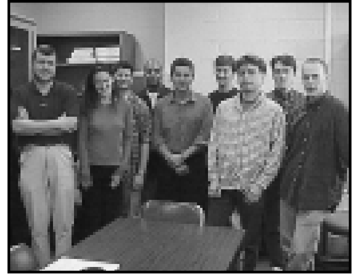


▲ *The Penn State Numerical Relativity Group. Jorge Pullin, Deirdre Shoemaker, Kenneth Smith, David Garrison, Pablo Laguna, Keith Lockitch, Erik Schnetter, Gioel Calabrese and Bernard Kelly. Not present: Manuel Tiglio.*

The Dance of Two Black Holes

Once upon a time, black holes were a fascinating theoretical artifact from the mathematics of general relativity—interesting concept, great stuff for science fiction. We've come a long way since 1915 when Einstein laid out his theory that rocked our world.

The Hubble Space Telescope and NASA's Chandra X-ray Observatory have convincingly lifted black holes from theory into reality. Still, the evidence is circumstantial. Looking for a black hole, says Stephen Hawking, is like trying to find a black cat in a coal cellar. As Penn State astrophysicist Pablo Laguna and postdoctoral fellow Deirdre Shoemaker like to point out, the way to clinch, indisputably, that black holes exist and that Einstein's equations are right is to detect gravity waves from two black holes.

Tuning the Gravity-Wave Radio

Detecting gravity waves is the job cut out for LIGO (Laser Interferometer Gravitational-Wave Observatory), Virgo and GEO600. LIGO is two NSF-funded gravity-wave detectors—in Louisiana and Hanford, Washington—now undergoing testing. Virgo and GEO600 are under construction in Europe. These projects represent a pioneering effort to develop an invaluable new set of eyes—gravity eyes—for seeing the universe.

Einstein's theory predicts that accelerating movements of massive objects in space, such as supernova explosions and black holes, will produce ripples traveling at light-speed through space-time. As with black holes, there's indirect evidence he was right, but compared to other wave phenomena, like electromagnetism, which brings us radio and TV, gravity waves are very weak. Einstein speculated they might never be detected. If you think of LIGO as the gigantic antenna for a radio receiver, the strongest possible signal might be a faint crackle as you turn the dial.

To improve chances of hearing the first crackle of gravity from the cosmos, researchers like Laguna and Shoemaker are using the most powerful supercomputers they can find to solve Einstein's equations. Their field is called numerical relativity, and with collaborators at the University of Texas and the University of Pittsburgh, the Penn State team used systems at PSC, at NCSA in Illinois and elsewhere, to simulate two black holes merging in what's called a grazing collision—only the second time this has been accomplished. Their numerical approach, called black-hole excision, makes a notable dent in the two-black-hole problem, the major challenge of this challenging field.

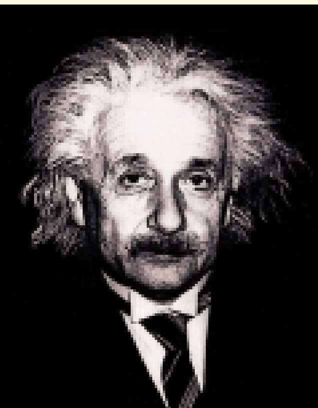
"Einstein's equations describe gravity via an elegant but complicated set of non-linear partial differential equations," says Laguna. "Their complexity requires the most powerful supercomputers available. Accurately solving the two-black-hole problem, formulated conceptually by Einstein 80 years ago, will represent an historic moment in the development of general relativity theory, with extremely important implications for astrophysics and cosmology."

A single black hole doesn't make gravity waves, and colliding black holes may be the best shot at detecting them. Theory says it's one of the strongest signals on the gravity-wave dial. To know if a crackle of static is the dance of two black holes or cosmic noise, the detectors need the answers numerical relativists are working to provide.

Black Holes without the Holes

The killer for simulating black holes is the singularity, the point of infinite density and space-time curvature that, mathematically speaking, makes a black hole a black hole. "Simply put," says Shoemaker, "the numbers get too big too fast, and the computation crashes." One approach, employed by researchers at the Albert Einstein Institute near Berlin with some success, is to exploit the relativity of time by slowing down how fast clocks tick near the singularity. This has the drawback that it adds to the already severe computational demands. With software they call AGAVE, the Penn State-Pittsburgh-Texas team took the less-traveled road of surgically removing the singularity from the domain of the calculation.

With 40 processors of NCSA's SGI Origin 2000, their simulation required nearly 100 hours. There's simplifying assumptions, such as two equal mass black holes, but the result is, you might say, a smashing success that pushes beyond prior work. Excision tamed the numerical instabilities long enough for



[Formulated by Einstein, the two-black-hole problem holds extremely important implications for astrophysics and cosmology.]

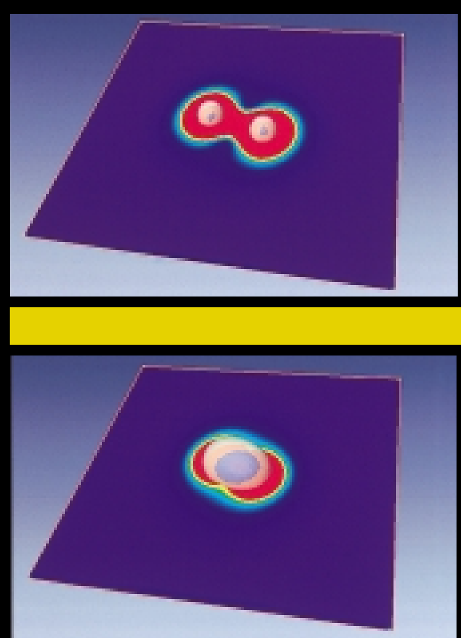
E. Schreier (STScI) and NASA

A jumble of blue star-clusters, glowing gas clouds and dust lanes surround an apparent black hole at the center of galaxy Centaurus A, a mere 10 million light years from Earth, recorded by the Hubble Space Telescope.

the black holes to merge and evolve for a short period as one large black hole before the simulation crashed. There's not yet accurate gravity-wave predictions to hand over to LIGO, but the next mountain now looks more climbable. That mountain, two black holes that orbit each other before they coalesce, is a few years away say the researchers.

Laguna lights up thinking of PSC's new terascale system, a leap forward that will allow the team to push further. "We believe one of the severe problems we have now is that the merged black hole gets too close to the boundaries of the computational domain. With the new machine, we can shift the outer boundary outward."

More information:
http://www.psc.edu/science/laguna.html



▶ Grazing Collision of Two Black Holes
In these two snapshots from the simulation, transparent spheres represent the "apparent" horizon of the black holes. The first snapshot shows two equal-mass black holes caught in each other's gravitational pull; the second shows the large black hole formed as they merge. The bluish area inside the spheres represents the excised region. Color gradations (from red to purple) indicate relative strength of the gravitational field.