Signatures of nanoflares and turbulence observed in EUV by SoHO/SUMER

Éric Buchlin[1,2]

Jean-Claude Vial[1] Philippe Lemaire[1]

[1]Institut d'Astrophysique Spatiale
CNRS – Université Paris Sud, Orsay, France

[2]Dipartimento di Astronomia e Scienza dello Spazio
Arcetri, Università di Firenze, Italy

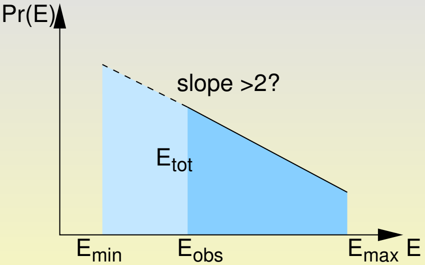
eric.buchlin@ias.fr

Four Solar Cycles of Space Instrumentation — Philippe Lemaire
19 November 2004

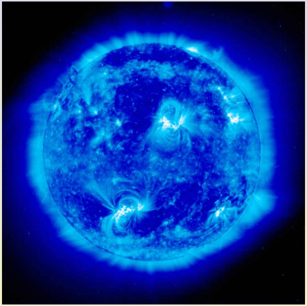
Small-scale heating events in the corona

Heating in the corona is *impulsive* $\longrightarrow$ "events", which may be small (nanoflares, Parker 1988)

Event energies distributed as power-laws.
Hudson (1991):



Need of *statistics*



EIT 17.1 nm, 11 Sep 1997

Turbulence and small scales

Reynolds number in corona: $\approx 10^{14}$

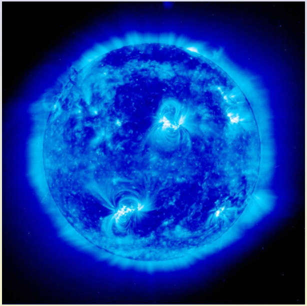
Turbulence $\Longrightarrow$ high complexity, and energy cascade on wide range of scales, up to 10 m (unresolved!)

Small structures:

$\longrightarrow$ allow high dissipation efficiency

$\longrightarrow$ dissipation in these structures could correspond to nanoflares

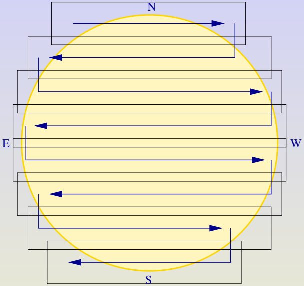
Need of *statistics*

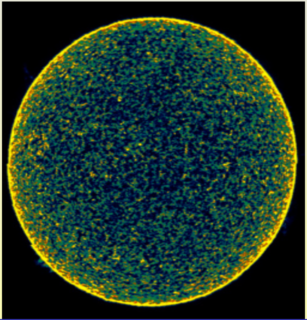


EIT 17.1 nm, 11 Sep 1997

SUMER data set

- *Full Sun* images, rastered by spectroheliograph slit
- 36 images,
  April to October 1996
- Resolution: $1.5 \times 1\,\mathrm{arcsec}^2$
- Line parameters *computed onboard* (information loss, but still spectroscopic measurement)
- Some reference spectra (whole detector)

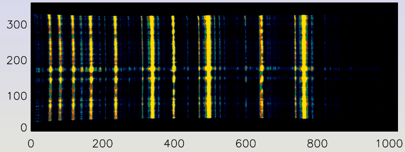


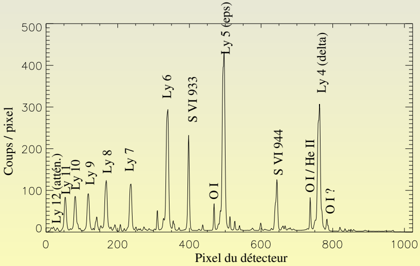


Lines

Parameters (computed onboard):

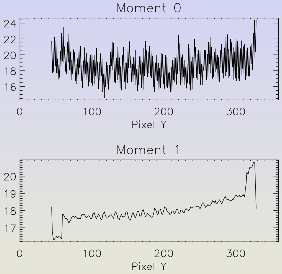
- (0) S VI 933 intensity (maximum)
- (1) S VI 933 Doppler velocity
- (2) S VI 933 line width
- (3) Ly ϵ intensity
- (4) S VI 944 intensity





Data correction and calibration

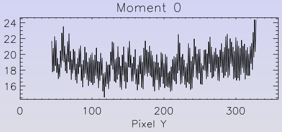
- Empirical correction of systematic errors due to instrumental effects (flat field, distorsion...)

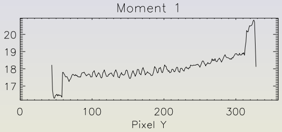


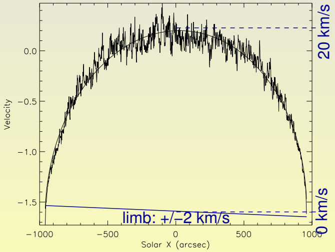
Data correction and calibration

- Empirical correction of systematic errors due to instrumental effects (flat field, distorsion...)

- Calibration with average profiles along equator
- Velocity unit: 1 pixel redshift (14 km/s)



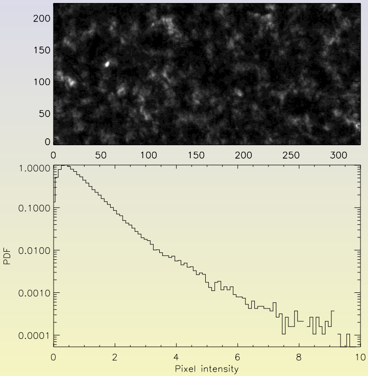




S VI 933 line shift

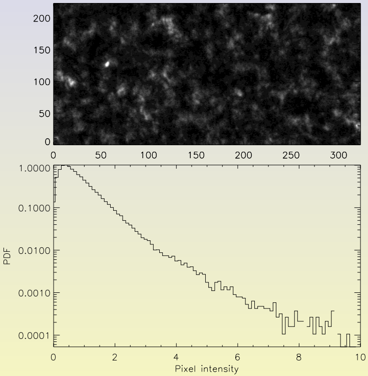
Field values distributions

S VI 933 intensity:

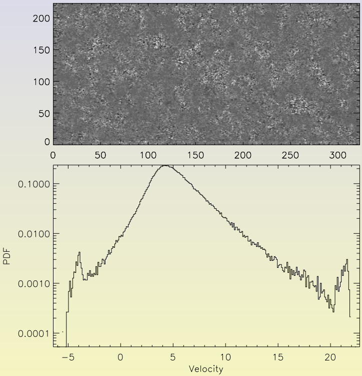


Field values distributions

S VI 933 intensity:



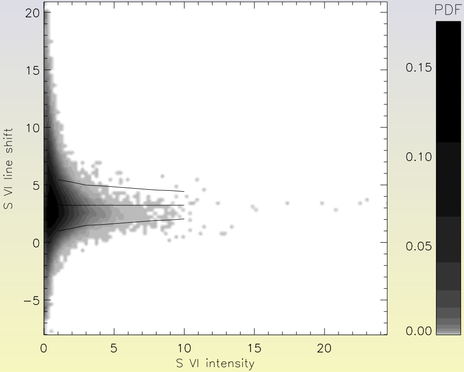
S VI 933 velocity:



Noise (S VI 933 velocity)

Problem: 3 s exposure time only

Noise simulations (as in Wilhelm 1989, ESA SP-1104), for velocity, superimposed on intensity-velocity scatter plot:



Noise is much lower for intensity

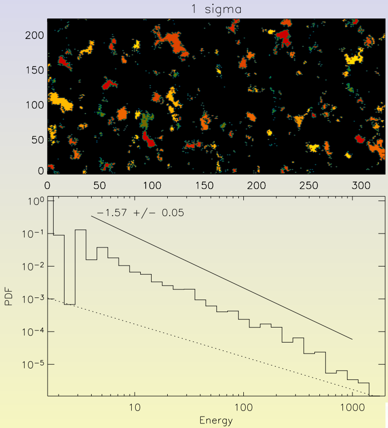
Distributions of SUMER intensity events

- *Detection* of events:
  one event = an area above an *intensity threshold*

- Get *statistics* of their characteristics.

S VI 933, threshold is $\bar{I} + \sigma_I$

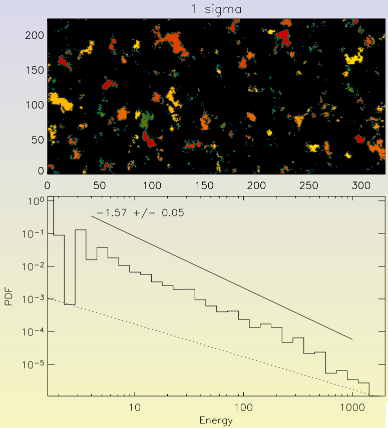
21 July 1996 (same for other dates)



Distributions of SUMER intensity events

S VI 933, threshold is $\overline{I} + \sigma_I$

21 July 1996 (same for other dates)

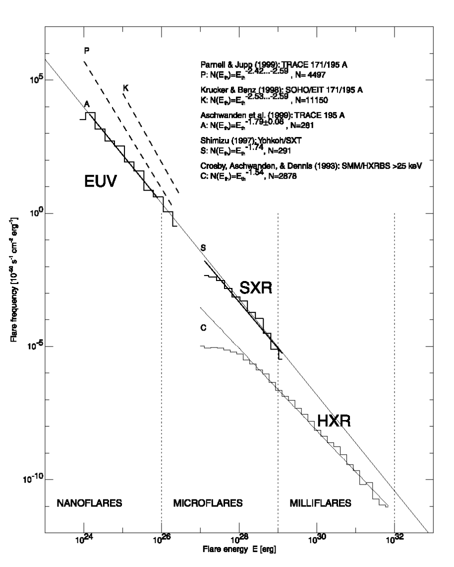


- *Detection* of events: one event = an area above an *intensity threshold*
- Get *statistics* of their characteristics.

Tried to find also "velocity events" (kinetic energy), but too much noise!

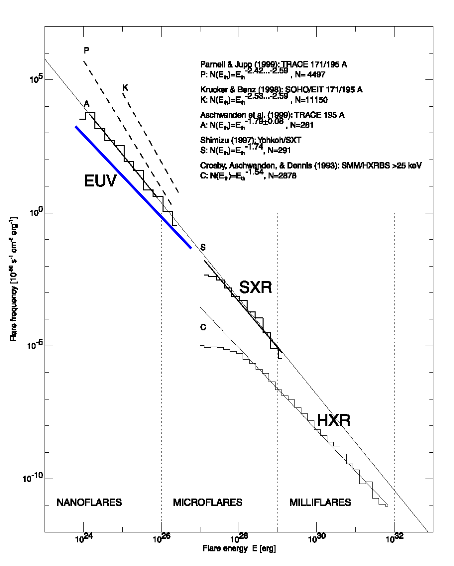
Distributions of events (literature)

- Aletti *et al.* 2000: EIT 195 intensity, threshold
- Parnell & Jupp 2000: TRACE intensity, with clustering (threshold) with some time information
- ...
- Some of them summarized in Aschwanden *et al.* 2000:



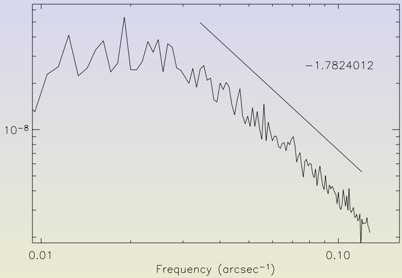
Distributions of events (literature)

- Aletti *et al.* 2000: EIT 195 intensity, threshold
- Parnell & Jupp 2000: TRACE intensity, with clustering (threshold) with some time information
- ...
- Some of them summarized in Aschwanden *et al.* 2000:



Fourier spectra of the fields

S VI 933 intensity:

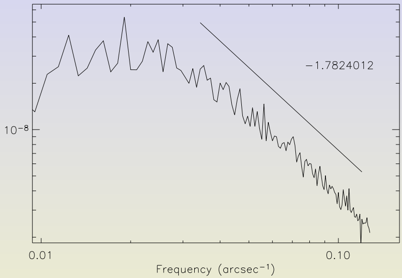


Martens & Gomez 1992,
Benz *et al.* 1997 (Yohkoh/SXT),
Berghmans *et al.* 1998 (SOHO/EIT)
$\longrightarrow \approx -2.5$

Espagnet *et al.* 1993 (photosphere)
$\longrightarrow \approx -5/3$

Fourier spectra of the fields

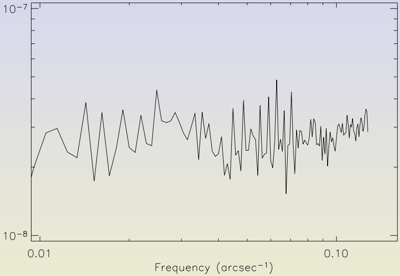
S VI 933 intensity:



Martens & Gomez 1992,
Benz *et al.* 1997 (Yohkoh/SXT),
Berghmans *et al.* 1998 (SOHO/EIT)
$\longrightarrow \approx -2.5$

Espagnet *et al.* 1993 (photosphere)
$\longrightarrow \approx -5/3$

S VI 933 velocity:



Would need less noise to get (the first?) velocity spectrum in the corona

Intermittency

$\longrightarrow$ deviation from Kolmogorov 41 turbulence theory

$\Longrightarrow$ shape of distribution of increments $\delta_\ell a$ of field a depends on scale ℓ

Signature: normalized structure functions $\frac{\langle|\delta_\ell a|^q\rangle}{\langle|\delta_\ell a|^2\rangle^{q/2}}$ get larger for small scales ℓ

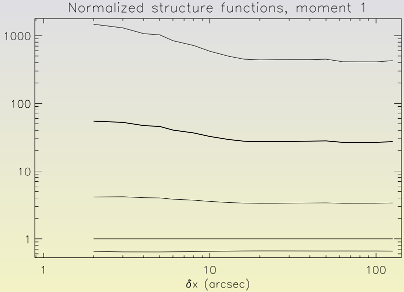
Examples:

- Abramenko *et al.* 2002, BBSO, Huairou and SOHO/MDI magnetograms
- Patsourakos & Vial 2002, SUMER lightcurves

Intermittency: normalized structure functions $\frac{\langle|\delta_\ell a|^q\rangle}{\langle|\delta_\ell a|^2\rangle^{q/2}}$

(flatness for $q = 4$)

S VI 933 intensity:

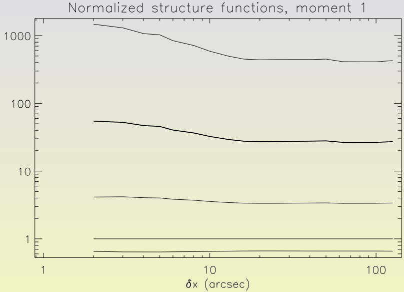


Intermittency

Intermittency: normalized structure functions $\frac{\langle|\delta_\ell a|^q\rangle}{\langle|\delta_\ell a|^2\rangle^{q/2}}$

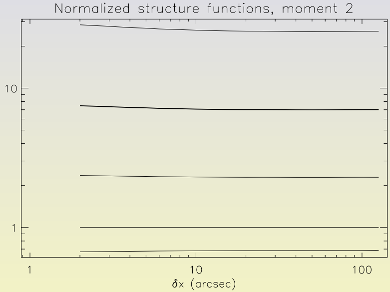
(flatness for $q = 4$)

S VI 933 intensity:



Intermittency

S VI 933 velocity:



Some slight intermittency visible in spite of noise

Conclusions

- Signatures of small-scale heating: events distributions, field Fourier spectra
- Too much noise in velocity field to get events or spectra. Compromise between low noise (exposure time, resolution) and large number of pixels (necessary for statistics)
- Intermittency: quite strong in intensity, still visible in velocity

Conclusions

- Signatures of small-scale heating: events distributions, field Fourier spectra
- Too much noise in velocity field to get events or spectra. Compromise between low noise (exposure time, resolution) and large number of pixels (necessary for statistics)
- Intermittency: quite strong in intensity, still visible in velocity

Conclusions

- Signatures of small-scale heating: events distributions, field Fourier spectra
- Too much noise in velocity field to get events or spectra. Compromise between low noise (exposure time, resolution) and large number of pixels (necessary for statistics)
- Intermittency: quite strong in intensity, still visible in velocity

Conclusions

- Signatures of small-scale heating: events distributions, field Fourier spectra
- Too much noise in velocity field to get events or spectra. Compromise between low noise (exposure time, resolution) and large number of pixels (necessary for statistics)
- Intermittency: quite strong in intensity, still visible in velocity

Thanks to Philippe!