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G4.4 - New tools for terrain gravimetry

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The benefits of performing continuous gravity measurements at active volcanoes using superconducting gravimeters

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Characteristics of gravity anomalies due to volcanic activity

Gravity anomalies depend on source characteristics and vary in:

✓ **space** (wavelength between 100s of m and 10s of km)

✓ **time** (periods between minutes and years)

✓ **amplitude** (a few to 100s of µGal)

The **amplitude** and **wavelength** depend on the mass and depth of the source

The **period** depends on the evolution speed of the source phenomena

Continuous measurements

- sampl T = secs to mins
- good time resolution

Time lapse measurements

- sampl T ≥ 1 month
- good spatial resolution

Continuous gravity measurements at active volcanoes

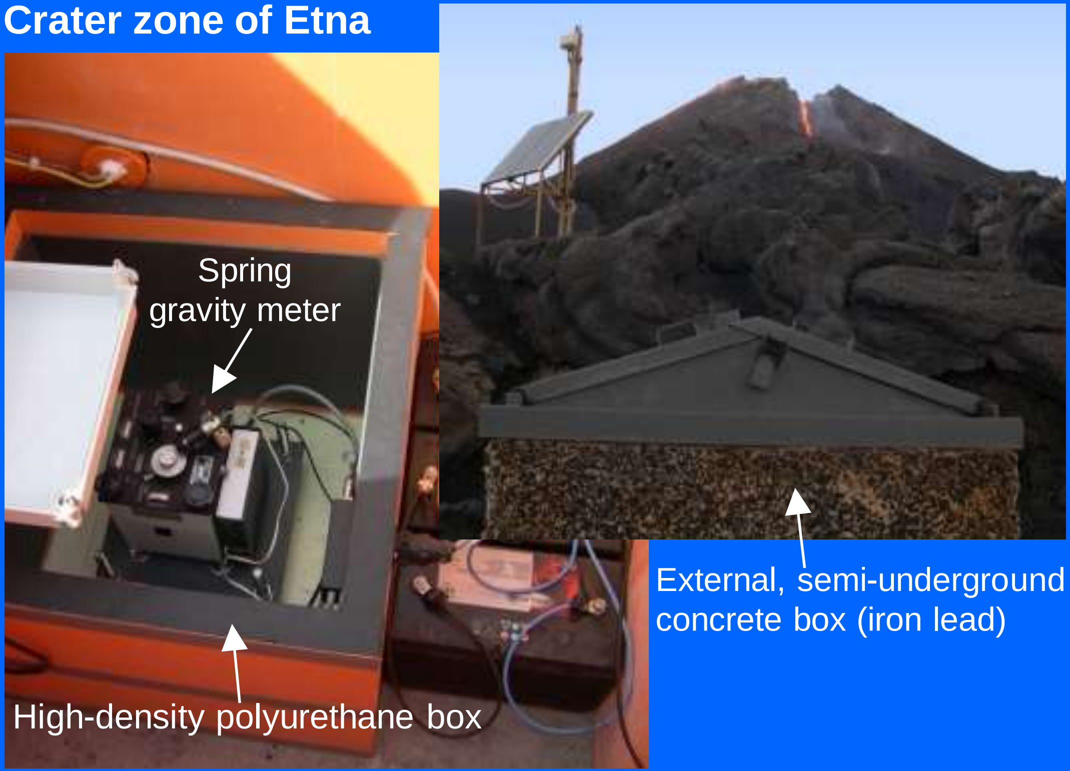
Spring-based gravimeters

Up to date, continuous gravity measurements at active volcanoes have been carried out through spring gravimeters that can be installed in close proximity of the active structures.

Due to intrinsic limitations (instrumental drift, effects of ambient parameters), these meters do not furnish reliable data about long-term changes (periods > some days).

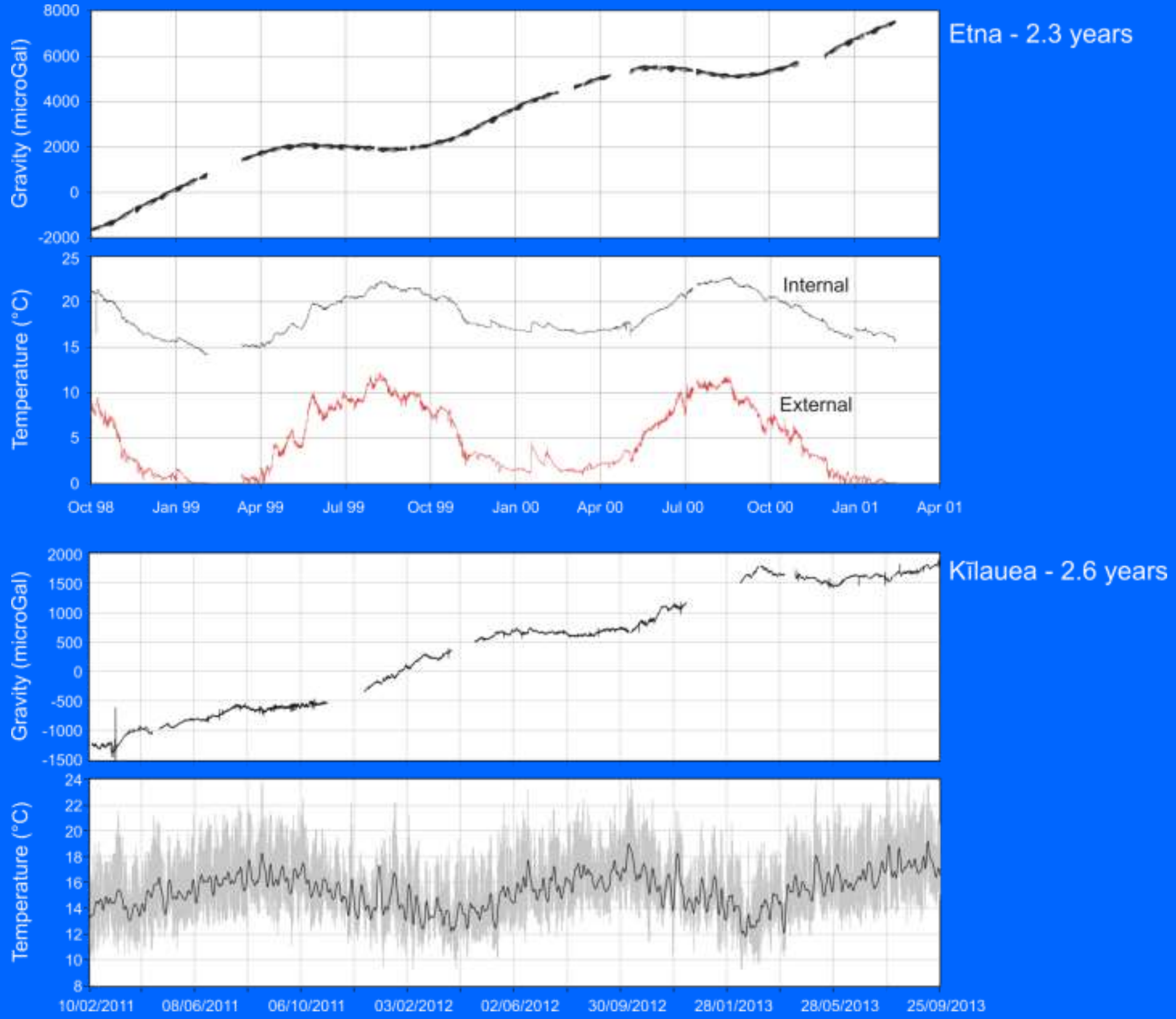
LaCoste & Romberg spring gravimeter

Crater zone of Etna



Continuous gravity measurement with spring gravimeters

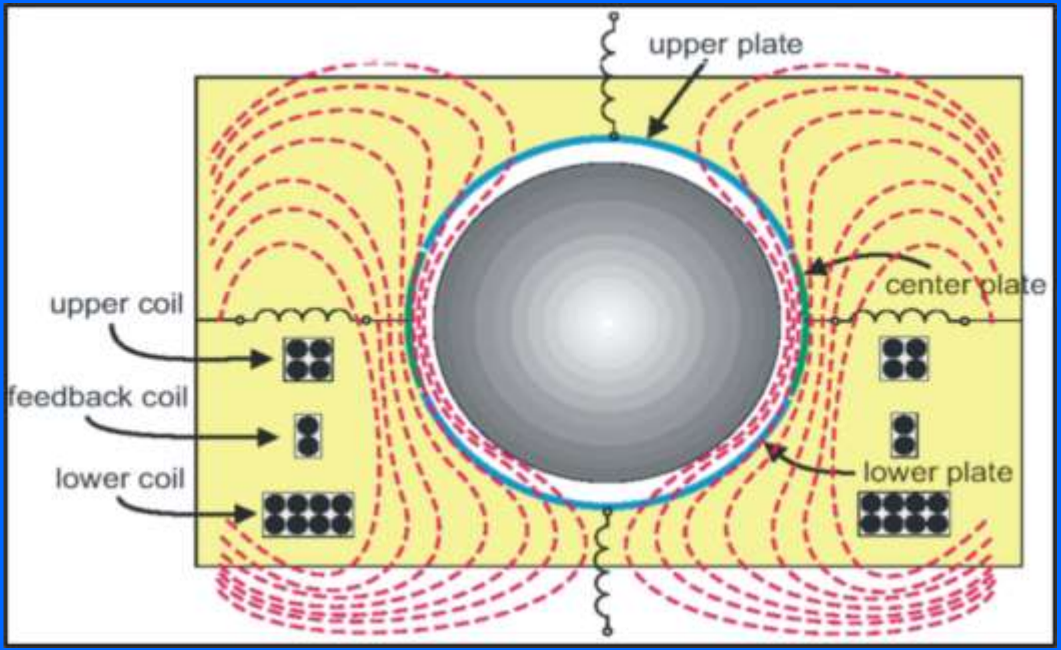
Effect of ambient temperature



Continuous volcano gravimetry with superconducting gravimeters (SGs)

Superconducting gravimeters furnish higher-quality data than spring gravimeters (high-precision, drift-less, not affected by ambient parameters), but require mains power to work, hence cannot be installed close to active structures on the summit of high volcanoes.

The iGrav superconducting gravimeter



SGs employ a superconducting sphere (test mass), that is levitated in a stable magnetic field. To keep the sensor unit superconducting, it is housed in a dewar filled with liquid Helium (temperature close to 4.2 K).

Superconducting vs spring gravimeters

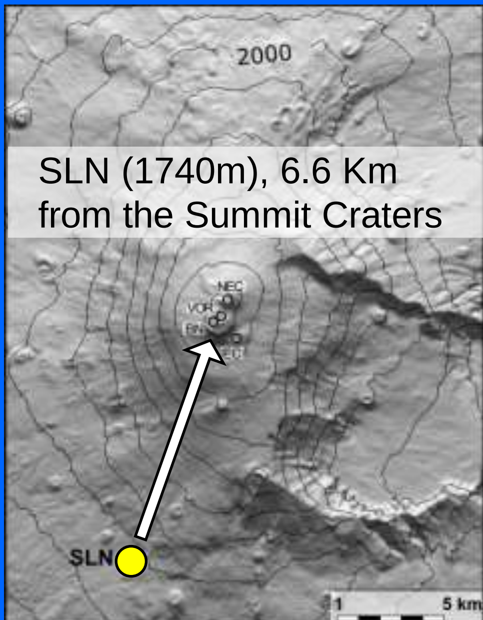
	Superconducting gravimeter (iGrav) 	**Spring-based gravimeter** 
Resolution	< 0.001 µGal	0.1 µGal
Precision	0.05 µGal	1 µGal
System noise	0.2 µGal/√Hz	3 mGal/√Hz
Instrumental drift	< 5 µGal/year (linear)	typically 500 µGal/month (unlinear)
External perturbations	Insensitive to changes in ambient parameters	Affected by ambient temp. (up to 200 µGal/°C)
Weight	> 100 kg	Few tens of kg
Occupied area	2-3 m^2	< 1 m^2
Power requirements	1400 W	10 - 100 W

The iGrav SG offers much better performances, with respect to spring gravimeters, especially from the standpoint of long-term stability

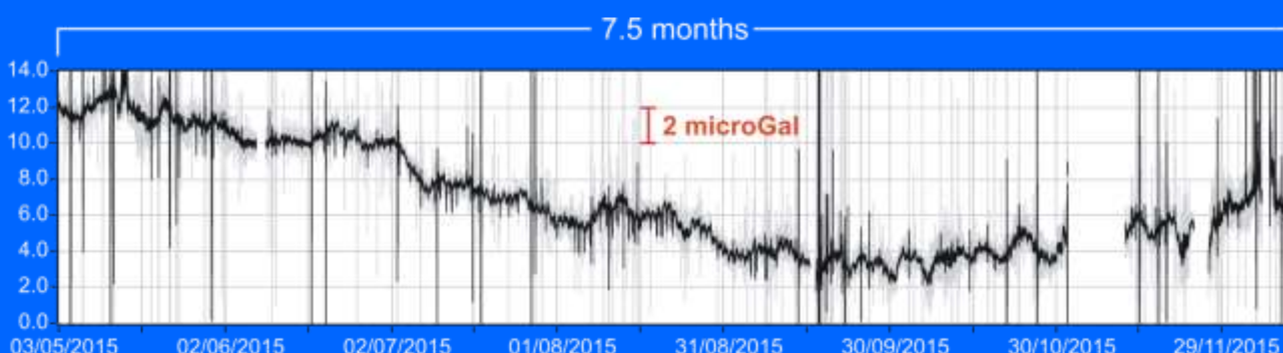
Nevertheless, due to power requirements + size/weight, SGs cannot be installed close to active structures on the summit of high volcanoes

Continuous measurements at Mt. Etna with the iGrav SG

SLN (1740m), since September 2014



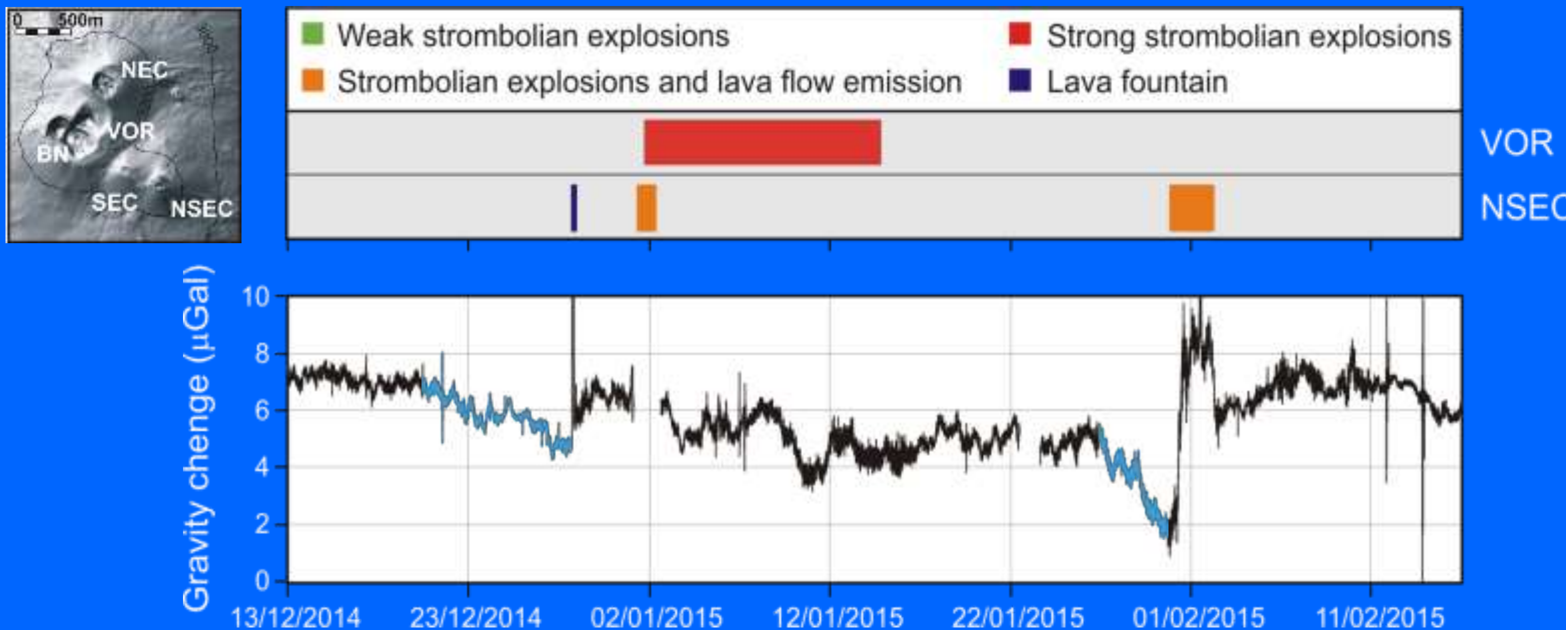
First SG ever installed on an active volcano!



Possibility to observe sub-microGal changes over periods from seconds to years

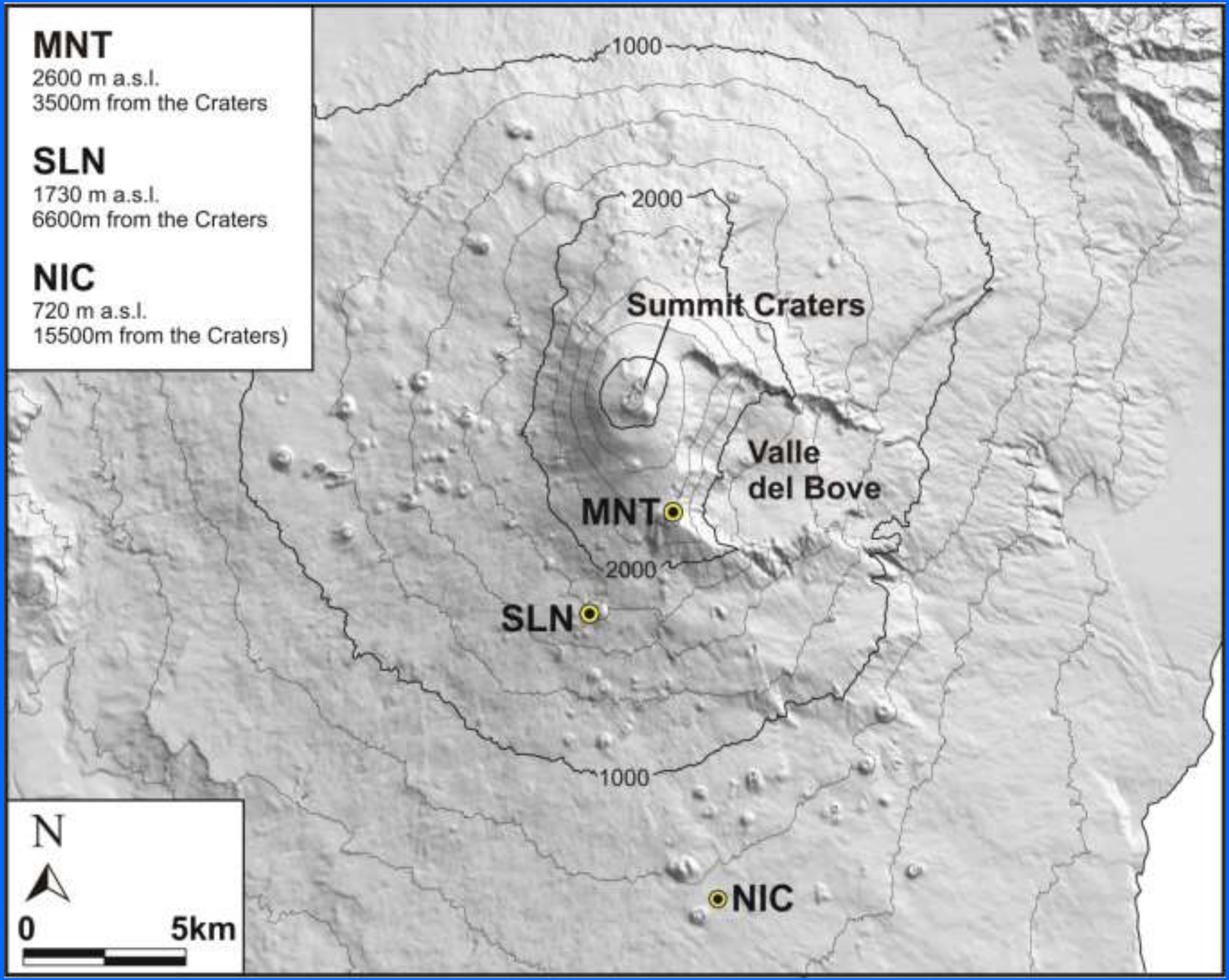
iGrav SG: continuous gravity measurements at SLN (Etna)

December 2014 – February 2015



Even though the gravity decreases (blue parts) are clearly related to volcanic activity, with the signal from a single station it is not possible to set constraints on the characteristics of the mass source.

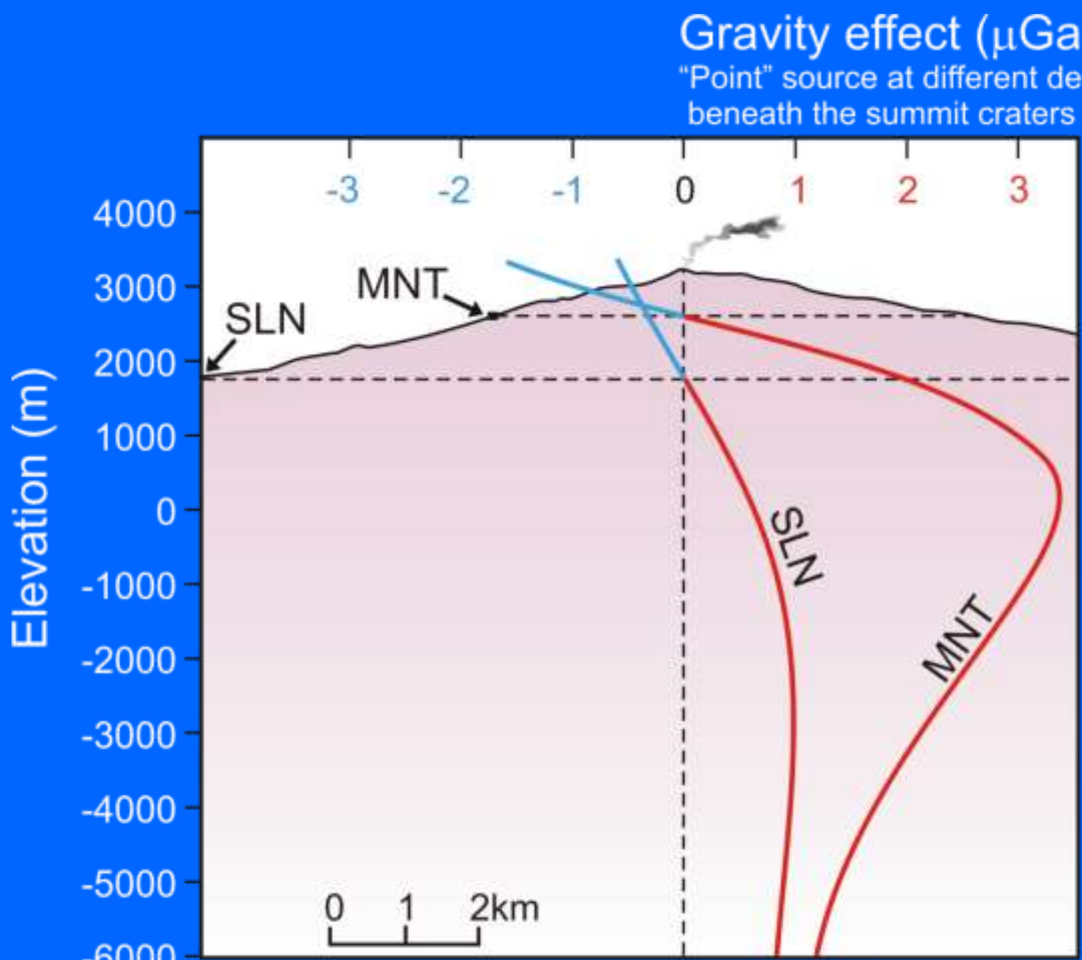
iGrav SGs: continuous gravity measurements at Mt. Etna



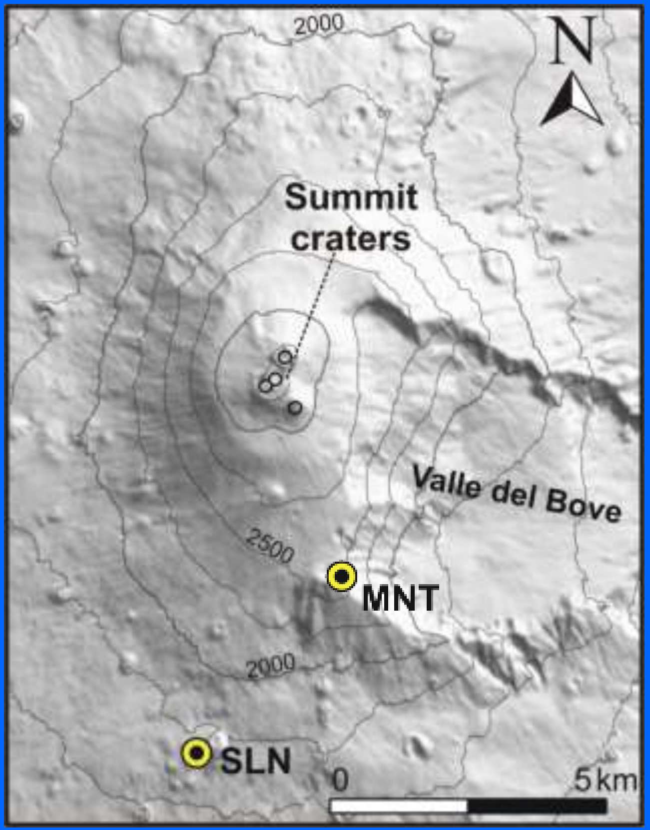
In July 2016 we installed two more iGravs on Etna.

Besides the one at MNT, one more iGrav was installed in the village of Nicolosi.

iGrav SGs: continuous gravity measurements at Mt. Etna

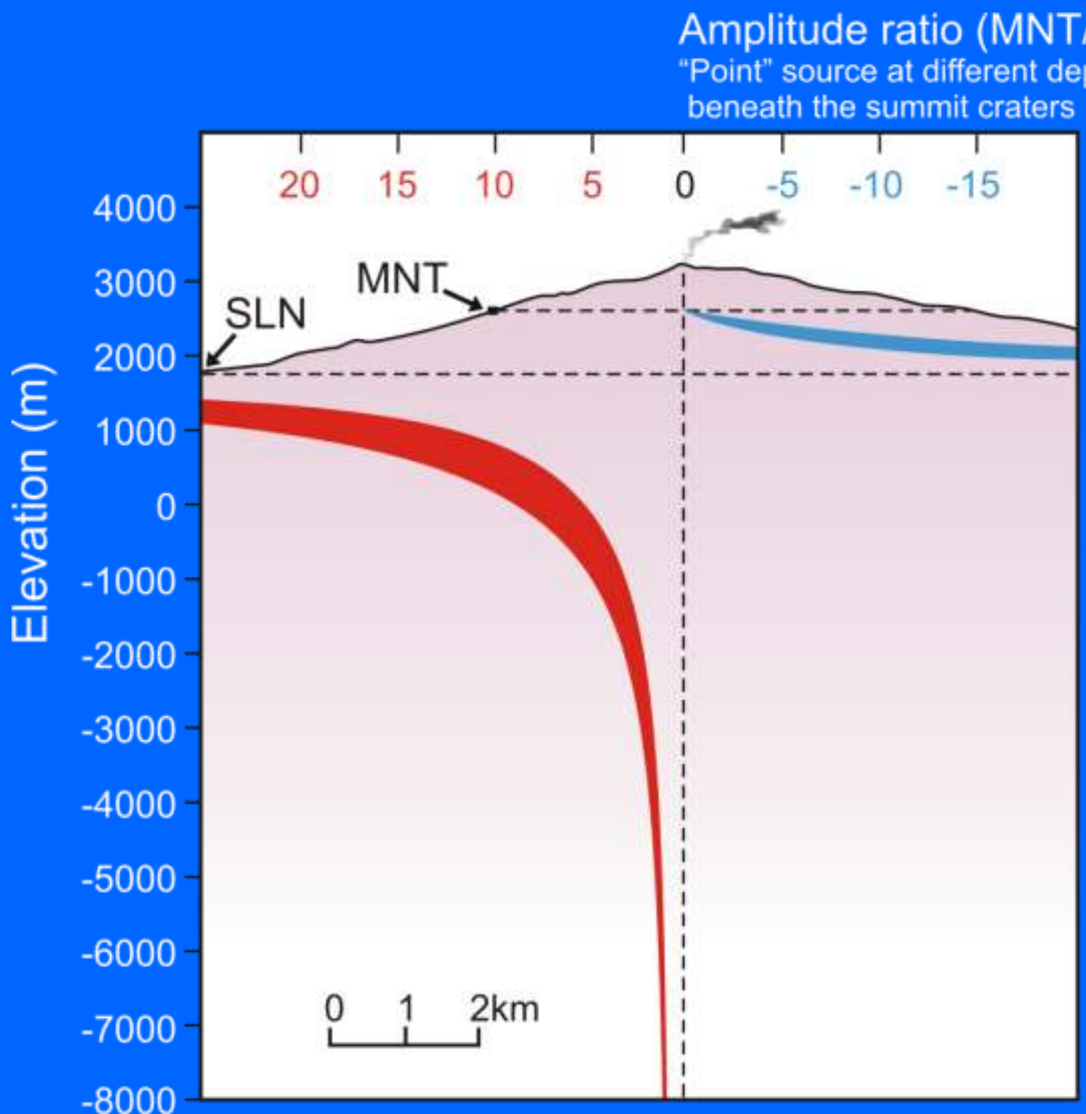


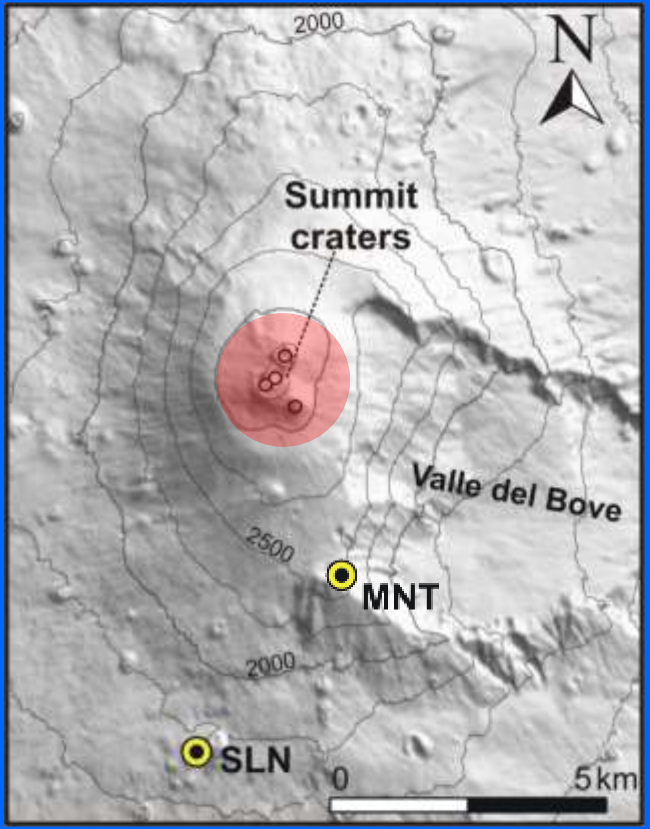
Positive mass change = 1.6×10^{10} kg



La Montagnola hut (MNT; 2600m)

iGrav SGs: continuous gravity measurements at Mt. Etna

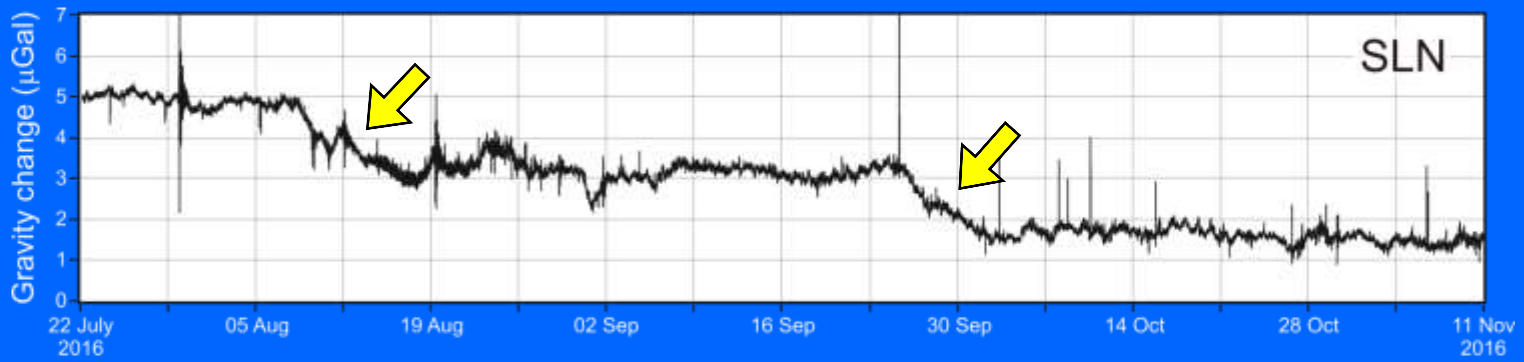


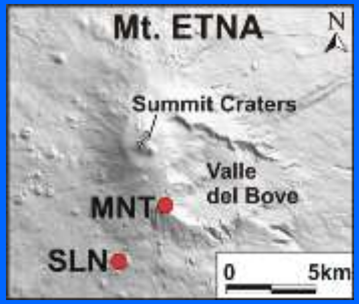


La Montagnola hut (MNT; 2600m)

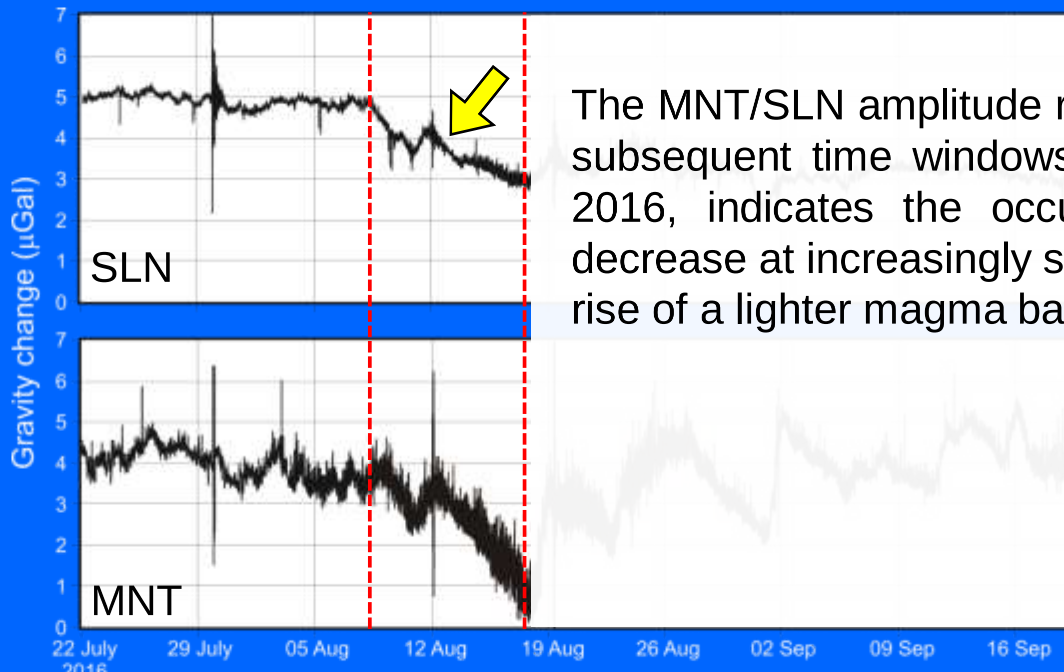
iGrav SGs: time series from Etna (July-October 2016)

During >100 days since July 2016, the most significant changes in the signal from SLN are two negative “steps” (< 2 μGal), occurring over intervals of ~10 days.

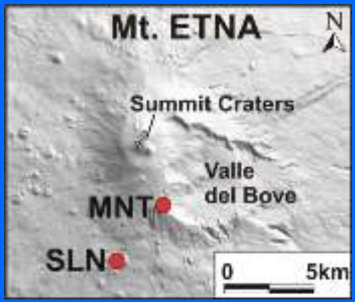


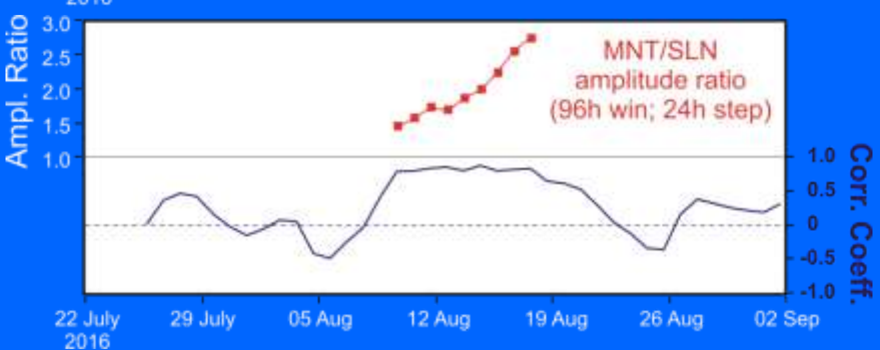


iGrav SGs: time series from Etna (July-October 2016)

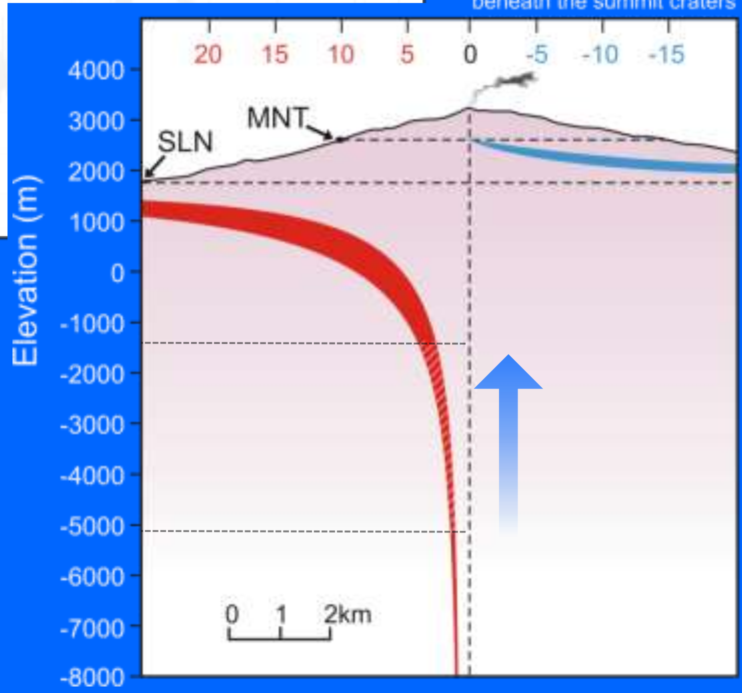


The MNT/SLN amplitude ratio, measured over subsequent time windows during mid-August 2016, indicates the occurrence of a mass decrease at increasingly shallower depths: rise of a lighter magma batch?

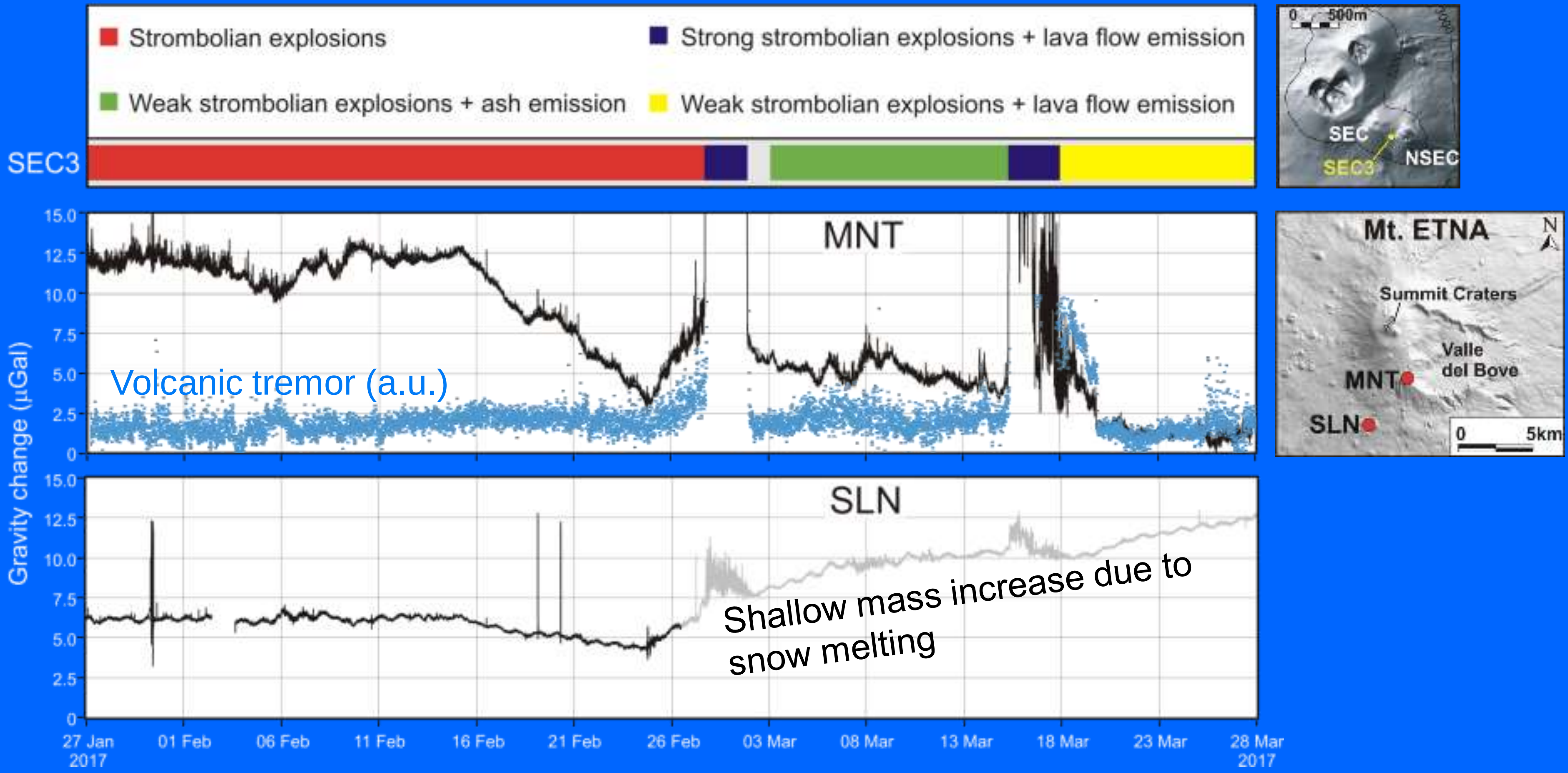




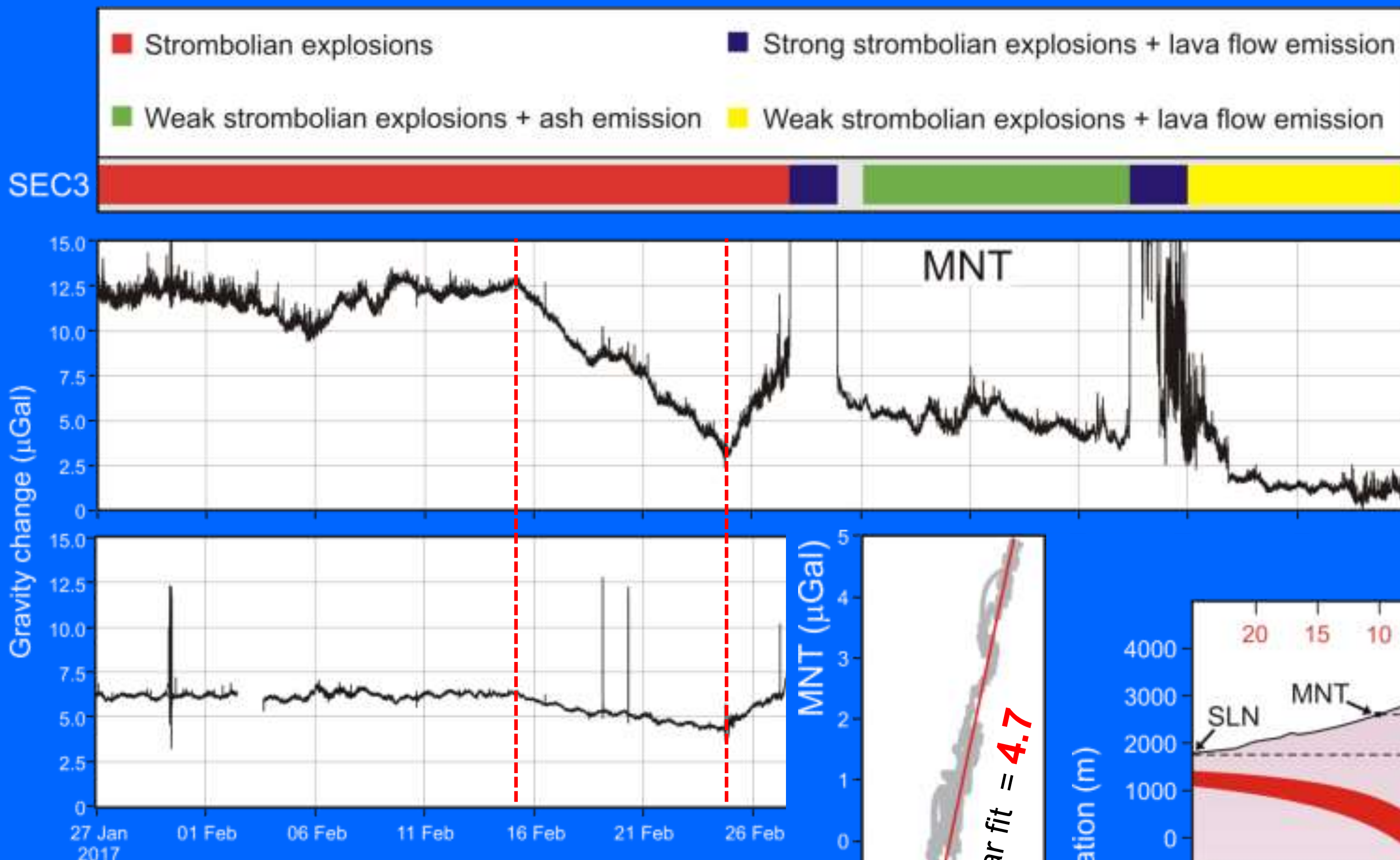
Amplitude ratio (MNT/SLN)
"Point" source at different depths beneath the summit craters

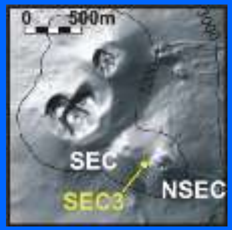


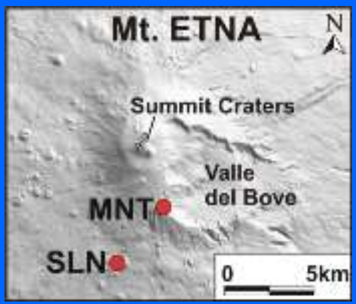
iGrav SGs: time series from Etna (January-March 2017)

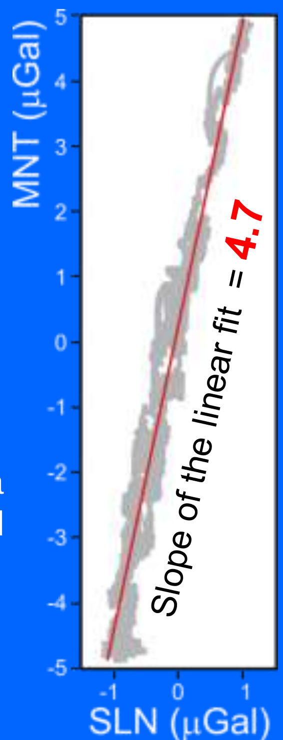


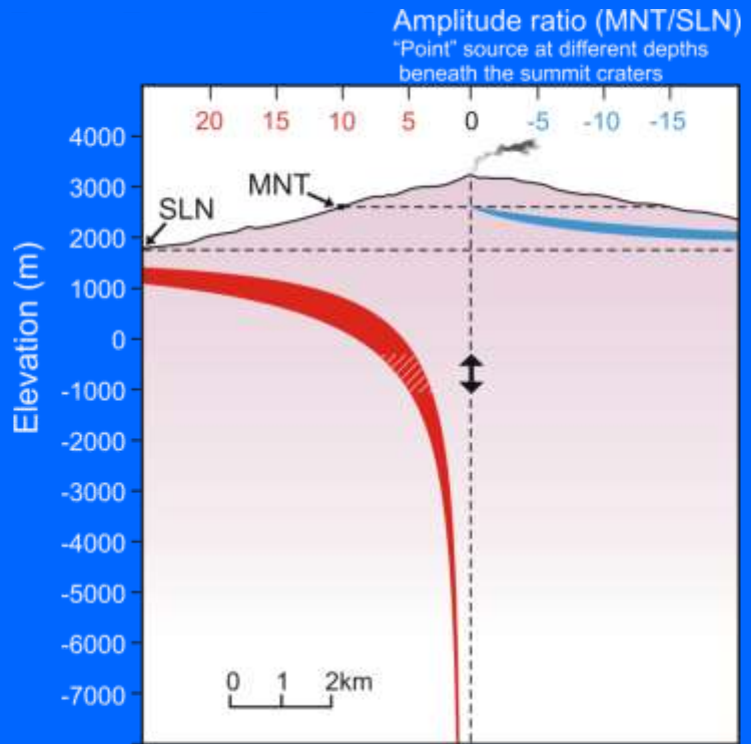
iGrav SGs: time series from Etna (January-March 2017)











The amplitude ratio MNT/SLN = ~5 indicates a mass source at depth between sea level and 1km b.s.l.

Inferences

Continuous gravity observations at active volcanoes through SGs

- ✓ The iGrav SG represents a powerful tool to perform continuous gravity observation at volcanoes with high precision and long-term stability.

- ✓ Classical limitations that arise when using spring gravimeters (instrumental drift and instrumental effects driven by ambient parameters) are not encountered with SGs.

- ✓ Due to power requirements + size/weight constraints, SGs cannot be installed on the summit of high volcanoes. However, thanks to the high quality of the signal, meaningful changes can be assessed even if the observation points are some km away from the active centers.

- ✓ When dealing with the high-quality signal from SGs, the effect of groundwater mass changes must be taken into account, especially when the installation site is not in close proximity to the active craters (the amplitude of the water-related changes may be comparable to that of volcano-driven effects).

- ✓ We demonstrate that, through comparison of the signals from two SGs in the summit zone of Etna, it is possible to recognize anomalies likely related to volcanic processes and to place constraints on the position of the source.