PolarQuest Detector Construction Days: CERN 20180522-24

Cosmic rays and applications: when fundamental Science helps everyday life

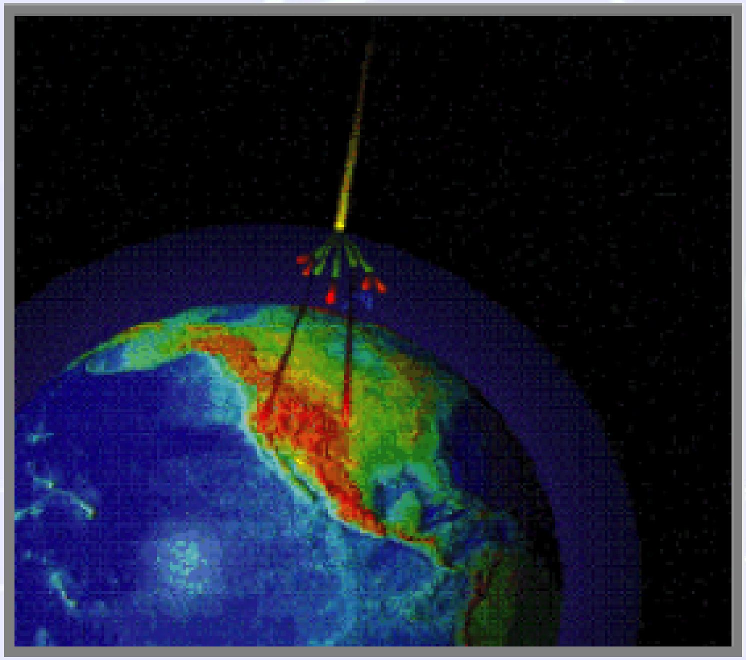
M. Garbini, I. Gnesi

courtesy of F. Riggi

First, what are they?

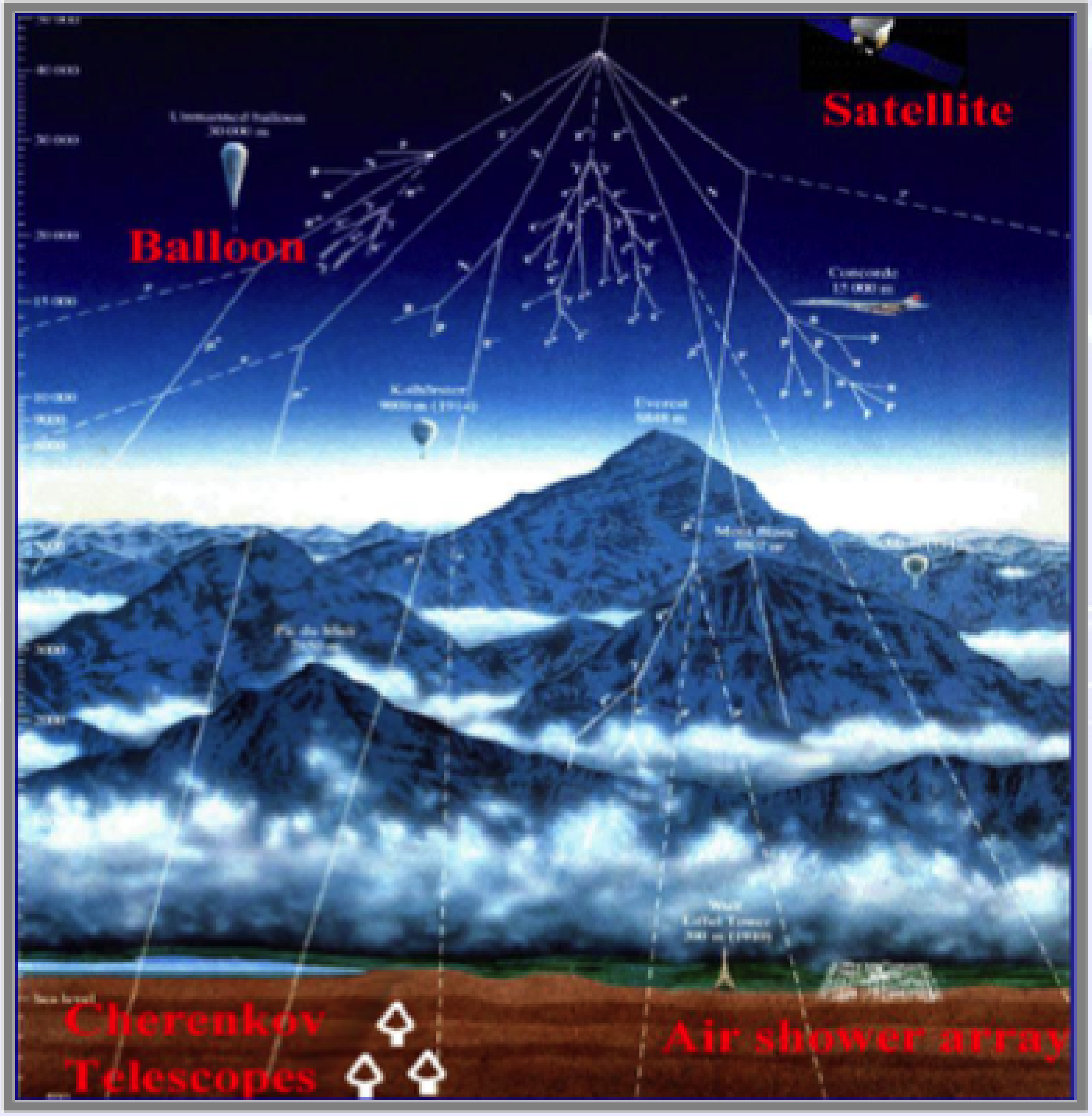
Cosmic Rays

Cosmic rays are particles impinging the Earth atmosphere from every direction!
They are mainly protons (90%) coming from galactic and extra galactic sources



They have been discovered by V. Hess in 1912
with pioneering measurements on baloon

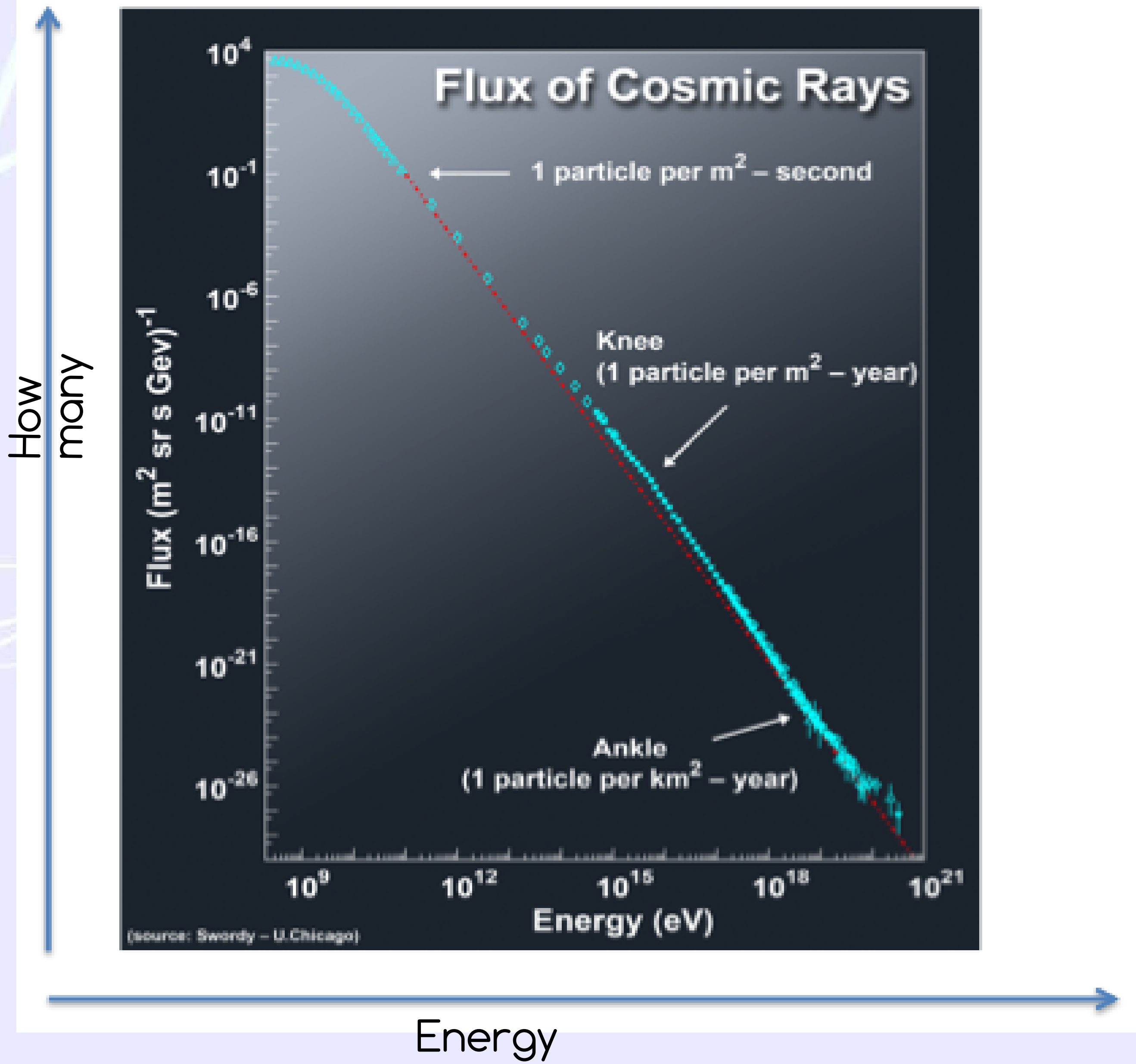
Cosmic Rays



Primary cosmic rays: those arriving at the top of the atmosphere

Secondary cosmic rays: those produced in the interaction of primary cosmic rays with the nuclei of the atmosphere

Cosmic Rays: Our knowledge after > 100 years

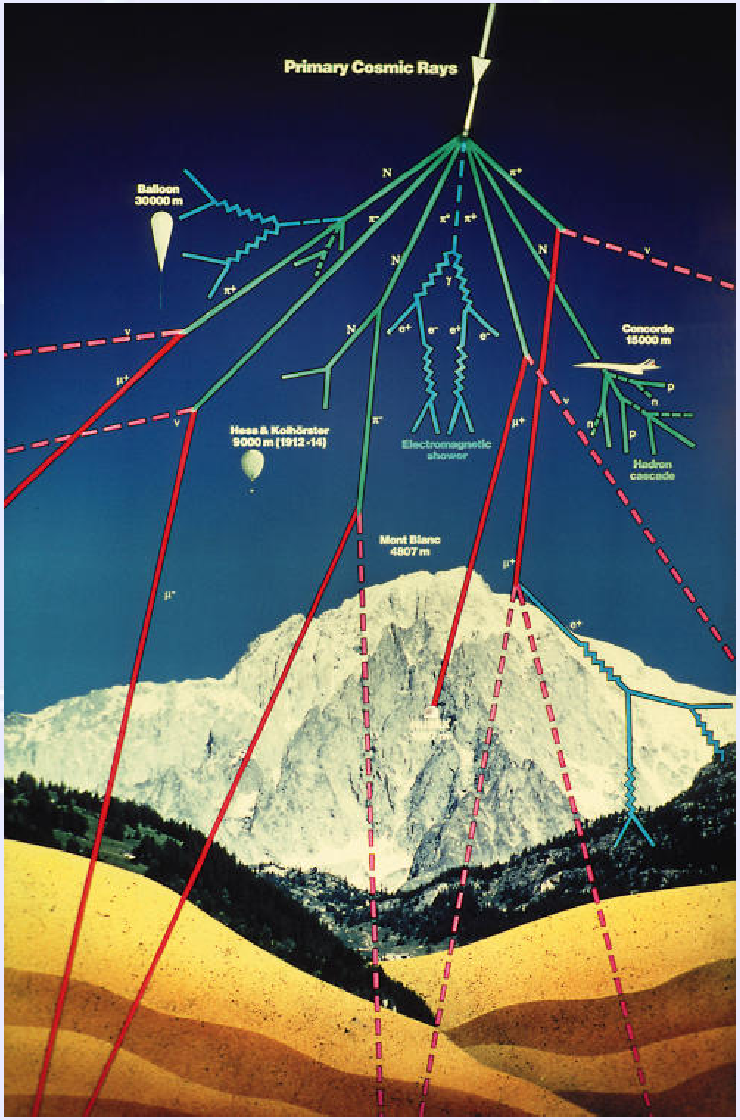


Secondary Cosmic Rays and EveryDay Life

Muons, secondary particles yield in airshowers initiated by primary protons or nuclei, are the “penetrating” component of cosmic radiation, able to reach the ground level.
They can be used to study several aspects related with environment, technology, cultural heritage….

- Clouds formation
- CR and consumer electronics
- Life evolution and living beings
- The inner tomography of vulcanos

  … with muons!
- How to identify illegal Uranium on trucks
- Non-invasive tests on stability of buildings
- … and many others …



The inner structures of buildings and muons

May we use muons for testing the inner of building, searching for structural problems and hidden spaces?

Muons can be used by their interaction modes with matter:

(A) **Absorption:** muons can be absorbed while traveling trough walls and solid structures, providing radiographies of buildings

(B) **Scattering:** muons undergoes to scattering when interacting with high Z materials. Diffusion centers identify the presence of heavier nuclei and Z dependent radiography of the building.

(C) **Seconday particles:** particles like gamma and electrons can be produced in the materials by muons interaction, providing additional information to the radiography.

(A) e (B) already available. (C) is under study

First attempts to a muon radiography

Looking inside a pyramid using Cosmic Muons, searching for hidden empty spaces (Alvarez, '60s)

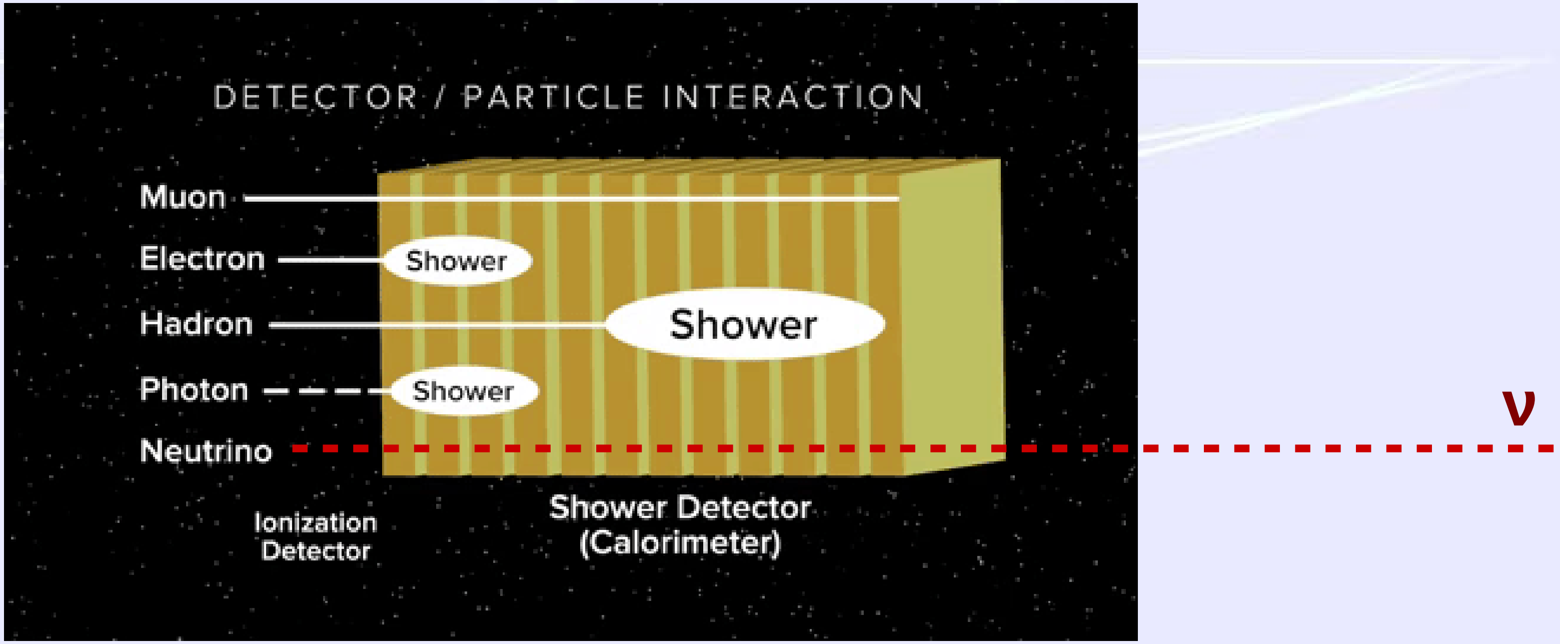
Luis Alvarez,
Nobel 1968

Muons absorption was used as the investigation channel

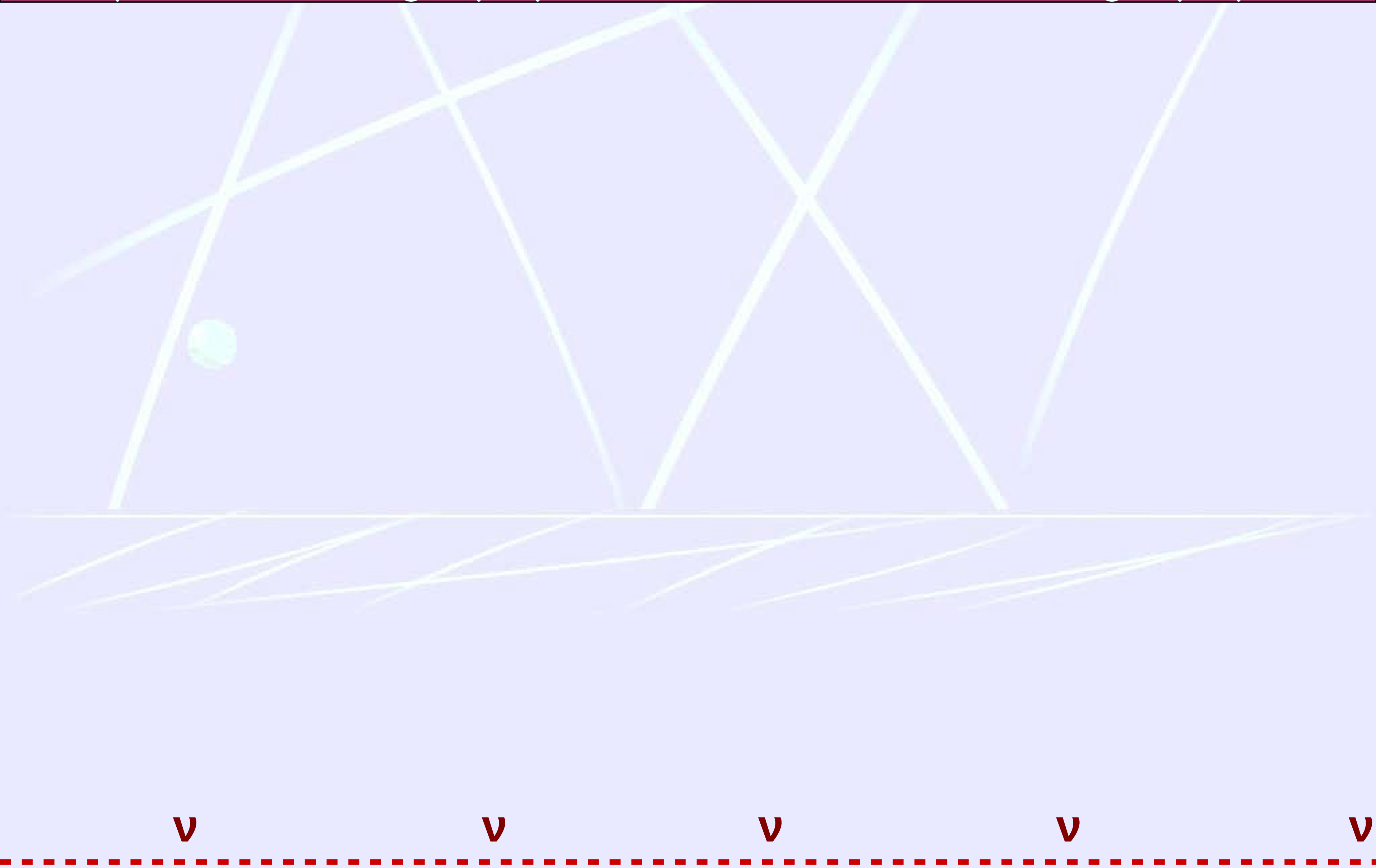
Alvarez, L.W. et al., Search for Hidden Chambers in the Pyramids, Science, 167, 832– 839, 1970.

Why muon tomography

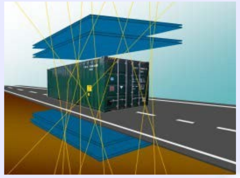
- Muons are strongly penetrating radiation
- No additional "artificial" radiation requested
- Relatively high flux (70 m^{-2} s^{-1})
- Muon cross section well known at 400 MeV - 4 GeV energies
- Scattering strongly dependent on material Z



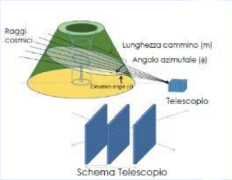
Why muon tomography… and not neutrino tomography



Exploring the environment with muons

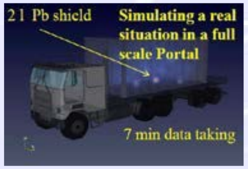


- Truck containers searching for radioactive materials

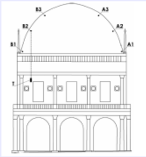


- Inner structure of vulcanoes and mountain

- Radioactive bars monitoring (exhaust from nuclear plants)



- Metal junk monitoring before its reuse in foundry (searching for forgotten piece of radioactive material)

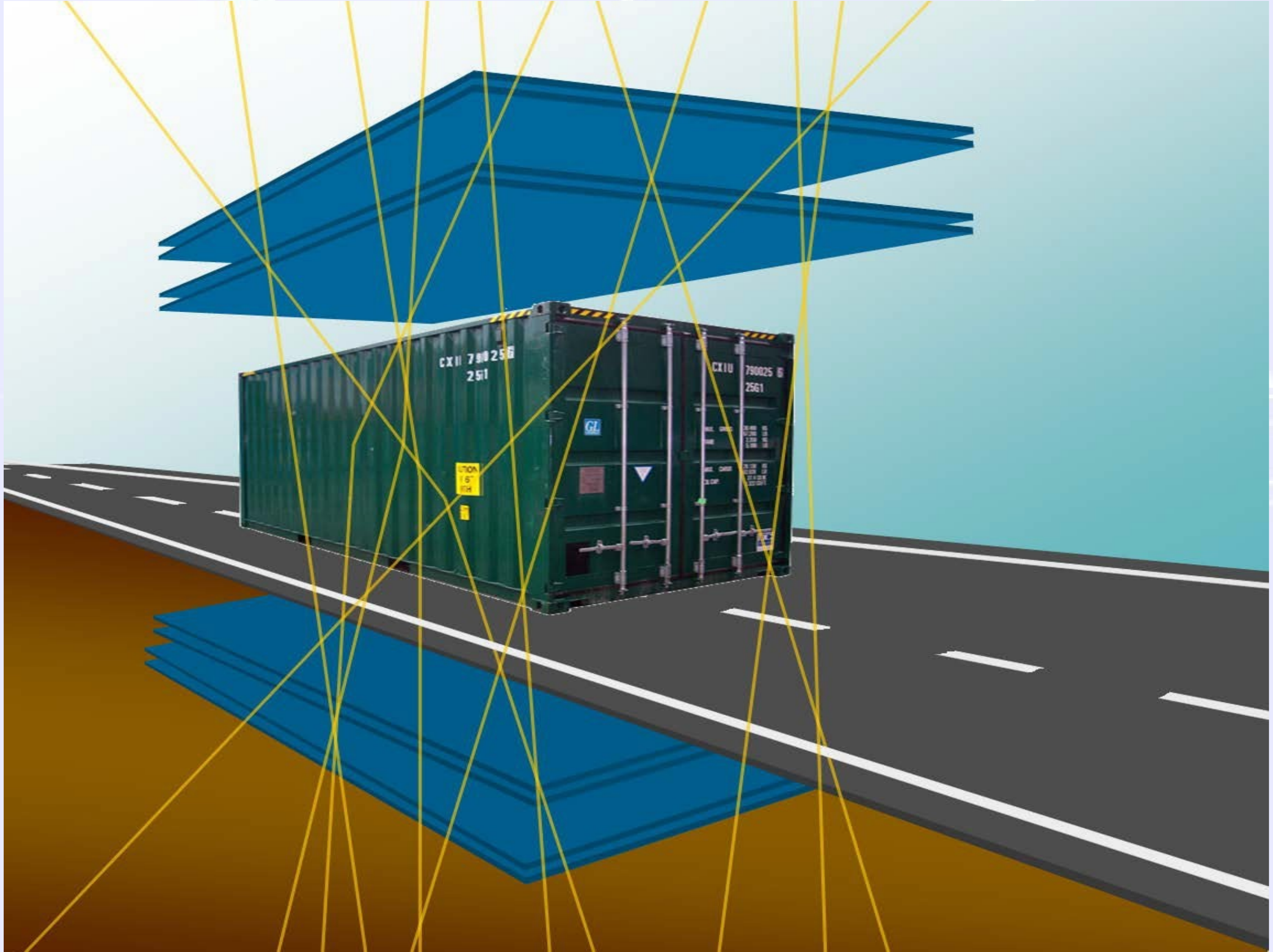


- Stability of buildings

- .... geological investigation of solar planets

How to inspect the inner of a truck

Cosmic muons are being tested as a probe for online search for nuclear material in trucks and containers



The interaction channel used is the muon diffusion on high Z materials (heavy nuclei)

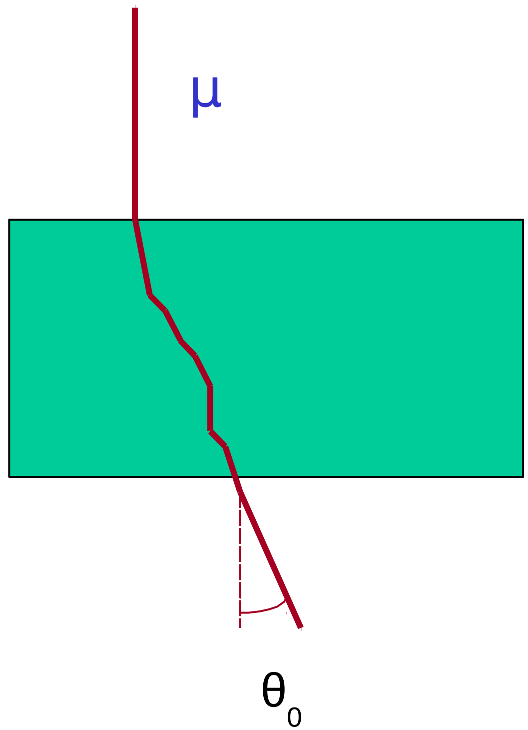
Why muon tomography

Effective for fast identification of Uranium, Plutonium and Lead

Muon scattering strongly depends on the nucleus charge (Z of material)

$$\theta_0 = \frac{13.6\text{MeV}}{\beta c p} \cdot z \sqrt{\left(\frac{x}{X_0}\right)} \cdot \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right]$$

$\beta c \rightarrow$ Velocity
$p \rightarrow$ Momentum
$z \rightarrow$ Charge Number
$x \rightarrow$ Width of Medium
$X_0 \rightarrow$ Radiation Length



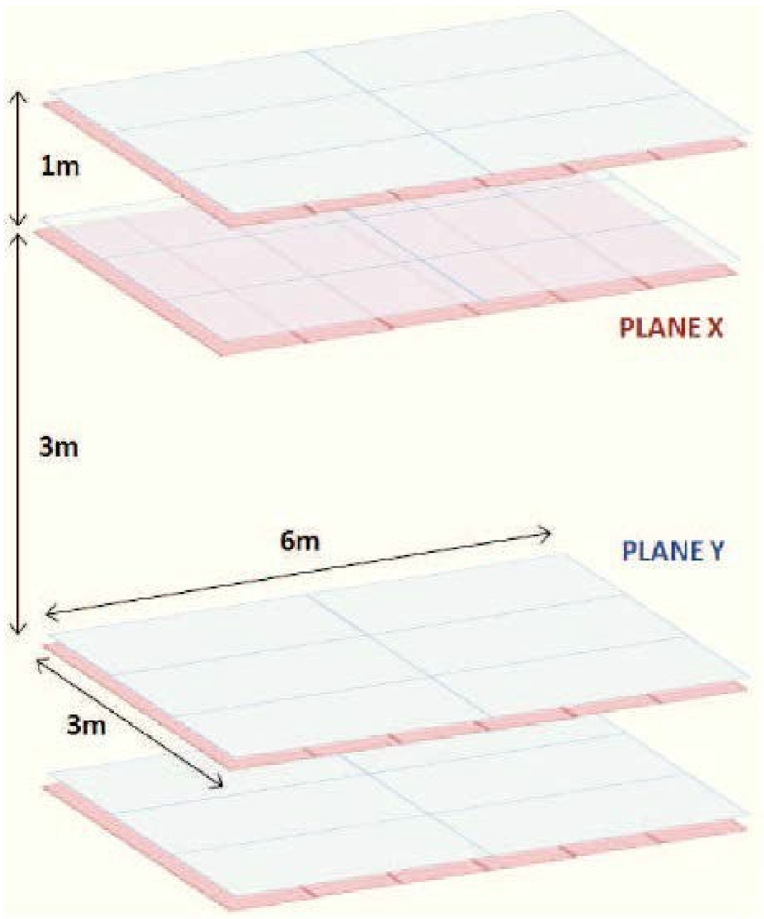
A muon tomography project in Catania (Italy)

Several projects are ongoing worlwide.
In Catania a prototype at realistic size has been implemented

A shared effort between Companies and University:
INAF-STMicroelectronics- MIWT-InSirio

A muon tomography project in Catania (Italy)

- 8 detection planes (4 X-Y), segmented in 48 modules (1 m x 3 m)
- Each modules is made of 100 scintillators strips, readout through scintillating fibers wavelenght shifters and SiPM light detectors



Numbers of the Project

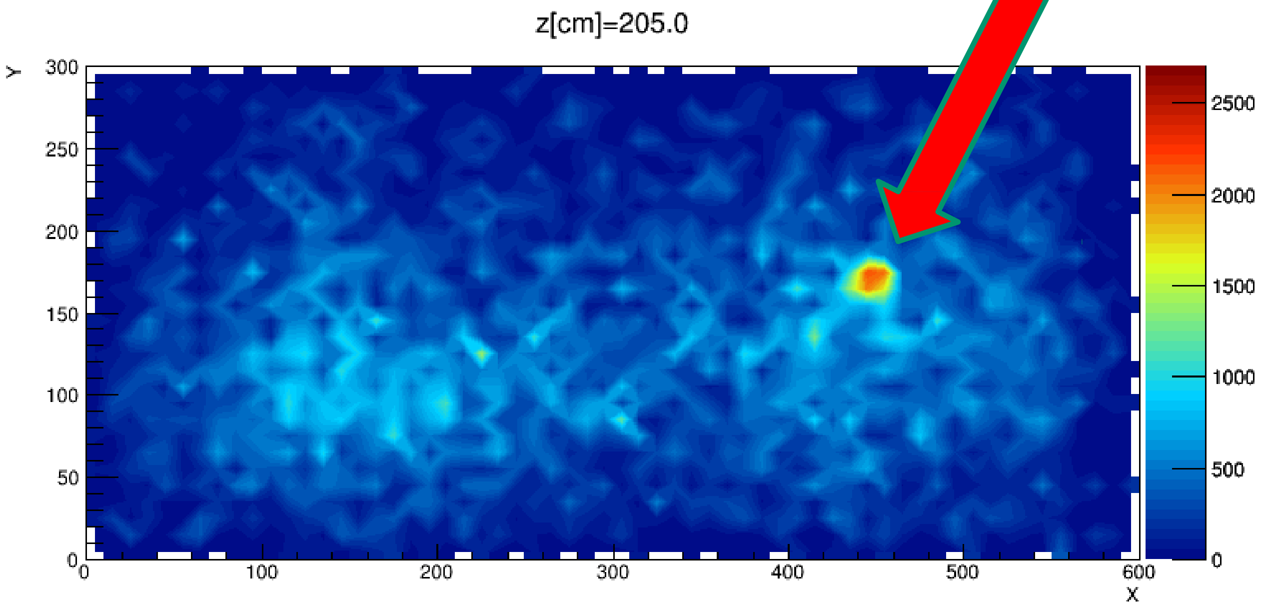
Optical fibers: 30 km
Scintillating strips: 15 km
SiPM: 9600

Effective area: 8 x 18 m^2
Effective volume: 30 m^3

Angular resolution 0.1°

First tomographic images reconstruction

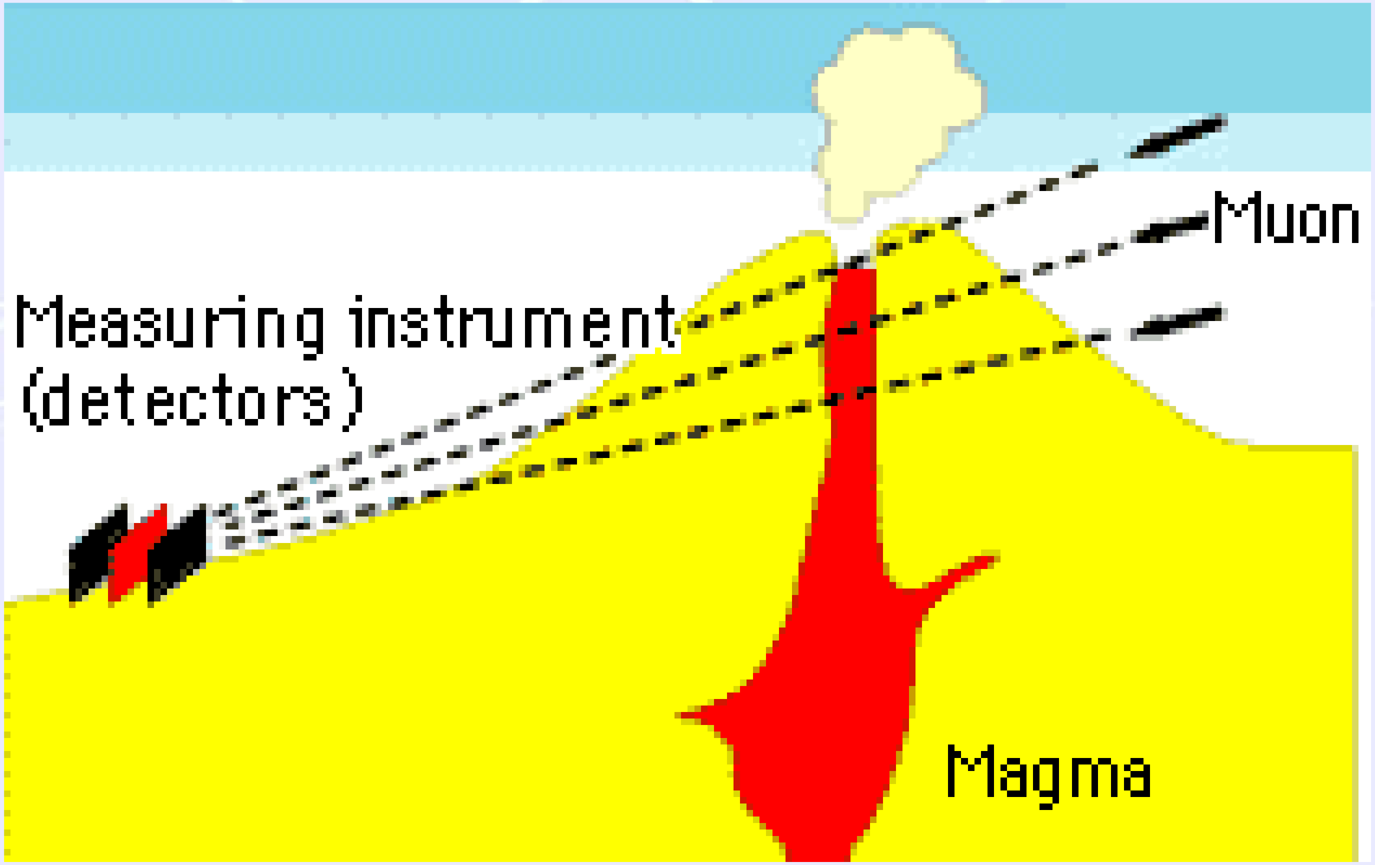
A lead brick 4 dm^3



Exploring vulcanos with cosmics

Recently several attempts to investigate underground volumes with cosmics

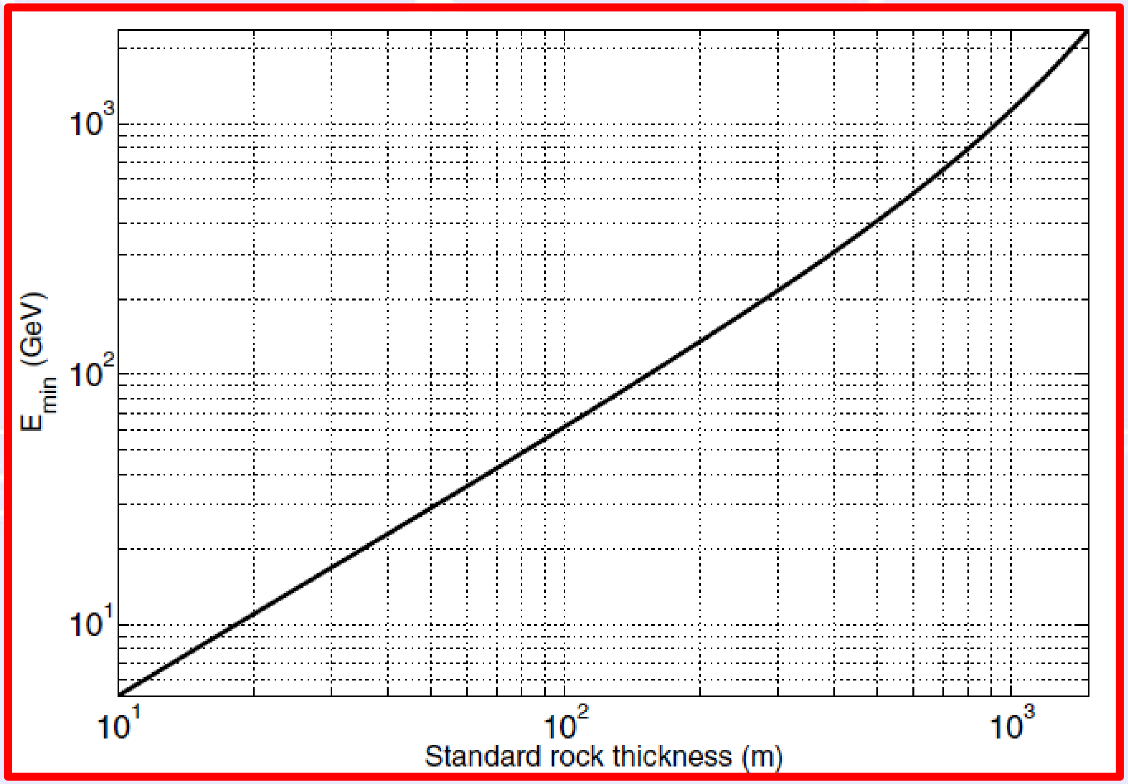
- Muon absorption through vulcanoes
- Caverns



Exploring vulcanos with cosmics

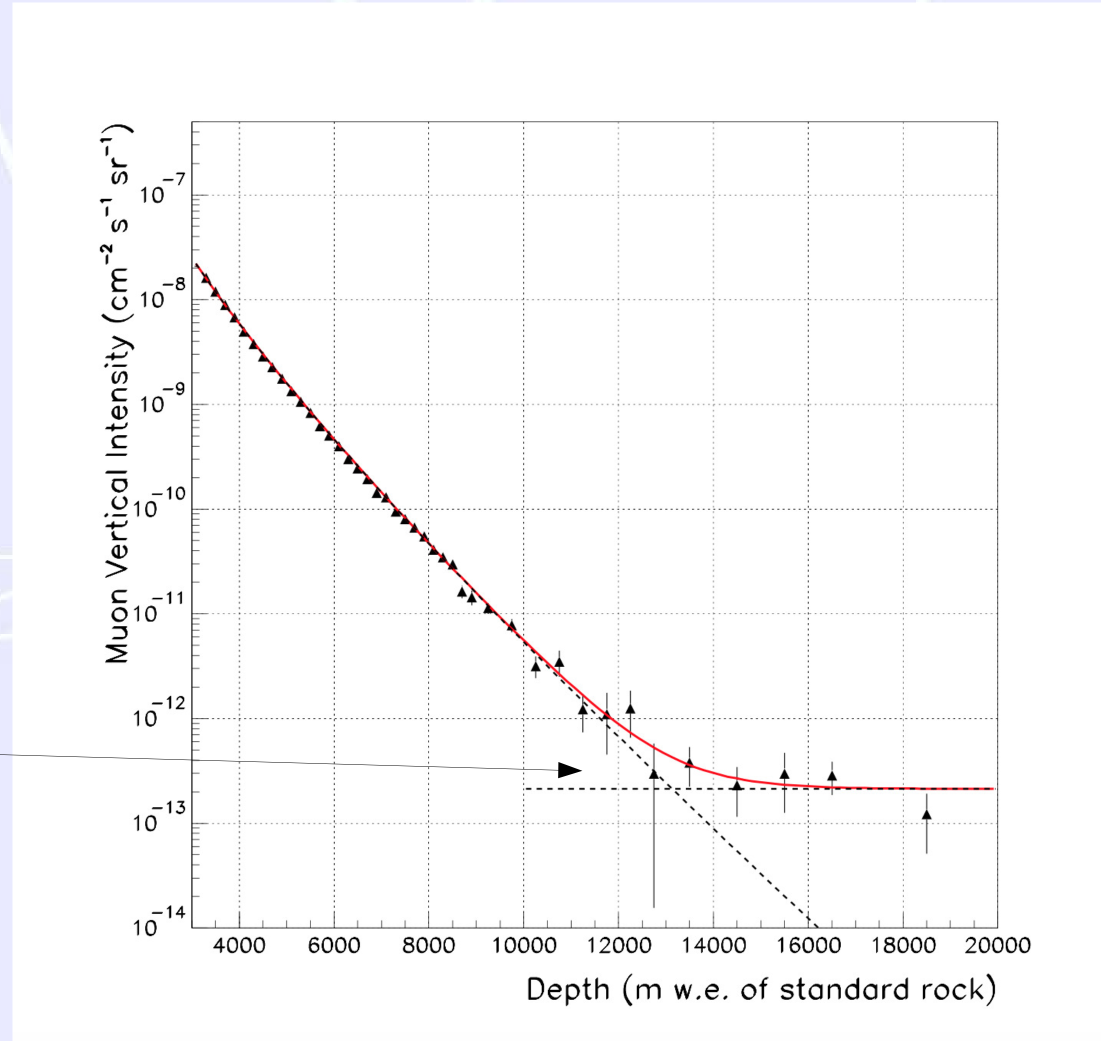
Energetic muons can travelled through 10 km of rocks before being stopped

Distance travelled by muons in rock



Exploring vulcanos with cosmics

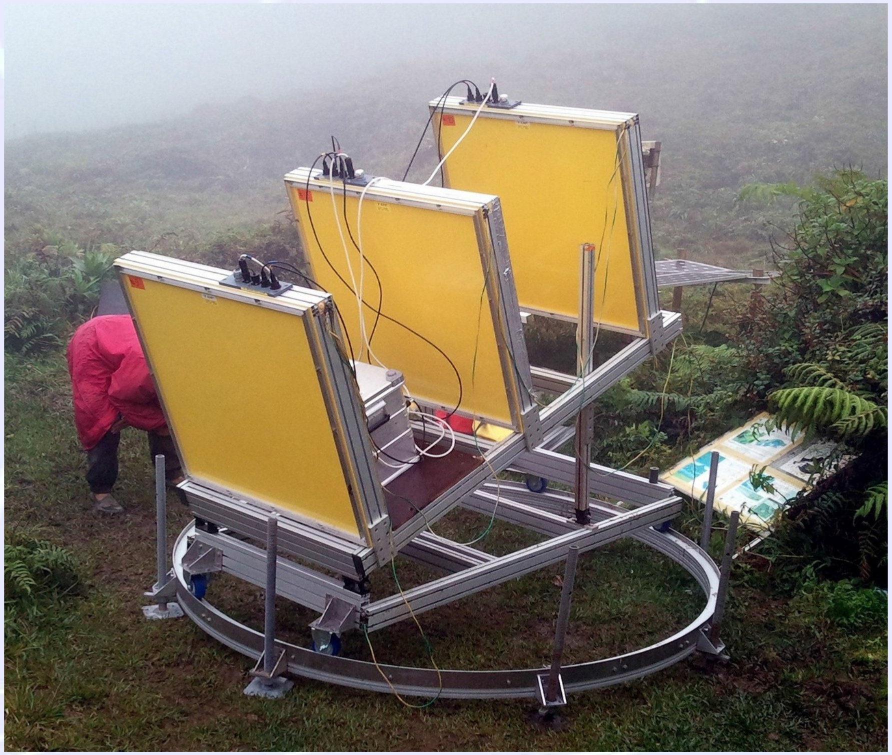
Energetic muons can travelled through 10 km of rocks before being stopped

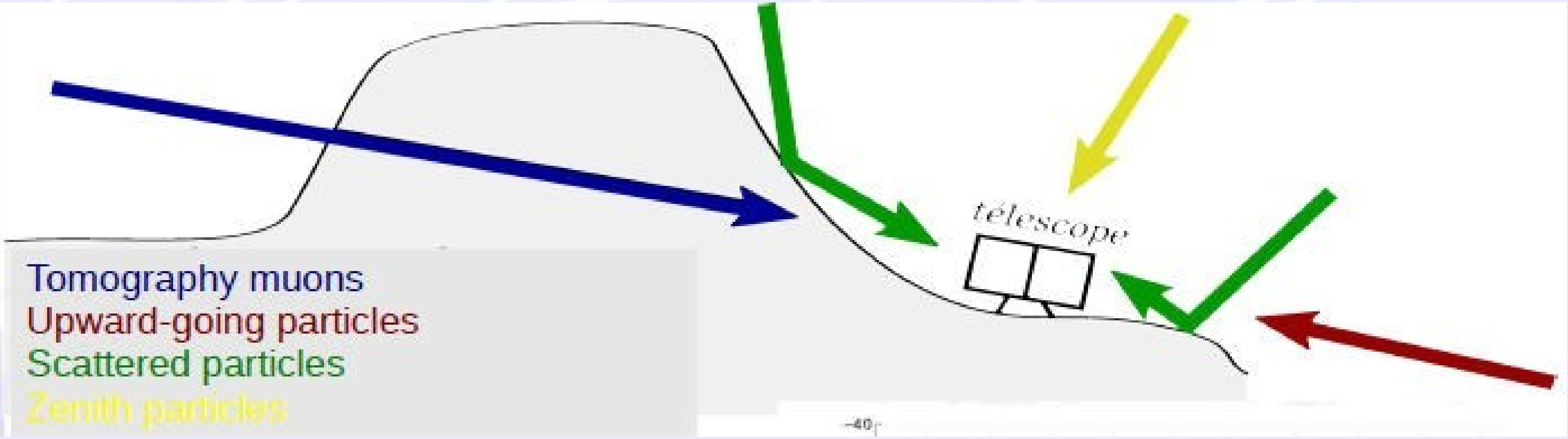


Muons induced by neutrinos

Exploring vulcanos with cosmics

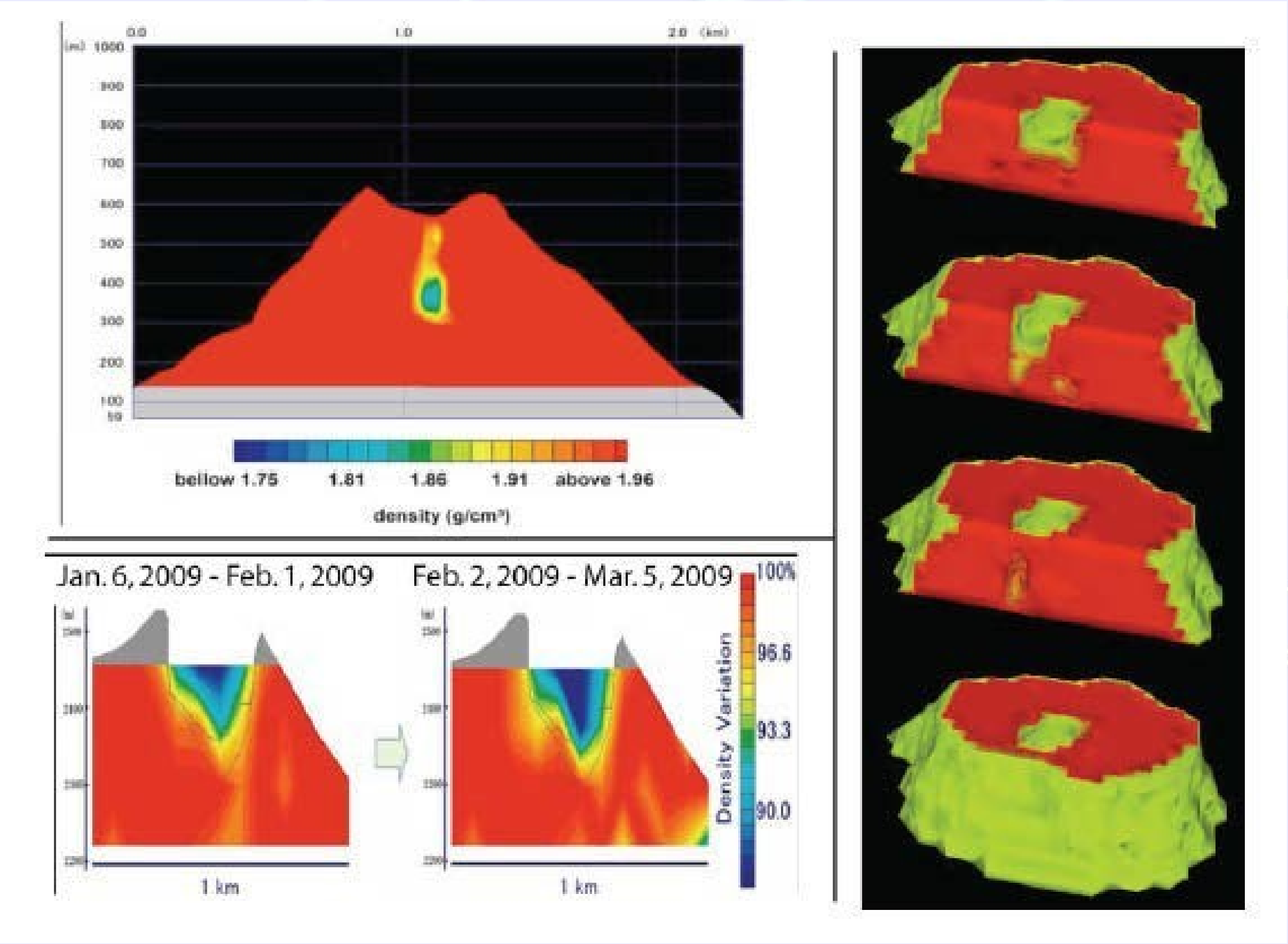
Anyway these are difficult measurements because of the several different background sources





Dangerous environment for doing measurement, anyway…

Exploring vulcanos with muons



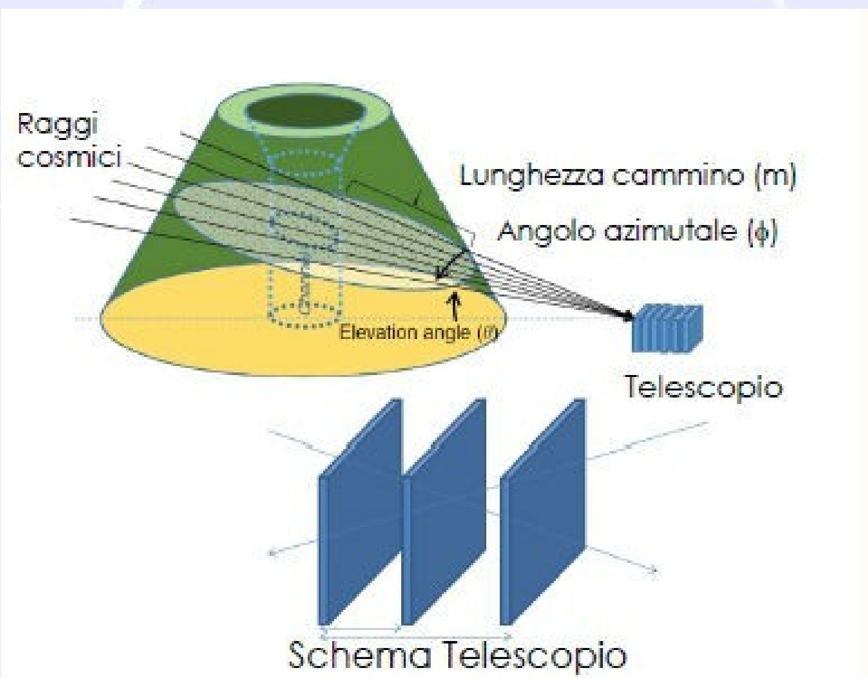
H.Tanaka et al., Geophys. Res.Letter 36(2009)L17302

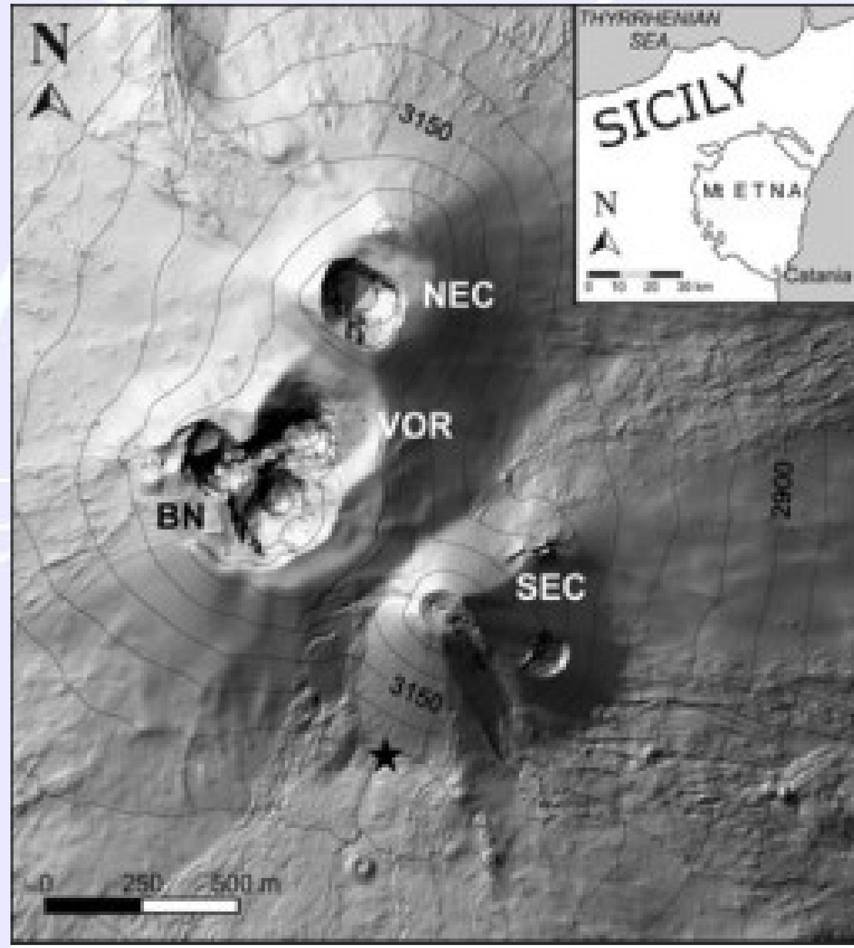
The Etna vulcano studied with cosmic rays

A telescope, similar to the one we're building for Polar, already in operation

The Etna vulcano studied with cosmic rays

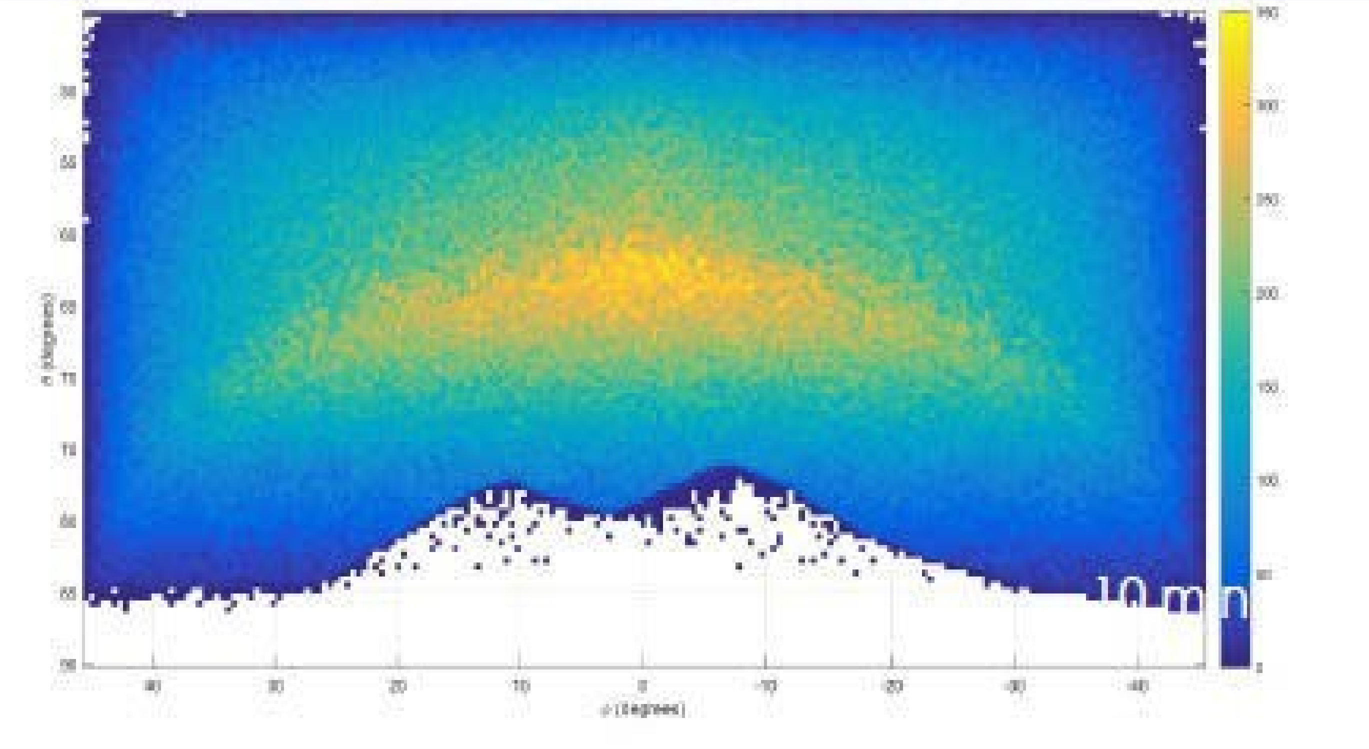
The aim is the study of the Etna upper craters (3400 m) using a set of telescopes for getting a 3D reconstruction of the inner structures of craters.



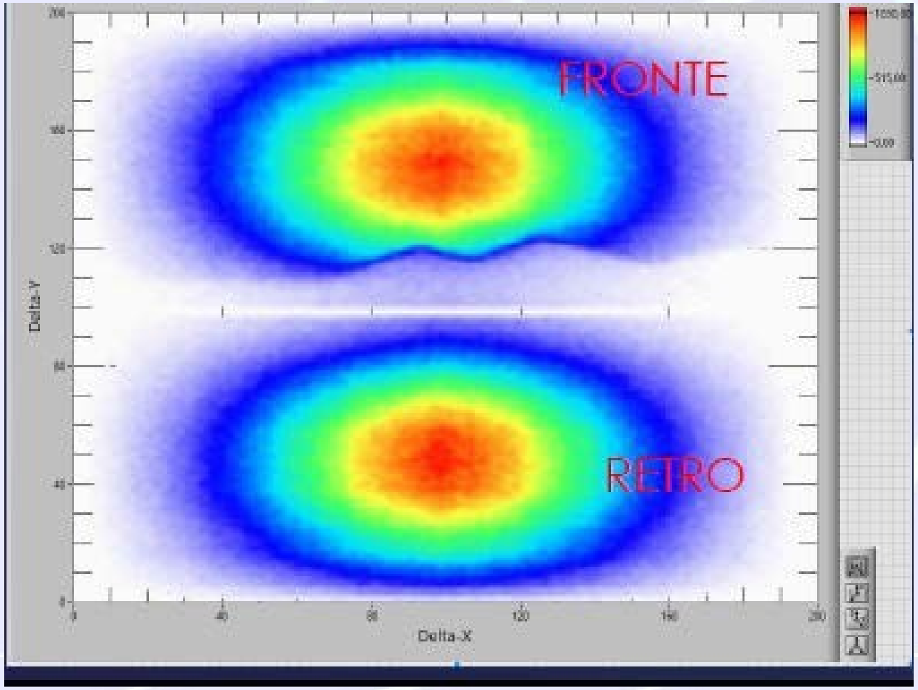


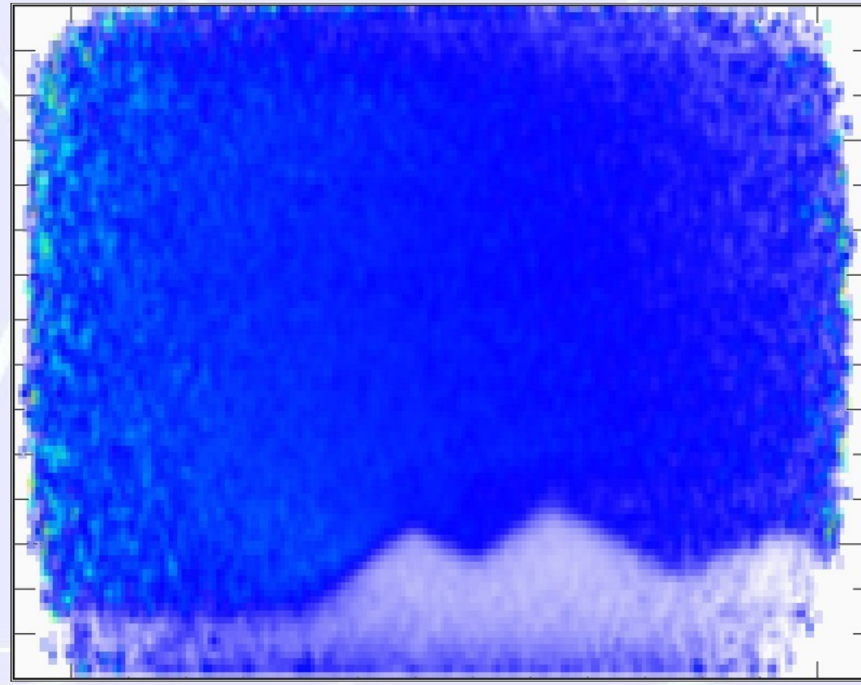
The Etna vulcano studied with cosmic rays

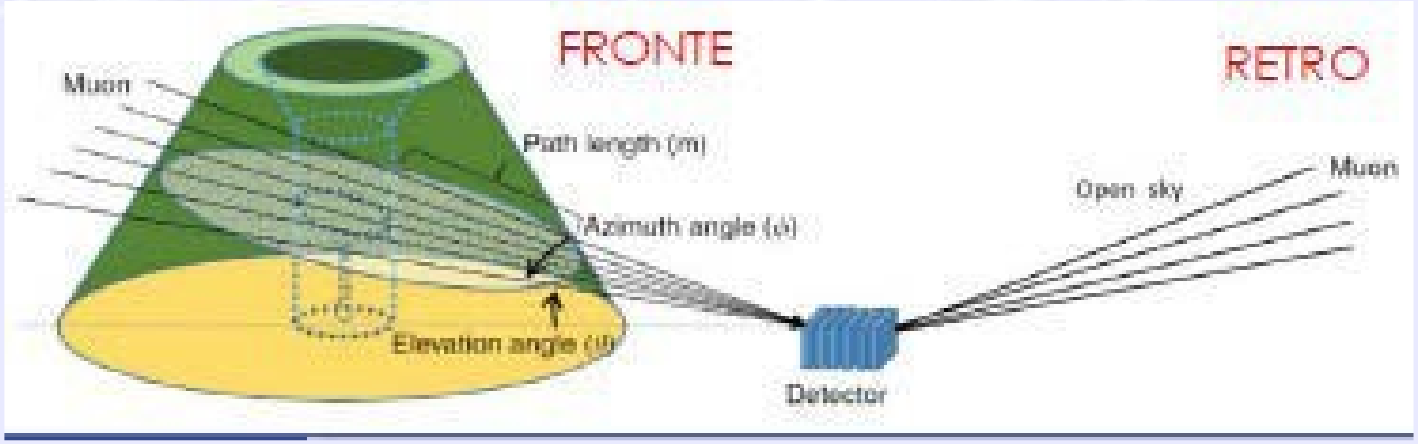
First test reconstructions at 900 m with exposition from Jan to May 2017



The Etna vulcano studied with cosmic rays







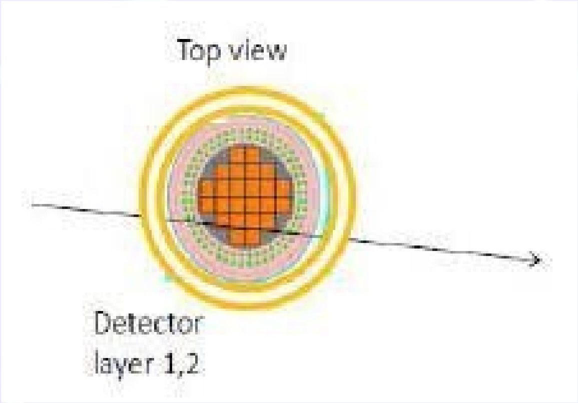
The inspection of exhaust nuclear waste

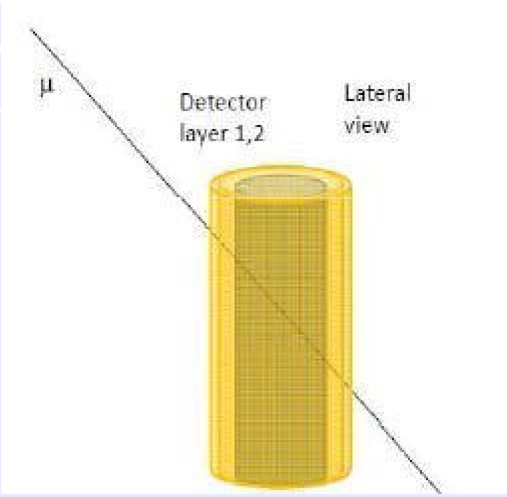
Exhaust Uranium bars have to be put in water and then in sealed containers

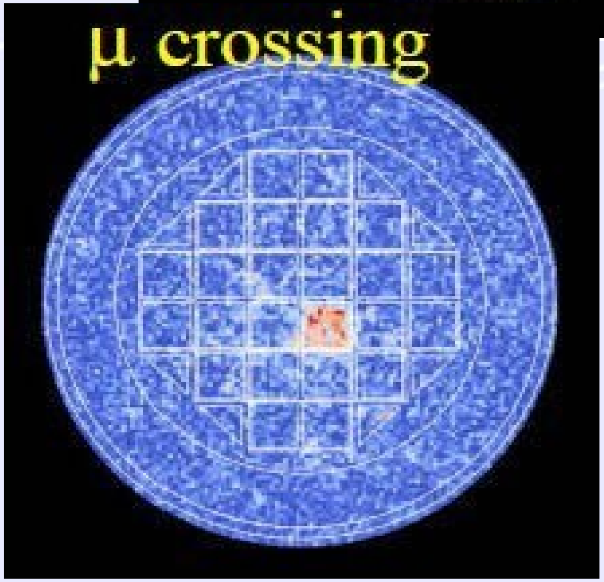
It is fundamental the survey the material and the status of the sealings

The inspection of exhaust nuclear waste

Muons will be used for monitoring the status of material inside the containers

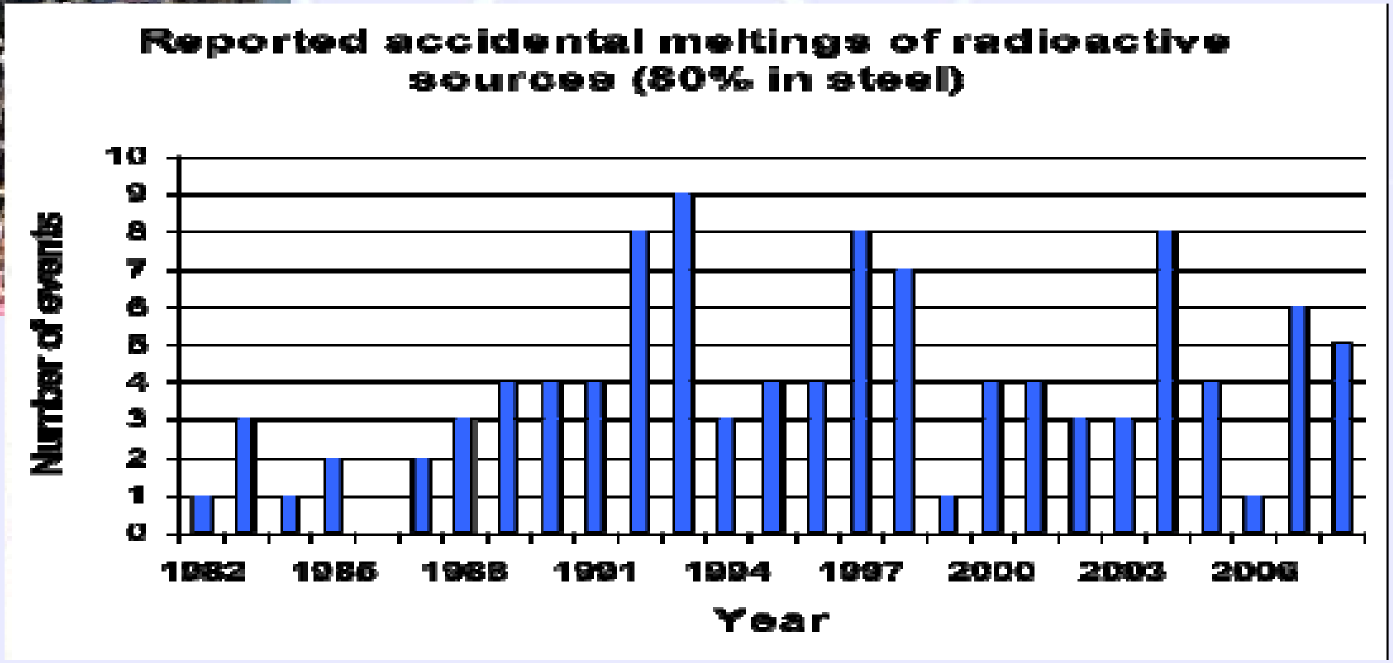






The "forgotten" radioactive sources in steel foundries

Metal waste, when brought to foundries, can accidentally contained forgetten pieces of radioactive materials (from medicine, laboratories ...)



http://www.johnstonsarchive.net/nuclear/radevents/radaccidents.html

Building structure integrity

Main idea:

Monitoring the stability and the alignment of both mechanical structures or buildings (bridges, tunnels, skyscrapers) via muon tracking

What we need:

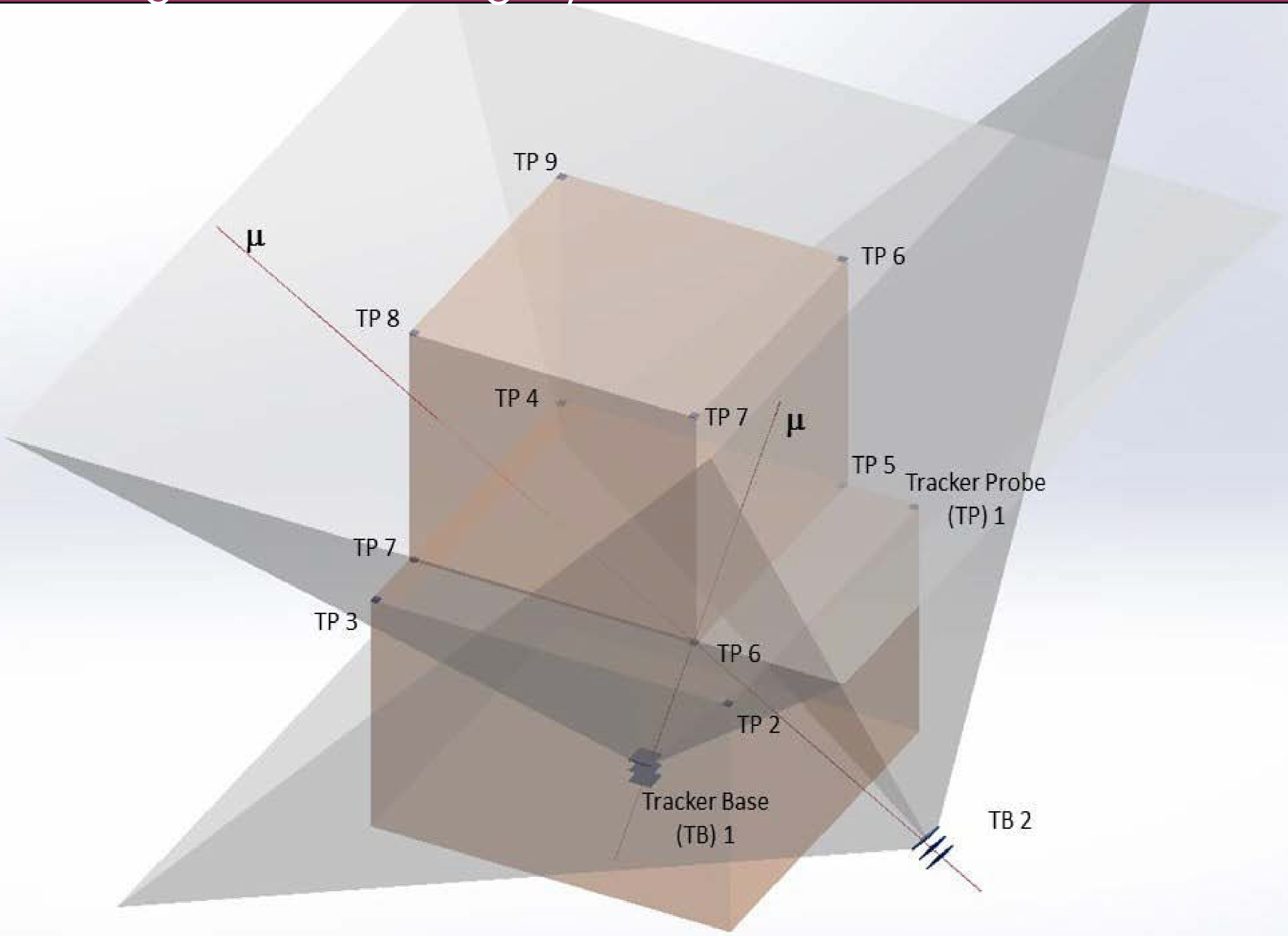
a) High angular resolution

b) Several detectors also sticked to the structure

These features allows for submillimeters anomalies identification

It requires long exposures time (weeks)

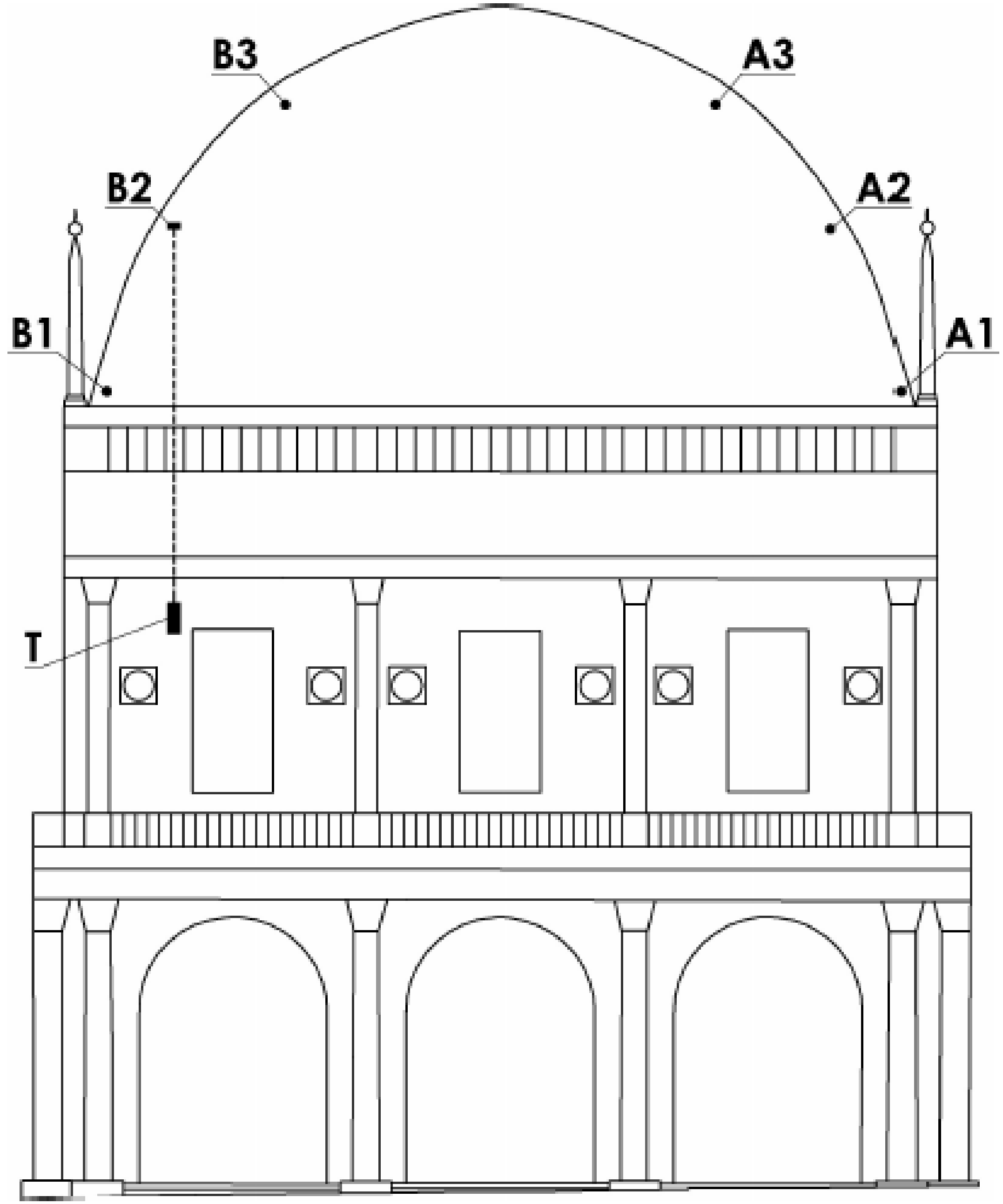
Building structure integrity



Building structure integrity

Palazzo della Loggia (Brescia):

Monitoring of stability

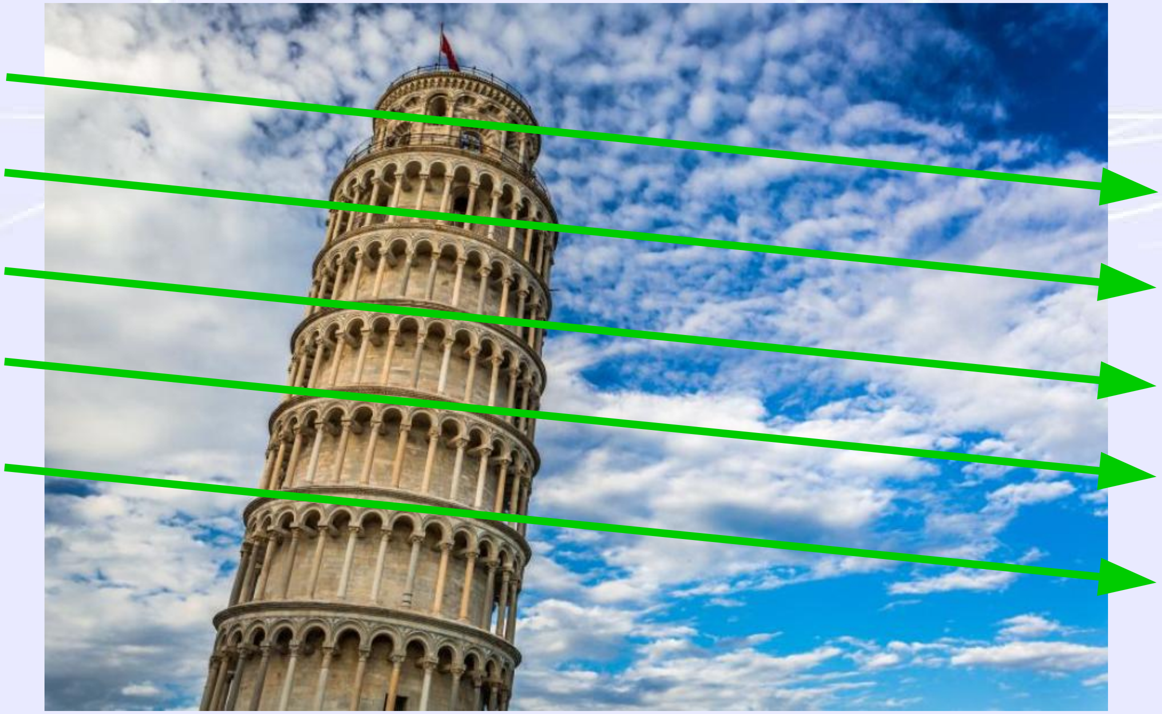


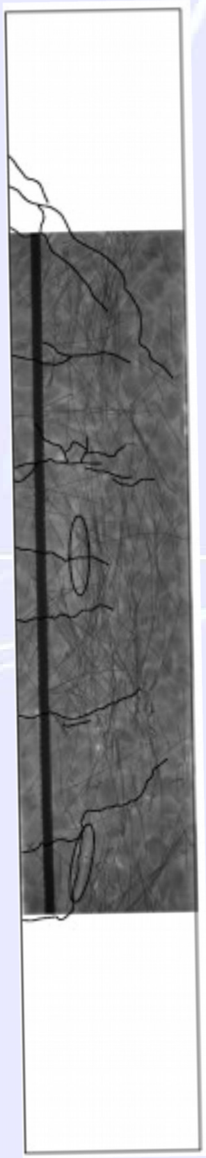
A. Zenoni et al., Collab. Brescia, Pavia, Padova

Building structure integrity

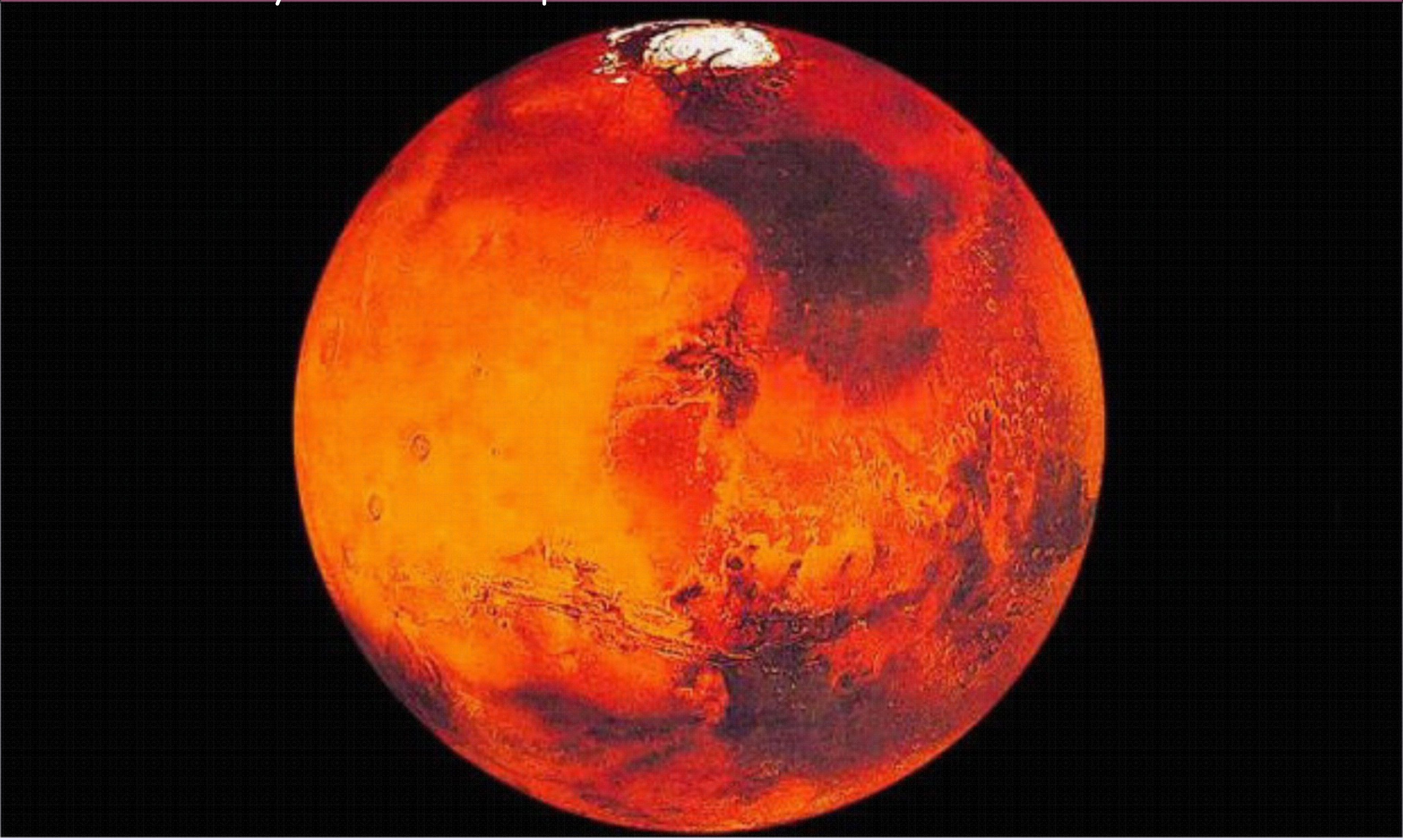
Advantages with respect to traditional approaches (laser, metal strings)

- Working also in position unreachable by lasers
- Easy to install and passive
- No mechanical parts
- Non-invasive for the building
- Allows also the global monitoring of the structure





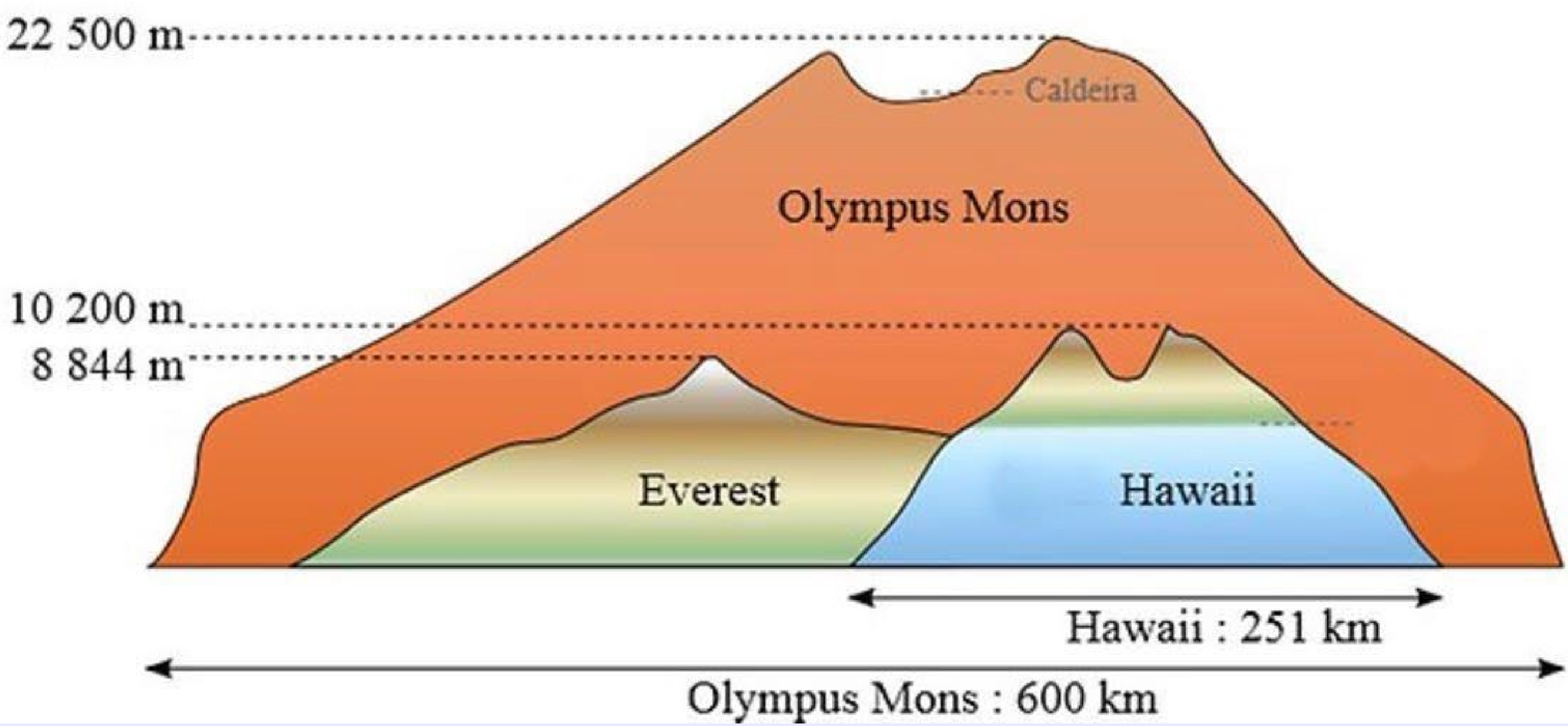
Cosmic rays on other planets



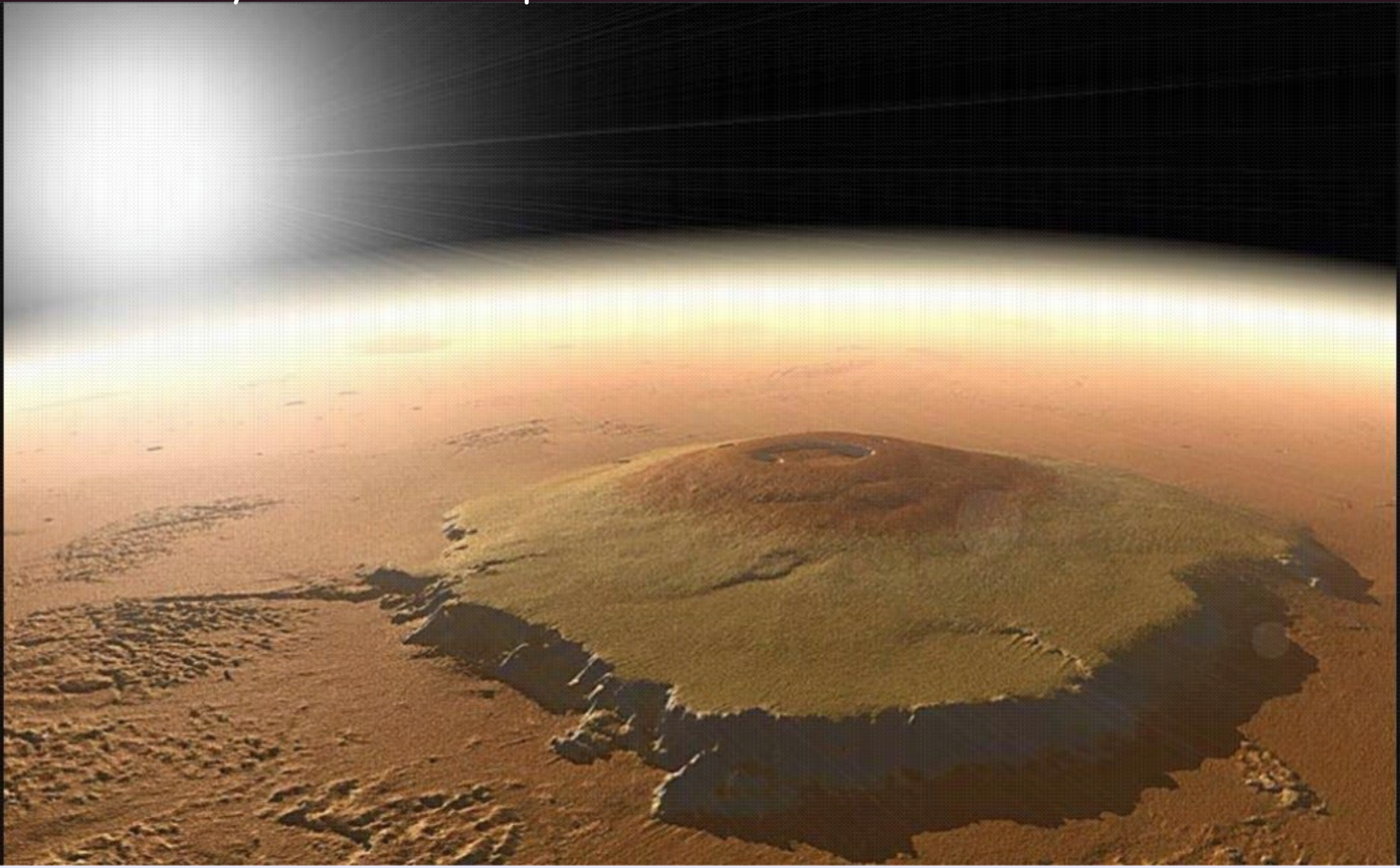
Trying to use cosmic radiation to study the planet geology

Mars geology

The solar system's largest known volcano, Olympus Mons, compared to Mount Everest and the Hawaii sea mount.



Cosmic rays on other planets



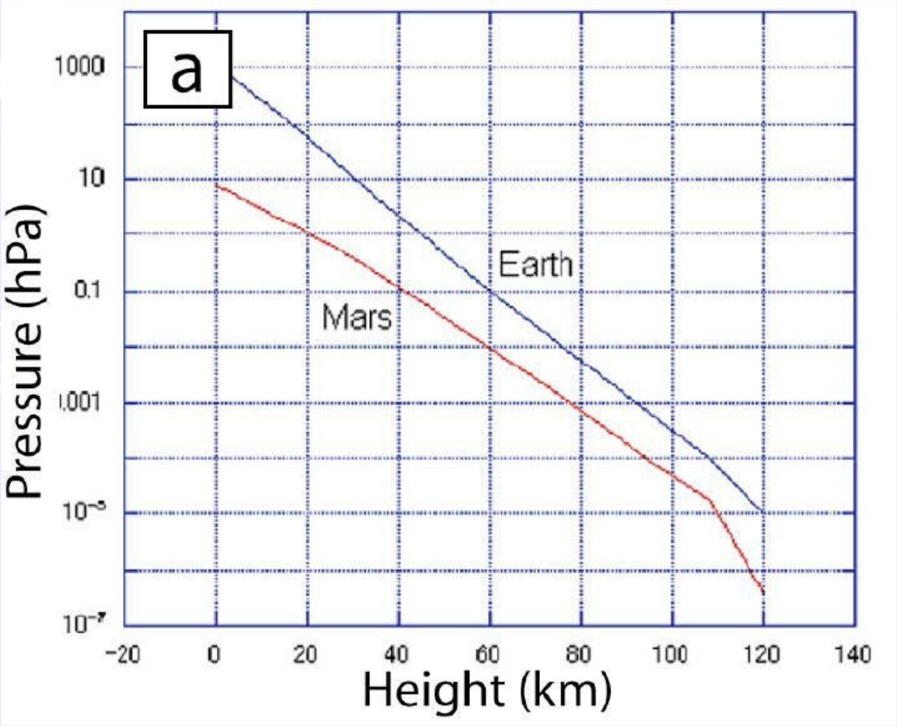
Olympus mountain on Mars

Mars atmosphere and relation with cosmic rays

With respect to Earth:

- Different composition and pressure
- Pressure 1/100 w.r.t. Earth
- Different air shower development

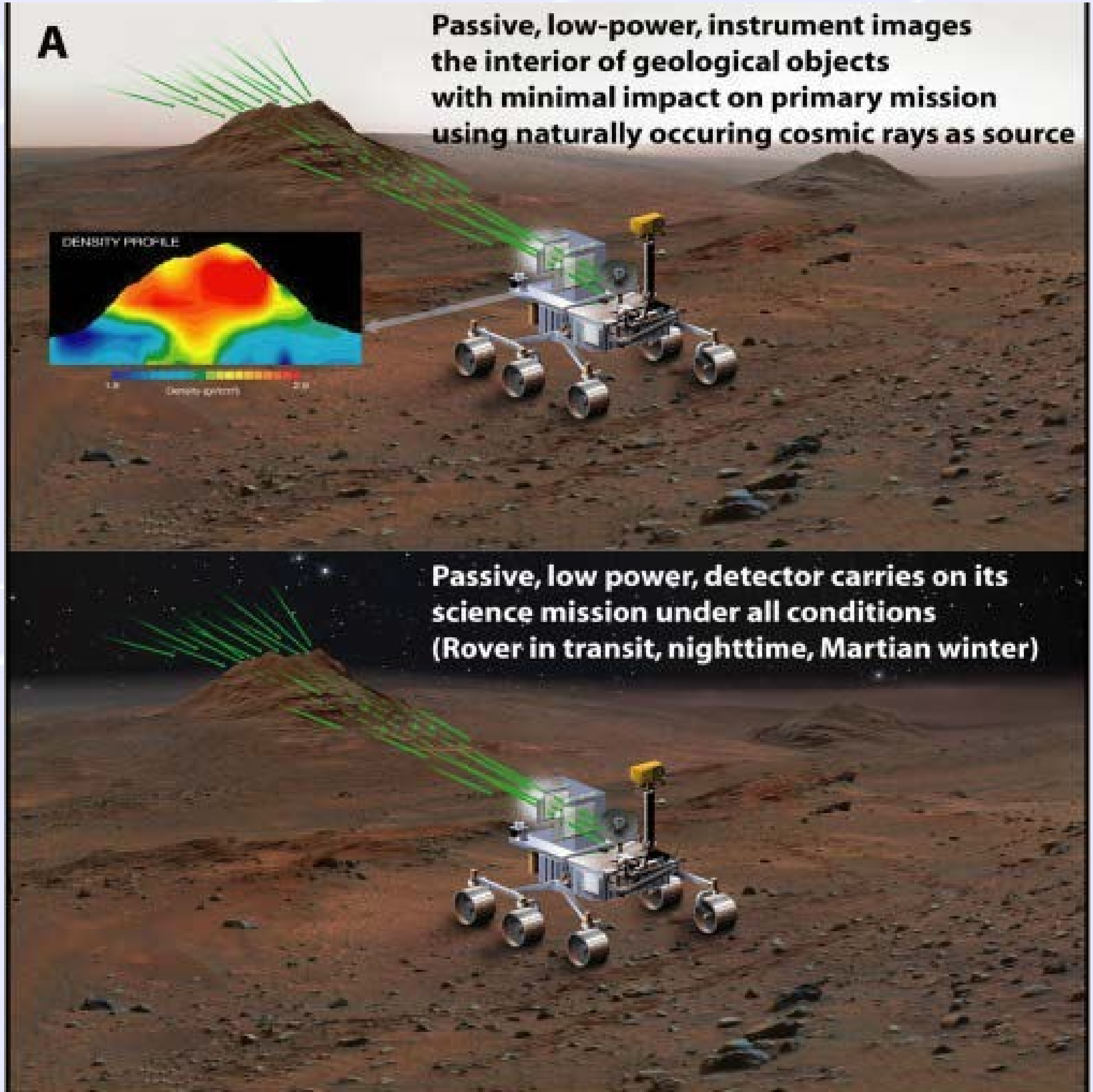
- On Earth the air shower maximum is at 15 km while on Mars several primaries reaches the ground.
- As a consequence on Mars we have fewer vertical cosmic rays but higher flux of horizontal muons, useful for inspections
- The main problem is the contamination with protons at ground



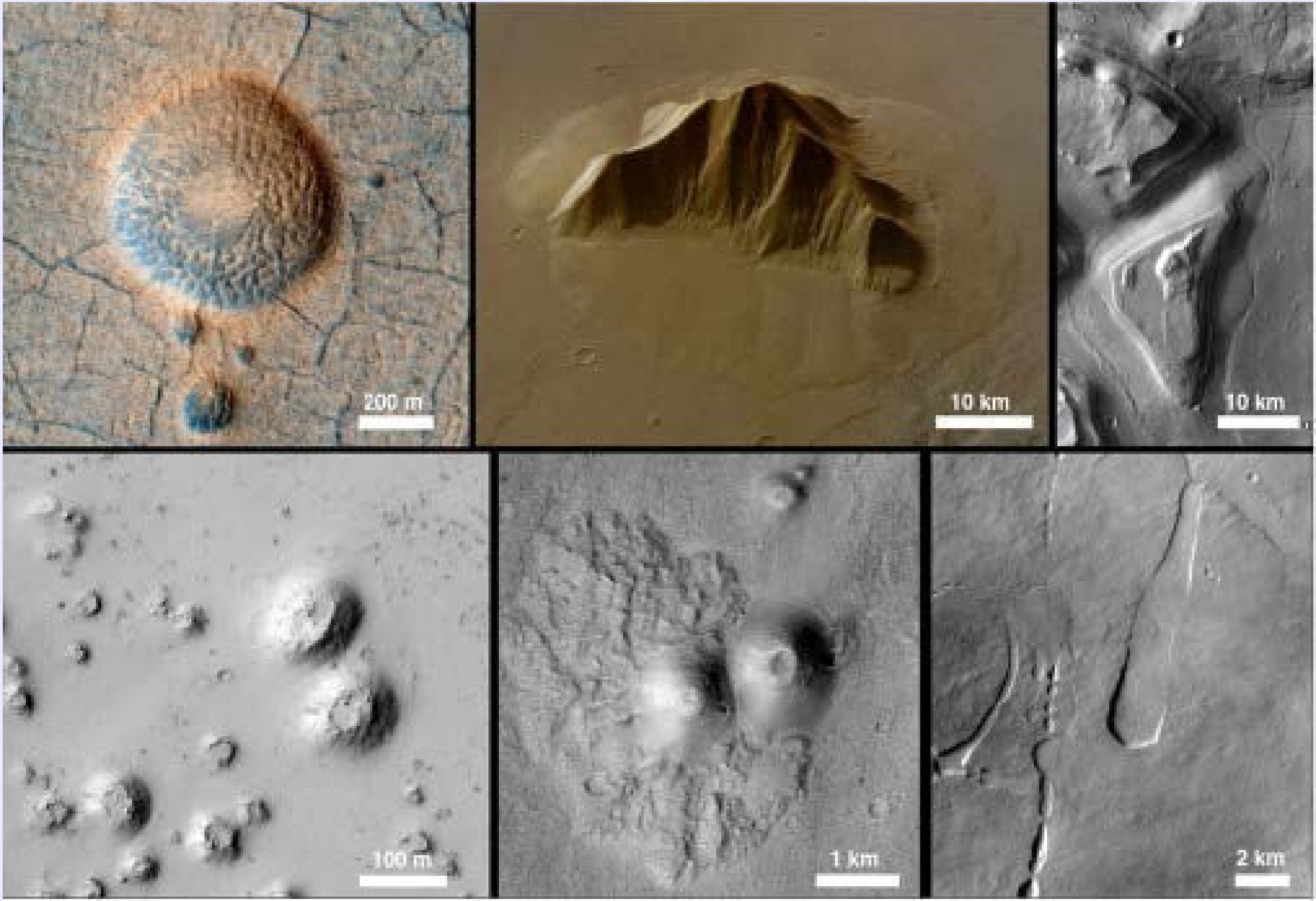
S.Kedar et al., Geosci. Instrum. Method. Data Syst., 2, 157–164, 2013

Mars: exploration hypotheses

An idea for future geological prospections with robots on Mars



Some examples of geological strucures to be studied



Summary

- Cosmic Rays may help in understanding both fundamental astrophysics issues and everyday life problems and applications

- Many different applications in the last few years

- Some of them are still challenging and will likely bring to important technological improvements