Quantum gravity predicts piecemeal space

Just as electrons in atoms can have only certain energies, space itself may come packaged in discrete units.

This possibility arises from an effort to integrate quantum theory, which applies to the behavior of matter on a microscopic scale, with the general theory of relativity, which holds that gravity is a geometric effect dependent on the curvature of space.

Using a particular formulation of quantum gravity, physicists Carlo Rovelli of the University of Pittsburgh and Lee Smolin of Pennsylvania State University in University Park show that measurements of the volumes and areas of regions of space are quantized. They can also calculate the range, or spectrum, of sizes that pieces of space can have.

"Many different approaches to quantum gravity incorporate a fundamental length," the researchers say. "The discreteness of areas and volumes found [in our work] supports and strengthens the evidence for the existence of a discrete, short-scale structure of space." They will report their findings in the May 29 NUCLEAR PHYSICS B.

The quantum gravity theory developed by Rovelli and Smolin evolved out of the work of Abhay Ashtekar, now at Penn State. In the mid-1980s, Ashtekar discovered that he could reformulate and drastically simplify the equations of general relativity by replacing a single variable, representing a unified, four-dimensional spacetime continuum, with two distinct spacetime variables. Such a transformation enabled him and others to find new solutions to the equations and suggested various possibilities for quantizing the theory.

In 1988, Rovelli and Smolin developed a way of interpreting solutions to the quantized theory as patterns of closed loops — lines of force of the gravitational field somewhat analogous to the lines of magnetic force around a bar magnet. Expressed in terms of loops, the quantum states of the gravitational field depend on how these loops are knotted and linked.

In their new work, Rovelli and Smolin construct two mathematical expressions, called operators, to represent measurements of the volumes and areas of regions of space. Applying these operators, they find that the measurements correspond to particular loop patterns described by spin networks (see diagram).

"Spin networks are the quantum states of gravity, just as electron shells are the quantum states of the atom," Rovelli notes.

In other words, the Smolin-Rovelli model of quantum gravity predicts that measurements of volumes and areas can't have just any value. A measured value must belong to a certain set of numbers.

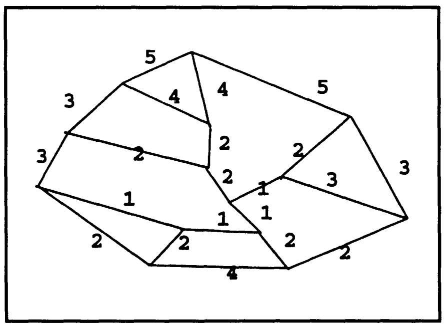
"One way to describe these predictions is that the geometry of space itself is made out of discrete quanta analogous to the photons of light or the electron shells of atoms," Smolin says.

These pieces of space are extremely small, having length scales on the order of 10^{-35} meters, compared to 10^{-15} m for the diameter of a typical atomic nucleus. If volume and area could be measured to this level of precision, "the answers would have to fit into the discrete spectra that we calculated," Smolin says.

The loop picture of quantum gravity may prove useful for studying the problem of what quantum theory has to say about singularities, Smolin says.

Arising in general relativity and many other physical theories, singularities are situations in which attempts to make predictions result in infinite quantities. When networks of loops define the structure of space, nothing can be smaller, and no infinities come up in the theory.

The same model could also provide a reasonable description of the nascent universe, particularly in order to establish the spectrum of primordial gravitational waves generated during the universe's earliest moments.



Smolin and Rovelli

Example of a quantum gravitational state represented by a spin network. Three links come together at each node, and each number indicates the number of loops running together along that particular link.

The researchers are interested in exploring the relationship between their results and those coming out of alternative approaches to quantum gravity, especially string theory (SN: 2/27/93, p.136). In string theory, the point particles of relativity and quantum mechanics are replaced by extended objects called strings, which can be visualized as either closed loops or segments with two free ends. But this theory says nothing directly about the background space in which the strings vibrate and move.

"I believe that our results and those of string theory are complementary," Smolin says. "They explore different regimes of quantum gravity and could easily be both true." — *I. Peterson*

Making light work of a cell's skeleton

Cancer therapy rarely has a light touch. In the battle against malignant tumors, physicians arm themselves with surgery, radiation, and chemotherapy, treatments potentially as dangerous as cancer itself.

Hoping for a gentler alternative, some researchers have spent more than 2 decades pursuing photodynamic therapy, a strategy in which light kills dye-infused cancer cells (SN: 1/14/89, p.26).

Now, a group from the Dana-Farber Cancer Institute in Boston suggests the method, which has enjoyed limited success, aim for a novel target in the cell: microtubules, the intracellular filaments made from the protein tubulin.

"If you wipe out microtubules, it's a very effective way of killing cancer cells," asserts Lan Bo Chen, who heads the Boston team. He notes that many current cancer drugs break up microtubules and that taxol, another well-known anticancer agent, stiffens the filaments. In either case, cells can no longer divide or perform basic maintenance functions, so they rapidly die.

Microtubules began to interest Chen when he, along with Christopher Lee, now at Stanford University, and Samuel S. Wu, now at Stanford University Medical School, investigated cyanine dyes, a class of light-sensitive compounds used in photography.

One such dye, when added to kidney cells grown in the laboratory, concentrates inside the cells in organelles such as mitochondria and the endoplasmic reticulum, they report in the May 15 CANCER RESEARCH. When they shine blue light on these cells, it destroys the microtubules but leaves other parts of the cells' skeleton intact.

One reason for the selective destruction may be that microtubules gather near or attach to the endoplasmic reticulum. Chen believes the endoplasmic reticulum releases its dye onto microtubules and free-floating tubulin. The dye, when activated by light, breaks down microtubules and prevents new filaments from forming. "The detailed mechanism we do not know," admits Chen.

Questions remain about the dye's toxicity, whether it can target cancer cells over healthy cells, and whether it can be modified to respond to longer wavelengths of light, which penetrate the body more easily, cautions James W. Foley of the Rowland Institute for Science in Cambridge, Mass.

"At this stage, as far as cancer therapy, I don't think it's very valuable," he says. Foley suggests that the dye may hold more immediate interest for cell biologists interested in the function of microtubules. — *J. Travis*