Observation of Solar Granulation and Supergranulation

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Astrophysical context

A knowledge of the physical nature of the different flows scales on the Sun is necessary to understand the generation and diffusion of the magnetic field on the surface of the quiet sun. Among the different flow scales on the Sun's surface, no direct relation has been evidenced between the well-known small-scale granular convective cells (scale ≈ 1Mm, life ≈ 10 minutes) and the supergranules (scale 30 Mm, life ≈ 48 hours). Whether supergranules originate from convective processes ([6]) or from a large-scale instability of the surface turbulent flow ([3]) is still in debate.

Answer to these questions require observations of the Sun's surface on a large field of view, with high resolution and for a few hours of continuous measurements. We present observations from the Pic-du-Midi (France) and from the satellite Hinode which fulfill some of these requirements.

CALAS

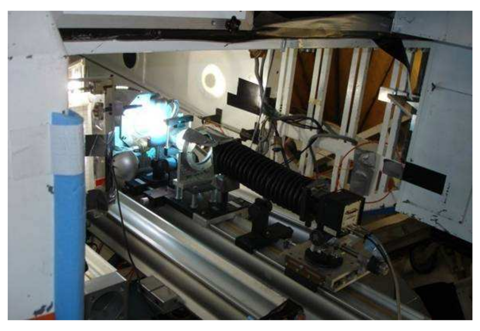
« CAmera for the LArge Scales of the solar surface »

Pic-du-Midi Observatory

Lunette J. Rösch, 50 cm-refractor, 14 Mpixel camera (4560 × 3048).
Two independent channels of measurements :

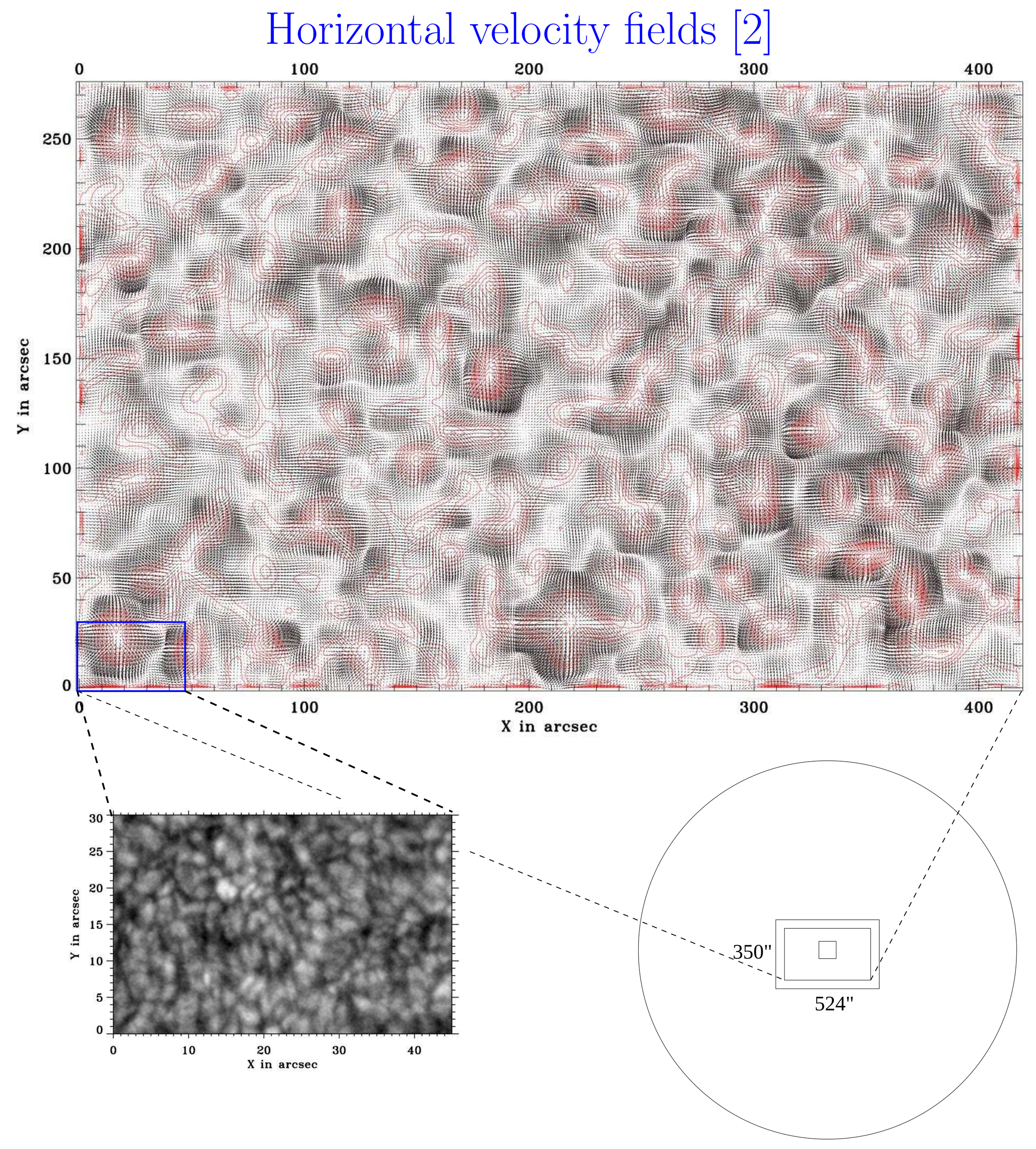
1) **Imaging** channel ⇒ $\vec{V}_H$ (image correlation tracking)
2) **MOF** channel ⇒ $\vec{V}_V$ and $\vec{B}_V$ (magneto-optical cell).

Lunette Jean Rösch

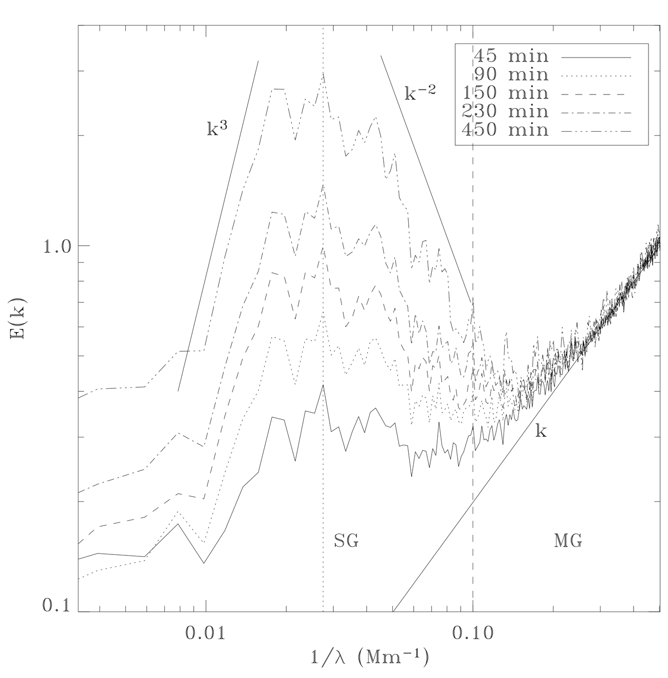


Imaging channel

Horizontal velocity fields [2]



Top : Supergranulation velocity field with the divergence contours superimposed obtained by CST granule tracking algorithm [5]. From images taken at $\lambda = 575 \pm 5$ nm. 150 minutes time-window from a 7.5 hours sequence. *Bottom right :* : the CALAS field of view on the Sun. Small square field of view of the SOT instrument on the Hinode satellite. *Bottom left :* a zoom on granulation showing the relative sizes of granules and supergranules.



$$\frac{1}{2} < v^2 >= \int_0^\infty E(K)$$

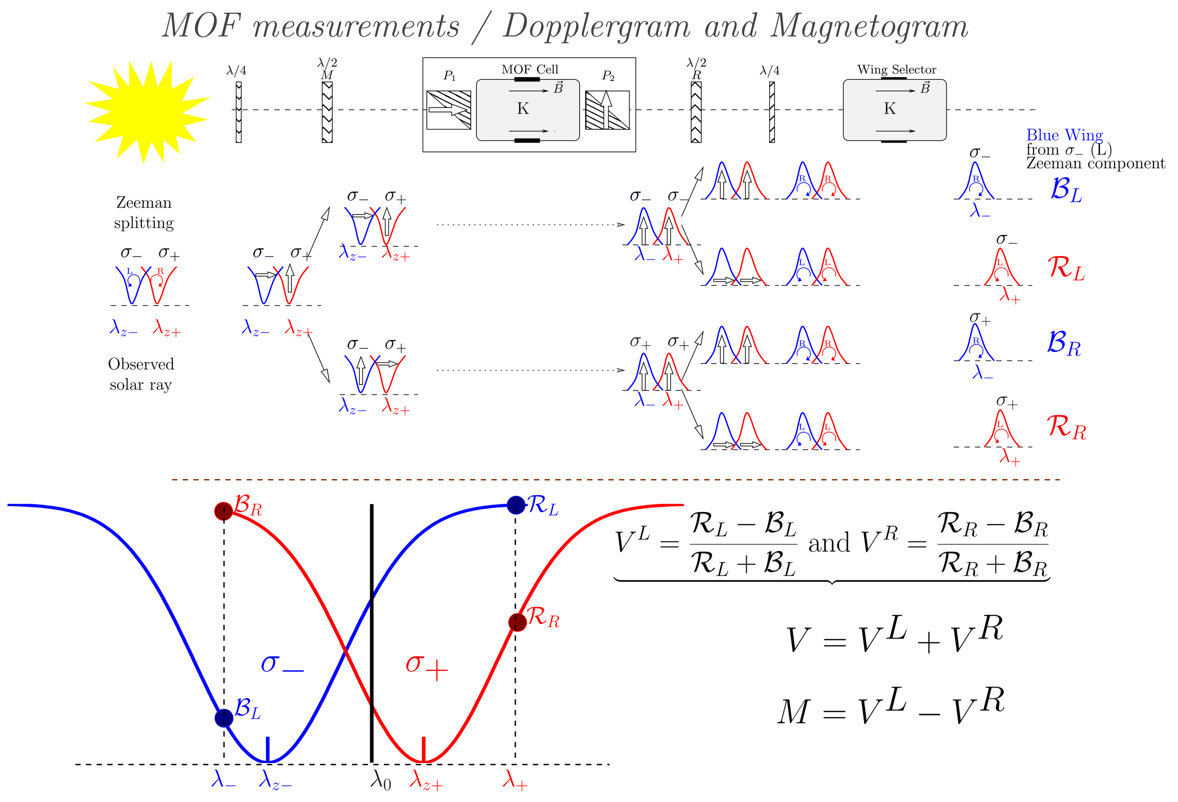
Kinetic energy spectra obtained for various time windows. The vertical dotted line indicates the position of the peak at **36.4 Mm**. The vertical dashed line emphasizes the 10 Mm scale, usually taken as the upper limit of mesogranular scale.

For the first time, the motion of well-resolved granules in a large field of view has been followed. The spectral peak of supergranulation has thus been determined in a very direct manner. Supergranulation, according to the data, has the most energetic motions at a scale of 36 Mm and encompasses all the scales ranging from 20 to 75 Mm. The data confirm the fact that supergranulation has a noticeable degree of intermittency, clearly appearing in the distribution of positive divergence values (not shown here, see [2]).

Magneto-Optical-Filter (MOF)

Physical principle

MOF measurements / Dopplergram and Magnetogram



$$V^L = \frac{\mathcal{R}_L - \mathcal{B}_L}{\mathcal{R}_L + \mathcal{B}_L} \text{ and } V^R = \frac{\mathcal{R}_R - \mathcal{B}_R}{\mathcal{R}_R + \mathcal{B}_R}$$

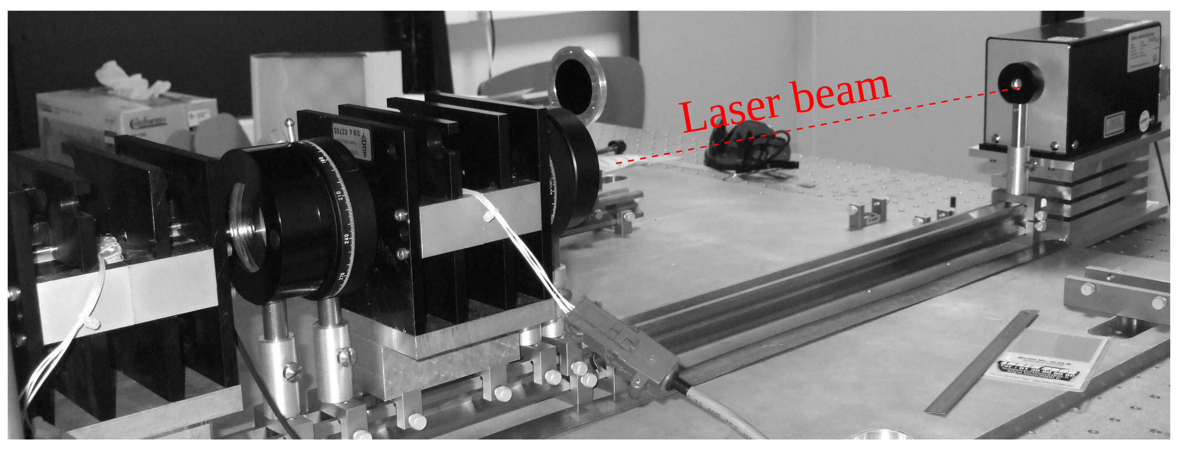
$$V = V^L + V^R$$

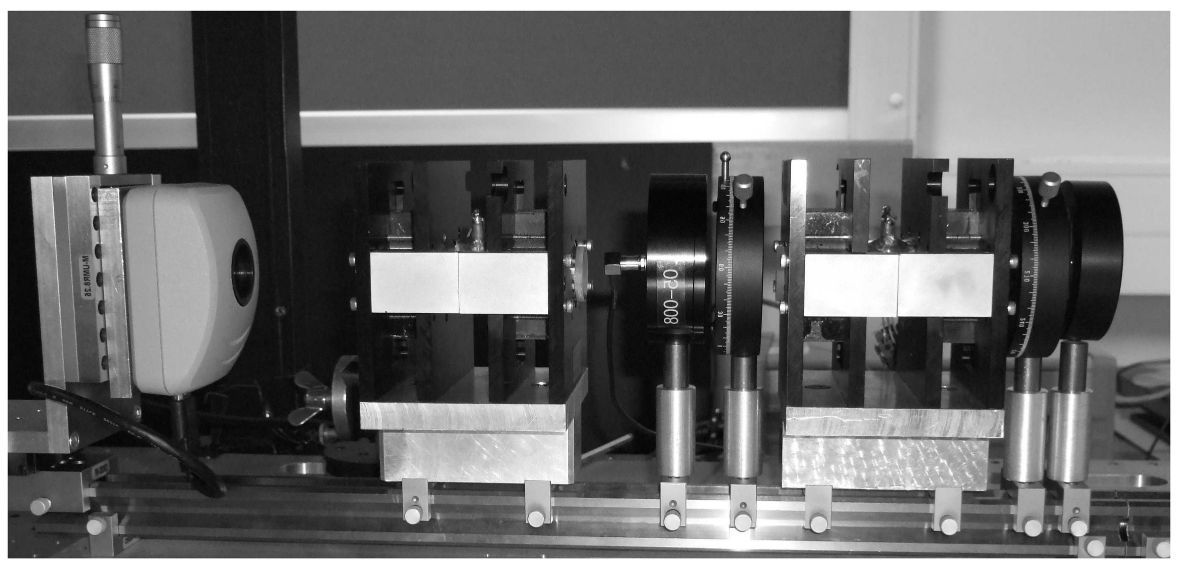
$$M = V^L - V^R$$

$\lambda/4$: quarter wave optical, $\lambda/2$: half wave optical (liquid crystal modulator), P : linear polarizor, MOF cell and Wing Selector : magneto-optical-filter composed of potassium around 100 ℃ under an applied magnetic field of 3000 G. λ_0 is the potassium D1 absorption line at 769.9 nm.

The intensity of the blue and red wings $\mathcal{B}_\mathcal{L}$, $\mathcal{R}_\mathcal{L}$, $\mathcal{B}_\mathcal{R}$, $\mathcal{R}_\mathcal{R}$ respectively of the original zeeman components coming from the sun enables to construct V and M, *i.e.* Dopplergrams and Magnetograms of the Sun's surface ([1]).

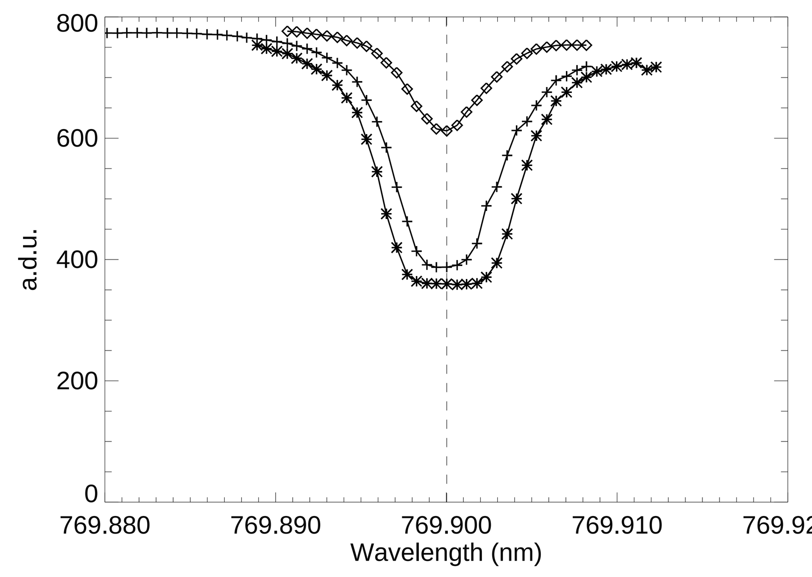
MOF cells calibration





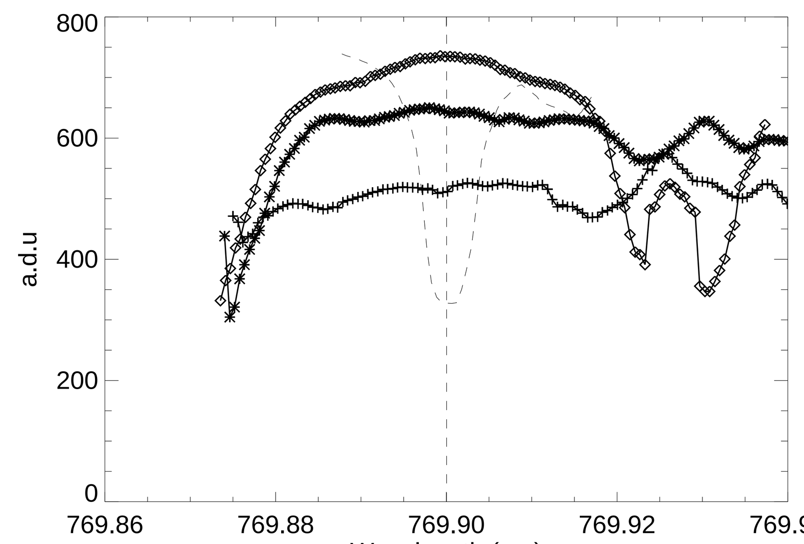
In order to calibrate the bandwidth wavelength of the *MOF* set-up, we use a tunable diode laser system in Littman/Metcalf configuration (top figure) with λ varying from 748 nm to 789 nm by steps of 5×10^{-4} nm.

MOF absorption as a function of temperature



Measurements of the laser beam light absorption by the *MOF* cell as a function of λ, for three different temperatures, $*$: 98℃, $+$: 91℃, $\diamond$: 70℃. ($B = 0$ in this set-up).

MOF emission as a function of temperature



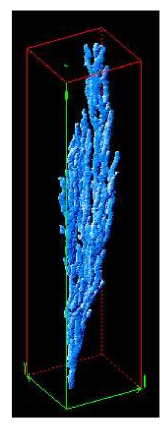
Measurements of *MOF* cell emission as a function of λ, for three different temperatures ($+$: 94℃, $*$ 91℃, $\diamond$: 85℃). Set-up with the *MOF* cell under B between crossed polarizers, with the WS cell ahead and with no optical modulation.

Calibration is under progress, the next step being the optical modulation in order to isolate the Zeeman components from the *MOF* emission signal.

HINODE mission satellite data

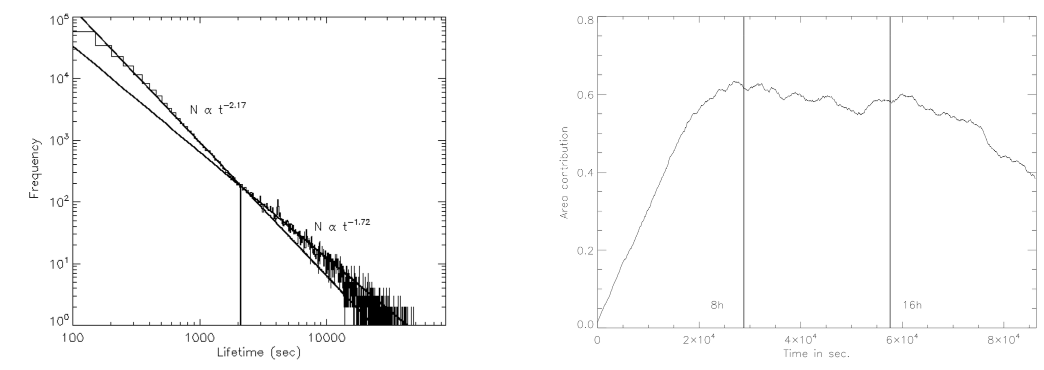
Multi-wavelength data sets of the SOT (Solar Optical Telescope) and instrument aboard the Hinode mission. The SOT has a 50 cm primary mirror with spatial resolution about 0.200. Exceptional continuous record for 48 hours except 7 minutes stop.

Characterization of « TFGs »



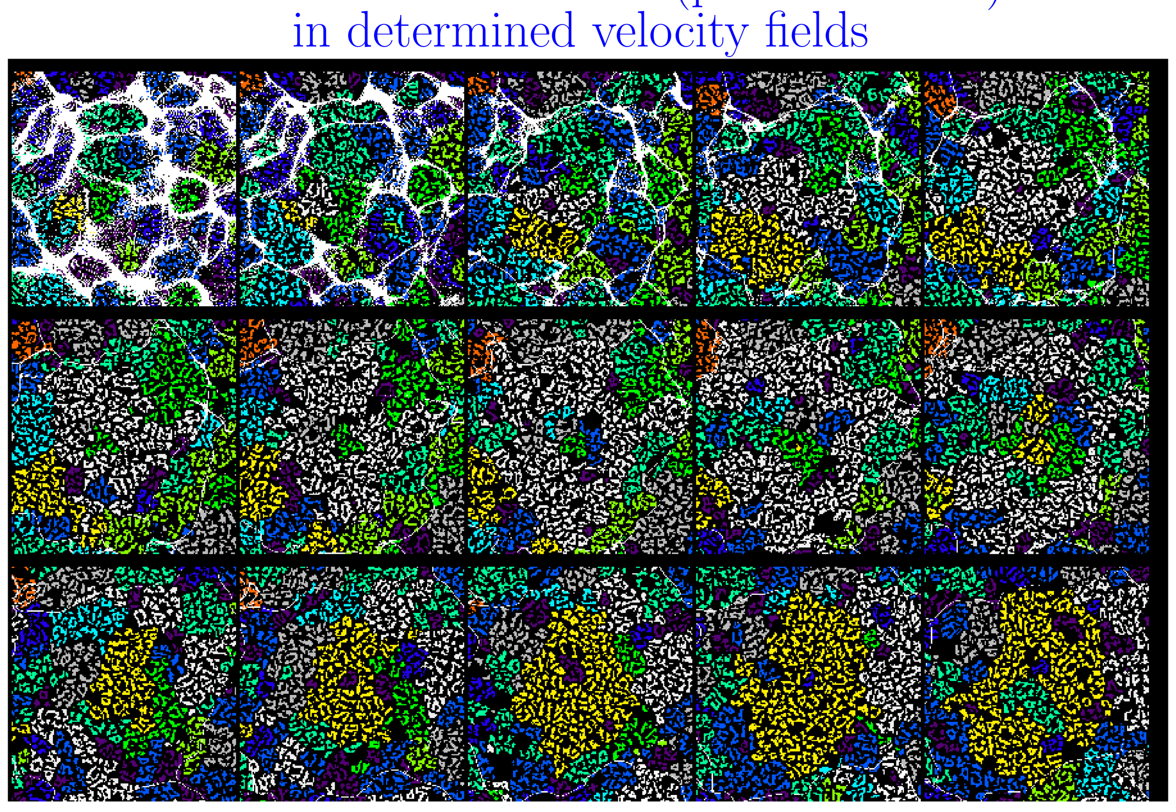
A TFG, « Trees of Fragmenting Granules »(see [4]) consists of a family of repeatedly splitting granules, originating from a single granule at its beginning. The TFGs are used in this study as a tool to quantify the temporal and spatial organization of the solar granulation at large scales.

Figure : Example of fragmentation of granules as a function of time (t is upward).



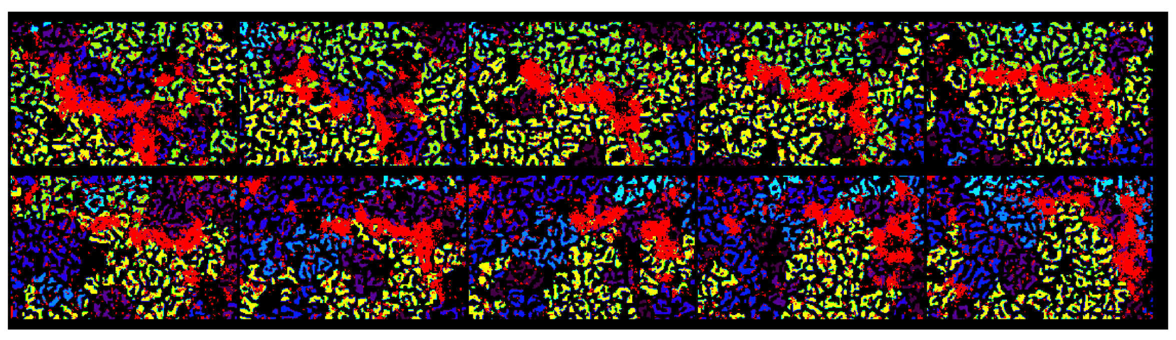
left : Lifetime histogram of individual granules and TFGs for the full time sequence of 48h, *right :* Evolution of the percentage of granules belonging to long-lived TFGs longer than 8h.
Long-lived TFGs lifetime is of the order of the supergranulation lifetime, up to 48 hours. A significant part of surface of the sun (> 60 %) is covered by long-lived TFGs.

Time evolution of corks (passive scalars) in determined velocity fields



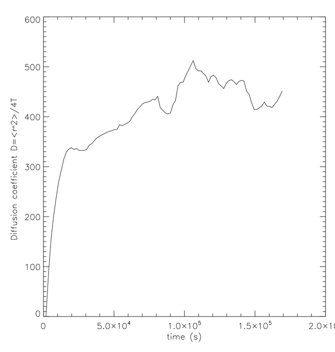
Snapshots of the evolution of families, $\Delta t = 1$ hour. Corks (white) are uniformly distributed at $t = 0$. Movies at `htpp ://www.lesia.obspm.fr/malherbe/papers/Hinode2008/`

Mutual interactions of TFGs expulse corks from initial granular cells and concentrate them on supergranular border lines in approximatively 3h-4h. Then, the long living families tend to control the corks evolution.



Module of the magnetic field (red) and the evolution of TFGs. $\Delta t = 1$ hour.
Corks positions correspond to high magnetic flux zones. The evolution of the magnetic field horizontal motions over the Sun's surface is driven by the evolution and combination of TFGs.

Diffusion coefficient



Diffusion coefficient over 48 hours obtained by corks tracking.

After an initial advection stage, a turbulent diffusion coefficient ≈ 450 km²/s is obtained.

An organization under the form of TFGs is confirmed at the Sun's surface using exceptional high resolution and longtime continuous measurements. CALAS and Hinode measurements are complementary in order to have the best picture of the physics underlying granulation and supergranulation at the Sun's surface. Numerical simulation are presently carried out to compare observations to modelization.

References

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Acknowledgments

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