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Evolution of Small Scale Magnetic Structures from Sunrise Data

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Abstract. We present the results of an analysis of small scale magnetic features in the quiet Sun, observed with the Sunrise balloon borne telescope. Our aim is to understand the contribution of different physical processes that drive the evolution of magnetic features in quiet regions of the photosphere. To this end, we study the rearrangement, addition, and removal of magnetic flux through splitting, merging, cancellation, and emergence of magnetic fields.

1. Introduction

Knowledge of the magnetic flux in quiet regions of the Sun is important to understand the physical mechanisms underlying the evolution of solar magnetism and hence solar activity. In this paper we carry out a statistical analysis of small scale magnetic features observed using the Sunrise balloon borne telescope (see Solanki et al. 2010; Barthol et al. 2011).

Magnetic fields generate net circular polarization signals due to the well known Zeeman effect more strongly than linear polarization. Therefore, we study the Stokes V/I_c images, where V denotes the circular polarization and I_c denotes the continuum intensity. A time series of 42 quiet Sun magnetograms, observed with the Imaging Magnetograph eXperiment (IMaX, see Martínez Pillet et al. 2011) onboard Sunrise in June-2009, was considered. The spatial sampling is approximately 40 km/pixel and the cadence is 33 sec.

The analysis is carried out by first identifying the magnetic features. For this we use a lane finding code (see Hirzberger et al. 1999), originally developed for studying granular features. We apply this code to V/I_c data to identify the magnetic features. This code identifies the collection of pixels which are connected in spatial (x, y) directions by applying a binary mask and follow such features in time. We identify positive and negative polarity structures separately. Although the interaction between opposite polarity features forms an important part of this study, in this paper we present only the results of the study of interactions between same-polarity features. Here we study the time evolution of spatially connected two-dimensional (2D) magnetic features. The interactions between the magnetic features is taken into account by checking if the 2D magnetic features overlap in two successive time steps.

2. Flux Determining Events

After identifying the magnetic features we classify different events as follows. Here t_1 and t_2 represent two successive time steps. Generally we classify the events into six categories. They can be described briefly as follows. More details will be provided in a forthcoming paper.

- If we see features at time step t_1 which disappear in next time frame t_2 we consider these features to have **simply died** at t_1.
- If any feature suddenly appears at time step t_2 we consider this features to be **simply born** at t_2.
- If a feature at t_1 splits into two or more features at t_2 (i.e., the feature at t_1 intersects with at least two features at t_2) we consider the feature at t_1 to be dead due to **splitting** and new features have been born at t_2.
- If two or more features at time step t_1 intersect with one feature at t_2 we consider the two features to be dead due to **merging** and a new feature is born at t_2.
- If two features with opposite polarities are seen near each other at time frame t_2 by simple appearance (i.e., not part of splitting or merging events in the previous time step t_1), then we consider this event to be an **emergence**.
- If two (or more) opposite polarity features next to each other at time frame t_1 disappear or appear with a reduced flux at time step t_2 then we consider this event to be a **cancellation**.

We remark here that definitions provided here are rather general and qualitative. More details on how exactly we treat different events will be explained in a forthcoming paper. Further, although we define events that are due to interaction between opposite polarity features (emergence and cancellation), we present the results from the study of interaction between same polarity features only in this paper.

3. Results and Discussions

In this section we present some preliminary results of our recent investigations of the Stokes V data from the Sunrise observations in June 2009. In all the calculations presented here, we have discarded the features in the first and last time steps of the time-series for a consistent study of the evolution of the 2D features.

3.1. Average Continuum Intensity

Figure 1 shows a histogram of the spatially averaged continuum intensity of the detected magnetic features (see also figure caption). The maximum of the average continuum intensity I_c distribution is at 0.9 which shows that the magnetic features are darker than the average quiet Sun intensity. It follows a normal plus a quadratic polynomial type distribution (asymmetrical about the maximum) given by,

$$f(x) = A_0\, e^{-z^2/2} + A_3 + A_4 x + A_5 x^2, \quad (1)$$

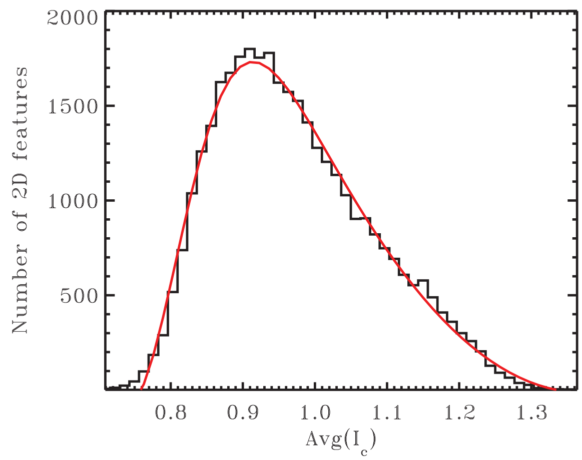

Figure 1. Histogram showing average value of the continuum intensity I_c associated with each magnetic feature. A normal plus a quadratic polynomial fit to the histogram is shown as the solid curve.

with

$$z = (x - A_1)/A_2, \tag{2}$$

and the fitting coefficients A_i, $i = 0, 1, ..., 5$.

3.2. Lifetime of Magnetic Features

The lifetime of a magnetic feature is defined to be the time interval within the observed 42 frames, during which an identified feature lives, without getting destroyed, by any of the events discussed above. Figure 2 shows a histogram of the lifetimes of the magnetic features, which follows a power law distribution of the form $f(x) = a\ x^b$ where a and b are fitting coefficients, with $b = 0.07$.

3.3. Area Distribution

Figure 3 shows a histogram of the area of the magnetic features. It follows a power law distribution of the form $f(x) = a\,x^b$ where a and b are fitting coefficients, with $b = 0.18$.

3.4. Growth and Decay of Magnetic Flux of the Features

Figure 4 shows the average magnetic flux evolution in magnetic features that live for at least 4 time steps. The magnetic features are classified according to the processes ending their lifetime.

From Figure 4 we can understand that,

- The features dying without any kind of interactions show the smallest maximum flux, and the flux evolution versus lifetime is nearly symmetric.

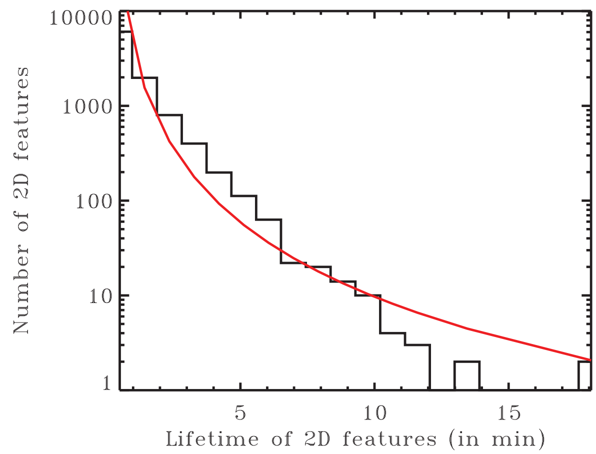

Figure 2. Histogram showing the lifetime distribution of magnetic features. A power law fit to the histogram is shown as the solid curve.

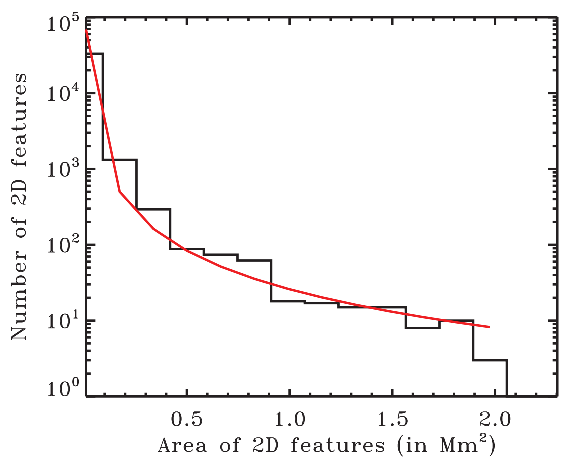

Figure 3. Histogram showing the area distribution of the magnetic features. A power law fit to the histogram is shown as the solid curve.

- For all other types of features the average flux increases with time and reaches a maximum at nearly 70% of the normalized lifetime, then it decreases to a value higher than their initial values, at the time of death.

- The merging features die with a flux closer to their maximum flux than the splitting features. The splitting features reach the highest maximum flux value, compared to all other types of features. i.e., it is the biggest features that tend to split.

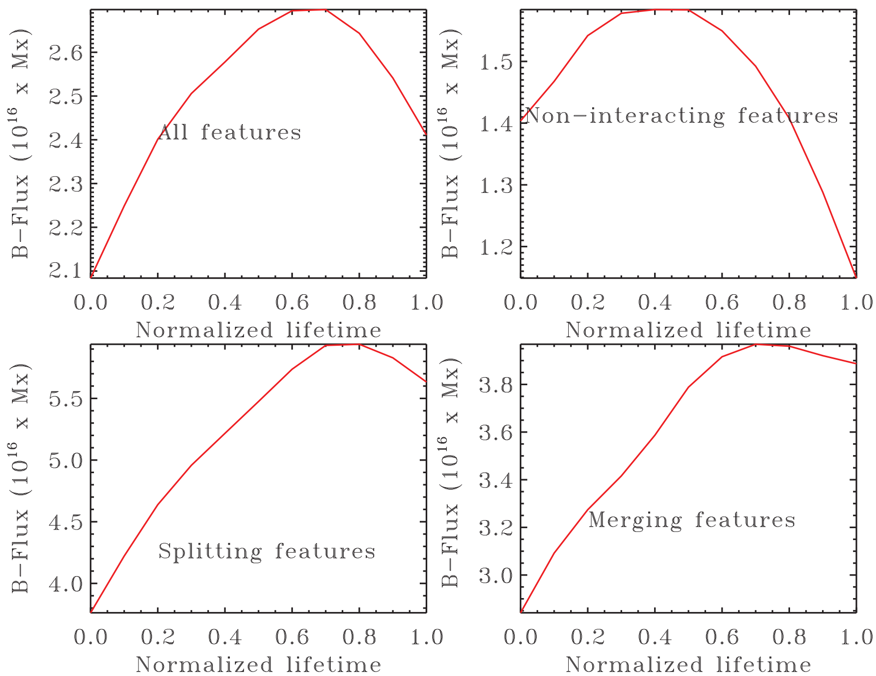

Figure 4. Growth and decay of the magnetic flux for different cases marked on the diagrams.

4. Conclusions

In this paper we present preliminary results of a study of the evolution of small scale magnetic features in the quiet Sun, using high spatial and temporal resolution data from the Stokes *V* time series obtained with the IMaX spectropolarimeter onboard the Sunrise balloon borne telescope. We focus on the statistical properties of the features, that take part in processes such as splitting, merging, emergence, and cancellation. The main results from same polarity studies are discussed in Section 3.4. The preliminary results from our study on opposite polarity features indicates that, interaction between opposite polarity features is rare compared to that between same polarity features. This is consistent with the results from other recent studies (see Iida et al. 2012; Lamb et al. 2013, and the preceding papers of the series).

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