When the Sun Went Strangely Quiet

A new analysis shows that the sun has not always behaved the way it does now. The realization may have profound consequences for solar science and, perhaps, climatology.

BY KENDRICK FRAZIER

The history of science contains more than a few instances in which an old idea or hypothesis, considered improbable, dubious or merely wrong by modern investigators, is, through a combination of new evidence and a more thorough look at the old evidence, shown to be correct after all. Something like this seems to be happening to modern science's view of the sun. The current dogma is that the sun is steady, dependable, constant. In this view, its well-known 11-year sunspot cycle is the manifestation of a smoothly running, well-ordered machine, clicking with regularity like astrophysical clockwork. It is a comfortable view, the sun being of some importance to us all here on earth.

Now an astronomer with a historical bent has delved back through past observational records and, by making numerous independent cross checks, resurrected and made a persuasive case for an old hypothesis that the solar cycle and the sun itself have changed in historic time. The evidence shows that for a 70-year period from A.D. 1645 to 1715 sunspots were almost totally absent on the surface of the sun. Solar activity was at a near-zero level, a true and strange anomaly.

"This is totally unlike the modern behavior of the sun," says the astronomer, John A. Eddy of the National Center for Atmospheric Research's High Altitude Observatory in Boulder, Colo., "and the consequences for solar and terrestrial physics seem to me profound."

The evidence shows not only a minimum in solar activity from A.D. 1645 to 1715 but also an earlier minimum from A.D. 1460 to 1550 and an even earlier maximum from A.D. 1100 to 1250. "We now have to realize," Eddy says, "that the sun's behavior has been better in the last 200 years than in the previous 1,000 years."

The view that solar activity can and has varied to such a major degree in long-term patterns in historic time alters widely accepted assumptions about the constancy of the sun. "We've shattered the Principle of Uniformitarianism for the sun," Eddy says. By this he means that the present behavior of the sun can no longer be considered a reliable guide to the behavior of the sun in the past.

Eddy's conclusions imply that the often-discussed 11-year solar cycle is of far less importance and concern than are longer term variations—the overall "envelope" of solar activity. That patterns of solar activity have varied over historic time is interesting enough in itself. But beyond that, Eddy believes that the long-term fluctuations may be due to changes in the solar constant, the total radiative output of the sun. Such an idea is of fundamental importance. Whether the solar constant may vary, once considered improbable, is now being much debated. The problem has taken on new significance as solar physicists and climatologists consider the possible effects of the sun on variations in earth's climate.

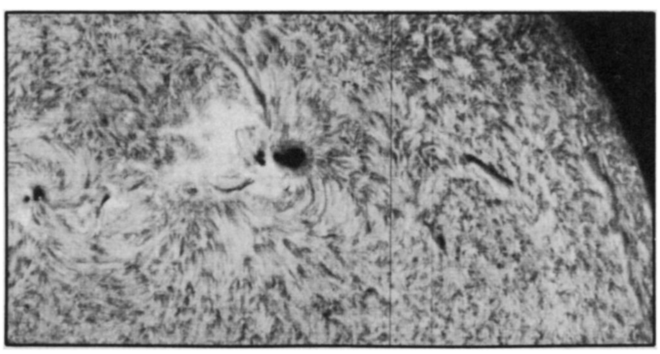
All this becomes even more intriguing when one observes that the period of near total absence of solar activity from 1645 to 1715 coincides almost precisely with the coldest point in the climatic minimum on earth that we now call the Little Ice Age. As Eddy puts it, "The climate curve looks a lot like the curve of variability in solar activity."

Eddy described his results in a session on the sun's effects on terrestrial climate at the annual meeting of the American Association for the Advancement of Science in Boston last week (his paper will appear soon in SCIENCE). When he finished, moderator George B. Field, director of the Center for Astrophysics of the Smithsonian Astrophysical Observatory and the Harvard College Observatory in Cambridge, turned to the small but crowded lecture room and said, "Maybe we've heard a turning point in the history of science."

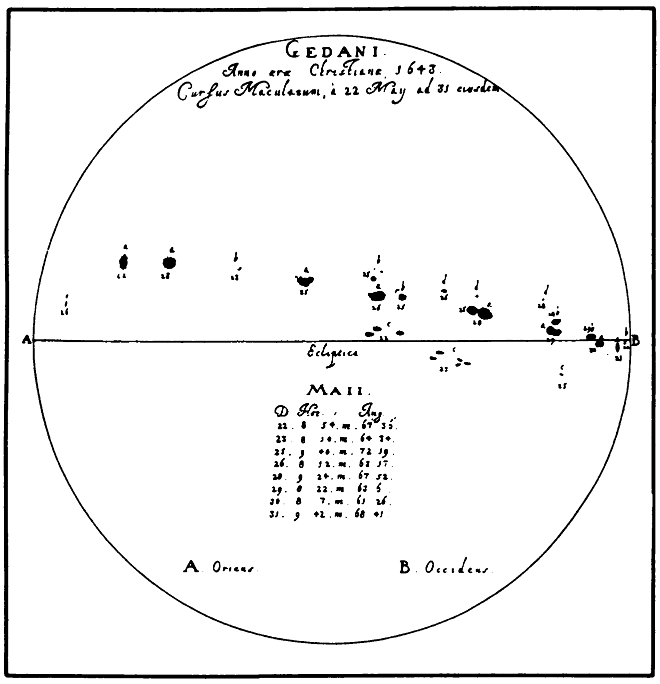
The main contribution of Eddy's analysis is to show that the prolonged sunspot minimum beginning in the 17th century is not an artifact of incomplete or spurious data but is in fact real. This has been the major stumbling block to acceptance of the idea, which has been around since at least the late 19th century. It was then that two well-known solar astronomers, Gustav Spörer of Germany in papers published in 1887 and 1889 and E. W. Maunder of the Greenwich Observatory in more detailed papers published in 1890 and 1894, called attention to the 70-year absence of sunspots. Maunder emphasized

The Polish astronomer Hevelius recorded these sunspots in 1643, just prior to onset of the Maunder minimum.

Sunspots, in closeup below, are associated with high solar activity.



Mt. Wilson Observatory



John A. Eddy

that this showed that the sun had changed in historic time and stressed its implications not only for our understanding of the sun but also for solar-terrestrial relations.

"It is not obvious that anyone in solar physics listened," observes Eddy. "The idea was so outlandish that it was ignored." The problem is that Spörer's original papers and Maunder's expansions on them leaned heavily on a *lack* of evidence in archival records and journals for sunspots and on contemporary statements about the infrequency of sunspot reports. "But," notes Eddy, "in the words of a modern astronomer, Martin Rees, absence of evidence is not evidence of absence."

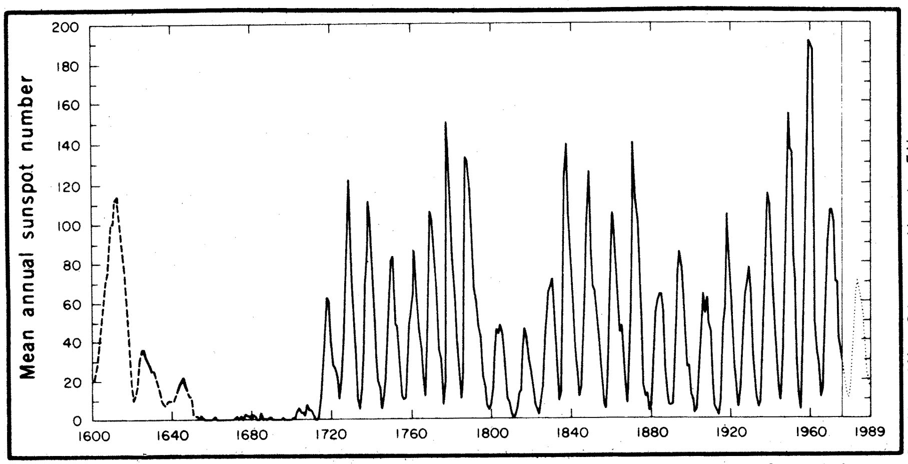
New evidence has come forth since Maunder's time. "We now have better catalogs of historical aurorae, compilations of Oriental sunspot observations, a fuller understanding of tree-ring records and a new tool in atmospheric isotopes as tracers of past solar activity," says Eddy. "New understanding of the sun since Maunder's day can sharpen our assessment of the facts." It is to this new evidence that Eddy turns for his analysis.

First Eddy reviews Spörer and Maunder's "striking" (Eddy's description) assertions: For a 70-year period, 1645-1715, practically no sunspots were seen. Fewer total spots were observed in that entire period than are seen in a single active year today. For nearly half that time, 1672-1704, not a single spot was observed on the northern hemisphere of the sun. In 1705, when two sunspot groups were seen on the sun at the same time, it was the first time in 60 years that this had happened.

Any contention that astronomers of the time did not have the means to observe sunspots, or did not look for them, does not stand up. Galileo and other later astronomers had produced beautifully detailed drawings of sunspots prior to the Maunder minimum. Telescopes were in common use and produced commercially. Most of the fine observational detail known of sunspots today had already been recorded. Astronomers in England, France, Germany, Italy and the world over were perpetually peeping at the sun with their telescopes.

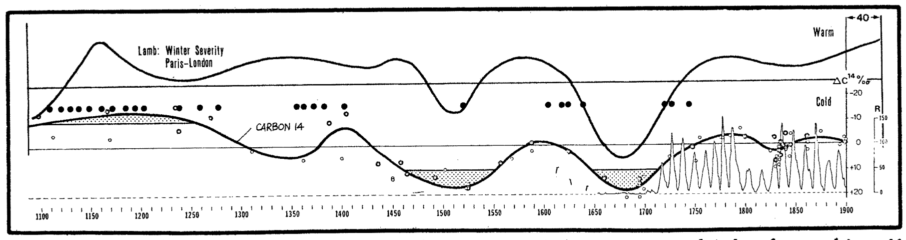
Sunspots were so rare that new ones were reported in the scientific literature of the day as "discoveries," and the sighting of a new spot or spot group was occasion for writing a scientific paper. "I don't think that is a situation we could tolerate today," Eddy quips. That would produce "an intolerable glut of manuscripts in the minimum years of the sunspot cycle and an avalanche in the years of maximum."

One independent check on past solar activity are records of occurrence of auroras, the northern and southern lights. Auroras are produced by collision of charged particles from the sun with air molecules in the earth's upper atmosphere. Particle-producing events on the sun arise in active regions on the surface, where there are also sunspots. So there is a strong positive correlation between sunspots and auroras.



Schneider and Mass, Science, based in part on Eddy

Virtually no sunspots were recorded from A.D. 1645 to 1715, the Maunder minimum.



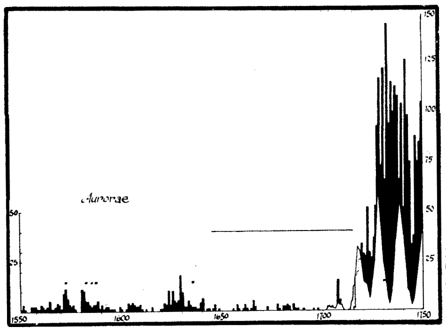
John A. Eddy

Carbon 14 variations (lower curve) and sunspots: "A pretty good job of matching." Solid circles are Oriental sunspot records; upper curve shows climatic variations.

The record shows that there were very few auroras between 1640 and 1700. By today's standards, there should have been between 300 to 1,000 auroral nights in Europe during that period. But there are reports of only 77 auroras for the entire world from 1645 to 1715, and 20 of these came in a brief active interval when sunspots were also seen. In one 37-year period of the Maunder minimum, not an aurora was reported anywhere. When in 1716 the first aurora in 63 years shone in the skies above London, the astronomer Edmund Halley wrote a now-classic paper on it. He was then 60 and had never seen one before. From 1716 on, sunspots had returned, and auroras were once again frequently sighted.

Another check on the reality of an extended sunspot minimum are reports of naked-eye sightings of sunspots seen from the Orient, where sunspots were important in legend and possibly in augury. The record is fragmentary, but Eddy finds it significant that no sunspots were recorded between 1639 and 1720—"a Far East gap that matches Western Hemisphere data very well." No auroras were reported either.

A further value of the Oriental records is that they extend back 2,000 years. They show sunspot gaps from A.D. 1520-1604, from 1403-1520 and from 579-808. They also show an intensification of sunspot and auroral reports in the 200-year period centered at around A.D. 1180, which is about halfway between the Maunder minimum and a more extended period of intense solar activity in the seventh and early eighth centuries.



John A. Eddy

Auroras: Rare during Maunder minimum.

Some of the most remarkable evidence confirming Maunder's prolonged sunspot minimum can be found in, of all things, trees. The amount of carbon 14 in tree rings has been shown in the last 15 years by such investigators as Minze Stuiver, H.E. Seuss and J.R. Bray to correspond well with solar activity. In fact, says Eddy, C-14 is an ideal yardstick for measuring solar activity.

The carbon 14 isotope is produced by the action of galactic cosmic rays on the carbon dioxide in earth's atmosphere. The C-14 is incorporated in all living things. When a tree, for example, dies, its C-14 begins decaying at an established rate. This is the principle used in carbon dating. But solar activity modulates, or blocks, some of the cosmic rays. Thus, during periods of higher solar activity, there is less C-14 in the atmosphere and less is found in tree rings formed then; during periods of lower solar activity, there is more C-14 in the atmosphere and more is found in tree rings formed then. So, during a prolonged period of quiet on the sun one would expect to detect it in tree rings of that era as an anomalously high abundance of C-14.

Such is the case. The first major anomaly found in the early studies of C-14 history, published in 1958, was a marked and prolonged increase that reached its maximum between about A.D. 1640 and 1720, "in remarkable agreement in sense and date with the Maunder minimum," Eddy comments. The phenomenon is known in carbon-dating as the DeVries fluctuation and, says Eddy, is the largest positive excursion found in the C-14 record—corresponding to a deviation from the norm of 20 percent. It has since been shown to be a worldwide effect.

Eddy has plotted the curve of relative deviation of C-14, with increasing concentration downward for direct comparison with solar activity, and included in the same figure the data for annual sunspot numbers and early naked-eye sunspot sightings in the Orient. "The C-14 envelope does a pretty good job of matching the cycle," Eddy said at the AAAS session. In his paper, he states the case more strongly: "The three quantities give a wholly consistent representation of the Maunder minimum."

The carbon 14 data show three clear periods of solar anomaly during the last 1,000 years: the Maunder minimum, an earlier minimum ("the Spörer minimum") from about A.D. 1460 through 1550 and a period of anomalously high activity in the 12th and early 13th centuries. "These extremes might be called Grand Maxima and Minima of the solar cycle, though we cannot judge from these data whether or not they are cyclic features."

There's still one more way to independently check all this. The solar corona seen during a total eclipse is more dramatic looking during times of high solar activity. This is because coronal streamers, extending outward like the petals of a flower, are rooted in concentric magnetic fields on the sun, which are in turn associated with solar activity and sunspots. X-ray photographs of the solar corona from Skylab have confirmed these associations. In total absence of solar activity one would expect to observe only a dim, uniform glow around the moon at eclipse. Eddy has gone back over records of eclipse observations in 1652, 1698, 1706 and 1715 and finds that for the first three none describe the corona as showing structure or significant size. Not one mentions streamers. By 1715, the last eclipse of the Maunder minimum, the annual sunspot number had reached 26 and was climbing. The corona is described in modern, familiar terms. "I can find no facts which contradict the Maunder claim," concludes Eddy, "and much that supports it. I am led to conclude that the prolonged sunspot mimimum was a real feature of the recent history of the sun."

Is the Solar Constant Constant?

Climatologists and solar astronomers badly need to know for sure whether the solar constant is constant or variable.

In his just-published book, *The Genesis Strategy,* Stephen H. Schneider of the National Center for Atmospheric Research urgently calls for measurement to high precision (about 0.1 percent) of the solar energy output, the so-called solar constant. (He prefers the term solar parameter.) "The measurement will be fiendishly difficult and costly, but I think justifiable. . . . In my opinion, the measurement of solar variability could turn out to be the most important single geophysical observation that could be made, from space or earth. The lamentable oversight that permitted the world to watch men skipping . . . and race driving across the moon, without quietly placing an instrument capable of shedding light on the debate as to whether variations in the sun cause variations in the climate, seems one of the major scientific omissions of the 1960s."

The report of the Study of Man's Impact on Climate in 1971 concluded that our knowledge of the solar parameter was too imprecise for climatic theory and modeling and recommended that it be determined to better than 0.5 percent accuracy.

John A. Eddy of NCAR laments that the solar constant hasn't been measured precisely over a long period. "The one measurement we needed is the one we didn't do." The reasons? "It is difficult, it requires a long commitment, and it has no pizazz. It is dull hard work. No major observatory has taken on the task of measuring the total output of the sun."

And climatologists are fond of quoting this remark by H. E. Landsberg: "One reliable observation is worth a thousand models and a million speculations."

Some help may be on the way. "The Smithsonian is getting back in the business of studying solar activity," according to George B. Field, director of the Center for Astrophysics, of which the Smithsonian Astrophysical Observatory is a part. The project will analyze the solar data obtained by Harvard and Smithsonian instruments on Skylab's Apollo Telescope Mount and also analyze the 50 years of data on solar variability accumulated by the late Charles Greeley Abbot of the Smithsonian. New theoretical studies will also be done.

—*K.F.*

How does this all relate to earth's climate? The coincidence of the Maunder solar minimum of the 17th century with the coldest part of the Little Ice Age has been noted by many investigators in the last 15 years. The Spörer minimum of the 16th century is coincident with the other severe temperature dip of the Little Ice Age. The prolonged solar maximum coincides with the warm climatic optimum of the 13th century.

Eddy's study, although it establishes no physical links, should help dispel doubts about the reality of the coincidence and encourage new attention to possible causes.

Eddy himself suggests a possible relationship between "the overall envelope of the curve of solar activity and terrestrial climate in which the 11-year cycle, and possibly the 80-year cycle, may be effectively filtered out, or simply be unrelated to the problem." He goes on to suggest that the amount of energy from the sun may vary: "The mechanism of this solar effect on climate may be the simple one of ponderous long-term changes of small amount in the total radiative output of the sun, or solar constant."

"We are seeing the long-term variation in the solar constant," Eddy told the AAAS meeting. "I think the solar constant follows the overall envelope but does not follow the 11-year cycle. Solar activity may follow slow changes in solar output, not the other way around."

(That idea is yet to be confirmed. As climate theorist Stephen H. Schneider of the National Center for Atmospheric Research says, "Statistical correlations in the absence of physics always lead to a fight." Two well-known studies, by the late Charles Greeley Abbot for the Smithsonian Institution and by two Soviet scientists using balloon measurements, have claimed a relation between the solar constant and sunspot number. Schneider and Clifford Mass of the University of Washington recently analyzed the claim of the Soviet scientists, K. Ya. Kondratyev and G.A. Nikolsky, without judging its validity. They combined the Soviet model with a model by British climatologist H. H. Lamb of the effect of volcanic dust on climate. Their computer model, published in November in SCIENCE (190:741, 1975), shows some similarities to known temperature histories. But they caution that its accuracy is not sufficient to permit much confidence in any correlation. They call for urgent efforts to make long-term measurements of solar variability from space.)

At any rate, as a result of Eddy's work, it now seems certain that during the last millenium the sun has been both considerably less active and possibly more active than it has been in the last 250 years. Concludes Eddy: "We've finally broken a block that has held us back—uniformitarianism. It was an assumption we took as fact." □