Development of an “iTomography” infrastructure for non-destructive documentation of cultural heritage objects

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Outline

- Introduction
- Mechanical Scaffold - Support
- Instrumentation and Software Development
  - Device – Technique Inventory - Toolbox
  - Acquisition Software
  - Registration Procedure and Algorithms
- Measurements and Data Registration
  - Case studies – Cultural Heritage Objects
  - **Combination/ Fusion of the data –**

(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …) Tomography …

“i” Tomography - iTomography (To be presented in IEEE IST 2018)

Introduction

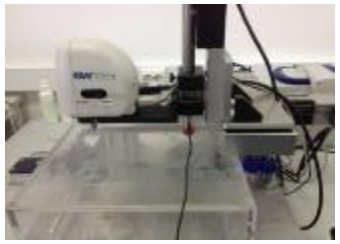
"ORMYLIA" Foundation mobile Lab NDT methods used for the acquisition of the "tomographic" information

Infrared imaging from 1μm to 5μm and thermal imaging form 3-5μm (XENICS FPA 640x480 elements)

Raman and micro Raman spectroscopy with 1064nm of laser source (BWTEK portable Raman spectroscope)

Infrared spectroscopy in various modes (Reflectance, Transmittance-Absorbance and ATR) with and without the use of optical fibers (2 BRUKER OPTICS FTIR systems one IR-CUBE, one ALPHA)

Acoustic Ultrasonic tomography from μm to cm level of display
(2 custom made acoustic microscopy tomographs based on Olympus-xPanametrics equipment parts, 1 medical operating in lower frequencies)



XYZ Scanners (CNC) or robotic devices with step resolution of 0.5 and 1 μm with the capability to mount all the above mentioned modalities or their remote probes (XRF modality is still not fully integrated)
(The scanners-stages are provided by AEROTECH)

Introduction

Objective

- Identification of the material and structural composition of an cultural heritage artwork (tomography with various excitations…)

Implementation

- Utilization of techniques from physics, chemistry and engineering, such as IR, UV/VIS, Ultrasound and XRF

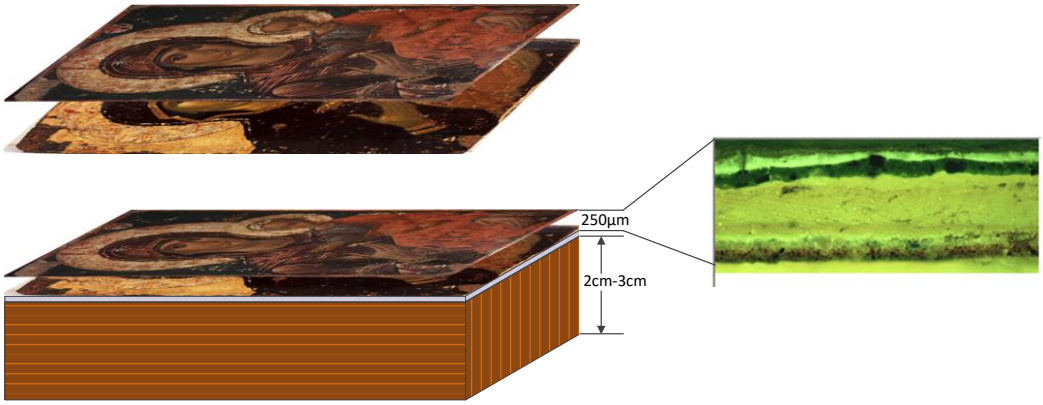
Challenge

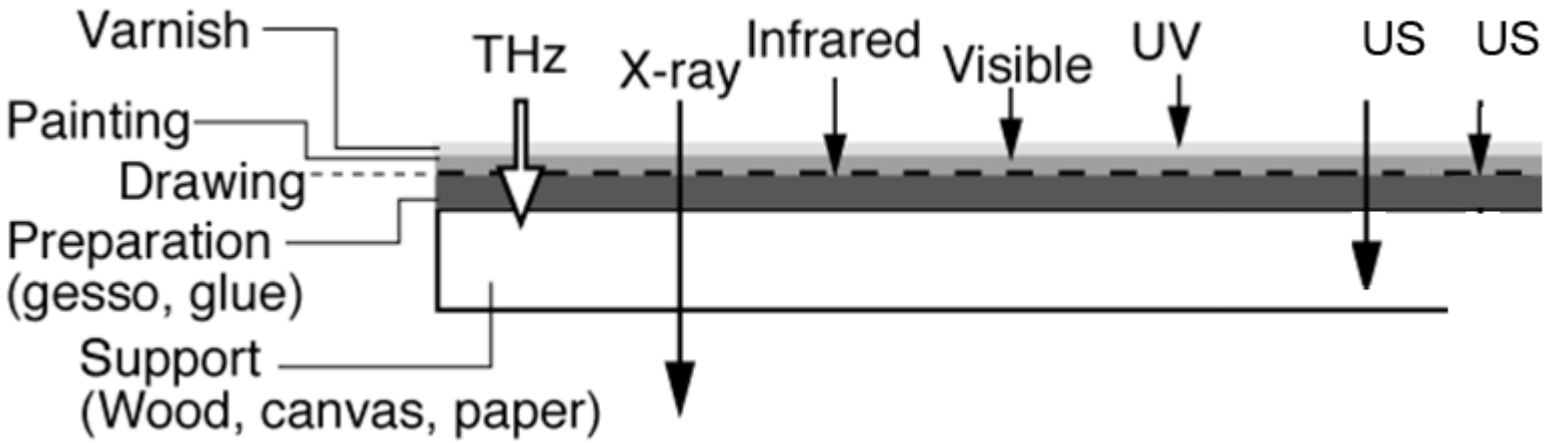
- Design of an autonomous, unified system that combines mechanical manipulation, multimodal, non-destructive scanning and efficient image post-processing

Integrated platform for the non-destructive evaluation of artworks

Introduction

Higher penetration depths are needed for the documentation of art objects serving also reconstruction non invasive.

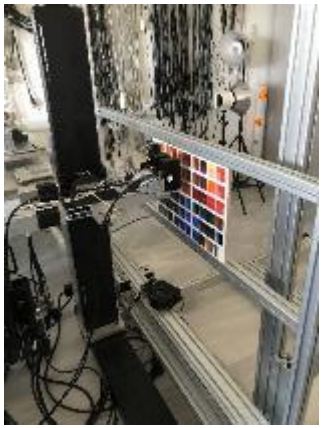


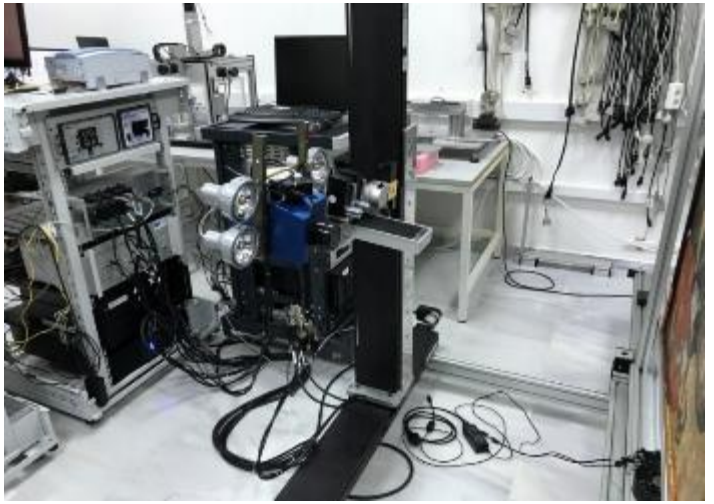


Mechanical Scaffold - Support

- Multiple modalities active at the same time
- 6 degrees of freedom of movement of the various modalities
- Robotic XYZΘΦ directions positioning system
- Coarse positioning allow different objects to be easily positioned
- Fine positioning includes 3 linear and 2 two rotation stages
- Linear stages
  - Accuracy ±1μm
- Rotation stages
  - Accuracy 3 arcmin
  - Repeatability 12 arcsec

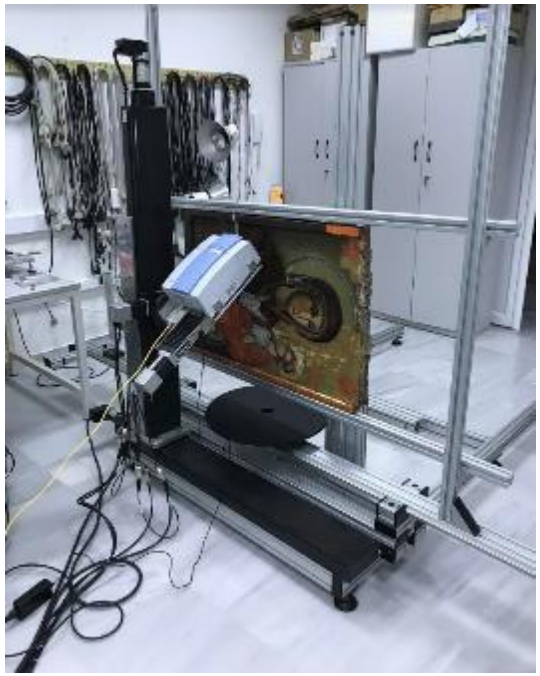
Mechanical Scaffold - Support

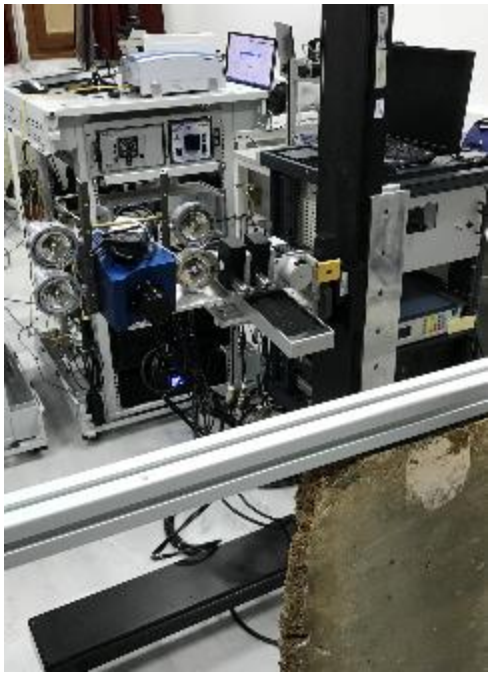




The platform on which the modalities are affixed is mounted on the pitch rotary stage while the yaw is performed by the stage on which the artwork is placed

Mechanical Scaffold - Support





Device - Technique Inventory - Toolbox

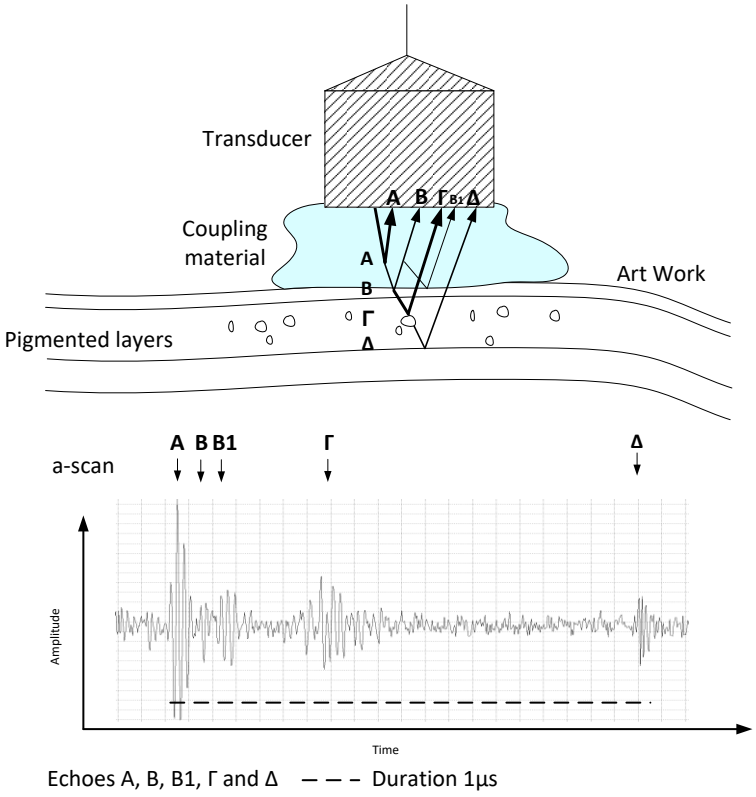
Principles, Conventional Ultrasound

Acquisition of a-c scan data from the multilayered structure using ultrasound frequencies of the order of **1-15MHz**, Resolution of the order of **millimeters**.

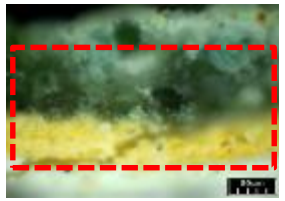
Device - Technique Inventory - Toolbox

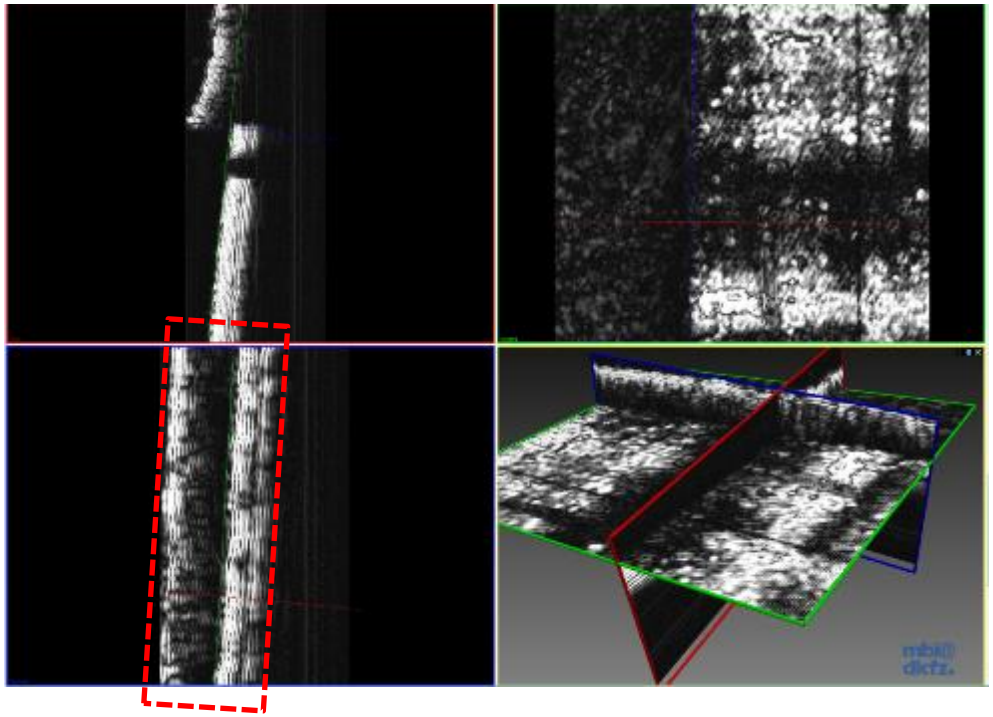
Principles, High frequency Ultrasounds, Acoustic Microscopy

Acquisition of a-c scan data from the multilayered structure using ultrasound frequencies of the order of **>50MHz**, Resolution of the order of **micrometers**.



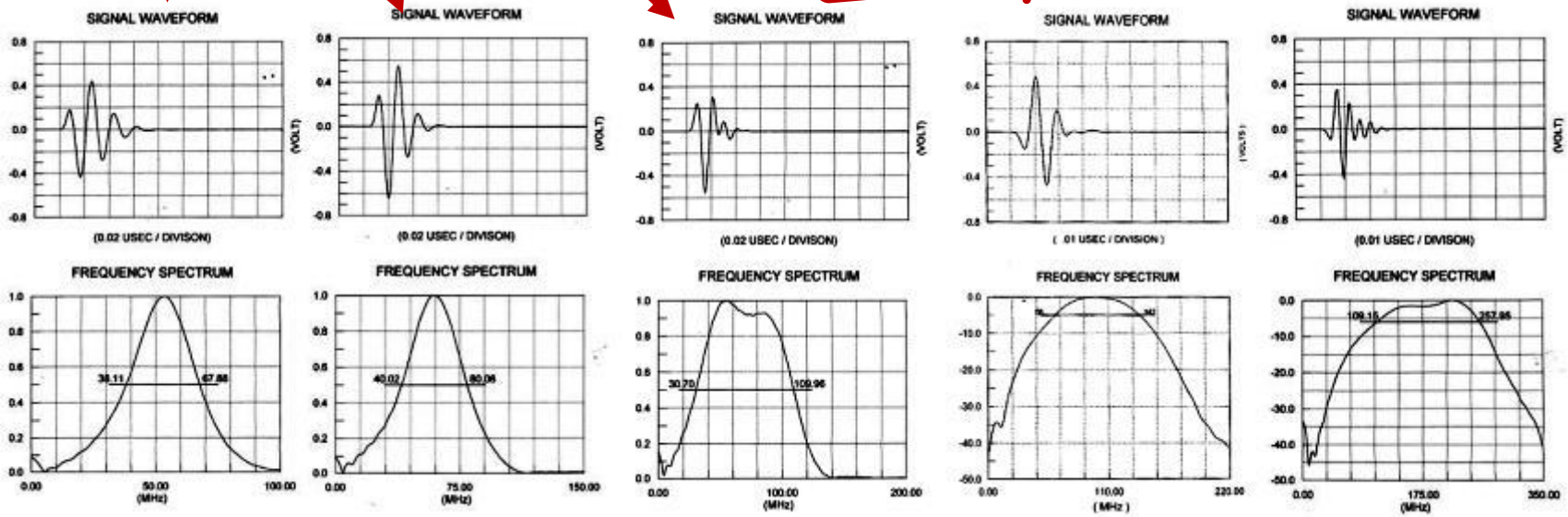
1st layer : 48.5μm with sampling 47μm
2nd layer : 43μm with sampling 46μm





Device - Technique Inventory - Toolbox

Broadband sensors

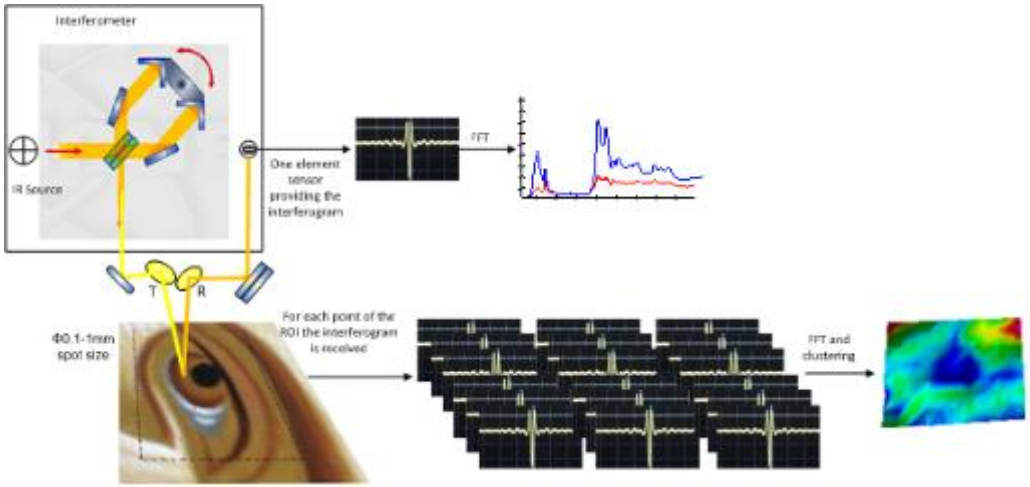


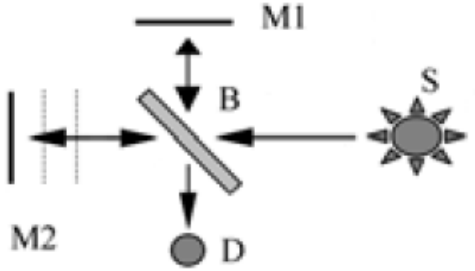
Operating Frequency Range : 38 - 250MHz

Resulting to a resolution from 42 - 3μm for an acoustic velocity of 1600m/sec

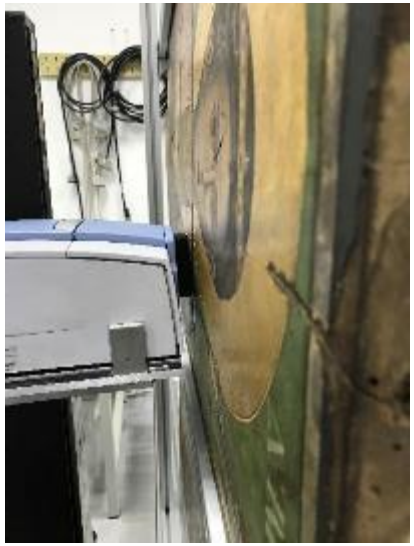
Device - Technique Inventory - Toolbox

Fourier Transform Infrared Spectroscopy – Mapping *Tomography*



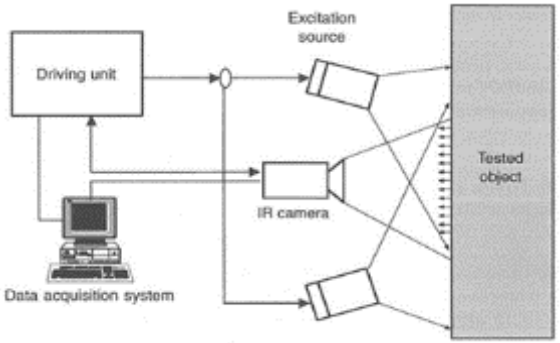


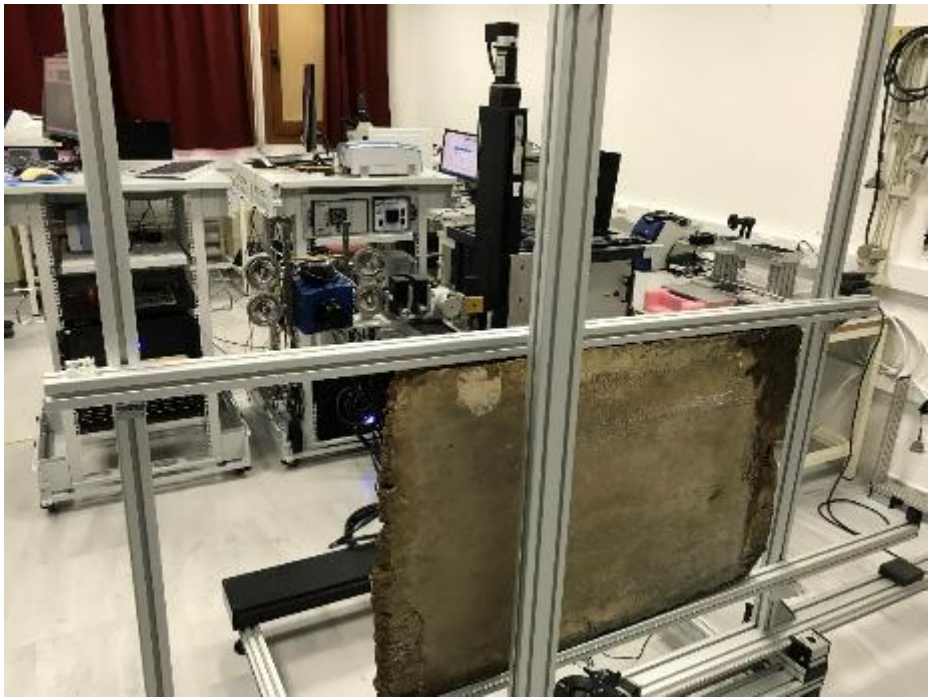
S: Source
B: BeamSplitter
M1: Fixed Mirror
M2: Moving Mirror
D: Detector

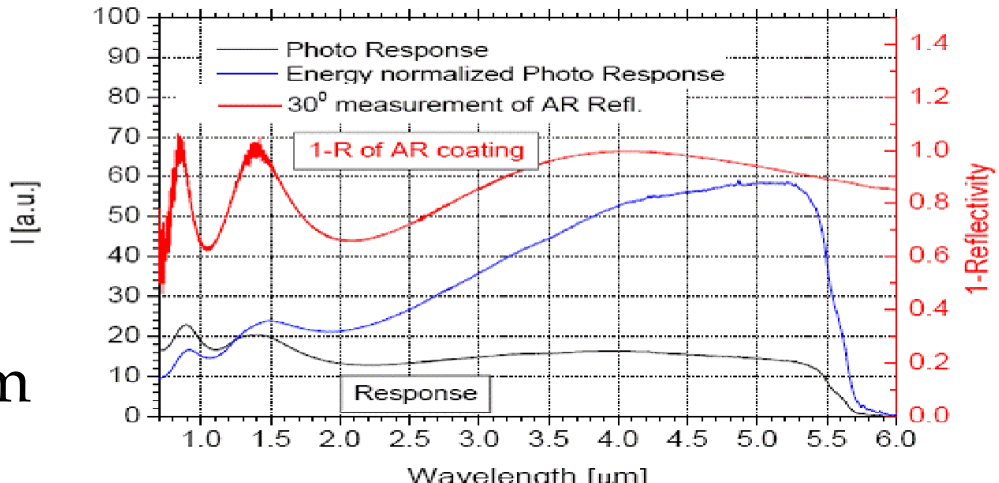


Device - Technique Inventory - Toolbox

IR Camera 1-5µm



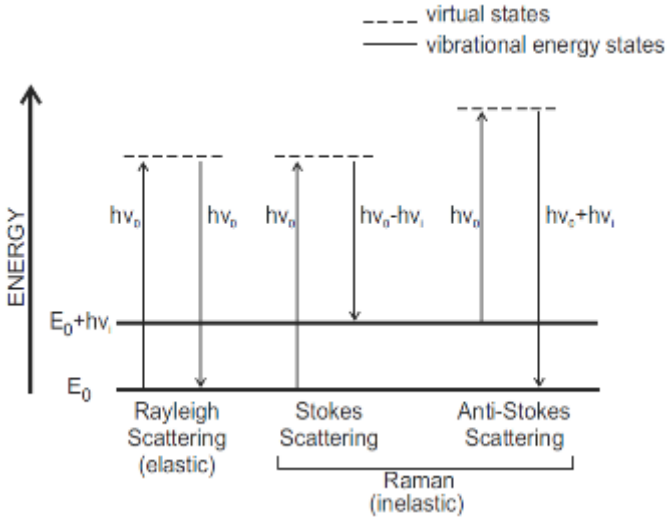




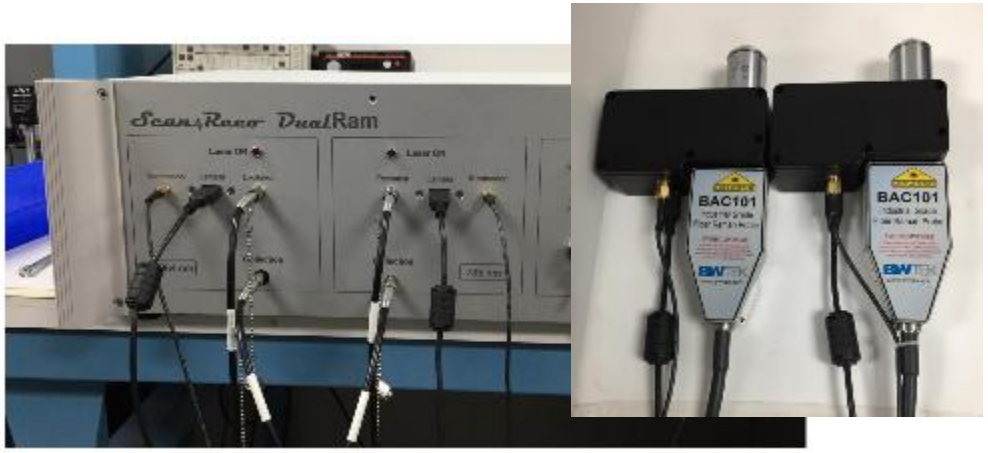
Focal Plane Array InSb 1-5µm

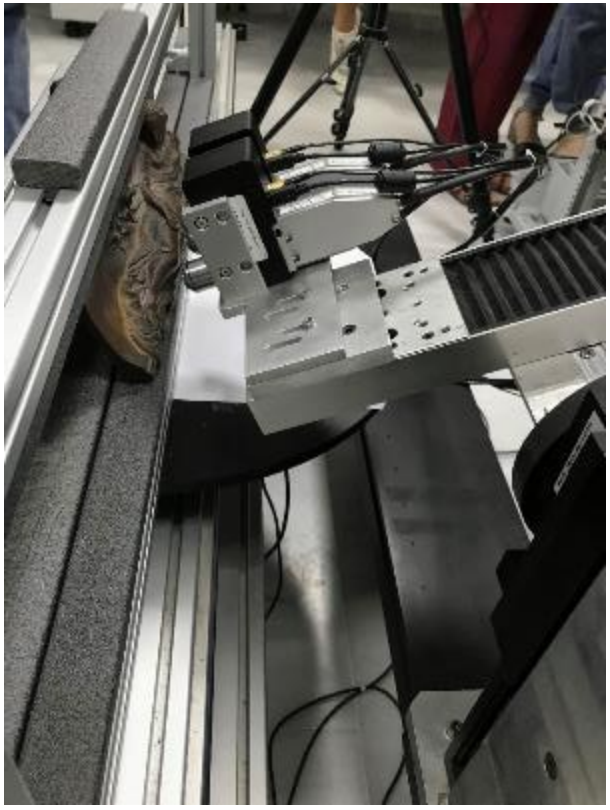
Device - Technique Inventory - Toolbox

Dual wavelength Raman Spectrometer - Mapping spectrophotometer



- Fiber coupled, fiber lengths TBD
- Integrated video camera to ensure correct positioning
- Black Foam or soft Tissue to protect against ambient light and to protect the samples against mechanical damaging

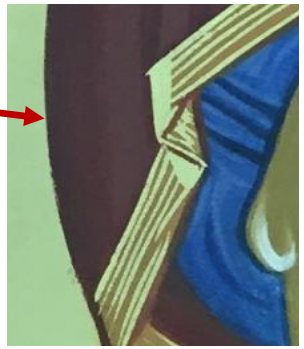


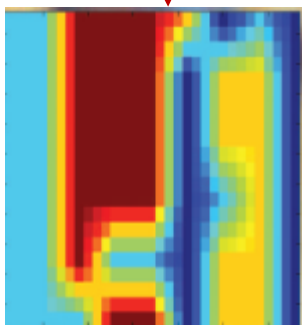


Device - Technique Inventory - Toolbox

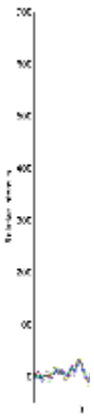
Dual wavelength Raman Spectrometer - Mapping spectrophotometer

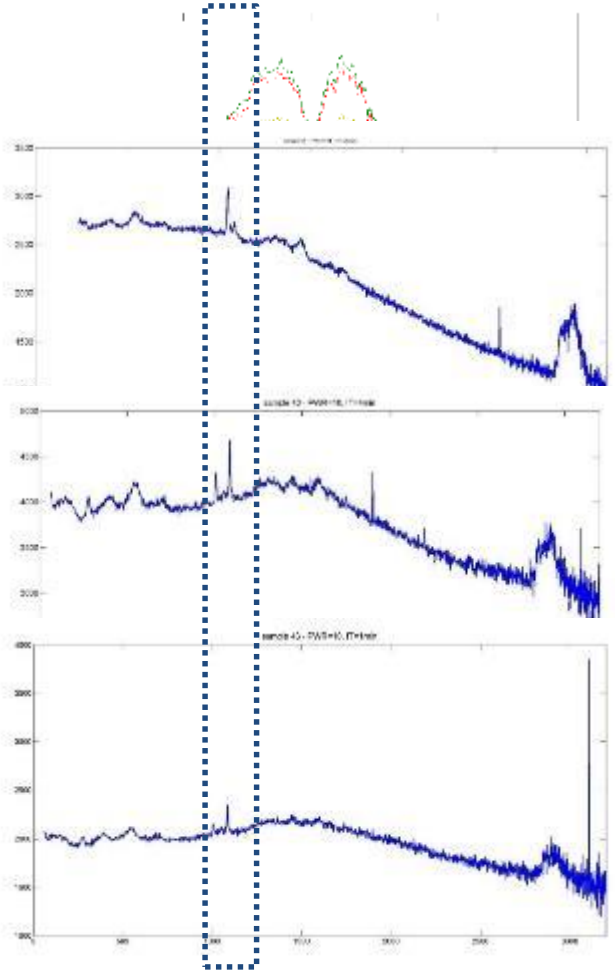
785 nm & 1064nm laser source





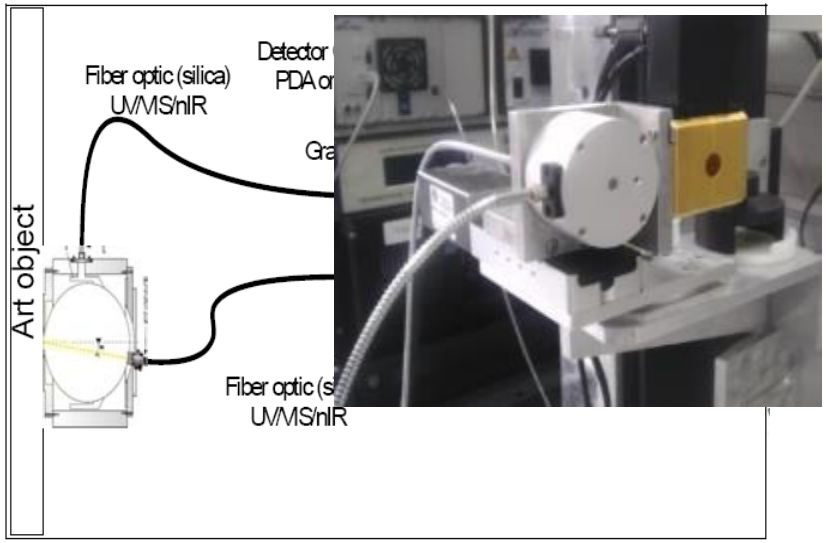
Semantic feature extraction & reconstruction

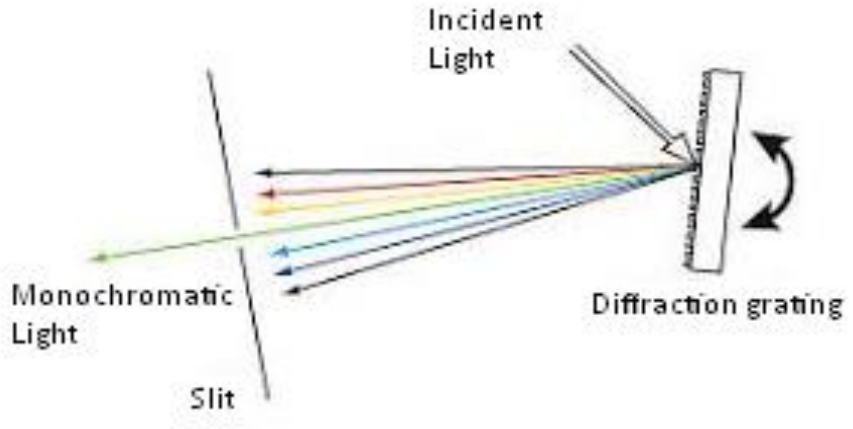


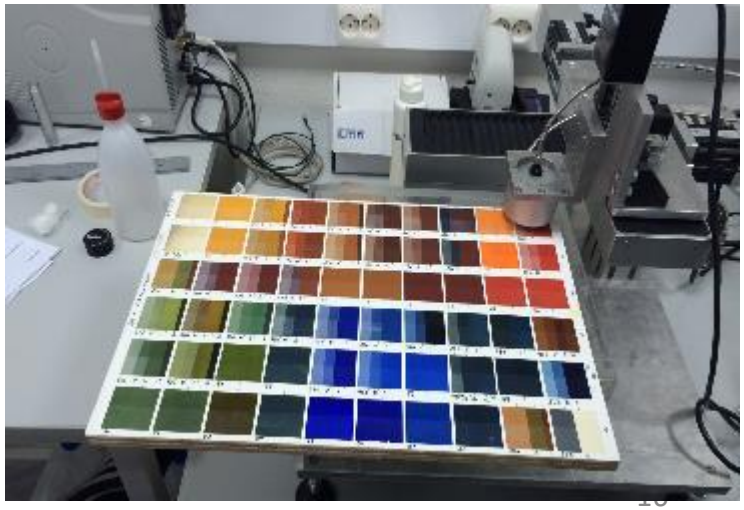


Device - Technique Inventory - Toolbox

Ultraviolet/Visual (UV/VIS) Scanning



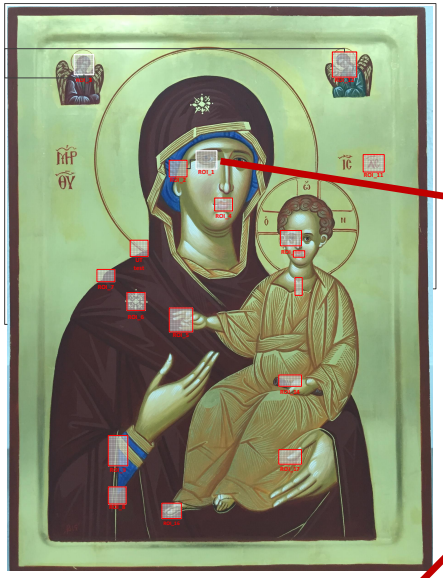


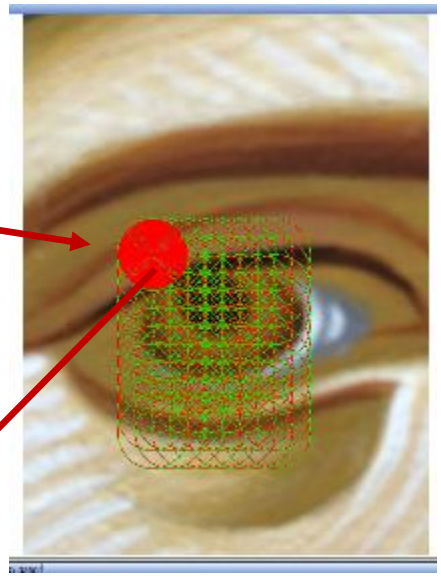


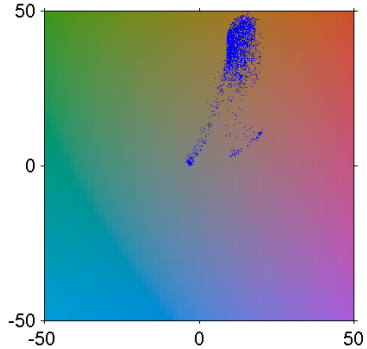
Device - Technique Inventory - Toolbox

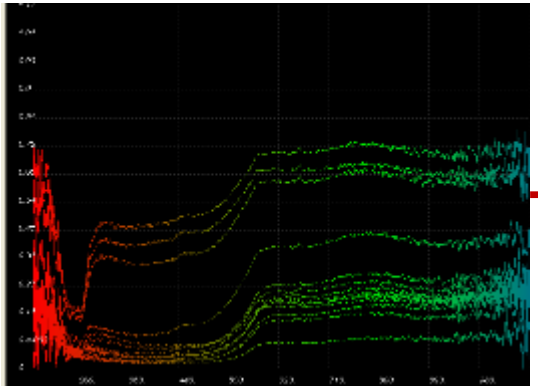
Ultraviolet/Visual (UV/VIS) Scanning

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$









$$X = \frac{K}{N} \int_{\lambda} S(\lambda)\, I(\lambda)\, \bar{x}(\lambda)\, d\lambda,$$
$$Y = \frac{K}{N} \int_{\lambda} S(\lambda)\, I(\lambda)\, \bar{y}(\lambda)\, d\lambda,$$
$$Z = \frac{K}{N} \int_{\lambda} S(\lambda)\, I(\lambda)\, \bar{z}(\lambda)\, d\lambda,$$

where

$$N = \int_{\lambda} I(\lambda)\, \bar{y}(\lambda)\, d\lambda,$$

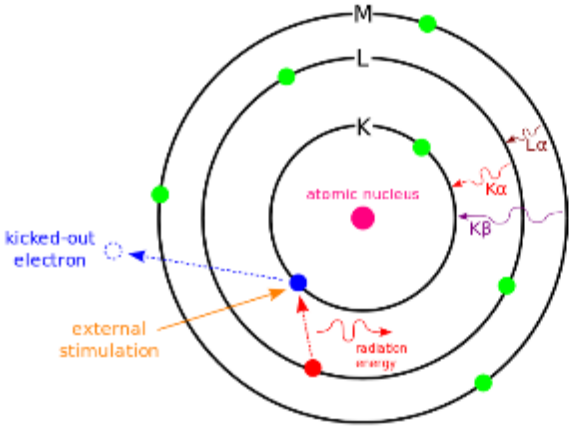
$$L^* = 116\, f\left(\frac{Y}{Y_n}\right) - 16$$
$$a^* = 500 \left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right)$$
$$b^* = 200 \left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right)$$

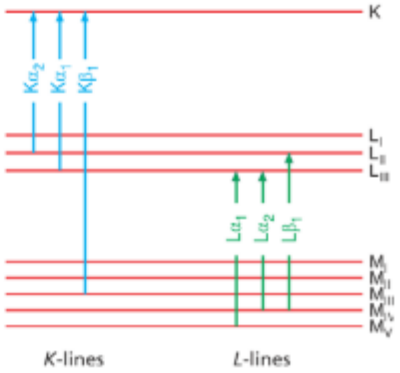
where

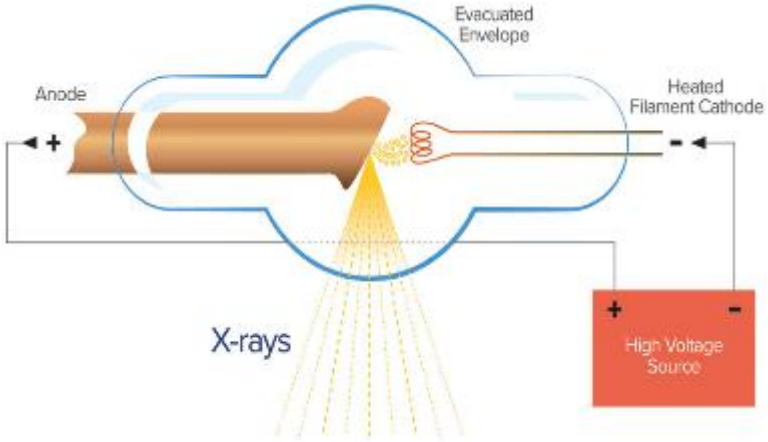
$$f(t) = \begin{cases} \sqrt[3]{t} & \text{if } t > \delta^3 \\ \frac{t}{3\delta^2} + \frac{4}{29} & \text{otherwise} \end{cases}$$

Device - Technique Inventory - Toolbox

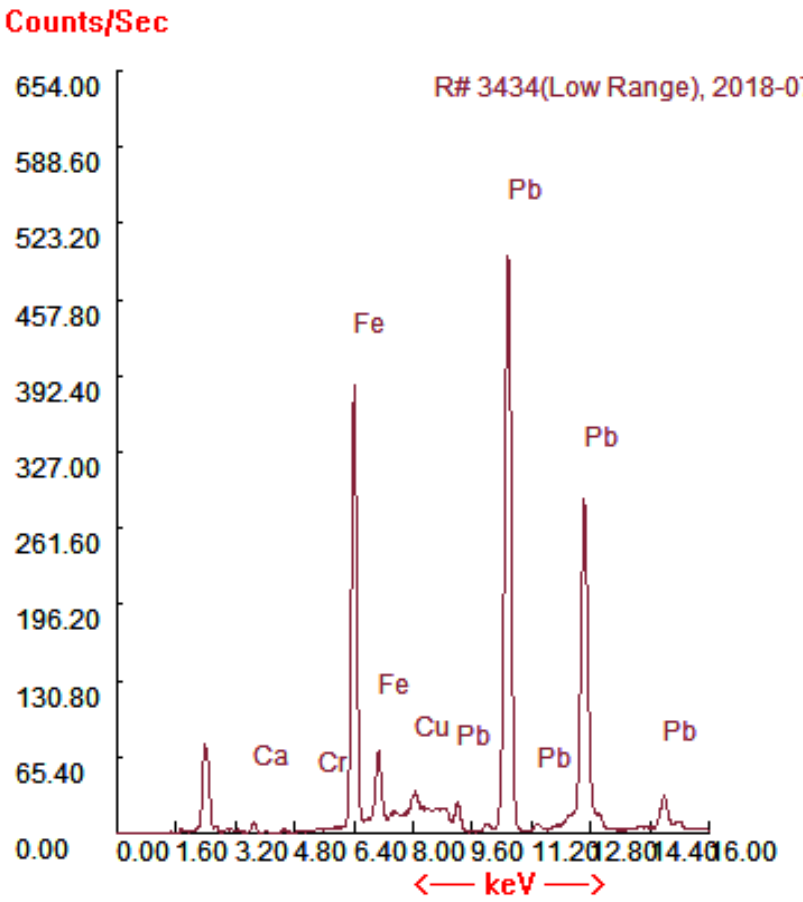
X-Ray Fluorescence (XRF)

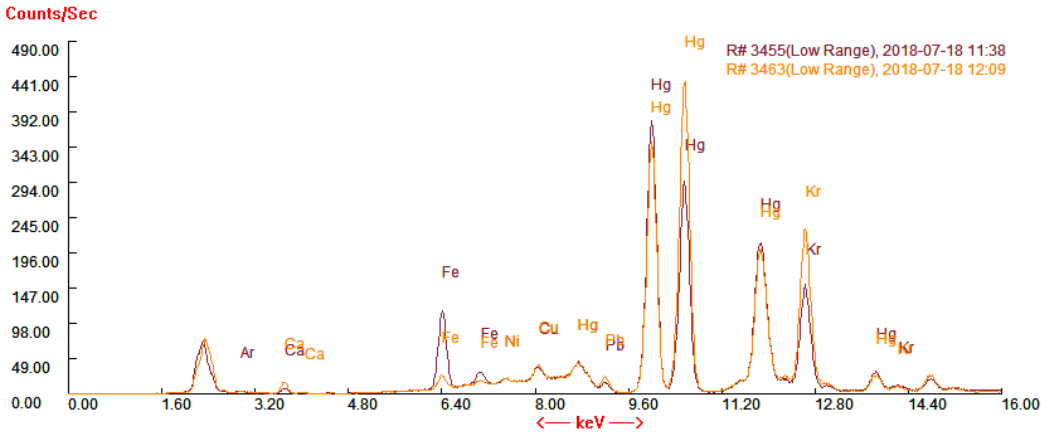


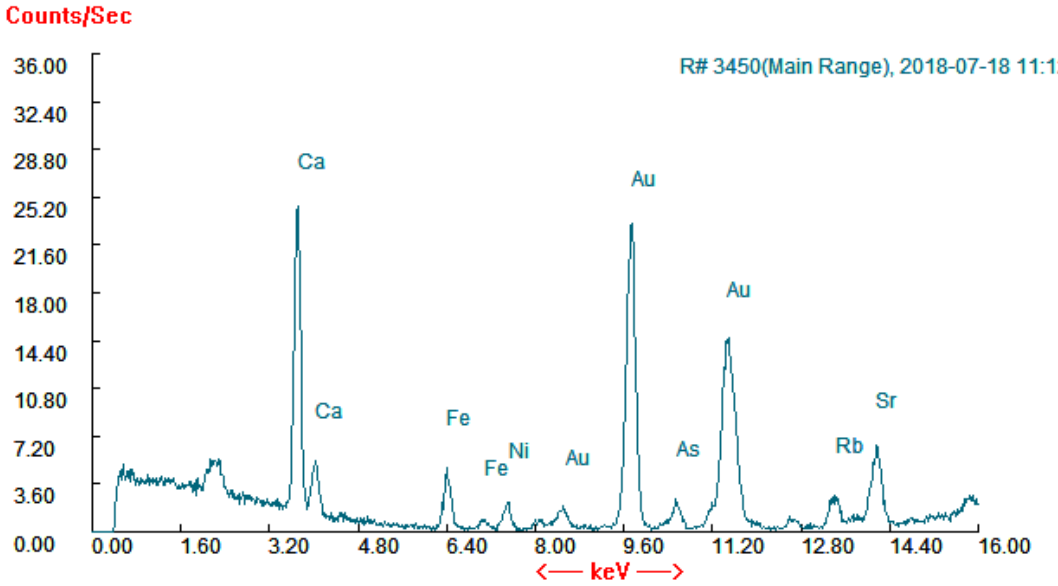




XRF measurements

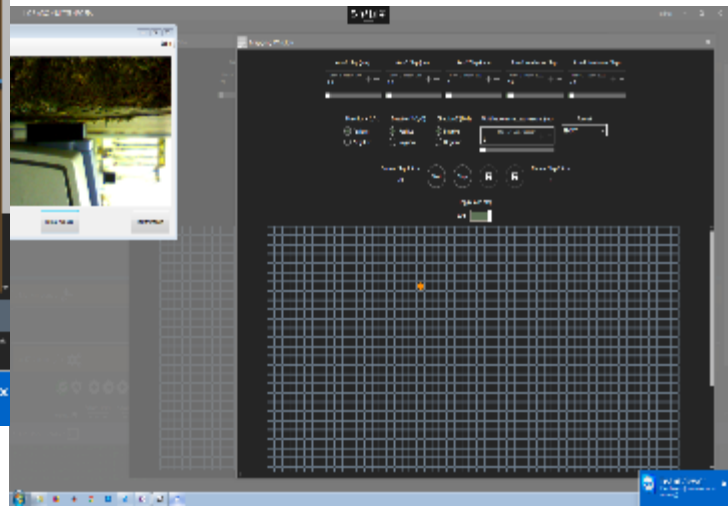






Device - Technique Inventory - Toolbox

MultiSensorial acquisition and processing Platform



- Pre-calibration of the iTomography devices
- The architecture of the platform follows the Model-View-Viewmodel (MVVM) pattern
- Surface mapping operations
- Fine positioning motion control system supports resolutions down to 1 µm
- DICONDE standard is followed

Cultural Heritage Objects

Cultural Heritage Objects

A … "trip" back to the past …
with all the technologies on board

ACTUAL

Database
«Ormylia» Foundation

Figure 2: Initial painting

Figure 3: Overpainted painting

CLONE

Cultural Heritage Objects

- Realization of a clone of the icon of Hodegetria
- Accurate historical reconstruction of the 14th century technique



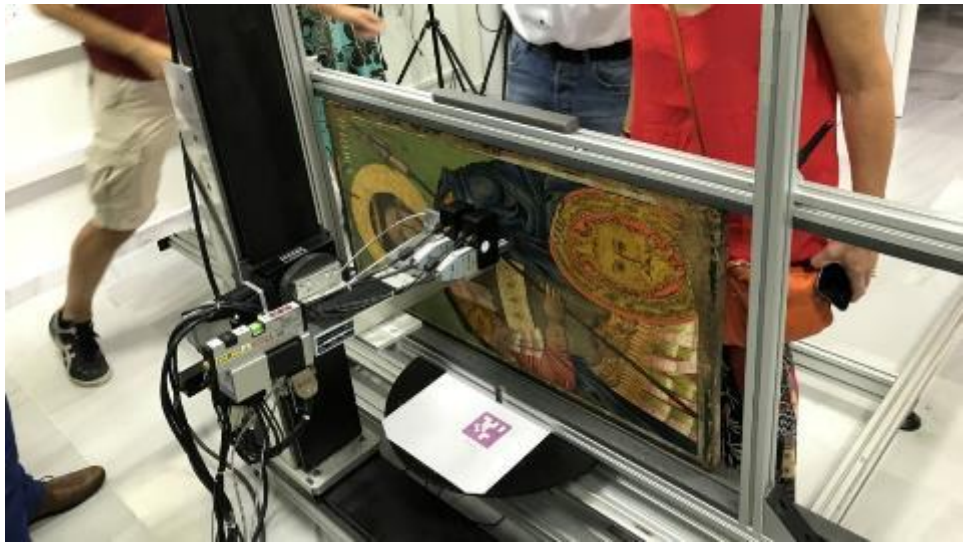


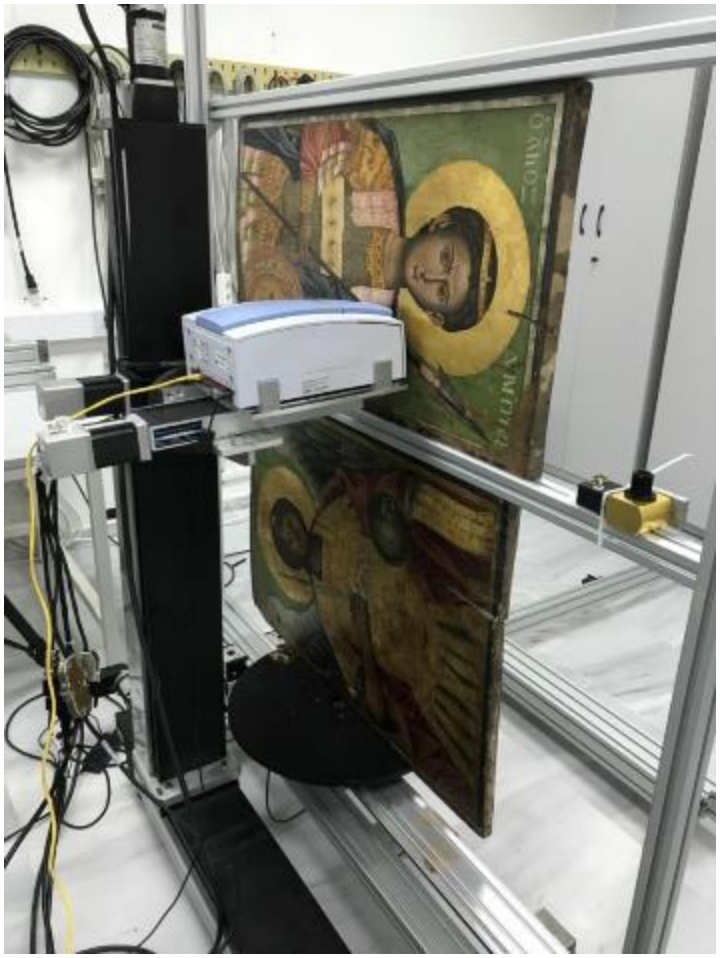



Point – Scanning Region of Interest and Imaging measurments

Physicochemical defects via ageing, creation materials and admixtures identification. Elemental analysis and supporting materials detection

Modalities
- FTIR spectrometer
- Raman spectrometer
- XRF spectrometer





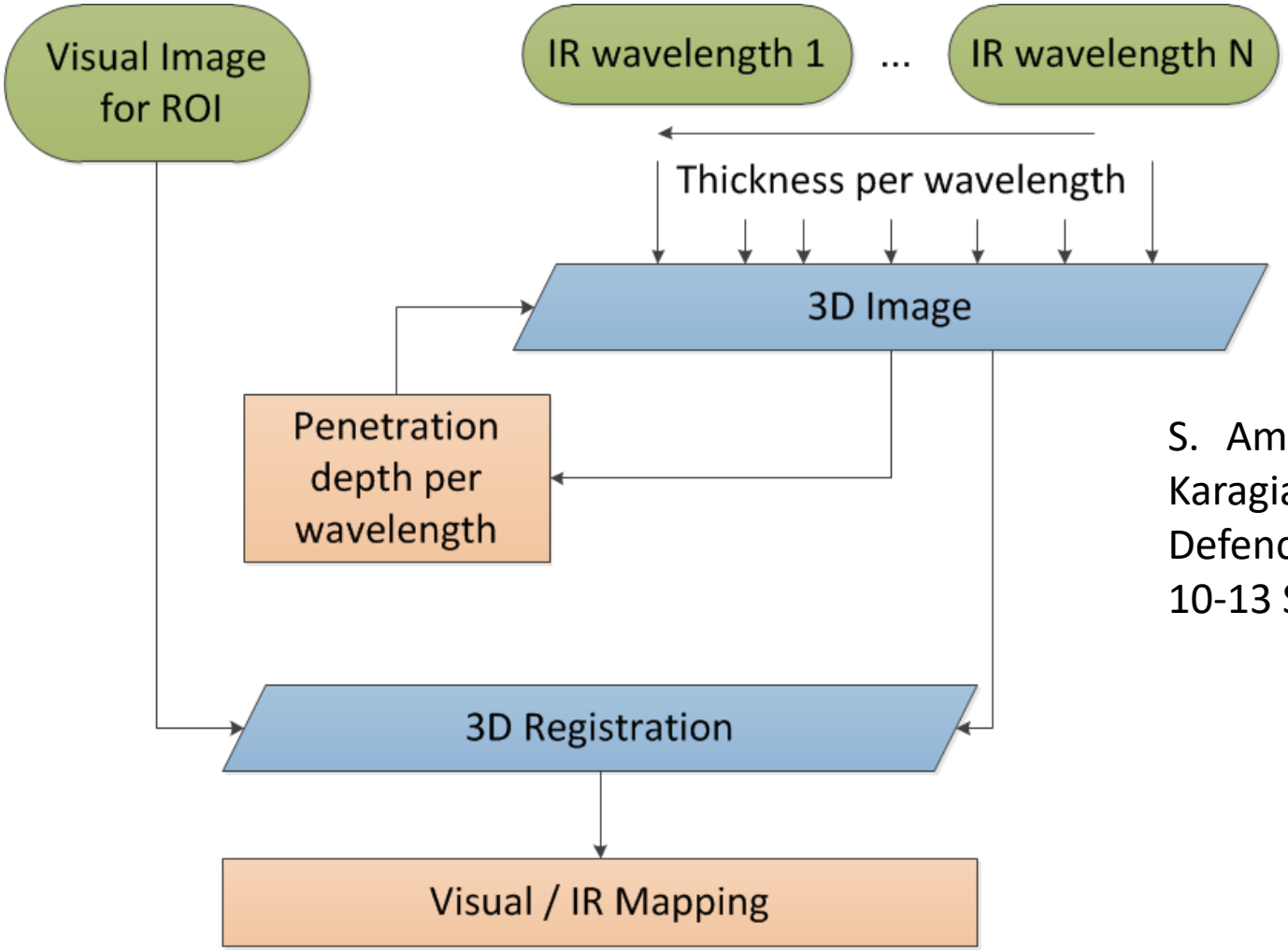
Registration Procedure and Algorithms

Registration

- Area-based
  - Cross-correlation
- Feature-based
  - Homography matrix via iterative algorithms such as RANSAC
  - Feature detection via SIFT, SURF and ORB algorithms

Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

Infrared mapping spectroscopy,
Infrared hyperspectral mapping imaging 1.3 – 5 - 26μm



S. Amanatiadis, Apostolidis, G. Karagiannis, SPIE Security plus Defence 2018, Berlin, Germany, 10-13 September 2018

Combination/ Fusion of the data –
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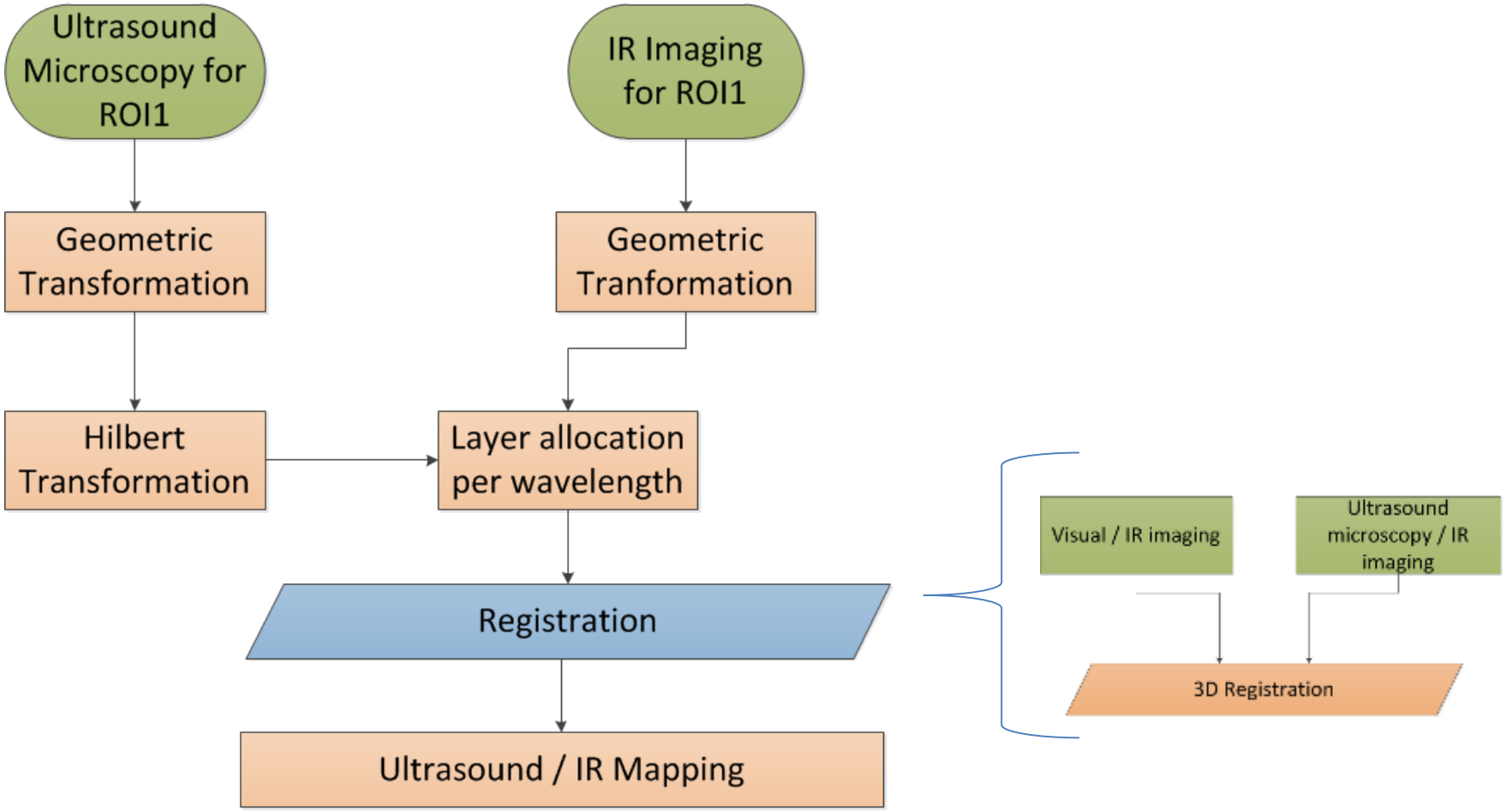
Fusion



Combination/ Fusion of the data –
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Combination/ Fusion of the data –
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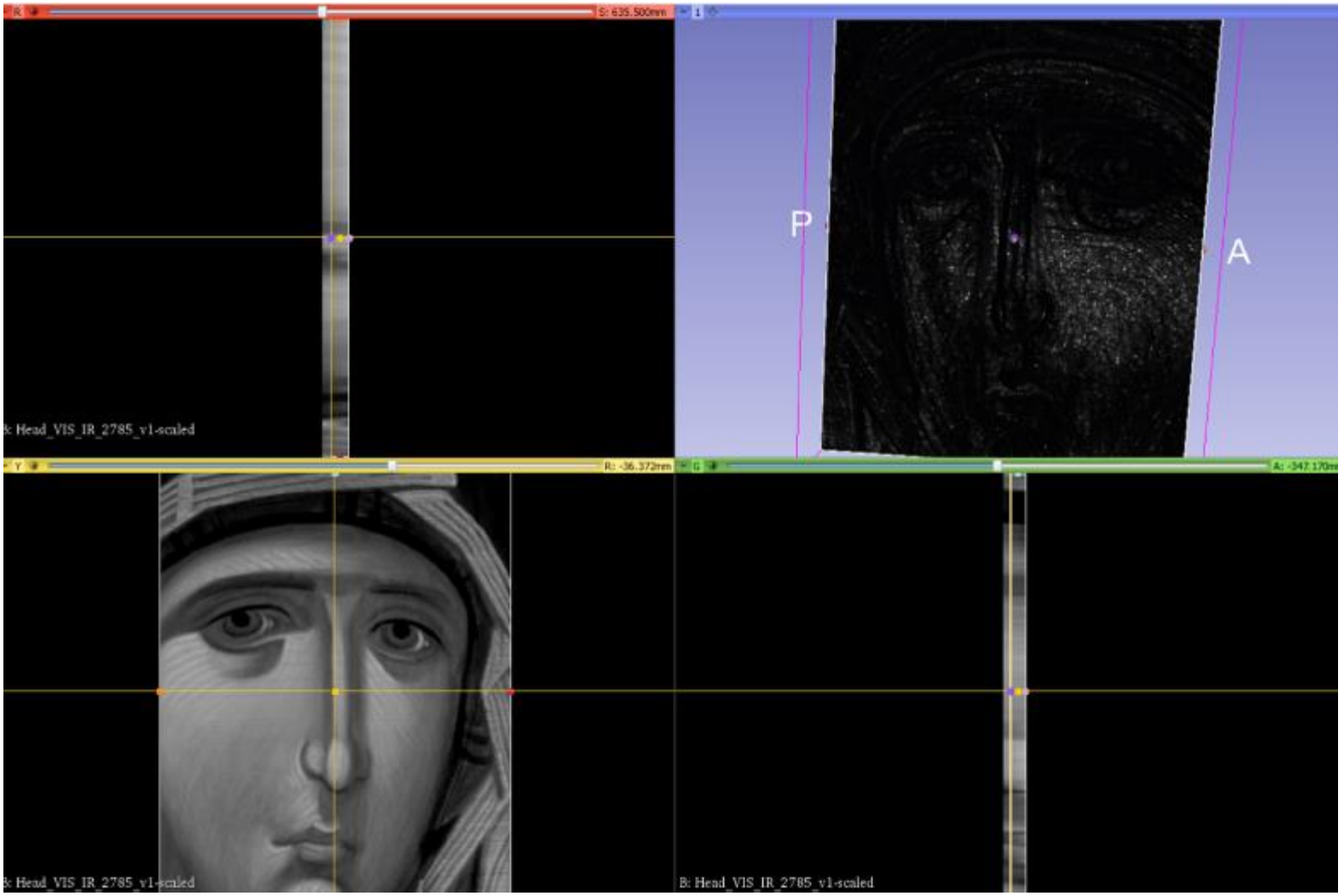
St. Demetrius

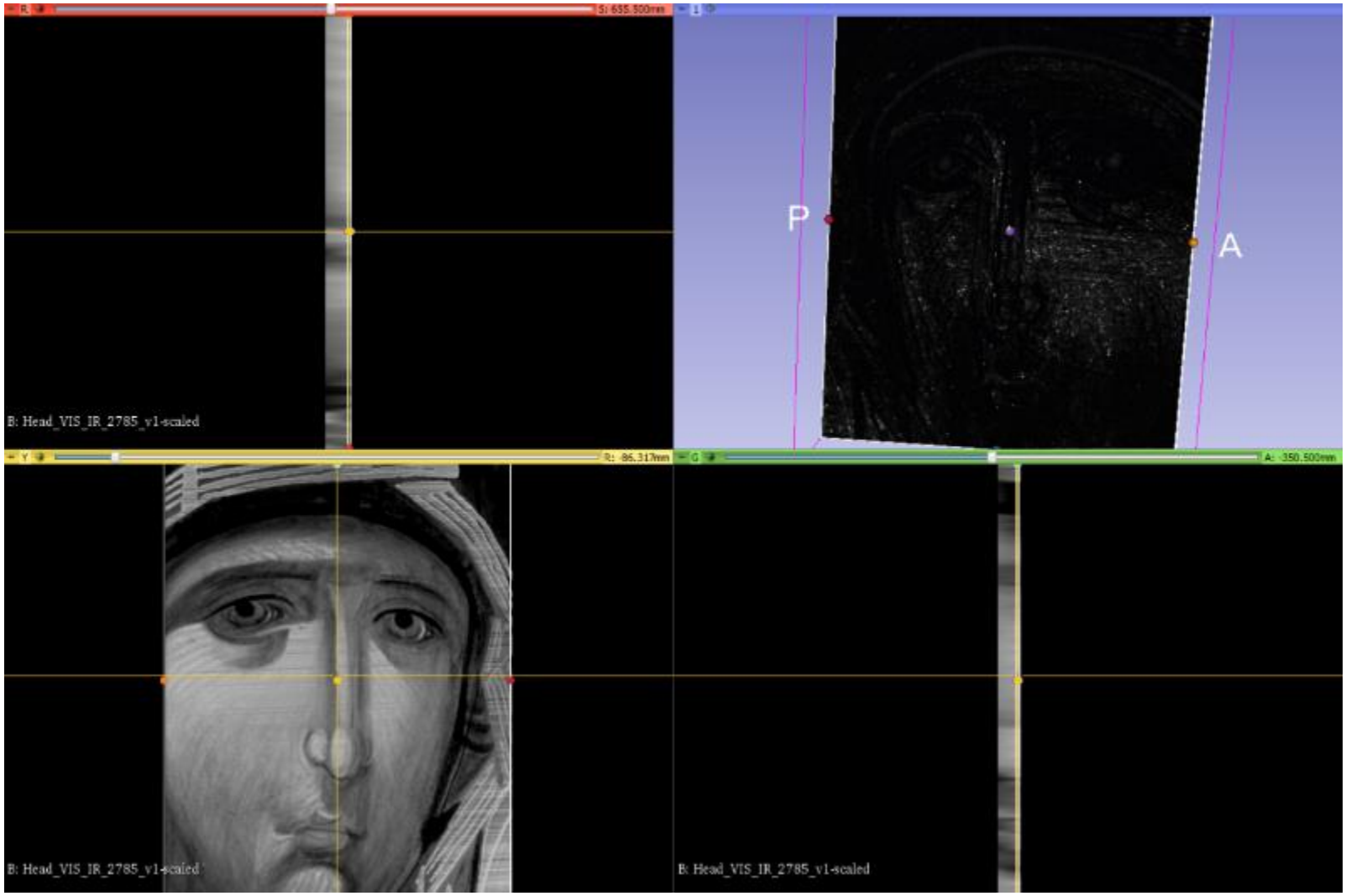
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

Infrared mapping spectroscopy
Infrared imaging 1.8-2.8µm



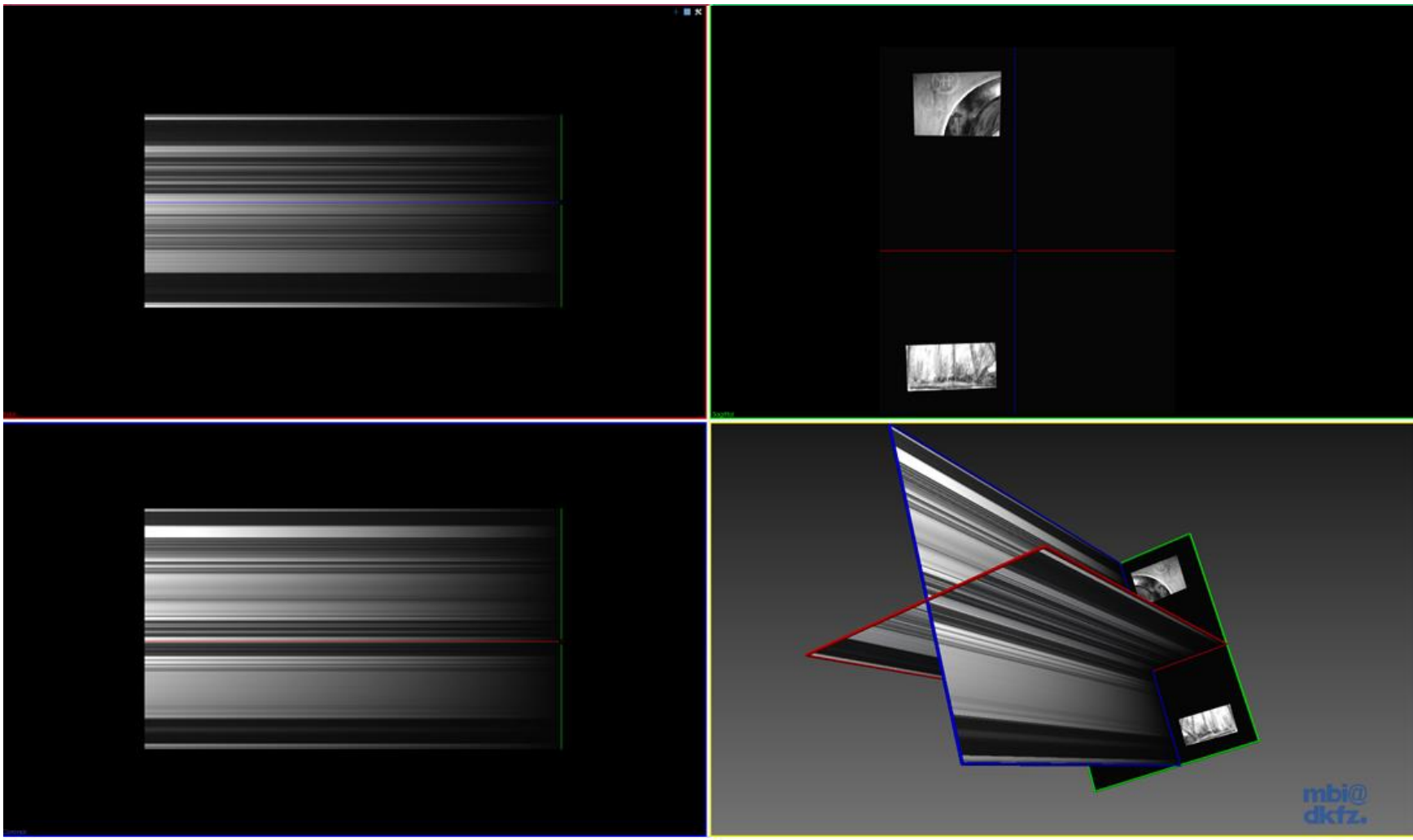
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

Infrared mapping spectroscopy
Infrared imaging 2.8-5µm



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

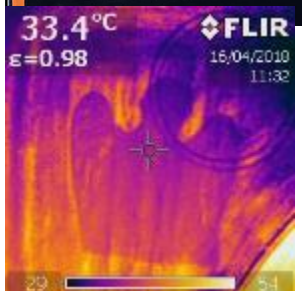
Infrared mapping spectroscopy
Infrared imaging 1.5-5µm



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

Infrared imaging 1.5-5μm
XENICS XMID InSb 1-5μm

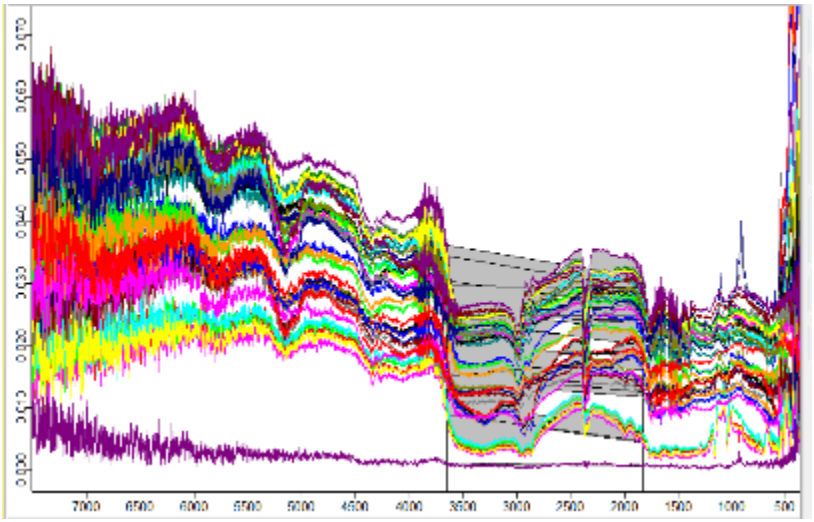
ared imaging 8-14μm
FLIR i60



DIAGNOSIS MULTISYSTEMS

Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

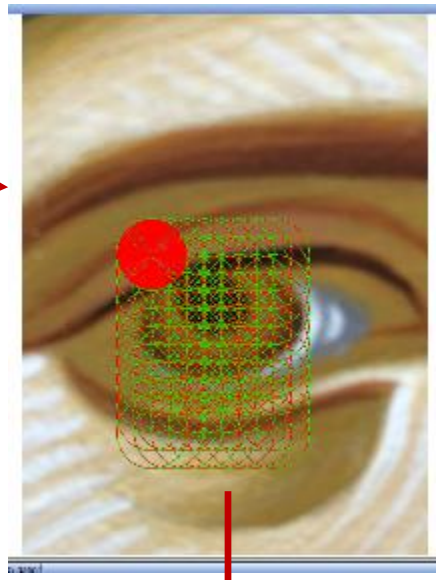
Infrared mapping spectroscopy,
Infrared hyperspectral mapping imaging 1.3 – 5 - 26µm

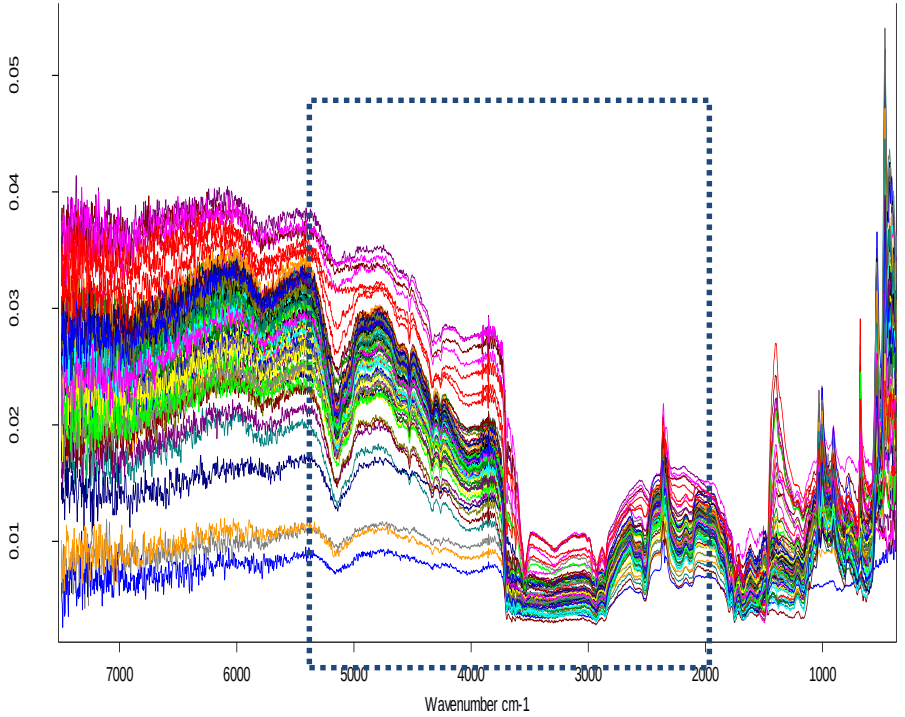


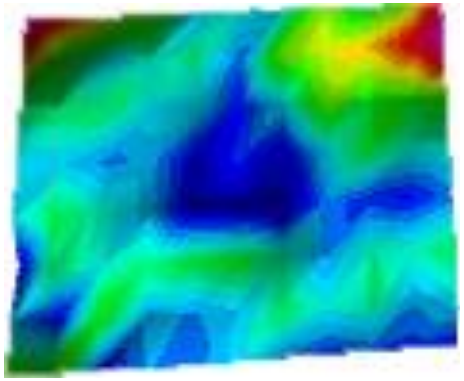
Combination/ Fusion of the data –

(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)

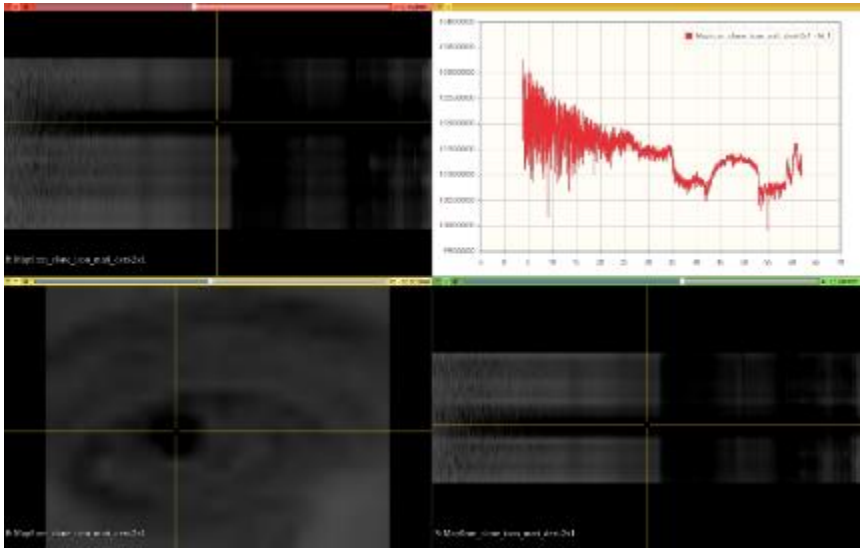
Tomography … “i” Tomography - iTomography

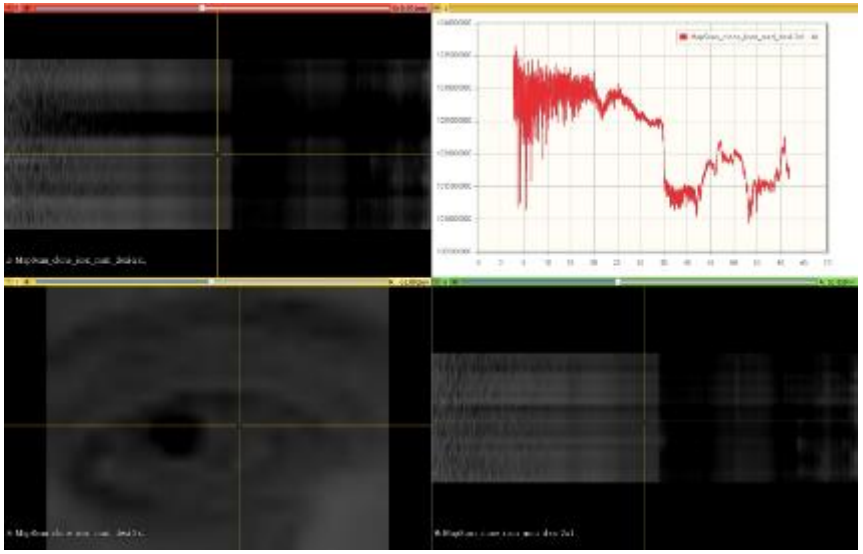




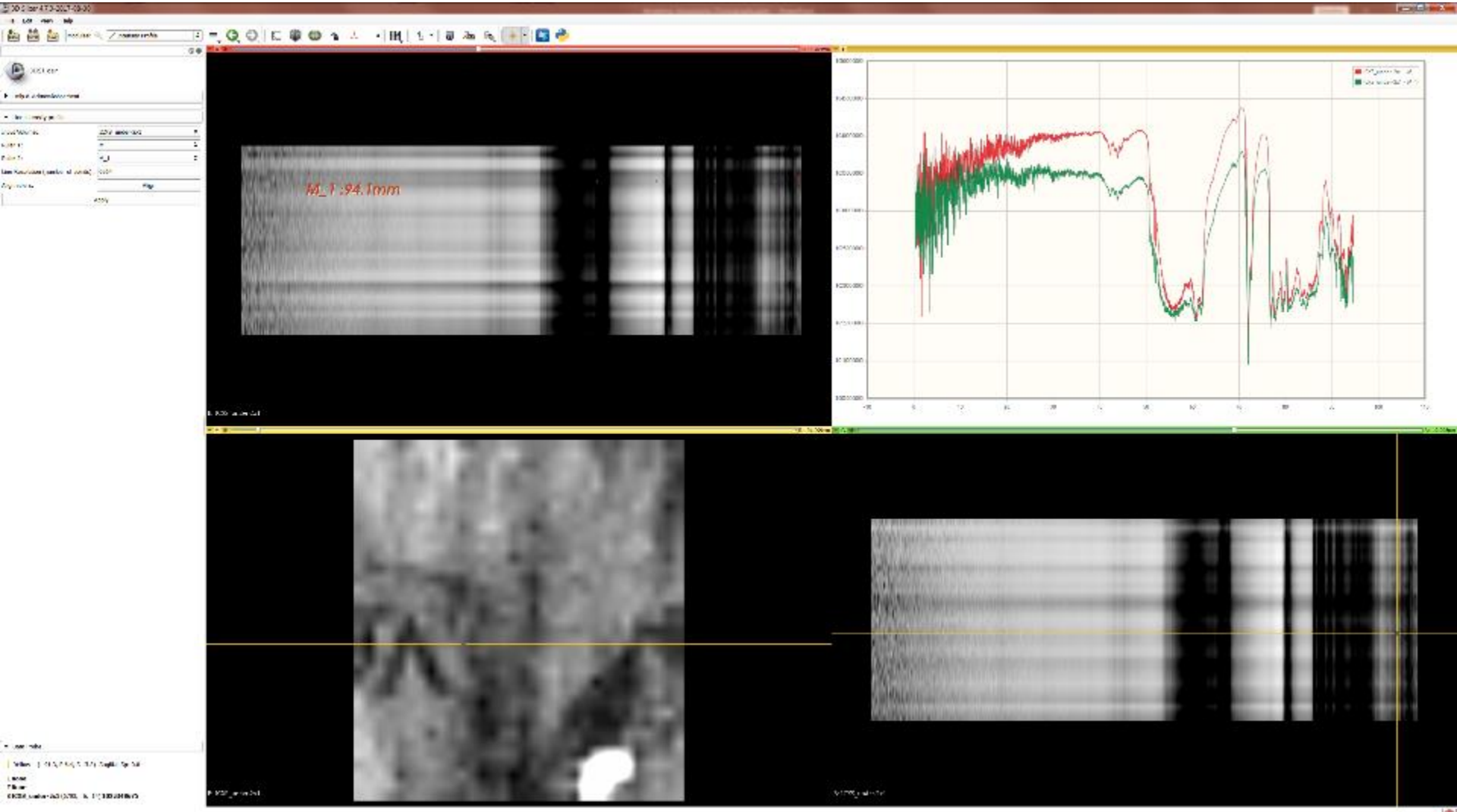


Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

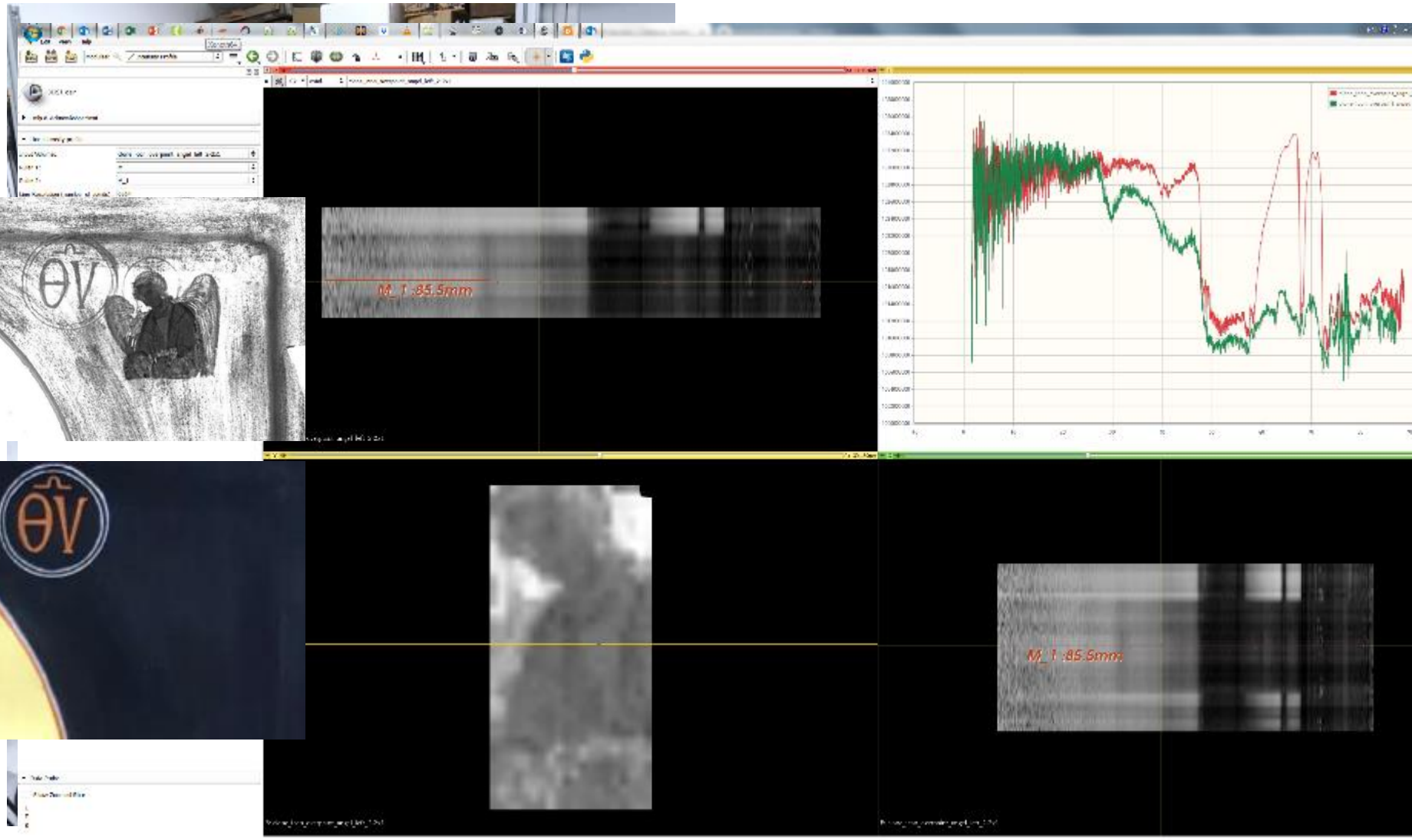




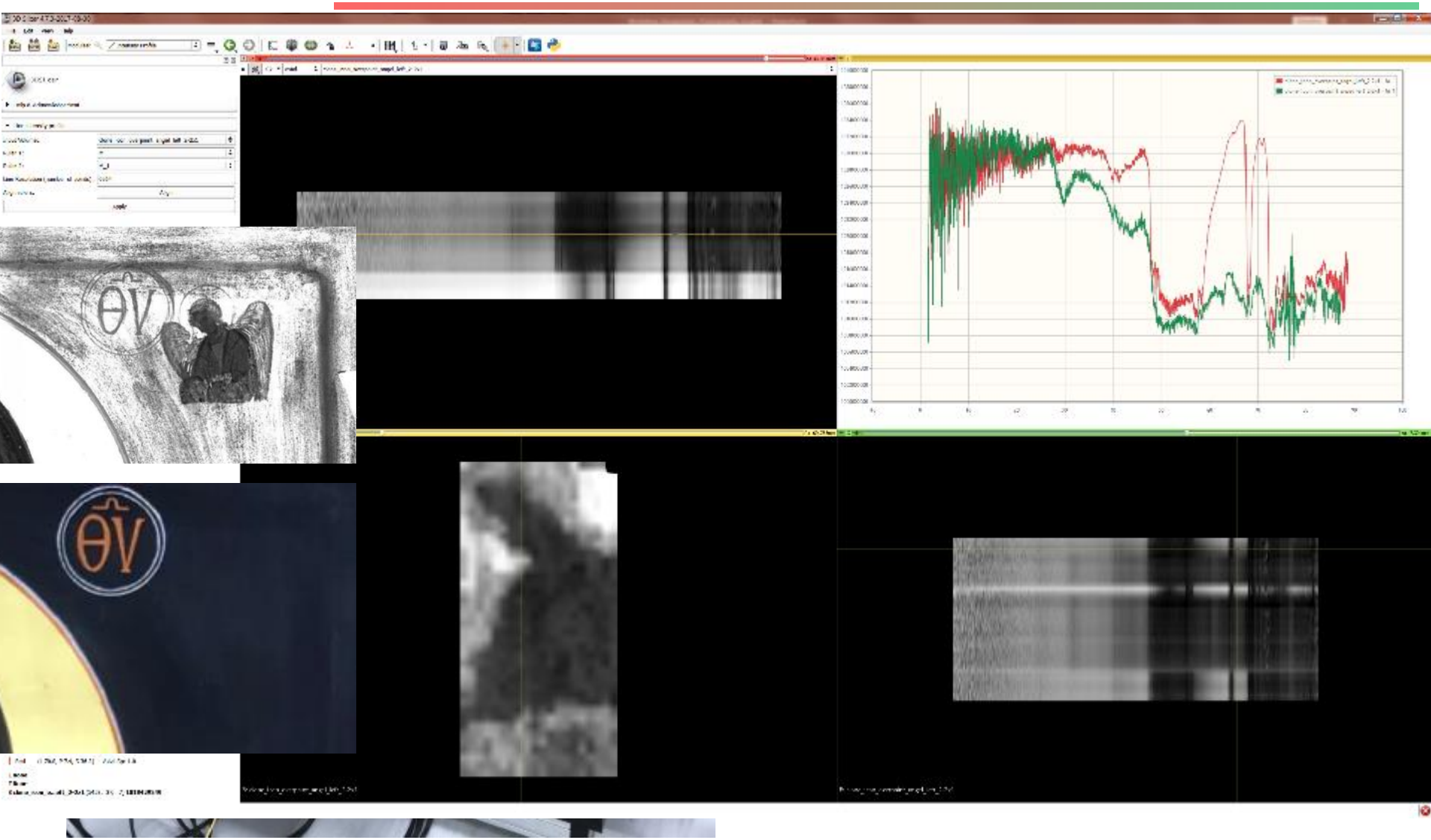
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



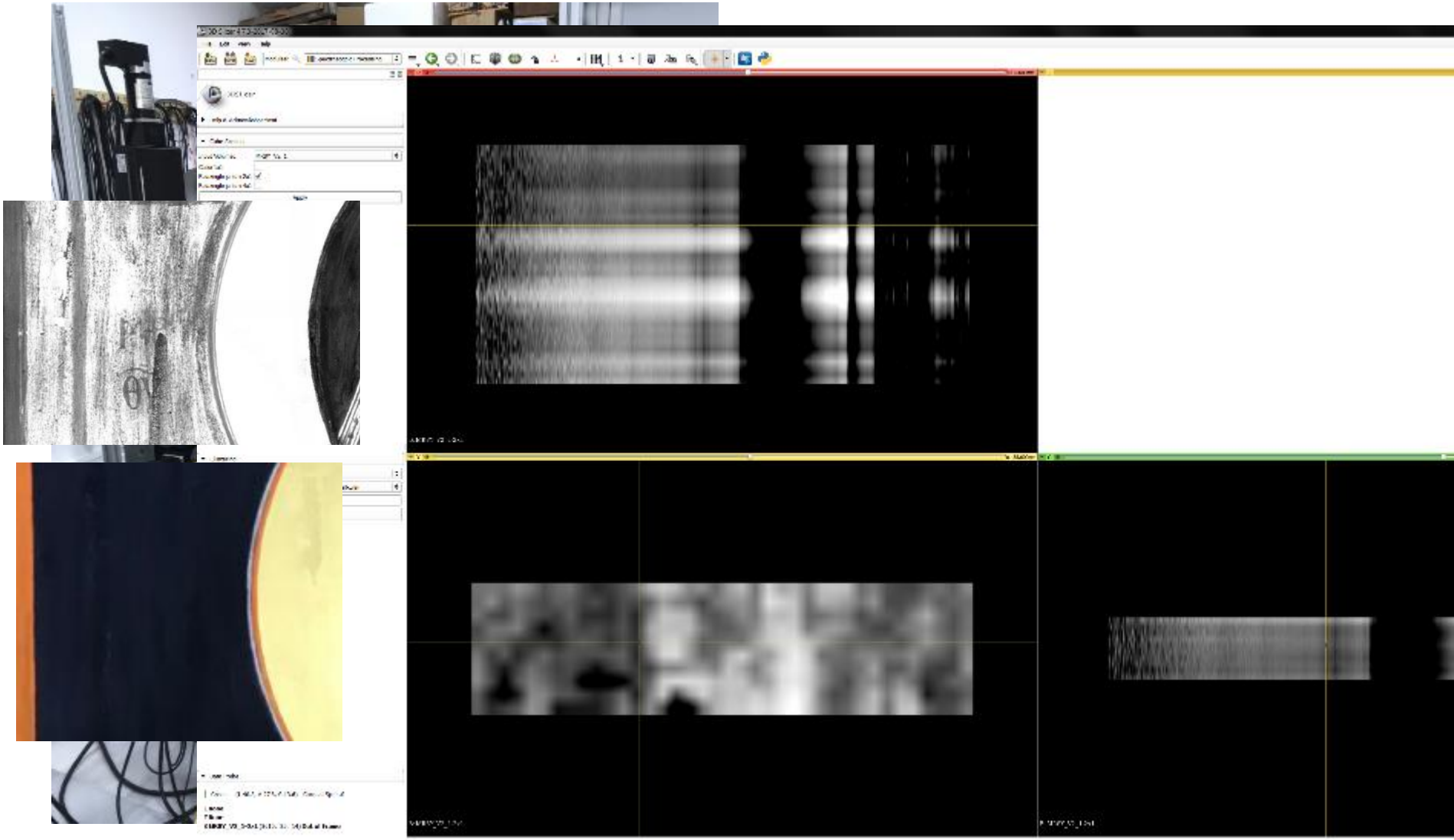
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



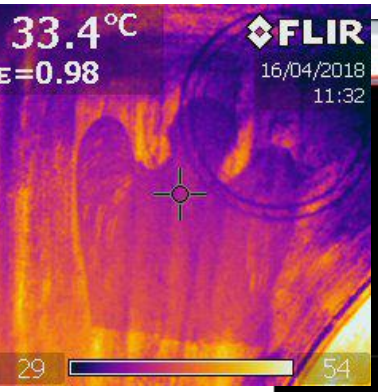
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

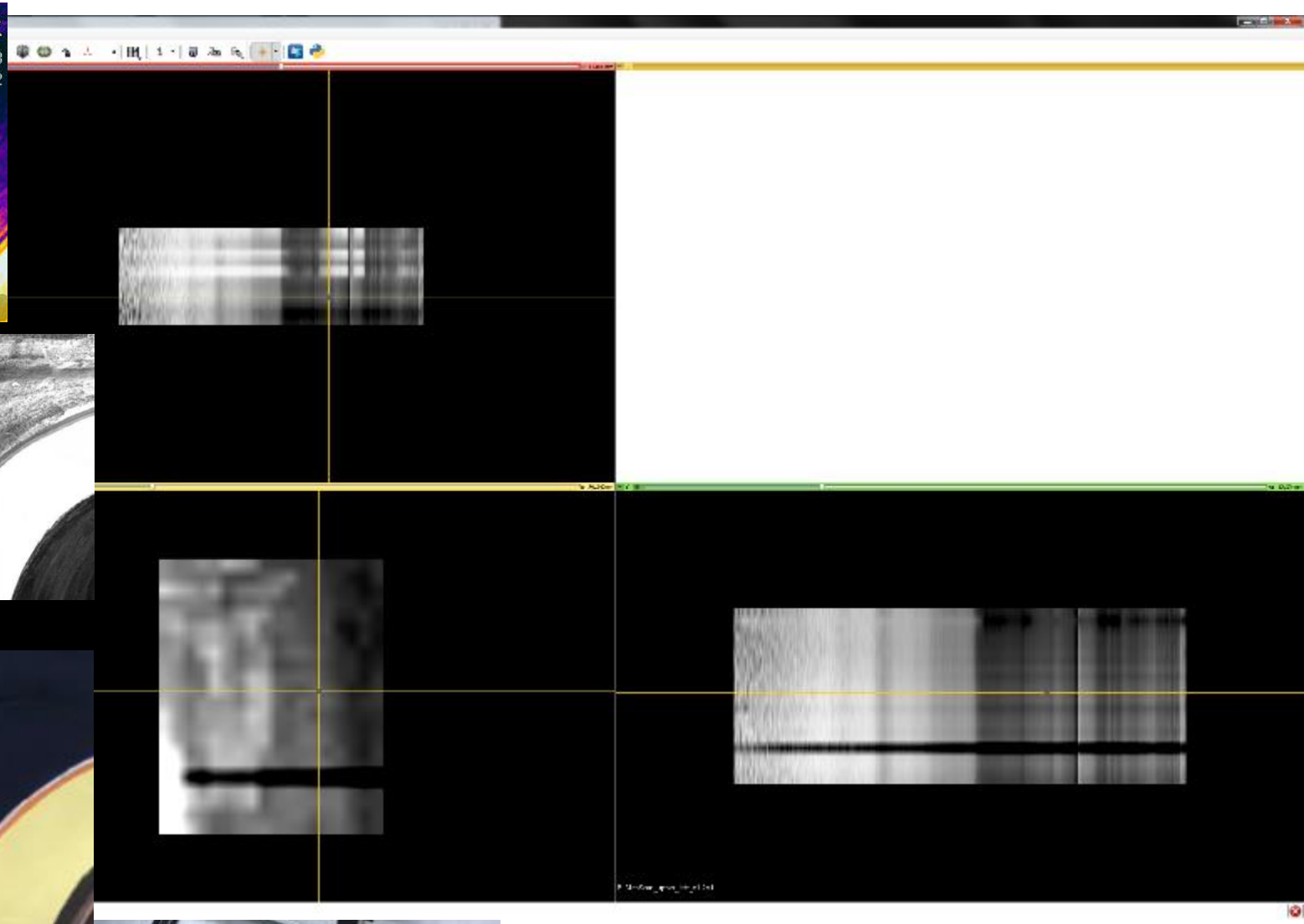


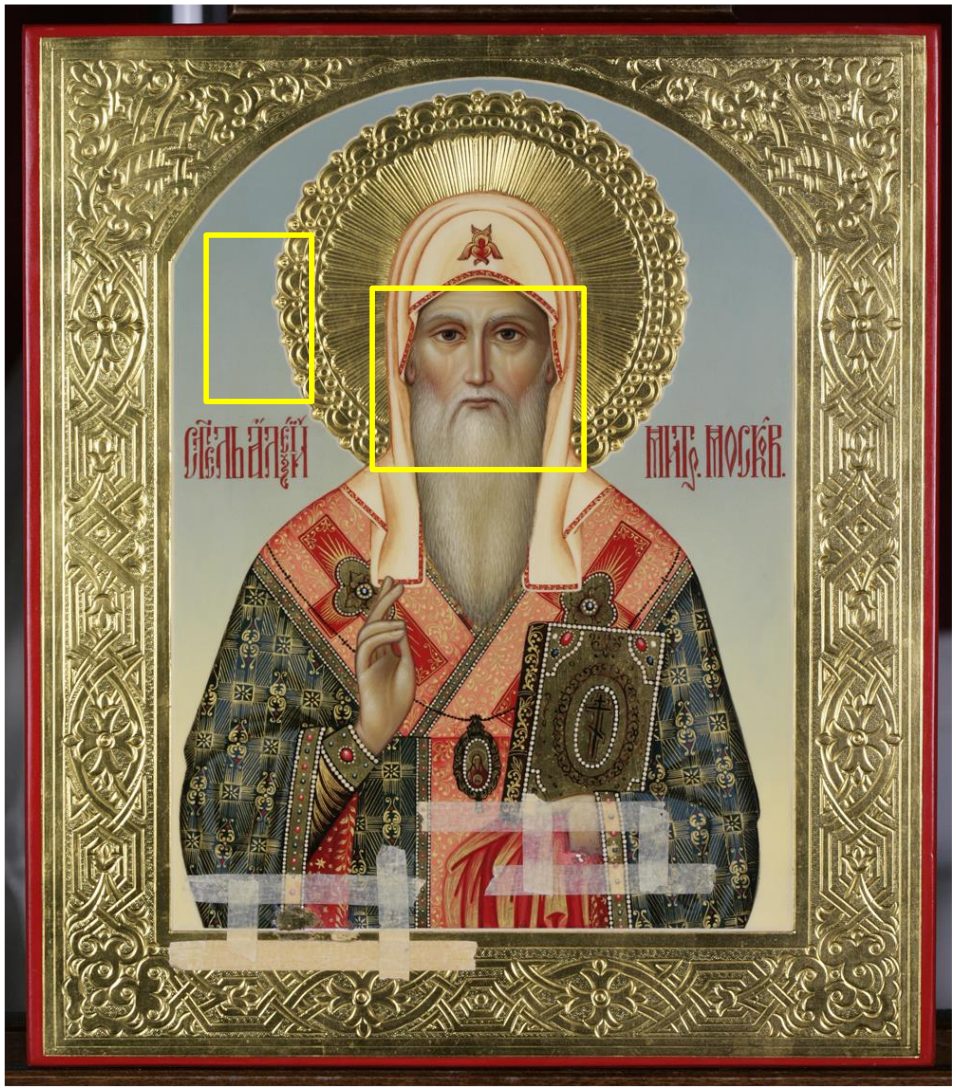
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



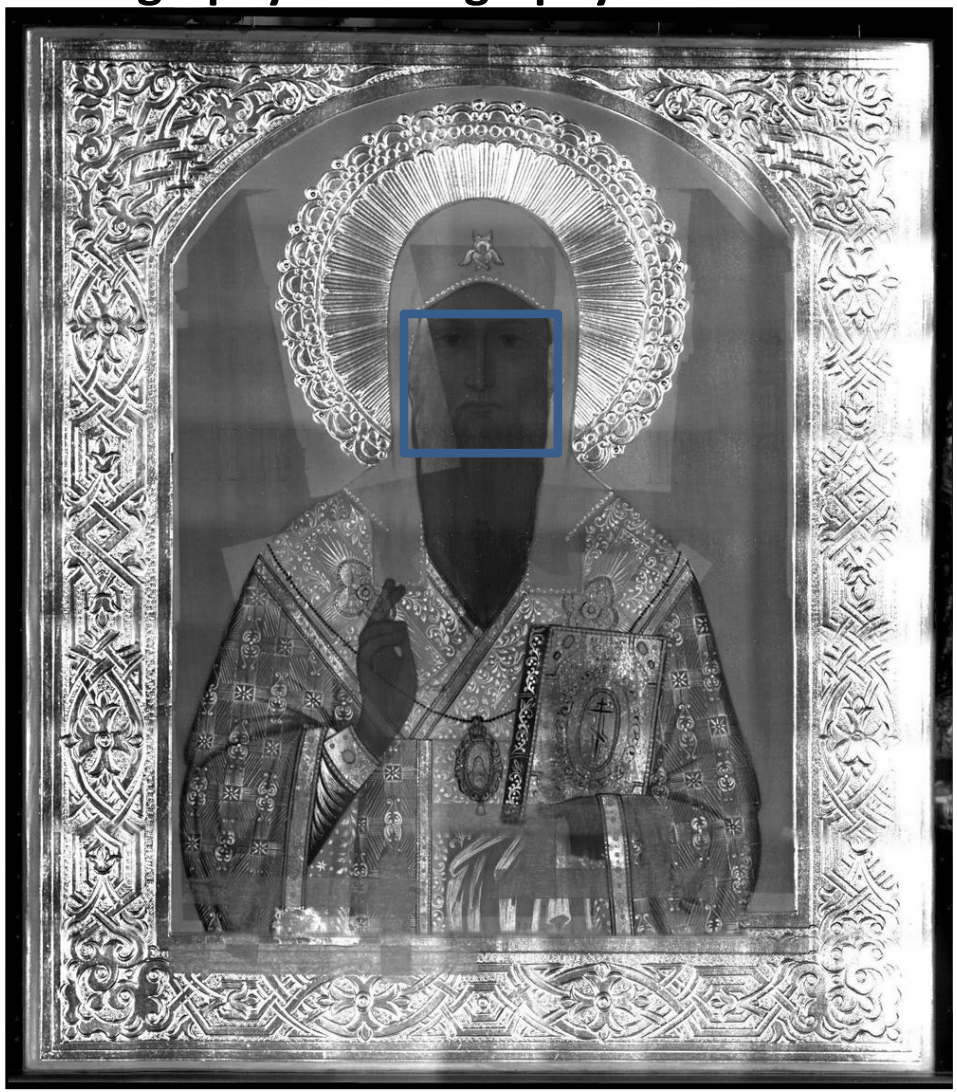



СВЯТЫЙ АЛЕКСІЙ
МИТР. МОСКОВ.

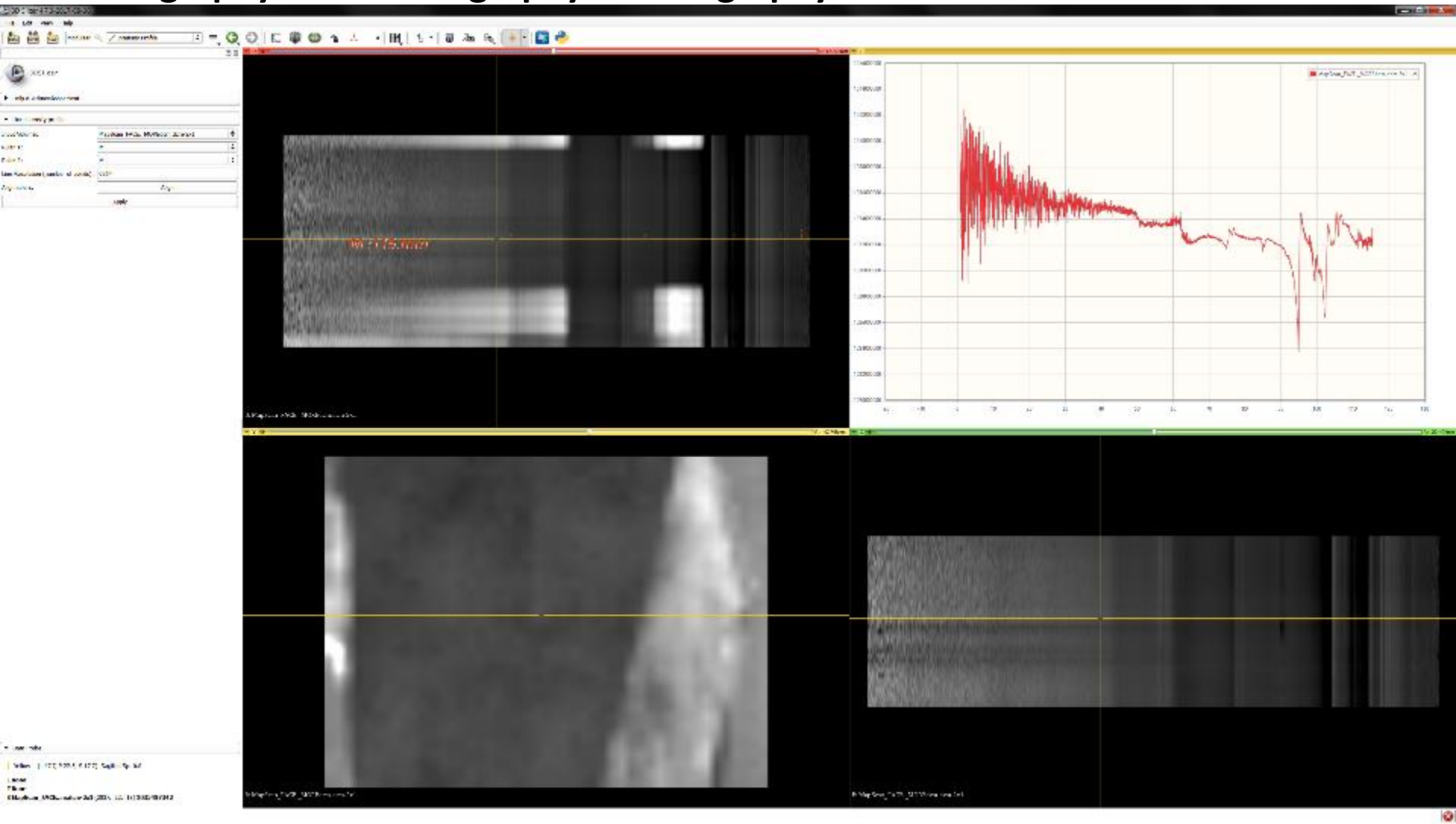
Combination/ Fusion of the data –

(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)

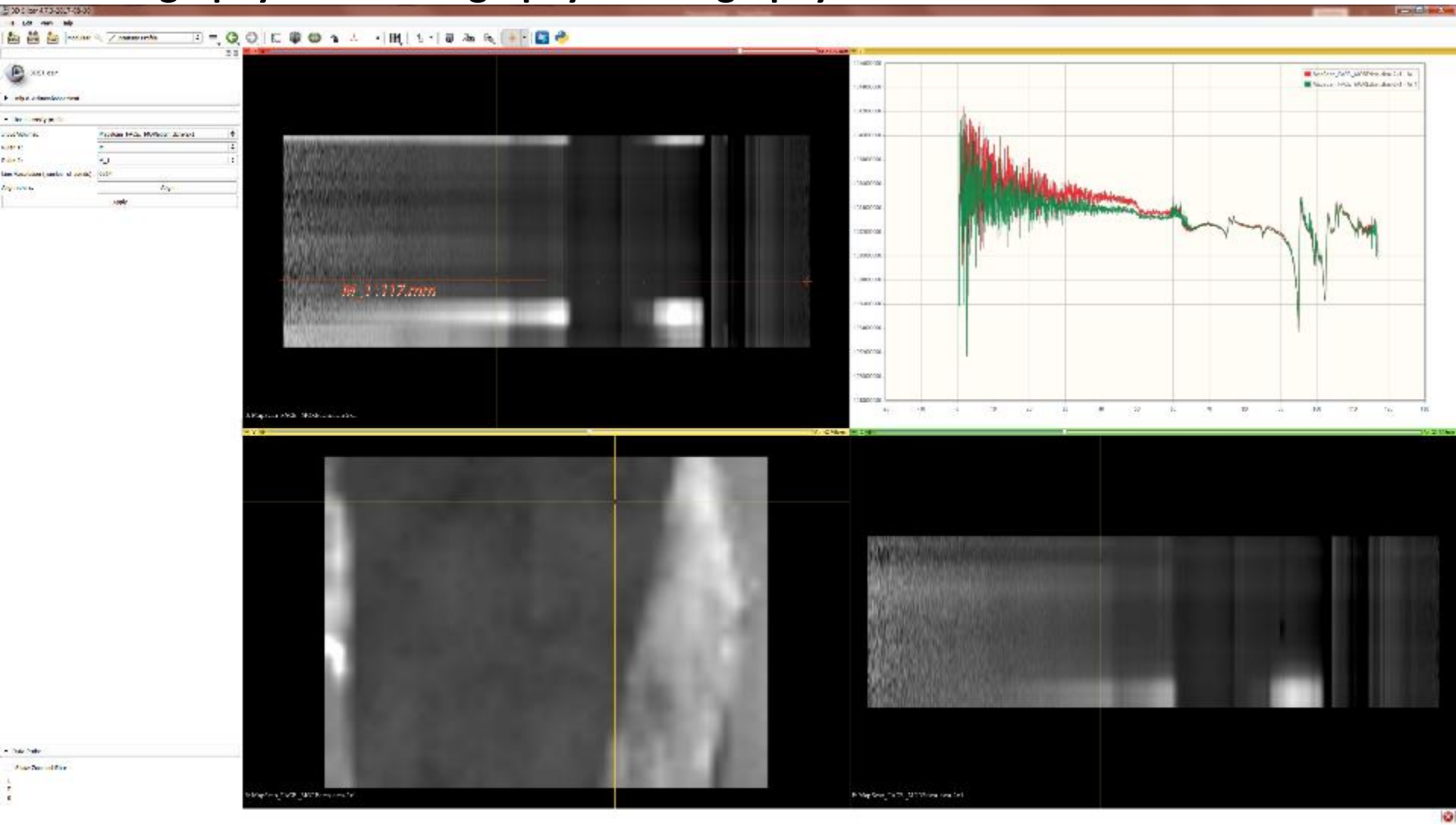
Tomography … “i” Tomography - iTomography



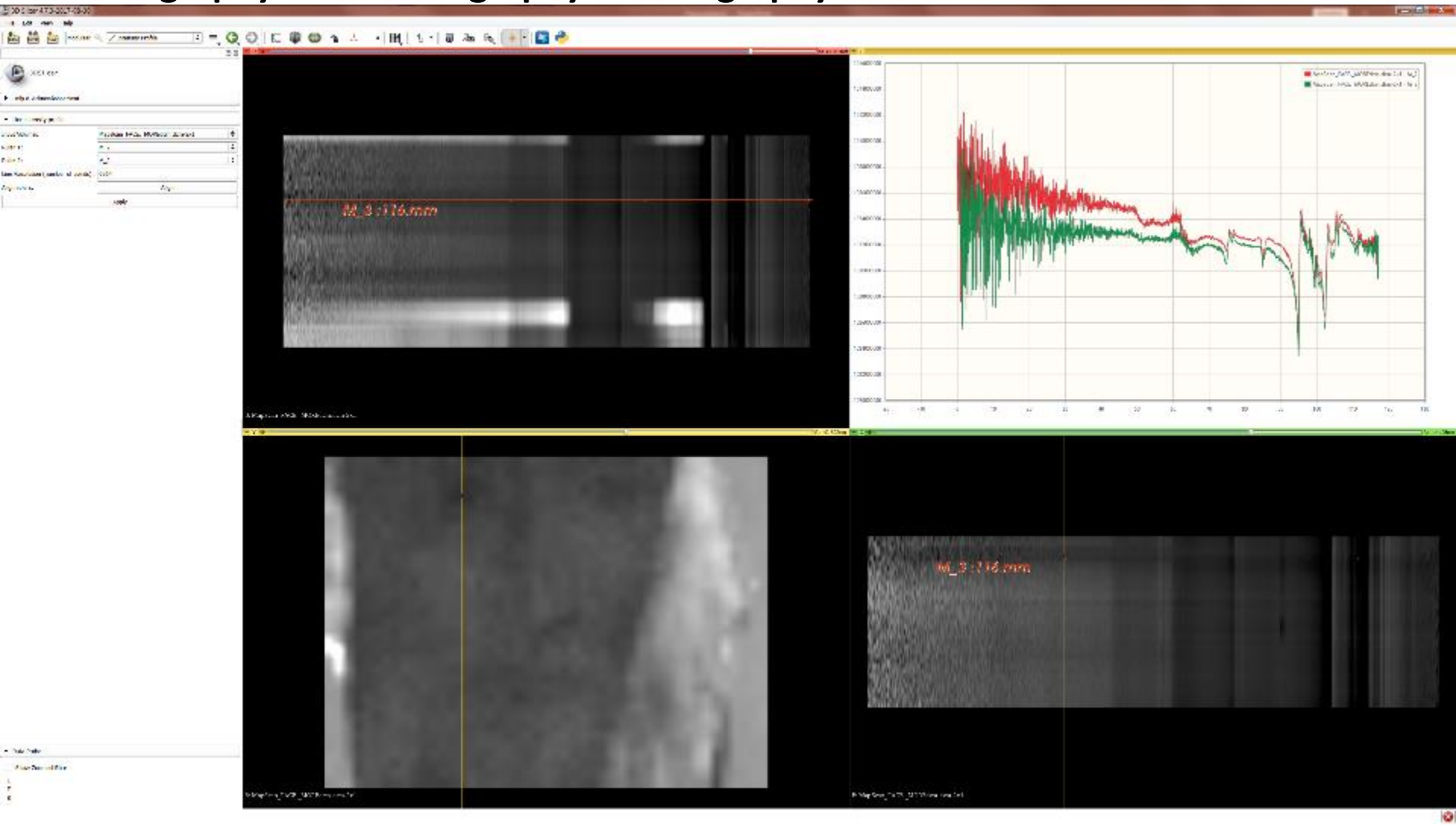
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



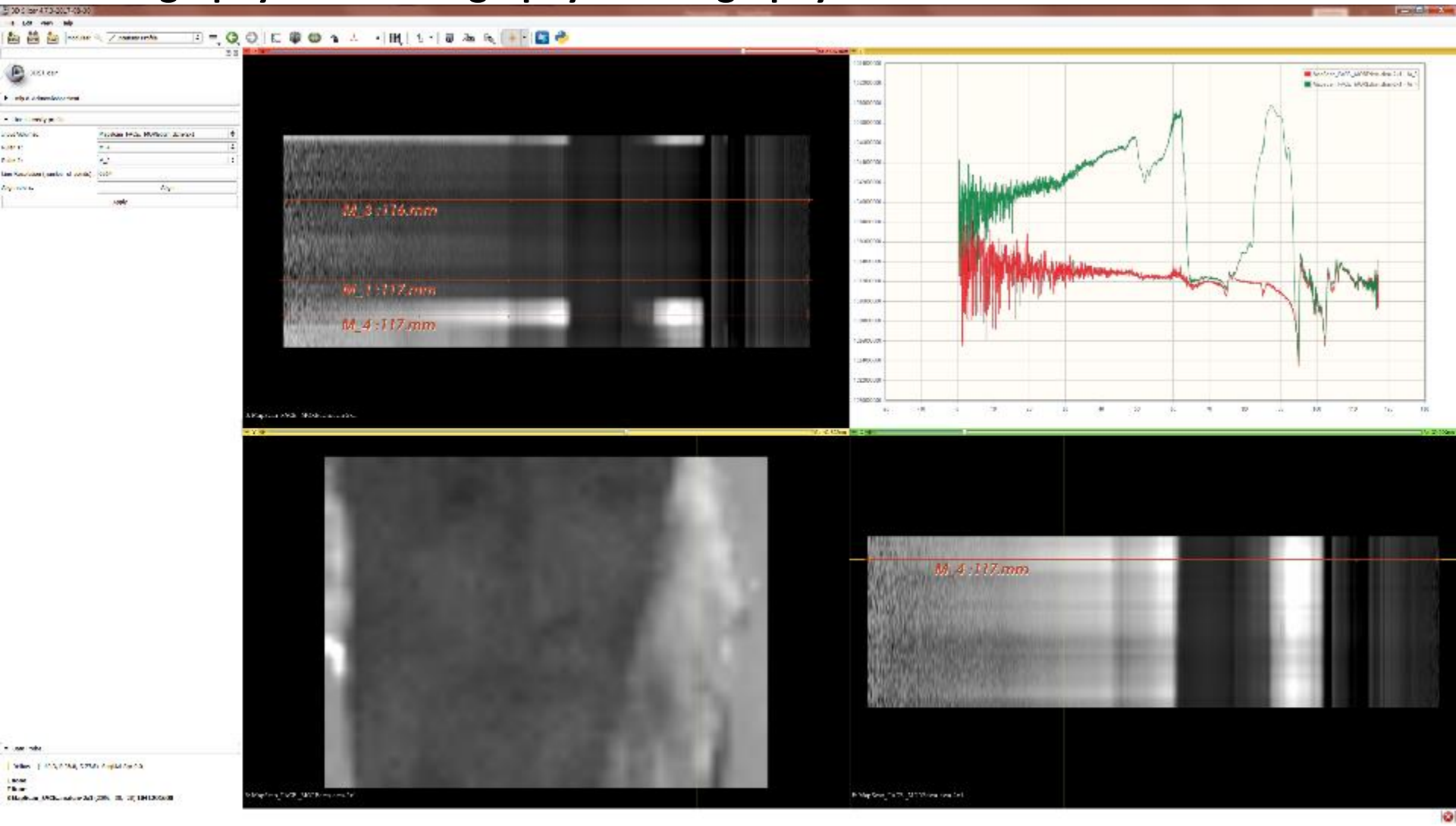
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



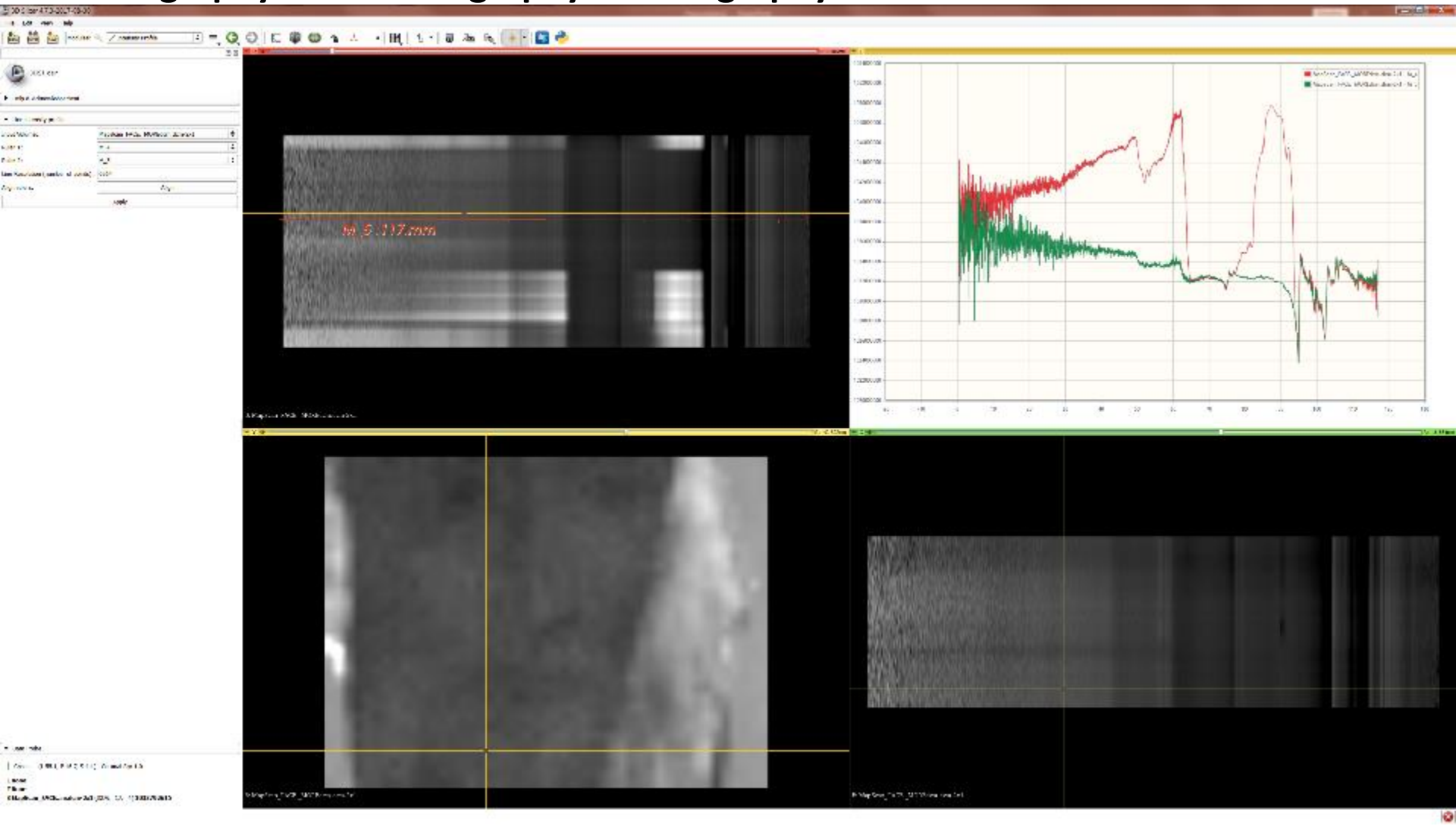
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



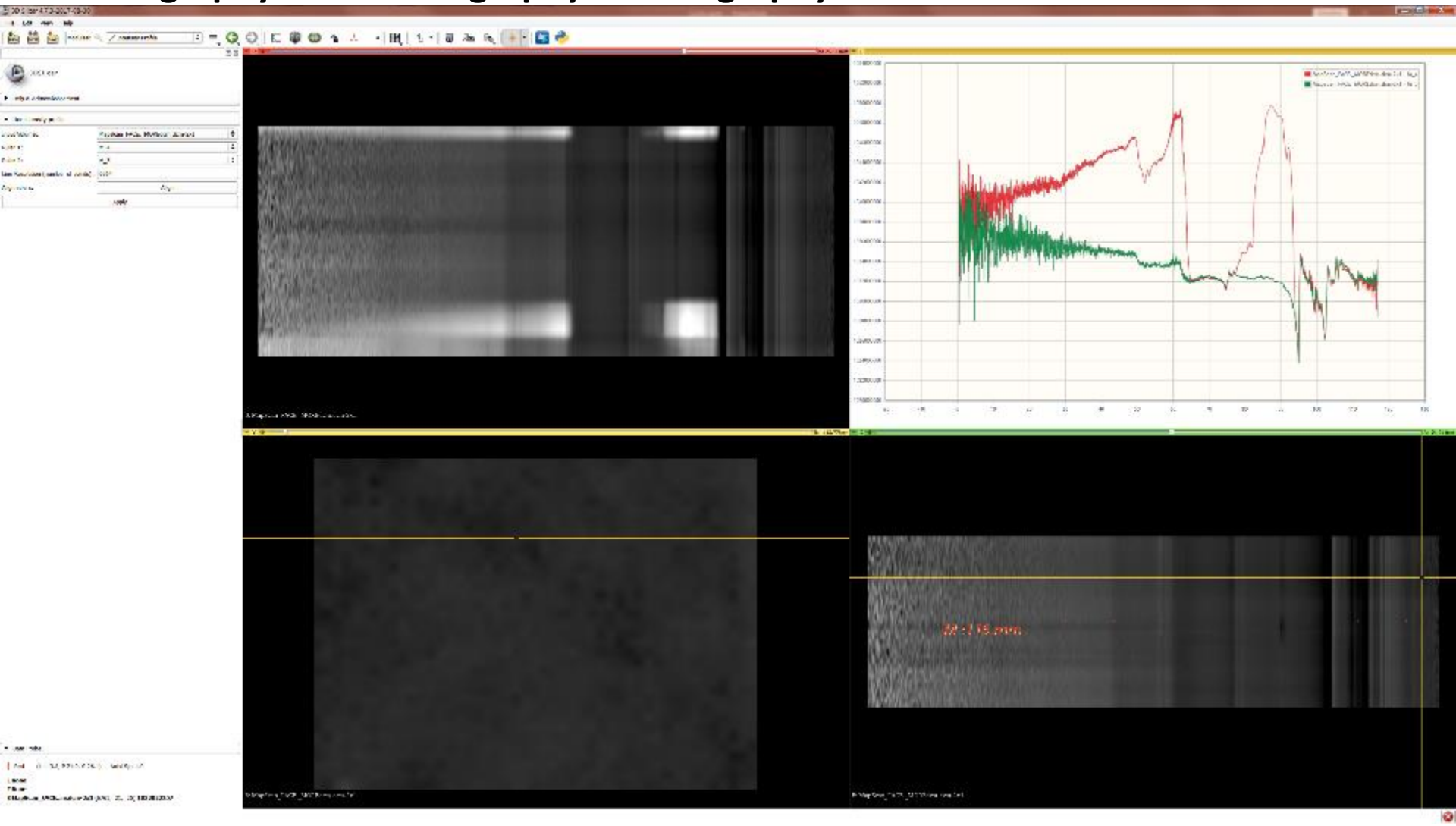
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



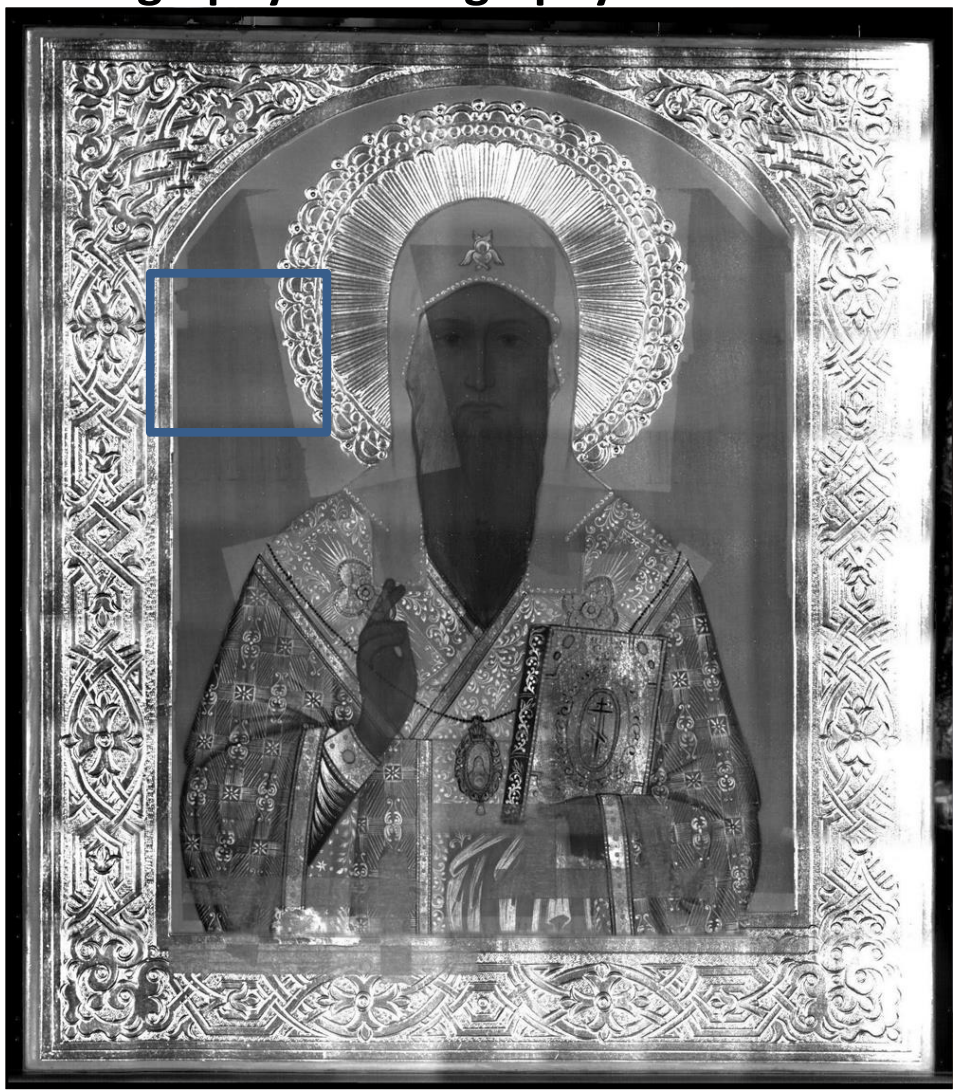
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



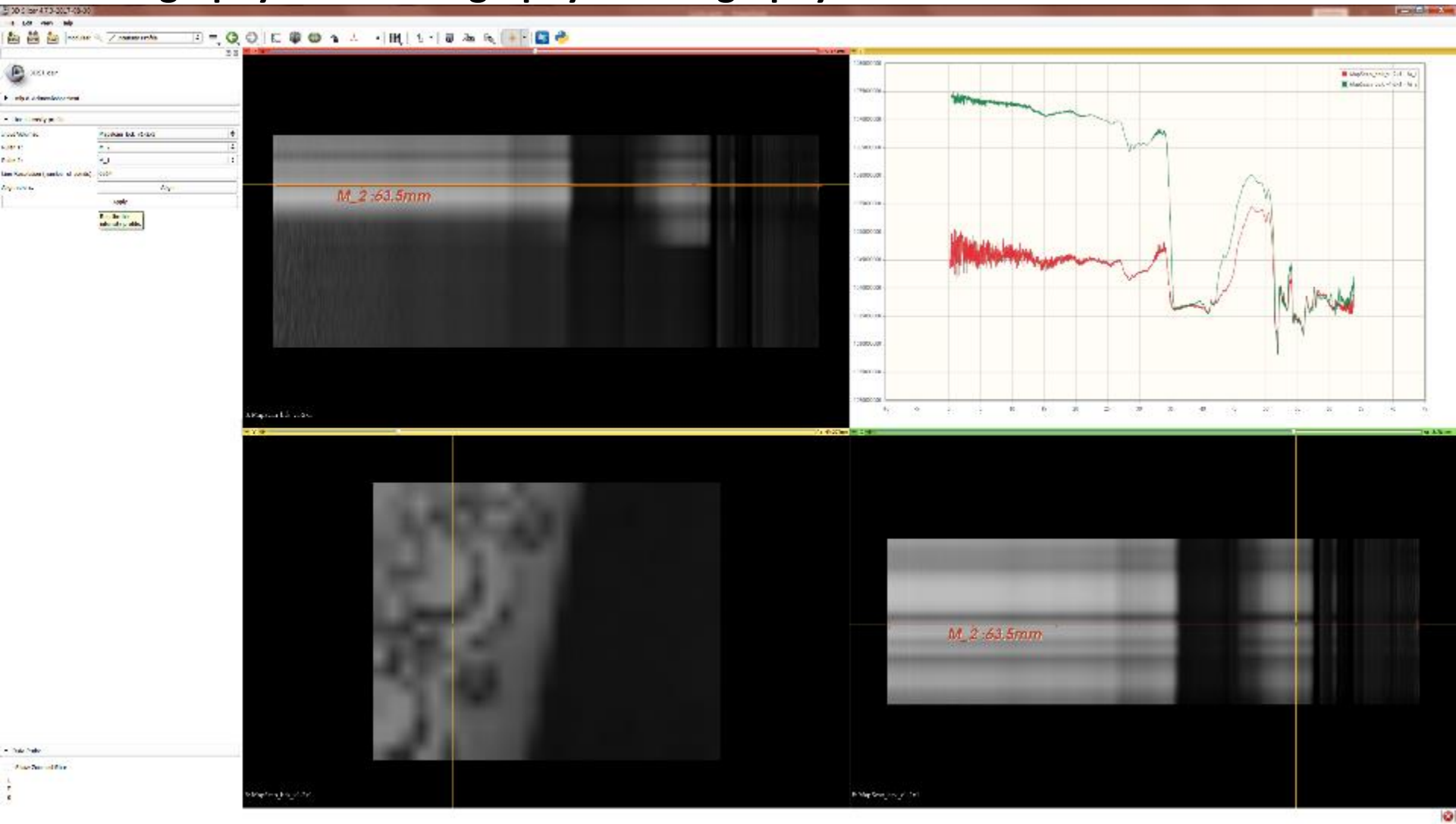
Combination/ Fusion of the data –

(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)

Tomography … “i” Tomography - iTomography

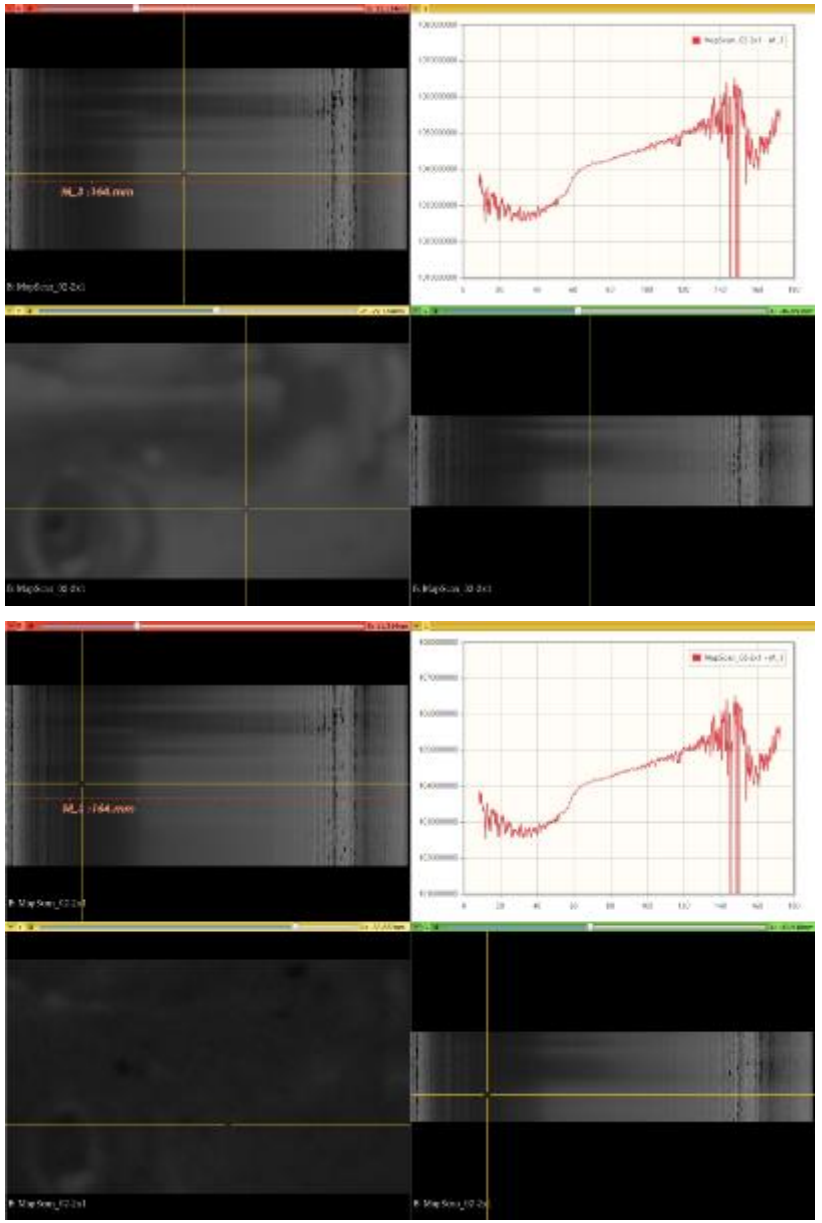


Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



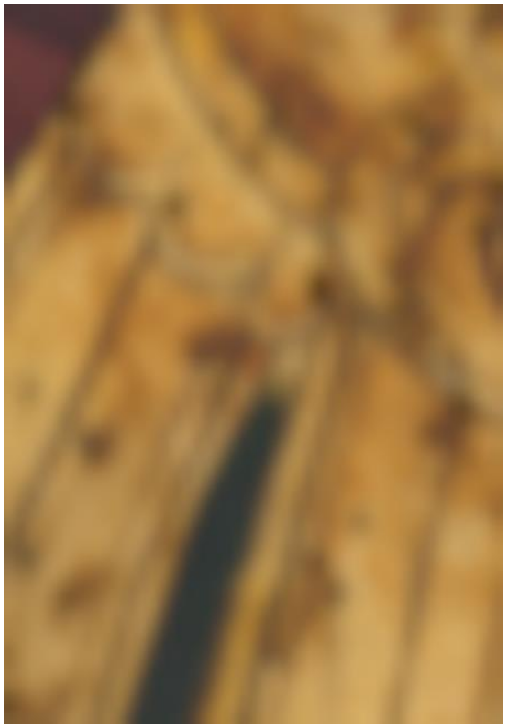
UV/Vis measurements

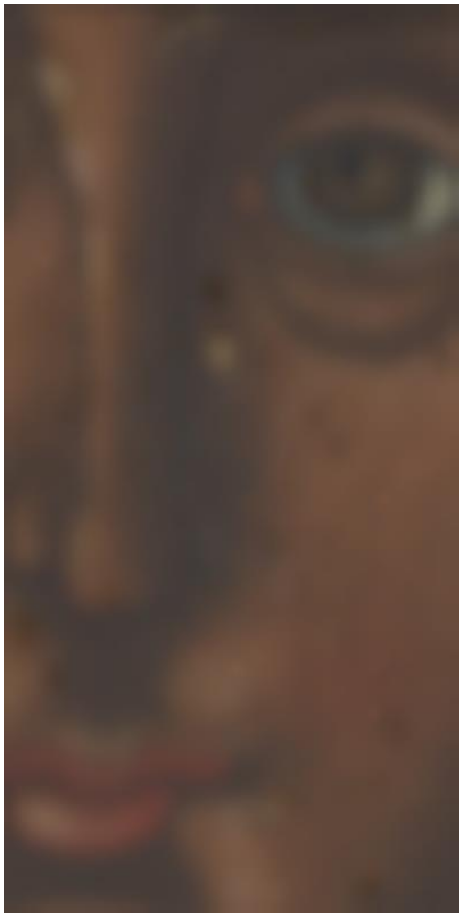
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

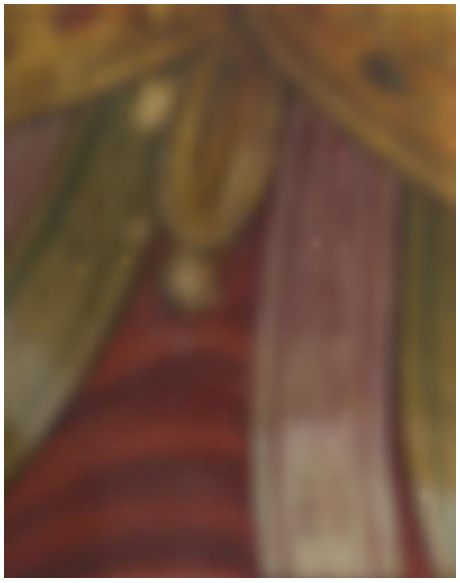
Archangel Michael

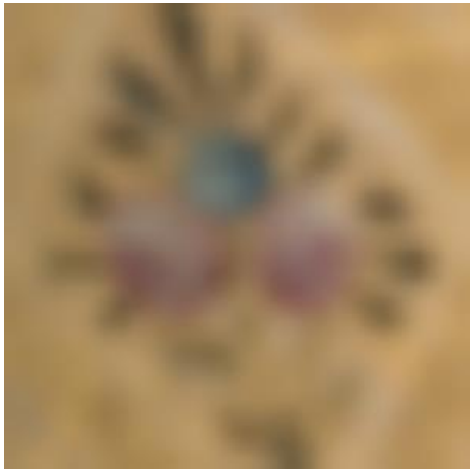


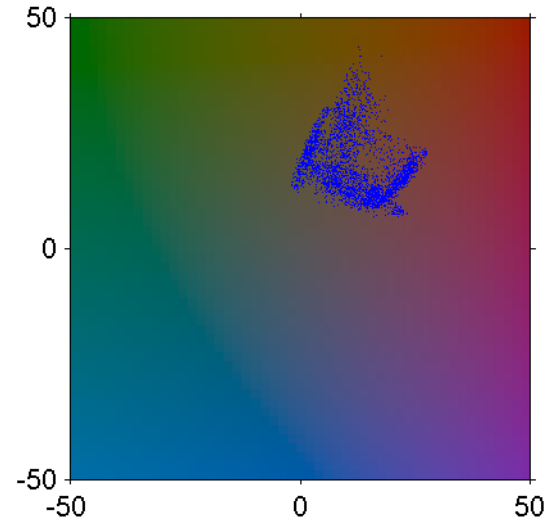


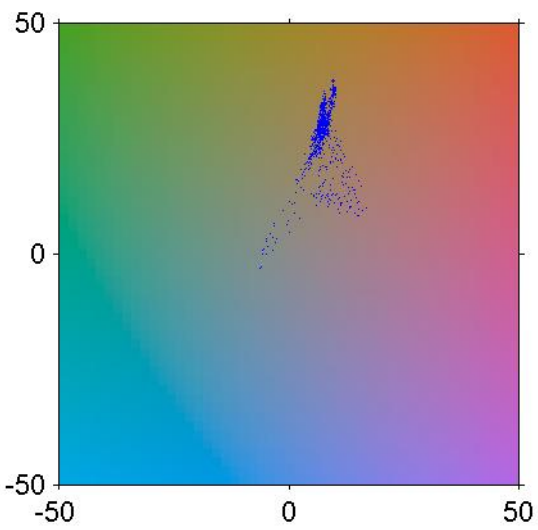
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

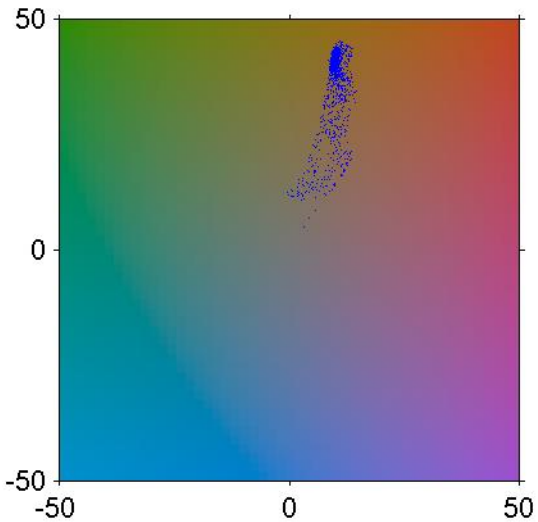
St. Demetrius





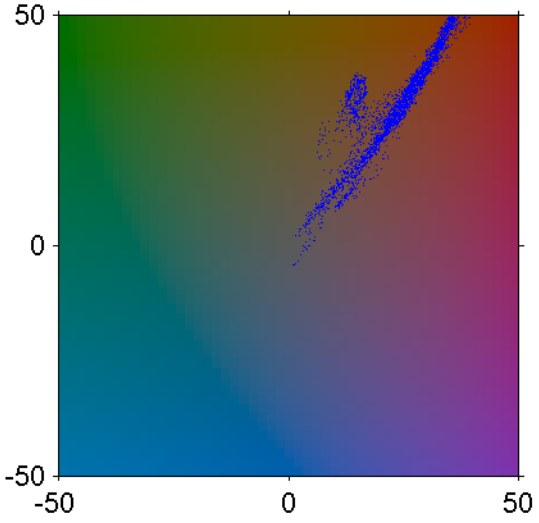


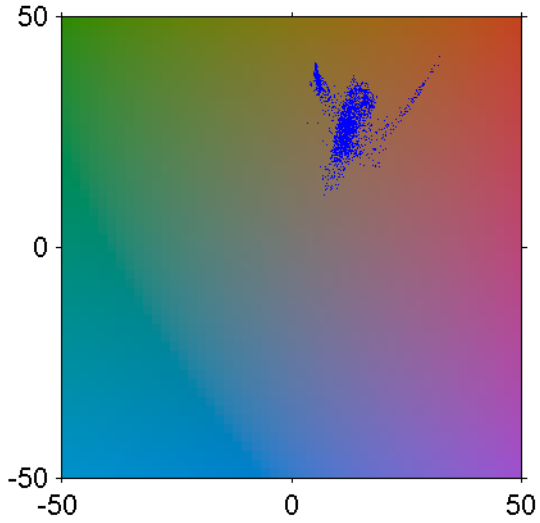


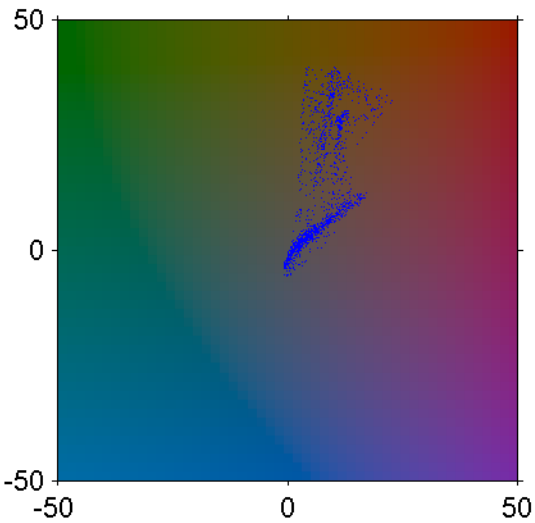


Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

Mother of God

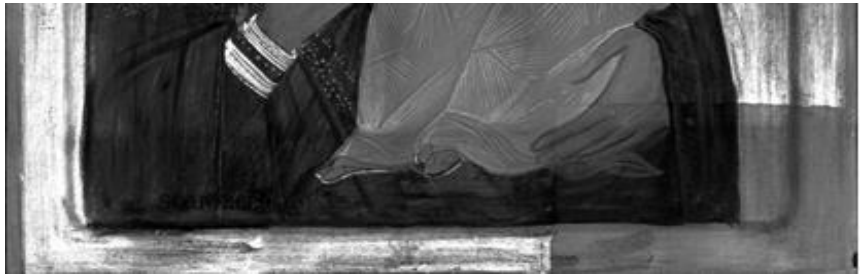


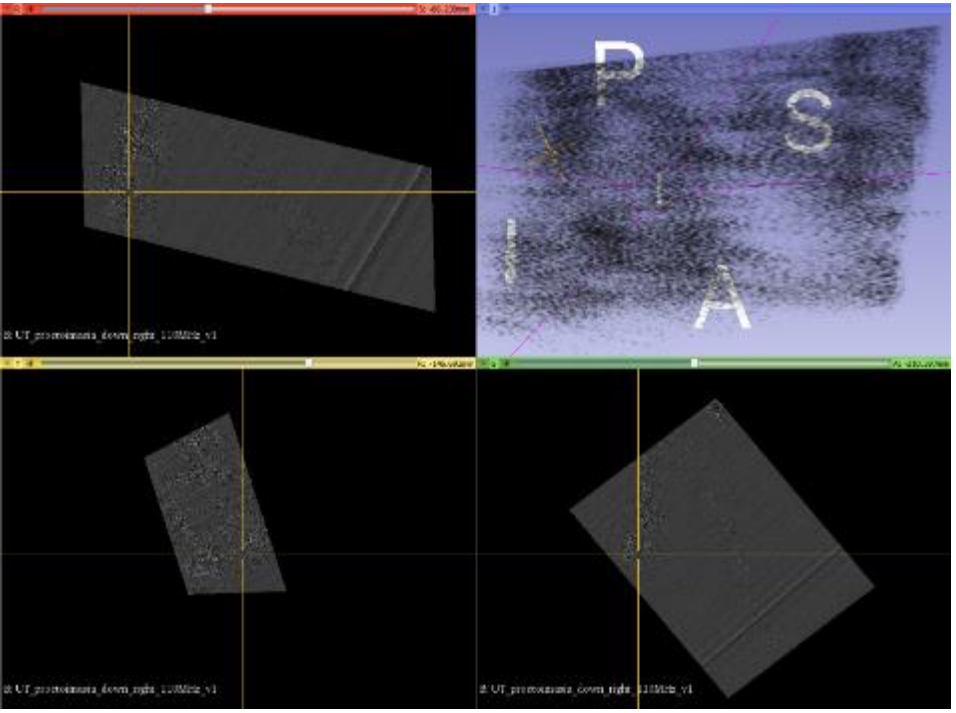


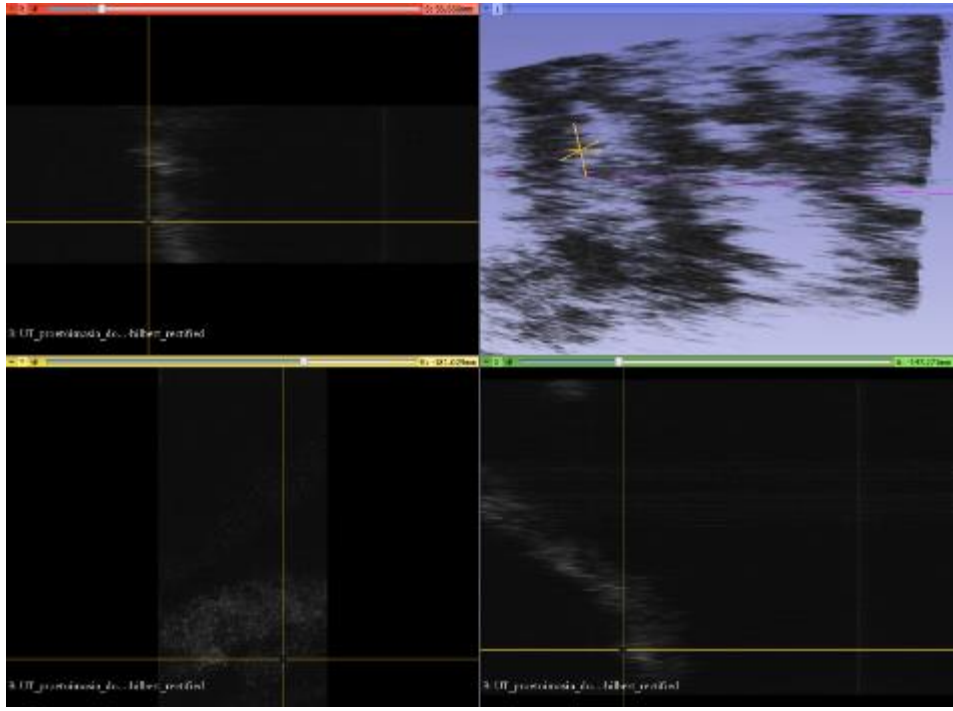


Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

Ultrasound µTomography

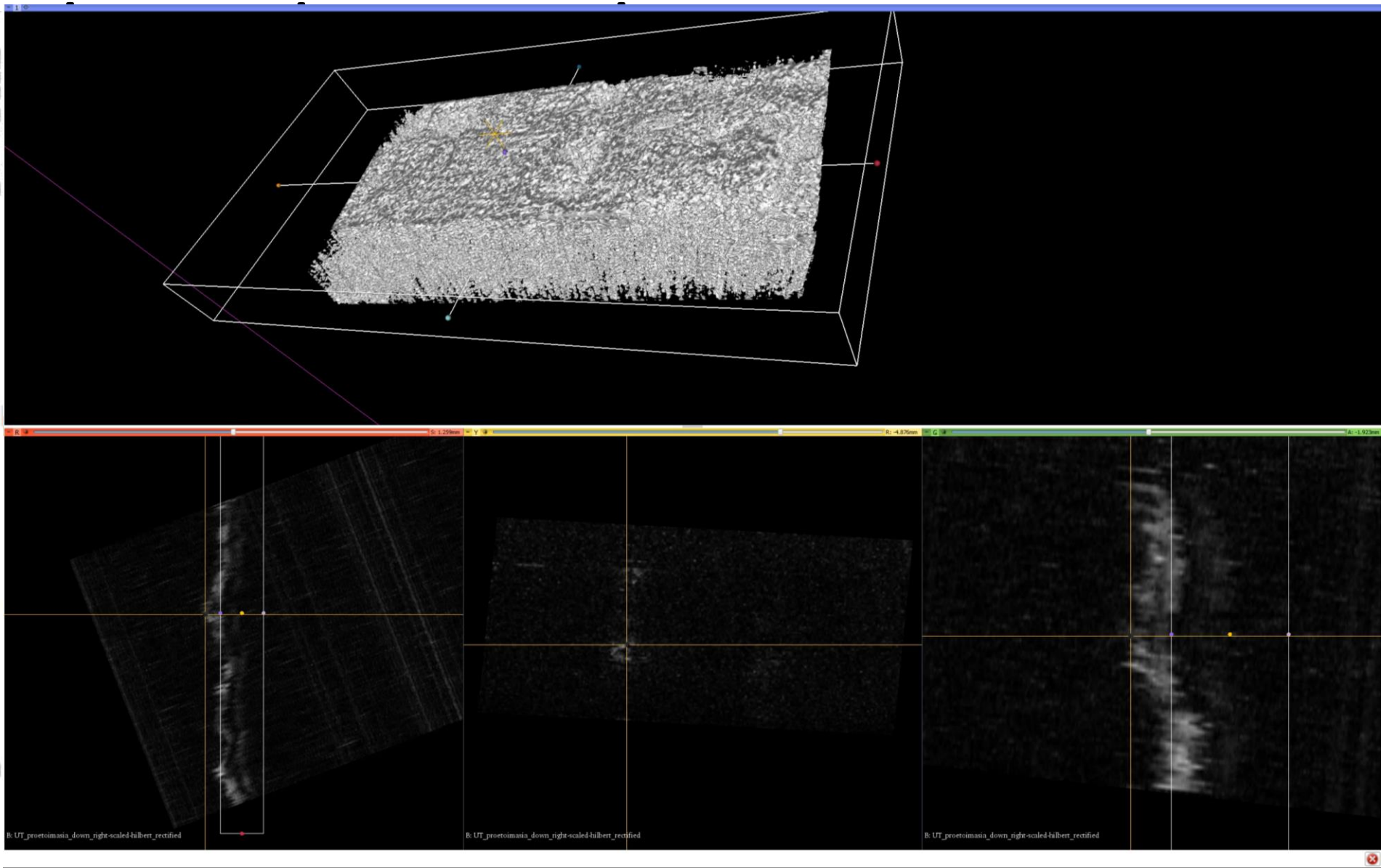






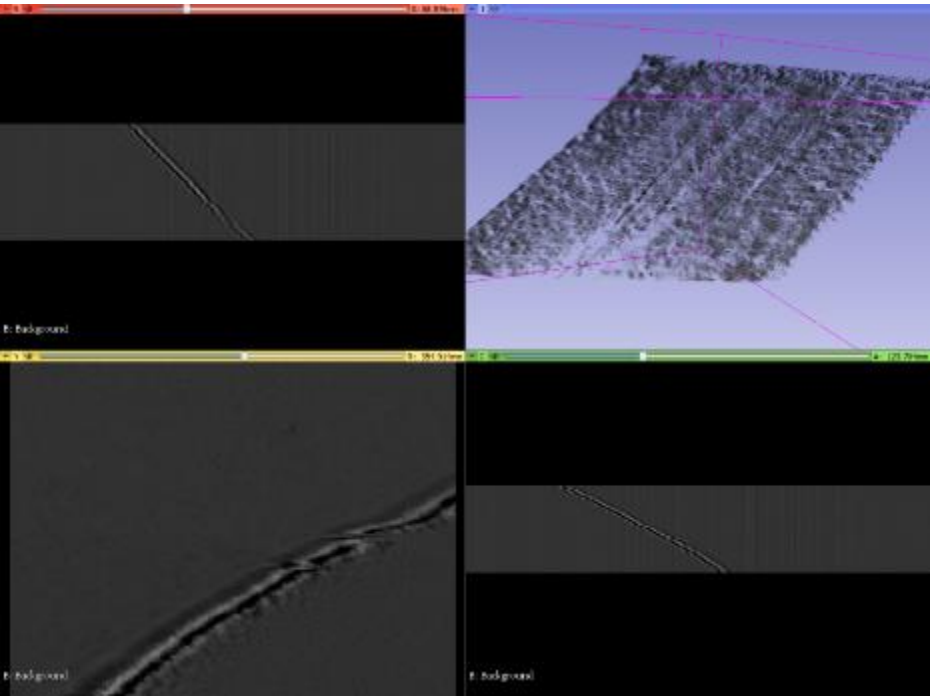
Hilbert transform is applied

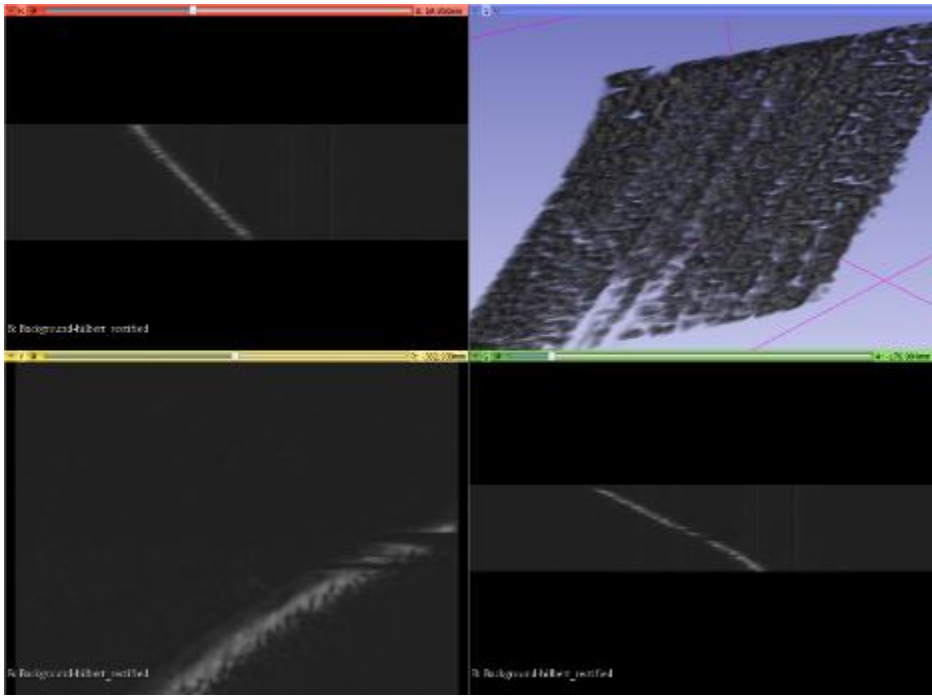
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

Ultrasound





Hilbert transform is applied

Combination/ Fusion of the data –
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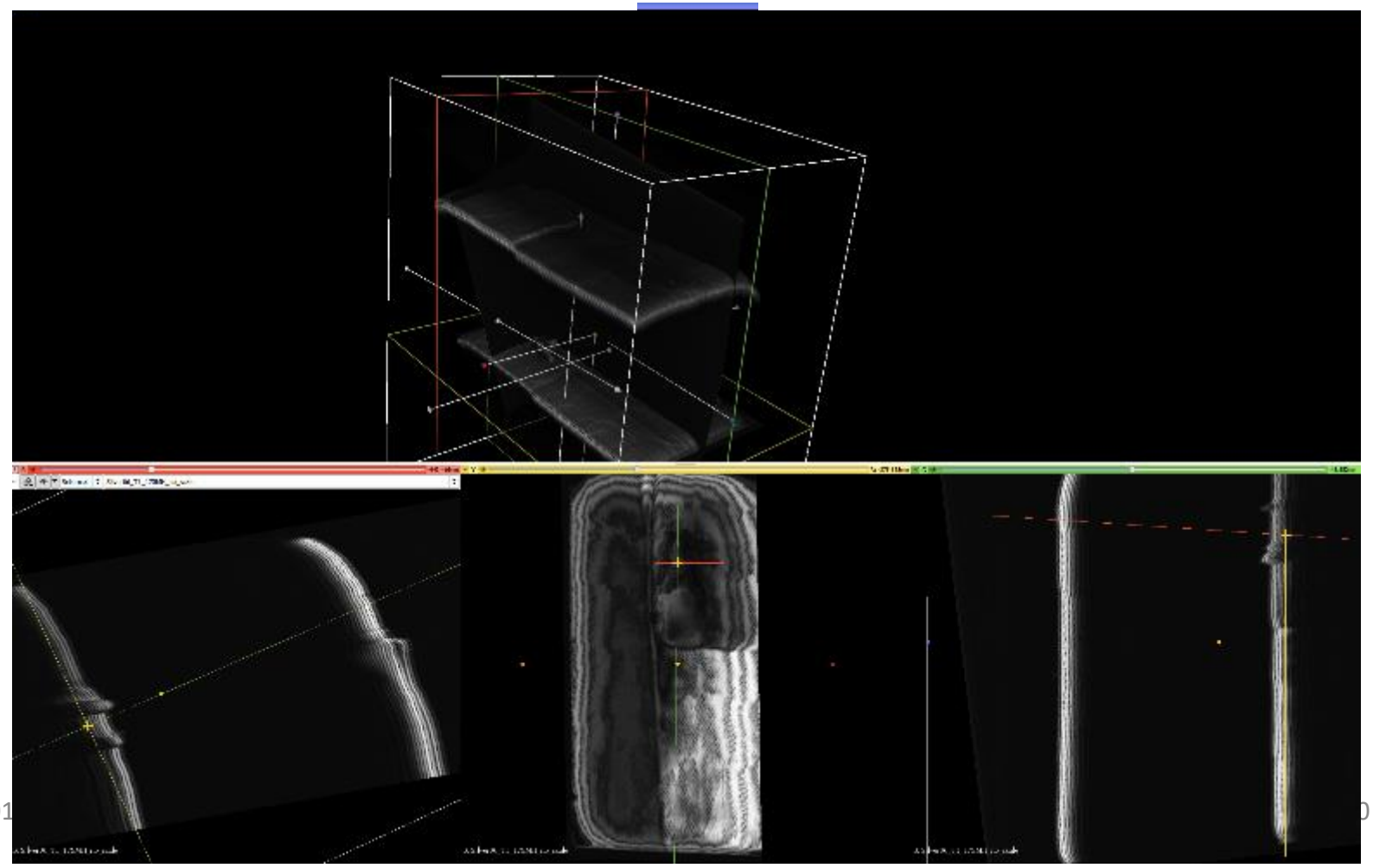
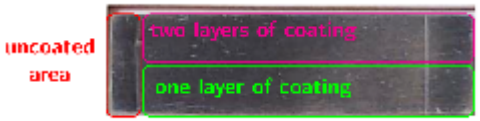
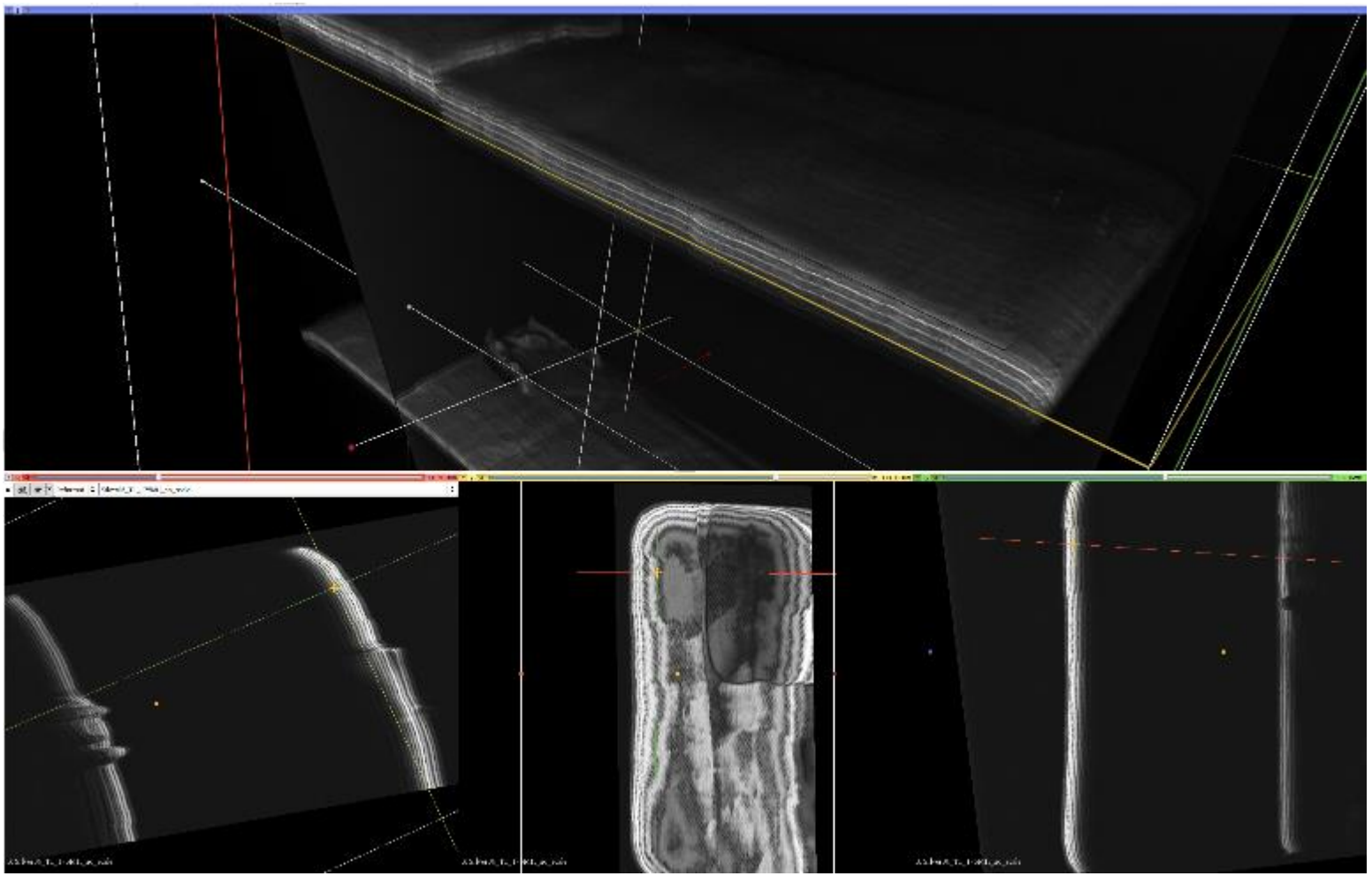
Tomography … “i” Tomography - iTomography

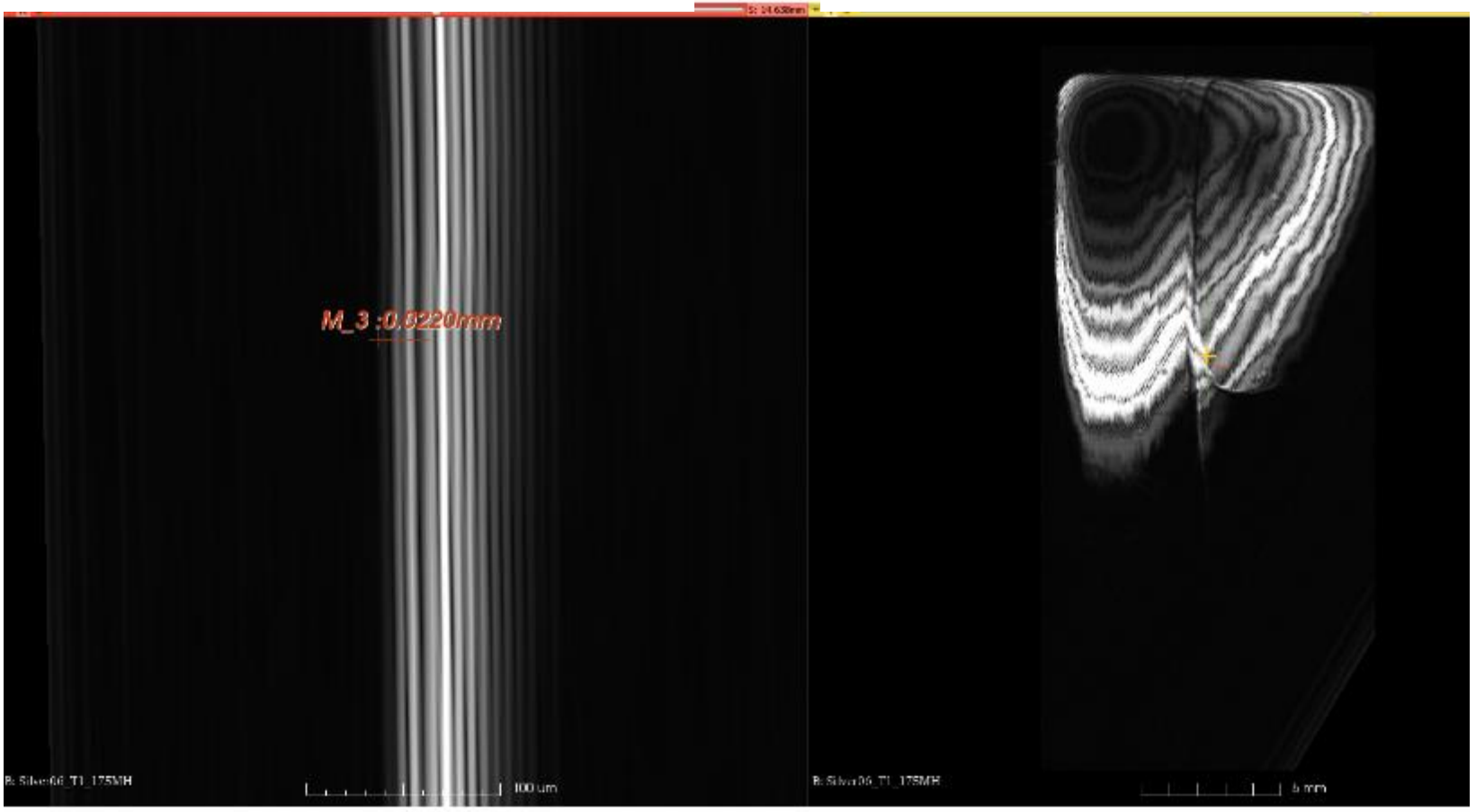


Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography





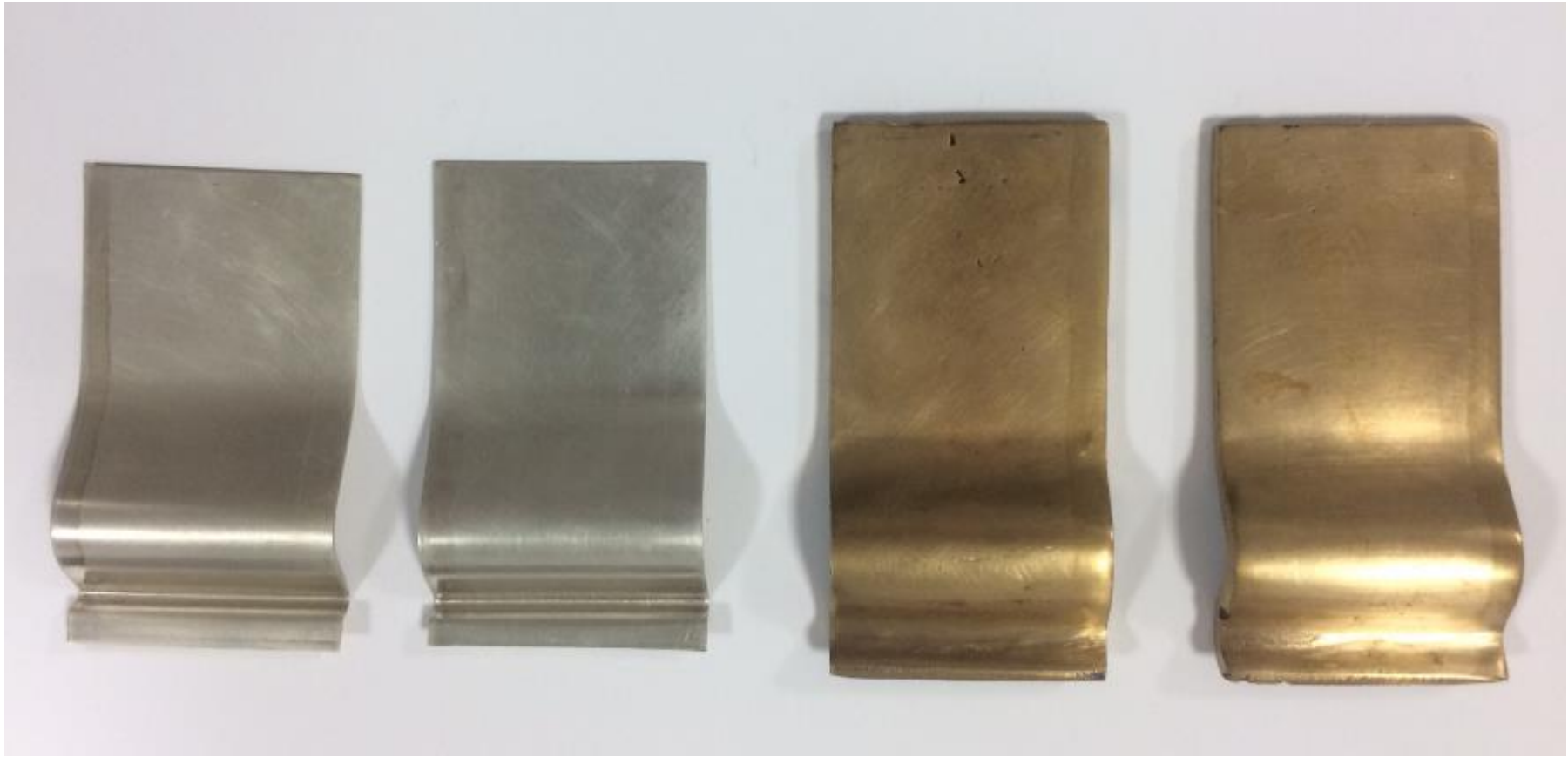
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



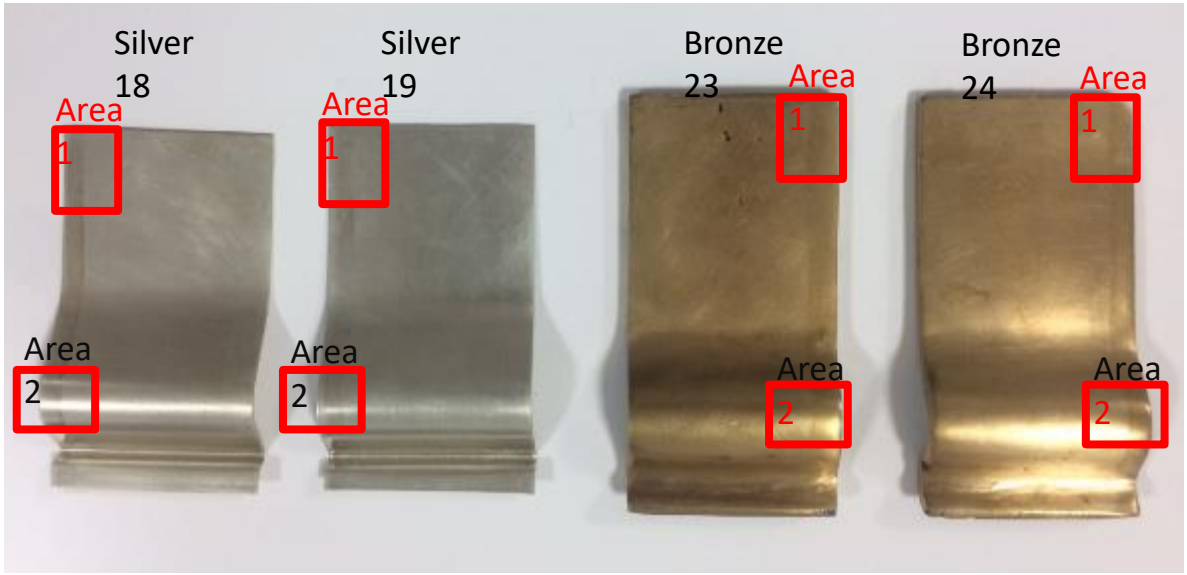
Silver 6_T1

Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

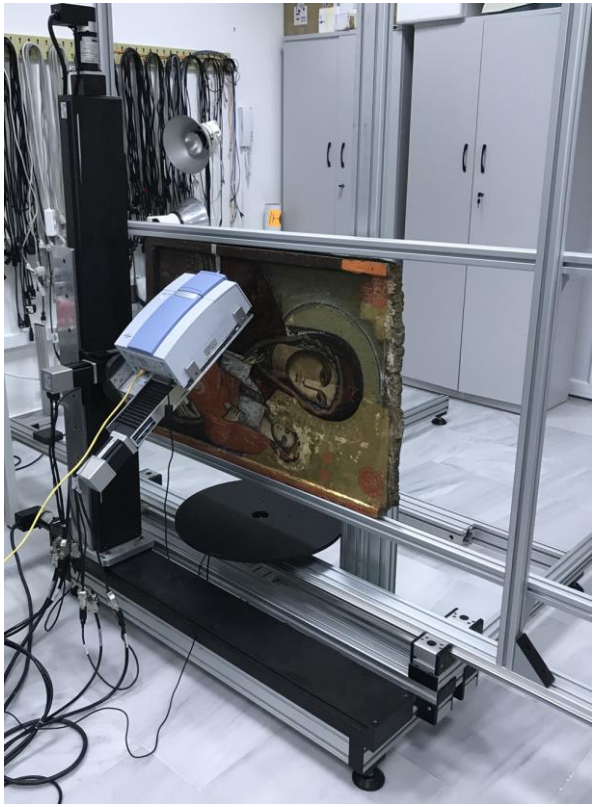
silver, bronze, iron



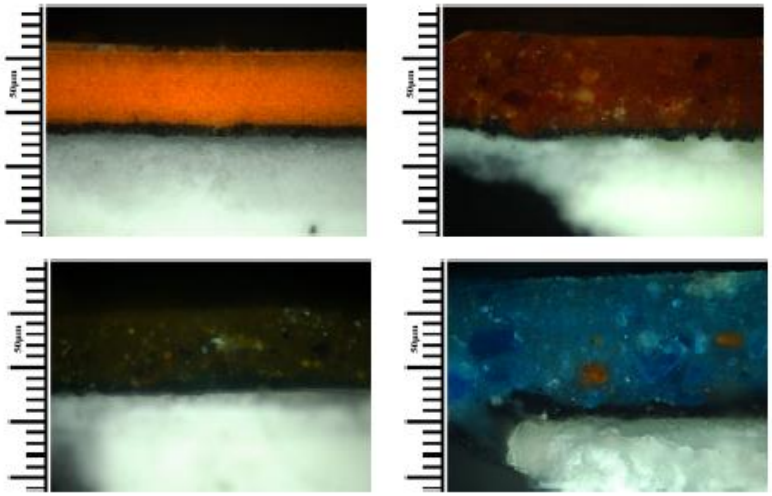
Thickness Measurement of Homogeneous Materials



Dimensions
Area 1: 10 x 10mm
Area 2: 10 x 3 mm

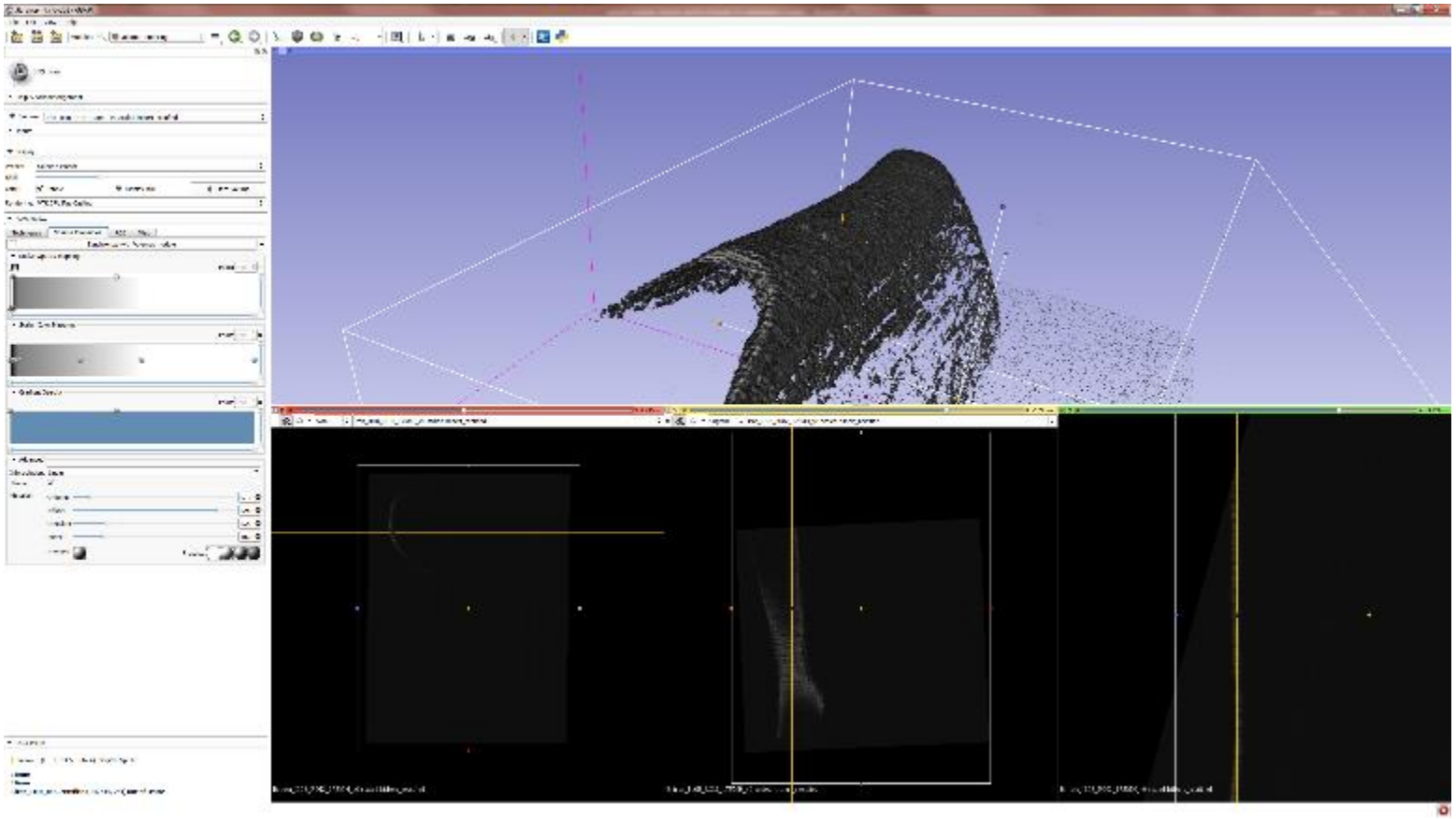


Varnishes
- Nitrocellulose
- INCRAL



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

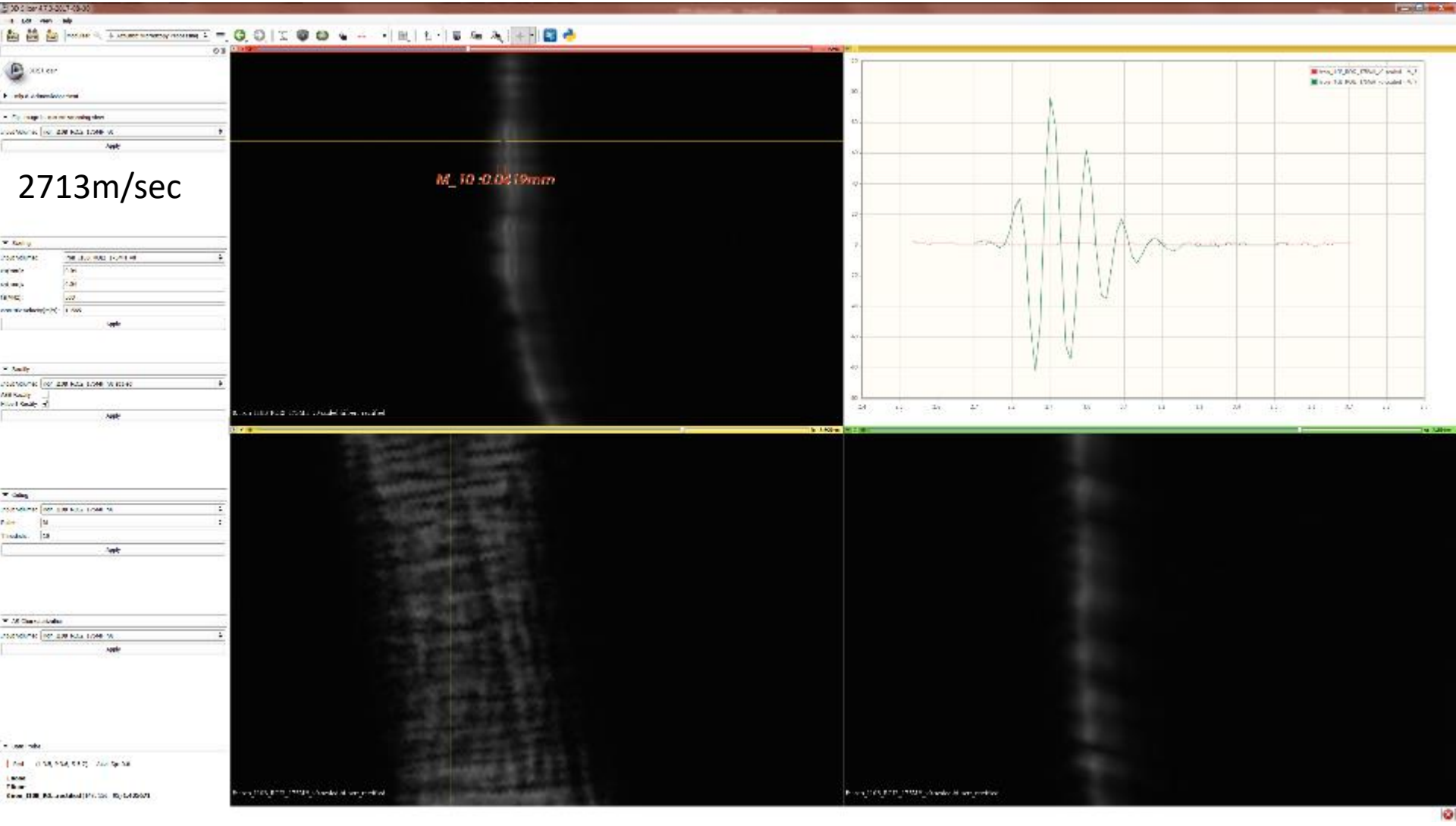
IRON I10B



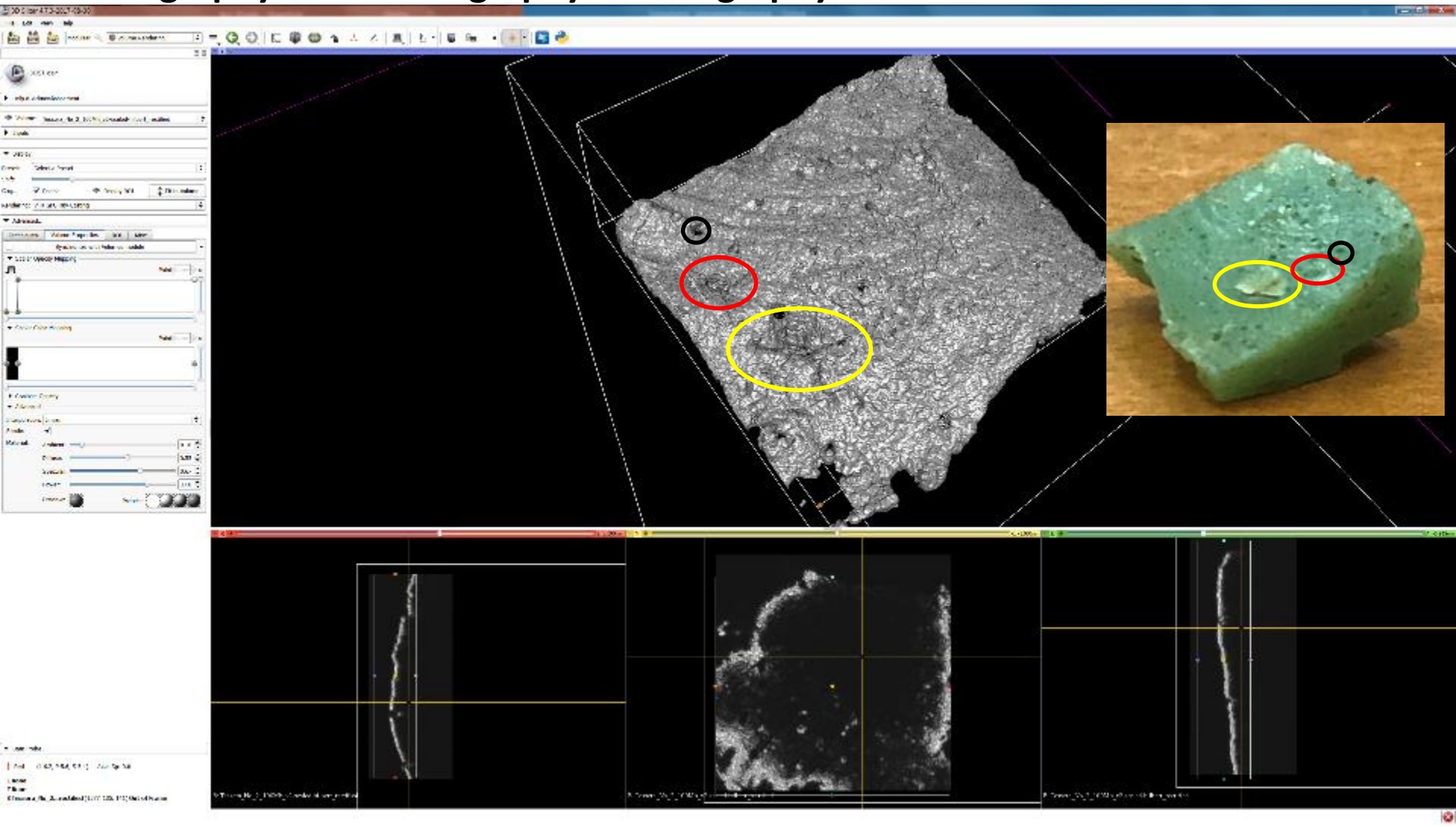
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

Ultrasonic µtomography

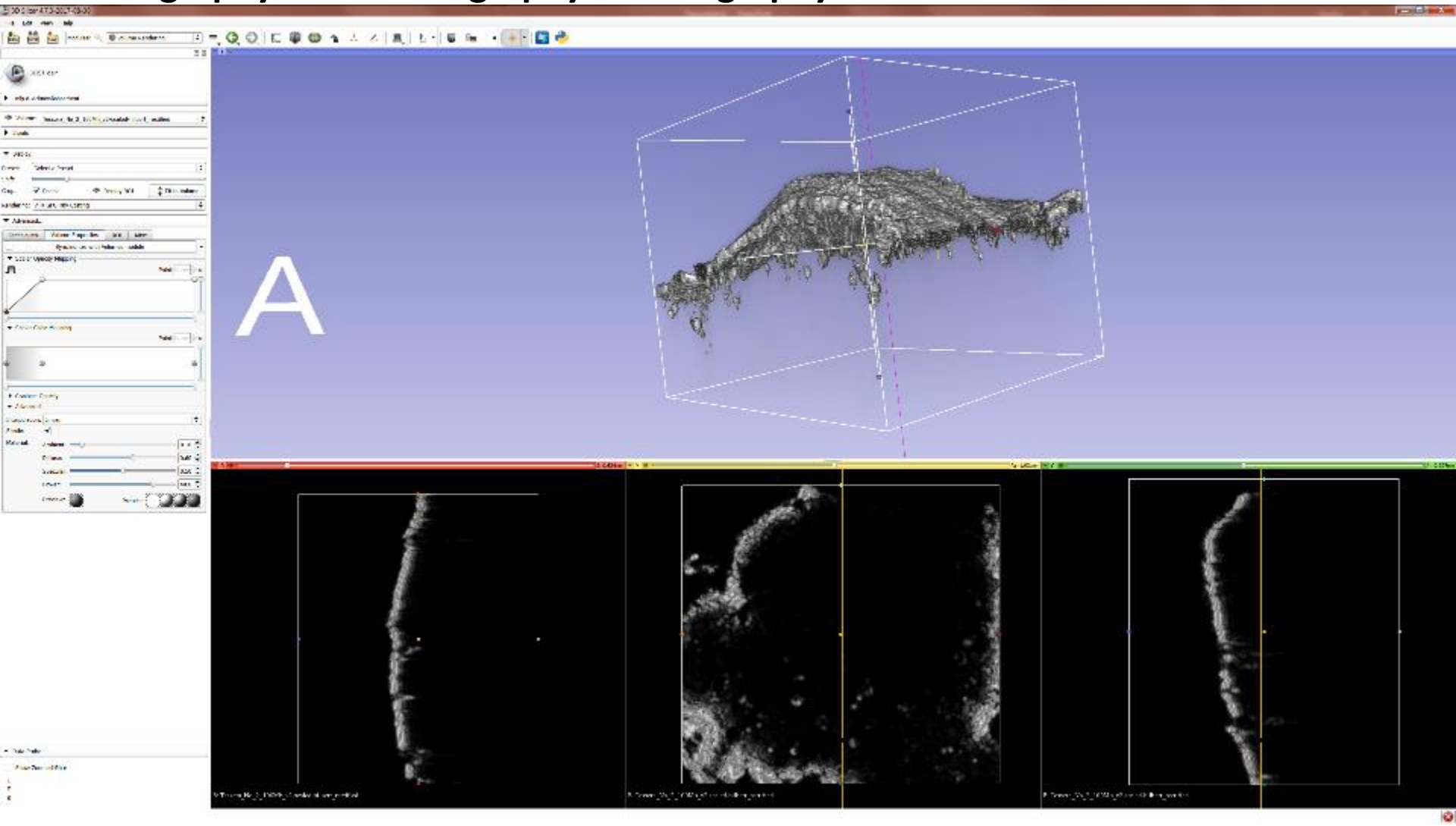
Iron 10



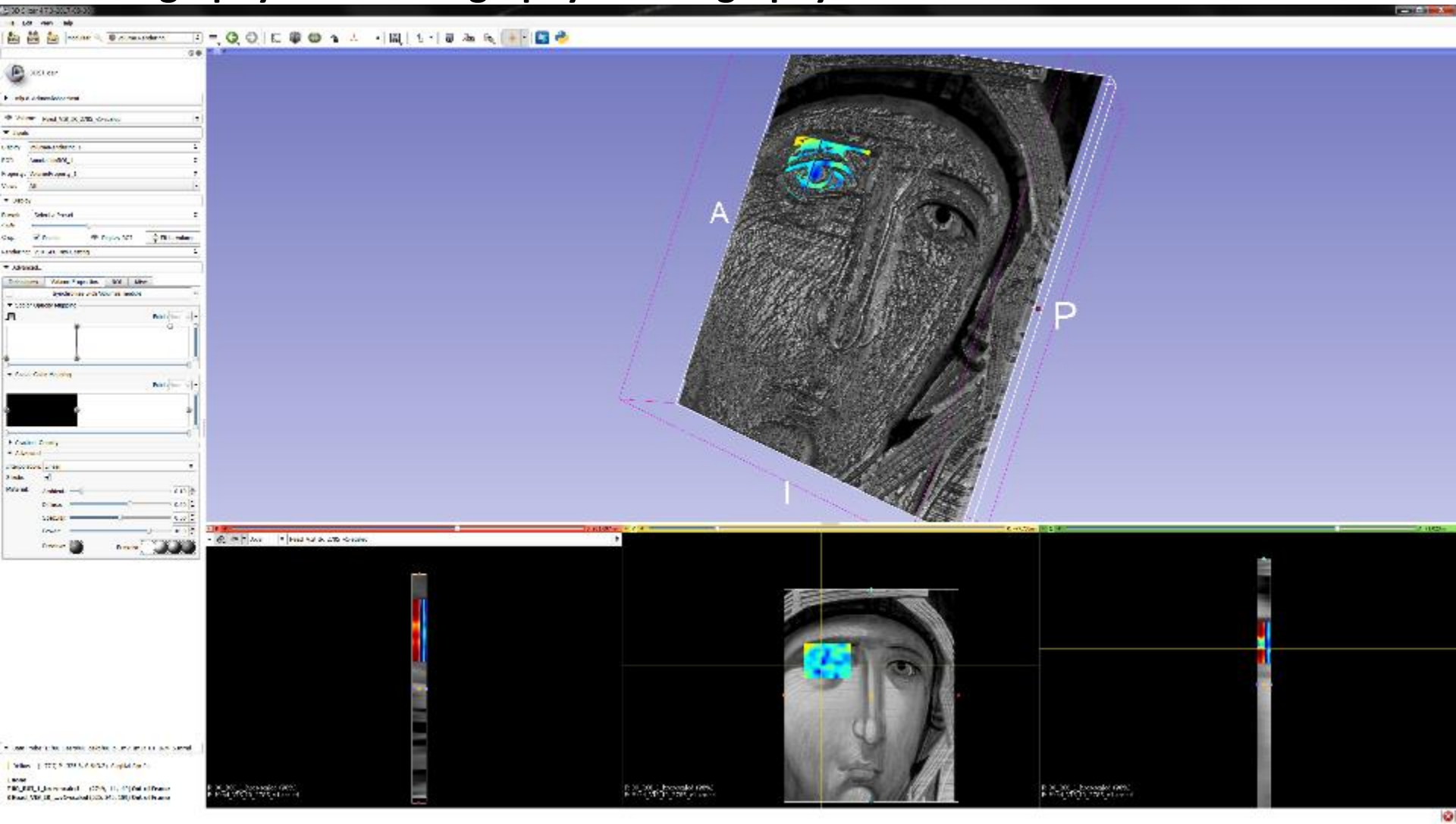
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

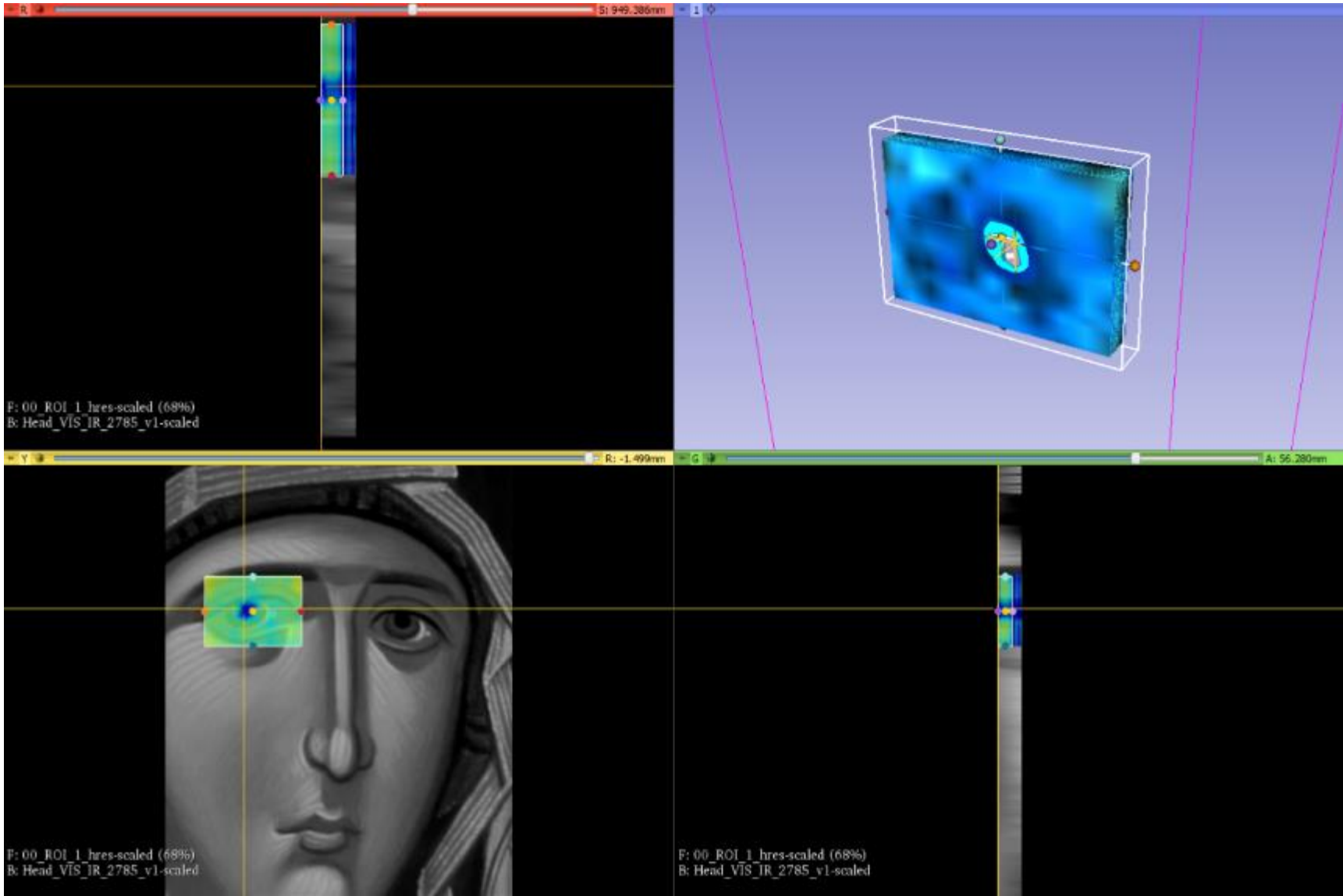


Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



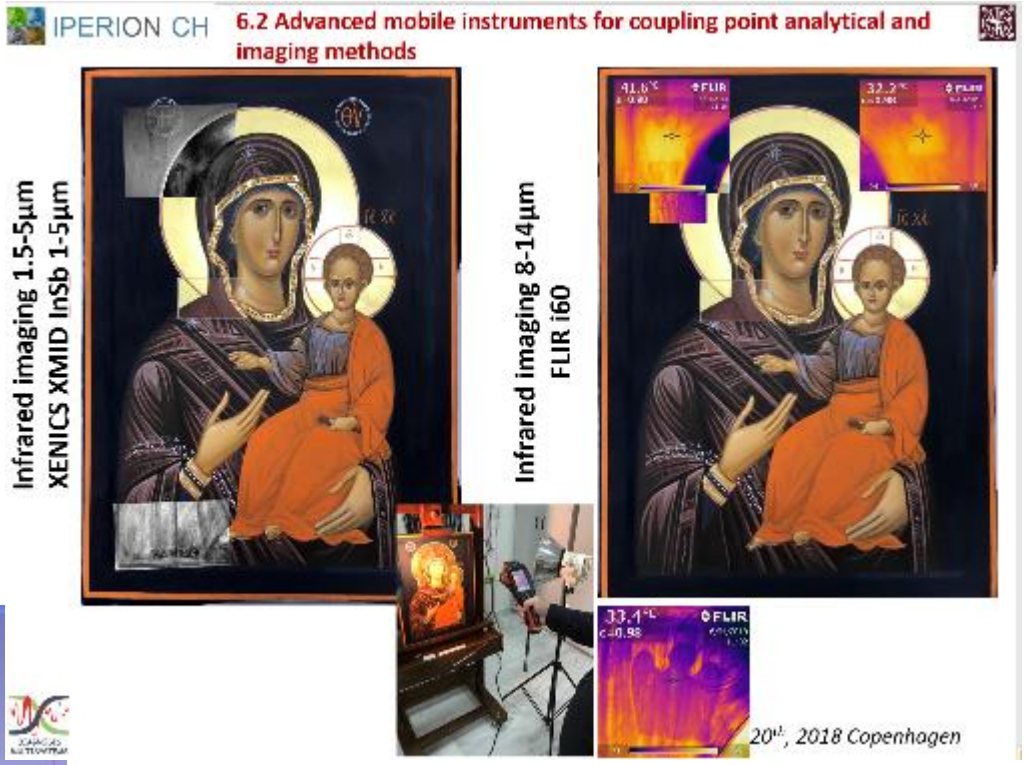
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography

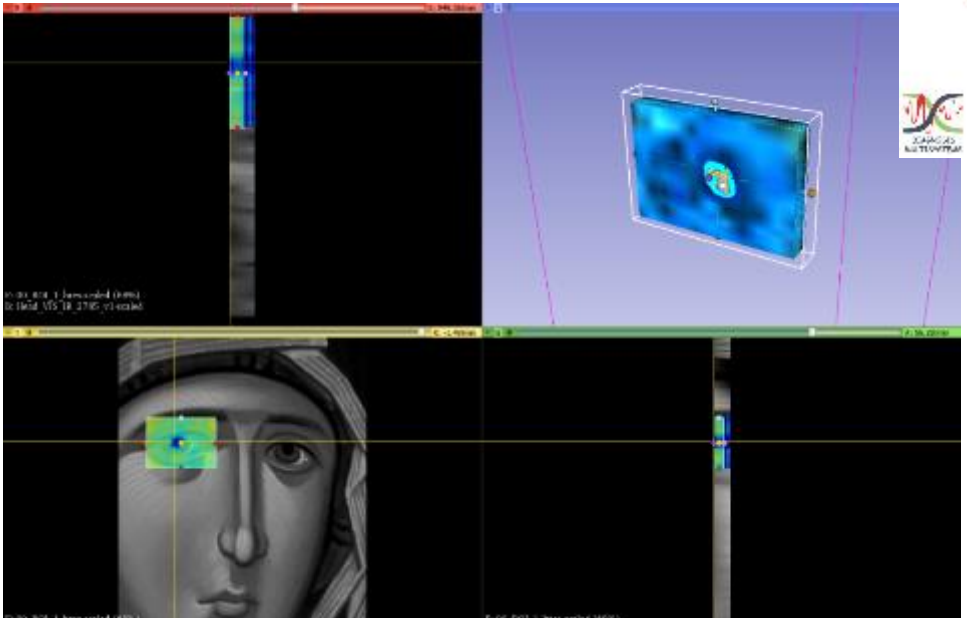
Infrared mapping spectroscopy
Infrared imaging 1.5-26µm



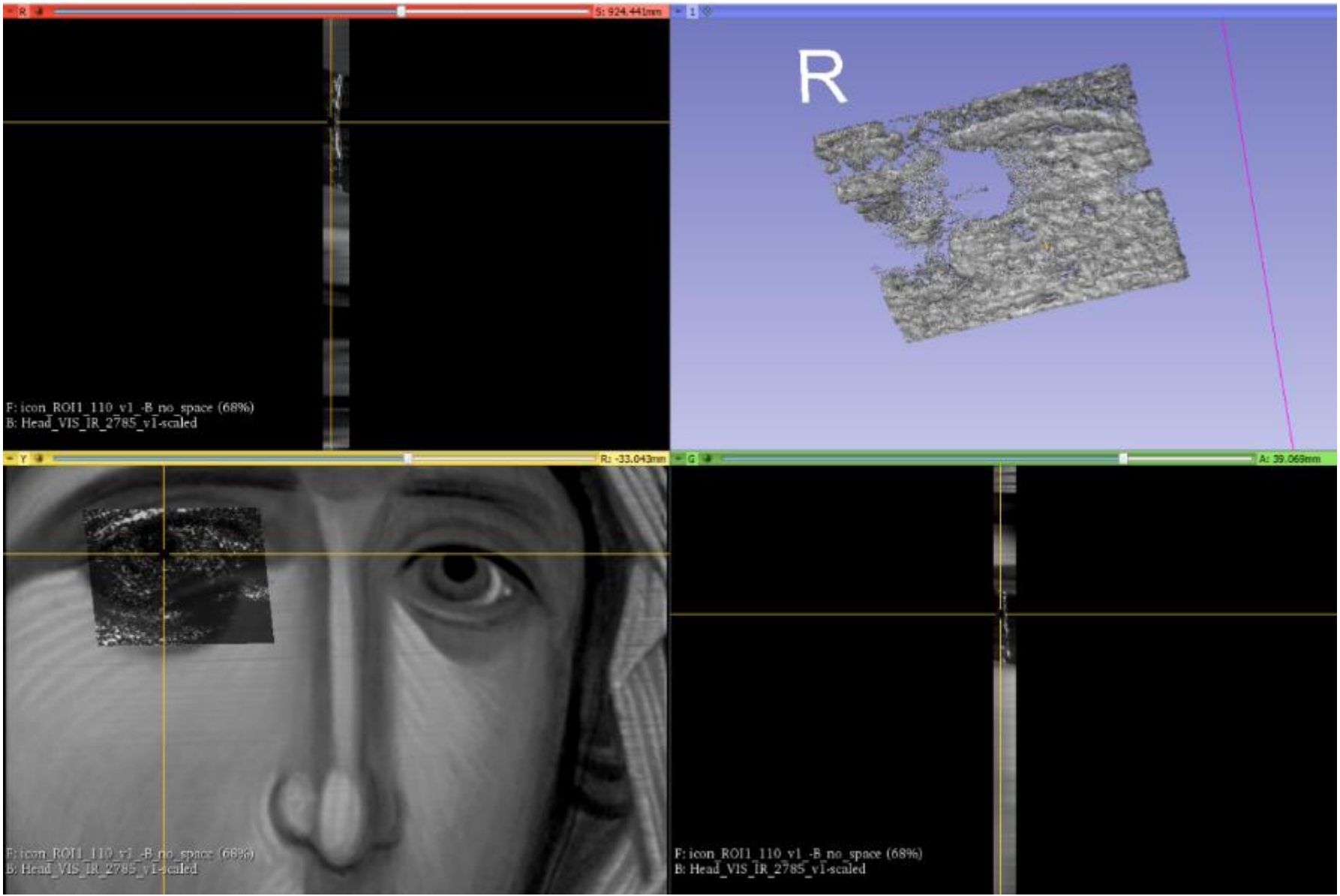
Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography

Infrared mapping spectroscopy,
hyperspectral mapping imaging
from 1.3-26µm
Infrared imaging 1.5-5µm

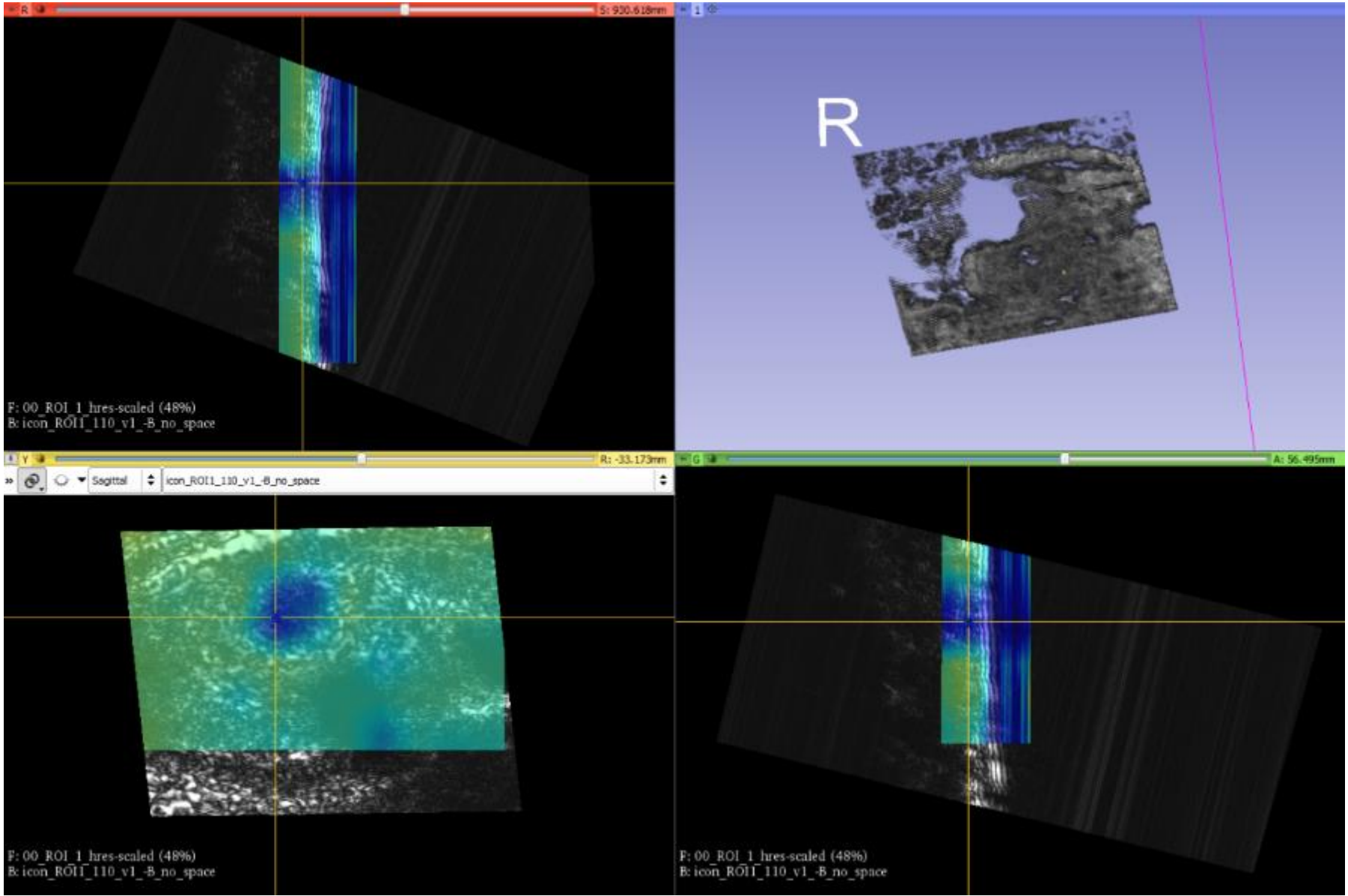




Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … “i” Tomography - iTomography



Combination/ Fusion of the data –
(IR Spectroscopic mapping, Infrared Imaging, Ultrasonic tomography, UV-VIS, …)
Tomography … "i" Tomography - iTomography



“i” Tomography – iTomography - eTomography