Università degli Studi di Ferrara

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Discriminating biomass and soil water content with proximal gamma-ray spectroscopy

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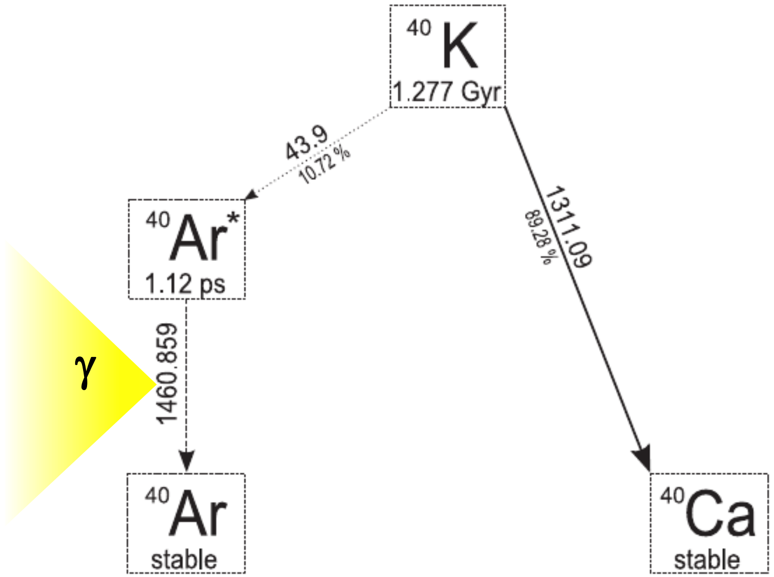
Terrestrial radioactivity: the potassium

Terrestrial radioactivity is due to naturally occurring radioactive elements with half-lives comparable to the Earth's age. Among them, **potassium** and some radioisotopes in the **uranium** and **thorium** decay chains emit γ-rays having energy of the order of MeV and can be easily detected via γ-rays spectroscopy.

Element	Radioisotope	Isotopic abundance	Half life	Typical abundance
Potassium	^{40}K	0.012%	1.3×10^9 years	0.02 g/g
Uranium	^{238}U	99.3 %	4.5×10^9 years	3 μg/g
Thorium	^{232}Th	100 %	14.1×10^9 years	10 μg/g

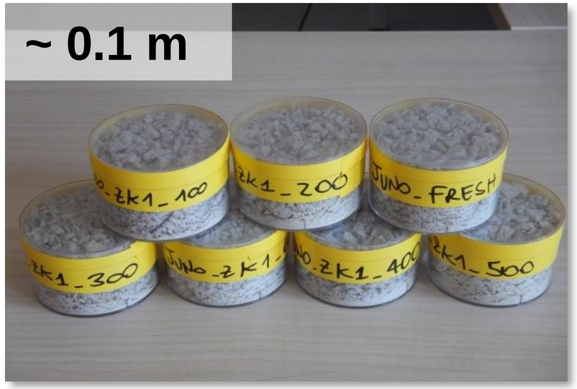


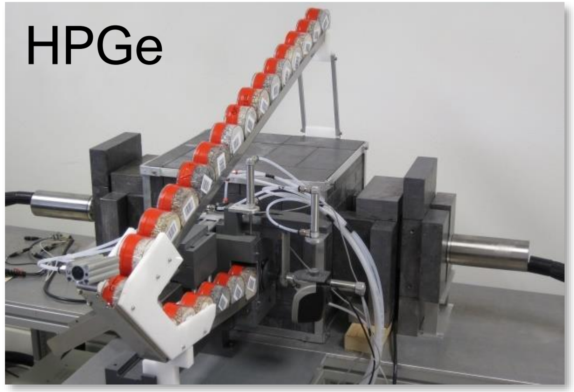
- K makes up about 2.6% of the weight of the Earth's crust and is the 7th most abundant element in the crust.
- K is one of the main building blocks of the most widespread minerals forming rocks and soils.



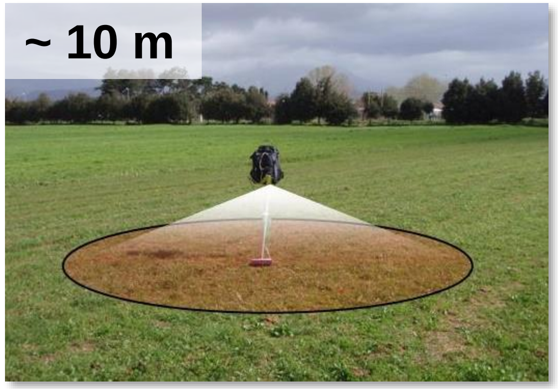

Different γ-rays measurements techniques

… in laboratory





… in situ

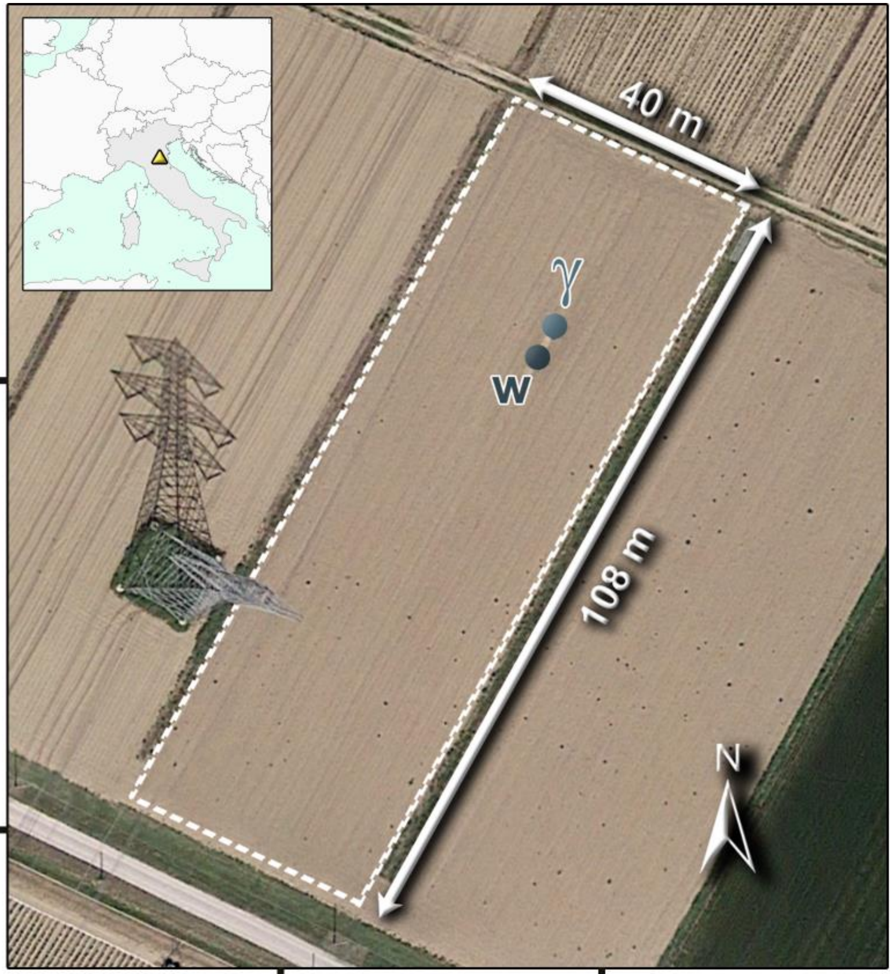


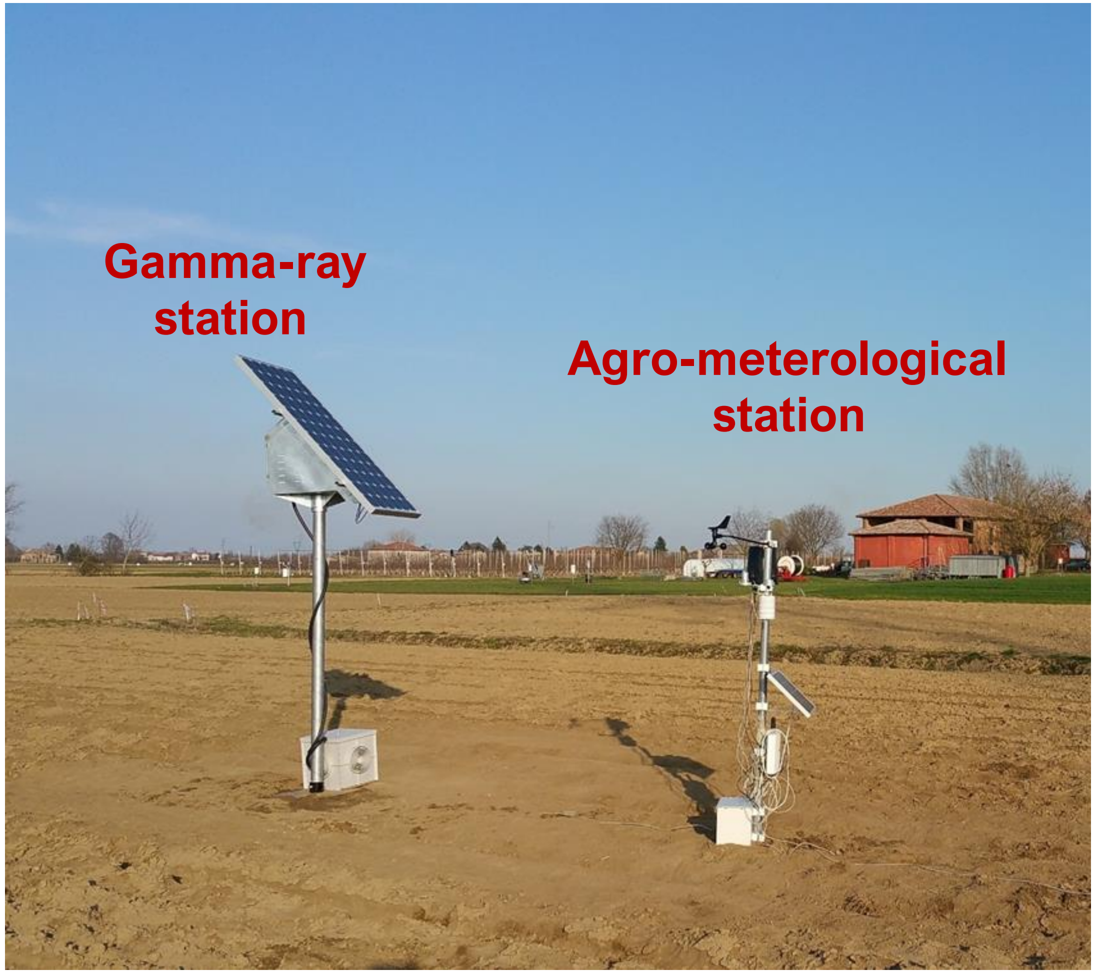
PROXIMAL

… airborne

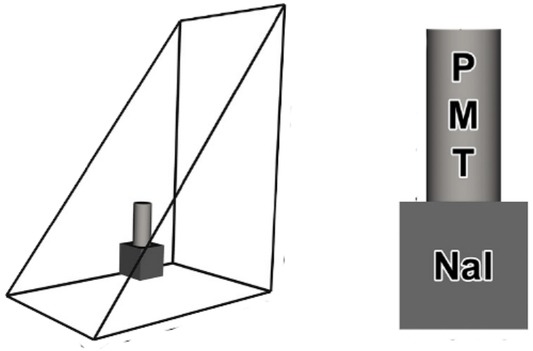
A proximal γ-ray spectroscopy experiment

GOAL: study the soil water content measuring the **attenuation effects** on gamma rays emitted by ^{40}**K** during a tomato crop season.



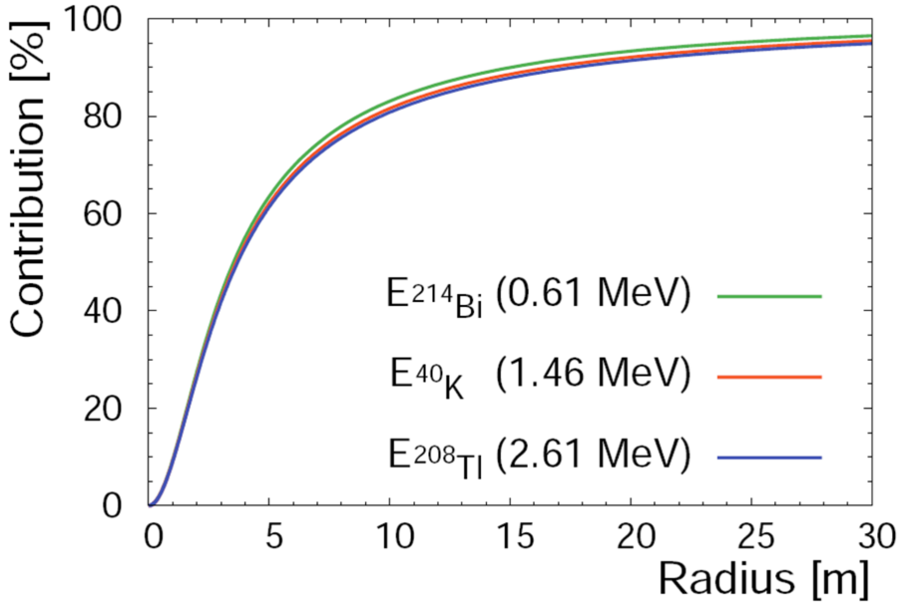


Fields of view of the proximal γ-ray station



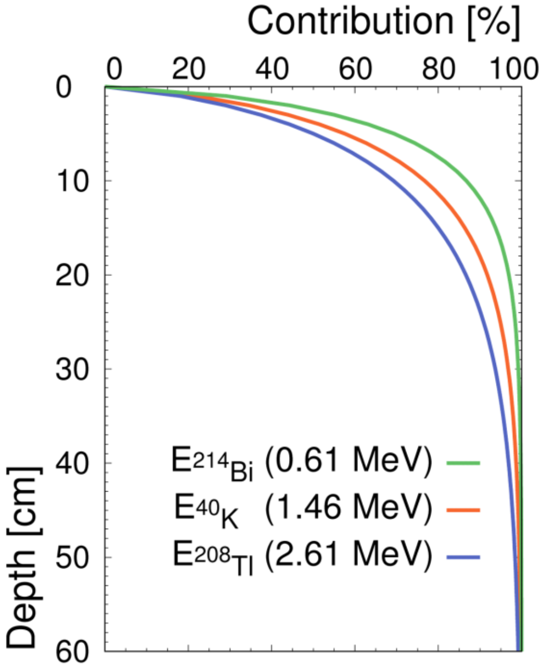
HORIZONTAL

Cumulative contribution of ground radioactivity in percentage as function of the source radius reaches ~95% at **~25 m** of radius



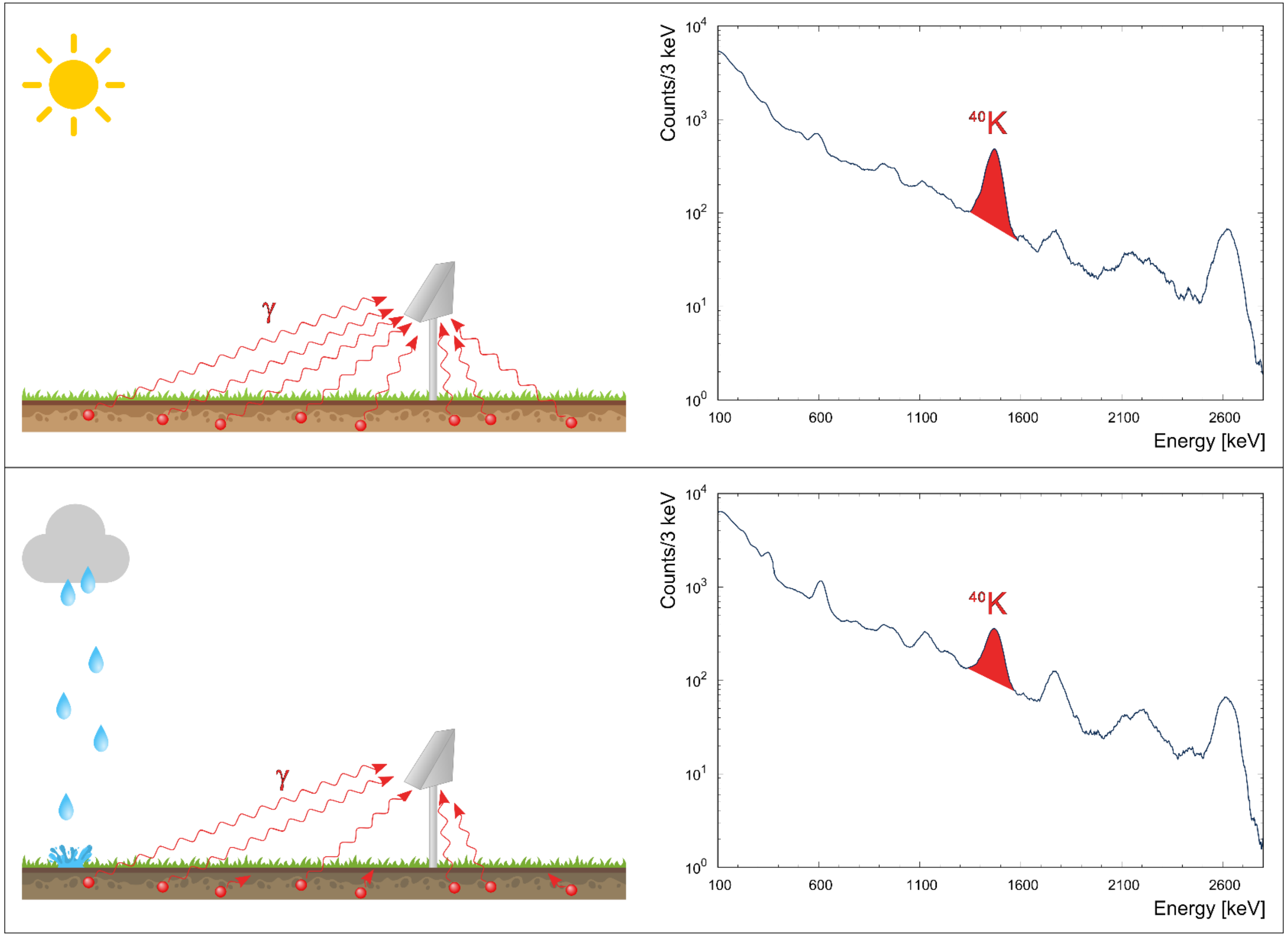
VERTICAL

In a typical soil ~95% of the gamma radiation is emitted from the top **25 cm** of the soil



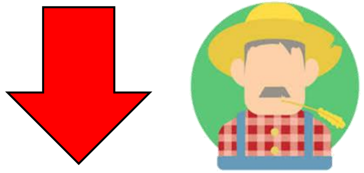
The rationale: a simple idea

- The water mass attenuation coefficient is significantly higher than those of minerals
- ^{40}K is everywhere and **homogenously** distributed in agricultural soils



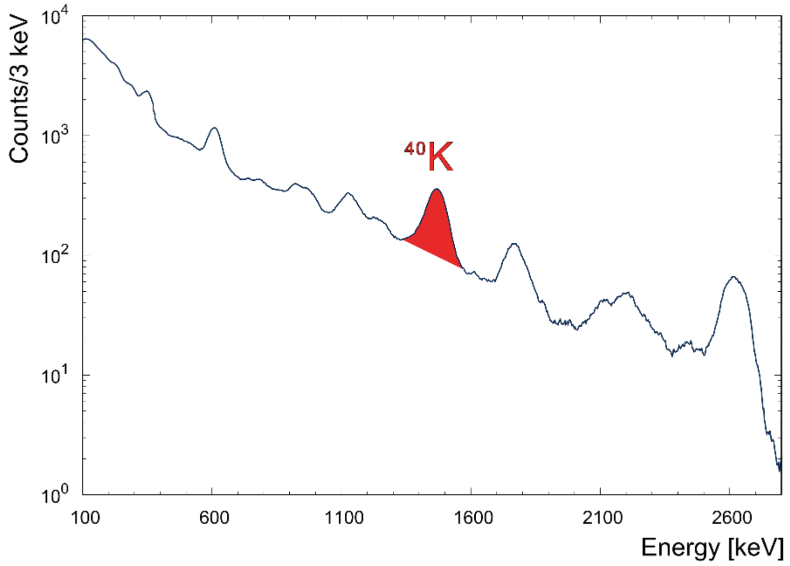
The **soil water content w** (M_{water}/M_{soil}) is **inversely proportional** to the signal **S(K)** produced by the ^{40}K decay measured by the gamma spectrometer:

$$w(t) = \frac{A}{S_K(t)} - B$$



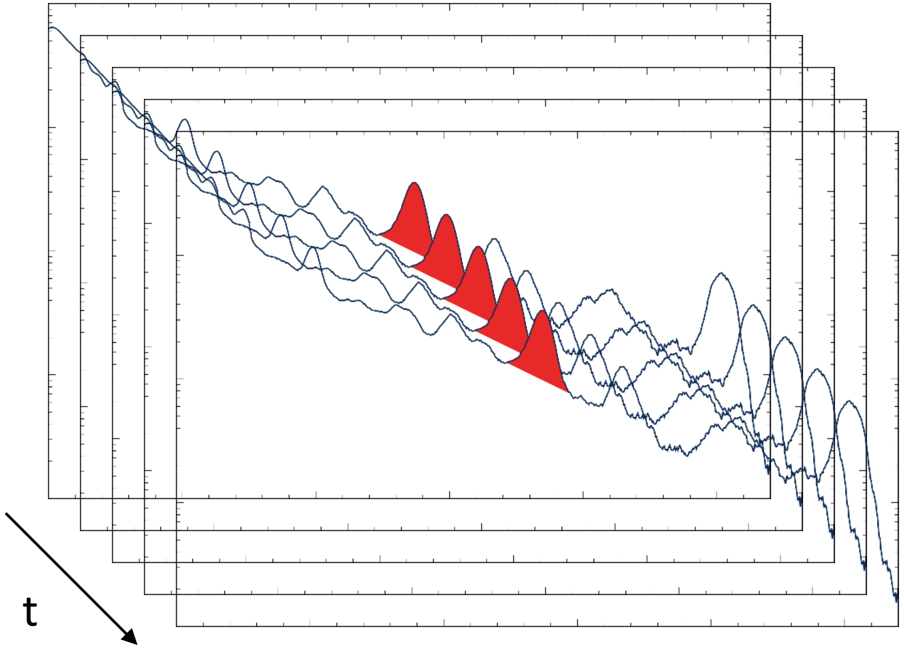
Crucial information for irrigation scheduling and efficient use of water

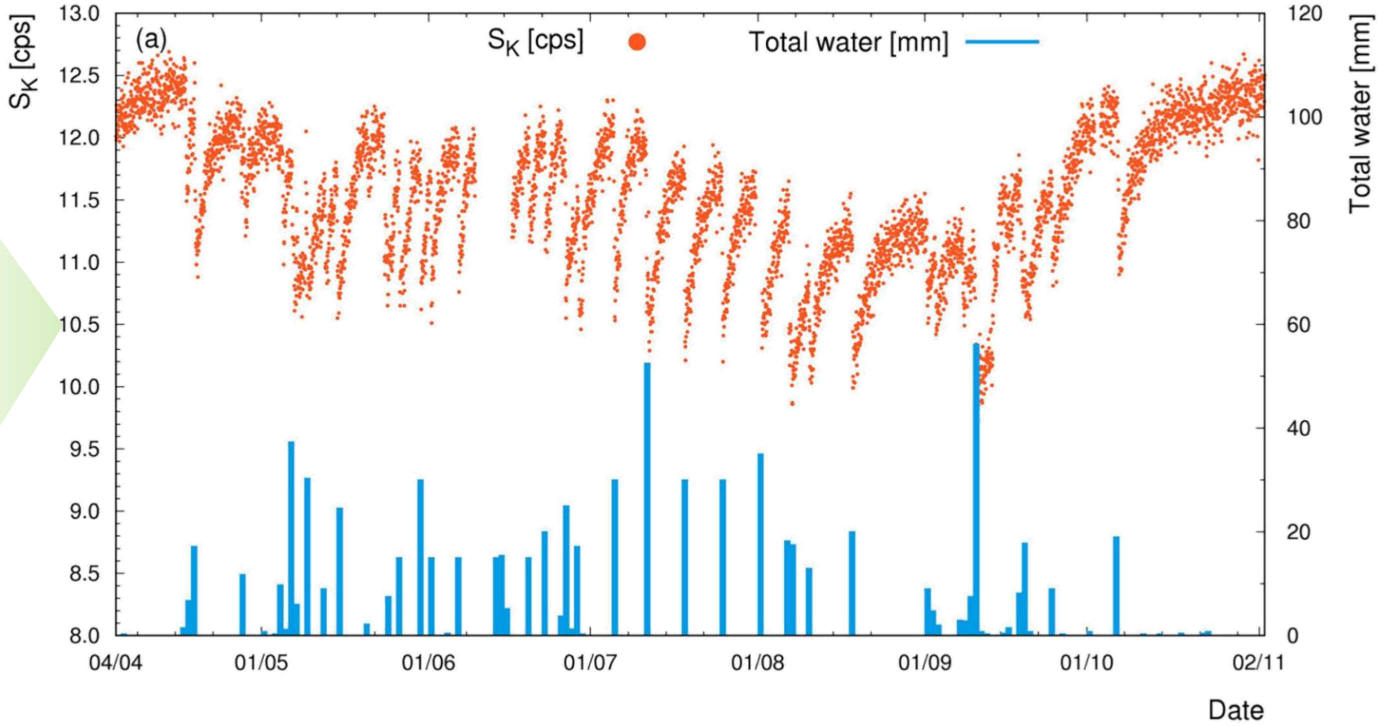
In 7 months of data-taking….



[4^{th} April – 2^{nd} November 2017]

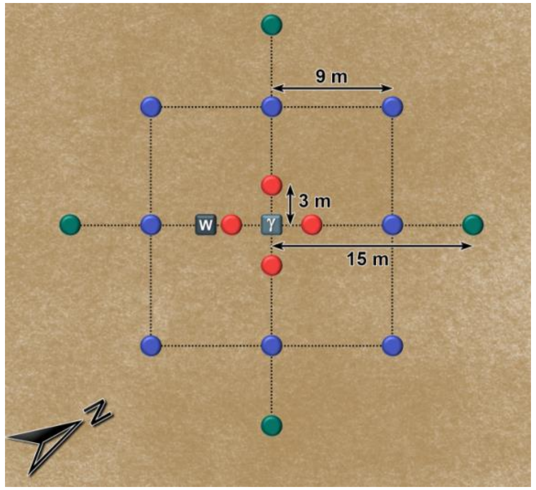
- **15 minutes** acquired spectrum
- Total counts ~180 10^3
- Net counts in ^{40}K window ~10^4
- Typical statistical uncertainty **~1.3 %** for 15 min acquisition
- We acquired 20502 spectra in 7 months (260 GB)
- 97.5 % of duty cycle





Calibration procedure: gravimetric measurements

BARE SOIL CONDITION



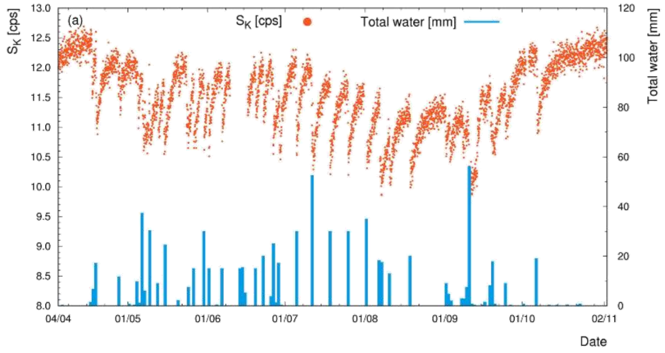
$$M_{Water} = M_{Wet} - M_{Dry}$$

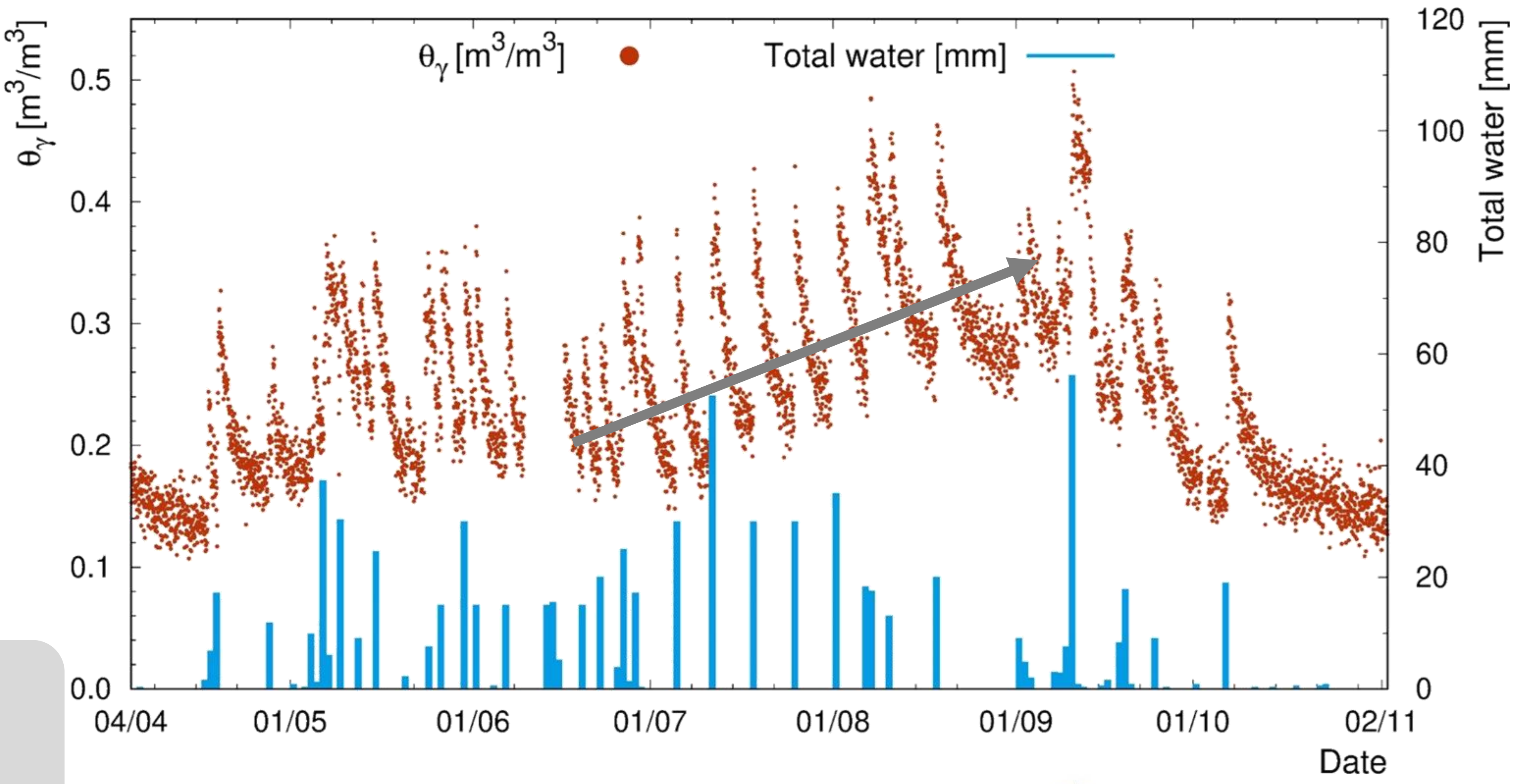
w_{CAL} : mean value obtained from 48 samples in the 0 – 30 cm depth range at 16 planar sampling points homogeneously distributed within 15 m from the detector.

CR_{CAL} : count rate in ^{40}K window.

$$w_t\left[\frac{kg}{kg}\right] = \frac{CR_{CAL}[cps]}{CR_i[cps]}(0.899 + w_{CAL}) - 0.899$$

From the count rates to the water content in soil





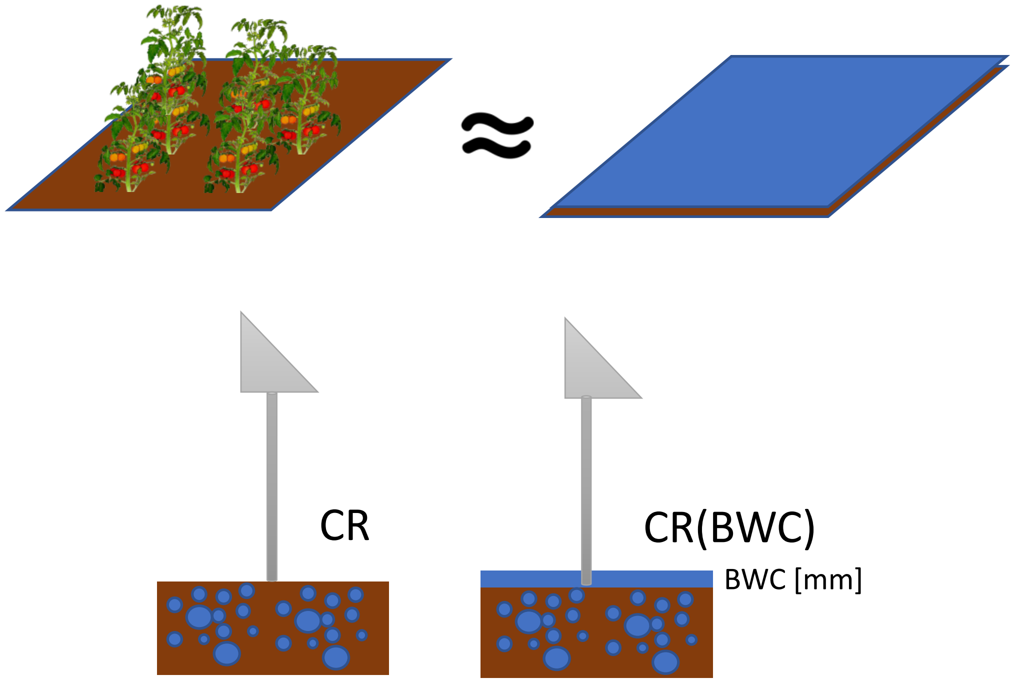
The presence of growing biomass introduces an extra attenuation which gives a strong positive bias on θ_γ values

Estimating plants shielding effect

- A tomato plant consist of about 90% of water: the vegetative cover produces a **shielding effect** and then an overestimation of water content:

Monte Carlo method: estimation of the effect of attenuation as a function of the Biomass Water Content

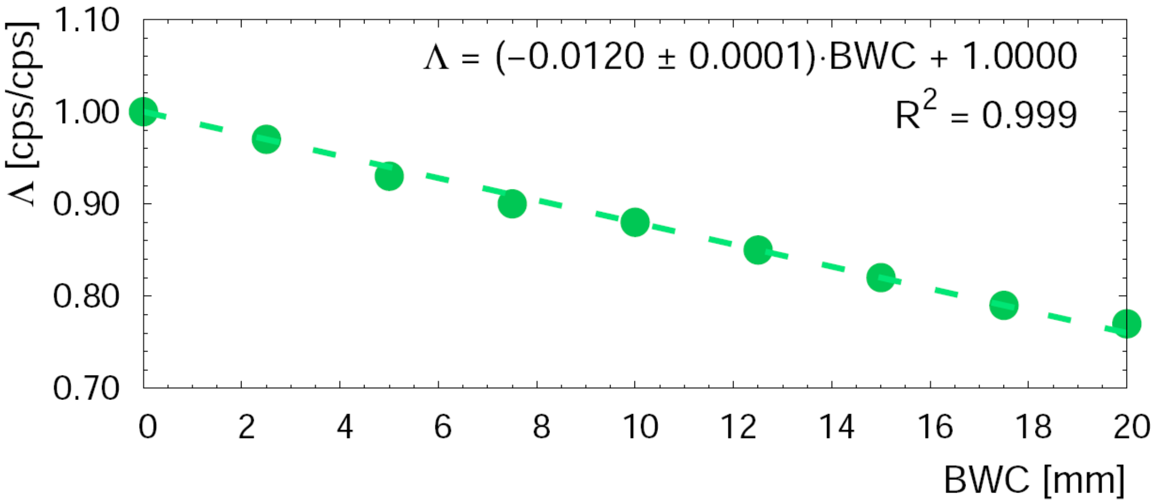
- The plants can be approximated to a layer of water that corresponds to the **BWC** in kg/m^2 (numerically equal to the water height in mm)



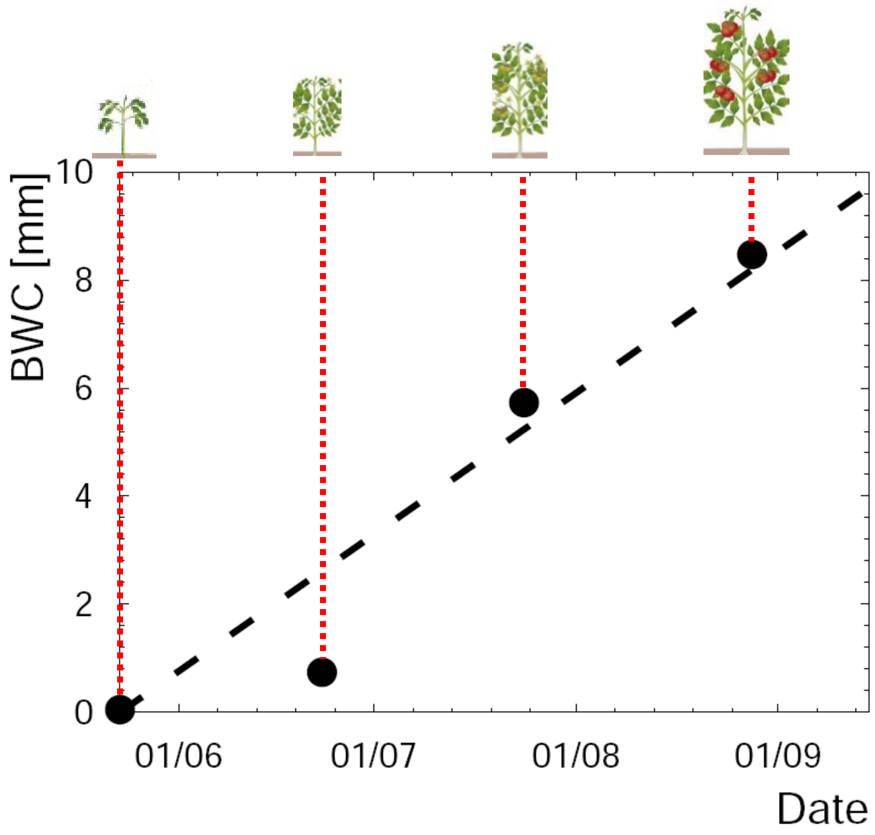
- The **count rate attenuation Λ** produced by the BWC is given by:

$$\Lambda = \frac{CR(BWC[mm])}{CR}$$

$$w_i = \frac{CR_{CAL}}{CR_i}\Lambda_i(0.899 + w_{CAL}) - 0.899$$



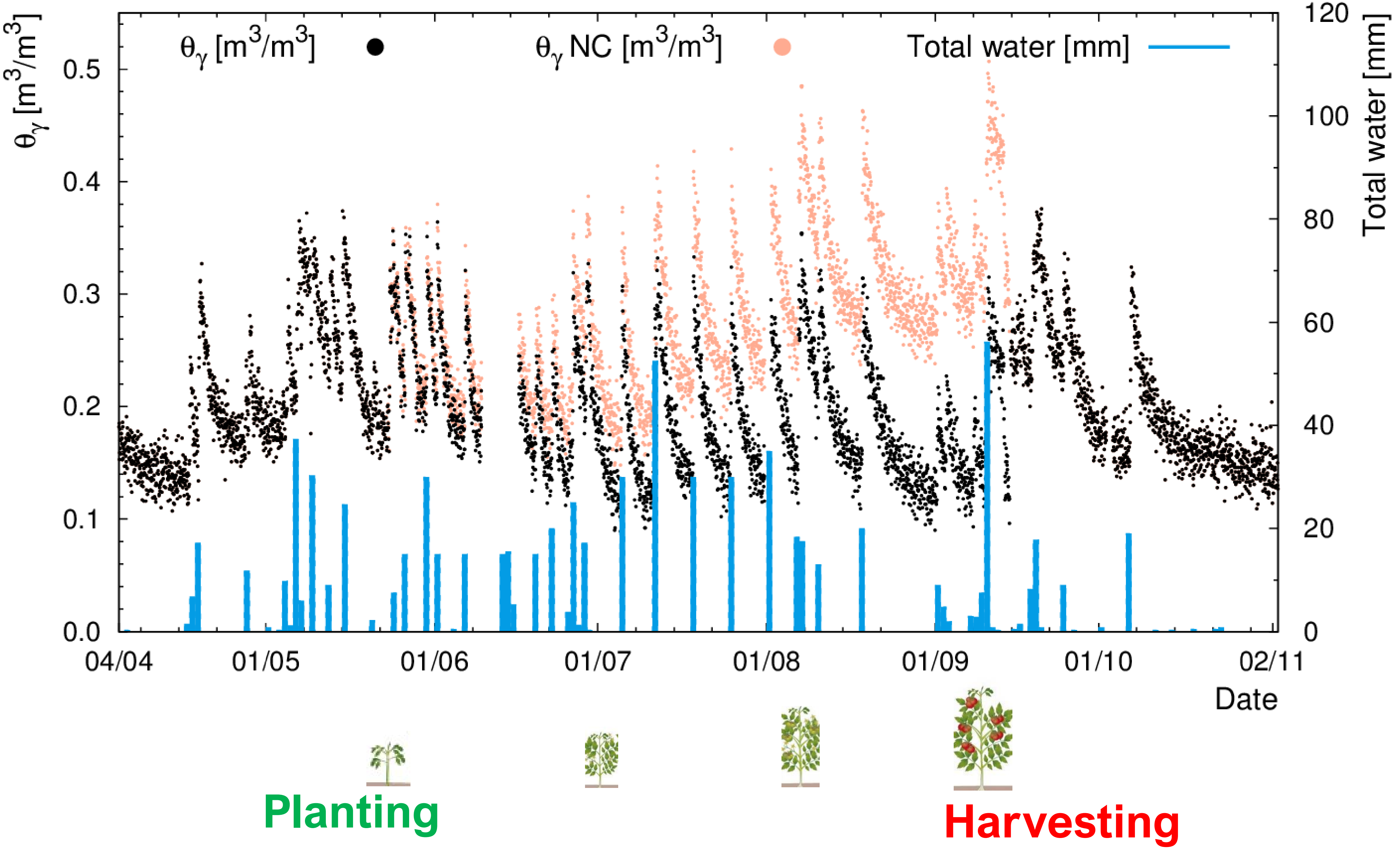
Biomass Water Content measurements



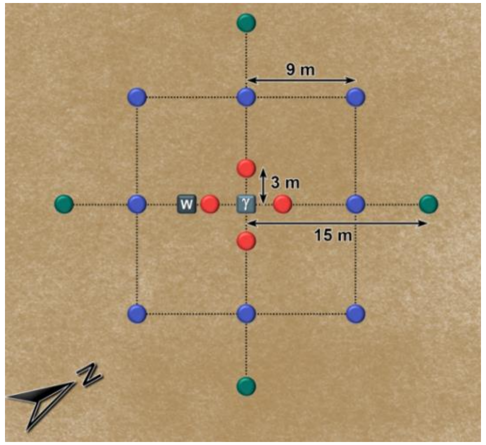
- The water content in tomato plants was estimated from destructive above-ground **biomass samples** at different stages of plant growth
- A straight line function was calculated for describing the growth of BWC in time:

$$BWC[mm] = 3.5 \cdot 10^{-3} \times t[h]$$

From the count rates to the corrected water content in soil



Validations measurements: gamma vs gravimetric method



θ_γ : soil water content inferred from gamma measurements
θ_g : measured with gravimetric measurements

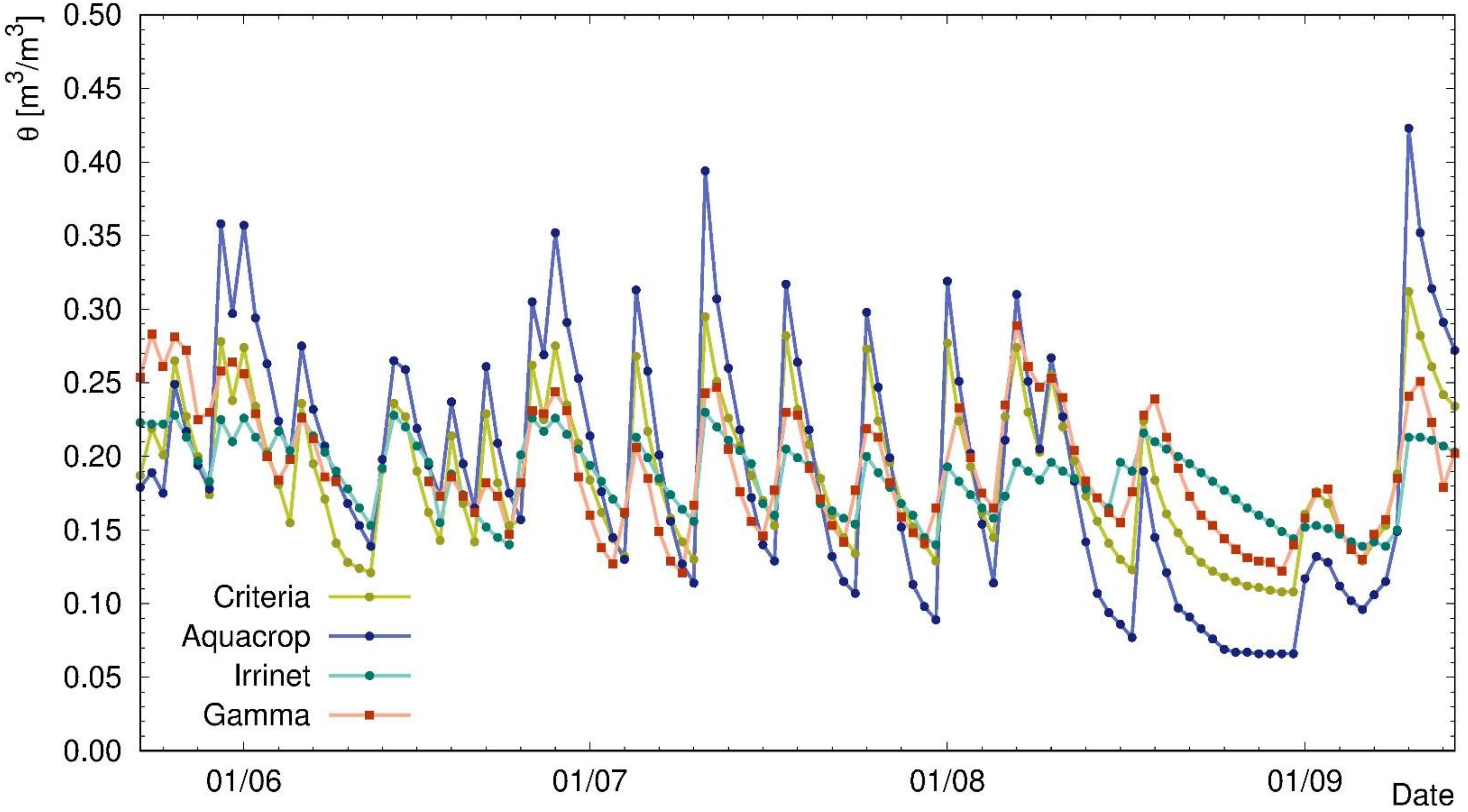
Bare soil			
Date	θ_G [m³/m³]	θ_γ [m³/m³]	Δθ
21/09/17	23.7 ± 1.5	24.5 ± 1.1	3.4 %

With plants			
Date	θ_G [m³/m³]	θ_γ [m³/m³]	Δθ
24/07/17	16.7 ± 2.8	17. 0 ± 1.9	1.8 %
26/07/17	26.5 ± 2.8	24.3 ± 1.3	-8.3 %
28/07/17	18.9 ± 1.5	17.9 ± 1.5	-5.7 %

Δθ ~ 2.1 %

Comparison with soil-crop system models

- **CRITeRIA** is a **physically-based numerical model** for simulating soil water balance
- **AquaCrop** is the FAO tipping-bucket **conceptual model** for soil water transport based on soil hydraulic properties and crop water demand
- **Irrinet** is a regional model for **irrigation management** implementing economic calculation of the crop-tailored irrigation profitability



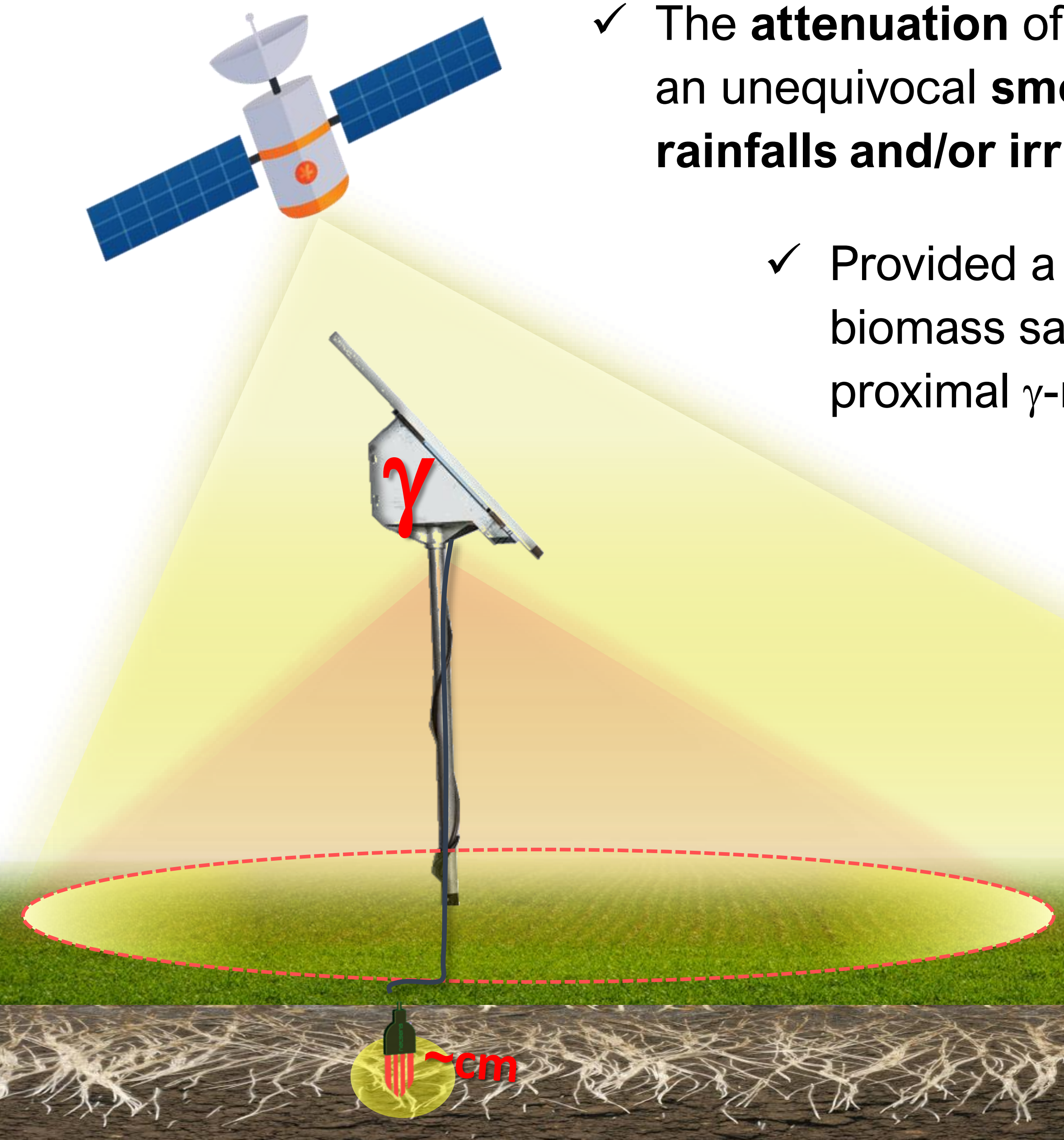
CRITeRIA show the best agreement with gamma data over the entire data-taking period while, **IRRINET** provides the best results in presence of the tomato crop.

Conclusions: what's next?

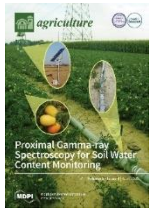
- ✓ The **attenuation** of the ^{40}K gamma signal coming from the ground is an unequivocal **smoking gun** for a **soil water content increase after rainfalls and/or irrigation**

- ✓ Provided a (single) soil **gravimetric calibration** measurement and biomass samplings, **soil water content** can be assessed via proximal γ-ray spectroscopy at the level of **10 %**

- ✓ Proximal γ-ray spectroscopy is an effective tool for estimating soil water content at **field-scale** makes it a promising technique in view of **satellite data calibration**



For more information…



Modelling Soil Water Content in a Tomato Field: Proximal Gamma Ray Spectroscopy and Soil–Crop System Models

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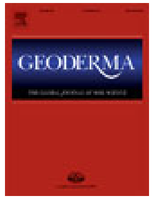

Biomass water content effect on soil moisture assessment via proximal gamma-ray spectroscopy

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Investigating the potentialities of Monte Carlo simulation for assessing soil water content via proximal gamma-ray spectroscopy

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Soil moisture as a potential variable for tracking and quantifying irrigation: a case study with proximal gamma-ray spectroscopy data.

Filippucci, P., A. Tarpanelli, C. Massari, A. Serafini, V. Strati, M. Alberi, K. G. C. Raptis, F. Mantovani and L. Brocca (2020).
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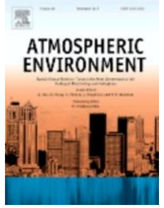

Rain rate and radon daughters' activity.
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