Coordinated Cosmic-Ray Observation System Conference
Lincoln, USA
15.10.2024

Pathways to CRNS: evolving detectors and neutron modeling

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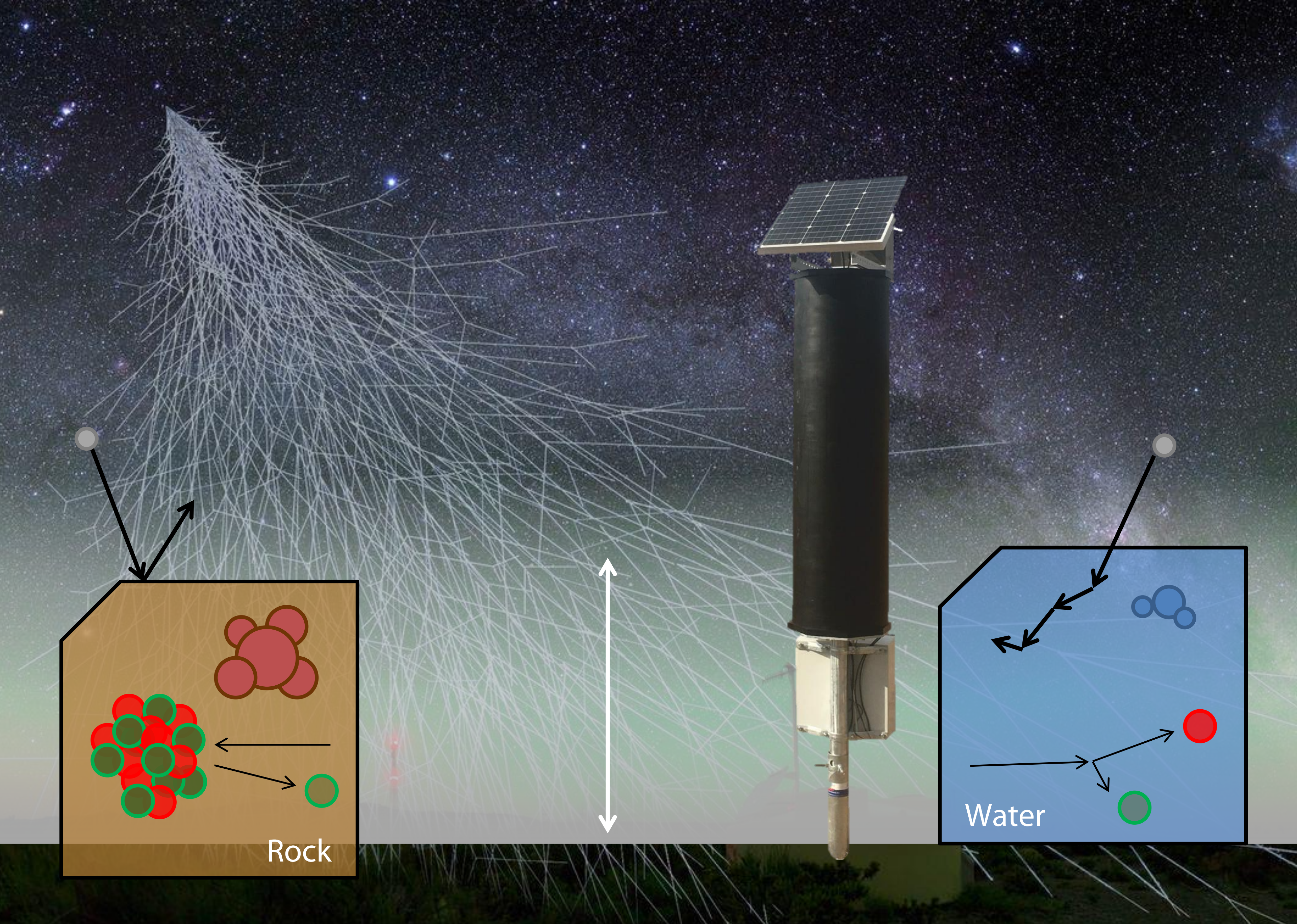
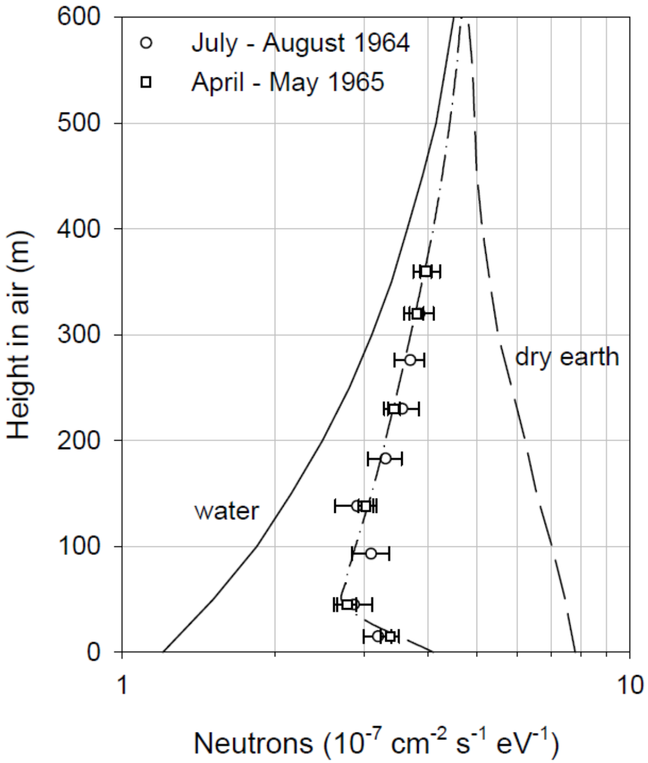
[2] StyX Neutronica GmbH, Mannheim, Germany

Physikalisches Institut
Heidelberg University
Germany



[1] Image by A. Chantelauze, S. Staffi, and L. Bret, https://www.theverge.com/2017/9/21/16335164/pierre-auger-observatory-cosmic-ray-galaxies-air-shower-particles

The History Channel



[1]

1966

[1] Hendrick, L. D. and Edge, R. D., "Cosmic-ray neutrons near the Earth", Phys. Rev. Ser. II, 145 (1966)
[2] Kodama, M. et al., "Application of atmospheric neutrons to soil moisture measurement", Soil Sci., 140 (1985)

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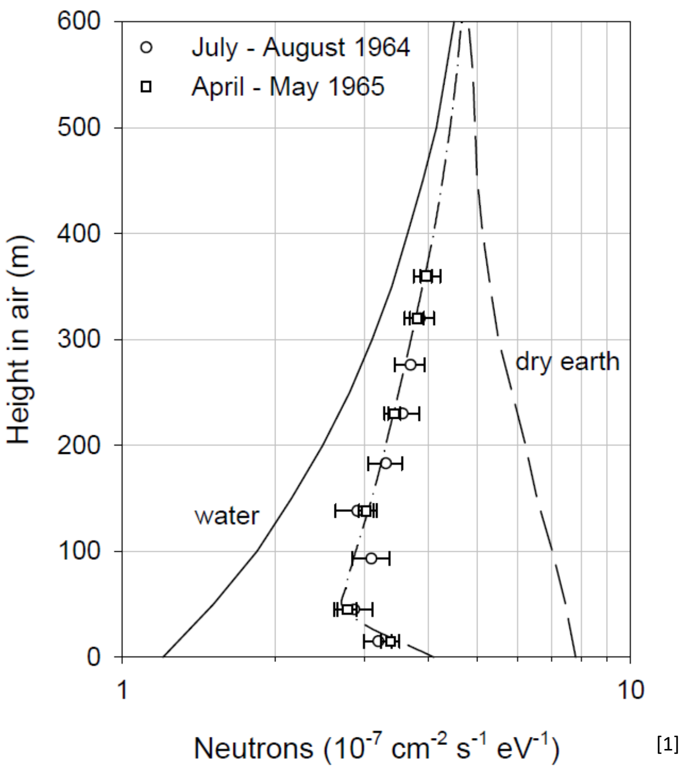

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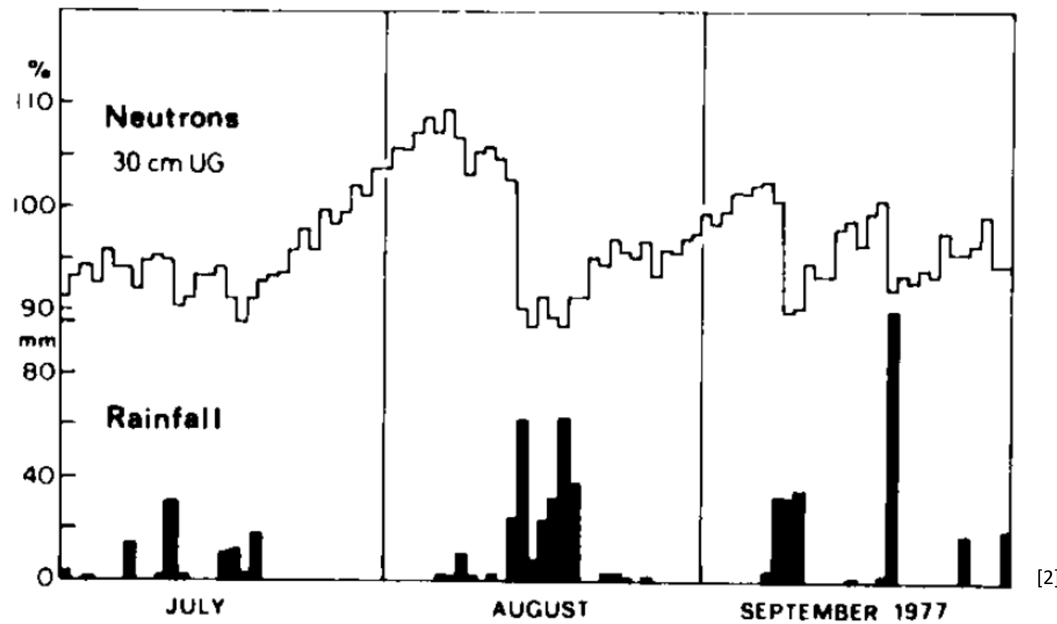

[2]

1966

1985

[1] Hendrick, L. D. and Edge, R. D., “Cosmic-ray neutrons near the Earth”, Phys. Rev. Ser. II, 145 (1966)
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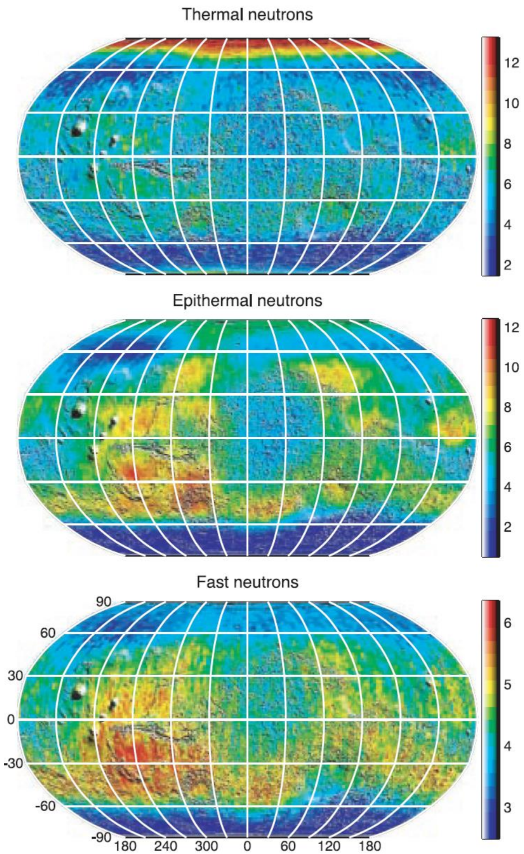
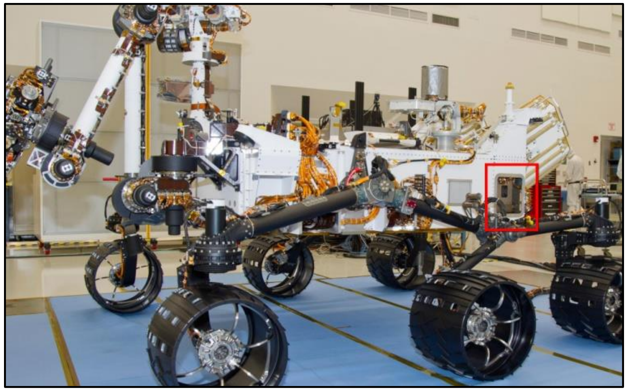


[1]

Curiosity Rover



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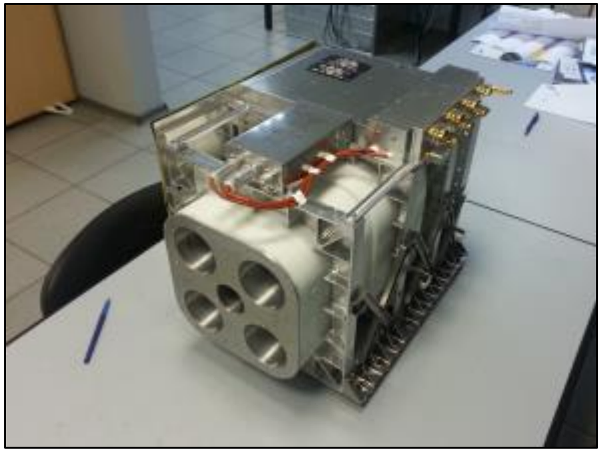
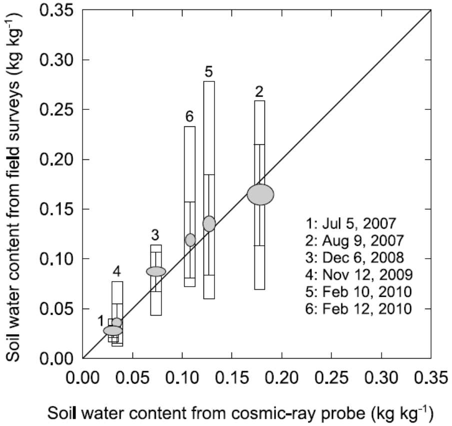


Trace Gas Orbiter

1966 | 1985 | 2000

[1] W.C. Feldman, et. al „Global Distribution of Neutrons from Mars: Results from Mars Odyssey“, Science 297 (5578) (2002), 75-78.
[2] http://exploration.esa.int/mars/48523-trace-gas-orbiter-instruments/?fbodylongid=2217

The History Channel

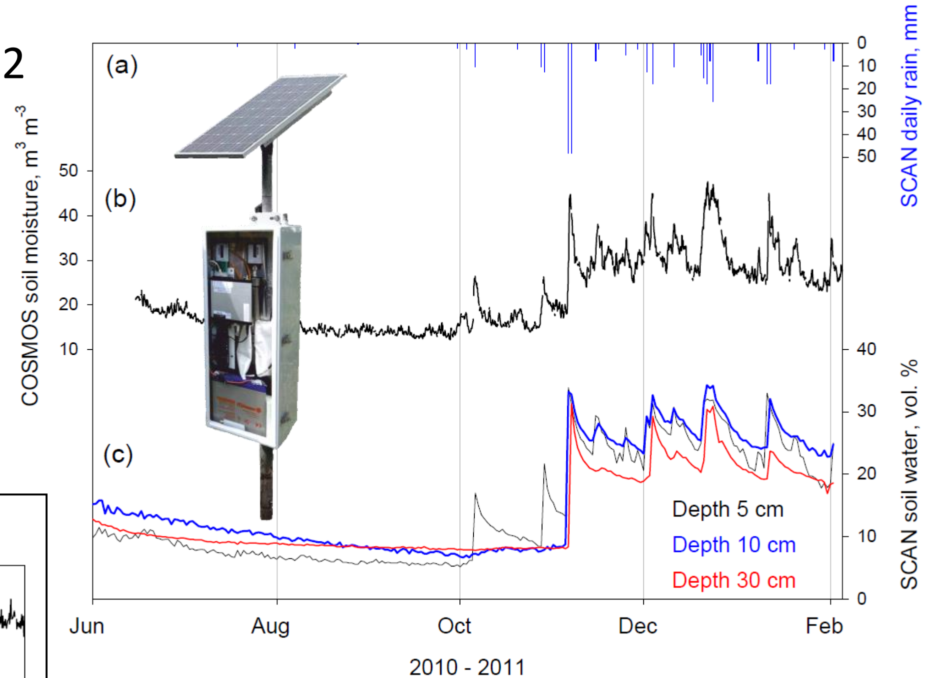


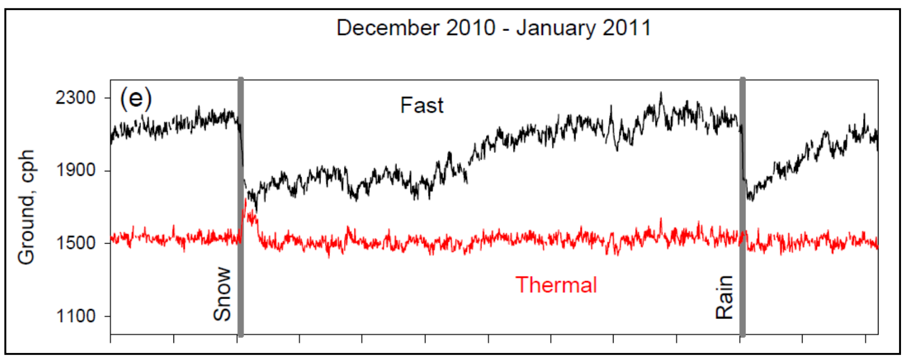
2010

[1]

2012

[2]





[1]

1966 | 1985 | 2000 | 2010

[1] Zreda, M. et al., “COSMOS: The COsmic-ray Soil Moisture Observing System.” Hydrology and Earth System Sciences 16(11) (2012)
[2] Desilets, D. et al.,“Nature’s neutron probe: Land surface hydrology at an elusive scale with cosmic rays.”, Water Resources Research 46(11) (2010)

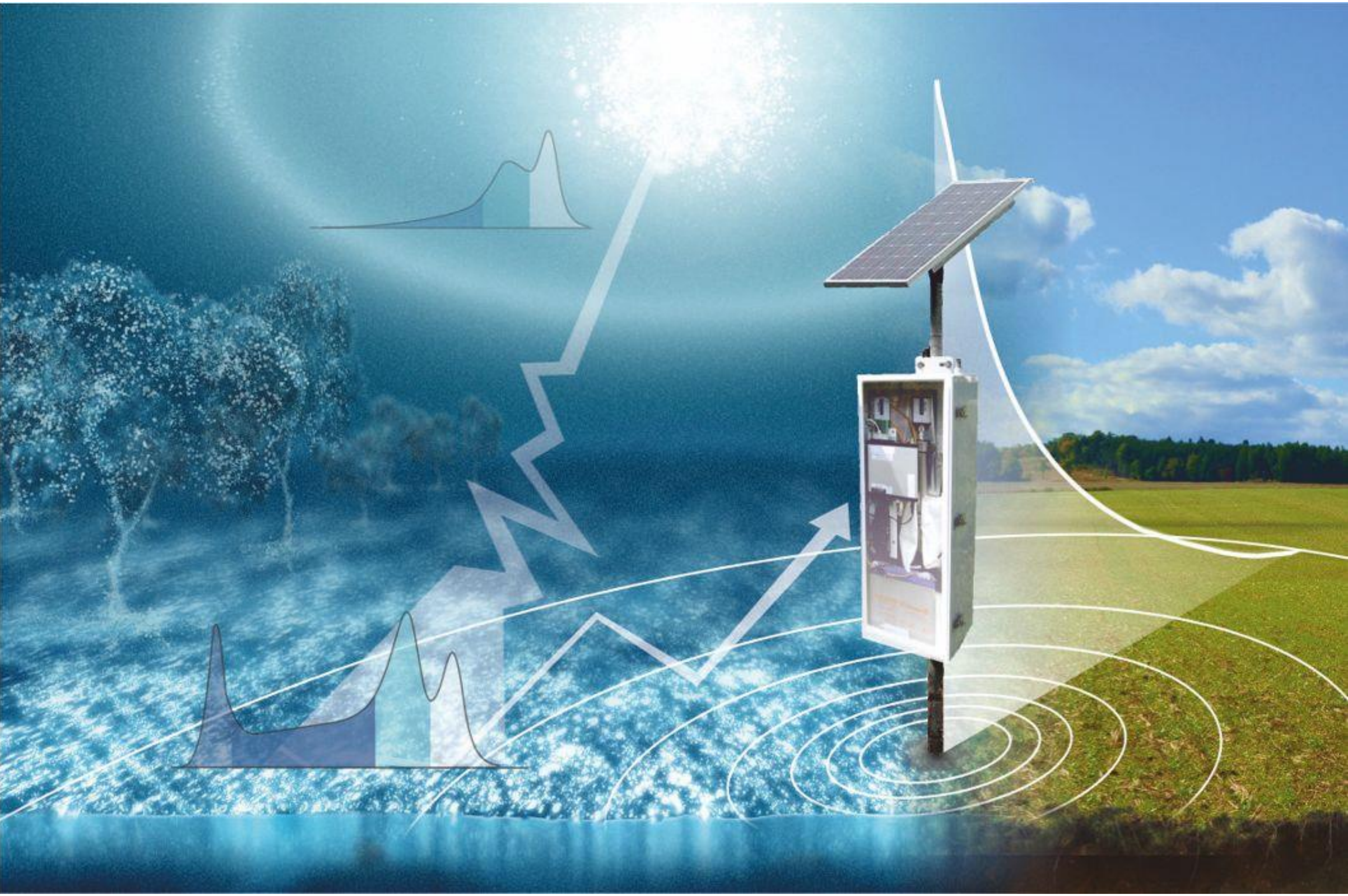
Stationary Instruments

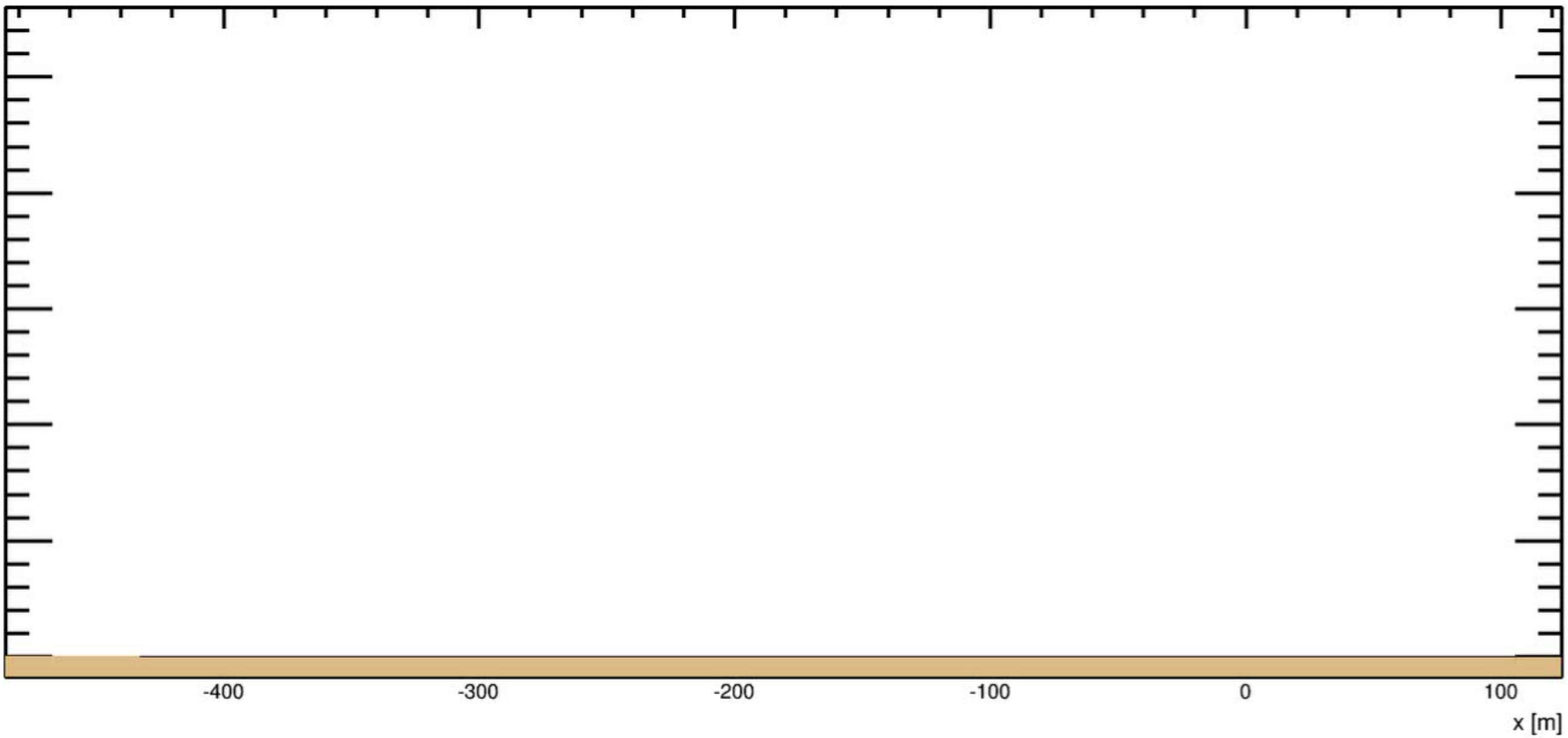
StyX Neutronica SP

Hydroinnova CRS1000

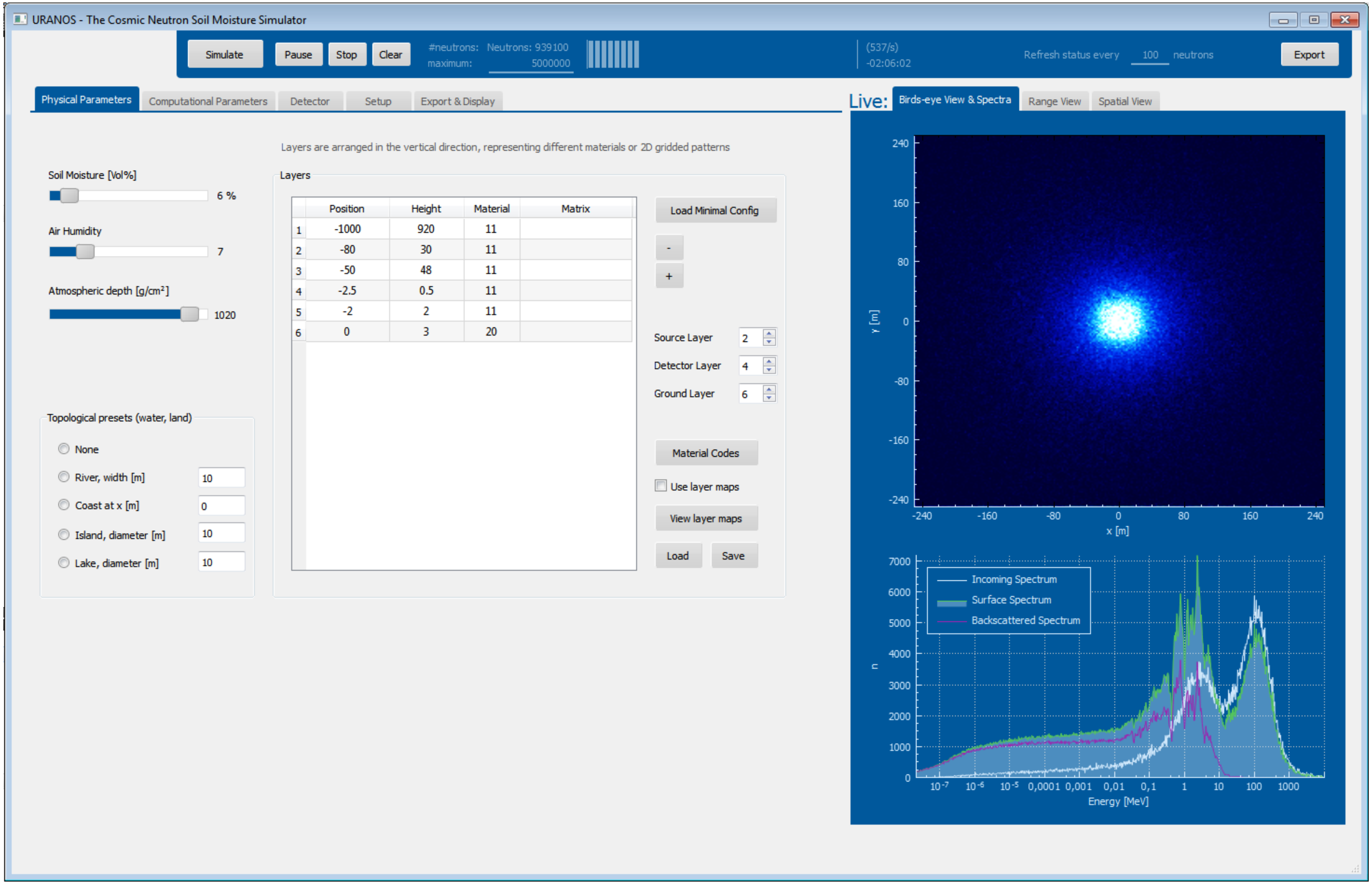
Finapp 3

StyX Neutronica S1



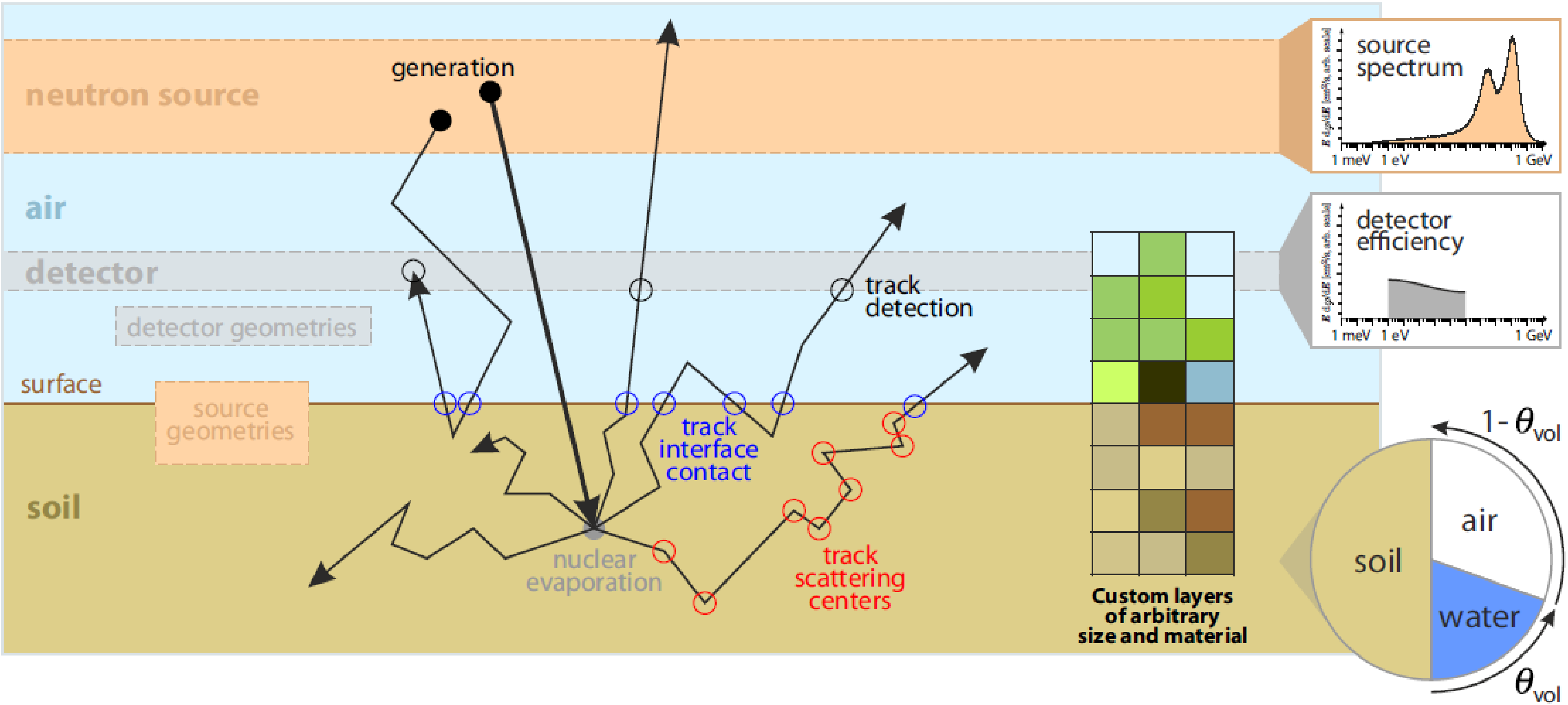

-400
-300
-200
-100
0
100
x [m]

In collaboration with Martin Schrön, UFZ Leipzig



URANOS Buildup

In collaboration with Martin Schrön, UFZ Leipzig



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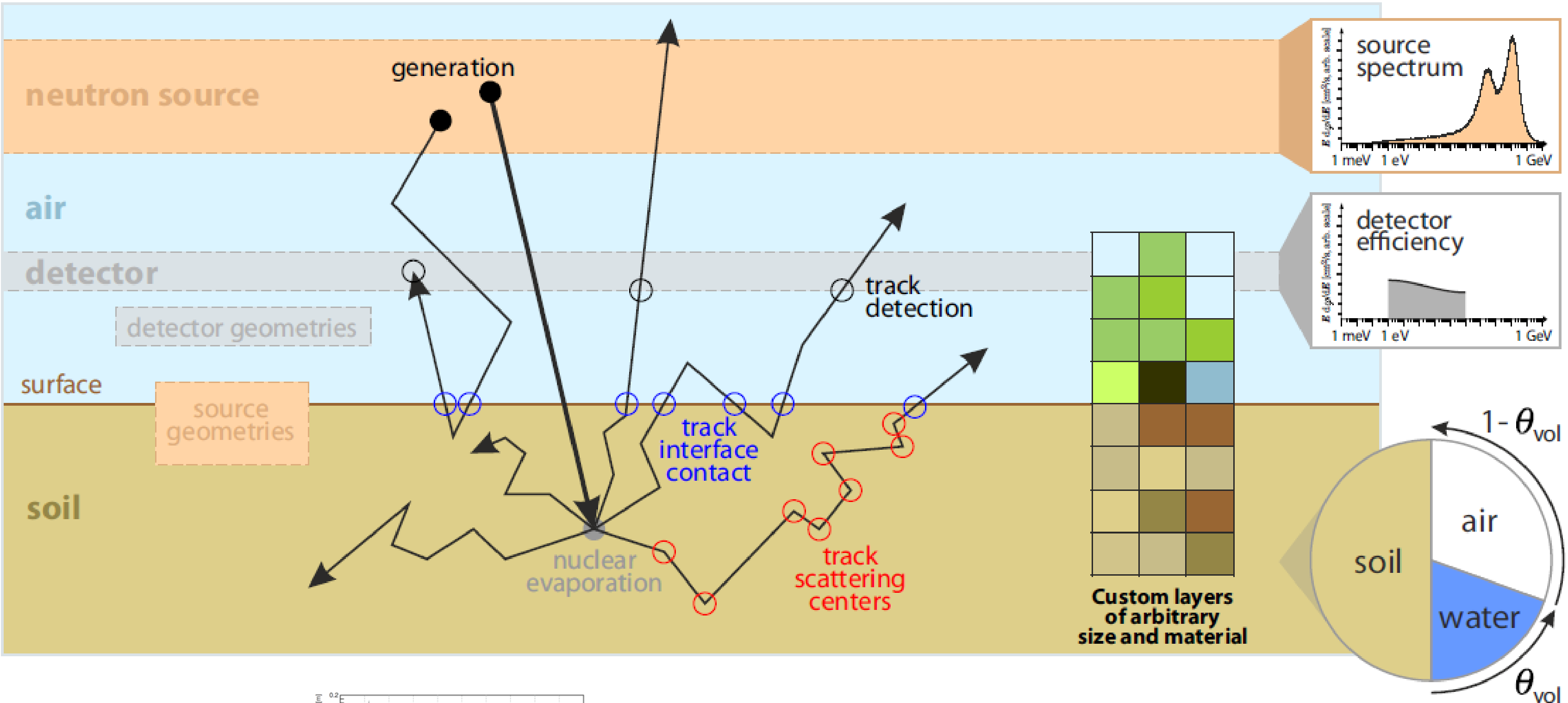
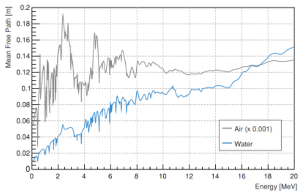


- written in C++



- linked against ENDF data bases

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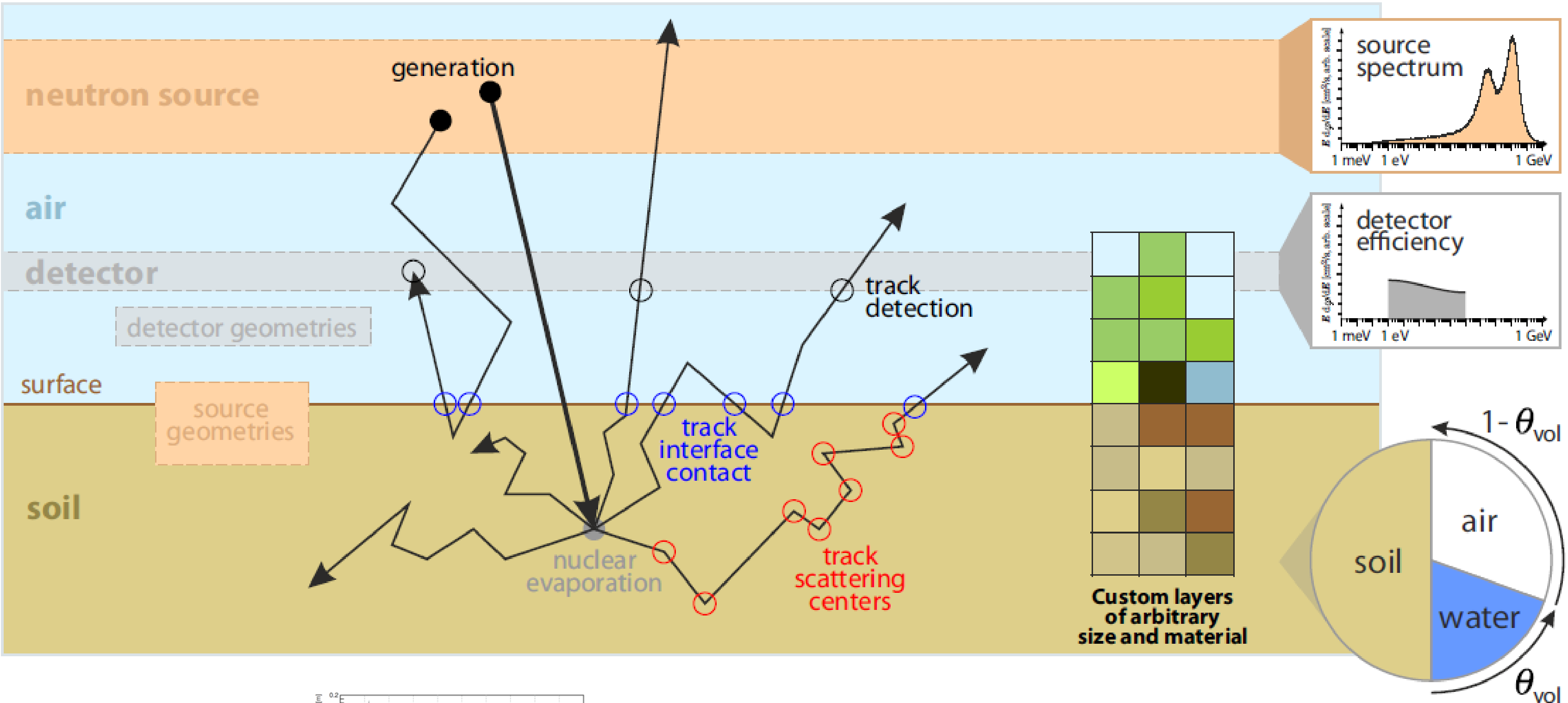

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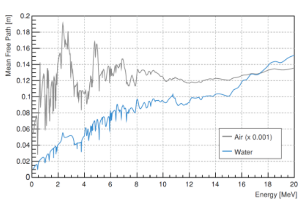
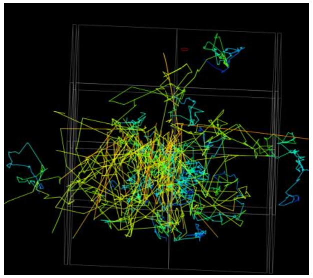


- linked against ENDF data bases

- Ray-Casting



URANOS Buildup

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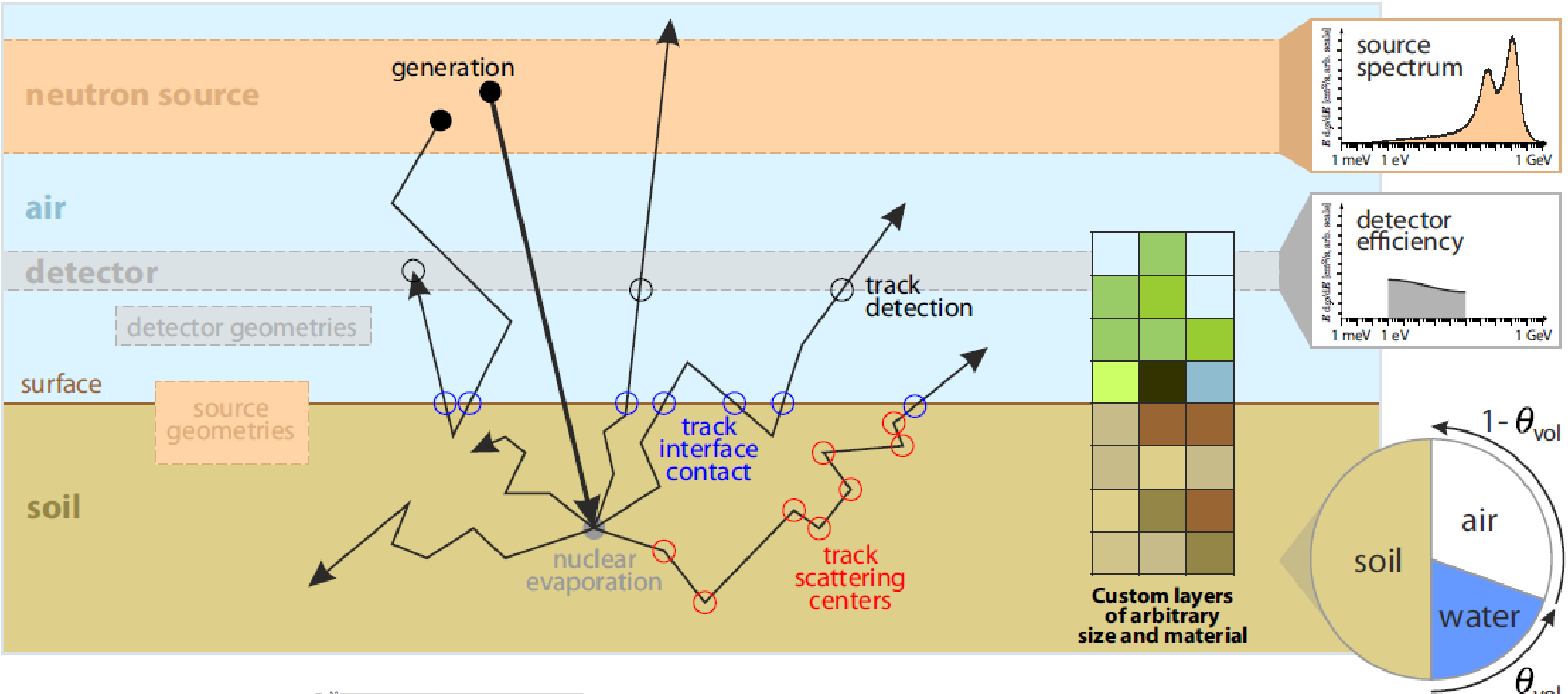
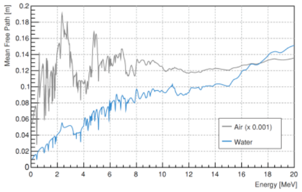
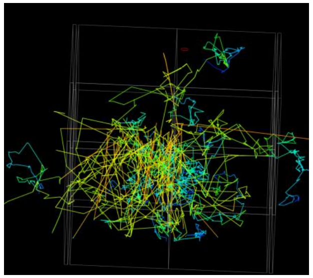


- written in C++

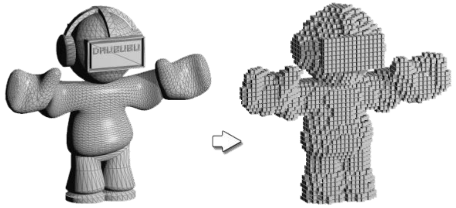


- linked against ENDF data bases

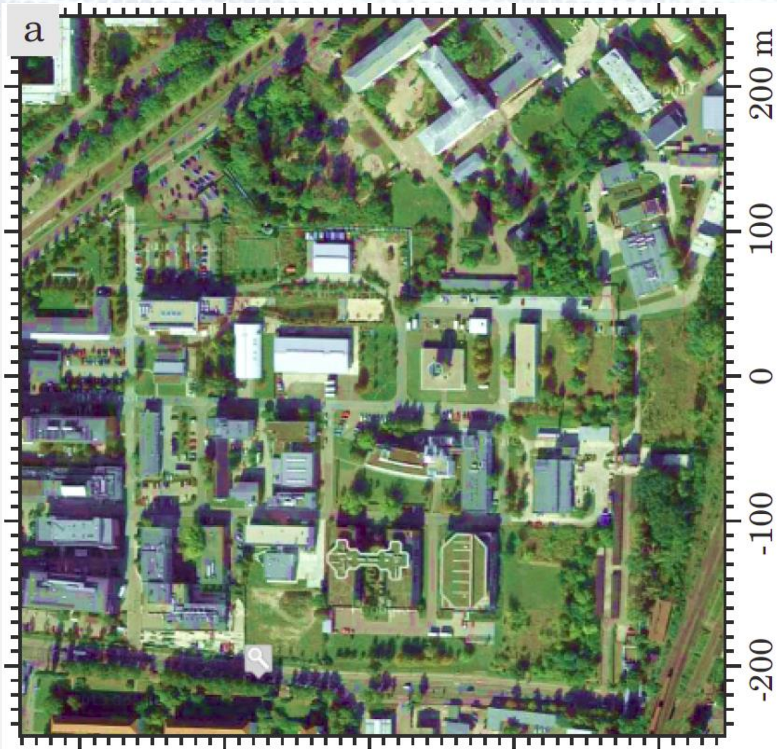
- Ray-Casting



- Voxel Engine

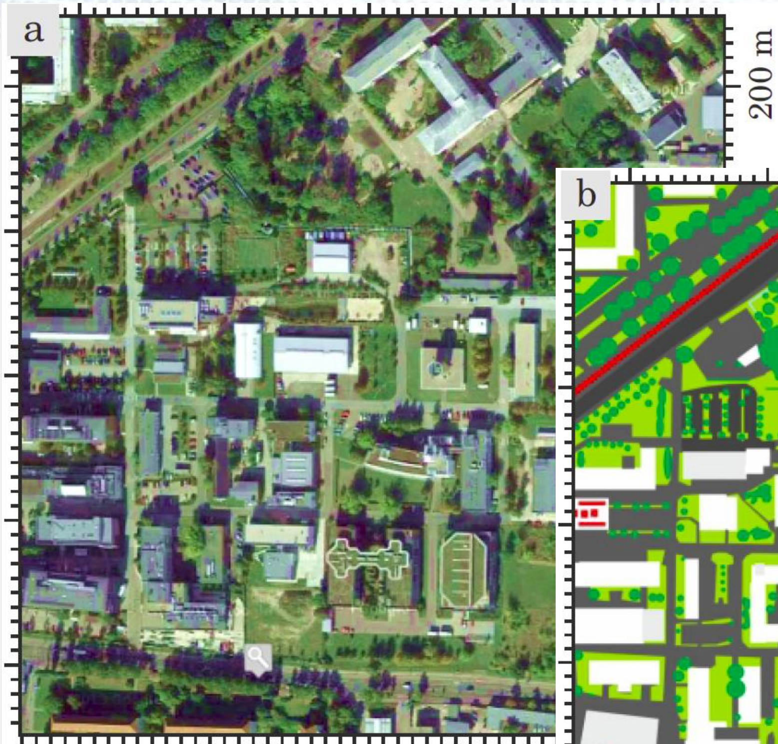


URANOS Modeling

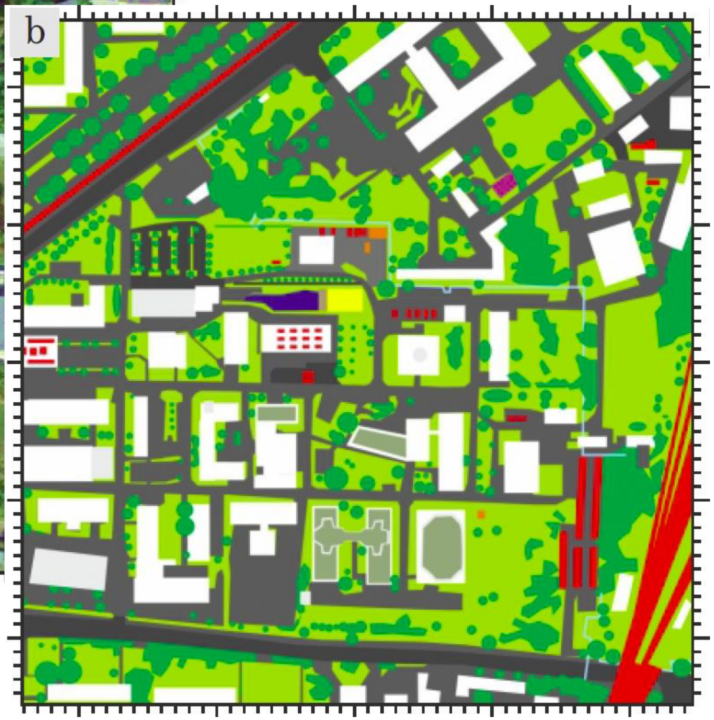


topography

URANOS Modeling

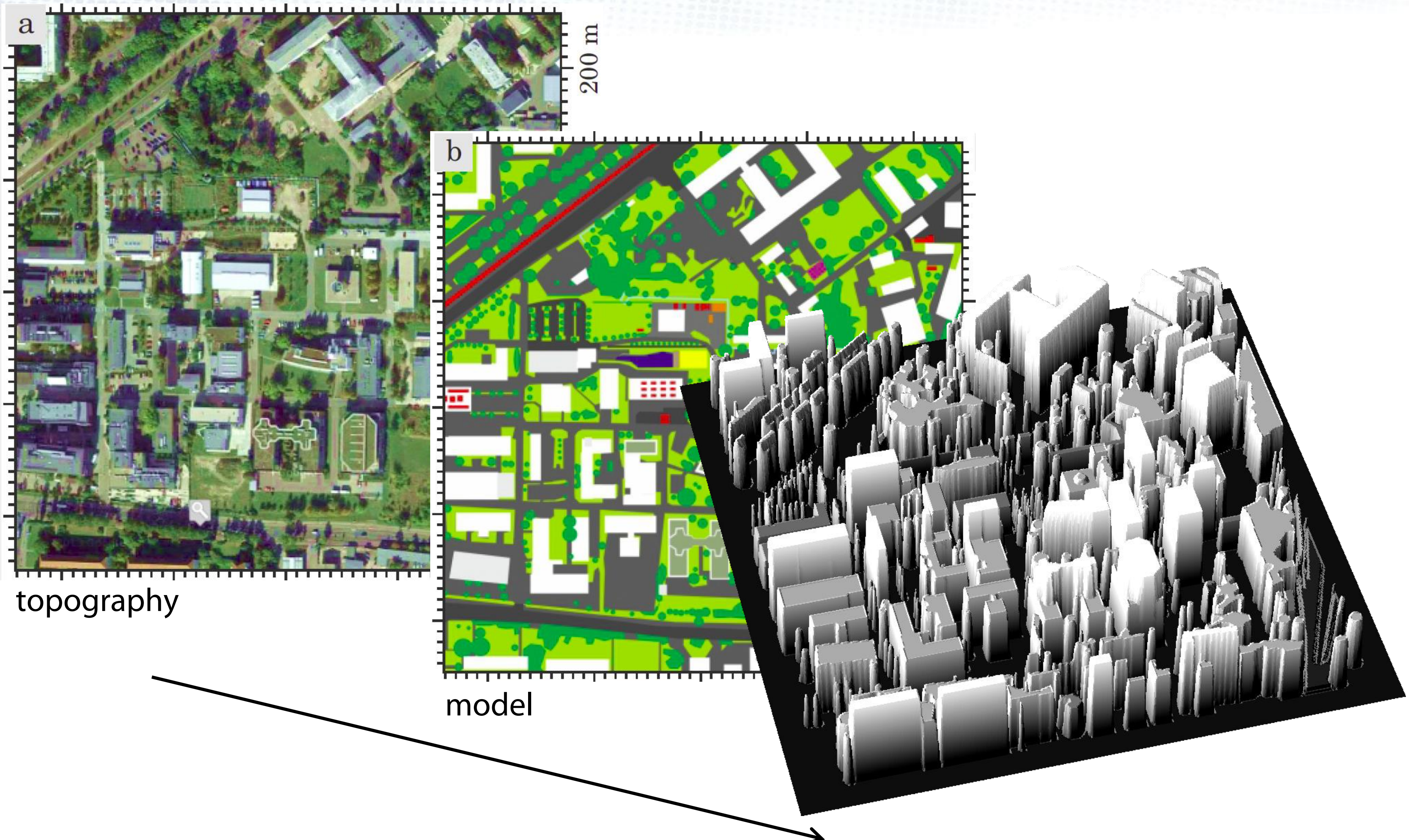


topography



model

URANOS Modeling



topography

model

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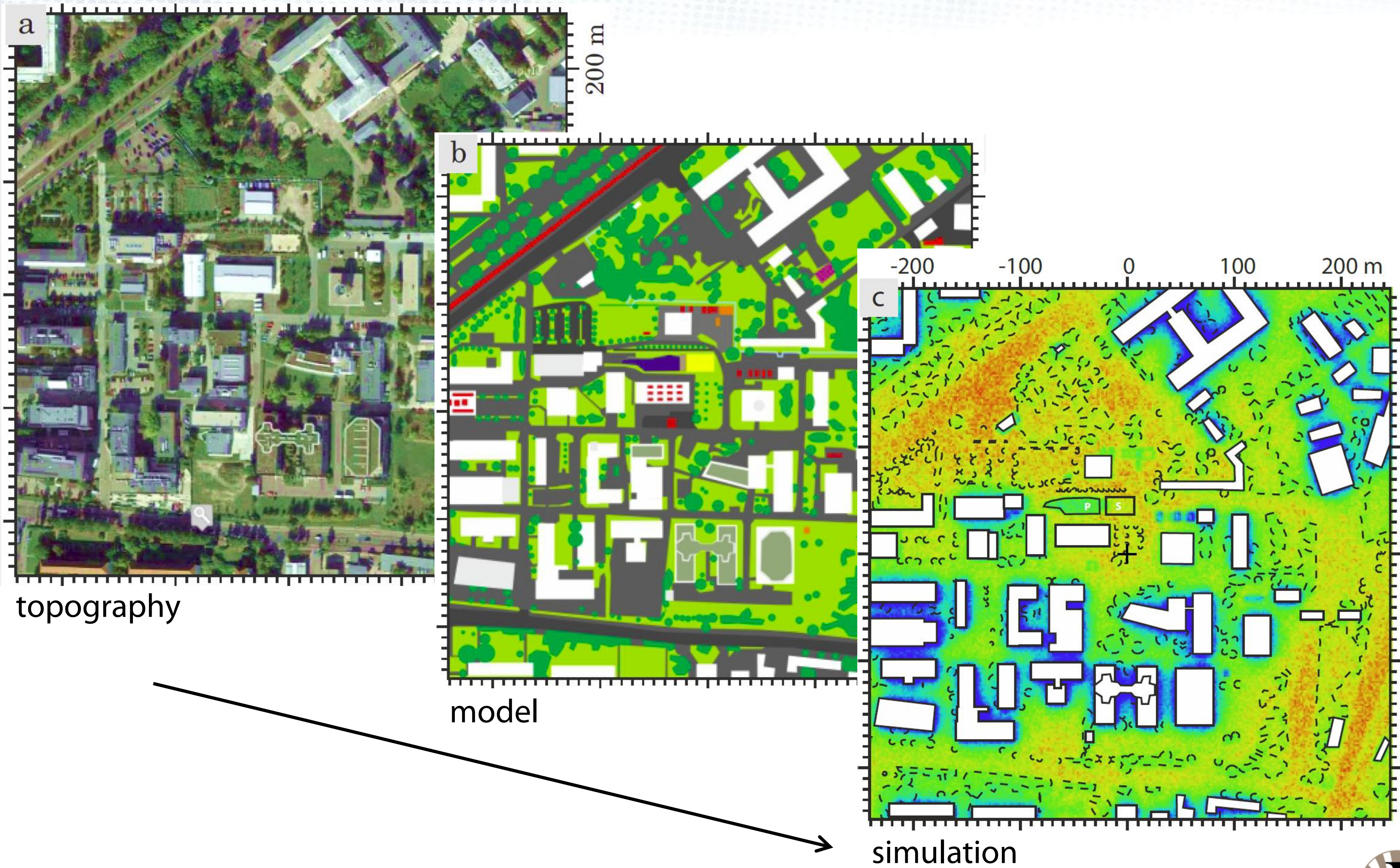

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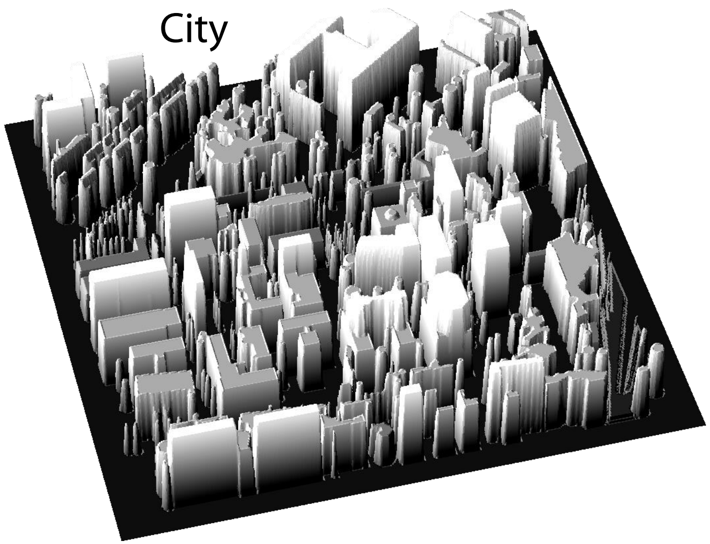

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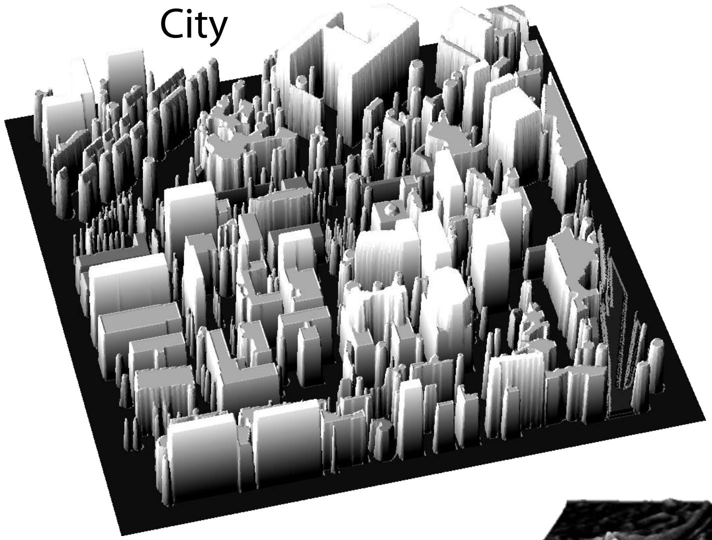

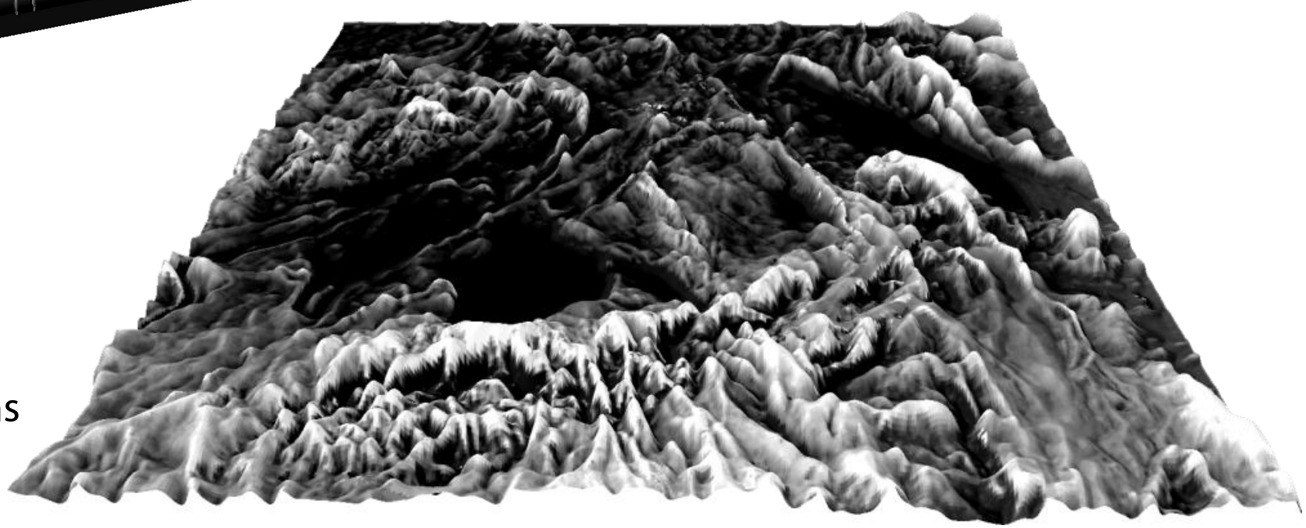

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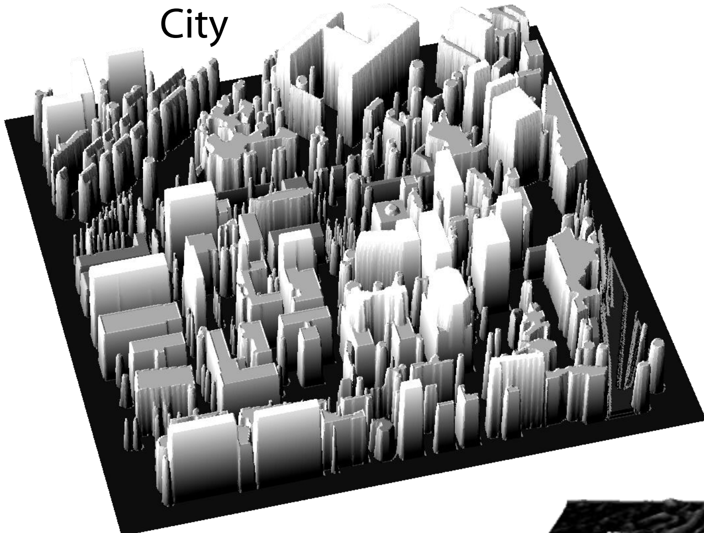

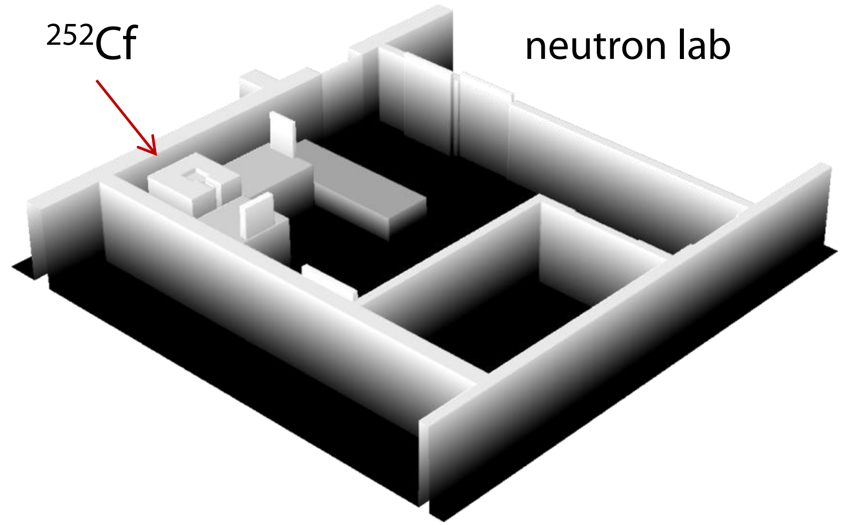

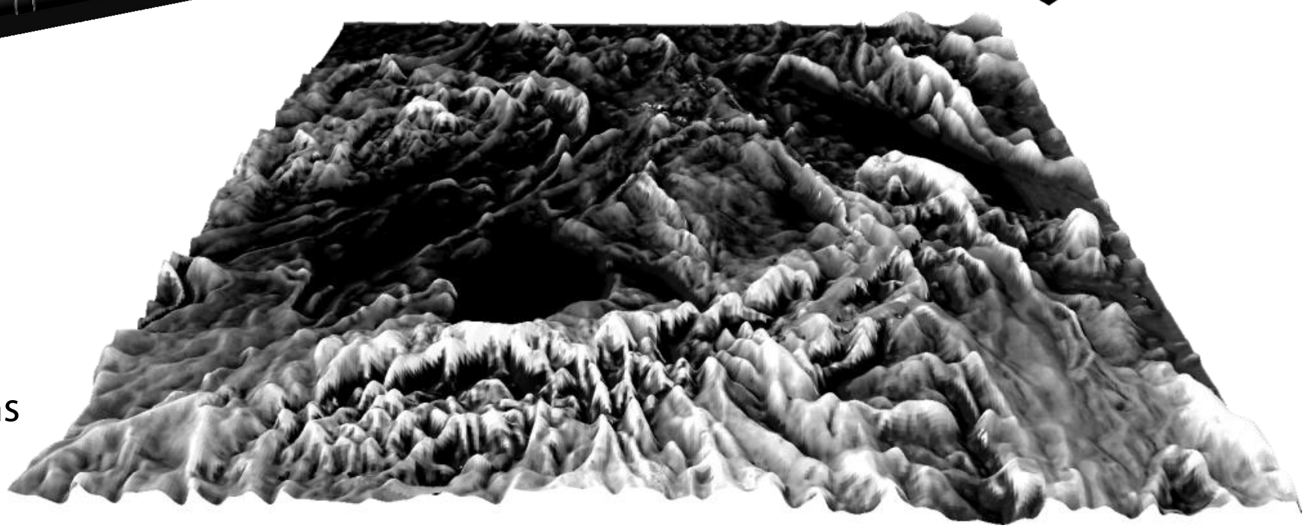

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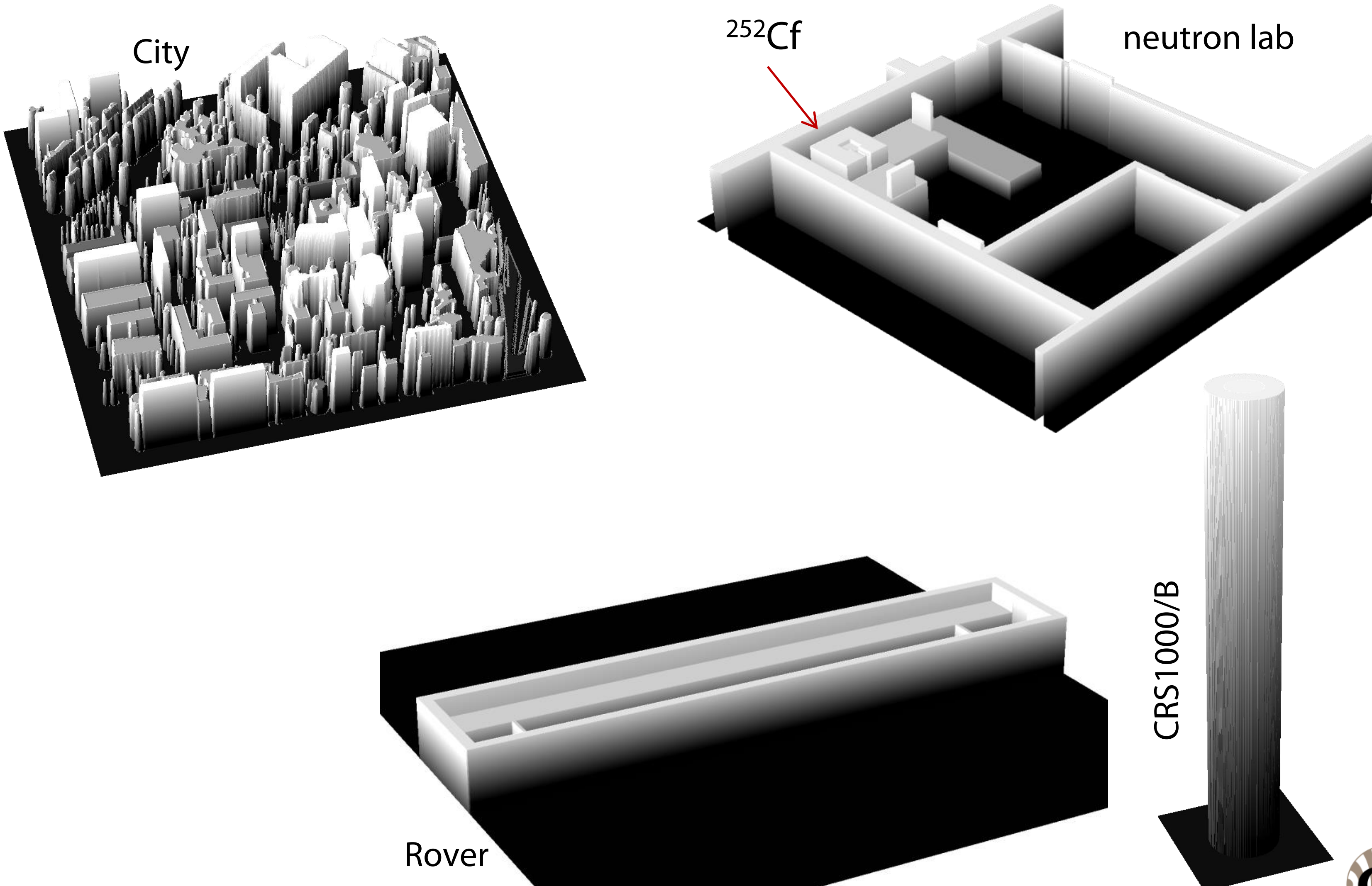

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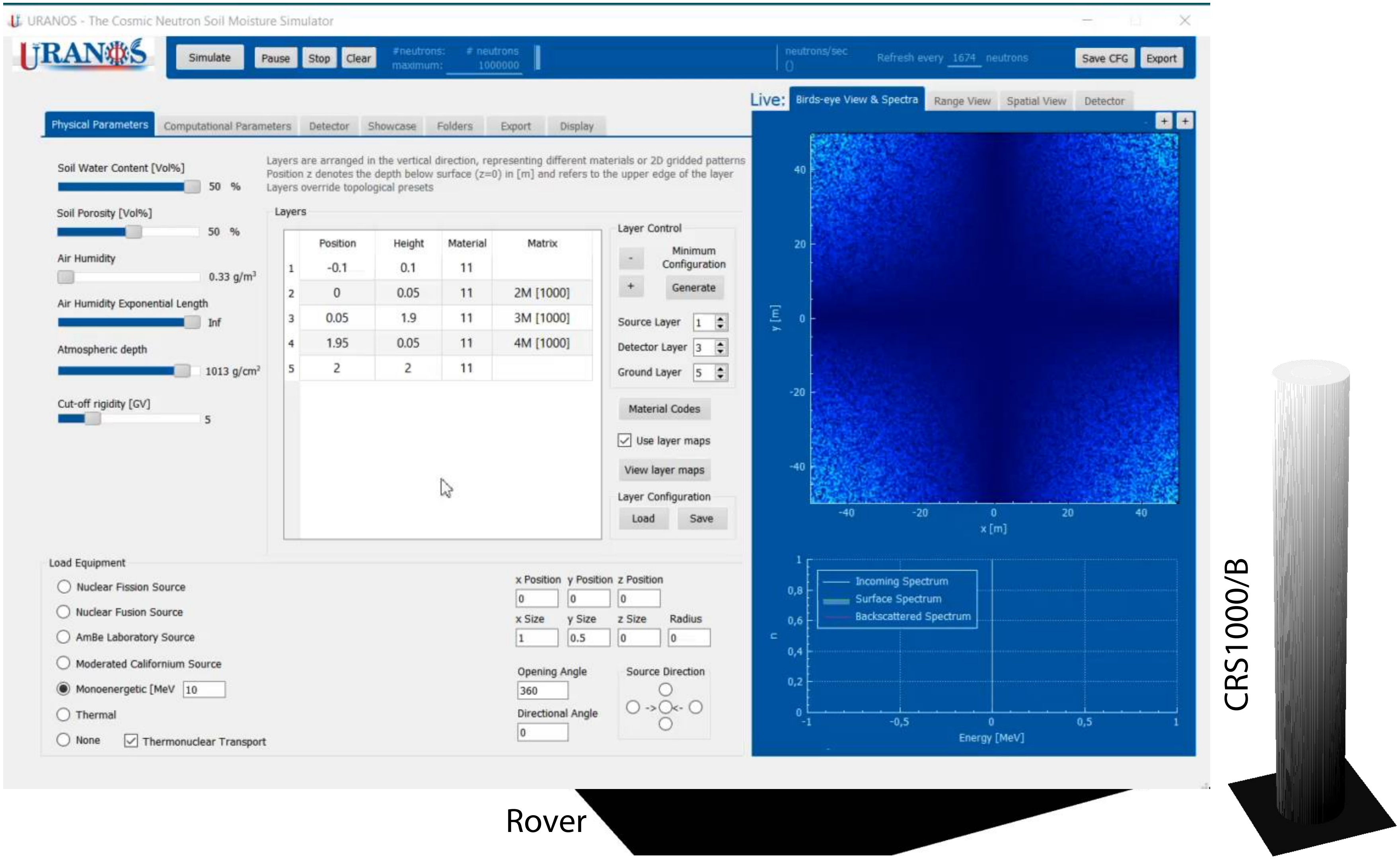

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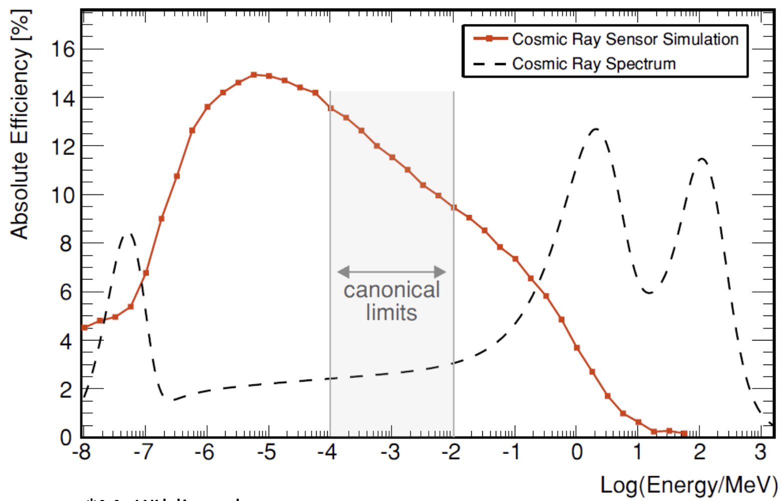
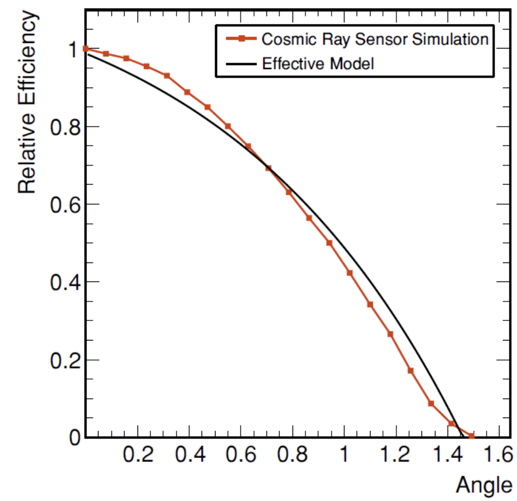
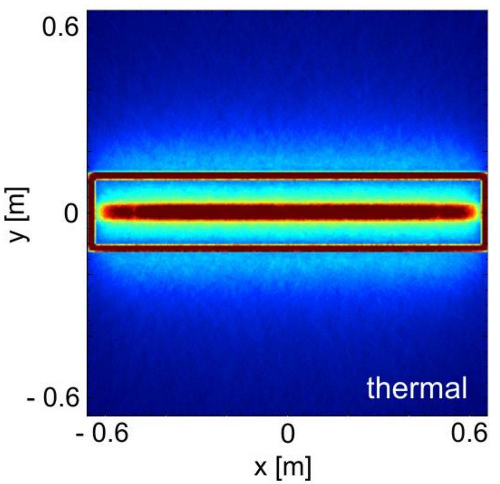
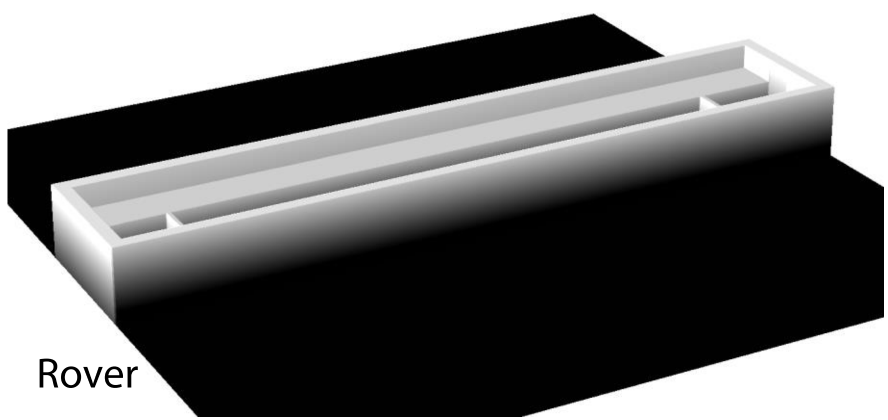
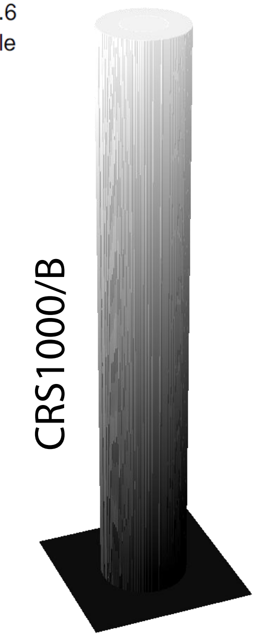




*M. Köhli et al.
Response Functions for Detectors in Cosmic Ray Neutron Sensing







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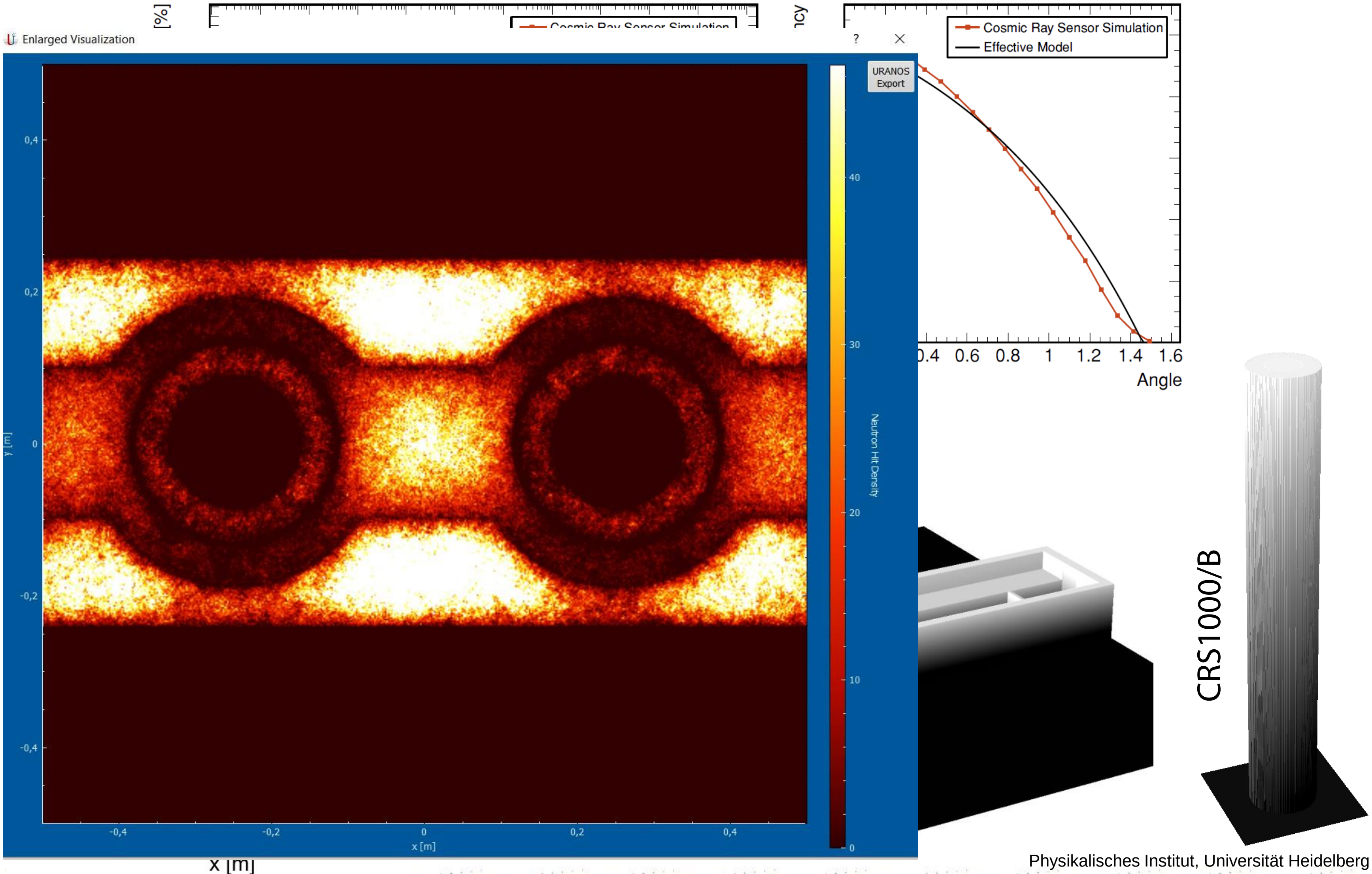
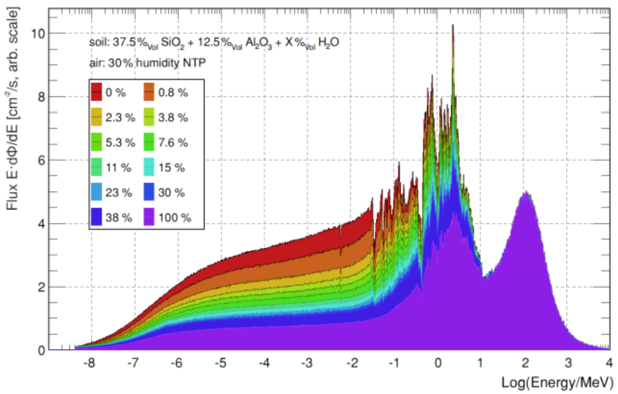
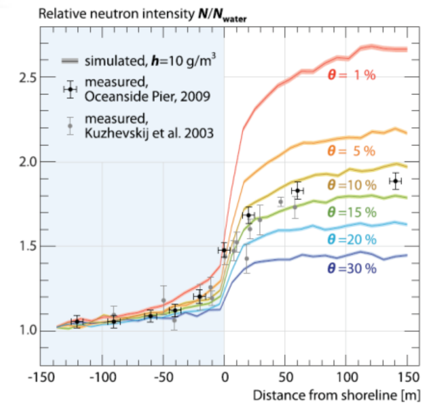
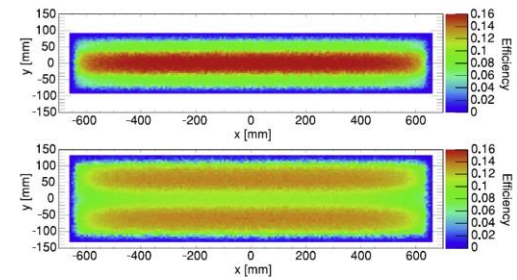
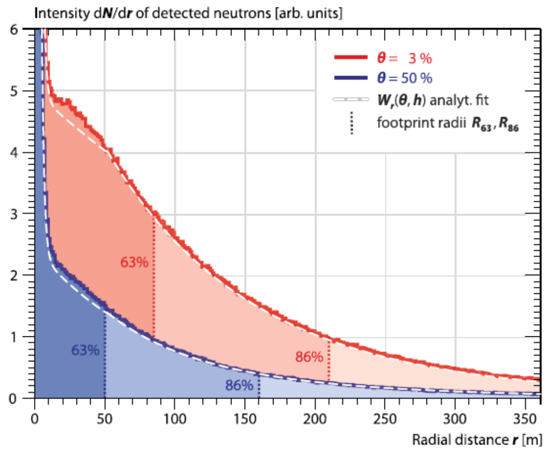


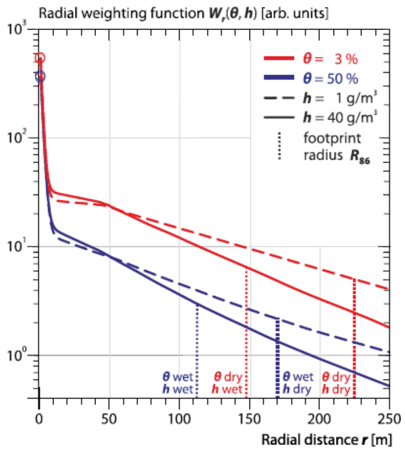
CRNS timeseries

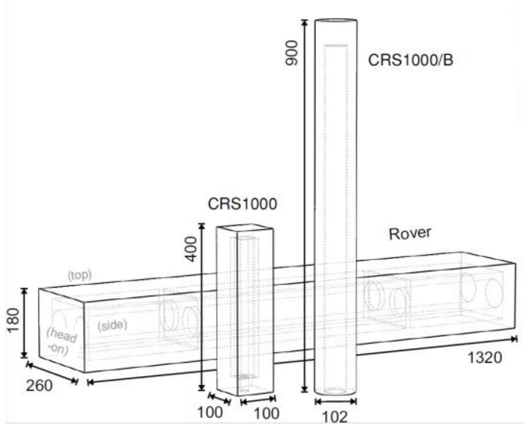












1966	1985	2000	2010	2015

2015 WWR paper

AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2015WR017169

Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons

M. Köhli[1], M. Schrön[2], M. Zreda[3], U. Schmidt[1], P. Dietrich[2], and S. Zacharias[2]

[1]Physics Institute, Heidelberg University, Heidelberg, Germany, [2]Department of Monitoring and Exploration Technologies, UFZ—Helmholtz Centre for Environmental Research, Leipzig, Germany, [3]Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, USA

M. Köhli and M. Schrön contributed equally to this work.

Key Points:
- Neutron transport modeling revised

1966	1985	2000	2010	2015

2015 WWR paper

1966 | 1985 | 2000 | 2010 | 2015

2021 Intensity Relation

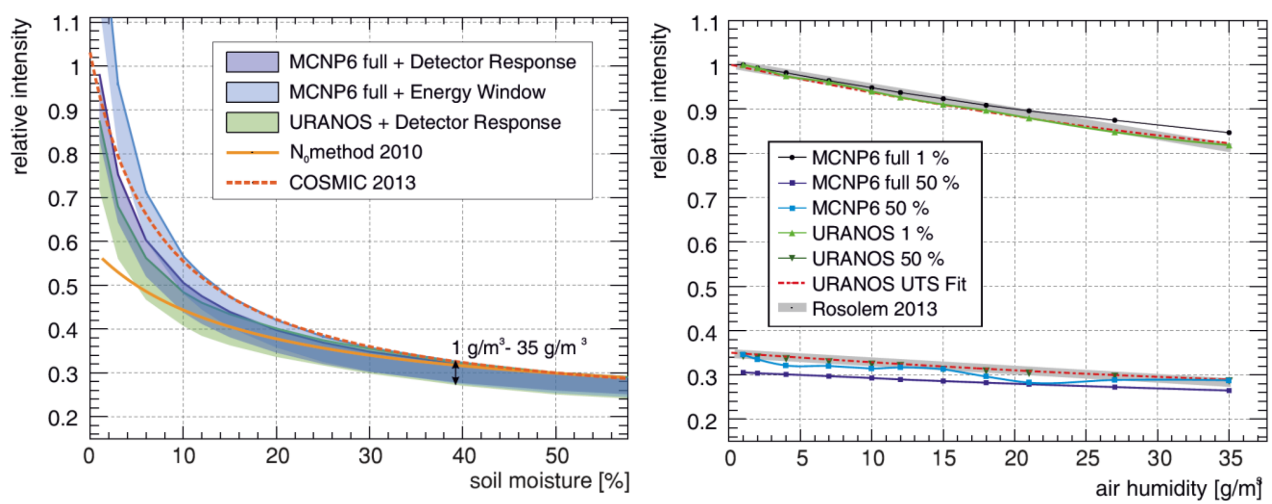
Our proposition: the universal transport solution (UTS)

$$I(\theta,h) = N_D \left(\boxed{\frac{p_1 + p_2\,\theta}{p_1+\theta}} \left(p_0 + p_6\,h + p_7\,h^2\right) + \boxed{e^{-p_3\,\theta}} \left(p_4 + p_5\,h\right) \right)$$

Hyperbola

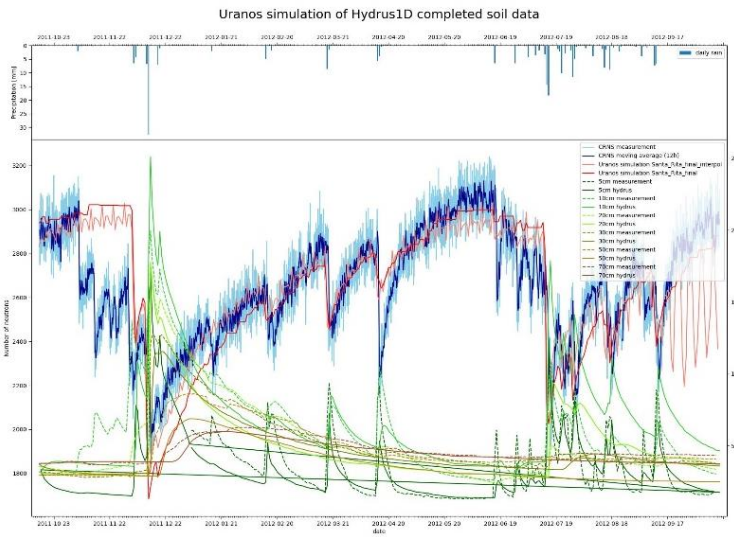
Exponential

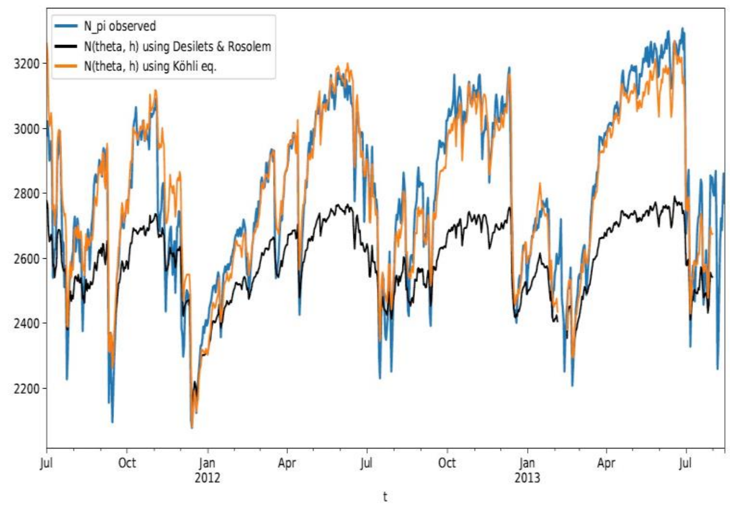
air humidity corrections

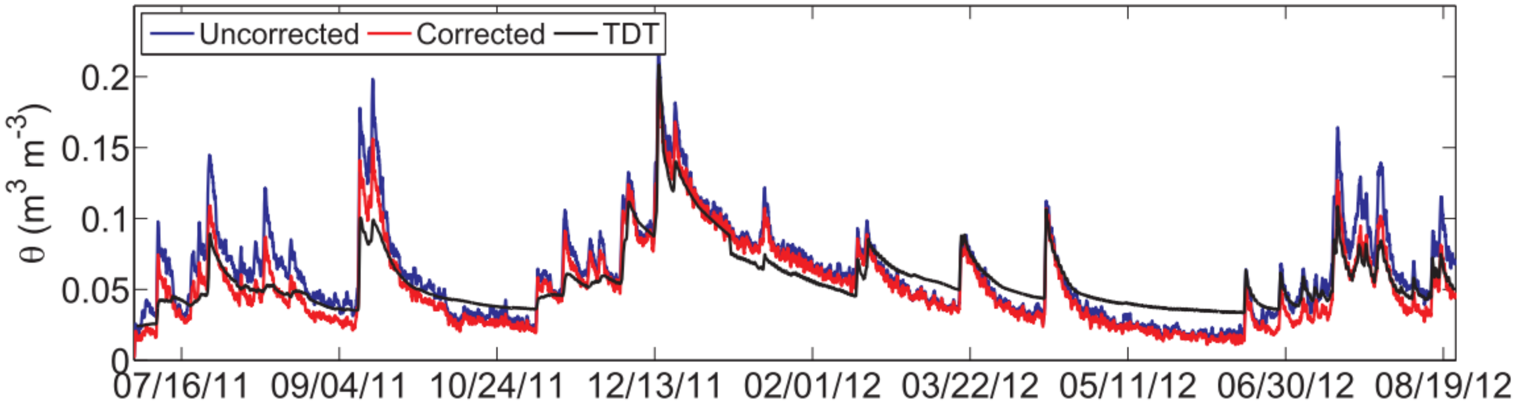


1966 | 1985 | 2000 | 2010 | 2015 | 2021

CRNS timeseries Stanta Rita

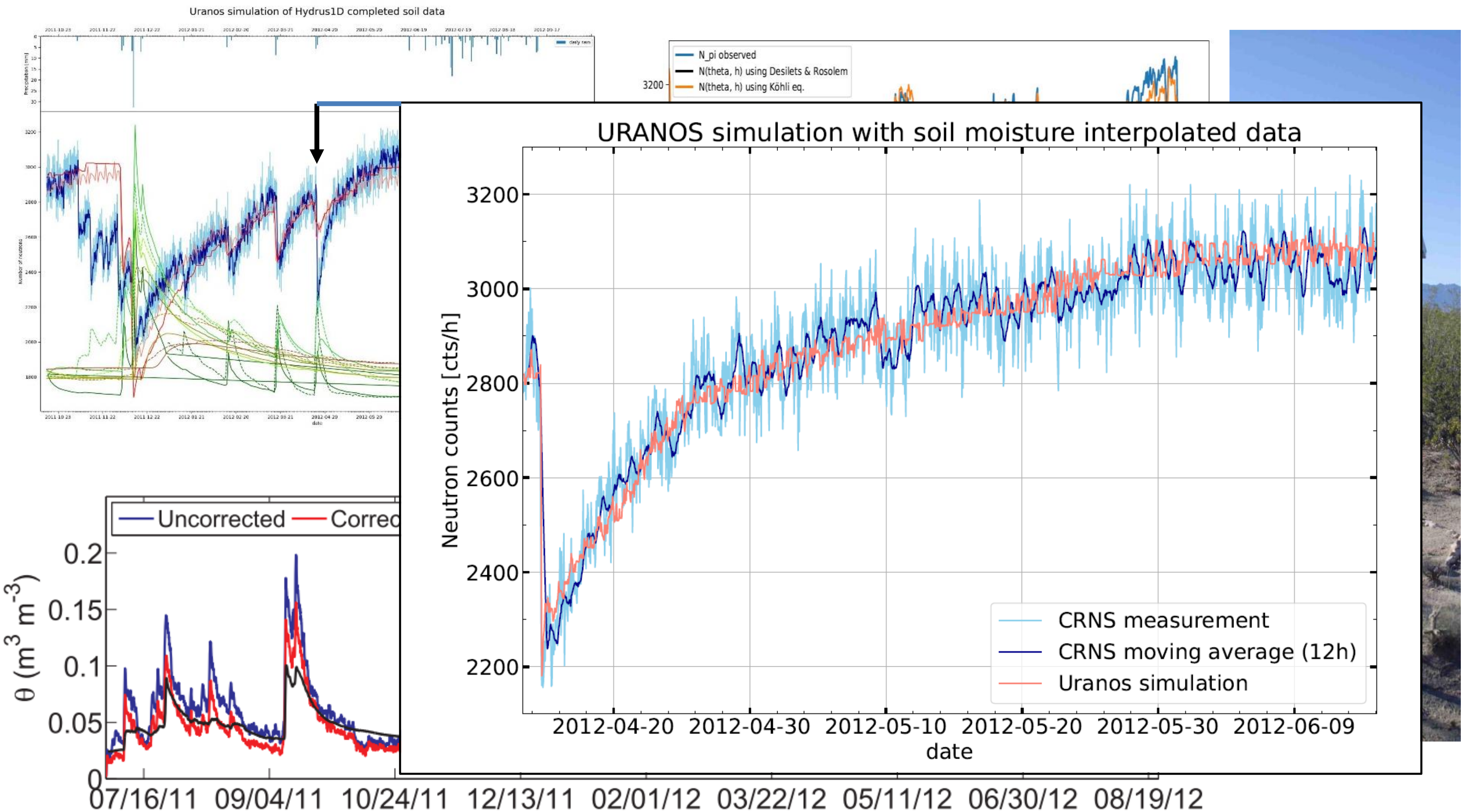






[1] Rosolem, R. et al. "The Effect of Atmospheric Water Vapor on Neutron Count in the Cosmic-Ray Soil Moisture Observing System." J. of Hydrometeorology 14(5) (2013)

CRNS timeseries Stanta Rita



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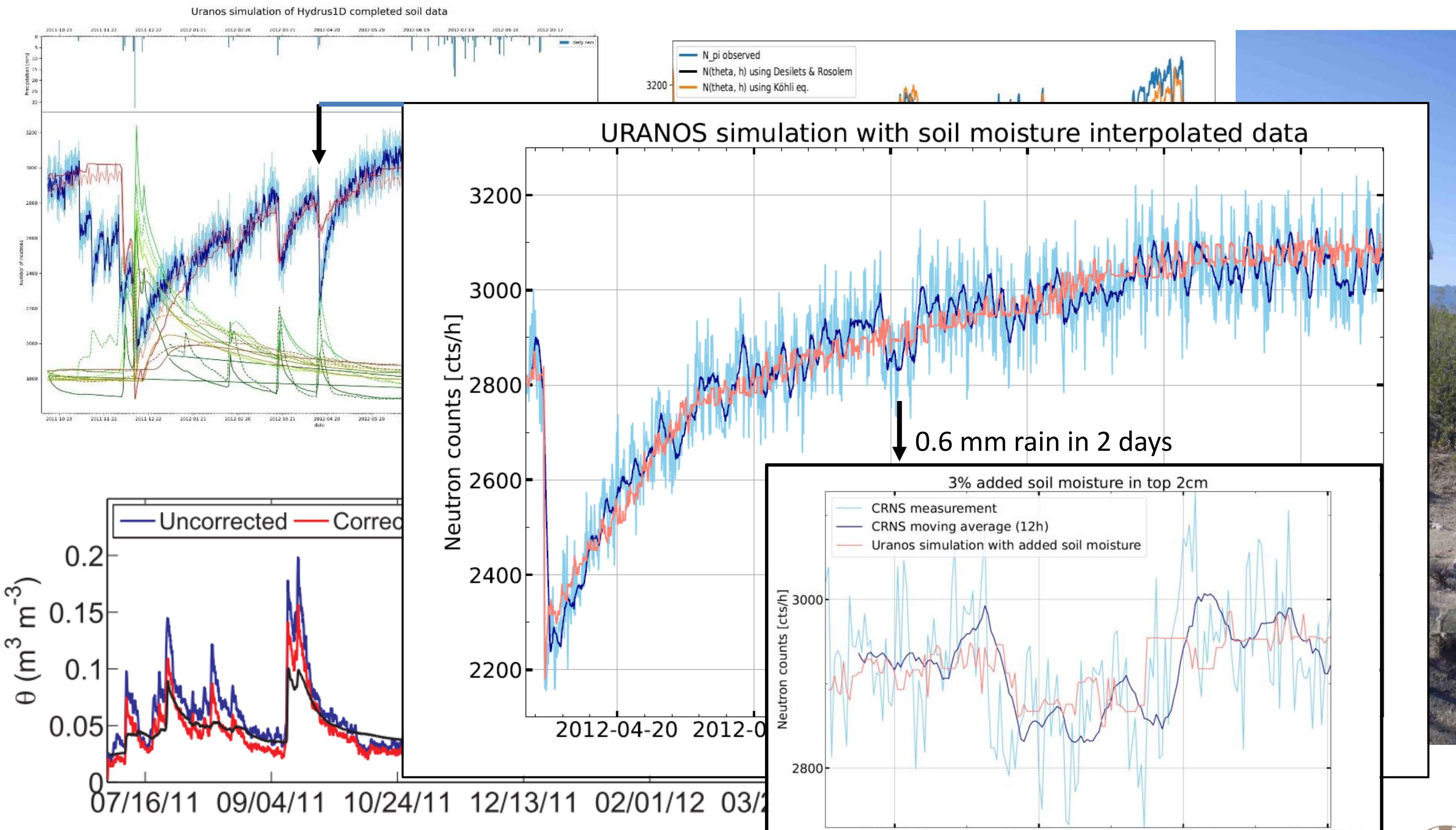

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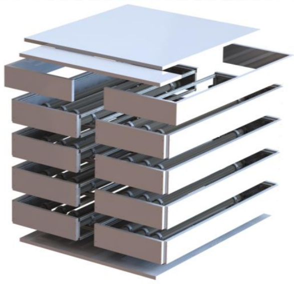
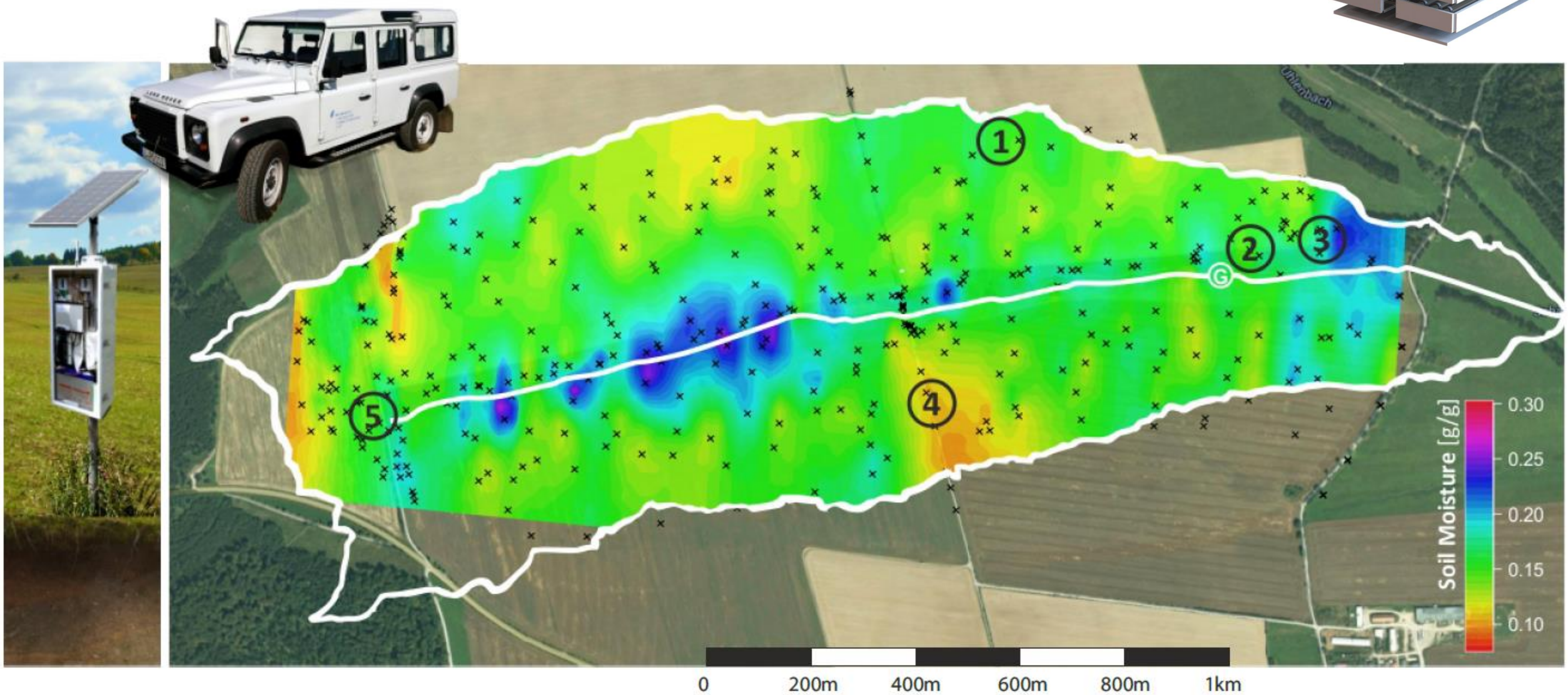
Stationary and Roving

In collaboration with Martin Schrön, UFZ Leipzig





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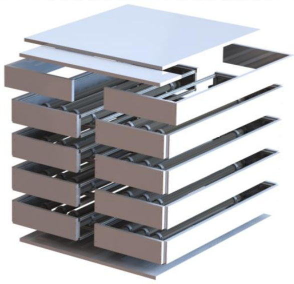
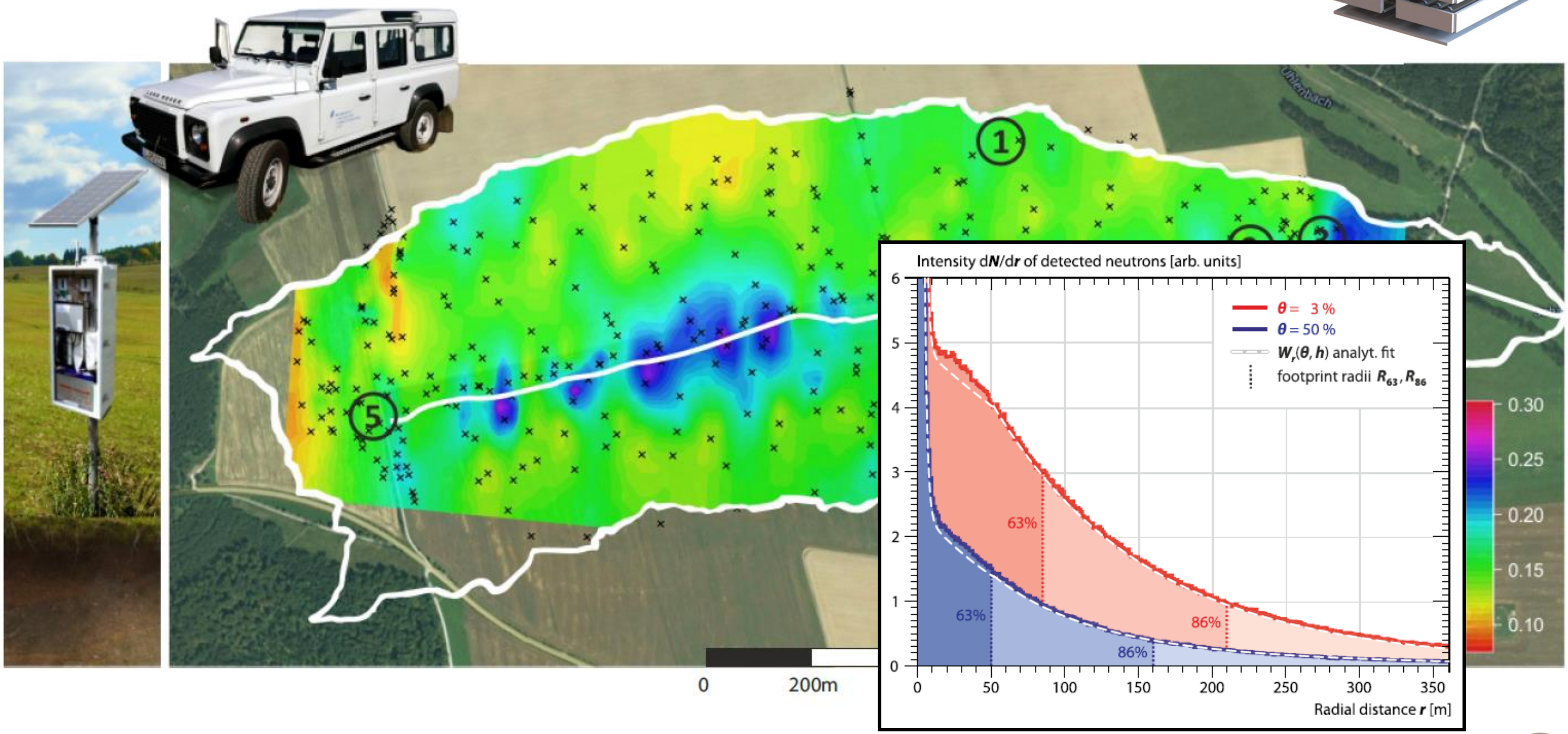
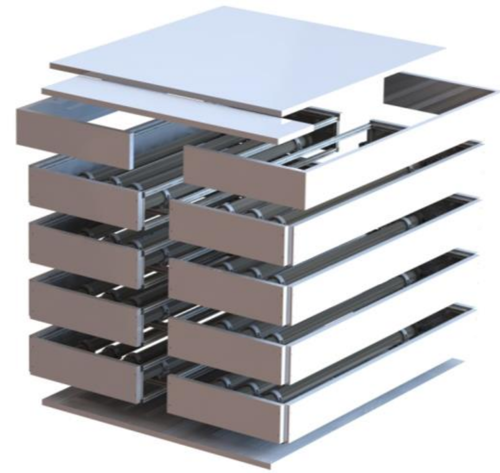




Stationary Instruments

Stationary - small

Stationary - large



Roving

Tubes and Frontend Electronics

Type*	Costs**	Abs. Eff.***
^3He	2500 €	60 %
$^{10}BF_3$	1500 €	20 %
$^{10}B_4C$ conv	1000 €	12 %

*Proportional counter tubes examples of different sizes to match similar instrument performances. Commercial tubes He: 2" x 12", BF_3: 2" x 30". Conventional sputter-coated B_4C tube 2.3" x 47".

**Costs for a proportional counter, for He mainly the gas filling, for BF_3 (hazardous) 1000 € for the tube, others 300 €.

***thermal neutron absorption efficiency.

Tubes and Frontend Electronics

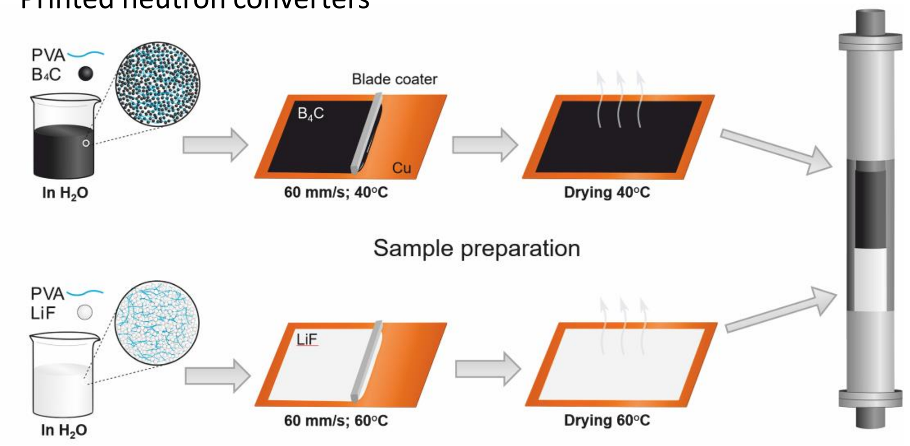
Type*	Costs**	Abs. Eff.***
^{3}He	2500 €	60 %
$^{10}BF_3$	1500 €	20 %
$^{10}B_4C$ conv	1000 €	12 %
^{6}LiF printed	700 €	12 %
$^{10}B_4C$ printed	400 €	11 %

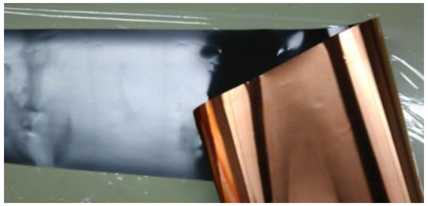
*Proportional counter tubes examples of different sizes to match similar instrument performances. Commercial tubes He: 2″ x 12″, BF_3: 2″ x 30″. Conventional sputter-coated B_4C tube 2.3″ x 47″.

**Costs for a proportional counter, for He mainly the gas filling, for BF_3 (hazardous) 1000 € for the tube, others 300 €.

***thermal neutron absorption efficiency.

Printed neutron converters





Tubes and Frontend Electronics

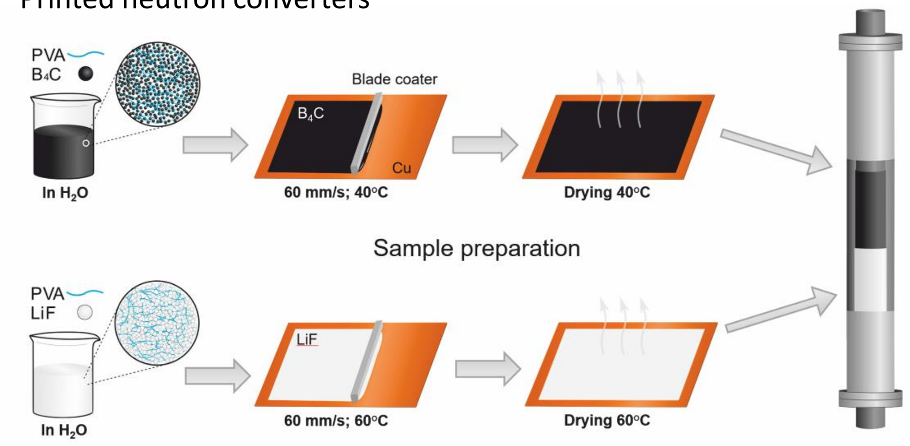
Type*	Costs**	Abs. Eff.***
^{3}He	2500 €	60 %
$^{10}BF_3$	1500 €	20 %
$^{10}B_4C$ conv	1000 €	12 %
^{6}LiF printed	700 €	12 %
$^{10}B_4C$ printed	400 €	11 %

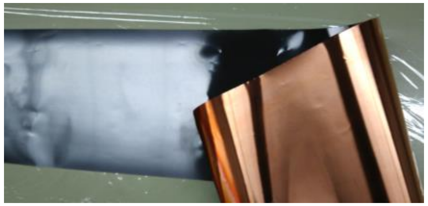
*Proportional counter tubes examples of different sizes to match similar instrument performances. Commercial tubes He: 2" x 12", BF_3: 2" x 30". Conventional sputter-coated B_4C tube 2.3" x 47".

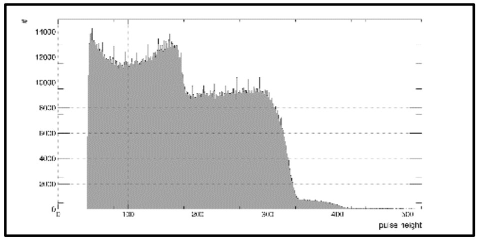
**Costs for a proportional counter, for He mainly the gas filling, for BF_3 (hazardous) 1000 € for the tube, others 300 €.

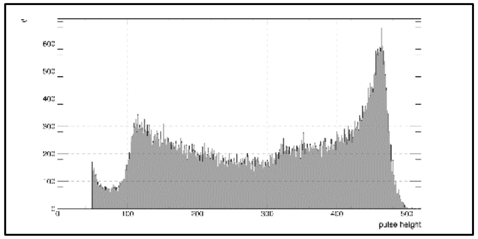
***thermal neutron absorption efficiency.

Printed neutron converters

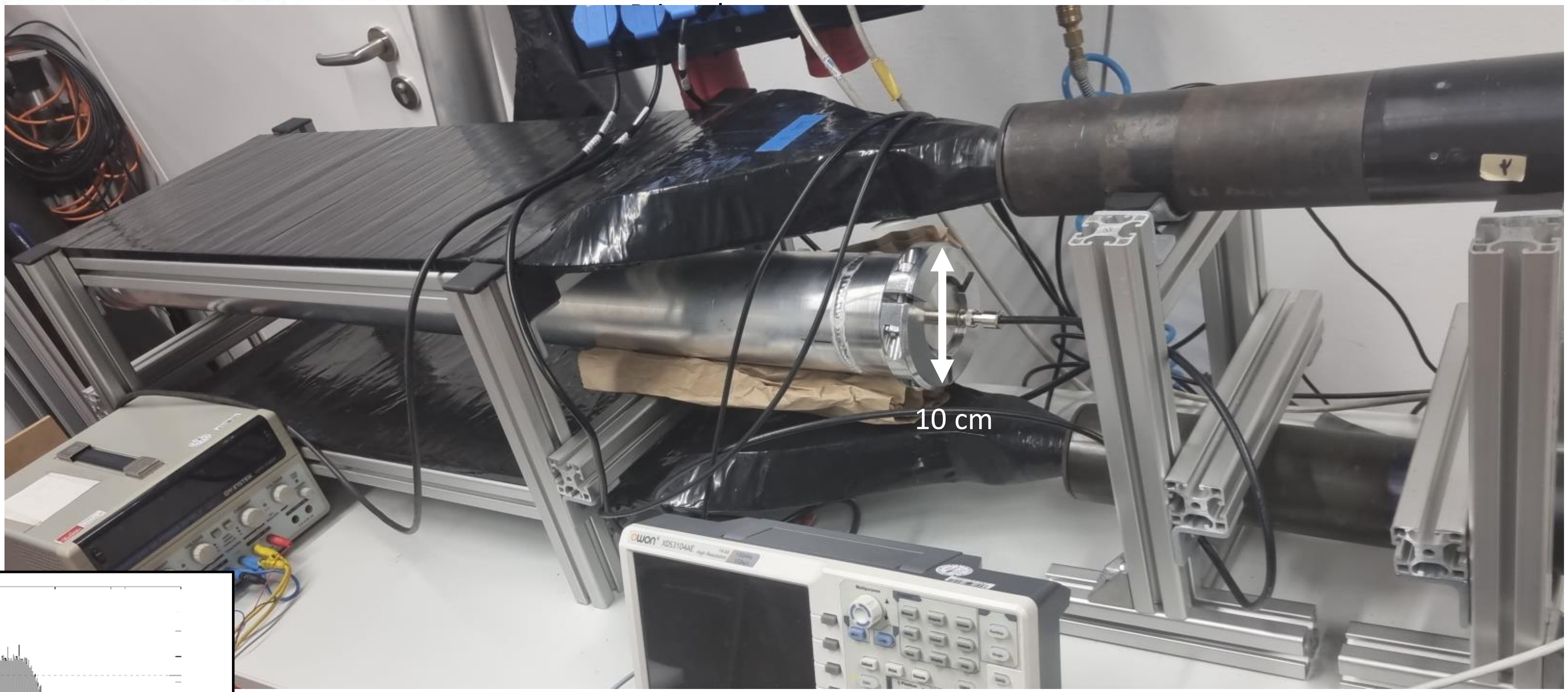


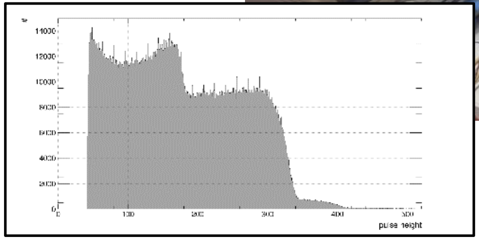


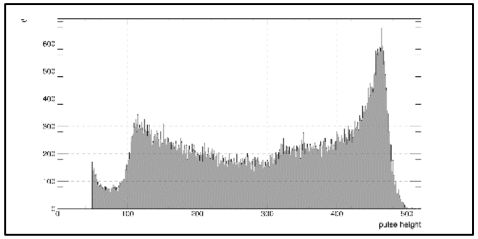




Tubes and Frontend Electronics

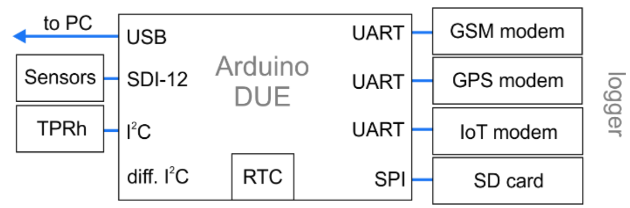


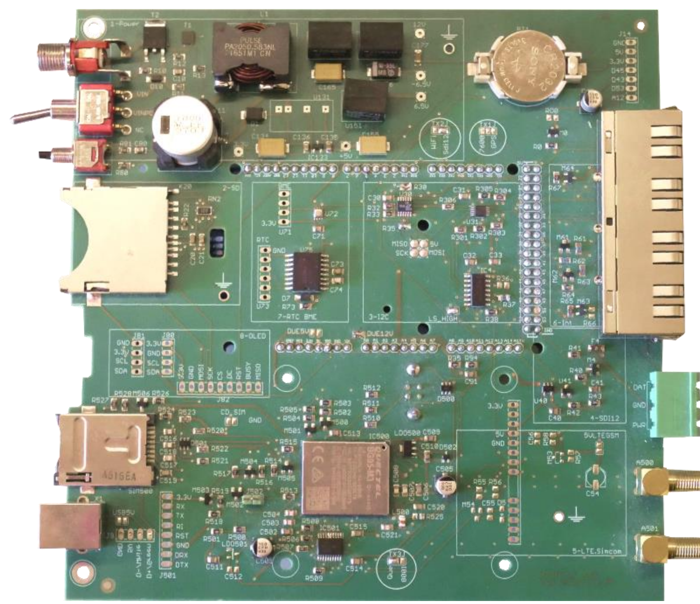




Data Logger

- Low temperature dependence
- Display: RL, p, event info
- High resolution for environmental variables
- Battery/voltage monitoring
- Multi-purpose RJ45 Connector
- SD card
- SDI-12 / RS485 implementation





Data Logger

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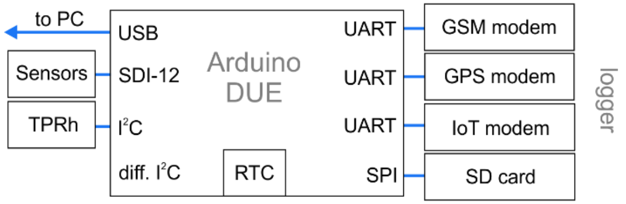
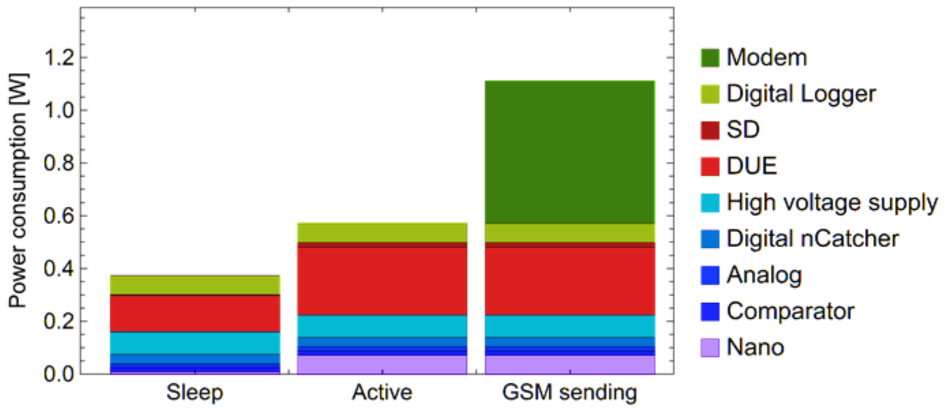
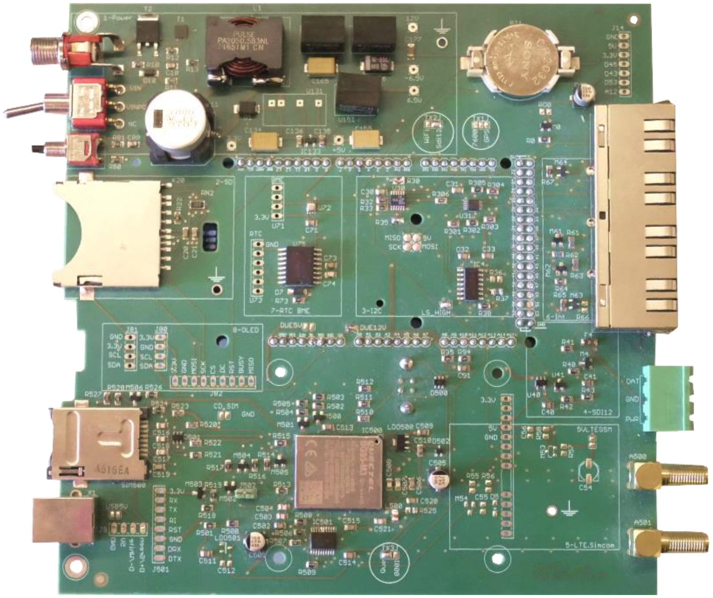
Real-time data interface

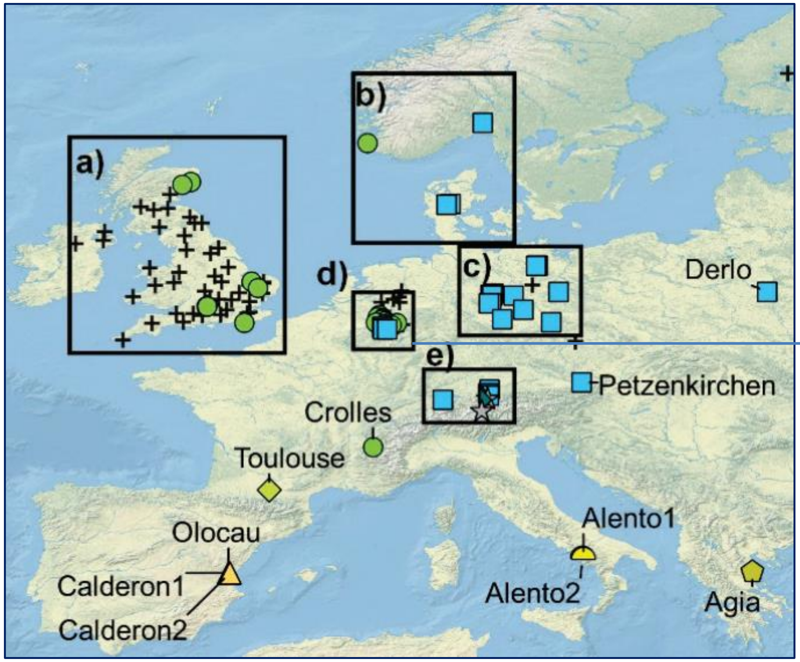


Power Consumption

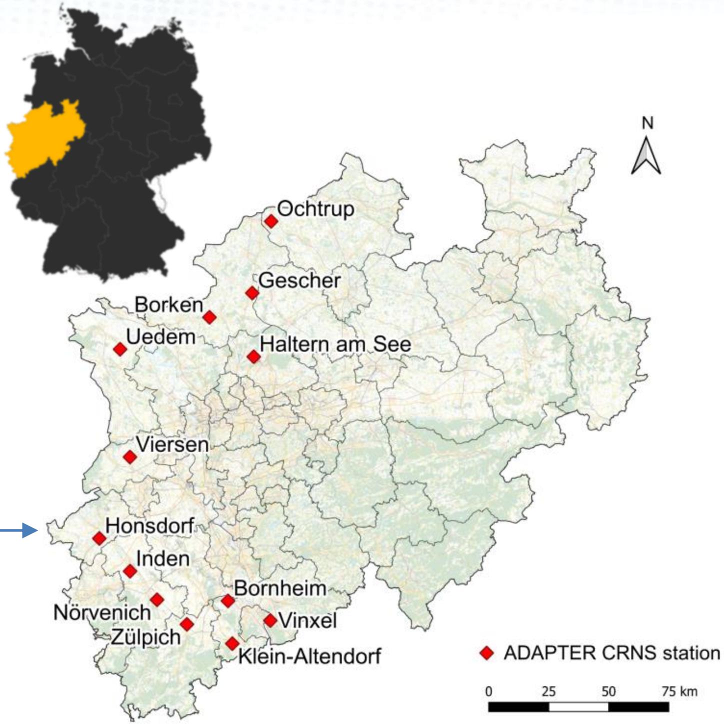




CRNS Networks



COSMOS-Europe sites (Bogena 2021, ESSD)



ADAPTER sites (Ney 2021, MetroAgriFor)

The ADAPTER Network

Devices with
NB-IoT modems

In collaboration with
Patrizia Ney
FZ Jülich

The ADAPTER Network

Devices with
NB-IoT modems

Cellular
Network

IoT–Provider

Packed
Gateway

VPN
Gateway

Open
VPN

Server
- Data processing
- Data storage
- Modelling

VPN
Gateway

❖ transmission of the observation data via **N**arrow **B**and **I**nternet **o**f **T**hings (**NB-IoT**) in near real-time

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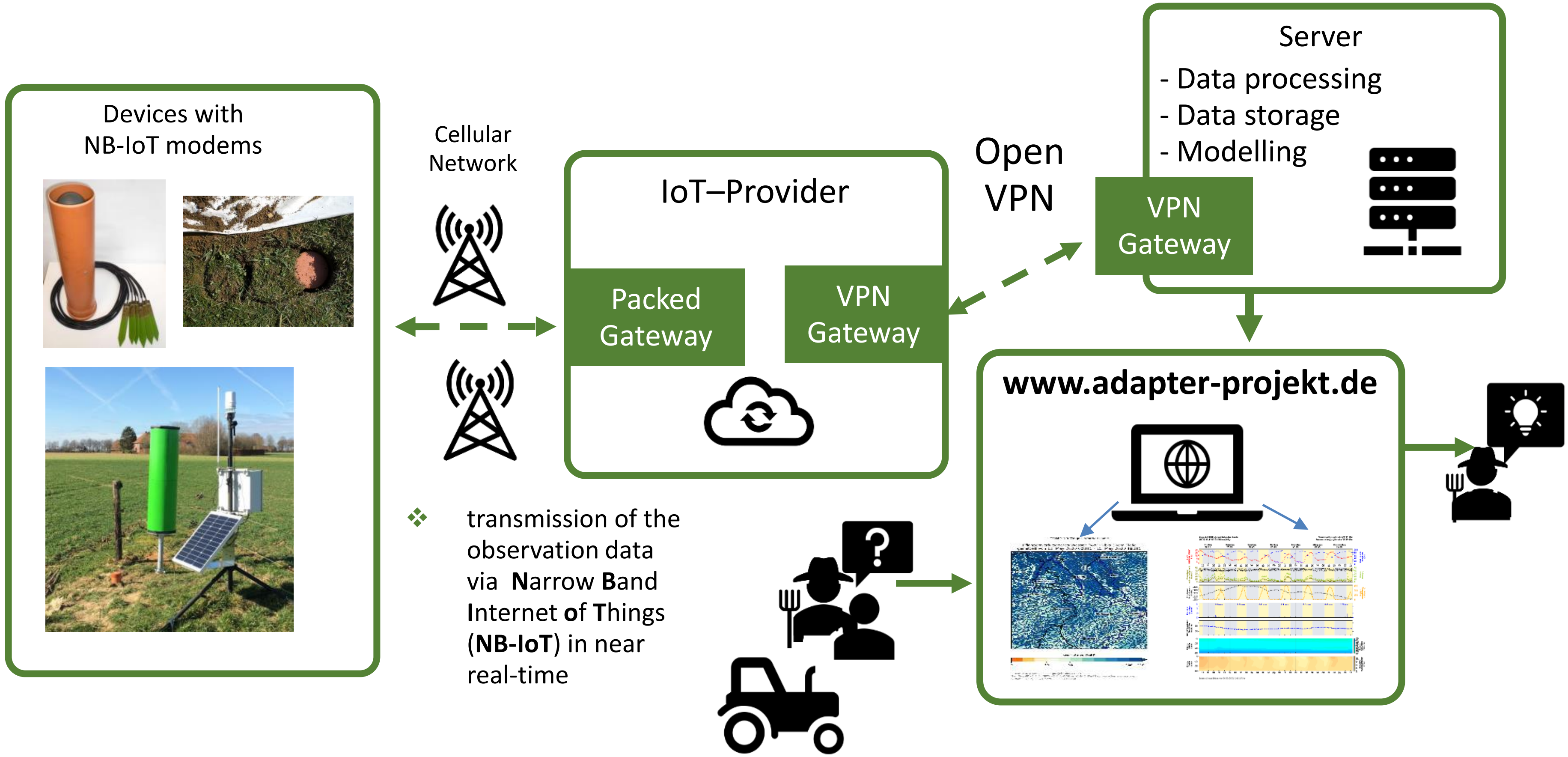
The ADAPTER Network



- transmission of the observation data via **N**arrow **B**and **I**nternet **of** **T**hings (**NB-IoT**) in near real-time

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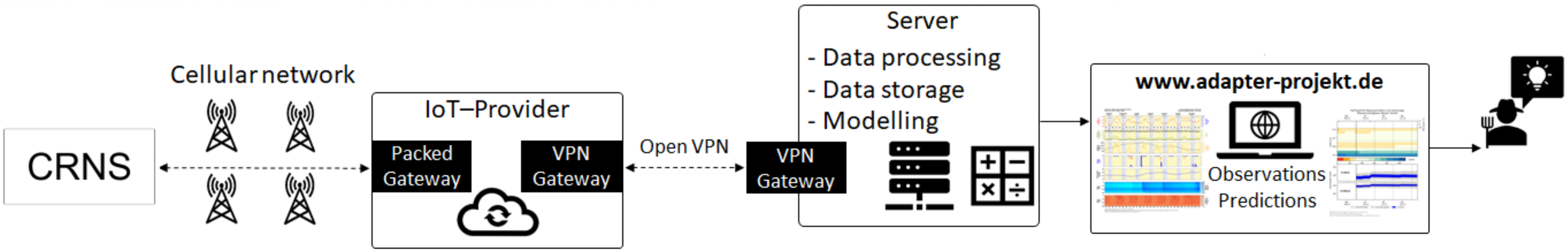
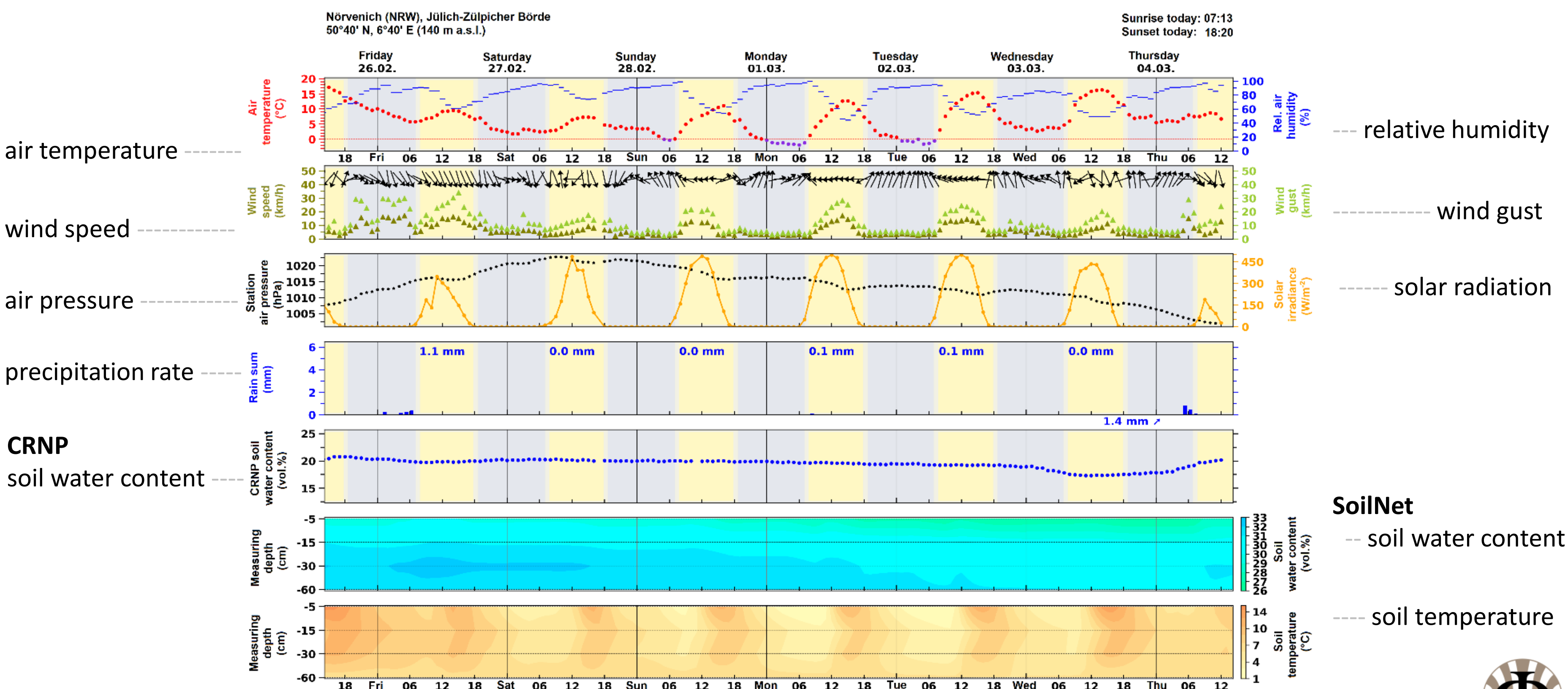
Telemetry Integration





SOMMET: Standardization

PROJECT PARTNERS:

- PTB — Coordination, Lead WP6
- Ciemat — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
- CMI — Czech Metrology Institute
- Danish Technological Institute — Lead WP1
- TÜBİTAK
- IRSN — Institut de Radioprotection et de Sûreté Nucléaire
- SMU
- INRiM — Istituto Nazionale di Ricerca Metrologica — Lead WP5
- Justervesenet
- Universität Potsdam — Lead WP2
- Alma Mater Studiorum Università di Bologna — Lead WP3
- CTU — Czech Technical University in Prague
- Politecnico Milano 1863
- IREA — istituto per il rilevamento elettromagnetico dell'ambiente — Lead WP4
- UK Centre for Ecology & Hydrology
- UFZ — Helmholtz Zentrum für Umweltforschung
- Institute of Agrophysics PAS

IMPACT & SUPPORT:

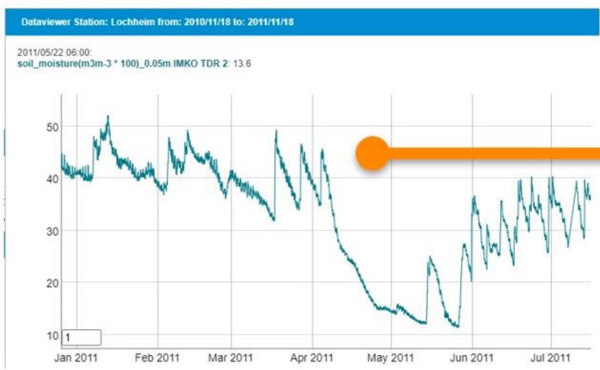
- esa
- ASI — Agenzia Spaziale Italiana
- UNESCO — United Nations Educational, Scientific and Cultural Organization
- International Centre for Water Resources and Global Change under the auspices of UNESCO
- WMO
- eLTER
- DWD — Deutscher Wetterdienst — Wetter und Klima aus einer Hand
- ECMWF
- The University of Arizona
- Landbrug & Fødevarer
- AHDB — Agriculture & Horticulture Development Board
- NMBU — Norwegian University of Life Sciences

Multiple scales of SOMMET

Comparison and harmonization of soil moisture measurement methods at multiple spatial and temporal scales

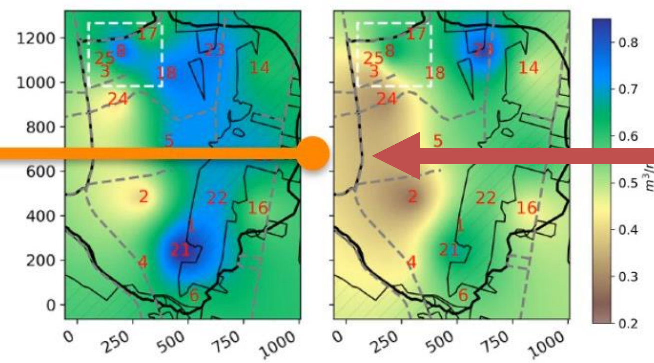
- Comparison of methods, their constraints and different spatial and temporal characteristics
  - Development of an approach to harmonize point scale, field scale and remote sensing

Point-scale *in situ* measurements
Example: Time series of a single sensor



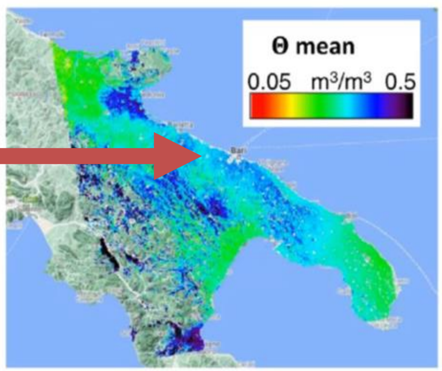
[International Soil Moisture Network]

Cosmic-ray neutron sensing
Example: Daily average soil moisture at catchment scale



[Heistermann, HESS 25 (2021) 4807]

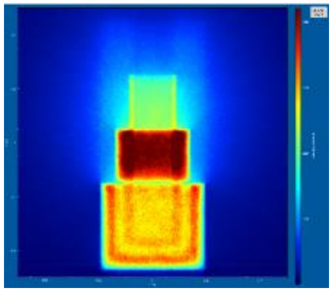
Satellite remote sensing
Example: Sentinel-1 surface soil volumetric water content product

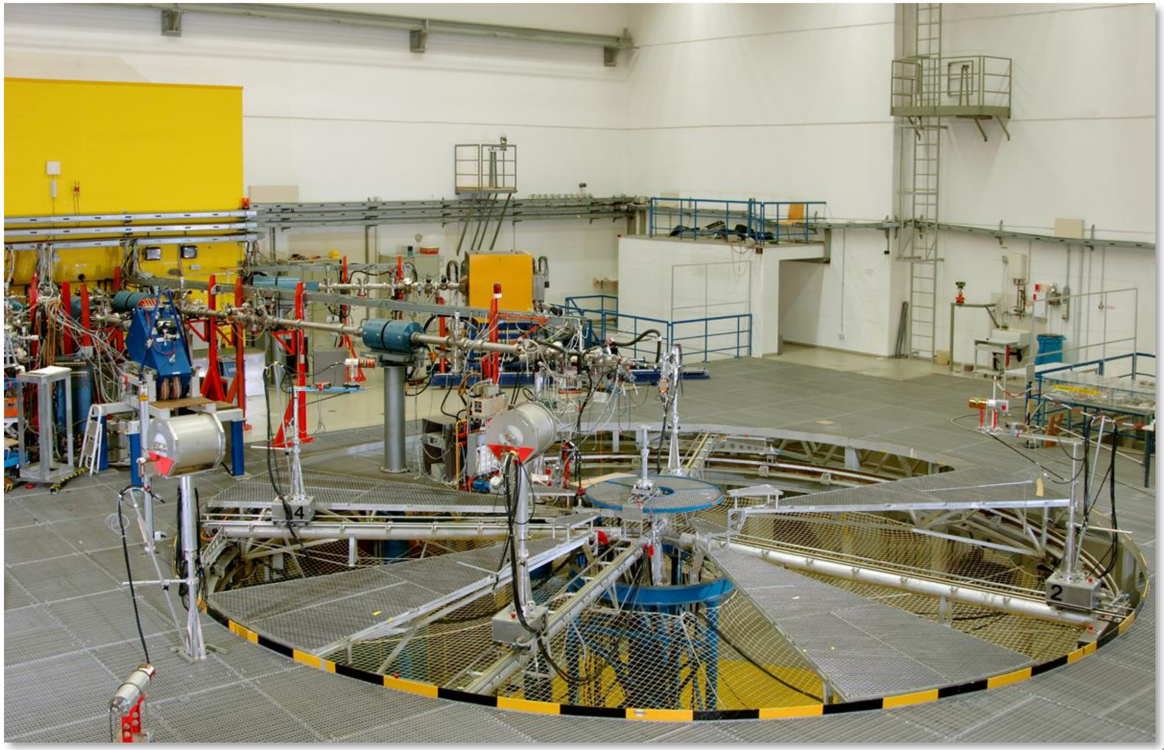


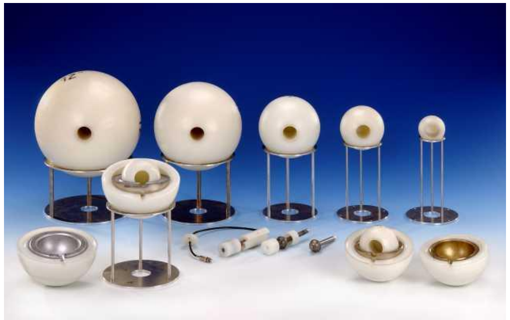
[Balenzano *et al.*, Data in Brief 38 (2021) 107345]

SI-traceable measurements

- Calibration facilities for point scale sensors
    - Primary measurement methods and transfer standards
        - Provide a traceability scheme to CRNS

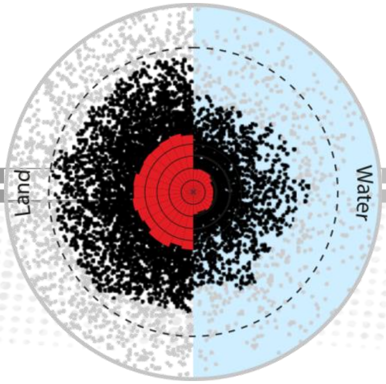






Pathways to CRNS: evolving detectors and neutron modeling

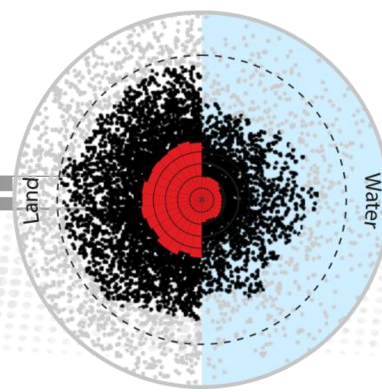
CRNS as an emerging technology platform



Physikalisches Institut
Heidelberg University
Germany

CRNS as an emerging technology platform

- Independent modeling and simulation results



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Pathways to CRNS: evolving detectors and neutron modeling

CRNS as an emerging technology platform

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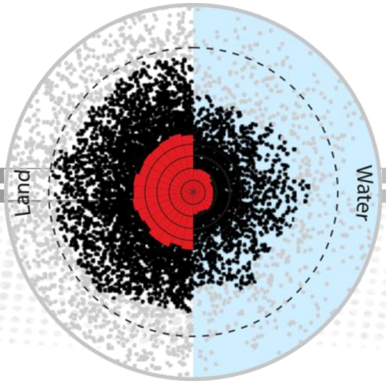
- Solutions for detection systems
  - Independent, non-invasive sensor operation and low maintenance



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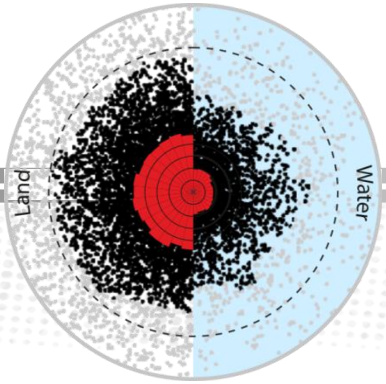

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