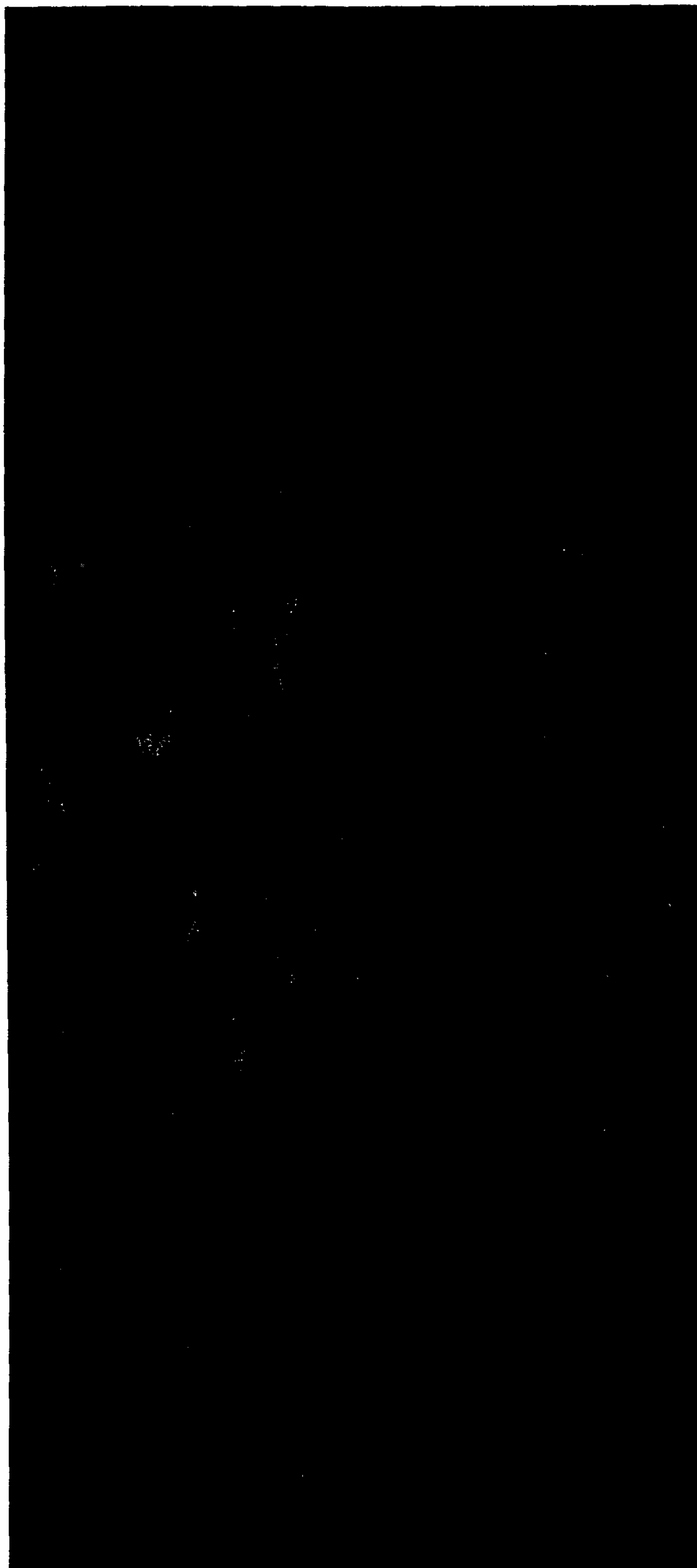
STAR SPOTS

In the middle of a career spent reaching for the stars, Sallie Baliunas has caught one near and dear to us all: the sun.



Astrophysicist Sallie Baliunas is studying the cycles of the sun and sunlike stars. Behind her is an image of the sun as captured by *Skylab* astronauts in the 1970s.

Growing up in New York City in the sixties, Sallie Baliunas dreamed of helping to fulfill President Kennedy's goal of putting a human being on the moon before the end of the decade. The problem was, Kennedy didn't exactly say "a human being." He said "a man," and though the word was meant colloquially, the bias was very real.

"As a child I wrote to NASA," Baliunas recalls, "to find out what I had to do to become an astronaut. They were very nice and wrote that all the astronauts up until then had been test pilots. I didn't realize that little girls didn't grow up to be test pilots."

Baliunas, now 38, eventually lost the ambition to go into space, but she kept her sights fixed firmly on the heavens: today she's a staff scientist with the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

PHOTOGRAPH BY RICK FRIEDMAN; BACKGROUND COURTESY NASA

BY SAM FLAMSTEED

"I've found," she says, "that I can do all the science I want from the ground."

Even so, she travels in a complex orbit that only an astrophysicist can comprehend. She is on the run constantly: dashing to scientific meetings all over the world; going on observing runs to Mount Wilson, near Los Angeles, and Mount Hopkins, near Tucson; taking satellite data at NASA's Goddard Space Flight Center outside Washington, D.C.; and serving as a visiting professor at both Tennessee State University and Dartmouth.

Sooner or later her trajectory brings her back to home base. Baliunas's office at Harvard bears the trappings of astrophysicists everywhere—a computer workstation, piles of papers on any available horizontal surface, bookcases filled with issues of the *Astrophysical Journal.* There are a few nonstandard items as well: a collection of small model cars, including a pink Cadillac; a piece of Plexiglas with the engraved words THE BEST MAN FOR THE JOB IS A WOMAN; a sepia-tinted photograph of herself in a saloon, done up in wild West garb. More significant, perhaps, is an item displayed on one wall: a plaque declaring her the winner of the American Astronomical Society's 1988 Newton Lacey Pierce Prize, an award that goes each year to an outstanding young observer. Baliunas got that honor for her research into the cycles of stars like our sun.

Astronomers have long known that every 11 years, on average, the sun goes through a frenzy of activity: localized magnetic storms, revealed by sunspots, suddenly multiply; white-hot gases leap into space in enormous arcs; violent eruptions send charged particles flying off in all directions. What astronomers didn't know, however, was whether other stars of the same size and age behaved the same way.

"We've always been able to study the sun up close," Baliunas says, "but astronomers have never been sure if the sun is a celestial oddity or a more or less normal object." In 1977, while still a doctoral student at Harvard, she was given an opportunity to help find out. "When I was in the midst of writing my thesis on solar dynamics, my adviser told me that a group of astronomers at Mount Wilson were looking for sunlike characteristics in nearby stars. As a student, I knew that all the great discoveries were made at Mount Wilson, so I hurried out there. It was like returning to my astronomical roots."

Measuring the brightness of a nearby star is no problem, except that it needs to be done carefully. But at first blush it might seem impossible to measure a star's magnetic activity. After all, even the closest stars show up as mere points of light in the most powerful telescopes, and the sunspots (or star spots) that might serve as clues to magnetic storms are utterly invisible. Fortunately, nature has supplied another way.

IF WE KNOW THAT SUNSPOTS ARE ASSOCIATED WITH CHANGES IN RADIANCE, IS IT POSSIBLE THAT THEY COULD AFFECT THE CLIMATE ON EARTH?

When magnetic activity increases, a star's atmosphere is heated, causing its gases to glow with very specific, characteristic wavelengths. Some of these are hard to detect except from space, but the signature wavelength from singly ionized calcium—calcium with one electron knocked off—readily makes its way through Earth's atmosphere and can be easily identified by spectrographs. Calcium light is such a small part of a star's visible light that it has no appreciable effect on overall radiant output; however, when this tiny sliver of the spectrum is brightest, it's a good indication that magnetic activity is highest.

By the time Baliunas came to visit in 1977, the Mount Wilson researchers had been monitoring selected stars for more than a decade, looking for spikes in calcium light. The work required patience, since a single cycle of a single star could take years to unfold. Over time, however, patterns did begin to reveal themselves: on several occasions stars that had held steady for years did brighten in the calcium wavelength, by as much as .5 percent. More important, they did so in approximately the same 11-year pattern as the sun.

The findings were tantalizing, and after Baliunas headed back East, she was able to include some of the Mount Wilson data in her doctoral thesis. Throughout the next year she continued conducting research and teaching at Harvard, but the work taking place a continent away held a lingering fascination for her. In 1978 she got her chance to return to it when the astronomer who had begun the Mount Wilson study retired and no one on the team appeared willing to step into his shoes.

"Here was this really important survey," says Baliunas, "and it looked like it was going to go headless and just wither away." To Baliunas the answer seemed obvious: try to take the job herself. She began traveling back and forth to Mount Wilson, helping out with the sky surveys as often as her schedule would allow. By 1980 she was there full-time, running the project and overseeing observations of up to 50 stars.

That year happened to coincide with the solar maximum, the peak of one of the sun's 11-year cycles. At the same time Baliunas and her colleagues were training their instruments on distant sunlike bodies, therefore, they were also keeping an eye on some curious developments concerning the star closest to home. So were many other researchers. During the solar maximum of 1980, two satellites, *Nimbus 7* and *Solar Max,* detected a surprising increase in the sun's radiance—surprising because the sun's radiant energy was long thought to be constant. Moreover, although the unexpected boost in brightness never grew greater than about .1 percent, it seemed to begin at the same moment magnetic activity started to rise, and it appeared to climb right along with it. For the next several years sun-watchers continued to monitor both types of energy; sure enough, as solar maximum began to wane toward solar minimum, radiance faded, too.

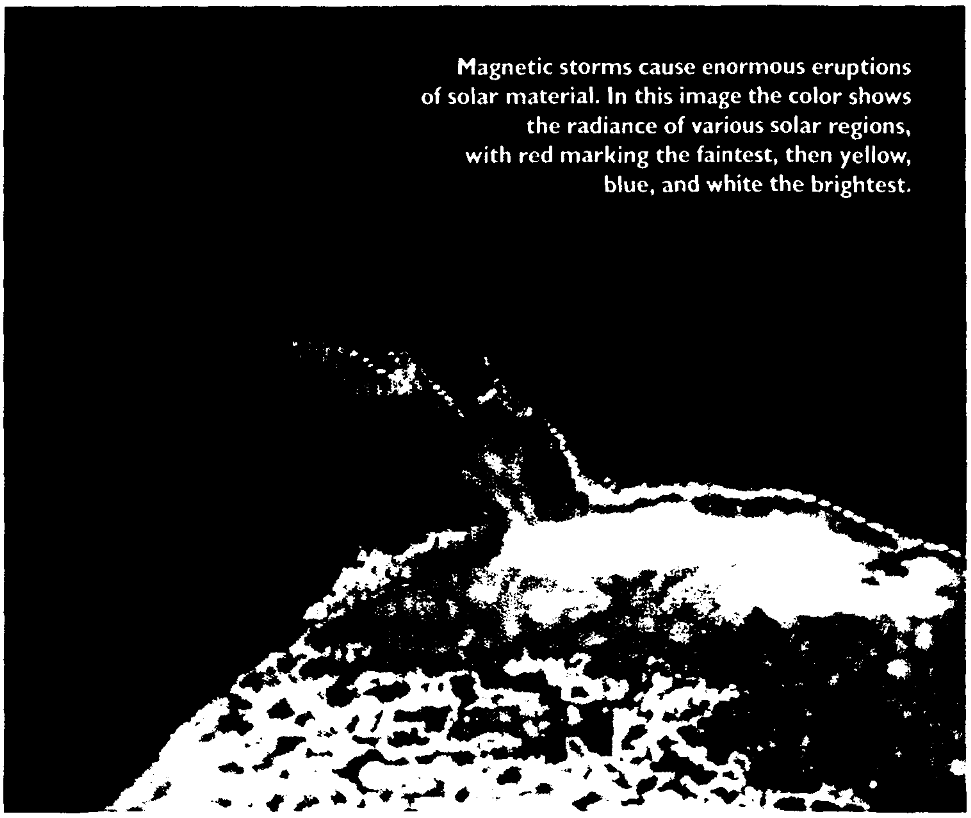
"The first assumption people made," said Baliunas, "was that both satellites were malfunctioning somehow. But it was nearly impossible that they should both be failing in exactly the same way."

The alternative was far more intriguing—that somehow there was a link between magnetic activity and brightness that no one had previously suspected. If this was true for the sun, it could also be true for the sunlike stars Baliunas and her group were studying. The problem was, they were not in any position to confirm this one way or the other; since 1966 the Mount Wilson researchers had been gathering data only on stellar magnetism, and starting over to include brightness readings would be a logistical nightmare.

In 1984, however, Baliunas and her colleagues got word of an observing project at Lowell Observatory outside Flagstaff, Arizona, where, since the mid-sixties, astronomers had been looking at the fluctuating radiance of a number of sunlike stars. Baliunas quickly contacted the Lowell observers to see whether it might benefit both groups to share data.

The Lowell group was interested, but there was a catch: it was studying only 12 stars. What's more, the readings were not terribly precise. To compare magnetism and brightness readings in such a small sample group with such imperfect data would result in misleading conclusions at best. As it happened, however, later that year the Lowell Observatory was scheduled to install new equipment that would allow it to increase both the scope and accuracy of its radiance studies. Once the equipment was on-line, the Lowell team began studying 36 stars from the list Mount Wilson was studying.

At first, of course, the two teams could not draw new conclusions about long-term star cycles; these could be determined only by years of patient observations as star spots slowly appeared and vanished. But the researchers could begin to make inferences by noting short-term changes. Because stars tend to rotate, presenting an always changing face to astronomers peering through telescopes, and because spots are scattered unevenly across the stellar surface, Baliunas and her colleagues reasoned that magnetic activity—and, presumably, radiance—should be seen to vary with the distribution of the storms.



Magnetic storms cause enormous eruptions of solar material. In this image the color shows the radiance of various solar regions, with red marking the faintest, then yellow, blue, and white the brightest.

PHOTOGRAPH BY NASA/SCIENCE SOURCE/PHOTO RESEARCHERS

Indeed, the Lowell and Mount Wilson teams discovered that as the stars rotated and their magnetic readings rose or fell their radiance readings changed in almost perfect lockstep. Over the next few years, these patterns would continue as the stars in the sample group underwent their more pronounced, cyclical changes. "There had been a few hints of this in scattered observations by others in the past," Baliunas says, "and there was even a little evidence of it in my thesis. But now the link was finally coming together."

In some cases, however, things weren't so tidy. Of the stars surveyed by Mount Wilson since 1966, one-fourth appeared to have no discernible cycles at all. In those bodies magnetic activity remained at a fixed intensity, far below the average of the other sunlike stars. When the Lowell team got in on the game, they detected similarly low radiance in the same bodies. The cause of the quiescence was not immediately apparent, but the answer, Baliunas believed, might once again be found in an analogy to our sun.

In addition to its 11-year cycles, the sun is also known to go through far more intense cycles, lasting many decades, during which sunspot activity rises to even higher maximums and falls to even lower minimums. The first evidence of this phenomenon was gathered in the nineteenth century by astronomer Walter Maunder. Consulting astronomical records dating back hundreds of years, Maunder discovered that between 1645 and 1715 sunspot activity was at a virtual standstill. After this decades-long dormancy, sunspot activity entered a phase of about a century during which it rose to a frenzied peak and then started to fall again. The 11-year cycles played themselves out within this longer, higher spike.

Other historical periods of extraordinarily high and low sunspot activity were soon found, including some dramatic lows in the thirteenth and fifteenth centuries, and still others stretching back through the millennia. Such periods are now collectively known as Maunder minima, and they seem to offer a good explanation for the tranquil stars the Mount Wilson and Lowell teams observed.

The discovery of apparent Maunder minima in distant stars was a breakthrough not only for these researchers but for solar astronomers in general. "We were able to make what I think was a reasonable assumption," Baliunas says, "and conclude, 'If the sun is typical in these important ways, it's probably not atypical in other ways.' " This meant that it was at last possible to study our local star with real confidence that it could serve as a good model for the billions of other members of its stellar class.

By itself, this deduction would have

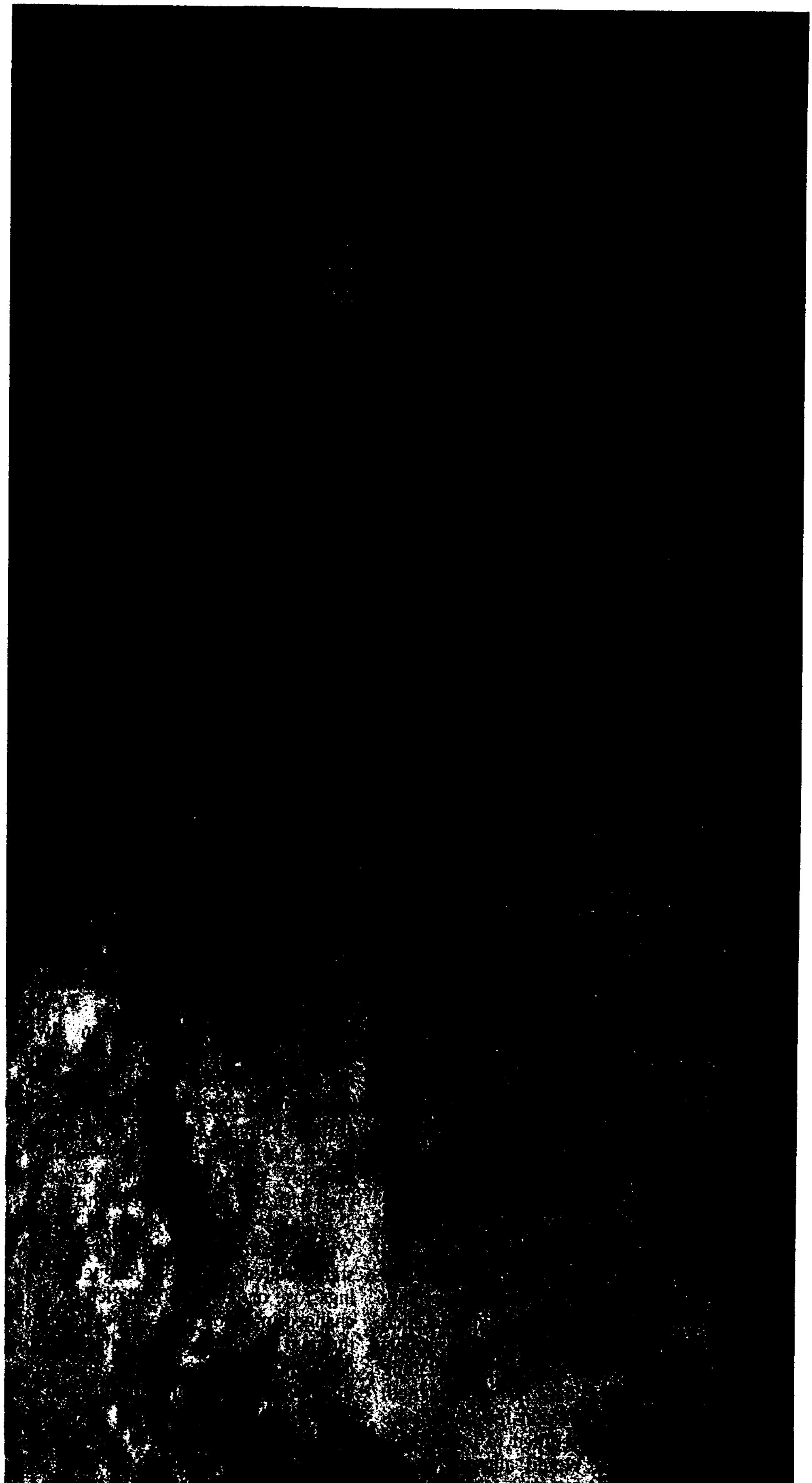
been enough to earn Baliunas kudos—and, indeed, it was enough to earn her the 1988 observing prize. But the research took Baliunas in other directions as well. If we know that magnetic fluctuations are associated with changes in radiance, she wondered, is it possible that these solar cycles could affect the climate here on Earth?

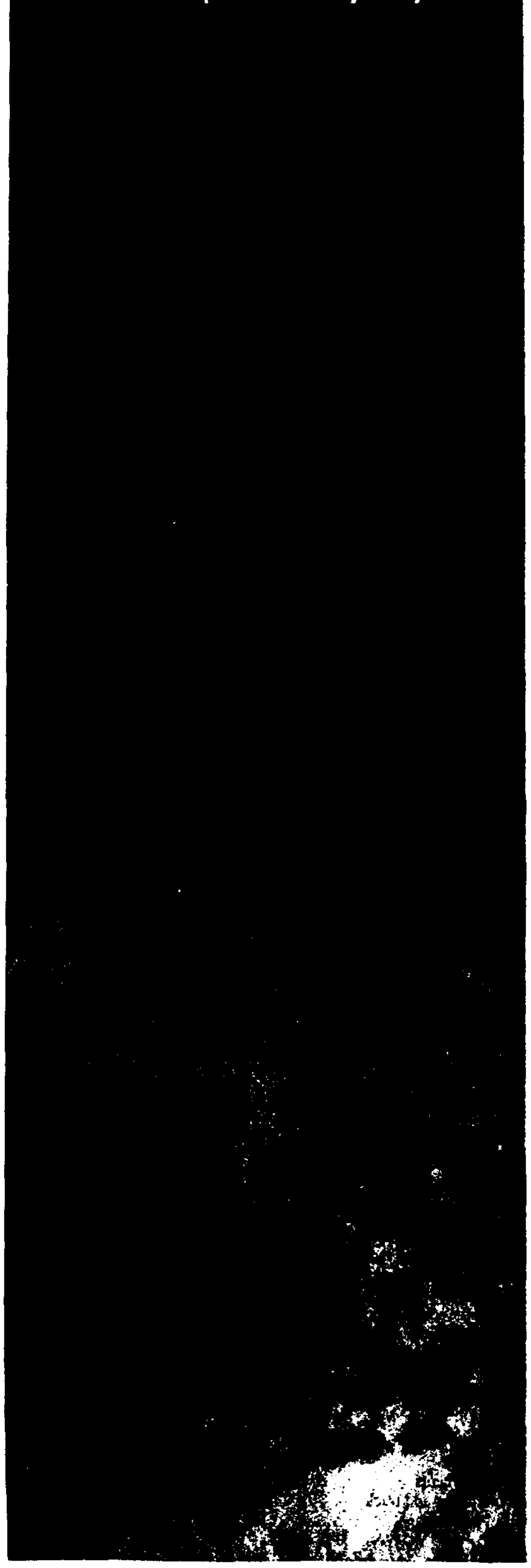
As far as the 11-year cycles are concerned, Baliunas knew that the answer was probably no; the changes in solar radiance were likely too subtle to be felt on a planet so far away from its mother star. The long-term cycles, however, would be another matter. These more dramatic fluctuations, says Baliunas, could produce a significant temperature change on Earth. Indeed, she says, exactly that effect can be found.

In the seventies, Jack Eddy, a researcher at the High Altitude Observatory in Boulder, noticed that Maunder's 70-year minimum corresponded directly with a period that has become known as the little ice age. In the second half of the seventeenth century Europe experienced a stretch of cold so unusual that growing seasons were drastically shortened and in winters the Thames River and the Venetian canals froze over. Baliunas's studies suggested that the magnetism-radiance link might be responsible. More important, she thought she knew a way to prove it.

Earth is constantly bathed by cosmic rays—fast-moving charged particles zooming toward us from somewhere out in the Milky Way galaxy. When the particles strike the atmosphere, they collide with carbon atoms and convert them to radioactive carbon-14. These isotopes then percolate down through the atmosphere, are absorbed by leaves of plants and trees during photosynthesis, and wind up in their shoots and trunks. When solar magnetism is high, the sun's magnetic field grows and begins to deflect cosmic rays away from Earth; this lowers the carbon-14 count. When solar magnetic activity is low, carbon-14 rises. By measuring levels of this isotope in tree rings, researchers can calculate how much protection the sun afforded at different eras.

"The technique isn't sensitive enough to detect the eleven-year cycle," says Baliunas, "because it can take decades for carbon-14 to percolate down and enter growing plants, and the year-to-year variations get smoothed out. But





Solar flares increase in proportion to the number of sunspots. This photo was taken during the solar maximum of 1969, when the sun was at a peak in its 11-year cycle.

PHOTOGRAPH COURTESY NASA

for longer cycles, the trees tell a lot."

Studying tree-ring data compiled by paleontologists from the University of Arizona and the University of Washington, Baliunas saw that the sun has indeed had periods of very high and very low magnetic activity extending back at least as far as the 10,000-year ring records go. She found that cycles like the one Maunder discovered appeared again and again, with an average 70-year low followed by highs that typically lasted for 200 years. She also noticed more dramatic 2,500-year cycles during which solar magnetism climbs even higher.

Baliunas's next step was to consult the agricultural record to see whether these periods of greater activity resulted in greater growth of vegetation—a direct measure of increased global warmth. To her delight, she found that they did. Time and again, ancient harvest records revealed crops being grown farther and farther north during the periods of higher solar radiance.

"Back in the eleventh century," Baliunas says, "the tree rings tell us that there was a period of high sunspot activity. And during that time, history records that vineyards were planted all over England and corn was grown farther north than usual." Botanical fossils and preserved pollen grains show that this pattern also held sway during the thousands of years before the written human record. Baliunas does not believe it would have taken much to trigger all this growth: a global temperature increase of less than two degrees would have given rise to milder winters, hotter summers, and higher ocean levels.

Dramatic as such a wholesale climate change seems, in the twentieth century it is just what we have come to expect: it is the scenario environmentalists have said would unfold as greenhouse gases accumulate in the atmosphere and trap the sun's heat. Fifty years of slowly rising temperatures culminating in a decade of record-breaking heat have convinced many people that greenhouse warming is now under way. But Baliunas's research has shown that we may now be near a peak in one of the sun's 200-year hot spells, making her wonder whether increasing solar radiance may not be at least partly responsible.

"The computer climate models that calculate greenhouse warming always assume that the sun's radiance will remain constant," she says. "But if solar radiance really does fluctuate as much as it appears to, it may well be partially responsible for the warming trend. If magnetic activity continues to increase as we go into a period of greenhouse warming, the warming could be even worse than the models suggest. Conversely, if we begin to enter a Maunder minimum, the decreased magnetism could counteract the effect of some of the greenhouse gases."

So far, Baliunas believes the latter, cooler scenario is the likelier one. About 1800 the sun entered a brief period of low sunspot activity lasting up to 40 years; many observers believe this was a mild Maunder minimum that simply showed up a century early. If that is the case, then the next Maunder minimum could occur in the early part of the next century. If that 40-year ebb was not part of the Maunder cycle, then we haven't had a minimum since 1715 and we're long overdue. Either way, things could be cooling off soon.

Of course, all this is still only theory. To refine her predictions, Baliunas is continuing her observations in hopes of capturing her stars in all their various cycles. Meanwhile, her research is stirring interest in other astronomical camps as well. Recently, Baliunas began using magnetic readings to determine not just the cycles of sunlike stars but also their precise ages. The findings will help NASA in its effort to look for theoretical solar systems where theoretical life-forms might be sending out radio signals.

"You don't want to pick a star that's too young, where planetary life would not have advanced very far," Baliunas says. "One-celled bacteria would not be sending out radio signals."

This work, plus Baliunas's other existing projects, keeps her constantly on the go. In her office for a brief stop recently, she pauses to take a telephone call from a colleague wanting to know whether she'll be at an upcoming conference in Seattle. "I'd like to," she says, "but I already promised to be at the American Geophysical Society meeting to give a talk. Nowadays, I find I have a lot more conflicts than ever." One of the most complex orbits in space science just got a little more complicated. ❑

Sam Flamsteed wrote about astronomer Tony Tyson's search for the edge of the universe in the July issue.