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Evolution of small-scale magnetic features on the quiet regions of the Sun

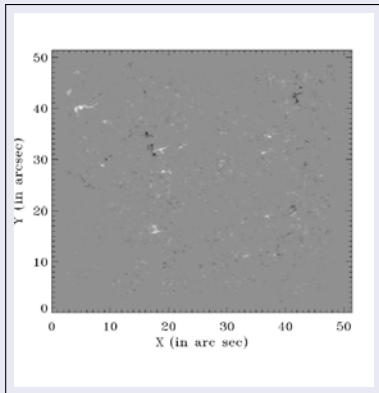
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Introduction

Gray Scale: ± 0.065



- Pixel sampling : approx. 40 km/pixel (~ 0.055 arcsec/pixel).

Aim

- Magnetic fields generate **circular polarization** signals due to **Zeeman effect** \Rightarrow Measured as Stokes V signals (=difference between left and right circular polarization components).
- In this study, our aim is to understand the contribution of **different physical processes** that drive the **evolution of small-scale magnetic features** in **quiet regions** of the photosphere.
- Can be achieved through **magnetic flux estimation** using time-series of Stokes V/I_c images (circular polarization).

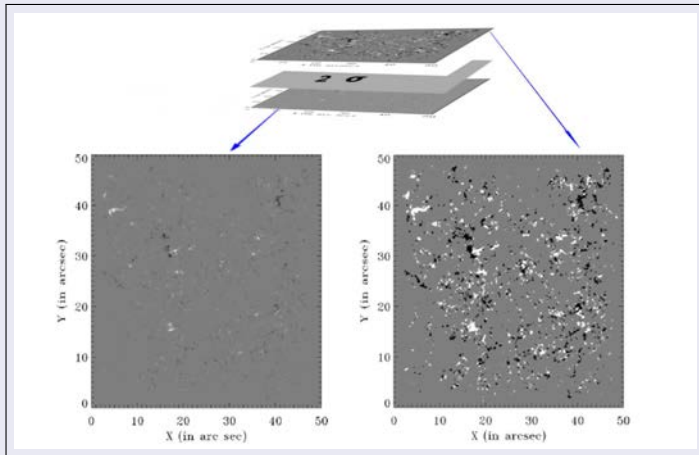
Specifications

- We study a time series of **42 quiet Sun magnetograms** observed with the Imaging Magnetograph eXperiment (IMaX) onboard Sunrise in June-2009.
- Fe I 5250.02 Å line,
 - sampled with 85 mÅ FWHM bandpass,
 - at positions \pm , 80 mÅ \pm 40 mÅ +227 mÅ .
- FOV 50 arcsec \times 50 arcsec.
- Pixel sampling : approx. 40 km/pixel (\sim 0.055 arcsec/pixel).
- Cadence : 33 sec.

- In recent studies of small scale magnetic features on the quiet Sun
⇒ major contribution to the magnetic flux is through
 - Unipolar emergence or simple **appearance** and **disappearance** of magnetic features,
 - **splitting** and **merging** of the field lines ⇒ rearrangement + some part of the magnetic flux goes beyond resolution.
- Only a **small fraction** of the flux goes into actual flux addition or removal due to **bi-polar emergence** and **cancellation** of opposite polarity fields (e.g., DeForest et al. 2007, Lamb et al. 2008, 2010, Parnell et al. 2009, Lamb et al. 2013, Iida et al., 2012).
- ∴ Here we carry out a **detailed statistical study** of such events.

Feature Identification

Left : Original V/I_c image (gray scale: ± 0.065), Right: After binary mask

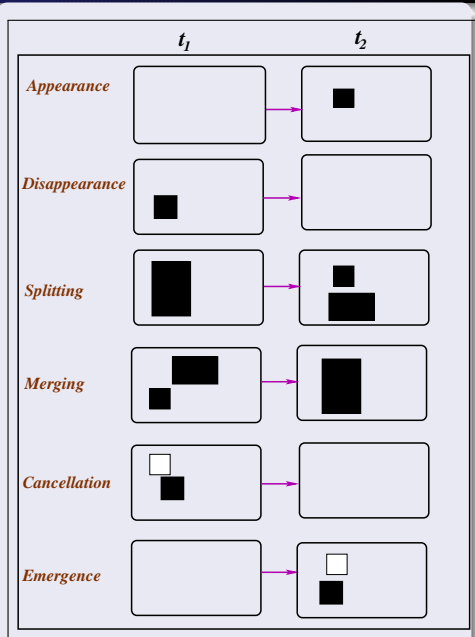


- **Lane finding code** (Hirzberger et al. 1999) – **binary mask**.
- Threshold $\rightarrow 2\sigma$, $\sigma = 1.5 \times 10^{-3}$, Total : **50255 2D features**.

Event classification

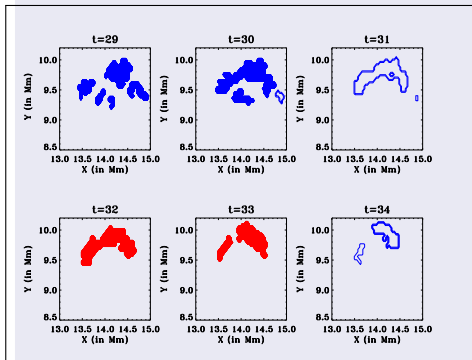
Birth and death of the magnetic features

- Features suddenly appear at $t_2 \Rightarrow$ **simply born** at t_2 .
- Features at t_1 – disappear at $t_2 \Rightarrow$ **simply died** at t_1 .
- Feature at t_1 splits into two or more features at $t_2 \Rightarrow$ **splitting event**. Parents are dead at t_1 , children are born at t_2 .
- Two or more features at t_1 intersect with one feature at $t_2 \Rightarrow$ **merging event**. Parents are dead at t_1 , children are born at t_2 .
- Two (or more) opposite polarity features next to each other at t_1 – disappear or appear with a reduced flux at $t_2 \Rightarrow$ **cancellation event**.
- Features with opposite polarities are seen near each other at t_2 by simple appearance \Rightarrow **emergence event**.



Feature Identification

Evolution of 2D features : Examples, pathological cases



- Limitations: Spatial and temporal resolution.
- Evolution of features between the time steps is unknown.
- Several ambiguous and pathological cases occur.

Scale range

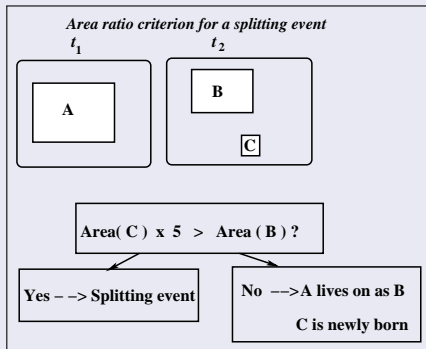
Minimum area : 5 pixels $\sim 7.6 \times 10^{-3} \text{ Mm}^2$

Maximum area : 1585 pixels $\sim 2.4 \text{ Mm}^2$

Feature Identification

Area-ratio criteria

- To rule out that a feature is **considered dead** just because a **tiny part of it splits off**, or because it **merges with a much smaller feature**, the areas of involved features at a given time step are compared. We consider **2:1, 3:1, 5:1 and 10:1** area-ratio cases.



Center of gravity technique : Rees & Semel (1979)

- The technique computes the **wavelength shifts** of the circularly polarized components of the intensity using the measured values of Stokes parameters I and V .

$$B = |\Delta\lambda_G / C_0 g \lambda_0^2|,$$

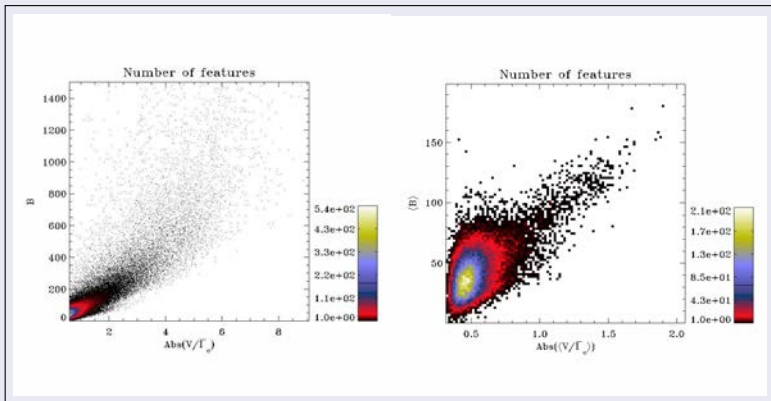
where $C_0 = 4.67 \times 10^{-13}$, g is the Landé factor, λ_0 is the line center wavelength, and

$$\Delta\lambda_G = \frac{\int_{-\infty}^{+\infty} V \Delta\lambda d\Delta\lambda}{\int_{-\infty}^{+\infty} (I_c - I) d\Delta\lambda}.$$

- The wavelength shift depends **linearly** on the **magnetic field strength** B .

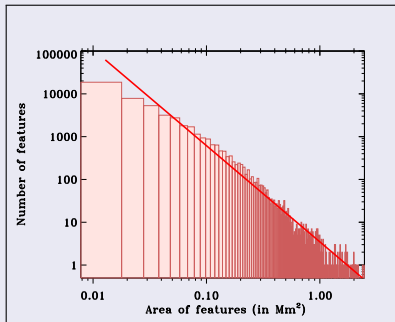
Magnetic Flux Calibration

3D histograms: left:pixel-by-pixel, right:magnetic feature-averaged



Results and Discussions-1: Statistics of feature properties

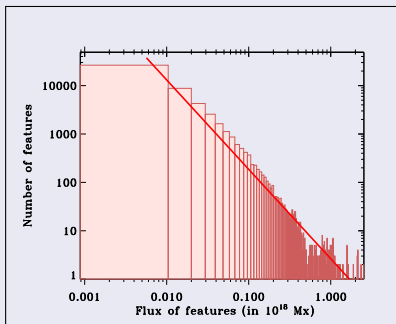
Area distribution : A power law fit : $f(x) = ax^b$ with $b = -2.25$



- Min. area : 5 pixels $\sim 7.6 \times 10^{-3} \text{ Mm}^2$; Max. area : 1585 pixels $\sim 2.4 \text{ Mm}^2$; Mean area : 37 pixels ($\sim 5.8 \times 10^{-2} \text{ Mm}^2$).
- Power-law index \sim studies by Buehler et al.(2013) using Hinode/SP.

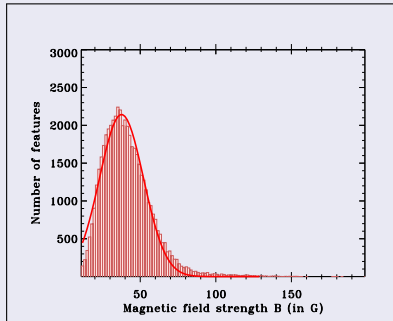
Results and Discussions-1: Statistics of feature properties

Flux distribution : A power law fit : $f(x) = ax^b$ with $b = -1.85$



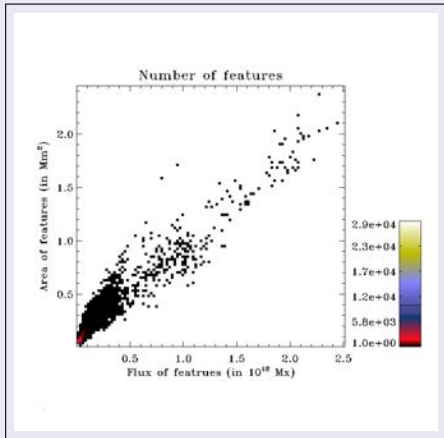
- Min. flux : 8.8×10^{14} Mx, Max flux: 2.5×10^{18} Mx;
Mean flux : 3×10^{16} Mx.
- Power-law index matches with recent studies by Parnell et al.(2009), Iida et al.(2012), Buehler et al.(2013).

Magnetic field strength distribution (feature averaged)



- Field strengths are weak; Mean value: 41 G.
- Min. field strength = 11 G; Max. field strength = 198 G.
- The field strength values nearly follow a normal distribution:
$$f(x) = A_0 e^{-z^2/2}, \quad z = (x - A_1)/A_2.$$

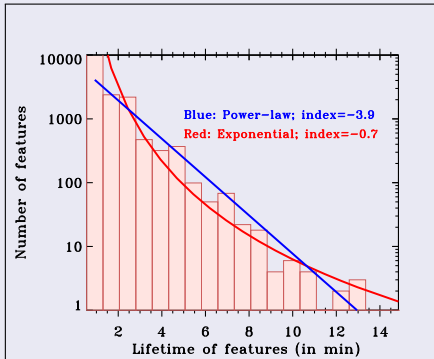
Relationship between area and flux



- 3D histogram of the number of features on the plane spanned by the magnetic flux Φ in the features and their areas A .

Results and Discussions-1: Statistics of feature properties

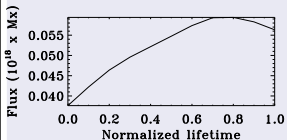
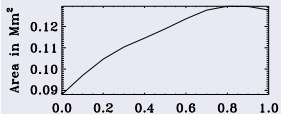
Lifetime distribution (10:1 area ratio): A power law fit (blue): $f(x) = a x^b$ with $b = -3.9$; Exponential fit (red): $a e^{bx}$ with $b = -0.7$.



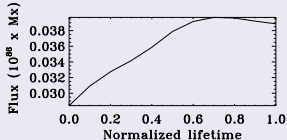
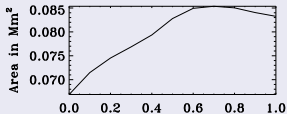
- The lifetime of a feature: the interval of time between the birth of a feature and its death (birth either through appearance, emergence, or from splitting or merging, death through disappearance, cancellation, splitting or merging).
- Min. lifetime - 33 sec (1 time step); Max. lifetime - 957 sec (29 time steps); Mean lifetime - 90 sec.
- Power-law fits better.

Results and Discussions-2: Growth and decay of area and magnetic flux

Splitting features



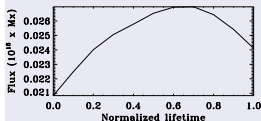
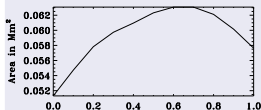
Merging features



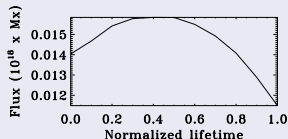
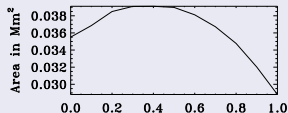
- The features are normally born with **small area and fluxes** which increase during their lifetime.
- The area and fluxes of features who die due to **splitting and merging reach maxima at ~ 70 %** of their lifetime and die with an area and flux slightly less than the respective maximum value.

Results and Discussions-2: Growth and decay of area and magnetic flux

All features



Disappearing features



- The area and flux of the features which die due to **disappearance** are symmetric, and reach **their maximum at ~ 50 %** of their lifetime. The area and flux of these features at their death are smaller than those at their births.

Results and Discussions-2: Growth and decay of area and magnetic flux

- The **maximum flux is smallest** for the features who die due to **disappearances** and
- ...is **largest** in the features which die due to **splitting**.
- **Largest features** are those who **tend to split**, followed by those who merge and finally those who disappear.

Results and Discussuins-3: Statistics of the births and deaths

Normalized, maximum flux distribution of the features involved in various events

Area ratio for unipolar events					
Type of birth	10:1	5:1	3:1	2:1	other results
Appearance	22 %	31 %	42 %	56 %	30 %
Splitting	42 %	36 %	29 %	22 %	50 %
Merging	36 %	33 %	29 %	22 %	–
Total	100 %	100 %	100 %	100 %	
Type of death	10:1	5:1	3:1	2:1	other results
Disappearance	23 %	32 %	43 %	56 %	80 %
Splitting	42 %	39 %	32 %	24 %	–
Merging	35 %	29 %	25 %	20 %	–
Total	100 %	100 %	100 %	100 %	

Results and Discussuins-3: Statistics of the births and deaths

Number and Flux distribution in opposite polarity interactions

Flux distribution					
Emergence events					
Flux and area ratio	10:1	5:1	3:1	2:1	other results
Maximum flux	1.87 %	1.7 %	1.35 %	0.98 %	1.6 %
Cancellation events					
Area ratio	10:1	5:1	3:1	2:1	other results
Maximum flux	11.9 %	15.1 %	18.9 %	22.6 %	12 %

Summary

- We used **Sunrise - I** high spatial and temporal resolution data.
- Statistics of **area, flux and lifetime distributions** are consistent with similar, recent studies using other data such as Hinode.
- We focus on **simple appearance, disappearance, splitting, merging, emergence and cancellation events** between magnetic features.
- We have carried out a **detailed study** by precisely defining and classifying different **birth and death events**.
- We eliminate **error or ambiguous births and deaths** by a set of carefully tested criteria based on **area and flux-ratios**.

- With this study we **disagree** with previous statistics on **uni-polar fluxes**.
- We **agree** with previous statistics on **bi-polar fluxes**.
- $\sim 25\% - 55\%$ flux goes into **simple appearances and disappearance** events.
- $\sim 20\% - 40\%$ flux goes into birth and death due to **splitting and merging** events.
- Very little fraction of the flux goes into **bi-polar emergence** ($\sim 2\%$), but a significant fraction of $12\% - 23\%$ in **cancellation** events.

- We have developed a new code for this study which can be used to carry out several other studies such as **analysis of bright points**.
- We can carry out similar studies using **MHD simulations** – – to understand if the source such fluxes is **local or global dynamos**.

THANK YOU



The speaker's attendance at this conference was sponsored by the Alexander von Humboldt Foundation.

<http://www.humboldt-foundation.de>

