Continuum contrast vs. B field: Why are magnetic elements brighter in the quiet Sun than in active regions at disk center?

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Magnetic elements:
similar B \sim kG, contain significant fraction of photospheric flux

- main constituents of the QS network and AR plages
- intrinsically bright relative to their quiet surroundings

continuum brightness is essential contributor to the total solar irradiance (timescales of solar cycle or shorter, *Domingo 2005*)

fundamental to quantify their continuum brightness in the QS network and in ARs and to investigate the underlying physics
Contrast dependence on size of flux tube

- **Contrast**: brightness relative to quiet surroundings
  continuum contrast $\Leftrightarrow T$ excess

- For kG magnetic elements, to first order contrast $\Leftrightarrow$ size...

\[ \rho_e, p_e, \rho_i, p_i + p_{mag} \]

\[ \tau_c = 1 \text{ ‘solar surface’} \]

Courtesy Oskar Steiner

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Magnetogram signal: calibration of \( V \sim B \cos \alpha \)

for unresolved features \( \sim \) size (unless several features in the resolution element)

Frazier (1971)
Studies of contrast vs. magnetogram

Active regions vs. quiet Sun

Topka et al. (1992), SVST La Palma
Active regions vs. quiet Sun

Lawrence et al. (1993), SVST
Why is the continuum contrast of magnetic elements larger in the quiet Sun than in active regions at disk center?

A Hinode/SP analysis
Hinode/SP dataset

- Constant spatial resolution
  ~ 0.3” (SOT 50 cm @ 630 nm)

- Avg of Stokes I in cont
  \[ I_c(x,y) \]

- Pointing coordinates, slit position
  \[ \mu = \cos(\theta)(x,y) \]

- Select only data at \( \mu > 0.99 \)
Inversion of Stokes Spectra

Very Fast Inversion of Stokes Vector (VFISV, JM Borrero 2009)

- Milne-Eddington, 1-component atmosphere
- Inverts only FeI 630.25 nm
- Observables of interest:
  \[ B_{\text{app},\text{los}} = |B_{\text{app}} \cos \gamma| \] (no filling factor treatment)
  \[ V_{\text{los}} \]
- All pixels were inverted & included in analysis
Contrast vs. flux density in AR and QS

Contrast = \(\frac{I_c - \langle I_c \rangle_{QS}}{\langle I_c \rangle_{QS}}\)

QS: \(B_{\text{app,los}} < 100 \text{ Mx cm}^{-2}\)
*Brightest* magnetic elements in AR & QS have similar sizes
Effect of inclination?

$B_{\text{app,los}}$ in (500, 900) Mx cm$^{-2}$

![Graph showing distribution of $\gamma$ values for different regions of the Sun.]

- Active region plage
- Quiet Sun network

PDF

$\gamma$ [°]

0.10

0.08

0.06

0.04

0.02

0.00

0 30 60 90

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Effect of flux & convective flows on contrast

Conjecture:
Is the contrast of magnetic elements affected by a magnetically-suppressed convection in their surroundings (Knoelker & Schüssler 1988)?

Title et al. (1989), data from SOUP onboard Spacelab
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Box experiment ($\mu > 0.99$)

Cropped from 70” x 70”
Effect of flux & convective flows on contrast

Box experiment ($\mu > 0.99$)

Strong network

Weak network and internetwork

$B_{\text{cap}} [\text{Mx cm}^{-2}]$
- physics behind brightness of the mag elements is sensitive to local mean flux density rather than target (network or plage)

- generalization of the lower contrasts in ARs compared to QS, not based on target but on the local degree of activity
Convective flows vs. mean flux density

- Estimate vigour of longitudinal flows with $\text{rms}(V_{\text{los}})$
- Outside magnetic elements: $B_{\text{app},\text{los}} < 500 \text{ Mx cm}^{-2}$
Effect of flux & convective flows on contrast

- Supports that contrasts are affected by intermediate of less efficient convection as mean flux density increases
- Linear relation independent of box size (slope varies by ~5% for boxes ranging from 20” to 70” side length)

→ Convection affected by flux confinement, not total flux

![Graph showing the relationship between rms $V_{los}$ and mean flux density in the box.](image-url)
Effect of flux & convective flows on contrast

Patches of concentrated fields \textit{Title et al. (1992)}

most flux contained within \( B_{\text{app,los}} > 100 \text{ Mx cm}^{-2} \)
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Patches of concentrated fields ~ ‘magnetic islands’

Ishikawa et al. (2007), SST
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Patches of concentrated fields

![Graph showing the relationship between fractional box area and mean flux density. The line has a slope of $(1.85 \pm 0.05) \times 10^{-3}$ with a correlation of 0.990.](Image)

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the more extended the strong field patch is within the box, the larger the area over which convection is disturbed, the cooler and darker the magnetic elements, 

*supposedly* bec. of reduced convective heat transport towards them.
Effect of flux & convective flows on contrast

Patches of concentrated fields

\[ \text{Slope} = (-5.1 \pm 1.0) \times 10^5 \]
\[ \text{Correlation} = -0.668 \]
Indicates lower vertical radiative energy output as $<B>$ increases (already found in simulation boxes, Voegler 2005)
Bolometric brightness
Summary

• Comparing contrast and magnetogram at disk center
  ⇔ contrast-size relation of magnetic elements

• Previous studies found (unexplained) larger contrasts of magnetic elements in QS compared to AR

From our work on Hinode/SP

• contrast of magnetic elements remains larger in QS, even at Hinode’s constant resolution

• Peak of average contrast occurs at similar values of flux density for QS and AR
  → suggest similar sizes for brightest magnetic elements
Summary

Hypothesis: contrast of mag elements affected by disturbed convection

Local box test with boxes from QS and AR:

- Peak contrasts and the rms of the longitudinal velocity (around magnetic elements) decrease with mean flux density
  
  Primarily attributed to extent of the strong field patches:
  the larger the patch, the larger the distance over which convection is disturbed, the less heat coming to the magnetic elements

- Magnetic patches affects contrast averaged over the boxes
  
  parcel of photosphere in strong network or plage appears darker than a purely quiet one.
Thank you for your attention...
Effect of flux & convective flows on contrast

Rms Contrast (outside mag. el.) vs. mean flux density

Slope = \((-0.45\pm0.03) \times 10^{-4}\)
Correlation = \(-0.909\)
Stability of box contrast reference

Correlation = -0.111

Mean flux density in the box [Mx cm^{-2}]
Using IN boxes as contrast reference.
Comparison with Topka et al.

Removing pores with single threshold
Removing pores with single threshold
Diffraction-spread signal from the pores