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Inversions of L12-2 IMaX data of an emerging flux mantle

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Abstract. We present the analysis of a flux emergence event observed with the IMaX magnetograph flown aboard the Sunrise balloon. IMaX took a 15' sequence with cadence of 31 s along the Fe I line at 525.0 nm, acquiring only Stokes I and V at 12 line positions (L12-2 mode). This sequence shows the emergence of a flux mantle at mesogranular scale, cospatial with a large exploding granule. An undesired cross-talk between Stokes U and V was found in such L12-2 data. We show that the use of a modified version of the SIR inversion code is able to remove such effect in inferring the physical quantities of interest.

Key words. Sun: granulation – Sun: magnetic topology – Sun: photosphere – Techniques: high angular resolution – Techniques: polarimetric

1. Introduction

The granular pattern of the solar photosphere is due to ceaseless plasma flows organized in convective cells. Exploding granules (EGs) are individual bright granules that expand larger than normal granular cells, and ultimately fragment into several smaller granules. Since their detection (Rösch 1960; Carlier et al. 1968), a number of studies dealt with EGs in order to determine more in detail their dynamics and physical properties, from both the observational and numerical point of view.

Recent observational studies benefited from two-dimensional spectroscopic measurements to analyze the distribution of temperature and velocity in EGs, through different levels in the photosphere (Roudier et al. 2001). Using spectral scans over the non-magnetic Fe I 557.6 nm line, Hirzberger et al. (2001) investigated the nature of the central dark spot observed in EGs and found a connection of this feature with downflows of cool gas. Moreover, De Pontieu (2002) found the presence of horizontal magnetic fields in some EGs, but the linkage of such phenomenon with magnetic flux emergence is still disputed.

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The Imaging Magnetograph eXperiment (IMAX, Martínez Pillet et al. 2011), mounted on the 1-m aperture telescope onboard the Sunrise mission (Solanki et al. 2010; Barthol et al. 2011), observed magnetic field emergence events in the quiet-Sun photosphere covering significant areas of EGs (Palacios et al. 2012). We study one of these events, analyzing the Stokes profiles observed during its evolution.

2. Observations

On 10 June 2009 a large EG was observed by IMaX near the disk center at high spatial resolution (0.″2) and high temporal cadence (31.5 s), during a 15' sequence. IMaX took polarization maps in longitudinal observing mode (L12-2), acquiring Stokes I and V at 12 wavelength positions over the Fe i 525.02 nm line, every 3.5 pm from -19.25 pm to +19.25 pm with respect to the line center. The pixel size of these maps is 0.″055 and they have a spectral resolution of 8.5 pm.

Figure 1 shows part of the IMaX field-of-view (FOV), where the location of the event is highlighted. It is possible to notice that the EG, clearly visible in the continuum map, is cospatial with a large structure ($\approx 5'' \times 5''$) found in the (measured) circular polarization map.

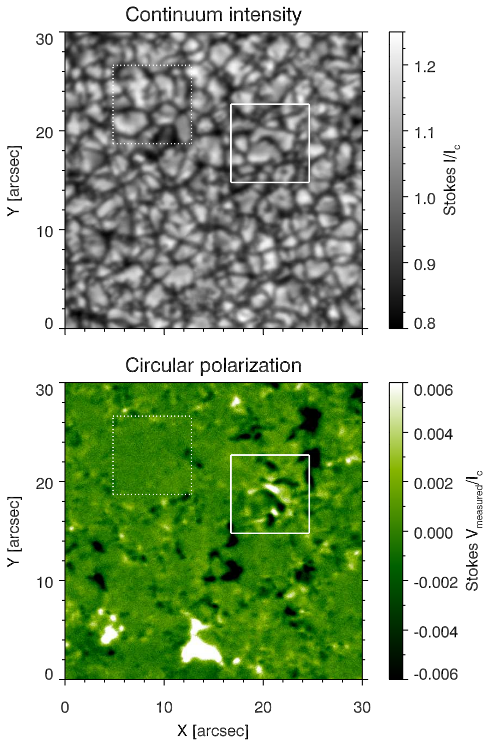

Fig. 1. IMaX/Sunrise observations on 10 June 2009 at 23:46:08 UT. *Top panel*: continuum intensity map. *Bottom panel*: (measured) circular polarization map. The solid-line square, with a FOV of 7.″9×7.″9, indicates the location of the event here analyzed. The dashed-line square, with the same FOV, shows a very-quiet Sun region, used for comparison.

3. Data analysis

In the IMAX longitudinal observing modes it is not possible to correct the instrumental cross-talk by applying the demodulation matrix described by Martínez Pillet et al. (2011), which takes into account the polarization effect induced by the telescope and by the Image Stabilization and Light Distribution system (Gandorfer et al. 2011). This leads to the presence of a conspicuous residual cross-talk between the Stokes parameters in the reduced data. An estimate of such cross-talk for Stokes V, measured during the pre-flight phase, is given by:

$$V_{\mathrm{measured}} = -0.88\, U_{\odot} + 0.55\, V_{\odot}\,,$$

where $U_{\odot}$ and $V_{\odot}$ refer to the original solar polarization signals.

We carried out inversions of the observed Stokes profiles by using a modified version of the SIR code (Ruiz Cobo & del Toro Iniesta 1992) – SirUV – to obtain some reliable physical information. This version allows the user to invert any linear combinations of the four Stokes parameters.

We have carried out a series of preliminary tests, using 2000 atmosphere models randomly chosen from those obtained from SIR inversions of an IMaX data set in V5-6 observing mode (see Guglielmino et al. 2012), with inclination of the vector magnetic field < 80° or > 100°. These models have been used as input for the synthesis - set up by using SirUV in synthesis mode - of 2000 profiles of Stokes I

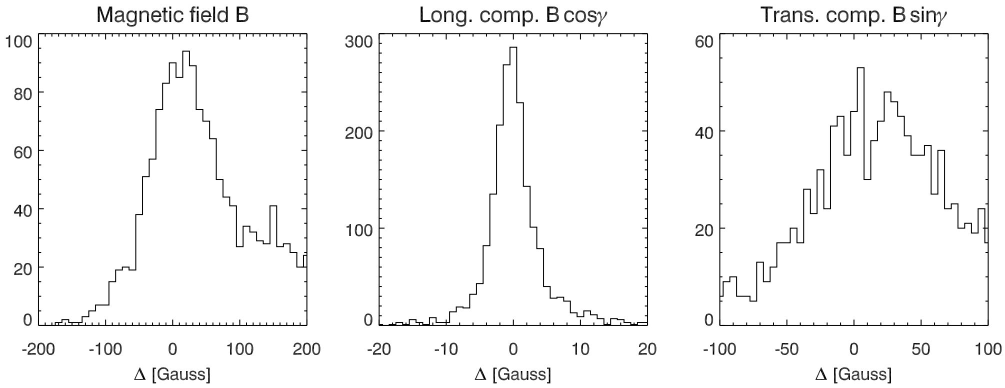

Fig. 2. Histograms of the deviations (Δ) between "real" and fitted values, for B, B$\cos\gamma$, and B$\sin\gamma$, obtained from the SirUV inversion tests.

and of the linear combination of Stokes U and Stokes V due to the cross-talk. The computed profiles have been convolved with the spectral Point Spread Function at the focal plane of IMaX, also adding random noise corresponding to the signal-to-noise ratio for these L12-2 IMaX measurements ($\approx 8 \times 10^2$).

The outcoming profiles, sampled at the same wavelength positions used in the L12-2 observing mode, have been inverted with SirUV. For each simulated profile, we have computed the deviation Δ between the "real" and the fitted values for several physical parameters: line-of-sight (LOS) velocity, magnetic field B, inclination γ, and azimuth φ. We have also examined the longitudinal and transversal components of the magnetic field vector, B$\cos\gamma$ and B$\sin\gamma$, respectively.

We display the histograms relative to some parameters in Fig. 2: we can see that B is often overestimated and that there is no information about B$\sin\gamma$. However, a very good estimate is provided for B$\cos\gamma$, with a deviation of about $\pm$ 10 G, that means reliable information about the longitudinal flux Φ.

We have also obtained an acceptable estimate for the LOS velocity (deviation of $\pm$ 0.5 km s^{-1}). As far as concerns the temperature stratification, it can be compared with that retrieved by SirUV for a very-quiet Sun region (see Fig. 1), that is found to reproduce quite well the HSRA model (Gingerich et al. 1971).

4. Preliminary results

The results of the SirUV tests are very encouraging, as they show that we are able to obtain some reliable information about the physical parameters of the magnetic patches, although in presence of a noticeable cross-talk in data.

Figure 3 shows the continuum intensity and longitudinal flux density maps obtained from the SirUV inversion of the IMaX sub-FOV in Fig. 1, during the EG evolution.

We found that a kind of magnetic flux mantle is seen growing during the EG expansion. This emerging flux structure has a multi-polar configuration. Note that the dark blobs, coinciding with the breaking center of the EG, occur over polarity inversion lines.

The flux distribution suggests that this flux mantle is expanding on mesogranular scale. Such a morphology is reminiscent of a flux structure with nearly horizontal magnetic field, perhaps generated by the explosion of an emerging flux tube during its rise across the convection zone.

Our next goals will be:

- to verify the fit to individual anomalous profiles, obtained with SirUV;
- to analyze in detail the dynamical and thermal distribution of the magnetic flux mantle;
- to complement the study of Palacios et al. (2012) with new information.

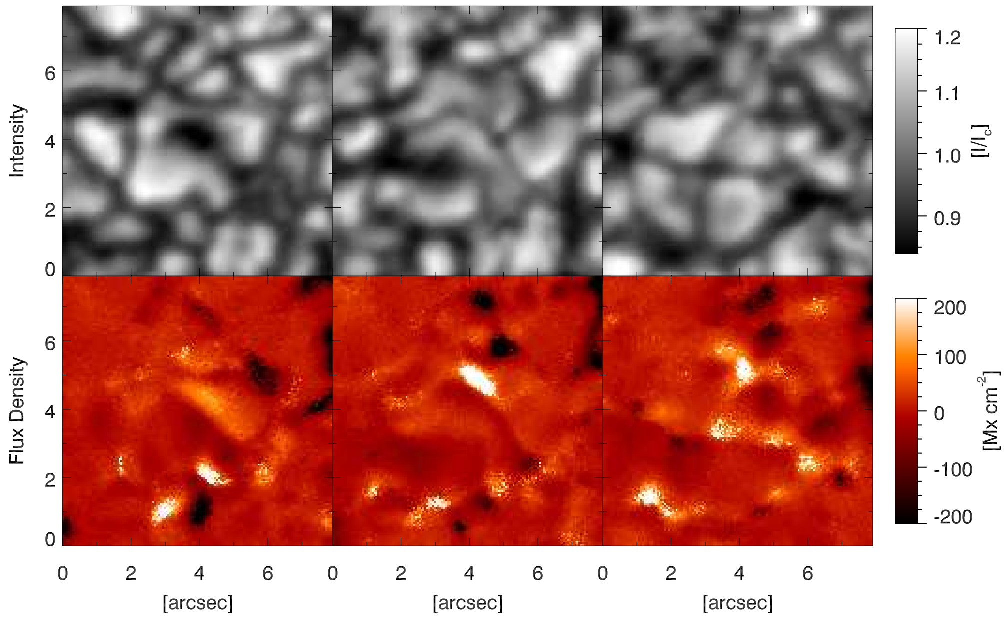

Fig. 3. *Top panels*: continuum intensity maps of the EG region, acquired by IMaX, with the same FOV of the square highlighted with solid line in Fig. 1. *Bottom panels*: longitudinal flux density maps for the same region, obtained from the SirUV inversion. Images shown with a cadence of 5 minutes.

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