Virgo Progress Report
For the EGO Council

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Abstract

This report describes the Virgo activities and progress for the November 2004 to May 2005 period. It starts by a quick status overview and collaboration news, the report is organized in three main sections: detector, commissioning and data analysis status, prepared by the corresponding coordinators.

Summary

1 Overview

1.1 Detector status:

Since the last council, a commissioning run (C5) took place in December with the interferometer in two configurations: recombined (Michelson plus two Fabry Perrot arms) and recycled (same plus the power recycling). Data taken have been used by the data analysis groups.

Since then, work has been focused on the setting up of the automatic alignment, noise hunting, automated procedure and lock robustness. Work is not yet complete on the automatic alignment, but some control loops can now be closed. This work has been slowed down by interferometer instabilities ("jumps") since late December. Some progress has been made on these instabilities leading again to good lock segments at the end of May, although these instabilities are not yet understood. The following figure shows the Virgo sensitivity recently achieved plus the ones of the five commissioning data taking (run C1 to C5) and the design one.

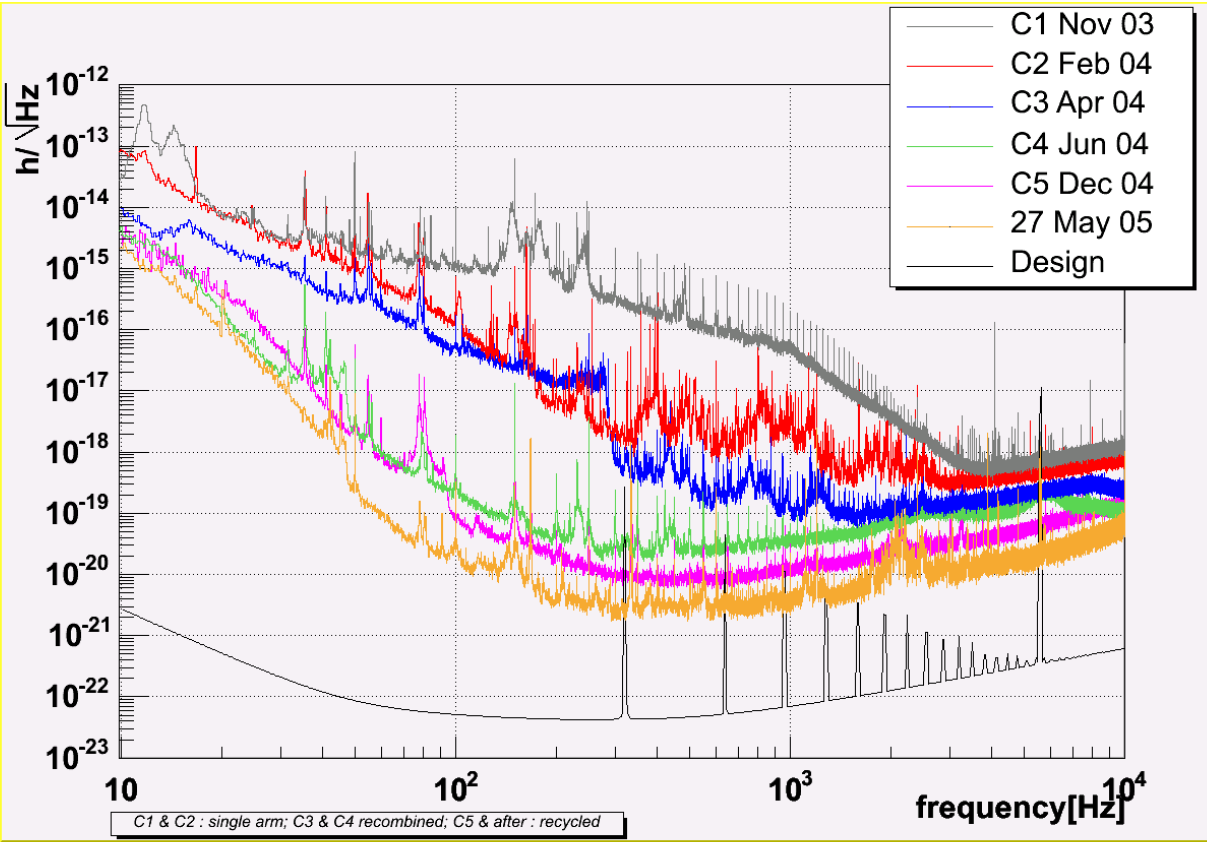

Figure 1: Virgo sensitivity curves. Note that the C4 sensitivity was obtained with the recombined configuration and an input power of 7 W while the C5 sensitivity was obtained with a recycled configuration and an input power of 0.7 W.

1.2 Up coming activities

The injection system will undergo a major upgrade during summer 2005. Several months of down time and re-commissioning are expected. On the other hand, progress has been made on the detector sensitivity. Therefore a two weeks run will take place before the summer shutdown. The run will be important for the shakedown of the data analysis.

1.3 Virgo upgrades:

The Virgo antenna sensitivity is not sufficient to guarantee the detection of astrophysical signals and therefore a scenario of improvement is being prepared. This scenario foresees at the 2011 time scale a major upgrade of the Virgo antenna ("Advanced Virgo") aiming at a sensitivity improvement of one order of magnitude. This upgrade will be contemporaneous of the advanced LIGO installation. In the preceding period, there will be long data taking runs plus smaller and more limited upgrades. This could give us a detector ("Virgo+") with an intermediate sensitivity at the 2008 horizon.

The preparation of this scenario started by the work of the Virgo working group that is preparing a white paper on this topic. This scenario has been discussed during Virgo meeting but also with GEO persons. A MOU between Virgo and GEO describing the organization of the study for an advanced version of the Virgo antenna has been drafted and is being discussed with GEO.

1.4 Collaboration organization

Over the last months, some of the coordinator appointments reached their term. Therefore we have a new commissioning coordinator (M. Barsuglia), a new locking coordinator (S. Braccini), a new alignment coordinator (H. Heitmann) and a new spokesperson (B. Mours). An outreach coordinator as also been appointed (C. Bradaschia).

Collaboration meetings take place on a more regular basis since February (ten times per year). A work to improve the internal organization of the collaboration has started with the upgrade of the web site, collaboration directory and will continue over the next months with the writing of documents describing the current contributions of each group.

1.5 Manpower

Bringing a detector as complex as Virgo to its design sensitivity requires a several years long commissioning and tuning period as it has been observed on any other such project. This requires a core commissioning group with persons spending a relevant fraction of their time at the site plus a steady support of the various groups for their subsystems. However, due to various reasons, it is difficult to staff such activities that are mandatory to reach the design sensitivity. Lack of manpower is observed periodically on some of these activities leading to some delay on the detector progress. Keeping the collaboration labs involved in these activities is also critical for the data analysis and the preparation of Virgo upgrades. Therefore, the collaboration feels the need for fellowships allocated to the Virgo collaboration groups, dedicated to commissioning and subsystem support.

1.6 External collaboration

The LIGO-Virgo working group on joint data analysis is very active and started by cross validation of detection methods. Presentation has been made during the annual Gravitational Waves Data Analysis Workshop leading to two joint publications. This collaboration is continuing with more complex validation projects. On the formal point of view attachments to the LIGO-Virgo MOU have been prepared,

A similar effort is starting with the Italian bars through a joint working group and the writing of a white paper describing the scientific project.

With GEO, data exchange is covered by the LIGO-Virgo agreements since now GEO is one of the LIGO project detectors. However, the involvement of GEO persons in the Virgo upgrades is also discussed as previously described.

1.7 Outreach

The collaboration recognizes the need for a strong enhancement of the outreach activity toward public and the media. To help developing this, the collaboration appointed an Outreach Coordinator (Carlo Bradaschia).

The collaboration suggests that he works in close collaboration with EGO where the support by a full time person skilled in this field would be welcome. The construction of the new EGO building is also seen as an opportunity to create some space dedicated to outreach with posters and a possible exhibition.

2 Detector Coordinator report

2.1 Introduction

The main activity in progress is the upgrade of the injection system (ISYS). This project is involving many Virgo laboratories (EGO, LAPP, Lyon, Nice, Perugia, Pisa, Rome); it can be divided in three large (and correlated) items:

1. Design and realization of the new IB
2. New Power Recycling (PR) and Mode Cleaner (MC) mirrors
3. New Auto-Alignment and Beam Monitoring System of the ISYS

The vacuum system and other subsystems status are then reported.

2.2 New Injection Bench (IB) design and realization

The design of the new IB is the result of the integration of two main activities:

- Optical layout design
- Mechanical structures design

2.2.1 Optical layout design

The design of the optical layout of the bench has been finalized after an iterative design process that attempted to satisfy the several requirements emerged during the study period. In the design, as much effort as possible has been put in allowing possible future modifications (e.g. insertion of an electro-optical modulator (EOM)).

The main problems, by the optical point of view, that have been taken into account in the new design are:

- Insertion in the bench of a Faraday Isolator (FI)
- Beam collimation with a plane Power Recycling mirror
- Use of larger mirrors in order to minimize as much as possible stray light on the bench
- Input beam entering directly into the mode cleaner dihedron.
- Possibility to automatically align the Reference Cavity separately from the Injection Bench.

The design has been drawn using Optocad (optical design) and Zemax. The mechanical layout has been drawn using Autocad. The present scheme, reported in Figure 2, has to be considered definitive. To match the beam size with the constraints due to the FI aperture and to the waist needed in the interferometer, a system of telescopes has been developed; particular attention has been put in the certification through simulation of the tolerances required in the positioning and alignment of the telescope optics. The alignment actuators have been designed according to the simulation results[1]. As it is described in the “New automatic alignment system for the ISYS” paragraph, the possibility of aligning separately the reference cavity and the input mode cleaner beams has been introduced.

Electro-optical modulator (EOM)

The possibility of placing an EOM after the Input Mode Cleaner, in order to overcome the possible problem of the matching of the sidebands with the Input Mode Cleaner length, has been taken into account. Since this point requires a more thorough study, it has been decided

[1] A first two spherical lenses afocal short telescope will reduce the beam dimension from about 5 mm waist to 2.65 mm waist. In order to have some control on the collimation, the distance between the two lenses of the first short telescope can be varied by mounting one of the lenses on a translation stage (Physik Instrumente, PI). A second two parabolic off axis mirrors afocal telescope will enlarge it from 2.65 mm to the about 20 mm waist required by the interferometer. The first parabolic off axis mirrors will be mounted on PI translators and will be steered using picomotors, and the second one (4.5” of diameter) will be steered using closed loop picomotors.

for the moment to keep the future possibility of placing it on the bench. For this reason some free space for an EOM has been reserved on the bench and an investigation of the commercial availability of such device has been started.

New Brewster window

The beam exiting from the parabolic telescope must have a diameter of about 40mm, larger than the size of the "Brewster window" placed between the IB and PR towers. A new Brewster window has been designed (and a new support) and the incidence angle has been adjusted to the Brewster angle. An anti-reflecting glass has been foreseen in front of the output port, for beam monitoring purposes.

New IB input flange window

In order to accommodate all the beams coming in and out from the IB tower it has been necessary also to change the IB input windows: the present two windows, one rectangular, 45 cm long and the other one a circular window at the Brewster angle (through which the beam is entering into the tower) will be replaced by two 390×80mm free aperture windows, AR coated on both sides.

To increase its rigidity a stainless steel rib will be welded to the flange along its vertical diameter. An ANSYS simulation has been performed to study the behavior of the flange and of the windows under a total load of about 10 tons (due to atmospheric pressure).

Faraday Isolator (FI) characterization

The FI, purchased at EOT together with a spare TGG rod, has been selected putting special attention on:

- aperture
- thermally induced focal lens
- optical isolation

The rotator is a 20mm aperture TGG rod; polarizers are dielectric films used at Brewster angle.

The large aperture has been chosen for ease of centering. The requirement to have a coupling in the interferometer which changes not more than 4%, between locked and un-locked states of the interferometer pushed to ask for a minimal thermally induced focal length of 24m for a beam radius of 2mm in the TGG rod and 20W power. The isolation specifications given by the manufacturer are better than 35dB under 20W.

Both the rods have been characterized in the Nice laboratory using the spare Virgo slave laser. The induced focal length dependence by the beam size is about 1/w2, as expected, and its value is larger than 68m for a 2mm beam radius (requirement F>24m). Extinction has been measured to be higher than 41db (specification is 35db). A possible problem source has been identified in the rear face supporting the polarizing coating:

- a secondary beam of 0.2mW is transmitted, parallel to the main one, which puts an interference pattern on the transmitted beam
- multiple reflection of the rejected wrong polarization by the rear face makes difficult to dump those spurious beams.

Possible solutions have been indicated changing the geometry or the coating of the polarizers, but a better quantitative estimation of the effective presence of the problem must be realized

Status

Part of the optical components is arrived: Faraday Isolator, Spherical lenses, plane optics, PI pzt and linear translators, $\lambda/2$ plates and respective holders. The other components should arrive within the first part of June. Some of the components have to be machined: in particular the mounts for the parabolic mirrors, the pedestals for the mounts, the mounts for the optics on the beam path below the bench (in particular the mirror holders to be mounted on the RFC pzt).

Plan and preparation of the assembling

It is planned to start mounting the new IB in the class 10 clean room of EGO. The assembly will start as soon as the bench and the first components will be available. It is planned to use a dummy dihedron, on which not reflecting mirrors are mounted, through which a Nd:YAG collimated at the dimensions needed for the Input Mode Cleaner is transmitted. This beam will be then aligned on the bench and the telescopes will be tuned. The instrumentation and components for the alignment and tuning of the parabolic telescope should be available, according to the companies delivery times, within the end of June.

2.2.2 Mechanical design of the new IB

A multi-holes octagonal bench has been designed. This new shape has the advantage to increase the total available surface (880 mm longest dimension) to better accommodate the optical components. The material selected for its construction is an Aluminium sheet (55 mm thick) on the back side of which rib reinforcements will be machined. As the present bench, the new one will be suspended to the marionette by using three metallic wires. However, the new wires will be monolithic and thinner (1 mm diameter instead of the 2 mm diameter of the present suspension wires) to increase the frequency (at about 200 Hz) of the violin modes and to decrease the frequency of the rotational modes. The design of the table has been studied in such a way to easily accommodate the future changes that can be necessary, as the installation of an EOM, or a different beam path.

A detailed modal analysis simulation of the new bench design has been performed by using ANSYS software package. This activity has been also done comparing the old design with the new one, trying to improve the bench response in different frequency regions. As outcome of this study, an optimization of the bench design has been obtained.

Status

The designs of the table and of the injection tower flange have been completed and their production has been commissioned to an external supplier.

The design of the Brewster window support is under completion and it will be machined in the INFN-Pisa mechanical workshop.

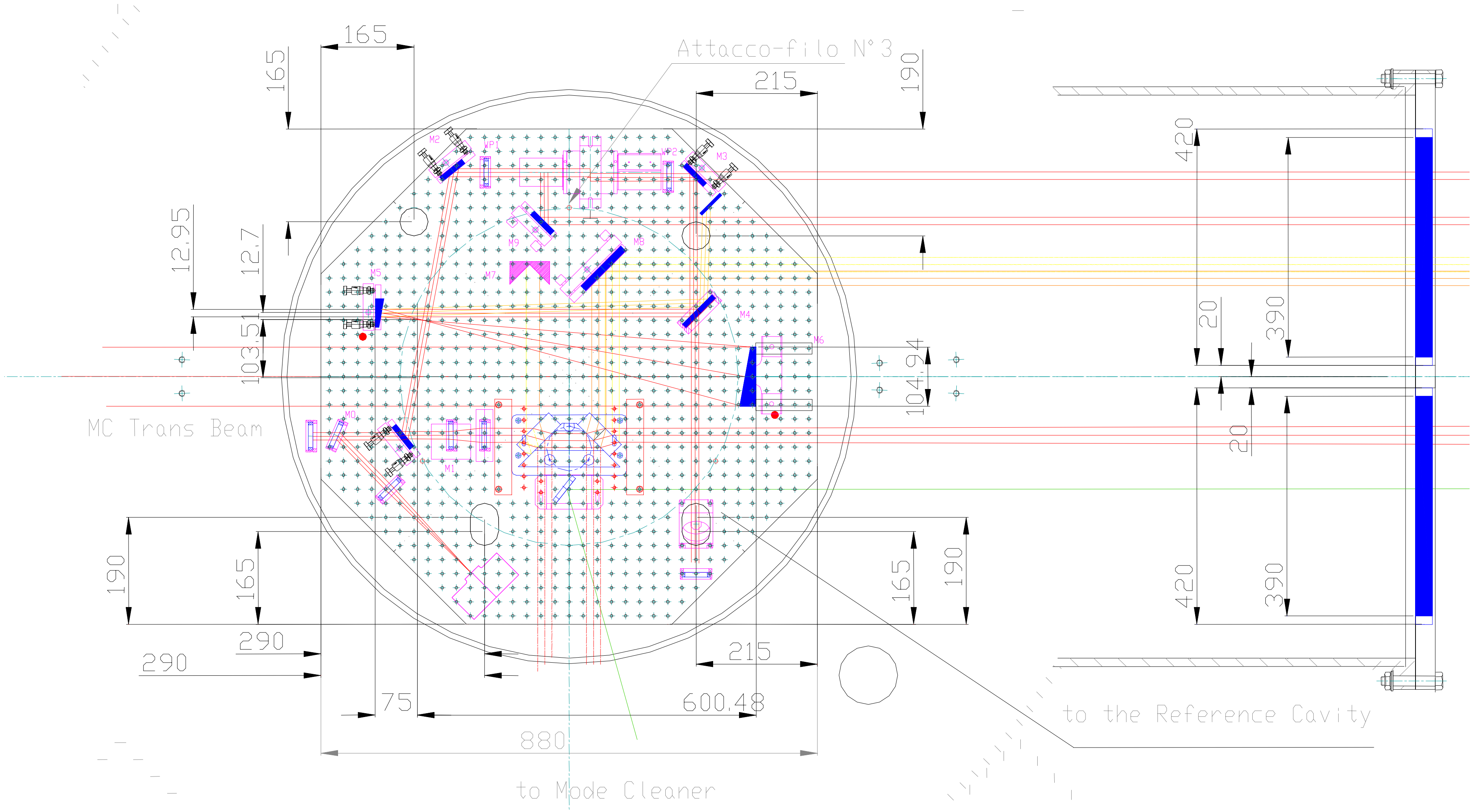

Figure 2- Injection bench optical layout

2.3 New Power Recycling Mirror

The new PR mirror will be realized using a standard input mirror substrate. This solution permits to reuse a component already available in the Lyon laboratory, having excellent optical properties (low absorption Suprasil and high quality polishing), saving time and money for the production of the PR mirror. The two faces of the substrate are flat and parallel. This is an advantage because it makes the ITF almost unaffected by the vertical position or fluctuation of the PR (on the contrary of the present one, being a lens), but it shows some drawbacks. Another undisputable advantage will be to have a PR mirror made of one single piece and not of a small mirror mounted inside a silica circular frame. This will eliminate several hardly controllable mechanical resonances.

The overall size of the new PR mirror is compatible with the geometry of the current reference mass and marionetta, reducing the construction effort.

The choice of the reflectivity of the new PR mirror is very critical and comes out from the compromise of several requirements:

- High carrier and sidebands (SB) recycling gains to improve the detector sensitivity[2]. This condition requires to have the PR reflectivity as close as possible to the Michelson reflectivity
- For locking purposes the PR reflectivity must be different from the Michelson one both for the carrier and the sidebands: phase rotations (i.e. due to thermal effects) can prevent to lock the ITF.
- The second stage of frequency stabilization is easier for $R_{PR} < R_{Mich}$. (which corresponds to the actual configuration).

The best compromise between all these requirements is to realize a PR mirror whose reflectivity is as high as possible, but safely below the reflectivity of the Michelson for the carrier and sidebands. For this reason an intense activity of optical characterization has been realized to determine, as precisely as possible, the effective optical parameters of Virgo. From this measure campaign has been obtained a safe value for the PR reflectivity of $R_{PR} = (r_{PR})^2 = 95\%$. The flat-flat geometry of the new PR substrate forces to bring particular attention to the residual reflectivity of the anti-reflecting (AR) coated mirror face. In fact this residual reflectivity transforms the PR mirror in a small Fabry-Perot cavity and the effective PR reflectivity is given by the reflectivity of this cavity. For this reason a production procedure in steps has been agreed with the Lyon laboratory:

1. the new PR mirror candidate is selected between the four flat-flat substrates available choosing the component that shows the largest residual curvature radius. In fact, from a simulation study it has been realized that the residual curvature radius affects the recycling gain (this simulation does not include BS real mirror surface since it has not been measured at 45 degrees, but it is the

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[2] For good contrast defect the Virgo sensitivity is proportional to $1/\sqrt{G_{rec}}$ where G_{rec} is the recycling gain of the carrier.

$$G_{rec} = \left[\frac{t_{PR}}{1 + r_{PR} \cdot r_{Mich}}\right]^2 \quad ; \quad G_{rec,SB} = \left[\frac{t_{PR} \cdot r_{MichSB}}{1 - r_{PR} \cdot r_{MichSB} \cdot \cos\left(\frac{\Omega \cdot \Delta l}{c}\right)}\right]^2$$

where the parameters are the reflectivity and transmittivity in amplitude of the PR and of the Michelson and Δl is the small Michelson asymmetry.

best effort that can be done with the available information). This step has been completed and the VIM-03 substrate has been selected

2. the AR coating is performed on the back face of the PR mirror
3. The residual reflectivity is measured
4. The high reflectivity coating is realized to reach an effective reflectivity of about 95%, value considered far enough from the R_{Mich} to compensate the temperature fluctuations.

2.4 New Input Mode Cleaner terminal mirror

The current IMC terminal mirror shows a poor substrate quality. This causes a large amount of diffused light in the interferometer. It has been decided to replace it with a similar geometry, better substrate quality, new mirror and, meanwhile, to operate few minor changes in the reference mass (larger mass, simpler geometry, reduction of the coil actuators) and in the camera targets. The substitution of this mirror could be postponed by the difficulties that the polisher (REOSC) is having in producing a better substrate. An alternative polisher or an alternative geometry is under investigation.

2.5 New automatic alignment system for the ISYS

During the Virgo commissioning some power fluctuations have been observed in the ISYS. These fluctuations have been explained as due to problems in the alignment of the input mode cleaner (IMC) with respect to the injected beam. In the original Virgo design the beam is automatically aligned on the reference cavity (RFC) using Ward signals and ABP actuators located on detector and laser benches.

IMC mode is automatically aligned on the beam using Ward error signals and actuating on θ_x and θ_y of the mode cleaner end mirror. The two other degrees of freedom (monitored by the remaining Ward error signals) are left free: it has been assumed a rigid connection between RFC and IMC input dihedron. As consequence of this assumption, the beam being clamped with respect to the RFC, should also be clamped with respect to the IMC input and it should not be necessary to control all degrees of freedom of IMC mode. Because of the experimental evidences, this hypothesis of rigid link between RFC and IMC dihedron has been suspected to be wrong.

2.5.1 The new strategy

In the new strategy it has been decided to control all degrees of freedom monitored by Ward signals. The beam is clamped on the detector bench using the so-called beam monitoring system (BMS) for monitoring and previous ABP actuators.

IMC mode is aligned onto the beam using 4 Ward error signals plus 2 signals monitoring the centring of beam onto the MC end mirror (photodiode located behind MC end mirror).

The table below gives the way the degrees of freedom of IB and MC masses are controlled.

IB	**MC**
$\theta_x^{(1)}$	$\theta_x^{(3)}$
$\theta_y^{(1)}$	$\theta_y^{(3)}$
$\theta_z^{(3)}$	$\theta_z^{(4)}$
$x^{(4)}$	$x^{(4)}$
$y^{(2)}$	$y^{(4)}$
$z^{(3)}$	$z^{(2)}$

(1) *controlled by MC end mirror photodiode*

(2) *controlled by thermal control of suspension, or frequency lock*
(3) *controlled by Ward error signals*
(4) *controlled by local controls or left free*

2.5.2 The Beam Monitoring System (BMS)

We use a far/near field telescope to be orthogonally sensitive to beam shifts and tilts.
Far field telescope has a 7.7m focal length. Such a high lever allows reducing the stability specification after the telescope (the photodiode itself) for tilt measurements.
The choice of an optimized opto-mechanical design gives a long-term stability much better than 4.5μrad tilt and 10μm shift for a 5°C degrees temperature variation in the laser laboratory (typical temperature dispersion in the laser lab. is +/-1 °C).
Sensitivity allows to measure 10 prad/sqrt(Hz) and 760 pm/sqrt(Hz) for beam tilts and shifts (4 orders of magnitude better than actual local controls). A view of the new BMS system is reported in Figure 3.
The status of the new BMS system is:

- Waiting for the delivery of the beam-splitter, which is to lighten the near field telescope.
- Far field telescope installed.
- Quadrant photodiodes are spare ones (waiting for the delivery of new quadrants)
- Connection to the data acquisition system under progress

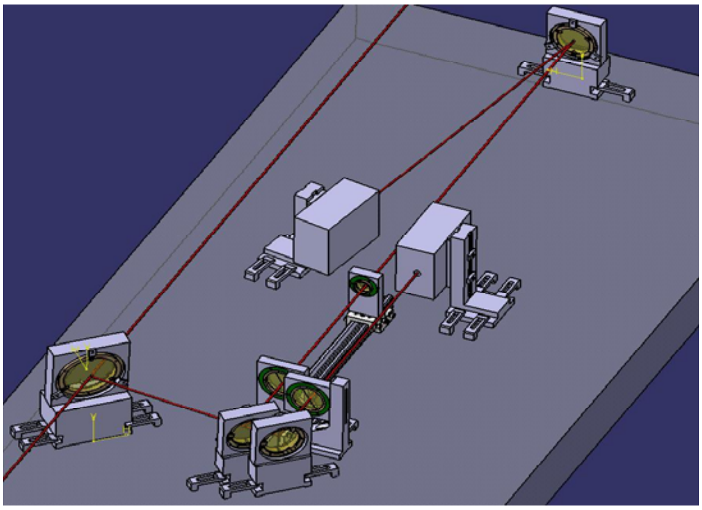

Figure 3- View of the new BMS

2.5.3 MC transmission monitoring quadrant photodiode

IMC end mirror is imaged onto a DC quadrant photodiode using a 0.25 magnification telescope. We can retrieve information on IB(θ_y) down to 4.4 prad/sqrt(Hz) and 9 prad/sqrt(Hz) for IB(θ_x). Long-term stability is limited by the table supporting the optical set-up (not so critical anyway).

2.5.4 Status:

- Installed with spare components (waiting for final ones)
- Connection to the data acquisition system under progress

2.6 Vacuum system

2.6.1 Tube

Both tubes have been under service over the whole year without failures.
Residual pressure ranges around 10^{-7} mbar, slightly changing with seasonal external temperature. Gases are constituted mainly by water, as normal for an unbaked stainless steel chamber. 'Outgassing' from tube walls is remarkably low, as example the vacuum load of both entire tubes is less than the towers one, despite the very large size difference.

Maintenance interventions have been concentrated during the periods of stop of the interferometer, without disturbing the commissioning activities.
Maintenance was devoted mainly to the realignment of the tube profile, to recover the displacements induced by ground subsidence, which otherwise would increase the mechanical stress on tube.
Subsidence rate was found to be corresponding to the past year figure, showing that saturation is not yet reached; furthermore subsidence showed a general seasonal behaviour: higher rates were measured during winter periods, while lower ones were found during summer.
With present conditions, about 30-40 tube modules per year need to be realigned: the job corresponds to about 10 days of maintenance, which shall be performed when convenient for Virgo activity. A major realignment operation is planned for this summer, in occasion of the stop for the 'injection upgrade'.
As a step toward a system to cope with permanent ground subsidence, we have recently installed two new tube supports at each arm end, able to compensate the different settling down rate between the end tower and the last tube module without interrupting Virgo service. 'Hydrostatic' sensors monitoring the local subsidence are also under installation, according to CERN advices, as a completion of the described system.

2.6.2 Large Valves

All the four Large Valves are regularly in service, and the remote control system is finally ready. Now their status can be checked from Control Room by the ITF operators.

2.6.3 Towers

Actually the residual gas in towers is essentially water, with a total pressure below 10^{-6} mbar (both in lower and upper part).
The hydrocarbon contamination, in each tower lower part, is within the normal performances of an unbaked UHV chamber (about 10^{-9} mbar).
Anyway contamination is characterized by the presence of a well-defined signature in the spectrum (masses 99/100), most likely due to a specific component, rather than generic grease/oil pollution.
Since unexpected, this contamination is worth to be understood.
Specific tests have been performed in the vacuum lab., but further investigations, directly on towers, are necessary to asses the origin of the contamination and possible means to reduce it. They could be achieved during the 'Injection upgrade' stop.
About the maintenance of the vacuum chambers, a small leak is present on bottom DN1000 flange of West End tower (around 10^{-4}mbar.l/s). The ultimate pressure in the tower lower chamber is $1x10^{-6}$ mbar, and the leak will be recovered as soon as we have a chance to open the tower.

A small leak has been detected also on the technical ring of the Injection tower. It shall be recovered during the summer stop for the 'injection upgrade' works.

2.6.4 Pumping system

Pumping equipment has attained a long-term running period, without Vacuum service interruptions. Normal maintenance activity has been carried out, mostly on 'intermediate stage' pumping groups (scroll pumps, turbomolecular pumps).
For reducing the mechanical vibration noise in the 'towers' area, we have adopted the following procedure: the scroll pumps installed on each tower (running at 25Hz) are normally switched off during most of the time, while they are operated just 5 minutes every week, normally at around 10:00 every Friday. On the contrary, the turbomolecular pumps (600 Hz) are continuously running.
From the vacuum point of view, the effect is a negligible increase of pressure of the towers upper part due to light gases accumulation (hydrogen) while there is not significant increase of other gases (water, contamination).
This procedure has also the effect to extend the operating time of scroll pumps, which would otherwise need a relatively frequent service (1 year or shorter). However, the Scroll pump on Injection tower and West End tower runs continuously, to cope with leak presence.
The control system of vacuum equipment has been completed and maintenance activity has been regularly accomplished. To be mentioned in particular the modifications carried out on the racks of the tube pumping stations, which are located in the tunnels, to cope with high room temperature and environmental pollution.
Several activities have been devoted to optimize the software 'vacuum supervisor' for driving the Vacuum system, and it is now still in progress to keep it updated with the Virgo software environment.

2.7 Detection system

Most of the recent on the detection system has been focused on the reduction of the electronic noise at high frequency:

- It was noticed during the run C4 that there was some unexpected noise on B2 photodiode which was limiting the sensitivity in the high frequency region. This noise was picked up on the long cable (35m) used to transfer the signal of the photodiode (located in the laser lab) to the demodulation electronic (in the detection lab). It has therefore been decided to move B2 electronics to the laser lab. This was done at the end of December 2004. The B2 electronic noise is now reduced to the standard noise.
- The C5 sensitivity was limited, at high frequency, by some phase noise introduced by the local oscillator (LO) board (used to distribute the 6.25MHz demodulation signal). The source of this noise has been identified and the LO board simplified. This noise is now smaller than the expected generator noise.

After the installation of a detection readout crate into the laser lab it has also been decided to use the detection electronic to demodulate some of the injection signal: the reference cavity error signal as well as the modulation frequency error signal. The demodulation of the reference cavity error signal by the detection electronics allowed reducing the electronic noise of this channel by more than an order of magnitude.

In addition to that, the photodiode readout as well as the slow monitoring software have been upgraded and maintained.

2.8 Electronic and Software

Basic software

Several fundamental malfunctioning of the Cm applications have been fixed. All the online servers run now with these improvements. These modifications allows to improve the time life of all the servers and improve the basic daemons reliability (El,Db, Cm)

Storage

The storage data area has been increase from 70TB to 120TB and the data access reliability improved.

Now more than five months of data are available for commissioning people.

Since December 2004, the frame file list building previously done by the DAQ is performed by the EGO for the raw data stream. The DAQ team still provide the frame file list for the 50Hz stream and the trend stream

Automation

Thanks to the work performed on the front-end servers and the *ALP* (Automation of Locking procedure) server the ITF can be lock in the several mode easily in few minutes. The automation have been used for the first time during the C5 run and now it's always use during the commissioning activities

Some works remains to do:

- Automate the ITF start-up phase
- Implement some recovering facilities

Locking loop elements: Photodiode readout, Global control and Suspension

Today, due to the complexity of the ITF control, the element involved into the locking loop runs near their computing limits. Some few improvements can be done, but the need of the new computing power will stress the R&D on the loop components.

3 Commissioning activities

3.1 Introduction

The interferometer, in its full (recycled) configuration, has been locked during October 2005. Details of the technique used (the *variable finesse* lock acquisition) have been given in the previous EGO council report.

From 2 to 7 December a data taking was performed (the C5 run) in both recycled and recombined configurations.

3.2 Run C5

The goal of the C5 run (2-7 December) was twofold :

1. Operate the recombined interferometer, with the automatic alignment and the re-allocation of the locking forces on the *marionetta*.
2. Operate the recycled interferometer (without automatic alignment and without marionetta control).

The first configuration was robust (several hours of lock achieved) and the correspondent noise level was stable. This allowed, as for the run C4, astrophysical-like signal injections, and correspondent tests of the data analysis algorithm.

The second configuration, even if less robust (max 1 hour lock, and noise level non stationary, due to the alignment fluctuations) allowed to start the study of the recycled interferometer noise.

The best strain sensitivity obtained in C5, with the recycled configuration, was around h ~ $8 \cdot 10^{-21}$ /√Hz. The C5 sensitivity, together with the other runs sensitivity and the Virgo best sensitivity (27 may 2005) is showed in figure 1. One should remark that the incoming power in the interferometer for the run C5 (only the recycled configuration is showed in the figure) was 10 times lower than the one used for C4. This is due to the attenuator placed between the injection system and the interferometer during summer 2004 to deal with the problem of the backscattered light. The noise sources for C5, in both recombined and recycled configuration has been identified and will be the subject of the section 3.5.

After the C5 run the recombined configuration (used extensively since June 2004 for control studies, noise analysis and data analysis studies) has been not operated anymore, and the commissioning work has been focused on the recycled configuration.

3.3 The automatic alignment

The reason of the fragileness of the recycled configuration is the absence of the *automatic alignment*. The angular position of the mirrors being *locally* controlled (referred to the ground), makes the overall interferometer alignment fluctuating and drifting out from the working conditions. As result, the robustness of the locking, the duty cycle and the stability of the noise of the recycled interferometer are limited. A global alignment system is necessary to operate the interferometer with good duty cycle and noise stability. This is called the *automatic (or linear) alignmen*t, already successfully implemented in the recombined interferometer, using the *Anderson* extraction scheme. The recycled configuration is much more complex, because the recycling mirror mixes all the optical signals, as it happens for the longitudinal control.

The automatic alignment work started in December 2004.

For the transition from the recombined interferometer to the recycled interferometer it was also necessary to upgrade the optical readout, the control and measurement software.

Together with the two set of quadrant photodiodes at the terminal buildings (transmission of the north and west cavity) already used for the recombined interferometer, two new optical readouts in the central building (quadrant photodiodes looking at the beam reflected from the interferometer and at the beam inside the recycling cavity).

In the following this new hardware was tested and tuned. In addition, the Global Control software has been updated so that it now provides the proper reconstruction and control algorithm.

The technique used is the following:

- Put angular lines (in the 2 angular degrees of freedom *pitch* and *yaw*) on all the mirrors.
- Measure the optical matrix between the angular displacement and the quadrant photodiode signals (a 16(signals)x5(mirrors) matrix).
- Reconstruct the mirror displacements, inverting the optical matrix
- Filter the reconstructed mirror displacement and send corrections to the mirrors.

A large amount of work has been invested in preparing and tuning an optical simulation. This simulation should allow to compute interferometer signal quickly using higher order modes. A set of standard simulations files for the various experimental interferometer conditions have been prepared. The simulation files have been used frequently since, mostly dedicated to investigating the lock instabilities.

The commissioning of the linear alignment has been almost entirely performed using the interferometer locked not at the dark fringe but with an 8% offset with respect to the dark fringe. This was decided because the offset lock provides a stable interferometer conditions in presence of an unexpected problem which affected the interferometer operation since January, the so called *jumps*. Details will be given in section 3.7.

To date we have installed all the necessary hardware and software. The implementation is well underway. In the past weeks we have been able to engage simultaneously 9 out of 10 linear alignment control loops, at 8% offset.

However, we have found the signals to be polluted by offsets which are not understood. These offset have been found also when the interferometer was working on the dark fringe. Such offsets could degrade the interferometer performance if they are found to be a consequence of an optical defect.

This offsets represent a concern for the conclusion of this work, and a deep investigation will be carried out in the following weeks.

3.4 Improvements in the mirror suspension control

After the implementation of the full hierarchical control of the superattenuator, successfully tested during C5, most of the work on the Mirror Suspension Control has been dedicated to reduce the effect of residual seismic noise on the mirrors. In fact, the operation of the interferometer is less reliable with strong winds (and high seismicity) conditions.

The superattenuator (SA) provides the required isolation performance above a few Hz. On the other hand, it amplifies the seismic noise at the frequencies of its normal modes. In order to reduce the resonant motions of the mirrors an active damping of the normal modes is needed. The *inertial damping* is performed at the level of the inverted pendulum (IP) and is based on the error signals of five accelerometers, allowing to sense four degrees of freedom (d.o.f.): three translations and the rotation around the vertical axis. At the moment only the three horizontal d.o.f. are controlled, since the need for a vertical damping is not evident.

A control based on accelerometers is *inertial* since the error signal is not referred to ground. The advantage of this choice is that the ground is a noisy reference system, since it is affected by seismic noise. The drawback is that accelerometers lose sensitivity at low frequency. The long term interferometer operation requires to keep the mirrors in the same working positions with good accuracy. This can be achieved by controlling the IP position with the available LVDT position sensors. The two requests (damping of the resonance and position control) are fulfilled by implementing a mixed control using position sensors in the range DC-70 mHz and inertial sensors in the range 70 mHz-5 Hz.

The use of position sensors (measuring the IP position with respect to ground) causes re-injection of seismic noise in the SA chain. When strong wind blows and the seismicity level is much higher this worsens the stability of the interferometer. An obvious solution would be to narrow the control bandwidth of the position sensors (and so to reduce the amount of seismic noise injected). This possibility is limited by the accelerometer response at very low frequency (below 50 mHz): the IP legs are not perfectly parallel. This causes an horizontal to tilt coupling which prevents the use of the accelerometers at very low frequency; the 1/f noise of the ADC dominates on the sensor signal.

We are trying to solve both problems: a strategy has been developed that allows correcting for the horizontal to tilt coupling using the information of the position sensors. Thanks to it, we have been able already to reduce the sensors crossover from 70 to 50 mHz, achieving a factor 3 reduction on the seismic noise injected at the microseismic peak; the sensors signal will be amplified in order to dominate the ADC noise. If ADC noise is really a limiting factor we will try to move the crossover down to 30 mHz and to achieve a further factor 3. This has been tested on one tower and the first results are promising: we have been able to move the crossover down to 30 mHz without any evident drawback.

The possibility that the vertical degree of freedom is also important in windy days is being explored: vertical motions may couple to the angular d.o.f. of the payload. If this is the case we will implement a pure inertial damping of the vertical d.o.f.. Also the effect of local controls (on the mirror and on the beam) is being investigated.

An effort is being done to update the SIESTA simulation for the suspension controls, introducing real noise levels and trying to reproduce the observed data.

3.5 C5 sensitivity analysis and noise hunting preparation

The sensitivity of the C5 interferometer was studied and understood. The low frequency part of the spectrum (10 Hz – 500 HZ) is dominated by control noises and the high frequency part (f > 500 Hz) is dominated by oscillator phase noise. Techniques to reduce both noises are under development. The noise produced by the injection bench resonances is also under investigation.

3.5.1 Control noises

These noises can be divided in two parts:

- Longitudinal noises: the locking of auxiliary degrees of freedom of the interferometer (small Michelson, power recycling length, common mode of the arms) has been done first with some robust filters (high gain and phase margin, high bandwidth) in order to make easier the lock acquisition and increase the lock stability. These controls are noisy. More sophisticated filters, and re-shuffling of the locking forces should be done to allow low noise operations. This work is in preparation, also through time domain simulation (SIESTA).
- Angular noises: the local alignment controls are noisy (referred to the ground). The automatic alignment, once ready, should allow switching off the local sensors, and controls the optics with a much higher SNR.

3.5.2 Oscillator phase noise

It has been observed during C5 that in the recycled configuration the sensitivity at high frequency (>500Hz) is about 40 times larger than the standard demodulation electronic noise and the shot noise. This extra noise has been associated to phase noise arising from the oscillator distribution board (*local oscillator* board). After the reduction of the LO board phase noise it is also expected that the generator (now a Marconi 2040) phase noise will limit the Virgo sensitivity.

The phase noise couples to the gravitational wave signal through the demodulation process: this noise is proportional to the signal present in the other quadrature of the interferometer main photodiode. To reduce it one should then reduce the LO noise itself and/or the other quadrature of the interferometer main photodiode.

The following actions are on going to reduce the phase noise itself:

- Have a better signal generator. A detailed analysis shows that to reach the Virgo sensitivity, the generator phase noise should be improved by a factor of 10. A technical analysis has been focused on the possible improvements to be done onto the actual Marconi 2040 signal generator. A market analysis has been focused on the research for a better (lower phase noise) Signal Generator.
- Improve the oscillator distribution system. A reduction of a factor 3 has already been achieved since C5.

The following actions are on going to reduce the other quadrature:

- Close the automatic alignment: a major component of the other quadrature of the main photodiode is proportional to the alignment defects. We expect to gain about an order of magnitude closing the automatic alignment (this reduction has been observed for the recombined interferometer)
- Active feedback: another way to reduce the phase noise is to cancel the other signal at the level of the photodiode preamplifier. Such a servo loop is used in the LIGO project: the other quadrature signal obtained after demodulation is again re-modulated with the oscillator signal in order to reconstruct the original signal and is subtracted from the preamplifier input signal. A prototype board based on this principle is under development at LAPP. As for now a reduction by a factor 3 has been reached.

3.5.3 Mode-cleaner length noise

It has already been pointed out after C4 that, above 30 Hz (mostly 30...80 Hz), there are lines in the gravitational wave signal, which are 5-6 orders of magnitude above the Virgo design sensitivity. Correlation measurements have shown that they are due to injection bench vibrations, excited by the noise of the amplifiers controlling the coil-magnet systems keeping the bench aligned. The resulting fluctuations of the mode cleaner length are coupled into the interferometer due to a non-perfect resonance of the Virgo main modulation sidebands in the mode cleaner.

From this result we have the following possibilities for reducing the lines:

1. reducing the electronic noise by modification of the coil drivers and DAC used to control the injection bench
2. preventing the introduction of the remaining noise into the interferometer by precise tuning of the modulation frequency to a mode cleaner resonance
3. passive (mechanical) filtering of the remaining noise

Due to the large factor to be gained, the potential of all of the above possibilities must be explored. Up to now, the following actions have been undertaken:

1/Noise reduction:

- modification of the coil drivers and introduction of switchable resistors (with increase of digital gain) after the coil drivers for "diluting" the electronic noise.
- modification of the mode cleaner length control loop for having the curved mirror follow the bench vibrations at the most notorious frequencies in order to keep the total length more stable
- modification of the injection bench control system (adding steep cutoff filters) for avoiding the emerging of control noise after th e electronic noise reduction. With the above three actions we obtain a 50-fold reduction of the noise going to the coils.

The results obtained up to now are:

- Three-fold reduction of the rms laser frequency noise, as measured in-loop by the reference cavity.
- The height of the lines, as they appear in the laser frequency noise, has been reduced by a factor 50 in the 30 Hz region, and 5 at 80 Hz.

2/ Tuning of the modulation frequency with the mode-cleaner length: preparation of a modulation frequency tuning system

The actions done are:

- Modification of the laser frequency stabilization system for avoiding the frequently observed frequency changes after switch-off, as a prerequisite for allowing control of the modulation frequency.
- Set-up of a monitoring system for the modulation frequency detuning, which delivers an error signal to be eventually used for a control system

The next steps to be undertaken are:

- Use of the low-noise coil drivers, presently being developed (ten-fold reduction of electronic noise).

- Switch of the injection bench control to lower noise error signals (wavefront sensing instead of local control with cameras) for avoiding control noise emerging after electronics noise reduction.
- Development of a modulation frequency tuning servo system.
- Depending on the possible noise reduction of this servo, a passive mechanical filter may be necessary. This requires a change in the bench suspension and a modified, and possibly quite complex, control system (to be avoided if possible). The attenuation could be of 100 at 30 Hz.

3.6 Last sensitivity obtained

The first figure of this report shows the last sensitivity curve, obtained on may 27th. A complete noise analysis is on going. Some improvements result from the work done on the phase noise and control noises reductions. The strain sensitivity is $h \sim 2 \cdot 10^{-21}$ /√Hz around 500 Hz.

3.7 The jumps

The automatic alignment and the noise hunting activity have been slowed down since January by an unexpected problem: instabilities in the locking point of the interferometer, jumping from one state (the correct one) to a second meta-stable state. This kind of instabilities (called *jumps*) sometimes unlocks the interferometer, make difficult a continuous operation of the interferometer for control studies (i.e. automatic alignment implementation) and noise hunting.

These *jumps* have been observed few times before C5 and a jump has been observed during C5. The occurrence of these events was in any case very low, and it was not disturbing at all the commissioning work before January. After January *jumps* are present almost continuously.

Despite the experimental and simulation work devoted to the study of this problem, the origin of this problem remains not understood.

In particular, we are investigating:

- Intrinsic optical effect (i.e. coupling locking-alignment as *the Anderson effect*, discovered during the recombined interferometer operation). This seems unlikely, because the interferometer was working correctly during C5.
- Clipping of beams on photodetectors
- Clipping of the main beams with in-vacuum optics
- Stray light on optical tables, and coming from in-vacuum optics (i.e. the injection bench)
- Secondary beams coming from the secondary surfaces of optics (AR surfaces)

3.8 Link commissioning – data analysis

In order to increase the link between commissioning and data analysis, few actions have been taken:

- Miniruns: a minirun is a small (few hours) data taking, in very controlled conditions. The frequency of the miniruns is about one each 2 weeks. The interferometer configuration during the minirun is representative of the present status of the detector. Up to now 4 miniruns have been performed, mostly dedicated to the study of the jumps.

- Contact persons commissioning/DA: a group of 4 people (one for each data analysis group) with commissioning experience has been set-up. The goal is to help the data analysis groups to deal with the detector issues during data analysis studies.

4 Data Analysis activity

During the last six months the attention was set mainly on the analysis of the data taken during the commissioning run. To improve our efficiency we asked have physicists, directly involved in the commissioning of the interferometer, acting as link between commissioning and data analysis groups.

Here we report the list of people appointed:

F. Bondu	Burst
R. Flaminio	Coalescent Binaries
E. Majorana	Continuous signals (Pulsar search)
L. Di Fiore	Stochastic Background

Moreover, E. Cuoco of the Noise group is acting as link toward the commissioning group and she is included in the commissioning board.

In the following sub-sections we summarize the progress of various groups focused on a specific task for detecting the GW signals:

- The *h-reconstruction group, dealing with the problem of extracting from the raw data the metric strain*
- *Study on the strategy for reducing fundamental noise*
- *Environmental noise study and correlation with the interferometer channels*
- *Interferometer noise characterization during the runs and software tool development*

Then we have the physics groups dedicated to the detection of a specific category of signals:

- *Burst*
- *Coalescent binary signals*
- *Continuous signals (Pulsar search)*
- *Stochastic background.*

4.1 h-Reconstruction group activities

During the past six months, the reconstruction group has essentially been dealing with the reconstruction of run C5 data.

Only data taken in recombined mode have been reconstructed, due to the absence of permanent calibration lines in recycled mode.

A first set of reconstructed data was delivered soon after the run. The necessity to include more data quality information (about detector status – like Pico motors active – or about the quality of data reconstruction itself) was evidenced by burst and inspiral analyses on these data.

A new set of reconstructed data was therefore processed, including more data quality information, and improving also the reconstruction in the 20-80 Hz range due to the removal of the beam splitter angular noise. The latter improvement increased the horizon distance for inspiral sources by 3 to 4 %. An estimate of the inspiral horizon distance is also provided as a by-product of the reconstruction.

4.2 Noise studies

4.2.1 Fundamental noise study

The group activity was focused on

1) Study of the low frequency tail of mirror thermal noise in the case of Gaussian and hyper Gaussian readout beams. [*See Classical Quantum Gravity 22 (2005) P.1395*]
2) Study of the thermoelastic noise in the case of Gaussian and hyper Gaussian readout beams
3) Study of the optothermal nonlinear couplings of laser power noise and shot noise with the readout beams in the cases of Gaussian and hyper Gaussian readout beams, and in the following channels:
    a. Optical power dissipation in the coating causing
        i. Thermal lensing
        ii. Thermal distortion
    b. Optical power dissipation in the bulk material causing
        i. Thermal lensing
        ii. Thermal distortion

These studies have been detailed in the Virgo Physics Book [*Virgo Physics Book sections "Thermal Noise", and "Heating issues"*]

4.2.2 Environmental Noise

In the last six months more effort has been dedicated to discover paths through which environmental noise can couple to the detector. The main disturbances that have been studied are the low frequency seismic noise induced by wind and sea, the external magnetic field coupling to the mirror magnets, and acoustic noise in the laser laboratory where the light beam is produced.

A detailed study of the seismic climate around the Virgo site is in progress. One of the aims is to document seism conditions before the installation of aeolic generators in the community of Pontedera with the nearest towers outside an area that extends 5.8 km from tube, central and end buildings. The low frequency band (0.1-4 Hz) was investigated and several interesting results were obtained. As expected wind and seismic noise are related as well as sea conditions. These effects show up below 1 Hz and can increase by a factor of ten the peak spectrum in that band. Further data are needed to better discriminate between sea and wind. A Virgo-GEO collaboration project has started (as part of ILIAS activities) aimed to study the seismicity and effects produced on the GEO interferometer by the existing wind power plant located just 1-2km from GEO. The results will be used to predict possible effects on Virgo.

Another result is that the inverted pendulum and the sensors used for its control can be used in place of the seismometers and accelerometers placed on ground. These studies are also part of the effort to improve inertial damping performance in rough weather. The rms accelerations over several frequency bands are now recorded as part of the monitoring data giving as a function of time the seismic conditions.

Further effort was dedicated to the analysis of magnetometer data. These instruments are quite sensitive and show saturation in several channels due to the electric power distribution at 50 Hz and harmonics. In addition a basic lightning recorder has been installed on the roof of the central building. First magnetometer signals correlated with lightning strokes have been seen, and further work will attempt to establish the amount of coupling with the mirrors.

The analysis on data collected in run C5 with a loudspeaker turned on in the laser laboratory has continued. It is established that below about 500 Hz acoustic noise causes beam jitter that appears as intensity fluctuations. At higher frequency there is still evidence for sound and vibration coupling. However due to the filtering properties of the mode cleaner intensity fluctuations cannot account for the observed dark fringe spectrum above 500 Hz. Work is in progress with further acoustic noise data remaining to be analyzed.

Finally a systematic search for frequency lines in dark fringe channel has been performed in C-runs data. Some lines of environmental origin have been identified as due to vacuum pumps motors or electronic devices. A database has been set up to store information of identified lines. A preliminary work has been done on the automation of lines detection and identification. Since C4 a simple and fast line detection algorithm is used to perform on-line the search for lines in the Virgo dark fringe channel
[REF: GWDAW-9: "A simple line detection algorithm applied to Virgo data" and "A First Study of Environmental Noise Coupling to the Virgo Interferometer"]

4.2.3 Development of Noise analysis software tools (NAP)

In December 2004 a first release of the Noise Analysis Package was done. The first application of this new software tool was reported at the GWDAW9 conference [*E. Cuoco and al. "NAP: a tool for noise data analysis Application to Virgo engineering runs", to appear in Classical and Quantum Gravity (GWDAW9 proceedings)*]. The application of a new tool (Multicoherence analysis) on the dark fringe and the environmental channels was reported. There were reported the tool for the data conditioning (whitening and adaptive lines removal) too.
In the following months many new algorithms were added to NAP and a general reorganization for the package was performed in such a way to make easier for the developers the implementation of new algorithms. The version vr01 of Nap was in the Virgo Common Software 3.0 release.
In the meanwhile the group is working to the v0r2 release: it contains also adaptive whitening, filtering application, resampling, non linear test, principal component analysis, etc.

4.2.4 Analysis of Commissioning and Miniruns data

The application of Nap utilities was performed either on C4 or on C5 data [*Noise analysis group: 'M1 analysis results', Virgo internal note, in preparation*]. In particular we tested the application of noise removal, using adaptive filter or multicoherence tool.
The group started a strict interaction with Commissioning group to help the understanding, using the data analysis tools, of the Interferometer features. In April and May were performed two short engineering runs, called minirun, (M1, and M2), and the collected data were analyzed by a mixed group of noise analysis people and commissioning people, with the aim of understanding the features of the jumps which occurs in the ITF.
During the first minirun an on-line glitch search was performed to find all the jumps (transient-like events) present in the data. Then the noise analysis group did a cross checks with the jumps and other ITF channels. A time-frequency analysis on whitened data was performed on different channels to identify the frequency content of the jumps and the behavior of the ITF before the occurring of the jumps.

4.3 Burst Group Activities

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

4.3.1 Development of filters:

The Time-Frequency method based on the S-transform has been presented at the GWDAW conference at Annecy last December. Since then alternative versions (implementing different kernels) have been developed. A paper aiming to compare all these methods is in preparation.
Different tools related to the noise properties have also been developed and tested. The two first ones are related to the detection of non-stationarities that can be annoying when trying to detect GW bursts. One is based on a Chi^2 test and the other on Rayleigh statistics. Both are described in [*M.A. Bizouard, A.C. Clapson, G. Guidi and P. Hello, "Burst search and non stationarity in C5 run data", Virgo Note, May 2005*] and have been used for analyzing the C5 run data. The last one is a dynamic improvement of the Kalman filtering methods used to remove lines in the noise spectrum, useful when whitening of data is required by some burst algorithm. The new version allows one to follow the thermal lines when they change with time (due to temperature changes for instance). A Virgo note is in preparation.

4.3.2 Analysis of C5 data:

Different filters have been used to analyze the C5 data (ITF in recombined mode). Besides stationarity studies have been performed. All studies have revealed clearly non-stationary events. More important, this work has shown our capability of: handling real data, analyzing real data and making the different analysis performed by different people converge. This work is described again in the same paper cited before [*M.A. Bizouard, A.C. Clapson, G. Guidi and P. Hello, "Burst search and non stationarity in C5 run data", Virgo Note, May 2005*].

4.3.3 Analysis of minirun:

We have also analyzed the short streams recorded during the miniruns. Jumps are obviously detected. Besides, a lot of much smaller transients (that can mimic GW events) have been seen, indicating again noise non-stationarities.

4.3.4 LIGO-Virgo joint working group:

A joint working group involving members of the Virgo and LIGO Scientific Collaborations has undertaken for the first time the task of defining and examining the prospects of joint burst searches involving data from their gravitational wave detectors. This is in anticipation of their future coincident observations at comparable sensitivities. As a first step, a comparative study of methods for burst searches using simulated data of the LIGO and Virgo instruments at design sensitivity was undertaken. The results have been presented in the GWDAW conference in last December. The next project is more ambitious: it aims at making coincidences between the three full scale (simulated) interferometers (Hanford, Livingstone and Cascina) with burst sources of different shapes located in the direction of the Galactic Center. This work is going on: the 3 simulated data streams have been produced and triggers lists are about to be given.
The work will be presented at the Amaldi Conference in next June.

4.3.5 Virgo-Bars common work:

As for the LIGOVirgo work, it is planned to perform a common Mock Data Challenges with Italian bars. The difference here is that we will use real data instead of simulated ones for the noise of the instruments. Discussions and works are going on.

4.4 Coalescing binaries group activities

The group was involved in five main lines of activity

- development of analysis code and pipelines based on Wiener filtering;
- analysis of real data (C4 and C5 run);
- development of analysis code based on adaptive line filtering;
- preparation to LIGO-Virgo network analysis;
- estimate of coalescing binaries rate for present and advanced detectors.

4.4.1 Development of analysis code and pipelines based on Wiener filtering

The CB group is developing a pipeline including two implementations of the Wiener filtering: a “flat search” parallel system (aka Merlino), which distributes the analysis over an MPI-based Beowulf cluster, and a “multi-band” system (aka MBTA), with a “divide and conquer” approach over the frequency band. Both Merlino and MBTA are capable of end-to-end analysis of real data; current work is mainly focused on the interface with the online system and the inclusion of external and internal vetoes.

The flat search parallel system (aka Merlino) has been interfaced with the online h-reconstruction, and with the “trigger manager” which collects events: a preliminary test was performed during C5; work is ongoing since then to complete the interface. Analogously, the MBTA code has been extended to run in-time, and might be tested during the next commissioning run.

The group has started studying the application to Virgo data of time-domain vetoes based on the behavior of the Wiener filter output.

Development of code for black-hole detection (BCV templates, non-spinning and spinning cases) has started. In relation to spinning BH, work has been started on the problem of grid generation in more than 2D

4.4.2 Analysis of real data (C4 and C5 run)

The analysis of C4 data has been presented at GWDAW 9, reporting both the flat-search and multi-band results, and characterizing the detector stability from the search point of view [*L.Bosi and al. Testing the detection pipelines for inspirals with Virgo commissioning run C4 data, to appear in Classical and Quantum Gravity (GWDAW9 proceedings)*].

The analysis of C5 data has been performed; results will be presented at the Amaldi VI conference. During C5, much of the run in recombined mode was populated with hardware injections of burst and coalescing binaries signals. The group has run both the flat-search and the multi-band pipelines on the science mode segments; the main goal was to investigate the recovery of the injected events and the discrimination of false alarms. Two levels of false alarm rejection have been applied: the first using auxiliary information, vetoing data segments affected by machine operations; the second applying Chi$^{\wedge 2}$ tests.

4.4.3 Development of analysis code not based on Wiener filtering

Methods alternative to Wiener filtering, less sensitive but more robust, are actively investigated. A method based on an adaptive line enhancer has been tested on simulated data, with promising results; a complete characterization of the detection performance is in progress.

A method based on a decomposition of data in “smooth chirps”, and in the reconstruction of chains of “short” chirps has been developed and characterized in simulation [*E. Chassande-Mottin and A. Pai, Chirplet chains: a quasi-physical model for near-optimal detection of gravitational wave chirps, presented at GWDAW-9, preprint in preparation*].

4.4.4 *Preparation to LIGO-Virgo common analysis*

The coalescing binaries group is participating to the developments and mock-data challenges in preparation to a common LIGO-Virgo analysis [*F.Beauville et al. "A first comparison between LIGO and Virgo inspiral search pipelines", to appear in Classical Quantum Gravity (GWDAW9 proceedings)*]. In the last six months:

- the simulation code has been extended to allow Monte Carlo simulation of signals received in a correlated way by different detectors [in collaboration also with the burst group];
- the template generation codes have been compared with LIGO codes; differences were found, related to different conventions and/or values of physical constants adopted. Fixing these differences simplifies the comparison of events, and is a prerequisite for a coherent analysis;
- data for a common, coherent analysis have been generated, and are being analyzed. The work will be reported at the Amaldi VI conference and will include coincidence analysis and some preliminary results of coherent analysis.

4.4.5 *Estimate of coalescing binaries rate for present and advanced detectors*

Another activity has been characterized by an end-to-end approach: from the astrophysics of the sources to their detection, by examining the specific contribution to the noise of the interferometer. We have been concerned with both establishing the detection rate for coalescing NS by the actual VIRGO configuration [*de Freitas Pacheco J., Regimbau T., Vincent S., Spallicci A., 2005. Expected coalescence rates of NS-NS binaries for laser beam interferometers, Mon. Not. R. Astr. Soc. (submitted)*], [*Regimbau T., de Freitas Pacheco J., Spallicci A., Vincent S., 2005. Expected coalescence rates of NS-NS binaries for ground interferometers, to appear in Classical Quantum Gravity (GWDAW 9)*] and estimating detection rates in future improved detector configurations [*Spallicci A, Aoudia S., de Freitas Pacheco J., Regimbau T, Frossati G., 2005. Virgo detector optimization for gravitational waves by coalescing binaries, Classical Quantum Gravity, 22, S461*].

4.5 Continuous signals - Pulsar search

We continued the development of the software mainly for the hierarchical search, implementing also new ideas.

A new pre-processing procedure was developed. This is used together with the creation of the short FFT data base. The module that deals with this is the PSS_sfdb library used to create the SFDB and the peakmap. It contains various utilities, such as a procedure to recognize and remove time disturbances; a procedure to perform a robust AR estimation of the noise; utilities to add simulated burst signals to the noise and/or simulated continuous signals, with the Doppler effect due to the Earth motion (PSS_sfdb is linked with the PSS_astro codes); utilities to extract sub-bands from the SFDB. It permits also to add simulated periodic source signals.

The “Adaptive Hough Map” (AHM) was introduced, that enhances the sensitivity in non-stationary data. The pss_hough module was updated to implement the AHM. This was tested with simulated peak maps.

A set of equations have been systematized, in order to define best strategies for the hierarchical search (optimizing the sensitivity given a certain computing power and parameter space).

Regarding the Matlab Snag toolbox, new functions have been added for the data simulation and data management.

The PSS_UG user guide was continuously updated
[*see* [*http://grwavsf.roma1.infn.it/PSS/OtherDoc/PSS_UG.pdf*](http://grwavsf.roma1.infn.it/PSS/OtherDoc/PSS_UG.pdf)].

Concerning the Grid activities, Lyon computing resources have been added to the Virgo Virtual Organization. The Grid has been used to perform a set of simulations of the neutron star population. *[C. Palomba, "Simulation of a population of neutron stars evolving through the emission of gravitational waves", MNRAS 359,1050, 2005]*.

We conclude this sub-section with the list of the papers presented during the conference GWDAW-9 and sent for publication*:*
[*P. Astone, S. Frasca, C. Palomba "The short FFT Data Base and the peak map for the hierarchical search of periodic sources" submitted to Classical and Quantum Gravity]*
[C.Palomba, P. Astone, S. Frasca"Adaptive Hough Transform for the search of periodic sources" submitted to Classical and Quantum Gravity]
[S.Frasca, P. Astone, C. Palomba "Evaluation of sensitivity and computing power for the Virgo hierarchical search for periodic sources" submitted to Classical and Quantum Gravity]
[C. Palomba, "Simulation of a population of gravitational wave-driven neutron stars"]

4.6 Stochastic background group.

The activity in the last six months is summarized as follows:

Software implementation.
The implementation of the first version of the stochastic background data analysis library was completed. This library contains a simulation, detection and a statistic section.

- The simulation section is devoted to the generation of stochastic background signals for a network of detectors accordingly with a given physical model, and uses both parametric and nonparametric techniques.
- The detection section contain, in this first version, standard algorithm for the generation of optimal filters and calculation of cross correlations.
- The statistic section contains tools for the statistical characterization of detection results.

Scalar stochastic background.
A Ph.D. student is working on the problem of detection of a stochastic background of scalar fields.

Collaboration with other experiments.
The collaboration with bar experiments is started. The writing of a white paper with a detailed scientific proposal is presently discussed inside the collaboration (Virgo-Auriga-Rog).

We had a significant change in the organization of the SB group in the last six months. In fact, Tania Regimbau and Luciano Di Fiore joined the stochastic background group. Tania has a big experience about astrophysical stochastic background and stochastic background data analysis. She worked several years for LIGO and GEO. Luciano is the contact with the commissioning group.