

Article

Multispectral Imaging of the San Lorenzo Palimpsest (Florence, Archivio del Capitolo di San Lorenzo, Ms. 2211)*

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Abstract

This paper details the findings presented at the International Conference on Natural Sciences and Technology in Manuscript Analysis held in Hamburg, Germany in December 2013 on the San Lorenzo Palimpsest (Florence, Archivio del Capitolo di San Lorenzo, Ms. 2211). The San Lorenzo Palimpsest contains over 200 secular compositions from the 14th and the beginning of the 15th centuries of invaluable importance to musicologists. However, most of these pieces have not been studied in detail due to the damage sustained in creation of the palimpsest. Recently, scholars and scientists from the University of Hamburg were granted the opportunity to image the palimpsest using an advanced multispectral system from the SFB 950 'Manuskriptkulturen in Asien, Afrika und Europa' / Centre for the Study of Manuscript Cultures (CSMC) in Hamburg. While the processing and evaluation of each folio is still ongoing, preliminary results are presented in the following sections.

1. Introduction

Today, multispectral imaging has become one of the standard procedures used to cope with damaged manuscripts, especially with palimpsests.¹ 'Standard' means the general way of pro-

ceeding here. However, the development of powerful new cameras and scanner systems is still continuing. Besides the fact that new technologies continue to be developed, this field is driven by the manuscripts themselves, which require the development of specific methods as each manuscript is unique and has particular characteristics as a result of its history.

This article seeks to present a case study on imaging the palimpsest Florence, Archivio del Capitolo di San Lorenzo, Ms. 2211. This manuscript is entitled *Campione dei Beni, 1504* and was used to record church properties well into the 17th century. By the end of the 15th century it was made of 111 parchment folios that originally belonged to a music manuscript compiled around 1420 in Florence. Having such a big collection of music from the first few decades of the 15th century in the form of a palimpsest is extremely rare since musical palimpsests from the 15th century usually only survive as fragments or are simply the result of corrections or new scribal initiatives within music manuscripts.² Fig. 1 shows an example of how the manuscript appears today with only faint remains of the original musical notation.³ Nearly all the surviving folios from the original music manuscript contain overwriting, with the exception of fols. 8r+v, 24v, 33v, 79r–80v, 83r, 86r+v, and 90r–109v.

* This article introduces work in progress on the San Lorenzo Palimpsest that will result in the forthcoming publication *The San Lorenzo Palimpsest: Florence, Archivio del Capitolo di San Lorenzo, Ms. 2211. Introductory Study, Commentary and Images*, edited by Andreas Janke and John L. Nádas (Lucca: Libreria Musicale Italiana). We would like to thank Monsignor Angelo Livi, Prior of San Lorenzo in Florence for kindly allowing us to image the San Lorenzo Palimpsest. We would also like to give special thanks to John L. Nádas. Further thanks go to Boryana Pouvkova (who took part in the imaging in Florence) and to Christian Brockmann, Roger L. Easton Jr., Ugo Giani, Giuseppe de Gregorio, Oliver Huck, Vito Lorusso, Sonja Puccetti, Miriam M. Wendling, and Francesco Zimei. The research for this article was carried out within the scope of the work conducted by the SFB 950 'Manuskriptkulturen in Asien, Afrika und Europa' / Centre for the Study of Manuscript Cultures (CSMC) funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG).

¹ The advantages of this technique regarding palimpsests have been discussed intensively in the past in connection with a variety of projects (Archimedes Palimpsest, Rinascimento Virtuale, Sinai Palimpsest Project).

² See for example Nádas and Ziino 1990, Memelsdorff 2004, and Mecconi 2011. For a list of music palimpsests from a different context, see Moran 1985.

³ See for example the remains of the underwriting between the last two paragraphs of the overwriting.

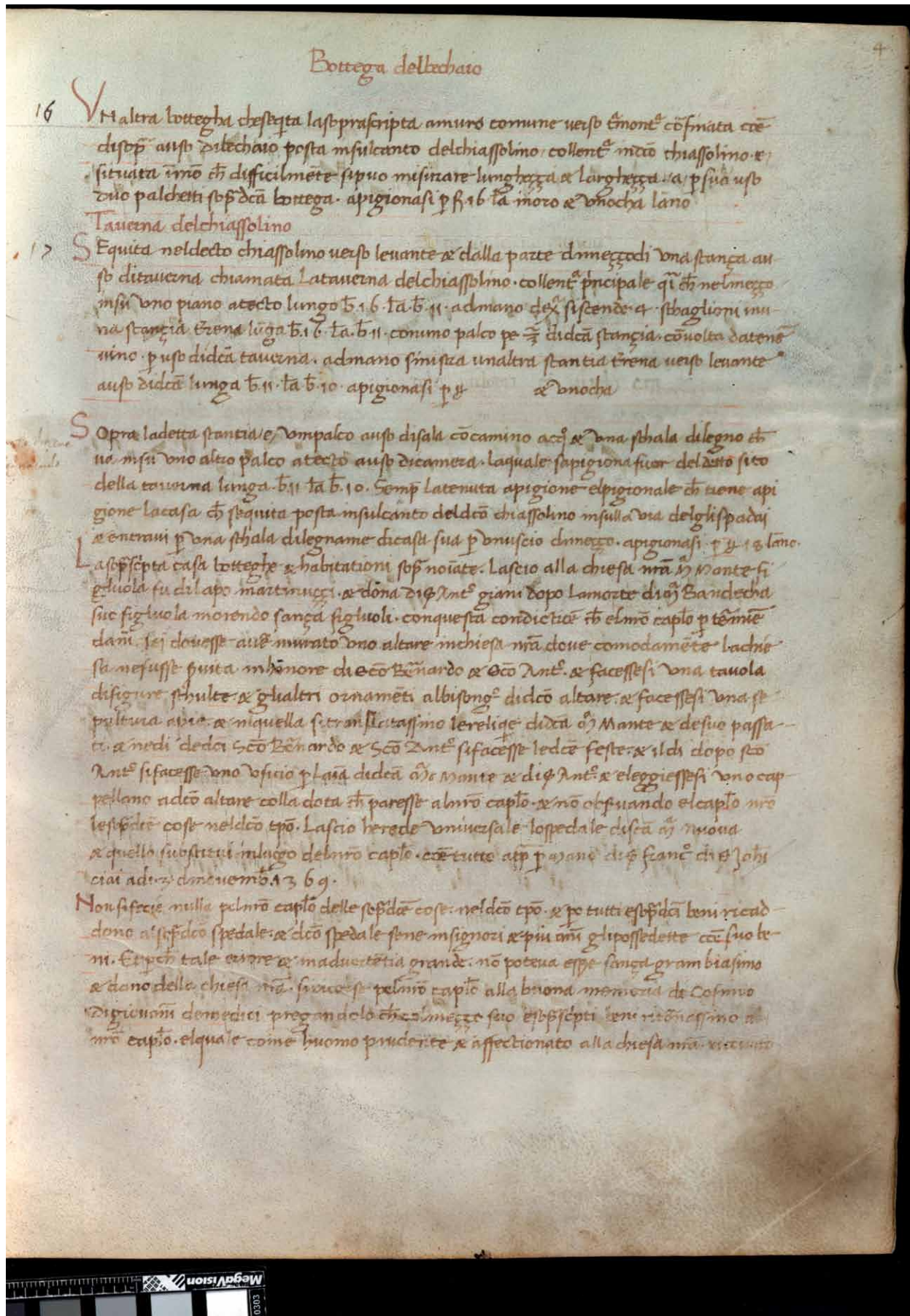


Fig. 1: ASL 2211, fol. 4r; the manuscript as it appears today with only faint remnants of the original musical notation.

The discovery of the San Lorenzo Palimpsest was reported in 1982 by the musicologist Frank A. D'Accone,⁴ who emphasised the importance of the manuscript as it contains the remains of what had once been a vast collection of mainly Italian secular polyphonic music. The pieces were composed between the 14th and the beginning of the 15th century and therefore belong to the Trecento repertoire, or the so-called *Ars Nova Italiana*.⁵

Since this discovery, scholars have tried to identify the compositions – a difficult task not only because of the scraped content, but also because of the fact that by the end of the 15th century the manuscript had been completely disassembled in order to be scraped and then put back together in a different order for the *Campione dei Beni*. Therefore the compositions appear in the wrong order today. Furthermore, in many cases, the two or three voice parts of one composition which were originally arranged on one opening⁶ are now separated and have to be located. In 1984, John Nádas undertook the first reconstruction of the original gathering structure.⁷ The only aids available then were ultraviolet (UV) lamps and later, in 1989, photographs taken under UV light, which led to a revised version of the gathering structure that year.⁸

There is no question about the importance of the collection, which not only includes new readings for compositions known from other contemporary manuscripts, but which, more importantly, contains completely unknown compositions by Italian composers from the beginning of the 15th century, most of whom were connected to the Florentine cathedral *Santa Maria del Fiore* as organists or singers, including Giovanni Mazzuoli († 1426), his son Piero († 1430) and the music theorist Ugolino da Orvieto († 1452).

In 2000, the *Digital Image Archive of Medieval Music* (DIAMM)⁹ started the first imaging campaign to provide scholars with high-resolution digital images (natural light and ultraviolet) from the palimpsest, permitting them to

apply several digital restoration techniques using software like Adobe Photoshop.¹⁰ However, despite the availability of the DIAMM images and the new techniques for enhancing the musical notation, the contents of the San Lorenzo Palimpsest were usually still described as 'unreadable' and therefore research focusing on the music and the context of this collection was limited.¹¹

This article will report on a new imaging campaign – this time using multispectral imaging – that took place in the summer of 2013 in the Archivio del Capitolo di San Lorenzo in Florence. It describes the first steps in developing methods to finally create a publishable set of images that enhance the original musical notation. One of the advantages of using multispectral imaging is that no decision on what information belongs to the underwriting is needed from the scholar in the early stages of the work. However, every change in the image's appearance has to be made transparent to scholars¹² since the final processed images are by no means perfect representations of the original manuscript. Therefore these images will contain unambiguously falsified colours, which not only result in better contrast between over- and underwriting for the reader, but the images cannot be mistaken for the original state of the manuscript.

2. Multispectral imaging

In the past few decades, multispectral imaging has emerged as a vital tool in the recovery of lost writing in manuscripts. The ability to record information beyond what the human visual system can see and interpret is indispensable for cases like palimpsests, where the person who scraped the *scriptio inferior* deliberately tried to remove all visible information. In many ways, the imaging and processing done in this project were inspired by the Archimedes Palimpsest project.¹³

⁴ D'Accone 1984.

⁵ An overview of the music of the Trecento can be found in Gozzi 2011.

⁶ For the layout of music manuscripts, see Schmidt and Vorholt 2009.

⁷ Nádas 1992.

⁸ John L. Nádas, 'The Lucca Codex and MS San Lorenzo 2211: Native and Foreign Songs in Early Quattrocento Florence', paper presented at the 55th Annual Meeting of the American Musicological Society, Austin, Texas, 27 October 1989.

⁹ <http://www.diamm.ac.uk>

¹⁰ DIAMM has organised many workshops on how to perform digital restoration and also provided a very useful workbook (Craig-McFeely and Lock 2006) which is available online (<http://www.diamm.ac.uk/publications/digital-restoration-workbook>).

¹¹ New research for example is found in Huck and Dieckmann 2007, Gehring 2012, 124–134, and Janke 2013 and 2014. A PhD dissertation focusing on the unique compositions in the San Lorenzo Palimpsest is currently being prepared by A. Janke.

¹² For a discussion on ethical considerations in image enhancing, see McFeely 2012.

¹³ Christens-Barry, Easton, and Knox 2011.

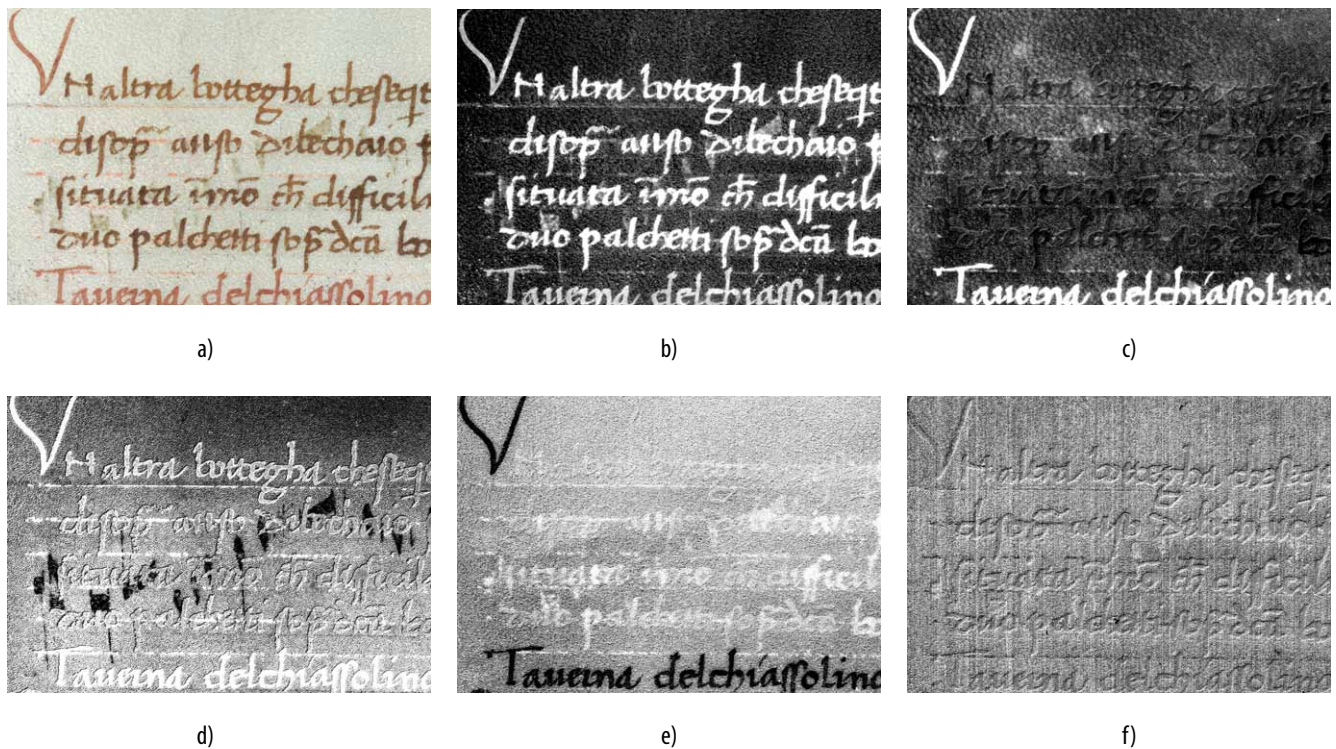


Fig. 2: ASL 2211, comparison of detailed area of fol. 4r: a) appearance under natural light; b) PCA band 1; c) PCA band 3; d) PCA band 6; e) PCA band 10; f) PCA band 20.

The camera and light system¹⁴ used for imaging in this study employs a 50-megapixel monochromatic camera, 13 different wavelengths between 365 and 1,050 nm, five filters and two raking lights in blue and infrared.¹⁵ The system is portable, so it was possible to transport it to the Archivio del Capitolo di San Lorenzo to image on site in one of the archive's rooms prepared to accommodate all the equipment. This included a cradle specifically designed to hold delicate manuscripts.¹⁶ Since it was not possible to remove folios from the binding and produce images of each page individually, an acrylic plate¹⁷ was placed over each folio to keep it standing upright and to keep the book from closing. The entire manuscript was imaged in two weeks, including the binding and notes folded into the cover accompanying the text.

¹⁴ The system was developed by Megavision (see http://www.mega-vision.com/cultural_heritage.html).

¹⁵ The wavelengths used were 365 nm, 455 nm, 470 nm, 505 nm, 535 nm, 570 nm, 625 nm, 700 nm, 735 nm, 780 nm, 870 nm, 940 nm, and 1,050 nm. The filter set included UV pass, UV block, red, green and blue.

¹⁶ The Traveller's Conservation Copy Stand was developed by Manfred Mayer on behalf of VESTIGIA, the Manuscript Research Center at Graz University, Austria.

¹⁷ Theoretically, the acrylic plate would increase scattering under UV light, but the impact is negligible in practice.

The five filters allow both reflectance and fluorescence images to be captured. Fluorescence describes the phenomenon of light being absorbed and then re-emitted at a longer wavelength (lower energy). Filters are used to isolate a specific band of fluorescence; illuminating the manuscript in ultraviolet light and using a green filter would cause the camera to only capture green fluorescence, for example. Often, parchment fluoresces under UV light, creating an image where the background support appears to glow and anywhere covered by ink remains dark. When viewing the manuscript, distinguishing between light-brown parchment and the faded brown ink of the underwriting can be quite difficult, so the fluorescence images play a critical role in the imaging of palimpsests.

Another problem deals with the issue of 'show through', where it is difficult to distinguish whether a particular note or a group of notes is from the back of the parchment or the side the reader is viewing. In order to mitigate this problem, light must be prevented from reflecting from the page underneath and then being transmitted back through the target page. Since the manuscript could not be unbound to image each folio separately, a sheet of black, acid-free paper was placed between the target folio and the one behind it to absorb any transmitted light and prevent it from being reflected back and travelling through the target folio on its way to the camera.

A total of 24 different reflectance and fluorescence images were taken of each folio, which were flattened (a form of pre-processing and calibration) on capture with images taken of a blank, white target. All of these captured images, except four which were raking-light images,¹⁸ were included in the current processing work using the statistical methods of principal component analysis (PCA) and occasionally independent component analysis (ICA)¹⁹ implemented in the Excelis ENVI software package.

3. Processing

The task of rendering captured multispectral images into a legible, publishable set of images of a palimpsest manuscript involves several steps. First, statistical techniques are applied to differentiate different kinds of information in the captured images. Second, perception-based decisions are made to render the results from the statistical techniques into a series of legible images for musicologists or other scholars.

Both PCA and ICA are eigenvector rotational transformations that produce the same number of output images, or bands, as input images used. It can be useful to think of these output images as analogous to displaying the differences between the captured images, where ideally at least one output image would show the difference between the parchment and

the traces of underwriting. However, the more subtle the differences, the more likely random noise is to overwhelm the results, making many of the output images of no consequence.

Fig. 2 shows a selection of PCA output bands (b–f) along with the natural light image (a). While there is little difference visually between the red and brown ink in the natural light image, output bands (c) and (e) enhance this small difference, as does (d) with respect to the musical notation.

The generated output bands can now be used to create pseudo-colour images, a technique that allows us to combine up to three greyscale images into one colour image. Using this method, it would be possible to display both the underwritten music and the overwriting in the same image and distinguish them from one another, a necessity since it is important for the reader to know where overwriting might be covering underwriting. If the overwriting is removed completely or looks like the parchment background, the reader might not be able to judge the visible outcome properly.²⁰ In the case of a music manuscript, for example, the note head of a *minima* (♦) might be covered completely by the overwriting, so what would be left would only be a small vertical line. If the overwriting is not recognisable as such, the remains of the *minima* might be mistaken for a rest, falsifying or at least confusing the process of transcribing the respective composition.

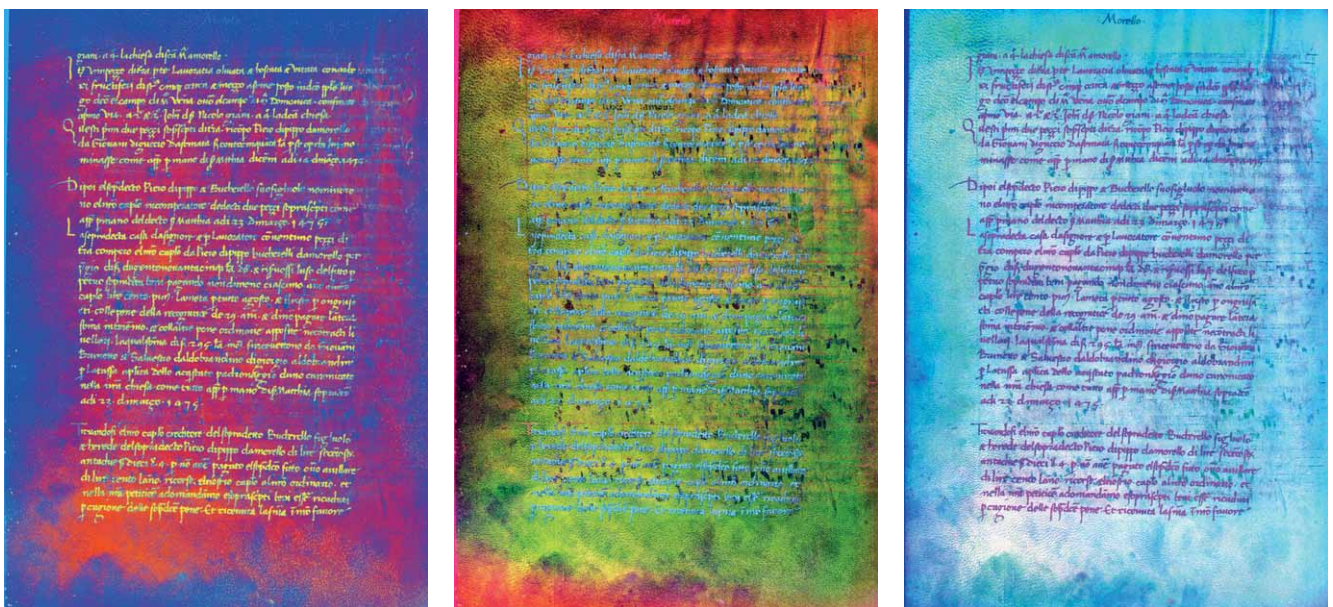


Fig. 3: ASL 2211, fol. 30v; initial attempts at creating pseudo-colour images.

¹⁸ The use of raking lights allows the capture of topographical and texture information relating to the folio. However, any buckling and warping can lead to dramatic shadows which overwhelm the subtler signal from the faded ink.

¹⁹ Christens-Barry, Easton, and Knox 2011.

²⁰ As has been discussed intensively in other projects (Christens-Barry, Easton, and Knox 2011).

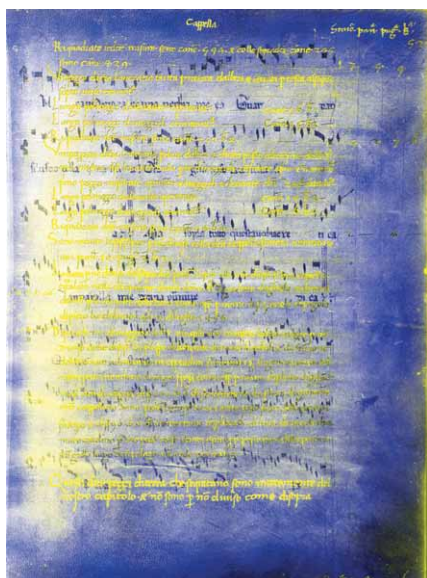


Fig. 4: ASL 2211, fol. 4r, detail; combining red, green and blue channels to create a pseudo-colour image.

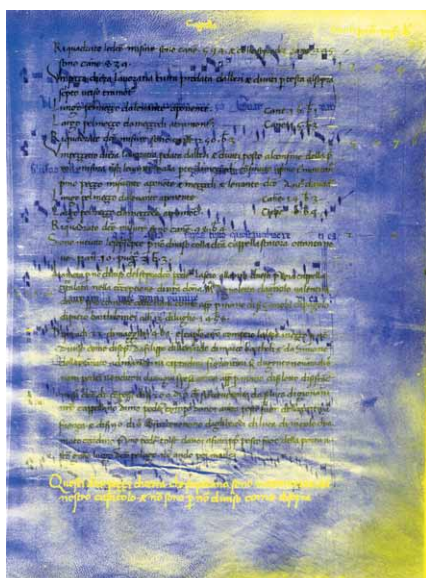
Creating pseudo-colour images provides the researcher with the opportunity to combine up to three images (captured or processed) into the red, green and blue channels of a colour image instead of having to choose a single image to represent all the information and details on a page. By trying out several colour combinations, we found this could create results with chaotic and distracting colours that might overwhelm the data being displayed (fig. 3). This led to the search for a simplified and consistent colour scheme that could be applied throughout the manuscript as it was important to have a standardised colour scheme that both enhances the readability of the set of publishable images and preserves some continuity throughout the work. In order to

achieve this, a set of criteria was needed to define a suitable image combination.

Since black text on a white background is the most familiar colour combination and the easiest one to read, creating images with the musical underwriting in black (or at least as dark as possible) on a light background became a starting point for developing the colour scheme. The challenge here was that some folios produced many processed output bands suitable for creating pseudo-colours, while others required the use of substandard images for the second and third colour channels. What was required was a method that would work with only a single useful processed image, would be consistent from one folio to the next and would display the



a)



b)

Fig. 5: ASL 2211, fol. 52r; a) PCA band 4 and b) PCA band 7.

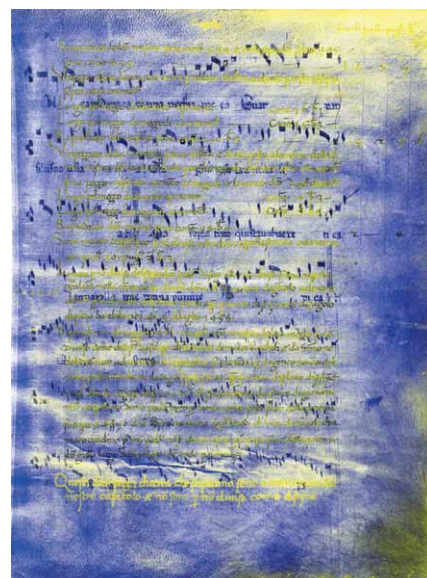


Fig. 6: ASL 2211, fol. 52r; mean of PCA band 4, PCA band 5 and PCA band 7.

two sets of writing and background in a way that made them clearly distinguishable from one another.

4. Our pseudo-colour method

We found that instead of trying to include as much information (and therefore as many colours) as possible, selecting the best processed output band of a folio and using it twice for both the red and green channels was a better approach. This had the advantage of keeping the colours consistent with dark underwriting, and only one acceptable output image was required. If necessary, the image that displayed the underwriting most clearly would be inverted to keep the musical notation as close to black as possible. The 455 nm blue reflectance image was used in the blue channel of the pseudo-colour. The blue image shows the difference between the parchment and overwriting well, but not the underwriting. It helps to separate the two sets of writing when combined with the red and green channels, as in fig. 4.

Using an image with distinct underwriting twice also means that two of the three channels display the underwriting as dark script, resulting in the musical notation being displayed in dark blue or black. While only using a single image to represent the *scriptio inferior* instead of three is a good solution for well-scraped pages, there is also a chance that by using only one of many good results, a great deal of useful information for other folios will be discarded. In some instances, there are many options from which to choose, each with their own pros and cons. Fig. 5 shows two pseudo-colour images (a and b) based on different processed output bands (PCA band 4 and PCA band 7), for example. In (a), it is especially difficult to distinguish the music on the left-hand side of the first image, which hides information, while image (b) does not provide enough contrast between the over- and underwriting to distinguish them both clearly.

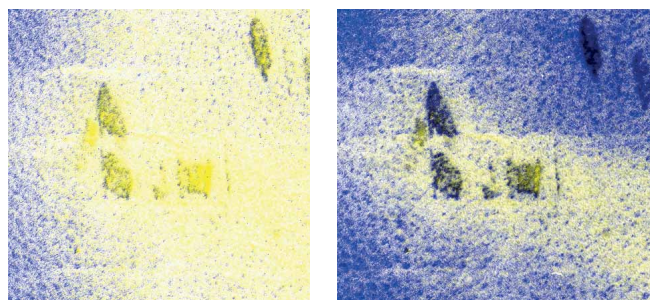


Fig. 7: ASL 2211, fol. 52r; details of figs. 5a and 6.

While neither image is ideal on its own, the mean of these two (or more) images performed in ENVI can preserve the contrast of the first (a) and the left-hand margin details of the second (b), as in fig. 6. This image preserves the contrast between the overwriting and underwriting notation from fig. 5a, but is not as susceptible to the problems of the left-hand margin in fig. 5b, mentioned above. Combining two or more images helps to mitigate the possible disadvantages of only being able to select one image and reduces the influence of very light or very dark areas on the readability of the underwriting.

A rest which appears as a small vertical line, can be used to demonstrate how details may be lost or recovered based on the band – or bands in the case of the mean used in fig. 6 – chosen (see details in fig. 7).

5. Results

It is important to keep in mind that there was a deliberate attempt made to erase the music. Therefore it must be emphasised that while multispectral imaging has produced an improvement on every examined folio compared to the actual state, it is impossible to recover anything that was completely removed due to the palimpsest creation process. In sum, the use of the method described above has been a success for the majority of folios processed to date. Fig. 8 shows the capabilities this method possesses (compared to the present state as shown in fig. 1). However, there are still a number of challenges to overcome such as folio 30v, shown in fig. 9: this folio suffered more from scraping than fol. 4r, for example (figs. 1, 2). Other techniques that are more powerful will therefore be necessary to further enhance and recover the music on the folio. While PCA and ICA are the default processing approaches, this project is by no means limited to those methods, and more techniques will be explored as needed.

The method presented here is designed to display the captured data in such a way that it is easy for scholars to read and study the musical notation. However, this requires an acceptable, legible processed image, which is sometimes a challenge in the case of particularly well-scraped or damaged folios. Uneven scraping, patching and other factors that vary spatially across a single page can contribute to output images that also vary from region to region. For example, it is not unusual for folios to have areas that are especially well scraped. These have different properties than the rest of the page.

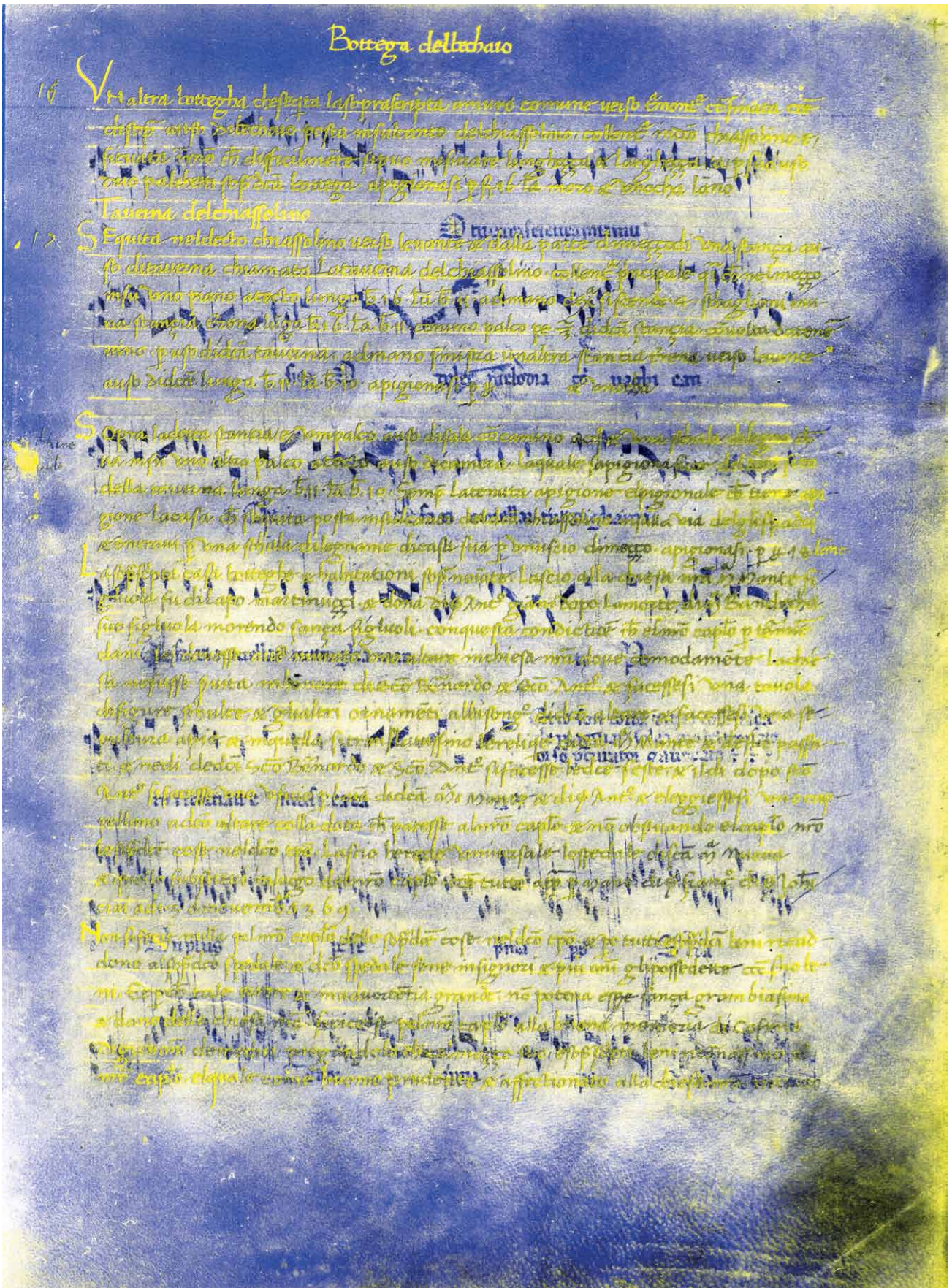


Fig. 8: ASL 2211, fol. 4r; pseudo-colour processed image showing the tenor voice of Giovanni da Firenze’s madrigal *O tu cara scienza* and another French piece, *Con plus je se*, (added as a ‘space filler’) as *scriptio inferior*.

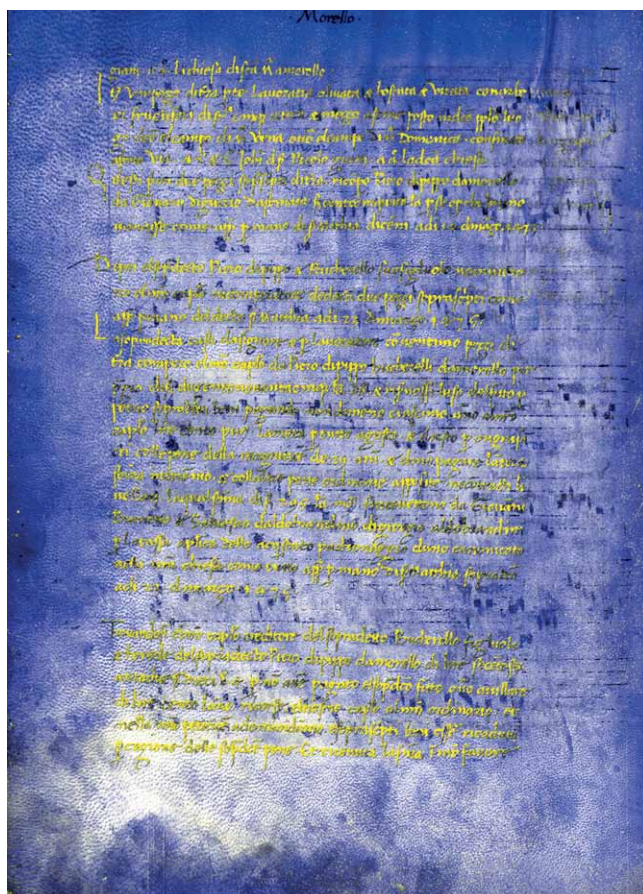
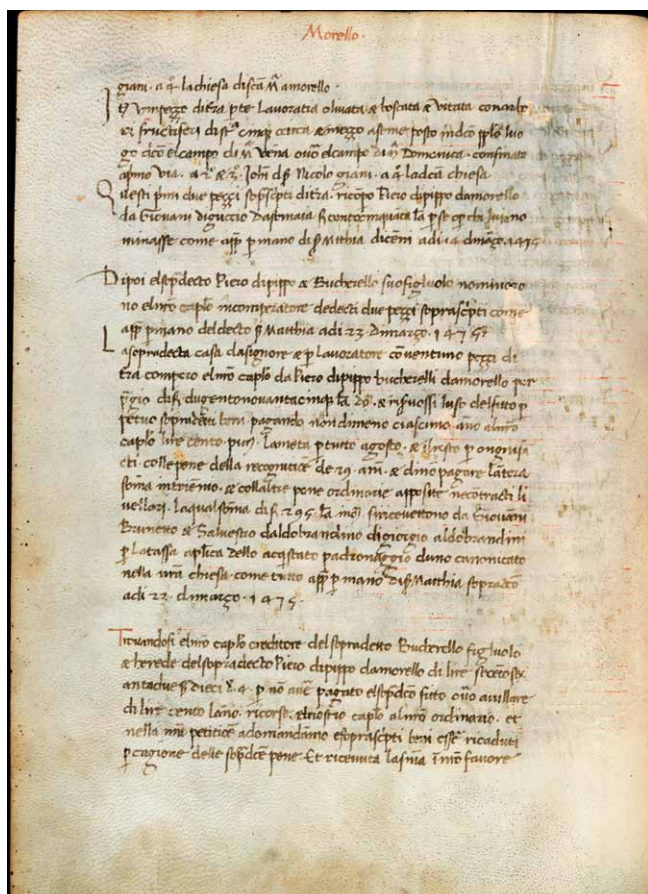


Fig. 9: ASL 2211, fol. 30v; present state of the folio compared to a pseudo-colour image created by the method described above.

The several different colours of ink used in the overwriting affect the colour distribution in each image, expanding this from a two-class to a multi-class problem. There may be four or even five different inks²¹ with different spectral properties, all contributing signals that influence the processing.

The criteria required for an acceptable image are focused on the underwriting as the ‘interesting part’ or signal, and other parts of the original music manuscript will not necessarily be enhanced as well. This is particularly true for red ink that was used for the staves, composer attributions, roman foliation numbers and the groups of red notes found in one composition. This suggests that by using the current method, several images may be needed to fully recover different layers of information within a single folio. Fol. 11v represents a special case since it contains many types of inks in the overwriting, which means that each ink region has

different statistical relationships between the overwriting, underwriting and the parchment. Processing the entire page as a single entity can cause the subtle differences the method aims to enhance to be overshadowed by stronger signals. Processing each area as a separate region can consequently lead to better results, as in fig. 10, which shows the beginning of a verse. The group of notes and the first syllable of the text underlay ‘Si-’ comes out much better when processing a small area compared to processing the whole folio.

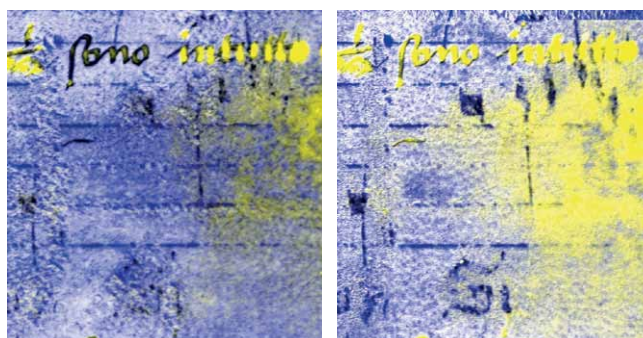


Fig. 10: ASL 2211, fol. 11v; detail, a) processing the whole page, b) processing a particular area.

²¹ E. g. red overwriting, which is a little darker than the red underwriting, one or more sets of dark brown or even black overwriting due to the different scribes over the centuries, red underwriting, which is used for composer attributions and roman foliation (only on recto pages) both found in the upper margin, the staves and small groups of red notes in one piece of music, and finally the brown underwriting of the notation and text underlay.

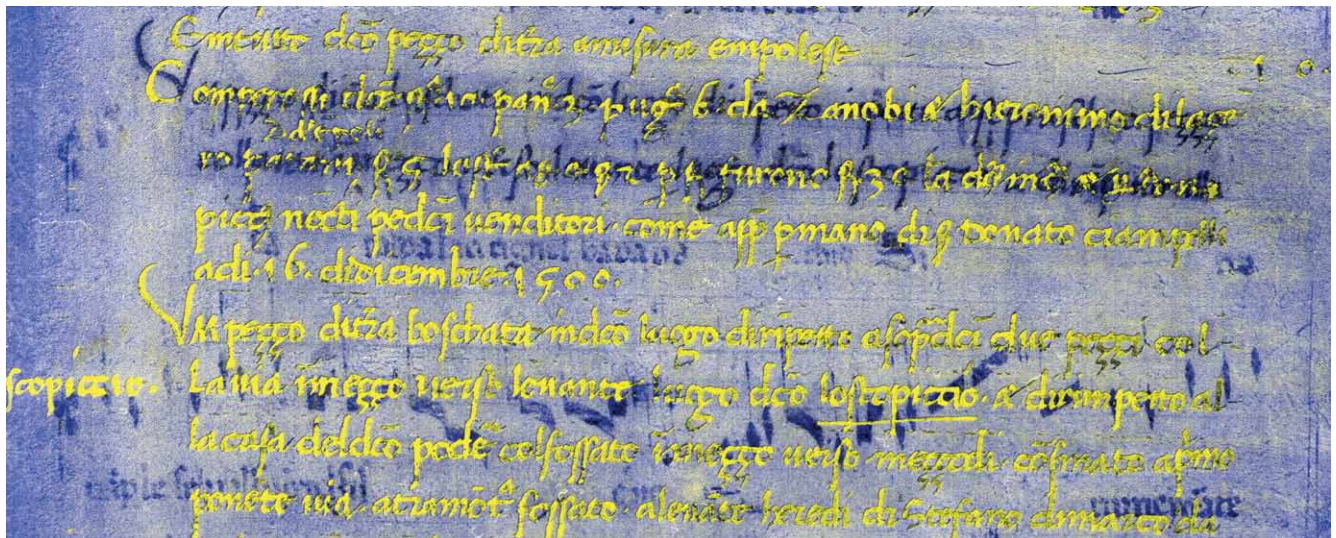


Fig. 11: ASL 2211, fol. 58r, detail.

Despite the challenges mentioned above, the results to date show improved readability of the original music and the text underlay in the *scriptio inferior*. In the case of fol. 4r (fig. 8), it is now possible to decipher the incipit of the added French composition *Con plus je se*.

Due to the fact that it is not necessary to decide which script belongs to the underwriting and to the overwriting in the first steps, unexpected outcomes can arise, as in the case of fol. 58r. In general, the separation between the music in the *scriptio inferior* and the overwriting is clear (fig. 11).

Surprisingly, another layer of erased text showed up in dark blue from part of the *Campione dei Beni* (in fig. 11). This provides an insight into the making of the manuscript. Apparently, after the scribe had copied the two lines beginning ‘Un pezzo di terra boschata in dicto luogo [...]’, he realised that he had left out a whole paragraph from his exemplar, so he erased the two lines and carried on with his work.

One significant further step regarding the compositions transmitted as *unica* in this source features a specific piece by Giovanni Mazzuoli. The organist and composer has been described as an ‘enigmatic figure’²² due to the fact that a section was laid out for his music in the lavishly decorated Squarcialupi codex²³ made in Florence around 1415. However, his compositions were never written down in the codex (fig. 12). This is also the case for Paolo

da Firenze, another Florentine Trecento composer whose compositions are known from other sources. Thanks to the specific decoration system of the Squarcialupi codex, it was possible to identify the madrigal *Girand’ un bel falcon* as the opening piece of Paolo’s section.²⁴ What proved helpful in the identification process was the historiated initial and the *bas-de-page* miniature, which always refers to the text of the composition to be written above it.

With the help of the San Lorenzo Palimpsest, it is now possible to identify the opening piece originally intended for the blank section of Giovanni Mazzuoli in the Squarcialupi codex. The decoration system on fol. 195v in the Squarcialupi codex includes a historiated initial – the letter ‘C’ – and a *bas-de-page* miniature with a dancing scene (fig. 12).

On the basis of previously deciphered text fragments, Janke²⁵ has formulated a hypothesis that this decoration might have been intended for the madrigal *Chome servi a Signor*. Thanks to multispectral imaging, this hypothesis has been verified since it is now possible to transcribe the entire text of the madrigal (see below). An important link between the decoration and the text of the madrigal is the description of women dancing a round dance with one dressed in white in the centre (for the text residuum, see fig. 13).

²² D’Accone 1968, 23.

²³ Florence, Biblioteca Medicea Laurenziana, Mediceo Palatino 87. The images can be found in the facsimile in Gallo 1992.

²⁴ Günther, Nádas, and Stinson 1987, 204; Nádas 1989.

²⁵ Janke 2014, 248.



Fig. 12: Florence, Biblioteca Medicea Laurenziana, Mediceo Palatino 87, fol. 195v.

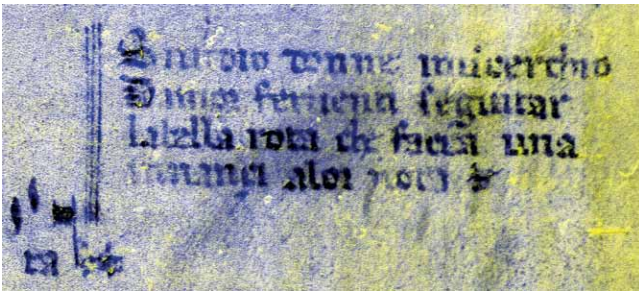


Fig. 13: ASL 2211, fol. 24v, text residuum.

Chome *servi* a signor giust'e umile
attenti a 'ntender lo suo disidero
3 e *chompresa* suo voglia e ognun legero

Si vid'io donne in *un* cerchio
D'Amor ferventi seguitar la bella rota
6 che facea una innanzi a lor nota

In biancha vesta *donçella* vestita
ch'è dat'a Lorença guido mie vita.²⁶

6. Outlook

As the project progresses, it is hoped that more of the illegible pieces will be identified, and the possibility of finding more *unica* means that the San Lorenzo Palimpsest will prove to be a treasure trove to musicologists and other scholars. The method for recovering the music is still under development, and more techniques will be tried in order to recover the more difficult pages.

By publishing the images in a printed format²⁷ (not discounting the possibility of a digital database), intensive research can finally start and can begin a new chapter in understanding the music and the manuscript's history and significance.

²⁶ Authors' translation: 'Just as servants pay heed to the just and the humble lord to understand his desire and having understood his will, everyone is light-hearted, / Thus I saw women in a circle, glowing for love, they follow the lovely round dance that highlights one of them / The maiden dressed in a white dress, which was given to Lorença, guides my life.'

²⁷ See fn. *.

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