4th Hinode *Science Meeting: Unsolved Problems and Recent Insights*
ASP Conference Series, Vol. 455
L. R. Bellot Rubio, F. Reale, and M. Carlsson, eds.

Supersonic Magnetic Flows in the Quiet Sun Observed with SUNRISE/IMaX

J. M. Borrero,[1] V. Martínez Pillet,[2] R. Schlichenmaier,[1] W. Schmidt,[1] T. Berkefeld,[1] S. K. Solanki,[3,4] J. A. Bonet,[2] J. C. del Toro Iniesta,[5] V. Domingo,[6] P. Barthol,[3] and A. Gandorfer[3]

[1]*Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D-79104, Freiburg, Germany*
[2]*Instituto de Astrofísica de Canarias,C/Vía Láctea s/n, 38200 La Laguna, Spain*
[3]*Max Planck Institut für Sonnensystemforschung, D-37191, Katlenburg-Lindau, Germany*
[4]*School of Space Research, Kyung Hee University, Yongin, Gyeongg 446-701, Republic of Korea*
[5]*Instituto de Astrofísica de Andalucía (CSIC), Apdo. de Correos 3004, Granada, Spain*
[6]*Image Processing Laboratory, University of Valencia, P.O. Box 22085, E-46980 Paterna, Valencia, Spain*

Abstract. In this contribution we describe some recent observations of high-speed magnetized flows in the quiet Sun granulation. These observations were carried out with the Imaging Magnetograph eXperiment (IMaX) onboard the stratospheric balloon SUNRISE, and possess an unprecedented spatial resolution and temporal cadence. These flows were identified as highly shifted circular polarization (Stokes *V*) signals. We estimate the LOS velocity responsible for these shifts to be larger than 6 km s^{-1}, and therefore we refer to them as *supersonic magnetic flows*. The average lifetime of the detected events is 81.3 s and they occupy an average area of about 23 000 km^2. Most of the events occur within granular cells and correspond therefore to upflows. However some others occur in intergranular lanes or bear no clear relation to the convective velocity pattern. We analyze a number of representative examples and discuss them in terms of magnetic loops, reconnection events, and convective collapse.

1. Introduction

The interaction between convective motions and the magnetic field in the quiet solar photosphere gives rise to a very rich variety of physical processes: flux emergence/submergence, flux reconnection/dissipation, convective collapse, thermal relaxation, and so forth. Most of these processes occur at very small spatial and short temporal scales, making their direct observations extremely difficult. Fortunately, the spatial resolution, temporal cadence and polarimetric accuracy of modern instruments have improved to a point where these observations are now becoming available, thus making it possible to directly confront theory with observations. Undoubtedly, the spectropolarimeter on-board of the *Hinode* satellite has played a crucial role in this advancement, helping to uncover many of these phenomena: emergence of magnetic loops (Centeno et al. 2007; Martínez González & Bellot Rubio 2009; Zhang et al. 2009; Ishikawa & Tsuneta 2009; Martínez González et al. 2010), convective collapse in intergranular lanes (Nagata et al. 2008; Fischer et al. 2009), horizontal supersonic velocities (Bellot Rubio 2009; Straus et al. 2010), supersonic downflows (Shimizu et al. 2007), horizontal internetwork fields (Ishikawa & Tsuneta 2009), and many more.

A major step has also been achieved thanks to the stratospheric balloon SUNRISE, which was launched from ESRANGE (Kiruna, Sweden) in June 2009 (Solanki et al. 2010; Barthol et al. 2011). During its flight, one of the scientific instruments on-board of SUNRISE, the Imaging Magnetograph eXperiment (IMaX; Martínez Pillet et al. 2011a) recorded spectropolarimetric data with an unprecedented spatial resolution (0.″15) and temporal cadence (32 seconds). These data have already been employed to reveal further details about the dynamics of the magnetic field in the quiet Sun, such as vortex flows (Bonet et al. 2010), vortex tubes (Steiner et al. 2010), dynamics of horizontal internetwork fields (Danilovic et al. 2010), and supersonic magnetic upflows (Borrero et al. 2010). The latter paper uncovered the existence of highly blueshifted polarization signals at the center/edges of granular cells, that were interpreted as the signature of supersonic magnetic upflows. Those authors also found evidence that supports the idea of these flows being caused by magnetic reconnection. However, only about 70% of the detected events could be ascribed to this scenario. In this contribution we investigate in more detail some of the events that were found and present a detailed study on whether they harbor supersonic velocities.

2. Observations

During SUNRISE's arctic flight, the IMaX instrument recorded polarimetric data (Stokes I, Q, U and V) in five wavelength positions across the Fe I 5250.217 Å ($g_{\rm eff} = 3$) spectral line. A full observing cycle was completed every 32 seconds. The spatial resolution of the observations has been estimated to be 0.″15 × 0.″18 in a 46″ × 46″ field of view. A number of factors contributed to IMaX's unprecedented spatial resolution. First and foremost, at a height of 35 kilometers most of Earth's atmospheric disturbances could be avoided. In addition, a great pointing stability was achieved by the Correlation tracker and Wavefront Sensor (CWS; Schmidt et al. 2004; Berkefeld et al. 2011). Finally, the excellent optical quality of the telescope and instruments left few remaining seeing effects and aberrations, which were subsequently corrected employing a phase-diversity calibration of the point spread function of the optical system.

The five tuning positions for IMaX dual-pass Fabry-Perot were $\lambda - \lambda_0 = -80, -40, 40, 80$, and 227 mÅ, with $\lambda_0 = 5250.217$ Å being the observed (solar) central wavelength for the aforementioned neutral iron line. The last tuning position, hereafter referred to as *continuum*, was employed in order to correct any residual cross-talk after the polarimetric calibration was performed. Even after the removal of excess cross-talk, a number of features could be detected in the 2D images of the circular polarization in the continuum, V_c (see Fig. 1 in Borrero et al. 2010)[1]. These features are spatially and temporally coherent, which points towards a solar origin and rules out instrumental effects as their origin. The value of the circular polarization in the continuum wavelength

[1] In addition, movies of V_c can be found at `ftp://ftp.kis.uni-freiburg.de/personal/borrero/sunrise/`

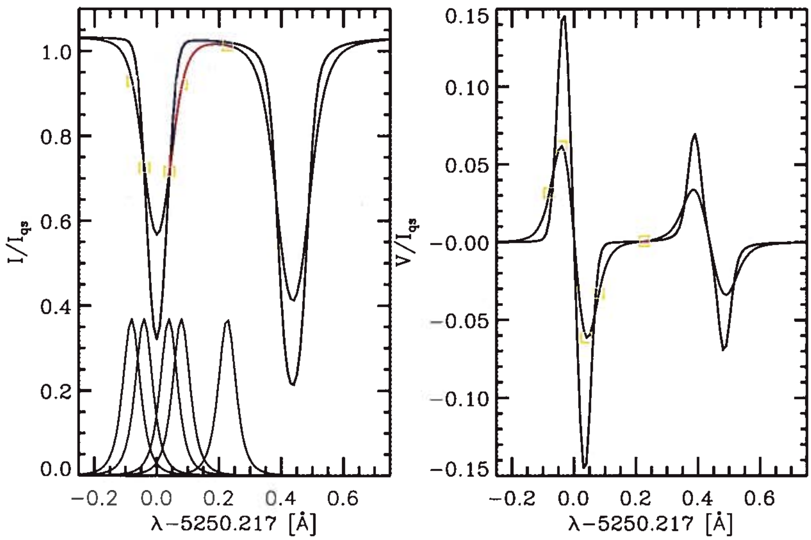

Figure 1. Synthetic spectrum of Fe I 5250.2 and 5250.6 Å using the temperature stratification of the granular model from Borrero & Bellot Rubio (2002), but setting the velocities to zero and adding and homogeneous vertical magnetic field of 250 G (blue lines; Stokes *I* in the *left* panel and Stokes *V* in the *right* one). Convolution of the blue profiles with IMaX's transmission profile (thin black curves at the bottom) yields the red curve. The yellow squares indicate the values measured by IMaX at each of the 5 wavelength positions.

(V_c) exceeds 1.5% (in units of the quiet Sun continuum intensity I_{qs}). A total of 87 events were detected in the combined 54.3 minutes of observations that we analyzed. The average lifetime and area of these events are 81.3 s and ≈ 23000 km^2, respectively.

As mentioned in Borrero et al. (2010), about 70% of these events are related to the appearance of magnetic fields of opposite polarity in their neighborhood. Whenever this happens, strong linear polarization signals (revealing the existence of horizontal fields) are usually seen in the pixels surrounding the event's location.

3. Signature of Supersonic Velocities

In order to produce polarization signatures 227 mÅ away from λ_0, line-of-sight (LOS) velocities of up to 12 km s^{-1} might be needed. This value however does not take into account the effects of the magnetic field, which shifts the σ-components in Stokes V away from λ_0. It also neglects the thermal and Doppler width of the spectral line, as well as the additional broadening induced by IMaX's filter profiles. In order to study these effects, we have performed a numerical experiment in which we produce synthetic Stokes profiles with varying LOS velocity. This is done with the aim of finding the

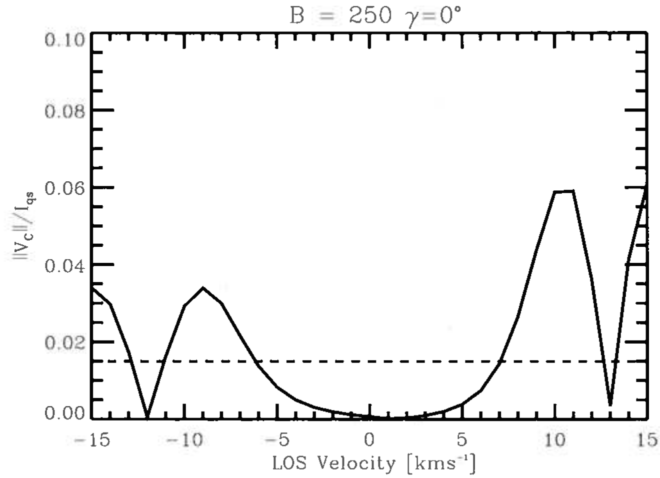

Figure 2. Absolute value of the circular polarization observed by IMaX in λ_c as a function of the LOS velocity, for a granular model with a vertical (inclination of the magnetic field with respect to the observer $\gamma = 0°$) magnetic field of $B = 250$ G.

minimum velocity required to produce V_c signals of about 1.5% (in units of the quiet Sun continuum intensity).

To this end, we have employed the synthesis module of SIR (Stokes Inversion based on Response Functions; Ruiz Cobo & del Toro Iniesta 1992) to obtain synthetic Stokes I and V profiles for Fe I 5250.217 Å and Fe I 5250.653 Å. The atmospheric model used was the granular model from Borrero & Bellot Rubio (2002), but adding a vertical magnetic field with the following characteristics: $B = 250$ G, $\gamma = 0°$ (strength and inclination of the magnetic field vector, respectively). Figure 1 shows the results for Stokes I and V in blue color. These profiles are then convolved with IMaX's transmission profiles (see Martínez Pillet et al. 2011), which are shown in black. The result of the convolution are the broadened red solid profiles. Finally, the yellow squares show the measurements taken by IMaX, whose tuning positions were given in Section 2. V_c corresponds to the rightmost yellow square in the right panel of Figure 1. For this particular figure we employed a LOS velocity of 0 km s^{-1} and therefore $V_c \sim 0$. However it is clear that, for very large blueshifted or redshifted velocities, a signal due to Fe I 5250.653 Å or Fe I 5250.217 Å respectively, should appear in V_c.

Figure 2 shows precisely this: the amount of V_c-signal detected as a function of the LOS velocity employed in the synthesis. The horizontal dashed line corresponds to the lower threshold for the detection of these events: $|V_c|/I_{qs} > 0.015$. This figure indicates that, once all additional broadening effects have been considered, LOS velocities larger than 6 km s^{-1} are needed to produce V_c-signals close to the observed values. Positive (redshift or downflow) and negative (blueshift or upflow) velocities are both possible, since the continuum point lies in between the two spectral lines Fe I 5250.217 and 5250.653 Å.

Note that this experiment was performed with a vertical magnetic field strength of 250 G. Increasing the value of longitudinal component of the magnetic field will

Table 1. Event classification in terms of the velocity fields around the event location. See text for further details.

Type	# Events	% from total
Cell center	44	51
Cell edge	17	19
Intergranule	5	6
Evolving granulation	6	7
Exotic event	7	8
Unclear	8	9

certainly decrease the absolute value of the velocity required to produce sufficient signal in V_c. However, from the measurements of the circular polarization in these events we have determined 250 G to be an upper limit. Therefore we conclude that, in order to produce $|V_c|/I_{qs} > 0.015$, LOS velocities equal to or larger than 6 km s^{-1} in absolute value are required. Considering that the total velocity is larger or equal than the LOS velocity, and that the speed of sound in the solar photosphere is about 6 km s^{-1}, we can ascribe the observed signal as being produced by supersonic and magnetized (because the polarization signal is shifted) flows. For this reason we will hereafter refer to these events as *supersonic*.

4. Statistics and Interpretation

We have classified the observed supersonic events in two different ways. The first classification was done attending to the number of patches of enhanced V_c that appear. If one single patch of $V_c/I_{qs} > 0.015$ is seen we refer to it as *single*. If two patches of enhanced V_c appear next to each other (within 2″), we refer to this event as *twin* (if the two patches have the same sign in V_c) or *double* (opposite sign). The most common type of event is the single one (78 cases out of 87, or 82%), whereas double events are rare (14 cases, 15%) and twin very rare (3 cases, 3%).

The second classification has been done in terms of the LOS velocity at the location of the event. Results are presented in Table 1. This table shows that most supersonic events occur within granular cells or at the edges of granules (70% of the total). A small percentage appear in intergranular lanes (6%), whereas 7% occur in what we call *evolving granulation*: a granule that turns into an intergranular lane as the event takes place or vice-versa. A non-negligible amount (9%) could not be classified since they occurred at locations where the LOS velocities are very close to zero. Finally, 8% of all events were classified as *exotic*. By exotic we refer to those events that occur in tiny granules that are surrounded by large downflows.

Figures 3–7 illustrate some examples of the above events. In these figures, the first row corresponds to the continuum intensity at each pixel normalized to the average quiet Sun continuum intensity, I_c/I_{qs}. The second row shows the circular polarization in the continuum: V_c/I_{qs}. This is the parameter that has been used to identify the supersonic patches (see Section 3): $|V_c|/I_{qs} > 0.015$. Regions that satisfy this condition are enclosed in all panels by the black contours. The third row displays the LOS velocity. Note that the LOS velocity was calculated from a Gaussian fit to Stokes I, and therefore these velocities are not necessarily equivalent to the velocities deduced from V_c

(Section 3). The forth row shows the line-averaged linear polarization ($\sqrt{Q^2 + U^2}$). By line-average we refer to the sum over the first four filter positions (see yellow squares in Figure 1). Finally, the fifth row displays the line-averaged circular polarization. In this case, the line-average sums the absolute value of the circular polarization at each of the first four filter positions. The sign of the line-averaged circular polarization is then taken from the sign of Stokes V at the first filter position. With this convention, positive values of the line-averaged circular polarization denote a magnetic field that points upwards from the solar surface or in order words, $\gamma < 90^\circ$ (with γ being the inclination of the magnetic field vector with respect to the vertical direction on the solar surface[2]). Negative values of the line-averaged circular polarization indicate exactly the opposite, that is, a magnetic field pointing downwards into the Sun ($\gamma > 90^\circ$).

Figure 3 highlights the most common type of supersonic event: one occurring within a granular cell in a *single* patch of enhanced V_c. Because it appears inside a granule, the associated velocities are always blueshifted. This indicates, as discussed in Section 3, that the observed signal in V_c is not due to Fe I 5250.217 Å but to Fe I 5250.653 Å. This kind of event was extensively analyzed in Borrero et al. (2010), where it was associated with the presence, in most cases, of opposite polarities in the magnetic field and significant linear polarization in the surroundings of the event. The example in Fig. 3 clearly fits this description. This led us to conclude that these events occur as a consequence of magnetic reconnection.

Figure 4 displays an example of a *double* event, where two patches of opposite V_c appear next to each other. The upper one has $V_c < 0$, while the lower one possesses $V_c > 0$. The fact that in both regions the velocities are blueshifted indicates that the different sign in V_c cannot be produced by one patch harboring an upflow and the other a downflow. Instead, the reason for the two different signs is to be found in the inclination of the magnetic field. This is demonstrated by the fifth row in Fig. 4, where the line-averaged Stokes V signal has a different sign. This configuration can be best explained by the lower patch being in a environment with $\gamma < 90^\circ$ (magnetic field pointing upwards), while the upper patch has $\gamma > 90^\circ$ (magnetic field points downwards). Attending to the line-averaged linear polarization (fourth row) the two polarities are connected by a horizontal magnetic field. This example is consistent with the configuration of a magnetic loop that reconnects. Therefore, this situation corresponds to a very similar case as in Fig. 3 with the exception that each polarity (footpoints of the loop) develops a supersonic magnetic upflow.

Figure 5 shows an example of a *twin* event, in which two patches of $V_c/I_{qs} > 0.015$ of the same sign appear. The upper one occurs at the center/edge of a granular cell, whereas the lower develops around a region of *evolving granulation*: an initial downflow that becomes an upflow later on. The upper patch coincides with a region of positive polarity and therefore the observed V_c signal corresponds to a blueshift from Fe I 5250.653 Å. The lower patch is more difficult to identify, as the polarity of the magnetic field is not clear and the associated velocities change sign in time. Nevertheless, the presence of magnetic fields of opposite polarities in a 2″ area around the event is evident. As in Fig. 4, the two patches of enhanced V_c are connected by horizontal magnetic fields (as seen in the linear polarization panels). Again, this magnetic configuration suggests the presence of a magnetic loop undergoing a reconnection event.

[2]In fact γ denotes the inclination of the magnetic field with respect to the observer's LOS, but at disk center (where these observations where taken) it coincides with the vertical direction on the solar surface

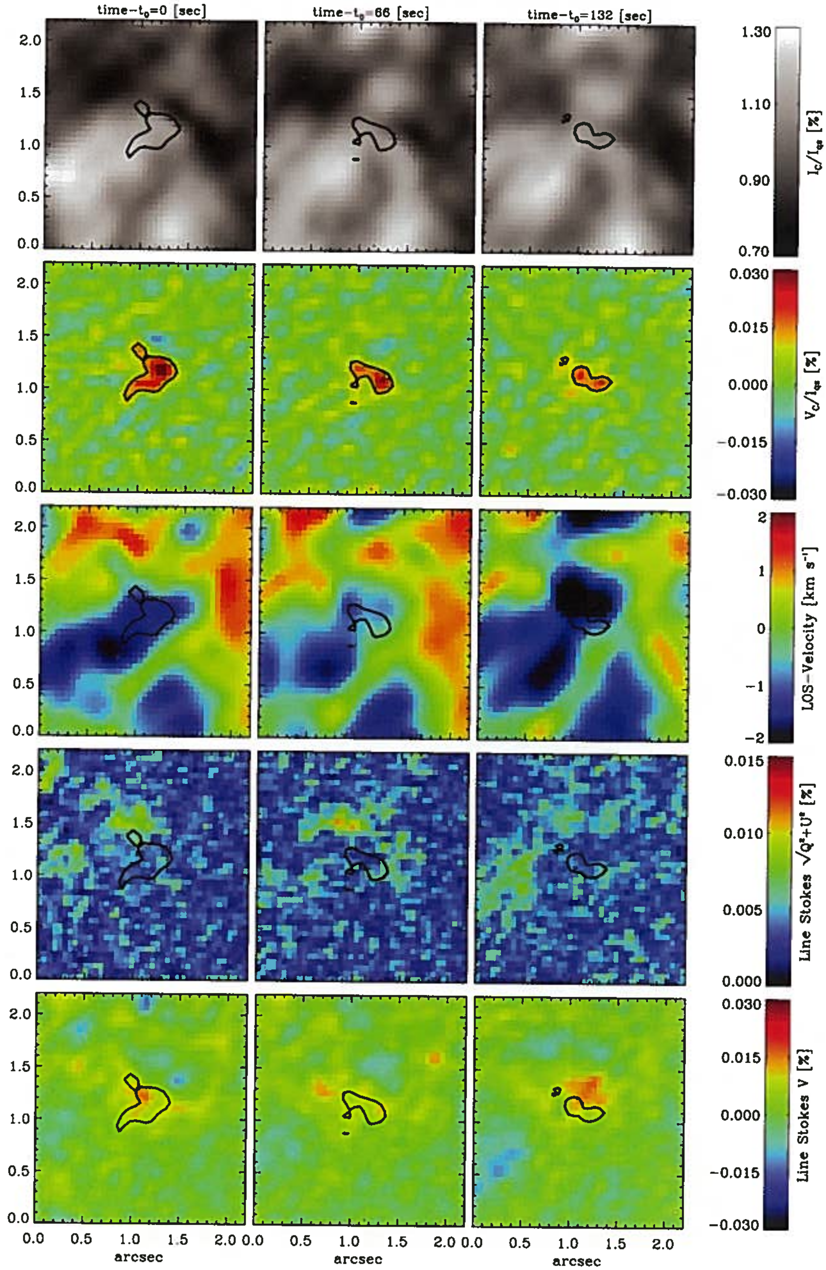

Figure 3. Example of a supersonic event classified as *single* and occurring within a granular cell. From top to bottom: continuum intensity, circular polarization at the continuum, LOS velocity, and line-averaged linear and circular polarization. *From left to right:* snapshots at different times during the evolution of the event.

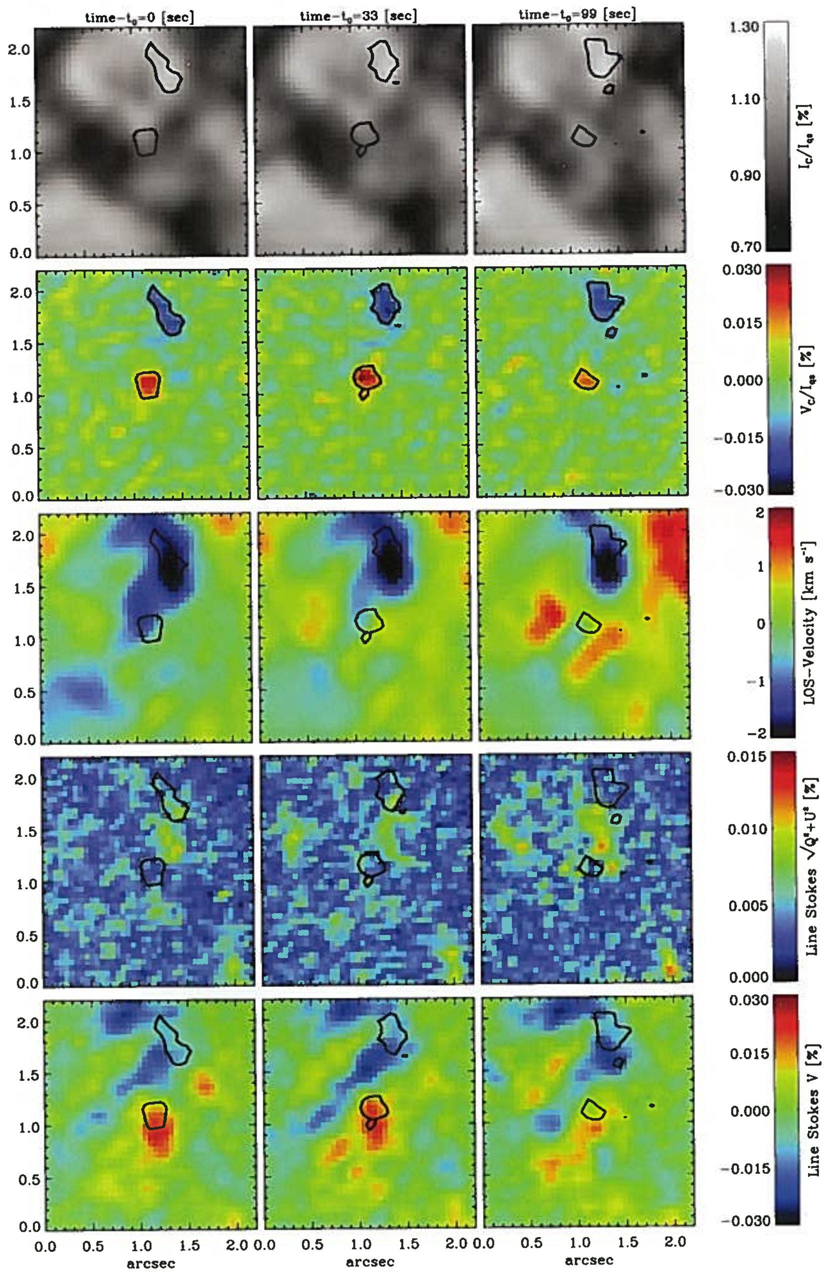

Figure 4. Same as Fig. 3 but for a supersonic event classified as *double*. See text for details.

Figure 6 illustrates an example of an *exotic* event. This particular case has been classified as such because of the unusual velocity pattern. This pattern reveals that the supersonic events occur at the edge of a tiny granule surrounded by very strong downflowing lanes. The presence of opposite polarities in the line-averaged Stokes V signal (fifth panel) reveals the presence of opposite polarities in the surroundings, which again points towards a reconnection event. The line-averaged linear polarization (fourth panel) does not show particularly large horizontal fields, thus making it difficult to associate this event to a magnetic loop.

The final case that we will discuss in this paper is an example of a supersonic event taking place in a *downflow* lane (Figure 7). The amount of V_c observed at the event location denotes that the downflow is magnetized. This signal is however negative, i.e., $V_c < 0$. This indicates that the red lobe of Stokes V from Fe I 5250.217 Å shifts into the continuum wavelength ($\Delta\lambda$ = 227 mÅ) due to a strong downflow embedded in a positive polarity magnetic field ($\gamma < 90°$). The supersonic event occurs at the center of the downflowing lane, at a location where an enhancement of the continuum intensity is also seen (upper panel). Remarkably, no clear opposite polarities are detected in the surrounding FOV during the event, and no large linear polarization is observed either. Therefore this event does not fit with the aforementioned scenario of reconnection of magnetic loops. Instead, it resembles more closely the initial stages of *convective collapse* (Bellot Rubio et al. 2001). However, this interpretation is not completely clear either, as the lack of large total (circular plus linear) polarization signals is not compatible with the presence of strong (kG) magnetic fields (Nagata et al. 2008; Fischer et al. 2009). A possible solution is that the strong downflow shifts the Stokes profiles away from the scanned wavelength region, thereby giving the impression that the magnetic field is low.

5. Conclusions

In this paper we have presented some of the recent observations carried out by the IMaX instrument on-board the stratospheric balloon SUNRISE. These observations comprise full Stokes polarimetry of the quiet Sun with a high temporal cadence and extremely high spatial resolution. This unique dataset has allowed us to detect a number of supersonic magnetized flows in the quiet Sun that appear as highly shifted circular polarization signals. We have illustrated several of these events and we have been able to interpret them in terms of events associated with the emergence of magnetic loops, magnetic reconnection, and convective collapse.

Because IMaX observes only 5 wavelength positions around Fe I 5250.217 Å, it is important to confirm our findings with additional observations. A first attempt has already been made by Martínez Pillet et al. (2011b) who, employing data from the *Hinode* spectro-polarimeter, have also detected these supersonic events in the quiet Sun. Their main result is that they seem to appear indistinctly in granular and intergranular lanes. In the future, hopefully some of these events will also be observed with instruments with better spectral and spatial resolution, thereby helping to narrow down the list of possible physical processes responsible for them. Instruments in future and current large solar telescopes such as NST (Goode et al. 2010), GREGOR (Volkmer et al. 2010), ATST (Keil et al. 2010), and EST (Collados et al. 2010) should also contribute to study these phenomena in more detail.

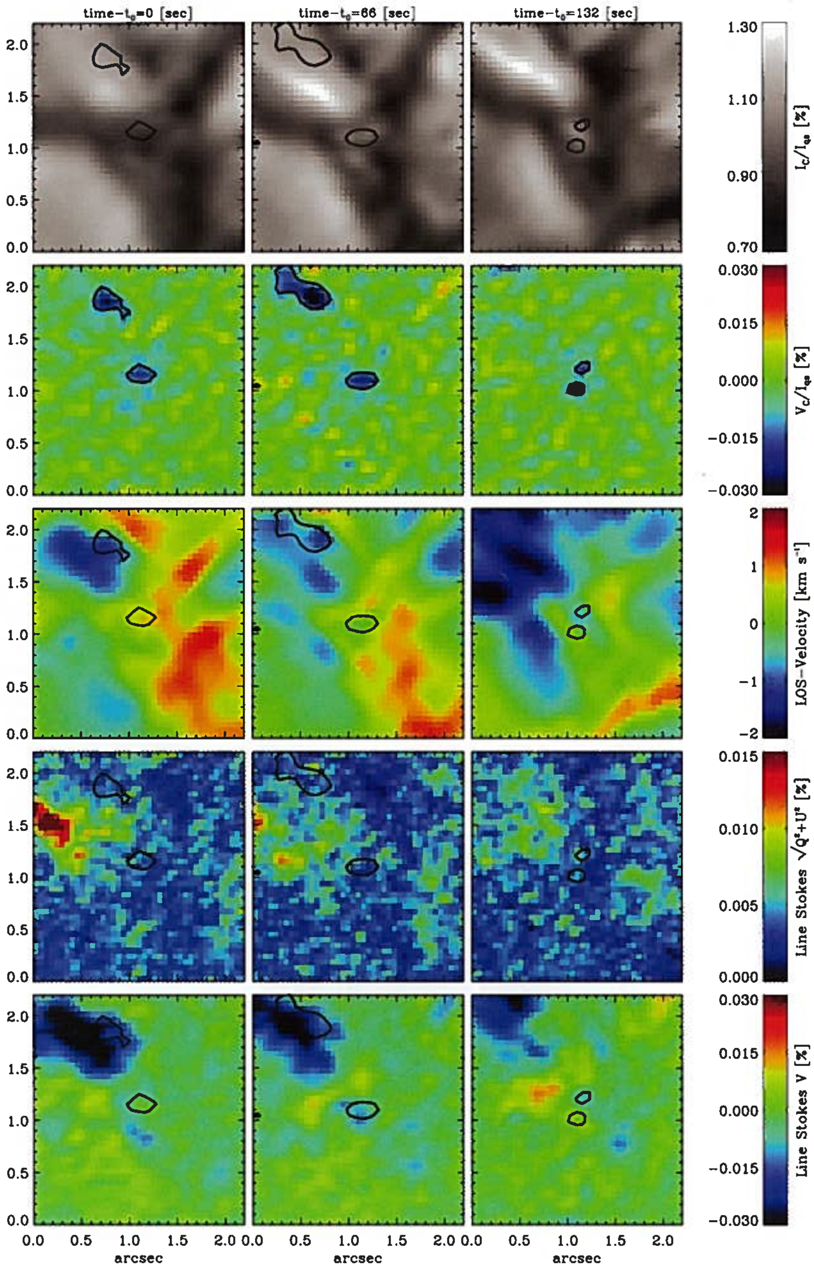

Figure 5. Same as Fig. 3 but for a supersonic event classified as *twin*. See text for details.

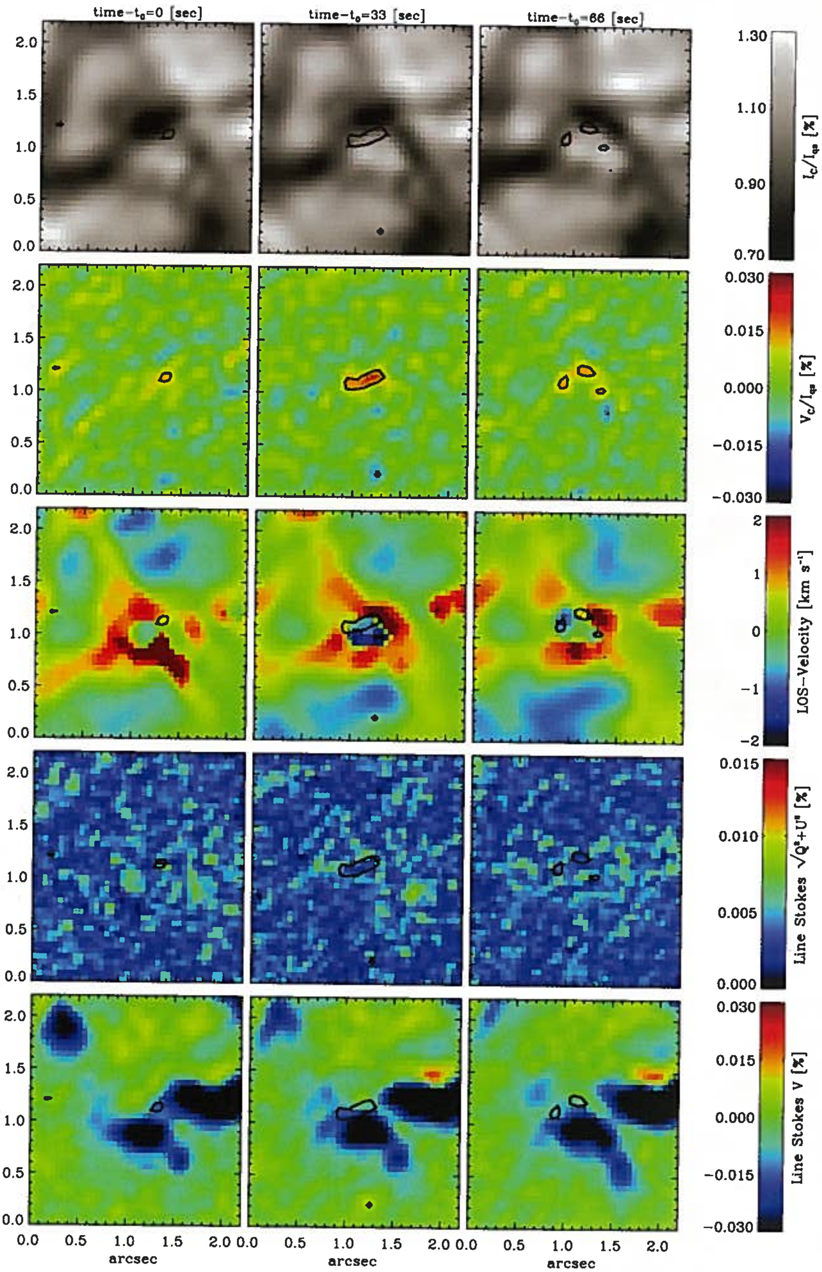

Figure 6. Same as Fig. 3 but for a supersonic event classified as *exotic*. See text for details.

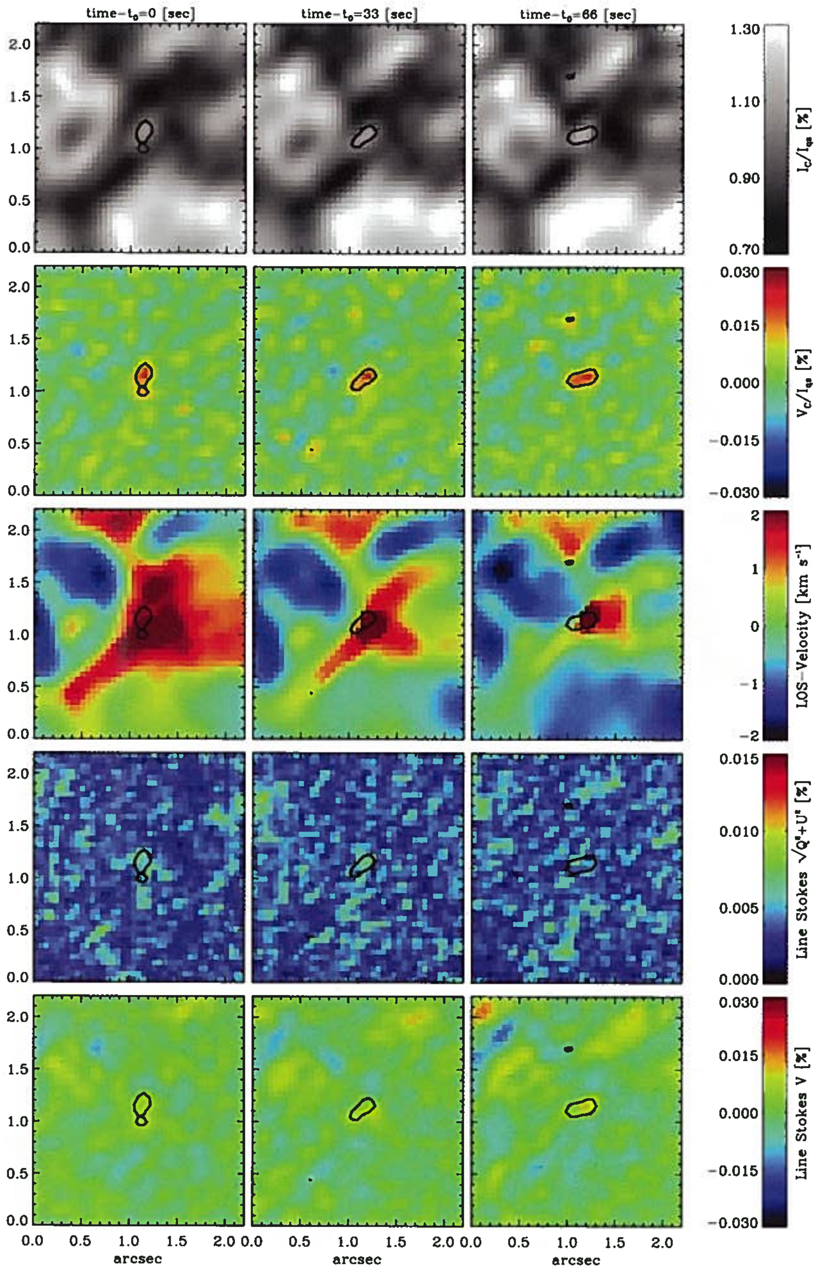

Figure 7. Same as Fig. 3 but for a supersonic event occurring in a downflowing lane. See text for details.

References

Barthol, P., Gandorfer, A., Solanki, S. K., Schüssler, M., Chares, B., Curdt, W., Deutsch, W., Feller, A., Germerott, D., Grauf, B., Heerlein, K., Hirzberger, J., Kolleck, M., Meller, R., Müller, R., Riethmüller, T. L., Tomasch, G., Knölker, M., Lites, B. W., Card, G., Elmore, D., Fox, J., Lecinski, A., Nelson, P., Summers, R., Watt, A., Martínez Pillet, V., Bonet, J. A., Schmidt, W., Berkefeld, T., Title, A. M., Domingo, V., Gasent Blesa, J. L., Del Toro Iniesta, J. C., López Jiménez, A., Álvarez-Herrero, A., Sabau-Graziati, L., Widani, C., Haberler, P., Härtel, K., Kampf, D., Levin, T., Pérez Grande, I., Sanz-Andrés, A., & Schmidt, E. 2011, Solar Phys., 268, 1

Bellot Rubio, L. R. 2009, ApJ, 700, 284

Bellot Rubio, L. R., Rodríguez Hidalgo, I., Collados, M., Khomenko, E., & Ruiz Cobo, B. 2001, ApJ, 560, 1010

Berkefeld, T., Schmidt, W., Soltau, D., Bell, A., Doerr, H. P., Feger, B., Friedlein, R., Gerber, K., Heidecke, F., Kentischer, T., v. D. Lühe, O., Sigwarth, M., Wälde, E., Barthol, P., Deutsch, W., Gandorfer, A., Germerott, D., Grauf, B., Meller, R., Álvarez-Herrero, A., Knölker, M., Martínez Pillet, V., Solanki, S. K., & Title, A. M. 2011, Solar Phys., 268, 103

Bonet, J. A., Márquez, I., Sánchez Almeida, J., Palacios, J., Martínez Pillet, V., Solanki, S. K., del Toro Iniesta, J. C., Domingo, V., Berkefeld, T., Schmidt, W., Gandorfer, A., Barthol, P., & Knölker, M. 2010, ApJ, 723, L139

Borrero, J. M., & Bellot Rubio, L. R. 2002, A&A, 385, 1056

Borrero, J. M., Martínez-Pillet, V., Schlichenmaier, R., Solanki, S. K., Bonet, J. A., del Toro Iniesta, J. C., Schmidt, W., Barthol, P., Gandorfer, A., Domingo, V., & Knölker, M. 2010, ApJ, 723, L144

Centeno, R., Socas-Navarro, H., Lites, B., Kubo, M., Frank, Z., Shine, R., Tarbell, T., Title, A., Ichimoto, K., Tsuneta, S., Katsukawa, Y., Suematsu, Y., Shimizu, T., & Nagata, S. 2007, ApJ, 666, L137

Collados, M., Bettonvil, F., Cavaller, L., Ermolli, I., Gelly, B., Grivel-Gelly, C., Pérez, A., Socas-Navarro, H., Soltau, D., & Volkmer, R. 2010, in Ground-Based and Airborne Telescopes III, vol. 7733 of Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 77330H

Danilovic, S., Beeck, B., Pietarila, A., Schüssler, M., Solanki, S. K., Martínez Pillet, V., Bonet, J. A., del Toro Iniesta, J. C., Domingo, V., Barthol, P., Berkefeld, T., Gandorfer, A., Knölker, M., Schmidt, W., & Title, A. M. 2010, ApJ, 723, L149

Fischer, C. E., de Wijn, A. G., Centeno, R., Lites, B. W., & Keller, C. U. 2009, A&A, 504, 583

Goode, P. R., Coulter, R., Gorceix, N., Yurchyshyn, V., & Cao, W. 2010, Astronomische Nachrichten, 331, 620

Ishikawa, R., & Tsuneta, S. 2009, A&A, 495, 607

Keil, S. L., Rimmele, T. R., Wagner, J., & ATST team 2010, Astronomische Nachrichten, 331, 609

Martínez González, M. J., & Bellot Rubio, L. R. 2009, ApJ, 700, 1391

Martínez González, M. J., Manso Sainz, R., Asensio Ramos, A., & Bellot Rubio, L. R. 2010, ApJ, 714, L94

Martínez Pillet, V., Del Toro Iniesta, J. C., Álvarez-Herrero, A., Domingo, V., Bonet, J. A., González Fernández, L., López Jiménez, A., Pastor, C., Gasent Blesa, J. L., Mellado, P., Piqueras, J., Aparicio, B., Balaguer, M., Ballesteros, E., Belenguer, T., Bellot Rubio, L. R., Berkefeld, T., Collados, M., Deutsch, W., Feller, A., Girela, F., Grauf, B., Heredero, R. L., Herranz, M., Jerónimo, J. M., Laguna, H., Meller, R., Menéndez, M., Morales, R., Orozco Suárez, D., Ramos, G., Reina, M., Ramos, J. L., Rodríguez, P., Sánchez, A., Uribe-Patarroyo, N., Barthol, P., Gandorfer, A., Knölker, M., Schmidt, W., Solanki, S. K., & Vargas Domínguez, S. 2011a, Solar Phys., 268, 57

Martínez Pillet, V., del Toro Iniesta, J. C., & Quintero Noda, C. 2011b, A&A, submitted

Nagata, S., Tsuneta, S., Suematsu, Y., Ichimoto, K., Katsukawa, Y., Shimizu, T., Yokoyama, T., Tarbell, T. D., Lites, B. W., Shine, R. A., Berger, T. E., Title, A. M., Bellot Rubio, L. R.,

& Orozco Suárez, D. 2008, ApJ, 677, L145
Ruiz Cobo, B., & del Toro Iniesta, J. C. 1992, ApJ, 398, 375
Schmidt, W., Berkefeld, T., Friedlein, R., Heidecke, F., Kentischer, T., von der Lühe, O. F., Sigwarth, M., Soltau, D., & Walde, E. 2004, in Ground-based Telescopes, edited by J. M. Oschmann Jr., vol. 5489 of Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 1164
Shimizu, T., Martínez Pillet, V., Collados, M., Ruiz-Cobo, B., Centeno, R., Beck, C., & Katsukawa, Y. 2007, in New Solar Physics with Solar-B Mission, edited by K. Shibata, S. Nagata, & T. Sakurai, vol. 369 of Astronomical Society of the Pacific Conference Series, 113
Solanki, S. K., Barthol, P., Danilovic, S., Feller, A., Gandorfer, A., Hirzberger, J., Riethmüller, T. L., Schüssler, M., Bonet, J. A., Martínez Pillet, V., del Toro Iniesta, J. C., Domingo, V., Palacios, J., Knölker, M., Bello González, N., Berkefeld, T., Franz, M., Schmidt, W., & Title, A. M. 2010, ApJ, 723, L127
Steiner, O., Franz, M., Bello González, N., Nutto, C., Rezaei, R., Martínez Pillet, V., Bonet Navarro, J. A., del Toro Iniesta, J. C., Domingo, V., Solanki, S. K., Knölker, M., Schmidt, W., Barthol, P., & Gandorfer, A. 2010, ApJ, 723, L180
Straus, T., Fleck, B., Jefferies, S. M., Carlsson, M., & Tarbell, T. D. 2010, Memorie della Societa Astronomica Italiana, 81, 751
Volkmer, R., von der Lühe, O., Denker, C., Solanki, S. K., Balthasar, H., Berkefeld, T., Caligari, P., Collados, M., Fischer, A., Halbgewachs, C., Heidecke, F., Hofmann, A., Klvaňa, M., Kneer, F., Lagg, A., Popow, E., Schmidt, D., Schmidt, W., Sobotka, M., Soltau, D., & Strassmeier, K. G. 2010, Astronomische Nachrichten, 331, 624
Zhang, J., Yang, S.-H., & Jin, C.-L. 2009, Research in Astronomy and Astrophysics, 9, 921