

Promises and Reality of Analysis using Vector Magnetic Field Data

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with help from *many* others, including
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- Solar and heliospheric research is increasingly magnetically-driven
- If you are content with the line-of-sight archives from Wilcox, Mt. Wilson, KPNO, MDI, *you can go to sleep now.*
- For additional physical insight (if you want to actually get the right answer) using vector field data, and some of what goes into the interpretation, *sit up & pay attention.*

Line-of sight data:

- Circular polarization of a magnetically sensitive line $\rightarrow B_{\parallel}$
- Sensitive to Doppler effects, some thermodynamics influences
- Without good spectral data, saturation is easy
- Generally thought to be acceptable approximation to B_n “near disk center” but really always subject to projection.

Vector data:

- Circular and linear polarization
 - $B_{\parallel} \sim V \sim dI/d\lambda$
 - $B_{\perp} \sim \sqrt{(Q^2+U^2)}$, where
 $Q, U \sim d^2I/d\lambda^2$
 - $\varphi \sim \tan^{-1}(Q,U)$
- Good spectral sampling critical to inversions.
- additional step needed (180° ambiguity must be resolved).
- After full processing, \mathbf{B} removes projection effects

**Some of the topics of interest to SHINE,
think about the physics required for:**

- **Modeling active region evolution**
- **Event initiation**
 - **Energy & Helicity changes**
- **Magnetic Topology of the corona**
 - **AR/low corona**
 - **Heliosphere**
- **CME acceleration and propagation**
- **SEP generation and shock geometry**
- **Heliospheric current sheet**

Data Constraints to consider:

- **spatial resolution**
- **field-of-view**
- **temporal cadence**
- **time-series lengths available**
- ***can what you want actually be done?***

Status of data available: Archives.

Ground-based line-of-sight data dominates:

- Mt. Wilson, Wilcox, KPNO

Space-based line-of-sight:

- MDI

General:

- Long time-line (multiple solar cycles),
- Low to medium spatial resolution (2"—10")
- Each individual instrument fairly stable
- Inter-comparisons published sporadically.

Vector field data: all ground-based

- Some synoptic data: MFSC, BBSO, Huairou, Mees (HSP, IVM), Mitaka
- ASP, FlareGenesis, other archived but sporadic observations.

General:

- Low -- medium spatial resolution (2" – 6")
- Accessibility varies
- Each individual instrument less stable
 - (spectral may be better than filter-based)
- Inter-comparisons difficult and rare

Status of data available: **Today**

(*not* a complete list!)

Line-of-sight :

MDI

- Everready Bunny....

GONG++

- High temporal cadence, moderate (5") spatial resolution, incredible stability

Vector:

- Various observer-driven programs (DLSP, IBIS, Spinor, ZIMPOL II)
- SOLIS is the only synoptic ground-based vector field observations being presently acquired. (Huairou?)
 - Full-disk
 - Moderate spatial resolution
 - Moderate temporal cadence possible; presently extremely limited

First space-based vector field data: Hinode

- Extremely high spatial resolution (0.2")
- slow cadence, very limited field of view.

Status of data available: **Coming Soon....**

SOLIS full deployment

- Global longitudinal network a possibility

BBSO

- Upgraded IVM, effectively.

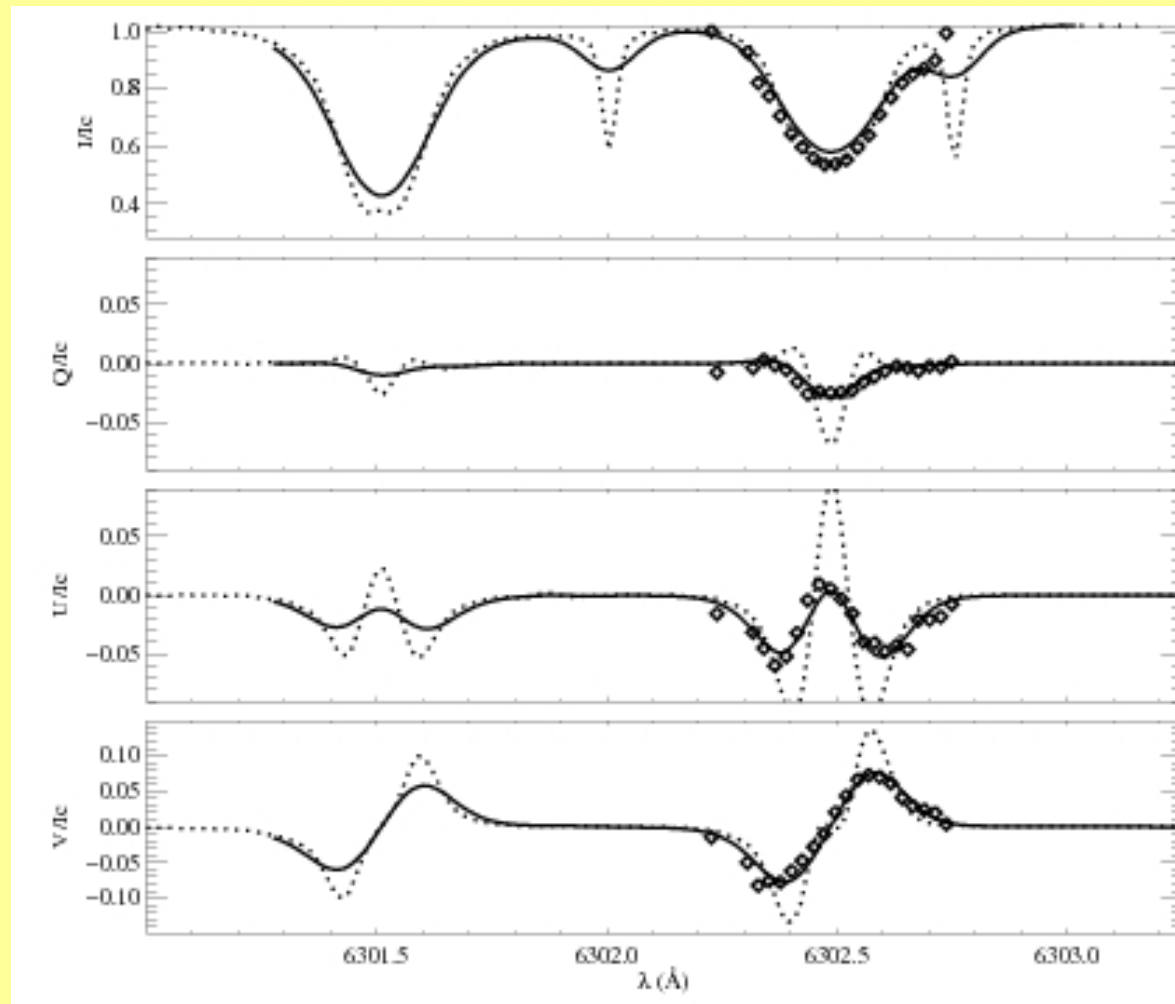
HMI on SDO

- Full-disk
- Moderate (1") resolution
- High temporal cadence ("firehose"): every few minutes

Inversion procedure:

$I, [Q, U, V]$ spectra $\rightarrow B_{\text{los}}, B_{\text{trans}}, \phi$

- Myriad methods exist, each with strengths and weaknesses
- Results can be directly (and embarrassingly!) influenced by
 - Spectral line sampled
 - Spectral sampling
 - Spatial sampling
 - Telescope design
 - Calibration
 - Atmospheric model
 - Source function
 - Fitting routine
- True for line-of-sight data, *doubly-(triply?)* true for vector field data.



ASP spectra (---) vs. convolved ASP spectra (—) vs IVM spectra (\diamond)

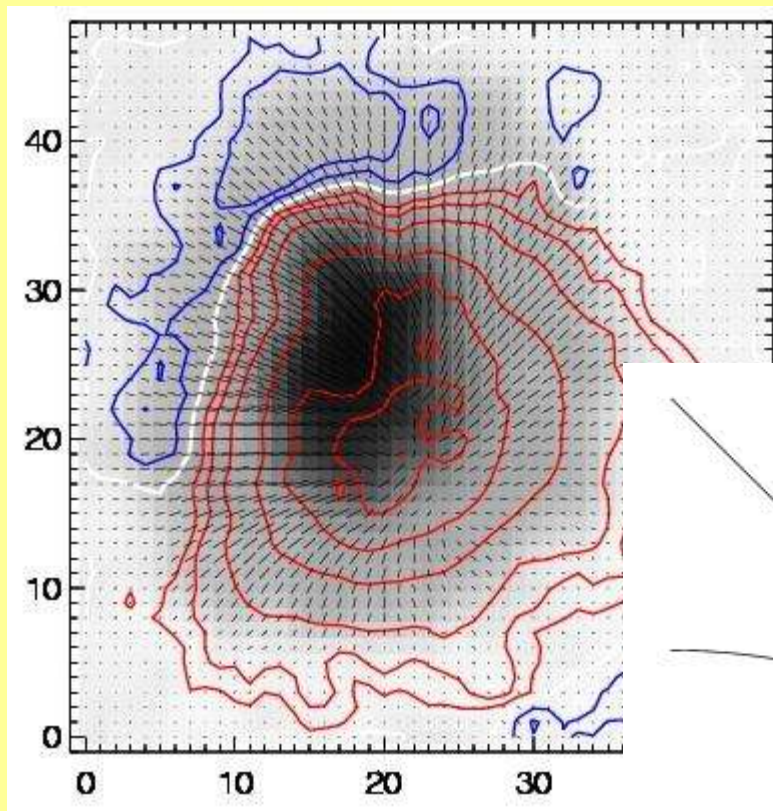
Vector data: one additional step needed:

180° Ambiguity Resolution

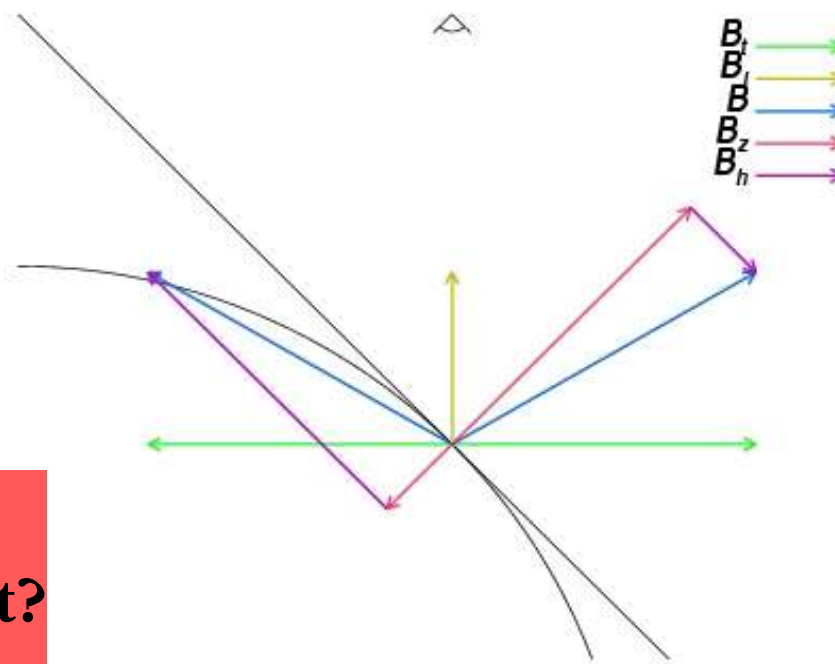
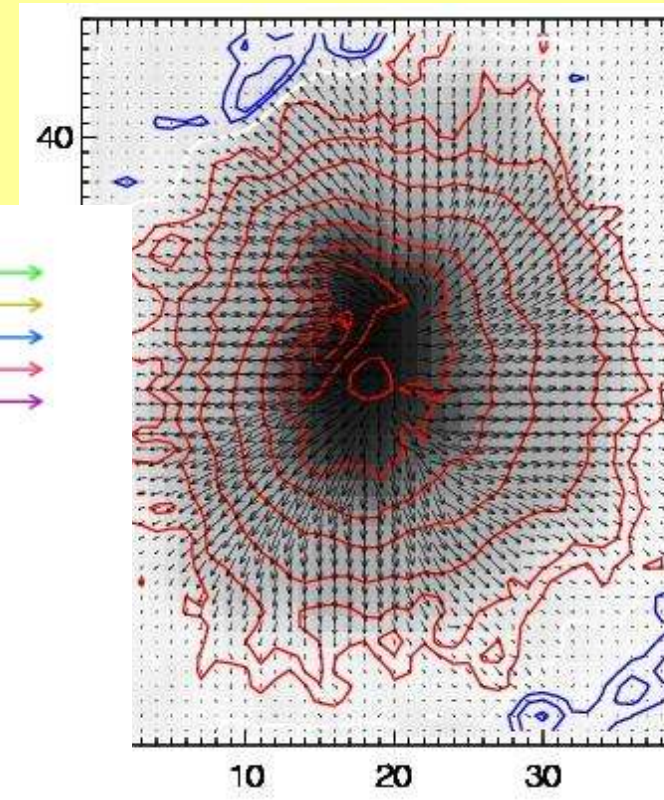
- Inherent in B_{\perp} from Zeeman/polarization observations
 - Myriad methods exist, each with strengths and weaknesses
 - *Results are only physical* after ambiguity resolution
 - *Luckily, this can be re-computed without loss of data*

Heliographic B results.

↓ (note shift in neutral line)

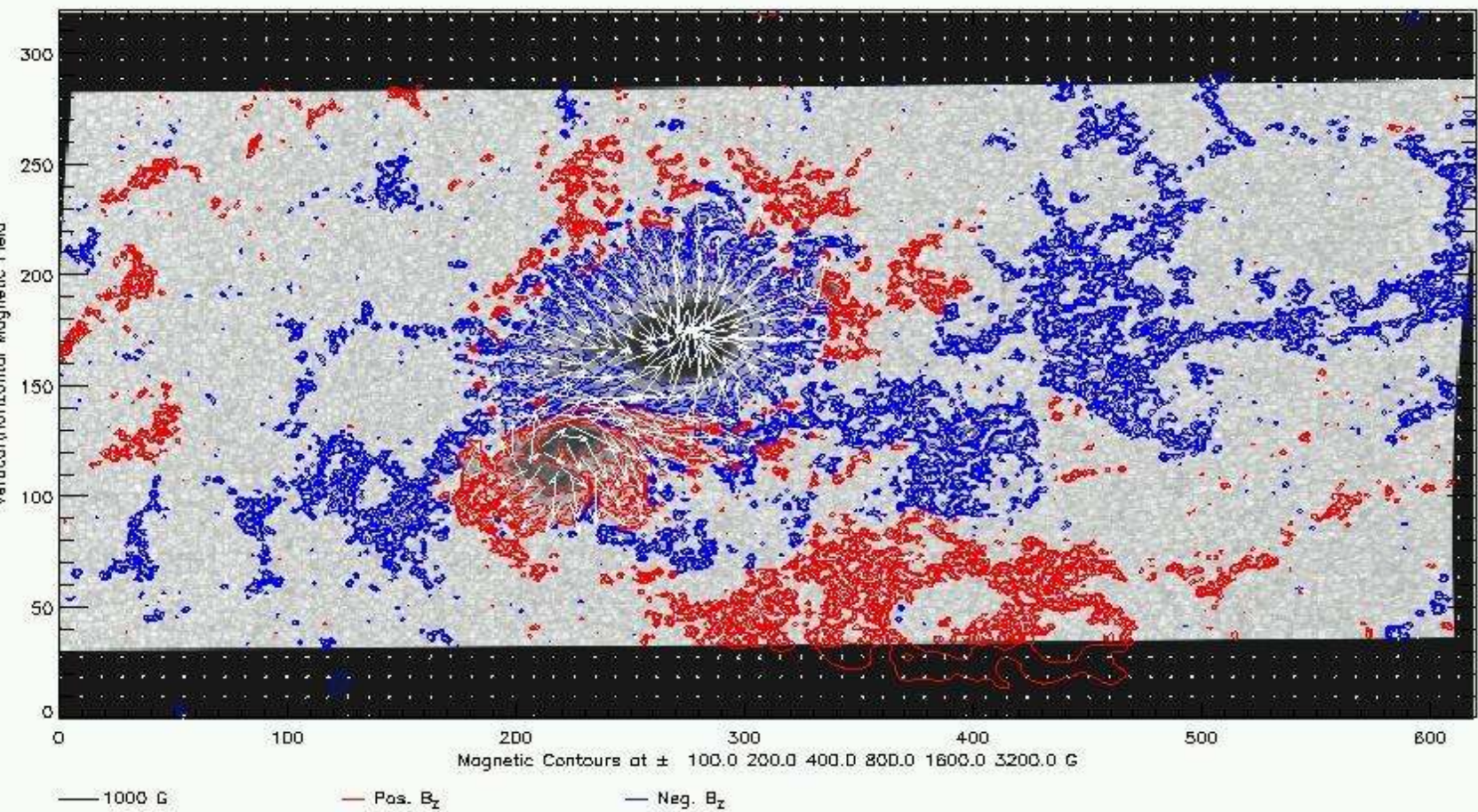
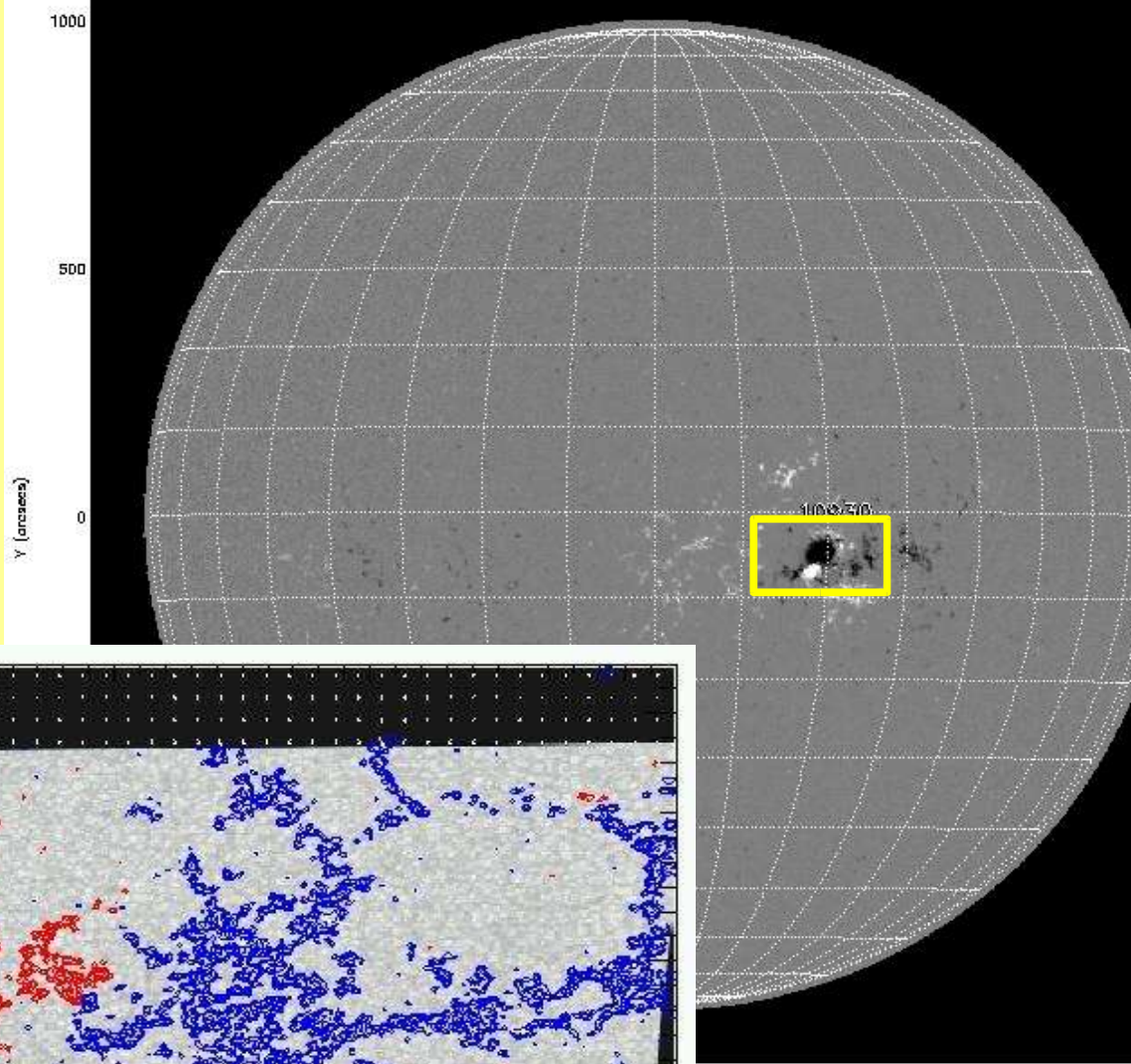


← Observed B_{los} , B_{trans} , ϕ
↓ B_{trans} direction is chosen.

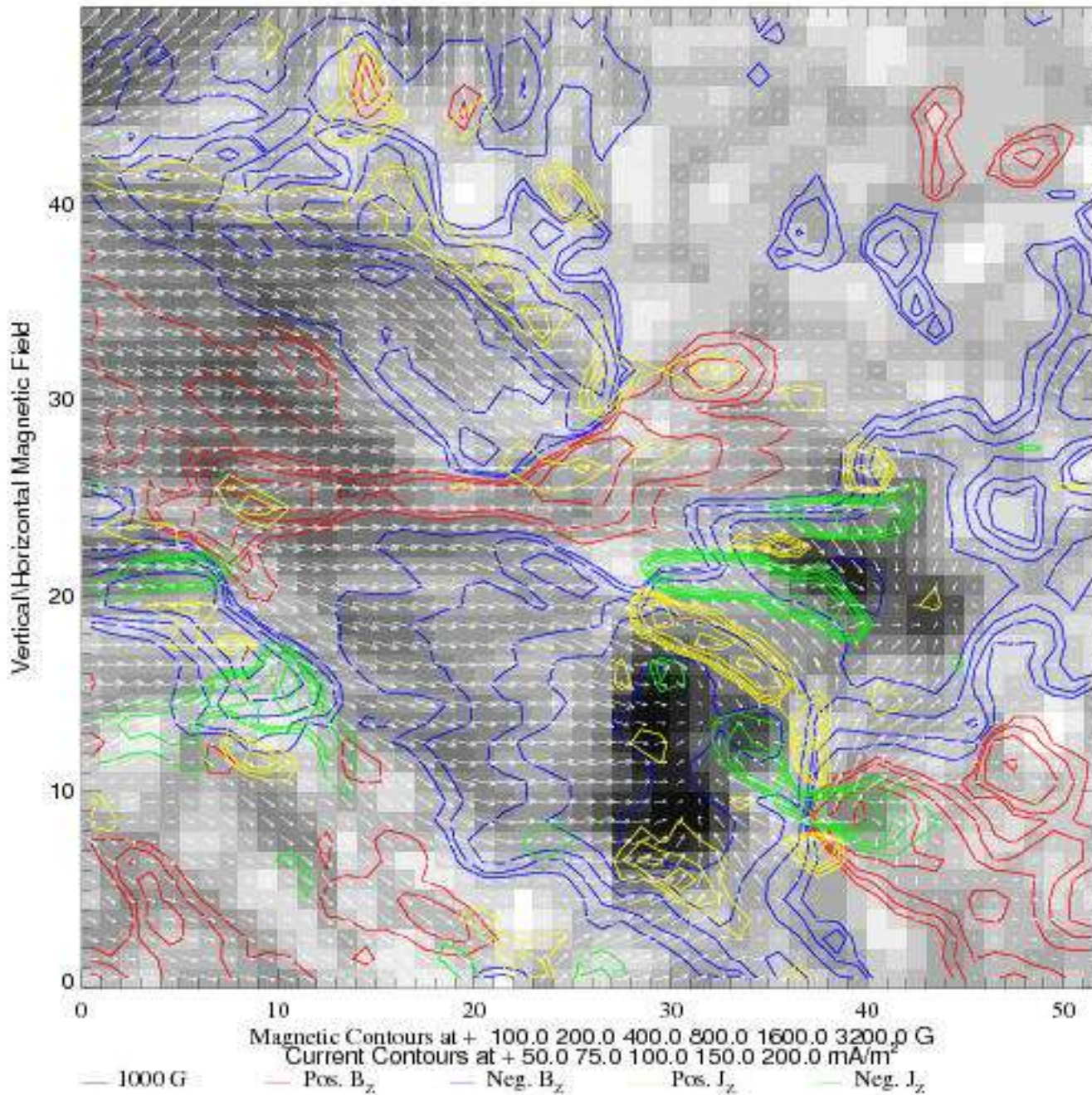
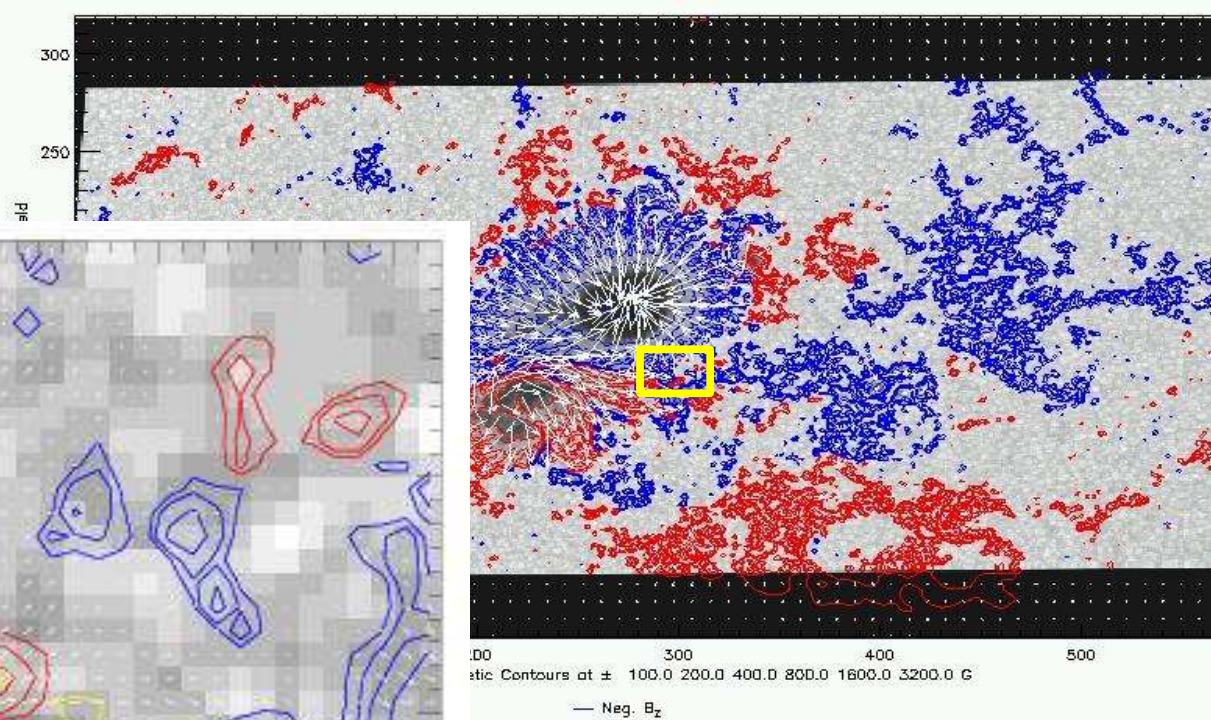


Q: What is the flux balance in this sunspot?

Hinode data example:



Not all is perfect....



Ambiguity resolution may be incorrect in this location, posing possible problems for NLFF extrapolations.

How tell it's wrong? User experience. *That's not a good algorithm...*

Continuing Challenges:

- **180° ambiguity**

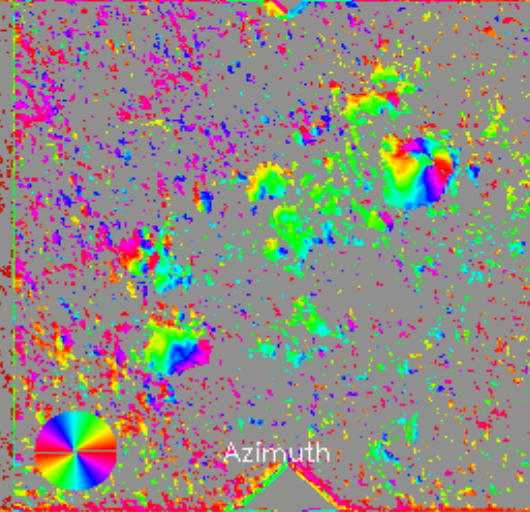
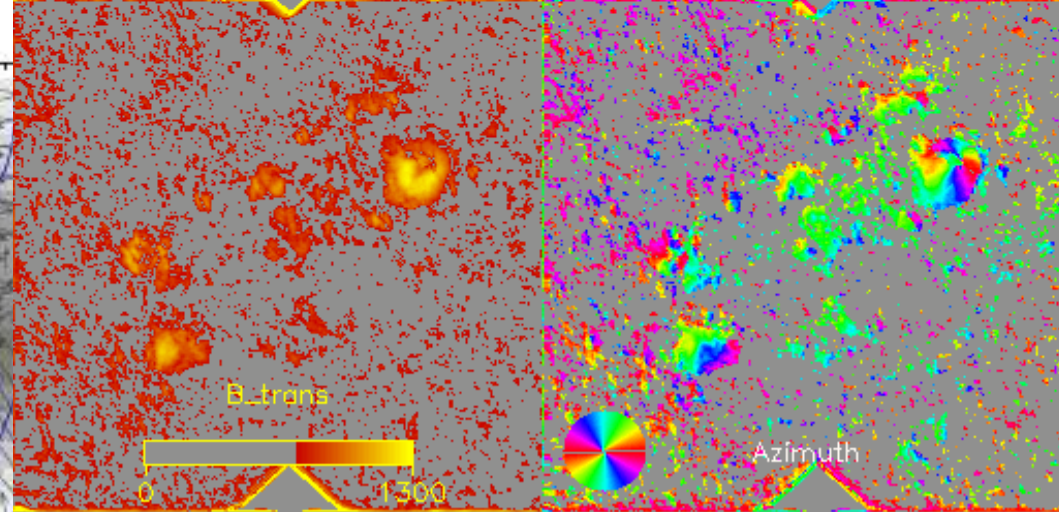
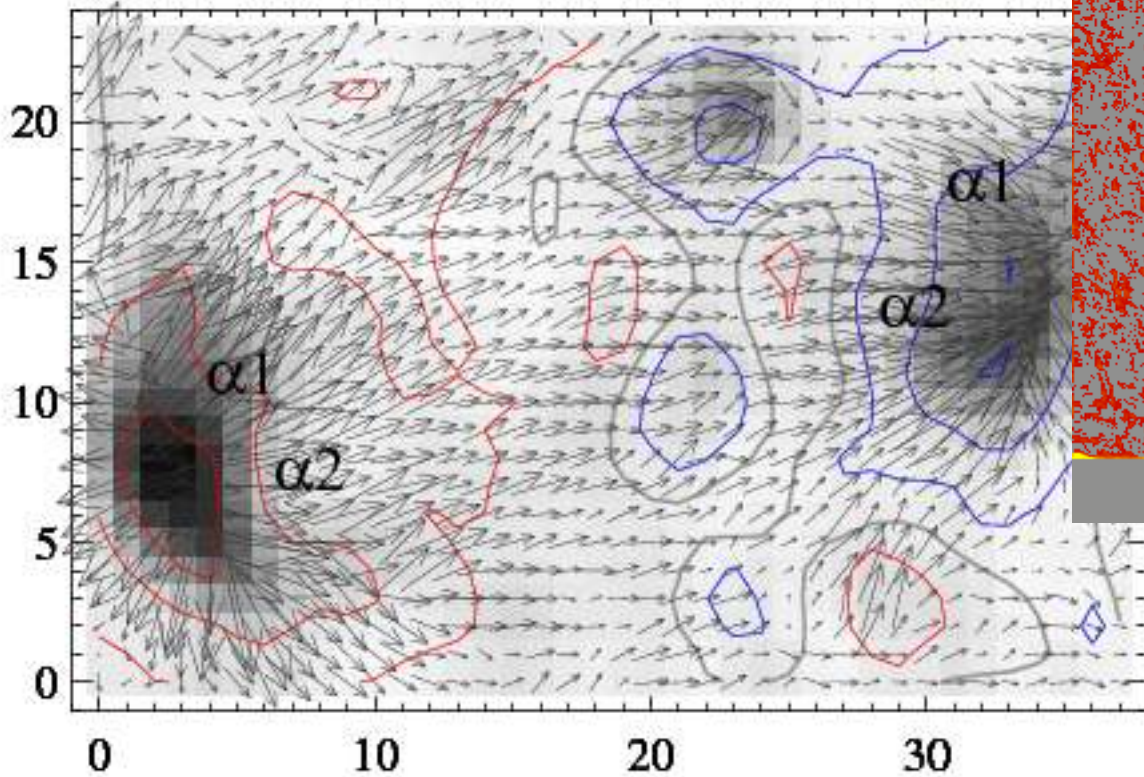
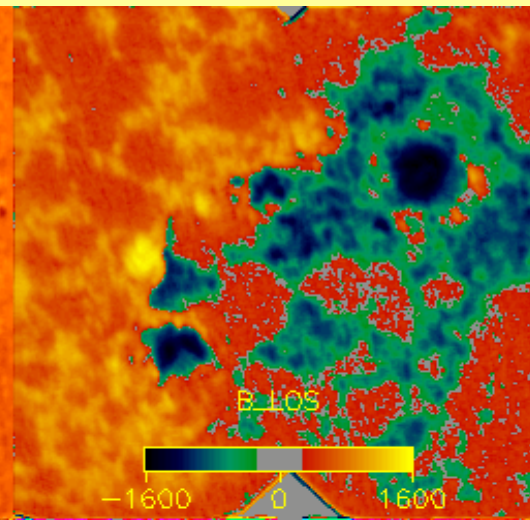
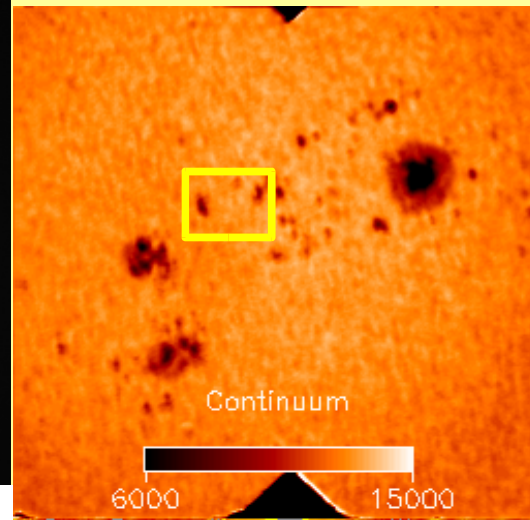
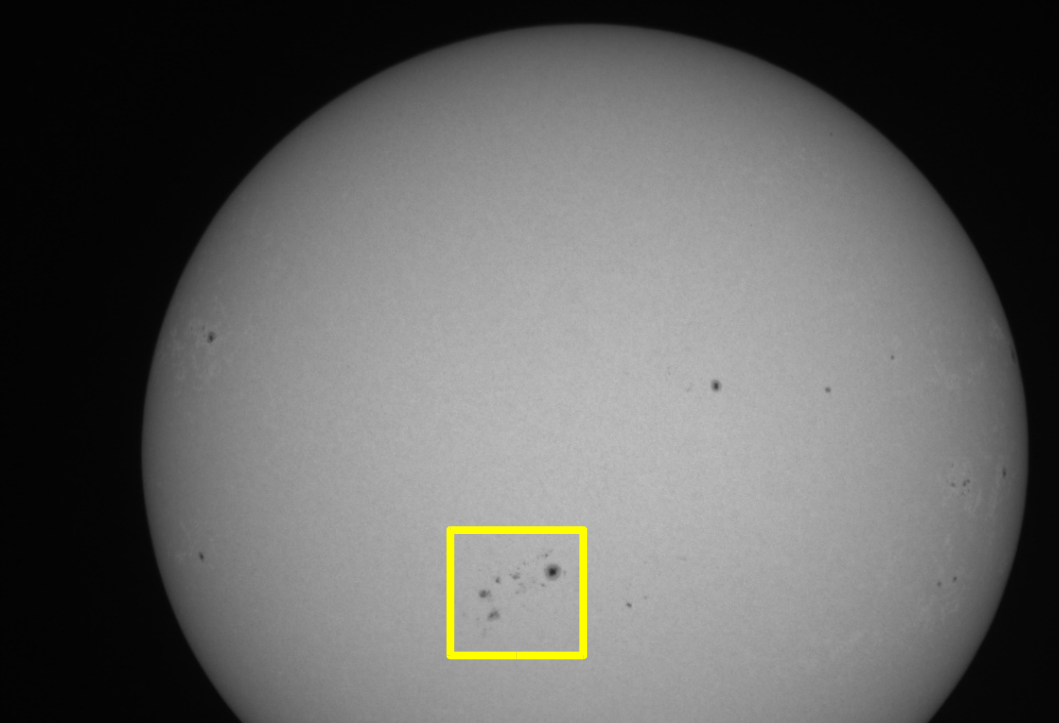
- Best algorithms being tested, nothing is perfect
- Nothing yet coded (SOLIS?) for full-disk data
- Anything is going to be extremely slow for full-disk data.

- **Extrapolations**

- Potential field extrapolations can yield very different results depending on method, boundary-condition assumptions
- Linear force-free fields almost toss out 99% of information gained from vector field data
- Non-Linear force-free extrapolations are “how to do this”, fully utilize information in ***B***
 - Still a forced boundary to feed a force-free extrapolation.
 - Resolving AR-sizescales, full-disk extrapolation, computation finishes before grant money expires, pick two.

Continuing Challenges:

- Visualization



AR9767_20020104.1752

A comment on potential fields from line-of-sight magnetograms.

- If the real field is potential, then it can be calculated from B_{\parallel} as the boundary data.
- If the real field is *not* potential, then that potential field determined from B_{\parallel} will *not* generally match the potential field determined from B_n
- This is true even 1° away from disk center.
- As J. Harvey pointed out, assuming the field is radial everywhere is a bad idea, too.

This is a great concern for analysis of Free Energy & Magnetic Helicity

- Focus is often on active regions that are highly event productive.
- These are regions known to be non-potential.
- It is unclear exactly how & by how much the calculated potential field could be wrong without knowing the true field.
- For helicity injection, B_n is needed on the boundary.
- Any comparison with a potential field will either be correct because the real field is potential (“uninteresting”), or incorrect by an unknown amount.

Some of the topics of interest to SHINE, revisited:

	GONG++	SOLIS	Hinode	HMI
• Modeling active region evolution	??	??	√√	√
• Energy & Helicity changes	X	??	??	√
• Magnetic Topology of the corona				
• AR/low corona	X	√	√?	√
• Heliosphere	??	√	X	√
• CME acceleration and propagation	√	√	??	√
• Heliospheric current sheet	√	√	X	√

Summary:

- **Be mindful of the match between data source and question posed**
- **Vector field data can provide physical answers**
- **I encourage all to embark on working with vector field data**

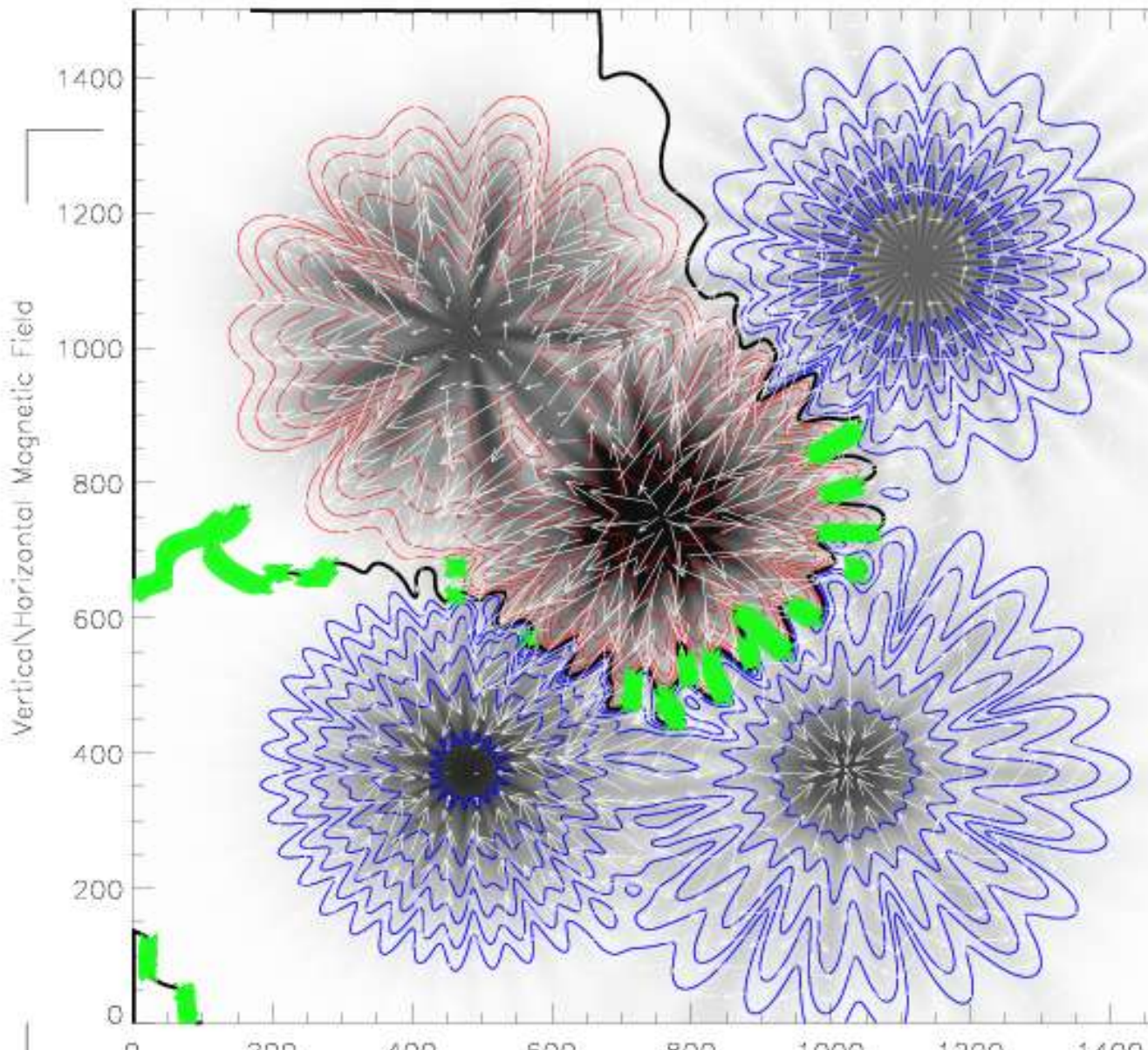
Case 2: fine-scale structure. Model field in a “box” described by:

$$B_z = B_0 e^{-(\mathbf{x}-\mathbf{x}_0)^2/(a_0^i)^2} + B_1 (\mathbf{x}-\mathbf{x}_0)^2 e^{-(\mathbf{x}-\mathbf{x}_0)^2/(a_1^i)^2} \left[1 + \cos(n_1 \theta + \phi_1^i) \right] + B_2 (\mathbf{x}-\mathbf{x}_0)^2 e^{-(\mathbf{x}-\mathbf{x}_0)^2/(a_2^i)^2} \left[1 + \cos(n_2 \theta + \phi_2^i) \right]$$

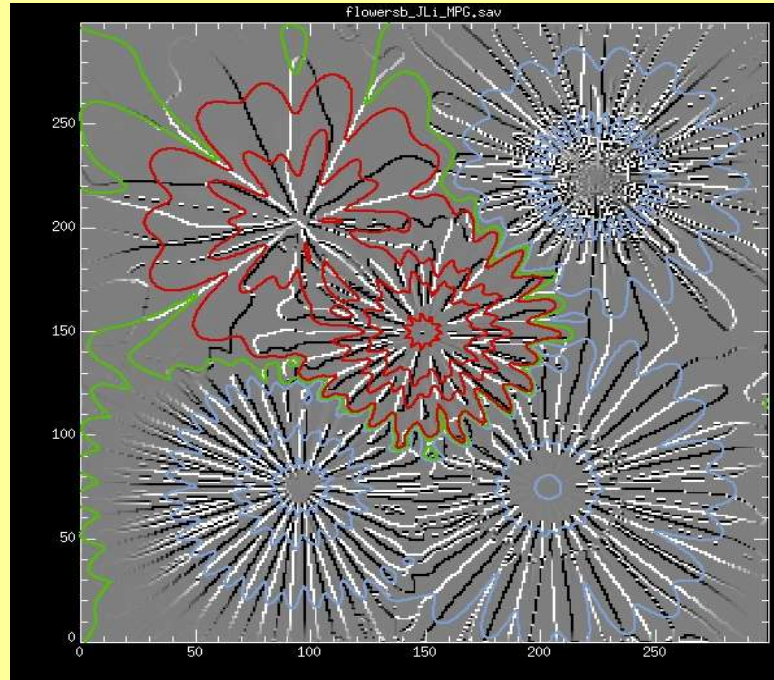
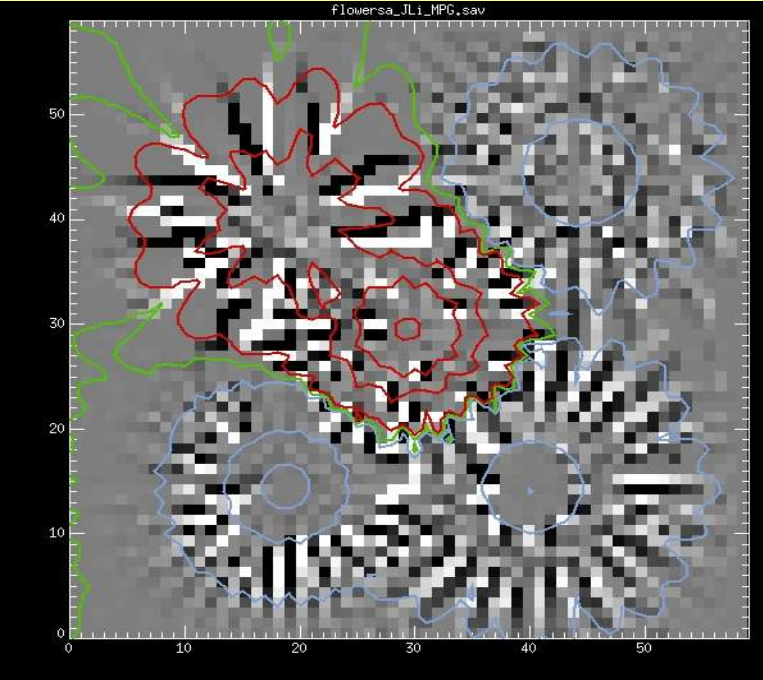
Tweaking a , ϕ determines morphology

- Model computed on a critically sampled grid
- profiles generated
- Spectra averaged. (range to simulate 0.2" – 1.0")
- Binned spectra re-inverted

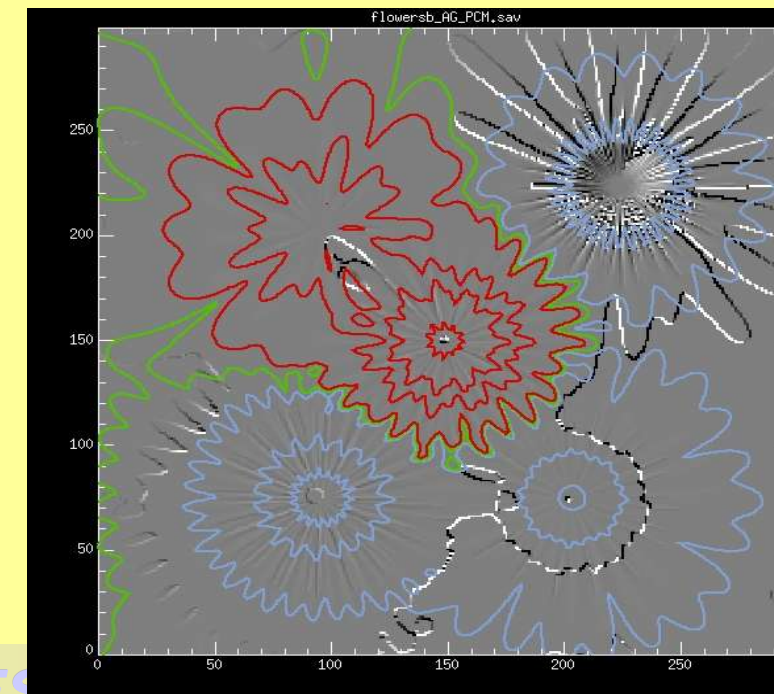
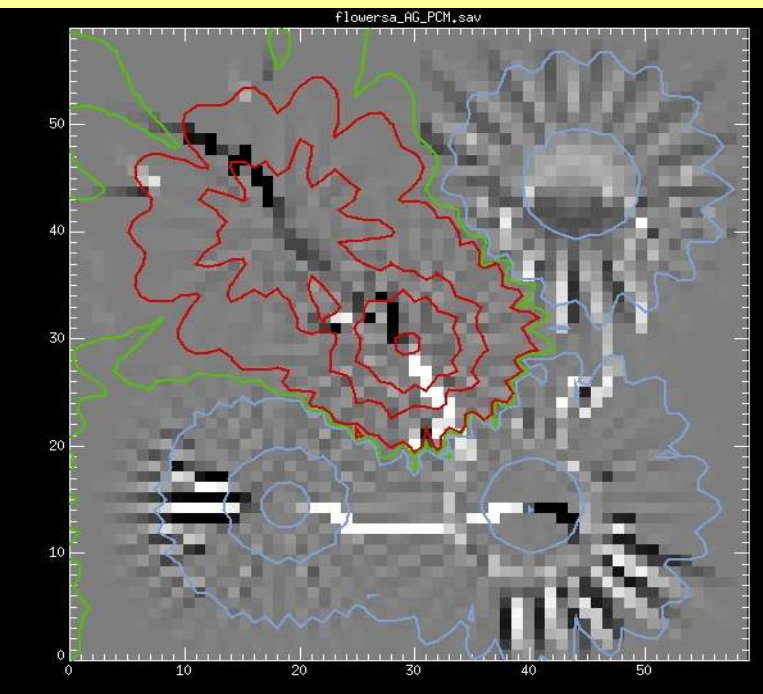
Believe it or not, this is a potential field construct!



Case 2: example results as indicated by consistently-scaled maps of J_z
bin 20 (1" resolution) bin5 (0.2" resolution)



Magnetic
Pressure
Gradient



Pseudo
Current

Recall: original
resolved model
is *potential*.
NO CURRENTS