The upgrade of GEO 600

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This article gives a short overview of the status of the British/German gravitational wave detector GEO 600 and the upgrades planned within 2010 and 2011

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1. Status Quo

The German/British interferometric gravitational wave (GW) detector GEO 600 has taken data for almost 3.5 years from the beginning of 2006 to July 2009, partly together with the other large GW detectors LIGO and Virgo in the S6/VSR1 data run (Jan. 2006 to Oct. 2007) and partly together with the 2 km H2 LIGO detector during 'Astrowatch' (Nov. 2007 to July 2009) in the upgrading process of the Virgo and LIGO detectors. All these detectors are cooperating in the LSC/Virgo network and jointly analyze the collected data, whenever simultaneously taken data are available at comparable sensitivities. For an overview of the worldwide GW network refer to the article of David Reitze in this issue.

Being the smallest of the detectors in the network, GEO 600 implemented several 'advanced' techniques to reach a comparable sensitivity.[1] Dual Recycling,[2] monolithic suspensions[3] and electro-static actuators[4] are novel techniques that are being used in the current GEO 600 configuration but are only foreseen for the advanced stages of LIGO and Virgo. Throughout the data taking period GEO 600 used 6 W of laser power incident to the Mode Cleaners,[5] i.e. two subsequent optical resonators of 8 m round-trip length , which remove optical higher order modes form the laser beam and thereby reduce angular beam fluctuations. Due to scattering losses in these Mode Cleaners about 3.2 W of laser power can be used at the interferometer. The GW signal and with it the longitudinal and angular control signals for the main interferometer are generated with the Schnupp modulation technique,[6] which involves phase modulating the laser beam before it enters the interferometer and demodulating the output beam at the same frequency. GEO 600 uses both Power- and Signal-Recycling to enhance the usable laser power inside the interferometer by factor of about 1000 and to enhance the signals at the output port in a band of about 700 Hz around the resonance frequency of the Signal Recycling cavity. This resonance frequency can be tuned by the exact position of the Signal Recycling mirror ($\approx$ 4 Hz/pm) and was set to 530 Hz during the data taking runs. With this set-up a peak sensitivity of 2E-22 /sqrt(Hz) has been reached (see figure1).

DC readout Schnupp modulation as mentioned above increases the detected shot noise above the fundamental limit by mixing shot noise from twice the modulation frequency into the detection band.[7] By direct detection of the light power at the

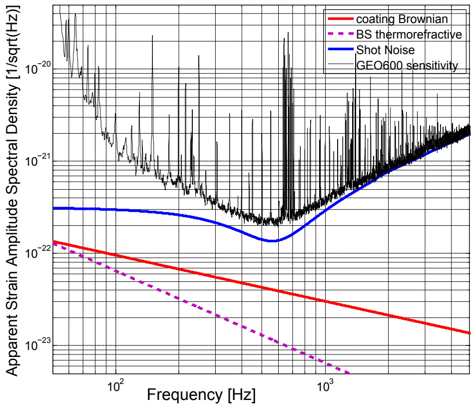

Fig. 1. Sensitivity of GEO 600 as of August 2009

Above 500 Hz the sensitivity of GEO 600 is currently limited by photon shot noise while technical noise sources dominate at lower frequencies. Coating Brownian thermal noise and thermo-refractive noise of the beam splitter are the dominant 'fundamental' noise sources at low frequencies. With the following changes the upgrades of GEO 600 will therefore aim at the frequency range above 500 Hz.

output port the shot noise can be lowered. GEO 600, LIGO and Virgo will use this so called DC read-out technique.[8]

Output Mode Cleaner Due to deviations of the mirror surfaces from an ideal sphere higher order optical modes of the Signal Recycling cavity exit to the output port of GEO 600. This light adds shot noise but does not contain GW signals. By removing this light with an additional optical resonator in the output port, the Output Mode Cleaner (OMC[9]), the signal to noise ratio can be improved. GEO 600 will use a 4-mirror OMC with a round trip length of 66 cm and a finesse of ≈150.

Squeezing The injection of light squeezed in the phase quadrature into the output port can lower the shot noise of an interferometric GW detector.[10] Using a squeezing level of about 10 dB and allowing for losses of about 15% on the way from the squeezer via the signal recycling (SR) mirror, through the OMC to the photo diode will reduce the shot noise by a factor of two in strain amplitude spectral density, equivalent to a power increase of a factor of four.

Tuned, broadband Signal Recycling To make use of squeezing over the full desired frequency range the squeezed light must undergo the same frequency dependent phase rotation as the light exiting the SR cavity. This is the case if the SR cavity is tuned to carrier resonance and both signal sidebands see the same resonance conditions. Changing the reflectivity of the SR mirror from 2% to 10% will widen the bandwidth of GEO 600 to about 3.5 kHz to improve the high frequency performance.

Light power increase The signal strength can be increased by increasing the light power inside the interferometer. At the same time the light power on the photo detector will increase yielding higher shot noise. The signal increases linearly with the light power whereas the shot noise only rises with the square-root. Hence a net gain with the square root of the light power is achieved. In GEO 600 the laser power used at the input to the mode cleaners will be increased from 6 W to 35 W.

With increasing light power, radiation pressure effects in the mode cleaners become increasingly problematic. The increased laser power can be compensated by lowering the finesse by a factor of 5, yielding the same intra-cavity light power as before. The reduced susceptibility to optical losses will raise the throughput by almost a factor of 2 and will increase the laser power inside the interferometer from about 3 kW to 30 kW. Thermal lensing from residual absorption in the beam splitter will be compensated by appropriately irradiating the beam splitter with infrared light from an incandescent source. The resonances of the triple pendulum mirror suspensions in GEO 600 are dampened at the upper stage by sensing the motion with shadow sensors and feeding back to magnet-coil actuators. These shadow sensors operate with DC LEDs as a light source and can sense light scattered from the main interferometer beam. This light disturbs the control loops and leads to mirror misalignments. In order to decrease this coupling and avoid problems after the light power increase, the shadow sensors will be operated with amplitude modulated light.

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