Beyond the visible: the Viterbo Crucifixion panel painting attributed to Michelangelo Buonarroti

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Abstract

The painting object of the present work, currently exposed in the Museum of Colle del Duomo in Viterbo (Italy), has been dated back by art historians to the 16th century and it owes its relevance to a still discussed attribution to Michelangelo Buonarroti. For this reason, art historians and the responsible curator of the Museum commissioned scientific investigations to support and explain their hypothesis about the painting attribution and dating.

Here we report the results of two sets of investigation: diffuse reflectance hyperspectral imaging and X-ray fluorescence spectroscopy of the painting; radiocarbon dating and identification of the panel wood. The hyperspectral dataset, coupled with X-ray fluorescence spectra on selected analysis points, reveals the presence of precious ultramarine blue and vermillion pigments, confirming the importance of the painting committer. Wood analysis and radiocarbon dating by wiggle matching technique revealed that the botanical species used for the panel is Cypress (*Cupressus sempervirens* L.), and enabled dating the painting around AD 1500± 25, providing to art historians a further element for the attribution of the artwork.

Keywords: Michelangelo workshop, *Cupressus sempervirens* L., dating, Hyperspectral Imaging, X-ray fluorescence spectroscopy, pigments.

1. Introduction

The “Viterbo Crucifixion” is an interesting 16^{th} century panel oil painting (59x46 cm), representing a Crucifixion, exposed in the Museum of Colle del Duomo in Viterbo (Italy) (Fig. 1) [1]-[4]. The great interest around this little panel painting is due to its attribution to the workshop of the Master Michelangelo Buonarroti. This hypothesis was made after the discovery of a will, dated 1725, reporting that a crucifixion by Michelangelo was donated to the Jesuits of Viterbo by Paolo Brunamonti [5]. Even though this document alone does not prove the attribution of the “Viterbo Crucifixion” painting to Michelangelo, there are some elements, such as the presence of Buonarroti in Tuscia and his relationship with Vittoria Colonna and with the reform movement known as *Spirituali* (or *ecclesia viterbiensis*), that suggest that an artwork of the Master should be present in Viterbo [5]-[11]. The deep friendship between Michelangelo and Vittoria Colonna, well-documented by their extensive epistolary relationship, had probably a role in the spiritual nearness of Michelangelo with the Ecclesia Viterbensis and influenced Michelangelo’s artistic thought and production, as reported in various relevant studies [8]-[14].

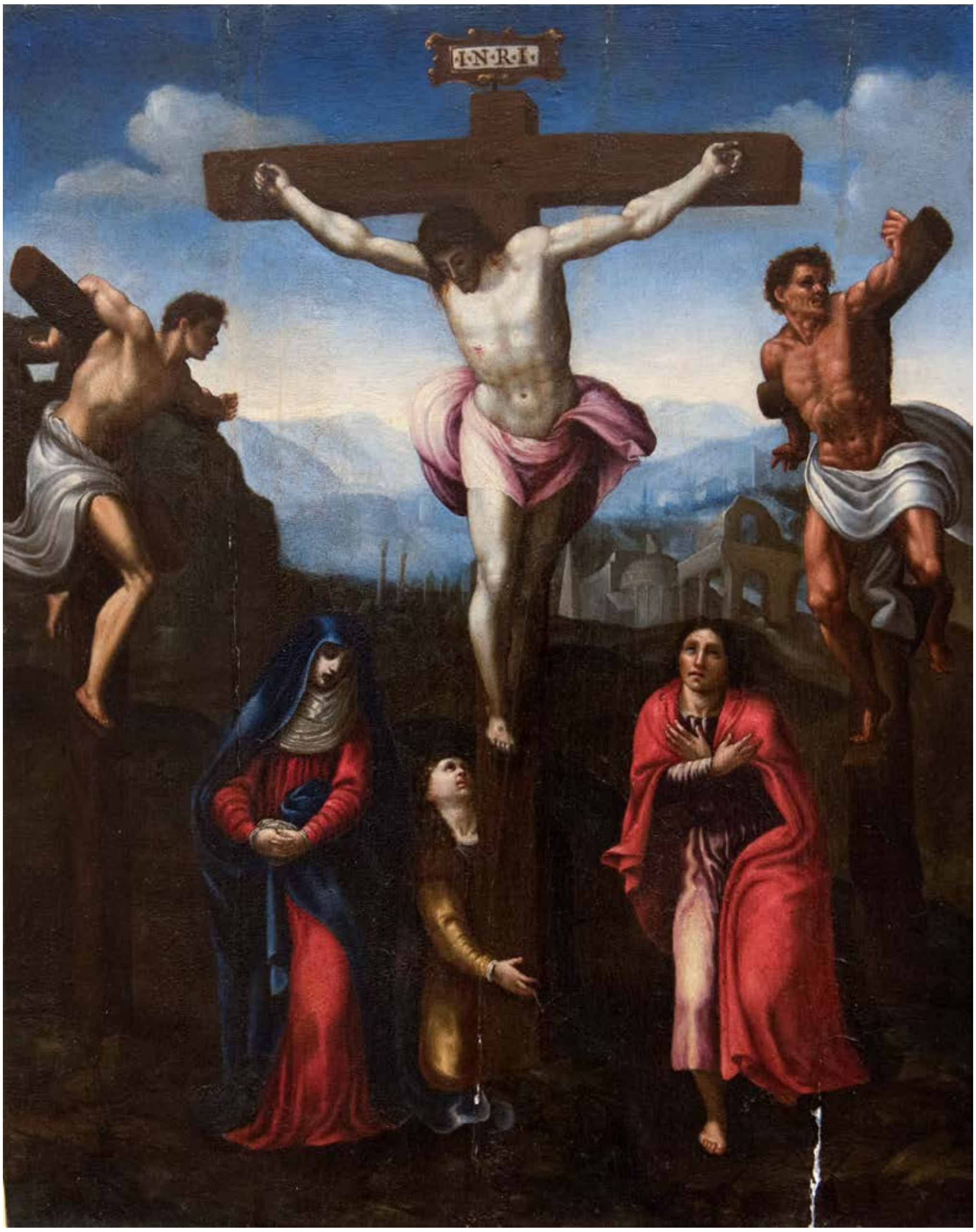

Figure 1: *The Crucifixion of Viterbo*, panel painting 46x59 cm, 16th century, Museum of Colle del Duomo, Viterbo (Italy).

Some interesting elements of the "Viterbo Crucifixion" painting support the proposed attribution hypothesis. One is the unusual landscape at the back of the cross: a view on a towered town, which recalls the present Porta Faul in Viterbo, while the ruins in the background evoke the Bacucco thermal baths [12].

A second interesting element of the painting concerns a garment detail, the perizoma of Christ that exhibits a quite anomalous pink hue. Indeed, in liturgical terms this is usually referred to Easter, and not to Crucifixion. According to Elisabetta Gnignera [12], the use of this unusual colour should be associated to the peculiar thinking expressed both by the *Spirituali* and by Vittoria Colonna (in two of her spiritual sonnets) that considers the death of Saviour as a joyful event because of man's salvation in Christ. Indeed, the anomalies and variants in the Crucifixion of Colle del Duomo (in comparison, for example, with later replicas by painter Marcello Venusti) strengthen the hypothesis of a link between this artwork and the religious debate that originated immediately after the publication in 1543 of the book *Beneficio di Cristo* (The Benefit of Christ's Death), which reflects the radical thinking of the *Spirituali* [13].

Another important element that contributes to the possible attribution of the painting is a letter by Vittoria Colonna [14], where she mentions a Crucifixion that she received from Michelangelo, and where she inquiries about its authorship (she wrote: … *per il che ho risoluta de non volerlo di man d'altri, et però charitemi, se questo è d'altri, patientia* … that is "as long as I don't want it if painted by others, please tell me if it is a creation of another painter").

According to art historians, the Crucifixion painting has other peculiarities: the anomalous appearance of Christ's face, very different from the rest of the figures; the plausible later addition of the figure of Magdalene at the foot of the cross; the face of Saint John, that changes when observed under different illuminations.

The later inclusion of Magdalene is presumed from the overlap of her garment to the Virgin's mantle; furthermore, on Magdalene's right shoulder some art historians recognise an anachronistic buckle, which was in use only from the second half of the 16th century (private communication from art historian Elisabetta Gnignera, specialist on Renaissance).

Art historians speculate that the change in Christ's face and the possible addition of Magdalene are a consequence of the 1556 catholic reforming decree of Pope Paul IV (born Gian Pietro Carafa), where some dictates in religious painting representations are established, including the fact that it was forbidden to depict the crucified Christ alive [15].

St. John's face is particularly intriguing since it has a female aspect when observed under visible illumination, but it assumes more masculine traits and a hollowed aspect when observed under UV excitation [1][4]. This phenomenon, which occurs only in the face of St. John and hence appears intentional, highlights a further link between Michelangelo and Vittoria Colonna. In fact, art historians relate this effect to a circumstance mentioned by Vittoria Colonna in her letter "del lume" ("about the lamp") to Michelangelo (presumably between 1543 and 1544) [2], where Vittoria Colonna expressed her astonishment regarding a "Crucifixion" sent her by Michelangelo, which she had "well observed with a glass, a lamp and a mirror" ("*Io l'ho ben visto al lume et col vetro et col specchio, et non viddi mai la più finita cosa*"). Noticeably, in another letter written between 1542 and 1543, Vittoria Colonna requested to Alvise Priuli, the secretary of Cardinal Reginald Pole (leader of *Spirituali* at Viterbo), some green-coloured glass manufactured in Venice ("*quell vetro verde che* *venne da Venezia"*) to donate to Michelangelo who, at that time, was working to the wall paintings of the Cappella Paolina in the Vatican palace [16]. It is beyond the scope of this paper to investigate whether and how Michelangelo made use of coloured glasses, but the optical properties of glass materials were empirically known since the age of ancient Romans [17], while at the Renaissance time it was common to admire works of art through coloured optical glasses, as it is well documented for several artists and patrons [18].

In this debated context, a further study of the Crucifixion was requested by the responsible of the Museum and by art historians of *Egidio17* project, which focuses on the historical panorama in Viterbo in the first half of 16th century [2]. In this paper, we discuss the results of some of these further analyses, achieved by combining diffuse reflectance hyperspectral imaging (HSI) [19], punctual X-ray fluorescence spectroscopy (XRF), wood characterization and wiggle matching dating, with the aim of investigating both the paints and the wooden panel of this small, but long-discussed painting. The HSI dataset and the XRF spectra on selected analysis points contribute to the knowledge of paint materials, techniques and pictorial details of the panel, and the related findings are compared with Michelangelo's artistic thought and production. Wood analysis enables the characterization of the botanical species and the peculiarities of the wooden panel, a further relevant aspect for the analysis and attribution of the painting [20][24]. In particular, the identification of the botanical species provides important information to set the wooden artefact in a clear geographical and cultural context. At last, radiocarbon dating, through wiggle matching technique, was performed for establishing a chronological range for the wooden panel [25].

2. Experimental

2.1 Hyperspectral imaging

Hyperspectral imaging is a set of methods and devices which enable the acquisition of the continuous light spectrum for each point in the image of a scene [26]. Starting from the spectral information, numerical methods enable extracting quantitative parameters related to chemical and physical properties of the imaged objects [27]. In this work, we acquired hyperspectral images of the Crucifixion by a HSI camera [19], which is based on Fourier-transform (FT) spectrometry [28] and employs an innovative, ultrastable birefringent interferometer [29],[30]. The camera combines the advantages of FT spectrometry, such as high signal-to-noise ratio [31], high throughput [32] and flexible spectral resolution, with the excellent compactness, stability and robustness of its interferometer. Thanks to these properties, the hyperspectral camera is able to acquire spectral absolute reflectance, transmittance and fluorescence images with spectral coverage ranging from

350nm to1100 nm and spectral resolution of 3 THz, corresponding to ~4 nm at λ = 635 nm and ~12 nm at λ = 1100 nm. The camera sensitivity enables the acquisition of a hyperspectral imaging dataset in a few minutes, with a spectral background level of only -30dB even with the low-illuminance recommended for the study of works of art [33]. The camera is equipped with an F1.4, 25 mm objective and it employs a 1/1.8" format CMOS sensor with 1280x1024 pixels and a 10 bit dynamic range. The angular FOV is ~ 16 degrees, and the working distance is from 0.2m to ∞. Spectral calibration of the camera has been performed by imaging the transmission of a set of bandpass interferential filters covering the spectral working range of the camera.

With this hyperspectral camera, we measured two parameters: the absolute reflectivity and the UV-induced fluorescence.

For the absolute reflectivity measurement, the panel painting was illuminated by a broadband 150-W Xenon lamp. The lamp was kept at 2 meters distance from the panel and, to reduce the specular reflection, it was placed off-axis with respect to the surface normal, at an angle of about 45°. The resulting illumination irradiance was about 0.1 mW/cm^2 in the spectral range between 400 nm and 2 μm, corresponding to illuminance of about 135 lux. The camera was at 2.5 meters distance from the panel. The acquisition time of the HSI of the entire painting was 200 seconds, corresponding to a light dose of 7.5 lux-hour.

Absolute reflectance was calculated after spectral calibration with a white Spectralon with (98.3±1.3)% reflectance in the range from 300 nm to 2.5 μm (Labsphere Inc., North Sutton, USA) and correction for spatial and spectral non-uniformities of the illumination by imaging a white Lambertian surface at the object plane. Once hyperspectral datacubes are generated, areas of the painting characterized by similar spectral features (i.e. similar pigment composition) are identified on the basis of a supervised classification algorithm. For the purpose we considered the spectral angle mapper classification (SAM) method, which calculates the similarity between a reference reflectance spectrum (chosen in correspondence to a certain region of interest – ROI – of the painting) and each reflectance spectrum in the datacube by treating reflectance spectra as vectors in an N-dimensional space (where N is the number of spectral bands in the wavelength dimension, in the present case N = 512) and considering the angle between them as the index of similarity [34]. The lower the angle the closer the spectrum is to the template. The similarity maps were plotted in grayscale form white (perfect match) to black, which corresponds to a full scale angle of 15 degrees (0.26 radians).

The UV-induced fluorescence was obtained by illuminating the painting with two custom-made UV-A lamps [35] symmetrically placed at the side of the painting at approximately 50 cm from its surface. The employed UV illumination provided a peak irradiance in the band 340-365 nm of approximately

100 μW/cm^2 on the painting. The weak fluorescence required longer integration, resulting in a total acquisition time of 800 seconds.

2.2 XRF spectroscopy

X-Ray Fluorescence spectra of selected points of the painting were acquired with a compact, portable and high performances XRF spectrometer (ELIO, XGLal srl/Bruker, Milano, Italy). The instrument is based on a rhodium anode as the excitation source and allows the detection of elements from $_{11}$Na to $_{92}$U with an energy resolution of 130 eV at Mn Kα. The X-ray beam is collimated to a spot diameter of about 1.3 mm in diameter. For all measurements on the painting the following experimental conditions were employed: tube voltage: 40 kV, tube anode current: 100 μA, acquisition time: 60 s. XRF measurements were performed in 14 points, whose positions are marked in Figure S1.

2.3 Wood analysis

By following a well-consolidated approach, the wood of the painting panel was carefully examined *in situ* before any micro-sampling [36], by measuring the weight and sizes of the panel. The panel thickness was measured with a gauge at left and right sides, in three positions: top, centre, bottom.
In order to identify the wood species, thin sections (thickness: 15-20 μm) on the transversal, radial and tangential surface of the wooden panel have been observed at the optical and electronic microscope.
For optical microscopy, we employed a Zeiss Axioskop, equipped with AxioCam digital camera. The anatomical features were compared with the identification keys of Nardi Berti [37] and Schweingruber [38], and following the IAWA list for softwood identification [39].
Scanning electron microscopy (SEM) was carried out using a Jeol model JSM-5200 scanning electron microscope. The wood samples were sputter-coated with gold in a Balzers MED 010 unit.

2.4 Wiggle matching dating technique

Wiggle matching technique [25] is suited for dating the wood of the painting panel and it is based on the radiocarbon analysis of a sequence at least three samples, selected in order to impose the following conditions to the subsequent statistical analyses [40]:
- the samples towards the pith are older than the samples towards the bark, due to the centrifugal direction of growth in plants;
- the number of years that separates the dating of the samples is equal to the number of rings among them, as a consequence of the annual growth rate of rings [40].

By applying to the conventional radiocarbon measurements the principles of Bayesian statistics [43] accounting for the above mentioned conditions, it is possible to improve the dating precision [39]-[45]. This technique is particularly suited in the case of paintings on tables [44] because the confidence interval of the dating reduces from > ±75 years to only ±25 years. In order to perform the dating of our table by wiggle matching technique, we collected three samples (Fig. 2). From the oldest to the most recent, they are labelled CDD1 (pith side), CDD2 (intermediate) and CDD3 (bark side). The distance between CDD1 and CDD2 samples corresponds to 34 years, while between CDD2 and CDD3 it is 31 years. In addition, the outer edge of the panel is at the bark side, and is 23 years younger than CDD3.

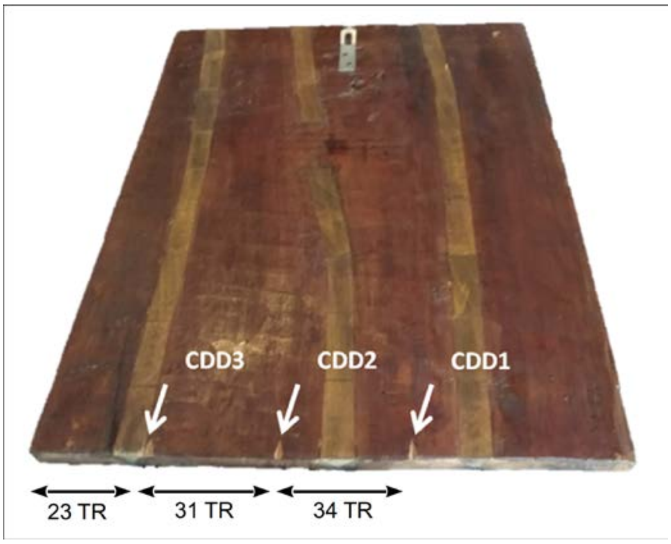

Figure 2. The sampling pattern for the wiggle matching analysis. TR = tree ring.

Radiocarbon dating was performed with the high resolution mass spectrometry technique (AMS), at the Dating and Diagnostics Center (CEDAD) of the University of Salento [35]. The calibration in calendar years was performed with the OxCal Ver. 3.10 software, based on atmospheric data as reported by Reimer et al. [45].

3 Results and discussion

3.1 XRF spectroscopy

Results of XRF spectroscopy on selected analysis points of the painting are provided in Table 1 in terms of the main detected elements and are synthetically resumed in the following. Furthermore, we took advantage of the complementarity of elemental analysis with spectral features of reflectance to strengthen the attribution of pigment composition whenever ambiguous interpretation was possible, as discussed in the section 3.2 *Hyperspectral imaging*.

(i) In all analysis points we detected Pb, Ca and Fe, suggesting the presence of ground and preparation layers mainly made of lead white, gypsum-and iron-based pigments.

Concerning the coloring agents, the palette appears to be pretty simple and most of the identified pigments can be related to the traditional artist materials employed in the Renaissance period:

(ii) red hues have been achieved by employing vermillion and red ochre;

(iii) blue hues have been achieved by employing azurite and ultramarine blue. Minor amounts of Fe (possibly ascribed to the presence of iron ochre) were also detected.

(iv) light pink hues and fleshy pink hues have been achieved with a mixture of red ochre and cinnabar. In some points, a Mn-based pigment (umber or Manganese brown) has been also used.

Interestingly, relevant amounts of Cu have been detected also in two non-blue areas: the dark-brown cross of Jesus and the dark skin of the right thief. This occurrence could be related to presence of an underneath painting layer made of azurite, hence suggesting that the sky was painted first and, over it, other details have been added.

Some elements, typical of modern pigments, have been further detected and can be ascribed to the use of semiconductor pigments in recent restoration treatments, such as cadmium red, titanium white and zinc white. The presence of titanium could be also associated to the presence of clay minerals in the earth pigments.

Table 1. Results of XRF spectroscopy analysis in terms of detected elements and proposed pigment identification.

Analysis point	**Color**	**Detected elements**	**Main pigments on the basis of XRF data**
P1 – Light blue sky	BLUE	Pb, Ca, Fe, Cu (minor), Si (minor), K (minor), Ti (minor)	Azurite + Ultramarine blue
P2 - Dark blue sky	BLUE	Pb, Ca, Fe, Cu (minor), Si (minor), K (minor), Ti (minor)	Azurite + Ultramarine blue
P3 - Jesus cross	DARK BROWN	Pb, Fe, Ca, Cu K (minor), Mn (minor), Si(minor)	Umber or Manganese brown
P4 – White drape of the right thief	WHITE	Pb, Ca, Fe (minor)	White lead + red ochre (traces)
p5 – Jesus pink drape	PINK	Pb, Ca, Fe, Cu (minor) K (minor), Mn (minor)	Lead white + red ochre + umber
p6 – Jesus leg skin	FLESHY PINK	Pb, Ti, Fe, Zn, Ca, K (minor), Cu (minor)	Lead white + red ochre
p7 – Maddalena skin	FLESHY PINK	Pb, Hg, Fe, Ca, Ti (minor), Zn (minor), Cu (minor), Mn (minor)	Lead white + vermillion + red ochre + titanium white (traces) + zinc white (traces)
p8 – Right thief skin	FLESHY DARK PINK	Pb, Fe, Hg, Ca, Cu Si (minor), K (minor)	Lead white + red ochre + vermillion
p9 – Saint John skin	FLESHY PINK	Pb, Fe, Hg, Ca, Cu (minor) Si (minor), K (minor)	Lead white + red ochre + vermillion
p10 - Saint John red mantle	RED	Pb, Hg, Fe, Ca Cu (minor), K (minor)	Vermillion + red ochre
p11 – Virgin Mary mantle	BLUE	Pb, Ca, Fe, Cu (minor), Si (minor), K (minor), Ti (minor)	Azurite + Ultramarine blue
p12 - Virgin Mary red dress	RED	Pb, Hg, Fe, Ca Cu (minor), K (minor)	Vermillion + red ochre
p13 - Saint John pink dress	WHITE-PINK	Pb, Ca (minor), Fe (minor), Cu (minor)	Lead white + red ochre (traces)
p14 – Jesus face skin	FLESHY PINK	Pb, Fe, Ca, K (minor), Cu (minor)	Lead white + red ochre

3.2 Hyperspectral imaging

The reconstructed color image of the painting in the RGB color space is displayed in Figure 3(a). Red-painted areas display close spectral features, as is highlighted by the similarity map constructed by considering as the reference reflectance spectrum the one in a squared area (1 x 1 cm^2 in size, equivalent to 10 x 10 pixels) of Saint John's mantle (Figure 3(b)). A comparison with the reflectance spectra of red paints typically employed in the 16th century (Figure 3(c)), available as published database of reflectance spectra [46], shows a strong similarity with both vermillion- (HgS) and red ochre- (Fe_2O_3) pigments. In particular, in the Crucifixion red paints it is possible to recognize the typical sigmoidal-shaped spectrum of vermillion, with a transition edge at 600 nm, as well as the spectral features of red ochre with an absorption band around 850-900 nm.

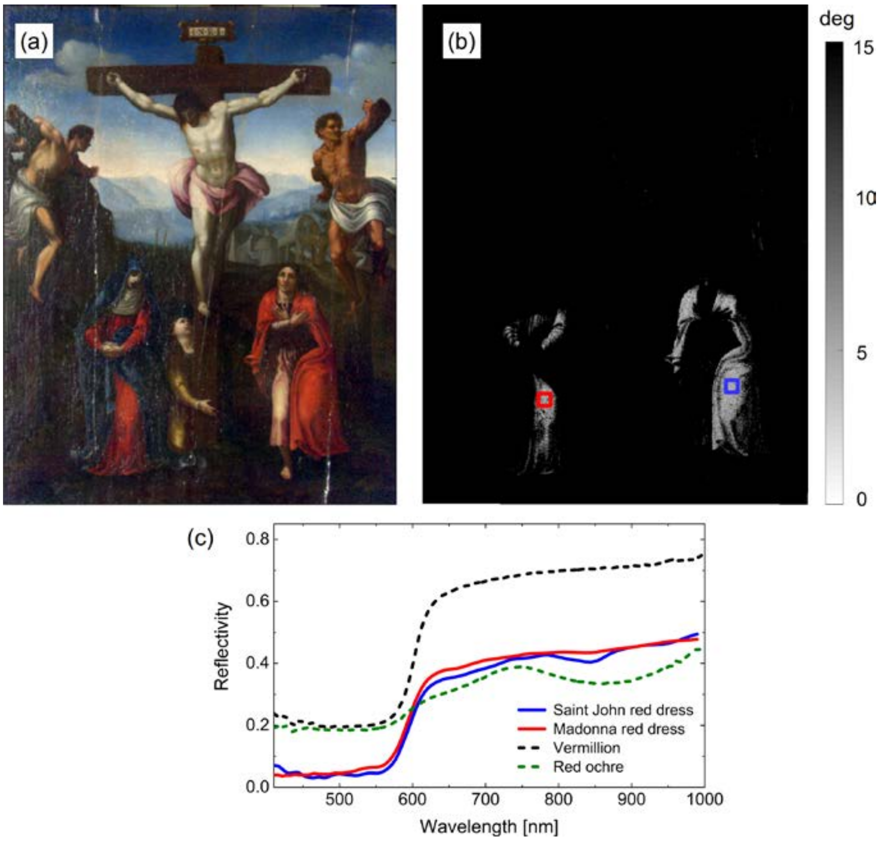

Figure 3 – (a) Color image of the painting reconstructed in the RGB color space on the basis of the hyperspectral dataset in the spectral range between 420 and 780 nm. (b) Similarity map achieved by considering as the reference spectrum the one collected on a ROI on the red mantle of Saint John (blue empty square) and the hyperspectral dataset in the spectral range between 420 and 1000 nm. Tolerance angle has been set to 15 degree (0.26 radians). (c) Mean reflectance spectra reconstructed in the red mantle of the Virgin Mary (red continuous line, red square of panel (b)) and in the red mantle of Saint John (blue continuous line, blue square of panel (b)) compared with the reflectance spectra of a vermillion paint (black dashed line) and a red-ochre paint (green dashed line) [46].

It is noted that these two latter spectral features are more evident in the red paint employed for depicting Saint John mantle, suggesting that - whereas both the paints are composed of a mixture of vermillion and red ochre - Saint John mantle's paint has a higher content of red ochre. While this issue is not disclosed by the similarity mapping method, this finding is in good agreement with XRF data of the two red paints, where, as already observed, both Hg and Fe have been detected, but with a higher relative content of Fe in Saint John's mantle (relative ratio between the area of the detected Fe_Kα and Hg_Lα emission lines equal to 0.39 and 0.16 in the red mantle of Saint John and the Virgin Mary, respectively).

Blue-painted areas of the painting show a common feature, i.e. a net increase in reflectance values between 700 and 950 nm, as it is demonstrated by the similarity map constructed considering hyperspectral data in the spectral range between 650 nm and 750 nm taking as the reference reflectance spectrum the one in a squared area (1 x 1 cm^2 in size, equivalent to 10 x 10 pixels) of the top blue sky (Figure 4(a)). This feature is indicative of the use of the precious ultramarine pigment in blue-painted areas of the sky and the blue mantle of the Virgin Mary. Indeed, a comparison of the reflectance spectra of these areas with the reflectance spectra of blue pigments typically employed in the Renaissance period (Figure 4(b)) demonstrates a close similarity with both azurite and ultramarine blue, in agreement with the detection of Si and Cu by XRF spectroscopy in analysis points with a blue color.

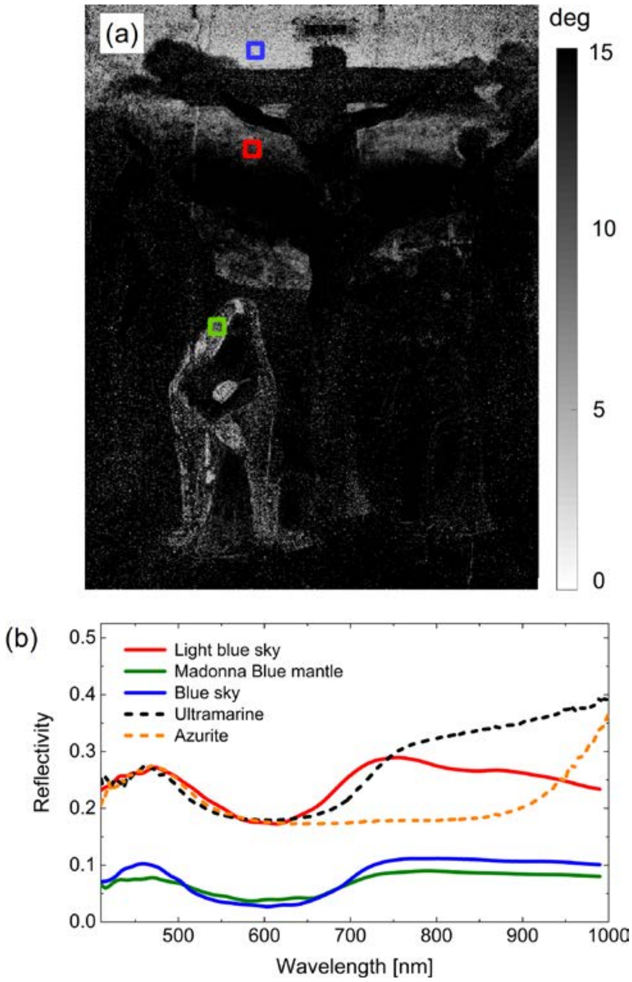

Figure 4: (a) Similarity map achieved by considering as the reference spectrum the one collected on a ROI on blue sky (blue empty square) and the hyperspectral dataset in the spectral range between 650 and 750 nm. Tolerance angle has been set to 15 degree (0.26 radians). (b) Mean reflectance spectra reconstructed in the blue sky (blue continuous line, blue square of panel (a)), in the light blue sky (red continuous line, red square of panel (a)) and in the blue mantle of the Virgin Mary (green continuous line, green square of panel (a)) compared with the reflectance spectra of ultramarine blue (dark dashed line) and azurite (orange dashed line) paints [46].

Hyperspectal imaging was finally focused on the detail of St. John's face. The RGB color image under visible and UV illumination (Figure 5(a) and (b), respectively) reconstructed on the basis of the corresponding hyperspectral datasets, highlights the change in the face aspect of St. John when observed under different illuminations, as already demonstrated in recent publications [1]-[4].

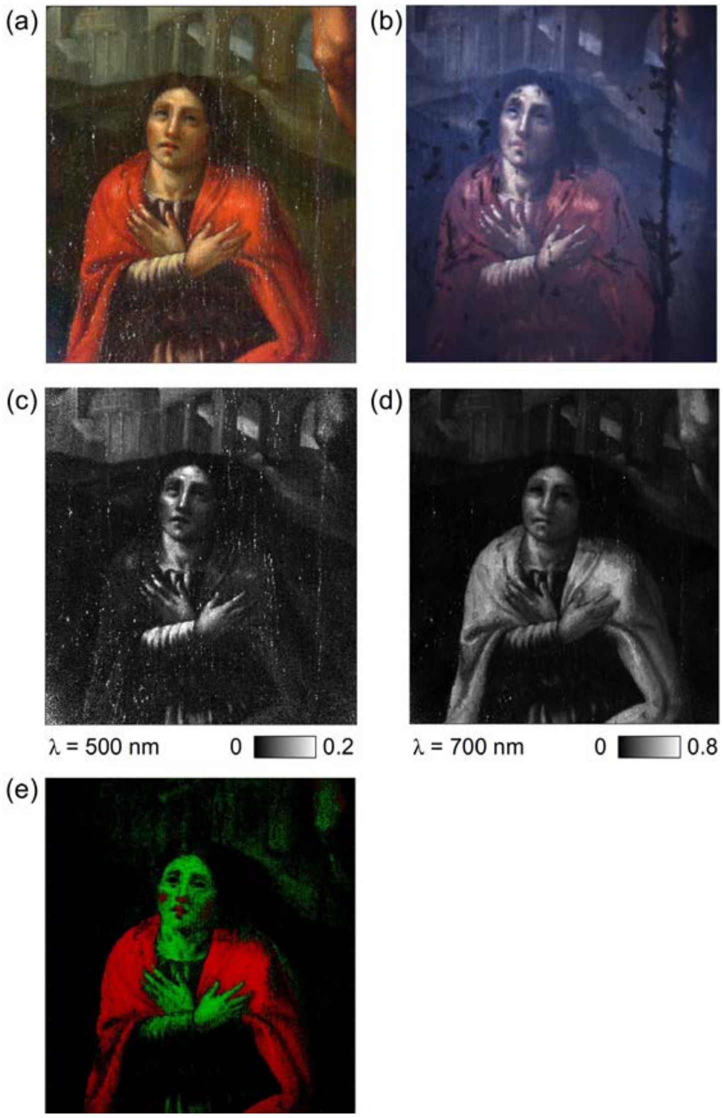

Figure 5: RGB color map of the detail of Saint John face under (a) visible and (b) UV illumination reconstructed on the basis of the collected hyperspectral datasets. Reconstructed images of the reflectivity at (c) 500 nm and (d) 700 nm. (e) Composite image of the similarity maps constructed by considering as the reference spectrum the one in the red mantle (red channel) and the one in the fleshy pink tone of the right hand (green channel). Tolerance value for both similarity maps has been set to 15 degree (0.26 radians).

This behaviour can be further appreciated when observing the reflectivity maps of the painting detail in two different spectral regions (Figure 5(c) and (d)) in the blue-green and in the near-infrared, where St. John aspect changes dramatically from a thinner and more masculine character to a feminine one with chubby cheeks. This finding could be related to the addition of a red-paint for finishing the cheeks of St. John on top the skin tone used to paint his face. It is worth nothing that, this specificity is observed in S. John's face only. Indeed, the combination of similarity maps, constructed by considering as the reference spectrum the one in the red mantle (red channel) and the one in the fleshy pink tone of the right hand (green channel), (Figure 5(e)) confirms that the cheeks have a more reddish hue than the rest of the face.

3.3 Wood analysis

The on-site visual examination of the painting panel (see Fig. 6) revealed that the painting was made on a single plank with a total mass 4.006 kg and an axial disposition whose dimensions are reported in Table 2.

Table 2. Panel painting dimensions.

Measurement position	Average	Standard deviation
Width (cm)	46.1	0.212
Length (cm)	58.9	0.009
Thickness (cm)	2.2	0.027

The plank was cut radially, as shown by the direction of the growth rings visible on the upper and lower edges. The wood is homoxylous, with irregular shaped rings and growth restarting (false or partial rings), as visible in Figure 6(c).

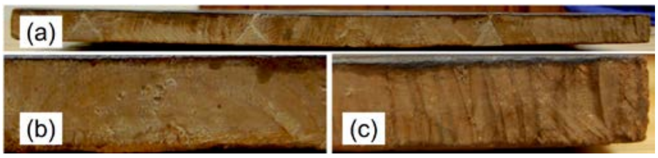

Figure 6: (a) Upper edge of the panel; (b) pith and adjacent rings; (c) false rings, characterized by faded boundaries: they are abnormal rings due to intraseasonal disturbance of growth.

The pith was also observed (Fig. 6(b)), positioned 29.4 cm from the right longitudinal edge (with respect to the painted surface, Fig. 6(a)). This suggests that the log from which the plank was obtained had a diameter of at least 60 cm.

The wooden panel exhibits a group of knots and traces of processing with manual tools (Fig. 7(a,c)). The knots are the portions of the branches incorporated in the tree stem. They do not show traces of biotic alteration (Fig. 7(b)).

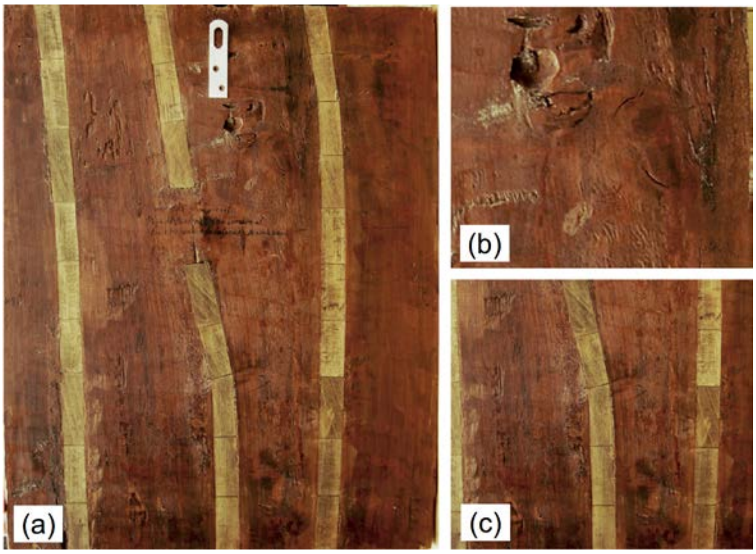

Figure 7: (a) Back of the painting; (b) detail of the knots; (c) traces of processing.

Resin canals were not observed. There are axial parenchyma cells scattered in the ring (Fig. 8(a)), sometimes arranged in tangential bands (Fig. 8(b)). Monoseriate rays were detected. In radial section, the tracheids showed bordered pits in a row (Fig. 8(c)). The rays in the cross-fields show from 2 to 3 cupressoid pit. The anatomical features examined with the optical microscope indicate that the wooden panel was obtained from the stem of Cypress (*Cupressus sempervirens* L.).

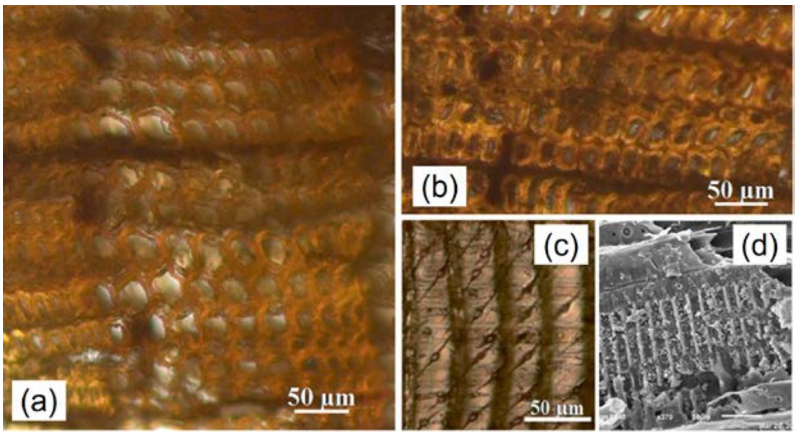

Figure 8. Transmission microscopy images in the visible spectral range: (a) transversal section, magnification 200X, axial parenchymal cells are visible; (b) transversal section, magnification 100X, axial parenchymal cells are arranged tangentially near the ring boundary, recognizable by thickness variation of the cell walls. Moneseriate rays are visible; (c) radial section, magnification 100X, tracheids show bordered pits with small orifice. SEM images: (d) radial section, parenchyma cells.

Typically, the radial cut is characterized by a lower tendency to dimensional variations and deformation caused by moisture changes and by shrinking and swelling wood. However, the painted surface assumed a convex shape over time, probably due to the different hygroscopic inertia between the painted surface and the back, which is more prone to react to thermo-hygrometric variations of the environment. These undesired deformations required an intervention to restore the flatness of the panel. This intervention led to an excess of reparation that caused an irregular arrangement of the painted surface, which was further enhanced by the lack of a containment system.

Also, the choice of this botanical species deserves a comment: cypress wood is very durable, it has a sacred meaning, it is a symbol of access to eternity. This species was also used for wooden icons, i.e. the icon of the Theotokos housed in the church of Santa Maria in Trastevere [47].

3.4 Wiggle matching dating

Wood species as Cypress (*Cupressus sempervirens* L.) are not suited for dating techniques based on dendrochronology [48][49] due to their growth peculiarities and to the lack of reference chronologies for the Italian area. For this reason, we applied wiggle matching dating. In Table 3 we show two results from radiocarbon measurements: the not calibrated one (BP, i.e. Before Present referred to year 1950) and the calibrated one (BC/AD), with the absolute error of the measurement [40]. Conventional radiocarbon dating has been corrected for the effects of isotopic fractionation both through the measurement of $\delta^{13}C$ (isotropic fractionation of ^{13}C), and through the calculation of the background values [41],[42].

Table 3. Radiocarbon dating, not calibrated and calibrated, with the absolute error.

Sample	*$\delta^{13}C$ (‰)*	***Radiocarbon Age* (BP)**	**Calibrated 14C-age (2σ, yr cal BC/cal AD)**
CDD1	-31.6 ± 0.6	507 ± 45	1311AD-1458AD (95%)
CDD2	-27.0 ± 0.4	490 ± 45	1317AD-1477AD (95%)
CDD3	-30.4 ± 0.6	335 ± 45	1457AD-1645AD (95%)

The wiggle matching analysis of the radiocarbon data allowed for refining the dating as shown in Fig. 9 and Table 4.

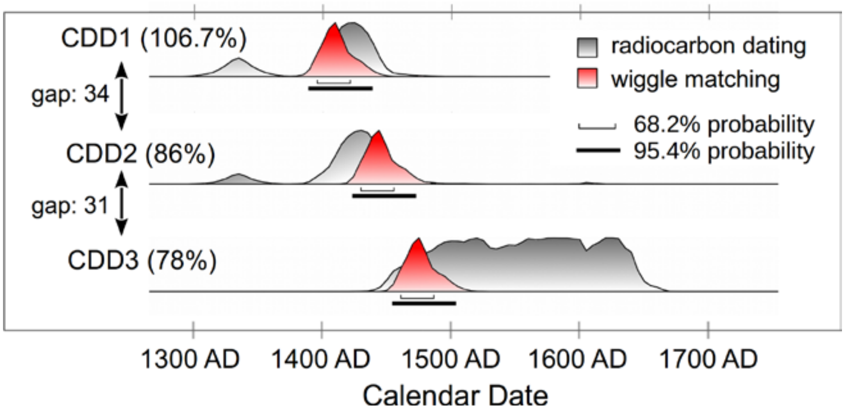

Figure 9. Wiggle matching analysis of the radiocarbon dating. The values in brackets are the agreement indices, conveying the robustness of the wiggle matching technique and the accuracy of the measurement. Atmospheric data from [45]. Data elaborated with OxCal v3.10 Bronk Ramsey (2005); cub r:5 sd:12 prob usp[chron].

This technique places the most recent sample (CDD3) in year 1478,5 ± 24,5. By adding 23 years (rings) to this range, we could date the outer edge of the panel. Hence, the dating of the painting table (*terminus post quem*) is established in year 1500 ± 25.

Table 4. Dating of CDD3 sample obtained through the application of the wiggle matching technique.

Sample	Calibrated 14C-age (2σ, yr cal BC/cal AD)
CDD3	1454AD-1503AD (95.4%)

The result of the radiocarbon dating refers to the last tree rings visible on the wooden panel, which was generated when the tree was still alive. To identify the date in which the painting has been made, a certain period of time, which is impossible to establish with certainty, must be added to the dating. This period is related to the wood loss due to the trimming of the panel and to its possible seasoning. Even taking into account these aspects, the dating of the panel definitely places the Crucifixion in the first decades of the 16th century, which is compatible with the period of more intense friendship between Michelangelo and the Marquise Vittoria Colonna during her stay in Viterbo (1541-1544) and of their connection with the Spirituali in the town. For art-historians this is a result of paramount importance. In fact, beyond the attribution of the painting to Michelangelo or other artists of his workshop, the painting represents the only remaining testimony of an important historical moment for the city of Viterbo and for the main European religious debate in the first decades of the 1600s.

4. Conclusions

In this paper, we reported a multi-disciplinary analysis of the enigmatic Viterbo Crucifixion panel painting attributed to Michelangelo Buonarroti. The study enabled to shed light on various aspects of the painting, as the pictorial technique, the paint materials and the dating of the wooden panel. Such valuable information assists art–historians to locate the artwork in the proper historical framework.
The present paper combines the study of the painting color palette, through HSI of the entire painting and XRF spectroscopy of selected points of interest, with the analysis and dating of the wooden panel of the painting.
The complementary hyperspectral and XRF data revealed considerable presence of the precious ultramarine blue and vermillion pigments in large areas of the painting, hence confirming the importance of the painting committer. In addition, the use of a radial plank, a single piece with no particular defects, and the botanical species of excellent durability, indicate that the table choice was based on a solid knowledge of wood. Also such high quality generally marks a wealthy commissioning, as could be that of Vittoria Colonna.
Finally, the wiggle matching dating locates the *terminus post quem* of the painting around AD 1500±25. This is a very relevant information for art historians, because the first half of the 16th century was important for the religious debate, as widely explained in [2]. According to art historians, the pictorial elements of the Crucifixion and the dating results reported here, are crucial to definitively locate the artwork in the period of *Spirituali*.

Acknowledgements
This work was made possible thank to the Society Archeoares that runs the Museum of Colle del Duomo of Viterbo, where the Crucifixion is exposed and also to the Association *Egidio17* that gave us a great support in the historical and artistic study of the painting. Specifically, the authors would like to thank Dr. Gianpaolo Serone, founder member of Archeoares, who helped us to obtain the permission of investigating the painting and performed the careful examination of the ruins in the background of the Crucifixion, and Dr. Antonio Rocca, art historian and member of *Egidio17* who carried out the historical research and constantly addressed us in the diagnostic campaign. Lastly, the authors would like to thank Dr. Elisabetta Gnignera, also member of *Egidio17* and Costume Historian, Specialist in Renaissance Costume, who studied the peculiarities of the Crucifixion with special attention to the Magdalene garment and to Christ loincloth.
This work was partially supported by the individual financial support to the basic research activities (FABR 2017 by Law 232/2016 to A. Lo Monaco and C. Pelosi).

This work was partially supported by the Italian Ministry for education, University and Research (MIUR) for financial support (Law 232/2016, Italian University Departments of excellence)—UNITUS-DAFNE WP4.

Author Contributions: conceptualization CP, GA, MB, CC, ALM, AP, CM, DC, GV; methodology, CP, ALM, MB, AP, CM, DC; validation, CP, GA, MB, CC, ALM, AP, CM, DC, GV; formal analysis, CP, GA, ALM, MB, AP, CM; investigation, CP, GA, ALM, MB, AP, CM, DC, GV; resources, CP, ALM; data curation, CP, GA, ALM, MB; writing—original draft preparation, CP, GA, MB, CC, ALM, CM, DC; writing—review and editing, CP, GA, MB, CC, ALM, AP, CM, DC, GV; supervision, CP; project administration, CP, ALM; funding acquisition, CP, ALM

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