

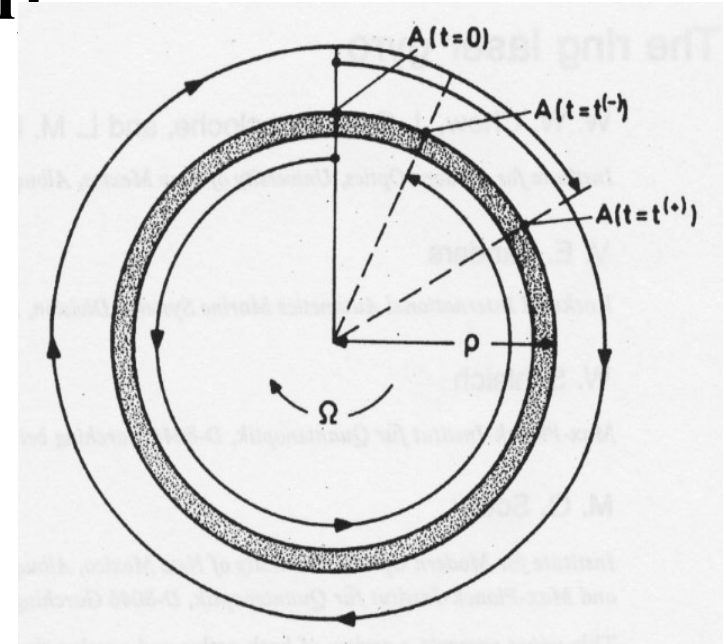
Are Gyrolasers suitable for future GW suspensions?

- Sagnac effect in short
- very high sensitivity “large” gyrolaser
- performances of a modified SA with a 3 axis gyro system
- Gyrolaser for Virgo suspension

Sagnac Effect (Electromagnetic waves under the effect of rotation)

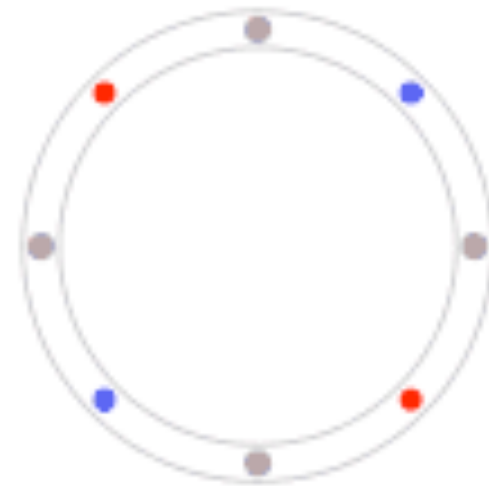
$$ct_+ = 2\pi R + R\Omega t_+ \quad t_+ = 2\pi R / (c - \Omega R)$$

$$ct_- = 2\pi R - R\Omega t_- \quad t_- = 2\pi R / (c + \Omega R)$$

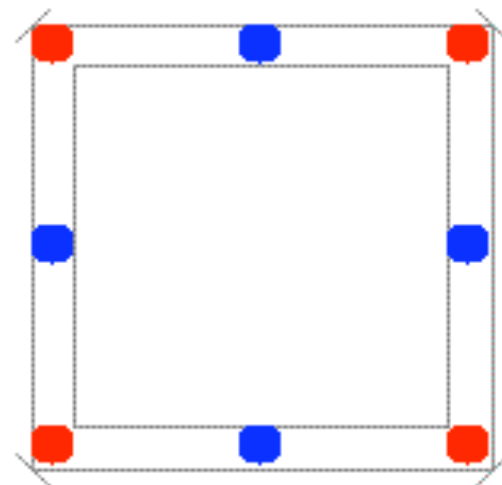
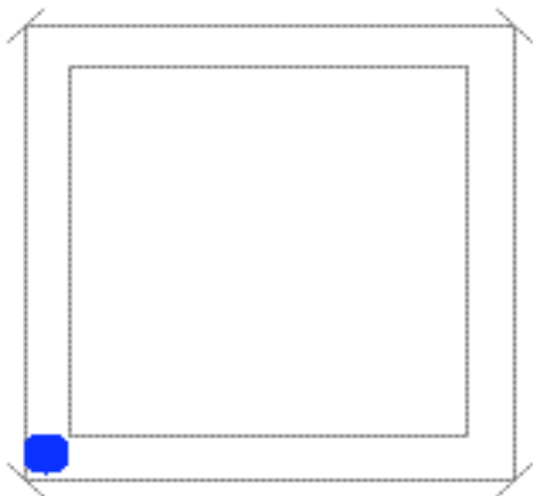


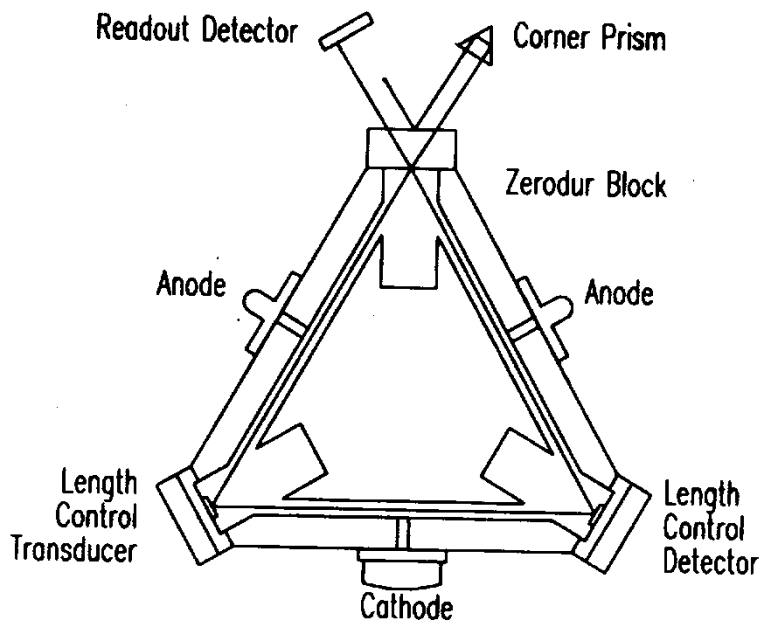
$$\Delta L = c(t_+ - t_-) \approx \frac{4\pi R^2 \Omega}{c}$$

$$\Delta\phi = 2\pi \frac{\Delta L}{\lambda} = \frac{8\pi}{\lambda c} A\Omega$$

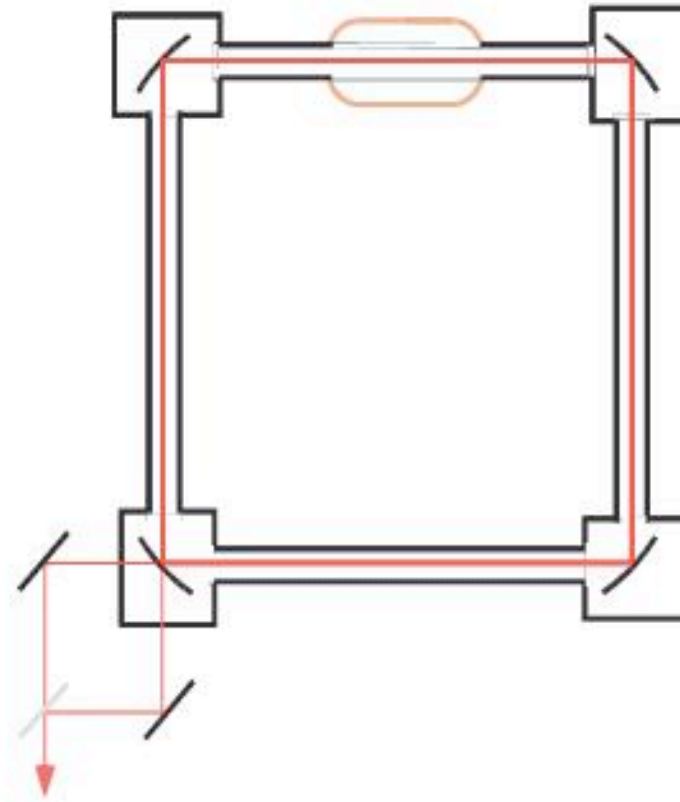


The Basic Concept

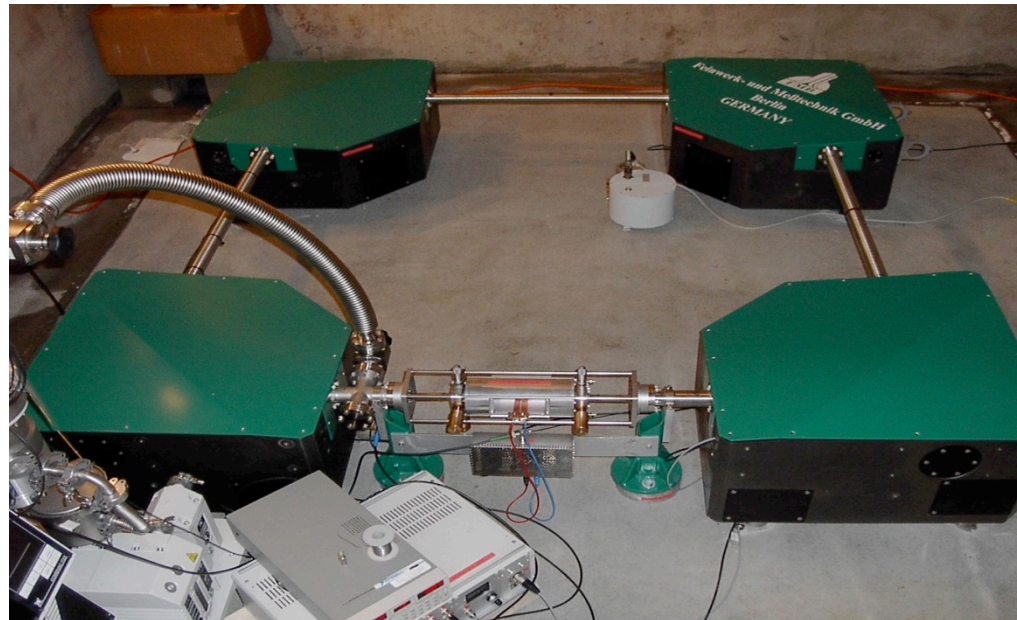
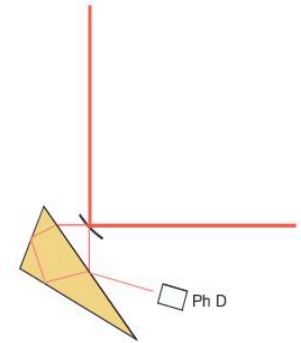
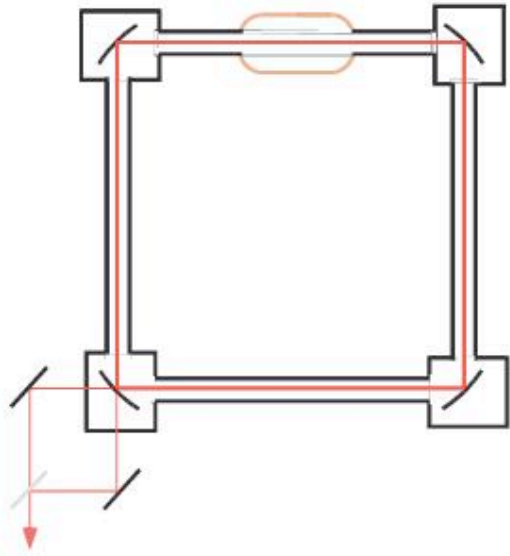




Typical Gyrolaser



- Several devices have been developed (passive and active rings and long fiber system)
- speed meters (advantages: no moving parts), no coupling with translations



GEO sens

Physics within the "Earth rotation" signal



Seismic waves
Local - teleseismic
Kaikoura
Sept 1996



Tidal effects
in the
solid
earth



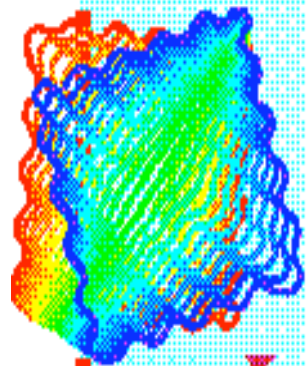
Effects from
general relativity

Fluctuations
in the Earth rotation



Relativity tests and
cosmic microwave
background





Interferometer: $\Delta\phi = 8\pi A \cdot \Omega / \lambda v$

Laser:

$$\delta f = 4A \cdot \Omega / \lambda P$$

1963: Macek

...

1970s, 1980s: Development for
inertial guidance & navigation

...

...

1988-90: C-I

1997: C-II

2004 G

2005 Geosensor

1893: idea (Lodge, Larmor)

1913: discovered (Sagnac)

...

1925: Earth rotation (Michelson)

...

1965: Superconducting electrons

...

1970s, 1980s: Fibre optic gyros

...

...

...

1991: Atoms

1993: Free electrons

1997: superfluids, ions

Time line

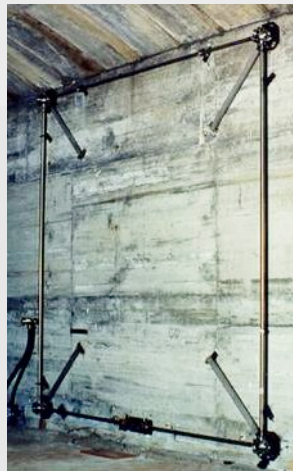


C-2

Monolith

Area: 1 m²

Noise: 7.5 ppm

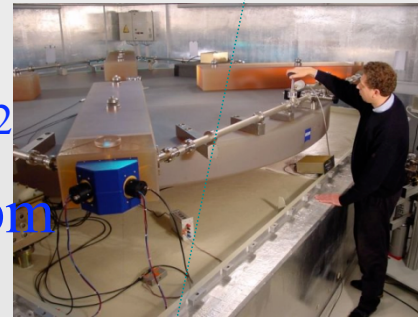


G0

Area: 12.25 m²

Noise: 140 ppm

UG-1
Area: 370 m²
Noise: 0.66 ppm

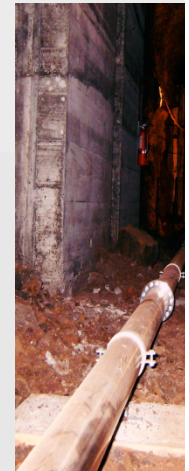


G

Monolith

Area: 16 m²

Noise: 0.007 ppm



UC

Area: 8

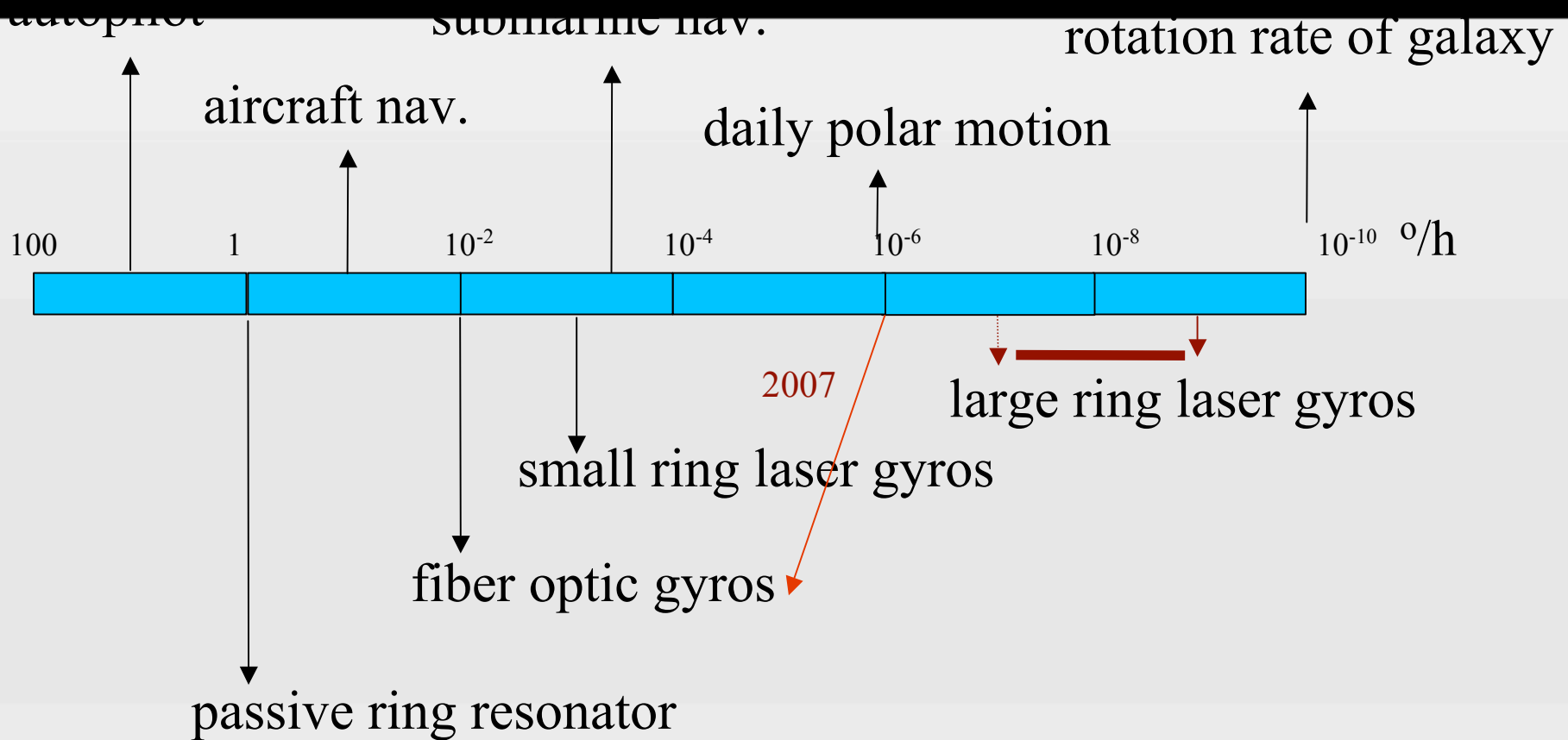
Noise: 1

Teleseismic
waves

Earth tides

Polar

several devices have been developed, "speedmeters",
main advantage: no moving parts



R. Rodloff (1990)

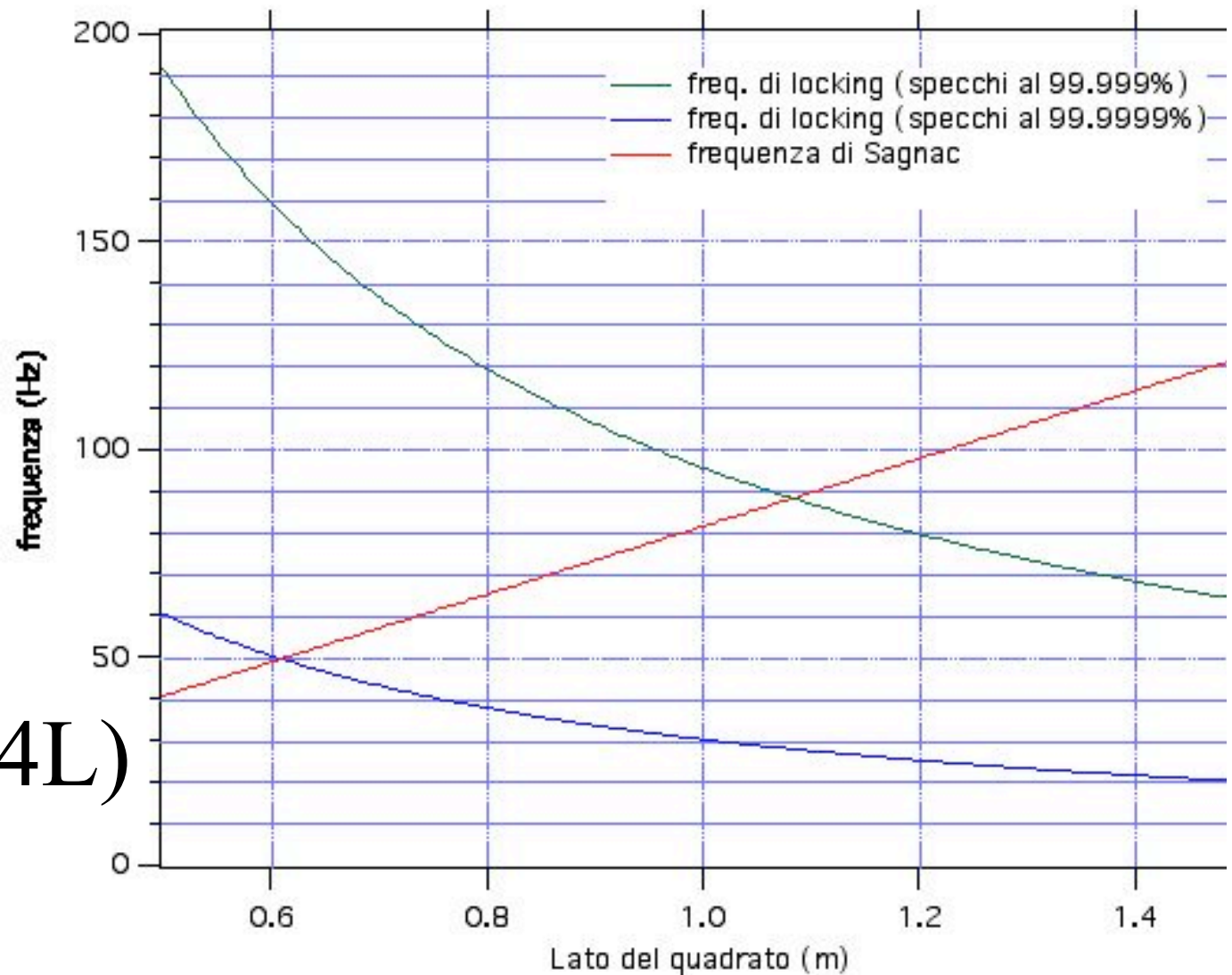
GyroLaser Problem

- Mode Locking: the two lasers are forced to lase at the same frequency.
- Frequency pulling: the response is not linear for very low rotation signals
- ✓ *mode locking and frequency pulling are caused by diffused light*

- In general this problem is solved by rotating the gyro with a constant Ω
- **Ω could be the Earth rotation (0.000073 rad/s, 15 degrees/h)**

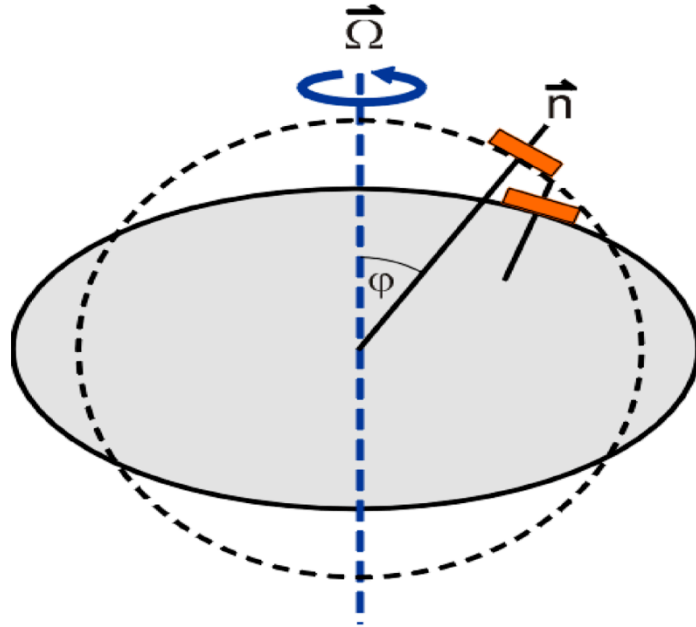
$$l \sim (cs\lambda)/(\pi d4L)$$

λ/d diffraction angle

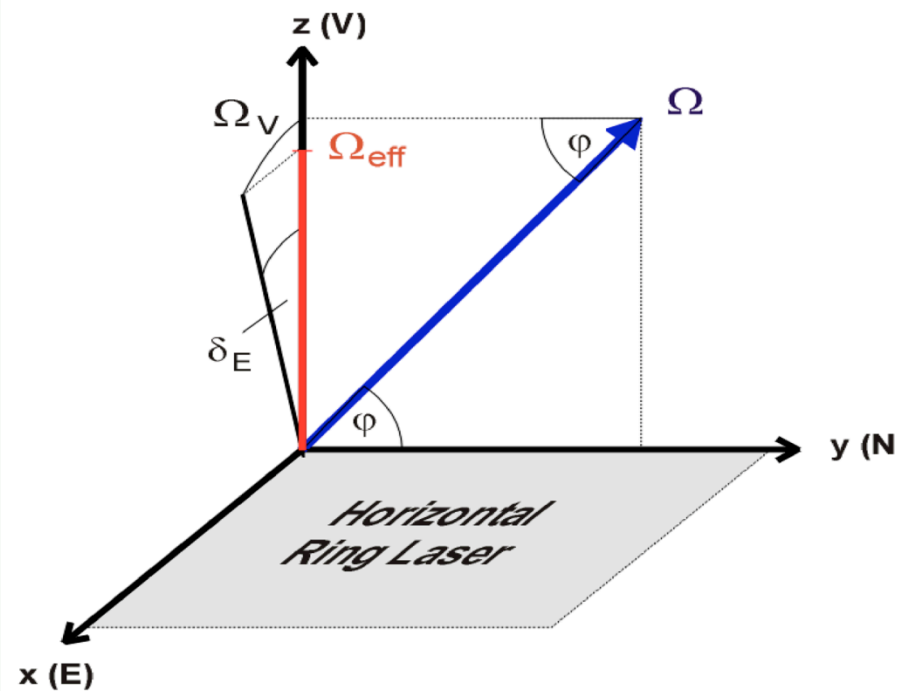


Frequency of injection locking compared with the Sagnac Frequency at P (Backscattering uniform).

Large Ring Lasers are directly linked to



$$\Delta f = \frac{4A}{\lambda L} \hat{n} \cdot \vec{\Omega}$$



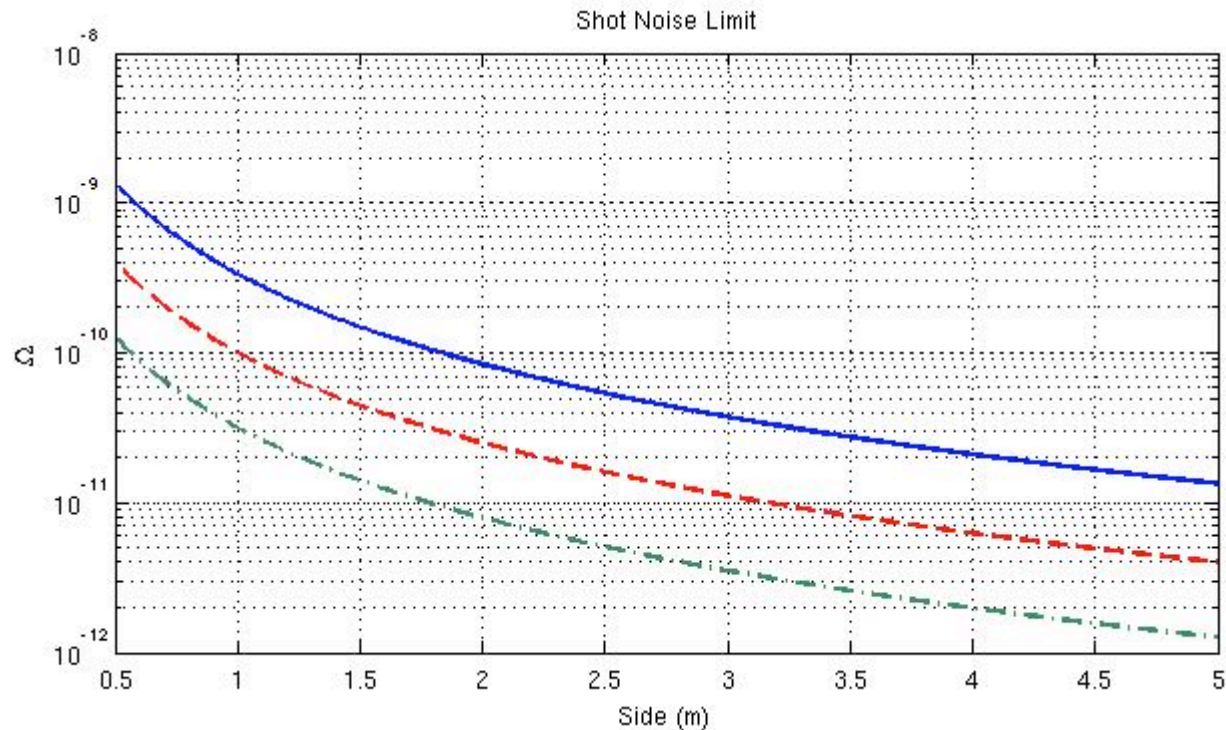
$$\Omega_{\text{eff}} = \Omega \sin(\varphi + \delta_N) \cos(\delta_E)$$

- Ω Rotation vector
- δ_N Tilt angle towards N
- δ_E Tilt angle towards E
- φ Latitude

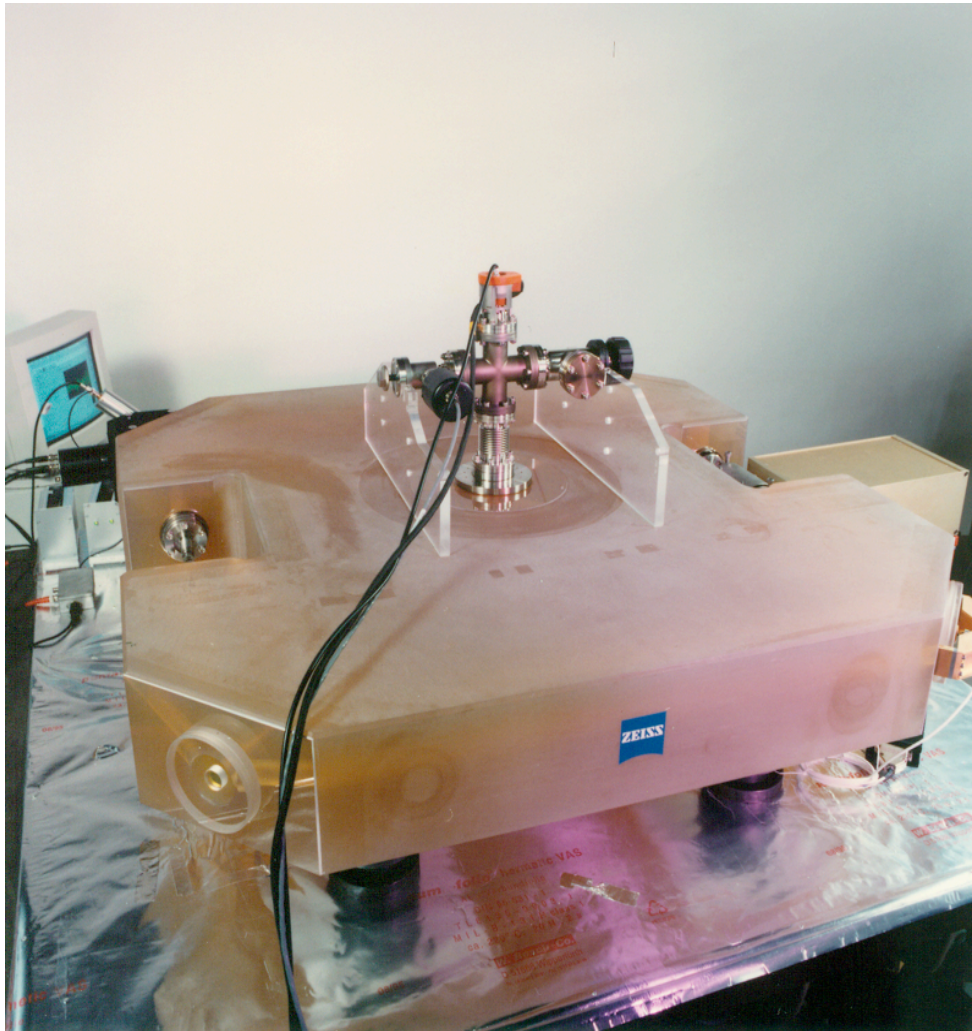
Shot Noise of a gyrolaser

$$\dot{U}_{sn} = \frac{c}{2\partial KL} \sqrt{h\nu \mu \frac{T}{2P_0 t}}$$

- K ring laser scaling factor: depends on perimeter and wavelength, for a square ring $K = 1.58 \cdot 10^6 L$
- present large gyrolaser are a factor 3 above theoretical shot noise limit (middle curve absorptions and transmission $\sim 1\text{ppm}$, power 10nW)



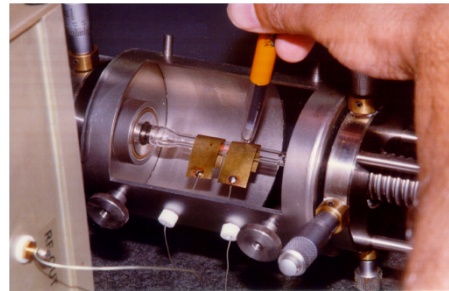
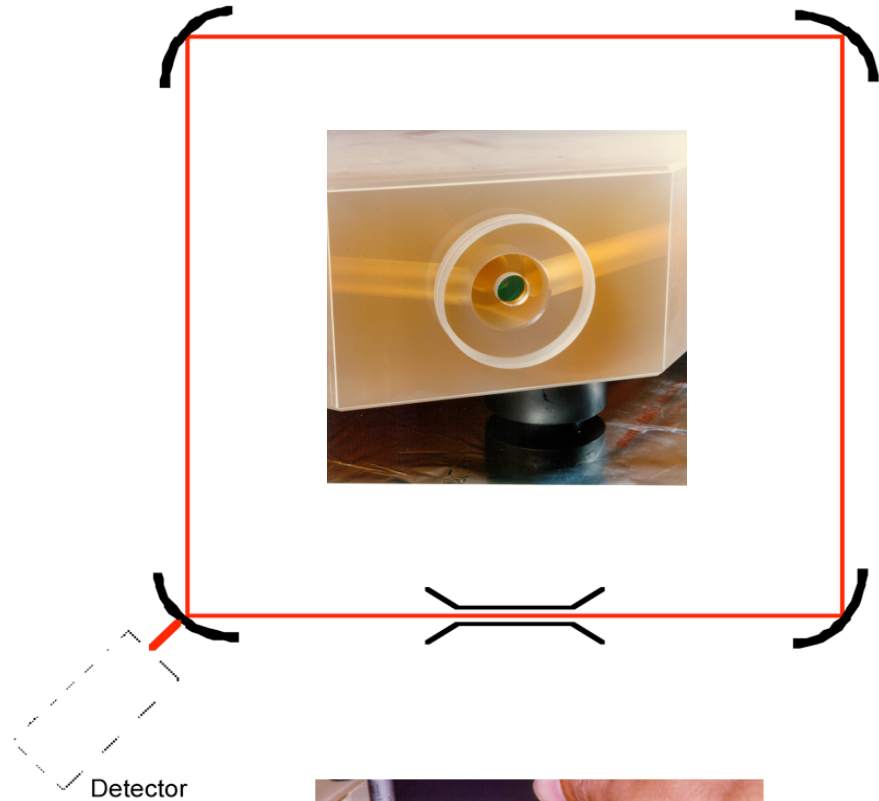
The Stedman-Schreiber recepy Monolithic Gyro Design



- Perimeter 4 m
- Area 1 m²
- Cavity in Neutra Plane
- UHV-Compatibility
- RF-Excitation

<http://www.ringlaser.org.nz/>

- HeNe Mono mode Laser
- Circul. Power ≈ 60 mW
- Ring down Time: 0.15 - 1 ms
- High Cavity Q $\approx 10^{12}$
- FSR 75 MHz
- 3 nW Beam power at Beam combiner

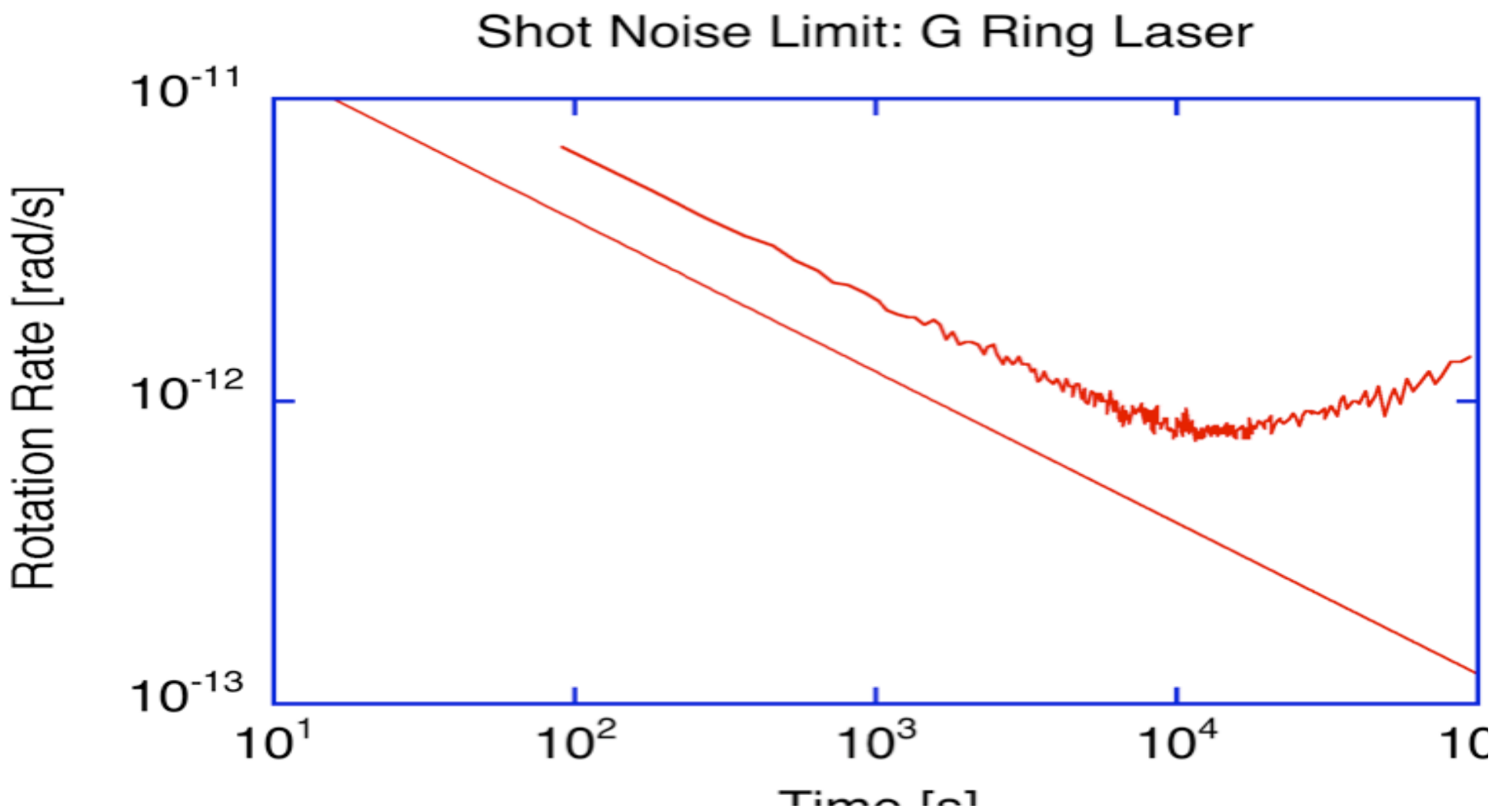


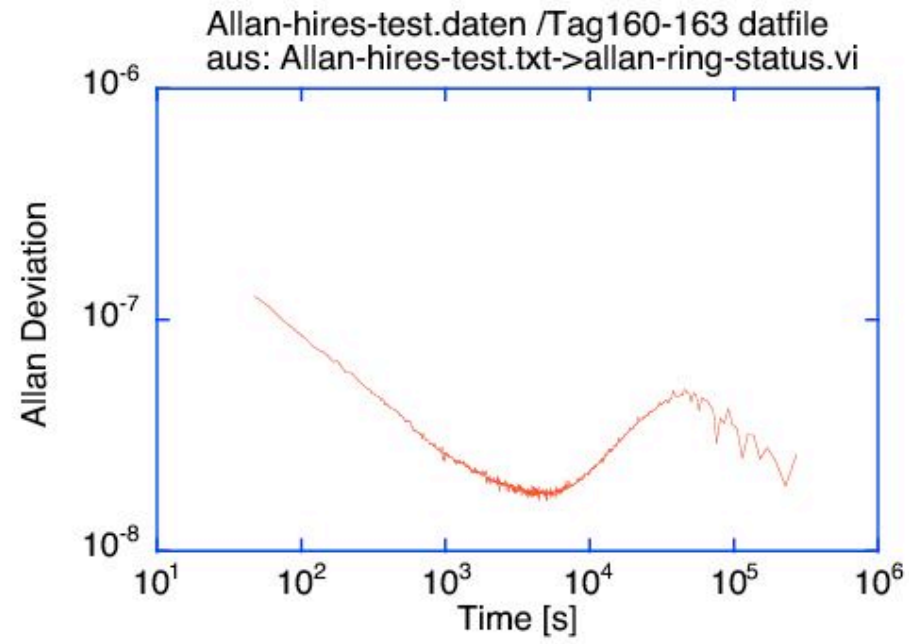
Measurement Quantities

- Scale Factor
- Rotation Rate
- Orientation
- Null shift Bias
- Backscatter

$$\delta f = \frac{4A}{\lambda P} \vec{n} \cdot \vec{\Omega} + f_{nr}$$

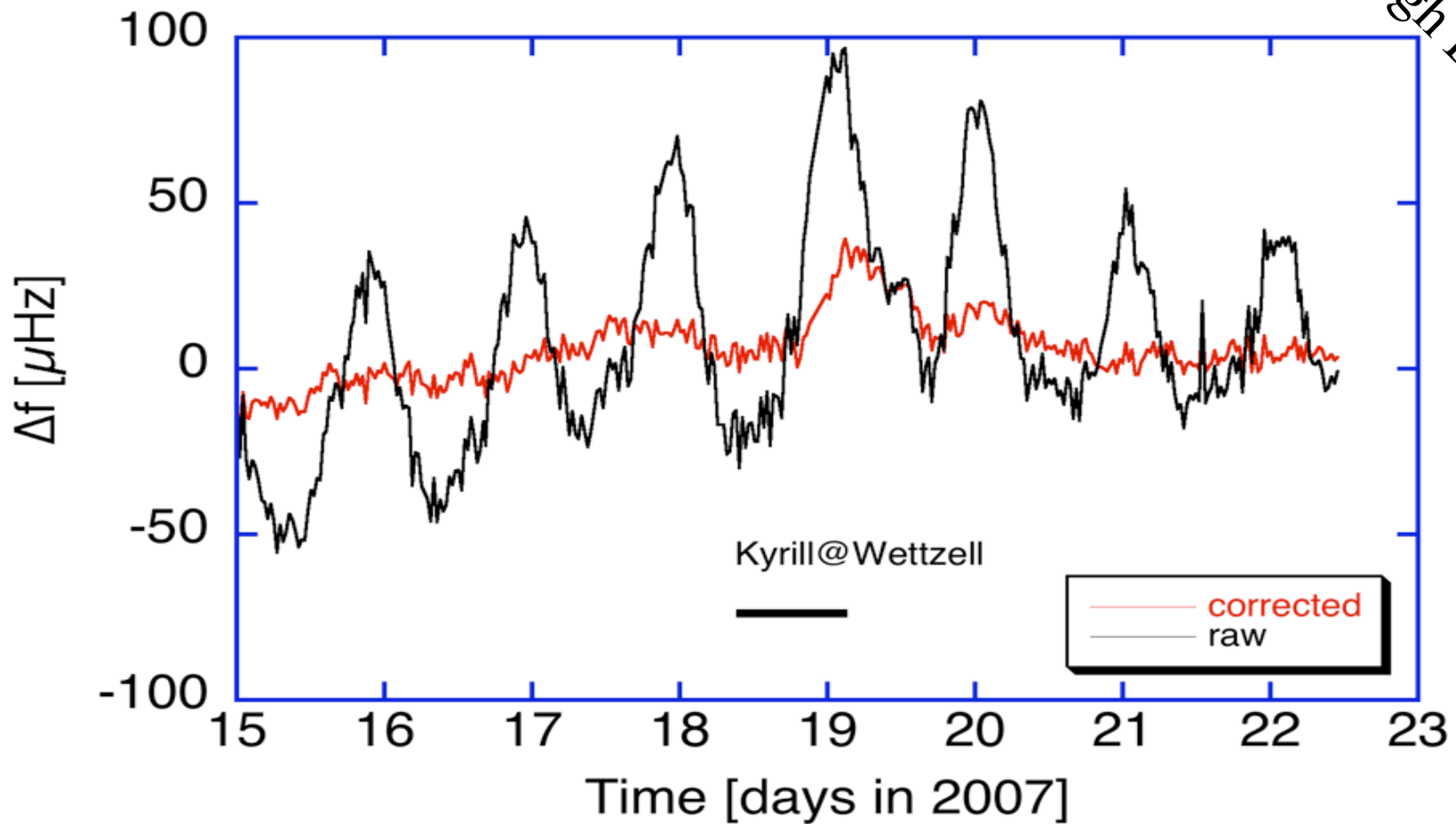
Ring Laser Resolution





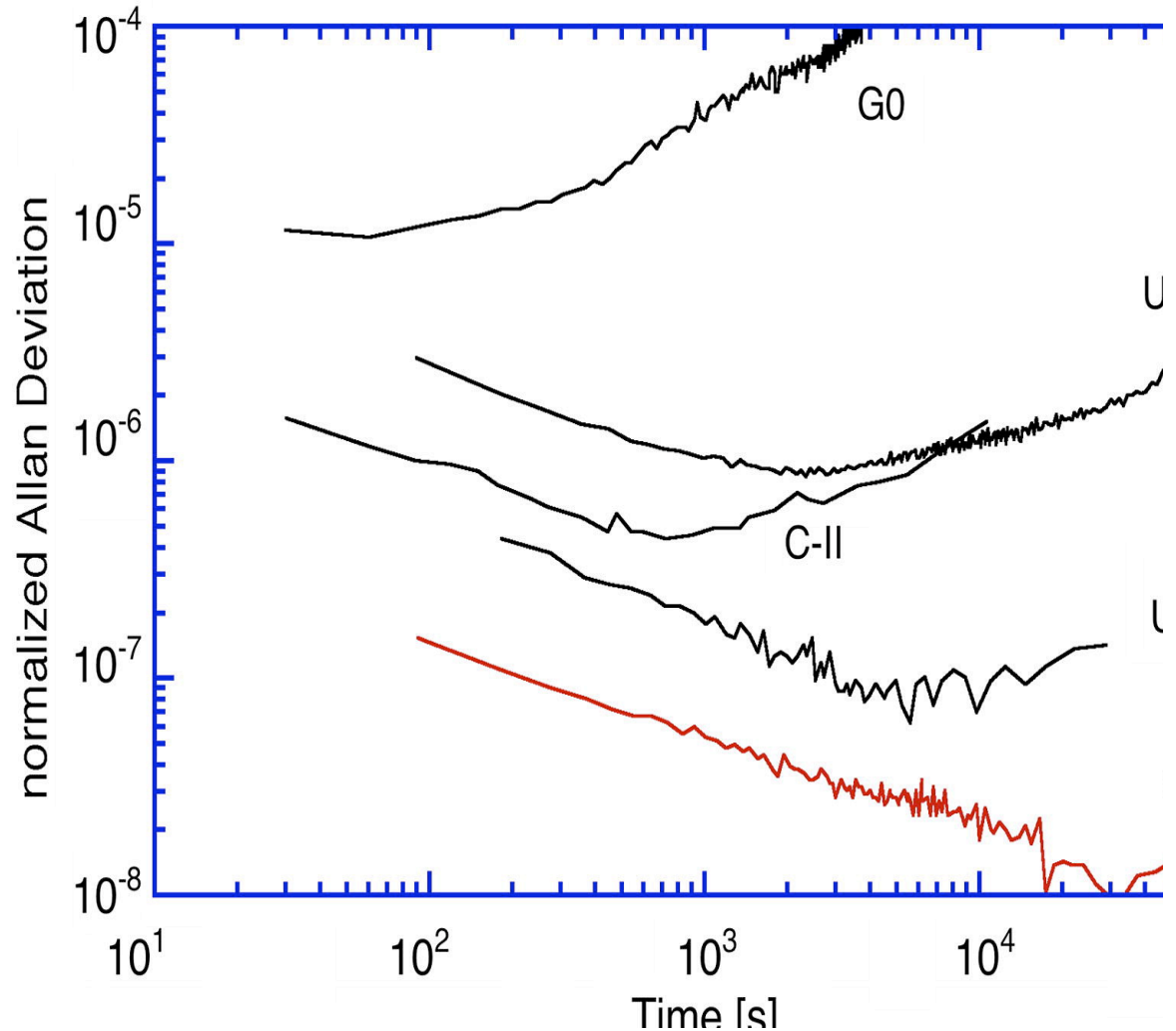
Regional Effect of Ring Laser Measurements

U. Schreier
Very High Duty Cycle



Ring Lasers Performance

- Resolution 10^{-10} rad
- Angle of a hair viewed from 2000 km
- Here assumed resolution of 10^{-11}
- Very low drift



Theoretical Resolution

U. Schrei

<i>device</i>	<i>area m²</i>	τ (s)	Q	Ω rad/s/sqrt(Hz)
C-II	1	150	$4.5 \cdot 10^{11}$	$7.2 \cdot 10^{-10}$
Geo Sensor	2.56	1200	$3.5 \cdot 10^{12}$	$4.5 \cdot 10^{-11}$
G	16	1000	$3.0 \cdot 10^{12}$	$9 \cdot 10^{-11}$
UG-1	367	1500	$6.0 \cdot 10^{12}$	$4.7 \cdot 10^{-12}$

G-Pisa

INFN-Group V

F. Bosi, A. Di Virgilio

INFN-Pisa

M. Allegrini, J. Belfi, N. Beverini, G. Carelli, I. Ferrante, E. Maccioni

Univ. of Pisa and CNISM

F. Sorrentino

Univ. of Florence

A. Porzio and S. Solimeno

Univ. of Naples and CNISM

in collaboration with

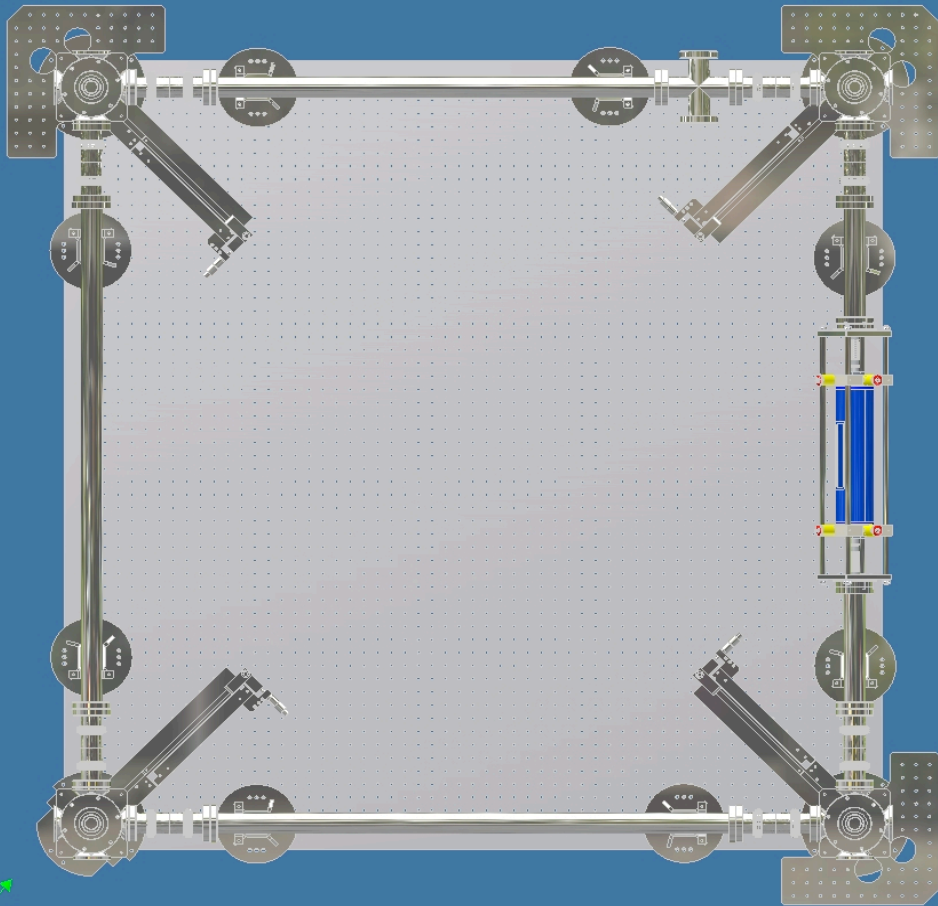
U. Schreiber, A. Velikoseltzev

Technischen Univ. Muenchen, and Fundamentalstation Wetzell, Germany

J.P. Wells and R. Graham

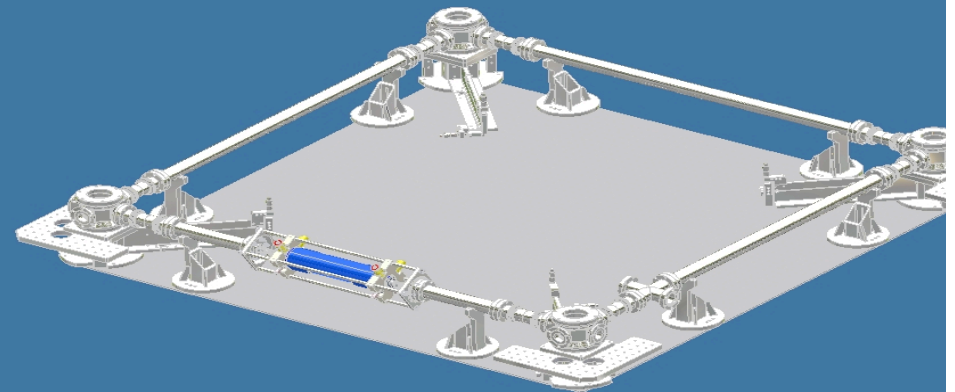
Univ. of Canterbury, Christchurch, New Zealand

- G-Pisa has been financed by the INFN Commission V with the following aims:
 - *learn the technique*
 - *develop a small device (side about 1m) to improve the performances of next generation gravitational wave detection*
 - *active stabilization of the gyro cavity*



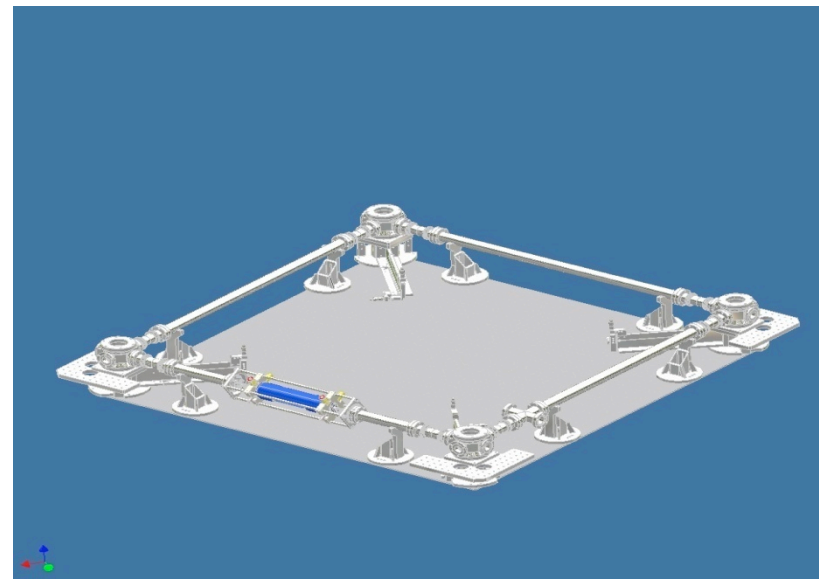
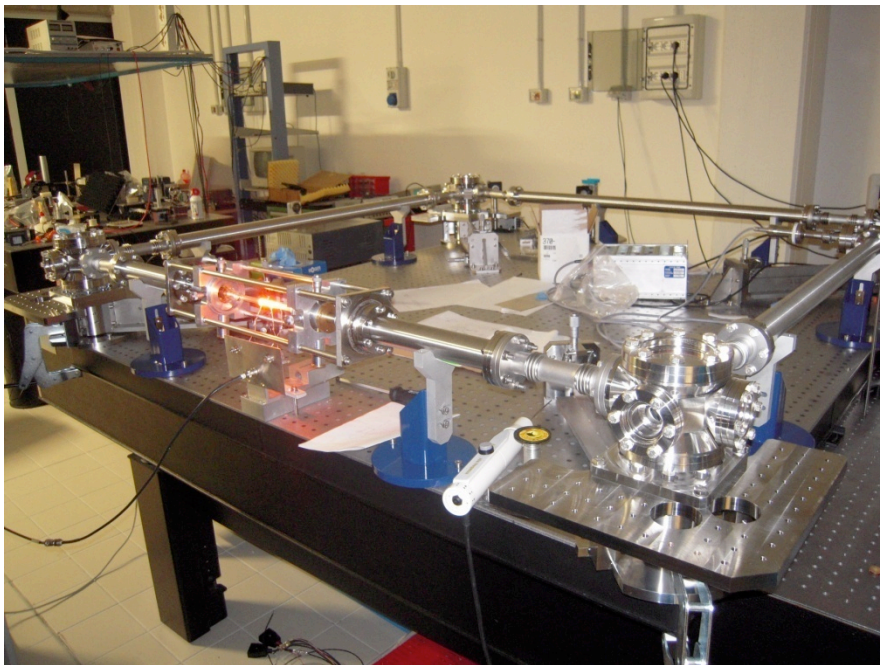
device scalable 1.4-0.9 m
 delivery time June 2008

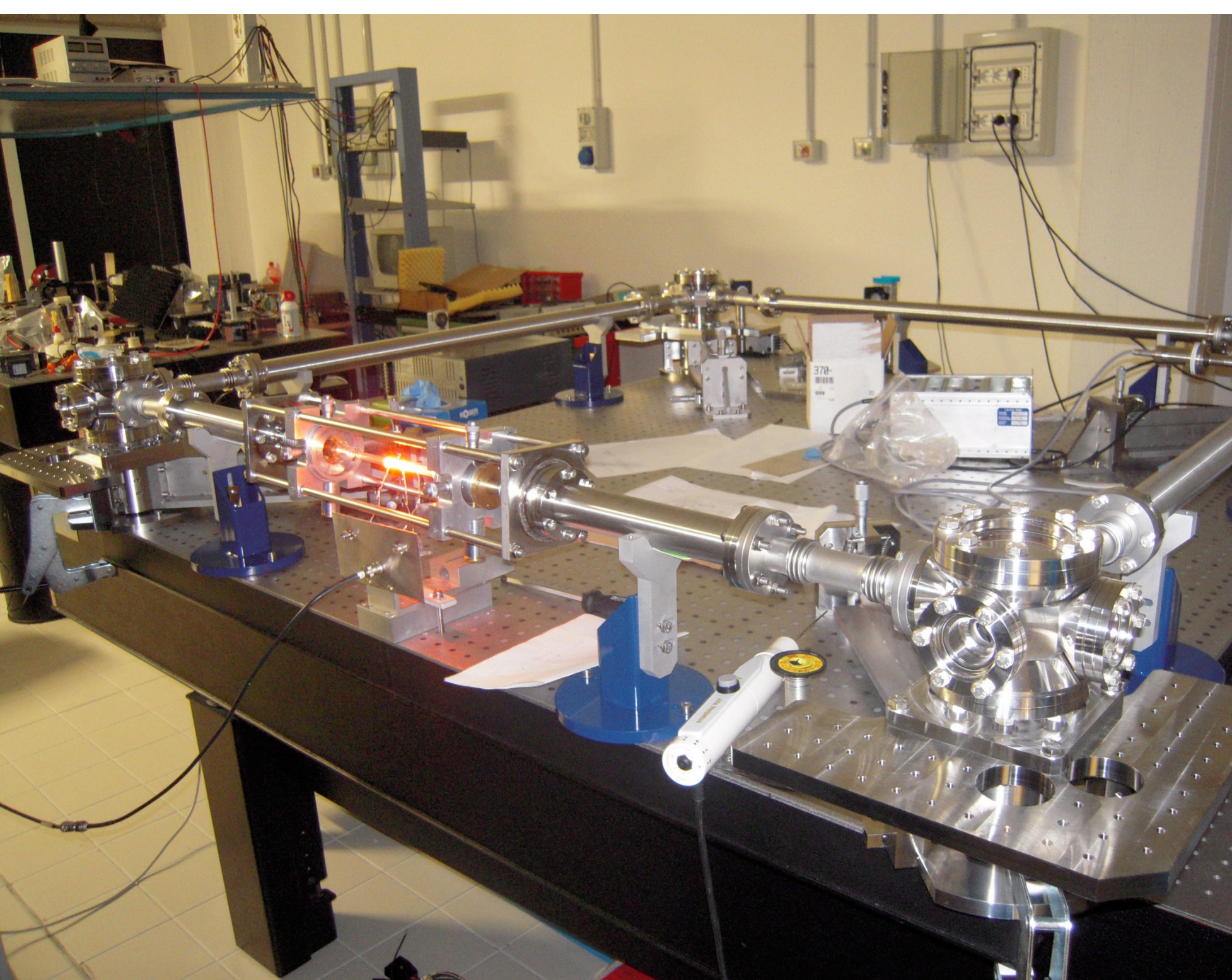
$$\Omega_{sn} = 10^{11-5} \frac{-10 \text{ rad}}{s \sqrt{t}}$$



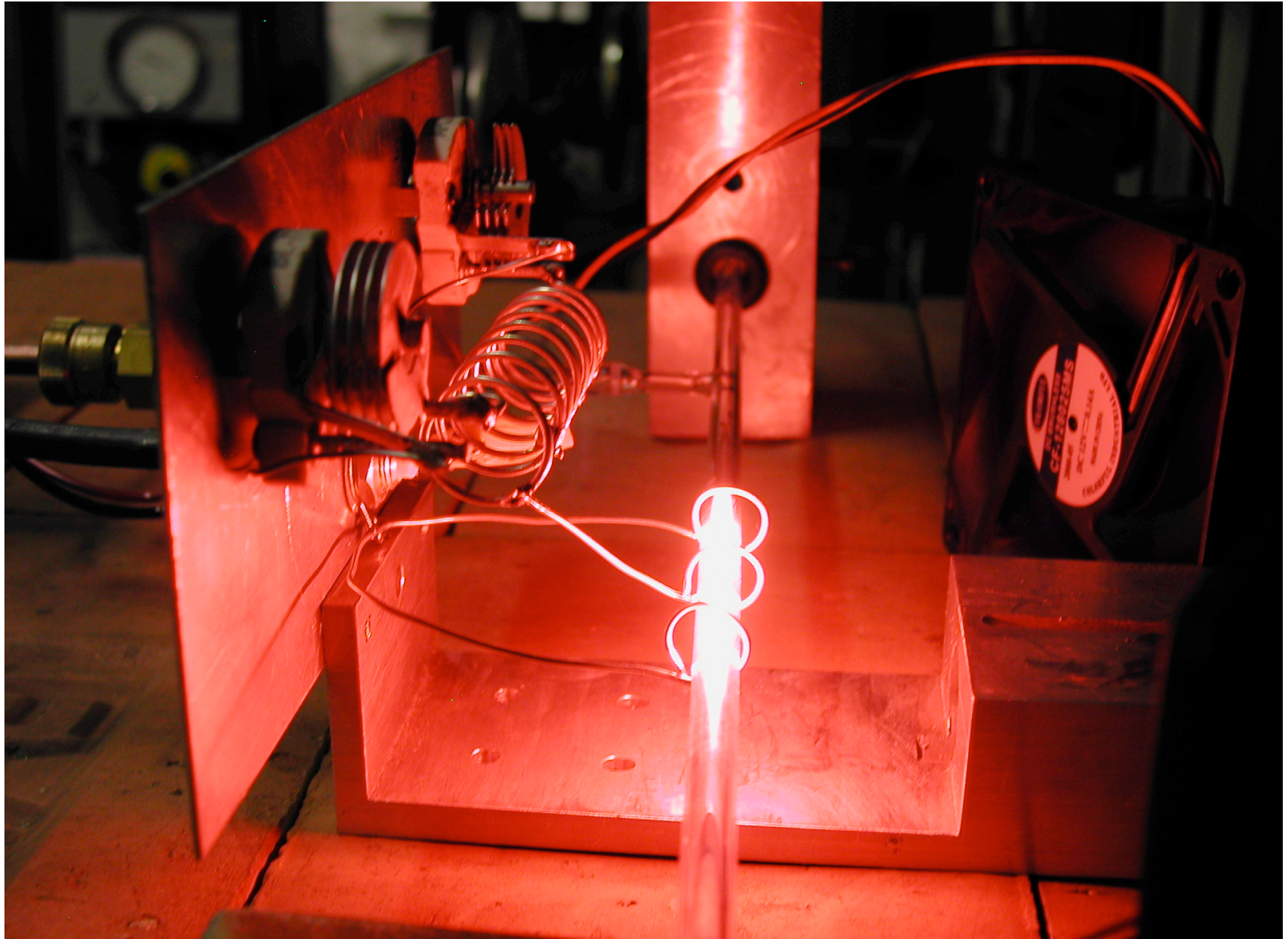
G-Pisa (Pisa-Napoli)

- 3 Luglio: Il prototipo e' stato completato
- 3-6 Luglio: il prototipo e' stato messo sotto vuoto
- la seconda settimana di luglio sono stati installati gli specchi, allineata la cavita', inserito il gas (Elio-Neon miscela standard)
- 8 Luglio il gyrolaser ha cominciato a laserare



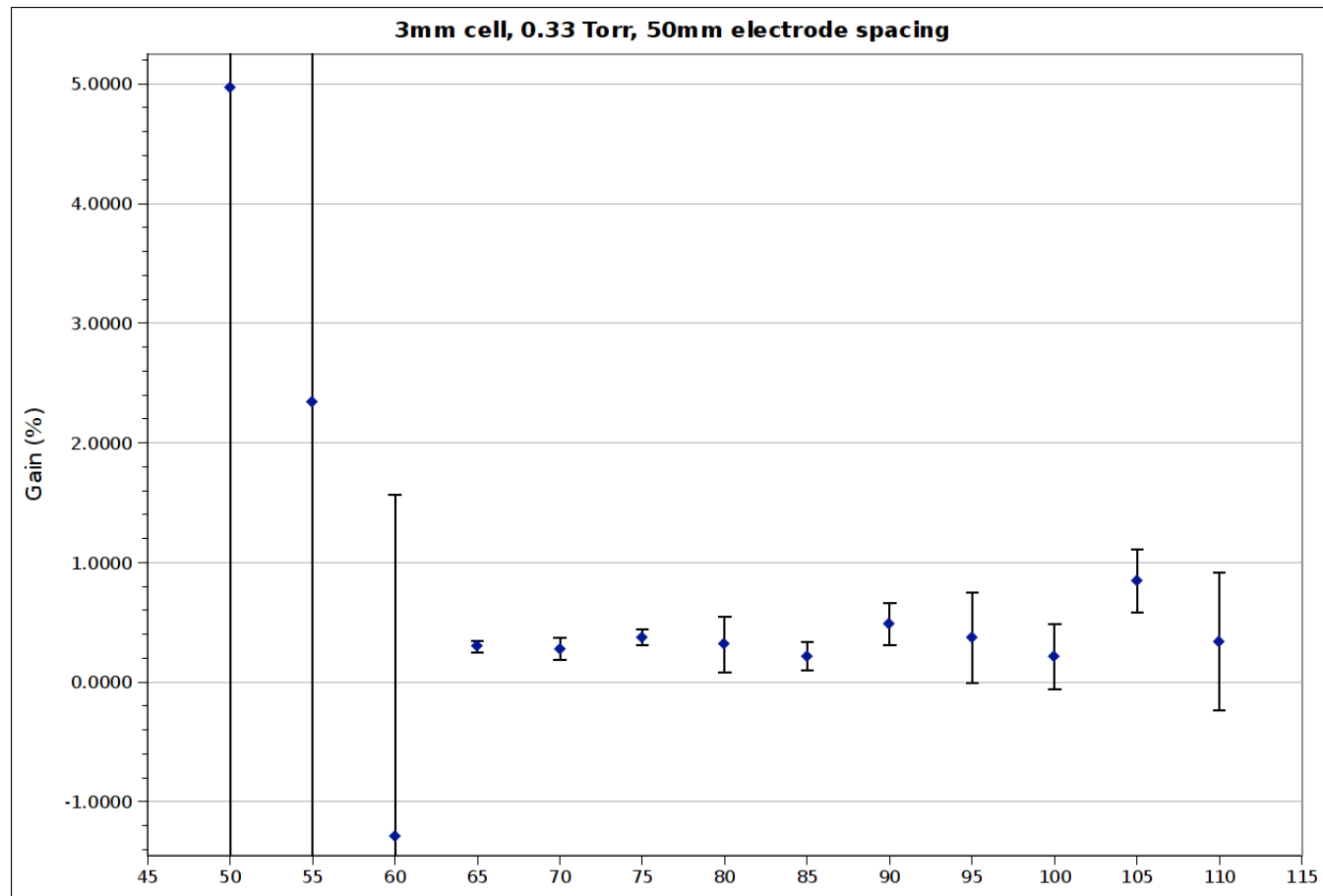


Gas cell experiments



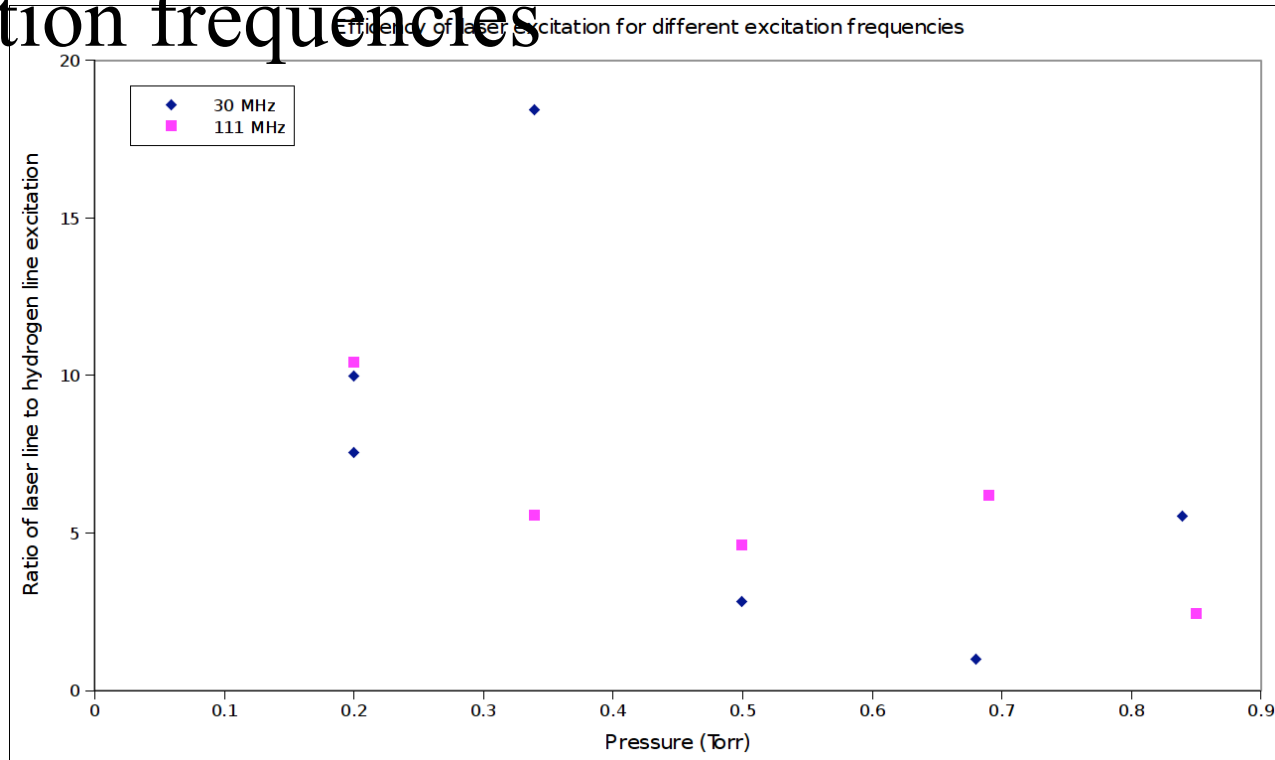
Gas cell experiments

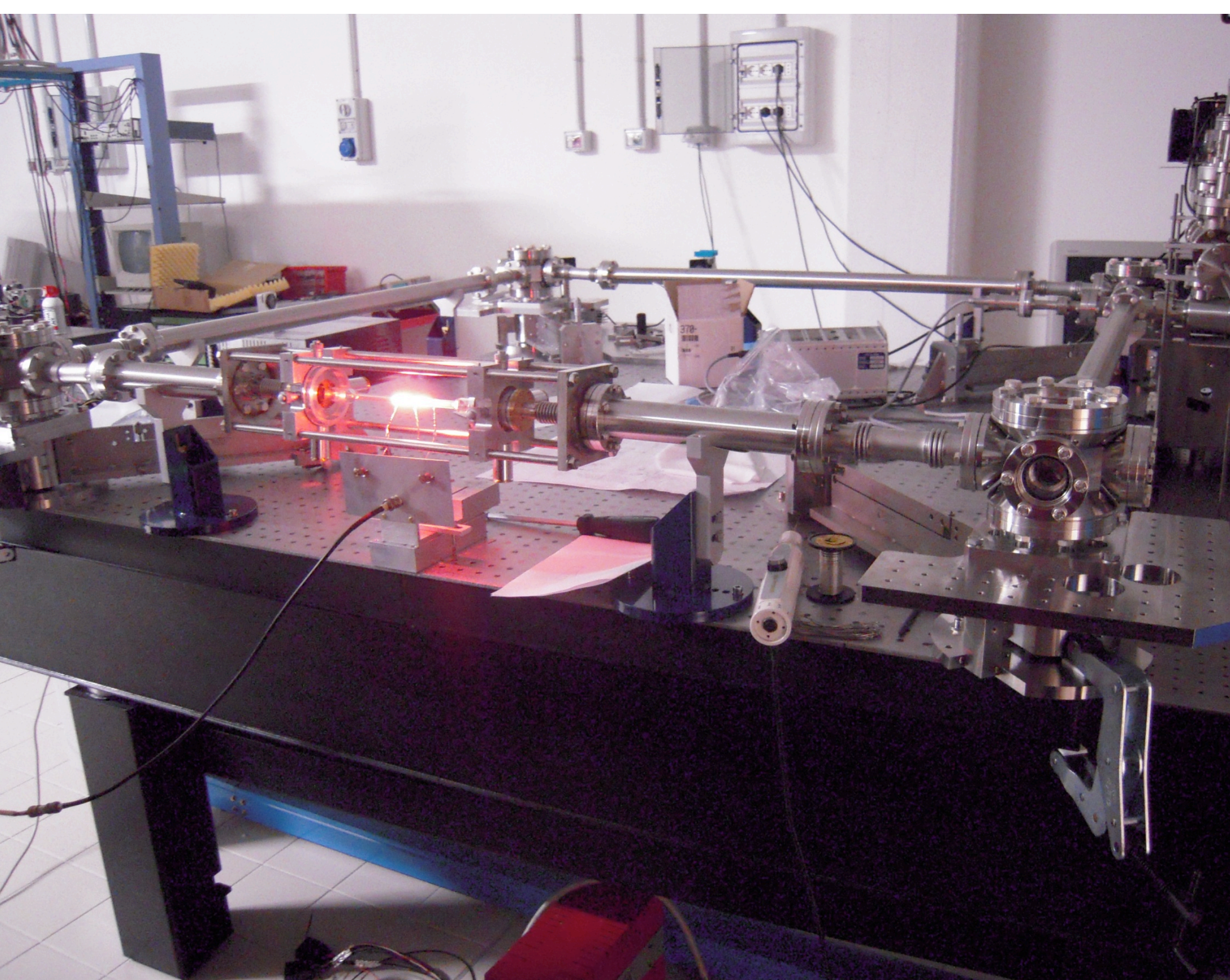
- Gain up to $\sim 0.5\%$ measured (low pressure) though losses from Brewster windows too large to sustain lasing

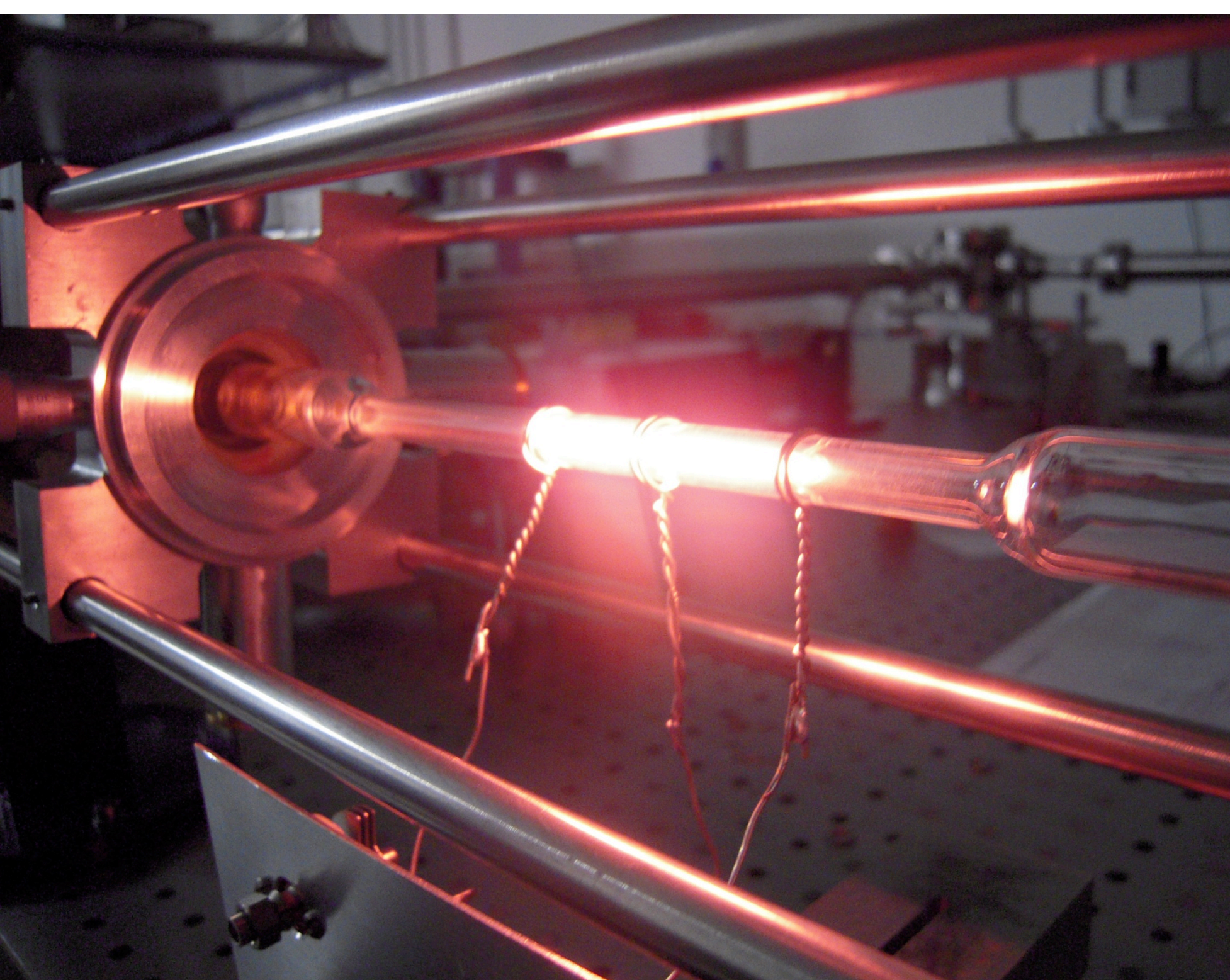


Gas cell experiments

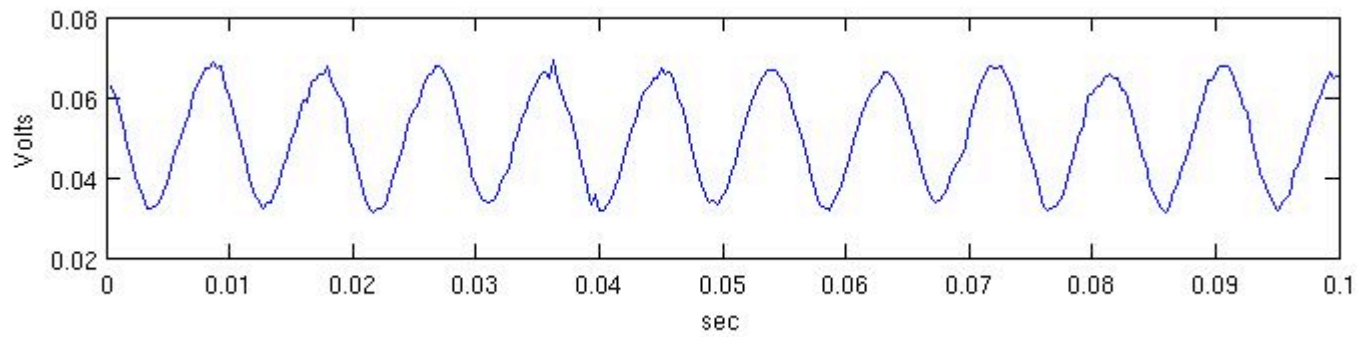
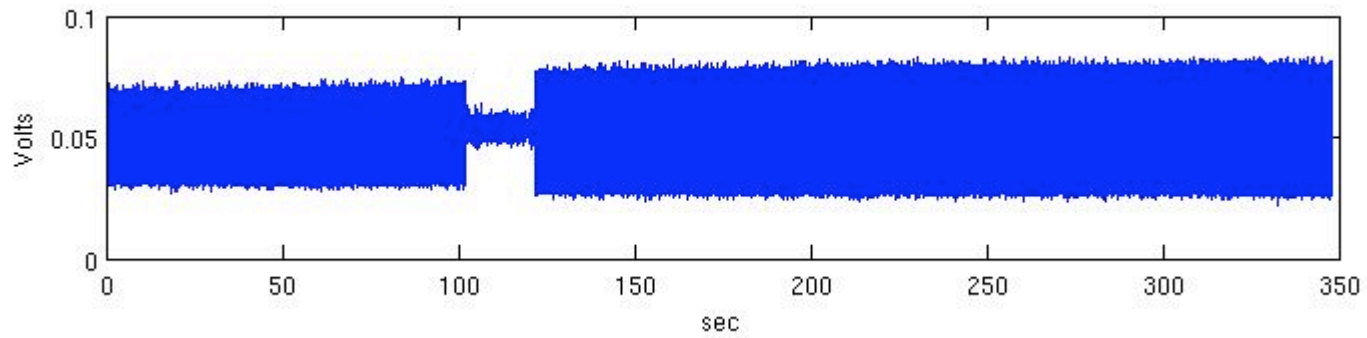
- Good conditions for lasing can be determined spectroscopically
- No obvious difference in performance with different excitation frequencies



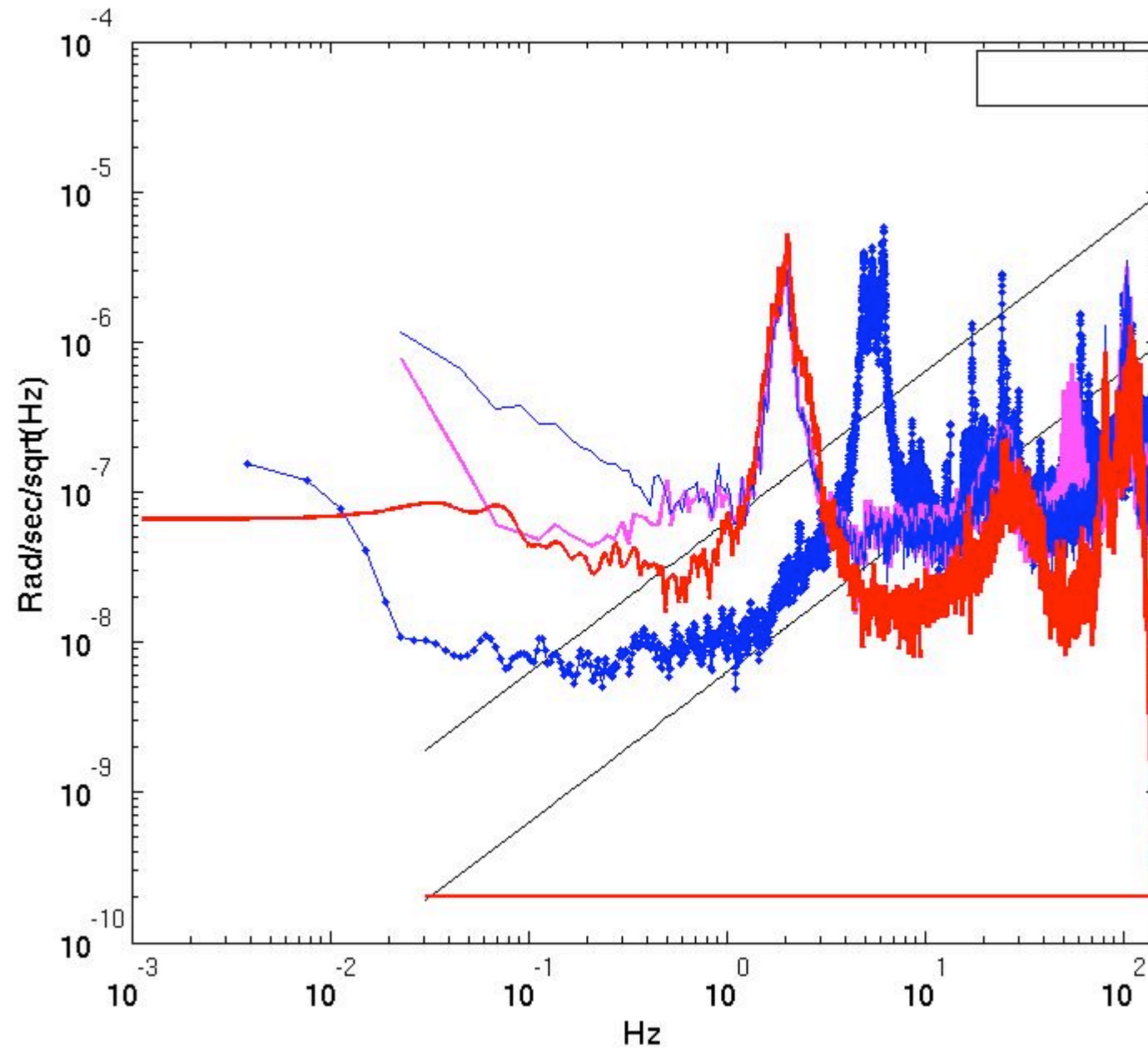




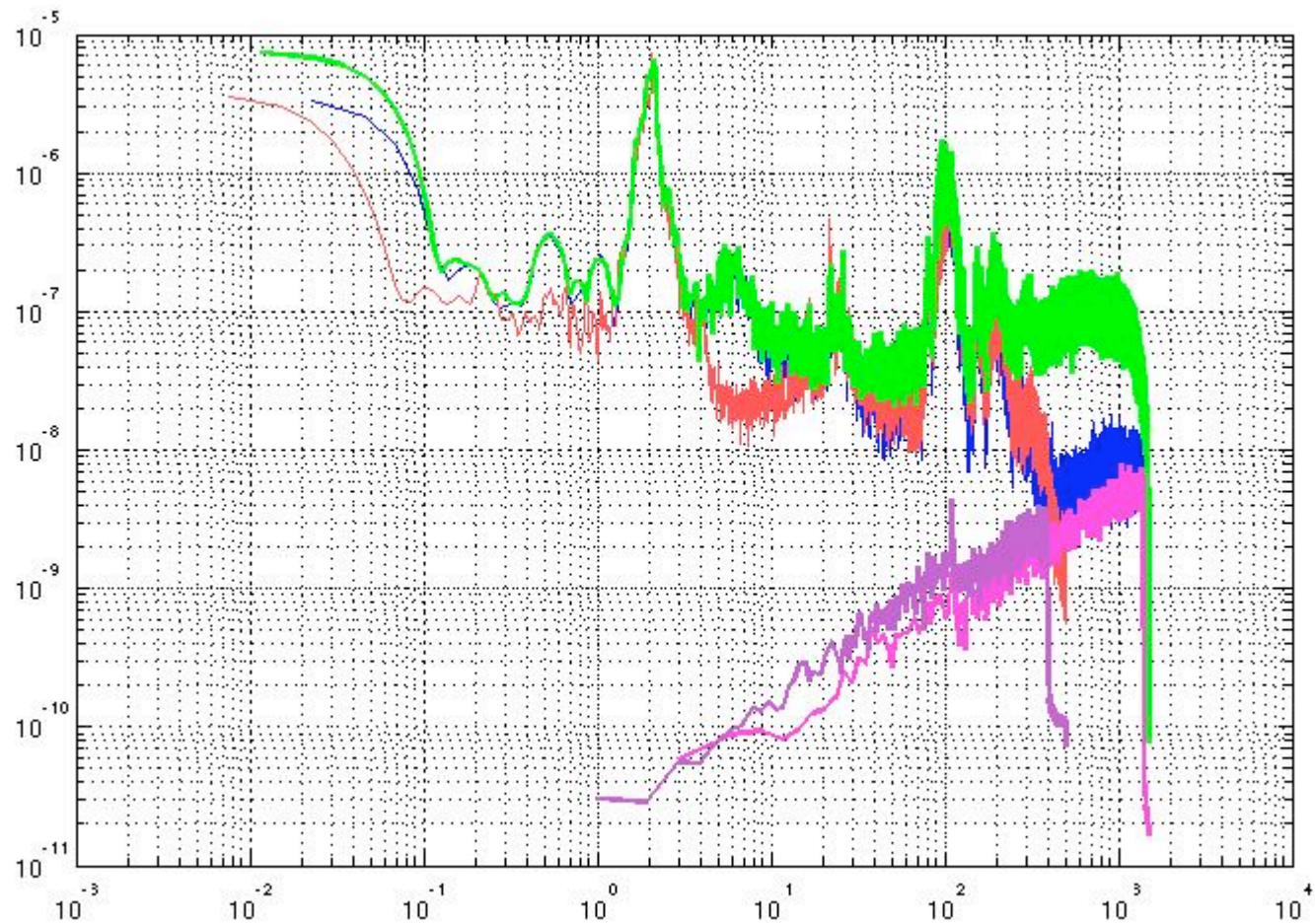
G-Pisa raw data (typical)



Typical spectrums, in different conditions



Purple curves: acquisition system noise



Upper Limit for the sensitivity evaluating the power spectrum at high frequency

- G better than $7 \cdot 10^{-10}$ rad/s/sqrt(Hz)
- G-Pisa better than $7 \cdot 10^{-9}$ rad/s/sqrt(Hz))
compatible with the acquisition noise

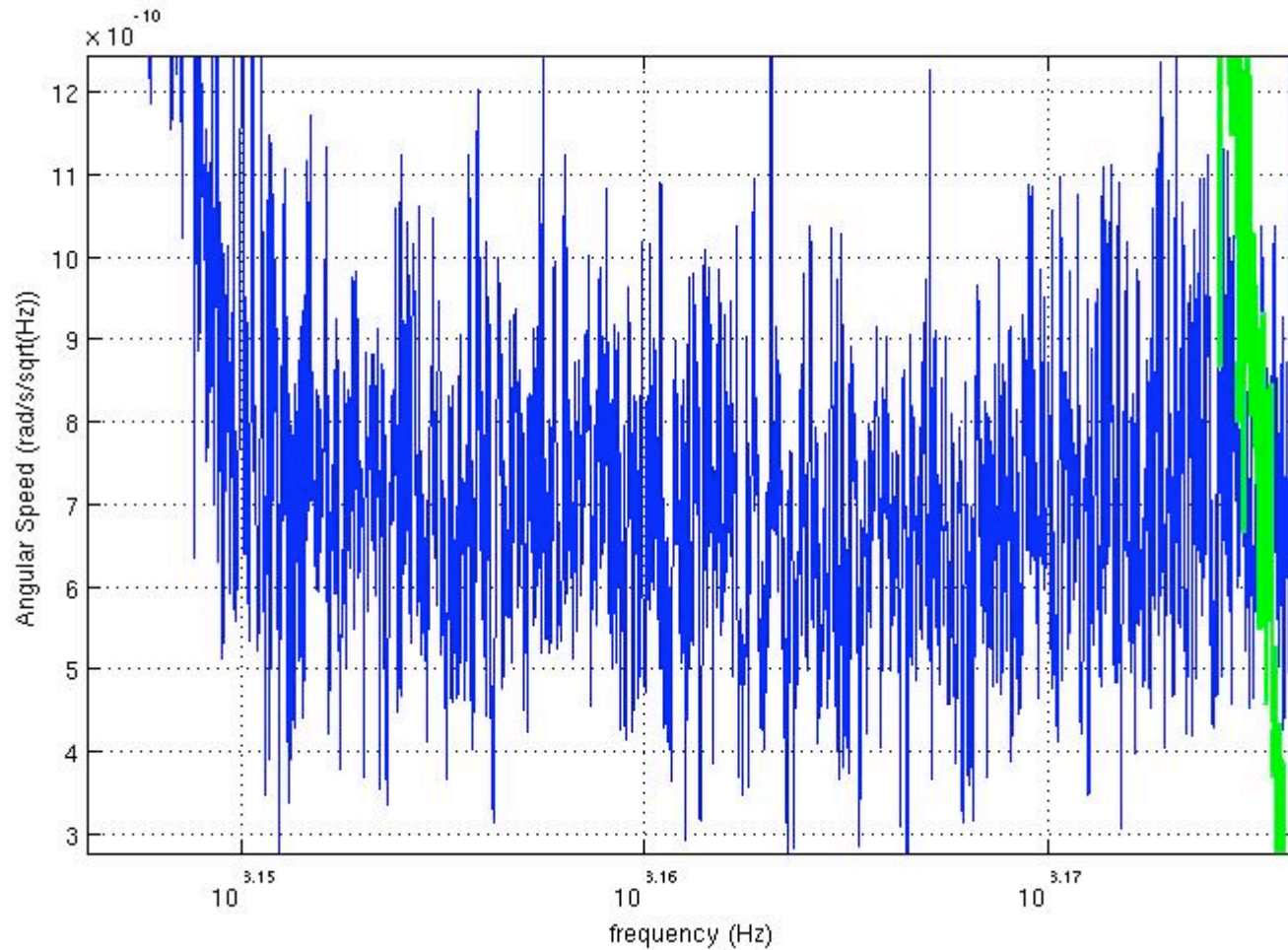
...but even better...

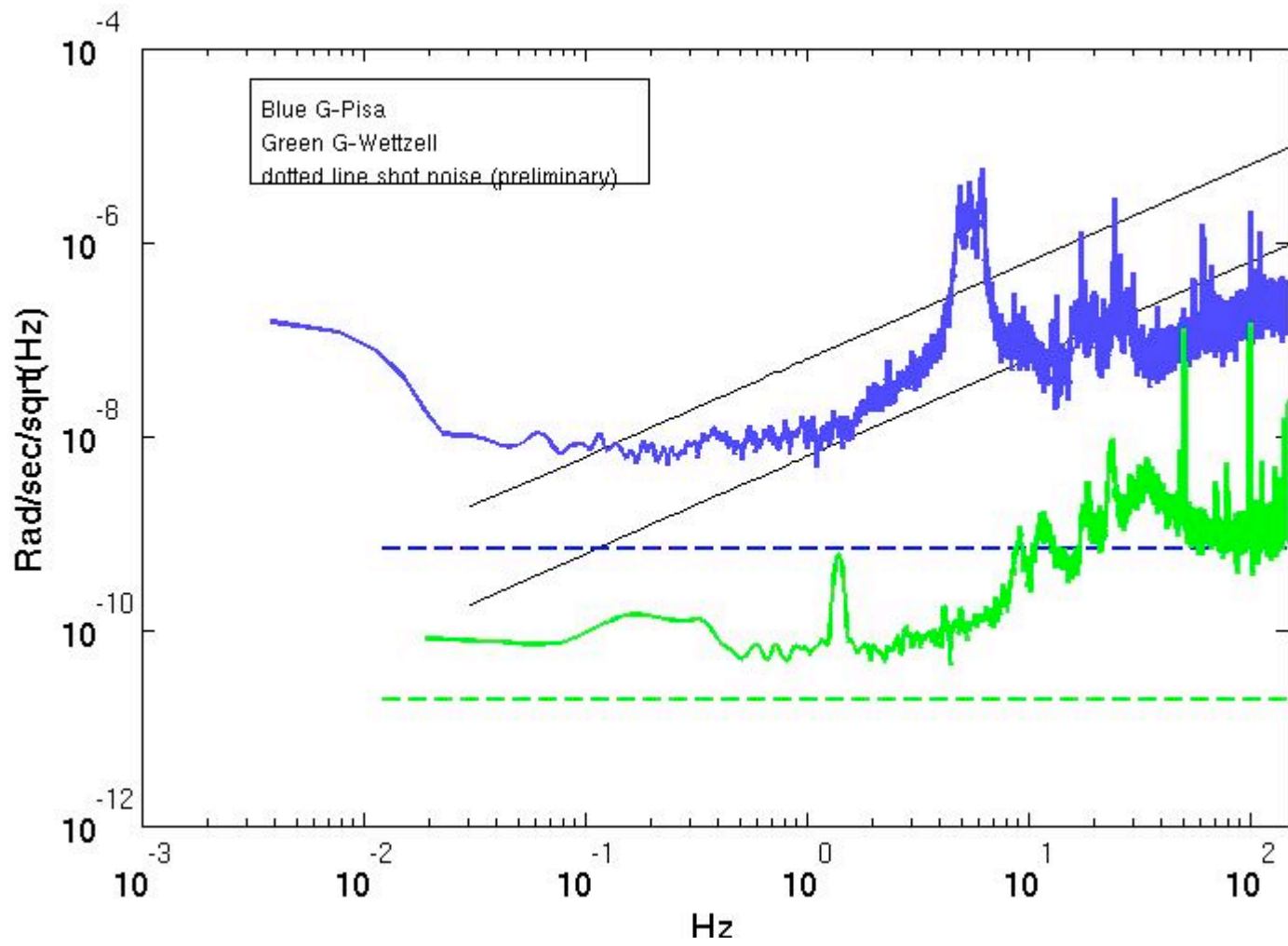
The “Shot Noise” has been evaluated looking at the high frequency part of the spectrum

G-Pisa noise $\sim 7 \cdot 10^{-10}$ rad/s/sqrt(Hz)

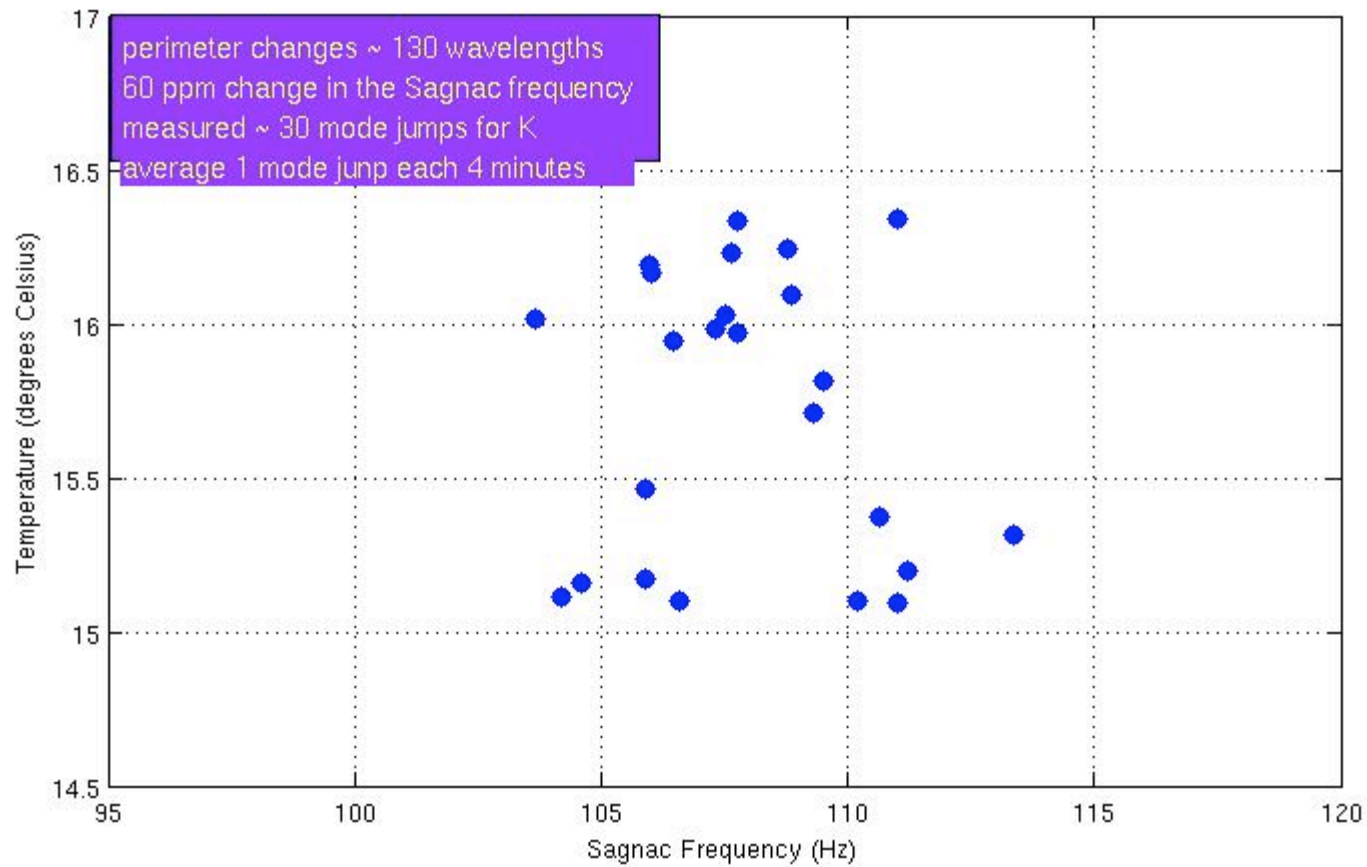
(G-Wetzell $2 \cdot 10^{-11}$ rad/s/sqrt(Hz))

preliminary





G-Pisa is insensitive to temperature!



Gyrolaser for Virgo (my view)

...let us keep in mind that...

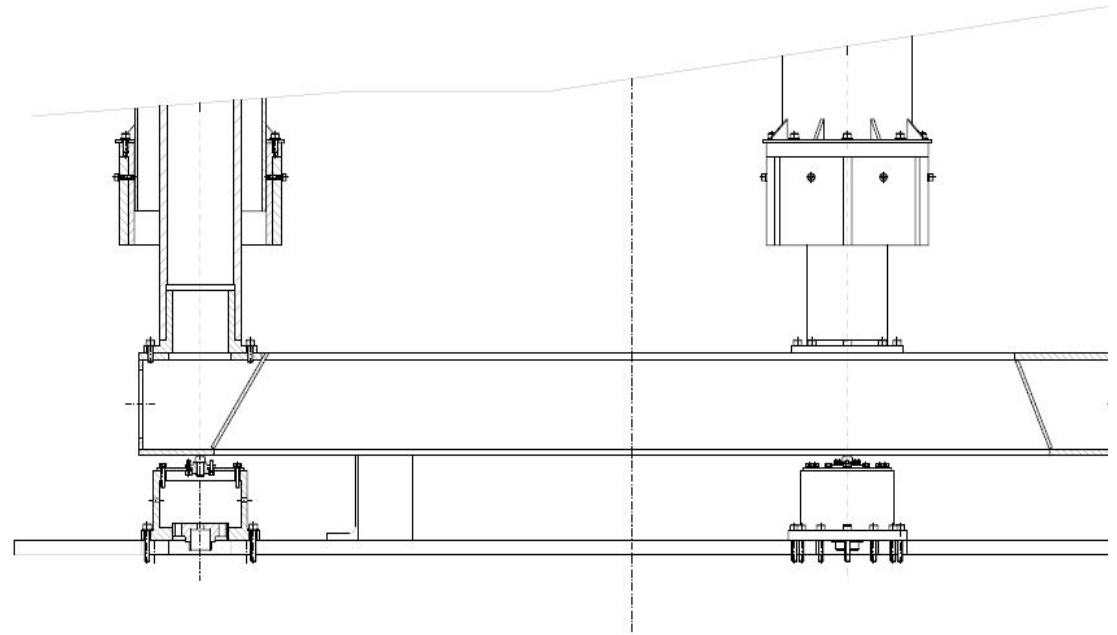
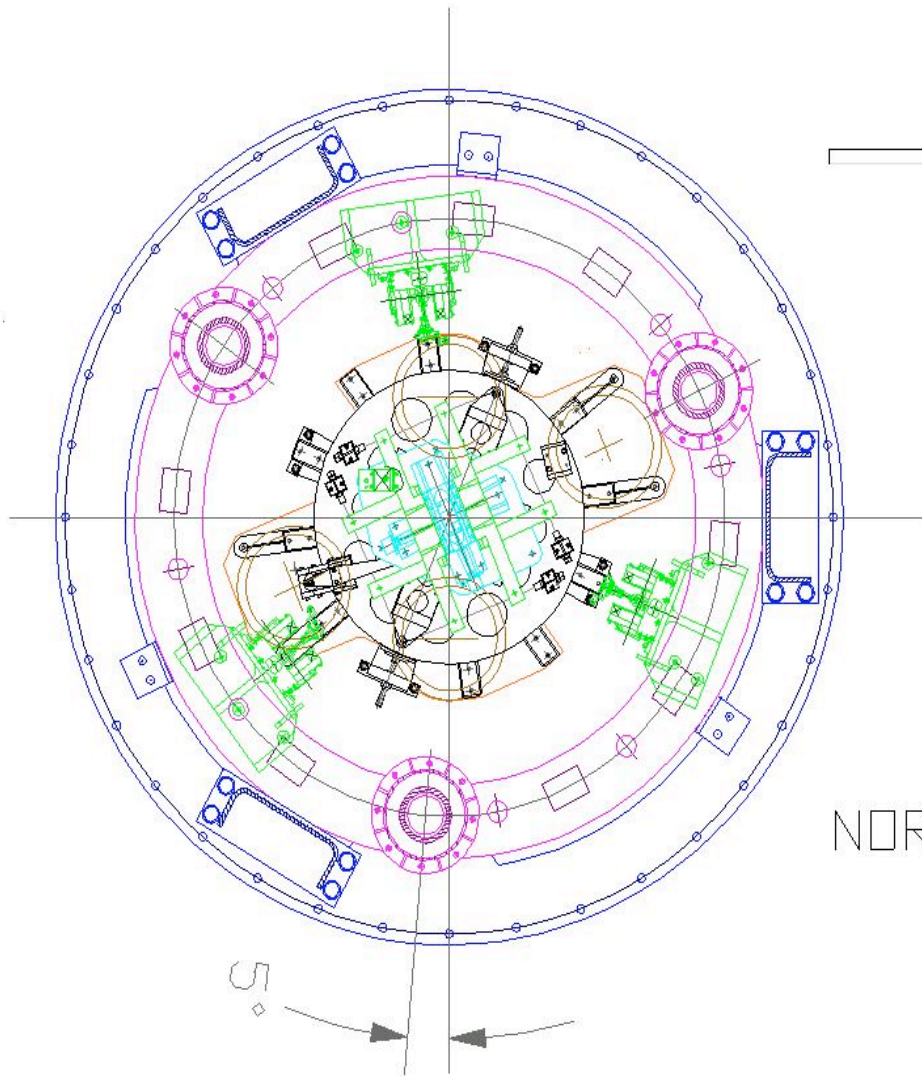
- following the G-recipe with a ring of area $\sim 1 \text{ m}^2$ we should get:
 - $10^{-10} \text{ rad/s/sqrt(Hz)}$
 - the DC velocity below $2 \cdot 10^{-12} \text{ rad/s}$ (about 3 hours integration time)

use in Virgo

- Improvements on the Inverted Pendulum (advantages: RMS displacement reduction, increase duty cycle during windy days)
- improve the performances of the SA suspension, with an active stage before the test mass (strong improvement on the low frequency angular motion (improvement for the alignment))

Inverted Pendulum Improvement

- Increase duty cycle, reduce very low frequency angular motion
- requirement 10^{-8} - 10^{-9} rad/sqrt(Hz) at 10 mHz
- size (possibly) around 60cm size
- (Roma2-Pisa mechanical tiltmeter)



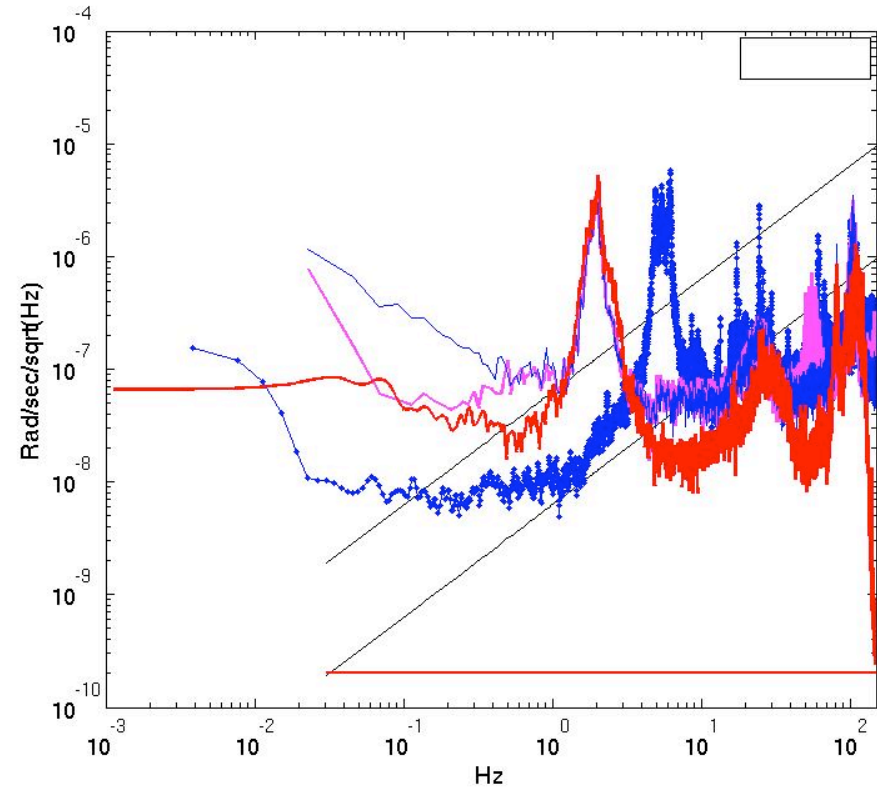
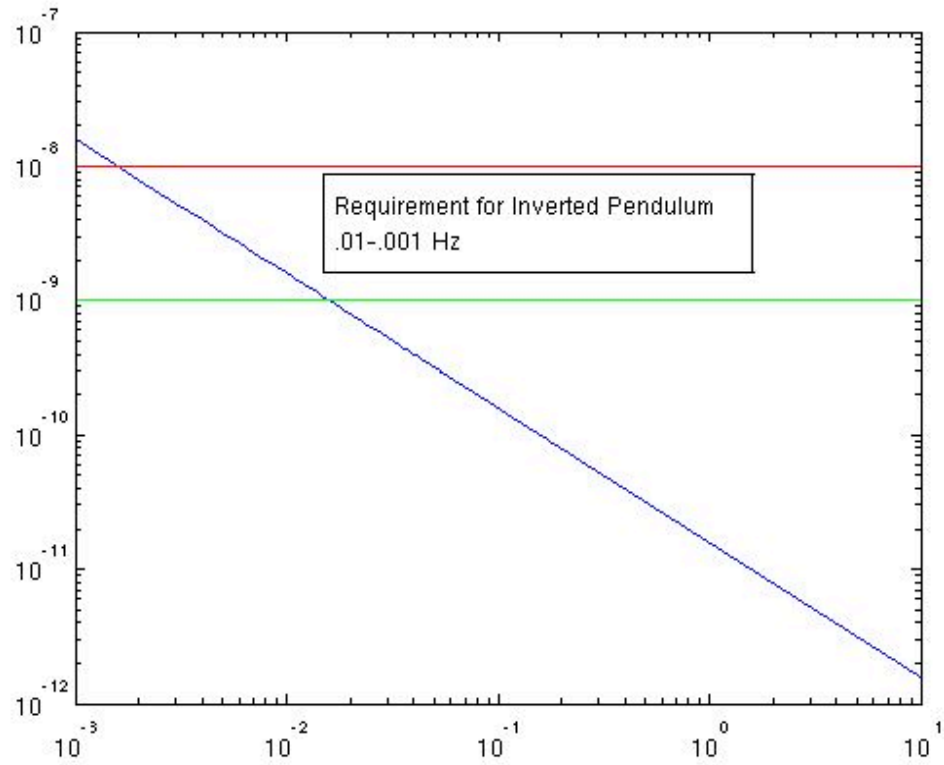
Sensors should sit on top of the IP bottom ring

NORTH INPUT
TOWER

Tilt control of Inverted Pendulum

- improve the duty cycle of the instrument, requirements 10^{-8} - 10^{-9} rad/sqrt(Hz) at 10 mHz
- Current gyros too large → is it possible to operate outside the tower?
- $L < 1$ m (0.6m)

rad/sqrt(Hz)

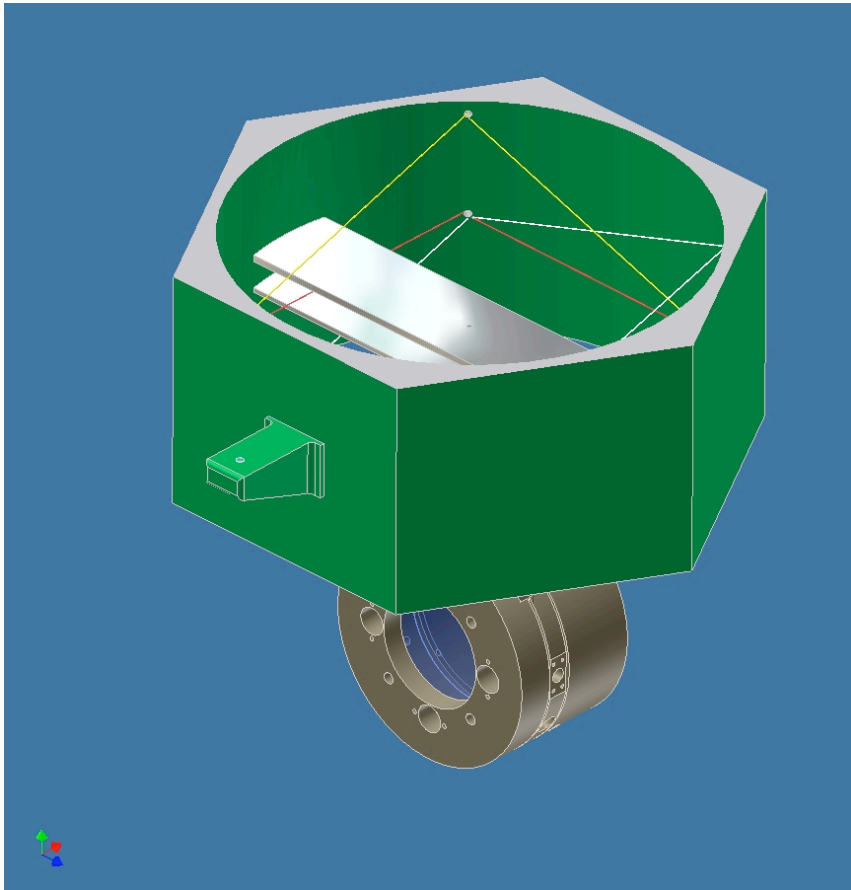


Hz

...but gyrolaser can do much more

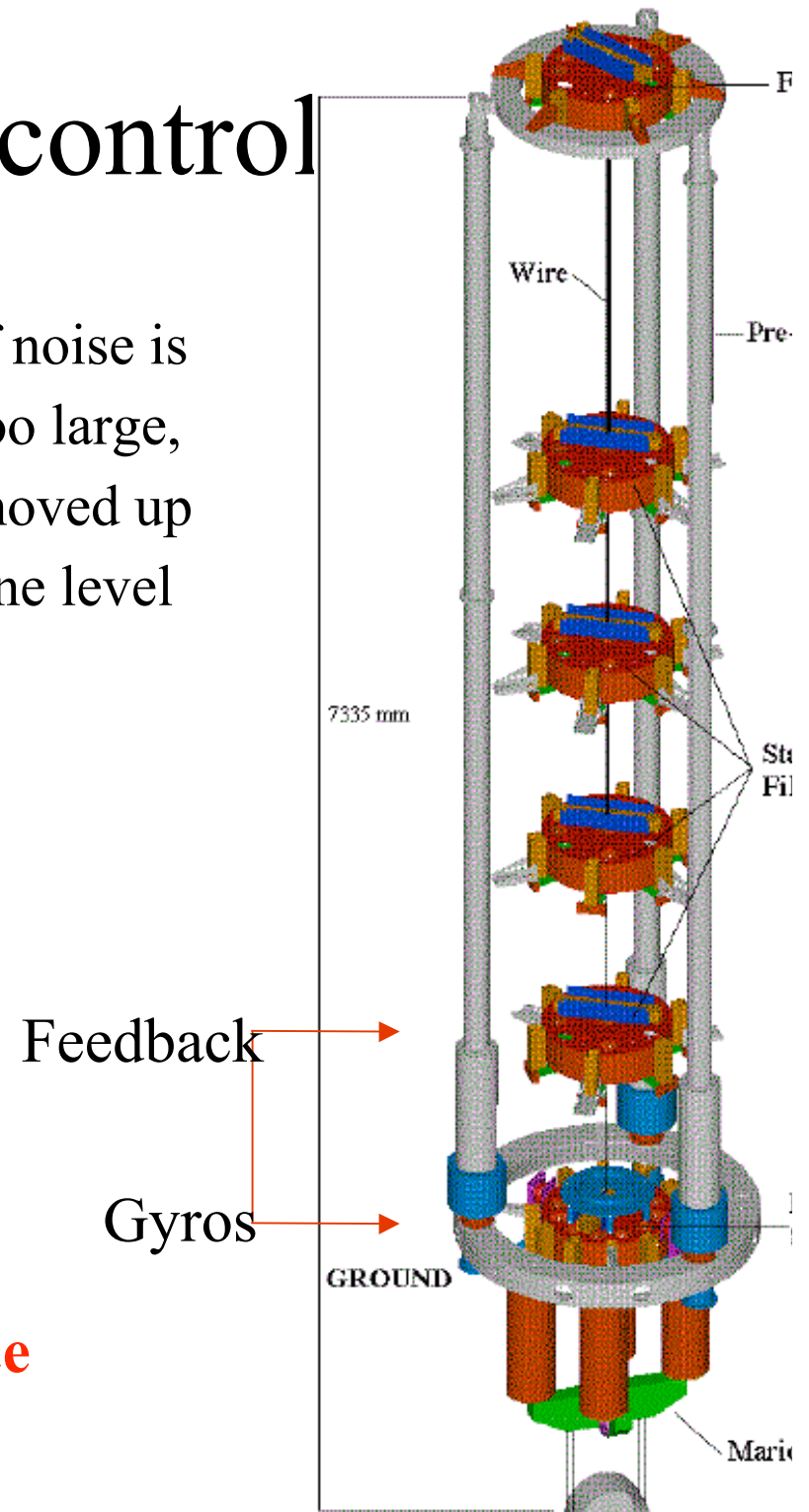
- Let consider 3 cavities in three different planes, forming angles of the order of 45 degrees, properly aligned with the rotational axis of the Earth. It is sensitive to all possible rotations and tilts and suitable to keep under control the angular motion of the test mass

Alignment control



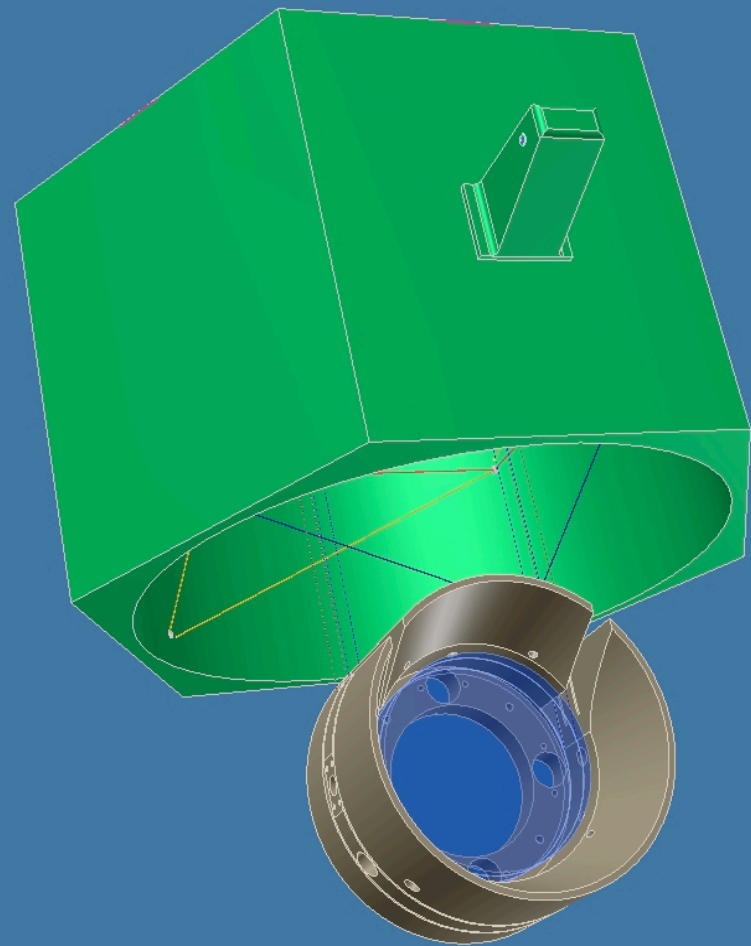
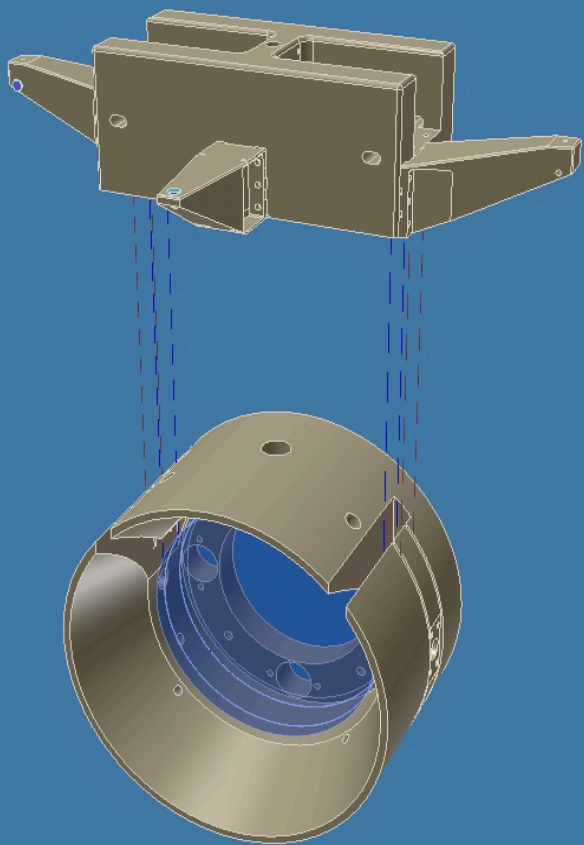
- if noise is too large, moved up one level

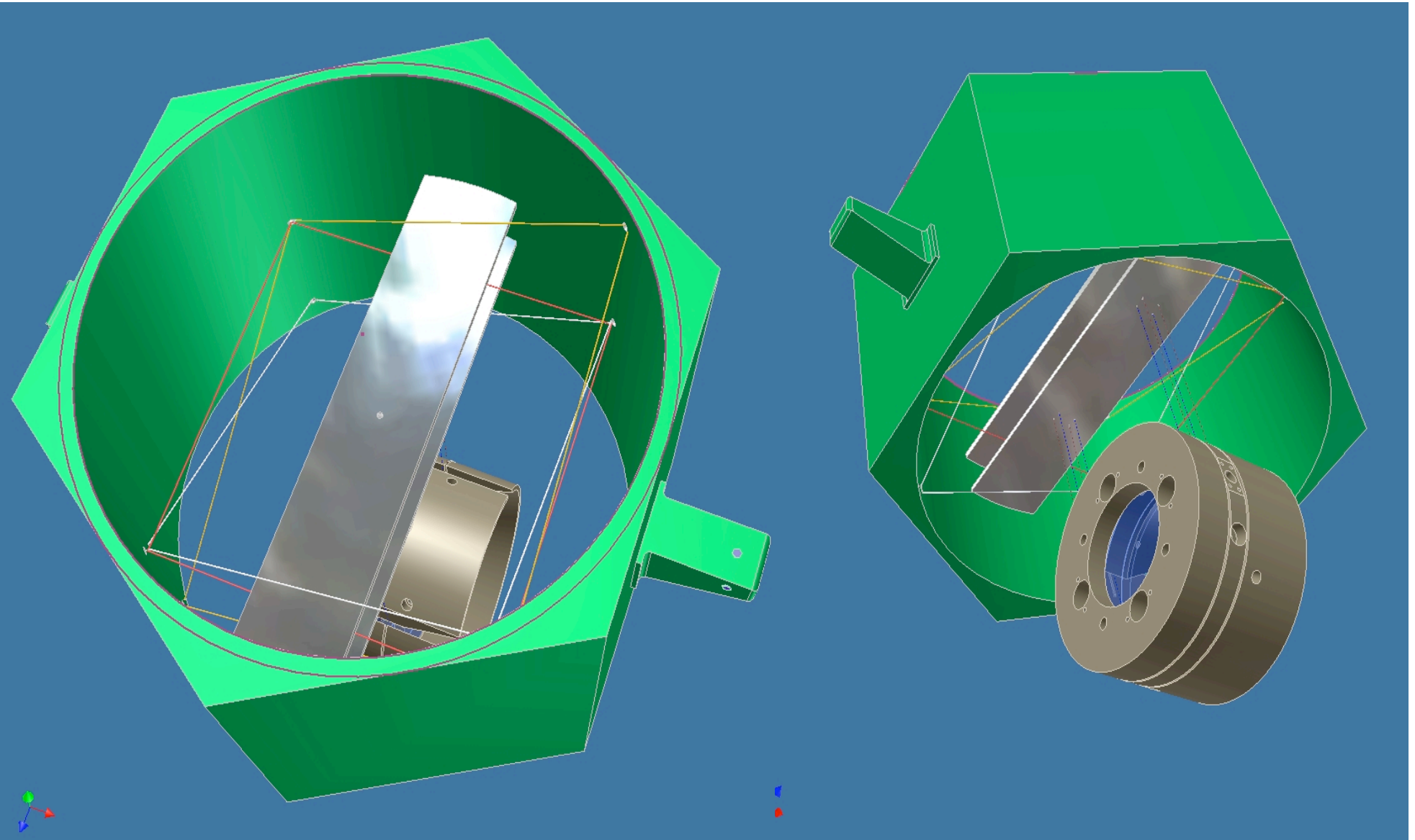
...the more sensitive is the sensing device the closer to the test mass can feedback

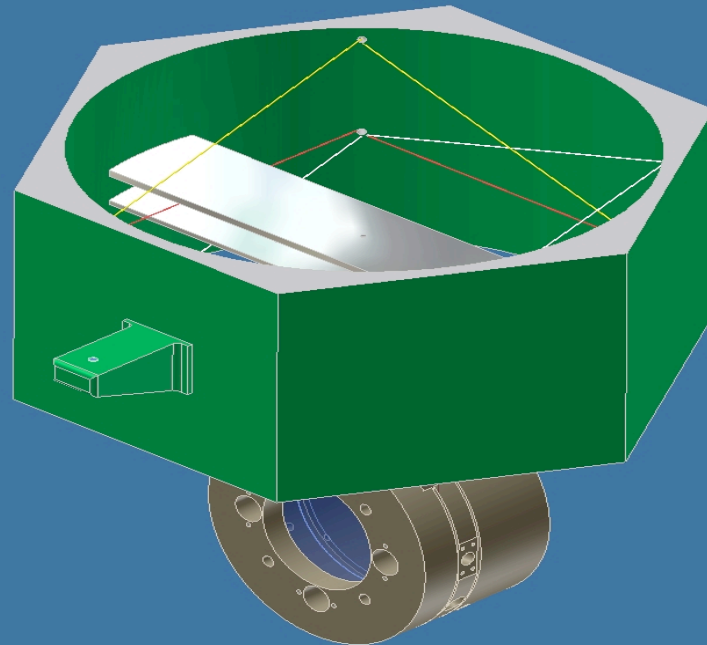
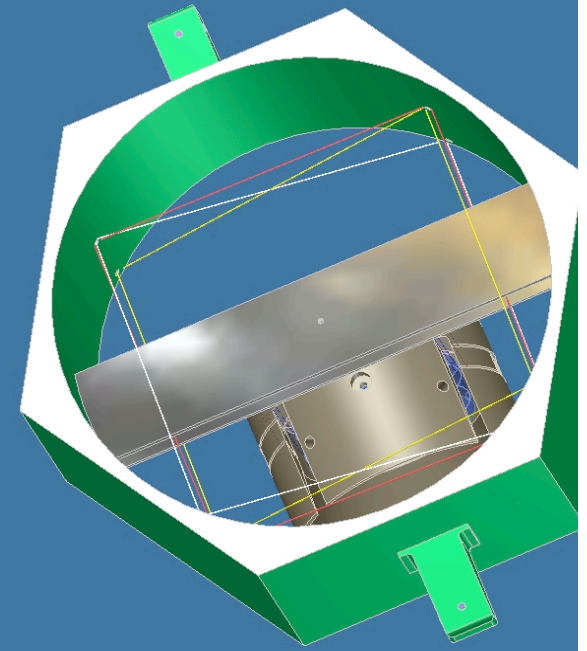
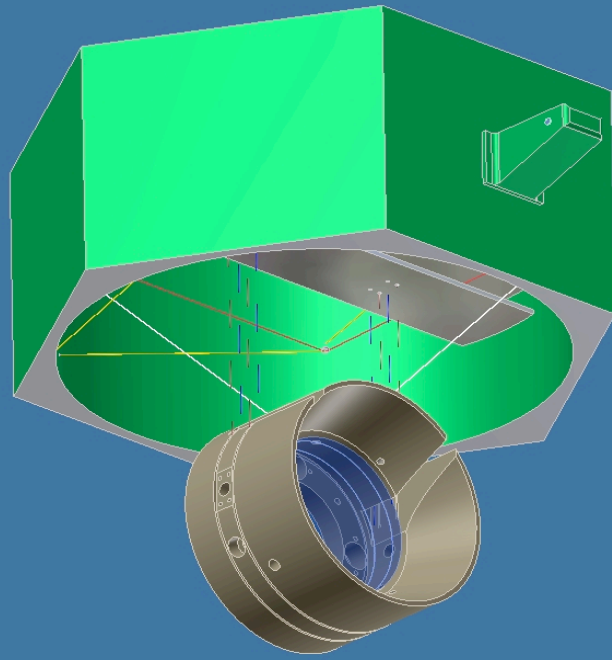


....

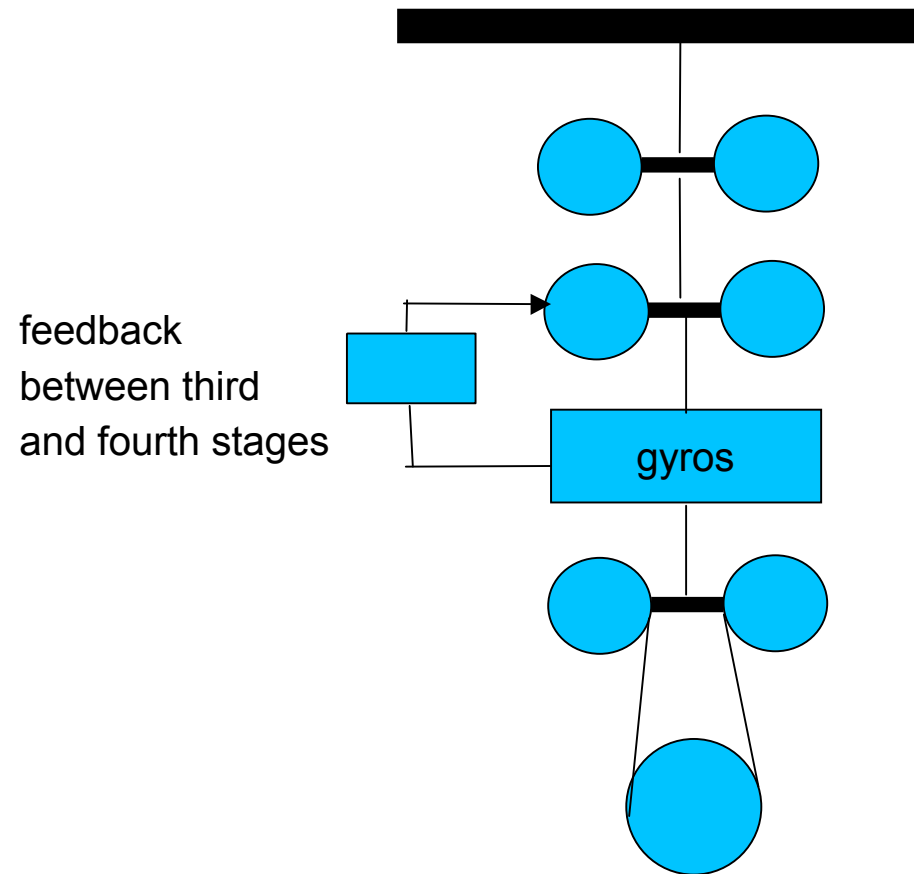
- in this case there is enough space for three gyros of about 1 m^2 .
- If the test masses rotates with angular velocity $2 \cdot 10^{-12} \text{ rad/s}$, the time to make 10^{-9} radians is roughly 7' (bandwidth below 10mHz for the angular control of the interferometer)



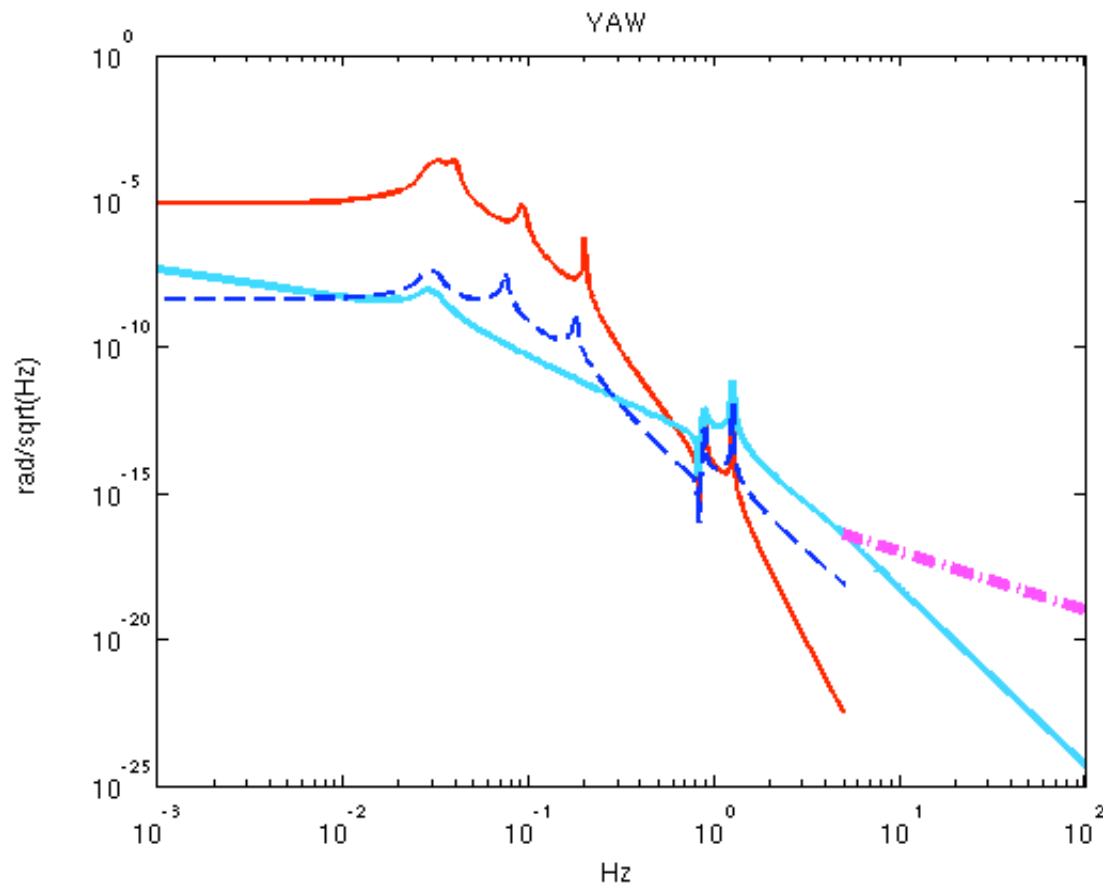


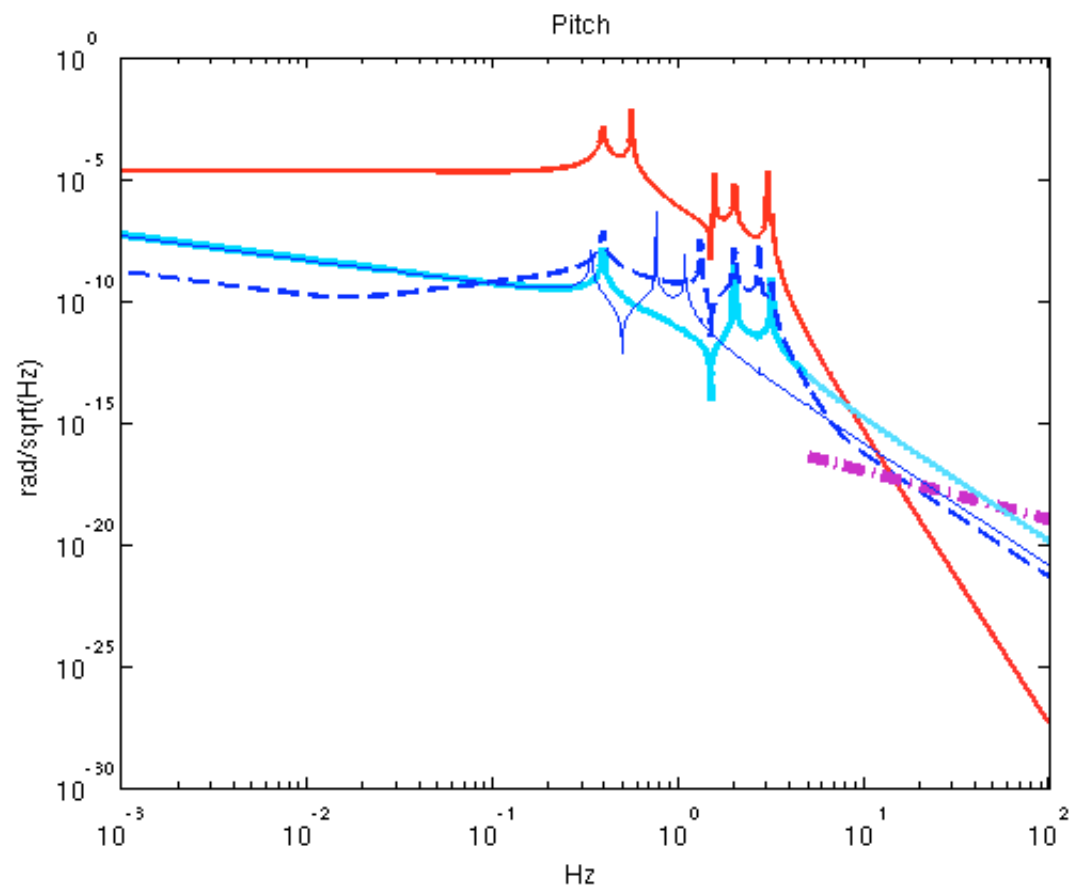


Simple Mechanical Model



In the model the parameter of the Virgo suspension has been Used (last three stages)





So....

A gyrolasers-SA integrated system can make
VIRGO more similar to an optical table!

- reduction of all kind of noise generated by non linearities
- all alignment control bandwidth below 1Hz
- actuators have to provide smaller forces (smaller magnets, electrostat actuators etc...
- simplified alignment circuit (less diffused light) ?
- alternative way of signal extraction avoiding the use of sidebands?
- improvements of the duty cycle

Conclusions

- Gyrolasers with area above 1 m² have very good sensitivity ($< 10^{-10}$ rad/s/sqrt(Hz)) and very long term stability
- G-Pisa (1.4 m side) device has already reached a sensitivity below 10^{-9} rad/s/sqrt(Hz) ($7 \cdot 10^{-10}$ rad/s/sqrt(Hz)) *Already fulfil the requirements for the IP control!*
- In the near future we will check the feasibility of reduced side cavity and will test an active perimeter control, to reduced temperature drifts (reduce mode jumps)
- Ring laser gyros could make the 3rd generation interferometers (virgo/ligo) closer to a “table top interferometer” reducing the rms angular motion of the test masses
- G-Pisa will extend the design to a 3 axis device. Geophysicists are interested on 3-axis gyros as well