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The source of the solar oscillations: below or above?(*)

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Summary. — The origin of the solar oscillations has not yet been clearly demonstrated. The downflows due to the convective rapid cooling at the surface have been invoked to be a possible source. The properties of the source as inferred from the local analysis of the intensity-velocity phase difference are investigated: the correlation between the so-called solar background with the Hα bright points and the same spatial and temporal characteristics of other observed events suggest the downward plasma jets related to the explosive chromospheric evaporation to be a possible candidate for the background.

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1. – Introduction

This paper wants to summarise a provocative discussion on the possible nature of the solar oscillations.

Despite of the large impact helioseismology has produced in solar physics, the origin of the oscillations has not yet been clearly revealed, that is, what mechanism generates the pressure fluctuations whose constructive interference in the solar cavity draw the trait of the p-modes.

The first experimental identikit of the source has been drawn by the asymmetry of the p-modes line profiles [1]. This effect has been primarily interpreted as the presence of a localised excitation source [2, 3] in a thin layer near the top of the convection zone.

Years after, Deubner [4] discovered a solar "background" in the ℓ-ν diagram of the phase difference between the intensity and velocity signals (I-V). Different scenarios have been invoked to explain the observed trait of the background.

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The model proposed by [5] interprets the background in terms of the response of a cavity in the atmosphere. Another model explains the results in terms of the source, primarily identified with the fast cooling associated to the "downdrafts" [6]. This latter interpretation is consistent with the observations of [7-9]. In fact, seismic events have been detected in correspondence of localised darkenings of downflowing collapsed plasma. These events last few minutes and extend over an area of few arcseconds. These downdrafts are thought to be due to the buoyant acceleration after a radiative cooling at the surface, that is, statistically triggered by convection. The Skartlien and Rast [6] "downdrafts" model is the only one which invokes a real physical mechanism for the source of the solar oscillations.

Recently, a correlation between the magnetic oscillations, Hα bright points and background locations as revealed with a local analysis has been found [10, 11].

Observational results are often in disagreement when finding spatial and temporal correlation between Ca K bright points, UV jets, etc. [12-14]. Nevertheless, the evidence in the photosphere of a strong seismic downplume associated to a big flare has been detected by MDI [15]; and high ℓ-degree modes excitation has been reported too [16]. Events of the same kind were predicted to be a possible origin of free oscillations in the Sun [17].

2. – The solar background as a signature of the source of the solar oscillations

The presence of a solar background in the ℓ-ν diagram of the phase difference between the intensity and velocity signals (I-V), has been associated to a possible signature of the source of the resonant oscillations. Many of the differences in the values obtained from different data sets (GONG, MDI, Kanzelhöhe) can be attributed to different formation heights of the used solar lines and to different ℓ and ν resolutions in the I-V phase difference spectra. To date, the experimental results in the ℓ-ν diagram draw the following trait [4, 18, 19]:

1) the phases are approximately independent of the degree ℓ;

2) the phases on the p-mode ridges depend on the height in the solar photosphere;

3) the phases in the solar background show a step-like behaviour with negative values below about 3.3 mHz and positive values above about 4 mHz.

The data obtained in the sodium D lines (with a local analysis at low-frequency resolution, $4''$ per pixel) show a positive phase in correspondence of the five-minute p-modes and a negative one for the background at the low-frequency band (the detailed data analysis can be found in [11, 20]). In the five-minute band, in correspondence of the high-velocity power locations, the shown phase is that found in the peaks of the p-modes, while where the velocity power is low, the negative phase is found (and attributed to the background).

The spatial distribution of the background along the frequency domain has been studied.

I summarise the obtained results and a possible interpretation.

1) The background locations, in the five-minute band, are associated to those points where the velocity power is low. This could mean that the p-modes are acting as a selective filter for a uniform background distribution over the disk. At this point, the correspondence to the magnetic oscillating points is not a proof of a physical relation between the magnetic field and the background, since the magnetic points usually cor-

respond to low-velocity power locations. For this reason the spatial distribution of the background is studied at low frequencies, where the contamination is largely reduced.

2) At low frequencies, the probability to found the background at the same location is much larger than expected. The increase of the area filled by the background is compatible with a 0.5 coverage of $4''$ border line of a $50'' \times 50''$ region; the non-uniform spatial distribution is confirmed by the trait of the coverage, that seems to cluster around structures of the same order of magnitude (this is consistent with the observations of [21], where a preferential occurrence of 560 events per second over the global solar surface is reported). This suggests the presence of localised phenomena.

3) The autocorrelation of the phase coverage maps shows the rotation of the structures associated to the p-modes (at the five-minute band), but not for the background, whose characteristic scale is of the order of one pixel. This can be interpreted with a rotating subarcsec structure during the observing run, or to structures at the limit of the spatial resolution but lasting a period whose trace during the rotation at disk center is confined in one pixel, that is, less than 30 minutes.

The characteristics of the events invoked by Skartlien and Rast [6] as the source of the solar oscillations seem to match very well with the results of the local analysis of the sodium D lines data, even if the spatial resolution is low. This limitation could make the determination of the phase values uncertain, but the results would not change since two distinct phases are observed, whose values are much different in comparison to the possible systematic errors. Nevertheless, the non-resolved events do not permit to establish a direct cause-effect relation with the distinct phenomena, and the investigation on the timeseries (instead of the FFTs) has not achieved a successful result. Higher-spatial-resolution multilayer observations are needed.

3. – A provocative suggestion

Some processes can be invoked to justify the spatial distribution of the background locations. Let the interpretation of the localised events be assumed: they are of the order of some arcsec and last some minutes.

Some questions remain unanswered? What are the border lines where the background locations seem to cluster? Are they related to the supergranular lanes, the magnetic network, or something else?

The bright points, where the morphology correlation has been found with the background locations, are those structures where typically the plasma downflows associated to flares have been reported [22]. Moreover, some observations confirm a close correspondence between the Hα and sodium events [23].

At this point, assumed the photospheric downflows to be the “bullets” of the solar oscillations, the search of a possible chromospheric “killer” is based on circumstantial evidence.

We look for events, at time and spatial scales comparable to the downflows in the photosphere, whose mechanisms can be physically related and whose observations are consistent. The “convective” downflows are correlated to the intergranular lanes, where the magnetic cancellations are expected to occur. This latter process may produce a magnetic island causing a secondary reconnection in the upper layers [21]; the observed upward UV plasma jets have been often observed with associated Hα bright points. The upflows have been investigated in detail [24] and the upward energy input in the corona is a long story [25]. What can deny the photospheric downflows to be related to the downward counterpart?

Some observations confirm the perturbation at the surface induced by a downplume after a big flare [15] and the lack of cospatiality suggests the non-vertical propagation of the plasma.

It has been established that when a Hα downflow has been detected (in the bright points) in correspondence of an upflowing plasma UV jet, the involved mechanism is mainly the chromospheric explosive evaporation [22, 26, 27]. The main characteristics of these events are selected through the atmosphere by the energy deposition rate, whose value leads to an explosive event or not. In the solar chromosphere these explosions are related to typical spatial and temporal scales: some arcsecs and few minutes. Moreover, the compressed downflowing plasma is cool (dark) in comparison to the surroundings [26] (Briand, private communication). Let us estimate, only from the observational evidence, the kinetic energy injected by the downward counterparts of the UV jets at scales of approximately 2 arcsec.

Following [22], the momentum of the downward plume is 2×10^{21} g cm s^{-1} and the average velocity 30 km s^{-1}, that is a kinetic energy per event equal to 3×10^{27} erg. In order to estimate the total injected energy input, the global Sun birthrate is needed. From the related UV measurements, the global Sun birthrate of the impulsive brightenings strongly depends on the threshold used to select the events. Using the recent results from EIT on board SOHO [28], the birthrate spans from 10 to 40 s^{-1}. In summary, the energy input varies from $\simeq 5 \times 10^{28}$ erg s^{-1} to $\simeq 2 \times 10^{29}$ erg s^{-1}. This range is consistent with the one measured by [29] for the energy input to the p-modes. Similar values are estimated by [9] for the energy input rate due to the 5000 s^{-1} photospheric downflows. At this point, the different phenomena (convective and flare downflows) seem to be in competition.

More energetic flares can be included to contribute to the total energy input, but they have longer temporal and larger spatial scales and such events should not satisfy the threshold imposed by the energy deposition rate to initiate the explosions.

We have assumed that, when the Hα and UV jets are observed at arcsec scales, the energy deposition rate in the chromosphere has been enough to inject the plasma in the lower layers of the solar atmosphere (referred to as an "electron beam flare" [30]). Did those downward jets reach the photosphere? Are they reflected by the magnetic topology or squashed into the higher density layers? The total energy input can be multiplied for a penetration coefficient to take into account these possibilities. We know the perturbation of the flare to reach, at least, the sodium formation layers. Nevertheless, the results obtained by the Kosovichev and Zarchova [15] show the seismic event to mainly preserve, in the photosphere, the spatial and temporal characteristics observed in the higher layers. This suggests the penetrability of such jets to be high. If this is true, there is a contradiction between the energy input and the number of events. In fact, I estimated the energy input from the downward counterpart of the chromospheric impulsive events to be sufficient to drive the p-modes. I used the larger coefficient of penetration (equal to one). Why the number of downflows in the photosphere (5000 s^{-1}) is much larger than the one related to the chromospheric events (40 s^{-1})? That is, are the chromospheric events missing due to an observational selection and the coefficient of penetration lower? Or are the photospheric downflows not related to the "raining" downplumes?

High spatial and temporal resolution, multilayer observations are needed to solve these dilemma: *Are the downward plumes caused by the flares the trigger for the con-*

vective photospheric instabilities and do they survive into the photosphere? Moreover, is really the solar background a signature of the source or simply the noise generated by the explosive events?

From the preliminary results, I invoke the downward counterpart of the chromospheric explosive events to justify only the behaviour of the solar background at low frequencies.

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REFERENCES

[1] Duvall T. L., Jefferies S. M., Harvey J. W., Osaki Y. and Pomerantz M. A., *Astrophys. J.*, **410** (1993) 829.
[2] Gabriel M., *Astron. Atrophys.*, **265** (1992) 771.
[3] Roxburgh I. W. and Vorontsov S. V., *Mon. N. R. Astron. Soc.*, **272** (1995) 850.
[4] Deubner F. L., Fleck B., Marmolino C. and Severino G., *Astron. Astrophys.*, **236** (1990) 509.
[5] Deubner F. L., Waldschik Th. and Steffens S., *Astron. Astrophys.*, **307** (1996) 936.
[6] Skartlien R. and Rast M. P., *Astrophys. J.*, **535** (2000) 464.
[7] Espagnet O., Muller R., Rouder Th., Mein N. and Malherbe J. M., *Astron. Atrophys.*, **313** (1969) 297.
[8] Goode P. R., Strous L. H., Rimmele T. R. and Stebbins R. T., *Astrophys. J.*, **495** (1998) L27.
[9] Strous L. H., Goode P.R. and Rimmele T. R., *Astrophys. J.*, **535** (2000) 1000.
[10] Moretti P. F., Cacciani A., Hanslmeier A., Messerotti M., Otruba W. and Warmuth A., *Dynamics of the Sun*, edited by A. Hanslmeier and M. Messerotti, *Astrophysics and Space Science Library*, **259** (2001) 243.
[11] Moretti P. F., Oliviero M., Severino G. and The MOF Development Group, *ESA SP*, **464** (2001) 661.
[12] Lites B. W., Rutten R. J. and Berger T. E., *Astrophys. J.*, **517** (1999) L1013.
[13] Hoekzema N. M., Rutten R. J. and Cook J. W., *Astrophys. J.*, **474** (1988) 518.
[14] Cook J. W., Rutten R. J. and Hoekzema N. M., *Astrophys. J.*, **470** (1996) 647.
[15] Kosovichev A. G. and Zarkhova V. V., *Nature*, **393** (1998) 317.
[16] Haber D.A., Toomre J. Hill F. and Gough D., *ESA SP*, **286** (1988) 301.
[17] Wolff C. L., *Astrophys. J.*, **176** (1972) 833.
[18] Straus Th., Fleck B., Severino G., Deubner F. L., Marmolino C. and Tarbell T., *ESA SP*, **417** (1998) 293.
[19] Oliviero M., Severino G., Straus Th., Jefferies S. M. and Apporchaux T., *Astrophys. J.*, **516** (1999) L45.
[20] Moretti P. F., Cacciani A., Hanslmeier A., Messerotti M., Oliviero M., Otruba W., Severino G. and Warmuth A., *Astron. Atrophys.*, **372** (2001) 1038.
[21] Chae J., Wang H., Lee C., Goode P. R. and Schouhle U., *Astrophys. J.*, **497** (1998) L109.
[22] Canfield R. C., Metcalf T. R., Strong K. T. and Zarro D. M., *Nature*, **326** (1987) 165.
[23] Warmuth A., Hanslmeier A., Messerotti M., Cacciani A., Moretti P. F. and Otruba W., *Solar Phys.*, **194** (2000) 103.
[24] Lee C., Chae J. and Wang H., *Astrophys. J.*, **545** (2000) 1124.
[25] Parker E. N., *Astrophys. J.*, **330** (1988) 474.
[26] Fisher C. H., Canfield R. C. and Clymont A. N., *Astrophys. J.*, **289** (1985) 434.
[27] Zarro D. M., Canfield R. C., Metcalf T. R. and Strong K. T., *Astrophys. J.*, **324** (1988) 582.
[28] Berghmans D., Clette F. and Moses D., *Astrophys. J.*, **336** (1998) 1039.
[29] Komm R. W., Howe R. and Hill F., *Astrophys. J.*, **545** (2000) 472.
[30] Mullan D. J., *Solar Phys.*, **121** (1989) 239.