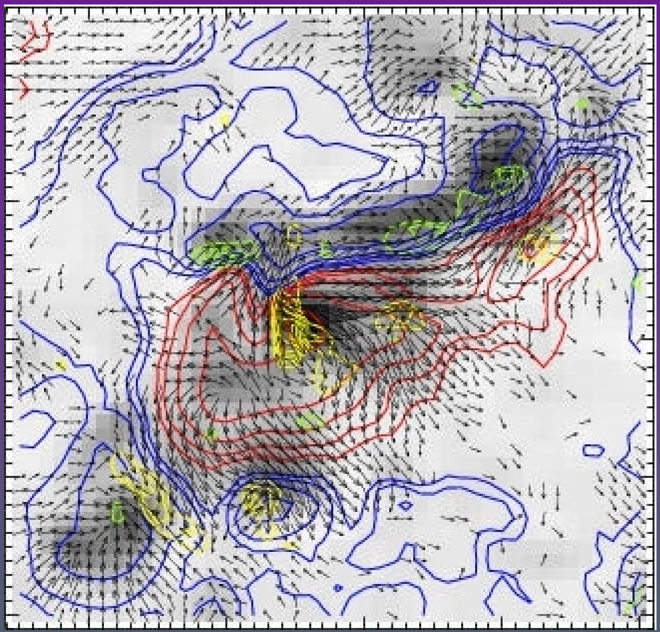
Applying Vector Magnetic Field Data to

"Real Problems"



Vector ***B*** and *Jz* of a "δ" spot, AR7815
Imaging Vector Magnetograph, Mees Observatory

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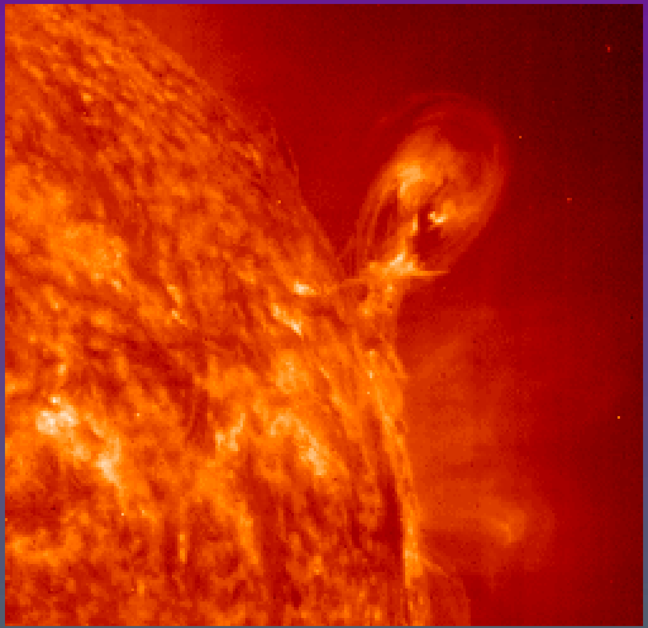


Erupting filament, EIT

RP #1: Energy Storage:
Measuring how, where, how much energy is stored and available for a flare CME.

RP #2: Energy Release:
Measuring how, where, when energy is released as a flare or CME

RP #1: Energy Storage

Goal: Quantify the amount of energy available for an eruptive event.

Restate #1: measure the deviation of the magnetic field from the **lowest-energy (potential) state.**

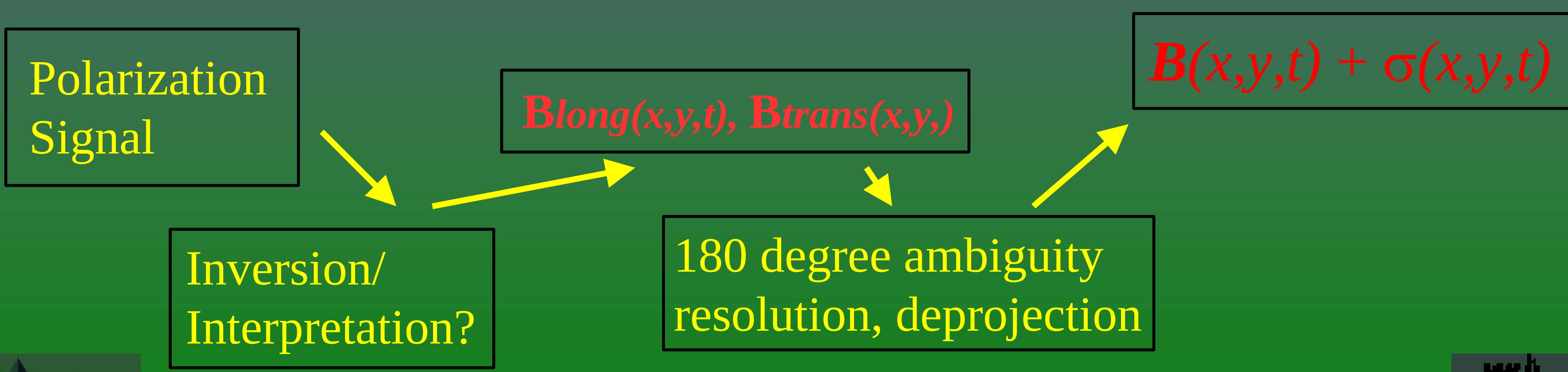
Restate #2: characterize the solar atmospheric boundary condition.

Have: ***B***(*x*,*y*,*t*), in physically-appropriate form of *Bx*,*By*,*Bz*.

*(NB: **B**(z) not usually available).*

Have also: uncertainties and errors associated with observing and deriving ***B***(*x*,*y*,*t*), both systematic and sporadic.

(NB: sensitivity in the signal is not the same as uncertainty in the answer!)



What can be measured?

Examples:

Horizontal Gradients
$$|\nabla_h B(x,y)| = \left[\left(\frac{\partial B}{\partial x}\right)^2 + \left(\frac{\partial B}{\partial y}\right)^2\right]^{\frac{1}{2}}$$

vertical current density
$$J_z(x,y) = \frac{C}{\mu_0}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)$$

measures of twist
$$\alpha(x,y) = \frac{[\nabla_h \times \boldsymbol{B}_h]_z}{B_z}$$

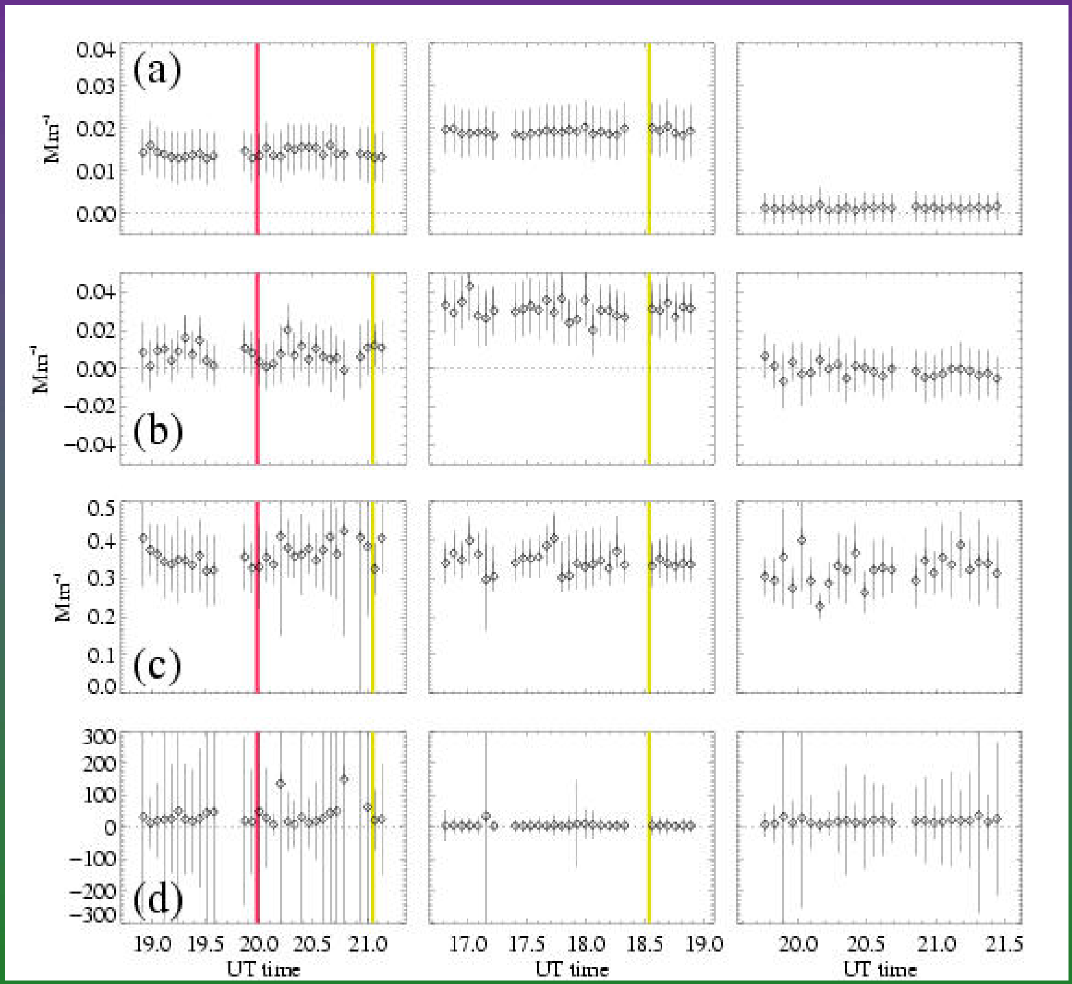
current helicity density
$$h_c(x,y) = B_z \cdot [\nabla_h \times \boldsymbol{B}_h]_z$$

magnetic shear angles
$$\Psi(x,y) = \cos^{-1}[\boldsymbol{B}^p \cdot \boldsymbol{B}^o / B^p B^o]$$
$$\psi(x,y) = \cos^{-1}[\boldsymbol{B}_h^p \cdot \boldsymbol{B}_h^o / B_h^p B_h^o]$$

Different parameterizations offer different weighting and sensitivity to non-potential, energy-storage measures.

What do we want to measure?

Example: Simple Stress & Release mechanism for energetic events:
Magnetic field is stressed away from potential configurations, storing energy which is then tapped to produce a CME or flare.



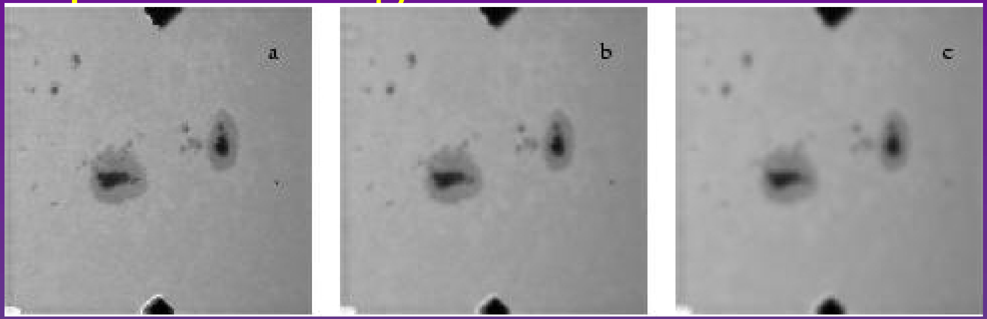
(a) the "best" force-free a,fit over entire active region
(b) the mean of a(x,y)
(c) the standard deviation of a(x,y)
(d) the kurtosis of a(x,y)
plotted as a function of time for three active regions relative to the start of an X and two M-class flares (red, yellow lines).

(poster 1.32, Leka & Barnes, ApJ, *in press)*

Thus far, little evidence that *any* single measure derivable from photospheric ***B*** implicates a stress/release mechanism in the photosphere.

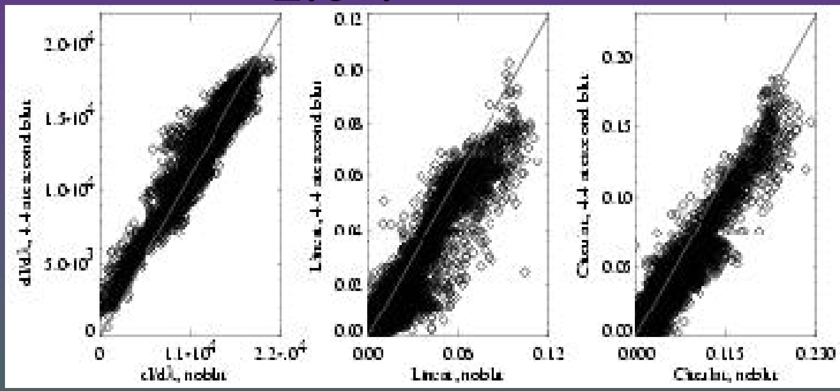
No single silver bullet

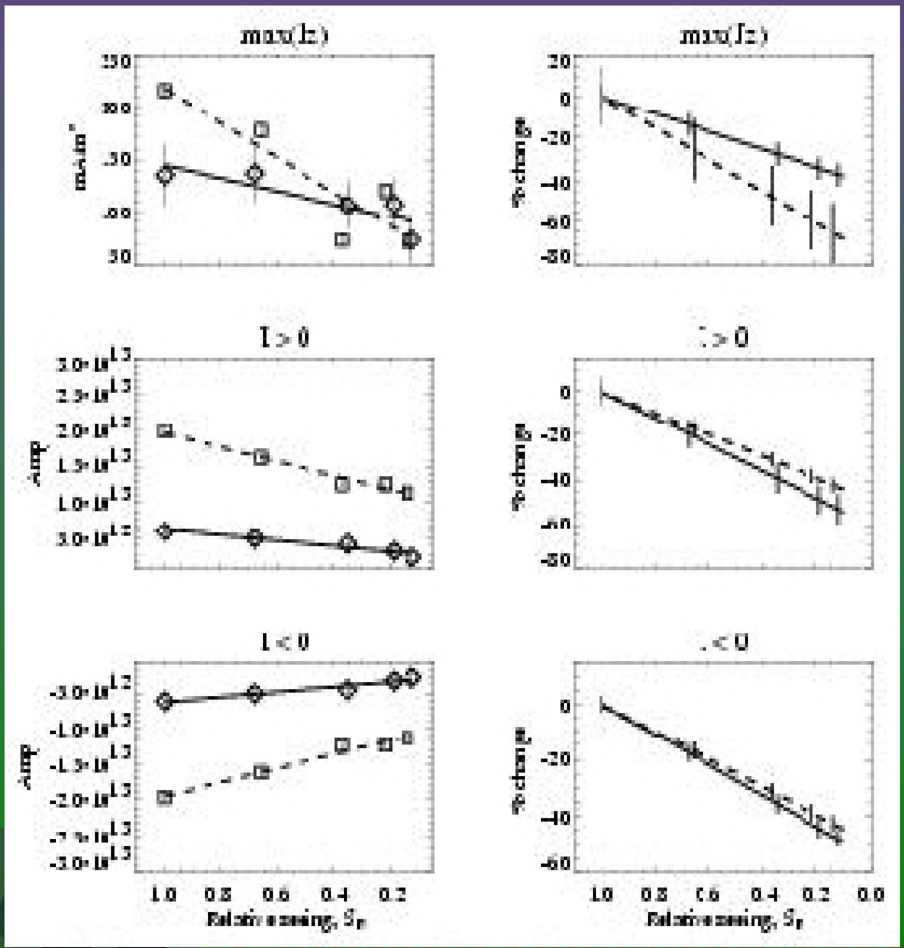
Handling the effects of atmospheric seeing:

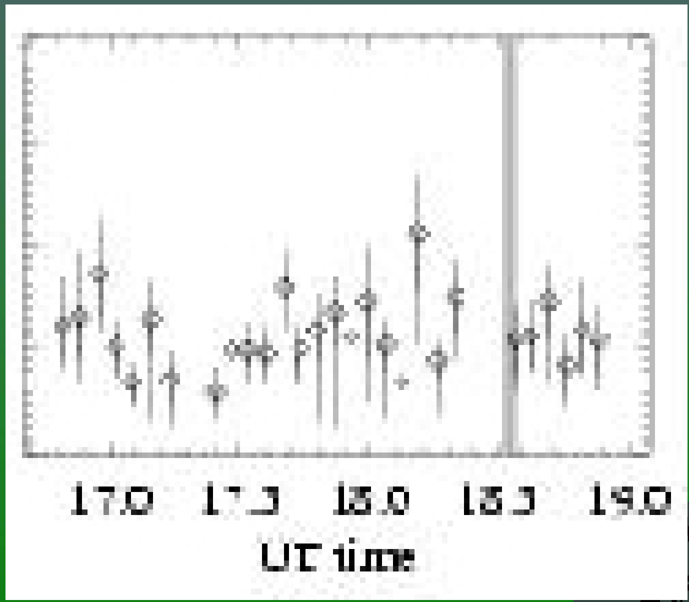


<1.0"   2.0":   4.0"

=A significant effect which must be accounted for in all time-series ground-based data.
=For imaging systems, one can model and account for the effects.
=(For spectrograph-based systems, seeing varies spatially and the effects are quite difficult to quantify)





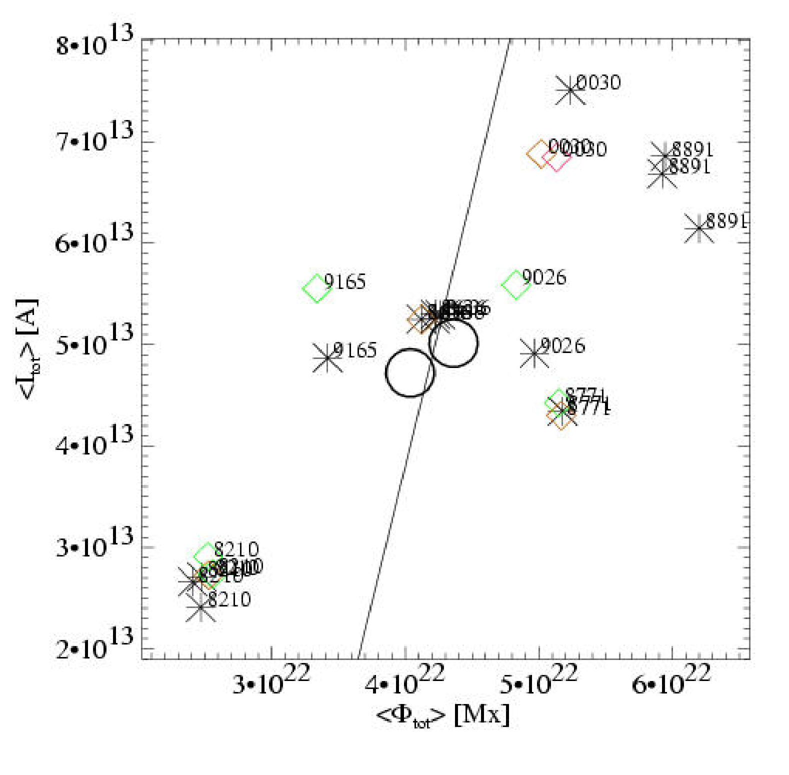


Getting greedy: need *many* silver bullets: (*poster 1.32, Leka & Barnes, ApJ in press*)

A **Statistical test of whether event-imminent, event-quiet photospheric magnetic states are distinguishable.**

A **Evaluation of a gazillion parameters derivable from photospheric *B***

Example:



AExample of Discriminant Function for total magnetic flux vs. total vertical current

AThese two variables do not well separate the two samples (probability=0.327).

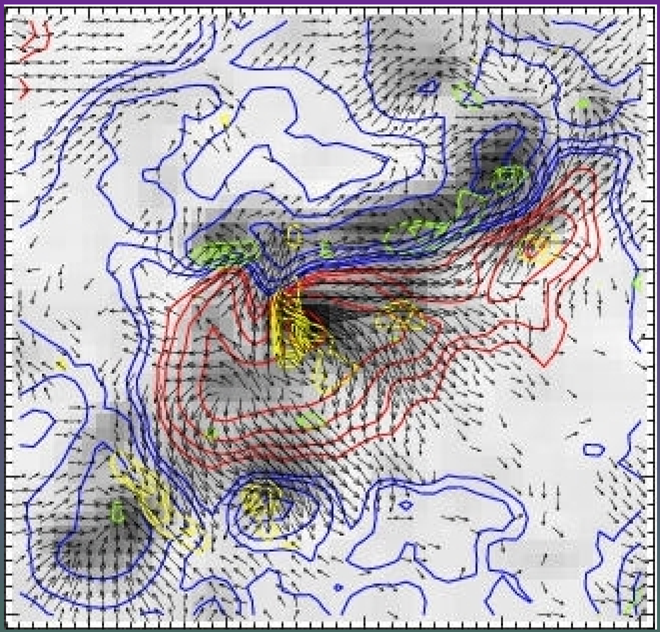
APower of DF analysis comes when considering many parameters at a time, caveat the sample size.

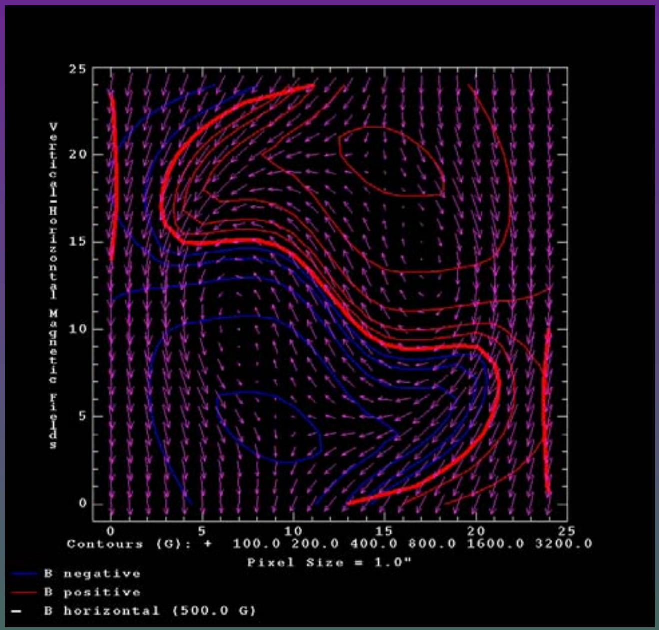
A **Demonstrate: by considering multiple parameters at the same time, samples from the two populations *can be distinguished*.**

(Demonstration of method only!)

Restate #2: Characterize the pre-event boundary state

Example: Detailed comparison of observational data and numerical simulations





Comparison of observed photospheric ***B*** and "observed" *B* from an analytical model of twisted flux system into overlying extant field. (Gibson, Leka, Fan, Barnes, work in progress)

Caveats:

APhotosphere is not necessarily force-free:

APhotospheric field may not give accurate measure of energy available for CMEs/flares.

AMeasured photospheric field may not represent the state of the atmosphere *where* energy release occurs.

Real Problem #2: Energy Release

Restate #1: Can photospheric ***B*** measurements detect the trigger or release of the stored magnetic energy?

Generally accepted:

ATrigger for energetic events (reconnection) occurs in upper atmospheric layers. Hence, will not be observed directly in photospheric ***B***.

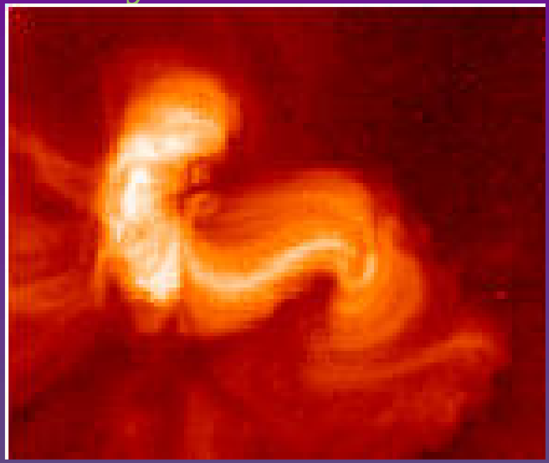
Other Notes:

AMagnetic disconnect between photosphere and chromosphere, the "magnetic transition region" between $\beta > 1$, $\beta < 1$ plasmas

AObservationally no well-determined evidence for trigger or magnetic reconnection in photosphere.

So, what can be done with Photospheric ***B*** to answer questions about the energy release process?

Restate #2: Can the photospheric B be used as the boundary condition for the coronal magnetic field?

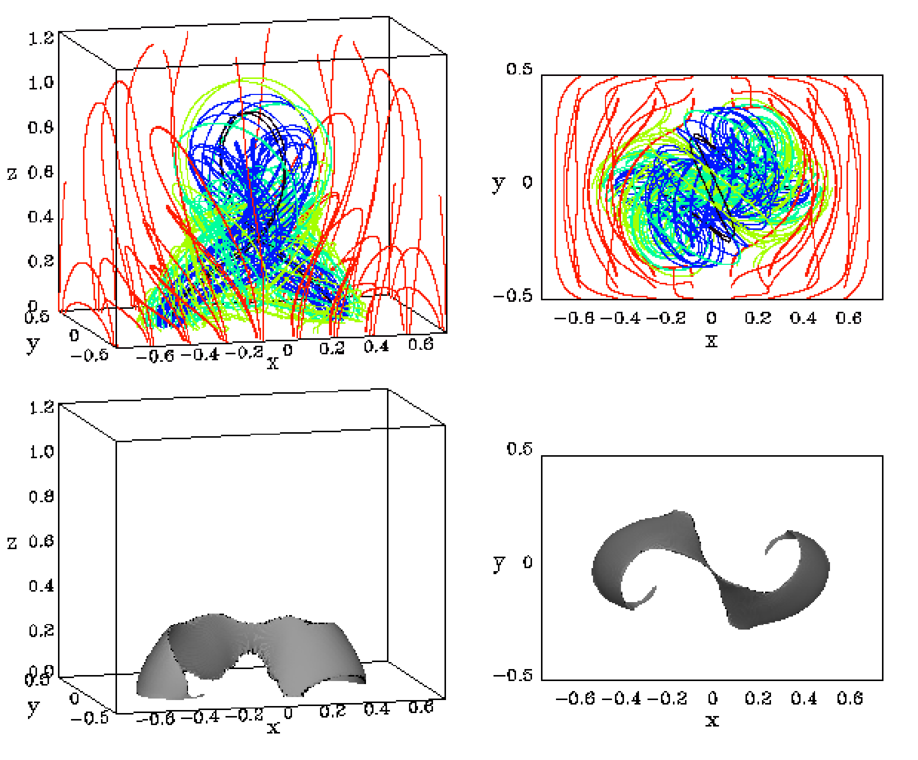


Extrapolations of various ilks (recall T. Metcalf's talk): potential, linear force-free, non-linear force-free...

Varying degrees of success at representing the corona. (General approach: compare extrapolated field lines to bright coronal structures to address issues of helicity, heating, structure, *etc.*).

Q: What are the coronal bright structures to which the extrapolations are being compared? Field lines? Current Sheets? Separators?

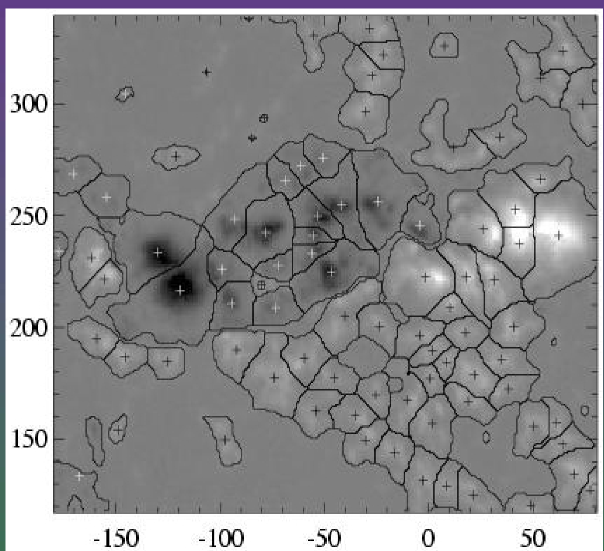
(Fan & Gibson 2003; see poster 1.16, by Fan, Gibson & Barnes)

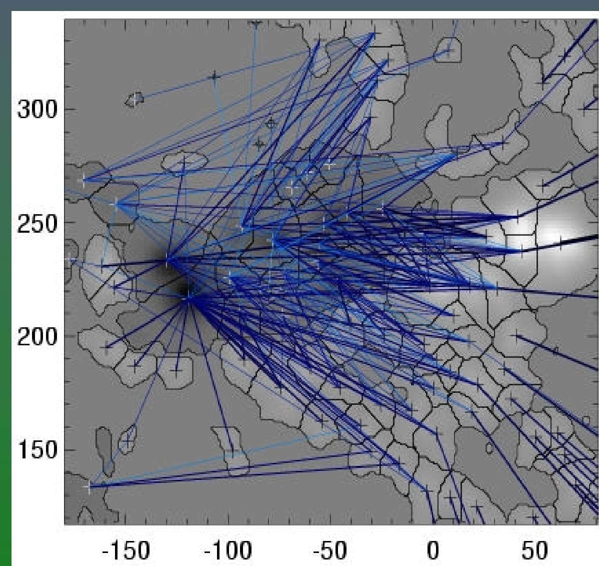


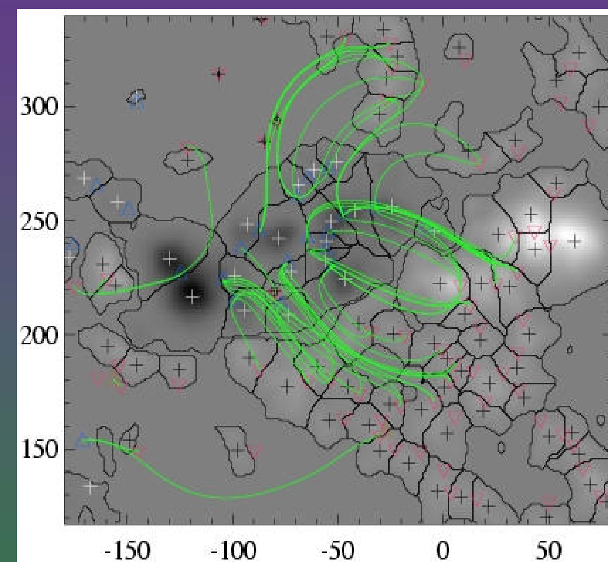
Quantifying the coronal magnetic complexity: Magnetic Charge Topology

(Barnes, Longcope & Leka, see poster 1.5)

- **Model the distribution of field in an active region**
- **Compute the magnetic flux in each magnetic connection**
- **Locate magnetic nulls, separators**
- **Use these topological measures to describe the coronal complexity**







What you can get from photospheric *B*: Helicity

(the current rage/ debate/hot-topic/ controversy)

Given: measures of ***B***, with/without ***v***, with/without temporal sampling, can (?) derive:

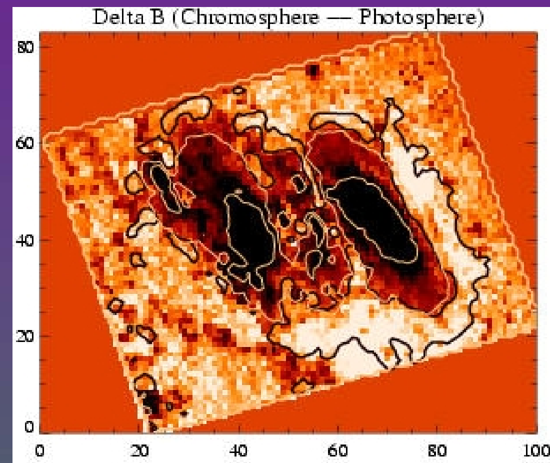
- Current Helicity density
- Magnetic helicity injection rate
- Relative helicity flux
- Magnetic helicity

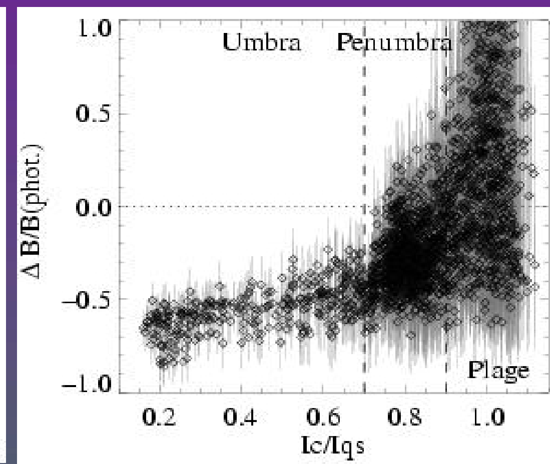
Kusano et al, Demoulin & Berger, Longcope & cohorts, Georgoulis, Moon et al.

Details to be thrashed out here....?

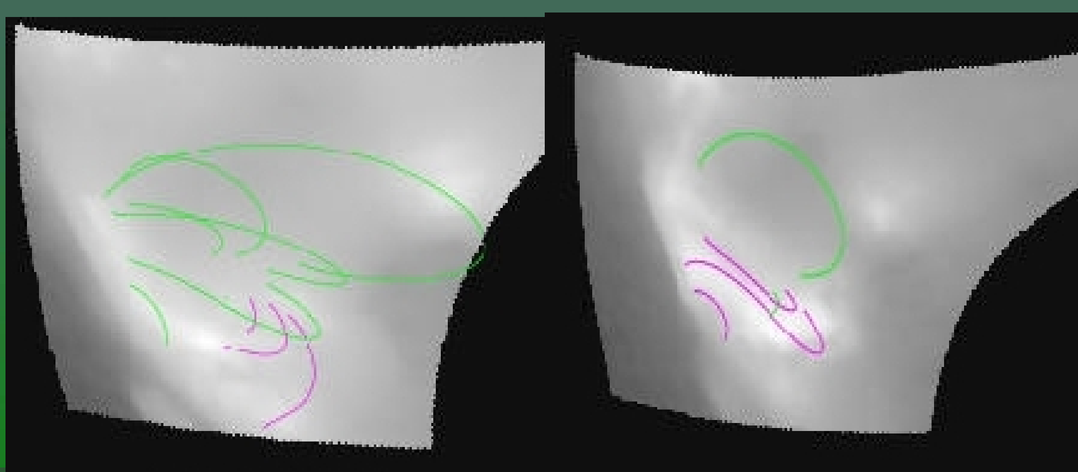
Consider the chromosphere: physically more appropriate measure of energy storage and release?

AChromospheric fields are force-free
ACannot be approximated by photospheric magnetic flux measurements without very, very sophisticated modeling efforts.





Q: Which provides a better boundary condition for extrapolations, photospheric or chromospheric B?



Comparison of SXT images to extrapolated field-lines using the photosphere (left) and chromosphere (right) vector field as boundary conditions.
(From Leka & Metcalf 2003)

To Answer David's Question(s): Practicalities and Considerations for measuring *B* given questions to be addressed:

=Instrument of choice is *f*(what question you are asking).

=Tradeoffs include:

Aspatial resolution *vs.*

Afield of view *vs.*

Apolarization sensitivity *vs.*

Atemporal resolution *vs.*

Aspectral resolution *vs.*

Aheight sampled

=(generally get good on two , decent on a third, fail on the rest

=(caveat new technologies/approaches, *cf* CdF's idea, others?).

Q: Active-Region scale magnetic changes
T: FOV, dx, P, t
A: IVM, MSFC, BBSO, Huairo, ASP;
future: DLSP , SOLIS, Solar-B, SDO

Q: Physical description of magnetic properties of Blarch (where Blarch is < 1" or thereabouts)
T: P, dx, $d\lambda$, z
A: ASP, DLSP (soon), IVM, Solar-B (soon)

Q: *Large*-scale magnetic changes
T: FOV, P, dt, z
A: SOLIS, SDO (nothing available now)

Q: Energetic event initiation
T: dt, dx, P, FOV
A: IVM, BBSO, Huairou, SDO (soon)

Summary

Do photospheric B measurements have any useful contribution to understanding Solar Energetic Events?

Ayes, qualitatively (it probably has something to do with the solar atmosphere, but there is a disconnect between the photosphere and where energetic events are initiated).

Apossibly, quantitatively (new methods are being developed to make use of but not over-use the photospheric measurements)

Ano, as has generally been approached ("bumps and wiggles" approaches to variations in photospheric B relative to flares/CMEs is now out-dated; causal relationships and statistical approaches must be used)

Are we looking for our keys where the street light happens to be?

APhotospheric vector magnetic field data are generally available and fairly well-understood.

AHowever, the degree to which the photosphere is directly informative about energetic events is unclear

AChromospheric vector magnetic field observations may provide more direct measures applicable to understanding solar flares/CMEs.