Bull. Astr. Soc. India (1998) **26**, 167-171

# Records of the past solar activity in terrestrial and meteorite archives

N. Bhandari
*Physical Research Laboratory, Ahmedabad 380 009, India*

**Abstract.** Time series of cosmogenic radioisotopes in tree rings, sedimentary deposits on sea beds and ice cores from the polar ice caps show a large number of periodicities. Many of them can be attributed to changes in galactic cosmic ray flux due to solar modulation and in this way the past activity of the sun can be determined. However, since the effects of the geomagnetic field and the climatic processes are superimposed on these records, these periodicities, particularly their amplitudes, may not be wholly due to solar activity changes. The meteorite records, acquired outside the terrestrial influence, reflect the solar modulation more faithfully. Specifically, a century scale periodicity, related to the Gleissberg cycle, is supported by the observed $^{44}$Ti activity variation in meteorites.

## 1. Introduction

Observations of the Sun from ground based and satellite borne instruments over the past few decades have shown that there are short term (minutes to years) variations in solar output in different wavelengths as well as in corpuscular emissions. These observations suggest the possibility of long term variability of the Sun which is not amenable to direct observations but its characteristics can be established from planetary records, since galactic cosmic rays which are modulated by the solar activity leave their imprints in the form of spallation products in planetary and interplanetary bodies. In this paper, we review the available records in terrestrial reservoirs and meteorites which may enable us to understand the long term behaviour of the Sun.

## Terrestrial records

The sun spot activity, in particular the heliospheric magnetic field (HMF), governs the influx of galactic cosmic rays into the heliosphere and modulates the low energy particles. The 22 year Hale magnetic cycle and the 11 year Schwabe sunspot cycle which modulate the low energy (E<5 GeV) galactic cosmic rays are well established. Cosmic rays, in turn, leave the imprints in isotope production in the Earth's atmosphere and in meteorites. Table

1 lists some of the useful isotopes. Their rate of production is expected to vary inversely with solar activity. The pathways of production and deposition are shown schematically in Fig1. These records go back to millions of years and some of them relate to the earliest stages of formation of the solar system (Table 2).

**Table 1.** Some radioisotopes useful for studying the solar activity in the past.

| Radio isotopes | Half Life | Reservoir |
|---|---|---|
| $^{46}$SC | 83.8 days | Meteorites |
| $^{22}$Na | 2.6 years | Meteorites |
| $^{44}$Ti | 66.6 years | Meteorites |
| $^{14}$C | 5730 years | Tree rings |
| $^{36}$CI | $3 \times 10^5$ years | Ice cores |
| $^{10}$Be | $1.6 \times 10^6$ years | Ice cores |

Time series of $^{14}$C in tree rings (Fig.2) and $^{10}$ Be in ice cores have been constructed (Stuiver et al. 1993; Beer et al. 1995). The power spectrum (Damon and Sonett, 1991) of the $^{14}$C time series ($\Delta$ $^{14}$C) show several periodicities (Fig. 2, Table 3). These periodicities have been generally ascribed to changes in their production and thence to solar activity (Damon and Sonett, 1991). Recent work in which similar periodicities have been found in width of tree rings (Sonett and Suess, 1984) or in $CaCO_3$ abundance in sediment core (Cini et al. 1990) and also their similarity to $\delta^{18}$ O time series in ice cores (Lal, 1987), which is only a climatic indicator, requires that their implications to solar variability should be critically assessed. All periodicities obtained from terrestrial records thus face the problem of partitioning between climate and solar dynamics.

**Table 2.** Terrestrial archives and their response times.

| | Reservoir | Time resolution | Period of record |
|---|---|---|---|
| 1. | Tree rings | annual | $1.2 \times 10^4$ years |
| 2. | Ice cores | annual to decades | $10^6$ years |
| 3. | Sediment cores | 10-$10^3$ years | $10^5$ - $10^8$ years |
| 4. | Lunar rocks | 10-$10^7$ years | 10-$10^7$ years |
| 5. | Meteorites | 10-$10^9$ years | 10-$10^9$ years |
| 6. | Gas rich grains in meteorites | $10^2$-$10^3$ years | ~ $4.5 \times 10^9$ year ago |

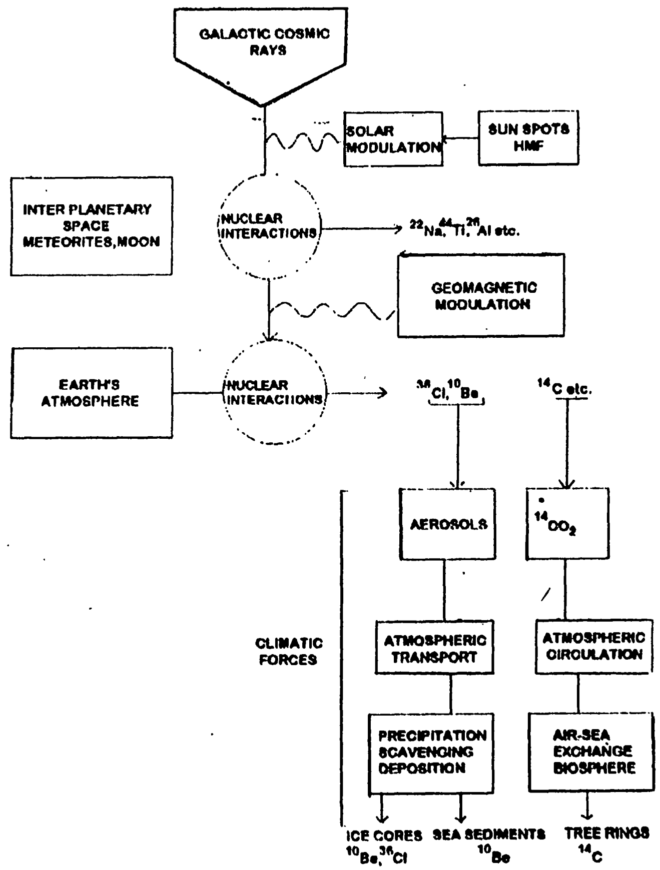


**Figure.1.** Solar connection of isotope production and their pathways in different reservoirs.

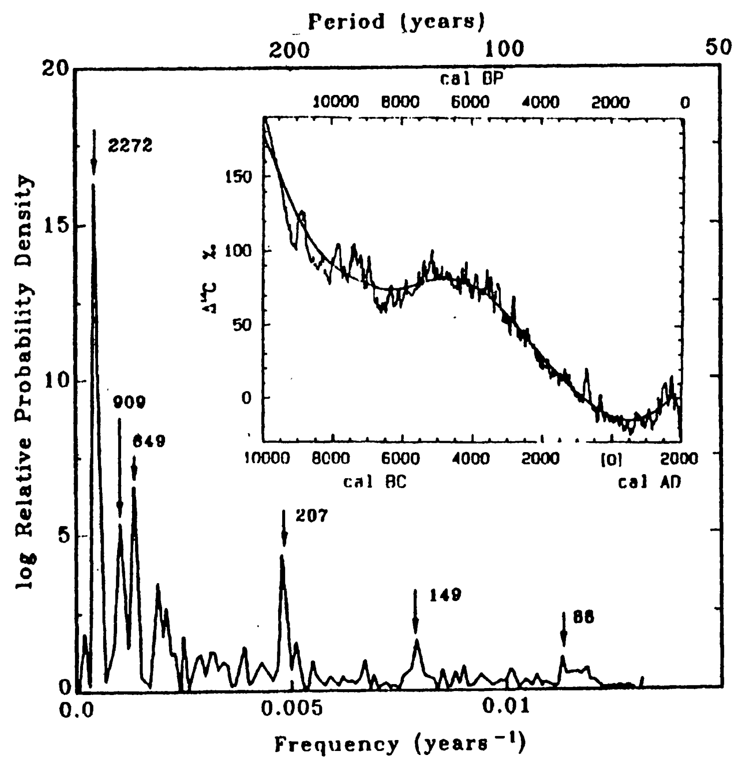


**Figure 2.** The Probability density of $^{14}C$ time series (inset, from Stuiver and Reimer, 1993) showing various periodicities. The long cycle is believed to be due to geomagnetic filter of the cosmic ray particles. The time series has been detrended for determining the amplitude of the discreet Fourier transform by using 5th order polynomial (from Damon and Sonett, 1991).

**Table 3.** Observed periodicities found in terrestrial and meteorite records (Damon and Sonett, 1991; Bonino et al. 1995).

| Period | Record |
|---|---|
| 11 | $^{10}Be$ in ice cores and $^{22}Na$ in Meteorites |
| 20 | Tree ring $^{14}C$ |
| 26 | Tree ring $^{14}C$ |
| 35 | Tree ring $^{14}C$ |
| 88 | Tree ring $^{14}C$, Meteorite $^{44}Ti$ |
| 149 | Tree ring $^{14}C$ |
| 207 | Tree ring $^{14}C$ |
| 649 | Tree ring $^{14}C$ |
| 909 | Tree ring $^{14}C$ |
| 2272 | Tree ring $^{14}C$ |

## 3. Meteorite records

To eliminate the interference caused by terrestrial processes on isotopic records on the Earth, meteorites may offer a suitable alternative as they move in the interplanetary space outside the influence of the geomagnetic field and climatic forces.

There are a large number of radioisotopes produced in meteorites by galactic cosmic rays which are suitable for studying variations on different time scales, depending on their mean life. However, a number of corrections for exposure history, size, shielding depth and target element abundances have to be applied before the results can be related to solar variation. Radioisotopes with mean life less than a few years e.g. $^{46}Sc$ and $^{22}Na$ ideal for studying the Schwabe cycle (Bhandari et al. 1994). $^{44}Ti$ which is largely produced in meteoritic iron and nickel is best suited for studying variations over longer periods e.g. on century scale. Recently several meteorites have been analyzed for $^{44}Ti$. The results, corrected for target element abundances and shielding are shown in Fig.3. The data clearly show a century scale periodicity, consistent with the Gleissberg cycle. The phase of the $^{44}Ti$ increase is consistent with the expected time lag based on the Sunspot numbers but the amplitude is 2 to 3 times higher, indicating that when the Sun is quiet for long periods of time, the HMF becomes regular and weak and a large number of GCR particles can enter the heliosphere, much more than can be expected on the basis of Sunspot numbers.

It thus appears that meteorites contain reliable records of the solar modulation, free of interferences from the terrrestrial effects and these records go back to billions of years, based on which the solar activity variations can be determined.

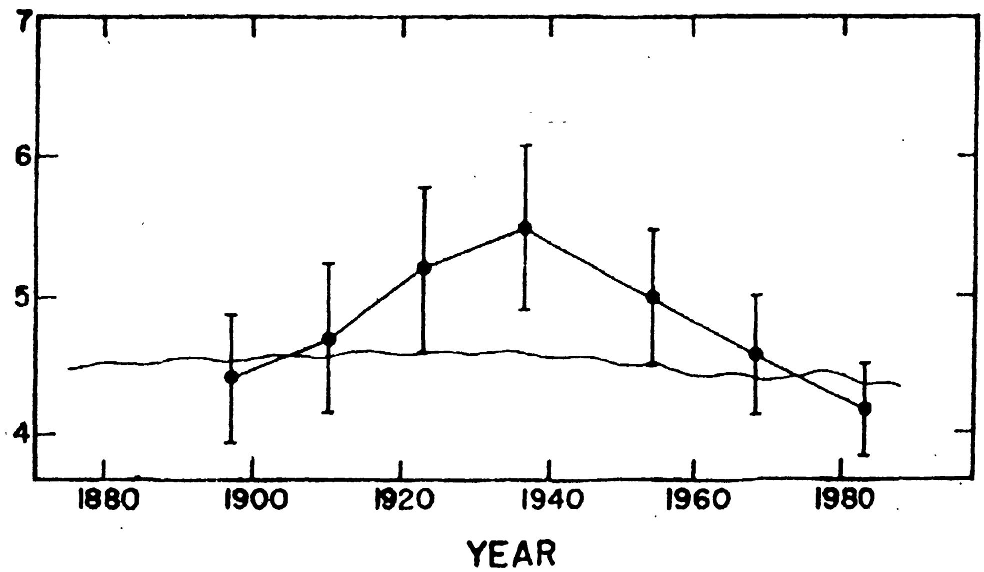


**Figure 3.** $^{44}$Ti time series observed in meteorites (from Bonino et al. 1995). The increase in activity occurs with the expected phase with Gleissberg cycle. The thin line represents the expected activity variation based on Sunspot numbers.

## References

Beer J., Mende W., Stellmacher R., White O.R., 1995, in Climatic variations and forcing mechanisms of the last 2000 years, eds P.D. Jones et al., Heidelberg, Springer.

Bhandari N., Bonino G., Cini Castagnoli G., Taricco C., 1994, Meteoritics, 29, 443.

Bonino G., Cini Casatagnoli G., Bhandari N., Taricco C., 1995, Science, 270, 1648.

Cini Castagnoli G., Bonino G., Caprioglio F., Serio M. Provenzale A., Bhandari N., 1990, Geophys. Res. Lett. 17, 1545.

Damon P.E., Sonett C.P., 1991, in The Sun in time.

Lal D., 1987, Geophys. Res. Lett., 14, 785.

Stuiver M., Reimer P.J., 1993, Radiocarbon, 35, 215.

Sonett C.P., Suess, H.E., 1984, Nature, 307, 141.