Solar Variability: Is the Sun an Inconstant Star?

The 17th-century reign of Louis XIV, the sun king, was surely a time when that star shone its brightest on France and all her glory. Or was it? A new look at ancient astronomical records and more recent evidence from the ^{14}C content of tree ring samples suggest that the years 1645 to 1715 were a period of unusually low solar activity. Indeed, what is now being suggested is that the sun, far from being the constant star of recent memory and astronomical theory, has in the past 1000 years undergone several significant changes in its magnetic activity and, perhaps, in its output of energy. If so, then future changes in solar activity cannot be ruled out—a prospect with profound implications for solar physics and, possibly, for the earth's climate.

Actually there are four or five independent lines of evidence consistent with the idea of solar variability, according to John Eddy of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado.* These include the incidence of sunspots and (on earth) auroras, the structure of the solar corona, the concentration of ^{14}C in the earth's atmosphere, and the temperature at the earth's surface. Except for temperature, all of these are related to solar activity, and all of them appear to show quite different behavior during the late 17th century from that now accepted as normal.

Sunspots, for example, have been observed and studied since the introduction of the telescope about 1610. These phenomena are now known to be regions of intense magnetic activity, and their numbers wax and wane with the sun's 11-year magnetic cycle—from as few as a half a dozen at any one time near solar minimum to more than 100 at a time near solar maximum. Between 1645 and 1715, however, there appears to have been a marked absence of sunspots. None at all were reported for periods of many years at a time, and the total observed for the entire 70-year period was less than the number that normally occur in a single year near solar maximum. The pattern was not at all in accord with the 11-year cycle, which was first discovered in the 19th century. Eddy's investigation of historical records for the period and of astronomical practice at the time suggests that the accounts are reliable. The technique used to observe sunspots was essentially that used today, and there was such interest in the phenomena that seeing a sunspot was usually an occasion for publishing a scientific paper. If the sunspot record is accurate, the solar cycle must have been shut down or severely disrupted.

Other modern indicators of solar activity were also at low levels or missing entirely from reports of the 1645 to 1715 period. The characteristic streamers of the sun's corona or upper atmosphere that are dramatically visible during solar eclipses are now known to be associated with intense magnetic fields on the sun's surface. Descriptions of solar eclipses in the 17th century and before, however, contain no mention of streamers.

Auroral Sightings Too

Sightings of auroras—the spectacular northern and southern lights that are often visible over wide areas—are sparse in the 17th-century records too. Auroral displays occur when streams of charged particles from solar flares and prominence eruptions strike the earth's atmosphere. Since these particle-producing events arise in magnetically active regions of the sun, there is a well-established correlation between solar activity and the number of auroras. Although inconsistent reporting of the phenomena may account for some of the discrepancy, Eddy believes that the comparatively huge number of aurora sightings beginning in 1716 and continuing since indicate that some physical change did occur.

Sunspots are sometimes visible without a telescope, especially large spots or groupings of spots characteristic of intense solar activity. In Japan, Korea, and China, where sunspots were important in legend, records of such sightings go back to at least 28 B.C. Sunspot and aurora reports in these countries seem to have been unusually frequent in a 200-year period centered around A.D. 1180, but there are none from the 1645 to 1715 period.

Historical records that depend on human observers are of course open to question, but in this instance there are radiochemical data to back them up. The ^{14}C is continuously formed in the earth's atmosphere by cosmic rays and, as CO_2, assimilated into trees. By analyzing the ^{14}C content of trees of known chronology ring by ring, the past abundance of this isotope can be determined. This isotopic history is in fact the basis of the ^{14}C dating method used in archeology. But it is also, Eddy points out, a measure of past solar activity, since the flux of cosmic rays reaching the earth is modulated by solar magnetic phenomena—increasing when the sun is inactive. Thus a prolonged period of solar inactivity should show up as anomalously high ^{14}C in tree rings, and vice versa.

Just such an anomaly, a 20 percent increase over the average abundance of ^{14}C, is found for the period between about 1640 and 1720, in excellent agreement with the sunspot and aurora data. The ^{14}C records also indicate the existence of another, earlier period of solar inactivity, from about 1460 to 1550, and a peak of activity from about 1100 to 1250. Evidently the seemingly regular behavior of the sun over the past 150 years is not, as solar physicists have long assumed, necessarily typical.

Eddy's results come from reviving and extending earlier studies of astronomical records by two 19th-century scientists, Gustav Spörer of Germany and E. W. Maunder of Great Britain. Their work was largely ignored, but Eddy's suggestion that the sun has indeed been variable is being taken seriously. Solar physicists familiar with it find his evidence and reasoning "physically very plausible," although they admit to being uncomfortable with the idea that the solar cycle could shut down entirely.

Models of the magnetic dynamo thought to be responsible for the sunspot cycle and for varying solar activity are not yet well enough developed to test the concept. They do suggest that the dynamo, in which motions of the electrically conducting solar gas stretch and twist the sun's magnetic field to produce the 11-year cycle, results from the interaction of convection and solar rotation. Hence long-term changes in solar activity—such as the extreme minimums and maximums indicated by the ^{14}C data—are most probably due to changes in convective activity on the sun. At the very least, according to Peter Gilman of NCAR, the existence of such variability will be an important constraint on improved dynamo models.

Striking as the idea of major, long-term variations in solar activity may be for solar physics, even more interest attaches to the still speculative implications of solar variability for the earth's climate. Eddy points out that the 1645 to 1715 period of solar inactivity corresponds to the coldest years of the so-called "little ice age" that chilled northern Europe during the middle of the last millennium. There is a similar correspondence between earlier periods of un-

*Much of the information on which this article is based was presented at a symposium on the magnetically varying sun held at the AAAS annual meeting in Boston, February 1976.

usually cold and warm temperatures, as reconstructed from a variety of climatic indicators and records, and the solar activity variations recorded in the ^{14}C data. Are changes in solar magnetic activity in fact related to past climatic changes on the earth? Are climatic shifts themselves an indication of changes in the sun's output of energy?

Not many years ago these questions would have been dismissed by both solar physicists and climatologists as unworthy of serious investigation, but now, even though answers are not yet forthcoming, most investigators would not rule out the possibility. The difficulty is that there is no unambiguous evidence of changes in the sun's output of energy—the solar "constant"—although even changes of 1 or 2 percent would be enough, according to current climatic models, to cause profound changes on the earth. On the other hand, changes in solar magnetic activity, either on an 11-year or a much longer cycle, have not yet been shown to cause climatic changes, whatever their other effects on the terrestrial environment.

Both lines of research are likely to receive more attention. It is now known, for example, that the solar magnetic field controls the flow of matter that eventually escapes the sun as the solar wind. According to Robert Noyes of the Harvard College Observatory, Skylab investigations have shown that the solar wind is emitted from so-called coronal holes—regions of weak magnetic fields in the solar atmosphere. Thus a mechanism linking long-term changes in the solar wind and climate, if one could be found, might indeed implicate solar magnetic activity. Eddy thinks that a more likely explanation will involve changes in the sun's radiated energy, which is emitted not in the corona but lower in the photosphere, where sunspots and other magnetic disturbances also originate. Really accurate measurements of the sun's radiated energy over a long period of time have yet to be done, but it is known that variations in this century have been small and show no correlation with the 11-year magnetic cycle. A possible gradual increase in solar output of about 0.5 percent since 1900 is the only reported change.

Some investigators speculate that convective instabilities on a very large scale within the sun might lead to changes in solar output on a much longer time scale, and might also conceivably cause long-term changes in solar magnetic activity. If so, then solar activity and the terrestrial climate may again experience significant fluctuations. In any case, it begins to look as if *le Roi Soleil* deserves to be remembered as one of history's most ironic misnomers.—ALLEN L. HAMMOND

Molecular Cloning: Powerful Tool for Studying Genes

Few scientific techniques have aroused more speculation and interest than those that permit molecular biologists to artificially join DNA from two different sources to form recombinant molecules. Ordinarily genes are exchanged only between members of the same species as part of the process of sexual reproduction. But the new techniques can join DNA from species as diverse as mammals and bacteria, and then put the recombinant DNA into cells, usually bacteria, where it can reproduce.

Many investigators think that this research may provide the key that will eventually permit practical "genetic engineering." A possible application is the inexpensive commercial production of insulin, human growth hormone, and other medically useful materials in bacteria into which the appropriate genes have been transplanted.

At the same time, research on recombinant DNA has engendered concern that researchers might inadvertently allow bacteria bearing new and unusual genetic combinations to escape from the laboratory and produce adverse effects on human, animal, or plant populations. This concern has in turn engendered a series of committees to produce research guidelines to protect against this eventuality (*Science*, 19 December 1975; 27 February 1976).

At this time the practical applications of recombinant research are still in the future, and the hazards have been realized only—albeit fortunately—in discussion and speculation. What is happening now is that the techniques of the research are enabling investigators to explore the structure and function of genes. This is especially true for the genes and chromosomes of eukaryotic (nucleated) cells because the methods that proved successful with regard to the much simpler chromosomes of prokaryotic (nonnucleated) cells are not easily applicable to eukaryotic chromosomes.

Recombinant DNA techniques are useful for analyzing chromosome structure because they permit investigators to isolate chromosome segments bearing specific genes and to grow the segments in quantities sufficient for study. This is done by a process called molecular cloning in which the DNA to be studied is covalently linked with a suitable vector or carrier that reproduces itself—and the DNA in question—in bacterial cells. The most common vectors are plasmids and bacteriophages. Plasmids are double-stranded, circular pieces of DNA that are found in bacteria. They replicate independently of the bacterial chromosome. Genes for resistance to many antibiotics are carried on plasmids.

The small plasmid designated pSC101 carries the gene for resistance to the antibiotic tetracycline and is frequently used as a cloning vehicle. It was developed for this purpose by Stanley Cohen and Annie Chang of Stanford University Medical School and Herbert Boyer and Robert Helling of the University of California in San Francisco. They found that they could open the plasmid and insert a piece of foreign DNA. Doing this did not destroy the plasmid's ability to enter and reproduce in the bacterium *Escherichia coli*. Nor did it prevent the plasmid from conferring antibiotic resistance on the cells. The latter is important because antibiotic resistance provides an easy means of selecting those bacteria that have acquired the plasmid. Bacteria containing pSC101 will grow in the presence of tetracycline whereas those lacking the plasmid will not.

Use of pSC101 as a cloning vehicle is permitted under the proposed guidelines for research on recombinant DNA because tetracycline resistance is already widespread among *E. coli* strains found in nature, and experiments with pSC101 will not result in any extension of the resistance capability of *E. coli*. The guidelines prohibit the transfer of genes conferring drug resistance to microorganisms not known to acquire such resistance naturally because the clinical effectiveness of the antibiotic in question might be compromised.

In order to open the circular pSC101 molecule and insert the additional DNA, Cohen and Boyer used the restriction enzyme Eco RI. Restriction enzymes are bacterial enzymes (Eco RI is isolated from *E. coli*) that recognize specific base sequences on double-stranded DNA and cut both strands (*Science*, 4 May 1973).

The discovery of restriction enzymes has greatly facilitated the production of recombinant DNA's because several of the enzymes, including Eco RI, break the two strands of DNA in such a manner that the cuts are staggered. This generates single-stranded "sticky" or cohesive ends with base sequences that are complementary to