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Martin Trtilek
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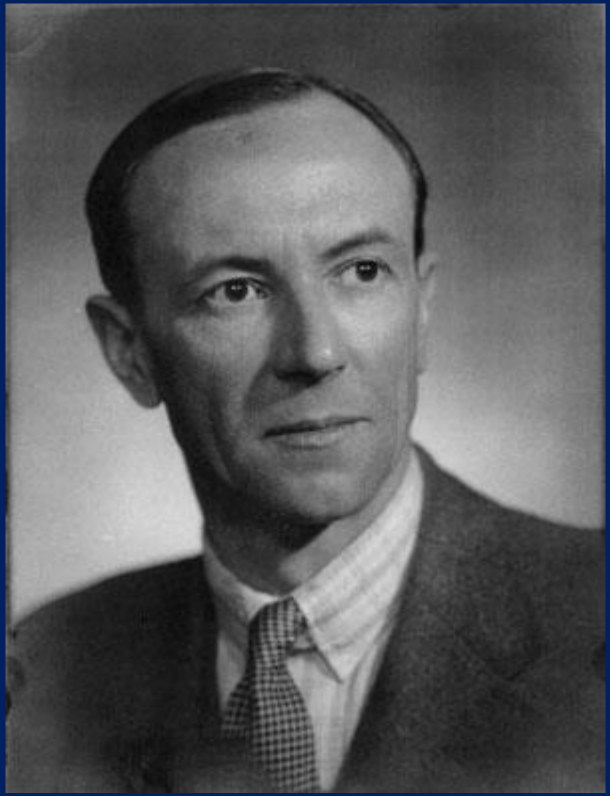
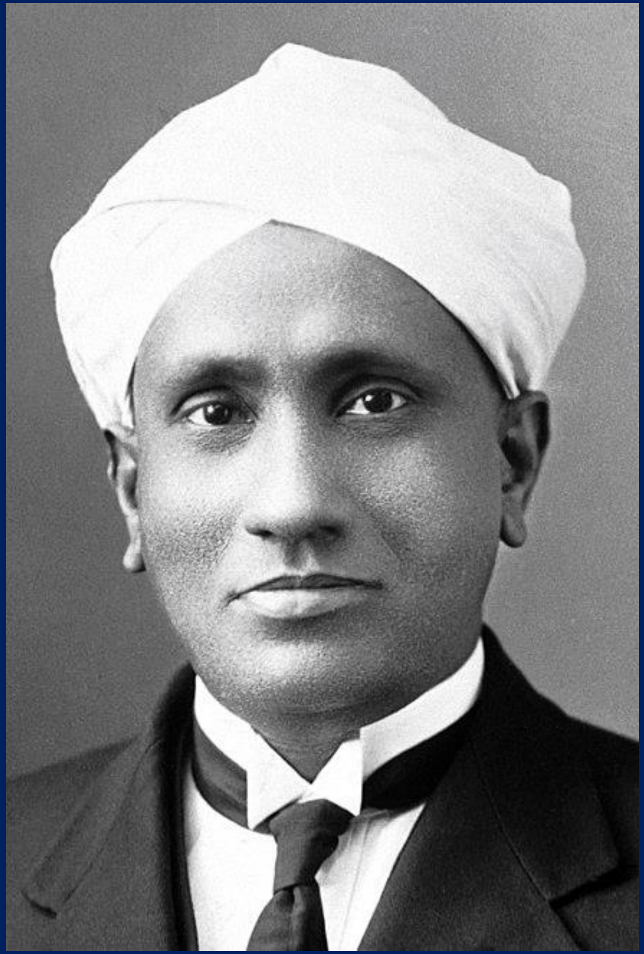
CropBooster

Our road to the future of phenomics: The actors are Neutron, Raman and X-Ray





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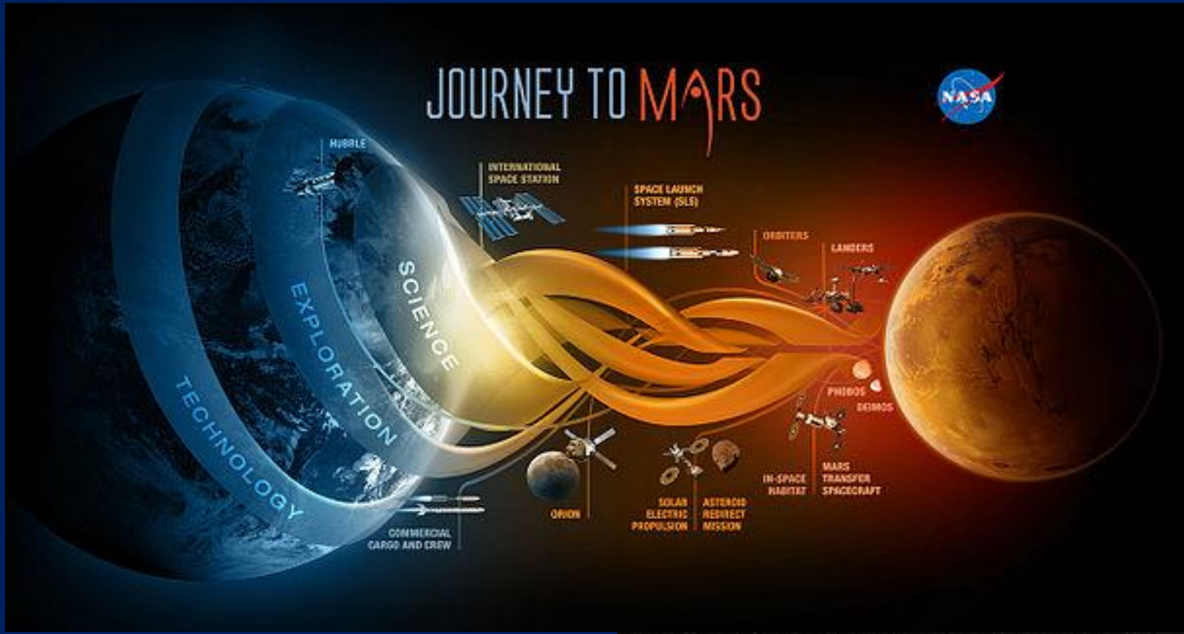

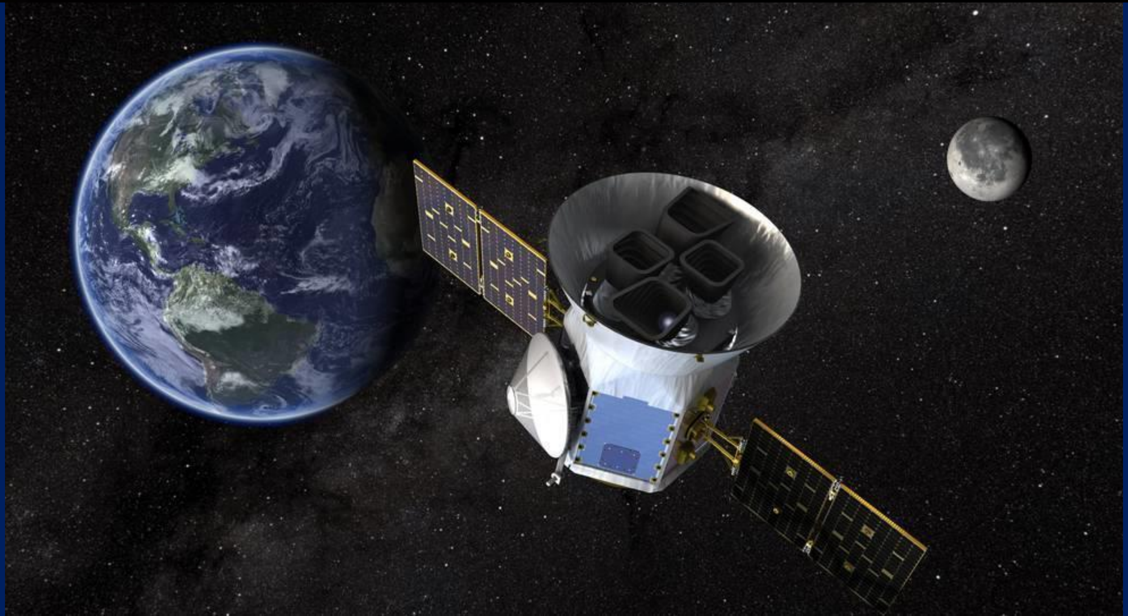

State of the Art Technologies for Plant Phenotyping

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Research
&
Development

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Sensors

Kinetic chlorophyll fluorescence Imaging

3D Imaging

Hyperspectral Imaging

X-RAY

Raman Spectroscopy

Neutron Imaging

Mass Spectroscopy

Root Imaging

RGB and Morphometric Imaging

Near Infrafed/Thermal Imaging

LIBSpectroscopy

Sensors

Kinetic chlorophyll fluorescence Imaging

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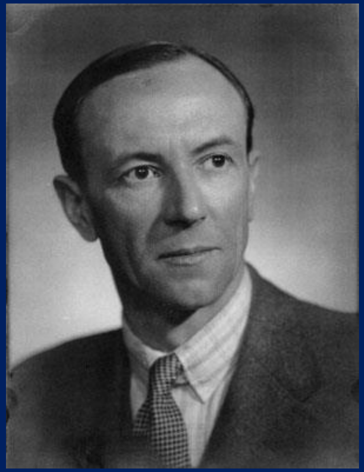
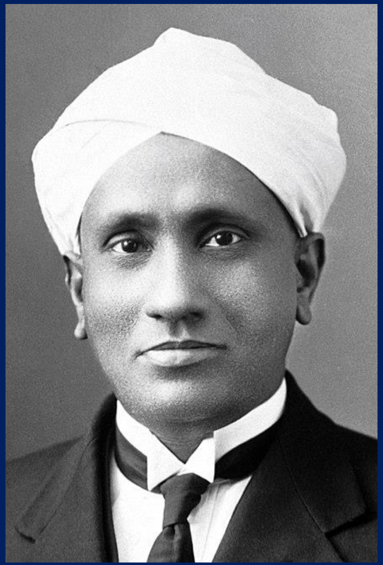


Chadwick

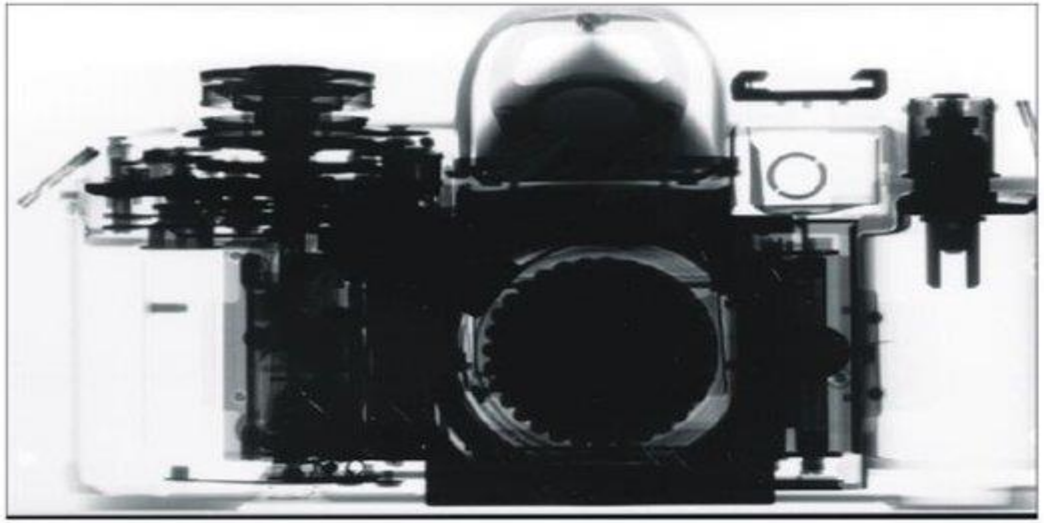
Roentgen



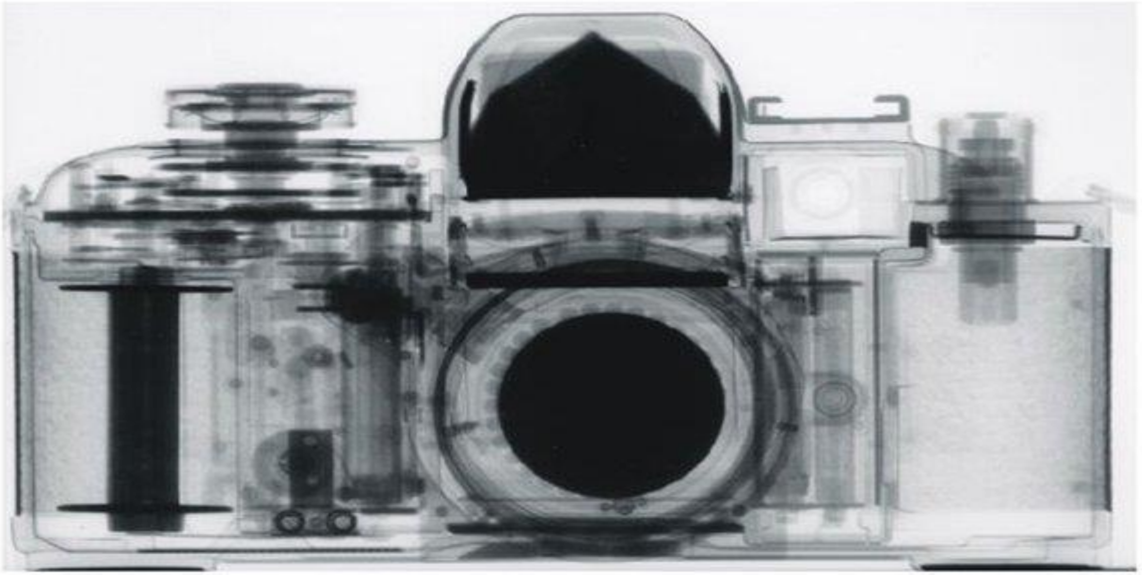
Raman

Look inside

Comparison of X-ray and Neutron Radiographs



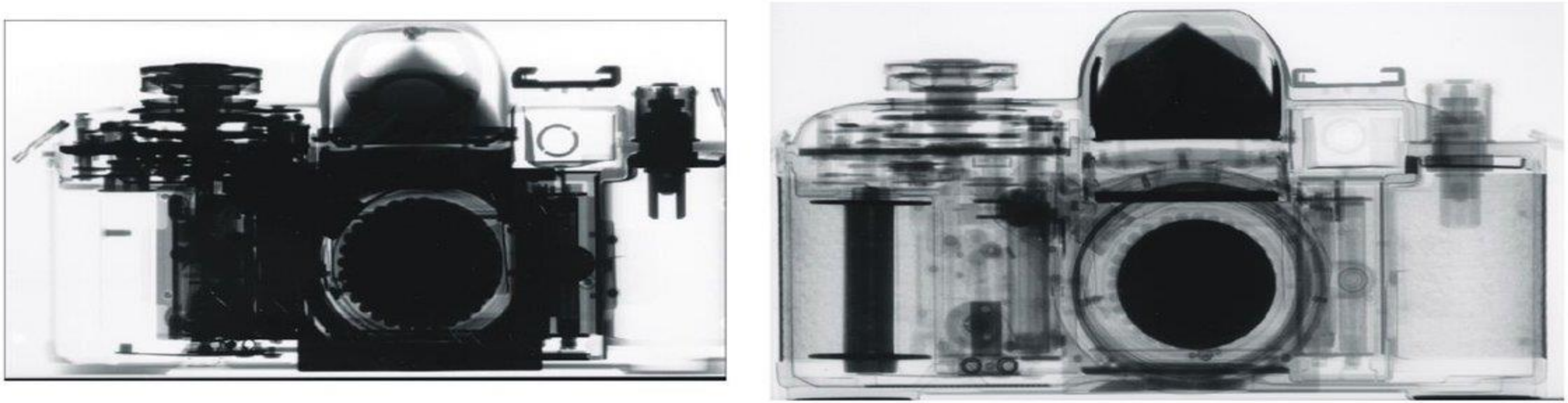
X-ray



Neutrons

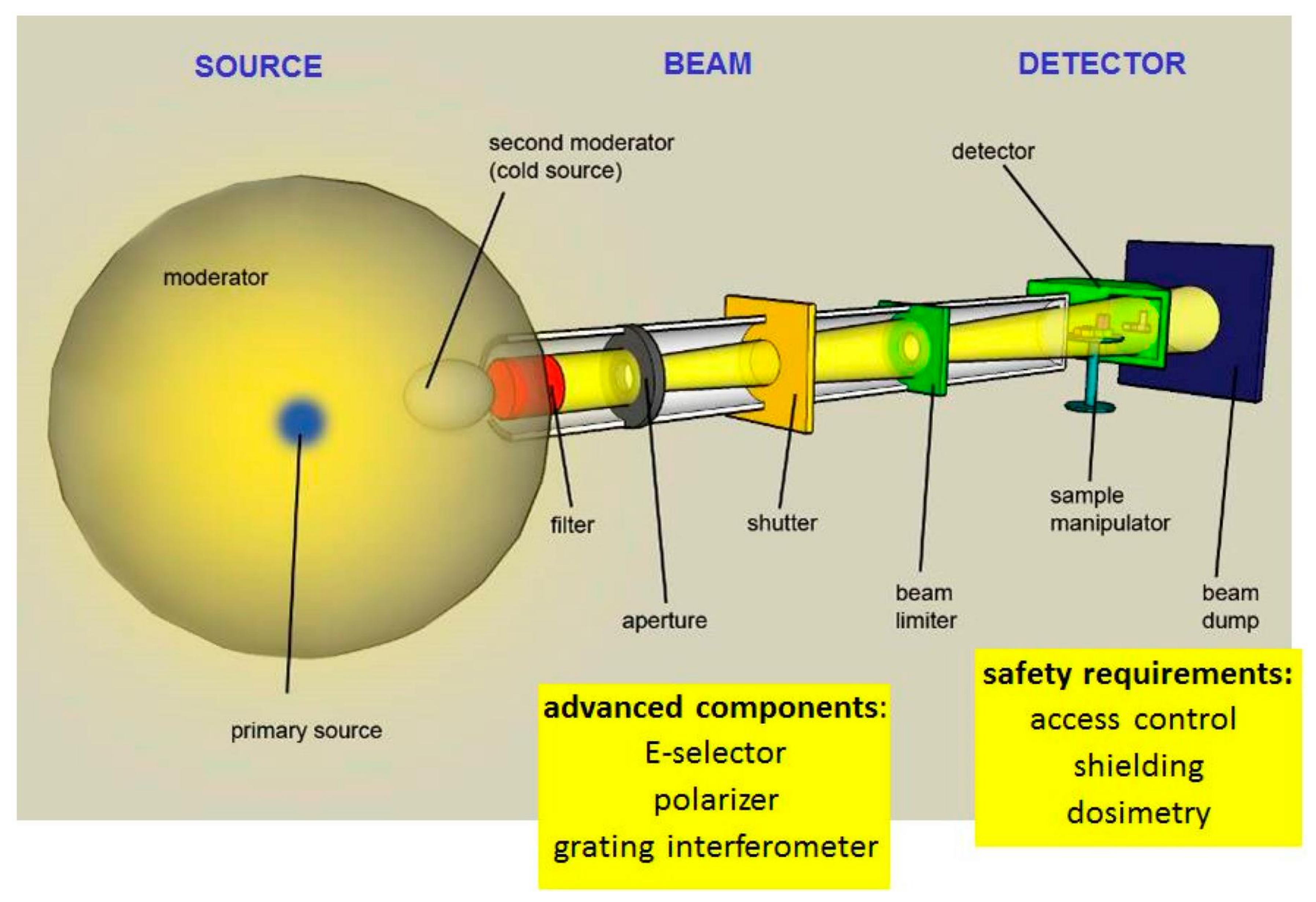
X-rays interact with an atom’s electron cloud, while neutrons interact with the nucleus—which means that they interact differently with different materials.
Neutrons will pass through some materials that X-rays cannot whereas X-rays will more easily pass through materials that neutrons cannot.

Comparison of X-ray and Neutron Radiographs



X-ray Neutrons

Neutron imaging



Neutron imaging

- Neutron imaging is a non-invasive non-destructive imaging technique
- Neutron imaging can provide two- or three-dimensional, spatially resolved images of the internal structure of bulk samples that are not accessible by other techniques
- Due to the interaction properties of neutrons with matter, some light nuclei such as H and D greatly **scatter neutrons**, whereas some heavier elements such as Al, Si (e.g., SiO2 – sand), Cu or Pb are not strong scatterers or absorbers of neutrons and can therefore be easily **penetrated.** [1]
- Neutron radiography measures the attenuation of a neutron beam caused by absorption and scattering within a sample using a two-dimensional position-sensitive detector that measures the transmitted neutron flux.[1]

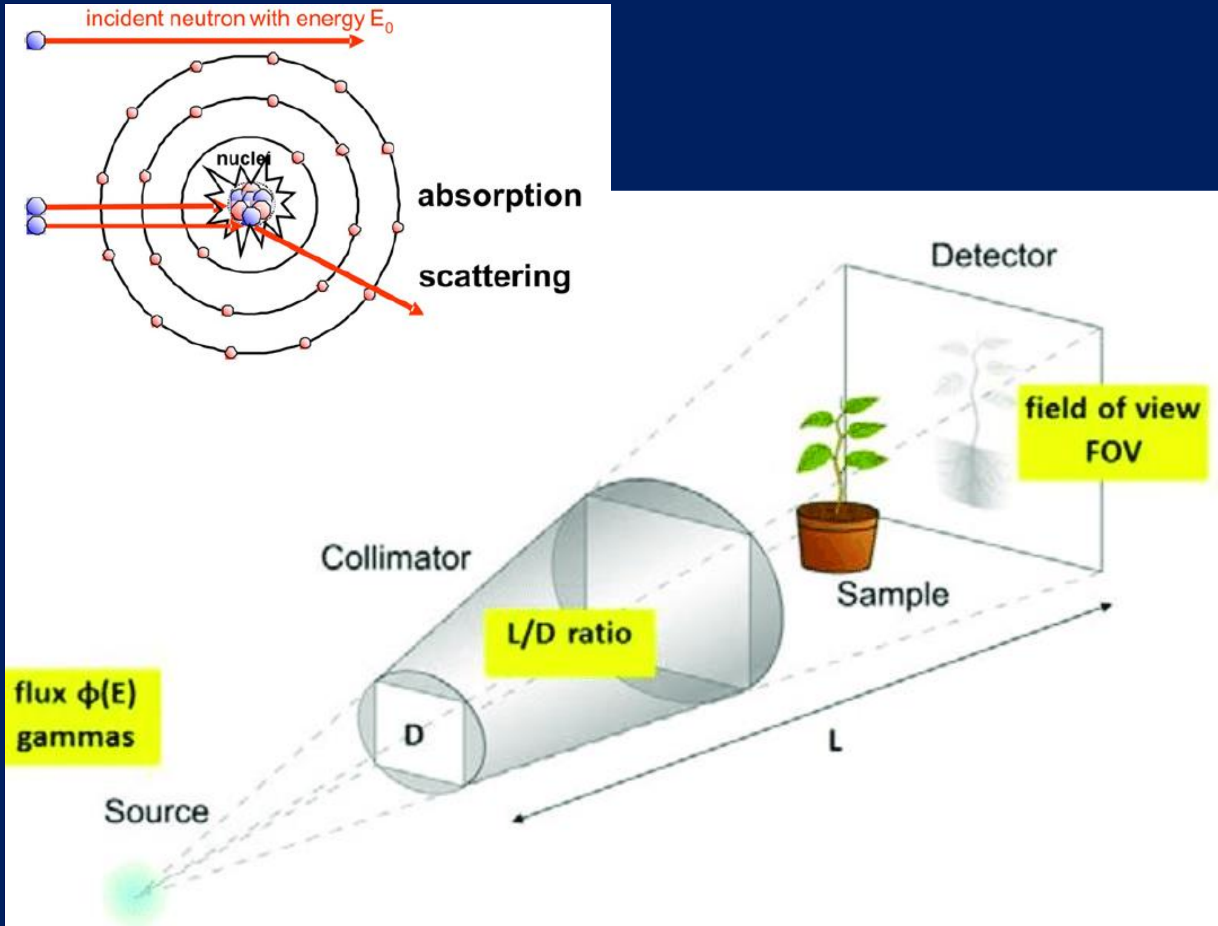


Figure: Neutron Imaging in the radiography mode: principle setting and essential parameters for the image quality determination [2]

1. M Strobl et al 2009 J. Phys. D: Appl. Phys. 42 243001
2.Lehmann, Eberhard & Raventos, Marc & Harti, Ralph & Trtik, Pavel & Kaestner, Anders & Mannes, David & Grünzweig, C.. (2017). Methodical Progress in Neutron Imaging at PSI. Physics Procedia. 88. 250-257. 10.1016/j.phpro.2017.06.035.

Neutron imaging - Applications

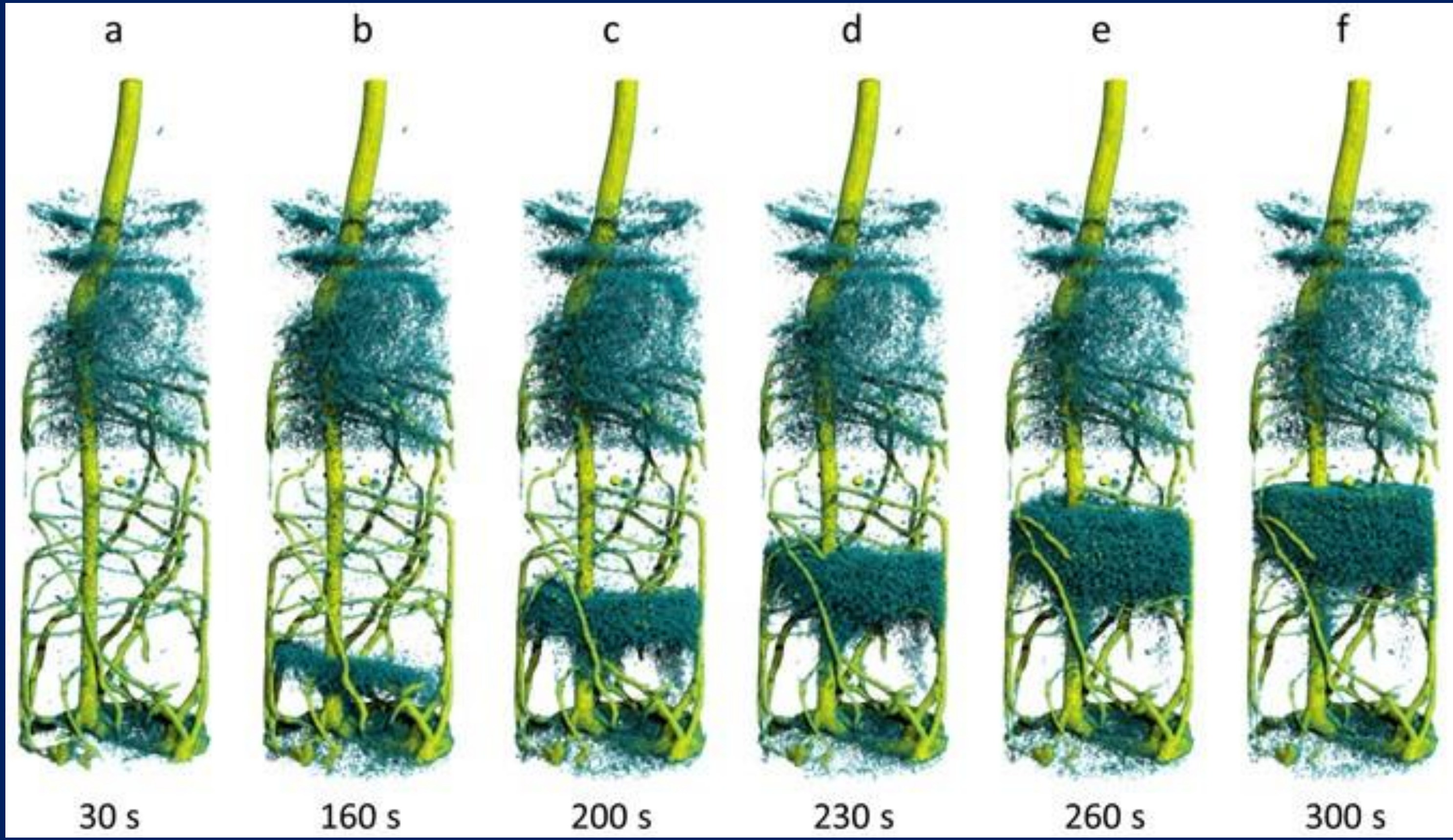


Figure: Time-resolved neutron tomography of the lupine root system after the injection of 4 ml deuterated water (D2O) through the bottom.
The time series (30 s ≤ t ≤ 300 s) shows the ascending front of water (H2O) displaced by deuterated water moving upwards. The time resolution for each tomogram is just 10 s.

Capturing 3D Water Flow in Rooted Soil by Ultra- fast Neutron Tomography

Christian Tötzke, Nikolay Kardjilov, Ingo Manke & Sascha E. Oswald

Neutron imaging - Applications

Neutron radiography and computed tomography of biological materials with complex geometries

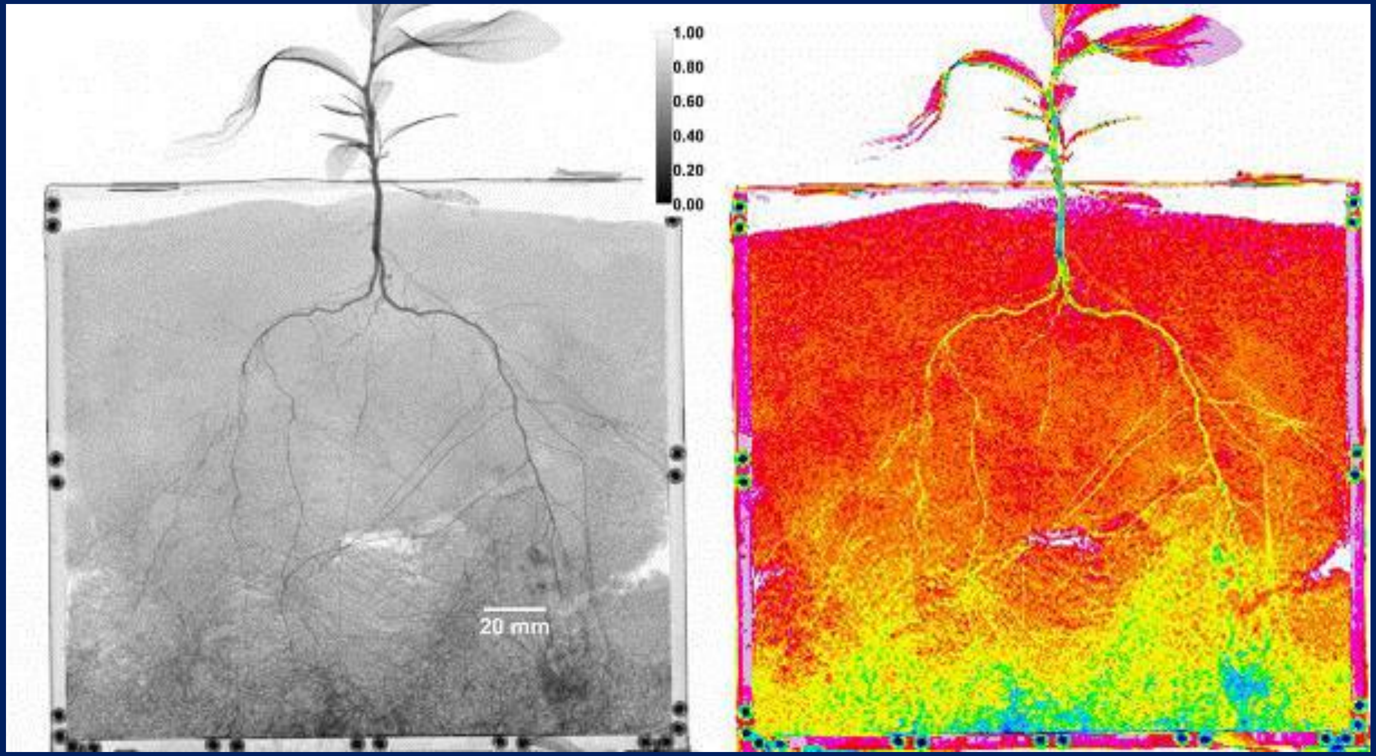
BER STRUCTURAL BIOLOGY AND IMAGING RESOURCES
Synchrotron, Neutron, and Cryo-EM
U.S. Department of Energy | Office of Science | Office of Biological and Environmental Research

Key Features of Neutron Imaging

- Spatial resolution of 10 to 50 µm
- High-penetrating and non-destructive
- Hydrogen/deuterium isotope contrast
- Accommodates versatile sample types including organisms, soil, rock, and experimental devices
- Boron, lithium, or gadolinium contrast agents

BER Researchers Use Neutron Imaging to Study:

- Water uptake by root systems
- Water transport in soils
- Soil structure
- Rhizosphere water dynamics
- Adaptation of root systems in the presence of pollutants
- Root behavior in extreme environments (e.g., drought)
- Belowground root system response to climate change



Water uptake under stress. Neutron radiography of a black cottonwood (*Populus trichocarpa*) planted in sand enabled examination of differences in water uptake by old and new plant roots following recovery from extreme drought stress. [Springer Nature - Dhiman I., et al. 2017. “Quantifying root water extraction after drought recovery using sub-mm *in situ* empirical data,” *Plant and Soil* 424, 1–17. DOI: 10.1007/s11104-017-3408-5. Copyright 2017.]

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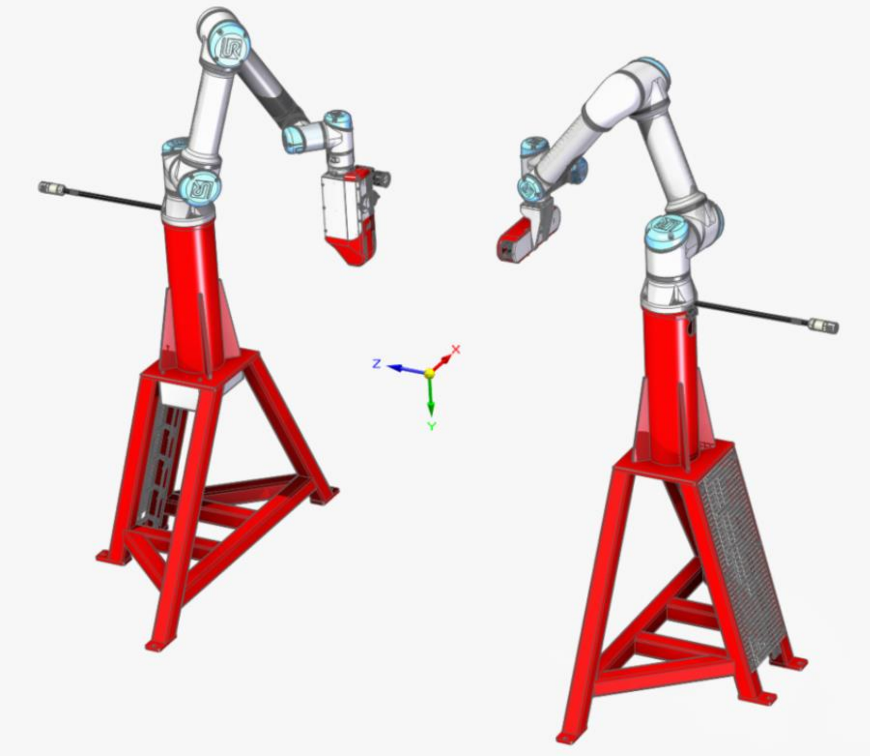
X-ray imaging

- X-ray imaging system combines single particle counting X-ray imaging detectors for high quality images with the flexibility of collaborative robots.
- The key parts of the scanner are two robotic arms with 6 joints. The first arm holds an X-ray tube, the second holds an imaging detector.
- The major benefit of the system is the viewing angle flexibility, superior image contrast and resolution..

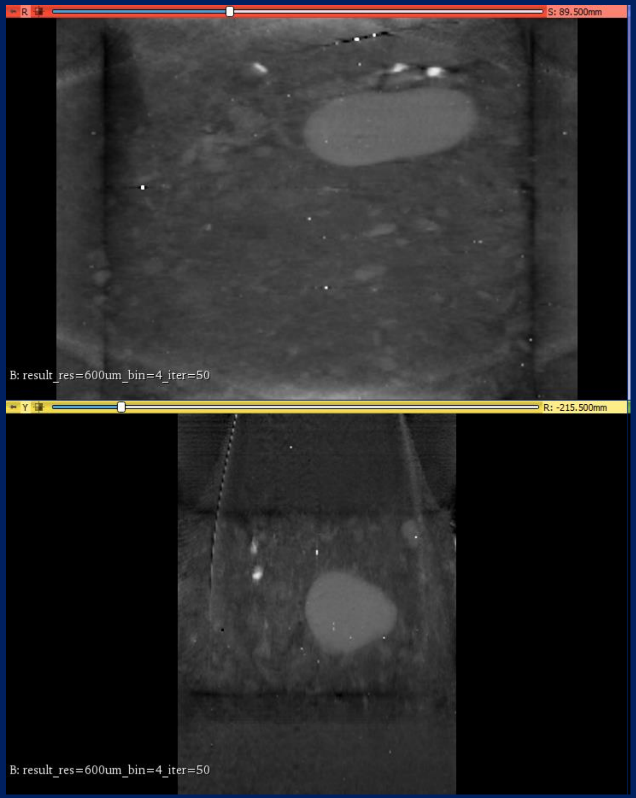


X-ray imaging application

- Uncover inner structures, areas concealed by the leaf canopy, exact biomass of the stalks and ears,
- X-ray computed tomography (CT) used in the analysis of underground structures - to analyse and interpret subtle volumetric changes of belowground organs such as tubers

Seed quality analysis

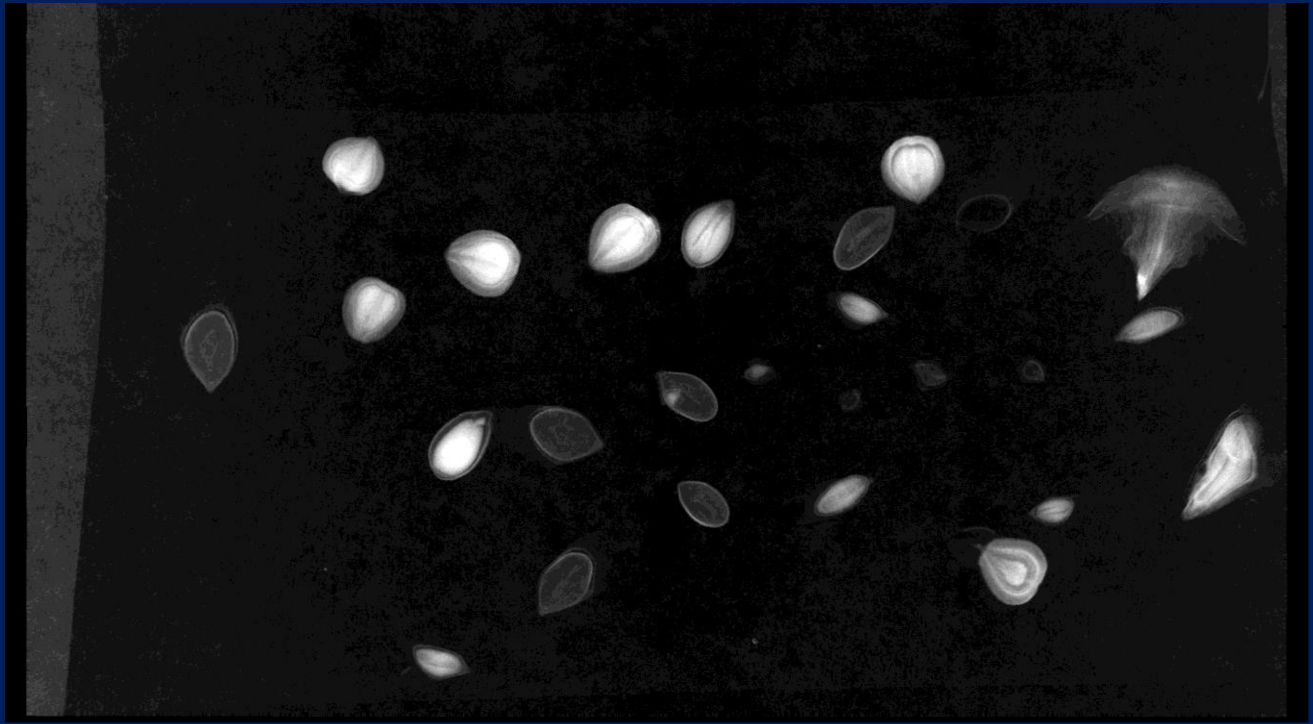
Spike development analysis



Tuber and root structure analysis

X-ray imaging

High-scale seed quality analysis



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Non-destructive spikelet development and grain filling analysis

RGB image showing two ears without obvious defects	X-ray image shows that some grains in the spike are empty

Non-destructive image-based characterisation of apical meristem and spike developmental stages

Early stages of spikelet development

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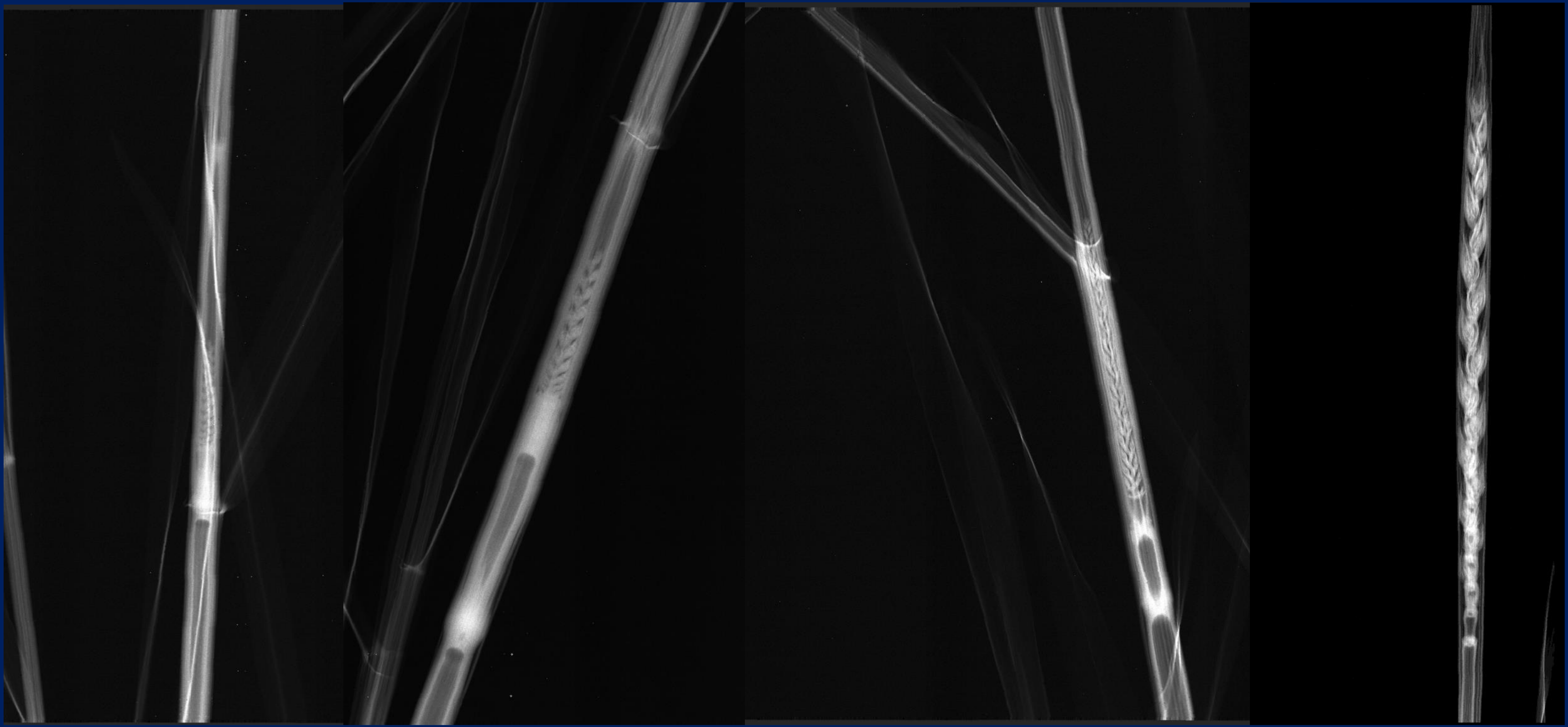
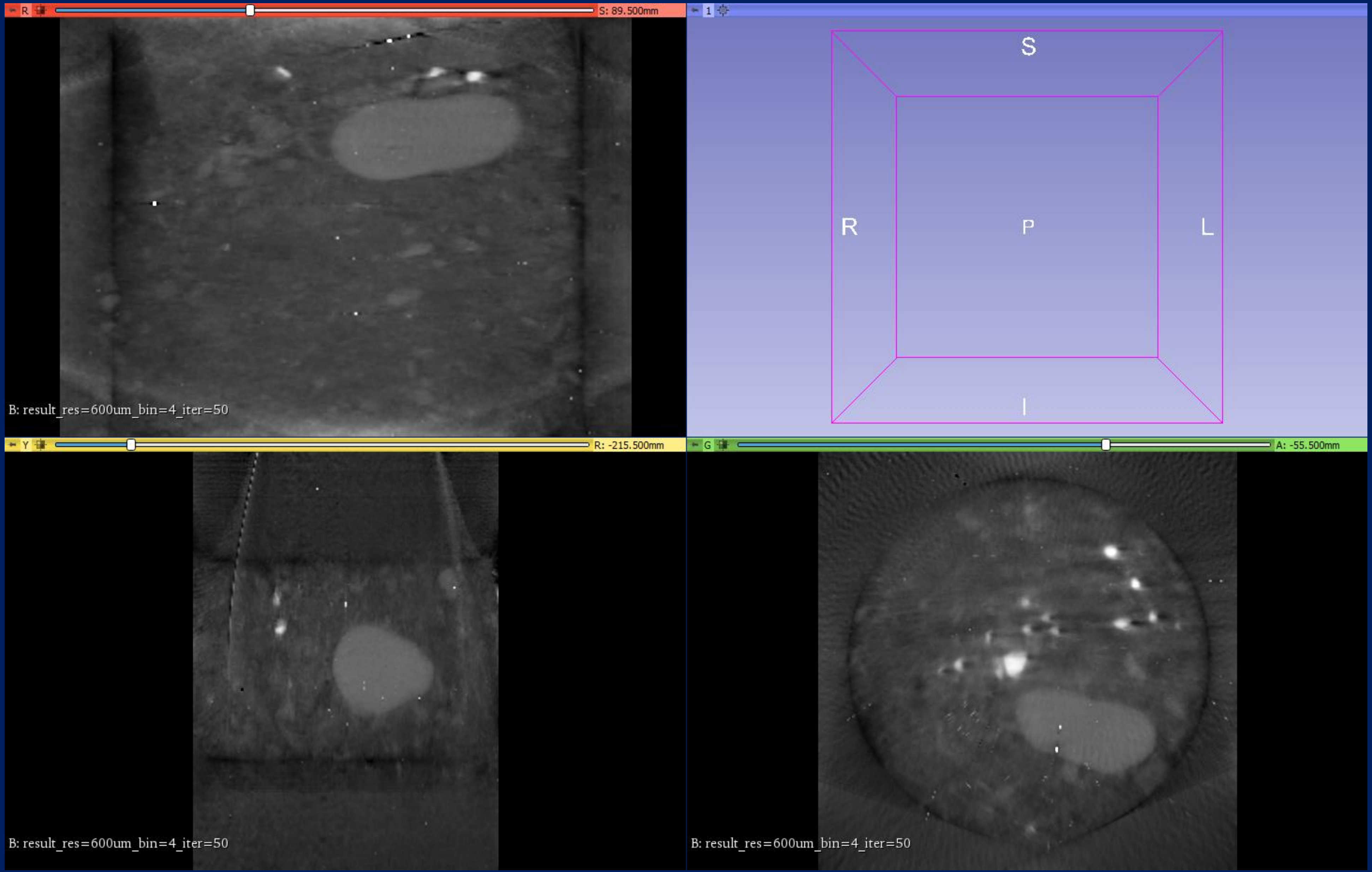
Non-destructive image-based characterisation of apical meristem and spike developmental stages

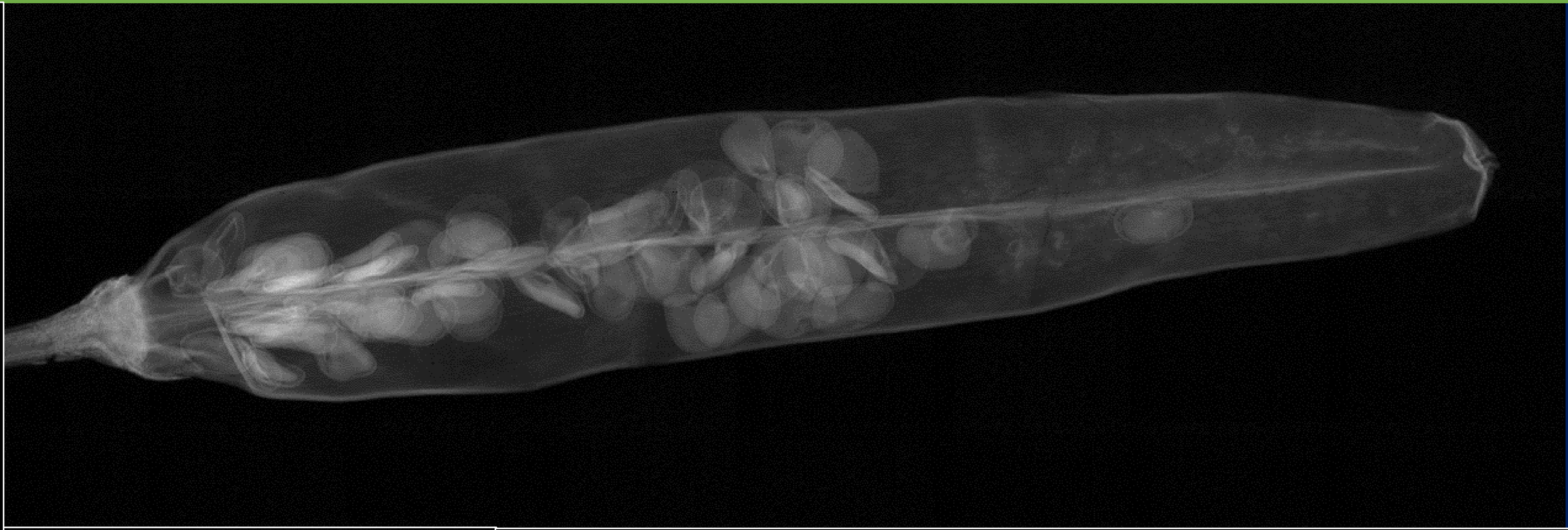


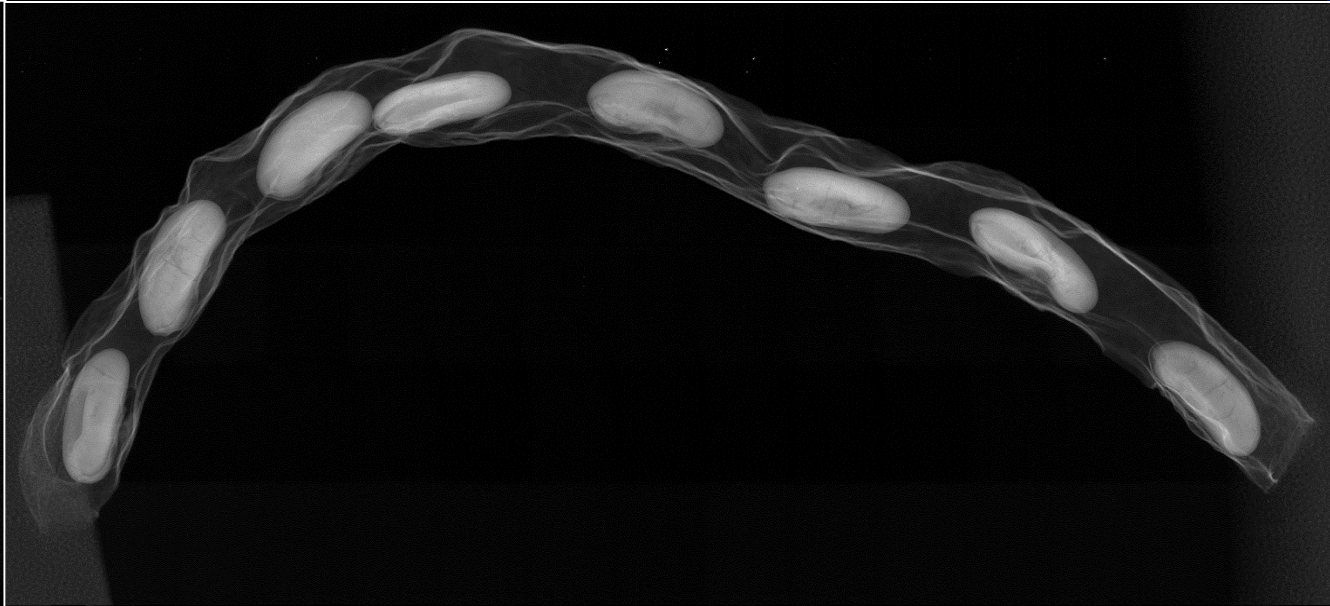
Tuber and root structure analysis

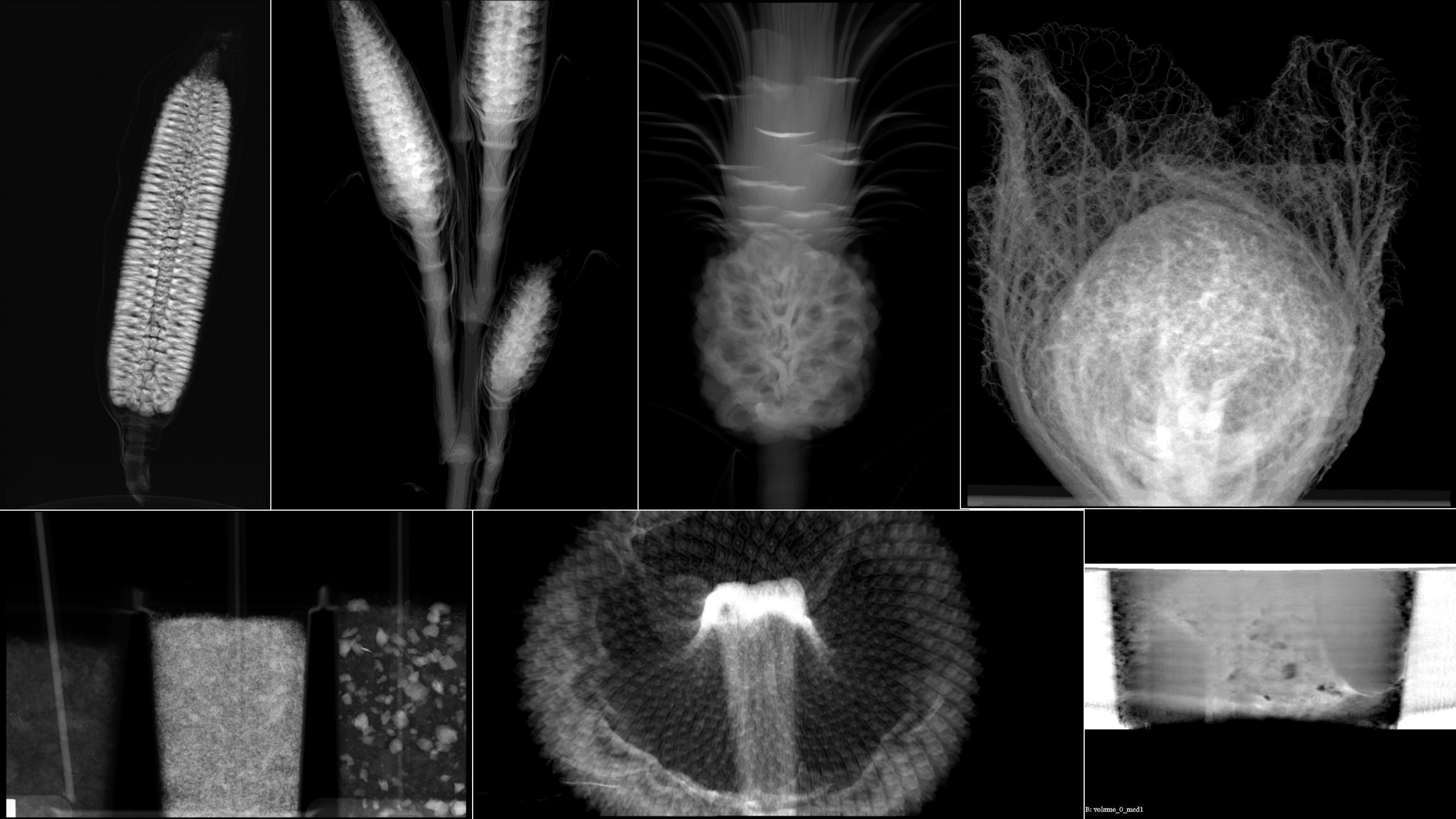


Inner structure of the objects

X-RAY - Morphometric Imaging



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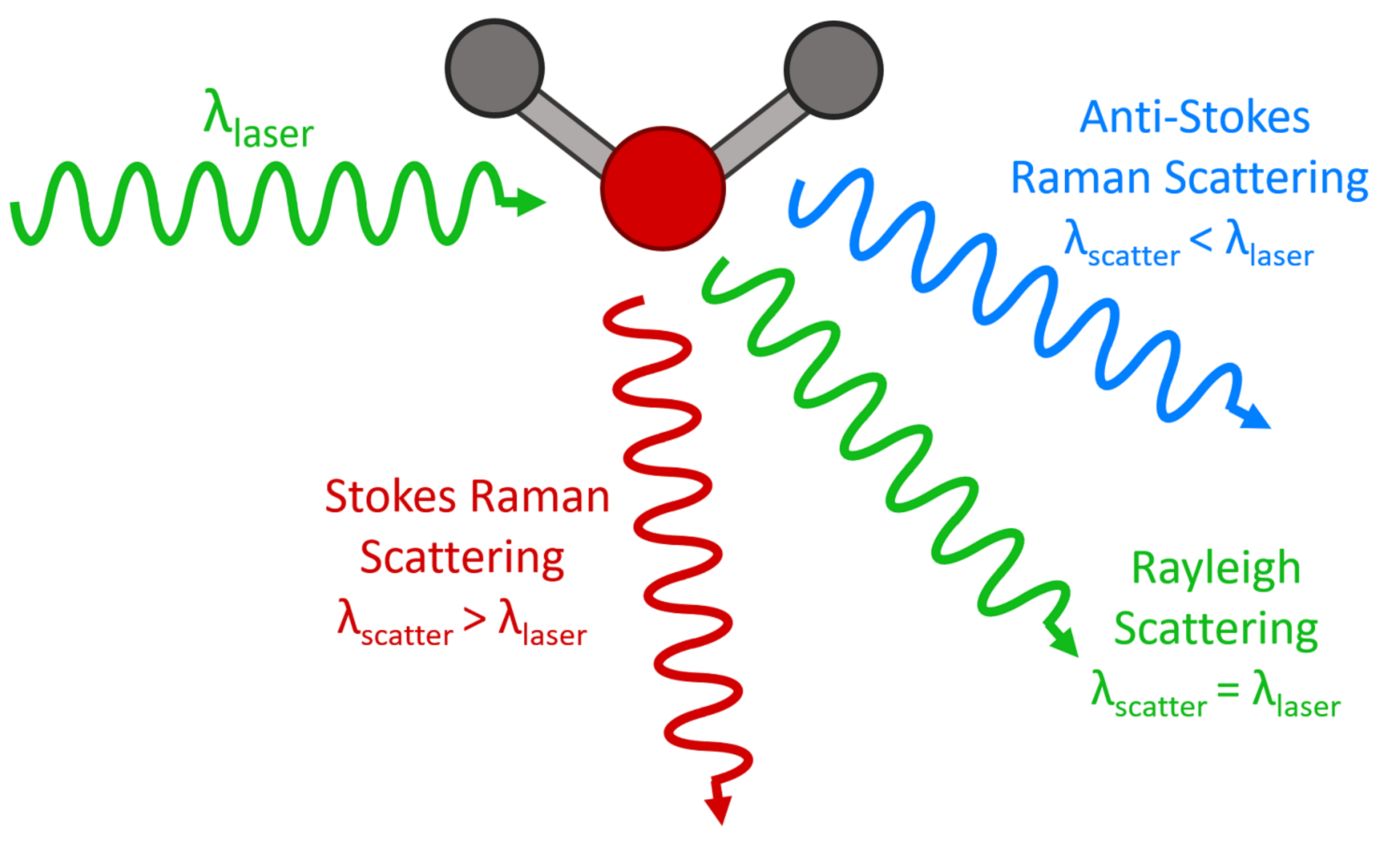
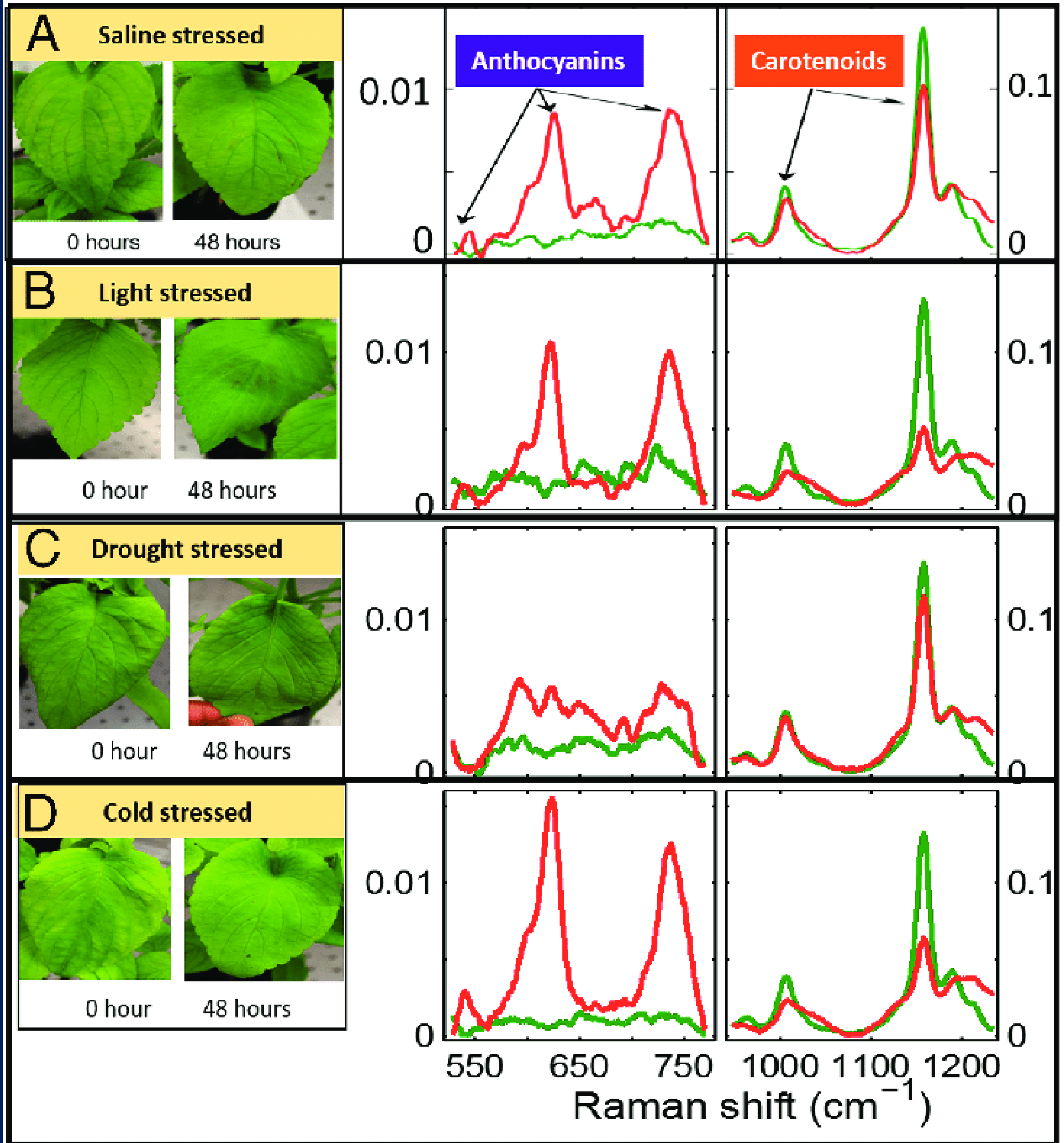
Raman - spectroscopy



Raman - spectroscopy

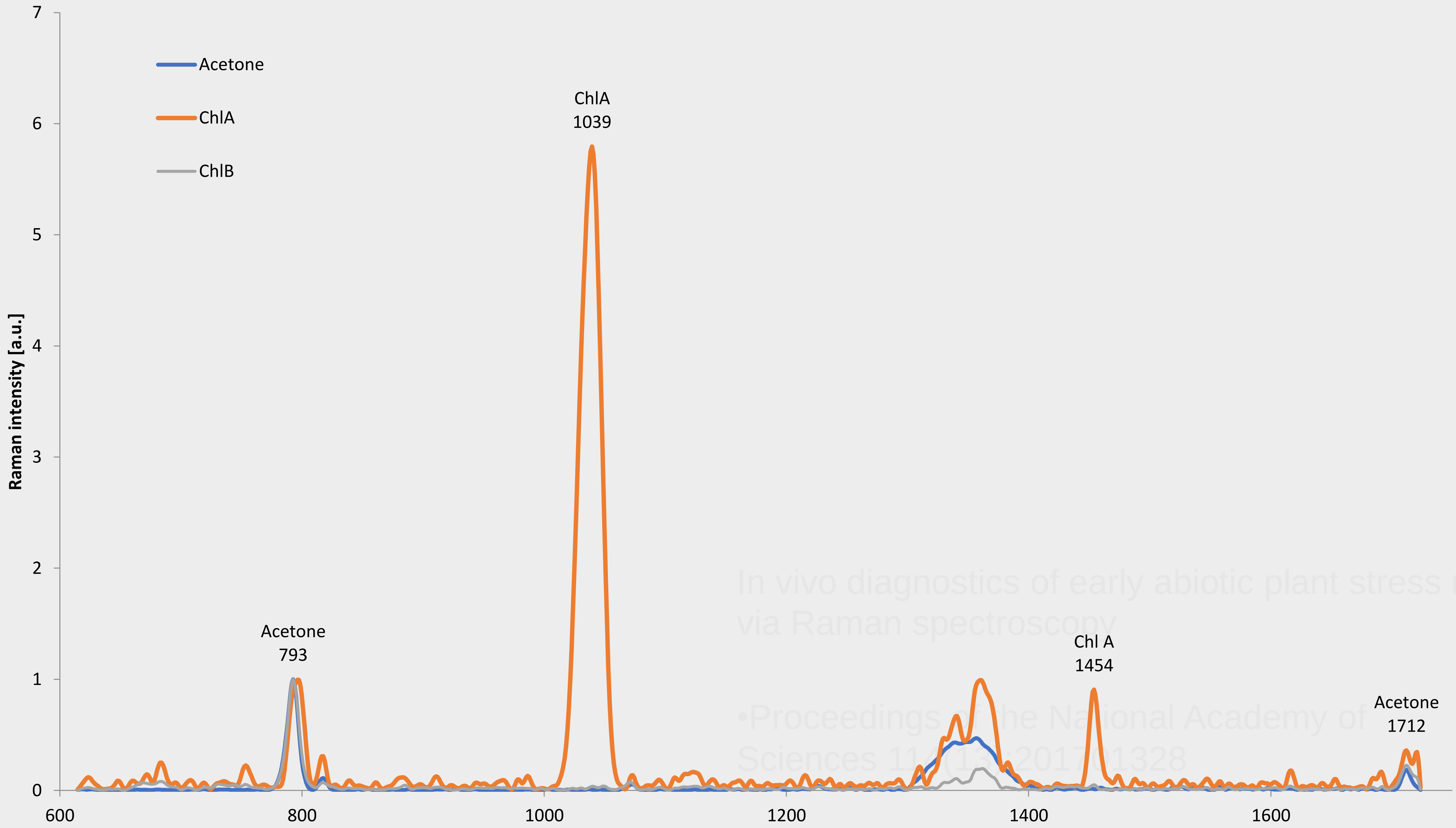


Molecular fingerprint

In vivo diagnostics of early abiotic plant stress response via Raman spectroscopy

Proceedings of the National Academy of Sciences 114(13):201701328

Raman – Chlorophyll A and B



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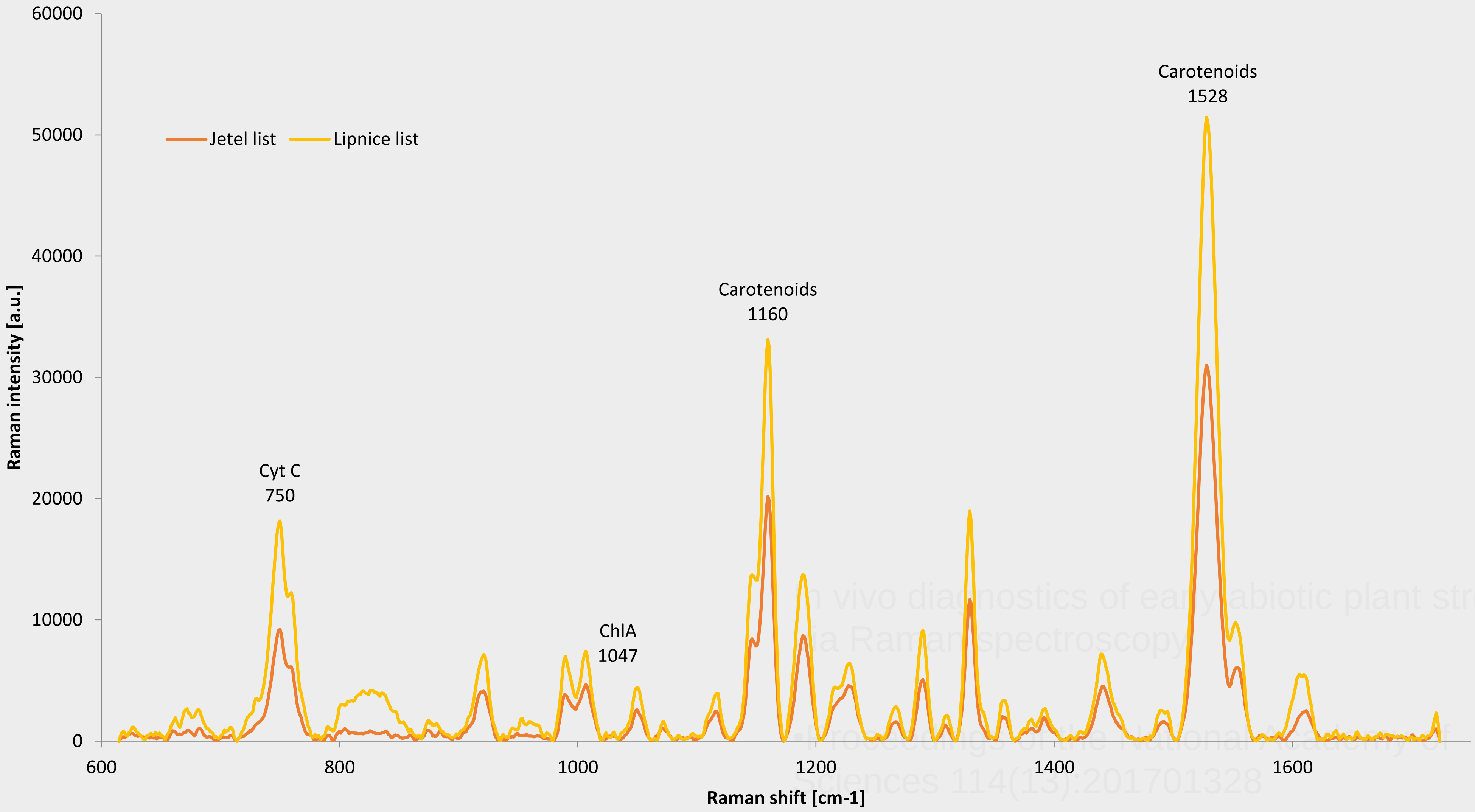
Raman – Chla – carotenoids – real samples



In vivo diagnostics of early abiotic plant stress response via Raman spectroscopy

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High throughput Raman spectroscopy

Object of interest recognition from RGB Using AI

Leading of Raman detector to the measuring spot