

# Physics 681: Solar Physics and Instrumentation – Lecture 17

*Carsten Denker*

*NJIT* Physics Department  
Center for Solar–Terrestrial Research



## Mean Line Profiles of Granulation

- ❑ Unresolved spectral lines of solar granulation differ from laboratory measurements
- ❑ Sun's motion with respect to the observer
- ❑ Gravitational redshift  $Gm_{\odot} / r_{\odot} c \approx 636$  m/s
- ❑ Residual blueshift: interplay between granular intensity and velocity field (a few 100 m/s at the disk center)
- ❑ Weak lines with lower excitation potential  $\chi$  are usually more blueshifted
- ❑ Stronger lines are formed higher in the atmosphere  $\Rightarrow$  the correlation between intensity and upward velocity is essentially lost
- ❑ Limb effect: convective blueshift decreases from disk center towards the limb (rotational Doppler shift component has to be removed  $\Rightarrow$  measurements along the central meridian)
- ❑ Granular contrast decrease towards the limb and LOS velocity decreases (geometry: projection effect!)



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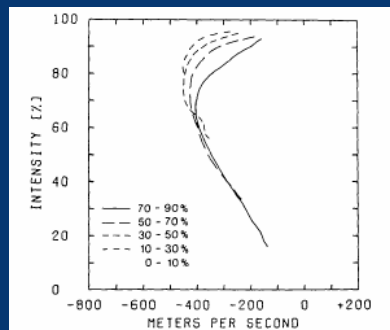
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- Near the limb, the projection effect might lead to a redshift, since the receding horizontal motion at the far side of granules is seen against bright granules behind
- Sunspots: convective energy transport is inhibited  $\Rightarrow$  only the predicted gravitational redshift is visible (none of the aforementioned phenomena apply)
- Line asymmetry: contributions from granules and intergranular lanes
- The line center originates at greater height than the wings & height dependence of the granular velocity field
- Bi-sector: iso-intensity line across the profile dividing the line into two halves ("C"-shape)
- The C-shape is a function of lower excitation potential  $\chi$ , the line strength, and the position on the solar disk
- Oscillatory velocity field and magnetic field affect the mean line profile as well
- Stellar granulation (impossible to resolve spatially)
- 3D model of radiative transfer explains the above phenomena and eliminates the necessity of "micro" and "macro" turbulence

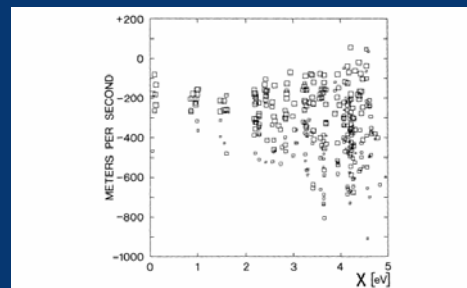


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**Figure 3** Dependence on line strength for spectral line bisectors in solar disk center spectrum. Each curve is the averaged bisector for a group of lines with central absorption depth limits as indicated. Intensity is in units of the spectral continuum and the wavelength scale is in absolute velocity units (Equation 1). Average wavelengths are  $\approx 550$  nm and average lower excitation potentials  $\chi = 3.5$  eV (Dravins et al. 1981).



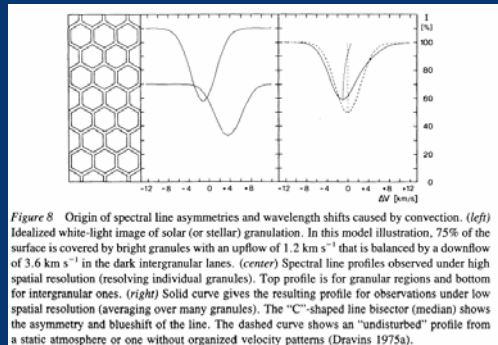
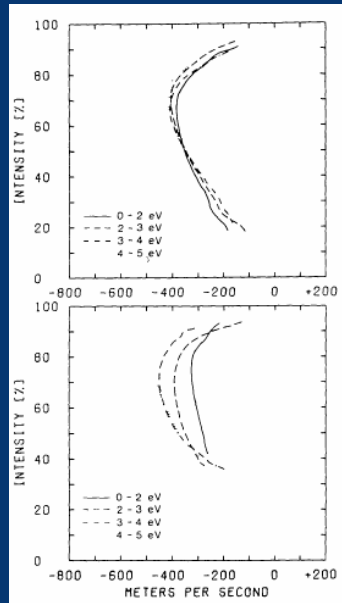
**Figure 1** Apparent radial velocities (Equation 1) for unblended Fe I lines in the visual region of the solar disk center spectrum, as a function of line depth and lower excitation potential  $\chi$ . Each square denotes one line, with the area proportional to the line absorption depth, so that larger squares represent stronger lines (Dravins et al. 1981).

Dravins (1982)



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**Figure 4** Dependence on lower excitation potential  $\chi$  for spectral line bisectors in solar disk center spectrum. The line groups have absorption depths  $70\% \leq d < 90\%$  (top) and  $50\% \leq d < 70\%$  (bottom). Each curve is the averaged bisector for a group of lines with lower excitation potentials as indicated. Average wavelengths are  $\approx 550$  nm (Dravins et al. 1981).

Dravins (1982)

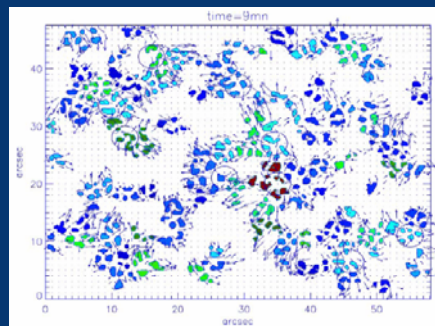


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## Mesogranulation

- ❑ Organization at larger scales?
- ❑ Active granules: expansion, fragmentation, expansion of fragments, fragmentation of fragments, ...
- ❑ Network with a mesh size of about 10 arcsec
- ❑ Network is correlated with photospheric brightness
- ❑ Mesogranulation has been detected in LCT and Doppler signals
- ❑ Vertical rms velocity  $\approx 60$  m/s
- ❑ Horizontal velocity  $\approx 500$  m/s
- ❑ Motion towards boundaries of supergranular cells



Tree of fragmenting granules (Roudier and Muller 2004)



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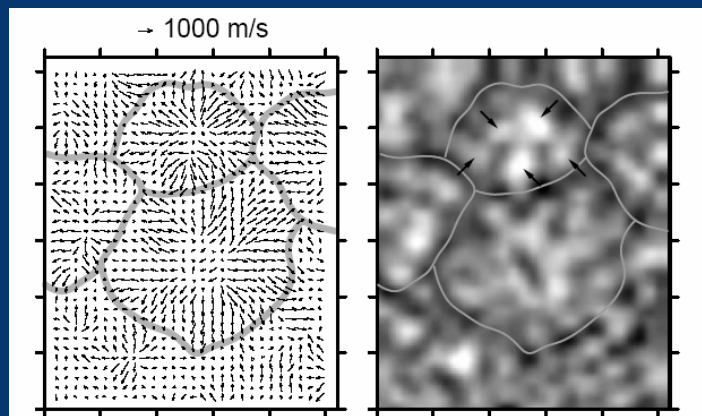
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# Supergranulation

- ❑ Spectroscopically discovered by Hart (1956)
- ❑ Autocorrelation function of velocity fluctuations shows a secondary maximum at  $d \approx 26,000$  km
- ❑ Doppler spectroheliograms (Leighton et al. 1962)
- ❑ Cell diameter  $\approx 16,000$  km, mean spacing between cell centers  $\approx 30,000$  km, and life-time  $\approx 1$  day
- ❑ Flow is almost invisible in Doppler maps at disk center  $\Rightarrow$  predominantly horizontal flow
- ❑ Horizontal velocity 300-500 m/s from LCT
- ❑ Vertical velocities: central upflow  $\approx 60$  m/s and peripheral downflow  $\approx 100$  m/s
- ❑ Downdrafts coincide with vertices of the supergranular network
- ❑ Supergranular boundaries coincide with the chromospheric emission network
- ❑ Rossby number (vortex-type velocity):  $Ro = u / (2\Omega l) = 10$  with  $l = 10,000$  km,  $u = 500$  m/s, and  $\Omega = 3 \mu\text{Hz}$

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*Figure 4.* The full-resolution horizontal flow map for the subarea indicated in Figure 3 and the derived divergence map shown as a gray scale within the range  $\pm 0.0006 \text{ s}^{-1}$  (negative is dark). A calibration arrow showing the vector length for  $1000 \text{ m s}^{-1}$  is at top center. Tick marks are every 10 Mm. We have drawn the boundaries of several supergranules based on the longer time averages in Figure 7 and possible mesogranules. We marked mesogranular features by arrows in one supergranule. The horizontal velocity pattern is clearly dominated by the supergranules, while the divergence is dominated by mesogranules.

Shine, Simon, & Hurlburt (2000)

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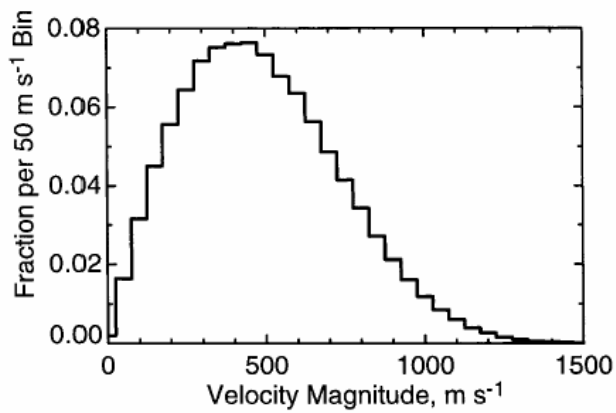


Figure 5. Distribution of  $|v|$  for the 45 one-hour averages. The peak velocity is consistent with previous observations.

Shine, Simon, & Hurlburt (2000)



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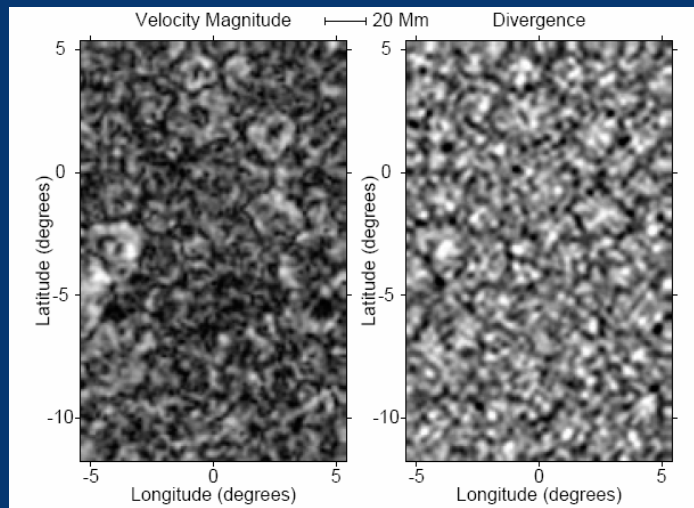


Figure 6. Velocity magnitude and divergence maps for the first hour averaged vector flow map shown in Figure 3.  $|v|$  is scaled from 0 to  $1.5 \text{ km s}^{-1}$  (black to white) and divergence is scaled  $\pm 0.0005 \text{ s}^{-1}$  (negative is dark). The typical supergranule size of 20 Mm is shown by a scale bar.

Shine, Simon, & Hurlburt (2000)



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