GCR Flux Decline during the last Three Centuries: Extra-terrestrial and Terrestrial Evidences

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Abstract

We have deduced the Galactic Cosmic Ray (GCR) annual mean spectra for the last 300 years (Bonino et al., 2001), using the open solar magnetic flux proposed by Solanki et al. (2000). From the GCR proton flux we have calculated the ^{44}Ti ($T_{1/2}$=59.2 y) activity in small stony meteorites and we have compared it with our measurements of the cosmogenic ^{44}Ti in different H chondrites fell in the period 1810-1997 (Bonino et al., 2003). The results are in close agreement both in phase and amplitude. The same primary flux has been used for calculating the production rate of ^{10}Be in the atmosphere of the Earth (using the model by Masarik and Beer, 1999), which is found to be in good agreement with its concentration profile measured in Dye3 ice core from Greenland. The results are all consistent with a decreasing flux of GCR over the past three centuries.

1. Introduction

Measurements of cosmogenic nuclides of suitable half-lives in meteorites bring information on the secular variation of the GCR flux modulated by solar activity. We have measured the ^{44}Ti activity in 15 chondrites which fell during the last 200 years, with a highly specific and selective low-level γ spectrometer located under 70 m w.e. shielding in the Monte dei Cappuccini Laboratory in Torino. Our HPGe-NaI γ detector operates in coincidence and allows to measure the very low activity of the 1157 keV and the positron annihilation lines for the β^+ decay of the ^{44}Ti daughter ^{44}Sc; the typical background of the system is ∼0.5 counts per day. Figure 1 shows the good phase agreement between our measurements and the sunspot number R series. The ^{44}Ti variations on century time scales from minima to maxima are found to be about four times higher than calculated on the basis of the GCR flux measured in the last decades and extrapolated in the past simply on the basis of sunspot number (Bonino et al. 1995). The precision of measurements is still low and our new challenge is now to increase the efficiency of

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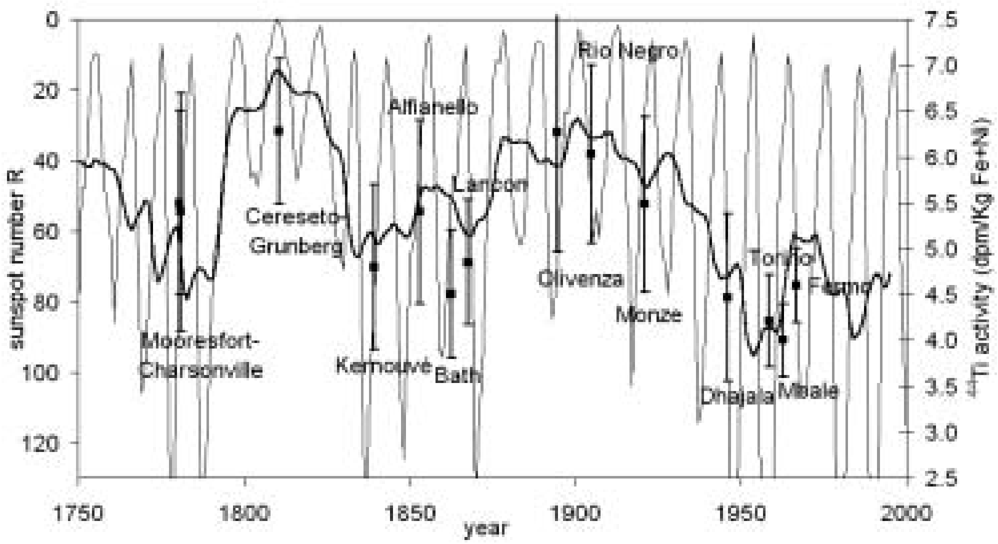

Fig. 1. Measurements of ^{44}Ti in different chondrites. Thin line: sunspot number; thick line: its 11-year running mean (reversed scale). The dates of fall of meteorites are anticipated of 30 years to to allow for the integrating nature of the ^{44}Ti activity.

counting and reduce the background so that the statistical errors of ^{44}Ti data can be reduced. For this reason a new detector has been designed and set up. With the new detector we will be able to measure the ^{42}Ar activity in meteorites (via 1524 KeV γ line of its daughter ^{42}K). It is desirable to use an isotope pair such as $^{42}Ar/^{44}Ti$, rather than a single isotope, since the ratio is largely independent of shielding depth but the activity of ^{42}Ar ($T_{1/2}$=33 y) is even lower (~0.3 dpm/kg).

2. Extrapolation of the GCR spectra

The differential flux $J_G(T, M)$ $(particles/m^2s\,srMeV)$ of GCR protons, in terms of the solar modulation parameter M, is described by the following equation (Cini Castagnoli and Lal, 1980):

$$J_G(T, M) = 9.9 \cdot 10^8 \frac{T(T + 2E_0)(T + M + 780 \cdot exp(-2.5 \cdot 10^{-4}T))^{-2.65}}{(T + M)(T + M + 2E_0)} \qquad (1)$$

where T is the kinetic energy per nucleon and E_0 is the rest energy of a nucleon. Figure 2 shows the M(t) series (Bonino et al., 2003) as a function of time reconstructed since the end of the Maunder minimum, based on the evolution of the Sun's large scale magnetic field since 1700 (Solanki et al., 2000). We observe that during the prolonged solar quiet periods M is lower than during the recent minima (with values of ~200 MeV during the Modern and Dalton Minima, compared to the present values of ~300 MeV); this gives a remarkable increase of the GCR flux during prolonged solar quiet periods, when J_G was respectively 1.5-2

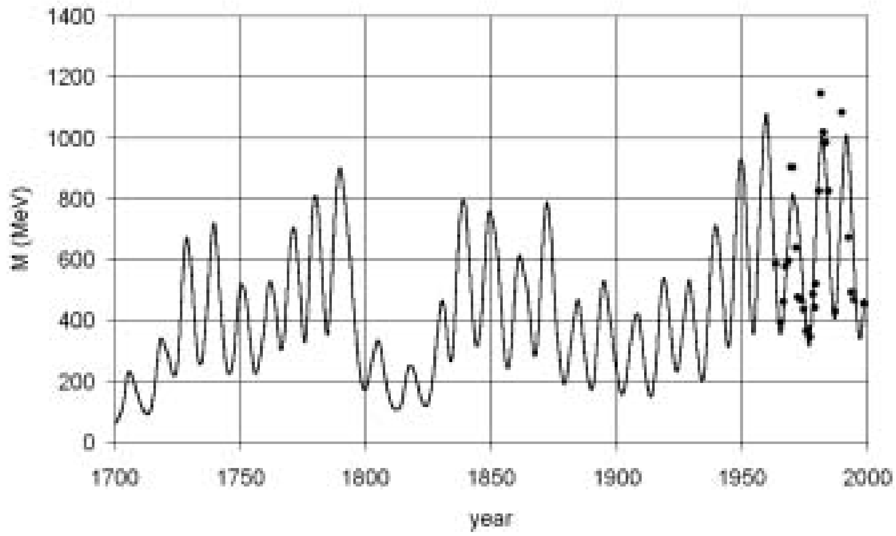

Fig. 2. Reconstruction of the modulation parameter M from the the open solar magnetic flux proposed by Solanki et al. (2000). Filled circles: experimental values calculated from the GCR spectra measured with balloons and spacecrafts.

times higher than the average J_G during the last 50 years. It may be noted that in this reconstruction the value of M never becomes negative, even at the end of Maunder Minimum, where it reaches the value of ~100 MeV.

3. Reconstruction of the ^{10}Be global mean production rate

To verify our reconstruction of M in the past we use here the mean global production rate of ^{10}Be in the atmosphere as a function of the modulation parameter (Masarik and Beer, 1999). We have calculated the global production rate of ^{10}Be in atmosphere from M given in figure 2 and compared it with the ^{10}Be concentration measured at the Dye3 ice core, assuming nearly constant accumulation rate during this period. The result is given in figure 3. There is a very good agreement in the amplitude of the variations between our calculations and measurements.

4. Conclusions

^{44}Ti activity in meteorites and ^{10}Be concentration in ice cores are two independent proxies of the GCR flux in the past. ^{44}Ti is not influenced by terrestrial processes and is only affected by GCR flux, and although the time resolution is poor (decades), provides true assesment of GCR fluxes. ^{10}Be concentration, on the other hand, is not independent from terrestrial reservoir influences and is affected by both, the GCR flux and the climate. Their agreement, as shown above,

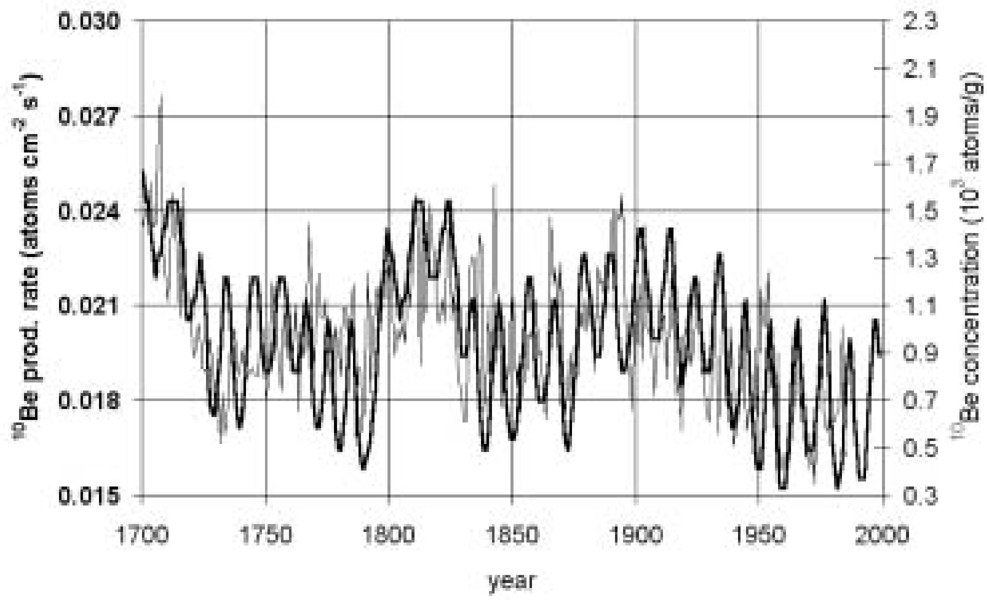

Fig. 3. Reconstruction of the ^{10}Be global mean production rate from M (thick line) confronted with the ^{10}Be concentration measured in Dye3 ice core (thin line).

indicates that ^{44}Ti in meteorites, ^{10}Be in ice cores and heliospheric magnetic field as deduced by Solanki et al. are mutually consistent and indicate a decreasing GCR flux with time by a factor 1.5 to 2, on the average, over the past 300 years.

Acknowledgements

While the work reported here was in progresses, prof. G. Bonino died on 29th of September, 2002. In his demise we have lost a very dear and a valued friend, an able scientist and a humane person. We are indebted to him for his invaluable experimental contribution.We are grateful to prof. C. Castagnoli for useful discussion and support and to Mr. A. Romero for careful technical assistance. This work was partially supported by FIRB 2001

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