Chromospheric Vector Magnetic Field Observations of Active Regions as related to Energetic Events

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Why the chromosphere?

Hopefully force-free, an assumption for many calculations using magnetic data.

Why *not* the chromosphere?

Measuring B in the chromosphere is not an easy measurement.

Lower S/N; smaller g_L in chromospheric lines, broader thermal widths.

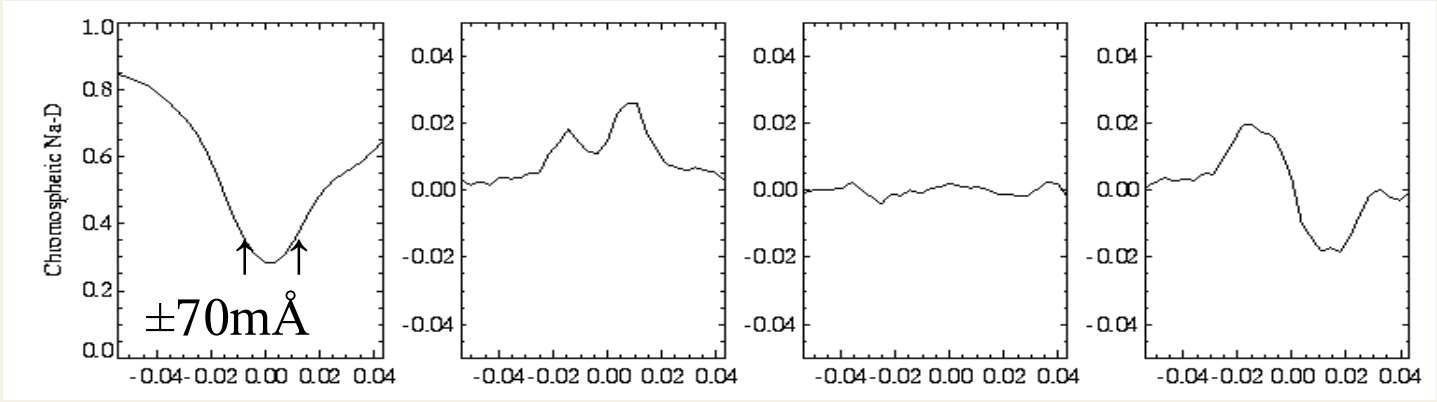
Questions *uniquely* addressable by chromospheric *B* as relating to energetic events:

- Magnetic topology of chromosphere and corona:
  - direct measures are closer to where magnetic reconnection likely occurs.
  - Force-free extrapolations will have a force-free boundary.
  - Tasks include detecting and evaluating Bald-patch separatrix surfaces, QSLs, coronal nulls, magnetic separators.
- Magnetic forces: is there a unique signature in the forces (or lack thereof) for event-producing ARs?
- **Magnetic energy: measured essentially directly**

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.

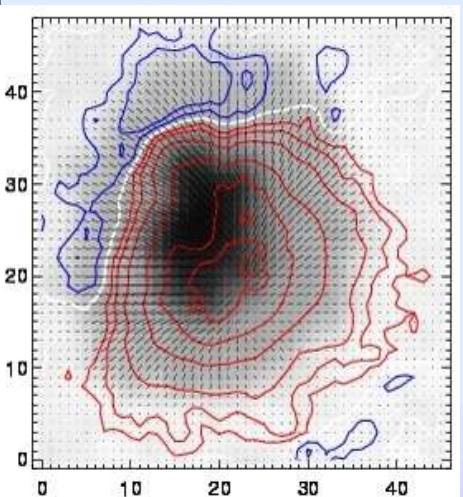
Jefferies, Lites & Skumanich 1989



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.

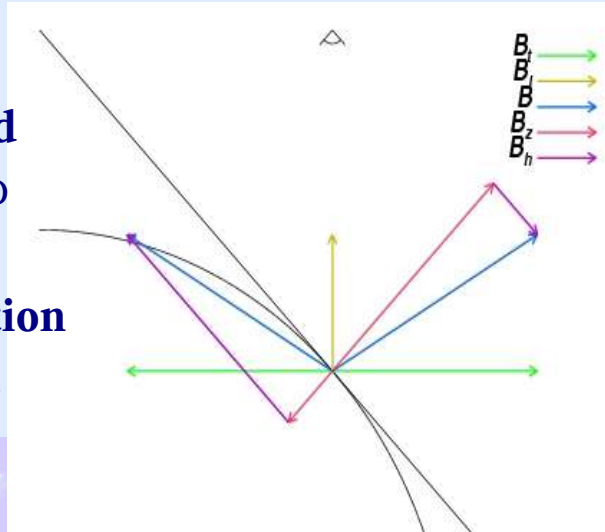
- Ambiguity in B_{trans} solved using "simulated annealing"
  - minimizes divergence and current simutaneously
  - Results in heliographic ***B***.

Metcalf 1995

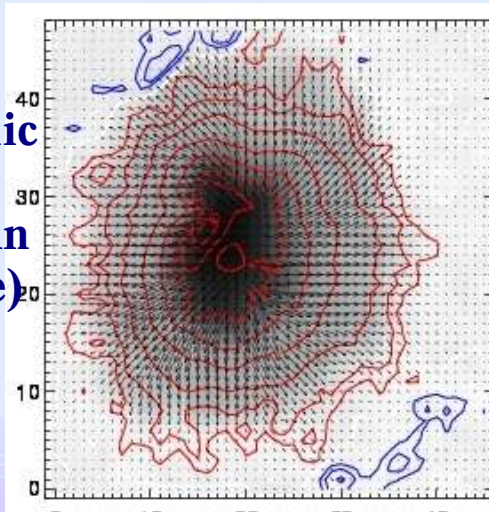


← Observed B_{los}, B_{trans}, ϕ

B_{trans} direction is chosen. →

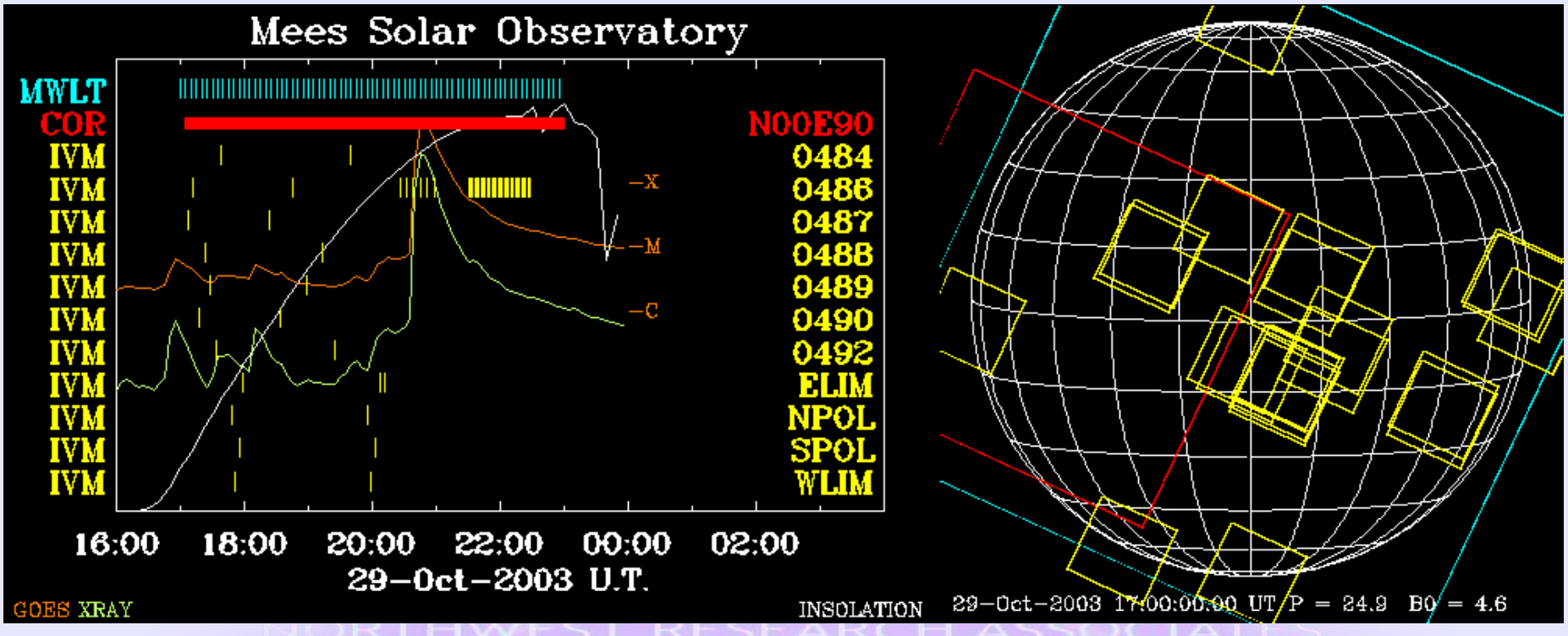


Heliographic *B* results. (note shift in neutral line)

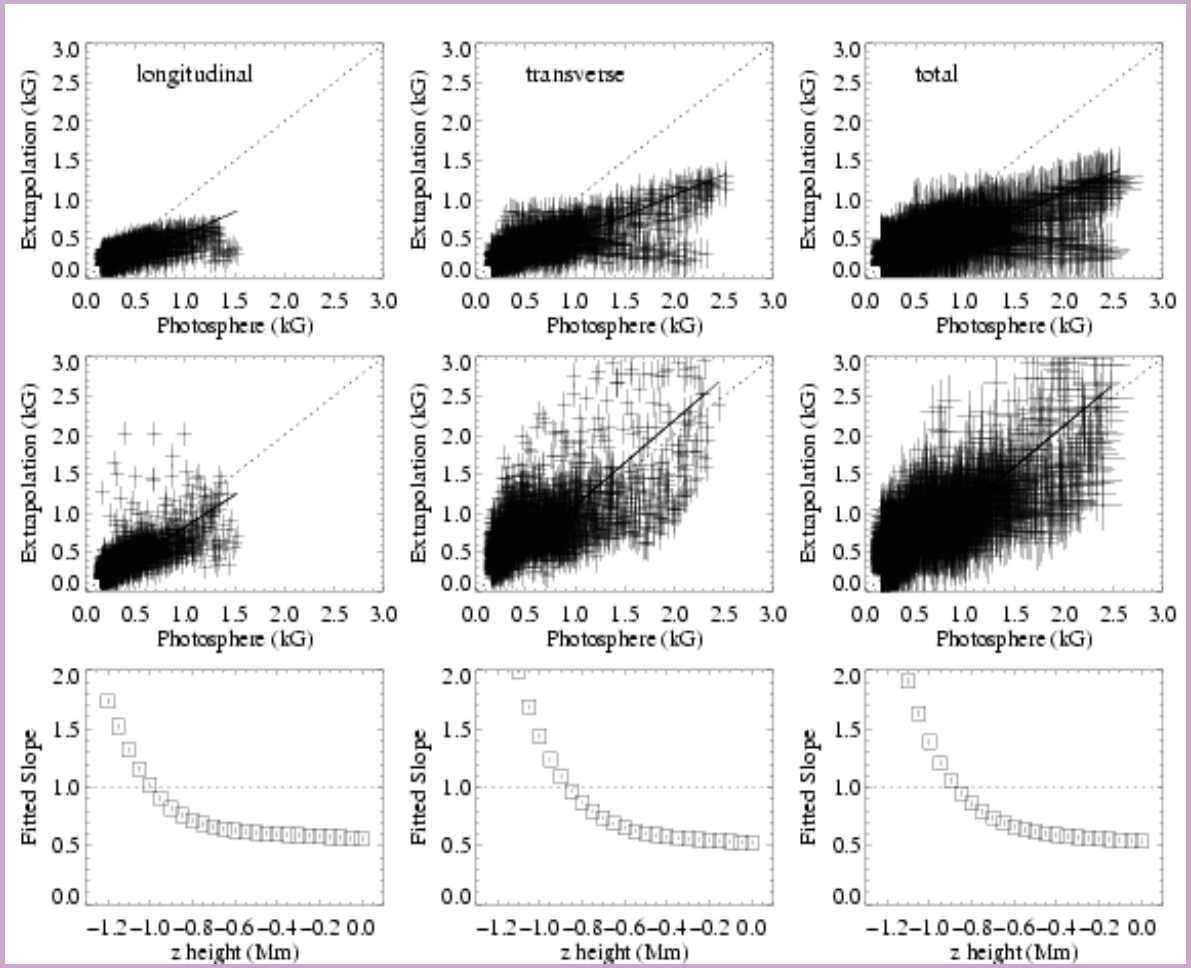


Measuring the Chromospheric Magnetic Field cont'd: Instrument

- 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.



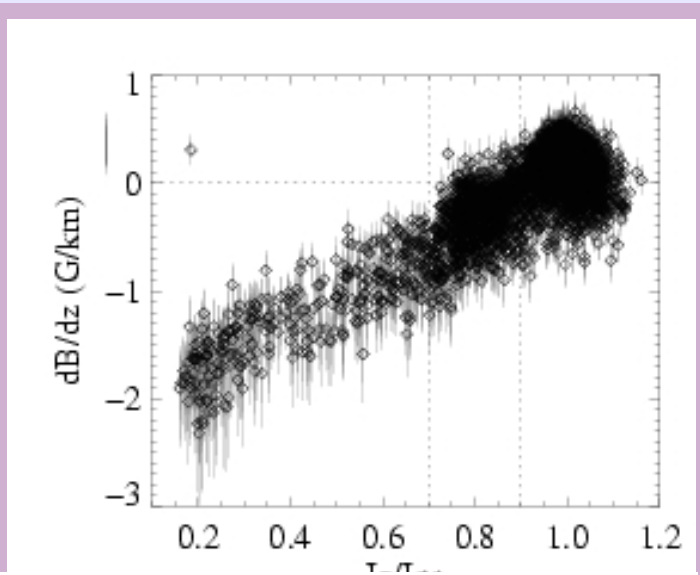
- ***Where*** are we measuring?
  - Response function is *broad*; spectral bandpass is, too.
  - Single-height (average over few x 100km) assumed.
  - Extrapolations between chromosphere, photosphere indicate measures originate *approximately* 1Mm above $\tau = 1$ ($\Delta z = 0.8$ Mm above photospheric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

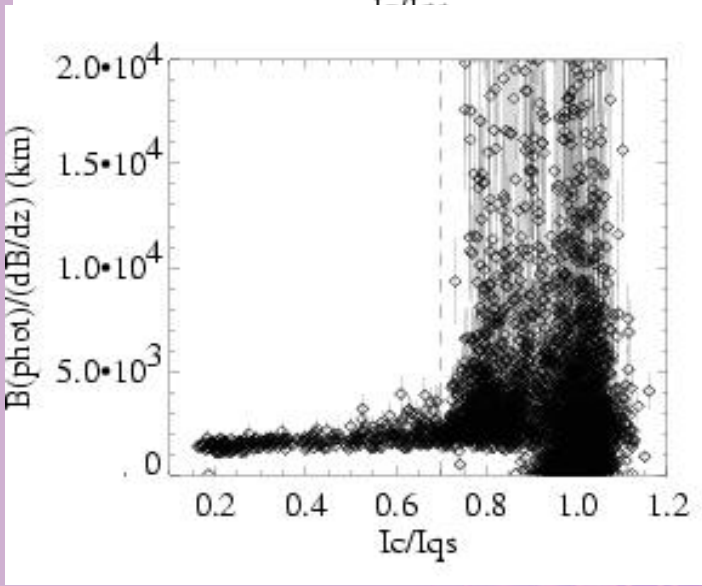


Comparison of photospheric magnetic flux with results of extrapolating the chromospheric magnetic flux *down* to photospheric levels. **Top**: Scatter plots for photospheric data *vs.* chromospheric data for $\Delta z = 0.0$ Mm, *i.e.*,for the *original*, non-extrapolated chromospheric data, for (left:right) B_{los}, B_{trans}, and $|B|$; $x=y$ line is also plotted. **Middle**: same, for $\Delta z = 1.0$Mm. **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 $\Delta z = 0.8$—1.1 Mm. Shown are data from AR8299; adapted from Leka & Metcalf, *Solar Phys*., 2003.

What's the difference between chromospheric and photospheric fields?

- ***Qualitatively***: not much. Visually indistinguishable.
- ***Quantitatively***: systematic differences in structure throughout active regions; self-similar in form with regards to sunspot size. Umbral/penumbral boundary can be distinct in ΔB.



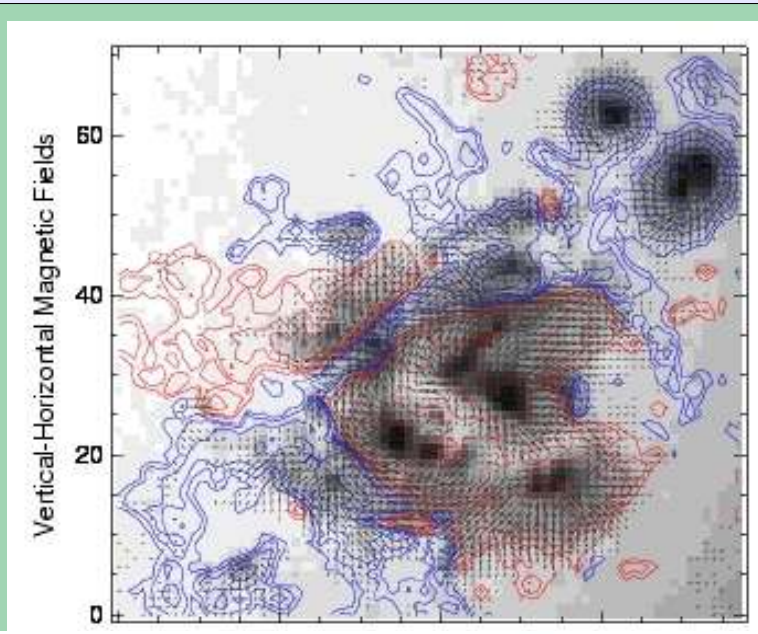


d|B|/dz in G/km between photosphere, chromosphere.

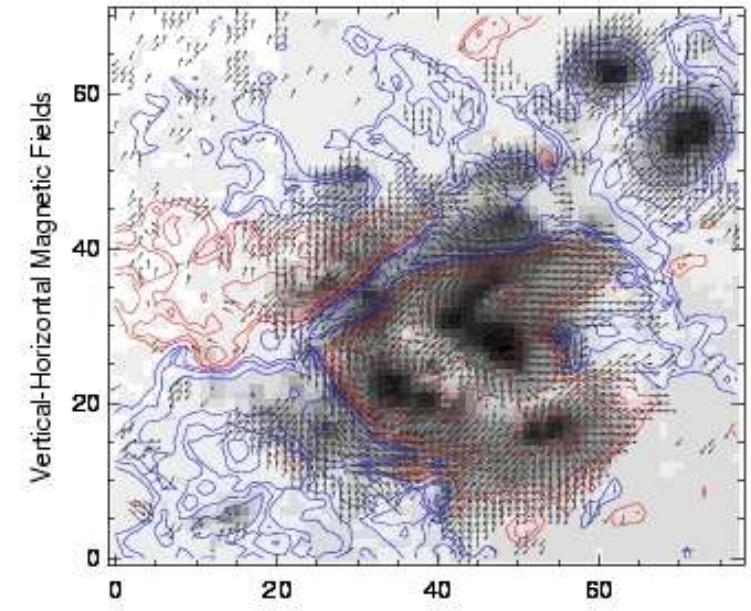
Both plotted as function of normalized continuum intensity with umbral, penumbral boundaries indicated.

Magnetic scale height (km)

(photosphere)



(chromosphere)



Measuring the **Magnetic Free Energy** using the **Magnetic Virial Theorem**

(*Amount of energy available for release with a solar flare or CME)*

$$Energy\,(total) = \frac{1}{4\pi} \int_{z=z0} (xBx + yBy)\, Bz\, dxdy$$

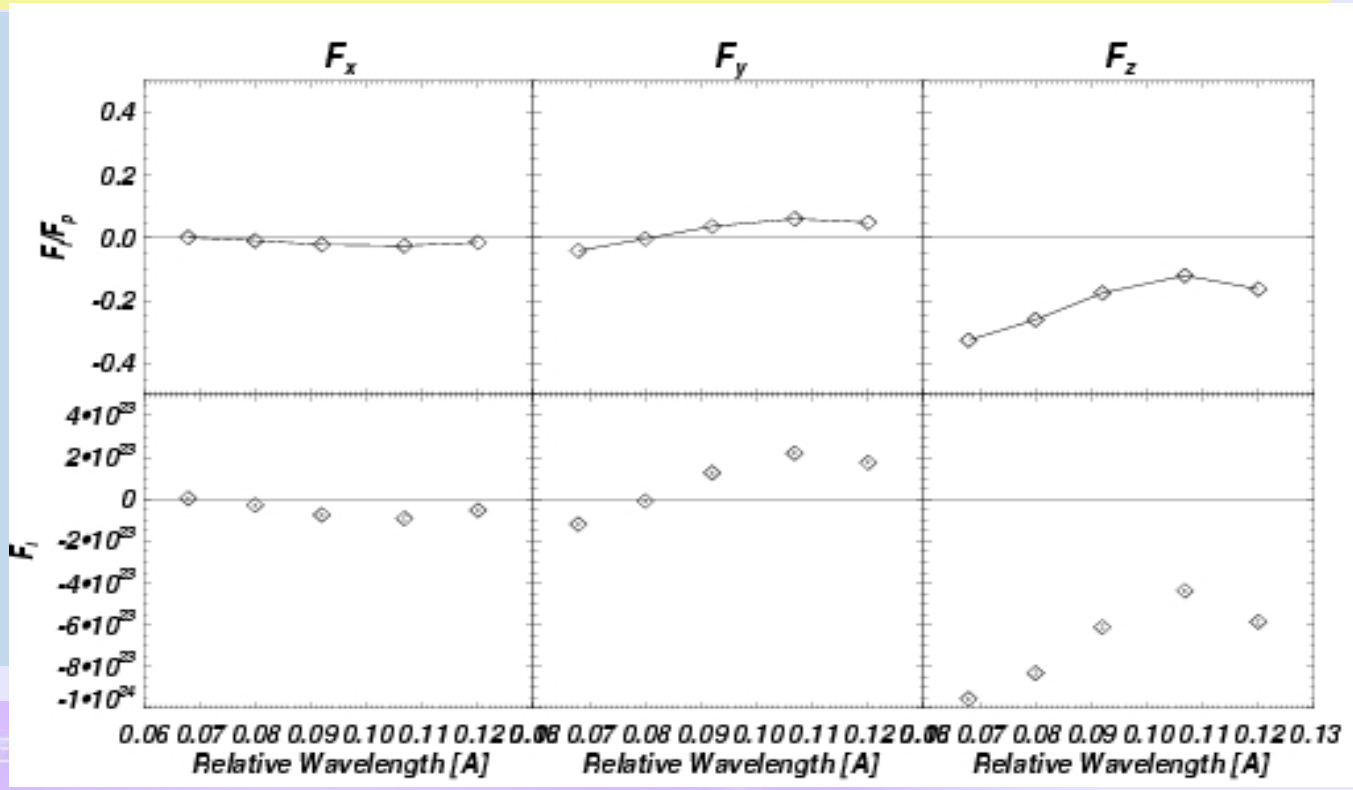
Assumptions:

- field is force-free
- all flux crossing the boundary is measured (flux-balanced)
- coronal field falls to zero.
- Deviations from the assumptions will appear as non-vanishing horizontal forces and positional variations in the energy calculation (which manifest as uncertainties).

$$Fx = \frac{1}{4\pi} \int_{x=x0} Bx\, Bz\, dxdy$$

$$Fy = \frac{1}{4\pi} \int_{y=y0} By\, Bz\, dxdy$$

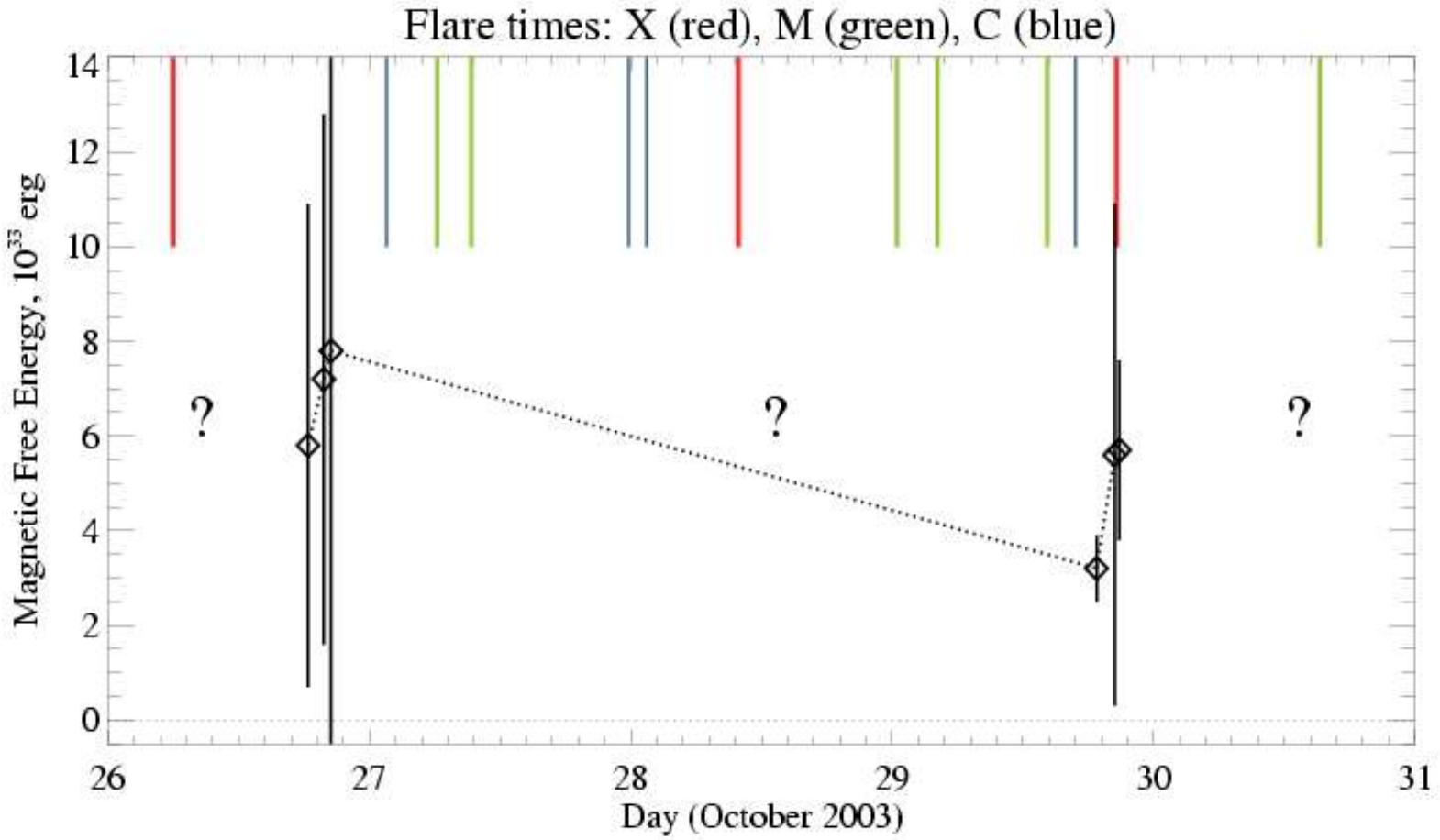
Horizontal and vertical forces (top: normalized by the pressure) computed as a function of wavelength for Na data. (right is away from line center). Error bars are not plotted. Fz is balanced by gravity.



Hot Topic: AR10486

- IVM's chromospheric capability had just come on-line.
- Free energy results for 29 October have just been published
  (Metcalf, Leka & Mickey 2005 *ApJL*)
- Data for 26 October are being analyzed now.
- Maddeningly incomplete data with regards to time series
  (...the story of our lives right now)

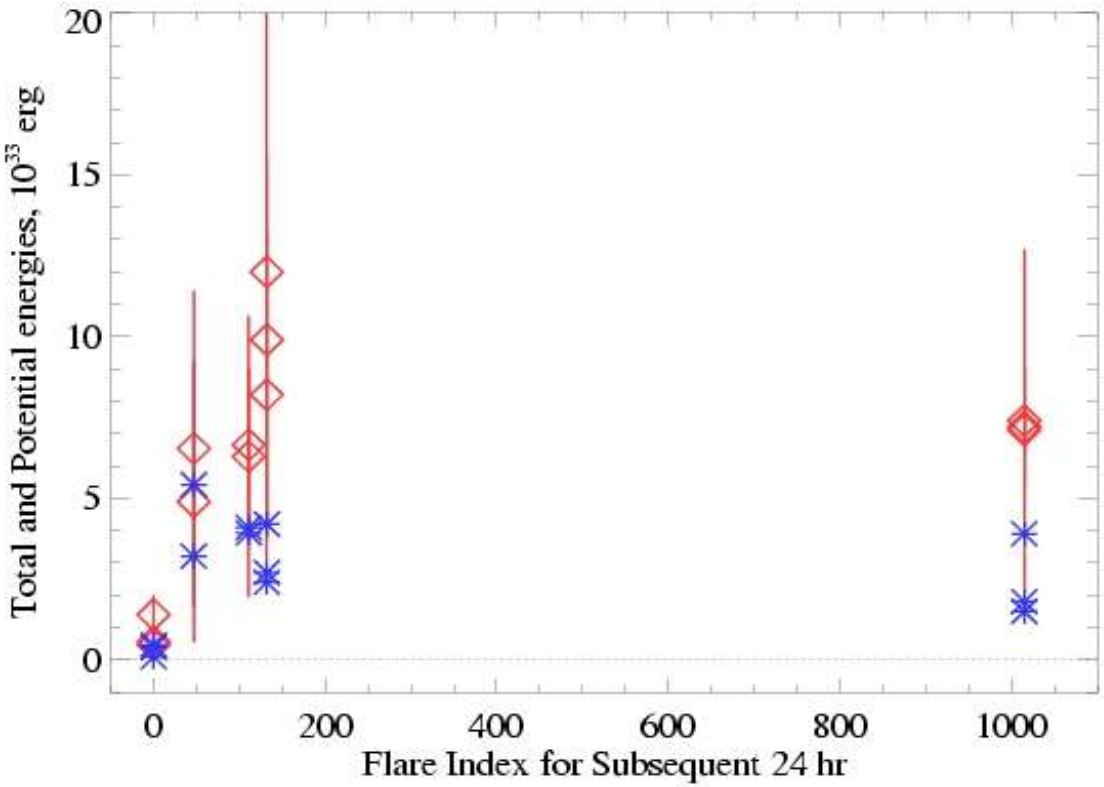
Magnetic free energy for AR10486 for 2003 October 26, 29. Start times for GOES SXR flares are indicated along the top, color coded for peak X-ray emission. Larger error bars on 26 October due in part to μ=0.74 observing angle.

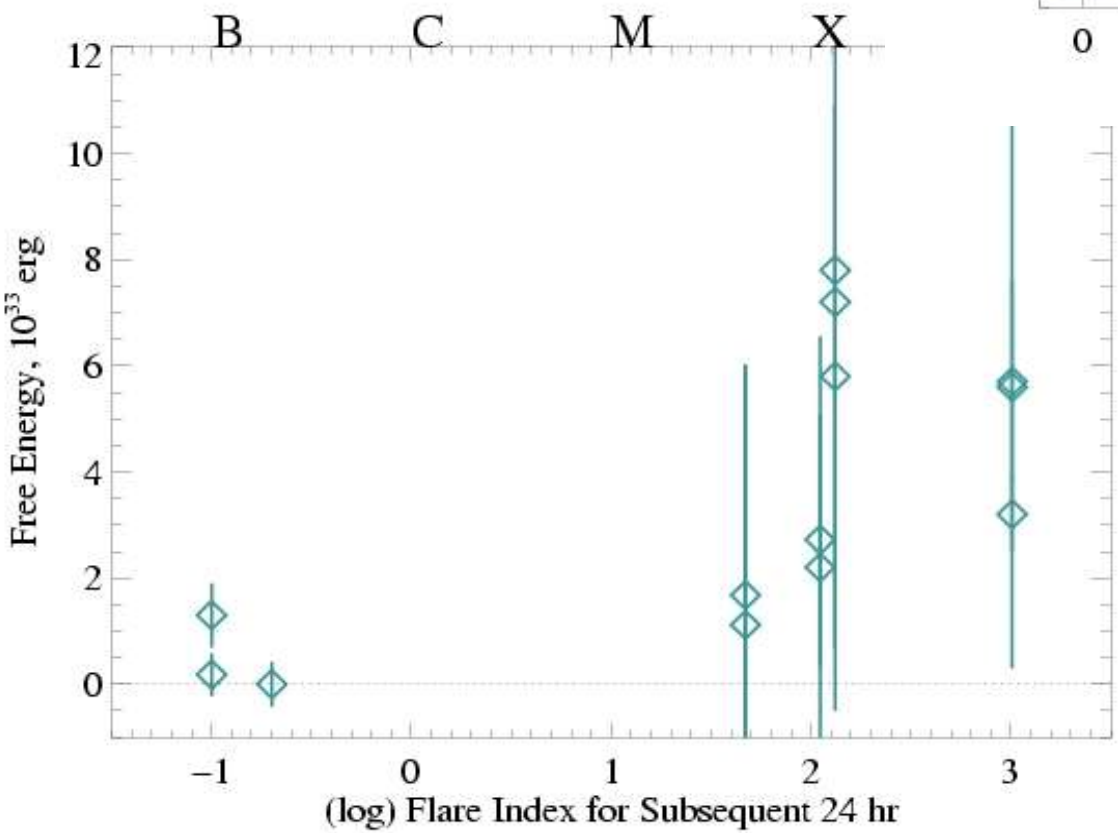


We *do* have (some) more analyzed:

- 5 active regions
- variety of sizes and flare activity
- some with multiple observations

RIGHT: Total and **potential-field equivalent** energies for 5 active regions as a function of flare index total for 24hr post magnetogram observation. Error bars indicate both random uncertainties and residual Lorentz forcing.





LEFT: Free magnetic energy (total less the potential energy) now plotted as log(24hr flare index) for clarity.

There is a trend, but that's as far as I'll go for the moment.

Summary:

- This is an on-going program to observe and analyze chromospheric vector magnetic field data.
- Numerous topics are available, however free energy measurements will continue to be a high priority.
- Long time series with good S/N covering energetic events have been elusive.
  - Golden rule of synoptic observations: 10% success rate on average.
- ***Possible*** relation between free energy and subsequent activity level has been observed.
  - Quite preliminary: don't quote me (yet)!