National Astronomical Observatory of Japan

Implication of the magnetic power spectra derived with the Hinode SP

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Power spectral analysis of solar surface structures

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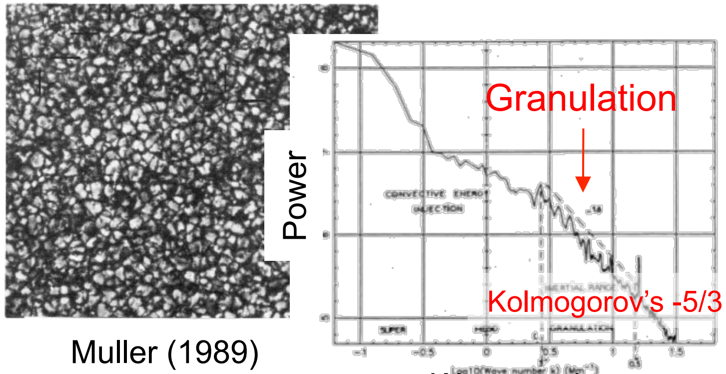
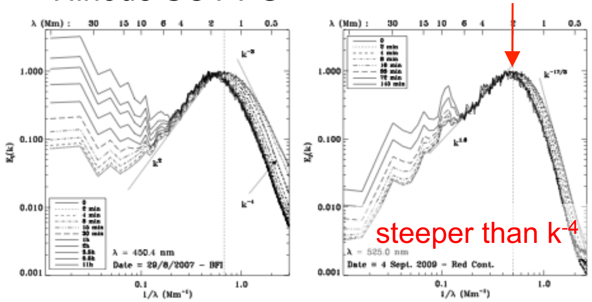
- Power spectral analysis is the most fundamental method to study surface convection and its action to magnetic fields.

<u>Intensity & velocity power spectra</u>



Muller (1989)
@ Pic du Midi

Rieutord et al. (2010)
Hinode SOT FG



<u>Magnetic power spectra</u>

Abramenko et al. (2001)
@SOHO/MDI & BBSO

Active regions

Quiet regions

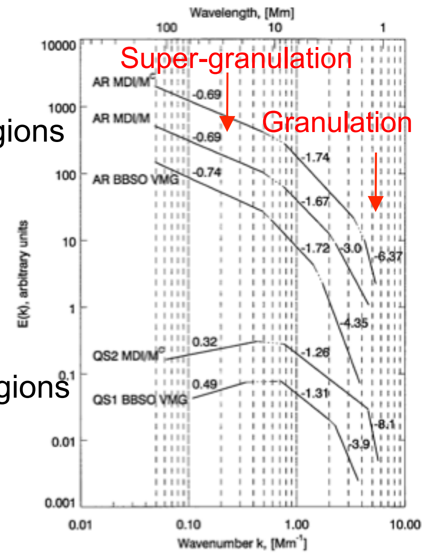


Figure 7. A schematic representation of all the magnetic power spectra obtained in the present study.

- Magnetic power spectra have been studied well at the super-granulation scale though the granulation scale is not well understood yet.

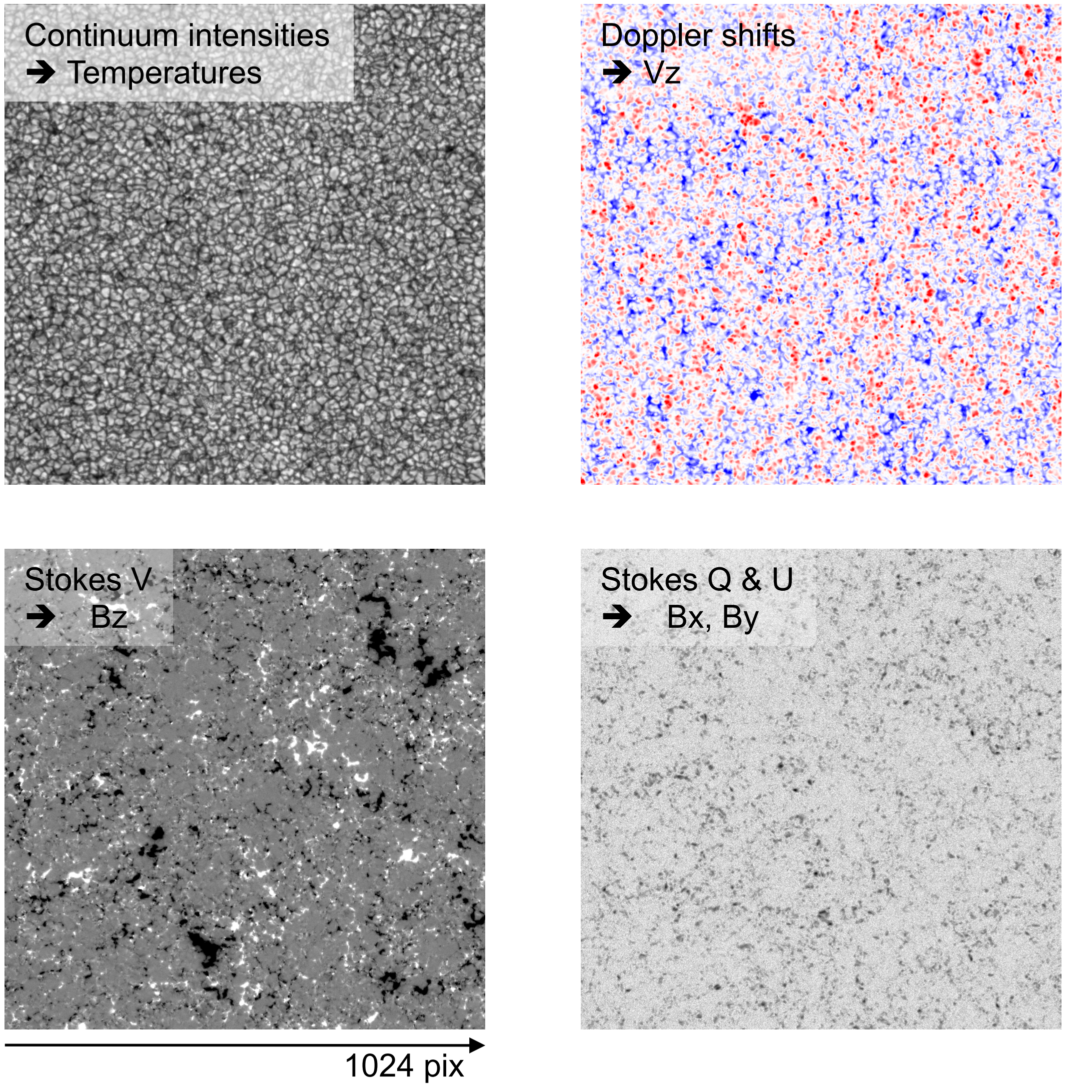
- It is more important to clarify how the magnetic and velocity power spectra are related.

(See also Lee et al. 1997, Petrovay 2001, Abramenko et al. 2001, Abramenko & Yurchyshyn 2010, Goode et al. 2010, Rieutord & Rincon 2010, Abramenko et al. 2012, Stenflo 2012, etc.)

HINODE SOT spectro-polarimetric obs.

- Because of the stable image quality and accurate polarimetric measurements, the SP data allows us to get reliable power spectra.

- (Bx, By, Bz) are obtained with wavelength-integrated polarization signals with the method described in Lites et al. (2008)

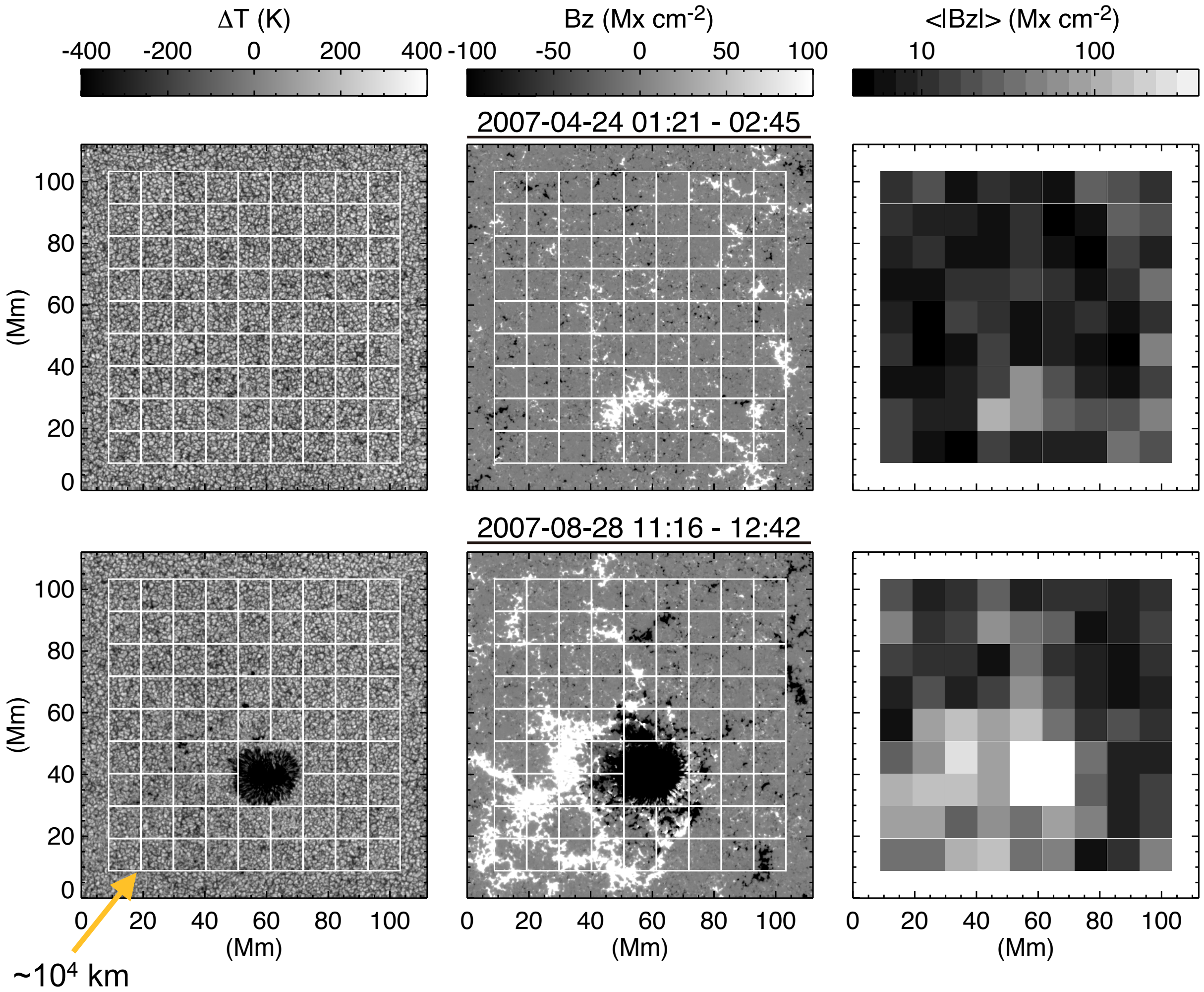


Power spectra in small boxes

- We use 30 normal maps (0.15”/pixel) taken at the disk center in 2006 and 2007. Both QS and AR are analyzed .
  - * QS (<|Bz|> < 20 G): 23 scans
  - * QS + AR: 7 scans

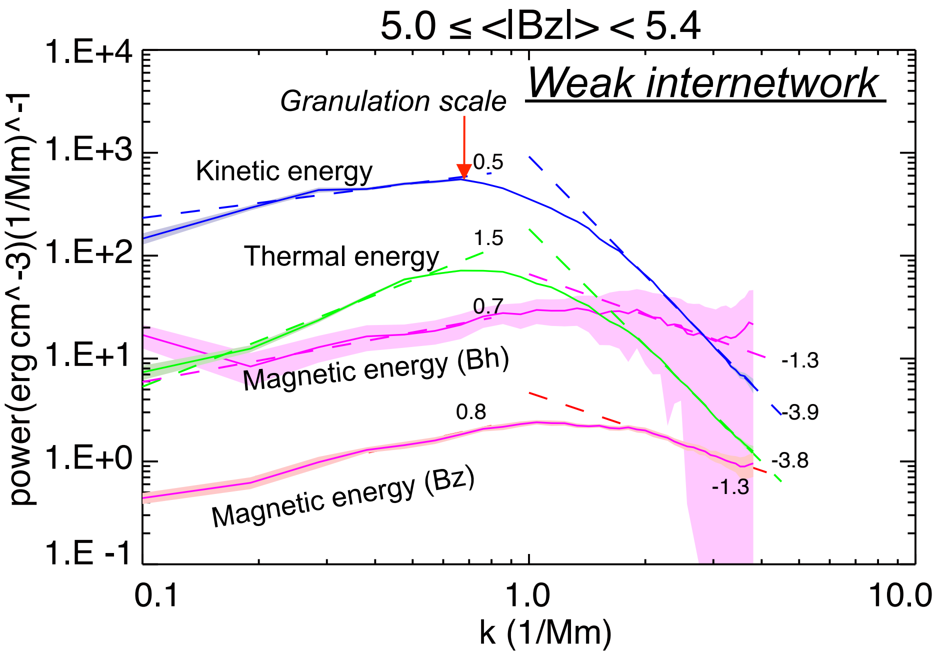
- To separate low flux regions (internetwork regions) and high flux regions (network, plages),1024 x 1024 pix^2 FOV is divided into small boxes whose FOV is 96 x 96 pix^2 (~10^4 km x10^4 km).

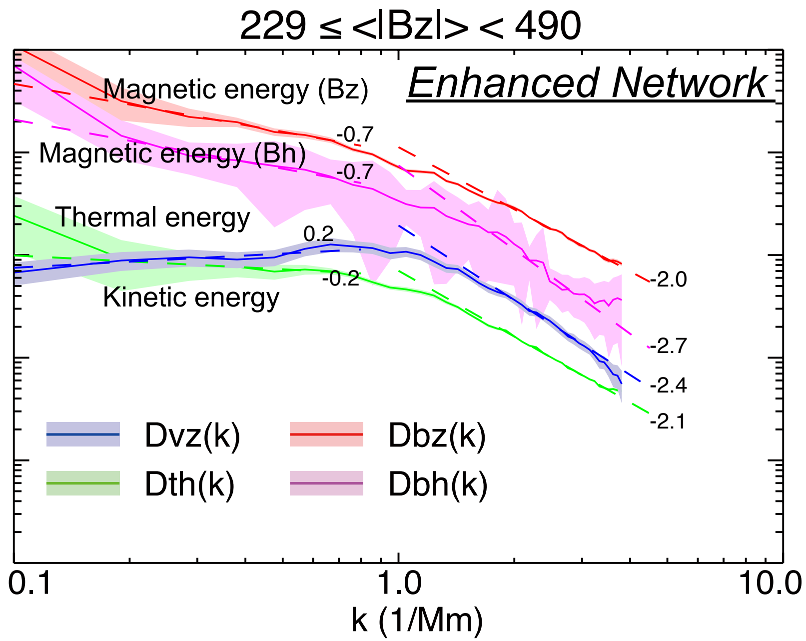
- The distinction of low flux regions and high flux regions is simply done by looking at average unsigned flux in each box.



Power spectra of surface structures

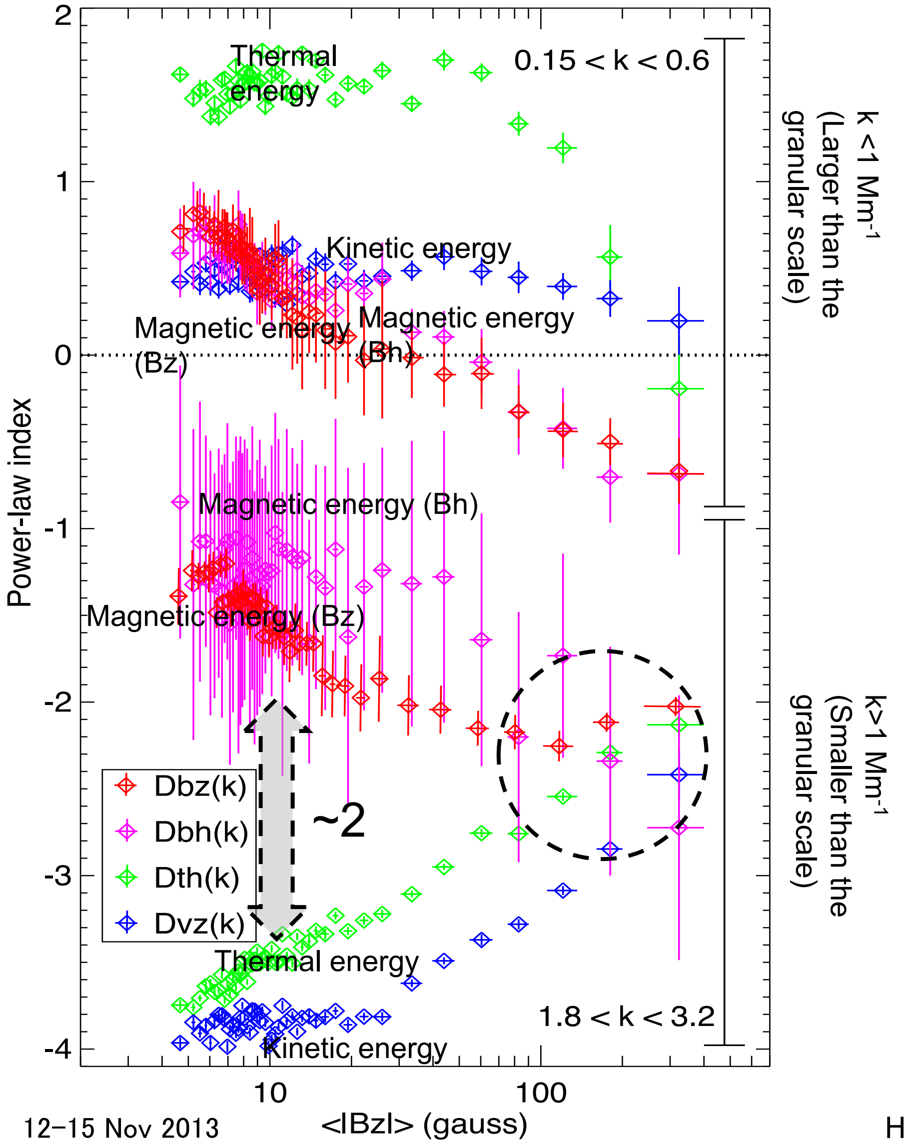
(Katsukawa and Orozco Suárez 2012)





- Low flux regions
  - Both the velocity and temperature (intensity) power spectra have a peak at the granulation scale (~1000 km). At the sub-granulation scale, the power-law indices are steeper than −3 (steeper than Kolmogorov's −5/3).
  - The magnetic power spectra have a peak at the granulation scale (~800 km). The power-law indices are −1 or slightly steeper than −1.
- Large flux regions
  - The velocity, temperature, and magnetic power spectra exhibit similar slopes at the sub-granular scale when the average unsigned flux is larger than 100 G.

Power-law indices vs unsigned flux



- In the low flux regions

  Magnetic power spectra are completely different from the velocity and intensity power ones. The magnetic power spectra are less steep than the kinetic ones. The difference of the power-law indices is ~2.

  Passive advection of magnetic fields by granular convection:

  B ~ (∇ · V) or (∇x V) ➔ $E_b(k) \propto k^2 E_v(k)$.

- In the high flux regions

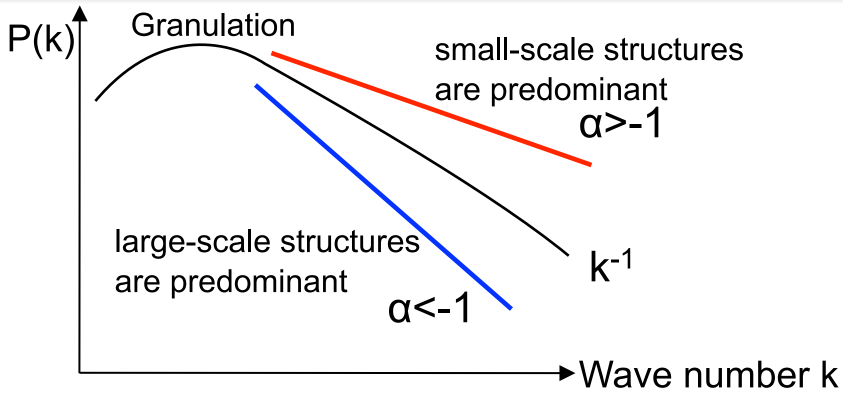
  The shapes of the power spectra (power-law indices) become similar at the sub-granular scale. Equipartition between convection and magnetic fields takes place at every spatial scales.

Which is more important, large-scale or small-scale?

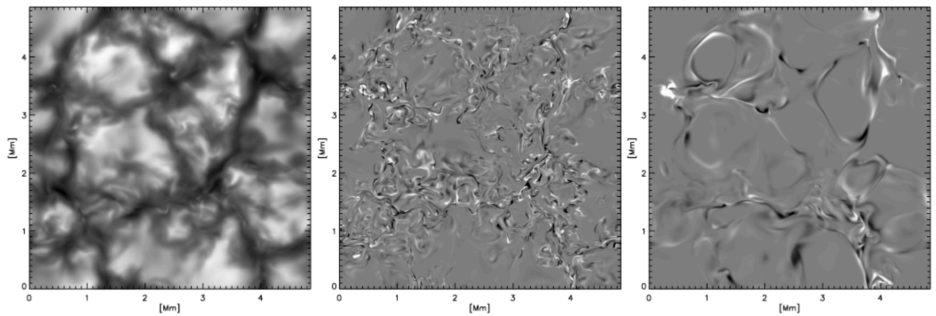
- Total magnetic energy budget:

$$E_B(k) \propto k^{\alpha}$$

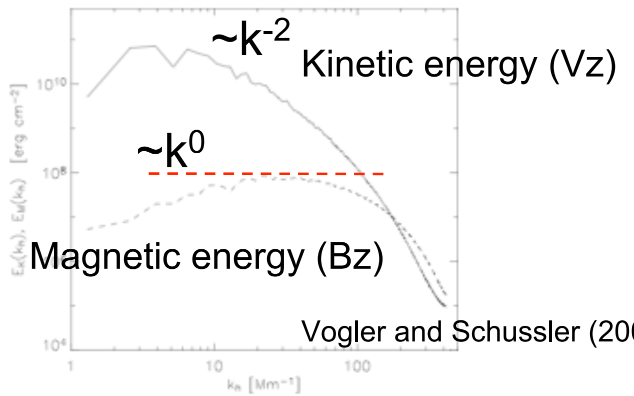
$$E_B \propto \int_{k0}^{k1} k^{\alpha} dk = \frac{1}{1+\alpha}\left[k^{1+\alpha}\right]_{k0}^{k1}$$



- In the observations with Hinode SP, $\alpha \sim -1$ or $\alpha < -1$. This means that the total magnetic energy mainly comes from either the granular-scale magnetic structures or both the granular-scale and smaller ones contributing evenly.
- Some numerical simulations of the surface convection suggest $\alpha \geq 0$, where small-scale (i.e. unresolved scale) structures are more important.



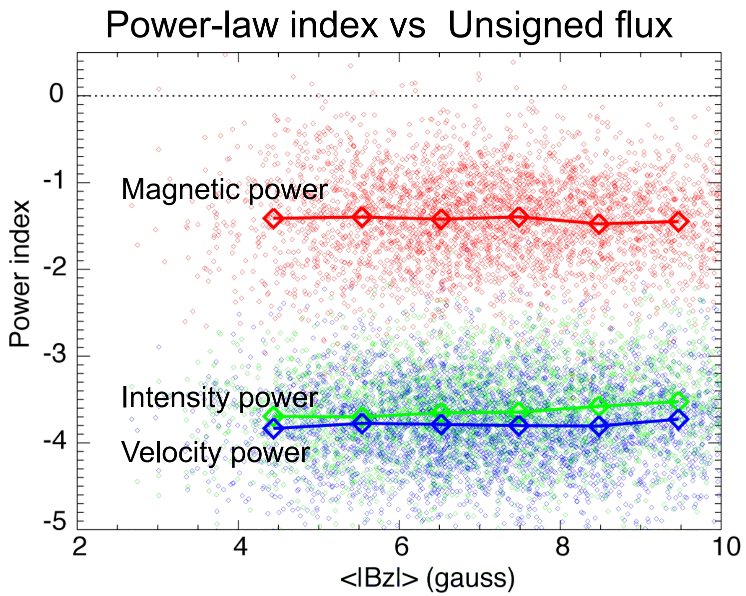
Vogler and Schussler (2007) Pietarila Graham et al. (2009, 2010)

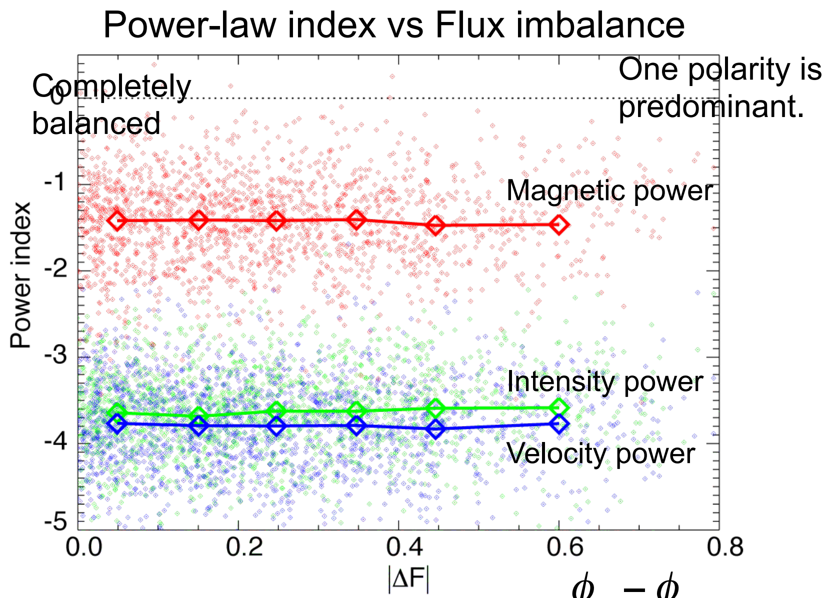


Vogler and Schussler (2007)

Cancellation of positive & negative polarities because of the limited resolution?

- Does the cancellation of positive & negative polarities due to the limited resolution make suppression of the magnetic power at the small scale?
- Answer: No
  - We calibrated influence of the telescope resolution (Modulation Transfer Function) at the spatial scale larger than 250km.
  - The power-law indices do not change dependent on the flux imbalance in the small boxes.

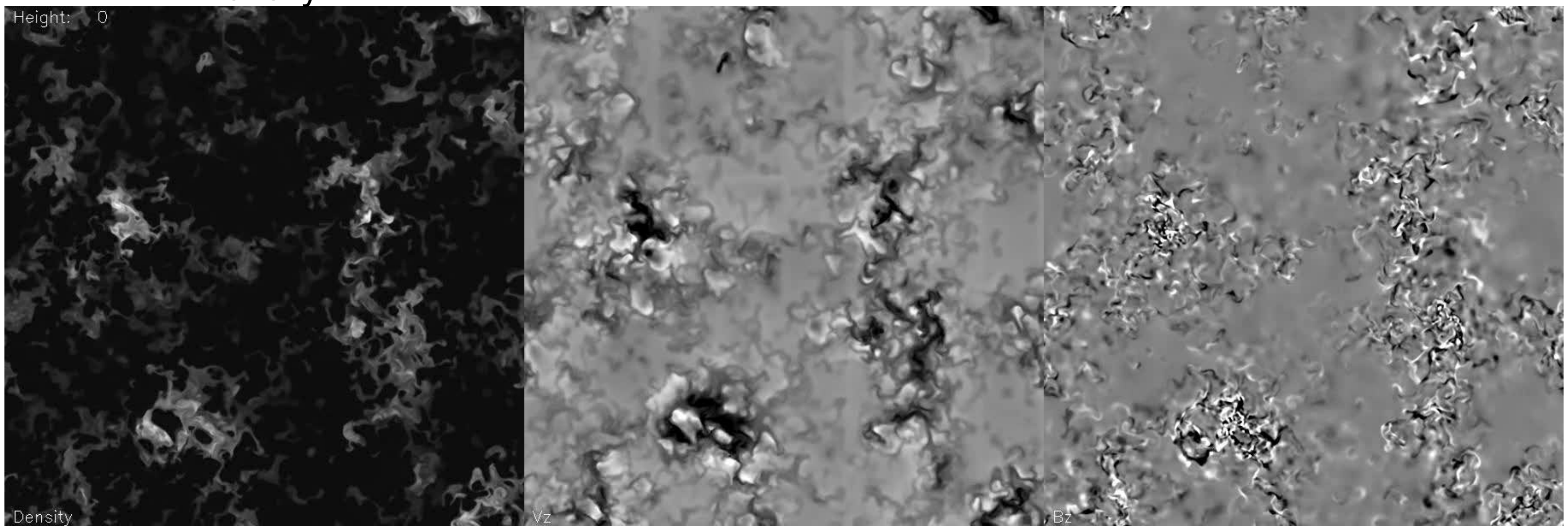




$$\Delta F = \frac{\phi_+ - \phi_-}{\phi_+ + \phi_-}$$

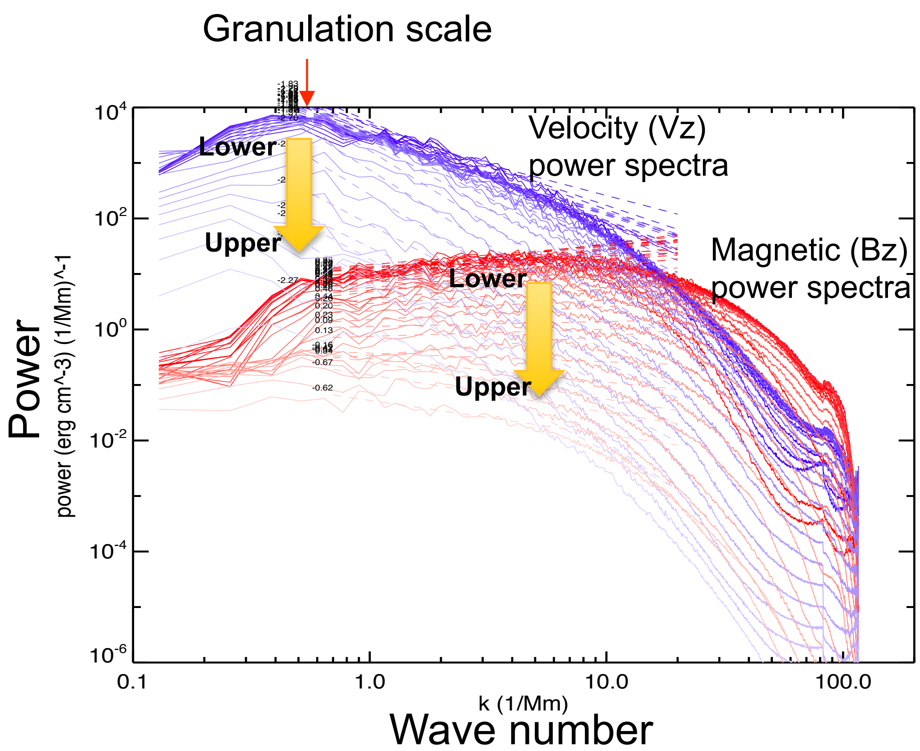
Comparison with the numerical MHD simulation

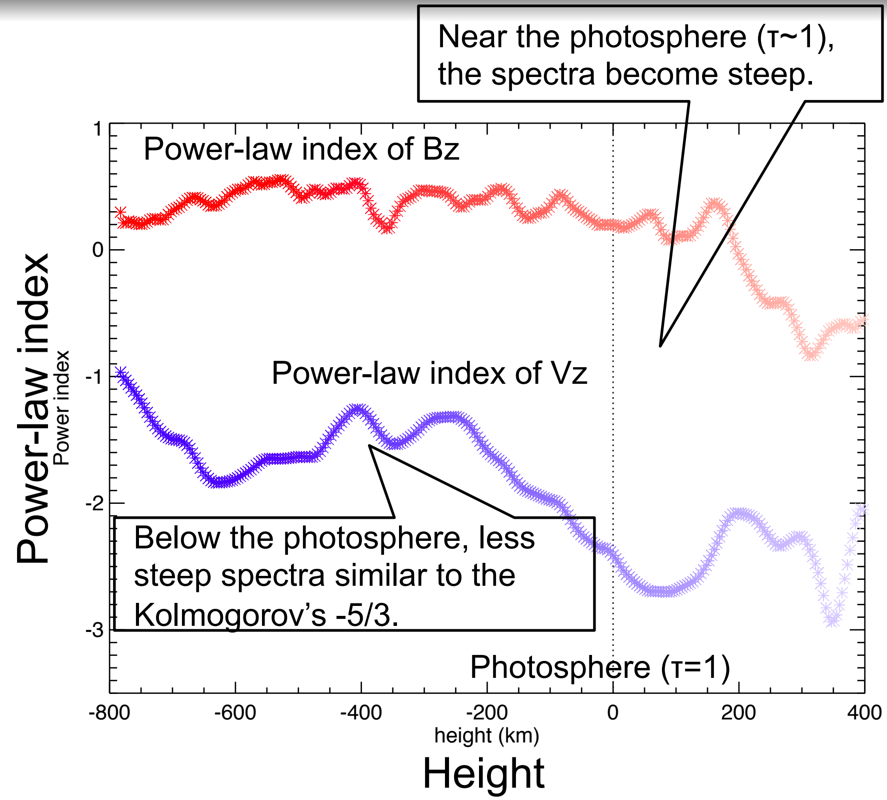
- What makes the discrepancy between the observation and the simulations:
  - Is the velocity structure near the surface not well reproduced by those simulations?
  - Does radiative transfer along height make relatively steeper power spectra ?
  - Or any problems in the observation?
- Height dependence of the power spectra is investigated using 3D cube data of velocities and magnetic fields provided by a numerical MHD simulation of the surface magneto-convection.



Height variation of parameters provided by the MuRAM simulation (Courtesy of Cameron et al.)

Power spectra from the simulation (h = -800 to +400 km)





- Near the photosphere, the spectra tend to be steeper because the atmosphere near the surface is convectively stable and turbulence does not develop much there.
- In the observable atmospheric layer ($\tau<1$), the power-law indices of the velocity and kinetic power spectra can be around -3 and -1, respectively.

Conclusion

- We obtained the reliable power spectra of the surface velocities and magnetic fields around the granulation scale using Hinode SP.
  - The velocity and magnetic power spectra have a peak at around the granulation scale.
  - The magnetic power spectra are less steep than the velocity power spectra in the low flux regions. The difference of the power-law indices is around 2.

    In the low flux regions,

    * Velocity power spectrum: $\alpha < -3$ (significantly steeper than Kolmogorov's $-5/3$)

    * Magnetic power spectrum: $\alpha \leq -1$

  → In the total magnetic energy budget, the granulation scale magnetic structures are important.

- By comparing the numerical MHD simulation of the surface magneto-convection, it was found that the spectra are steeper (i.e. less power at the small scale) near the surface ($\tau \sim 1$) though less steep (~Kolmogorov's) spectra are found below the surface.

  → If the turbulent dynamo makes the small-scale structures, it can happen only below the surface.