ries, says Amitava Bhattacharjee, a theorist at the University of Iowa. "Real solar and magnetospheric configurations are three-dimensional," says Bhattacharjee.

So far, the team has shown that the reconnection rate is fastest when the merging field lines are nearly antiparallel. That matches a relationship seen in the "space weather" generated when magnetized plasma flies outward from the sun and strikes Earth's magnetosphere, notes James Drake, a plasma theorist at the University of Maryland, College Park. Storms are most likely, Drake notes, when the fields of the solar wind and the magnetosphere are antiparallel. The size of the reconnecting region also roughly matches the predictions of Drake's own computer model of reconnection. "This experiment is going to be a very nice place to test my theory," he says.

These laboratory flares and exploding stars mimic relatively familiar events. But researchers are considering other experiments that would probe far more exotic astrophysical environments. Toshiki Tajima of the University of Texas, Austin, and Pisin Chen of Stanford University have pointed out that the pressure of light from ultraintense, tabletop lasers (*Science*, 5 January 1996, p. 25) can shove electrons with a force equivalent to that of gravity's tug in the vicinity of a black hole with the mass of millions of suns.

By colliding with the sea of "virtual" photons that, according to quantum mechanics, pop in and out of existence throughout space, such electrons might scoop an occasional photon out of the vacuum, causing empty space itself to glow. The process would mimic the so-called Hawking radiation that theorists predict is sparked by the powerful gravity of black holes. Tajima cautions that "the practical difficulties would be formidable"—especially picking the radiation out of a background of ordinary light.

Such challenges, together with the vast gulfs in scale between the cosmos and the lab bench, mean that these astrophysical microcosms won't be putting telescopes and supercomputers out of business anytime soon. But there is no question that a new player has arrived on the scene, says Bhattacharjee: "There is, in the final analysis, no substitute for comparison with experiment."

–James Glanz

Additional Reading

B. A. Remington *et al.*, "Supernovae hydrodynamics experiments on the Nova laser," *Physics of Plasmas* **4**, 1994 (1997).

M. Yamada *et al.*, "Identification of Y-shaped and O-shaped diffusion regions during magnetic reconnection in a laboratory plasma," *Physical Review Letters* **78**, 3117 (1997).

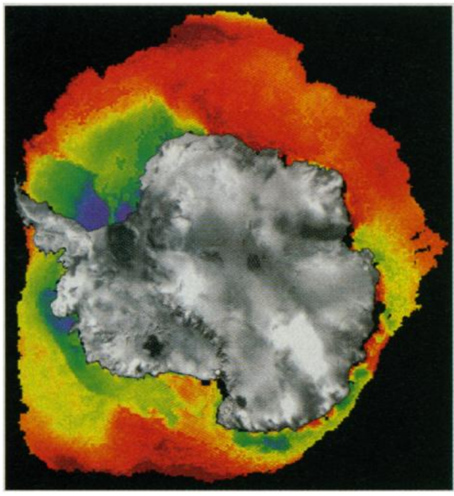
P. M. Bellan, "Solar Drivers of Interplanetary and Terrestrial Disturbances," in *Astronomical Society of the Pacific Conference Series* **95**, 1996, K. S. Balasubramaniam, S. L. Keil, R. N. Smartt, Eds., p. 242.

ECOLOGY

Taking the Measure of Life in the Ice

At first glance, the seventh continent's pack ice seems like an eerie wasteland. But looks can be deceiving. Hidden inside the meter-thick slabs of ice that form each year across 20 million square kilometers of the Southern Ocean, a diverse ecosystem is thriving. The interior of an ice floe is much like a frozen honeycomb, laced with channels of slushy brine. These waterways teem with algae, which capture light filtering through the ice and help form the basis of a frosty food web that cycles carbon and other nutrients up through krill and fish to penguins, seals, and whales.

Scientists have long known that this "crop" of algae grows each year in the ice. But they have had difficulty quantifying it because the ice—and its suitability as algae habitat—varies enormously across the ocean. Now, on page 394, ecologist Kevin Arrigo of NASA's Goddard Space Flight Center in Greenbelt, Maryland, and colleagues unveil a mathematical model that uses data and equations derived from remote-sensing satellites and laboratory and field studies to put real numbers on the total primary production, or plant life produced through photosynthesis, in pack ice. Among other findings, the model reveals that this ice yields fully one-quarter of the primary production in the part of the Southern Ocean that is covered with ice.



ARRIGO ET AL.

Bumper crop. The most productive (red) ice surrounding Antarctica forms annually.

With the model, researchers say they will finally be able to begin unraveling the Southern Ocean's complex food web and better understand the role these tiny organisms play in cycling carbon through the biosphere. "It's great progress for the field," says Cornelius Sullivan, director of the Office of Polar Programs at the U.S. National Science Foundation, who adds that the study is one of the first to look at the overall contribution of algae in pack ice to the ocean ecosystem.

More than 150 years have passed since British botanist Sir Joseph Dalton Hooker first described "microscopic vegetables," or brown algae, in Antarctic sea ice. Since then, researchers have learned that sea-ice populations of algae are determined by basically two resources: sunlight and nutrients—the phosphates, nitrates, and silicates in seawater. But getting a fix on the total algal production in pack ice has proved difficult. The ice is vast, cold, and unstable, making it a dangerous place for fieldwork. "Scientists have not been able to carry out large-scale synopses or studies on sea-ice ecology," says study coauthor Gerhard Dieckmann of the Alfred Wegener Institute for Polar Marine Research in Bremerhaven, Germany.

What's more, says Arrigo, "the ice isn't a single slab. It's dynamic and heterogeneous." As a result, the amount of algae can vary considerably even within the layers of a single floe. In the deeper layers, for instance, algal growth may be stifled by lack of light, while populations near the top may not get the nutrients that flood into the base of the ice from the seawater below.

So, Arrigo and his colleagues set out to estimate primary production by simulating this icy habitat in a computer. They turned to satellite images of the region for basic information about cloud cover and snow cover. From field studies, they incorporated information about the pack ice's porosity and other physical characteristics. Then they worked in equations describing how algal growth responds to changes in light, temperature, and nutrient supply.

According to the model, even during the gloomy Antarctic winter, an average of 50 micrograms of algae grow in each square meter of ice every day. The total production each year turned out to be about 35 billion kilograms of carbon, or about one-fourth of the total primary production in the ice-covered Southern Ocean, say the researchers.

According to the model, the most important factor in algae production was snow cover. In general, regions that got a lot of snow produced the most algae per square meter of ice, says Arrigo. The snowy Weddell Sea, for instance, just one-quarter of the ice-covered waters around Antarctica, produced half the algae in pack ice. While a light dusting of snow can limit algal growth by blocking out sunlight, a heavy snow can dunk an ice floe, flooding it with fresh nutrients from deeper seawater. Algae in the ice then feast on the sudden, free lunch. The other crucial determinant of algal growth turned out to be ice porosity. As the ice became more porous, usually as a result of warming weather, nutrient-rich brine flushed through the ice, spurring algal blooms.

Scientists are still uncertain how sea-ice algae affects the Southern Ocean food web. Overwintering crustaceans—like copepods and juvenile krill—feed on algae living on the bottom of ice floes, says Robin Ross, a biologist at the Marine Science Institute at the University of California, Santa Barbara. And each spring, a variety of organisms—including larval fish and ocean-floor sponges and sea stars—get fat grazing on algae and other plankton poured into the ocean as pack ice melts. But it is not yet clear how much these events affect other animals, such as whales and other marine mammals, further up the food web. Says Ross, "We're still working out the details of sea-ice dynamics."

–Kathryn S. Brown

Kathryn S. Brown is a science writer in Columbia, Missouri.

CHEMISTRY

Researchers Make Slick and Sticky Films

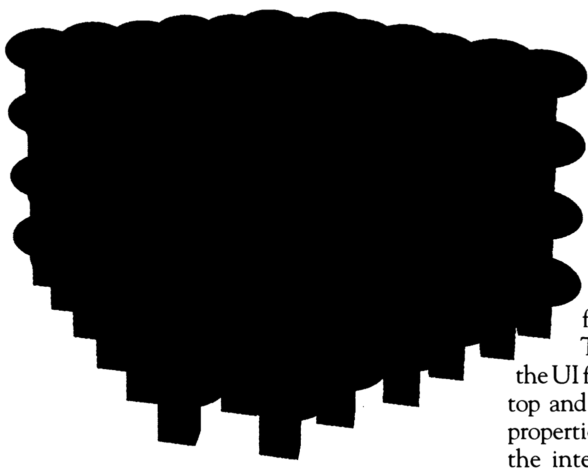
Living cells are masters of hierarchical building. For much of their molecular architecture, they first string together amino acids into proteins, then assemble proteins into more complex structures. Chemists have been working to imitate this skill, in the hope of making new materials tailored right down to the arrangement of molecules. Researchers have logged some initial successes, designing molecules that take a first step toward hierarchy by linking together into aggregates resembling tiny balls, sheets, and webs.

Now, on page 384, researchers at the University of Illinois (UI), Urbana-Champaign, report taking this assembly process to a new level of sophistication, creating molecules that assemble themselves over several size scales, first forming clusters, then sheets, and, ultimately, thick films. Because the building-block molecules are all oriented in the same direction, the films' properties mirror those of the individual molecules, yielding a bottom surface that's sticky and a top that's slick. This property could make the films useful for everything from anti-icing coatings on airplane wings to anti–blood-clot linings for artificial blood vessels, says Samuel Stupp, who led the UI effort. "It's a tour de force of chemistry," says Edwin Thomas, a materials scientist at the Massachusetts Institute of Technology in Cambridge.

At the heart of the new films is a pencil-shaped organic molecule that Stupp and his colleagues call a "rodcoil," because one half of the molecule is rigid and the other half is flexible. The rigid end is composed of compounds called biphenyl esters that lock stiffly together. The floppy end is made up of compounds called isoprenes, which, in turn, are connected to other flexible groups called styrenes. Finally, an ultrasticky phenolic group sits on the end of the rod portion, while a slippery methyl group caps the flexible coil end.

Rodcoils aren't brand-new. Stupp and his UI colleagues first constructed the molecules 2 years ago. Their hope was that the rodcoils would assemble themselves into a continuous thin sheet in which all the molecules would point the same way. They found instead that the molecules formed thick films (*Science*, 28 April 1995, p. 500). At the time, they assumed that the rodcoils simply lined up, regiment style, to form sheets that then became layered into films. But in the current paper, the UI team reports that the film is, in fact, the product of a more involved, three-step hierarchical process.

At the smallest scale, groups of about 100 rodcoils aggregate into mushroom-shaped clusters, with the rodcoils' rigid ends forming the stems and the flexible coils forming the caps. The mushroom shape, says Stupp, is the result of two opposing forces. An attractive intermolecular force among biphenyl esters on neighboring rods draws this portion of the molecules tightly together, while a repulsive force pushes the floppy coils apart. Once the mushrooms have grown to about 5 nanometers in diameter, "the repulsive force of the coils overcomes the attractive force of the rods, and they stop growing," says Stupp. The result is the creation of thousands of nearly identically sized mushrooms.



STUPP *ET AL.*

Tight fit. Mushroom-shaped molecules pack together into a layered film.

In the next level of organization, the mushrooms pack side by side, same side up, to form sheets. And finally, in the last level of the hierarchy, the sheets stack in layers—again, same side up—to form a thick film. Just why the sheets stack up this way "is a bit mysterious," says Stupp. The arrangement requires the water-loving, or hydrophilic, sticky phenolic groups on the tip of the stems to sit next to the water-fearing, or hydrophobic, methyl groups on the top of the caps. And hydrophilic and hydrophobic molecules typically want little to do with one another.

But after running a series of computer models, Stupp and his colleagues now believe that what forces the hydrophilic and hydrophobic groups together is nature's even greater abhorrence of a vacuum: The stacked arrangement may be the most space-saving way to pack together the mushroom-shaped clusters. The rigid stems in one layer of mushrooms press down into the flexible caps in the layer below. But rather than crushing the caps, the stems nestle down into them, pushing aside the floppy molecules so that they fill in some of the space around the stems. As a result, despite the natural repulsion between caps and stems, the film ends up having a "polar" order, with all the caps facing up and all the stems facing down.

This polar stacking is likely to make the UI films a hit production, as it endows the top and bottom surfaces with very different properties. Already, the films have sparked the interest of researchers at Foster-Miller Inc., a technology-development company in Waltham, Massachusetts, who are investigating them for use as anti-icing coatings for airplane wings. The most common of the deicing treatments now used—spraying an antifreeze compound on airplane wings just prior to takeoff—isn't foolproof because rain and wind can quickly remove the antifreeze. By contrast, the sticky side of the UI films adheres so "tenaciously" to metal and other surfaces, says Stupp, that one day, a coating made of the films might be able to prevent ice buildup for months or years at a time.

Down the road, Stupp and his colleagues also hope to create films with other properties, by replacing the sticky and slippery groups capping the rodcoils with compounds that perform other functions, such as conducting electricity or changing their size in response to an electric jolt. If successful, these sequels might even upstage the originals.

–Robert F. Service