

MoonBase Workshop - Moscow

Absolute Measurement of Free-Fall Acceleration as Reference for Selenodesy Studies and Applications



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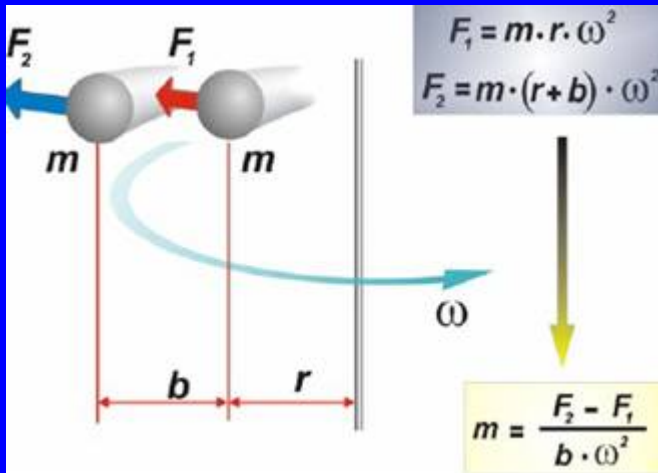
G. Noci

Alcatel Alenia Space – Italia (AAS-I) – Firenze – Italy

- INRIM (AAS-I/ESA) Space Projects Overview
- Selenodesy and lunar gravimetry
- Space Gravimetric Missions Overview
- INRIM Absolute Gravity Meters Evolution
- INRIM - *IMGC-02* Absolute Gravimeter
- INRIM Absolute Gravity Meter Activity
- Future Development

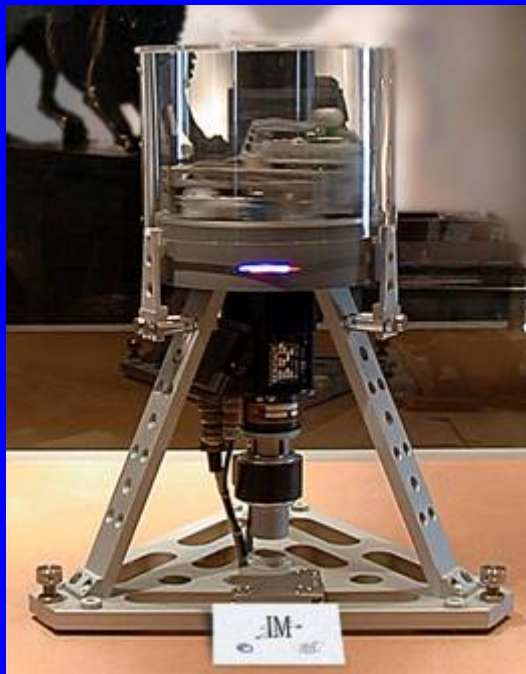
INRIM – National Institute for Research in Metrology
AAS-I – Alcatel Alenia Space - Italy

INRIM Space Projects Overview



Inertial Balance (BIC)

Designed in view of a possible use on board the International Space Station for measuring the mass of little specimens



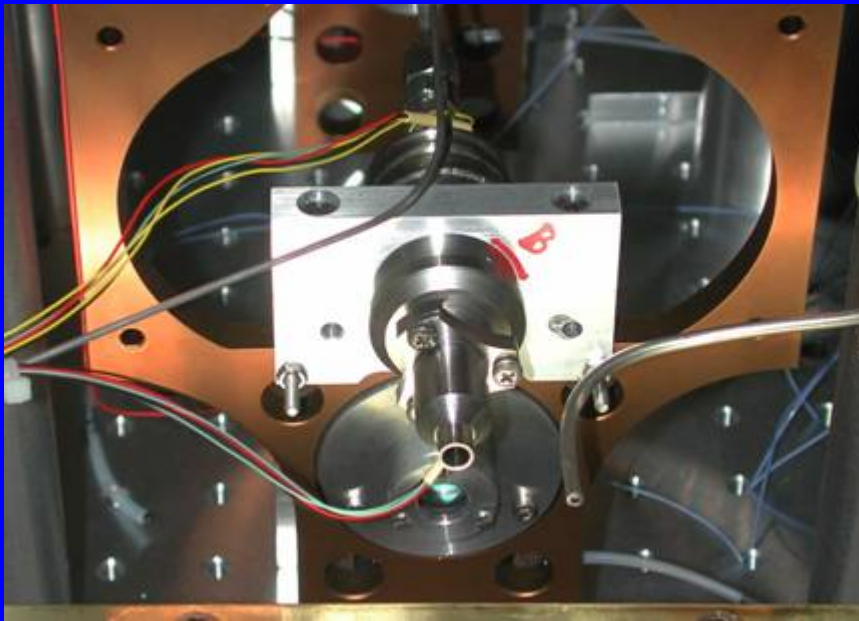
BIC 2

Weight: 70 kg
Full scale: 500 g
Uncertainty: 100 mg
(2×10^{-4} @ 500 g)



BIC 3

Weight: 17 kg Uncertainty: 3 mg
Full scale: 120 g (2.5×10^{-5} @ 120 g)



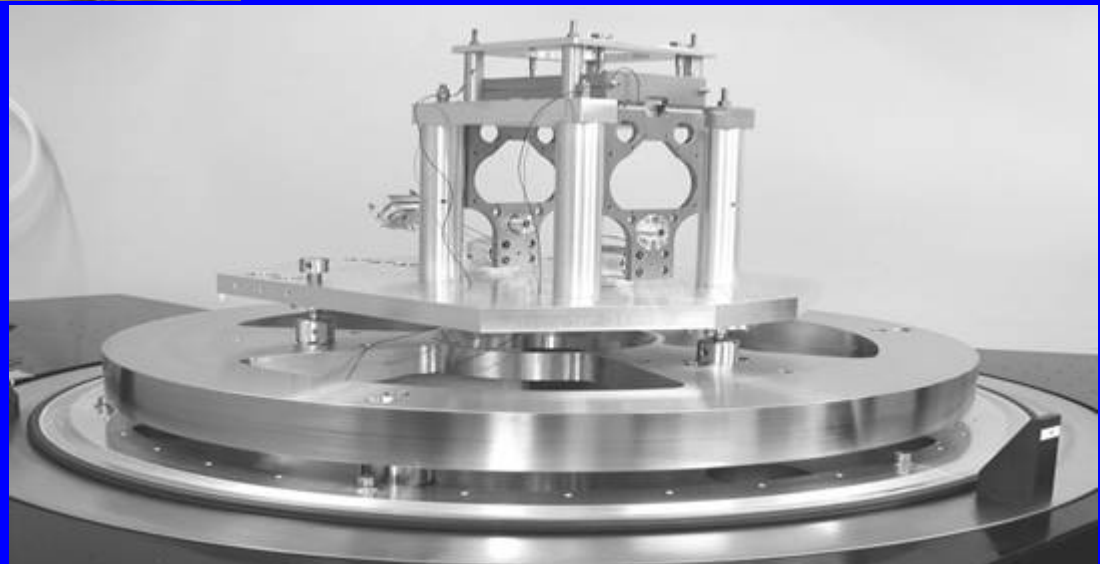
Micro-thrusters

- ✓ Used for spacecraft positioning and orbit adjustments
- ✓ Flow and pressure regulators with piezo technology
- ✓ Under test on nano-balance
- ✓ (INRIM - Alcatel Alenia Space)

Thrust Measurement System

(ESA Contract, 2001-...)

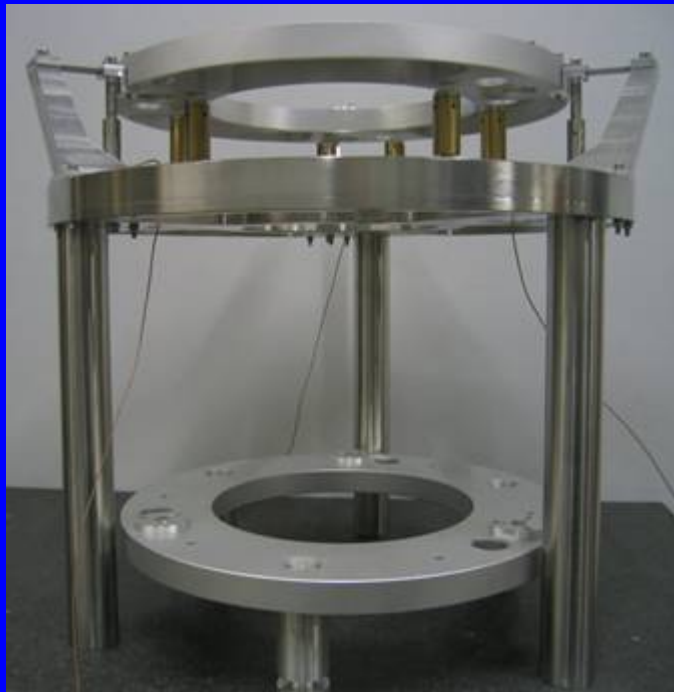
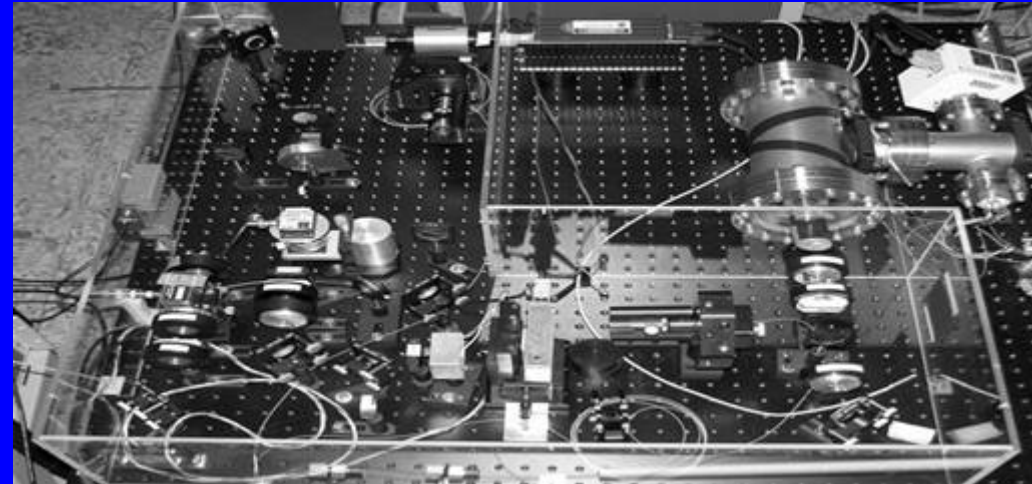
Sub-micronewton resolution thrusters characterization (nano-balance)



Laser Metrology

(ESA Contract, 2003-2005)

Sub-picometer resolution
metrology system
for the GAIA astrometric instrument



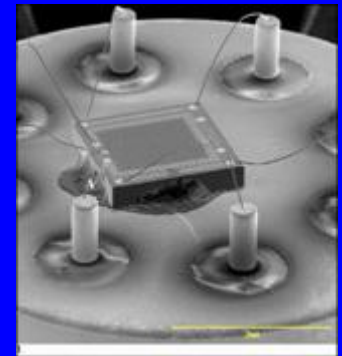
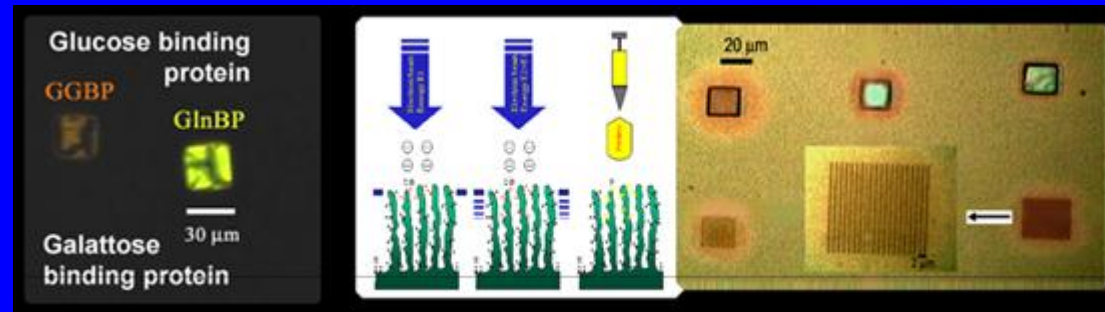
Active Pointing of Large Telescope (ESA Contract, 1997-1998)

Picometer resolution
displacement measurement
for space telescope pointing

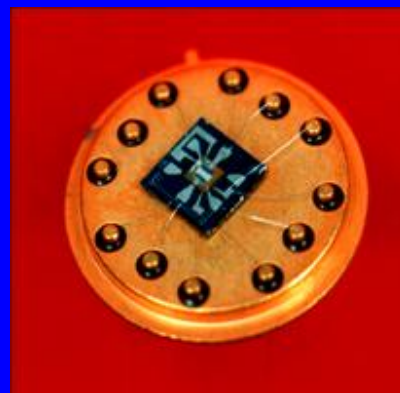
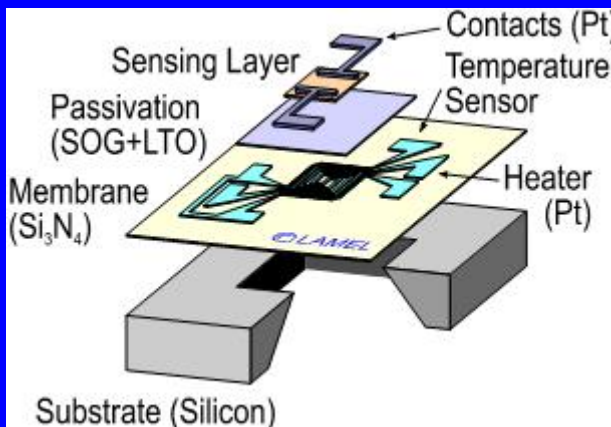
INRIM Space Projects Overview

- Project, fabrication and testing of nanobiosensors for environmental application
- Complete lightweight sensing system for monitoring plant growing in space missions

- ✓ Contamination
- ✓ Real time monitoring of closed environments
- ✓ Shelled light system (Patented)
- ✓ Application of electronic noses to VCOs monitoring



(INRIM-Alcatel Alenia Space) **Humidity**



Ethylene, VOCs



CO2



Color

Gravimetry is the science dealing with the gravitational fields of the Earth and celestial bodies.

Earth => geodesy Moon => selenodesy (lunar gravimetry)

Applications:

- ✓ mission analysis and planning,
- ✓ studies into the figure and internal structure

It is based on measurements. Enhancements in measurement techniques and the possibility to obtain a global set of data => developing precise gravitational field models.

Artificial satellites and advanced electronics => new techniques for studying the gravitational fields of the Earth and planets.

Since the Moon's rotation is in phase with its orbital motion around the Earth tracking from the Earth can never yield the desired global coverage of the lunar surface.

In order to study in greater detail the gravitational field of the Moon, lunar scientists have been calling for a tracking technique giving high accuracy coverage also at higher latitudes and on the far side of the Moon.

Historical tracking data:

- ✓ Lunar Orbiter, Apollo missions (mid-1960s to early 1970s) and Clementine mission (1994)

=> low-resolution representation of lunar gravity fields.

- ✓ Lunar Prospector's Doppler Gravity Experiment (DGE)

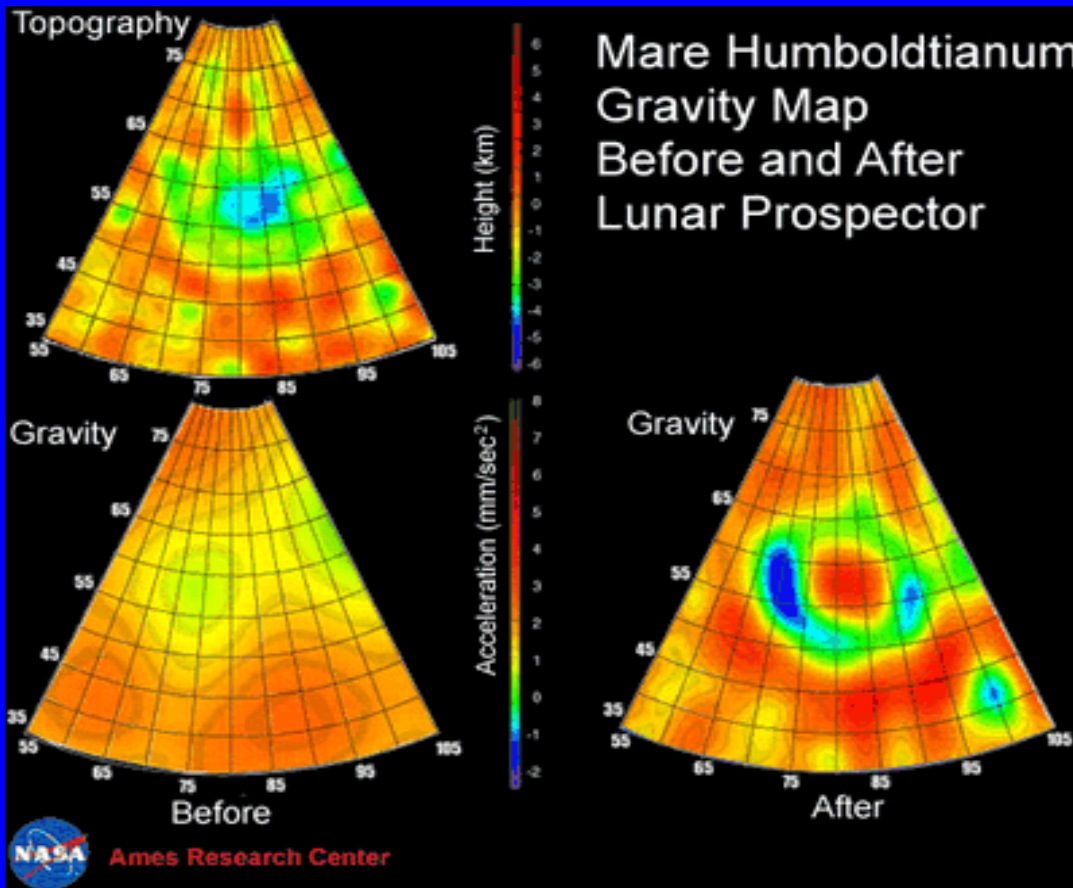
=> first polar low altitude measurement of the lunar gravity field

=> first truly operational gravity map of the Moon and immediately improved orbit and fuel efficiency

Improved gravity information => help also in estimating the lunar core size and metallic iron content.

DGE experiment => more precise gravity map of the Moon

(for planning fuel-efficient journeys to the Moon and identifying potential resources)



Contours of the lunar gravity field, represented by changes in acceleration.

Negative values indicate decreases in what's called the "*central term*" (average surface gravity of 160,000 mGal), in the case of perfectly spherical shape of the Moon were with no density changes across its surface.

(lunar prospector website)

Up to now, harmonics coefficients:

- ⇒ calculated only through Doppler measurements on a single probe orbiting the Moon
- ⇒ only data on the visible side have been obtained
- ⇒ the entire gravity field has been modelled through interpolation of such data

In order to have more precise set of coefficients

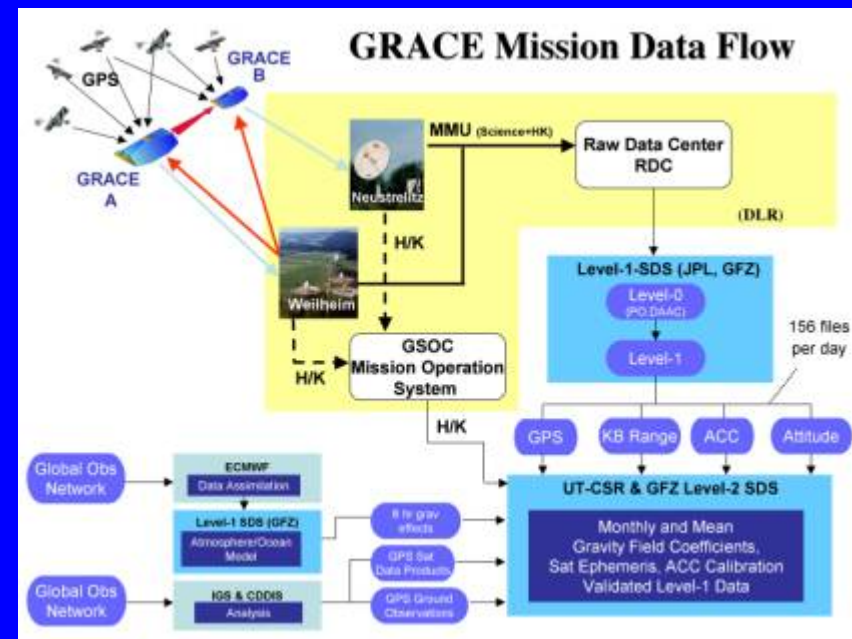
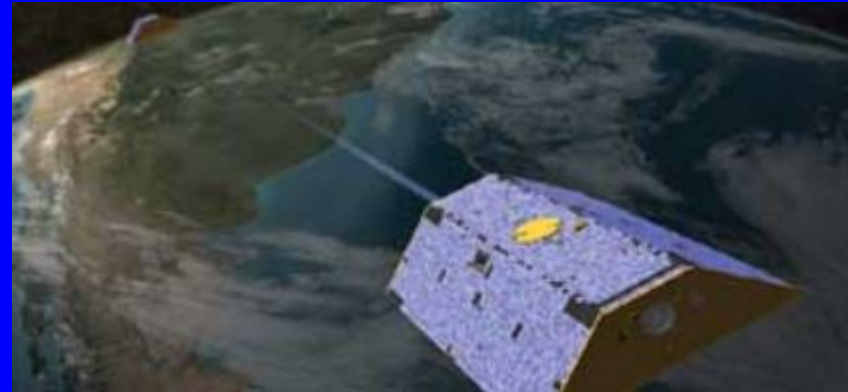
- ⇒ it is necessary to gain experimental data also on the hidden side of the Moon (M. Gregnanin et al. presented a Phase A study of a mission employing two micro-satellites aimed at mapping the lunar gravity field on the hidden side. Using two crafts, a “relay satellite” on a high elliptical orbit and a small “probe” on a low circular orbit (on which the effects of high order harmonics mainly act) it is possible to measure harmonics coefficients up to an order of at least 80.)

At higher order, however, the detailed knowledge of the gravity field of the moon, can be achieved only by means of ground measurement.

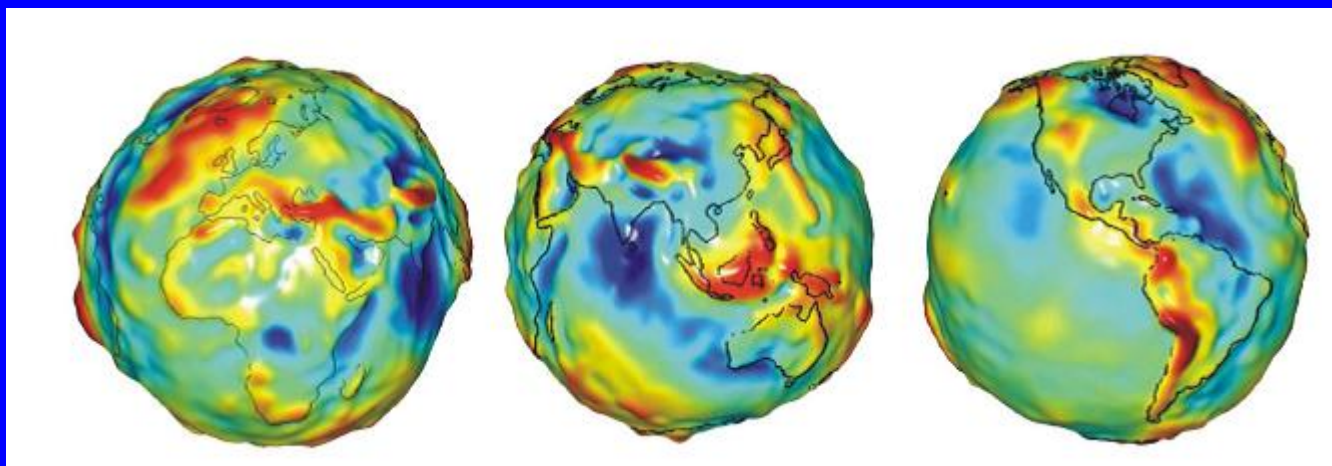
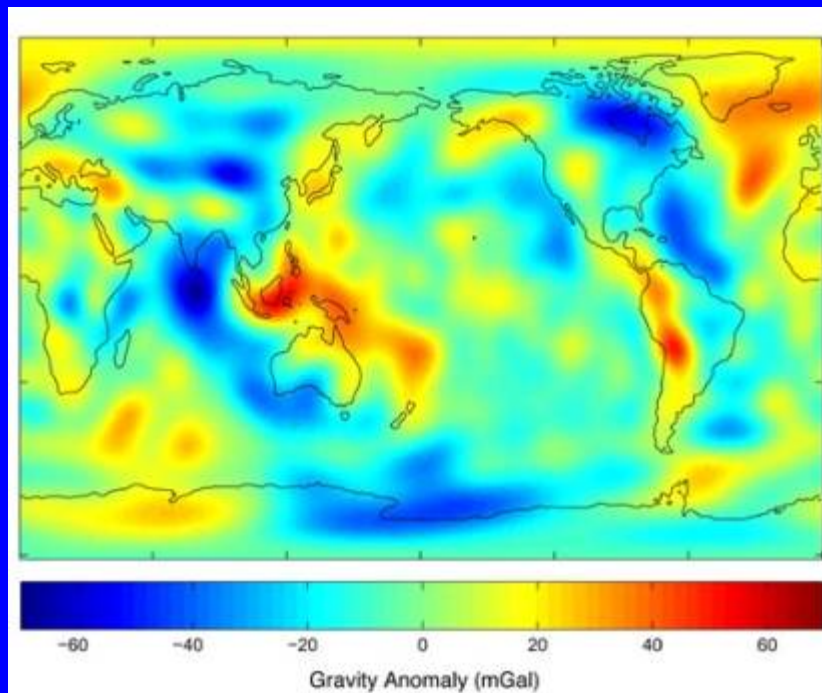
Already in 2000, NASA has evaluated the feasibility of a gravity instrument to be used on Mars.

Space Gravimetric Missions Overview

- On March 2002, a couple of satellites are launched for earth gravitational field measurement
- Satellites fly over the whole earth surface (30 days periodicity)
- Accuracy estimated: 10^{-5} m s^{-2}
- Other space gravimetric missions are expected: e.g. Gravity Field and Steady-State Ocean Circulation Explorer (GOCE)

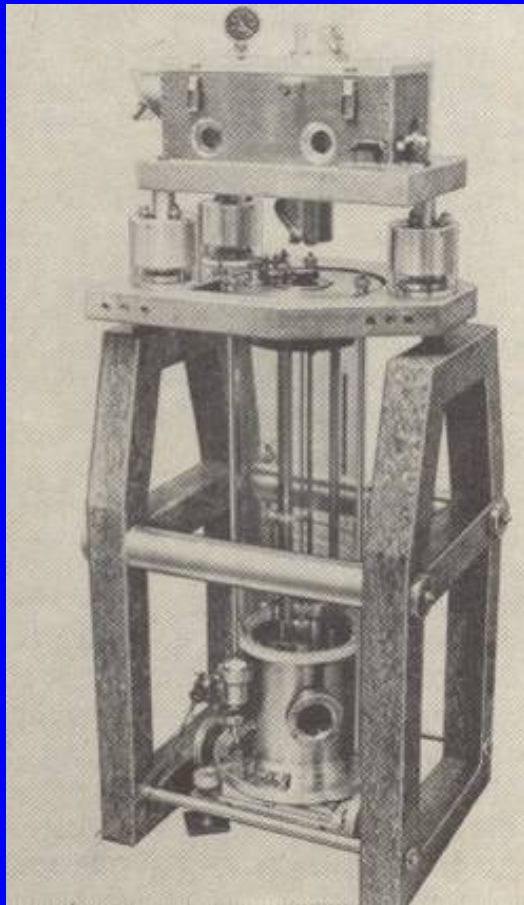


Gravity Recovery And Climate Experiment (GRACE) mission



INRIM Absolute Gravimeter Evolution

- Beginning in the first '70
- Metrology, geodesy
- International comparisons



1974 ...1991



1992 ...

...2002

INRIM Absolute Gravimeter Evolution



2003 ...

The new *IMGC-02* absolute gravity meter adopting the rise and fall method



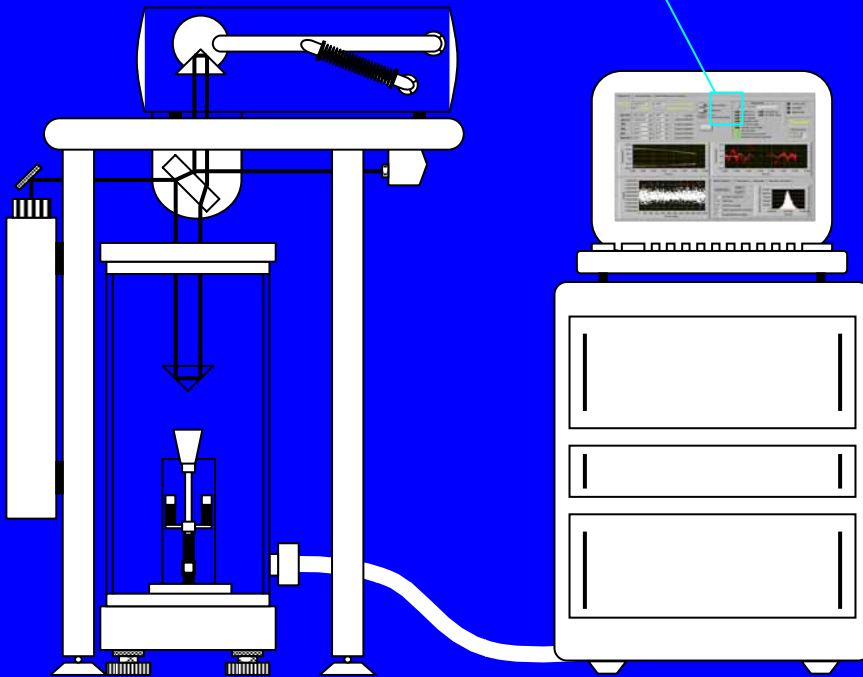
Previous (1992-2003) launch chamber

Present (after 2003) launch chamber

Graphic Interface

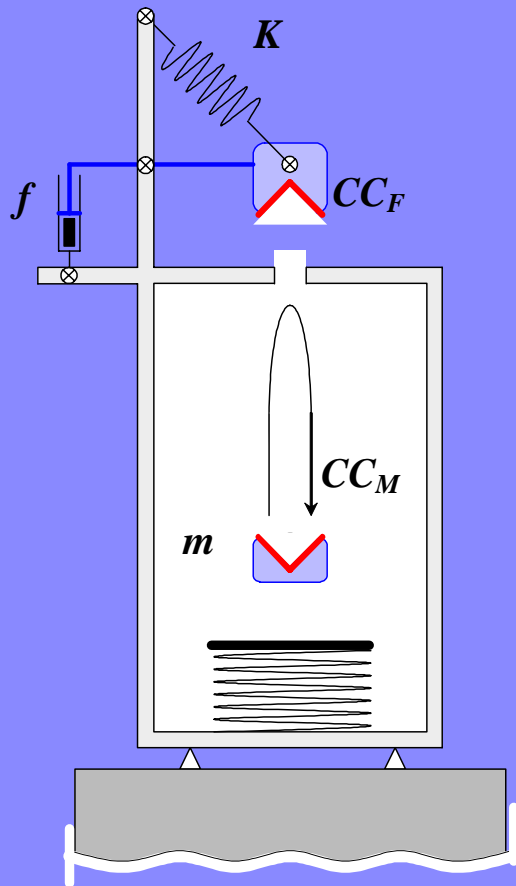


- ✓ Automatic launch system and measurement
- ✓ Experimental data recording
- ✓ 120 launches / h



Launch system

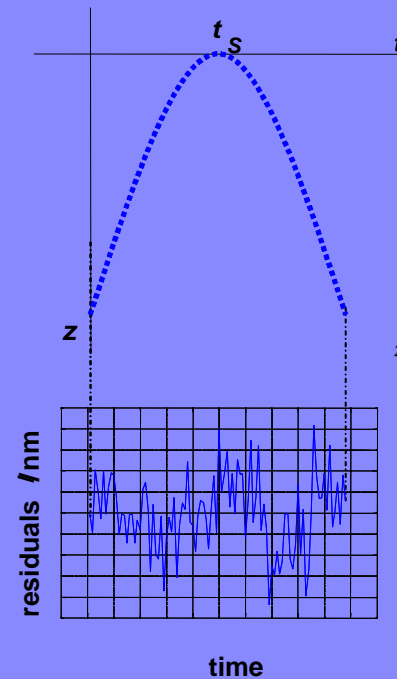
MEASUREMENT PRINCIPLE



Symmetric motion

- ✓ Primary ballistic method
- ✓ Time and length standards

Trajectory Fitting



Position time data



motion model

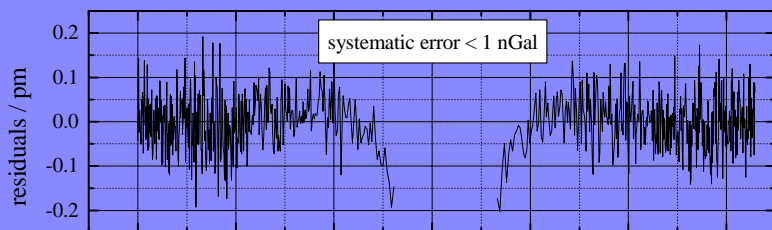
$$z = \frac{1}{2} g_s (t - t_s)^2 - \frac{\varphi}{6} g_s (t - t_s)^3 + \frac{\gamma}{24} g_s (t - t_s)^4$$



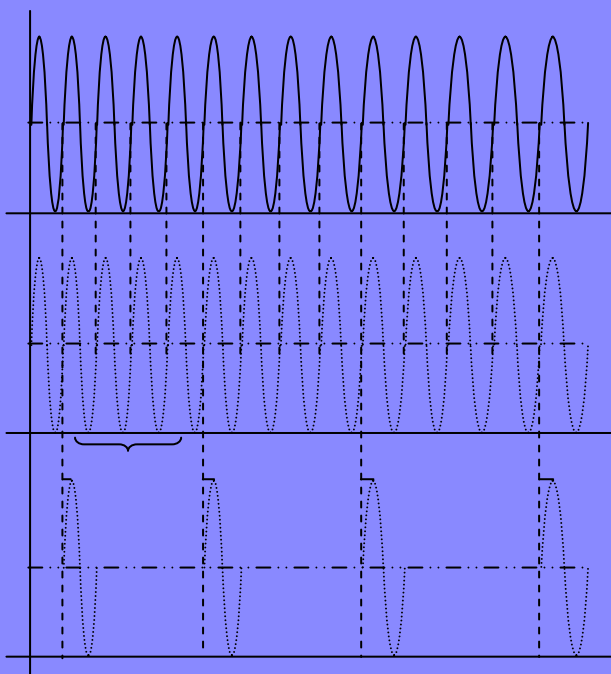
total least squares algorithm



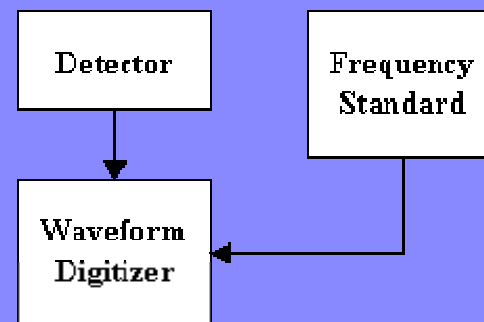
g, σ_g



Numeric errors



fringes sampling

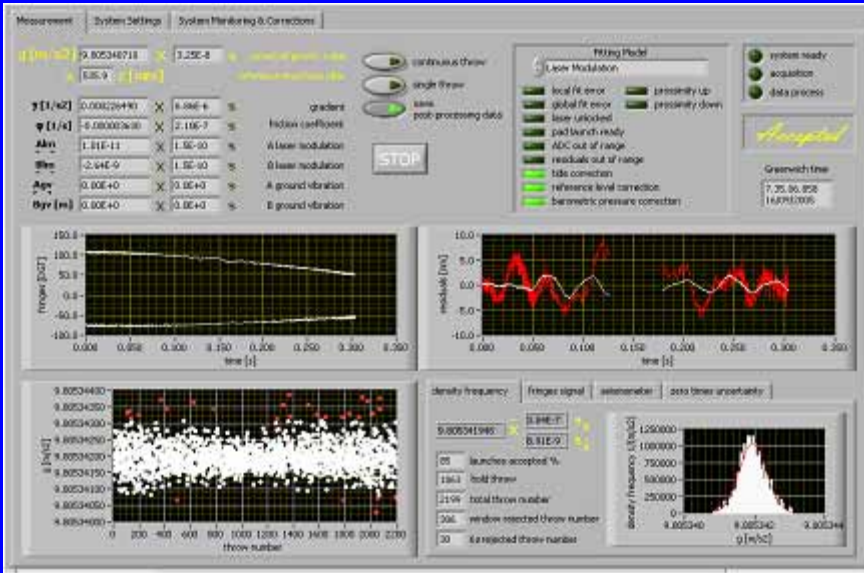


Measurement block diagram

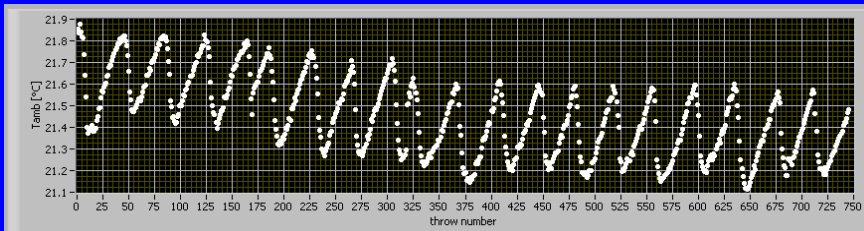
- ✓ Signal frequency independent delay
- ✓ Algorithm validation by data simulation

INRIM - IMGC-02 Software Control

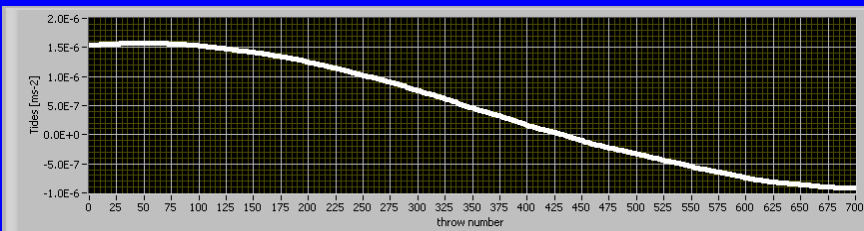
- Gravisoft_M_1.0 measurement software
- Gravisoft_PP_1.0 processing software



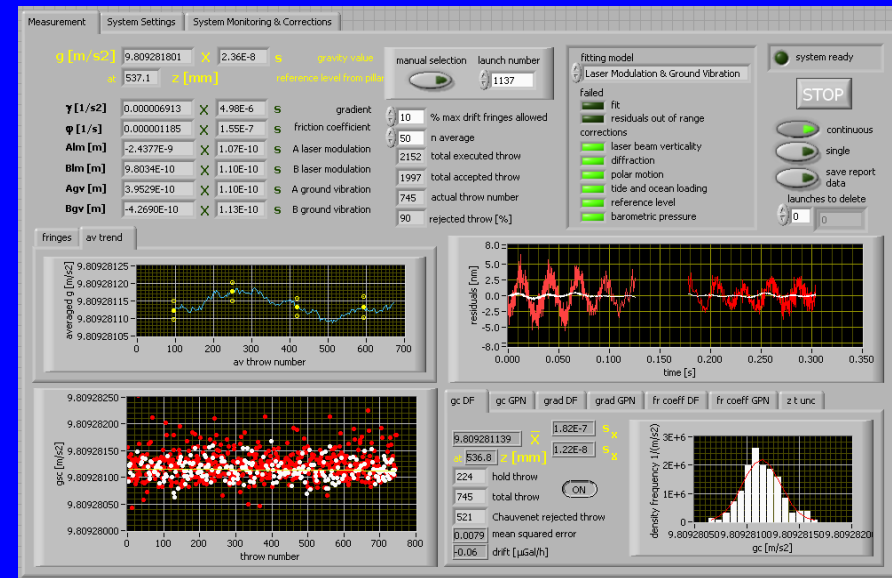
Gravisoft_M_1.0



Environmental temperature



Gravimetric tides



Gravisoft_PP_1.0

INRIM - IMQC-02 Instrumental Uncertainty

Influence parameters, x_i	Value	Unit	u_i or a_i	Type A, s_i	Type B, a_i	Δg	Type of distribution	Equivalent variance	Sensitivity coefficients $c_i = \frac{\Delta g}{\Delta x_i}$	Contribution to the variance $u_i^2(g) = c_i^2 u_i^2(x_i)$	Degrees of freedom, ν_i	Equivalent standard uncertainty
Drag effect			negligible									
Outgassing effect			negligible									
Non-uniform magnetic field effect			negligible									
Temperature gradient effect		m·s ⁻²	±1,5E-09		1,5E-09		U	1,1E-18	1,0E+00	1,1E-18	10	1,1E-09
Effect for Electrostatic			negligible									
Mass distribution effect		m·s ⁻²	±5,0E-09		5,0E-09		rectangular	8,3E-18	1,0E+00	8,3E-18	10	2,9E-09
Laser beam verticality correction	6,6E-09	m·s ⁻²	±2,1E-09		2,1E-09	6,6E-09	rectangular	1,5E-18	1,0E+00	1,5E-18	15	1,2E-09
Air gap modulation effect			negligible									
Laser accuracy effect		m·s ⁻²	1,0E-09	1,0E-09				1,0E-18	1,0E+00	1,0E-18	30	1,0E-09
Index of refraction effect			negligible									
Beam divergence correction	1,14E-07	m·s ⁻²	1,1E-08	1,1E-08		1,14E-07		1,2E-16	1,0E+00	1,2E-16	10	1,1E-08
Beam share effect	unknown		unknown									
Clock effect		m·s ⁻²	6,0E-09	6,0E-09			rectangular	3,6E-17	1,0E+00	3,6E-17	30	6,0E-09
Finges timing effect			negligible									
Finite value of speed of light effect			negligible									
Retroreflector balancing	0,0E+00	m	±1,0E-04		1,0E-04		rectangular	3,3E-09	6,3E-04	1,3E-15	15	3,6E-08
Radiation Pressure effect			negligible									
Reference height	5,2E-01	m	±5,0E-04		5,0E-04		rectangular	8,3E-08	3,0E-06	7,5E-19	30	8,7E-10
						1,21E-07	m·s ⁻²	Variance $u^2(g) \approx \sum_{i=1}^N u_i^2(g)$		1,5E-15	m ² ·s ⁻⁴	
						Combined standard uncertainty, u				3,8E-08	m·s ⁻²	
						Degrees of freedom, ν_{eff} (Welch-Satterthwaite formula) $\frac{u^4(y)}{\nu_{eff}} = \sum \frac{u_i^4(y)}{\nu_i}$				19		
						Confidence level, p				95%		
						Coverage factor, k (calculated with t-Student)				2,10		
						Expanded uncertainty, $U = ku$				8,1E-08	m·s ⁻²	
						Relative expanded uncertainty, $U_{rel} = U/g$				8,2E-09		

- Absolute measurement for establishment and setting of Italian fundamental gravimetric network
- Taking part with Calibration for International Gravity System (IGSN'71)
- Taking part with Calibration for gravimetric network of other countries (Germany, Austria, Switzerland, Greek, China,...)
- Taking part with national and international projects
- Periodic monitoring for italian volcanic area (Etna, Eolie, Vesuvio, Campi Flegrei, Ischia, Castelli Romani)
- Gravity relationship with weighting
- Regularly participating to International Comparisons of Absolute Gravimeters

INRIM Absolute Gravity Meter Activity

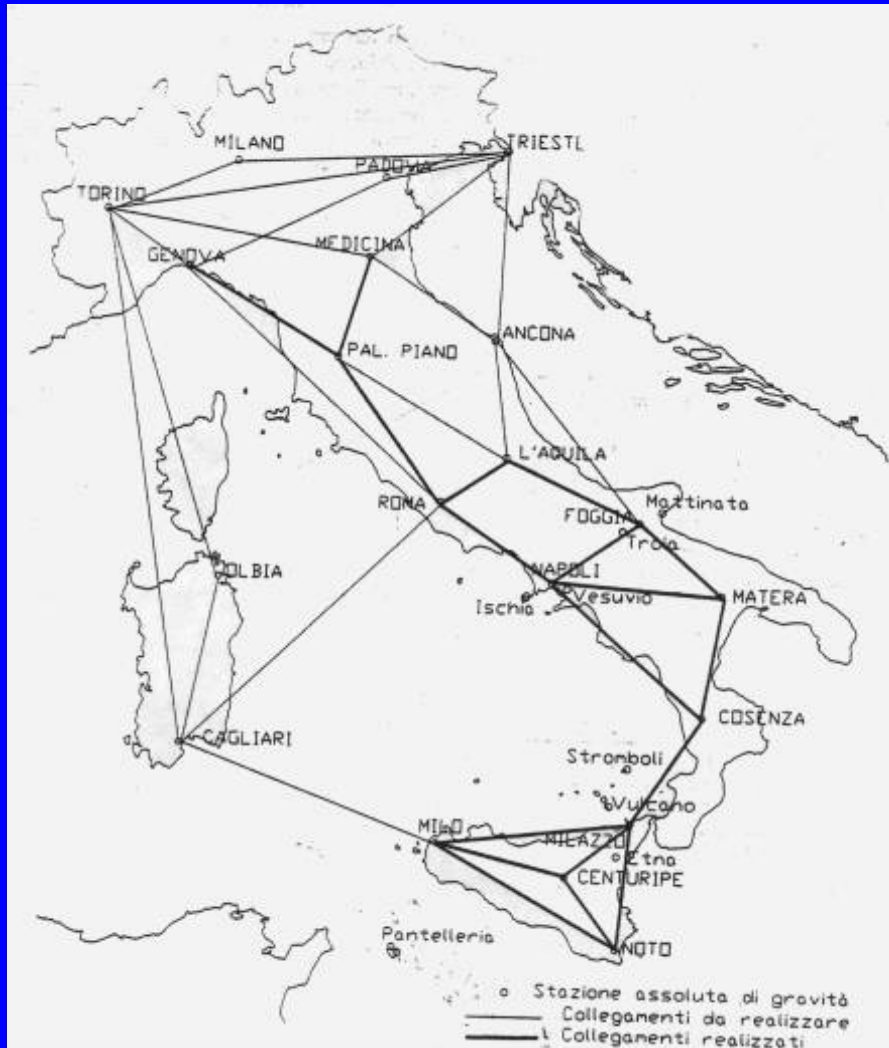
Absolute measurements in Antarctica
Italian base of Terra Nova – 1990/1991

ENEA - PROGETTO ANTARCTICE - ITALY
GRAVIMETRIC BASE STATION
POINT: A
SPITAGLIH ANTARCTIC EXPEDITION 1987/88

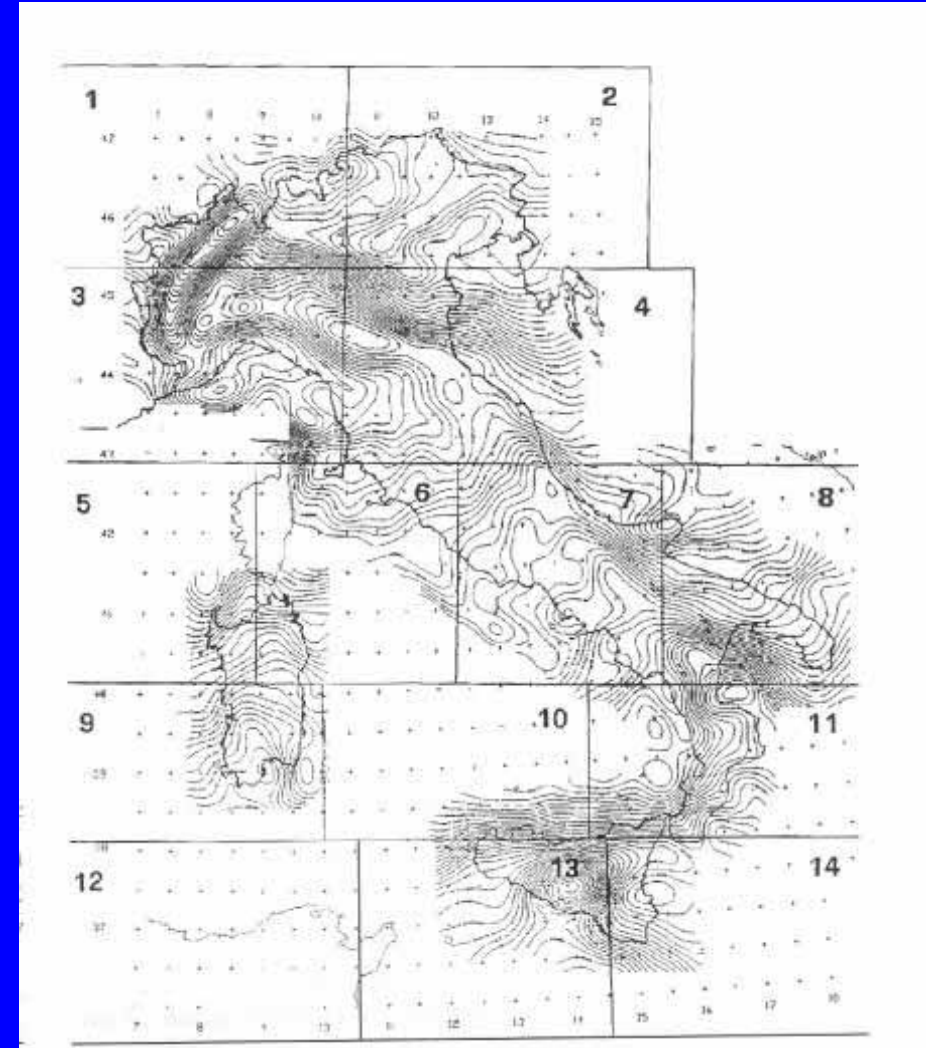


INRIM Absolute Gravity Meter Activity

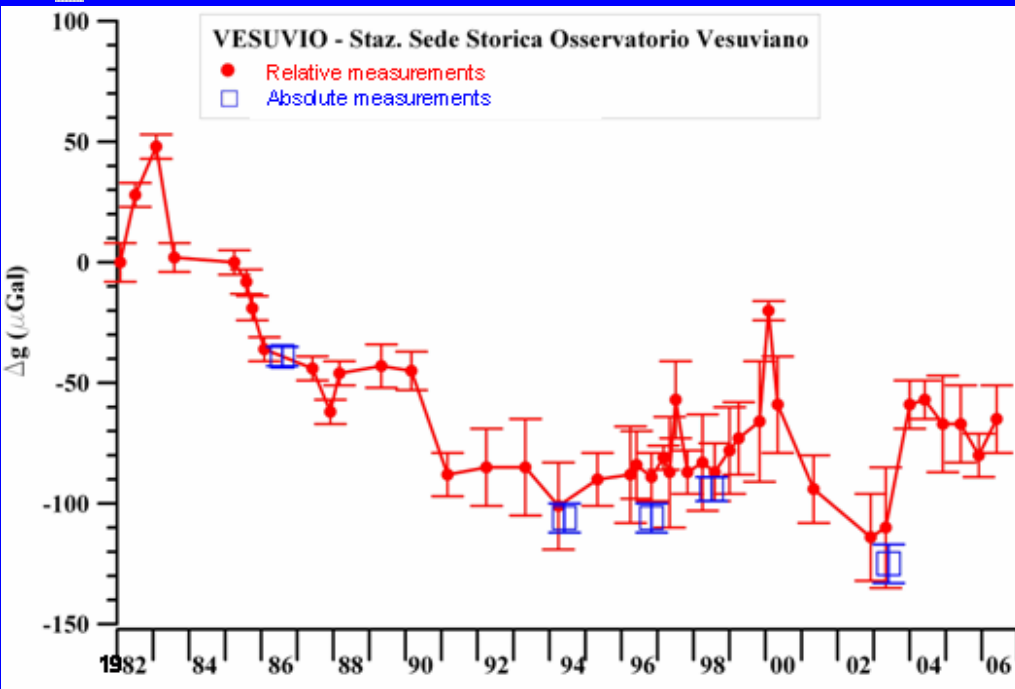
Absolute stations for the Zero order italian gravimetric network



Isometric contour of g



INRIM Absolute Gravity Meter Activity

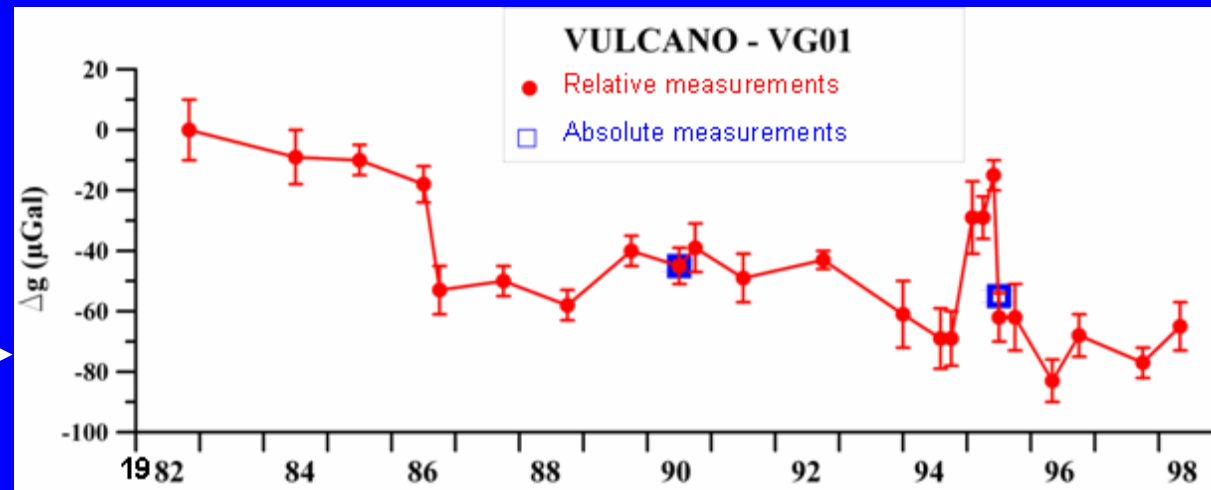


Gravimetric measurements for the past 20 years, confirm that absolute and relative measurements of g are both necessary to discriminate brief and long term variations

Naples (Vesuvio)



Aeolian Islands (Vulcano - Milazzo)



- Increasing interest for applications in Geophysics and Volcanology gives rise for the necessity of an instrument available to any kind of measurers

- A new absolute transportable country gravity meter is under study with the following characteristics
 - ✓ Simple assembly and installation
 - ✓ Low weight and size
 - ✓ Low power consumption
 - ✓ Full automatic control, measurement and processing

- Interest goes forward...

- Increased interest and necessity of absolute gravity measurement as tangible tool for investigating
 - ✓ Geological strata
 - ✓ Phreatic surface
 - ✓ Geological, tectonic and magmatic dynamics
 - ✓ Gravimetric tides

- Absolute g measurement on the Moon as reference for:
 - ✓ selenodesy studies and applications
 - ✓ support for infrastructural human activity
 - ✓ scientific exploration

- The country absolute gravimeter under study is the base for future development of a lunar absolute gravimeter