the two must be kept very low. And according to classical mechanics, there would not be enough energy to excite the electrons to jump across the gap. This is analogous to trying to throw a ball over a mountain. In the quantum mechanical world, however, the ball has a certain probability of tunneling through the mountain, if the mountain is very thin.

The scanning tunneling microscope has reached a horizontal resolution of 2 angstroms and a vertical resolution of a few hundredths of an angstrom, opening up new dimensions in the study of surfaces. Scientists are eager to define the arrangement and electronic states of surface atoms. This knowledge could lead to a better understanding of subjects ranging from integrated circuits to the details of electrochemical reactions on surfaces.

—R. Monastersky

Getting to the bottom of supermassive black holes

A supermassive black hole is an object (though philosophers may argue whether such a thing can truly be called an object) in which an amount of matter equivalent to millions or billions of suns drops out of the universe, so to speak. Characterized by Alexei V. Filippenko of the University of California at Berkeley as the "monsters" residing in the centers of quasars, Seyfert galaxies and similar structures collectively known as active galactic nuclei, supermassive black holes are generally held responsible for the high-powered activities characteristic of those structures. Controversy surrounds their existence, their outward appearance and their "feeding habits." As was illustrated in a cartoon displayed by Filippenko at last week's Third George Mason University Fall Workshop in Astrophysics, held in Fairfax City, Va., supermassive black holes can be seen as the Darth Vaders of astrophysics.

There is no *direct* evidence for the existence of supermassive black holes; they are Darth Vader-like in veiling their presence in clouds of secondary evidence. There *is* some direct evidence for ordinary black holes, the kind that have at most a few times the sun's mass. These ordinary black holes are supposed to be the end-stages of fairly heavy stars. When fuel runs out and the star's thermonuclear reactions cease, the gas and radiation pressures generated by those reactions fail, and the star can no longer maintain itself against its own gravity. It collapses until it is so dense and has such a strong gravitational field that nothing — no matter, no radiation, no signal of any kind — can escape it. It is thus consigned to oblivion, cut off from the rest of the universe. Observationally, some visible stars appear to orbit something invisible, and from the motion of the visible star, the invisible something seems to have the right density to be a black hole.

Supermassive black holes are another breed of oblivion. In the two-body case of the stars, astronomers can calculate the gravitational field in which the star orbits fairly precisely. In the case of the centers of quasars, Seyferts, liners, blasars and other subclasses of active galactic nuclei, they have only the evidence that extremely energetic activities, which produce between 10^{44} and 10^{47} ergs per second, are taking place in a very narrow space. This argues that something supermassive and superdense is there.

Some astrophysicists believe that supermassive black holes inhabit the centers of nearly every galaxy, including our own. In the case of our own and some nearby galaxies, which have fairly quiet nuclei rather than active ones, there is some dynamical evidence: The behavior of stars near the center of the galaxy seems to indicate the presence of a massive, dense object there. In the same location, the light output shows a sudden sharp dip, indicating that this ultraheavy thing is dark, ergo a black hole.

However, as Douglas O. Richstone of the University of Michigan at Ann Arbor pointed out at the George Mason workshop, all this evidence can be interpreted otherwise. He discussed work done by himself, Alan Dressler of the Mt. Wilson Observatory in Pasadena, Calif., and Scott Tremaine of the Canadian Institute for Theoretical Astrophysics in Toronto that reviews in detail and discounts the evidence for supermassive black holes in the centers of these nearby galaxies. With the aid of a computer model of a likely distribution of mass, light production and star velocities through the volume of the galaxy, they conclude that the specific evidence can be explained in other ways and that none of it is conclusive.

Filippenko argues the positive side. He concedes that part of the argument rests on assuming a continuity between active galactic nuclei and other galaxies, but he attacks Dressler's analysis in detail on a number of points. Basically, Richstone and his collaborators call the evidence circumstantial and inconclusive; Filippenko insists that it is better than they make out. Filippenko calls the nearby galaxy M87 "a low-luminosity Seyfert" and suggests that some local galaxies are dead quasars. This requires believing in what some astronomers refer to as "starving black holes," black holes sitting quietly, only rarely snapping up a passing star. "The monster is still there, but he's on his deathbed," Filppenko says.

While the quiet galaxies are controversial, probably everyone at the workshop would agree that active galactic nuclei most likely have supermassive black holes. Stuart L. Shapiro of Cornell University in Ithaca, N.Y., points out that everybody believes they're there; he set out to find out how they got there. In his scenario, the precursor of the supermassive black hole is a dense cluster of compact stars, something one might plausibly find in the center of a galaxy, which collapses under its own gravity. At first the collapse is fairly slow — "secular" is the technical term Shapiro uses — and explicable in terms of Newtonian gravity theory. However, the core of the cluster is driven into an Einsteinian, relativistic state, and then the collapse becomes catastrophic. At first the stars, gradually drawing closer to each other, begin to collide and sometimes coalesce. Eventually the coalescences produce objects so massive that they become neutron stars, stars in which pressure has crushed atomic nuclei to the point where no structures are left, only a lot of neutrons jammed tightly together.

In the catastrophic part of the collapse, the neutron stars collide and coalesce, eventually becoming black holes, which then ultimately gather into one giant black hole. It took a large computer program devised by Shapiro and Saul A. Teukolsky of Cornell to solve the problem. The computer produced an animated motion picture illustrating the collapse. In support of his contention, Shapiro points out that back in the 1970s, Stratoscope II, a balloon-borne telescope flown by astronomers from Princeton (N.J.) University, found such dense clusters in the centers of some galaxies.

Considering a similar kind of collapse of a dense star cluster, Leonid Ozernoy of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., finds it able to eventuate in four different kinds of objects. First is a supermassive black hole slowly absorbing the rest of the stars in the galactic nucleus. Second is a supermassive star with a black hole in its center, which Ozernoy calls "an unstable system" — to say the least. Third is a "frozen black hole," one that gets stuck at a certain size because the galactic nucleus starts to expand and deprives it of further material. Fourth is a giant black hole with mass equal to 100 million to 1 billion suns. Each of these things could be the powerhouse of a different class of active galactic nuclei, he suggests.

Once the supermassive black holes form, they eat anything that comes near enough to get caught in their gravity. This infalling matter — interstellar gas and disrupted stars — gathers in an accretion disk around the black hole. The stuff in the accretion disk gradually spirals inward toward the "event horizon," the black hole's point of no return, beyond which the infalling matter is lost to the observable universe.

There has been much controversy over the configuration of the accretion disk.

Some astrophysicists argue for a hot, fat disk; some for a cool, thin disk; others for a combination, a cool, thin disk surrounded by a hot corona. Now, according to Mitchell C. Begelman of the Joint Institute for Laboratory Astrophysics in Boulder, Colo., all three may be right under different circumstances. According to Begelman's theoretical analysis, each of these disk configurations can develop out of different initial conditions, and it may be the disk configuration that determines what kind of active galactic nucleus we see in a given instance.

Not all the matter that goes through the accretion disk crosses the event horizon. A lot of it gets deflected and shot away. Electromagnetic radiation is produced by and comes along with this outflowing matter. The spectrum observers see is a complicated combination of visible light, ultraviolet, X-ray and radio. Observers generally agree that this is a secondary spectrum much processed and reprocessed on the way out.

Forces stressing matter nearest the event horizon seem to produce high-energy gamma rays, according to Jean A. Eilek of New Mexico Tech in Socorro and A. C. Fabian of the Institute of Astronomy in Cambridge, England. These gamma rays, interacting with other matter, produce pairs of electrons and positrons. Thus the "atmosphere" – the matter immediately surrounding the black hole – consists of electrons and positrons mixed with gamma rays. Accelerated by shocks or by electric and magnetic fields, this atmosphere produces the observed spectrum.

However, the situation in the atmosphere is complex. As Fabian points out, electrons and positrons can annihilate each other, producing new gamma rays. There is thus a complicated interplay of linked cycles of production and destruction of electrons, positrons and gamma rays. This makes it difficult to find unambiguous spectral evidence for this electron-positron atmosphere. The annihilation produces gamma rays of a specific energy, but because of the complexity of the situation, says Fabian, this "is going to be hard to see." *– D.E. Thomsen*

Late-night legislation: New laws include revised Superfund

In an apparent eleventh-hour turnabout last week, President Reagan offered the departing 99th Congress a much-sought prize – his signature on the five-year, $9 billion Superfund bill. Environmental Protection Agency (EPA) Administrator Lee M. Thomas describes the bill as "strong legislation." Sen. Frank R. Lautenberg (D-N.J.) goes even farther, calling it "the most significant piece of environmental legislation [in] this decade."

The President had threatened to veto the bill, not only because of its cost – more than five times that of the initial five-year toxic-waste cleanup program – but also to protest how the program would be financed (SN: 10/11/86, p.230).

The new law requires that EPA ensure that long-term cleanup commence over the next five years at a minimum of 375 new sites, almost four times as many as during the initial five years. Moreover, it gives EPA less discretion; both the standards and the cleanup schedules it enforces will be set by statute.

Under the new legislation, health assessments are required for the most hazardous dumps – those on the "national priority" list. (The current priority list of 703 sites is eventually expected to at least double.) EPA must also compile a toxicological profile for each of the 275 most commonly found waste-site chemicals affecting health. Another new provision extends the period during which individuals can file health-related claims against dumpers; the statute of limitations now starts not upon exposure but upon illness.

In addition, the law sets up a $100 million research, demonstration and training program on new cleanup technologies; a $98 million research program to detect and evaluate waste hazards and their health effects; and specific authority for EPA to study indoor-air problems and their mitigation, especially those posed by radon (SN: 9/27/86, p.201).

The President has also just signed:

- the Federal Technology Transfer Act of 1986, on Oct. 20. The law establishes a monetary incentive system to reward inventors in federal laboratories, permits the federal laboratories to enter into exclusive licensing agreements with private companies and funds the Federal Laboratory Consortium – a network of people in the federal laboratories who assist inventors in translating the fruits of their creativity into marketable products. The act's budget is anticipated to be about $900,000 per year.
- the Computer Fraud and Abuse Act of 1986, on Oct. 16. This law makes it a federal offense to use a computer to damage or steal data from the federal government or from federally insured financial institutions, to damage or steal data through interstate computer manipulations or to traffic in computer passwords.

At press time, bills still awaiting the President's signature included:

- the Clean Water Act Reauthorization, passed unanimously, both in the House on Oct. 15 and in the Senate on Oct. 16. In addition to providing $18 billion over nine years for sewage treatment facilities, the bill proposes two new programs. One would provide $400,000 a year in grants so that state governments could set up programs to control chemical runoff from "nonpoint" pollution sources, such as farms, city streets and construction sites. A "toxic hotspots" provision would require that EPA and the states set stricter requirements for the discharge of emissions in areas where several heavy industrial polluters are sited nearby. This bill represents a "breakthrough" of sorts, according to Sharon Newsome of the National Wildlife Federation in Washington, D.C., which lobbied for its passage. Since the Clean Water Act expired in 1982, she says, the House and Senate have not been able to agree on funding for the reauthorized program, so money has been appropriated at about the same level from year to year. The President has objected to this bill's high price tag. But even if he pocket-vetoes it (does not sign it within 10 days after it reached his desk), the bill will probably be reintroduced, says Newsome. And, she says, a passage next year with anywhere near the support it got this month would suggest that there would be enough votes to override a presidential veto.
- the Asbestos Hazardous Emergency Response Act of 1986, also adopted unanimously, both by the House on Oct. 1 and by the Senate on Oct. 3. This would give EPA a year to develop regulations on the inspection, abatement and disposal of asbestos for the estimated 30,000 primary and secondary schools that may pose an asbestos hazard to a total of 50 million children. Public and private schools would have 33 months to prepare their asbestos management plans. The bill would also require EPA to develop an accreditation program for asbestos abatement contractors, and have the National Bureau of Standards develop a complementary accreditation program for asbestos analysis labs. Finally, it would add $100 million to the existing seven-year school asbestos-hazard-abatement loan program, now funded at $600 million; loans repaid to the federal government would be entered into a new "trust fund" from which additional school loans could be issued. According to Rick Hind at the Washington, D.C.-based U.S. Public Interest Research Group, "The President has indicated that he thinks the bill is overly regulatory" and may not sign it. But, says Hind, in addition to the bill's unqualified support from the Congress, there apparently is "quiet support for the bill at EPA." *– J. Raloff*