

STRUCTURE AND DYNAMICS OF INTERCONNECTING LOOPS AND CORONAL HOLES IN ACTIVE LONGITUDES

ELENA E. BENEVOLENSKAYA¹, A. G. KOSOVICHEV² and P. H. SCHERRER²

¹*Pulkovo Astronomical Observatory, St. Petersburg, 196140, Russia*

²*W.W.Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305-4085, U.S.A.*

(Received 13 September 1999; accepted 19 November 1999)

Abstract. Using SOHO/MDI and SOHO/EIT data we study properties and dynamics of interconnected active regions, and the relations between the photospheric magnetic fields and coronal structures in active longitudes during the beginning of solar cycle 23. The emergence of new magnetic flux results in appearance of new interconnecting loops. The existence of stable coronal structures strongly depends on the photospheric magnetic fluxes and their variations. We present some initial results for a complex of solar activity observed in April 1997, and discuss the role of reconnection in the formation of the interconnected loops and coronal holes.

1. Active Longitudes

Solar magnetic fields and complexes of solar activity are distributed on the Sun non-uniformly. Complexes of solar activity are zones of field concentration 20° – 60° wide that during subsequent rotations tend to reappear at constant longitude or drift slightly eastward or westward (Gaizauskas *et al.*, 1983). These active zones may persist for 20–40 consecutive rotations and are called ‘Magnetic Active Longitudes’ (Bumba and Howard, 1969). Each complex of solar activity rotates around the Sun at a steady rate. The period is often close to the 27.28-day Carrington rotation period. Using WSO synoptic maps (B_{\parallel} component of magnetic field) covering the period from Carrington rotation number 1909 (CR 1909) until CR 1940 (3 June 1996–27 November 1998) we constructed distributions of the relative magnetic flux. The relative magnetic flux (F_R) is represented by absolute values of the B_{\parallel} component averaged over a longitudinal zone 40° wide and divided by the averaged $|B_{\parallel}|$ component for a given Carrington rotation (CR) separately for the northern and southern hemisphere:

$$F_R(\mu, l_i, t) = B_{\parallel}(\mu, l_i, t) \left/ \frac{1}{9} \sum_{i=1}^9 |B_{\parallel}(\mu, l_i, t)| \right., \quad (1)$$

where $\mu = \cos \theta$ is colatitude; l_i are longitudes ($i = 1, \dots, 9$); and t is the time in periods of Carrington rotation. Using the relative magnetic flux we can estimate activity of the 9 longitudinal zones and compare them for a given Carrington



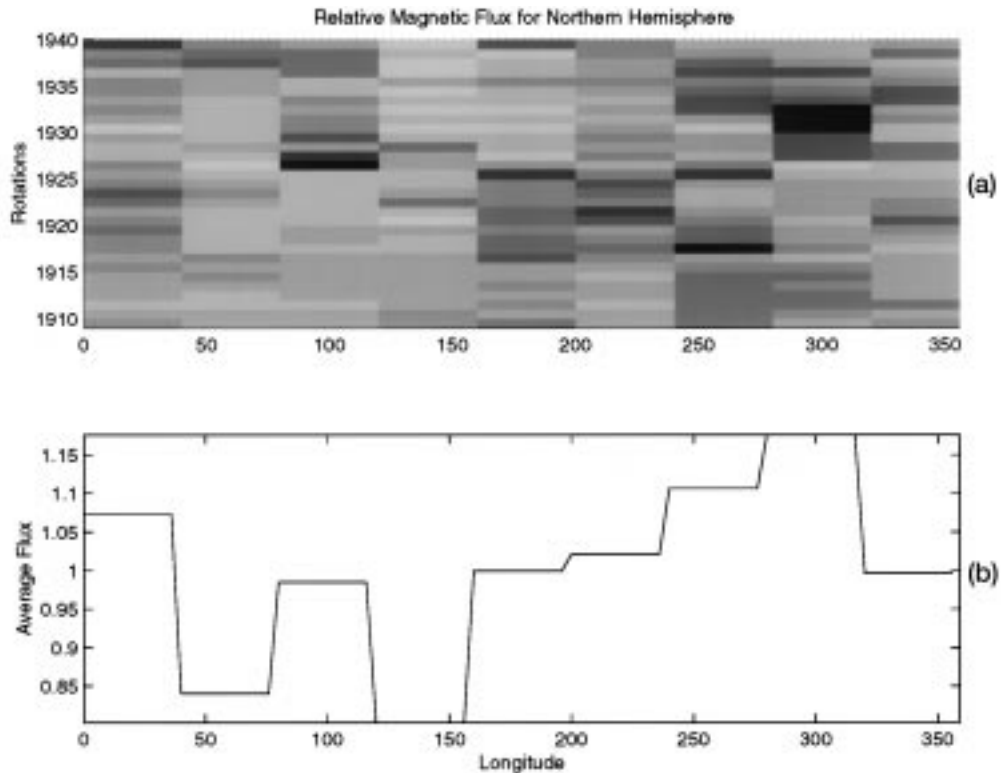


Figure 1. (a) Longitudinal distribution of the relative magnetic flux. The grayscale shows relative magnetic flux in the range from 0 to 2. (b) Averaged magnetic flux at the beginning of the cycle 23 obtained from the WSO data for the northern hemisphere.

rotation. Figures 1(a) and 2(a) display non-uniform distributions of the relative magnetic flux in the northern and southern hemispheres respectively as functions of longitude and time. Figures 1(b) and 2(b) show the average flux for the investigated period also in the northern and southern hemispheres. Clearly seen are zones with suppressed activity in both hemispheres at 120° – 160° longitude, and active longitudinal zones at 240° – 320° in the northern hemisphere and at 240° – 280° in the southern hemisphere. The existence of these zones could be a consequence of relatively stable non-axisymmetrical modes of magnetic field.

2. SOHO/MDI and Coronal SOHO/EIT Data

Using SOHO/MDI magnetograph and coronal SOHO/EIT data we focus our investigation on complexes of solar activity which lived longer than two rotations during the period 3 June 1996–27 November 1998 when the ‘old’ magnetic flux was replaced by the ‘new’ magnetic flux. Earlier it was found that the ‘old’ mag-

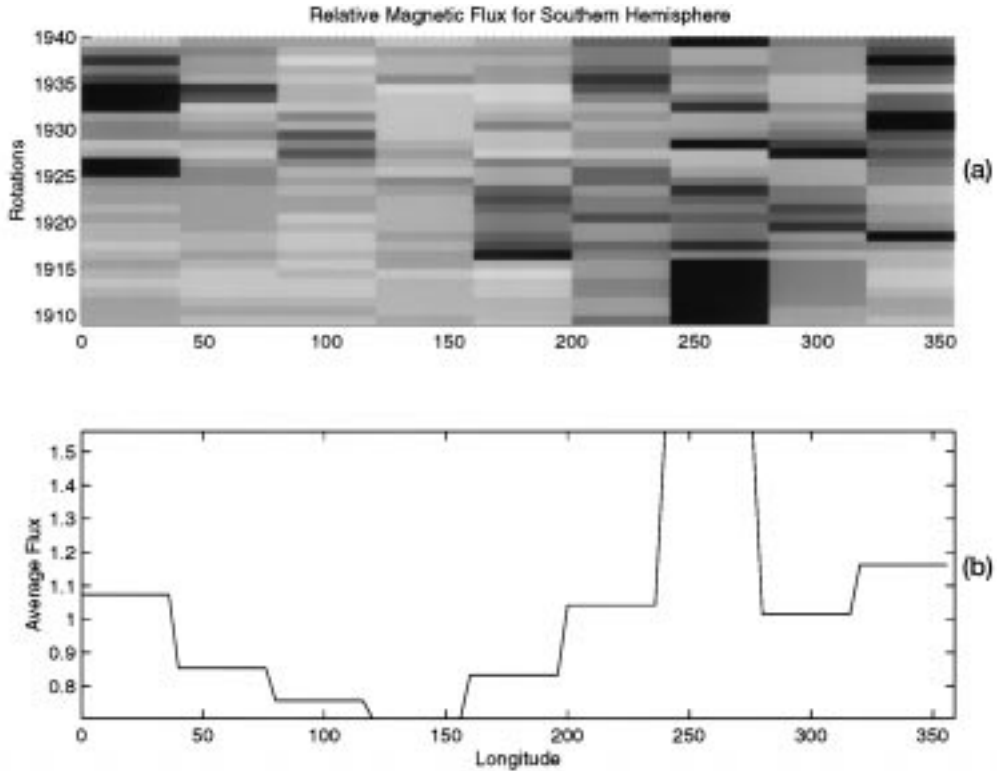


Figure 2. (a) Longitudinal distribution of the relative magnetic flux. The grayscale shows magnetic flux in the range from 0 to 2. (b) Averaged magnetic flux at the beginning of the cycle 23 obtained from WSO data for the southern hemisphere.

netic flux was replaced by the ‘new’ magnetic flux in fixed longitudinal zones (Benevolenskaya *et al.*, 1999).

Harvey and Zwaan (1993) investigated the process of emergence of active regions and found that the active regions predominantly emerged with a basic bipolar structure. The complexity of the solar magnetic fields was created only by new bipolar active regions emerging within the existing active regions. The bipolar sunspot groups represent ‘ Ω -loops’ structures of the toroidal magnetic field that erupted through the solar surface. These magnetic structures are seen in coronal lines, e.g., Fe XII (195 Å).

According to Hale’s law (Hale *et al.*, 1919) we call a magnetic flux observed in Cycle 23 ‘old’ if the preceding sunspot is negative (positive) and the following sunspot is positive (negative) in the northern (southern) hemisphere. We call the magnetic flux ‘new’ if the order of polarity sunspot is reversed. For example, one major zone of the ‘old’ flux occurred at Carrington longitudes 160° – 220° . It drifted slowly westward. In this zone the old-cycle flux was replaced by the new-cycle flux. After CR 1923 all significant bipolar regions were of the new cycle and through

CR 1934 the number of sunspots substantially increased and covered latitudinal zones 10° – 40° wide in both hemispheres (Benevolenskaya *et al.*, 1999).

The Fe XII (195 Å) EUV coronal images are mainly dominated by closed field regions of the quiet Sun. All hot active region loops are visible in this wavelength. Eruptions of ‘new’ and ‘old’ magnetic fluxes and reconnections among them in low corona are clearly seen in the EIT data. The comparison between MDI and EIT images provides a more detailed picture of the process of magnetic polarity reversal in active longitudes. For the investigated longitudinal zone at 160° – 220° the ‘old’ magnetic flux was replaced by ‘new’ magnetic flux during the CR 1921 and CR 1922. In CR 1921 we see co-existence of a ‘new’-cycle region (active region B) in the southern hemisphere and an ‘old’-cycle (active region A) in the northern hemisphere (Figure 3(a)). Both active regions form an extended longitudinal ‘ Ω ’-loop structure seen in the EIT image (left panel). Emergence of the ‘new’-cycle region (C) inside the ‘old’-cycle region should be clearly seen in Figure 3(b). The evolution of the ‘new’-cycle active region is represented in the two bottom panels (Figures 3(c) and 3(d)).

After the emergence of active region C a coronal hole (D) is formed on the east side of the longitudinal complex of activity. The positive and negative parts of activity complex AB are connected by ‘ Ω -loops’ elongated in the meridional direction. The emergence of active region C inside the negative polarity part of active region A resulted in the formation of additional loops between the positive part of active region (A) and the negative part of region C. Some of the disconnected magnetic lines from the positive part of active region A might participate in the formation of the coronal hole. Looking at the whole sequence of the EIT images we can conclude that the formation of the coronal hole is related to opening ‘ Ω -loops’ – magnetic structures, starting from mid latitudes and continuing in the poleward direction close to the longitudinal complex of activity. By comparing with Figures 1 and 2 we conclude that the coronal hole was formed in a low-activity longitudinal zone at 120° – 160° .

When the complex of activity was at the west limb we see loops connecting the active regions of the ‘new’ and ‘old’ cycles (Figure 4). It is possible that these interconnecting loops appeared as a result of reconnection between the ‘old’-cycle and ‘new’-cycle magnetic fluxes similar to the process observed by Sheeley *et al.* (1975). However, we cannot rule out that the magnetic connection between the ‘old’ and ‘new’ fluxes existed in the interior prior the emergence of the ‘new’ flux. The emergence of the ‘new’ magnetic flux region inside the ‘old’-cycle region and the connection between them lead to the idea that the solar corona may play a very important role in the evolution of photospheric magnetic fields, and in the formation of longitudinal extended active structures.

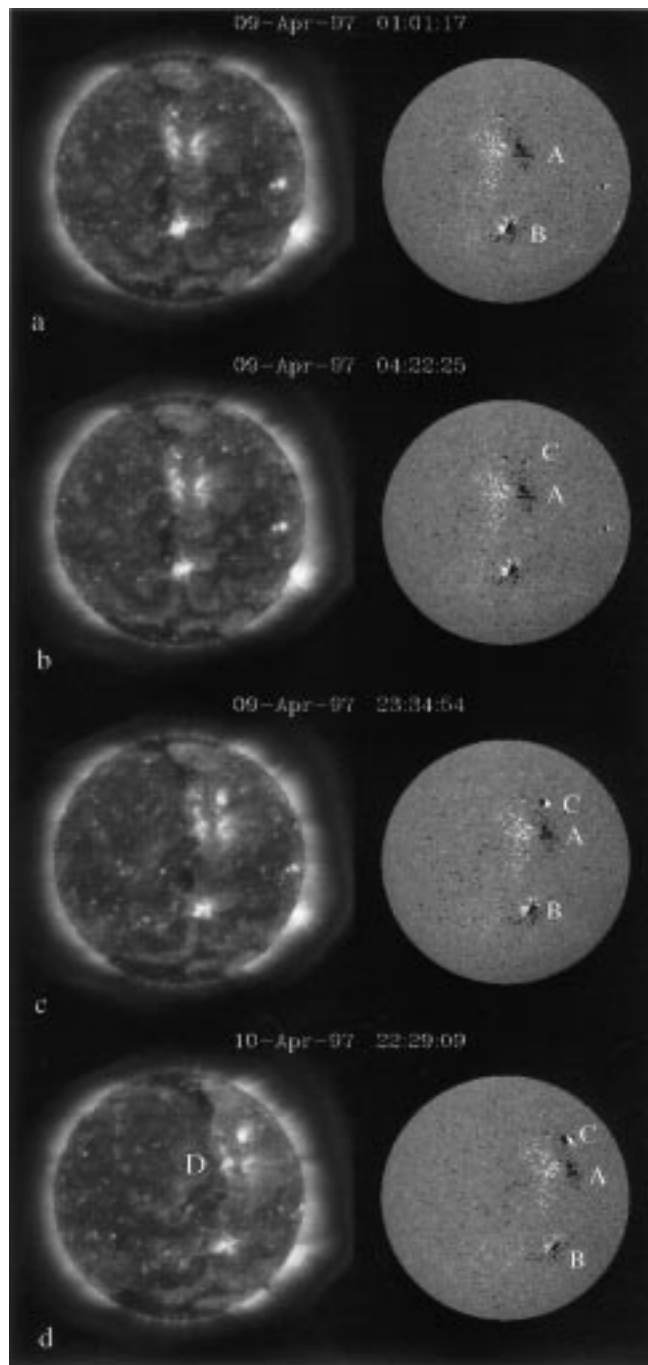


Figure 3. The EIT (195 Å) images (*left*) and the corresponding MDI magnetograms (*right*) showing the emergence of an active region (C) of the new cycle at the same longitude which contains a decaying active region (A) of the ‘old’ cycle. Coronal hole D was formed after the emergence of region C.

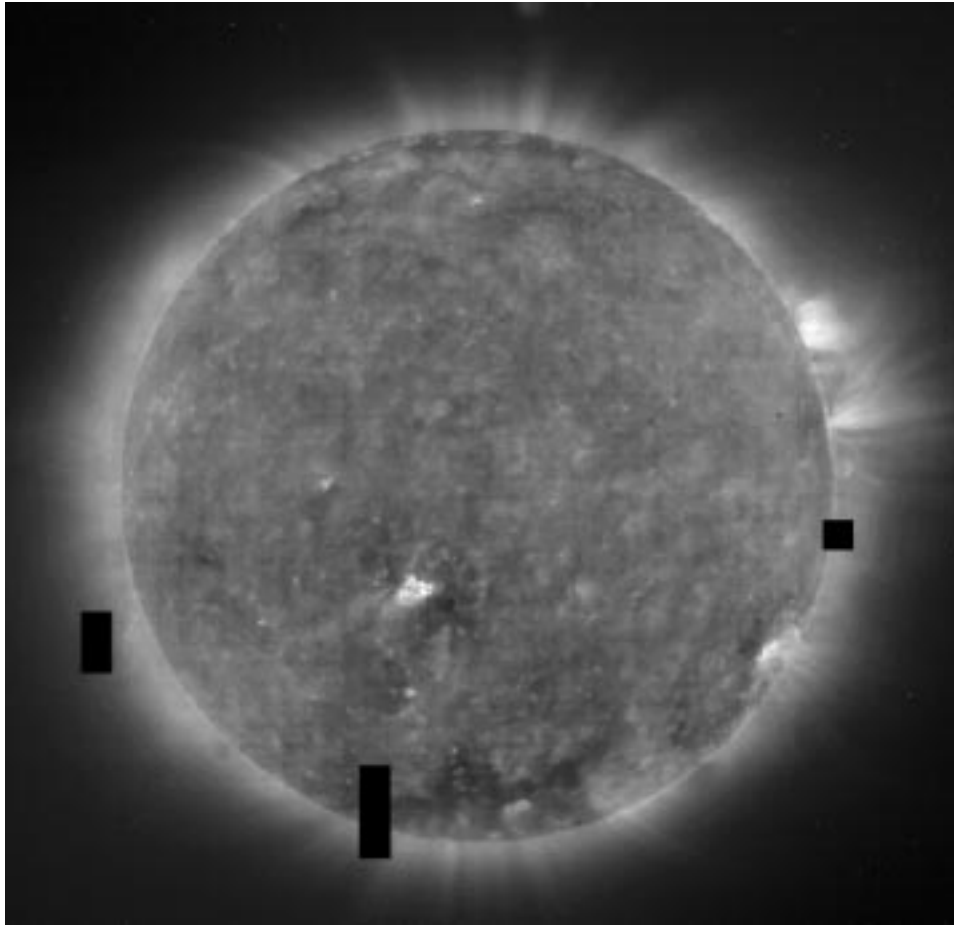


Figure 4. The SOHO/EIT (195 Å) full-disk image of 15 April 1997, showing the loops connecting the active regions of the ‘old’ and ‘new’ magnetic fluxes on the west limb.

3. Conclusions

(1) Emergence of the ‘new’ flux and its reconnection with the magnetic field of the ‘old’-cycle complex activity resulted in an extended longitudinal structure of activity.

(2) This extended longitudinal magnetic structure produced a very long coronal hole connecting the polar regions.

(3) The regions of the ‘new’ and ‘old’ cycles were connected in the corona via large-scale loops. Further investigation of MDI and EIT data should show whether the interconnected loops result from magnetic reconnection in the corona, or some kind of magnetic connection between the ‘new’ and ‘old’ fluxes already existed when the ‘new’ flux emerged from the interior.

Acknowledgements

This work was supported by JURRISS Program NASA NRA 98-OSS-08 and by the Russian Federal Programme 'Astronomy', Grant 1.5.3.4, and the SOI-MDI NASA contract NAG5-3077 at Stanford University. SOHO is a project of international collaboration between ESA and NASA.

References

- Benevolenskaya, E. E., Hoeksema, J. T., Kosovichev, A. G., and Scherrer, P. H.: 1999, *Astrophys. J.*, **517**, L163.
- Bumba, V. and Howard, R.: 1969, *Solar Phys.* **7**, 28.
- Gaizauskas, V., Harvey, K. L., Harvey, J. W., and Zwaan C.: 1983, *Astrophys. J.*, **265**, 1056.
- Hale, G. E., Ellerman, F., Nicholson, S. B., and Joy, A. H.: 1919, *Astrophys. J.*, **49**, 153.
- Harvey, K. L. and Zwaan, C.: 1993, *Solar Phys.* **148**, 85.
- Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V., and Tousey, R.: *Solar Phys.* **40**, 103.