^{3}He Tells Death Knells from the Seafloor

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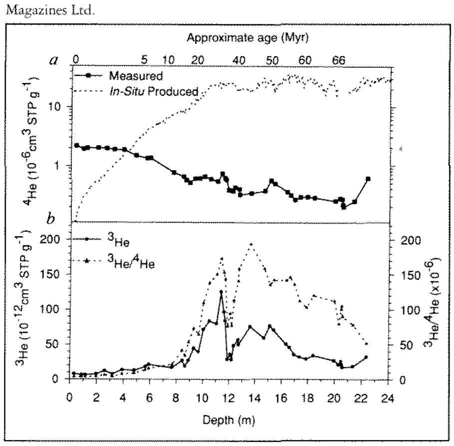
If you can write your name in the dust on top of your piano, it's not your sloppy housekeeping that's to blame, but the fact that you're engaged in an unequal struggle with the universe. Every year, some 40,000 metric tons of interplanetary dust rains down on us—from the tails of Earth-crossing comets, from asteroids grinding against one another, from Heaven knows what. Not all of this goes straight to your living room, of course—most of it falls in the ocean and eventually settles to the bottom. Now Assistant Professor of Geochemistry Ken Farley has found a way to measure the amount of extraterrestrial dust in seafloor sediments, and has discovered that it has varied by a factor of 10 over the last 70 million years.

Furthermore, the highest dust concentrations correspond with epoch-ending extinctions. There's a dust spike 66 million years ago at the end of the Cretaceous period—the so-called K/T boundary—when most scientists agree that an object nearly the diameter of the city of San Francisco walloped Earth and nuked the dinosaurs. But the most dramatic leap occurs near the end of the Eocene. The dust flux nearly triples in the interval between 37.6 and 36.3 million years ago—a twinkling, in geologic time—and remains elevated for several million years thereafter. The Eocene ended with a major (the biggest since the death of the dinos), but gradual, extinction, notes Farley. "It's not like the K/T boundary, where everyone's happy one day and dead the next." The dust date coincides with the age of several layers of tektites—glassy blobs believed to be melted ejecta from meteorite impacts—found around the world. The lingering dust cloud and the multiple tektite layers suggest that Earth was hit by a flurry of dusty objects, possibly a comet shower, over an extended period. (This could happen if a comet whose orbit crosses Earth's began to disintegrate, leaving a thick trail of debris. As Earth swept along its orbit like a dust cloth, it could cross this trail millions of times, but it wouldn't collect a tektite layer until it had the bad fortune to run into one of the larger pieces.) The two million years leading up to the present are also very dusty, and—perhaps not coincidentally, Farley thinks—have been an era of extensive glaciation.

Farley's samples come from a core pulled from the seabed some 1,100



The graph's top panel shows the measured concentration of ^{4}He (solid line), in millionths of a cubic centimeter of gas at 25° C and one atmosphere of pressure per gram of sediment, compared with the amount expected to be produced (dotted line) based on the sediments' ages and their uranium and thorium contents.

The bottom panel shows the concentration of ^{3}He (solid line), in *trillionths* of a cubic centimeter of gas at 25° C and one atmosphere of pressure per gram of sediment, along the left vertical axis. The right vertical axis shows the number of ^{3}He atoms per million ^{4}He atoms (dotted line). In both plots, the analytical uncertainty is smaller than the symbols.

kilometers north of Honolulu—as far from the continents as you can get—in order to minimize the amount of terrestrial sediment. The core was taken by a Woods Hole Oceanographic Institution team with a piston corer—"it's like sticking a soda straw into pudding, then pulling the straw back up," Farley explains—and consists of very fine clay, reminiscent of talcum powder, laid down so painfully slowly that 20 meters' worth spans 70 million years. Even so, most of the material is homegrown. Farley estimates that only a few particles per million are outlanders.

You can't tell the space aliens from the locals by looking at them, but the spacefarers have been tattooed with exotic helium-3 nuclei. Helium comes in two varieties: ^{3}He comes primarily from the hydrogen-fusion reactions that power the sun; ^{4}He, which is heavier by one neutron, is created by the radioactive decay of uranium and thorium. Most of Earth's original stock of helium has been lost back to space over the last 4.5 billion years, and since the world isn't fusion-powered, what little helium we have now comes almost exclusively from decaying elements in the planet's crust. (There are a million atoms of ^{4}He for every atom of ^{3}He in the air.) But beyond our atmosphere, the ^{3}He-rich solar wind bombards interplanetary dust with such ferocity that ^{3}He nuclei lodge in the particles' skin. The dust also has trapped "primordial" ^{3}He—remnants of the gas from which the solar system formed. Thus, measuring the ^{3}He reveals the amount of space dust in the sample. And, assuming the sedimentation rate is known, you can deduce the rate at which Earth wiped up the stuff.

In principle, analyzing a core is a straightforward application of a standard lab technique. The extracted helium is ionized in a mass spectrometer, which sorts the ions by shooting them through a magnetic field. The lighter $^3He^+$ nuclei get pulled farther off course and emerge from the field at a very different angle than their pudgier brethren. But extraction entails cooking the sample at 1100° C to melt the minerals that carry the helium, which also breaks down calcium carbonate—the vast bulk of many sediments—to calcium oxide and a huge exhalation of carbon dioxide. And if gas molecules and helium ions ricochet off one another willy-nilly in the mass spectrometer, the ions emerge from the magnetic field in random directions. So the system has two cold traps to freeze out the carbon dioxide, and arrays of filters and chemical scavengers to remove other gases, before the sample reaches the instrument. Then there's the mathematics. The terrestrial ^{3}He component has to be subtracted out—small amounts of it are produced as byproducts of some radioactive decay processes. And the sedimentation rate really *isn't* constant, because the core site has traveled thousands of miles in 70 million years—from the East Pacific Rise, some thousand kilometers south-southeast of Acapulco, to its current Hawaiian address. As the site passes under various ocean currents, and as its distance from land changes, the sedimentation rate varies. So Farley uses oceanographers' estimates of the changing sedimentation rates en route, to adjust the calculations.

Although this core was taken in the early 1970s and has since been "studied to death," Farley says, no one had ever tried to use ^{3}He as an alien-dust tracer. Helium is such an accomplished escape artist that it wasn't expected to have lingered long—it diffuses through almost everything, according to Farley. In fact, "you can't use ordinary Pyrex vacuum lines to analyze it, because it just blows right through the walls." So within 10 million years at most after the splashdown of an alien dust mote, all its ^{3}He should have snuck away and any helium found in the samples would be from the decay of radioactive elements in the sediment. In fact, Farley originally started these experiments to prove exactly that. He expected that the older samples from lower in the core would contain decreasing amounts of ^{3}He in a smoothly diminishing curve, while containing increasing amounts of ^{4}He as decay products accumulated. Instead, the ^{4}He content declined as the samples got older, and both the absolute abundance of ^{3}He and the ratio of ^{3}He to ^{4}He varied in sync with each other. "So these results are real," says Farley. "They can't be a loss phenomenon."

The cores don't preserve short-term

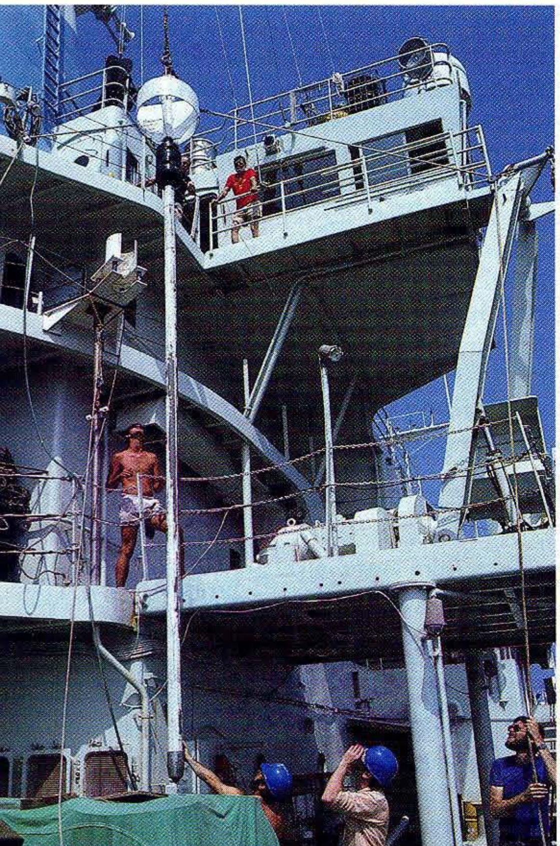


Photo by T. Kleindinst

Left: A piston-coring rig at sea.
Right: The core library at Woods Hole. The core sections on the table in the foreground aren't really curved, but have been distorted by the camera lens.
Photos courtesy of the Woods Hole Oceanographic Institution.

dribbles and spurts in the dust flux because marine worms, which have been around for longer than the cores are deep, constantly churn through the sediment's top 20 or so centimeters as it's deposited. In this case, 20 centimeters represents up to 900,000 years, so the Hawaiian core has a very low time resolution. But in locales where sedimentation is faster, 20 centimeters is a smaller slice of time. In principle, says Farley, such high-resolution cores might show details as fine as 900 years. But faster sedimentation means fewer foreign particles per unit volume, so getting enough dust to analyze requires larger samples, which means that much more gas to cope with. So the researchers are working on cleverer ways of extracting the helium.

Farley and postdoc Desmond Patterson are now looking at a core from the North Atlantic, where sediment accumulates 100–1,000 times faster. The preliminary results, just presented at the International Astronomical Union's Conference on Interplanetary Dust, are from samples spanning 240,000 to 440,000 years ago at 20,000-year intervals. The dust rate seems to fluctuate in correlation with a pronounced glacial cycle that recurs every 100,000 years. Most of the glacial cycles are known to derive from changes in Earth's orbit that modulate the amount of sunlight we receive, but the 100,000-year cycle cannot be so easily explained.

But before cosmic dust can be linked to climate change, cores from sites around the world need to be examined. (Fortunately, the international Ocean Drilling Program, which provided the North Atlantic core, has been circumnavigating the planet since 1968.) If all the cores display a similar pattern, then there's truly a global effect; if they don't, then the cores are recording the influence of winds, currents, or other factors on the dust's local accumulation rate.

Farley plans to run both the high- and low-resolution records further back in time. He hopes to survey the last million years at high resolution, because, in geologic terms, 200,000 years is nothing—the 100,000-year cycle, for instance, only appears twice in the current data, and who knows what slower cycles remain to be discovered? And there's no telling how far back the low-resolution technique can be pushed before the ^{3}He peters out. All the other known extraterrestrial tracers, such as iridium, record the impacts of large bodies—rare events with spectacular consequences. But this incessant drizzle of dust, while admittedly less dramatic, may be more important in the short term as a herald of climate change. Are we on the brink of another Ice Age? There may be a way to find out. ☐ *—DS*

It's the Dawn of a New Sunspot Cycle

The first sunspot in the new sunspot cycle was identified on Saturday, August 12, by Professor of Astrophysics Harold Zirin and colleagues at Caltech's Big Bear Solar Observatory. The new sunspot marks the beginning of the end of the sun's current quiescent period.

Sunspots are relatively dark spots on the sun's surface. They look dark because they're cooler than their surroundings—a balmy 4,000 K in the umbra, or darker central region, compared to the 6,000 K typical of the sun's visible surface, or photosphere. (The sunspot's penumbra, the not-quite-so-dark region surrounding the umbra, generally runs around 5,700 K.) But if you could see a typical midsized sunspot—one whose umbra is about the diameter of Earth—in isolation, it would appear about as big as Saturn currently does in the night sky, yet shine as brightly as 50 full moons.

The solar maximum for this new cycle should occur in the year 2000 or 2001.

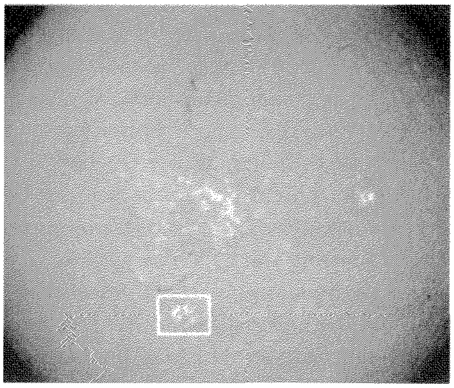
Sunspots are associated with strong magnetic fields and with solar flares, and follow an approximately 11-year cycle of activity, as measured from maxium to maxium or minumum to minimum. Early in the cycle, sunspots appear rarely and at relatively high solar latitudes around 20 to 30 degrees. Thereafter, their points of origin drift toward the solar equator until the end of the cycle, although some spots may still appear at high latitudes. Simultaneously, sunspots increase in size and frequency until they reach "solar maximum." Solar flares and related phenomena also peak in intensity at this point. Then the number of sunspots (and the level of related activity) slowly declines until a relatively quiet phase called solar minimum is reached. The solar maximum for this new cycle should occur in the year 2000 or 2001.

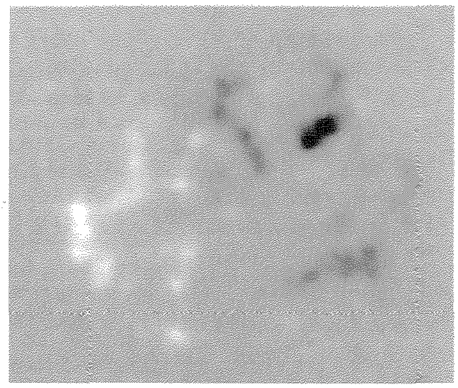
There is typically some overlap between successive sunspot cycles. As the last sunspots of one cycle appear near the equator, at solar latitudes of 0 to 10 degrees, the next cycle starts again with sunspots near 30 degrees. The magnetic polarity of the new spots, however, is reversed—a discovery made by Caltech's George Ellery Hale at the solar telescopes he built atop Mount Wilson, overlooking Pasadena.

The sun has been at solar minimum through much of 1994 and this year, with a few spots showing up near the equator. The new-cycle sunspot group appeared at a solar latitude of 21 degrees, and its magnetic polarity is opposite to that seen over the last decade, thus identifying it as the start of a new cycle—the 23rd since astronomers began keeping track. There were as many as five sunspots in the group, which remained visible for five days. After the sunspots vanished, the magnetically active region, or plage, remained observable until carried from view by the sun's rotation, says chief observer William Marquette. "We watched it for a week and a half, until it disappeared over the sun's west limb as a decaying magnetic structure."

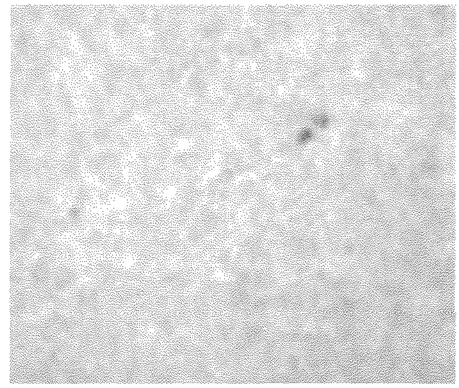
Sunspot polarity is a complex business. Sunspots generally appear in pairs or in larger groups. Each spot maintains its relative position within the pair or group as the sun rotates. The two sunspots in a pair have opposite polarity and polarities within a group are even more complex, so by convention, solar astronomers use the leading spot (called the p-spot, for preceding spot) to determine the group's polarity. And once you cross the sun's equator, the polarties reverse, so if the p-spots are negative in the northern hemisphere, as they are in the waning sunspot cycle, they'll be positive in the southern. The new-cycle sunspot region appeared in the south, and has a negative p-spot. (Negative, in this case, means a south magnetic pole.)

You can't tell a sunspot's polarity just by looking at it. (Kids, don't try this at home!) But when light waves pass through a magnetic field, that portion of the field that's oriented along the waves' direction of travel gives them a little twist—what's called circular polarization. Unpolarized light waves vibrate in all directions perpendicular to their direction of travel. Plane-polarized light waves (the kind that your polarized anti-



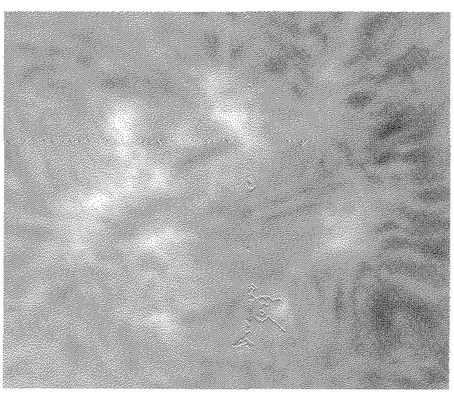


A magnetogram of the boxed area. The sun rotates from left to right in this image, so the leading sunspot is dark, indicating south, magnetic polarity—the opposite of the old cycle.



The same area as seen in visible light. The larger sunspot is approximately 4,000 kilometers in diameter—somewhat bigger than the moon.

Above: The first sunspot region of the new solar cycle is marked with a box in this full-disk image of the sun, taken at the hydrogen-α wavelength on August 16. There are two old-cycle regions along the equator. North is to the top. Below: A close-up of the boxed area, as seen in hydrogen-α light.



These images are available on the World Wide Web at http://sundog.caltech.edu under "First New Solar Cycle Spot." Images courtesy of Anders Johannesson and Bill Marquette, Big Bear Solar Observatory.

glare sunglasses filter out) all vibrate in the same direction—vertically, say. Circularly polarized light waves still vibrate in random directions, but the direction in which they vibrate rotates in unison—either clockwise or counterclockwise—as the wave travels. This effect is so small, however, that it's only observable in monochromatic light—light of a single wavelength. So the observer picks a wavelength of interest—which isn't necessarily one at which hydrogen or helium emits light—and photographs (or, in this day and age, videotapes) the sun through an appropriate filter. By setting the filter slightly to the blue, or shorter-wavelength, side of the observing wavelength, the counterclockwise-polarized component of the light shows up. (Counterclockwise polarization translates to negative polarity, or a south magnetic pole.) Repeating the process with the filter set a bit to the red, or longer-wavelength, side reveals the areas of clockwise polarization. And finally, subtracting the two images from each other gives a magnetogram—an image in which the positive areas appear bright and negative areas appear dark in proportion to the field strength.

This new sunspot appeared a bit earlier than astronomers expected. Typically, as a solar cycle comes to a close, late bursts of sunspot activity will appear near the equator before the new cycle starts. Scientists had seen such late pulses of sunspots in 1972 and 1984, but saw little late activity this time and therefore expected an early beginning to the new cycle, but not this early.

Sunspots have effects far beyond the sun itself, so while solar astronomers are excited by this news, people in many other fields are keenly interested as well. Solar flares often occur above sunspots, spewing high-energy electrons, x-rays, and other particles that slam into Earth's ionosphere, disrupting radio communications, painting the polar skies with the aurora's colorful lights, and sometimes even causing widespread power outages. These high-energy collisions also heat the upper atmosphere, expanding it farther out into space where it can grab hold of low-orbiting satellites and slowly drag them down, or tug on their outstretched solar panels and set them spinning like pinwheels. The sudden onset of the new cycle means that the operators of these satellites may have to use their boosters—if they have any—to loft them into higher orbits out of harm's way, while aging satellites whose fuel reserves are spent will wind up taking a fiery early retirement. And estimates of the useful lifetimes of satellites as yet unlaunched will need to be revised to account for the increased atmospheric drag. □