▶ in the shock waves around supernovae, says Alexander Tielens, an astrophysicist at Leiden University in the Netherlands. "I think Herschel really nailed that supernovae make a lot of dust."

Outside the Milky Way, Herschel enabled observations of dusty galaxies from 10 billion years ago — when most of the Universe's stars were forming. The data show that stars tended to form evenly across these early galaxies, rather than being spurred by galactic mergers, says Gordon Stacey, an astronomer at Cornell University in Ithaca, New York. They also show that some giant black holes at the centre of galaxies, known as active galactic nuclei, hurl out jets of gas so powerful that they may prevent stars from forming in the vicinity. "It's pretty exciting to actually see these processes in action," says Phil Appleton, head of the NASA Herschel Science Center at the California Institute of Technology in Pasadena.

Herschel also allowed astronomers to look at a range of molecules in the Milky Way. Hydrogen fluoride worked as a tracer to reveal larger clouds of hydrogen gas, the building blocks of star formation. And water vapour turned up sometimes in unexpected places: stars made mainly of carbon and Jupiter's atmosphere, to name but two.

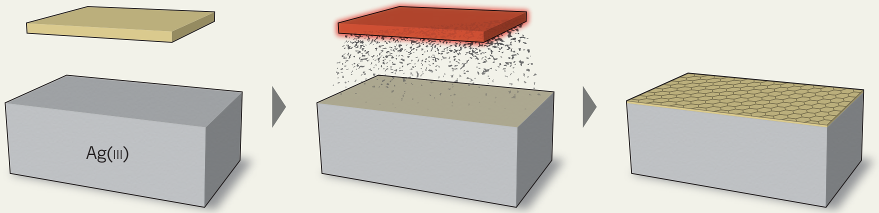
A new generation of instruments will follow up on Herschel's discoveries. From a perch in the Chilean Andes high enough to observe in the far-infrared, the Atacama Large Millimeter/submillimeter Array (ALMA) will point its dishes at distant galaxies first catalogued by Herschel (see page 156). The Stratospheric Observatory For Infrared Astronomy (SOFIA), a telescope carried by a high-flying 747 jet, will also be able to build on Herschel's observations. So will NASA's James Webb Space Telescope, scheduled for launch in 2018.

But "without Herschel there will certainly be a gap", says Stacey. Infrared astronomers want another space telescope that could make the same ultra-cold observations as Herschel, but with the sensitivity to reach farther into the Universe. To that end, the European Space Agency, which built Herschel, now hopes to collaborate with Japan to build the Space Infrared Telescope for Cosmology and Astrophysics (SPICA), a 3-metre-class telescope that would chill its mirror as well as its instruments. If the project wins funding, it could be launched sometime in the 2020s, says Pilbratt.

In May, after it shuts down, Herschel will be shunted to an orbit around the Sun to eliminate the risk of it falling back to Earth (an alternative plan to send it crashing into the Moon was abandoned owing to cost). But the observatory's public data archive will continue to lead to discoveries for years to come. "This is not the end of the mission," says Pilbratt. "This is the end of observing." ■

MAKING SILICENE

Atom-thick sheets of silicon — silicene — were first produced in 2010 but researchers have yet to grow the material on an insulating surface to test some of its predicted properties.



Step 1: Place silicon wafer above crystalline silver (Ag) in a vacuum.

Step 2: Heat the silicon until it begins to sublimate.

Step 3: Silicon atoms spontaneously organize on the silver surface as silicene.

MATERIALS SCIENCE

Sticky problem snares wonder material

Graphene-like form of silicon proves hard to handle.

BY GEOFF BRUMFIEL

In 2011, physicist Guy Le Lay stood before a half-filled room on the last day of the American Physical Society's March meeting in Dallas, Texas, and presented data on a new form of silicon. In his laboratory at Aix-Marseille University in France, Le Lay had grown sheets of honeycombed silicon with layers just one atom thick. He had only preliminary evidence that was unpublished at the time. "It was a risk, you know?" he says now of his decision to present the data.

At this year's meeting, on 18–22 March in Baltimore, Maryland, scientists will deliver about two dozen talks on silicene (see 'Speaking of silicene'), the material that Le Lay tentatively described two years ago.

The name recalls graphene, the current darling of the materials-science world — and the flurry of interest suggests that silicene could be the next one. But for that to happen, Le Lay and others will have to overcome silicene's unfortunate tendency to stick to practically everything it touches.

Structurally, silicene looks a lot like graphene, which is also a honeycombed sheet, but of carbon atoms rather than silicon. Silicene's two-dimensional structure should lead to strange quantum effects and allow electrons to streak across it at incredible speed — properties that, in graphene, have entranced physicists and builders of electronic devices since it was first characterized in 2004. In 2010, work on graphene won a Nobel prize, and earlier this year, graphene research was selected by the European Commission as one of its billion-euro flagship projects (see *Nature* **493,** 585–586; 2013).

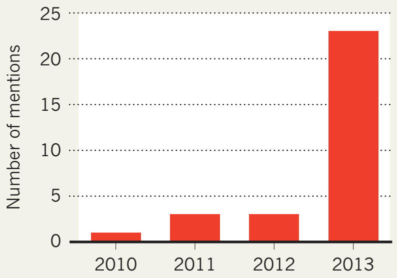
Silicene could even have some extra attractions. It is predicted to have characteristics similar to topological insulators — materials that conduct electrons only on their outer surfaces — another trendy area of research.

Above all, silicene is made of silicon, the same material that drives the modern electronics industry. Bringing it all together could lead to "a new era" in silicon electronics, says Kehui Wu, a physicist at the Chinese Academy of Sciences' Institute of Physics in Beijing.

There's just one problem: silicene is super sticky. "Graphene is a very stable material," says François Peeters, a condensed-matter theorist at the University of Antwerp in Belgium. But silicene reacts easily with the environment — oxidizing in the air and bonding chemically with other materials. And unlike graphene, which lies flat, silicene crinkles into bumps and ridges as a result of the way neighbouring silicon atoms bond with each other. That makes it more likely to stick to surfaces.

SPEAKING OF SILICENE

The number of times that silicene is mentioned in abstract titles for the American Physical Society's March meetings has shot up this year.



Silicene's reactivity makes it much harder to produce than graphene. The Nobel prize-winning work on graphene began by peeling sheets from a block of graphite with a piece of sticky tape. Silicene, by contrast, can only be grown in an ultra-high vacuum on top of a material that matches its natural structure (see 'Making silicene').

Crystalline silver has proved to be the best fit because its atomic structure allows it to lock together with silicene's wavy ridges, and the silver's non-reactive surface means that it doesn't pull the silicene apart, Le Lay says. Reversing a technique he honed for depositing silver onto silicon, Le Lay grew the first samples of silicene on silver[1].

Only two other materials have been found to support silicene up to now. One, zirconium diboride, has the advantage of naturally sucking silicene onto its surface from a block of silicon positioned below[2]. The other, crystalline iridium, was reported as a possibility only in January this year[3].

Unfortunately, all three of these materials conduct electricity, says Yukiko Yamada-Takamura, a materials scientist at the Japan Advanced Institute of Science and Technology in Nomi. The bulky conductors mask silicene's delicate electrical properties, making it impossible to check whether the theoretical predictions of strange quantum effects are correct.

To see if silicene performs as expected, experimentalists will have to find a semiconducting or insulating surface on which to grow it. Better still would be to develop a technique to create free-standing sheets of silicene, Yamada-Takamura says. It's not entirely clear how that would be done, but given the increasingly competitive nature of the field, she says, "I will not tell you even if I had an idea."

As Peeters isn't racing to grow silicene himself, he's more willing to speculate. He thinks that sandwiching silicene between two sheets of another material, such as graphene, could stabilize it and prevent it from reacting with the outside world.

"I think if it will be used, it will be used in sandwich form, because that's the way in which you can stabilize it," he says. The outer sheets "can be any material; it really depends on what you want to do with it".

Despite its troubles, silicene's future looks bright. It has been included as part of Europe's massive graphene programme, and is catching on in the United States, Le Lay says.

The talks on it at the March meeting are likely to be more popular than they were two years ago, but Le Lay won't be there to find out. He's too busy giving seminars at departments everywhere from Hawaii to Austria to Japan. "It's crazy," he says. "But it's good!" ■

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MATERIALS SCIENCE

Exotic conductors from lab and nature

Mineral proves to be remarkably clean topological insulator.

BY ZEEYA MERALI

They say that it's what's on the inside that counts. But that is not true for topological insulators — exotic materials that conduct electricity only along their surfaces. A team of physicists has now demonstrated this property in a naturally occurring mineral[1], and another group has synthesized the first two-dimensional topological insulator that conducts at room temperature[2].

Having a broader range of such materials could boost researchers' efforts to build spintronic devices — in which currents are driven by an intrinsic property of electrons called spin, rather than by voltages. The materials could also help the design of quantum computers that would use spin to encode information.

Predicted to exist in 2005 (ref. 3), topological insulators that work at low temperatures were first synthesized from heavy elements in 2008 (ref. 4). Their odd conducting abilities arise because each electron's spin becomes coupled to its motion. This relationship compels each electron to circle around a specific spot, preventing them from moving through the bulk material, which means that they cannot conduct electricity. But at the material's edge, the electrons do not have enough space for this circling motion; instead, they are forced to hop along the surface in semicircular jumps, enabling conduction.

The thin conducting layer of a topological insulator makes it relatively easy for physicists to manipulate the spin current. "Topological insulators raise the possibility of building spintronic devices that use electron spin, rather than charge," says Pascal Gehring, a solid-state physicist at the Max Planck Institute for Solid State Research in Stuttgart, Germany, and a co-author of the mineral study. Spins can be rotated quickly without expending much energy, so spintronic devices should be more efficient than their electronic counterparts, in which energy is required to change charges, he adds.

Physicists attempting to construct quantum computers that would outperform the best current machines are also interested in encoding information in electron spins. In theory, it is difficult to corrupt spin values in a topological insulator. That is because, to flip the spin value accidentally, you would have to knock the system hard enough to cause the electron to make a complete U-turn.

In search of materials that display these properties, Gehring and his colleagues examined a natural sample of kawazulite, which contains bismuth, tellurium, selenium and sulphur, found at a former gold mine in the Czech Republic. Lab-made samples of kawazulite have already been shown to be topological insulators, but no one had checked for the property in natural samples.

The team cleaved off single crystalline sheets 0.7 millimetres wide and applied the standard test for a topological insulator: photoelectron spectroscopy. This involves measuring the properties of electrons dislodged when ultraviolet light is fired at a material's surface. Their results[1] confirm that the electrons' energy and momentum distribution matches predictions for a topological insulator.

"It may turn out to be cheaper to use a natural supply."

Feng Liu, a materials scientist at the University of Utah in Salt Lake City, notes that the team's natural sample contains fewer structural defects than its lab-made counterparts, reducing unwanted conduction in the bulk. "It may turn out to be cheaper to use a natural supply of topological insulators," says Liu.

Even in the lab, topological insulators require less exotic conditions than had been thought. Jeroen van den Brink, a physicist at the Leibniz Institute for Solid State and Materials Research in Dresden, Germany, and his colleagues stacked bismuth-containing sheets with a honeycomb structure like that of graphene. The result is a bulk material that acts as topological insulator at room temperature[2].

The next step should be to find organic materials that act as topological insulators, says Liu. His team recently proposed a design for such a compound[5], and says that another group has synthesized a candidate structure. "Ultimately, these will be these cheapest and most versatile materials to work with." ■

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