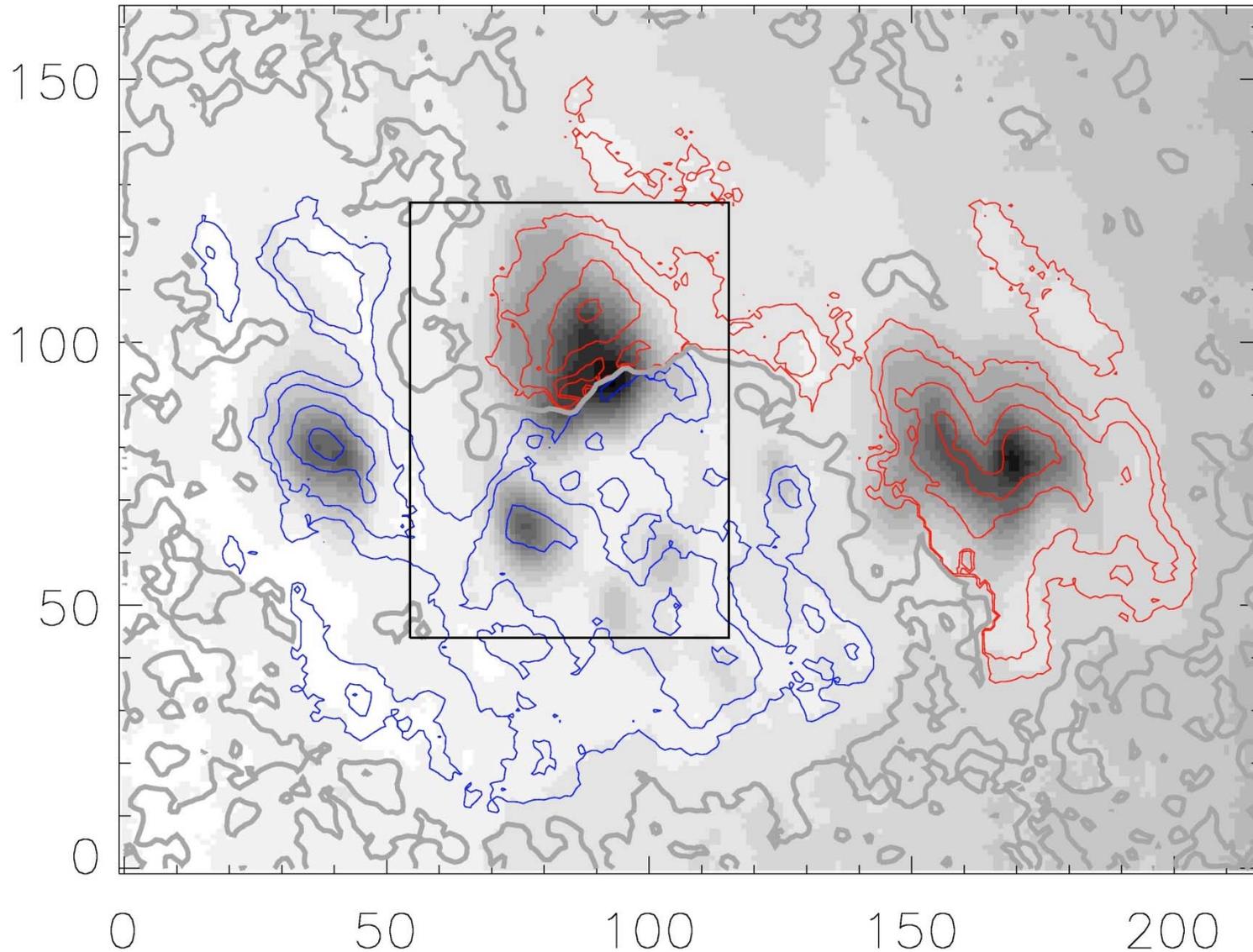
Analysis

- Identified 2 possible pairs of α_{peak} .

	α_1	α_2
$L = d$ (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
$T/2\pi$ range	1.0 - 2.6	0.5 - 3.5

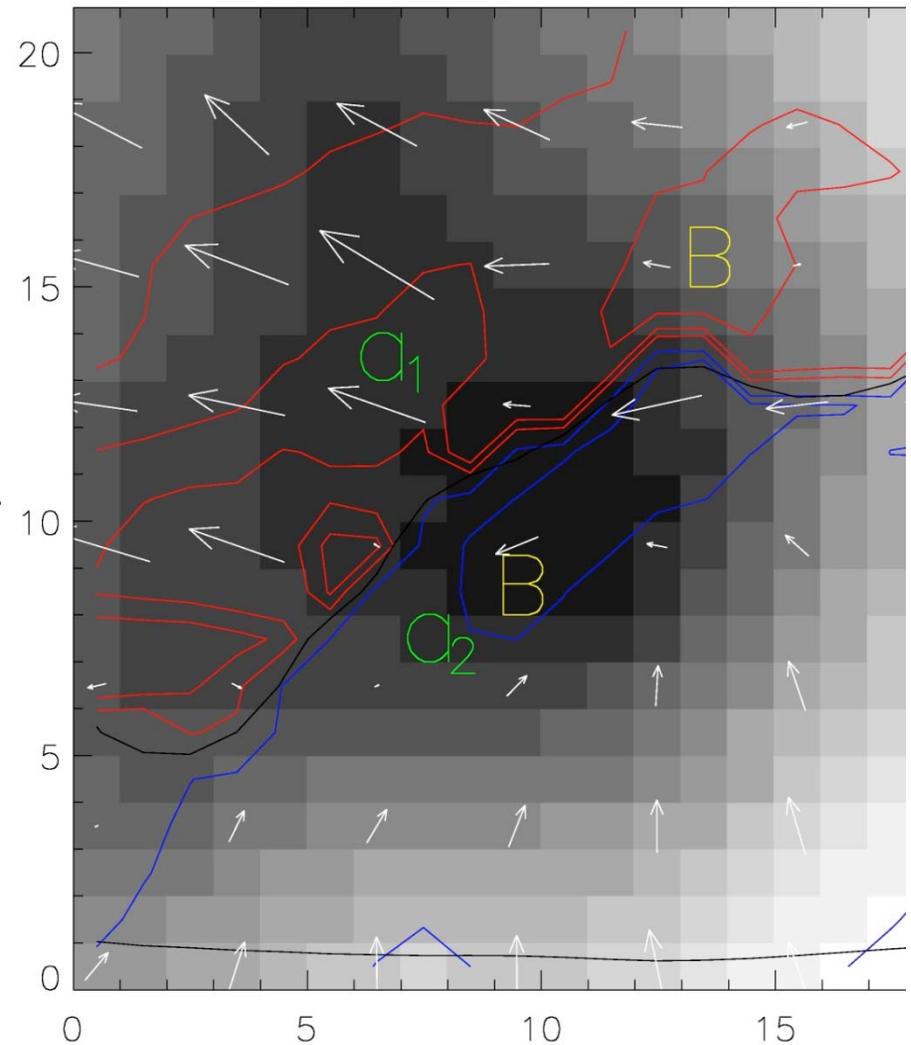
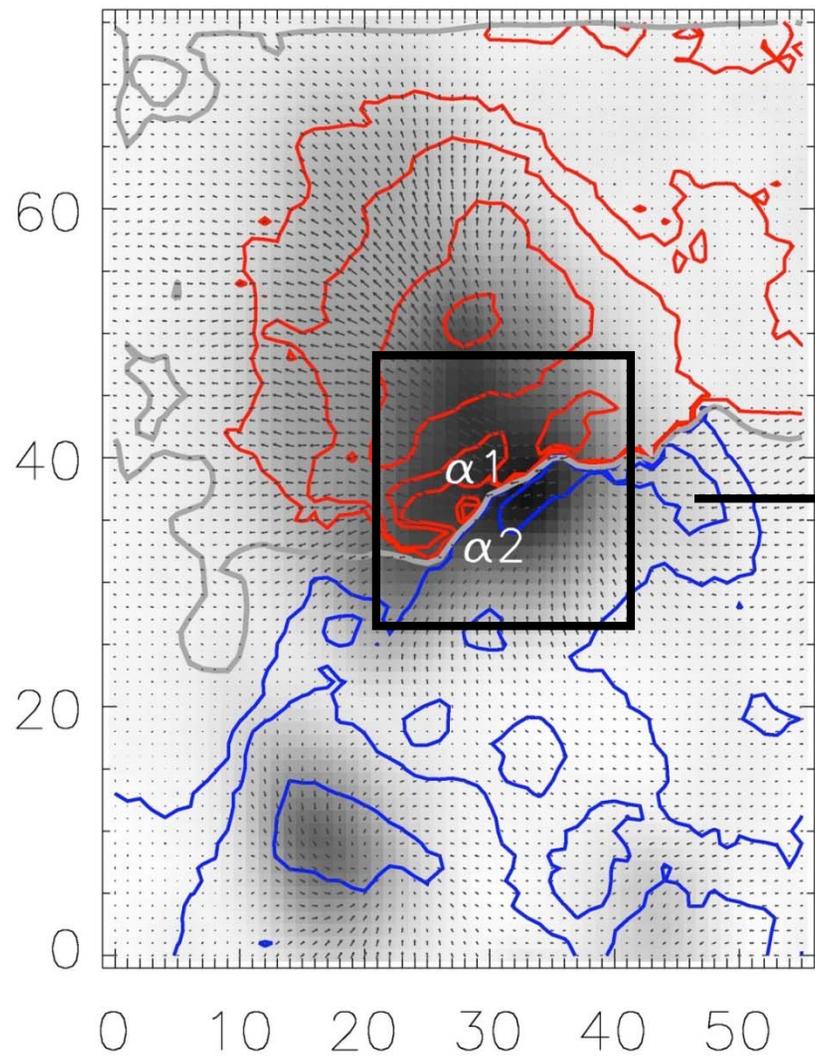
Similar winding numbers for each pair. It is possible that this bipole contained super-critical twist, though uncertainties make it difficult to determine.

AR10646: 2004/07/13



B @
17:50 U
M6.2 fl
@ 19:24

δ -Spot: Opposite Polarities Within One Penumbra

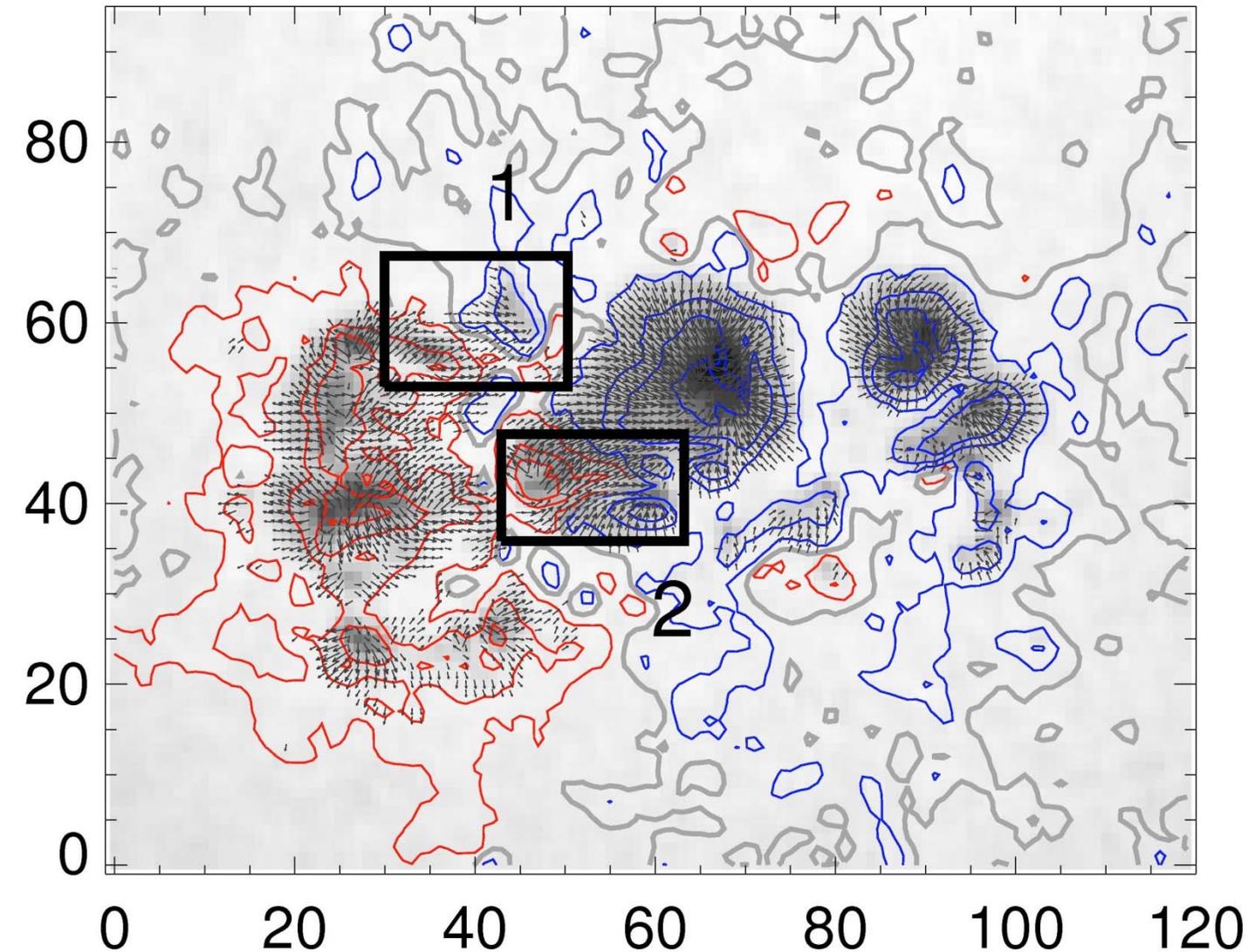


Analysis

$L = d$ (Mm)	5.1
$L = \pi d/2$ (Mm)	8.0
α_{peak} (Mm ⁻¹)	0.7 ± 0.12
$T/2\pi$ range	0.28 - 0.45

- Values of α_{peak} at footpoints are significantly different, reported value is the mean of the two.
- Unsure if bipole has emerging flux, and if it does, if the axis has emerged
- Kink instability probably not the trigger in this case

AR10656: 2004/08/10

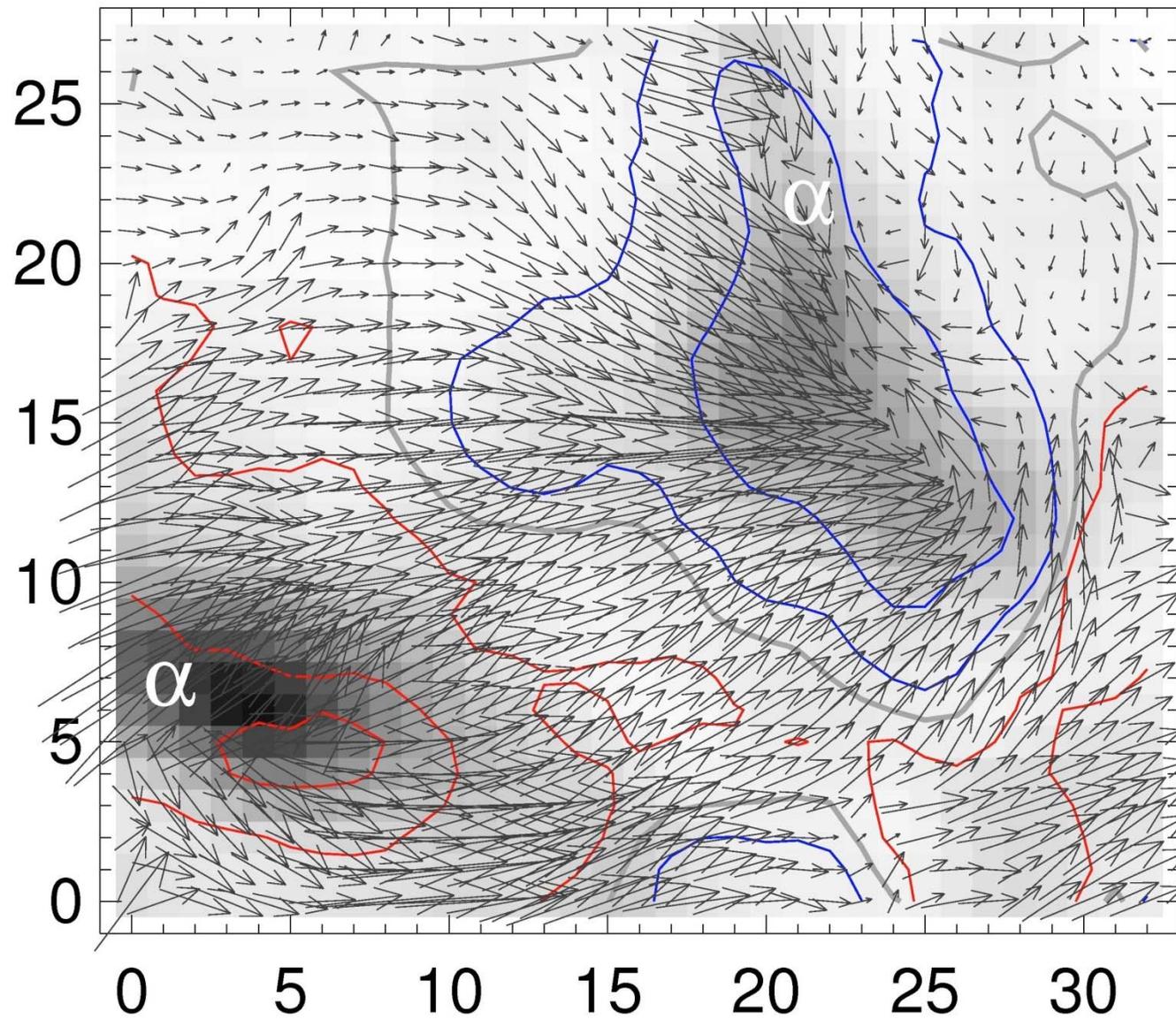


B @ 17:09 UT

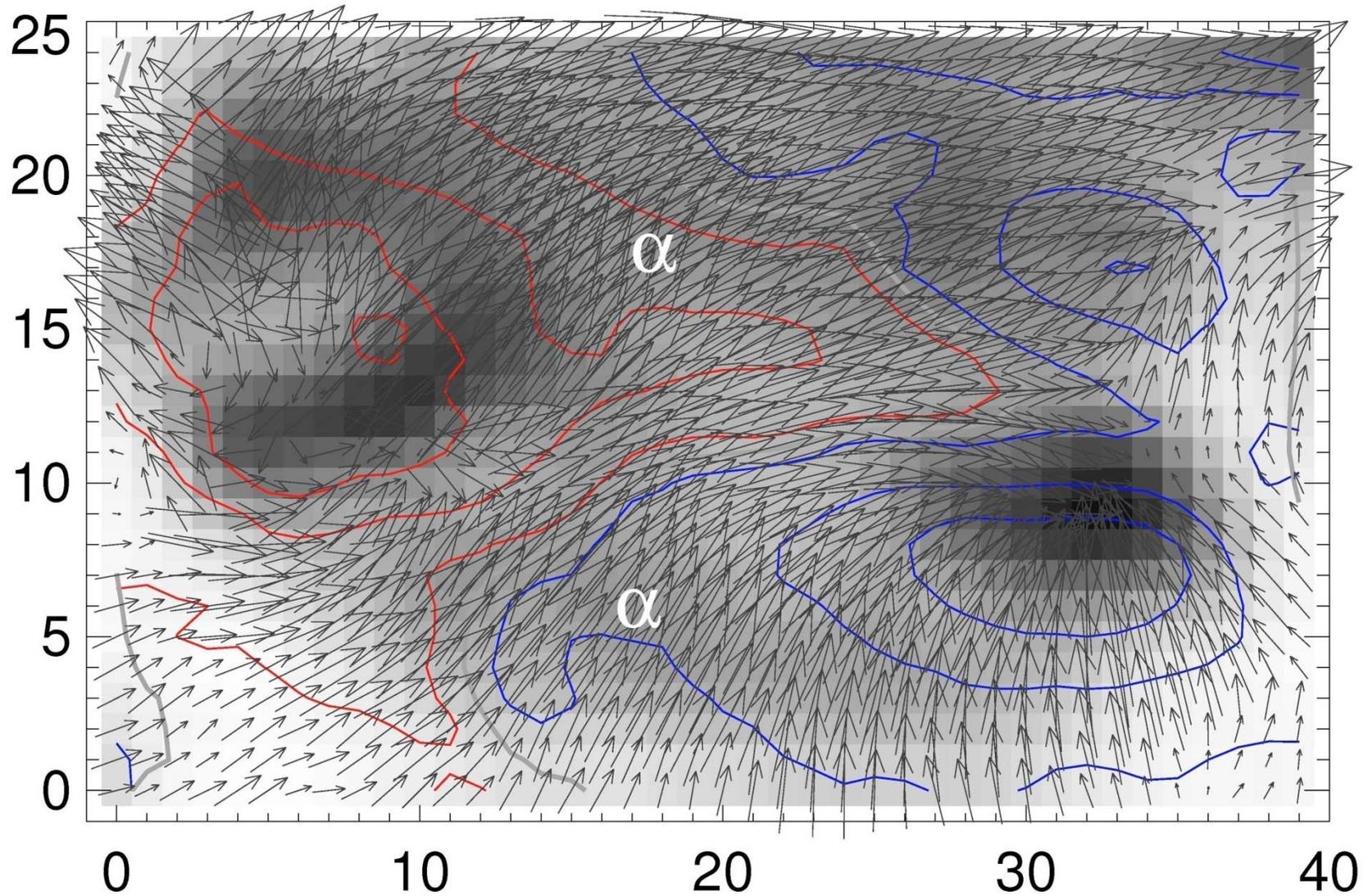
C1.0 Flare
17:25 UT

Two possible
bipoles

Bipole #1



Bipole #2



Analysis

	Bipole 1	Bipole 2
$L = d$ (Mm)	21.7	11.0
$L = \pi d/2$ (Mm)	34.1	17.3
α_{peak} (Mm ⁻¹)	-0.9 ± 0.1	-0.95 ± 0.49
$T/2\pi$ range	1.4 - 2.7	0.40 - 1.98

- In Bipole #1, $T/2\pi$ is definitely >1.0
- Bipole #2 is more uncertain, though.
- Has a different winding number than Bipole #1.

Is the Kink Instability a Flare Trigger?

- Possibly
- We have examples of regions with critical values for $T/2\pi$ that flared.
- We also have a region without a critical $T/2\pi$ which flared.
- There's more work to do.

The Future

- Do similar analysis on other target regions we've identified.
 - Regions were chosen based on ease of obtaining the data, given the available time.
 - Many other appropriate targets exist.
- More analysis using TRACE data? → other instruments
- Look at more δ spots

The Future

Fill in this chart:

Flare Observed?

Kink Possible?

	Yes	No
Yes	<input checked="" type="checkbox"/>	
No	<input checked="" type="checkbox"/>	

Is the kink instability a necessary/sufficient condition for flares and other energetic events?

Clearly more research is needed.

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

Questions?



2003/03/18 07:19