



Physikalisches Institut  
Heidelberg University  
Germany

# URANOS

## a voxel engine Neutron Transport Monte Carlo Simulation

Position Sensitive Neutron Detectors 2024

10.4.2024

Markus Köhli<sup>1,2</sup>, M. Schrön<sup>3</sup>, S. Zacharias<sup>3</sup>, U. Schmidt<sup>1</sup>

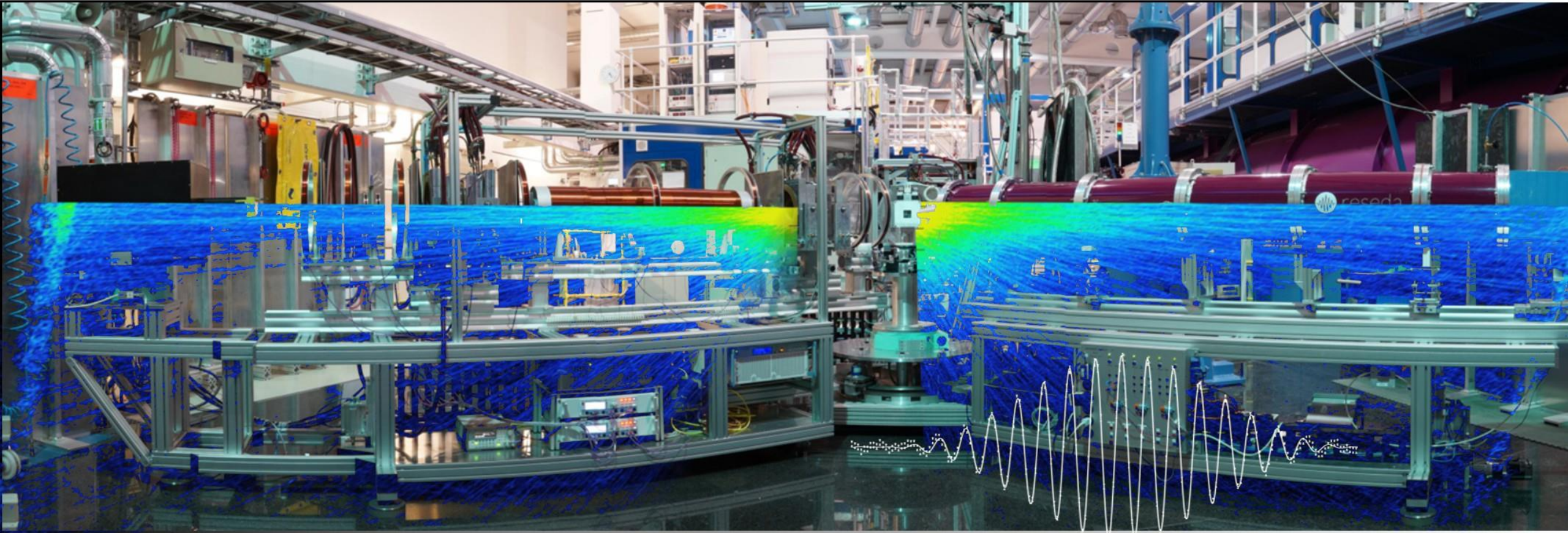
<sup>1</sup>Physikalisches Institut, Heidelberg University, Germany

<sup>2</sup>StyX Neutronica GmbH, Mannheim, Germany

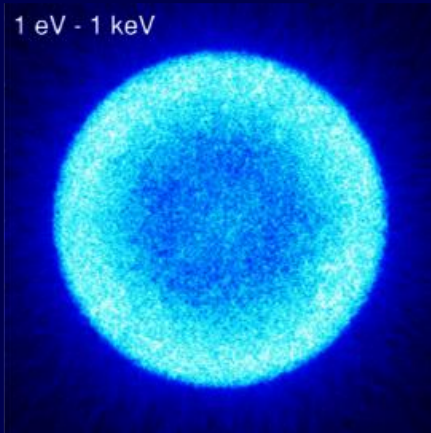
<sup>3</sup>Dep. Monitoring and Exploration Technologies, Helmholtz Centre for Environmental Research GmbH – UFZ, Leipzig, Germany



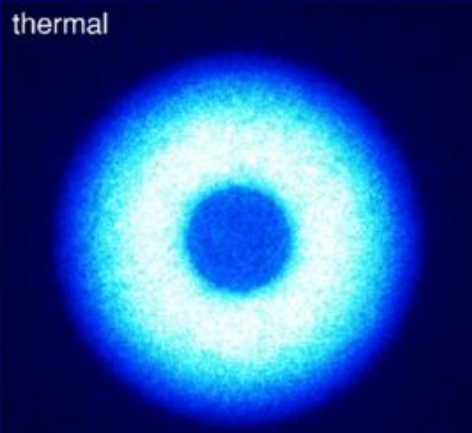
Gerördert durch  
**DFG** Deutsche  
Forschungsgemeinschaft



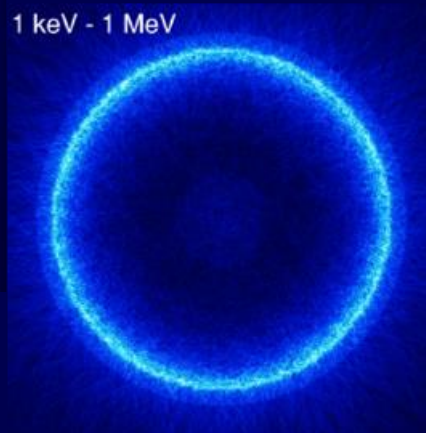
1 eV - 1 keV



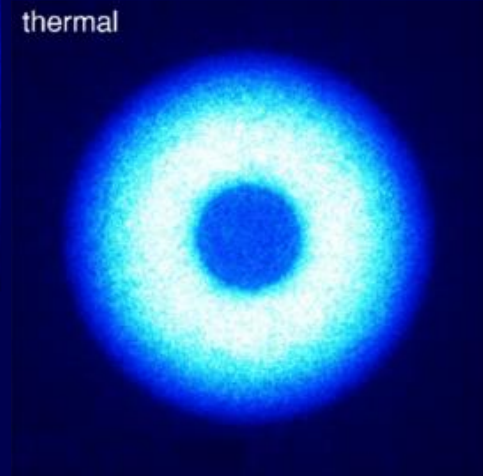
thermal



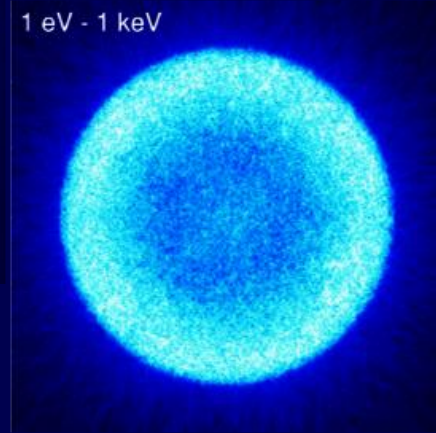
1 keV - 1 MeV



thermal



1 eV - 1 keV





# URANOS concepts

- written in C++

```
if (detectorEnergyModel2->Eval(TMath::Log10(energy)) > r.Rndm() )  
{  
    detectorRealisticallyHitted = true; layerRealisticallyHitted = true;  
}
```

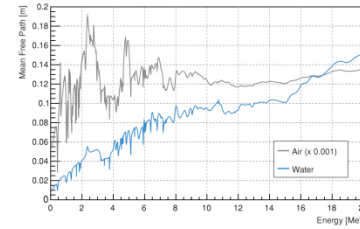


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- linked against ENDF data bases



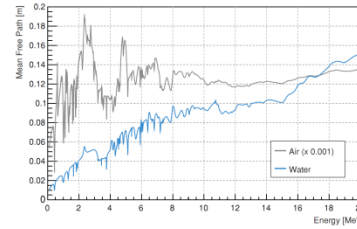


# URANOS concepts

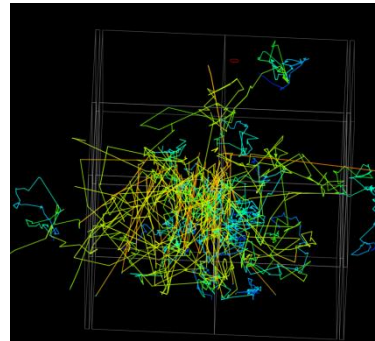
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- linked against ENDF data bases



- Ray-Casting



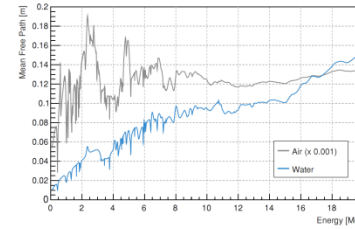


# URANOS concepts

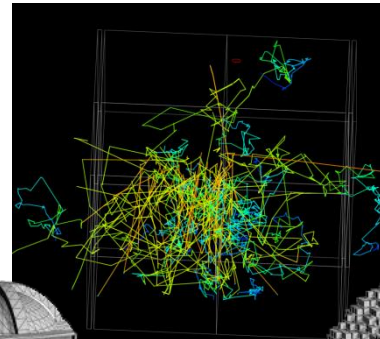
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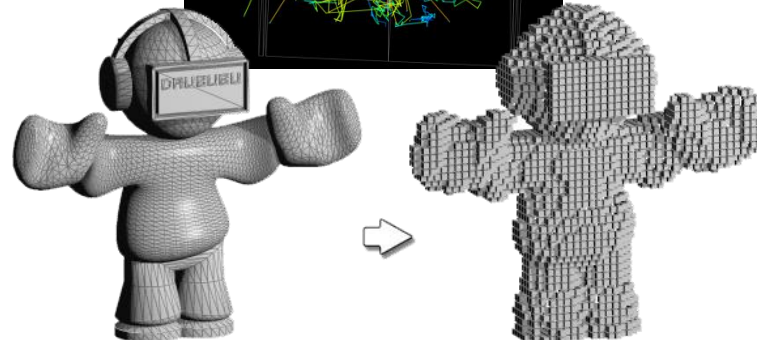
- linked against ENDF data bases



- Ray-Casting



- Voxel Engine



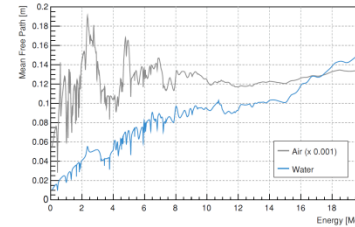


# URANOS concepts

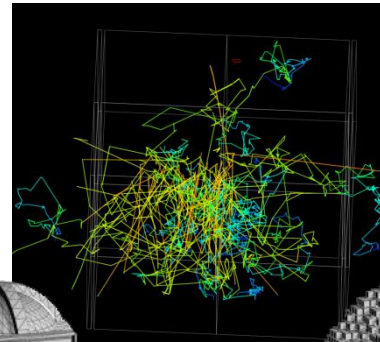
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```
if (detectorEnergyModel2->Eval(TMATH::Log10(energy)) > r.Rndm() )  
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    detectorRealisticallyHitted = true; layerRealisticallyHitted = true;  
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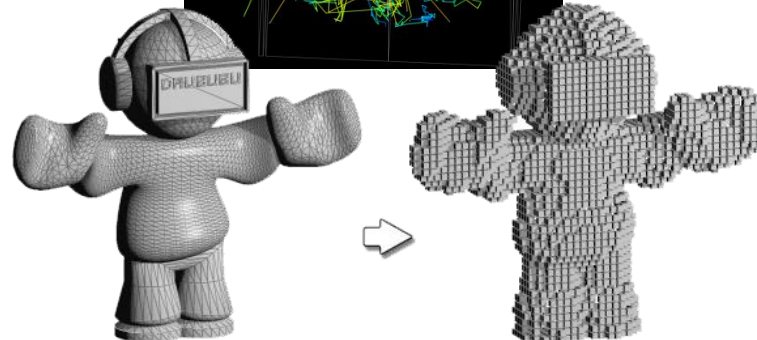
- linked against ENDF data bases



- Ray-Casting



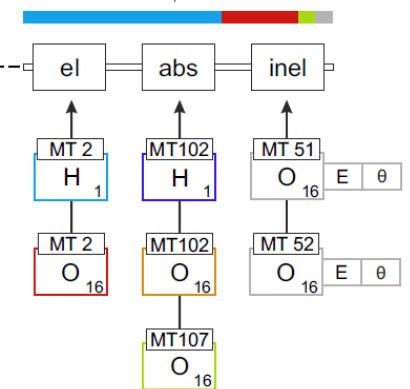
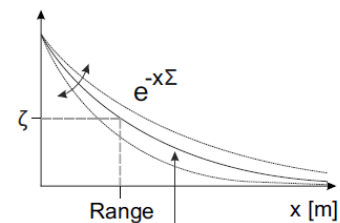
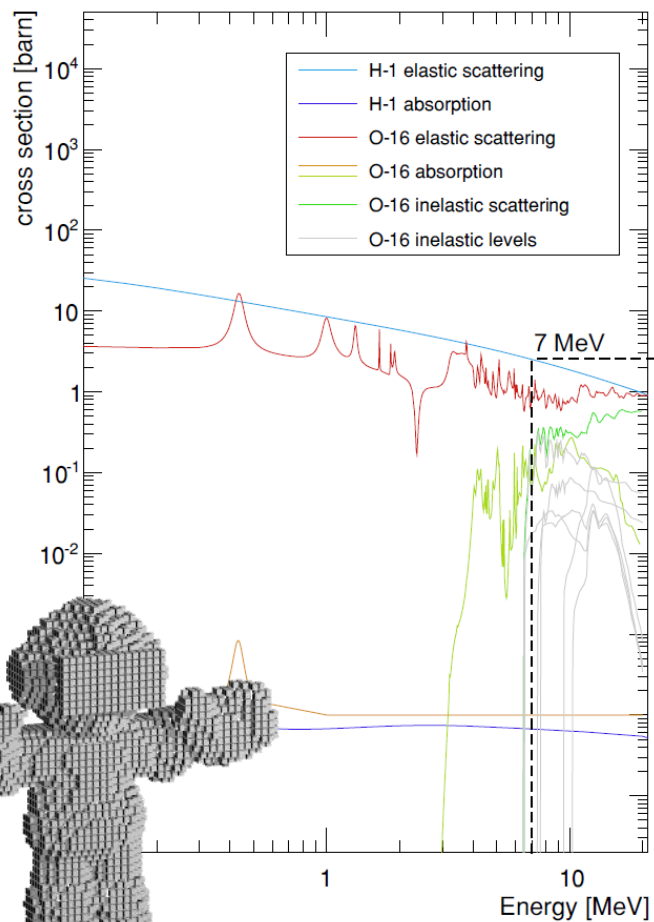
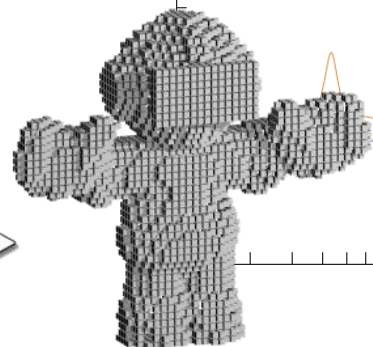
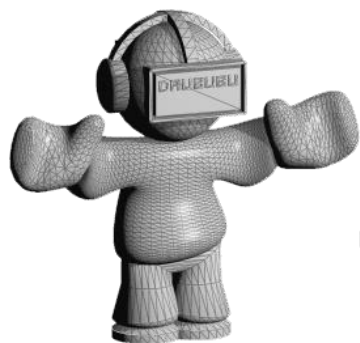
- Voxel Engine



Neutrons interact with volumes,  
(typically) not with surfaces



# Why a voxel engine?







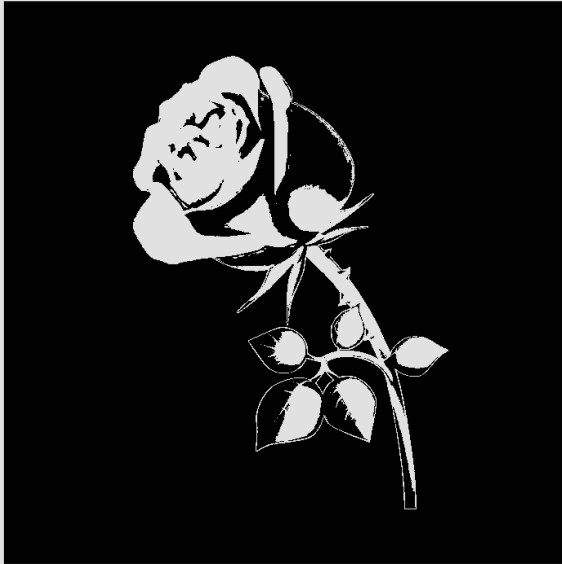
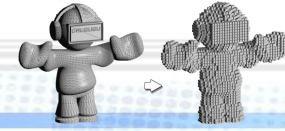
# MCNP input file

```
File Edit Options Buffers Tools Help
[*-mcpngen-*] Pd-103 photon source,H2O phant filled w/cubes,1 cube has a sphere
c Cell Cards
1 1 -10. -1 2 -3          $ sr-90 source in silver foil
2 10 -2.7 -2 4 -3        $ Al filter
3 2 -8.02 -6 20 -5 (1:3:-4) $ SS encapsulation
4 2 -8.02 -8 6 -7        $ SS rod
10 0 -20 21 -22 23 -24 25 fill=1 $ large water box
c 11 4 -1.0 -32 33 -34 35 -30 31 u=1 lat=1 $ water cubes
11 4 -1.0 -32 33 -34 35 -30 31 u=1 lat=1 fill=-1:1 -1:1 -1:1 &
    2 1 25r                $ water cubes
12 3 -1.293e-3 -90 u=2    $ air sphere inside cube
13 2 -8.02 90 u=2        $ SS surrounding sphere inside cube
90 3 -1.293e-3 -100 -21   $ air below box
91 3 -1.293e-3 -100 -20 21 (22:-23:24:-25) $ air around box
92 3 -1.293e-3 -100 20 #1 #2 #3 #4 $ air outside src/rod
100 0 100                $ bounding region

c SURFACE CARDS
1 pz .03574              $ source top plane
2 pz .03074              $ source bottom plane
3 cz .475                $ source outer radius
4 pz .00574              $ Al filter bottom plane
5 cz .525                $ SS encapsulation outer radius
6 pz 1.4                 $ SS encapsulation top plane
7 cz .2                  $ rod outer radius
8 pz 2.4                 $ rod top plane
20 pz 0.                 $ large box top plane
21 pz -1.2               $ large box bottom plane
22 px .6                 $ large box xmax
23 px -.6                $ large box xmin
24 py .6                 $ large box ymax
25 py -.6                $ large box ymin
30 pz -.4                $ cube top plane
31 pz -.8                $ cube bottom plane
32 px .2                 $ cube xmax
33 px -.2                $ cube xmin
:-- samp1 (Mcpngen)--L29--C0--Top
```

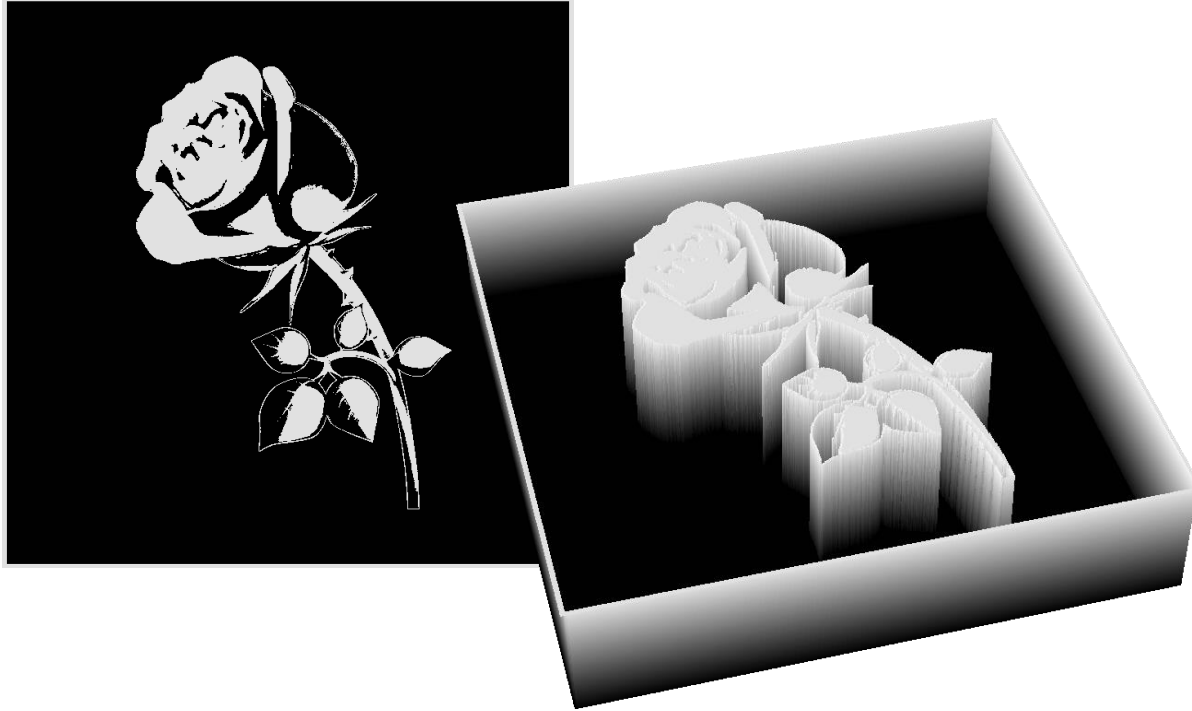
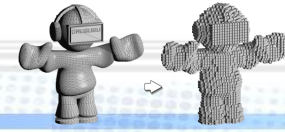


# URANOS voxel engine





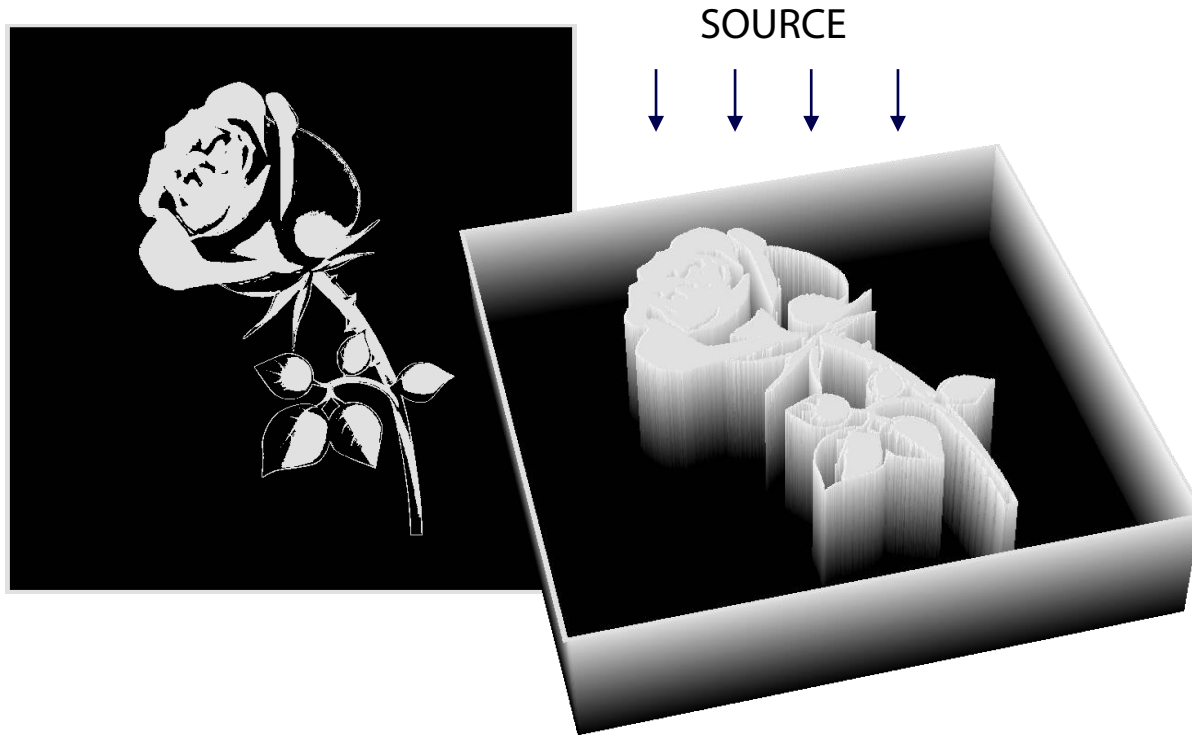
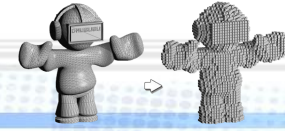
# URANOS voxel engine



polyethylene rose in a box



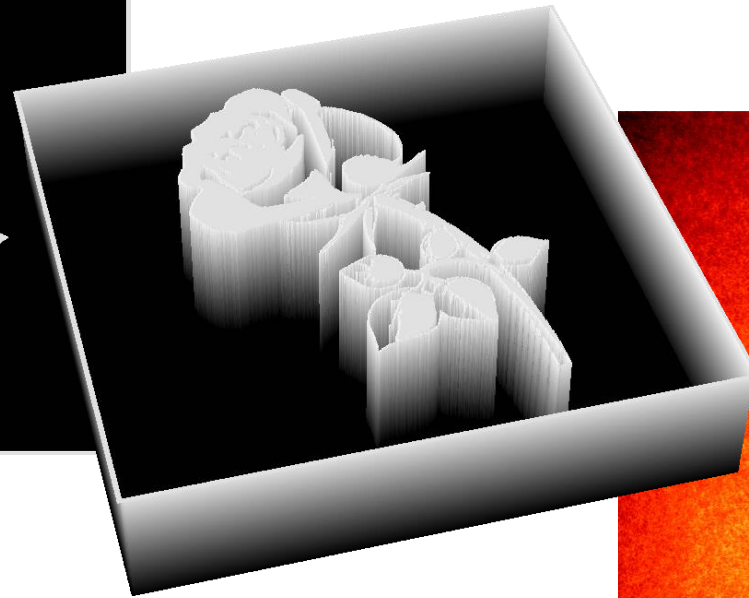
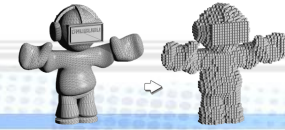
# URANOS voxel engine



polyethylene rose in a box



# URANOS voxel engine



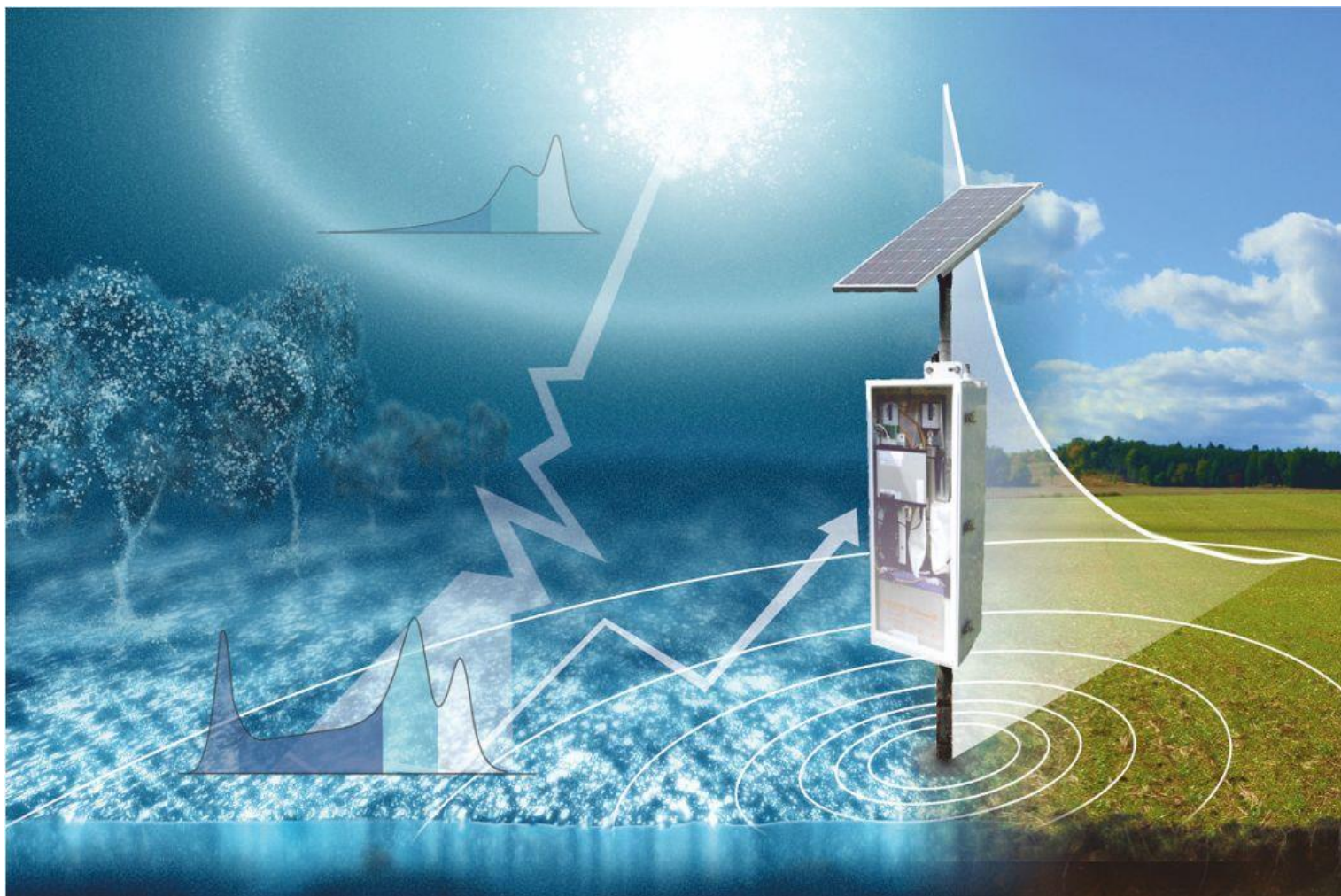
polyethylene rose in a box





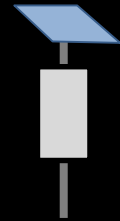
# URANOS

Neutron tool developed in collaboration with environmental sciences



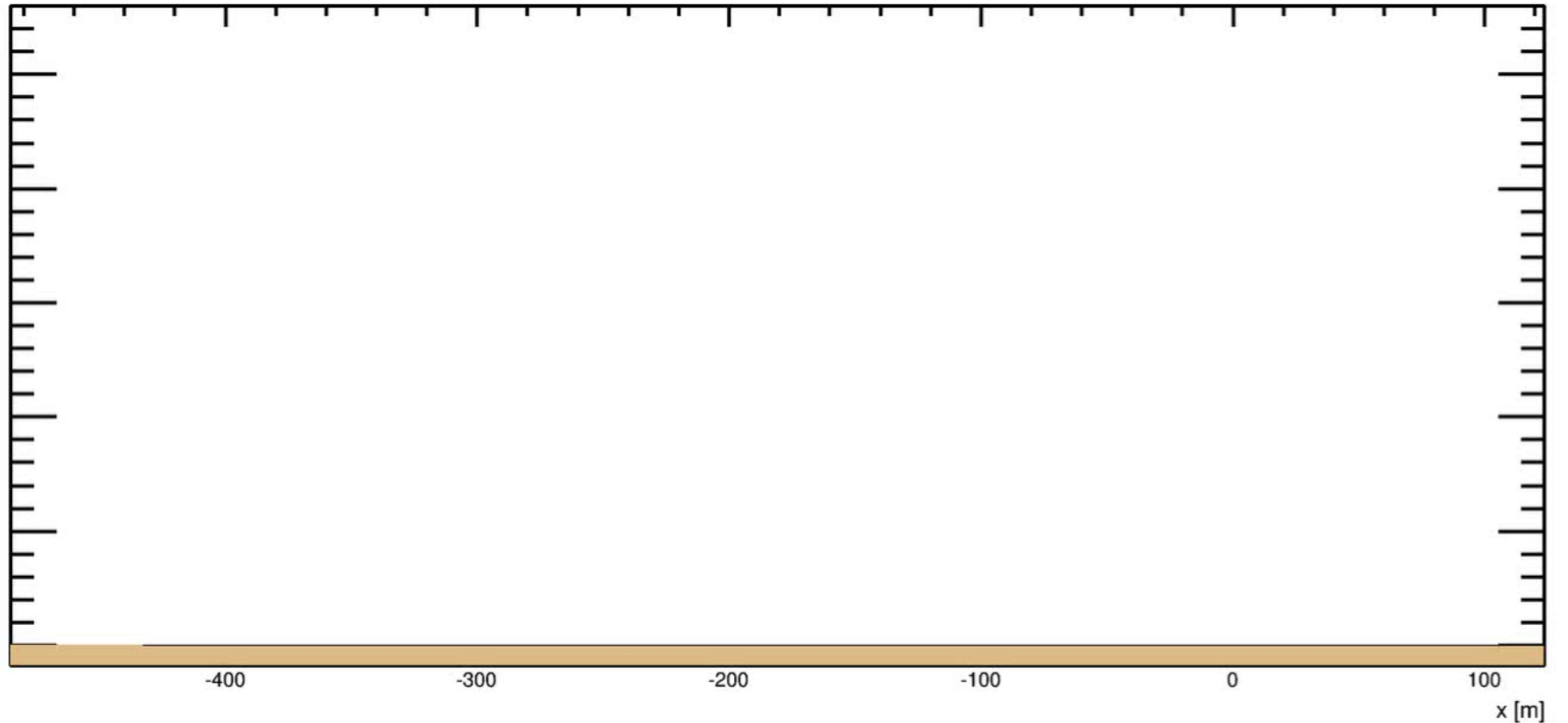


# Neutrons on soil and water





# Neutron Animation (Evaporation)







# USER Interface

URANOS - The Cosmic Neutron Soil Moisture Simulator

Simulate Pause Stop Clear #neutrons: Neutrons: 939100 maximum: 5000000 (537/s) -02:06:02 Refresh status every 100 neutrons Export

Physical Parameters Computational Parameters Detector Setup Export & Display

Soil Moisture [Vol%] 6 %  
Air Humidity 7  
Atmospheric depth [g/cm<sup>2</sup>] 1020

Topological presets (water, land)  
 None  
 River, width [m] 10  
 Coast at x [m] 0  
 Island, diameter [m] 10  
 Lake, diameter [m] 10

Layers are arranged in the vertical direction, representing different materials or 2D gridded patterns

Position	Height	Material	Matrix
1	-1000	920	11
2	-80	30	11
3	-50	48	11
4	-2.5	0.5	11
5	-2	2	11
6	0	3	20

Source Layer 2  
Detector Layer 4  
Ground Layer 6

Material Codes  
 Use layer maps  
View layer maps  
Load Save

Live: Birds-eye View & Spectra Range View Spatial View

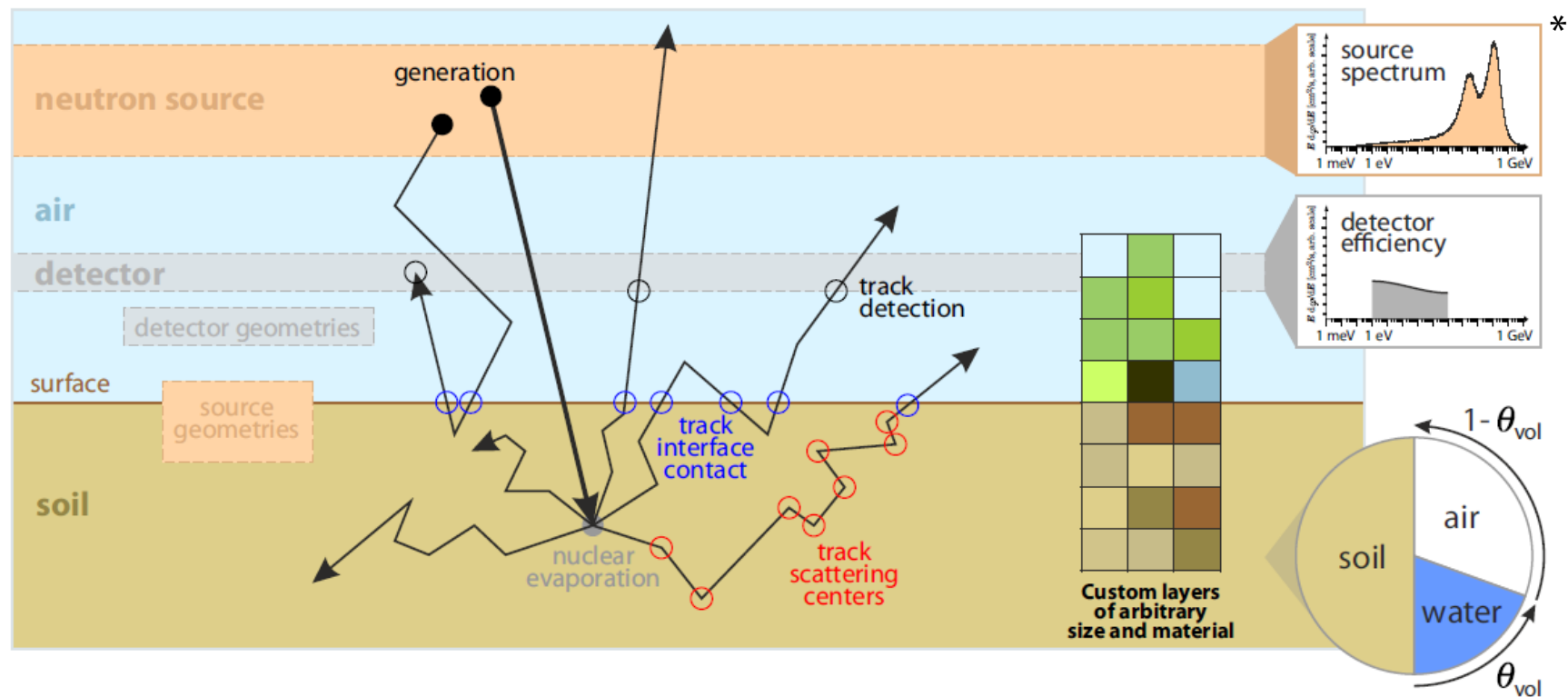
x [m] y [m]

Incoming Spectrum  
Surface Spectrum  
Backscattered Spectrum

n  
Energy [MeV]



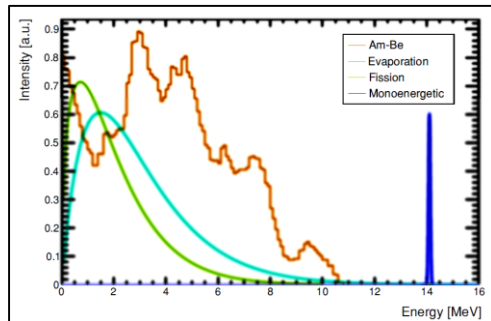
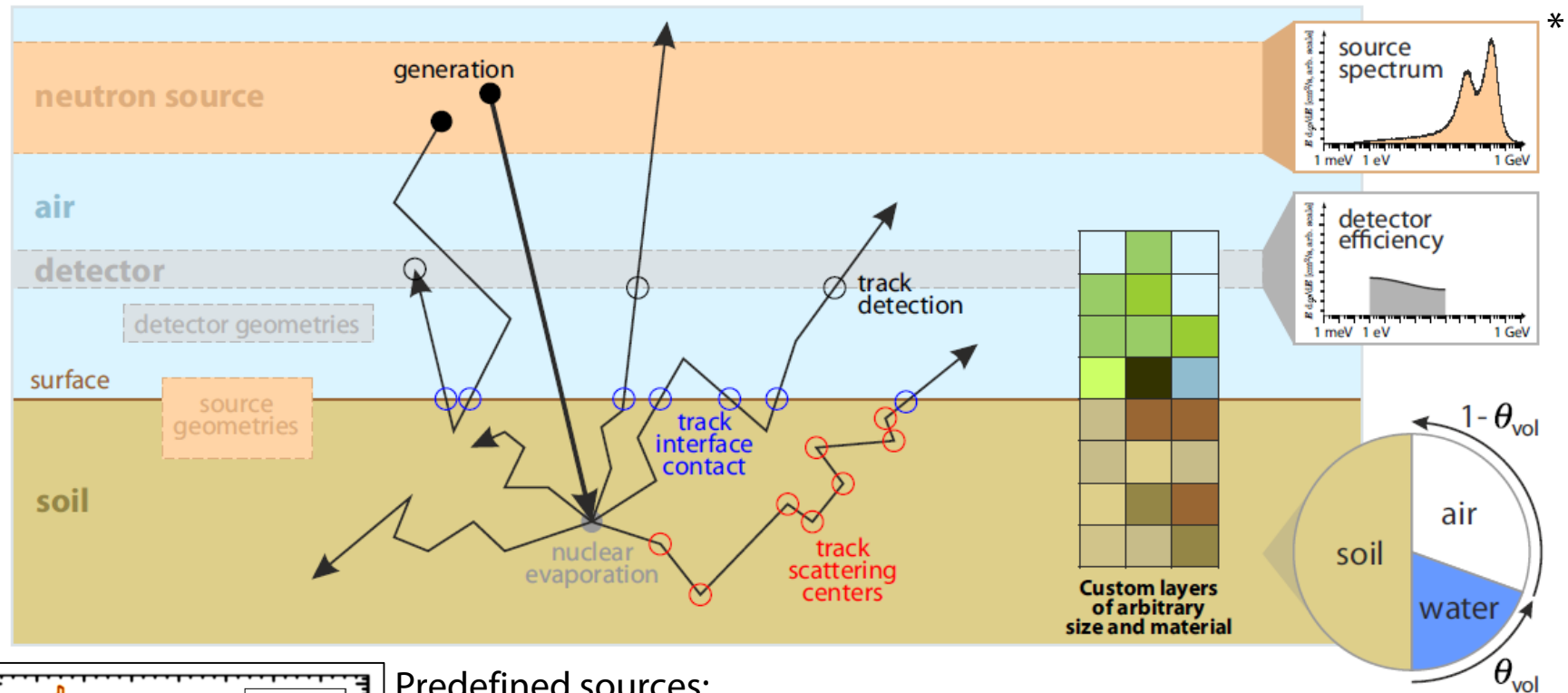
# URANOS Buildup



\* T. Sato  
Features and applications of  
the analytical model for  
estimating terrestrial cosmic-  
ray fluxes: PARMA/EXPACS



# URANOS Buildup



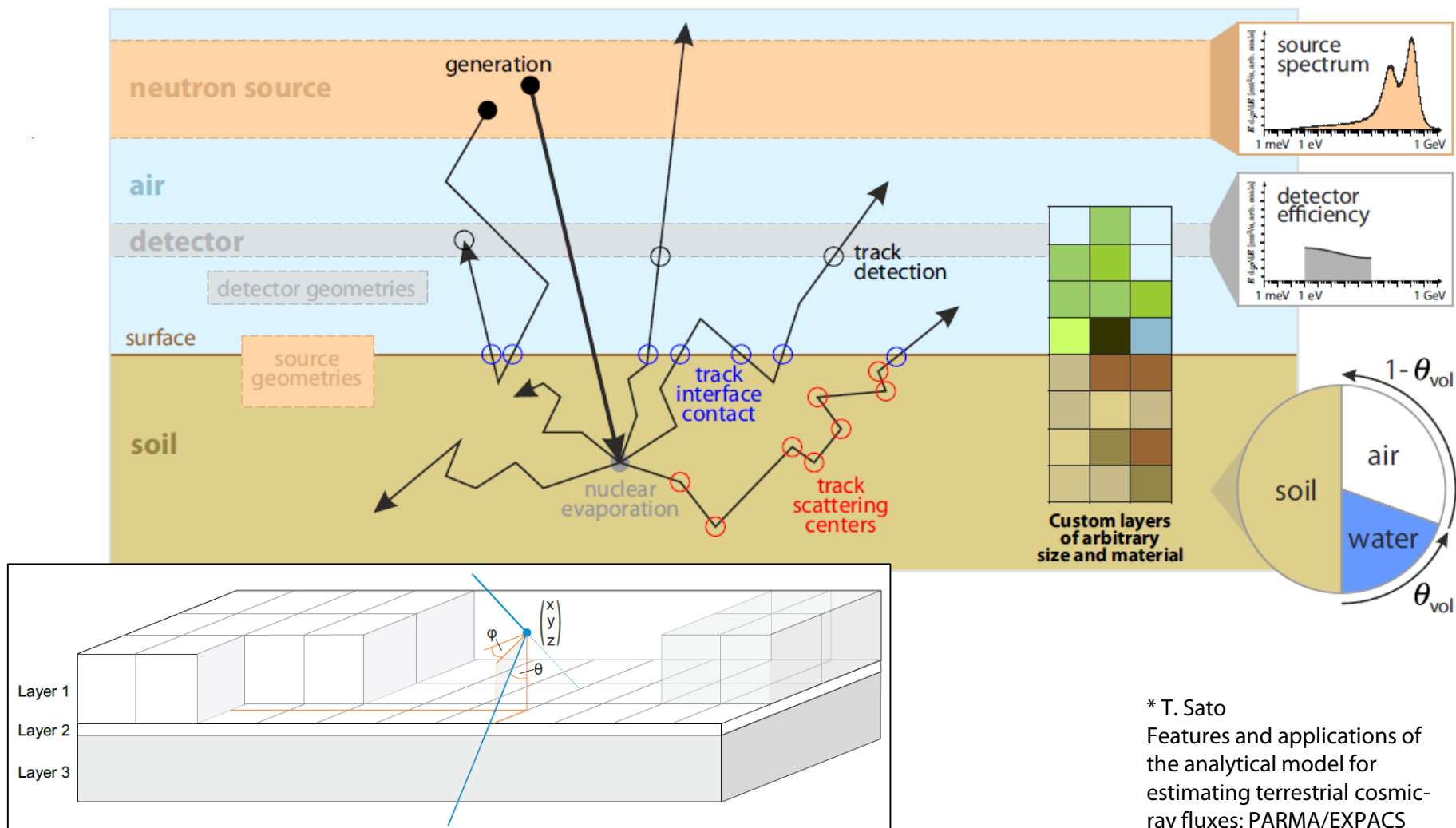
Predefined sources:

- Thermal
- Fusion
- Fission
- AmBe
- Moderated Cf

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 Features and applications of  
 the analytical model for  
 estimating terrestrial cosmic-  
 ray fluxes: PARMA/EXPACS



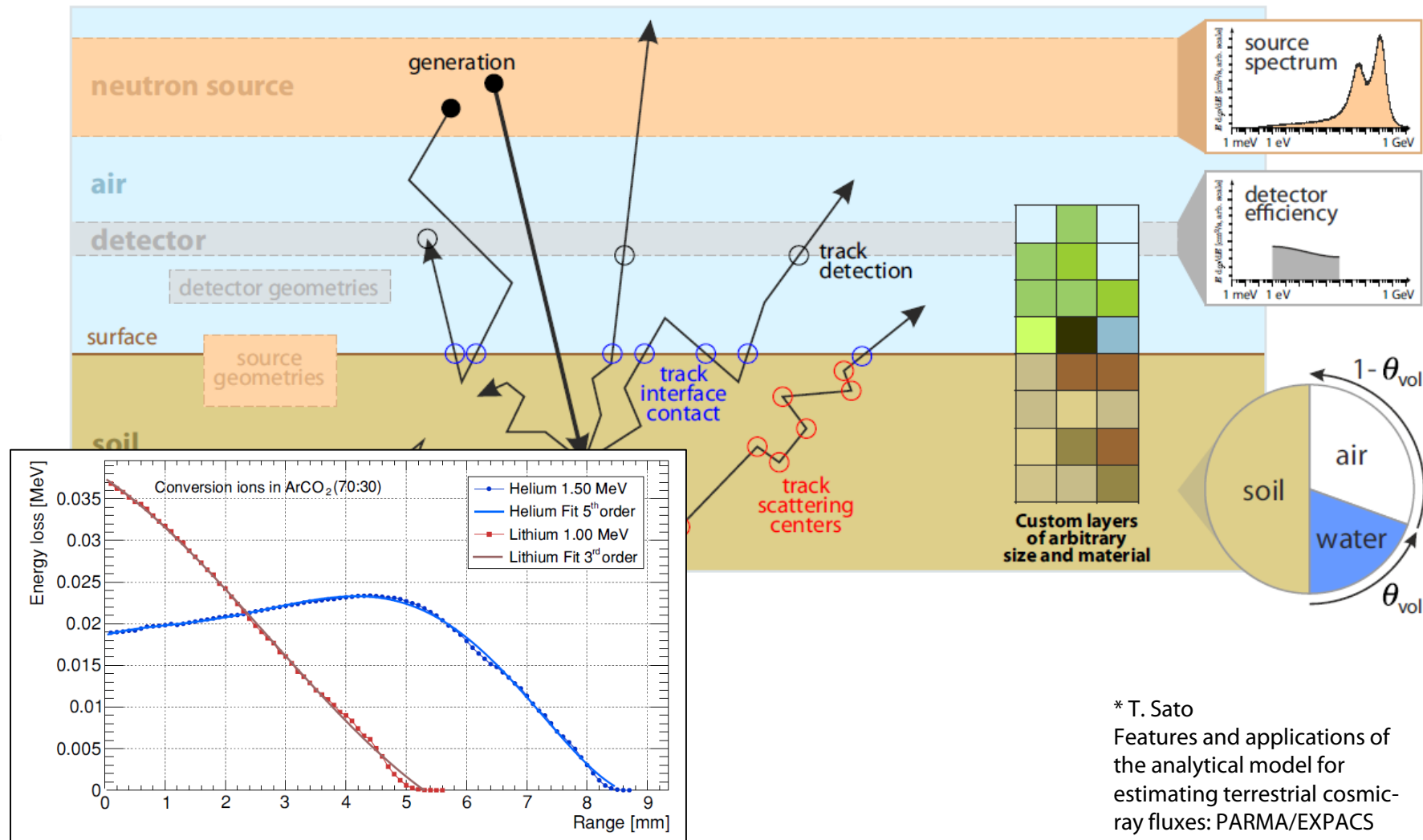
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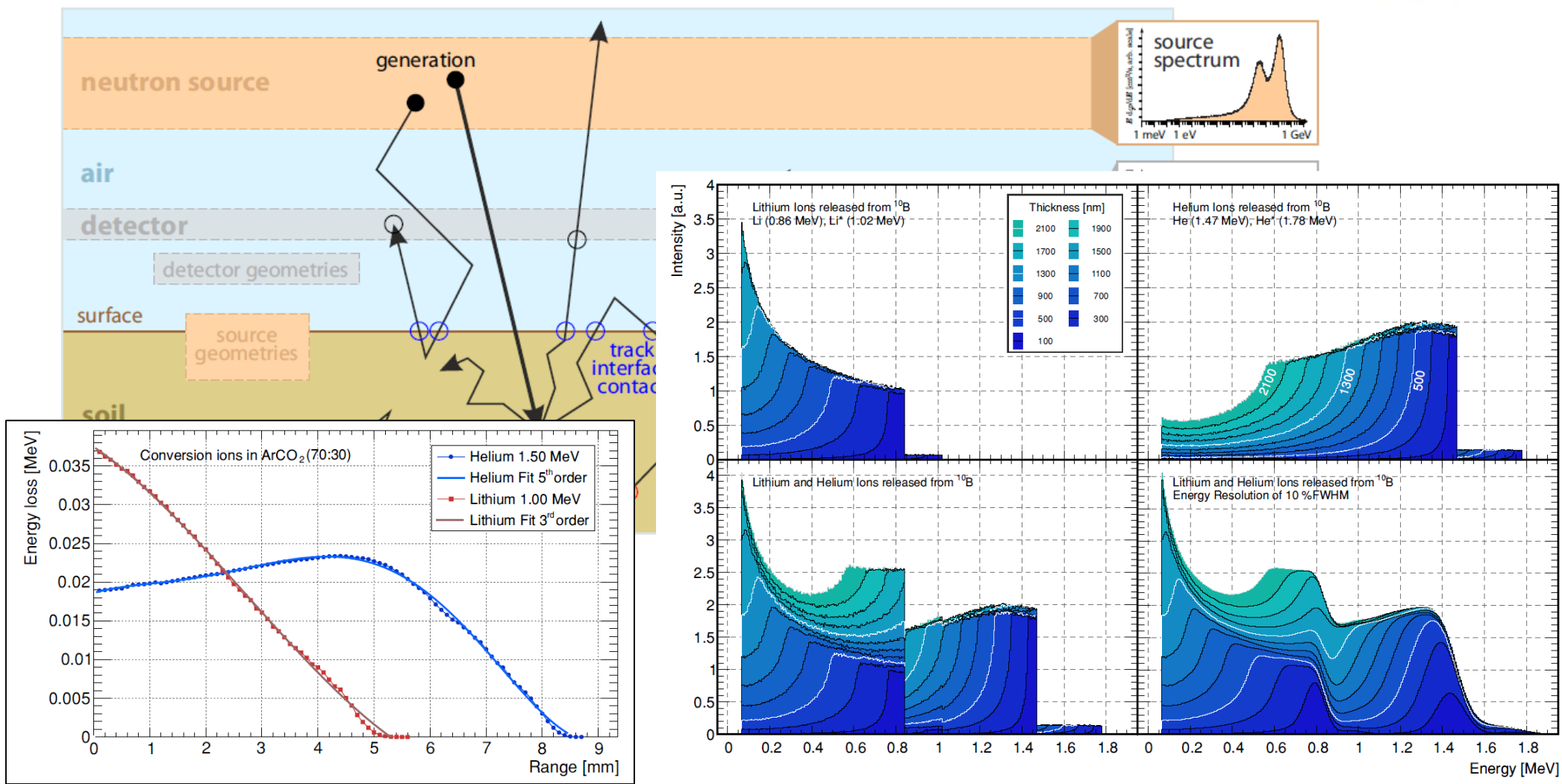
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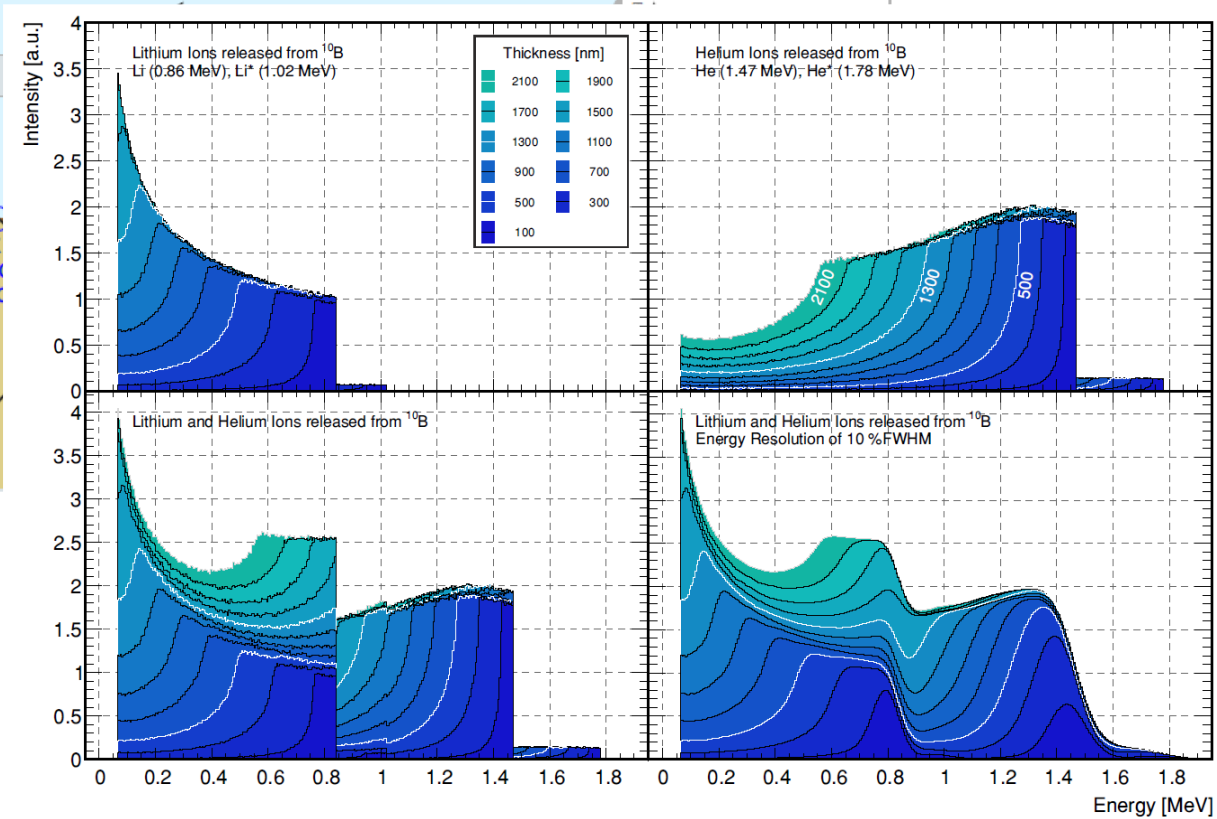
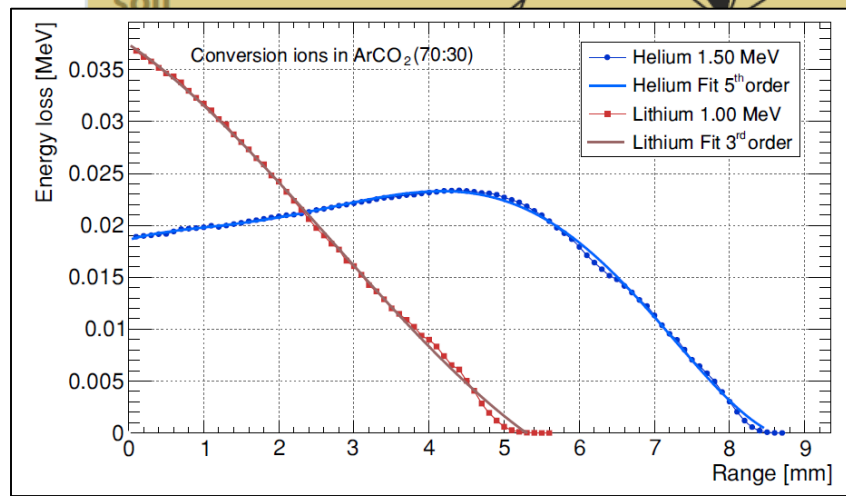
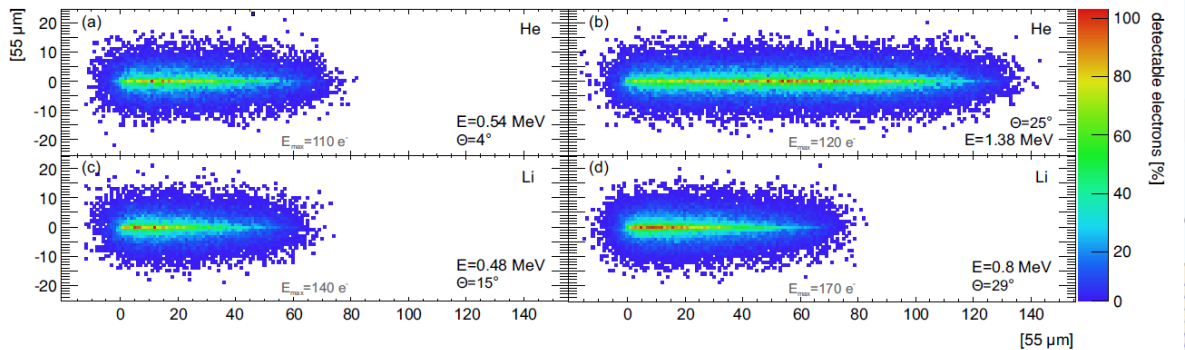


# URANOS Buildup





# URANOS Buildup





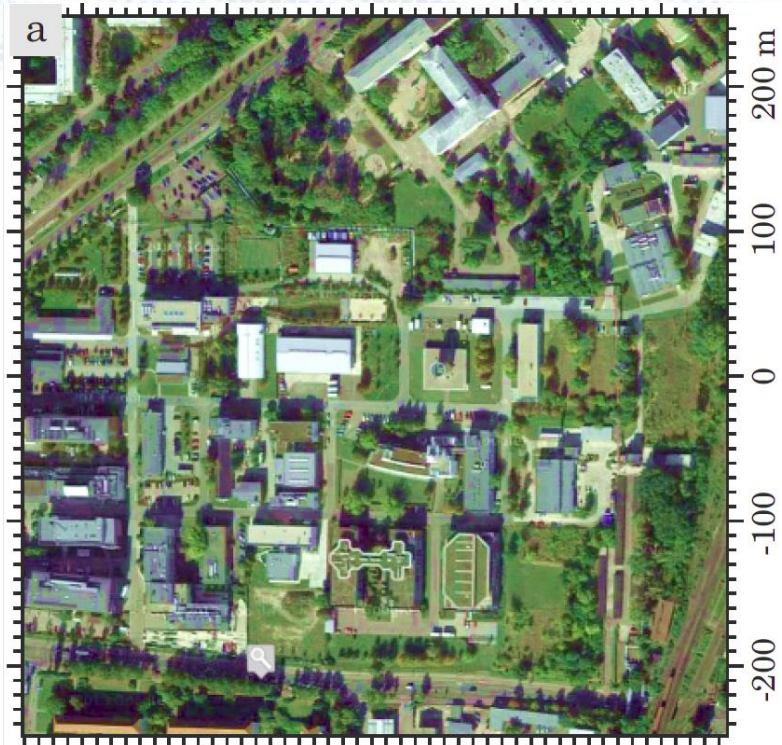
# Performance

N <sup>o</sup>	name	description	Performance [n/(s·GHz·core)]			
			URANOS	MCNP6	GEANT4	
1	std. setup	water body, 5 g/m <sup>3</sup> air humidity NTP	930	300	70	Epithermal & Fast & High Energy
2	std. setup	ground with 10 % soil moisture, 5 g/m <sup>3</sup> air humidity NTP	450		31	
3	std. setup	ground with 1 % soil moisture, 5 g/m <sup>3</sup> air humidity NTP	265	250	17	
4	std. setup	like N <sup>o</sup> 1, with full domain tracking enabled	710			With Thermal
5	std. setup	like N <sup>o</sup> 1, with thermal transport enabled	260	260	16	
6	std. setup	like N <sup>o</sup> 3, with thermal transport enabled	130	220	9	
7	std. setup	like N <sup>o</sup> 3, with thermal transport and full domain tracking enabled	120			
8	UFZ site	with 10 % soil moisture	500			
9	UFZ site	like N <sup>o</sup> 8, without voxel geometry but same layering	420			
10	detector	thermal spectrum onto a side face with $\vartheta = 0^\circ$	9170			
11	detector	like N <sup>o</sup> 10, with an americium-beryllium spectrum	4060			

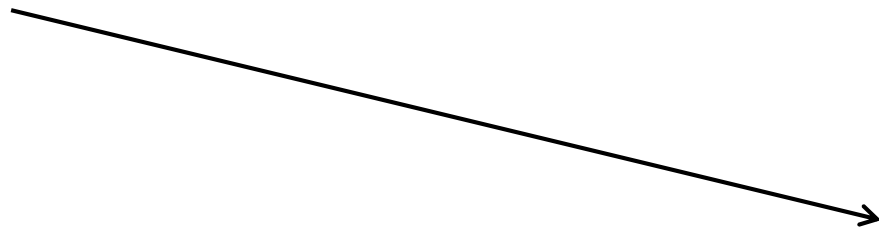




# Modeling steps

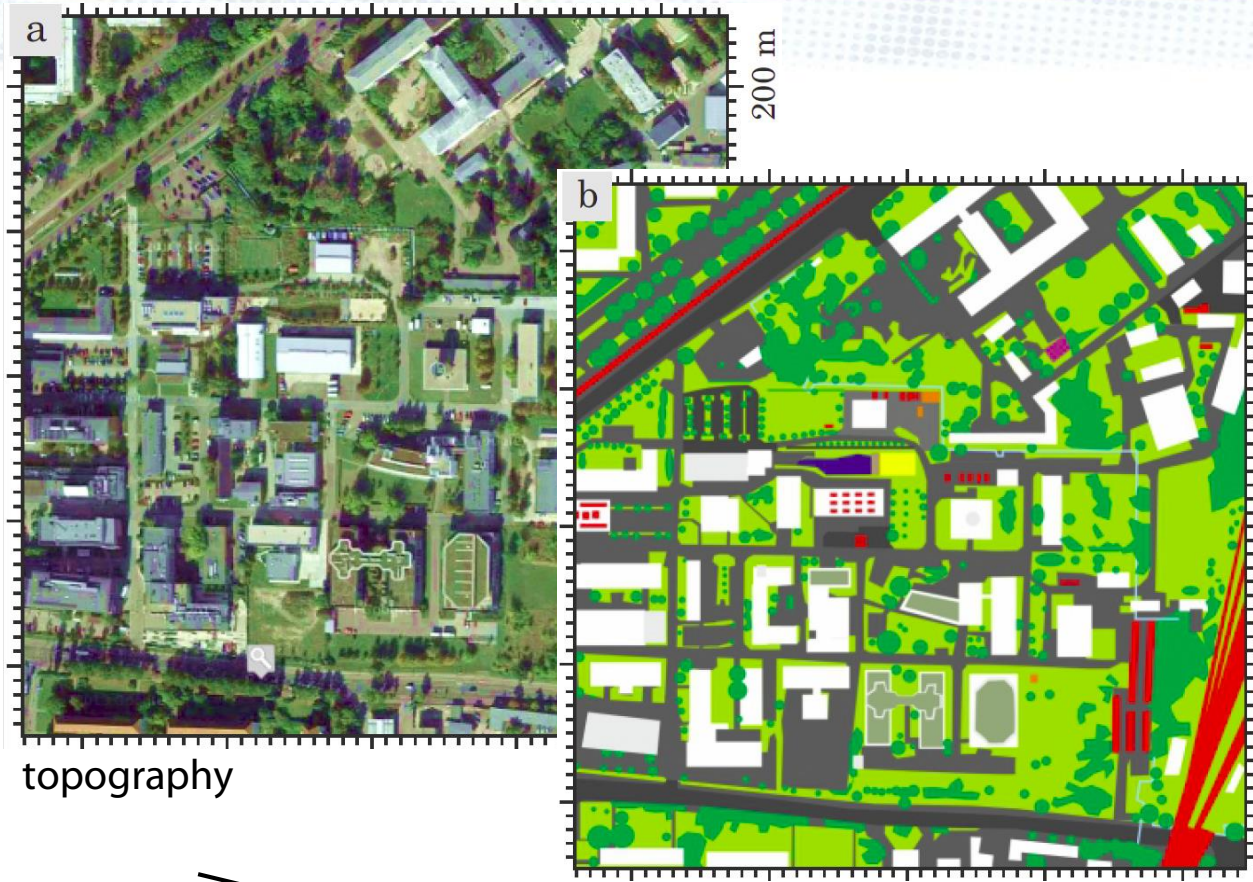


topography



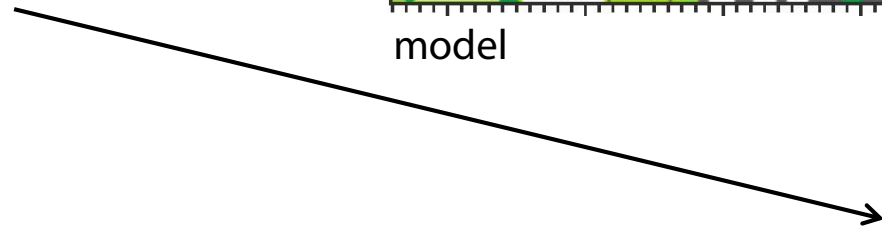


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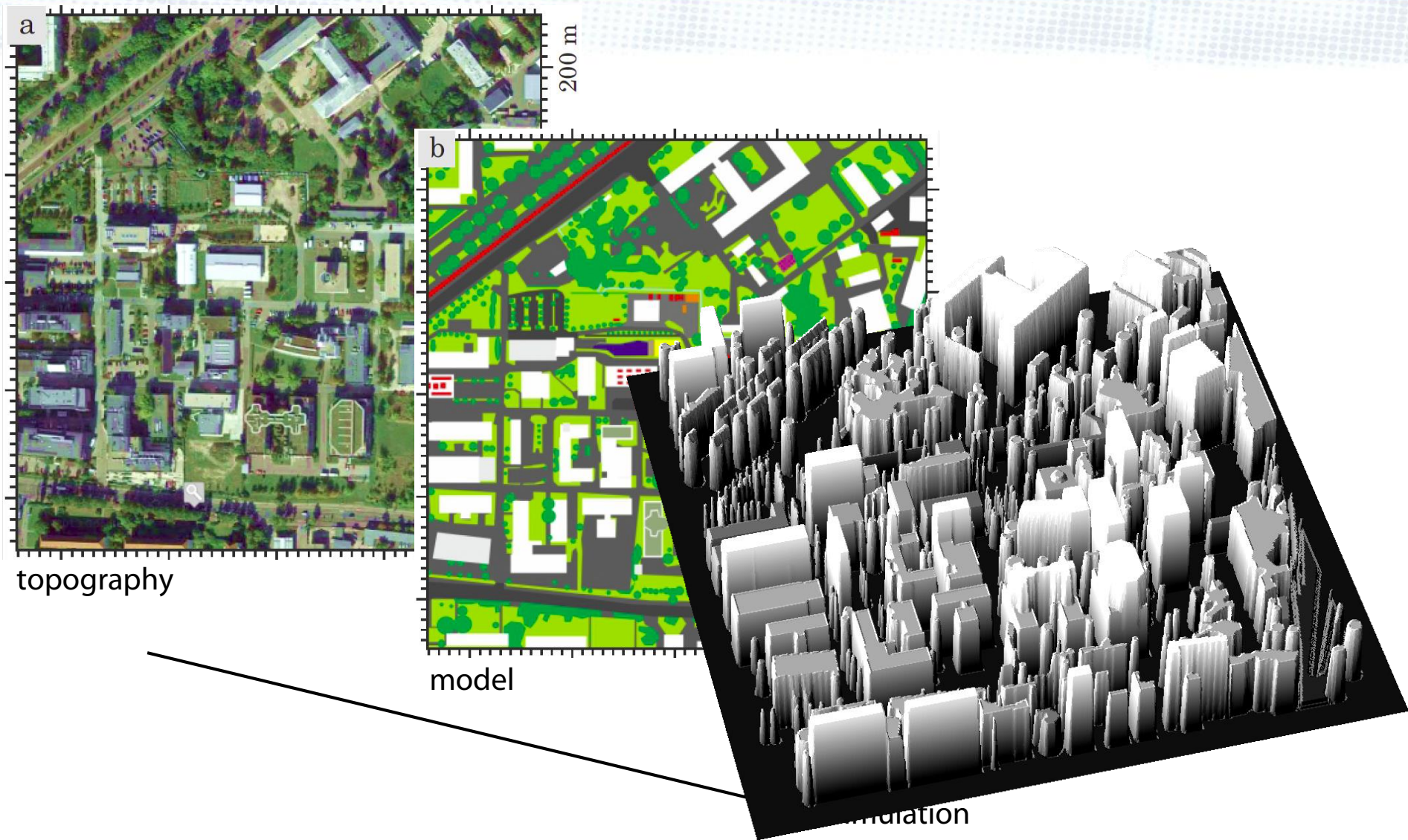
topography

model



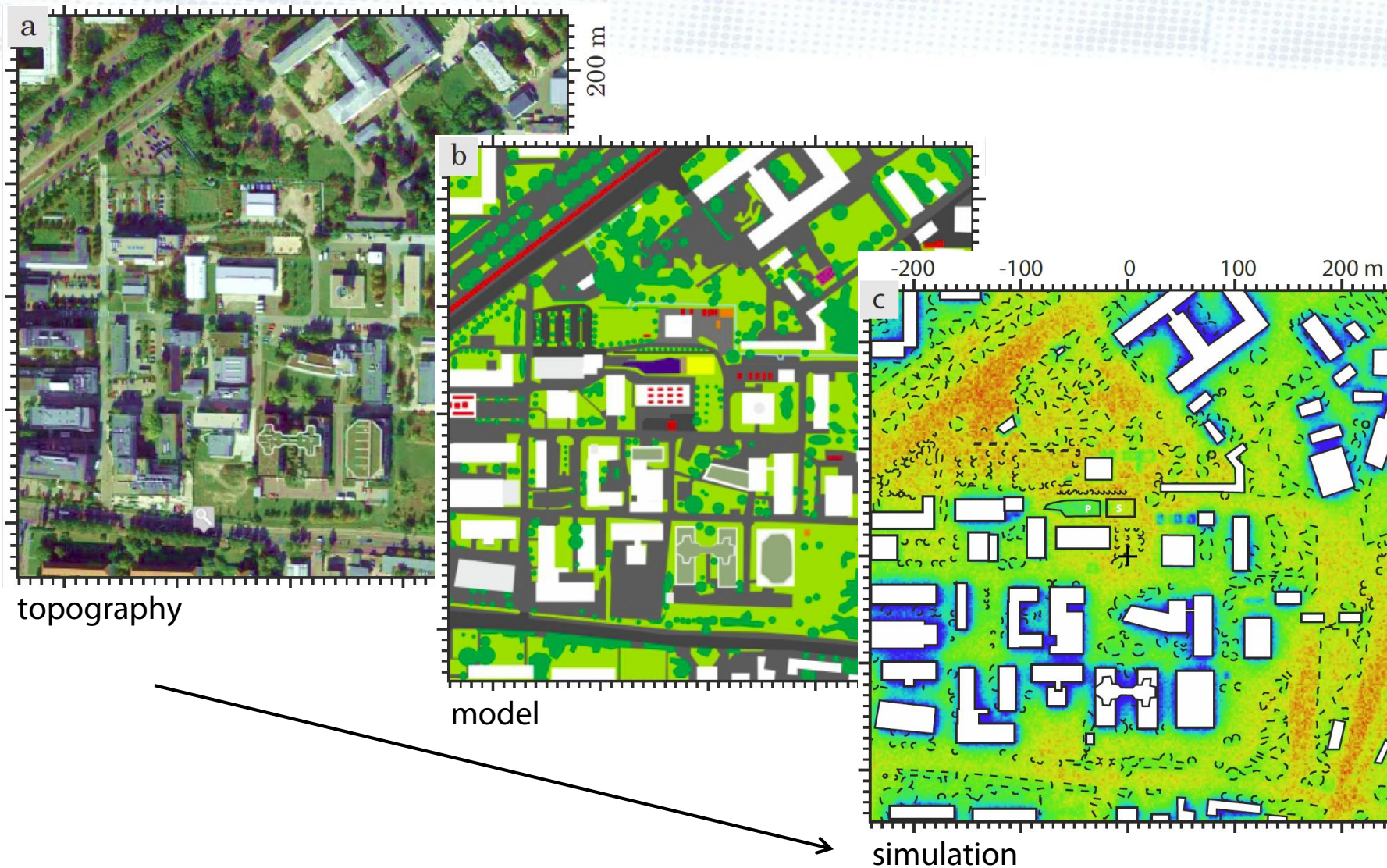


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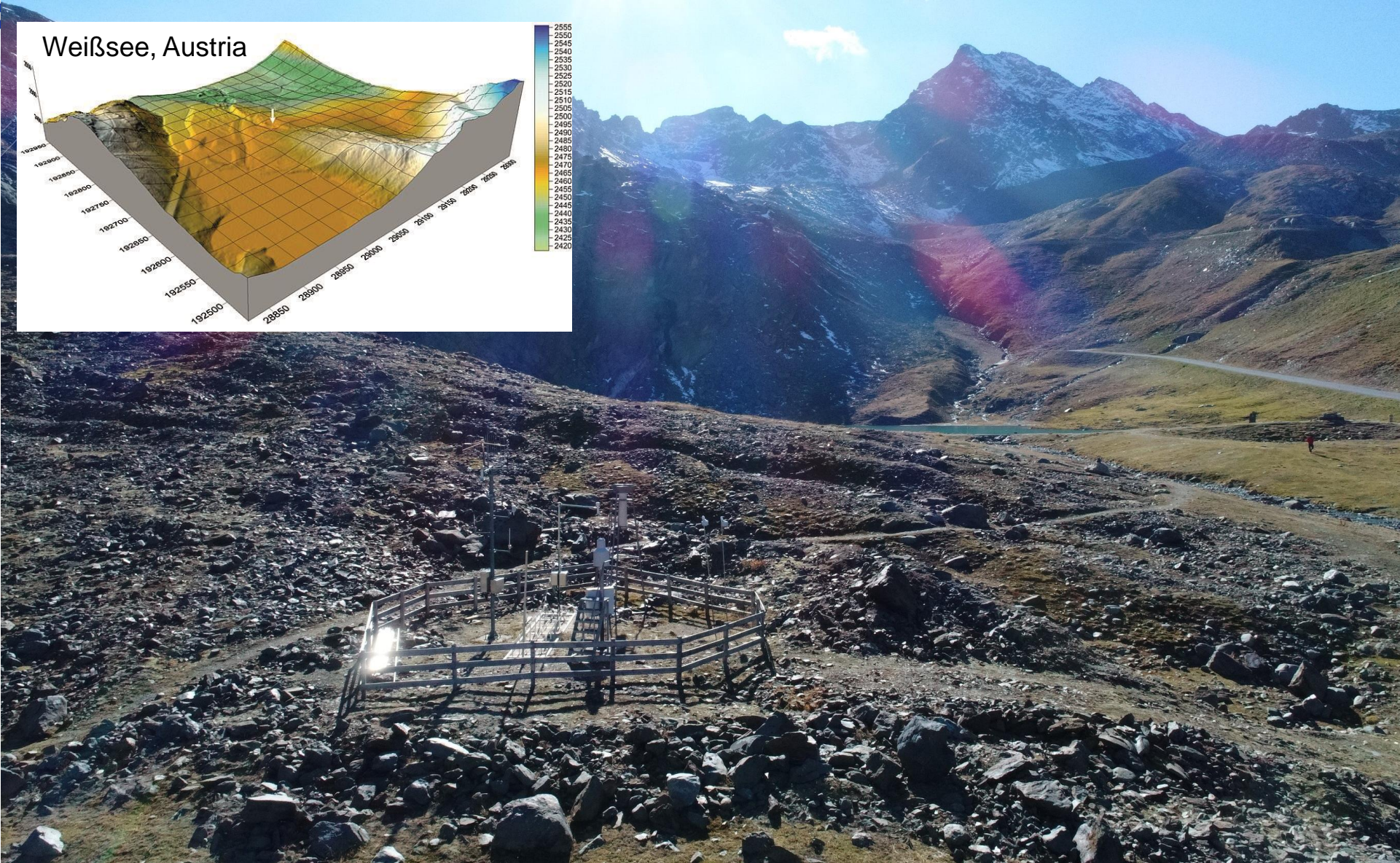


# Modeling steps





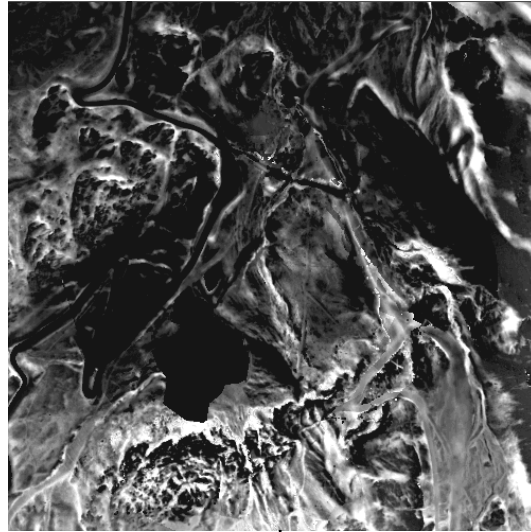
# Snow Water Equivalent



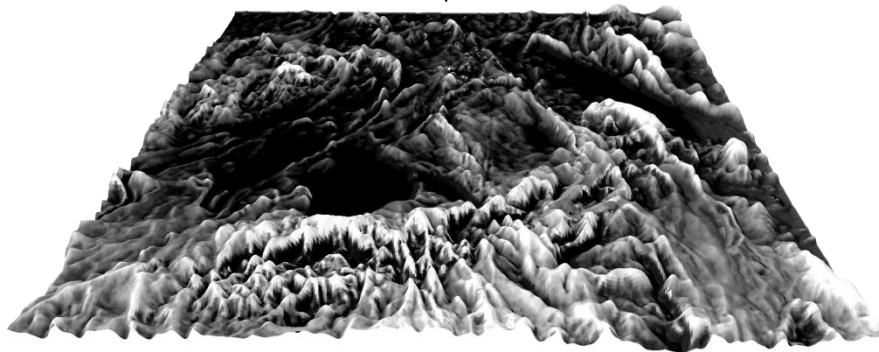


# URANOS voxel engine

3D Laser Scanner



P. Schattan  
– Kaunertal  
Glacier at  
N46° 52.2  
E10 °42.6

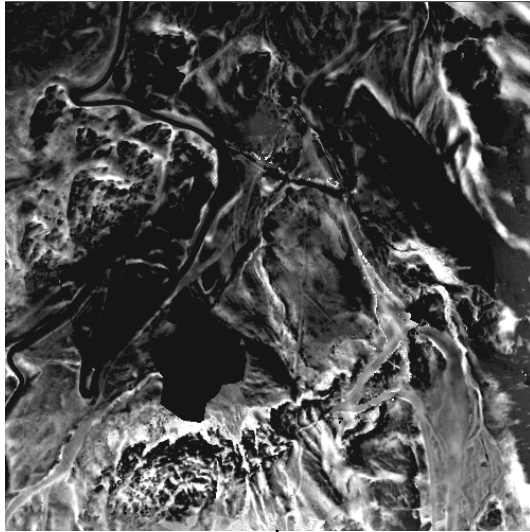


\* P. Schattan  
Cosmic-ray neutron sensing of snow water equivalent in heterogeneous alpine terrain

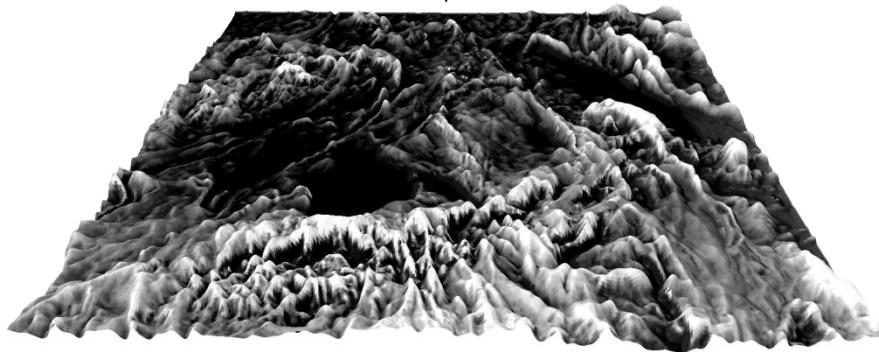


# URANOS voxel engine

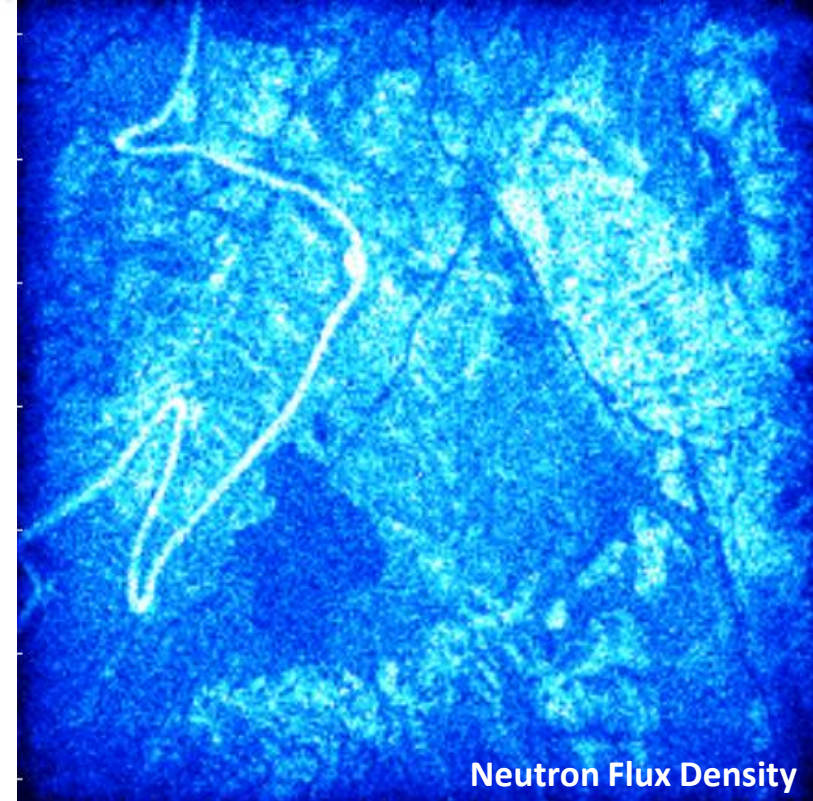
3D Laser Scanner



P. Schattan  
– Kaunertal  
Glacier at  
N46° 52.2  
E10 °42.6



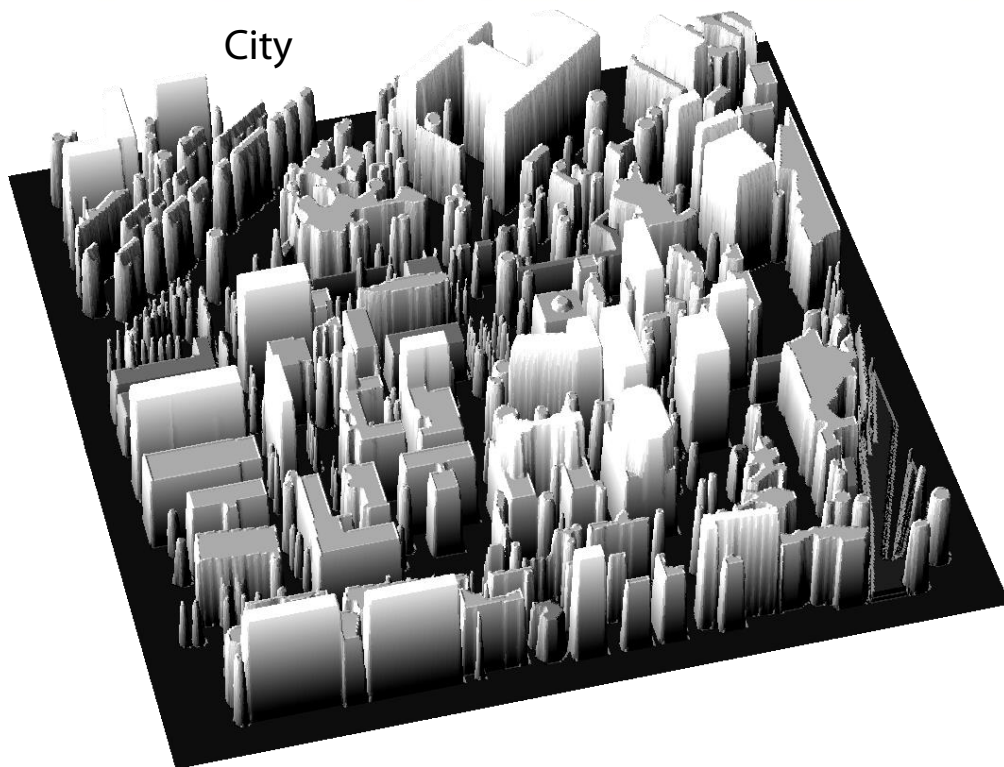
\* P. Schattan  
Cosmic-ray neutron sensing of snow water equivalent in heterogeneous alpine terrain



Neutron Flux Density



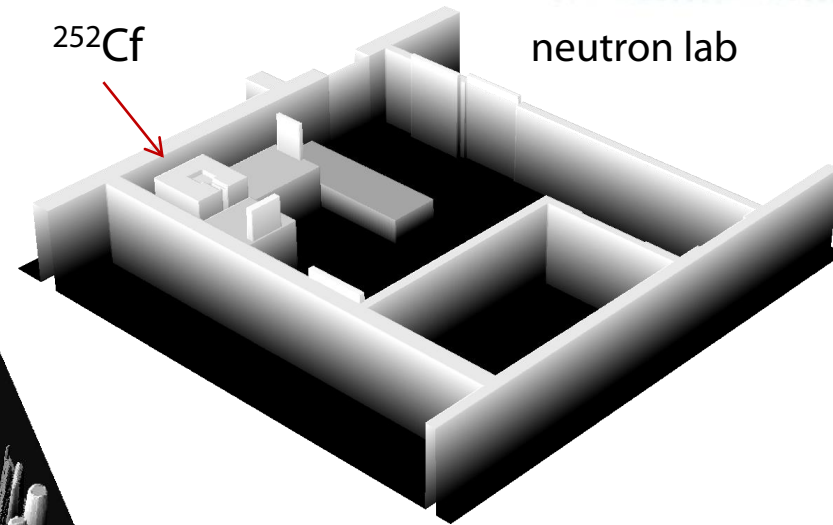
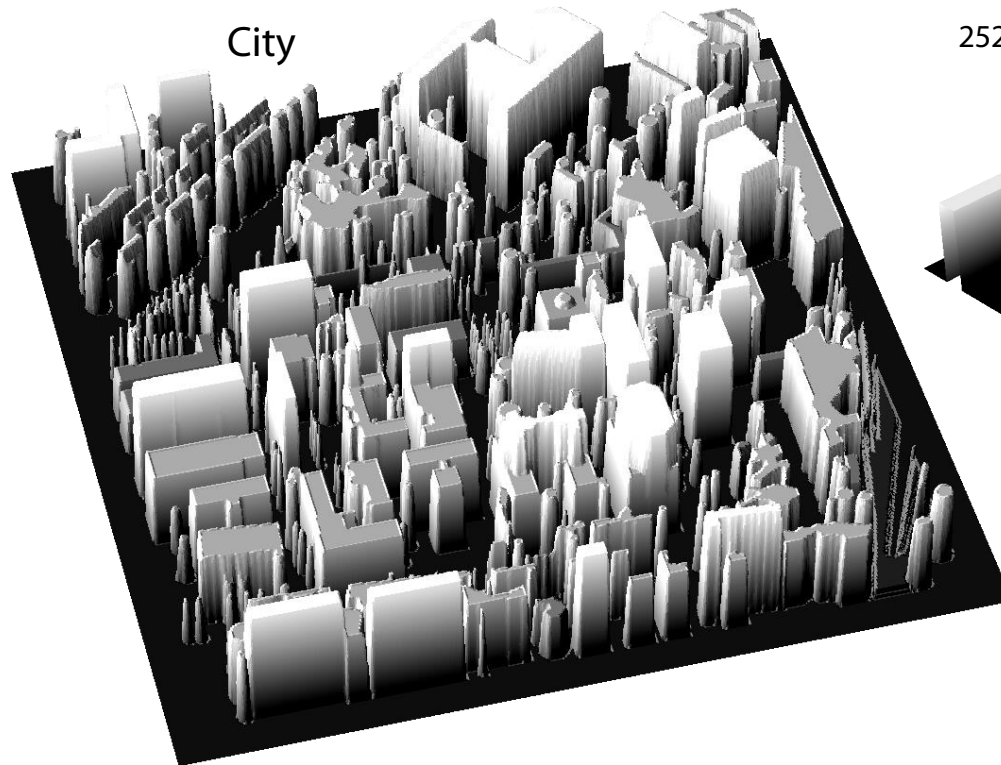
# URANOS voxel engine





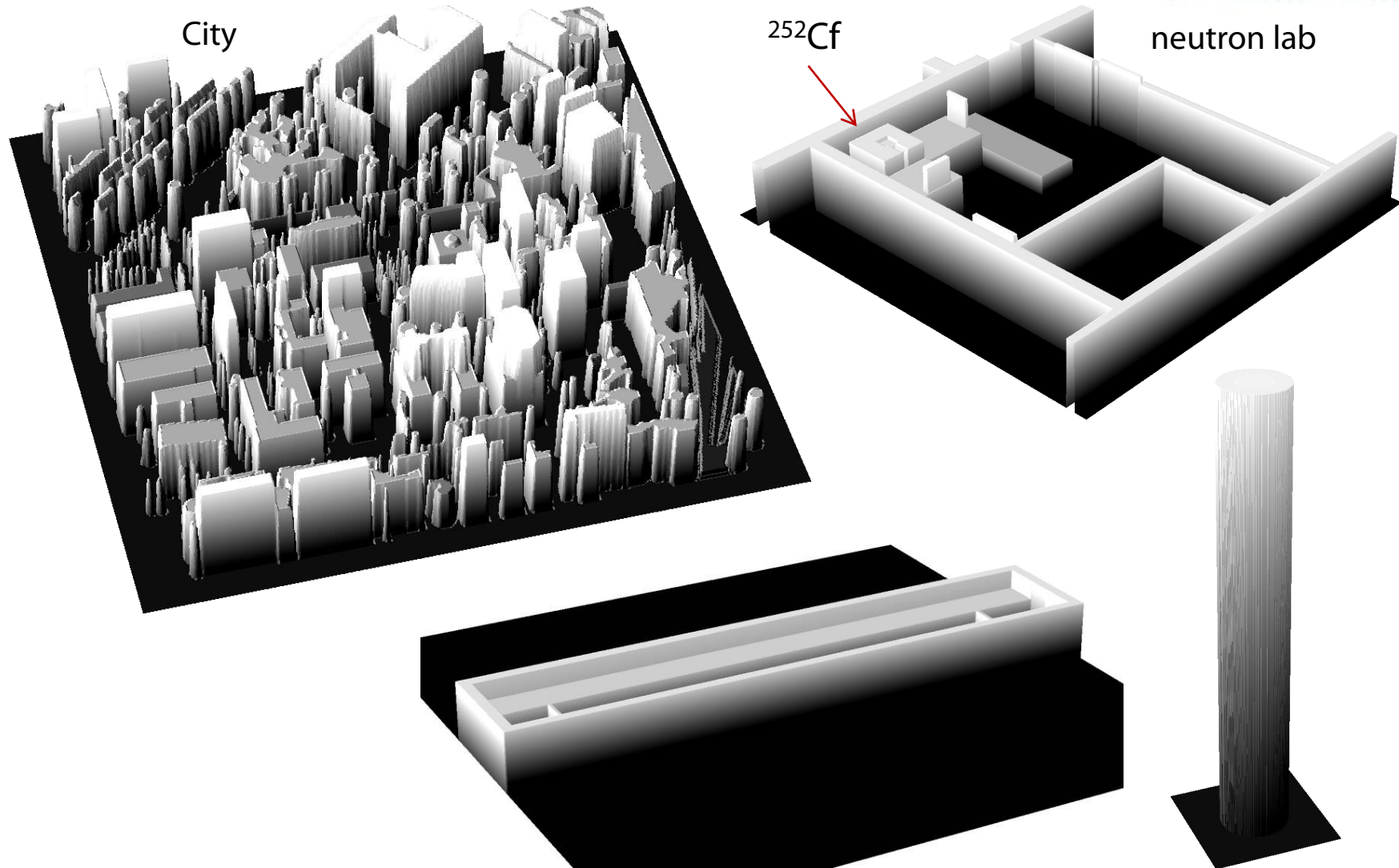


# URANOS voxel engine





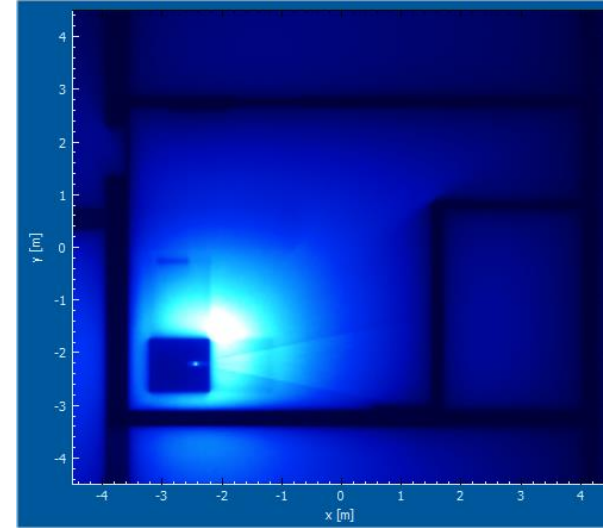
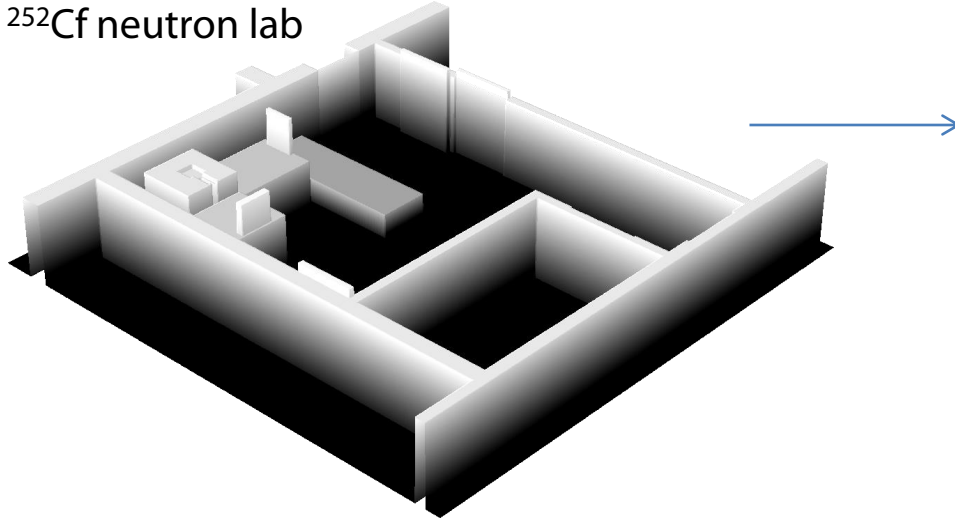
# URANOS voxel engine





# URANOS voxel engine

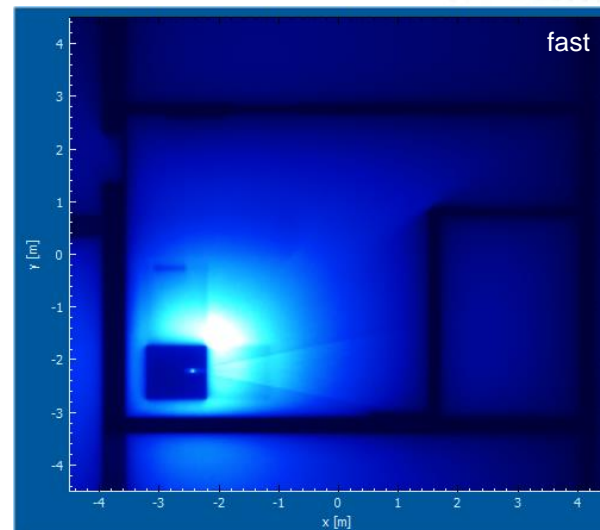
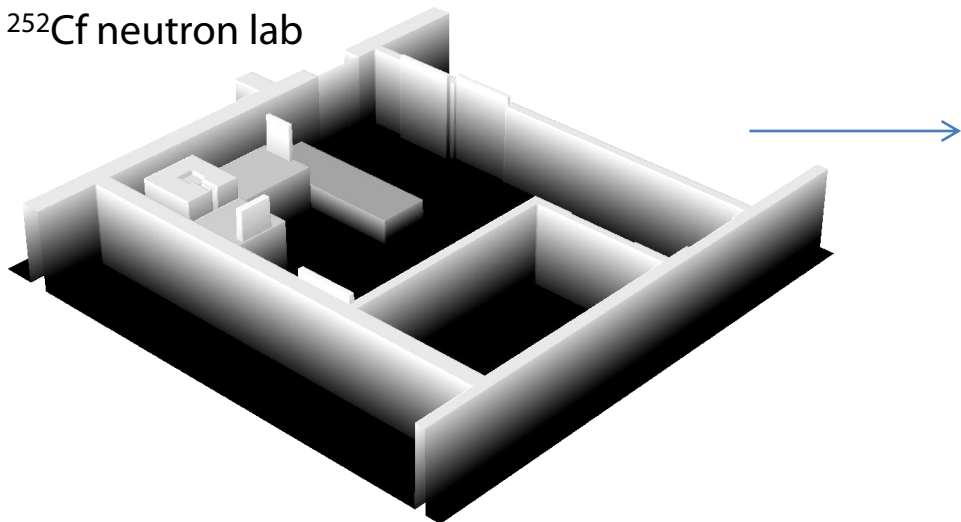
$^{252}\text{Cf}$  neutron lab



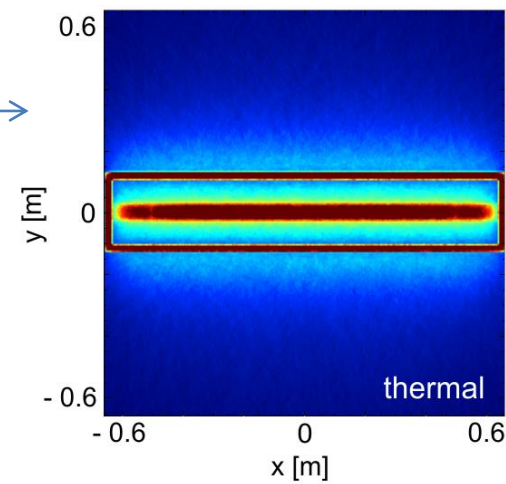
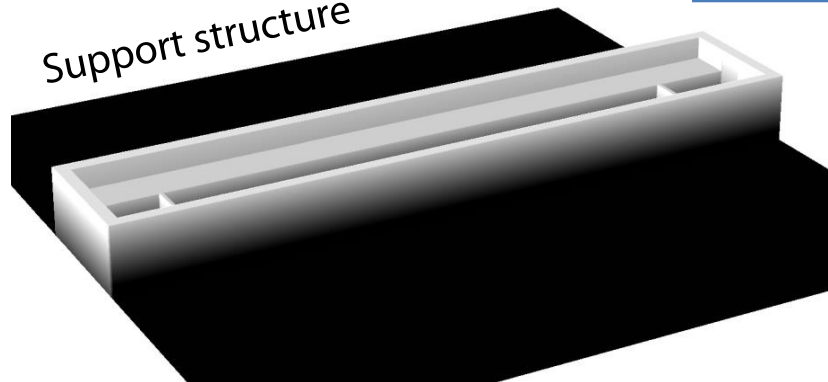


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$^{252}\text{Cf}$  neutron lab

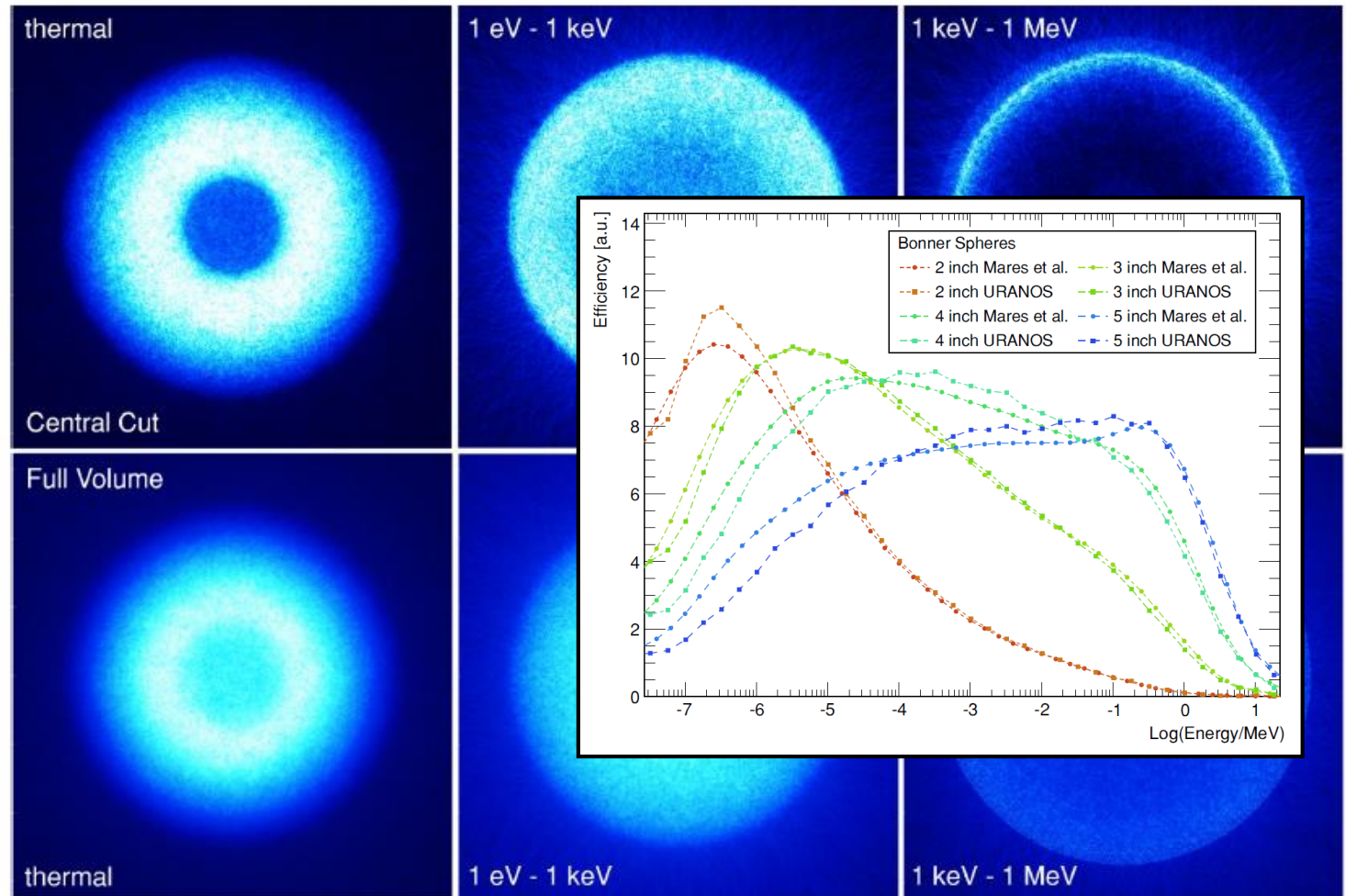
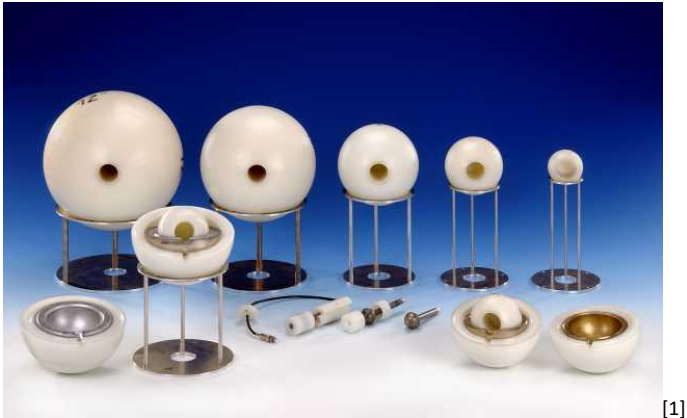


Support structure



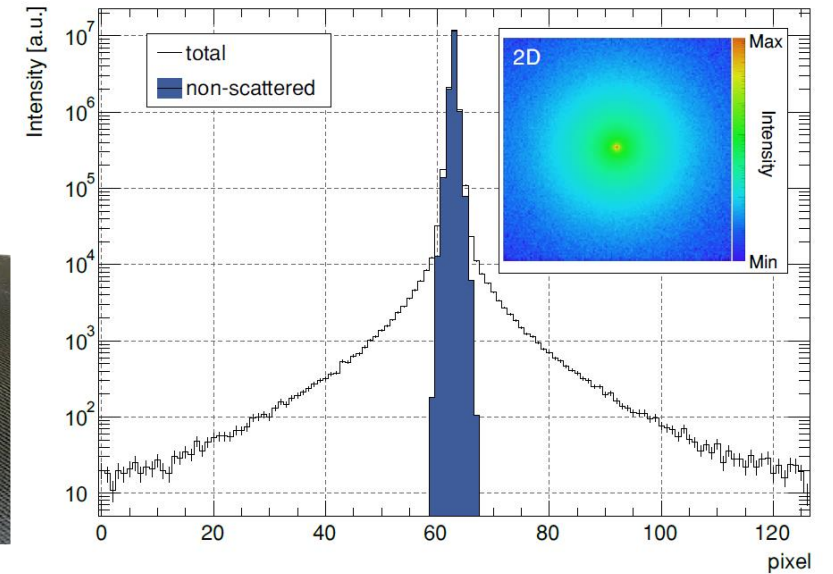
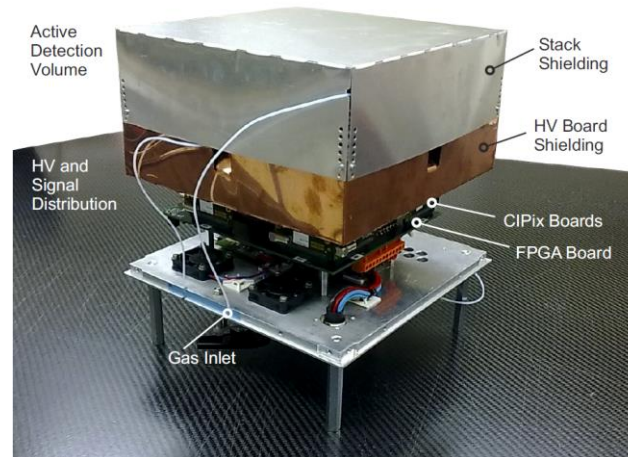
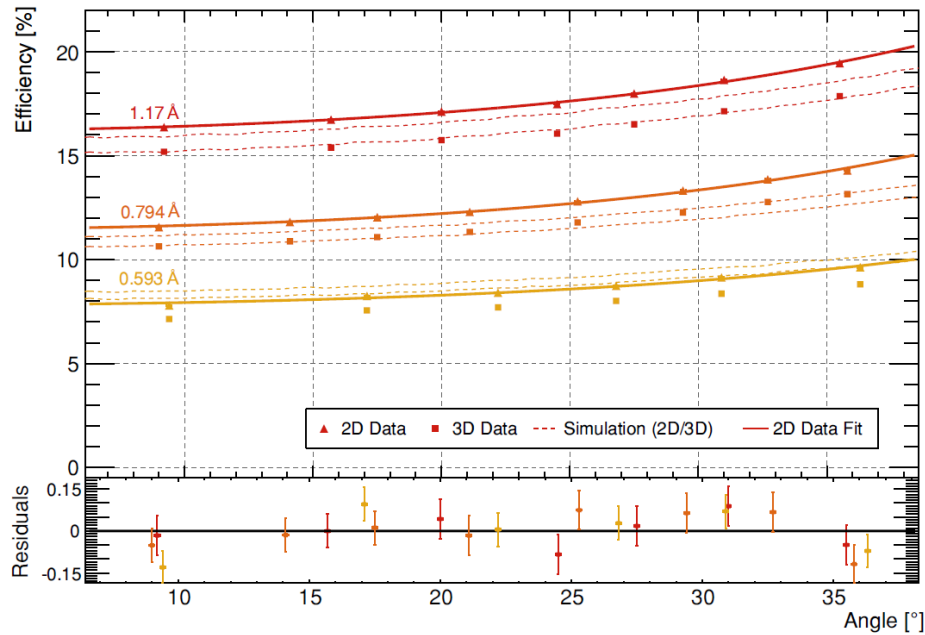
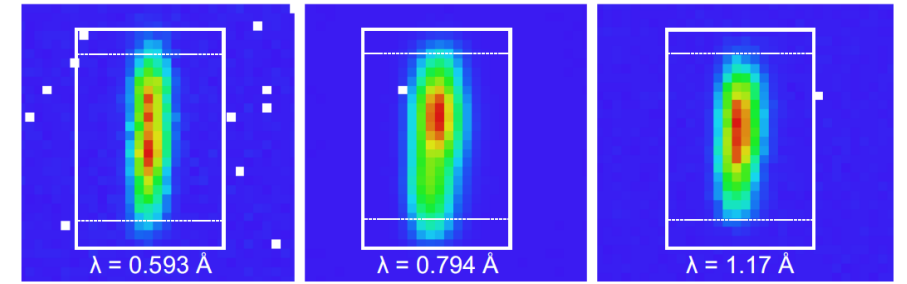
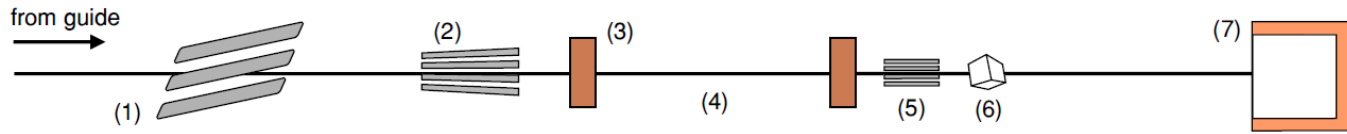


# Bonner Spheres





# Detector efficiency calculation





# URANOS Demonstration

---



# User interface

URANOS - The Cosmic Neutron Soil Moisture Simulator

URANOS

Simulate Pause Stop Clear #neutrons: 317730 maximum: 2000000 (1062/s) Refresh every 210 neutrons Save CFG Export

Physical Parameters Computational Parameters Detector Showcase Folders Export Display

Soil Water Content [Vol%] 10 %  
Soil Porosity [Vol%] 50 %  
Air Humidity 0.40 g/m<sup>3</sup>  
Air Humidity Exponential Length Inf  
Atmospheric depth 1020 g/cm<sup>2</sup>  
Cut-off rigidity [GV] 10

Layers are arranged in the vertical direction, representing different materials or 2D gridded patterns  
Position z denotes the depth below surface (z=0) in [m] and refers to the upper edge of the layer  
Layers override topological presets

Layers	Position	Height	Material	Matrix
1	-0.45	0.05	11	1M [700]
2	-0.4	0.15	11	2M [700]
3	-0.25	0.05	11	3M [700]
4	-0.2	0.15	11	4M [700]
5	-0.05	0.05	11	5M [700]
6	0	0.003	20	

Layer Control  
- Minimum Configuration  
+ Generate  
Source Layer 3  
Detector Layer 3  
Ground Layer 6  
Material Codes  
 Use layer maps  
View layer maps  
Layer Configuration  
Load Save

Load Equipment  
 Nuclear Fission Source  
 Nuclear Fusion Source  
 AmBe Laboratory Source  
 Moderated Californium Source  
 Monoenergetic [MeV] 1  
 Thermal  
 None  Theronuclear Transport

x Position 0.404587 y Position 0.03125 z Position -0.225  
x Size 0 y Size 0 z Size 0 Radius 0  
Opening Angle -1 Directional Angle -1  
Source Direction  
  ->  <-

Live: Birds-eye View & Spectra Range View Spatial View Detector

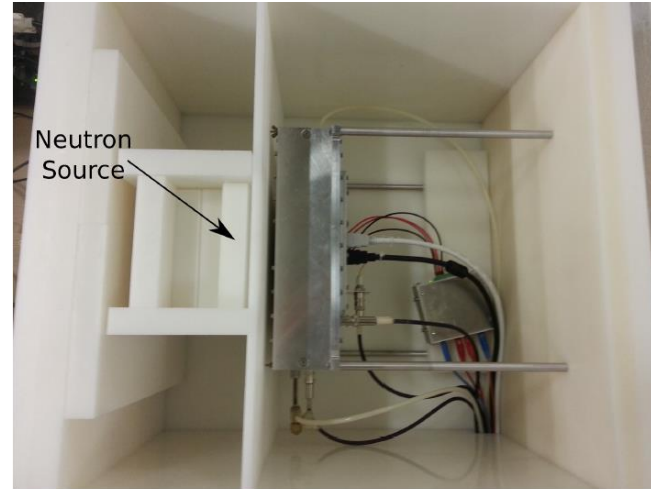
1421852064 + +

7000  
6000  
5000  
4000  
3000  
2000  
1000  
0  
n  
10<sup>-6</sup> 0,0001 0,01 1 100  
Energy [MeV]  
Incoming Spectrum  
Surface Spectrum  
Backscattered Spectrum



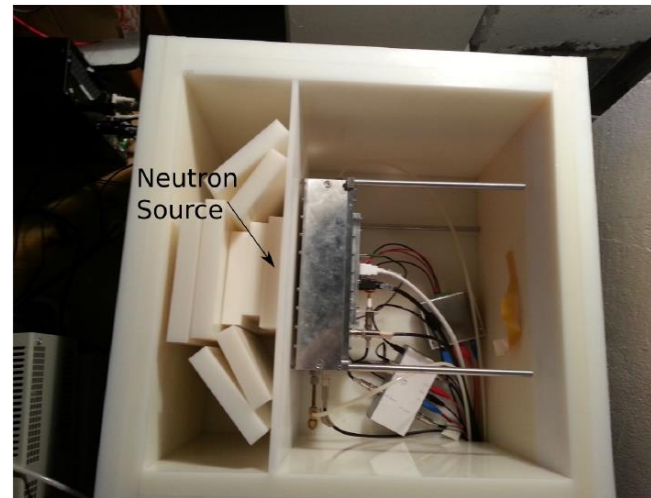
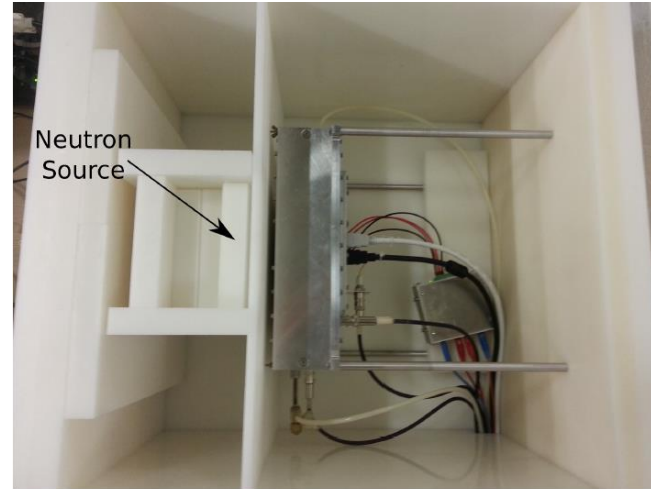


# Small-scale detector test



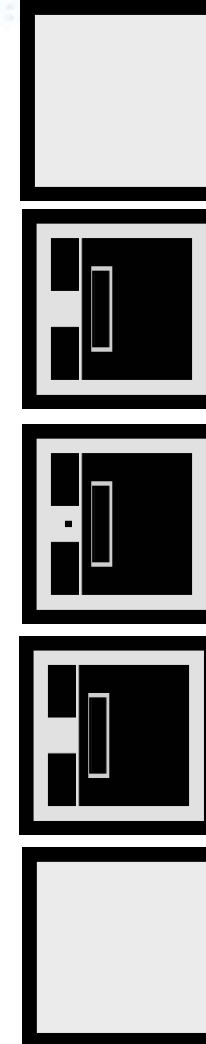
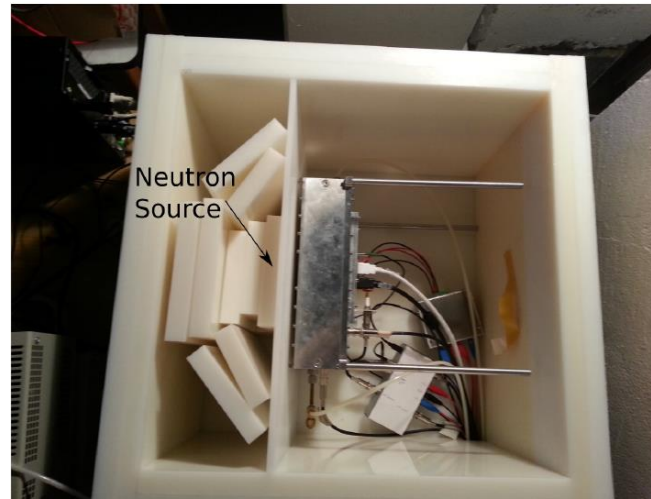
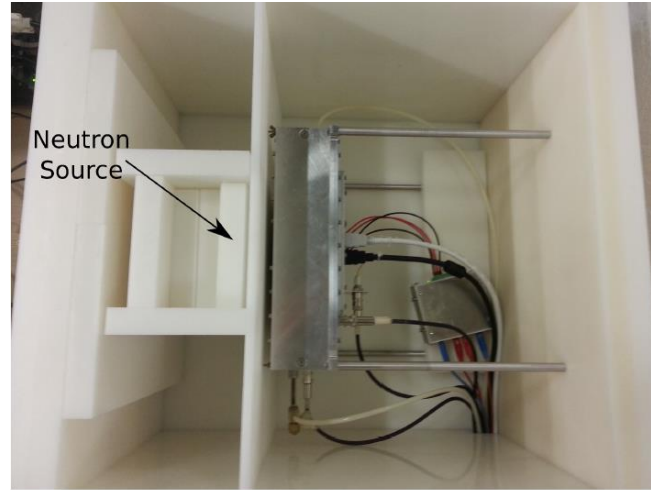


# Small-scale detector test





# Small-scale detector test





# Small-scale detector test

URANOS - The Cosmic Neutron Soil Moisture Simulator

Simulate Pause Stop Clear #neutrons: 2000000 maximum: 2000000 Uranos.dfg written 0 Refresh every 227 neutrons Save CFG Export

Physical Parameters Computational Parameters Detector Showcase Folders Export Display

Soil Water Content [Vol%] 10 %  
Soil Porosity [Vol%] 50 %  
Air Humidity 0.40 g/m<sup>3</sup>  
Air Humidity Exponential Length Inf  
Atmospheric depth 1020 g/cm<sup>2</sup>  
Cut-off rigidity [Gv] 10

Layers are arranged in the vertical direction, representing different materials or 2D gridded patterns  
Position z denotes the depth below surface (z=0) in [m] and refers to the upper edge of the layer  
Layers override topological presets

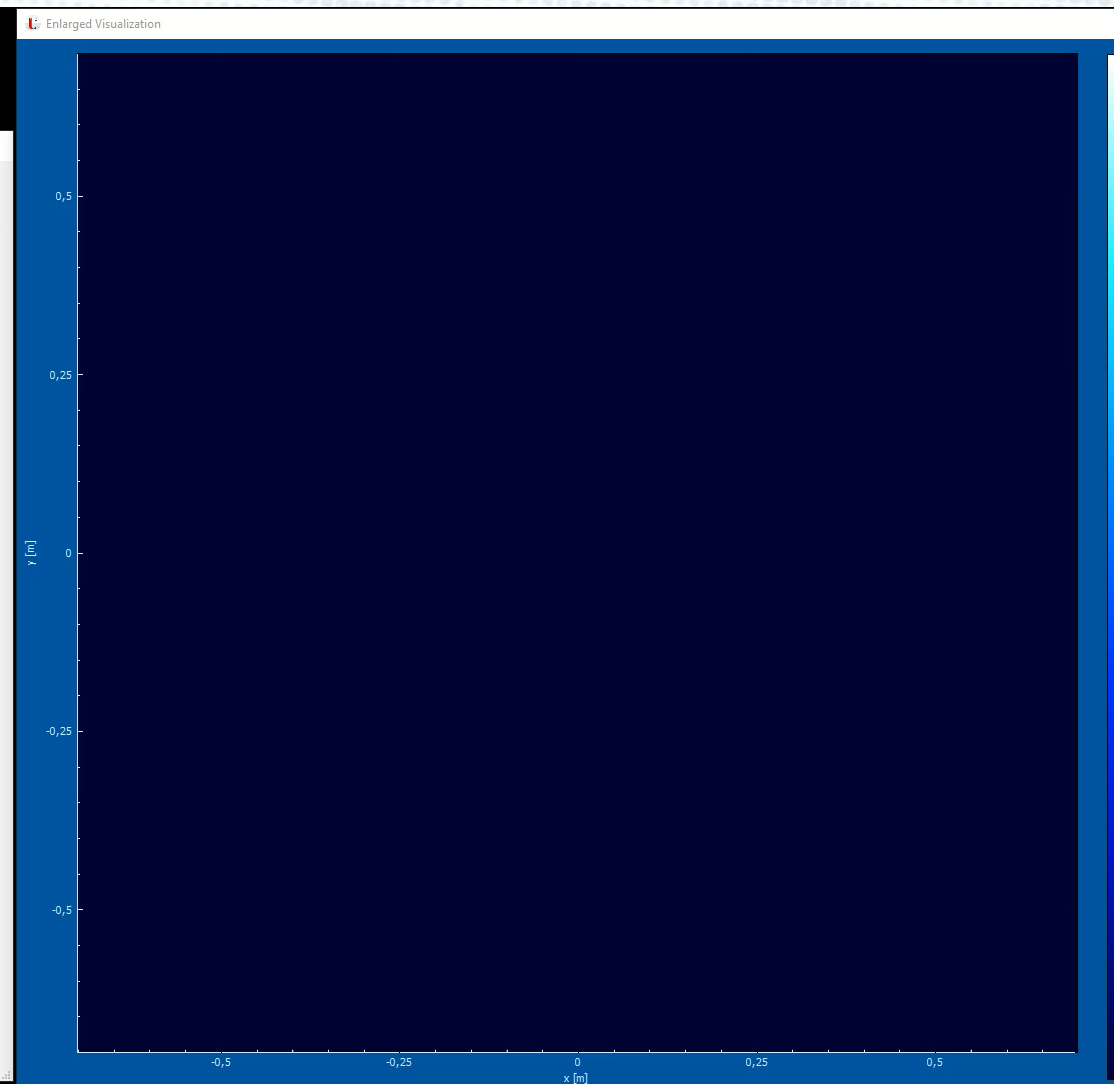
Layers	Position	Height	Material	Matrix
1	-0.45	0.05	11	1M [700]
2	-0.4	0.15	11	2M [700]
3	-0.25	0.05	11	3M [700]
4	-0.2	0.15	11	4M [700]
5	-0.05	0.05	11	5M [700]
6	0	0.003	20	

Layer Control  
- Minimum Configuration  
+ Generate  
Source Layer 3  
Detector Layer 3  
Ground Layer 6  
Material Codes  
 Use layer maps  
View layer maps  
Layer Configuration  
Load Save

Load Equipment  
 Nuclear Fission Source  
 Nuclear Fusion Source  
 AmBe Laboratory Source  
 Moderated Californium Source  
 Monoenergetic [MeV] 1  
 Thermal  
 None  Thermonuclear Transport

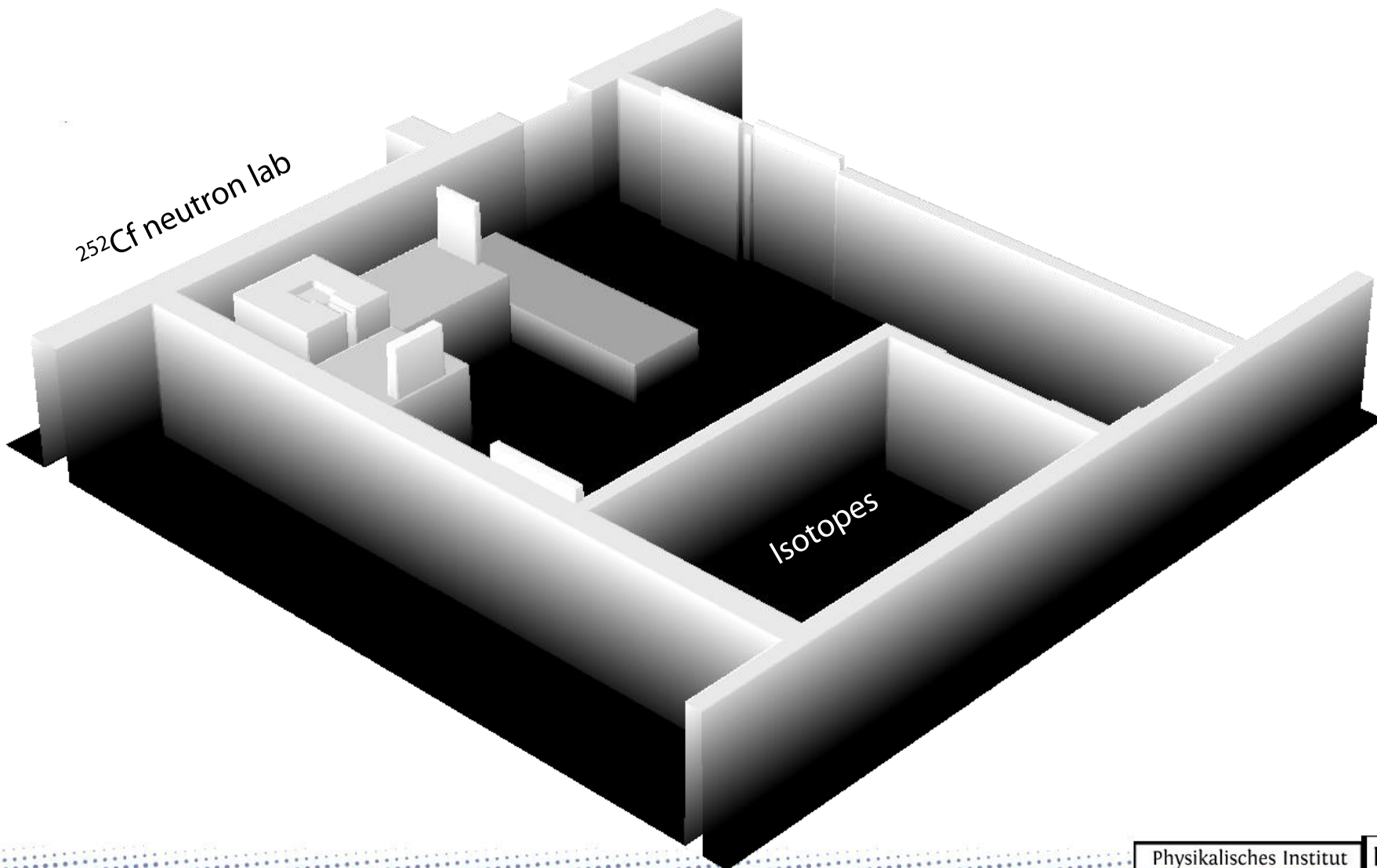
x Position 0.6482 y Position 0.707007 z Position -0.225  
x Size 0 y Size 0 z Size 0 Radius 0  
Opening Angle -1 Source Direction -> -<-  
Directional Angle -1

Live: Birds-eye View & Spectra Range View Spatial View Detector





# Small-scale laboratory test





# Small-scale laboratory test

URANOS - The Cosmic Neutron Soil Moisture Simulator

Simulate Pause Stop Clear #neutrons: 0 Refresh every 449 neutrons Save CFG Export

Physical Parameters Computational Parameters Detector Showcase Folders Export Display

Soil Water Content [Vol%] 9.5 %  
Soil Porosity [Vol%] 50 %  
Air Humidity 0.40 g/m<sup>3</sup>  
Air Humidity Exponential Length Inf  
Atmospheric depth 1020 g/cm<sup>2</sup>  
Cut-off rigidity [Gv] 10

Layers are arranged in the vertical direction, representing different materials or 2D gridded patterns  
Position z denotes the depth below surface (z=0) in [m] and refers to the upper edge of the layer  
Layers override topological presets

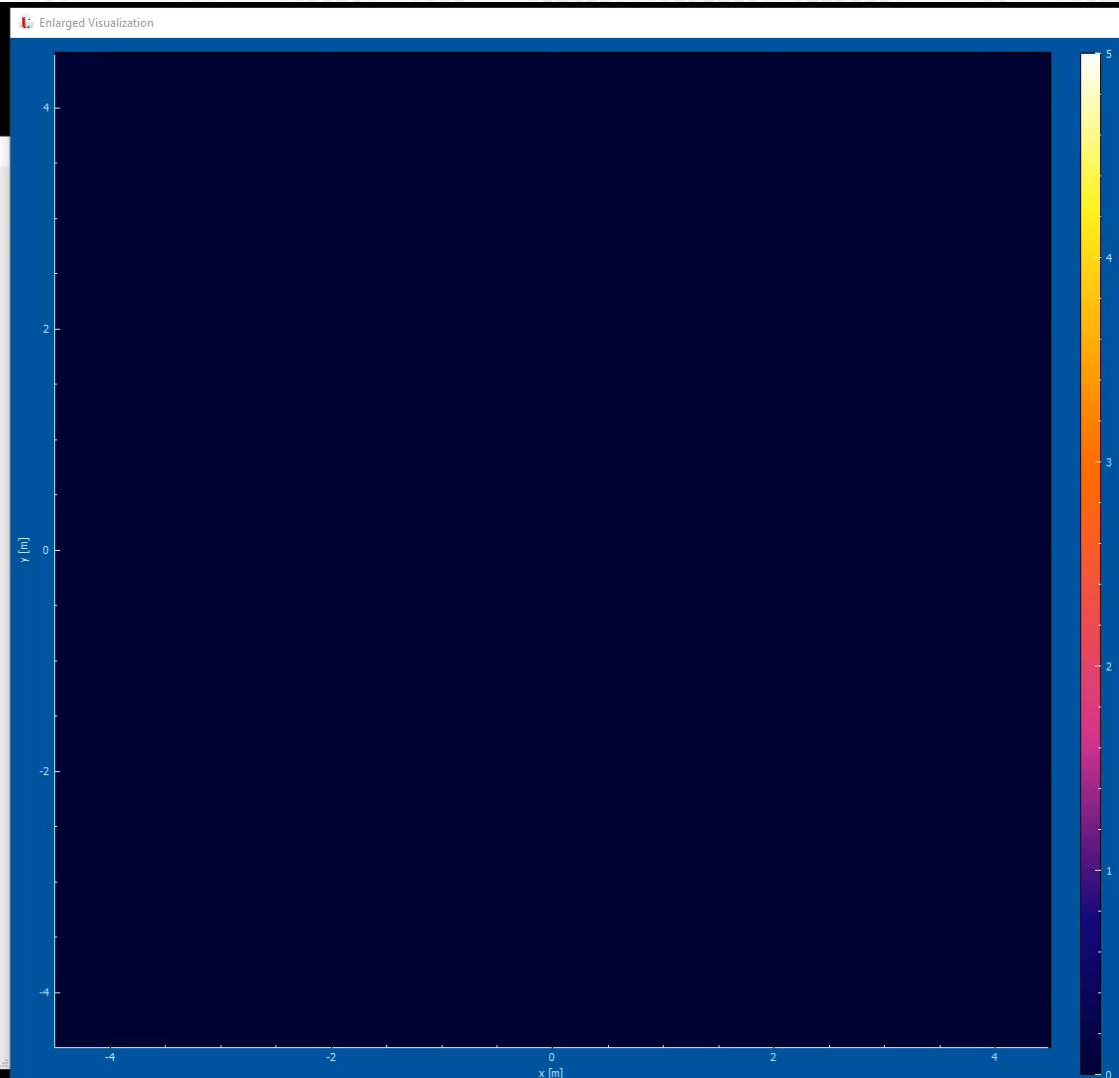
Layers	Position	Height	Material	Matrix
1	-4	0.37	20	
2	-3.63	1.63	11	2M [900]
3	-2	0.53	11	3M [900]
4	-1.47	0.43	11	4M [900]
5	-1.04	0.1	11	5M [900]
6	-0.94	0.05	11	6M [900]
7	-0.89	0.1	11	7M [900]
8	-0.79	0.115	11	8M [900]
9	-0.675	0.2	11	9M [900]
10	-0.475	0.475	11	10M [900]
11	0	0.5	20	

Layer Control  
- Minimum Configuration  
+ Generate  
Source Layer 6  
Detector Layer 8  
Ground Layer 11  
Material Codes  
 Use layer maps  
View layer maps  
Layer Configuration  
Load Save

Load Equipment  
 Nuclear Fission Source  
 Nuclear Fusion Source  
 AmBe Laboratory Source  
 Moderated Californium Source  
 Monoenergetic [MeV] 1  
 Thermal  
 None  Thermonuclear Transport

x Position 2.30973 y Position -2.39063 z Position -0.93  
x Size 0 y Size 0 z Size 0 Radius 0.3  
Opening Angle -1  
Directional Angle -1  
Source Direction

Live: Birds-eye View & Spectra Range View Spatial View Detector





# URANOS model paper 2023

## Paper:

Articles / Volume 16, issue 2 / GMD, 16, 449–477, 2023

<https://doi.org/10.5194/gmd-16-449-2023>

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Article

Assets

Peer review

Metrics

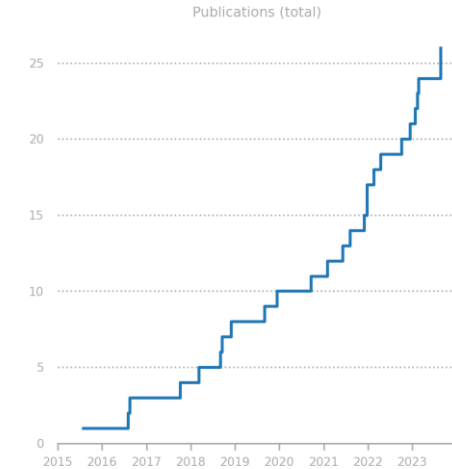
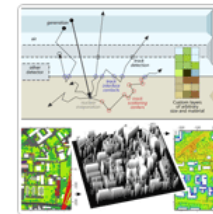
Related articles

Model description paper |

## URANOS v1.0 – the Ultra Rapid Adaptable Neutron-Only Simulation for Environmental Research

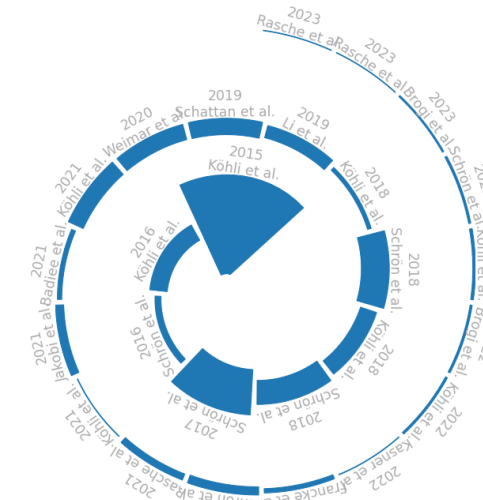
Markus Köhli , Martin Schrön, Steffen Zacharias, and Ulrich Schmidt

23 Jan 2023



## Public repository (Sources, Wiki, Windows, Linux):

file	OS	requires
URANOS*	Windows	ROOT 6.22.08
URANOS64bit	Windows	ROOT 6.30.02
URANOS-Ubuntu20-*	Linux/Ubuntu 20	ROOT 6.30.02, QT 5.14.2
URANOS-Ubuntu22-*	Linux/Ubuntu 22	ROOT 6.30.02, QT 5.15.3
URANOS-Ubuntu23-*	Linux/Ubuntu 23	ROOT 6.30.02, QT 5.14.2
URANOS-CentOS7-*	Linux/CentOS 7	ROOT 6.22.08, QT 5.9.7, QT 5.13.1



<https://gitlab.com/mkoehli/uranos>



## ■ URANOS

- Novel neutron Monte Carlo tool





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- Novel neutron Monte Carlo tool
- Ready-to-use User Interface



## ■ URANOS

- Novel neutron Monte Carlo tool
- Ready-to-use User Interface
- Voxel engine with simple png based material codes



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- Fast calculation routine with predefined spectra and detector response functions



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■ URBANOS Community Version: **Now available!**  
(and in development)



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