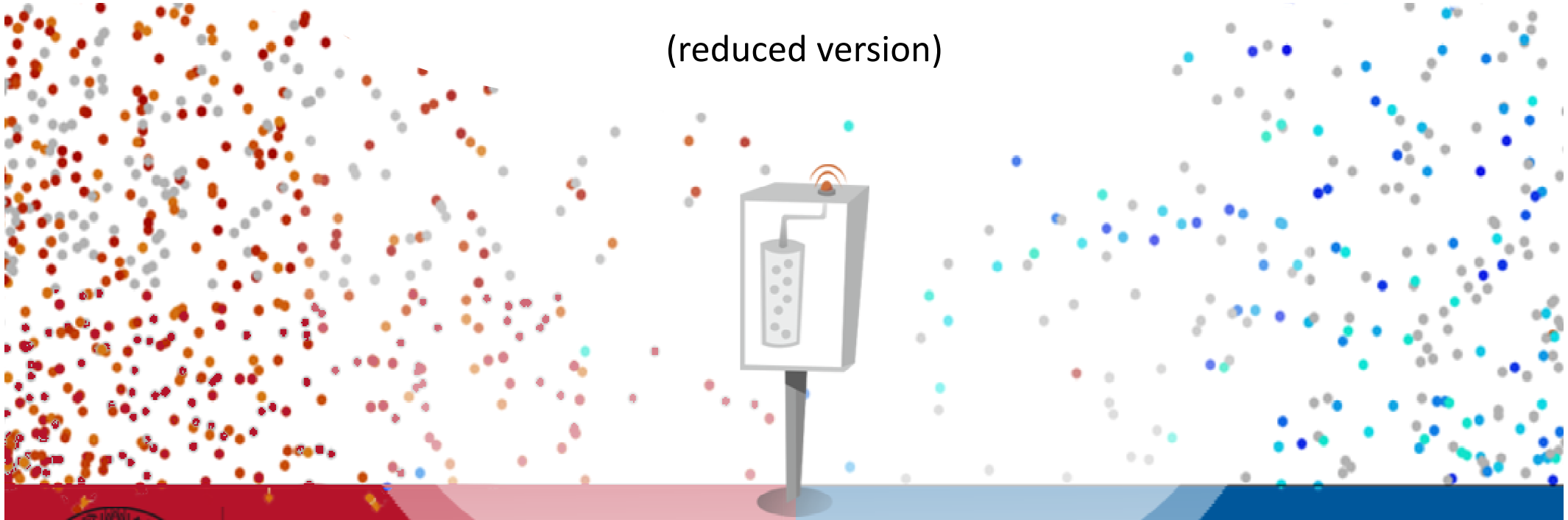
The method of soil moisture sensing by cosmic-ray neutrons

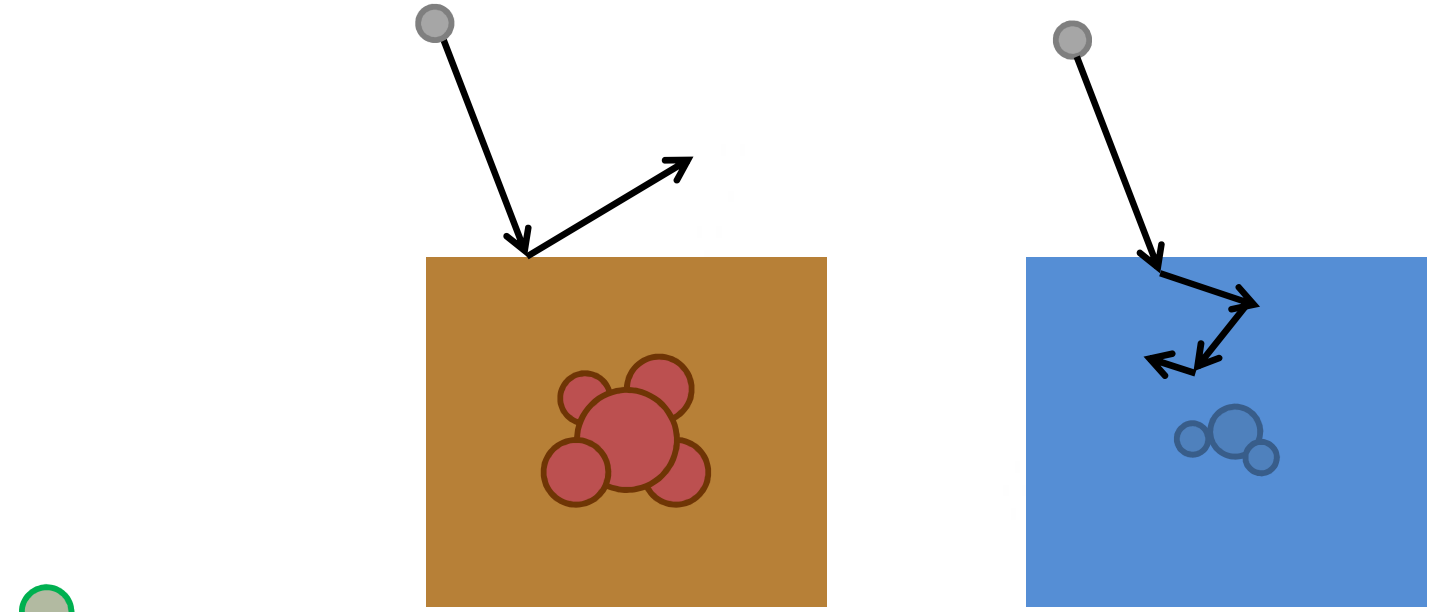
(reduced version)



UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

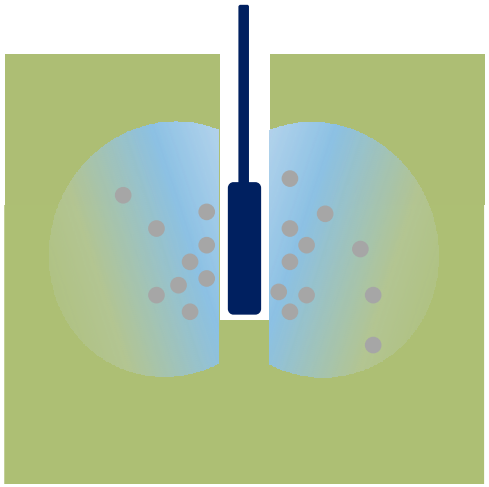
Neutron response to water



Neutron response to water

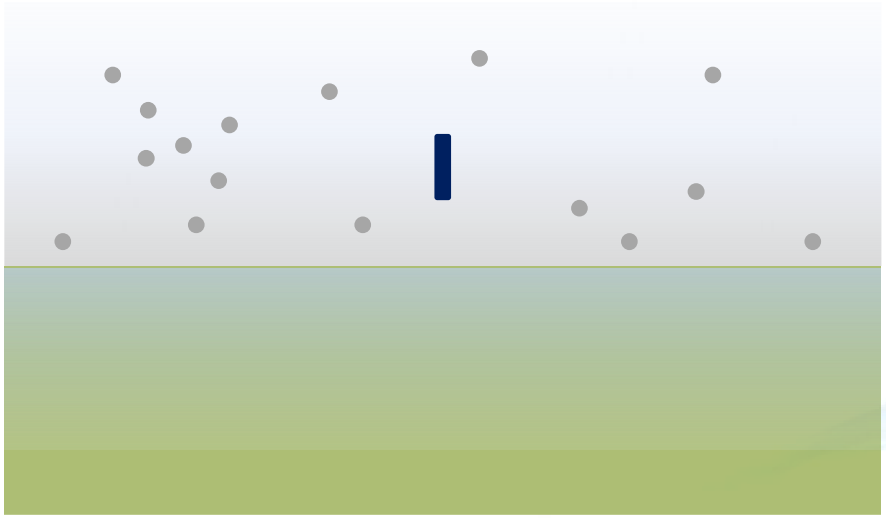
active

small distinct domain
thermalization



passive

large area, diffusive
reflection

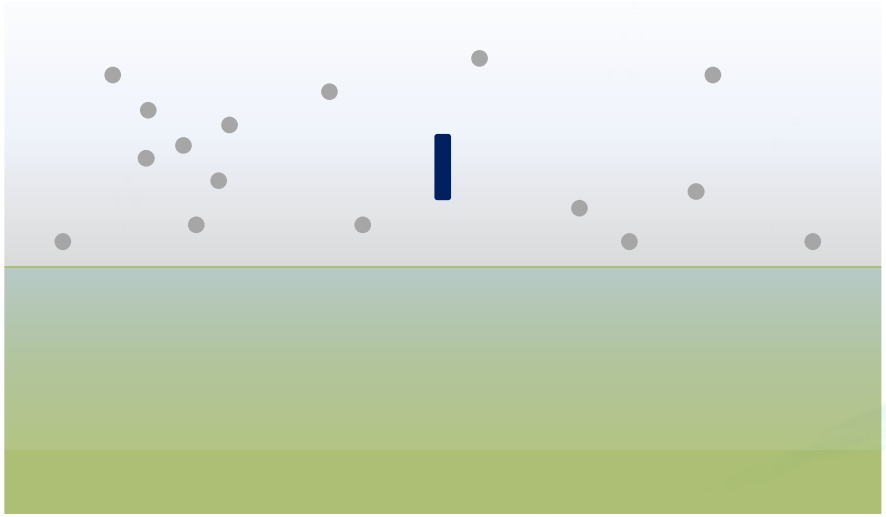


Neutron response to water

passive

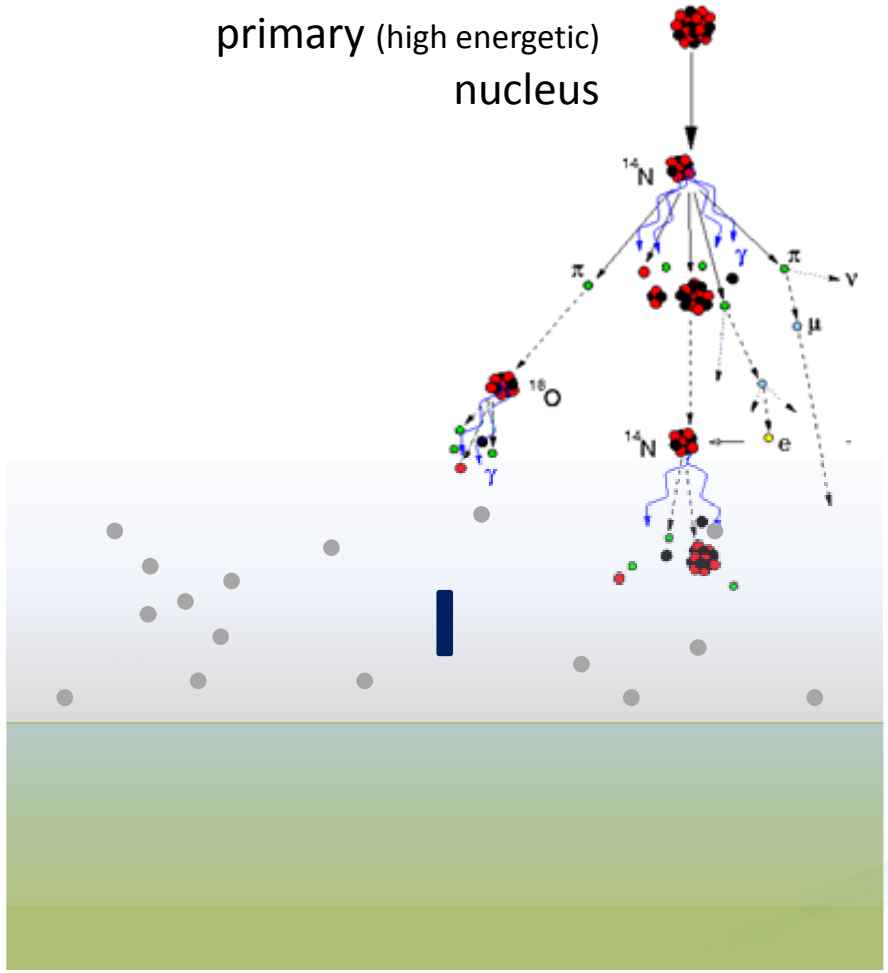
large area, diffusive

reflection



Cosmic Neutrons

primary (high energetic) nucleus



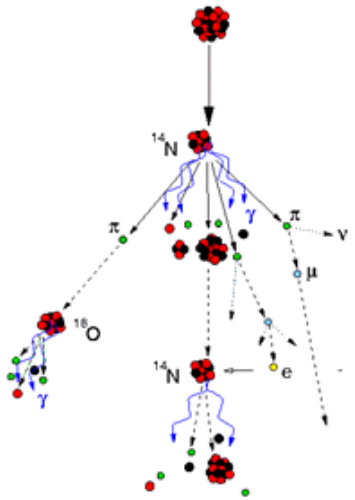
Land-Water Interface Simulation

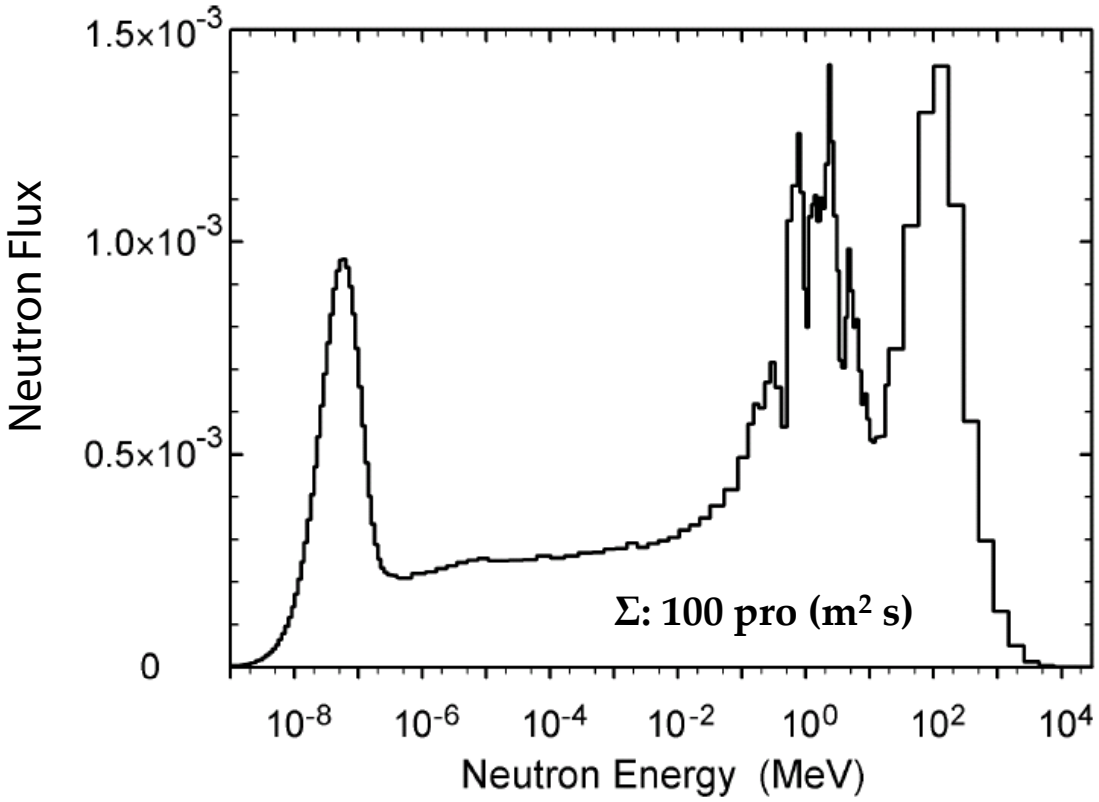
(Movie Removed)

dry soil

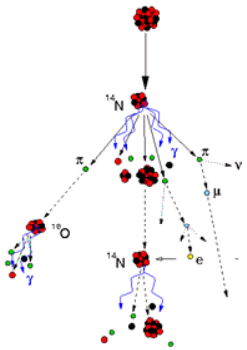
water

The Cosmic Neutron Spectrum

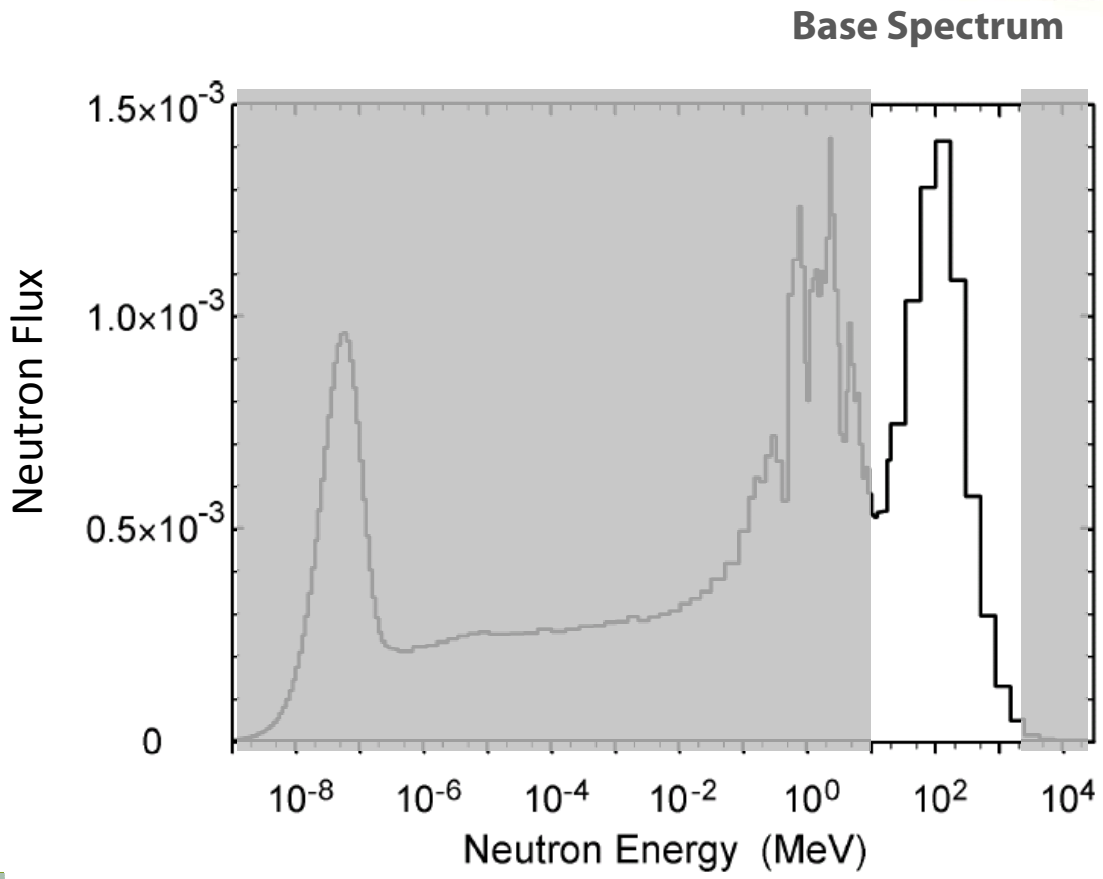




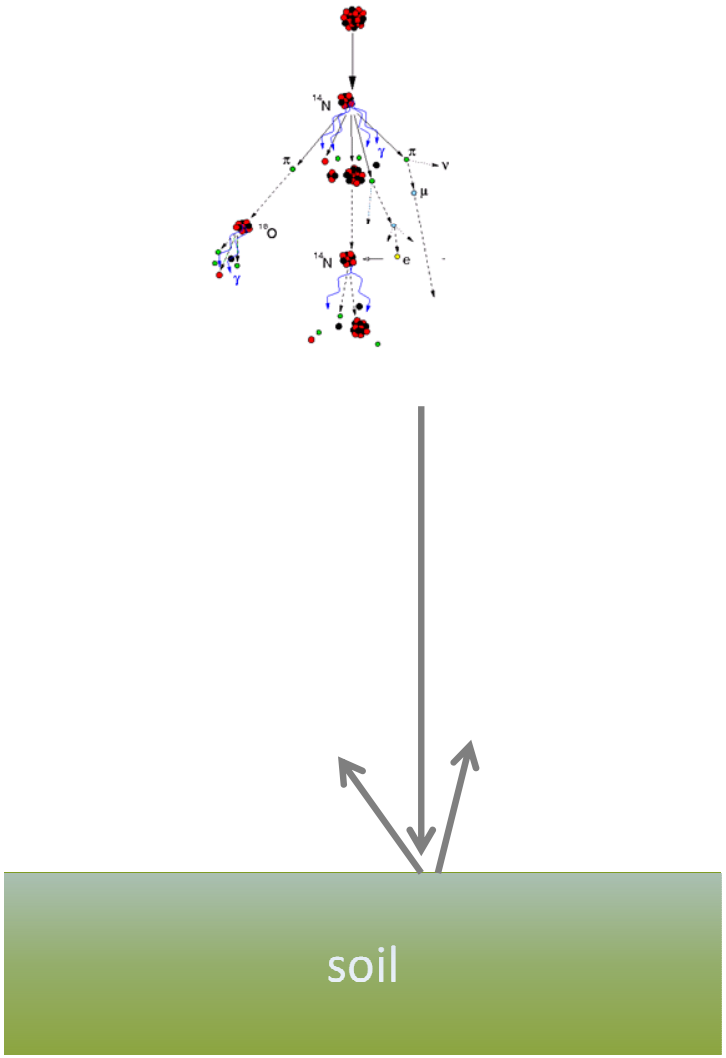
The Cosmic Neutron Spectrum

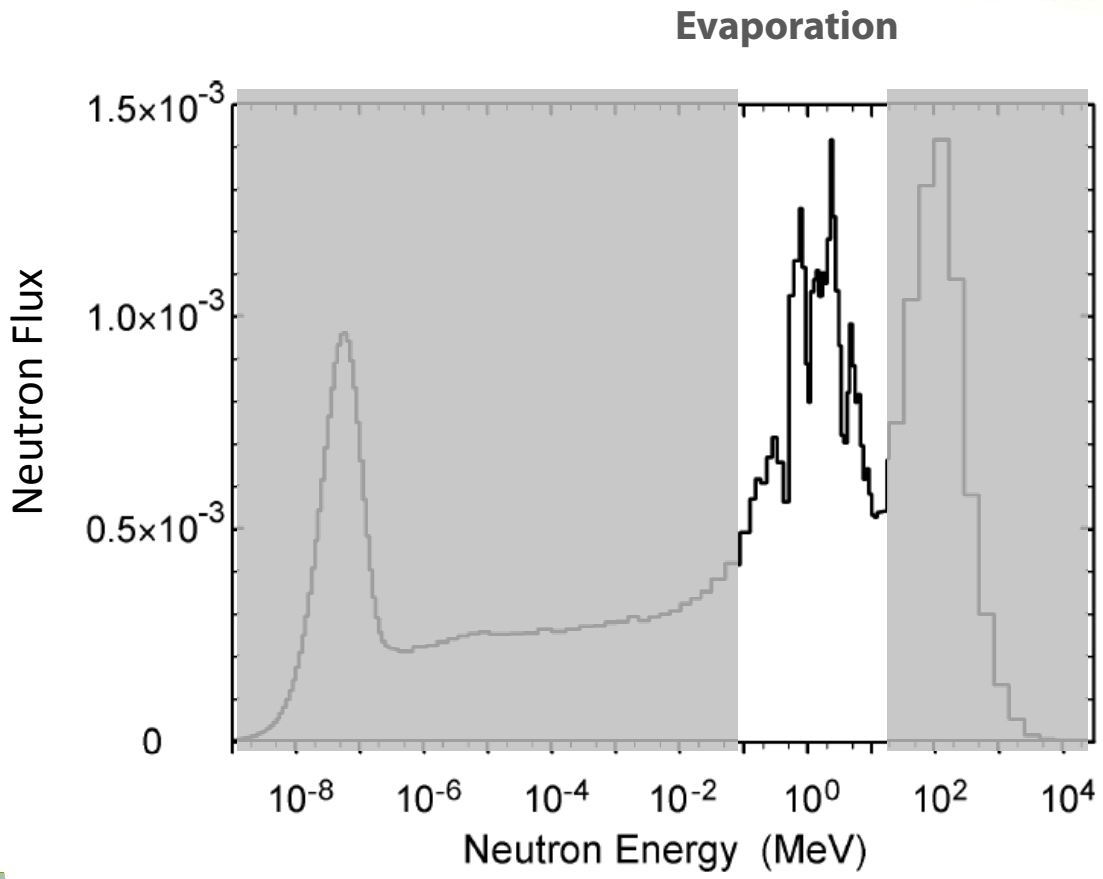


soil

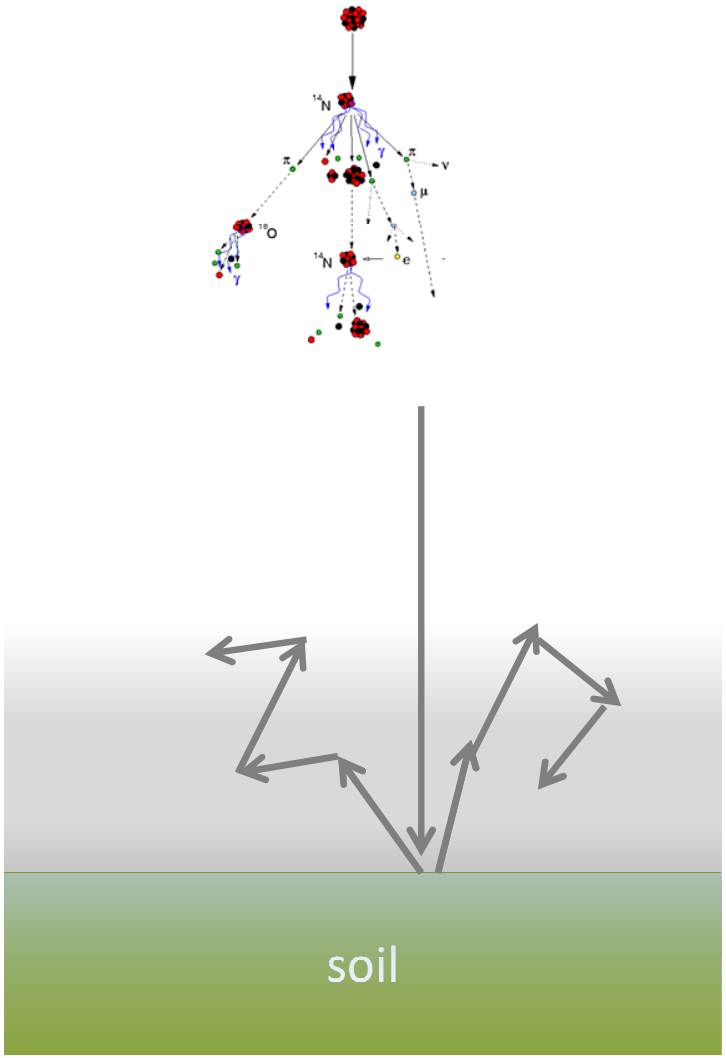


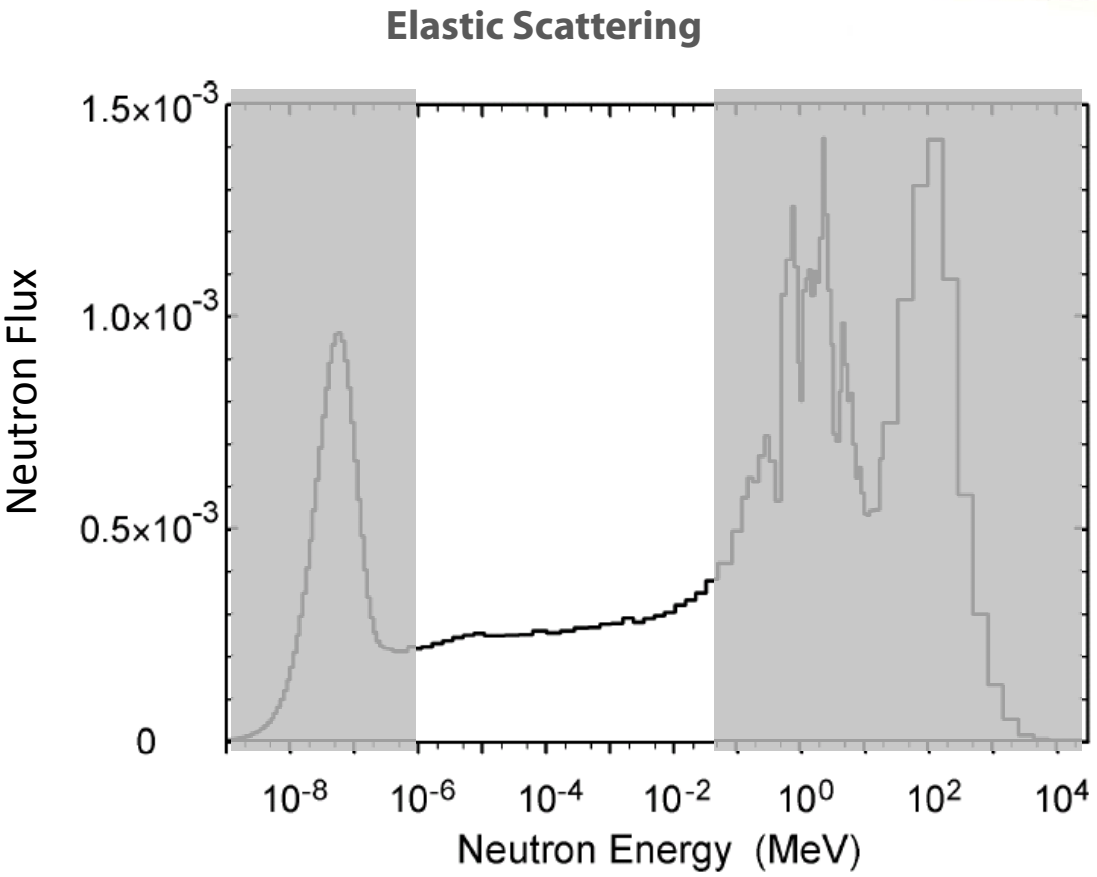
The Cosmic Neutron Spectrum



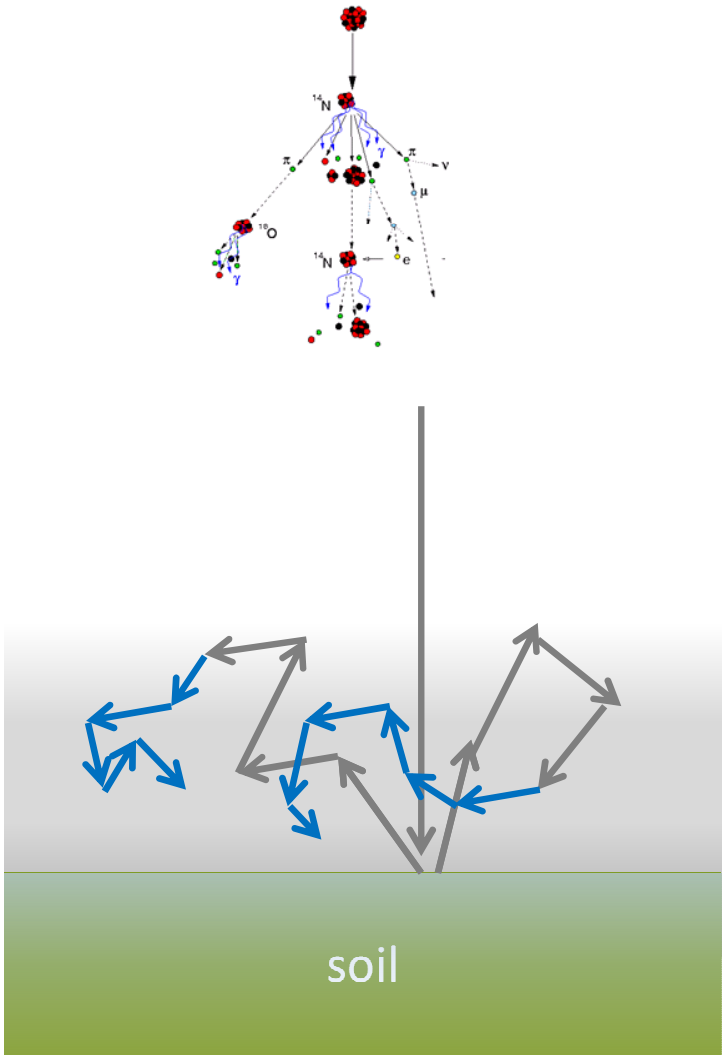


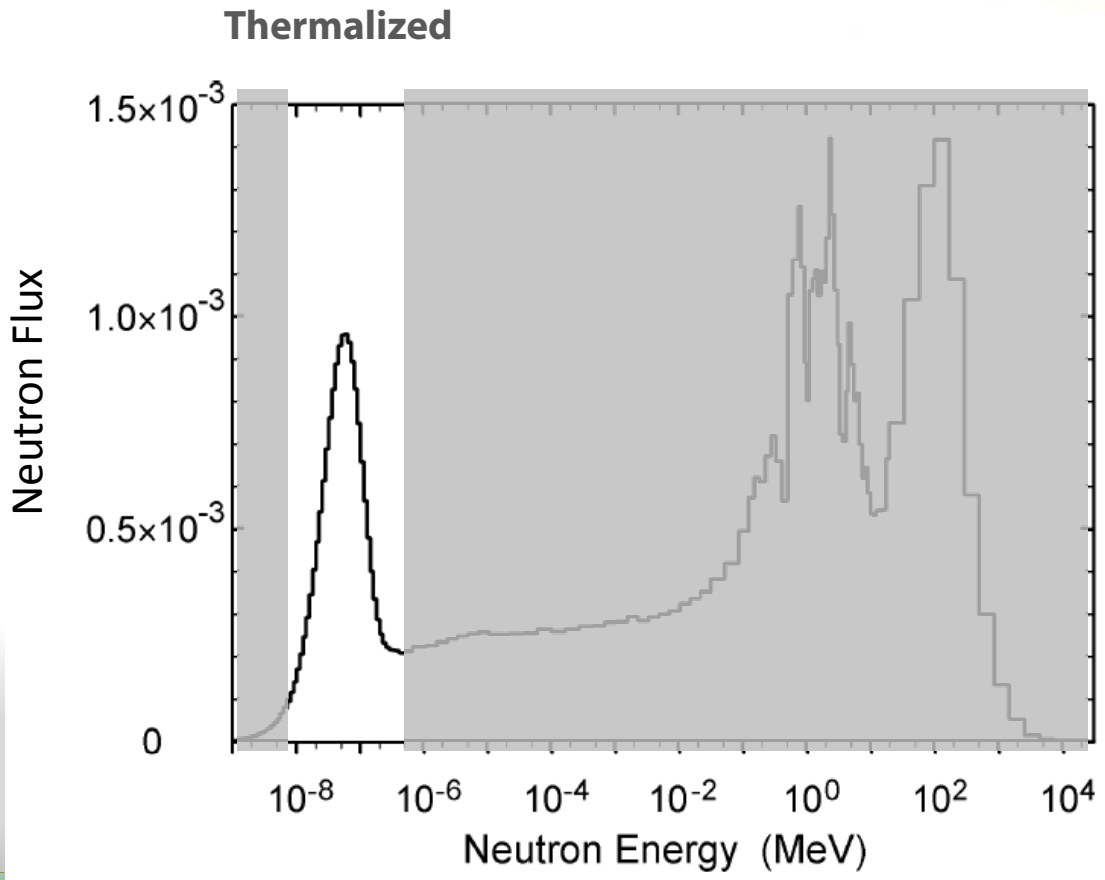
The Cosmic Neutron Spectrum



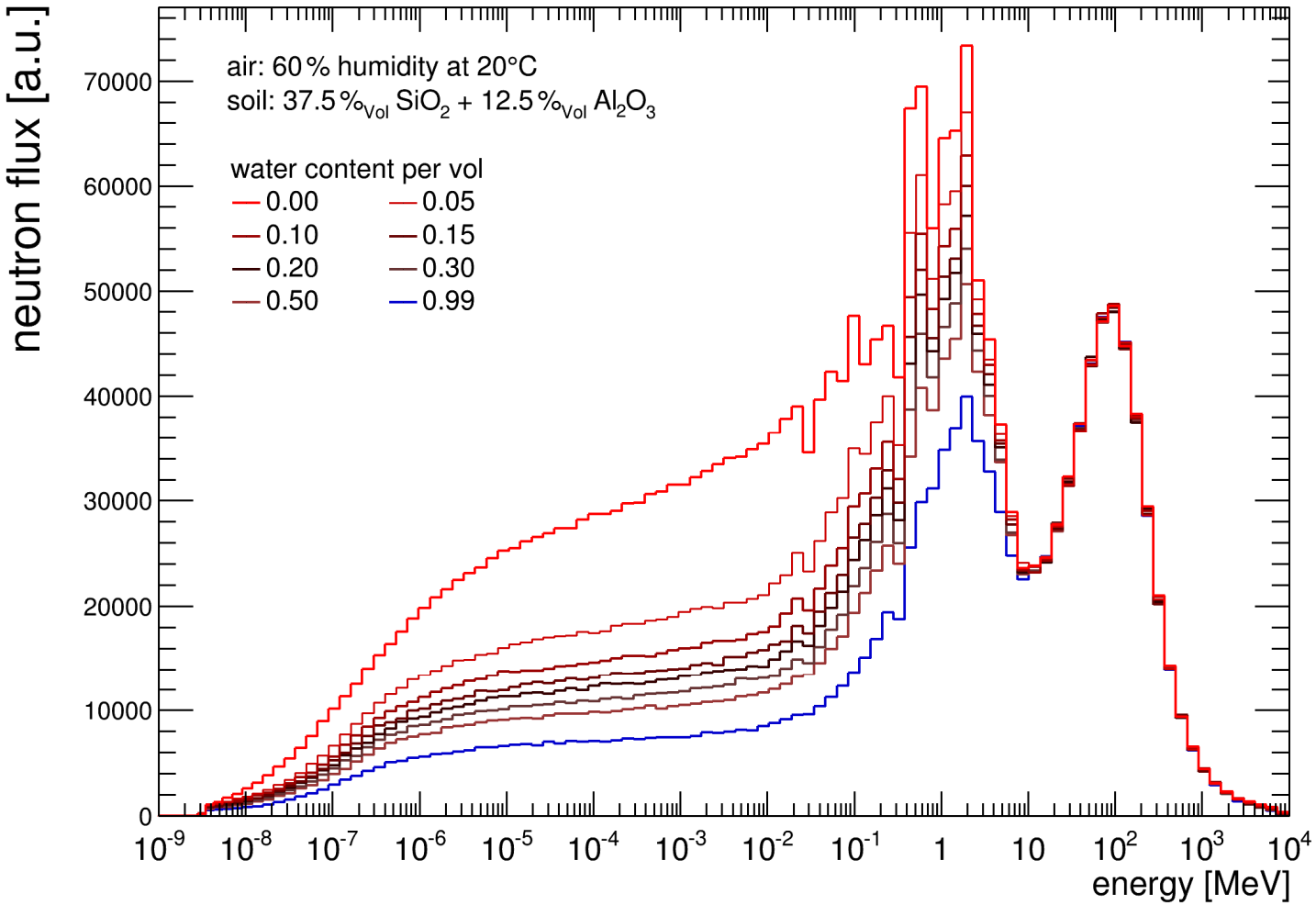


The Cosmic Neutron Spectrum

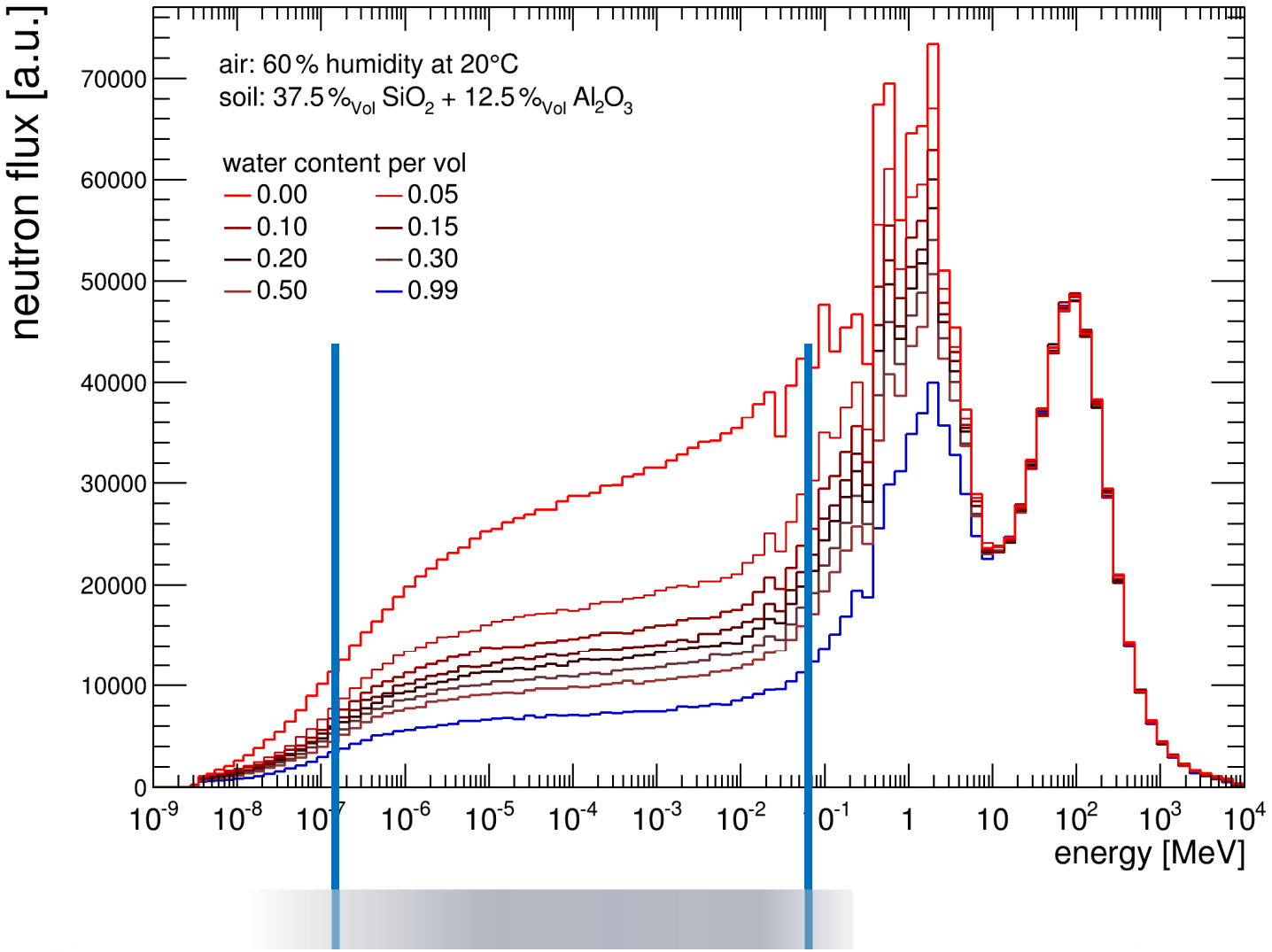




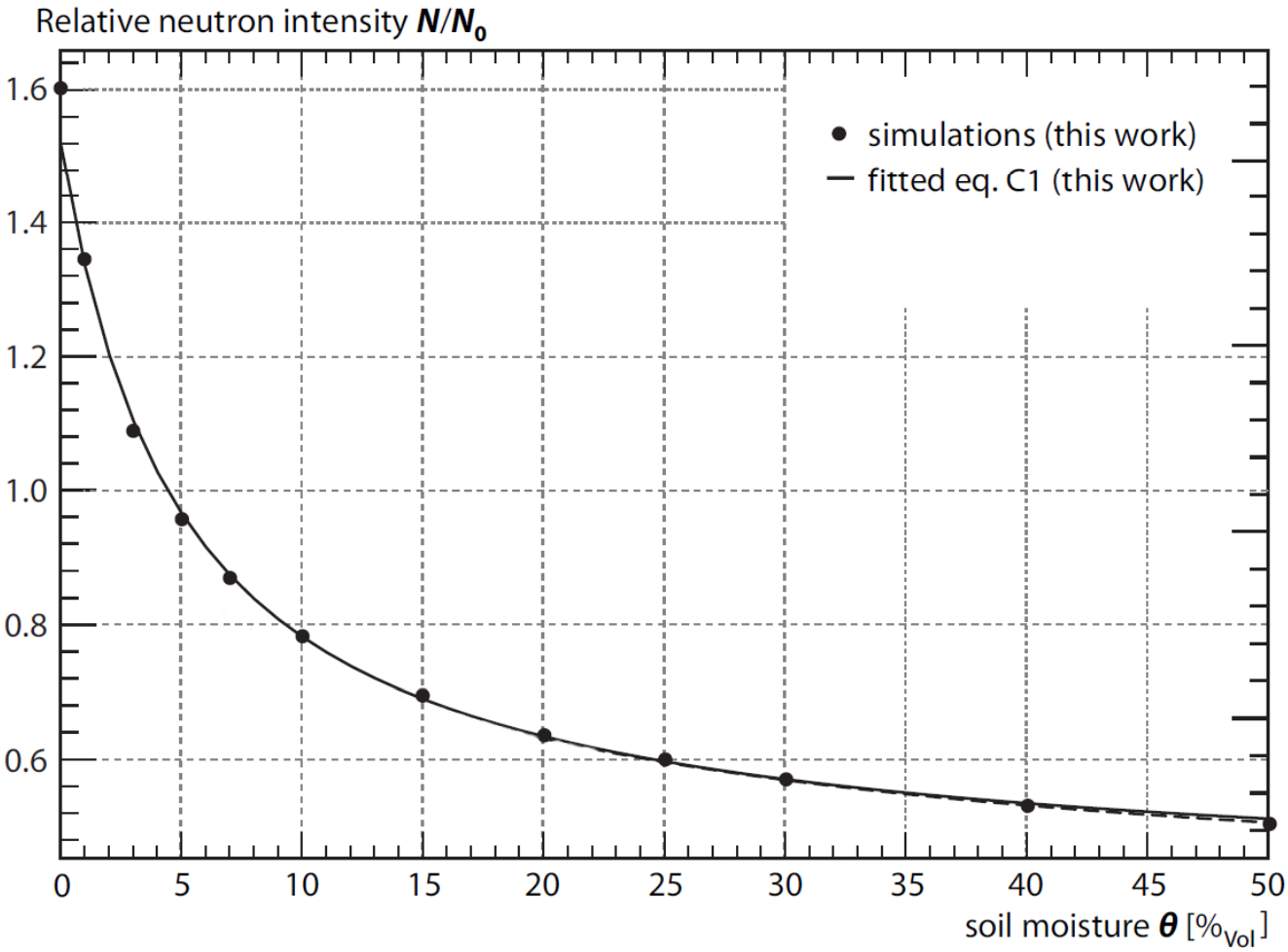
The Cosmic Neutron Spectrum



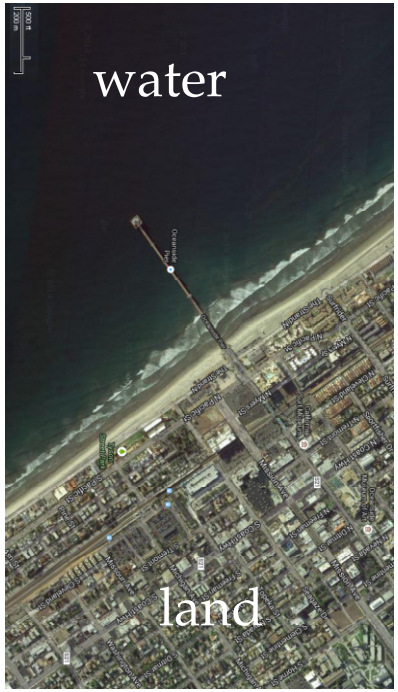
The Cosmic Neutron Spectrum

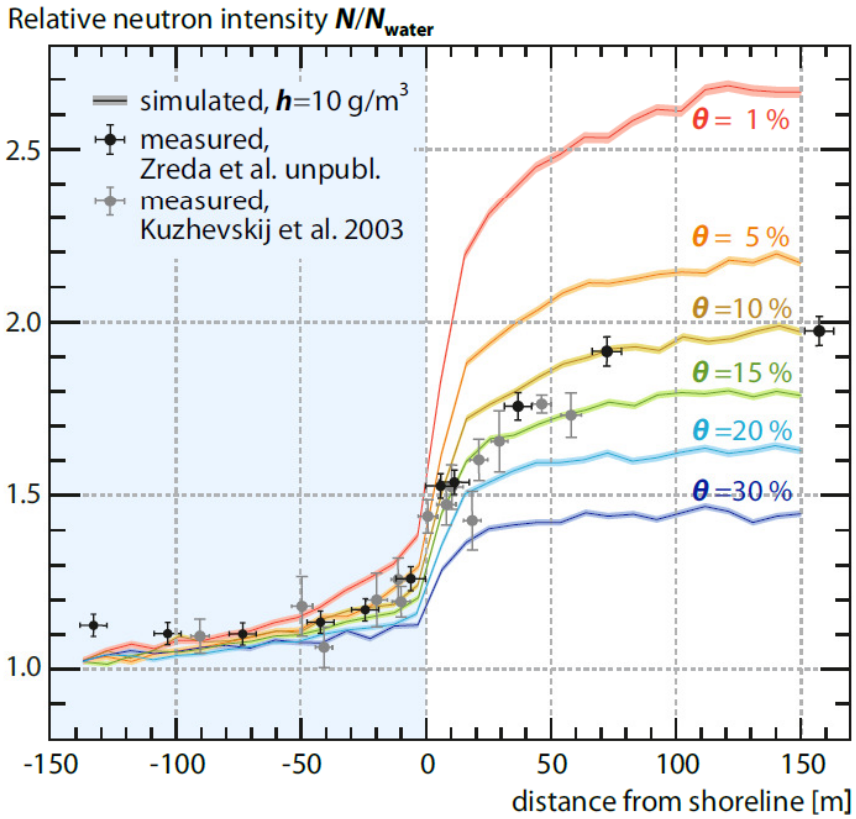


Intensity vs. soil moisture



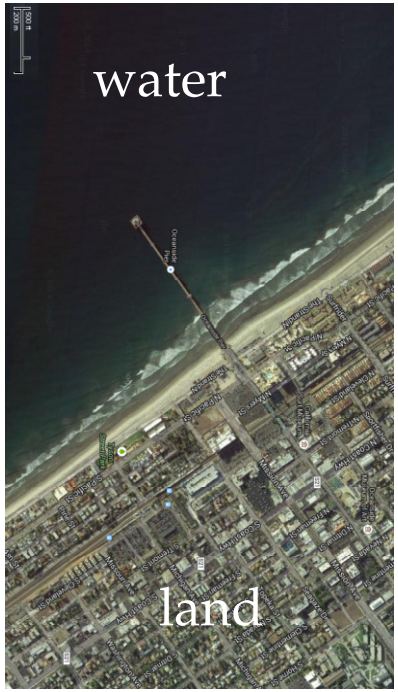
Coastal Transect

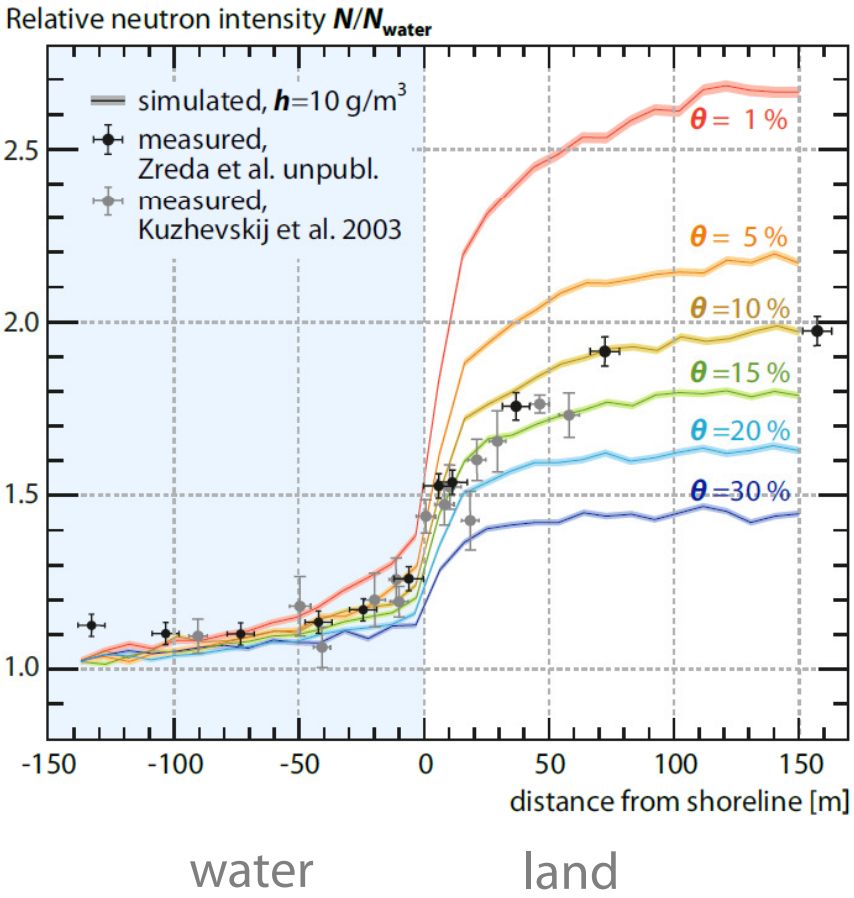


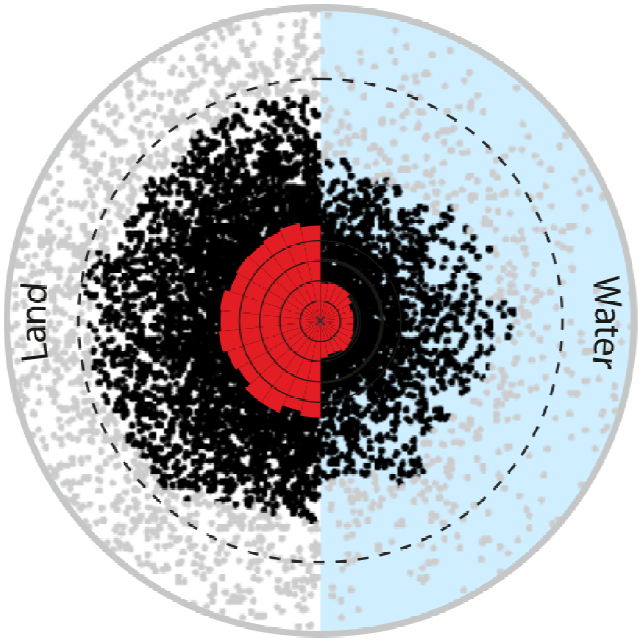


water land

Coastal Transect





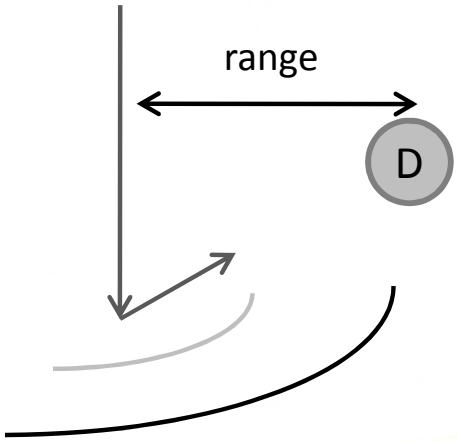


Detected neutron origins (first contact to soil)
Closest 86% of neutron origins for each 12° sector
Neutron intensity for each 12° sector [arb. units]
Footprint R_{86}(5g/m^3, 5 %)=210m for homogeneous soil

The Footprint

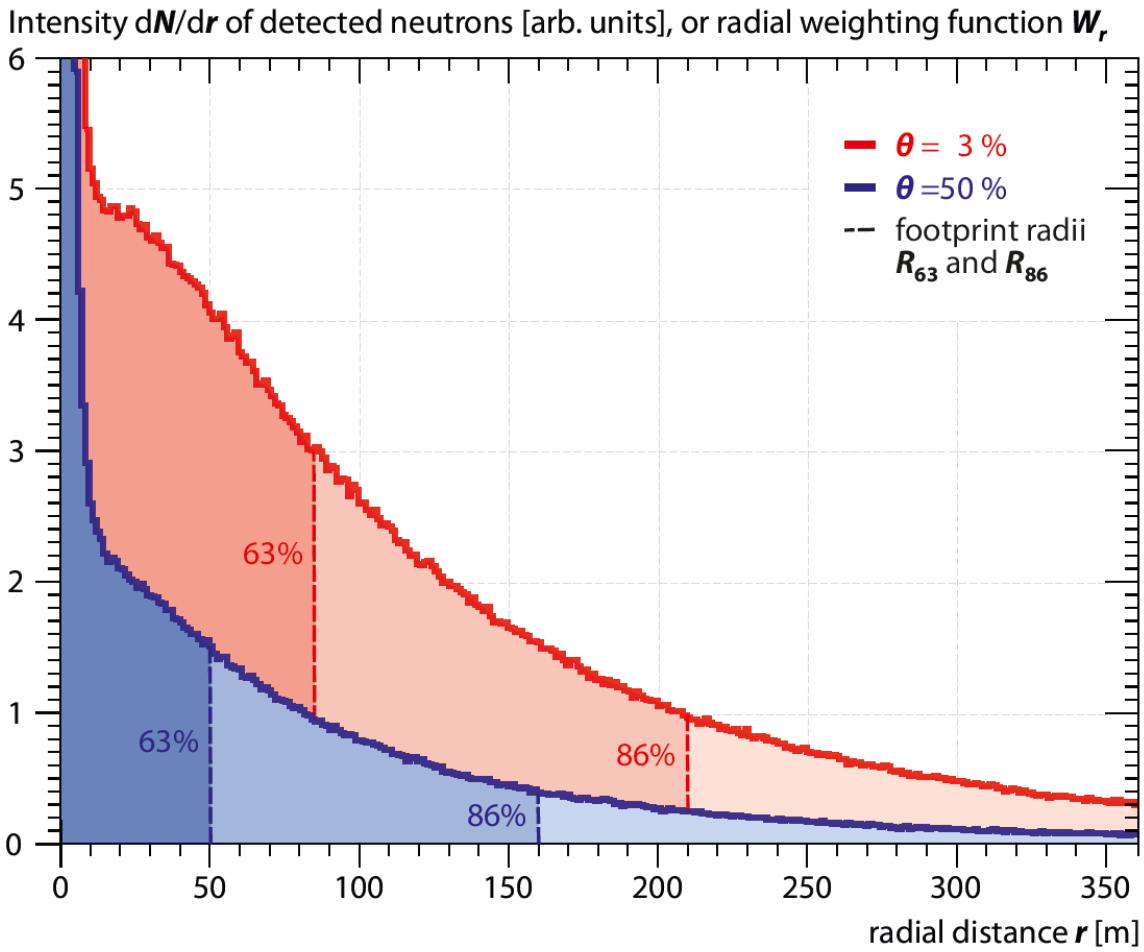
How far do reflected neutrons travel?

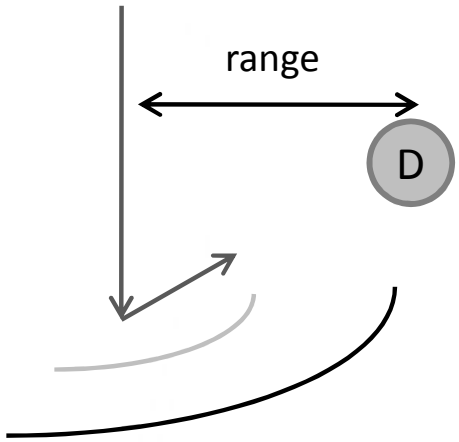
(Movie Removed)



The Footprint

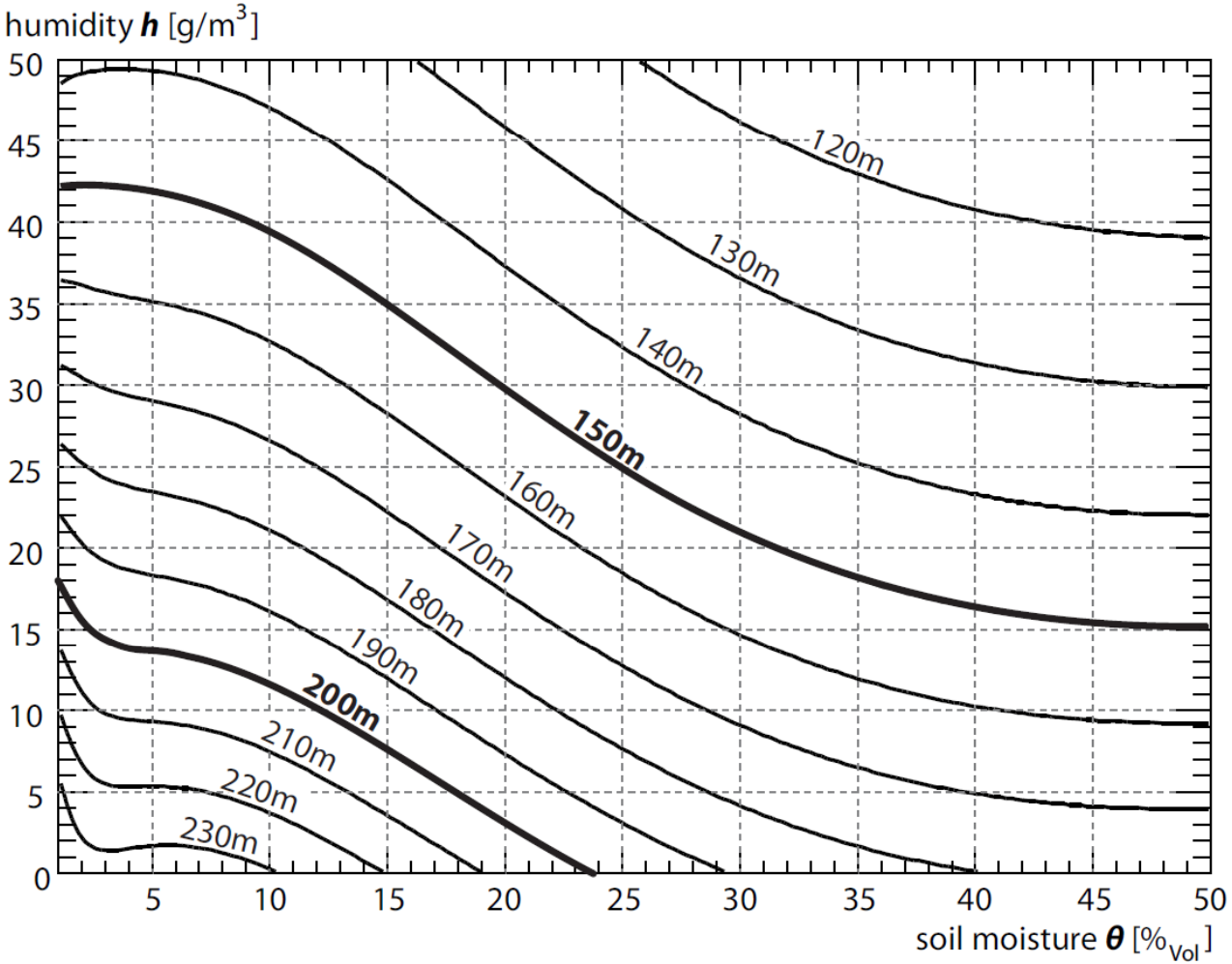
How far do reflected neutrons travel?

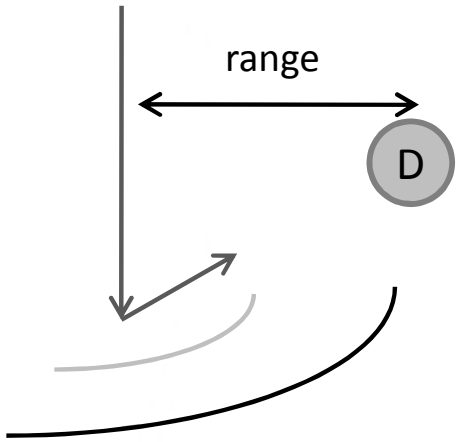




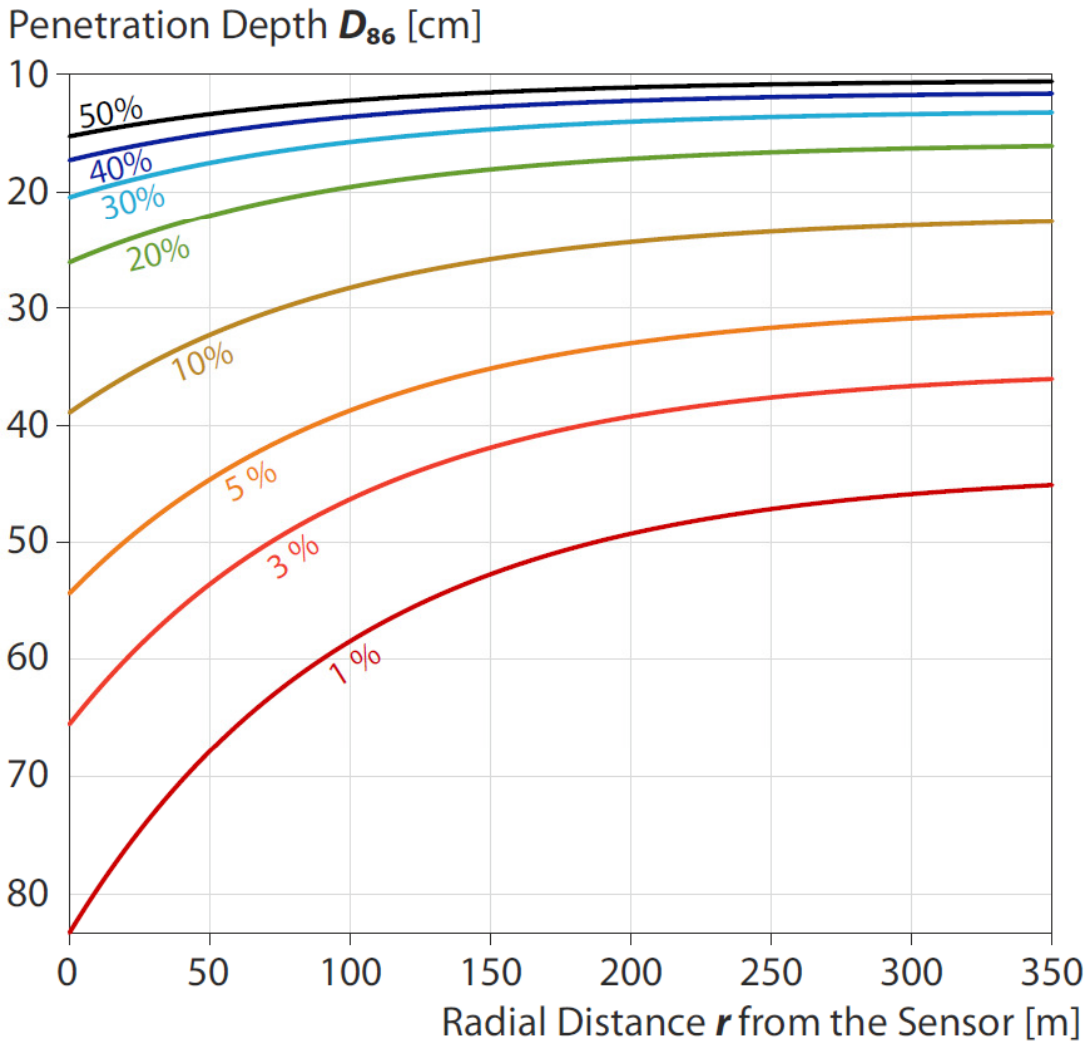
The Footprint

How far do reflected neutrons travel?

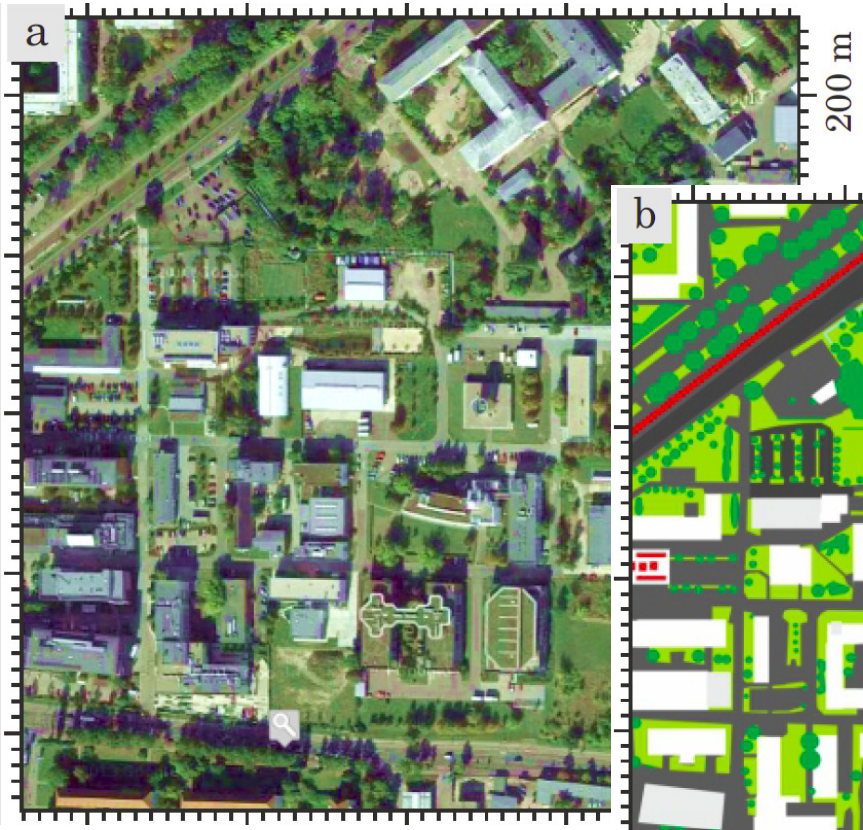




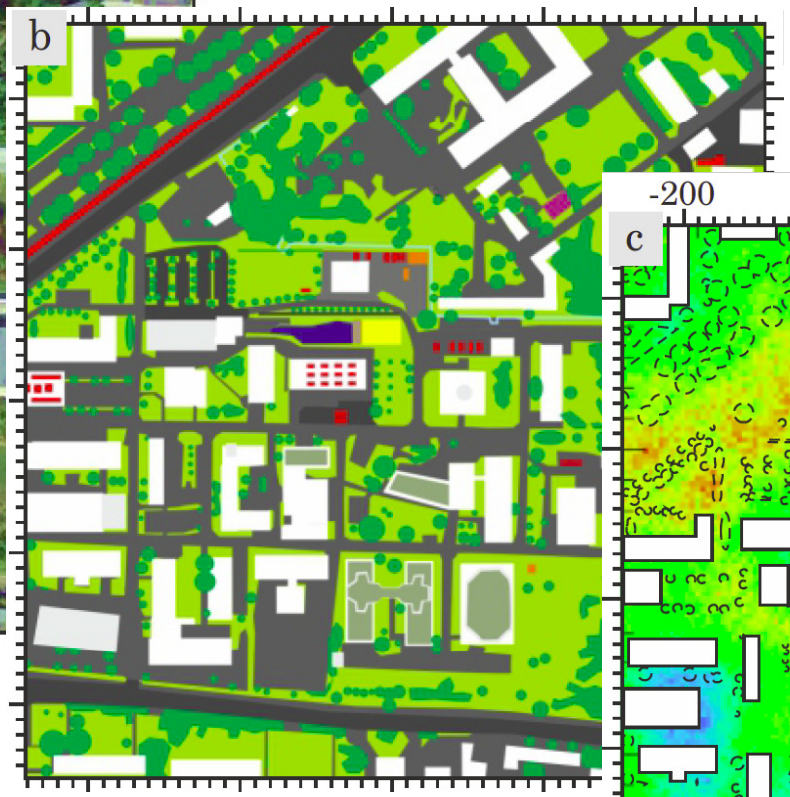
Penetration Depth



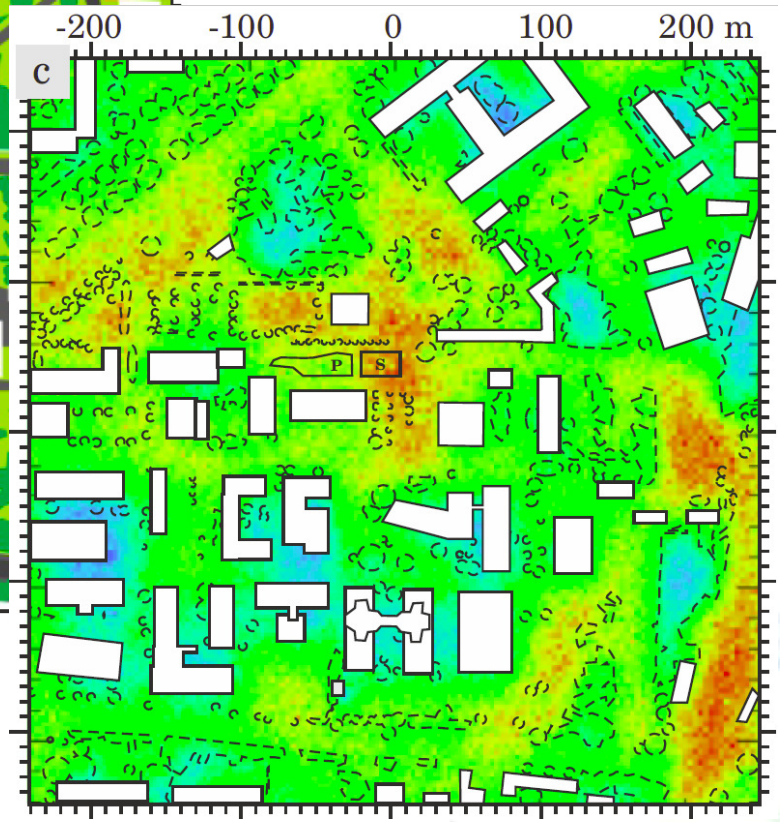
Inhomogeneous Terrain



topography

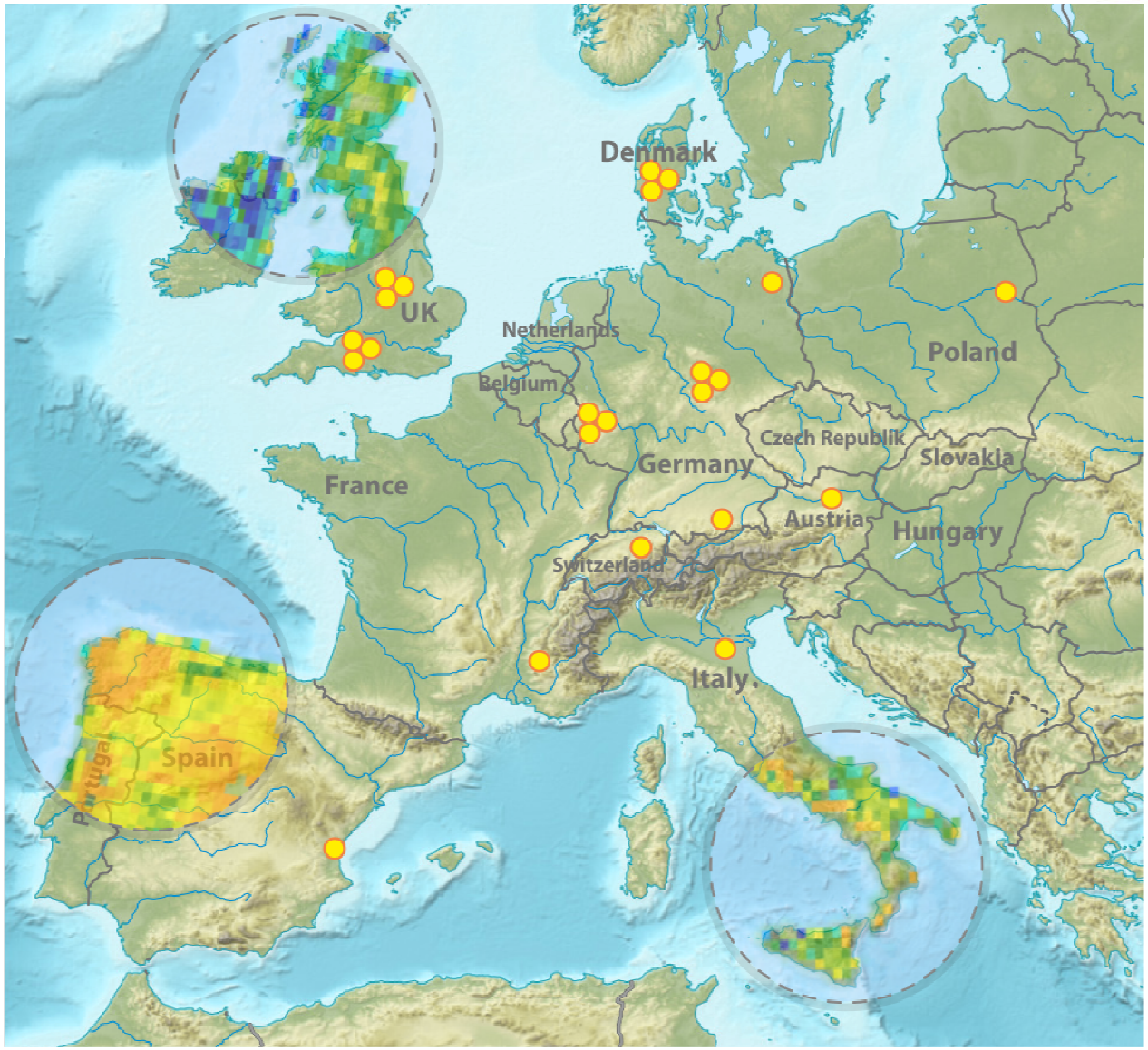


model



simulation

The COSMOS Collaboration

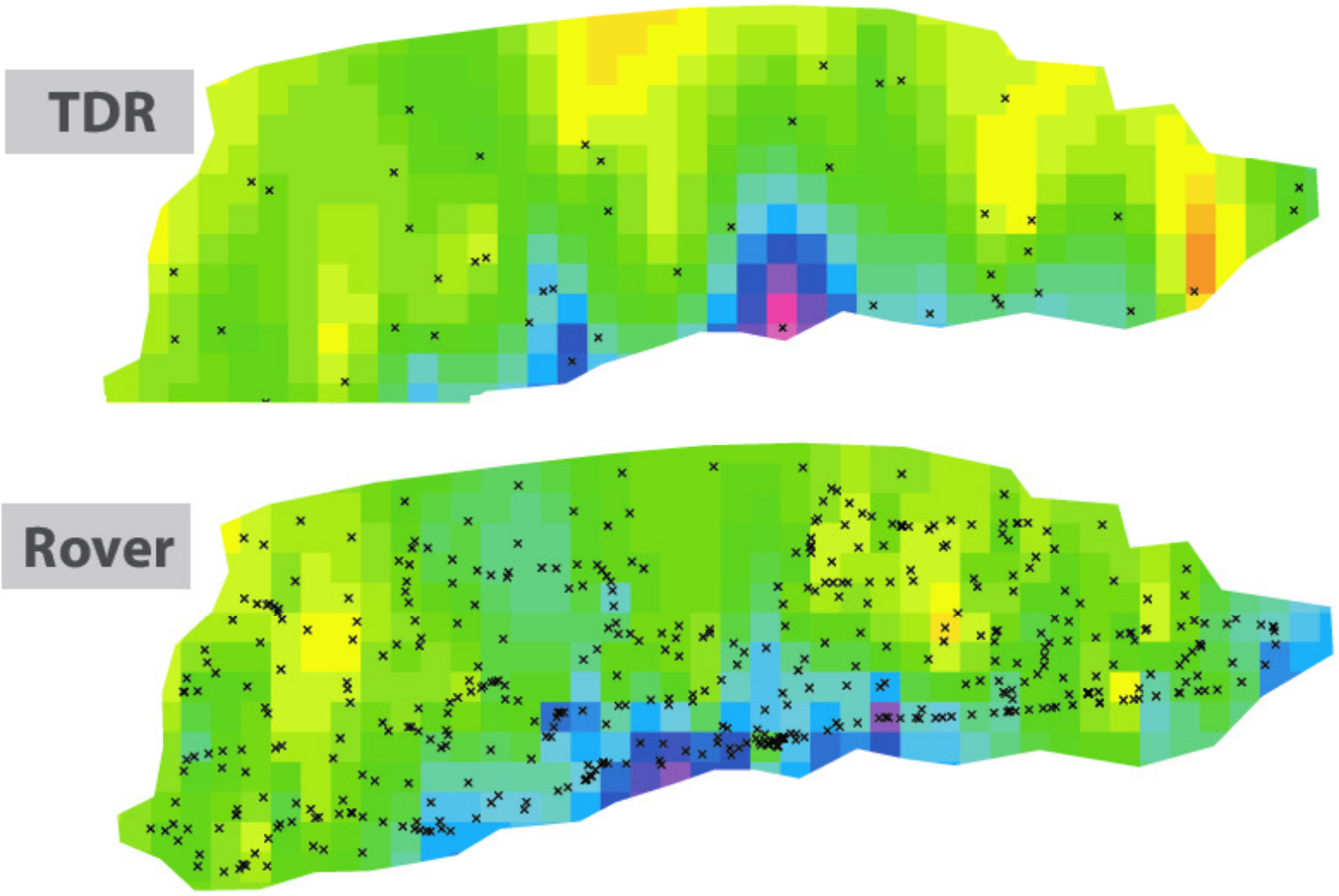


COSMOS probes: existing single, existing clusters, SMOS

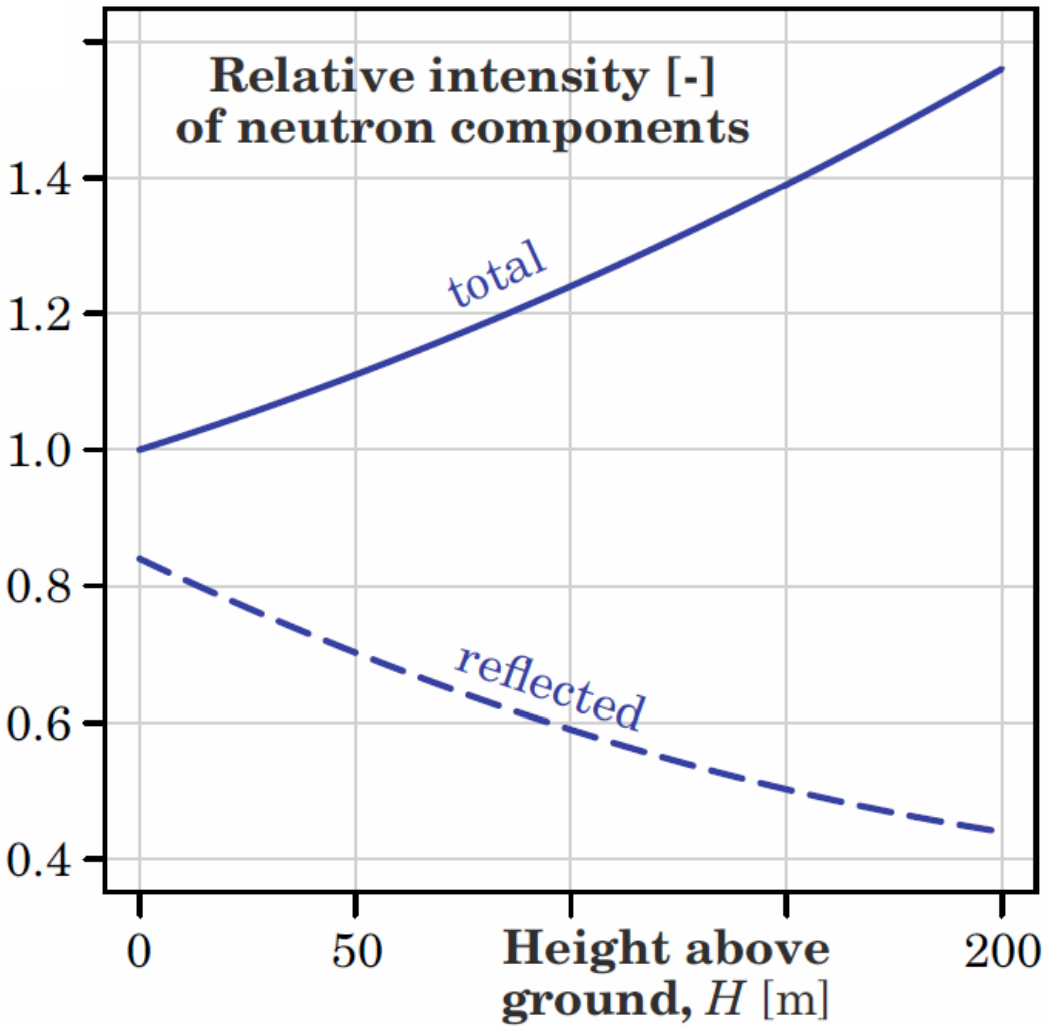
The COSMOS Sensor

The Schäfertal Site

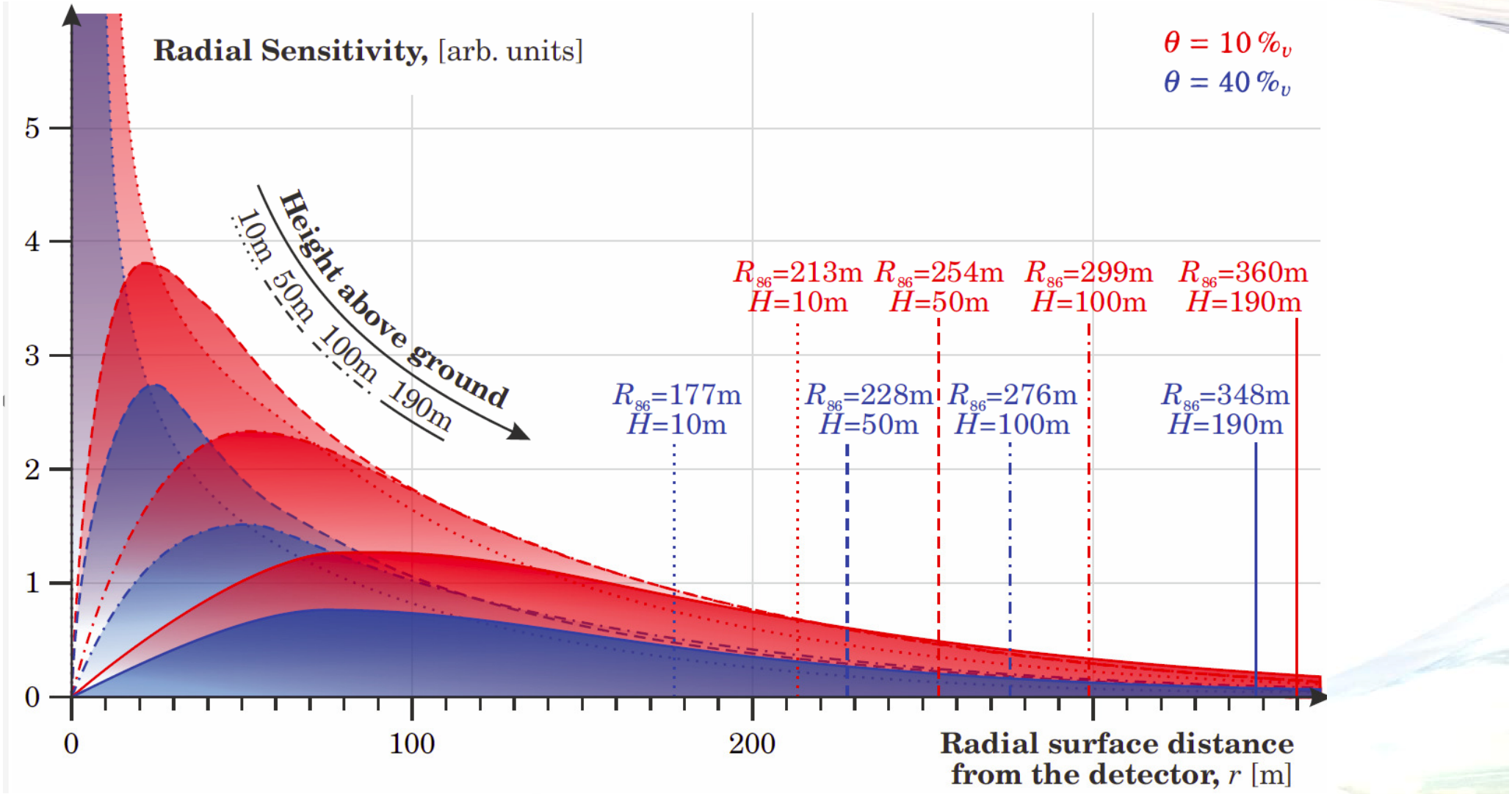
The Schäfertal Site



The Elevated Footprint

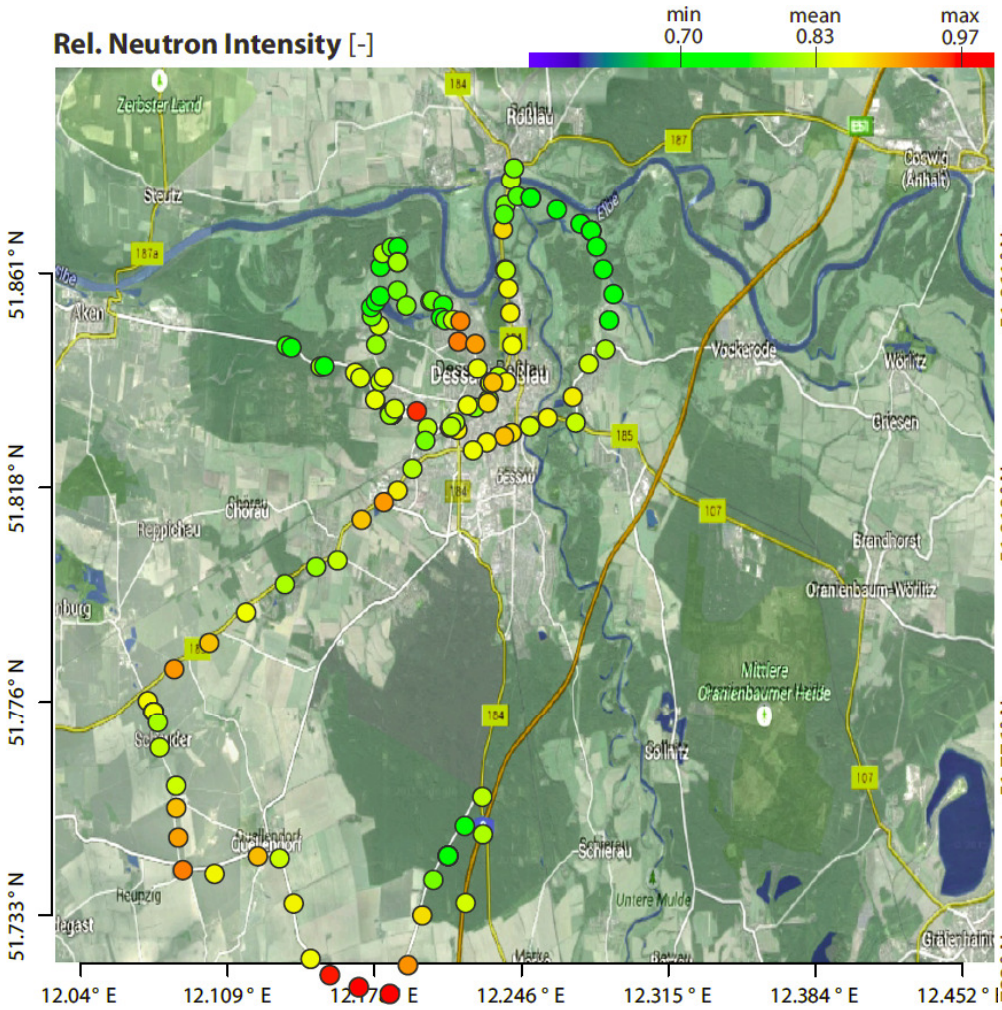


The Elevated Footprint

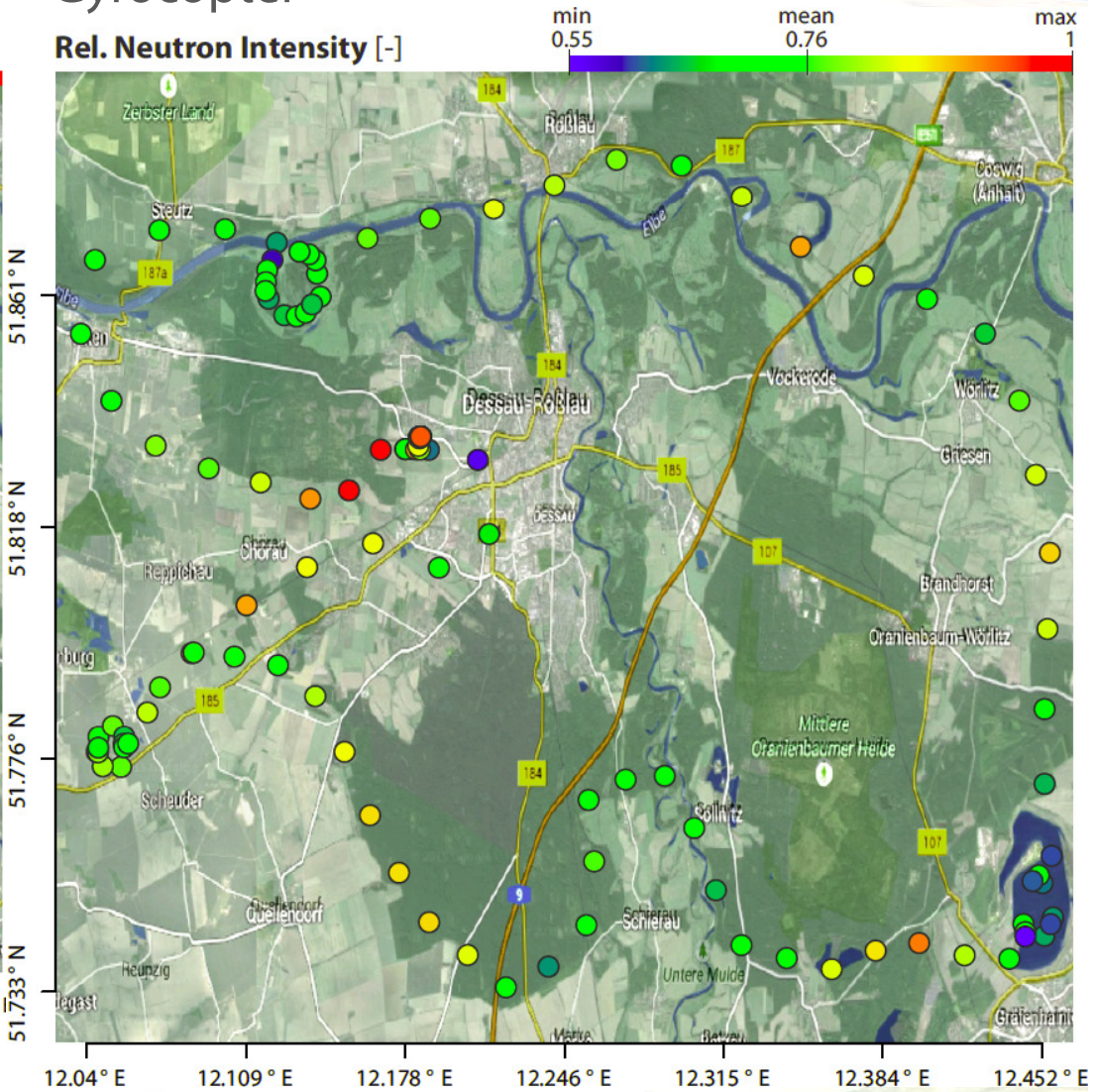


Airborne measurements

Rover



Gyrocopter



Summary

- Cosmic-Ray Neutron Detecion

- Outlook:

Summary

- Cosmic-Ray Neutron Detecion
  - can be understood by Monte-Carlo transport modelling

- Outlook:

Summary

- Cosmic-Ray Neutron Detecion
  - can be understood by Monte-Carlo transport modelling
  - signal depends on various factors containing hydrogen humidity, plants, snow…

- Outlook:

Summary

Cosmic-Ray Neutron Detecion

- can be understood by Monte-Carlo transport modelling
- signal depends on various factors containing hydrogen humidity, plants, snow…
- provides an average soil moisture measurement over **several hectares** and **0.5 m in depth** stationary and mobile

Outlook:

Summary

- Cosmic-Ray Neutron Detecion
  - can be understood by Monte-Carlo transport modelling
  - signal depends on various factors containing hydrogen humidity, plants, snow…
  - provides an average soil moisture measurement over **several hectares** and **0.5 m in depth** stationary and mobile
- Outlook: Development of airborne technologies

Summary

Cosmic-Ray Neutron Detecion

- can be understood by Monte-Carlo transport modelling
- signal depends on various factors containing hydrogen humidity, plants, snow…
- provides an average soil moisture measurement over **several hectares** and **0.5 m in depth** stationary and mobile

Outlook: Development of airborne technologies

to be continued
EGU Vienna M. Schrön

HS2.3.3

Backup Slides

The COSMOS Collaboration

M. Zreda et al. (2008)

$$W_r(h,\theta) \approx \begin{cases} F_1\, e^{-F_2 r} + F_3\, e^{-F_4 r}\,, & r \leq 50\,\mathrm{m} \\ F_5\, e^{-F_6 r} + F_7\, e^{-F_8 r}\,, & r > 50\,\mathrm{m} \end{cases}$$

$$\begin{aligned}
F_1 &= p_0\,(1+p_3 h)\exp\left(-p_1\theta\right) + p_2\,(1+p_5 h) + p_4\theta, \\
F_2 &= \left((1+p_4 h)\exp\left(-\frac{p_1\theta}{1+p_6\theta}\right) + p_2\right)(1+p_3 h)\,, \\
F_3 &= p_0\exp\left(-p_1\theta\right) + p_2 + p_4\theta + +p_5 h, \\
F_4 &= p_0\,(1+p_3 h)\exp\left(-p_1\theta\right) + p_2 + p_4\theta \\
F_5 &= p_0\left(0.02 + \frac{1}{p_5(p_5+p_6\theta+h)}\right) \\
&\quad \cdot(\theta - p_4)\exp(-p_1(\theta-p_4)) + p_2\,(0.7 + h\theta p_3)\,, \\
F_6 &= p_0(h-p_1) + p_2\theta, \\
F_7 &= \left((p_0+p_4 h)\exp\left(-p_1\frac{\theta}{1+p_5 h+p_6\theta}\right) + p_2\right) \\
&\quad \cdot(2+hp_3), \\
F_8 &= \left(p_0\,(1+p_6 h)\exp\left(-p_1\theta\left(1+p_4\frac{h}{\theta}\right)\right) + p_2 + p_5\theta\right) \\
&\quad \cdot\,(2+p_3 h)\,.
\end{aligned}$$

F_1	$p_0 = 8735$	± 30
	$p_1 = 17.1758$	± 0.0873
	$p_2 = 11720$	± 21
	$p_3 = 0.00978$	± 0.00014
	$p_4 = -7045$	± 56
	$p_5 = 0.003632$	± 0.000026
F_2	$p_0 = -2.79257 \cdot 10^{-5}$	$\pm 1.52 \cdot 10^{-8}$
	$p_1 = 5.0399$	± 0.0134
	$p_2 = 2.85445 \cdot 10^{-5}$	$\pm 1.27 \cdot 10^{-8}$
	$p_3 = 0.002455$	$\pm 6 \cdot 10^{-5}$
	$p_4 = 6.8517 \cdot 10^{-8}$	$\pm 5.5 \cdot 10^{-10}$
	$p_6 = 9.2927$	± 0.0382
F_3	$p_0 = 5.4818 \cdot 10^{-5}$	$\pm 9 \cdot 10^{-7}$
	$p_1 = 15.921$	± 0.421
	$p_2 = 0.0006373$	$\pm 3.155 \cdot 10^{-7}$
	$p_4 = -5.99 \cdot 10^{-5}$	$\pm 1.3 \cdot 10^{-6}$
	$p_5 = 5.425 \cdot 10^{-7}$	$\pm 1.28 \cdot 10^{-8}$
F_4	$p_0 = 247970$	± 1695
	$p_1 = 17.63$	± 0.21
	$p_2 = 374655$	± 1098
	$p_3 = 0.00191$	± 0.00022
	$p_4 = -195725$	± 2840
F_5	$p_0 = -1383701$	± 143180
	$p_1 = 4.155$	± 0.574
	$p_2 = 5324$	± 543
	$p_3 = -0.00238$	± 0.00105
	$p_4 = 0.0156$	± 0.0014
	$p_5 = -0.130$	± 0.026
	$p_6 = 1520$	± 289
F_6	$p_0 = -1.543 \cdot 10^{-5}$	$\pm 1.6 \cdot 10^{-6}$
	$p_1 = 10.06$	± 0.94
	$p_2 = 1.807 \cdot 10^{-5}$	$\pm 1.6 \cdot 10^{-6}$
	$p_3 = 0.0011$	± 0.0007
	$p_4 = 8.81 \cdot 10^{-8}$	$\pm 3.9 \cdot 10^{-9}$
	$p_5 = 0.0405$	± 0.0049
	$p_6 = 20.24$	± 1.57
F_7	$p_0 = 6.031 \cdot 10^{-8}$	$\pm 4.37 \cdot 10^{-10}$
	$p_1 = -98.5$	± 0.93
	$p_2 = 1.0466 \cdot 10^{-6}$	$\pm 7.1 \cdot 10^{-8}$
F_6	$p_0 = 11747$	± 208
	$p_1 = 41.66$	± 1.7
	$p_2 = 4521$	± 49
	$p_3 = 0.01998$	± 0.00055
	$p_4 = -0.00604$	± 0.00034
	$p_5 = -2534$	± 127
	$p_6 = -0.00475$	± 0.00026