of the QCD equations with a four-dimensional grid and then tries to solve the theory at each discrete point on the lattice. The approach reduces the problem from an infinite one to a finite, albeit enormous one. Over the last 15 years, perhaps a half-dozen collaborations have built special-purpose massively parallel supercomputers to work out QCD calculations, while theorists have developed ways to simplify lattice QCD and cut the required computing expense without sacrificing accuracy.

An early success in this game came in 1993, when, after a year and a half of supercomputer calculations, Weingarten and collaborators predicted the masses of a dozen hadrons, including the proton, to within 6% of their measured values (*Science*, 21 May 1993, p. 1077). That same year Weingarten, Sexton, and Vaccarino offered their first mass prediction for the lightest possible glueball: 1740 million electron volts (MeV), plus or minus 70—a little less than twice the mass of the proton.

The candidates multiply

This prediction coincided with a 1710 MeV particle known as the theta, which was first observed back in 1981 at SLAC's SPEAR electron-positron collider in the decay of J/Psi particles. These are particles composed of a charm quark and its antiquark, and their decay products were already under suspicion as potential glueballs, explains Close. Researchers speculated that after the quark and the antiquark annihilate each other in the course of the decay, the gluons that held the two quarks together would linger for a moment. "People had proposed that [the theta] might be a glueball," says Weingarten, "but not with very much conviction."

Weingarten thinks he has now eliminated most doubts. After two more years of calculations, he says, "we found that the [theta's] lifetime is long enough that for sure it should be observable in experiments. And then we calculated individually its decay rates, and those agree with the observed numbers within statistical uncertainties." Weingarten believes his new results clinch the issue—the 1710 MeV theta is a glueball. His colleagues are impressed, although slightly less confident. Says Michael Creutz, a QCD theorist at Brookhaven, "It looks good to me. It is fairly convincing."

But the theta has a rival as the lightest glueball. Since 1993 Close and Claude Amsler of the University of Zurich in Switzerland have mounted their own glueball search. Guiding it was a mass prediction from UK QCD, a collaboration of seven British universities, which has its own massively parallel supercomputer for lattice QCD calculations and has predicted a glueball mass of 1550 MeV, plus or minus 100. Close and Amsler went hunting in the data generated by Amsler's experiment, known as the Crystal Barrel, at the Low-Energy Antiproton Ring (LEAR) at CERN. The experiment, says Close, has been running for 5 years, accumulating millions of events in which neutral hadrons are created and then decay into photons and perhaps glueballs. When Close and Amsler searched the Crystal Barrel data, one decay product, a particle with a mass of 1500 MeV, seemed to fit the requirements, as Close and Amsler reported in June in *Physics Letters B*.

While Weingarten and Amsler have doubts about each other's glueball candidate, Close suggests that both might be the same light glueball in two different guises, with slightly different masses. "What's possible," he explains, "is that the Crystal Barrel state and the theta are two complementary mixed states of glueball and conventional quark states."

The next heaviest glueball should weigh in at roughly 2200 MeV, according to both Weingarten and UK QCD, and it may have been sighted in the early 1980s at SLAC. Labeled the ξ, the particle appeared briefly along the path by which a J/Psi decays into a photon and two hadrons. However, since the SLAC sighting it had not reappeared.

This past August, however, a collaboration known as BES at the Institute of High-Energy Physics in Beijing reported at the International Symposium on Lepton-Photon physics in Beijing that it, too, had observed the ξ, at exactly the same energy SLAC had reported. Moreover, says Walter Toki of Colorado State University, a member of the collaboration, their candidate apparently decays as QCD suggests a glueball should: into a pair of pions (quark-antiquark pairs) as well as into proton and antiproton pairs. Carnegie Mellon's Gilman agrees: "It's a very good candidate to be a glueball."

What's needed to confirm these candidates as glueballs, everybody agrees, is more experimental data and even finer QCD calculations. Amsler's Crystal Barrel experiment will close up shop at the end of 1996, when CERN shuts off LEAR to begin building its Large Hadron Collider, but the BES collaboration is finishing a major upgrade of both the detector and the experiment, says Toki, and will go back on-line next spring. Meanwhile, three collaborations—one Japanese, one Italian, and one U.S.—are in the process of developing QCD-friendly supercomputers that will be up to 100 times faster than the current generation. And recently a handful of theorists have derived new schemes that may speed up the calculations by another factor of 1000 or more (see box).

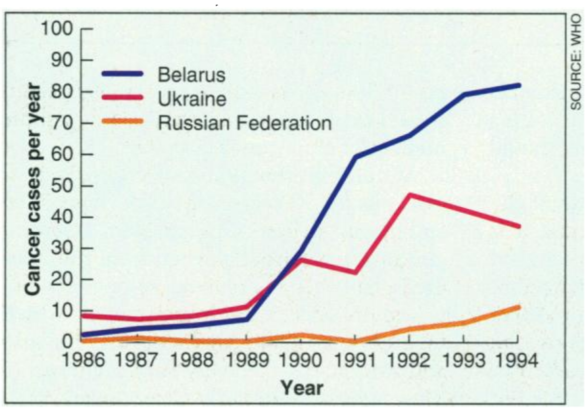
In the end, lattice QCD theorists hope that the accuracy of their predictions will rival that of the other Standard Model theories. At that point, having mastered the theory, they'll be able to look for holes in it—discrepancies between its predictions and observations that might point to new physics, beyond the Standard Model, says Wilson. "I have to remind people from time to time that general relativity, for instance, showed up in the *n*th decimal place of the orbit of Mercury—a very small correction. But that was the first indication that something was wrong" with Newtonian mechanics.

–Gary Taubes

RADIATION BIOLOGY

Chernobyl's Thyroid Cancer Toll

GENEVA—Last month, at an international meeting of some 600 radiation scientists,* an expert panel put its imprimatur on a scientific conclusion that has recently gained increasing acceptance: The explosive increase in childhood thyroid cancer in Belarus, the Ukraine, and the Russian Federation—the countries most contaminated by the 1986 Chernobyl nuclear accident—can be directly linked to the released radiation, and most likely to contamination by radioactive iodine isotopes.



Sharp increase. Childhoood thyroid cancer is rising in the three republics most affected by Chernobyl.

And the toll could be high. Keith Baverstock, coordinator of the World Health Organization's (WHO's) International Thyroid Project, says that the most conservative mathematical model for estimating risk predicts that "a few percent" of the approximately one million children exposed to radiation in Belarus could eventually contract the disease. And Dillwyn Williams, a thyroid expert at Cambridge University in the United Kingdom, told the meeting that for very young children in the most heavily exposed areas, this figure could rise as high as 10%.

But even though radiation is the main suspect in this thyroid cancer epidemic, questions remain about which radioactive isotopes are responsible and whether other factors—such as industrial pollution or a genetic predisposition to thyroid cancer—might help explain why the children have been so susceptible to the disease. "That's the challenge, to retrospectively reconstruct what the relative contributions of those [factors] are," says Bruce Wachholz, chief of the radiation effects branch of the U.S. National Cancer Institute (NCI).

Researchers originally suspected that the heavy contamination by cesium-137 caused the thyroid cancer increase. But they are currently focusing most of their attention on radioactive iodine, because the geographical distribution of the cancers most closely matches the pattern of fallout from this element. If iodine is indeed the main culprit, the finding could be significant for public health: Based on what is already known, WHO recommended last August that iodine tablets, which would saturate the thyroid and prevent it from taking up large amounts of radioactive iodine, be made available to all schoolchildren in Europe, where there are many nuclear power plants, in case of an accident.

Although it may make little difference for such preventive measures, knowing which iodine isotopes are at fault could help explain why the Chernobyl cancer epidemic is so virulent. I-131 has the longest half-life (8 days), but it's never been shown to cause thyroid cancer in humans, says Shigenobu Nagataki, dean of the Nagasaki University medical school. And this despite the fact that I-131 has been extensively used as a diagnostic tool and for therapy in such maladies as Graves' disease.

Nevertheless, says NCI's Wachholz, an effect in humans could have been missed, because these earlier studies were restricted to adults and adolescents. Little or no data exists for young children, who may be especially sensitive to I-131's effects. Other radioactive iodine isotopes, such as I-132, I-133, and I-135, might also be responsible, although their half-lives are counted in minutes or hours and their carcinogenic potential is poorly understood.

Even if most of the blame is pinned on radioactive iodine, other factors—including environmental pollution—may help explain why the thyroid cancer epidemic in children has been so explosive. "I am mostly convinced that the sharp increase is due to the radiation," says Nikolai Tronko, head of the Institute of Endocrinology and Metabolism in Kiev, "but we have to consider that the ecological situation is very poor in the Ukraine, so this could be a factor."

And Elisabeth Cardis, head of the program on radiation and cancer at the International Agency for Research on Cancer in Lyons, France, suspects that a possible genetic predisposition in some affected families may help explain why children have been so sensitive to the effects of radiation. Cardis notes that a preliminary survey she carried out with scientists in Belarus showed that a small but possibly significant number of children with thyroid cancer also had brothers or sisters with the disease. She is now planning a case control epidemiological study to further investigate the contribution that genetic factors might be making to the surprisingly high cancer toll.

Cardis's proposed study is just one of some two dozen studies of childhood thyroid cancer currently under way in the three republics. But even though the information that comes out of these studies will be too late to help the children already exposed to the Chernobyl radiation, it could prove valuable in case of future accidents. As WHO's Baverstock points out, "We are seeing [thyroid cancer] 500 kilometers from Chernobyl." And in Europe everyone lives within 500 kilometers of a nuclear power station.

–Michael Balter

* "Health Consequences of the Chernobyl and Other Radiological Accidents," sponsored by the World Health Organization, Geneva, Switzerland, 20 to 23 November.

ASTRONOMY

Just Another Billion-Sun Black Hole

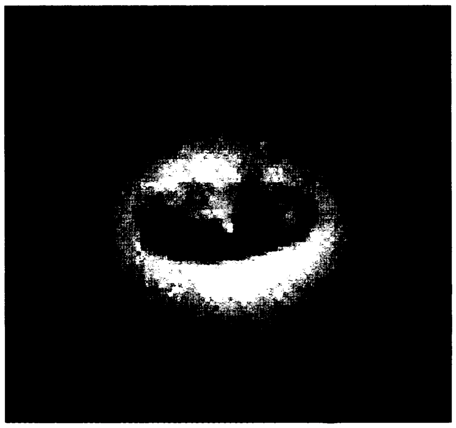
It's time, says Holland Ford, for astronomers to stop worrying about whether black holes exist at the centers of galaxies and start worrying about how they got there. Using the Hubble Space Telescope, the Johns Hopkins University astronomer and his colleagues looked into the heart of the galaxy NGC 4261 and saw a maelstrom that they say could only be stirred by an outsized black hole, more than a billion times as massive as the sun. The finding, announced last week, would bring to three the number of galaxies, all identified in the past 2 years, that seem to host black holes.

The clinching evidence for NGC 4261, like that for two other black hole candidates, is the speed at which a disk of material is whirling around an unseen center point. Three years ago, when Douglas Richstone, a theorist at the University of Michigan, saw a picture of the same disk without the velocity measurements, he said it looked enough like what he'd expect of a black hole that he'd bet $10 on it but not his car. Now, he says, "it's probably time to bet the car."

Theorists will also be putting heavier bets on their picture of active galaxies, the galaxy type to which all three black-hole hosts belong. Active galaxies give off far more radiation than expected from their population of stars. Theorists have speculated that the source of this radiation must be matter being torn apart in the vicinity of a black hole. The process has never been seen directly, but what the Space Telescope revealed at the center of NGC 4261 is powerful indirect evidence.

Within its bright nucleus is a dark disk of dust, 800 light-years across. The spectrum of the disk shows that it is rotating at up to 1.5 million kilometers an hour, implying that it is in the grip of a mass 1.2 billion times that of our sun. The rotational velocity of the dust increases toward the center, adds Laura Ferrarese, Ford's co-discoverer, which suggests that the mass is concentrated there. If so, the ratio of mass to light at the center of the disk is about 1000 times greater than in a normal elliptical galaxy. According to Ferrarese, Ford, and their colleague, Walter Jaffe at the Netherlands' Leiden Observatory, the combination of evidence all but mandates a black hole.

No one knows how a black hole could grow to the enormous size implied by these observations, but a peculiarity about NGC 4261 may suggest one answer. The dark disk is offset from the center of the galaxy, and its axis is perpendicular to the galaxy's axis. "That tells you that the disk was formed separately," says Ford, "and may have originated when NGC 4261 captured another small galaxy." Such captures, says Richstone, "are efficient ways to feed black holes. It seems plausible."



STSCI

Heart like a wheel. A dusty disk in nucleus of NGC 4261 betrays the black hole at its center.

But so far, plausible is as good as it gets. Says Ford, "We really have no idea how black holes get this large. We're just beginning to learn what the facts are."

–Ann Finkbeiner

Ann Finkbeiner's forthcoming book is on the effects of parental bereavement.