Ripples in Spacetime - Solved!

Lonestar supercomputer instrumental in solving binary black-hole simulations

The location of the two black holes is marked by the singularities in the function psi, one of the components of the gravitational field. In the moving puncture approach these singularities move about the computational grid, which led to the computational breakthrough.

Einstein would be proud. One hundred years after the great scientist and humanist challenged conventional wisdom and published his famous Special Theory of Relativity (1905), a team of modern-day physics researchers at The University of Texas at Brownsville (UTB) and the Rochester Institute of Technology have finally solved the Einstein field equations for coalescing black hole binaries on supercomputers.

This groundbreaking research has produced a radical change in the field of numerical relativity with important consequences for gravitational wave detection and astrophysics. See published paper: Merger Recoils and Spin Flips from Generic Black-Hole Binaries.

Through sheer ingenuity, innate curiosity and great dedication, scientists Manuela Campanelli, Carlos Lousto, Yosef Zlochower and David Merritt have - for the first time - produced simulations of generic, highly-spinning black holes with unequal masses that can actually be observed in nature. Research had so far only focused on "idealized" cases of non-spinning black holes.

Lousto, an associate professor at the Center for Gravitational Wave Astronomy at UTB, says that observing, understanding and making predictions about black holes fulfills a deep-seated desire for curiosity in all of us. "As scientists, we are compelled to conduct this very hard research. The human spirit yearns to learn more about nature, our origins and how the universe continues to evolve."

Since the 1970s, scientists have been trying to find the right mathematical formulas to solve the Einstein field equations for black holes, but the equations were so complex that every attempt, until now, failed; the code would crash because computers simply could not handle the complexity of numerical requirements and the number of variables involved.

Today, major advances in computation are enabling scientists to solve increasingly larger and more complex problems, such as simulating how black holes form, evolve and interact. The Lonestar supercomputer at the Texas Advanced Computing Center (TACC) was instrumental in running the simulations that led to this scientific breakthrough.

"Lonestar is a really fantastic machine," says Lousto. "At UTB, we develop new code using adaptive mesh refinement (AMR) which improves the speed and capability of the code. But to do this successfully, we require excellent communication between the nodes. With its high-speed InfiniBand interconnect, Lonestar offers a huge advantage over other machines, and we have benefited greatly."

This new discovery provides much greater insight into one of the most awe-inspiring events predicted by Einstein's theory of general relativity, the merger of two black holes, making it easier for scientists to map black holes in space. As a result of this work, scientists around the world have published more than 50 follow-up papers in the past year.

Spinning black holes play an important role in some of the most energetic astrophysical phenomena in the universe. They reside at the core of most galaxies and form part of the main engine of gamma-ray bursts, being much more efficient at converting matter into radiation than non-spinning black holes. They are also responsible for the radio jets observed in active galactic nuclei, and the merger of two non-aligned spinning black holes is a possible explanation for the rapid directional changes observed in these jets when galaxies collide.

For more info, contact: Faith Singer-Villalobos, Public Relations, faith@tacc.utexas.edu, 512.232.5771

According to Campanelli, Lousto, Zlochower and Merritt, these breakthroughs are particularly exciting because the current ground-based gravitational wave detectors, such as Laser Interferometer Gravitational-Wave Observatory (LIGO), are just on the verge of detecting gravitational waves, and binary black hole coalescences are a key source of gravitational waves for both these detectors and future space-based detectors, such as Laser Interferometer Space Antenna (LISA). These detectors will enable society to learn more about gravity, how gravitational waves propagate, and the sources that emit them. Once detected, gravitational waves will give humanity a revolutionary new view of the universe.

In a 2006 Congressional report, Congressman Solomon P. Ortiz of the U.S. House of Representatives shared with Congress that the results from this discovery will prepare the NASA/European Space Agency's 2015 gravitational wave mission, which aims to detect the gravitational waves produced from super massive black hole collisions, also considered the most potent source of energy in the universe.

Ortiz said of the physicists, "Several groups have attempted to reach a solution to the computational complications involved in gravitational wave detection, leaving most researchers predicting that this elusive discovery would be incremental, through an arduous series of small improvements. UTB scientists, however, have contradicted this belief with their out-of-the-box thinking and relentless perseverance...they are establishing south Texas as a force in space science issues and as a leader in innovation."

The University of Texas at Brownsville is an institution within The University of Texas System. Dr. Lousto plans to continue his research with support from UT System and the National Science Foundation TeraGrid Project.

Recent published results about spinning black holes:

Spinning-black-hole binaries: The orbital hang up. M. Campanelli, C. Lousto, Y. Zlochower, Phys.Rev. D74:041501, 2006. E-Print Archive: gr-qc/0604012.

Spin-orbit interactions in black-hole binaries. M. Campanelli, C. Lousto, Y. Zlochower, Phys.Rev. D74:084023, 2006. E-Print Archive: astro-ph/0608275.

Spin Flips and Precession in Black-Hole-Binary Mergers. M. Campanelli, C. Lousto, Y. Zlochower, B. Krishnan, D. Merritt, 2006. E-Print Archive: gr-qc/0612076.

Tracing black hole mergers through radio lobe morphology. D. Merritt and R.D. Ekers, Science 297:1310-1313, 2002. E-Print Archive: astro-ph/0208001.

Merger Recoils and Spin Flips From Generic Black-Hole Binaries. M.Campanelli, C. O. Lousto, Y. Zlochower, D. Merritt, 2007. E-Print Archive: gr-qc/0701164.