Another Piece of the Elephant: Chromospheric Vector Magnetic Field Observations

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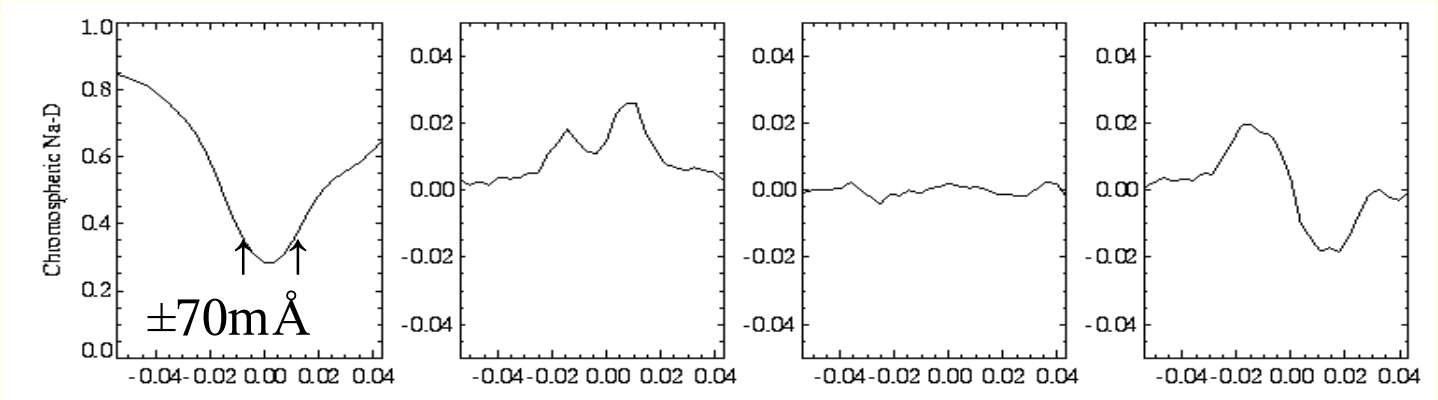
Summary:

- Measuring chromospheric magnetic fields.
- Where are we measuring, anyway?
- Key results regarding sunspot structure.

Measuring the chromospheric magnetic field: Stokes spectropolarimetry:

- Observe both circular and linear polarization in Na D-1 line (589.6nm)
- Inversion procedure: I, Q, U, V spectra → B_{los}, B_{trans}, ϕ
  - "Derivative Method", performed 70mÅ from line center
  - Unity magnetic fill-factor assumed
  - Weak Field Approximation ($\Delta\lambda$ (Zeeman) < $\Delta\lambda$ (thermal)) assumed.

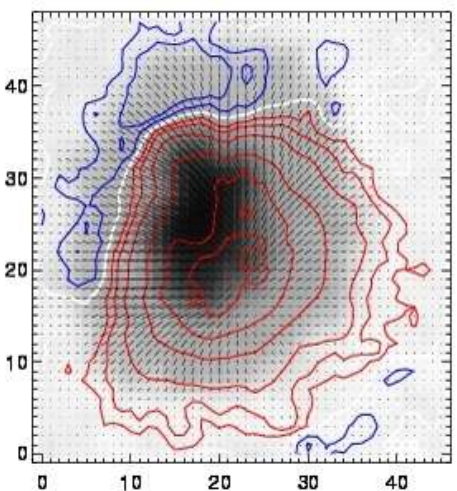
Jefferies, Lites & Skumanich 1989



Stokes I, Q, U, V polarization spectra in Na D-1 line near a sunspot penumbra from the Imaging Vector Magnetograph. X-axis is in nm, y-axis in normalized intensity and polarization fraction.

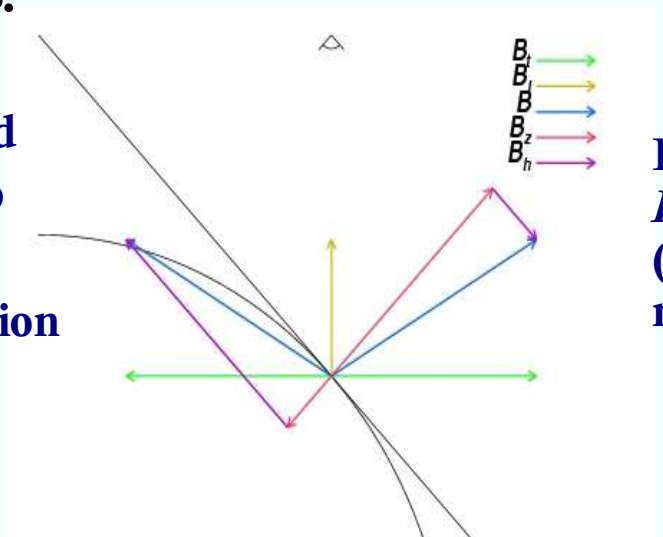
- Ambiguity in B_{trans} solved using "simulated annealing"
  - minimizes divergence and current simutaneously
  - Results in heliographic ***B***.

Metcalf 1995

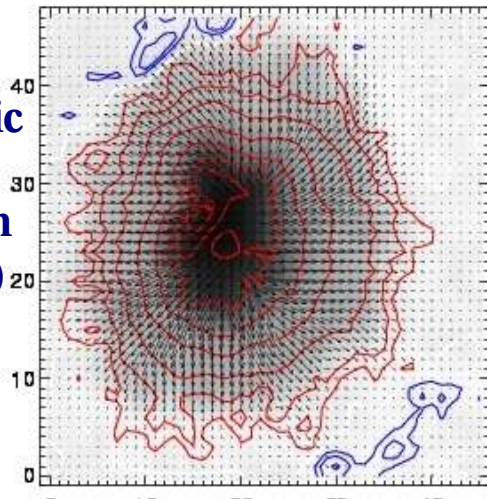


← Observed B_{los}, B_{trans}, ϕ

B_{trans} direction is chosen. →

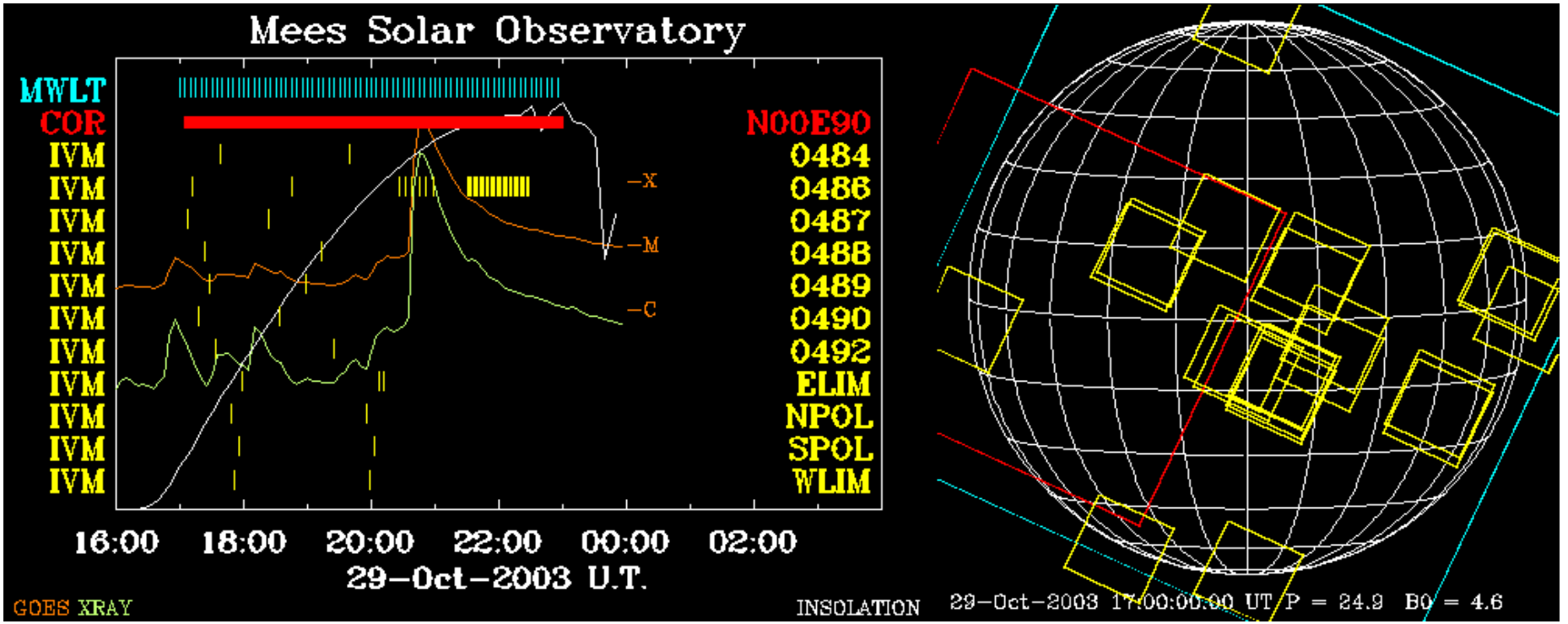


Heliographic *B* results. (note shift in neutral line)

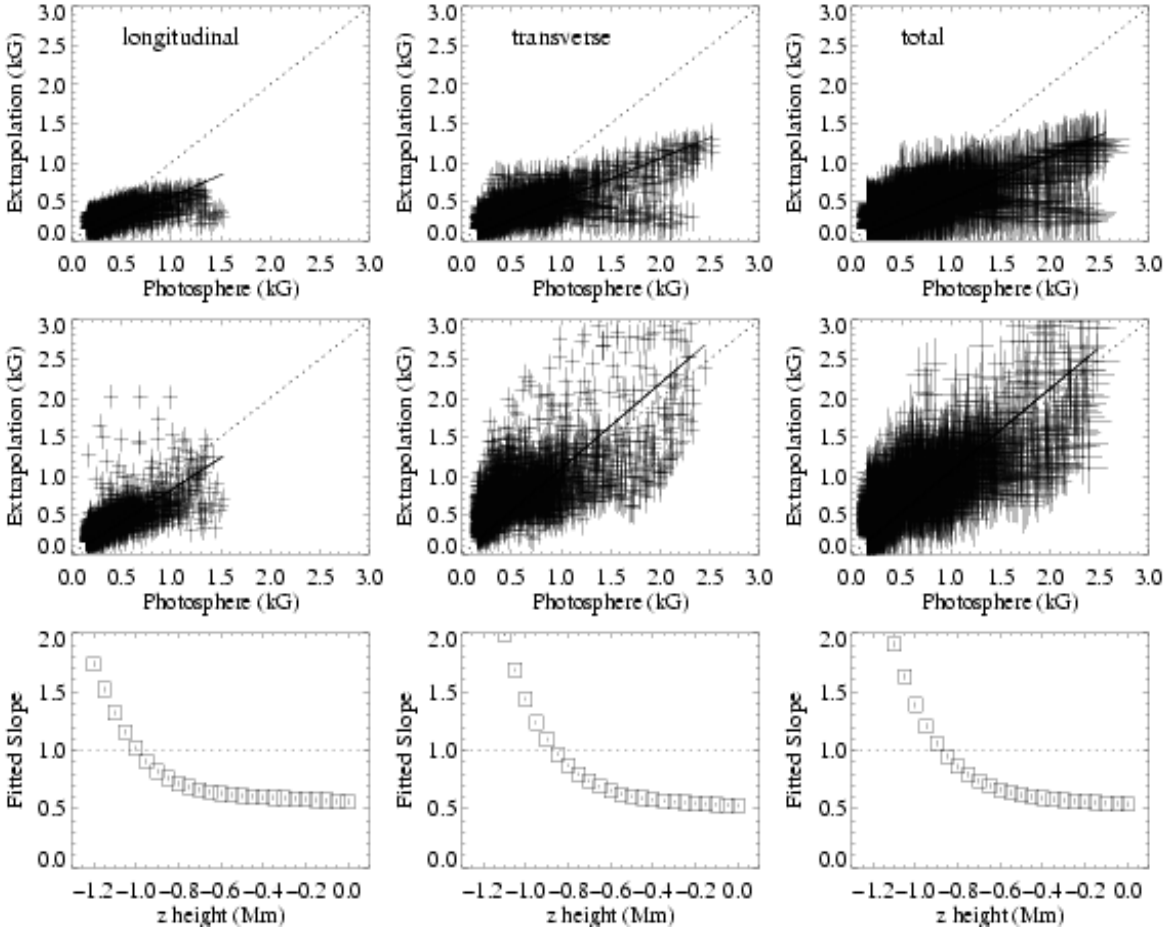


Measuring the Chromospheric Magnetic Field cont'd: Instrument

- Imaging Vector Magnetograph at U. Hawai`i/Mees Solar Observatory
  - Imaging Fabry-Perot system
  - 4' field-of-view, 0.55" spatial resolution, 0.07nm spectral resolution
  - polarization spectra sampled @ 40 positions across Na D-1 line
  - Few-minute cadence
- Routine chromospheric observations began October 2003
  - General observing procedure begins with both photospheric and chromospheric "survey" magnetograms (single magnetograms of every visible active region)
  - Followed by chromospheric time-series observations of Max Millenium target region.
    - IVM down April 2005 -- ?? due to camera problems.



- *Where* are we measuring?
  - Response function is *broad*; spectral bandpass is, too.
  - Single-height (average probably over few x 100km) assumed.
  - Extrapolations between chromosphere, photosphere indicate measures originate *approximately* 1Mm above τ=1 (Δz=0.8Mm above photospheric data).

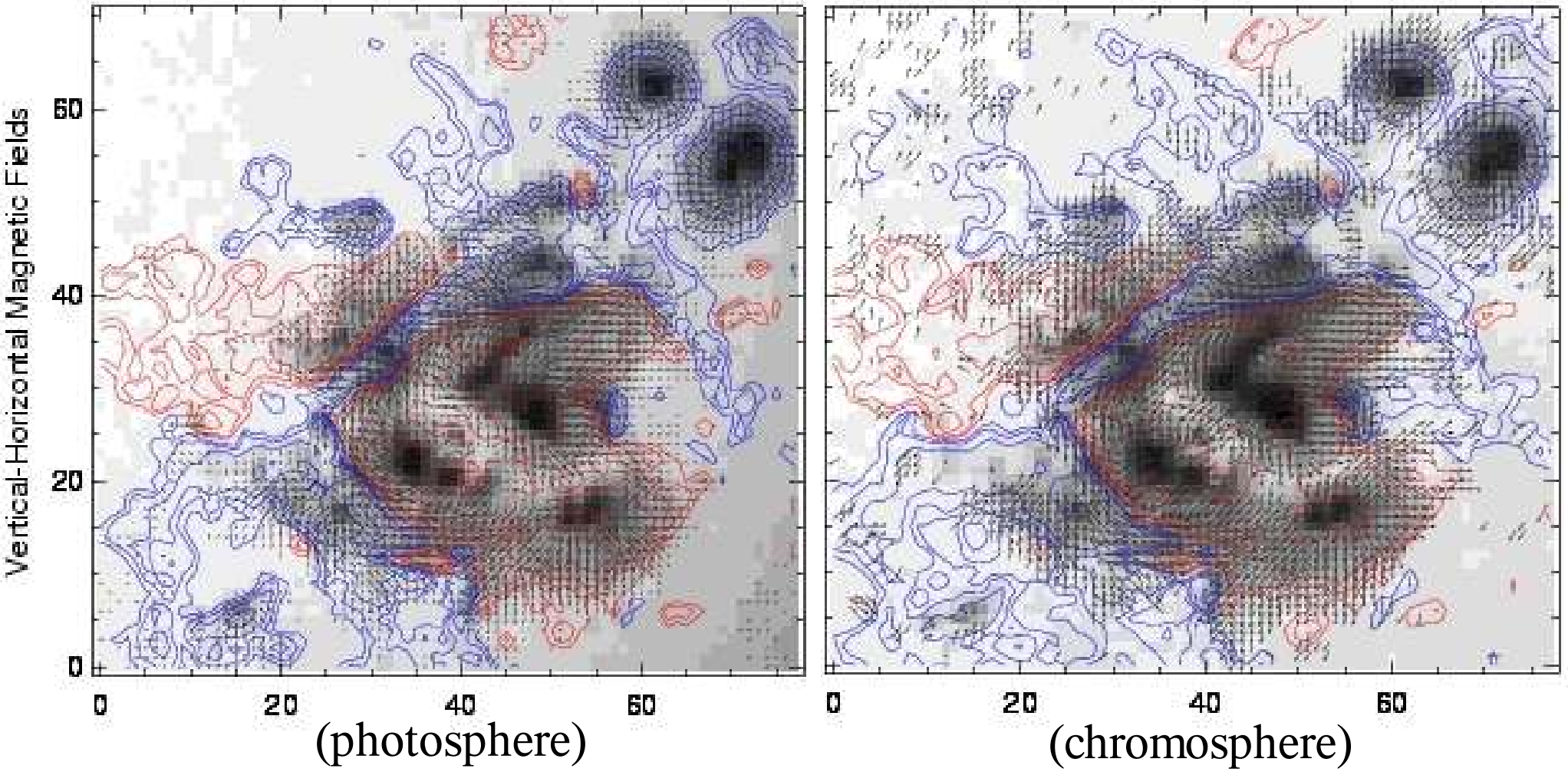


Comparison of photospheric magnetic flux with results of extrapolating the chromospheric magnetic flux *down* to photospheric levels. **Top**: Scatter plots for photospheric data *vs.* chromospheric data for Δz = 0.0 Mm, *i.e.*,for the *original*, non-extrapolated chromospheric data, for (left:right) B_{los}, B_{trans}, and $|B|$; $x=y$ line is also plotted. **Middle**: same, for Δz = 1.0Mm. **Bottom**: The slope derived from fitting a linear function to the scatter plots, as a function of Δz from the chromosphere. All comparisons point toward the best agreement (slope consistently closest to unity) for Δz= 0.8—1.1 Mm. Shown are data from AR8299; adapted from Leka & Metcalf, *Solar Phys.*, 2003.

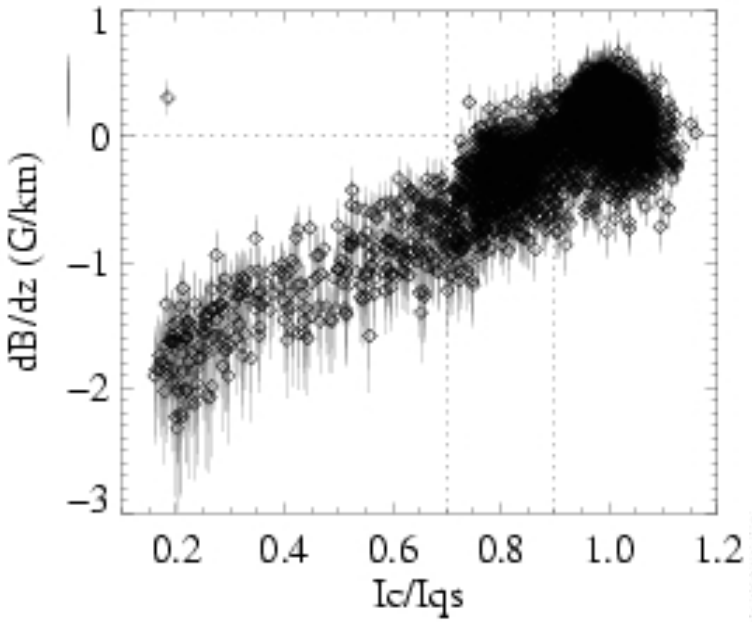
What do we see?

- Qualitatively: same as the photosphere.
  - There is no distinctive feature that is visually tell-tale for the chromosphere except possibly less distinct small-scale structure.
    - Chromospheric data are noisier.

AR 10486, 29 October 2003

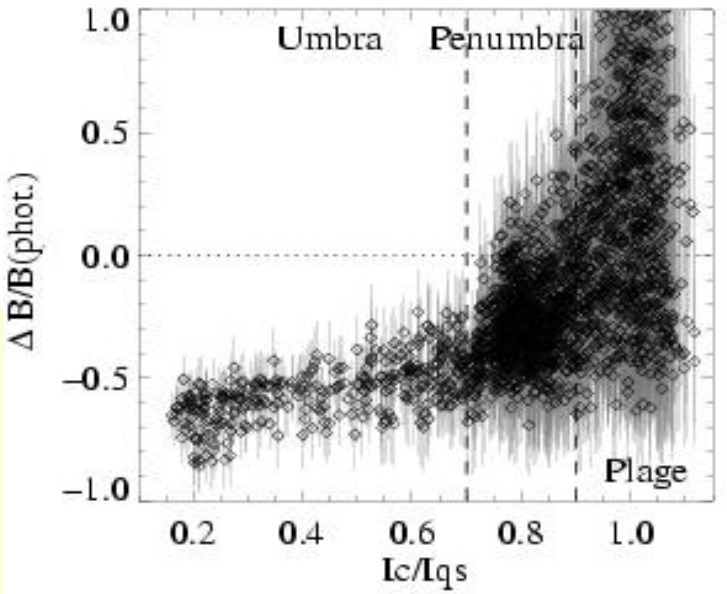


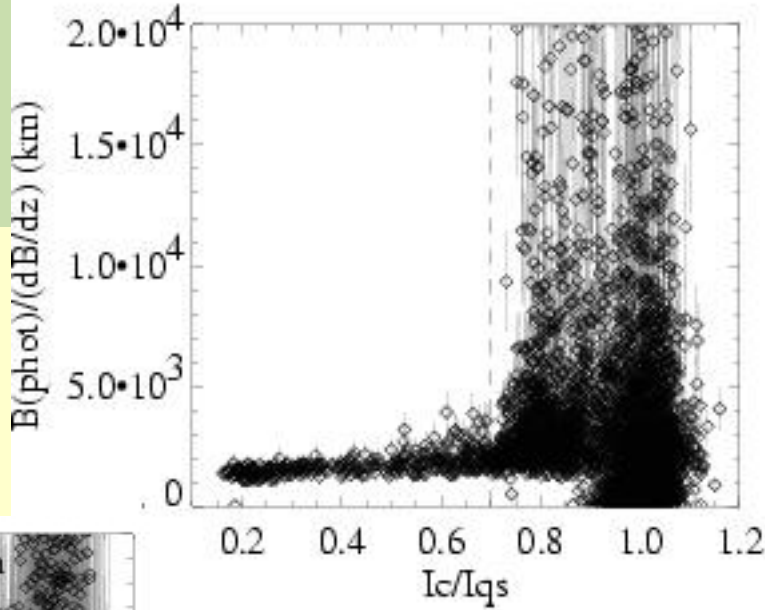
- Quantitatively: systematic structural differences.
  - Umbrae: field strengths decrease systematically; varying dB/dz, but constant percent change and magnetic scale height.
  - Penumbra/plage: less variable dB/dz, however widely varying percent change, implying wildly varying scale heights. Magnetic canopy in outer penumbra also visible (dB/dz > 0).
  - Umbral/Penumbral boundary can be very distinct.
  - Quantitative values depend on observing specifics.



d|B|/dz in G/km as function of normalized continuum intensity

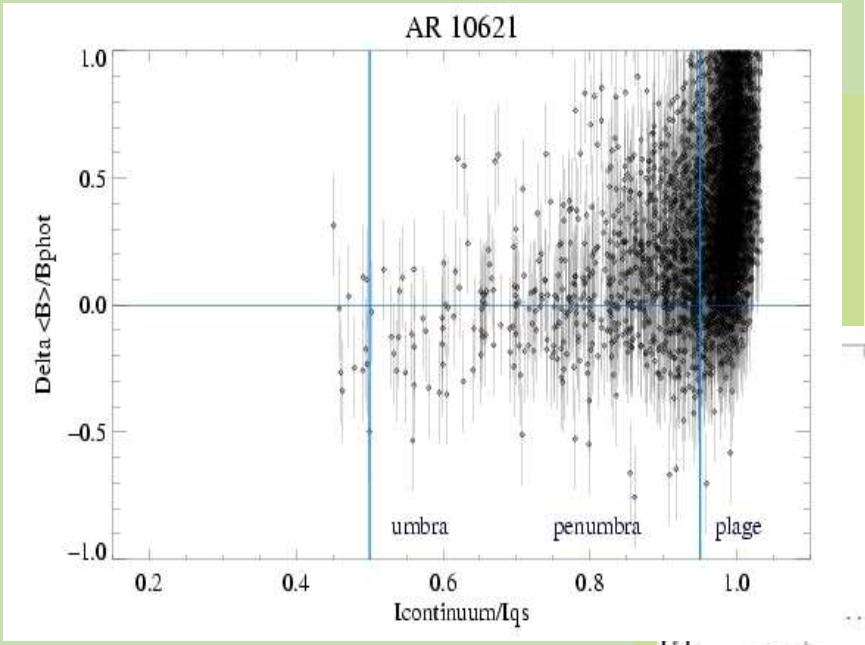
Percentage change in total |B|as a function of normalized continuum intensity.





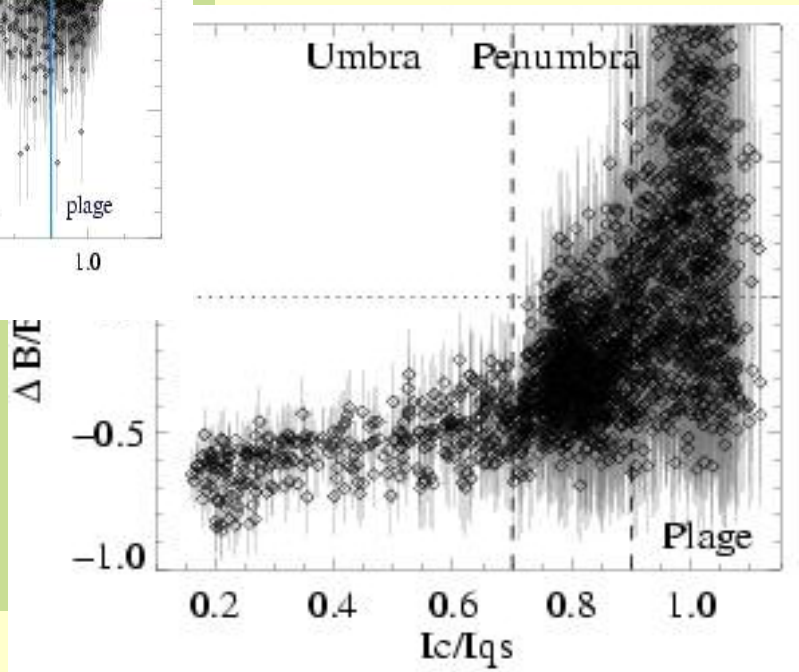
Magnetic scale height (km) as function of normalized continuum intensity

Also: self-similarity between large and small active regions.

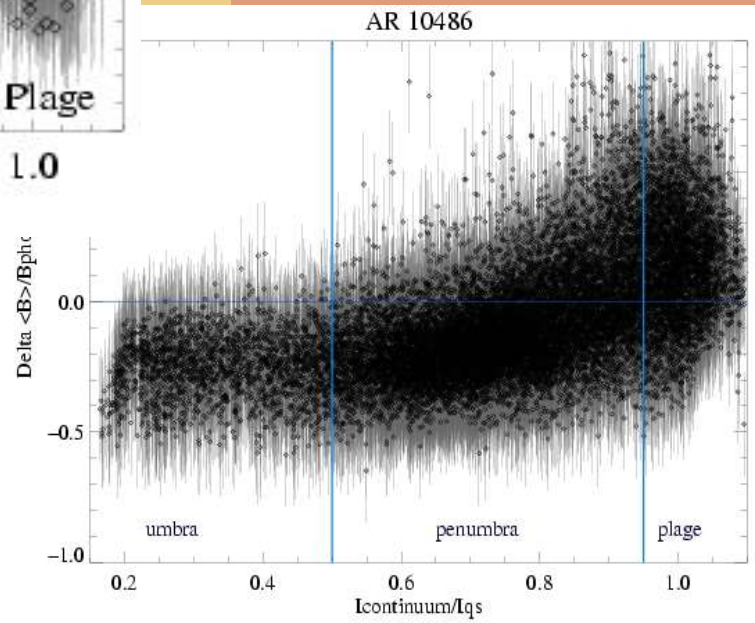


AR 10621:
barely any sunspots,
IVM/IVM

AR 8299: medium-sized spots, limb. IVM/ASP.



AR 10486:
big, big, big.
IVM/IVM.



Chromosphere sits in the middle of a "magnetic transition zone":

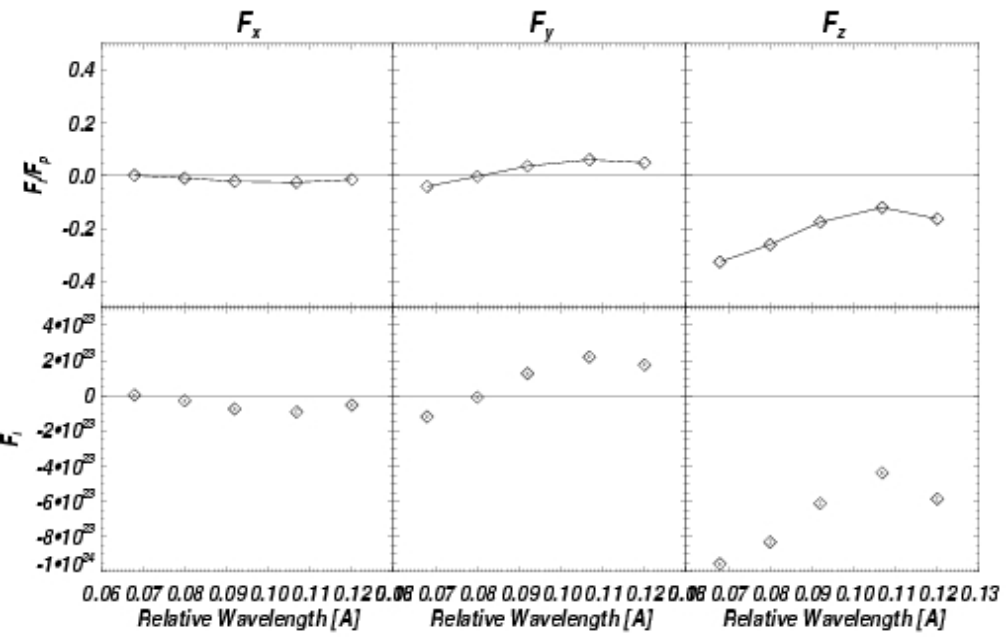
- Plasma/magnetic pressures transitioning from $\beta > 1$ to $\beta < 1$.
- Forces decreasing toward $J \times B = 0$.

Q: Do the Na D-1 observations support this?

Lorentz Force Tests:

Compute Horizontal Net Lorentz Forces; integral should be zero if force-free.

A: yes, in some cases, with variation toward non-zero forces when ***B*** computed farther from line-center (deeper in atmosphere).
However, some active regions appear to be forced in the chromosphere.

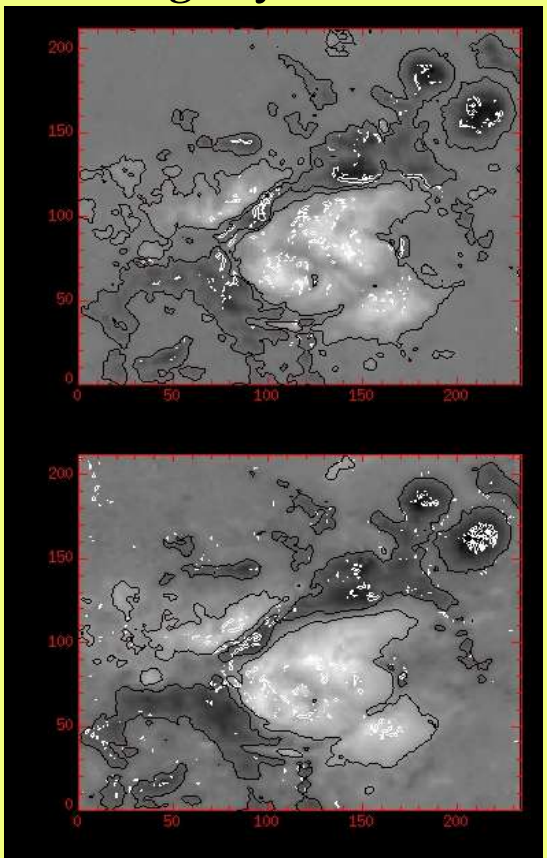


Cross-Field Currents Tests:

Non-zero Jz along magnetic neutral lines (Bz=0) indicate cross-field currents. Are there fewer NL regions with Jz in the chromosphere?

A: yes, in some cases, e.g., AR10486. Very dependent on ambiguity resolution. Preliminary!

Images of Bz for (top) photosphere and (bottom) chromosphere, with contours of Jz. This is too small to see intentionally: it's too preliminary! Sorry!



There are others....a *long* "to do" list.

Conclusions:

- We can measure an integrated magnetic flux vector which is consistent with the low chromosphere and differs quantitatively from photospheric fields.
- We are still at the beginning of the relevant analysis;
- Collaborative efforts for comparisons with chromospheric magnetic field characteristics *derived from other methods* are most welcome.

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