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The evolution of magnetic network elements in the quiet Sun

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Abstract. Using the 155-h coordinated magnetograph data of Huairou and Big Bear Solar Observatories, we have studied the evolution and lifetime of magnetic network elements in an enhanced network region. Both statistical and counting methods give a mean lifetime of network elements of 50 h. The network elements are divided into two categories according their evolution: "breakup" and "merging". They have similar average lifetimes. We also find that the number of the elements that disappear by merging is about twice that by breakup. This may indicate that the creation and disappearance of magnetic network elements are balanced.

Key words: Sun: magnetic field – Sun: photosphere

1. Introduction

Magnetic fields appear everywhere at the surface of the Sun. Those in quiet regions generally include network elements, intranetwork elements and ephemeral regions. Their existence and evolution play an important role in the activity and evolution of the solar magnetic fields.

The study of magnetic fields in quiet regions involves determination of their physical parameters, characteristics of their evolution, and relationship to convection such as the supergranulation, mesogranulation and granulation (Simon et al. 1964, 1988; Topka et al. 1986; Title et al. 1987, 1989; Wang & Zirin 1989). Our understanding of the size, flux, and lifetime of these magnetic features has improved considerably in recent years, especially those with small spatial scales such as intranetwork magnetic fields and ephemeral regions (Martin et al. 1985). The evolution of magnetic features on short time scale can be easily determined by just a single observatory. Study of their long term-evolution, however, requires observations from two well-placed observatories, as some features cannot be identified easily after a 12-h night gap.

Since 1987, the Huairou Solar Observing Station of Beijing Astronomical Observatory and Big Bear Solar Observatory of Caltech have made coordinated observations of solar magnetic fields for studying the long-term evolution of magnetic features. From the first series of coordinated observations, Wang et al. (1989) found that magnetic network cells have an average lifetime of about 90 h. Later, from coordinated observations of an enhanced network in May 1988; Wang et al. (1991) determined that the average lifetime of network cells is 66 ± 28 h. In this paper, we use the same May 1988 data to study the evolution of individual features in network cells known as magnetic network elements (Zirin 1987). In Sect. 2, we present the observational data. In Sects. 3 and 4, we study the evolution and lifetime of magnetic network elements. In Sect. 5 we present the conclusions and discussions.

2. Data

Our coordinated observations were made with the solar magnetic field field telescope (SMFT) at Huairou Solar Observing Station and videomagnetograph (VMG) system at Big Bear Solar Observatory (BBSO). The SMFT system composes a 35-cm vacuum telescope, a magnetograph with an 1/8-Å birefrigent filter and 3 sets of KDP crystal modulators, a CCD camera, and an Imaging Technology 151 System. The latter is controlled by an AST-386 system, which transmits the data to a VAX/11-750 (Ai 1987). The SMFT uses two spectral lines: the Fe Iλ line at 5324.19 Å and the Hβ line at 4861.34 Å. The spatial resolution of magnetograms is $2''$, temporal resolution is as short as 10 min. The VMG system at BBSO has been described in detail by Mosher (1976) and Zirin (1985).

We obtained a time series of magnetograms of a quiet region. The observations spanned 155 h from 11 May to 17 May 1988 with 6 night gaps of an average length of 5 h. The time resolution of the data was about 20 min. The magnetograms were corrected for geometric foreshortening.

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3. The evolution of magnetic network elements

The target of our coordinated observations was the enhanced network region shown in Fig. 1. The Kitt Peak daily magnetograms showed that this region was an active region in the previous rotation. The sunspots from the previous rotation had already disappeared when the region appeared on the East Limb on 10 May, 1988 (Wang et al. 1991).

The long lifetime of a network (Wang et al. 1991) implies that there must be an equilibrium between the creation and destruction of network elements. Creation of network elements may occur by the merging of existing elements, the emergence of ephemeral regions, or the concentration of intranetwork elements. Their destruction can result from the cancellation of opposite polarity elements, or breakup into smaller fragments (Zirin 1987). An example of the evolution of a magnetic element group is shown in Fig. 2. The magnetic elements A1, A2, A3 merge together and form a new element A. After 21 h, A breaks up into three fragments moving in different directions. Subsequently, they all cancel with magnetic elements of opposite polarity (two disappear completely and one cancels partially by the end of the observation, see Table 1).

The time variation of the total magnetic flux of the elements in the group A is shown in Fig. 3. As expected, when the network elements merged with the same polarity or broke into fragments, the total magnetic flux hardly changed. When they canceled with magnetic features of opposite polarity, the total magnetic flux decreased rapidly. In Table 1, we list the proper motion speed of magnetic elements at different stages of evolution.

4. The lifetime of network elements

There are three possible methods to derive the lifetime of magnetic networks that outline the boundaries of supergranule cells: (i) by calculating the cross-correlation coefficients for the VMG images, where the lifetime of network cells is the e-folding time of the cross-correlation; (ii) by determining, as a function of time, the ratio of the number of surviving cells to the total number of cells, where the e-folding time of the ratio is the average lifetime of the cells (Wang et al. 1989); and (iii) by identifying and tracking each cell from birth to death, so that the average lifetime of these cells can be derived directly by averaging the lifetimes of individual cells (Wang et al. 1991). Using the same methods, we can determine the lifetime of network elements as well.

In a sample of 50 network elements, Zirin (1987) found that five elements changed completely in a 9-h period. This implied that the lifetime of network elements is about 80 h. As many network elements change substantially from one day to the next, they could not be identified after a 12-h gap. Thus the methods (i), (ii) and (iii) mentioned above can only roughly give the lifetime of network elements if data exists for one observing station. The 155 h of coordinated

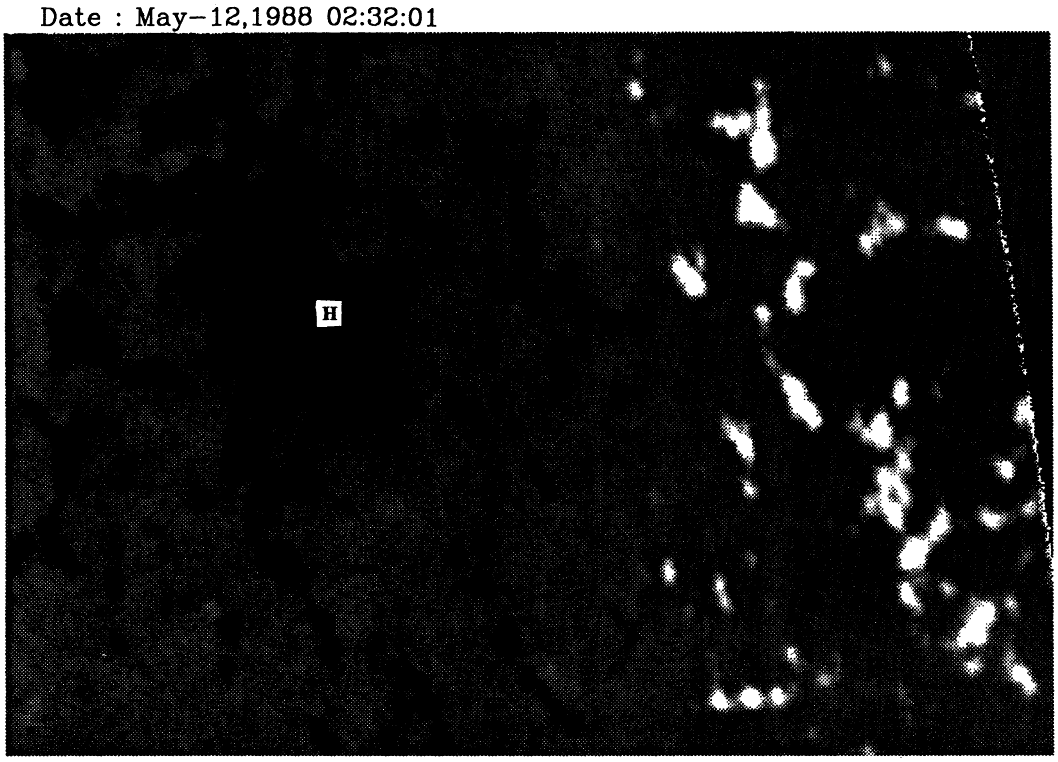

Fig. 1. One of the longitudinal magnetograms from our 155-h coordinated observations

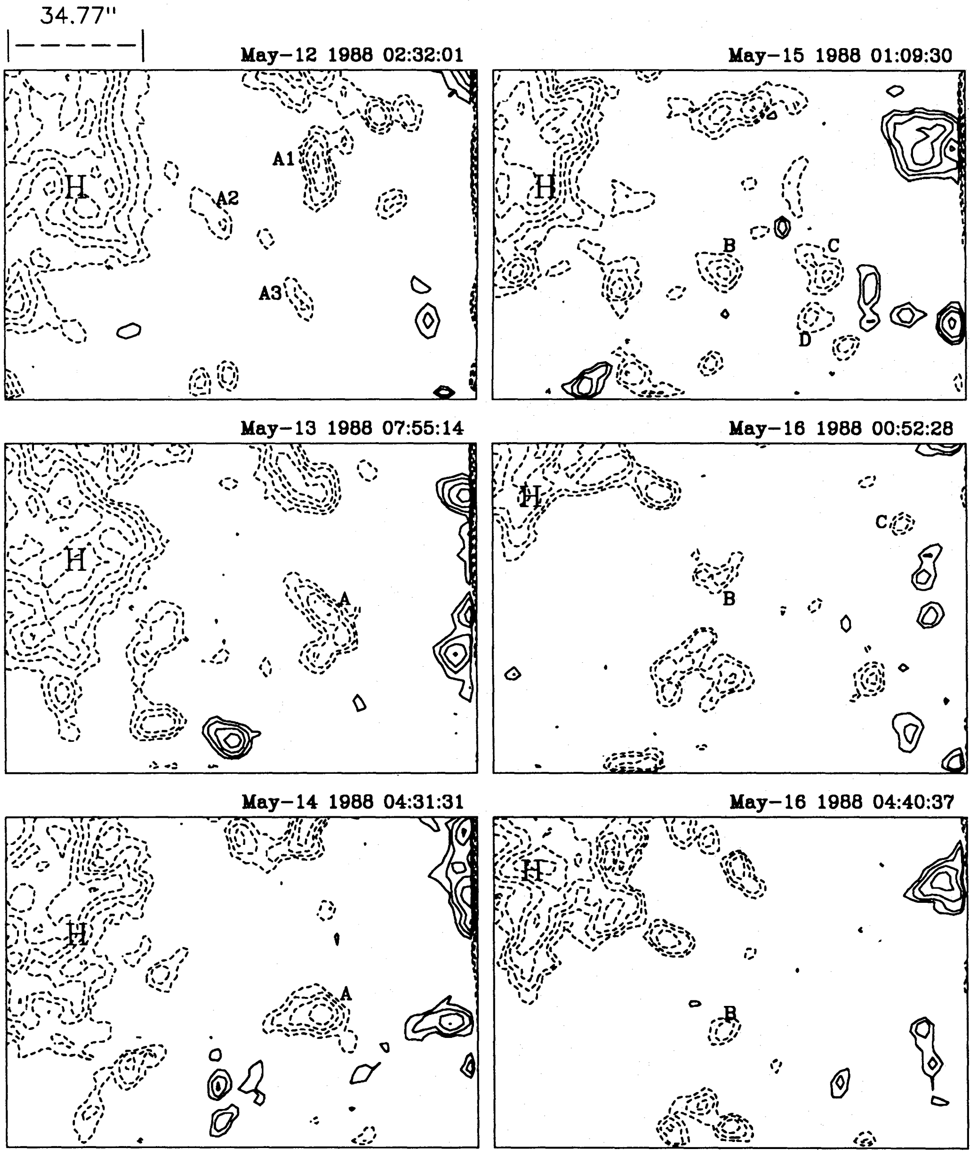

Fig. 2. A series of magnetograms showing the evolution of network element A. The contour levels are: 20, 40, 80, 160, 320 G

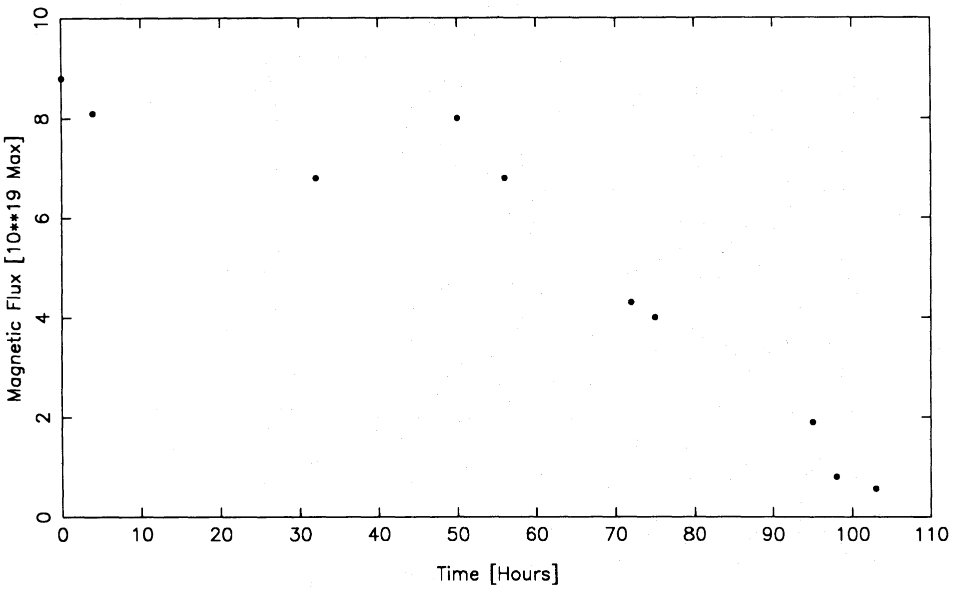

Fig. 3. The total magnetic flux of network element A as a function of time

Table 1. The evolution of network element A

Element	Interval	The mean velocity (10^2 m^{-1} s)	Average rate of magnetic cancellation (10^{13} Mx^{-1} s)	Remark
A1	0516 UT(12th)– –0748 UT(13th)	3.0		Merging into element A
A2	0516 UT(12th)– –0748 UT(13th)	4.0		
A3	0518 UT(12th)– –0748 UT(13th)	5.5		
A	0748 UT(13th)– –1400 UT(14th)	0.69		Element A moves
B	1400 UT(14th)– –2340 UT(14th)	2.4		Element A broke into Elements B, C, D. And B, C and D separated
C	1400 UT(14th)– –2340 UT(14th)	3.1		
D	1400 UT(14th)– –2340 UT(14th)	3.4		
C, D	0109 UT(15th)– –0204 UT(15th)	3.6		C and D separated
C, D	0204 UT(15th)– –0513 UT(15th)	0.56		C and D separated
D	0100 UT(15th)– –1400 UT(15th)		19	Element D cancelled with opposite polarity.
C	0100 UT(15th)– –0400 UT(16th)		18	Element C cancelled with opposite polarity.
B	0100 UT(15th)– –0630 UT(16th)		8.7	Element B cancelled with opposite polarity partly.

observations presented here can be used more easily and accurately to obtain the lifetime of magnetic elements.

4.1. Sampling

We selected all network elements in the field of view that have magnetic fluxes greater than 10^{18} Mx, except those in an area of 15″ in the radius around the letter "*H*" where the field is much stronger than in other areas (Fig. 1). We divided the evolution of network elements into three possible categories.

(1) Merging of elements. We further divide them into two categories: (a) merging of elements with the same polarity; and (b) merging of elements with opposite polarities (i.e. cancellation).

(2) Breakup. One network element breaks into two or more fragments.

(3) Unipolar decay. Magnetic elements diffuse into weak fields below the sensitivity of the instrument.

We define an element as dying if it breaks up or merges with another element. For example, when the element A breaks into elements B, C and D, element A dies, while B, C and D are born. We define the lifetime of an element as the duration from its birth to death.

4.2. Lifetime of network elements

4.2.1. Lifetime derived by the counting method

From the 155-h coordinated observations, we selected a period of 123 h during which the seeing was constant. During this period, we were able to follow 76 network elements from birth to death. Figure 4 shows a histogram of the lifetime of these elements. As we can see, the lifetimes of these elements range from 5 to 106 h. We use the following weight factor for each element:

$$X = \frac{123}{123 - T}, \tag{1}$$

where 123 is the length of the observing period, and T is lifetime of an element. The weighted average lifetime of the network elements is 55 h. The results are compiled

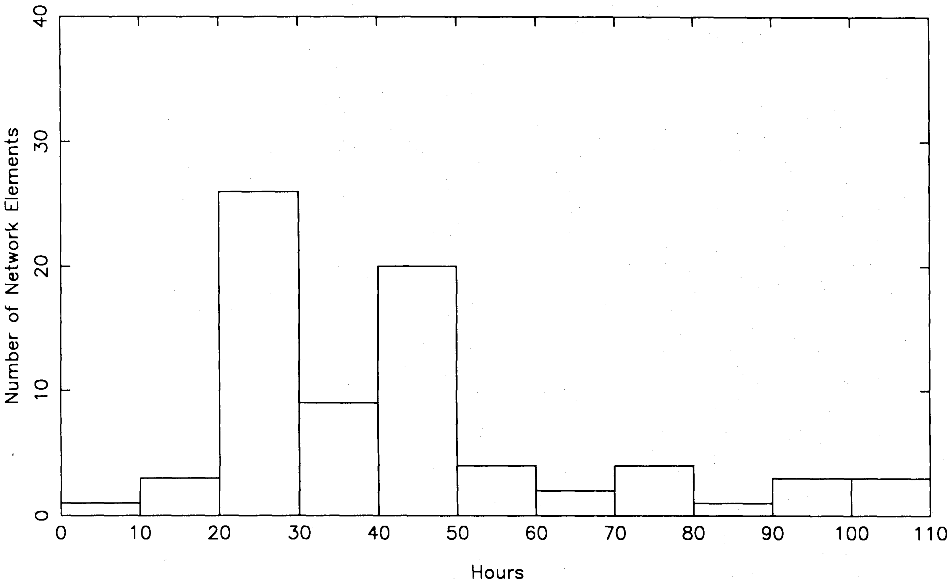

Fig. 4. The histogram to show the distribution of network element lifetimes

Table 2. The lifetime of network elements

Sample	Categories	Number	Lifetime
Merging	a: (Merging with the same polarity)	36	51
	b: (Cancellation with the opposite polarity)	15	
Breakup		25	61
⟨1⟩ : ⟨2⟩		2.04	55

Remark: ⟨1⟩ means the number of the network elements that merge with other ones, ⟨2⟩ means the number of the network elements that break into fragments.

in Table 2. Among the 76 elements, 36 merged with the elements of the same polarity, 16 canceled with elements of opposite polarity, and 25 fragmented (Table 3).

4.2.2. Lifetime derived by the statistic method

With this method, we first identify and track every network element beginning at the 0000 UT, May 12. We follow these elements and note the time ($T1$) at which each one dies. Because we do not know the time when an element was born, the average of $T1$ is half the mean lifetime. As we discussed earlier, magnetic elements die in two ways: merging and fragmentation (breakup). We found that the mean lifetime of elements that died by merging is 47 h; by fragmentation, 53 h. The average lifetime of all the elements is 49 h, consistent with the result of Sect. 4.2.1.

5. Discussion

Using two different methods, we derived similar lifetimes for magnetic network elements. We conclude that the average lifetime of magnetic network is around 50 h. Because we do not have longer continuous observation, we may have underestimated the lifetime of network elememts. For example, if the lifetime of an element was 100 h, in the 123-h coordinated observations, we could follow the element from birth to death only when it was born during the first 23 h of the observation. So we may have excluded some long-lived elements. The weighting method shown in Eq. (1) may correct some of this effect. Looking at the distribution of the lifetimes, it is obvious that the number of elements with lifetime longer than 60 h was small, so this effect may not be very significant. On the other hand, we only included the

Table 3. The lifetime of network elements

Sample	Number	Lifetime
a:	24 (Mergence with the same polarity)	
Merging		47
b:	2 (Cancellation with the opposite polarity)	
Breakup	12	53
Average		49

Remark: The category ⟨a⟩ is the merging of the same polarity elements and ⟨b⟩ is the cancellation of the opposite polarity elements.

elements with flux greater than 10^{18} Mx. The lifetime may be reduced if we include smaller flux elements. However, if we want to study the network elements only and avoid intranetwork fields, 10^{18} Mx is a reasonable lower limit.

By examining the evolution of the 76 elements, we found that the number of elements that die by merging was about twice those that die by fragmentation (see Table 2). As the network elements that died by merging had approximately the same average lifetime as those that died by fragmentation, the ratio of 2 : 1 has a physical interpretation. One element usually broke in two fragments, while in the inverse process, two elements usually merged into a new one. If we only considered the number of events for merging and fragmentation, we could find that these two numbers are similar. This may explain why the total number of network elements is conserved during our observation.

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