PROCEEDINGS OF SCIENCE

The status of Virgo

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Abstract: In this paper the main characteristics of the interferometric gravitational waves detector Virgo are presented as well as its present status and perspectives.

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1. Introduction

Virgo [1] is a 3km long laser interferometer aiming at the detection of gravitational waves in a range of frequencies between 10 Hz and 10 kHz. The effect of a gravitational wave is to modify the distance between free falling masses in phase opposition along two orthogonal directions. A Michelson interferometer is therefore well suited for their detection since it allows to measure the length difference between two orthogonal axes.

The sensitivity of such a detector is defined as the smallest measurable relative arm length difference. The design sensitivity of Virgo reaches $h = 3 \times 10^{-23}/\sqrt{Hz}$ around few hundred Hertz. Virgo has been built close to Pisa in Italy. Its construction ended mid 2003 and the detector is currently under commissioning. In section 2 the Virgo layout is described while section 3 is devoted to its present status. Perspectives are discussed in section 4.

2. The VIRGO layout

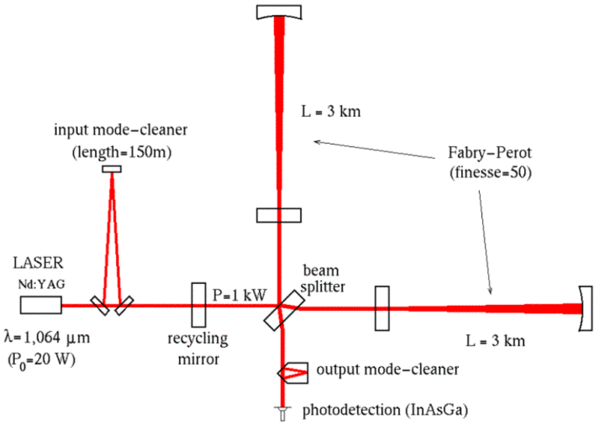

Figure 1: Optical scheme of VIRGO.

The optical layout of Virgo is shown in Figure 1. The passage of a gravitational wave induces a phase difference between the two arm beams which is measured at the output port of the interferometer. The statistical fluctuation on the number of detected photons (shot noise) limits the sensitivity of such a Michelson interferometer. This limit is given by:

$$h = \frac{\lambda}{4\pi}\frac{1}{L}\sqrt{\frac{2\hbar\omega}{P}} \tag{2.1}$$

where ω and $\lambda = 1064$ nm are the laser frequency and wave length, L=3km is the arms length and $P = 20$ W is the input power. In order to reduce this limit, each arm contains a Fabry-Perot cavity so that the phase shift created by a gravitational wave is amplified: the beam makes an average of 30 round trips in the cavity, therefore increasing the effective arm length up to 100km. Moreover, to achieve maximal sensitivity the interferometer arm length difference is set in order to have a destructive interference at the interferometer output port. In this condition all the light is reflected toward the laser and can be reinjected into the interferometer using a recycling mirror. This power recycling technique increases the amount of light impinging on the beam splitter by a factor 50, and as a consequence increases the interferometer sensitivity. An important limiting factor for ground based detectors is the seismic noise. In order to allow gravitationnal waves detection above 10 Hz this noise has to be attenuated by many orders of magnitude above this frequency. This is acheived by suspending the mirrors to a chain of pendulums called the superattenuators [2]: the seismic noise is attenuated by 14 orders of magnitude at 10 Hz and falls well below the shot noise. All the mirrors of the interferometer are suspended to a chain of pendulums so that they are equivalent to free falling masses at frequencies above the pendulum resonant frequency.

At low frequencies (typically below 1 Hz) the mirror motion is of the order of 1 mm. The interferometer has to be kept in the required interference conditions with a precision of the order of 10^{-12} meters. Moreover all mirrors have to be aligned with respect to each other. Active controls are therefore needed. Local sensors (CCDs, accelerometers, LVDTs) are used in a first step to keep each mirror at a fixed position with respect to the ground. This allows to reduce the speed of the mirror to about 1 μm/sec and to obtain interference fringes. These interference fringes measured by the photodiodes are then used to control the position of the mirrors in order to lock the whole interferometer in the needed interference conditions.

All the system is under ultra-high vacuum (below 10^{-9} mbar) in order to avoid acoustic and thermal exchange which could create phase variations along the beam path.

3. The commissioning of VIRGO

The commissioning of Virgo started mid 2003 and has been performed in several steps: the alignment and the longitudinal controls of the Fabry-Perot cavities have first been implemented, then the two arms were operated with the Michelson locked on the dark fringe (recombined interferometer) and finally the alignment and longitudinal control of the recycling mirror were implemented to reach the full Virgo configuration (recycled interferometer). After each main step an engineering run of 3 to 5 days is performed in order to check the stability of the machine, to measure its sensitivity, to find and understand which are the noise sources which limit the sensitivity and test the data analysis processes. The summary of the sensitivities measured during these runs is shown on Figure 2 as well as the last measurement at the time of the conference (May 27th), reaching a best sensitivity of few $10^{-21}/\sqrt{Hz}$ around 700 Hz. The sensitivity improves with the complexity of the interferometer configuration and when controls are implemented or improved. As an example the interferometer was run in the recombined configuration for C3 and C4 runs but the longitudinal control has been improved for C4 and the automatic angular alignment had been implemented. More details on the commissioning can be found in [3]. Since then the C6 run announced at the conference took place: the interferometer was operated in the recycled configuration for 2 weeks and its sensitivity and stability have been further improved. At the time of the conference the noises limiting Virgo sensitivity were mainly due to:

- the longitudinal and angular controls of the mirror: the electronic noise of the mirror position controller or the intrinsic noise of the sensor introduced by the control loops induce a displacement of the mirror. To reduce the impact of these noises the control loops can be optimised and/or the electronic can be improved.

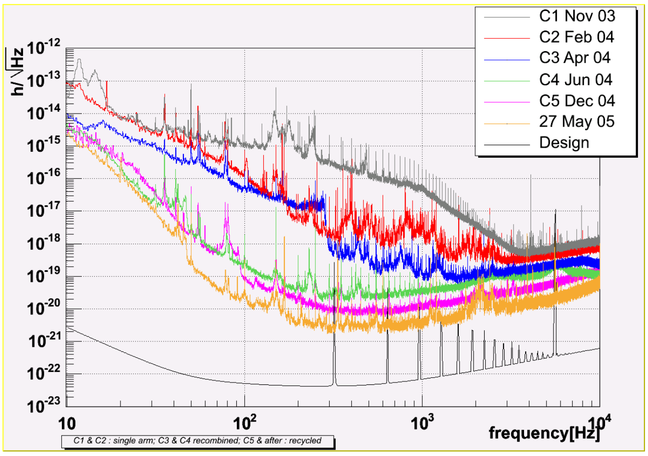

Figure 2: Summary of the sensitivities obtained in different optical configurations: single Fabry-Perot cavity (C1, C2 runs), recombined interferometer (C3, C4 runs) and recycled interferometer (C5 and May 27th).

- laser noises: these are due to power and frequency fluctuations. This requires a good stabilisation of both the laser power and frequency. These control loops also introduce the noise from their sensor and are regularly improved.

The global angular control of the interferometer is being implemented. It has two advantages: it increases a lot the stability of the system and it reduces the angular control noise since the sensors used (photodiodes) are much less noisy than the sensors used by the local controls.

The commissioning activity has also to face unforseen difficulties. As an example it was discovered that, when the recycling mirror is aligned (i.e. in the full Virgo configuration), a small fraction of the light reflected towards the injection system is retrodiffused to the interferometer and creates spurious interference fringes which prevented the lock acquisition. The final solution to this problem will be to install a Faraday isolator and requires the replacement of the injection bench. A shutdown will take place in autumn 2005 to that purpose. Meanwhile, a temporary solution has been used which implies a reduction of the incident power by a factor 10. Note that the sensitivity of C5 and May 27th have been obtained with this reduced input power.

4. Conclusion and perspectives

The commissioning of Virgo is progressing well and the full interferometer was locked for the first time one year ago. The sensitivity is making progress towards the design and further improvements are expected with the implementation of the full global alignment of the interferometer and the replacement of the injection bench which will allow to work with the full laser power. The first Virgo science run is expected to take place in 2006.

References

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