

Limits and advantages of different 2D VIS-NIR multi- and hyper-spectral imaging systems in addressing conservators' concerns

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WG1 - *spectral object documentation*

- PT1: Theoretical identification and practical exploration of important characteristics of instruments and their potential impact on data quality, usability and information content with respect to typical surfaces.
- st1.1: *Identification, characterization and testing of spectral imaging techniques in the visible and near IR field*

Spectral imaging techniques undergo a comparable change in technology as do spatial imaging techniques. New developments in optical techniques lead to new means of splitting light resulting in new characteristics for instruments dedicated to monitor the optical spectrum for imaged surfaces. It is therefore necessary to explore the limits and advantages of the actual instruments in this waveband.

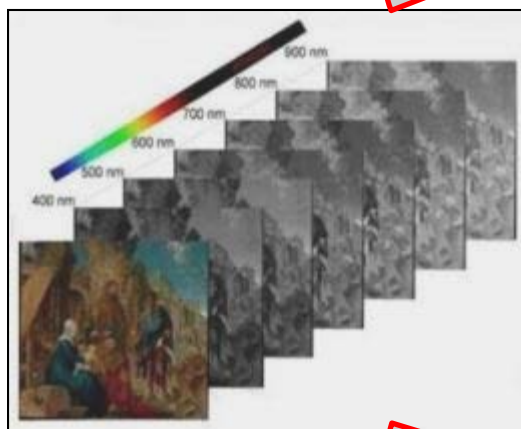
- st1.2: *Identification, characterization and testing of imaging techniques beyond the visible and short wave radiation*

The physical and chemical composition of surfaces is an important factor determining the interaction with light and reflection behavior. As not all of these factors have an impact in the visible spectrum, instruments exist which are able to measure beyond this radiation. It is necessary to exploit and qualify also these type of instruments because they are often essential for the analysis of the surface composition.

Imaging Spectroscopy

Extracting images

Digital archives and documentation



Non-invasive analysis

Extracting spectra

HD Elaborated images
(color calibrated images;
false-color maps;
IRR, PCA maps, etc.)

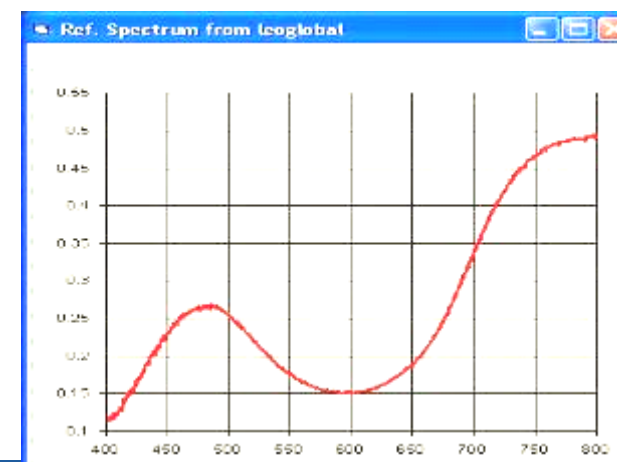
Inspection of the inner
paint layers
(underdrawings,
pentimenti, etc.)

Spectroscopic data
(materials identification
and distribution map)

High Spatial resolution



High Spectral resolution



DEFINITIONS

Multi-band imaging. The process of acquiring a set of images in a wide spectroscopic range (UVa; R/G/B; photographic IR; IRFC; IRR; X-ray radiography; etc.) at each spatial point of a sample with diverse imaging systems/devices.

Multi-spectral imaging. The process of measuring a spectrum at each spatial point of a sample with a multispectral imaging system/device. These devices are designed to acquire a sequence of images on a limited number of spectral bands, usually selected by means of suitable set of filters, with bandwidths of tens to hundreds of nanometers.

Hyper-spectral Imaging. The process of measuring a complete spectrum at each spatial point of a sample with a hyperspectral imaging system (www.middletonresearch.com). These devices are designed to acquire a fine spectral selection of **almost contiguous spectral-bands** in the investigated spectral region and a separate image for every band can be extracted from the acquired image-cube / cube-file. A sensor is classed as hyperspectral if it is capable of imaging a line / an area in many (e.g. hundreds) bands simultaneously with bandwidths of a few nanometers or less.

From:

Glossary of Terms – SpecTIR: <http://www.spectir.com/tools-resources/glossary-of-terms>;

Riccardi et al. 2013, Journal of the American Institute for Conservation. 2013 (52), 13-29.

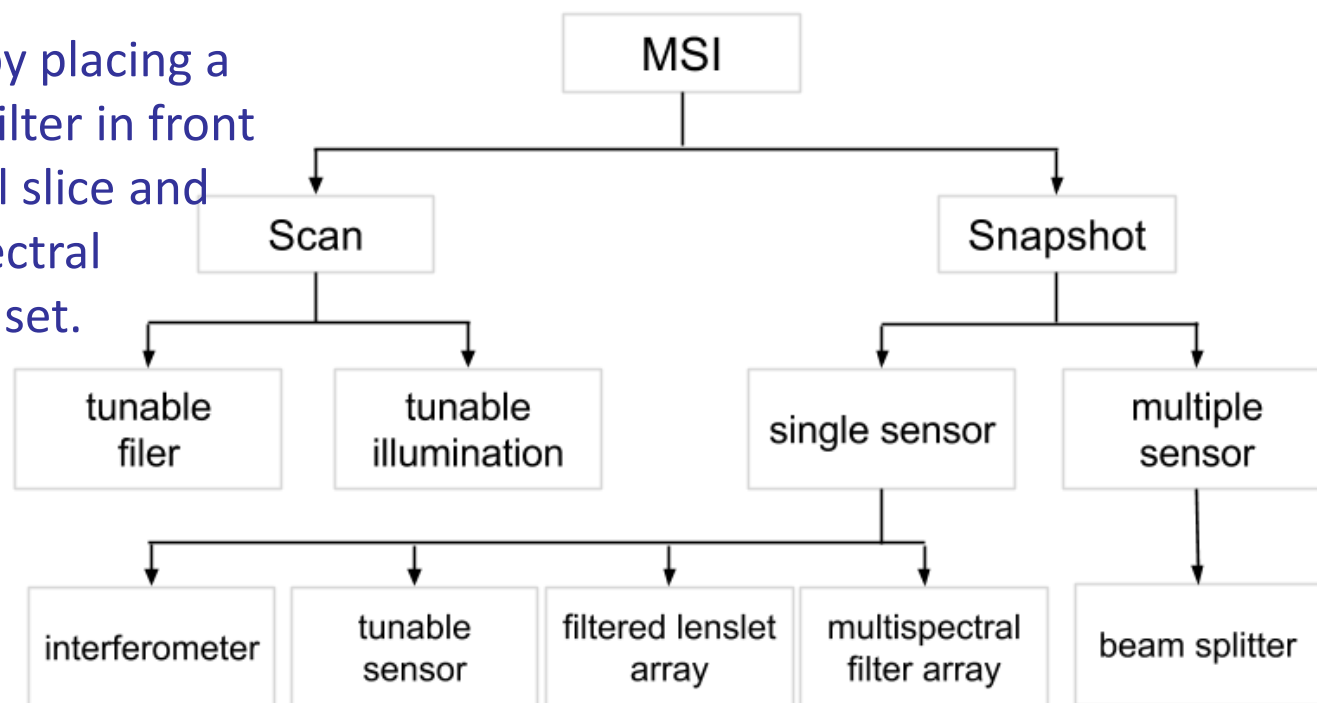
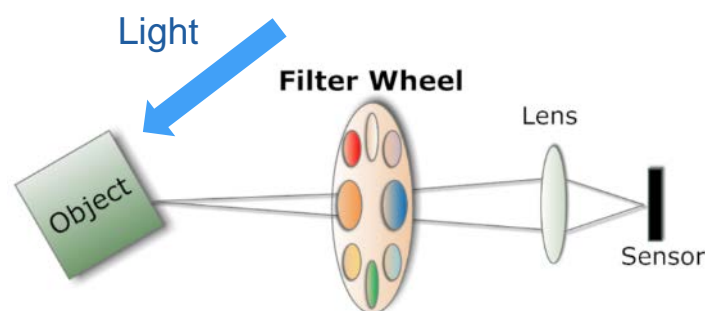
Multi-spectral Imaging (MSI) acquisition systems

Imaging spectrometers collect data over three dimensions: 2 spatial and 1 spectral. The most common method for categorizing the various types of imaging spectrometers is by the portion of the data-cube collected in a single detector readout.

A filtered camera, constructed by placing a filter wheel or tunable spectral filter in front of a camera, collects a horizontal slice and thus needs to scan along the spectral dimension to complete the data set.

LED-based lighting systems

Filter-based lighting systems



Classification tree of the main methods for multispectral capturing

From: P.-J. Lapray et al., Sensors 2014, 14, 21626-21659; doi:10.3390/s141121626

Hyper-spectral Imaging (HSI) acquisition systems

Imaging spectrometers collect data over three dimensions: 2 spatial and 1 spectral. The most common method for categorizing the various types of imaging spectrometers is by the portion of the data-cube collected in a single detector readout.

Fourier Transform imaging spectrometry (FTIS).

Whiskbroom spectrometers, which use a linear array of detectors, collect a single column of the datacube at a time and thus scan across the two spatial dimensions of the data-cube.



Pushbroom spectrometers use a 2D detector array, and thus collect a vertical slice of the data-cube at once so that only one spatial dimension needs to be scanned to fill out the cube.



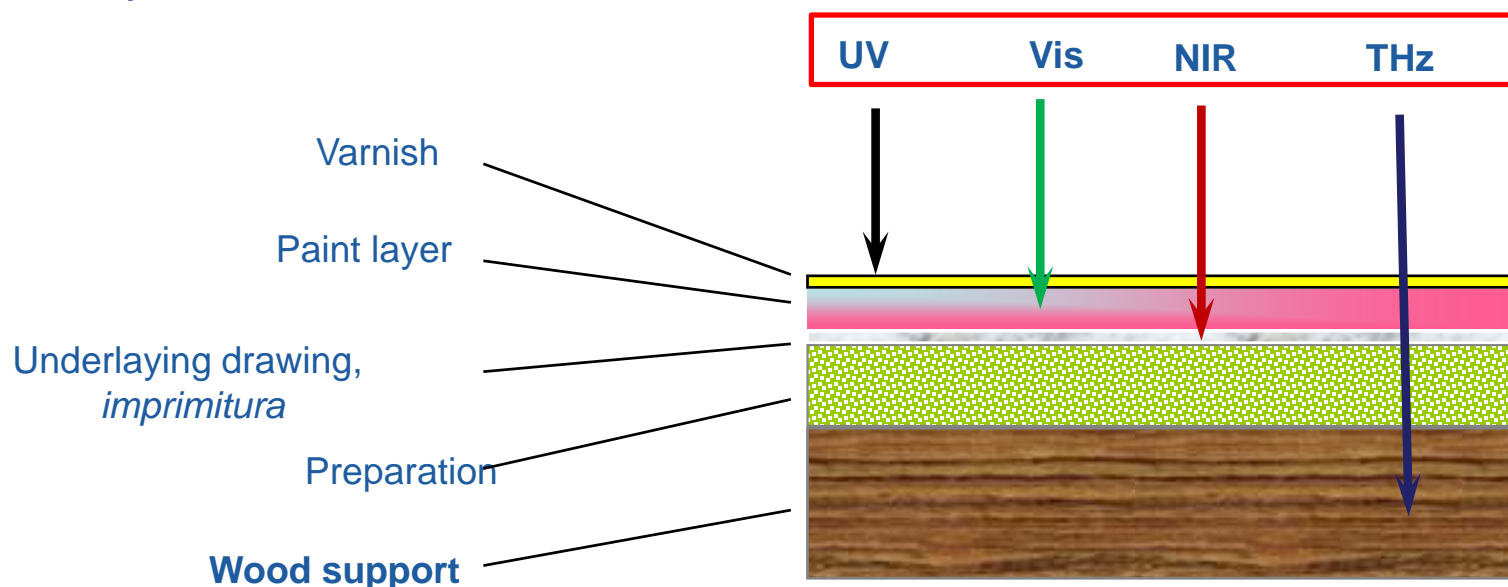
Snapshot imaging spectrometers collect the entire 3D data-cube in a single integration period without scanning.

Round Robin Test (RRT): Objectives

To work towards standardised methodologies and best practices for spectral imaging in the CH field

To better understand:

- instrumentation
- elements of data acquisition
- the effects of the instruments and methodology to the accuracy and reliability of the data



Round Robin Test (RRT) objects

From E.K. Webb STSM presentation in
Neuchatel COSCH meeting, October 2015



Image of RRT objects. Left to right:

- SphereOptics Zenith Polymer Wavelength Standard (A. Jung);
- X-rite white card (top) & ColorChecker Classic (bottom) (M. Hauta-Kasari);
- Painted panel target (made by E. Prandi and M. Ginanni – M. Picollo);
- Russian icon (L. MacDonald).

RRT Participating Laboratories/Institutions

Participating Institute	Country	Participating Institute	Country
CNR-IFAC	IT	CRCC Paris	FR
University of Eastern Finland	FIN	ITAM AS CR - Prague	CZ
Leipzig University	DE	IML Universität Basel	CH
University of Minho	PT	CEGE UCL	UK
Technical University of Catalonia	ES	Institute Sustainable Heritage UCL	UK
The National Museum in Krakow	PL	Czech Technical University in Prague	CZ
Università di Milano-Bicocca	IT	STARC, The Cyprus Institute	CY
Laboratoire Hubert Curien at University Jean Monnet	FR	Specim	FIN
Gjovik University College	NO	NTK Academy of Fine Arts	AU
C2RMF Musée du Louvre	FR	Norsk Electro Optics	NO

Research: RRT Short Term Scientific Missions

Date	Researcher	Host	Objectives	Test Object
2014-09	T. Vitorino	IFAC-CNR	Organise and analyse RRT data. Discuss advantages and limitations of IFAC-CNR push-broom HSI system	Sphere Optics Color Checker Russian Icon Painted Panel
2014-11	I. M. Ciortan	Gjøvick Univ. Coll.	Evaluate quality of different imaging systems. Propose and define taxonomy for evaluation. Establishing a set of attributed according to which the systems are evaluated	Color Checker Painted Panel
2015-04	E. K. Webb	IFAC-CNR	Process and compare SWIR RRT data. Assess spatial and spectral resolution of resulting data	Sphere Optics Painted Panel
2015-11	T. Vitorino	UCL CEGE	Qualitative comparison of Russian Icon data	Russian Icon
2016-03	E. K. Webb	IFAC-CNR	Summarize to-date the results and findings of the RRT. Assess the variability of the received RRT data sets and determine why initial data sets were unfit for elaboration comparison. Establish what further evaluation and comparison needed to be conducted to conclude the RRT initiative	Sphere Optics Color Checker Russian Icon Painted Panel
2016-06	R. Pillay	IFAC-CNR	Evaluate quality of the HSI data received within RRT	Sphere Optics Painted Panel

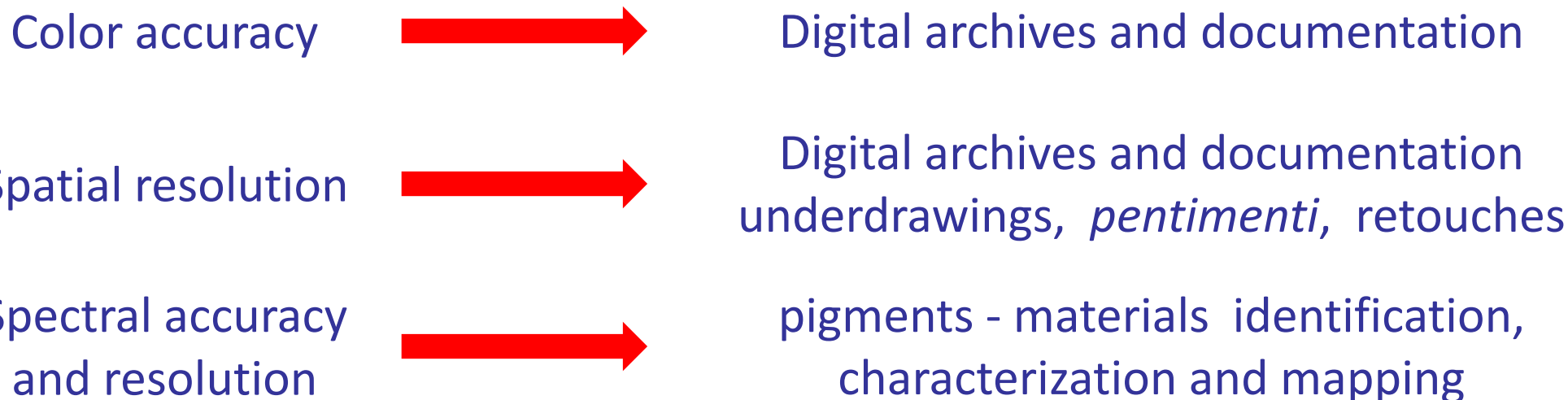
Limits and advantages of different 2D VIS-NIR MSI and HSI systems in addressing conservators' concerns

Things to know before starting:

Scope / Goal of imaging data acquisitions; Access to the object; Time / Funds

Which are the most important MSI-HSI systems' characteristic?

RGB accuracy; Spatial resolution; Spectral resolution; ...



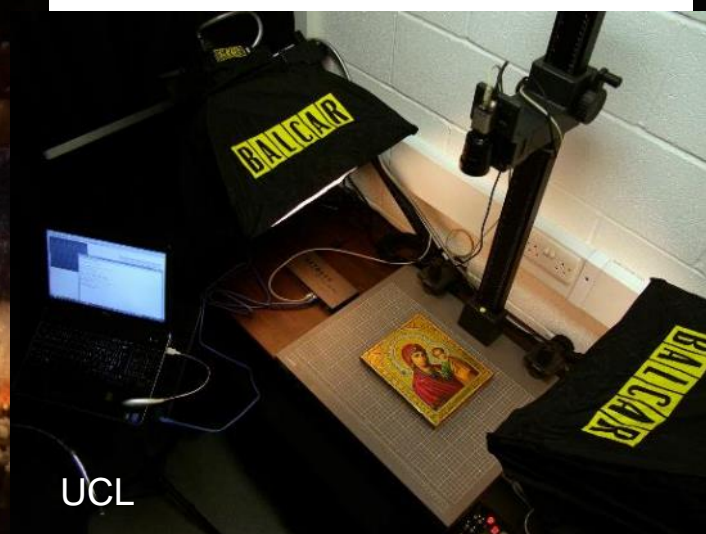
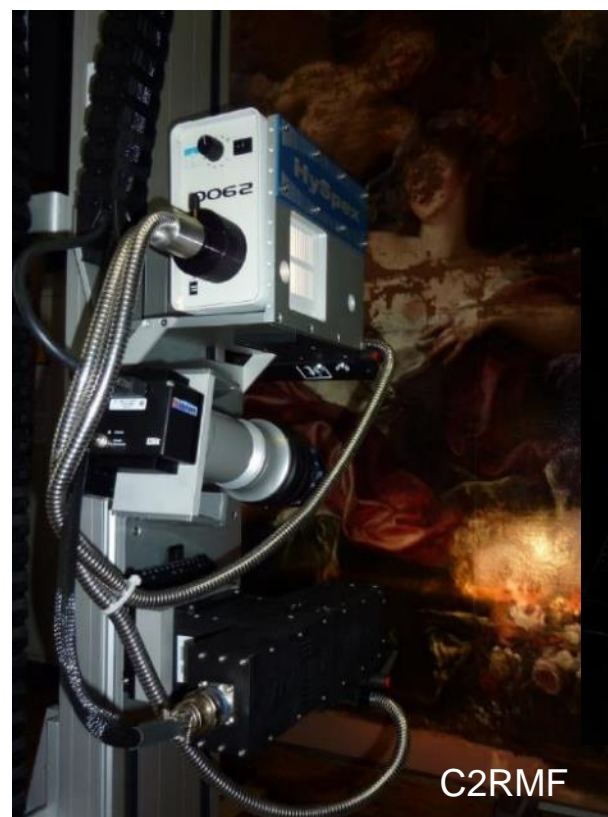
high spectral and spatial resolution
transportable-portable imaging devices
designed and optimized or modified
for application on paintings and polychrome surfaces



high quality documentation

(calibrated RGB reproductions, IR reflectography, false colour, etc.)

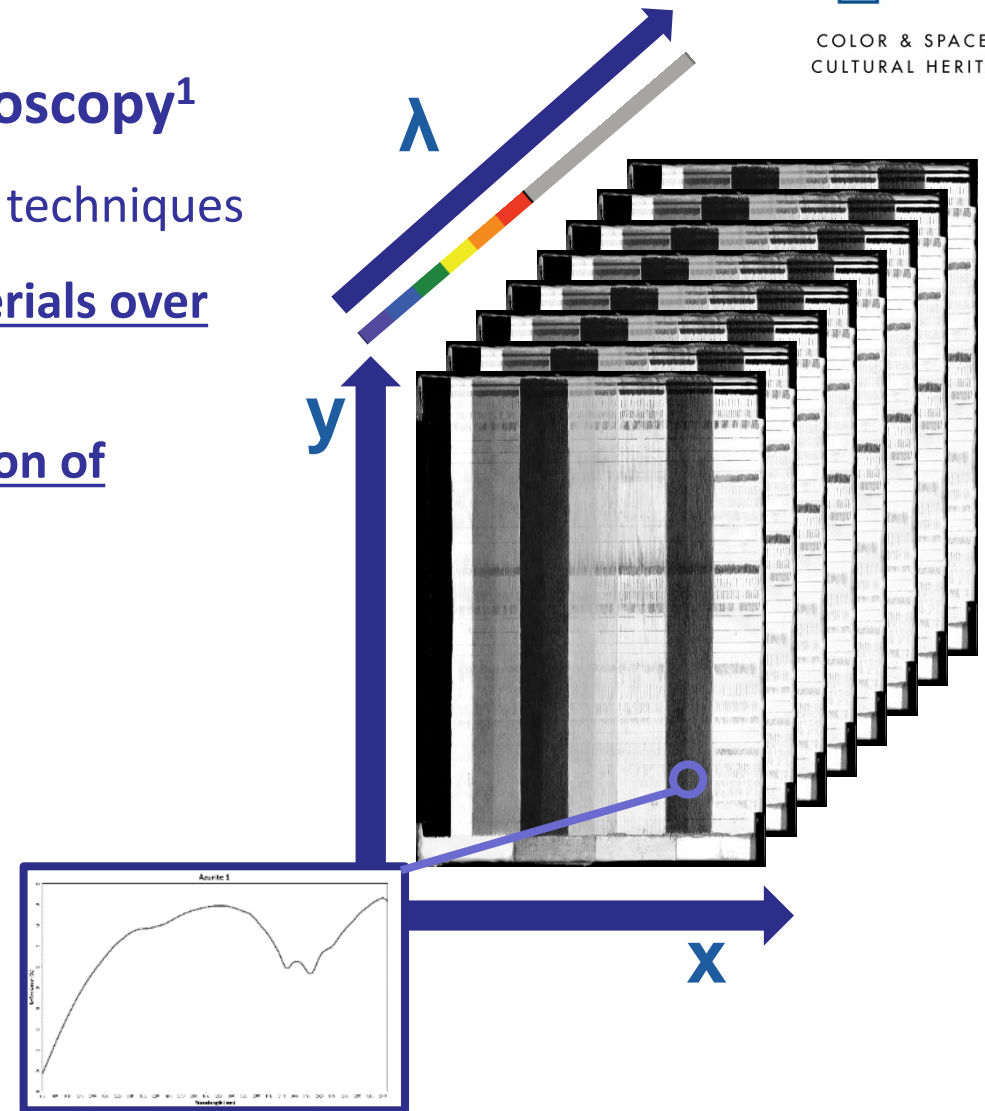
non-invasive diagnostics (materials identification and mapping)



Imaging Spectroscopy

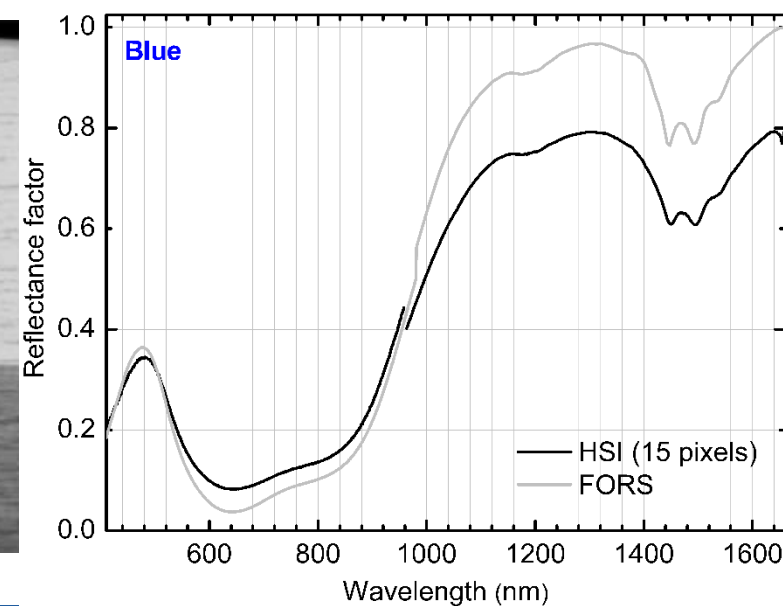
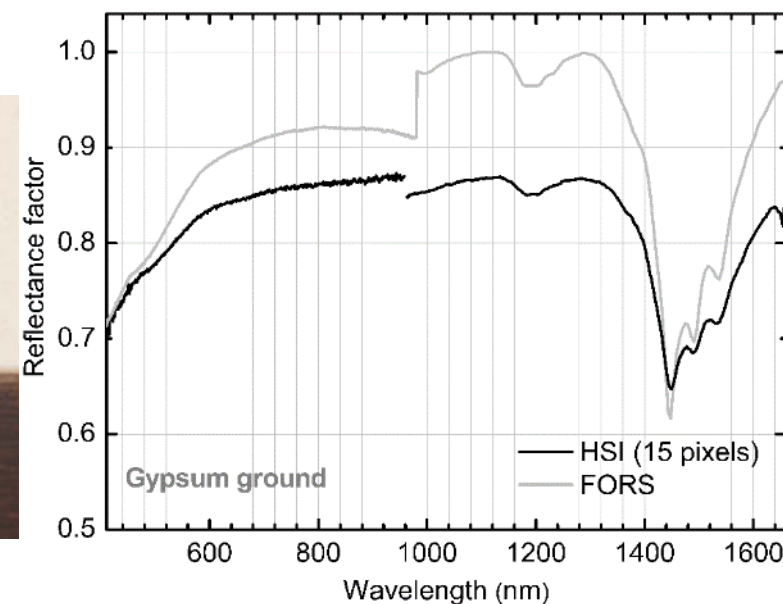
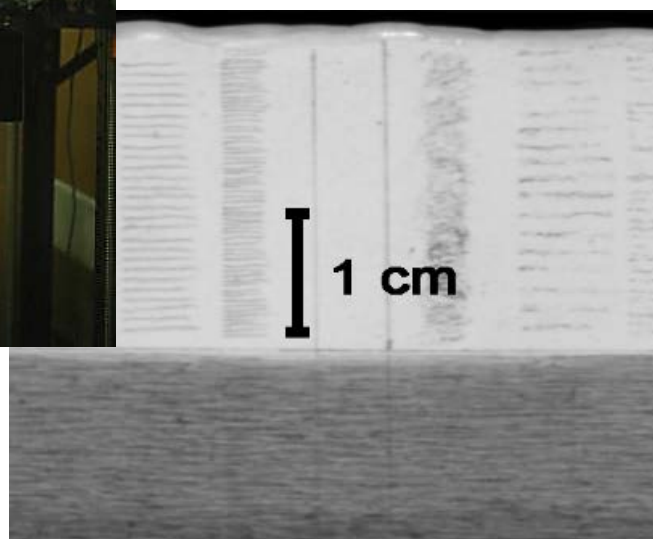
Combining digital imaging and spectroscopy¹

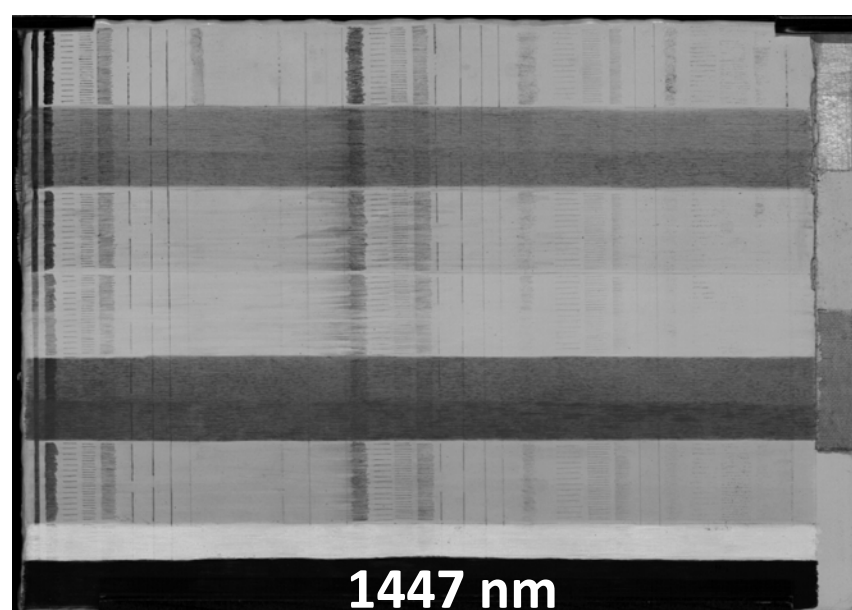
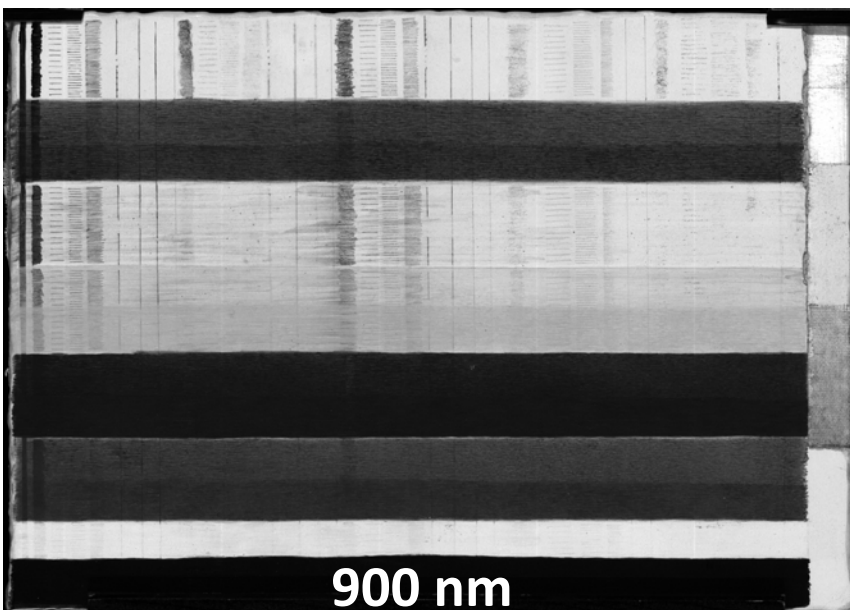
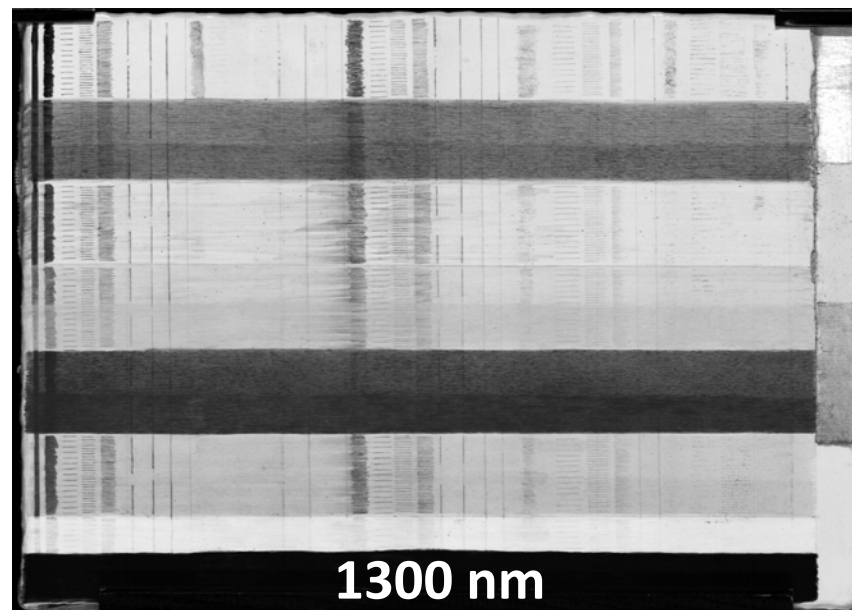
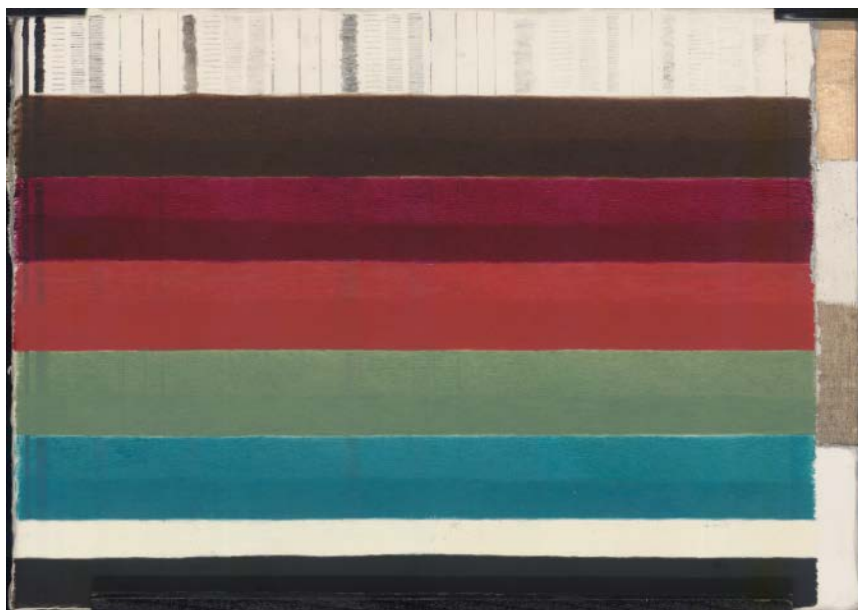
- Expands point-based, or 1D, spectroscopic techniques
- Ability to map spatial distribution of materials over entire object;
- Extract reflectance spectra for identification of materials;
- Enhance and reveal underdrawings;
- Reveal *pentimenti*;
- Identify past conservation treatments;
- Calculate colour (only in VIS).



1. Liang, H., 2012. Advances in multispectral and hyperspectral imaging for archaeology and art conservation. *Applied Physics A* (2012) 106: pp309-323.

spectral and spatial resolution



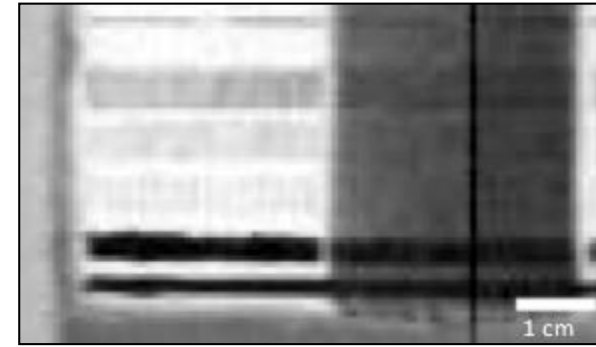
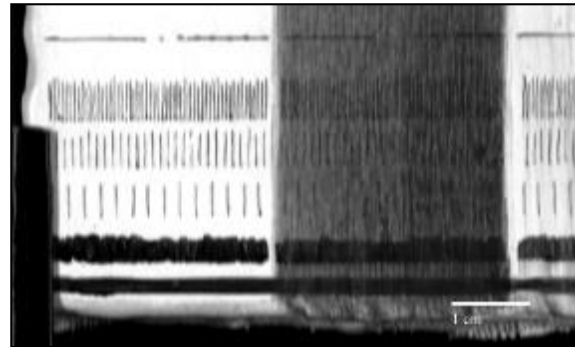


From T. Vitorino CAA Conference, Sienna March-April 2015

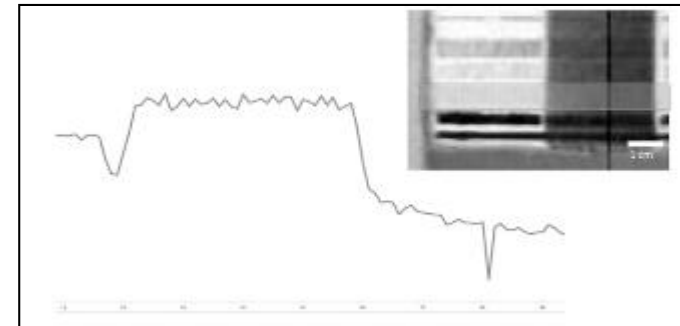
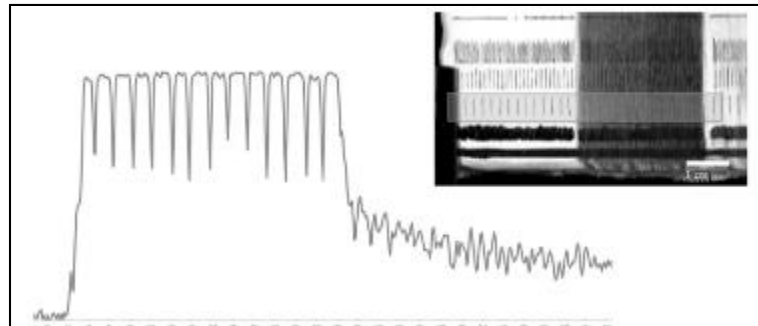
Assessing Spatial Resolution

From E.K. Webb STSM presentation
Neuchatel COSCH meeting, October 2015

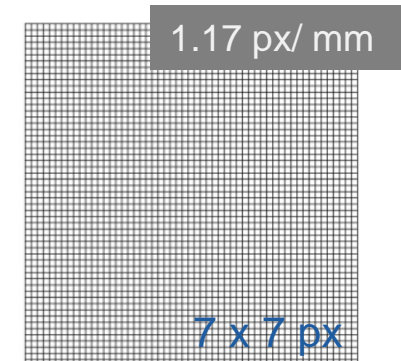
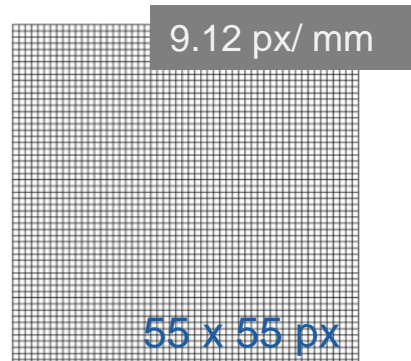
Visual Comparison



Plotting Vertical Profiles

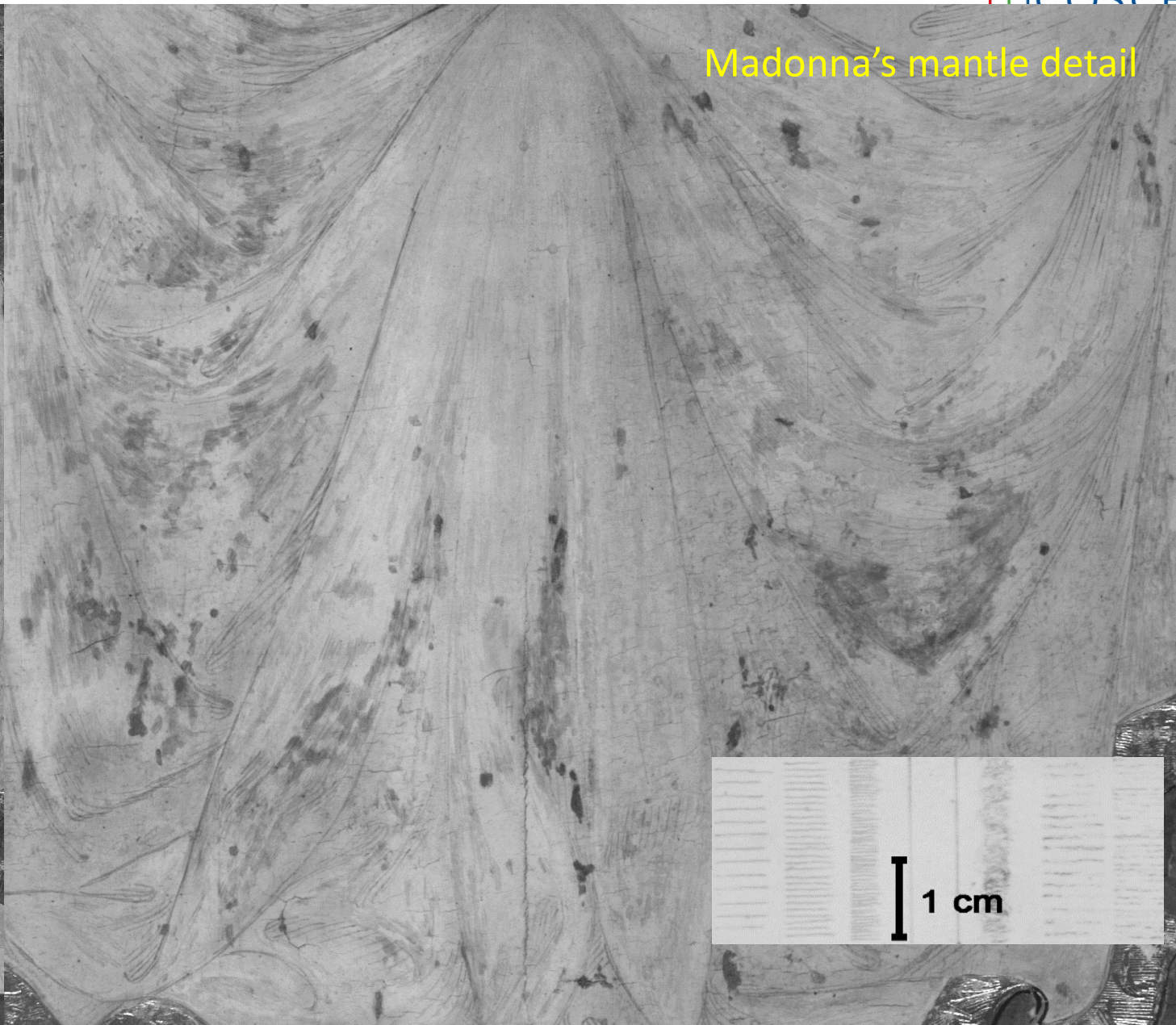


Calculate Sampling Density





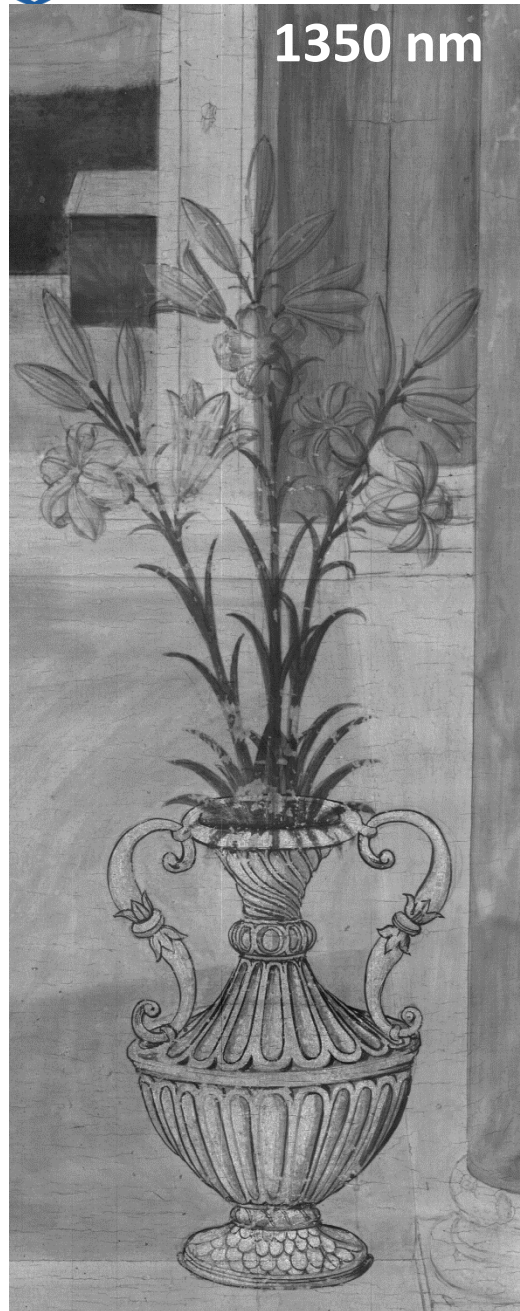
Annunciazione e Cacciata di Adamo ed Eva dal Paradiso terrestre
(1450-1455), attributed to Machiavelli Zanobi (Firenze, 1418-1479)
Florentine School of Beato Angelico
Located at San Martino a Mensola, Fiesole (Firenze)



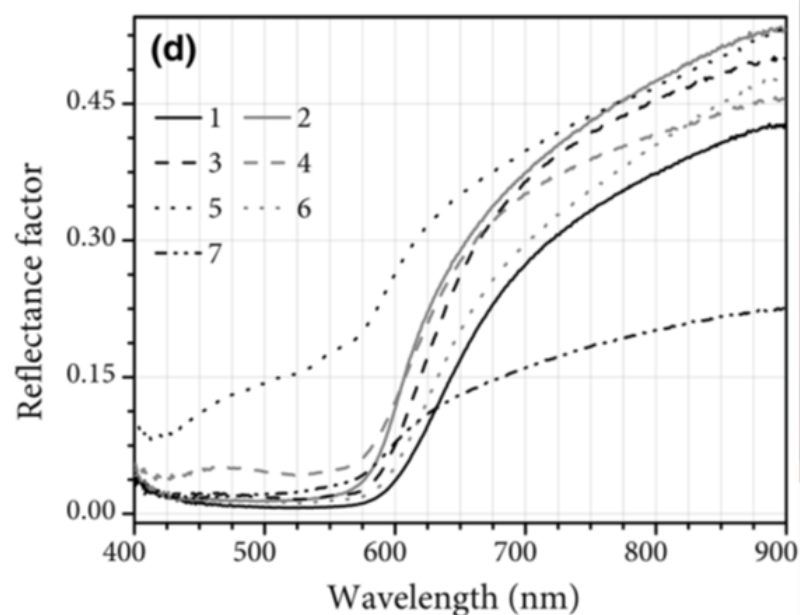
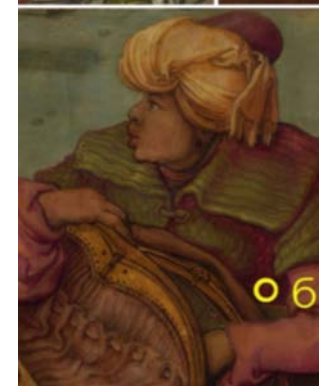
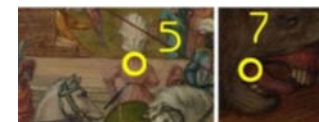
Madonna's mantle detail

1 cm

1350 nm

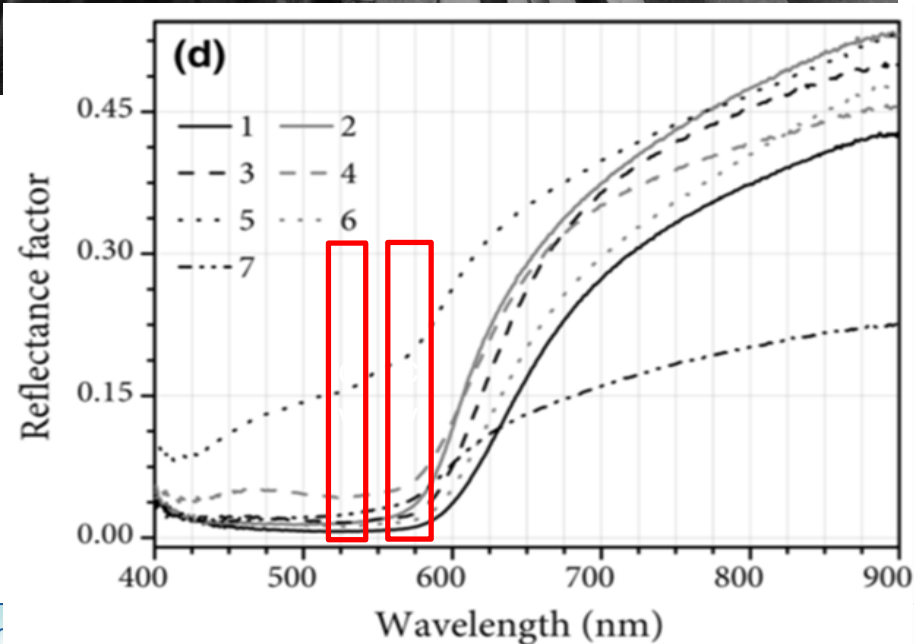


RGB colour image reconstructed from the cube file of the oil painting Adoration of the Magi (1504, 100 cm x 114 cm) by Albrecht Durer (1471–1528), Galleria degli Uffizi





(a) RGB image of the *Adoration of the Magi*
(b) Distribution map of the red lake considering a parabolic fit in the 519-544 nm and 558-580 nm ranges reconstructed from the cube-file.



To summarise:

1. Assessment and comparison of MSI and HSI data to keep more uniform the acquisition and processing procedures → Calibration and normalization for both spectral imaging systems.
2. Define limits of the proposed MSI-HSI devices and let the end-users be informed about them!
3. Keep in mind the multidisciplinary level of professionals involved in the CH conservation/documentation field before moving towards the definition of 'guidelines' and 'best practice' recommendations.
4. The investigation of artworks / archaeological objects requires a collaborative and interdisciplinary team to acquire the data, process the data, and interpret the results.
5. Is the definition of recommendations for the acquisition and processing of spectral imaging data in the CH field really a challenging task?

ACKNOWLEDGEMENTS

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- **Silvia Verdianelli**, private conservator;
- **COST-Action TD 1201 Colour and Space in Cultural Heritage (COSCH)**
- **Friends within COSCH**

Thank you for your attention from WG1 RRT colleagues

