Virgo Progress Report
For the STAC and EGO Council

VIR-COU-DIR-1000-235
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Abstract

This report describes the Virgo activities and progress for the June 2006 to November 2006 period. It starts by status overview and collaboration news, and is followed by five sections describing in more details the detector, commissioning, data analysis, Advanced Virgo and outreach activities. These sections haven been prepared by the corresponding coordinators with inputs from various persons.

Summary

1 Overview

1.1 Recent activities:

Since the last progress report for the EGO council, the main results have been the achievement of stable lock conditions with 250-300 W inside the recycling cavity, the start of noise hunting in addition to some detectors improvements and the beginning of Week-end Science Runs (WSR).

The stable lock has been possible after learning how to handle the lock instabilities due to the thermal effects in the recycling cavity. These thermals effects affect strongly the RF "side bands" and therefore the control signals during the first minutes of a lock segment. It is a remarkable achievement to have locked the interferometer with high power despite the thermal effects and no thermal compensation. The price to pay is a touchier and longer lock procedure. The handling of the thermal effect remains difficult and a slight reduction of the laser power has been needed later on. Then a noise hunting phase has started with detector improvement like the acoustic enclosure installed in October in the laser lab or the enhancement of the electronic of the coil drivers. The commissioning and optimization of the various controls is also ongoing.

The Virgo sensitivity started to be competitive with LIGO in the high frequency band at the end of August. The figure 1 shows a comparison of the Virgo sensitivity with respect to the four LSC detectors.

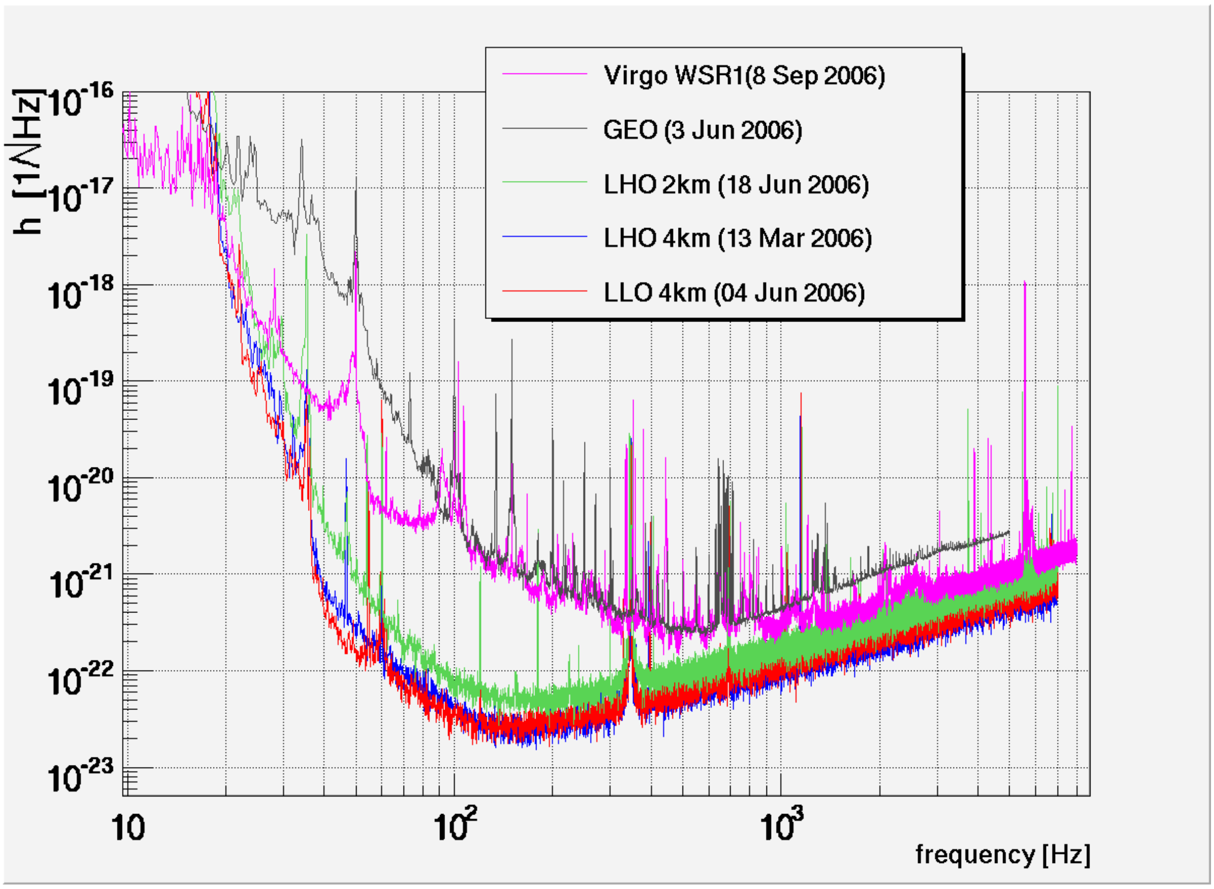

Figure 1: Virgo sensitivity during WSR1 compared to the LSC detector sensitivities running at the same time.

Therefore a series of Week-end Science Runs (WSR) has started in September. These runs let us shake down all the procedures, including shift organization, data handling and provide valuable data for the data analysis group (online and offline) and also the commissioning team, especially for noise studies.

The success of these runs has been uneven, alternating from week-ends with very good duty cycle (around 90%) to week-ends where the run was cancelled because the detector modification and related commissioning required more time than the scheduled one. However this corresponds to our policy since our current priority is the commissioning and therefore we prefer to take the risk to cancel a week-end instead of freezing all the detectors changes now. Nevertheless, periods of detector changes and robustness work have been defined and the WSR schedule adjusted to fit this work plan.

The data analysis continues to develop around the analysis of Virgo data with the newly available WSR data and the long term preparation with especially the joint LIGO-Virgo effort. On this latter topic one interesting achievement was the successful cross analysis of three hours of real data from LIGO, Virgo and GEO. The joint work between the Italian Bars and Virgo using one day of C7 data was also almost completed. Even if the obtained upper limits are not very significant because of the limited sensitivity and poor statistic, this work was the opportunity to develop a full analysis from a consistent model of black holes ringdown events up to the upper limit and this, in collaboration with other experiments.

1.2 Up coming activities

The commissioning plus WSR mode of operation will continue during the next few months with the goal to extend the frequency band where Virgo is competitive versus LIGO. This means working on the sensitivity and on the noise stability.

We expect to start next year a science run of several months in coincidence with the LIGO S5 run. The exact date of this run will be decided according to the schedule of the LIGO data taking and the progress of the Virgo commissioning.

The data analysis will continue its work on the WSR data to test the pipelines in real conditions, develop data quality and veto information and to provide feedback for the commissioning. The joint activity with LIGO will continue with the start of the integration of the activity of the different Virgo search groups (stochastic, burst, inspiral and periodic) with the LIGO ones.

The detector improvement is focused on the commissioning support with short term upgrades and on the Virgo+ preparation with intense activity on the laser power upgrades, monolithic suspension and new electronics. The target is a shutdown for the Virgo+ installation in 2008. Part of this activity is overlapping the Advanced Virgo preparation work that is gearing up, especially for the optical configuration working group. The Advanced Virgo working groups are working with the aim to provide a detailed proposal around the end of 2007. They have provided very recently guidelines for the R&D that need to be pursued for Advanced Virgo.

1.3 Collaboration organization

The application of the Roma Tor Vergata group has been accepted by the collaboration during the July meeting. Their contribution is in the process to be defined and the group started its integration inside the collaboration.

All the MOU between the groups and the collaboration, including the attachment of the MoA with EGO haven also been completed and are available on the web.

A coordinator for the Advanced Virgo has been appointed. His primary duty is to organize the work of the working groups and to lead the effort for the preparation of the Advanced Virgo proposal.

1.4 External collaboration

The main activity is the preparation of the joint work with LIGO. While waiting for the return of the EGO council changes of the LIGO-Virgo MOU and then the LIGO comments, the attachment that details the organization of the work is being prepared. Several meetings took place between the data analysis coordinator and the chairs of the different LSC and Virgo search groups to discuss these details.
The joint meetings schedule for the up coming two years is also being prepared and the current proposal contains five meetings per year alternating between Europe and the US. The agenda of these meetings may not always cover all the topics to optimize the work.
Some direct collaboration with GEO took place with joint Virgo-GEO commissioning meetings in the framework of ILIAS and the participation of a few GEO scientists to the Advanced Virgo design.

2 Detector report

2.1 Introduction

The "detector activities" are addressed toward the preparation of the largest upgrades needed for the commissioning activities and, then, toward the Virgo+ scenario. To reduce the impact on the commissioning plan, all the upgrade activities that haven't an immediate effect on the sensitivity and duty cycle of the detector, but affect the commissioning progresses (new input mode cleaner payload, thermal compensation…) have been postponed in the Virgo+ scenario. For this reason the Virgo+ package is transforming in a complex and progressively more detailed action list.

2.2 CRE decisional process

In the last 6 months the decisional process based on the change request tool has been deeply (but not universally) used by the collaboration to define the technical content of each upgrade activity and its impact on the detector.
See the web page:
http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/index.html under the detector coordination website.

2.3 Upgrades

2.3.1 New Pre-mode cleaner (PMC)

The new PMC has been already described in the previous detector report. For sake of completeness an extract of the previous description is reported here. The Pre Mode Cleaner (PMC) is a triangular Fabry-Perot cavity, used in transmission, and located on the laser bench. Its aim is to filter out the amplitude fluctuations of the slave laser, in order to be shot noise limited at the Virgo modulation frequency (6.25 MHz). The presence of this component was already foreseen in the original Virgo design, but it has been decided to reduce the PMC finesse (down to 500), thanks to the increase of the interferometer contrast; this modification is reported in this CRE document, and the assembling plan is described in the same detector coordination web page. The effective installation in the Virgo detector is currently under analysis; in fact, while the effectiveness of the pre-MC is well defined in Virgo+, still the benefits with the current sensitivity are unclear.

Name	New Virgo Pre-mode cleaner
Code	Virchrq0022006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0022006.html
Responsible	F. Cleva

2.3.2 Acoustic Isolation

Acoustic isolation in the laser lab has been described in the previous detector report. Commissioning activity discovered a coupling between acoustic noise in the laser lab and dark fringe signal. For this reason an acoustic shielding of the optical benches in the laser lab has been realized. Because of the complex geometry of the benches in the laser lab and the lack of space the adopted solution is based on two small enclosures having movable panels to permit the access to the optical components. The performances of these enclosures are currently under evaluation (and see the commissioning section of this report) because, while they reduce the acoustic noise by a factor 3-4 in the 100-1000Hz and the seismic noise by a

factor 5 in the same range, they have shown problems of turbulent air flux increasing the beam jittering at low frequency and the overall attenuation is lower of the expected. The turbulent air flux problem has been currently patched and will be completely solved in the next weeks.
The acoustic noise mitigation campaign is continuing and the isolation of the end benches is under design. The simpler geometry, the available space and the absence of overpressure in the terminal buildings permit the realization of a simpler design of the acoustic isolation rooms and surely a better effectiveness. This upgrade is under evaluation and the time scheduling could fit in a two-three months scenario. The last and more difficult isolation is in the detection lab; a progressive isolation is under evaluation.

2.3.3 New Brewster windows

The existing Brewster windows (BW), connecting the interferometer with the Injection Bench and with the Detection Bench, have respectively apertures barely sufficient to cope with the general Virgo specification for any beam passage.
Larger aperture (vertically) BWs are suggested by the need of accommodating comfortably the beams entering and exiting the interferometer, avoiding cutting them and of preventing any light scattering, due to missing absorbing baffles. The maximum aperture possible with the present vacuum system is limited by the 250 mm gate valves separating the towers. As described in the commissioning report, recently the detection tower BW has been replaced with a larger one, available, but still at the limit with the dimension requirements, if we take in account a possible misplacement of the beam. A CRE document has been realized and discussed at the detector meeting describing the design of new BW that can fully use the clear aperture permitted by the vacuum system; the implementation of this system is almost defined and it is foreseen to be implemented in the spring 2007.

Name	Large aperture Brewster windows
Code	Virchrq0122006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0122006.html
Responsible	C. Bradaschia

2.3.4 Eddy current thermal noise reduction

Eddy current problem has been discussed and presented at several detector and STAC meetings. The final solution consists in the replacement of the metallic reference masses with dielectric ones and this will be performed in the Virgo+ upgrade; nevertheless, if the eddy current dissipation will limit the noise performances of the detector a patch solution has been found and it is described in the CRE document. This solution consists in reducing the magnetic field “seen” by the reference mass applying ferromagnetic “hats” on the Virgo magnets attached to the mirror. New tests and simulations have been performed after the last STAC report to ensure the effectiveness of the solution: a 3D finite elements analysis has been performed and presented at the October detector meeting and a simple test on the actuation force reduction has been realized. Analysis and tests are confirming the goodness of the solution (while some numerical incertitude is still remaining; a reduced force test locking trial must be attempted soon).

Name	Eddy current reduction in the reference masses
Code	Virchrq0062006

Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0062006.html
Responsible	M. Punturo

2.3.5 Replacement of the Virgo IMC payload

The design activity of the new Input Mode Cleaner (IMC) payload has been already described in the previous STAC report; in the current injection system (ISYS) system a large fraction of the injected power is lost and the main culprit seams the poor substrate quality of the terminal curved mirror in the IMC. Furthermore the entire payload is very light, enhancing all the control issues of the IMC. For this reason a CRE activity has been started, defining first the new requirements and designing and heavier and better substrate quality terminal IMC mirror. Recently, the size of the substrate has been finalized optimizing also the re-use of the Herasil substrates available at EGO: a 140 mm diameter, 45 mm thickness substrate has been defined and the optical quality requirements of the polishing has been submitted to the polisher company. The design of a payload, compatible with these dimensions, is underway. Since the control issues of the current IMC terminal mirror payload aren't limiting the Virgo performances, the replacement of this component has been included in the Virgo+ scenario.

Name	Replacement of the Virgo MC payload
Code	Virchrq0032006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0032006.html
Responsible	M. Punturo

2.3.6 New quadrant diode front end modules for the Virgo Linear Alignment

This activity has been already described in the previous STAC report; it is driven by the need of refurbish the spare parts of the quadrant diode (QD) front end modules used in the Virgo linear alignment. At this occasion, some improvements in the performance should be obtained for overcoming presently felt limitations, while maintaining full compatibility (interchange ability) with the existing modules. The desired improvements concern lower noise, higher possible incident light power, lower DC offset (and resulting lower DC offset drifts), and changing the geometry from 'X' to '+' configuration. The design specifications and the implementation planning are described in a CRE document. Thanks to the backward compatibility with the previous electronics, the replacement of the old electronics will be progressive.

Name	New quadrant diode front end modules for the Virgo Linear Alignment
Code	Virchrq0082006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0082006.html
Responsible	H. Heitmann

2.3.7 New Virgo Control and DAQ electronics

This group of activity has been already described in the previous report to the STAC (see it for a more detailed description). R&D activities have been supported by EGO in the Pisa and Annecy laboratories to develop new control and DAQ electronics; the need of new electronics is due to the obsolescence of the current one and to more stringent requirements (larger bandwidth, larger computing power of the DSPs, …) defined thanks to the commissioning activity. The components under development are:

2.3.7.1 New Coil Drivers

The reduction of the Virgo noise, mainly at low frequency, requires the reduction of the actuation noise. The coil drivers currently used in Virgo have been modified to reduce the large noise due to the magnets large strength. These modifications have been engineered in the new coil drivers that contains also new features suggested by the commissioning activity (i.e. reduction of the offsets). Four prototypes will be available within the end of November, while the production is foreseen to start before the end of the year.

Name	New Coil Drivers
Code	Virchrq0052006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0052006.html
Responsible	A. Gennai

2.3.7.2 New DACs

To be compliant with the Virgo+ requirements, the replacement of the coil drivers is not enough. Few years ago it is already started an R&D activity to investigate the possibility to replace the current DACs with new ones having a larger dynamic range (24 bits). Four bits more than the current ones have been evaluated to be compliant with the Virgo+ requirements. The implementation is foreseen in the Virgo+ timescale.

2.3.7.3 New DSPs

The computational power of the current DSPs limited sometime the complexity of the algorithms used in the Virgo control; this limit has been often solved optimizing the code with a important time and resource engagement or simplifying the control filters. Nevertheless, the optimize the performances of the detector at low frequency a larger CPU power is needed and the development of a new generation of DSP board has been started. The four available prototypes were deeply tested during the last few months. No manufacturing problem was detected and only a few minor problems were detected at *netlist* level (PCI- DSP local bus dual port memory available only for 1/4 of its total capacity and on board SDRAM not accessible in 'burst' mode). Schematic design was updated to correct those problems. A communication test between DSP prototype and LAPP TOLM board was successfully performed in first half of September. Software development progressing as well with EGO software group contribution. The PCB design will be ready during coil driver first prototypes production. Production is suppose to start within the end of the year, while implementation plan must be still defined, but it will be anyway in the Virgo+ timescale.

Name	New DSP Board
Code	Virchrq0042006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0042006.html
Responsible	A. Gennai

2.3.7.4 Timing Distribution Box (TDB)

The first prototype of the TDB box had been produced and tested successfully at LAPP and the phase jitter is the one expected.

2.3.7.5 Timing and Optical link Mezzanine (TOLM)

Today four prototypes based on PCI 32bits@66MHz are available and usually used. The TOLM/DSP interface has been successfully tested. The IRGB decoding has been implemented.

New boards based on the same design are in production to carry out more setup tests. The new design based on new FPGA with external serializer / deserializer and PCI 64bits@66MHz is under studies.

2.3.7.6 Mux/Demux Board

The layout has been complete and the first prototype is currently under production. The tests will be done during November 2006

2.3.7.7 ADC board

Several ADC types have tested using the TOLM board .Two 18 bits ADC have been chosen: there sampling frequency are 800 KHz and 2 MHz. A digital anti aliasing filter implemented into the FPGA and based on 6 order filter has been successfully tested. The specifications of the final design is under writing

2.3.7.8 Related software

Several PC server architecture platforms based on INTEL/AMD bi-processors or dual-core processors are under tests to check their real-time properties with *LINUX-RTAI* kernel.

Using a single AMD dual core platform with 2.2 GHz clock and 1GBits Ethernet we succeed to test:

- all the photodiode readout (readout of 200 32bits words from a TOLM and computing)
- to send the correction to the suspension(32 32bits words writing to a TOLM)
- all running at 40Hz
- sending the corresponding data (14Mbytes/s of compressed data) through Ethernet

2.3.8 New 50W laser amplifier for Virgo+

The increase of the laser power injected in the interferometer is one of the main activities of the Virgo+ project. The activity is described in the Working Package document on the Detector Coordination web pages. A laser amplifier developed by the Laser Zentrum in Hannover (LZH) should provide 50W when feed with the current Virgo slave laser. This amplifier is under completion now and it should be delivered by LZH within few weeks (before the end of November).

The first activity is the characterization of its performances and the certification of the compliance with the Virgo requirements. A series of tests are foreseen in the Nice-OCA laboratories to characterize the frequency noise[1], the beam shape[2], the beam jitter, the

[1] To complete the information reported in the work package document, few description lines are here reported. To measure the frequency noise, we intend to make interfere amplifier input (20W laser) and output, and measure the residual frequency beat. Assuming acoustic noise is low enough, one can easily reach the level of frequency noise of standard NPRO laser

amplitude noise, the transfer function "frequency noise"/RIN, the transfer function RIN/"diode pumping current", the long term stability of the output power. An integration plan is foreseen in collaboration with the EGO team. Obviously, this activity is in the Virgo+ timeline

2.3.9 New input optics for Virgo+

A larger power injected in the interferometer requires the upgrade of some of the injection optics. A complete survey of the compatibility of the current injection optics has been started and some change is already under evaluation. New Faraday isolators are foreseen in the laser bench (LB): EOTech 8 mm aperture between Slave and Amplifier; Isowave between Amplifier and Pre-Mode Cleaner and between Pre-Mode Cleaner and Input Mode cleaner. EOT Faraday has been already ordered. Isowave Faradays are being ordered. A spare EOM with new electronics is under evaluation. The KDP crystal is available, but in any case the current on is compatible with the increased power. The presence in the laser bench of the new PMC will force to review the optical layout in that table; in fact the LB cannot accommodate all the new optics and two possible options are under evaluation: replace the current table with a longer one (but this will affect the acoustic isolation around the table), transport some of the optical components (a telescope) of the LB in the external laser bench (EIB). The last solution is under evaluation. No particular changes should be needed in the EIB, but a complete investigation is still to be performed.
In the suspended injection bench (SIB) some changes are already under investigation (with implementation time scale to be defined according to the commissioning needs); in the Faraday isolator in the SIB should be implemented a remote tuning of isolation with a $\lambda/2$ plate. A spare Faraday isolator is under assembling. The modification of the Reference Cavity (RFC) periscope is planned to make a remotely aligned and larger mirrors periscope, so that parabolic telescope alignment is less critically coupled with RFC alignment.
Furthermore, because of the problems still shown by the dihedron in the SIB (resonant modes still present in the Virgo spectrum, jumps of the dihedron in case of shocks of the SIB) the possibility to suspend that component through a controlled pendulum suspension is just being evaluated.

2.3.10 Thermal stabilization in Virgo+

Thermal lensing has been found to be a big issue for the Virgo operations, because its effect on the sidebands amplitude. Thermal deformation of the input mirrors during the locking procedure is affecting and delaying the commissioning progresses, as described in the commissioning section of this document, but, thanks to the commissioning team a strategy to reach and maintain the lock has been found and this permits to develop the thermal compensation solution in the Virgo+ scenario.

2.3.10.1 The Scanning Fabry Perot

The main tool used until now to evaluate the sidebands behaviour during the locking has been a scanning Fabry-Perot (SFP) installed at the output(s)[3] of the ITF. The modification implemented and the optical layout design of the SFP system is described in a CRE

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[2] We intend to interfere amplifier input (20W laser) and output, and locked on the "dark fringe"; we will measure the residual energy in the interference pattern in order to give an over-estimation of possible beam deformation brought through the amplifier. We will also evaluate the classical M^2 parameter of the 50W beam (although this experimental data is of less insight).
[3] Mainly the dark fringe signal, before the output mode cleaner (OMC) has bee studied.

document. The use of this device is described in the commissioning section of this document, in the thermal lensing section. A second SFP is under installation on the detector.

Name	Sidebands acquisition with Scanning Fabry-Perot spectrum analyzers
Code	Virchrq0102006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0102006.html
Responsible	P. Lapenna

2.3.10.2 The phase camera

The SFP, however, is a useful but limited tool. Indeed, it does a spectral analysis of the incoming beam but it is not able to detect relative spatial misalignment between the carrier and the sidebands, nor is able to detect their relative phase.
On the contrary, there are several reasons why the measure of the spatial mode of the RF sideband field independently of the carrier field will be really useful. First of all, it is known that the RF sidebands are significantly more sensitive to misalignments or other spatial distortions of the power-recycling cavity than the carrier field. Consequently, the spatial modes of the carrier and RF sideband fields exiting the interferometer may be quite different. Maximum signal sensitivity requires perfect spatial overlap between the transverse modes of the carrier and RF sidebands. Furthermore, before the detector is fully optimized the RF sideband fields at frequencies above and below the carrier frequency, referred to as the upper and lower sideband, respectively, can experience different spatial distortions thermal lensing effects, and knowledge of the spatial profiles of the upper and lower sidebands circulating in various parts of the interferometer is expected to be a valuable tool in optimizing the sensitivity of the detectors. In the LIGO experiment, combining the advantages of the heterodyne detection with a scanning system to provide the amplitude and phase maps of each frequency components of the laser field, a device capable to discriminate the amplitude and phase of each sideband from that of the carrier has been realized (the so-called *phase camera*). The implementation in Virgo of a similar device is described in a CRE document, and the realization of a table-top setup is starting now in Pisa thanks to the collaboration of the Annecy, Napoli and Nice groups.

Name	Development of a frequency resolving wavefront detector
Code	Virchrq0112006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0112006.html
Responsible	S. Bigotta

2.3.10.3 The compensation system

The phase camera is supposed to give the error signal to a thermal compensation system. The effective realization of this compensation system must pass through a simulation phase based on a finite element modelling (FEM) of the complex Virgo payload and, in the next future, through the realization of a test facility, where the compensation system must be tested in a realistic scenario to evaluate the drawbacks on the mirror suspension. Currently the Nikhef and Roma Tor Vergata groups are working at the FEM studies.

2.3.11 Monolithic suspension for Virgo+

The realization of a fused silica suspension to reduce the suspension (and mirror) thermal noise in Virgo is the largest and more challenging activity in the Virgo+ upgrade. The activity is described in a Working Package document in the detector coordination web pages; currently the EGO, Lyon, Perugia and Roma groups are engaged to this Virgo effort, but other Virgo groups are interested to enter in the collaboration. At the site the fiber production machines[4], supported by EGO thanks to the R&D program, are used to realize the suspension wires of a test payload; this test payload has been successfully suspended[5] in the laboratory placed in the 1.5km West building, using a dummy steel marionette, hybrid steel-fused silica clamps, fused silica *ears* silicate-bonded to a dummy mirror. A first assembling procedure has been defined with several trials, suggesting important modification in the design of some of the monolithic suspension components[6]. A further development, foreseen in the next months, will be the realization of a full suspended payload, realized with the dummy mirror, a dielectric reference mass currently under design and a steel marionette. All these activities are monthly reported at the detector meeting, while at least another working meeting is organized each month at the site.

In parallel to the development of the suspension, the new mirrors requirements have been investigated and defined in collaboration with the Lyon group. Suprasil 311-SV mirrors will be used for all the long cavities and their reflectivity[7] and optical requirements have been defined.

The use of the monolithic suspension in Virgo, if (in a quite optimistic view) the thermal noise (or, better, the so-called Newtonian noise) limit is reached, will give to the detector a sight distance of about 153Mpc for a 1.4-1.4M_S neutron stars binary, optimally oriented. Instead, if a Virgo standard steel suspension is kept, while the mirrors and the laser are upgraded, the detection distance at the thermal noise limit will be of about 70Mpc. It is evident the interest on the installation of this upgrade, but the technical difficulties are still unresolved. An intense engineering program is foreseen in the next year, mainly at the site, to demonstrate the feasibility of this suspension design, but a backup solution must be continuously evaluated. In any case, the monolithic design of the suspension will be part of the advanced Virgo project where the continuation of the Virgo+ development will be pursued, taking care of the new requirements presented by the advanced Virgo design[8].

4 The O_2-H_2 flame machine, realized by the Perugia group, is currently used as reference while the fibers produced with the new CO_2 laser machine, realized by Glasgow and maintained thanks to EGO personnel, will be compared soon.

5 Important milestone of the whole project.

6 Different fused silica clamp design have been tested and a optimal design is under definition. *Ears*, minimizing the flexural point problem are under design. A steel marionette, permitting a fine adjusting of the suspension points of the four fibres is under design.

7 The best value for the Virgo+ cavities finesse has been defined to be about 150, as described in a Virgo note.

8 See the advanced Virgo report and white paper.

3 Commissioning report

3.1 1. Introduction

As described in the last commissioning report, the main problem in June was the presence of thermal lensing in the interferometer mirrors, making the lock acquisition much more difficult than expected. In particular, the lock was very fragile during the first ~15 minutes, corresponding to the transient associated with the thermal effects.

In early June a test with a reduced power (1/3) was planned as preliminary step, in order to better understand the effect observed. However, during the preparation of the power reduction, it has been discovered the possibility to *survive* systematically to the thermal transient using a more sophisticated locking scheme and a better automatic alignment. It has then been decided to continue to operate the detector with the full power.

Even if the lock acquisition problem has been cured, the thermal lensing is still considered a big concern. Investigations are ongoing about the mirror absorptions, the exact thermal lensing mechanisms and the consequences for the carrier and sidebands fields.

It should be underlined that the thermal lensing not only makes more fragile the lock acquisition, but also slows down the overall commissioning activity, because of the large time needed to bring the interferometer in science mode. During noise hunting activity, when it is needed to artificially inject perturbations and in general "shake" the sub-systems, interferometer unlocks are very common. The time needed to re-acquire the steady "hot" state is then an important contribution to the detector downtime.

Once a stable lock with full power (~300 W on the beam splitter) has been systematically achievable, the months of July and August have been spent for the standard control tunings needed to recover a good sensitivity after a major hardware change. Furthermore, the automatic alignment was improved to ensure long term locks.

At the end of August a new sensitivity curve was measured, better than C7 in the high frequency part of the spectrum (see figure 2), where the improvement was expected due to the increase of input power.

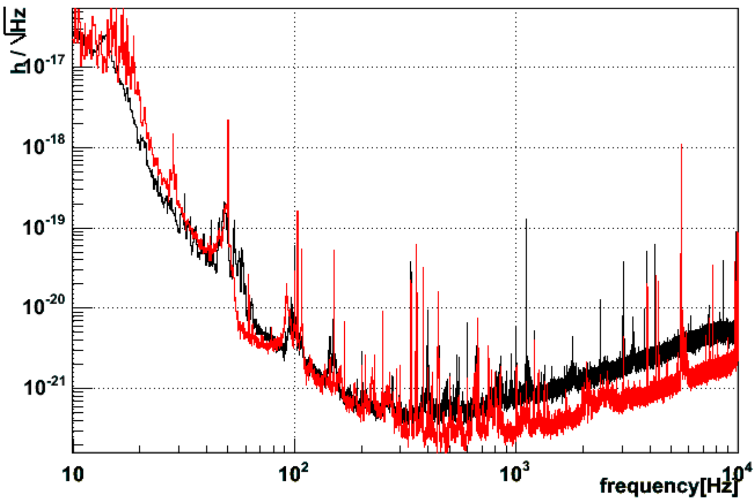


Figure 2: comparison between the C7 sensitivity (black) (September 2005, 0.7 W input power) and the WSR1 sensitivity (September 2006, 7 W input power)

In September a week-end data takings program (WSR's) has been started. The sensitivity, noise budget and the long term interferometer behavior have been widely studied during two data takings WSR-1 (September 8th-11th) and WSR-2 (September 22nd-25th).

The duty cycle was ~90% for WRS-1 and 65% for WSR-2. This last value was not due to an intrinsic weakness of the detector, but an isolated failure in the air conditioning system. After the failure repair, the duty cycle was better than 95%. The NS-NS inspiral range (or *horizon*) for optimal oriented source for WSR-1&2 was ~ 2 Mpc (the best horizon, 2.6 Mpc was obtained in early September, during a short data taking). This is roughly a factor 2 higher than the mean horizon for C7 (see figure 3).

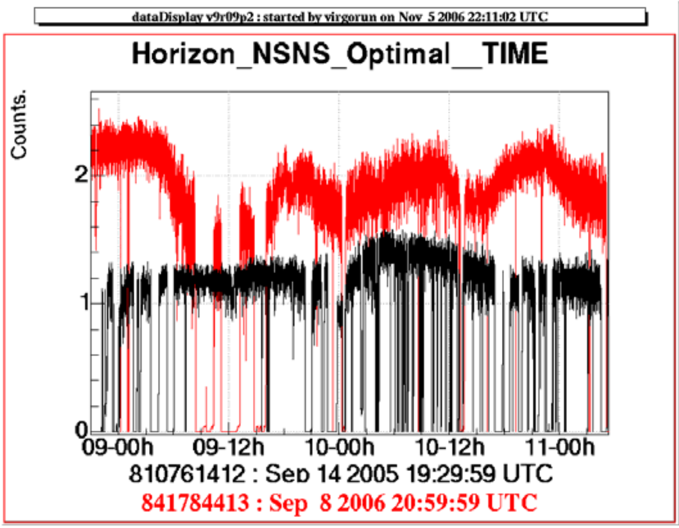


Figure 3: Comparison between the NS-NS inspiral range for optimally oriented sources during C7 (black) and during WSR-1 (red). Since C7 was longer than WSR-1, the comparison is made on the first part of C7.

Interferometer unlocks and horizon slow fluctuations during WSR-1 and WSR-2 are mainly related to bad weather conditions. For this reason the improvement of the mirror suspension control in order to increase the immunity of the interferometer to seismic noise is another priority of the next months.

Following the noise budget computed during WSR-1 some hardware upgrades have been performed in the months of September and October: optimization of the Faraday isolation, implementation of an acoustic enclosure of the laser laboratory, reduction of the actuators noise, replacement of the detection Brewster window. This important changes in the interferometer set-up have made the detector not enough stable for long term science mode operations, and no week-end data takings have been successfully performed in October.

The current commissioning activity is meant to re-tune the interferometer parameters after the hardware changes described above, in order to recover the interferometer robustness and measure a new sensitivity curve.

3.2 Thermal lensing

As described in the last June report, a decrease of the sidebands recycling factor during the first minutes of lock revealed the presence of thermal effects inside the interferometer.

A finite element modeling (FEM), developed *ad hoc* with Matlab, explained it as a thermal lensing in the input mirrors. The confirmation of the drift of the sidebands amplitude during the locking procedure (and for about one hour from the locking) has been obtained recording an optical spectrum analyzer output (or *scanning Fabry-Perot, SFP*) on the B1p channel (dark fringe, before the OMC), as shown in figure 4.

The Virgo input mirrors have been considered immune by any thermal lensing issue at the design time, basing the evaluation on the carrier power decrease with the excellent absorbing properties of the Suprasil 311-SV material of the substrate (0.7 ppm/cm) and of the coating (≈1.3 ppm). The problem is that the sidebands, that aren't resonant in the long cavities, are strongly affected by the variation of the refraction index of the substrate (dn/dT) with the temperature.

While the finite element modeling has been used to evaluate the geometrical effects of the thermal lensing (variation of the radius of curvature seen by the sidebands and by the carrier) a large optical modeling effort has been started using two different packages (finesse and DarkF) to evaluate the effect of the lensing on the sidebands field.

Obviously, to obtain realistic results from the simulations it has been important to select the right input parameters; the most crucial and most difficult to determine is the effective absorption of the input mirrors. To evaluate the realistic absorption it has been introduced an innovative procedure: the first resonant modes of the test masses (and mainly the drum mode, which is about 5540-5580Hz) are inside the detection range of the interferometer. An ANSYS detailed FEM has been realized, some year ago, to evaluate the temperature dependence of the resonant modes, giving a coupling of 0.61Hz/K for the drum mode for an uniform temperature distribution. An *in-time* monitor of the frequencies of the resonant modes of all the Virgo main mirrors has been implemented and used to monitor temperature of the test masses for several days. The frequency-to-temperature coupling, predicted by the FEM, has been confirmed observing the period where, for some malfunctioning of the air conditioning system, the temperature of the whole building is increased.
The sensitivity of this method, if the environmental temperature is well stabilized, is of the order of few milliKelvin of temperature variation; this impressive sensitivity permits to appreciate the warming up of the mirror, when the interferometer is locked and the full power is stored in the long cavities (see figure 5). The incertitude of this method is mainly due to the fact that the frequency-to-temperature conversion factor has been obtained with a uniform temperature distribution, while the temperature map due to the beam is different (and follows the beam profile). A refining of the FEM is currently under development to take in account this effect. Meanwhile, the Matlab FEM has been used to evaluate the true absorption of the input optics, comparing the expected temperature increase with the measured one. As shown in figure 6, the temperature increase in the input mirrors (in the figure is reported the WI) has been followed during many locking cycles of Virgo and a good correspondence is found if the nominal losses are multiplied by an adjusting factor (10 in the WI, 4 in the NI). Note that in figure 6 each main tick in the scale corresponds to one day of data taking and then, the environmental temperature fluctuations play a dominant role in the measurement error. Hence, according to these measurements, the absorption in the current mirrors is extremely larger than the nominal value.

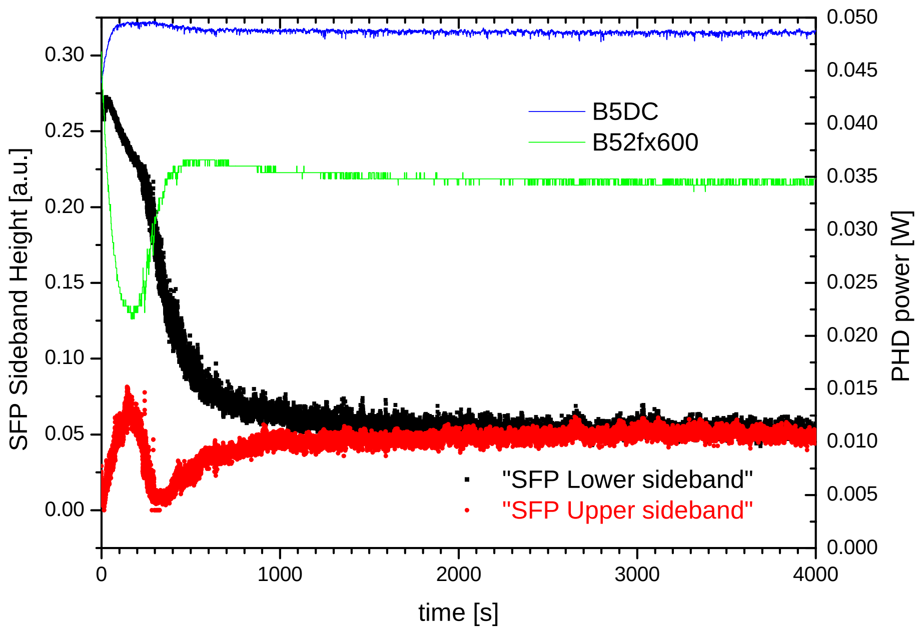


Figure 4: Sidebands power inside the interferometer measured by the SFP compared to the ITF outputs Pr_B5_2f_ACq, in green). The sideband power decreases drastically in the first 10 minutes of lock on the dark fringe, then it stabilizes at about 30% of its initial value. In order to balance the two sidebands, strongly imbalanced at the beginning of the lock, almost one hour is needed. The blue curve represents the carrier power

The prediction of a larger absorption in the input mirrors seams to be confirmed by the optical simulation with darkF; in fact, the huge reduction in the sidebands recycling gain cannot explained using the nominal value for the absorption, while a more realistic simulation output is obtained adopting the asymmetric absorption values measured with the drum mode method. The predictions of the optical simulation are still to be completely understood and then the activity is continuing.

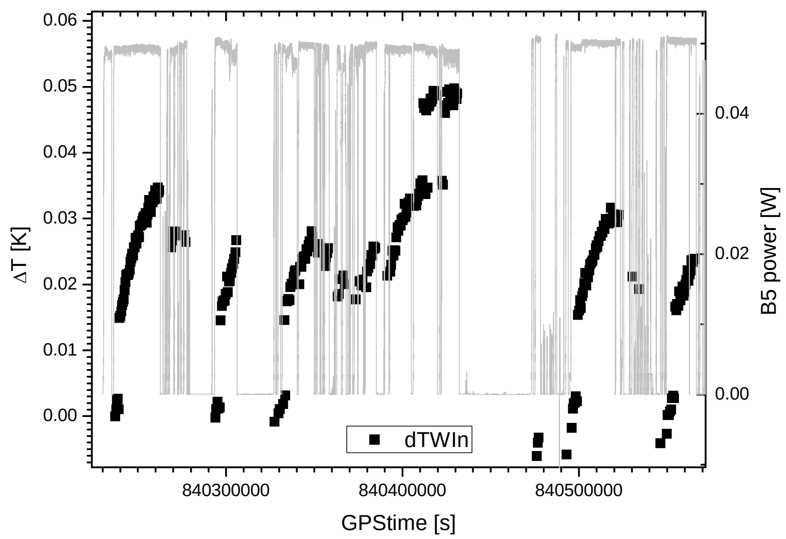


Figure 5: Temperature increase in the WI mirror, measured with the drum mode method, compared to the locking cycles of Virgo

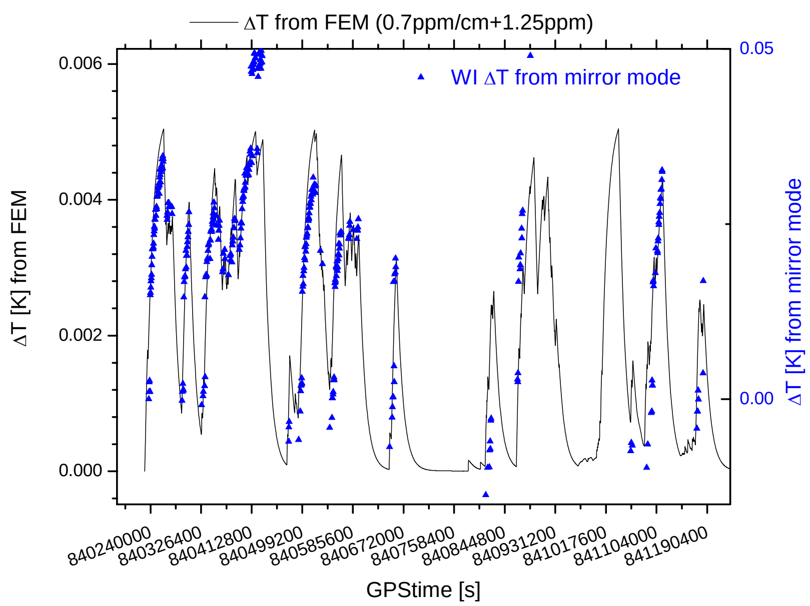


Figure 6: Temperature increase in the WI, compared to the FEM predicted values.

3.3 Length sensing and control

With respect to the low power state, the thermal lensing has made more complicated and changing with time the behavior of the longitudinal signals.

The Variable Finesse locking technique, successfully applied for the commissioning runs C6 and C7, was able to bring the detector to its operating point, but wasn't sufficient, in its original implementation, to ensure the interferometer stability during the thermal transient. In particular, strong variations of locking parameters, such as the gains of the loops and the demodulation phases of the error signals, prevented stable lock for more than a few minutes after reaching the dark fringe.

Moreover, several effects complicate the analysis of the lock losses occurring during the thermal transient: the strong coupling between the longitudinal degrees of freedom, in particular between the short Michelson (*MICH)*, the power recycling control (*PRCL*) and the sensitivity of the ITF to angular misalignment, and the changes in the optimal demodulation phases.
In order to face all these problems, several actions were performed. The most important are the following:

- on-line monitor of the locking parameters by injecting permanent lines in all degrees of freedom, and automatic adjustment of the differential arm (*DARM)* loop gain. As shown in figure 7 (bottom right plot), the automatic adjustment is crucial in the first ~15 minutes of the lock, after which the gain reaches the steady state.

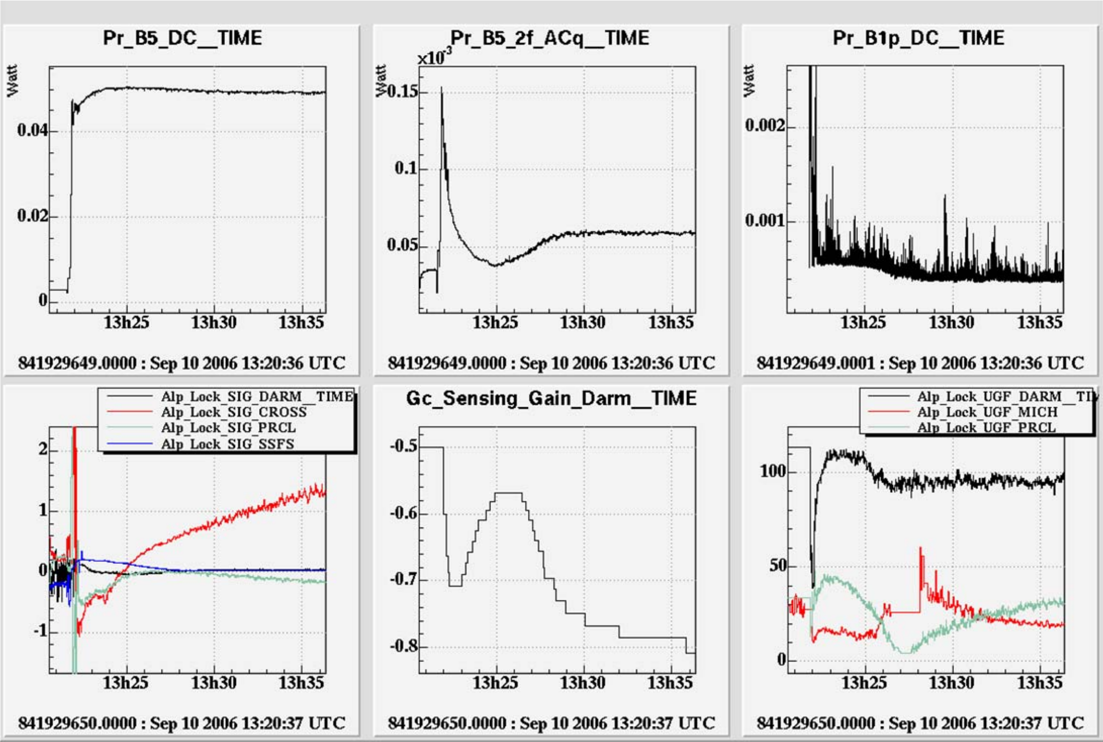


Figure 7: first 15 minutes of a typical lock acquisition sequence. The first row shows the behavior of the powers inside the interferometer: carrier stored power (left), sidebands stored power (middle), antisymmetric port (right). The second row shows the monitor of the locking parameters: the demodulation phases of the error signals deduced from the monitor of the permanent lines (left),the automatic change of the DARM loop gain (middle) done in order to stabilize the unity gain frequency of the loop (right).

- Implementation of the automatic alignment of the power recycling mirror (see also the section "angular sensing and control") during lock acquisition. It was observed that, after realigning the power recycling mirror, the level of sideband power inside the recycling cavity changed drastically from a lock to the next. Even very small misalignments of the PR mirror, of the order of fractions of µrad, were enough to reduce the sideband power by more than 50 %. Automatically aligning the PR during each lock guarantees that the dark fringe status is reached always in the same conditions (see figure 8).

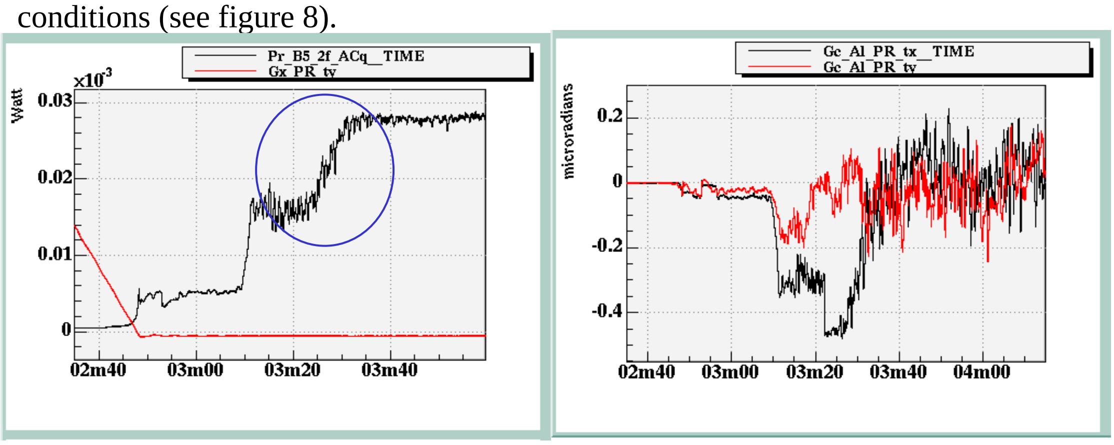


Figure 8: (left) Increasing of the sideband power (Pr_B5_2f_ACq) after closing the automatic alignment of PR during lock acquisition. As shown by the reconstructed signals (right), a realignment of about half a µrad is enough to increase the power by a factor 2.

- Fine tuning of the modulation frequency. Due to presence of the input mode-cleaner, a mistuning of the modulation frequency with respect to its length changes the optimal demodulation phases of the signals used for the interferometer control. A change of 10 Hz is equivalent to 4 degrees of change in the demodulation phase of the 3f demodulated signal used to control PRCL (Pr_B2_3f_ACp). It was observed that, during the locking sequence and the thermal transient, very small change of this demodulation phase (of the order of 5 degrees) were enough to cause the unlock of the ITF. For this reason, the tuning of the modulation frequency was improved so to have an accuracy of hundreds of mHz.

- Improved decoupling of the central cavity signals (MICH and PRCL), by using a not diagonal sensing matrix to reconstruct the two error signals.

These improvements are not enough to survive to the thermal transient. An empiric procedure was found, consisting in intentionally mistuning the locking parameters at the beginning, so to have good values when the transient is finished.
The current scheme requires therefore to wait at least ~15 minutes (the thermal transient duration) on the dark fringe before operating the ITF in low noise state (roll-off in the controllers, re-allocation of the force to the marionette, switch to low noise actuators).
The reliability of this procedure has been tested for a couple of months, with "long" term tests performed during the weekly science runs WSR1 and WSR2.
It should be noticed that, because of the extremely narrow range in which the locking parameters require to be tuned in order to survive to the thermal transient, the last step of the locking sequence (the one related to the transient) has to be retuned in case of changes affecting the interferometer state, and this requires several days of experimental work.

3.4 Angular sensing and control

As already pointed out in the previous section, the automatic alignment plays a crucial role not only in the long term behavior of the interferometer and in the reduction of the angular control noise, but also in the lock acquisition.

We have discovered that 4 degrees of freedom are crucial during the lock acquisition and during the thermal transient: the differential end mirrors (tx and ty) and the power recycling control (tx and ty). These 4 d.o.f. are controlled with a full bandwidth (~ 3 Hz) and the corresponding local controls are switched off.

- The differential end mirrors control is engaged when the interferometer reaches the dark fringe, and uses a quadrant on the dark fringe itself as error signal. This control is important since it allows to minimize the power lost through the dark fringe and then to stabilize the interferometer internal power (and then the optical gains of various signals used for the control).

- The power recycling control is engaged during the lock acquisition, as soon as the power recycling is aligned, and it uses as error signal a quadrant placed on the beam B5 (an interferometer pick-off extracted through the second face of the beam splitter). This control is important since allows to minimize the variations of the optimal demodulation phases for some important signals, such as B2_3f, used for the power recycling longitudinal control.

When the interferometer is on the dark fringe, the remaining 10 degrees of freedom are engaged: the 2 input mirrors (4 d.o.f.), the beam splitter (2), the beam (2) and the common end mirrors (2).

Some of them (the common end and the beam splitter) are controlled with full bandwidth and some of them (input mirrors and beam) with a reduced bandwidth (~ mHz). These latter are important mostly for long term locks (hours), even if the common end control play also a role during the thermal transient.

With this scheme all the 14 angular d.o.f. are controlled, allowing to completely defining the interferometer alignment through global variables (with some limitations discussed in the following). We recall that during C7 only 10 d.o.f. were controlled, with a full bandwidth (common and differential end mirrors, power recycling, beam splitter and north input).

This configuration allows to obtain locks of several hours (i.e. during WSR-1 and WSR-2). Even for very long lock (~ 26 hours, during WSR-2) no degradation of the interferometer performances related to alignment drifts has been observed.

One of the problems of the current scheme is the use of only 8 demodulated (wavefront) signals, and 6 DC quadrant asymmetries. In particular, the common end mirrors control is made with a DC error signal. This does not guarantee a complete reproducibility of the alignment, since the DC asymmetries depend on the local position of the quadrants and not only on the wavefront field distributions, as for the demodulated signals. One of the main priorities for this activity is to find good demodulated signals to replace the DC ones.

As explained in the following, alignment fluctuations can couple several noises with the interferometer sensitivity. The accuracy of the alignment, and then the feedback gain at low frequency, plays an important role in the noise reduction activity. Furthermore better roll-off filters above the unity gain frequency of the alignment loops can avoid the reintroduction of the angular control noises. New alignment filters have already been designed for these purpose and they are ready to be tested.

3.5 WSR-1 noise budget

The noise budget relative to the WSR-1 sensitivity is shown in figure 9. Above 500 Hz the measured sensitivity (black curve) is limited mainly by dark fringe shot noise and laser frequency noise, below 200 Hz it's limited by control noises. The purple curve is the incoherent sum of all the noises: the superposition of this curve with the measured sensitivity indicates a good understanding of the interferometer noise. We observe that the noise is well understood except in the central region of the spectrum (200-500 Hz).

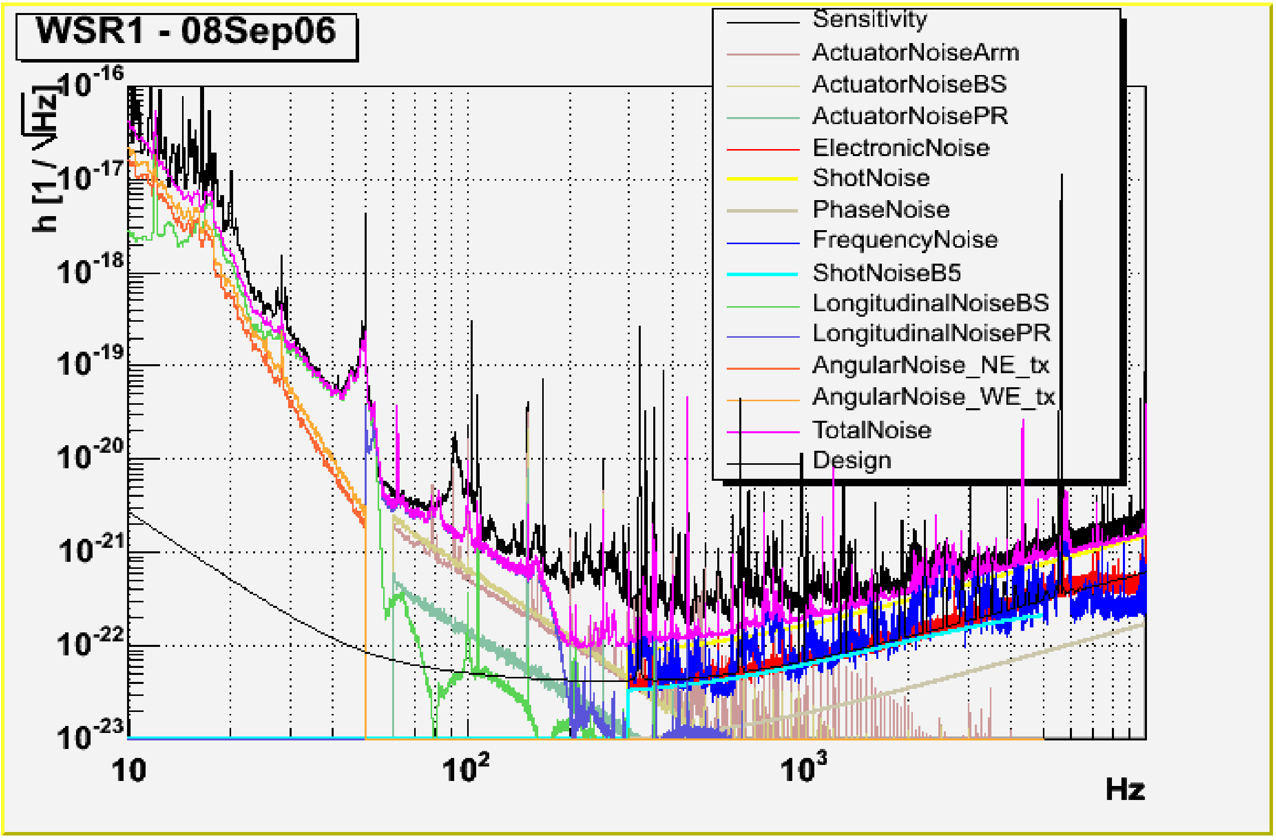


Figure 9: WSR-1 measured strain sensitivity (black), incoherent sum of all the known noises (purple), projections of the different noise sources on the dark fringe (other colors)

The sources of noise are briefly analysed here and the planned actions for their reduction are listed.

3.5.1 Dark fringe shot noise

The measured dark fringe shot noise (yellow curve) is the main limitation at high frequency.

Despite the fact that the contrast defect is good (1-C ~10^{-5}), the dark fringe shot noise is about a factor 2 above the standard Virgo design sensitivity. The discrepancy is due to

a) the output mode-cleaner transmission (1 in the design) was only 80% (matching and alignment still need to be improved)
b) the interferometer stored power (500 W in the design) is ~ 300 W

Moreover a conservative value of the actuators gain (V/m) is used for the calibration. This could result in an overestimate of the sensitivity by up to 40% (but only up to 20% for the horizon which use a sensitivity computed in a different way).

No actions are planned to improve the measured shot noise in the medium term.

3.5.2 *Frequency noise*

The laser frequency noise limits the high frequency part of the spectrum (> 1kHz), being coupled to the dark fringe mainly through the losses asymmetry of the Fabry-Perot cavities (intrinsic losses or mismatching). Four main actions are possible in order to reduce this noise:

- Reduction of the coupling: It has been shown that the matching of the beam with the 3-km cavities can affect the frequency noise coupling with the dark fringe. During WSR-1 the matching was about 96%. After the Faraday isolation optimization a worsening of the matching has been observed (from ~96% to ~93%), and the frequency noise coupling has increased by ~ 2 (WSR-2). This has been the one of the motivations for the recent matching optimization activity (second half of October). The present matching, after the recovering, is about 97.5%, and the correspondent performances should be checked as soon as the interferometer will be again in science mode. The theoretical matching is about 99% even if some preliminary simulations put a limit on the achievable matching due to thermal effects (see also section 8.5)

- Increase of the frequency servo gain: present bandwidth of the frequency stabilization electronics is limited to 10-15 kHz. This limits the servo gain and then the achievable frequency noise suppression. Better electronics is under study, with a possible bandwidth of ~30 Hz, which can allow a reduction of the frequency noise by ~10 below 2 KHz.

- Diffused light investigation: the increase of the frequency servo gain results in a decrease of the frequency noise only if the performances are limited by the noise of the sensor used for the frequency control itself. Diffused light in the detection electronics, driven by acoustic/seismic excitations can spoil the sensitivity of the error signal. A diffused light mitigation program is then planned, by beam dumping and use of larger aperture optics.

- Input frequency noise: with a similar mechanism part of the input frequency noise can be due to the acoustic/seismic excitations in the laser laboratory, and then in the sensor used for the primary frequency stabilization (used to lock the laser frequency to the mode-cleaner length). The recent installation of the laser laboratory acoustic enclosure should have decreased this noise. The performances will be checked as soon as the interferometer will be again in science mode.

3.5.3 *Longitudinal control noises*

From 30 Hz to about 200 Hz the sensitivity is limited by longitudinal control noises.

- Beam splitter control: the control of the BS mirror introduces a longitudinal noise which couples directly to the dark fringe below 50 Hz. Being the unity gain frequency of this loop already very low (~10 Hz), further filtering of this noise through roll-off seems to be not feasible.

Its impact can be reduced in two ways:

- The online subtraction (so called *α–technique*). This technique is efficient at the ~8% level and it can be further improved introducing a frequency dependent coupling coefficient.

- The reduction of the sensor noise (B5_ACq). A noise budget for this signal is in progress. The noise seems now be dominated by the power recycling mirror control noise and should therefore be reduced with the improvement of this last control (see below).

- Power recycling control: the control of the PR mirror introduces a longitudinal noise which also couples directly to the dark fringe. Two actions can be performed to reduce this noise:

- The reduction of the coupling factor: The coupling is computed measuring the dark fringe signal produced by a corresponding monochromatic excitation of the power recycling mirror and is not understood so far. Variations of an order of magnitude have been observed, probably related with the interferometer alignment. More long term data could help to isolate the important parameters needed to understand and decrease this effect.

- The SNR increase of the error signal: B2_3f, the signal currently used to control the power recycling, is intrinsically limited by the use of the third harmonics of the modulation frequency. This signal is needed for lock acquisition, but a switch to the B2 signal (demodulated at the first harmonics) can be done once the interferometer is on the dark fringe. The use of the B2 can increase the SNR by a least a factor 10. Some attempts have been started. See section below.

- Actuators: the electronics noise of the mirror actuators (mainly DAC's) directly creates longitudinal noise (maroon curves). This noise is not yet a limiting factor for WSR-1 but it cold become as soon the power recycling noise is reduced. For this reason, after WSR-2 all the mirrors coil drivers have been modified in order to accommodate emphasis-deemphasis filters. The impact of the current actuators noise on the sensitivity is shown in the chapter 8.4.

3.5.4 Angular control noises

The angular control noise is a significant limitation for the sensitivity only below ~30 Hz.

We recall that angular control noise was limiting the C6 and C7 sensitivities below 200 Hz. This was probably due also to the off-centering (of the order of the cm) of the beam on the mirrors. During last spring the mirrors of the central cavity have been centered with a precision of about 2 mm, while the centering of the beam on the end mirrors has not been checked so far.

In order to reduce the angular noise two actions are on-going:

a) Measurements of the angular-to-longitudinal coupling by the mean of monochromatic angular excitations, and decreasing the coupling by better mirror centering and/or coil actuator balancing.
b) Filtering of the angular noise by the mean of roll-off inside the control filters.

3.5.5 Other sources of noise

- The phase noise introduced by the modulation/demodulation electronics does not limit the sensitivity any more (grey curve) thanks to the good stability of the alignment.

- The intensity noise does not limit the present sensitivity and has been found compatible with the Virgo design.

3.6 Transition to B2

As already pointed out above, the transition to B2 is one of the important points to improve the sensitivity in the ~100-200 Hz.

Some attempts to move the power recycling control from B2_3f to B2 have already been performed. Even if the transition between the two signals have been made, a stable lock has not yet been obtained using B2. The figure 10 shows a typical transition from B2_3f to B2. (The transition flag is the bottom left plot Pr_SW_B2_3f). After a few minutes the interferometer unlocks.

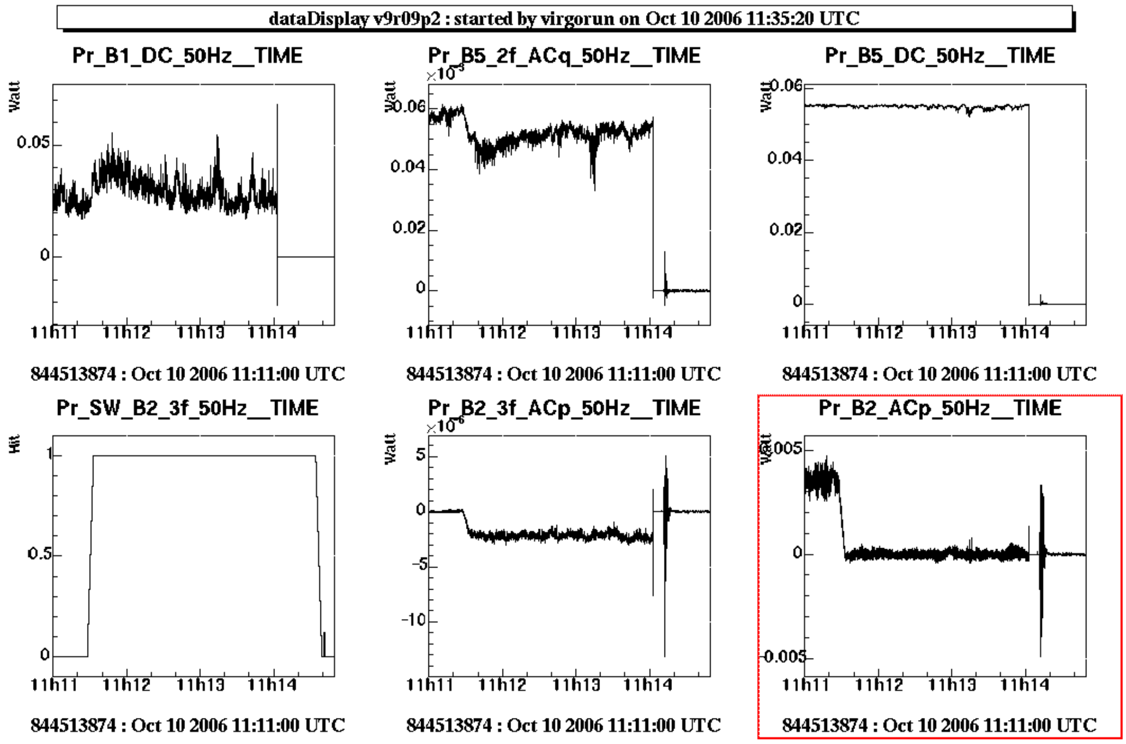


Figure 10: transition B2_3f→B2 experimental test. The bottom left plot is the transition flag (0=B2_3f, 1=B2). When the transition is made the B2 signal become "in-loop" and moves to zero. After a few minutes the interferometer unlocks

The difficulties observed in the use of B2 can be due to several factors: a unexpected behavior of the transfer function between the two signals, which is currently considered as a constant, or some impact of the high order modes, or to some coupling of B2 with other degrees of freedom.

In order to better understand the behavior of the interferometer optical matrix, and in particular of the B2 signal, simulations studies are ongoing, in both the time domain (SIESTA) and the frequency domain (FINESSE). In particular the transfer function for both signal have been simulated. The figure 11 shows a transition B2_3f→B2 made with SIESTA, using some realistic longitudinal control scheme of the interferometer and of the laser frequency. No evident problems in the use of B2 have been put in evidence so far.

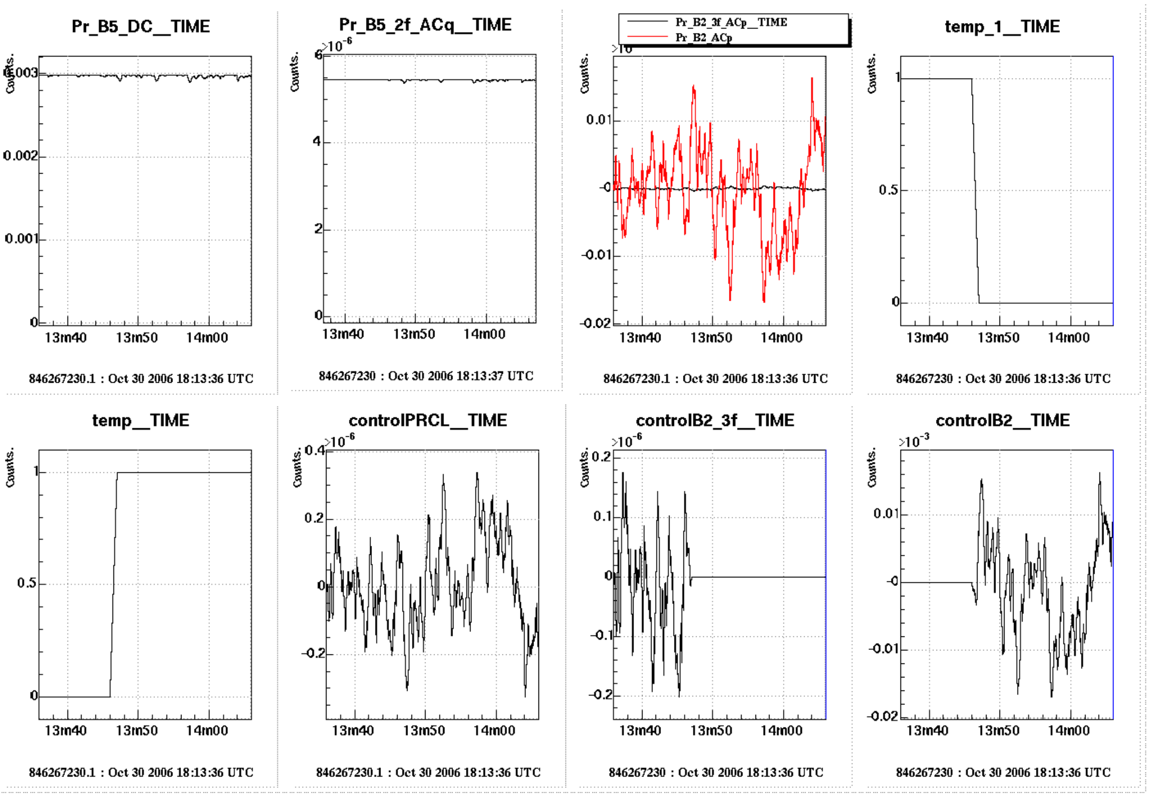


Figure 11: simulated transition made with SIESTA. The bottom left plot is the transition flag, called here "temp" (0=B2_3f, 1=B2).

A scanning Fabry-Perot device should be also installed in the following weeks on the interferometer reflected port (B2 and B2_3f) to understand the sidebands and carrier fields behavior independently.

A study of the possibility to move the laser frequency control on B2, and the power recycling control on B5 (a scheme used in other GW experiments), is under investigation.

3.7 Mirror suspension control

Mirror Suspension Control task is to ensure good performances of the Virgo suspension system, with the goal to improve the duty cycle and the sensitivity of the interferometer. This has obviously strict interactions with the alignment and longitudinal control strategies.

Several actions have been performed during the last months, listed below:

- Measurement of the actuation noise, and improvement of the suspension electronics, better described in the paragraph 8.4
- Local controls standard maintenance activity
- Check of the beam centering on the suspensions and angular-to-longitudinal coupling reduction: work started during the last month, check of the centering techniques in progress
- Tide control for the PR suspension (now all the suspensions are under tide control)
- Filter7 control for all the suspensions
- Locking re-allocation to the BS marionette: preparatory work started, to be checked on the interferometer
- Vertical inertial damping control: modeling work concluded, first attempt started

3.7.1 Global inverted pendulum control

The interferometer performances, both in term of duty cycle and sensitivity is spoiled during bad weather conditions.

The figure 12 shows the superposition of the NS-NS inspiral range for optimal oriented sources measured during WSR-1 and WSR-2 (in black) with the empirical formula: 2.7 Mpc-k(*wind*+*sea*) (in red).

Where:
- *k* is a constant scaling factor (Mpc/micron)
- *Wind* is the inverted pendulum motion in the region mostly sensitive to wind (30-100 mHz)
- *Sea* is the inverted pendulum motion in the region of the microseism/sea activity (0.1-1 Hz)

The good superposition between the horizon and the empirical formula seems to indicate that the interferometer behavior is ruled by the weather. The exact mechanism is not fully understood, but can be related with a not enough gain of the alignment control system at low frequency.

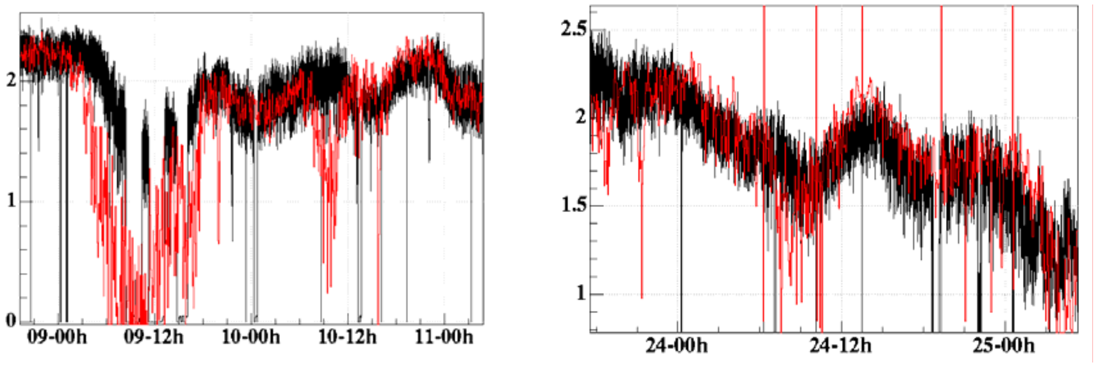


Figure 12: black NS-NS inspiral range for WSR-1 (left) and WSR-2 (right). Red: empirical formula 2.7 Mpc – (wind+sea). "wind" is the inverted pendulum motion of the WE suspension in the region 30-100 mHz, "sea" is the motion in the region 0.1-1 Hz

Even if the mechanism is not clear, the re-introduction of the wind and microseism (sea) activity to the mirror can be reduced by changing of the suspension control configuration.

Virgo suspensions uses position (LVDT) and acceleration sensors, placed at the top of the inverted pendulum, whose signals are suitably pre-filtered, combined, and sent to electromagnetic actuators acting at the top level (*inertial damping*).

Inertial damping operates through a critical blending of accelerometers and LVDT's. The crossover currently used is 30-70 mHz.

- Inertial sensors are intrinsically affected by tilt at low frequency, which is mainly due to the wind
- LVDT's are re-injecting microseism noise, due to sea activity.

If the crossover is decreased (i.e. 30 mHz) the system is more sensitive to the wind, if the crossover is increased (i.e. 70 mHz) the suspension is more sensitive to the microseism (sea activity).

A way to overcome to the problem of the blending is to use the interferometer global correction signals, much less sensitive to microseism as shown in figure 13, instead the LVDT's.

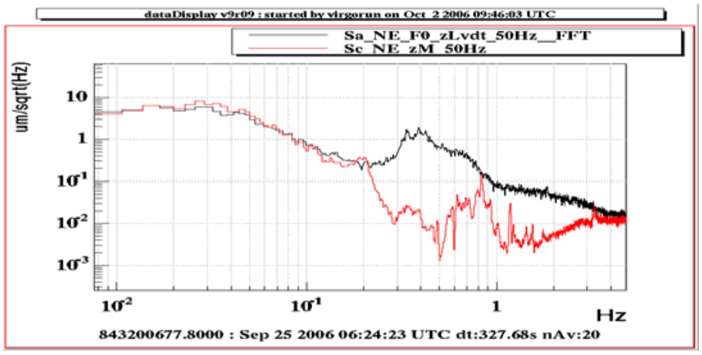


Figure 13: LVDT signal compared to mirror correction, cleaner from μseism, due to the SA filterin).

The method has been called GIPC (Global Inverted Pendulum Control), and consists in pre-filtering and re-allocating at the top stage of the IP level the mirror correction signals (usually applied at the reaction-mass and marionette), and leaving LVDT out-of-loop. In such a way the crossover between position and acceleration signals can be set at higher frequency (70-80 mHz) and the overall effect of the wind and microseism can be reduced.

GIPC strategy has been partially and successfully tested on 3 suspensions. However, the completion of the feasibility and performance study has to be done in science-mode and its actual effectiveness must be checked under critically weather condition.

3.8 Set-up improvements after WSR-1

We detail here the set-up improvements after WSR-1 (September 8^{th}-11^{th}).

3.8.1 Faraday isolation improvement

After the new IB installation and commissioning, it came out quite soon that the isolation provided by the Faraday isolator on the suspended IB was much poorer than expected: several measurements, either of the IMC transmission and of the reflection of the ITF to the laser bench, showed an isolation factor of about 100, whereas the maximum value of the isolation as measured in air was 10,000 (40 dB). This isolation factor was comparable with that of C7, thus enough to allow locking acquisition. Therefore, it was decided not to intervene on this problem in the first phase of realignment and restart of the ITF.

In September, once recovered again the C7 sensitivity and in view to improve it, it was decided to try to solve also this problem, which could be a possible cause of noise, even if not easily predictable at this level.

Previous measurement had already shown that in order to attain the 40 dB attenuation it was necessary to turn the Faraday isolator input polarizer by about 5°, which would result in very high losses at the level of the second (output) Faraday polarizer (more than 10%). Such a rotation seemed too large to be explained by thermal effects or misalignments in the Faraday (some tests changing the power impinging on the Faraday and accordingly measuring the possible isolation change were also tried, with no significant effect).

Around half of September an intervention inside the tower was organized, in which a dedicated setup for measuring and improving the Faraday isolation with about 10 W of input power on the Faraday was implemented. When investigating again the problem, the Faraday isolator was accurately examined and it turned out that a very small iron Allen key had been unintentionally sucked by the rotator magnet, likely during an accident happened during the clean room bench assembling, and the key was so deeply inserted into the rotator that could be seen only after careful inspection. This iron key modified the magnetic field distribution inside the rotator, thus modifying its polarization rotation and consequently the isolator isolation. Once removed the key, the Faraday isolation was tuned to 40 dB with the polarizer in an acceptable position (no significant losses at the level of the second Faraday polarizer).

Once the IB was put in vacuum again and realigned, measurements showed that the isolation was now about 1,000 (30 dB), i.e. still about 10 times less than measured in air. We think that this degradation could be now ascribed either to thermal effects or/and slight misalignment of the beam with respect to the setting alignment. Similar isolation degradations, even in air, are commonly experienced by people working in the field.

After the isolation increase of a factor 10, several measurements show improvements in the ITF behavior, in particular in the low frequency range (below 10 Hz) alignment: the noise in the automatic alignment signals of the IB is significantly reduced when the PR is aligned (see figure 14). This can result in global reduced noise in the ITF, and it's still under investigation.

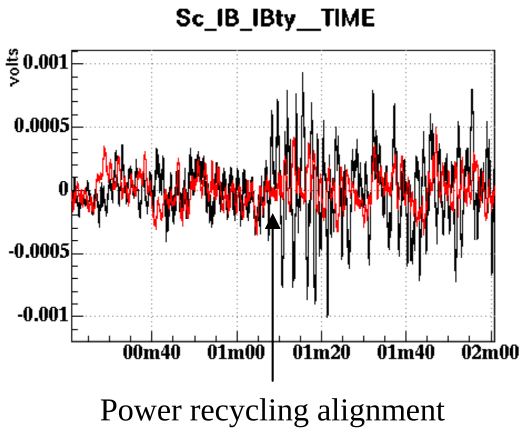


Figure 14: improvements in the injection bench automatic alignment signal after the Faraday isolation optimization. Before (black) and after (red)

In any case, it is possible to further improve the isolation by modifying the Faraday setup, in the hypothesis that the degradation is due to global heating of the crystal (e.g. thermal dependence of Verdet constant of refraction index) or beam misalignment: if a remotely commanded λ/2 is inserted between the first polarizer and the rotator, the isolation can be tuned, at the expense of introducing some more losses at the level of the second Faraday polarizer. This modification would require to enter into the injection bench tower, dismount the first Faraday polarizer, mount it on a dedicated mount, slightly move away it from the rotator, and insert the remotely rotated waveplate between the polarizer and the rotator. This operation should not affect significantly the alignment of the bench, since the weight of the added device should not exceed 1 kg.

The technical implementation and the planning of this further optimization are under investigation.

3.8.2 Laser laboratory acoustic isolation

Acoustic noise couples with the dark fringe through several mechanisms: beam jitter, laser frequency noise, laser power noise. Some coherence between microphones on the laser tables and the dark fringe has been observed during the last data takings. Furthermore, acoustic noise injections (using a loudspeaker in the laser laboratory) had showed that the acoustic noise, mainly in the region 100 Hz – 1 kHz, is not far from the current Virgo sensitivity and well above the design one. Consequently, as described in the Detector Coordinator Report, an acoustic shielding for the laser and the external injection benches have been built and installed in last September-October

One of the unexpected drawbacks of the box was the worsening of the low frequency beam jitter (below 10 Hz), as measured by the beam monitoring system (a set of two far-field and near field quadrants measuring the shift and tilt of the beam at the mode-cleaner input). This was found to be due to turbulent air motion inside the enclosure sustained by the pressure gradient between the laser room and the nearby central hall and chaotic air flows through small apertures in the enclosures. The current solution is to leave one aperture in the acoustic box large enough to remove the turbulent air flux without spoiling the acoustic isolation. The final solution is to put a *silenced door*, already ordered to the external firm which built the acoustic box.

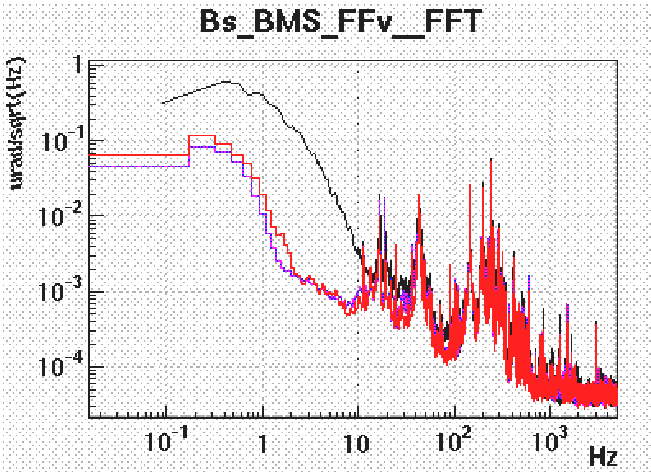


Figure 15: Effect of the turbulent air flux inside the acoustic enclosure. beam jitter measured by the far field vertical quadrant signal. With the acoustic box completely closed (Black), with an aperture (purple), with the acoustic box closed and the air conditioning system OFF.

We have tested the performance of the enclosure box using white noise injection, by comparing the acoustic noise inside with the enclosure panels open and closed (test repeated independently for both enclosures). For both enclosures (laser bench and external injection bench) we have measured an attenuation factor of 3-4 of the acoustic pressure noise and a correspondent factor 5 reduction of (vertical) acceleration of the optical benches (which indeed seems to be acoustic driven), effective from 100Hz to at least few kHz. The figure 15 shows the microphone spectrum with the acoustic box panels open and closed. A similar attenuation is measured for the external injection bench.

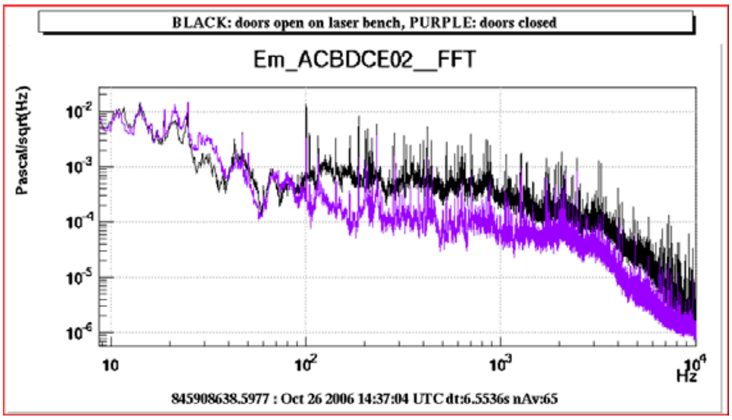


Figure 16: Spectrum of the microphone on the laser table with the acoustic enclosure open (black) and closed (purple)

The performance is less than expected. This is likely due to the enclosures complicated design (with many edged, corners and possible noise shortcuts) which was necessary in order to fit them in the tight space. Some actions are on-going to identify and remove the possible short-cuts.

Coherence measurements and acoustic noise injections using loudspeakers are planned as soon as the interferometer will be again in science mode to compute the new acoustic noise projection on the dark fringe.

Acoustic enclosures are planned for the end benches and for the detection bench. Their design, using the experience made with the acoustic isolation of the laser laboratory, has been started and is being discussed (see Detector Coordinator report).

3.8.3 Detection Brewster replacement

The main Virgo vacuum chamber is separated by the injection and detection vacuum chambers by two optical windows at the Brewster angle, in order to minimize the light reflection (called respectively "injection Brewster" and "detection Brewster").

During the noise hunting activity it was found an extreme sensitivity of the dark fringe signal with respect to seismic/acoustic excitations of the Brewster. This was demonstrated by the coherence of accelerometer attached to the optical window with the dark fringe signal while tapping on the Brewster itself.

Figure 16 shows the involved signals in science mode standard conditions (black) and during the tapping test (purple). The top-left plot is the dark fringe signal, the top-right is the Brewster accelerometer, the bottom-left is their transfer function and the bottom-right is their coherence.

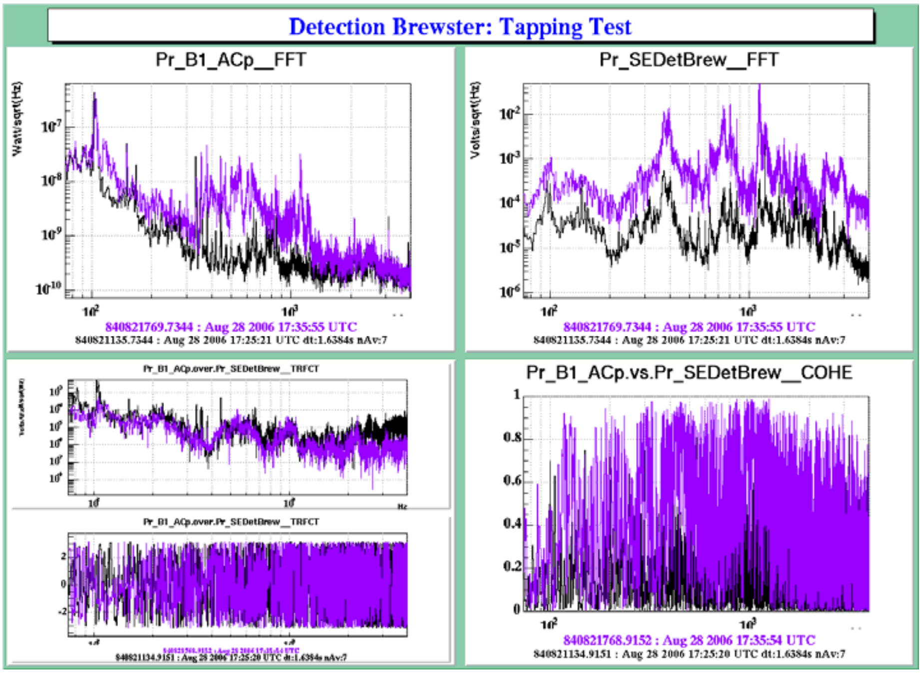


Figure 17 : tapping test on the detection Brewster window

After a more careful investigation, it was found that the window installed was not the right one, which was supposed to have an aperture of 110 mm, but a window with an aperture of 80 mm. The true Brewster has also been found.

The mistake can explain the problems observed in terms of diffused light due to a too small aperture, and consequent couplings with acoustic/seismic noise.

At the beginning of October the vacuum system has been vented the true Brewster (with an aperture of 110 mm) has been mounted. An evaluation of the new performances will be made as soon as the interferometer will be again in science mode.

Following the standard rule to avoid diffuse light effects (aperture > 5 beam waist), it turns out that even the Brewster currently installed is too small. The size of the beam is 20 mm and the vertical shift of the light inside the silica is 13 mm; then the minimum aperture should be 20x5+13 = 113 mm. If the laser beam is not perfectly centered inside the window the rule is not satisfied. Since in the past we have observed miscentering of the beam with respect to the interferometer optics of the order of half of centimeter, it becomes necessary to prepare some larger Brewster for the future. See detector coordinator reports for details.

3.8.4 Actuators noise reduction

As pointed out in the chapter about the WSR-1 noise budget, the actuators noise during WSR-1 and WSR-2 was very near the sensitivity curve.

The actuators noise have been found to be dominated by the DAC noise harmonic distortions, while the coils are driven by the locking forces: the theoretical DAC noise (300 nV/sqrt(Hz)) is larger by a factor 4-5.

In order to reduce this noise without spoiling the dynamics of the actuators some filter shaping a emphasis-deemphasis filter has been installed: a 3 Hz high pass (emphasis) digital filter before the DAC, and a 30 Hz low pass analog (de-emphasis) filter after the DAC. The implementation has been performed for the 4 arm mirrors and for the beam splitter. For the power recycling a simple reduction of the dynamics (factor 10) was enough.

The resulting actuators noise projection on the dark fringe is shown in figure 18. Even if it does not fit the Virgo design sensitivity it can be considered an improvement enough for the short-medium term. For the long term new coil drivers, with more aggressive filters, are under production (see Detector Coordinator report).

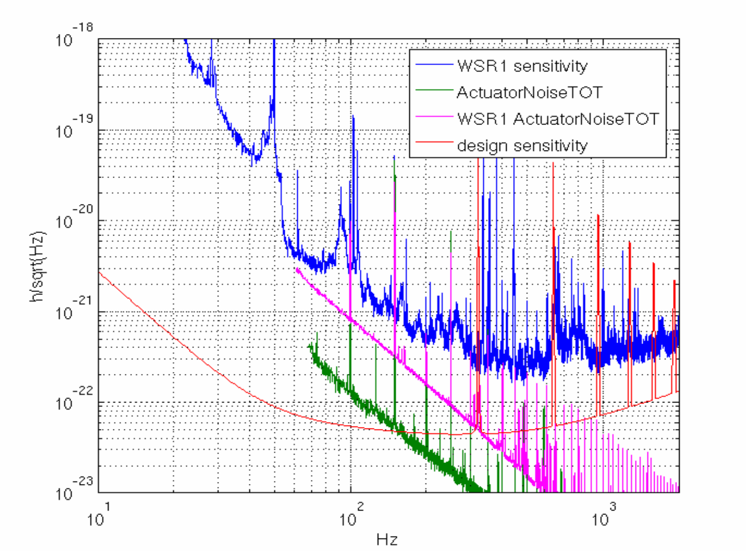


Figure 18: actuators noise impact on the sensitivity, before and after the emphasis-deemphasis filter installation. The Virgo design sensitivity is also reported

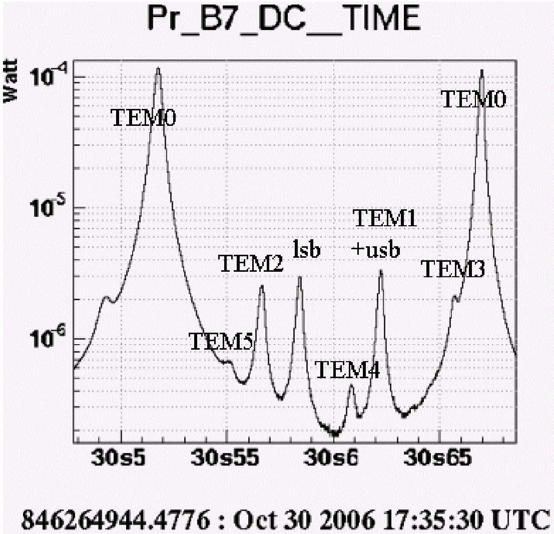
3.8.5 Matching improvement

As already explained, after the Faraday isolation optimization, the matching of the beam with the 3-km cavity was spoiled (from ~96% to ~93%).

The matching of the input beam on the Fabry Perot cavities has been recently improved to 97.5%, through a tuning of the parabolic input telescope, while keeping the beam aligned and at the same position in the interferometer.

The method used to measure the matching is recalled here: the cavity is carefully alignment and left freely sweeping, the different high order modes becomes resonant for different cavity length, then for different times. The mismatching is computed as the fraction of the light coupled with the first Laguerre mode.

The following figure shows the power transmitted by the West cavity freely sweeping. One can see that TEM2 is 2.5% of TEM0.



A better matching ~1-1.5% is achievable with further tuning of the input telescope. Since this operation requires a big realignment of the injection system, a decision will be taken after a new sensitivity measurement.

The free-sweeping cavity measurements are made with a "cold" system. The ongoing activity is meant to study how the thermal effects affect the matching when the interferometer is locked. Two effects are under study: the thermal lensing of the Faraday isolator and thermal lensing of the input mirrors.

3.9 Electronics and software

Global Control:

Provided all upgrades needed to support alignment and locking development activities. Optimized synchronization procedures among Pr, Locking and Alignment. The new architecture with:

1. Parallelization between the data transfer and the data processing
2. Algorithms optimization is running satisfactorily and allowed to perform more complex locking algorithms.

Detector Monitoring

The centralized interface allowing to monitor the state of all Virgo subsystems by integrating the information coming from the DAQ channels and other monitoring tools is almost finalized including advanced features like alarms notifications. The advancements on the system configuration side are making it a very useful tool for supporting detector operations.

Suspensions

Many corrective actions performed as identified during the commissioning noise hunting phase. Among them:

- Serial connection enabled on all long towers (ready for tidal control implementation)
- Implementation of Filter7 damping functionality on central area long suspensions.
- NE/NI, WE/WI + BS Coil Drivers equipped with de-emphasis filters
- Added a series resistor to PR mirror coils.

DAQ and dataDisplay

A major reorganization of the Suspension Data has been done for improving the corresponding signals processing CPU load balance and to reduce the stored data flow.
Provided all needed software upgrades and configuration changes in order to support at best commissioning activities. A new version of the dataDisplay tool with many fixes/upgrades has been put into operation.

Platforms and new Virgo Release VCS-5.0
Finalized test on Scientific Linux SL4 platform, ready for planning upgrade of all detector machines from Linux RH9. VCS-5.0 new common packages baseline frozen, application software is being built and tested on top. Tentative deadline set for end of November.

3.10 Commissioning short term priorities

After the set-up upgrades made in September and October and the recent matching improvements, the following step is to recover the science mode operation and measure a new sensitivity curve and a new noise budget.

This will be a starting point for the following noise hunting actions.

Despite the set-up changes, improvements are not expected for the power recycling control noise (limiting the sensitivity at ~ 100-200 Hz), and not definitive improvements are expected for the laser frequency noise (near the sensitivity curve during WSR-1, with a matching of ~4%). For these reasons next priorities are anyway:

- the understanding of the power recycling coupling with the dark fringe and the transition to B2
- the improvements of the frequency servo electronics and a better understanding of the input frequency noise

At the same time:

- diffused light mitigation will start on optical benches (injection, detection and end benches). Even if there is not direct evidence that this is a noise limitation for the sensitivity, the other GW detector’s experience tells that this could be an important noise source at the present Virgo sensitivity level
- acoustic enclosures will be installed on end benches and detection bench
- mirror centering and coil balancing will be improved, in order to decrease the angular to longitudinal coupling.

In parallel with these “pure” noise hunting actions, the following control activities are considered crucial:

- the global inverted pendulum control, to deal with bad weather conditions, especially during winter.
- the automatic alignment, in order to increase the bandwidth of the existing controls and to improve the feedback filters (more gain at low frequency and roll-off at high frequency to filter the reintroduced noise).

The main concern for the following months is still the not fully understood behavior of the fields inside the interferometer in presence of thermal lensing, and their influence on the lock acquisition and on the noise couplings with the dark fringe.

4 Data analysis report

4.1 Services and tools

A number of activities have been continued or started in order to address general analysis needs.

4.1.1 Data Replica

A working group has been created to work on data replica, in view of the need of transferring regularly and automatically data to the Computing Centers, of making it possible to access data in an efficient way, and of distributing data to the analysis group and the laboratories of the Collaboration.
Currently, the data transfer to the CC is based on scripts which use BBFTP to perform the transfer, and which have been fully automatized in the last months for the Cascina -> Lyon transfer. However, their degree of robustness and automatism is believed to remain inferior to what can be obtained with GRID tools.
For this reason, the current data transfer solution is being kept for production, but the working group has defined a strategy based on GRID tools, with the advantage that a GRID solution will address also the replica of selected data outside the CCs.
The transfer chain starts in Cascina, where EGO has set up robust code in order to decouple data acquisition and storage from data transfer. A set of scripts feeds data into a Storage Element in Cascina, registered in the Virgo Virtual Organization. From this SE, the standard File Transfer Service can be used to replicate the data across two channels linking Cascina to Lyon (the main Virgo repository) and Lyon to Bologna (the secondary Virgo repository).
The FTS service has been tested on a limited amount of data, and it remains to be tested for production.

4.1.2 Bookkeeping database

Work has been started to define the requirements for the Bookkeeping Data Base. A possible solution discussed makes use of the GRID replica manager for knowing where the files are, and of a Virgo specific database (the BKD proper) to associate conditions with file names.
The Physics Groups are preparing Use Cases which will allow to precisely define the needs and the best way to address them.

4.1.3 Reduced datasets

Preliminary estimates have been done about the bandwidth necessary to transfer data during a long Science Run, evidencing that stringent requirements on the latency would result into heavy requirements for the bandwidth.
To loosen the requirements, work has been started to define Reduced Data Sets which could comprise the most important channels used by the Physics Groups, and which would be transferred to the CCs with priority, thus allowing to start the off-line analysis early after the data acquisition. The goal is to keep these RDS below 10% of the Raw Data.

4.1.4 Computing farm reconfiguration

The computing farm for on-line analysis has been enlarged including 65 new nodes, each equipped with 2 Dual-Core CPUs (4 cores/node, 260 cores in total).
The sharing of these resources among the Physics Groups is under way. Most of the resources will be taken by Coalescing Binary searches, but it is expected that also the other groups, and particularly the Burst and Noise group, will need part of the computing resources.

4.2 Offline computing in Bologna and Lyon

We recall that the off line computing for Virgo is performed in part in Cascina (as long as the on-line farm is not fully booked for on-line analysis) and mainly in the two computing centers of INFN and IN2P3 located in Bologna and Lyon.
We recall also that the two computing centers use different accounting units for the CPU usage. In order to unify and compare the impact of the Virgo activity in the two centers, we assume the following conversion factor:

1 CPU @ 1GHz ~1 kSP2000.
480 UI of CCIN2P3 UI ~ 1kSP2000.day

4.2.1 Virgo at INFN Tier1-Bologna

We try to summarize shortly the usage of Tier-1-INFN resources for the year 2006, both for what concerns data storage and computational resources.
Computational resources have been used mainly through the submission of grid jobs and to a lesser extent using directly the local batch system (see later for some problems encountered).
The main use has been the analysis of the Virgo Commissioning Runs C6 and C7 for the search of periodic gravitational signals and the 'calibration' of the software through the injection of simulated signals in real data.
In the following we report some figures concerning the usage of resources (to Nov. 3).

Jobs completed	CPU time used (h)	Average CPU time per job (s)	KSpecINT2000*day
42635	41198	3284	1088

A relevant problem has been found in the direct submission through the local batch system of MPI jobs. A similar status is produced also in case of the submission of MPI jobs done through the grid.
The CNAF experts spent a significant amount of time in the debugging process, but unfortunately the problem is not fixed yet.
This is an important problem for VIRGO also in view of the software migration of the coalescent binary search for which a extensive use of MPI is needed.
The bug seems to be related to the specific configuration of the INFN-Tier-1 farm that does not allow users to log on the Worker Nodes, a condition which prevents the successful submission of MPI jobs.
If this interpretation is correct, the solution of the problem is not straight forward, because the farm reconfiguration can conflict with the activity of the other main users of the CC.

Concerning data storage, about 27TB of data are stored at Tier-1, most on disks (both SAN and NAS systems) and part on CASTOR. A migration of the data older than about 2 years (i.e., run E*, C0-2) on CASTOR has been foreseen to free some space needed for the WSRs. According to the original schedule of WSR, 33TB of disk space should be made available up to December. Now, WSR have been re-scheduled and may be also our needs have changed accordingly.

4.2.2 Virgo at CCIN2p3 - Lyon

Lyon computing centre (CCIN2P3) is used to store permanently the Virgo data (all streams recorded during data taking periods). CCIN2P3 is also intensively used for off-line data analysis. The main use of the computational resources is done by submitting jobs via standard batch queue (BQS). We started also this year submitting jobs through Grid. We summarize the Virgo resources used in Lyon:

Storage:
36 TB used in HPSS by Virgo (all data taking periods)
Data access:
The access of data stored in HPSS has been greatly improved thanks to the use of XrootD.
Data Processing:
use of the CPUs: up to the end of October 4200 kSI2000.day (our request for 2006 is 6000 kS2000.day).
For 2006 we asked a large fraction of the CPU time to be used via Grid. This fraction is still not used but used by other groups.

4.3 The analysis activity of Physics groups.

We recall here that in Virgo we have organized five Physics groups having different scientific targets of data analysis:

Burst signal search
Coalescent Binary signal search
Pulsar signal search
Stochastic background signal search
Detector Noise study

To these groups we need to add the *h-Reconstruction* which takes care of calibrating the data and of removing some of the known disturbances.

4.4 h-Reconstruction Group

During the last six months, the reconstruction activity touched on the following topics:

- Development of a new version of the reconstruction code implementing several improvements, including the possibility to use frequency domain anti-aliasing filters for decimation.
- Actuator calibration: some measurements have been done to measure and reduce the overall calibration uncertainty due to the imperfect knowledge of the DC gain value of the mirror actuators.

4.5 Burst Group

The Burst Group activities are as usual manifold: analysis of the run data, definition of vetoes, network analysis with LIGO and with bars and continuation of previous works on development/improvement of filtering methods for burst detection.

4.5.1 Analysis of WSR data

After spending much of our time on the analysis of C7 data during the first half of 2006, we have naturally dedicated time to the analysis of WSR1 and WSR2 data. An important (but still preliminary) result is that a clear correlation between the trigger rate of burst pipelines and the seismic activity has been recently identified [1]. This means that a large part of the excess of trigger rate with respect to the ideal Gaussian case is due to the seismic activity level. High seismic activity means in particular large mirror angular motions that couple to frequency noise and thus induce variations of the RMS of the dark fringe signal. This is nothing but the BoB mechanism, already seen in the C7 data.

4.5.2 LIGO-Virgo joint working group

The paper about the comparison of burst pipelines in LIGO and Virgo is now finished and has been reviewed by LSC and Virgo Editorial boards. It should be submitted soon.
The second step of the joint studies has been successfully completed (“project 2a”). The goal

of this exercise was to exchange 3 hours of real data (C7 for Virgo) in order to understand each other's segment definition or set of vetoes. There has been no bad surprise as each party has been easily able to run their pipelines on each other's data and understand the vetoes.
We are currently tackling the project 2b. The goal is now to analyse 24h of coincident data from the 5 instruments (the 3 LIGO interferometers, the Virgo interferometer and the GEO interferometer). Despite Virgo is not yet at its design sensitivity and cannot compete at least with the two 4km LIGO interferometers, this project is meant to be a methodological one, setting all the tools needed for a real complete analysis from trigger lists generation to the assessment of an upper-limit. The details are being discussed now: what kind of burst sources are we targeting? Which pipeline will we use?

4.5.3 Virgo-Bars

Virgo-bars working group has examined one day of coincident data acquired by Auriga, Explorer, Nautilus resonant detectors and Virgo detector during September 2005 (C7 run for Virgo) [2].
The goal of the study was to assess interpreted confidence intervals on the flux of gravitational waves (damped sinusoids with central frequency in the bandwidth [850-950]Hz and damping time from 1 to 100 ms) coming from the galactic centre. The interpretation comes from software injections which are used to compute the efficiency of detection for a source population.
The main methodology was the standard one based on coincidence search on trigger lists provided by each detector: the coincident counts, divided by the efficiency and by the observation time, become observed rates (or upper limits on rates).
However, a new approach was used in setting the thresholds for each detector. The thresholds were in fact optimized using, for each template and each given target amplitude until the best compromise between efficiency and FAR is searched. When the null hypothesis test is fulfilled, than the confidence interval is an Upper Limit.
In order not to bias results by feedbacks on methods from looking at results, a blind analysis procedure was adopted by adding a "secret" time offset to the detector times of the exchanged data. The zero-lag analysis has been eventually performed and the confidence intervals set according to the confidence belt already used by IGEC1.
No excess of coincidences has been found and the null hypothesis confirmed at 99%. Thus one can interpret the confidence intervals is an Upper Limits at 95% coverage.

As the 2-fold coincidence searches on which the work was based have a high level of accidental background, single detection is not possible: the plan is to extend the study by performing 3-fold coincidence searches with the goal to be able to issue a claim at 99.5% confidence on a single observed triple.

4.5.4 Coincidences with Gamma-Ray Bursts

We are also starting to look at coincident events between Virgo and GRB detectors during C7 run. A dedicated study concerns the (long) Gamma-Ray Burst GRB 050915a that occurred during one of the stable segments of C7. A coincident detection is unlikely but the goal is rather to compute an upper limit on the strength of the possibly associated GW signal. No results yet, the study is ongoing.

[1] https://workarea.ego-gw.it/ego2/virgo/data-analysis/burst/
[2] L.Baggio et al, *First joint search of GW waves by the Auriga - Explorer - Nautilus - Virgo Collaboration*, Virgo note VIR-NOT-FIR-1390-328.

4.6 Coalescing binaries group

During the last six months, the coalescing binaries group activity touched on the following topics:

- Analysis of C6 and C7 data. This activity has been continued, focusing on veto studies and a comparison between triggers produced by the Merlino and MBTA pipelines.
- LIGO-Virgo joint analysis preparation, especially the finalization of the paper (to be submitted to PRD) describing the work done within project 1b.
- A study to define a new reference time for inspiral signals, more suited to perform coincidences, has been pursued.
- Coherent network analysis. A code is being developed and tested; first tests focused on checking the performance of the coherent analysis with respect to the source direction determination.
- NS-BH spinning binaries. A preliminary study has been performed to assess the efficiency of a search that would be based on 2PN templates, investigating how best use the information from the correlators across the template grid.
- Grid generation. Work has been done in order to be able to compute locally the metrics from fitting a paraboloid. The goal is to use this tool to generate template grids with a metrics based on other models than the usual 2PN templates.
- Analysis of WSR data:
  - Both Merlino and MBTA pipelines are run online during the weekly science runs.
  - The group is providing tasks to be performed by the scientist on shift to monitor how the detector behaves with respect to coalescing binaries analysis.
  - The WSR data are also analyzed off line to refine the results, especially concerning data quality and vetoes.
  - Special attention is brought to the inspiral hardware injections performed during the WSR, to check how the pipelines are able to detect them.

4.7 Pulsar Group

The main goal of the work in this period was the presentation of two papers to the Marcel Grossmann Meeting and the analysis of simulated signal data (added to the C7 run data).

Main data analysis

- **First coincidence search among periodic source candidates with the Virgo data,** presented to the MG11 Conference in Berlin. We analysed the data of the C6 and C7 in search of periodic signals in the band between 50 Hz and 1050 Hz. We found about 450 million candidates from C6 and 150 million candidates from C7, finding about 900000 coincidences. With another analysis, dividing both the runs in two different subsets, we found two groups of about 17 million candidates, with about 190000 coincidences.

    1. **Incoherent strategies for the network detection of periodic gravitational waves**, presented to the MG11 Conference in Berlin. We analysed different strategies to perform coincidences between subsets of data, in order to reduce the false alarm probability without significantly reducing the detection probability.

1. **We simulated signals, adding them to the real data (C7 run)**. We did three different studies:
    - one pilot study with signals without spin down: this is now completed. The results permitted to discover and correct some bugs.
    - one simulation with 500 signals many of them with non-null spin-down.

- one simulation with the same signals, but with dilated time scale, in order to cover, with the C7 data, about one year (dilation factor 80).

These last two studies are not yet finished.

2. **Fast simulation program**: we are working on a new faster simulation program (it should be more than 100 times faster).
3. **Enhancement in the SFDB creation**: new high pass filter for the time big event detection, new FFT window.
4. **New more efficient candidate database**: the preceding database divided the data depending on the sky position; this uses the estimated spin-down; it is better if there is heavy clustering in the candidates.

Service procedures

1. **Modification of the Supervisor**: there has been some substantial changes in some libraries of the Grid middleware, so we started to upgrade (with some problems).
2. **Snag enhancement**: we added some new possibilities in the gd management. In total we added or changed about 150 m functions (on the total of about 1000). A new rough Doppler shift computation function was added (for checking purposes).
3. **Automatic analysis report generator**: in order to automate some analysis, thanks to the new features of Matlab 7.
4. **Batch report diary**: there are to programs, one in C and one in Matlab, that are used to submit batch jobs in the two environments, automatically registering a report in a diary file.
5. **General log-file format**: a standard format has been developed for the creation of the log-files of all the production procedures (SFDB and peak map creation, Hough map candidate creation, etc.).
6. **New format of the PSS_UG user guide**.

The most part of this work is documented in the PSS_UG and in the reports that can be find in http://grwavsf.roma1.infn.it/PSS/

4.8 Stochastic Background

In short, the activity of the group is mainly concentrated around the collaboration with LSC. The project of collaboration with bars experiments (Auriga, Explorer and Nautilus) is currently in stand by, as there is not enough manpower to manage it at this time.

4.8.1 Virgo/LSC collaboration

This project is in progress. There are a pair of scientists in Virgo which are fully involved in it, and another pair which are starting to collaborate. In the medium term it is foreseen that at least a couple of student, probably Ph. D. candidates, will join.

Currently we are working on simulated data. Here is a list of the current activities:

1. Comparison among three different detection pipelines: the Virgo detection pipeline (NAP/SB), a pipeline based on the LAL library and a matlab based one (matapps). In the initial phase there was a disagreement between the results of the different codes, which is now almost completely disappeared. The Virgo code has been adapted in some aspects to the two LSC ones in order to simplify the comparison. There is now a common basis which can be used to produce independent “standard” analysis on both sides of the collaboration. In the future we will plan to implement alternative strategies, in particular filtering (adaptive or not) in the time domain, in order to address well known problems connected to non stationarity of noise in a innovative way.
2. Signal simulation. The simulation of a set of correlated streams for a Gaussian, stationary and isotropic model of stochastic background and an arbitrary number of detectors is fully contained in the Virgo code. Currently the simulation code has been

used to produce signals with a power law spectrum. We are now starting to produce and study spectra with an astrophysical motivation. We do not expect problems on this side because the code is fully parametric.
3. Anisotropic models. Some initial activity as been done. A postdoc will join the Nice group, and will work fully on this item.

In September 7th and 8th there was the first face to face meeting in Pisa. The next one is foreseen in Nice in November 20th and 21th.

4.8.2 Virgo/Bars collaboration

No progress on this side. An initial short set of data has been analysed. But the analysis is not yet finalized. We hope to do this as soon as there will be more manpower. But it must be said that it seems not to be a great interest from our partners.

4.8.3 Software

The data analysis code has been continuously tested and debugged. At this time we are adding codes for simulation and detection of anisotropic models. The status of the documentation cannot be considered completely satisfactory, but it was improved and still it will be in the future. The main problem here is that currently only a single scientists is working on this item.

4.8.4 Conferences and publications

There was a couple of presentations in which recent results of the groups have been presented. The first in the annual ILIAS meeting, the second at the Marcel Grossman conference this year. A report on the Virgo/LSC activity is foreseen for the next GWDAW, and the preparation of a paper on the simulation of stochastic background is in progress.

4.9 The Noise group activity

In the last six months the noise hunting activity was developed mainly in the commissioning group due to the close connection between locking and noise hunting in this phase of the commissioning of Virgo.
Still some activities were specifically performed by this group.

4.9.1 Study of WSR1 data

After WSR1 there was a discussion on outliers and loud burst events emphasizing the need for further tools like injection of loud burst events and tests e.g. for gaussianity of data.

4.9.2 Study of the acoustic isolation in the laser laboratory

An analysis of the performance of the acoustic isolation in the laser laboratory was performed by use of a loudspeaker. The effective isolation factor achieved is around a factor of five in pressure, showing that further improvements should be possible.

4.9.3 Monitoring of non stationariness

A process for the monitoring of non-stationariness of noise (nonStatMoni) is now running on-line. The output is routinely used to understand the interferometer behaviour, in particular with respect to misalignments and related suspension resonances. A project to study in a systematic way non stationarity with channel to channel correlation is starting these days.

Items like numerical noise or magnetic coupling are postponed to when reasonably stable data taking conditions are achieved.

5 Advanced Virgo report

5.1 Introduction

The Advanced Virgo coordinator has been appointed by the VSC in July 2006, with the following mandate:

The task of the Advanced Virgo coordinator is to coordinate the Virgo Activities needed to provide a ***full design for Advanced Virgo****. This covers the coordination of the different* ***work groups*** *working on this matter as well as the specific* ***R&D activities*** *needed for Advanced Virgo.*
To achieve this coordination, he will organise ***regular meetings*** *of an Advanced Virgo coordination group with the co-chairs of the different working groups, the detector coordinator, the data analysis coordinator and any other persons needed.*
He is responsible to provide a document that will describe the Advanced Virgo design, including a list of task, a planning and a cost evaluation. If different options exist for part of the detector, he will have to describe the path needed to down select the final solution. The target date for the delivery of this document is ***November 2007****.*

The activity so far has been mostly dedicated to:

- the kick-off of the activity of the four working groups;
- the writing up of the document on the R&D priorities for Advanced Virgo[9];
- the organization of a regular Advanced Virgo session within the Virgo Collaboration meetings;
- the preparation of a web page dedicated to Advanced Virgo[10].

5.2 Working groups

Four working groups had been setup in September 2005 with the aim of carrying out the development of some Virgo+ items and the design of Advanced Virgo. The VSC appointed the corresponding coordinators (WG1: A.Freise, P.Hello – WG2: N.Man, P.La Penna – WG3: G.Losurdo, M.Punturo – WG4: A.Gennai, A.Masserot). In September 2006 G.Losurdo was replaced by P.Puppo as co-chair of WG3, while in October A.Masserot was replaced by N.Leroy as co-chair of WG4.

Although the work of the WGs starts to be visible and the attendance to the meetings is good, there are concerns on the availability of the people to do real work on the design. The commitment on the commissioning and on the preparatory work for Virgo+ prevents most of the young people from taking responsibilities in the WGs. The design work would certainly be boosted by having one or two dedicated post-docs.

A short activity report for each WG follows.

5.2.1 WG1: interferometer optical configuration, sensing and control

The work for the definition of the Advanced Virgo optical design has started[11]. The topology of the interferometer is obviously not yet fixed and may evolve in the future. This first optical

[9] The Advanced Virgo Team (for the Virgo Collaboration), *Guidelines for Advanced Virgo R&D*, VIR-NOT-DIR-1390-325 (2006)
[10] http://wwwcascina.virgo.infn.it/advirgo
[11] A.Freise and M.Mantovani, *Initial set of optical parameters for numerical simulations towards Advanced Virgo*, VIR-NOT-EGO-1390-330 (2006)

layout is meant as a starting point for further optical studies and is going to be used for initial optical simulations for Advanced Virgo. Moreover, a new simulation code for quantum noise in advanced interferometers is being developed[12]. This code not only handles quantum noise aspects but also classical noises such as various thermal noises and could be used to optimize the optical design with respect to the detector sensitivity.
More recently the working group has worked on the guidelines for R&D with respect to Advanced Virgo. Three lines of action have been defined: simulations, table top experiments and larger 'suspended' experimental tests. Top priority items have been identified: design and test of locking and alignment schemes for a complex interferometer including Signal Recycling, design and test of lock acquisition scheme, test of the DC readout scheme and studies of the dynamics of high finesse cavities.

5.2.2 WG2: laser and optics for high power

The objective of the WG2 group is to study the possible options for the high power laser and the corresponding input optics, in order to find the best solution for Advanced Virgo in terms of feasibility, performances, planning, cost and maintenance as well as simplicity or robustness.

A large documentation has been consulted about the fiber lasers and there seems to be no theoretical limitations to extract power as well as to get good beam quality from such lasers. This has to be continued eventually in collaboration with French Institutes such as Limoges, Institut d'Optique, Ecole Polytechnique and German Institutes such as the Fraunhoffer Institute in Jena.
The solid-state laser is being taken care inside the LSC collaboration by LZH, we have regular contacts with LZH for their progress and this should be carried on in parallell.

In the next months the investigations on the two options for the laser system will start: solid-state laser or fiber laser. The group plans to establish milestones in the progress of the investigations. Each milestone should contain some criteria like performances vs feasibility, simplicity, maintenance, availability time. For equal technical performances, comparisons should be made in terms of parameters such as geometry, size of the resulting benches. The WG2 group will make the list of items involved in the comparison and solicit the experts for each field inside or outside Virgo.

For the input optics different choices are possible if either a solid state laser or a fiber laser will be used. Since this point has still to be decided, both directions have to be taken into account and investigated:

- Investigations on components for high power (100-200 W) are envisaged:
  An R&D proposed to EGO is intended to test materials and devices using a commercial high power laser (possibly a fiber laser), and test the thermal behaviour. In particular tests are needed on:
  - Faraday isolators (either in air and in vacuum)
  - Electro-optic modulators (either in air and in vacuum)
  A possible group of people available to perform this task has been identified (from EGO and Pisa).

- A new Input Mode Cleaner (IMC) has to be studied: possibilities are either a photonic fibre IMC (being investigated in Nice), or a suspended mirrors IMC: problems like

[12] J.-M. Courty and J. Lebars, in preparation

radiation pressure, scattering, one or two IMC, triangular or other configurations have to be taken into account. The suspended IMC has to be studied by means of optical design and simulation. People to perform this task to be identified.

- Input telescope: either in this case, the design of a new input telescope, accordingly to the shape that the beam will have in the Input Mode Cleaner and in the Interferometer, has to be studied taking into account problems like optical aberrations, shape of the mirrors, scattering, suspensions, tenability. People to perform this task to be identified.

5.2.3 WG3: suspension and thermal noise issues

WG3 deals with the upgrades of the vibration isolation system of the test masses. It also takes care of the upgrades needed to fulfill the mirror cleanliness requirements.

The activity of the WG3 group has started with the study and the realization of a first prototype of the monolithic suspensions for the test masses of Virgo+. In the first half of 2006 the new marionette and reaction mass for the monolithic payload has been designed. A dummy steel marionette built to test the hybrid steel-fused silica clamps has been assembled and tested to suspend a dummy mirror with fused silica silicate-bonded *ears*. A more detailed description of the Virgo+ activity can be found in the report of detector coordinator. In the last months a parallel work has been carried out to build the control system of the monolithic suspension.
The activity being carried out in the frame of Virgo+ is crucial to acquire the experience for the design of the monolithic suspensions in the Advanced configuration in which several improvements and modifications must be added, taking into account the different dimensions of the new mirrors the possible modifications of the superattenuation chain and the possibility to use ribbons instead of fibers.
For this purpose, two meetings were held in September and October. Some topics that are crucial for the design have been discussed: the choice of the fiber neck shape, the determination of the fiber bending point, the violin and bouncing frequencies, the stresses, the coupling of the fiber to the mirror and marionette, the design of the ears and the clamp. A tool has been proposed by the Florence group to measure the fibers bending point that will be helpful to fulfill the mechanical requirements necessary for the mirror control system. The next months the activity will continue with the aim of deciding the geometry of the fibers for Virgo+ and to define the modifications for Virgo Advanced.

In the next months the group will follow all the R&D activities for Advanced Virgo within its scope, concerning:

- **the upgrades of the test masses and coatings:** heavier mirrors will be probably used in Virgo Advanced to cope with the radiation pressure effects, moreover lower losses coatings and lower absorption substrates must be studied for the reduction of the thermal lensing problems due to the use of a higher power laser.
- **the upgrades needed to fulfill the cleanliness requirements:** the problem of the mirror contamination will become a crucial point because of the power increase foreseen in the Advanced configuration. In Virgo, the payload assembly activities represented the major source of contamination. A new design of the payload including a reference mass for the marionetta has been proposed to simplify considerably the assembly procedure and the mirror handling time. The study of an in-situ cleaning procedure for the mirror has been proposed as well.
- **the upgrades of the suspension control:** the WG3 will also follow, together with the WG4, the activity dedicated to reducing the mirror residual motion, crucial point for

the locking and the duty cycle of an advanced detector. At present, the inertial damping performance is limited by the ground tilt. Hence a six d.o.f. control of the inverted pendulum could be a way to improve the performance of the superattenuator. A dedicated R&D has been proposed.

- **the electrostatic actuators:** another R&D activity, being pursued in the Napoli laboratory, is devoted to the study and design of the electrostatic actuators. They should allow a lower dissipation on the mirror, the increase of the optical quality (no magnets on the mirror face) and the absence of magnetic couplings. The WG3 is following this activity, and some new results should be provided in next months.

5.2.4 WG4: electronics and controls

In the last months the WG4 activity was focused mainly on defining the aims and purposes as control system design for Advanced Virgo will require a close integration on a large number of items ranging from ultra low noise electronic hardware to real-time software architectures passing through advanced feedback control methodologies. Complex embedded systems, realized by various combinations of analog and digital hardware and software parts, will cooperate to form a complex real time control system.

The working group has been definitely set up recently and will work in the next months on defining the requirements for Advanced Virgo on the E&S and check in which way the R&D already done for Virgo+ fulfilled the needs. The work will be then necessarily focused in the definition of applicable standards for electronics, software and controls. Next step will be mainly composed by feasibility studies and definition of specifications at sub-system level. An open design must be foreseen to allow specific upgrades to follow new technologies available like computing power.

The first meeting of the working group will take place in November and future meetings will be planned to ensure a follow up of the different activities. We will also keep in touch with others working groups for the definition of the requirements.

5.3 R&D document

A design of Advanced Virgo is not mature yet. The state of the art of the design process is represented by the Advanced Virgo White Paper[13] released in November 2005. The Virgo Collaboration has decided to start a discussion on the R&D needed to build up the know how and the technology necessary for a second generation detector. The main task for the WGs in the last months has been the definition of the priorities for the Advanced Virgo R&D. The discussion has been carried out first in the WGs and then in the Collaboration meeting and in the VSC. The result is a document that defines a shortlist of R&D lines to be pursued for the upgrade of Virgo to a second generation detector. The document is conceived as an addendum to the White Paper, an evolution of the section 6 dedicated to Advanced Virgo.

Eight crucial items have been identified: high power laser, input optics, output optics and photodiodes, optical configuration, monolithic suspensions, suspension mechanics and control, electronics. For each of such items the foreseen changes, the open options and the needed R&D are listed. Several options remain open, especially for what concerns the optical configuration and the laser. The results of the R&D being carried out inside and outside Virgo, together with the activity of the WGs, should help to get rid of some of the open options. On the other end the document stated that Advanced Virgo will not use cryogenics, flat beams and squeezing.

[13] The Advanced Virgo Team (for the Virgo Collaboration), *Advanced Virgo White Paper*, VIR-NOT-DIR-1390-304 (2005)

5.4 Advanced Virgo meetings

Since september 2006 an Advanced Virgo session is regularly planned within the Virgo Collaboration meetings.

- 9/06: the meeting has been dedicated to a first discussion of the Advanced Virgo organization and to the presentation of the workplan for WG1 and WG2;
- 10/06: the meeting has been dedicated to the discussion of the document on the Advanced Virgo R&D. The R&D priorities as defined by each WG have been presented. Morevoer, a WG1 meeting was held in the same session;
- 11/06: this was a special meeting, lasting one whole day, entirely dedicated to the presentation of the proposals for the EGO call for R&D.

5.5 Advanced Virgo web page and mailing list

A web page has been setup. The page is divided in two parts: a repository of documents and presentations and a space dedicated to the WG activity. The richness of the page's contents is expected to grow together with the WG activity.

A mailing list has been created (advirgo@ego-gw.it), open to the members of GEO600.

5.6 Next steps

After the completion of the document on the R&D the work will be focused on the writing up of the Advanced Virgo Design Document, to be released by November 2007. A draft roadmap towards the goal has been discussed at the Collaboration meeting of September:

- Oct. 06: release of the R&D document (done)
- Spring 07: hold a workshop where each WG presents the work done and a preliminary skeleton of the Design Document is presented
- Aug. 07: draft of the Design Document released for discussion in the Collaboration
- Fall 07: peer review by a panel of experts
- Nov. 07: Design Document final version, including cost plan.

The feasibility of such plan depends on the possibility to involve enough forces in the design process, inside and outside Virgo.

6 Virgo/EGO Outreach report

6.1 Site visits

The visit activity restarted with a good momentum. The period October–December has been fully booked by 10 high school classes, one group from Perugia University and one by the Caffe' della Scienza of Livorno.

6.2 Newspapers, reviews, radio, TV, Web

A few articles on local and national newspapers and reviews have been published. Among them an article on Virgo, on Eureka, a French teenager magazine. Eureka, with the subtitle "*le monde est dans vos mains*", is published quarterly on paper and WEB, and deals with Science, Environment and Society (www.eureka-mag.com).
The US magazine Science interviewed recently Benoit Mours; the following short, but significative text has been published on October 6 (Science, Vol 314, no 5796, p. 33):

> ***ScienceScope***
> *An agreement to share data could turn the world's gravitational-wave observatories into one big instrument. It would allow researchers working with the Virgo detector near Pisa, Italy, and their counterparts with the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the United States to share data and jointly publish all results, says Benoit Mours, Virgo spokesperson and a physicist at the Annecy-le-Vieux Particle Physics Laboratory in France. LIGO has already joined forces with GEO 600, a smaller gravitational-wave detector near Hannover, Germany. The new deal must still be approved by the Italian and French agencies that fund Virgo, but Mours says he's confident that will happen.*

6.3 Expositions, exhibitions, conferences

The two transportable mock-up interferometers (working) continue to travel around. One of them was in Alexandria (Egypt) with the INFN exposition, the other was in Genova at the yearly Festival della Scienza.

"*h* - the Gravitational Voice" is the title of the EGO/Virgo quarterly newsletter, published on the web. The first issue appeared in July and the second in October (http://www.ego-gw.it/public/hletter/hletter.aspx).

Sidereus Nuncius, the announced theater – music – multimedia event, scheduled around June 22, the same day of Galileo's abjuration in 1633, took successfully place. It is reported in the last issue of the EGO/Virgo newsletter "**h**".

6.4 Photovoltaic generators

The investigation by Virgo and the EGO Infrastructure Department, to evaluate the opportunity to install photovoltaic generators on tunnel roofs is in progress. Limiting the coverage to the South oriented half of the West tunnel, a 1 MW peak power could be reached. Some detail can be found on last "h" issue.
The value of this initiative is twofold:

- promotional (most relevant, in our opinion), showing the EGO/Virgo and CNRS/INFN vocation to the use of clean, renewable energy sources.
- economic, thanks to the very convenient rates, forced by law, applied by ENEL to buy the excess produced power; the large investment, of the order of 5 MEuro could be recovered in about 10 years

The EGO Director signed an agreement with AEP (Agenzia Energetica di Pisa), to prepare a joint preliminary design to be presented to GRTN, the state agency in charge of evaluating and approving the proposals.