The Big Chill

Does dust drive Earth's ice ages?

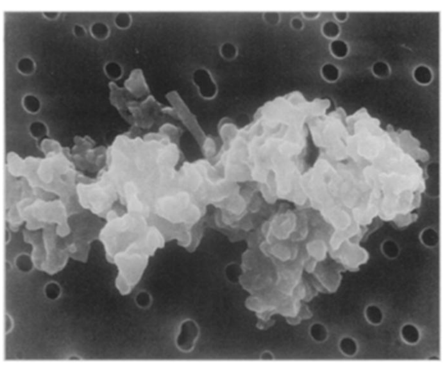
By RICHARD MONASTERSKY

Earlier this year, as millions of people gazed upward to watch Comet Hale-Bopp sail through the heavens, some observers may have caught specks of space dirt in their eyes. More than 40,000 tons of extremely fine extraterrestrial dust rains down on the planet annually, gathering imperceptibly on windowsills, furniture, poodles, people, and every other available object.

In the long run, these interplanetary motes may have profound consequences for Earth and its inhabitants. Two scientists propose, in a radical new theory, that dust from space caused the last 10 ice ages, which have gripped the planet like recurrent cases of the flu over the last million years.

"I suspect that to really understand the climate in general, we're going to have to take into account the presence of

Donald Browlee/Univ. of Washington



An interplanetary dust particle.

this extraterrestrial dust, which right now is being ignored," says Richard A. Muller, a physicist at the University of California, Berkeley who collaborated with Gordon J. MacDonald of the International Institute for Applied Systems Analysis in Laxenburg, Austria.

In proposing their hypothesis, Muller and MacDonald have, in effect, picked a fight with the scientific establishment. The theory challenges the accepted explanation of the ice ages, first proposed by Scotsman James Croll in the late 1800s and then expanded by Serbian mathematician Milutin Milankovitch early in this century. The so-called Milankovitch theory holds that periodic flutters in Earth's orbit drive the ice ages by altering the strength of sunlight hitting the north.

"We have shown there is a very serious problem with Milankovitch. I think it's the most serious challenge that has ever been mounted. It's not easy for them to handle this," says Muller of those who hold to the old model.

Muller's strong rhetoric and his unorthodox views have won few converts among climate scientists who specialize in the ice ages. At the same time, opponents arguing from the standard Milankovitch theory cannot easily dismiss his points. This leaves a major gap in knowledge about both how the climate worked in the past and how it may behave in the future.

The new theory focuses on a climatic conundrum called the 100,000-year problem: Why have the last 10 ice ages struck every 100 millennia or so? Muller and MacDonald claim that the standard theory fails to account for this behavior, whereas extraterrestrial dust does. They present their argument in the July 11 Science.

To understand the disagreement, it's important to go back to 1914, when strife in the Balkans dragged Europe into what would become World War I. Milankovitch, who was held as a prisoner of war by the Austro-Hungarian army that year, escaped from the surrounding chaos by immersing himself in the predictable and stately wiggles of Earth's orbit. He isolated two orbital effects that he thought had a major influence on climate.

The first was the tilt of Earth's rotation axis. Currently 23.5°, the axis bobs toward the vertical and then dips toward the horizontal every 41,000 years. During times of the greatest dip, the amount of sunlight falling on the North and South Poles increases during summer and decreases during winter, causing the seasons to become more extreme.

The second factor, orbital precession, describes the time of year in which Earth comes closest to the sun. Every 23,000 years, the planet's orbit carries it nearest the sun during the Northern Hemisphere's summer solstice, thereby strengthening the sunlight bathing the Arctic.

Milankovitch reasoned that the intensity of summer sunlight hitting the far north is critical to the creation of an ice age. When Earth's orbital cycles conspire to weaken summer sunlight near the Arctic Circle, snow can accumulate from one winter to the next. As the ice sheet spreads, its surface reflects sunlight back into space and cools the climate even further.

In 1976, a trio of oceanographers discovered support for Milankovitch's hypothesis in cores of mud pulled from the seafloor. James Hays and John Imbrie of Columbia University and Nicholas Shackleton of Cambridge University in England measured two oxygen isotopes whose ratio in the ooze reflects the amount of ice on Earth at the time the sediments fell to the ocean floor. This technique enabled them to date the ice ages over the last 500,000 years.

By analyzing the times at which the great ice sheets advanced and retreated, researchers could see hints that Earth's climate was following the beat of several long-term cycles running concurrently. The two most prominent cycles had periods of 41,000 and 23,000 years—the same periods displayed by the variation of orbital tilt and precession. Here at last was evidence supporting Milankovitch's contention that orbital processes played a major role in causing the ice ages.

At the same time, the oceanographers' work pointed out a major problem. In recent ice ages—those occurring in the past million years—the strongest pattern of ice sheet contraction and expansion was one with a period of about 100,000 years, something not anticipated by Milankovitch. Imbrie and his colleagues suggested that the 100,000-year cycle may have arisen from changes in orbital eccentricity, or the amount of distortion of Earth's path around the sun.

Every 100,000 years or so, the orbit varies from completely circular to slightly oval then back to circular. In a round orbit, Earth lies slightly farther, on average, from the sun.

Milankovitch had discounted eccentricity because the variations in the shape of Earth's orbit had a minuscule effect on the amount of sunlight hitting the planet. To explain how such a small flicker can cast such a large shadow, Imbrie and others have hypothesized that the eccentricity changes are somehow amplified by Earth itself. Some factors inherent in the climate must be particularly sensitive to that 100,000-year cycle and enhance it.

Many climate scientists suspect that the amplification stems from the behavior of the largest ice sheets—the time it takes them to grow and decay. The biggest glaciations have occurred only in the last million years, beginning precisely when the 100,000-year cycle kicked in. During earlier times, between 2.5 million and 1 million years ago, the dominant cycles of the ice ages centered on periods of 41,000 and 23,000 years, just as Milankovitch had predicted.

While the more recent ice ages turned out to be more complicated than Milankovitch had envisioned, climate scientists credit his general theory with explaining the timing of the ice ages. "The Milankovitch orbital changes are the pacemaker determining when the large ice sheets grow and decay," says Imbrie, now at Brown University in Providence, R.I.

Muller and MacDonald, however, thought they heard a different drummer setting the rhythm of the ice ages. When the two analyzed the pattern of glaciation for just the last million years, they uncovered something new. By reducing the ice-age variations to a series of frequencies, the scientists found that the dominant 100,000-year cycle was surprisingly exact. It formed a single sharp peak on their graph, with no hint of other frequencies playing a substantial role in the ice ages.

The standard model cannot explain this, they say, because orbital eccentricity varies in a complicated way, involving cycles with periods of 400,000 years and 125,000 years as well as the one close to 100,000. If eccentricity changes were driving the ice ages, all three separate beats should echo through the ice ages, but they do not.

While examining astronomical records, Muller happened on a different cycle that matched exclusively the 100,000-year pattern. The plane of Earth's orbit, he found, tilts gently with respect to the orbits of the other planets every 100,000 years. At times, Earth's orbit around the sun lines up with the plane of the solar system. At other times, Earth travels in a cockeyed orbit, its plane inclined 2.5°.

Muller and MacDonald surmise that when Earth's orbit reaches a certain plane, the planet plows through an extra-thick cloud of interplanetary dust. These small particles drift through the upper atmosphere and set in motion a series of climatic effects, perhaps blocking out sunlight, stimulating cloud growth, or weakening Earth's ozone layer. Such factors cool the planet enough to produce an ice age. Later, as the planet's orbit pulls out of the dust, the climate warms enough to fight back the ice.

Records of extraterrestrial dust offer some support for this hypothesis. Kenneth A. Farley of the California Institute of Technology in Pasadena has measured the variations in helium-3—a tracer for extraterrestrial dust—in seafloor sediments. His studies show that helium-3 values swing up and down over a 100,000-year-long cycle, as Muller and MacDonald predict.

What's more, the amount of helium-3 increased markedly between 2 million and 1 million years ago. This may explain why the 100,000-year climate cycle did not dominate before then, says Farley.

One interpretation of these findings is that large asteroids collided around a million years ago, creating a rich supply of dust that filled the inner solar system. Prior to that time, the ice ages were governed by the regular Milankovitch factors of orbital tilt and precession. When the dust appeared, it overwhelmed the other factors, making ice ages larger and longer.

The dust data do not totally support Muller and MacDonald's idea, however. "These variations in dust amount are quite small; at most, they go up and down by a factor of 3 to 5. I'm skeptical that such variations could change the climate. We're only looking at a little bit of extraterrestrial dust," says Farley.

Even more troubling is the question of how the dust alters climate. While Muller and MacDonald have general ideas, they lack a solid hypothesis to explain how adding dust to the upper atmosphere could plunge the planet into an ice age. "That is what we're most severely criticized for. We do a lot of hand waving at this point. There are many possibilities, but we don't have a good mechanism," says Muller.

When Muller and MacDonald came up with their dust theory in 1993, they had a hard time getting climate scientists to listen. Last year, Wallace S. Broecker of the Lamont-Doherty Earth Observatory in Palisades, N.Y., invited Muller to present his case to the top researchers interested in the ice ages. Broecker dubbed the meeting the "Mullerfest," and the discussions continued for weeks via E-mail.

Muller scored the most points at the meeting when he attacked a standard technique, called tuning, that oceanographers use for dating layers in sediment cores. The task of dating these strata is difficult because sediments may accumulate more quickly during some eras and more slowly in others. To tell the age of layers between known benchmarks, researchers often use the Milankovitch orbital cycles to tune the sediment record: They assume that ice volume should vary with the orbital cycles, then line up the wiggles in the sediment record with ups and downs in the astronomical record.

"This whole tuning procedure, which is used extensively, has elements of circular reasoning in it," says Muller. He argues that tuning can artificially make the sediment record support the Milankovitch theory.

Muller's criticisms hit home with many researchers. "He scared the hell out of them, and they deserved it," says Broecker.

Oceanographers soon rose to the challenge. In the August PALEOCEANOGRAPHY, Maureen E. Raymo of the Massachusetts Institute of Technology presents an untuned sediment record that corroborates the ice age dates determined by tuning.

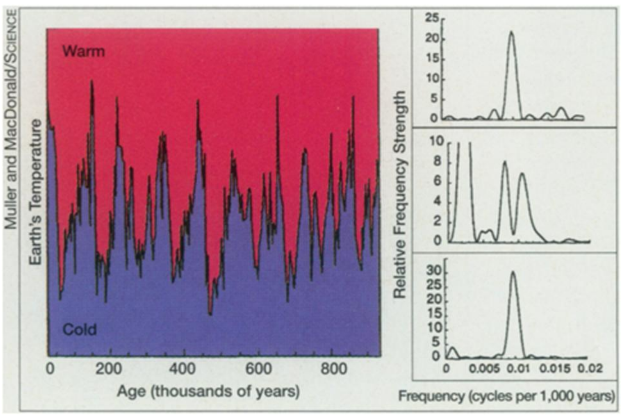
To get at the causes of the ice ages, Raymo takes a different approach. Instead of doing frequency analysis to pick out the cycles in the record, she looks at the actual timing of the ice ages: their beginnings, endings, and the intervals between each. She finds that ice ages don't come like clockwork every 100,000 years. Instead, they seem to hit sporadically, sometimes ending 85,000 years apart, other times 125,000 years apart.

What is consistent is that the ice ages almost always end when Milankovitch's orbital cycles combine to warm the northern lands during summertime, as the mathematician hypothesized 80 years ago.

Still, nobody can explain satisfactorily how Earth's climate amplifies the changes in sunlight to drive the ice ages of the last million years. Until the theory is complete, it leaves the door open to challengers.

"It's not clear what is causing this cycle in the last million years. I would say it is one of the great puzzles of earth sciences," says George H. Denton, a glacial geologist at the University of Maine in Orono.

Most climate researchers do not think that extraterrestrial dust will provide the answer, but Imbrie, a longtime supporter of the Milankovitch hypothesis, says that Muller and MacDonald's concept may have some merit. It is possible that Earth's climate could respond to the unsteady orbital plane as well as to the kinds of astronomical twitches that preoccupied Milankovitch, he says. "These are not mutually exclusive ideas. Nature doesn't always follow a neat little paradigm." □



Planetary shivers: Oxygen isotopes in seafloor sediments track the ice ages over the last 900,000 years (left). An analysis of the frequencies present in the isotope record (right) shows a single peak corresponding to a 100,000-year-long cycle (top), which matches the pattern expected for orbital inclination (bottom), but not the triple peak of orbital eccentricity (middle).