Solar Corona Irradiance Variability and Cosmic Rays

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(Received January 30, 1995; Revised September 26, 1995; Accepted November 14, 1997)

The impulsive behaviour of the green emission line corona brightness over the years is emphasized and illustrated by means of butterfly diagrams constructed for the last five solar cycles. This peculiar property of the solar coronal activity is supposed to be reflected by the heliospheric medium, as well. Evidence of coincidences of the coronal impulsive periods with the maximum values in the solar modulation of galactic cosmic rays is presented.

1. Introduction

One of the basic problems of solar-terrestrial physics is to understand what phenomena on the sun, what processes of their development and what space distribution of them over the sun’s surface play the most important role from the point of view of energy and/or perturbation entries into the heliosphere. Questions arise what disturbances from solar radiation and particle ejections determine predominantly the structure and physics of the 3-dimensional interplanetary space in time.

Though the birth, development and decay of any single active region on the sun create an individual and non-repeatable process, characterized by a chain of physical causes and consequences, still there exists a number of regularities in the development of solar activity, namely as for its long-term and large-scale distribution over the solar surface. Hence, we speak about solar variability and periodicity. Both these features have clear responses in the heliosphere, as well.

In the present paper we would like to indicate and underline the real utility of the analysis of the green emission corona FeXIV 530.3 nm radiation for the understanding of some properties of solar modulation of galactic cosmic rays.

2. FeXIV 530.3 nm Emission Corona in the Period 1943–1993

The intensity of the green-line corona is a very appropriate index of solar activity, namely because the intensity of its radiation is proportional to the density and to the temperature of the medium in which this line originates. Moreover, for about fifty years there exists a regular patrol service of a few high-altitude coronal observatories (at present, Sacramento Peak, Norikura, Kislovodsk and Lomnicky Štít only), where intensity of this coronal line is measured daily every five degrees around the sun’s limb (see Storini and ŠÝkora (1997) for a brief history of the monochromatic corona measurements). We are even daring to say that there is no other index of solar activity, registered with a comparable time- and space-resolutions for more than a half of century and, at the same time, recorded (after necessary homogeneization of measurements of different observatories) in the form very suitable for analysis by a computing technique. That is why, recently, studying modulation phenomena of galactic cosmic rays induced by solar activity, we were able to consider effects arising from different latitudinal belts on the solar surface, separately in ascending and descending phases of each sunspot cycle and, to look also for differences in effects connected with even and odd solar cycles (Parisì et al., 1992; Bavassano et al., 1994; Storini et al., 1994, 1995; ŠÝkora et al., 1994a; Storini and ŠÝkora, 1995, 1997).

As for the large-scale and long-term distributions of the green corona brightness, some of the
Fig. 1. Time variations of the FeXIV 530.3 nm green corona brightness for selected zones of the heliographic latitude are drawn by the half-yearly averaged data. The vertical scales are in absolute coronal units (a.c.u.), while the sunspot number $R_z$ and the north/south asymmetry ($A$) have their own scales.
regularities were already described (Sýkora, 1992, 1994; Sýkora et al., 1994b; Storini and Sýkora, 1997), while the source data and the problems connected with their combined utilization from different observatories were described long time ago (Sýkora, 1971). Here we would like only to pick-out once more the fact that coronal activity in each solar cycle consists of several large well-isolated impulses, usually not occurring simultaneously in both solar hemispheres. This is partially emerging from Fig. 1, where the temporal trends of the green corona brightness in different latitudinal belts of the northern (N) and southern (S) hemispheres (covering the 1943–1993 epoch) are drawn by using the data on half-yearly basis. A conspicuous long-lasting north-south asymmetry \( A = (N - S)/(N + S) \), where N and S stand for brightness over 0–90N and 0–90S, respectively) of green coronal activity is observed. Comparison with the sunspot number activity trend (see the lowest part of Fig. 1) reveals that almost identical variations of both parameters are observed giving clear presence of the 11-year solar-activity cycles. However, at the same time, fluctuations in the coronal curve are substantially more evident than those for sunspot number cycles. On the other hand, absence of time coincidence of the coronal brightness fluctuations is seen in the three middle panels of the figure. Unsimilarities of different latitudinal zones (the second part from below) and of the same zones at different hemispheres (next two parts of Fig. 1) follow from a real space distribution of coronal activity above discrete zones of the sun’s surface, creating the mentioned hemispheric asymmetry, as drawn at the top of Fig. 1.

To demonstrate the impulsive character of the coronal activity we draw a succession of butterfly diagrams (Fig. 2) in form of the contour plots of the coronal intensity. We notice that the coronal impulses (shadowed areas in the plots) are not global phenomena of the sun’s body. They are local phenomena appearing as a consequence of the birth, development and decay of the so-called complexes of solar activity, the lifetime of which seems to be very often about 1.5–2.0 years. The term “complex of activity” was for the first time introduced by Bumba and Howard (1965) and briefly reviewed by Bumba (1982) later. In the 20th solar cycle, for example, the impulses seen in our Figs. 1 and 2 can be well identified with the known complexes of activity which appeared in 1967, 1969, 1970, 1972 and 1974 (e.g., Bumba et al., 1972; Bumba, 1980; Bumba and Hejna, 1981).

3. Cosmic Ray Modulation

Half-yearly pressure-corrected data of the Climax (N39.4, W106.2, altitude 3400 m, cutoff-rigidity about 3 GeV) and Huancayo (S12.0, W75.3, altitude 3400 m, cutoff-rigidity about 13 GeV; from 1992 on,
data from Haleakala detector have been used to update the series) neutron monitors (Solar Geophysical Data, 1994) are displayed in Fig. 3 and show the entity of the solar modulation on galactic cosmic rays at two different energies. Apart from the modulation levels the basic “structures” of both histograms are more or less similar. However, looking for impulsive phenomena, any direct comparison with green coronal trends or butterfly diagrams is almost impossible, except for some general coincidence of the 11-year cycles for the cosmic ray modulation with those of coronal activity. In spite of that, good linear correlations were found between Climax data and the corona brightness when the datasets on half-yearly basis were divided according to the solar activity phase (Bavassano et al., 1994). This possible relationship between green corona data and cosmic ray modulation was extensively emphasized in the past (e.g., Moraal, 1975 and references therein). Moreover, the same cosmic ray data, displayed on yearly basis, showed to be productive in testing solar activity features during sunspot cycle 22 (Storini, 1995); this is particularly true for the expected cosmic ray bimodal behaviour around the sunspot maxima, according to the “dual-peak” in the green corona data claimed by Gnevyshev (1963).

Hence, a more detailed look on the problem is necessary. In Fig. 4 we present a curve connecting the difference (markers) between the extreme values of the isotropic nucleonic intensity found in each month of the daily data set (Pase and Storini, 1993) and averaged on half-yearly basis. Maxima of this curve (for example in the 20th cycle) are identical (except of 1970) with those of the green coronal line. The word “gap” stands for the “valley” periods connected with the presence of the so-called double maxima of the coronal solar cycle, discussed by Gnevyshev, i.e., the gaps are minima between Gnevyshev’s double maxima. The gaps, caused probably by the large-scale re-distribution of the solar magnetic fields in the period of the sunspot cycle maxima, seem to be reflected in the cosmic ray modulation clearly, so as in some other solar-terrestrial parameters (e.g., Storini and Pase, 1995 and references therein).

To go still deeper into the matter, the Mt. Washington (44.2N, 71.3W, altitude 1909 m, cutoff-rigidity about 1.4 GeV) neutron monitor data, reported by Lockwood (1990) have been used to estimate the cumulative effect of transient interplanetary perturbations on half-yearly basis. The amplitude (in %) of all the Forbush decreases (occurring from January to June and from July to December) greater than 3%
have been accumulated to analyse long-term effects. The result is shown in Fig. 5. The choice of a minimum depression of 3% is very appropriate to exclude non-transient cosmic-ray decreases related to high-speed solar-wind streams coming from coronal holes (e.g., Storini, 1990 and references therein). Only the co-rotating plasma streams with a speed increase greater than 600 km/s (namely, the wind speed exceeding 950 km/s or so) are able to produce depressions in the nucleonic component greater than 3%. Hence, residual effects from such kind of non-transient disturbances are negligible, and Fig. 5 represents the cumulative effects of transient perturbations.

From Fig. 5 we conclude that the cumulative method of analysis here employed is revealing on long-term basis an impulsive character in the cosmic ray modulation, which is similar to the one found in the large-scale behaviour of the solar corona activity. Certainly, this is only a preliminary study on the matter. But it is enough to indicate the necessity of still more work in the field of coronal-heliospheric relationships.

Fig. 4. Differences in the six-monthly averages of the extreme (maximum and minimum) values observed in each month in the daily data set of the isotropic nucleonic intensity (after Storini and Pase, 1995, see the text). Thick dotted segments remark the bimodal behaviour of cosmic ray intensity near to the sunspot maxima.

Fig. 5. Cumulative amplitude of the Forbush decrease (FD) events obtained on the half-yearly basis from the Mt. Washington neutron monitor data.
4. Conclusion

Past investigations, as well as the present short contribution, indicate that looking for the possible solar cycle (corona) effects upon the cosmic ray modulation is a hopeful endeavour. Sometimes, only an appropriate smoothing and averaging of the original data leads to the understanding of more global relations—till now only half-yearly averaged green-corona data were at our disposal. Nevertheless, data sets on daily- and monthly-basis are in preparation. They will be used to check and to quantify more precisely our findings.

This work was performed in the frame of the CNR/SAV Agreement (1992–1994), theme 9: Modulation of Cosmic Rays by Solar Activity, and it was completed during the 1994 visit of J. S. to the Istituto di Fisica dello Spazio Interplanetario (IFSI/CNR). M. S. Thanks the Antarctic Research Program of Italy (PNRA/MURST) for supporting work with data from geographical polar regions. Support of the VEGA grant 2/2007/95 of the Slovak Academy of Sciences is acknowledged, as well.

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