Chromospheric impact of an exploding solar granule

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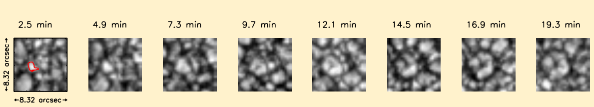
Exploding granule event



A small bright granule (area of 1.35 arcsec^2, contoured in red) is seen in the *Hinode* SP continuum map two and a half minutes into the co-observing sequence. The granule explodes by expanding with a rate of about ~ 0.77 arcsec^2 per minute, and then develops a dark core before splitting into several fragments, finally reaching a ring shaped form with an overall size of about 14 arcsec^2 at T = 19 min. The morphological evolution of our exploding granule in the photosphere is consistent with Hirzberger et al. (1999).

Hinode (Tsuneta et al. 2008)

Spectropolarimeter (SP)

- binned full Stokes 630 nm slit spectra
- spatial sampling of ~ 0.32′′)
- region of about 9 × 81 arcsec^2
- spectral sampling of 21.5mÅ, and a cadence of ~ 70s.

IRIS (De Pontieu et al. 2014)

Slit spectra

- two-step raster (*IRIS*-program: medium sparse 2-step raster)
- cadence of 19 s
- several wavelengths including MgIIh&k at 279.6 nm
- spatial sampling along the slit of 0.166′′
- step size of the 0.33′′wide slit was 1 arcsec.

Additional Hinode Broadband Filter Imager and Narrowband Filter Imager filtergrams were used to align to IRIS slitjaw images. The images were beforehand rebinned to a common spatial scale. To find co-temporal data, the middle of exposure times for filtergrams and the time of the central slit position of the Hinode SP map were chosen.

"Squeezing" of magnetic elements

There is a group of mixed polarity strong magnetic elements (> 500 G) that occupies the intergranular lanes in the vicinity of the exploding granule. After the exploding phase they are arranged in a circle around the granule, outlining its border and tracing the same ring-like pattern as seen in the *Hinode* SP continuum maps. We use the Fourier Local-Correlation-Tracking (FLCT) code by Fisher & Welsch 2008 to obtain two-dimensional (2D) velocity fields inferred from the *Hinode* SP continuum maps.

At T = 9.7 min, the magnetic elements at the edge of the exploding granule at around x = 2′′ and y = 5′′ (Figure on the right, position A) experience strong horizontal velocities from both sides; the interior of the exploding granule and the surrounding granules. This gives the impression of the magnetic elements being squeezed by the opposing flows. This is confirmed by the magnetic flux density evolution.

The contours of the magnetic flux density maps show a stretching out of the magnetic elements, leading to a more elongated shape (compare, for example, panel one at T = 8.5 min and panel three at T = 13.3 min in the middle row of the Figure on the right) and a separation of the magnetic flux elements. This is accompanied by a decrease in the total magnetic field strength as seen in the last row and is therefore not due to a change of the inclination angle tilting the magnetic field.

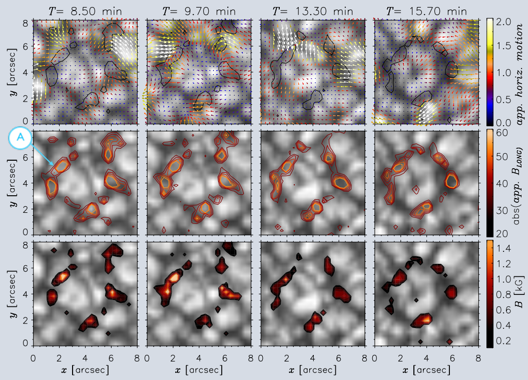


FIGURE CAPTION:
First row: Hinode SP continuum maps with apparent horizontal velocities shown with colored arrows. Black contours long. B_{app} ± 30 Mx cm^{-2}

Second row Hinode SP continuum maps overplotted by contours of the absolute of long. B_{app} magnetic flux density

Last row: Hinode SP continuum maps with filled contours of the magnetic field strength inferred with MERLIN inversions obtained with the default inversion parameters from http://www2.hao.ucar.edu/csac.

Fischer, C. E., Bello González, N., & Rezaei, R. 2017, A&A, 602, L12

Triggering of oscillation

We follow the time development of the (high) photospheric line-of-sight velocity obtained from fits to the *IRIS* Fe I 2799.9 Å line and the *IRIS* Mg II k2v peak intensity (a good indicator of the chromospheric temperature according to Pereira et al. (2013)) in a spatial section along the *IRIS* slit. In both diagnostics, a similar oscillatory pattern is seen, although out of phase, and starting at around T = 10 min for the high photosphere and around 12 min for the chromosphere lasting for a few minutes and located at the area ±0.7′′of the magnetic element location observed in the *Hinode* SP magnetic flux density maps. The oscillatory pattern appears one to two minutes after the previously described squeezing of the magnetic elements at the *IRIS* slit location.

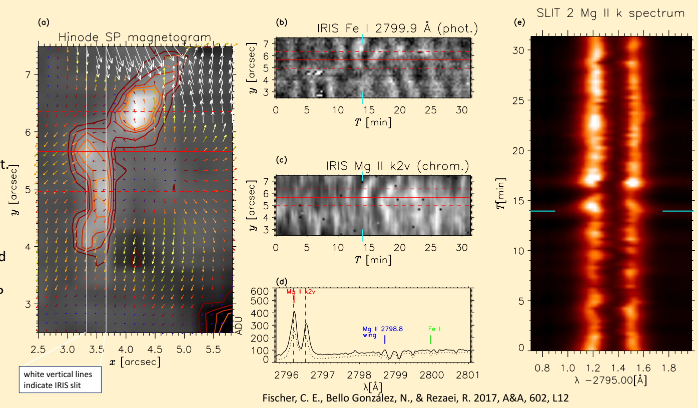


FIGURE CAPTION:
Left to right: panel a): Hinode SP long. B_{app} map now rebinned to the IRIS slitjaw scale with the same contours and horizontal flows as in the Figure above. The two vertical white lines delimit the position of the IRIS slit in use. Two dashed red horizontal lines and a solid red line mark a region of interest.

Panels b) and c) are time-space images derived from spectra recorded by the second IRIS slit. Panel b): line-core velocity of the Fe I 279. nm line (±1.9 km s^{-1} , where down flows are positive) retrieved with the MOSiC code (Rezaei 2017). Panel c): the intensity of the Mg II k2v peak (in data units) obtained by the *iris_get_mg_ f eatures_lev2.pro* code is plotted. The red horizontal lines indicate the same area as in panel a). The short vertical lines in cyan indicate the time of the map in panel a), and panel d) shows a spectrum at that time (solid) and average quiet Sun spectrum (dotted). The dashed vertical lines denote the average position of the Mg II k2 peaks.

The *right panel* demonstrates the temporal evolution of the IRIS slit spectra at the slit location marked by the solid red horizontal line in panels a) to c) with the time of panel a) indicated again with lines in cyan.

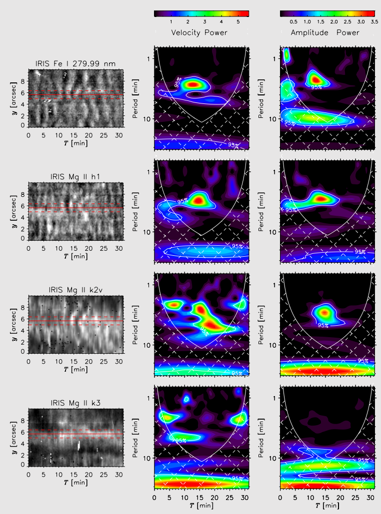
Fischer, C. E., Bello González, N., & Rezaei, R. 2017, A&A, 602, L12

Wavelet analysis

We apply a wavelet analysis on various parameters derived from the *IRIS* slit spectra using the code provided by C. Torrence and G. Compo (http://atoc.colorado.edu/ research/wavelets/) and using the default Morlet wavelet. In the Figure to the right we show the results for the velocity and intensity fluctuations in 1.) the photospheric Fe I 2799.9 Å line, 2.) the Mg II h1 minimum, 3.) the Mg II k2v peak sampling the low to mid chromosphere (Pereira et al. 2013), and 4.) the Mg II k3 sampling the high chromosphere (Leenaarts et al. 2013).

The wavelet analysis shows a power peak in both the velocity and intensity fluctuations of the photosphere to mid-chromosphere diagnostics, with a delay increasing with height between the maximum power. The maximum power is located at a period of between 2 and 3 minutes including also larger periods in the mid chromosphere of up to 5 to 6 minutes. The high chromospheric signatures, as seen with the Mg II k3 amplitude (rightmost panel), show no power and only a weak response in the velocity power. As seen in the left panel mapping the amplitude in intensity, there is an increase visible in the amplitude which implies a change of the transition region height (Pereira et al. 2013).

This could signify dissipation of the shock wave energy and local heating of the high chromosphere. Upward-propagating shock fronts are common in quiet Sun chromosphere, both in observations (Beck et al. 2008) and numerical simulations (Carlsson & Stein 1997; Wedemeyer et al. 2004). We do not find a significant excess emission co-spatial with the chromospheric emission in the C II 1335 Å line of IRIS, which is consistent with our finding that dissipation happens at the middle chromosphere.



Fischer, C. E., Bello González, N., & Rezaei, R. 2017, A&A, 602, L12

FIGURE CAPTION:
Left to right: upper row: a time-space image retrieved from the velocity parameter of the Fe I 2799.9A line(±1.9kms−1) obtained from the IRIS slit spectra using the MOSiC code. The dashed and solid horizontal red lines mark again the same region as in the Figure above. The next two panels show the power for the velocity and the intensity fluctuations at periods ranging from 0.6 min to 21 min at the slit location marked with the red solid horizontal line in the first panel. The power is shown in a logarithmic scale with the hashed area marking periods in which the wavelet analysis yields untrustworthy results. The results obtained with a confidence level of 95% are contoured with a white solid line (not all are labeled).

The *following rows* are in the same format as the first row, now showing first maps of the Mg II h1 minimum obtained through the MOSiC code and the Mg II k2v peak and the Mg II k3 core obtained with the *iris_get_mg_features_lev2.pro* code, where blacked out or white pixels signify a failed feature finding. The power for the velocity and the intensity fluctuations for these parameters are shown in the *second and third panels in each row.*

Conclusion

A magnetic element at the edge of an exploding granule is squeezed by opposing horizontal flows, resulting in an elongation of the isocontours in magnetic flux as seen with the *Hinode* SP, with a chromospheric response consequently being triggered and observed in the *IRIS* spectra. Signatures of an energy deposit in the middle chromosphere are seen through a wavelet analysis of different spectral features in the Mg II h & k spectra.

Our finding is consistent with an upward-propagating shock front triggered by the exploding granule.

Outlook

QUEST (QUiet-sun Event Statistics) is a 5-year Junior research group project at the Kiepenheuer Institute for Solar Physics from May 2018 and co-financed through a Leibniz SAW grant. The aim is to systematically study the quiet-sun using multi-wavelength spectropolarimetric data sets from various telescopes. Such events as described in this poster as well as flux cancellation, convective collapse events and so on will be searched for and characterized from the photosphere to the transition region.

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Hinode is a Japanese mission developed and launched by ISAS/JAXA, collaborating with NAOJ as a domestic partner, NASA and STFC (UK) as international partners.

IRIS is a NASA small explorer mission developed and operated by LMSAL with mission operations executed at NASA Ames Research center and major contributions to downlink communications funded by ESA and the Norwegian Space Centre.

References

Beck, C., Schmidt, W., Rezaei, R., & Rammacher, W. 2008, A&A, 479, 213
Carlsson, M., & Stein, R. F. 1997, ApJ, 481, 500
De Pontieu, B., Title, A. M., Lemen, J. R., et al. 2014, Sol. Phys., 289, 2733
Fisher, G. H., & Welsch, B. T. 2008, ASP Conf. Ser., 383, 373
Fischer, C. E., Bello González, N., & Rezaei, R. 2017, A&A, 602, L12
Hirzberger, J., Bonet, J. A., Vázquez, M., & Hanslmeier, A. 1999, ApJ, 527, 405
Leenaarts, J., Pereira, T. M. D., Carlsson, M., Uitenbroek, H., & De Pontieu, B. 2013, ApJ, 772, 90
Pereira, T. M. D., Leenaarts, J., De Pontieu, B., Carlsson, M., & Uitenbroek, H. 2013, ApJ, 778, 143
Rezaei, R. 2017, ArXiv e-prints [arXiv:1701.04421]
Tsuneta, S., Ichimoto, K., Katsukawa, Y., et al. 2008, Sol. Phys., 249, 167
Wedemeyer, S., Freytag, B., Steffen, M., Ludwig, H.-G., & Holweger, H. 2004, A&A, 414, 1121

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Poster

2. Chromospheric heating and dynamics

Chromospheric impact of an exploding solar granule

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Connecting magnetic field and velocity dynamics in the photosphere with the energetic response in the chromosphere are crucial for our understanding of the physical processes that couple these different regimes in the solar atmosphere. We analyze photospheric full Stokes polarimetric data in the Fe I 630 nm doublet as well as narrowband filter magnetograms in Na I D and broadband images in Ca II H from the *Hinode* satellite. Additional co-temporal and co-spatial NUV and FUV spectra were obtained with the *IRIS* satellite. We follow the process of a rapidly expanding granule in the photosphere interacting with the surrounding magnetic elements. The magnetic elements are squeezed by the convective flows of the granular motions and are compressed. In reaction to the squeezing, we detect a chromospheric intensity and velocity oscillation pulse with a period in the range of 2 to 3 min. Using a wavelet analysis on the chromospheric emission features such as Mg II k2v and Mg II k3 we identify the signal as an upward traveling hot shock front which dissipates in the chromosphere.