Analyzing Solar Cycles
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of bacteria by suppressing the Fenton reaction and stimulating SOD and catalase production. Interestingly, the authors also show that H_2S can act as a diffusible protective agent in bacterial populations. Further, cells deficient in H_2S produced increased amounts of NO, and the two gases can act synergistically to induce antibiotic tolerance, demonstrating some redundancy in these protective mechanisms.

The antibiotic tolerance mechanisms presented in these two studies have several strong similarities. The most obvious common aspect is that the stringent response and H_2S both induce tolerance by elevating the production of antioxidant enzymes. These effects can be explained, in part, by considering that nutrient limitation and the production of toxic H_2S are forms of cellular stress. One possibility is that these mechanisms may act as low-level stress conditions that activate antioxidant responses, priming bacterial cells to counteract the more lethal oxidative stress induced by antibiotics—thus confirming the adage, "that which does not kill you only makes you stronger."

The benefit of oxidative stress hormesis has been demonstrated in yeast, worms, and flies (*10*), and it is likely, as shown by Nguyen *et al.*, Shatalin *et al.*, and related work on low-level antibiotic stress (*11*, *12*), that a similar mechanism functions in bacteria.

The treatment of bacterial infections is becoming more difficult because of a decline in the current arsenal of useful antibiotics, the development of antibiotic resistance, and the slow rate of new drug development (*13*). This situation is further aggravated by biofilms and other tolerant bacteria that underlie chronic and recurrent infections. This is particularly problematic with implantable devices such as prosthetic hips, which often require surgical removal to eliminate the infection.

Potentiation of currently available antibiotics presents a cost-effective option to overcome these challenges. Both Nguyen *et al.* and Shatalin *et al.* identify critical aspects of bacterial biology that could be commandeered as part of new potentiation strategies. For example, each study indicates that it may be worthwhile to target bacterial antioxidant enzymes and associated pathways as a means to enhance the killing efficacy of bactericidal antibiotics. This could have a great impact on clinical practice and patient outcomes.

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ASTRONOMY

Analyzing Solar Cycles

Does the recent longer-than-usual minimum in sunspot activity indicate that we are heading for an extended period of solar inactivity?

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Since observational records began about 300 years ago, and very likely for millions of years before that, the Sun has displayed cyclically varying magnetic activity (*1*). Approximately every 11 years, a maximum of activity is reached, with a large number of sunspots (see the figure, panel A) present on the solar surface, strong x-ray emission from the corona, and a peak in the number of flares and coronal mass ejections. The latter cause mid- and low-latitude aurorae, disrupt radio communications, perturb navigation systems and radars, produce electric power outages, and can pose radiation hazards for astronauts and aircraft crew.

Solar cycle activity maxima are separated by minima during which only a few or no sunspots are present on the solar surface and other indicators of solar activity are equally muted (see the figure, panel B). Minima have lasted typically 2 to 3 years in the 20th century. Consequently, as solar activity decreased to near-minimum levels in 2005–2006, most solar astronomers expected that the Sun would be bubbling with activity again by 2007 or 2008. However, the Sun did not restart displaying appreciable activity until 2010. Also, the rise in activity has been slow relative to most other cycles during the last century.

Surprised by this unexpectedly long minimum, the solar physics community reacted in various ways. Interpretations ranged from a lull before the storm, with the next cycle to be particularly strong, to the beginning of a grand minimum, a multidecadal episode of almost nonexistent solar activity. Such a prolonged period of quiescence last occurred in the 17th century, when almost no sunspots were visible for around 60 years—the so-called Maunder minimum (*2*). Which, if any, of these scenarios is correct? In particular, are we heading for a grand minimum?

Predictions of solar activity have been notoriously wayward in the past, with similar scatter of predicted behavior also true for the maximum of cycle 23, as little as 5 or 6 years before it was reached (*1*, *3*). The best record is produced by empirical methods relying on precursors, but even they give reasonably accurate predictions of its maximum only after a cycle is well under way.

To estimate the future of solar magnetic activity beyond the next cycle, we must therefore take guidance from its past. During the past 70 years or so, the Sun has been in a grand maximum, a period of strong activity cycles, which by chance coincided with the space age and the great variety of data that it has provided. In the 19th century, the cycle minima were similarly long and quiet as the one we have just left. Also, the slow start of the present cycle—cycle 24—suggests (according to a rule named after the Swiss solar physicist Max Waldmeier) that it will be relatively weak, peaking at a yearly averaged sunspot number value of 60 to 100 (*1*, *3*), compared with 120 in cycle 23 and even larger values in four of the five cycles before that. There is similarity between the present cycle and the beginning of solar cycle 14 (see the figure, panel C). Cycle 14, the weakest cycle of the 20th century, peaked in 1905 at a yearly averaged sunspot number of 63.5. The sunspot number averaged over the first 9 months of 2011 is 45.5 (solid orange circle in panel B). Although this is low relative to the past nine cycles, it still exceeds 20, the amplitude of the two last cycles preceding the Maunder minimum (*4*). This speaks against, but does not rule out, a grand min-

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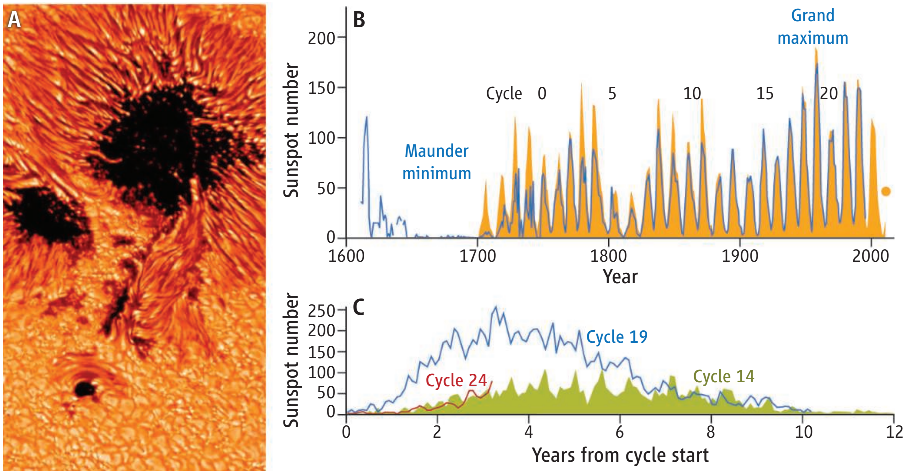

Solar (in)activity. (**A**) High-resolution image of a sunspot. (**B**) Yearly averaged Zurich (orange) and group (blue) sunspot number (*4*, *10*, *11*). Before around 1880, group sunspot number is thought to be a more robust representation of actual levels of activity. The Zurich number (also called the Wolf number) was introduced in the 1840s by Rudolf Wolf as an objective measure of the number of sunspots. The group sunspot number is a latter-day improvement, but is not yet officially available for cycle 23. The solid orange circle marks the average over the first 9 months of 2011. (**C**) Monthly averaged Zurich sunspot number for cycles 14 (green), 19 (blue), and 24 (red). Cycle 19 is the strongest on record.

imum starting within the next two decades.

A statistical analysis of earlier grand maxima and minima may provide a bigger-picture view of longer-term behavior of solar activity. As these occurred well before the invention of the telescope, we rely on indirect indicators such as the cosmogenic isotopes ^{14}C and ^{10}Be, produced when cosmic ray particles collide with constituents of our atmosphere. Modeling allows solar activity to be reconstructed back to the beginning of the Holocene period, about 11,000 years ago. The records reconstructed in this manner (*5*–*7*) reveal a rich array of grand minima and maxima. A statistical analysis of the grand maxima shows that they were in general shorter than the one that just ended (*5*, *6*, *8*). Its demise was (statistically) overdue.

What happens after a grand maximum is over? ^{10}Be data indicate that the probability of a grand minimum occurring within 40 years of the end of a grand maximum is 8%, rising to 40 to 50% within 200 years (*9*). Similar results are found from the compilation of 27 grand minima and 19 maxima since 9500 B.C.E. based on ^{14}C data (*6*). However, there is no guarantee that the Sun will gradually slide into a grand minimum after the just-ended grand maximum. Half the grand maxima in (*6*) were followed by one or more subsequent grand maxima before a grand minimum finally occurred.

In addition, the mean time between the end of a grand maximum and the beginning of the next grand minimum was 318 years. This average interval is also only slightly shorter than the 349 years that passed on average between the end of a grand minimum and the start of the next one. The Maunder minimum ended approximately 300 years ago, which is longer than the majority of such intervals (the median time between grand minima is 240 years), but still short relative to the 1420 years that passed between the two grand minima that occurred between 3000 and 5000 years ago.

Prediction of solar activity has not been reliable, because of the nonlinearity of the solar dynamo producing the magnetic field that is responsible for solar activity. On long time scales, our best bet is to consider the statistical evidence gleaned from previous grand minima and maxima. But these also give a mixed message. A grand minimum might be just around the corner and could hit us in the next 30 years, although with a probability below 10%. It is not even clear in which direction solar activity will develop in the longer term. Thus, the next grand extremum is just as likely to be a maximum as a minimum.

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MATERIALS SCIENCE

True Performance Metrics in Electrochemical Energy Storage

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Exceptional performance claims for electrodes used in batteries and electrochemical capacitors often fail to hold up when all device components are included.

A dramatic expansion of research in the area of electrochemical energy storage (EES) during the past decade has been driven by the demand for EES in handheld electronic devices, transportation, and storage of renewable energy for the power grid (*1*–*3*). However, the outstanding properties reported for new electrode materials may not necessarily be applicable to performance of electrochemical capacitors (ECs). These devices, also called supercapacitors or ultracapacitors (*4*), store charge with ions from solution at charged porous electrodes. Unlike batteries, which store large amounts of energy but deliver it slowly, ECs can deliver energy faster (develop high power), but only for a short time. However, recent work has claimed energy densities for ECs approaching (*5*) or even exceeding that of batteries. We show that even when some metrics seem to support these claims, actual device performance may be rather mediocre. We will focus here

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