Atypical Cosmic Ray Propagation During the qA>0 Sunspot Minimum of 1954

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Abstract

The balloon data obtained by Neher between 1933 and 1965, and the concentrations of ^{10}Be in polar ice show that the intensity of the GCR at <1 GeV was substantially higher during the sunspot minimum of 1954 than during 1944 and 1965. This and other data indicate that the access of cosmic rays to the vicinity of Earth was enhanced during 1954 compared to the other qA>0 minima of 1976 and 1997, possibly due to higher values of $\lambda_\perp$ associated with the very low sunspot numbers observed during 1954.

1. Introduction

As a consequence of the 22 year periodicity in the solar magnetic field, the GCR enters the heliosphere from equatorial latitudes during the sunspot minima with qA<0, and from high heliospheric latitudes for qA>0 [4]. We show that the intensity of the cosmic radiation <1 GeV/nucleon was anomalous for the qA>0 sunspot minimum of 1954, and possibly associated with very low solar activity, and anomalous cosmic ray anisotropies observed at that time.

2. Methods

Figures 1A displays the cosmogenic ^{10}Be from Dye 3, Greenland, for the period 1750-1980. The ^{10}Be is produced by cosmic rays with energies in the vicinity of 1-2 GeV/nucleon [5]. Figure 1A exhibits a steady decline in the GCR intensity from 1900 to 1965, interrupted by a short lived (<5 year), 30% increase centered on the sunspot minimum of 1954. H.V. Neher flew balloon borne ionization chambers to pressure depths of 5-15g cm^{-2} during the period 1933-1965 [8], and some of his observations at Thule (geomagnetic 88° North) are displayed in Figure 1B. Note that the curves for 1954 and 1955 diverge from the other curves in the vicinity of 70-100g cm^{-2}, and that they become steeper at higher altitudes. Note the contrast with the curve for the sunspot minimum in 1965, which remains well below those for 1954 and 1955 at high altitudes.

The high values of ionization, and the increasing ionization with height,

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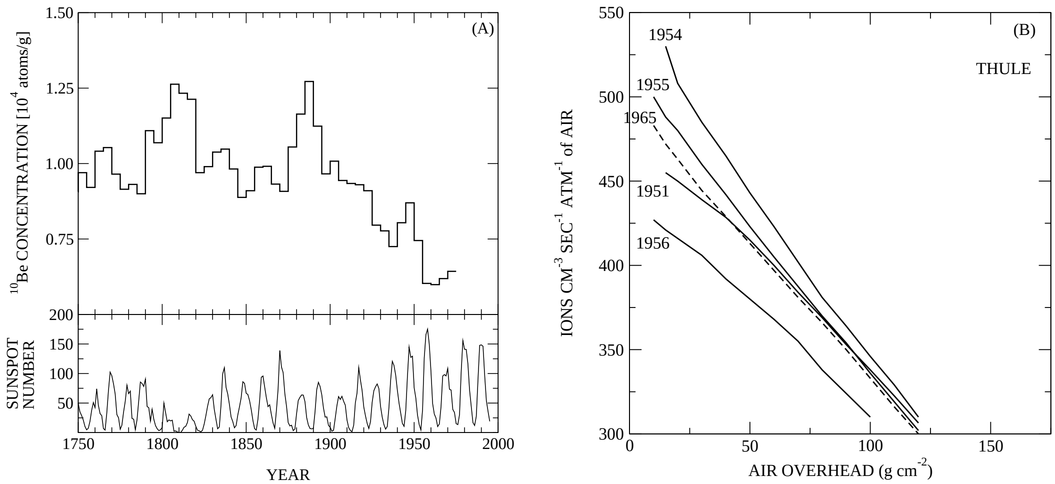

Fig. 1. **A.** Eleven year averages of the ^{10}Be data from Dye 3, Greenland centered on each fifth year, and the annual sunspot number, 1750-1980. **B.** The ionization versus atmospheric depth data obtained by Neher at Thule, Greenland [8].

indicate that there was a substantial flux of low energy cosmic rays in 1954 and 1955 that was not present during the sunspot minimum of 1965. Neher has shown that these cosmic rays were in the energy range 100-500 MeV, and he used the ionization versus depth curve to estimate their energy spectra [8]. Using the response function for the production of ^{10}Be [5], this spectrum was shown to be consistent with the increase in ^{10}Be in Figure 1A in the vicinity of 1954 [6].

The sunspot minimum of 1954 was anomalous in two other ways:

(1) Figure 2A displays the correlation between ^{10}Be concentration and sunspot number at sunspot minimum. This shows the remarkable result that the GCR intensity exhibits a well defined dependence upon the minimum sunspot number. It is noteworthy that the sunspot number during the 1954 minimum was one of the lowest ever recorded outside of the Maunder or Dalton minima, while those during the minima of 1944, 65, 76, and 86 were the highest recorded in 400 years. There are usually few sunspots visible at sunspot minimum, and they are usually restricted to a single Carrington longitude. Consequently it is not *a priori* evident that the sunspot number provides any information about the extended region of the heliosphere that influences the GCR. Figure 2A therefore conveys the important result that the sunspot number is providing a proxy for the magnetic conditions over a substantial region of space at sunspot minimum.

(2) First Forbush [3], then Beiber and Chen [2] showed that the "free space" phase of the diurnal variation exhibits a 22 year variation, remaining near 1800 hours for the majority of the period 1936-88, and moving to 1300 and 0800 hours for the qA>0 sunspot minima of 1976 and 1954, respectively. The diurnal anisotropy indicates the direction of the cosmic ray flows in the vicinity of Earth,

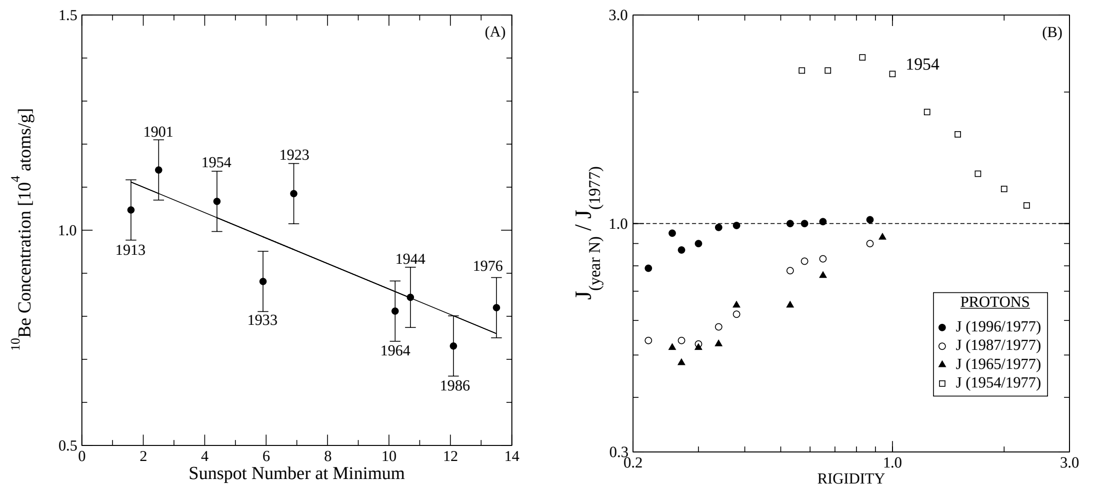

Fig. 2. **A.** The ^{10}Be concentrations (weighted average of 3 years about sunspot minimum) versus minimum annual sunspot number. **B.** The proton spectra $J_{(yearN)}$ for N = 1954, 65, 87, and 96 plotted relative to the spectrum $J_{(1977)}$ for 1977.

and this observation indicates that the predominant flow in 1954 was outwards along the Parker spiral from the Sun, and that this was markedly different from 1976. The flows are driven by the density gradients of the cosmic rays, and this observation indicates that the gradients were substantially different in 1954 than for the qA>0 minimum of 1976.

3. Discussion

Figure 2B displays spectra for the 5 sunspot minima 1954-96 as measured by the IMP spacecraft [7], and by Neher in 1954. Note that the spectra for the two qA<0 minima are depressed below the spectra for the three qA>0 minima. The spectrum for 1954 is consistent with those for 1976 and 1997 in that it is enhanced above those of the qA<0 minima; however it is about a factor of 3 greater than those of 1976/97 at rigidities in the vicinity of 0.7 GV, and it extends to higher rigidities. Note that the annual mean sunspot numbers for 1976 and 1997 were substantially higher than that for 1954 (12.6 and 8.6, compared to 4.4).

The cosmic ray observations made using balloons, cosmogenic ^{10}Be, and satellite and ground level detectors therefore indicate that the qA>0 minimum of 1954 exhibited the following unique features compared to those of 1976 and 1997. *(1)* Substantially higher fluxes for GCR <1 GeV/nucleon; and *(2)* Cosmic ray flows at and above 10 GeV that were outward directed along the Parker spiral magnetic field. During the qA>0 phase of the heliomagnetic cycle, cosmic rays reach the vicinity of Earth by entering the heliosphere at high latitudes: propagating to the plane of the ecliptic via curvature and gradient drift motions [4]; and then being convected out of the solar system by the solar wind. The above evidence suggests that these processes were more pronounced in 1954 than in 1976 or 1997. The inverse association between cosmogenic ^{10}Be and the minimum value of sunspot number in Figure 2A then indicates that the higher intensities in 1954 were associated with the low value of the sunspot number for the minimum of 1954. The high concentrations of ^{10}Be in the vicinity of 1890 in Figure 1A occurred at and after the sunspot minimum between sunspot cycles 12 and 13. Assuming phase stability of the heliomagnetic cycle, this was a qA>0 minimum. This reinforces the interpretation that the intensity of GCR <1 GeV is high during qA>0 minima at times of low solar activity (1890 was near the minimum of the Gleissberg cycle).

The cosmic ray drift motions are most efficient in well ordered magnetic fields; the presence of scattering inhomogeneities reducing the drift velocities [4]. The higher intensities, and the cosmic ray flows during 1954 may be explicable in terms of higher values of $\lambda_\perp$, leading to more efficient drift transport than in the later qA>0 minima. This would suggest that there is an association between low values of sunspot number at sunspot minimum, and high values of $\lambda_\perp$.

4. Conclusions

It is concluded that *(1)* the balloon data of Neher, and the concentrations of ^{10}Be in polar ice, agree that there was a substantial increase in the <1 GeV GCR during the sunspot minima of 1954, compared to 1944, and 1965; and *(2)* the cosmic ray flow during the 1954 sunspot minimum was outwards along the interplanetary magnetic field. These observations show that cosmic ray access to the vicinity of Earth was enhanced during 1954 compared to the qA>0 minima of 1976 and 1997, possibly due to higher values of $\lambda_\perp$. The sunspot number at the minimum of 1954 was very low, and the ^{10}Be concentration shows an inverse correlation to the sunspot number at minimum. This, and the occurrence of a similar enhancement of the ^{10}Be concentration in 1890, provides evidence that for qA>0, the values of $\lambda_\perp$ are inversely correlated with the minimum sunspot number.

5. References

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