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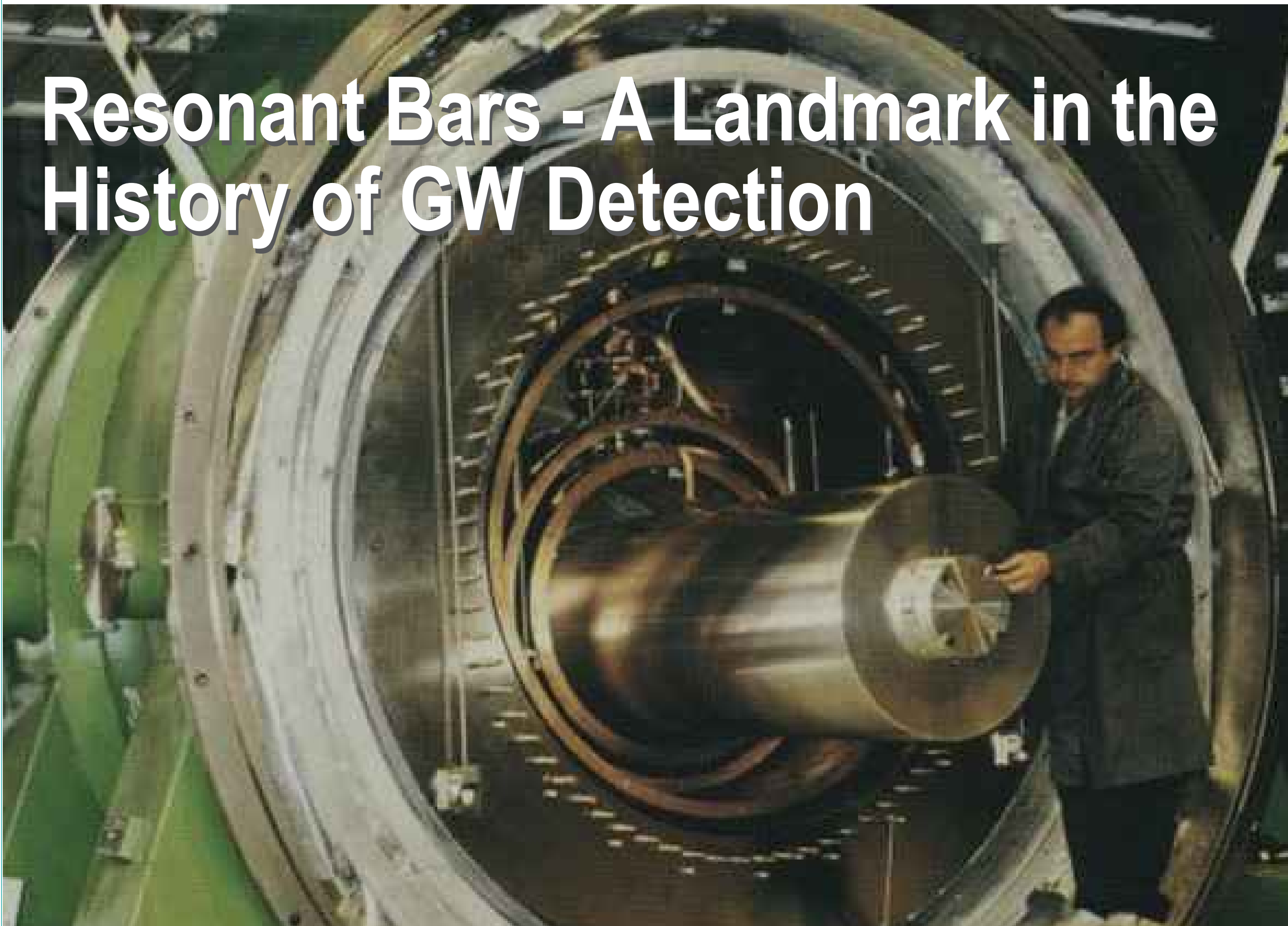
Resonant Bars - A Landmark in the History of GW Detection



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"h - The Gravitational Voice" is an internal publication of the European Gravitational Observatory (EGO) and the Virgo Collaboration.

The content of this newsletter does not necessarily represent the opinion of the management.

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READERS' LETTERS

I am glad to have a new way to know about Virgo, different with respect to reading the Log-book. Why the title of the newsletter is "h"? Why do you use these strange units: $1/Hz^{1/2}$ for the sensitivity curve?

Simon Mataguez, CERN, Geneve

In the Gravitational Wave (GW) community jargon, *h* is the amplitude of the wave, as E_0 (with dimensions of an electric field) is the amplitude of the EM wave represented by:

$$E = E_0 f(kx - ct)$$

Contrary to E, *h* has null dimensions. In fact *h* represents the perturbation to the "flat" space, due to the passing GW. We know that space-time is distorted by gravitational fields, hence also by GWs. Assume the distance between two free point-like masses be L, in absence of GWs, it becomes L+d(t) in the presence of a GW. The amount of perturbation is d(t) and the amplitude of the GW may be defined as $h(t) = d(t)/L$. Being the ratio of two lengths, *h*(t) is dimensionless. To learn more, you can look at: http://en.wikipedia.org/wiki/Gravitational_wave.

In general it is interesting to know the amount of power transported by a radiation at the different frequencies (the power frequency distribution). In the radio-engineering world, this is measured by the power delivered in each unitary frequency interval, hence it is naturally measured in W/Hz. Since the power transported by radio waves (electromagnetic radiation) is proportional to the square of the amplitude E, the power distribution can also be measured in units of E^2/Hz, neglecting the dimensions of an appropriate constant. Also for GWs, the power is proportional to the square of the amplitude *h*, hence the power distribution has dimensions of h^2/Hz, that is 1/Hz.

GW detectors have the peculiarity of being sensitive to the amplitude of GWs (e.g. the arm length L of an interferometer becomes L+d(t)), while, in general, EM radiation detectors are sensitive to the transported power (e.g. the light intensity seen by a telescope). For this reason it is interesting to know the square root of the power distribution, which is proportional to the GW amplitude *h*; this quantity $\sqrt{(h^2/Hz)}$ has dimensions $\sqrt{(1/Hz)} = 1/\sqrt{Hz}$.

The sensitivity curve (technically called "linear power spectral density distribution") represents the square root of the power per unitary frequency interval, transported by GWs having the same intensity of the noise present in the detector. Hence it is a measure of the noise level of Virgo: the lower the noise, the better the sensitivity.

EGO Council and STAC Autumn Meeting Outcomes

At EGO this autumn the meetings of the EGO Council were held, on 8-9 December, preceded by that of its Scientific and Technical Advisory Committee (STAC), on 20-21 November.

The main issues for the STAC were an assessment of the status of EGO and of the advancement of Virgo commissioning and of Virgo upgrades, and the evaluation of the R&D proposals. The issues for the Council were also these, along with the approval of the 2007 provisionary budget and of the R&D program, as well as the approval of the staff plan and salary adjustment.

A few sentences extrapolated from the STAC report to the Council may give a sense of its evaluations:

■ The EGO organization continues to play leading roles in many of the activities around the Virgo instrument. The infrastructure is moving forward, with the new building and a new computing space taking most of the attention. The STAC looks forward to the completion of the site for a steady-state operation, allowing funds currently needed to complete these one-off expenses to be used for supporting the instrument development. The fact that EGO staff play such a strong role beyond the day-to-day operations, in the form of commissioning support and participation in near and long-term advancements in the detector, is a sign of the health of the personnel organization.

■ The progress in commissioning Virgo has been significant, and has led to a decrease in the mid-band noise of up to a factor of 10 since the last STAC meeting. The sensitivity in the high frequencies, above 500 Hz, is well understood and within a factor of 2-3 of the Virgo design. A significant effort both to measure and improve the noise at lower frequencies has allowed some progress and equally importantly guided the plans for future commissioning. The STAC believes that the further commissioning must be seen as absolutely the first priority for EGO's manpower and financial resources, as well as the Virgo Collaboration manpower and financial resources, in the next 6 months. This time scale is chosen due to the target of opportunity to join in the current LIGO observing run.

■ Regards the 20 R&D proposals that were submitted to EGO to be part of its 2nd R&D program and that the STAC has examined, it recommended, among other things, that all funded proposals be identified as addressing issues of one of the identified Working Groups in the Advanced Virgo organization, and to see their contribution in the structure of that working group.

About the Council meeting it is worth remembering that extensive reports on the status of EGO, VESF and the Virgo collaboration were presented, followed by specific reports on Virgo commissioning, Virgo upgrades, Advanced Virgo, Data Analysis and Outreach. After these, the STAC Chairman presented the STAC report, and the recommendations contained therein were endorsed by the Council.

After these presentations, the Council went to the heart of the meeting in which decisions had to be taken. Among these decisions we may quote a few relevant ones:

■ The 2007 budget was approved for a total contribution by the members of the Consortium at somewhat over 9 M€, plus other incomes for 240 k€, giving a total figure of about 0.5 M€ less than that available 2006. The effect of inflation would further reduce the effective value of the 2007 budget with respect to that of 2006.With this amount of contribution however, EGO shall be able to run the site and the Interferometer as well as to support the on-site and off-site computing for Virgo as well as to complete the Virgo upgrades and Virgo+ programs foreseen for the year and to complete the construction of the new building and its connection to the area, although without completing its outfitting to be completed in the following year. What is going to suffer from the reduction of the budget is the maintenance and upgrades of the equipment and of the infrastructures.

■ Approved the launch of the 2nd EGO R&D program with 7 projects, which had received the highest grades in the STAC recommendation, to be financed and 6 more proposals to be re-considered after their adaptation to the recommendations given by STAC.

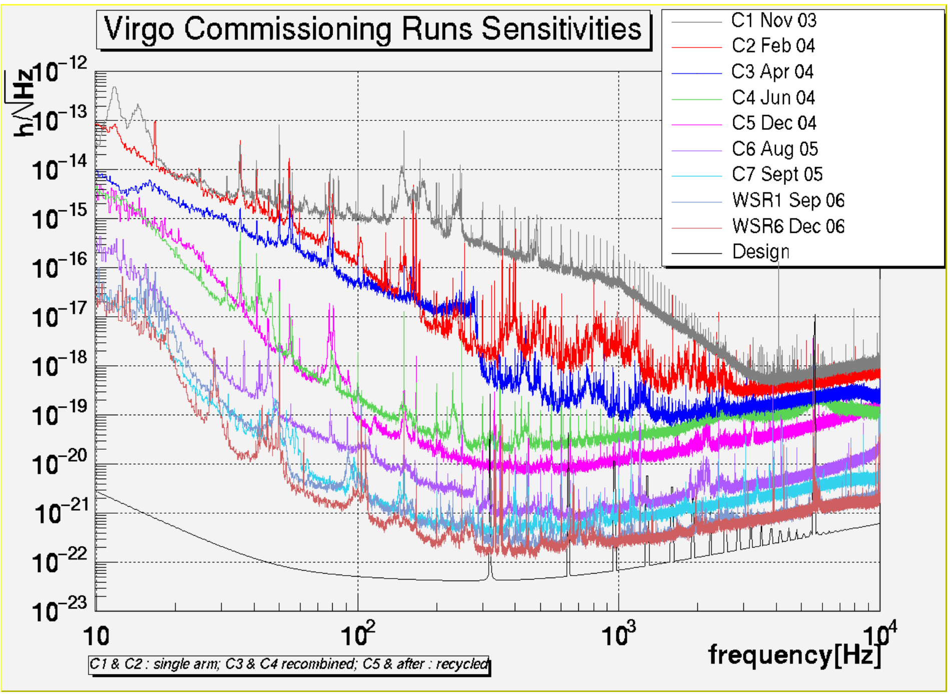
■ The Council also agreed to renew its support for 2007 to the Virgo-EGO Scientific Forum, VESF, authorizing the launch of a second theoretical fellowships program, the support to the 2nd VESF School and the support to its yearly congress.

■ The staff plan has also been approved keeping during 2007 the same total as available at the end of 2006 of 49 staff members plus 11 other paid personnel with different kinds of contracts. The Council increased the value of the parameter that governs the salary scale to partially compensate (by ¾) the increased cost of life during the past year.

■ Furthermore the Council approved a draft MoU LIGO-VIRGO that also includes EGO, to be agreed on finally by LIGO, and a draft MoU EGO-NIKHEF, to regulate the presence of the NIKHEF group on the site, to be agreed on by NIKHEF.

F. MENZINGER

From WSR1 To WSR6



After the week on improvement of the Faraday isolator and the discovery of the mysterious Allen key, already reported in the last issue of h, there were plenty of activities to restore the standard conditions required to perform a new Weekend Science Run (WSR2).

On the evening of the 22nd of September, after a lot of work on the alignment of the injection bench, tuning of mismatching and locking, we were able to reach our science mode and ready to take data. Unfortunately, a huge leak in the hot water pipe introduced temperature instabilities in the Laser Lab making things a little difficult. In the end, thanks to the work of the Infrastructure group, it was possible to lock again, starting from Saturday morning, until the end of the weekend.

First analyses of WSR1 and 2 show strong correlations between the trigger rate of bursts and sea plus wind conditions. The same thing has been observed with inspirals looking to the optimal horizon. Winter conditions will increase noise and actions will be needed.

A few weeks ago it was decided by the collaboration to install an acoustic enclosure around the injection benches in order to avoid noise propagation to the laser before entrance into the interferometer. After a week of installation by the company, EcoSilent, we tried to recover the lock. The starting operations were quite difficult due to significant beam jitter. The first conclusion was that the acoustic enclosure increased the noise! But, following closer examination, we discovered that one of the optical tables was touching the enclosure and this was amplifying the seismic noise. However moving the bench by a few millimeters was not enough to resolve the problem. New investigations showed that leaving the enclosure's panels open enabled a reduction of the noise. Checking again we found that a few holes were still present for the climatisation system. It seems that the increasing of noise was related to air-flow and leaving one panel open was required to continue the commissioning activities.

The third WSR started on Friday the 6th of October with lot of difficulties: after being able to reach the science mode, we were not able to keep it due to very bad weather conditions and the run coordinator decided not to fight against the elements anymore.

With a quiet climatic condition the following Monday, it was possible to reach science mode and the locking group restarted its noise hunting activities and tried to use a new photodiode signal to control the interferometer. The first attempts were unfortunately unsuccessful, but the story will not end here.

During the same week, the Mirror Suspension Control (MSC) group also started a new activity to improve the robustness of the lock in windy conditions, the "Global Inverted Pendulum Control" (GIPC) technique. The method is to use the global corrections signals (from the mirrors) to control the top of the suspensions. After a few improvements in locking and alignment, the WSR 4 was started on the 13th of October. However, once again, the weather fought against us. As it was too hard to have a stable interferometer, the run coordinator was forced to cancel the remaining shifts on Saturday evening.

In order to finish the acoustic enclosure inside the Laser Lab, a second intervention was planned just after WSR4. At the same time the Brewster window of the detection tower was replaced, as the size of the window could introduce clipping of the beams.

The work done on the isolation showed positive results but (as everything cannot be perfect) we need to leave one small door open.

In order to improve the beam shape, the commissioning team spent some time on improving the matching of the cavities. After ten days of work the goal of 2-3 % was reached for the maximum mismatching (which corresponds to the defaults of the alignment).

The relock of the interferometer started just after, but a new problem occurred, the instrument was not anymore able to survive the thermal transients. The origin of such behaviour seems related to the increase of the power since the Allen key removal and the work on beam matching. By reducing the incoming power by 25% we were able to recover a stable lock.

During the same week, the Virgo Week meetings gave us the occasion to glance at the proposed activities to prepare the Advanced Virgo project. After some time spent on improving the sensitivity, WSR 5 could start on the 11th of November. When environmental conditions started to worsen, the science mode was difficult to reach and stable only for short periods. But our shifters continued their duty until the Monday morning. Finally the duty cycle was not so bad with nearly 64% of time spent in science mode.

Activities then continued on locking and alignment and also on understanding the central frequency region of our sensitivity, where the computed noise budgets were not able to understand all the contributions. Several investigations on diffused light and acoustic noise took place all over the instrument. Finally the locking team was able to lock Virgo with a new photodiode (B2, looking at the beam reflected by the power recycling mirror) which seems less noisy and improves the sensitivity up to a factor 5 in the 20-50 Hz region!

Almost at the same time some tests done in the Detection Lab showed that it was possible to hear people chatting next to the new Brewster window using the dark fringe signal. Injecting Vivaldi or Pink Floyd can give impressive results, at least transforming the Detection Lab into a new and trendy place.

The MSC team have also continued their work on the GIPC technique and were able to lock the interferometer during a beautiful stormy night without any problem.

The subsequent weeks were dedicated to preparation for WSR6. The locking group was able to lock the interferometer in a stable way, using the B2 photodiode, for a few hours. The electronics group, with the help of the calibration team detected a failure on the coil drivers of the WE tower. This modification solved the discrepancy observed with calibration and allowed us to obtain a more accurate calibration with an improvement of more than 10% on all of the Virgo bandwidth. The WSR started on Friday evening, using B2 photodiode - after some robustness tests it was decided not to use this photodiode for the run, in order to have a robust way to lock the instrument. This weekend was quite a success with more than 80% of the time spent in science mode!

The continuing progress is shown by the sensitivity curve approaching more and more the Virgo design sensitivity.

N. LEROY, LAL

Cours de Francais

Thanks to Severine Perus French lessons are once again taking place at the EGO facilities - a tradition initially started by Sophie Oblette. The weekly sessions cover a wide array of topics, ranging from grammar and conversation to exercises dealing with common situations. Without doubt, Severine's effort and the high level of preparation explain the loyal audience and the success of the initiative.

B. LOPEZ

GEO600 Update

GEO600 is a laser-interferometric gravitational wave detector located close to Hannover, Germany, and operated by the German-British GEO collaboration. Since the early 2006 GEO600 has been running nearly all the time, taking data in coincidence with the LIGO detectors for what is known as the fifth LIGO Scientific Collaboration Science Run. In October the GEO collaboration decided to take GEO

off-line for a few months to allow commissioning work to improve the sensitivity, glitch rate, and long-term robustness of the detector. After this, the potential scientific impact of GEO600 will be evaluated, and based on this a decision will be made about whether to rejoin Science Run S5 or continue commissioning.

J. SMITH, GEO

ASPERA

More coordination for astro-particle physics in Europe under the motto "per aspera ad astra"

Note from the Editor: ASPERA is an ERA-NET activity, started last July inside the Sixth Framework Programme (FP6) of the European Commission. FP6 is known to EGO and Virgo through ILIAS, the Integrated Infrastructure Initiative, dedicated to promoting European efforts in astroparticle physics and gravitational waves detection. The aim of ASPERA is described in the following article by its management team.

ASPERA is a three year ERA-NET activity under the Sixth Framework Programme of the European Commission (EC), with an EC contribution of €2.5 million. Its aim is to improve coherence and co-ordination across European funding agencies for the financing of astroparticle physics.

ASPERA has come about through the existence of ApPEC (Astroparticle Physics European Coordination), a consortium of national funding agencies whose aims are to develop long-term strategies, express the views of European astroparticle physics in international forums, and establish a system of peer-review assessment applicable to projects in astroparticle physics.

Europe is a leading worldwide player in the field of astroparticle physics, involving about 2000 European scientists in some 50 laboratories. The cost of the current programme is close to €100 million per year and the investment cost of proposed future large infrastructures is near €1 billion. This level of activity means that consolidation of existing coordination among the different projects at the European level has become a necessity.

ASPERA will study the current funding and evaluation mechanisms across Europe and will identify formal and legal barriers to transnational coordination. It will define a roadmap on infrastructures and R&D and will test the implementation of new European-wide procedures of common funding of large infrastructures and the accompanying R&D. The further linking of existing astroparticle physics infrastructures will also be explored. A common information system (database, website) will be constructed and studies on the differential emergence of particle astrophysics in various European countries will be performed. The network is coordinated by CNRS.

In particular, the proposition for a roadmap that is being prepared by ApPEC's Peer Review Committee will be examined in a series of workshops with the aim of formulating a common action plan, including common evaluation and funding schemes, for the upcoming large infrastructures on high-energy neutrino, gamma-ray and cosmic-ray telescopes, gravitational antennas and underground observatories for dark matter, double beta-decay or low-energy neutrinos and proton decay. These efforts surrounding the roadmap will also take account of similar European efforts in particle physics (the CERN Council Strategy group) and astrophysics (the European strategic planning group for astronomy, ASTRONET) and will be input, through ApPEC, to national agencies and European committees on large infrastructures (such as the European Strategy Forum on Research Infrastructure). Coordination with other regional roadmaps, in the US and Asia, will also be sought, with a view to an optimal distribution of global infrastructures.

ASPERA comprises the following funding agencies CNRS (Fr), BMBF (Ge), CEA (Fr), FCT (Pt), FNRS (Be), FOM (Nl), FWO (Be), INFN (It), MEC (Sp), MEYS (Cz Rep.), SNF (Sw), DEMOKRITOS (Gr), PPARC (UK), PTDESY (Ge), FECYT (Sp), VR (Swe), and also CERN. One of its goals is to include all European national agencies that have programmes in astroparticle physics.

For further information please contact Nathalie Olivier (Coordination Manager of ASPERA, nolivier@admin.in2p3.fr).

Websites:

http://www.aspera-eu.org

http://appec.in2p3.fr/

http://ilias.in2p3.fr/

FP6 Glossary:

http://cordis.europa.eu/fp6/dc/index.cfm?fuseaction=UserSite.FP6GlossaryPage

N. OLIVIER, CNRS
COORDINATION MANAGER OF ASPERA

S. KATSANEVAS, CNRS
COORDINATOR OF ASPERA

The Phase Camera: A New Diagnostic Tool for Virgo

A gravitational wave detector such as Virgo can be viewed as a huge Michelson interferometer with a Fabry-Perot cavity (FP) in each arm. When the interferometer is tuned for destructive interference in the detection arm (Dark Fringe) and all the mirrors are fixed, the detector is said to be 'locked' and all of the light is trapped inside.

The beam cannot escape and reach the detector, except when the interferometer is crossed by a gravitational wave. In real life, however, the mirror position is not perfectly fixed and several displacement noises move the interferometer away from the locking point; many control loops are needed to compensate such displacements and to keep the detector aligned.

The usual technique to extract signals is to phase modulate the laser light at radio-frequency f_{mod} (in Virgo 6.26 MHz). In this way three beams are created: a carrier at the frequency of the laser source, and two additional beams with frequencies higher and lower with respect to the carrier, called sidebands. Each beam has a different story inside the cavities and, from the interference between carrier and sidebands - picking the right component using the heterodyne technique - it is possible to extract the signals to lock the interferometer.

The situation is ideal when the two sidebands are equal, but they are significantly more sensitive than the carrier field to misalignments or other spatial distortions of the power-recycling cavity. The study of the sidebands has shown what really happens inside the interferometer and, at the same time, it allows to improve the sensitivity of the detector.

How can we get information about the sidebands? The first thing to do is to separate the different frequency components of the laser field.

The Scanning Fabry-Perot (SFP) does just this. It is a FP cavity with variable length (see Fig. 1) and it is well known that the Fabry-Perot cavity can be used as a transmission filter, whose transmittance has peaks located where the distance between the mirrors is an integer multiple of half the laser wavelength. By continuously varying the length of the cavity of a SFP the fine details of the optical spectrum of the sidebands and carrier can be analysed.

enough for the purposes, but does not provide a full resolution, as is clearly visible in Fig. 2, where three complete scans are shown. On the vertical axis the light power stored in the SFP cavity is presented as a function of the wavelength. In each of the scans, the carrier and two sidebands are visible, but not fully resolved. It will be necessary to increase the reflectivity of the mirrors to fully separate carrier and sidebands.

This simple device has already proved to be very useful for Virgo. It has been able to detect power levels as low as few nW with a signal-to-noise ratio of ~30, and allowed to measure the sidebands.

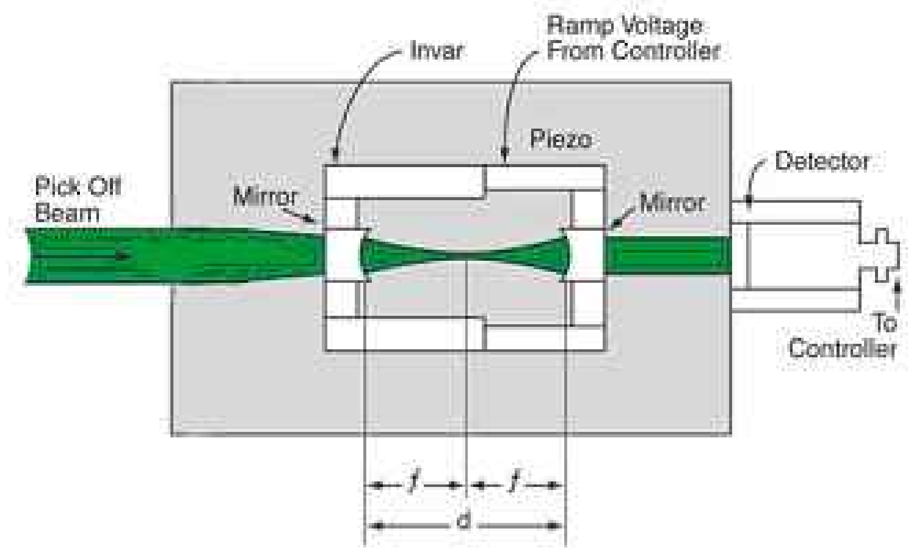


Fig. 1 - Schematic of a Scanning Fabry-Perot (SFP)

The resolving power of a cavity is expressed by its finesse, which depends on the mirrors reflectivity. The SFP used in Virgo has a free spectral range (FSR) equal to 300 MHz and a nominal finesse of 200, it can resolve lines separated by more than 1.5 MHz from each other. Since the separation between carrier and sidebands is 6.26 MHz, it is just

SFP has also shown that the global amplitude of both sidebands decreases after locking because of thermal effects and that their amplitudes are unbalanced. So far, the use of the SFP has been decisive in the solution of the problem of stable locking acquisition of the ITF. A natural evolution of the spectral analysis carried with the SFP is a

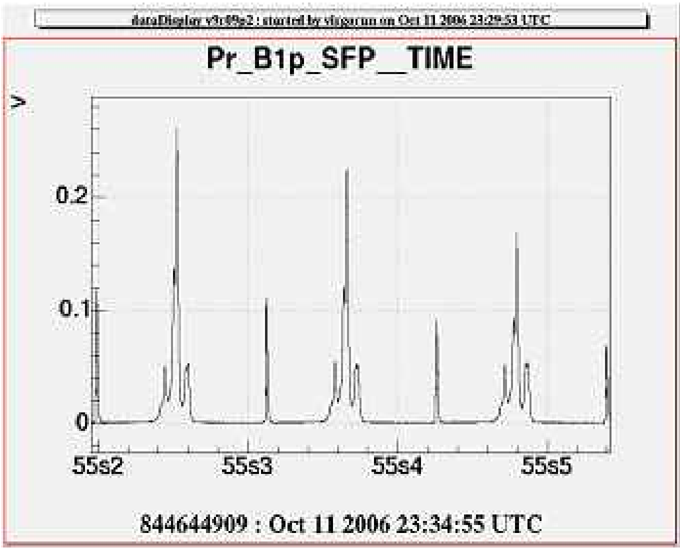


Fig. 2 - Output of the SFP (from logbook entry #13695)

device which measures the spatial profile of the carrier field with each sideband at the output port of the interferometer. It combines the advantages of the heterodyne detection with a scanning system to provide the amplitude and phase maps of each frequency component of the laser field. The basic scheme is depicted in Fig. 3. Part of the laser beam is picked up from the main optical path before entering the electro-optic modulator (EOM) and is sent to an acousto-optic modulator (AOM).

The AOM frequency shifts the beam by a fixed amount Δf = 80 MHz: this beam will be used as a reference beam (the red line in Fig. 3). The main beam (the blue line in Fig. 3) passes through the EOM and, as a consequence, the sidebands appear at a frequency equal to that of the modulation (f_{mod} = 6.26 MHz). The reference field is superposed to the test field exiting from one of the ports of the ITF on a beam splitter (BS). The scanning system, a computer controlled piezoelectric or galvanometric mirror, is used to displace the beam across a circular pinhole (PH) and obtain a spatial profile of the sensed beam. The photodiode (PD) then measures the beat notes between the reference and the test lasers. The photocurrent from PD is sent to three demodulators, each demodulator being triggered by a reference signal (LO) having a frequency equal to the difference between the reference beam and one of the components of the sensed beam. The demodulators output contains two orthogonal quadratures, I- and Q-phase voltages, and a DC signal for each component of the laser field. The amplitude and phase of carrier and sidebands from I and Q quadratures, can be obtained by:

$$|E(x,y)| = \left[I^2(x,y) + Q^2(x,y)\right]$$

$$\varphi(x,y) = \tan^{-1}\frac{I(x,y)}{Q(x,y)}$$

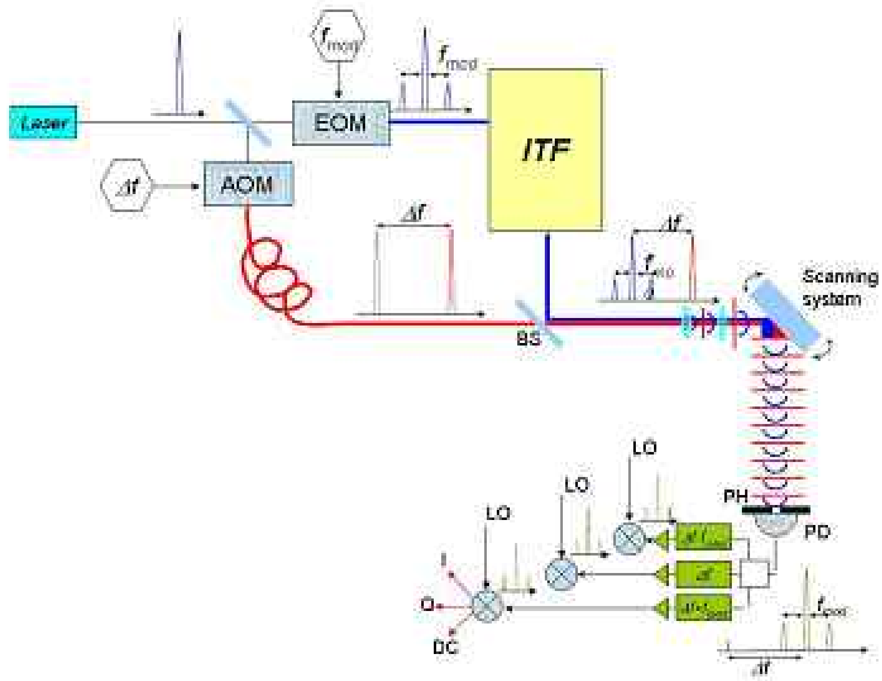
Then, by combining all of the data with the displacement (x,y) introduced by the scanning system, the spatial profiles of the phase and amplitude of the field can be reconstructed.

The prototype device created at LIGO, and also known as "phasecamera", has been shown to be able to discriminate transversal modes with 300 times less power than the carrier power, provide information about phase and amplitude of the carrier and the sidebands at the same time, and achieve a better frequency resolution with respect to the SFP.

The more the sensitivity of the interferometer increases the more all details of the signals have to be investigated in order to reach the fundamental limits of the measurement.

S. BIGOTTA, UNIVERSITY OF PISA

Fig. 3 - Schematic of a frequency resolving wavefront detector (phase camera)



Resonant Bars - A Landmark in the History of GW Detection

The experimental search for gravitational waves was started by Joseph Weber in the early '60s, at a time when very little was known about their possible sources. He developed the first resonant-mass detector, operating at room temperature, made of a massive bar with a fundamental longitudinal frequency of about 1.6 kHz and a motion sensor converting the vibrations of the bar into an electric signal. His efforts stimulated the birth of new generations of resonant detectors involving the use of cryogenic and superconducting techniques for the noise reduction, and the development of new detectors based on laser interferometry between widely spaced bodies. Since Weber's time, the conceptual scheme of resonant detectors has not been modified, but, thanks to technological progress, their sensitivity has improved by a factor of one thousand.

Resonant mass detectors can be classified into three generations, according to the different operating temperature: the first generation working at room temperature, was the one initiated by Weber, the second generation, working around the temperature of liquid helium (4.2 K) and the third generation cooled down to even lower temperatures, near the absolute zero (0 K - corresponding to -273.15C).

The cryogenic resonant-mass detectors were conceived in the '70s with the aim of improving the sensitivity of room temperature Weber type detectors, by reducing the temperature of the bar. This allowed a reduction of the thermal noise and the use in the readout system of less noisy amplifiers, made of superconducting electronic devices.

The first cryogenic detector was operated at the beginning of the 1980s by the Fairbank group in Stanford, followed by the Rome group detector EXPLORER, located at CERN, and by ALLEGRO at the Louisiana State University. Only at the beginning of the 90s, however, did cryogenic detectors enter the continuous operational mode and hence the field of reliable instruments of physics. The Stanford antenna, damaged by the 1989 earthquake, was shut down. Another detector, called NIOBE, started operating at the University of Western Australia in Perth in 1993 (NIOBE stopped its data taking in 2000).

In the years 1982-1984 a feasibility study was conducted to establish the technical possibility to cool a multiton Al 5056 bar to milliKelvin temperatures. In 1995 and in 1997, respectively, the ultracryogenic detectors NAUTILUS, located at the INFN Frascati Laboratories, and AURIGA, located at the INFN Legnaro Laboratories, started taking data.

A layout of NAUTILUS is shown in Figure 1. Inside the external vacuum chamber, the cryostat contains two helium gas cooled shields, the liquid helium reservoir (2000 liters of capacity), three copper massive shields with high thermal conductivity and, through the top central access, a special 3He-4He dilution refrigerator, that allows to cool the bar to temperatures below 4 K. The shields are suspended to each other by means of titanium rods and constitute a cascade of low pass mechanical filters. The bar is suspended to the first shield by a U-shaped copper rod wrapped around the bar central section. The overall mechanical vibration isolation at the bar resonant frequency (around 915 Hz) is of the order of -220 dB. This means that the external disturbances in the frequency range around the sensitive frequencies of the bar, are reduced by a factor of 100 billion. The thermal path from the mixing chamber of the refrigerator (that is the coldest point of the dilution refrigerator itself) to the bar is constituted by soft multiwire copper

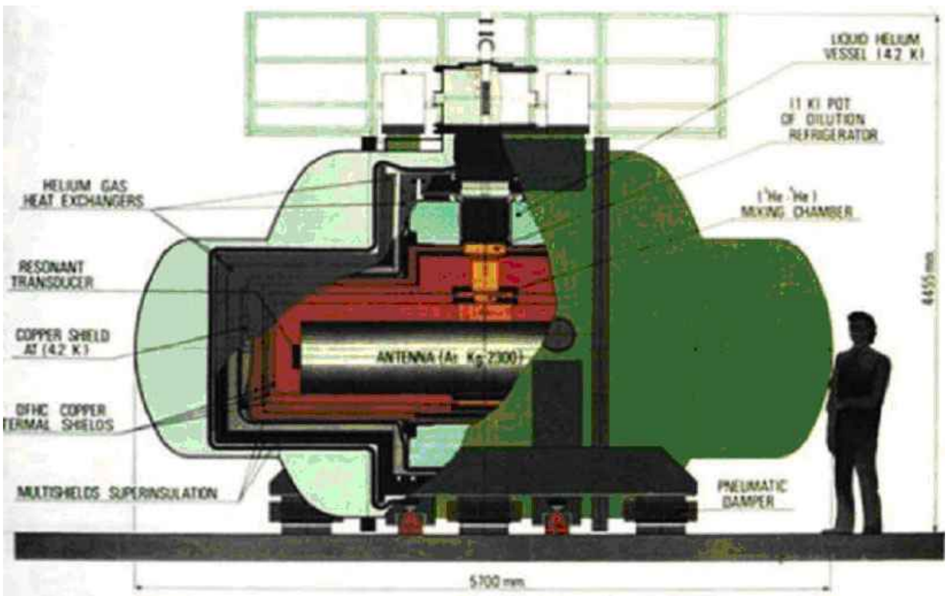


Fig. 1 - Layout of the NAUTILUS detector

"spaghetti", connected to the ends of the copper suspension rod. NAUTILUS was the first massive body cooled in 1991 at very low temperatures (one tenth of a degree above absolute zero). Similar schemes also describe the other resonant detectors, the main differences concerning the features of the suspension system and, in the second generation detectors, the absence of the dilution refrigerator.

The principle of operation of resonant-mass detectors is based on the fact that a resonant body has vibrational modes that can be excited by a gravitational wave. These modes must have a well-defined symmetry, in order to be sensitive to gravitational waves. In the case of a cylinder, the mode that interacts more strongly is the first longitudinal mode.

The mechanical oscillation induced in the antenna, made of a low mechanical dissipation material, by interaction with the gravitational wave, is transformed into an electrical signal by a motion or strain transducer and then amplified by an electrical amplifier. The principle of all transducers is to store electromagnetic energy in a given volume, usually the narrow gap between the plates of a capacitor, one of the plates being part of the antenna. The motions of this wall, arising from vibrations in the antenna, induce a modulation of this energy, which is detected and amplified as an electrical signal.

Strain transducers are classified as belonging to the following three categories: capacitive (electrostatic), inductive (magnetostatic) and optical (electromagnetic). Piezo-electric, magnetostrictive and microwave cavities are respective examples of such transducers. We can also distinguish between passive and active transducers. Passive transducers are linear transducers in which the source of energy in the gap is a permanent field, either electric (as in AURIGA, EXPLORER and NAUTILUS) or magnetic (as in ALLEGRO) or both. These transducers preserve a linear phase and amplitude relation between input and output. Because of their relatively simple construction they are widely used.

In active transducers the gap is fed with an oscillating bias field at high frequency wp. The mechanical vibration at the antenna resonant frequency w0 modulates the phase of this oscillating field and produces side-bands which contain the information of the mechanical signal. Good performance of this type of transducer is obtained because of the gain wp/w0 resulting from the conversion of the pump frequency wp into the antenna frequency w0 (this scheme was adopted by NIOBE).

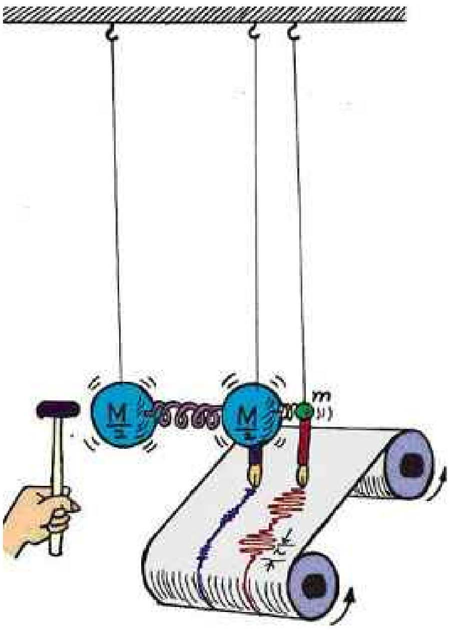


Fig. 2 - Pictorial representation of the operating principle of resonant transducers (courtesy of H.J. Paik)

The transducers used in the operating bar detectors are built so that they resonate at the same frequency as the fundamental longitudinal mode of the bar. In this case the system bar+transducer is a system of two coupled oscillators and the energy deposited by the gravitational wave in the bar is transferred to the transducer. Since the mass of the transducer is much lower than the mass of the bar (some hundreds of grams compared with about two tons), the oscillations of the transducer have a much larger amplitude (about a factor of one hundred). This first mechanical amplification makes the signal to be detected higher.

A further enhancement of the signal is given by the electrical amplifier. At present, all the operating bar detectors make use of superconducting amplifiers, called SQUID (acronym for Superconducting Quantum Interference Device), characterized by a very low noise, with a sensitivity near the quantum limit.

The importance of cooling the bar to a very low temperature and using low noise amplifiers is due to the fact that the sensitivity of this kind of detector is limited in principle by two sources of noise: the thermal noise, generated by the stochastic dissipative force, due to the internal friction in the resonant masses, and the amplifier noise.

In particular, the useful bandwidth of such detectors is limited by the amplifier noise. As a consequence any reduction in the amplifier noise increases the antenna bandwidth.

In a real detector, other spurious and usually random disturbances are present, and it is not possible to eliminate them completely. For this reason it is very important to have more detectors in simultaneous data taking, far away from each other, so that their noises can be considered uncorrelated. If the "same" signal is seen at the "same" time by different detectors, it becomes a candidate for a gravitational wave detection. The relevance of a candidate event becomes stronger and stronger as the number of detectors, that see that event, increases.

For this reason, all the resonant-mass detector groups formed the International Gravitational Event Collaboration (IGEC), during the Second Amaldi Conference in 1997 at CERN, and agreed upon a data exchange protocol to search for short GW bursts.

During these years, experimentalists have devoted a continuous effort to improving the antenna sensitivity.

All the upgrades have been mainly devoted to:

- Increasing the duty cycle and lowering the background noise, by upgrading the cryogenics to minimize maintenance stops and to ensure a more stable operating temperature, and by acting on the vibration attenuation system, including the thermal links between refrigerating stages and the electromechanical sensitive components. All these studies have made it possible to reach very robust and stationary performances, with duty cycles in the order of 90%.

- Improving the sensitivity and the useful bandwidth, by acting on the readout components. These efforts resulted in an enlargement of the bandwidth which is now of some tens of Hz, up to one hundredth of Hz, around the resonant frequency (typically about 1 kHz). The present bandwidth, even if much larger than the typical bandwidth of the first operating bars, still remains the limiting factor of this kind of detector. In order to avoid such bandwidth limitations of resonant detectors, different conceptual schemes must be adopted, such as the proposed "Dual" detector.

Bar detectors have been taking data for the last few years with a very high duty cycle, mainly limited by cryogenic operations, and with a sensitivity capable of monitoring astrophysical events in our Galaxy.

A better performing geometry for resonant detectors, widely investigated and considered of interest by the bar community because of its properties, is the sphere. Unlike a cylinder, where only one resonance mode interacts strongly with the gravitational wave, a sphere has five modes sensitive to gravitational waves. Thanks to this feature, a single spherical antenna is capable of detecting gravitational waves from all directions and polarizations and to determine the direction information and all the characteristics of the incident wave.

At present, two small (about 60 cm diameter) spherical detectors are in preparation: MiniGRAIL at Leiden University (Holland) and Mario Schenberg at São Josè dos Campos, INPE (Brazil), with a predicted sensitivity in the 3 kHz range, competitive with that of present generation interferometers. MiniGRAIL and Schenberg are both made of a copper aluminum alloy. The use of a copper aluminum alloy allows these detectors to have a mass of about one ton in a very compact size. This is important because the sensitivity of resonant antennas increases with their mass.

In order to fully exploit the capabilities of a spherical detector, a multimode readout is required. Commissioning to optimize cryogenics and readout setup is on-going.

For more info on resonant mass detectors see:

http://www.lnf.infn.it/esperimenti/rog

http://sam.phys.lsu.edu

http://www.auriga.lnl.infn.it

http://www.minigrail.nl

http://www.das.inpe.br/~graviton

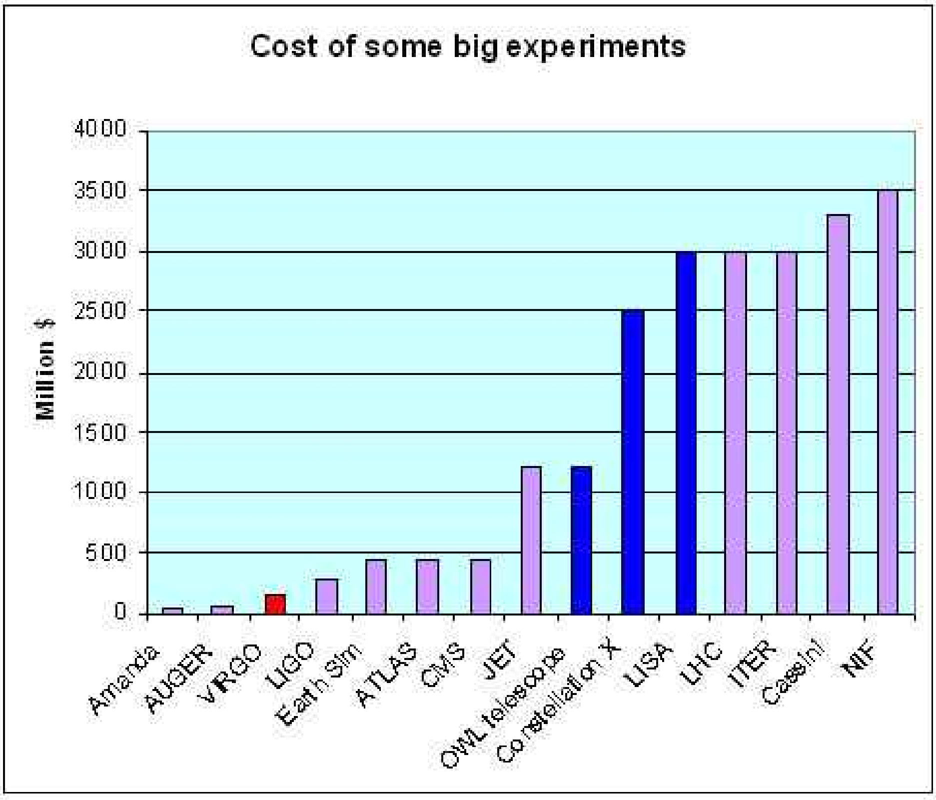
http://igec.lnl.infn.it/igec

V. FAFONE, UNIVERSITY OF ROME TOR VERGATA AND INFN

How Much Does Virgo Cost?

As anybody who has lead a visit to the Virgo site knows, one of the most common questions, either asked by researchers or by the man on the street, the taxpayers, is: "How much does all this cost?". An answer is that Virgo cost, for its construction (in about ten years), about 90 M€ (77.6 M€ for direct construction, 12.2 M€ for site acquisition), plus 60.9 M€ for personnel directly provided by CNRS and INFN, that is about 150M€. The expense for its running, maintenance and upgrades amount to about 10 M€ per year (which does not include for example the salaries of the researchers working in the CNRS and INFN laboratories), almost equally shared between Italy and France. People, including many researchers, are often impressed by this number. But, any number is big or small compared with other numbers. What could this number be compared with? I found it interesting to compare the expenses of a big experiment such as Virgo with other expenses, first of all to other analogous "big things" in the area of research, then to more common examples with which ordinary people should be more familiar.

The first term of comparison is with what is made in the analogous field of activity of Virgo, that is big structures/experiments aimed at scientific/technological research, altogether known as "big science". If we regard as "big" an experiment that costs more than several M$ and involves hundreds of researchers, there are a huge amount of big experiments presently running or being proposed or designed, amounting to several hundreds. To make a complete list is really difficult. These experiments are often the result of international collaborations, even if they are sometimes lead by single countries (most of all the USA). Within this



family Virgo is without doubt not among the most expensive. In the histogram above only a sample of the biggest ones are shown (purple: existing or approved, blue: to be decided), and Virgo is definitely in the lower tail. It's clear that a graph like this is not exhaustive: a complete investigation should include all "big experiments" that are running or being designed, and show where Virgo is placed inside this group, but this investigation is not easy and goes beyond the purpose of this paper.

Things can be made even clearer by referring to the expenditure for analogous initiatives spent by Italy and France on research and, in particular, by the national agencies involved in our experiment, i.e. INFN and CNRS.

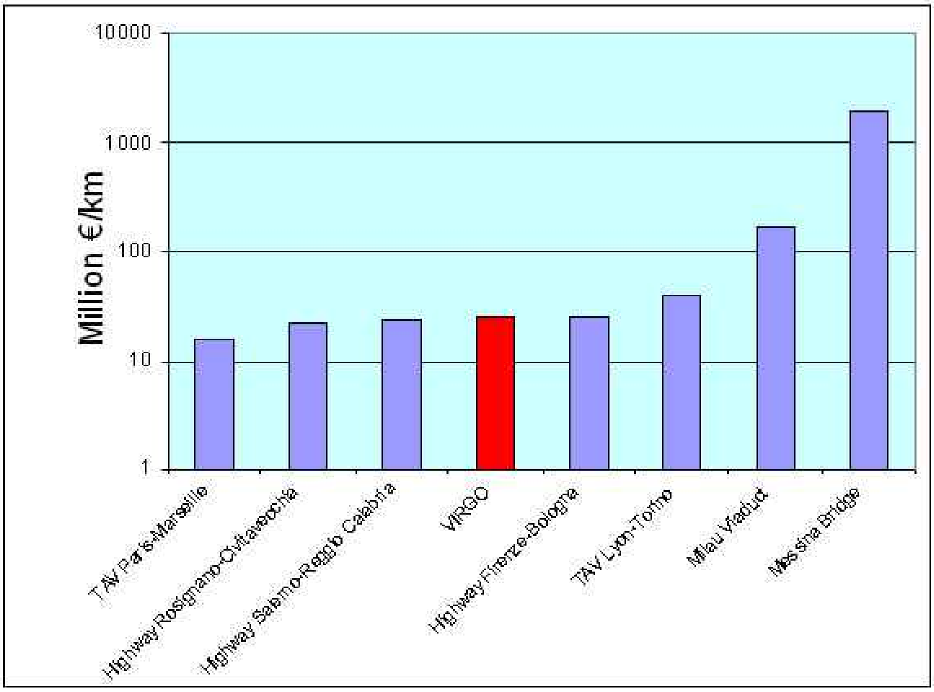
In 2001 the total Italian investment in research was about 1.07 % of GDP, i.e. about 13 B€ (43 % public, 50.8 % private, 6.2 % from abroad). In France the total investment in research was about 2.2 % of GDP, i.e. about 31.6 B€ (52.5 % public, 38.7 % private, 9.8% from abroad) (sources: European Commission, Key Figures 2003-2004, EUR 20735).

INFN has (2006) a yearly budget of about 290 M€ (Italian CNR has a budget of about 1.1 B€). CNRS has (2006) a yearly income of about 2.7 B€. France and Italy contribute to CERN with about 100 M€ per year. Compared with other astroparticle experiments in which, for example, the INFN is involved, Virgo is almost the most expensive, comparable only with space missions like GLAST (gamma rays detection in space). But the largest amount invested by the INFN is in the high energy field: the Italian contribution to CMS is, for example, almost 1 B€. For the INFN and CNRS Virgo is not the biggest investment (and hopefully also not the most risky).

All this is far from being an exhaustive analysis: figures should be given depending on duration, number of people and countries involved, existing or future projects, observation time, results, spin off, and so on. There would surely be matter for a very interesting analysis of the scale and fallout of a scientific enterprise, but it goes beyond the purpose of this very short paper, which would be to give a short answer to visitors. So, an answer to "enlighten" visitors, for example researchers, involved in activities similar to ours, could be told, referring to the aforementioned figure, maybe in a playful tone: "It's a lot of money, but there is much worse around."

But ordinary people, not familiar with the needs and numbers of the research, may not be convinced by this argument. Thus I found it interesting to also compare the cost/km of Virgo with other more familiar entities quantifiable in €/km. Virgo, in this sense, which is 6 km long, cost about 25 M€/km, if the total cost is assumed to have been 150 M€. In the following table a list of the costs of several civil engineering activities is shown (TAV: Treno ad Alta Velocità, i.e. High Speed Train):

	Total cost	Cost per km
TAV Paris-Marseille	4.5 B€	15 M€
TAV Lyon-Torino (estimate)	10 B€	40 M€
Highway Salerno-Reggio Calabria	10.3 B€	23 M€
Highway Rosignano-Civitavecchia (estimate)	2.5 B€	22.7 M€
Higway Firenze-Bologna (first 20 km "variante di valico")	500 M€	25 M€
Milau Viaduct	415 M€	172.5 M€
Bridge on the Strait of Messina (estimate)	6 B€	2 B€



The previous table is summarized in the graph at the top of this page (mind the logarithmic scale).

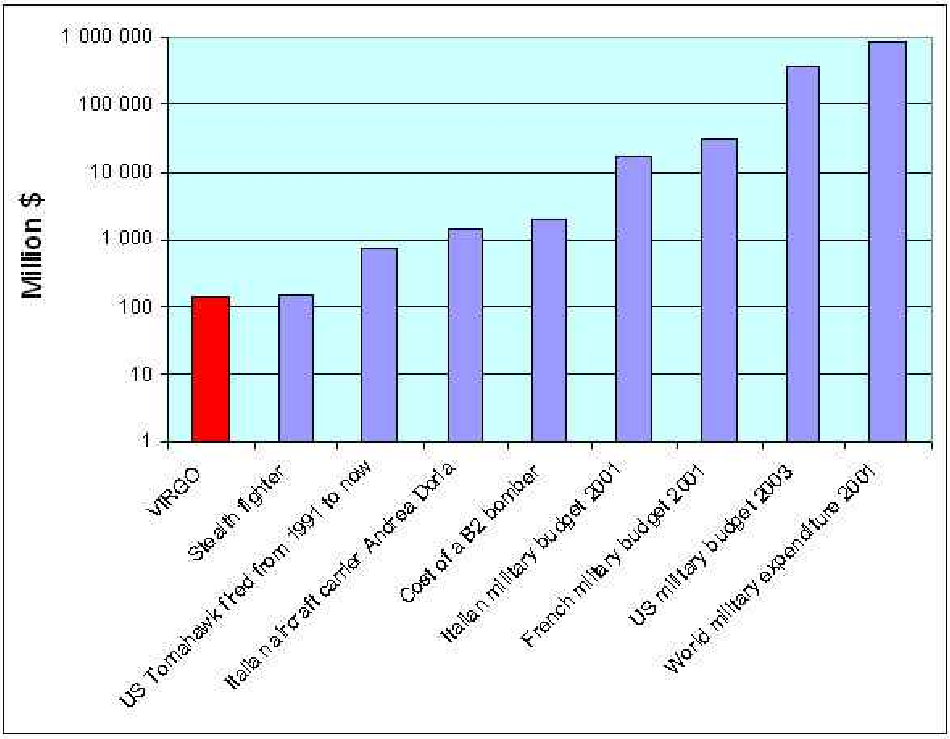
These are only some examples, just to show the order of magnitude of the cost of some civil engineering structures. There would be plenty of other similar structures, the list would be endless, but the message should be clear: Virgo costs, per km, less than many familiar building enterprises. One can also say that one km of Virgo is a lot more complex and technological than one km of highway. So, at this point one could say that it is wise and reasonable that a rich and industrialized country invests, in fundamental research programmes, an amount of money equivalent or comparable to the cost of a few km of highway.

Now, an objection: right, it is true that Virgo costs less than a few km highways, but, would you compare the usefulness of a road, in terms of jobs, work, business, with something that will enable no-one to gain money?

At this point the guide to the site could change expression, from the playful to the grave, and start listing costs less obviously useful and less harmless, expenditure, such as on military equipment and defence. Here numbers fluctuate in a completely different sphere of orders of magnitude. Just to give some examples, to our knowledge: a Stealth fighter already costs more than Virgo, $ 158 million, a B2 bomber $ 2.1 billion, the US spent about $ 365 billion in 2003 ($ one billion, or more than seven Virgos (!), per day), which was almost half of the world military expenditure in 2001 ($ 839 billion). Numbers that are graphically presented in the respective graph at the bottom of this page (logarithmic scale). And so on and so forth. Also in this case the list will be endless. How much public money is employed in these productions? And, how many physicists and engineers are employed in these kinds of activities? Are these things more "useful" than gravitational wave interferometers?

So, once again, "it's a lot of money, but there's much worse around". At this point the time for the visit will probably have elapsed, and the public should have more than enough to think about.

P. LA PENNA



The Road to Cascina is Paved with Good Intentions

Following on from our trip from Pisa to EGO in the previous 'h', in this edition we visit a couple of hidden gems within easy cycling distance of EGO. Unbeknownst to many, the area between Pisa and Cascina does not simply contain a tract of main road that is to be completed in as short a time as possible. The discerning visitor can also find much to see in the various localities along the way. Two such places of interest are the church of San Casciano a Settimo in San Casciano and the church of San Jacopo in Zambra (see photos on the next page).

The church of San Casciano a Settimo was built, in the Pisan style, in the twelfth century on the site of a pre-existing church. Constructed entirely from stone extracted from La Verruca (the excavated mountain that overlooks Cascina and is easily visible looking north from EGO) it is particularly impressive for its three large doors, sculpted by Biduino in 1180. San Jacopo meanwhile, is a rare example of a well-preserved high medieval church, dating from the ninth century. It stands out particularly for its pre-Romanesque murals of crowned fish.

Route 2: The road to Cascina is paved with good intentions

Distance: 16km

Duration: 1 hour (on the bicycle and not including the time spent at the locations themselves)

So, now that we've whetted our appetite a little, how do we get there? Well, we begin from the front gate of EGO and take a right along 'Via Amaldi' (1) until we meet 'Via Macerata' and take a right. We stay on this, passing 'Chiesanuova' and the 'Via Arnaccio' (2), until we cross the bridge over the 'FI-PI-LI' (3). At the foot of this bridge, we encounter a crossroads, which crosses over 'Via Fosso Vecchio'.

Here we go straightover and head in the direction of the locality of San Frediano a Settimo. We stay on the 'Macerata' all the way to the 'Via Tosco Romagnola' (4), passing underneath the railway line in the process. At this busy crossroads we go straightover again onto 'Via 4 Novembre'. At this point a couple of possibilities open up to us, but we will take the first left onto 'Via Renato Fucini', which we stay on until we reach the T-junction where we are forced to make a decision on our next step.

Here we head right onto 'Via Stradello' (5) and it is this road that brings us to San Casciano. To reach the church we pass through two crossroads, the second being over 'Via di Mezzo Nord', and then take our second left-hand turn onto 'Via Barbaiano', which brings us up alongside the church itself, passing by the bell-tower, which was re-built having been destroyed by shelling during WWII (although one may suspect that the original was slightly sturdier), and into the spacious piazza that opens out in front of the main doors (6).

Having soaked up the available delights, and quite possibly the rain if we imagine making this journey over the next couple of months, we are now ready to move on to the next stop on our journey. We head away from the church, with the doors at our shoulders, onto 'Via Filicaia', before taking a left onto 'Via dei Palazzi Nord'. Shortly, we meet a crossroads and take a right onto 'Via di Mezzo Nord'. We subsequently take the third right turn onto 'Via Alberto Profeti' (7), which brings us up to 'Via Carlo Cammeo', which leads over the Arno to Caprona.

However, today, this road is not for us, although we can now enjoy the fine view of the tower at Caprona. Instead, we go straight on to 'Via della Liberta', which brings us directly to the church (8).

Following a closer inspection of the aforementioned regal fish, we are now ready to head back to EGO. I should note here that there are many other places of interest in the local area, not least the remains of a castle at Ripoli, inside the walls of which a number of houses have been built, giving it a new lease of life. However, time presses, so we begin our journey home. First of all we head back onto 'Via Alberto Profeti', it's best to avoid 'Via Carlo Cammeo' due to the volume and speed of traffic that may be encountered there, and then re-join 'Via di Mezzo Nord'. On the road back, to vary our journey slightly, we take our first right-hand turn, onto 'Via dei Palazzi Nord', before turning left onto 'Via Pedichella' (9). This road quickly brings us to a crossroads, where we go straightover onto 'Via Amerigo Vespucci', which we stay on until we re-join 'Via Renato Fucini'. Here we go left and then turn right on to 'Via 4 Novembre', before re-crossing the 'Via Tosco-Romagnola' to again re-join the 'Via Macerata', which brings us all the way back to 'Via Amaldi' and the entrance to EGO.

G. HEMMING

GOOD NEWS!

In Italy one says: 'non c'e' due senza tre'! The number three is very important this time…

We have seen the arrival of two new children who are both the third child of the family:

Our congratulations go to Agnes and Raffaele Flaminio for Marco, born October 9, and to Melanie and Daniel Sentenac for Margot, born October 12.

Not to forget of course, that we have also seen another new child - Camilla, born November 3. - our congratulations to Maria Antonietta and Roberto Cavalieri.

Congratulations also to Manuela Mercatali. On October 23 she earned her degree on Languages and Foreign Literatures, defending a thesis with the title:"Sherwood Anderson, Winesburg, Ohio: <<the procession of grotesques>>".

FELLOWS AT EGO

"My work in the field of gravitational-wave interferometry began when I started as a graduate student at Caltech in 1996. My first few years of graduate study included topics ranging from optical characterization at the 40m lab, to binary-neutron-star population analysis and LIGO event rate estimation.

After two years of focused work, with Barry Barish as my advisor, I finished my doctoral thesis work on lock acquisition. The system I developed, though perhaps not optimal or enlightened, locks the LIGO interferometers every day.

Once graduated, I continued to work on the simulation tool I had created to enable my thesis work, at this point as a Caltech employee. A few years spent programming the End-To-End simulation left me longing for more direct contact with the interferometer, so I began to dedicate more time to commissioning. Finally, in April of 2005, I changed my status with LIGO from employee to contractor so that I could more freely travel between commissioning visits to the sites.

The past year and a half has seen me working both at LIGO and Virgo as a commissioner. I also spent some time at NAOJ working on TAMA and helping to build a small, suspended interferometer.

My time outside LIGO has brought me into contact with aspects of the detector of which I knew little before including table-top optics, analog electronics design and construction, control of complex suspensions, and low-level digital signal processing. In the past years I have also spent considerable time developing systems for interferometer automation, monitoring and diagnostics.

I've spent the last year at Virgo learning the details of how many of the sub-systems work, and how they fail. From automation to electronics, from optics to suspensions, I feel like I've touched everything, often to the dismay of whomever was responsible for that part of the detector. Antonio is probably proud to say "Matt never changed any part of the vacuum system.", but I'm not gone yet!

The experience has been rich with challenges, successes and failures. Some of these have been technical, others social, but all have been instructive."

Matt Evans

PERSONNEL MOVEMENTS
1 September - 30 November 06

ARRIVALS

Staff

Francesco Berni
Technical assistant for the operation of the Interferometer, Interferometer Operation (Operations)

Rodolphe Maillet
Technical assistant for the operation of the Interferometer, Interferometer Operation (Operations)

Nicola Menzione
Technical assistant for the operation of the Interferometer, Interferometer Operation (Operations)

*Daniel Sentenac**
Software Engineer, Interferometer Operation (Software)

Collaborators

Irene Fiori
Commissioning Project

DEPARTURES

Staff

Sophie Oblette
Direction Secretariat and Personnel Service Assistant, Administration

Collaborators

*Daniel Sentenac**
Commissioning Project

*Change in role