The status of virgo

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Abstract. After almost 4 years of commissioning Virgo has started its first long science run. The recent commissioning and data analysis activities are summarized here.
1. Introduction
Virgo [1] is a gravitational wave antenna based on a Michelson interferometer with 3 km long arms (see Fig. 1); each arm contains a Fabry-Perot cavity and the power recycling technique is used [2]. The commissioning of Virgo started mid 2003 and the full interferometer was first locked in autumn 2004. In order to make possible the control [3] of the full interferometer the incident power had to be temporarily reduced by a factor 10. The final solution was implemented at the end of 2005 and the commissioning was restarted with the full power early in 2006. These activities are summarized in Section 2. After a period of commissioning with the increased power, the interferometer was stable enough to allow some long data taking on weekends starting from September 2006 (the Weekend Science Runs: WSRs). Recently a long scientific run (VSR1) has started whose data are analyzed in coincidence with the LIGO S5 run data.

2. Overview of recent detector activities
Until September 2005 a problem of light retrodiffused by the input mode cleaner towards the interferometer prevented to reliably control the interferometer. To overcome this problem a temporary solution was adopted. This involved a reduction of the power incident on the interferometer by a factor 10. The final solution was the installation of a Faraday isolator between the input mode cleaner and the interferometer. This was implemented between September 2005 and January 2006. Other improvements were also made to the injection bench during this period. The power recycling mirror was also replaced with a larger one with a higher reflectivity in order to increase the recycling gain.

Unfortunately the increase of the power revealed some thermal lensing effects: a small fraction (around 10 ppm) of the high power stored inside the Fabry-Perot cavities (about 4 kW) is absorbed by the input mirrors leading to thermal lensing effects and therefore to a distortion of the beam shape (mainly the sidebands). It was found that the lock acquisition could not survive this thermal transient if the power is too high. Therefore the input power had to be reduced by 25%. The final solution will be the implementation of a thermal compensation on the input mirrors early in 2008.

**Figure 1.** Virgo optical scheme

**Figure 2.** Comparison of the Virgo sensitivities during C7 commissioning run, WSR1 and VSR1 science runs.

Figure 2 shows the sensitivity measured before the 2005 shutdown (C7 run, September 2005) and after (WSR1 in September 2006 and VSR1 started in May 2007). At high frequency the difference between the measured curve and the design is mainly due a smaller power incident on the Beam Splitter. The sensitivity of Virgo is similar the LIGO sensitivity at high frequencies,
slightly worse at intermediate frequencies due to environmental noises and it is better below 40 Hz thanks to the very good seismic isolation provided by the mirror suspension system.

3. Detector performance

The sensitivity of VSR1 is shown in Figure 3 together with the known and modeled noises (colored curves). At high frequency (above 1 kHz) the sensitivity is shot noise limited (dark green curve), at low frequency (below 50 Hz) it is limited by the noises introduced by the servo loops used to control the position of the mirrors (see 3.1). In the intermediate frequency band it is dominated by unmodeled environmental noises like diffused light or magnetic noise (see 3.2).

3.1. Control noises

The mirror position is controlled at low frequency in order to fulfill the resonance conditions. These controls introduce some position noise inside the detection band. The dominant longitudinal control noise arise from the control of the Beam Splitter mirror. This is due to the fact that any motion of the Beam Splitter is equivalent to a differential motion (up to a multiplicative factor) of the end mirrors as would do a gravitational wave. Since this control noise is known and its coupling can be well measured and modeled it can easily be subtracted on-line by moving the end mirrors in order to compensate for the Beam Splitter motion. This subtraction technique allows to reduce the impact of this noise by a factor 50 to 100. This noise nevertheless still limits the Virgo sensitivity below 50 Hz. Further reduction will imply a reduction of the control noise itself.

3.2. Diffused light

Part of the environmental noises is due to light retro-diffused into the interferometer. Optics located on the external optical benches can retro-diffuse light into the interferometer due to, for example, the imperfections of their surface. Since these objects are not isolated from seismic noise the retro-diffused light carries some phase noise (proportional to the motion of the optic) which is equivalent to a de-phasing induced by a gravitational wave. This noise has been reduced in two steps: first the setup of the optical benches has been improved (more rigid mounts, larger optics, ...); then acoustic enclosures have been installed around all the optical benches. After these improvements the identified sources of diffused light do not limit the sensitivity anymore. The sensitivity is nevertheless still limited by environmental noises. Other possible sources of diffused light are under investigation like the Brewster windows used to separate low and high vacuums inside the interferometer.

3.3. Stability

Another key ingredient to allow long data taking is the stability of the detector. The very good isolation system of Virgo needs complex controls [4]. As an example it is known that the longitudinal control of the mirror creates an angular recoil of the suspension which has to be compensated; but the stability has been greatly improved only when a quadratic compensation has been implemented. Thanks to these improved controls the VSR1 duty cycle (80%) is not limited by control instabilities but by technical problems, strong environmental disturbances like earthquakes or planned interruptions (maintenance, commissioning).

4. Data analysis

The data taken during the commissioning runs (like C7 in 2005) and the weekly science runs (WSRs started in September 2006) have been used for detector characterisation and to train the data analysis pipelines as well as to prepare the joint analysis with LIGO.
4.1. vetoes
After and before the event selection experimental vetoes are applied in order to remove high SNR events. These vetoes are based on environmental channels, on the interferometer error signals, or on suitable statistical quantities. A recently developed veto is based on the fact that a gravitational wave gives a signal in the dark fringe differential channel ('in-phase') while it should be seen with a much smaller SNR in the other phase of the dark fringe channel ('in-quadrature'). This veto was introduced in WSR8 at an expense of only a small dead time (1.2%) and good efficiency (83% for events with SNR>10). It allows to remove events due to disturbances affecting the beam path in air, such as small dust particles crossing the beam.

![Figure 3](image.png)

**Figure 3.** Noise budget during the VSRI run: Virgo sensitivity (black) compared to all known noise contributions (colored curves).

![Figure 4](image.png)

**Figure 4.** Limit on the event rate from the C7 data.

4.2. All sky search and GRB searches
The pipelines searching for coalescing binaries, supernovae and pulsars are run on most of the runs. For instance, the burst analysis of the C7 run (September 2005) has been recently completed: loud events have been understood and the methodology to be applied in subsequent runs developed. An upper limit on the event rate similar to that obtained during LIGO S2 run could be deduced from these data and is shown in Figure 4. Dedicated searches in coincidence with gamma ray bursts are also performed since the C7 run. Upper limits on the amplitude of the event are determined from the measured detection efficiency and from the value of the highest SNR in coincidence with the GRB.

5. Conclusion
After almost 4 years of commissioning Virgo started its first long science run. The present Virgo sensitivity is comparable to that of the LIGO detectors. A MOU has been signed between Virgo and the LSC data are exchanged and analysed in coincidence and data analysis groups have been merged as well as run planning committees. Characterisation studies of VSRI data have started for all searches. After the end of VSRI1 (September 2007) further improvements to the interferometer and upgrades (Virgo+ configuration, in 2008) will be performed, aiming at an improvement of the sensitivity of a factor 2 to 3 (see [5]).

References

