Future Virgo Upgrades

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FUTURE VIRGO UPGRADES

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The Virgo detector will enter soon in a scientific data taking period. An ambitious upgrade plan has been planned for the next future (Virgo+ project) and for the long term (Advanced Virgo project). The set of improvements designed for Virgo+ and their motivation will be described; few highlights on the Advanced Virgo evolution will be also presented.

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1 Status of Virgo

The Virgo detector [1] is a French-Italian collaboration aiming to detect gravitational waves from astronomical sources. Among the other current ground based gravitational wave detectors, Virgo is the one having the best design sensitivity at low frequency, thanks to the particular seismic attenuators [2], from which the mirrors are suspended. Construction at the site of Cascina, close to Pisa (Italy), started in 1996 and ended in July 2003. Since then, Virgo is in a very active commissioning phase. The performances of the detector are now very close to the design ones [3] which were judged interesting enough to have a first scientific data taking period of about 4 months starting from middle of May 2007. Here are described the last steps to be done to reach the design sensitivity.

1.1 Persisting technical noises

The main performances of the apparatus are characterized by the sensitivity curve of the instrument (Fig. 1). This sensitivity is limited by different sources of noise [4] depending on the bandwidth. At low frequencies (below 100Hz), the sensitivity is limited essentially by "control noises" (angular and longitudinal). In the middle frequency range (100-1000Hz), the limiting noises are environmental noises coupled by various sources of diffused light. Finally above 1kHz, the sensitivity is shot noise limited. Increasing the input power is currently not possible due to thermal lensing effects in the input mirrors of the Fabry-Perot cavities, which change the optical fields resonance properties in the interferometer, and consequently affect the longitudinal control of the cavities. All these limitations can be described as persisting technical noises.

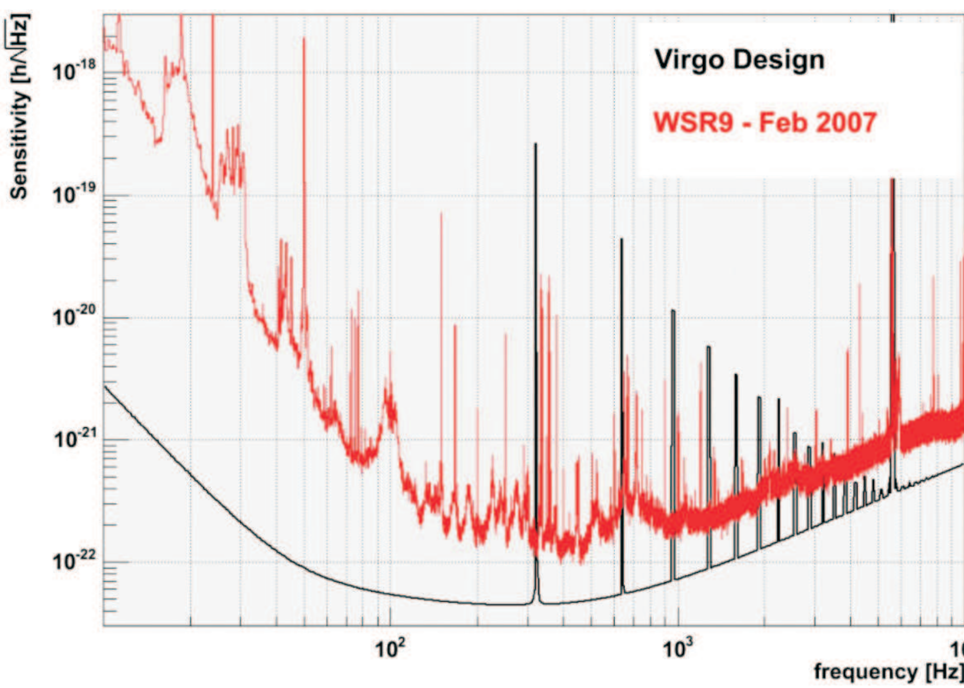

Figure 1: Recent Virgo sensitivity curve compared with Virgo design sensitivity

1.2 Towards Virgo design sensitivity

Virgo is currently facing 2 major problems in term of sensitivity performances: diffused light related noises and input pwer limitation due to thermal lensing effects. Many activities have already started to tackle these issues and will go on after the first scientific run.

Diffused light issue

For what concerns the diffused light, we are fighting on 3 fronts: the transmission of the far end mirrors, the dark port and the reflection port of the interferometer. In each case, some light from the main beam is backscattered and acts as a vector which couples the environmental noise (acoustic and seismic) to the interferometer output limiting the sensitivity in various spectral intervals between 10 and 1000Hz. A huge effort has been made to decrease both the amount of diffused light and the acoustic/seismic noise floor at the different interferometer ports. The mitigation of the environmental noise is essentially done by installing acoustic enclosures around the optical benches and replacing optical mounts with stiffer ones. The mitigation of the diffused light is a more tricky issue as it is very difficult to measure. The work consists mainly in using better optics (roughness, coating, large aperture) and dumping all spurious beams generated by the optics used in transmission (this appears particularly critical for the optics in vacuum and much of our effort is concentrated on a Brewster plate at the detection port).

Thermal lensing issue

As a consequence of the thermal effects [5], the interferometer is being run with 7W at the input instead of the 10W that could be delivered. This has been shown to be an experimental limit. Beyond this limit, the resonance properties of the sidebands' fields (mandatory to build the Pound-Drever signals used to control the lenght of the cavities) in the recycling cavity is changed in such a way that the longitudinal control of the optical cavities becomes unstable. The phenomenon can be explexained as follows: the input mirrors of the Fabry Perot cavities are absorbing some energy (typically, 1ppm/cm for the substrate and 1ppm for the coating). As the temperature of the mirror is changed in a non spatially uniform way, the optical index of the material is changed in a proportional way creating a virtual lens in the recycling flat-flat cavity. The sidebands, which are resonating only in the recycling cavity (and not in the arms FP cavities as the carrier), are then degenerated in higher order modes whom resonance properties are different.

As we are using the optics with the lowest absorption available right now, the only solution is to implement a thermal lensing compensation system. A concept based on the systems already running in equivalent experiments (LIGO, GEO) is currently being developed and should be integrated at the beginning of 2008. It consists on a CO2 laser focalized on the mirror with a shape designed to uniformize the temperature in the substrate.

Another idea has been followed as well, and partially implemented in order to improve the longitudinal and angular control of the interferometer. The input light is frequency modulated at an additional frequency so that the sidebands' field is not resonating in any cavity of the interferometer and give directly an information in reflection, without depending on the resonance properties in the recycling cavity. This signal is already used for alignment purpose and will be used later on for longitudinal control.

2 Virgo +

The idea of going towards a second generation of interferometers, to get a sensitivity enhanced by a factor 10 respect to the first generation, is already concrete for Ligo and in discussion for Advanced Virgo. These second generation interferometers will be based on the infrastructure of the first generation, but will need important upgrades of the apparatus. In the meantime, there is the possibility to perform minor upgrades, thus improving significantly the sensitivity of the detector. The list of these modifications have been gathered under the project name "Virgo+" [6].

2.1 *Virgo nominal sensitivity limitations*

The Virgo design sensitivity is limited essentially by 3 kinds of noise (Fig. 2): pendulum thermal noise at low frequency, suspension and mirror thermal noise at the intermediate frequency range and shot noise at high frequency. The next sections describes the list of proposed reasonable upgrades to enhance the sensitivity without any heavy infrastructure changes. These upgrades have been divided in 3 packages: "shot noise", "electronics and control" and "suspension". Reviews are planned during the year 2007 to decide what is the strategy for the upgrades: all at the same time or in sequence depending on detector status and R&D maturity.

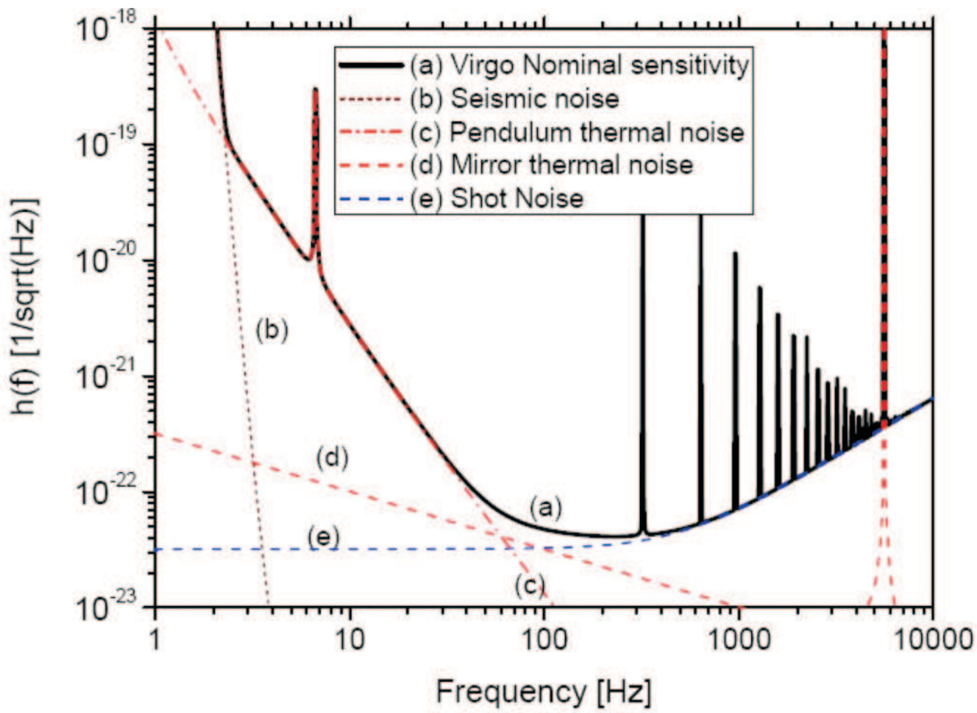

Figure 2: Virgo design noise budget

2.2 *Shot noise package upgrade*

The first challenge is to increase the power reaching the interferometer up to 30W. To obtain this goal, assuming a typical 50% transmission of the IMC, there is the need to add a 40W amplifier module in the laser chain, a Pre Mode Cleaner cavity (Fig. 3), and to decrease the losses inside the Input Mode Cleaner cavity. Of course, we'll have to deal also with stronger thermal effects, in particular in the Faraday isolator and in the input mirrors of the Fabry Perot cavities.

The amplifier module has been already acquired to the Laser Zentrum Hannover and is currently under test. A power of 64W has been demonstrated on a test bench.

The Pre Mode Cleaner cavity, a triangular 13 cm long cavity (finesse=500) made of Zerodur and located in a vacuum tank, will be devoted to filter out the amplitude fluctuations of the laser.

Finally, an improvement of sensitivity will be obtained by enhancing the power stored in the interferometer by increasing the finesse of the Fabry Perot cavities up to 150 [7].

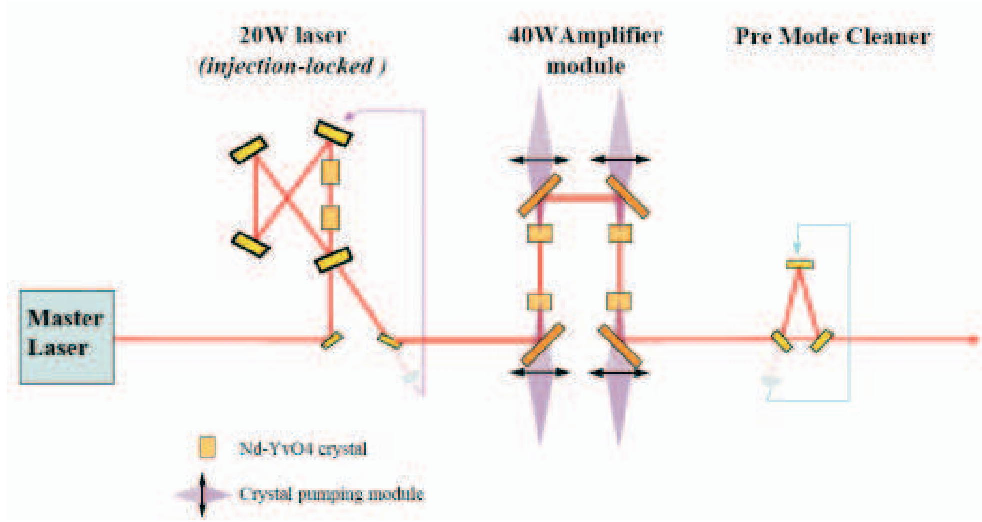

Figure 3: Input laser optical scheme for enhanced power

2.3 Electronics and control package upgrade

The current electronics and control system has been designed for Virgo sensitivity performances. In many cases, the control noises are close to be limiting factors. So there is the need to upgrade many of the electronics boards and the various elements of the control chain in general. Already, many peaces are under development: timing system, modulation/demodulation boards, Digital Signal Processing boards, quadrant diode front-end electronics, quadrant centering system...

2.4 Suspension package upgrade

The core optics payloads will be modified to deal with the 2 limiting effects at low frequency: Eddy current generated by the coils and thermal noise [9]. The new payload design includes a dielectric reference mass, a stainless steel marionette and monolithic fused silica fibers attached to the mirror through silicate bounding and soldered to fused silica clamps at the level of the marionette.

One specific payload is on the way to be redesigned: the one of the input mode cleaner. Radiation pressure effects have been demonstrated [8] in the input mode cleaner cavity. This issue is characterised by a change in the transfer function of the mechanical chain as the power builds up in the cavity, thus affecting the quality of the control of this mirror. A heaviest (larger and thicker) mirror is being polished to replace the present one. Other minor technical reasons have lead to a completely new design of this mirror payload. Another new feature that has been added is the possibility to displace the mirror over a wider dynamic range thus allowing change the phase modulation sidebands, which are transmitted by the input mode cleaner cavity.

One issue has been raised during the last year concerning the all suspension chain: the ground tilt effect. This problem, mainly affecting the locking stability and interferometer duty cycle, is under study and new sensors will have to be setup to cancel this effect at the level of the top stage of the suspensions.

2.5 Noise budget and performances of Virgo+

The Virgo+ design sensitivity depends on the completion of the various packages described above (Fig. 4). The sensitivity could be increased by a factor 2 to 10 with respect to Virgo, depending on the frequency region. The average horizon for NS-NS and BH-BH inspiral range should be multiplied by a factor 3 to 6. The commissioning phase for Virgo+ should start in 2008 and end in 2009 to start a science data taking period in parallel with Enhanced-Ligo in 2009.

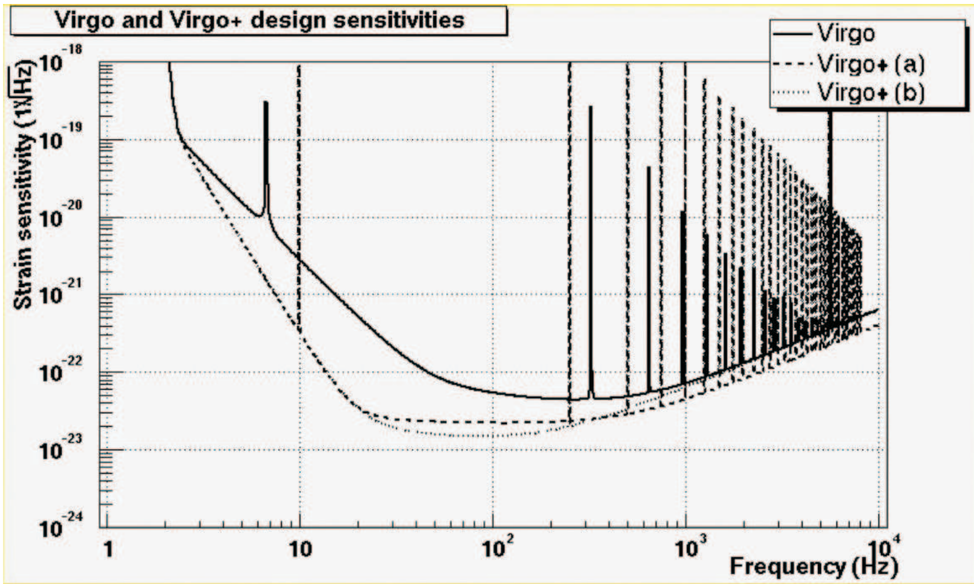

Figure 4: Virgo+ design sensitivity for a Fabry-Perot finesse of 50 (a) and 150 (b)

3 Advanced Virgo

Even if a first detection is possible, the sensitivity of Virgo and LIGO will not be sufficient to open the era of the gravitational wave astronomy. For this reason it is important to prepare the upgrades of the present detector, considering that, for a uniform distribution of sources , an increase of the sensitivity by only a factor 2 will increase the expected event rate by about 2 [10]. The first goal for Advanced Virgo is to enhance the sensitivity by a factor 10 respect to Virgo design sensitivity. A preliminary design will be ready by the end of 2007.

3.1 Advanced Virgo project status

Four fields of concern have been defined to carry out the design of Advanced Virgo [11]. A first working group will deal with the "interferometer optical configuration, sensing and control" and will make essentially the decisions about the Signal Recycling cavity, DC detection, new Output Mode Cleaner cavity, stable Recycling cavity, heavier/larger mirrors. The second group is in charge of the "laser and optics for high power" to deliver a 100W beam at the input of the interferometer while taking care that the optics are compliant with such a high power. Innovative ideas to use optical fibers are also taken into account. The third group is facing the "suspension and thermal noise issues" willing to improve the quality of the coatings (in order to reduce thermal noise effects and losses) and the monolithic suspension performances (in particular the fibers' geometry to suspend the mirrors). The last group "electronics and controls" has the duty to design a system compliant with the new control requirements.

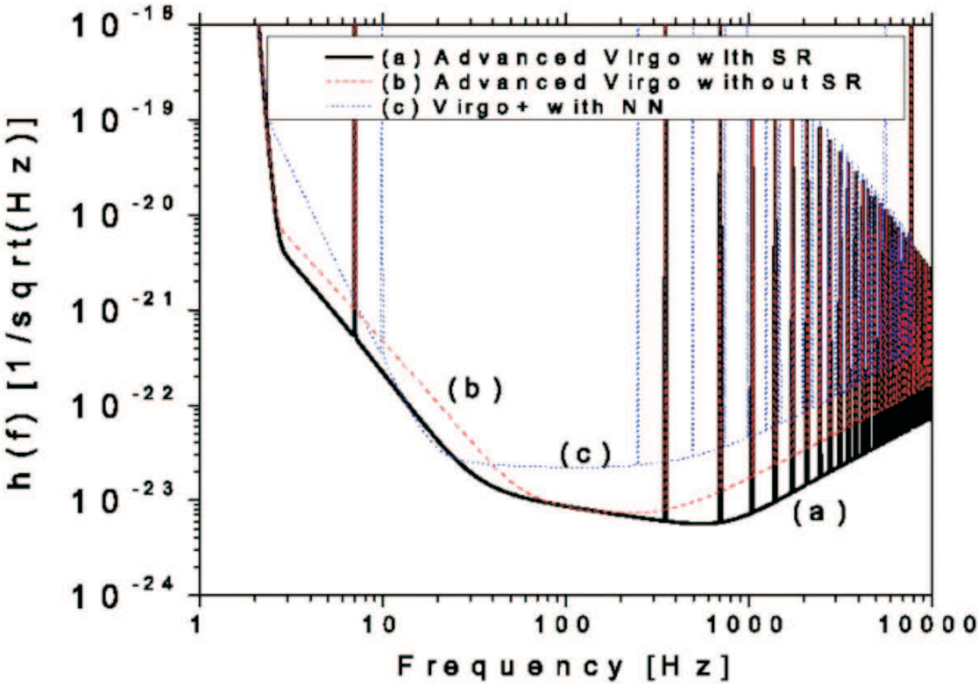

Figure 5: Preliminary Advanced Virgo noise budget assuming an input power of 100W, a mirror weight of 40kg, a recycling gain of 50 and a Fabry Perot finesse of 600

3.2 Major ongoing R&Ds

The main upgrade of Advanced Virgowill be the increase of the input power up to 200W. Already, the Laser Zentrum of Hannover is working on a 200W amplification module to be added in the optical path. Such a high power will add new constraints on the optics like the Electro-Optical Modulators, the Faraday isolators, the polarizers in term of birefringence and thermal lensing effects. Test benches are on the way to be set up to design compensation systems when needed. A huge effort is also made in the "all fibers system" direction. In particular, the possibility to replace the Input Mode Cleaner cavity with a fiber is under investigation. Main issues deriving from higher power will be thermal effects. Side effects will concern the increase in scattering light.

Thermal problems will require better general performances for the mirrors. Studies are being carried out for lower mechanical loss dielectric coatings [12], larger mirrors and corrective coatings. A peculiar attention is brought on the mirror installation in the tower process to avoid any kind of contamination.

A new optical configuration and sensing scheme is needed to include a Signal Recycling cavity, add extra pick up beams to improve the controllability, change the modulation frequencies for more appropriate ones, design a more stable Power Recycling cavity,... About angular controls, the choice between the so-called Ward and Anderson technique is under discussion. For longitudinal controls, a prototype is going to be set up to test new locking acquisition strategies with different wavelenghts using auxiliary lasers.

The detection optical scheme performances should be improved as well. The idea of using DC detection would improve the sensitivity at high frequency. Current problems with diffused light are also indicating the necessity to set up all critical optics and sensors in vacuum and suspended.

Many upgrades are under study for what concerns the suspension chain. The top stage performances at low frequency may be improved by adding tiltmeter sensors. A full scale protoype of fused silica suspension is projected to test new marionette and reference mass design, electrostatic actuators. In parallel, the development of laser fabricated silica ribbons [13] for monolithic suspension is pursued.

3.3 Possible sensitivity and performances of Advanced Virgo

The Advanced Virgo performances will depend obviously on the optical configuration chosen, in particular with or without Signal Recycling cavity (Fig. 5). The construction and commissioning of Advanced Virgo is planned in parallel with the Advanced Ligo one starting from 2011.

4 Conclusion

The commissioning of the Virgo interferometer has to continue, after the first science data taking in October 2007, to approach Virgo design sensitivity in 2008. Intermediate minor upgrades can then be implemented to improve the sensitivity of the instrument by at least a factor 2. This intermediate step is called Virgo+. Changes that will need major system and infrastructure upgrades are planned for 2011: Advanced Virgo has the scope to improve the sensitivity by a ratio of 10 over nominal Virgo.

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