NEWTON – New portable multi-sensor scientific instrument for non-invasive on-site characterisation of rock from planetary and sub-surfaces

Newton novel magnetic instrument. Potential application to unveil key questions as the origin of the Moon

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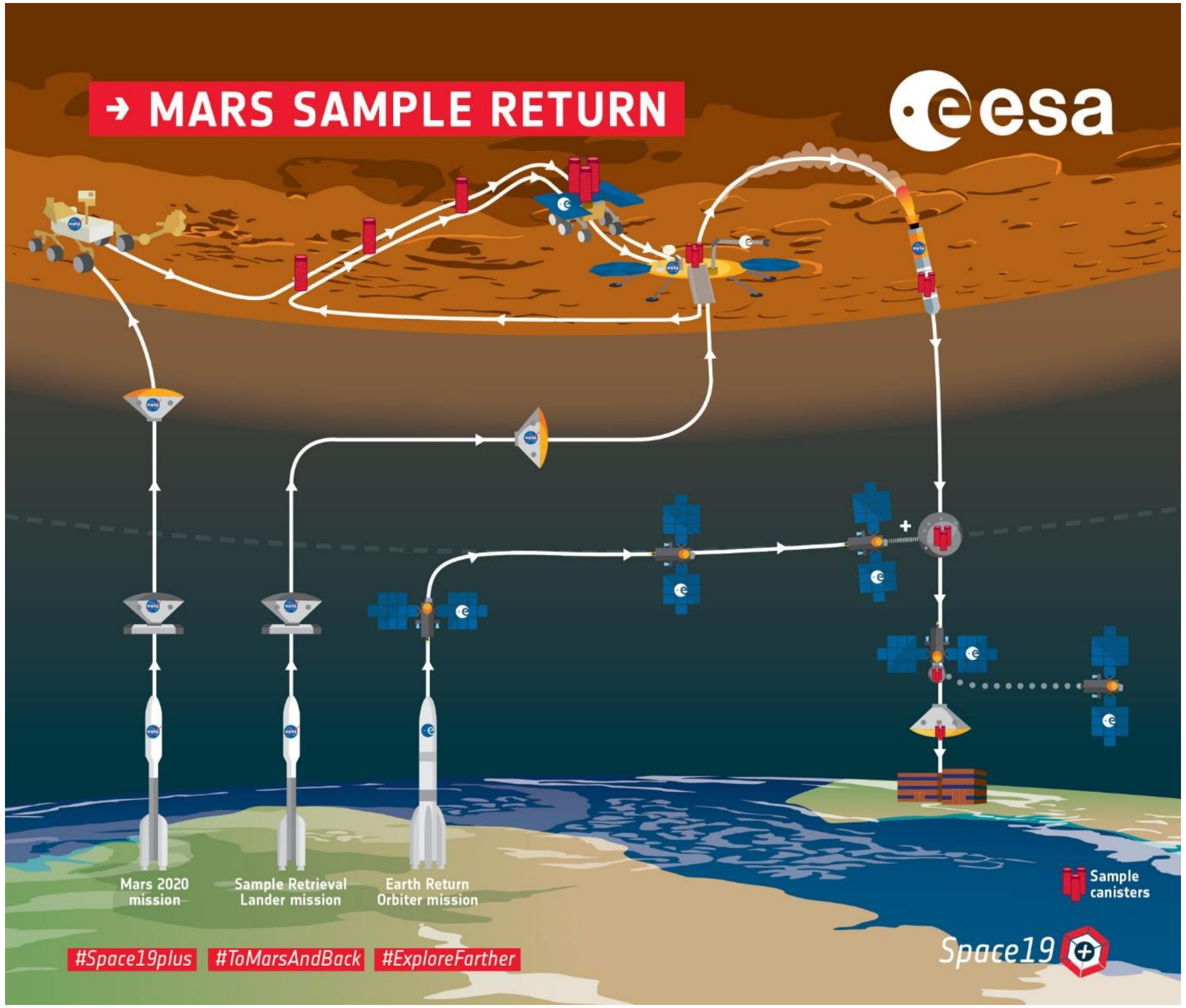
HORIZON 2020
THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

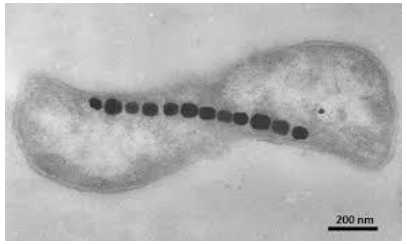
The role of NEWTON instrument: in situ measurements during space missions



Source: www.esa.int

Image: Price 1980

Dolerite
(medium grained mafic intrusive rock)



BIOPRODUCED?

- Sample return missions
- Material origin identification
- Regolith maturity

The role of NEWTON instrument: in situ measurements during space missions

Comments on slide 2: The role of NEWTON instrument: in situ measurements during space missions

The space scientific community is focusing efforts in future sample return missions. The general idea is to collect samples from rocky bodies of the Solar System, take them to the Earth and perform an exhaustive analysis of these sample with the most advanced laboratory techniques.

However, the samples must be selected with some criteria, and to do this, in-situ and fast measurement of some characteristics of the samples must be performed. The susceptometer that we have developed and that is presented in this slices is a potential instrument for this purpose, as its measures the complex magnetic susceptibility, an intrinsic property of minerals and materials, in an in-situ and fast way, and without the need of sample preparation, during space missions.

In the nature it can be found samples from different origins (volcanic, mafic, or even biological, like the magnetotactic bacteria) which have almost the same chemical composition and, therefore, can not be differentiated by some techniques. But the magnetic susceptibility of these samples is very different from one to each other due to the concentration, type and phase of their magnetic carriers.

A susceptometer like NEWTON instrument has a great potential during space exploration not only in sample return but also in scientific missions, helping in the material origin identification and in the characterization of soils, crusts and rocky bodies' regolith.

Open questions on the Moon

•Origin

Giant-impact hypothesis

Huge multiple impact event hypothesis (Rufu et al. 2017)

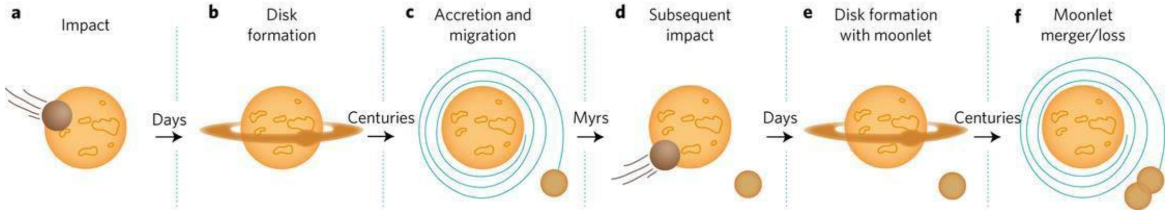


Figure 1

•Evolution

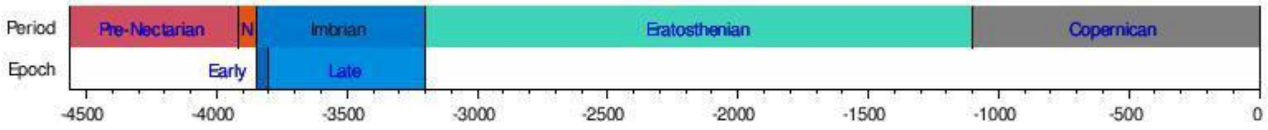


Figure 2: Geological time table of the moon. Millions of years before present

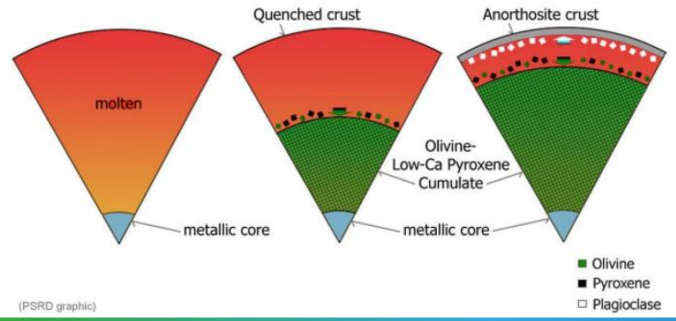


Figure 3: Illustration of the idea of the lunar "magma ocean concept" (e.g. Taylor 2011; Elardo et al. 2011).

•Internal magnetic field

Pros:

- Metallic core
- Global NRM
- Anomaly field orientation
- Homogeneous distribution
- Stable field

Cons:

- Small size of the core
- High NRM values
- Very strong magnetic field
- High range of NRM values
- High coercitivities

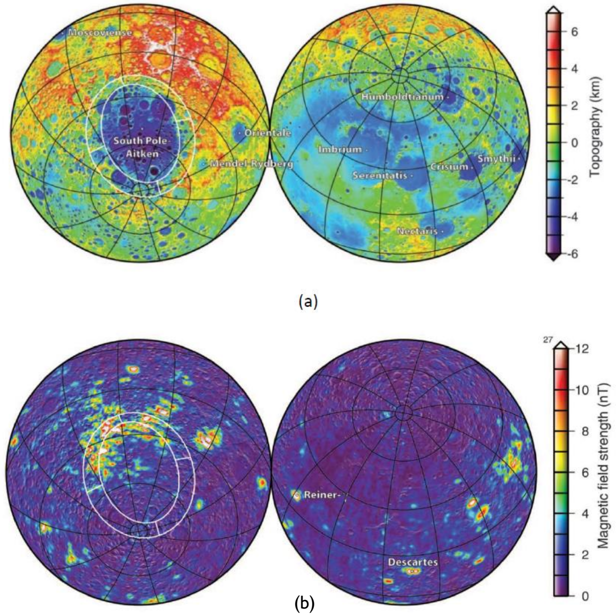
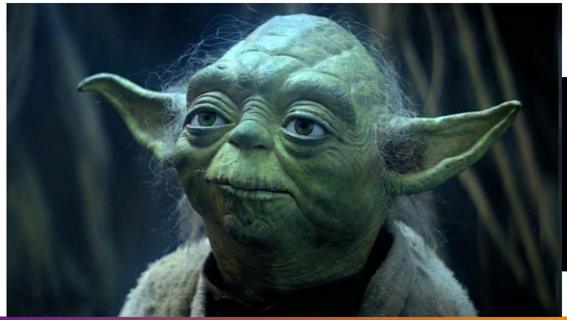


FIGURE 4



Many questions,
we still have.
Hrmmm

NEWTON Capabilities in the Moon

Comments on slide 4: NEWTON Capabilities in the Moon. Further investigations in the open questions of the Moon

ORIGIN

The chemistry and the mineralogical studies on lunar samples have been fundamental in the understanding of its origin.
The formation of the Earth's moon is best explained by the giant-impact hypothesis, which is the most accepted theory.
However, since not all the distinct features of the moon could be explained, Rufu et al. (2017) proposed a huge multiple impact event as more reasonable scenario.

EVOLUTION

The geological history of the Moon has been divided into six major periods starting at around 4.51 Ga with the Pre-Nectarian and ending with Copernican which includes the last 1 Ga (Figure 2).
The mineralogy and petrography of lunar rocks indicate that the Moon has been covered initially by a deep magma ocean (Elardo et al. 2011) before first rocks crystallized at around 4.51 Ga (Barboni et al. 2017; Taylor 2015), nearly coeval with the oldest rocks which formed from a magma ocean on Earth (Valley et al. 2014). FIGURE 2 illustrates the crystallization of olivine, pyroxene and plagioclase in this magma ocean and there density-related vertical separation which led to the formation of the lunar mantle and crust (up to 60 km thickness).

INTERNAL MAGNETYIC FIELD

Most hypotheses to explain the magnetic characteristics and anomalies on the Lunar surface invoke a thermally driven core dynamo during its Pre-Nectarian and Nectarian history. However, this theory is problematical given the small size of the core and the required strong magnetic field strength of an ancient dynamo.
The age of its TRM is uncertain, but must have been less than the 3.3 Ga age for the basalt clasts in the breccia and trapped Ar data suggest a lithification age of perhaps only ~1.3 Ga. If these results become confirmed, this would extend the lifetime of the lunar dynamo by at least 0.2 to 2 billion years, suggesting that the dynamo operated in two different intensity regimes: a pre 3.3 Ga high field epoch and a post 3.3 Ga weak field epoch (Weiss & Tikoo 2014).
The existence of such a very long living dynamo with a low magnetization force can be explained based on recent modelling which considers a depletion of the lunar mantle by siderophile elements and suggests a bulk core sulphur abundance of ~6 wt. %. Such chemistry could have provoked a core crystallization process which played an important role in sustaining a weak late lunar dynamo (Weiss & Tikoo 2014).

NEWTON instrument at a glance

Instrument schematic design

NEWTON Multisensor

PDU
(Power distribution Unit)

Control electronics

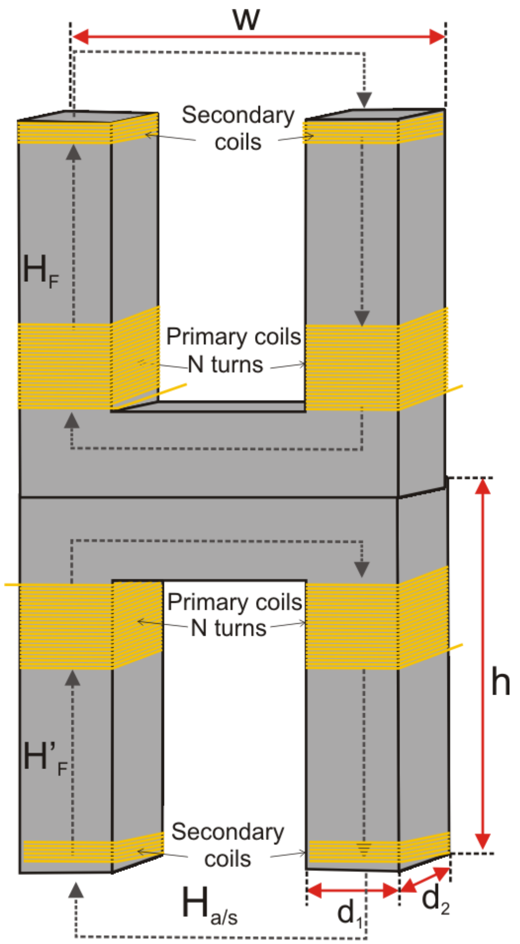
Inside vehicle structure. Protected against environmental conditions.

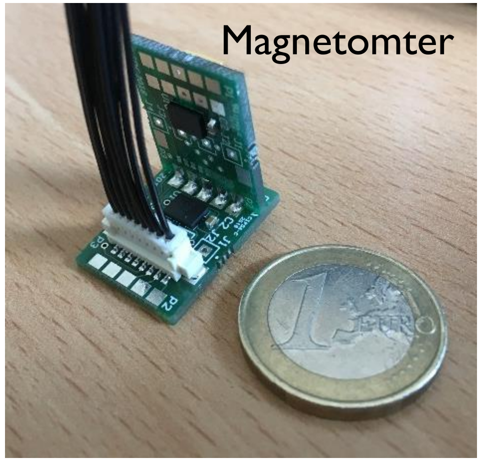
Physical interface. Deployable mechanism.

Sensor Unit
Susceptometer
Magnetometer
Thermometer

Outside vehicle. In contact with the samples.

Susceptometer





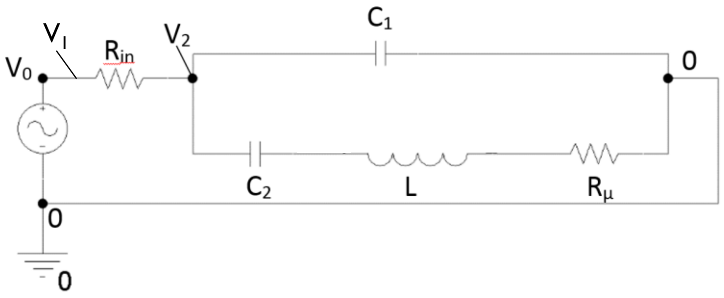
NEWTON instrument at a glance

Comments Slide 6: NEWTON susceptometer at a glance

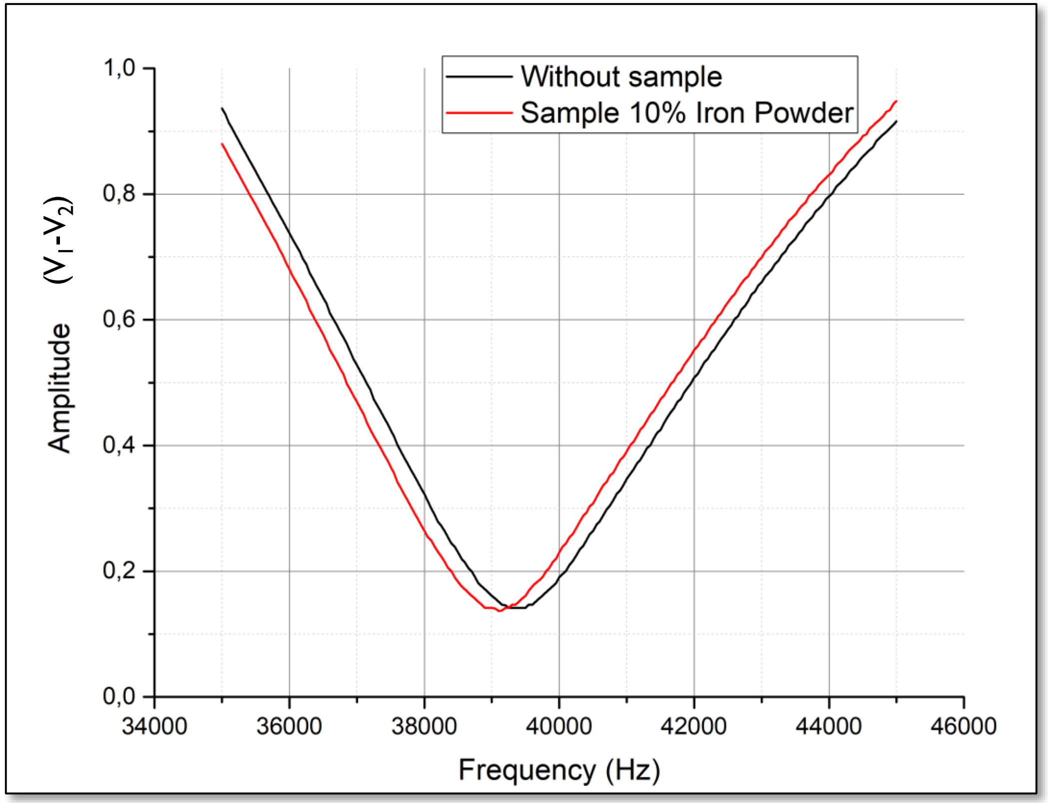
The Space Magnetism Laboratory at INTA has been working during the last years in the development of magnetic devices for space exploration. The objective is to provide a complete characterization of not only the magnetic field but also the sources of the magnetic field. The NEWTON multisensory instrument has been developed within the frame of a European H2020 project, a collaboration between 6 different partners around Europe, three of them technological partners which have developed the three different units of the instrument: the PDU (TTI Norte), the Control Unit (UPM) and the Sensor Unit, developed by INTA, which includes a vector magnetometer based on COTS technology, thermometers for the monitoring of the sensor temperature and the susceptometer sensor head.

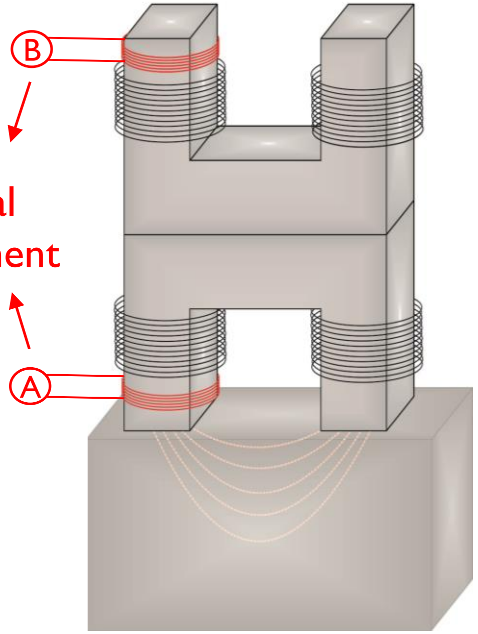
On the following the presentation is centered in the development and features of the susceptometer. It is based on a H shaped ferrite cored coiled with primary coils for the induction of the AC magnetization and secondary coils to pick-up the signal of the magnetization state of the ferrite core.

NEWTON working principles



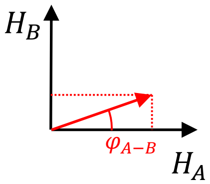
$$\chi'_s = \frac{f_{0,a}^2 - f_{0,s}^2}{f_{0,s}^2 - \frac{l_F}{2\pi^2 N^2 C S_F \mu_F}}$$





$$\varepsilon_{A/B} = -N\frac{d\Phi}{dt}; \Phi = \oint B \cdot S;$$

$$B = \mu \cdot H_0 sen(\omega t + \varphi);$$



NEWTON working principles

Comments on slide 8: NEWTON working principles. Real and imaginary susceptibility determination.

The ferrite core and its primary coil form part of a resonant circuit, a modified RLC with resonance frequency values which depends on the value of the self-inductance of the susceptometer core. The circuit is design to obtain an optimum relation between input power (minimum) and current in the primary coil (high) generated at the working resonance frequency.

Real Part: The value of the resonance frequency modifies when a sample is approached to one of the extremes of the ferrite core, and the real component of the complex magnetic susceptibility of the sample can be determined by means of the resonance frequency values.

The secondary coils monitor the magnetic induction state of the ferrite core, performing a differential measurement of the AC signal (amplitude and phase) between the active secondary coil (A) on the side presented to the sample and the passive or reference coil (B). The phase difference induced between the two secondary coils is proportional to the imaginary component of the complex magnetic susceptibility of the sample under measurement.

This way, we can measure the complex magnetic susceptibility of the sample, including the imaginary susceptibility, with information about the magnetic/electric loss mechanisms, spin relaxation, etc.

NEWTON performance in natural rock scenarios

NEWTON

INTA

EGU General Assembly 2020

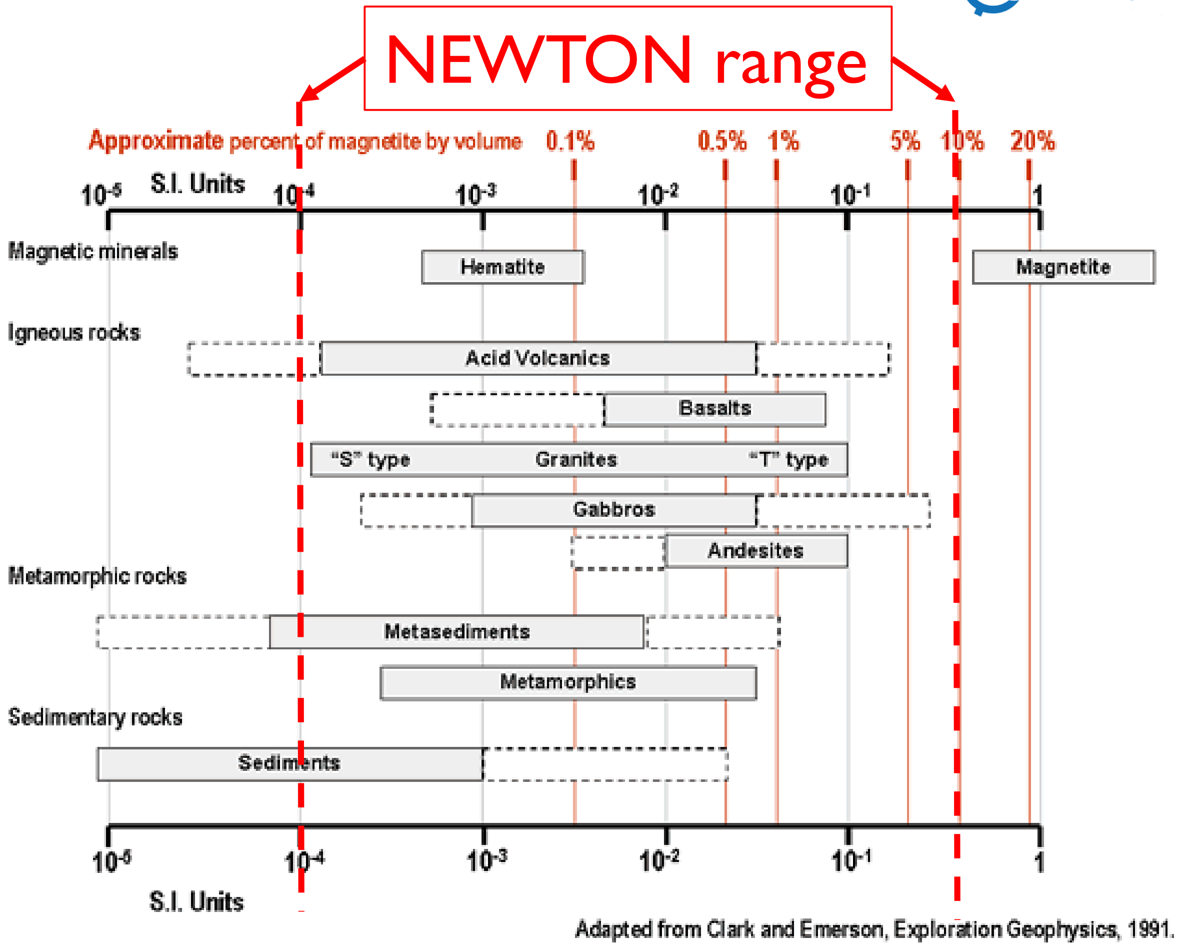
Mineral	Chemistry	Average susceptibility (SI)	Comments
Magnetite	Fe_3O_4	$6000 * 10^{-3}$	ferrimagnetic
Ulvospinel	Fe_2TiO_4.	~0	paramagnetic at room temperature
Ilmenite	$FeTiO_3$	$1800 * 10^{-3}$	antiferromagnetic
Hematite	Fe_2O_3	$6.5 * 10^{-3}$	antiferromagnetic
Maghemite (another form of hematite)	Fe_2O_3	similar to Magnetite	ferrimagnetic
Pyrite	FeS_2	$1.5 * 10^{-3}$	paramagnetic at room temperature
Pyrrhotite	$Fe_{1-x}S$ (Fe_7S_8)	$1500 * 10^{-3}$	ferrimagnetic

(https://www.eoas.ubc.ca/~fjones/aglosite/objects/bkgr_6c/4susceptibility.htm)

The susceptiblitlites of various rocks and minerals

Material	Susceptibility x 10-3 (SI)	Material	Susceptibility x 10-3 (SI)
Air	about 0	Limestones	0 - 3
Quartz	-0.01	Sandstones	0 - 20
Rock Salt	-0.01	Schist	0.3 - 3
Calcite	-0.001 - 0.01	Gneiss	0.1 - 25
Sphalerite	0.4	Slate	0 - 35
Pyrite	0.05 - 5	Granite	0 - 50
Hematite	0.5 - 35	Gabbro	1 - 90
Illmenite	300 - 3500	Basalt	0.2 - 175
Magnetite	1200 - 19,200	Peridotite	90 - 200

Adapted from T.M. Boyd of the Colorado School of Mines



Bulk magnetic susceptibilities of magnetic minerals as well as igneous, metamorphic and sedimentary rocks.

(https://www.eoas.ubc.ca/~fjones/aglosite/objects/bkgr_6c/4susceptibility.htm)

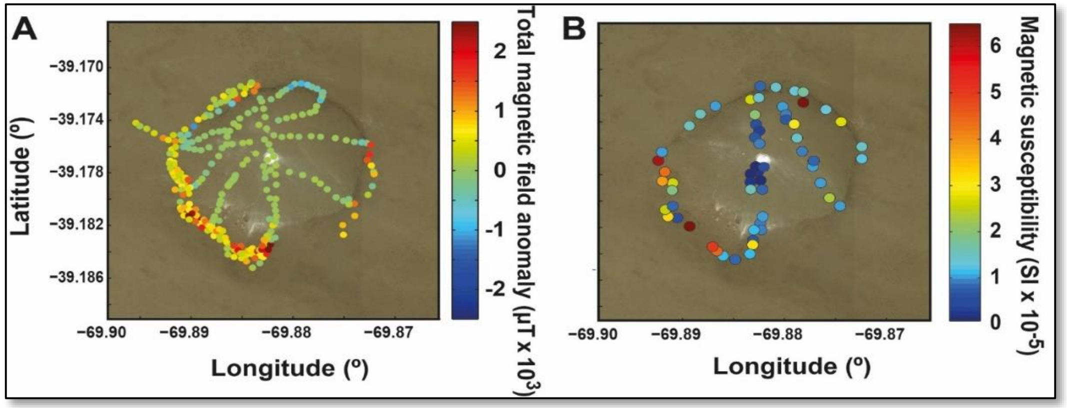
NEWTON performance in natural rock scenarios

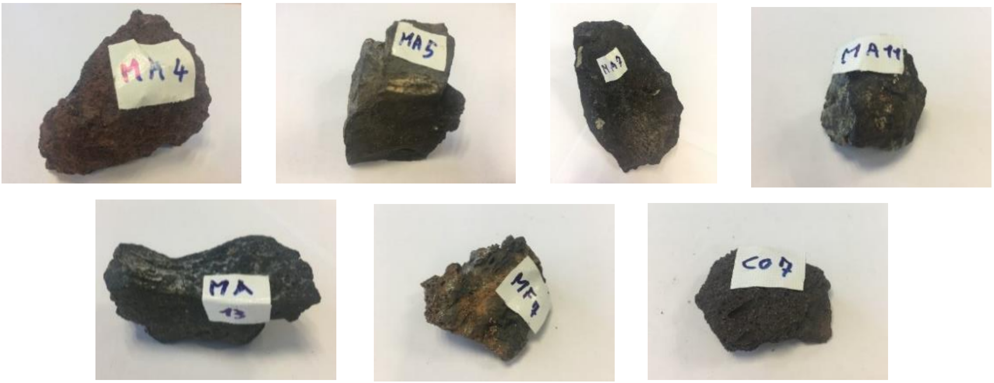
Comments on slide 10: NEWTON performance in natural rock scenarios

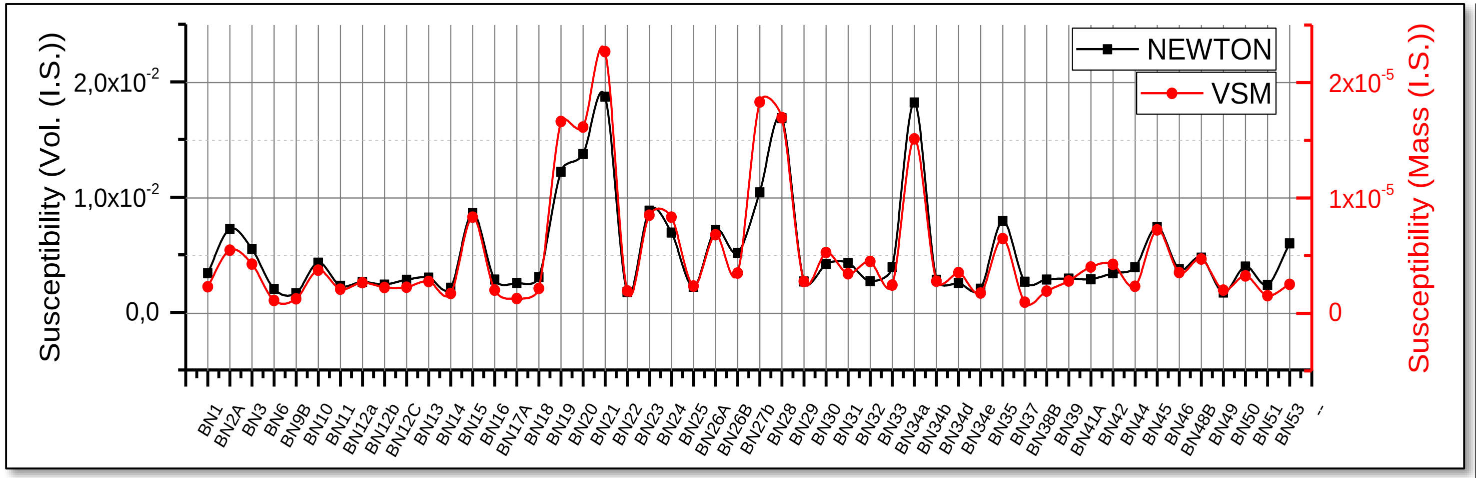
The NEWTON susceptometer has been used to measure natural samples from different origins. The samples were picked-up during different field campaigns and measured with NEWTON instrument and reference equipment, like the Vibratins Sample Magnetometer available at our facilities. The results show good correlation between NEWTON and reference equipment measurements, as we will see in the next slice, and a wide demonstrated operation range, with a sensitivity sufficient to characterize the most common natural magnetic minerals and materials expected to be found during Earth field campaigns and Solar System rocky bodies exploration.

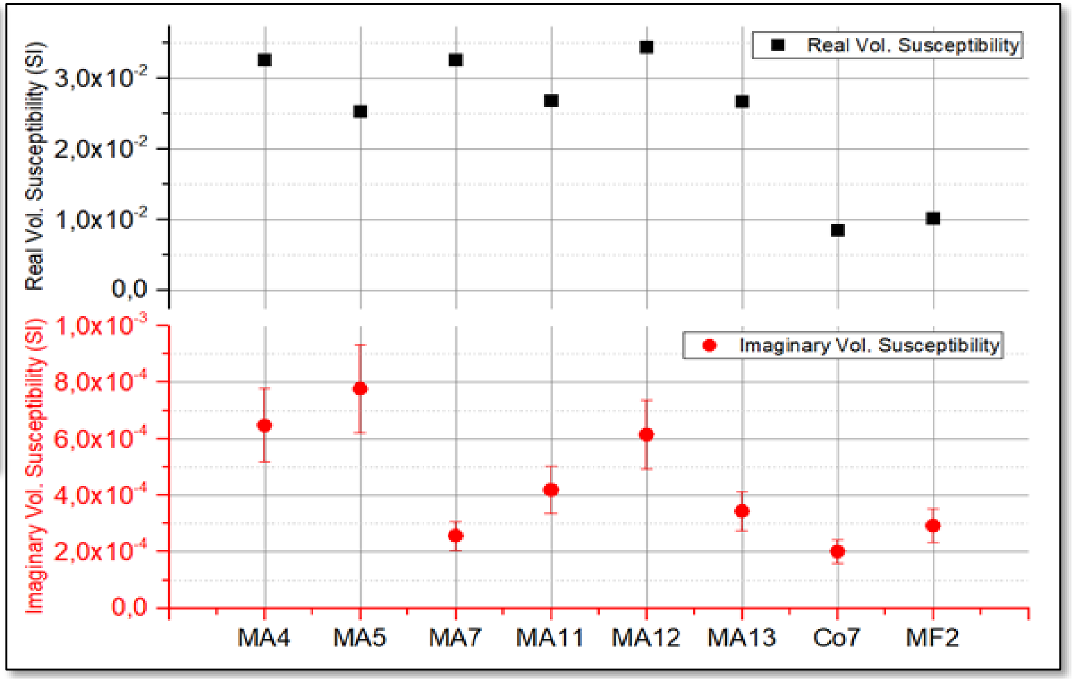
Examples of NEWTON application

Real case application: Barda Negra Crater magnetic mapping









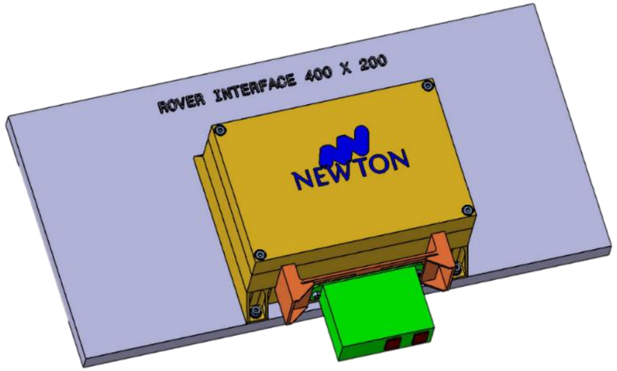
Up - Barda Negra crater magnetic characterization: Scalar magnetic field and magnetic susceptibility in a sinkhole crater [Diaz-Michelena, et al. 2020. *In press*.]
Right – Canary Islands volcanic region samples. Complex magnetic susceptibility of volcanic samples.

Examples of NEWTON application

Comments on slide 12: Examples of NEWTON application

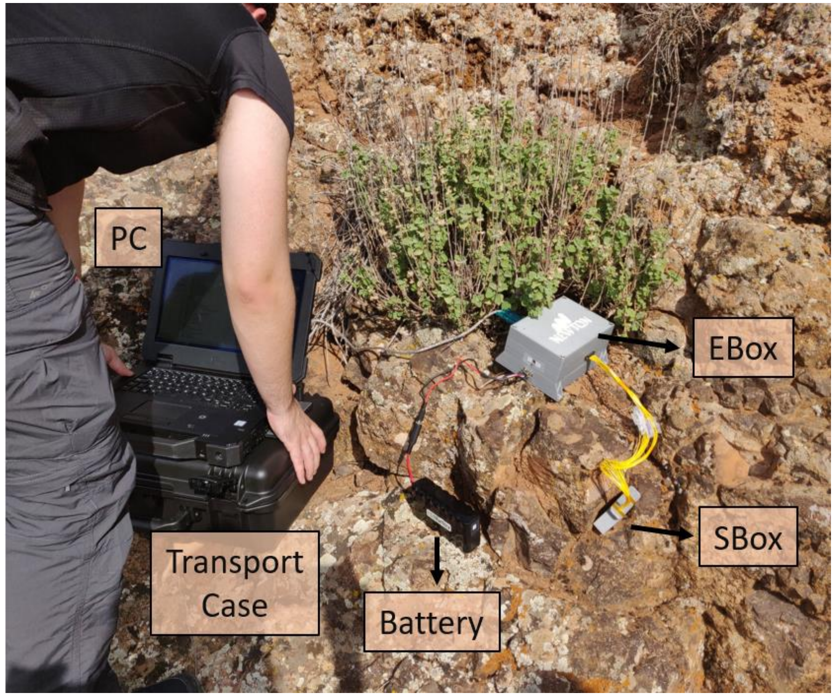
Some interesting results of the use of Newton instrument in natural scenarios are presented in this slice. Like the Barda Negra crater, where a deep investigation suggested the collapse of the area as a possible origin for the analyzed crater (sinkhole) (publication in press); or samples from a volcanic region, like the samples from Montaña de Maso, Montaña de Fuego de Calderas Quemadas and Caldera del Corazoncillo de Lanzarote, with a high value of the real susceptibility which allows the measurement the imaginary component, casting results of the complete complex magnetic measured with the NEWTON susceptometer.

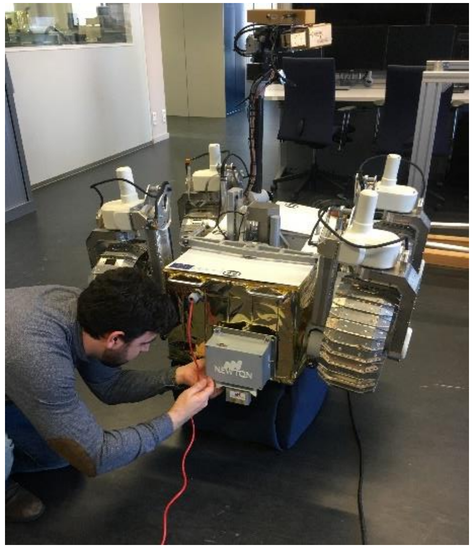
Current state



Electronics Box
- Control electronics
- Power electronics

Sensor Box
- Magnetometer
- Susceptometer
- Thermometer





Current state

Comments on slide 14: Current state. Ready for implementation in a rover space vehicle

The NEWTON instrument constitutes nowadays a portable instrument with capability to perform fast in-situ measurement of the magnetic susceptibility during geological field campaigns. The instrument is divided in two boxes: the Electronics Box (EBox), containing the PDU, control and proximity electronics; and the Sensor Box (Sbox), containing all the sensing elements in a mass (<150 grams) and volume envelope (smaller than a cigarette case) suitable for a handheld device. The model counts on an application for Windows than can be installed in a laptop and provides a interface that allows the user to control all the features and performance of the instrument.

The NEWTON sensor has been designed to be compatible with space vehicles architecture. This compatibility was tested and verified during a campaign with LUVMI rover, a rover prototype designed and developed by Space Applications Sevices NV/SA for surface investigations on the Moon.

The most critical parts of the instrument were submitted during its development to some critical test, such us outgassing, vibration or thermal-vacuum test to verify the capabilities of the instrument to withstand the hard conditions of a interplanetary space mission.

The instrument successfully pass al the tests, reaching a significant technological maturity level (TRL 6) and is ready to be adapted and included in future space missions.

Conclusions

- Compact instrument with multi-sensor capabilities
- Robust and compatible with space vehicles architecture
- Compatible with "non-magnetically clean" environments
- Capability to determine the complex magnetic susceptibility in a wide range
- No sample preparation required
- Non destructive analysis of different materials
- Demonstrated sensitivity and accuracy for planetary minerals and soils characterization

Thank you very much for your attention.

Please do not hesitate to comment on the live chat.

Have a beautiful Star Wars day. May the force be with you.