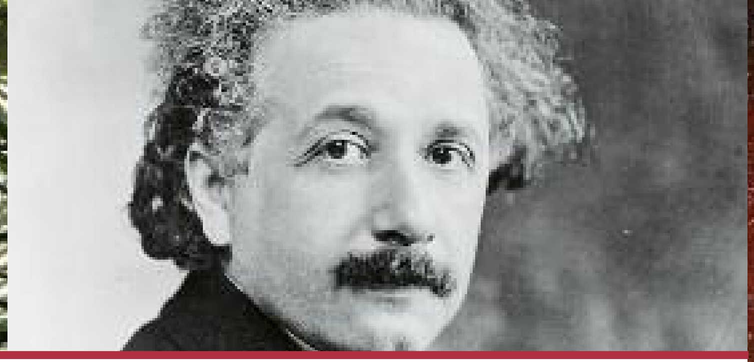

The Max Planck Society for the Advancement of Science e.V.

is an independent non-profit research organization. It was founded on February 26, 1948, and is the successor organization to the Kaiser Wilhelm Society, which was established in 1911. The primary goal of the Max Planck Society is to promote research at its own institutes.

The currently 84 Max Planck Institutes and research facilities conduct basic research in the service of the general public in the natural sciences, life sciences, social sciences, and the humanities. Max Planck Institutes focus on research fields that are particularly innovative, or that are especially demanding in terms of funding or time requirements, thus ideally complementing the research work in key disciplines conducted at universities.

MAX-PLANCK-GESELLSCHAFT

Albert Einstein's Theory of Gravitation

The Theory of General Relativity is one of the most important scientific achievements of the past millennium. It describes the structure of space-time and of gravitational forces on a cosmic scale. According to Einstein's theory, every body gravitates because it bends the space surrounding it, changing the flow of time in the process. At the same time, the movement of a body in a gravitational field is determined by how it "fits" into the warped space-time.

An important prediction from Einstein's theory of general relativity is the existence of gravitational waves, which were directly detected for the first time in September 2015. Accelerated motions of large masses create these ripples in space-time, which lead to tiny relative distance changes between faraway objects. Even astrophysical sources like merging black holes or stellar explosions change the length of a one-kilometer measurement distance on Earth only by one thousandth of the diameter of a proton (10^{-18} m). Only recently have the detectors reached a level of sensitivity at which they can measure strong gravitational waves from merging black holes and neutron stars. These first observations of the until then dark "Gravitational Universe" have ushered in a new era in astronomy.

Image: AIP Emilio Segre Visual Archives, W. F. Meggers Gallery of Nobel Laureates

The Max Planck Institute for Gravitational Physics has two sites:

The departments *Quantum Gravity and Unified Theories*, *Astrophysical and Cosmological Relativity* and *Computational Relativistic Astrophysics* are based in Potsdam.

The departments *Laser Interferometry and Gravitational Wave Astronomy* and *Observational Relativity and Cosmology* are based in Hannover.

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Image: NASA/JPL-Caltech/Univ. of Toronto

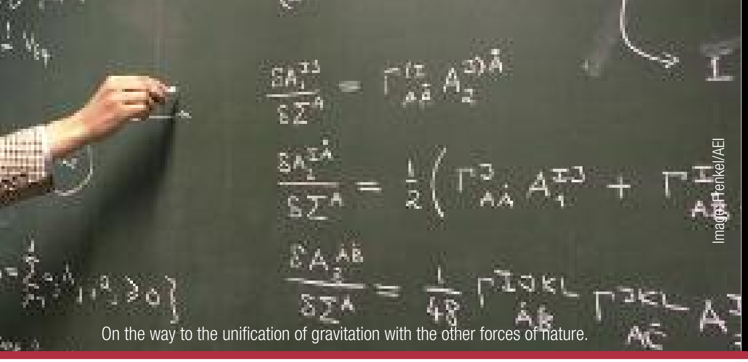
MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS

ALBERT EINSTEIN INSTITUTE

Image: AEI

The Albert Einstein Institute

Since its foundation in 1995, the Max Planck Institute for Gravitational Physics has established itself as a leading international research centre. The research program pursued in five divisions and several independent research groups covers the entire spectrum of gravitational physics: from the giant dimensions of the Universe to the tiny scales of strings. The AEI is the only institute in the world that brings together all of these key research fields. One group of AEI scientists works towards the unification of both fundamental theories of physics – general relativity and quantum mechanics – into a theory of quantum gravity. Others do research on gravitational waves, neutron stars, black holes, two-body problems in general relativity, and the analytical and numerical solutions of Einstein's equations. The development and implementation of data analysis algorithms for a variety of gravitational wave sources and follow-up analyses to infer properties of sources are central research topics of the institute. AEI experimental physicists work on gravitational wave detectors – both earthbound and in space. All these efforts enable a new kind of astronomy, which began with the first direct detection of gravitational waves on Earth on September 14, 2015.

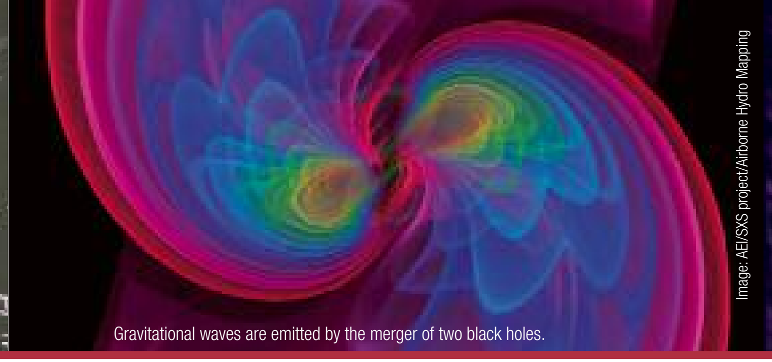

On the way to the unification of gravitation with the other forces of nature.

Quantum Gravity and Unified Theories

In the 1970s, physicists had already managed to unite three of the four fundamental forces of nature into one theory – the standard model of particle physics. Only gravity is still firmly resisting integration. Although the inherent contradictions between quantum theory and general relativity become apparent only in the unbelievably small dimensions of the Planck scale (10^{-33} cm), they must be resolved if we want to understand what “happens” inside a black hole or at the Big Bang.

Thus, gravitational physicists are searching for a new theory of quantum gravity to unite general relativity and quantum field theory, solving the mathematical contradictions in the process. The main approaches to quantum gravity (canonical quantization, supergravity and string theory, as well as nonperturbative schemes) are all represented in the division, with special emphasis on novel ansätze that may overcome difficulties with the existing approaches.

The sought-after theory of quantum gravity is likely to revolutionize our current concepts of space and time at extremely small distances in radical ways. In particular, the familiar distinction between spacetime and matter may well turn out to be invalid at the Planck scale.

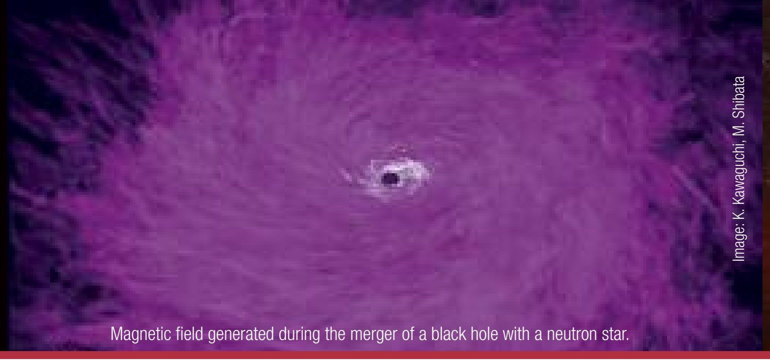


Gravitational waves are emitted by the merger of two black holes.

Astrophysical and Cosmological Relativity

The observation of gravitational waves from coalescing binary black holes and neutron stars provides the unique opportunity to probe fundamental physics, dynamical gravity and matter under extreme conditions. Successful searches, precise inference of astrophysical properties and correct identifications of sources require detailed knowledge of the expected signals. Scientists in the *Astrophysical and Cosmological Relativity* division predict accurate waveform models of binary systems in General Relativity by combining fast, but approximate analytical methods, with exact, but time-consuming numerical simulations on high-performance computers. They employ those templates to detect gravitational-wave signals, infer astrophysical and cosmological properties of the sources, and test General Relativity in the highly dynamical, strong-field regime. Waveform models developed by members of the division were employed to identify the gravitational waves observed by Advanced LIGO and Virgo, and were crucial in detecting GW151226, GW170806, and GW170817.

Researchers in the division are members of the LIGO Scientific Collaboration, and the Laser Interferometer Space Antenna (LISA). The division also participates in building the science case for the next generation of gravitational-wave detectors on the Earth.

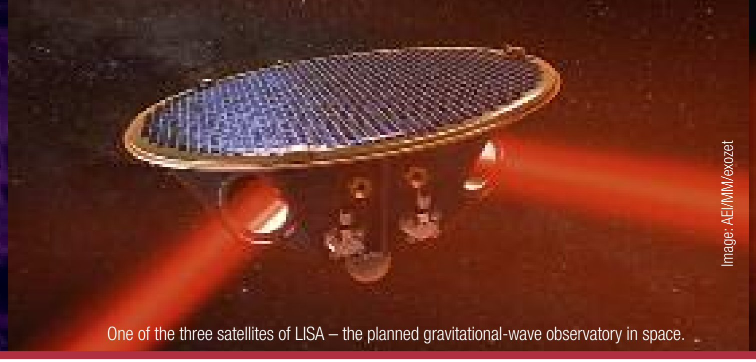


Magnetic field generated during the merger of a black hole with a neutron star.

Computational Relativistic Astrophysics

In 2017 astronomers observed both gravitational and electromagnetic waves from the merger of two neutron stars for the first time. This event marks the beginning of multi-messenger astronomy which combines gravitational-wave and electromagnetic observations. Together, the complementary methods will enhance our understanding of extreme astrophysical events.

The *Computational Relativistic Astrophysics* division focuses on numerical relativity simulations of astrophysical events that generate gravitational waves, solving Einstein’s equations of general relativity on high-performance computers. These simulations play a crucial role in predicting accurate gravitational waveforms for the search in the detector data and for exploring high-energy phenomena such as gamma-ray bursts. The scientists study mergers of binary neutron stars and mixed binaries – binary systems of a black hole and a neutron star – as well as stellar core collapse that form black holes. They investigate the merger and post-merger phases, elucidating the physical conditions to produce electromagnetic signals of the kind detected in association with the first binary neutron star merger observed by Advanced LIGO and Virgo.



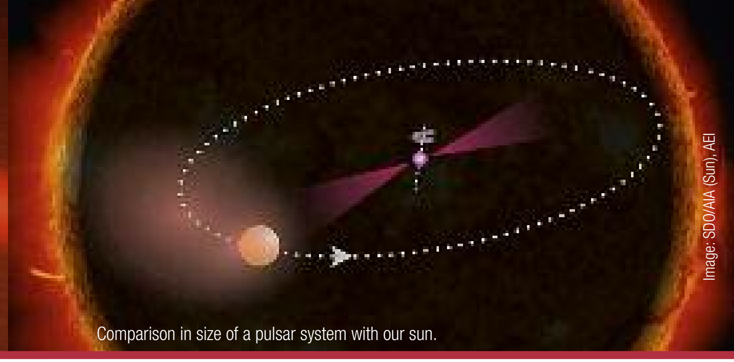
One of the three satellites of LISA – the planned gravitational-wave observatory in space.

Laser Interferometry and Gravitational Wave Astronomy

The scientists of the *Laser Interferometry and Gravitational Wave Astronomy* division play a globally leading role in developing cutting-edge technologies for gravitational wave observatories. Together with UK colleagues they operate the gravitational-wave detector GEO600. Many of the methods initially demonstrated at the AEI are now being used in the large observatories of the LIGO Scientific and Virgo Collaborations and have significantly increased their sensitivity.

The AEI is the worldwide leading research institution in the development of the Laser Interferometer Space Antenna (LISA), a gravitational-wave observatory in space scheduled for launch in 2034. LISA will consist of three satellites spanning million kilometer long laser arms, enabling it to detect gravitational-wave signals from the entire Universe, maybe even from the Big Bang.

The laser interferometry developed for gravitational wave detectors is now being used for the Earth’s benefit. The German-US GRACE Follow-On mission will observe changes in the water supplies of our planet by monitoring the Earth’s gravitational field. The AEI is the German lead of the Laser Ranging Interferometer on board of GRACE Follow-On.



Comparison in size of a pulsar system with our sun.

Observational Relativity and Cosmology

The worldwide network of ground-based gravitational-wave detectors collects large volumes of data. Researchers of the *Observational Relativity and Cosmology* division are the largest team specialized in data analysis in the international scientific community. They develop and implement advanced and efficient data analysis methods to search for weak gravitational-wave signals in the LIGO and Virgo detector data streams and to characterize them afterwards. These methods enabled the first discovery of a gravitational wave in September 2015; members of the group were the first to identify this signal as well as the later GW170104 and GW170608 events. The majority of the worldwide computational resources for the analysis of these data are provided by the AEI computer cluster Atlas, which consists of more than 42,000 CPU cores and 1,000,000 GPU cores.

The division also plays a leading role in the distributed volunteer computing project Einstein@Home. Volunteers from all around the world participate in the search for unknown neutron stars by donating idle computing time on their PCs, laptops, or smartphones. Einstein@Home searches for neutron stars in data from gravitational-wave detectors, from the Fermi gamma-ray satellite, and from large radio telescopes. More than 70 new neutron stars have already been discovered in the radio and gamma-ray data.