The Status of Virgo

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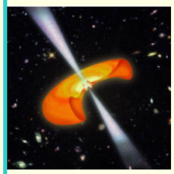
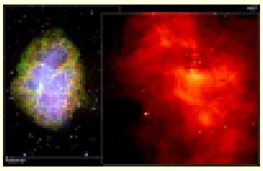
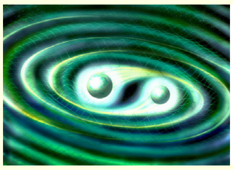
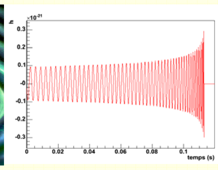
Virgo motivations

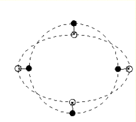
The Virgo interferometer (ITF) is designed to **detect gravitational waves** (GW) emitted by astrophysical sources in the frequency range from a few Hz to a few kHz [1]. It is a recycled ITF with two 3-km-long Fabry-Perot cavities, located close to Pisa (Italy). The expected sources of GW are continuous wave signals from **neutron stars,** burst signals (<100 ms) from **supernova explosions,** 'modeled' signals (~0.1 s to a few 10 seconds) from **coalescences of binary compact objects** (neutron stars (NS) and black holes (BH)) and stochastic signals from **cosmological sources.**

Detection principle

Passing GW h(t) → **Differential variations of the arm lengths** ($\Delta L = hL \sim 10^{-18}$ m) → Variations of the ITF output power

The position of the mirrors are longitudinally controlled to keep the detector at its working point. The effect of such controls are taken into account to reconstruct the amplitude h(t) of the passing GW.

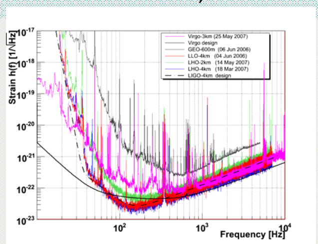







Virgo during VSR1 (May 18th to October 1st 2007)

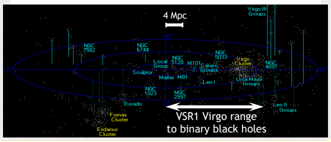
During its first science run (VSR1), the ITF was **in science mode for 81% of the time**.

The **sensitivity of Virgo** at the end of the run is shown along with the LIGO and GEO sensitivities.



Detector range: distance of a coalescing binary system whose signal would be seen with a signal-to-noise ratio of 8, averaged over the source sky position, inclination and polarization. During VSR1, the range reached

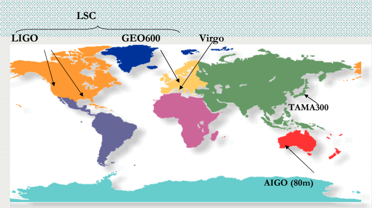
- **3.5 Mpc** for binary neutron stars (1.4 $M_\odot$)
- **15 Mpc** for binary black holes (10 $M_\odot$)



LSC-Virgo Agreement

The data from the different ITFs, LIGO, GEO and Virgo, are being **jointly analyzed since May 2007** in order to:

- reconstruct the source parameters (direction, polarization)
- improve time and sky coverage
- reduce the false detection rate



VSR1/S5 data analysis activities

LSC-Virgo common analysis groups are looking into the data to search for GW signals. Analysis is on-going and results will be published soon.

« All-sky » searches are being done for the different types of GW signals. A non-detection would result in upper limits on the rate of detectable events or on the GW strain amplitude for continuous signals.

Known pulsars are being studied. The non-detection of GW emission sets upper limits on:

- the fraction of the ***spin-down energy*** emitted through GWs (i.e. less than 73% for the Crab pulsar at 95% CL [2])
- the ***pulsar ellipticity*** (for the Crab, $\varepsilon < 9\times10^{-4}$ at 95%CL [2])

Emphasis is put on searches that focus on **astrophysical triggers** [3] detected through other messengers (γ-ray, X-ray, optical light, radio, neutrinos). It allows to search for GW with amplitude closer to the noise floor of the ITF. A detection would be of main interest to study the inner structure of the objects. However, useful limits can be derived from non-detections. Some examples are given below.

Gamma-ray bursts (GRB) and soft gamma-ray repeaters (SGR) –

Short GRB (Merging of binary system ?) → *Matched-filtering analysis* → Limits on ***distance and mass of the system*** [4]

Long GRB (hypernovae) and SGR (non-radial motion of stellar matter ?) → *Burst analysis* → Limits on the ***energy emitted in GW***

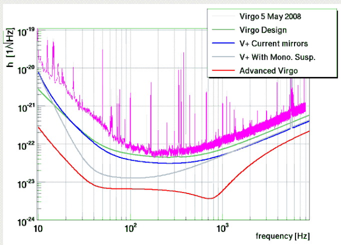
Pulsar glitches –
Step increases in the rotation frequency of pulsars are observed. They are possibly caused by reconfiguration of the neutron star. Excited oscillation modes of the neutron star are expected to be damped by GW emission.
Specific analysis of the GW data could be triggered by such radio observations.

The reconstruction of the location of the GW events gives the possibility to **follow-up observations with optical telescopes**. This approach is currently being developed to get ready for the advanced detectors area.

Status of Virgo+

Commissioning following VSR1 allowed Virgo to reach a range of 7 Mpc for BNS in May 2008.
At present, commissioning is ongoing to reach the Virgo+ design sensitivity and get ready for the **next run scheduled for mid-2009**, in coincidence with enhanced-LIGO.
The **main upgrades** done to move to Virgo+ sensitivity are:

- To reduce the shot noise:
  - new input mode-cleaner end mirror
  - new laser amplifier (20 W → 50 W) and compliant injection system optics
  - system to compensate the thermal deformation of the mirrors
- To reduce the control noise, new control electronics
- To reduce the thermal noise, installation of monolithic suspensions for the mirrors



	BNS (Mpc)	BBH (Mpc)	Sensitivity at 1 kHz	Crab (at 60 Hz)
Virgo design	11	58	7.2×10^{-23}	1.4×10^{-25}
Virgo+ (1)	15	76	5.1×10^{-23}	-
Virgo+ (2)	54	272	5.0×10^{-23}	-
AdvVirgo	163	757	1.8×10^{-23}	$\sim10^{-26}$

Figures of merit of the different phases of the detector: range for binary systems and typical strain sensitivity level to bursts and to the Crab pulsar (integrating over 1 year, with 1% false alarm rate and 90% detection efficiency). AdvVirgo sensitivity to the Crab pulsar ellipticity will be of the order of 10^{-5}.
Virgo+: (1) without and (2) with monolithic suspensions.

Towards AdvancedVirgo

The goal of Advanced Virgo is to **improve the sensitivity by a factor 10** (increasing the observed volume by a factor 1000) compared to the nominal Virgo design. A document describing the AdvVirgo baseline design has been released with preliminary budget and execution plans. The schedule is in parallel with the upgrades towards Advanced LIGO.

Conclusions

The Virgo detector made its first scientific run in coincidence with the 3 LIGO detectors in 2007. A first detection is unlikely, but several upper limits on GW emission will be set in the next months, starting to probe astrophysical models.
The upgraded ITF, Virgo+, will start a new run in 2009, making a first detection plausible.
The proposal for Advanced Virgo, designed to achieve a sensitivity a factor of 10 better in all the detection band, should allow to detect several events per months, opening the GW astronomy era.
Astrophysical triggered searches are being developed and might help to give confidence in the first GW detections.

[1] http://wwwcascina.virgo.infn.it
[2] Abbott et al., ApJ Lett. 683 (2008) 45
[3] Abbott et al., Class. Quantum Grav. 25 (2008) 114051
[4] Abbott et al., Astrophys. J. 681 (2008) 1419

- Rencontres de Moriond 2009 -
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