Virgo Progress Report
For the STAC and EGO Council

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Abstract

This report describes the Virgo activities and progress for the November 2005 to June 2006 period. It starts by a quick status overview and collaboration news, the report is organized in four sections: detector, commissioning, data analysis and outreach status, prepared by the corresponding coordinators with inputs from the various persons in charge.

Summary

1 Overview

1.1 Recent activities:

Since the last progress report for the EGO council, the Virgo injection system has been upgraded and the recycling mirror replaced. The detector has been back to vacuum in December. Then the commissioning of the injection system started, followed by the commissioning of the full Virgo. The interferometer has been locked with 280W on the beam splitter, which is more than a factor 10 compared to the last commissioning run (C7) and part of the alignment loops have been closed. However, the lock conditions are not yet stable. Quite often the interferometer unlocks after a few minutes although some long locks (more than an hour) have been observed and are becoming more frequent.

The data analysis activity was targeted to two main activities: the analysis of the previous commissioning runs (including a joint analysis with the Italian bars) and the joint analysis with the LIGO to prepare the future. This latter activity is expending with the setting up of a new agreement between LIGO and Virgo.

1.2 Up coming activities

The commissioning is going full speed to achieve a stable lock and to reduce the technical noises in order to start science data taking this fall. For this data taking we expect to improve the sensitivity by about one order of magnitude compared to C7, using the horizon distance for binary system as figure of merit. This means a factor 2 to 3 compared to the currently running LIGO detectors. An intermediate period of week-end data taking plus weekly noise hunting is expected before the continuous data taking. The detailed list of commissioning activities needed to reach this goal is described in the updated commissioning plan.

Once the noise floor will be well understood and some data taken, a short shutdown followed by commissioning activity is scheduled in early 2007 to do the fixes that will enable us to reach the design sensitivity.

In parallel to this commissioning activity, the preparation of the data analysis will continue to be ready for the first science data, with special attention to the joint analysis with the other detectors.

1.3 Virgo upgrades:

The Virgo upgrade activity has been focused on the Virgo+ configuration. This is a set of medium scale improvements that are limited to part of the detector, mainly the installation of monolithic suspensions, a laser power improvement and the electronic upgrade. The expected sensitivity improvement is about a factor 3.

The Virgo+ activity is well started. The laser amplifier has been ordered. The new mirror (blanks) has been produced. The machine that produces silica fibber is installed at the site. The prototyping effort of the suspension is actively pursued. The electronic R&D is close to provide the full set of prototype modules and the thermal compensation activity is in progress. The installation of this last upgrade is scheduled for early 2007.

The second main upgrade, "Advanced Virgo", will require larger detector changes since the optical layout will be modified to improve the sensitivity by another factor 3. The working groups looking at this issue have started their work. A detailed proposal is expected around the end of 2007

1.4 Collaboration organization

Over the last months, there has been some modification of the collaboration and its enlargement has made progress:

- The existing Frascati group has stopped their contribution to Virgo.
- A new group from the Roma Tor Vergata University and also Frascati (persons from the ROG collaboration) has declared its interest in joining Virgo.
- The LMA and ESPCI groups have decided to act as a single group inside the collaboration.
- The discussion with the NIKHEF group has led to a Memorandum of Agreement between the NIKEF group and the collaboration that defines the proposed activity. This as been communicated to the EGO council who is taking care of the financial issue. Meanwhile, the NIKHEF group has started working on the hardware side (production of electronic boards for the alignment) as well on the data analysis (tools for data transfer and binary pulsar search).

Most of the Memorandum of Agreement between the collaboration and the groups are written and approved. The corresponding document with EGO is also in preparation. They provide a better definition of the responsibilities and activities of each group.

The fellowships for the commissioning and subsystem support have been awarded and most of the persons start working on the various topics.

1.5 External collaboration

The LIGO-Virgo working group continues to be very active with regular teleconference and face to face meeting a few times per year. A sub-group looking at the stochastic noise search has been added. The exchange of 3 hours of real data has started.

But the main new step is the setting up of an agreement for a full data sharing and joint analysis between LIGO and Virgo. This is a major move for Virgo as well as for the field because it will enable us to extract the best science of our data. The MOU that describes the agreement is ready and the collaboration asks the EGO council to approve it. This MOU will be completed by an attachment which will describe more details of this joint activity.

A consequence of the agreement for data sharing is the beginning of a joint planning of data taking with the LIGO detectors (that include GEO). The following figure describes one of the possible foreseen plannings.

Finally, the MOU with GEO for the participation of GEO members to the study of Advanced Virgo has been completed and signed.

2 Detector coordinator report

2.1 Introduction

After the upgrade of the injection system (ISYS) the detector activity has been concentrated on the identification and study of the upgrades needed in the detector to reach and then improve the nominal Virgo sensitivity. A list of detector changes is under definition, taking also into account the foreseen Virgo+ upgrade.

2.2 New decisional process

As usual, all the detector technical improvements evaluated by the collaboration are discussed in the detector meeting, but, now, as requested by the EGO Council, the decisional process has been better defined and the restored Change Request procedure again enforced. All the proposed changes must be defined in a change request document (CRE) that describes the problem (motivations), the technical solution, the needed tasks and deliverables, the time schedule and the expected costs. The realization of the CRE document is strongly suggested even if a real modification of the apparatus is still not identified; in this case the documentation is a useful tracking system of the performed studies. The CRE document is realized by the Virgo member, responsible for the proposed upgrade, and maintained in the Virgo web server
(http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/) by the detector coordinator, that manages all the decisional process. Each main step (discussion in the detector meeting, VSC approval, …) is recorded in the document with an appropriate versioning system.

2.3 Scenario

As described in the Virgo commissioning plan document, the commissioning of Virgo will evolve in two main steps: the approaching of the Virgo nominal sensitivity in the middle-high frequency range (>50-100 Hz) in 2006, to be ready to make a coincidence run with LIGO, and the convergence toward the nominal Virgo sensitivity at low frequency, foreseen in 2007. Between these two phases, it is foreseen a possible short shutdown of the machine, in the early 2007, to implement the needed upgrades of the detector. After these (almost) two years of activity, a longer shutdown is foreseen to upgrade the machine to Virgo+.
The first changes aiming the attainment of the Virgo sensitivity in the middle-high frequency range are the insertion of a pre-mode cleaner, already foreseen in the Virgo design, and the reduction of the acoustic contamination of the Virgo signal, through the sequential acoustic shielding of the Virgo external benches.
Borderline between the upgrades dedicated to the high frequency and to the low frequency ranges is the replacement of the mode cleaner terminal payload. In fact, the replacement of the mirror could be necessary to insert more power in the ITF, while a better payload could improve the control noise at low frequency and the detector duty cycle.
Surely dedicated to the low frequency regime, is the mitigation of the eddy current issue, already discussed at the October 2005 STAC meeting and now defined by an opportune CRE document.
A progressive improvement of the linear alignment electronics is also foreseen, to compensate the possible lack of light power on the alignment quadrants.
The upgrades needed for the Virgo+ step are shortly described in this document; possible anticipations before 2008 can play a positive role in the Virgo nominal sensitivity attainment (i.e. new DSP's).

2.4 Upgrades

2.4.1 New Virgo Pre-mode cleaner

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 PMC is a 10 cm long, Zerodur cavity; its finesse is 1500 (estimated on the basis of 1 W on the dark fringe). PMC will be put under vacuum (10^{-6} mbar) in a small vacuum tank (0.35 m long, 0.2 m diameter) and standing on the laser bench. The presence of this component was already foreseen in the original Virgo design. Recently it has been decided (virchrq0022006) to reduce the PMC finesse (down to 500), thanks to the increase of the interferometer contrast (only 50 mW on dark fringe instead of 1 W foreseen at the very beginning). This change should also permit to use the same PMC in the Virgo+ configuration, when a 50 W laser amplifier will be installed.

The installation of this device is, obviously, affected by the commissioning evolution, but the realization has been already supported by EGO.

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

2.4.2 Acoustic shielding of the main Virgo external benches

Acoustic cross-talk in the Virgo dark fringe signal has been identified during the commissioning run C5 (and later). A noise entrance path has been identified in the optics of the external injection bench in the Laser lab and in the terminal benches (end buildings). A solution for the injection bench has been already identified and an acoustic shielding coverage has been studied and ordered. This activity is described in the commissioning document. After the understanding of the performances of this acoustic isolation, the realization of similar shielding frames is foreseen for the terminal benches.

Name	Acoustic isolation in the laser lab
Code	
Documentation	
Responsible	F. Fidecaro

2.4.3 Eddy current thermal noise reduction

If all the control noises actually limiting the sensitivity of the detector at low frequency will be reduced to the design value, the main noises in Virgo, between 4 and 100 Hz will be the “pendulum” thermal noise, where the eddy current dissipation component could have an abnormal value because the actuation magnets on the mirrors and the reference masses (RM) don’t respect the design requirements. Too strong magnets and aluminium reference masses (RM) have been used in the Virgo construction. The main solution to this problem is the replacement of the aluminium RM with stainless steel RM and the reduction of the actuation magnet strength. This solution is not compliant with the Virgo+ requirements and it is really expensive in terms of money and time costs. In fact in Virgo+ a dielectric reference mass is necessary to null completely the eddy current dissipation. For this reason a quick patch has been investigated and suggested; the current Virgo mirror magnets can be covered with ferromagnetic hats, to drive the magnetic field lines far from the RM metal. Preliminary tests suggest that a reduction of the eddy current problem, down to a factor 10, is possible.

Name	Eddy current reduction in the reference masses
Code	Virchrq0062006
Documentation	http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0062006.html
Responsible	M. Punturo

2.4.4 Replacement of the Virgo MC payload

In the current ISYS system a large fraction of the injected power is lost. The exact amount of losses must be still determined, but the most probable responsible is the MC end mirror, because of its large scattering and poor quality substrate. A new substrate, having the same geometry of the current mirror, has been sent to the polisher, but many experimental facts pushed to investigate the possibility to replace the current mirror (and consequently the full payload) with a heavier one. In fact, the current mode cleaner mirror is realized with a substrate of 80 mm diameter and about 31 mm thickness; this mirror is so light that the radiation pressure effects are easily visible in the MC and instabilities can occur. Furthermore the entire payload is very light, enhancing all the control issues of the MC. Two scenarios are possible; a minimal one, where the MC mirror will be replaced by a similar size substrate and a more advanced one, where the MC mirror will be substituted by a heavier mirror. Since the second option seems also preferable in the Virgo+ case, and since the impossibility to correctly control the MC payload is still not confirmed, it has been decided to continue with the production of the few elements needed in the small payload scenario (with the aim to be ready for a quick replacement, if needed) and to deeply evaluate and prepare the heavy payload replacement, to be in time with the Virgo+ upgrade.

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

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

Due to lack of spare parts, new quadrant diode (QD) front end modules for use in the Virgo Linear Alignment system (LA) must be fabricated. At this occasion, some improvements in the performance should be obtained for overcoming presently felt limitations, while maintaining full compatibility (interchangeability) 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. Computing the noise budget for LA reveals that it might not be possible to operate all QD with sufficient light power in order to overcome the intrinsic noise of the electronics (e.g. the dark fringe QD). So reducing the electronics noise is desirable and it is reachable by a newer electronics, with lower thermal drifts, possibly based on InGaAs quadrants.

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

2.4.6 New Virgo Control and DAQ electronics

New Read-out and DAQ electronics The full upgrade of the Virgo electronics is foreseen to solve several problems. The main ones are:

- Obsolete electronics with limited number of spares part. The modules have been built more than 10 years ago and several electronic components do not exist any more. This puts a high risk on the maintenance of the detector and limits also the extension of the number of channel sometimes needed to handle more complex control strategies.
- Limited bandwidth: to provide more stable control, feedbacks with good phase margin are needed. The delay between the sensing and the actuation of the main control loop that run at 10 kHz is about 0.5 ms given the current pipeline of readout, processing and actuation. The new system with a faster bandwidth (faster clock and/or less elements in the pipeline) is needed.
- Limited computing resources: the more demanding control strategies for the locking and alignment have pushed the computing elements (DSPs and VME CPUs) of the Virgo control system to their limit. This computing limit is set not only by the processor clock but also by the data transfer speed between elements taking part of the available time. A new design will provide faster bus and processors.

To address these issues, an R&D activity has been started a few years ago. The scope of this R&D was to design new electronic modules and start the software development for this upgrade. This activity includes:

- A new timing system with the distribution of the GPS signal, more compact module and a reduced phase noise with two operation mode (slaved clocks or straight distributed clock signals).
- New communication modules (TOLM) to replace the Digital Optical Link modules and the current timing boards. The prototypes achieved a 10 times faster throughput; provide a PCI interface, link ports for DSP direct access and a more compact design.
- Faster ADCs with more dynamics (A 18 bits ADC running at 800kHz is under test)
- More analog conditioning modules
- The replacement of VME CPUs by PC's running under a real time Linux operating system.

This development phase is close to be completed. A full integrated test is needed in the coming months before deciding on the detailed layout of the final architecture and the number of boards/modules of each type to be produced.

Name	New Control Readout and DAQ electronics
Code	
Documentation : R&D report for the STAC	
Responsible	LAPP

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 coil drivers are disconnected, if not used, when the lock is acquired or large resistors are inserted to reach a low noise operational condition. This *ad hoc* modification has been engineered in the new Virgo coil drivers, where two different sections are foreseen for the high power and low noise conditions. In addition, a further noise reduction is foreseen with the introduction of a emphasis/de-emphasis filtering procedure The use of these coil drivers (whose production is foreseen for the end of 2006), with the appropriate force suppression resistor, will permit to reduce the actuation noise below the Virgo nominal sensitivity.

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

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.

Name	New DACs
Code	
Documentation	
Responsible	A. Gennai

New DSPs

The achievement of the Virgo sensitivity at low frequency is not only matter of having low noise hardware, but it is necessary to utilize several sophisticate digital filters to control the payloads. The computational and memory load of the current control and alignment filters have already pushed the utilization of the DSP resources at the limit. For this reason it has been already decided a series of steps that should transfer part of the computational load, related to the alignment procedures, into the Global Control environment. The computational load in the "Damping" DSPs will be reduced transferring to the DAQ the anti-aliasing filtering. These steps will free enough resources to realize the required low noise control strategy at low frequency; nevertheless it is obvious that more computational power is and will be necessary for any further control noise reduction at low frequency. For this reason a long term R&D has been started few years ago with the aim to realize new DSPs with an order of magnitude larger computational power. This R&D is now in a final phase, and the first DSPs can be delivered at the beginning of 2007. This permits the possibility to evaluate the progressive insertion of these machines in the ITF control chain, if needed, slightly before the Virgo+ upgrade.

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

3 Commissioning report

3.1 Outline

Following the classification given in the previous commissioning plan, this period was mainly dedicated to the c*ommissioning of the new injection bench* and to the *interferometer restart*. Furthermore some commissioning activities classified as *completion of recycled interferometer commissioning* were performed.

The commissioning of the new injection bench is described in section 3.2. A first beam entering in the interferometer was delivered in January 2006. From January 2006 to April 2006 we started to work in parallel: improving the beam quality and restarting the interferometer controls.

The cavities have been locked during the second half of February and the new power recycling mirror mechanical transfer function has been also measured. The re-lock of the interferometer is described in section 3.3. The interferometer was fully relocked at the end of March, after some improvements of the second stage of the frequency stabilization, and some modifications of the variable finesse technique.

In order to solve some locking instabilities we decided to improve the astigmatism of the beam and to check the beam centering on the mirrors (section 3.4). At the end of this activity, in early May it was possible to lock the interferometer with a 7 W input power, and 280 W internal power, 10 times more than before the shutdown.

Since then, the commissioning has been slowed down by not understood instabilities. Three explanations could be possible: thermal lensing effects, as described in section 3.5, incomplete auto-alignment system, still under commissioning, or some other spurious effects (beam clipping, diffused light,…). On the other hand the commissioning of the automatic alignment is heavily affected by the short locking time available (<5 minutes). The instabilities also limit the possibility to perform some systematic attempts to measure a new sensitivity curve, and to start some noise projections.

Several activities took place in parallel with the ones described above: the new injection system alignment scheme (section 3.6), the improvement of the suspension control (section 3.7) and some electronics, software and automation upgrades (section 3.8).

Conclusions and short term plans are given in section 3.9.

Appendix A contains a schematics of the new injection bench, and appendix B a schematics of the new injection system alignment.

3.2 Commissioning of the new Injection Bench

3.2.1 Local controls restart

See appendix A for a schematics of the new suspended injection bench

The new suspended injection bench (SIB) was installed in the tower at the beginning of November. The first activity planned was the restart of the local controls of the bench.
Before to start a real re-commissioning of the local controls, mechanical and alignment adjustments have been performed, the most important of which are:

- positioning of the IB ground coils (to be adapted to the new SIB shape)
- positioning of the local control target on the bench (its alignment had to be tuned carefully)
- centering of the upper part of the suspension (to be tuned considering the weight of the bench)
- rough alignment of the bench (the dihedron had to be aligned with respect of the MC mirror), which, owing to the presence of the Faraday isolator, was made difficult by the impossibility to use a former alignment HeNe beam. The alignment of the optics of the SIB was roughly checked sending the Nd:YAG beam directly through the IMC dihedron with the polarization turned by 90°, then placing a $\lambda/2$ waveplate before the Faraday isolator in order to have light transmitted through it.

At mid of December the SIB was locally controlled and roughly aligned (within 1 mrad) with respect to the mode-cleaner mirror (at 150 m), the entire input mode-cleaner was put in vacuum.

3.2.2 Mode-cleaner alignment and lock

The alignment and locking of the IMC took about two weeks: the input Nd:YAG beam was steered from the External Injection Bench (EIB) in order to centre the dihedron mirrors and to send the direct beam to the MC mirror. Then the MC mirror was steered until cavity resonances were detected.

At end of December the IMC was locked and the optics of the suspended bench could be remotely aligned.

During this phase a picomotor of the steering mirror M4 (centering of the parabolic telescope) stuck, and the centering of the photodiode (DPS) measuring the power transmitted by the IMC resulted not centered. This problem required a venting of the tower and an in-air operation. In this circumstance the mount of the mirror sending the light to the DPS, which was fixed, was replaced with a motorized one. After the replacement of the M4 motor it was possible to centre the parabolic telescope, to send the beam into the interferometer and to align the suspended cavities. At beginning of January either the North, West and recycling cavities were aligned.

Several different measurements of the power transmitted by the mode-cleaner yielded an output power of about 7 W.

3.2.3 Reference cavity alignment

In the month of February the alignment of the SIB was completed by aligning and locking the Reference Cavity (RFC). Differently from the old SIB, the beam arriving to the RFC is picked off from the IMC transmission, after the Faraday isolator.

Its alignment resulted more difficult than expected.

More than one week was spent trying to remotely align the RFC optics using a probe YAG beam, coming from the upper stage of the SIB, superposed to the main beam. Then the probe beam was sent from the opposite direction, through the reflection port of the RFC. After several days of trials it came out that the position of the RFC was different than what expected. This required entering again into the tower to rearrange the mirrors sending the light to the RFC and its collimating telescope, since the misalignment (several mrad) was beyond the dynamic range of the remote actuators.

One explanation for these alignment difficulties of the reference cavity is that, during its dismounting and remounting operations, the ULE block has slightly moved inside its tank.

In the last week of February the main beam was remotely aligned on the RFC by overlapping the inverse path probe YAG beam (coming out through the ITF reflection port) with the beam reflected by the PR mirror in the aligned ITF configuration. This operation eventually led to the RFC alignment: the first contrast was 56%, which was lately improved (thanks to improved matching and alignment) to 75%, comparable with that before the shutdown. The long term locking stability of the RFC results better than the previous one, allowing to operate for months without the necessity of a RFC automatic alignment (this is the main advantage of having the RFC locked on the IMC transmission). This automatic alignment implementation has however already been partly implemented and it is planned to be restarted anyway.

On the other hand, it came out that the mirror (M17) sending out of the tower the RFC transmission was incorrectly aligned. Since it is fixed, this will require a realignment entering into the tower. This operation is planned for the week of June 5th.

3.2.4 Frequency noise reduction and Faraday optical isolation

After the restart of the activity on the ITF, owing to a new tuning of the SIB local controls (due to the different SIB mechanical transfer function), the frequency noise resulted too high (~100 Hz RMS instead <10 Hz).

In order to reduce the frequency noise, the IB local control filters were optimized. Some residual low frequency noise couldn't be completely cancelled: it is expected to improve with the optimization of the SIB automatic alignment. The MC-RFC locking filter was also optimized, according to the new optical setup (RFC after the IMC instead of before it). These two operations (SIB LC improvement and RFC filter optimization) led to a frequency noise roughly of the same level as in C7.

The beam back reflected from the PR, when the PR is aligned, does not prevent any more the locking acquisition, thus confirming the effectiveness of the Faraday isolation. Even if an exact quantification of the back reflection reduction is difficult to obtain, this factor is surely larger than 200. More investigations are on going on this item.

3.2.5 Beam matching and astigmatism improvement, parabolic telescope tuning

The last operation which involved significant activity on the new SIB optical alignment was related to the beam matching and astigmatism improvement. The parabolic telescope had been aligned in air, before mounting the SIB, with an expected tolerance of about 1 mrad with respect to the ITF axis. When sending the beam into the ITF it turned out that actually the last parabolic mirror (M6) had to be steered, with respect to the perfect aligned position, by about 850 μrad in θy and 650 μrad in θx, in order to have the light centered at the end mirrors. This misalignment resulted in an astigmatism of almost 10% (different x and y waists dimensions and positions). Another source of astigmatism was a (vertical) miscentering by about 2 mm of the IMC output beam from the centre of the first short telescope (T1), used to collimate the 5 mm waist of the IMC to the 2.65 mm waist beam passing through the Faraday isolator. In order to correct this, the bench was first raised by about 2 mm, this resulting in the centering of the IMC with T1, and then the SIB was turned, both in θx and in θy, following the IMC alignment by turning the input beam. In this way it was possible to put back the M6 mirror to the aligned position and at the same time align the ITF. All these operations, besides improving matching and astigmatism, were performed improving the centering of the suspended mirrors (see section 3.4). An advantage of the present setup resides in the possibility to perform beam translations and angles directly from the SIB, getting rid of the lens effect of the previous PR mirror.

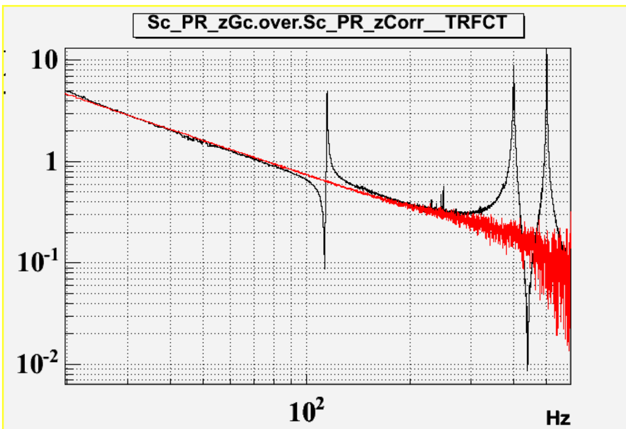
At the end of these operations the mismatching beam-ITF, due to residual astigmatism, was measured as being of the order of 4%. It could be improved by better centering the beam vertically on the parabolic telescope, this being prevented for the moment by the need not to change the vertical position of the beam on the suspended mirrors, and optimising the M5-M6 distance (using the mirrors' remote actuators). This improvement would require a raising of the SIB and of the input beam by more than one cm. Measurements and computations show that the SIB can be operated, with an M5 vertical off centering of 2 mm (about 1.5 cm on M6) without spoiling the ITF matching by more than 1% (it must be noted that M6 design diameter is 4.5" (114.3 mm), that is 15 mm more than the safety margin of 5 times the beam waist on that mirror. This is important in order to allow off-centering, at least by the point of view of diaphragm or diffraction effects).

The activities remaining to be done connected with the commissioning of the injection bench are;

- Beam-ITF fine matching
- Complete RFC automatic alignment restart
- Realignment of M17 (planned the week of June 5th)
- Fixing of SIB Marionette-Filter 7 touching and improving SIB balancing (planned also for the week of June 5th) (a mechanical contact has been found, between marionette and filter7, this leads an excess of seismic noise in presence of bad weather conditions.

3.3 Interferometer re-lock

At the end of January the reference cavity alignment was still not optimized, and the frequency noise was very high (>100 Hz RMS), more than one order of magnitude above the specifications, but low enough to lock the central interferometer and the single 3-km cavities. The cavities were locked without difficulties and their pre-alignment system using the quadrants on the transmitted beams was restarted. The lock of the central cavity has been made as intermediate step for the preparation of the full lock, but it was also useful to measure the transfer function of the new monolithic power recycling mirror (see figure below).



Red: new monolithic power recycling
Black: old composite power recycling

The use of a monolithic mirror was proven to be very helpful: before the change the notch-peak pairs, due to the composite mirror structure, needed a special compensation in order to avoid loop oscillations, especially during lock acquisition, due to the wide gain loop changes induced by the optical gain variations during transitions to the dark fringe. Since the frequency of these structures was drifting, continuous readjustments of the compensation filters were necessary.

Once the frequency noise reached roughly the C7 level (<10 Hz RMS) it was possible to fully re-lock the interferometer, with the variable finesse technique.

The biggest efforts during this phase were made to re-start the second stage of the frequency stabilization and increase its robustness (a weak point before the shutdown). The change of the optical gain during lock acquisition should be compensated with an inverse change in the SSFS electronic gain. This operation was done before the shutdown with 2 gain switches remotely controlled. During the interferometer re-lock we increased the number of gain switches, leading to a gain dynamics higher than 1000. This allows to use the SSFS in the complete range from a single cavity to the fully locked interferometer (which corresponds to an increase of power of 800, considering the reflectivity of the new power recycling mirror).

Thanks to this improvement, now the SSFS can be engaged at the very beginning of the locking acquisition with the PR mirror strongly misaligned (by 150 microrad). The common motion of the arms (the one at which all photodiodes are most sensitive) is frozen at the very beginning of the locking procedure, essentially in a configuration similar to the recombined interferometer. The PR is then realigned, and the interferometer is brought on the dark fringe.

Once the interferometer was locked on the dark fringe several stability problems were observed:

a) jumps in the interferometer internal power, of the same type of the ones observed before the shutdown with some tuning of the demodulation phases,
b) drifts in the mirrors alignment, which were discovered to be connected with heating of the mirrors wires (mainly beam splitter).

In addition, a clipping of the beam on the detection Brewster window was discovered (see next chapter).

In order to solve these problems, or at least to understand better the interferometer behaviour we decided to stop the interferometer re-lock activity and to improve the shape of the beam (still astigmatic, with a coupling with the cavities lower than 90%). For reasons already explained in chapter 3.2. this operation was performed in parallel with centering of the beam itself on the mirrors.

3.4 Astigmatism improvement and beam centering on the mirrors

This astigmatism improvement was planned after a complete restart of the interferometer, but for the reasons explained in the previous section, we decided to anticipate it to the second week of April.

As already explained in section 3.1, in order to fix the astigmatism of the beam one should move the position of the beam itself with respect to the two telescopes (T1 and the parabolic telescope T2) of the injection bench. This leads to a vertical shift of the beam inside the interferometer.

A simulation of the propagation of the beam through the SIB telescopes showed that fixing the astigmatism would also reduce the clipping discovered on the detection Brewster window.

A clipping of the beam was in fact discovered on the Brewster window between the interferometer and the suspended detection bench, discovered through the image of the diffused light on the detection bench optics (see figure below).

Clipping on one of the detection bench mirrors (on the left). During this data taking the interferometer is locked on the dark fringe and slightly misaligned in vertical direction.

Experimental evidences led to the conclusions that this clipping was already present before the shutdown. It was probably not discovered before because of the small amount of light present inside the interferometer. Geometry measurements with teodolite are being performed to understand the reason of this clipping..

The evidence of this clipping led to the decision to test, in parallel with the astigmatism removal, the centering of the beam on the various interferometer mirrors. The measurement of the coupling of angular control noise to the longitudinal degree of freedom was performed during previous commissioning runs and pointed to a beam miscentering of 1 to 2 cm in the central area. This operation was already planned after the interferometer restart, in order to decrease the angular→length couplings, and then decreasing the noise of the angular controls.

The check of the beam centering was performed in 2 ways:

a) by visual check, looking the diffused light on the mirrors
b) measuring the angular→longitudinal coupling

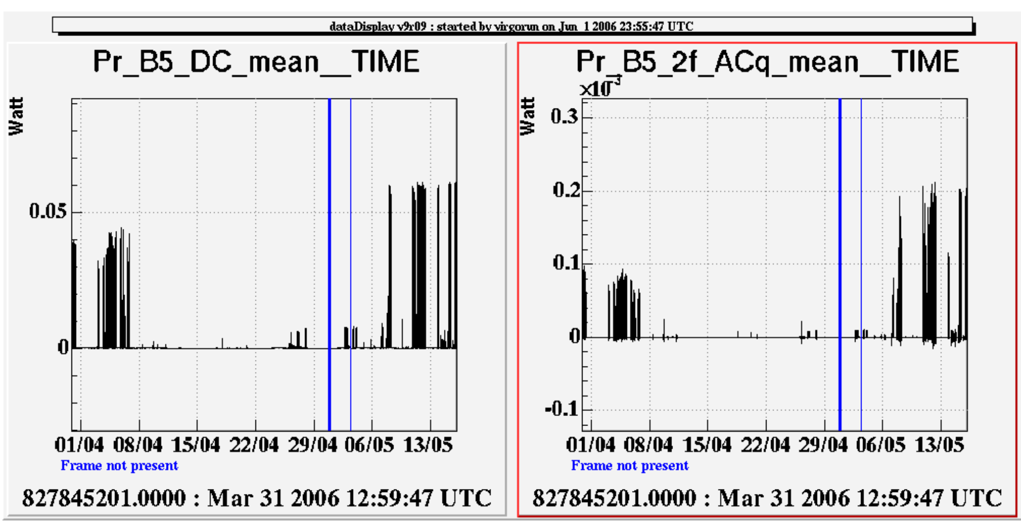
Between the beginning of this operation (beginning of April) and its end (beginning of May) the beam was raised by 1-1.5 cm, acting on the injection bench mirrors (a precise estimation is difficult since no centering measurement were performed before). At the end of this operation the beam was vertically centered on all the mirrors in the central area with a precision of a few mm with the exception of the input bench where the beam is high on the last mirror of the telescope by about 1.5 cm.

Due to the new input beam position, 14 mm spacers were put below the first two optics of the suspended detection bench to center the beam on these optics. This required a venting of the detection tower.

The absence of experience with these measurement techniques, and the iterative nature of the process between beam centering and astigmatism removal (through the displacements of the injection bench mirrors) made this overall operation roughly 1 month long.

After the astigmatism removal and beam centering, several results have been obtained:

a) the wire heating of the beam splitter almost completely disappeared.
b) "jumps" disappeared.
c) it was possible to obtain a max recycling gain for the carrier ~ 40 (30 before the centering) and a max recycling gain for the sidebands ~ 30 (15 before). With a 7 W input beam and a recycling gain of 40, the interferometer stored power is then ~ 280 W. See figure below.
d) The matching with the cavities increased from 88% to 96%



Trend of data before and after the mirror centering: the left plot is the carrier stored power and the right plot is the sidebands one. After the centering (at the beginning of may), the carrier power increased by a factor 1.5 and the sidebands power by a factor 2.

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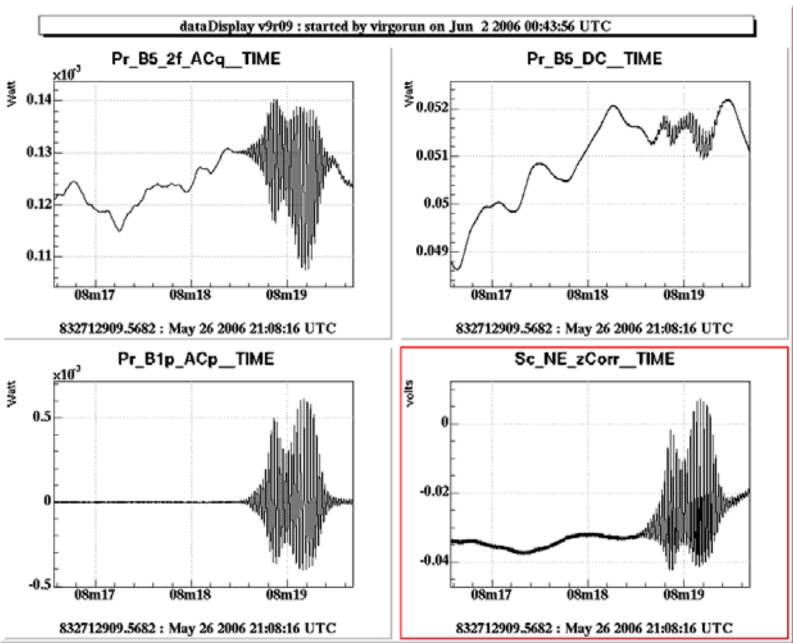
3.5 Interferometer signals oscillations

After the beam centering on the mirrors, new interferometer behaviours were discovered: temporary (lasting ~1 s) oscillations on the interferometer error and control signals, typically between 30-50 Hz, which often unlock the interferometer, and which start few minutes after the interferometer lock (see figure). These oscillations are not yet understood.

Some hypothesis for these oscillations are the following

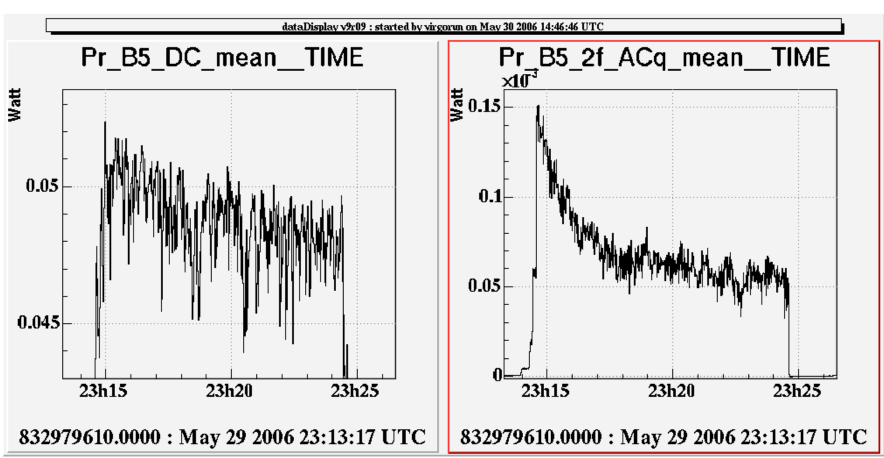
1. Thermal lensing effects
2. Incomplete automatic alignment
3. Other spurious effects (i.e. clipping, diffused light)



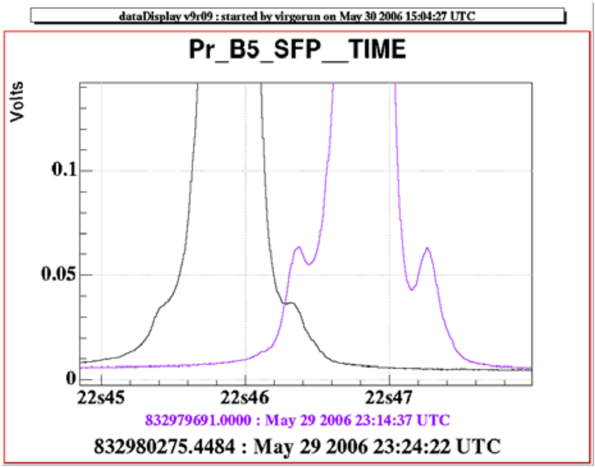
Typical interferometer Oscillations in the region 30-50 Hz in the sidebands power (upper left), carrier power (upper right), differential arm error signal (lower left) and differential arm control signal (lower right)

3.5.1 Thermal lensing evidences

Preliminary evidences of thermal lensing effects (already observed in LIGO) have been seen in term of exponential decrease of carrier and sidebands powers.



Carrier power (left) and sidebands power (right) over ~15 minutes of lock.



Another (more direct) measurement of the sidebands decrease: optical spectrum taken with a scanning Fabry-Perot on the pick-off beam of the interferometer (B5), at the beginning of the lock (purple) and at the end (black). The big peak is the carrier, and the small lateral peaks are the sidebands.

Some preliminary simulation confirm that the effect should be much more important for the sidebands because these fields resonate in a flat-flat cavity only (the recycling cavity) and not in the long arms. This is exactly what is measured (decrease of a factor 4 of the sidebands and of 10% of the carrier). Other simulations of the thermal change of the mirror curvature show that this effect is not excluded with the Virgo mirror absorption levels; a more careful analysis is in progress.

The connection between the thermal lensing and the interferometer instabilities could be explained as a progressive deformation of the sidebands wavefront inside the recycling cavity, and then to an enhancement of the sidebands sensitivity field to misalignment. This can give bad superposition carrier-sidebands, and then a temporarily instabilities of the locking loops.A decrease of the power by a factor 3 (planned in June) should help to understand better these effects.

3.5.2 Automatic alignment

If the thermal lensing couples with the interferometer global alignment fluctuations, the automatic alignment should also increase the interferometer robustness.

Unfortunately the difficulty to achieve long lock periods heavily limits the commissioning of the automatic alignment, which requires preliminary measurements of the sensing matrix. However some long locks allowed to control 5 out of 10 alignment degrees of freedom with the full bandwidth. Unfortunately no improvement in the interferometer stability was observed: the typical locking time is still limited to a few minutes. If the hypothesis of interaction between thermal effects and alignment fluctuations is correct, the decrease of power should also help to commission the automatic alignment system.

3.5.3 Spurious effects

A third possibility for the oscillations is the presence of spurious effects (i.e. beam clipping or diffused light). The diagnostics of these effects is very difficult and there are no clear plans up to now to understand better this point.

3.6 New injection system alignment

See appendix B for a schematics

We took the occasion of the new input bench integration to implement a new automatic alignment scheme for the injection system. The main constituents of this system are: a beam monitoring system, used for input beam autoalignment with respect to the external injection bench; an autoalignment system acting on the injection bench (new) and on the curved mode cleaner mirror (unchanged); and a new autoalignment system for the reference cavity. With this system, all possible misalignments between Input Mode Cleaner, input beam and reference cavity are controlled, as opposed to before, where for some degrees of freedom we relied on the internal mechanical stability of the injection bench for keeping the initial alignment.

Basically, the main input beam is now clamped with respect to a reference system (Beam Monitoring System, BMS) on the external injection bench, before entering the Input Mode Cleaner (IMC). All IMC alignment degrees of freedom are controlled using 6 correction signals, of which 4 go to the IB, and 2 to the mode cleaner curved mirror.

The next step, not yet implemented, will be to use pointing information given by the quadrant photodiodes behind the Virgo end mirrors, to "adjust" the BMS mechanical reference (adding the relevant offsets to the BMS error signals) and, hence, pointing the main beam towards the North end mirror centre.

In parallel, the Reference Cavity (RFC) is kept aligned by adjusting the tilts of the mirror driving the beam towards RFC, using wavefront error signals as in the scheme before the shutdown.

3.6.1 Beam Monitoring System (BMS)

The BMS optics has been installed in its final configuration at the end of 2005; it allows monitoring the 20 W beam position with respect to BMS quadrant photodiodes, in terms of beam shift/tilt. The beam position can be corrected using 2 piezo-mounted mirrors, which are located on the laser bench and on the external input bench. A digital servo loop keeps the beam clamped with respect to the BMS quadrant photodiodes, which act as position reference for the beam. This loop is running continuously since January 2006.
The optical setup, based on near/far field monitoring, gives an unambiguous correspondence between beam shift/tilt and BMS error signals; as a result, one can easily steer the beam entering the IMC, playing with error signal offsets (this has been widely used for injection bench alignment purposes). The unity gain frequency of the BMS loop is set to 0.1 Hz (it can be as high as 50 Hz).
The BMS allows also the direct monitoring of the beam jitter noise.

3.6.2 Reference Cavity (RFC)

The RFC pre-alignment has been achieved in February 2006. The RFC is needed as a reference for the IMC length in order to reduce low-frequency length fluctuations to a level where the SSFS can be engaged; therefore, a perfect alignment is not required. Anyway, we made one attempt to install an RFC automatic alignment, such as the one we had before the

shutdown; this attempt failed due to a quadrant photodiode hardware failure (repaired successively).
Major changes with respect to the previous autoalignment system concern the location and characteristics of the piezoelectric actuators, and a different method of mode matching.

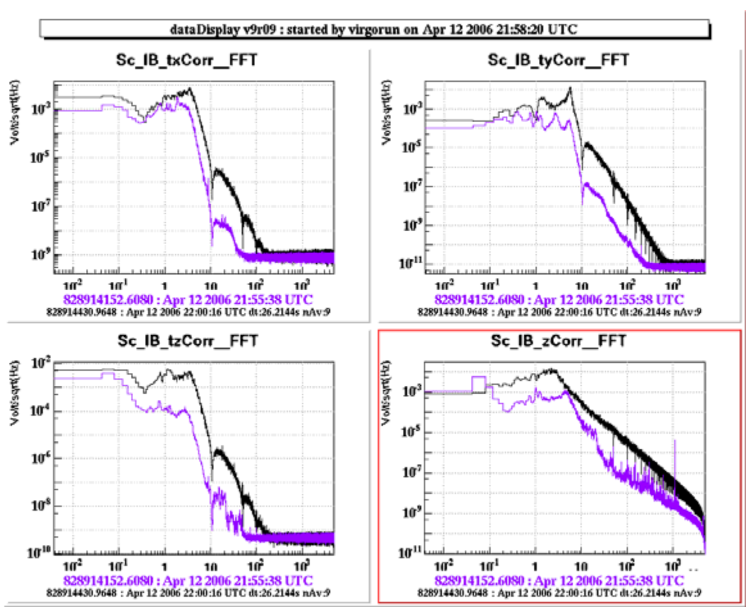
3.6.3 Injection bench autoalignment

Before the shutdown, the suspended injection bench was controlled in 6 degrees of freedom by a local control system based on a camera and HeNe beams as optical levers. The new system foresees an autoalignment system for 4 degrees of freedom of the IB using signals coming directly from the resonating YAG beam.

The present configuration uses two wavefront error signals which before the shutdown had not been used (the other two were and are used for autoalignment of the MC mirror); they control the IB_z translational movement (in direction of the IMC axis), and the IB_θz rotation (around the z axis). IB_θx and IB_θy rotational degrees of freedom are controlled by DC error signals delivered by a quadrant diode located behind the MC mirror (142m far away).

The wavefront error signals depend only on the relative alignment between beam and IMC and not anymore on possible drifts of the measurement setup itself (as in the case of local control); the two DC signals can be considered as local control systems, but with a lever arm of 142 m instead of 1-2 m as in the case of the local control HeNe beams. In both cases, one should not be limited anymore by the monitoring system.

As a result the IMC is guaranteed to be always perfectly aligned on the beam, and the measurement noise is about 2 orders of magnitude lower than before.

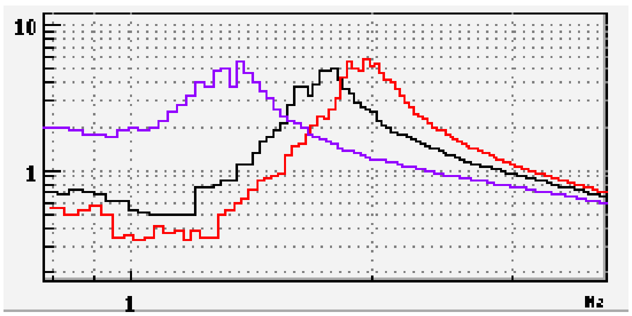


Correction signals for the four degrees of freedom concerned by the new IB autoalignment system (first attempt of implementation). Black: IB under local control; blue: IB under autoalignment.

3.6.4 Mode cleaner curved mirror autoalignment and radiation pressure effects

The autoalignment system for the curved mode cleaner mirror is in principle unchanged with respect to before the shutdown. However, some problems with instabilities in the so-called low noise mode (where the loop bandwidths are only 1-2 Hz) led us to re-measure the mechanical transfer functions used for the loop design. We found that the resonance frequencies of the mirror suspension changes very strongly between the state with and without light in the IMC, so that in the locked state the control was close to instability; in the θx degree of freedom, the resonance frequency decreases (from 2.17 to 1.96 Hz), whereas in θy it increases (from 1.27 to 2 Hz).

Simulations showed that this change can be precisely explained by the additional forces acting on the mirror due to radiation pressure (optical torque). The effect is very strong due to the very small dimensions (30 mm thickness, 80 mm diameter) and the low mass of the mirror. The new autoalignment correctors take into account the resonance frequency shifts.



Zoom on the transfer function of the θy (yaw) degree of freedom of the mode cleaner mirror. The measurement was made with zero (purple), 70% (black), and 100% power in the mode cleaner cavity; the resonance frequency shifts correspondingly.

3.7 Mirror suspension control

The MSC activity in the last months has been dedicated to:

1. improve the seismic noise rejection in the inertial damping strategy;
2. improve the decoupling of angular and translation modes at the level of the payload.

Both the actions pursue a common goal: to ease the angular control of the mirrors, make possible to reduce the bandwidth of the automatic alignment loops and, therefore, to reduce the control noise in the detection bandwidth.

1. The frequency at which the position and inertial sensors are blended has been lowered down to 30 mHz on all the suspensions. To make this possible we successfully subtracted the cradle effect that messes up the accelerometers signals at low frequency using the position sensors signals. This allowed to reduce the seismic noise re-injected in loop by a factor 10 at the frequency of the microseismic peak. We understood that a further reduction of the blending frequency is useless since the input noise at very low frequency is dominated by the tilt of the soil.

2. The frequency dependent driving matrices used to act upon the marionettes have been improved achieving two goals: reducing the number of zeros and poles thus reducing the DSP load; reducing the excitation of the angular d.o.f. of the mirror observed when the locking force is reallocated upon the marionette.

3.8 Electronics, software and automation

Several upgrades were made on the software packages used by the different interferometer sub-systems. Here below a list of the main ones.

3.8.1 Injection system

A common server managing all newly installed actuators (PicoMotors, Piezos, Translation Stages) of the new injection bench was put in operation.

3.8.2 Global Control

In order to reduce the elapsed time in the critical control loop and to allow performing more complex locking algorithms a new architecture was developed with:

1. Parallelization between the data transfer and the data processing
2. Algorithms optimization

This new architecture should be tested as soon as stable interferometer configuration is reached.

3.8.3 Detector Monitoring

Using the channels sent to the DAQ by each server is now possible to monitor the state of all Virgo subsystems. A centralized interface for the operator based on PHP technology has also been developed integrating the information coming from the DAQ based monitoring and other monitoring tools like BigBrother.

3.8.4 Standardization of GxS version for IB tower.

The long pending problem of a customized and obsolete version of the Galaxy Server running on the IB tower has been solved and now all long and short towers are running the a unified version of this software.

3.8.5 Suspensions

- The EServerDSP latency and reliability was improved
- New digital filter algorithm was implemented
- DOL readout time was decreased from 5μs to 1.2 μs
- The Vertical Control architecture has been changed so that vertical LVDTs are acquired directly by the DSP and no more forwarded by another server.

3.8.6 LabView User Interfaces

LabView was introduced as a tool to provide common front-end for Interferometer Monitoring and Control. We developed the blocks needed for LabView integration into Virgo environment, as bridges with the Cm Communication Layer and the DAQ chain. We provided Engineering/User interfaces for the Injection Subsystem and some general purpose graphical user interfaces (GUI) like the Debug Logs Interface.

3.8.7 Data acquisition (DAQ)

- DAQ Latency at Automation was improved, now is less than 2 s
- DAQ servers are less sensitive to the NFS data accesses
- Shared memory management was improved and this fixed a problem of data losses.

3.9 Conclusions and near term plans

The injection bench commissioning is almost completed: the beam delivered is ~7 W, matched at 96% level with the 3-km cavities. Further improvements in the matching are possible and planned in the following months. The new injection system alignment scheme has been implemented.

The interferometer has been locked for tens of minutes, with a maximum carrier recycling gain of ~40 (within 10% from the expected value) and a maximum sidebands recycling gain of 30. The internal power is ~280 W, more than 10 times the power before the shutdown, and less than a factor 2 with respect to the design.

The new power recycling monolithic mirror solved the problem of mechanical resonances in the region 100-500 Hz, and the increase of its reflectivity seems to be compatible with the current lock acquisition scheme.

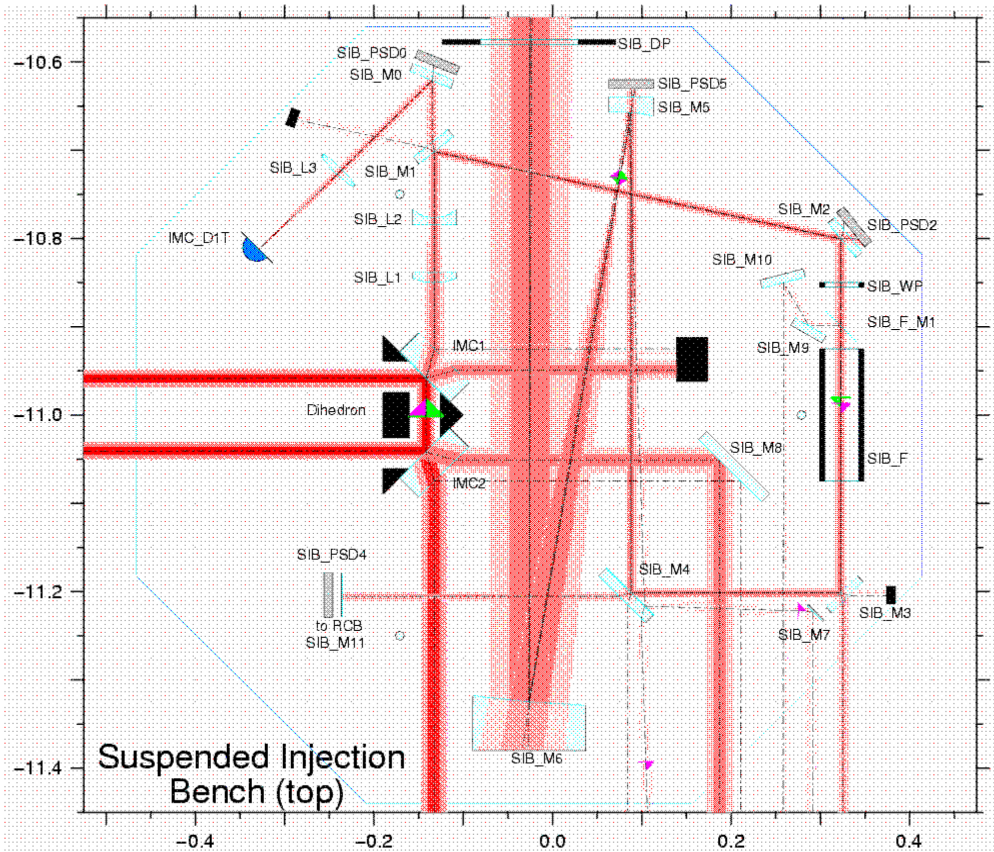
Locking instability problems, through not understood interferometer signals oscillations, limit the speed of the commissioning activity. Possible reasons could be thermal lensing of the mirrors, incomplete auto-alignment system (5 loops over 10 closed), or other spurious effects.

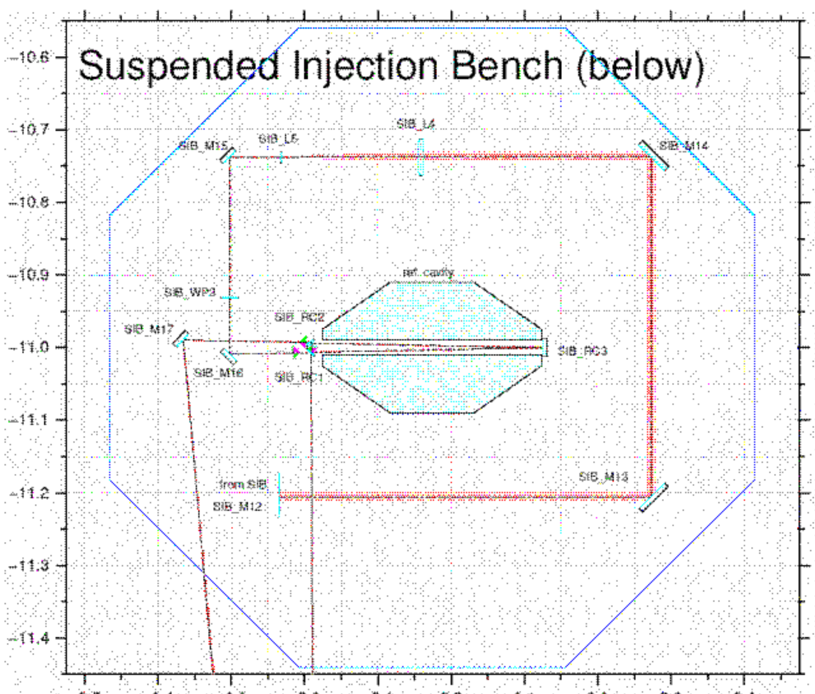
The two priorities now are to increase the locking robustness, and to finish the interferometer automatic alignment. Once the locking stability will be increase also noise hunting can be restarted.

A temporary decrease of the laser power by a factor 3 is planned in the following weeks. At the same time a simulation work about the thermal effects and a more careful analysis of these oscillations, and in particular of their relationship with the interferometer global alignment, is planned.

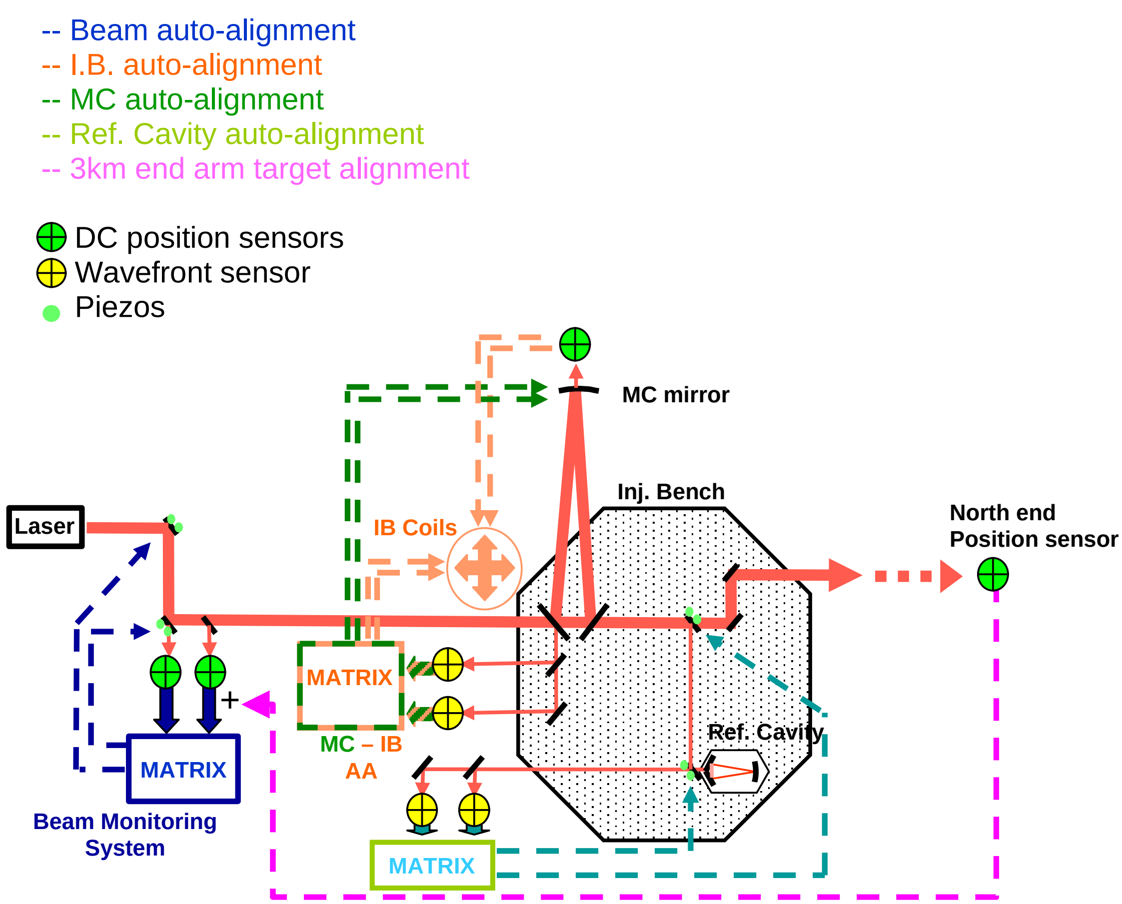
Longer terms plans are contained in: “commissioning plan update, June 2006”

3.10 Appendix A: new injection bench schematics





3.11 Appendix B: new injection system alignment schematics



4 Data analysis report

4.1 Virgo at the Computing Centers.

Let us recall that the off line computing for Virgo is performed in part in Cascina and mainly in the two computer centers of INFN and IN2P3 located in Bologna and Lyon.
The data taken during the runs are transferred to the computer centers via network at 3 Mbytes/s. After a tuning period, now the transfer requires less operator assistance and few manual checks. The set up of a fully automatic procedure for the data transfer EGO --> Bologna --> Lyon and the development of a book-keeping data base is in progress. In view of this effort tests based also on Grid tool already available at the computer centers is on the way.
Before to summarize the resources used by Virgo in the two places, we need to recall that the two computer centers use different units for accounting 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

4.1.1 Virgo at INFN Tier1-Bologna

Storage status : 29 Tbyte of data. Data related to the runs from E0 to C7 plus the 50 Hz trend data, are stored on disks. In these days we are moving the runs from E0 to C1 from the NAS disks to the buffer disk of Castor.
For the CPU time we used up to the end of May 3672 kSI2000.day (our request for 2006 is 7000 kSI2000.day)
Data Processing:
1)1 computing node ui02-virgo.cr.cnaf.infn.it fully dedicated to data transfer access, to the CNAF farm via ui01-virgo.cr.cnaf.infn.it interface. The farm works as a Grid farm but is also available for submitting jobs via the standard job scheduler LSF.
The Virgo software installed here is synchronized periodically to the Cascina version. At present we have the version VCS 4.0.

4.1.2 Virgo at CCIN2p3 - Lyon

Until this date the main use of the computational resources is done by submitting jobs via standard batch queue. We tested also the Lyon Grid access and we are discussing how to improve this access and solve the present technical difficulties. We summarize the Virgo resources used in Lyon:
Storage:
27 TB used in HPSS by Virgo (E0 –C7 run)
Data Processing:
use of the CPUs: up to the end of May 2700 kSI2000.day (our request for 2006 is 6000 KS2000.day).
These resources have been shared at 90% by the Virgo groups of LAPP and LAL.
For 2006 we asked a large fraction of the CPU time to be used via Grid. This fraction is still not used.

4.2 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

Here we synthesize the status of the software developed in each group.

4.3 Burst Group Activities

The Burst Group activities since the last council are manifold: analysis of the run data, definition of vetoes, preparation to the future network analysis with LIGO and with bar detectors and continuation of previous works on development/improvement of filtering methods for burst detection.

4.3.1 Development of filters

A new filter is on the market: WDF (Wavelet Detection Filter) is based on discrete wavelet transformation. Its efficiency and robustness are similar to time-frequency representations. It is currently used both for gravitational channel and external channel analysis (for veto purposes), showing its robustness against signal signatures.

4.3.2 Analysis of C7 data

This activity has been the most important since last fall, occupying intensively most of the burst group active members. There are two aspects.

1. analysis of the main ("h") channel in order to see the statistics and typology of transients that mimic GW signals.
2. (following the first step) analysis of pertinent environmental channels in order to set vetoes.

For the first point, a variety of filters have been used: time domain filters, correlators and time-frequency methods. A huge statistical excess of events has been found with respect to montecarlo simulations (typically by a factor 2). The first source of transient is what we have called BoBs (Bursts of bursts). Their origin is related to mirror angular motions that couple to the laser frequency noise, the main responsible being the NE mirror. When NE tilt angles (mainly θy) become important, this results in a shortscale increase of the RMS noise within a typical range from a fraction of second up to 5 seconds; all the filters see then excess of events. The feedback to the commissioning team is clear: the angular motion of mirrors is out of specification. This has to be corrected. Other sources of transients have been identified or found again (already seen in previous runs): air conditioning in the MC tower, re-alignment with motors of some quadrant photodiodes located on the detection bench…
Concerning the definition of vetoes, we have run in a systematic way either the burst filters themselves or other simple filters like moving RMS …
Dead time, use percentage and efficiency have been computed with trigger lists for known sources of glitches: BoBs (for which the criterion is based on mirror angle values), DB picomotors or MC air conditioning (seismic channels) and channels related to the SSFS (different channels have been studied and proved to be equivalent).
Taking into account vetoed data periods allows to define an effective duty cycle for burst analysis. For C7, the duty cycle reduction due to vetoes is of the order of 20%. The BoBs have of course the main impact and are responsible for most of this reduction.
Concerning the collection of confirmed results, all the informations are systematically reported on the burst web page [1].

4.3.3 LIGOVirgo joint working group

The paper about the comparison of burst pipelines in LIGO and Virgo is about finished and will be soon sent for internal review to the LSC and Virgo Editorial boards. This will mark the end of the first joint project ("project 1").

The second step of the joint studies is starting ("project 2a"). The goal of this exercise is now to exchange 3 hours of real data (C7 for Virgo) in order to understand each other's segment definition or set of vetoes. We are currently working on the selected data and we are defining the vetoes for the Virgo data. The data segment and vetoed periods list should be delivered in the next few weeks.

The other topic addressed by the joint group is the network coherent analysis. Some technical progresses have been made but, due to low priority, nothing fundamentally new has been shown.

Related to this item, but independent, we must finally mention the studies about source location reconstruction in case of detection in coincidence in a network of detectors. The angular resolution we should obtain with the LIGO-Virgo network is of the order of 2 degrees and a factor 3 can be gained if a fourth detector is built in Australia and added to the network.

4.3.4 VirgoBars

The Virgo-bars collaboration has begun to analyze part of the data that are planned to be used for the final analysis. The data (4 hours) were taken from C7 Virgo run and from coincident AURIGA and ROG data streams. After having estimated the noise background, software injections of Damped Sinusoid with different parameters were performed at coincidence times in the Virgo and bar data, taking into account the observatories localization. At first we chose to use circularly polarized signals coming from the center of the Milky Way. The data analysis has been performed independently, i.e. AURIGA provided lists of candidate triggers that were compared with the corresponding list on Virgo side, in order to compute efficiencies and ROCs in a coordinated way.

This coincidence analysis between AURIGA and Virgo has been concluded, whereas the analysis in coincidence of the triple software injections AURIGA-ROG-Virgo has been delayed by organization problems in the ROG collaboration.

Currently we are producing data for software injections in a longer data chunk of 24 hours to better evaluate the noise background, the detector's' efficiencies and timing accuracy, taking into account the relative change in source position in one sidereal day. For these software injections the choice of the signals was determined by astrophysical considerations and in such a way that the signals are "optimal" for bar's sensitivity. We decided to use Damped Sinusoid waveforms with central frequency in the bars' band, damping time between 1 ms and 100 ms, and elliptical polarization with random parameters. These signals can be produced by BH-BH ring-down and f-mode of neutron stars.

After the coincidence analysis of the 24 hours, it is planned to analyze the «good» C7 Virgo data issued by the on-going studies of vetoes, in coincidence with the corresponding bars' data, in order to give reasonably interesting upper limits.

[1] http://wwwcascina.virgo.infn.it/DataAnalysis/Burst/home.html

4.4 Coalescing binaries group activities

The group was involved in several lines of activity

- improvement of analysis code and pipelines based on Wiener filtering;
- upgrade of inspiral simulation codes;
- development of vetoes based on auxiliary channels;
- analysis of real data (C6 and C7 run);

- development of code for coherent analysis;
- LIGO-Virgo network analysis;
- studies for future detectors.

4.4.1 Improvement of analysis code and pipelines based on Wiener filtering

The MBTA pipeline has been reviewed to improve the analysis speed, gaining roughly a factor of 2; further, the code is being modified to take into account and remove the effect of line excitations following re-locks.
The Merlino pipeline has been reviewed to improve the robustness and to cope with technical issues as missing frames or changes in the data quality level.

4.4.2 Upgrade of inspiral simulation codes

The code for simulating binary systems with amplitude corrections has been upgraded to include post-newtonian phase corrections up to 3.5 order in phase and 2.5 order in amplitude.

4.4.3 Development of vetoes based on auxiliary channels

A veto which detects sudden drops in the cavity power, exploiting the DC signal from the B2 photodiode, has been developed and tested on C6 and C7 data.

4.4.4 Analysis of real data (C6 and C7 run)

The MBTA and Merlino analysis pipelines have been run offline on C6 and C7 data, over the same physical space and using as similar as possible analysis parameters, including the same grid density and the same thresholds on the SNR. Noise event lists are ready.
A comparison of the results has been carried out, using selected data portions; while showing a good agreement on the estimated parameters of the coincident noise events, the comparison evidenced also differences in the event statistics, in particular a factor ~2 difference in the event rate, possibly related with spectral density estimation strategies, and with strategies to exclude data portions after relocks.
The events resulting from hardware injections have been re-analyzed to estimate the parameters, using the Markov-Chain Monte Carlo method, finding very good agreement between estimated parameters and injection ones. A report about C6/C7 analysis by the CB group is in preparation.

4.4.5 Preparation for LIGO-Virgo analysis

A paper covering in detail the work done by the LIGO-Virgo group on simulated data has been submitted to the LSC and Virgo review committees[1].
Three hours of real data from Virgo C7 have been selected for carrying on technical analysis tests in the LIGO-Virgo framework. The purpose is to cope with those technical issues related with not-uniform data quality, a-priori vetoes, data interruptions and similar, which need to be ironed out before addressing issues of statistical analysis. The plan is to quickly carry out the work on these three hours, and then move on some 24 hours of real data, for a more detailed study.
A code for partially coherent analysis is in preparation. It exploits double coincidences as triggers to carry on coherent analysis over data from three or more detectors. It is based on the theory for coherent analysis (Bose, Dhurandhar and Pai) and is right now tuned for the LIGO-Virgo analysis.

4.4.6 Studies for future detectors

Work has been carried out within the ILIAS framework to estimate to sensitivity to inspiral events for some configurations of future detectors, and to estimate the achievable source location resolution in the LIGO-Virgo framework.

[1] *Detailed comparison of LIGO and Virgo Inspiral Pipelines in Preparation for a Joint Search* - F.Beauville, M.-A.Bizouard, L.Blackburn, L.Bosi, P.Brady, L.Brocco, D.Brown, D.Buskulic, F.Cavalier, S. Chatterji, N.Christensen, A.-C.Clapson, S.Fairhurst, D.Grosjean, G.Guidi, P.Hello, E.Katsavounidis, M.Knight, A.Lazzarini, N.Leroy, F.Marion, B.Mours, F.Ricci, A. Viceré, M.Zanolin - submitted to LSC and Virgo review committees.

4.5 Pulsar signal search

The main goal of the work in this period was the creation of the candidate collections for the C6 and C7 commissioning runs and the coincidence between them, in a band of about 1000 Hz.
In the following we analyze in detail the status of each step of this complex search activity:

- *Creation of the clean SFDB* (short FFT data base):
for C6: 35.8 GB in 23 files
for C7: 8.7 GB in 6 files
- *Creation of the time-frequency peak maps:*
for C6: 4 files in vbl format (3.7 GB), 4 in old format (5.5 GB)
for C7: 1 file in vbl format (0.9 GB), 1 in old format (1.3 GB)
- *Cleaning of the peak maps:* because of the survival of many spurious lines, the peak maps must be cleaned before to be submitted to the Hough map procedure. This was accomplished on the basis of the density of the found peaks.
- *Production of the Hough map candidates:* we started from 0.6 Hz, then 20 Hz, 200 Hz and at last the full band 50-1050 Hz, with subsequent refinements of the software. We produced about 450 million candidates for C6 and about 153 million for C7. For each candidate 7 numbers are given (16 bytes).
- *Analysis of the candidates:* a number of procedures has been developed (in Matlab, as part of SNAG) to analyze statistical and individual characteristics of the candidates.
- *Coincidences between candidates:* some efficient procedure has been developed in order to find and analyze them.

Moreover we spent time in the development and tuning of service procedures:

- *Refinement of the Supervisor*: we increased the robustness in the Grid environment.
- *Input file creation procedure:* it extracts subsets of the peak map files in a directory, that will be utilized by the Hough map procedure.
- *Candidate collection synthesizer:* it collects candidates produced by the Hough map jobs (2100 for C7 and 10490 for C6), producing the candidate directory basic structure (102 files and subdirectories for each run – one file for every 10 Hz).
- *Final organization of candidate collections:* for each file of the basic structure, 242 files are produced in order to highly enhance the coincidence procedure performance.
- *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.).

We have a first outcome of the C6-C7 analysis: the main results are useful for the commissioning of the interferometer:

- *Identification of 10 Hz disturbance:* a train of small pulses were detected (using a comb filter); they were caused by a video camera.
- *Production of a list of strong lines in the power spectrum:* this was a by-product of the SFDB procedure, using the log-file.
- *Analysis of anti-aliasing filters:* a frequency domain anti-aliasing procedure, that is more efficient, was proposed.

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

4.6 Stochastic Background Physics Group

The activity of the stochastic background group in the last six months was dominated by three different issues:

- Finalization of the project of collaboration with Auriga/Nautilus/Explorer
- Start up of the project of collaboration with LIGO/LSC
- Work on the stochastic background data analysis library

4.6.1 Collaboration with Auriga/Nautilus/Explorer

This is a project started several months ago. It was designed to be a methodological study of the standard data analysis techniques for an isotropic background with a flat spectrum in Ω_{GW}. Each detector prepared a set of real data, with a duration of 4 hours. The data were not taken at the same time, as no study of correlated noise was foreseen. For Virgo the data were extracted from the C6 run.

In the first phase of the project the activity was mainly focused on understanding the peculiarities of each stream of data in term of noise spectra, stationarity and linearity. A second important point was the design of a pre-processing strategy. This was particularly important as the approach used by each experiment to store data was different. In particular the sampling frequency was different and an heterodyne procedure was used by bar experiments to compress data.

Analysis of data confirmed some evidence of non stationarity in the data of each detector. For Virgo these results were confirmed by other independent analyses performed by noise hunting groups.

The second phase of the project consisted of injection of simulated signals. The simulation and injection was done under the responsibility of the Virgo part of the group, using the SB/NAP code. Several checks confirmed the good quality of simulated data.

The last phase was the validation of standard detection algorithms. The generation of the sequence of estimators for the optimal correlation is completed. The statistical analysis of the results is in progress, the delay is connected with the start of collaboration with LIGO/LSC (see next section) and to the lack of manpower.

Partial reports on the results can be found in presentations done during the Virgo weeks, in a poster presented at the last GWDAW, and in two presentations done at the ILIAS meetings of Palma de Mallorca and Florence.

4.6.2 Start-up of collaboration with LIGO/LSC

This is a joint data analysis project between Virgo, LIGO (Hanford and Livingston detectors) and GEO600. The study of two different issues is foreseen:

- Standard analysis of an isotropic, stochastic background (just started)
- Extraction of the sky luminosity map of gravitational waves (will be started before the summer).

The details of the project can be found on a white paper document written jointly by the members of the collaboration. We stress here only some relevant points.

In the first phase the analysis will be done using simulated data for both signal and noise. Currently we are just testing the pipelines available to each member of the collaboration, in order to understand their level of compatibility. The first study is the evaluation of the estimator of the optimal cross correlation applied to a simulated stream containing only noises. This evaluation is done using three different codes, which are

LAL, the standard data analysis library of LIGO

MATAPPS, an independent Matlab code written inside the LSC

SB/NAP, the stochastic background data analysis library of Virgo

The second issue is the simulation of stochastic background signal. This was done using SB/NAP. In particular a refined algorithm which avoids loss of coherences was tested with good results. The reason for that is to be able to test detection a algorithm which uses overlapped analysis windows.
In a second phase software injection will be done on A4/C7 data. Work on real, synchronized data will be done when the sensitivity of the detectors involved will become comparable.
There are regular meeting (one each two weeks) between the members of the working group, and a face to face meeting will be organized during the summer.

4.6.3 Work on the stochastic background data analysis library

The reorganization the stochastic background data analysis library continued. In particular on algorithms which could be used by other data analysis tasks (noise hunting, other data analysis activities) was migrated to the NAP library.
Specialized algorithm was inserted inside the SB library, which works on the top of the NAP one.
Implementation of pipelines is now entirely based on scripts. The approach used was to generate bindings for the classes of the SB library in an interpreted language (python). In this way a complex pipeline is implemented as an interpreted script, which can be rapidly modified and tested.
Some modifications of the standard pipeline for the analysis, initially tested in the framework of Virgo/Auriga/ROG joint project, were introduced. Some were mandatory owing to the different peculiarities of the large band analysis, which will be tested in the Virgo/LSC collaboration. Other ones were introduced to ease the comparison with the LSC pipelines.
A first “officially stable” version of the SB library was released. The main reason for that is to easily share the code inside the Virgo/LSC project for a common review.

4.6.4 Manpower

Several people joined the group during these last months. Their reference groups are the Pisa and Nice ones. This will help to speed up the activities, especially in the context of the Virgo/LSC project. The current number of active people is nearly equivalent to 4 full time scientists.

4.7 The Noise group activity

In the last six months the noise hunting activity was developed mainly in the other Physics groups because it was optimally related to the definition of the veto procedure applied in search of the specified signal.
However we have to quote here some peculiar activities of this group.

4.7.1 Development of the on-line noise monitor.

The group focused the attention in the preparation of new hardware and software tools for the on-line identification of noise and in setting up the on-line noise monitor. It will cover different aspects.
One of them is the creation of an Automatic Noise Budget (ANB) tool able to:

- measure the transfer function between dark fringe and error points, correction signals or input laser noises;
- estimate the contribution of control and input laser noises on the dark fringe spectrum and on the sensitivity;
- track the evolution in time of transfer function using calibration lines (permanent or semi-permanent).

This tool can be easily made general enough to allow to compute also the noise budget for auxiliary degrees of freedom.

Moreover the on-line monitor is focused also

- for searching new spectral lines and update the line data base,
- to look at the glitches
- for characterizing the non-stationary features of the system noise

4.7.2 Monitoring of non stationarity

A process for the monitoring of nonstationarity of noise (nonStatMoni) is now running online. It produces plots and output that will help to monitor the state of the interferometer.

4.7.3 Numerical noise evidence

In difficult conditions numerical noise may emerge. DC offsets and pole zero arrangements enhance the problem, which was detected in the study of mirror feedback control. Guidelines will be issued on how data in the DSP should be treated to minimize propagation of errors due to finite representation of numbers.

4.7.4 Magnetic noise study

A study dedicated to the environmental magnetic noise has been carried on during the last six months. The goal is the evaluation of the magnetic coupling with the em-actuators driving the mirror relative position.

We proceeded by

- measuring the shielding effect of the vacuum chamber hosting the mirrors
- analyzing dark fringe data taken during a run with a big magnetic coil driven by monochromatic signals and set up in various locations of the Virgo central building.

The results of these transfer function measurements have been compared to a theoretical model so that the sensitivity limitation due to the environmental magnetic noise has been established.

5 Virgo/EGO Outreach report

5.1 Site visits

The visit activity continues with success. In the period October–June almost every Saturday morning we had one group, sometimes two. The first Saturday not booked for a visit is the last one in June.
Saturday, March 18 an "open doors at EGO day" has been successfully organized, as in the past years.
Unfortunately we still miss visits from France.
The visits have been successfully managed thanks to the secretarial work of S. Perus and L. Coltelli and to the scientific guidance of C. Bradaschia, F. Carbognani, C. Corda, I. Fiori, F. Frasconi, F. Paoletti, D. Passuello.

5.2 Newspapers, reviews, radio, TV, Web

A few articles on local and national newspapers and reviews have been published.
Two times Virgo has been shortly illustrated in national italian TV emissions (Superquark and Ulisse), thanks to the good collaboration existing with INFN Ufficio Comunicazione.
We hope to establish soon a link also with the appropriate CNRS service.
A picture of the new injection bench will be published on the central double page of the next issue of the new INFN magazine "Asimmetrie".

5.3 Expositions, exhibitions, conferences

Since four years EGO/Virgo participate to a one-month didactical exposition, in May, in Pisa, directed to students, up to high school level. Also this year the construction of "100 Euro" interferometers (that, after the assembly are donated to the schools for further use) has been a highlight. Nine interferometers have been assembled, doubling the number with respect to the previous years.

Sidereus Nuncius is a theater – music – multimedia event scheduled around next June 22, the same day of Galileo's abjuration in 1633.
The event will take place contemporarily in several places in Pisa, connected through the web. EGO/Virgo contribution consisted essentially in supplying data strings to be converted in audible music. Electronic musicians spent four days at EGO to acquire data strings and to record sounds and images. A first performance took place in Florence on May 19, at Stazione Leopolda (the first railway station ever built in Tuscany). A few EGO and Virgo members were present and enjoyed the unusual event.

Beyond Einstein, the 12 hour world wide webcast, of last December 1st, organized by CERN, took place as last event of the World Year of Physics. It consisted of several web connections among laboratories and institutions all around the world, involving Einstein relatives, scientists and journalists. The public were the internet users, being able to follow the webcast from home.
EGO/Virgo participation consisted in a videocoference link from the Virgo control room. Our contribution was not really satisfactory, due to a not foreseen too detailed introduction from CERN and to a successive shortening of the time slot. Anyway the connection with Cascina was the only live connection with a working scientific laboratory.
Several e-mail questions on gravitational waves have been received by CERN and we have been requested to prepare video-clip-answers, to be made available on the Beyond Einstein web page.

5.4 *h* - the Gravitational Voice

This is the title of the EGO/Virgo quarterly newsletter to be published on the web. The first issue is being prepared for July. It is not properly an outreach item, since it is directed to EGO/Virgo staff; it will be, anyway, accessible by the public and may have potential readers in the VESF and in the other gravitational wave collaborations.

5.5 Photovoltaic generators

Together with the EGO Infrastructure Department, we are considering the opportunity to install photovoltaic generators on tunnel roofs. Limiting the coverage to the South oriented half of the West tunnel, a 1 MW peak power could be reached.

The value of this initiative could be twofold:

- 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 5-10 years
- promotional, showing the EGO/Virgo and CNRS/INFN vocation to the use of clean, renewable energy sources.

In order to achieve the large initial investment several solutions will be investigated: CNRS/INFN, local authorities, industries, banks.