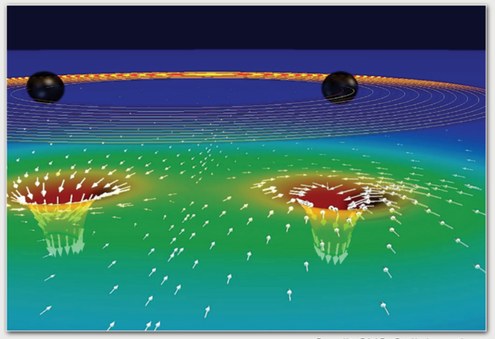
Listening Closely for Black Hole Collisions

Ben Farr
McCormick Fellow - Enrico Fermi Institute

Vibrations in Spacetime



Credit SXS Collaboration

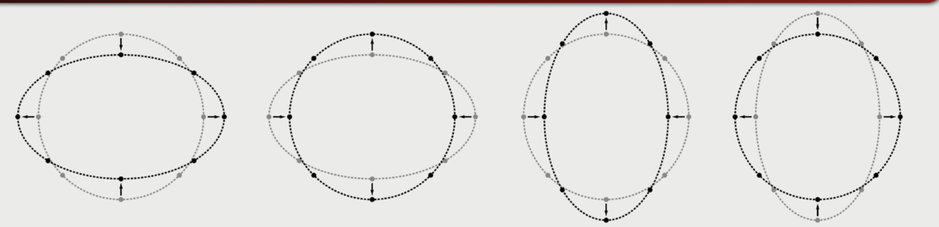
Like ripples in a pond, the movement of massive objects creates outward-traveling ripples in spacetime, called gravitational waves.

Some of the loudest progenitors of these waves are compact binary systems, composed of neutron stars or black holes. As these objects orbit one another, outgoing gravitational waves extract energy from the orbit, causing it to steadily shrink until the objects collide.

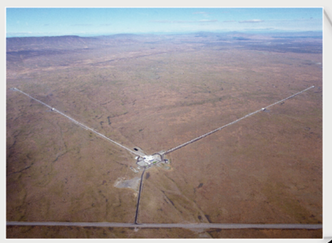
Detection of these waves will open a new window to the universe, enabling the observation of systems otherwise impossible to observe using electromagnetic radiation.

Detecting Gravitational Waves

The oscillating effects of a passing gravitational wave on a ring of freely falling particles.

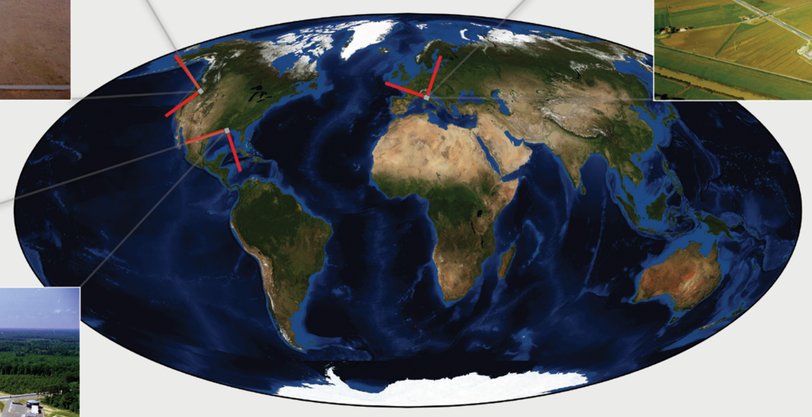


LIGO-Virgo Network



LIGO Hanford

VIRGO



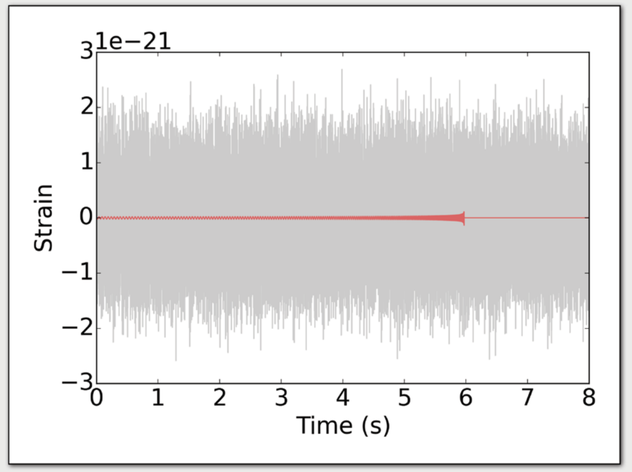
LIGO Livingston

A global array of Michelson interferometers has been constructed to detect gravitational waves.

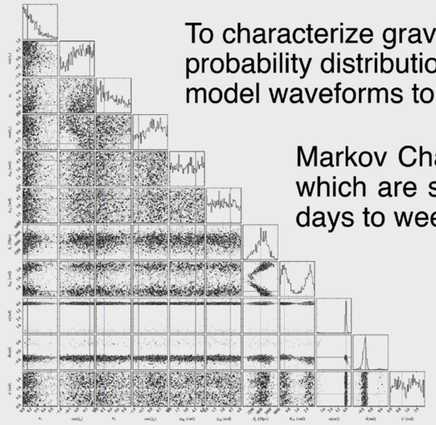
Feats of Engineering and Data Analysis

Advanced LIGO detectors will measure strains as small as 10^{-23}. That's a change in length of their 4 km arms smaller than the a proton; comparable to measuring fluctuations in the distance to the nearest star (Alpha Centauri) to the size of an E. coli bacterium.

The noise associated with such measurements is immense. (Right) A stretch of simulated noise with a simulated gravitational wave from a 10 $M_\odot$ - 10 $M_\odot$ binary black hole merger over 3 billion light years away; a signal above detection threshold.



Enabling Gravitational Wave Astronomy



To characterize gravitational wave sources, a 15 dimensional posterior probability distribution must be sampled. Sampling requires millions of model waveforms to be generated.

Markov Chain Monte Carlo techniques are used for sampling, which are serial algorithms by nature. Analyses typically take days to weeks to complete.

Lower latency results would aid greatly with the search for electromagnetic counterparts; a difficult task due to search areas of hundreds of square degrees on the sky.

Ensemble Sampling

Ensemble sampling combines many MCMC chains in parallel, using the ensemble's distribution to build a proposal.

We propose a new approach to ensemble sampling by building an estimate of the ensemble's distribution using a modified kernel density estimator. Between proposal updates, chains evolve completely independently, allowing for vast parallelization.

(Right) Cumulative distributions of wall (thick) and CPU (thin) times for analyses using standard MCMC (dashed) and ensemble (solid) sampling methods, showing reductions in wall times by orders of magnitude are possible.