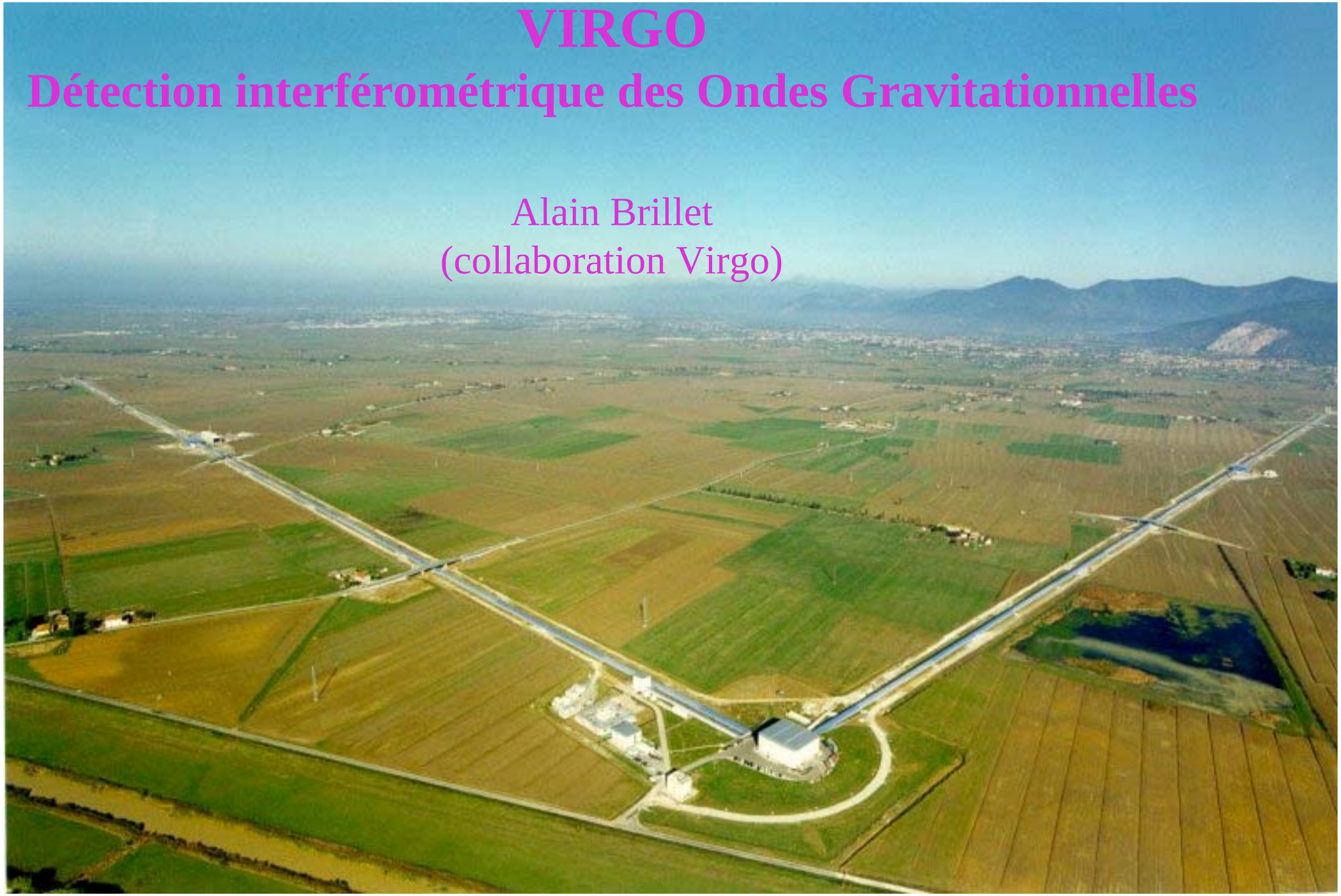
VIRGO
Détection interférométrique des Ondes Gravitationnelles

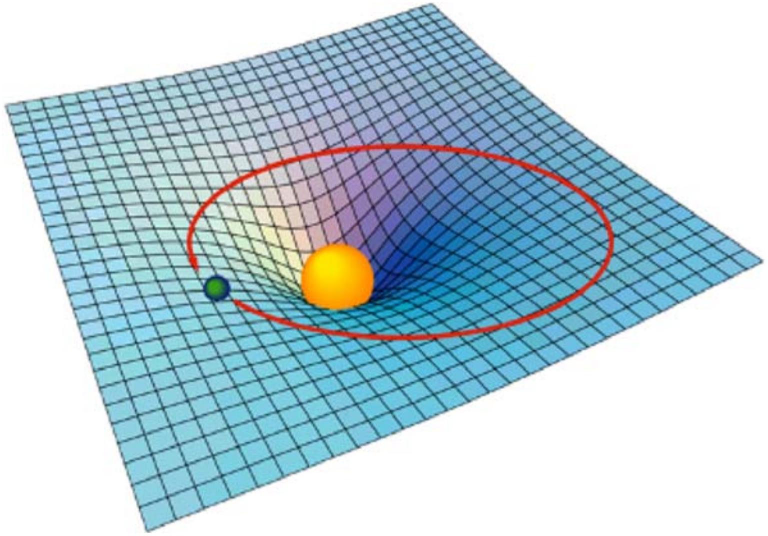
Alain Brillet
(collaboration Virgo)



Ondes gravitationnelles

RELATIVITE GENERALE

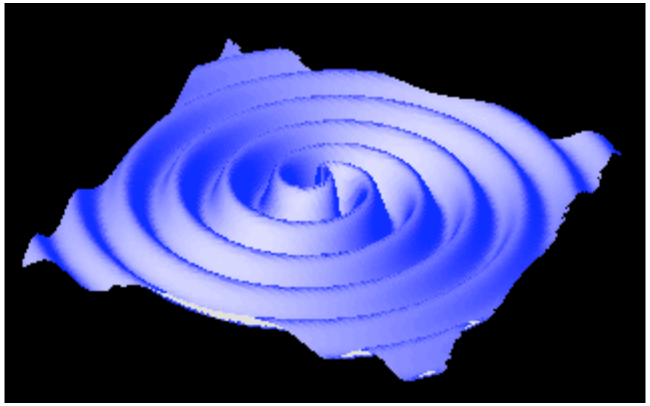
(Einstein 1915)



La matière dit à l'espace-temps
comment se courber
et l'espace-temps dit à la matière
comment se déplacer.

Quand la matière est accélérée
ou change de configuration,
elle modifie la courbure de l'espace temps.

Ces modifications se propagent :
ce sont les ondes gravitationnelles.

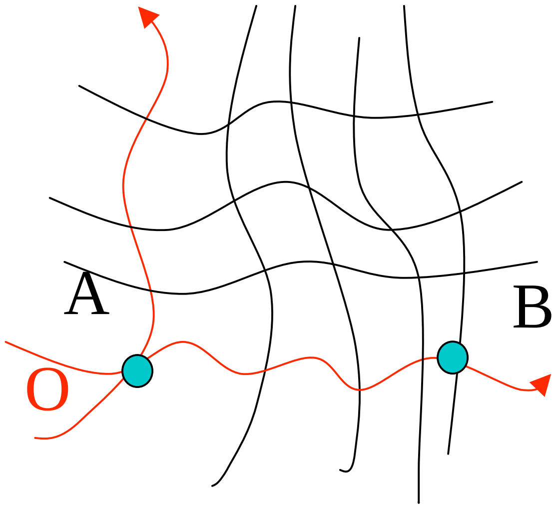


Ondes gravitationnelles

RELATIVITE GENERALE

Dans la « jauge transverse sans trace »,

OG = écart dynamique à l'espace-temps euclidien



élément d'espace-temps
pour une OG se propageant selon z

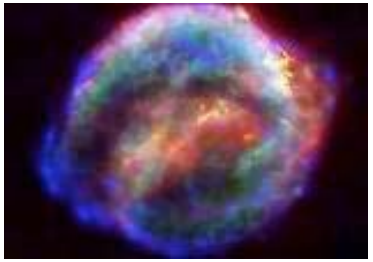
$$\mathrm{d}s^2 = c^2\mathrm{d}t^2$$
$$-(1+h_+(t))\mathrm{d}x^2 - (1-h_+(t))\mathrm{d}y^2$$
$$-2\,h_\times(t)\,\mathrm{d}x\,\mathrm{d}y$$
$$-\mathrm{d}z^2$$

>> 2 polarisations

>> OG tensorielles

Sources

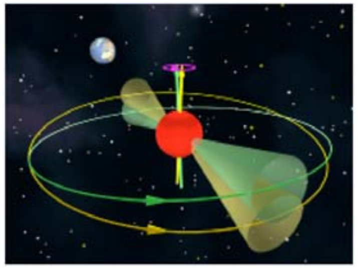
Les effets des ondes gravitationnelles ne sont perceptibles que dans des conditions extrêmes de densité et de vitesse.



➢ **sources impulsionnelles**

• formation d'étoiles à neutrons ou de trous noirs

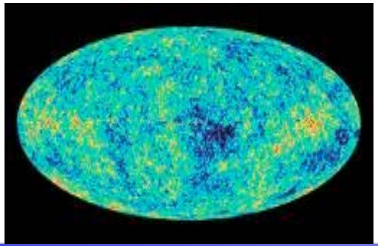
• collision de systèmes binaires massifs (étoiles à neutrons, trous noirs)



➢ **sources périodiques**

• étoiles à neutrons en rotation rapide

• coalescence de systèmes binaires massifs



➢ **fond gravitationnel stochastique**

• cosmologique (époque du Big Bang)

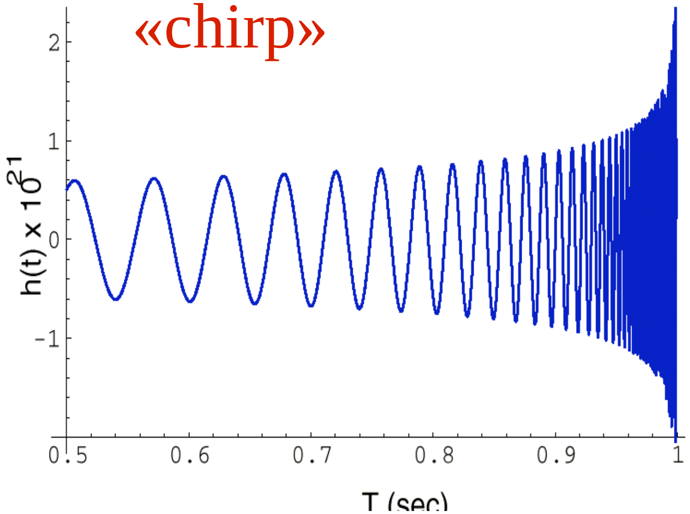
• astrophysique

Sources

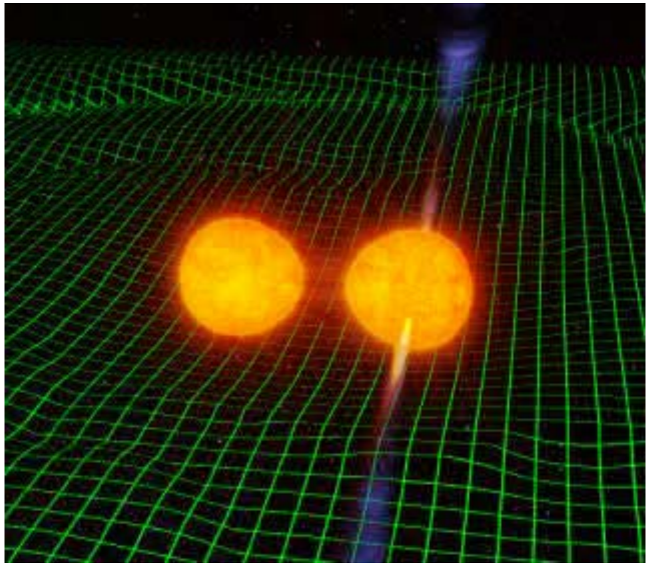
Source impulsionnelle :

***exemple de forme d'onde
pour une coalescence
de deux étoiles à neutrons***

«chirp»



Après le « chirp » ???
→Relativité numérique



GW acting on a ring of freely falling masses

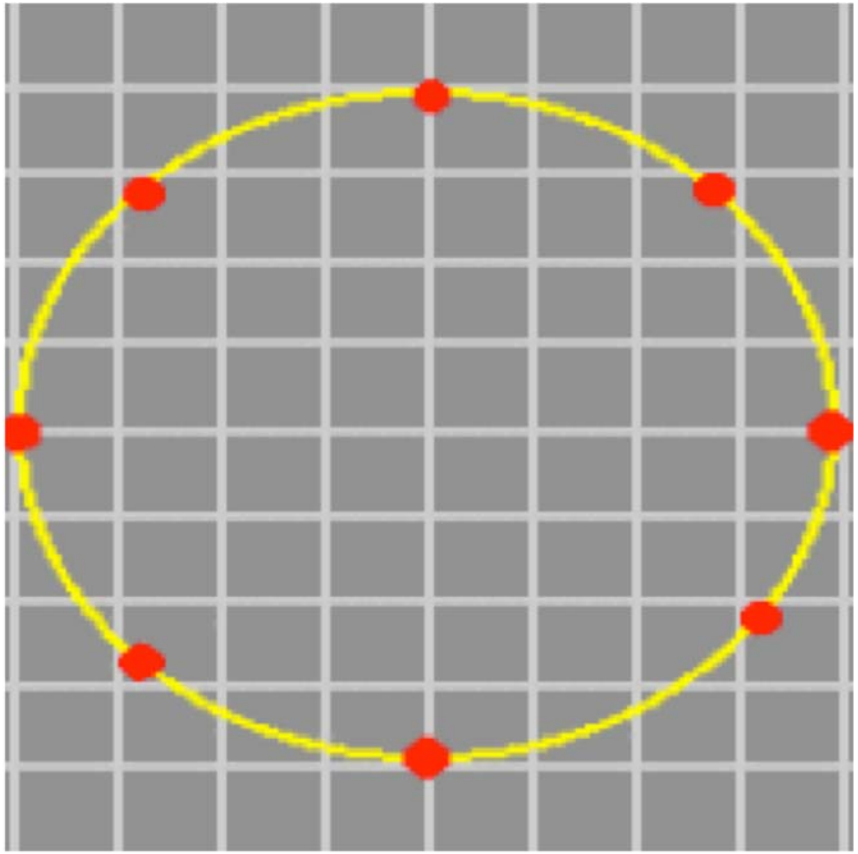


Figure from G.Sanders

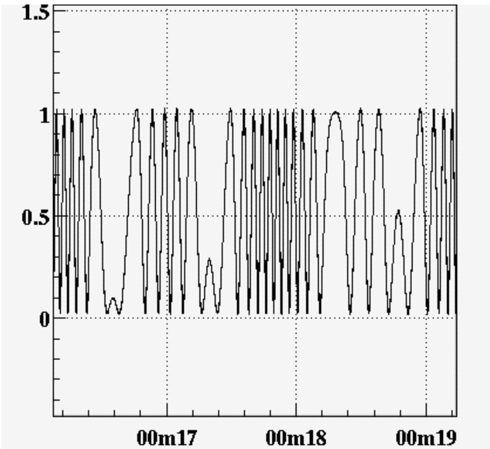
Measure the space-time strain using light

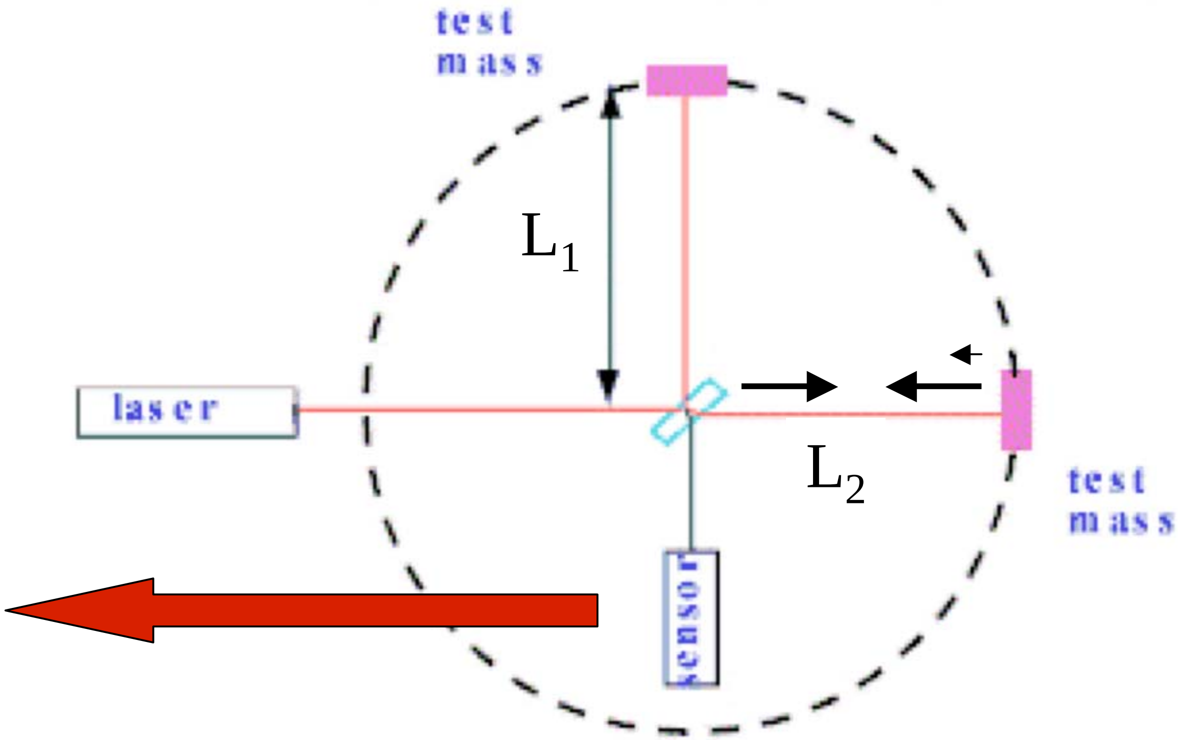
$$L1-L2=\Delta L=h\times L$$

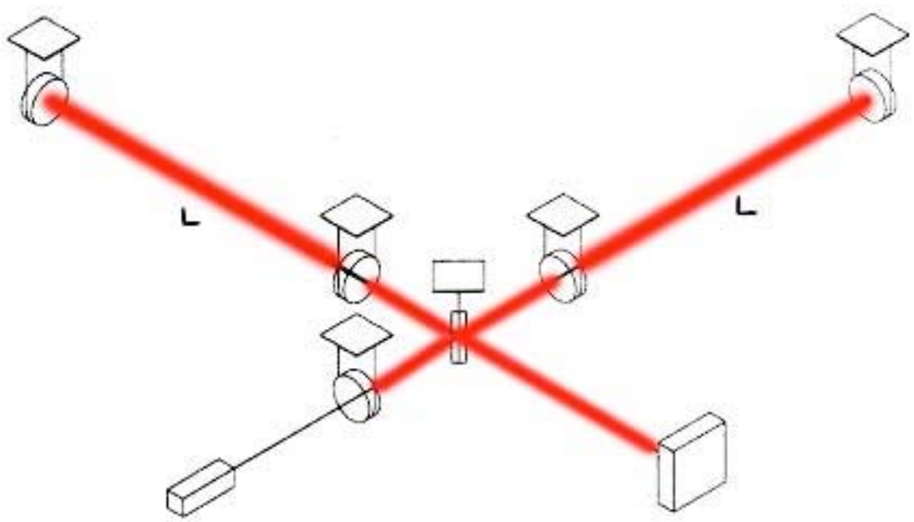
$$S = \sin(4.\pi.h.L/\lambda)$$

nb: $h < 10^{-21}$

Interference fringes



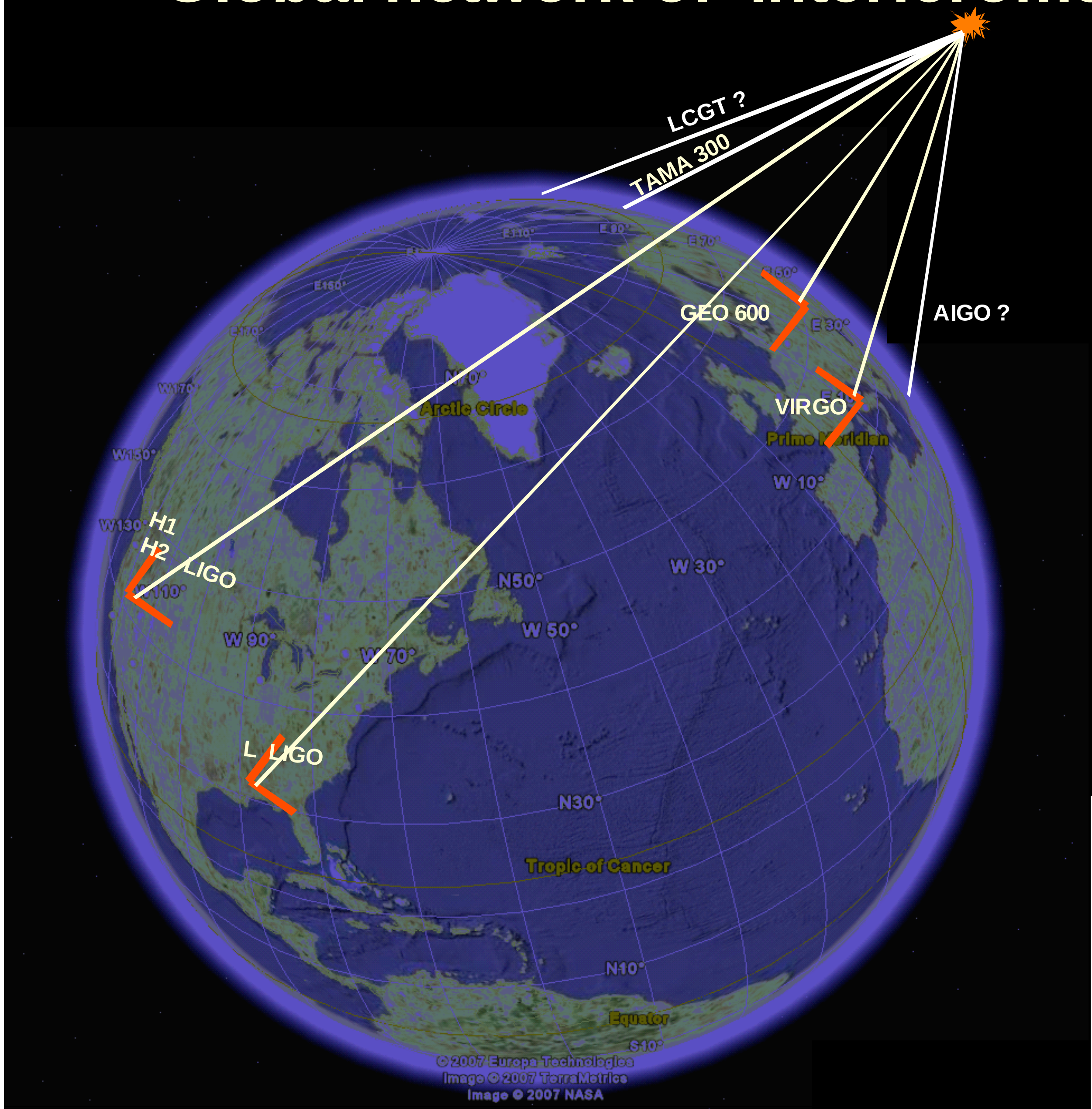




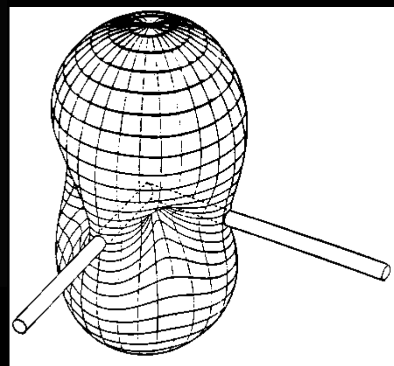
- To improve the sensitivity of the interferometer :
  - Fabry-Perot cavities in the 3 km length arms in order to increase the effective optical length *L'* from 3 km to 100 km ($L' = L(2F/\pi)$).
  - ITF + recycling mirror form an optical cavity: which enables to reduce the shot noise by a factor ~7.

⇒ Designed to measure a relative displacement smaller than $10^{-21}/\sqrt{Hz}$ between 20 *Hz* and 10 *kHz*.

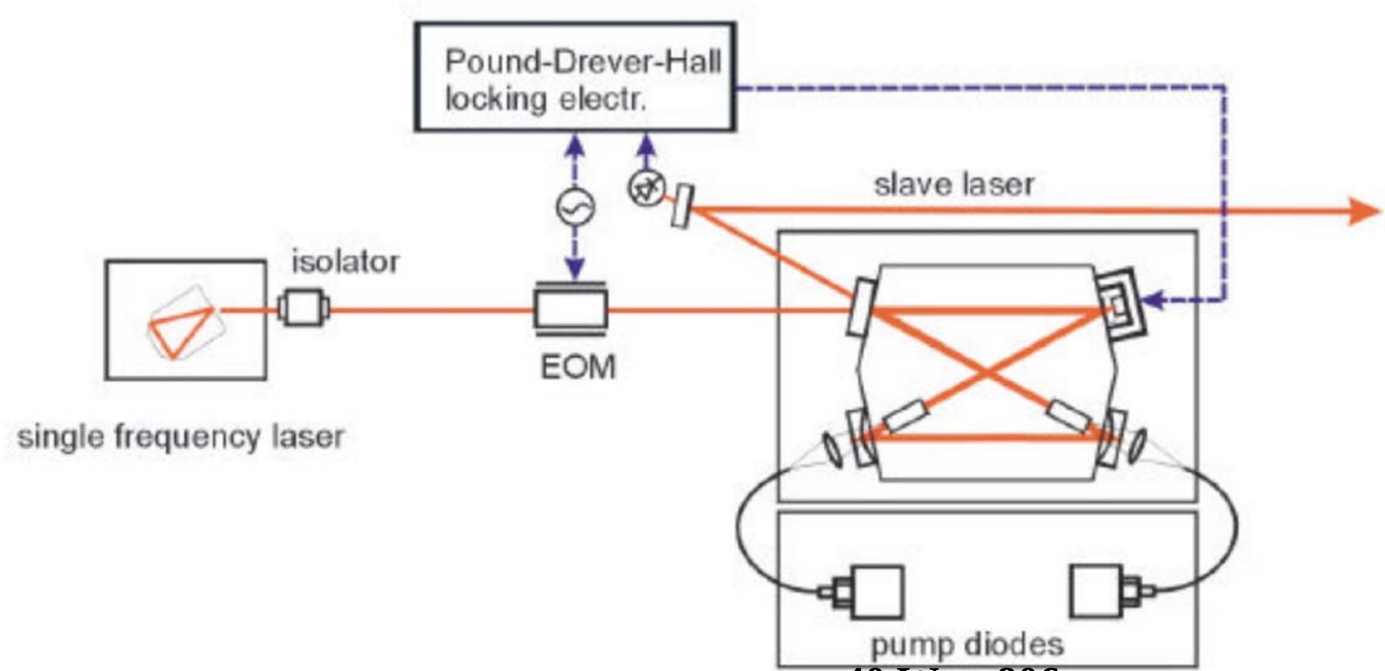
Global network of Interferometric Detectors



- Sensibilité améliorée
  (analyse cohérente)
- Robustesse
  (coïcidences)
- Localisation et paramètres des sources
  (amplitude,polarisation)



The laser : Injection locked master-slave solid state laser

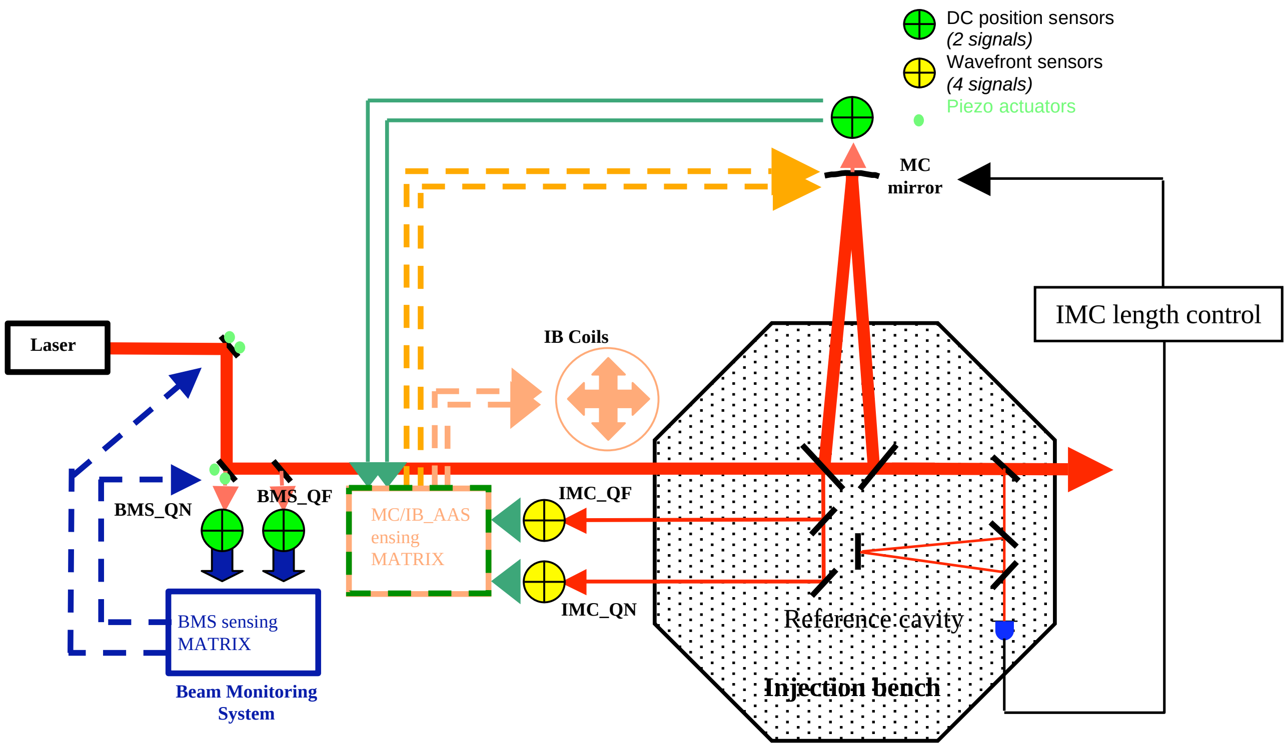


40 W at 806 nm

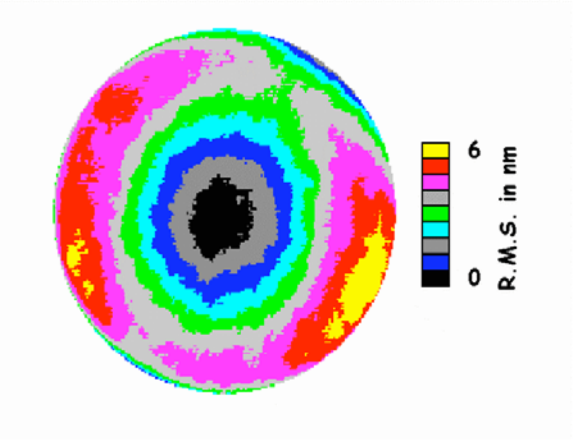
- Nd:YAG master commercial CW single mode (1 W) @1064 nm
- Injection locking technique is used to capture all the power of a multifrequency laser (slave laser) into a single frequency output without any loss of power. The output laser beam copies the master laser frequency and amplitude stability properties.
- In order to keep the Nd:YVO4 slave in the locking range of the master laser, its length is controlled using PDH technique and 2 piezo actuators.

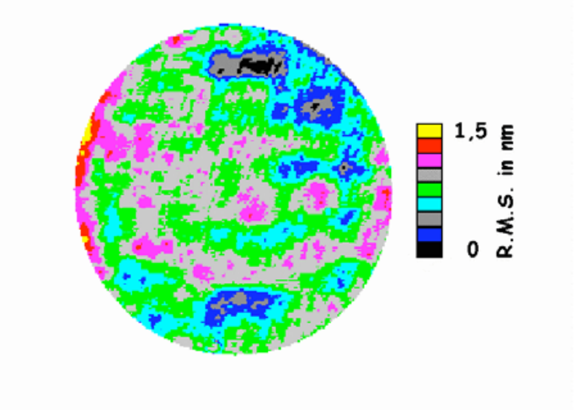
⇒ Output power: 20 W $M^2 = 1.07$

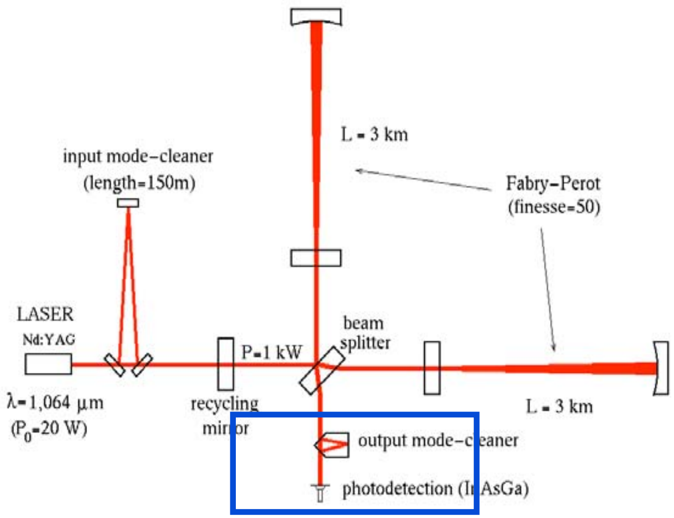
- Prestabilization of the laser frequency
  - Laser frequency locked to the Input Mode cleaner.
  - Input Mode Cleaner length locked to the reference cavity (monolithic triangular cavity, ULE).
- Laser beam filtering (with the IMC).
- Matching of the laser beam in the ITF using a parabolic telescope.



35 cm diameter, 10 cm thickness
Substrate losses: 1 ppm/cm
Coating losses: <5 ppm
Roughness < 0.5 Å RMS

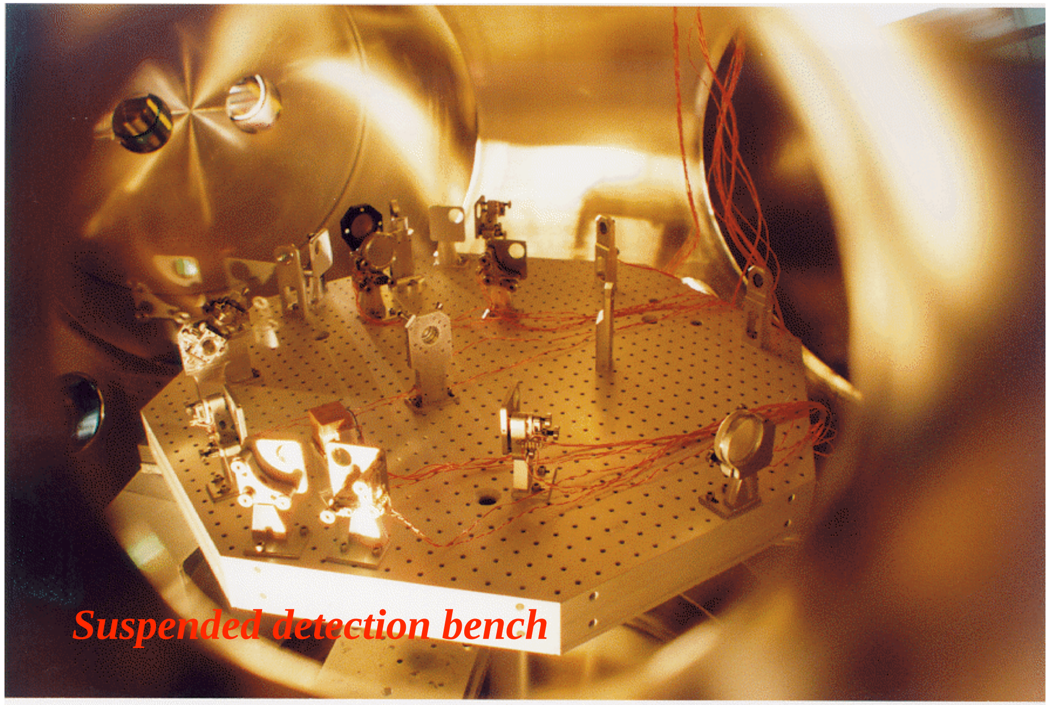




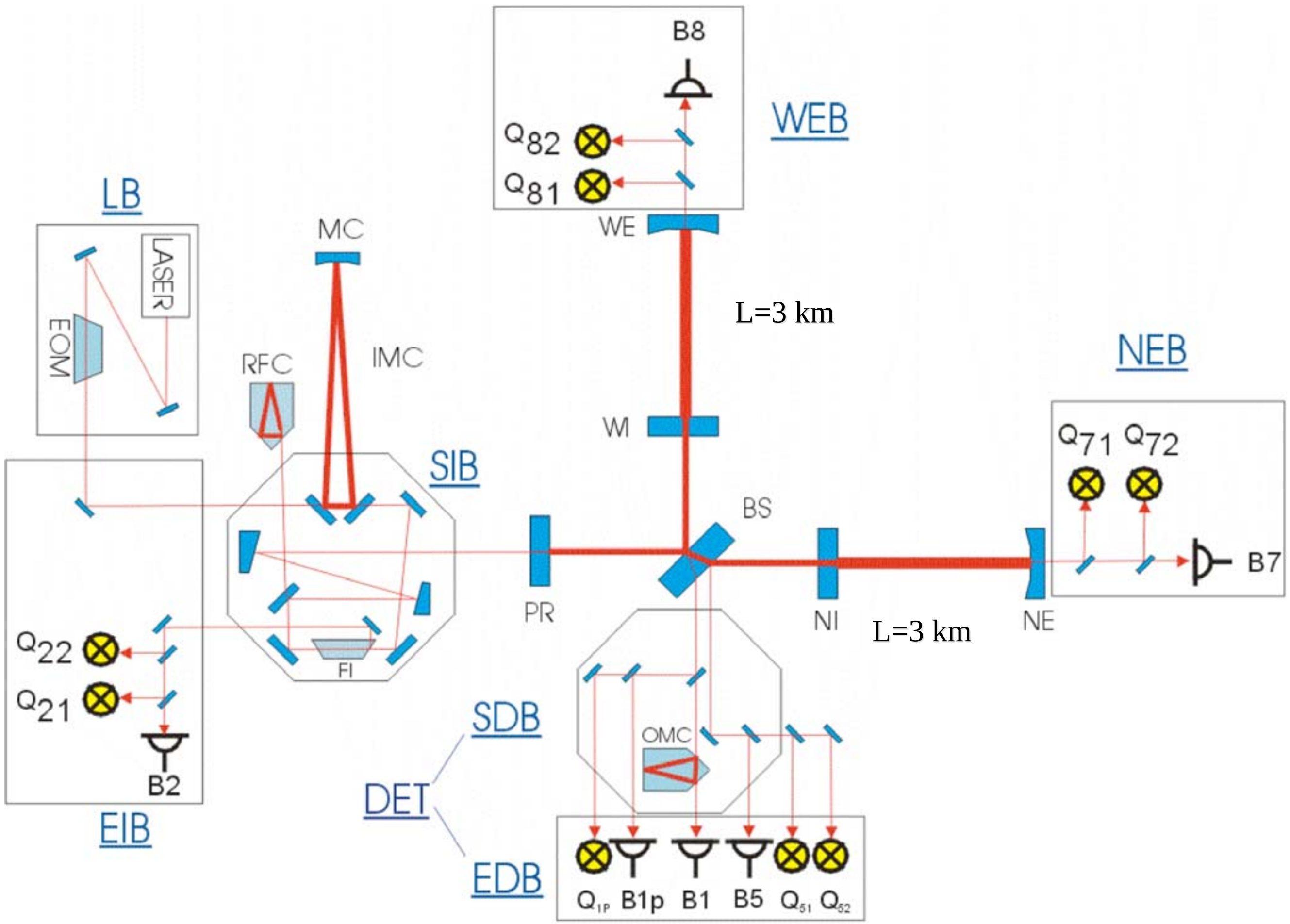


- Detection, amplification and demodulation in air on the external bench (InGaAs photodiodes)

- In vacuum output mode cleaner (spatial filtering of the ITF output beam)
  - Monolithic triangular cavity.
  - 2.5 cm long, Finesse = 50.
  - Locked on TEM_{00} (thermal and piezo control).

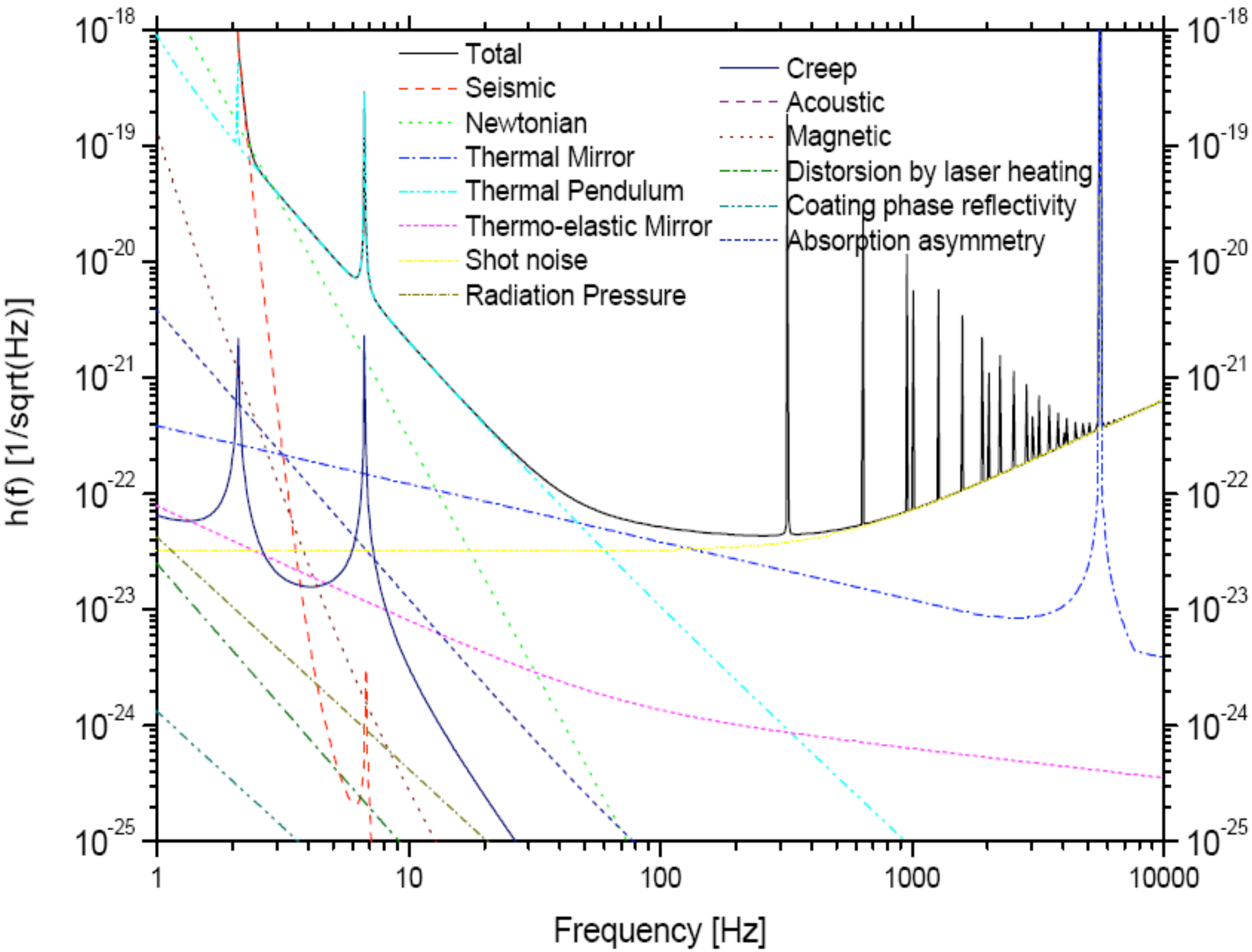


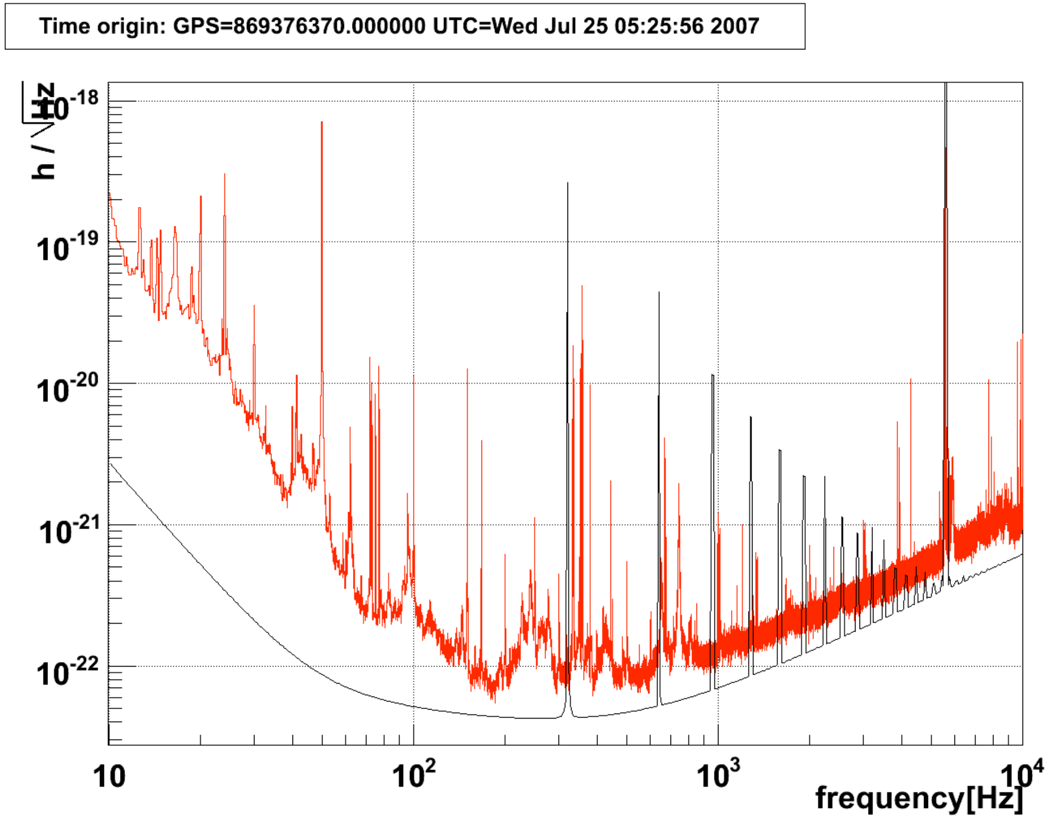
Interferometer control system



Instruments

Densité spectrale de la résolution de Virgo (Conception)

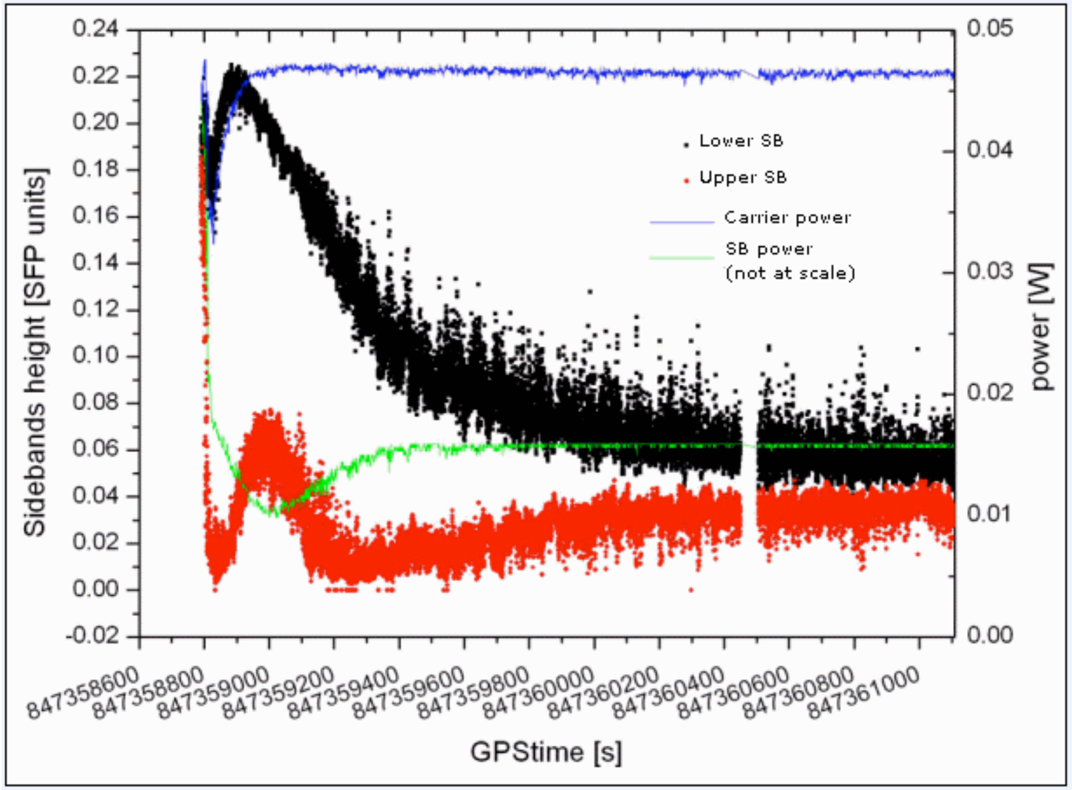


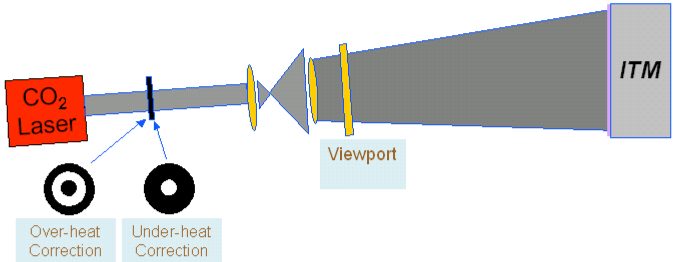


- Persisting technical noises:
  - Low frequency ⇒ Control noises: longitudinal and angular.
  - Medium frequency ⇒ Environmental noises coupled by diffused light.
  - High frequency ⇒ Shot noise: we cannot run with higher power due to thermal lensing problems.

Optical fields are changing during lock acquisition (Power recycling cavity gains of the Sidebands are decreasing) due to the thermal lensing effect in input mirrors

=> Thermal lensing compensation system needed (actuator = annular heating with Co2 laser).



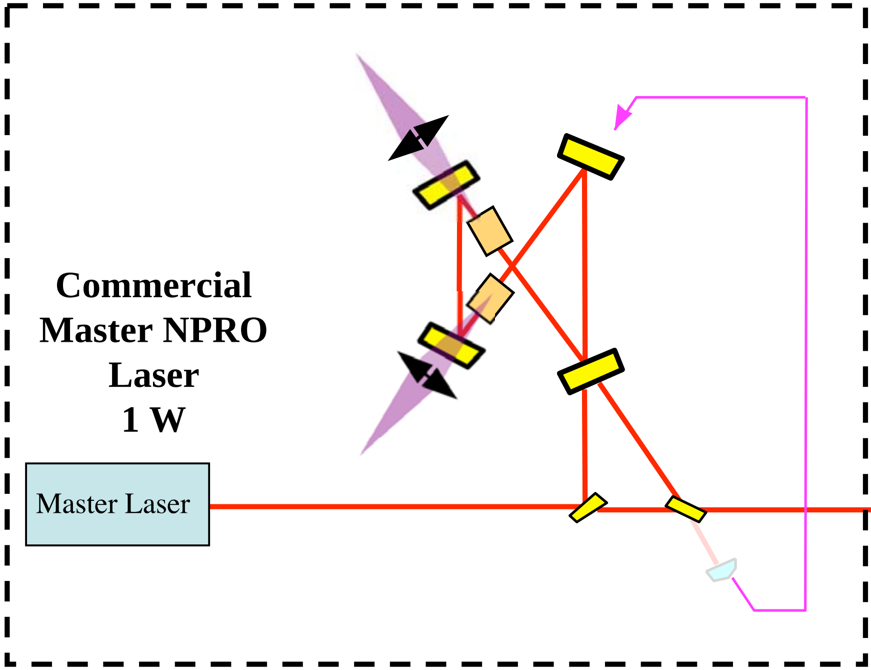


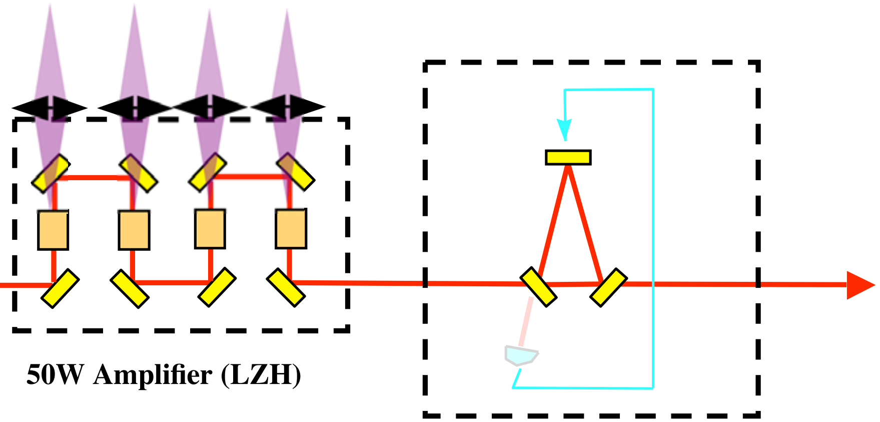
SB behaviour during first 30mn of lock as seen by scanning FP on dark fringe

⇒*This solution has already been sucessfully implemented on the american detectors*

Four-stage end-pumped Nd:YVO4 amplifier

20 W Nd:YVO4 slave laser
(injection-locked)





The Pre Mode Cleaner is a triangular 13 cm long FP cavity (finesse=500), devoted to filter out the amplitude fluctuations of the laser (to be shot noise limited at the modulation frequency)

Nd-YvO4 crystal

Crystal pumping module

⇒ Tested at OCA-NICE: 20 W slave output power
64 W delivered by the amplifier