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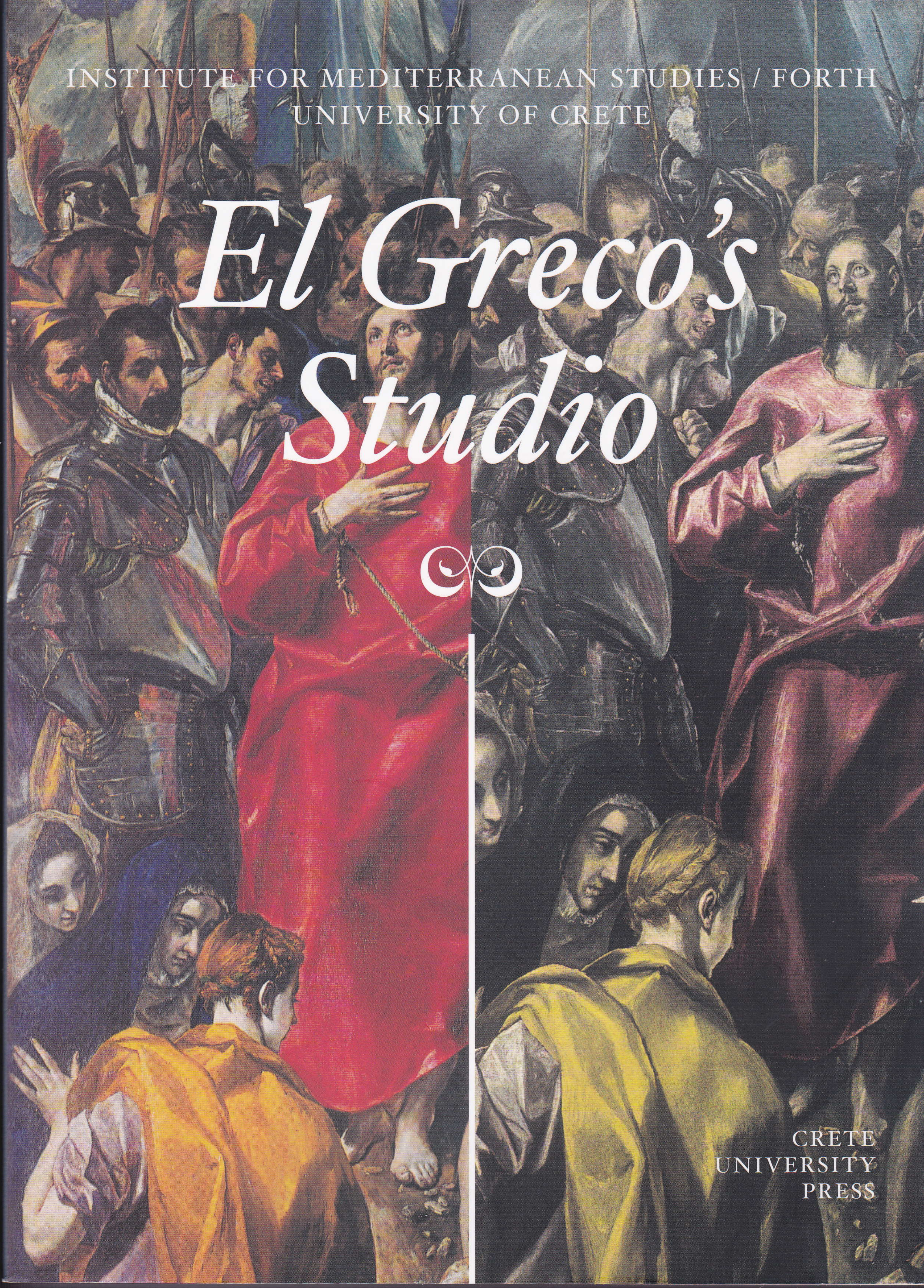
# *El Greco's Studio*



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# The Iraklion *Baptism of Christ*: Hyper-Spectral Analysis with MuSIS-HS Hyper-Spectral Imager

PAINTINGS ARE PERCEIVED BY THE HUMAN EYE through its three-band (Red-Green-Blue) optical detection system. The same light detection principle applies in conventional colour imaging devices. In both cases, the obtained analytical information about the chemical composition of the inspected object is very poor. This is due to the fact that the multiplicity of the light wavelengths that are contained in the returned spectrum are recorded in the three, wide spectral bands. Thus, differences in the spectral characteristics, carrying chemical information, would eventually remain undetected. In addition, the same inefficiency of the three-band detectors results in the degradation of the perceived contrast between features having similar colour but different spectral characteristics and chemical composition. Another limitation of the three-colour imaging systems is associated with their property to detect light only in the visible part of the spectrum thus missing the information carried by the spectra in the ultraviolet and infrared bands. And it is well known that the latter has proved very helpful mainly for the imaging of hidden underdrawings.

Today, special infrared-sensitive cameras allow us to see differences in the absorption of infrared light upon the underlying layers, thereby revealing the initial stages of a composition. Infrared reflectography is especially valuable for studying underdrawing, or the initial laying out of a composition with charcoal or graphite. Typical instrumentation employed in infrared reflectography operates in broad infrared bands at low spatial resolutions thus providing poor image quality and contrast. In addition, and as discussed above, broad-band operation cannot provide chemical information for material identification, which is a critical part of the technical analysis.

In order to address the above mentioned limitations, a variety of imaging and spectroscopic techniques and instruments are employed to work either autonomously or in conjunction with each other and the data generated are analysed by experts in various fields. Although the data generated by multiple instruments is rich in information, data correlation is problematic and the technical analysis is expensive, labour intensive and error prone.

Recent developments in imaging and computer technologies have enabled the development of advanced "HyperSpectral" imaging devices integrating high-definition imaging sensors with tuneable optical filters. HyperSpectral imagers are capable of providing imaging in a variety of narrow spectral bands in the visible and the non-visible part of the optical spectrum.

In this article a new Hyper-Spectral imager is presented together with the results obtained from the non destructive analysis of El Greco's painting *Baptism of Christ*, recently acquired by the Municipality of Iraklion.

## Hyper-spectral imaging and analysis

MuSIS-HS imager (fig. 1) is a multimodal imaging device developed for the non-destructive analysis of objects of artistic and historic value. MuSIS-HS has been designed and developed by the author[1] and is manufactured by FORTH-Photonics.

MuSIS-HS integrates and overall upgrades a series of analytical and imaging technologies in one portable device including, but not limited to:

a) High definition colour imaging, analysis and imaging colorimetry.
b) False colour infrared.
c) Two-dimensional spectroscopy (one full spectrum per image pixel) in the spectral range 400-1000nm.
d) High definition, infrared spectral imaging (1600 x 1200 pixels) in the spectral range 700-1550nm.
e) Ultraviolet imaging in the spectral range 360-400nm.
f) Operation in both reflectance and fluorescence imaging and spectroscopy modes.

## The Iraklion *Baptism of Christ*

Hyperspectral analysis of the *Baptism of Christ* was carried out in the framework of a large project involving a series of destructive and non-destructive analytical techniques, provided by institutions with established expertise in their respective fields. The project was coordinated by the Benaki Museum. Its targets were:

a) To provide advanced technical information to art historians for assisting their efforts in dating and authenticating the painting.
b) To determine the physical condition of the painting with the purpose of assisting conservation undertakings.

MuSIS-Hyperspectral analysis of the painting was conducted in two phases: before and after conservation.[2] Data obtained during the first phase was used for guiding conservation tasks performed by the Benaki's conservation department, whereas the second phase results were used for evaluation and interpretation purposes. An art historical study of the obtained data has been carried out by Prof. N. Hadjinicolaou. His analysis and conclusions will follow.

The entire surface of the painting was scanned and 30 narrow band images in the spectral range of 400-1000nm of the spectrum (visible and non-visible) were collected from every painting sub-area. Selective results obtained mainly from the colour, visible and infrared

1. C. Balas, V. Papadakis, N. Papadakis, A. Papadakis, E. Vazgiouraki, G. Themelis, "A Novel Hyper-Spectral Imaging Apparatus for the Non-Destructive Analysis of Objects of Artistic and Historic Value", *Journal of Cultural Heritage*, vol. 4, Supplement 1, January 2003, pp. 330–337. See also K. Rapantzikos and C. Balas, "Hyperspectral imaging: potential in non-destructive analysis of palimpsests", *IEEE-International Conference on Image Processing (ICIP)*, Genova, 2005, pp 11–14.

2. We would like to thank Prof. Alexis Kalokairinos for providing access to the panel, kept at the Historical Museum of Crete.

Fig. 1. The MuSIS-HS Hyper-Spectral Imager.

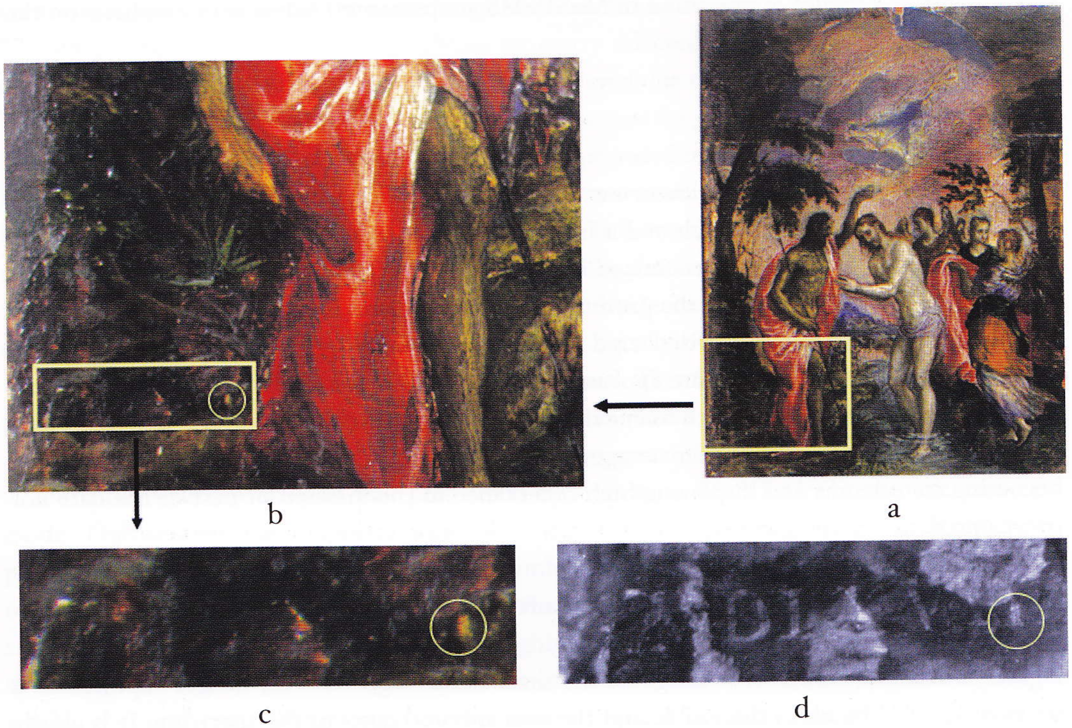


Fig. 2. *The Baptism of Christ* (a), colour image detail (b, c), and the infrared image of the same detail showing the date discovered (d).

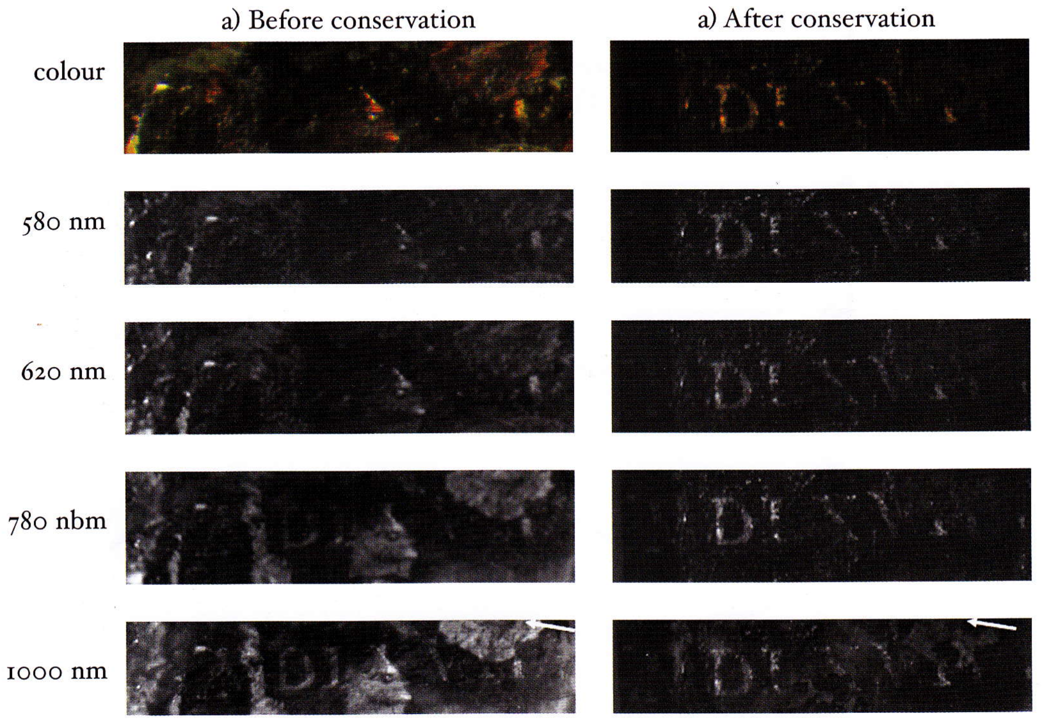


Fig. 3. Colour and spectral images of the detail before (a) and after conservation (b).

spectral imaging modes of operation of MuSIS-HS are presented below with emphasis on the revealed date.

## The discovery of the date

Figure 2a illustrates the colour overview of the painting. The lower left side detail of the painting is illustrated in figure 2b and a further detail of figure 2b is illustrated in figure 2c. Figure 2d illustrates the infrared image of the same detail obtained at an optimum near infrared spectral band revealing the presence of a hidden date written in roman numerals.

The overpainted numbers discovered for the first time were: MDLXVI indicating the year 1566. A second "I"-like feature appears next to the last numeral ("I") indicating a possible date of 1567. Careful analysis of the same detail shows that this feature (surrounded by a circle in fig. 2 b, c, d) appears in colour images indicating that it is either a surface feature, not becoming transparent and displaying high reflectance in the infrared or part of the date not overpainted.

## Spectral imaging of the date before and after conservation

Figure 3a illustrates the colour image of the same detail together with images captured in a series of spectral bands in the visible and the near infrared parts of the spectrum. It is clearly seen that as the wavelength increases the overpainting becomes transparent and the first signs the presence of the date appear in 780nm and with the 1000nm image providing the maximum

MDLXVI(I?)

a

b

Fig. 4. The infrared image of the hidden date (a) and its enhanced version (b).

contrast. Figure 3b illustrates the same image series obtained after conservation of the painting. The image brightness is low due to lighting geometry selected in order to avoid reflections of the protecting glass and the letter "M" is poorly displayed due to the shadow of the frame. Data illustrated in figure 3a, obtained during phase one, was used for guiding conservation procedures. An evaluation of the conservation that took place is provided in figure 3b, showing that the date has been recovered successfully, except for the last controversial "I"-like surface feature, which has been subjected to remarkable material removal. It is worth noticing that the intervention effectuated had the same effects on both the "I"-like feature and the neighbouring surface features designated by white arrows in figure 3 (a, b). Evidence for the latter is provided by the fact that the grey shade of both features has almost equally become darker, as compared with the non treated images (fig. 3a), due to material removal. This finding could further support the position that the "I"-like feature was a surface feature and not a part of the date, since it has been removed together with the overpainting attempting to reveal the (real) hidden date.

Per pixel spectral analysis was performed by operating MuSIS-HS in the spectroscopy mode. Diffuse reflectance spectra were obtained from the painting after conservation, in particular from pixels corresponding to unambiguous letter areas in order to be used as reference. They were then compared with the spectra corresponding to the "I"-like feature and with the spectra corresponding to its neighbouring area. Analysis showed higher spectral similarity between the "I"-like feature and its corroded neighbouring area, thus indicating a similar chemical composition, even further supporting the position that the "I"-like feature is not a part of the date. Nevertheless, spectral analysis corresponding to the cleaned areas needs to be treated carefully due to the remarkable material removal which occurred during conservation and subsequently to the high contribution of the background in the measured spectra.

Figure 4a illustrates the infrared image of the discovered date and figure 4b its enhanced version through image analysis. Infrared imaging with high spatial and spectral resolution enables the visualization of fine details of the painting, something unattainable with conventional general purpose infrared imagers. It is clearly seen that the "I" and the other letters of the hidden date have a serif stylistic feature, which is absent from the controversial "I"-like feature. This obviously provides additional evidence, strongly suggesting that the "I"-like feature is not part of the date but a surface feature instead.

## Conclusions

In the particular case of the painting under analysis, conventional broad band infrared reflectography could provide the reading of the date. However, it would be unable to furnish data for discriminating the latter from possible artefacts. In other words, on the basis of the data provided with traditional systems the date would be 1567, which is misleading. Consequently, what is necessary in these processes is the analysis to be performed with multimodal spectral imaging as the most advanced diagnostic tool for the non-destructive analysis and documentation of objects of artistic and historical value. This technology enables the direct comparison of the data obtained by a series of imaging modalities (colour spectral imaging, infrared reflectography, etc.), integrated in one portable device, thus maximizing the obtained information and facilitating data interpretation even by users with limited technical background.