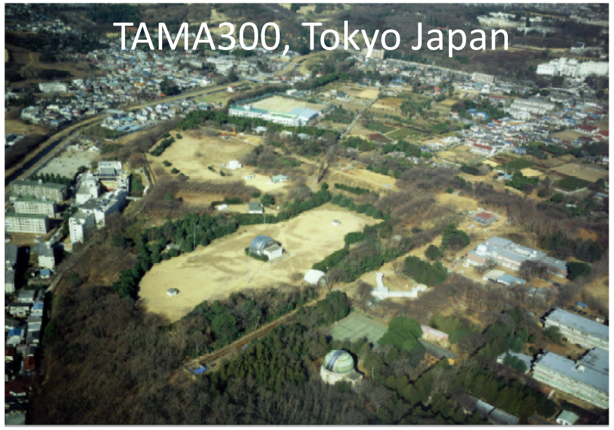
The status of Virgo experiment.

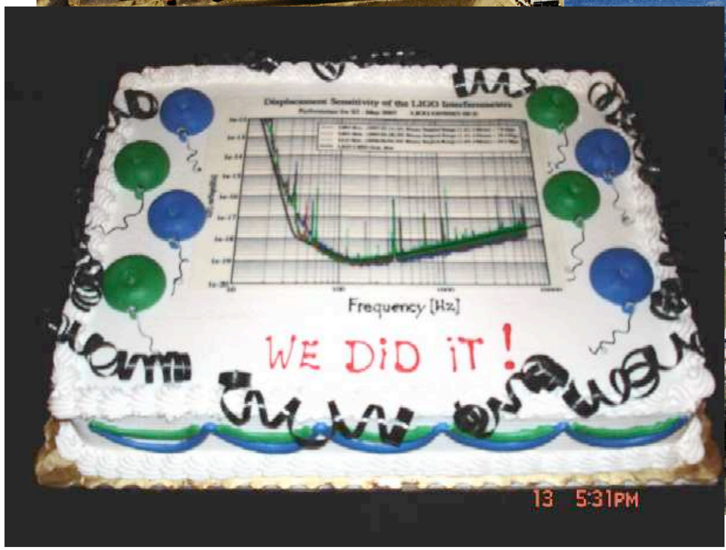
E. Majorana

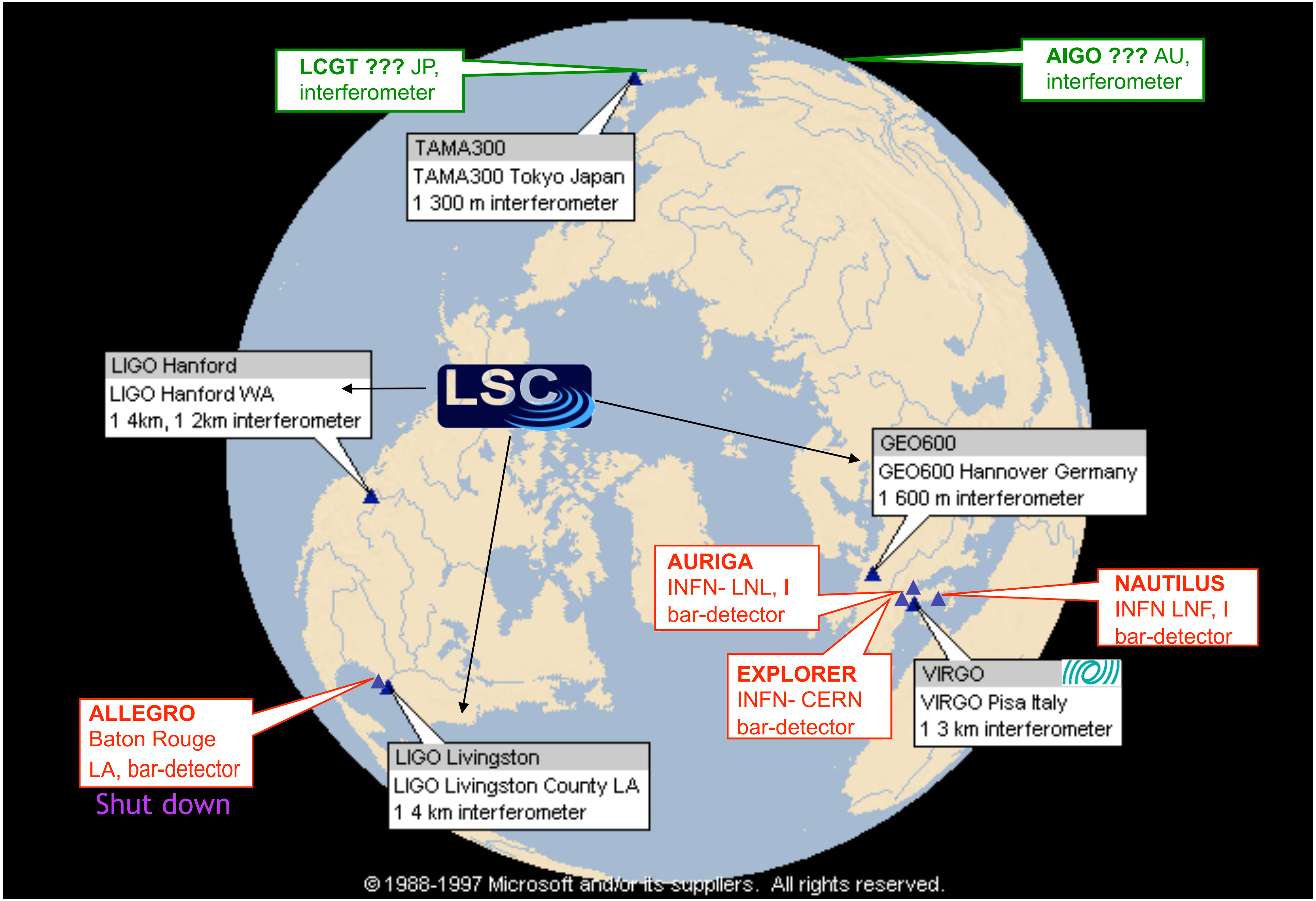
National Institute for Nuclear Physics - Rome branch

National Astronomical Observatory of Japan, 3 July, 2009



First generation of interferometric GW detectors





LCGT ??? JP,
interferometer
AIGO ??? AU,
interferometer
TAMA300
TAMA300 Tokyo Japan
1 300 m interferometer
LIGO Hanford
LIGO Hanford WA
1 4km, 1 2km interferometer
LSC
GEO600
GEO600 Hannover Germany
1 600 m interferometer
AURIGA
INFN- LNL, I
bar-detector
NAUTILUS
INFN LNF, I
bar-detector
EXPLORER
INFN- CERN
bar-detector
VIRGO
VIRGO Pisa Italy
1 3 km interferometer
ALLEGRO
Baton Rouge
LA, bar-detector
Shut down
LIGO Livingston
LIGO Livingston County LA
1 4 km interferometer
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Outline

I) GW detection basics / interferometers

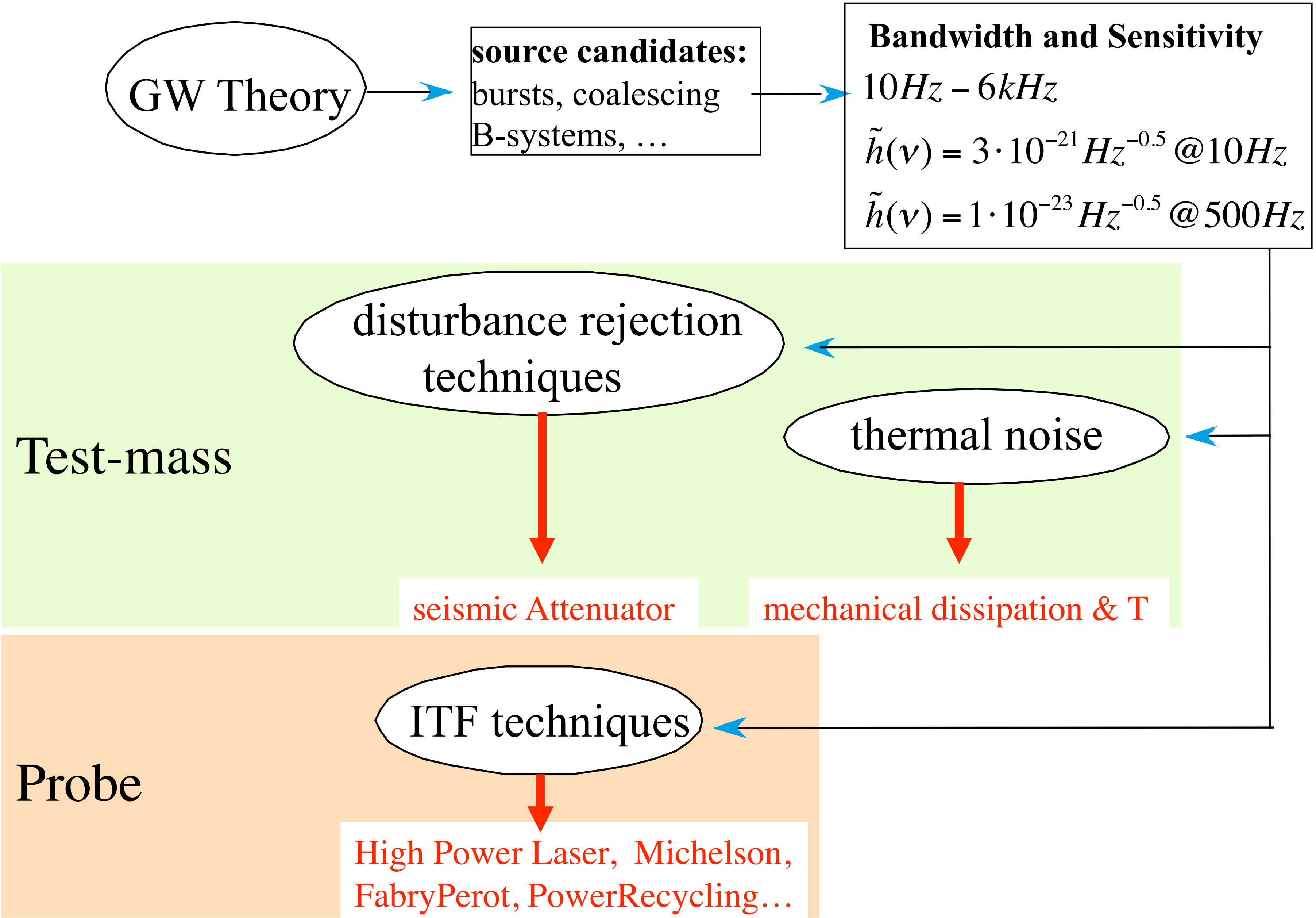
VIRGO

II) The intermediate steps

advanced VIRGO

Virgo scientific case

Design of a wide-band ground-based GW detector



Designing Sensitivity requirements: initial Virgo

Pushing on the development of all the edge-technology solutions it is possible in principle to reach 10^{-21}-10^{-23} $Hz^{-1/2}$ strain sensitivity over a quite large bandwidth

Expected rate of coalescences:

3/yr within 40 ÷ 200 Mpc

[Grishchuk et al. Astro-ph/0008481]

Coalescence event rate

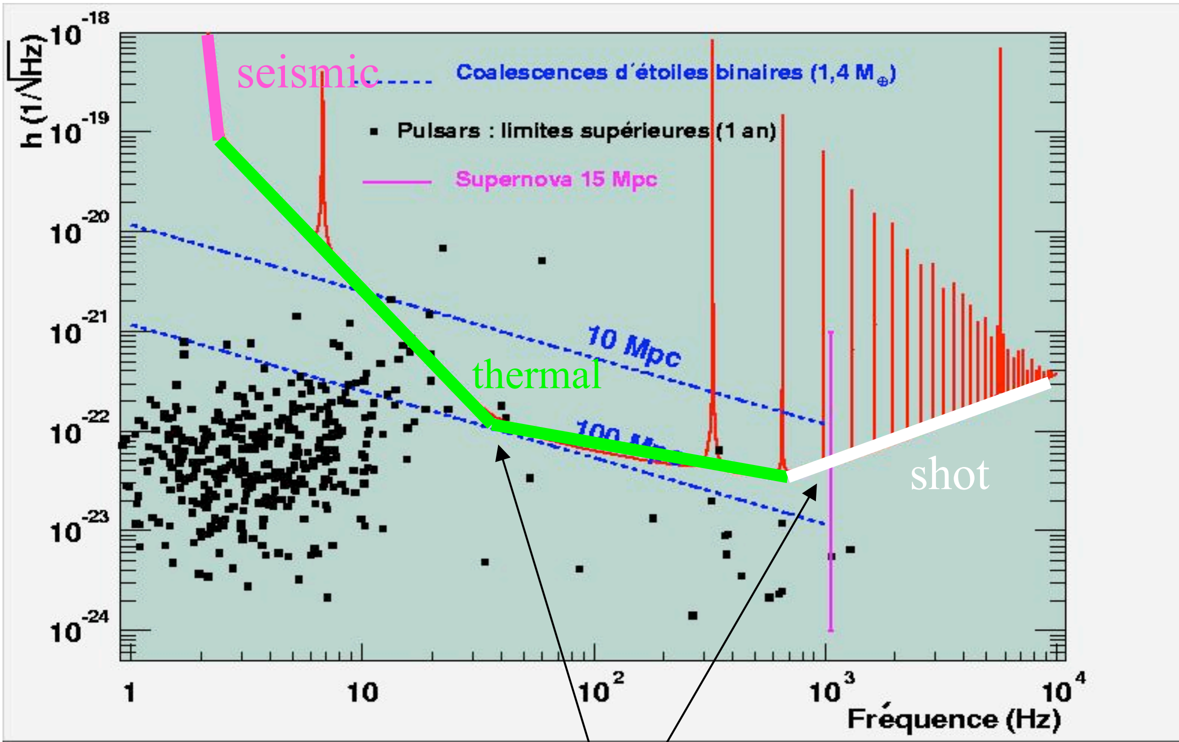
at ~ 20 Mpc

[Kalogera et al. ApJ. 601, L 179, 2004]

– 0.3/yr for NS/NS

– 0.6/yr for BH/BH

INITIAL VIRGO !!!!



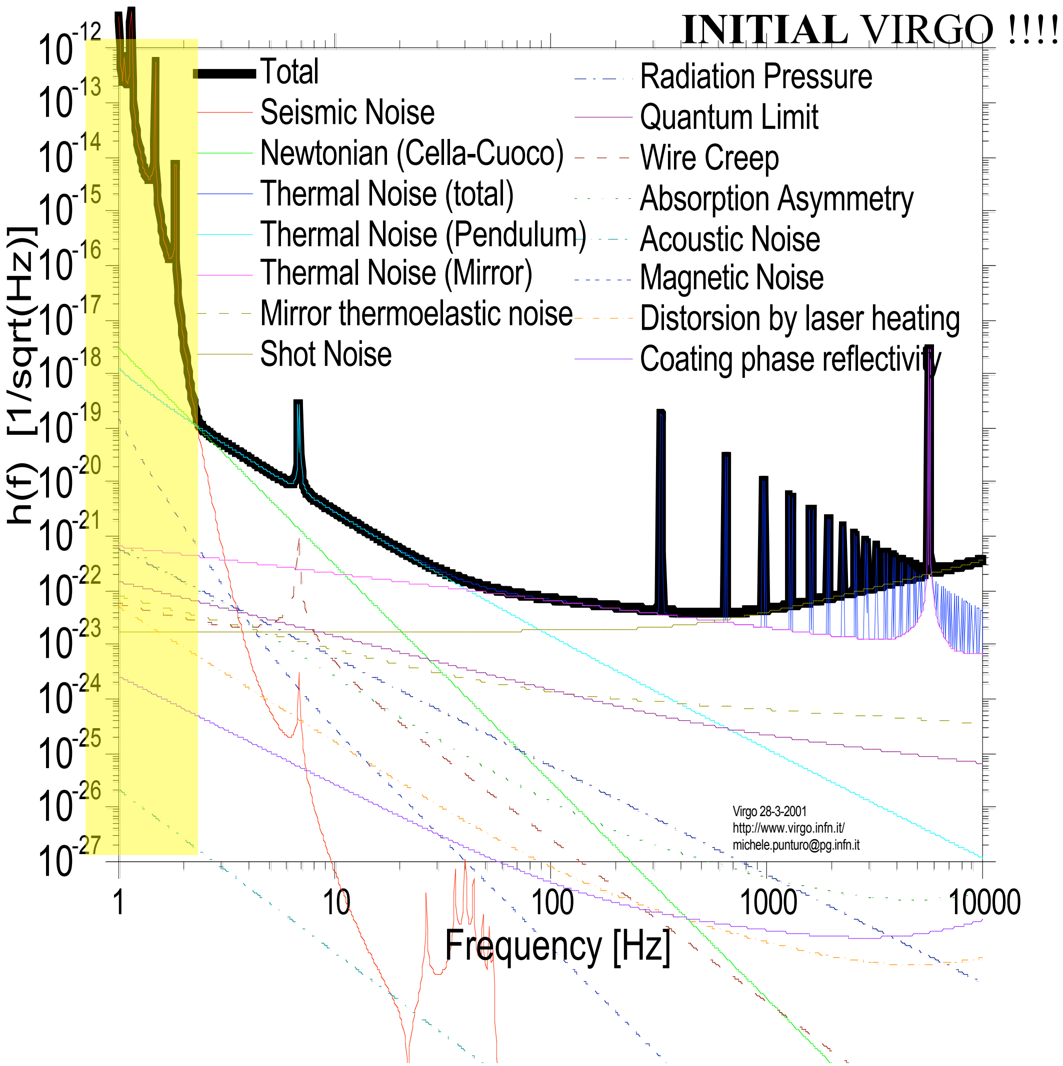
Intrinsic test-mass and readout noise sources

Estimated rate of SNe:

several /yr in the Virgo cluster (20 Mpc).

Designing Sensitivity requirements: initial Virgo

Pushing on the development of all the edge-technology solutions it is possible in principle to reach 10^{-21}-10^{-23} $Hz^{-1/2}$ strain sensitivity over a quite large bandwidth



Virgo

Final Design 1998

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VIRGO
COLLABORATION
http://www.virgo.infn.it/
Manpower:
~100 physicists, 100 technical support
Overall cost:
76 MEuro INFN-CNRS +
15 MEuro INFN for site preparation
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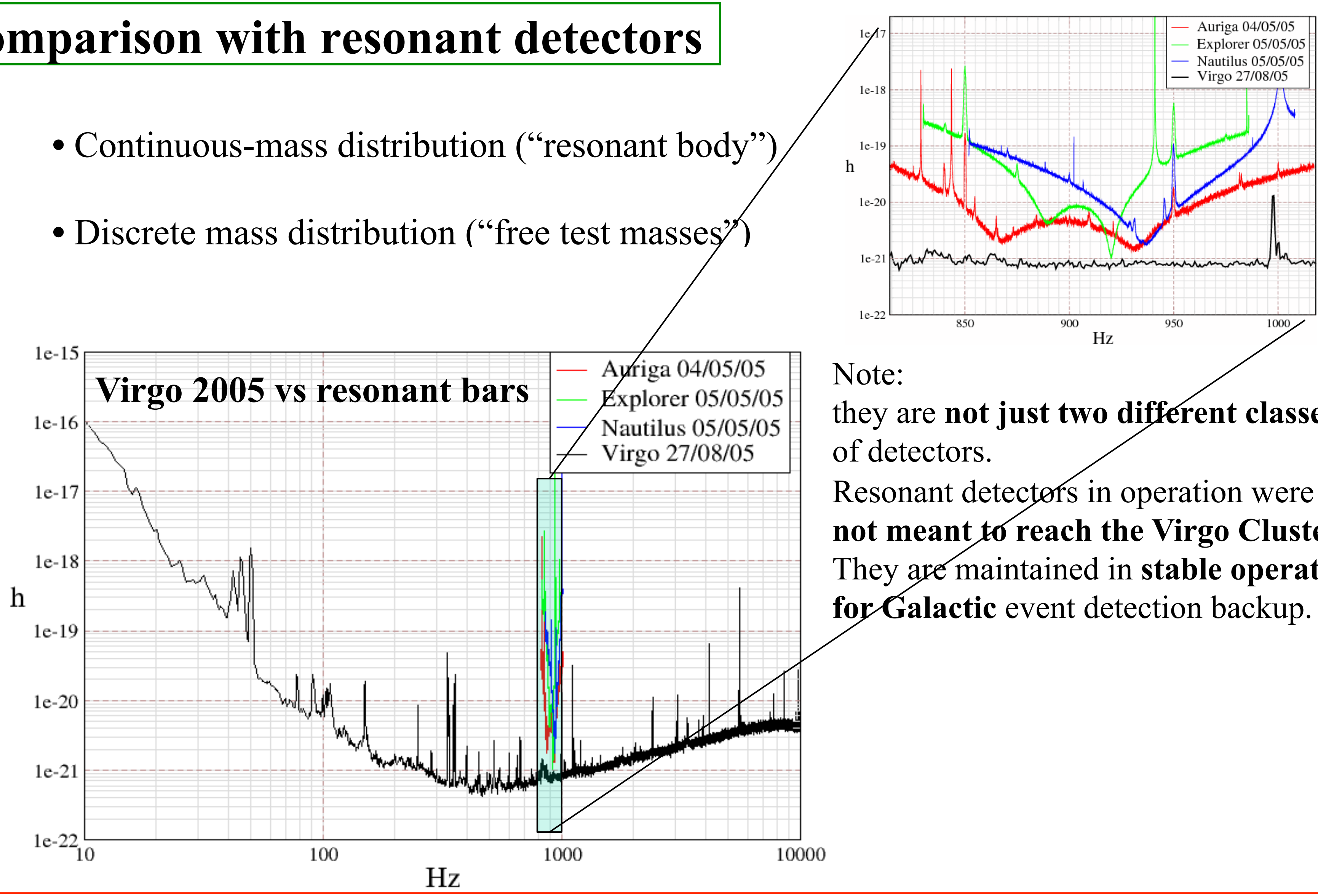
Site:
European Gravitational Observatory
Consortium (Cascina, Italy)
~10 Meuro/y

Comparison with resonant detectors

- Continuous-mass distribution ("resonant body")
- Discrete mass distribution ("free test masses")

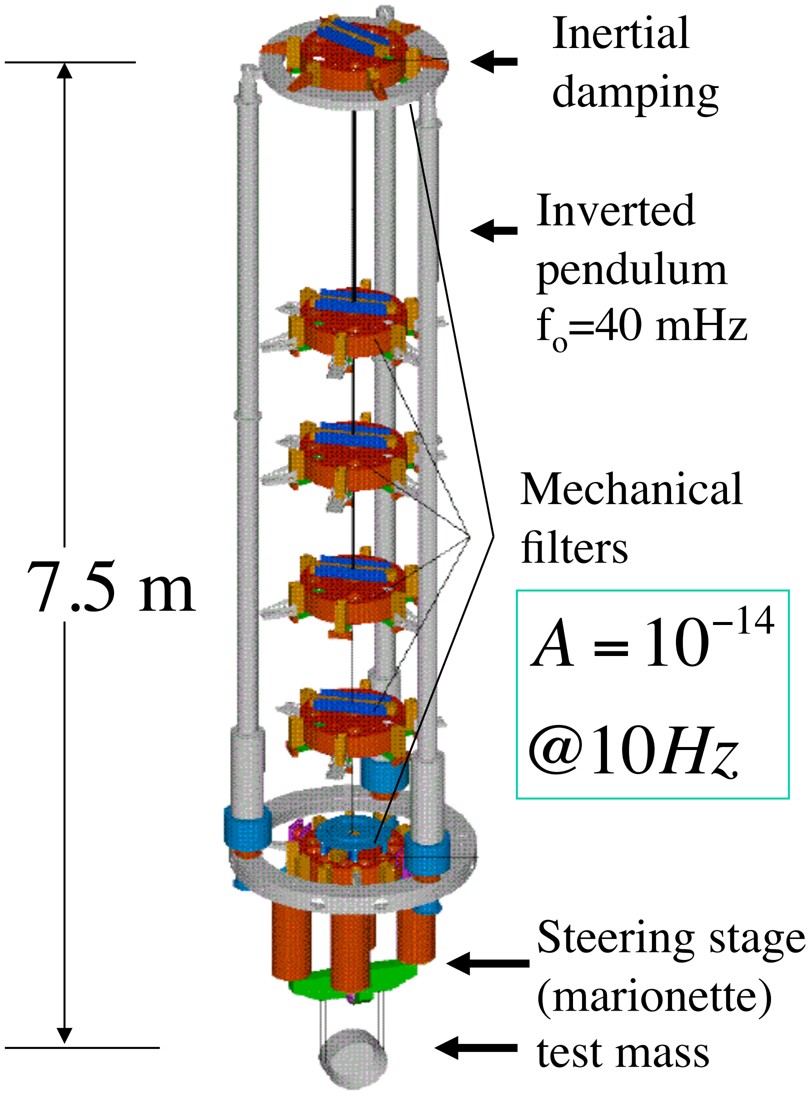


Note:
they are **not just two different classes** of detectors.
Resonant detectors in operation were **not meant to reach the Virgo Cluster**.
They are maintained in **stable operation for Galactic** event detection backup.

The European roadmap was delineated to concentrate resources on GW interferometers

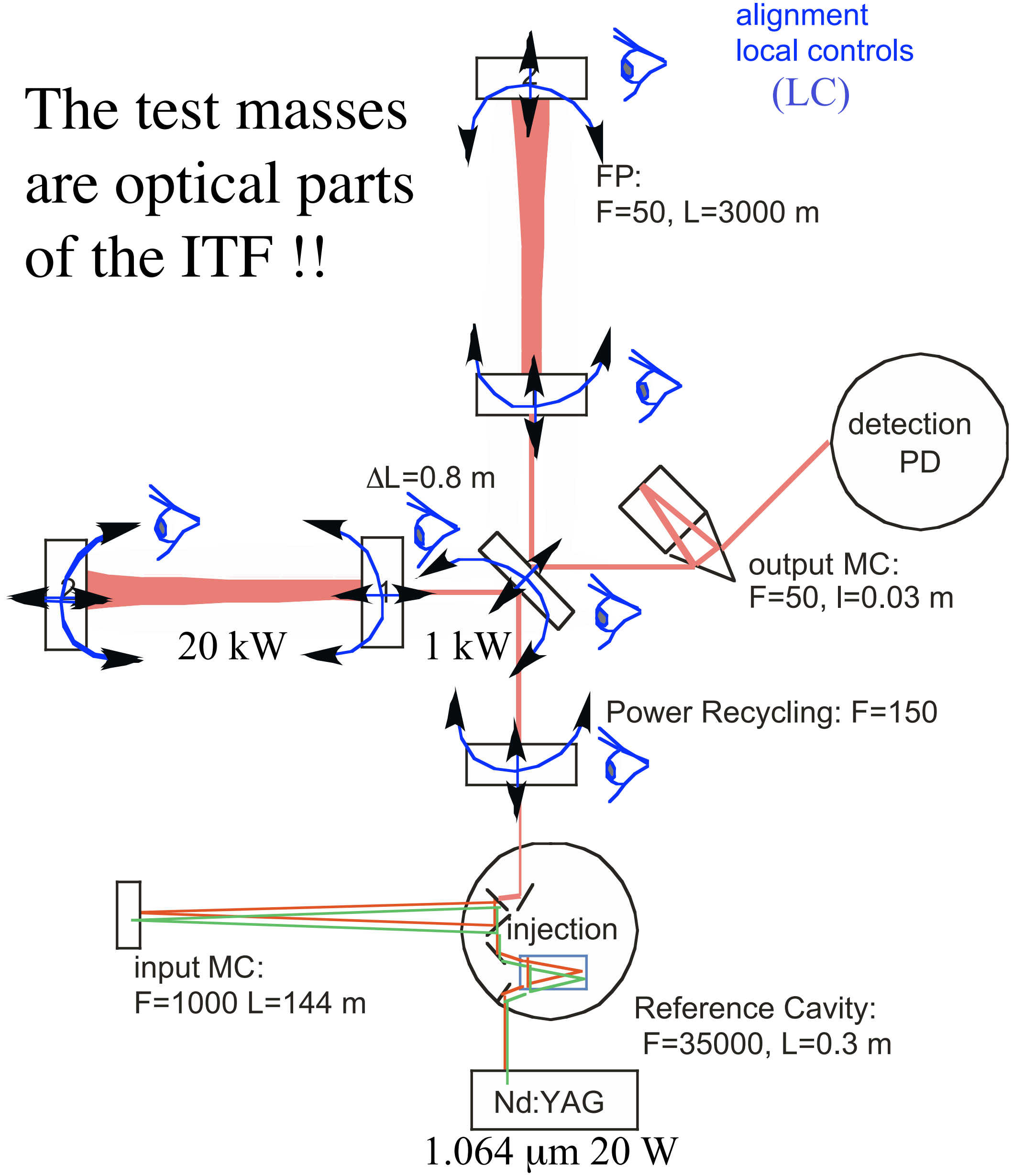
Demanding seismic isolation system

test masses



$$A = 10^{-14}$$
$$@10Hz$$

The test masses are optical parts of the ITF !!

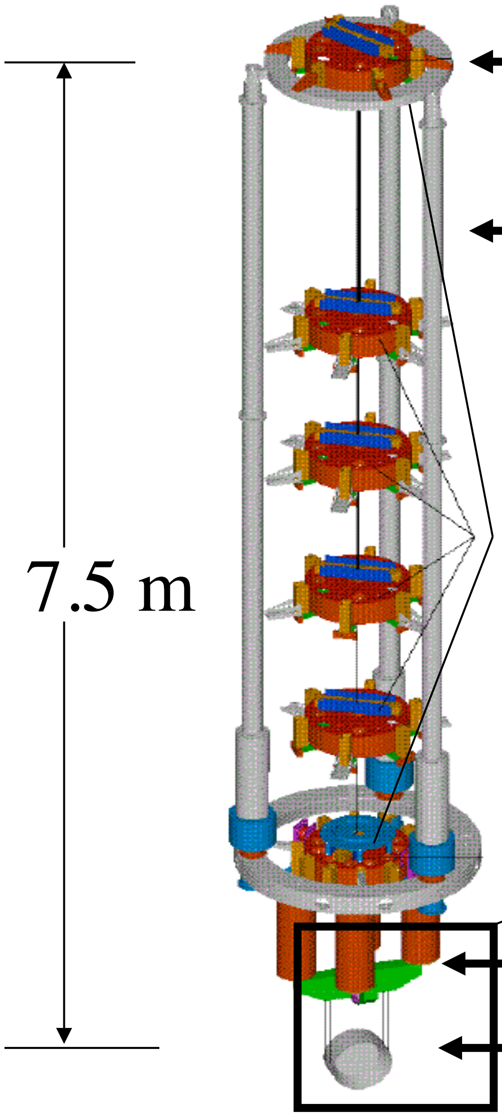


Low-frequency sensitivity: main hardware components (7slides + photo gallery)

Last suspension stage

Soft isolator concept:

1. very efficient passive attenuation
2. active controls for suspension mode damping



$$A = 10^{-14}$$

$$@10Hz$$

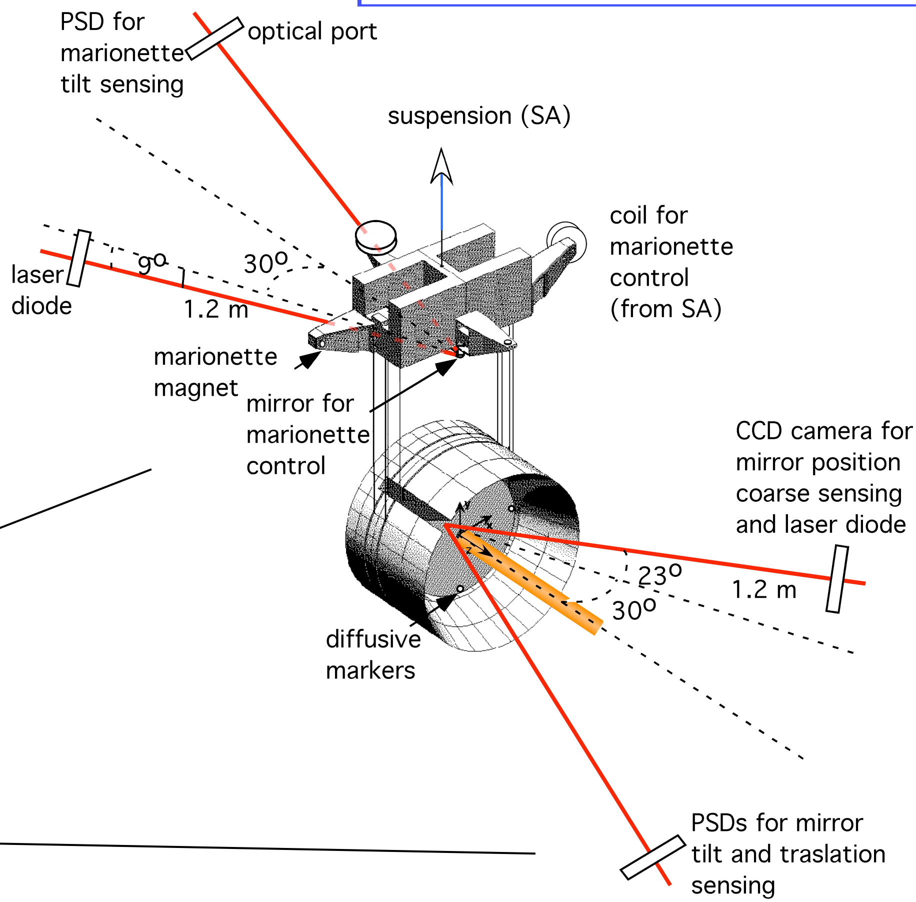
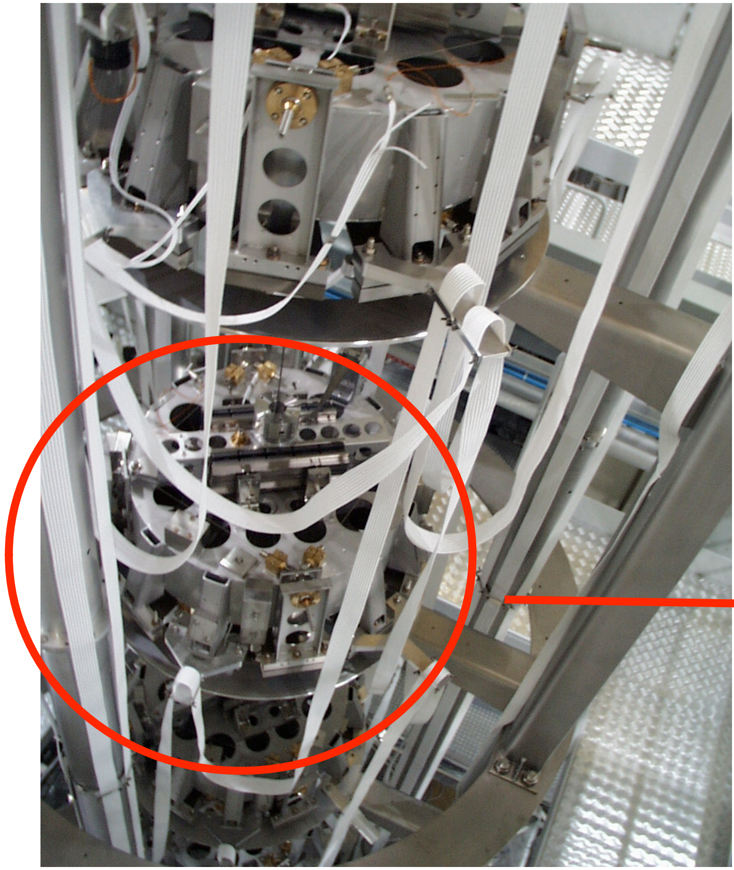
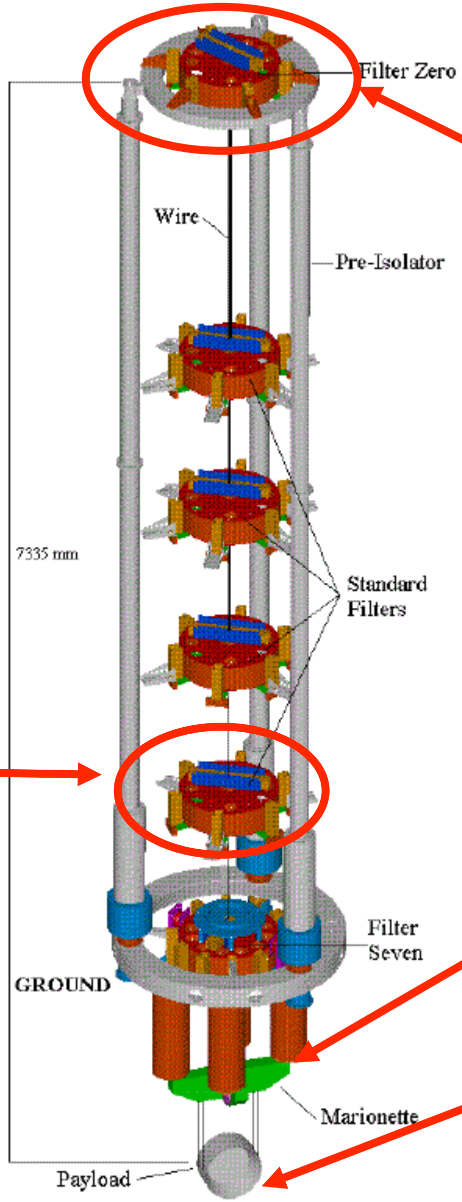
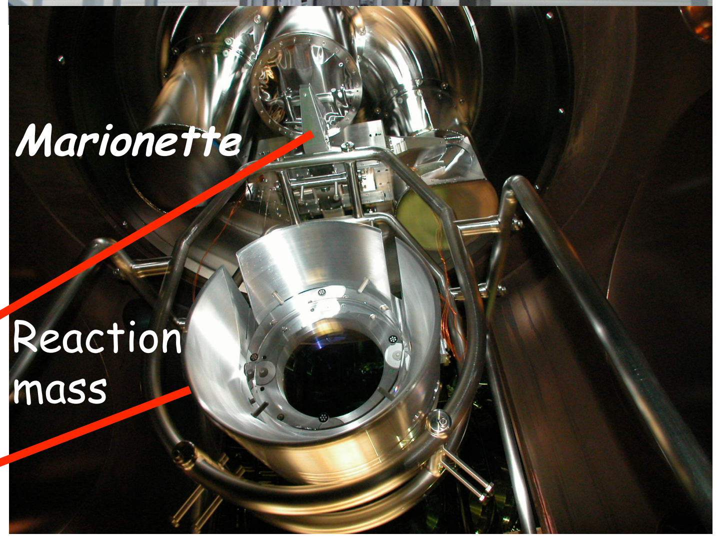


Image gallery (3 slides)







At 10 Hz seismic displacement is 10^{12} times larger than expected GW

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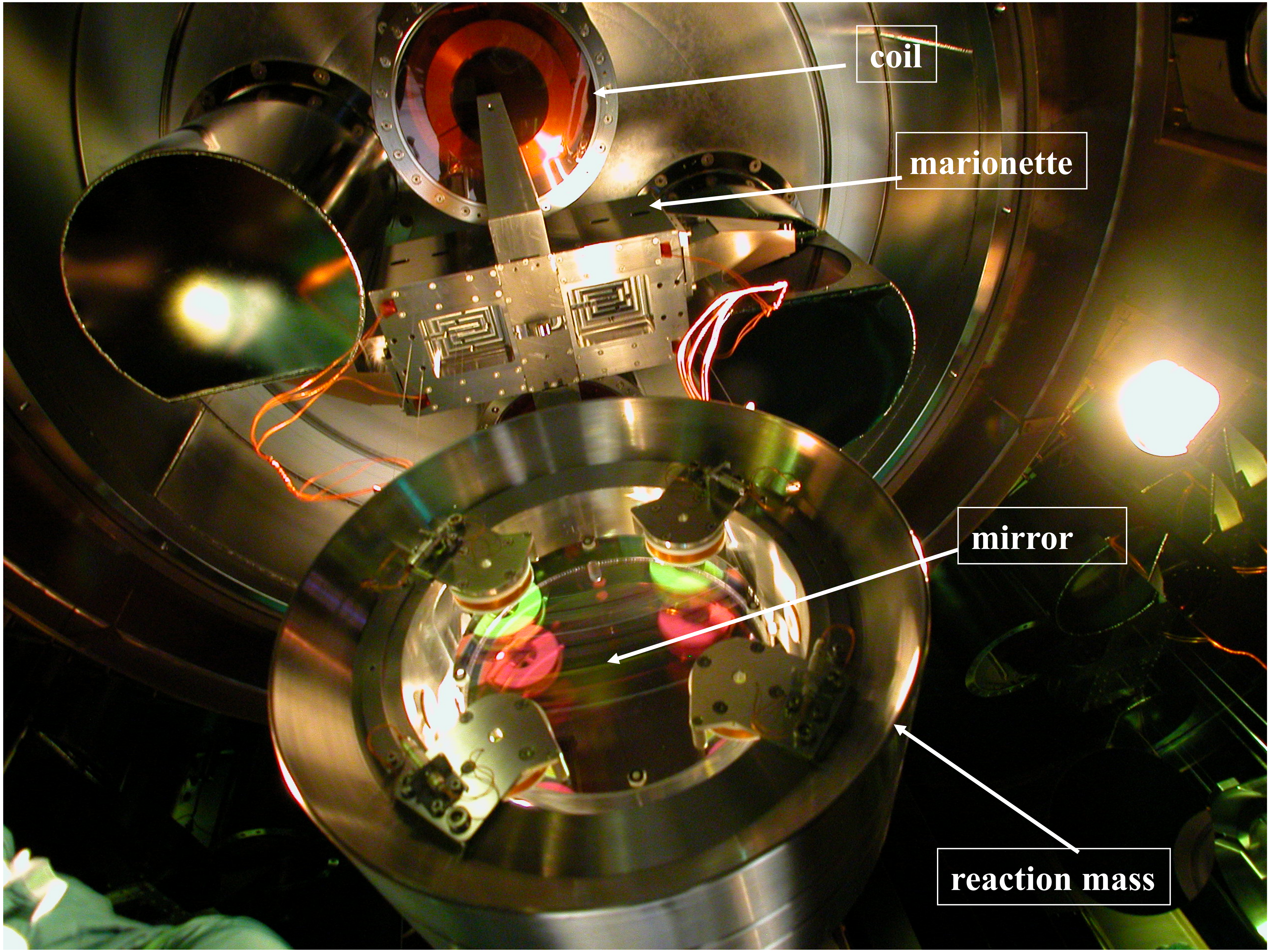
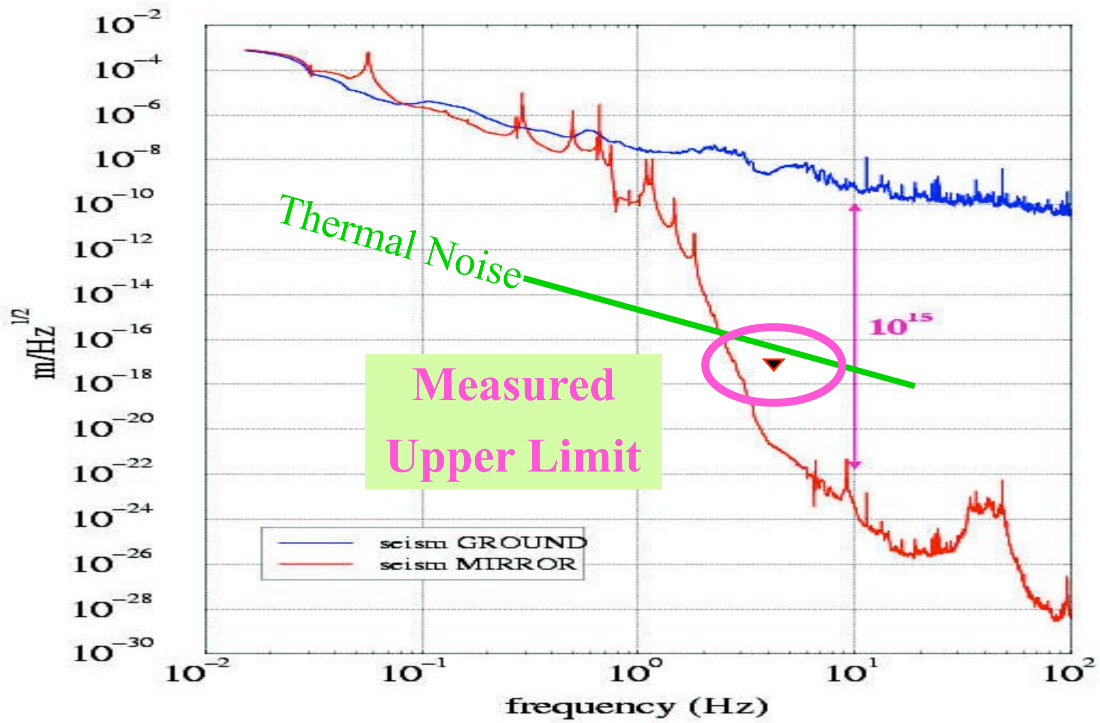

coil
marionette
mirror
reaction mass

Suspension digital control

The mechanics of SA suspension is designed to reach 10^{-18} m/Hz$^{1/2}$ at 10 Hz (thermal noise)



[Braccini et. al.,
AP. Ph. **23**, 6, 557 2005]

- The SA filters off the seismic noise above 4 Hz
- Below 4 Hz the mirror moves at the SA resonances by few tens of μm
- ITF locking requires resonance damping

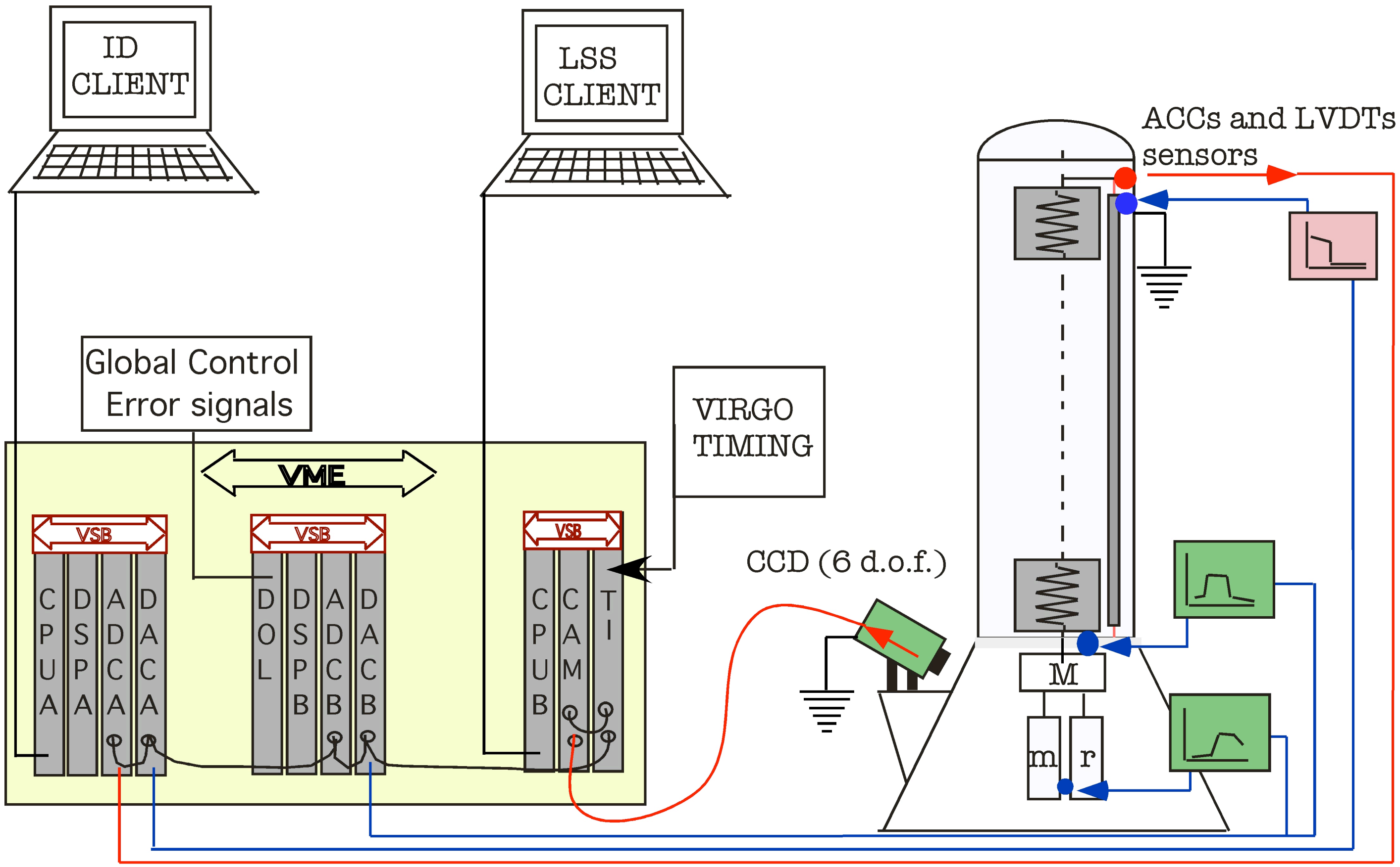
TOP: Sophisticated control system for the suspension chain

BOTTOM: Efficient and noiseless payload control

Suspension digital control (9 stations)

I) Local controls apply corrections to mirror position from local sensors. NO LIGHT

II) Local controls receive error signals from global sensors. ITF LOCKED



Local Controls: Inertial Damping

- Inertial sensors (accelerometers):
  - DC-100 Hz bandwidth
  - Equivalent displacement sensitivity: 10^{-11} m/sqrt(Hz)

- Displacement sensors LVDT-like:
  - Used for DC-0.1 Hz control
  - Sensitivity: 10^{-8} m/sqrt(Hz)
  - Linear range: ± 2 cm

- Coil magnet actuators:
  - Linear range: ± 2 cm
  - 0.5 N for 1 cm displacement

- Loop unity gain frequency:
  - 5 Hz

- Sampling rate:
  - 10 kHz

OVERALL CONFIGURATION OF A VIRGO SUSPENSION

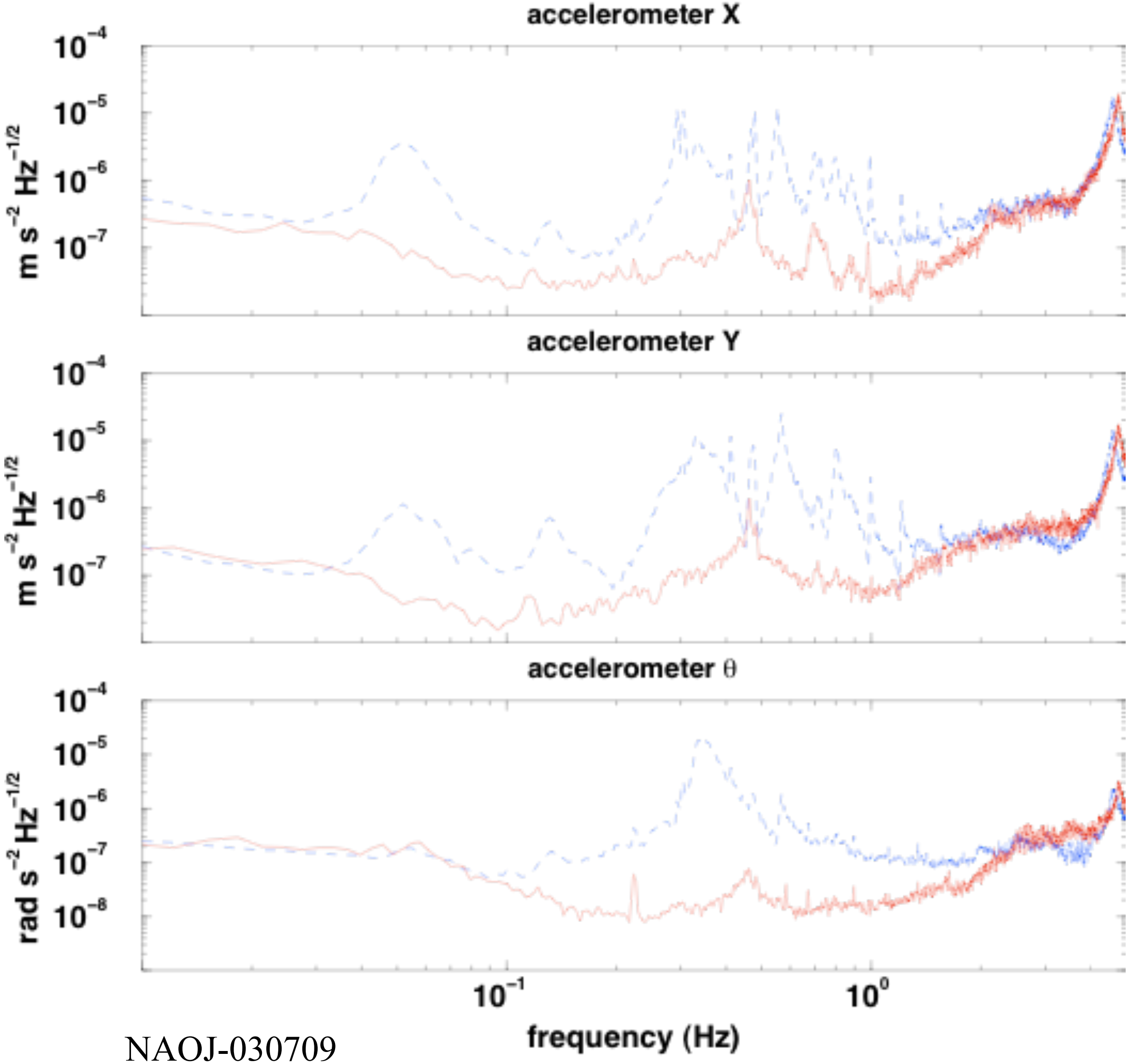
	stage	variable	actuator ref
SA: meant to prevent external disturbance	SA TOP	**Pos/Accel** 3D+yaw	Ground(~)/stars
	SA BOTTOM	**Position** 2D+yaw	Ground
Payload: meant to use test masses as optical elements	MARIONETTE	**Position** 2D+pitch/yaw	SA BOTTOM
	REACT. MASS	**Position** 1D+pitch/yaw	REACT. MASS

Basic requirements: sensing and actuation diagonalization

+

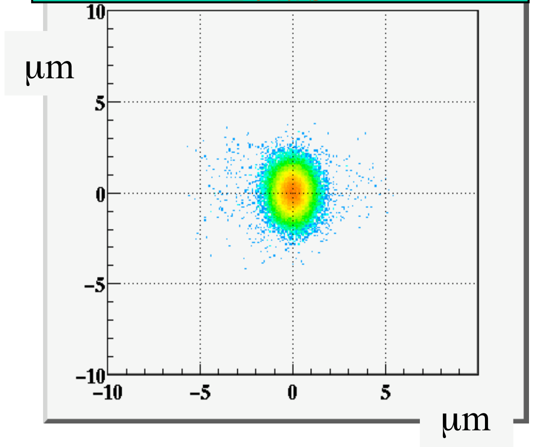
hiearchical control

I.D. Performance



- 1 μm relative displacement
- 0.25 um/sec relative speed

Inverted pendulum motion 24 hrs



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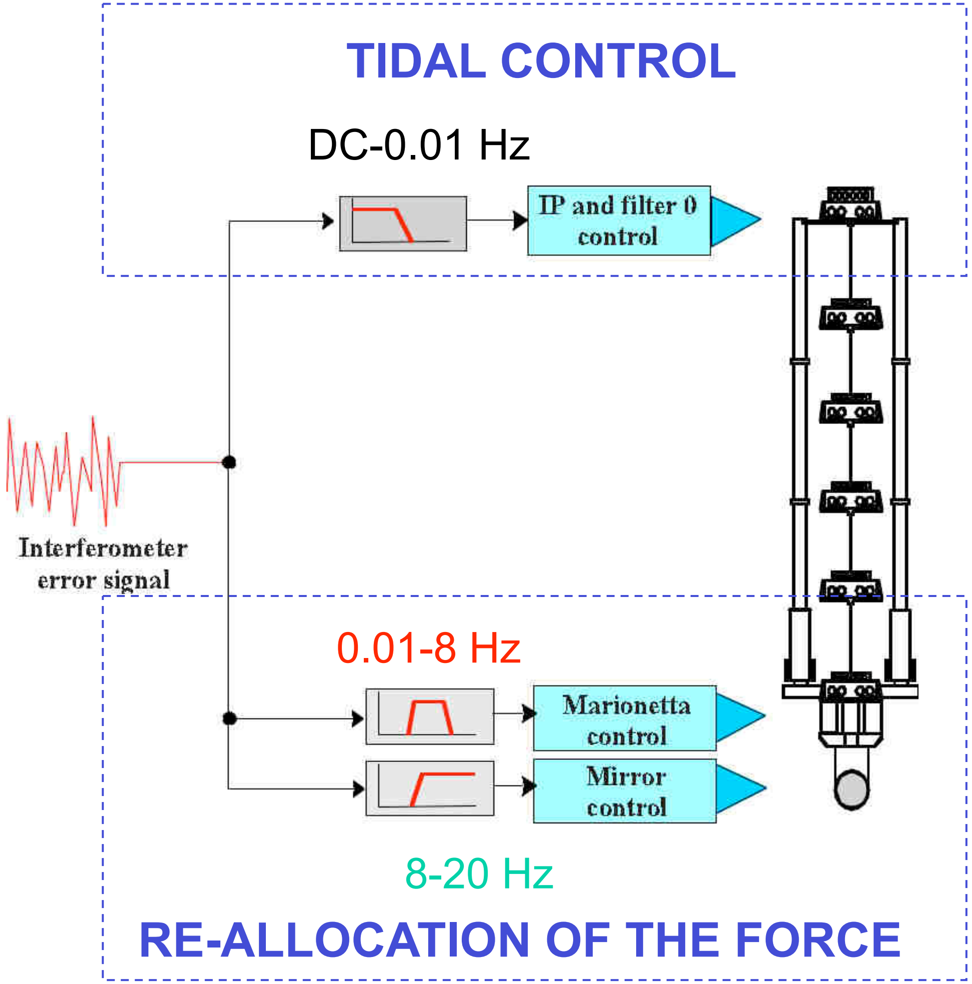
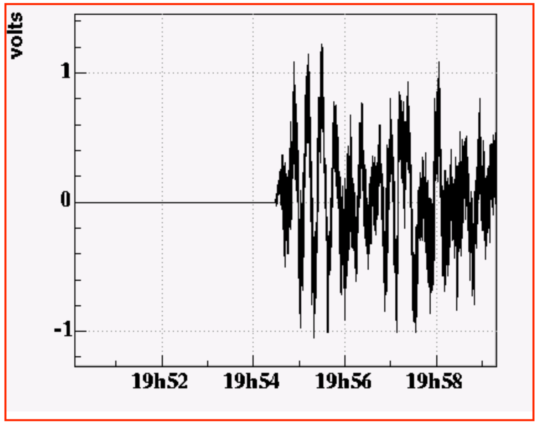
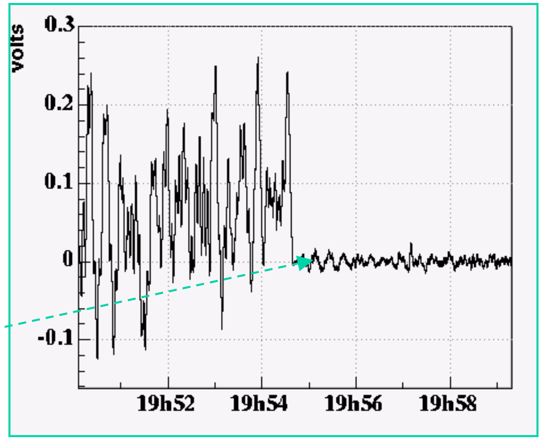
Actuation on the test masses: hierarchical control



Corrections sent to the Marionette coil/magnets



Corrections sent to the mirror coil/magnets



Magnetic actuation force on the mirror reduced
Switch to low noise coil drivers

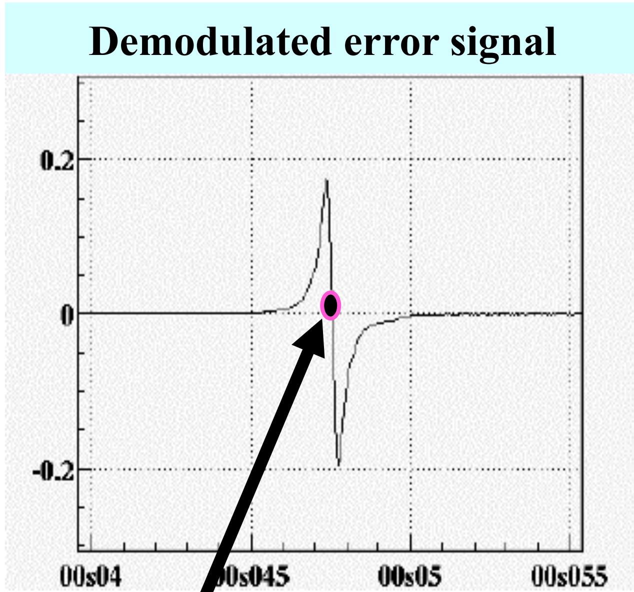
Basic optical control scheme

Suspension digital control

Mirror Optical Surface

0.5 μm/s

Mirror swing

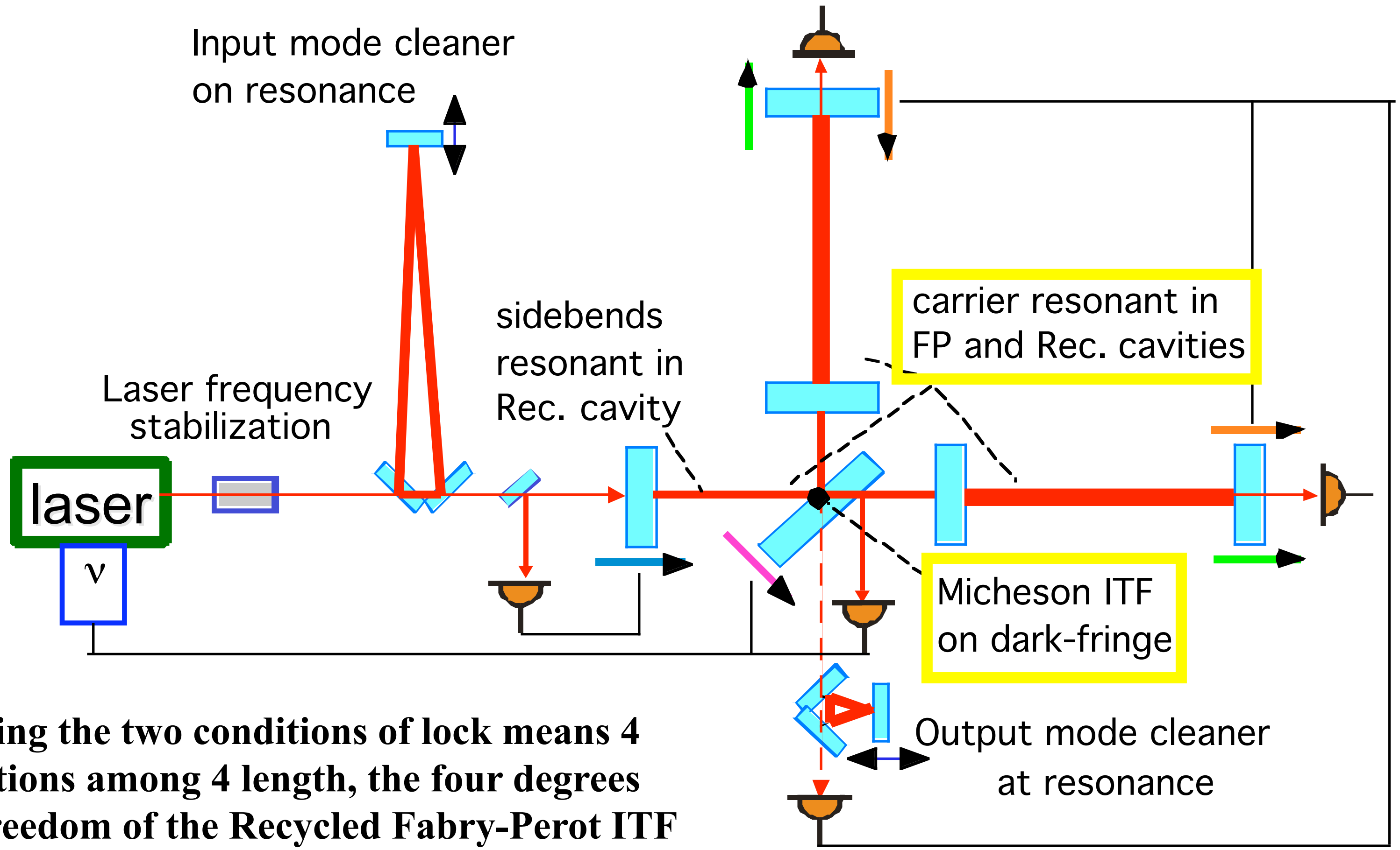


λ/2

Longitudinal working point (to be locked)

Resonance Crossing
λ /100

Basic interference setup: two conditions



Setting the two conditions of lock means 4 relations among 4 length, the four degrees of freedom of the Recycled Fabry-Perot ITF

- Dark Fringe set point (MICH)
- Differential Arm length (DARM)
- Power Recycling Cavity Length (PRCL)
- Common Arm length (CARM)

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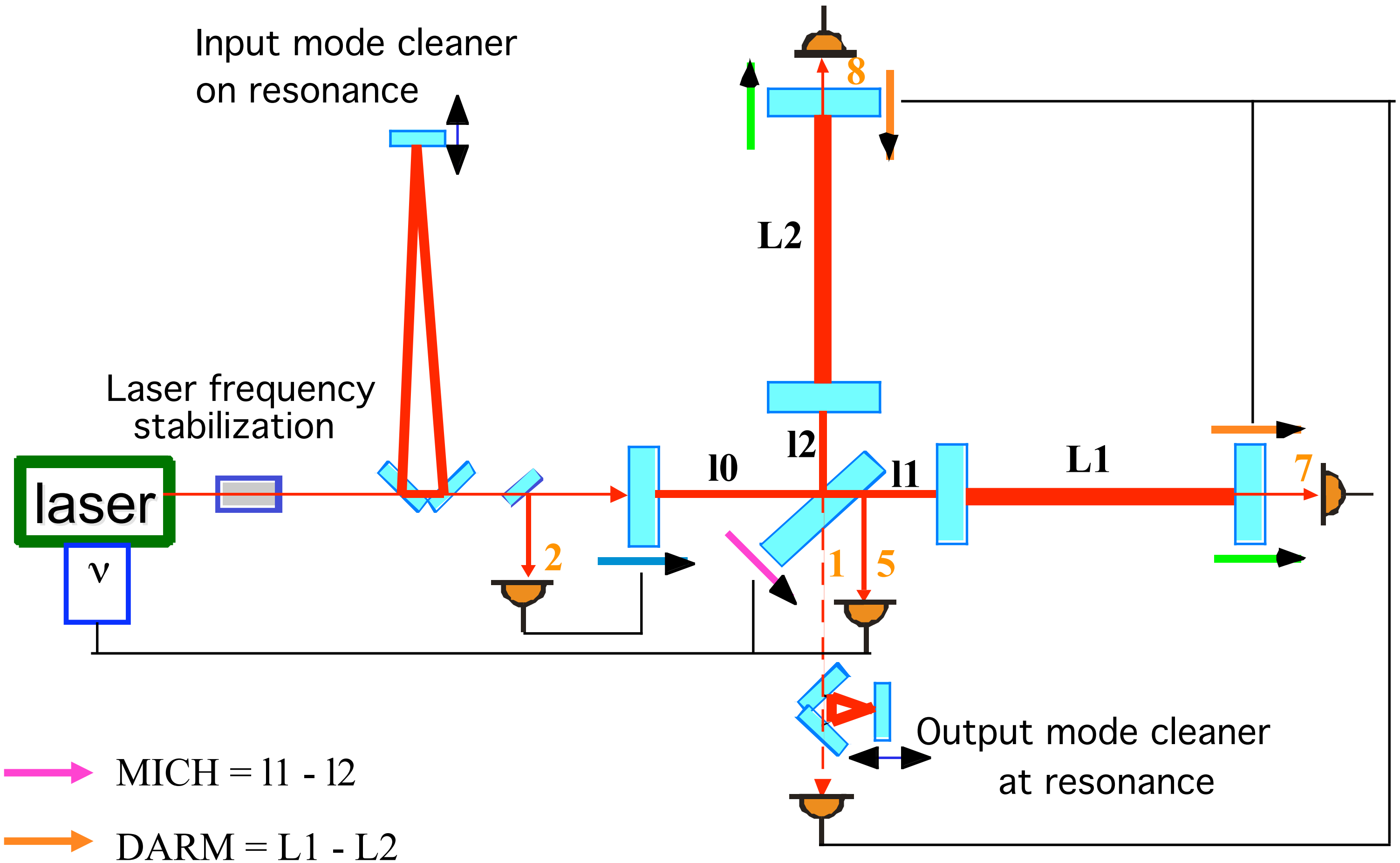
Basic interference setup: two conditions



MICH = l1 - l2

DARM = L1 - L2

PRCL = l0 + (l1+l2)/2

CARM = L1 + L2

1,2,5,7,8: standard port labeling in Virgo and LIGO:
1 = dark fringe, 5 = central cavity power pick-up.

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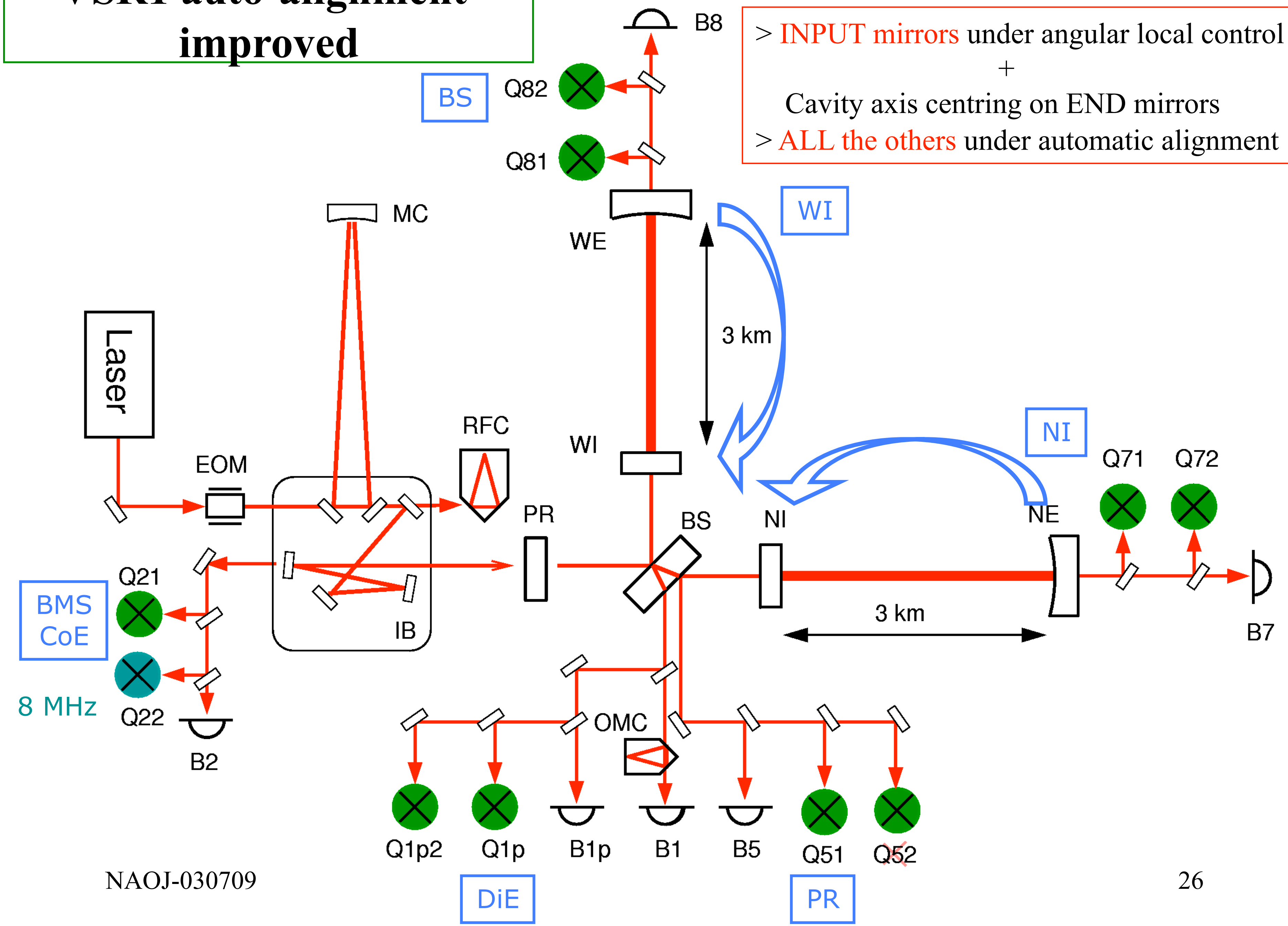
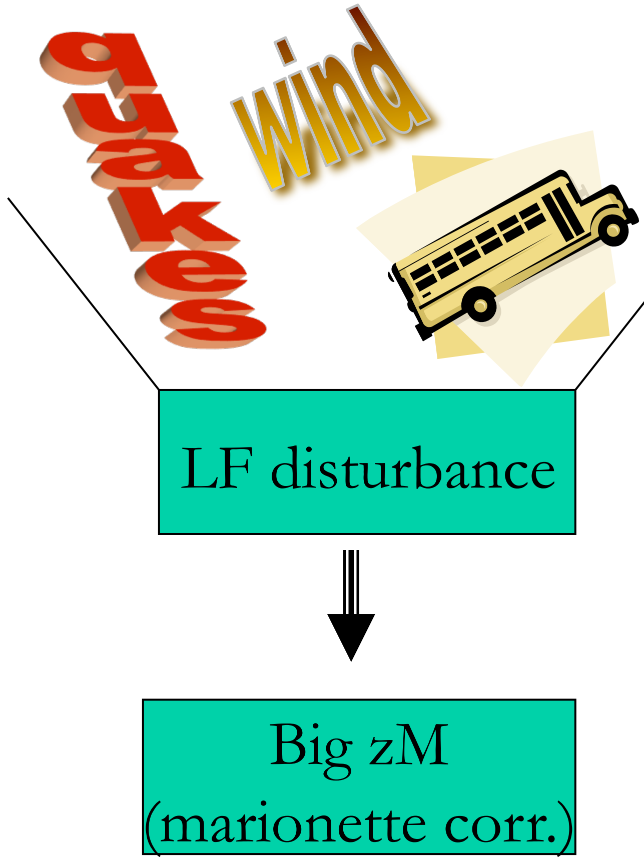
VSR1 auto-alignment improved

> INPUT mirrors under angular local control
+
Cavity axis centring on END mirrors
> ALL the others under automatic alignment



Suspension dedicated work : further “cost” of LF sensitivity demand

Enjoing digital control in practice
(with suspensions)



Position/Acceleration prefiltering for top-stage control

qi = quasi-inetrial
x_s = seism driven sensor reference

$$L(s)\cdot(x - x_s) + s^{-2}\cdot H(s)\cdot a_x(s) = x_{qi}$$

$$L(s) + H(s) = 1$$

$$x_{qi} = x - L(s)\cdot x_s$$

→ Increase L(s) slope

→ Reduce Position/Acc crossover frequency

→ "Reduce" x_s

Position/Acceleration prefiltering for top-stage control

qi = quasi-inetrial
x_s = seism driven sensor reference

$$L(s)\cdot(x - x_s) + s^{-2}\cdot H(s)\cdot a_x(s) = x_{qi}$$

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$$x_{qi} = x - L(s)\cdot x_s$$

→ Increase L(s) slope

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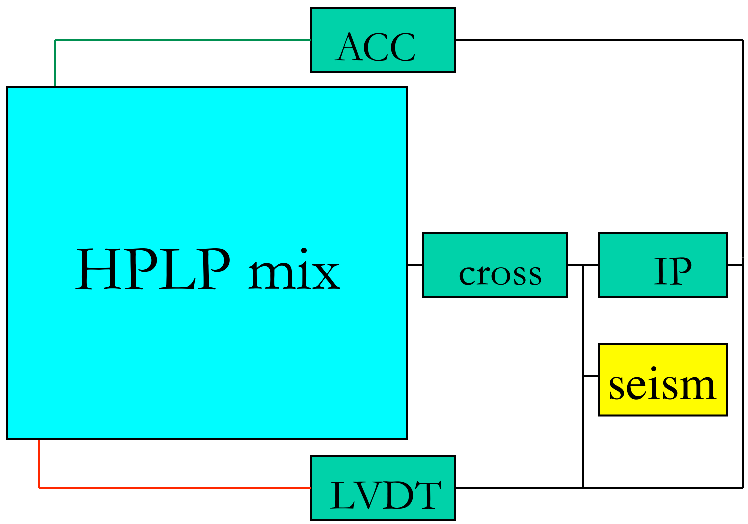
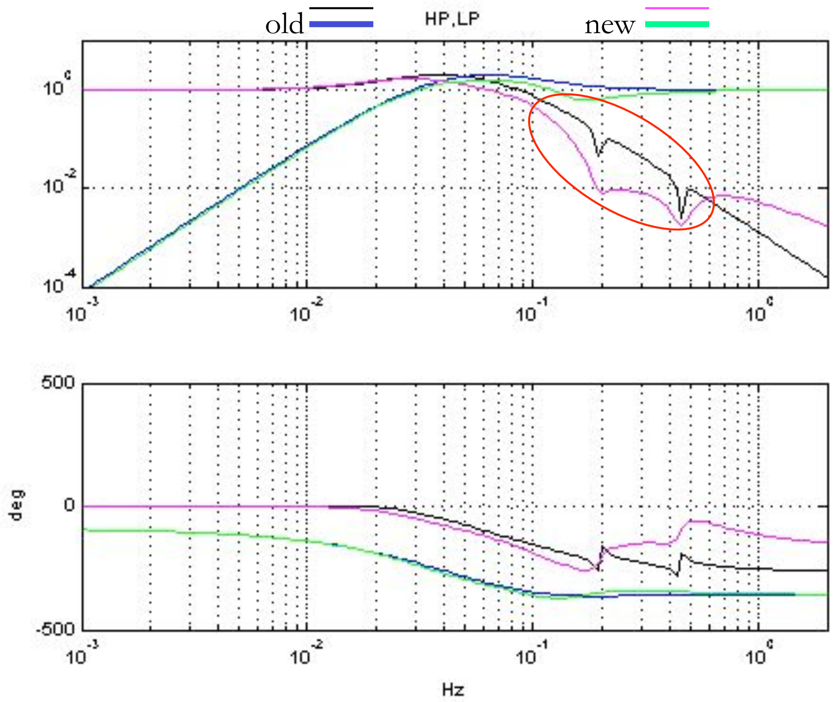
on-fly tuning using two different blending filters



Position/Acceleration prefiltering for top-stage control



mix =0.5 'medium' attenuation of LVDT μseism noise
Comparable to the optimal configuration (fx @ 50 mHz)

two main issues

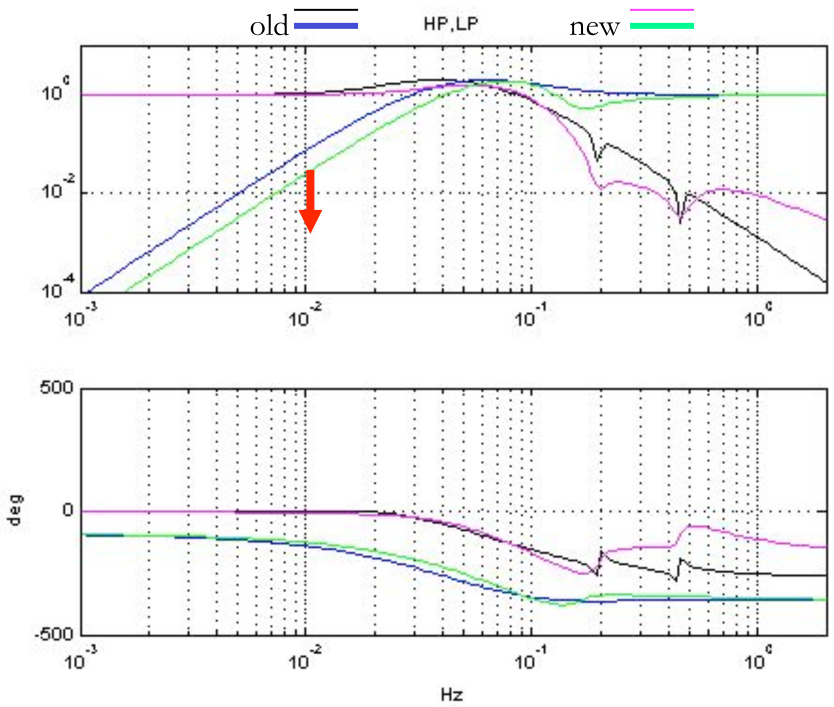
The problem of improving the system through independent optimization of each suspension:

wind-tilt noise
(through accelerometers, f < 70 mHz)

μseism sea disturbance
(through position control, 0.15-0.6 Hz)

Trade-off: **f_x=50 mHz**

Position/Acceleration prefiltering for top-stage control



mix =0.5 'medium' attenuation of LVDT μseism noise
Comparable to the optimal configuration (fx @ 50 mHz)

mix =0 (wind-earthqukes, f <70mHz):
"aggressive" attenuation of accelerometer tilt noise.

two main issues

The problem of improving the system through independent optimization of each suspension:

wind-tilt noise
(through accelerometers, f < 70 mHz)

μseism sea disturbance
(through position control, 0.15-0.6 Hz)

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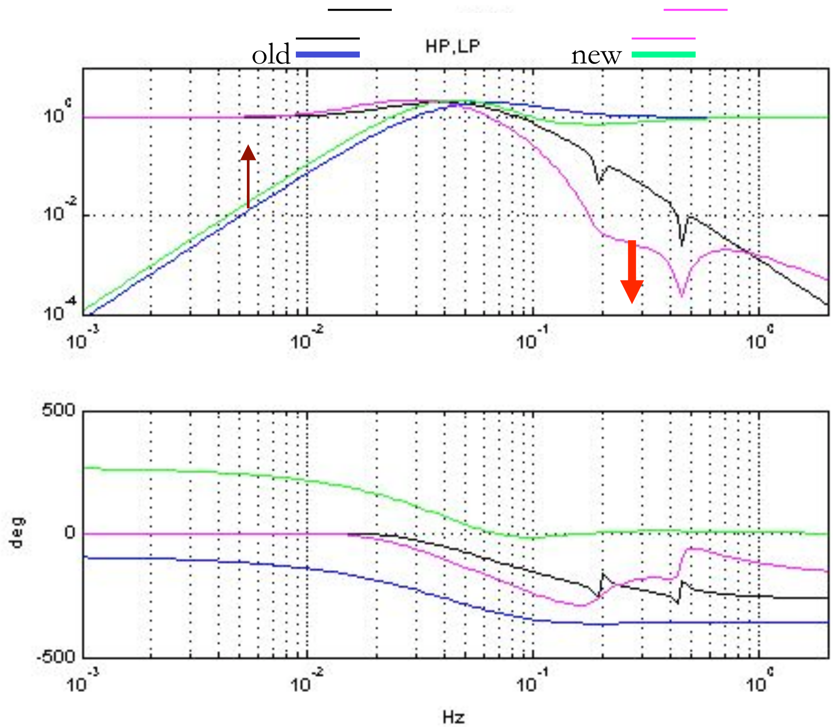
Position/Acceleration prefiltering for top-stage control



mix =0.5 'medium' attenuation of LVDT µseism noise
Comparable to the optimal configuration (fx @ 50 mHz)

mix =0 (wind-earthqukes, f <70mHz):
"aggressive" attenuation of accelerometer tilt noise.

mix =1 (µseism, 150-600 mHz) :
"aggressive", slightly worsened against tilt noise.

two main issues

The problem of improving the system through independent optimization of each suspension:

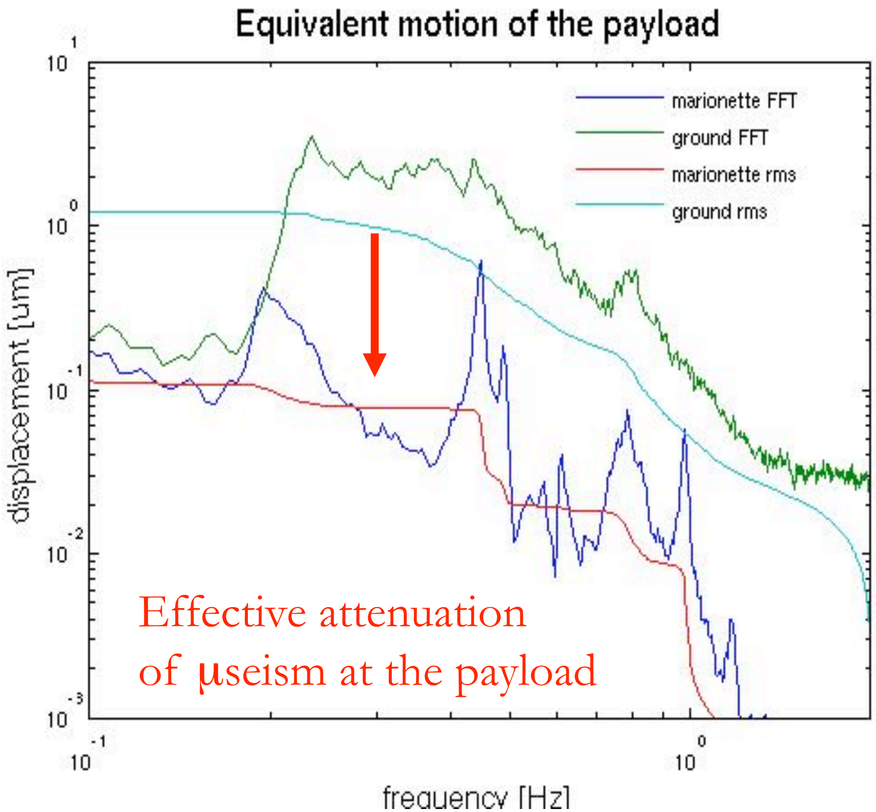
wind-tilt noise
(through accelerometers, f < 70 mHz)

µseism sea disturbance
(through position control, 0.15-0.6 Hz)

Trade-off: **f_x=50 mHz**

µSeism disturbance attenuated downstream (=>the concept of Global Inverted Pendulum Control)

What would be the payload displacement due to sea µseism without VirgoSuperAttenuator ?



The lock force applied to the marionette corrects the residual payload motion, whose rms above 100 mHz is ~ 1 order of magnitude smaller than the ground motion.

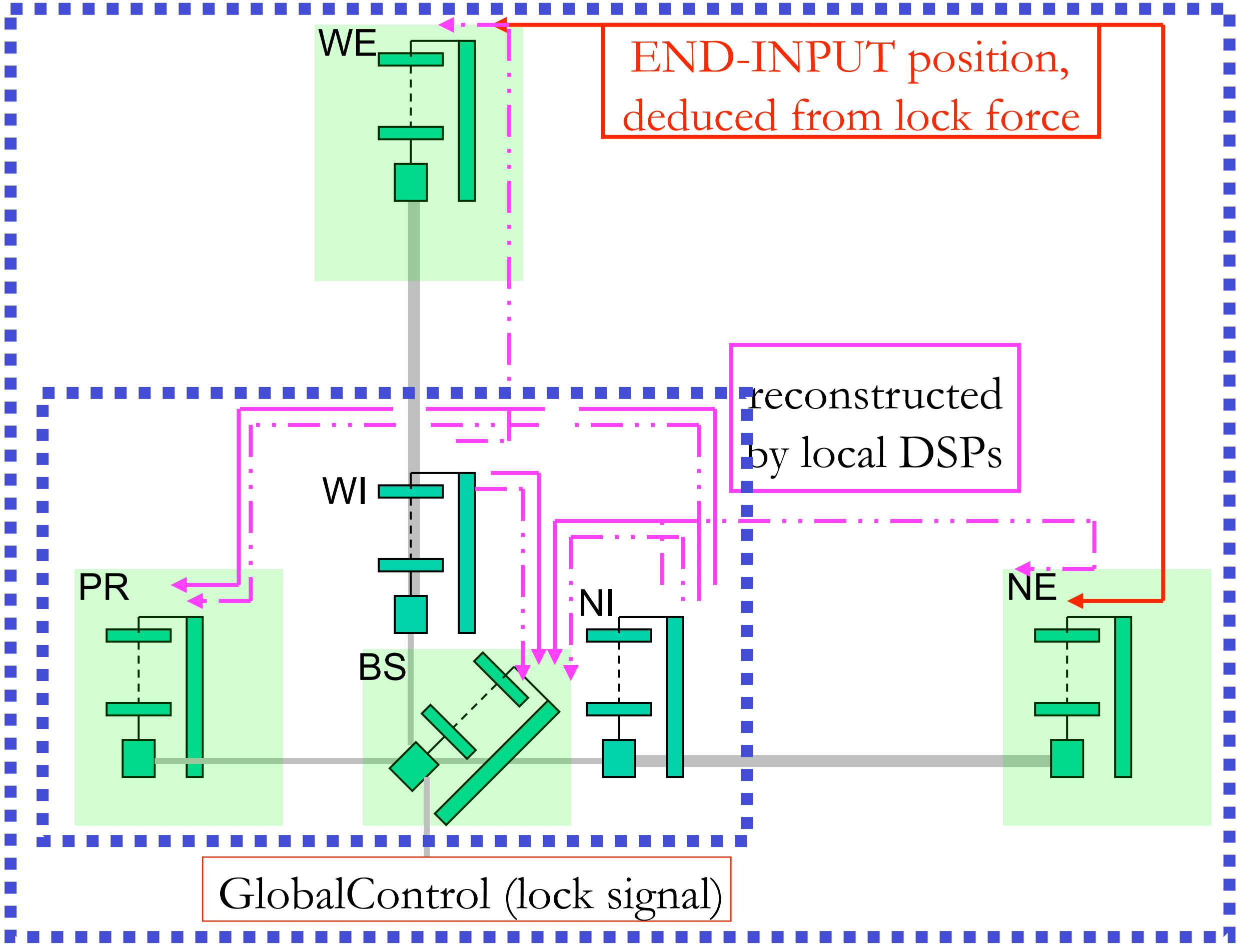
A top-stage control position reference with smaller x_s seismic noise allows to increase f_x without risks

µSeism-Free and Global Inverted Pendulum control

µseism is **incoherent**
along the arm baseline
=>µSeism reduced at
END suspension top-stages
by using position referred to
INPUT mirrors (GIPC);

Also the Acceleration !

µSeism is **coherent**
in the central area
=> µSeism-Free signals can
be reconstructed with respect
to **INPUT mirrors (µSF)**



INPUT TOWERS USED AS REFERENCE

MSC Vs robustness (2): earhquakes/GIPC

A "lucky" occurrence !*

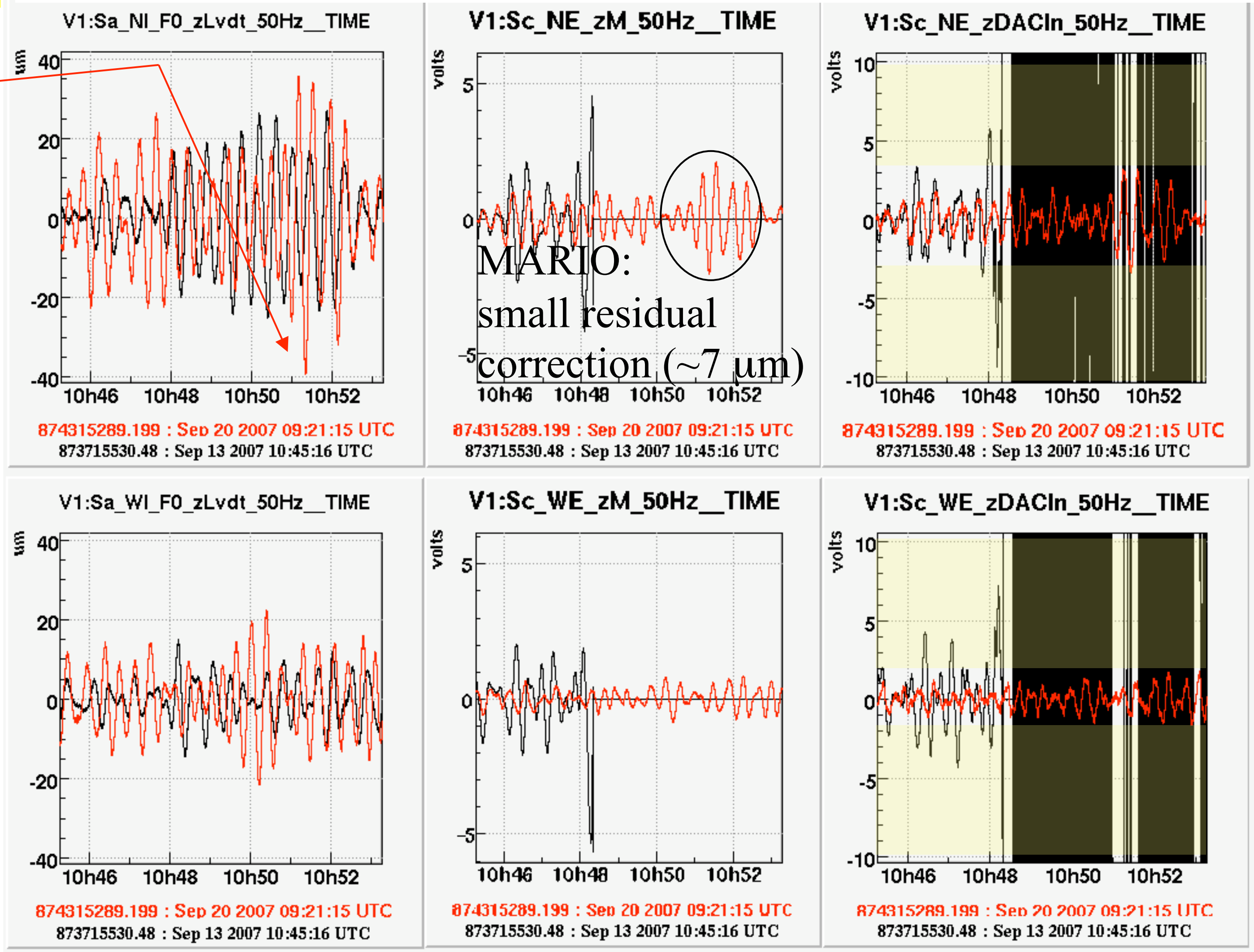
Comparison of two events with similar local amplitude with and without reallocation of acceleration at end top-stages

40 µm peak

Previously we had saturation as the amplitude approached **20 µm**

The system is much more robust .

Correction dynamics more than doubled.



Mario Corr **Mirr Corr**

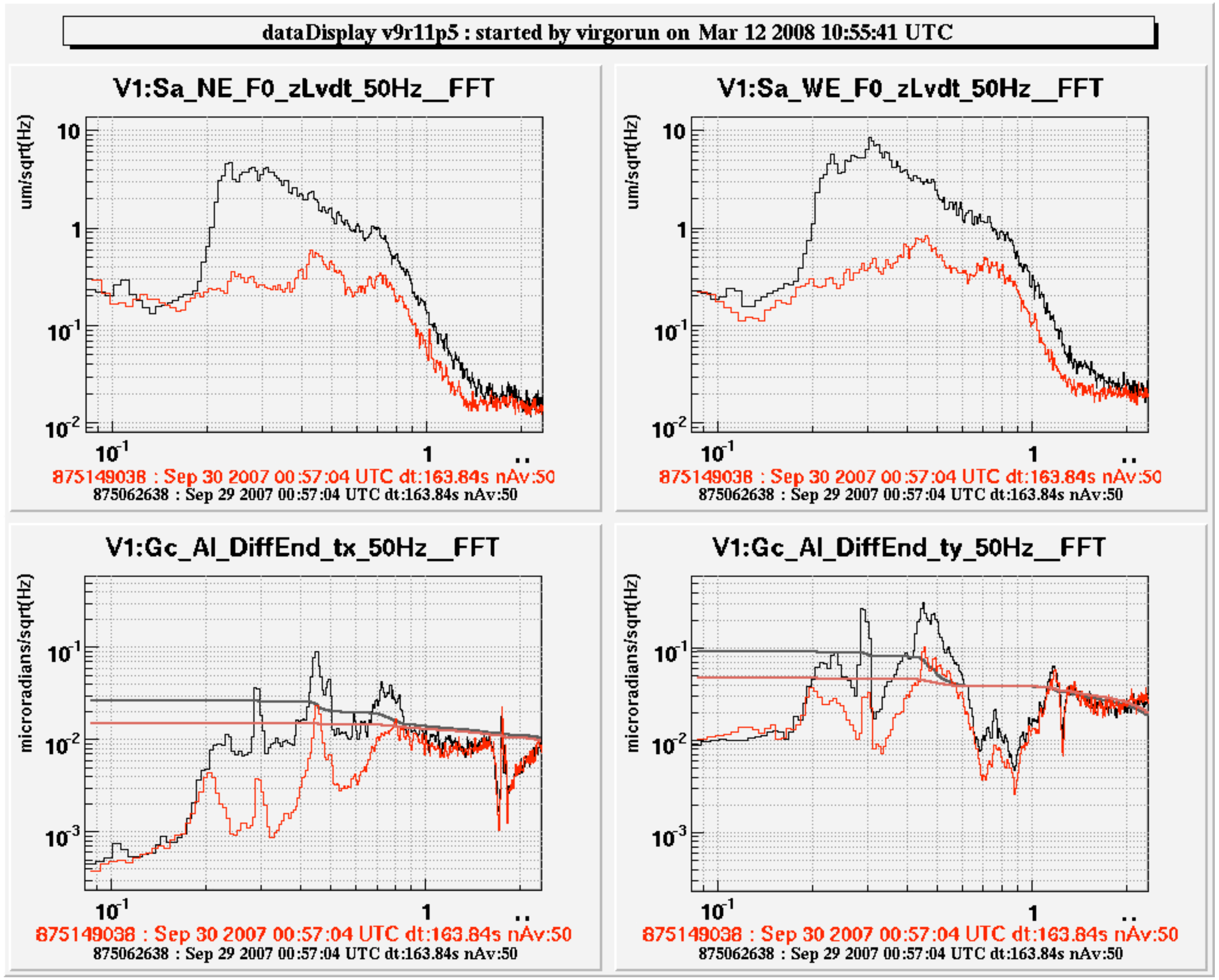
(*Indonesia M6.8, Sep-20-08.31):

briefly… **(sea activity versus quiet): combining sensors in order to reduce the impact of ground disturbance injected by suspension position sensor is worth !**

Micro-seism

Worse alignement

Worse sensitivity



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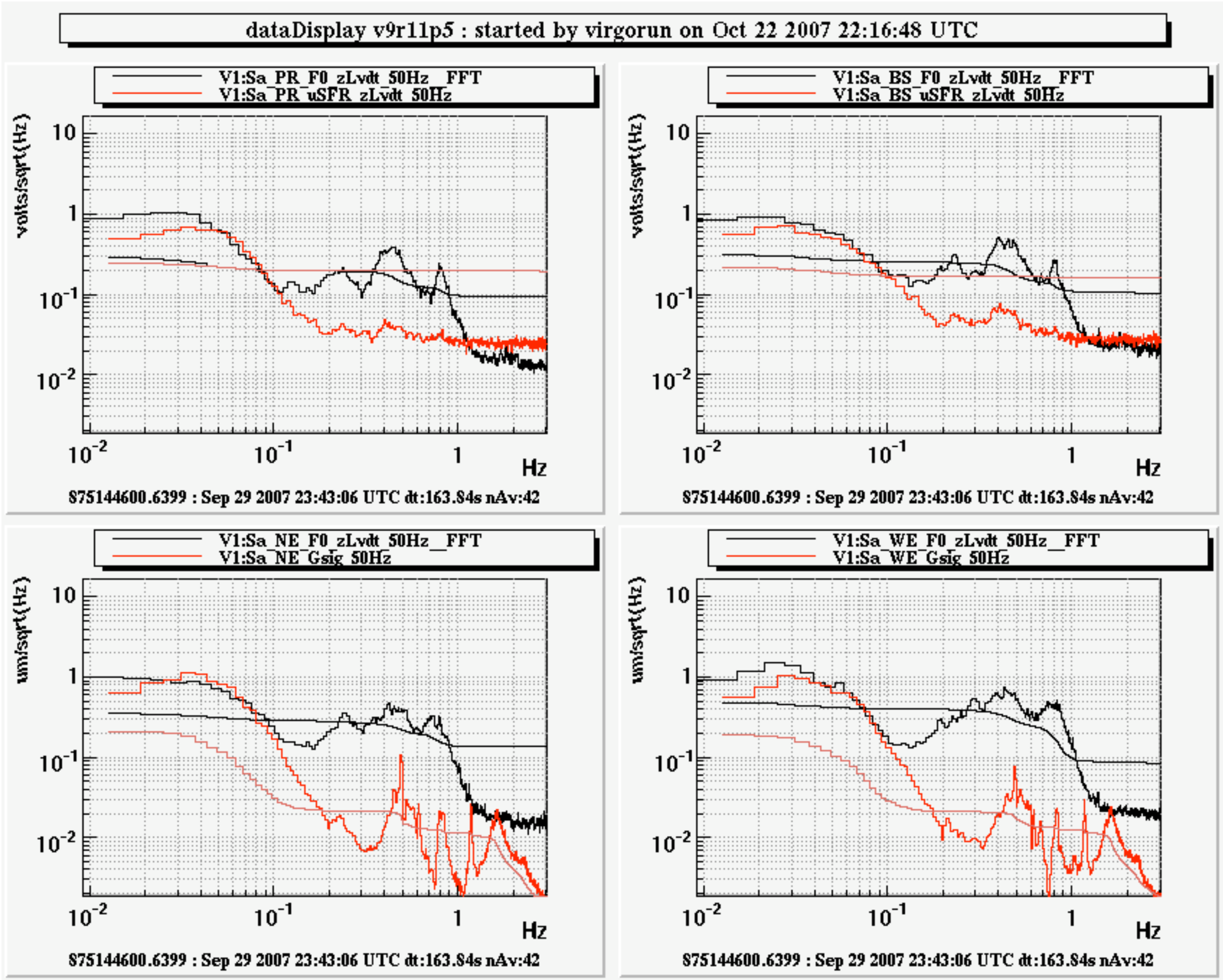
μSeism rejection strategies: VSR1start-VSR1stop (4 month run 2007)

quiet

INPUT mirror suspensions used as reference



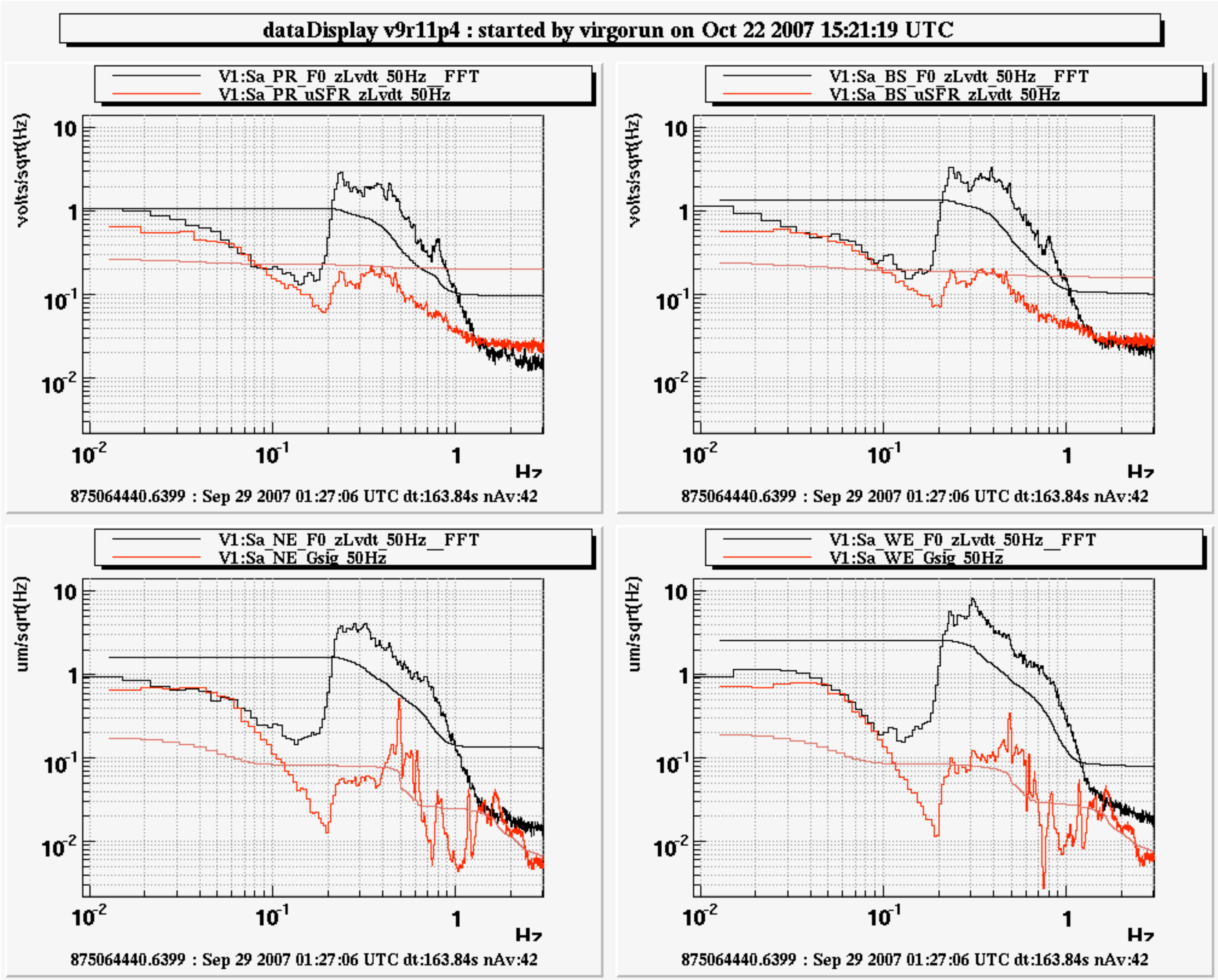
Local LVDTs, used for top-stage control at VSR1 start provide μseism monitoring as global suspension control strategies were engaged (VSR1 end)

Combined channels used at VSR1 stop: **μSFR** (μSeism-Free Reconstruction) and **GIPC** (Global-Inverted-Pendulum Control)

µseism: rejection VSR1start-VSR1stop

sea

INPUT mirror suspensions used as reference

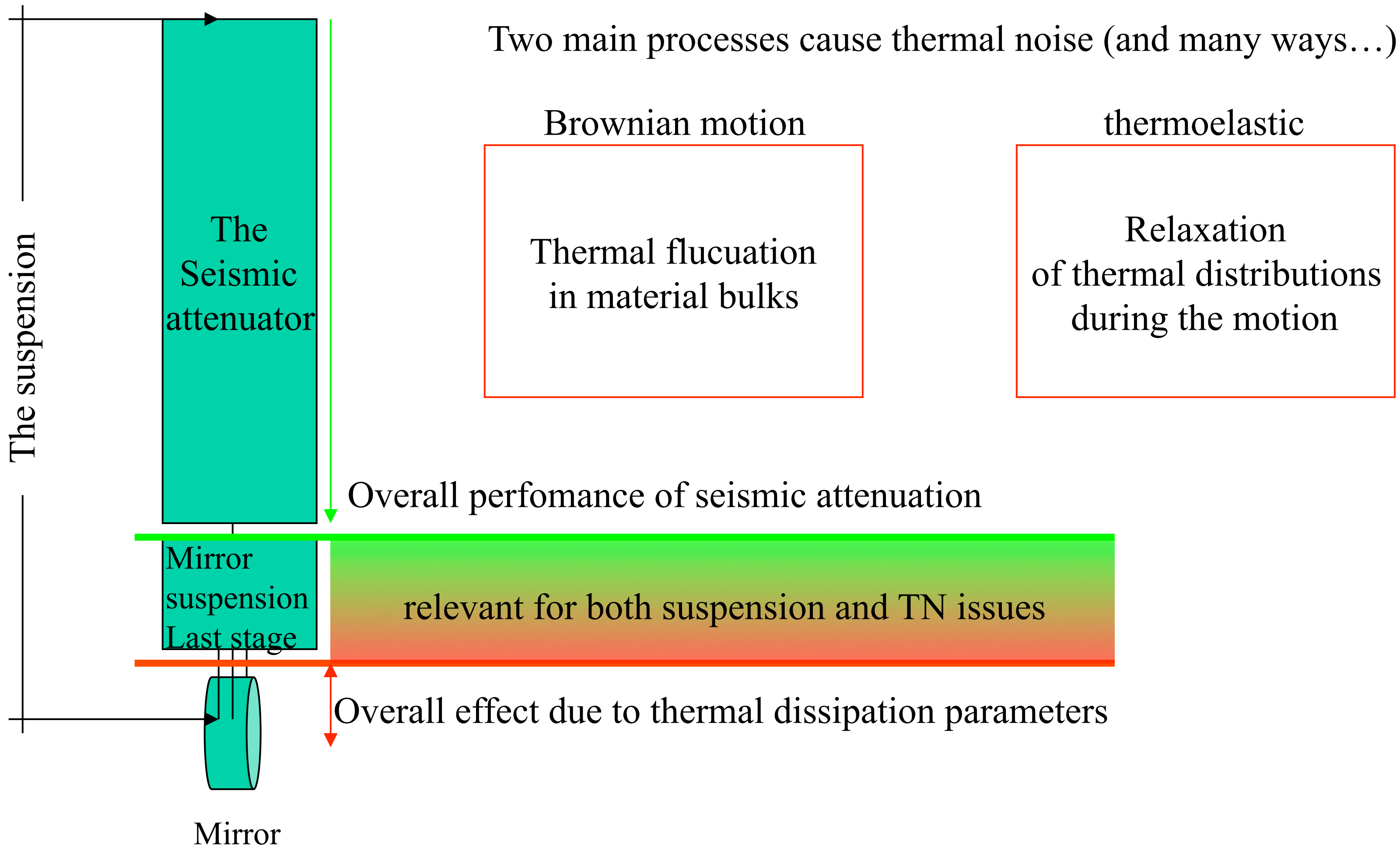


Local LVDTs, used for top-stage control at VSR1 start provide µseism monitoring as global suspension control strategies were engaged (VSR1 end)

Combined channels used at VSR1 stop: **µSFR** (µSeism-Free Reconstruction) and **GIPC** (Global-Inverted-Pendulum Control)

Thermal noise

Intrinsic test mass noise source: thermal



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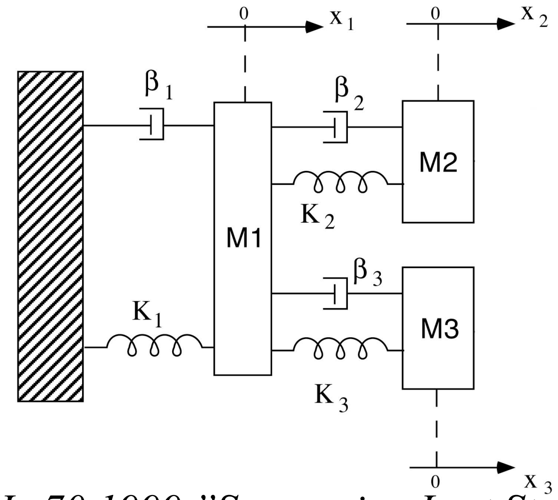
Mechanical thermal noise in suspension last stages

BRANCHED SYSTEM



**RSI v70,1999,"Suspension Last Stage…"*

1. **Marionette** **(M_1, $\beta_1 = M_1/\tau_{01}$)**
2. **Mirror** **(M_2, $\beta_2 = M_2/\tau_{02}$)**
3. **Reaction Mass** **(M_3, $\beta_3 = M_3/\tau_{03}$)**

$$\hat{D}\begin{pmatrix} X_1 \\ X_2 \\ X_3 \end{pmatrix} = \begin{pmatrix} F_{thI}/M_1 \\ F_{thII}/M_2 \\ F_{thIII}/M_3 \end{pmatrix}$$

Equations of motion with thermal stochastic forces

$$F_{thI} = f_{th1} - f_{th2} - f_{th3}$$

$$F_{thIII} = f_{th2}$$

$$F_{thIII} = f_{th3}$$

Stochastic Thermal forces related to the uncoupled thermal forces

Impedance Matrix $\hat{Z}\,\dot{X} = F_{th}$

$$\hat{Z} = \frac{1}{i\omega}\begin{pmatrix} M_1 D_{11} & M_1 D_{12} & M_1 D_{13} \\ M_2 D_{21} & M_2 D_{22} & M_2 D_{23} \\ M_3 D_{31} & M_3 D_{32} & M_3 D_{33} \end{pmatrix}$$

$$\mathbf{D} = \begin{pmatrix} -\omega^2 + \omega01^2 + \mu21\,\omega02^2 + \mu31\,\omega03^2 + i\,\omega\left(\frac{1}{\tau01[\omega]} + \frac{\mu21}{\tau02[\omega]} + \frac{\mu31}{\tau03[\omega]}\right) & -\mu21\,\omega02^2 - \frac{i\,\mu21\,\omega}{\tau02[\omega]} & -\mu31\,\omega03^2 - \frac{i\,\mu31\,\omega}{\tau03[\omega]} \\ -\omega02^2 - \frac{i\,\omega}{\tau02[\omega]} & -\omega^2 + \omega02^2 + \frac{i\,\omega}{\tau02[\omega]} & 0 \\ -\omega03^2 - \frac{i\,\omega}{\tau03[\omega]} & 0 & -\omega^2 + \omega03^2 + \frac{i\,\omega}{\tau03[\omega]} \end{pmatrix}$$

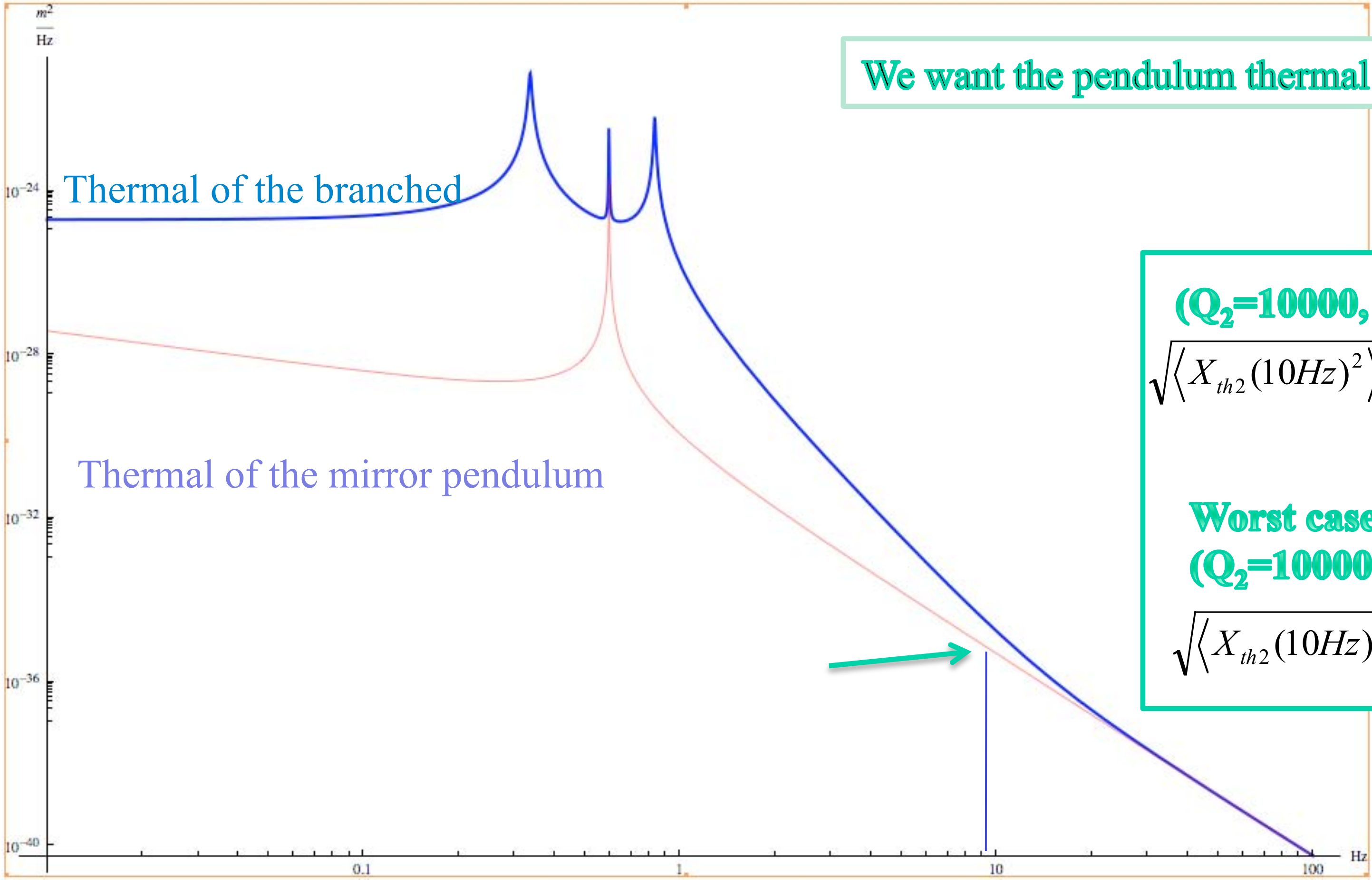
$$\mu_{21} = M_2 / M_1$$

$$\mu_{31} = M_3 / M_1$$

$$\omega_{0i}^2 = K_i / M_i$$

$$Q_{0i} = \omega_{0i}\tau_{0i} = 1,\ldots,3$$

TN of the overall suspension should be considered



We want the pendulum thermal noise at 10Hz

(Q_2=10000, Qmir viscous)

$$\sqrt{\left\langle X_{th2}(10Hz)^2\right\rangle / \left\langle X_{pendulum}(10Hz)^2\right\rangle} = 1.08$$

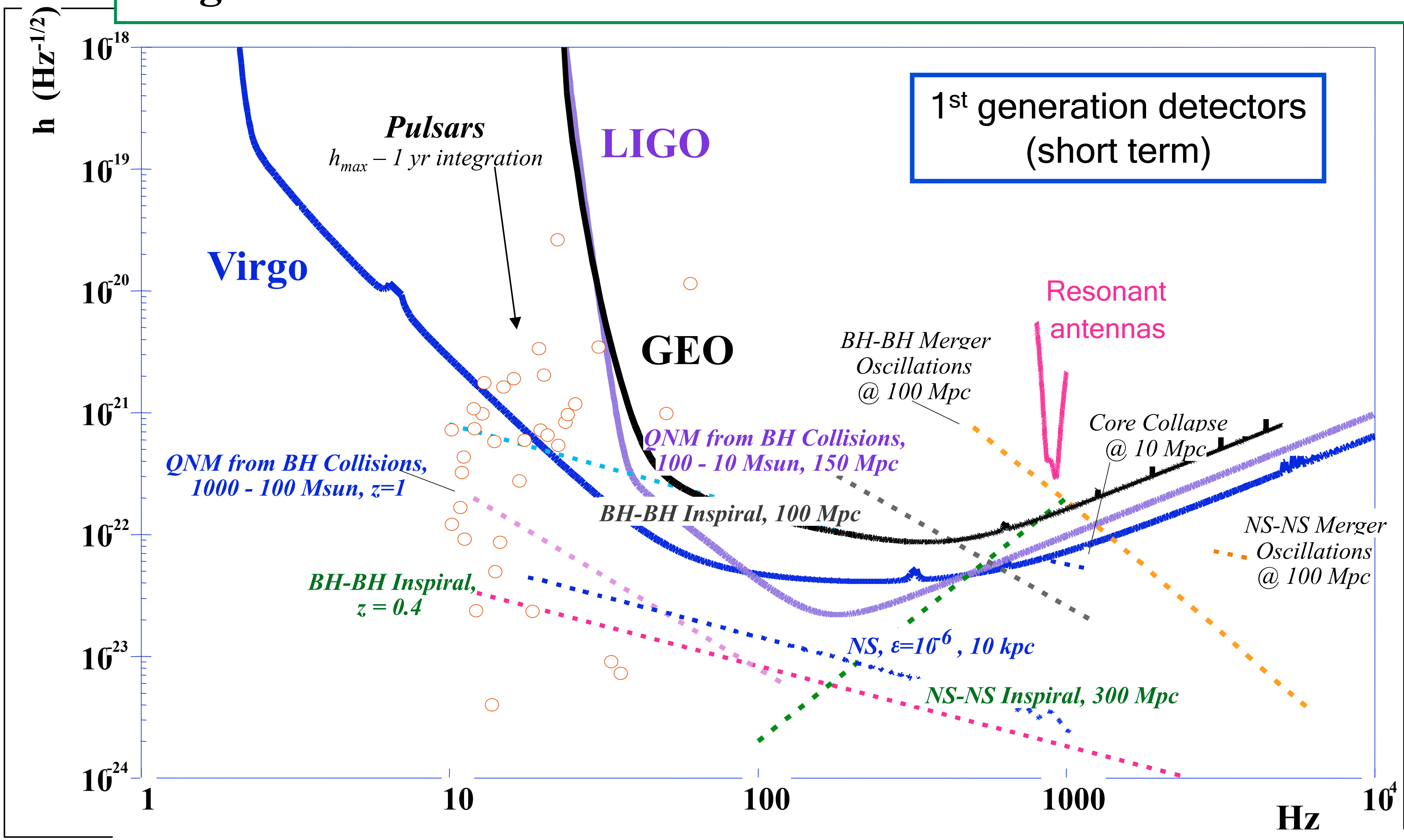
Worst case
(Q_2=10000, Qmir internal)

$$\sqrt{\left\langle X_{th2}(10Hz)^2\right\rangle / \left\langle X_{pendulum}(10Hz)^2\right\rangle} = 1.4$$

In Virgo “the payload” is the last multistage suspension system meant to control the mirror, isolated from external disturbance and subject to thermal fluctuation.

The need of advanced detectors

1st generation GW detectors sensitivities: few and rare events



Interferometric Network	NS-NS	NS-BH	BH-BH	SNe
Event Rate (per year)	$3\ 10^{-4}$ - 0.3	$4\ 10^{-4}$ - 0.5	10^{-3} - 3	0.05
Range (Mpc)	30	60	145	0.1

Advanced detectors target: few events/year

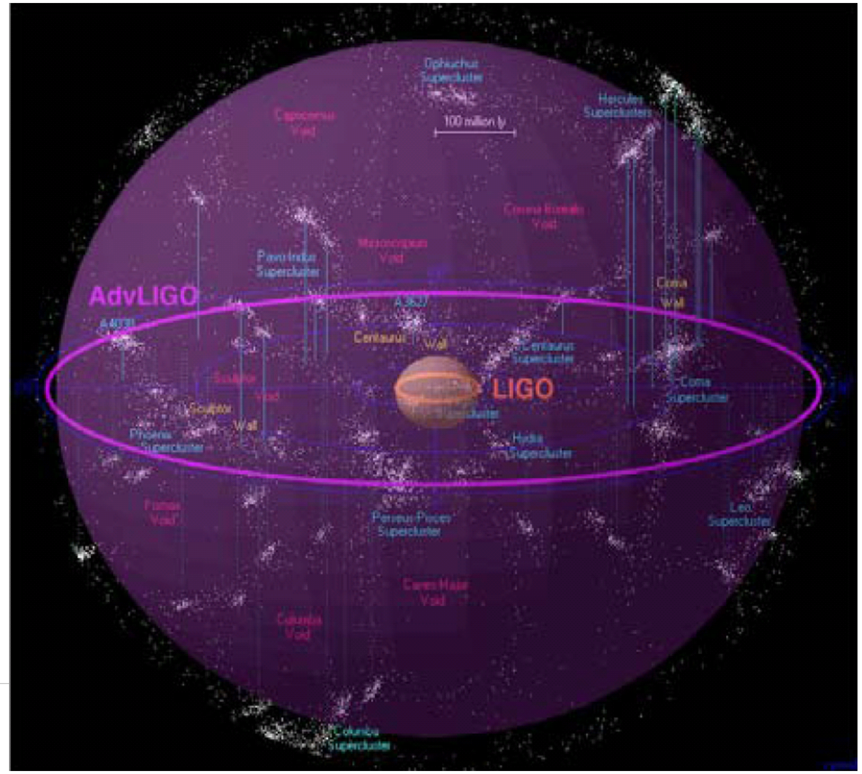
Several sensitivity improvements are possible using present infrastructures of Virgo and LIGO in two steps

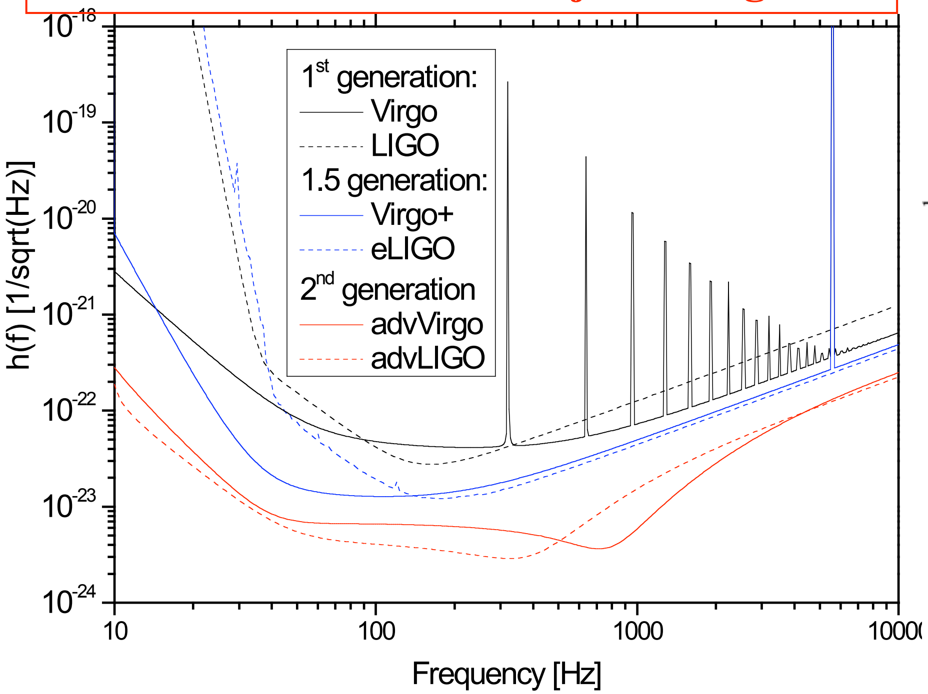
Enhanced interferometers

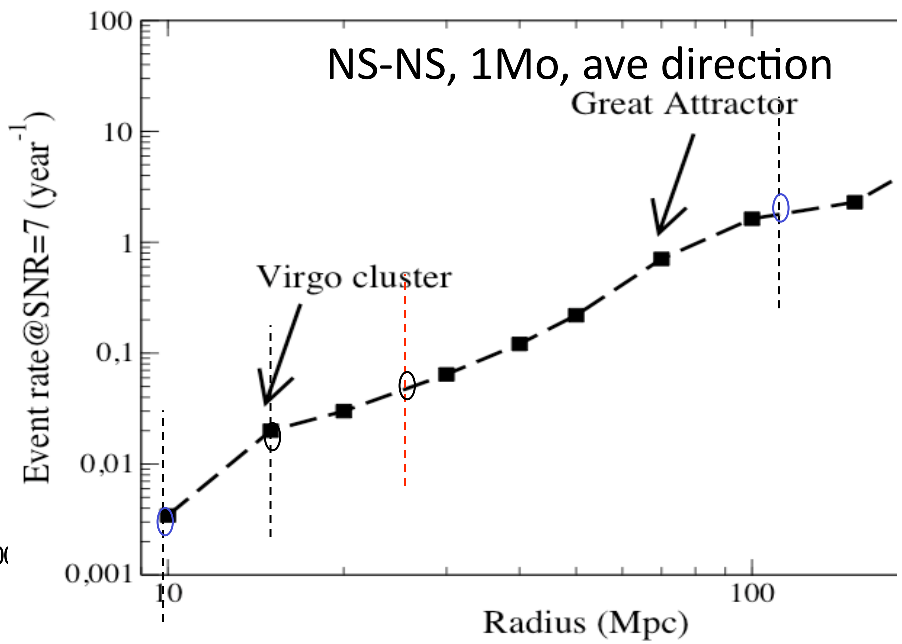
=> **no major changes**

Advanced interferometers

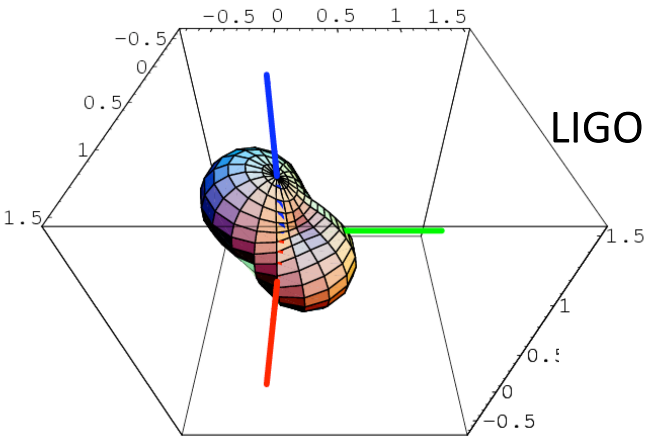
=> **major changes**



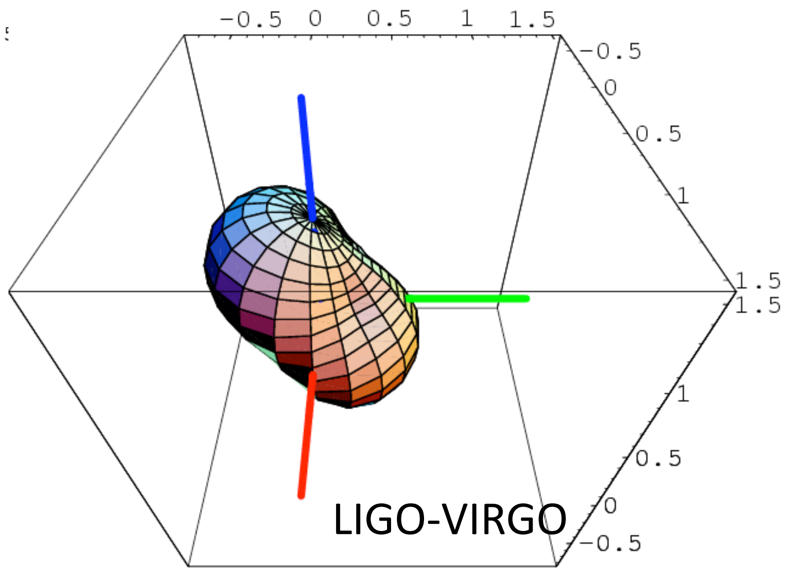


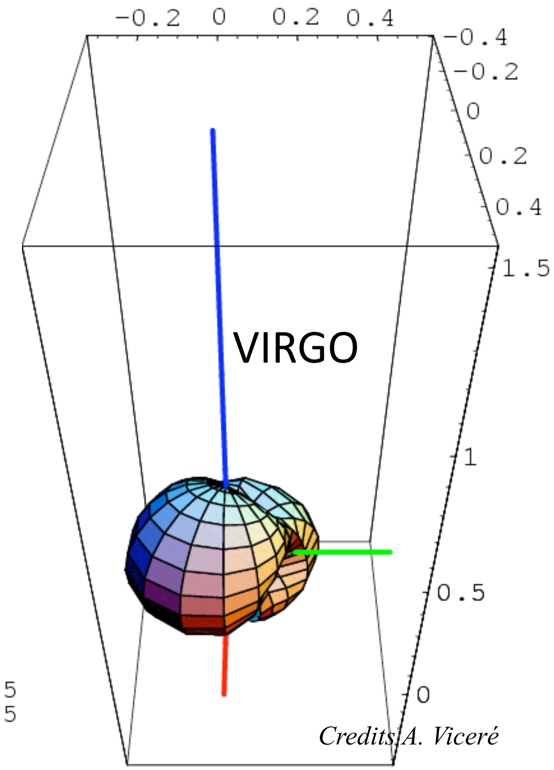


The Network of Gravitational Detectors as a Global Instrument



Network crucial for false-alarm rejection, but not only for that.





By coherent combination of LIGO-Virgo Advanced SNR=8 detection with 90% efficiency is enhanced from 150-170 (single detectors) to 270 Mpc

INFN Roadmap
A Proposal
for the Gravitational Wave Experiments

The CSN2 GW Working Group:
M. Bonaldi (Auriga, DUAL), S.Braccini (CSN2), R.Dolesi (LISA), V. Fafone (ROG, SFERA), M. Punturo (Virgo), P. Rapagnani (CSN2, Convener)

Contents:

1 Next future evolution strategy 2
1.1 The Extended Network of Detectors as an Instrument for Discovery and Astronomy 2
1.2 The Near Term Evolution (2006 – 2007) 3
1.3 The Medium Term (2008 – 2011) 5
1.4 The Long Term (2012 – 2018) 7
1.5 The Future: Beyond 2018 ....
2 Summary

2006 – 2007: Near Term Network
2008 – 2012: Medium Term Network
2012 – 2018: Long Term Network

Limited resources => focusing needed
I Actual status analysis
II Perspective
III Cost analysis

EM-INFNRM1-060509

The intermediate step

Virgo ⟹ Virgo+ ⟹ AdvVirgo

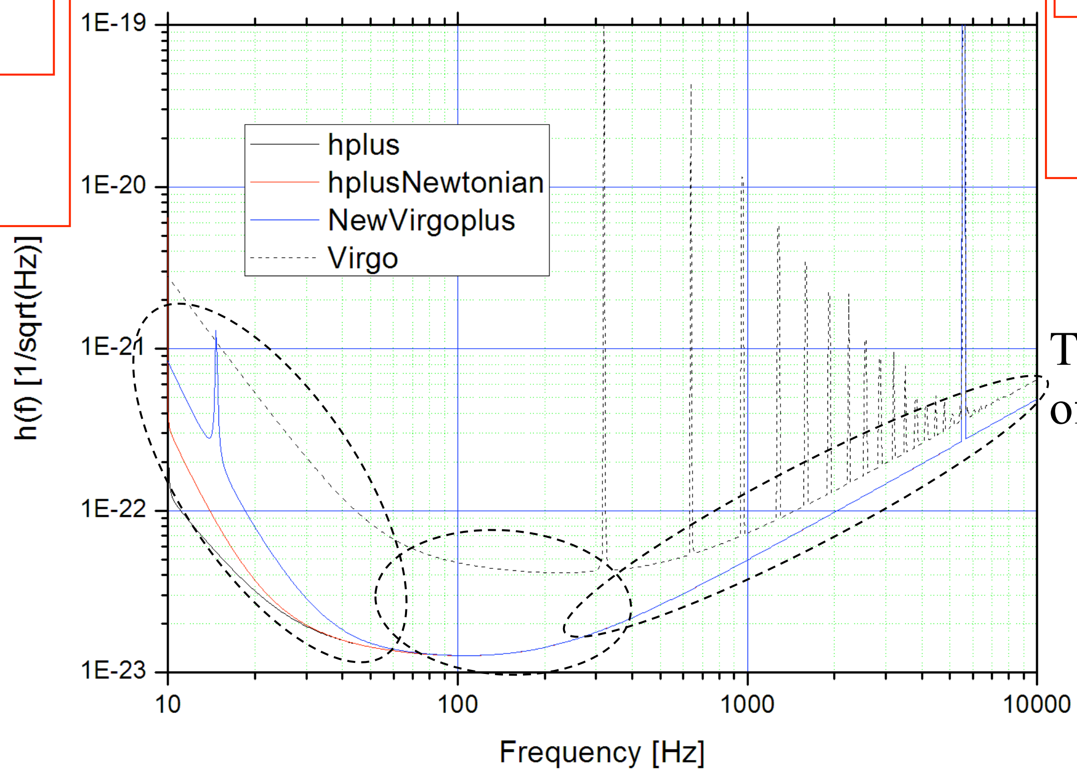
Practical issues and commissioning

Virgo+, first step towards Vadv: main improvements (many others underlaying)

Monolithic suspension (marionette-mirror)

new mirrors (Hi-Q)

Dedicated R&D to validate new test-mass payload (done!)



Powered injection

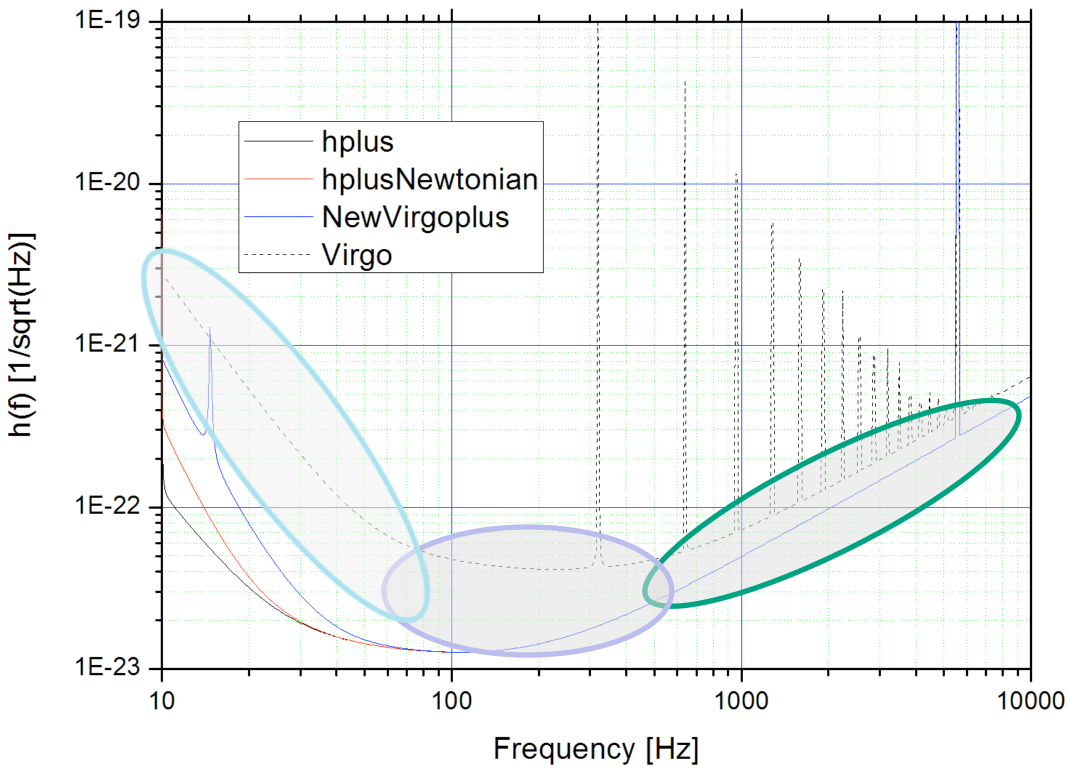
new mirrors (Hi-Finesse)

Thermal deformation of FP cavity mirrors

Thermal Compensation System needed

Schedule: Virgo+ with monolithic suspension in 2010

Virgo+, first step towards Vadv: main improvements (many others underlaying)



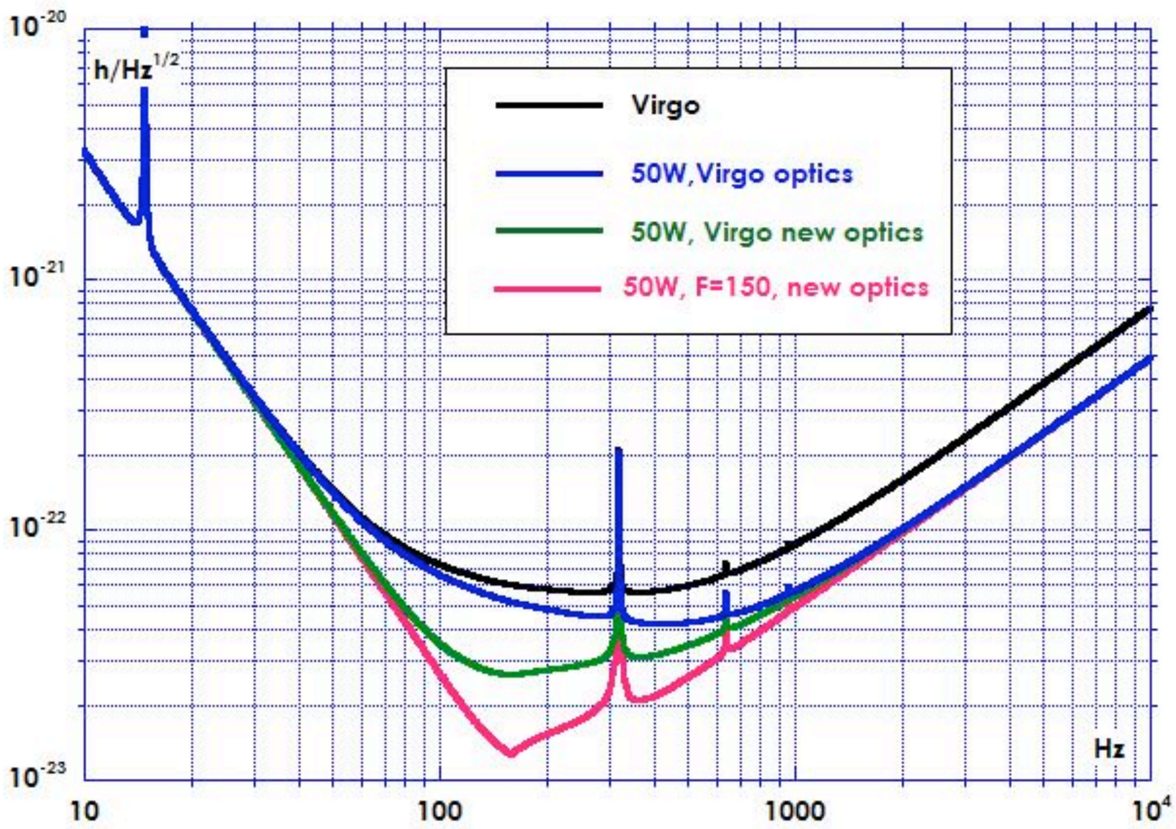
suspension thermal noise (monolithic)	Mirrror thermal noise (new mirrors)	Higher power (Powered Injection System+TCS)

New mirrors and coatings

- New Suprasil end and input mirrors
  - According to the Penn's noise model the loss angle expected for this material is about 10^{-9}, a new perspective is open in the middle frequency range;
  - But an higher finesse is needed: F=150 instead of the current 50.

- New coatings (TiO2 dopants: lower mechanical dissipation)
- New cleanliness procedures
  - Use of a special protecting film (Lyon);

Virgo, 50W, F=150
BNS: 24.7 Mpc
BBH: 126 Mpc



The evolution of the Virgo collaboration towards Advanced-Virgo project

New groups joined the collaboration

INFN

- Firenze/Un.Urbino
- Genoa
- Napoli/Un. Federico II
- Perugia/Un. Perugia
- Pisa/Un. Pisa
- Roma/Un. Sapienza
- Roma 2/Un. Tor Vergata
- Padova/ Un. Trento

- EGO Physics group

CNRS

- APC – Paris
- ESPCI – Paris
- LMA – Lyon
- LAL – Orsay
- LAPP – Annecy
- OCA – Nice
- NIKHEF –Amsterdam
- POLGRAV – Warsaw (Polish Ac. Sci.)
- RMKI (Hungarian Ac. Sci. Budapest
- Birmingham Un. –UK (MOU GEO-VIRGO)

The collaboration is fully engaged in Virgo upgrades (V+) and Advanced Virgo project

Virgo ⟶ Virgo+: milestones

May ‘07 – Oct ’07 VSR1, First Virgo Science Run

Oct ’07 – May ’08 Commissioning

- scattered light mitigation, output Brewster window replaced by LN_2 cryotrap;
- ThermalCompensation (TCS) installation. Actuator magnets reduction.

9 May 2008 viewport breakdown at terminal NorthEnd !!!

May - Oct ’08 Recovery & Virgo+ scheduled shutdown

- injection system infrastructure and electronics upgrade;
- NE payload dismount/mirror substitution;
- viewport breakdown investigation and replacement of all critical viewports;

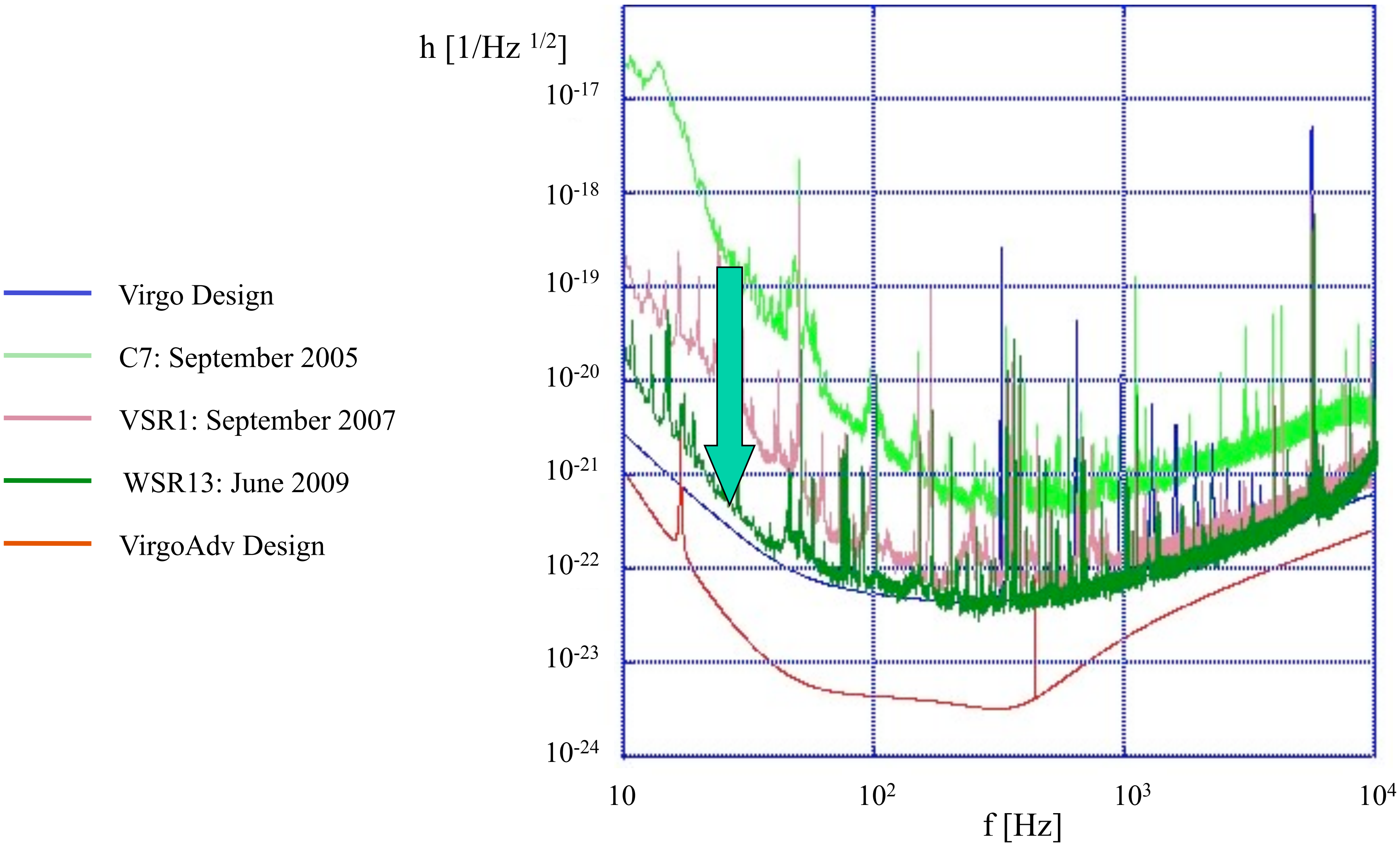
Oct ’08 - now commissioning

- electronics upgrade;
- power enhancement and TCS operation;
- viewport breakdown investigation and replacement of all critical viewports;
- baffle breakdown during misalignment with higher power.

7 July ‘09 VSR2, start of second Virgo Science Run

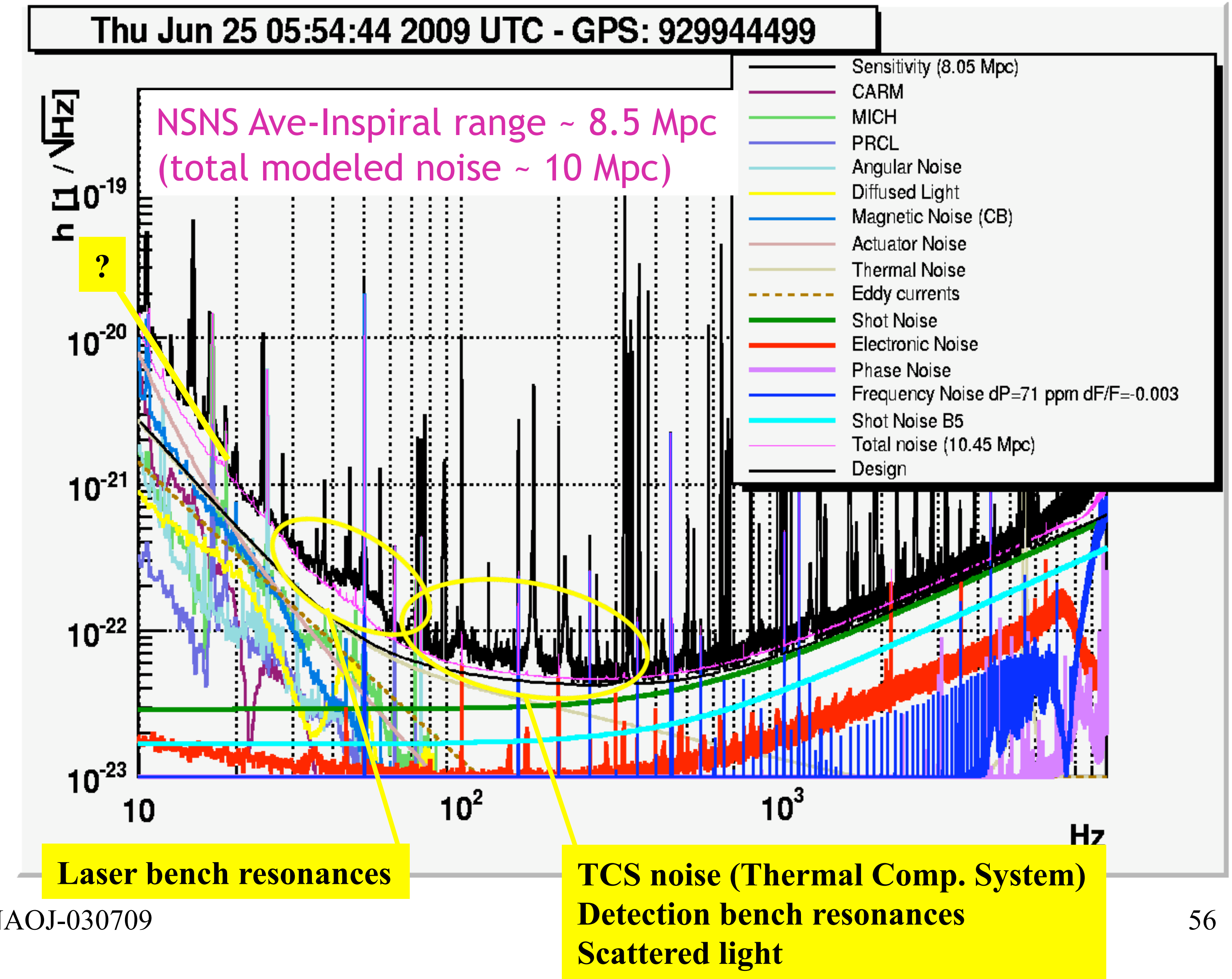
Beginning if 2010 Monolithic Suspension upgrade.

Sensitivity improvements during commissioning and scientific runs

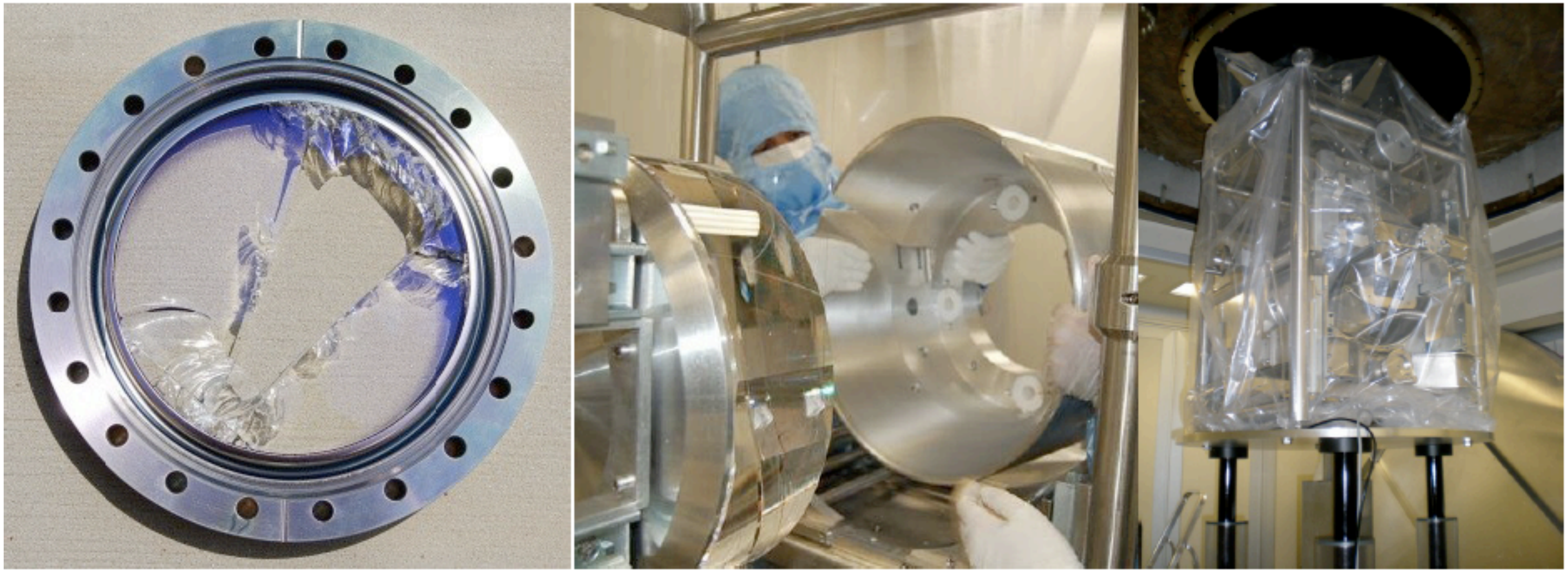


Background activity: four years spent to prepare preliminary Advanced Virgo design

Present staus of noise hunting: few ununderstood noise sources



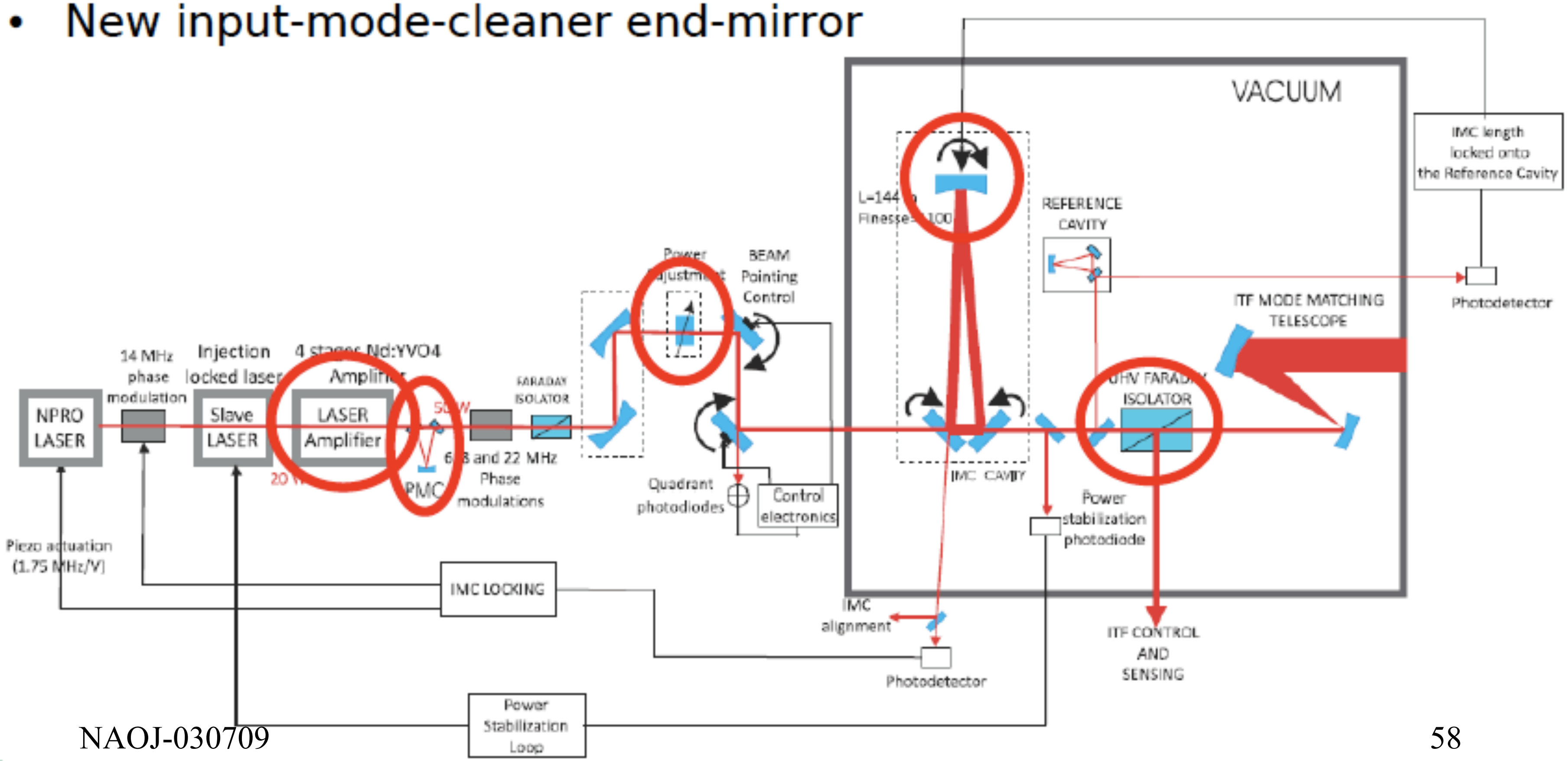
After-accident recovery



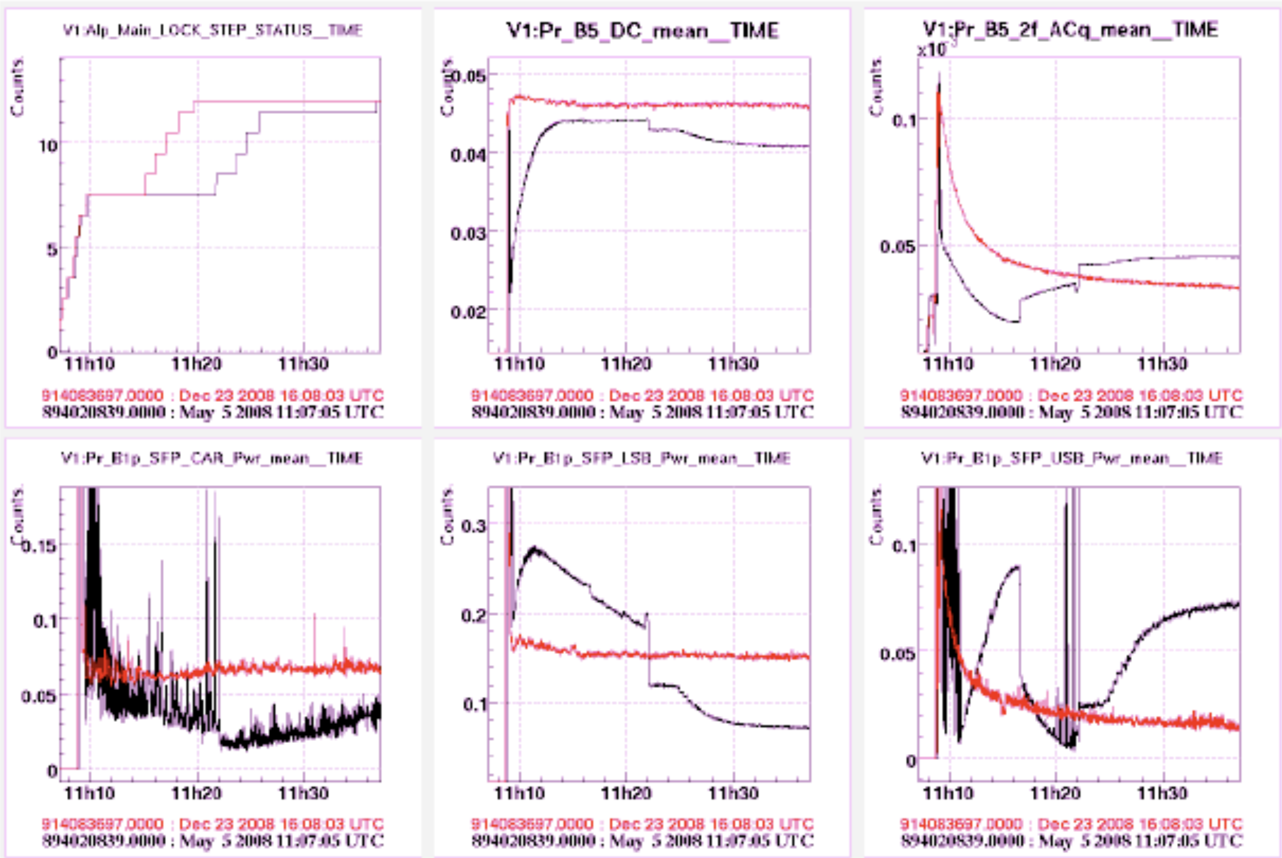
- Caused by weak design of viewport, identified and tested safer model
- Replaced about 90 view-ports throughout whole interferometer
- Cleaned and tested North-End tower
- New payload at North-End: coating of already polished spare mirror

New injection system

- New laser amplifier: up to 60 W (25 W at interferometer input)
- New pre-mode-cleaner
- Remotely tunable in-vacuum Faraday Isolator
- New input-mode-cleaner end-mirror

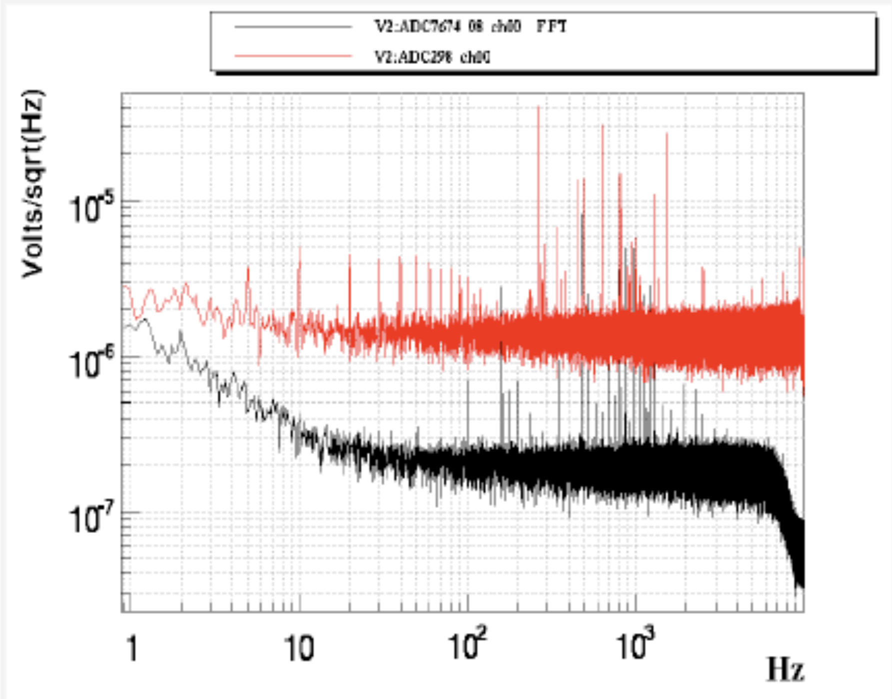


Stable locking signals



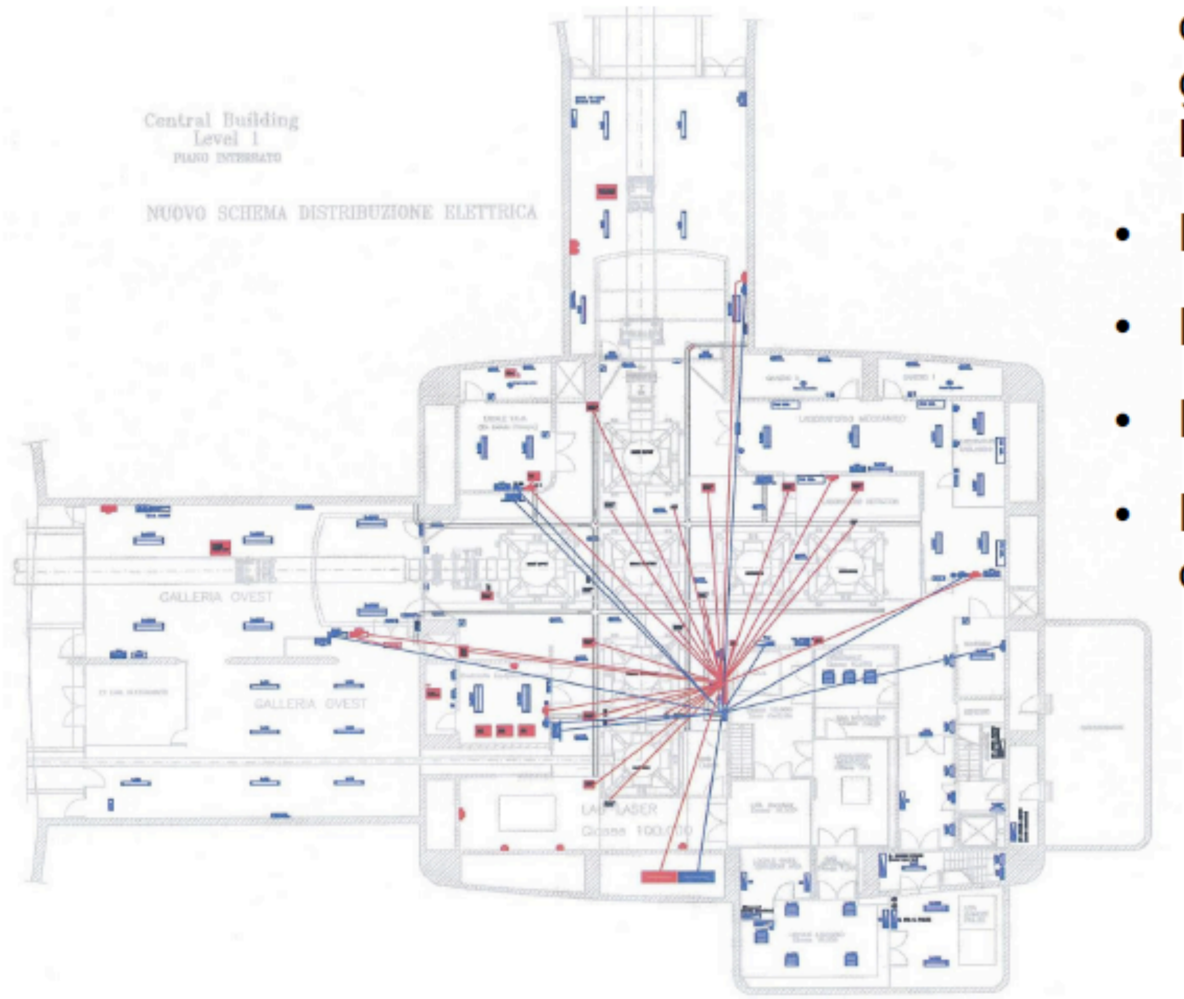
- Interferometer no longer shows bi-stability during lock acquisition
- Different working point: modulation frequency changed 700 Hz
- Maybe caused by slightly different radius of curvature of new mirror

New electronics for Virgo+



- Replaced old real-time fiber links, more flexible signal routing
- Replaced old RIOs by real-time PC
- New ADCs: from 16 to 18 bit
- New quadrants and electronics for alignment

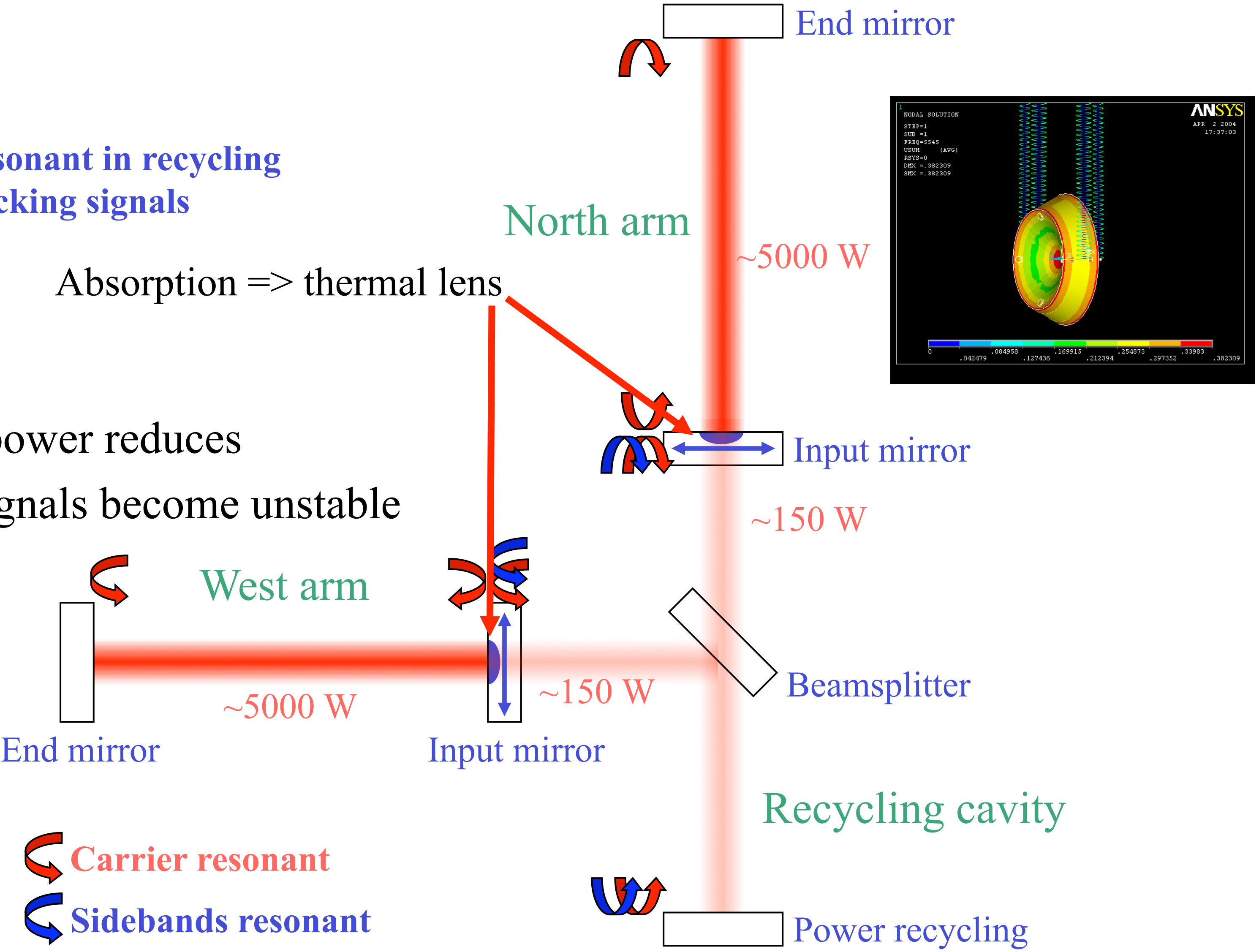
E.m. Environmental cleaning



- Replaced complete wiring of main power and grounding in central building
- Hot water pipes
- Replaced and doubled UPS
- Replaced 15 kV transformer
- Lowered air-speed of air-conditioning

Virgo with 7W input laser power (Virgo+ > 20W)

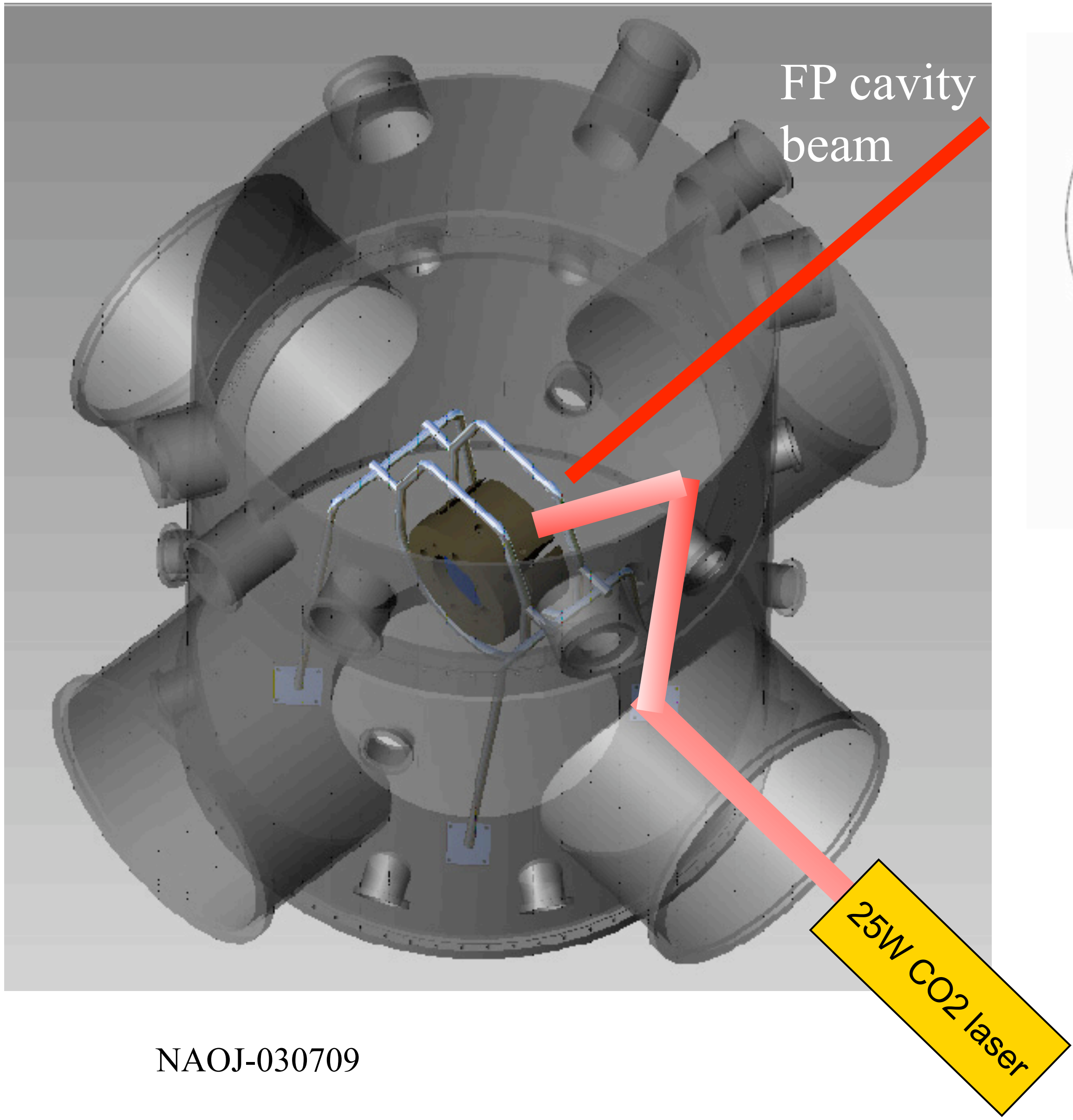
Sidebands resonant in recycling cavity give locking signals

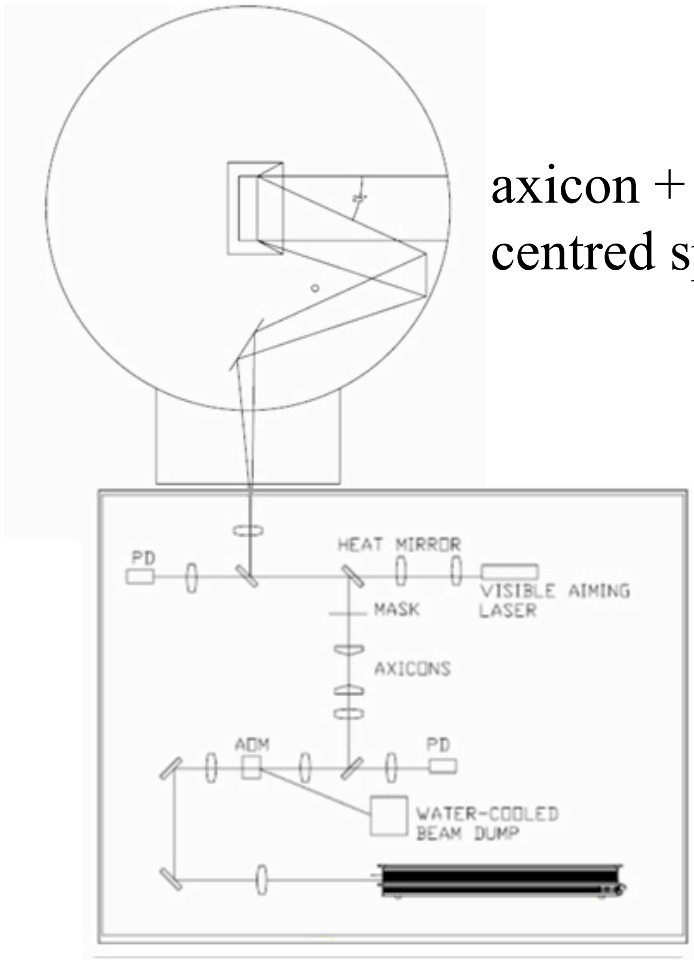


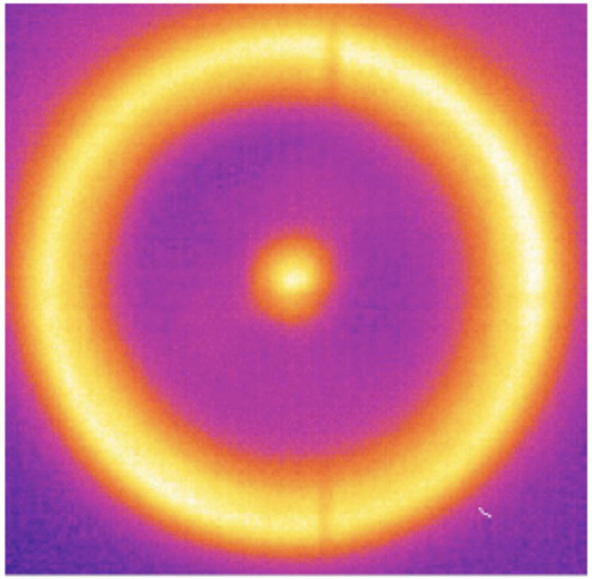
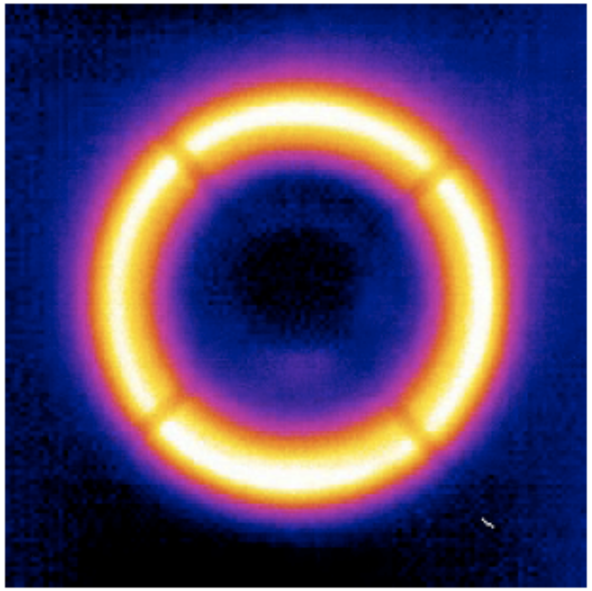
→ Sideband power reduces

→ Locking signals become unstable

Thermal Compensation Scheme (concept)





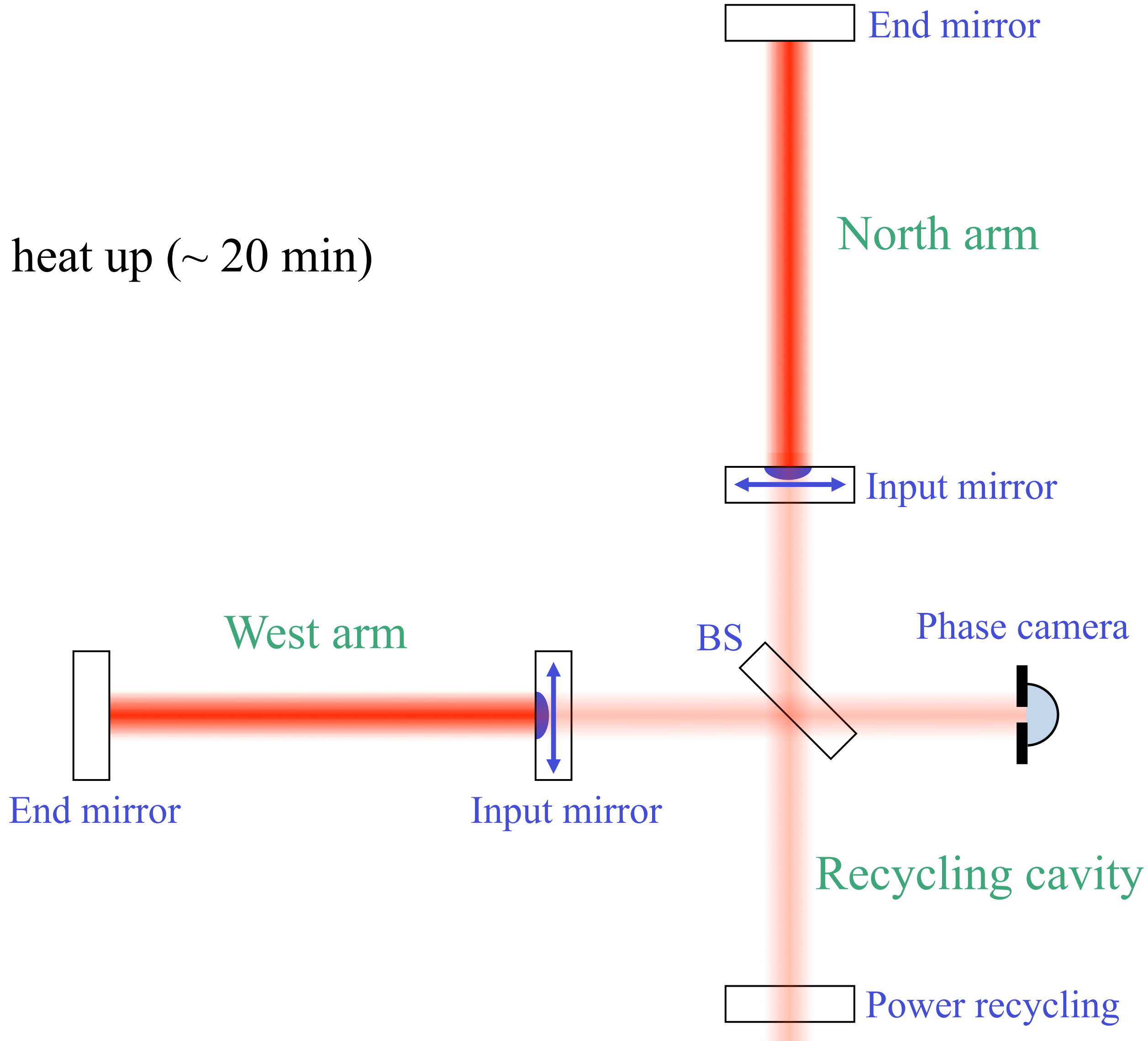



- Annulus and central spot from CO2 laser on both input mirrors
- Essential for compensating thermal lensing in input mirrors when working with high input powers
- Not yet stabilized in amplitude, some evidence for introduced noise

Finding the right TCS alignment & powers not easy;
→ Time constants very long (~ 2 hrs) making adjustments time consuming
→ Signals limited for understanding sideband behavior

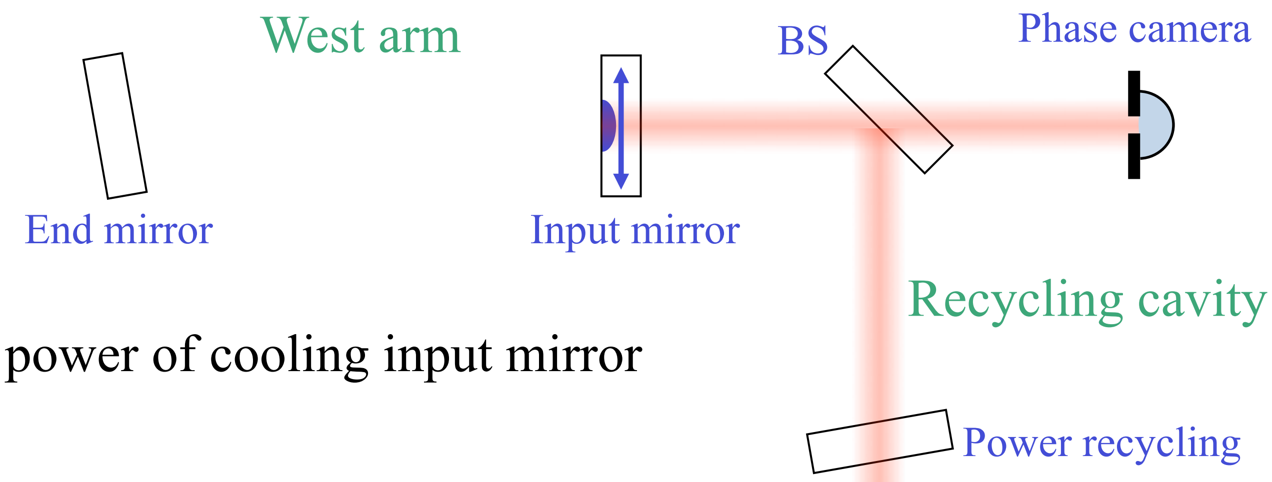
Phase camera is a high precision wavefront sensor used measure individual fields (carrier and sidebands) deformed by thermal effects.

- Lock the interferometer
- Wait for input mirrors to heat up (~ 20 min)



Phase camera is a high precision wavefront sensor used measure individual fields (carrier and sidebands) deformed by thermal effects.

- Lock the interferometer
- Wait for input mirrors to heat up (~ 20 min)
- Misalign everything except BS and input mirror to measure
- Input mirror cools down
  → Measure wavefront of beam using phase camera
  → Change in wavefront corresponds cooling input mirror

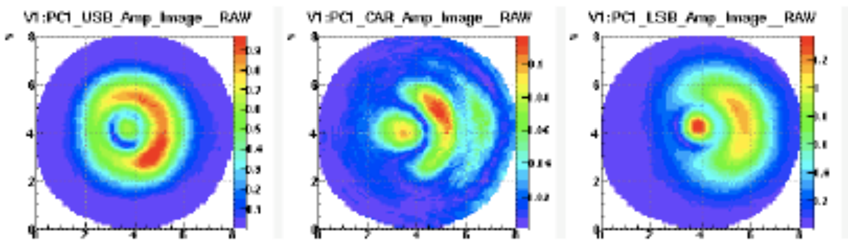


- Calculate effective lens power of cooling input mirror

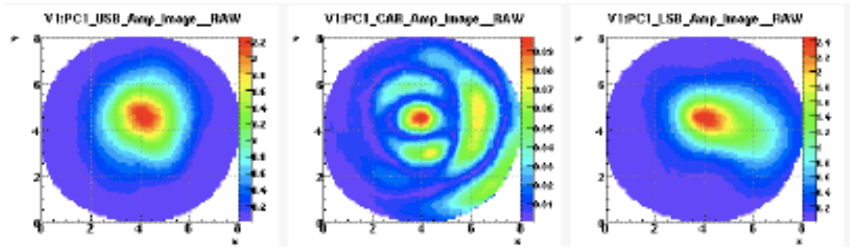
Thermal effect monitor & control

Thermal compensation power studied by using field amplitudes measured by Phase Camera

→ "seed values" found in order to balance and make symmetric wavefront profiles.



without TCS

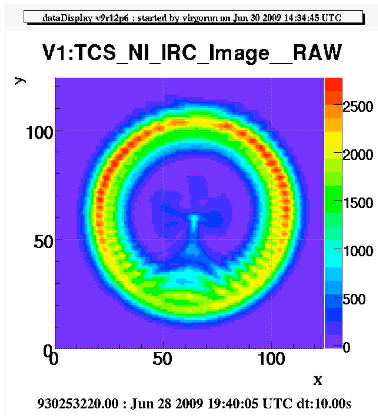


with TCS

17 W actual injection (Virgo+) equivalent to 8 W injection

→ Slow drift control of TCS power implemented to stabilize sideband amplitudes

Note: critical TCS noise (high) and
TCS set point parameters (stability/environmental)



NAOJ-030709

VSR2 parallel activities

Virgo ⇛ Virgo+ ⇛ AdvVirgo

Focus on monolithic suspension

The suspension thermal noise *is* reduced with the FS suspensions

In the low frequency range, the mirror pendulum thermal noise plays an important role

$$\Phi_{wire} = \Phi_o + \Phi_{th}(\nu) + \Phi_e$$

Thanks to the lower mechanical dissipation of the fused silica, a monolithic suspension promises an excellent performance by reducing all Φ_{wire} components.

Thermoelastic Loss Angle

$$\Phi_{th}(\omega) = \Delta \frac{\omega\tau}{1+(\omega\tau)^2}$$

$$\Delta = \frac{Y_{FS}\alpha_{FS}^2 T}{\rho_{FS} c_{FS}}$$

$$\tau = \frac{c_{FS} d_w^2}{2.16 \cdot 2\pi \cdot k_{FS}}$$

d_w wire diameter

$\Phi_o = 4.1 \cdot 10^{-10}$ loss angle

Y_{FS} Young modulus

α_{FS} thermal expansion

c_{FS} specific heat

ρ_{FS} density

Cagnoli G and Willems P A Phys. Rev. B, 65, 17

Φ_e **Eccess loss angle**

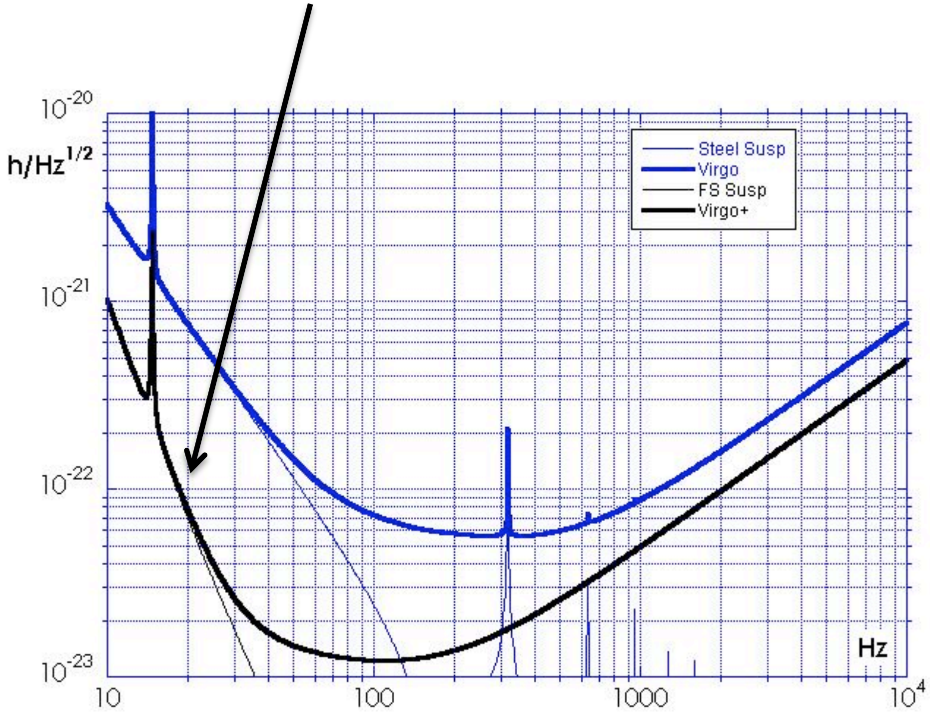
Frictional losses in the marionetta-wire clamps

Frictional losses in the mirror-wire clamps

Surface losses

$$\phi_{surf} = \phi_{FS}\left(\xi \frac{d_s}{V/S}\right) \approx 2 \times 10^{-7}$$

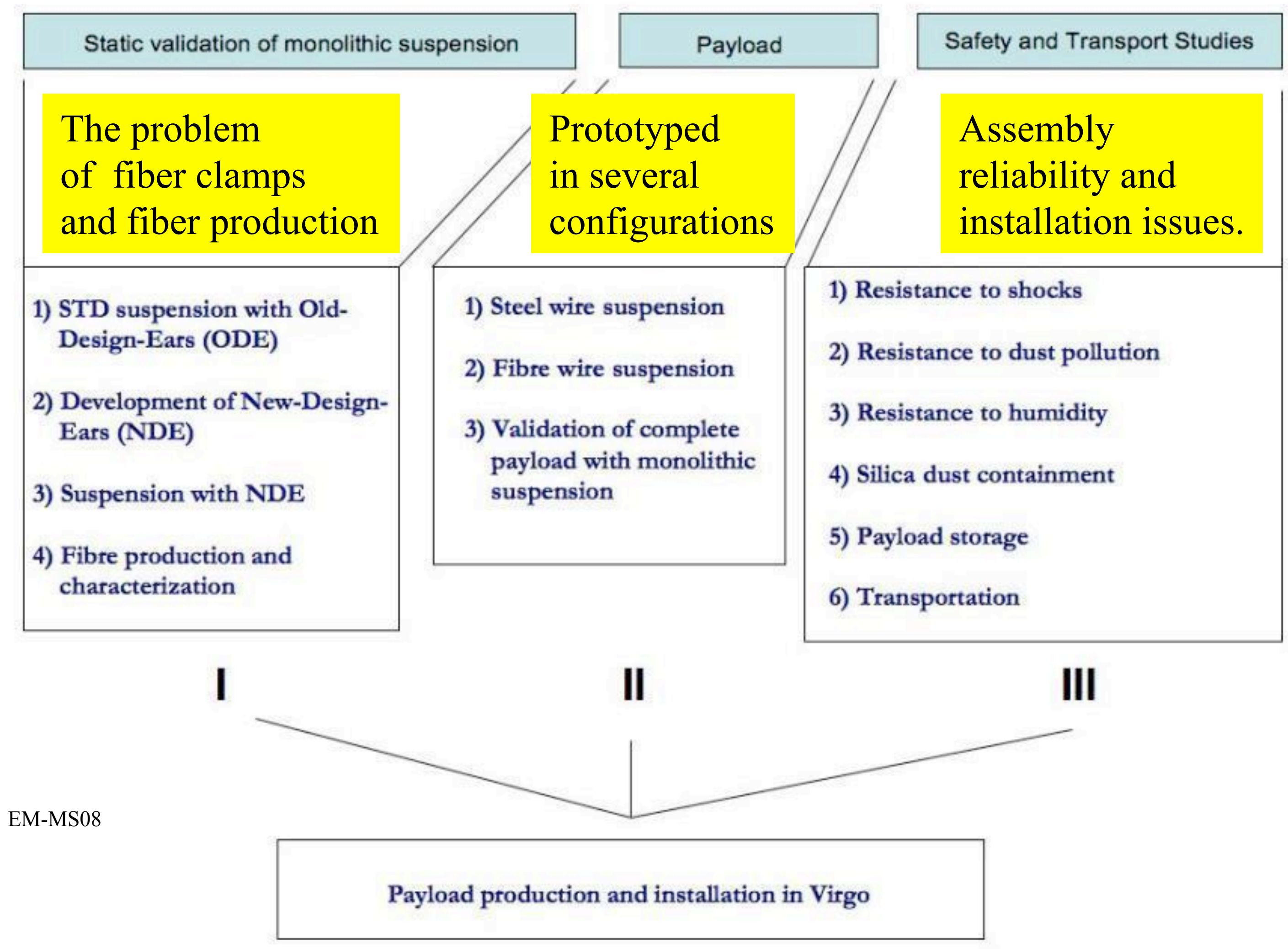
A.M. Gretarsson et al, PLA 270 (2000), 108-114



Virgo+ average sight
BNS: 53.6 Mpc
BBH: 284 Mpc

A new payload with mirror monolithic mirror suspension

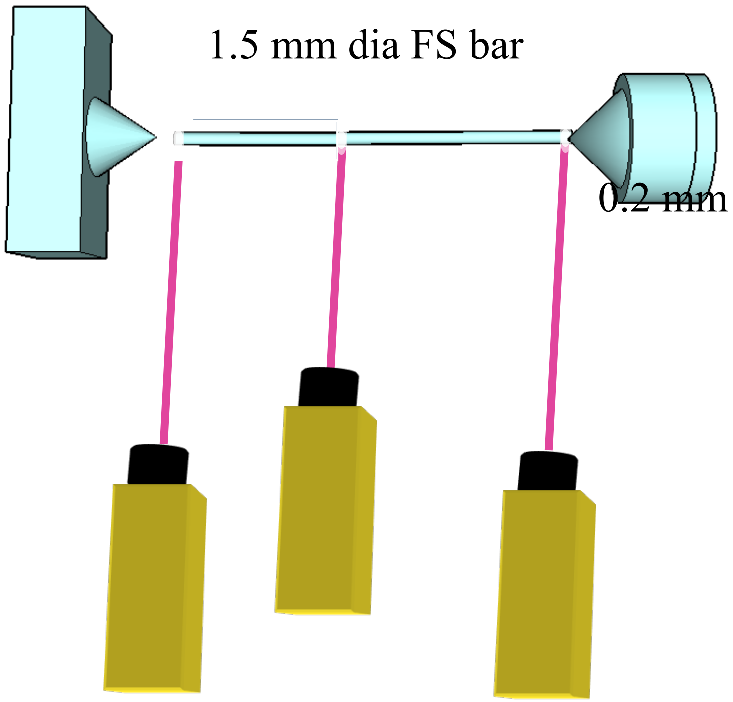
Virgo+ payload will be an evolution of standard Virgo payload embedding several “small” changes.
In January 2008 we needed a development speed-up to converge in an actual installation project.
=> 3 main tasks

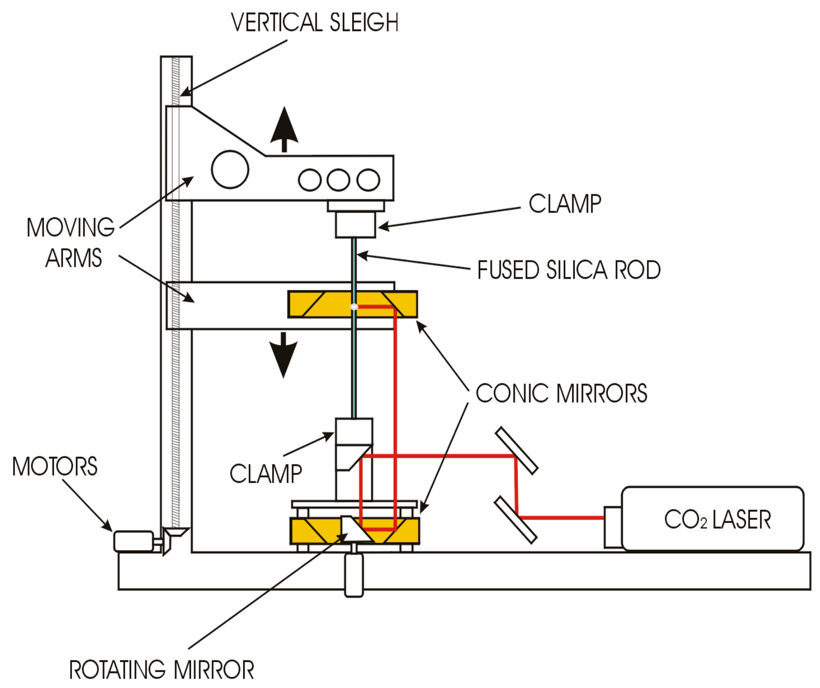


TASK I

Clamped-fibre production

- Precision and reproducible welding performed **before** the payload assembling
- Fused silica annealing
- Controlled pulling



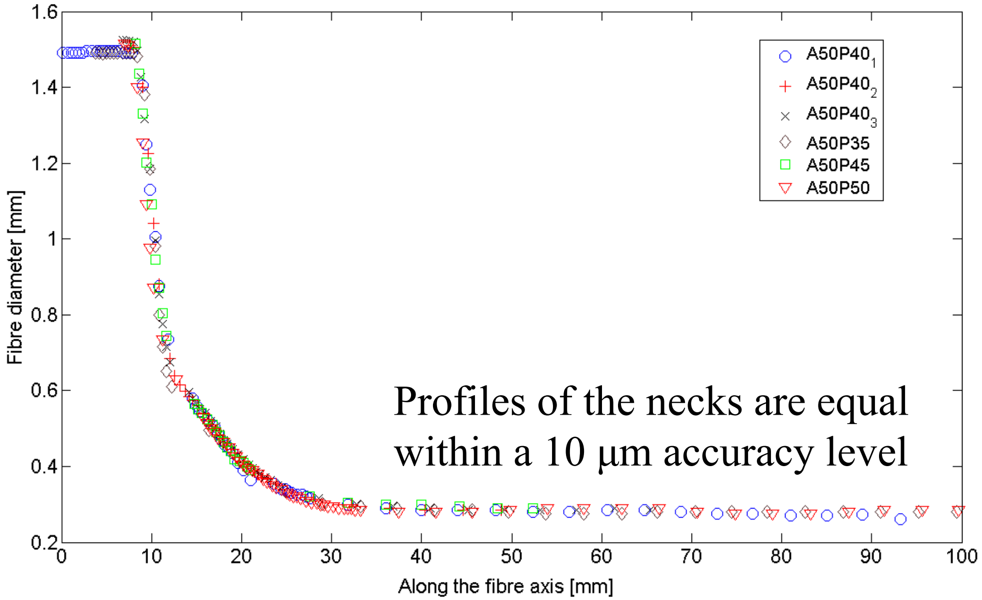


100 W CO2 laser pulling machine provided by the Glasgow group and re-adapted at the Virgo site.

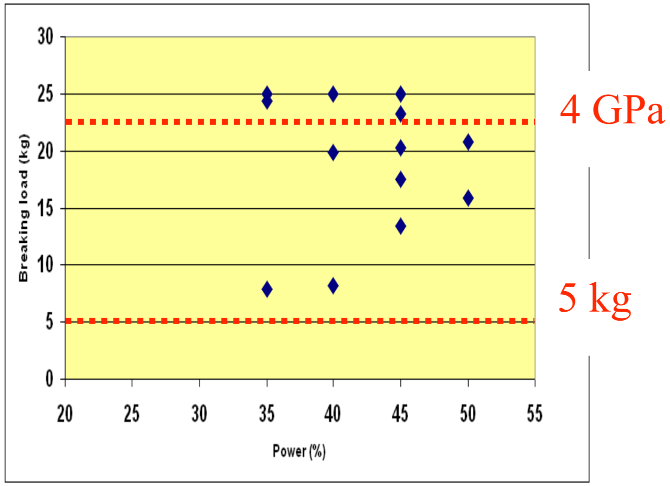
TASK I

Production Accuracy

profiles



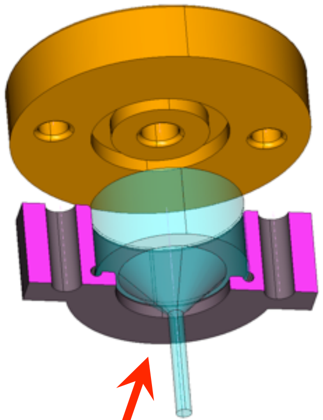
dynamical



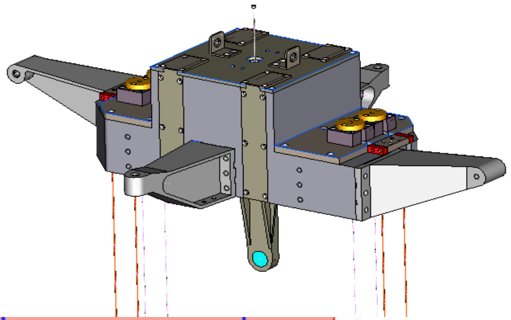
Violin mode	Bouncing Mode (Hz)	Distance between bend. Points (mm)
453±1	6.0±0.1	669.5±0.2
453±1	6.0±0.1	669.8±0.2
452±1	6.0±0.1	670.2±0.2
451±1	6.0±0.1	669.6±0.2
450±1	6.0±0.1	669.6±0.2

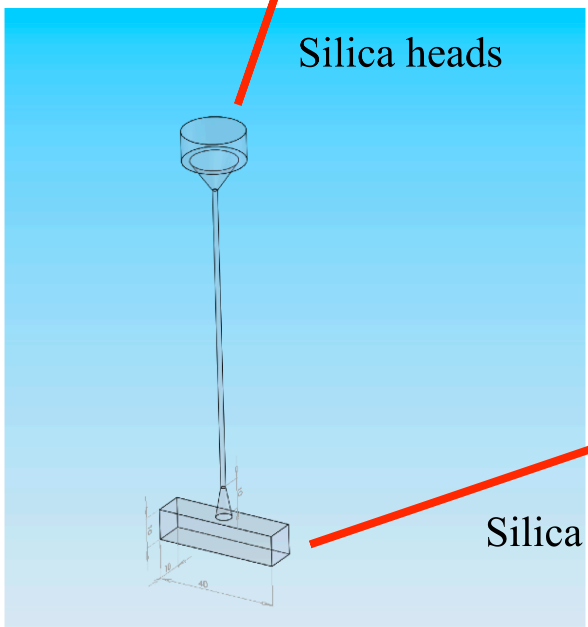
TASK I

The assembly

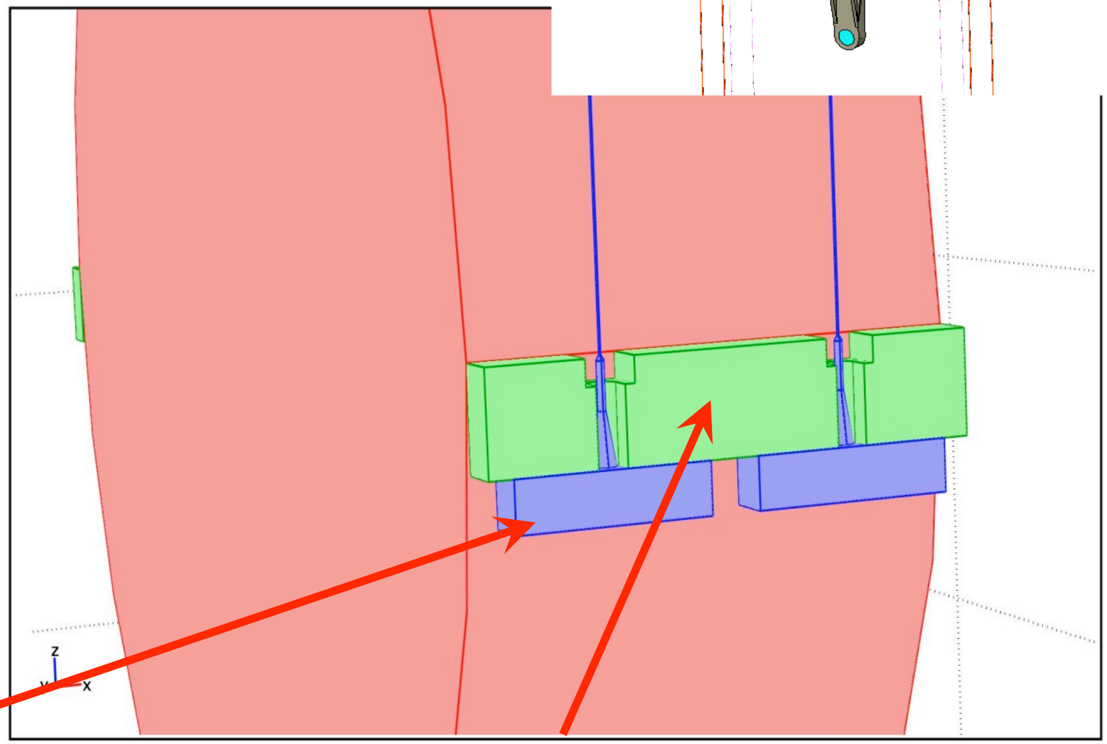


Clamp on the marionette





Silica heads

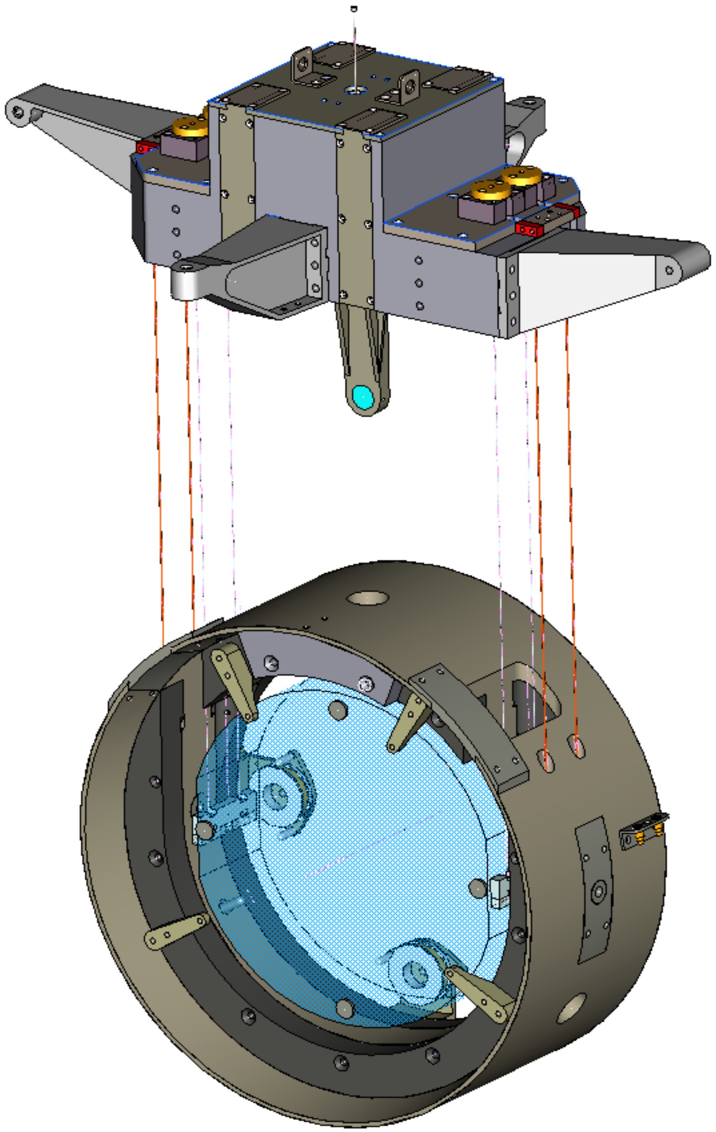


Silica ears bonded to the mirror flats

Silica anchors

TASK II

V+ payload



Marionette (110 kg):

• amagnetic steel AISI 316L, dielectric arms (peek)→ no eddy current and magnetization effects;

• designed to be fully compatible with the monolithic suspensions assembly;

• equipped with mirror for LC purposes;

• step motor to displace a balancing weight;

Recoil Mass (60 kg):

• amagnetic steel AISI 316L outer cylindric mass (500 mm diam);

• dielectric inner ring (peek CF30) → no stray currents or magnetization effects

• it carries four coils for e.m. actuation on magnets attached the mirror rear side;

• suspended with steel C85 wires (0.6 mm diam.)

• option: it can carry the markers for the LC purposes

• equipped with safety stop (peek made)

Mirror (21 kg):

• FS with lateral flats (350 mm diam), silica ears attached with silicate bonding

• suspended with silica wires (285 μm diam)

• magnets attached on rear side

• option: markers attached on front side (LC)

TASK II

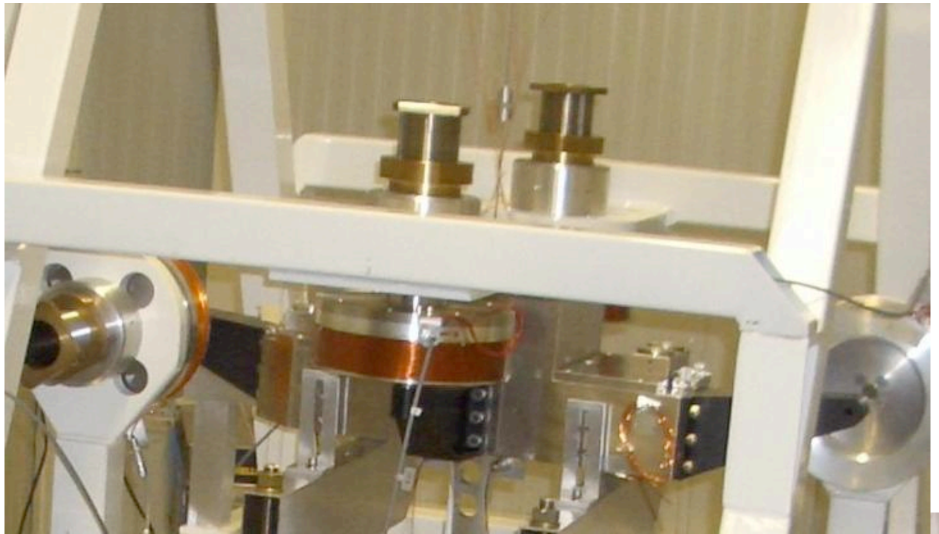
Payload prototyping

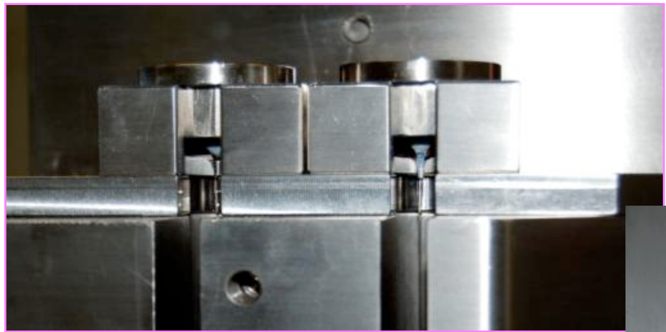
- **Steel AISI304 Marionette prototype with PVC arms.**

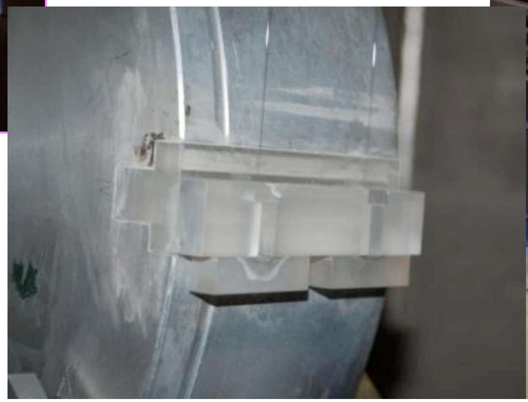
- **Dummy reaction mass, coils with peek supports.**

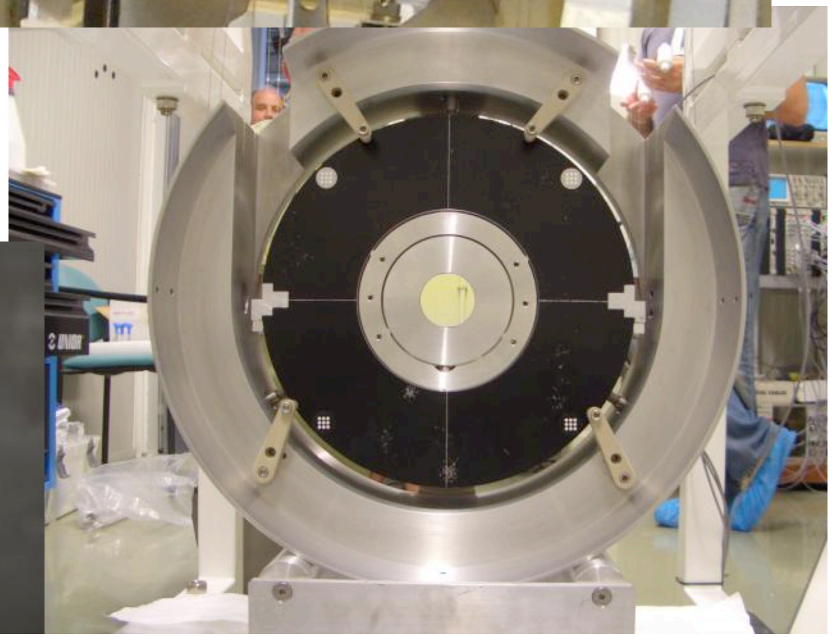
- **A mirror is inserted in the holder, and the system is balanced.**

- **All the pieces are secured by safety structures fibers bending point placed on the marionette's center of mass.**

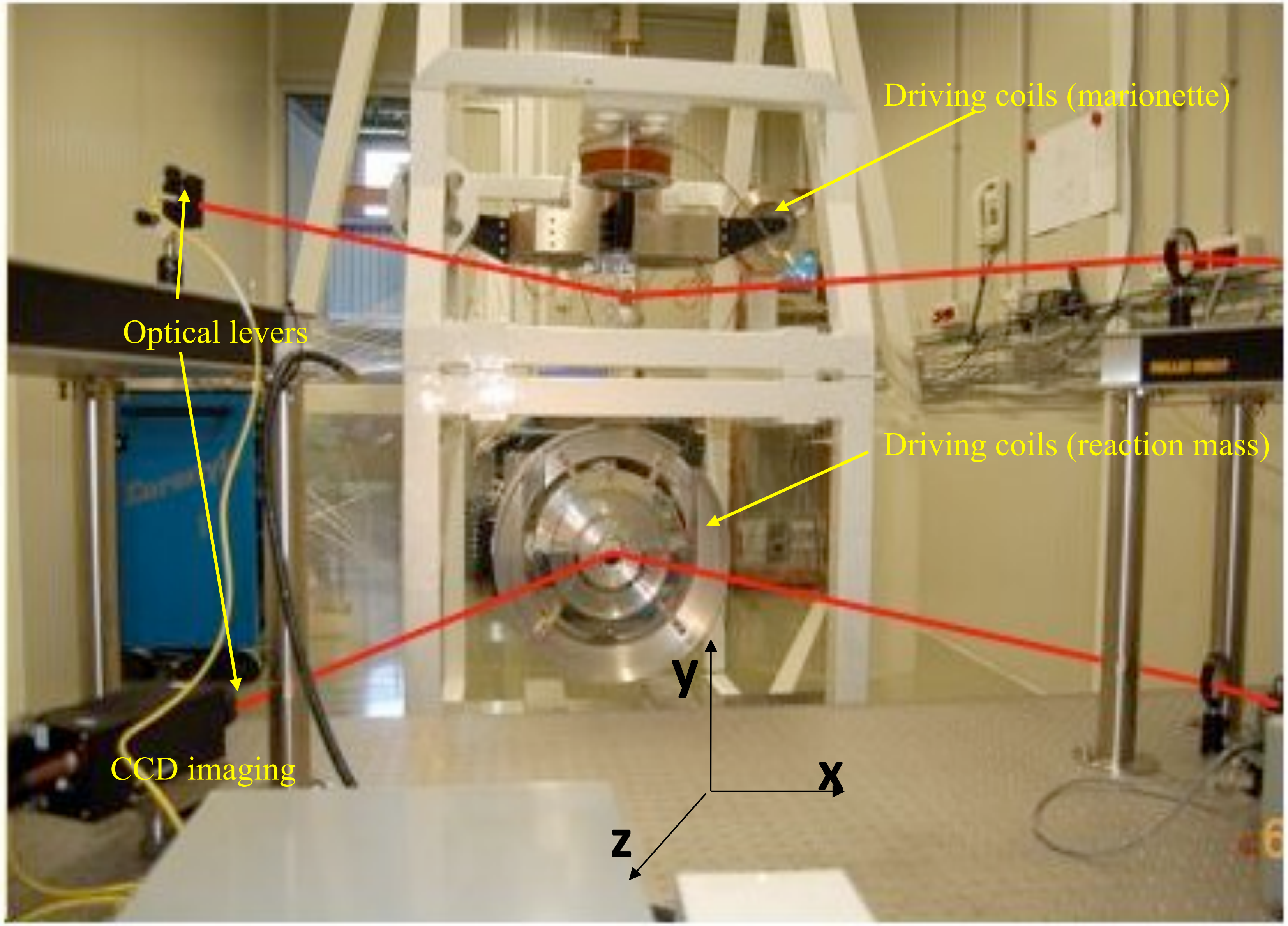








TASK II

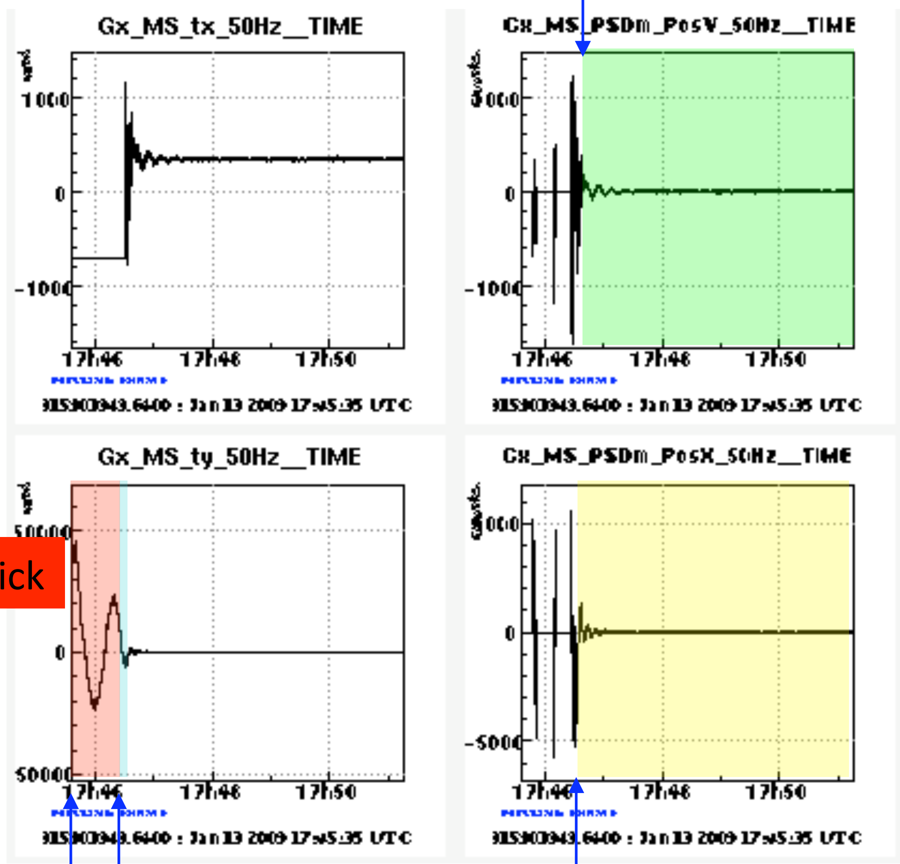

Driving coils (marionette)
Optical levers
Driving coils (reaction mass)
CCD imaging
y
x
z

TASK II

"Open air" laboratory...: Local Control with monolithic suspension

3b: optical lever tx mario =>mario act

5: optical lever tx mirror =>RM act

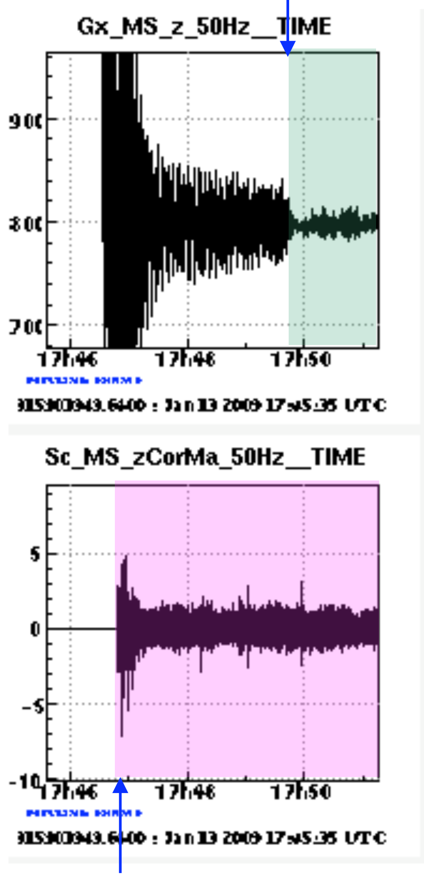


environmentally sustained oscillation (5 mrads)

- 8 error signal used, 7 loops activated (5 in this plot + tx ty RM dampers)

- damper from both ground => mario and RM => mirror

- few microrads tx,ty rms accuracy at regime



4: optical lever z mirror =>mario act

3a: optical lever ty mario =>mario act

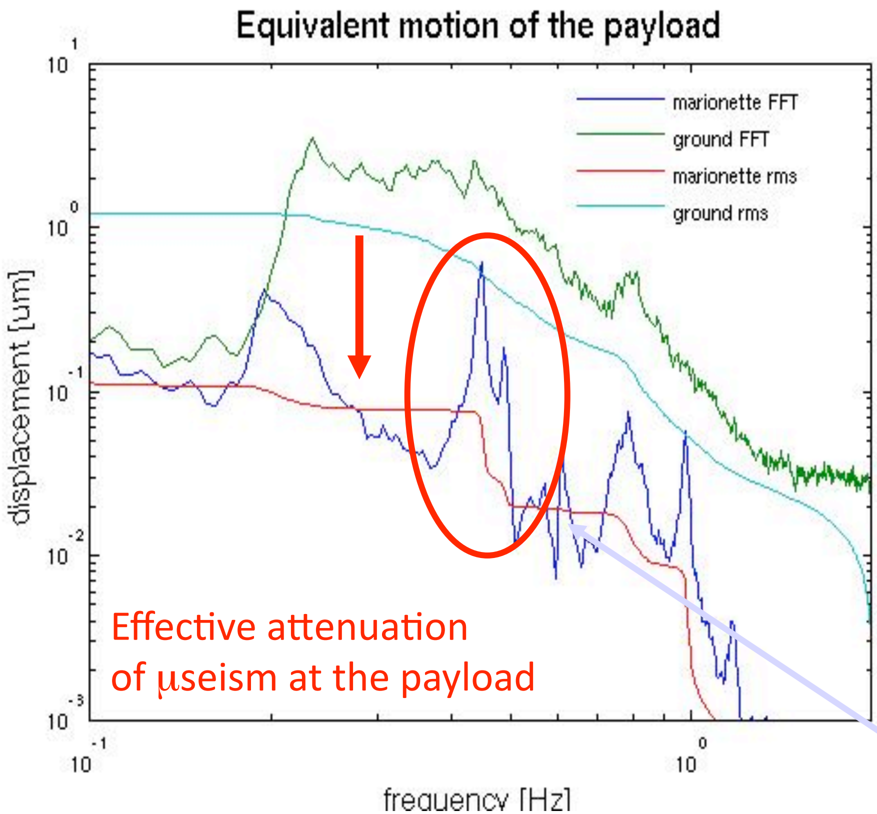
2 : optical lever ty mirror =>mario act

1: coarse ty mirror =>mario act

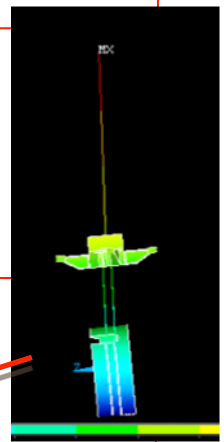
TASK II

Virgo commissioning experience must be embedded in new payload design

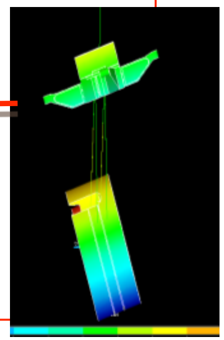
microseism due to sea activity is often active in the range 0.2-0.6 Hz



Thanks to IP inertial damping and suspension performance the lock force applied to the marionette corrects the residual payload motion, whose rms above 100 mHz is ~ 1 order of magnitude smaller than the ground motion (MSC,Hannover 25 10 07).



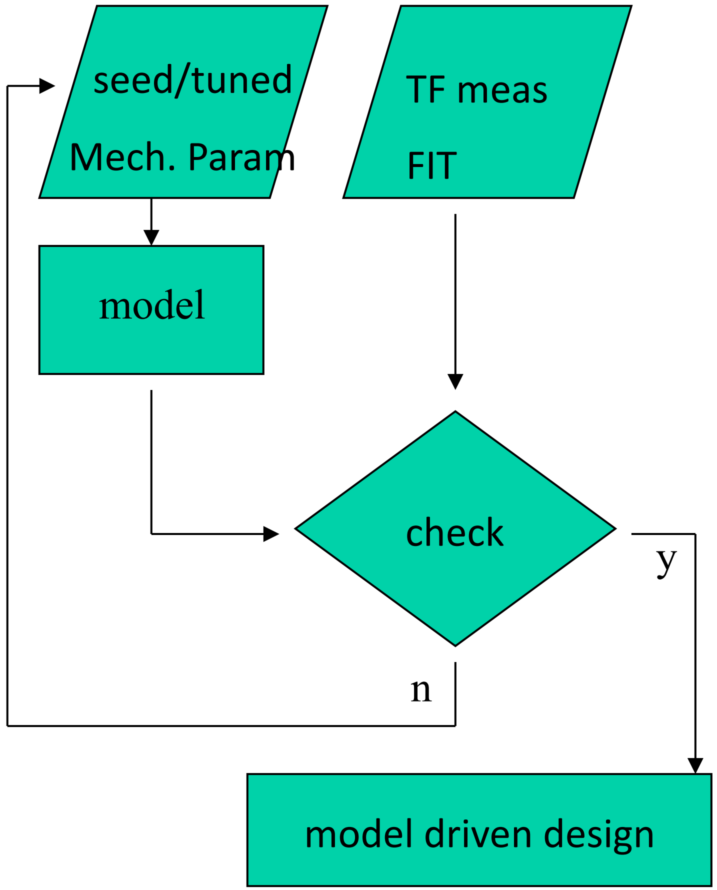
Pitch (in present payload):
g=-88 urad/V (DC);
cp=[0.409 300]
cz=[0.449 60]
cp=[0.4525 60]
cz=[1.705 1500]cp=[1.753 1500]
cp=[3.205 1500]
sp=10



Murphy law: Virgo suspension chain and running payloads have z/p couples in the same range, which is in the microseismic frequency band => pitch alignment suffers …

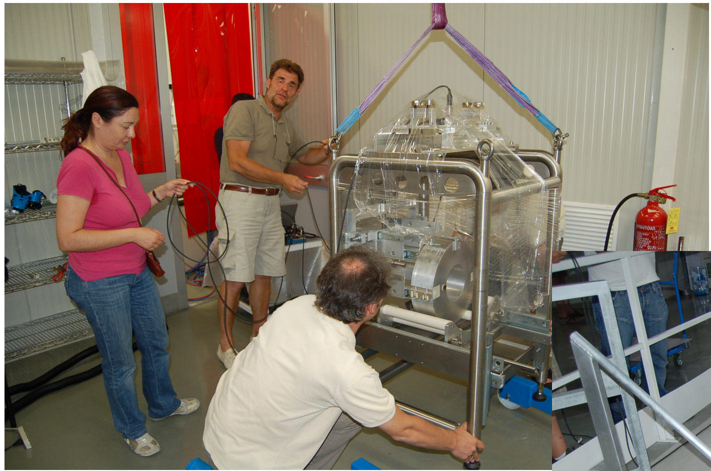
TASK II

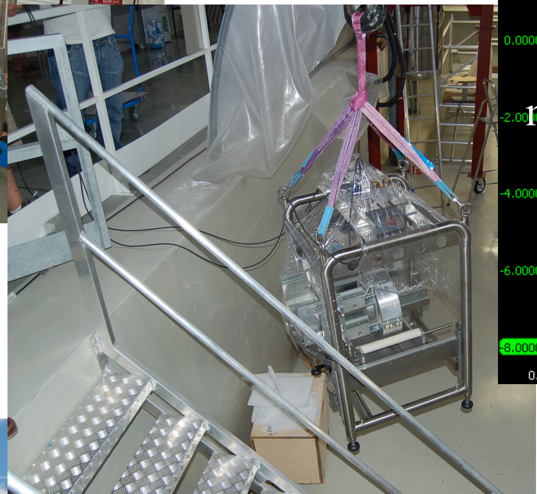
Mechanical model of the payload can be validated and then used to finely predict the mechanical parameters to have specific internal modes

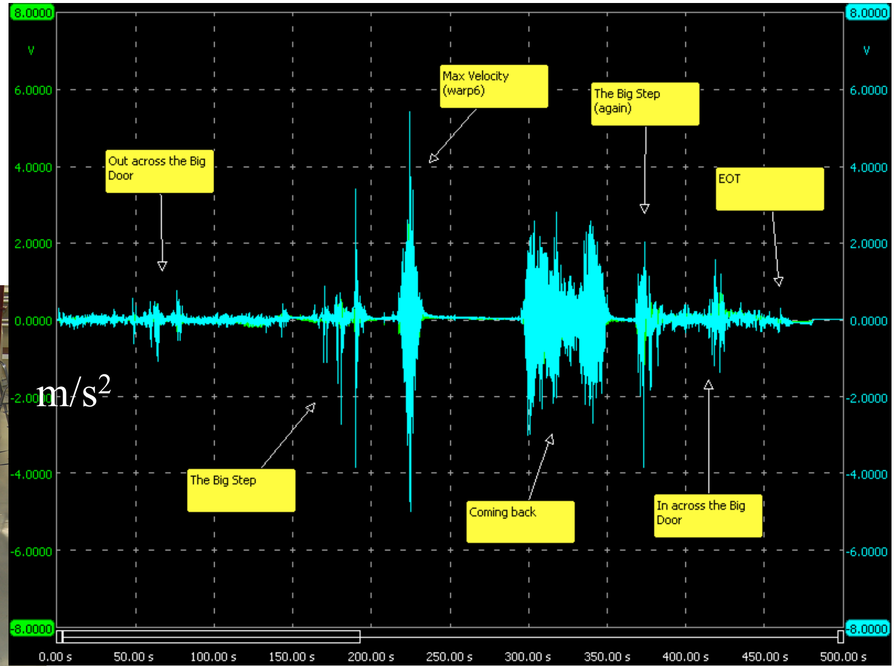


TASK III

Resistance to shocks, dust pollution, to humidity







Transportation test:

- On the dummy payload
- Mechanical vibration monitored with accelerometers
- The test was successful (no broken fibers!

Crash Test : see movie on YouTube (search monolithic crash), fiber robustness tested

Conclusions

- Virgo is approaching its second Science (VSR2) run with **sensitivity and reliability significantly improved**.
- The present configuration take into account a **first set of Virgo+ improvements** (small magnets, cleaner e.m. environment, injection, mode cleaner, TCS, cryotrap link).
- Further work improving TCS stabilization (non trivial), before the run.
- Non invasive further environmental noise cleaning (e.g. turbo pump fans…)
- **Science run starting on July 7th** : good duty cycle, expected to be limited by standard earthquake rate (~1/week) and weekly maintenance.
- **During VSR2** some noise sources recently identified (e.g. TCS power stabilization, AR output window, etalon thermal stabilization) will be addressed.
- Continuous operation is always a good opportunity also to improve the suspension system and to use the interferometer as a unique accelerometer.
- **Second Virgo+ set** in early 2010: monolithic suspension and high finesse (50 => 150).

VirgoAdvanced baseline document defined;
High priority assessment from founding authorities;
Actual funding will be **sustained by Virgo+ reliability**.

VadV: COST & milestones

20 MEuro (Nikhef will contribute by ~10%)

Year	2009	2010	2011	2012	2013
FTE	19	35	25	27	20

Virgo + EGO personnel fulfill this request.

1. July 2009 The Project starts with the mirror bulk order.
2. July 2011 Shutdown of Virgo+ for Advanced Virgo installation.
3. Dec 2013 Completion of assembly and integration phases.
4. July 2014 First one-hour-long operation (i.e. needed degrees of freedom controlled).