Bull. Astr. Soc. India (1984) 12, 404–410

Coronal holes and long-lived unipolar magnetic regions

Rajendra N. Shelke and M. C. Pande
Uttar Pradesh State Observatory, Manora Peak, Naini Tal 263 129

Received 1984 July 6; accepted 1984 August 8

Abstract. Association of coronal holes with long-lived unipolar magnetic regions (LLUMRs) which survived for four solar rotations is examined. It is noticed that every coronal hole fits in well within the LLUMR. The coronal holes are also seen to dissolve as a consequence of the LLUMR boundary zone evolution and emergence of opposite polarity regions within the coronal hole boundary.

Key words : magnetic regions—coronal holes—the sun

1. Introduction

Coronal holes are seen as regions of reduced coronal emission intensity, implying that the electron density and/or the temperature is lower. These holes always occur in large unipolar magnetic regions called magnetic cells and do not seem to cross magnetically neutral lines (*cf.* Bohlin & Sheeley 1978 and references therein). At the photospheric level, the magnetic field intensity is weak in the coronal holes than in the surrounding areas (Vaiana *et al.* 1973; Bohlin 1977). Timothy *et al.* (1975), Levine (1977) and Bohlin & Sheeley (1978) have investigated the relationship of coronal holes with the underlying solar magnetic fields, with special emphasis on the magnetic configuration necessary for the formation of holes. The disappearance of individual holes has been discussed by Nolte *et al.* (1978a). Growing coronal holes evolve, *i.e.* they grow and shrink through the opening up and closing of the field respectively (Nolte *et al.* 1978b).

Coronal holes are predominantly long-lived magnetic features. The most important and striking aspect of these holes is their apparent occurrence in weak, open and diverging unipolar magnetic regions which leads one to infer that the coronal holes may have a close association with long-lived unipolar magnetic regions (LLUMRs) and thus the positions of coronal holes could be identified from the LLUMRs. Here, for the first time, an attempt has been made to show a possible gross identity of the coronal holes with such LLUMRs which survived for four solar rotations and to study the physical relationship of coronal holes with the LLUMRs.

2. Identity of LLUMRs and coronal holes

2.1. Observational data

To investigate the gross identity of LLUMRs and coronal holes, negative and positive LLUMRs were delineated by superposing on each other four consecutive Stanford synoptic charts of large scale magnetic fields and then by locating the unipolar magnetic patterns which survived for four solar rotations (figures 1a–f). In figures 2a–i, the temporal evolution of LLUMRs through rotation to rotation is shown. The positions of coronal holes taken from 10830 Å synoptic charts (which are expected to have a close correspondence with emissions from coronal holes, *cf.* Harvey *et al.* 1975) were drawn onto them (see figures 1 and 2). Both these types of synoptic charts for rotations 1676 through 1683 and 1716 through 1731 were taken from the Solar Geophysical Data.

2.2. Magnetic cells and LLUMRs

Magnetic cells are the large scale unipolar magnetic patterns into which the solar surface is divided at any given time. The LLUMRs are those regions of magnetic cells which survived for more than one solar rotation. The LLUMR always remains within the boundary of magnetic cell and therefore does not necessarily match with the magnetic cell.

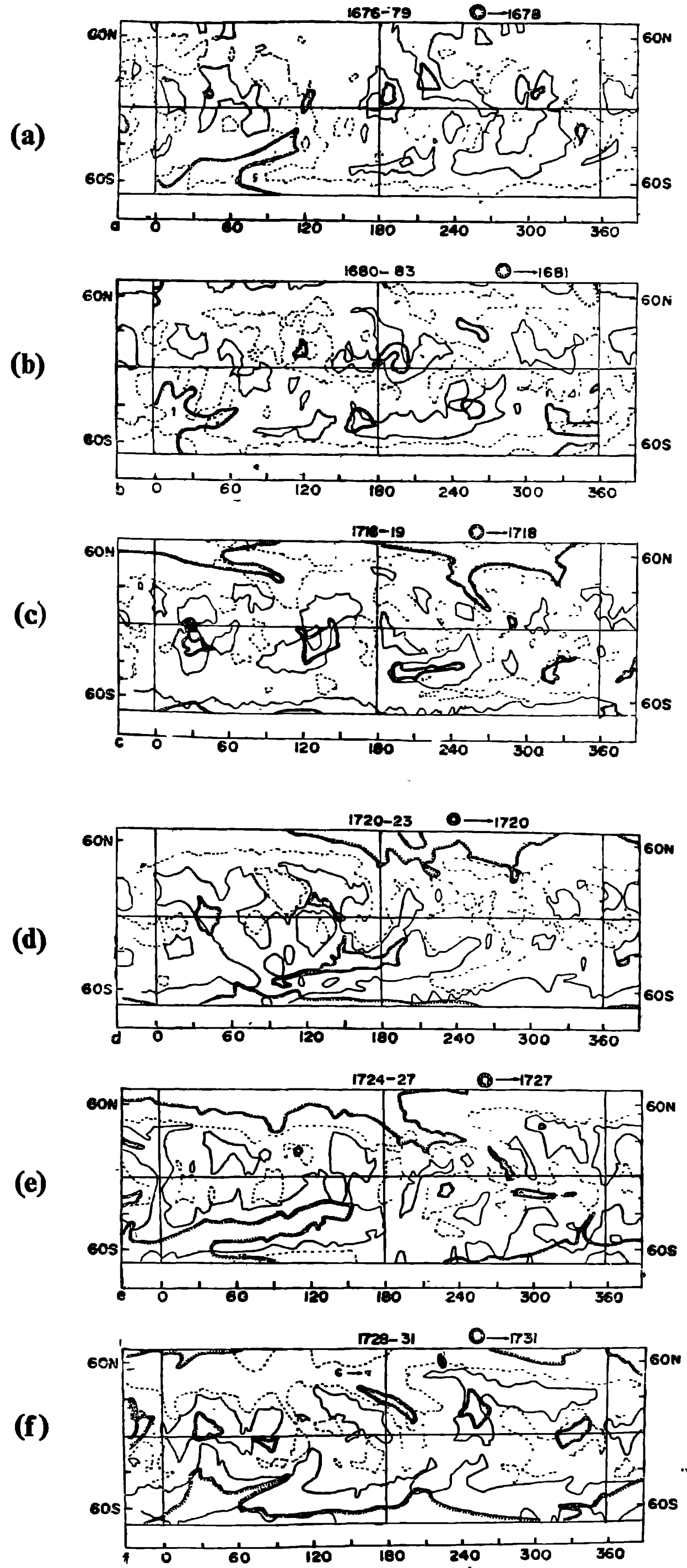
The neutral line which always forms the boundary of the magnetic cell does not necessarily form the boundary of LLUMR. The position of the neutral line seems to vary in a well-defined zone between the boundaries of two adjacent LLUMRs of opposite polarities, and the boundary of LLUMR is the extreme limit of the position which the neutral line can take. If the magnetic cell develops, the neutral line (*i.e.* magnetic cell boundary) will be farther away from the boundary of the corresponding LLUMR. On the other hand, if the magnetic cell shrinks, the magnetic cell boundary may match with the LLUMR boundary.

2.3. Existence of coronal holes within LLUMRs

The present analysis leads us to the following inferences.

(i) Every coronal hole is found to occur in the LLUMR which survived for four solar rotations (see figures 1a–f). In figures 1a–f every polar and low-latitude hole appears to fit in well into the global pattern of the LLUMRs analogous to interlocking pieces of a jigsaw puzzle. The classic example is offered by southern polar coronal hole no. 1 (CH 1) of figure 1. This lotus-shaped hole (CH 1) clearly agrees in position with the lotus-shaped LLUMR.

(ii) However, in some cases, both holes and LLUMRs apparently seem to be displaced mutually even though holes occur in the magnetic cells as can be seen in cases of holes at lat. S 50, long. 60 (figure 1a); lat. S 15, long. 300 (figure 1–e); and lat. S 05, long. 80 (figure 1f). The source of this displacement may lie in the circumstance that the magnetic cell does not necessarily match with the LLUMR. However, during its evolution the corresponding LLUMR may get shrunk down enough to appear as displaced from the magnetic cell in which the hole was located. If this is the case, then the holes may cross the LLUMR boundary, even though they do not cross the neutral line which forms the boundary of the magnetic cell.



Figures 1(a–f). Superpositions of synoptic charts of LLUMRs which survived for four solar rotations (rotation numbers are written on top centre) and of the helium 10830 Å (rotation number is written on the right-hand side on the top). Solid and dashed lines form the boundaries of positive and negative LLUMRs respectively. The coronal holes are shown by hatched solid lines.

(iii) Although every coronal hole of figures 1 and 2 occurs in LLUMR the converse, namely that every LLUMR excepting polar cap LLUMR necessarily has a hole, does not seem to be true. There are many LLUMRs illustrating this fact quite clearly. Thus, it appears that the mere existence of LLUMR is not sufficient to produce a hole.

2.4. LLUMR boundary zone

Bohlin & Sheeley (1978) and others (references therein) pointed out the existence of a well-defined zone, called boundary zone, between the edge of a coronal hole and the adjacent neutral line which marks the edge of the magnetic cell. For convenience, we call this boundary zone as 'cell boundary zone'.

We have found that a well-defined 'LLUMR boundary zone' appears to exist between the edge of a coronal hole and the adjacent boundary of the corresponding LLUMR in which the hole is located. These LLUMR boundary zones can distinctly be seen in figures 1 and 2. Since neutral line does not necessarily lie along the boundary of LLUMR, the size of a cell boundary zone will be equal to or larger than the size of the LLUMR boundary zone. When the neutral line occurs along the edge of LLUMR, the cell boundary zone seems to match with the LLUMR boundary zone. Later shrinking of the cell boundary zone leads to the shrinking of LLUMR boundary zone also. In other words LLUMR boundary zone is the minimum size that the cell boundary zone can have.

The LLUMR boundary zone may be interpreted as the zone over which all the magnetic field lines are connected to the adjacent opposite polarity on the other side of the neutral line to form arcades of magnetic loops in the corona. Magnetic flux further inside the LLUMR is unable to get connected with the opposite polarity and presumably forms an open field line system, characterizing a coronal hole.

3. LLUMR and evolution of coronal holes

There is a relationship between solar active regions and coronal holes (Bohlin & Sheeley 1978; Nolt *et al.* 1978a). The evolution of LLUMR also follows the appearance of solar active regions. The LLUMR shrinks as the flux of opposing polarities erupts near the boundary of LLUMR and/or encroaches into the LLUMR. This evolves the LLUMR boundary zone, which in turn leads to the evolution of an existing coronal hole. Therefore we examine here the relationship between the temporal evolution of coronal holes (especially their dissolution) and that of the underlying solar magnetic fields, through a qualitative consideration of LLUMR geometry.

Only two forms of coronal hole dissolutions have been recognized by us, namely (i) slow dissolution, and (ii) fragmentation and disruption. In the former case, coronal holes get thinned while in the latter case they get fragmented into places and/or disappear altogether.

3.1. Slow dissolution

The coronal hole becomes thinner enough to get fragmented into pieces if the corresponding LLUMR boundary zone shrinks. The best example is CH 2 of rotation 1725 (figure 2d). This hole suffered successive thinning down in rotations 1726 (figure 2e) and 1727 (figure 2f) owing to shrinking of LLUMR boundary zone. Another example is CH 1 of figure 2a which thinned down enough to get fragmented into pieces (*cf.* figures 2b and 2c) due to shrinking of LLUMR boundary zone to about 10° in longitude and appearance of two opposite polarity regions designated by a and b. These examples go to show that slow dissolution of the holes is a consequence of the shrinking of LLUMR boundary zone.

3.2. Fragmentation and disruption

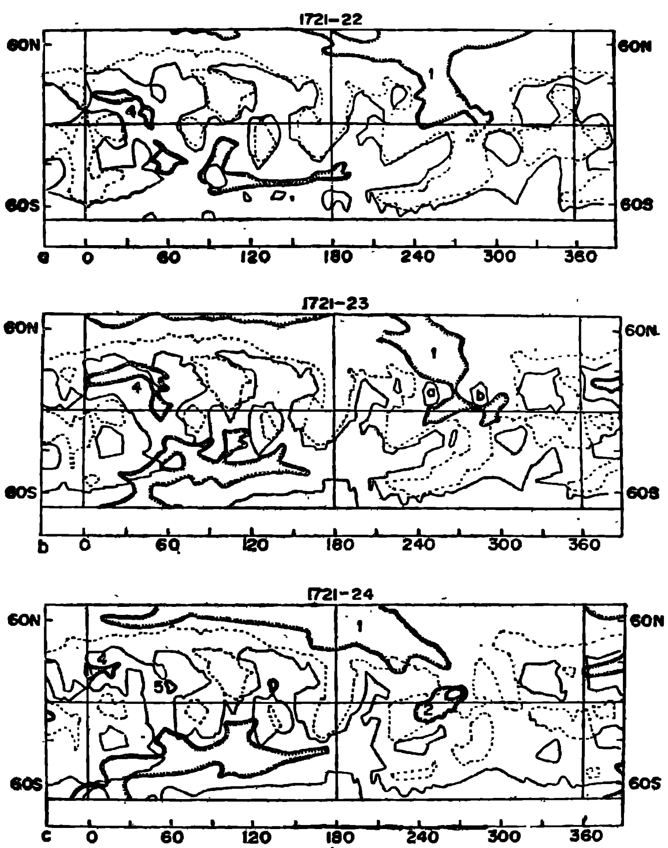
Consider an example of the northern polar cap hole (CH 1) of rotation 1728 (figure 2h). An emergence of opposite (positive) polarity flux, designated by c in the location of CH 1 fragmented the hole and detached the extended lobe of CH 1 from polar cap hole in rotation 1729 (figure 2i). This example explains more specifically how fragmentation of a hole is related to the eruption of new disc activity into the coronal hole.

The shrinking of the LLUMR boundary zone also leads to the fragmentation and disruption of coronal holes. The examples are offered by CH 2 of rotation 1724 which fragmented into CH 2 and by CH 3 in rotation 1725 (figure 2d) due to shrinking of LLUMR boundary zone near equator at longitude around 260°; CH 4 (figure 2b) which fragmented into CH 4 and CH 5 in rotation 1724 (figure 2c) due to shrinking of LLUMR boundary zone at longitude around 30° and CH 6 in

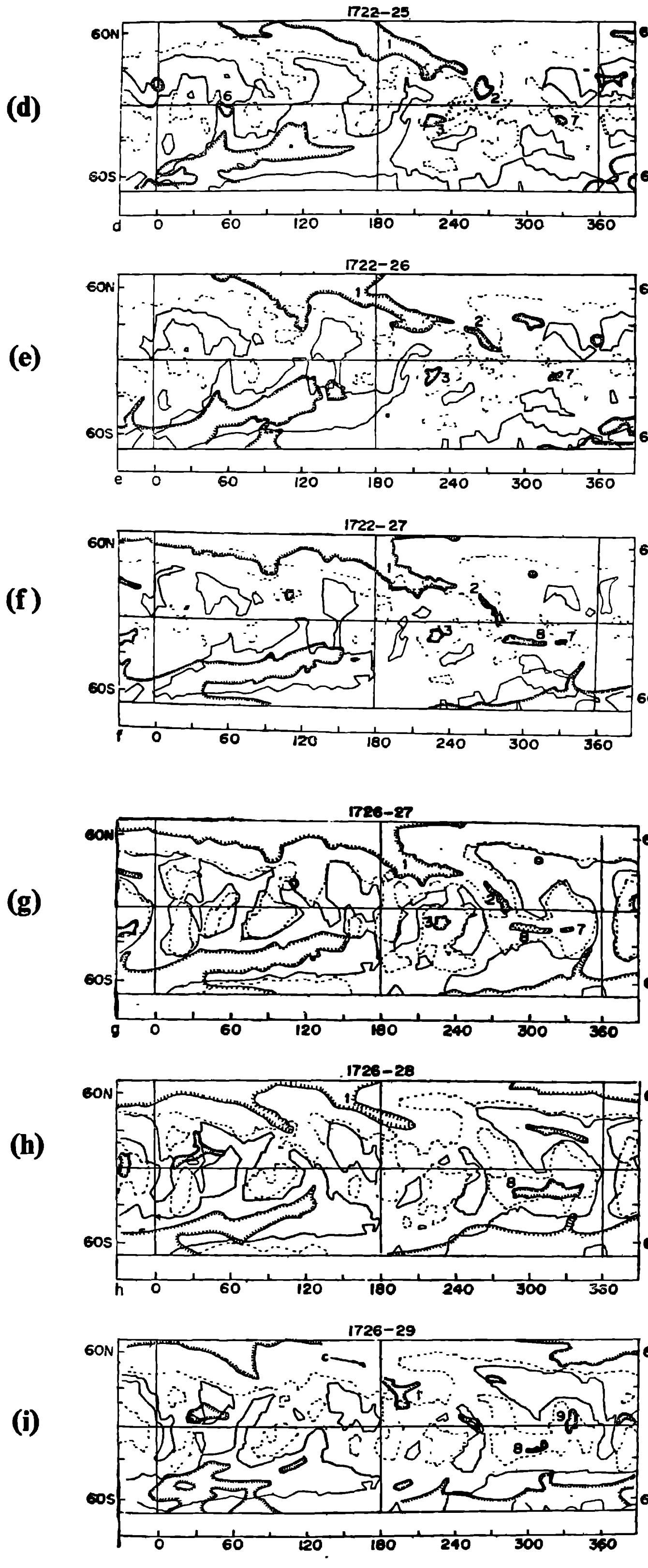
(a)

(b)

(c)



Figures 2(a–c)



Figures 2(a–i). Temporal evolution of the LLUMRs through rotation to rotation (rotation numbers are written on the top). The last rotation number indicates the synoptic chart of helium 10830 Å which was superposed on it.

rotation 1725 (figure 2d) which disappeared due to shrinking of LLUMR boundary zone at the equator (figure 2e).

4. Low-latitude coronal holes as extension of polar cap holes

There is one case which indicates that the low-latitude holes are a direct extension of polar cap holes. The classic examples are CH 2 and CH 3 of figure 2d. Although these holes appear as separate holes, they represent the lobes detached from the extended polar cap hole CH 1 of rotation 1722 (figure 2a). The case of CH 1 getting fragmented into CH 1 and CH 2 and also the case of further fragmentation of CH 2 into CH 2 and CH 3 have been ascribed by us to the shrinking of LLUMR boundary zone (sections 3.1 and 3.2). Further shrinking of LLUMR in rotation 1726 (figure 2e) detached the LLUMR, in which CH 3 was located, from the polar cap LLUMR. Thus CH 3 appeared as a distinct low-latitude hole, located in a separate LLUMR from that of the polar cap LLUMR.

The relationship between the polar and low-latitude holes also gets support from the fact that nearly all LLUMRs in which holes developed were a direct extension of, or were strongly connected to, the polar cap LLUMR.

5. Conclusions

The coronal holes always occur in the LLUMRs. It also appears that the mere existence of LLUMR is not sufficient to produce a hole. A well defined LLUMR boundary zone appears to exist between the edge of a coronal hole and the adjacent boundary of the LLUMR. In this zone, the magnetic field lines are able to form closed field configuration with the adjacent opposite polarity regions. The inner region is, however, unable to connect to opposite polarities and thus forms an open field system, characterizing a coronal hole.

An emergence of new flux of opposite polarity in or near the boundary of LLUMR and/or an encroachment of adjacent opposite polarity regions into the LLUMR shrink the LLUMR boundary zone. Owing to shrinking of LLUMR boundary zone the magnetic field lines which were open earlier to form a coronal hole may connect adjacent opposite polarity flux to form arcades of loops in the corona, thus leaving little or no open lined flux. This leads to shrinking and/or fragmentation of an existing coronal hole.

It is also seen, in one case, that low-latitude holes are the detached lobes of the extended polar cap holes.

References

Bohlin, J. D. (1977) *Solar Phys.* **51**, 377.

Bohlin, J. D. & Sheeley, N. R., Jr. (1978) *Solar Phys.* **56**, 125.

Harvey, J., Krieger, A. S., Timothy, A. F. & Vaiana, G. S. (1975) in *Osservazioni e Memori dell Osservatorio di Astrofiscio di Arcetri* (ed : G. Reghini) **104**, 50.

Levine, R. H. (1977) in *Coronal Holes and High Speed Wind Streams* (ed. : J. B. Zirker) Colorado Associated Univ. Press, Boulder, Colorado, p. 103.

Nolte, J. T., Davis. J. M., Gerassimenko, M., Krieger, A. S. & Solodyna, C. V. (1978a) *Solar Phys.* **60**, 143.

Nolte, J. T., Gerassimenko, M., Krieger, A. S. & Solodyna, C. V. (1978b) *Solar Phys.* **56**, 153.

Timothy, A. F., Krieger, A. S. & Vaiana, G. S. (1975) *Solar Phys.* **42**, 135.

Vaiana, G. S., Krieger, A. S. & Timothy, A. F. (1973) *Solar Phys.* **32**, 81.