Relation between quiet-time low energy particle fluxes and chromospheric activity

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***Abstract*. The relation of quiet-time fluxes of 0.3-8 MeV/n protons and helium nuclei with parameters of solar activity is studied over 3 solar cycles using IMP 8 and SOHO data. Quiet periods were selected requiring a) 1 MeV proton intensity should not exceed 10^{-1} protons/cm^2 s sr MeV at least for 2 days; b) no flare above soft X-ray class C1 should be observed during that period and one day before. Positive correlation is found between quiet-time fluxes and the background X-ray and radio emission 10.7 cm fluxes. The closest correlation is found between particle fluxes and the value of the MgII core-to-wing ratio (the MgII index) i.e. a measure of chromospheric activity. During the 21^{st} and 23^{rd} SC minima both the particle fluxes and the MgII index are found to be lower than their corresponding values at the 22^{nd} SC minimum revealing the influence of 22-year magnetic solar cycle. During other phases of solar activity the lowest particle fluxes were preceded (or were observed simultaneously) by the lowest values of the MgII index. These intervals also exhibited lower values of the H/He ratio than other quiet-time periods. Our previous studies indicated that at 1 AU the quiet-time particle fluxes are of solar (predominantly flare) origin throughout the solar cycle except minimum. A possible assumption is that the lowest particle fluxes originate from small active processes in the solar chromosphere and/or in the quiet low corona.**

***Keywords*: solar quiet-time particles**

I. INTRODUCTION

The origin of the ubiquitous low-energy particles in the heliosphere under quiet Sun conditions is not entirely understood yet. Previous investigations of time variations of quiet-time low energy (0.3-8 MeV) proton fluxes, energetic spectra and radial gradients indicated that these protons are predominantly of solar origin over the whole solar cycle at 1 AU [1]. The solar component of this population can consist of remnants of solar energetic particle events and particles accelerated by weak active processes on the Sun such as micro flares and X-ray bright points. To determine the possible sources of low-energy protons on the Sun during the quietest time periods including the SC minima we examined the flux variations along with values of the MgII core-to-wing ratio (the MgII index, [2]) serving as a proxy of minor chromospheric activity, solar radio emission at 10,7 cm and soft X-ray background.

II. THE MGII INDEX AND 0.3-0.5 MEV PROTONS DURING SOLAR ACTIVITY MINIMA

Particle intensities used here were measured by the CPME (IMP-8) [3] and COSTEP/EPHIN (SOHO) [4] instruments. The MgII index values were obtained from NOAA data in 1979 - 2000. The MgII index, formed by combining various MgII core-to-wing data sets, has been used in EUV, UV, and total solar irradiance models. Further on MgII time series, the most popular indices for this purpose are several MgII indices based upon the MgII k and h doublet near 280 nm. The MgII core-to-wing ratio is an index that is well suited to create a single time series despite the fact that the seven different instruments measuring the solar flux near 280 nm have different spectral resolutions and sample rates.

The Upper Atmosphere Research Satellite (UARS) Solar Ultraviolet Spectral Irradiance Monitor (SUSIM), UARS Solar Stellar Irradiance Comparison Experiment (SOLSTICE), ERS-2/Global Ozone Monitoring Experiment (GOME) and five NOAA solar backscatter ultraviolet data sets were used. Initially, the best data sets selected to create a time series starting from 1978 was prolonged up to 2009 using correlations of NOAA data with GOME and SPICE (Global Ozone Monitoring Experiment, 1995-present) and SCIAMACHY (SCanning Imaging Absorption Spectrometer for Atmospheric ChartographY).

The time behaviors of low-flux low-energy protons and MgII index have been surveyed over three cycles. The quiet-time (background) particle intensity was compared with the minimum MgII index value in each Bartels rotation denoted as $MgII_{min}$. Figure 1 presents the time behavior of the $MgII_{min}$ values during the 21^{st}-23^{rd} SC minima and shows that these values in 1985-87 and in 2007-09 were slightly lower than in 1995-97 indicating a 22-year variation. The comparison of the quiet time 0.3-0.5 MeV proton fluxes during the 20-22^{nd} SC minima revealed a similar difference - the intensities in 1985-87 were lower than both in 1975-77 and 1995-97 (Fig. 2). This similarity of the 22-year variation of

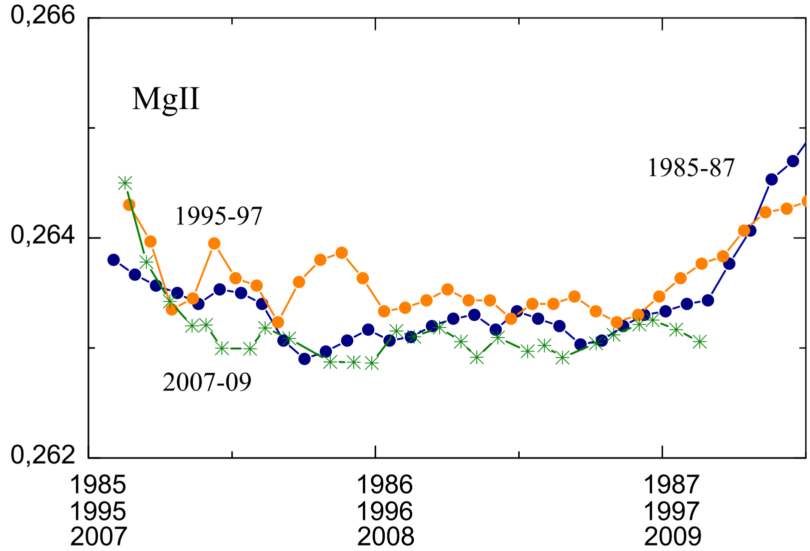


Fig. 1. Minimum values of the MgII index in each Bartels rotation $MgII_{min}$ smoothed for 3 rotations during three SC minima (blue circles - 1985-87, orange circles - 1995-97, asterisks - 2007-09).

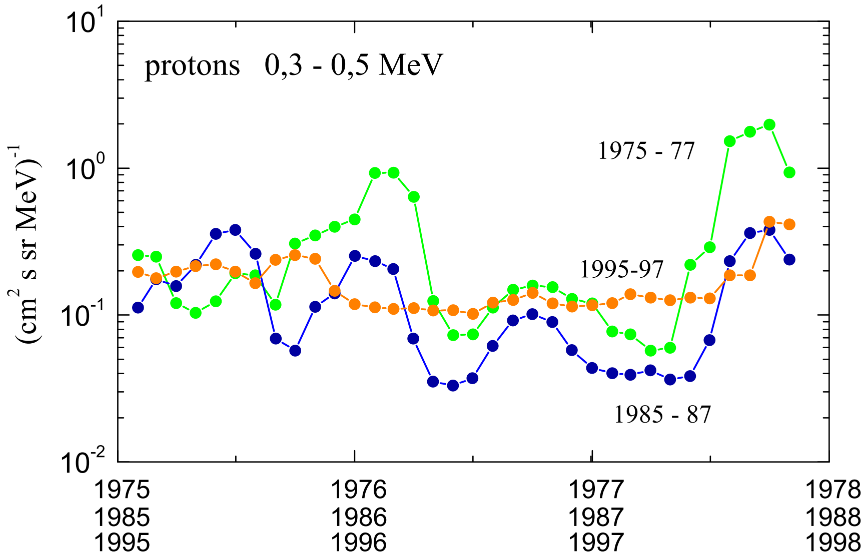
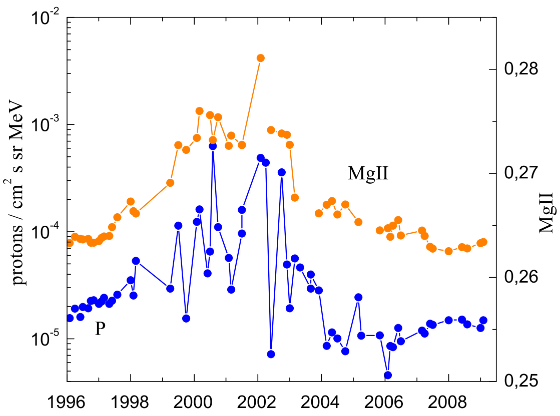


Fig. 2. Monthly minima of 0.3-0.5 MeV proton fluxes (CPME, IMP 8) intensities smoothed for 3 months during three SC minima (orange circles - 1975-1977, blue circles - 1985-87, green circles - 1995-97).

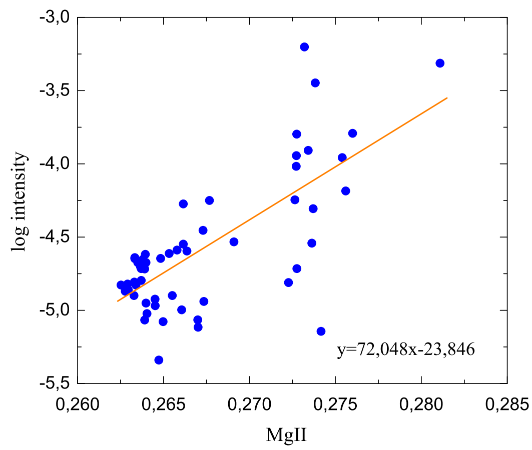
the MgII index and low-energy proton fluxes suggests the existence of close relation between them. It should be noted that the same comparison of background 10.7 cm radio flux intensity during subsequent SC minima throughout 1953 to 2008 did not show any noticeable variation caused by solar magnetic cycle.

III. Low fluxes of low-energy protons, He nuclei and the MgII index

The quiet-time 4-8 MeV proton intensity and MgII index exhibits a close correlation throughout the 23^{rd} SC (Fig. 3). Low particle fluxes were obtained by averaging during quiet time periods requiring that the daily intensities do not exceed 10^{-3} protons/cm^{2}s sr MeV. The corresponding minimum values of the MgII index were taken within a half of Bartels rotation of the



(a)



(b)

Fig. 3. a) Values of the MgII index (orange circles) and of 4-8 MeV proton EPHIN intensity (blue circles) during quiet-time periods in the 23^{rd} SC. b) Quiet-time proton intensities vs. the MgII index in 1996-2009.

selected quiet-time periods of proton intensity. Figure 3a shows that in 1996-98 both the quiet-time 4-8 MeV proton flux and the MgII index were higher than in 2004-09 confirming the 22-year variation of particle fluxes and solar index. Here the contribution of galactic protons cannot be neglected. Nevertheless, lower-energy proton fluxes (0.3-0.5 and 1-2 MeV [1]) also showed the 22-year variation at the SC minima. It should be noted that for protons with energy lower 2 MeV the contribution of galactic and anomalous particles is extremely low and cannot supply the quiet-time fluxes with additional non solar particles.

The correlation obtained for 1-2 MeV proton intensity (IMP-8) in 1976-90 showed a stronger dependence (logJ=102.7x-29.9) on the MgII index than 4-8 MeV protons as displayed in Figure 3b. This result indicates that the relation between proton intensity and MgII index varies with the proton energy and may depend on the magnetic polarity of the Sun.

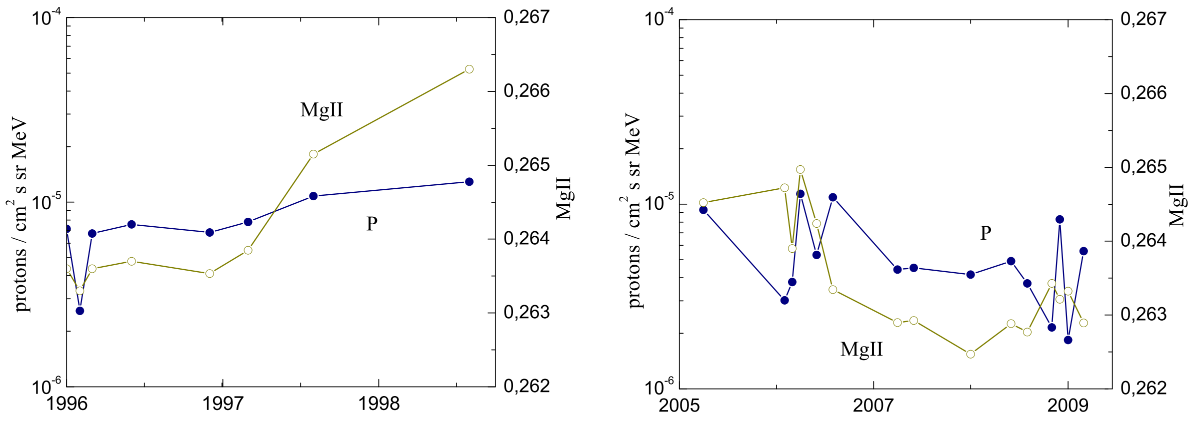
The time behavior at two SC minima of low fluxes of 4-6 MeV protons was obtained by averaging the daily pulse height analyzed (PHA) EPHIN intensities during quiet-time periods (Fig. 4). The proton intensity in 1995-98 also was also higher than in 2006-09 confirming the suggestion of 22-year variation of background particle fluxes. A similar variation can be observed in the MgII index.

Figure 5 presents the quiet-time 4-8 MeV/nucl H/He ratios as a function of proton intensity during the 23^{rd} SC. The background H/He ratio increased with background proton intensity due to larger increase of proton amount in comparison to helium nuclei, a characteristic feature of particle acceleration in major solar flares. During the SC minima the H/He ratio values were lower. Here the contribution from the anomalous component for He nuclei and galactic protons cannot be neglected for energies 4-8 MeV/nucl. Figure 5 shows very quiet periods during other phases of the SC when the lowest proton and H/He fluxes were observed when the fluxes of anomalous particles and of galactic protons were extremely low. Previously, the behavior of the quiet-time 0.3-2 MeV/nucl H/He values was investigated [5] and the lowest values of the proton intensity and H/He were obtained during the separate short time periods near the 21^{st} and 22^{nd} SC maxima. These results lead us to conclude that the particle population in these quiet-time periods was predominantly of solar origin and consisted of genuine background particles free from remnants from earlier SEP events. The corresponding MgII index and soft X-ray background were also very low suggesting that the lower is the chromospheric activity the higher is the amount of He accelerated on the Sun.

IV. Discussion and Conclusions

The comparison of quiet-time low energy particle intensity and parameters of solar activity revealed the possible existence of the 22-year variation in 0.3-8 MeV proton fluxes and the MgII index indicating the influence of magnetic polarity of the Sun. The best correlation was found for solar activity minima. During other phases of solar activity very quiet periods with very low proton intensity and low H/He ratio were found what permitted us to assume the presence of genuine particle background here free from other than solar sources.

The relation found between low-flux quiet-time proton intensity and the value of MgII index leads to the conclusion that the MgII core-to-wing ratio can serve as a solar index for low-energy particle intensity in the interplanetary space. The results obtained show that the



(a) (b)

Fig. 4. The quiet-time PHA 4-6 MeV proton intensity (blue circles) and the value of MgII index a) in 1996-97 and b) in 2006-09.

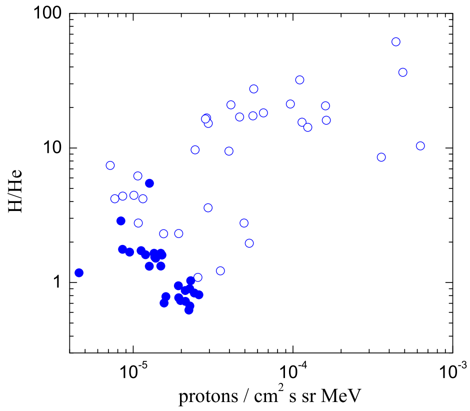


Fig. 5. Quiet-time 4-8 MeV/nucl H/He ratio vs. proton intensity in 1996-2009. Full circles are for the SC minima in 1996-98 and in 2006-09, open circles: in 1999-2005.

studied correspondence varies with the proton energy and maybe with the solar cycle. Lower energy protons show a stronger dependence on the MgII index. Considering the probability that background particles originate from any active processes on the Sun we ought to have in mind that flare-accelerated particles have different abundance ratios depending on the properties of the flare. The He/H ratios (at 15 MeV/nucl) were found to vary between $4{*}10^{-4}$ and 0.6 for 120 events depending on the characteristics of a particular flare loop (such as size, [6]). Flare particles in major events have abundances different from those in small events enriched in He [7]. The observed low background particle fluxes during quiet time periods together with low H/He ratio suggests that the genuine background particles are accelerated in very small, maybe invisible flares whose altitude in the solar atmosphere we intend to estimate with the help of studying the temperature and height of the acceleration region relying on the MgII index. Recent studies of solar active phenomena below the flare threshold showed that background fluxes of low-energy particles are probably connected with bipolar structures constantly arising on the Sun (bright X-ray points) accompanied in most cases by the ejection of solar plasma according to HINOTORI satellite. Speeds of a part of such emissions can allow particles to escape to the interplanetary space. It can be assumed that if the background particles were accelerated in any processes on the Sun on a longer time scale than solar flares the efficiency of these processes should depend on the level of solar activity.

V. Acknowledgements

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