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THE VIRGO INTERFEROMETER FOR GRAVITATIONAL WAVE DETECTION

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The Virgo interferometer for gravitational wave detection is described. During the commissioning phase that followed the first scientific data taking run an unprecedented sensitivity was obtained in the range 10–60 Hz. Since then an upgrade program has begun, with the aim of increasing the sensitivity, mainly through the introduction of fused silica wires to suspend mirrors and by increasing the Finesse of the Fabry–Perot cavities. Plans until the shutdown for the construction of the Advanced Virgo detector are given as well as the status of the upgrade.

Keywords: Gravitational waves; interferometer; thermal noise.

1. The Virgo Interferometer

The Virgo interferometer[1] has been built and is operated by a French–Italian collaboration, joined recently by The Netherlands and now also including Polish and Hungarian groups. It is located in Cascina, 15 km from Pisa (Italy). The Virgo interferometer is part of a global network, together with the two LIGO[2] interferometers in Hanford (WA) and Livingston (LA) and the GEO600[3] detector, located near Hannover (Germany), which aims to detect signals in the 10–10^4 Hz band. This network would significantly improve its performance with the inclusion of LCGT[4] in Japan or AIGO[5] in Australia. Gravitational wave detection capability is complemented by the AURIGA,[6] EXPLORER and NAUTILUS[7] resonant bar detectors in the 850–950 Hz band, although with a spectral sensitivity one order of magnitude smaller. Recently the International Pulsar Timing Array[8] was formed aiming to detect gravitational waves at 10^{-9}–10^{-6} Hz.

The first Virgo Science Run (VSR1) was performed in 2007. Data were taken and analysed jointly with LIGO in the framework of a data sharing Memorandum of Understanding between the LIGO Scientific Collaboration (LSC) and the Virgo Collaboration. Years 2008 and 2009 were dedicated to the completion of Virgo commissioning, reaching essentially the design sensitivity at low frequency and thus confirming the performance of the seismic isolation system and the reliability of the overall choices made in that direction. The second Virgo Science Run (VSR2), performed jointly with the LSC Science Run 6 (S6) confirmed the excellent behavior of the Virgo interferometer and led to the decision to use mirrors with fused silica suspension fibers for scientific data collection.

This article describes the main characteristics of the Virgo interferometer and presents recent results on the performance of the interferometer.

2. The Apparatus and Its Performance

The Virgo detector uses 21 kg fused silica mirrors as test masses that are suspended by Superattenuators,[9] which provide seismic isolation down to 4 Hz. The Superattenuators implement a cascade of harmonic oscillators obtained with pendula for the horizontal degrees of freedom and Maraging® steel springs for the vertical motion. Sufficient attenuation is obtained for excitations with a frequency higher than 4 Hz, higher than the system resonance frequencies. Rotational degrees of freedom have even lower resonant frequencies. Although the measurement is performed along one direction only, achieving sufficient attenuation in all degrees of freedom is essential to reduce noise to the required level, due to the unavoidable presence of residual coupling between degrees of freedom.

The last stage of the suspension consists of a marionette that can steer the mirror and move it along the beam direction. Forces are applied to the mirror by means of coils attached to a reference (or recoil) mass, which is seismically isolated by the same Superattenuator. In Virgo the wires used to suspend the mirrors were of C85 carbon steel, with low dissipation in order to reduce thermal noise. In the Virgo+ upgrade a monolithic assembly will be used by bonding fused silica wires to the mirror. A significant improvement in thermal noise due to the lower dissipation in the fibers is expected.

The optical setup to compare the length of two 3 km arms in perpendicular directions is based on the Michelson interferometer. The arms contain Fabry–Perot cavities with a Finesse of 50, which will be increased to 150 in the Virgo+ upgrade. Light coming back from the interferometer is reflected back by a Power Recycling mirror. Thermal deformation effects have proven to be significant, introducing aberrations, and for VSR2 a Thermal Compensation System using CO_2 lasers to heat portions of the input mirrors was introduced.

The light is produced by a high power laser which is phase-locked to a master laser and sent through a 144 m long mode cleaner to the interferometer. Frequency stabilization uses the mode cleaner and the interferometer itself, once their servo loops have been closed. This is called Second Stage Frequency Stabilization (SSFS). The gravitational wave signal is obtained from variations in the light intensity at the output of the interferometer once the instrument is tuned on the dark fringe. The interferometer has a complex feedback system to maintain an accurate working point which is reached in a few minutes by applying an automated procedure.

The VSR2 run started on July 7, 2010 and lasted until January 8, 2010, when the installation of monolithic suspensions began. A duty cycle of more than 80% was achieved, counting also the routine maintenance operations, with a reach for an optimally oriented binary neutron star system of about 20 Mpc with a Signal-to-Noise-Ratio (SNR) of 8. The glitch rate with a threshold of SNR of 10 was 0.01 Hz. Fig. 1 shows the achieved sensitivity together with the Virgo design curve.

3. Virgo+ Status and Perspectives

The main step for the upgrade consists of suspending four new mirrors that will provide a Finesse of 150 instead of 50. This introduces, among others effects, an increased thermal load on the cavity mirrors. With lower dissipation in the silica fibres a reduction in thermal noise of up to one order of magnitude is expected. At present the monolithic input mirrors have been produced and are ready to be suspended, while the end mirrors are entering the assembly phase. Recovery of Science mode is planned for the end of July 2010. It can be seen from the predicted sensitivity curve (Fig. 1) that achieving the Virgo+ sensitivity, which may require quite some time, will be a significant step toward the Advanced detectors.

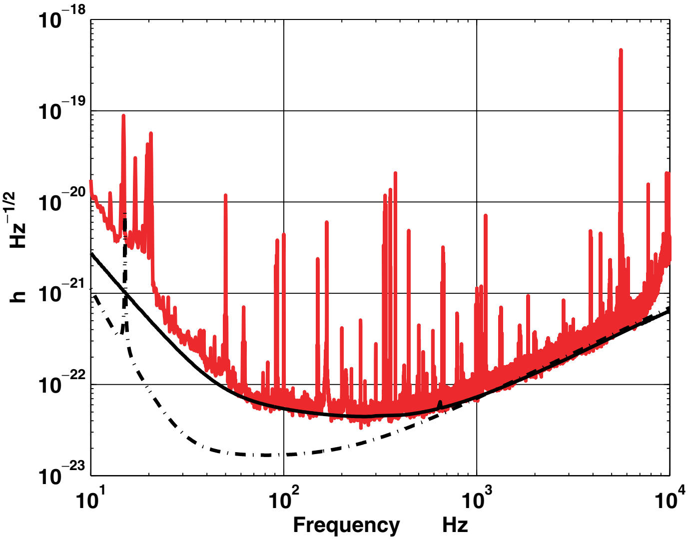

Fig. 1. Virgo sensitivity during VSR2 (red). Design sensitivities for Virgo (black solid) and Virgo+ (black dashed). (Color online)

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