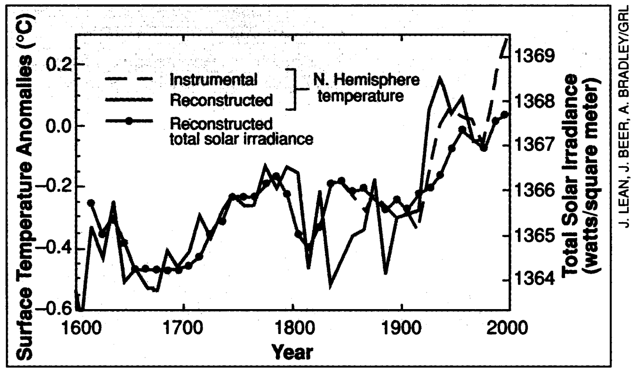


Eerie likeness. Global temperature records closely trace a reconstruction of the sun's brightness over the past 400 years.

each ocean basin, and that higher latitudes cool instead of warm as the sun brightens. Says White, "These patterns look a heck of a lot like the patterns for El Niño," a periodic interaction of the equatorial ocean and atmosphere that heats the eastern tropical Pacific and alters climate worldwide. That suggests to him that "the same physics that accelerates the El Niño on time scales of 4 to 7 years seems to operate here to intensify the solar signal on the decadal scale."

Another such amplifier may help the sun shape climate over the longer term as well. At least that's an implication of recent comparisons between the sun's inferred behavior over the past 400 years and long-term temperature records. Estimating long-term solar brightness changes is even harder than reconstructing 11-year cycles, as Lean and Foukal did in their study, because the satellite records give no hint of century-scale variations. So Lean and her colleagues Juerg Beer of the Swiss Federal Institute for Environmental Science and Technology and Raymond Bradley of the University of Massachusetts sought clues in the behavior of other, sunlike stars.

Astronomer Sallie L. Baliunas of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, had identified two classes of sunlike stars: those that, based on brightness variations at two near-ultraviolet wavelengths, seem to have sunspot cycles like the present-day sun's, and those that do not (*Science*, 26 November 1993, p. 1372). The noncyclers, Baliunas proposed, resemble the sun 300 years ago, during the so-called Maunder minimum, when sunspots disappeared from the face of the sun for decades and Earth was locked in a prolonged cold period. And because those ultraviolet wavelengths are also a measure of faculae in the present-day sun, Lean and her colleagues were able to estimate the abundance of faculae on noncycling stars. From that figure, they inferred that the sun was 0.25% dimmer in its own quiescent period 300 years ago.

The group then relied on sunspot records to reconstruct the sun's irregular brightening in the following centuries. Comparing the reconstruction with a long Northern Hemisphere temperature record, Lean's group found a strong correlation between the shape of the two records. Between 1610 and 1800, before industrial emissions of greenhouse gases could have affected climate, the records track each other so closely that fully three-quarters of the warming after the Little Ice Age of the late 1600s could have been driven by the brightening sun, according to the group. Later, the sun could have driven about half the 0.55°C warming seen since 1860 but only about one third of the warming since 1970, with the remainder possibly being greenhouse warming. Paleoclimatologist Thomas Crowley and Kwang-Yul Kim of Texas A&M recently compared two long temperature records and two irradiance reconstructions, including the pair used by Lean, and reached similar conclusions.

Lean notes that her reconstruction of the sun's long-term behavior has plenty of uncertainties. But if the sun did indeed play a large role in recent climate warming, the greenhouse gases that have been pouring into the atmosphere in the same period must have had a smaller influence than most climate modelers have thought. And that would imply that future greenhouse-gas increases may heat the climate less than predicted—perhaps 20% less, Crowley guesses.

Climatologist T.M.L. Wigley of the National Center for Atmospheric Research in Boulder, Colorado, isn't ready to amend the greenhouse models, however. Wigley, who has traced solar influences on climate himself, says Lean's "qualitative conclusions, I think, are right." But he wouldn't give the sun as big a role in the warming of the last century. "I think it's probably somewhere between 10% and 30% of the past warming." For the sun's slight brightening to rival the influence of burgeoning greenhouse gases, Wigley says, Earth's climate would have to have "a big difference in [climate] sensitivity according to the character of the forcing"—something even the most sophisticated computer models don't show.

Others, however, are prepared for the sun to surprise them again. "In this business, observations drive theory," says climate modeler David Rind of the Goddard Institute for Space Studies in New York City. "So if it turns out that somehow the climate system has within itself the capability of amplifying [solar] forcings, maybe the theoreticians and modelers, myself included, will be the last ones to find that out."

–Richard A. Kerr

Additional Reading

T. J. Crowley and K.-Y. Kim, "Comparison of proxy records of climate change and solar forcing," *Geophysical Res. Lett.* **23**, 359 (1996).

PHYSICS

Oil-Drop Trap Is Set for a Lone Quark

Throughout 1995, there was a steady drip in the corner of a graduate student office at the Stanford Linear Accelerator Center (SLAC). No one called the plumbers, however, because physicists hoped the leak would reveal a hole in their current ideas about matter. So far, their theories have remained watertight, but the Stanford University group is still hoping that it might find some gaps when the drip starts up again later this year.

The drip consists of tiny droplets of silicone oil, about 7 micrometers in diameter, falling languidly between two electrically charged plates while a charge-coupled device video camera records their movements. The rate at which each drop falls through the varying electric field indicates the charge it carries. It's the same principle that Robert Millikan applied 85 years ago in his classic measurement of the charge of a single electron. This time, however, investigators led by Martin Perl, co-recipient of the 1995 Nobel Prize in physics, are hoping to find a droplet bearing a still smaller morsel of charge—the amount that a quark, one of the fundamental particles that make up protons and neutrons, would carry on its own.

No free quarks were spotted in the first round of this experiment, which concluded late last year after examining a milligram of silicone oil. The results were not surprising. Indeed, they're precisely what quantum chromodynamics (QCD), the theory of the strong force that binds quarks, predicts: It holds that these particles can only exist in groups, like the trios that form protons and neutrons. But far from being discouraged, Perl and his Stanford colleagues—Nancy Mar, Eric Lee, and Edward Garwin—are now rebuilding the apparatus for a faster and more extensive search.

The effort is a "very long shot," concedes Perl, but the case against free quarks is "mainly a reflection of the experimental data." Conceivably, he says, there are still some lone quarks, born in the early universe, that withstood peer pressure to join a quark triplet or quark-antiquark pair. "A positive finding would overturn 30 years of our thinking about strong interactions," Perl adds. "Present QCD would be like Newtonian mechanics—accurate for just about everything we see, but breaking down in certain cases."

It's worth the trouble to look, agrees Los

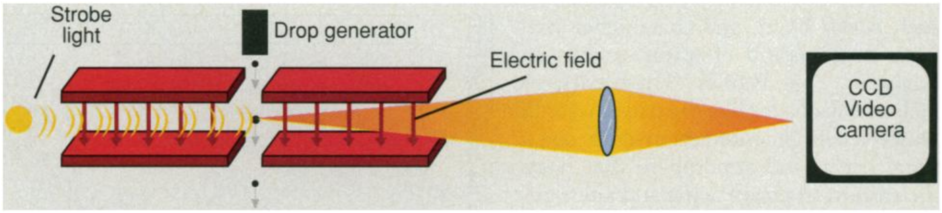
Alamos physicist George Zweig: "Every theory needs to be checked out thoroughly. Compared to general relativity, which has been tested over and over again, QCD is relatively untested." Still, the prospect of a payoff is so small that "a younger scientist trying to make a reputation would be well-advised to avoid this line of work," says Roger Bland, a physicist at San Francisco State University who has conducted quark searches himself.

Searches for free quarks got under way soon after Murray Gell-Mann and Zweig published papers in 1964 independently proposing the quark model. On the off chance that an unconfined quark could somehow have survived the cooling since the big bang, either attached to an atom or flying through space on its own, investigators have employed a number of methods—the oil-drop technique, magnetic levitation, particle accelerator experiments, and cosmic ray searches—and combed through materials ranging from metals to moon dust and even oysters. All these efforts have turned up empty-handed, save for a Stanford project headed by William Fairbank, who claimed in the late 1970s and early 1980s to have found evidence of fractional electric charge in niobium spheres—results that were never substantiated.

Every other research group except for Perl's has since called off the search. Bland's team quit a decade ago for the same basic reasons others have given up: the lack of positive results and the lack of funding. "Not finding anything means you either have to search more matter or search in a very clever way in just the right places," Bland says. "We didn't know where to look, nor did we see a way of measuring much more than a few milligrams of matter with our technique."

Perl and his collaborators have improved the oil-drop method used by Bland's group, making the droppers more reliable, automating the measurement process, and reducing measurement error to a fortieth of the charge of an electron—the best charge resolution ever achieved in such experiments. When the SLAC team conducts its second run later this year, these and other modifications should enable them to examine 100 times more material than has ever been sifted through before, at a cost of a few tens of thousands of dollars a year.

Perl and company are no further along than their predecessors are in determining the right places to look for free quarks, however. Perl suspects that metallic substances like mercury may offer the best prospects, as unbalanced charges tend to be attracted to metal surfaces. He also thinks that primordial solar-system material might be a good hunting ground, which means looking at meteorites. For now, though, "we're working with silicone oil because it's easy and we know how to do it," Perl says. After establishing the methodology with silicone oil, he plans to check out other candidate materials.



Slow leak. The speed at which droplets of silicone oil fall through a changing electric field reveals any unbalanced charge—including the fractional charge that would signal a free quark.

"It takes a certain type of personality to pursue projects with such a low chance of success and little glory if you don't find anything," Zweig notes. Yet Perl, as a tenured Nobel laureate, has the "luxury" of continuing the search. "I like the technique, and I like watching the experiment run and improve," he says, adding that he means to quit before he becomes obsessed—within 3 or 4 years at most. He still holds out some hope that free quarks exist and that his group might be lucky enough to find some. "Life is easier for theorists if there are no free quarks," he says. "But it's more interesting if there are, because that means there's more work for all of us to do."

–Steve Nadis

Steve Nadis is a writer living in Cambridge, Massachusetts.

BIODIVERSITY

Focal Species Offer Management Tool

BRISBANE, AUSTRALIA—Patches of untouched vegetation are scarce in this vast country, where the rural landscape is dominated by a mosaic of cropland and pastures. But these patches are prized by conservationists because they often provide the only suitable habitat for a significant number of endangered plants and animals. Unfortunately, it's not always clear how to rebuild this highly degraded and impoverished landscape and to stem the rates of extinction. And because the land is not public, preservation efforts must also benefit the farmers that own it.

Enter Robert Lambeck. An ecologist for the Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Wildlife and Ecology, Western Australia, Lambeck has adopted an approach that makes the very complexity of the problem part of the solution. Rather than focusing on what's needed to protect a single species, say the spotted owl in North America or the Australian numbat, a banded anteater, Lambeck has begun to gather data on a range of "focal" species to help define the attributes of a viable landscape. Once that landscape is defined, scientists and public officials can work with private landowners to preserve both biodiversity and the value of the enterprise.

Ecologists find the notion an attractive one. "The main value of his model is that it helps break the single-species mindset of Australian ecologists," says ecologist David Goldney from Charles Stuart University, New South Wales. And Dan Simberloff, a leading conservation biologist from Florida State University in Tallahassee, says the idea may actually work. Species sometimes have conflicting requirements that make it hard to form a single conservation plan for a single habitat, he says, citing the "nasty" legal battles over water-level regulation in the South Florida Everglades based on the differing needs of two endangered species, the snail kite and the wood stork.

Imperiled patch. This mix of wheat fields, grazing lands, and nature reserve in western Australia highlights the need for a unified approach to biodiversity.

Lambeck, who presented his model at a conference here last month,* hails from southwestern Australia, where wheat fields dominate the landscape. Thirty percent of the native mammals are extinct, populations are declining in half of the bird species, and 24 plant species have disappeared from the wheat belt.

To conserve as many species as possible, conservationists would prefer to set aside large tracts of pristine land. Unfortunately,

* "Conservation Outside Nature Reserves," 2 to 5 February, University of Queensland.