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Coronal holes and solar-terrestrial relationships

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RESUMEN

En este trabajo se discute el papel que juegan los hoyos coronales del Sol en las perturbaciones del viento solar y en las alteraciones del ambiente terrestre. Se presentan evidencias de la relación de estos hoyos con el flujo de rayos cósmicos galácticos en la Tierra, los comienzos repentinos de tormentas geomagnéticas y las auroras. Se incluye también una discusión de la capacidad de los hoyos coronales para producir tales efectos y se hacen algunos comentarios sobre su relación con eventos solares transitorios tales como ráfagas, protuberancias eruptivas y eyecciones de masa coronal.

PALABRAS CLAVE: Relaciones Sol-Tierra, hoyos coronales, perturbaciones geomagnéticas, rayos cósmicos, medio interplanetario.

ABSTRACT

The role of long-lived and unstable coronal holes in perturbing the solar wind and disturbing the Earth's environment is discussed. Evidences of their relationship with galactic cosmic-ray flux at Earth, geomagnetic storms sudden commencements, and aurorae are presented. A discussion about the capability of coronal holes to produce such effects is also included, as well as some comments on their relation to solar transient events such as flares, eruptive prominences, and coronal mass ejections.

KEY WORDS: Solar-terrestrial relationships, coronal holes, geomagnetic perturbations, cosmic rays, interplanetary medium.

INTRODUCTION

Coronal holes were first discovered by Waldmeier (1957) but were studied only after the Skylab X-ray and EUV images (see for instance Zirker, 1977). They proved to be the solar sources of the high speed streams found in the solar wind (Krieger *et al.*, 1973). Their role in the recurrent geomagnetic perturbations was soon realized when they were identified as the long-sought "M" regions (Neupert and Pizzo, 1974). Recurrent high-speed streams from long-lasting coronal holes are responsible for recurrent geomagnetic perturbations with a period of about 27 days.

The importance of coronal holes in understanding the solar wind genesis has been extensively treated in the literature. Many details are still unclear but no doubt remains that they are the main and perhaps the unique source of the solar plasma flowing permanently in the interplanetary medium. We review the various correlations found between coronal holes and those geophysical events which imply not a constant but a sudden changing emission of solar plasma. A general discussion on the role played by coronal holes in solar-terrestrial relations is presented.

POLAR CORONAL HOLE AREA AND GALACTIC COSMIC RAY FLUX AT EARTH

Hundhausen *et al.* (1980) found a very good positive correlation between the evolution of polar coronal hole area and the flux of galactic cosmic rays at Earth from 1965 to 1976 (Figure 1). This was interpreted by them as an indication that the propagation of cosmic ray particles in the interplanetary medium is influenced by the three-dimensional structure of the heliosphere; an alternative interpretation was given by Bravo *et al.* (1988). Based on findings by Hewish and Bravo (1986), by means of interplanetary scintillation (IPS) technique, that interplanetary shocks may be related to some kind of coronal hole activity, Bravo *et al.* (1988) interpreted the correlation found by Hundhausen *et al.* as the result of the modulation of cosmic rays by the interplanetary shocks associated to the evolution of coronal holes. At any rate, the influence of coronal hole changes on the intensity of galactic cosmic ray particles reaching the Earth is out of question.

CORONAL HOLES AND AURORAE

Following the idea that coronal holes are the sources of interplanetary shocks, Bravo and Otaola (1990) explored the possible relation between the evolution of coronal holes and the frequency of aurorae at the poles of the Earth. They found that the frequency of aurorae exhibits a bimodal structure over the solar cycle, which seems to be well correlated with the evolution of the size of polar coronal holes around the *minimum* of solar activity, and with the evolution of low latitude coronal holes around the *maximum* of solar activity. This is shown in Figure 2. Bimodal structures have also been observed for the number of geomagnetically disturbed days (Thompson, 1988) and for the distribution of intense geomagnetic storms (González *et al.*, 1990). We interpret the geomagnetic effects of polar coronal holes around solar minimum as due to the low-latitude long-lived extensions of these holes which produce corotating interaction regions about the ecliptic plane. The geomagnetic effects associated with the evolution of low-latitude non-stable holes is interpreted as due to the interplanetary shocks associated with rapid changes in their structures.

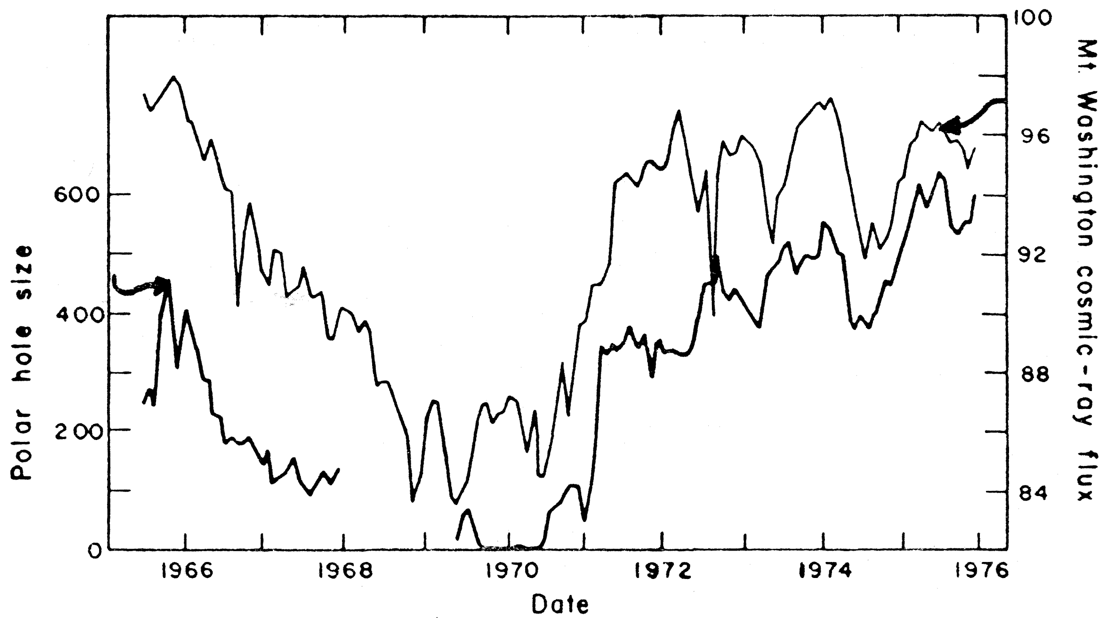

Fig. 1. Size of polar coronal holes (bold line, scale at the left) and the normalized cosmic ray flux observed at Mt. Washington (thin line, scale at the right). From Hundhausen *et al.* (1980).

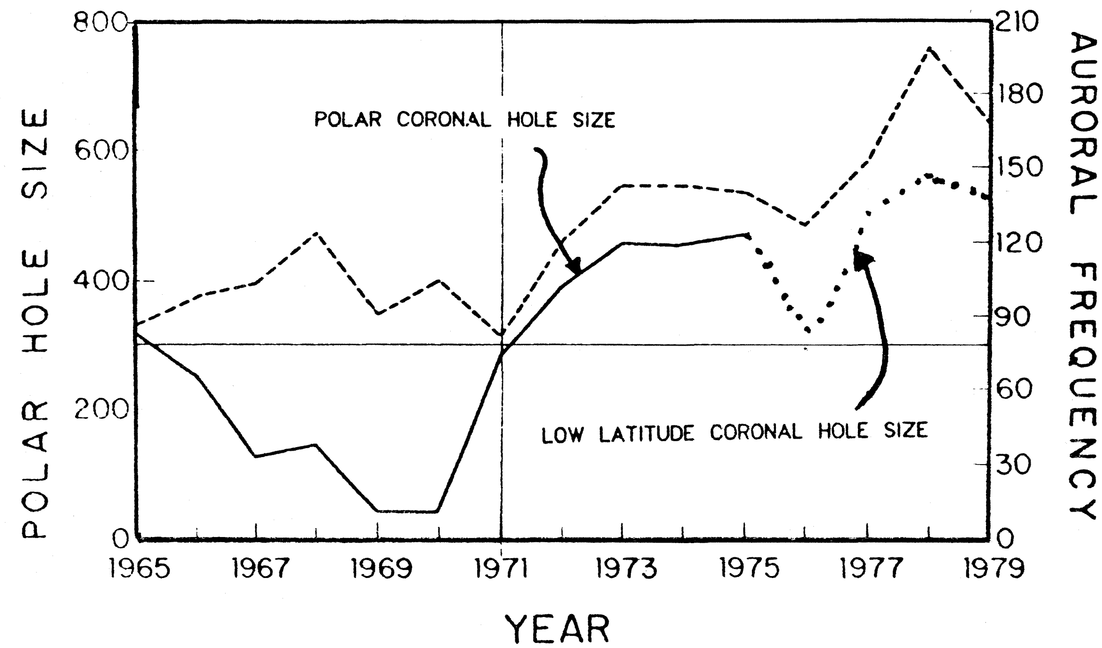

Fig. 2. Annual mean of polar coronal holes area (solid line) and low latitude (±60°) coronal holes area (pointed line), and the annual frequency of aurorae at $\lambda_{inv} \leq 62°$ (dashed line). From Bravo and Otaola (1990).

CORONAL HOLES AND GEOMAGNETIC STORM SUDDEN COMMENCEMENTS

A number of specific interplanetary disturbances associated with geomagnetic storm sudden commencements were studied for a period of about one year from July 1978 to September 1979 (Hewish and Bravo, 1986; Bravo and Hewish, 1988). Within this period we observed the propagation of the disturbances in the interplanetary medium by means of the interplanetary scintillation (IPS) of a large number of stellar radio sources, which allowed us to make daily maps of the sky showing the evolution and advance of the regions of high plasma density in interplanetary space. It was possible to distinguish CIRs from radially moving shocks and to locate approximately their source regions at the Sun. A subset of observations considered only those radially moving shocks which led to the sudden commencement of a geomagnetic storm, traditionally associated with flares or eruptive prominences at the Sun. Bravo *et al.* (1990a and b) showed a better spatial correla

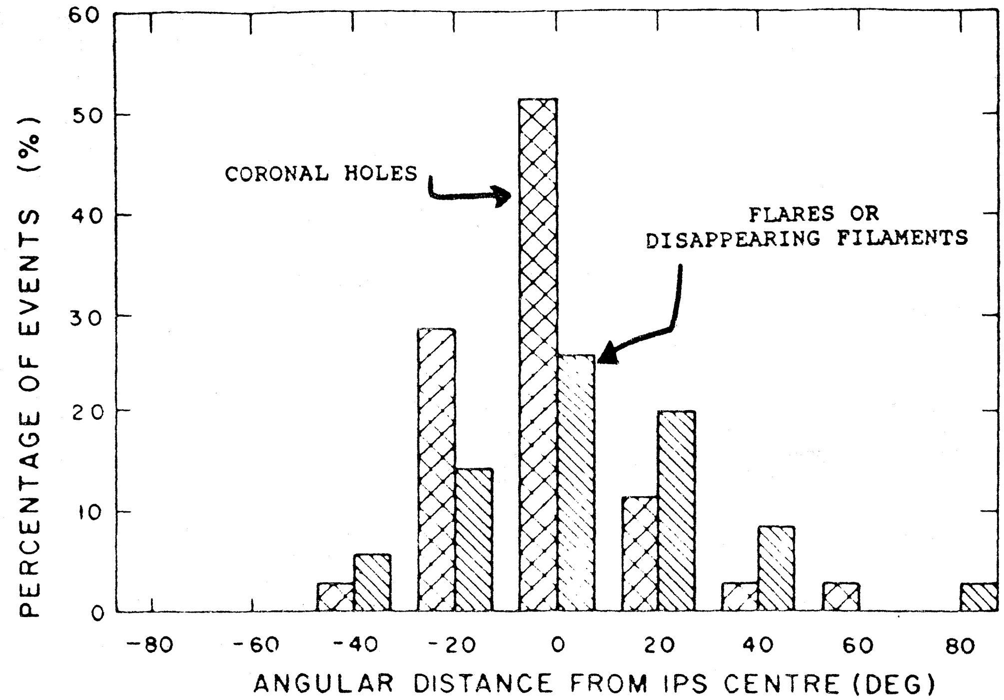

Fig. 3. Angular longitudinal distance distribution from the IPS source to the nearest coronal hole (crosshatched histogram) and flares or disappearing filaments (hatched histograms). From Bravo *et al.* (1991a).

tion of the solar source of these shocks with the location of a coronal hole than with the site of flares or eruptive prominences which might be temporarily associated with them (Figure 3). We even found some cases of shocks producing geomagnetic storm sudden commencements where no flare or disappearing filament had occurred for a period of five days before the arrival of the shock at the Earth.

DISCUSSION AND CONCLUSIONS

The observations of different kinds of interplanetary and terrestrial phenomena seem to suggest that not only *corotating interaction regions,* but also the *radially moving shocks* in the interplanetary space are due to high speed solar wind fluxes coming from coronal hole regions. In the first case, the shock structure is formed by a continuous corotating high-speed flux of plasma from a long-lived coronal hole. In the second case, the shocks could be associated with a sudden increase in the velocity of the wind due to rapid changes in the structure of low-latitude unstable coronal holes. Theoretical studies based on numerical simulation of the time dependent flux in a hole in which the cross-section area changes rapidly with time show the formation of shock structures (Hasan and Venkatakrishnan, 1982).

Recent research, combining coronal and interplanetary observations, has shown a very close relation between massive high-velocity coronal mass ejections (CMEs) and interplanetary shocks (see for instance Sheeley *et al.,* 1985). At present there is no doubt about the association between these coronal and interplanetary phenomena, but the surface solar event causing CMEs is not clear. A natural relation of CMEs to explosive solar events (flares or eruptive prominences) must seriously be doubted. On the one hand, less than 50% of the observed CMEs can be associated with such explosive events (Wagner, 1984); on the other hand, the explosive event associated with a CME frequently takes place *after* the first observations of the coronal transient (see for instance Jackson and Hildner, 1978). In a recent study, Bravo and Pérez-Enríquez (1991) have found a close spatial relation between the site of departure of CMEs and coronal holes. This reinforces the association of coronal holes with interplanetary shocks suggested from the other observations mentioned in this paper.

Due to the huge amount of mass involved in a CME, it is not likely that it comes from an already open field region. A more plausible explanation of the spatial relation between CMEs and coronal holes can be suggested in terms of a global rearrangement of the large-scale coronal magnetic field in an extended region, due to the emergence of material with a different polarity at a spot within the region. Thus some open field lines may close and some closed field lines may be opened. Coronal streamers, which are large magnetically closed structures next to coronal holes, usually contain large amounts of mass trapped in their magnetic structure. If some of the lines of the streamer open as a consequence of the emergence of a new polarity field, part of the material contained in it will be released and the structure of the adjacent coronal hole (which now will be larger) may change suddenly. This sudden change can be the cause of the formation of a shock in the plasma emitted from this hole which will accompany the

CME out of the corona into interplanetary space. The same rearrangement of field lines might be the cause of the flares and eruptions of protuberances also associated with the CME.

Unfortunately, short-time records of evolving coronal holes are not systematically obtained, to let us know whether or not the transmission of a solar perturbation into the interplanetary space is always accompanied by a rapid change in the size of a hole. Further effort in observations and numerical simulations of both coronal and interplanetary phenomena is necessary in order to understand the role actually play by coronal holes in solar-terrestrial relationships.

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