Status of the VIRGO experiment

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The Virgo detector will be a 3 km long interferometer antenna with a design sensitivity aiming at the direct observation of gravitational waves.The construction of this detector which will be installed near Pisa is under way. The data taking should start in year 2000 with a design sensitivity close to $\tilde{h} \simeq 10^{-23} Hz^{-1/2}$. The motivations, detector principle, main sources of noise and status of the experiment are presented.

1. INTRODUCTION

Gravitational waves are travelling perturbations of the spacetime curvature emitted by motions of matter. They are predicted by the General Relativity and other theories of gravitation. Given the weakness of the gravitational constant, they can be produced with a reasonable amplitude only by astrophysical sources involving large masses moving at high velocity. Therefore, their observation will be not only a test of the theories of gravitation in strong field conditions but also a new window opened on the universe.

Since the pioneer work of J. Weber in 1960, several groups all around the world using various techniques have built gravitational wave detectors with improving sensitivity but without detection success. Meanwhile, the accurate observation of the binary pulsar PSR 1913+16 by J. Taylor and colleagues [1] over more than 15 years has provided the first indirect evidence of the existence of gravitational radiation and has increased the interest for the direct observation of gravitational waves. Today, two big projects, the French/Italian VIRGO project [2] and the US LIGO project [3] are now on their way to build detectors with a design sensitivity aiming at the direct observation of gravitational waves.

2. The detector principle

The goal is to measure the perturbations of the spacetime curvature. Locally they produce a perturbation of the flat metric described by a time dependent and dimensionless amplitude h(t). In the simplest theoretical model, this perturbation will change the distance L between two test masses by ΔL with

$$h(t) = \frac{2\Delta L}{L} \tag{1}$$

Therefore to optimize the detection we will simultaneously maximize the detector length L and minimize the position resolution ΔL. This measurement is performed by tracking over the time the positions of test masses. To get the maximum sensitivity, interferometric technics are used. The test masses are the mirrors of a large Michelson interferometer and the arm length difference is measured. Given the quadrupolar nature of the gravitational waves, one arm will be expanded while the other will be contracted when such a wave hits the detector with a direction normal to the interferometer plan (the best situation).

With such a detector principle, the noises are coming either from the fact that our test masses are not free or because our distance resolution is limited. The first factor limiting this resolution is the photon counting noise (the shot noise). To reduce its effect we use as much light as we can. To do so we will use a high power laser (a diode pumped Nd:YAG laser of 20 W) and we will recycle coherently the light reflected by the interferometer with a mirror located in front of the beamsplitter (the expected recycling factor is more than one order of magnitude). To increase the signal we stretch the effective arm length by using Fabry Perot cavities in the arms (cavity finesse of 50). With such an optical layout, the light power in the arms will be around 10kW. This power puts very strong requirements on the mirror quality otherwise it could be converted into heat. This heat would induce temperature gradients, index gradients which are translated into wavefront distortions, and reduce the interferometer contrast and the detector sensitivity. The mirrors losses by absorption must therefore be smaller than a few ppm.

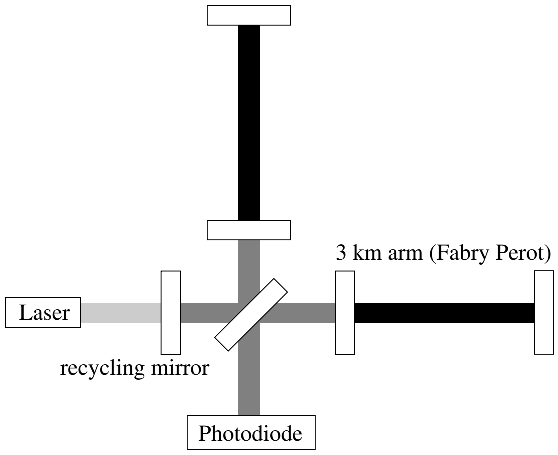

Figure 1. The interferometer layout

The second difficulty is to build free test masses. This is done by using suspended mirror which thus become equivalent to free masses above the pendulum resonance frequency as described in [4].

Other potential sources of noise exist but will not give a dominant contribution if special care is taken. For instance, the laser frequency fluctuations coupled with small arm asymmetries will be seen as arm length variations. To avoid such effects, the laser will be stabilized using several reference cavities and we expect a frequency noise spectral density less than 10^{-4} Hz/$\sqrt{\text{Hz}}$. Another example is the vacuum system. The whole interferometer needs to be operated under a high quality vacuum (less than 10^{-8} torr) to reduce pressure fluctuations which induce optical path length variations. We have to build two 1.2 m diameter stainless vacuum pipes of 3 km length, plus vacuum tanks for the optical elements and their suspensions. All this system needs high cleanness to be able to reach the vacuum design value and to avoid pollution of the optical surfaces.

3. Expected sensitivity

The figure 2 shows the expected sensitivity. The low frequency is dominated by the seismic noise. Then the thermal effect of the mirror suspension is dominant up to a few hundred Hertz with various resonances coming from the normal modes of the last stage of the mirror suspension. Finally the high frequency is shot noise limited with an increase due to the Fabry-Perot cavity when the storage time in the cavity becomes of the same order of magnitude as the period of the signal.

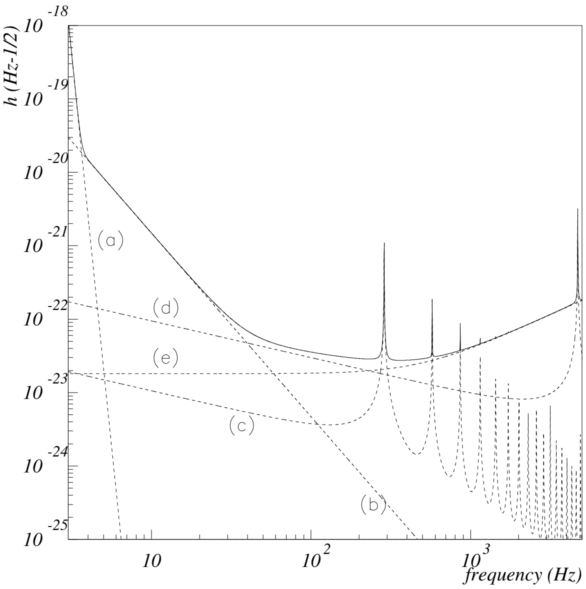

Figure 2. The expected sensitivity. The curve (a) refers to the seismic noise, (b) refers to pendular thermal noise, (c) refers to the wires thermal noise, (d) refers to mirror thermal noise, (e) refers to shot noise.

4. Status of the experiment

The VIRGO experiment was formally approved by France (CNRS) in June 92, and by Italy (INFN) in September 93. The site acquisition procedure should be completed at the beginning of 96. The building design for the central part has been frozen and a company selected for the construction. A detailed R&D program has been completed for the vacuum system with the construction and test of a full scale prototype for the mirror vacuum tank and for a section of the main beam tube. A 6 W laser prototype was successfully operated. The mirror technology is now available with the required specification for medium size mirror (8 cm diameter) and needs a scaling with the mirror size. Prototypes of the suspension stages have been built and tested with adequate filtering performances. The software environment of the experiment is in development with the on-line system tested on some prototypes and with a simulation program used to defined the control scheme of the interferometer.

The central part of the experiment should be available in 98 to start the tests using the Fabry-Perot input mirrors as end mirrors of a small recycled Michelson interferometer. Most of the components of this interferometer will be the final ones. While learning to run the interferometer we will be constructing the long arms, vacuum tube and terminal buildings and developing the process for elaborating the large mirrors. The operation of the full VIRGO experiment should start at the beginning of year 2000.

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