strange quark paired with a down quark) and emit neutrinos in the process.

Because the protons don't absorb the kaons as they would electrons, the protons remain protons rather than turning into neutrons. The result is a mixture of protons and neutrons steeped in what's called a kaon condensate, a state of matter described first in 1986 by David Kaplan and Ann Nelson, then junior fellows at Harvard, and in more detail in 1991 by David Politzer and Mark Wise of Caltech. And because the attraction between protons and neutrons is stronger than between neutrons and neutrons, the collapsed material is more compressible than theorists had previously assumed—and easier to squeeze down into a black hole.

The collapse into a black hole doesn't happen immediately, though, because the neutrinos trapped in this nuclear matter heat it, temporarily stabilizing it from further collapse. "Only when the neutrinos all leave," says Brown, "does the star cool down"—and, if the core weighs more than 1.5 solar masses, collapse further into a black hole. If the core weighs less than 1.5 solar masses, it will remain what Bethe and Brown call a nucleon star, made of both protons and neutrons, rather than a neutron star.

How Brown and Bethe's revisionist view of supernovas will be accepted remains to be seen. Woosley thinks "we could still live in a universe with a maximum mass of a neutron star at 1.8 or even 2 solar masses, and not be in contradiction with anything we know." Adds Weaver, "There's a fair amount of uncertainty in the physics of the core collapse process. [The] idea is a good one, but it's premature to say it solves the problem."

Still, there may be a way to test the theory, says Kulkarni of Caltech. The places to look, he says, are globular clusters, the tight knots of old stars that form a halo around the galaxy and dot its disk. Over their long lifespans, globular clusters have experienced a lot of supernovas, and if Brown and Bethe are right, they should be rich in small black holes. In the crowded environment of a globular cluster, the black holes would tend to pair up with ordinary stars, forming binary systems that might be revealed by rare, powerful x-ray outbursts, caused when material from the companion star falls into the black hole.

Watching for these outbursts isn't a perfect test, though. One catch is that their violent birth process might have left many of the black holes traveling fast enough to fly out of the globular clusters before they paired up. Another is that the x-rays from a black hole binary may look a lot like those from a neutron star binary. Concludes Kulkarni, "It will take a while to say anything."

Bethe isn't worried. For now, he says, the scenario will stand or fall not on observational tests but on the plausibility of its picture of collapsing nuclear matter. When asked whether other astrophysicists will come around, he said, "Yes. Maybe not all, but many."

–Gary Taubes

SOLID-STATE PHYSICS

Artificial Atom Unveils Quantum Effects

Imagine you could attach electrodes to a single atom and directly measure its behavior as you add electrons or slowly vary a magnetic field. It sounds far-fetched, but in the last several years, physicists have learned to do something like that. The physicists' toolbox isn't quite up to managing that trick with real atoms, though. Instead, they work with "artificial atoms": tiny patches of metal or semiconductor in which electrons are so tightly confined by electric fields that they fall into the kind of quantum energy levels seen in a real atom. But so far, physicists have had trouble making meaningful measurements on artificial atoms holding fewer than 100 electrons.

In last week's *Physical Review Letters*, Massachusetts Institute of Technology (MIT) physicist Ray Ashoori announced a new artificial atom, developed while he was a postdoc at AT&T Bell Laboratories, in which he can study as few as one or two electrons. "[Other physicists made] artificial uranium—we're making artificial hydrogen and helium," says Ashoori. "It's a much simpler thing to think about." With it, he can map out the atom-like energy levels with unprecedented resolution and study interactions among small numbers of electrons—phenomena that could become critical as technology starts to incorporate devices this tiny. "We all believe that these small semiconducting devices will be at the heart of computers," says physicist Ned Wingreen of the NEC Research Labs.

Ashoori makes his version of an artificial atom—also known as a quantum dot—in a thin layer of the semiconducting material gallium arsenide sandwiched between two layers of insulating material. Electrodes go on the top and bottom. When he applies a tiny voltage, electrons in the bottom electrode "tunnel" through the insulating layer into the gallium arsenide. Ashoori configures the top electrode so that it generates an electric field, drawing the electrons into a patch of gallium arsenide only a few hundred angstroms across. That region is still several hundred times the size of an atom, and each electron's quantum "wave function" spans many real atoms in the semiconductor. But the confinement area is still small enough to give rise to large quantum mechanical effects, mirroring what happens in a real atom.

Monitoring the electrons isn't easy, though. Ashoori relies on the fact that the movement of an electron from the bottom electrode into the dot creates a tiny, fraction-of-an-electron change in the charge of the upper electrode, which he measures using an ultra-sensitive transistor known as a HEMT—a High Electron Mobility Transistor, which amplifies a small change in input to a large voltage. MIT physicist Marc Kastner, who coined the term artificial atom, says he's impressed. "It's just awesome that anyone can measure single electrons," he says. "It's mind boggling."

That ability is opening the door to phenomena researchers have long wanted to observe in action, such as the effects of a magnetic field on the behavior of a pair of electrons in a confined region. In a larger area, the electrons would steer clear of each other, repelled by their identical negative charges. In the dot, however, they are forced to lie right on top of each other, like the electrons of a helium atom. However, a rule of quantum mechanics known as the Pauli exclusion principle prohibits two electrons in an atom from occupying the same quantum state at the same time, and these electrons generally distinguish themselves by a directional property known as spin.

An applied magnetic field tends to force the spins into alignment, which would make the electrons identical again. To conform to the Pauli rule, the electrons must find a new way to distinguish themselves, and so one jumps to a higher energy level. In an ordinary helium atom, forcing an electron to make the jump takes a magnetic field of hundreds of thousands of tesla—stronger than the magnetic field on the surface of the sun. In the artificial atom, theorists predicted just a year ago, it should it take just a few tesla. Ashoori explains that the spacing between energy levels is much smaller in the artificial atom, and the repulsive force between electrons plays a much larger role. As a result, they are more prone to jump out of each other's way given a magnetic push. Ashoori has now been able to demonstrate this effect in his two-electron artificial atom.

There's much more to explore in the world of artificial atoms, says Ashoori. Among them are the interactions of three to 10 electrons, a range that Ashoori says is "the subject of theoretical speculation." He also hopes to build artificial atoms that would mimic the magnetism of real iron. Beyond that, he envisions artificial molecules, formed by putting two artificial atoms in close enough proximity to form artificial chemical bonds. He might start with a hydrogen molecule, he says, and move on from there.

–Faye Flam