GEO600 starts continuous search for Gravitational Waves

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The joint German-British Gravitational Wave Detector GEO600 has now entered an 18-month run of continuous measurement. Researchers are optimistic that they will be able to observe a never before seen phenomena the Gravitational Wave which is one of the great untested predictions of Einstein's General Theory of Relativity. Gravitational Waves can be used to do "ark astronomy", studying those aspects of the Universe for which ordinary astronomy using light (and the rest of the electromagnetic spectrum) can provide limited information.

"If there is a supernova in our vicinity during the next couple of months, our chances of detecting and measuring the resulting gravitational waves are good. The first step towards gravitational wave astronomy has been taken, at last allowing us to observe the 96% of our universe which have been hidden to us up to now" says Prof. Dr. Karsten Danzmann, head of the International Centre for Gravitational Physics which is jointly run by the Max Planck Society and the University of Hannover. Data is taken in conjunction with the two US LIGO observatories.

The sensitivity of the GEO600 detector has been continuously improved since the start of test runs in 2002. "We could only reach out towards a small fraction of our own galaxy, the Milky Way, in those days. Today our sensitivity has increased by a factor of 3000 and we can detect events in distances many times greater than the distance between us and our galactic neighbour, the Andromeda Galaxy" Karsten Danzmann explains.

Professor Jim Hough of the Institute for Gravitational Research at the University of Glasgow adds ¡§I am optimistic about the chances of a detection over the next eighteen months.¡¨ When Ladbrokes offered odds of 500-1 against the detection of gravitational waves by 2010, Professor Hough was one of many who were quick to place their bet and the odds fell to 2-1 in days, before the book was closed. The bookmakers could well find themselves paying up in the next 18 months.

The direct measurement of gravitational waves is one of the most profound challenges of modern physics as it will allow us to observe the hitherto inaccessible and, at 96%, greater part of our universe. "We are very curious and eager to see what new insights we will gain. We are opening a wholly new chapter in the long history of astronomy with the direct observation of the "dark side" of our universe¡VBlack Holes, Dark Matter and the reverberations of the Big Bang", says Prof. Danzmann.

GEO600 is the most modern Michelson laser interferometer in the world. Its laser beams run in two underground vacuum tubes which are 600 m long. The GEO600 gravitational wave detector incorporates lasers of unmatched stability, absorption-free optics, a highly sophisticated vibration damping arrangement and an innovative signal enhancement system. The technology developed in Hannover will also be implemented in the next generation of the US LIGO observatories.

Listening to the dark side of the Universe

GEO600 allows a final test of Albert Einstein's general theory of relativity and serves as a completely new kind of telescope. Vast parts of the Universe are obscured by dark clouds and cannot be observed by means of conventional astronomical techniques (e.g. using light or radio waves). However, gravitational waves pass these clouds unhindered. Furthermore, the Universe consists up to 96 % of the enigmatic Dark Matter and Dark Energy that we know interact with gravity. Thus gravitational wave astronomy will come up with exact information on the distribution of neutron stars and black holes in the Universe as well as on the detailed course of cosmic catastrophes like the collapse and the explosion of a star (supernova) or the merger of two compact stars or black holes. Even the gravitational waves produced during the Big Bang are expected still to be crossing the Universe. The observation of waves from binary star systems allows us to determine the expansion of the Universe with a high degree of accuracy. All this will substantially broaden our knowledge of the creation, composition, development, and fate of the Universe.

Gravitational Waves Ripples in Space-Time

In his general theory of relativity Albert Einstein (1879-V1955) depicts a completely new view of gravitation. In contrast to Newton it is not a force, but a consequence of the geometry of space-time. In general relativity space is described by means of a curved geometry instead of a flat one. Furthermore, it is influenced by the distribution of matter and energy in the Universe. The basic idea of general relativity is: Matter tells space-time how to curve and space-time tells matter how to move. The path of a moving mass is thus influenced by the warping of space produced by another mass. This is the cause of the apparent attraction between masses. Moving masses give rise to perturbations in space-time that spread in all directions. In this way a wave phenomenon arises that propagates with the speed of light, a gravitational wave.

How to measure gravitational waves

Gravitational waves are disturbances in the curvature of space-time caused by the motions of matter. Though gravitational waves pass straight through matter, their strength weakens proportionally to the distance travelled from the source. A gravitational wave arriving on

Earth will alternately stretch and shrink distances, though on an extraordinarily small scale. Because it is not possible to create detectable gravitational waves in the lab, the field for the observation of gravitational waves is the Universe where very large masses (e.g. neutron stars and black holes) are moving very fast. But even in the most favourable case (a supernova within the Milky Way) the gravitational wave changes the Earth-Sun distance only about the diameter of an atom, merely for several hundredths of a second. Since one wants to observe gravitational waves from neighbouring galaxies, too, one has to be more sensitive by a factor of 1000: With a measuring distance of about 1 km a distortion of a thousandth of the diameter of an atomic nucleus has to be detected. This means a relative sensitivity of 10ƒ{21.

The tiny distortions are measured by means of a laser interferometer. The incident laser-beam is divided; both partial beams propagate along the interferometer arms (600 m), are reflected and then recombined at a photo detector. The lengths of the arms are chosen in such a way that the returning light waves are always 180¢X out of phase so that they cancel each other out and the output is dark ("destructive interference"). If a gravitational wave changes the lengths of both arms, the relative phase changes, and the beams no longer annihilate: at the output a signal can be seen. By means of additional mirrors the light going back to the laser as well as the signal at the output can be superposed several times with itself and thus be amplified ("dual recycling"). Signal recycling is a speciality of GEO600.

GEO600 Technology: A front-line technical challenge

The detection of gravitational waves is a front-line technical challenge. In every aspect of the detector one has to go beyond the limits of existing technology: laser stabilisation, optics without absorption, control engineering, vibration isolation, data acquisition and data processing. Only the further development of these branches, initiated by GEO600, made a gravitational wave detector possible. At the same time GEO600 had to manage with a material budget of only 7 Mio. Euro (while the whole budget of both US LIGO detectors was $ 365 million). The realisation of this project at the forefront of research has thus been enabled only by innovative ideas, reduction to the essentials, and manufacturing of most parts by our own workshop. Without the enthusiasm and the help of our diploma and PhD students GEO600 would not have been realised.

GEO600: Part of a worldwide network of gravitational wave detectors

GEO600 is part of a worldwide network of gravitational wave detectors. Two detectors have been constructed in the USA (LIGO in Hanford/Washington and Livingston/Louisiana) and one each in Italy (Virgo: measurement will begin probably at the end of 2006) and Japan (TAMA 300). One can only be sure not to be confused by local perturbations if measurements are made in coincidence with a distant detector. If one wants to obtain further information on the position of the source as well as on the time structure and mode of oscillation of the waves, one needs at least four detectors. Therefore all the projects have agreed to exchange their data. GEO600 serves at the same time as a source of new ideas and as an experimental lab for the technical improvements that are needed for the second generation of detectors.

Limits on detection

The performance of GEO600 is limited because various disturbing sources produce fluctuations ('noise') of the output signal thus mimicking or hiding a gravitational wave signal: For signals with frequencies between 30 Hz and 100 Hz, beam position fluctuations predominate the noise spectrum, even though the researchers manage to adjust the laser beam at the mirrors (600 m far away) within the range of a tenth of a human hair. For frequencies above 100 Hz, a combination of the light's quantum noise (shot noise), thermal noise and stray light limits the accuracy of GEO600. Shot noise is a fundamental limit due to the wave/particle nature of light. Thermal noise comes from the Brownian motion of the molecules of the mirrors. Even a minor amount of light power, scattered for instance at dust particles or at the mirror's roughness, is able to fake a gravitational wave signal by means of interference with the main laser beam. Heavy earthquakes (6 or more on the Richter scale) pose a problem for all gravitational wave detectors. Such a quake, no matter where on Earth, produces seismic motions that stop every measurement for some time.

On the Net: http://www.geo600.de

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