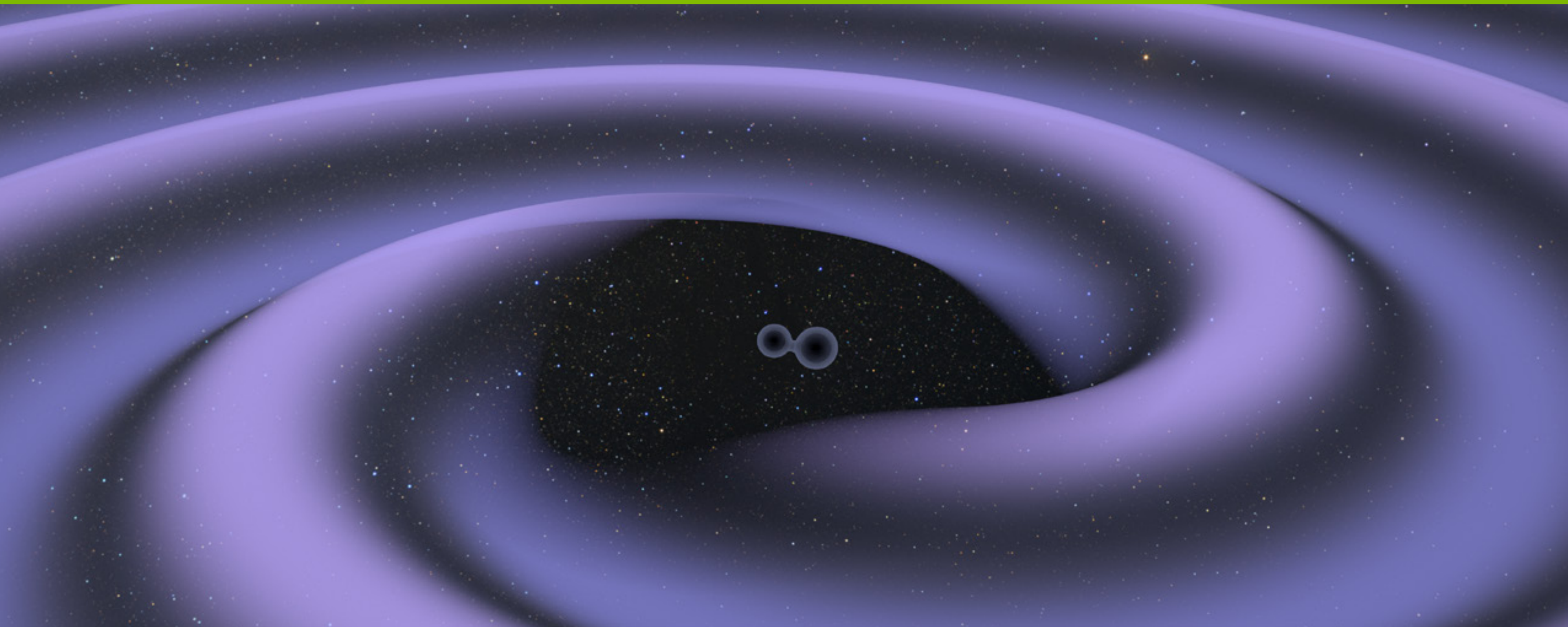
SUCCESS STORY | NCSA GRAVITY GROUP

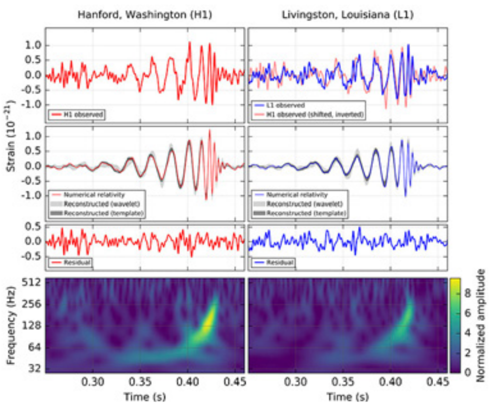
SEEING GRAVITY IN REAL-TIME WITH DEEP LEARNING



NCSA: Scientific visualization of the first binary black hole merger detected by advanced LIGO. Numerical simulation by NCSA Gravity Group. Scientific visualization by NCSA Advanced Visualization Lab.

The Laser Interferometer Gravitational-wave Observatory (LIGO) detects gravitational waves millions of light years away in real-time.

A NEW ERA IN ASTROPHYSICS



NCSA: Panels shows the gravitational wave (GW) event GW150914 as observed by the LIGO Hanford (LH1) and Livingston (L1) detectors

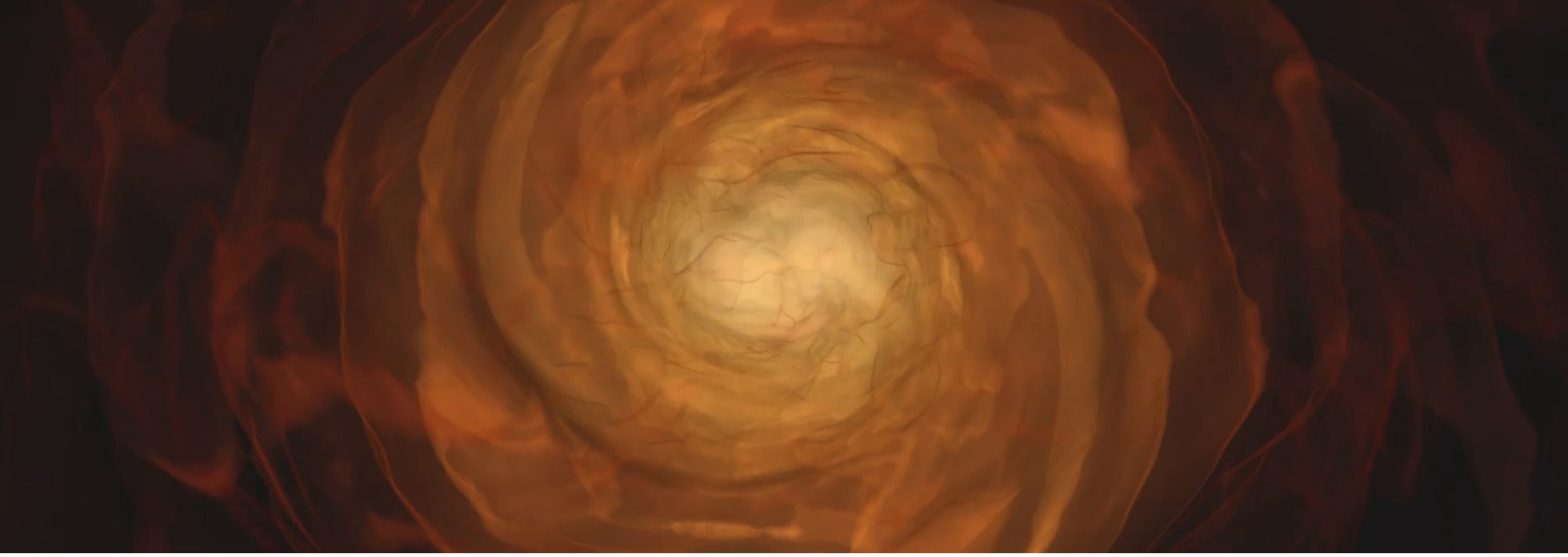
Just over a century ago, Einstein introduced his revolutionary theory of general relativity. Neither Einstein nor any of his contemporaries initially accepted certain natural consequences of this theory, such as the existence of black holes and gravitational waves.

One hundred years later, on September 14, 2015, the twin detectors of the Laser Interferometer Gravitational Wave Observatory (LIGO) detected a signal that matched Einstein's predictions—the inward spiral and merger of a pair of black holes and the resulting single black hole. With these observations, LIGO confirmed the existence of gravitational waves and proved that black holes can form binary systems. A feat that, to-date, LIGO has accomplished a total of four times. And recently the LIGO and VIGRO detectors heard, for the first time, gravitational waves emitted by the collision of two neutron stars—a cosmic event which also emitted observable light. This event marks the beginning of multi-messenger astrophysics, in which astrophysical events are seen and heard simultaneously.

Detecting and characterizing gravitational waves is a computationally demanding task. LIGO Data Grid centers around the world are used to search for gravitational wave signatures in highly noisy data. To accelerate gravitational wave detection, and enable low latency electromagnetic and astroparticle follow-ups with astronomical facilities, LIGO scientists use high performance and high throughput computing resources including XSEDE, Blue Waters, and Open Science Grid.

CUSTOMER PROFILE

Organization	Industry	Location	Website
Gravity Research Group at NCSA at the University of Illinois at Urbana-Champaign	Astrophysics	Illinois	https://gravity.ncsa.illinois.edu



NCSA: Collision of two neutrons stars heard in gravitational waves and observed in light. Numerical simulation by NCSA Gravity Group. Scientific visualization by NCSA Data Analytics and Visualization Group.

PRODUCTS

NVIDIA® Tesla® GPUs

MXNet framework

TRAINING NEURAL NETWORKS

To push the frontiers of multi-messenger astronomy, scientists are using deep learning and NVIDIA® Tesla® GPUs to capture and analyze the data in real-time. Specifically, Daniel George and Eliu Huerta, scientists at the NCSA Gravity Group developed and trained a deep convolutional neural network (CNN) running 15 layers. Then, they implemented it with the MXNet framework on NVIDIA Tesla GPUs.

Designing the architecture of the CNNs by random search took more than 300 hours over the course of three weeks. An additional 10 hours were needed for fine-tuning. Two types of neural networks were developed, a classifier and a predictor, to detect and estimate parameters of the signal. The classifier detects signals whose amplitude is significantly weaker than the background noise, and the predictor then estimates the masses of the black holes from these signals with very low error rates.

Once the NSCA system was trained and tuned, pattern matching with conventional and AI inference methods were compared. The results were astronomical. The CNN performed best with raw time series data, enabling it to skip extra computational steps which contributed to increased speed and reduced latency. The AI inference method improved performance by a factor of 100X, and the GPU improved the performance of the AI inference by another 50X. The overall benefit for the inference method combined with the GPU hardware was over 3 orders of magnitude. The new system delivered results within real-time tolerance, making multi-sensor coordination possible.

“Gravitational wave astrophysics is a multidisciplinary effort. At NCSA we combine our expertise in HPC, HTC, analytical and numerical gravitational wave source modeling. Then we boost it with innovative applications of artificial intelligence to push the frontiers of the field. Our partnership with NVIDIA is a key element in our daily research activities.”

Dr. Eliu Huerta, Head of the NCSA Gravity Group at the University of Illinois at Urbana-Champaign

Furthermore, this novel paradigm also enables the detection of new classes of gravitational wave sources that are currently missed with established gravitational wave detection algorithms, paving the way for new scientific discoveries.

PEERING INTO THE DARK SECTOR OF THE UNIVERSE

Trained CNNs, running on NVIDIA GPUs, offer the ability to explore a deeper parameter space of gravitational wave sources with LIGO. This, combined with the ability to coordinate observations with astronomical facilities, will enable the study of astrophysical phenomena that cannot be observed through any other means.

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From the first signal detection in 2015 to the invention of a computationally intensive approach using NVIDIA GPUs, LIGO has changed the way we see gravity. Over the last sixteen months of operation, more than 1,000 members of the LIGO Scientific Collaboration (LSC) have participated in the detection of gravitational waves originated by the collision of not one but three pairs of black holes. With advanced detectors like LIGO and Virgo observing together, along with space and ground-based electromagnetic telescopes, and neutrinos and cosmic-ray detectors, there is the potential to give the scientific community and astrophysics unlimited opportunity to explore the universe through all its messengers.