IMPROVED TRUMPET INITIAL LAPSE AND SHIFT FOR BINARY BLACK HOLE SIMULATIONS

Nicole Rosato, Rochester Institute of Technology
2019–2020 Graduate Fellow

EXECUTIVE SUMMARY

This research project focuses on reducing error in simulations of merging pairs of black holes in order to better study the gravitational wave emission at merger. It currently takes months of supercomputer time to perform difficult simulations (for example, where the black holes are spinning quickly or are very differently sized), and increasing the accuracy of these simulations translates to an increase in required computational resources. We would like to change the initial values given to the gauge equations to be closer to their settled shape, allowing the gauge to settle more quickly and reducing error in the simulations.

RESEARCH CHALLENGE

The challenge of this research is to gain accuracy in the most challenging binary black hole simulations without increasing computational cost. The low mass-ratio and high-spin areas of parameter space are very sparsely covered; we hope this project will fill out that parameter space so that researchers have waveforms to compare to potential detections from the Laser Interferometer Gravitational-Wave Observatory.

METHODS & CODES

To perform numerical relativity simulations, we use the Einstein Toolkit and specifically modify the Rochester Institute of Technology TwoPunctures initial data thorn. We are constructing new initial data values for the gauge based on their expected settled shape.

RESULTS & IMPACT

We are seeing a reduction in error using these new initial data, and therefore are gaining accuracy without actually having to use more computational resources.

WHY BLUE WATERS

These simulations require the use of large-scale computing resources due to computational intensity. The staff itself is knowledgeable about both the system and about the software I use.

Nicole Rosato is in the second year of a doctoral program in mathematical modeling at the Rochester Institute of Technology. She is working under the direction of Carlos Lousto and hopes to graduate in 2021.

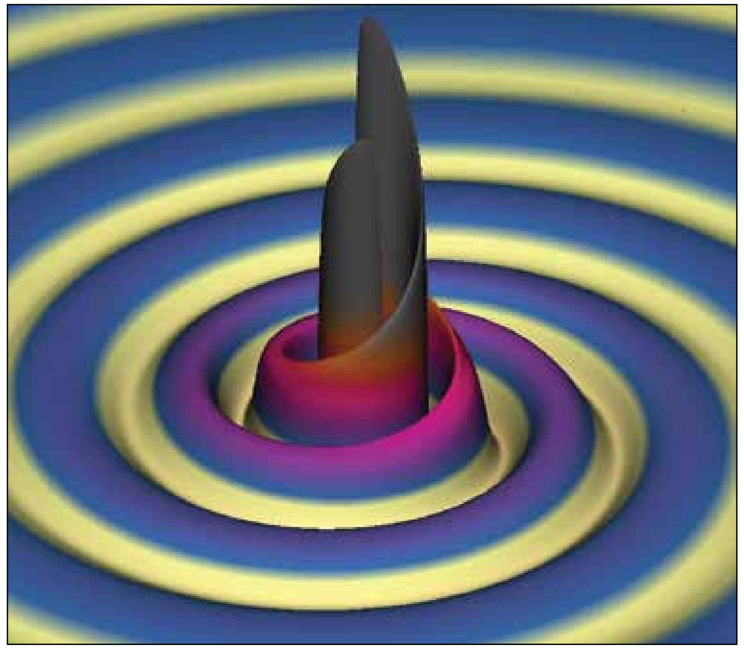

Figure 1: A visualization of gravitational radiation emitted 7 milliseconds after the merger of binary black hole system GW150914, detected by the Laser Interferometer Gravitational-Wave Observatory on September 14, 2015.

UNDERSTANDING THE PHYSICAL PROCESSES CAUSING INTERMEDIATE-DEPTH EARTHQUAKES

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EXECUTIVE SUMMARY

This project aims to constrain the mechanisms of intermediate-depth earthquakes, which are rare but can be incredibly damaging, especially at large magnitude. (The recent magnitude 8.0 earthquake in Peru, fortunately, struck in a sparsely populated region.) These earthquakes occur under conditions where the standard physical model for earthquakes occurring in the crust breaks down, and because they do not occur on known faults, they can potentially be harder to forecast. Furthermore, data from these earthquakes show different frequency characteristics than shallow earthquakes, so it is important to understand how intermediate-depth earthquakes nucleate and how they vary from region to region, not only for scientific curiosity but also for earthquake engineering purposes. This work was done by applying a novel approach—simulating the physics of these earthquakes by utilizing the hypothesized mechanisms—and comparing the simulation data to real data, to better understand intermediate-depth earthquakes and to formulate a better fundamental model for them.

RESEARCH CHALLENGE

Intermediate-depth, intraslab earthquakes, which account for less than 1% of the world's seismic activity, occur above the temperatures and pressures where the brittle failure found in shallow earthquakes is thought to be possible. Seismologists have generally agreed that the mechanism of initiation for intermediate-depth earthquakes is, thus, distinct from that of shallow earthquakes, and that it is highly likely some sort of dynamic weakening mechanism is involved. Data from intermediate-depth earthquakes also show characteristic differences from shallow earthquakes, such as high stress changes and low radiated efficiency. However, in the absence of good fundamental physical source models, most studies of intermediate-depth earthquakes utilize models extrapolated from the physics of shallow earthquakes. The aim of this project is to refine the source model for intermediate-depth events to better test the hypothesis of a dynamic weakening mechanism.

METHODS & CODES

In this project, the PI looked at waveform data from intermediate-depth earthquakes in Kyushu, Japan, which are available from the Hi-Net and Kik-Net seismometer and strong motion catalogs from the National Research Institute for Earth Science and Disaster Research. Previous work examined the scaling of seismic stress drop with the earthquake moment using the generalized circular crack model. However, that work determined that the results were harder to extrapolate to larger earthquakes, which appeared less cracklike.

The PI used the Support Operator Rupture Dynamics (SORD) code to synthesize earthquake waveforms. An entire fault surface was modeled by coupled nodes, where rupture is subject to local stress conditions and a friction law. Dynamic weakening mechanisms, which the researcher hypothesizes to be more important in intermediate-depth earthquakes, can be approximated by spatial variation of the simpler slip-weakening law. She modeled large earthquakes for which kinematic finite-source models exist and determined the physical feasibility of these model slip maps. The PI also tried to incorporate dynamic weakening mechanisms into the earthquake source to observe the impacts on waveforms and spectra.

RESULTS & IMPACT

The major result of this work thus far is the finding that slip map results from kinematic inversions (unconstrained by governing physics) can be physically impossible under conditions for dynamic rupture. Currently, physical models for intermediate-depth earthquakes are nonexistent; however, incorporating effects of dynamic weakening in these simulations is beginning to create better explanations for the atypical data retrieved from these earthquakes. Although analysis is ongoing, the technique of applying a physics-based simulation, enabled by high-performance computing, to study intermediate-depth earthquakes will help to bridge the gap between hypothesized mechanisms and the data. In addition, although rare, large intermediate-depth earthquakes can be very damaging, as the 2017 Chiapas event illustrates. Hence, having an accurate source model of these earthquakes for better ground motion prediction is also important to earthquake engineers.

WHY BLUE WATERS

Access to the Blue Waters system, where the SORD code is already optimized, has been pivotal to running the forward dynamic rupture simulations. The Blue Waters project staff were extremely helpful and prompt in their responses, which has greatly accelerated the progress of this research.

A fifth-year Ph.D. candidate in geophysics, Shanna Chu expects to graduate in March 2020 and is working under the direction of Gregory Beroza at Stanford University.