

IFSI: Experimental Gravitation (Detection of small displacements)

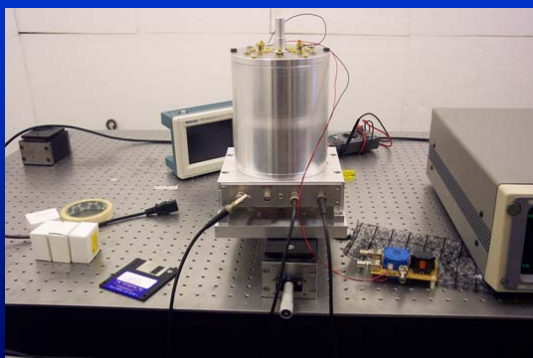
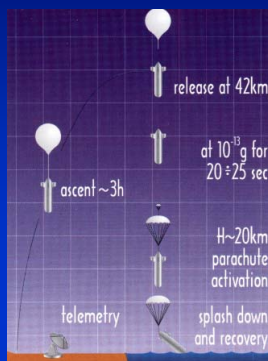
V. Iafolla, E. Fiorenza, C. Lefevre, A. Morbidini, S. Nozzoli, R. Peron, M. Persichini, A. Reale, F. Santoli.

Istituto di Fisica dello Spazio Interplanetario (IFSI/INAF), Via Fosso del Cavaliere, 100 (00133) Roma, Italy;

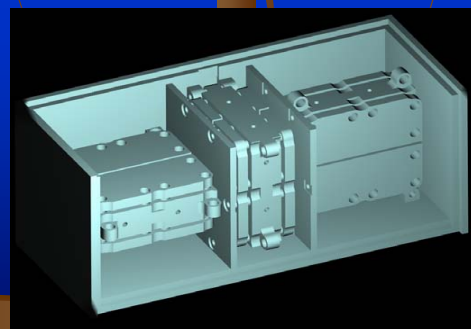
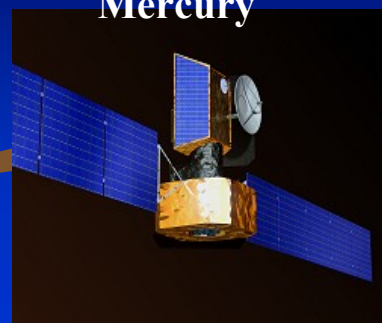
IFU Tor Vergata
22 Aprile 2007

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GReAT: General Relativity Accuracy Test



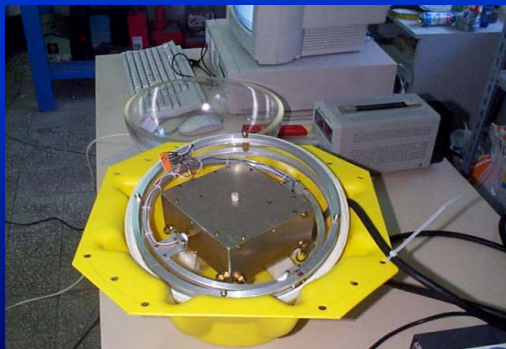
ISA: An accelerometer for the BepiColombo Mission to Mercury



GEOSTAR: gravimeter for deep-sea measurements



G measurement with a one axis gravity gradiometer



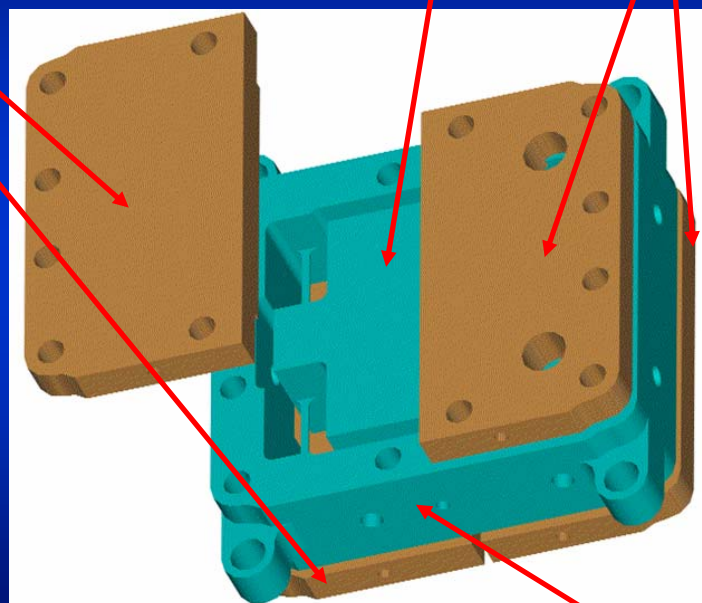
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The ISA accelerometer

Actuator Capacitors

Test Mass

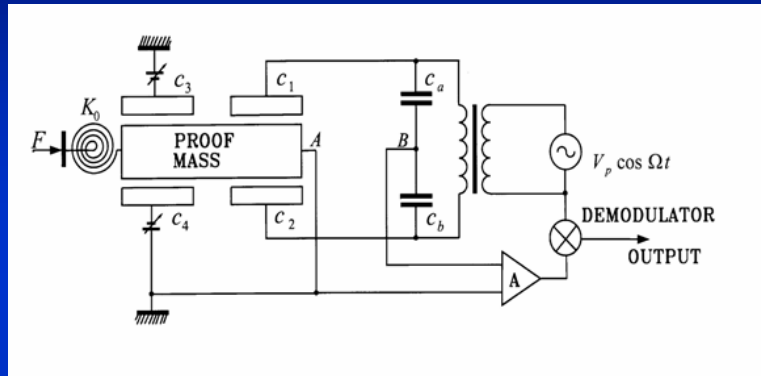
Detector Capacitors



Reference Frame

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Base concept of the accelerometer



$$\beta = \frac{\alpha^2 C}{m_r \omega_o^2}$$

$$\frac{1}{Q_e} = \left(4 \frac{\omega_o}{\Omega_p} \frac{tg \delta}{\beta} \right)$$

$$\frac{1}{Q} = \left(\frac{1}{Q_m} + \frac{1}{Q_{de}} \right)$$

$$a_{bW} = \left(\frac{4k_b T \omega_o}{m_r Q} \right)^{1/2}$$

$$a_t^2(\omega) \approx \frac{4k_b \omega_o}{m_r} \left[\frac{T}{Q} + T_n \frac{2Z_n C \omega_o}{\beta} \right] \Delta f$$

no matching

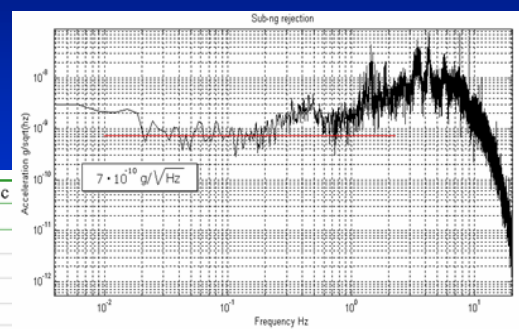
$$a_t^2(\omega) \approx \frac{4k_b \omega_o}{m_r} \left[\frac{T}{Q} + T_n \frac{2}{\beta} \frac{\omega_o}{\Omega_p} \right] \Delta f$$

matching

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Accelerometer for space use

		Actual value	Possible value	Cryogenic
a_{min}	Sensitivity $g/\sqrt{Hz}$	$3.3 \cdot 10^{-12}$	$4 \cdot 10^{-14}$	$5.7 \cdot 10^{-15}$
m_r	Proof mass (Kg)	0.22	10	10
f_o	Frequency of resonance (Hz)	3.5	1	1
f_p	Polarisation frequency (KHz)	10	10	10
P	Pressure condition (mbar)	10^{-4}	10^{-6}	10^{-6}
C_i	Sensing capacity (pF)	300	300	300
$tg \delta_{C_i}$	Angle of loss of C_i condenser	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
C_e	External fixed capacity (pF)	300	300	300
$tg \delta_{C_e}$	Angle of loss of C_e condenser	$3 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
	Electronic device	AD743/AD	OPA128	OPA128
v_n	Voltage noise of amplifier ($V/\sqrt{Hz}$)	$3 \cdot 10^{-9}$	$15 \cdot 10^{-9}$	$15 \cdot 10^{-9}$
i_n	Current noise of amplifier ($A/\sqrt{Hz}$)	$7 \cdot 10^{-15}$	$0.1 \cdot 10^{-15}$	$0.1 \cdot 10^{-15}$
T_n	Temperature noise of amplifier (K)	0.76	0.06	0.06
α	Transducer factor (V/m)	10^5	10^5	$5 \cdot 10^5$
β	Electromechanical transducer factor	$2.8 \cdot 10^{-12}$	$7.6 \cdot 10^{-13}$	$1.9 \cdot 10^{-11}$
Q_e	Electric merit factor	$6.6 \cdot 10^4$	$6.3 \cdot 10^4$	$1.5 \cdot 10^6$
Q_m	Mechanical merit factor	$5.7 \cdot 10^3$	10^5	10^5
Q	Total merit factor	$5.7 \cdot 10^3$	$6.3 \cdot 10^4$	10^5
a_{bn}^2	Brownian noise (m/sec^2) ² / Hz	$2.9 \cdot 10^{-22}$	$1.6 \cdot 10^{-25}$	1.410^{-27}
a_{en}^2	Electronic noise (m/sec^2) ² / Hz	$8.4 \cdot 10^{-22}$	$4.9 \cdot 10^{-26}$	$1.9 \cdot 10^{-27}$



Differential measurement in order to eliminate the seismic noise in the laboratory performed with two accelerometers with sensitive axes parallel. The residual flat noise is due to the electronics. The setup electronic (that used for the geophysics) was not the best one in order to reach the actual sensitivity of $3.3 \cdot 10^{-12} g/\sqrt{Hz}$. Anyway the level of the mechanical rejection is quite good.

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GReAT: General Relativity Accuracy Test

EP test balloon experiment

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(3) Boston University, Boston, MA;

GReAT experiment

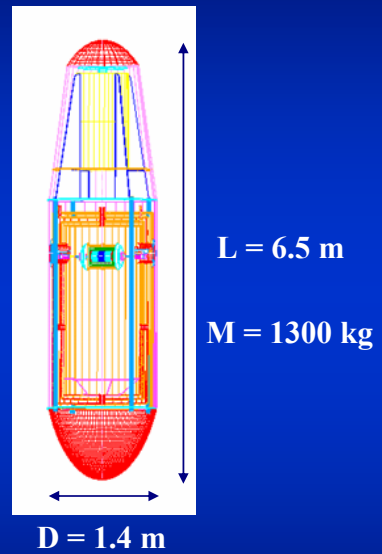
The goal of the **GReAT** experiment is to test the Weak-Equivalence-Principle (**WEP**) with an accuracy of a few parts in 10^{15} , i.e., 2 orders-of-magnitude better than the actual ground-based measurements:

- The differential accelerometer composed of two test masses of different material free falls inside a 3 m long cryostat dropped from a 40 km altitude balloon;
- the **FF** duration is about 30 s inside an evacuated capsule;
- the falling masses are part of a high-sensitivity differential accelerometer with a sensitivity in detecting differential accelerations of about $10^{-15} g_{\oplus} / \sqrt{\text{Hz}}$ at the liquid-helium temperature (4.2 K);



GReAT experiment

- the differential accelerometer apparatus is spun about an horizontal axis at a frequency of 1 Hz (1ω) in order to modulate the signal during free fall;
- the experiment is isolated from external noise sources acting on the capsule, such as air drag;
- a non-zero differential acceleration appearing at the rotation frequency will indicate a violation of the Equivalence Principle;
- once the instrument package reaches the capsule's floor, the capsule is decelerated by a parachute for retrieval and re-flight;

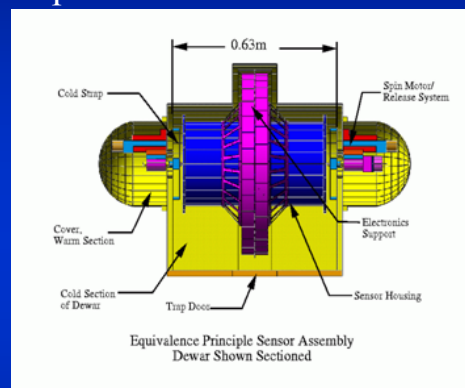
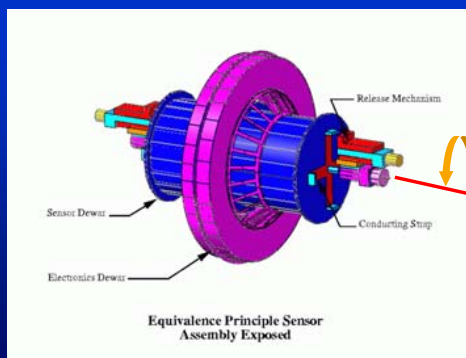


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GReAT experiment

The liquid-helium refrigeration is important to provide:

- low thermal noise;
- high thermal stability;
- low thermal gradients;
- high Q-factors of the differential accelerometer detector;



- Small cryostat to refrigerate the instrument package (blue/purple);
- Open doors at bottom of cryostat;
- Instrument package span at $\leq 1 \text{ Hz}$ before release into room-temperature capsule;

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GReAT experiment

GReAT compared to the other proposed flying experiments to test the **WEP**:

■ STEP:	10^{-18}	(drag-free satellite)	NASA;
■ GG:	10^{-17}	(drag-free satellite)	INFN/ASI;
■ MicroScope:	10^{-15}	(drag-free satellite)	CNES/ESA;
■ GReAT:	$5 \cdot 10^{-15}$	(drag-shielded capsule)	ASI/NASA;

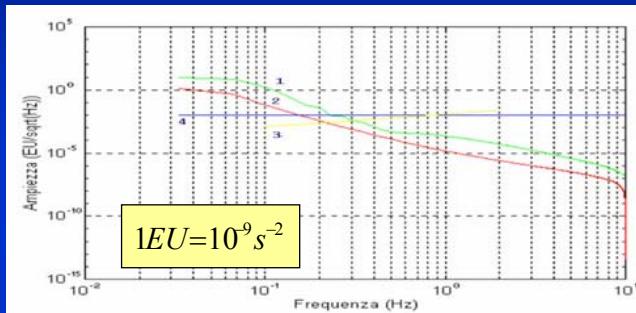
GReAT experiment

The work of the teams involved in the **GReAT** experiment to test the **WEP** has been subdivided in the following main aspects:

- Free-Fall system (SAO):
 - cryogenic system (with Janis Research);
 - release mechanism (cooling and clean release);
 - room temperature electronics and detector power source;
- Detector (IFSI/CNR):
 - achieving the required values (e.g., Q-factor);
 - attenuating initial transients;
 - common-mode rejection;

GReAT experiment

Numerical simulations.

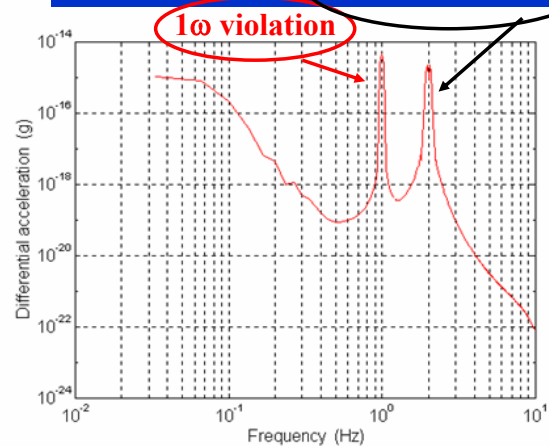


Spectral densities:

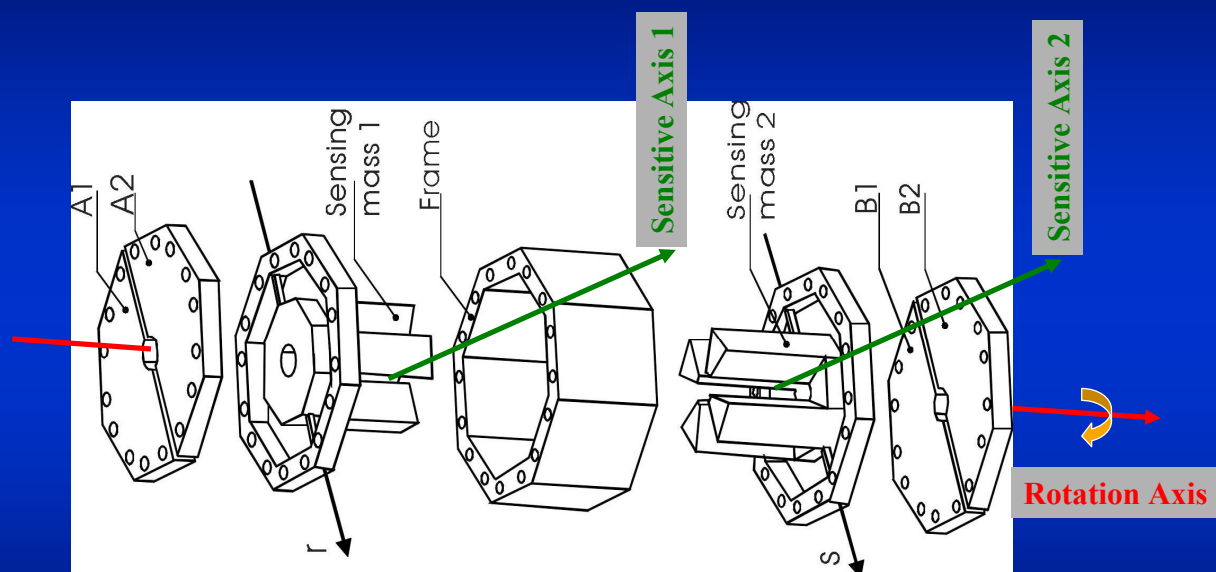
- Capsule gravity gradients;
- Earth's gravity gradients;
- Inertial gradients due to the vibrations of the capsule walls and to the platform, via the residual gas in the capsule;
- Reference gravity gradient: $10^{-2} \text{ EU}/\sqrt{\text{Hz}}$;

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FF simulation with the instrument package spun at 1 Hz including a possible violation of the WEP at the level of $10^{-15} g_{\oplus}$. The violation signal at 1ω is well separated from the 2ω signals.



Differential accelerometer

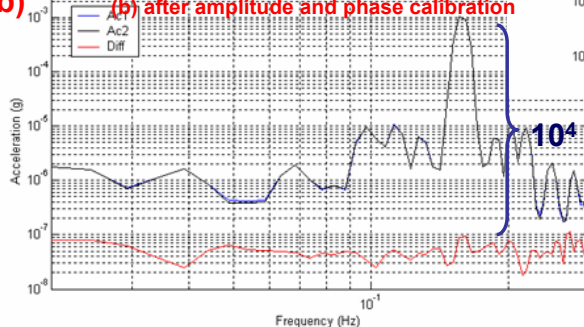


Experimental results with a differential accelerometer prototype

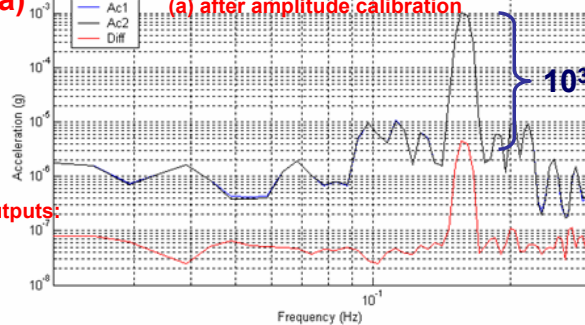
Rejection of the common-mode signals.

Figure (b) shows that after calibrating for amplitude and phase a 10^4 attenuation is readily obtained for the differential signal. This level of attenuation is effective not only at the perturbation frequency of 0.15 Hz but also over a larger frequency band.

(b) Spectra of individual and differential acceleration outputs: (b) after amplitude and phase calibration



(a) Spectra of individual and differential acceleration outputs: (a) after amplitude calibration

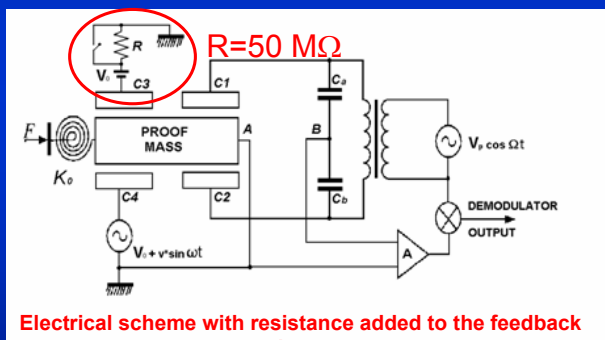


An attenuation of 10^4 or equivalently a common-mode rejection factor of 10^{-4} meets the present requirement on the CMRF for the proposed tests of the WEP.

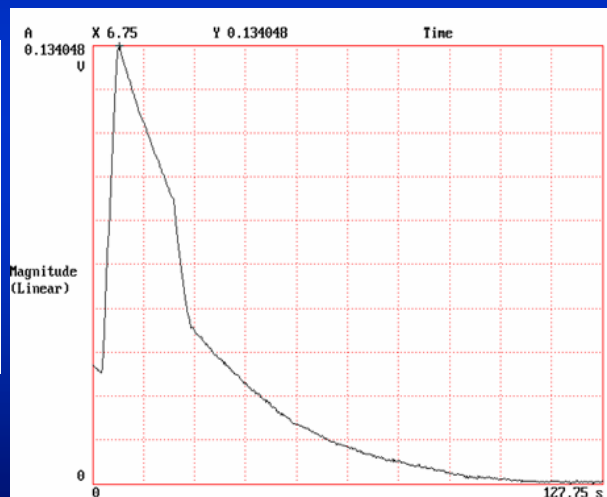
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Experimental results with a differential accelerometer prototype

Abatement of the natural dynamics excited by the instrument release into the capsule.



$$\frac{1}{Q_t} = \frac{1}{Q_m} + \frac{1}{Q_e} \quad \frac{1}{Q_e} = \beta \frac{\omega_0 RC}{1 + (\omega_0 RC)^2} \quad \beta = \frac{C \cdot E^2}{M \cdot \omega_0^2}$$

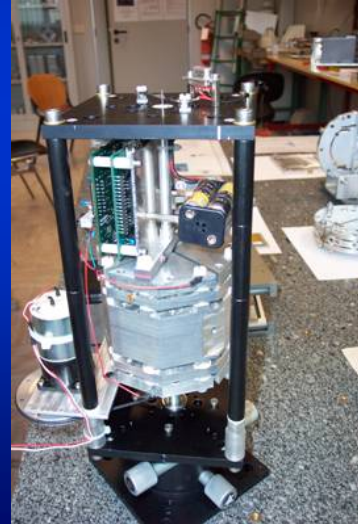
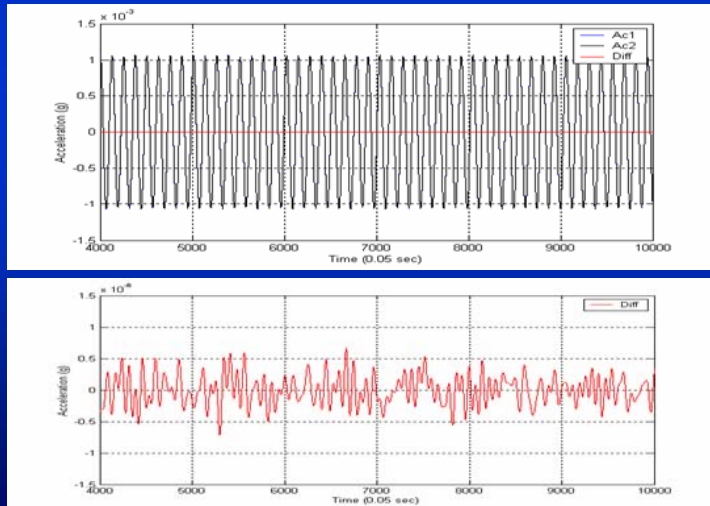


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Experimental results with a differential accelerometer prototype

Rejection of the common-mode signals.

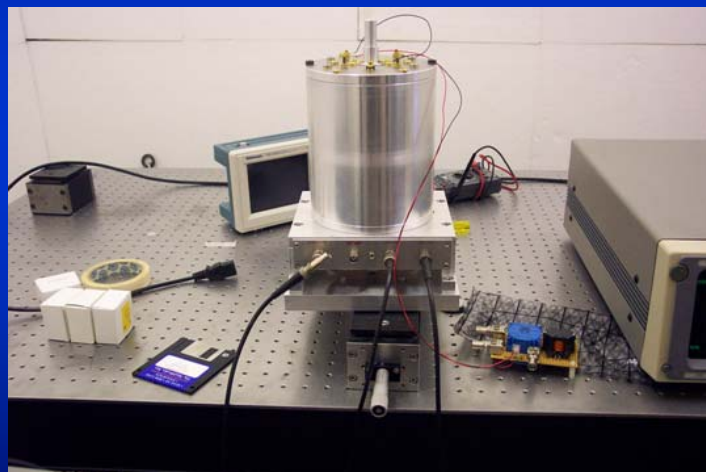
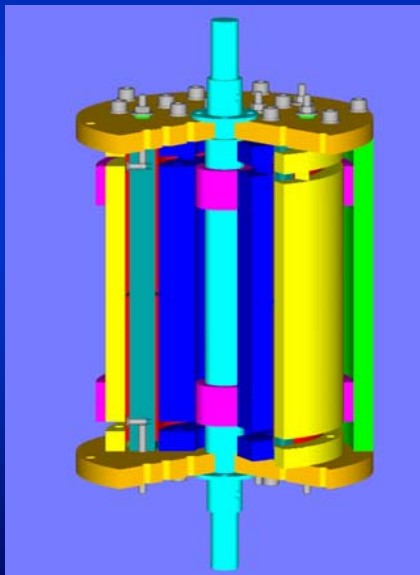
One important characteristic of a differential accelerometer is its ability to reject perturbations that are not differential, i.e., common-mode disturbances. This ability is quantified by the common-mode rejection factor (CMRF).



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New configuration of the differential accelerometer

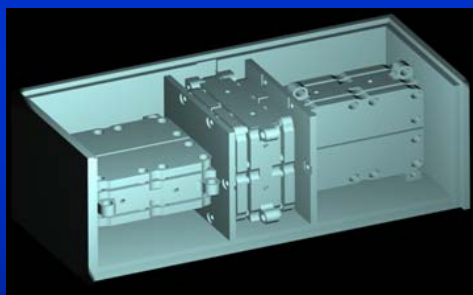
The second differential accelerometer prototype built at IFSI/CNR.



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ISA (ITALIAN SPRING ACCELEROMETER): AN ACCELEROMETER TO MEASURE THE INERTIAL ACCELERATIONS ACTING ON THE MPO.



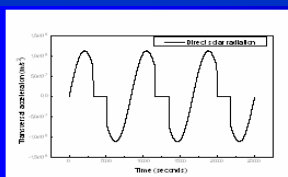
Iafolla V.; Fiorenza E.; Nozzoli S.; Morbidini A.; Peron R.; Ravenna M.; Santoli F.;
iafolla@ifsi.rm.cnr.it

BepiColombo Radio Science Experiments ISA (Italian Spring Accelerometer)

The **ISA** (Italian Spring Accelerometer) accelerometer — developed at IFSI/CNR — considered to fly on-board the **MPO**. It is a three axes accelerometer.

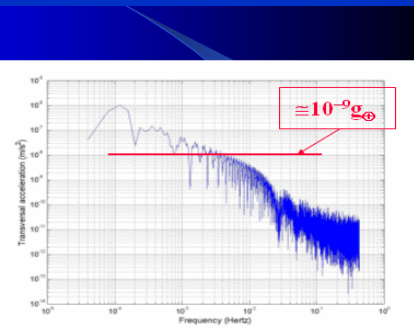
- The key role of the accelerometer is to remove from the list of unknowns the non-gravitational perturbations, i.e., the strong non-conservative accelerations on the **MPO** produced by the Sun visible radiation and by Mercury infrared radiation;
- To fulfil the **RSE** the non-gravitational accelerations must be limited to a level of $10^{-9} g_{\oplus}$, which has been taken as the accelerometer accuracy, in the frequency band $3 \cdot 10^{-5} - 10^{-1} \text{ Hz}$;

Direct solar radiation pressure: the transversal acceleration and its spectrum



3 orbital periods ≈ 7 hours

The perturbing effect at the orbital period (2.3 h) is 2 orders-of-magnitude larger than the accelerometer accuracy of $\approx 10^{-8} \text{ m/s}^2$



Acceleration acting on ISA

The acceleration on a point **P** (ISA proof-mass) close to the **MPO COM** is:

$$\ddot{\vec{R}} = (\vec{\nabla} \cdot \vec{g})\vec{R} - \vec{\omega} \wedge (\vec{\omega} \wedge \vec{R}) - \dot{\vec{\omega}} \wedge \vec{R} - 2(\vec{\omega} \wedge \dot{\vec{R}}) - \vec{A}_{NGP}$$

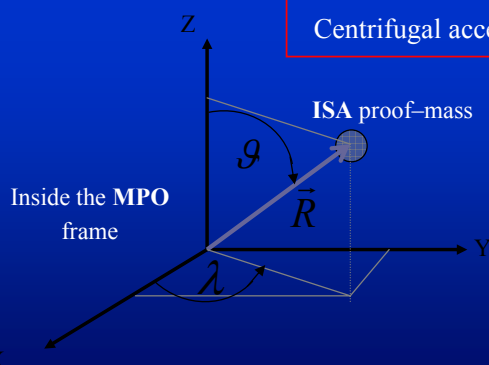
Acceleration due to Mercury gravity field gradients

Angular acceleration

Non-Gravitational accelerations

Coriolis acceleration

Centrifugal acceleration



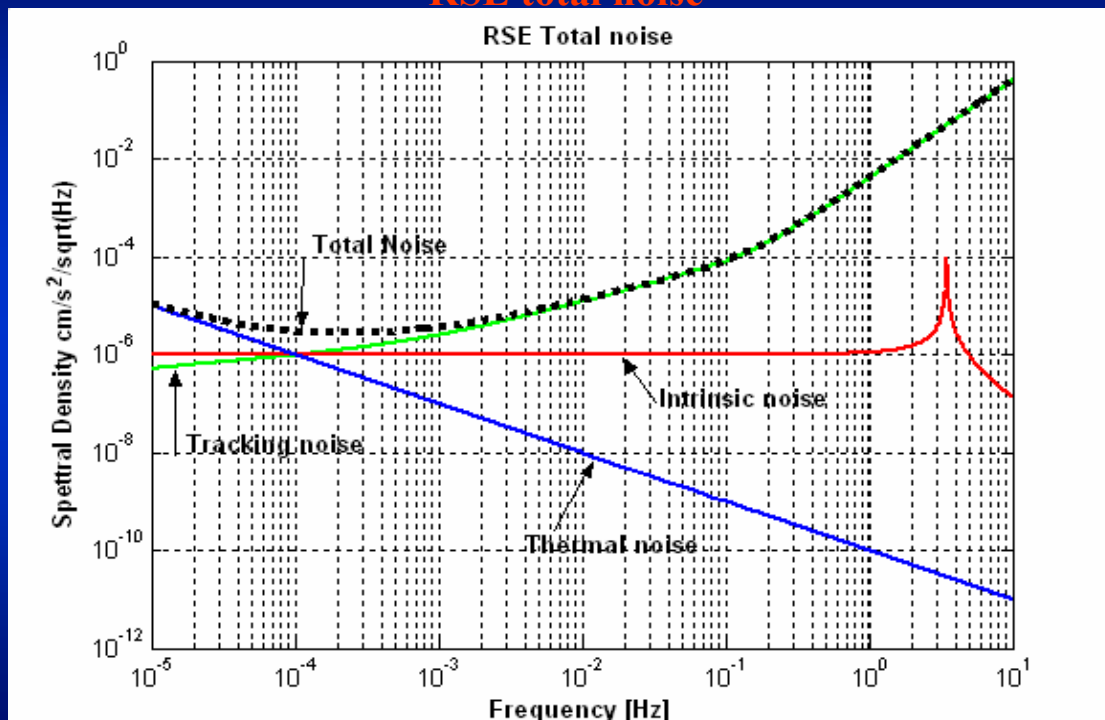
$\vec{g}$ = **Mercury** gravity;

$\vec{\omega}$ = **MPO** angular rate:

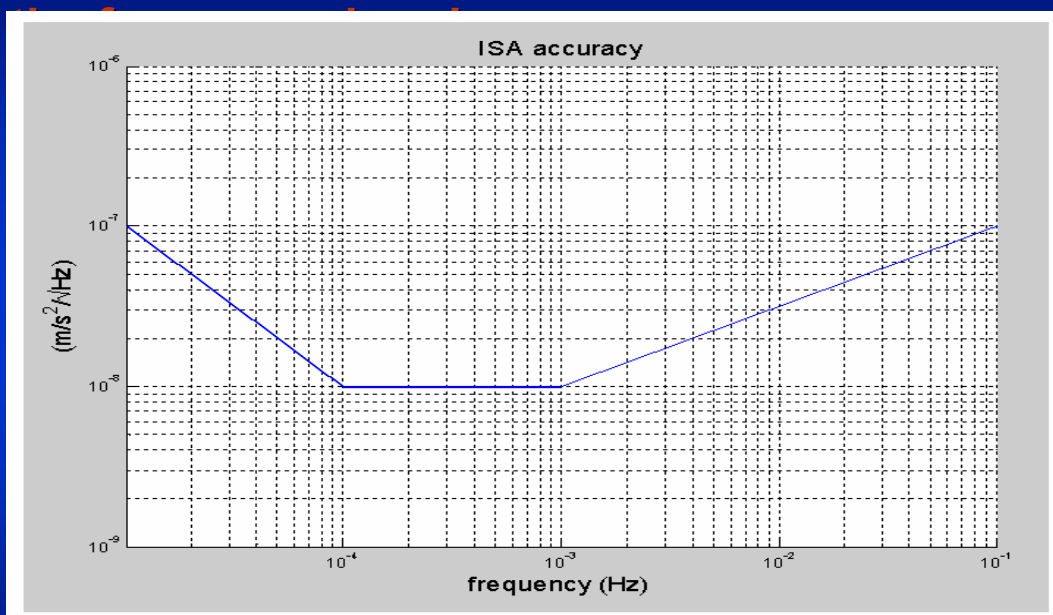
$\dot{\vec{\omega}}$ = **MPO** angular acceleration;

$\vec{R}$ = **MPO-proof-mass** vector;

RSE total noise

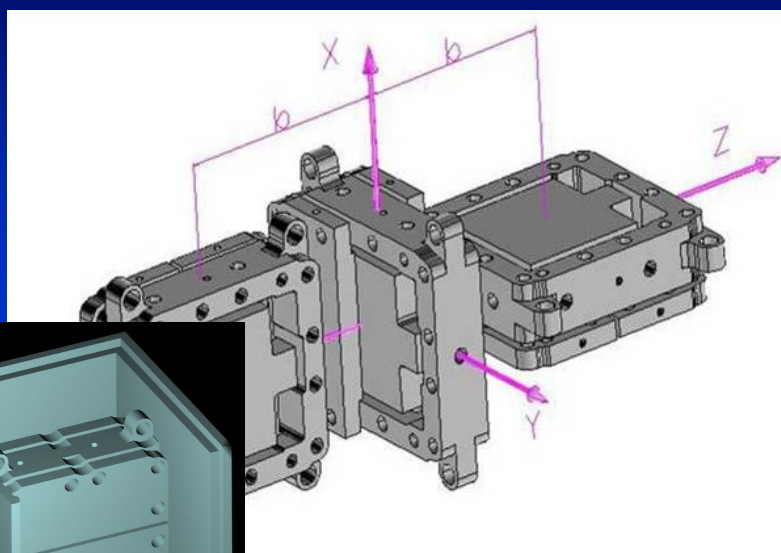
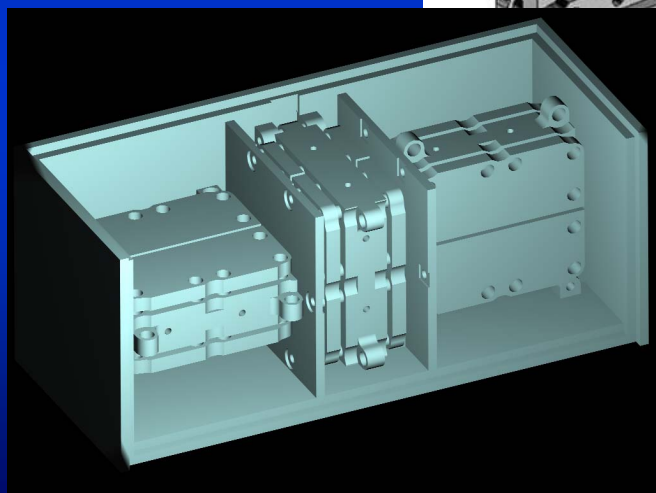


ISA accuracy requirement inside



Frequency Hz	$3 \cdot 10^{-5}$	$10^{-4} - 10^{-3}$	10^{-1}
Acceleration values $m/s^2/\sqrt{Hz}$	$3 \cdot 10^{-8}$	10^{-8}	10^{-7}

ISA (Italian Spring Accelerometer) Three-axis



Requirements on the angular rate and angular acceleration for the following fixed values of the position of the spacecraft COM: $X_i = 30$ mm, $Y_i = 20$ mm and $Z_i = 40$ mm.

	Case A)	Case B)
$\delta\omega$	$1.34 \cdot 10^{-5} \text{ rad/s} / \sqrt{\text{Hz}}$	$0.54 \cdot 10^{-5} \text{ rad/s} / \sqrt{\text{Hz}}$
$\delta\dot{\omega}$	$1.76 \cdot 10^{-8} \text{ rad/s}^2 / \sqrt{\text{Hz}}$	$0.56 \cdot 10^{-8} \text{ rad/s}^2 / \sqrt{\text{Hz}}$

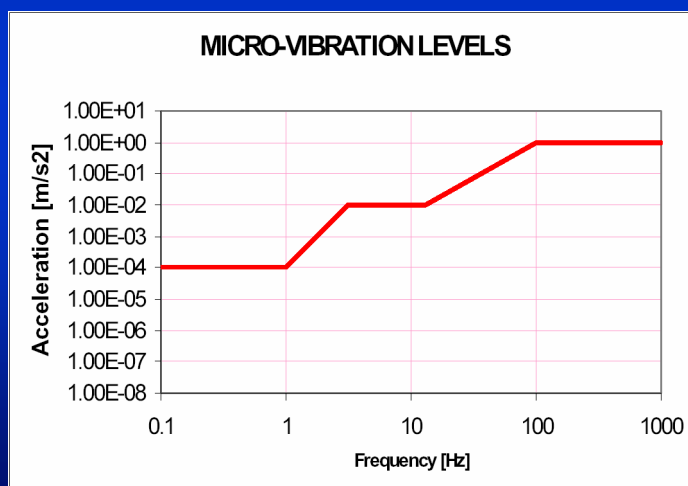
Case A: $com \equiv \text{COM}$

Case B: $com + 20 \text{ cm} \equiv \text{COM}$

Vibrational random noise on board the MPO inside the frequency band

Frequency Hz	$3 \cdot 10^{-5}$	$10^{-4} - 10^{-3}$	10^{-1}
Acceleration values ($\text{m/s}^2 / \sqrt{\text{Hz}}$)	$3 \cdot 10^{-9}$	10^{-9}	10^{-8}

Micro-vibration random noise on board the MPO outside the frequency band



ISA thermal system overview

One of the main characteristics for the accelerometer to be considered in the **BepiColombo** mission to **Mercury** is its thermal stability, i.e., the immunity of the accelerometer to temperature variations:

over one orbital period (2.3 h) of the $\approx \pm 2^\circ\text{C}$

MPO; $\approx \pm 12.5^\circ\text{C}$

over one sidereal period (44 days) of $\approx 4^\circ\text{C}/\sqrt{Hz}$

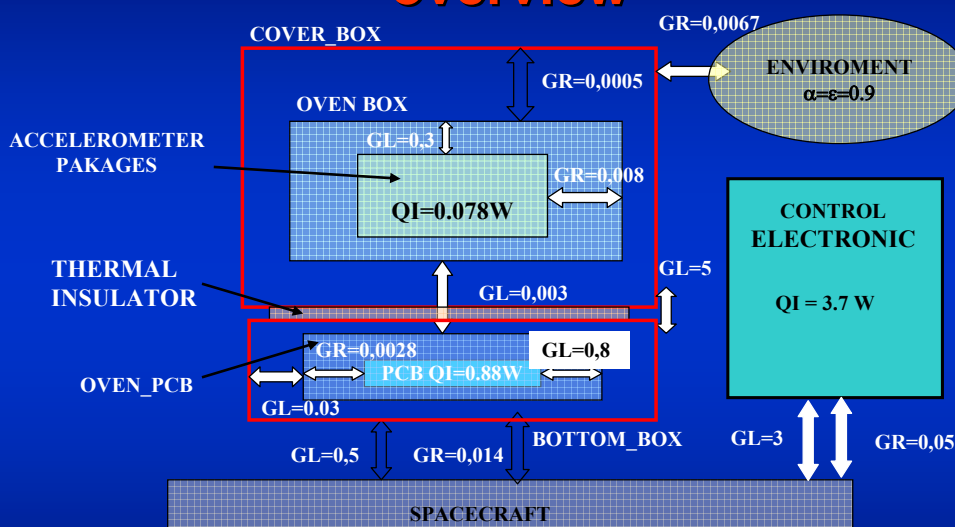
Mercury;

In the actual version of the **ISA** accelerometer the thermal stability is: $5 \cdot 10^{-8} g_\oplus / ^\circ\text{C}$
Random noise;

That is a temperature change of 1 degree produces a voltage output equivalent to:

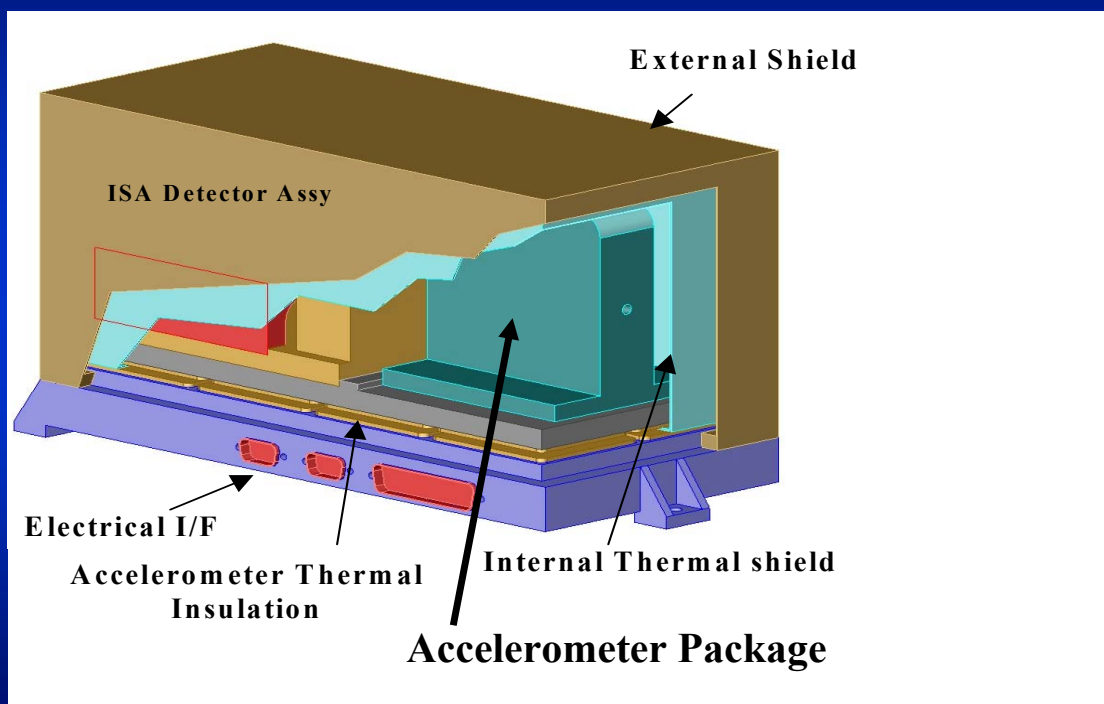
$$5 \cdot 10^{-8} g_\oplus \cong 5 \cdot 10^{-7} m/s^2$$

ISA thermal system overview



ISA Thermal Mathematical model

ISA DETECTOR ASSY OVERVIEW



V. Iafolla

ISA Error Budget: Pseudo Sinusoidal Contributions

Type	Due to	Spectral content	requirement on	Error % A_0
Gravity-gradients	n	Orbital period P and $\frac{1}{2}P$	$\Delta \vec{R}_0 ; \Delta \vec{R}_t(t)$	85% A_0
Apparent forces	$\omega_0 ; \dot{\omega}_0$	Orbital period P and $\frac{1}{2}P$		
Thermal effects	2 °C	Orbital period P and $\frac{1}{2}P$	ΔT	15% A_0
Components coupling	Misalignment angle	Orbital period P and $\frac{1}{2}P$	$\Delta \alpha$	Negligible
Total				100% A_0

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ISA Error Budget: Random Contributions

Type	Due to	Spectral content	requirement on	Error percent
Apparent forces	$\vec{R}_0; \vec{R}_t(t)$	Random	$\delta\omega; \delta\dot{\omega}$	60%A ₀
Thermal effects	$4^\circ\text{C}/\sqrt{\text{Hz}}$	Random	ΔT	30%A ₀
Noise on the MPO	Movements due to the HGA, fuel sloshing ecc.	Random		10%A ₀
MPO COM displacement	Movements due to the HGA and fuel consumption ecc.	Random	$\Delta\vec{R}_t(t)$	70%A ₀
Components coupling	Misalignment angle	Random	$\delta\alpha$	Negligible
ISA intrinsic noise		Random		Negligible
Total (not correlated noise)				<100%A ₀

MORE: Science Goals

- Spherical harmonic coefficients of the gravity field of the planet up to degree and order 25.
- Degree 2 (C_{20} and C_{22}) with 10^{-9} accuracy (Signal/Noise Ratio $\sim 10^4$)
- Degree 10 with SNR ~ 300
- Degree 20 with SNR ~ 10
- Love number k_2 with SNR ~ 50 .
- Obliquity of the planet to an accuracy of 4 arcsec (40 m on surface – needs also SYMBIO-SYS)
- Amplitude of physical librations in longitude to 4 arcsec (40 m on surface – needs SYMBIO-SYS).
- C_m/C (ratio between mantle and planet moment of inertia) to 0.05 or better
- C/MR^2 to 0.003 or better.

MORE: Science Goals

- Spacecraft position in a Mercury-centric frame to 10 cm – 1m (depending on the tracking geometry)
- Planetary figure, including mean radius, polar radius and equatorial radius to 1 part in 10^7 (by combining MORE and BELA laser altimeter data).
- Geoid surface to 10 cm over spatial scales of 300 km.
- Topography of the planet to the accuracy of the laser altimeter (in combination with BELA).
- Position of Mercury in a solar system barycentric frame to better than 10 cm.
- PN parameter γ , controlling the deflection of light and the time delay of ranging signals to $2.5 \cdot 10^{-6}$
- PN parameter β , controlling the relativistic advance of Mercury's perihelion, to $5 \cdot 10^{-6}$
- PN parameter η (controlling the gravitational self-energy contribution to the gravitational mass to $2 \cdot 10^{-5}$
- The gravitational oblateness of the Sun (J_2) to $2 \cdot 10^{-9}$
- The time variation of the gravitational constant ($d(\ln G)/d\hat{t}$) to $3 \cdot 10^{-13} \text{ years}^{-1}$



Istituto di Fisica dello Spazio Interplanetario



Istituto Nazionale Di Astrofisica



G measurement with a gradiometer

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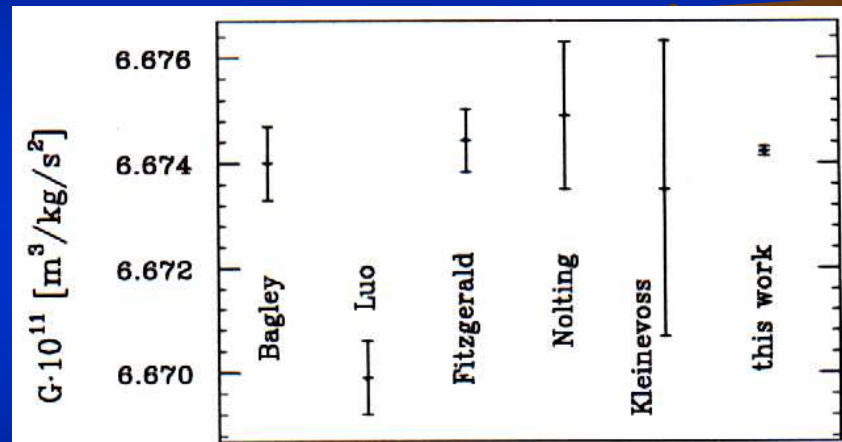
Istituto di Fisica dello Spazio Interplanetario
CNR Roma, Italy



Value of the gravitational constant G

CODATA value: $(6.673 \pm 0.010) \times 10^{-11} \text{ m}^3 \text{ Kg}^{-1} \text{ sec}^{-2}$

Corresponding uncertainty : 1500 ppm

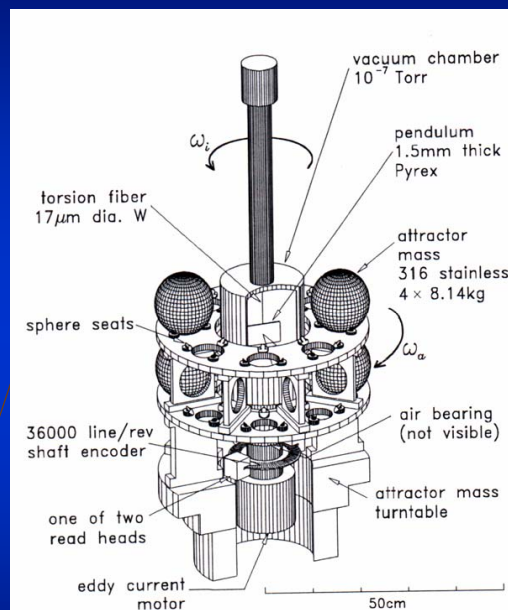
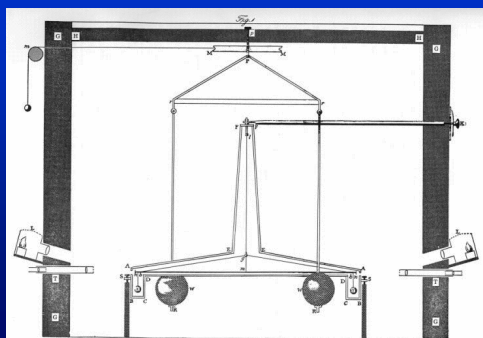
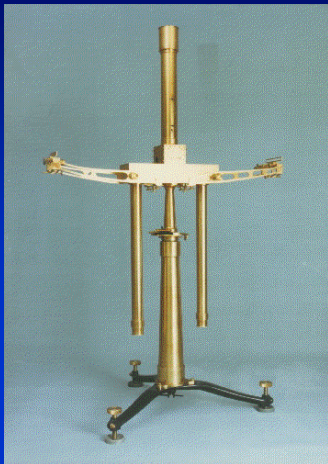


Gundlach, J. H. and Merkowitz, S.M. Phys. Rev. Lett. 85, 2869-2872 (2000)

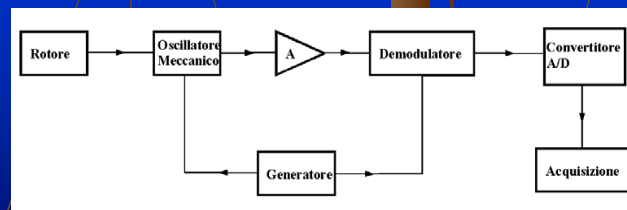
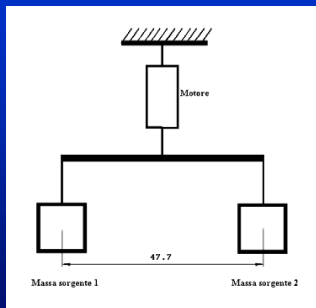
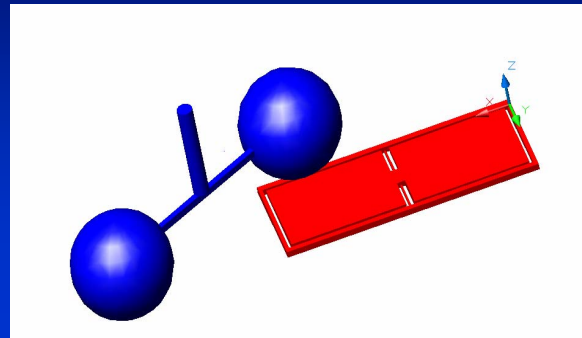
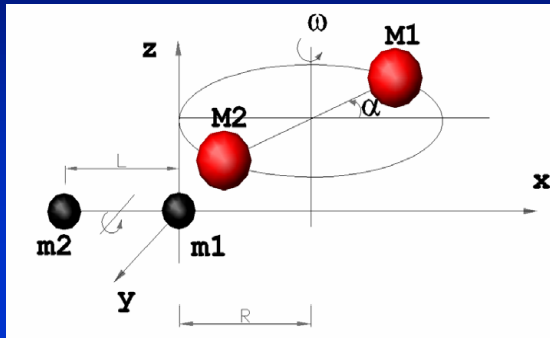
$$G = (6.674215 \pm 0.000092) \times 10^{-11} \text{ m}^3 / (\text{Kg s}^2)$$

Corresponding uncertainty : 14 ppm

Torsion Balances for the measure of G



Experimental set-up

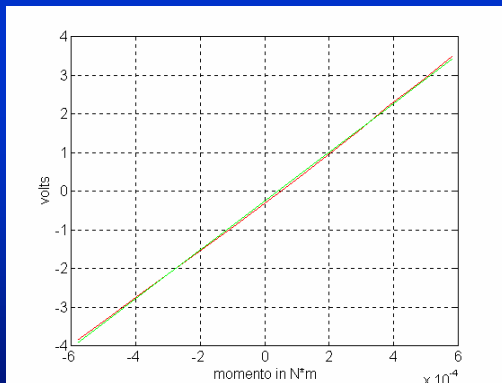
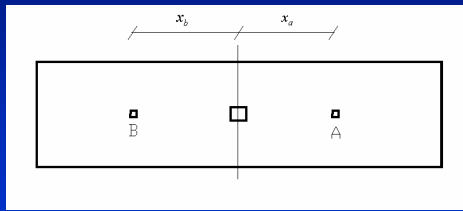


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CNR Roma, Italy

One axis Gravity Gradiometer

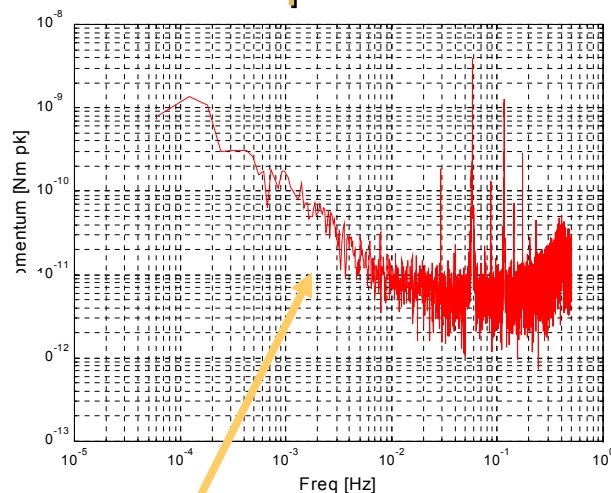
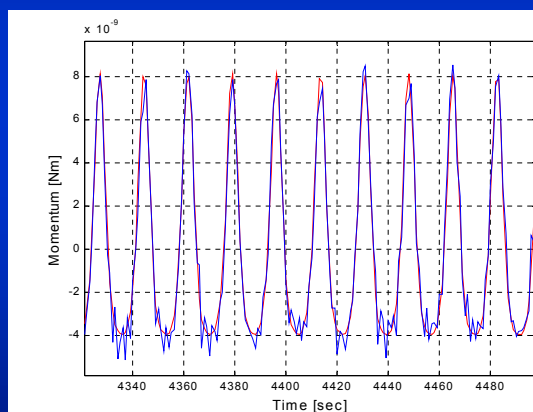
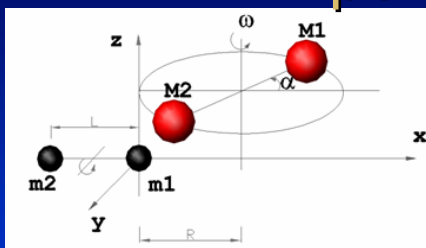


Gradiometer calibration



Peso in A [*23mgr]	Peso in B [*23mgr]	Vout [V]
6	0	3.4873
5	0	2.8310
4	0	2.2305
3	0	1.5629
2	0	.9289
1	0	.2904
0	1	-0.9104
0	2	-1.5065
0	3	-2.1025
0	4	-2.6846
0	5	-3.2775
0	6	-3.8562

Experimental set-up

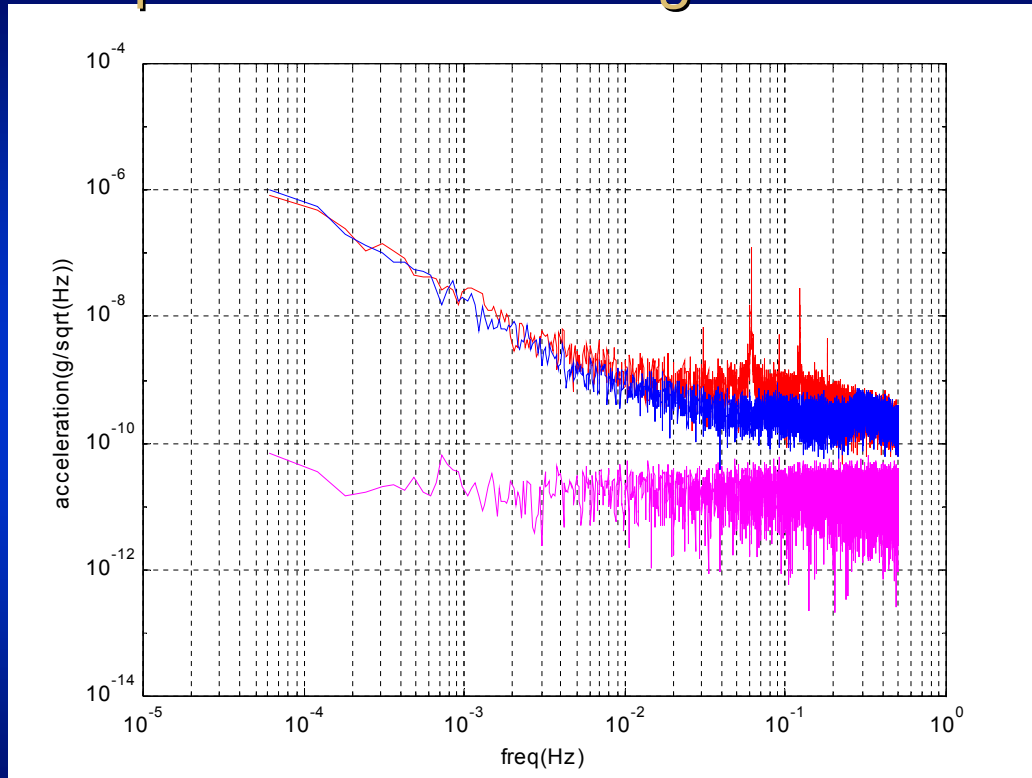


$$\kappa_t = 1.7 \text{ N}\cdot\text{m}/\text{rad}$$

$$\mathcal{G} = \frac{M}{\omega_0^2 \cdot I} = \frac{M}{\kappa_t}$$

$$\theta_{\min} = \frac{10^{-11}}{1.7} = 5.8 \cdot 10^{-12} \text{ rad (8h int.time)} \Leftrightarrow 7.5 \cdot 10^{-10} \text{ rad}/\sqrt{\text{Hz}}$$

Comparison between signal and noise



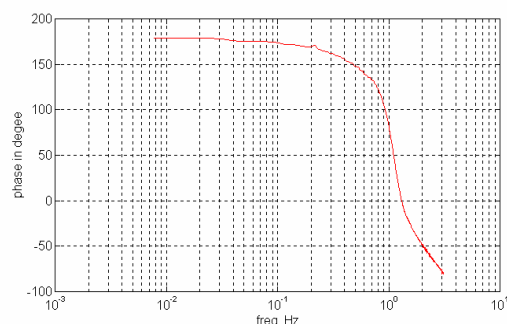
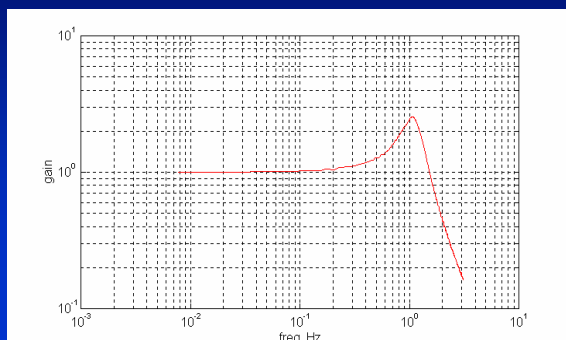
■ Rumore elettronica

■ Rumore con simulacro di rotore

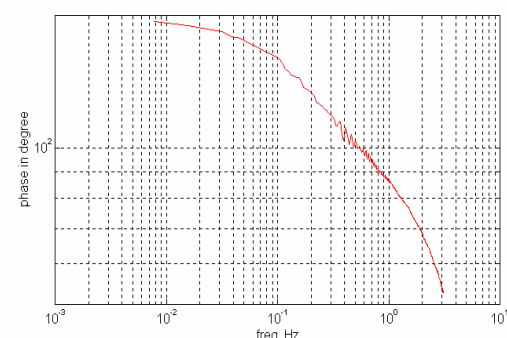
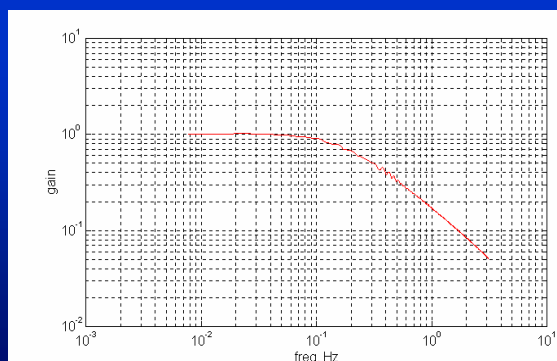
■ Rumore con rotore in azione

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Gradiometer transfer function



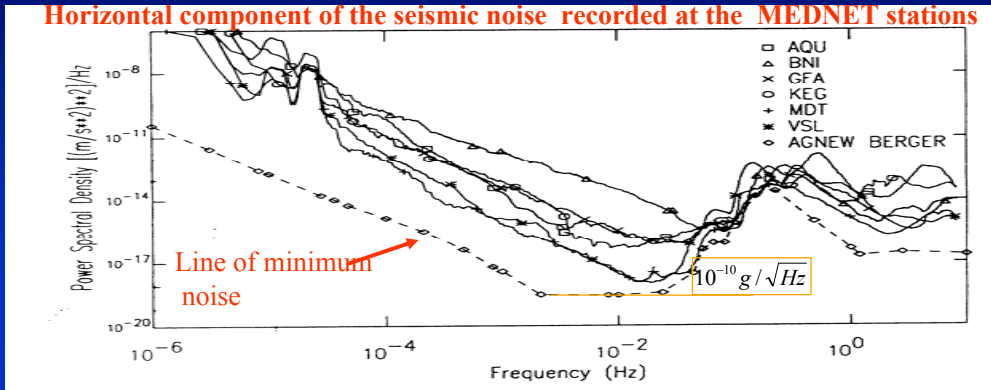
$Q=3$



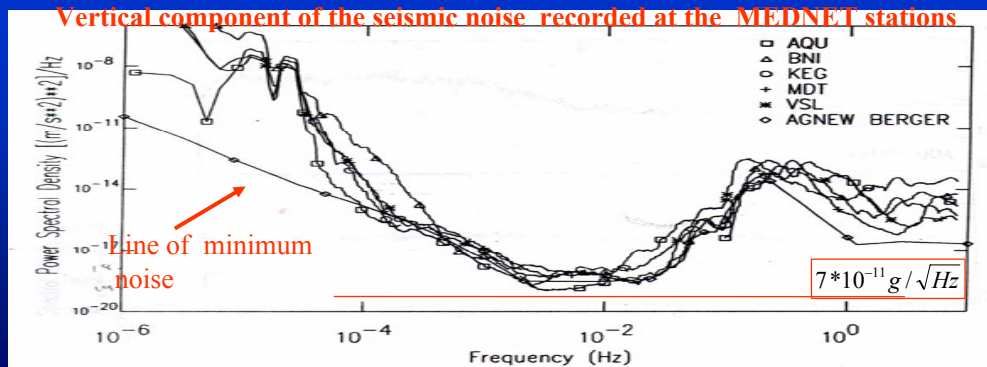
$Q=0.1$

Geophysical Measurements

Horizontal component of the seismic noise recorded at the MEDNET stations



Vertical component of the seismic noise recorded at the MEDNET stations



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Geophysical Measurements

Brasimone



Cryogenic Gravimeter

Nuclear Power Station of Brasimane

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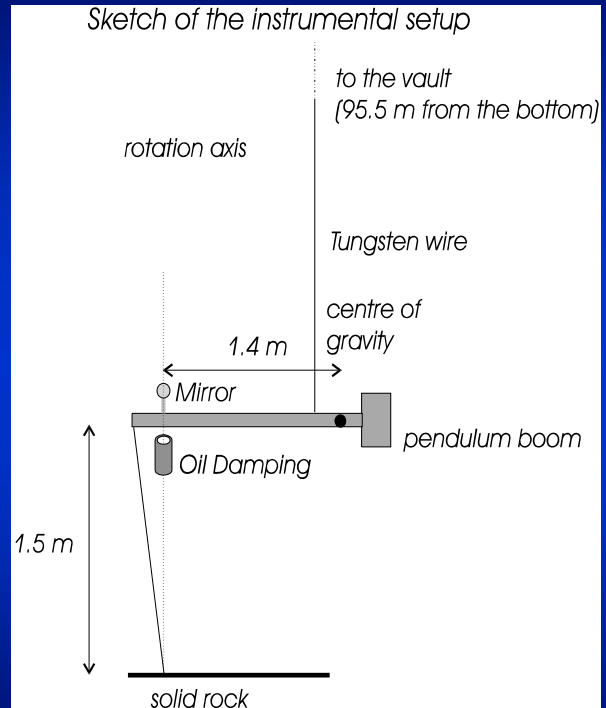
Geophysical Measurements



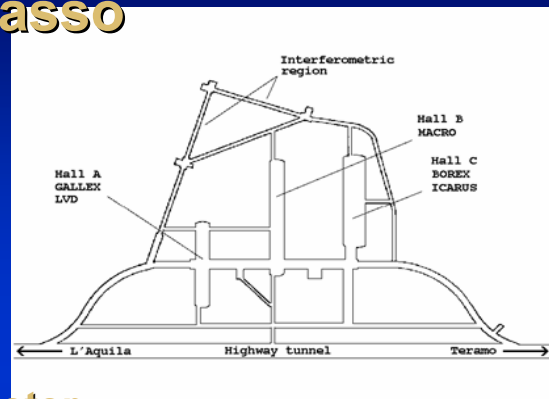
Trieste Grotta Gigante

$$Y(s) = F(s) \cdot X(s)$$

$$Y(s) = \frac{a \cdot \omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \cdot X(s)$$



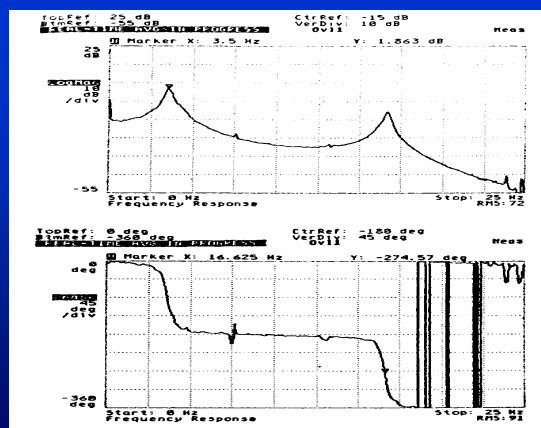
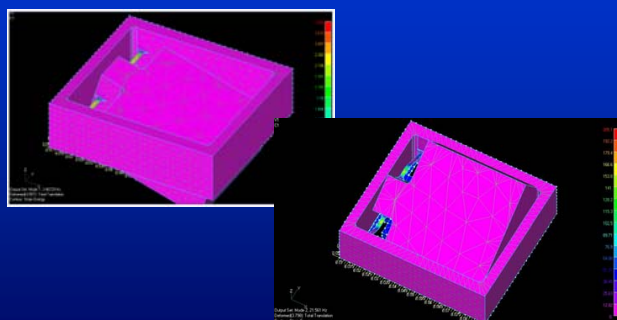
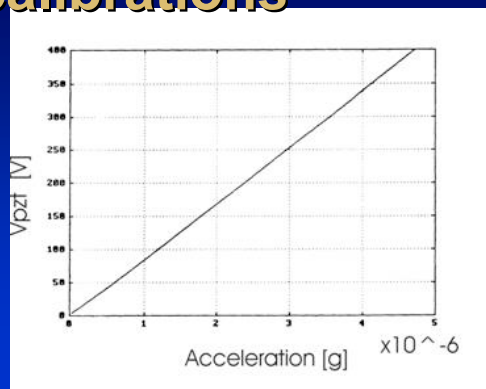
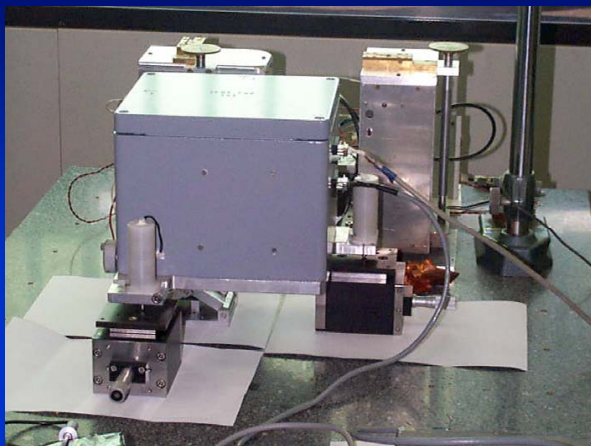
Istituto Nazionale di Fisica Nucleare (INFN) Gran Sasso



Interferometer

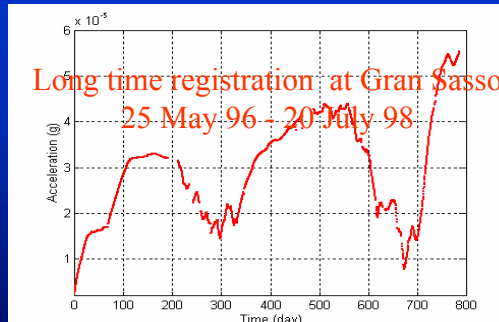
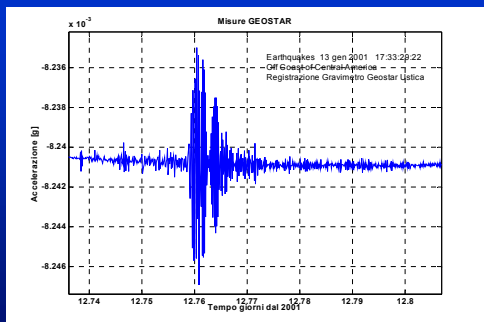
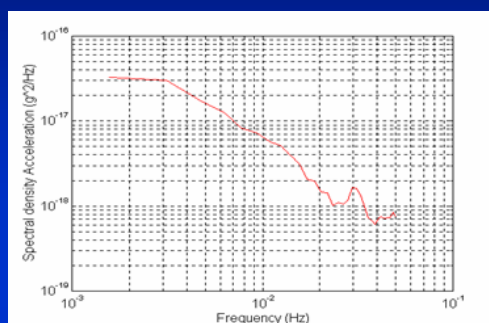
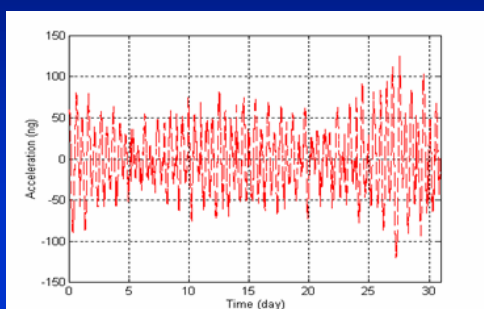


ISA laboratory calibrations



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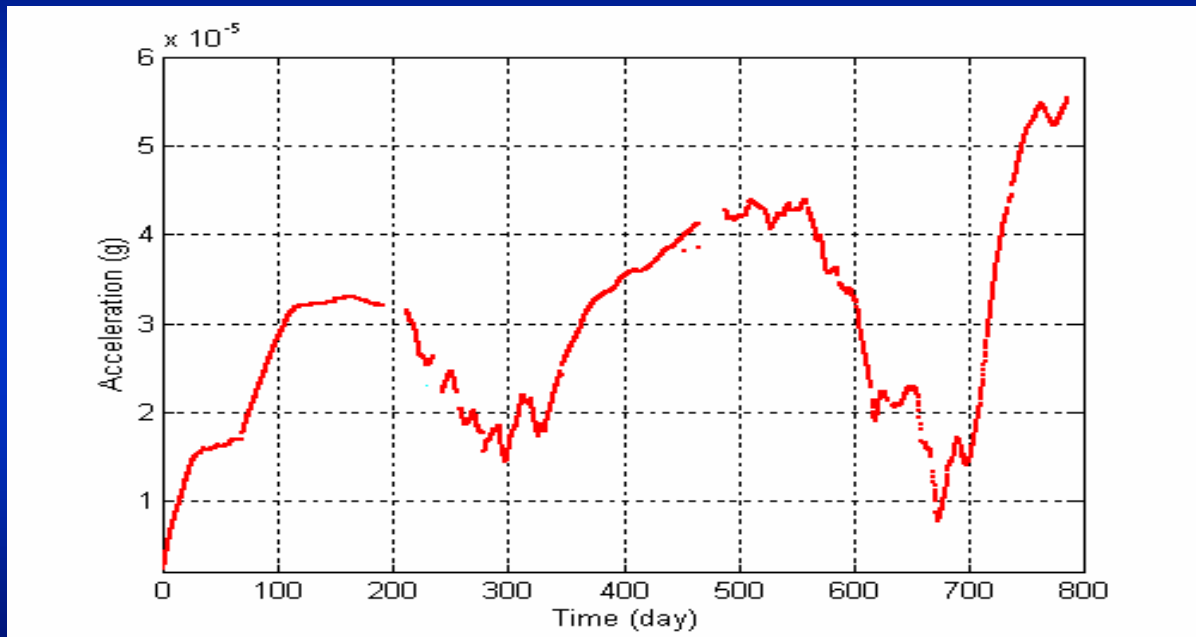
Geophysical Measurements



Long time registration at Gran Sasso
25 May 96 - 20 July 98

Valerio Iafolla

Long time registration at Gran Sasso 25 May 96 - 20 July 98



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Istituto di Fisica dello Spazio Interplanetario



Istituto Nazionale Di Astrofisica



Gravity Gravimeter for Deep-Sea Measurements

Valerio Iafolla and Sergio Nozzoli

Istituto di Fisica dello Spazio Interplanetario
Rome, Italy

Valerio Iafolla

Gravimeter

General Characteristics

Sensitivity	$10^{-9} g / \sqrt{Hz}$
Frequency Range	$10^{-5} - 10^{-1} Hz$
Power dissipation	300mW
Volume	10X10X10 cm
Weight	2Kg

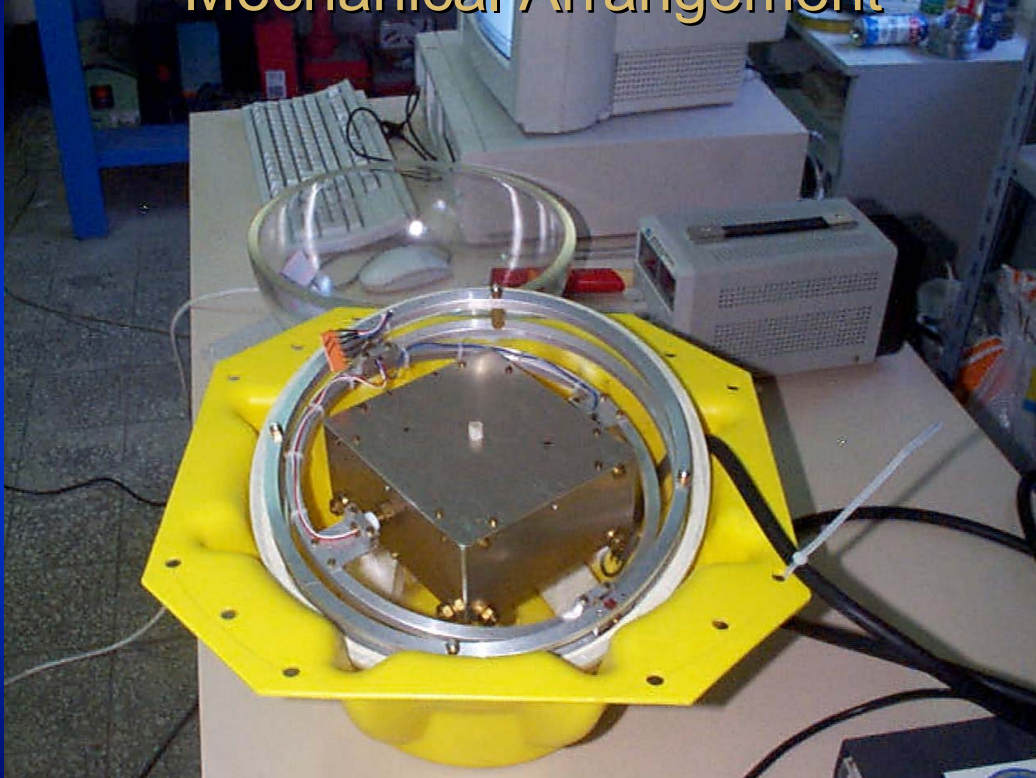


Benthos VacuSealed

GEOSTAR Platform

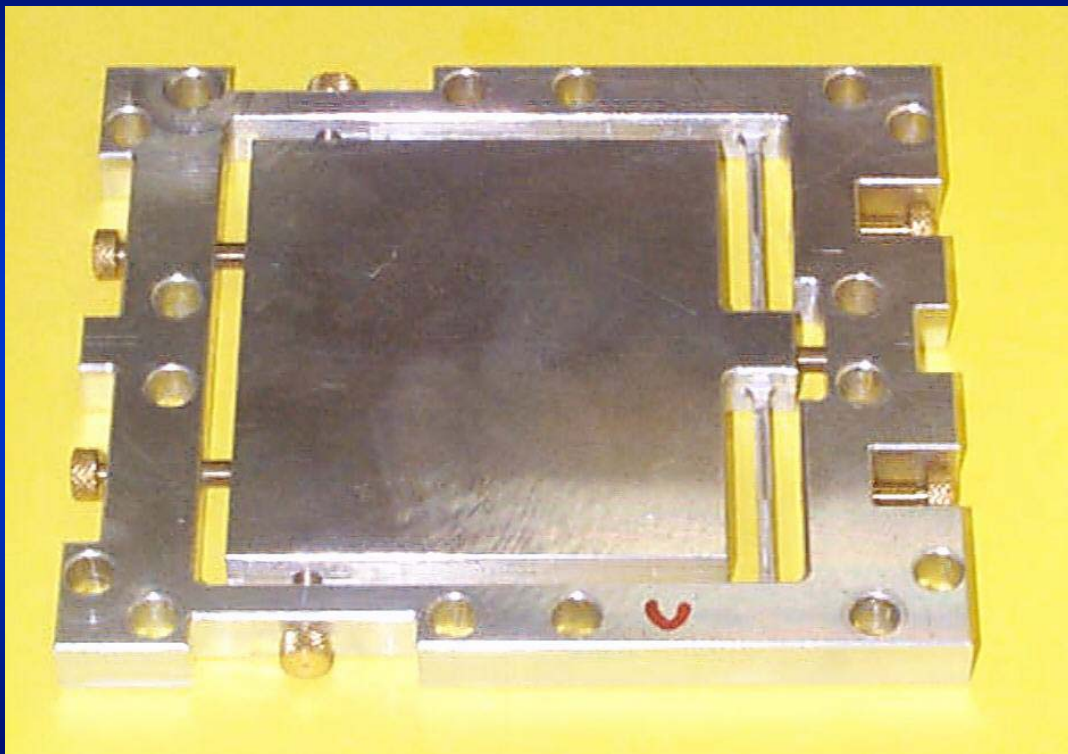


Mechanical Arrangement



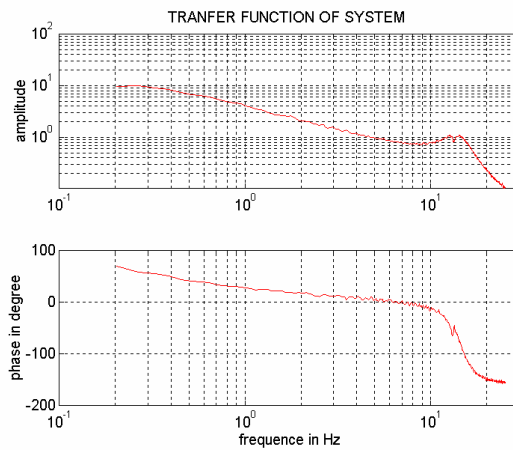
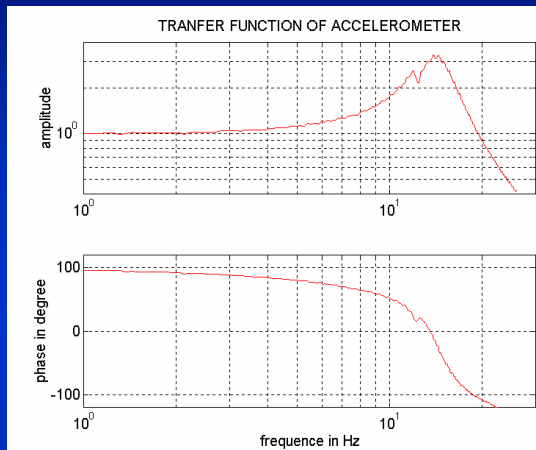
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Mechanical Oscillator



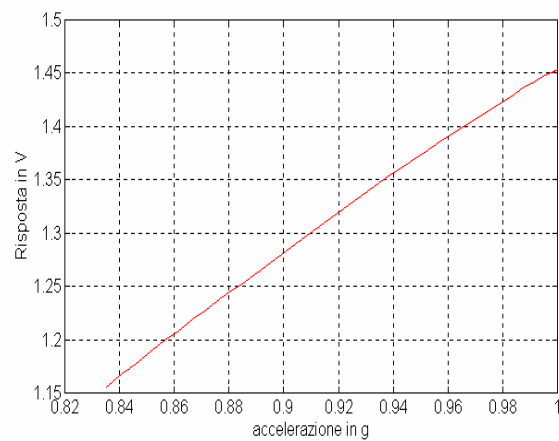
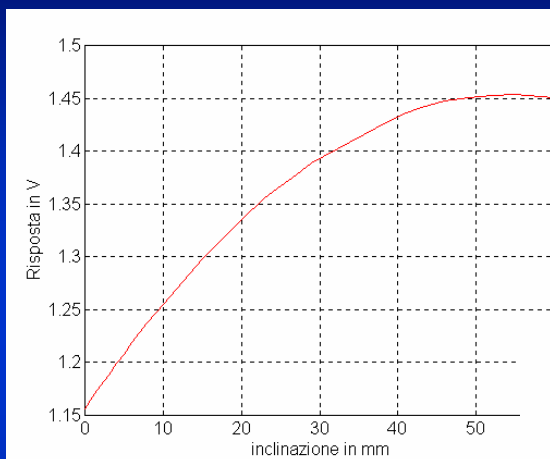
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Transfer Function



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Gravimeter Calibration



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Gravimeter experimental value

$a_{\min}$	Sensitivity $g / \sqrt{Hz}$	10^{-9}
m_r	Proof mass (kg)	0.22
f_o	Frequency of resonance (Hz)	15
f_p	Bias frequency (kHz)	10
P	Pressure (mbar)	10^3
C_1 and C_2	Sensing capacitors (pF)	300
$tg\delta_{C1}$	Tangent loss angle	$4 * 10^{-4}$
C_a and C_b	External fixed capacitors (pF)	300
$tg\delta_{Ca}$	Tangent loss angle	$3 * 10^{-4}$
C_3 and C_4	Control capacitors (pF)	300
	Electronic device (Analog Device)	AD743/AD
v_n	Voltage noise of amplifier ($V / \sqrt{Hz}$)	$3 * 10^{-9}$
i_n	Current noise of amplifier ($A / \sqrt{Hz}$)	$7 * 10^{-15}$
T_n	Temperature noise of amplifier (K)	0.76
α	Transducer factor (V / m)	10^5
β	Electromechanical transducer factor	$15 * 10^{-4}$
Q_e	Electrical quality factor	10^3
Q_m	Mechanical quality factor	10^{-1}
Q	Total quality factor	10^{-1}
a_{bw}^2	Brownian noise ($(m / sec^2)^2 / Hz$)	$7 * 10^{-17}$
a_{el}^2	Electronic noise ($(m / sec^2)^2 / Hz$)	$29 * 10^{-20}$

Problems of Dynamic

Mechanics

$$d_0 = 100 \mu m$$

Electronics

$$A / D \quad 14 bit \quad 10 KHz$$

Temperature

$$T_{opp} = 12C \quad \Delta T_{day} = 10^{-4} C \quad \frac{\Delta g}{\Delta T} = 10^{-4} \frac{g}{^\circ C}$$

Time

$$10^{-5} g / day$$

Pressure

$$4.7 * 10^{-4} g / atm \quad \Delta P_{day} = 10^{-2} mbar$$

Sensitivity

$$\Delta a_{\min} = 10^{-9} g$$

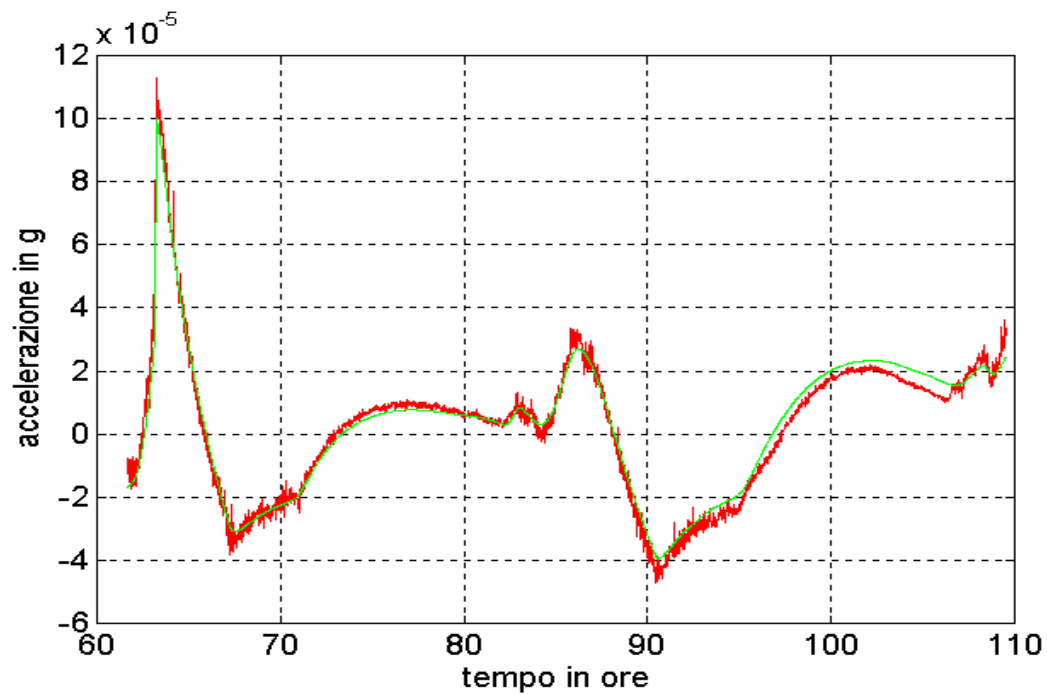
Frequency Range

$$10^{-5} - 10^{-1} Hz$$

$$\Delta x_{\min} = 10^{-8} / (2\pi 14)^2 = 1.2 * 10^{-12} m$$

$$v_{\min} = e_n = 10^{-8} V$$

Signal Variation VS Temperature

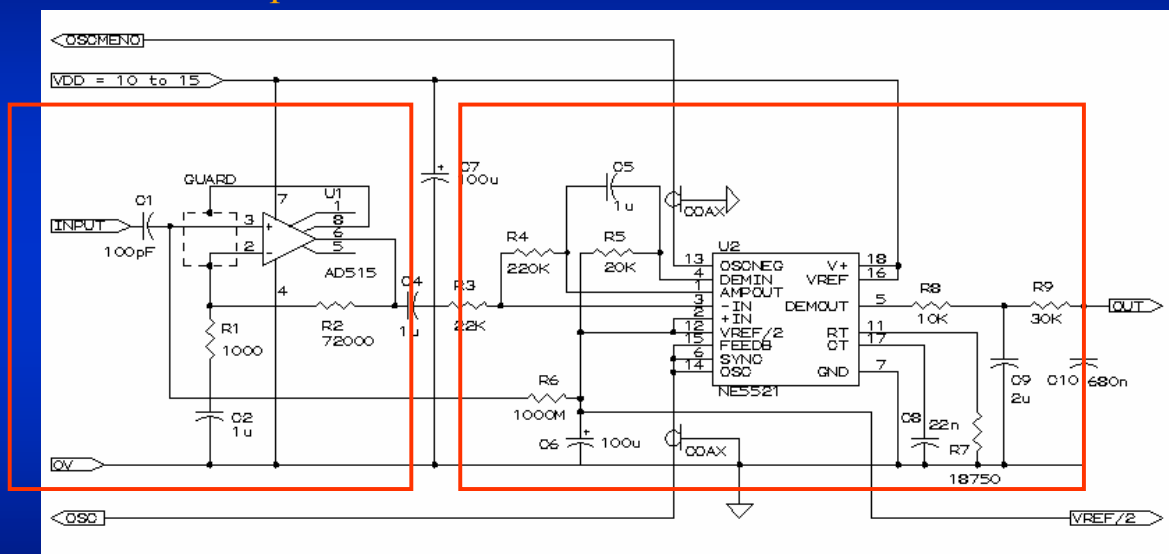


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Low Dissipation Electronics 1

Low Noise Amplifier

Demodulator



30mW

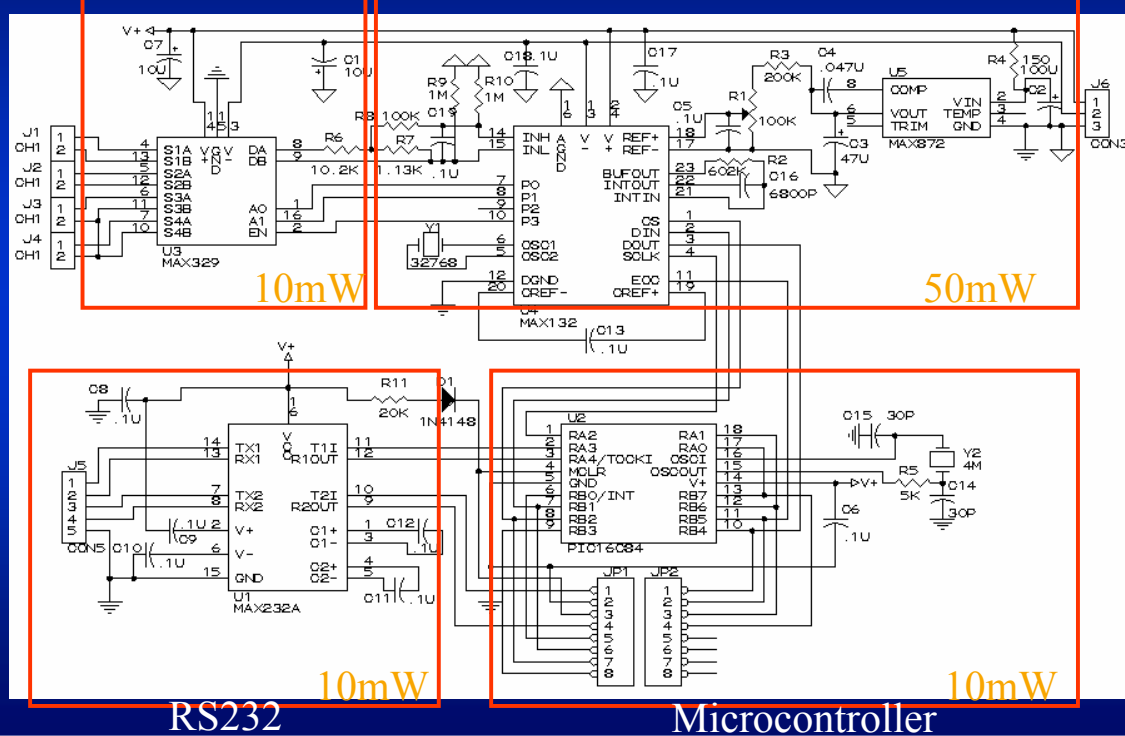
150mW

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Low Dissipation Electronics 2

Multiplexer

A/D



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SN-1 MISSION LOCATION



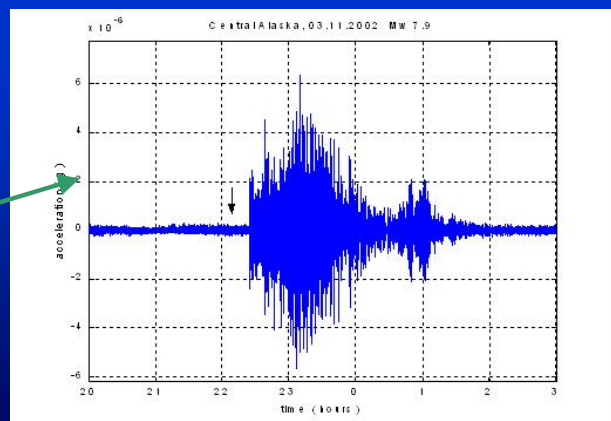
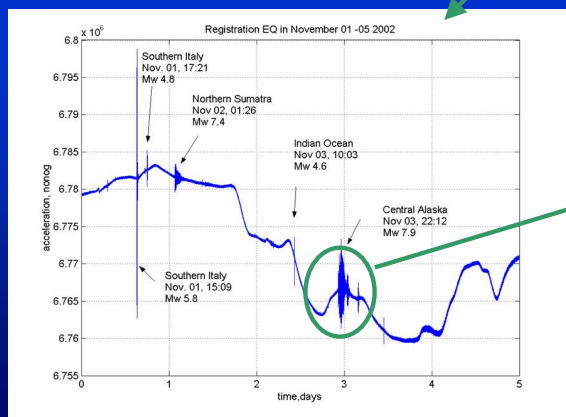
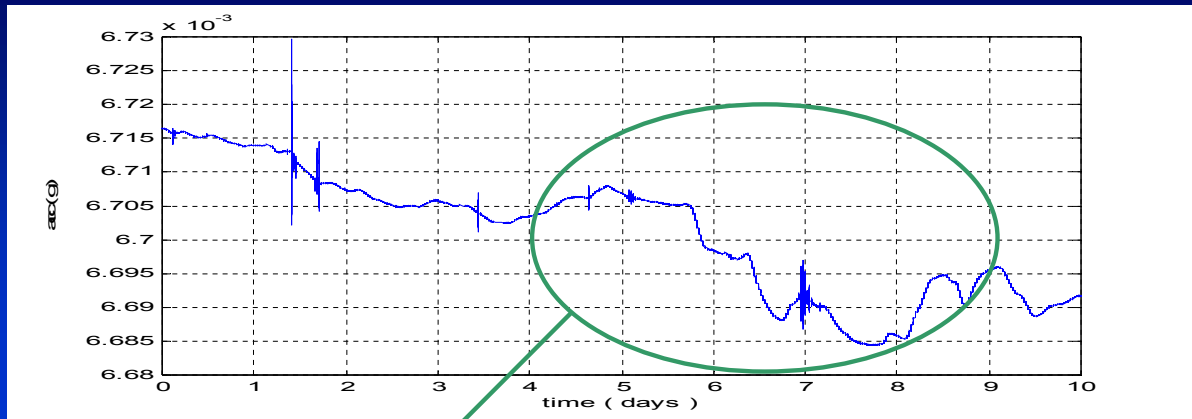
Location: 37° 26,533 ' N, 15° 23,587 E ;
 Depth: 2105 m w.d. (210 atm.)
 Start of acquisition : 9 October , 2002
 End of acquisition: 20 February, 2003
 Gravimeter sampling rate: 1Hz
 Sismometer sampling rate: 100Hz



The SN-1 location is comprised within the Ibleo-Maltese escarpment area, the most important seismogenic structure of the western Ionian Sea.

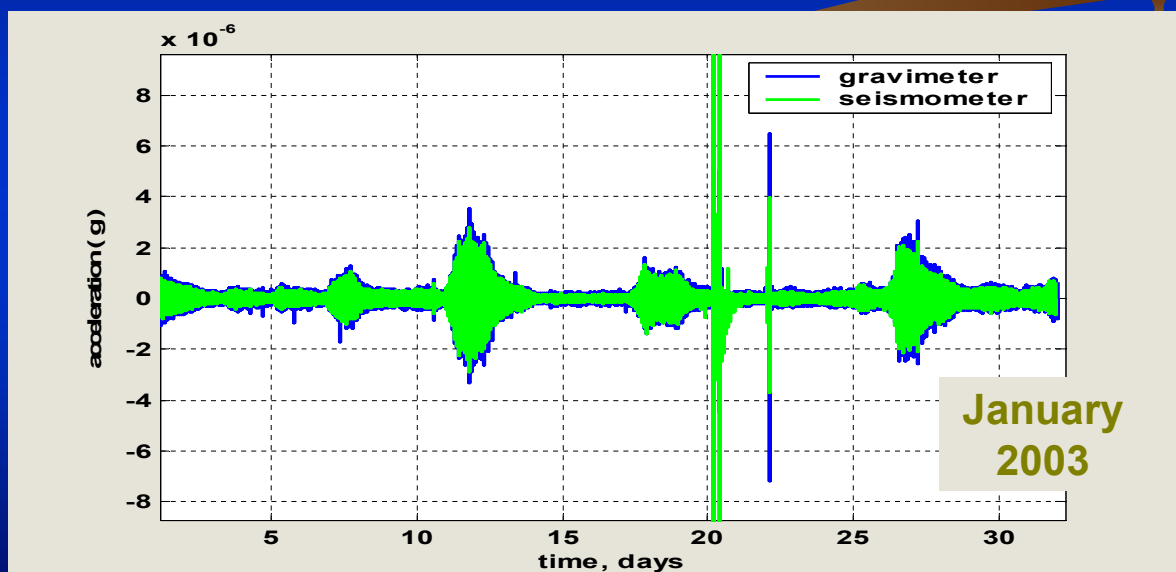
The site is also near the Mt. Etna, the highest and most active volcano in the western Europe, supposed to have two active magma reservoirs with radii of about 2 and 5 Km.

Gravitymeter 28 October - 6 November 2002

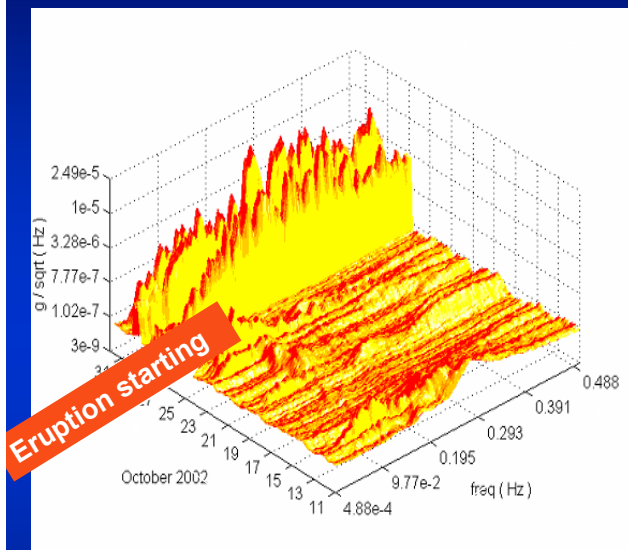


Seismometer and gravity meter signals

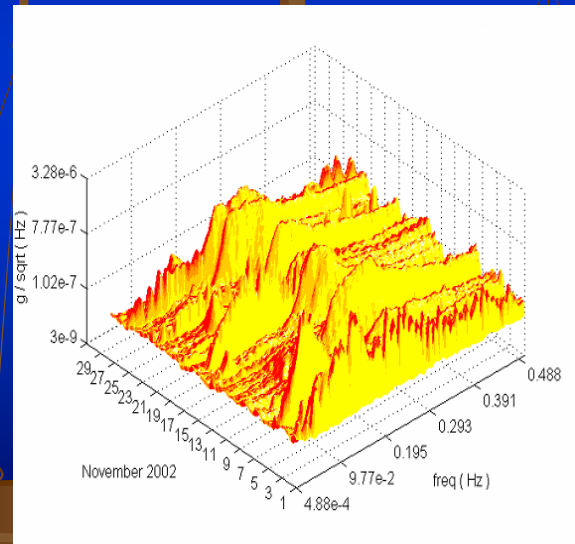
For the comparison, the seismometric signal was derived to be reported in acceleration



Gravitymeter

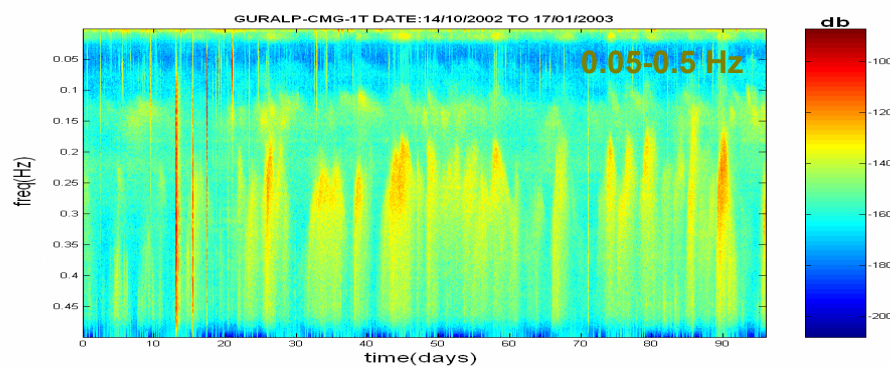
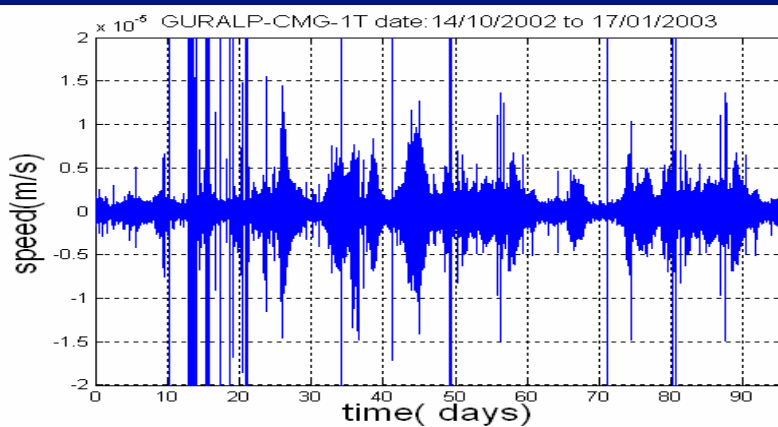


Spectrogram October 2002

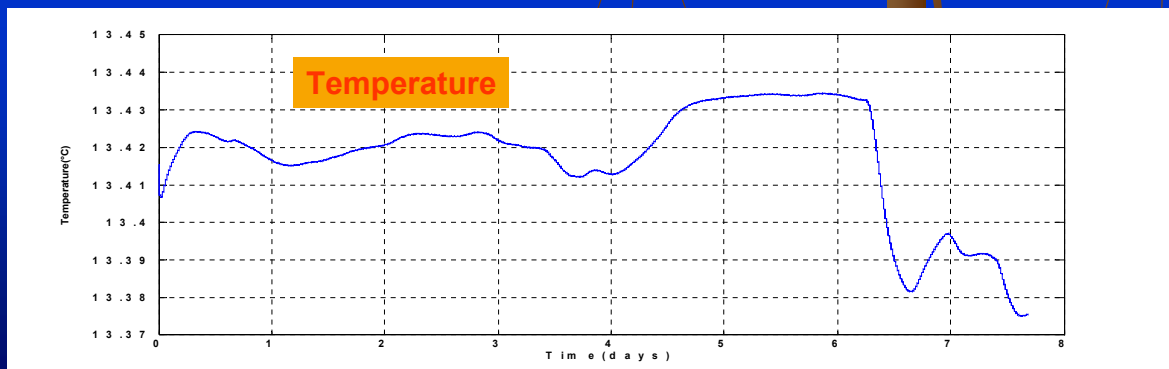
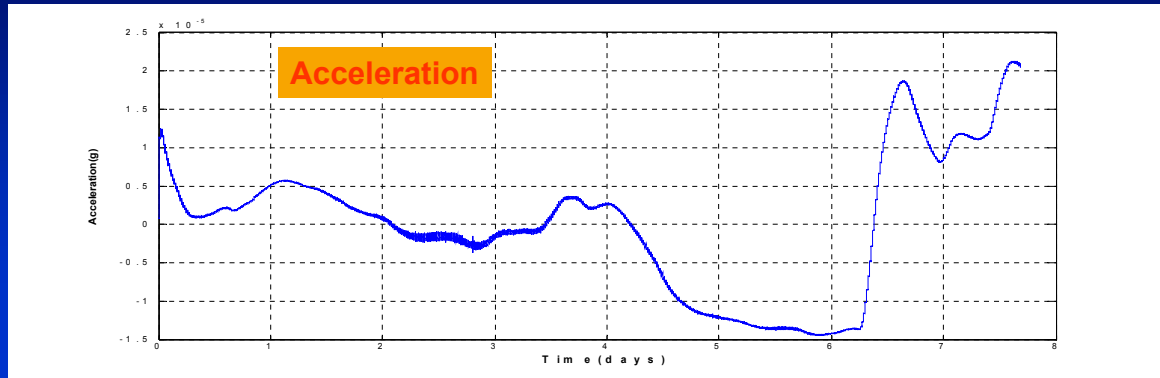


Spectrogram November 2002

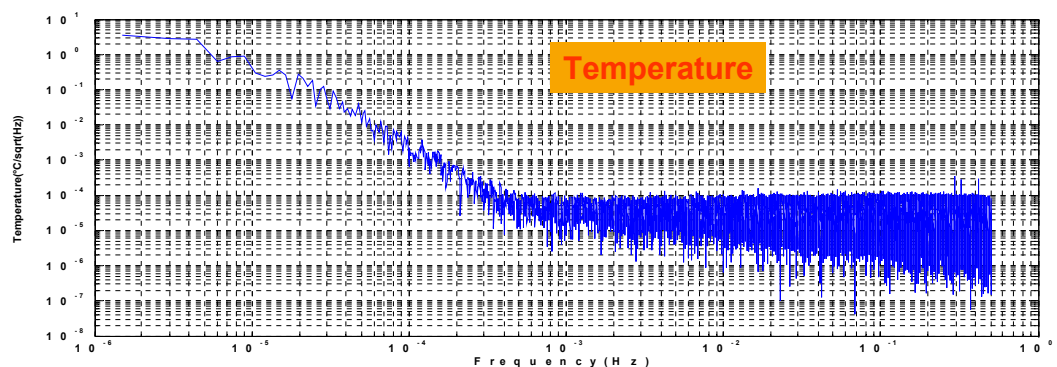
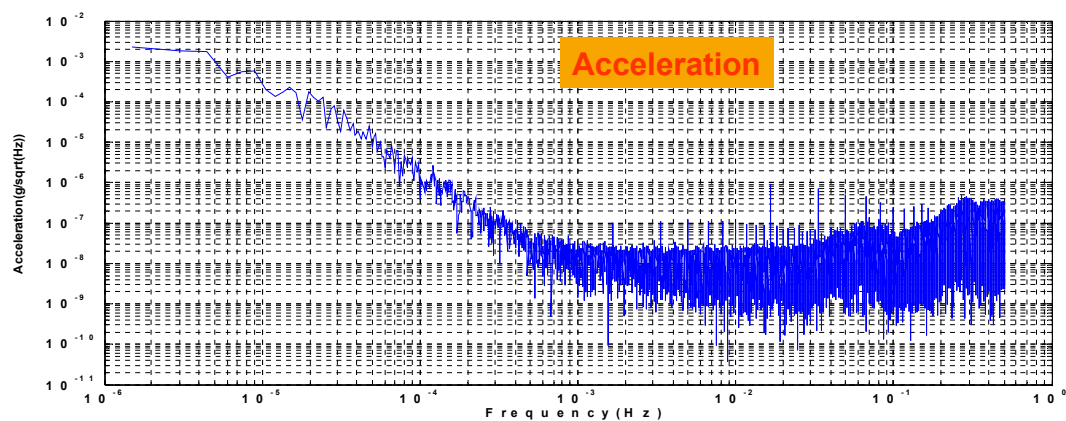
Seismometer Oct. 14 - Jan. 17



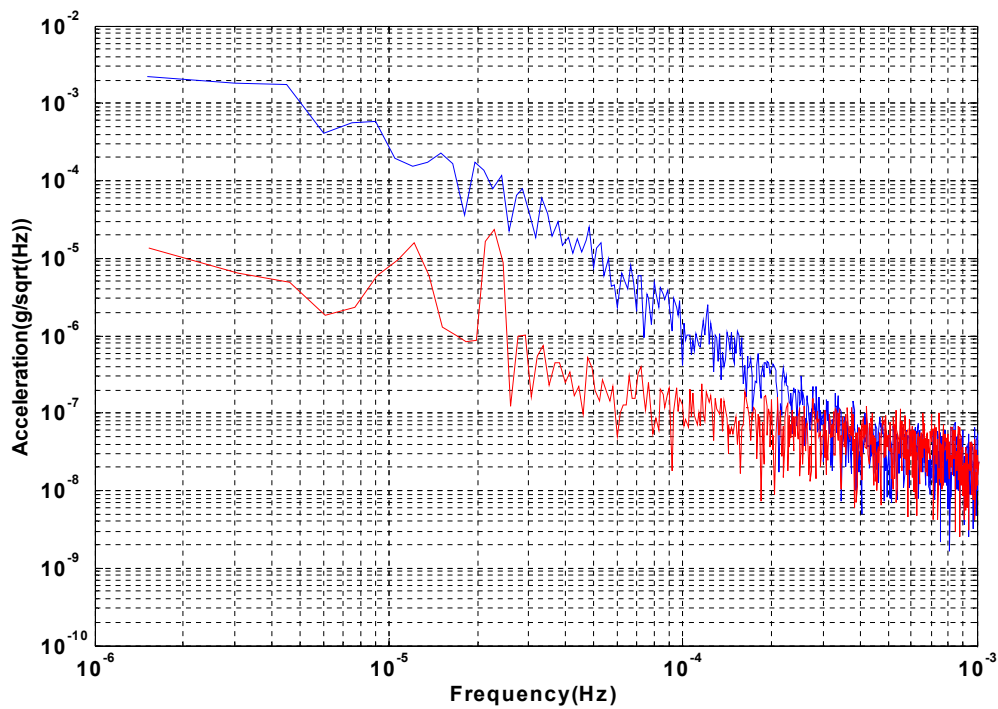
Rejection of the temperature effects using a very sensitive thermometer



Rejection of the temperature effects using a very sensitive thermometer



Rejection of the temperature effects using a very sensitive thermometer



Rejection of the temperature effects using a very sensitive thermometer

