Thermal convection and the Sun's supergranulation

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Outline

The Sun's supergranulation
The Doppler image

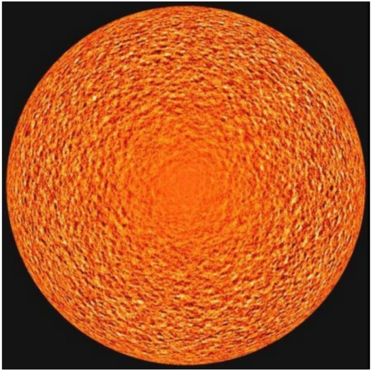

FIG.: from SOHO/MDI.

The Sun's supergranulation
The spherical harmonic spectrum : SOHO/MDI

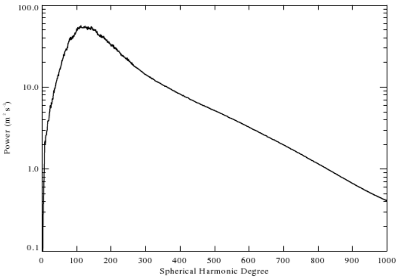

FIG.: From Hathaway et al. 2000 ; L_{max}=120, $\lambda_{SG} = 36.4$Mm.

The Sun's supergranulation
The network in the chromosphere

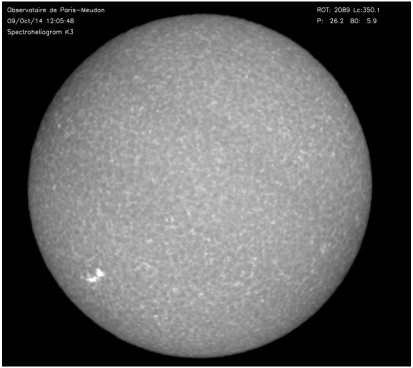

FIG.: Image of the Sun at $\lambda = 393.37$nm, Ca^+ K3 line (Meudon observatory).

The Sun's supergranulation
The network in the photosphere

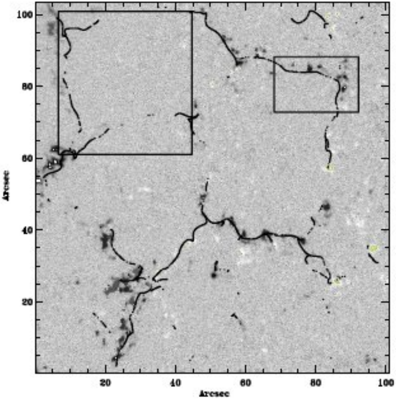

FIG.: Network magnetic fields (Roudier et al. 2009).

Problems with supergranulation

- This scale singles out of a continuum
- No consensus about its origin or models
- Obviously some connection with magnetic fields
- Is it a universal feature of stellar convection ?

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Various explanations

- Simon & Leighton (1964) : He^{2+}+e^{-} $\rightarrow$ He^{+} + heat
- Cloutman (1979) : Rip currents
- Rieutord et al. (2000) : Large-scale instability of surface convection favoured by strong stratification
- Rincon & Rieutord (2003) : Linear instability from fixed-flux BC, scaled limited by $\vec{B}$-field.

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Three attempts by DNS

- Rieutord, Ludwig et al. (2002), resol. $315^2 \times 96$ ($30^2 \times 3\mathrm{Mm}^3$)
- Rincon, Lignières and Rieutord (2005), resol. $1024^2 \times 82$
- Stein et al. (2008), resol. $1000^2 \times 500$ ($96^2 \times 20\mathrm{Mm}^3$)

Large amount of computing power but no sign of supergranulation !

Spectra from DNS

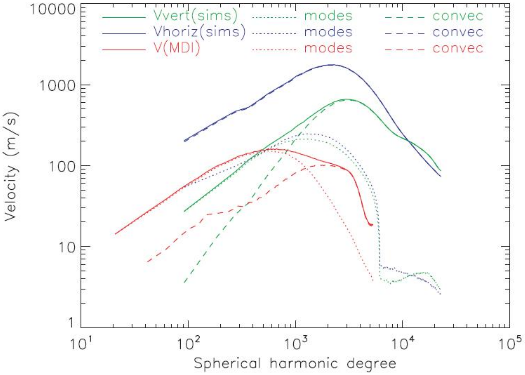

FIG.: LES within a box $48 \times 48 \times 20\text{Mm}^3$, resol. 500^3 (Georgobiani et al. 2007).

Direct modeling
Some ideas

Granulation forms in the thermal boundary layer where the radiative cooling is strong and the entropy gradient strong as well.

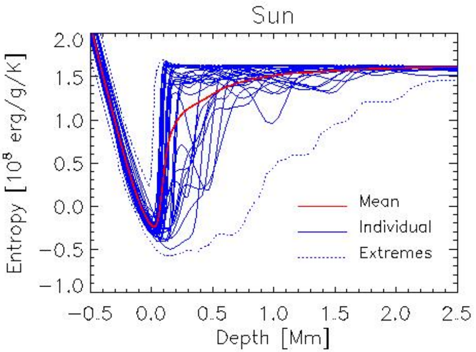

FIG.: From Bob Stein simulations.

Direct modeling
Some ideas (2)

- Below the thermal boundary layer, the gradient is still superadiabatic but the flux is fixed.
- Larger scales have to cope with this constraint.

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Thermal convection at fixed flux

First results

- Hurle et al. (1966) showed that when boundaries at fully insulating, namely conductivity$\rightarrow 0$, then $k_{\rm crit} \rightarrow 0$. Unstable scales are larger and larger horizontally.
- In fact, it turns out that $k = 0$ is the most unstable mode. But how this result changes when a vertical magnetic field is imposed ?

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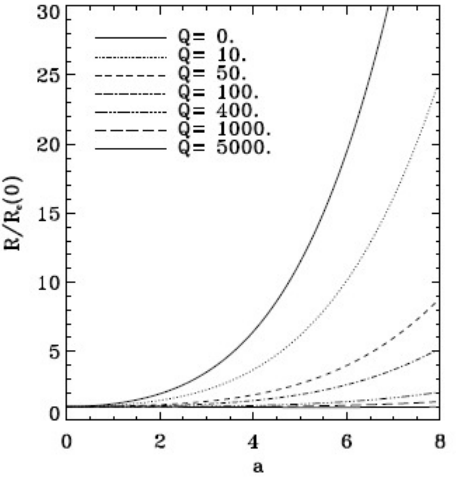
Fixed flux and magnetic field

This case was investigated by Rincon and Rieutord in 2003.



Fixed flux and magnetic field

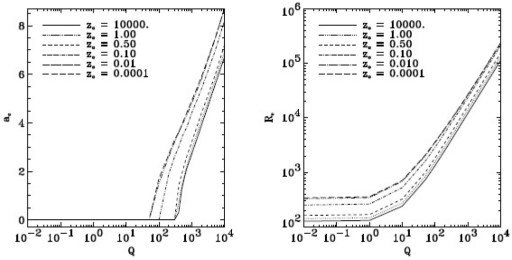


FIG.: Critical Rayleigh number and critical wavenumber as a function of the magnetic field.

$Q = (B_o^2 d^2)/(\mu_o \mu\eta)$ is the Chandrasekhar number.

Fixed flux and magnetic field

- This model shows that there is a critical magnetic beyond which the critical wavenumber is finite. It is characterized by the Chandrasekhar number Q=61 for a very strong stratification typical of the Sun.
- Putting solar numbers shows that the supergranulation scale is selected if the magnetic field is in the range 100G to 1kG at 5Mm deep.

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Outlooks

The preceding numbers are in the right orders of magnitude. They suggest investigating this instability in a more realistic framework :

- Use the spherical geometry
- Introduce a slight rotation to check the drift of convective cells
- Use entropy diffusion instead of heat (temperature) diffusion.

In fact follow up the early work of Glatzmaier and Gilman 1981 and the recent work of Jones et al. 2009.

END