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The Cosmic Ray 1.68-Year Variation and the Large-Scale Solar Photospheric Motions

José F. Valdés-Galicia[1] and Blanca Mendoza[1]
[1] Instituto de Geofísica UNAM Circuito Exterior C U, 04510 México D.F
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Abstract
Valdés-Galicia et al. (1996) reported on a newly found 1.68-year cosmic ray variation which seems to be correlated with periodicities in x-ray Long Duration Events and low latitude coronal hole area changes. As those phenomena are related with magnetic flux emergence we investigate the possible relationship of the referred variation with characteristic times of different tracers of meridional circulation. Our results indicate that several of the calculated times might be related to the 1.68 cosmic ray variation. A physical mechanism through which this connection may operate is discussed.

1 Introduction:

On top of the well known eleven year wave, several periodic fluctuations have been found in cosmic ray intensity over the years, which are reasonably well correlated with one or another phenomenon of the active Sun. Recently Otaola et al. (1995) and Valdés-Galicia et al. (1996) have reported on a 1.68-year variation in the cosmic ray intensity observed at the Earth in the neutron monitor range of energies (several GeV). Valdés-Galicia et al. (1996) proposed that this cosmic ray variation might appear as a consequence of phenomena rooted in the convection zone and could help in understanding the origin of the solar magnetic cycle.

2 Results:

Photospheric large-scale motions related to the solar global convection seem to be present in several scale sizes ranging from the granulation to the giant convection. Results of characteristic times of these large-scale patterns such as giant cells, sunspots, plages Hα filaments, magnetic features, movements of polar fields and Doppler measurements are presented in Table I as follows: Column 1 names the observed phenomenon, a bracketed E means an equatorward flow, no letter means poleward flows. Column 2 gives the measured or estimated average velocities v with their standard deviations. Column 3 indicates the latitude bins L discussed by each author. Column 4 contains the length scale of the phenomenon l, calculated considering that $1° = 1.22 \times 10^7$ m . Column 5 presents the characteristic times $\tau = l/v$ where l is the length scale of column 4 and v is the velocity of Column 2. The error is calculated with the standard theory of propagation of uncertainties. The periodicity of the cosmic ray variation in question is also shown for comparison

3 Discussion:

From Table I we notice that the calculated characteristic times for the giant cells and for most of the sunspot observations fall within the range of the 1.68 year cosmic ray variation. The estimates based on observations of sunspots at low latitudes (0°-12°) by Howard (1996) and by Ribes and Bonnefond (1990) imply characteristic times which are not commensurable with the rest. The Hα filament measurements, two of the three magnetic features and the Doppler measurements show periods in good agreement with the cosmic ray periodicity of interest here. However, characteristic times for plages are smaller than required. Due to the associated uncertainties some superficial as well as some deep features might coincide in the values of meridional drift speeds.

Sunspots, plages, Hα filaments and possibly large-scale magnetic features are supposedly phenomena anchored deep into the Sun.. On the other hand Doppler and small magnetic features are superficial phenomena. However there is agreement between the small scale superficial observations of Komm et al. (1993) and those large-scale deep observations of Latushko (1994). Moreover, the results by Snodgrass and Dailey (1996) for superficial small magnetic features indicate a latitudinal meridional circulation more similar to that of sunspots that are deep features. In our opinion the magnetic features might be giving a mixed information about several levels in the Sun, such information has not been properly discriminated in order to identify the different layers. Therefore, from Table I we cannot associate de 1.68 year cosmic ray variation to either superficial or deep feature.

What is the physical mechanism through which the phenomena on the Sun modulate the cosmic rays? We shall try to advance an answer.

It is well known that the changing structure of the current sheet affects the cosmic ray intensity level (i.e. Smith and Thomas, 1986). A possible way of distorting the current sheet is the following: Hundhausen et al. (1980) found a very strong positive correlation between cosmic ray intensities and the area of polar coronal holes from 1972-1976, which made them suggest that the propagation of cosmic ray particles was influenced by the three-dimensional structure of the heliosphere, modulated by the polar coronal holes. There is now considerable evidence that the Sun's polar magnetic fields are confined to relatively small caps of high average field strength (e.g. Sheeley et al., 1989). Numerical simulations have shown that the maintenance of such concentrated fields requires the presence of a meridional (poleward) bulk flow of $\approx$10 m s^{-1} (Wang et al., 1989). Moreover Benevolenskaya (1995) has found a high frequency harmonic of 1.5-2.5 years period in the solar poloidal magnetic field with a zonal structure clearly moving to the poles, where it reaches its maximum intensity. The deformations of the polar hole boundary depend on the relative amount of flux among the new cycle bipolar regions that arrive at the poles and the polar fields. The distortion of the polar-hole boundary is accompanied by a corresponding distortion of the neutral current sheet in the outer corona, this distortion becomes evident along some months. The amount of current sheet warping depends again on the relative magnitude of the erupted bipolar flux relative to the strength of the concentrated polar magnetic fields (Sheeley et al., 1989). Therefore, both the polar hole areal changes and the distortion of the current sheet depend on the concentrated fields brought up by the poleward motion of the magnetic flux.

It has been argued that middle and low latitude coronal hole dynamics is also reflected in the cosmic ray intensity variations (Bravo et al., 1988). Moreover, there is a good relationship observed among middle and low latitude growing coronal holes, active regions and the heliospheric current sheet observed during the ascending phase of cycle 21 (Gonzalez et al., 1995). We also know that LDE-type flares and middle and low latitude coronal holes are related, and that they present periodicities compatible with the cosmic ray variation as reported by Valdés-Galicia et al. (1996). Outstanding flare centers tend to be members of long-lived sunspot groups (Svestka, 1968). Therefore we suggest that sunspots and their related active regions produce areal perturbations in low and middle latitude open field structures which distort the current sheet and generate magnetic irregularities in the solar wind which in turn modulate the cosmic ray intensity.

The changing structure of the current sheet caused by either polar or middle and low latitude coronal hole areal distortions modulate the cosmic rays. The 1.68 y variation seems to be stronger in odd cycles when the cosmic rays are guided to penetrate the Heliosphere through the current sheet by the drifts caused by the interplanetary magnetic field (Jokipii and Thomas, 1981; Kota and Jokipii, 1983). In even cycles, when the cosmic rays drift into the Heliosphere from the polar latitudes, the current sheet distortions in the activity zone are apparently of a lesser importance to produce the 1.68 y modulation. It is worth to remember that during this cycle the most important peak of cosmic ray fluctuations is that of 1.3 years which seems to be more related to solar wind and solar activity parameters (see Valdés-Galicia et al., 1996 and references therein).

TABLE 1

Characteristic times of large-scale circulation patterns

Pattern	v (m s^{-1})	L (deg)	l (m)	τ (years)
Cosmic Ray				1.68 ± 0.3
Giant cells	1-12[a]		$2.1x10^8$	0.55 - 6.66
Sunspots	4.13 ± 2.48[b]	12 - 38	$3.2x10^8$	2.46 ± 1.48
Sunspots (E)	5.07 ± 2.94[b]	0 - 12	$1.5x10^8$	0.94 ± 0.54
Sunspots	5.4 ± 1.4[c]	2 - 27	$3.2x10^8$	1.88 ± 0.52
Sunspots	1 ± 0.1[d]	0 - 35	$4.3x10^8$	13.64±1.37
Sunspots	0 - 100[e]	0 - 15	$1.8x10^8$	¤ 0.06
Sunspots	3 ± 2[f]	0 - 16	$2 x10^8$	2.11 ± 1.3
Plages	13.28 ± 14.01[b]	0 – 18	$2.2x10^8$	0.53 ± 0.56
Plages (E)	8.96 ± 6.85[b]	18 - 38	$2.2x10^8$	0.78 ± 0.60
Hα Filaments	8.83 ± 3.57[g]	35 - 70	$4.3x10^8$	1.54 ± 0.45
Magnetic Feature	6.78 ± 4.86[h]	10 - 50	$5x10^8$	2.71 ± 1.67
Magnetic Feature	6.09 ± 5.02[i]	H	$1.1x10^9$	5.73 ±4.71
Magnetic Feature	9.31 ± 4.78[j]	H	$1.1x10^9$	3.75 ± 1.94
Polar Field		H		1.5 - 2.5[k]
Doppler	16 ± 4[l]	H	$1.1x10^9$	2.18 ± 0.73
Doppler	20 ± 5[m]	H	$1.1x10^9$	1.74 ± 0.44

(a) Weiss, 1964; Howard et al., 1991
(b) Howard, 1996
(c) Lustig and Wöhl, 1991
(d) Ribes and Bonnefond. 1990
(e) Ribes et al., 1985
(f) Tuominen et al., 1983
(g) Topka, et. al., 1982
(h) Snodgrass and Dailey, 1996
(i) Latushko, 1994
(j) Komm et al., 1993
(k) Benevolenskaya, 1995
(l) La Bonte and Howard, 1982
(m) Duvall, 1976

4 Conclusions:

We have found that the characteristic times of several features on the Sun such as giant cells, sunspots, Hα filaments, magnetic features, poloidal magnetic fields and Doppler motions are compatible with the dominant fluctuation of cosmic ray intensity found between the years 1947-1990. The 1.68 years cosmic ray variation seems to be closely related with motions that are reflected in the meridional circulation of sunspots and high latitude meridional motions. Both groups produce area changes of polar middle and low latitude coronal holes. These restructuring of the holes distort the heliospheric current sheet and produce magnetic irregularities which modulate the cosmic ray intensity with periodicities close to 1.68 y. This fluctuation is stronger in odd cycles, when the cosmic rays penetrate the heliosphere through the current sheet, than in even cycles, when the cosmic rays drift into the heliosphere from polar latitudes.

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