Jakob disease. He observes, however, that some family members in the NIH group's study have the mutation but don't appear to be getting sick, including one woman who is 75 years old, well beyond the age when Creutzfelt-Jakob disease usually develops. "She's a crucial lady, but we don't know what to think about her," Brown says. She might be an indication that something besides the mutated gene is required. Or she might just be an example of a well-known phenomenon that geneticists call "incomplete penetrance," meaning that a disease gene just doesn't cause its ill effects in everybody who inherits it.

Prusiner's group is already working on an experiment that may clarify the issue of whether the prion protein works alone. The researchers are attempting to show whether brain extracts from the sick transgenic mice can transmit the disease to other mice. That would indicate that the presence of the mutant transgene is all that it takes to get infectious prions.

It's been 220 days since the animals were injected with the brain extracts, however, and so far they are doing just fine. The transgenic mice generally develop their symptoms before they are 200 days old, but, says Price, it may still be too early to conclude that the transmission experiment is negative. Depending on conditions, he notes, it can take more than a year for neurological symptoms to develop in animals injected with scrapie brain extracts.

A good many other questions remain as well. Researchers want to know what the prion protein does normally, as well as what might cause it to go awry and produce disease. And then, of course, there is the question of how prions can reproduce without nucleic acid.

Prusiner and his colleagues addressed this issue in the 16 November *Cell,* in which they show that an interaction between the scrapie prion protein and the normal cell protein is involved. Proteins can induce changes in each other's shapes when they bind to one another, and the Prusiner group suggests that the scrapie prion protein has an abnormal three-dimensional configuration that can be transmitted to any normal prion protein with which it interacts, and so on in a sort of chain reaction ultimately leading to disruption of brain cell function and nerve degeneration.

Nevertheless, neither the replication issue nor the other remaining questions about prions are likely to be resolved soon. But the identification of the mutations in GSS and Creutzfelt-Jakob disease and, just as important, the ability to create transgenic mice in which to study the effects of the prion protein genes at least open the door to addressing those questions. ■ JEAN MARX

Viewing the Universe as a Coat of Chain Mail

New calculations have pointed the way to quantum gravity and suggested a novel structure for the sub-sub-microscopic world

IT MIGHT SEEM LIKE QUITE A philosophical journey to get from a medieval coat of chain mail to the fundamental nature of reality. But according to theoretical physicists Abhay Ashtekar and Lee Smolin of Syracuse University, and Carlo Rovelli of the University of Pittsburgh, it's not very far at all.

If their latest calculations are correct—and the three physicists put a heavy emphasis on the "if"—then the sub-sub-microscopic fabric of space and time is best understood as a densely woven skein of loops and coils and braids, all described by a branch of mathematics known as knot theory—precisely the same mathematics that describes the intricate linkages of chain mail or the tangled snarls in a garden hose.

These intertwining loops are *not* superstrings, they are quick to point out. Those hypothetical strands of energy got a lot of press a few years back as a promising Theory of Everything, but since then they have bogged down in mathematical intractability. The loops that Ashtekar, Smolin, and Rovelli are talking about are much simpler entities, roughly analogous to the "lines of force" that surround a bar magnet, and that cause compass needles to align with the magnetic field of the earth.

Ashtekar and his colleagues say their model of loopy space-time suggests a whole new way of searching for a truly unified theory of all the fundamental forces, including gravity. And it goes a long way toward answering such previously unanswerable questions as "What happens at the center of a black hole?" and "Where did the Big Bang come from?"

All of which makes it rather startling to realize that Ashtekar, Smolin, and Rovelli have actually been quite conservative in their theorizing. "If there is strength in what we're doing," explains Rovelli, "it's that we're not just pushing some idea that we like. We're sticking on the solid ground of general relativity [Einstein's theory of gravity] and quantum mechanics. All the results are forced on us from those two." Indeed, everything they've done so far comes from looking at exactly the same equations that physicists have been staring at for generations—but looking at them in a totally new way.

Like many other physicists before him, Ashtekar had been struggling with the equations of general relativity, which express Einstein's insight that gravity is actually the result of subtle distortions in the shape of space. General relativity is widely considered to be one of the most conceptually elegant theories in physics. It successfully describes phenomena ranging from Big Bang cosmology to tiny variations in the ticking of atomic clocks. But it is also one of the most mathematically difficult theories to work with. When the equations are expressed in their conventional form—the way Einstein first wrote them in 1915—they are a tangled, nonlinear mess.

This mathematical muddiness is one reason that it's been almost impossible to reconcile Einsteinian gravity with the quantum theory of atoms and elementary particles, says Ashtekar. Physicists have been trying to achieve that feat for nearly 70 years now, ever since they first started talking about quantum jumps and probability waves back in the 1920s. It just didn't seem reasonable that quantum principles should govern everything in nature except gravity. And yet the mathematics of the two theories went together about as well as oil and water.

Until 1986, that is. What Ashtekar discovered in that year was that Einstein's equations could be simplified enormously, just by rewriting them in terms of a certain set of mathematical variables related to the intensity of the gravitational field. The effect was magical: In their new, streamlined form, Einstein's equations looked almost exactly like the equations that govern electric and magnetic fields. And if there is one thing that physicists know how to quantize, it is electricity and magnetism. "Quantum electrodynamics," as the latter theory is known, describes the properties of electrons, positrons, and photons as precisely as anyone has been able to measure. Moreover, the mathematical form of quantum electrodynamics is also the mathematical form that governs the weak forces involved in radioactivity, and the strong forces that hold the proton and neutron together. So suddenly, a consistent quantum theory of gravity—and perhaps even a new unified theory of all the forces—began to seem very possible.

The impact of this discovery was somewhat muted at the time, since so many theorists were devoting so much effort to the much sexier superstrings. But within the small quantum gravity community, people were intrigued. "Very productive," says Chistopher Isham of the Imperial College, London. "Ashtekar's invention of these variables is one of the most interesting things in general relativity in the last decade."

Among that group were Smolin and Rovelli. Working with the University of Maryland's Theodore Jacobson and others, they were soon able to verify that the analogy to the more conventional quantum equations worked. Einstein's equations in their new form would indeed produce a theory of quantum gravity. However, the content of that theory was decidedly unconventional. Instead of describing the gravitational energy at each *point* in space, as the three physicists had expected, the solutions to the quantum equations seemed to describe gravitational energy distributed around little loops in space.

In fact, as Smolin and Rovelli slowly came to realize, the equations seemed to be telling them that at the most fundamental level, space and time themselves are made of loops—infinite numbers of loops, all linking and knotting and intertwining with one another in infinitely complex ways. Unfortunately, the equations seemed to have nothing to say about what the loops are actually made of. "It's mysterious," admits Rovelli. But even in the present state of the theory, where the loops are simply abstract mathematical curves, this new picture of space-time is a rich and evocative one. Moreover, these intertwining loops turned out to be exactly the kind of structures that mathematicians have been thinking about for more than 50 years, under the rubric of "knot theory." So the physicists found a host of analytical techniques ready at hand to help them understand what was going on.

Just this year, for example, Ashtekar, Smolin, and Rovelli have finally discovered how the quantum loops are linked up to form ordinary "empty" space—which of course, isn't empty at all. The structure turns out to be an infinite, three-dimensional lattice of loops, with each one linked to its neighbors like the little rings of metal on a coat of chain mail. The physicists have also shown that minor ripples in empty space, such as the kind that might be caused by a passing gravity wave, correspond to extra loops woven into the lattice like embroidery on the chain mail. Other types of gravitational curvature may correspond to missing loops, or lattice defects of the type seen in ordinary crystals.

Meanwhile, says Smolin, this loop picture may have some intriguing implications for the Big Bang and the centers of black holes. According to Einstein's original, non-quantum equations, these points are "singularities": bizarre regions of space-time where an infinitely strong gravitational curvature is concentrated in an infinitesimal volume. Most physicists prefer to believe that some kind of quantum effects kick in to avoid such catastrophes, says Smolin—indeed, there's been a lot of speculation about the universe being born as some kind of quantum leap out of nothingness—but no one has ever been able to say how those unknown quantum effects might work.

The quantum loop model may provide an answer, says Smolin. When he and his colleagues were analyzing their empty space latticework, they were surprised to find that the quantum equations were consistent only if the interloop spacing were precisely equal to the Planck length: 10^{-33} centimeters. This has long been thought to be a natural scale for quantum gravity effects, he says, but this is the first time anyone has exhibited an explicit model of how such a scale arises. Furthermore, he says, the fact that the lattice of loops has a minimum spacing gives a natural way of explaining why gravitational curvature can't be concentrated at an infinitesimal point. First, it makes no sense to talk about "points" in this model, only loops. And second, if you try to insert a loop into the lattice that's smaller than the Planck length, it will disconnect. It will be too small to link with anything. It will effectively drop out of space-time entirely.

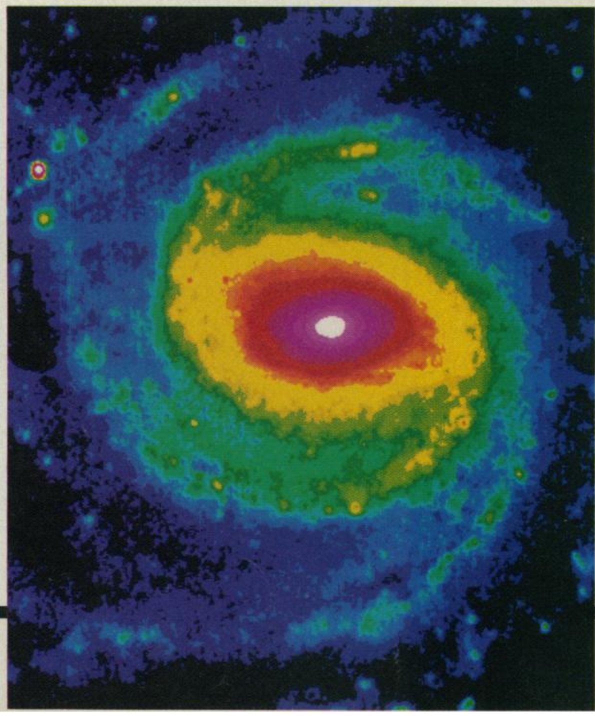
Admittedly, says Smolin, he and his colleagues are still a long way from understanding all that the equations are trying to tell them. "I have this funny feeling about the situation," he says, "that we're only seeing pieces of the solution." But what makes this work so exciting, he says, is that the pieces keep fitting and the picture gets more intriguing.

■ M. MITCHELL WALDROP

Keck's First Light

On the night of 24 November, with only nine of its 36 mirror segments yet in place, the Keck Telescope atop Hawaii's Mauna Kea turned its giant eye skyward and produced the "first light" image shown here. Rendered in false color, the galaxy NGC 1232 clearly reveals bright knots of gas where stars are forming along its spiral arms.

The image also proves that the Keck's builders, the California Institute of Technology and the University of California, have won an enormous gamble. To create the largest telescope mirror in the world—a full 10 meters in diameter—the designers built it as a mosaic of glass hexagons instead of as the traditional monolithic disk. But to make the concept work, they had to prove they could control the 6-foot wide, 1000-pound segments with micrometer accuracy.



On 24 November, they did. "All of us are surprised and completely delighted," says Terry Mast, one of the Keck's key designers. "We had nightmares about all the things that could go wrong, and they didn't." If all continues to go this well, he adds, the other segments should be installed by the end of 1991. ■ M.M.W.