Gravitational Capture of Binary Black Holes in Parabolic Orbit

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Introduction

The strongest source of gravitational radiation is believed to come from the interaction of black holes. Due to the complexity of Einstein's Field Equations, supercomputers are used to simulate binary black holes in parabolic orbit. These simulations make it possible to calculate the chance of gravitational capture

Black Holes:

- ✧ Evolutionary endpoints of super massive stars
- ✧ Gravitational field is so strong that not even light can escape

Gravitational Waves:

- ✧ "Ripples of spacetime"
- ✧ Travel at the speed of light (3 x 10^8 m/s)
- ✧ May lead to the direct identification of the existence of black holes [1]

Gravitational Waves

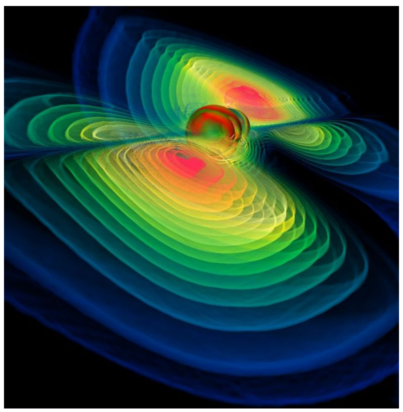

Figure 1: Gravitational waves radiate through space as two black holes merge in this computer visualization of the process. Although gravitational waves have not been seen, relativity theory suggests they exist. *Werner Benger, Zuse-Institut Berlin and Max-Planck-Institut für Gravitationsphysik.*

Materials and Methods

To simulate binary black holes and to calculate Einstein's Field Equations, the following materials were used:

- ✧**Einstein Toolkit:** simulating and analyzing general relativistic astrophysical systems
- ✧**Cactus Framework:** enables parallel computation across different architectures
- ✧**LONI (Louisiana Optical Network Initiative):** connects universities allowing for greater collaboration on research in order to produce results faster and with greater accuracy
- ✧**Queen Bee:** the core supercomputer of LONI and a 50.7 Tflops, 668 node cluster housed in Baton Rouge, Louisiana

Results

The initial conditions of the black holes were chosen to simulate a parabolic orbit. In Newtonian Gravity, two black holes in parabolic orbit approach each other once before receding to infinity. Due to the emission of gravitational waves in General Relativity, the black holes will be captured [2].

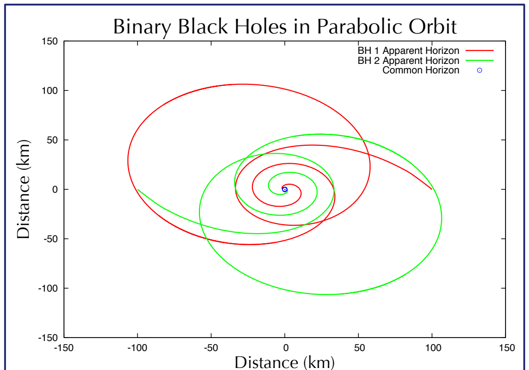

Figure 2: Simulation of binary black holes in parabolic orbit. The curves show the location of the black holes and the circle shows the final black hole. In this case, the mass of each black hole is 5 $M_\odot$, the initial separation is 200 km, and the Pericenter distance is set to be 110.524 km.

A primary goal of numerical relativity is to provide estimates of wave strains from strong gravitational wave sources. The simulations measure gravitational waves in terms of gauge resilient quantities, such as the Weyl curvature component, Ψ_4 [3].

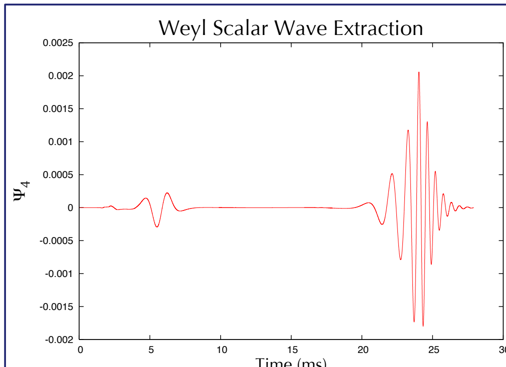

Figure 3: Extracted spherical harmonic mode $(l, m) = (2, 2)$ of Ψ_4 of an equal mass binary black hole merger simulation, as seen in Figure 2.

Conclusion

The calculated radiated energy (Fig. 4) comes from subtracting the total initial mass of the binary black hole system from the mass of the final black hole. As mass is lost it is converted into energy.

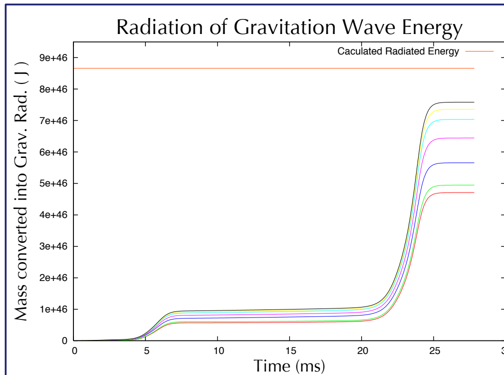

Figure 4: Wave extraction mode by mode. The contributions from the different modes can be seen, the lowest being 2 (*red*) and the highest being the combination of 2 though 8 (*black*). The wave extraction comes from the simulation in *Figure 2*.

The first increase corresponds to the first passage of the black holes. As they move away from one another, the radiation emitted decreases until the second passage of the black holes occur.

Future Work

The gap between the calculated radiated energy and the radiated energy from the contribution of all of the extracted modes (Fig. 4) shows the need to use more modes in the gravitational wave extraction. The use of more modes will increase accuracy and reduce error.

To calculate the error, several resolutions will be simulated. There will also be simulations with various initial separations and Pericenter distances to perform a systematic study of the dependence of the radiated energy by gravitational waves on these distances.

References

[1] Papantonopoulos, E. Physics of Black Holes: A Guided Tour. Berlin: Springer, 2009.

[2] V. P. Frolov and I. D. Novikov. Black hole physics: basic concepts and new developments. Netherlands: Kluwer Academic Publishers, 1998.

[3] Christian Reisswig and Denis Pollney. "Notes on the Integration of Numerical Relativity Waveforms". General Relativity and Quantum Cosmology. Jun 2010. 25pp.e-Print:arXiv:1006.1632 [gr-qc].

Acknowledgments

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LONI Institute is funded by the Louisiana Board of Regents contract number LEQSF(2007-12)-ENH-PKSFI-PRS-01 and LI partner institutions. Allocation: loni_cactus05. http://www.loni.org.

Einstein Toolkit is supported by NSF 0903973/0903782/0904015 (CIGR), 0701566/0855892 (XiRel), 0721915 (Alpaca), 0905046/0941653 (PetaCactus/PRAC). http://www.EisteinToolkit.org. 2010.