PETASCALE SIMULATIONS OF MERGING BLACK HOLES AND NEUTRON STARS

Allocation: NSF PRAC/8,200 Knh
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EXECUTIVE SUMMARY

The primary purpose of the project is the numerical solution of Einstein's equations of general relativity. The goal is to track the coalescence and merger of binary black hole systems and to calculate the emitted gravitational waves (GWs). Another goal is to carry out a similar project for binary systems containing a black hole and a neutron star or two neutron stars. The work is aimed at providing theoretical predictions that can be compared with the signals measured by the National Science Foundation's LIGO (Laser Interferometer Gravitational-Wave Observatory) GW detector.

RESEARCH CHALLENGE

The primary scientific objective of our project is to theoretically underpin and improve the ability of LIGO to extract the rich information that the observed GWs carry. Gravitational waves provide a new window on the universe that will enable us to test our understanding of fundamental physics as well as learn about the most extreme events in the cosmos.

METHODS & CODES

Most of the computations are done with the SpEC code (Spectral Einstein Code) [1] developed by the collaboration. The numerical methods it uses make it the fastest and most accurate code for treating black holes [2]. We are also developing a new code, SpECTRE, with innovative methods to treat neutron star systems.

RESULTS & IMPACT

We will release a new version of our public catalog of gravitational waveforms for use by all researchers, largely through simulations on Blue Waters. The new version will increase the size of the catalog from 174 waveforms to well over a thousand. These waveforms have already been used to produce a very accurate waveform model that LIGO can use in its data analysis.

WHY BLUE WATERS

Our numerical code runs most efficiently on 50 to 70 processors for each waveform. Blue Waters' nodes are perfectly sized for us to use one or two nodes per waveform and explore hundreds of different parameter values to develop our catalog.

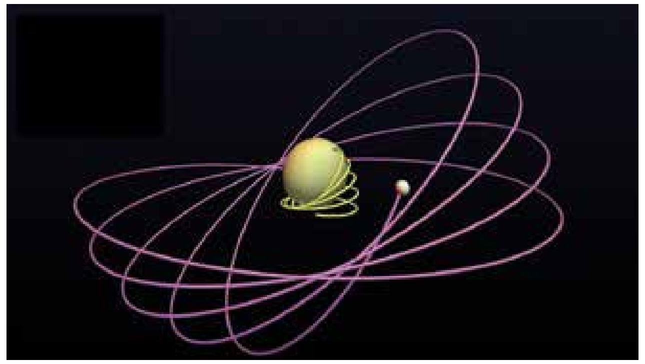

Figure 1: Two spinning black holes in orbit around each other, calculated by full solution of Einstein's equations of general relativity. In Newtonian gravity, the orbits would stay in a plane. Because the holes are spinning, the orbits precess (tilt).

CHEMISTRY AND THE EARLY UNIVERSE

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EXECUTIVE SUMMARY

This project focuses on constructing and executing models of the formation of the stellar nurseries of the first stars in the universe, simulating their hydrodynamic and chemical properties to high resolution. In doing so, we hope to constrain the masses of these stars and better understand their end products and descendants. In support of this, we have constructed a cross-domain software package for the efficient solution of chemical species abundances in hydrodynamic simulations. We also implemented a solver for the gravitational potential as defined in spherical coordinates in three dimensions.

RESEARCH CHALLENGE

Understanding the initial mass function of the first stars will guide our understanding of the sources of chemical elements in the modern universe, as well as help to refine our understanding of the progenitors of gravitational wave events.

METHODS & CODES

We used the GAMER-2 simulation code, the Dengo rate construction package, and the Grackle software package.

RESULTS & IMPACT

These developments will help to contextualize observations from the James Webb Space Telescope; making these software packages available and accessible will enable scientific inquiry in a number of related domains.

WHY BLUE WATERS

Blue Waters provided the necessary environment to ensure that our solver would scale to the size and capacity we require for high-resolution studies.