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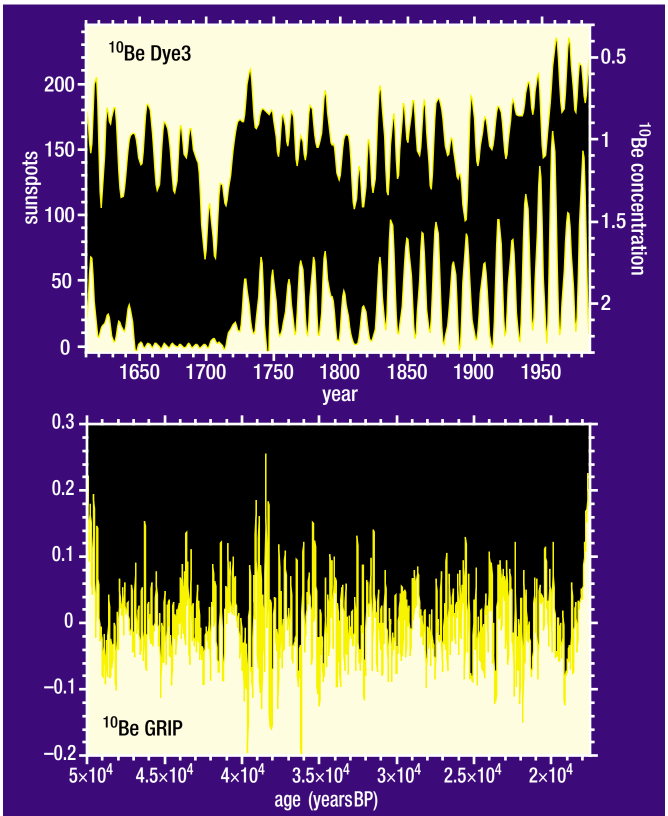
Long-term prediction of solar activity – a discussion…

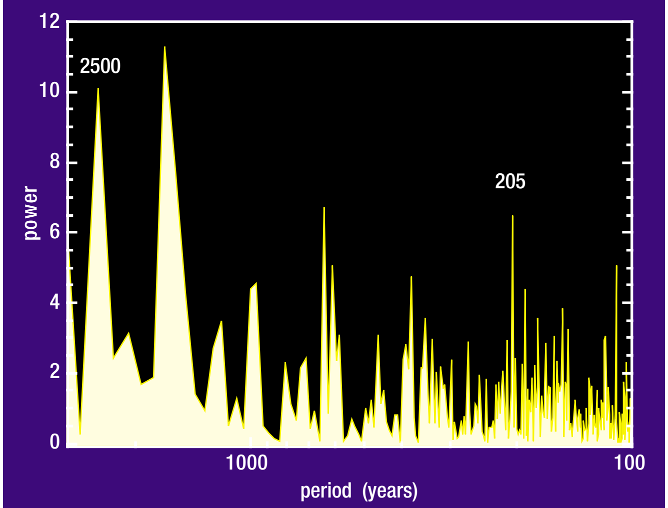
Solar activity is associated with the emergence of strong magnetic fields at the surface of the Sun, giving rise to sunspots, flares and coronal mass ejections. The incidence of all these features varies cyclically with an average period of about 11 years. The sunspot cycle is also modulated on longer timescales, most notably by the Maunder Minimum in the mid-17th century, when sunspots almost completely disappeared (Weiss 2002). Although direct telescopic observations of sunspots are limited to the past 400 years, the solar magnetic record can be extended back for thousands of years by using the proxy data sets provided by the abundances of cosmogenic isotopes. Cosmic rays impinging on the Earth's atmosphere result in the production of the isotopes such as ^{10}Be and ^{14}C. Moreover, these cosmic rays are partially diverted by the magnetic field in the solar wind and the geomagnetic field; hence the production of these isotopes varies in antiphase with the solar cycle (Beer 2000). The abundances of ^{10}Be (preserved in polar ice cores) and ^{14}C (preserved in tree rings) reveal not only the short term 11-year cycle but also recurrent minima in the envelope of cyclic activity, extending back up to 50 000 years into the past (Stuiver and Braziunas 1993, Stuiver *et al.* 1998, Wagner *et al.* 2001), as shown in figure 1.

In a recent article, Clilverd *et al.* (2003) attempt to predict the level of solar activity a century from now. They assert that long-term modulation of magnetic activity is dominated by the 2300-year Hallstatt cycle (Damon and Sonett 1991). Relying on a superposed epoch analysis of the ^{14}C record, they claim that the level of solar activity in 2100 will have significantly decreased.

The level of cyclic magnetic activity in the Sun may well go up or down but we believe that it is not feasible to make any meaningful long-term prediction. The evidence suggests that stellar magnetic cycles are chaotic, and the difficulties of predicting chaotic behaviour are by now well known. Furthermore Clilverd *et al.* (2003) only consider a very limited data set. In the ^{14}C record, which extends back for 11 500 years, the principal periodicity determined by frequency analysis is that of the 205-year de Vries cycle, though the 2300-year Hallstatt cycle is also present (Beer 2000). The de Vries cycle is also prominent in the ^{10}Be record, which Clilverd *et al.* do not exploit. Over the last decade, ^{10}Be abundances have been measured in ice cores from Greenland, yielding a proxy record that so far extends back for 50 000 years (see figure 1b). Statistical analysis of this rich data set (Wagner *et al.* 2001) reveals a significant peak in the power spectrum at a 205-year period that is definitely solar in origin (see figure 2).



1: The upper panel compares the proxy ^{10}Be data from the Dye 3 ice core (measured in 10 000 atoms/g), filtered using a low pass (six-year) filter, with the sunspot group number as determined by Hoyt and Schatten (1998). Note that the ^{10}Be is anticorrelated with sunspot activity. The lower panel shows the ^{10}Be flux data from the GRIP core for the interval 25 000–50 000 years BP. These data have been band-pass filtered with a 100–3000 year filter.



2: Power spectrum (after Lomb-Scargle) for the unfiltered GRIP data shown in the lower panel of figure 1 (after Wagner *et al.* 2001). Note the strong significant peak at 205 years.

Predicting solar activity has always posed a challenge – and forecasting the level of the next cycle is difficult enough (see for example the website science.nasa.gov/ssl/pad/solar/). Long-term prediction is much more tricky. Even if we accept that the record is simply a superposition of periodic oscillations, the procedure adopted by Clilverd *et al.* is tantamount to attempting to predict 11 years ahead solely on the basis of the 205-year periodicity, while ignoring the 11-year cycle completely. The record of solar activity in figure 1 does, however, appear to be aperiodic rather than multiply periodic: the aperiodicity might have a stochastic origin but we believe that it is more likely to be an example of deterministic chaos (Weiss and Tobias 2000, Weiss 2002). Experience shows that it is possible to recognize periodicities in the power spectra of chaotic data sets. (They correspond to the periods of unstable periodic or multiply periodic orbits – ghost attractors – in the phase space of the system.) What affects the issue here is that the future behaviour of such a chaotic system is intrinsically unpredictable. Given the Maunder Minimum and the de Vries cycle, a naive extrapolation would have predicted the occurrence of another Grand Minimum by now. Of course, it will be gratifying for us if such a minimum does arrive soon – but we wouldn't dare to predict it.

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