COLLISION

If Earthquake is shattering, Jaws engulfing and The Towering Inferno incinerating, imagine the crash of two black holes. Supercastastrophe.

BY DIETRICK E. THOMSEN

Einstein's equations are probably his greatest legacy to physics. They are a summation of his theory of general relativity and describe the characteristics of the gravitational field and space-time under the assumptions of the theory. Since they were published in 1916 it has been one of the tasks of general relativists to derive from them solutions describing particular situations involving bodies with very strong gravitational fields.

The only solutions derived so far concern static situations, the configuration of and gravitational fields surrounding one such body. The Schwarzschild solution is for a single black hole; the Kerr solution for a single rotating black hole. If the interaction of other bodies with the black hole is considered, the other bodies are made to be very small so that their gravitational fields are negligible and do not disturb the arrangement appreciably.

There is now a chance of obtaining a dynamic solution of Einstein's equations, one that would describe the interaction of two heavy, general-relativistically gravitating bodies. The simplest situation of this sort, the collision of two black holes, is now being worked on, and according to Larry Smarr of Princeton University Observatory, who spoke at the recent Symposium on Theoretical Principles in Astrophysics and Relativity at the University of Chicago, the prospect for success is good.

The situation in general relativity now is as if Newton, after hitting on the idea of universal gravitation, had been able to solve his equations to get a description of the earth's gravitational field and the motion of the apple that fell (let us hope not really on his head), but had never reached his even greater achievement, explaining the interaction of the earth and the moon, two bodies of comparable size and gravitational field strength. (Incidentally, that's as far as Newtonian solutions ever got. In 300 and some years nobody has managed yet to solve the Newtonian three-body problem, and the influence of a third body can be treated only if it is marginal compared to the interaction of the other two, what mathematicians call a small perturbation.)

Solution of the Newtonian two-body problem had some practical, if not quite down-to-earth, results. Without it Aldrin and cohorts would never have trod the lunar regolith. Solution of the Einsteinian two-body problem takes us to a much more esoteric realm. A number of astrophysicists believe it will be important in understanding the physics of the centers of galaxies.

Galactic centers are places where some kind of energetic phenomena is going on. So much is observed fact. They emit a good deal of radiation in various ranges of the electromagnetic spectrum. What follows is hypothesis. Some astrophysicists say galactic centers are places in which numbers of exotic objects such as black holes (and possibly ordinary stars as well), are jumbled together much more closely than they are in the outer reaches of galaxies. These objects interact with each other in various ways to produce the observed energy. One possibility is a black-hole collision.

It thus becomes important to know what happens when two black holes collide. Do they bounce? Do they coalesce? If they coalesce, does the union then have a greater probability for attracting and swallowing others and so on until the whole universe . . .? Or do two colliding black holes destroy each other, leaving behind naked singularities? (A singularity is the place at the center of every black hole where space-time becomes too twisted for general relativity to deal with. A singularity stripped of its opaque black-hole covering is frightening for general relativists to contemplate (SN: 7/12/75, p. 28). The proper solution to the Einstein equations should answer the questions.)

To solve his equations, Newton had to invent the branch of mathematics known as integral calculus. Today college students learn what he invented. Einstein's equations belong to a much more difficult mathematical breed than Newton's differential equations, and they are particularly intractable examples of their breed. Furthermore, there are ten of them.

Newton could regard space and time as a fixed framework, in which his physics operated. In Einsteinian physics space-time is a participant in the action. Einstein viewed gravity as an effect of the curvature of space-time so that where there are strong gravitational fields there are sharp curvatures and weird distortions of space and time. When there are two bodies contributing significantly to the distortions, the complexities of describing them are multiplied many fold compared to the single-body case. In fact, says Smarr, the distortions of space-time and the nature of gravitation conspire to frustrate a solution unless the theorists figure out how to force them to yield one.

The work involved inventing an entirely new mathematical and computer technology to do the job. It was started under Bryce DeWitt at the University of North Carolina and has been continued by Smarr and Irvin York.

Basically, the work involves following the changes in the curvature of space as the black holes come together. The theorists want to follow the evolution of a three-dimensional hypersurface through time as the collision proceeds. The hypersurface of especial interest is the event horizon, the place where communication between inside the black hole and outside breaks off. If the area of the event horizon decreases, the system is evolving toward a naked singularity and all the problems that entails.

But serious difficulty surfaces when the theorists simply try to follow the evolution of a hypersurface through time and calculate the gravitational fields it sees. Each element of the surface moves through time along its own lines. Gravity is an attractive force, and the effect of the attractiveness on this kind of space-time problem, says Smarr, is to focus the coordinates, to bend all those lines of development together to a point. Such a point is a singularity. There the various quantities become mathematically undefined; time stops, and so does the computer.

What the theorists want to do then is to build singularity avoidance into the mathematical program. This amounts to choosing coordinates with the least convergence. It can also be viewed as choosing the right time scale. Time scales vary greatly from observer to observer in a situation like this. What is microseconds to one can be centuries to another. What is wanted is the optimum clock rate for following the evolution of the collision as far into the future as possible. The way the theorists developed goes by the name of "maximal slicing." It sets up the mathematics "to let space-time itself more or less sniff out how to go forward," as Smarr puts it. When it sees increasing curvature, it imposes an automatic singularity avoidance, veering the coordinates away from the focus.

They have computed the collision part way, to a point where they see a constriction in the horizon, a kind of dumbbell shape that indicates "two black holes have actually merged." By now the coordinates that started out as squares have been badly stretched and have become hard to compute. To compensate, York and Smarr have invented what they call a "shear vector" to push the coordinates back into a more tractable shape. With this they think they can compute as far into the future as they want.

It appears that future will be stormy. "The actual collision is a terribly violent event," says Smarr. It generates strong bursts of gravitational radiation that use up several percent of the mass in the system, a truly magnificent rate of mass-to-energy conversion for any kind of physical process. The means for computing the detailed shape of this cosmic thunderclap are on the computer now, ready to go. □