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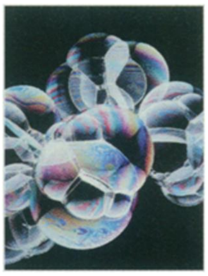

Cover: A cluster of soap bubbles provides one way to visualize the microstructure of space on distance scales much smaller than the diameter of a proton. Such a picture emerges from recent efforts to determine the relationship between gravitation, general relativity, and quantum mechanics. **Page 376**

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Letters

Life on Mars from Earth?

In NASA's careful attempt to avoid contamination of Martian rocks by Earth's sources of life, nothing was mentioned about the possibility of organic artifacts from Earth being found on Mars ("Scooping Up a Chunk of Mars," SN: 4/25/98, p. 265). If Mars rocks can land on Earth, is it not likely that, in the past, Earth material made it to Mars?

Thus, even if some "evidence" of life is found in the retrieved samples, how can we be sure that it did not originate on our own planet in a previous era?

Del Dietrich
Campbell, Calif.

Testing the biological quarantine process for the Mars robot on an actual mission to Mars sounds expensive and time-consuming. Why not test the process with a trip to the Moon?

It would be quicker and probably less expensive. Moreover, previous visits to the moon would provide adequate controls for comparison of possible contaminants, and any snafus in handling the landing craft would be exposed.

Tim Davis
Broomfield, Colo.

Long before the probe's expected return in 2008, NASA's International Space Station should be in operation. What better laboratory for investigating potentially dangerous samples while remaining completely isolated from the atmosphere?

Ian Randal Strock
Brooklyn, N.Y.

CORRECTION

Geoffrey Schmidt

In "Blood test, 3-D graphics win top prize" (SN: 5/23/98, p. 327), a photo of Jonathan Kelner was incorrectly identified as a photo of Geoffrey Schmidt.

It seems odd to me that no discussion is presented regarding the worst-case scenario represented by the *Andromeda Strain* example given at the beginning of the article. In the climax of that fictitious classic, the strain gets loose despite all precautions.

This brings me to my point.

Why parachute the samples down to Earth at all? Why not conduct the testing for toxicity in an orbital facility that can be directed into the sun should the worst occur?

Bill Chandler
Shawnee, Kansas

John Rummel, NASA's Planetary Protection Officer, replies:

"We tested some of the quarantine procedures as part of the Apollo missions to the moon.

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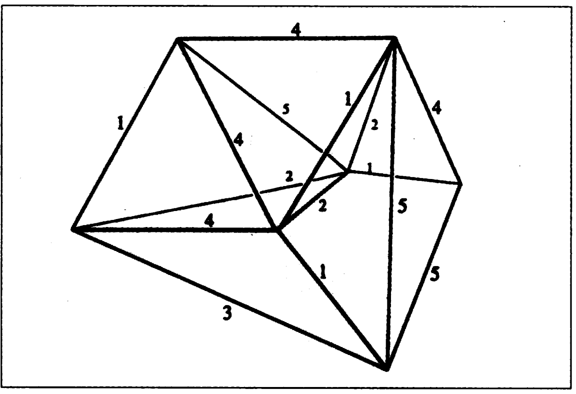
face called an event horizon. An object can pass through the horizon into a black hole, but it can never get out again. Such an escape would require traveling faster than the speed of light.

If a black hole absorbs even the tiniest amount of energy but never emits any, it acts like a body at the absolute zero of temperature. In the 1970s, however, Stephen W. Hawking of the University of Cambridge in England showed that a black hole isn't quite black. According to his calculations, a black hole should radiate energy at a temperature proportional to the gravity at its event horizon.



Courtesy of Carlo Rovelli

This example of a spin network corresponds to a possible quantum state of the geometry of space. Roughly speaking, the number along an edge counts the units, or quanta, of area of a surface associated with that edge.

Hawking's surprising discovery both built on and helped explain an earlier finding from Jacob Bekenstein, then at Princeton and now at Hebrew University in Jerusalem, who had established that a black hole has a thermodynamic entropy proportional to the surface area of its event horizon.

In a quantum theory of gravity, it should be possible to derive the Bekenstein-Hawking formula linking a black hole's entropy, temperature, and area from more fundamental ideas. In loop quantum gravity, that means finding the right connection between microscopic quantum states of space, represented by spin networks, and the macroscopic surface area of a black hole's event horizon.

The trouble is that recognizing the presence of a piece of an event horizon crossing a small patch of space-time is a tricky business. In particular, one needs a way to describe the geometry of a black hole's event horizon and how it changes as time passes.

It took considerable mathematical ingenuity on the part of Rovelli, Kirill Krasnov of Penn State, and others to overcome the problem and finally develop an expression compatible with the Bekenstein-Hawking formula for black hole entropy. Those calculations represent a significant success for loop quantum gravity, Rovelli says.

Interestingly, theorists have also recently derived the formula for black hole entropy on the basis of string theory. That result hints that loop quantum gravity and string theory share certain features.

At present, the loop approach offers an incomplete theoretical picture of quantum gravity. In particular, the spin networks of loop quantum gravity turn out to be more suitable for describing three-dimensional space than four-dimensional space-time.

As one attempt at a quantum description of the geometry of space-time, Rovelli, John C. Baez of the University of California, Riverside, and others have been exploring mathematical structures called spin foams. Slicing through a four-dimensional spin foam reveals a spin network—just as a cross section through a mass of soapsuds unveils a collection of curved lines and vertices of adjoining soap films.

Spin networks are used in quantum loop gravity to describe the geometry of space at a given time, Baez says, so it's natural to hope that they're the slice of something that describes the geometry of space-time.

Some researchers are trying out different sorts of spin foam structures and various rules for specifying the number of faces that meet along an edge. One promising model builds space-time from four-dimensional analogs of tetrahedra. Applying appropriate numerical labels to such a spin foam's edges and faces turns it into a quantized four-dimensional geometry.

Theorists are now busy debating the merits of different approaches to drawing and labeling such spin foams. Their goal is to find a structure that not only corresponds to a four-dimensional quantum geometry but also represents a process that evolves over time.

"We need to show that some such model gives results that are well approximated by general relativity . . . on distance scales about the size of an atom as well as a planet," Baez says.

Spin foams "offer the prospect of a simple and beautiful picture of the microstructure of space-time which takes both general relativity and quantum mechanics into account," he concludes. "This is what we need, and any step in that direction, no matter how flawed, is a good thing."

The problem of understanding the quantum properties of space-time is today at the core of fundamental physics, Rovelli said at a quantum gravity conference held last year in Poona, India.

"The recent explosion of interest in quantum gravity has led to some progress and *might* have taken us much closer to the solution of the puzzle," he commented. "The main approaches . . . have produced predictions that are at least testable in principle and whose indirect consequences are being explored."

Both loop quantum gravity and string theory, however, are highly tentative models with no experimental evidence to support them, Rovelli warned. No one knows whether either theory correctly describes the universe.

In the face of such uncertainty, "the only way to make serious progress is for different people to push on different fronts simultaneously," Baez says.

The spin-network picture of quantum geometry is still developing, and major problems remain, Smolin notes.

It is possible that loop quantum gravity and string theory have uncovered complementary aspects of quantum gravity. Baez favors combining the best elements of both approaches, despite their vast differences. "Maybe we are just seeing two faces of the same theory," he says.

Smolin speculates that a loop in an enormous, complex network could turn out to be a close-up of the same phenomenon that string theory describes as a string moving in a smooth space-time geometry.

Or maybe not. The search for the next level of understanding goes on. □

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Many of the lessons we learned from Apollo are pertinent to Mars, and what was not learned there can be suitably tested using Earth-based methods (airdrops of containers, laboratory studies, and so on), so a new lunar mission is unnecessary.

"There are two problems with using the Space Station as a laboratory. First, one of the reasons for having the Space Station is to understand the adaptation of life to microgravity and to use microgravity as a probe to study organisms in a novel way. The requisite controlled studies for a sample's biological effects cannot be done on the Space Station until we have extensive knowledge of microgravity physiology—a process that could take decades (to be optimistic).

"Second, the Space Station is preferable to Earth's surface only if you believe that containment might be breached and, if so, you would be prepared to sacrifice the crew in the event of an 'unknown or adverse reaction' to the sample. Similar concerns obtain in a Space Shuttle recovery of samples while in orbit. Moreover, a Shuttle recovery might be less safe, overall, than direct entry.

"As to our ability to sterilize a sample, there is no doubt that high temperatures will be able to break carbon bonds and eliminate a threat posed by carbon-based life. The trick is learning how to sterilize such a sample without destroying the scientific information that led you to collect it in the first place. Between containment, corrosives, and heat, there should be ample margin for a safe analysis of materials returned from Mars."

—R. Cowen