# Photospheric *vs*. Chromospheric Magnetic Field Measurements

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***Brought to you through funding by AFOSR and NASA***



or, do

# Old Questions + New Data = Any Answers?

**Old Questions:**

- What is the solar coronal magnetic topology above active regions?
- How is energy stored in the solar magnetic field ?
- How is energy then released in Energetic Events?

**New Data:**

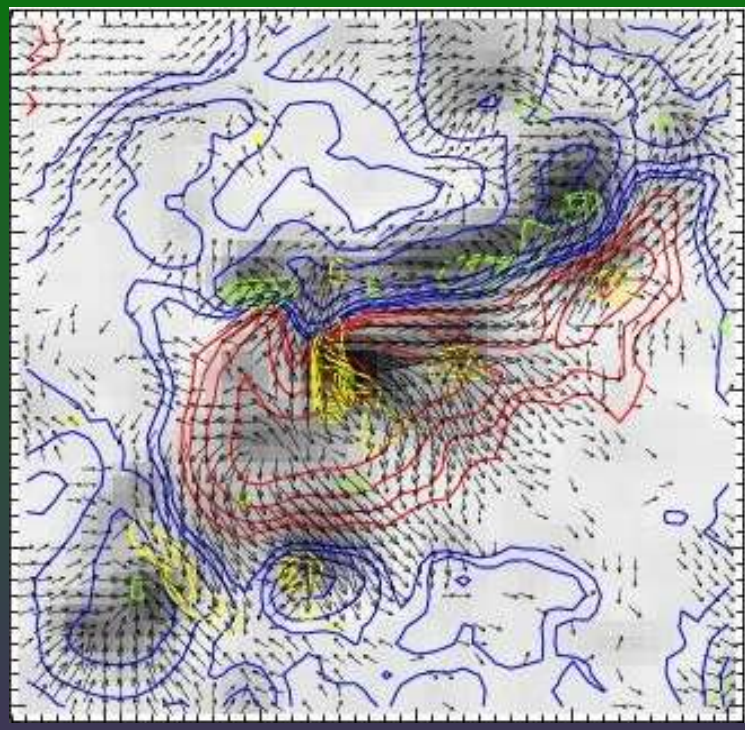
at SHINE '03, Tom Metcalf and I were given a challenge as we remarked that

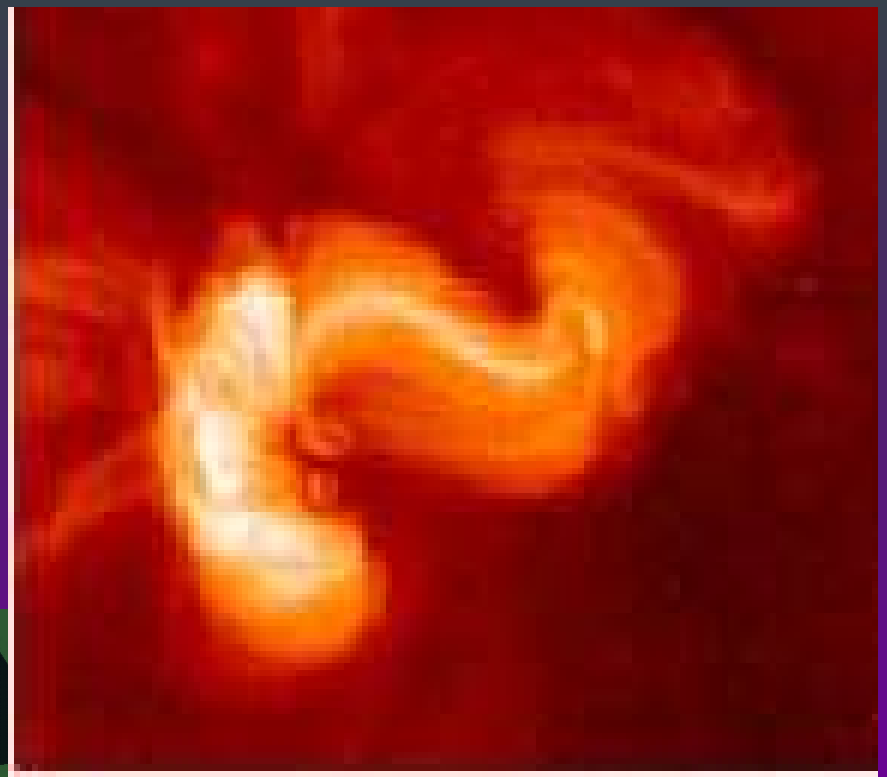
- chromospheric vector magnetic field measurements would provide an important step to answering those questions, and
- were about to become routine:

***Ok, let's see it!***

# Present Situation re: Determining 3-D Magnetic Field:

- Cannot (yet) measure coronal ***B*** routinely (only in limited circumstances).
- Oft it is assumed that the morphology of coronal brightness is related to the magnetic field (field lines, separatrix surfaces, *etc*.)
- Use observed magnetic boundary (e.g., photosphere, generally) and a range of assumptions to perform numerical integration and determine the 3-D magnetic field.





Problems:

- Photospheric magnetic field is forced:

  **J x B .ne. 0.**

- Thus, applying force-free extrapolation techniques is inconsistent with state of the boundary.
- Forced/force-free issue present whether using a linear (constant-a) or non-linear extrapolation.

## Why *else* do we want chromospheric *B* measurements?

- **With *B*(z), additional information is available for ambiguity resolution in observed B_trans (a *required* step to physical interpretation of *B* measurements!)**
- **Direct measure of magnetic free energy is available.**

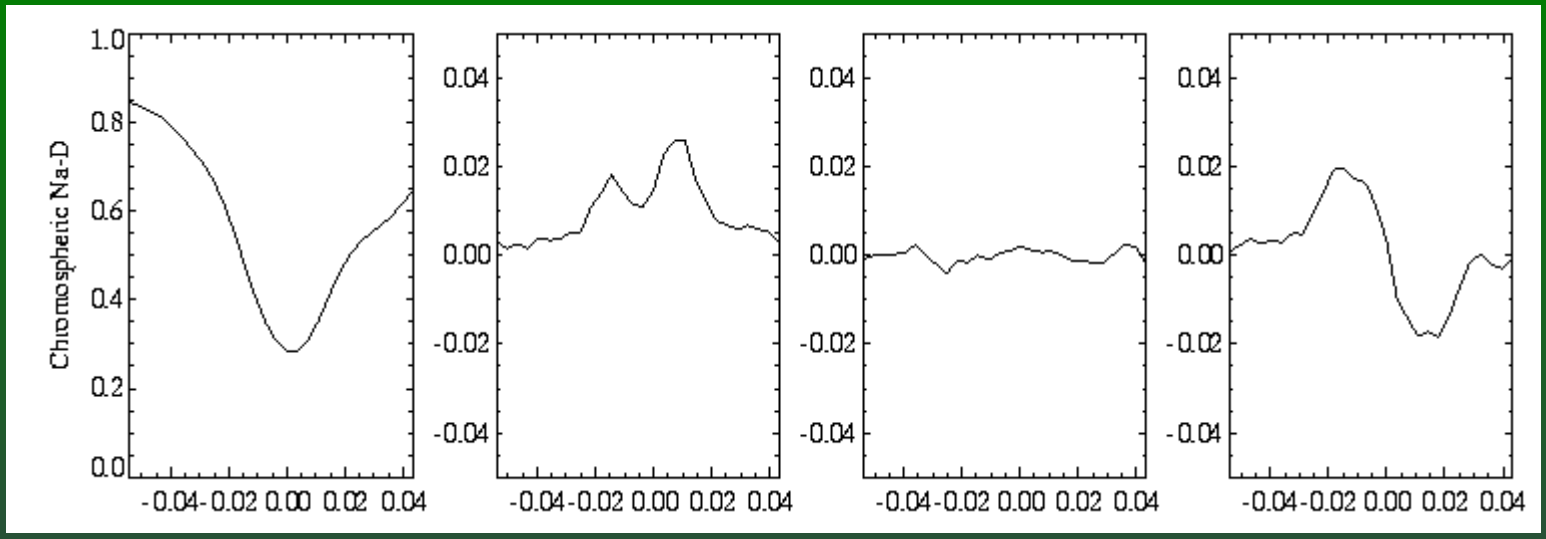
## Why has it taken us so long?

- Measuring the chromospheric magnetic field is *hard*: field is intrinsically weak, chromospheric spectral lines are broad and less magnetically sensitive. Add in NLTE and chromospheric inhomogeneities, and finding the "answer" is difficult.
- Na D-lines better than some other chromospheric lines, and TRM has investigated the JLS inversion method used and its suitability. By no means perfect, but "good 'nuf for now"
- Lack of person-power and funding. Very encouraging to hear "measuring chromospheric fields" mentioned for DASI, for example. Still, we have a lot of data ***now***, and it's coming ***fast***. See Tom/myself for research opportunities.

# Imaging Vector Magnetograph, Mees Solar Observatory, U. Hawai`i

- Imaging Spectropolarimeter: obtains images in a magnetically sensitive spectral line to create *(x,y, ,P)* data cube
- Full dataset obtained every 1—2 minutes; averages performed to 5—15 min, depending on S/N required.
- Large, active-region-sized field-of-view, 0.55'' pixels critically sampling 1'' spatial resolution.
- Data cube is then processed and fed into one of various inversion procedures and 180deg ambiguity-resolution algorithms to produce *B(x,y)*
- Photospheric observations have been routine *(630.25nm FeI)* since 1992.
- Autumn 2003, *years* of thought & labor (& money!) paid off: filter wheel installed so spectropolarimetry in different lines possible *with minimal delay*.
- Chromospheric *vector field* observations in Na-I D2 line (589.6nm) are now routine.

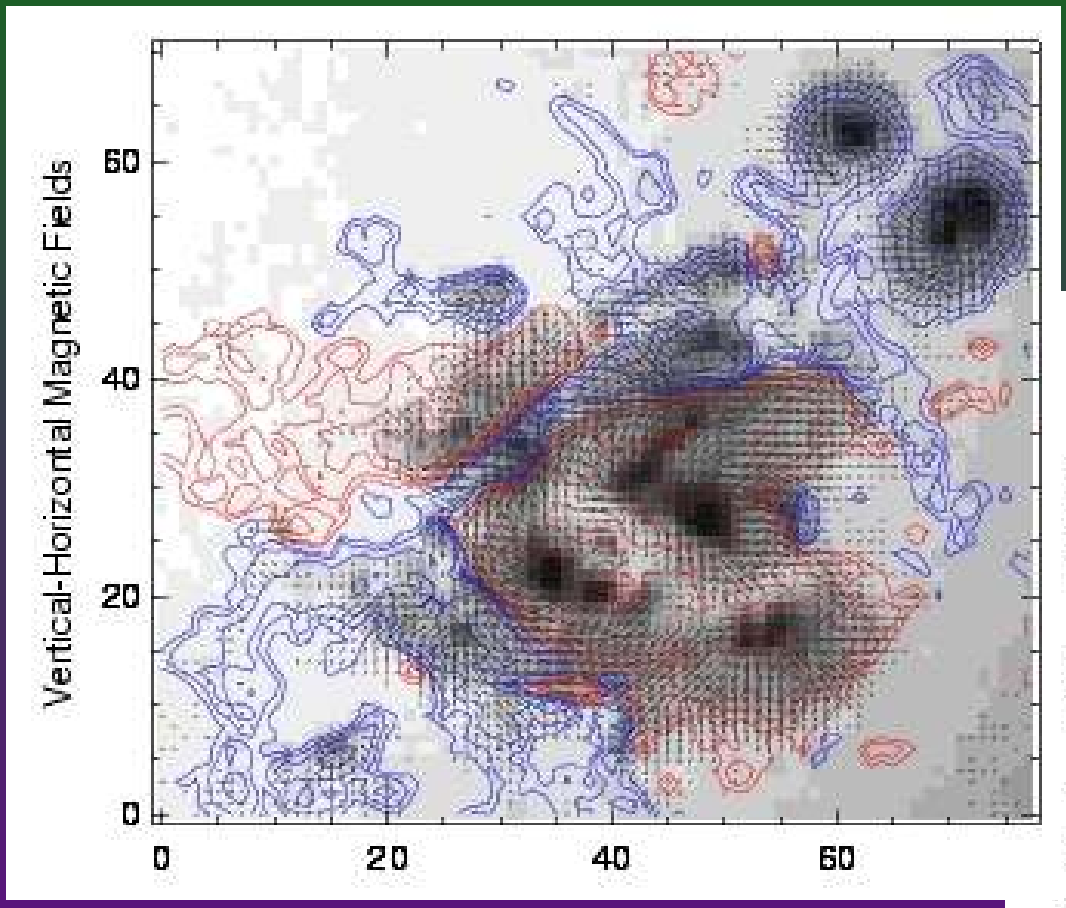
## A Few Details:




- g(effective) = 1.3
- Na-I lines are very broad: JLS-scheme inversion performed @ 68 mA from line-center, away from the worst of the line-core, but still in the chromosphere where the field is force-free. [Metcalf et al 1995]
- Height of formation (semi-empirical and models) is 600-1000 Km above Fe-I 630.25nm photospheric line (not a 100% settled issue yet...)
- Noise in chromospheric ***B:*** 25-50 G (B_long), 200-300 G (B_trans)
- (*cf.* photospheric observations: 10-25G (B_long), 100-150G (B_trans)).

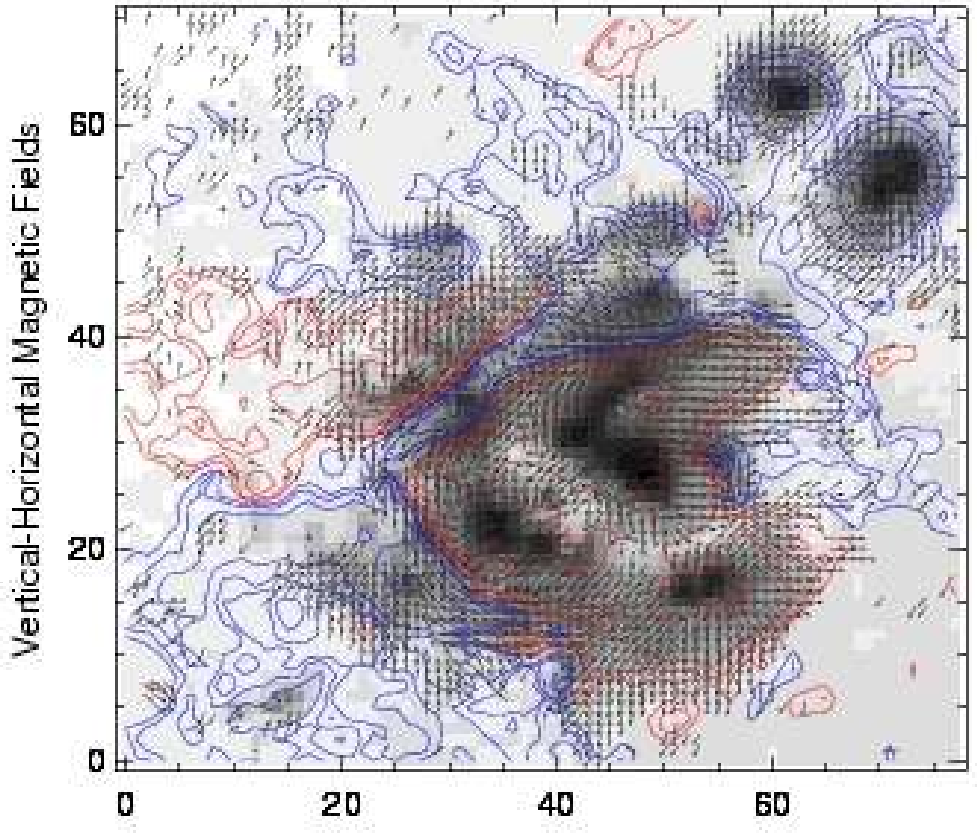
**NOAA AR 10486, 29 October 2003** (almost IVM Na observations' "First Light")

- 2680 millionths in size, Fkc/ group, S12 W04 ( = 0.96)
- Photospheric 'gram @ 1712 UT; Chromospheric 'gram @ 1846UT
- C7.8 @ 18:10UT, X10.0 @ 20:37UT

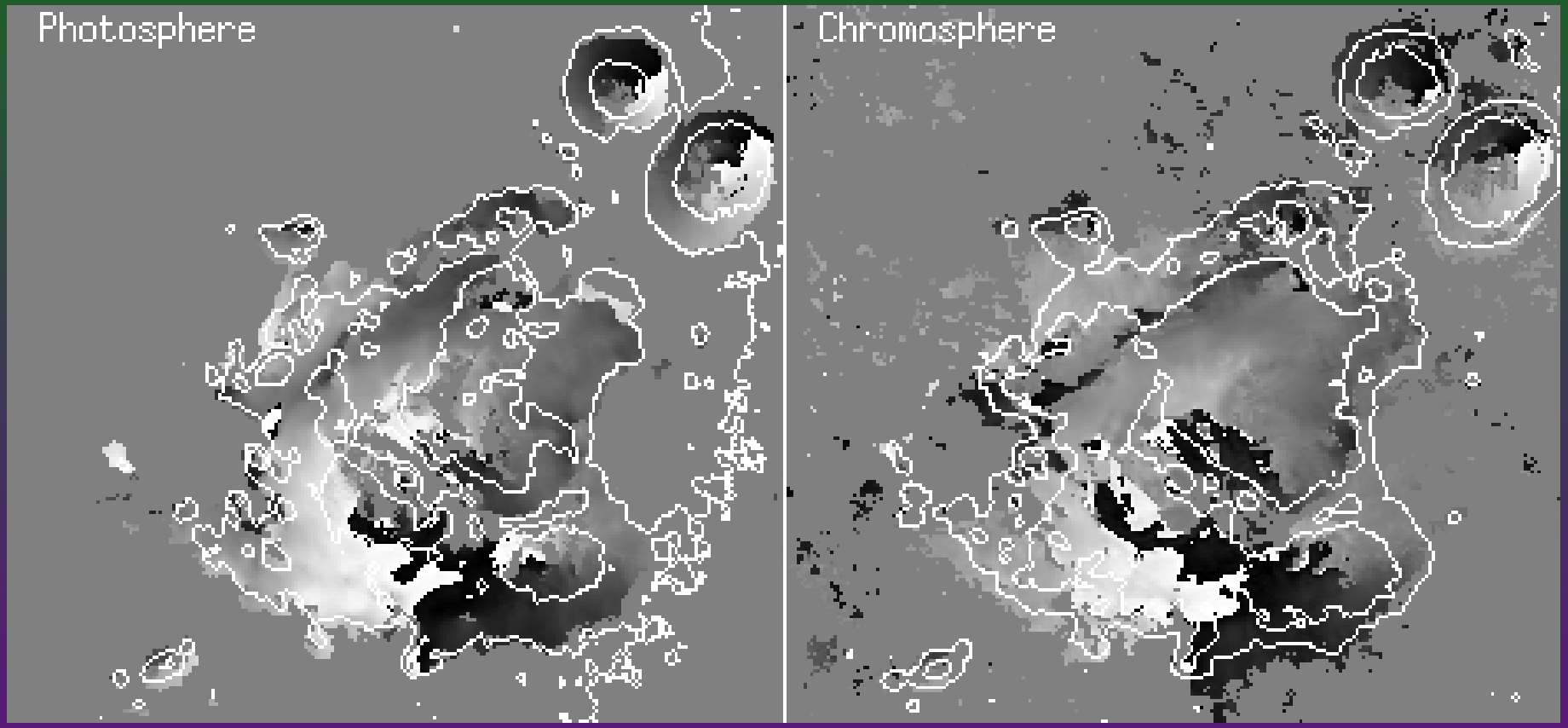



*photosphere*

*chromosphere*



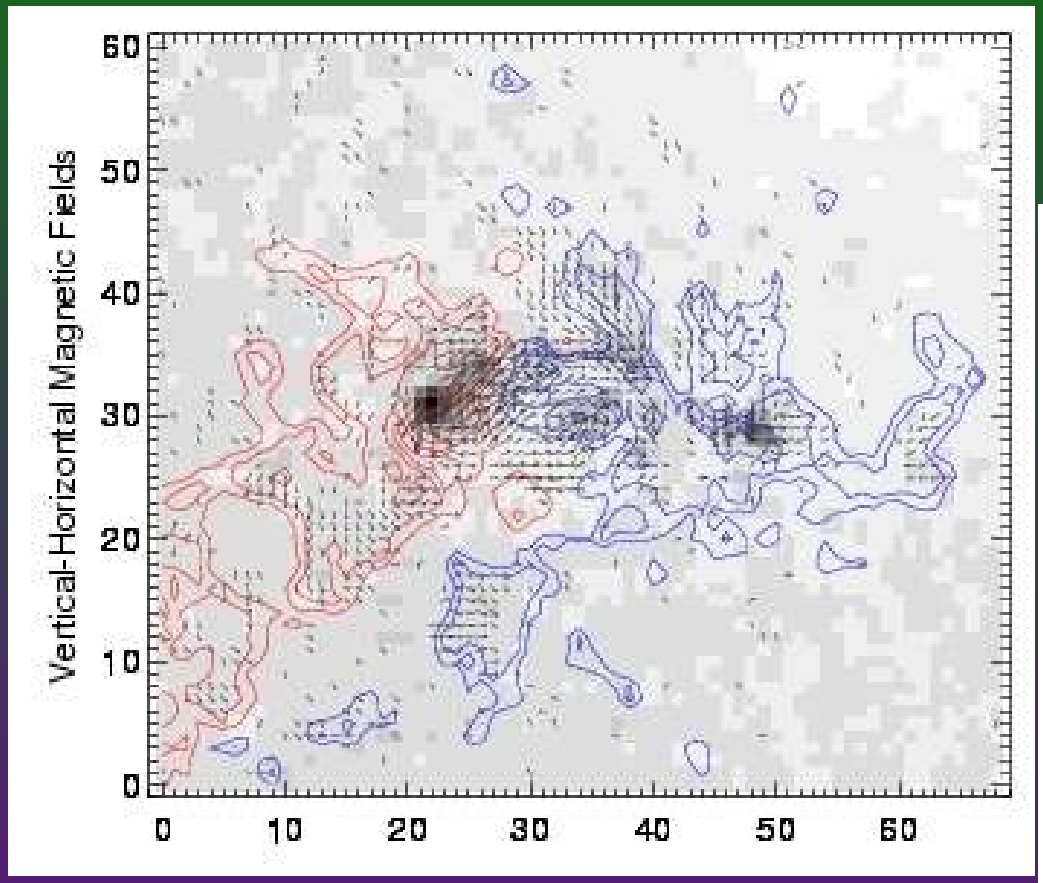
# Hot off the presses: Azimuthal Comparison for 10486




It's pretty durn similar....

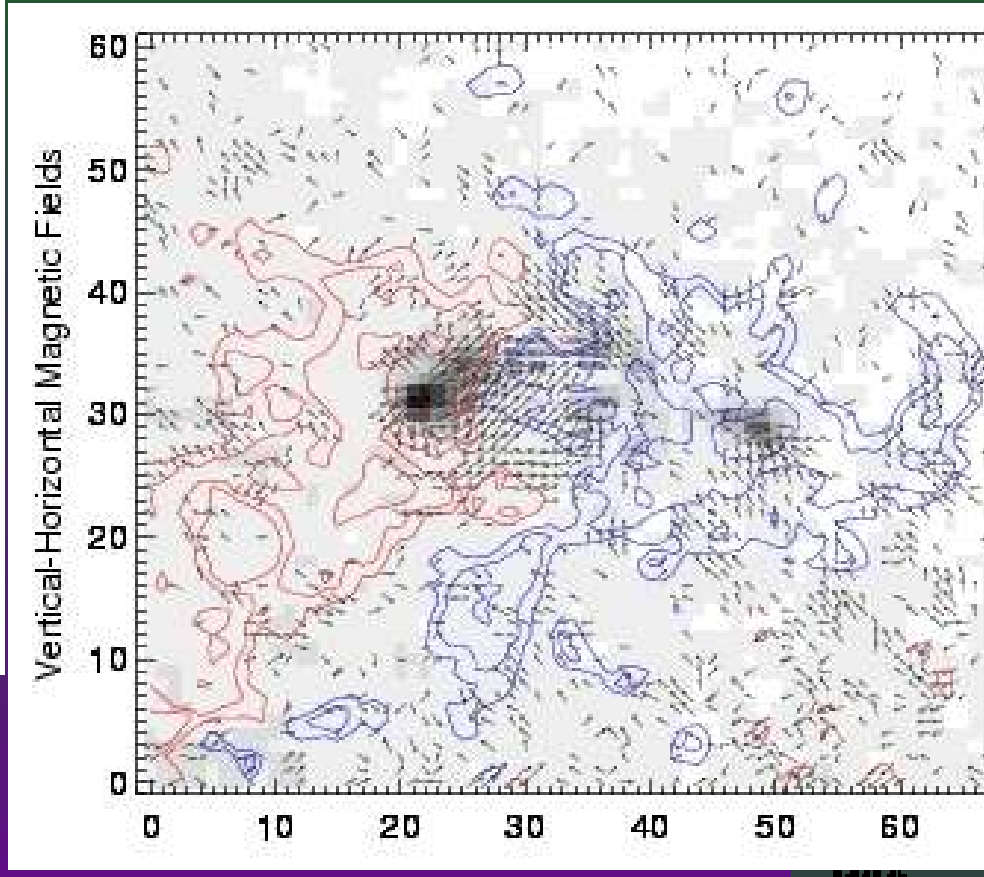
For comparison: **NOAA AR10621, 02 June 2004**

- 60 millionths in size, Dao/ type, E12 S15 ( = 0.95).
- No energetic events.



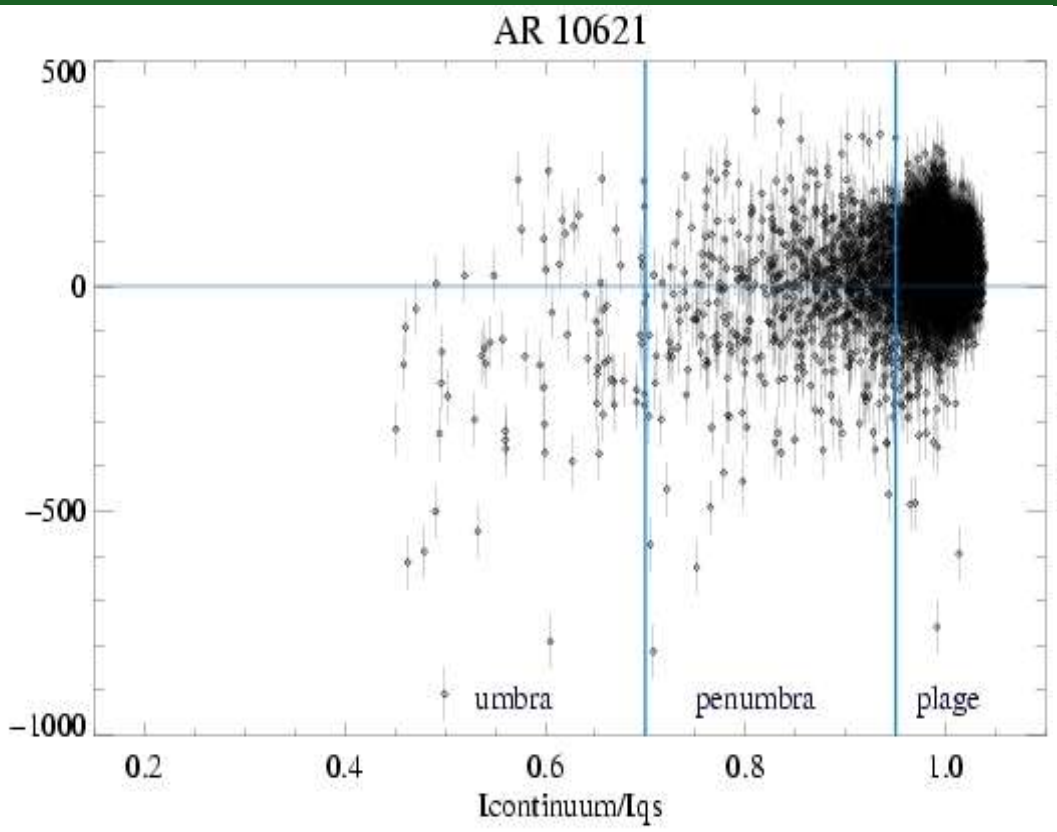

*photosphere*

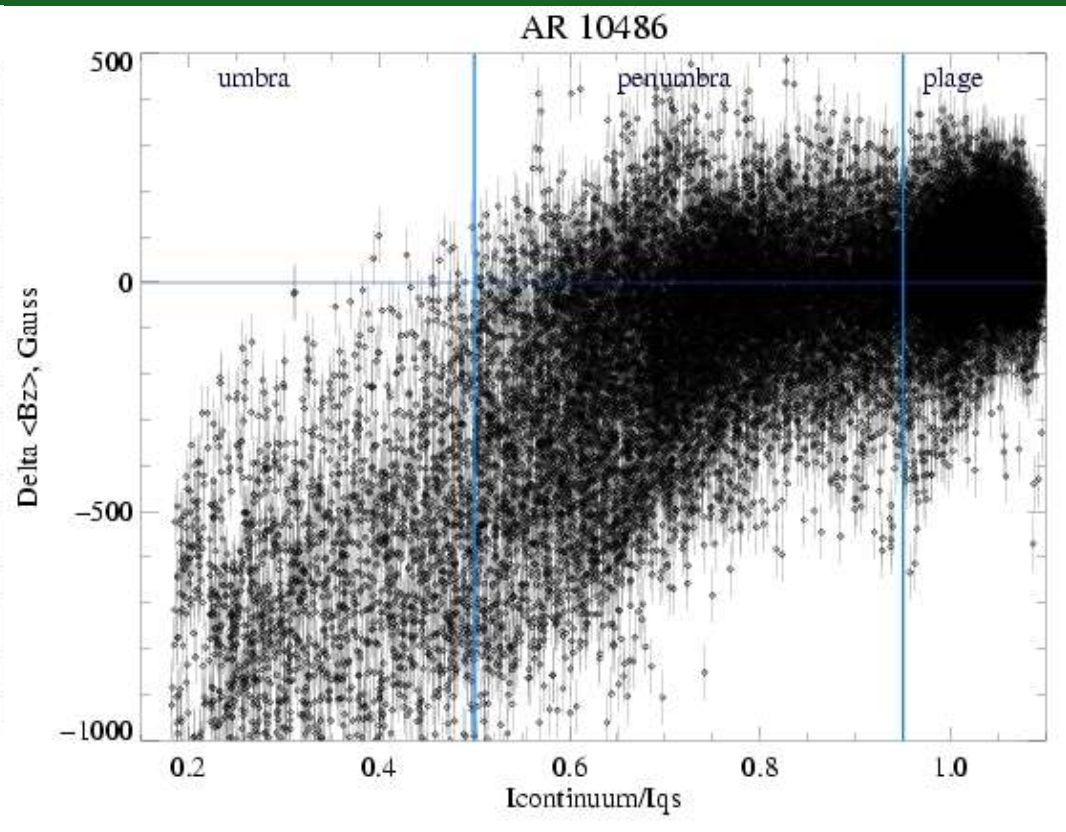
*chromosphere*



What can we do, #1: **Quantify d*B*/dz.**

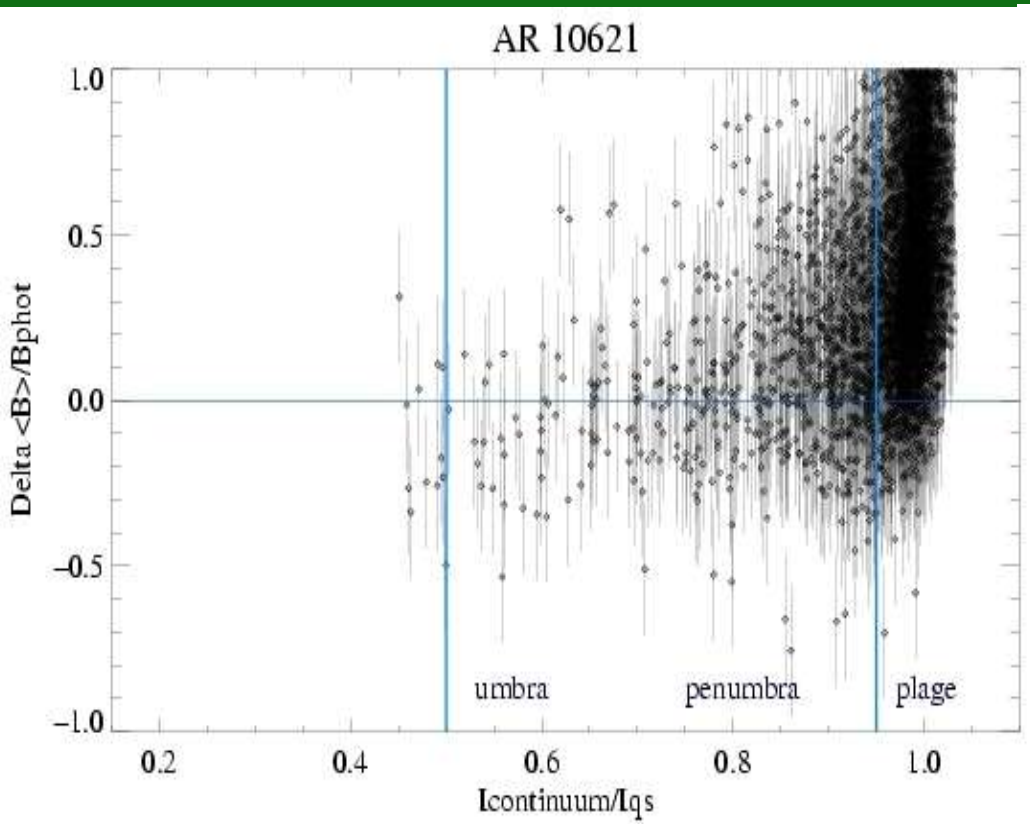
**Provide basic understanding of magnetic structure of active regions.**

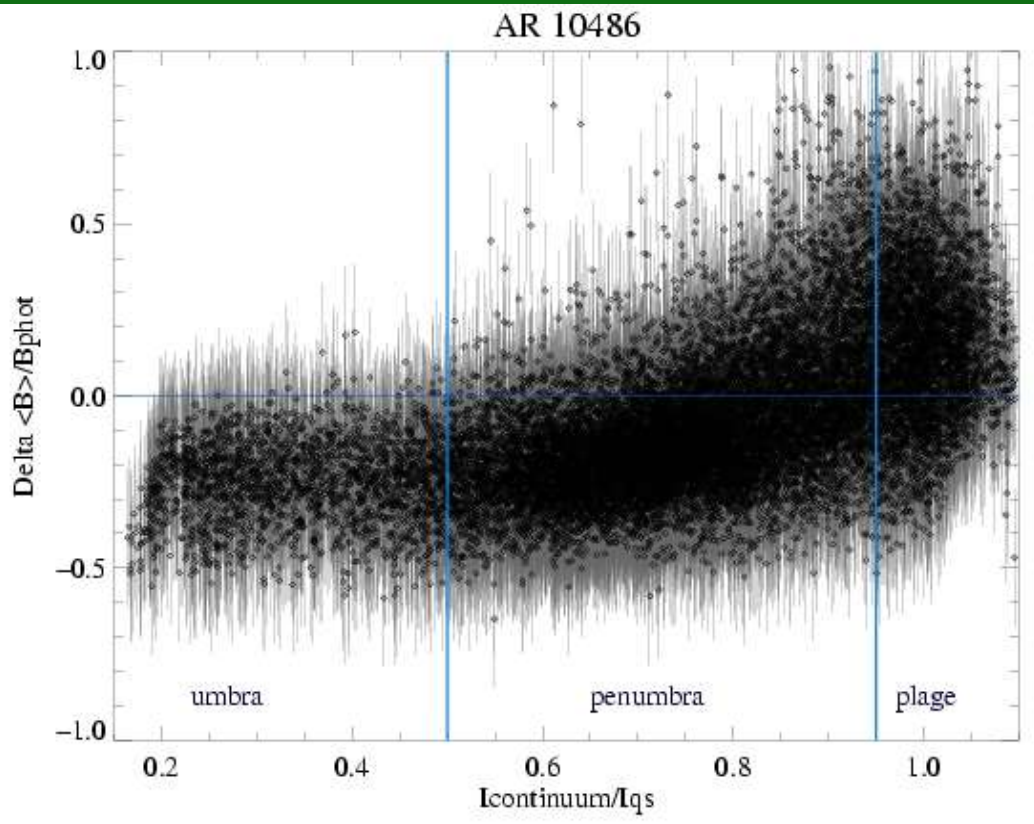



**Plotted: Normalized Continuum intensity (1.0 = QS) *vs.* Bz (G)**

# Plotted: Ic/Iqs *vs* |B| / |Bphot|



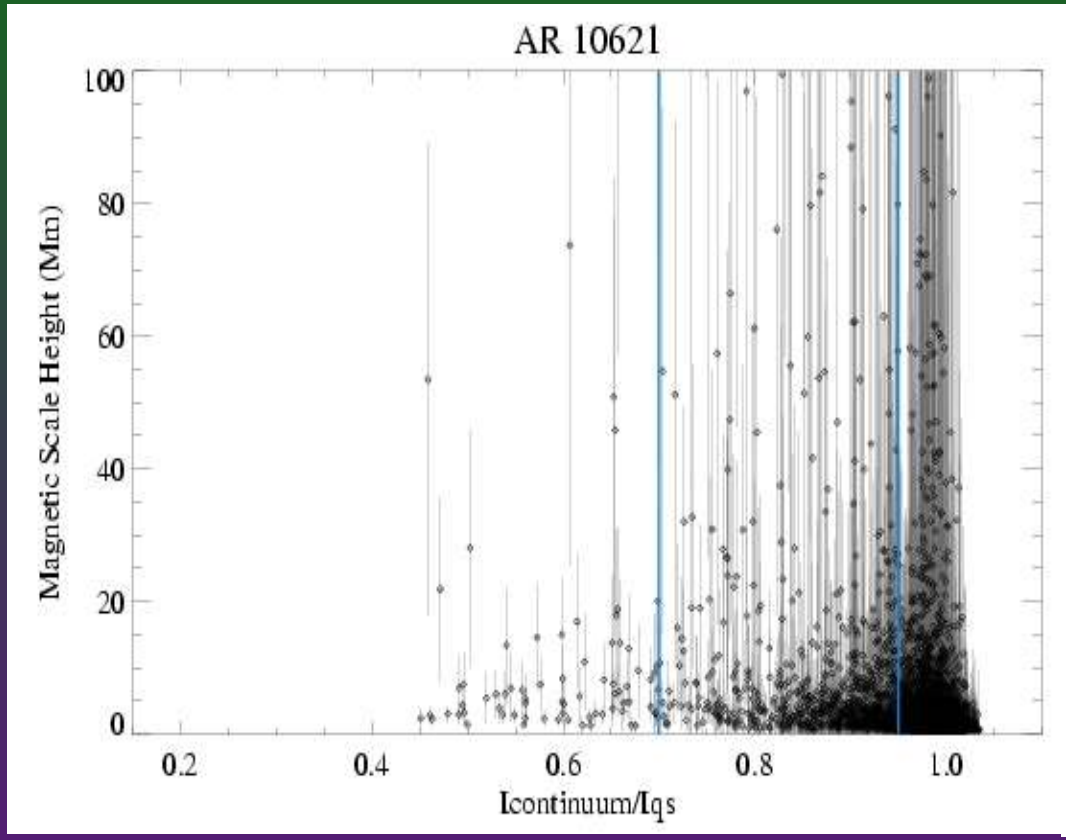

## Results: consistent with earlier studies

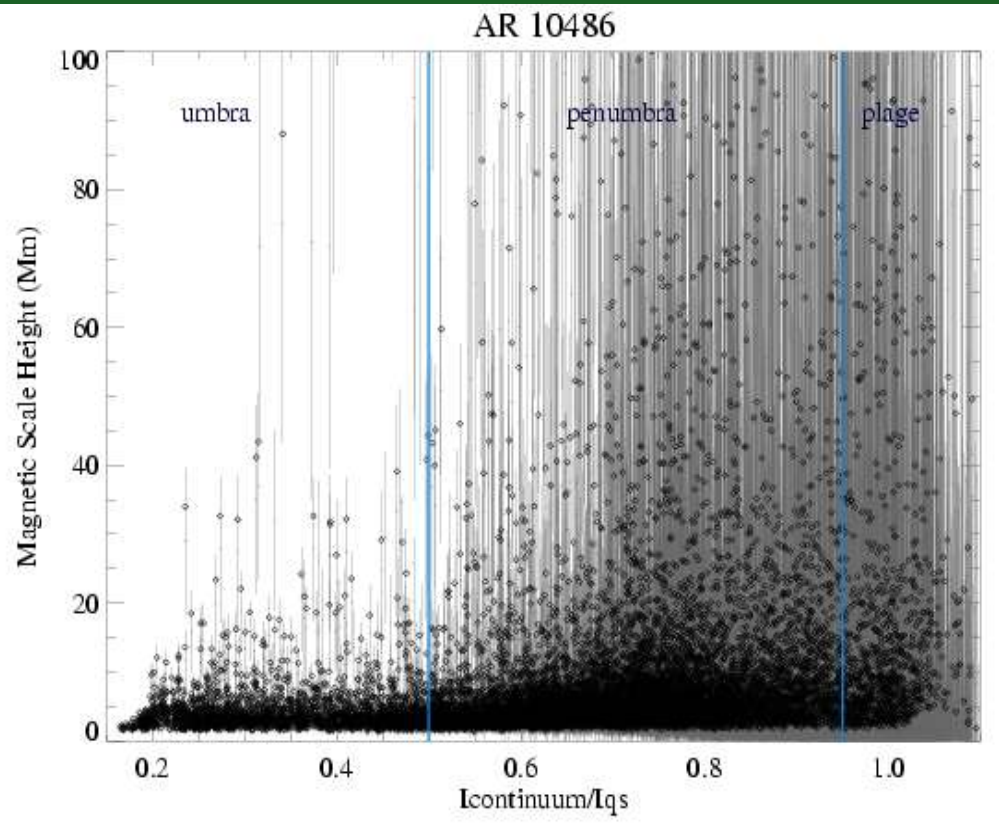
- Consistent fractional change in umbrae, but wide variation in penumbra and plage.
- Direct detection of super-penumbra and canopy
- Intriguing self similarity between small/large regions?

# What we can do #2: **Magnetic Scale Height**

**(More) basic understanding of magnetic structure in sunspots.**

**Plotted: |B(phot)| / ( B/ z), (Mm)**

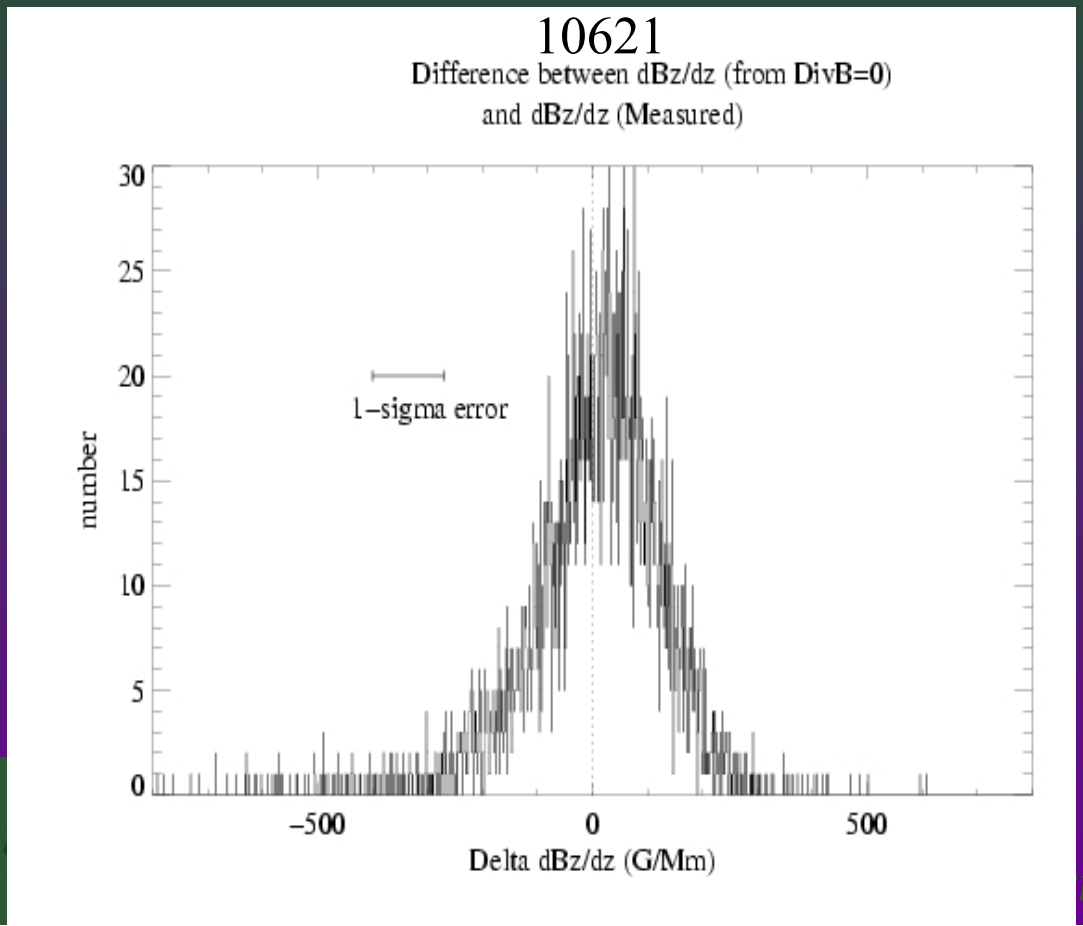


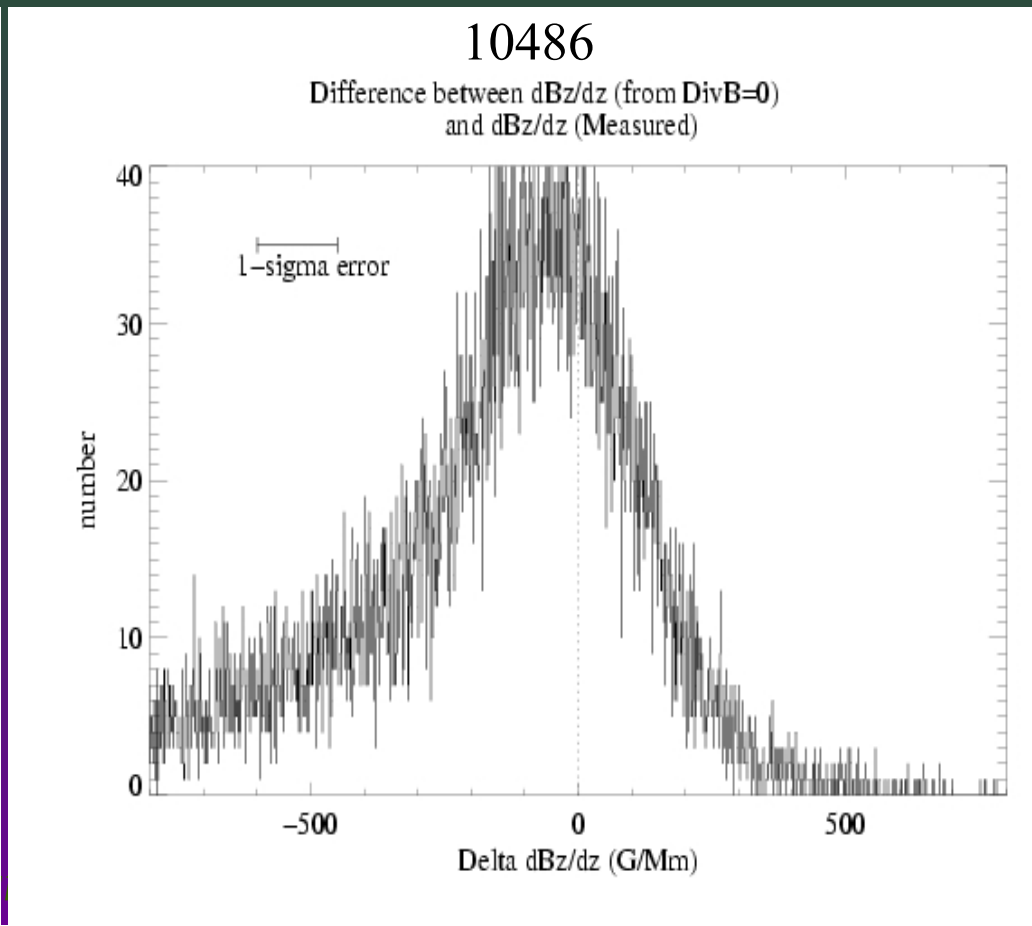




**Again, consistent with earlier studies showing dramatic change between umbral and penumbral regions.**

# What can we do, #3: **Measure Div B, Compare to Zero**

- **Often minimized for 180deg ambiguity resolution.**
- **Now with *B(x,y)* at multiple heights, this information can be used (for multiple-height observations and as test-cases for single-height algorithms.* [not done yet – but just got funding to work on it! Thanks, NASA/LWS!]**
- **Plotted: difference between dBz/dz (from DivB = 0, photosphere) and z/ z (straight difference). Expect this to be centered at 0.**



## What we can do #4: **Determine magnetic free energy**

**Magnetic virial theorem: only applies if field is force-free**

**AR 10621:**

- Ef: 4.30 +/- 4.02 x 10^32 erg.
- Consistent with zero free energy.
- Simple AR; relatively few points with 3- field
- Consistent w/ lack of activity from this region.

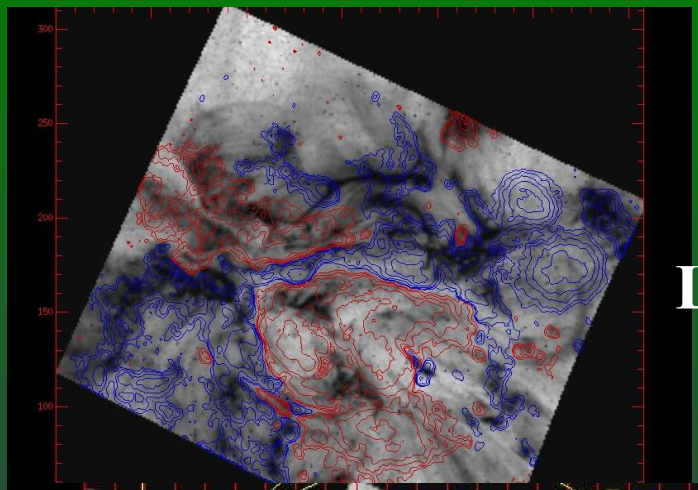
**AR10486**:

- Ef: 8.66 +/- 2.3 x 10^33 erg.
- Very large amount of free energy.
- Large AR; very complicated but adequate 3- fields.
- Consistent with large activity from this region.

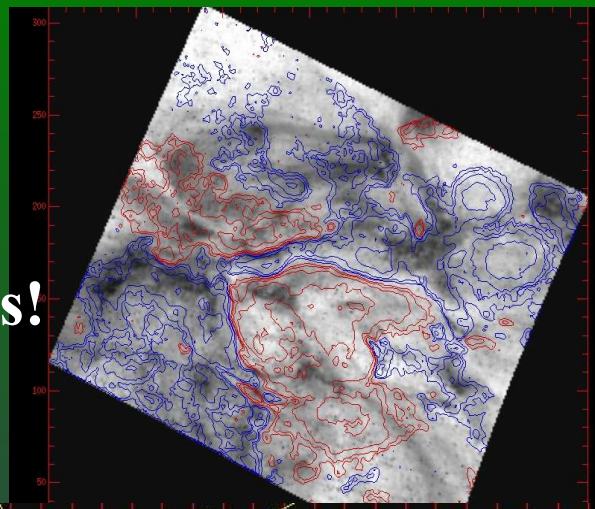
# What can we do #5: Extrapolations.

## AR 10486:

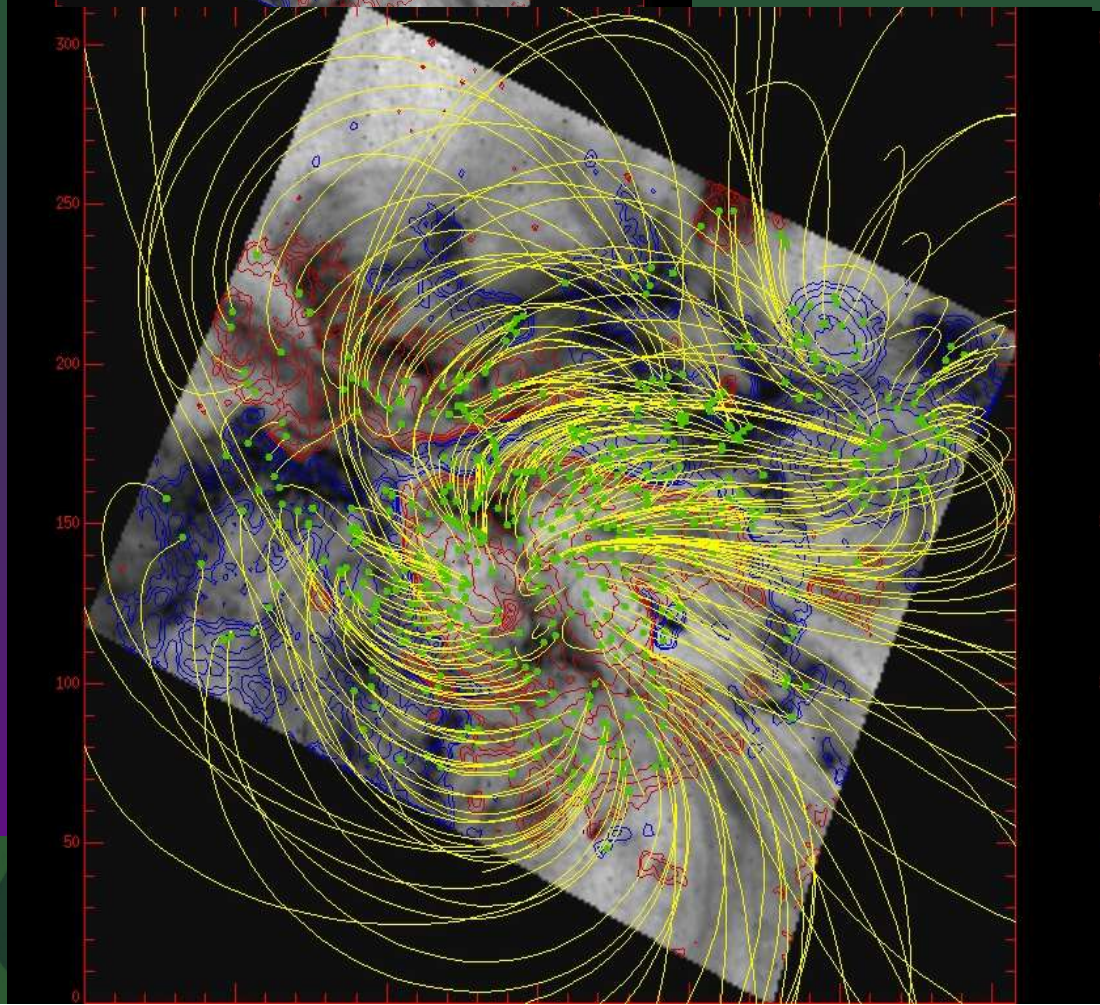
## Let's not start here, it's a mess!

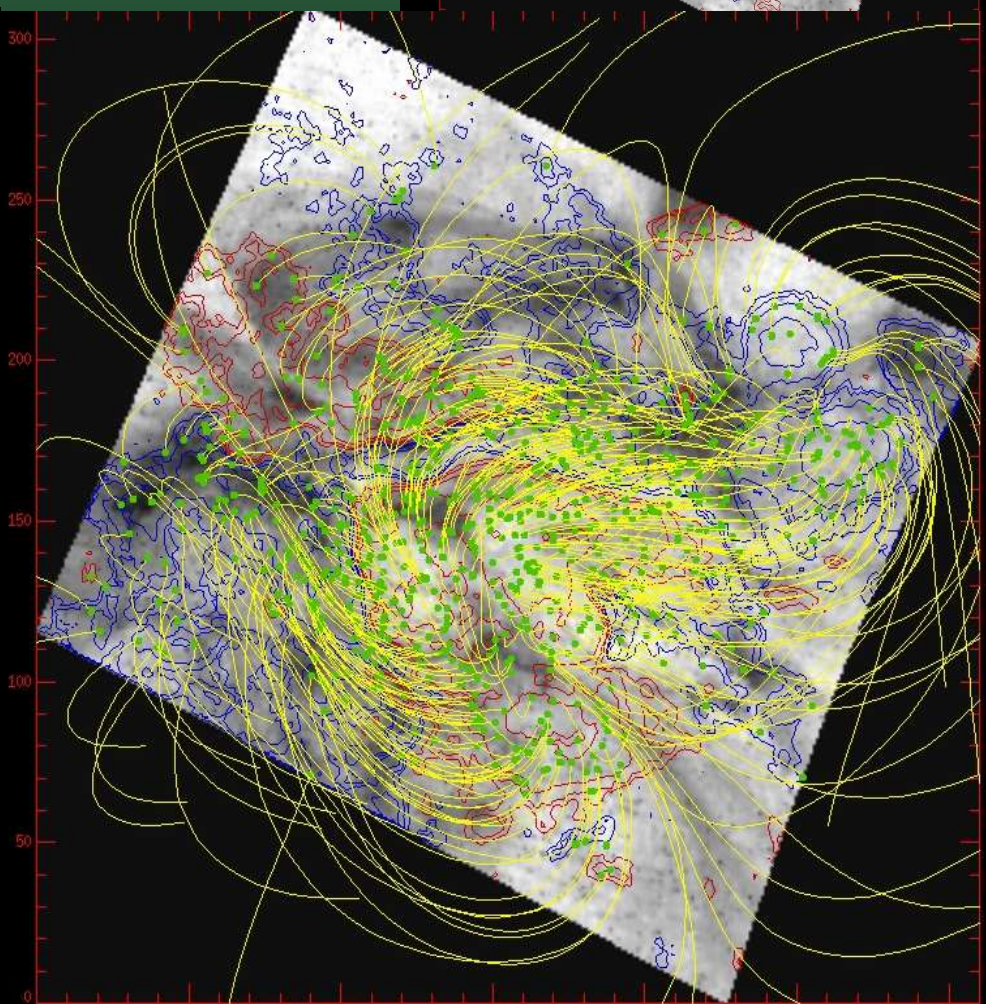


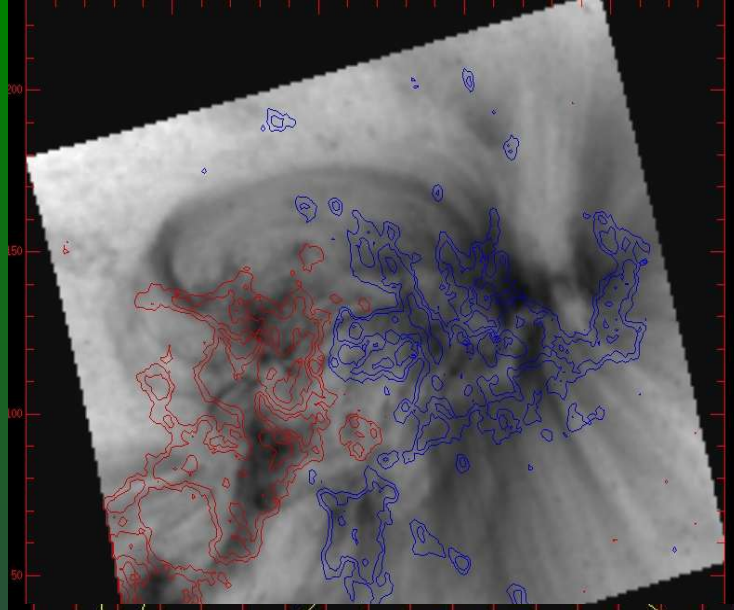
*photosphere*



*chromosphere*

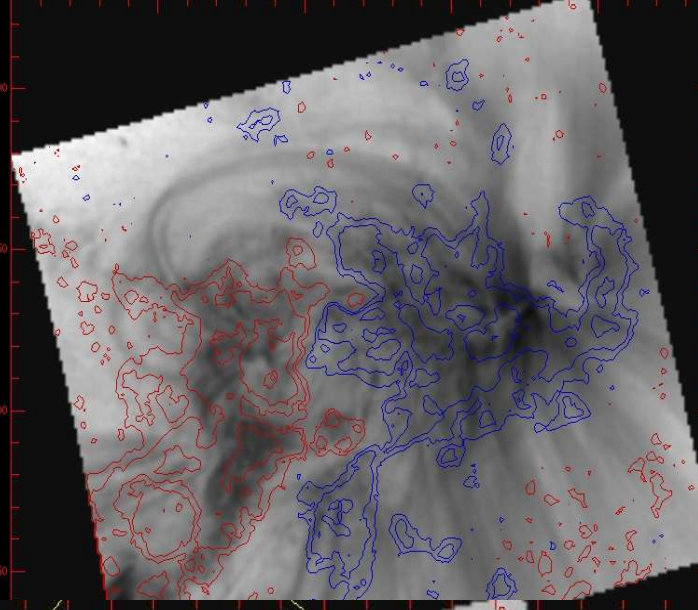


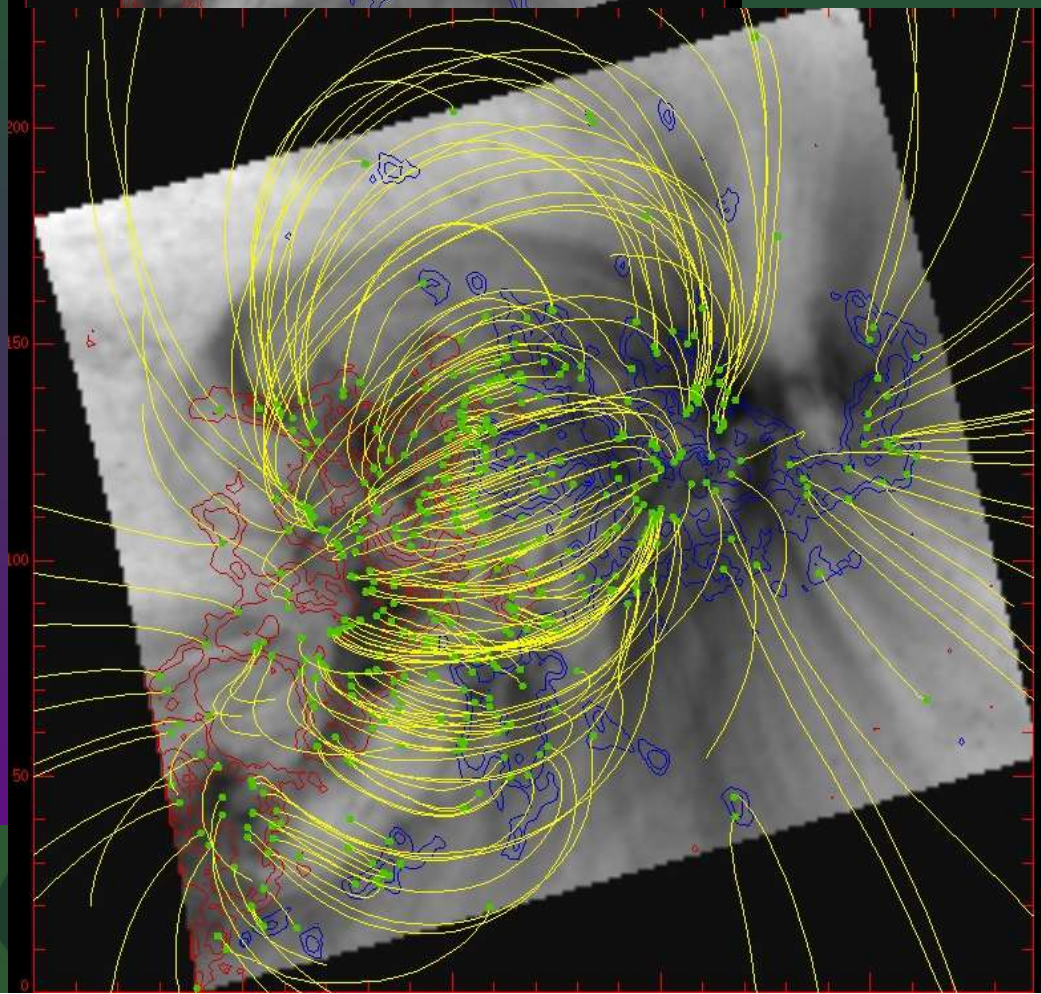


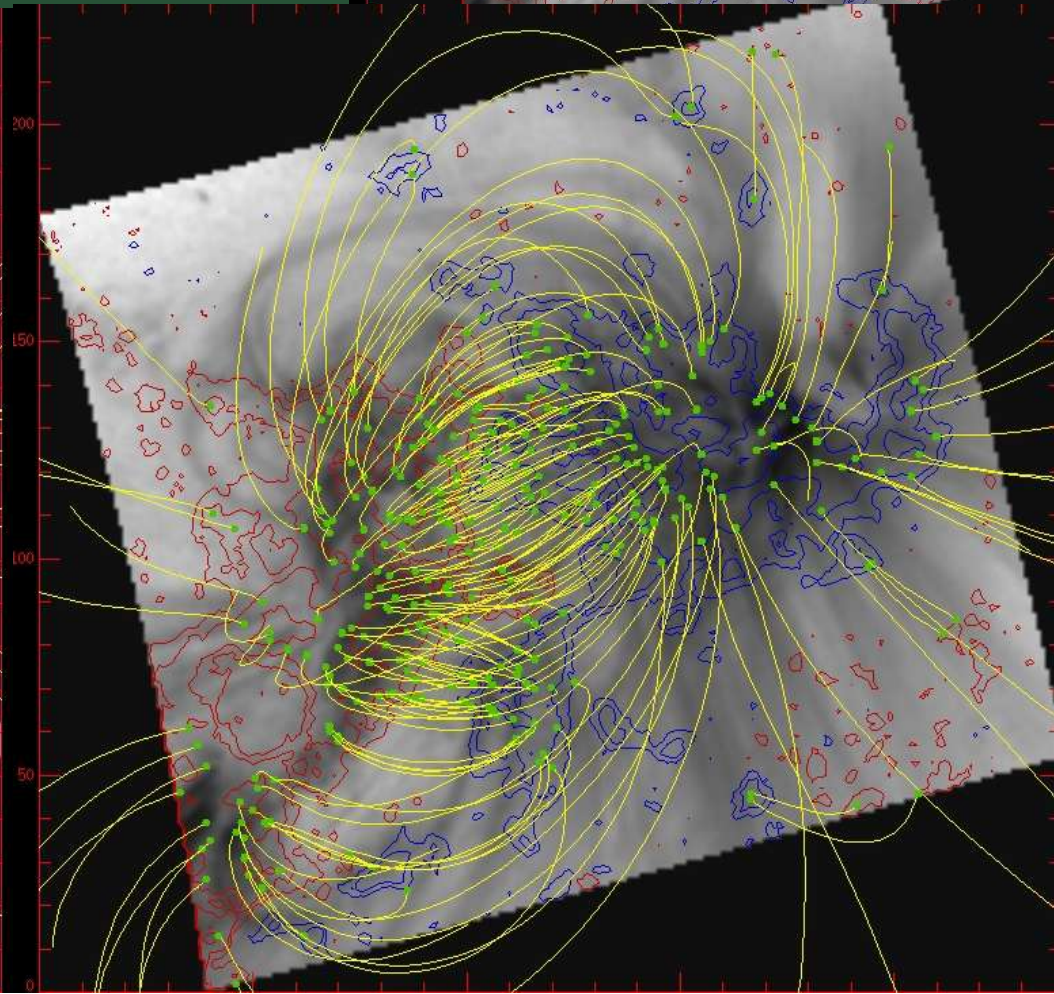


**AR 10621:**
**Simple,**
**isolated on the disk.**
**(too small?)**

*photosphere* *chromosphere*







**Extrapolations:**
**Initial results are inconclusive but very preliminary**

- **AR10486**: eye candy, but too complicated for a good evaluation.
- **AR10621**: simple and isolated, but a very small AR with (too) small photospheric and chromospheric fields.

(Goldilocks is not yet happy....)

- How do you measure "goodness of extrapolation?" What is the extrapolation compared to? [*e.g.*, magnetic connectivity as indicated by coronal loops? The morphology of the field-line tracings as compared to bright coronal loops? Magnetic topology as indicated by magnetic separators? Or....?]

Known limitations of constant- force-free extrapolation methods (see, e.g., poster #49, Barnes *et al*). Applying a non-linear force-free extrapolation is obviously the next step.

## Conclusions:

- **Quantitative comparison of photospheric *vs.* chromospheric vector fields are consistent with both previous studies and expectations from physics. Still, there's a lot to learn here just about basic sunspot physics.**

- **Extrapolations using the two boundaries differ, indeed. Quantitative analysis of how to best *utilize* chromospheric data in order to best *quantify* the coronal magnetic field has just begun.**

- **Chromospheric Vector Field data have been obtained routinely since October 2003*. While uncertainties still exist, this is the *only* instument presently operating *or proposed for the near future* to acquire such a database. You wanted it, you saw it, let's use it!**

*http://www.ifa.solar.hawaii.edu