Virgo progress report

to the STAC & the EGO Council

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The Virgo Collaboration

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Summary

1) Perimeter of the Collaboration

The Virgo Collaboration (VC) currently comprises 18 teams coming from Italian, French, Dutch, Polish and Hungarian laboratories.

8 Italian teams (INFN+Universities):
- Firenze/Urbino (10)
- Genova (4)
- Napoli (12)
- Padova/Trento (12)
- Perugia (10)
- Pisa (27)
- Roma1 (18)
- Roma2 (11)

7 French teams:
- ESPCI, Paris (1)
- LAL, Orsay (10)
- LAPP , Annecy (21)
- LMA, Lyon (15)
- OCA-ARTEMIS, Nice (8)
- Paris6-ENS-LKB (3)
- Paris-7-APC (8)

Other European teams :
- NIKHEF, Amsterdam (22)
- POLGRAW, Varsaw (9)
- RMKI, Budapest (9)

The figures in parentheses are an estimation of the size of these groups. Those are subject to some uncertainty or even fluctuations, due to departures and arrivals of permanent researchers, post-docs and PhD students, engineers, technicians. The total is around 250 persons.

To give an idea of the total resources, to these academic groups should be added about 30 persons within the EGO consortium.

The different groups cooperate in the main domain of activity of the project :

a) Hardware

Optics in a large sense
- Optics : 10 groups + EGO
- Optical simulation : 3 groups + EGO
- Mirrors : 1 group
- TCS : 2 groups + EGO

Suspensions : 6 groups

Payloads : 4 groups

Vacuum : 5 groups + EGO
Cryogenics : 3 groups + EGO

Electronics & control : 6 groups + EGO

b) Data Analysis

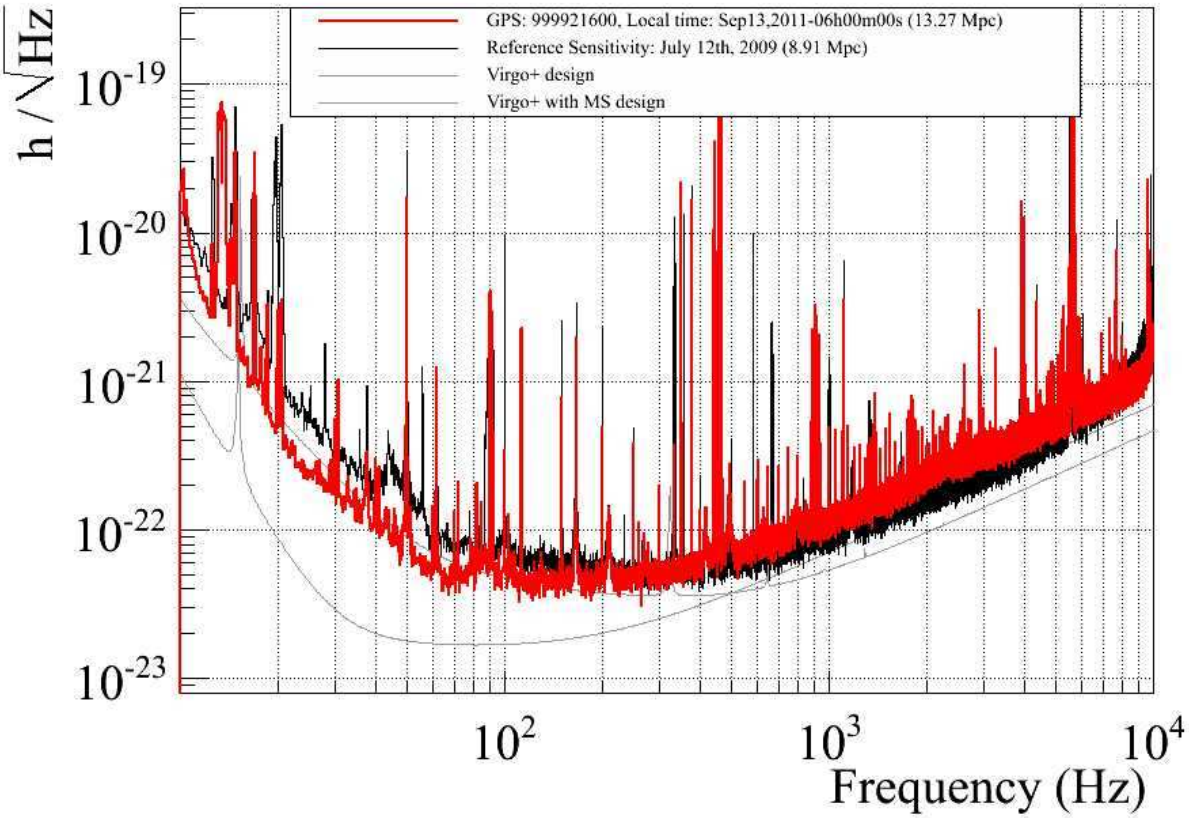
Permanent sources : 4 groups
Bursts, transients : 5 groups
Compact Binary Coalescences : 7 groups
Stochastic Background : 3 groups
Multimessenger : 4 groups
Noise studies, DQ : 5 groups

NB : A report on DA is due for the next STAC/Council session. This field is therefore not addressed in the present report.

2) Last phase of Virgo+

The last phase of Virgo+ has been devoted to commissioning, essentially understanding of the noise structure, and to a science run (VSR4) in common with GEO HF. Moreover, one goal was to test some improvements AdV-oriented. The details are in the Commissioning report, and the Detector report, but salient facts may be pointed :

- The noise structure has not been completely understood, and the detailed contribution of thermal noise in monolithic suspensions has been questioned. This is an open question, which should be carefully addressed in the context of advanced Virgo. See below a typical sensitivity curve during last summer. A series of tests is in progress at Roma-La Sapienza for measuring the Qs of the different elements of the payloads.
- A first positive result is the efficiency of the CHRoCC (Central Heating for Radius of Curvature Correction) system, allowing a fine tuning of the focal lengths of the mirrors and retrieving a better symmetry between the two arms.
- A second positive (recent) result is the possibility of a large reduction of the magnetic strengths involved in the mirror control system by a measure of velocities and anticipation of the motion of the test masses. This reduction could drastically reduce the spurious couplings with external fields, and the noise produced by the coils at too high intensity.
- The sensitivity has been increased by a factor of ~3 with respect to VSR2. The duty cycle was about 80%.
- The injection system has been tested with the new dihedron produced for AdV.
- Noise hunting allowed to reduce several sources like non-linear coupling, scattered light from suspended baffles, environmental
- Some noise lines and harmonics pollute the sensitivity up to 100 Hz and are still to be understood and fixed.



Virgo+ spectral sensitivity during VSR4

The sensitivity has been nevertheless increased with respect to Virgo (see Figs.1,2 below) but not as much as expected.

– **Data Analysis related to VSR4**

A detailed report on Data Analysis works and developments will be delivered at the next STAC/EGO Council meeting, as accepted by the STAC recently, who agreed on the fact that such reports can be issued on an annual basis until science data are again produced by the instrument. I nevertheless include a summary by Marie-Anne Bizouard (LIGO/Virgo DAC co-chair) and Pia Astone of the work done and in progress about the common GEO/Virgo science run during last summer.

Between June 3rd and September 5th Virgo has taken science data in coincidence with the GEO detector. The sensitivity improvements at low frequency, a factor 2.9 with respect to VSR2 at the Vela frequency, provided a last opportunity for Virgo to take science data and carry out sound searches. A duty cycle of 81% has been achieved although data taking has been interrupted by few usefull commissioning and noise hunting breaks. The evolution of the horizon to a neutron star binary coalescence signal is shown on Figure 1. By the end of VSR4, the horizon was higher than 11 Mpc. Figure 2 compares the Virgo sensitivity in VSR2 and VSR4 in the low frequency region.
The calibration has been checked before the run starts and all monitoring tools were running online. Thanks to years of automation, many outputs (h(t), data quality, etc) were generated online and a light but efficient team of data quality experts has also provided feedback to commissioners and noise hunters during the summer. For instance, a non linear coupling between calibration and control lines has been identified in the first weeks as a source of noise in the region of the Vela frequency.

Two kinds of GW signal had been identified as interesting [1]: GW emitted by low frequency

known pulsars. This involves only Virgo data. The second subject is the triggered GW search in coincidence with GEO and Virgo data of transient events at high frequency, above ~700 Hz where GEO and Virgo had similar sensitivities this summer.

Preliminary studies of the low frequency pulsar searches have been presented at the last LSC Virgo general meeting in September. Combining VSR2 and VSR4 data one can expect an improvement of a factor 1.8 on the upper limit set on the amplitude of a signal. The S5 results for the Crab pulsar are also likely to be improved when combining S6/VSR2 and VSR4 data by a factor ~1.6. For the Crab, The Virgo groups plan also to do a specific search around the orbital frequency instead of 2 times the orbital frequency. The spin down limit of some some low frequency pulsars (<100 Hz) could also be beaten assuming non canonical but plausible value for the momentum of inertia.
In addition to these known pulsars studies, an all-sky search in the low frequency region (< 60Hz) where Virgo VSR4 data are unique will be carried out. In order to improve the livetime of the search, results of VSR2 and VSR4 data will be combined.
A directed search (where the position of the source is known but not its frequency) is also under consideration. The supernova remnant G266.2-1.2 whose frequency is unknown but is likely young and near is a good candidate.
The coincident GEO/Virgo GRB search has already started using the GW burst search carried out with S6/VSR2-3 data. No nearby GRB have been detected during VSR4 run. In addition to the long GRB search, a supernova (SN2011dh) has been detected on May 30th, 3 days before the official start of the VSR4/S6e run. GEO and Virgo were taken data in astrowatch mode. This is a compact IIb type supernova located at ~ 8 Mpc (M51 galaxy) which is too far away to have any chance to observe a GW signal. This supernova is anyway included in a small set of known supernova which occurred since LIGO and Virgo are taking science data and for which a dedicated search is underway.
In parallel to the summer GEO/Virgo run, data analysis groups are working hard to complete S6/VSR2-3 searches. 3 papers directly involving Virgo members are going to be submitted very soon. One concerns the low latency compact binary coalescence search associated to the alert system to trigger an electromagnetic follow up of the most interesting candidates. The Virgo members of the burst group have led the all-sky burst search and the long GRB searches. Two upper limit papers are going to be submitted to journals soon.

The completion of all S6/VSR2-3 searches will still require between 1 and 3 years of work. In parallel to this, we are trying to move manpower on developments for the advanced detectors era. A list of scientific goals has been defined in each group in the last edition of the white paper [2].

[1] The Data Analysis LSC/Virgo groups, "Joint Virgo-GEO science run in summer 2011: the science case", VIR-063B-11 /LIGO-T1100131.
[2] The Data Analysis LSC/Virgo groups, "The 2011-2012 data analysis, software and computing, detector characterization white paper", VIR-0353A-11/LIGO-T1100322.

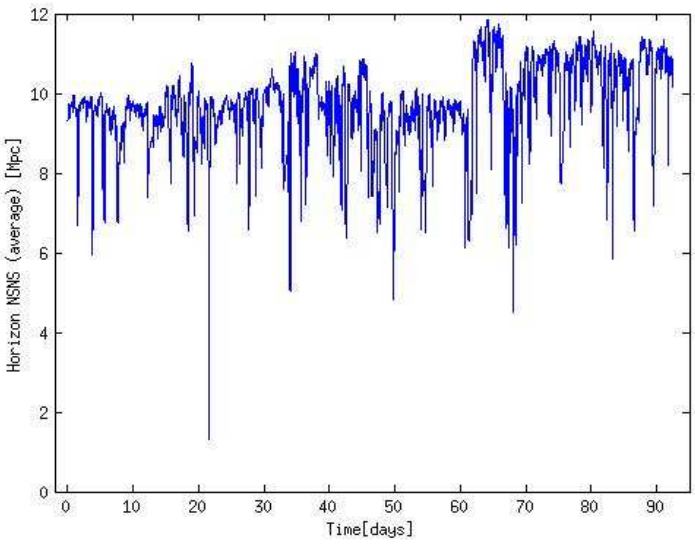


Figure 1: Horizon (distance at which a neutron star binary coalescence is observed with a SNR of 8 in the Virgo detector) as function of time during VSR4.

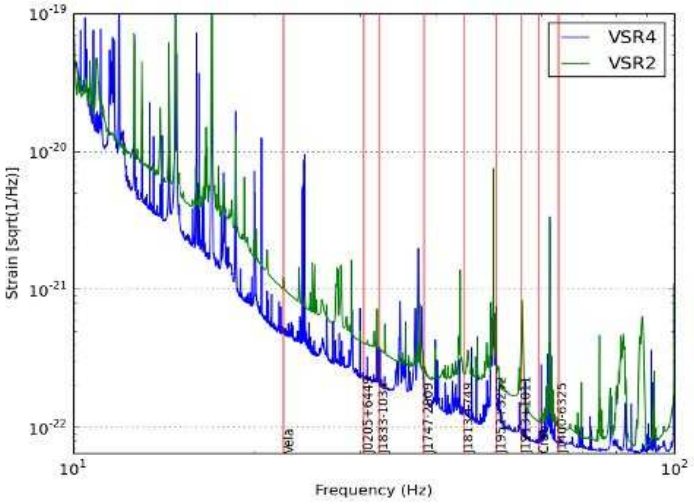


Figure 2 :
VSR2 (green) and VSR4 (blue) sensitivity curves at low frequency.

Remarks on the Advanced Virgo progress

The activity of the collaboration has changed of nature with the end of Virgo+ and the beginning of the path to Advanced Virgo. The definition of the optical layout, which is the kernel of the project was particularly difficult owing to the principle of Marginally Stable Recycling Cavities, very sensitive to mirrors defects and thermal effects. A wide effort of numerical simulation, of R&D about thermal compensations systems has been necessary. A complete report is released in the AdV report, but it is possible to summarize some salient facts.

Questions still to be addressed :

- The detailed planning : The coming months will be spent mainly in installation of the External Input Bench (until first days of February). The displacements of the vacuum towers should start in March 2012. The year 2015 is still maintained for the start of commissioning of AdV. However, a detailed planning will be worked out in the next months together with the new WBS.

- The excess thermal noise in the monolithic suspensions observed in V+.

- The Q of the pendulum modes is found to be one order of magnitude lower than expected, a and the Qs of the mirrors bulk drum modes are also low. Moreover the Qs are very different depen-ing on the considered TM. Studies are in progress to modify the payloads.

- The question of a wedge in the input test masses and corresponding metrology at LMA. No wedge causes etalon effects in the test masses perturbing the measurements. On the other hand, a wedge causes spurious beams that must be dumped.

- A lack of manpower has been pointed out several times: We need some EGO grants for the coming period.

Significant recently solved (or almost) questions :

- The optical layout, finally adopted after several months of discussions, of calculations and numerical simulations. The long cavities are bi-spherical. The arm cavity finesse has been set at 450, the power recycling gain is 37.5, the finesse of the signal recycling cavity of 26 with a length of the order of 12m.

- The thermal compensation systems, which promises to be efficient in correcting the ROCs, the long wavelength mirror defects, symmetrical or not. Even the short scale defects could be corrected, provided a suitable measurement system (under development). Several devices have been tested, using heating rings, scanning CO_2 laser and double axicon systems. Measurement systems are based on phase cameras and Hartmann sensors.

- A company has been found for supplying a rod fiber laser having suitable properties. It will be tested in the coming months for reliability. At a power of about 100W, the coupling with a cavity was about 92%.

- Since the Virgo+ mirrors, a strong improvement of the uniformity was done. LMA is now able to produce a flarness of 0.5 nm RMS over 160 mm, at the condition of 1 substrate per run. For obtaining two optically identical pieces, in order to insure the symmetry between arms, a common run is needed, and the only possible solution is a planetary motion. Conclusion of the studies in following months.

- The installation of the external Input Bench and its commissioning will be the first action of the AdV assembly and integration phase.

Some remarks about the coordination :

The OSD activity is now finished stricto sensu, since the optical layout is almost frozen. But a large effort of simulation is still necessary in the context of the development of the TCS and of the mirrors features assessment. Several codes were developed in the collaboration and in the EGO team, besides commercial packages for optical design. Several codes based on modal expansions of the optical fields and of real mirrors, or propagation by Fourier Transforms, were also written by the different involved groups. This has a benefit: cross checking possible surprising results. Now, we need to proceed in this effort with a systematic and optimizes use of well documented codes.

New question :

Squeezing techniques are presently not foreseen for AdV. It is nevertheless useful to watch the progresses of this field of R&D in particular in GEO and LIGO. We recently asked a collaborator of the Nice group, having skills in quantum optics to digest and report significant advances for the collaboration. Contacts with the EGO team are mandatory.

3) EGO Contribution

Though a report on the activity of the EGO teams is under the responsibility of its Director, it is difficult not to give a short summary from the point of view of the interaction of EGO with the collaboration teams.

Contact with DA teams :

Several experiments and studies for reducing the external noises. Noise monitoring tools developed in collaboration with the Roma-1 group. Identification and mitigation of scattered light effects, Contributions to Data Quality and glitches investigations. Important contribution to VSR4

Contact with Optics groups :

Installation of diaphragms for beam dump, input Mode Cleaner dihedron installation, a Central Heating ROC Correction for the end mirror of the input mode-cleaner final design is under construction and planned for installation within a month. Design of the Faraday isolator, complete study of the mode-matching telescope. Specifications of the IMC flat mirrors. Specifications for the jitter of the input beam have been released.

4) Relations with LSC, LIGO, GEO

LSC :

- We have biweekly “LVdir” meetings with the LSC spokesperson Gabriela Gonzalez, with the LIGO laboratory director David Reitze and the deputy director Albert Lazzarini.

- In the domain of Data Analysis, we have working groups in each sector of physics:
  i) Marie-Anne Bizouard is co-chair of the DAC (Data Analysis Council)
  ii) Giovanni Prodi is co-chair of the “burst” group
  iii) Frédérique Marion is co-chair of the “Coalescing Binaries”group
  iv) Giancarlo Cella is co-chair of the “Stochastic Background” group
  v) Pia Astone is co-chair of the “Continuous Waves”group
  vi) Didier Verkindt takes care of a Data Quality group
  vii) Elena Cuoco is in the noise characterization group

- We have appointed « liaisons » between corresponding subsystems of LIGO/Virgo:
  viii) Joint Run Committee co-chairs : Nicolas Leroy, Fred Raab
  ix) Detector Characterization Committee liaisons : Didier Verkindt, Josh Smith
  x) Calibration liaisons : Loic Rolland, Xavier Siemens
  xi) Joint Computing and Software Working group co-chairs : Marie-Anne Bizouard, Patrick Brady
- We have appointed a committee for organizing the common meetings LSC/Virgo, Composed of Francesco Fidecaro and Erik Katsavounidis
- We have currently a discussion about the policy regarding the way of releasing the future science data after 2015. A debate on that question is scheduled at this EGO Council meeting.
- “Big Dog”

A gravitational event was found on September 16th (2010), localized in the sky cell corresponding to the constellation “canis major”and therefore surnamed “big dog”.
It appeared later that the event was a blind injection (but the exercise was a convincing demonstration of the efficiency of collaborative DA). A paper was nevertheless prepared and there was a long discussion between LSC and Virgo about making public or not that paper in the web page maintained by the LSC. LSC finally agreed to restrict access of the paper to some specific requests from astronomers.

- “open data policy” : There is a strong pressure from LSC to define as soon as possible the way data may be made public. We are linked with a MoU for data sharing with LIGO, so that we have to define our own position. We have delayed the answer to a release of guidelines by the EGO Council.

– **GEO:**
Common run in August reported above, contacts for squeezing studies foreseen

5) Relations with other experiments

- **LCGT :**

Visit organized by the Italian Foreign affairs Ministry in October for a common workshop, the status of LCGT has been presented, as well as the status of AdV. A number of possible exchange fields have been indentified: and R&D about cryogenics, optics, suspensions. It was proposed that next time, other Virgo groups could be represented, after suitable diplomatic arrangements.

- **Indigo** : visit in November (2d,3rd) conclusions will be reported later.

6) Publications

Thanks to Andrea Viceré (Editorial Board)

Papers published in 2011

T. ACCADIA et al. (The Virgo Collaboration)
THE VIRGO INTERFEROMETER FOR GRAVITATIONAL WAVE DETECTION.
INTERNATIONAL JOURNAL OF MODERN PHYSICS D **20** (2011) 2075- 2079

T. ACCADIA et al. (Virgo Collaboration)
A state observer for the Virgo inverted pendulum.
REVIEW OF SCIENTIFIC INSTRUMENTS 82 (2011), 094502-1- 094502-9

J. ABADIE et al. (The LIGO Scientific Collaboration and the Virgo Collaboration)
Beating the spin-down limit on gravitational wave emission from the Vela pulsar
THE ASTROPHYSICAL JOURNAL **737** (2011) 93- 108

J. ABADIE et al. (The LIGO Scientific Collaboration and the Virgo Collaboration)
Search for gravitational wave bursts from six magnetars.
THE ASTROPHYSICAL JOURNAL LETTERS **734** (2011) L35- L43;

T. ACCADIA et al. (The Virgo Collaboration)
Status of the Virgo project
CLASSICAL AND QUANTUM GRAVITY **28** (2011) 114002-1- 114002-10

J. ABADIE et al. (The LIGO Scientific Collaboration and the Virgo Collaboration)
Search for gravitational waves from binary black hole inspiral, merger, and ringdown.
PHYSICAL REVIEW D **83** (2011)., 122005-1- 122005-20;

T. ACCADIA et al. (The Virgo Collaboration)
Performance of the Virgo interferometer longitudinal control system during the second science run.
ASTROPARTICLE PHYSICS **34** (2011) 521- 527;

T. ACCADIA et al. (The Virgo Collaboration)
Automatic Alignment system during the second science run of the Virgo interferometer.
ASTROPARTICLE PHYSICS **34** (2011) 327- 332;

T. ACCADIA et al. (The Virgo Collaboration)
Calibration and sensitivity of the Virgo detector during its second science run.
CLASSICAL AND QUANTUM GRAVITY **28** (2011) 025005- 025029

Submitted

J. ABADIE et al. (The LIGO Scientific Collaboration and the Virgo Collaboration)
Directional limits on gravitational waves using LIGO S5 science data
http://arxiv.org/abs/1109.1809, submitted to Phys. Rev. D

7) Outreach (Carlo Bradaschia)

European Researcher's Night 2011
Last September EGO and Virgo took part, for the third time, to the European Researchers' Night during two days, September 23 and 24.

On the occasion, we organized several activities which included guided visits, astronomical observations, "build your own interferometer" workshops and a Science Café.

The main event was however, on the evening of Saturday 24, at Palazzo dei Congressi, in Pisa. An actress and playwright (Lucilla Giagnoni), played an enthralling monologue, "Big Bang", accompanied by beautiful images and original music. It must be said that she went through most of the hot questions of modern physics in an absolutely correct way, contributing to the main goal of the Night: science dissemination. All points of view have been taken: science, art, religion and philosophy.
The debate which followed the spectacle was very interesting thanks to the contributions of a philosopher, of a priest/astronomer from the Vatican Observatory and of physicists and cosmologists. We were pleased to see a large audience, exceeding 400 persons.
For the 2011 Researchers' Night, we observed that almost all the events we proposed got a saturated booking list several days before the closing date.
We had more than 50 visitors at each guided tour; one group of students for the workshop "build your own interferometer" and about 150 participants in the Science Café and astronomical observations. The large majority left the site very late, and as in 2010, we succeeded in making them go back home with a smile on their face, which says a lot on our results and make us very satisfied.

Newspapers
Several newspapers announced the Researchers' Night, following a suitable press conference at Comune di Pisa.
We have also written a short news for the November issue of CERN Courier.

Radio and TV
We have been invited to perform the assembly of a 100 € interferometer at GEOMagazine, a popular afternoon science show of the state TV RAI3. It has been recorded on October 28.

Site visits
After the summer break, the site visits restarted regularly early October, with the frequency of one per week.
As in the previous years, next November 3rd, we will have a special visit of 40 high school students who come to Cascina to spend a full "researcher's day". Divided in four groups of 10, each followed by a tutor, they will take part in several practical activities, after having visited our site. These activities include:

- Seismic measurements
- Noise analysis (time domain and frequency domain)
- Comparison of a pendulum with an inverted pendulum
- Air refraction index vs pressure (counting fringes in a small interferometer).

At the end, the results of the various groups will be discussed and, upon a quiz contest, the best group will be granted a Galileoscope (working reproduction of Galileo's instruments), developed in

2009 for the International Year of Astronomy.