Observatory Superconducting Gravimeter

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Contents

1. Gravimetry laboratory.

The CDT-Yebes Gravimetry Laboratory hosts some of the most accurate state of the art gravimeters in the world.

Specially designed to host gravimeters given the delicacy of these instruments and their high sensitivity, presents a very controlled thermal behavior (double chamber with air conditioning system in the external one) and structural behavior (isolated concrete pillars). We offer this laboratory for future RICAGs (regional AG comparisons, up to 6 instruments).

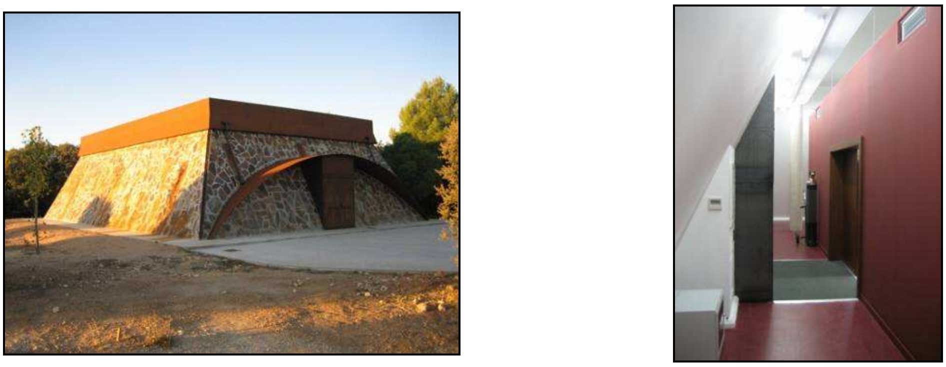


fig. 1 Gravimetry laboratory

Instrumentation:

- GWR OSG (Superconducting Gravimeter) is permanently installed in the laboratory.

fig. 2 Observatory Superconducting Gravimeter

Besides, the following instrumentation is available (not always installed in the Gravimetry laboratory because they participate in different measurement projects).

- FG5 absolute gravimeter.
- A10 absolute gravimeter.
- L&R (LaCoste and Romberg) relative gravimeter.
- gPhone, Scintrex.

fig. 3 Gravimeters (FG5, A10 and Scintrex)

Auxiliary instrumentation.

- Seismometers.
- GNSS stations.
- H maser for clock measurement/calibration.
- Maintenance stuff.

CDT Yebes participate in the international organizations/projects related with Gravimetry Science (GGP, AGrav, ECAG, ICAG).

fig. 4 GWR-OSG and FG5 installed in Yebes

2. OSG principles of operation.

A spherical superconducting mass is levitated using a magnetic force that exactly balances the force of gravity. The superconducting property of zero resistance allows the currents that produce the magnetic field to flow forever without resistive loss as long they are kept below a critical temperature. This explains the extreme stability of the sensor and hence the name –Superconducting Gravimeter (SG).

fig. 5 OSG dewar, vibration isolation frame and refrigerator

Other relative gravimeters and seismometers are based on a test mass that is suspended by a spring attached to the instrument support. A change in gravity or motion of the ground moves the test mass and this motion generates a voltage that becomes the output signal (velocity or acceleration). Even in a thermally well-regulated environment the mechanical aspects of a spring suspension causes erratic drift that is difficult to remove by post processing. The SG solves the drift problem by replacing the mechanical spring with the levitation of a test mass using a magnetic suspension.

Next figure shows a diagram of the GSU; the three major superconducting elements are the levitated mass (sphere), the field coils, and the magnetic shield. The displacement transducer is formed by a capacitance bridge that surrounds the sphere and is sealed with a partial pressure of helium gas in a separate cavity inside the coils. The field is generated by two niobium wire coils (superconducting below a temperature of 9.2 °K) that carry, in principle, perfectly stable and persistent superconducting currents to provide an extremely stable magnetic field. The stability depends on the zero resistance property of superconductors –after the currents are “trapped” no resistive (ohmic) loses are present to cause them to decay in time. The test mass is a small 2.54 cm diameter sphere, also made of niobium, that weighs about 5 grams. The coils are axially aligned;

one just below the center of the sphere and one displaced about 2.5 cm below the sphere. When current is trapped in the coils, currents are induced on the surface of the sphere. As with the currents in the coils, the induced currents are perfectly stable in the absence of any ohmic losses.

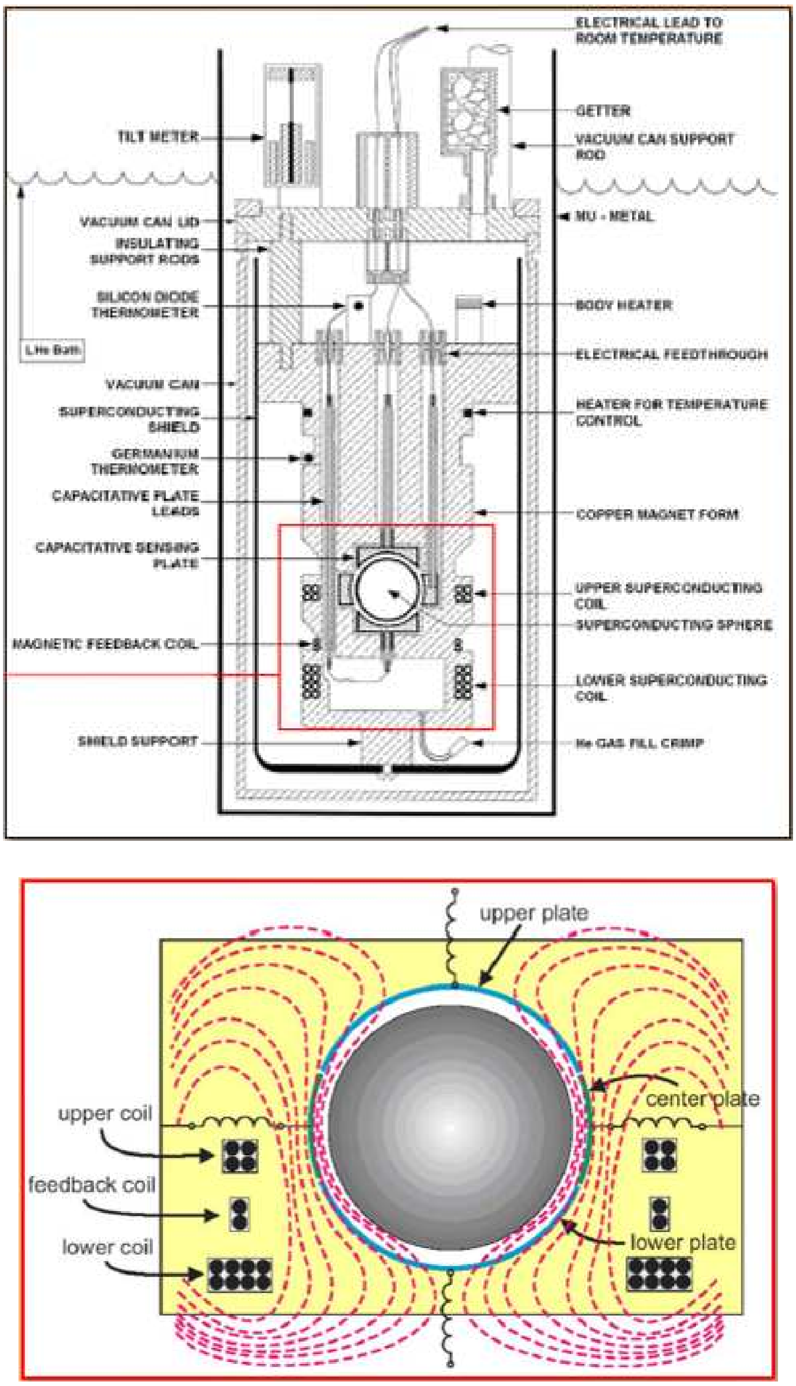


fig. 6 Gravity Sensing Unit (GSU) and conceptual drawing of flux lines, plates and Nb sphere

The levitation force is produced by the interaction between the magnetic field from the coils and the currents induced on the surface of the superconducting sphere. The figure above shows a schematic of the sphere, coils, capacitance bridge, and magnetic flux lines induced on the surface of the superconducting sphere. The current in the coils can be precisely adjusted to balance the force of gravity on the sphere at the center of the displacement transducer. The ratio of currents in upper and lower coils is adjusted so that the magnetic force gradient (spring constant) is very weak. As a result, a very small change in gravity (acceleration) gives a large displacement of the test mass. This allows for the instrument to achieve very high sensitivity. Because the levitation is magnetic, changes in the Earth's magnetic field would seriously degrade its stability. A superconducting shield is used to exclude the earth's magnetic field from entering the space where the sensor is housed.

To maintain superconductivity, the SG sensor operates in liquid helium at 4 Degrees Kelvin inside a highly efficient vacuum insulated Dewar.

An OSG uses a 4 °K refrigeration system that uses only 1.3 kW to operate. The 4 °K coldhead liquefies helium gas in the Dewar neck and returns it to the Dewar storage volume.

The Dewar-Coldhead operate as a "closed cycle system" that can operate indefinitely without the need for refilling. No Liquid Helium refills are needed! New advances in the iGrav™ Dewar allow for cool down from room temperature in a matter of days!

At cryogenic temperatures all materials are extremely stable and the sensor can be temperature regulated to a few micro-Kelvin. Therefore, material "creep" and sensitivity to local temperature and humidity changes are totally eliminated.

3. Subsystems.

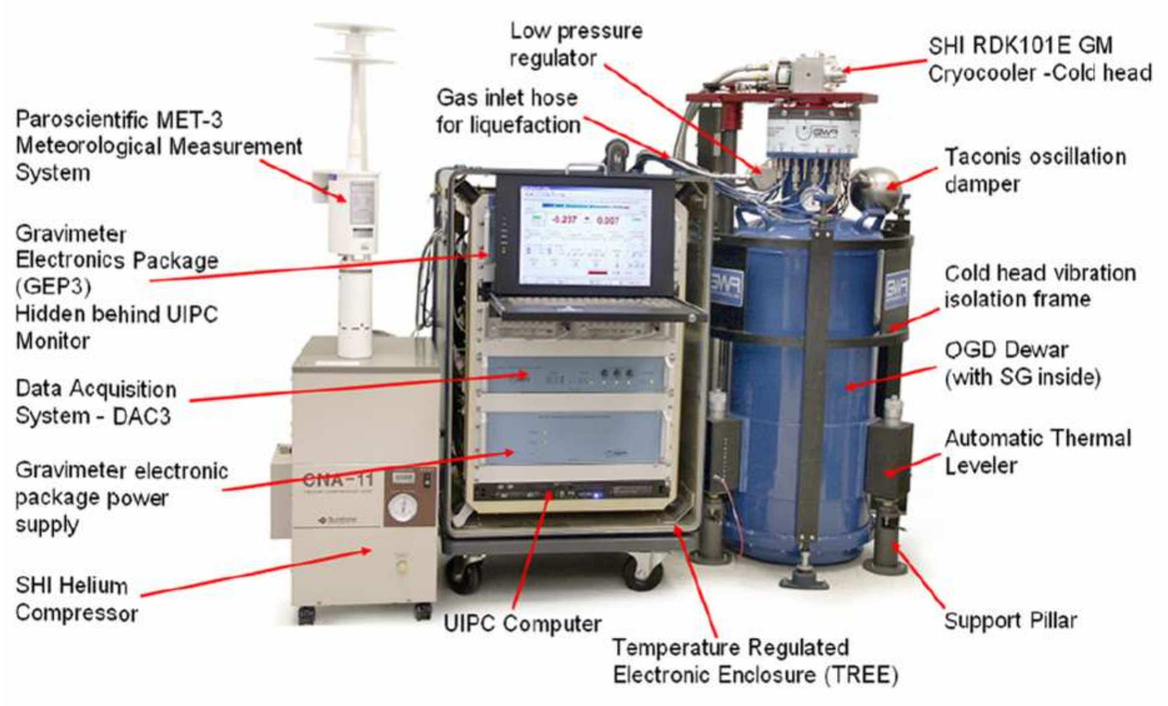


fig. 7. OSG subsystems

3.1. OSG Dewar and Refrigeration System

The OSG sensor is kept at 4 K inside a highly efficient super-insulated and evacuated 35 L helium dewar. The dewar is cooled by a Sumitomo 4 K closed cycle refrigeration system that consists of the RDK-101 Coldhead (expander) and a CNA-11C Compressor unit that is attached to the coldhead via flexible stainless steel pressure hoses and a power cable**.** The Figure shows the coldhead inside the dewar and with it removed. The coldhead uses a modified Gifford McMahon cycle for cooling and is supplied high pressure helium gas by the compressor. The gas entering the coldhead is first pre-cooled by exhaust gas and then cools further when it is allowed to expand. The RDK-101 coldhead has two cooling stages referred to as the first or upper stage and the second or lower stage. During normal operation near atmospheric pressure, the second stage operates close to 4.2 K where it produces 0.1 W of cooling power and the first stage operates at 45K where it produces about 1 W of cooling power. The important point is that the second stage has plenty of excess power so that it can cool well below 4.2 K. This means that any gas that boils off from the belly will be liquefied at the second stage and will drip back into the belly. In this way, no helium is lost during normal operation. During power failures or when the refrigerator is turned off the helium loss rate is about 5% per day. In these cases, the SG sensor will remain cold at 4 K for 20 days. With this safety margin neither refrigeration maintenance nor refrigeration failure should interfere with achieving a long continuous gravity record. Nonetheless, since refrigeration is so critical to continuous operation, GWR highly recommends that a spare refrigeration system is kept at each observatory site.

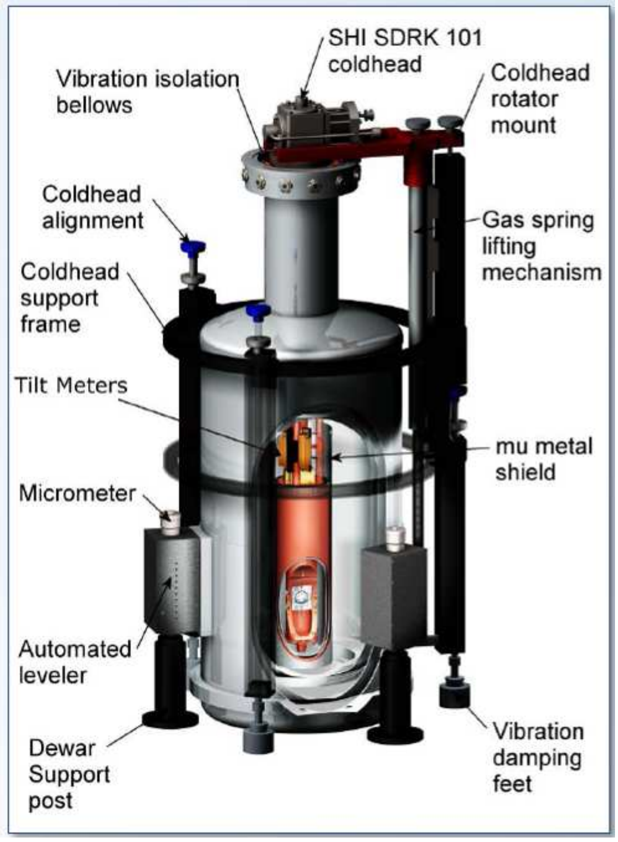


fig. 8 Cutaway view of dewar showing sensor mounted inside

3.2. Coldhead Vibration Isolation

In order to prevent the mechanical vibrations of the coldhead from disturbing the gravity measurement, the coldhead is mechanically de-coupled from the dewar. At the head of the SG a thin diaphragm is used to isolate the coldhead from the dewar while maintaining a gas-tight seal. An external frame with rubber feet supports the coldhead inside of the neck of the dewar and positions it so there is no tension on the diaphragm. The coldhead support frame incorporates a spring-activated slide mount that lifts the coldhead vertically out of the dewar. The slide mount guides the coldhead during insertion or removal so that it does not contact the inside of the neck. This minimizes disturbances and prevents offsets in the gravity record during coldhead maintenance which must be at one to two year intervals.

Figure 6: OSG Dewar and Refrigeration System shown with the coldhead lifted out of the dewar. The compressor is connected to the coldhead with flexible metal hoses and a power cable.

fig. 9. OSG dewar and refrigeration system shown with the coldhead lifted out of the dewar

3.3. Cryogenic Tiltmeters and Automatic Leveling System

When making high precision gravity measurements it is crucial that the sensor be kept precisely aligned with the gravity vector **g**. When a gravity meter is tilted by an angle θ, the component of gravity along its axis changes in magnitude by $g\cos(\theta - \theta_0)$, where at angle $\theta = \theta_0$ the sensor is aligned with the vertical. For small angles, the decrease in gravity is $g(\theta) = (g*\cos(\theta - \theta_0) - g) \approx g(\theta - \theta_0)^2/2)$ or about 10^{-3}µGal/(µRadian)^2. Local tilts are common on floors or piers where gravity meters are located. Tilts can be caused by the settling of the underlying substrate, varying substrate density, heating and cooling of the support platform, solar heating on the outside of the building or changes in humidity or water table. Tilt induced signals contaminate the entire spectrum of the gravity record but predominately occur in the daily, twice daily, annual and secular signals. Typical tilts observed on a concrete pad depend on many parameters but common variations are from 20 to 50 µRadians, which will cause gravity variations of 0.4 to 2.5 µGal. As shown in fig.6 the OSG dewar is supported by three points in an equilateral triangle. The rear point is a fixed height, and the height of the other two points (the Left and Right points) can be adjusted using micrometers. In addition to the micrometers, the Left and Right points are supported by Thermal Levelers that bolt directly to the outside wall of the dewar. Each Thermal Leveler contains an oil filled bellows, which expands when heated. The SG incorporates two tilt meters mounted orthogonally inside the gravity sensing unit as shown in fig.6 and fig.8. With the Thermal Levelers set to their mid-point expansion, the Left and Right micrometers are used to align the gravity meter precisely with **g**. At this position, the X and Y tiltmeters are electronically adjusted to read zero volts. After completing this procedure, the leveling system is switched to an automatic feedback mode where the length of the X Leveler is controlled by the output of the X tiltmeter and the Y leveler by the Y tiltmeter. In this mode, the tiltmeters and gravity meter sensor are held aligned with **g** to a precision of 0.1 μRadians. The dynamic range of the leveling system is 1mm which provides ample tilt compensation for most sites.

3.4. Integrated Electronics and Data Acquisition Package

The Integrated Electronics and Data Acquisition Package (IEDP) shown in Figure 9 is used to control and monitor all SG functions and to record data with a precision time stamp. The IEDP is designed to attain a high precision gravity record that is free of offsets, drift, and gaps. To achieve this goal, remote access by the Internet provides access to all gravimeter subsystems so that optimal performance can be verified on a daily basis. If any problems occur, a GWR engineer can retrieve and diagnose data in San Diego and ship any components needed to rapidly repair the system. This instant access to the system improves long-term data quality and reduces the manpower needed to operate the SG.

fig. 10. IEDP installed at Yebes

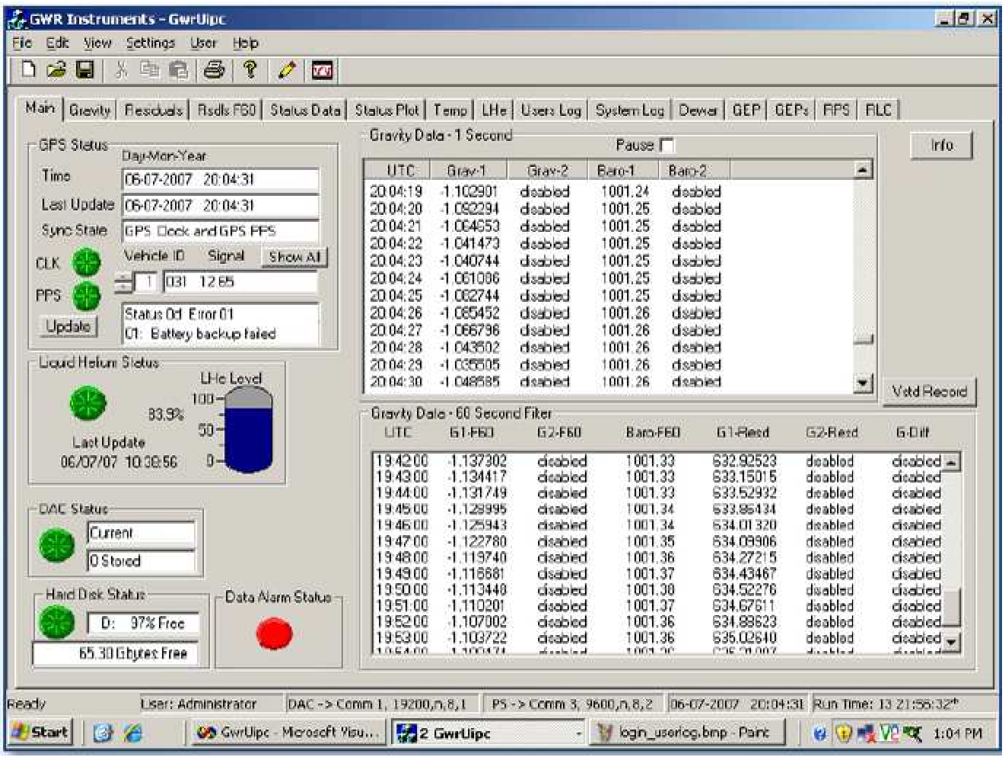
3.4.1. *Data Acquisition Controller (DAC).*

The primary function of the DAC-3 is to record uninterrupted data from both the gravity sensor and the barometric pressure sensor. Additional signals are logged to verify system health and for maintenance purposes. Data sampling time is referenced to UTC through a GPS receiver which communicates via a precision time pulse and a serial interface. Data sample timing accuracy is maintained with a few milliseconds of UTC. Data is internally buffered and continuously exported to a PC where it is written to disk. From the PC it can be automatically uploaded via FTP to an external data archiving site. The Data Acquisition Controller contains a processor and ten (10) serial I/O ports that communicate with the other electronics.

3.4.2. *User Interface PC and UIPC software*

A fully configured, high-quality PC using Windows OS is provided which runs a custom user interface program UIPC. This hardware/software combination allows the operator full remote control via the Internet of virtually all of the SG functions including setup procedures, monitoring for maintenance, data logging and archiving. Remote control operation is simplified by using virtual instrument screens which are accessed by tabs as shown across the top of the ***Main*** virtual screen shown in Figure 10. The UIPC requires users to login with a password before access to program features is granted.

- The ***Main*** screen shows the 1 sec Gravity and Barometer data and filtered data being recorded , the status of the GPS, Liquid Helium, DAC, Hard Disk and Data Alarm. A comprehensive alarm system can be set to trigger when any channels exceed normal limits. When alarms are triggered, one can choose to notify the operator in a number of ways including automatic email notification. An automated FTP routine can be configured to automatically upload data to up to five archival sites on a daily basis. Configurations are easily accomplished through an intuitive graphical user interface (GUI).
- The ***Gravity*** tab shows up to 30 days of 1 sec gravity and barometer data, while the ***Residuals*** (1 sec data) and ***RsdlsF60*** (1 minute data) display the daily gravity residual after subtraction of a user determined input tide model. These allow daily examination of residual gravity signals at the µgal level, which is of primary importance in judging daily performance of the SG.
- The ***LHe*** and ***Dewar*** tabs monitor the level of liquid helium, pressure control of the dewar and performance of the refrigeration system.
- The ***Status Data*** and ***Status Plot*** tabs access both numerical and graphical displays of all channels and are primarily used for debugging or verifying operating of all subsystems.
- The ***RPS*** and ***RLC*** tabs access remote control of the Remote Power Supply and Remote Levitation Current Supply used during sphere levitation.
- The ***Users Log*** tab accesses a log where the operator can enter time stamped notes when visiting the system either on site or remotely.



GPS Status

Day-Mon-Year

Time: 06-07-2007 20:04:31

Last Update: 06-07-2007 20:04:31

Sync State: GPS Clock and GPS PPS

Vehicle ID: 1

Signal: 031 12.65

Status 0d Error 01

01: Battery backup failed

Liquid Helium Status: 83.9%

Last Update 06/07/07 10:38:56

DAC Status: Current, 0 Stored

Hard Disk Status: D: 97% Free, 65.30 Gbytes Free

Gravity Data - 1 Second

UTC	Grav-1	Grav-2	Baro-1	Baro-2
20:04:19	-1.102901	disabled	1001.24	disabled
20:04:20	-1.092294	disabled	1001.25	disabled
20:04:21	-1.064653	disabled	1001.25	disabled
20:04:22	-1.041473	disabled	1001.25	disabled
20:04:23	-1.040744	disabled	1001.25	disabled
20:04:24	-1.061086	disabled	1001.25	disabled
20:04:25	-1.062744	disabled	1001.25	disabled
20:04:26	-1.065452	disabled	1001.26	disabled
20:04:27	-1.066796	disabled	1001.26	disabled
20:04:28	-1.043502	disabled	1001.26	disabled
20:04:29	-1.035505	disabled	1001.26	disabled
20:04:30	-1.048585	disabled	1001.26	disabled

Gravity Data - 60 Second Filter

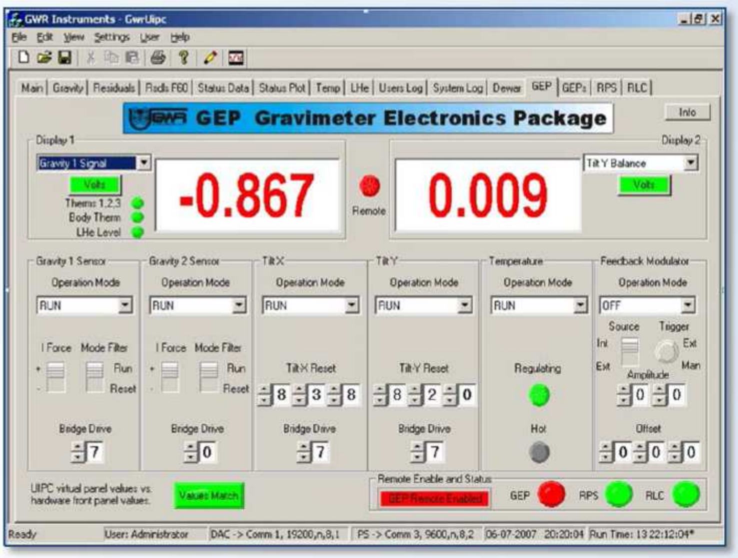
UTC	G1-F60	G2-F60	Baro-F60	G1-Resd	G2-Resd	G-Diff
19:42:00	-1.137302	disabled	1001.33	632.92523	disabled	disabled
19:43:00	-1.134417	disabled	1001.33	633.15015	disabled	disabled
19:44:00	-1.131749	disabled	1001.33	633.52932	disabled	disabled
19:45:00	-1.128995	disabled	1001.34	633.85434	disabled	disabled
19:46:00	-1.125943	disabled	1001.34	634.01320	disabled	disabled
19:47:00	-1.122780	disabled	1001.35	634.09906	disabled	disabled
19:48:00	-1.119740	disabled	1001.36	634.27215	disabled	disabled
19:49:00	-1.116681	disabled	1001.37	634.43467	disabled	disabled
19:50:00	-1.113448	disabled	1001.38	634.52276	disabled	disabled
19:51:00	-1.110201	disabled	1001.37	634.67611	disabled	disabled
19:52:00	-1.107002	disabled	1001.36	634.88623	disabled	disabled
19:53:00	-1.103722	disabled	1001.36	635.02640	disabled	disabled

Ready | User: Administrator | DAC -> Comm 1, 19200,n,8,1 | PS -> Comm 3, 9600,n,8,2 | 06-07-2007 20:04:31 | Run Time: 13 21:56:32*

fig. 11. UIPC main page

3.4.3. *The Gravimeter Electronics Package (GEP-3)*

The GEP-3 electronics is used for controlling the Gravity sensor, the X and Y Tiltmeters, the Temperature and the refrigeration and dewar systems. The Feedback modulator is used for measuring the amplitude and phase response of the gravimeter. The two digital meters allow viewing all of the data channels monitored. All GEP-3 functions can be controlled by the Virtual GEP3 front panel in the UIPC software which is shown in Figure 11.



Display 1: Gravity 1 Signal — -0.867

Display 2: Tilt Y Balance — 0.009

	Gravity 1 Sensor	Gravity 2 Sensor	Tilt X	Tilt Y	Temperature	Feedback Modulator
Operation Mode	RUN	RUN	RUN	RUN	RUN	OFF
Tilt X Reset			8 3 8			
Tilt Y Reset				8 2 0		
Amplitude						0 0
Bridge Drive	7	0	7	7		
Offset						0 0 0

UIPC virtual panel values vs. hardware front panel values: Values Match

GEP Remote Enabled

Ready | User: Administrator | DAC -> Comm 1, 19200,n,8,1 | PS -> Comm 3, 9600,n,8,2 | 06-07-2007 20:20:04 | Run Time: 13 22:12:04*

fig. 12. GEP-3 virtual instrumentation

3.4.4. *Agilent 34420A NanoVoltMeter(s)*

Records the high precision Gravity signal(s) with 7 ½ digit resolution.

3.4.5. *Trimble GPS Receiver*

Provides a precision 1 PPS times base. Data time stamp is accurate within a few milliseconds of UTC.

3.4.6. *Paroscientific Digiquartz Met-3 Station*

Provides precision measurement of atmospheric pressure and temperature. Barometric pressure resolution is better than one microbar with total accuracy of ±0.08 hPa. Temperature resolution is 0.01°C with total accuracy of 0.5°C. The instrument is enclosed in a durable weatherproof package suitable for mounting outdoors on a pole or rooftop.

3.4.7. *The Transportable Voltage Standard*

The voltage standard accuracy is better than 20 ppm/year and its temperature coefficient is better than two ppmper °C. The standard is sampled periodically by the Agilent NanoVoltmeters but can be disconnected and sent out for calibration at a NIST-qualified calibration site as part of regular system maintenance.

3.4.8. *The Temperature Controlled Electronics Enclosure*

This enclosure protects the electronics in a sealed rack with a thermostatically controlled heat exchanger. External temperature fluctuations are attenuated by a factor of more than 10 and rubber gaskets protect against contaminates present in a harsh environment. Additional EMI gaskets provide an effective Faraday shield, providing additional immunity to electrical interference.

4. Fundamental electronic systems

4.1. Gravity sensor electronics

The Gravity Sensor circuit card assembly (CCA) is mounted in the Analog Control chassis. This card generates precisely matched drive signals that are applied to the upper and lower capacitor plates surrounding the sphere. The resulting signal from the centre capacitor plate indicates the sphere's displacement from its null position.
The position of the sphere can be detected to within a few angstroms (1A=100pm).

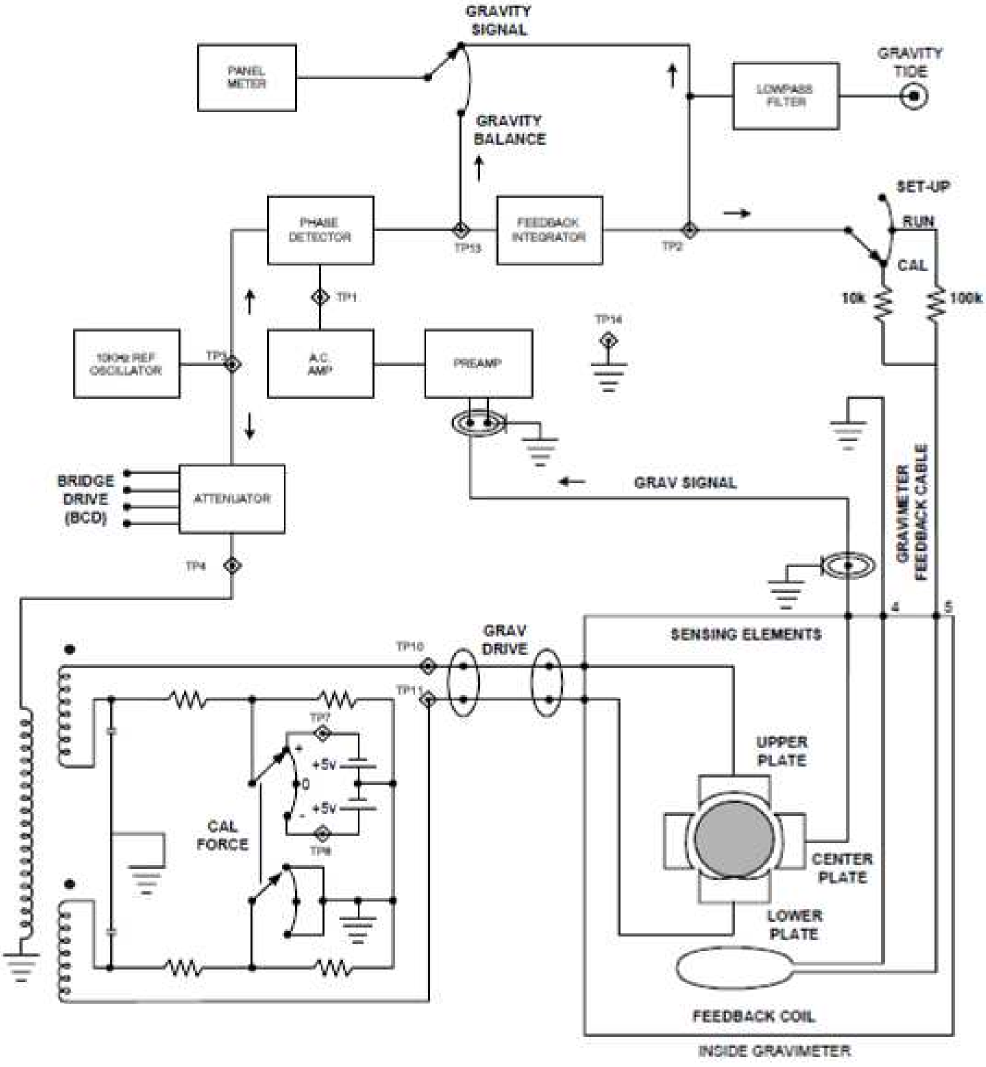


fig. 13. Gravity control electronics

4.2. Temperature electronics

The temperature sensing circuit uses a germanium thermometer in a whetstone bridge to sense the temperature of the superconducting elements within the GSU. The signal is detected using a phase sensitive lock-in amplifier, then fed back to control the temperature of the GSU slightly above the ambient temperature of the liquid helium bath. Using this technique, the core of the sensor is controlled to within a few µOK.
The temperature of the gravimeter core is controlled by measuring a temperature sensitive resistance bridge and applying power to a heater to keep the bridge at a preset

balance point. The temperature is detected by using a Whetstone bridge in conjunction with a phase sensitive detector. The temperature control electronics consist of two circuit boards: the Thermostat Board (A1), and the temperature preamplifier. The temperature electronics have been carefully designed to achieve a long-term temperature stability of 1m° K.

When the instrument is being cooled down from room temperature, it is desirable to know its approximate temperature. However, under this circumstance, the normal temperature signal path is saturated. Therefore, a second lower gain path with its own phase detector is provided. In addition, this second phase detector is followed by a logarithmic amplifier. The log amplifier helps compress the roughly log(R) versus 1/T response of the temperature so that it may be observed on the panel meter when set in the **TEMP** setting.

After the sphere has been levitated and the magnetic gradient adjusted, the magnetic currents must be ***"annealed"*** .Annealing consists of heating the core temperature of the gravimeter to about 5°K and then letting it re-cool slowly back to its control point. This process removes the hysteresis in the magnetic-temperature curve up to the annealing temperature. Therefore, after annealing, fluctuations in the temperature above the control point, but below the annealing temperature, will not cause drift in the gravimeter signal

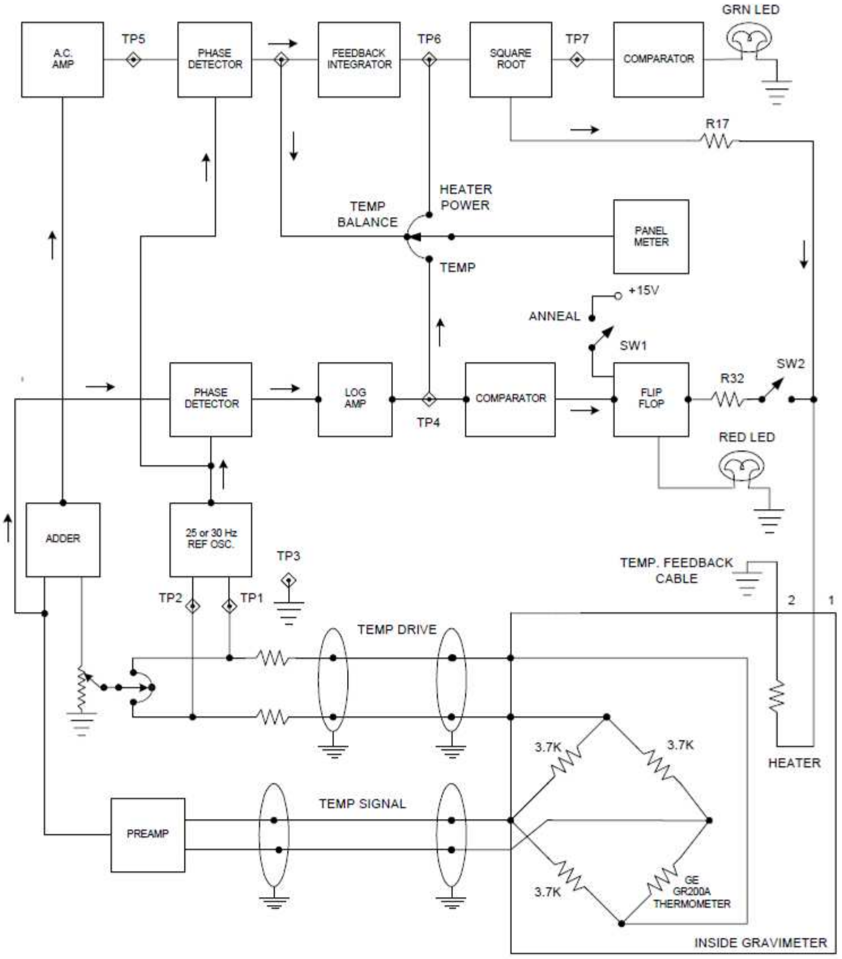


fig. 14. Temperature electronics circuit

4.3. X-Y tilt electronics

The gravimeter is positioned using a triangular support frame. The three support points of the frame are located in a right isosceles triangle so that the micrometers define two orthogonal axes, the Left (or X) axis and the Right (or Y) axis. The micrometers rest on two thermal levelers that expand when heated and contract when cooled. The thermal levelers are initially set at their midpoint by controlling their temperature at a preset value. During set-up procedures, the micrometers are used to manually tilt the gravimeter and to position it at its tilt insensitive position. In final operation, the support frame, tilt electronics, thermal levelers, and tiltmeters provide an active feedback system that holds the gravimeter at its tilt insensitive position.

Tilt variations of the gravimeter are monitored by two tiltmeters placed just above the gravimeter itself. The tiltmeters are positioned orthogonally with their axes lining up with the X and Y axis of the support frame. Each tiltmeter consists of a rectangular mass (pendulum bob) that hangs from a thin metal foil and is positioned between two side capacitor plates. The pendulum bob and the side plates make up a capacitance bridge so that the position of the pendulum is measured by the differences in its capacitance to the side plates.

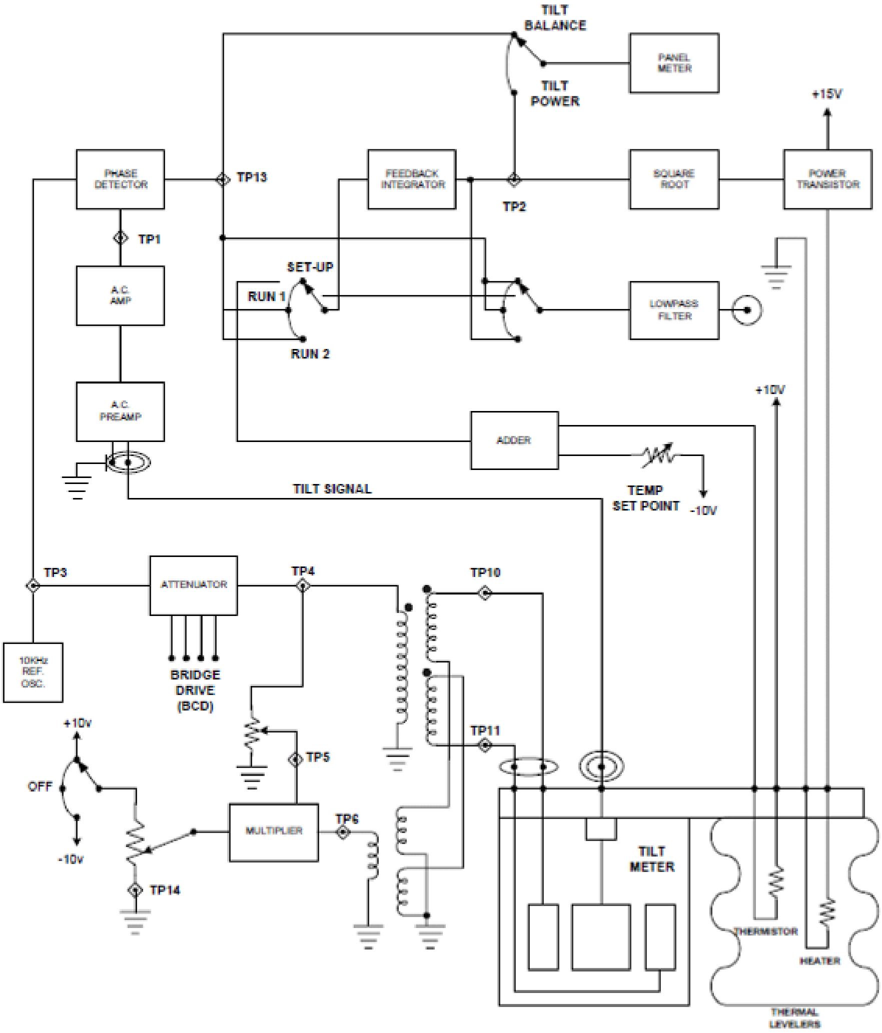
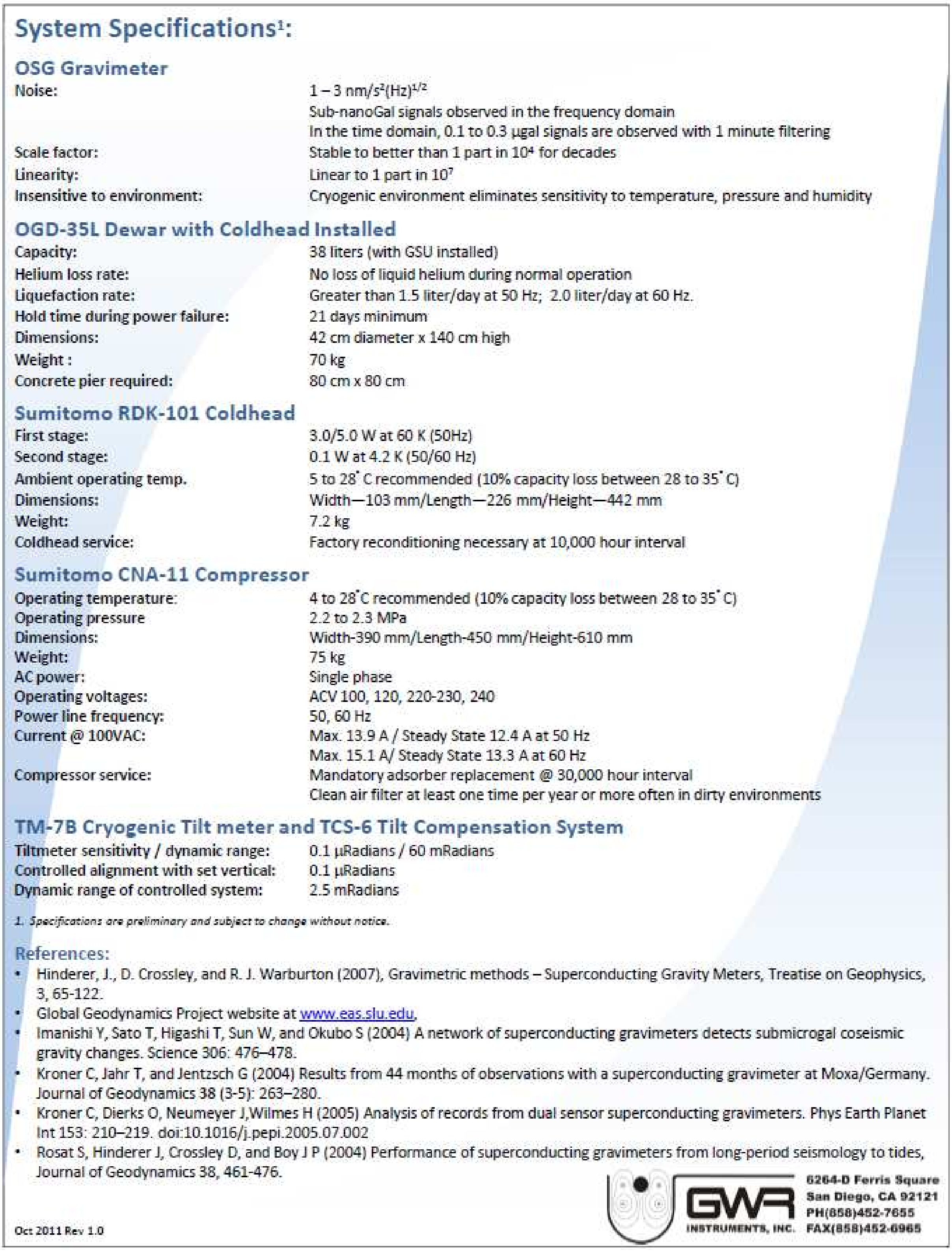


fig. 15. Tilt control electronics

5. System specifications



System Specifications[1]:

OSG Gravimeter

Noise:	1 – 3 nm/s^2(Hz)$^{1/2}$ Sub-nanoGal signals observed in the frequency domain In the time domain, 0.1 to 0.3 μgal signals are observed with 1 minute filtering
Scale factor:	Stable to better than 1 part in 10^4 for decades
Linearity:	Linear to 1 part in 10^7
Insensitive to environment:	Cryogenic environment eliminates sensitivity to temperature, pressure and humidity

OGD-35L Dewar with Coldhead Installed

Capacity:	38 liters (with GSU installed)
Helium loss rate:	No loss of liquid helium during normal operation
Liquefaction rate:	Greater than 1.5 liter/day at 50 Hz; 2.0 liter/day at 60 Hz.
Hold time during power failure:	21 days minimum
Dimensions:	42 cm diameter x 140 cm high
Weight :	70 kg
Concrete pier required:	80 cm x 80 cm

Sumitomo RDK-101 Coldhead

First stage:	3.0/5.0 W at 60 K (50Hz)
Second stage:	0.1 W at 4.2 K (50/60 Hz)
Ambient operating temp.	5 to 28° C recommended (10% capacity loss between 28 to 35° C)
Dimensions:	Width—103 mm/Length—226 mm/Height—442 mm
Weight:	7.2 kg
Coldhead service:	Factory reconditioning necessary at 10,000 hour interval

Sumitomo CNA-11 Compressor

Operating temperature:	4 to 28°C recommended (10% capacity loss between 28 to 35° C)
Operating pressure	2.2 to 2.3 MPa
Dimensions:	Width-390 mm/Length-450 mm/Height-610 mm
Weight:	75 kg
AC power:	Single phase
Operating voltages:	ACV 100, 120, 220-230, 240
Power line frequency:	50, 60 Hz
Current @ 100VAC:	Max. 13.9 A / Steady State 12.4 A at 50 Hz Max. 15.1 A/ Steady State 13.3 A at 60 Hz
Compressor service:	Mandatory adsorber replacement @ 30,000 hour interval Clean air filter at least one time per year or more often in dirty environments

TM-7B Cryogenic Tilt meter and TCS-6 Tilt Compensation System

Tiltmeter sensitivity / dynamic range:	0.1 μRadians / 60 mRadians
Controlled alignment with set vertical:	0.1 μRadians
Dynamic range of controlled system:	2.5 mRadians

1. Specifications are preliminary and subject to change without notice.

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Oct 2011 Rev 1.0

6. Physical installation of the OSG at Yebes

Interconnection and suggested spacing for the components. These distances, when maintained, will allow for all cabling and hoses to be connected with sufficient slack for maintenance and access. The user should start with the placement of the Dewar first as this is the most critical for instrument operation.

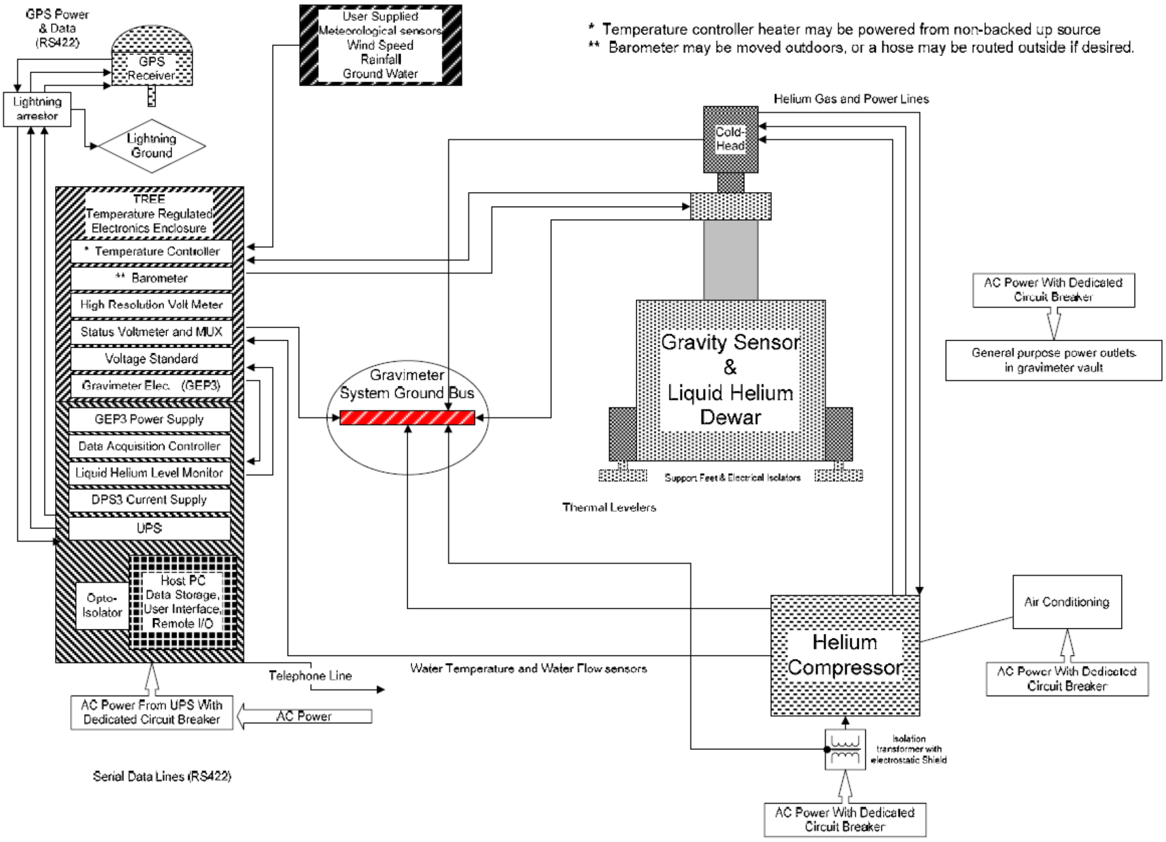


fig. 16. Suggested spacing for the components

Next, the steps related with the installation are presented. For a more complete description of the entire procedure, consult references.

a. Physical Installation of the system
  i. Unpacking the SG crates and storing empty crates
  ii. Placement of Components
    1. SG Dewar
    2. Electronics Rack
    3. Compressor
    4. Compressor Hoses
    5. He Gas Bottle
    6. De-Ice and re-charge Hoses
  iii. Connecting Power cables
    1. Electronics Rack
    2. Compressor
  iv. Installing Dewar
    1. Cooling down Dewar with LN2
    2. Transferring Liquid Helium

      - 3. Installing the Dewar on feet
      - 4. Rough Tilting
  - v. Installing Refrigeration frame
      - 1. Adjusting frame height
      - 2. Adjusting rotator mount on top of Dewar
      - 3. Placing Frame feet on ground
  - vi. Installing coldhead on Rotator mount
  - vii. Routing Refrigerator Hoses and Cables

b. Setting up the Data Acquisition System (EB)
  - i. Checking GPS signals
  - ii. Checking Barometer signals
  - iii. Setting up Operating Parameters
      - 1. Station name, email address
      - 2. Approximate Gain coefficient, Latitude and Longitude
      - 3. TSoft generated wavegroup numbers
      - 4. Setting up alarms
      - 5. Setting up email notifications
      - 6. Setting up Archiving FTP
  - iv. Checking different signals
      - 1. G1 GGP (DVM1/DVM2 Signals)
      - 2. Status signals
          - a. Gravity signals and Controls
          - b. Temperature Signals and Controls
          - c. Tilt Signals and Controls
          - d. Dewar Pressure Signals and Controls
          - e. SG - Thermometers (N1, N2, Belly, Body)
          - f. External Pressure sensors
          - g. External Thermometers
  - v. Checking system health – description

Initialization of the SG (RJW)

a. Demagnitization
  - i. Heating up the system to 32K
  - ii. Demag and fast cool

b. Levitation (I)
  - i. High temp Anneal
  - ii. Mechanical Tilt Minimization
  - iii. Centering of sphere
  - iv. Low temp anneal
  - v. Putting the system to RUN

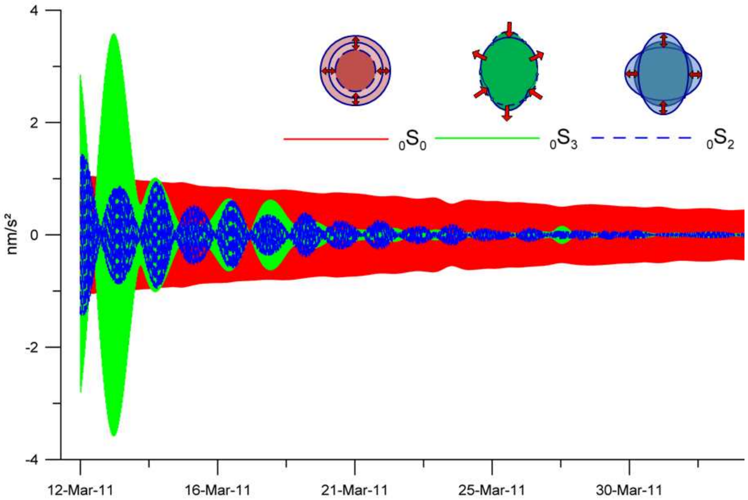
c. Levitation (II) – Time permitting
  - i. 2nd Levitation by Trainees
  - ii. Thermal tilt minimization

fig. 17. OSG-059 installed in the Gravimetry laboratory at the CDT Yebes

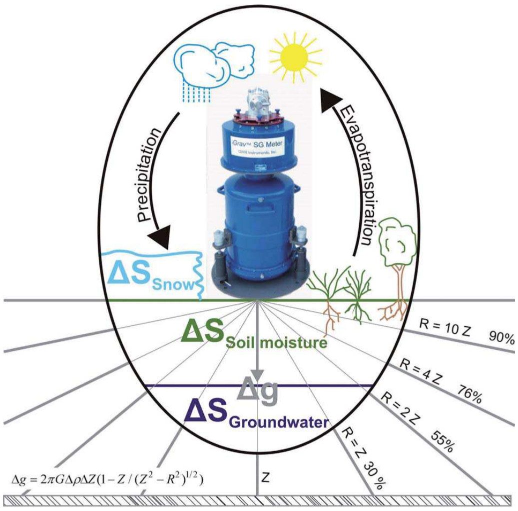
fig. 18. OSG-064 and OSG-059 installed at Yebes

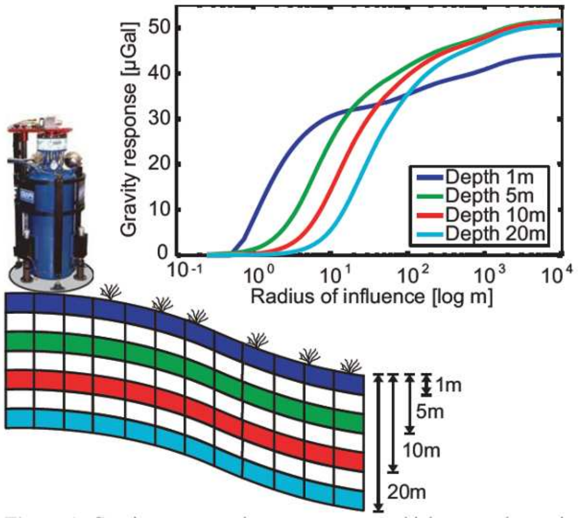
7. Applications

- High-precision *continuous* gravity monitoring for the study of geophysical phenomena, such as normal modes, mantle rheology, tides, solid Earth–oceans–atmosphere interactions, hydrology, and Earth rotation.

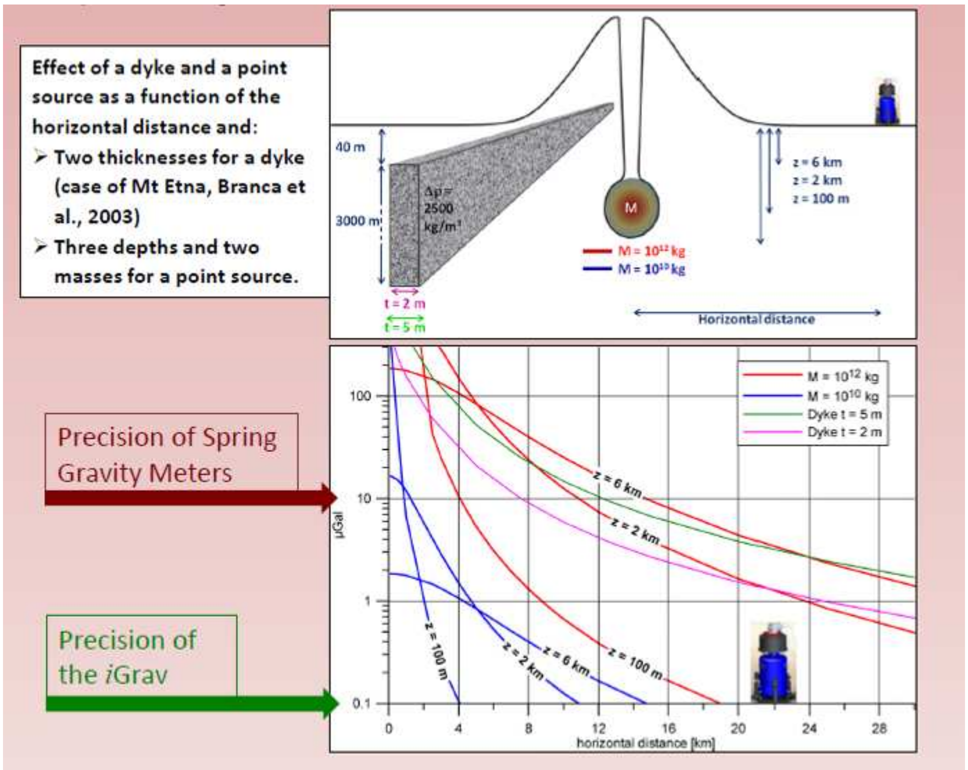


- Resolving mass density changes associated with elevation changes measured by GPS, VLBI, SLR, LLR, DORIS and GLONASS.
- Hydrological, geothermal, and non-invasive ground water monitoring.





- Volcano monitoring.



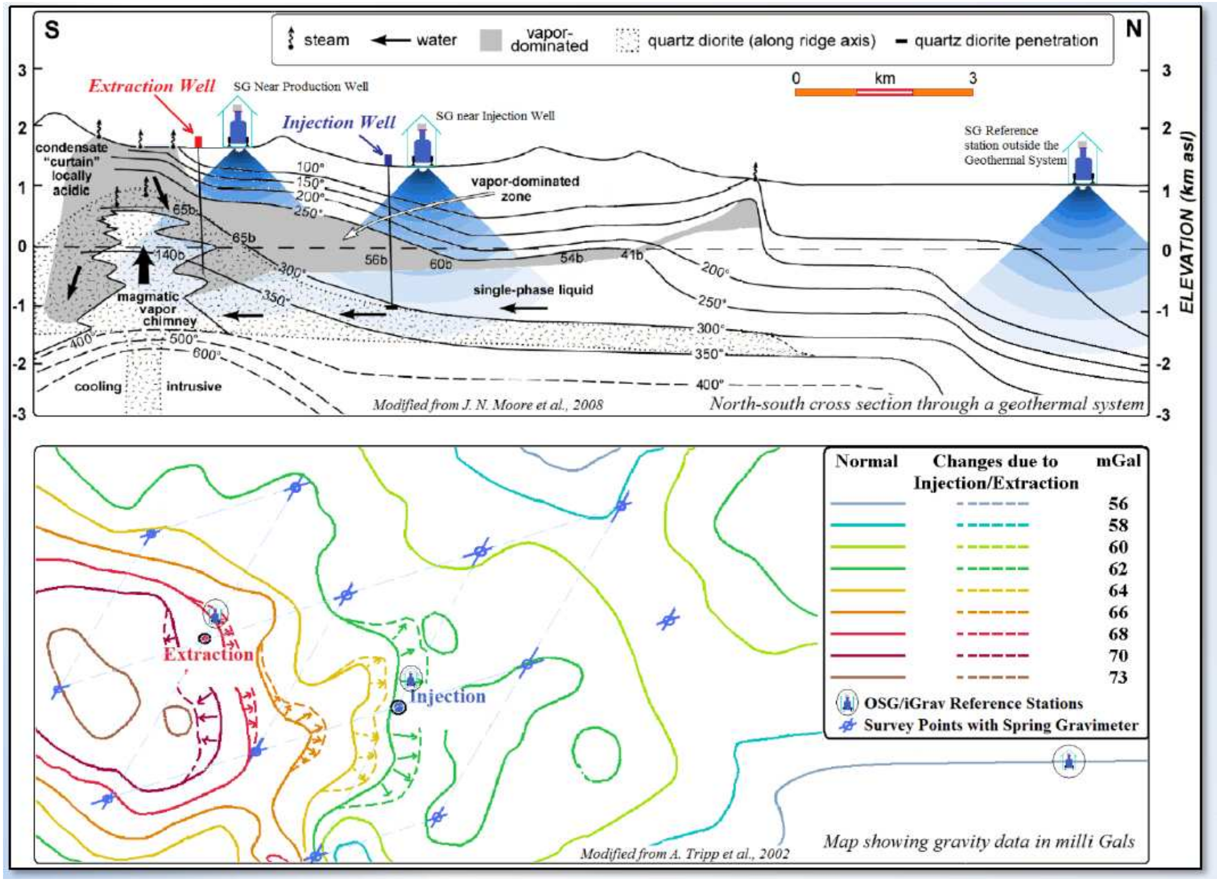
Effect of a dyke and a point source as a function of the horizontal distance and:

- Two thicknesses for a dyke (case of Mt Etna, Branca et al., 2003)
- Three depths and two masses for a point source.

Precision of Spring Gravity Meters

Precision of the *i*Grav

- Measurement of subsidence caused by oil, gas, or water extraction.



Modified from J. N. Moore et al., 2008

North-south cross section through a geothermal system

Modified from A. Tripp et al., 2002

Map showing gravity data in milli Gals

- Long term crustal motion and sea level monitoring.
- Correlation & validation with satellite gravity including GRACE, CHAMP, GOCE.
- Aquifer monitoring and management, measuring depletion and recharging of municipal water supplies.
- High accuracy gravity reference stations when combined with periodic Absolute Gravimeter observations.

8. References.

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