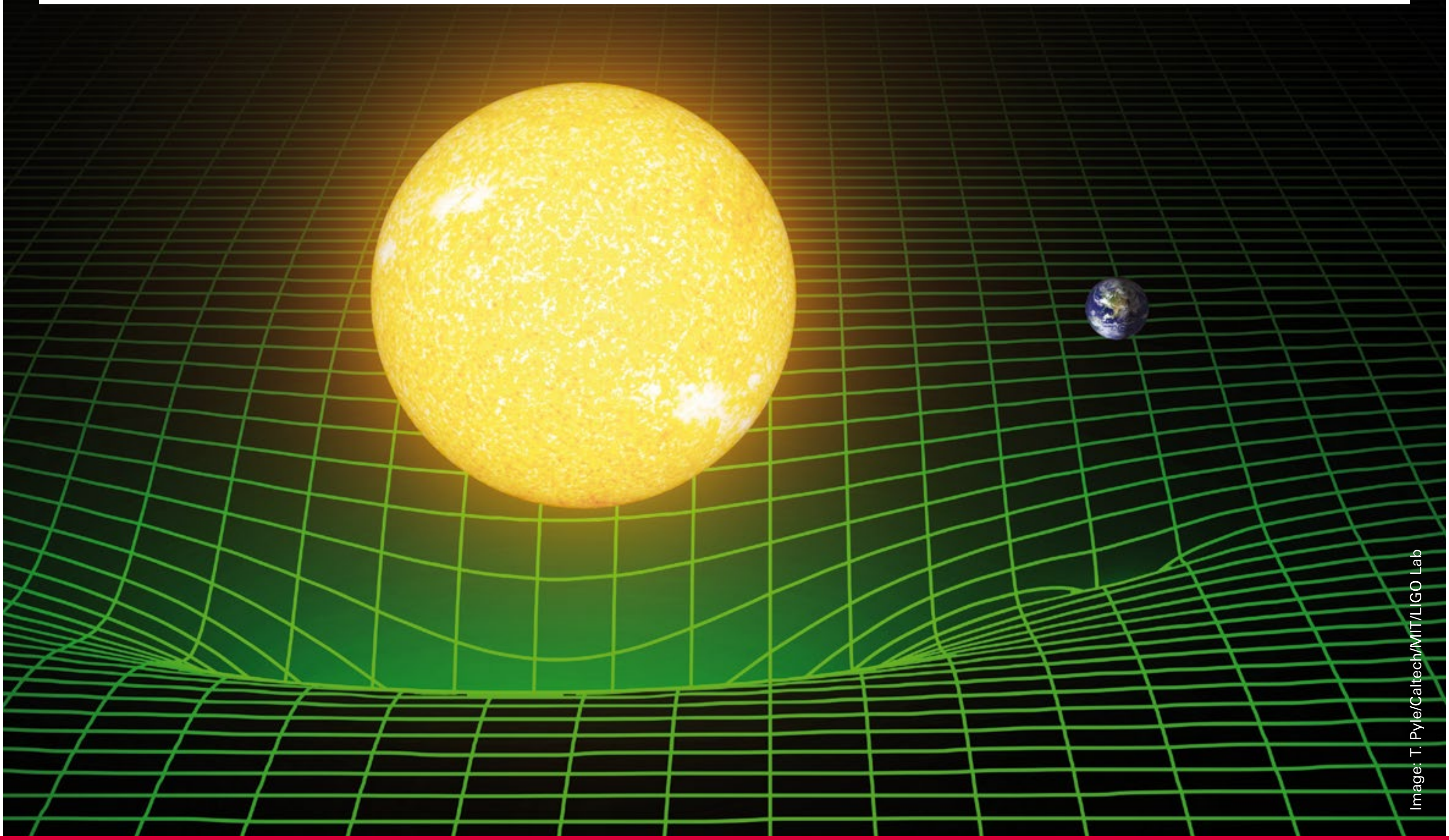
PFEIFFER VACUUM



WITH VACUUM IN EINSTEIN'S FOOTSTEPS

Interview with Prof. Dr. Rainer Weiss, one of the LIGO founders

In September 2015, the LIGO observatories in Louisiana and Washington, USA, detected gravitational waves directly on the Earth for the first time and thus confirmed Einstein's theory in the limit of strong field at the source – a breakthrough for astrophysics. Vacuum technology played a crucial role in the spectacular measurements at LIGO. Solutions from Pfeiffer Vacuum were involved in the measurements of both the LIGO observatories and the connected basic experiments. In the interview, Prof. Dr. Rainer Weiss, one of the founders of LIGO, talks about the findings of LIGO and the role of Pfeiffer Vacuum solutions.

$E = mc^2$: This formula as part of the relativity theory, developed by Albert Einstein in 1905 to describe the equivalence of mass and energy, is probably the most famous physical formula ever. Several years later, the world-famous physicist expanded his observation to gravity and mathematically described the existence of gravitational waves as part of his general theory of relativity in 1915. For 100 years, this theory has been recognized in physics.

With the help of LIGO (Laser Interferometer Gravitational-wave Observatory) in the US states of Washington and Louisiana, scientists were able to detect the radiation of a pair of colliding black holes for the first time. Therewith, the existence of binary black holes was proven and it was verified that their dynamics obey Einstein's equations.

Gravitational waves – deformations of space-time

Gravitational waves are formed when objects with large mass such as neutron stars or black holes are accelerated and circle closely around each other. They approach significant fractions of the speed of light when they collide. As they orbit, they emit gravitational waves which compress and and stretch the space deforming space-time. The deformations are extremely small and oscillate. They can be compared to a stone that has been thrown into water and creates outward-moving waves on the surface.

Spectacular proof of Einstein's theory

In September 2015, for the first time, LIGO detected the gravitational waves of two black holes merging in a likely 1.3 billion light years distant galaxy. This did not only once again prove Einstein's theory, but with these findings it was also possible to demonstrate the existence of a pair of black holes for the very first time. For researchers, this discovery signifies the start of a new era in astronomy – comparable to the moment when Galileo Galilei began his astronomical studies in the 17th century.

This step into a new era was made possible by using two detectors at LIGO in the U.S., which are located 3,000 kilometers apart, namely in Hanford (Washington) and Livingston (Louisiana). The project was begun in 1992 to conduct research and experiments on the registration of gravitational waves. Today, several thousand scientists from 16 countries work there.

The detectors work with an interferometric method according to Michelson. Inside them, a laser beam that has been split by a beam splitter passes on two paths, which are as long as possible, through an optical mirror system. The laser beams are then joined in the detector. In this way, the smallest time-of-flight differences of the laser beams can be measured, which are created by gravitational waves. The distance changes of the laser beams created by gravitational waves are only 1/1000 the size of a nucleus of an atom of 10^{-18} meters, even at a mirror separation of 4 kilometers.

Fig. 1: Overlooking one of the two 4 km long vacuum tube arms of the LIGO detector in Louisiana

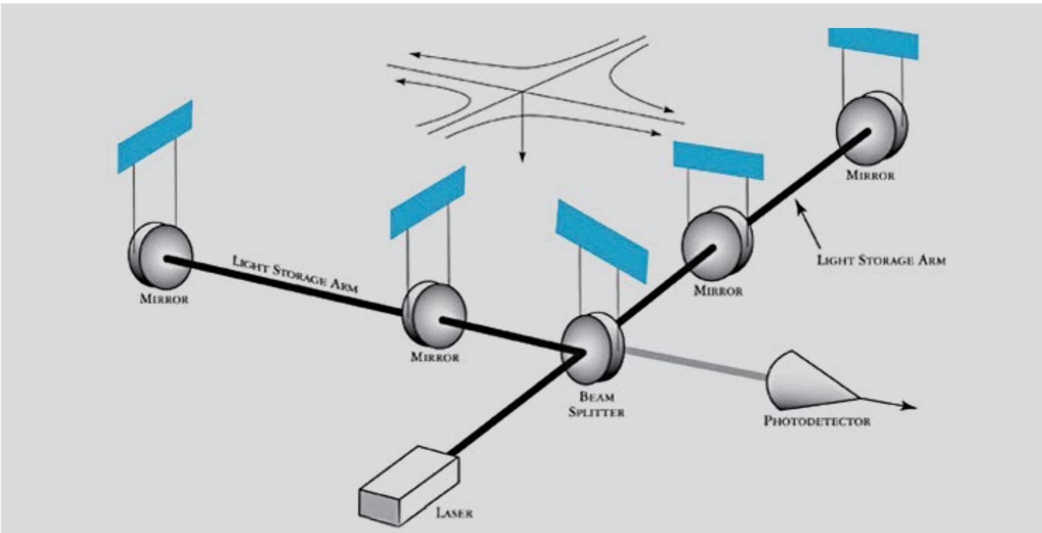


Image: LIGO

Fig. 2: Scheme of the LIGO interferometer for the detection of gravitational waves

Vacuum technology from Pfeiffer Vacuum used at LIGO

This experiment, and thus the proof of gravitational waves on the Earth required vacuum technology. To ensure proper functionality, the two paths of the laser must be kept free of all disturbing influences. For this reason, the laser beams and optical mirrors are placed in an ultra-high vacuum system. In order to ensure the quality and reliability of the system and thus be able to guarantee the successful completion of the experiment, a decades-long preparation was necessary. As part of this preparation, an intensive basic research for the preparation of gravitational wave experiments was conducted at different physical institutes worldwide.

Pfeiffer Vacuum provided vacuum equipment for many of these basic experiments. Also at the LIGO observatories, the vacuum in the detectors is monitored by analytical systems from Pfeiffer Vacuum. For diagnosing the bakeout of the huge beam tubes, HiPace turbopumps and numerous mass spectrometers from Pfeiffer Vacuum are used for quality assurance and leak detection. They ensure that the necessary vacuum conditions in the tube systems are continuously maintained and that the environmental conditions for the successful execution of the experiments are given.

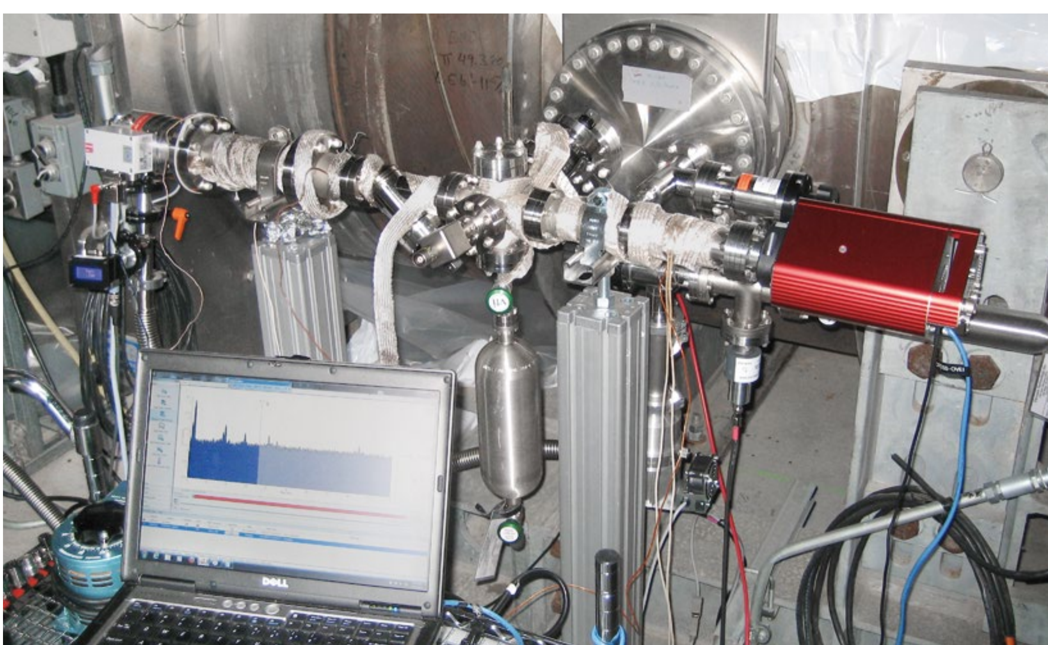


Image: LIGO

Fig. 3: The vacuum solutions of Pfeiffer Vacuum used at the LIGO experiment – HiPace turbopump and Prisma Plus mass spectrometer

INTERVIEW WITH RAINER WEISS, ONE OF THE FOUNDERS AND SCIENTIFIC LEADERS OF LIGO

Prof. Dr. Rainer Weiss, one of the founders of Ligo

Dr. Weiss, you are one of the founders and scientific leaders of the LIGO project and have been working with the detectors for more than 25 years. Please tell us how it all began: How did the project develop and what was your motivation?

It is a long story. It began when I was a starting faculty member at MIT and was asked to teach a general relativity course. The time was 1968 and I had just started a new research group in the physics department to work on experimental gravitation and observational cosmology. I hardly knew the general relativity theory and was typically one day ahead of the students. To be honest, they may have been ahead of me in the tensor calculus. The class wanted to know more about the Weber experiments. These were the measurements Joseph Weber, pioneer in the research of Einstein's gravitational waves, made in the 1960's with the excitation of aluminium bars. I had a terrible time understanding the interaction of a bar with a gravitational wave. I thought I could understand and calculate how a pair of objects travelling along neighboring geodesics changed their separation when a gravitational wave came by. The next idea was to measure this separation using the time it took light to go between the objects. The math was reasonably easy. I gave it as a problem to the students. Later I thought about it some more and realized that one could actually make a sensitive gravitational wave detector this way. That was the beginning of LIGO in my thinking.

Now gravitational waves were indeed physically detected. How did you feel when you first heard about this detection?

I was in Maine on vacation with my family. We had a date with Peter Saulson from the LIGO working group at Syracuse University and his wife to go kayaking along the Maine coast. By chance, Richard Isaacson was also going to join us. Richard is a student of Charles Misner's, he wrote an important paper showing that gravitational waves did carry energy and were real physical things. He was the discipline chief for gravitational physics at the NSF at the critical time when interferometric detection of gravitational waves was being proposed. He was absolutely central to the NSF taking the gamble to first develop and then fund LIGO. After getting permission from the LIGO directorate, Peter and I told Richard about the "event". He looked quite skeptical and plied us with perfectly sensible questions – "how do you know it isn't due to…" – but after seeing the data and a pretty thorough grilling, we all went out to a really memorable dinner, toasted the "event" and talked about the good and bad old times.

Which role does vacuum technology in general play for the experimental work at LIGO?

Vacuum at levels lower than 10^{-9} torr in the 4 km long arms is needed to avoid forward scattering from residual gas molecules which would cause phase noise in the interferometer output. The most serious phase noise would come from large molecules which have larger polarizability and move slowly.

Vacuum at levels lower than 10^{-8} torr is required in the test mass chambers to avoid momentum fluctuations of the test masses due to collisions with residual gas atoms. Again heavier molecules are more serious sources of noise than lighter ones.

Which specific demands does the vacuum system have to fulfill?

Aside from the pressure requirements given above, the vacuum system has to run reliably for months at a time. Also we do not want vibrations from the vacuum pumps to disturb the test masses.

Which products from Pfeiffer Vacuum are used at LIGO and why did you choose them?

In general, we use vacuum components from many manufacturers. We used residual gas analysers from Pfeiffer Vacuum because we received knowledgeable information and excellent advice from the Pfeiffer Vacuum representatives in the United States in two particularly difficult problems we encountered in LIGO. The first was in establishing whether the LIGO beam tubes could make the residual gas pressure specification before we accepted them from the manufacturer. The second was later when we searched for the location of leaks developed on welds of the 4 kilometer tubes due to corrosion by hydrochloric acid from mouse urine. Both of these problems required stable, drift free and sensitive residual gas analysers.

How do you assess the cooperation with Pfeiffer Vacuum?

The long-term, trustful collaboration with Pfeiffer Vacuum has been very effective and useful. Our contacts were available for any questions that occurred concerning the residual gas analyzers or turbopumps as well as the connected processes.

The existence of gravitational waves and therewith the accuracy of Einstein's theory of relativity has been proven. What does this mean for the experimental work at LIGO? How is it going to proceed?

The great goal has not yet been achieved. Only the first step has been made. Now with further improvement to design sensitivity, LIGO will open the field of gravitational wave astronomy. This a new field of astrophysics which explores the dark universe best observed through gravitational waves that are emitted by accelerating masses throughout the universe. We know of binary black holes and neutron stars. There is much to learn about them. The mass spectroscopy of black holes will give information about their formation and their importance in astronomy. Neutron stars will give information about the equation of state of nuclear matter and possibly about the process for making heavy elements in the universe. Should we be able to observe a supernova, gravitational waves will expose the inner processes in the stellar collapse. There may well be new sources of gravitational waves we have not thought of.

Thank you very much for the interview!

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