EPHEMERAL REGIONS VS. PSEUDO EPHEMERAL REGIONS

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ABSTRACT

Our new studies of the quiet sun reveal that ephemeral active regions constitute a minority rather than a majority of all the short-lived, small-scale bipolar features on the sun. We retain the definition of an ephemeral region as a feature which appears to originate as a compact bipole and grows as a unit in total flux for at least a short time after its birth. In contrast to the recognized patterns of growth and decay of ephemeral regions, we illustrate various examples of the creation of other temporary bipoles nicknamed "pseudo ephemeral regions." We show that the pseudo ephemeral regions are the consequence of combinations of small scale dynamic processes of the quiet sun including: (1) fragmentation of network magnetic fields, (2) the separation of opposite polarity halves of ephemeral regions as they grow and evolve, and (3) the coalescence of weak network or intra-network magnetic fields. In long-exposure videomagnetograms (~1 min.), having spatial resolution of 2-5 arc seconds, the pseudo ephemeral regions outnumber the real ephemeral regions by about a factor of 2. These new observations offer the possibility of resolving the discrepancies that have arisen in the association of ephemeral regions with X-ray bright points. We suggest that many X-ray bright points may be related to those pseudo ephemeral regions which have begun to exhibit magnetic flux loss. We also suggest that vector magnetograms should also

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reveal distinct differences between real and pseudo ephemeral regions similar to the differences that are sometimes seen in Ha filtergrams. Ha images show the opposite polarities of some ephemeral regions to be connected by fibrils or arch filaments. In contrast, the pseudo ephemeral regions sometimes reveal a fibril, like a small filament, dividing the opposite polarity fields, but no well-defined fibrils connecting the opposite polarities.
I. INTRODUCTION

Ephemeral regions are small, short-lived bipolar magnetic fields. They were recognized and characterized by their short lifetimes in CaII filtergrams years before their magnetic nature became known (Harvey and Martin 1973). Their name was adopted from the tabulations of active regions in Solar Geophysical Data (SGD); short-lived small CaII plages listed for only one or two days are designated as "ephemeral" (for example, see SGD 1963 to 1965). CaII plages are now more frequently called by the more general name "active regions" and hence small Ca plages are now known as "ephemeral active regions" or just "ephemeral regions."

In this paper we clarify the currently recognized properties of ephemeral regions as seen in magnetograms and Hα filtergrams. The Hα properties of these regions are especially important because Hα observations are currently our only direct source of information on the magnetic field component of ephemeral regions parallel to the solar surface; current-day vector magnetographs are not sufficiently sensitive to detect most ephemeral regions.

We further clarify the properties of ephemeral regions by comparing them with other features which can look like ephemeral regions but do not evolve like ephemeral regions. We call these "pseudo" ephemeral regions.
II. THE DATA

We have previously shown that long exposure videomagnetograms from Big Bear Solar Observatory are effective for studying ephemeral regions and other magnetic fields on the quiet sun (Martin 1983). Exposure of a videomagnetogram consists of many successive scans of the TV camera used as the primary detector in the videomagnetograph. The quiet sun images illustrated in this paper consist of 1024 or 2048 scans, which respectively require scan times of 68 or 138 sec. The final digitized image may be recorded both on magnetic tape and as a photographic image of the magnetogram from the initial display on a television monitor. Magnetograms in both of these formats are illustrated in this paper.

III. EXAMPLES OF EPHEMERAL REGIONS AND PSEUDO EPHEMERAL REGIONS

The properties by which we define ephemeral regions are illustrated by an example in Figure 1. The figure shows small sections of a single field of view taken during an 8 hour observing day on 4 September 1983. The oval in the second frame, 1930 (UT) in the left column of images, encloses a new ephemeral region not seen in the earlier image at 1751. The periphery of the positive pole is white and the periphery of the negative pole is black. The grey contour within the negative pole is not a polarity reversal. It is a contour intentionally included to show that the magnetic signal has reached saturation. By the next frame, 2040 UT,
the bipole has increased in total flux as seen by the appearance of additional saturation contours within each pole. Saturation contours of negative polarity are grey and saturated contours of positive polarity are white. This example illustrates the three defining properties of ephemeral regions:

(1) a new bipole with opposite polarity fields adjacent to each other

(2) growth of the bipole

(3) separation of the maxima of the opposite polarity fields from each other

A useful, non-defining property that is often but not always seen is:

(4) continued separation of the opposite poles

Note that the definition of an ephemeral region can include:

(5) emergence of one or both poles within pre-existing network

(6) a lack of exact simultaneity in the appearance of the opposite polarities (assumed to be an effect of field geometry or limited spatial resolution)
In contrast to ephemeral regions, next we illustrate features which temporarily look like ephemeral regions but lack the above defining properties of ephemeral regions.

The first example of such a pseudo ephemeral region is marked by a rectangle in Figure 1. In the first two frames at 1751 and 1930, the bipole looks exactly like the ephemeral region enclosed in the oval at 1930 UT. However, as we follow its evolution in the subsequent frames, we see that it is a disappearing bipole. The flux in both polarities is rapidly reducing relative to neighboring fields. We categorize this feature as a "pseudo ephemeral region," an apparent bipole that does not exhibit any of the defining properties of ephemeral regions except that it appears temporarily to resemble an ephemeral region. This type of pseudo ephemeral region reveals new, important distinctions from real ephemeral regions: (1) the opposite polarity fields move together, (2) they show a mutual loss in magnetic flux (cancellation), and (3) the gradient of the magnetic field between the centers of opposite polarity increases with time and typically exceeds the intra-pole gradient of ephemeral regions.

Small-scale, adjacent opposite polarity magnetic features are very common on the quiet sun. The corner of the rectangle to the lower right of the ephemeral region (Fig. 1) encloses a fragment of positive polarity field adjacent to network of negative polarity. It does not look like an ephemeral region because of the very large imbalance of flux in the
adjacent opposite polarities. However, even in this example, if our only available image were the one at 1751, we could not be certain that the positive polarity was not one of the halves of an ephemeral region which had its opposite pole buried in the negative polarity network. However, the next several frames show that this is not an ephemeral region. The first sign that this feature is not a new ephemeral region is the steady loss of flux in the positive pole. Concurrently there appears to be loss of flux in the negative polarity indicated by the indentation of the negative flux at the point of contact with the small positive fragment of magnetic field. The positive fragment has only a small point left at 2150 and has completely disappeared by 2234.

During a day's observation of the quiet sun, we typically observe many such examples of the mutual loss of flux in closely-spaced opposite polarity fragments of magnetic field. Since there are several possible physical processes which might adequately describe this phenomenon, we choose at present to use the observational term "cancellation" and to defer introducing interpretations of the cancellation process until the observational properties are more completely established. Only a few examples of cancellation have been previously mentioned in the literature (Martin 1984; Komle 1979; Martin and Harvey 1976). In the context of this paper, the observation of cancellation is a new and significant means of differentiating pseudo ephemeral regions from real ephemeral regions.
Next we illustrate examples of pseudo ephemeral regions whose origin can be traced.

One of the most common ways for a pseudo ephemeral region to form is simply by the collision of opposite polarity fragments of network. This class of pseudo ephemeral region is expected to frequently occur in filament channels (whether or not a filament is present in the channel) because filaments and filament channels always occur at boundaries between areas of opposite polarity network magnetic fields. An example is shown in Figure 2.

Figure 2 shows the full field of the videomagnetograph in the upper section and, in the lower section, the corresponding Hα filtergram. The network magnetic field is dominantly negative above the filament and positive below it. The site of the approaching network fields of opposite polarity is designated by the "1" in the lower right corner just below the filament.

Figure 3 shows a sequence of images in a limited window immediately around this pseudo ephemeral region, 1 in Figure 2. The positive pole of the pseudo ephemeral region is enclosed within the open-ended rectangle in the image at 2231. Tracing the two halves of the pseudo ephemeral regions backward in time, we see that at 1703 the pseudo ephemeral region fields originated from clumps of network field of opposite polarity. The distance between the maxima of the fragments that became the pseudo
ephemeral region was 10,000 km at the beginning of the observing day (1703). Following the sequence of images in Figure 3, forward in time, we see that the opposite polarity fields come into contact between 2124 and 2231. The relative velocity of approach of the two fragments between 1703 and 2231 is 0.5 km/sec. The fields appear to be in contact when the separation of the maxima within the opposite polarities is between 3800 and 4500 km. After their collision, it is only a short time, less than two hours and 35 minutes time gap between the last two frames, until the smaller of the two fragments of opposite polarity flux has completely disappeared.

Another common way in which a pseudo ephemeral region can form is by the encounter of one half of an ephemeral region with a fragment of network or intra-network magnetic field. An example is shown in Figure 4. A growing ephemeral region is enclosed by the oval. The opposite polarities are seen to separate from each other at a relatively rapid rate of 0.3 km/sec. The positive pole either follows or pushes an adjacent fragment of positive field into an area of strong network magnetic field of negative polarity. The negative pole of the ephemeral region during the 6 hour interval shown here is moving in the opposite direction toward a small clump of weak positive field. This weak positive fragment is either a fragment of intra-network magnetic field or a very weak fragment of network field. At 1935 we see that the negative pole of the original ephemeral region is now adjacent to both the positive fragment and a weak
negative fragment. At 2045, the negative pole of the ephemeral region and the adjacent background field of similar polarity are seen to be merging.

In the final frame at 2238, the merged negative fields are abutted against the positive polarity fragment, resulting in the creation of a pseudo ephemeral region. In addition to the formation of a pseudo ephemeral region, we have illustrated in this figure the phenomenon of coalescence of magnetic fields of similar polarity, a common phenomena occurring both in the network and intra-network magnetic fields.

Figure 5 also illustrates both the coalescence of similar polarity magnetic field and the splitting of opposite polarity network field to form a pseudo ephemeral region. In this example, the videomagnetograms are shown in the form of isogauss contours. The contour levels that are shown are 10, 20, 40 and 80 gauss. Several fragments of negative polarity network or intra-network magnetic field (thinner lines) are seen in the lower part of the first frame. These fragments merge to form a single unit with simultaneous concentration of the field (second frame). Concurrently, an adjacent positive polarity fragment of network field (thicker lines) splits away from its adjoining network and in the second frame is seen to have moved toward the concentration of negative field. The result is a pseudo ephemeral region. The lower frames show a cross section of the magnetic flux (the dashed line in the upper frames) across components of the pseudo ephemeral region. In the lower part of Figure 5, the cross section profile of the positive flux in the pseudo ephemeral
region is seen to be approximately the same in both frames while the negative polarity coalescence results in an apparent increase in peak flux.

IV. ASSOCIATED Hα STRUCTURES

We are also studying concurrent Hα data to learn whether ephemeral regions and pseudo ephemeral regions can be distinguished from each other by means of the appearance of Hα structures and to learn the direction of the component of the magnetic field parallel to the solar surface in both ephemeral regions and pseudo ephemeral regions. We have found no invariable association with any specific Hα structure but we are beginning to see some trends in the data as illustrated in Figure 2. Some, but not all, opposite polarity components of ephemeral regions are seen to be connected by distinct long fibrils or arch filaments. Examples are the small region A and B in the lower left. We have found no examples where comparably long, obvious fibrils connect the opposite polarities of cancelling magnetic fields of the pseudo ephemeral regions. The cancelling pseudo ephemeral region "1" in the lower right of Figure 2 shows a small filament or fibril dividing rather than connecting the opposite polarities. Such dividing fibrils, however, are not invariably observed. No unique structure is associated with cancelling feature "2" in the right side of this figure. To date, we have found no definite
signatures whereby ephemeral regions or pseudo ephemeral regions can always be identified in Hα.

Some pseudo ephemeral regions are associated with microflares. An example is shown in Figure 6, a superposition of Hα and 10 gauss contours. A new, small ephemeral region is labelled ER in the first frame. As it grows, the negative (dashed lines) of the ephemeral region collides with adjacent positive polarity (solid lines) network and a small two point micro-flare occurs at the junction of the ephemeral region and opposite polarity network. This relationship to the associated magnetic fields is exactly the same as described by Marsh (1978) in his study of ephemeral region flares. We only emphasize the newly recognized process of cancellation. We also call attention to the fact that the time scale of cancellation is on the order of a few hours for small-scale quiet sun features while microflares are typically seen only for a few minutes in the chromosphere. However, if microflares are analogous to larger flares, the coronal part of the microflares could last ten times longer than the chromospheric part of the event.
V. ASSOCIATED FEATURES AT OTHER WAVELENGTHS

We anticipate that pseudo ephemeral regions, during the stage of cancellation, may have more or less steady signatures at radio, ultra-violet and soft X-ray wavelengths, if the cancellation represents slow reconnection or any other type of slow conversion of magnetic energy to other forms of energy. In addition, at these wavelengths, we expect transient signatures associated with microflares.

The cancelling pseudo ephemeral regions are excellent new candidates for a direct association with many X-ray bright points which are also known to produce tiny flares (Golub et al. 1974). If our hypothesis is correct, many more X-ray bright points may be associated with pseudo ephemeral regions than with real ephemeral regions. The association with ephemeral regions would in many cases still be very close since many pseudo ephemeral regions are the consequence of one-half of an ephemeral region colliding with network magnetic fields. Additionally, we do not rule out the possible association of some X-ray bright points with real ephemeral regions; we only note some new possible associations. The circumstance of two mutually cancelling ephemeral regions would be an excellent candidate for association with X-ray bright points, although it is relatively rare.
A principal difficulty with previous hypotheses (Harvey et al. 1975; Golub et al. 1977; Golub 1980) of a one to one association between ephemeral regions and X-ray bright points was the uncertainty of whether there were sufficient small-scale, uncounted, ephemeral regions to match one for one with the X-ray bright points. The existence of cancelling pseudo ephemeral regions, as well as many cancelling magnetic features which would not be mistaken for ephemeral regions, offers a sufficient number of distinct magnetic features to account for all X-ray bright points.

Our hypothesis that many X-ray bright points may not be the counterparts of ephemeral regions is in direct contradiction to the assumption of Golub (1980) that X-ray bright points represent emerging magnetic flux. We emphasize the importance of the simultaneous observation of quiet sun magnetic fields at X-ray, optical and radio wavelengths.

VI. DISCUSSION

Out of hundreds of ephemeral regions observed from birth, we have not yet observed a single one in which the growing and separating opposite polarity fields reverse their direction of motion, come together, and disappear, except in one case in which there is also evidence that two ephemeral regions mutually cancel each other. Thus we must suspect that
the cancellation of an ephemeral region within itself is something that
either does not happen or is extremely rare. We therefore have a sharp
distinction between ephemeral regions and pseudo ephemeral regions that
can be used to distinguish these two phenomena when the origin of the
fields has not been observed. A few hours observation is sufficient to
determine if the fields are moving together and cancelling, are stationary
or unchanging, or growing and separating. However, we also need to point
out that some circumstances are ambiguous, especially when an ephemeral
region grows in the middle of network magnetic fields. In these cases, we
usually observe a more rapid growth in the half of the ephemeral region
that is the same polarity as the network and less rapid apparent growth in
the half of the ephemeral region that is opposite in polarity to the
network. We interpret the slowly growing half as due to growth and
concurrent cancellation of that half of the ephemeral region. In such
cases it is clear that the growth rate of the ephemeral regions must
exceed the rate of flux loss due to cancellation. Otherwise ephemeral
regions would not be found amidst the network fields. Outside of the
network there is no requirement for the ephemeral region growth rate to
exceed the flux loss of cancelling features in general. The consequence
of these differences is that we expect to find a minimum size for
ephemeral regions that occur coincident with network. Additionally, the
lifetime of such ephemeral regions occurring in or very near network are
thus greatly shortened in comparison to ephemeral regions that do not
occur either in or very close to network fields.

Pseudo ephemeral regions cover the entire range of total fluxes found in ephemeral regions. This is not surprising since elements of opposite polarities covering a wide range of magnetic flux may move together on the sun. In contrast to the ephemeral regions, pseudo ephemeral regions do not originate as new bipolar fields. They constitute opposite polarity fragments of magnetic fields that have previously constituted network and intra-network magnetic fields, separate halves of ephemeral regions or any combination of these sources. They are brought together by the motions of the network magnetic fields along the boundaries of supergranule cells, by convection within the supergranule cells, by the growth and separation of the opposite polarity halves of real ephemeral regions. Even though the opposite polarity halves of the pseudo ephemeral regions originate from separate sources, it is noted that they often have some properties in common:

(1) cancellation of the opposite polarity fields when they come within a critical distance from each other (cancellation is here defined as a mutual decrease of the magnetic field of both features)

(2) increasing gradient between the opposite polarities

(3) continued motion of the opposite polarities towards each other as the cancellation proceeds, resulting in a continued concentration
and reduction of the total flux of the pseudo ephemeral regions.

The above properties of pseudo ephemeral regions are all characteristics not shared by isolated ephemeral regions. Since they are evolutionary characteristics, one or more hours of observation may be required to correctly identify whether any apparent bipole is a new ephemeral region or whether it is a pseudo ephemeral region. However, the gradient of the magnetic field in the region between opposite polarities can be used to identify some cancelling pseudo ephemeral regions with only a single magnetogram. In Figure 7, we illustrate both a real ephemeral region, in the middle of the field, and a pseudo ephemeral region, in the lower right. In the second frame at 0027 UT, the steepness of gradient of the pseudo ephemeral region alone is sufficient evidence that this feature is not a real ephemeral region. In Big Bear magnetograms the gradient measured in the polarity inversion line between points separated by about 2000 km will very seldom exceed 0.01 gauss/km in a real ephemeral region.

We also note that the maxima in each polarity of the magnetic field in the ephemeral region are centered nearly symmetrically within the contours of lower field strength. In the pseudo ephemeral region, we observe that the maxima in opposite polarities crowd towards each other as the gradient of the field increases. Because of these very obvious characteristics, it is easier to identify pseudo ephemeral regions than real ephemeral regions, especially in data sets with low time resolution.
VII. DIRECTIONS OF CONTINUING RESEARCH

The existence of the pseudo ephemeral regions presents additional factors not accounted for in previous estimates of the number of ephemeral regions that truly exist on the whole sun at any one time. We now recognize that the number of ephemeral regions, that can be counted on a set of data, depends on:

(1) the spatial resolution of the telescope used,

(2) the instrumental sensitivity coupled with exposure time,

(3) the spacing of observations (continuous time-lapse observation, one per minute, affords the ability to recognize more ephemeral regions than more widely spaced observations such as once an hour or once a day),

and the following solar factors:

(4) the distribution of network magnetic fields over the solar surface,

(5) the time in the solar cycle.

The primary limitation is making new estimates is item (4) above, our yet incomplete knowledge of the interaction of ephemeral regions with the network. We need to know whether or not there is any preference for ephemeral regions to occur in the presence of network magnetic fields as
we might suspect from the results of Garcia de la Rosa (1983), Martin et al. (1983), Gaizauskas et al. (1983), and Liggett and Zirin (1984). We also need to know the distribution of the rates of separation of the opposite polarity components of ephemeral regions and the rates of cancellation of ephemeral regions. All of these unknowns limit our ability to extrapolate to find the population of ephemeral regions on the full sun from limited field observations. However, these are only temporary limitations which we are attempting to solve through the continued analyses of the data on hand and the acquisition of additional data.

VIII. CONCLUSIONS

We have found that ephemeral active regions can be differentiated during their growth stage from other apparent bipoles on the sun by their characteristic evolution. Ephemeral regions are new bipolar magnetic fields that originate with their opposite polarities adjacent or very close to each other. Ephemeral regions always show a growth stage in which the maxima of the opposite polarity fields separate as a function of time.

Pseudo ephemeral regions can either be unchanging, stationary bipolar fields or opposite polarity fragments of magnetic field which have moved together and exhibit cancellation of both polarities at their mutual boundary. Our study of limited fields of the quiet sun shows that pseudo
ephemeral regions with cancellation outnumber pseudo ephemeral regions
with little or no cancellation, and pseudo ephemeral regions outnumber the
real ephemeral regions by about a factor of two.

The origin of the magnetic fields of pseudo ephemeral regions can be
from:

(1) fragmentations of very old network magnetic fields,

(2) from relatively new concentrations of intra-network fields,

(3) from halves of ephemeral regions which are no longer recognizable,
or

(4) from any combination of the previous three possibilities.

In Hα the opposite polarity fields of some ephemeral regions are
connected by fibrils and the opposite polarities of some pseudo ephemeral
regions are divided by small filaments. Most ephemeral regions and pseudo
ephemeral regions are difficult to recognize in Hα photographs without the
aid of magnetograms. Micro flares occur in at least some pseudo ephemeral
regions. This evidence of energy release is consistent with our
hypothesized association of many X-ray bright points with pseudo ephemeral
regions and other cancelling magnetic features. We further expect
distinct radio signatures from pseudo ephemeral regions, at least during
the occurrence of microflares.
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Figure Captions

Fig. 1 - The evolution of the new ephemeral active region enclosed in the oval (1930) can be compared to the pseudo ephemeral region enclosed in the rectangle in the upper right. As the ephemeral region grows, the pseudo ephemeral region exhibits "cancellation," the mutual loss of magnetic flux in closely spaced features of opposite polarity. Another example of cancellation of a small positive polarity fragment (white) of field with negative polarity (black) network magnetic field is enclosed within the corner of the rectangle to the lower right of the ephemeral region.

Fig. 2 - Pseudo ephemeral region 1 shows a small filament or fibril dividing the opposite polarity fields as cancellation occurs. Cancelling feature 2 shows no unique signature in Hα. Non-cancelling bipolar regions A and B reveal fibrils or arch filaments connecting their opposite polarities.

Fig. 3 - The open-ended rectangle marks the site of a pseudo ephemeral region which originates from opposite polarity fragments of network coming together. The Hα structures corresponding to this pseudo ephemeral region and other features are shown in Figure 2.
Fig. 4 - The negative half (black) of a growing, separating ephemeral region (in oval) is seen moving toward opposite polarity (white) network magnetic field and forms the "pseudo ephemeral region" within the open ended rectangle at 2238. The positive half of the ephemeral region pushes an adjacent positive field fragment toward a large clump of negative polarity network where field "cancellation" has the opportunity to begin.

Fig. 5 - A pseudo ephemeral region is formed from the coalescence of positive polarity magnetic field fragments and the simultaneous approach of a network fragment of opposite polarity. Contour levels are 10, 20, 40, and 80 gauss.

Fig. 6 - The positive (dashed contour line) and negative (solid contour line) poles of the small ephemeral region (ER) separate from each other between 1836 and 2135. After the positive pole collides with a fragment of negative polarity network, a two point microflare occurs (2135). Meanwhile, the negative pole of the ephemeral region undramatically merges with network of the same polarity.

Fig. 7 - An important distinguishing characteristic of pseudo ephemeral regions is increasing field gradient. The appearance of the pseudo ephemeral region is shown in contrast to the real ephemeral region which appears in the center of the second frame. The magnetic field near
the polarity inversion line separating the two halves of the pseudo
ephemeral region is characterized by higher gradient than near the
polarity inversion line in the real ephemeral region. Contour levels are
5, 10, 20, 40, and 80 gauss.
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Figure 1