SCIENCE NEWS OF THE WEEK

Physics at the Edge of the Universe

Black holes are coming to be blamed for almost every celestial phenomenon that astronomers don't understand. With that sort of popularity it is not surprising that theorists have recently accelerated their studies of what happens or ought to happen in and around black holes.

The big surprise is that "all of a sudden," in the words of one interested theorist at the Eighth Texas Symposium on Relativistic Astrophysics last week in Boston, such studies have produced an interaction of quantum field theory (the theory of subatomic particles), general relativity and thermodynamics. Or, to put it another way, theorists began to look at what actually happens in the neighborhood of a black hole and found particle physics and thermodynamics lurking there.

This is not only a highly significant theoretical development, tending as it does toward the reunion of three separate branches of physics, it makes an observational prediction that may be verifiable by gamma-ray detectors. The prediction comes from Stephen F. Hawking of Cambridge University. Black holes, he says, can evaporate or explode, and black holes of a proper size formed at the beginning of the universe, if any such exist, may be in the last throes of popping off right now. If they are, the pops should give rise to bursts of gamma rays that should be observable by the next generation of gamma-ray astronomy equipment. Such explosions also leave the older theory in a somewhat bombed-out state. It becomes "fuzzy," as William Unruh of the University of British Columbia puts it; it can no longer predict what it used to be able to predict.

A black hole is a body so dense that it produces a gravitational field so strong that nothing, neither matter nor radiation, can escape from it. The body is thus effectively cut off from the rest of the universe. Astrophysicists have long believed that such a condition could be one of the endings for the life of a star. Its dead bulk would collapse under its own gravitation until it reached the black hole state.

Theorists used to suppose that once a black hole formed, it just stayed that way indefinitely. But when Hawking began to study the situation in detail he found that things can indeed come out of a black hole, subatomic particles to be specific.

"When quantum effects are taken into account, black holes are not completely black," Hawking told the symposium. The reason for the incomplete blackness, Hawking says, lies in the Heisenberg uncertainty principle. One of the things the uncertainty principle says is that a physical observation cannot measure to any desired precision both the amount of energy possessed by a given particle and the time of its emission or absorption. The more precisely the energy of a given particle is known, the more uncertain is the time of its emission or absorption by something else.

This uncertainty of time brings in the concept of virtual particles. A virtual particle is intrinsically undetectable because its whole existence lies within the uncertainty of the measure of time; it is emitted and absorbed very fast. A sophisticated view of the consequences of the uncertainty principle leads to the proposition that spacetime is full of a continual dance of virtual particle-antiparticle pairs. Such pairs are continually being created and annihilating themselves, but their lifetimes are so short as to be under the umbrella of the uncertainty principle so they do not cause any disturbance as far as physical observation is concerned.

This may be the situation in ordinary space, but not in the neighborhood of a black hole. Hawking's investigation shows that in the neighborhood of a black hole something rather strange can happen. One of such a virtual pair can fall down the hole, leaving its partner nothing to annihilate with. The partner thus left alone may follow its opposite number down the hole, but, Hawking says, "it may also escape to infinity where it appears to be radiation emitted by the black hole." Infinity to a physicist means any place sufficiently far away, so that what Hawking is saying is that to an observer far from the black hole, it will appear as if the black hole is emitting radiation. Furthermore that radiation will have a thermal spectrum and its emission will gradually deplete the black hole.

In this business everything depends on where the observer is, as Unruh made clear, approaching the problem from a different angle. He wants to see what particle physics looks like near a black hole. The usual mathematical definition of a particle that works well enough in the weak gravitational fields (that is, relatively flat spacetime) in which particle physicists usually work runs into difficulties when you try to apply it in the strong gravitational field of a black hole. Nevertheless, working within the constraints of the problem, Unruh manages to devise a hypothetical particle detector that ought to work in a strong gravitational field, and general relativists tend to agree that an Unruh detector will click if it emits or absorbs a particle. But the results of this hypothetical investigation are passing strange. Whether it emits or absorbs particles and how many depends on how the detector is seen to be moving through the field. An observer for whom the detector's motion appears accelerated will see it emit particles. The energy for this creation comes from the field (through the strain on the "rope" by which the detector is being dragged). The field is due to the black hole.

To a very distant observer (that's us, or at least we hope it is) the Unruh detector will appear to be accelerated as if it were in the constant gravitational field of the black hole. The spectrum emitted in the view of this distant observer is related to the particular acceleration produced by that field. Since a thermal spectrum gives the temperature of its emitter, Unruh and his fellow theorists are now able to assign a specific temperature to a given acceleration, and by way of the acceleration, to the mass of the particular black hole. Thus, as Dennis Sciama of Oxford University puts it, black holes obey the laws of thermodynamics. The temperatures that are assigned to them by this means are a measure of the speed of their self-dissipation and thus of their lifetimes.

And so the question arises: Might we be able to observe the radiation from a black hole? For one of stellar mass, the answer is not likely. The dissipation process is much too slow. The lifetime of a black hole with a mass equal to the sun's comes out to be 10^{54} times the present age of the universe.

One can figure out—and Hawking has done this—the mass of a black hole with a lifetime just equal to the age of the universe, one that would just be boiling off the last of itself right now. It comes to 10^{15} grams. This is the mass of a good sized meteoroid, say, a rock about a kilometer across. Today one would not expect such a rock to become a black hole by selfgravitation. The forces that engineers refer to as "strength of materials" are more than enough to prevent it.

But in the early moments of the universe things were far more tightly packed. This amount of mass might have been compressed in a space so small that it was on the verge of being a black hole. Irregular motions that disturbed the primordial homogeneity might have tipped the balance. We know that certain irregularities disturbed the original homogeneity slightly; matter articulated itself into galaxies and stars, but whether such mini black holes were produced is still somewhat moot.

If such mini black holes do exist, they would be the size of subatomic particles (about 10^{-10} centimeters across). Their last bursts would have about one percent of the sun's power, would take a tenth of a second and be mostly gamma rays. This is what the general relativists suggest that gamma-ray astronomers look for. How many there ought to be no one can say, but there might be enough for a pop a month.

Observable or not, as the black holes dissipate themselves, they leave behind certain problems for theory. In the center of each black hole is a singularity, and the evaporation or explosion of the black hole leaves the singularity naked and exposed. This is bad because theory is unequipped for singularities.

One can describe a singularity in several ways. It is a point where the mathematics becomes intractable or where the laws of physics fail. It is the place where spacetime disappears. Several physicists at the meeting were ready to refer to it as "the edge of the universe."

According to Hawking, the black-hole radiation process results in an extra degree of randomness or unpredictability in what is going on. In classical mechanics one can definitely predict both the position and velocity of an object. In ordinary quantum mechanics one can definitely predict one of those values at the expense of an uncertainty in knowing the other. In the physics around a naked singularity, one can predict neither. It is as if some of the necessary information has fallen off the edge of the universe, or alternately, that through the singularity a certain amount of random information has been introduced to our universe from elsewhere.

Information is not the only thing that falls off the edge. One of the longstanding rules of particle physics goes too, the rule of conservation of baryons. Particle physicists have always observed that in any kind of particle behavior the net number of baryons—particles belonging to the same class as the neutron and proton—is always conserved. But look what happens in a black hole. At black hole densities, what goes in is mostly neutrons. What comes out is a random distribution that includes antineutrons and other antibaryons. Since antibaryons count as minus, the net baryon number coming out is less than what went in, and it seems that somehow baryons have fallen off the edge of the universe. Of course as Bryce De Witt of the University of Texas points out, not all theorists agree with the edge-of-the-universe definition of a singularity. There is a belief that if a theory of general relativity completely compatible with quantum field theory is achieved—there is still a long and difficult road to go—it will show us how to deal with a singularity.

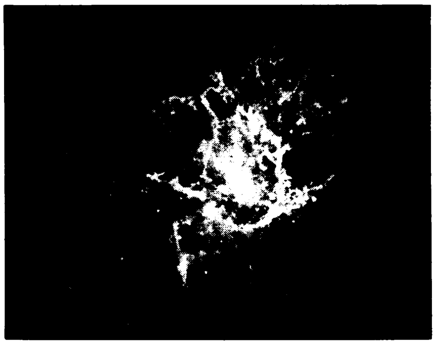
However that may be, if the gamma-ray astronomers should see what Hawking says they ought to see, we may have to conclude that out there in some direction or other are one or more putative edges of the universe, lurking nakedly, challenging us to deal with them. □

Gamma-ray laser in the sky

Physicists in terrestrial laboratories would love to be able to make X-ray or gamma-ray lasers. There is so much that could be done both in scientific experiments and practical procedures with coherent radiation in those parts of the spectrum. If a group at Bell Telephone Laboratories is correctly interpreting its data, the first gamma-ray laser may have been found—in the sky. It is everybody's favorite neutron star, the Crab nebula pulsar.

Martin Leventhal of Bell Labs told the Eighth Texas Symposium on Relativistic Astrophysics that gamma-ray spectra of the Crab turned up a line emission at 400 kilo-electron-volts energy. The line does not appear in the nebular background, so it must come from the pulsar.

Such a line is indicative of electron-positron annihilation on the surface of the neutron star. The strength of this line requires 10^{41} positrons per second to fall on the surface of the pulsar. Theory says that if as many as 10^{40} positrons per second fall on its surface, the Crab pulsar must have a surface coated with a kind of electron-positron fluid that forms real macroscopic drops. This fluid would produce induced annihilation radiation, or says Leventhal, "a gamma-ray laser in the sky—pretty fantastic." □



Hale Observatories

Crab nebula: Site of a natural laser.

A preview of the science budget for '78

Basic research is scheduled to receive a 3 percent increase in funds over and above an allowance for inflation in the federal budget to be submitted to Congress early in 1977. This word comes from presidential science adviser H. Guyford Stever, who offered a brief pre-Christmas preview of the science budget in a press briefing at the White House on Dec. 16. The briefing came after a meeting of Stever and 19 leaders in science and engineering with President Ford. The budget in question is for fiscal 1978, starting Oct. 1, 1977.

The final figures will, of course, have to be reviewed by incoming President Carter, but the press of time will limit the number of detailed changes that can be made. Also, it is to be remembered that all budget announcements are only proposals; Congress can, and usually does, reshape them considerably.

Detailed figures had not been finally determined, but Stever listed certain programs that do receive special emphasis in the proposed science budget.

- The National Aeronautics and Space Administration would receive money to begin development of the on-again, off-again orbiting space telescope, to be launched and tended by the space shuttle. NASA would also receive funds to begin work on a Jupiter Orbiter and Probe, scheduled for launch in 1981, and on LANDSAT D, the fourth in a series of earth resources satellites. No money will apparently be provided for a follow-up Viking Mars probe, which some scientists had hoped to launch in 1981. Also, no mention was made of a Lunar Polar Orbiter, which NASA has been pushing.
- The earthquake research program would receive roughly a doubling of its present $25 million budget. Stever said President Ford has personally taken a "growing interest in the earthquake problem" and that there will be "strong acceleration" of efforts to predict and mitigate the effects of earthquakes. The renewed interest will include an increase in the number of monitoring devices that measure uplift around faults, and more speculative precursors of earthquakes—such as excitement among animals—will also gain attention.
- A competitive grant program will be set up to encourage scientists from a wide range of disciplines to perform agriculture-related research. The program will be administered by the Agriculture Department in much the same manner as research projects funded by the National Science Foundation, rather than relying so heavily on scientists working for the department. Some $25 to $35 million will be available for the grants.
- Defense R&D is scheduled to increase 15 percent. Some new initiatives can be expected in the general health science area, but no particulars were yet available.

Stever said the Soviet Union had requested LANDSAT data to confirm its estimates of its bumper wheat crop this year, and the data did confirm that. NASA has been making wheat estimates under a project called LACIE (Large Area Crop Inventory Experiment). Stever said that National Academy of Sciences president Philip Handler announced at the budget meeting that the Academy will soon be releasing a report on how such satellite programs as LANDSAT can be used to help developing countries. □