Positron Emitting Isotopes for Spatial Resolution of Microbial Activity in Soils: Applications and Future Directions in In Situ Bioremediation

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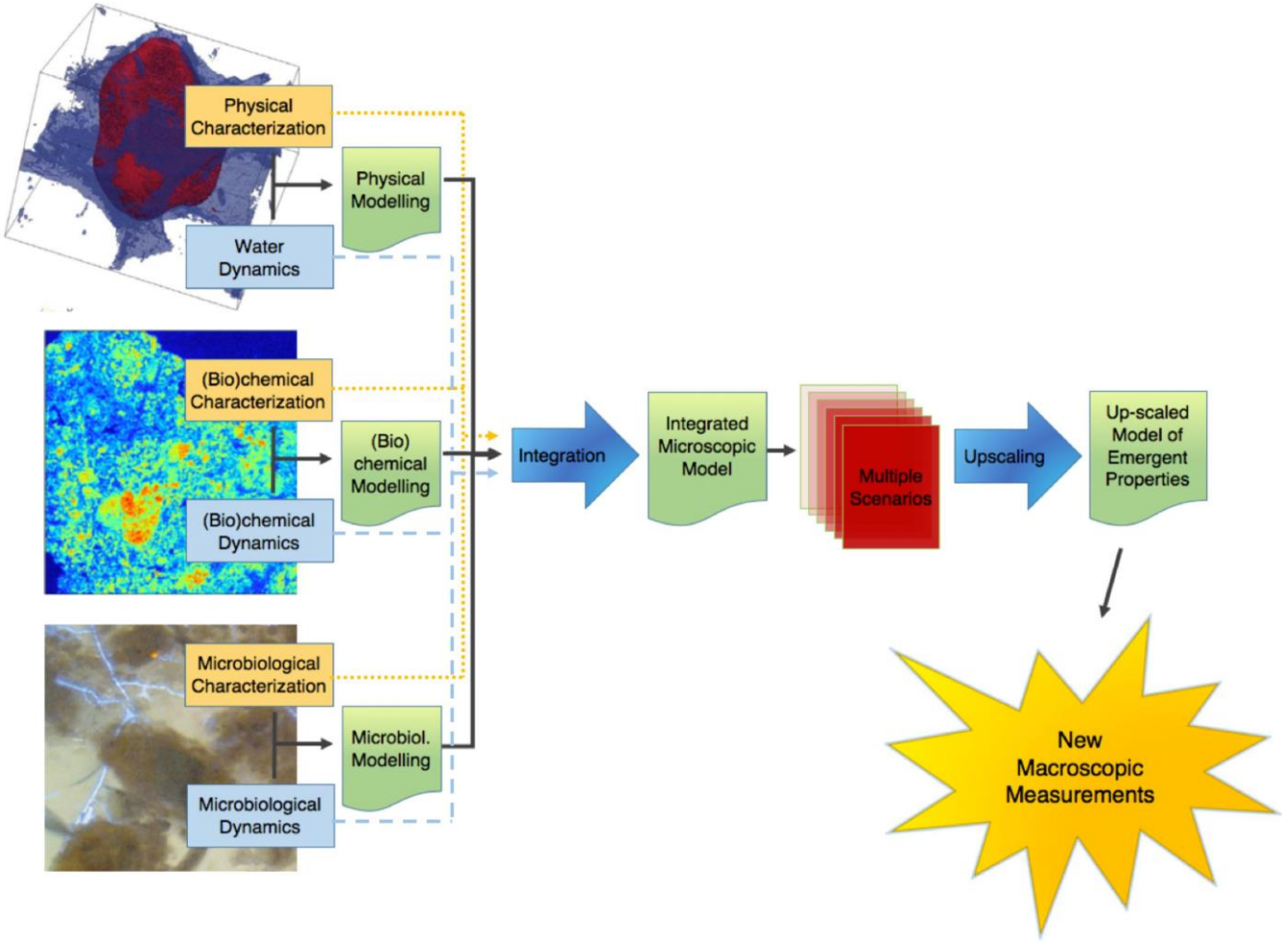
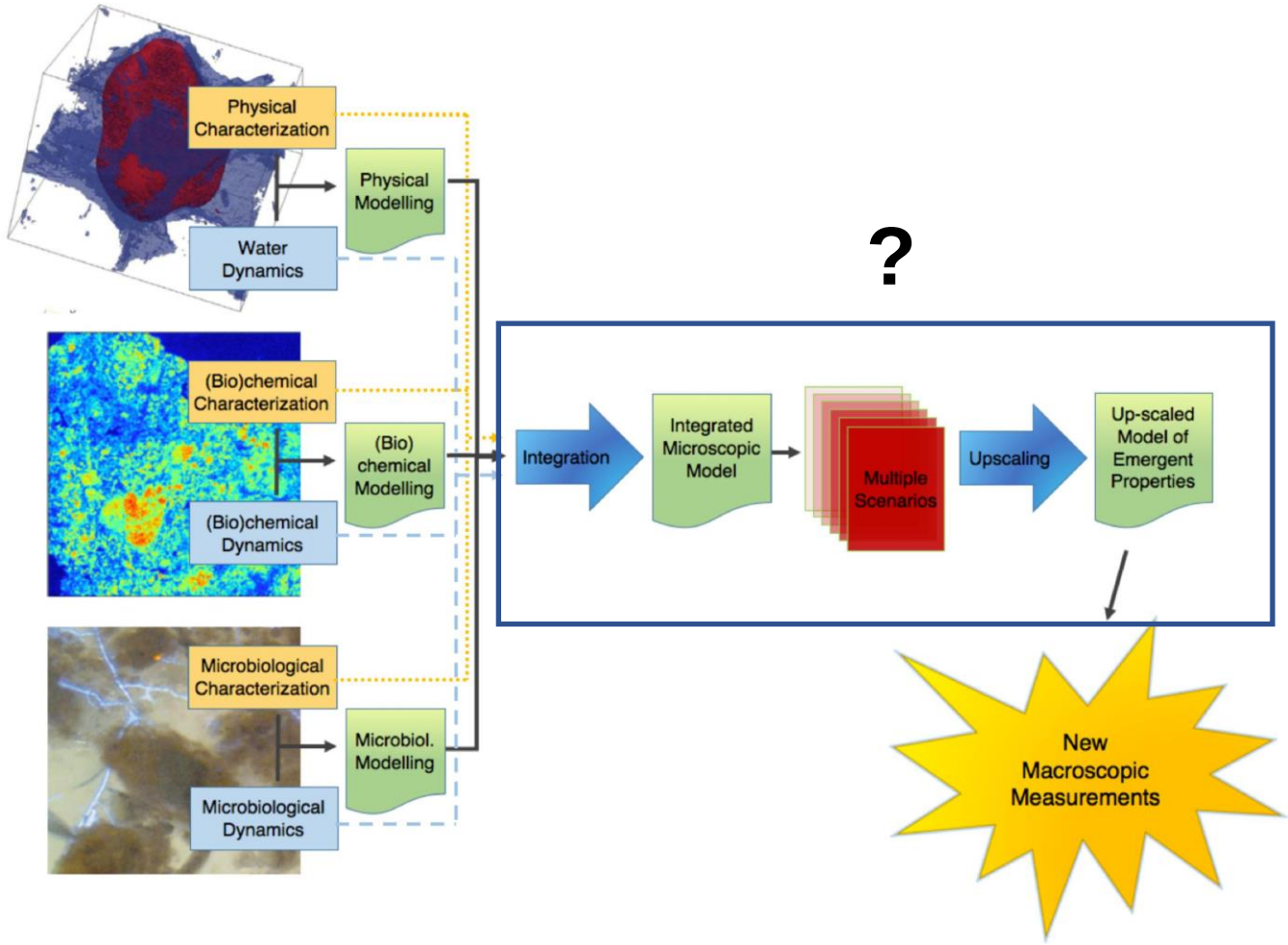
Soil heterogeneity and microbial activity

- Soils are highly heterogeneous media, variety of microenvironments in a given sample
- Microbial activity (e.g. contaminant transformation) favors certain microenvironments over others based on physical and biogeochemical characteristics



Baveye et al. *Front. Microbiol.* **2018**

Soil heterogeneity and microbial activity

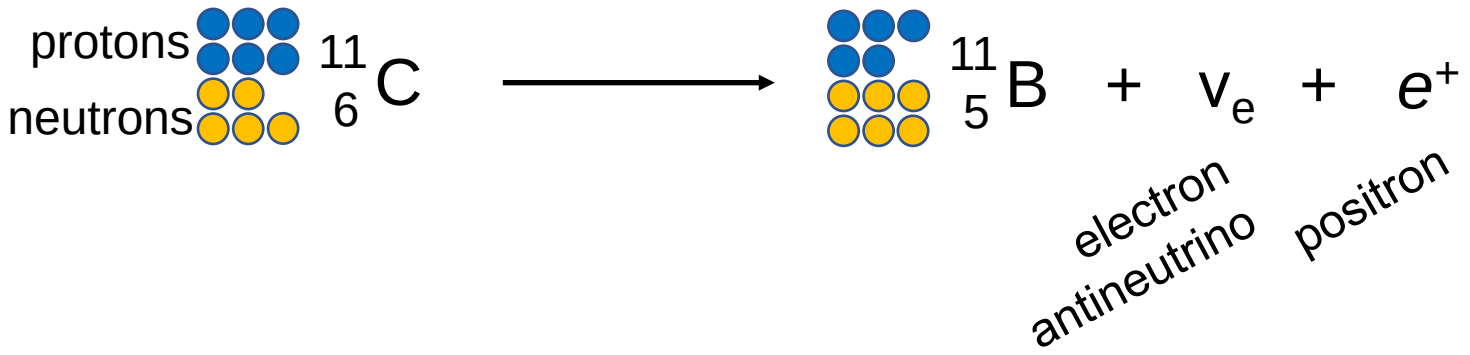


Baveye et al. *Front. Microbiol.* **2018**

- Bulk measurements of these properties often do not correlate well with activity
- Unraveling spatial relationships between activity and local environment key to better understanding microbial processes in soils, including bioremediation
- Positron imaging may reconcile these points

What is positron imaging?

Positron: a subatomic particle with the same mass as an electron and a numerically equal but opposite charge

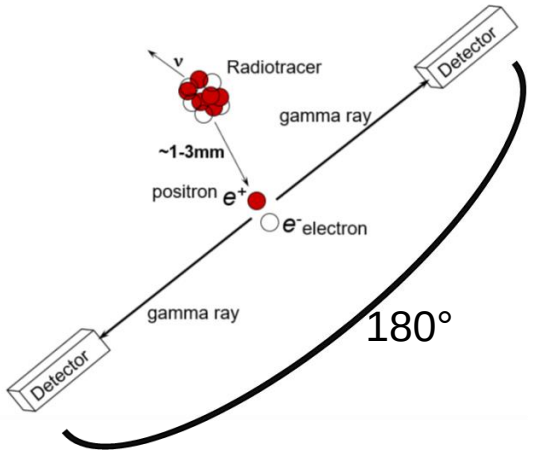


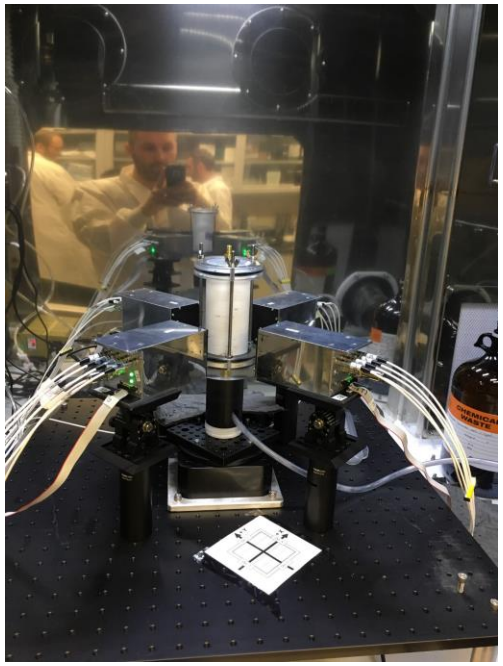
Positron-emitting Radionuclides produced at cyclotron facilities

Positron emitting isotope	Half life
^{11}C	≈ 20 minutes
^{13}N	≈ 10 minutes
^{15}O	≈ 2 minutes
^{18}F	≈ 119 minutes

What is positron imaging (PET and autoradiography)?

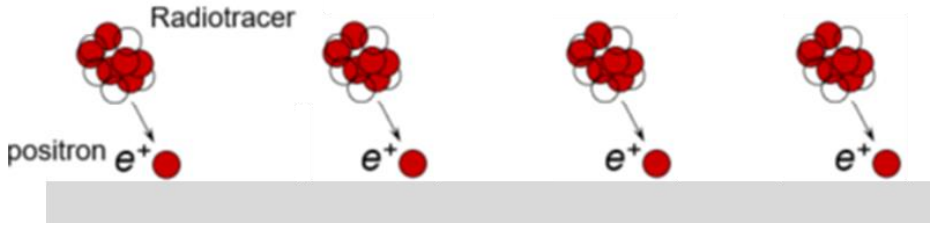
Positron emission tomography (PET)

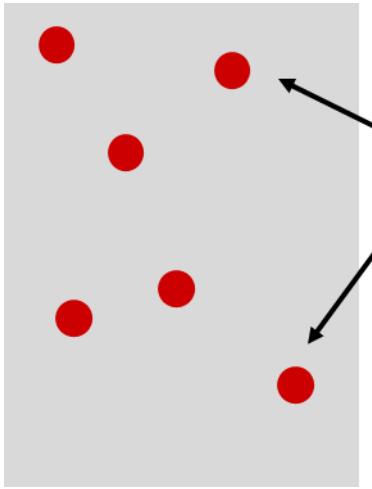




Using detector arrays, three dimensional tracer distribution accessible

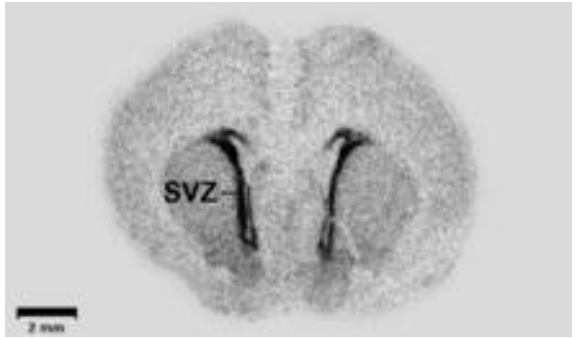
Autoradiography





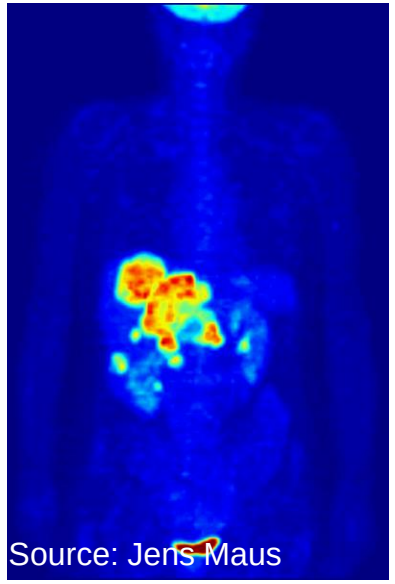
Regions exposed to radiotracer

Tracer distribution in rat brain



What are the benefits of positron imaging?

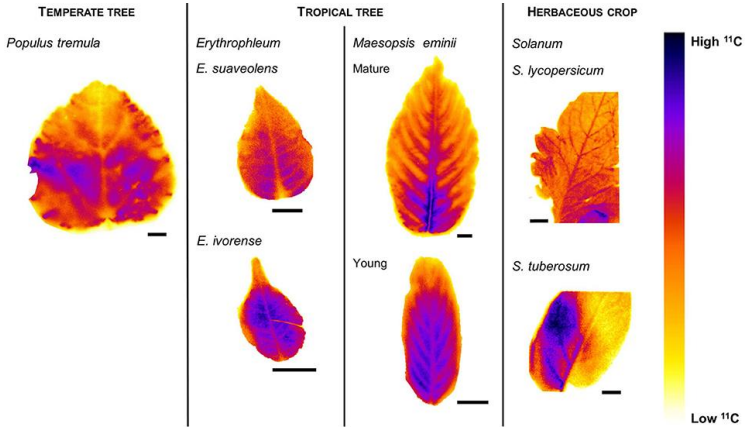
Medical diagnostics



Source: Jens Maus

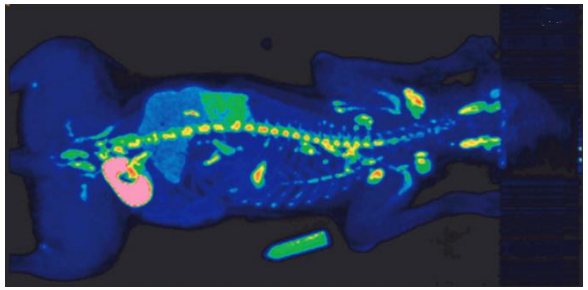
Property of Positron imaging	Benefits
Radiation penetrates well in many media	Visualization in opaque media
Numerous isotopes and chemistries available	Tracers tailored to many systems
Uses synthetic isotopes	What we see is what was added (i.e. no natural background)
Short half-life of radiotracers	Active regions visualized
Able to detect low tracer levels (sub-picomolar concentrations)	Minimal disturbance to sample chemistry and biology
Repeated scanning/imaging	Time-resolved visualization of tracer movement

Plant Science



Hubeau et al. *Front. For. Glob. Change.* **2019**

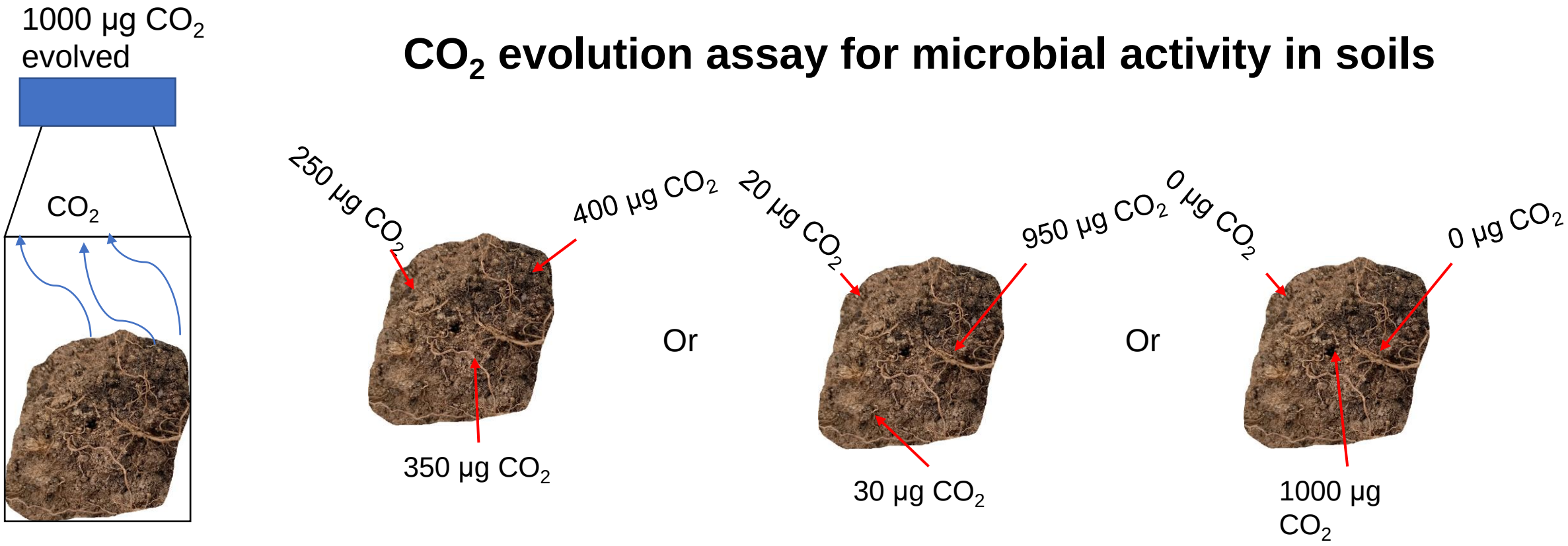
Veterinary medicine



Rohren et al. *Vet. Comp. Oncol.* **2010,** *8,* 163-187

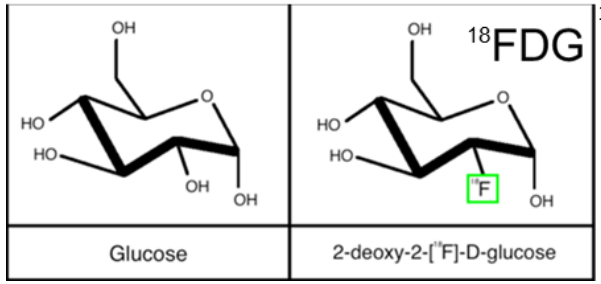
Some example projects from our lab applying positron imaging to questions in soil science

Visualizing microbial metabolism in soils



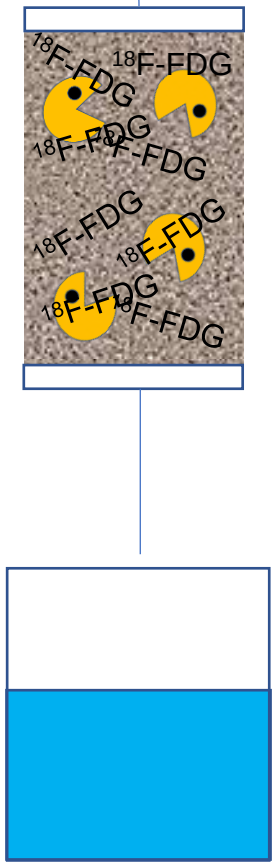
- Localized soil environments vary greatly in 3-dimensional space
- Many existing methods for measuring metabolism destructive and/or lack spatial resolution

Mapping microbial metabolism with PET

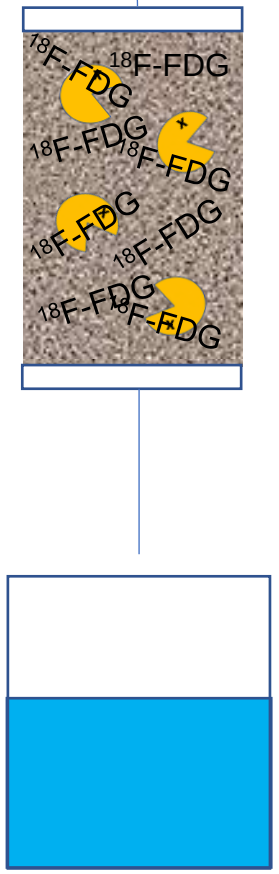


^{18}F-FDG + Growth medium

Column with active *P. fluorescens*

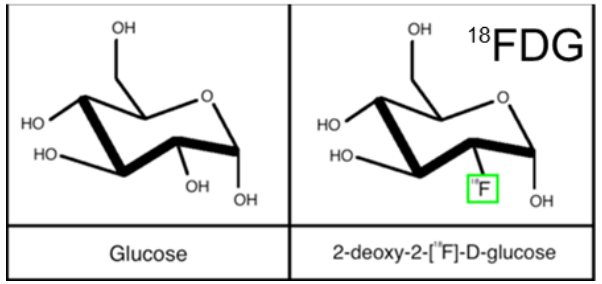


^{18}F-FDG + Growth medium

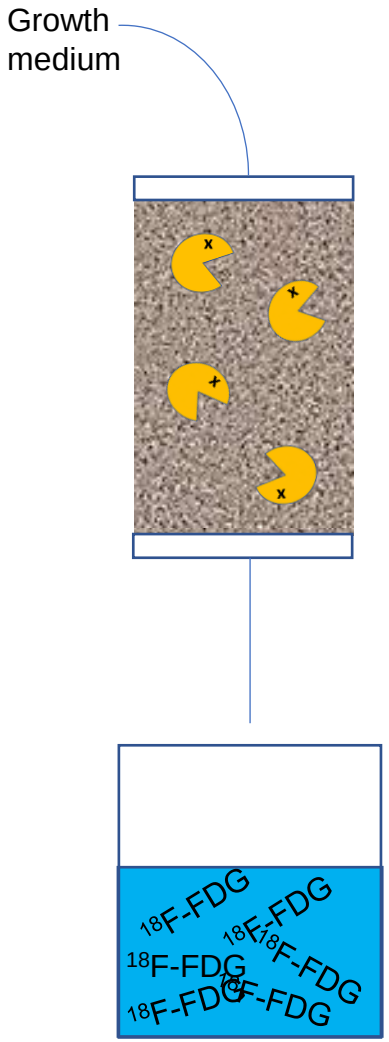


Column with autoclaved *P. fluorescens*

Mapping microbial metabolism with PET



Column with active *P. fluorescens*



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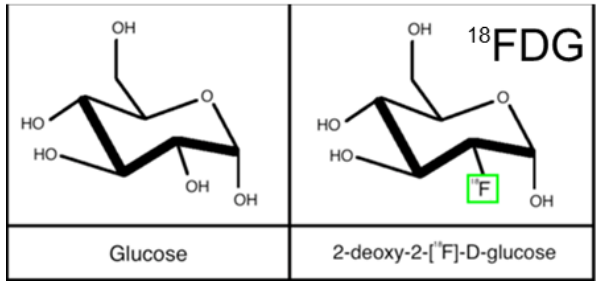
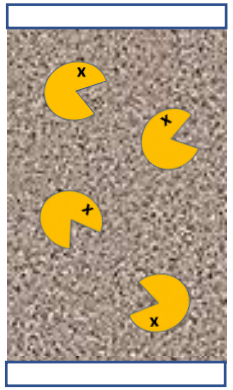
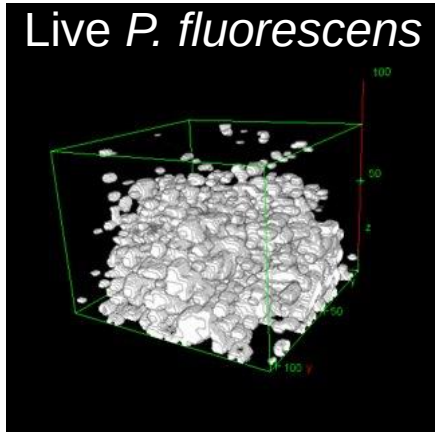


Column with active *P. fluorescens*

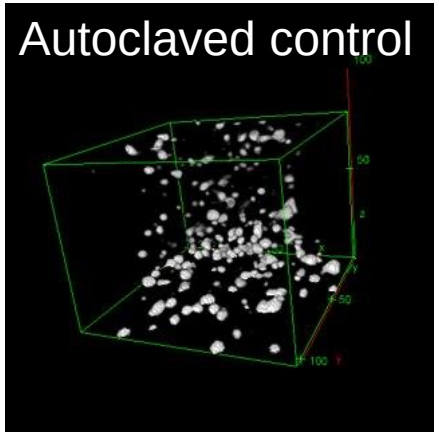


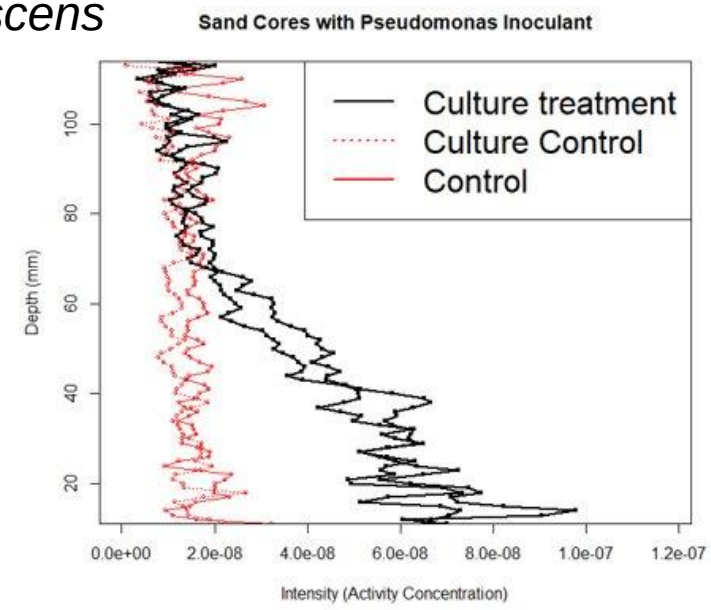
Column with autoclaved *P. fluorescens*

Live *P. fluorescens*



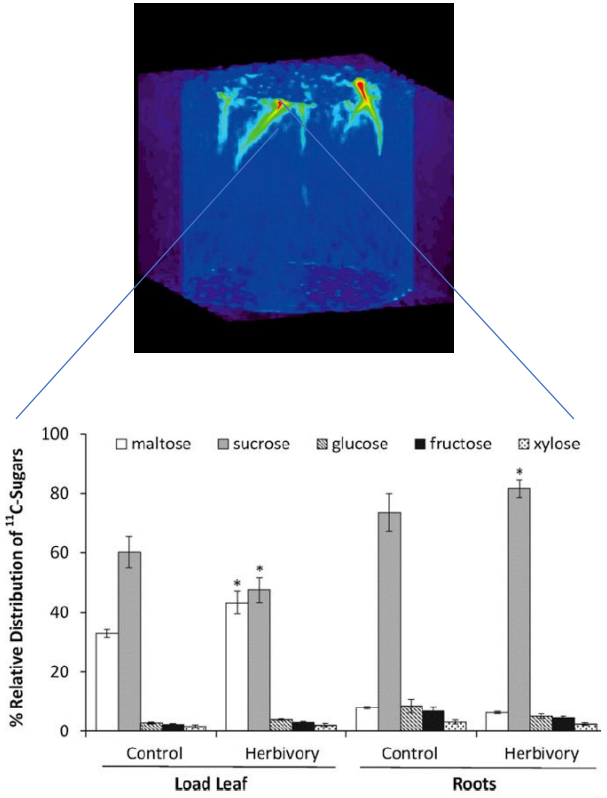
Autoclaved control





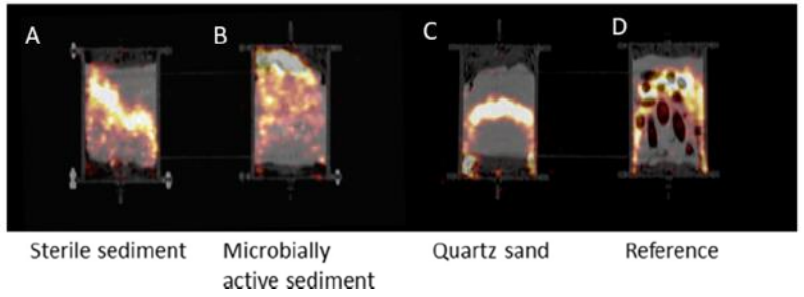
Positron imaging defines region of activity, then what?

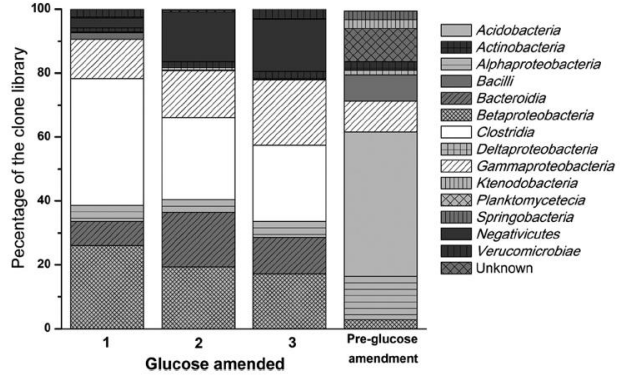
Targeted biochemical analysis



Qu et al. *Plant Physiol.* **2016,** *172,* 776-788

Targeted genetic analysis

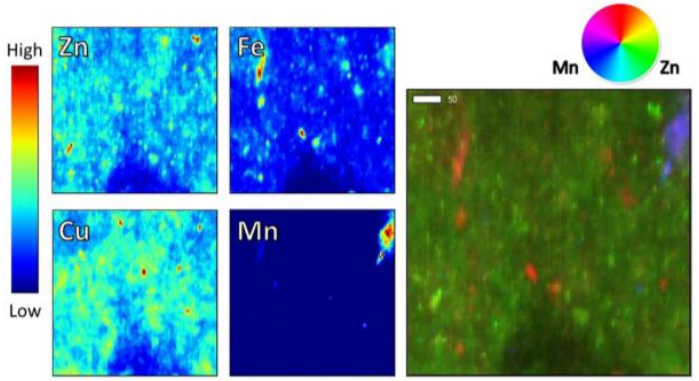




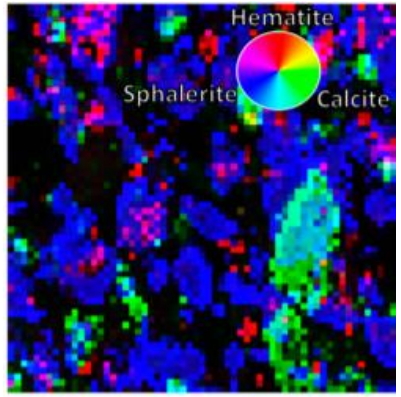
Thorpe et al. *Appl. Radiat. Isotopes* **2019,** *144,* 104-110

Focused chemical and physical imaging

X-ray fluorescence mapping



Microdiffraction studies



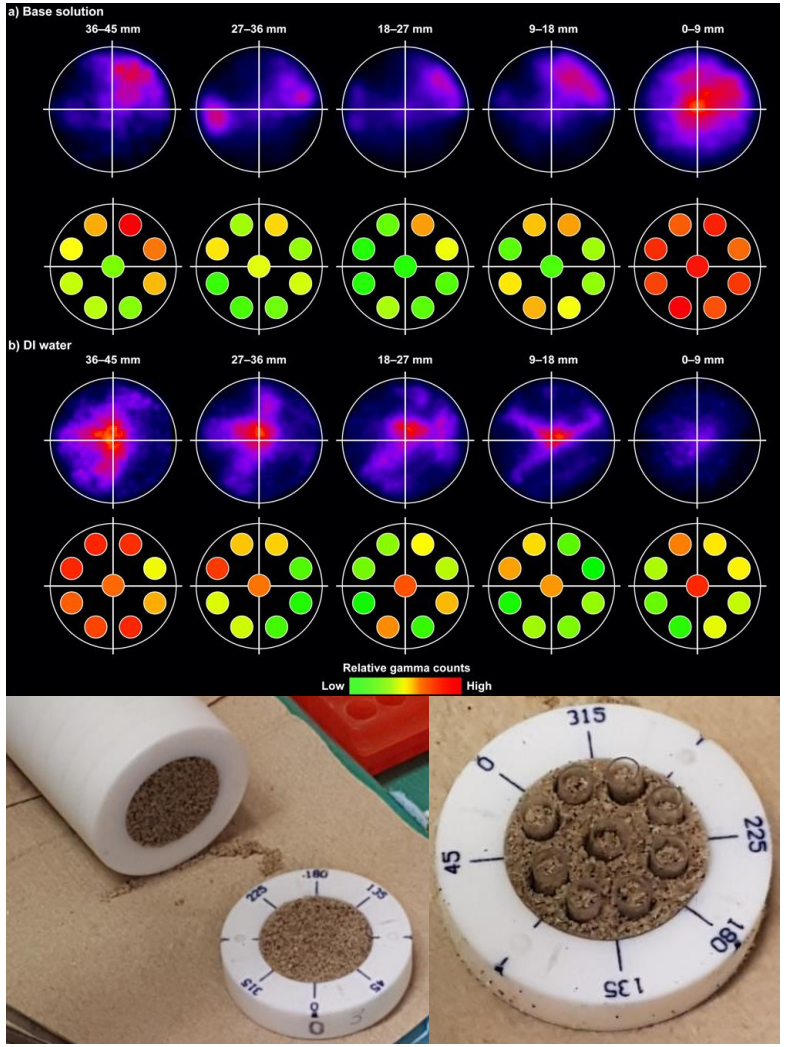
Hamilton et al. *JEQ* **2016,** *45,* 684-692 and Hamilton et al. *ACS Earth Space Chem* **2018,** *2,* 1161-1167.

… as well as some more examples from our lab

Visualizing heterotrophic activity in diesel contaminated soil with PET

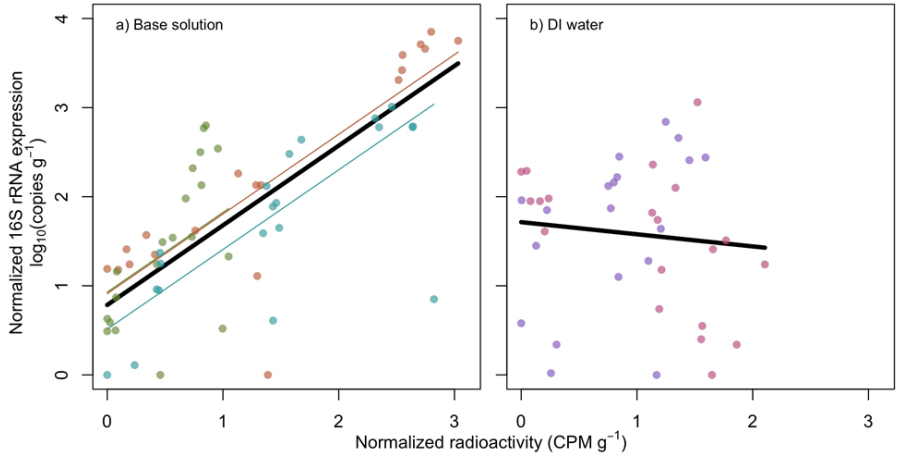
Soil core with biostimulatory solution

Soil core with water



Biostimulatory solution alters distribution of microbial activity locally

Targeted genetic analysis



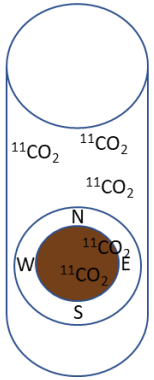
Bulk measurements in system correspond with higher activity from PET

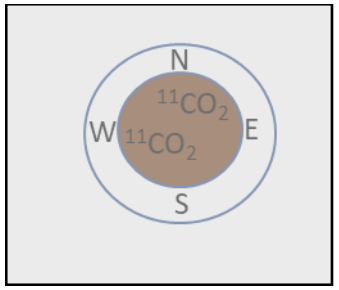
With biostimulatory solutions:

- ↑ Overall microbial activity
- ↑ Nitrogen uptake
- ↑ Hydrocarbon degradation rates

Radiographic imaging of methanotrophs and autotrophs in soils

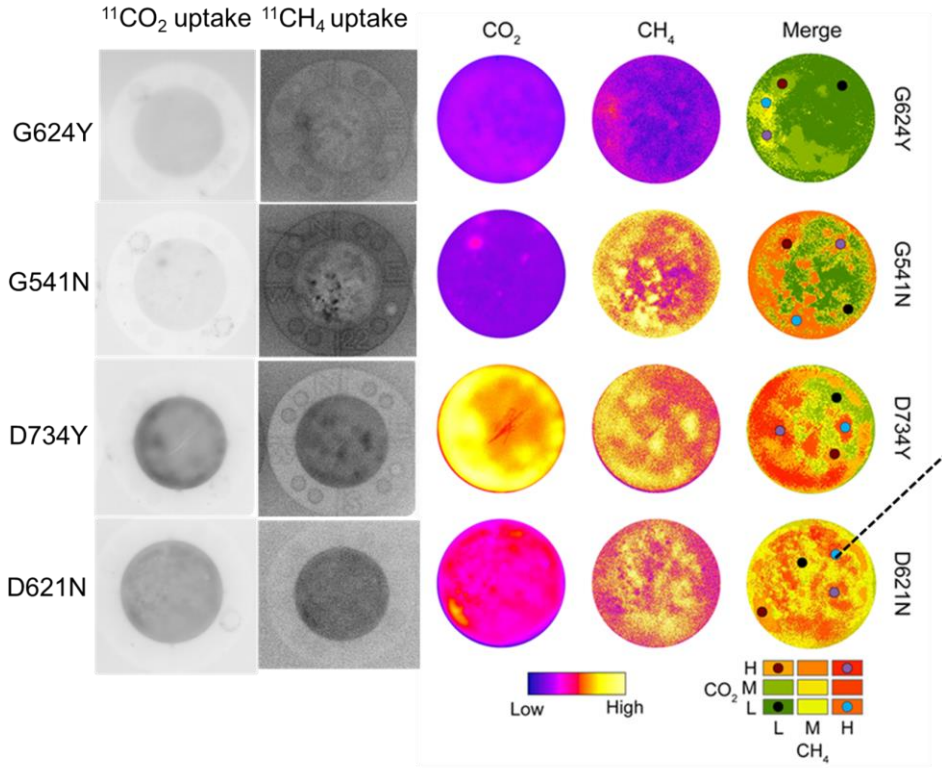
Soil dosing and imaging



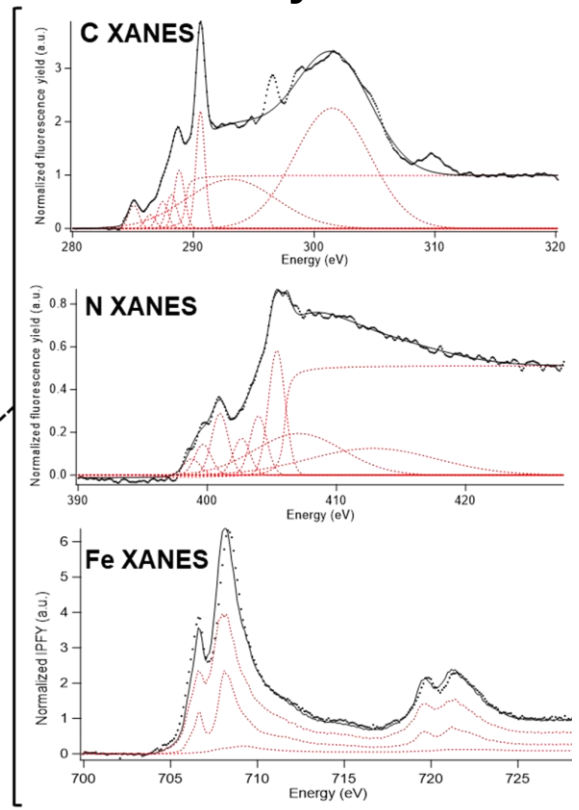


Imaging film

Images of radiotracer uptake



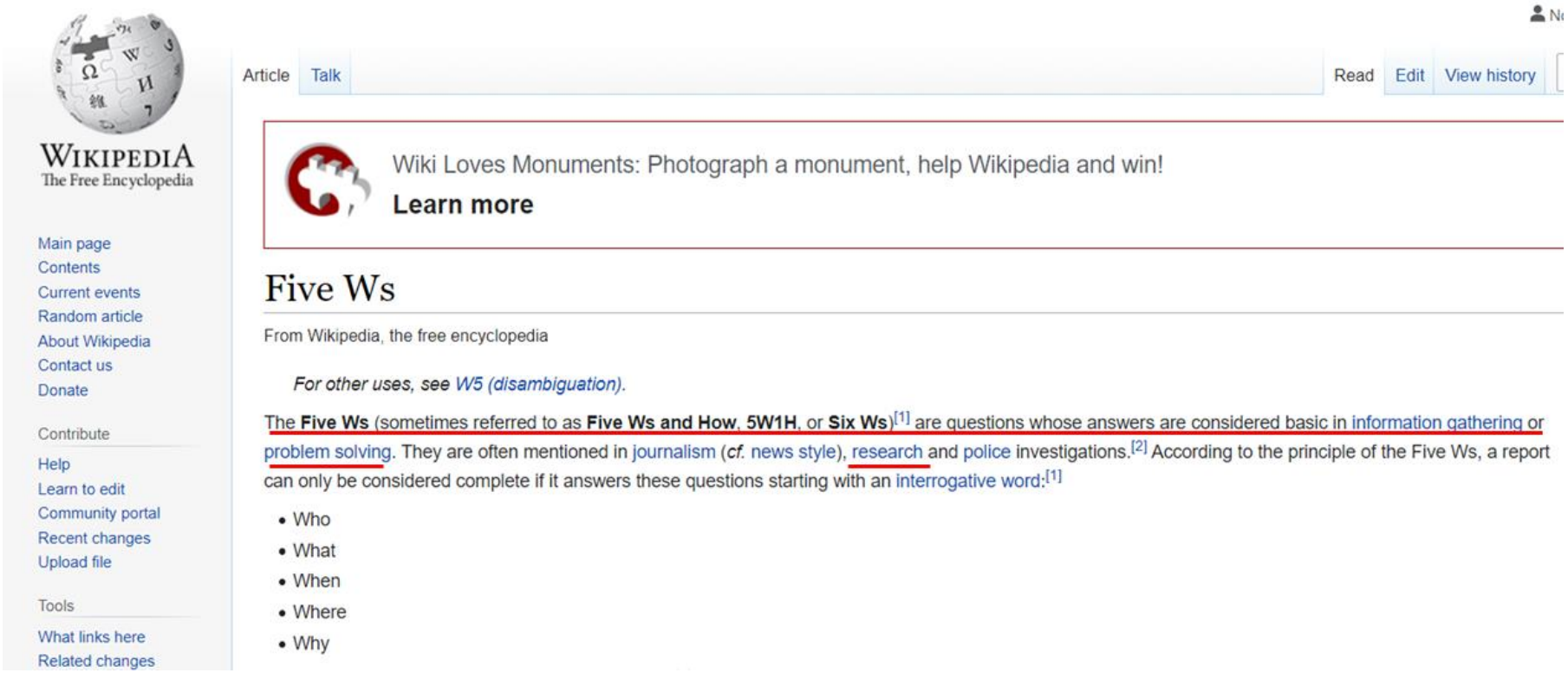
Targeted biogeochemical analysis



Regions of methantrophic activity have greater proportion of inorganic N (nutrient controlled)

Regions of autotrophy associated with greater presence of carbonate minerals and shifts in Fe mineralogy (mineralogy controlled)

Summary of positron imaging applications in research



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Five Ws

From Wikipedia, the free encyclopedia

For other uses, see W5 (disambiguation).

The **Five Ws** (sometimes referred to as **Five Ws and How**, **5W1H**, or **Six Ws**)[1] are questions whose answers are considered basic in information gathering or problem solving. They are often mentioned in journalism (*cf.* news style), research and police investigations.[2] According to the principle of the Five Ws, a report can only be considered complete if it answers these questions starting with an interrogative word:[1]

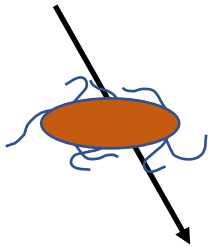
- Who
- What
- When
- Where
- Why

- Positron emitting radiotracers can follow molecule-specific activities (**<u>what</u> is happening?**)
- Positron imaging allows for time-resolved visualization of activity (**<u>where</u> did it happen?, <u>when</u> did it happen?**)
- Subsequent genetic analysis has potential to characterize communities (**<u>who</u> is there?**)
- Local biogeochemical speciation may help understand underlying factors (**<u>why</u> did it happen?**)

Future applications of positron imaging in bioremediation processes

Remediation of BTEX compounds

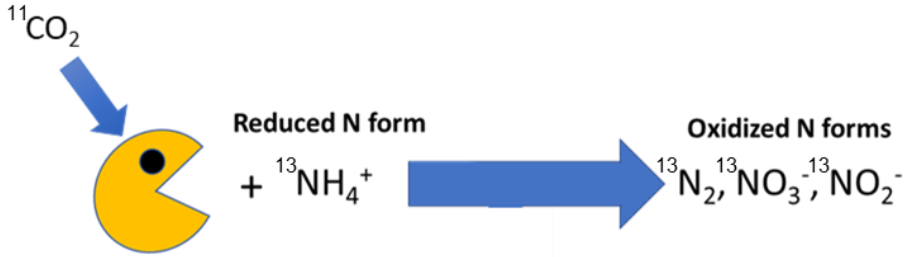
[^{11}C]toluene
[^{11}C]benzene
[^{11}C]ethylbenzene



BTEX degrading bacterium

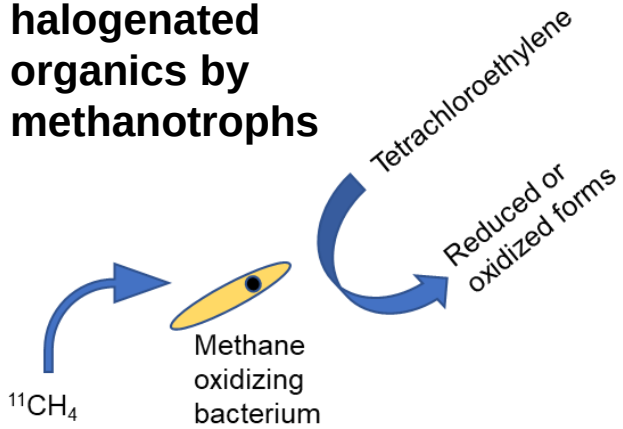
[^{11}C]metabolites

Remediation of ammonium in soils



Autotrophic ammonium oxidizing bacterium

Remediation of halogenated organics by methanotrophs



Varying tracer chemistry can open up spatial visualization of many biodegradation/transformation processes (modify the “what”)

Acknowledgments

- Peak and Siciliano lab groups at U of S
  - Curtis Senger
- Dr. Katherine Stewart
- Collaborators at University of Regina
  - Dr. Aram Teymurazyan
  - Dr. Mehran Talebitaher
- Saskatchewan Center for Cyclotron Sciences
  - Dr. Jacquie Cawthray
- Natural Sciences and Engineering Research Council

University of Regina

Fedoruk Centre
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