Measuring Soil Water Content with Proximal Gamma Ray Spectroscopy

Virginia Strati

In collaboration with:

Matteo Albèri, Enrico Chiarelli, Fabio Mantovani, Kassandra Raptis, Andrea Serafini

Nuclear Technologies For Agriculture 4.0

December 18 December, 2020

Nice to meet you!

Laboratory for Nuclear Technologies
Applied to the Environment

Università degli Studi di Ferrara

https://www.fe.infn.it/radioactivity/

INFN

Matteo Albéri

The main interests of my research activity regard the multiparametric remote sensing with attention to in situ and airborne gamma ray spectroscopy for environmental monitoring.

Planetarist. Photography and drumming enthusiast.

Gamma spectroscopy | Environmental radioactivity | Physics education

Enrico Chiarelli

I graduated in Computer Science in 2016 and I have been working in the research field since then. Most of the time of my work is dedicated to writing software for our needs like data processing and Monte Carlo simulations. I also develop programs to automate time consuming processes that needs to be performed many times. Another task of my work is taking care of the hardware that we use every day to keep them in good working order, from personal computers to scintillation detectors.

Algorithm Design | Data Processing | Hardware Maintenance

Fabio Mantovani

When I was a child I dreamed to be a scientist: now I try to be a scientist with child's eyes.

Geoneutrinos | Airborne gamma spectroscopy | Environmental radioactivity

Barbara Ricci

I am mainly interested in neutrino physics, moving from the Sun to the Earth. In the last few years I have been also involved in outreach activity. I am a lucky person: I make a wonderful job within a great team.

Geoneutrinos | Reactor antineutrinos | Neutrinos

Giovanni Fiorentini

Main interests are Neutrinos and applications of Nuclear Physics to different disciplines, such as Astrophysics, Earth Sciences and Nuclear Medicine.

Neutrinos | Astroparticle physics | Geoneutrinos

Michele Montuschi

I'm an engineer loving physics and what's beyond the future. My main interest is neutrino physics and huge detectors. In particular the most of my work focuses on Liquid Scintillator purification, control software and waveform analysis.

Liquid Scintillator purification | Digital control software | Waveform analysis

Andrea Serafini

I am a PhD student in Physics who enjoys facing new challenges everyday. My main research interest lies in the study of terrestrial radioactivity, with particular attention to geoneutrinos. I am currently working on the evaluation of the terrestrial antineutrino signal at surface through the use of geochemical/geophysical models and Monte Carlo simulations. I am also involved in activities of gamma spectroscopy for geochemical investigation.

Terrestrial neutrinos | Gamma spectroscopy | Monte Carlo

Andrea Maino

I graduated in Physics at Università Statale di Milano with a thesis on Lorentz Invariance Violation applied to the propagation of Cosmic Rays and now I'm trying to give my contribution to the study of Environmental Radioactivity.

Jack of all trades, master of none.

Astroparticle Physics | Lorentz Invariance Violation | Environmental Radioactivity

Kassandra Raptis

I received the BSc in Physics from the University of Ferrara in 2016; currently, I have a post laurpam fellowship at the Department of Physics and Earth Sciences of the University of Ferrara. My research interests lie mainly in the field of Nuclear Geophysics and gamma ray spectroscopy, with a special focus on the modelling of the effective dose due to natural radionuclides and the realization of thematic environmental radioactivity maps.

Effective dose | Thematic radioactivity maps | Graphic design

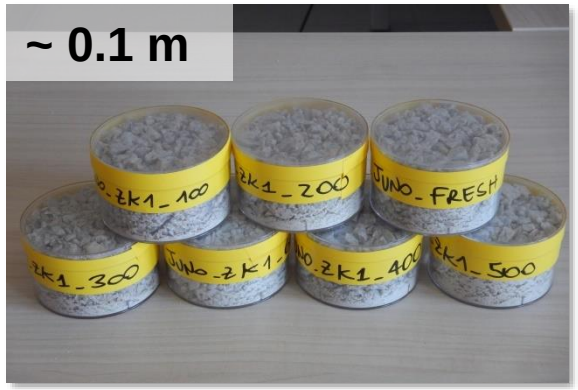
Virginia Strati

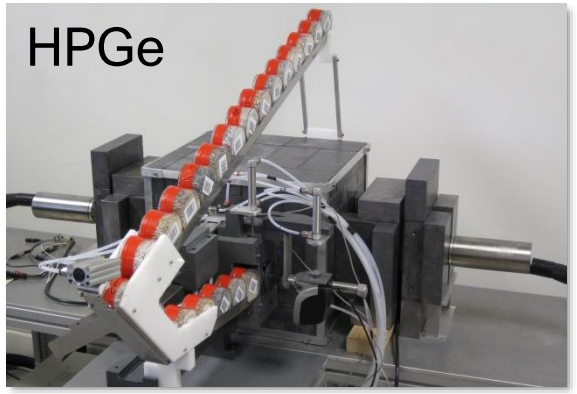
My research interest lies in the interaction field of Earth Sciences, Statistics and Physics. I like to explore the potentialities of interdisciplinary applications and to face scientific challenges emerging from the interaction of these different, but not distant, fundamental disciplines.

Environmental radioactivity | Geoneutrinos | Spatial data analysis

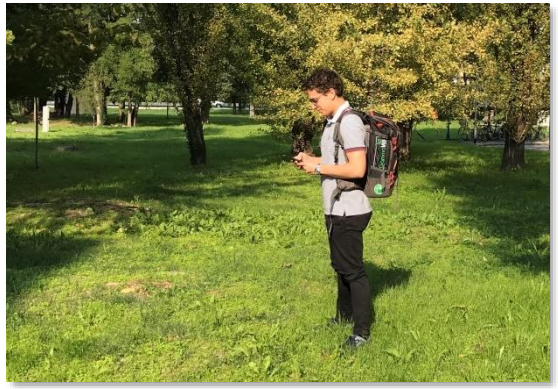
Different γ-rays measurements techniques

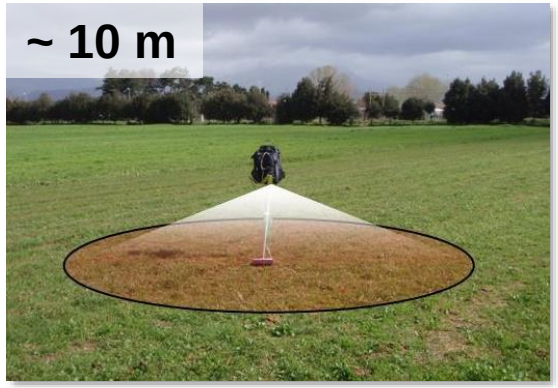
… in laboratory





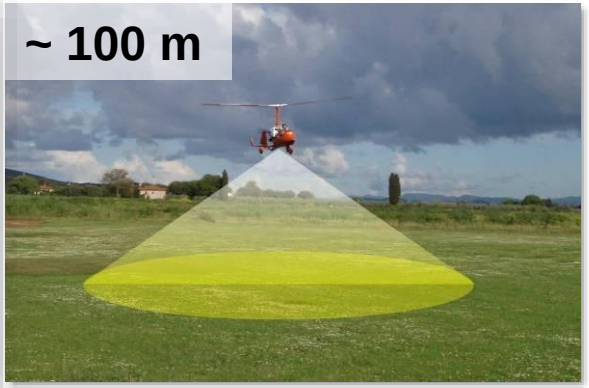
… in situ





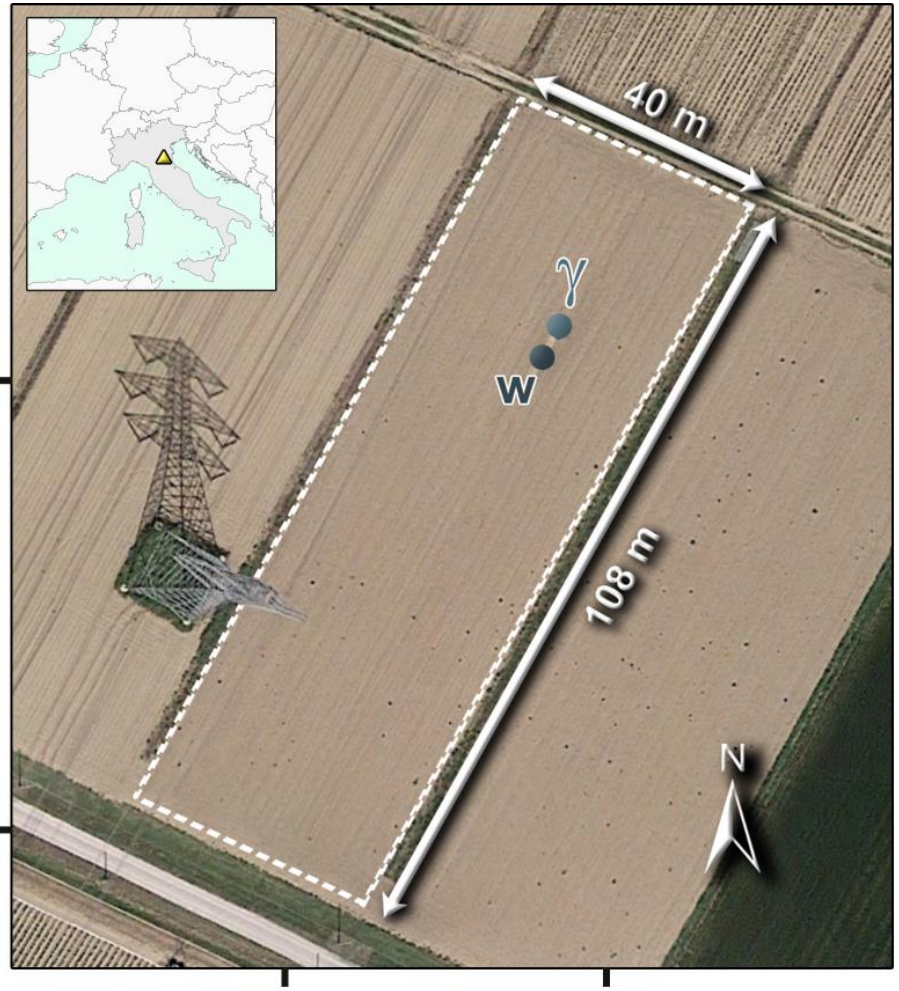
PROXIMAL

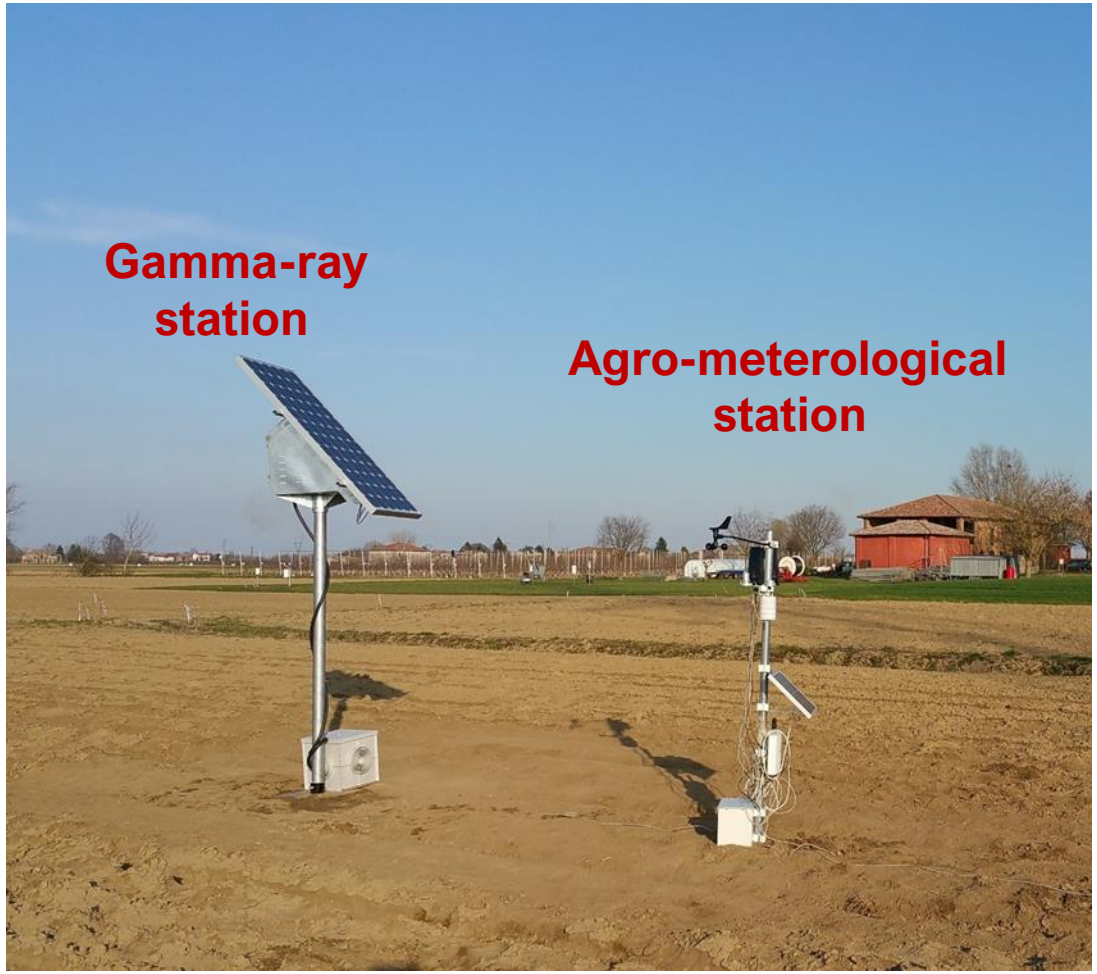
… airborne



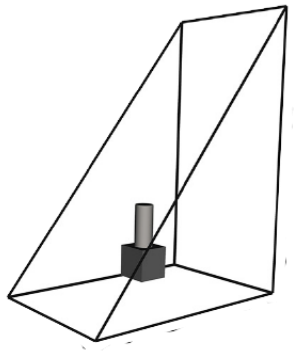
A proximal γ-ray spectroscopy experiment

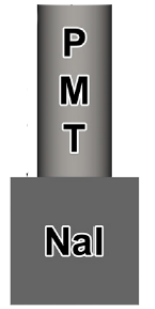
GOAL: study the soil water content measuring the **attenuation effects** on gamma rays emitted by ^{40}**K** during a tomato crop season.





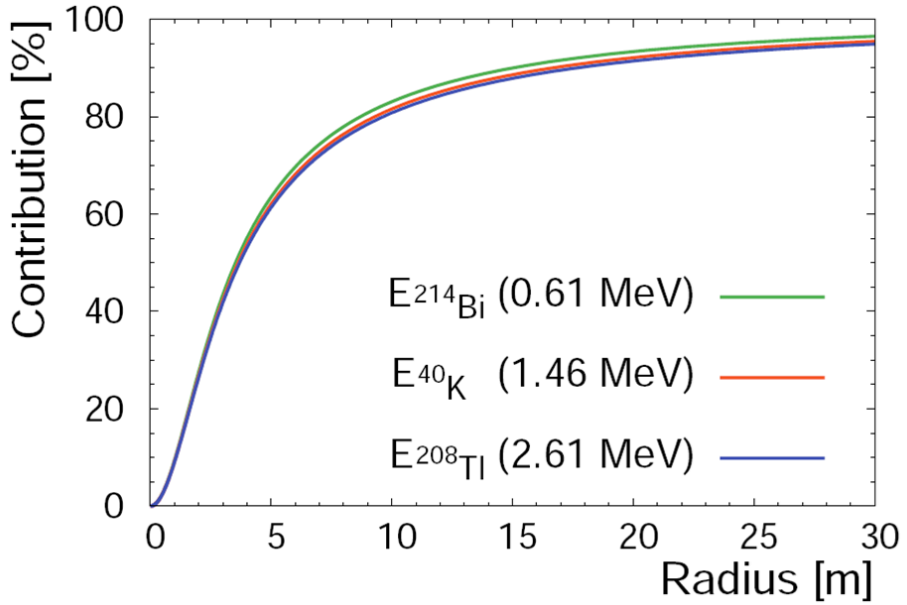
Fields of view of the proximal γ-ray station





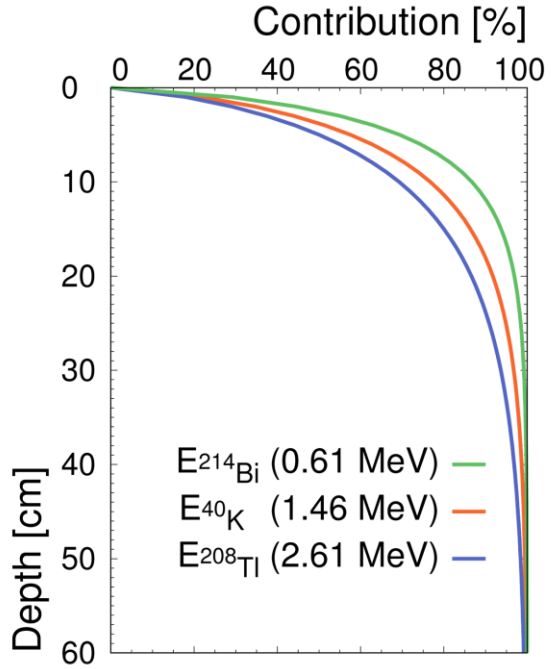
HORIZONTAL

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



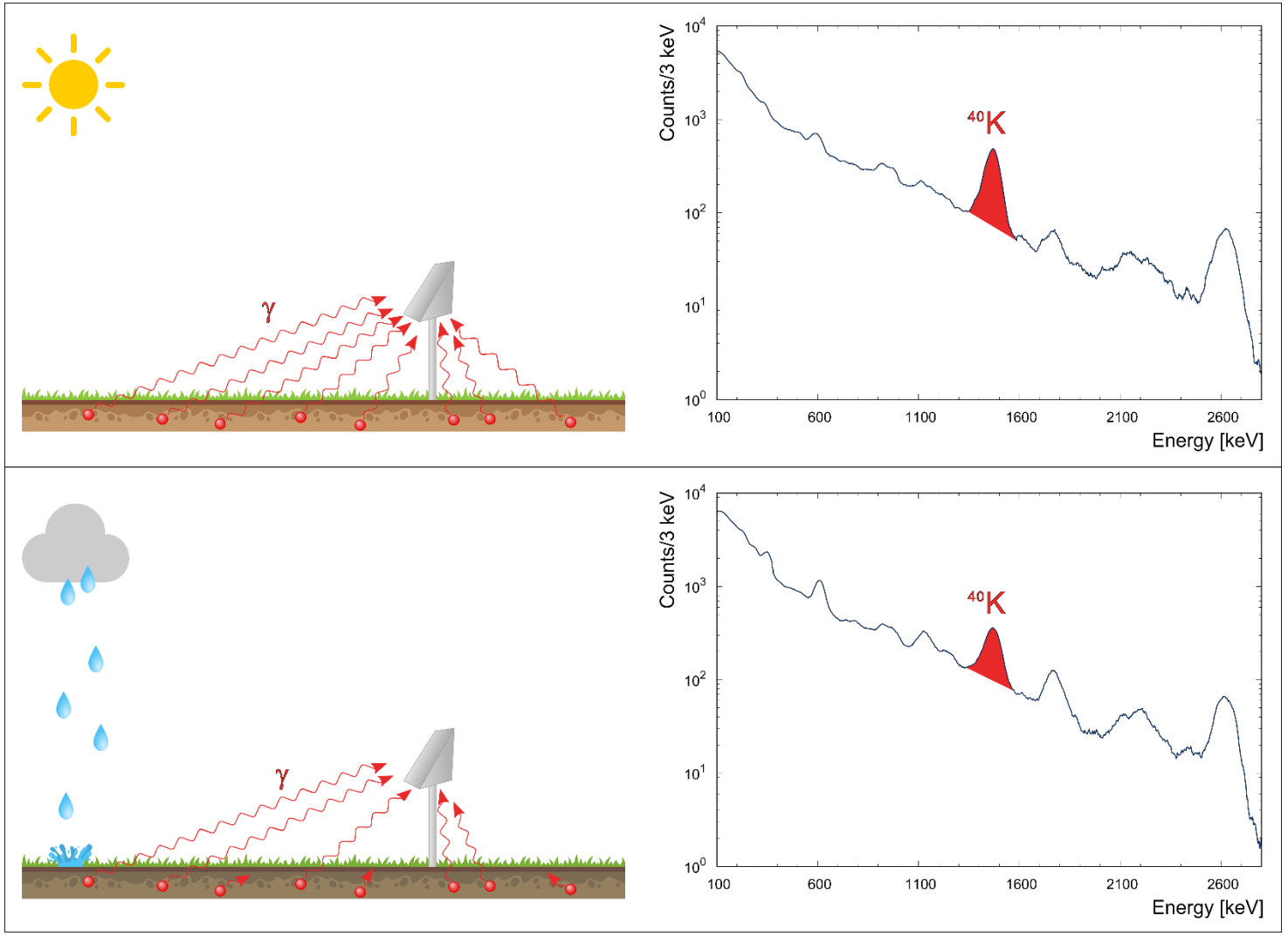
VERTICAL

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



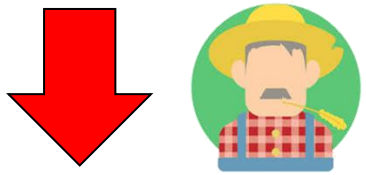
The rationale: a simple idea

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



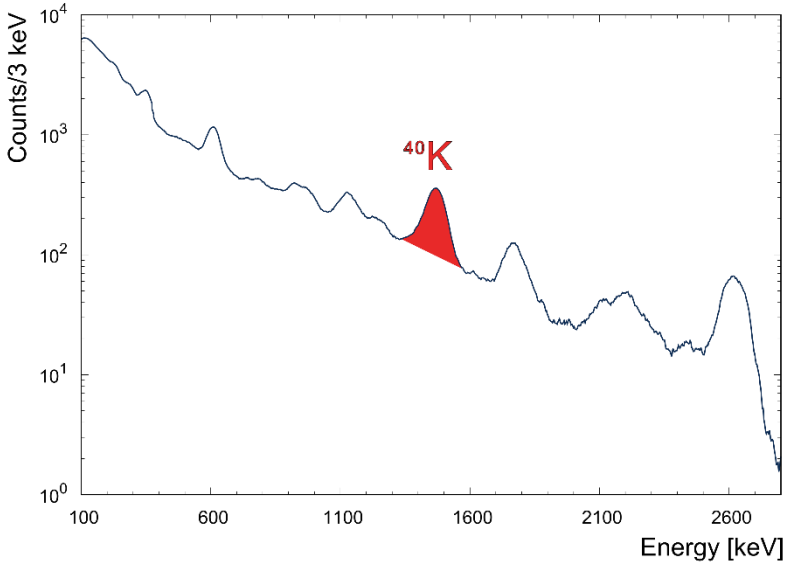
The **soil water content w** (M_{water}/M_{soil}) is **inversely proportional** to the signal **S(K)** produced by the ^{40}K decay measured by the gamma spectrometer:

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



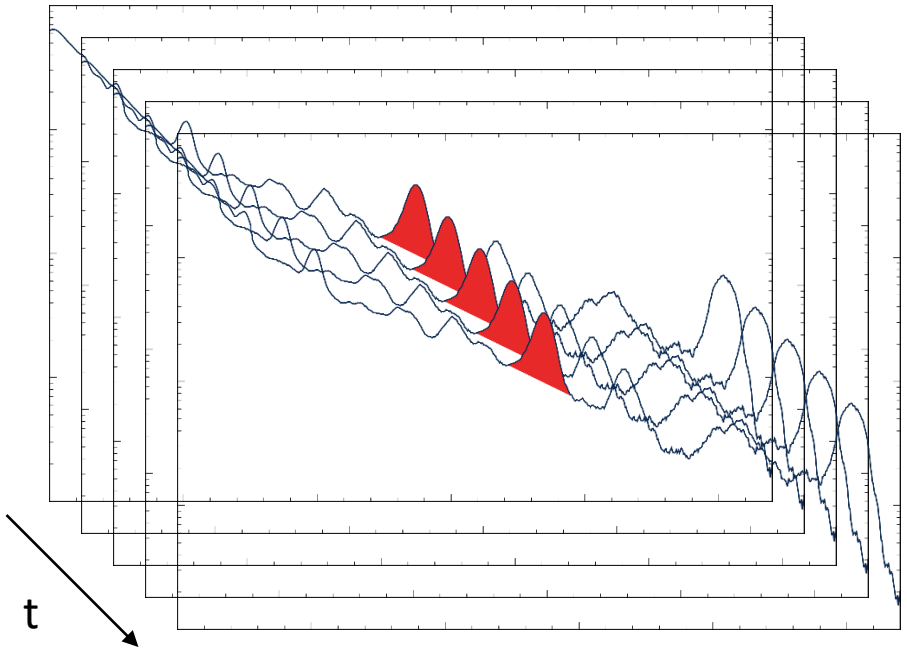
Crucial information for irrigation scheduling and efficient use of water

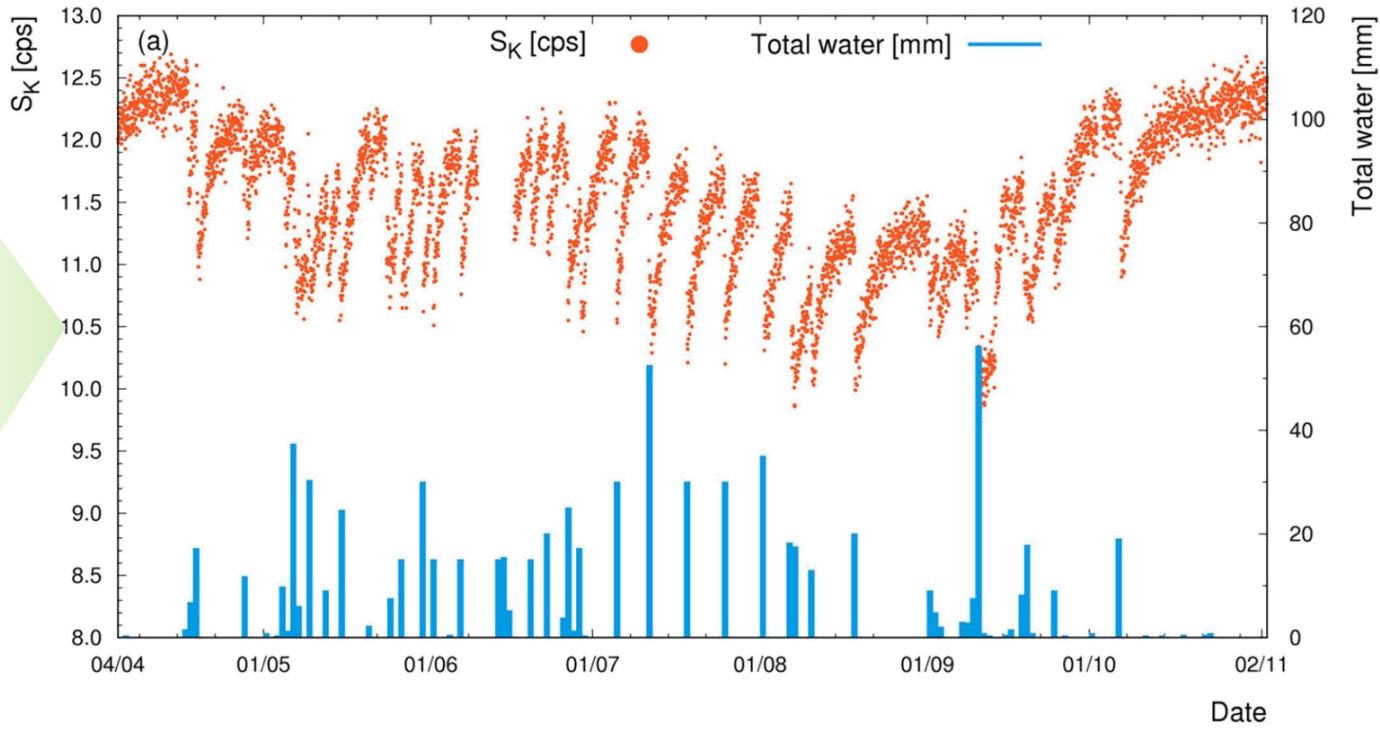
In 7 months of data-taking….



[4th April – 2nd November 2017]

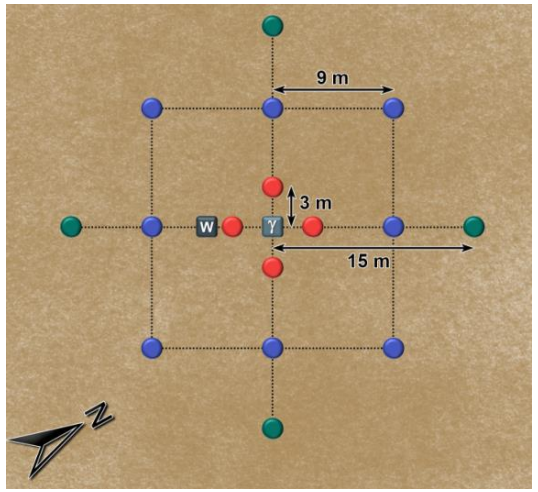
- **15 minutes** acquired spectrum
- Total counts ~180 10^3
- Net counts in ^{40}K window ~10^4
- Typical statistical uncertainty **~1.3 %** for 15 min acquisition
- We acquired 20502 spectra in 7 months (260 GB)
- 97.5 % of duty cycle





Calibration procedure: gravimetric measurements

BARE SOIL CONDITION



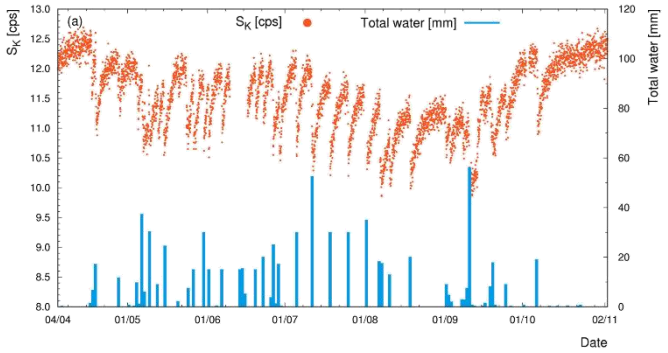
$$M_{Water} = M_{Wet} - M_{Dry}$$

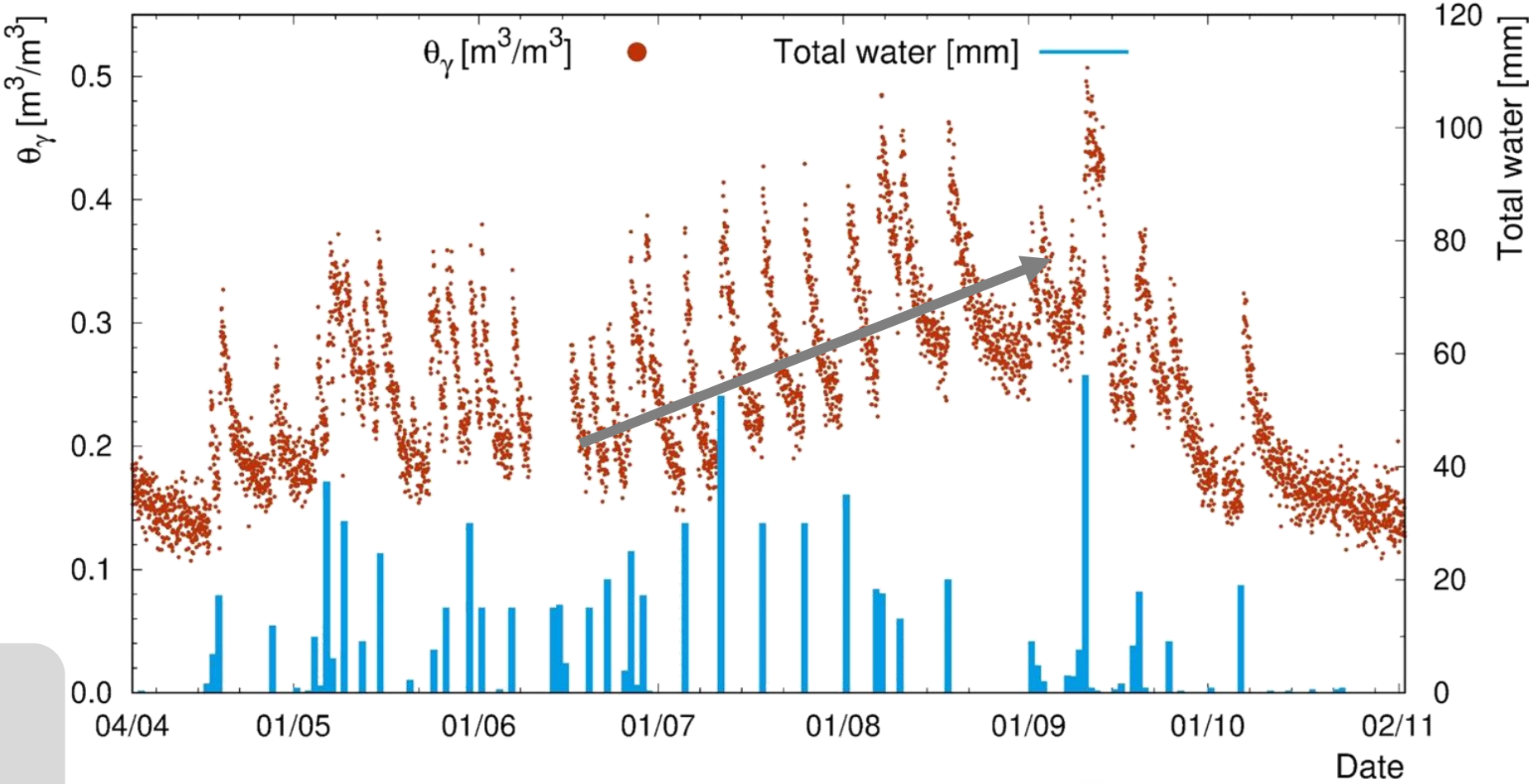
w_{CAL} : mean value obtained from 48 samples in the 0 – 30 cm depth range at 16 planar sampling points homogeneously distributed within 15 m from the detector.

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

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

From the count rates to the water content in soil



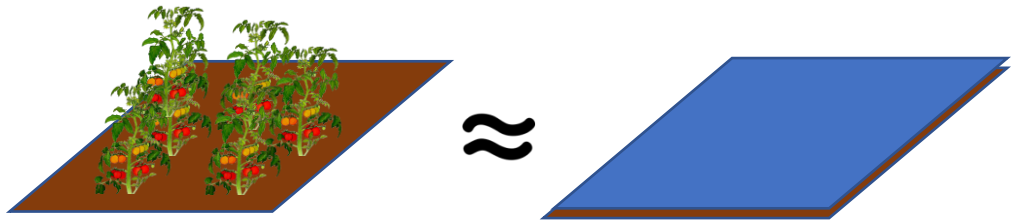


The presence of growing biomass introduces an extra attenuation which gives a strong positive bias on θ_γ values

Planting **Harvesting**

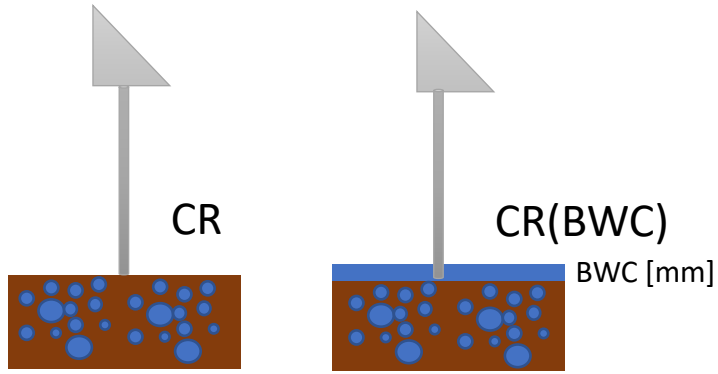
Estimating plants shielding effect

- 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

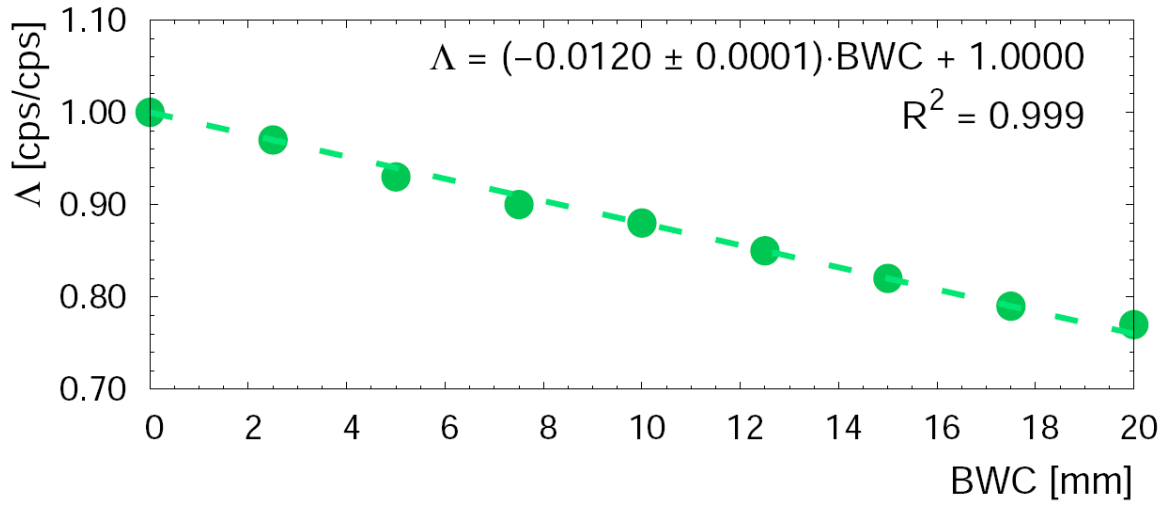
- The plants can be approximated to a layer of water that corresponds to the **BWC** in kg/m^2 (numerically equal to the water height in mm)



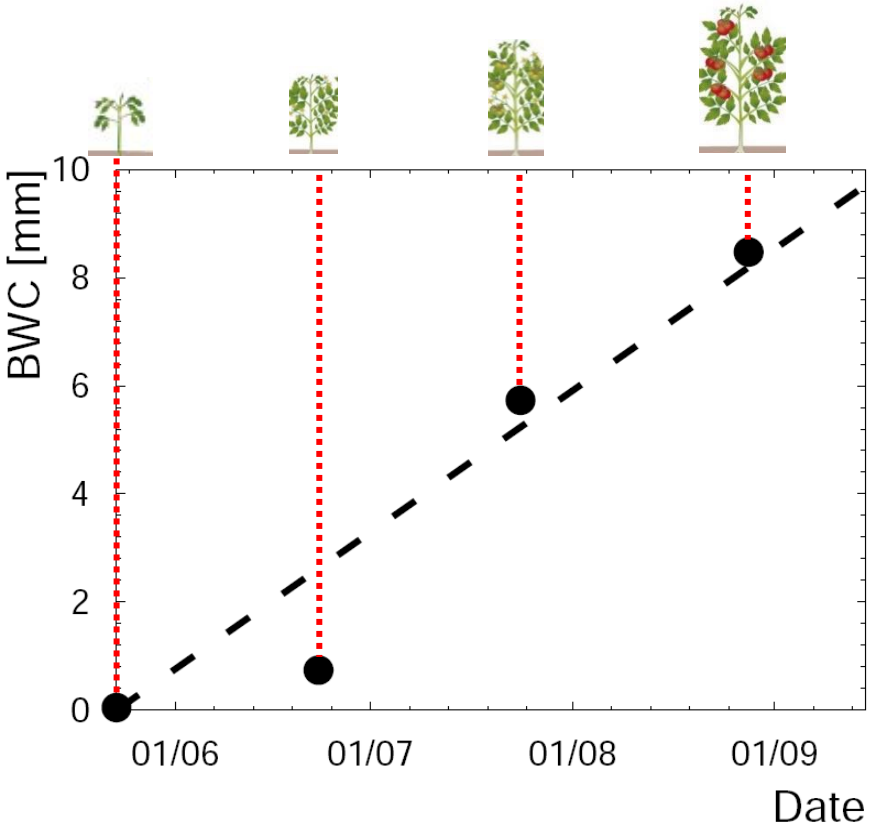
- The **count rate attenuation Λ** produced by the BWC is given by:

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

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



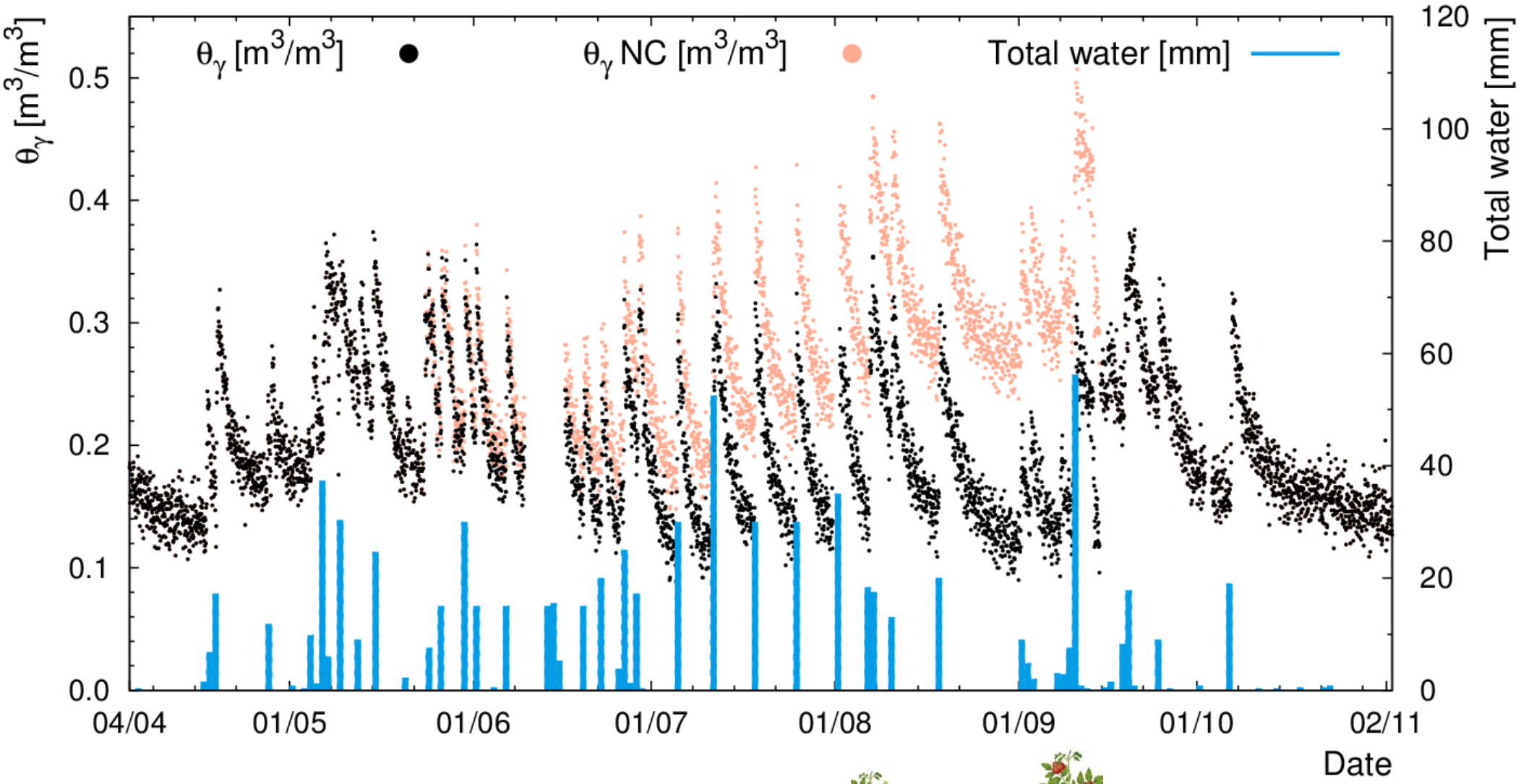
Biomass Water Content measurements



- 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:

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

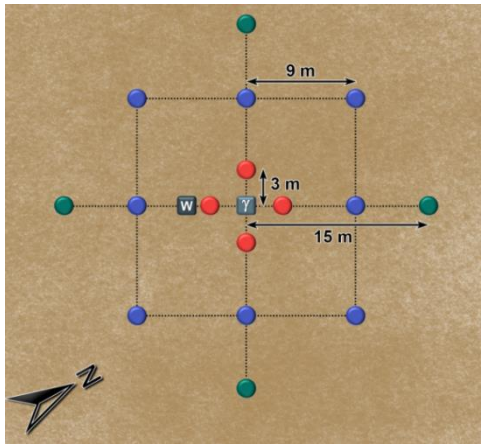
From the count rates to the corrected water content in soil



Planting

Harvesting

Validations measurements: gamma vs gravimetric method



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

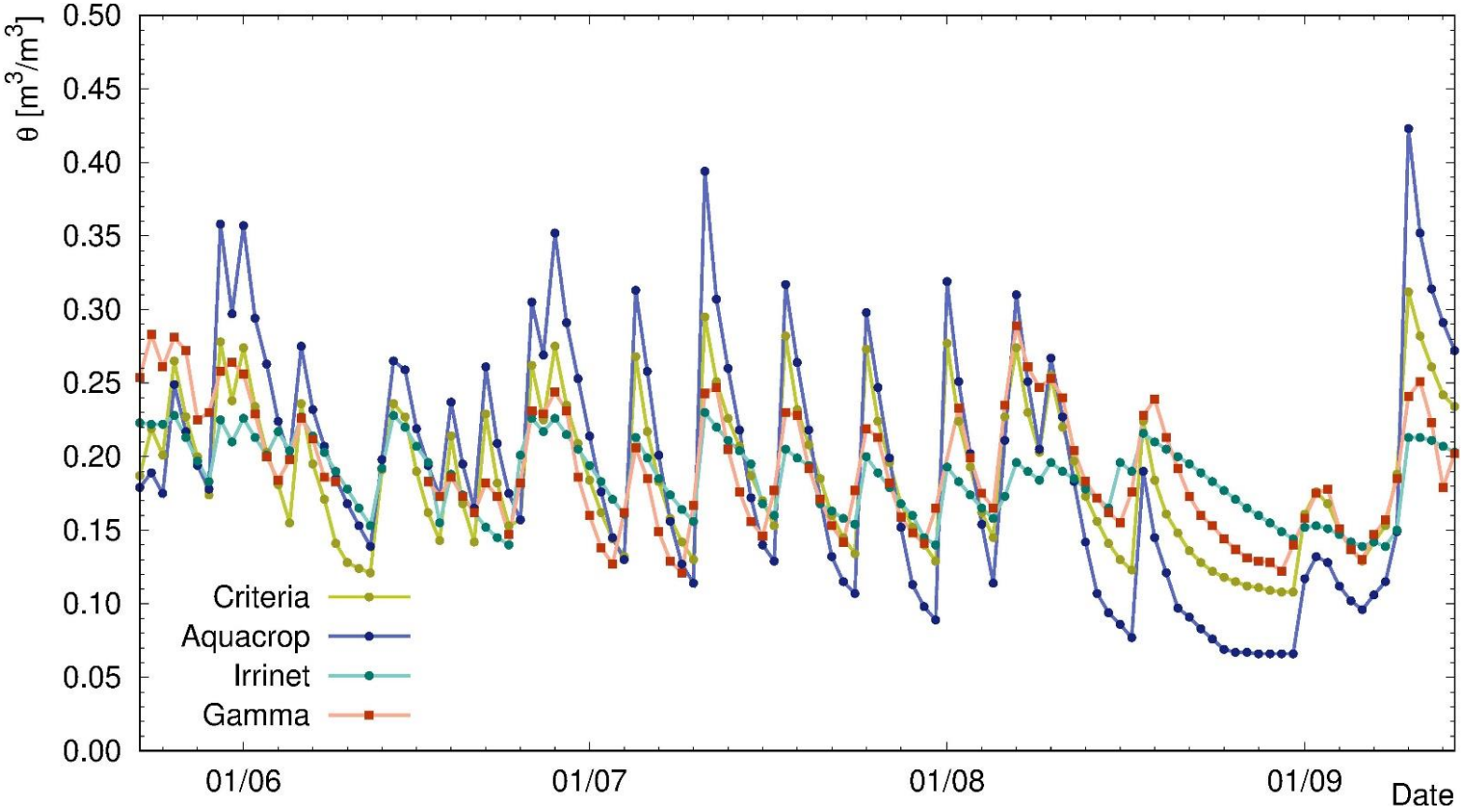
Bare soil			
Date	θ_G [m³/m³]	θ_γ [m³/m³]	$\Delta\theta$
21/09/17	23.7 ± 1.5	24.5 ± 1.1	3.4 %

With plants			
Date	θ_G [m³/m³]	θ_γ [m³/m³]	$\Delta\theta$
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 %

$\Delta\theta$ ~ 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

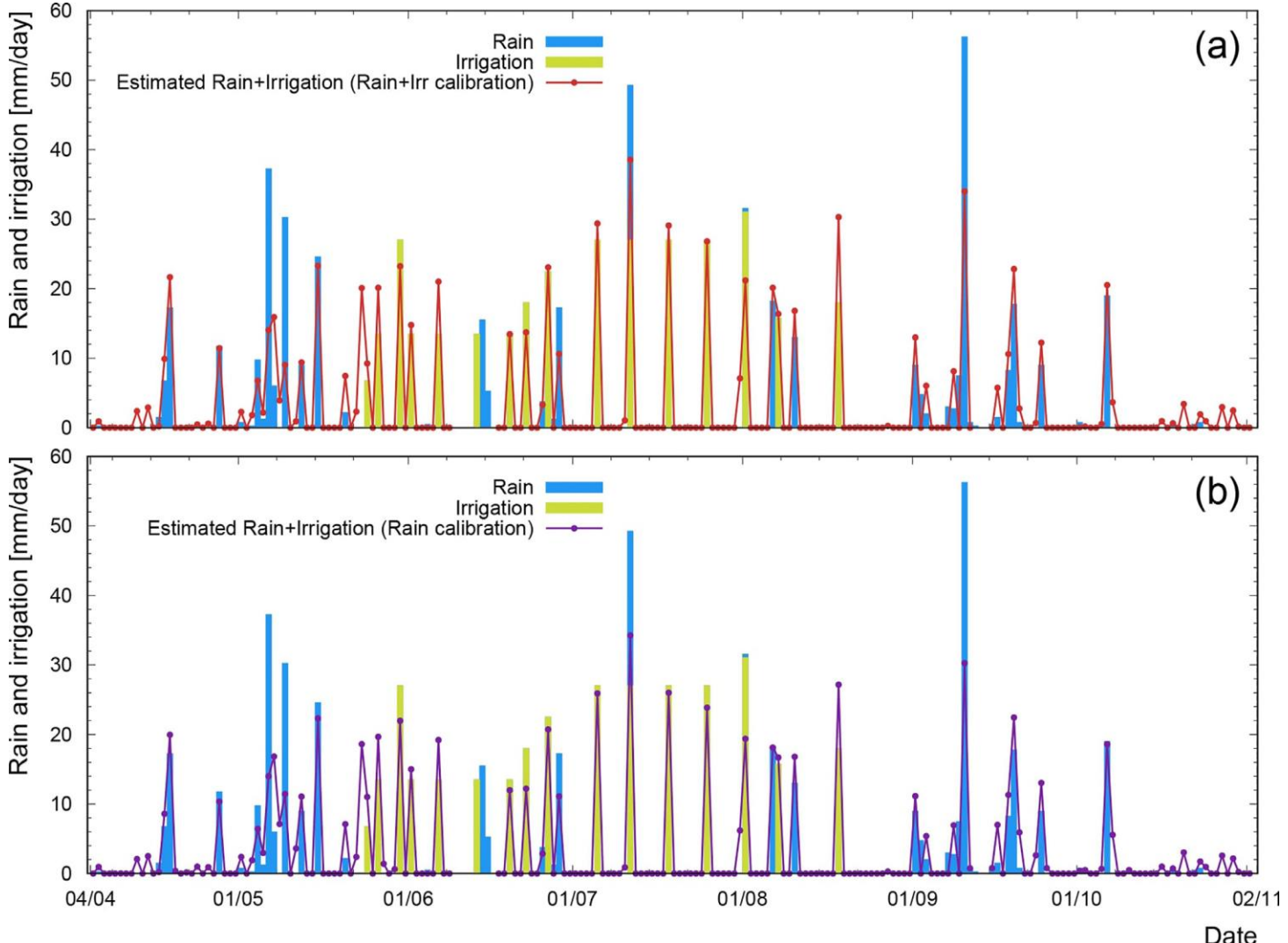


CRITeRIA show the best agreement with gamma data over the entire data-taking period while, **IRRINET** provides the best results in presence of the tomato crop.

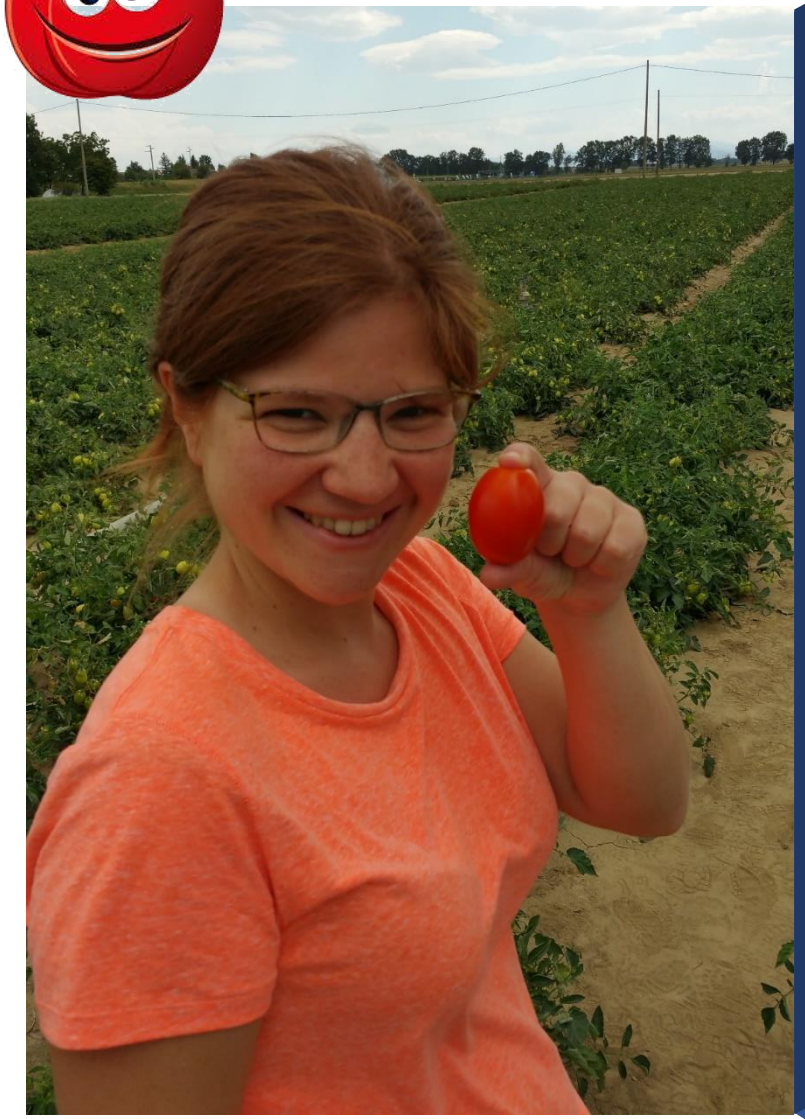
Soil moisture as a potential variable for tracking and quantifying irrigation: a case study with proximal ɣ-ray spectroscopy data

Filippucci, P., A. Tarpanelli, C. Massari, A. Serafini, V. Strati, M. Alberi, K. G. C. Raptis, F. Mantovani and L. Brocca (2020). Advances in Water Resources 136, 103502 (2020)

- *Can we quantify irrigation by the inversion of the water balance equation?*
- *Can we use as input the soil moisture retrieved from gamma ray spectroscopy?*



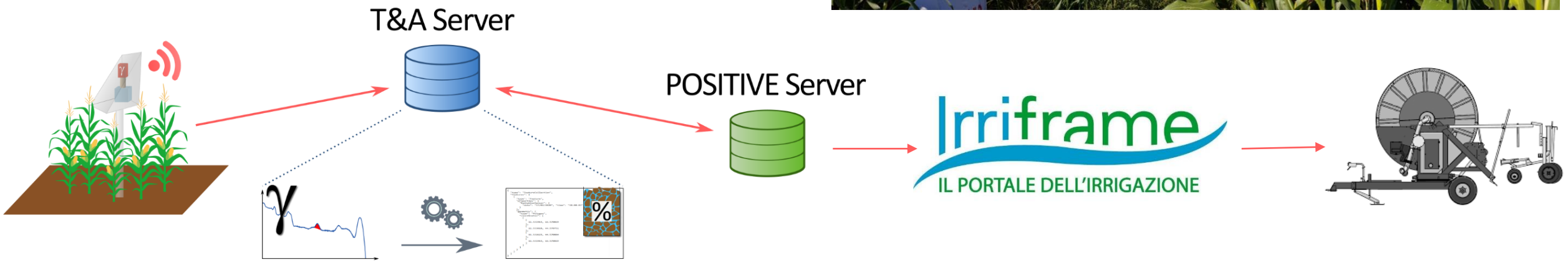
Times goes on…!



2017

2020

From the gamma ray station to the decision support system



Protocolli Operativi Scalabili per l'agricoltura di precisione POSITIVE

POR FESR EMILIA-ROMAGNA 2014/2020

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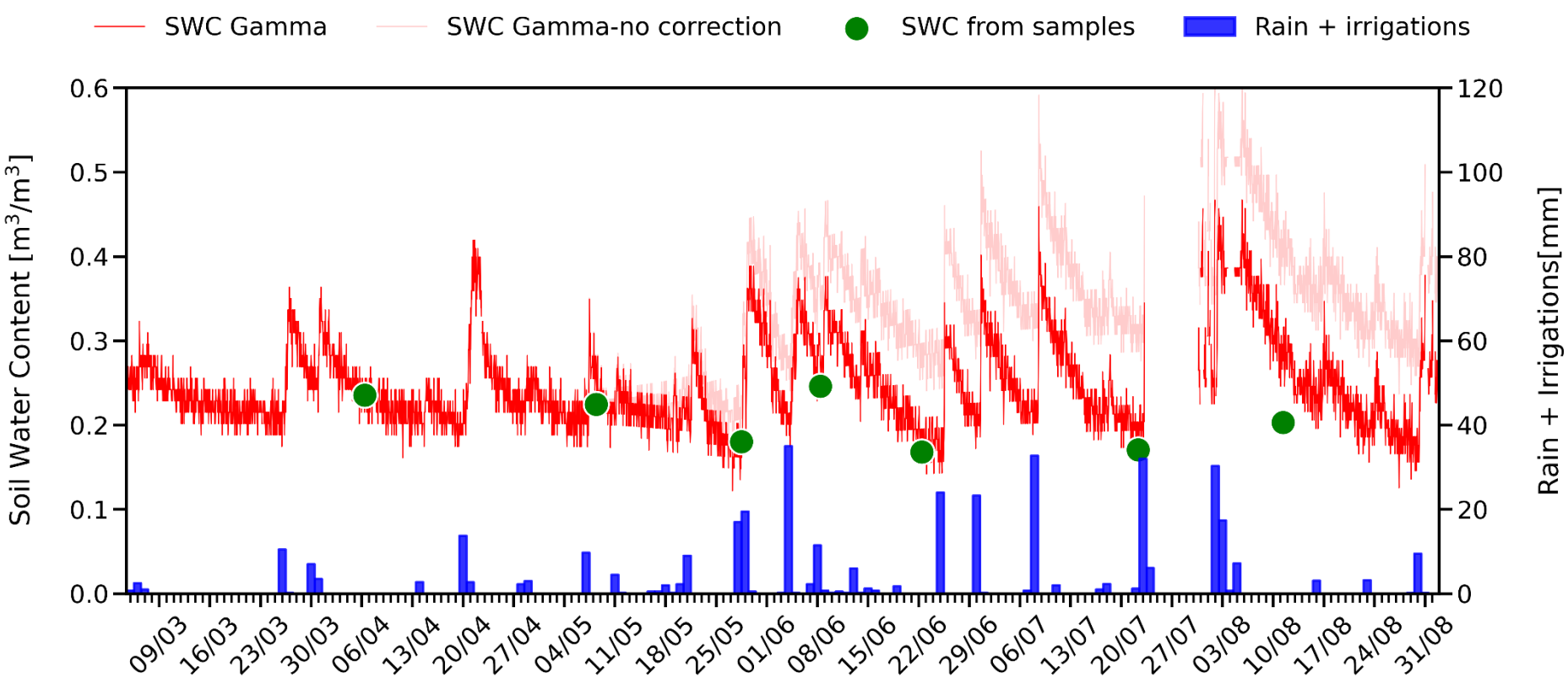
Results after 6 months of data-taking



Date	SWC campioni (m^3/m^3)	SWC gamma (m^3/m^3)
06/04/20	0.24 ± 0.02	0.24 ± 0.02
08/05/20	0.23 ± 0.02	0.25 ± 0.03
28/05/20	0.18 ± 0.02	0.18 ± 0.02
08/06/20	0.25 ± 0.03	0.26 ± 0.03
22/06/20	0.17 ± 0.03	0.20 ± 0.02
22/07/20	0.17 ± 0.03	0.19 ± 0.02
11/08/20	0.20 ± 0.02	0.24 ± 0.03

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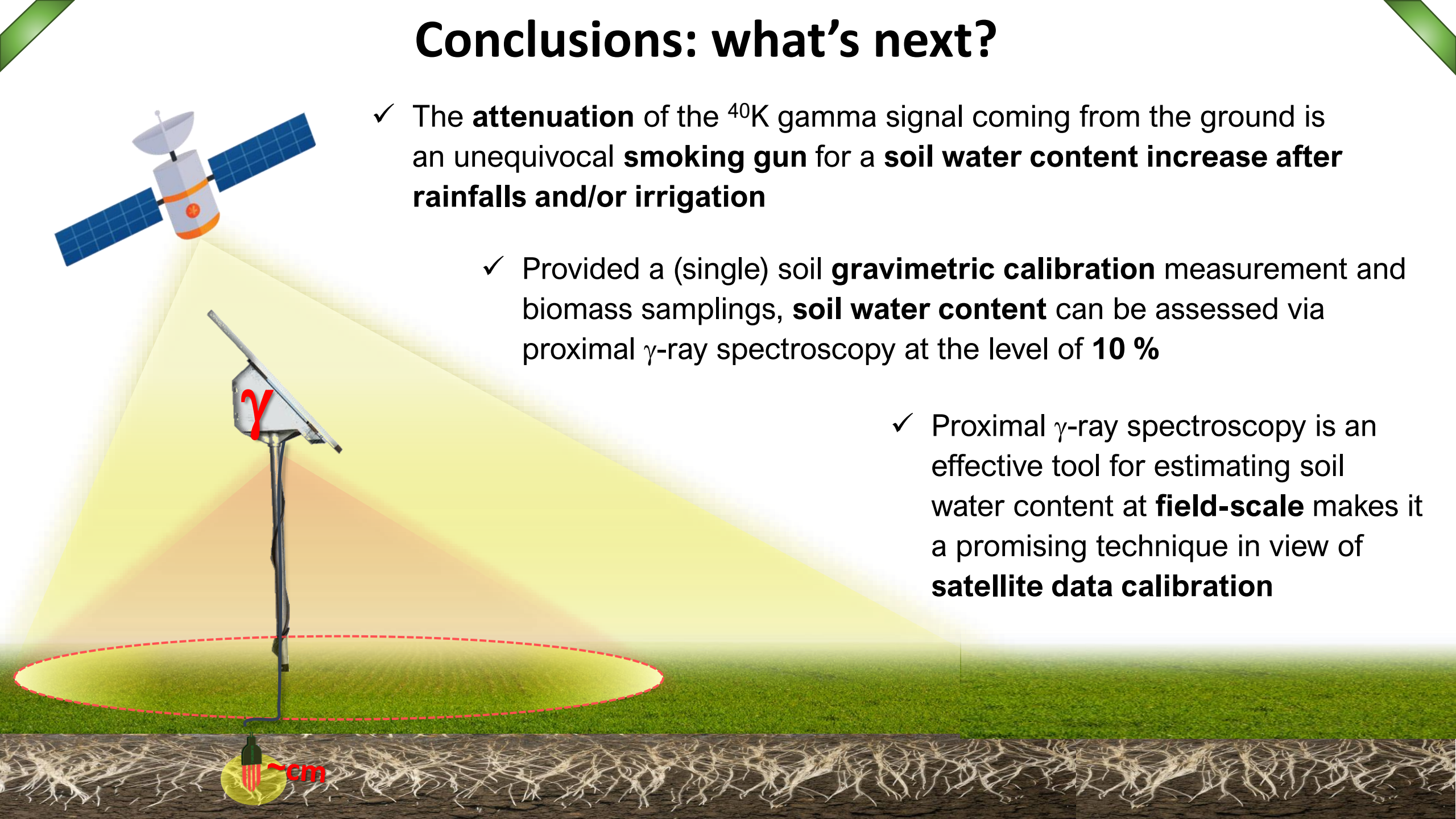
Conclusions: what's next?



- ✓ 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**

If you're still curious...

Laboratory for Nuclear Technologies Applied to the Environment

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

Strati V., Albéri M., Anconelli S., Baldoncini M., Bittelli M., Bottardi C., Chiarelli E., Fabbri B., Guidi V., Raptis K.G.C., Solimando D., Tomei F., Villani G. and Mantovani F.
Agriculture, 8(4), 60 (2018)

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

Baldoncini M., M. Albéri, C. Bottardi, E. Chiarelli, K. G. C. Raptis, V. Strati, and F. Mantovani.
Geoderma, 335, 69-77 (2019)

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

Baldoncini, M., M. Albéri, C. Bottardi, E. Chiarelli, K. G. C. Raptis, V. Strati, and F. Mantovani Journal of Environmental Radioactivity, 192, 105-116 (2018)

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

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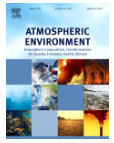

Rain rate and radon daughters' activity.

Bottardi, C., M., Baldoncini, M. Albéri, E. Chiarelli, M. Montuschi, K. G. C. Raptis, A. Serafini, V. Strati, and F. Mantovani
Atmospheric Environment, 238, 117728 (2020)

Discriminating irrigation and rainfall with proximal gamma-ray spectroscopy

Serafini, A., Albéri, M., Chiarelli, E., Montuschi, M., Raptis, K. G. C., Strati, V., & Mantovani, F.
2020 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), 191-195 (2020)

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