

Muon tomography of La Soufrière of Guadeloupe

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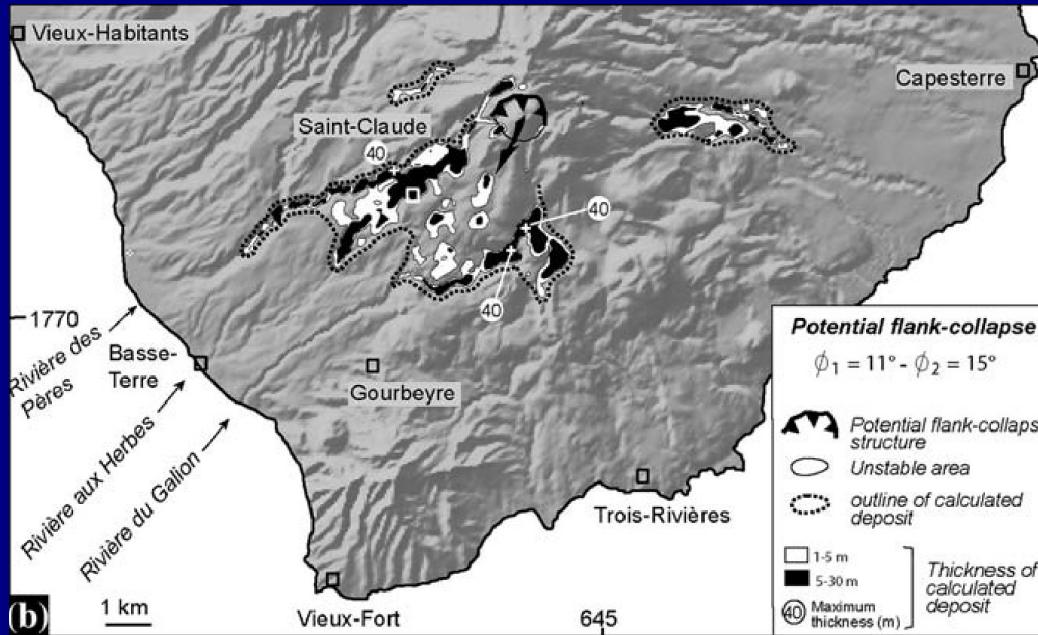
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Utility of muon tomography for La Soufrière



Le Friant et al., Nat. Haz., 381–393, 2006

Risk assessment:

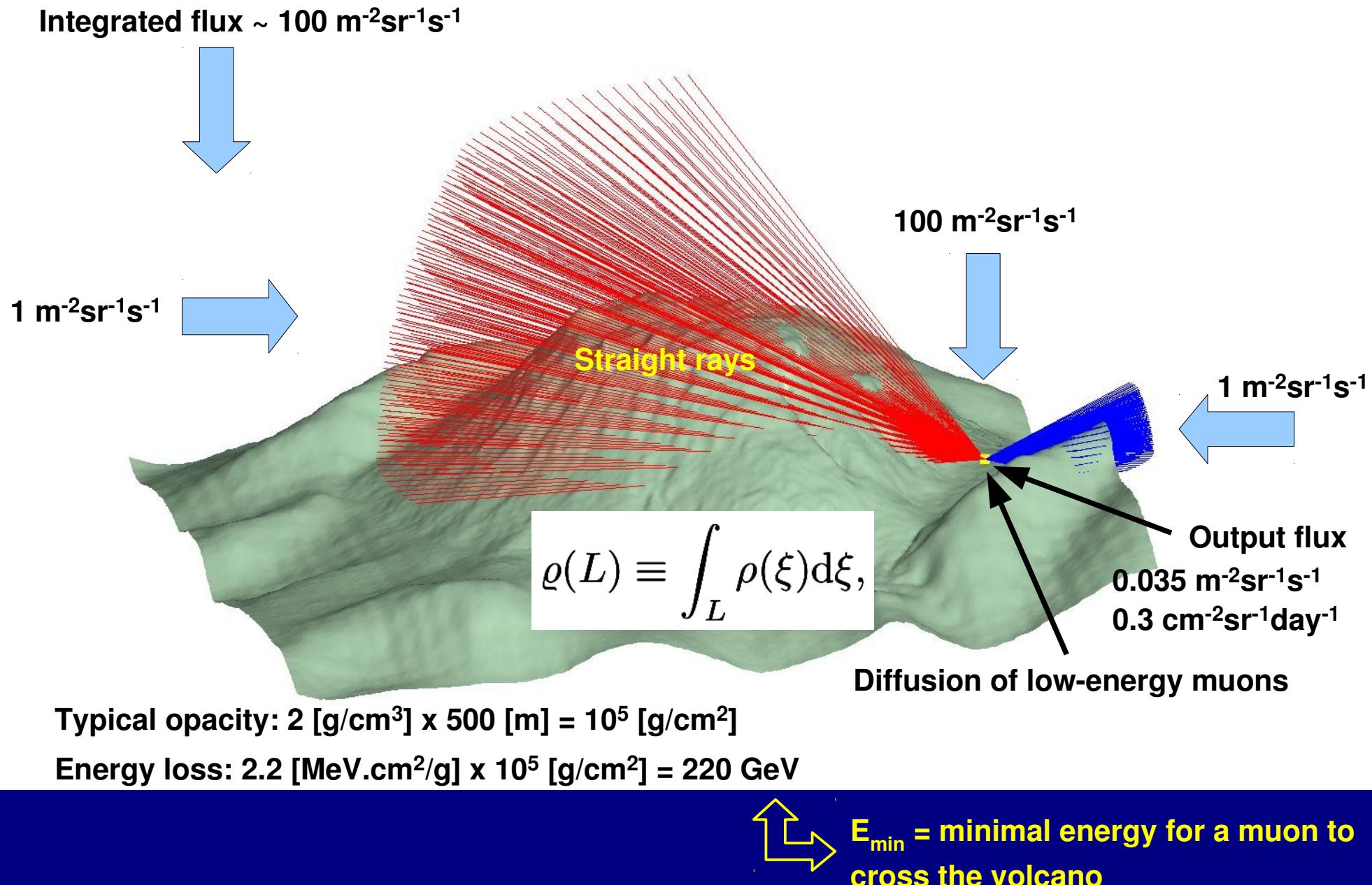
From the eruptive history of the region the most probable hazards are:

- * flank destabilization
- * phreatic explosion

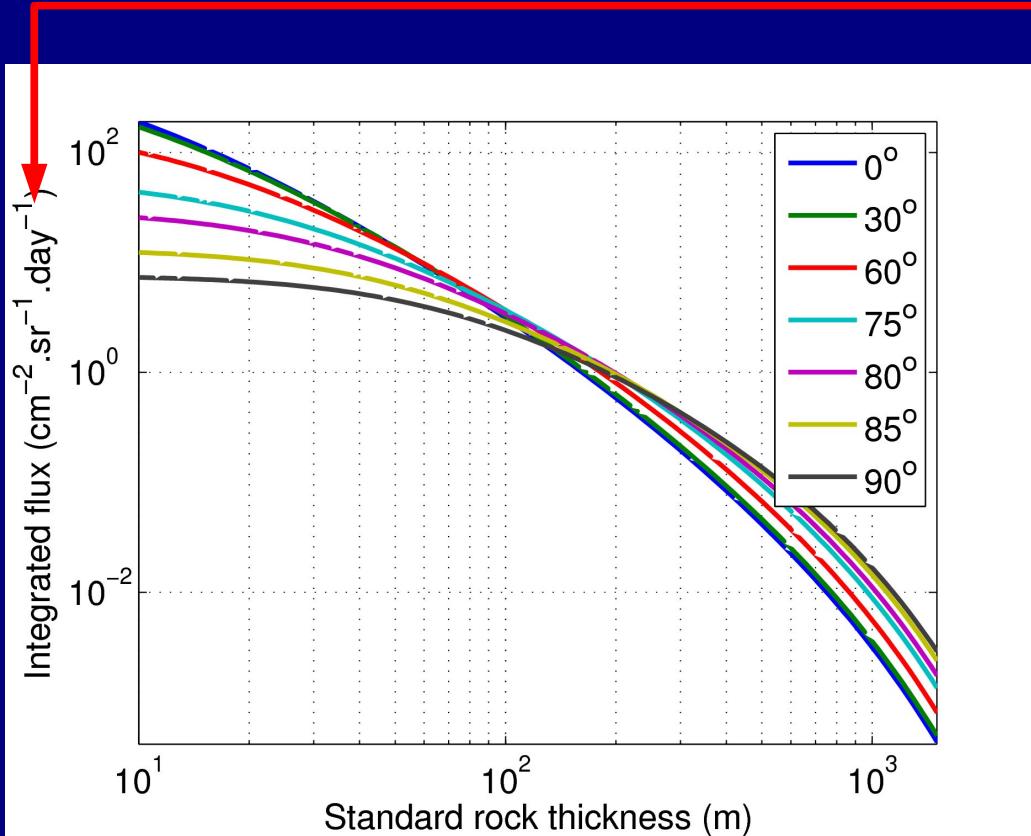
Muon tomography is useful to:

- * evaluate the mechanical integrity of the lava dome
- * provide initial conditions for destabilization models
- * evaluate the volume (i.e. amount of energy) of the hydrothermal reservoirs inside the dome
- * monitoring of mass transfer and density changes
- * tomography problem is simple when compared with other geophysical methods

Density tomography with cosmic muons: 1



Density tomography with cosmic muons: 2



\downarrow
 $\rho = 2.65 \text{ g/cm}^3$

Flux models are less accurate at low energy and/or large zenith angles

$$I[\varrho, \theta] = \int_{E_{\min}(\varrho)}^{\infty} \Phi(E_0, \theta) dE_0 \ (\text{cm}^{-2} \text{sr}^{-1} \text{s}^{-1}).$$

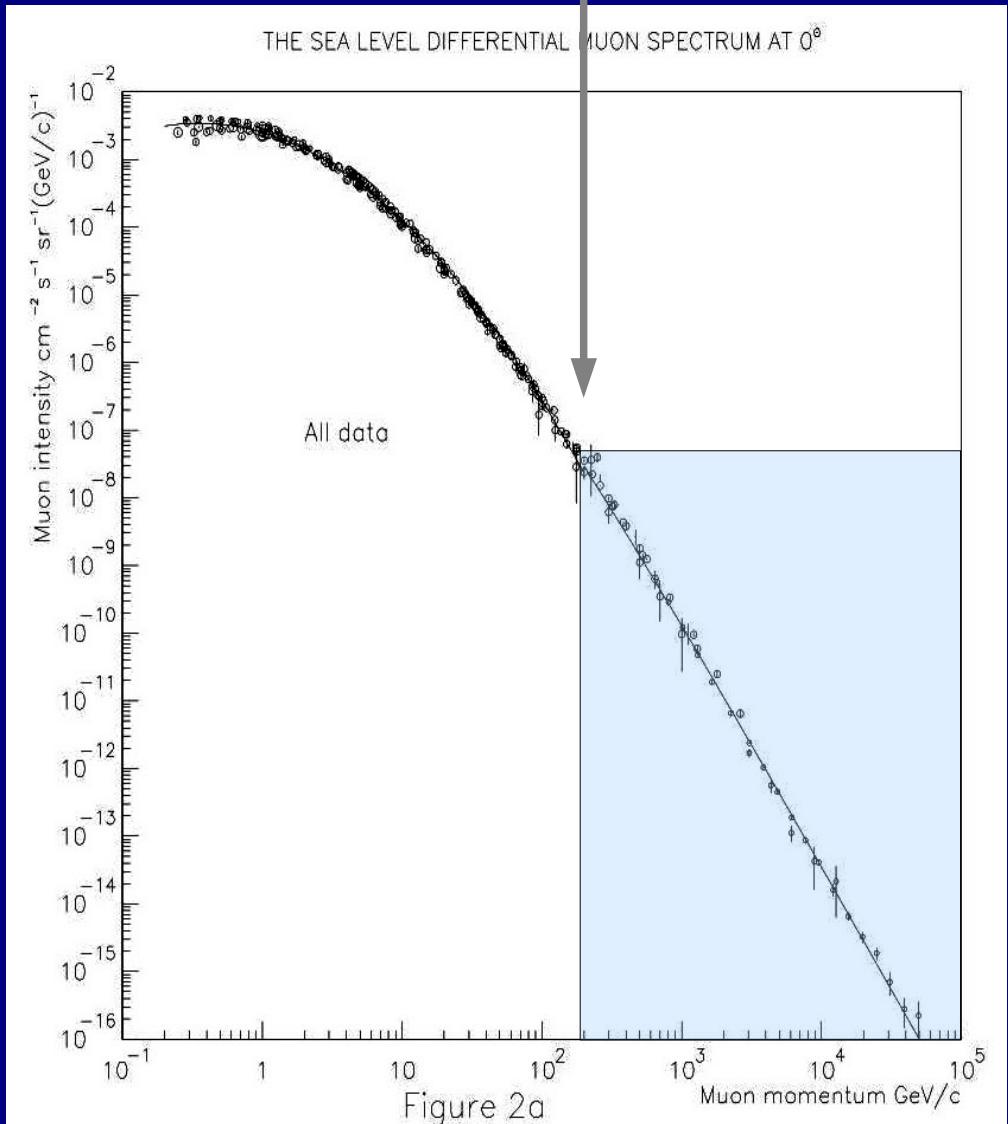
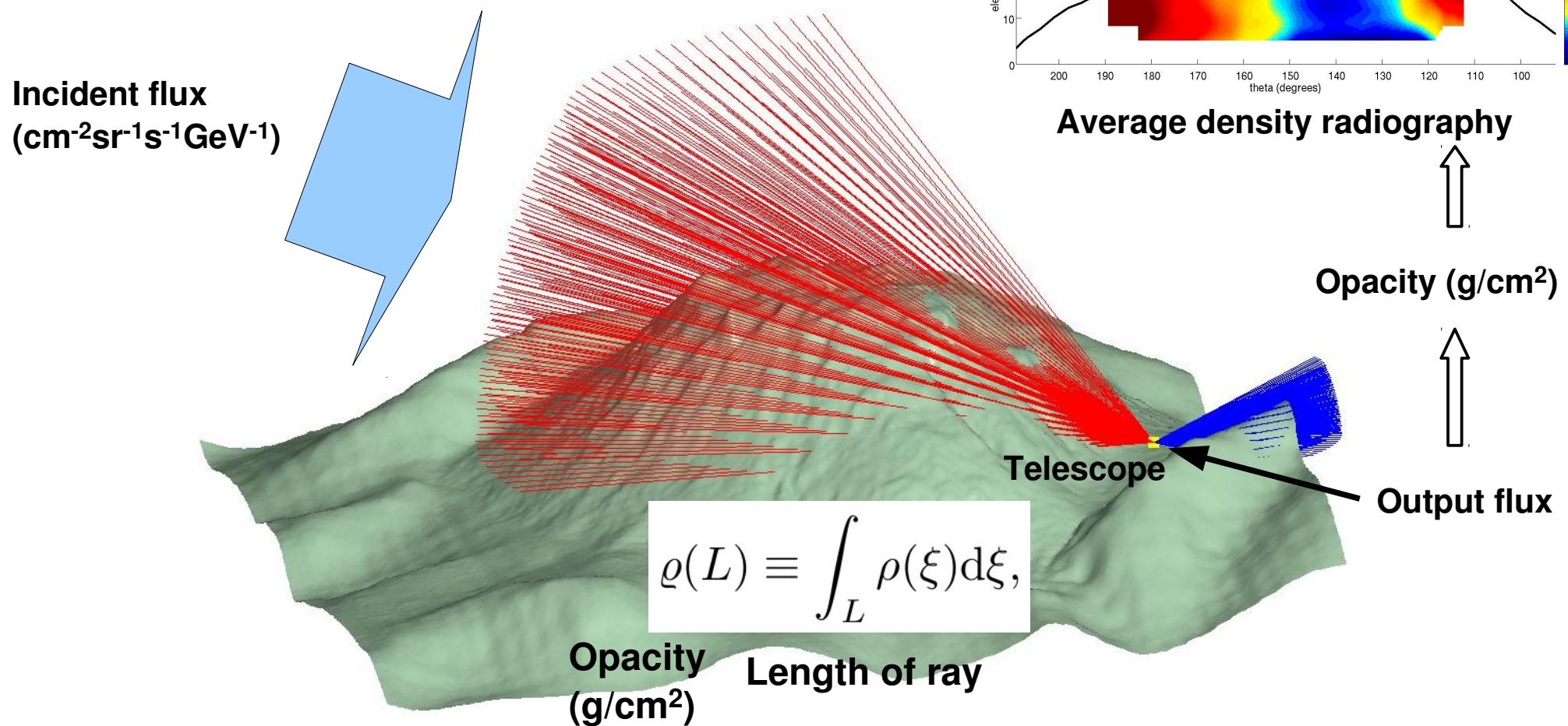
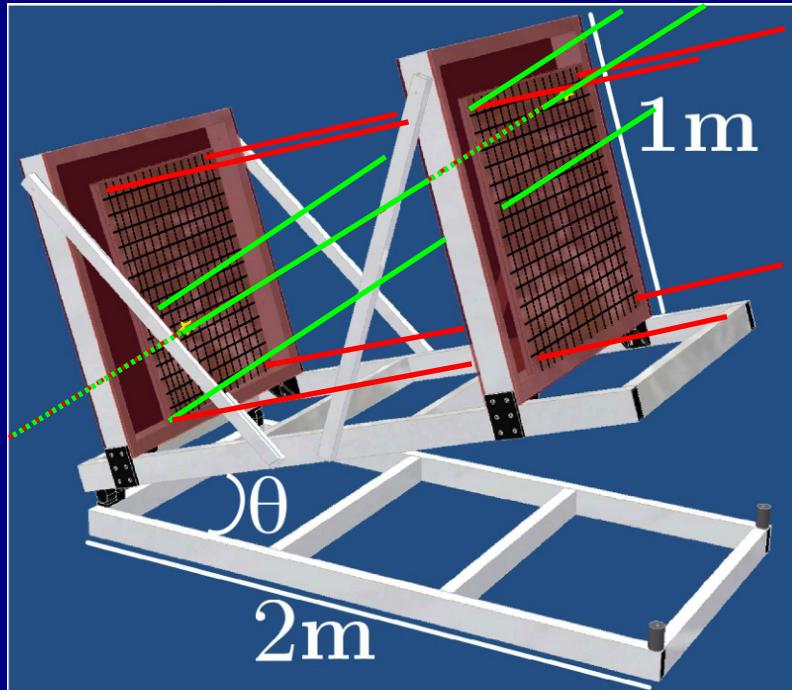


Figure 2a

Density tomography with cosmic muons: 3



Telescope acceptance



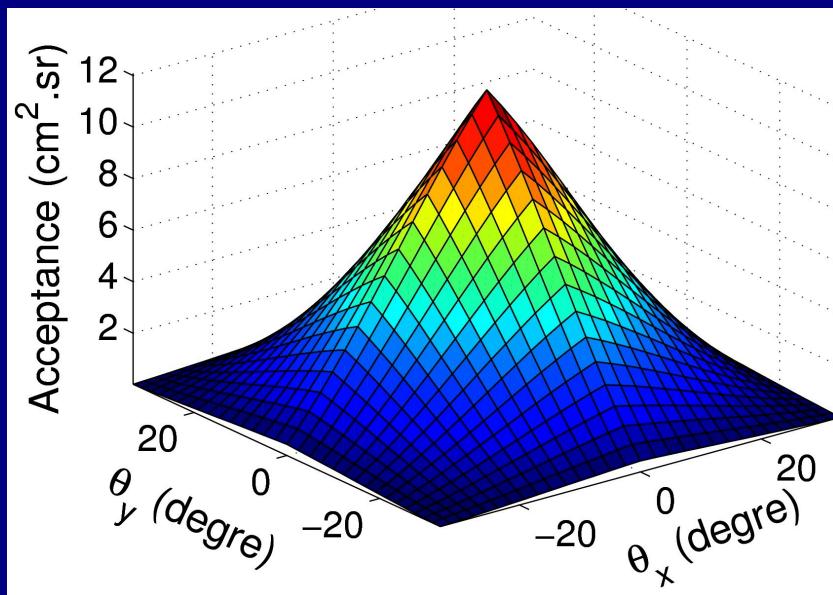
The acceptance is used to convert the number of detected particles into a flux value necessary for modelling

$$N(\varrho) = \Delta T \times \mathcal{T} \times I(\varrho),$$

Integrated flux
($\text{cm}^{-2}.\text{sr}^{-1}.\text{s}^{-1}$)

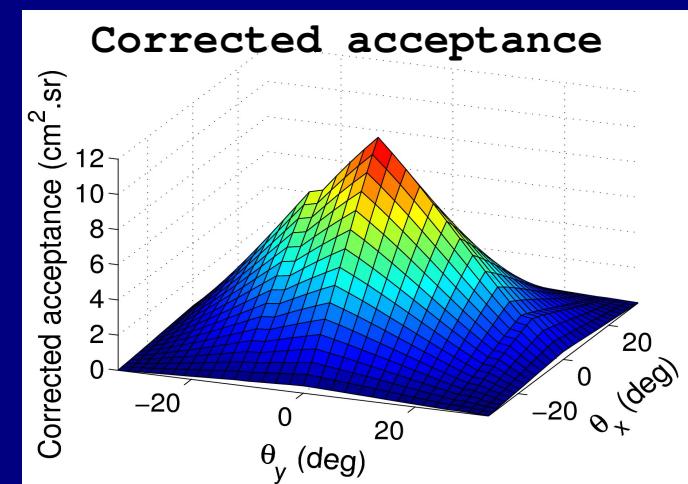
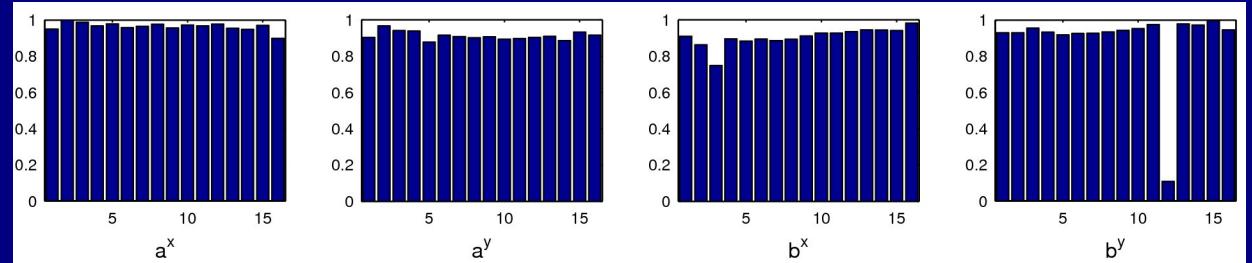
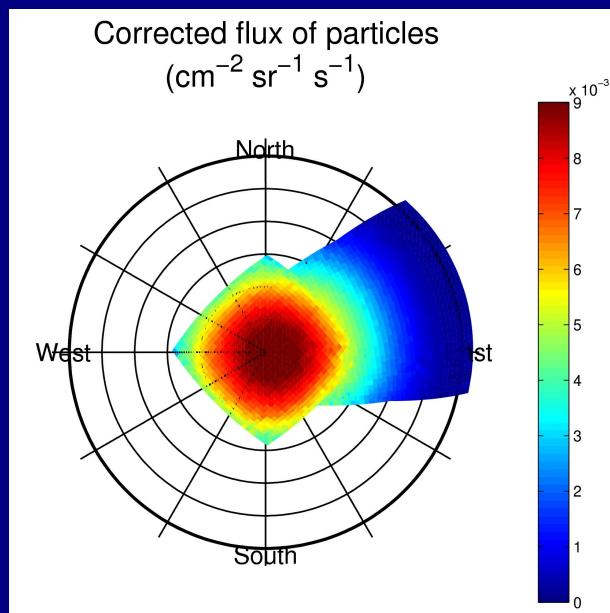
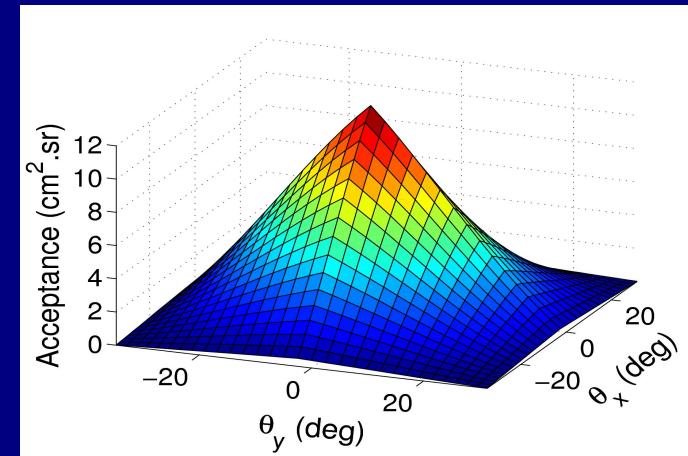
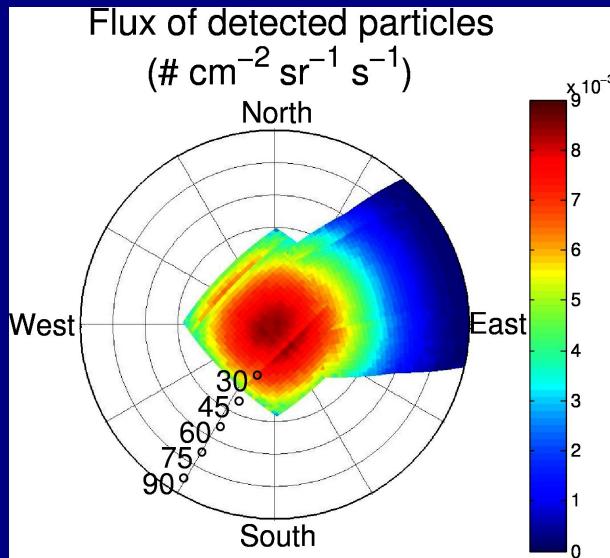
Duration of measurement period

Telescope acceptance
($\text{cm}^2.\text{sr}$)



Resolution = 50 mrad (i.e. 25 m at 500 m)

Bayesian modelling of acceptance



Lesparre, N., D. Gibert & J. Marteau, Bayesian Dual Inversion of Experimental Telescope Acceptance and Integrated Flux for Geophysical Muon Tomography, Geophysical Journal International, Vol. 188, 490-497, 2012.

Time-space resolution

$$N(\varrho) = \Delta T \times \mathcal{T} \times I(\varrho),$$

Integrated flux
($\text{cm}^{-2}.\text{sr}^{-1}.\text{s}^{-1}$)

Duration of measurement period

Telescope acceptance ($\text{cm}^2.\text{sr}$)

$$N(\varrho_0) - N(\varrho_0 + \delta\varrho) > \alpha \times \sigma_N$$

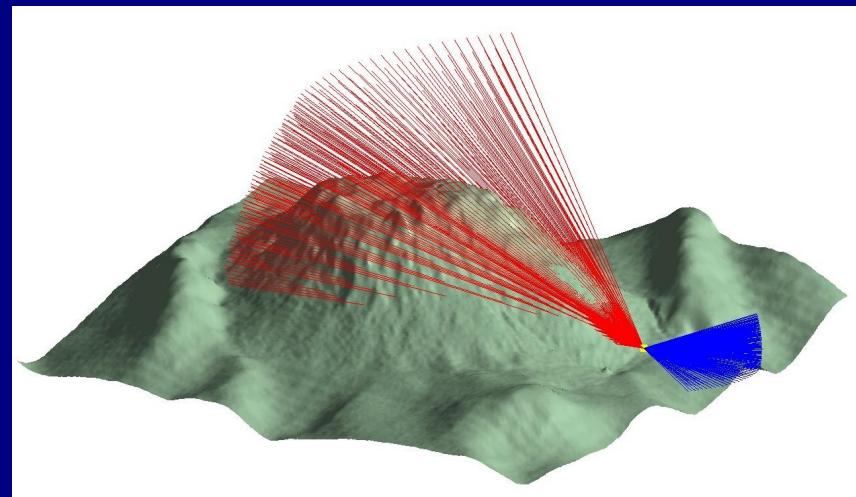
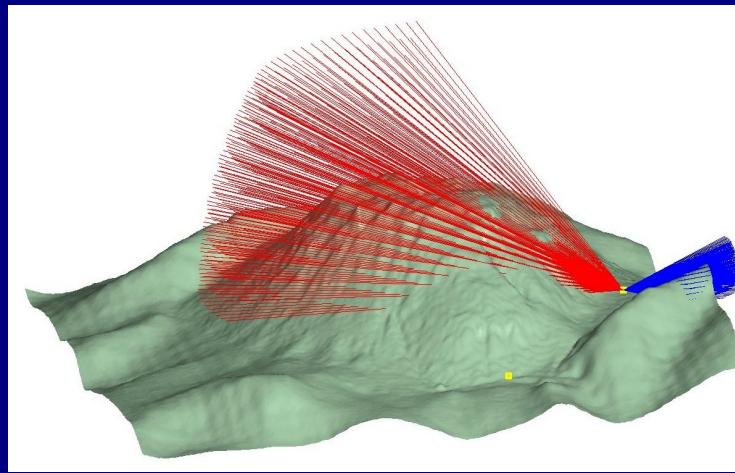
$$\delta N(\varrho_0 | \delta\varrho) > \alpha \sqrt{N(\varrho_0)}$$

$$\sigma_N^2 = N(\varrho) \quad \text{Poisson law}$$

$$\Delta T \times \mathcal{T} \times \frac{\Delta I^2(\varrho_0, \delta\varrho)}{I(\varrho_0)} > \alpha$$

The « feasibility » formula relies the desired opacity resolution to telescope acceptance and duration of the measurement period

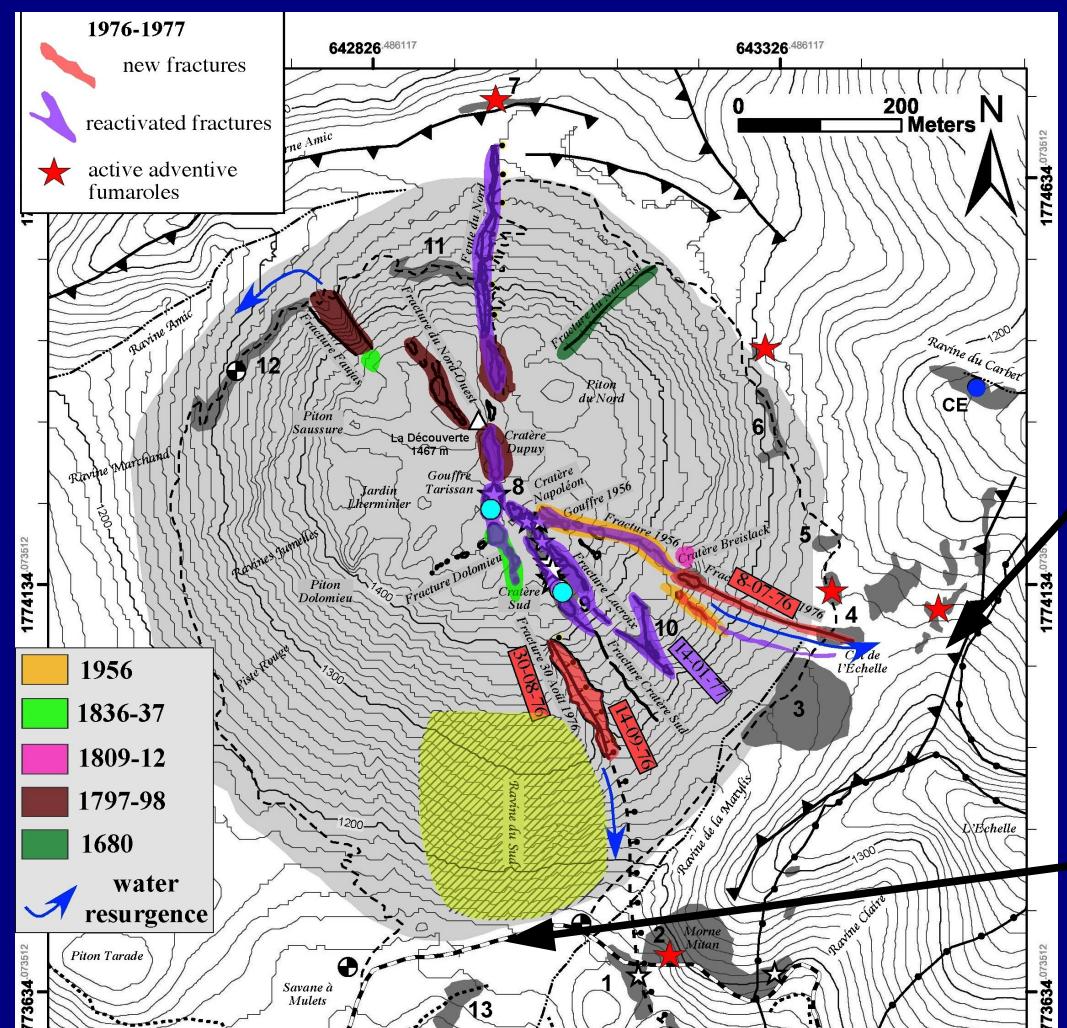
Experiments on la Soufrière of Guadeloupe



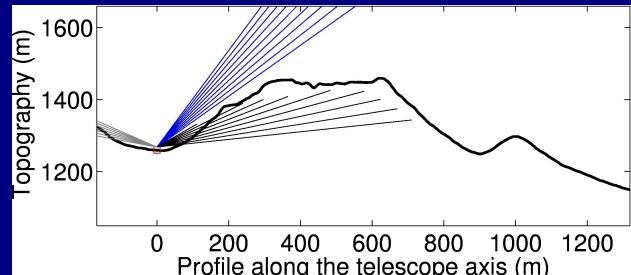
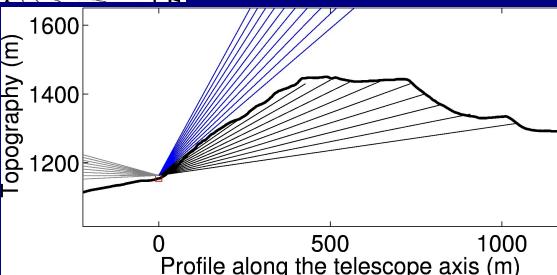
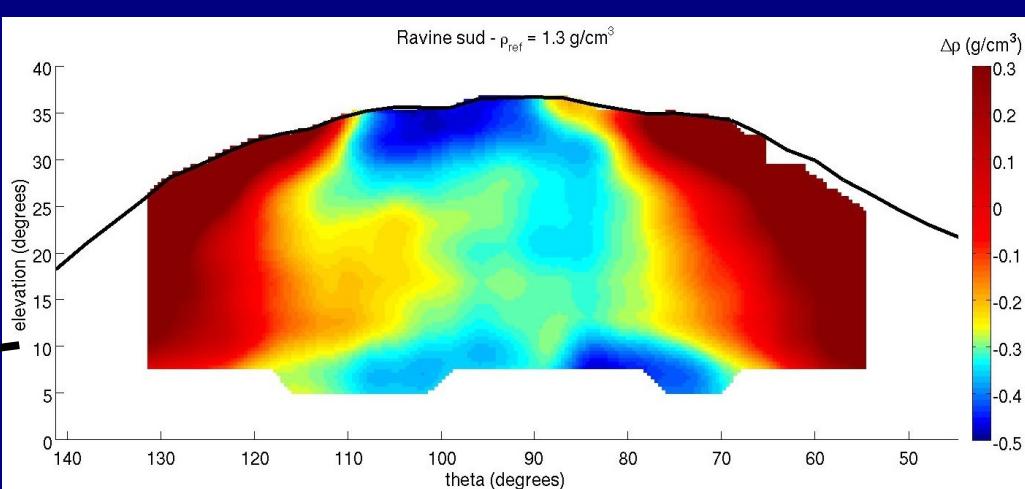
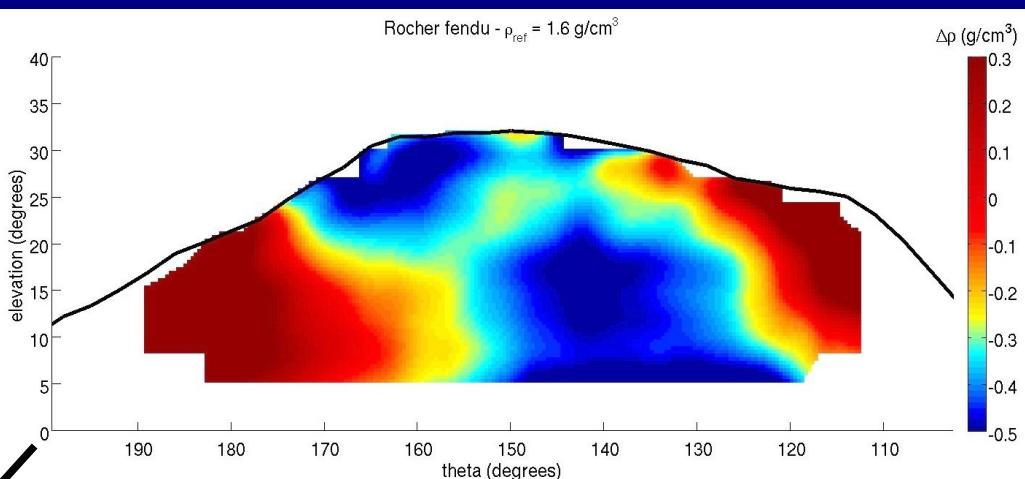
- * Structural imaging and temporal imaging
- * Resolution 30 m, $L = 200 - 900$ m, measurement time of 3 months
- * Scan of the whole volcano from single location

Gibert, D., F. Beauducel, Y. Déclais, N. Lesparre, J. Marteau, F. Nicollin & A. Tarantola, Muon Tomography: Plans for Observations in the Lesser Antilles, *Earth Planets and Space*, Vol. 52, 153-165, 2010.

Radiographies of La Soufrière



structural map: J.-C. Komorowski
measurement time = 8 weeks



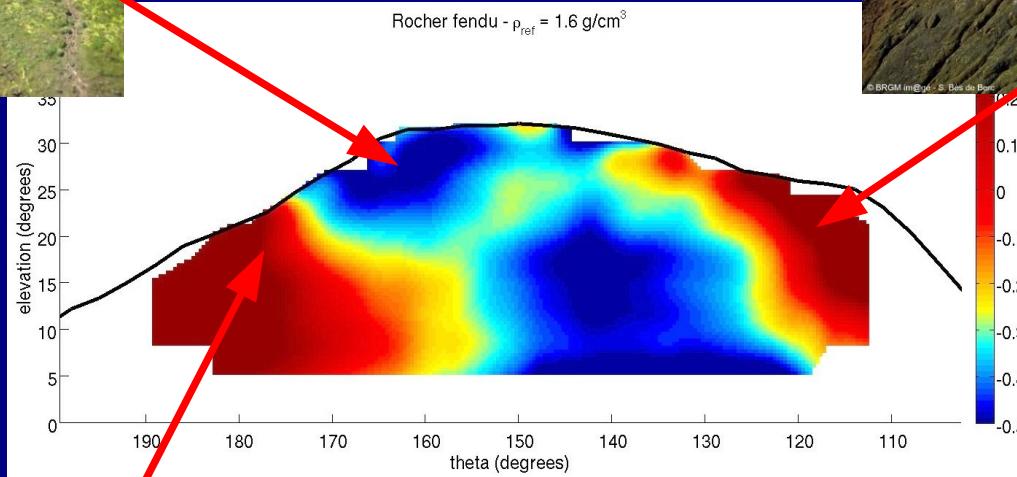
Comparison muon tomography / geology



South crater
region with
altered rock and
many voids



Massive and
dense andesitic
lava



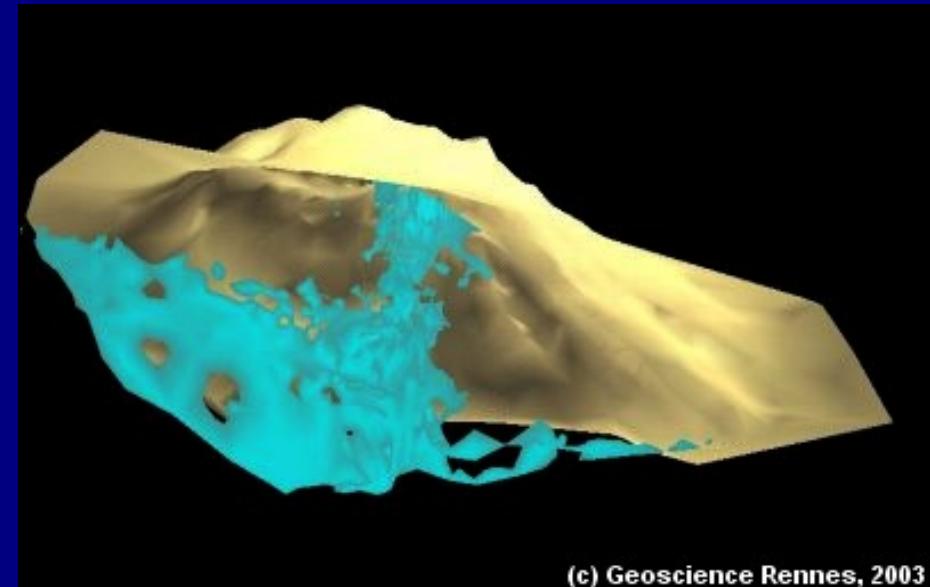
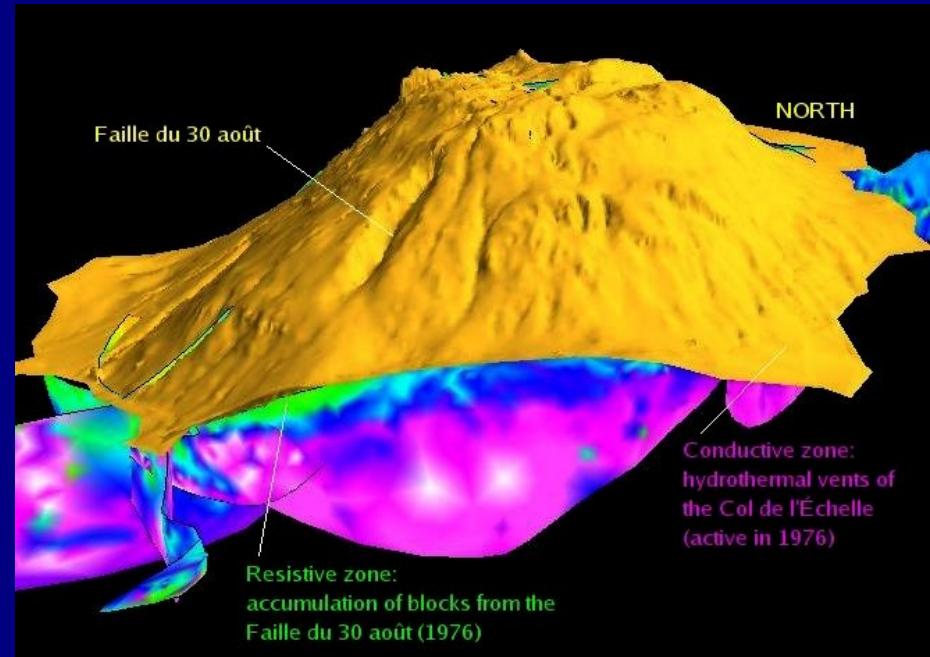
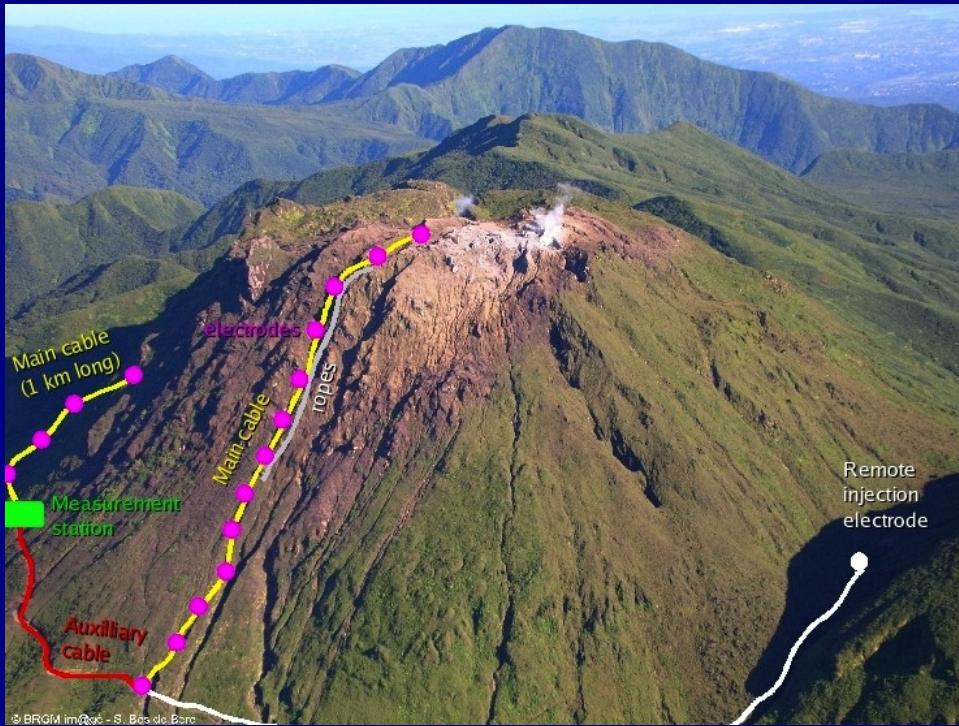
Steep slopes with
massive and dense
andesitic lava



This low density region
might be partly due to the
presence of the Spallanzani
cave described in ancient
texts. No more accessible.



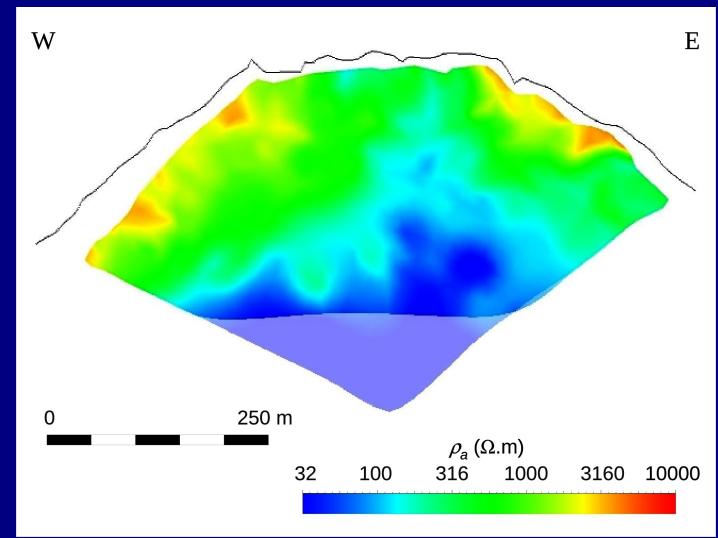
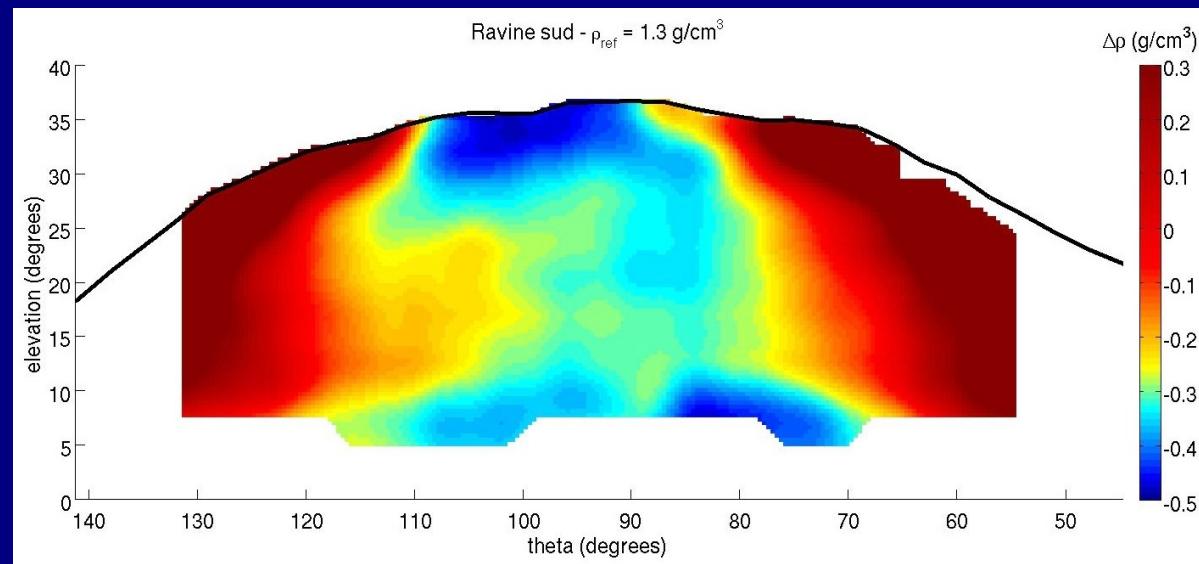
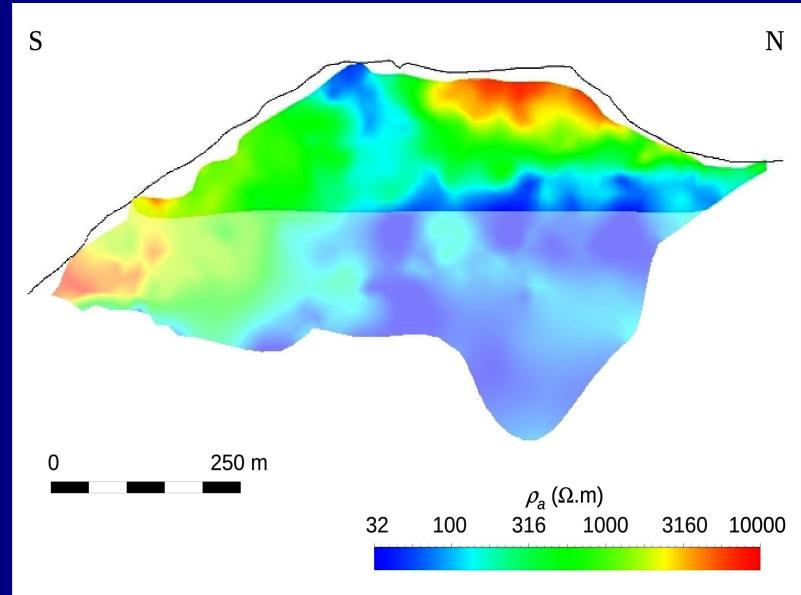
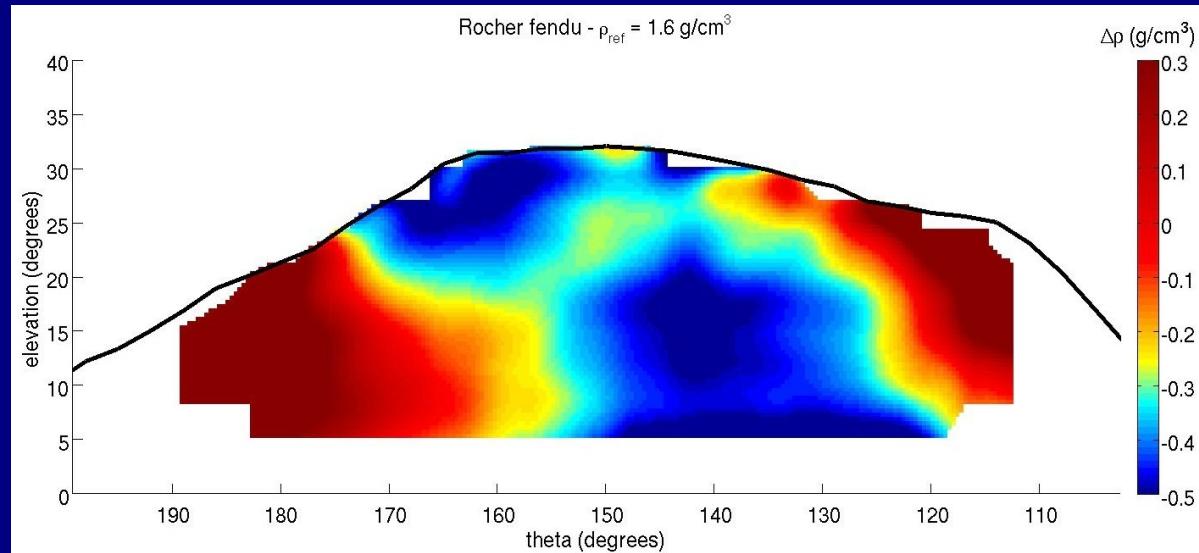
Electrical resistivity tomography



(c) Geoscience Rennes, 2003

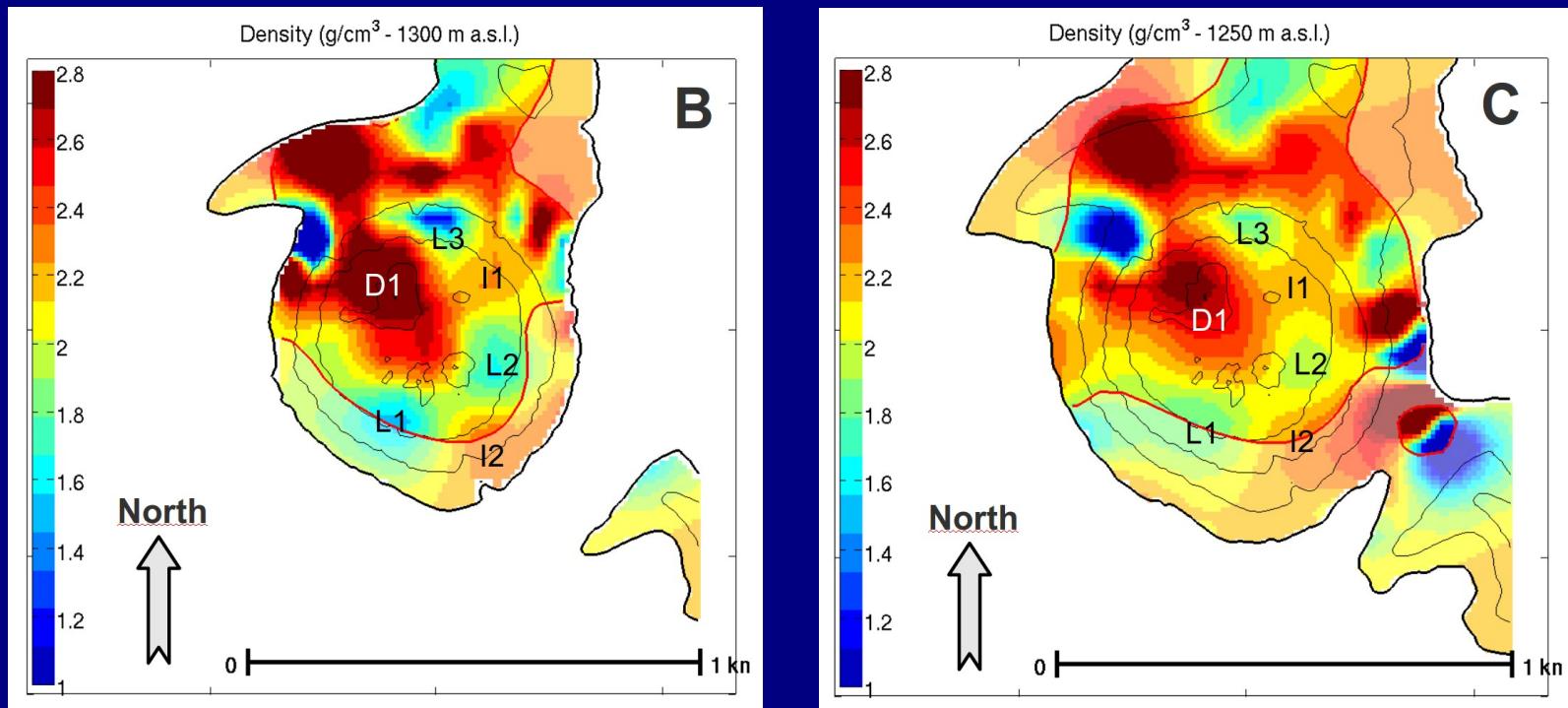
Nicollin, F., D. Gibert, F. Beauducel, G. Boudon & J.-C. Komorowski, Electrical Tomography of La Soufrière of Guadeloupe Volcano: Field Experiments, 1D Inversion and Qualitative Interpretation, Earth and Planetary Science Letters, Vol. 244, 709-724, 2006.

Comparison muon tomography / ERT

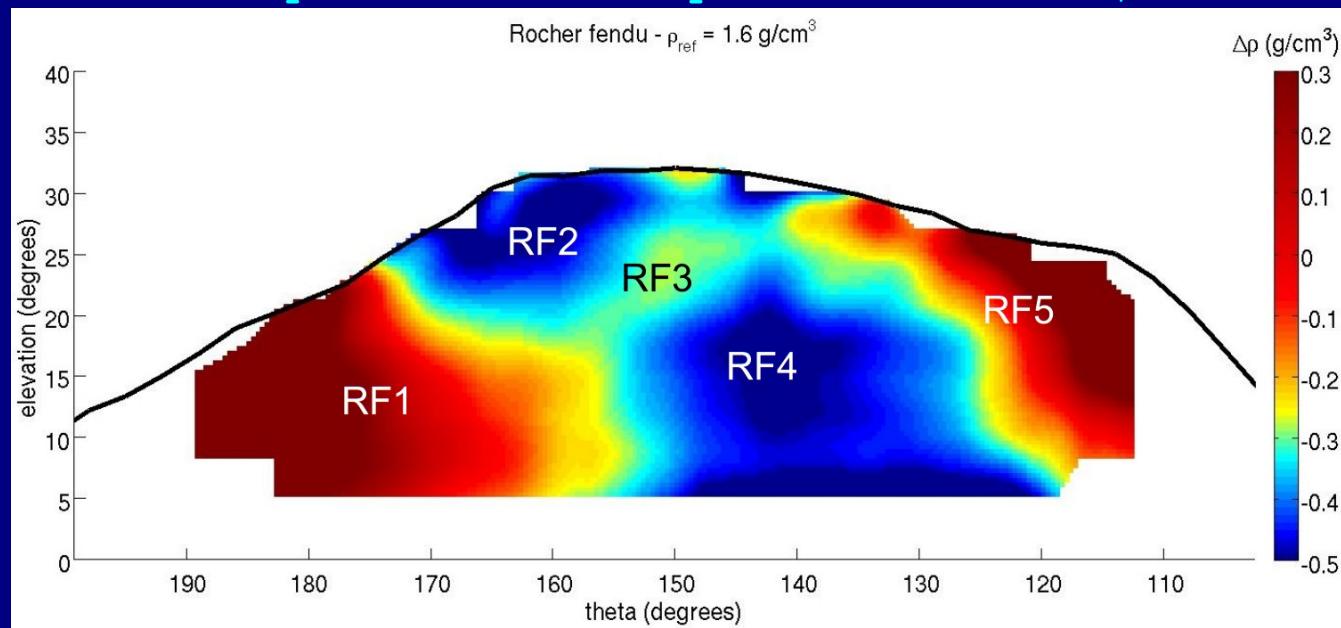


Joint inversion is appealing but density/resistivity relationship may be complicated and certainly not bijective: e.g. massive lava and voids have high resistivity

Comparison muon tomography / gravity data



Gravity data inversion by O. Coutant et al., 2012



Conclusions

Good agreement between muon radiographies and geological, electrical resistivity and gravity data

Joint inversion is appealing and constitutes a key-step to be addressed to integrate muon tomography in the toolbox of geophysicists

Joint inversion of muon data and gravity data is certainly the first problem to address and significant results have been obtained (please look at the poster by Nishiyama et al.)

Joint inversion with electrical resistivity data seems more delicate because both methods are not sensitive to the same physical properties



Next week:
EGU 2012 Vienne (Austria)
Monday 23rd April 15:30
GI3.6 session:

« Geophysical tomography with high-energy particles: recent developments and applications »

co-conveners: D. Gibert, H. Tanaka, J. Marteau,
N. Lesparre, P. Hernandez, P. Strolin

