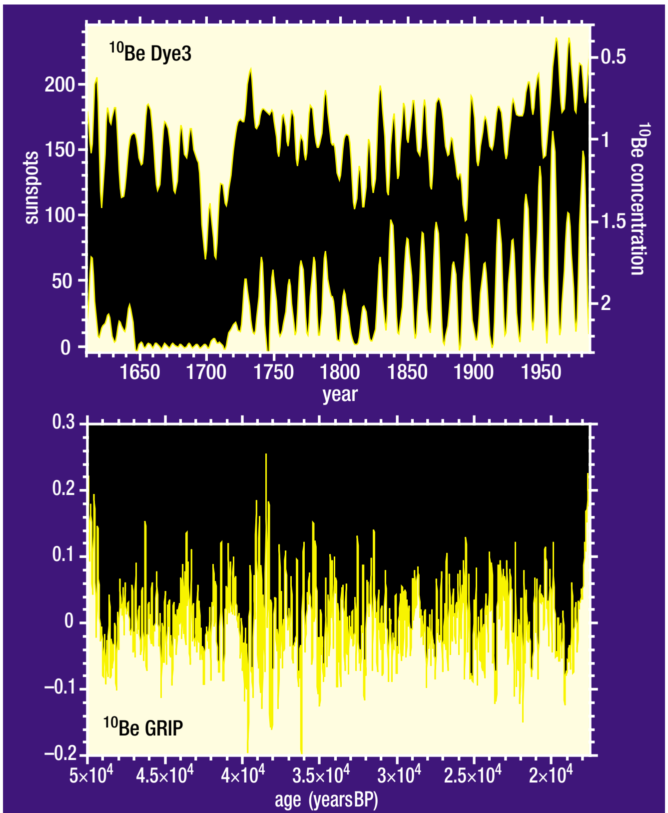
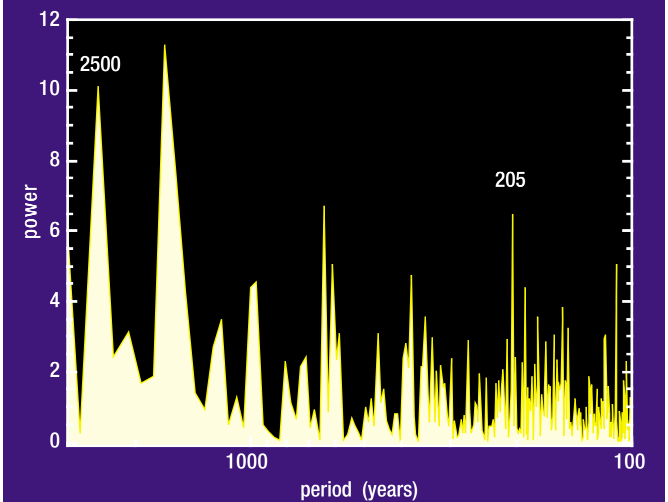
Steven Tobias, Nigel Weiss, Jürg Beer

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.



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.

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).

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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Mark Clilverd, Ellen Clarke, Toby Clark, Henry Rishbeth, Thomas Ulich

...and a reply

In a recent article (*A&G* **44** 5.20) we discussed likely solar activity levels a century from now using a superposed epoch analysis of Hallstatt cycles evident in the ^{14}C cosmogenic isotope series. In this issue Tobias *et al.* have quite reasonably indicated that it is a process fraught with uncertainties as evidence suggests that predicting stellar magnetic cycles will always pose a challenge. This reply allows us the opportunity to clarify a few points in the process we have undertaken in order to make the prediction.

The analysis we undertook on the ^{14}C series was based on the presence of the 2300-year Hallstatt cycle in the data. This cycle can be clearly seen in the series, as well as determined by frequency analysis. However, the Hallstatt cycle itself is not used solely to predict the minimum in solar activity in 2100. The principal role of the Hallstatt cycle analysis in our paper was to determine which parts of the ^{14}C data were influenced by solar activity and which were not. Damon and Jirikowic (1992) showed that the effect of "Hallstatt gating" results in a period of time every 2300 years or so where ^{14}C shows century-scale oscillations associated with solar activity. At other times solar activity variations in ^{14}C are suppressed. The window of the "gate" is about 1000 years and roughly centred on the time of the Maunder Minimum-like features. Thus we used the Hallstatt cycle principally to select the sections of the ^{14}C series that were relevant for solar activity analysis, and superposed the Maunder Minimum-like features to provide a consistent time frame.

In this way we have not ignored the shorter-length cycles such as the de Vries cycle as suggested by Tobias *et al.*, they are intrinsically included in the ^{14}C data that was selected for the analysis. Interestingly the superposition of four sections of ^{14}C data shows that little of the de Vries cycle survives the averaging process, suggesting that either these cycles are not strongly phase-locked to the Grand Minimum or that the period is variable enough to average the cycles out. The cycle that does survive the superposition process is the 420-year cycle, which is why we predict a minimum 400 years or so after the Maunder Minimum. The 420-year cycle has been postulated to be associated with oscillations in the solar convective zone (Stuiver and Braziunas 1989).

In summary, we recognize that predicting solar activity is a difficult task and one that is likely to generate as many questions as answers. If we are in a period of cyclic solar activity behaviour at present, as is possible even in chaotic datasets, then our expectation that solar activity will not increase in the same way as it has in the last 100 years or so is a message to take away. Like Tobias *et al.* we would be very satisfied if a minimum does arrive soon.
Mark Clilverd (corresponding author).

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Chris Trayner

A resource for meteor lovers

With Leonid storms over for now, solar system astronomers might be forgiven for thinking we only have solar eclipses and the occasional transit of Venus to relieve the boredom. In fact, plenty is afoot in meteor science and there is now an excellent way to keep on top of developments in this field. *WGN* (the journal of the International Meteor Organization) is a resource worth knowing about. It is produced as a non-profit enterprise and costs €20/$20 per year (more for airmail). Six issues are produced per year, making about 200 pages in total. Subscription details can be found on the website www.imo.net.

In *WGN* you will find news of developments in observational techniques, such as automated CCD-based meteor recording, which is now widespread in Europe, and forward-scatter radio meteor observation, coming to the fore in Japan. Video meteor recordings and photographs of persistent trains are allowing better understanding of how meteoroids flare and fragment in the atmosphere. Hypothetical newly-detected showers are debated endlessly, as are changes in the behaviour of established ones.

As the Editor of *WGN*, I am hardly an unbiased correspondent, but I do think that *A&G* readers may find much of interest in this journal. All the above topics appeared during 2003. Although most papers are scientific, historical pieces are published too. A recent article (*WGN* **31:6** 193) explains that, in Bulgarian folklore, meteors were dragons called Zmeys: "stealing away girls to be their wives or lovers". So when the Leonids come again this November, remember to lock up your daughters – or, of course, encourage them to take up astronomy!
Chris Trayner, Editor of WGN.

Persistent trains from two Leonid fireballs photographed by Valentin Grigore at Targoviste, Romania.

Anthony Hewish

Passionate about pulsars

In her lively Presidential Address describing the discovery of pulsars (*A&G* **45** 1.7), Jocelyn Bell Burnell did not mention the precision timing measurements which, for me, provided the strongest evidence that we were not dealing with extraterrestrial intelligence. During the days after Jocelyn phoned me about the pulses (actually I had not been "dealing with some twit" in a practical class but lecturing to a delightful group of second year physicists!) I was confined to Churchill College marking the scholarship examination. At lunch one day, chatting to the late Sir Edward (Teddy) Bullard, he said quite seriously, "if the pulses are narrow-band they are probably ET".

So when I got back to the observatory on 11 December I asked John Pilkington to start bandwidth measurements while I set up precision timing using second time-pips broadcast from Rugby. After a few days the astonishing timekeeping of the pulses became evident and I realized that it would be possible to detect planetary orbital motion of the source using the Doppler effect. Thereafter I made daily timing measurements, including 25 December, when the transit unfortunately occurred during lunchtime! Not until early January was I satisfied there was no detectable orbital motion apart from the Earth's. By then John had found that the instantaneous bandwidth was indeed narrow, about 80 kHz, but sweeping down in frequency, indicating pulse dispersion in the interstellar plasma, from which I estimated the distance.

One small final point concerns the one-sided nature of the first records of PSR 1919 (see Jocelyn's figure 2) obtained before the pulses had been identified. At that time we thought that the "scruffy" fluctuations might be strong scintillation, in which case a major recalibration of earlier results using the scintillation technique would have been required. Jocelyn now says this was a "silly idea" because scintillation produces symmetrical fluctuations. I disagree. Strong scintillation is characterized by a Rayleigh distribution of intensity, which is unsymmetrical, in contrast to the displaced Gaussian distribution of weak scintillation.

The first recording of pulses from PSR 1919 is currently preserved in the Archives Centre of Churchill College and may be seen on request (her figure 3 shows a later record when time-pips had been added).
Anthony Hewish, Cavendish Laboratory, Cambridge.