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Modeling the solar irradiance background via numerical simulation

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Abstract Various small scale photospheric processes are
responsible for spatial and temporal variations of solar emer-
gent intensity. The contribution to total irradiance fluctua-
tions of such small scale features is the solar irradiance back-
ground. Here we examine the statistical properties of irradi-
ance background computed via a *n*-body numerical scheme
mimicking photospheric space-time correlations and cal-
ibrated by means of IBIS/DST spectro-polarimetric data.
Such computed properties are compared with experimen-
tal results derived from the analysis of a VIRGO/SPM data.
A future application of the model here presented could be
the interpretation of stellar irradiance power spectra ob-
served by new missions such as Kepler.

Keywords Solar irradiance background

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1 Introduction

The fast and erratic variations, in time and space, of small
scale solar surface features ($\sim 10^3$ km) produce an integrated
high frequency noise signal called Solar Irradiance Back-
ground (Rabello Soares et al. 1997). Such a high frequency
signal is the response to rapid change in physical properties
associated to surface magnetic and convective features.

Space-borne measurements of solar irradiance performed
since 1978 show that the irradiance background varies on all
accessible time scales (Willson and Hudson 1988; Fröhlich
1994; Fröhlich and Lean 1998). However, the physical sce-
nario behind this variation remains a subject of debate.

For short time scales (i.e., between few days and few
minutes), the source of variability is still not well under-
stood. Many models have been proposed to reproduce such
rapid variations in solar surface irradiance by means of gran-
ulation, mesogranulation and supergranulation (Andersen et
al. 1994; Rabello Soares et al. 1997) or granulation and mag-
netic fields (Solanki et al. 2003).

Here we present a simple irradiance model based on a
simulation of photospheric downflow dynamics in which
the velocity field is characterized by space-time correla-
tions in agreement with the ones observed on the solar sur-
face. In this paper we explore the reliability of our model
to mimic stellar surface space and time correlations pos-
sibly responsible for the different power spectrum indices
of the intensity background. The modeled stellar surface
space-time correlations are analogous to the observed so-
lar granulation–mesogranulation (see Viticchié et al. 2006;
Berrilli et al. 2008). The temporal evolution of photospheric
downflow plumes produced by the model is here exploited
to mimic the variation of the intensity background due to the
appearance/disappearance of downflows on the solar photo-
sphere. The intensity contribution of each downflow plume

is calibrated through spectroscopic and broad-band observations.

2 Dataset and calibration

To obtain the relationship between the velocity field and the intensity that will be implemented in the irradiance model, we used observations performed at the NSO/Dunn Solar Telescope in November 21, 2006 from 16:24 UT to 17:17 UT. These consist of a time sequence of a 2.3 pm-step sampling of the FeI 630.15 nm photospheric line plus simultaneous broad-band (633.32 ± 5 nm) counterpart. The whole sequence is of 36 images with a time cadence of 90 sec. The target of the observation was a 39.1″ × 39.1″ quiet Sun region at disk center. The velocity along the line-of-sight for each point of the field-of-view has been calculated via Fourier transform.

We derived a dependence between broad-band intensity normalized to the average intensity over the whole time sequence (I_{BB}) and the velocity along the line-of-sight (v_{los}). To do this we considered average broad-band intensity values calculated over 65 m s^{-1} velocity bins. A 3rd order polynomial fit has been performed to obtain an analytic relation between I_{BB} and v_{los} (see Fig. 1).

3 Irradiance model

3.1 Dynamical model of photospheric velocity field

The model simulates the dynamics and evolution of photospheric downflow plumes on the solar surface as resulting from an advection profile modeled as in Rast (1998). The movement of each plume at each simulation step is defined by the interaction with the other plumes in the computational domain. This model, originally proposed by Rast (2003) to investigate the origin of solar surface convective scales, spontaneously creates stable downflows over mesogranular pattern from the sole interaction taking place over granular scales (for a detailed description of the model, see Viticchié et al. 2006; Berrilli et al. 2008).

3.2 Irradiance model

In the preliminary version of the irradiance model, the upflow contribution is not taken into account, i.e., the power spectrum is defined by the intensity variation due to the sole appearance/disappearance of downflows on the solar surface. This choice is motivated by the fact that the dynamical model described in Sect. 3.1 only mimics the evolution of downflows on the solar photosphere. This means that, referring to the polynomial fit reported in Fig. 1, we take into account only the relation for positive values of the line-of-sight velocity. The simple idea to model the time variation of the irradiance is to rescale the downflow velocity range retrieved by the dynamical model to the one obtained from observations. More in detail, we associated the velocity measured in the strongest observed downflow to the velocity of the strongest downflow in each simulation.[1] In this way, we can easily get a relation between the downflow velocities from the simulation and the observed broad-band intensity values. By integrating the contribution of the intensities related to all the downflows we get the temporal evolution of irradiance from the model.

The model simulates the irradiance emerging from a small portion of solar surface (about 30 × 30 Mm^2) that is considered to be representative of the properties of the solar irradiance integrated over the whole disk.

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[1]This association can be done since the values of the velocity from the model are represented with arbitrary units.

Fig. 1 Broad-band intensity vs. velocity along the line-of-sight for the whole dataset (*yellow scatter plot*). Triangles represent average broad-band intensity values calculated over 65 m s^{-1} velocity bins; error bars are calculated as $10 \times \sigma/\sqrt{N}$, where N is the number of counts in each bin. The *red line* represents the 3rd order polynomial fit
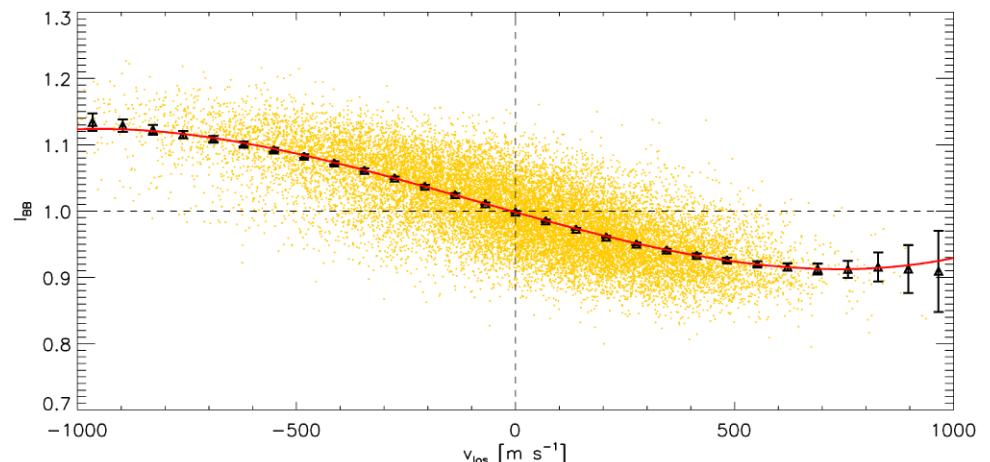
4 Preliminary results

Four simulations have been performed, each representing an equivalent of about 2000 min of photospheric evolution with a temporal resolution $\lesssim 1$ min. The total time interval of the simulations is set to be larger than the mesogranular time scale (i.e., the largest time scale produced by the model). The four simulations differ only in the initial spatial distribution of the plumes that is set randomly. The variation of the intensity with time derived from the four simulations (Fig. 2, left panel) allows to calculate four simulated power spectra in the frequency range 10^2–10^4 μHz (Fig. 2, right panel); the results are shown in comparison with the power spectrum derived from VIRGO/SPM[2] data with a temporal cadence of one minute.

The simple irradiance model here described is able to reproduce the right power spectrum for frequencies between 10^2–0.5×10^3 μHz. In the range 0.5×10^3–10^4 μHz, a strong deviation with respect to the observational spectrum is found, indicating a too high power associated to high-frequencies.

We have to remember that, at the present stage, we are not taking into account any information related to the spatial extension of the downflows on the 30×30 Mm^2 domain; i.e., downflows chains extending over typical scales of few arcseconds should be identified as a single intergranular lane, not as many point-like downflows. From this follows that

the effect of a large number of highly-variable downflows produces the obtained excess of power at high frequencies.

5 Conclusions

The knowledge of the solar irradiance background is of great importance for solar and stellar physics. Here we present a model for the description of the solar irradiance background based on a numerical simulation of the photospheric velocity field (Rast 2003).

The present implementation of the irradiance model presented in Sect. 3 allows a good description of the portion of the irradiance spectrum in the 10^2–0.5×10^3 μHz frequency range. A new implementation of the code, to take into account the effect of the spatial coherence of the downflows into spatially extended intergranular lanes should allow a much better description of the spectrum also in the range 0.5×10^3–10^4 μHz, where the model retrieves an excess of power; we are currently working on this aspect.

A further aspect to take into account is that the n-body simulation here used has been tuned via free parameters to reproduce the solar photosphere space-time correlations (Viticchié et al. 2006). A further step in our investigation will be to check whether the modification of the simulated space-time scales affect the irradiance background spectrum. If so, the model could help us to perform a classification of the stellar surface properties through the analysis of the irradiance power spectrum. The NASA Kepler mission[3]

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[2]See the VIRGO/SPM web page: http://www.ias.u-psud.fr/virgo.

[3]See the Kepler mission web page: http://kepler.nasa.gov.
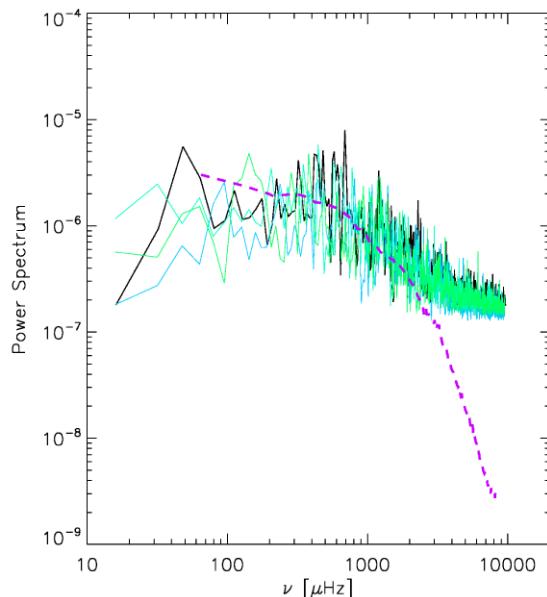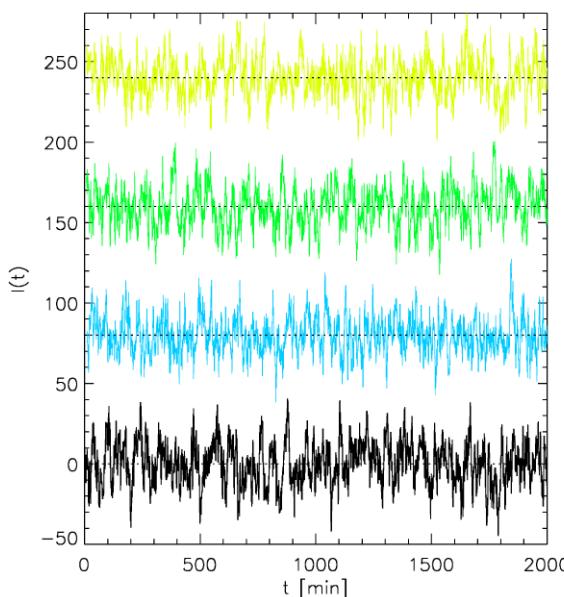
Fig. 2 *Left panel*: temporal variation of the intensity as derived by the four simulations (here reported in arbitrary units). *Right panel*: Power spectrum derived from the four curves in the *left panel*; the

different colors adopted refer to the ones used in the *left panel*. The VIRGO/SPM power spectrum is also reported in the plot (*pink dashed line*)

will observe all stars brighter than $V \simeq 11.5$ at a cadence of 1 minute over a period of 1–3 months in order to analyze p-mode oscillations. These observations will be optimal to compute intensity background power spectrum of the observed stars and derive space and time correlations from our model.

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