# MULTI-WAVELENGTH OBSERVATIONS OF VORTEX-LIKE FLOWS IN THE PHOTOSPHERE FROM GROUND-BASED AND SPACE-BORNE TELESCOPES

P2.3 CSPM

**J. Palacios** (Universidad de Alcalá (UAH), Madrid, Spain), **S. Vargas Domínguez** (Universidad Nacional de Colombia), **L. A. Balmaceda** (ICATE-CONICET, Argentina), **I. Cabello** (UTN/FRM-CONICET, Argentina), **V. Domingo** (Universitat de València, Spain)

## ABSTRACT

In this work we follow a series of papers on high-resolution solar observations (Balmaceda et al. 2009, Balmaceda et al. 2010, Vargas Dominguez et al. 2011, Palacios et al. 2012, Vargas Domínguez et al 2015, Cabello et al., in preparation), utilizing several long multi-wavelength data series. These were acquired from both ground-based (SST) and space-borne (Hinode), thus obtaining high-cadence and high resolution data, including SOT-SP data, in a joint campaign of the Hinode Operation Program 14, in Sept 2007. Diffraction-limited SST data, taken in G-band and G-cont, were restored by MFBD, whilst Hinode obtained multispectral data from SOT-FG in CN, Mg II, Ca II and also SP in Fe I lines. In these series we have thoroughly studied vortex flows and their statistical occurrences, horizontal velocities by means of local correlation tracking (LCT), divergence and vorticity; but we also have studied bright point statistics and magnetic field intensification, clearly highlighting the importance of the smallest-scale magnetic element observations.

**Table 1** Characteristics of the time series acquired from ground-based and spacecraft facilities.

| Telescope | Obs. | Series # | Time [UT] | Duration [minutes] | Number of images | Cadence [sec] | FOV [″] |
|---|---|---|---|---|---|---|---|
| SST | G-band | 1 | 08:47 – 09:07 | 19 | 76 | 15 | 68.5 × 68.5 |
| | | 2 | 09:14 – 09:46 | 32 | 128 | 15 | 68.5 × 68.5 |
| *Hinode* | CN | 1 | 08:40 – 09:20 | 40 | 70 | 35 | 19.2 × 74.1 |
| | Ca II H | 1 | 08:40 – 09:20 | 40 | 71 | 35 | 19.2 × 74.1 |
| | Mg I | 1 | 08:40 – 09:20 | 40 | 143 | 20 | 15.4 × 65.3 |
| | SP | 1 | 08:20 – 09:44 | 84 | 2558 scans | 2 | 2.7 × 40.6 |

### Observations of magnetic elements in the quiet Sun internetwork (ASPC, 2009)

L. A. Balmaceda, J. Palacios, I. Cabello, V. Domingo

Magnetic, MgI

G-band

CN

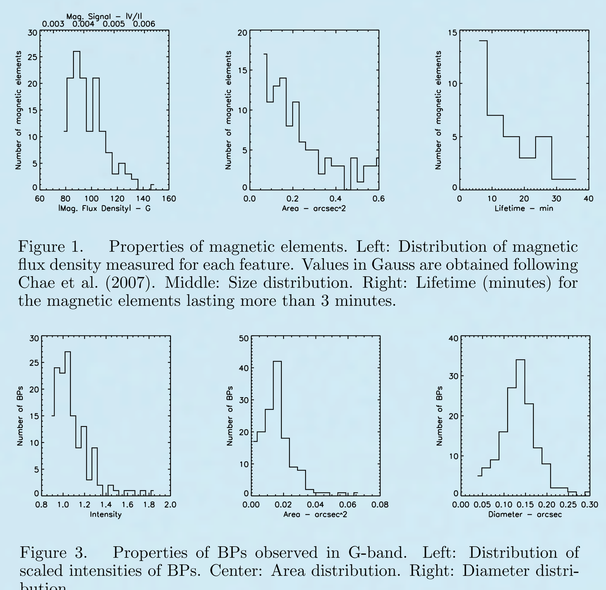


Figure 1. Properties of magnetic elements. Left: Distribution of magnetic flux density measured for each feature. Values in Gauss are obtained following Chae et al. (2007). Middle: Size distribution. Right: Lifetime (minutes) for the magnetic elements lasting more than 3 minutes.

Figure 3. Properties of BPs observed in G-band. Left: Distribution of scaled intensities of BPs. Center: Area distribution. Right: Diameter distribution.

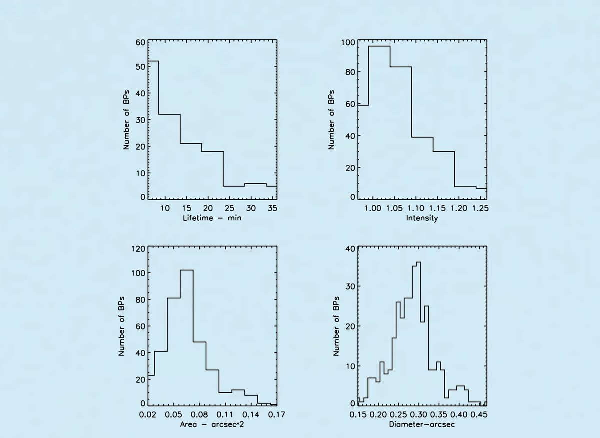


Figure 2. Distribution of properties of BPs detected in CN bandhead. Upper panel, left: Lifetime (minutes) of each feature. Right: Distribution of scaled intensities measured for the BPs detected during the observing period. Bottom panel, left: Area distribution. Right: Diameter distribution.

### Evidence for small-scale magnetic concentrations dragged by vortex motion of solar photospheric plasma (A&A, 2010)

L. Balmaceda, S. Vargas Domínguez, J. Palacios, I. Cabello and V. Domingo

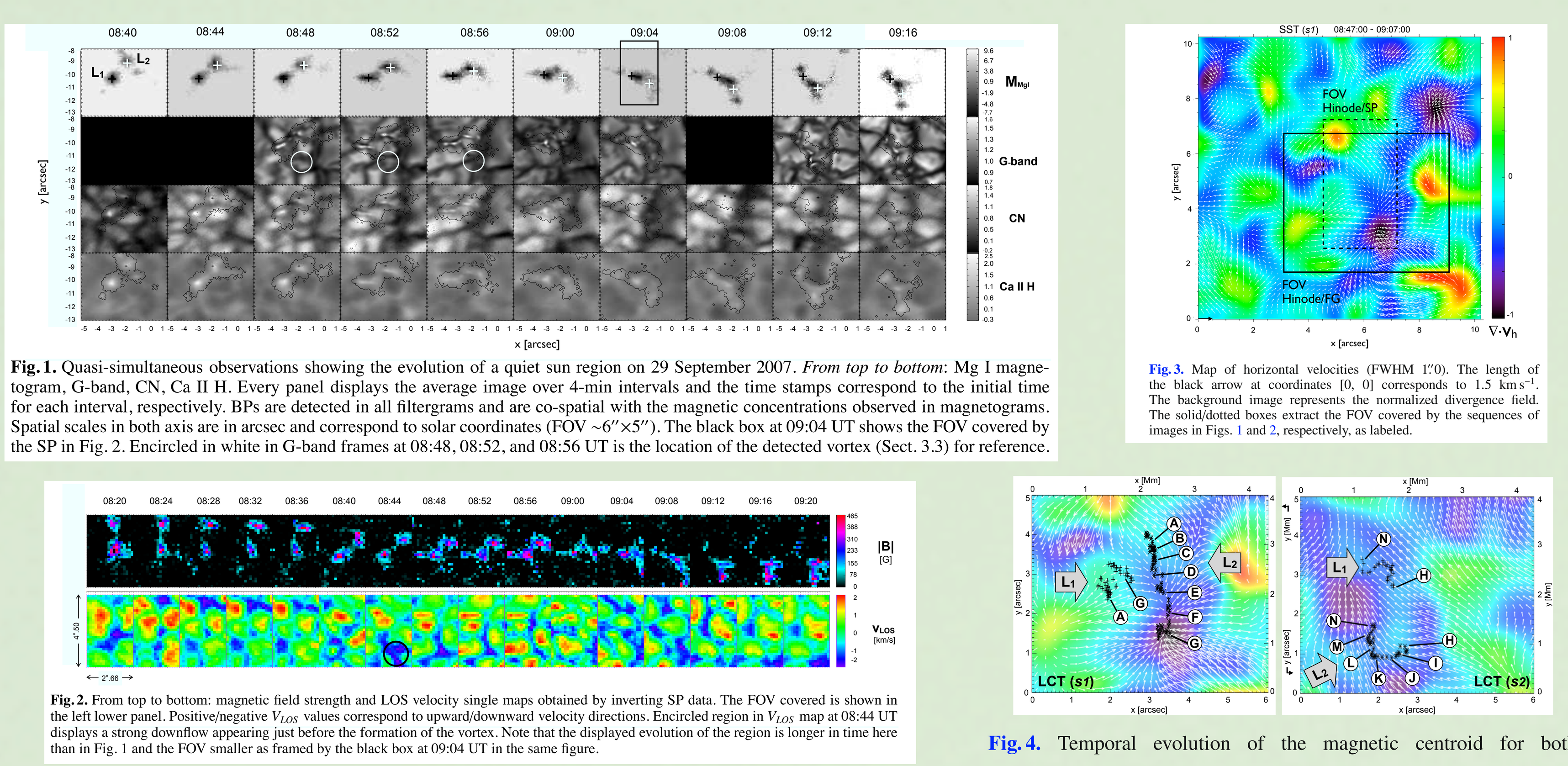


**Fig. 1.** Quasi-simultaneous observations showing the evolution of a quiet sun region on 29 September 2007. *From top to bottom*: Mg I magnetogram, G-band, CN, Ca II H. Every panel displays the average image over 4-min intervals and the time stamps correspond to the initial time for each interval, respectively. BPs are detected in all filtergrams and are co-spatial with the magnetic concentrations observed in magnetograms. Spatial scales in both axis are in arcsec and correspond to solar coordinates (FOV ~6″×5″). The black box at 09:04 UT shows the FOV covered by the SP in Fig. 2. Encircled in white in G-band frames at 08:48, 08:52, and 08:56 UT is the location of the detected vortex (Sect. 3.3) for reference.

**Fig. 3.** Map of horizontal velocities (FWHM 1″.0). The length of the black arrow at coordinates [0, 0] corresponds to 1.5 km s⁻¹. The background image represents the normalized divergence field. The solid/dotted boxes extract the FOV covered by the sequences of images in Figs. 1 and 2, respectively, as labeled.

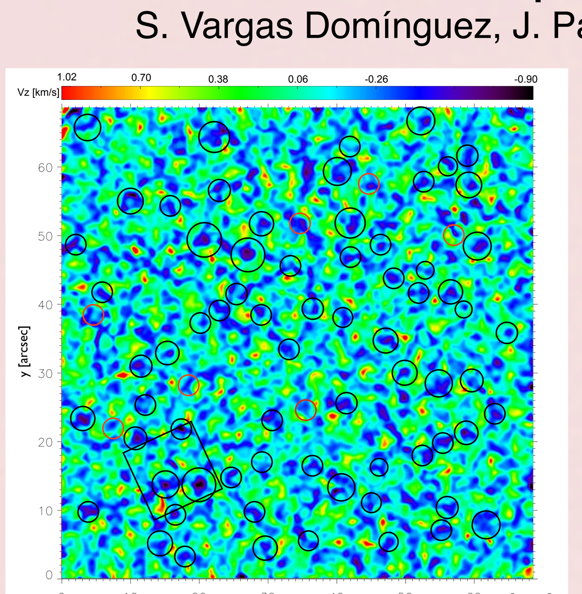
**Fig. 2.** From top to bottom: magnetic field strength and LOS velocity single maps obtained by inverting SP data. The FOV covered is shown in the left lower panel. Positive/negative $V_{LOS}$ values correspond to upward/downward velocity directions. Encircled region in $V_{LOS}$ map at 08:44 UT displays a strong downflow appearing just before the formation of the vortex. Note that the displayed evolution of the region is longer in time here than in Fig. 1 and the FOV smaller as framed by the black box at 09:04 UT in the same figure.

**Fig. 4.** Temporal evolution of the magnetic centroid for both

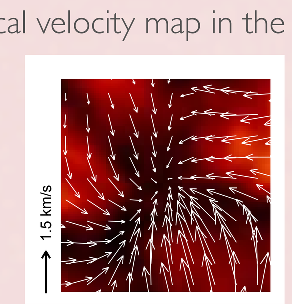
Magnetic element rotation, revealing a vortex flow, rotating about 150° in < 1h

### Spatial distribution and statistical properties of small-scale convective vortex-like motions in a quiet Sun region (MNRAS, 2011)

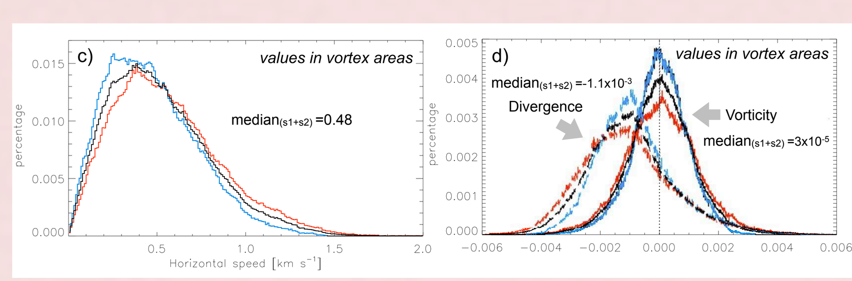
S. Vargas Domínguez, J. Palacios, L. Balmaceda, I. Cabello and V. Domingo



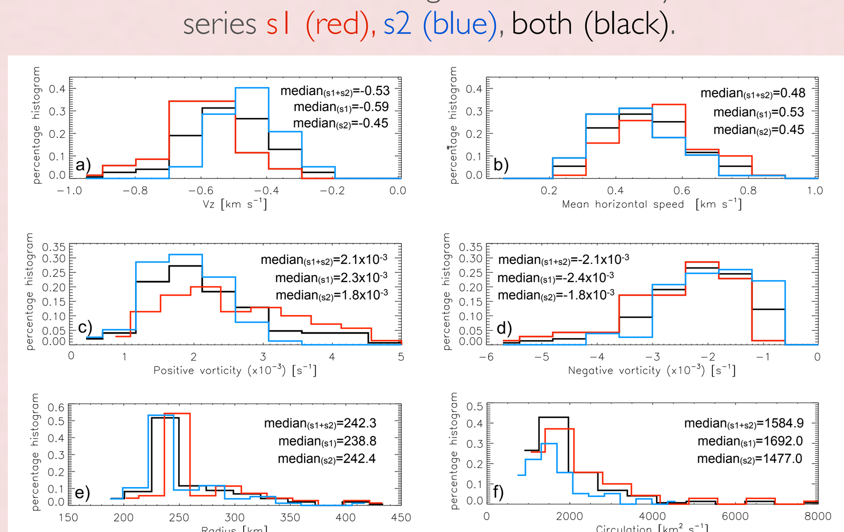
Vortex locations in G-band series s1, with a vertical velocity map in the background.



LCT horizontal velocities of a vortex (3″x3″)



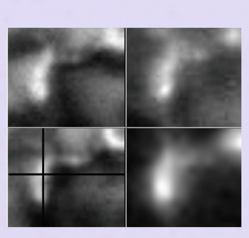
Horizontal velocities and divergence and vorticity for G-band series s1 (red), s2 (blue), both (black).



Distributions of LOS speed, horizontal speed, positive and negative vorticity, radius and circulation for series s1 (red), s2 (blue), both (black).

### Structure of small magnetic elements in the solar atmosphere (ASPC, 2012)

Vicente Domingo, Judith Palacios, Laura A. Balmaceda, Santiago Vargas Domínguez, Iballa Cabello.



Intensity profiles of facular points in Aug 6-7, 2008 (HOP72). Frame size 2″x2″.

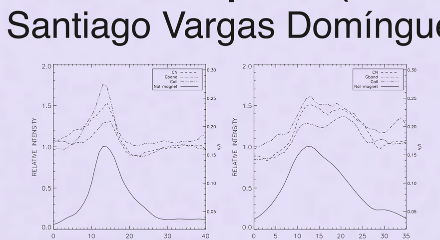


Figure 3. West-east (left) and north-south (right) relative intensity profiles. The scale on the right shows the V/I signal of the Na I magnetogram

### Observations of Vortex Motion in the Solar Photosphere Using Hinode-SP Data (ASPC, 2012)

Judith Palacios, Laura A. Balmaceda, Santiago Vargas Domínguez, Iballa Cabello, and Vicente Domingo

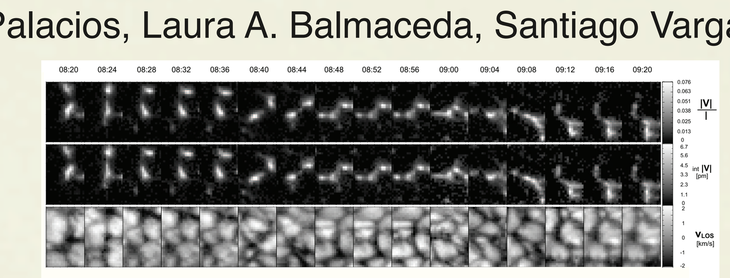


Figure 1. From top to bottom rows: sequences of unsigned LOS magnetograms, integrated Stokes V profile and LOS velocity, respectively.

Max |V|/I; integrated V (from -29 to +29 pm); LOS-velocity

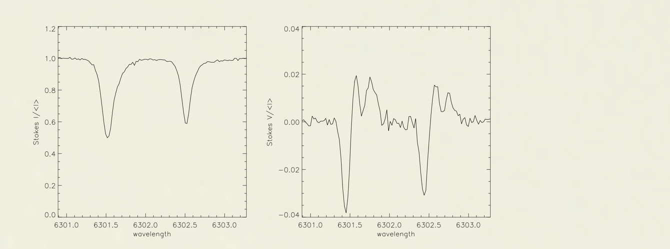


Figure 3. Left panel: Stokes I profiles. Right panel: abnormal V Stokes profiles.

Three-lobed Stokes V: a hint for gradients. Plausible convective collapse

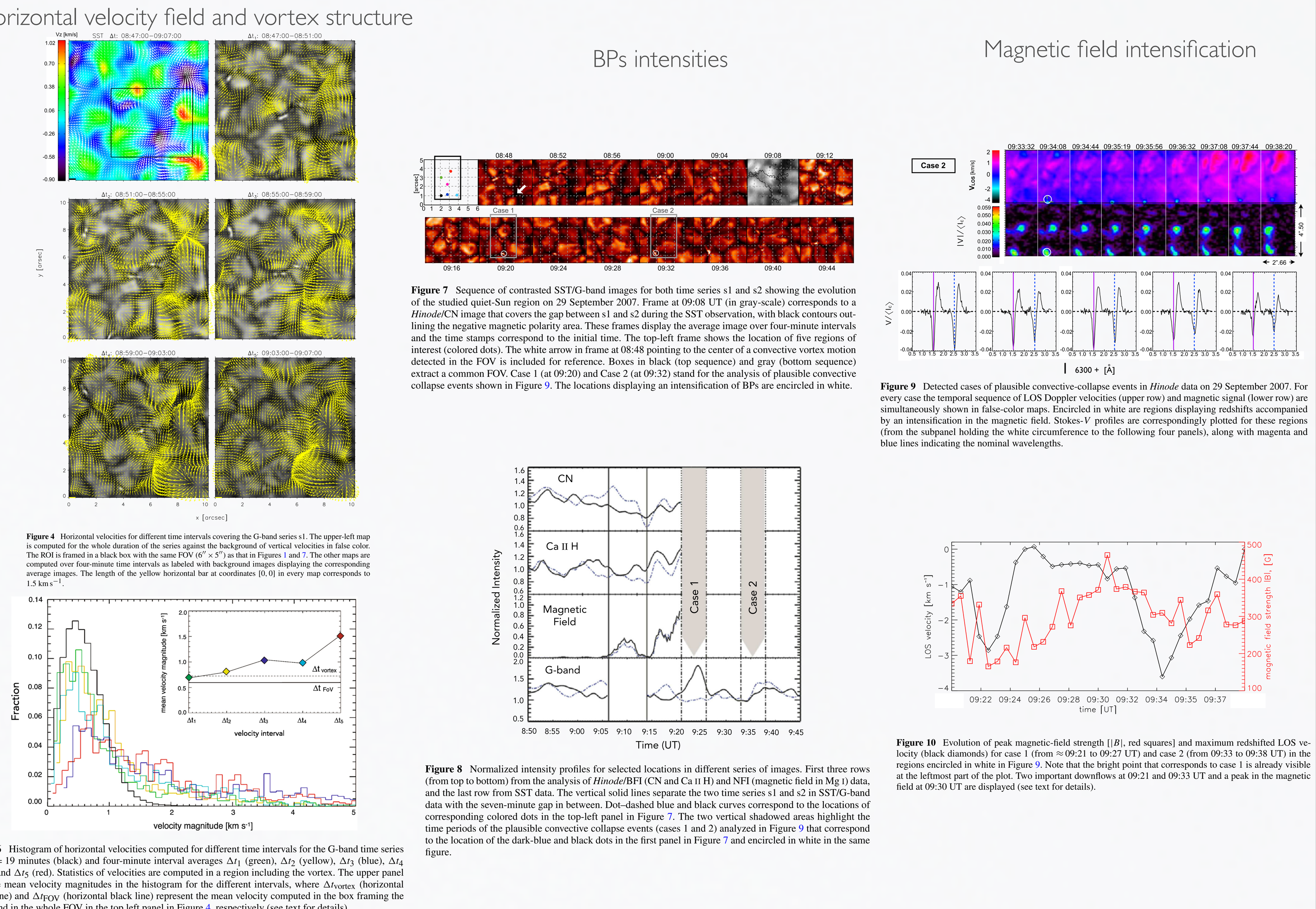
### Evolution of Small-Scale Magnetic Elements in the Vicinity of Granular-Sized Swirl Convective Motions (Sol. Phys., 2015)

S. Vargas Domínguez · J. Palacios · L. Balmaceda · I. Cabello · V. Domingo

Horizontal velocity field and vortex structure

BPs intensities

Magnetic field intensification



## Methods

**MFBD:** image restoration process, mainly applied to ground-based images. Method from Löfdahl 1996 and 2002.

**LCT:** (Local Correlation Tracking, November & Simon 1988; Molowny-Horas & Yi 1994) is a key technique to infer horizontal velocities, flow shapes and for further calculation of divergence and vorticity. It also provides estimation of vertical velocities.

**BP detection:** to distinguish BPs from granular fragments, with segmentation and recognition. We have used two methods: MLT4 (Bovelet & Wiehr, 2007); and Sánchez Almeida (2004).

**Centroids:** method to calculate the center of gravity of various structures; in this case, in MgI magnetograms.

**Inversion and weak-field approximation:** the inversion code LILIA (Socas Navarro, 2001) and weak-field approximation (as in d'egli Innocenti, 1992) for inferring magnetic flux densities.

## Main results

**-Magnetic elements, CN, G-band BPs properties:**

*Magnetic elements have a typical area of 0.1 sq-arcsec, and lifetime of 5-10 min. CN BP typical size is 0″27, and median intensity is 1.05; while G-band BP typical diameter is 0″14 and median intensity of 1.1. Surface coverage for CN is 0.22%, while 0.26% for G-band.*

**-Average divergence and vorticity values.** *Vortex occurrence is about 1.5 ·$10^{-3}$ /Mm² · min; density values of 3 ·$10^{-2}$ /Mm². Horizontal velocities are about 0.5 km/s; however, this mean value increases when vortices increase the circulation. Vortex mean radius is 250 km. Vortex downflow speed is about 0.5 km/s.*

**-Magnetic field intensification**: *We have observed some cases of plausible magnetic field intensification followed by supersonic downflow up to 7 km/s.*

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1) Balmaceda, L. A.; Palacios, J.; Cabello, I.; Domingo, V. :Observations of Magnetic Elements in the Quiet Sun Internetwork, 2009, ASPC, 415, 156.
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