



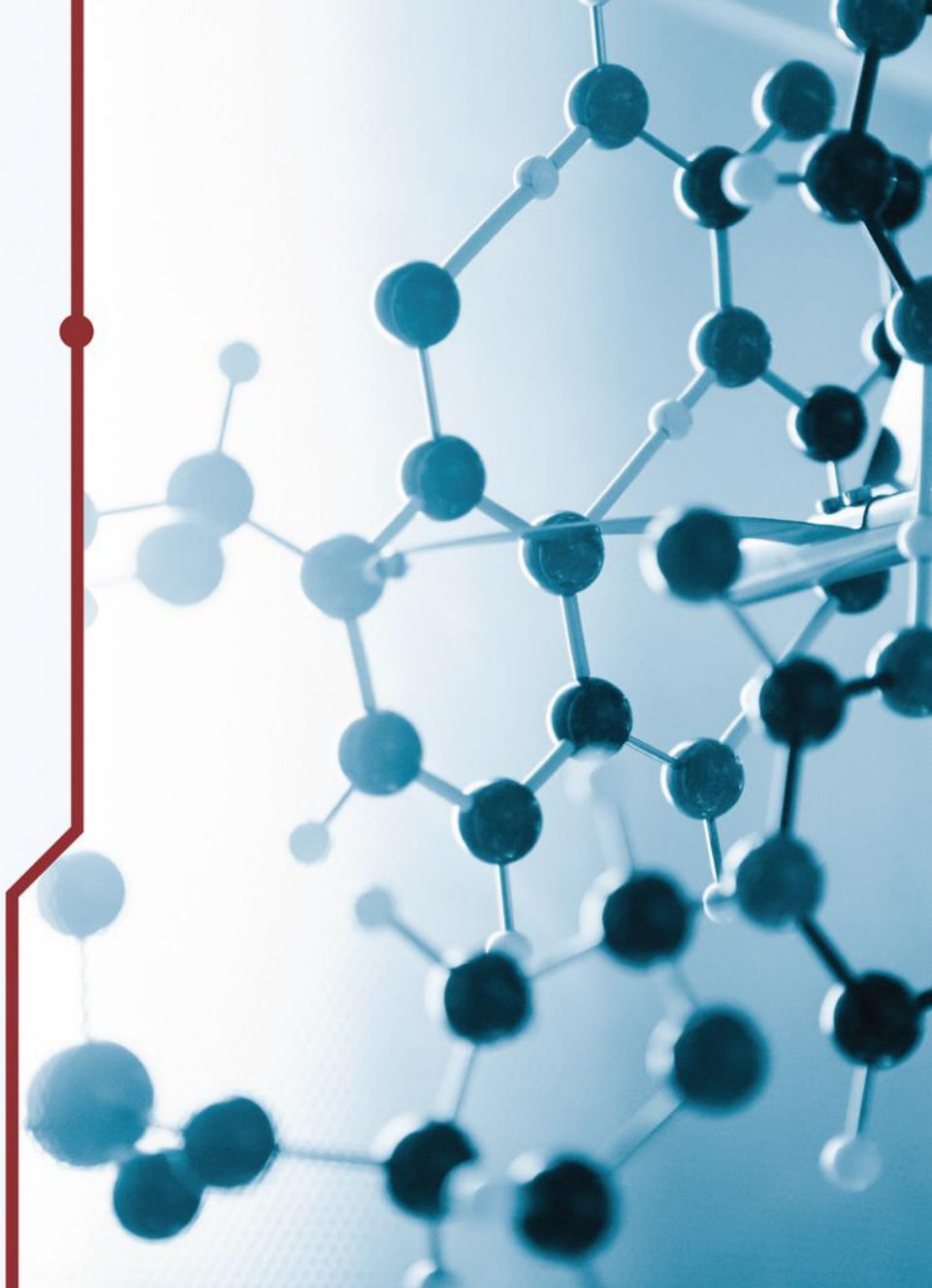
REINFORCE

REsearch INfrastructures FOR Citizens in Europe

COsmic Muons Images for Citizens (COMICs)

WEBINAR

June 1, 2020, 11:00 AM CEST

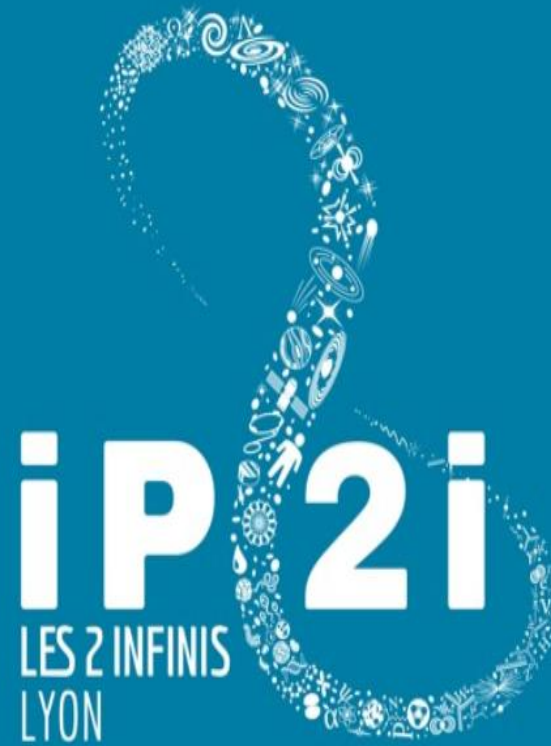




REINFORCE
REsearch INfrastructures FOR Citizens in Europe

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19



Muography = μ -ray imaging technique : absorption / scattering \rightarrow sensitive to ρ (opacity)

Geosciences



- Volcanology
- Geology
- Hydrology
- Atmosphere physics
- CR physics
- ...



Archaeology



- Tumulus
- Anthropic structures
- Ruins
- ...



Industrial controls



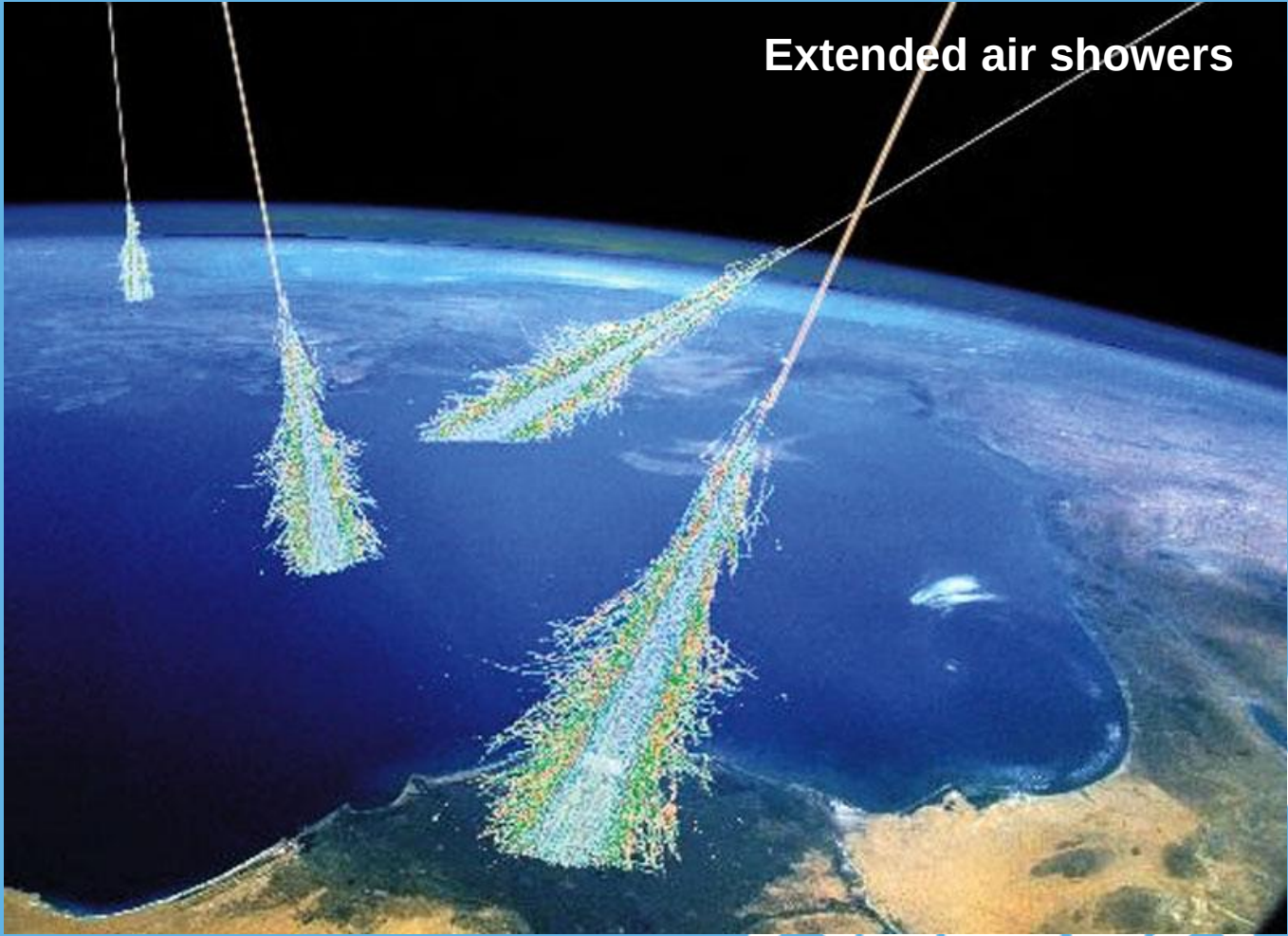
- Non invasive controls
- Nuclear cycle production
- Civil engineering
- Tunnel boring machines
- Prospection & mining
- ...



Technological transfer

Standard Model of Elementary Particles

	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
mass	=2.2 MeV/c ²	=1.28 GeV/c ²	=173.1 GeV/c ²	0	=124.97 GeV/c ²
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
QUARKS	u up	c charm	t top	g gluon	H higgs
	=4.7 MeV/c ²	=96 MeV/c ²	=4.18 GeV/c ²	0	
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	d down	s strange	b bottom	γ photon	
	=0.511 MeV/c ²	=105.66 MeV/c ²	=1.7768 GeV/c ²	=91.19 GeV/c ²	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS	<1.0 eV/c ²	<0.17 MeV/c ²	<18.2 MeV/c ²	=80.39 GeV/c ²	
	0	0	0	±1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
					GAUGE BOSONS VECTOR BOSONS
					SCALAR BOSONS



Extended air showers

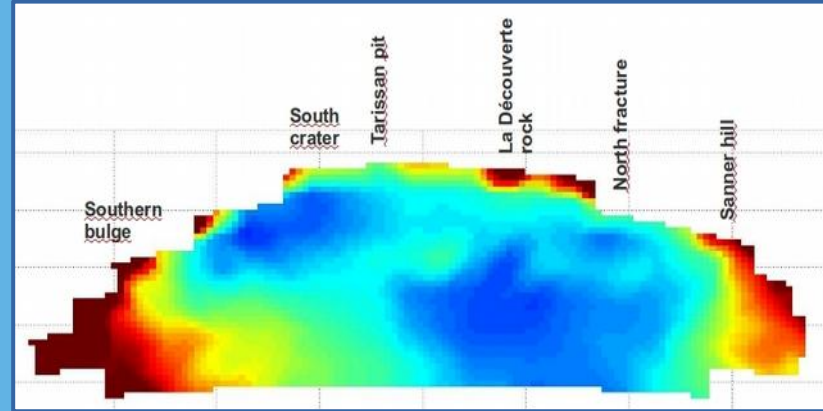
Here are the muons



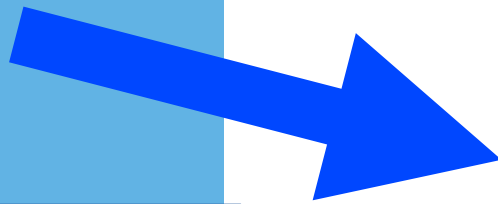
Muon flux emerging from the target \leftrightarrow opacity (amount of matter)

$$\varrho(L) \equiv \int_L \rho(\xi) d\xi$$

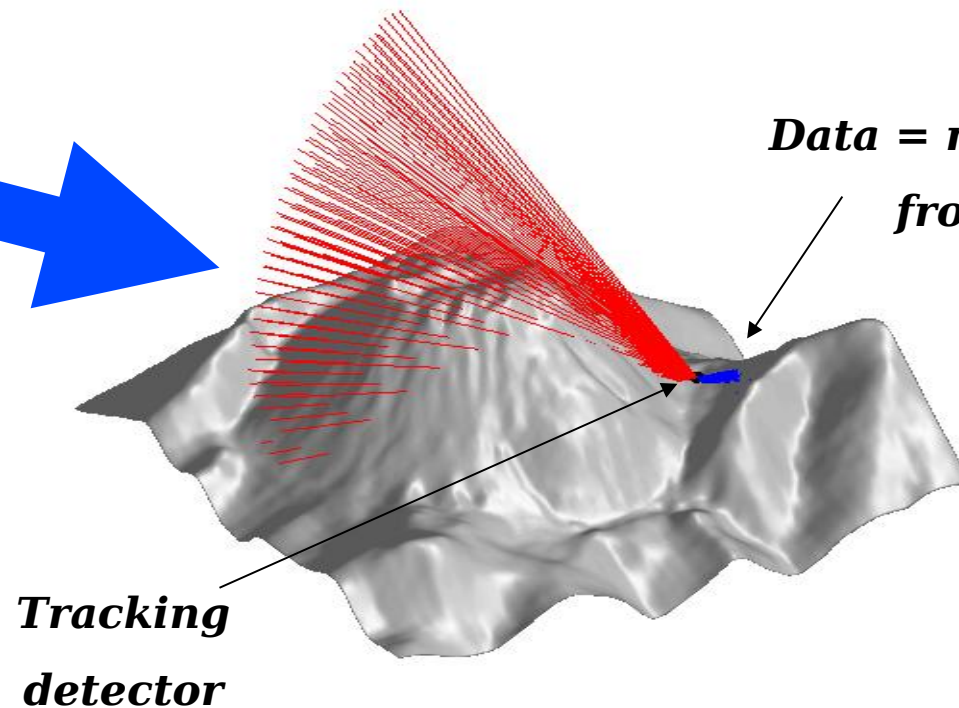
ϱ = opacity ρ = density



Incident muon flux

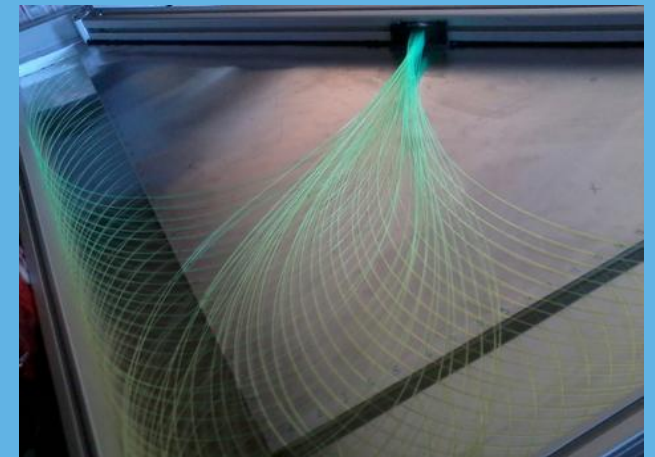
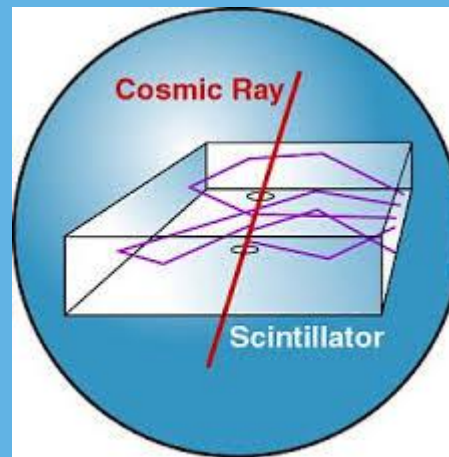


Data = muon flux emerging from the volcano



Tracking detector

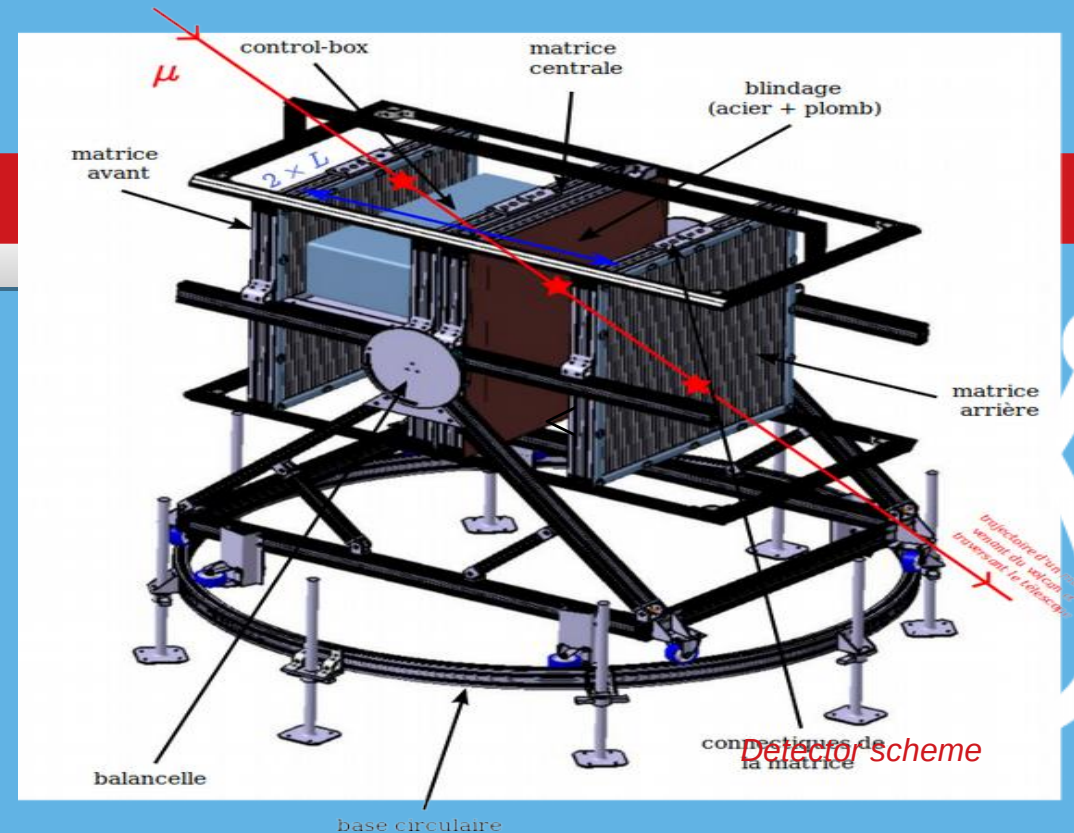




A field detector



Muon detector @ Soufrière



A simple **tracking++** device using scintillators, emulsions, micro-megas, RPC's...

DIAPHANE projects : 10++ years



Mayon (Philippines)



Etna (Italy)



Blast furnace



TBM



Croix-Rousse



Soufrière

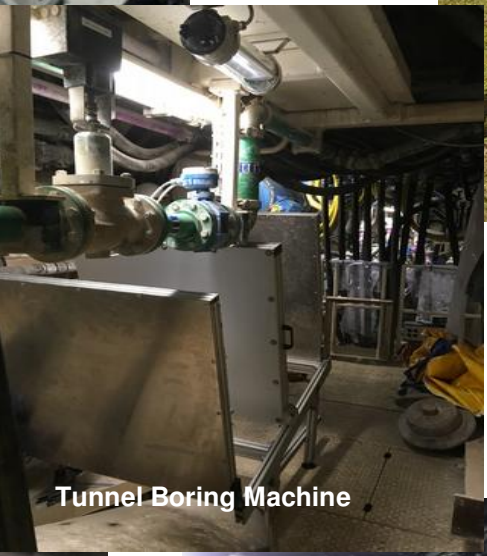
μ -gravimetry coupling



Greek tumulus



Water tank monitoring



Tunnel Boring Machine



Mont-Terri (Switzerland)



Blast furnace



rehole



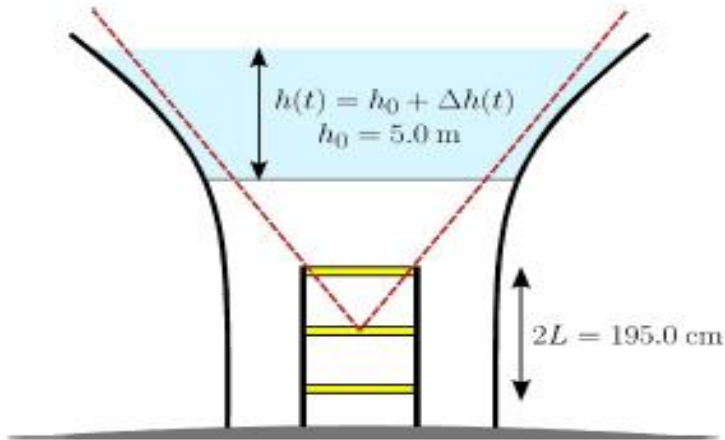
LSBB



Nuclear evaporator

Monitoring capabilities – P & T sensitivity

Water level monitoring of a water tower tank

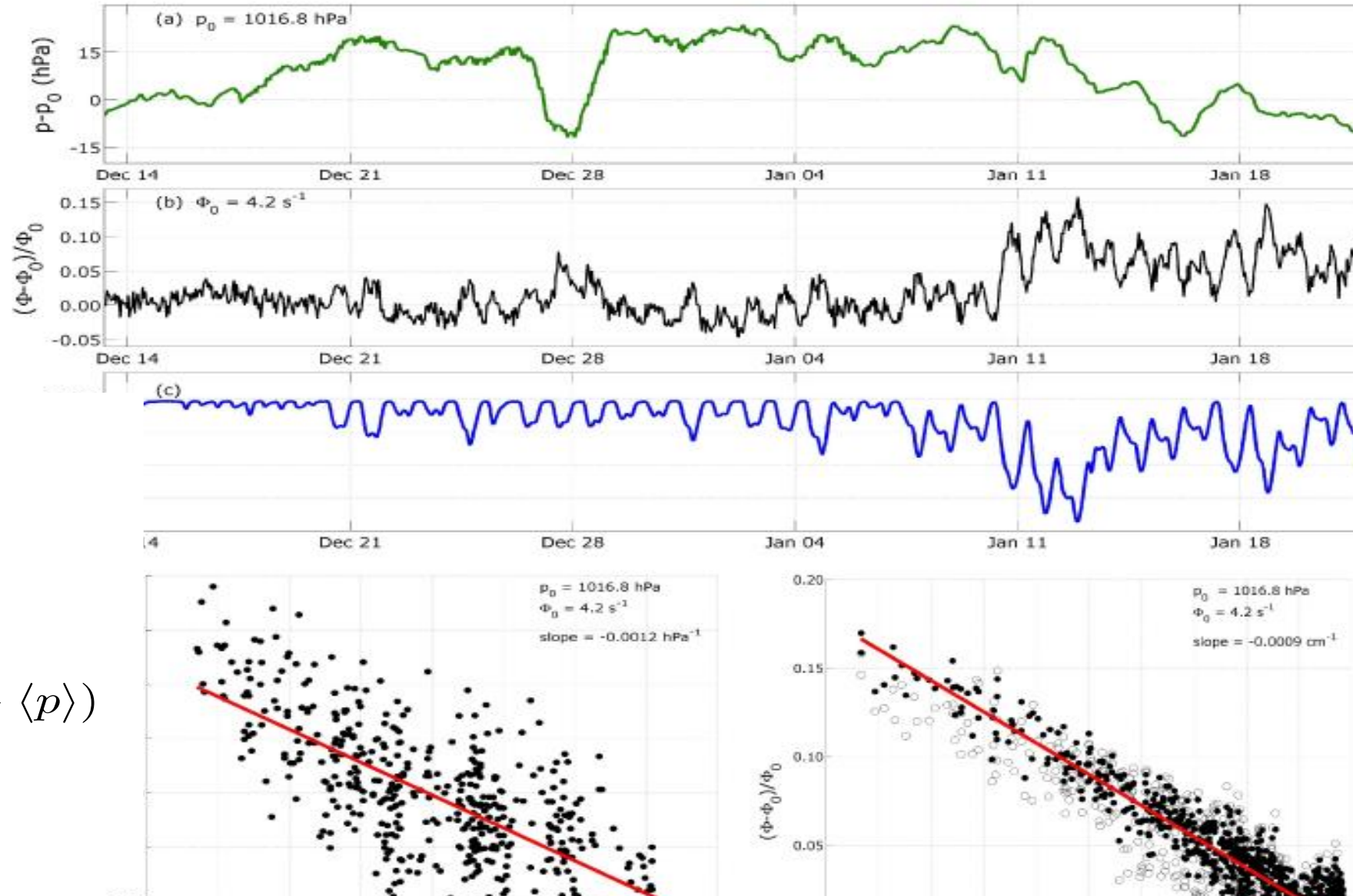


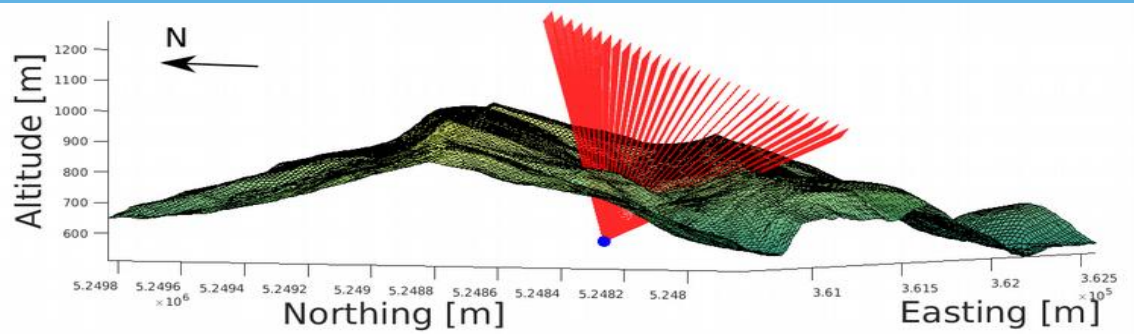
Low energy cut ~ 1.5 GeV:

- ▶ high statistics
- ▶ time resolution
- ▶ E-dependent barometric effects

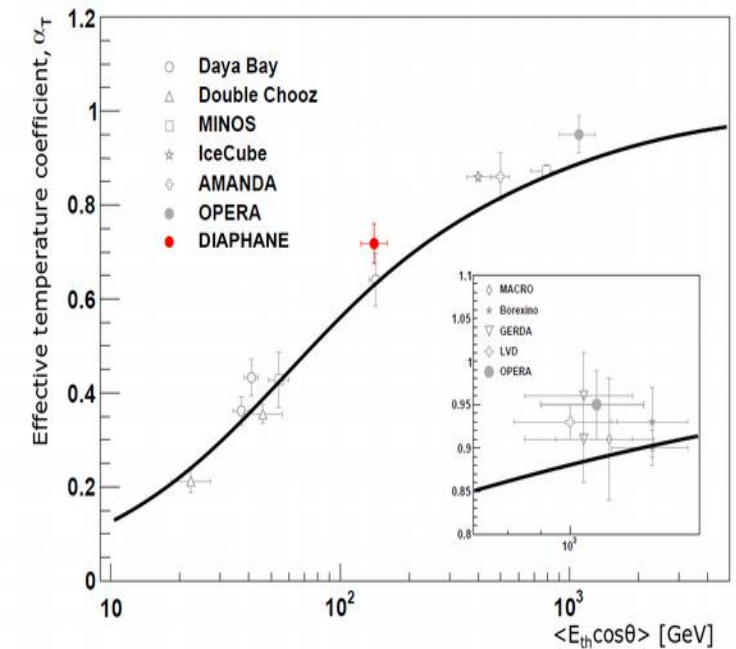
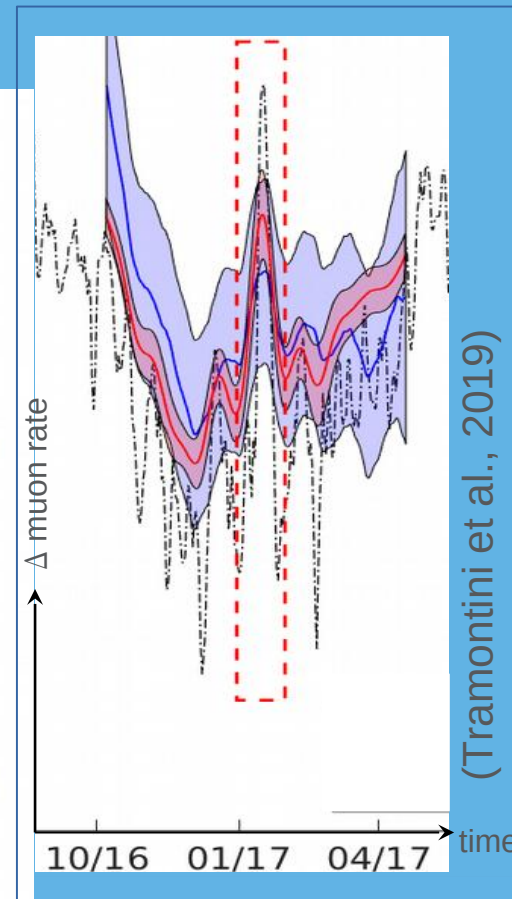
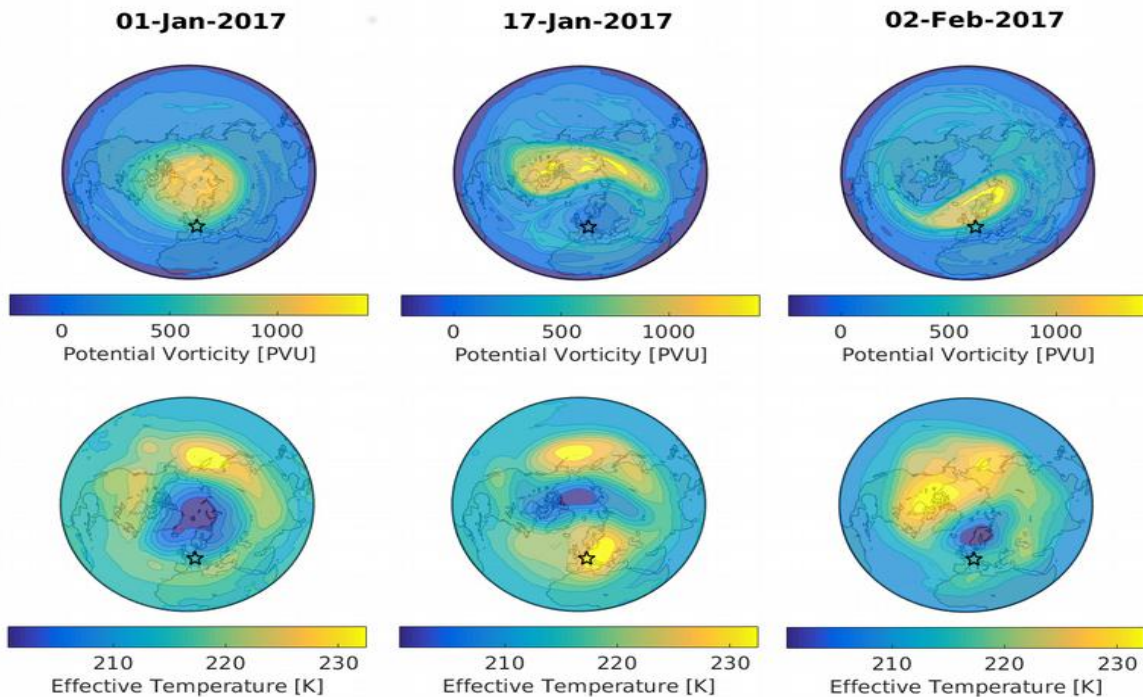
$$\frac{\Delta R}{\langle R \rangle} = \alpha_T \frac{\Delta T_{\text{eff}}}{\langle T_{\text{eff}} \rangle} + \beta_P (p - \langle p \rangle)$$

- ▶ geomagnetic effects
- ▶ solar activity effects

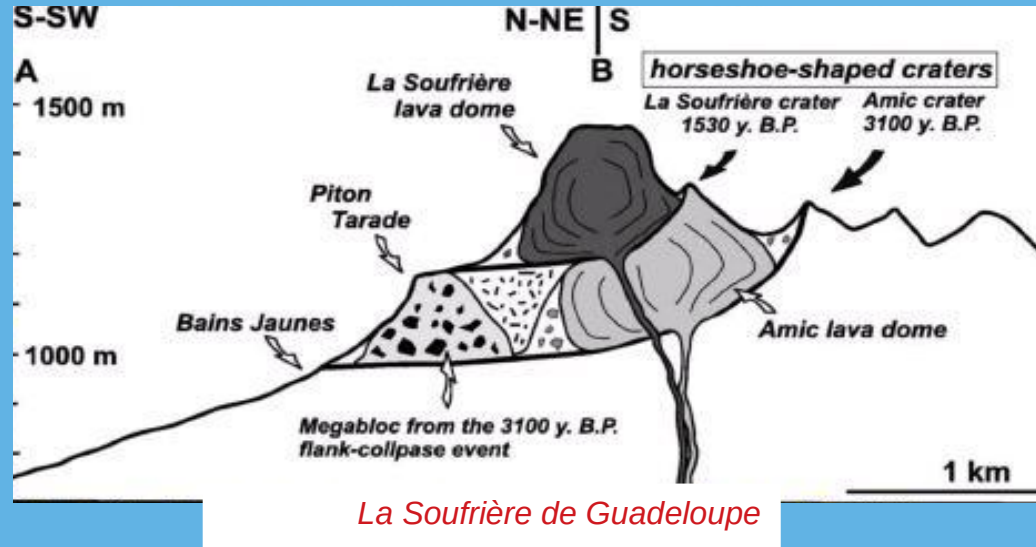




$$\frac{\Delta R}{\langle R \rangle} = \alpha_T \frac{\Delta T_{\text{eff}}}{\langle T_{\text{eff}} \rangle} + \beta_P (p - \langle p \rangle)$$



Sudden Stratospheric Warming

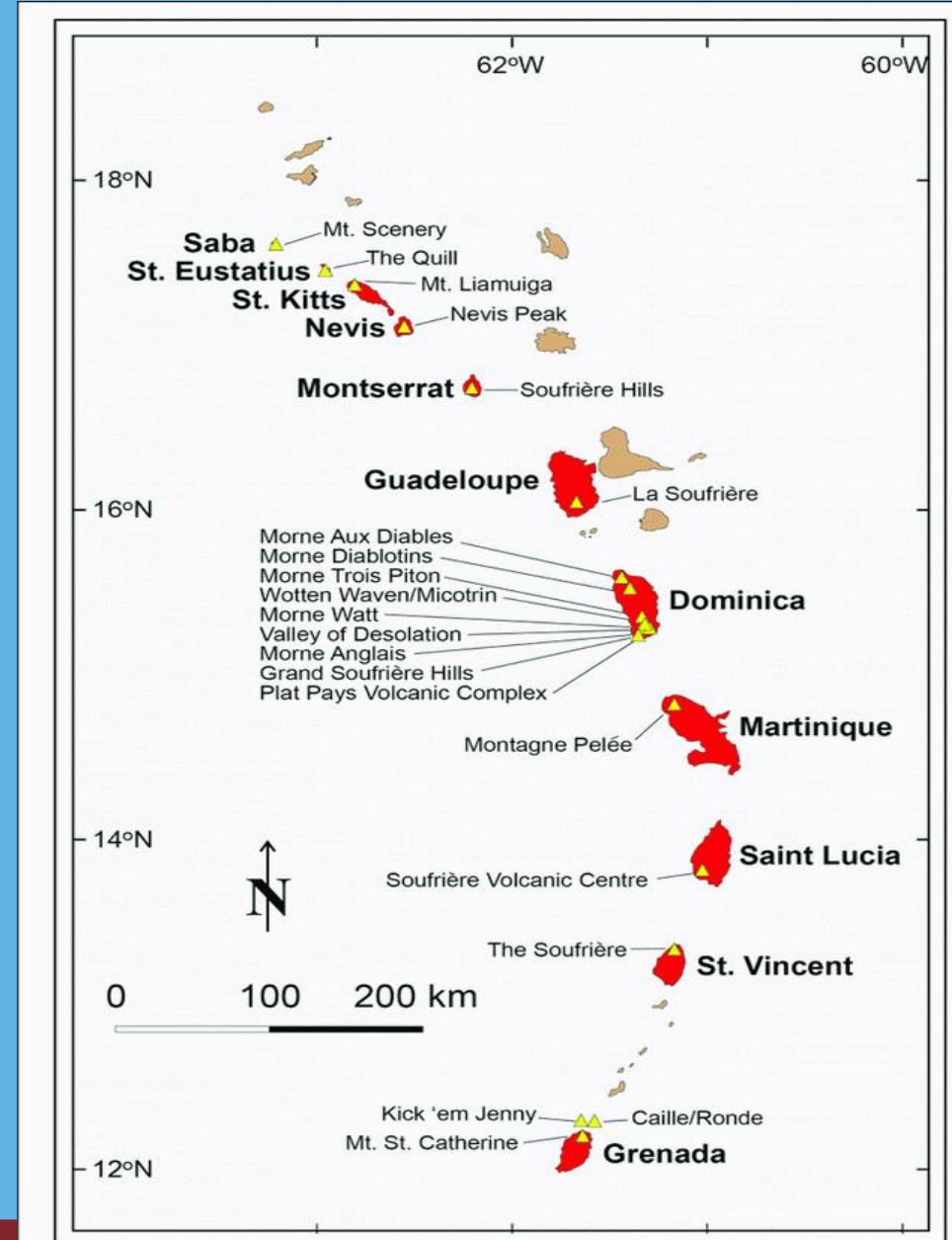
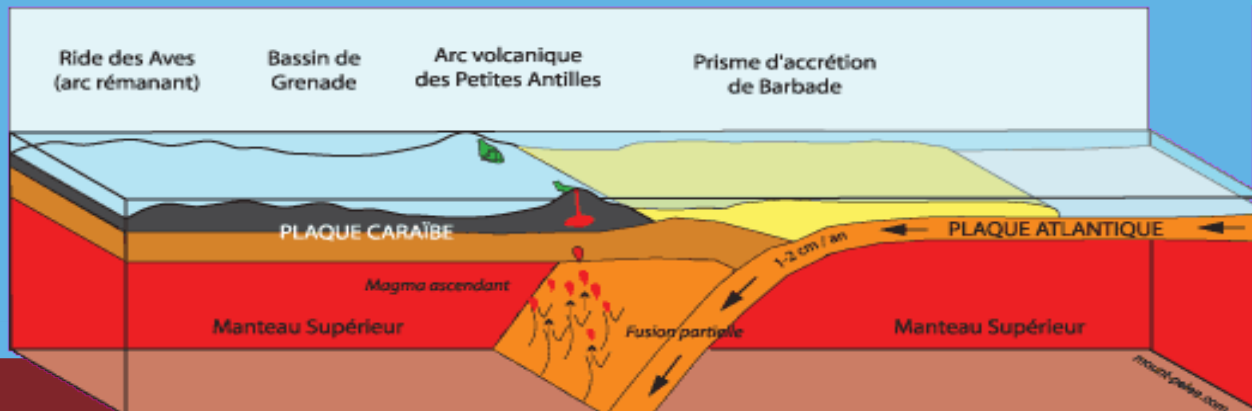


3 active volcanoes (N to S):

The Soufrière Hills, Montserrat : magmatic eruption since 1995, pyroclastic jets, risks of dome collapse, magmatic explosion etc. Activity decrease since a few months.

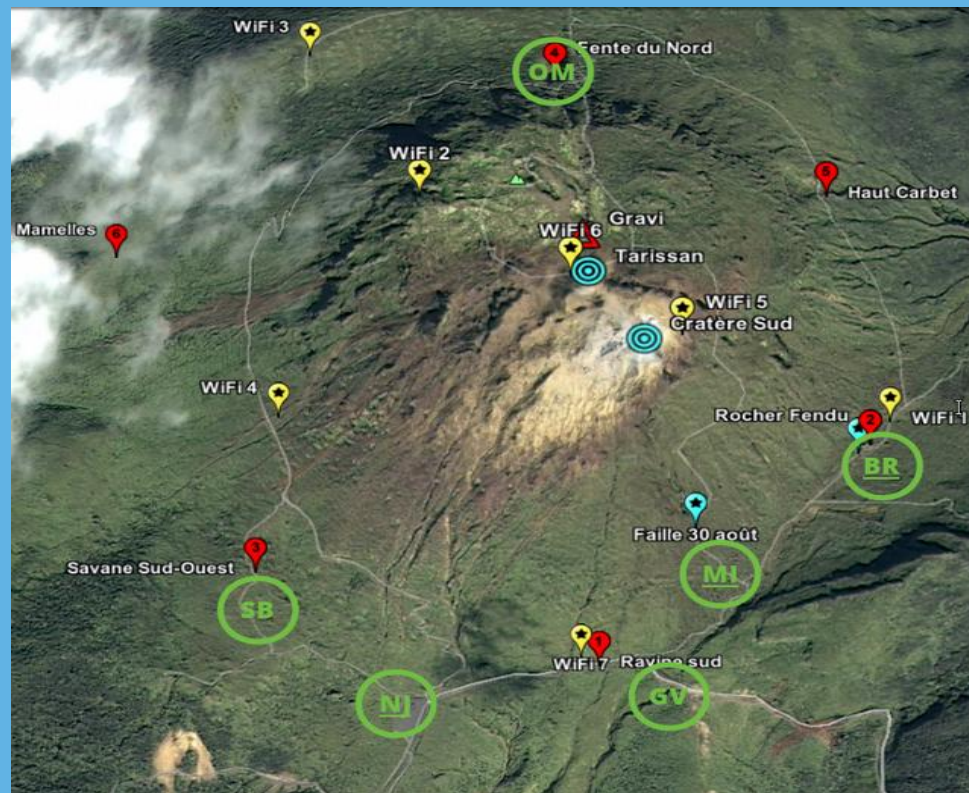
La Soufrière, Guadeloupe : active, young dome (~500y), phreatic eruption risks, flank destabilization

Montagne Pelée, Martinique : no sign of activity at the moment, the most important natural catastrophe in France (1910)

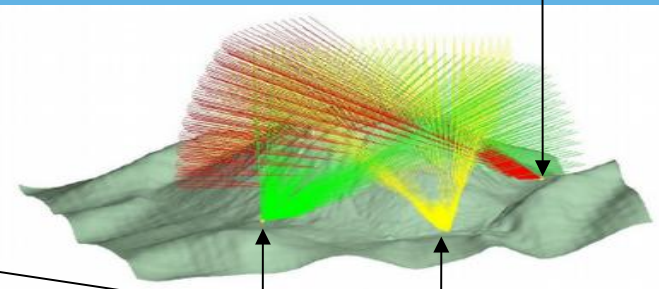
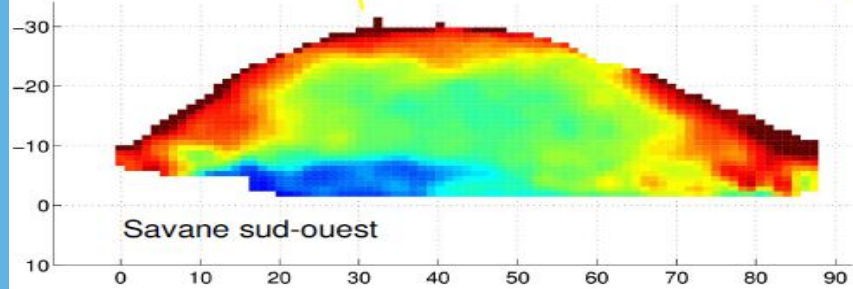
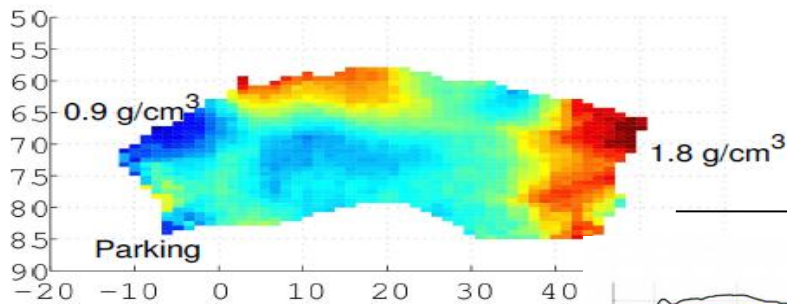
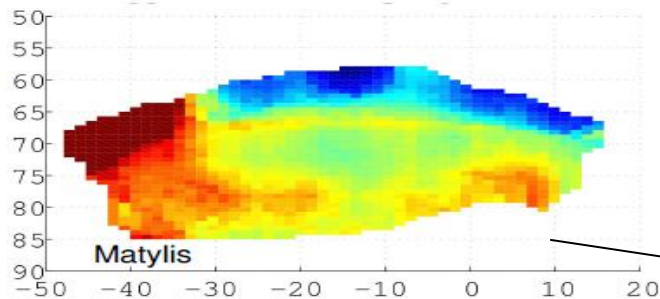
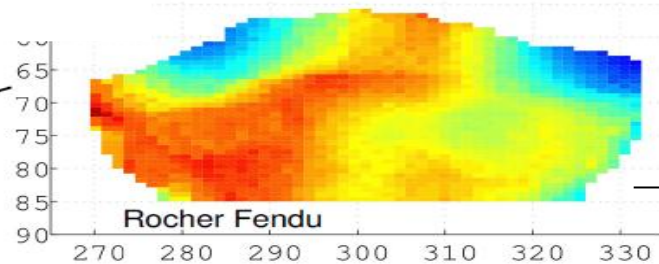
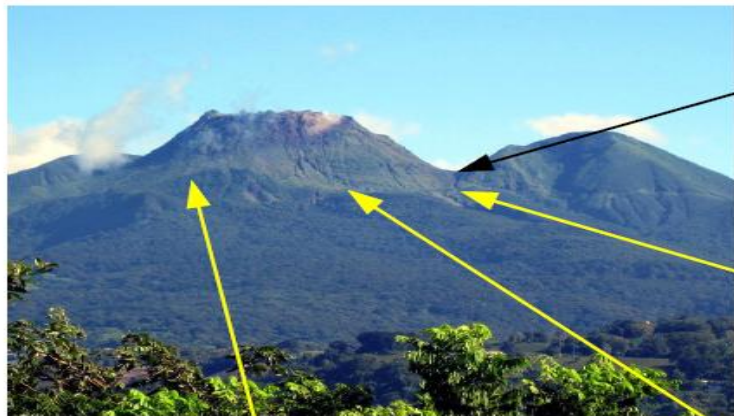




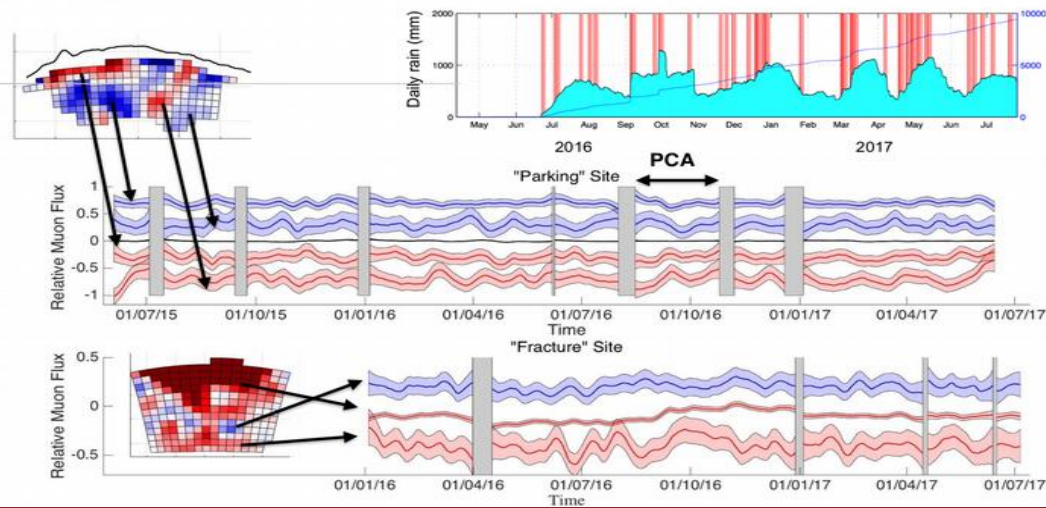
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Imaging & monitoring



World's largest muon station

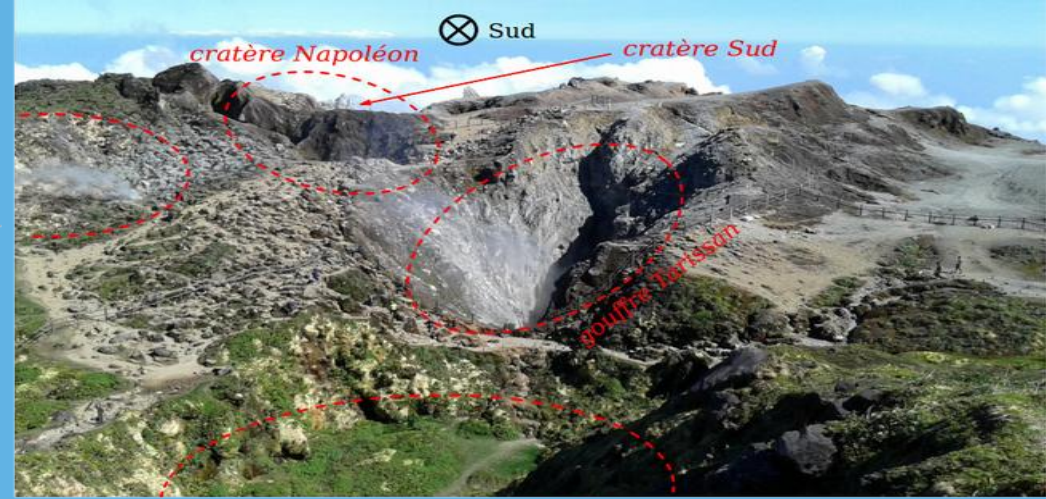




Gouffre Tarissan, Napoléon Nord



zone Napoléon Nord



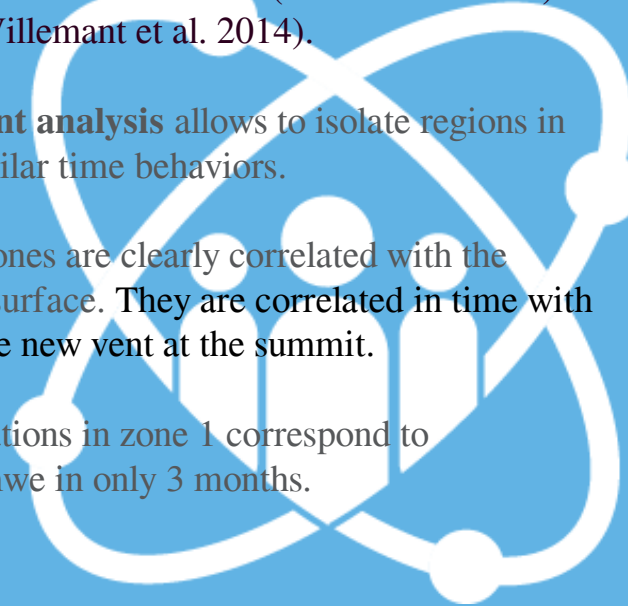
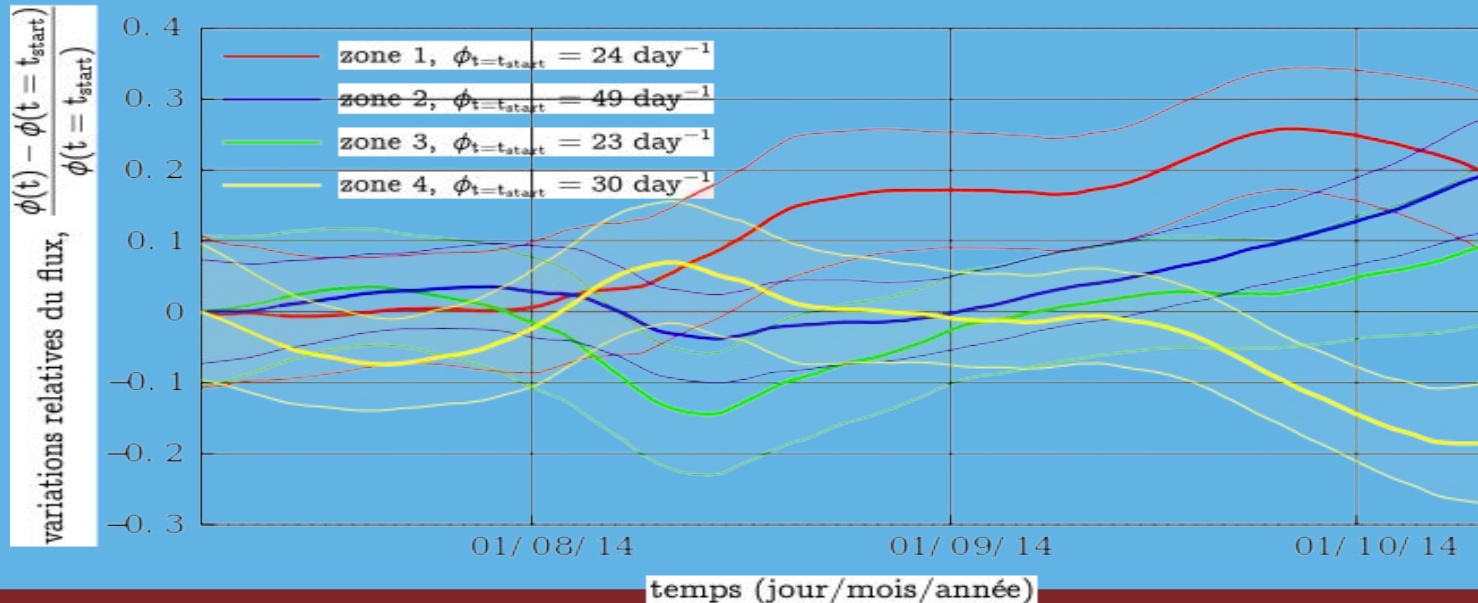
gouffre Dupuy

The volcano is under cautious surveillance as a **regain of activity** has been noticed in the fumes (Allard et al. 2014) and in the sources (Villemant et al. 2014).

Principal component analysis allows to isolate regions in the volcano with similar time behaviors.

The various active zones are clearly correlated with the observations on the surface. They are correlated in time with the appearance of the new vent at the summit.

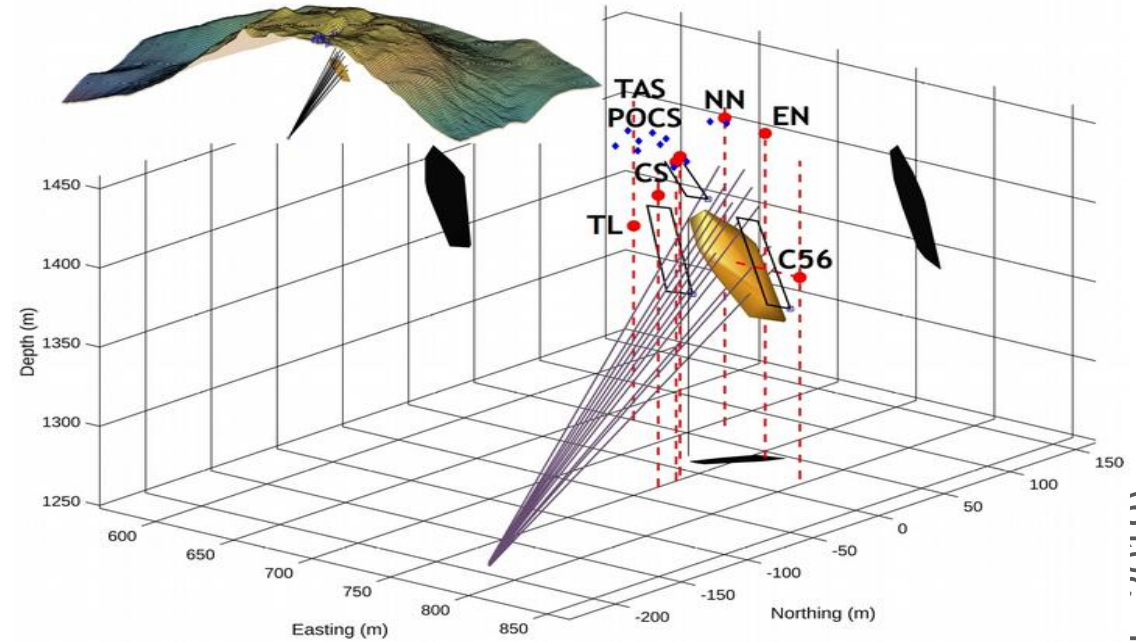
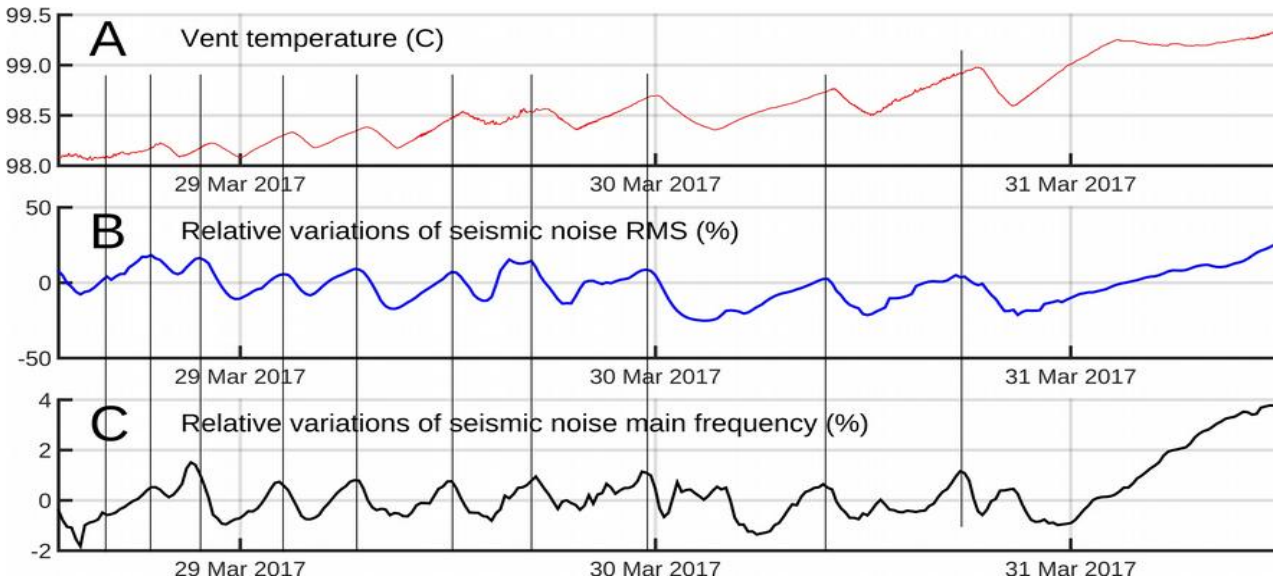
The observed fluctuations in zone 1 correspond to vaporization of 40 mwe in only 3 months.



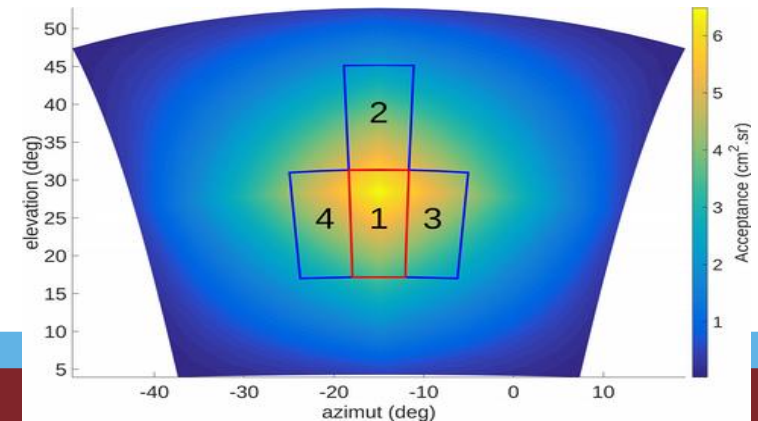
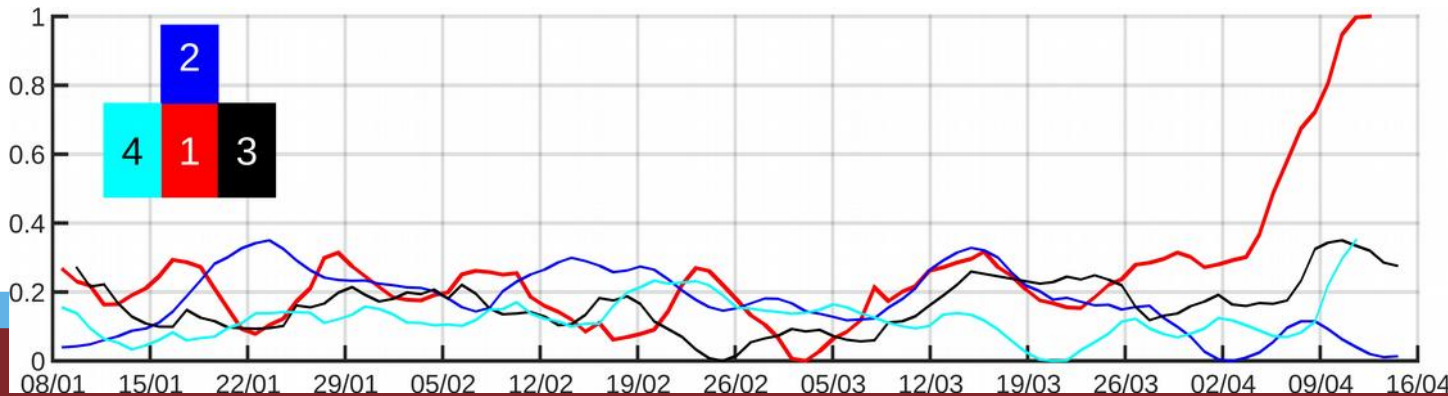
Joined monitoring : muon flux variations in region determined by seismic noise

Density changes are expected as a result of fluid content variations

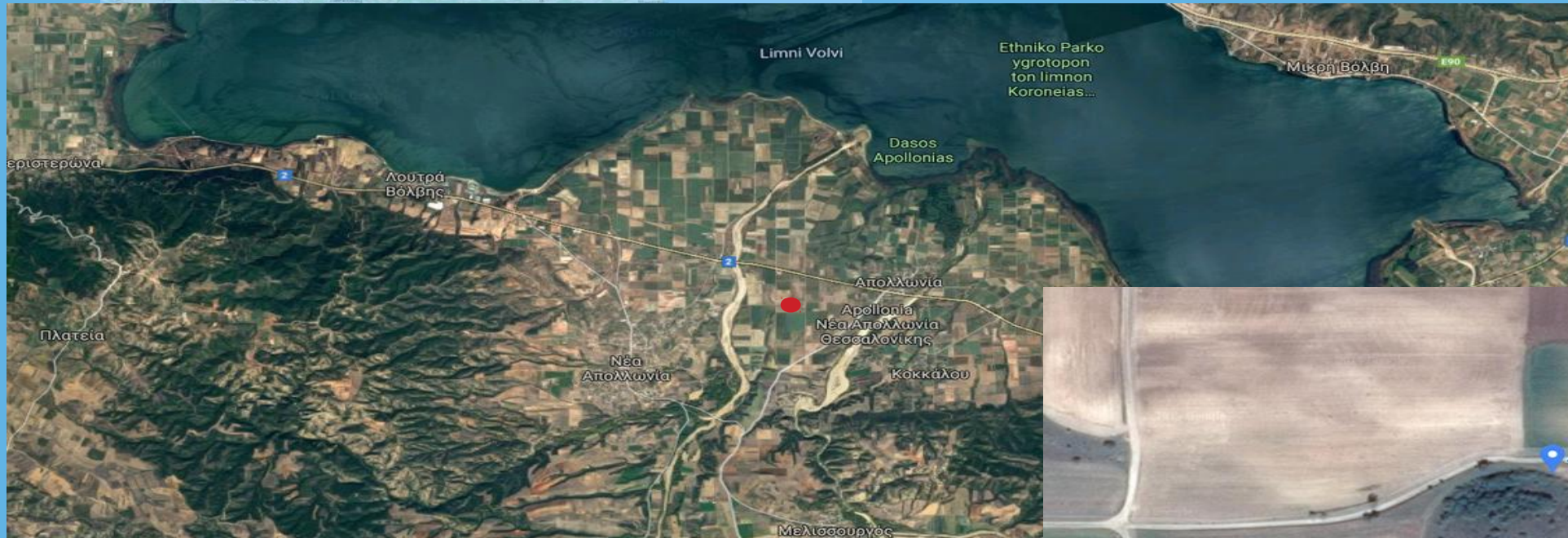
These variations are related to meteoric and magmatic mass input, and/or phase transitions



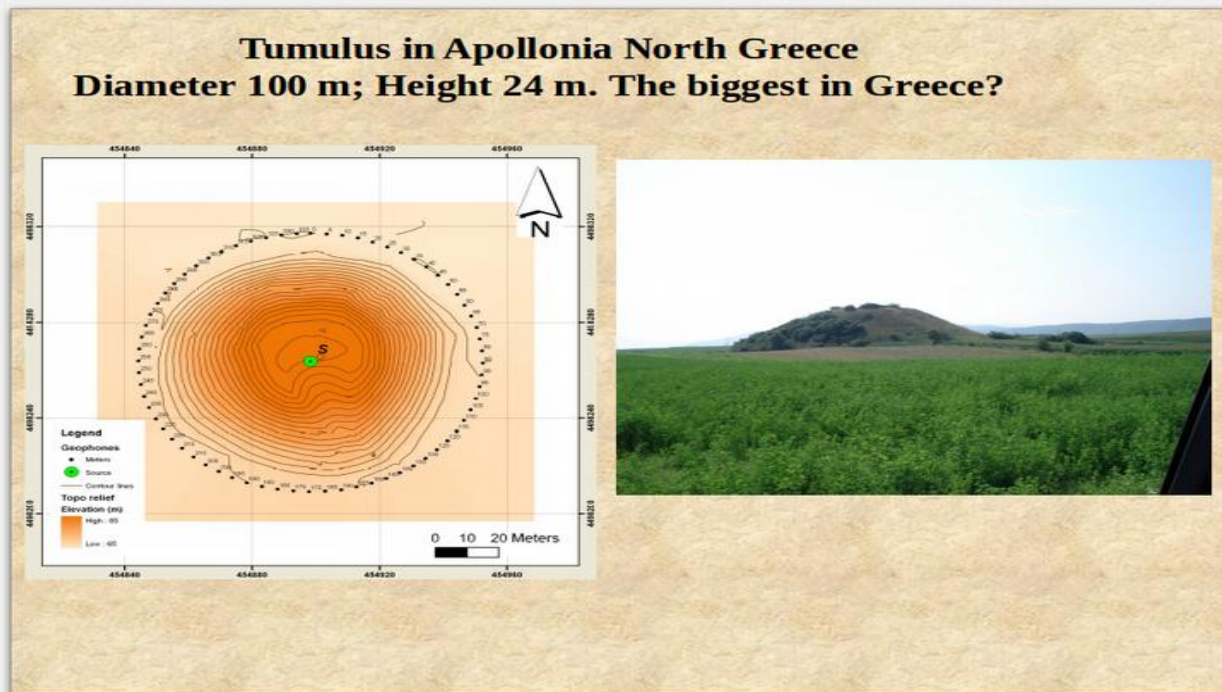
Relative muon flux variations



Archaeology : Apollonia tumulus (IP2I, APC, LAPP, labex UnivEarth, AUTH)

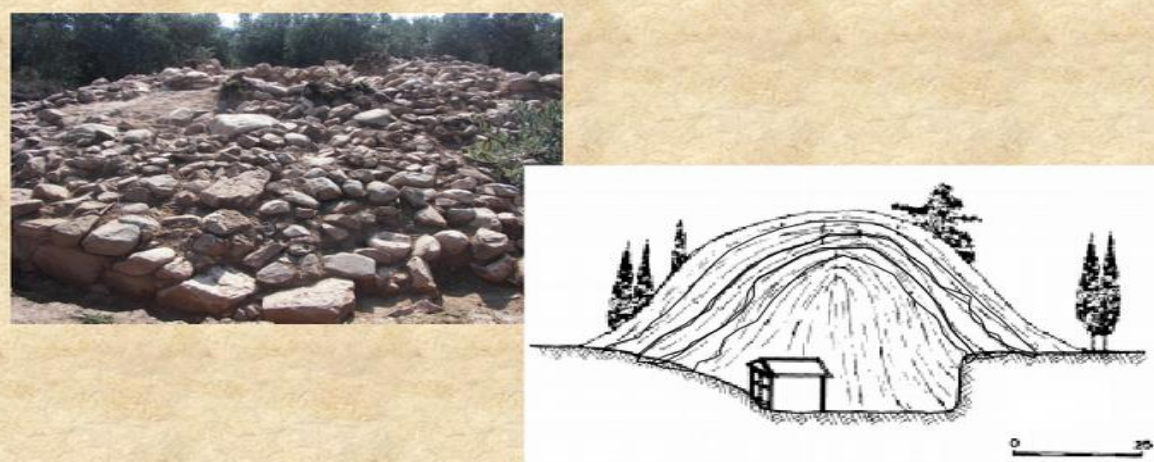


A massive “Macedonian-type” tumulus



CHALLENGES OF THE GEOPHYSICAL SURVEYS ON TUMULI

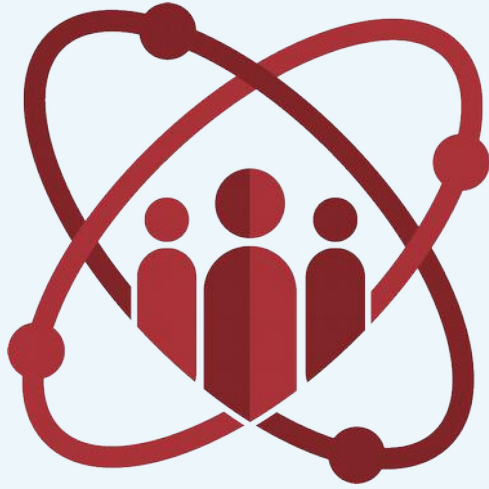
The material of the tumulus might be highly inhomogeneous (a fact that renders difficult the data interpretation). In some cases, stratification of the tumulus infill material has been observed.



The complex block contains two images. On the left is a photograph showing a close-up view of the tumulus's surface, which is composed of large, irregular stones and earth, showing signs of stratification. On the right is a cross-sectional diagram of a tumulus. The diagram shows a mound with a small rectangular structure at its base. The interior of the mound is depicted with various layers and textures, representing the inhomogeneous and stratified infill material. A scale bar at the bottom right indicates 0 to 25 meters.

 G. Tsokas et al. (2015)

What kind of information can the Muon tomography provide to non-destructive tumulus survey ?



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**WELCOME TO THE MUONS HUNTING
HELP US GETTING BETTER IMAGES**

