X-ray image analysis of Lorenzo Lotto's *Husband and wife*

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ABSTRACT

Underdrawings and pentimenti reveal intermediate states of a painting and thus may shed light on the working methods of some artists. It has been claimed that Lorenzo Lotto used optical projections during the execution of *Husband and wife* (1543) and, recently, that underdrawings in that work might reveal evidence of tracing of optical projections. We analyze x-ray images of this painting—captured under careful, museum-laboratory conditions and enhanced through digital image processing—with special attention to the possibility of evidence of the use of optical projections in the central passage of the depicted carpet. We also study the work *in situ* and in high-resolution macro optical images of the central portion of the carpet pattern. These photographs reveal that the top portion of the keyhole pattern is not "blurry, like an out-of-focus image," but instead was merely executed in a somewhat broader brush than was neighboring passages. Furthermore, x-ray, infra-red and visible light inspection show that the white portions and black contours were executed atop a broad layer of dark red and reveal no record of an optical projection would have been present when Lotto executed the visible portion. As such, an evidence of putative underdrawings in this region has no bearing on the optical projection claim. There is no evidence of tracing marks—in charcoal or in any medium—in the top, visible portion of this passage either. As such, this visual, infra-red and x-ray evidence does not support the claim that this painting was executed under optical projections. We also discuss the difficulties with the projection theory with special reference to Lotto's preparatory drawing in the Rijksmuseum—specifically the need for a needlessly complex optical system (two lenses rather than one). We also review briefly contemporary textual evidence in early 16th-century Venice that has been used to support the optical projection claim for Lotto and conclude that it also fails to support the projection claim for this painting.

Keywords: Lorenzo Lotto, underdrawings, infra-red reflectography, Hockney projection theory, *Husband and wife*, *Family portrait*, optical aids, concave mirror projector, computer image analysis of art

1. INTRODUCTION

It is well known that some artists have used optically projected images during the execution of portions of some of their works. The earliest master for whom this procedure is securely established is Giovanni Antonio Canal, better known as Canaletto (1697–1768), who used a simple camera obscura to project cityscape images, for instance of Venice, and trace them as preparatory drawings. He would later transfer his preparatory drawings to large canvases by blocking, that is, by means of a grid.[1] Other artists for whom optical procedures is securely established include the American realist Thomas Eakins (1844–1916), who projected his black and white photographic plates onto his canvas directly and traced the images.[2] More recently, numerous photorealists, such as Richard Estes, would likewise project photographs onto their canvases and trace the images.[3] Philip Steadman has studied the works of the Dutch Golden Age master Johannes Vermeer and argued that this artist traced images projected in a large camera obscura.[4] While it seems quite likely that Vermeer *saw* such projected images, Steadman's argument that Vermeer *directly traced* projected images has not yet received broad scholarly support.[5–7]

Artist David Hockney and physicist Charles Falco have argued that artists as early as the Master of the Flémalle (1420) and Jan van Eyck (1434) traced optical projections—a date nearly two centuries earlier than

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Figure 1. Lorenzo Lotto, *Husband and wife* (1523), 98 × 116 cm, oil on canvas, State Museum Hermitage.

any scholar had ever suggested any artist employed such a method.[8,9] Their prime case is the late Renaissance Venetian master Lorenzo Lotto, whom they claim traced an image, optically projected by concave mirror or converging lens (but see below), during the execution of *Husband and wife* (1543), also known as *Family portrait*. It is this claim we examine here by mean of a close reading of x-ray, infra-red and visible light evidence in that painting and a consideration of Lotto's preparatory sketch.

In Sect. 2 we review the claim that Lotto employed optical projections directly in this work, as well as earlier evidence and arguments pro and con. In Sect. 3 we briefly review some of the sensor technology for revealing underdrawings in paintings, both in the conservation studio and in museum settings. In Sec. 4 we describe our close reading of the work and its x-ray image as they relate to the projection claim, and in Sect. 5 we summarize our conclusions.

2. THE TRACING THEORY AND *HUSBAND AND WIFE*

As mentioned, Hockney and Falco claim that some artists as early as the Flemish Master of the Flémalle (1420) secretly traced optically projected images during the execution of some of their works, and that this procedure was a key source in the rise of realism—or "opticality," as Hockney calls it—in the art of that time.[8]

Figure 2. Lorenzo Lotto, preparatory drawing for *Husband and wife* (1543), 16.9 × 21.5 *cm*, ink and red pencil grid on paper, Rijksmuseum, Amsterdam. (The red grid was likely added by another artist to aid in copying the work.) The left-right parity[10] of this work matches that of the painting (Fig. 1); this is important evidence for any optical theory. Both a concave mirror and a *pair* of converging lenses will preserve the parity of projected images, while a simple converging lens (such as a traditional camera obscura) would reverse the parity of the image.[11]) Thus if Lotto wanted to set up his carpet in his studio to yield a projected image with the same overall orientation (parity) as in this preliminary sketch, he would have had to use a concave mirror or *two* converging lenses. Sophisticated computer ray-tracing simulations show that the concave mirror setup by Hockney and Falco simply cannot work, since the inclusion of the canvas precludes the kind of depth of field effects they infer.[12] Thus Lotto would have had to use an extremely complex (for its time) *two* converging lens projector. In short, the existence of this preparatory study, and its parity shows the projection explanation is even less plausible than previously thought. (Photo by DGS.)

Hockney and Falco consider Lorenzo Lotto's *Husband and wife* of 1543 (Fig. 1) to be their "Rosetta stone," which "proves" the artist traced and optical projection, claiming that "it simply is not possible" the artist did not use optics.[8,9,13] These optical proponents believe Lotto placed the table out in direct sunlight (needed to create a sufficiently bright image[14]), enclosed the canvas with some manner of baffles (to block stray light), projected an image of the carpet onto his 116-wide canvas, traced that image (likely in charcoal), then applied paint. (Pencils were unknown at that time.) Based on his frustrating attempts to paint under optical projections, Hockney has stated numerous times that no artist—including Lotto—would paint *directly* under projections. For instance, an artist would find it difficult to distinguish the dim image and the applied paint, and it is extraordinarily difficult

for the artist to get the colors correct because the illumination is itself colored.[14]

Hockney and Falco's putative projector would have a limited depth of field,[11] and thus they claim that the artist would have refocused his projector in order to obtain a sharp image throughout the range of depths. The theory's proponents adjust a number of parameters—x-, y- and z-location of the concave mirror, its focal length f, its diameter d, the depth of the first focus, etc.—in order to fit some (but by no means *all* relevant) image evidence in the painting. The evidence generally centers on shape irregularities in the carpet pattern.

As noted elsewhere, [12,15,16, among other publications] such a projector would have been the most complicated optical system on the planet—the early Renaissance world's "Hubble Telescope." The possible presence of the optical components (lenses or concave mirrors) does not mean they were understood and configured for projection onto a screen, the first step in the proposed Hockney-Falco procedure. Incidentally, as Sara Schechner, a curator of historical scientific instruments at Harvard has pointed out when reviewing the claims by Hockney and Falco, sufficiently high-quality concave mirrors likely did not exist at that time.[17] Moreover, the "mirroring" process—vaporizing aluminum or other metal onto polished glass—did not exist in Lotto's time. In fact, the world's leading optical scientists (natural philosophers) up to that time—in particular the distinguished Alhacen, who wrote 16 books on optics—never describe such a complicated projection and tracing procedure, and Hockney and Falco have given no plausible reason for this lack of documentary evidence. Historian of optics Yvonne Yiu reviewed the prior and contemporary Renaissance optics texts and concluded, "With regard to the Hockney-Falco thesis the silence of this considerable body of texts on the concave mirror projection method is deafening. Written by well-informed contemporaries who were keenly interested in the relationship between the mirror and painting and eager to impart any 'secret knowledge' to willing listeners, it seems inconceivable that they would not have described a method that according to Hockney and Falco revolutionized the art of their time."[18] Vincent Ilardi's thorough study of lenses, lens making, spectacles, and such, specifically highlights the unexplained lack of documentary evidence in the case of Lorenzo Lotto: "On the other hand, the evidence on the use of concave mirrors to project clear images for pictorial compositions [by Lotto] seems to be scanty or *missing altogether* except for the paintings themselves, as Falco has contended."[19] Here Ilardi relies upon—but does not analyze—Falco's claims that the paintings themselves somehow provide evidence that optics were used.

One must avoid the naive assumption that if an optical system or optical procedure is simple by 21st-century standards then it would have been simple by 15th-century standards, of course. No optical system known from the early Renaissance required a higher quality optical elements (needed to project a sharp image *onto a screen*) or a more complicated lighting arrangement (sunlight on the subject, light blocked from the screen, careful focus, etc.) than the Hockney-Falco concave mirror projector. This point was made by a broad range of international experts in a four-day workshop to devoted to testing that theory, and these experts rejected the projection claims (or at best find the claims unproven).[12,15,16,20,22–24]

Figure 5 shows Lotto's preparatory drawing for *Husband and wife*. Note that the parity of this drawing matches that in the final painting. A concave mirror projector would preserve the parity of the projected image and thus match the artistš tableau and the preparatory drawing while a single convex lens would not. In fact, that was one of the prime reasons Hockney and Falco favored the concave mirror over a converging lens. Given the manifest difficulties in using a concave mirror revealed by Robinson and Stork,[12] the projection proponents' arguments would seem to demand a very complex *two* converging lens system in order to get the parity proper.

Rigorous image analysis also rebuts the projection claim for this painting. Tyler showed that the perspective within a single putative "exposure" of the Lotto carpet was incoherent (multiple vanishing points, for instance)—too incoherent to be compatible with the Hockney and Falco stated precision in tracing.[20] Robinson and Stork showed that once the 116-cm-wide canvas was included into the Hockney and Falco setup, the concave mirror projector simply could not work as optical proponents claimed, in particular the projected images would not have gone in and out of focus as proponents claimed.[12] Furthermore, the Hockney-Falco explanation that the top of the keyhole looks "blurry, like an out-of-focus image" is unorthodox. They claim Lotto tried to reconcile his memory of a previously out-of-focus passage with his current view of an in-focus image. The fact that the Hockney-Falco concave mirror setup cannot explain the visual evidence in the painting, seems to demand that any revised projection claim be based on a converging lens, and such lenses would lead to awkward problems relating to the parity (or symmetry) of the painting, as mentioned in Fig. 5.

Figure 3. Lorenzo Lotto, *Husband and wife*, visual spectrum detail of the central portion of the carpet. Close inspection of this passage, *in situ*, shows that the top of the rosette and octagon are not "blurring, like an out-of-focus image," but rather merely executed with a brush that is roughly the same width as lower portions. The white and orange lines are executed atop the red ground and show no signs of tracing claimed by Hockney and Falco—no pencil marks, no incision marks, no indication that the white paint was applied to conform to any tracing mark, etc. In fact, at this time, black underdrawings in charcoal were not used at all by artists working on red grounds or, in Lotto's case, red imprimature. Moreover, Tyler showed that the perspective within a putative "exposure," such as the straight portions near the bottom, are in poorer perspective (inconsistent vanishing points), than is consistent with the claims of Hockney and Falco.[20,21]

The Hockney-Falco analyses rely fundamentally upon their assumption that Lotto's particular carpet was spatial symmetric, to three significant figures. Stork showed, however, that such Lotto carpets are generally more asymmetric than needed for the Hockney and Falco analysis.[25] Subsequent analysis of the symmetry of surviving Lotto carpets further confirms their significant asymmetry (even allowing for age and wear), thus confirming the rejections of the foundations of the projection argument.[26,27]

It is natural to ask: Why would Lotto want to build one of the world's most complicated optical systems and employ the world's most complicated optical procedure—unknown to the greatest optical scientists of the day—all in order to draw a manifestly simple carpet pattern? Clearly this question is relevant to addressing whether Lotto in fact *did* in fact trace a projected image, given the fact that the visual evidence hardly "proves" he did so. Moreover, Lotto executed such carpets (now named for this artist) in numerous paintings, such as *Mystic marriage of St. Catherine with Niccolò Bonghi* (1524), *The alms of St. Anthony* (1542), *Portrait of Giovanni della Volta with his wife and children* (1547), and several others. These were surely executed without the use of optics, as described elsewhere. Why would he employ a very difficult—and different—method for this one painting? Even if Lotto were to build a projector, it seems far more likely that he would project an image onto a white screen and trace it in black charcoal, rather than project an image onto a red imprimature and mark it in white.

3. IMAGING TECHNOLOGY FOR REVEALING UNDERDRAWINGS

Recent work addressed the question of optical projections in *Husband and wife* by means of infra-red reflectography.[13,28] We first examine the relevant technology itself—a simple modification of a commercial Canon camera by removal of its infra-red filter—and turn below to an analysis of underdrawings themselves.

There is a long and deep literature on the science and technology of imaging underdrawings through infra-red reflectography, x-ray imaging, as well as in the subtle challenges in the scholarly reading and interpretation of

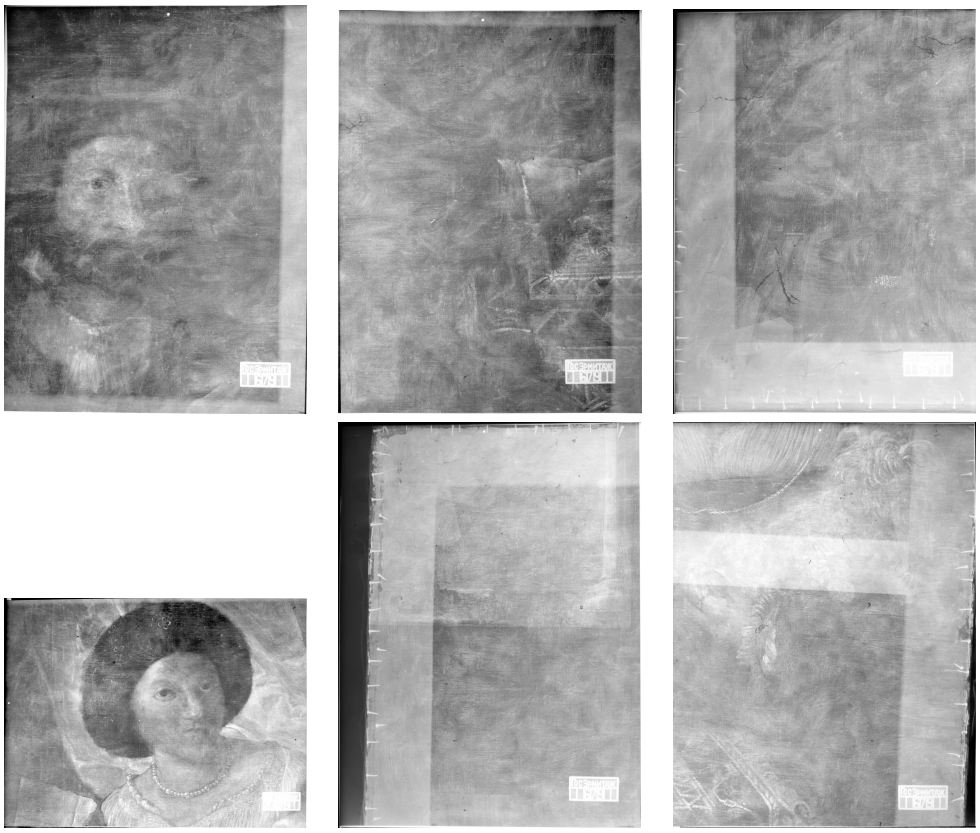

Figure 4. X-ray images of portions of *Husband and wife*—originals at 1:1 scale of the painting. Such images reveal spatial detail in lead-based underdrawings.

such images.[29–31] The reading in interpretation of underdrawings and pentimenti is a subtle skill, requiring years of training and experience and intimate knowledge of the imaging technology and its limitations. In fact, Wilhelm Conrad Röntgen himself, the discoverer of x-rays, first took x-ray images of paintings in the 19th century to reveal underdrawings and pentimenti. More recently, computer image processing methods have aided analysis of underdrawings in paintings.[32] The National Gallery London's discovery, with infra-red reflectography, of another composition under Leonardo's *Madonna of the rocks* led to a redating of the work, new connections among drawings, and more.[33] There is, too, a large literature on computer image processing of historical and cultural documents, such as palimpsests, and even standardization of such systems. [34, and references therein]

The approach of modifying a high-resolution commercial digital camera for art analysis, including in the museum setting, is nearly two decades old and very well known in the art conservation community. For instance, Kossolapov showed the properties of common lens for use in the visual range can be estimated and corrected (including for chromatic aberration) when such a lens is used in the infra-red.[35] The Canon sensor employed by Falco is sensitive only to about 1100 nm, and hence will not provide optimal penetration to the paint, and thus the images are inferior to those acquired through careful museum infra-red reflectography. As such, we do not see any new developments in the recent work of Falco.[28] In fact, Kossolapov and Sizov described a similar camera with a Si sensor for use as an instrument for infra-red reflectography in museums.[36] The modified IR Canon 5D has been available in the US since 2003 as XNITE Canon 5DIR[37] and described by amateurs and professional.[38]

Since 2007, the scientific conservation laboratory at the Hermitage Museum, home of *Husband and wife*, has used a somewhat superior camera—the STL-11000M by SBIG.[39] The camera's CCD sensor is a KAI-11002M having 11 megapixels (4008 $\times$ 2672 active pixels), each pixel is 9 μm square, in a 35 mm-format, with peak quantum efficiency of 50%, three-channel (RGB) and 16-bit on-chip A/D converter. Such sensors are often used

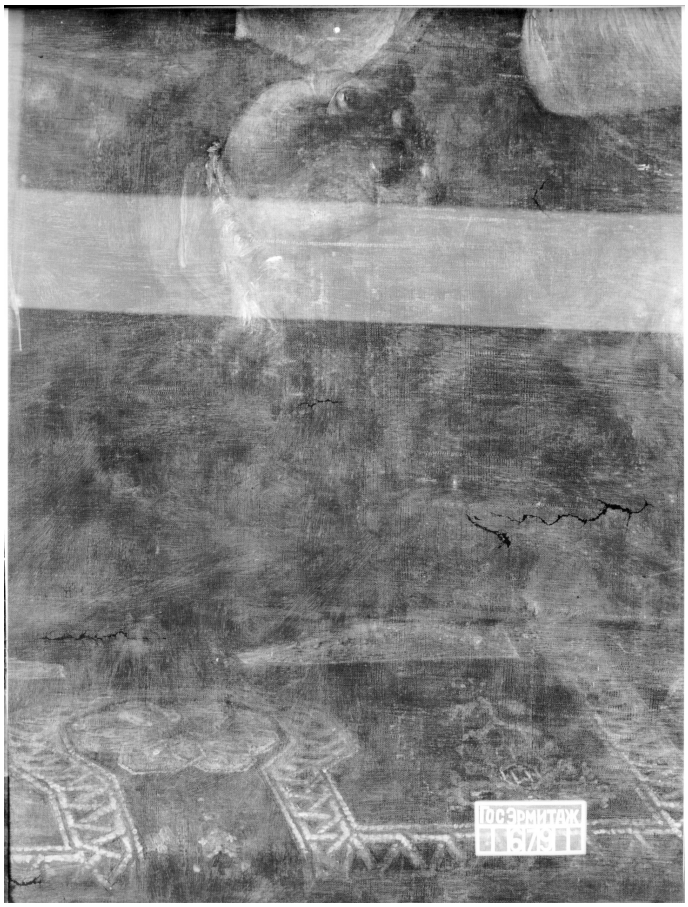

Figure 5. An x-ray of the carpet pattern, which reveals lead-based paint. A close reading of this x-ray reveals no new evidence for tracing beneath the red paint layer—no tracing marks, no incisions, etc. Regardless, any underdrawings (beneath the broad, uniform layer of red paint) would have been invisible to Lotto as he executed the work as we find it. It was the visible image that Hockney and Falco claimed used as evidence for their claim of tracing.[9]

in astronomical telescopes and conservation studios as well. The Hermitage's STL-11000 is equipped with a cooled silicon sensor that permits higher eposure times in cases (e.g., wavelength regions) when the sensor's sensitivity is low.[30,35]

X-rays of paintings—which are almost always at a 1:1 scale to the painting—generally provide higher spatial resolution than camera-based infra-red reflectography and better penetration. Of course the different wavelength radiation reveals different visual and material information.[40] X-ray is most effective in revealing the distribution of lead white because lead has very high absorption for X-radiation while infra-red reveals carbon black of charcoal. The majority of artistic pigments do not absorb (are transparent) in infra-red and this is the reason why infra-red is effective in revealing preparatory underdrawings under paint layers. Normally free carbon in underdrawings may be revealed with the optimal contrast in the wavelength range $1.7 - -1.8\ \mu m$ but there are also situations (when underdrawing is made with certain sorts of ink) when the optimal contrast may be reached at 0.9–1.0 μm.

4. UNDERDRAWINGS AND EVIDENCE AGAINST TRACINGS

Stork was the first scientist to analyze infrared infra-red reflectograms and x-ray images of artworks to test claims about the use of optical projections.[41] He showed that significant pentimenti in Jan van Eyck's *Portrait of Giovanni (?) Arnolfini and his wife* (1434)—particularly around the figures, Arnolfini's hand, the window

region and elsewhere—were incompatible with the Hockney-Falco claim that these passages were executed by tracing a projected image. Images projected by relevant concave mirrors or converging lenses are inverted.[11] Thus if any portion of this work was executed by painting directly under a projection (as Hockney and Falco's revised claim stands for *Husband and wife*), there would likely be at least some upside-down brush strokes, that is, *upward* in the work as we find it. The underdrawing revealed many right-side-up brush strokes, but no inverted brush strokes. Nor was there clear evidence of tracing—tracing lines, incision marks—as might support the projection claim.

We studied carefully the x-rays of the full work for evidence of underdrawings, and for evidence of tracing (Fig. 4). There is no need for infra-red imaging in this work. This is confirmed by the fact that the infra-red images reproduced by Falco contain the same information as the visible in regards the matters at hand, though the contrast may differ slightly. He presents infra-red reflectograms taken with a modified commercial camera.[13] His infra-red evidence for this painting is in relevant aspects the same as visible evidence, concerning primarily the shape of the carpet pattern.

4.1 Visual inspection

The rebuttal of the projection claim based on visual analysis of *Husband and wife* has been presented elsewhere,[12,20] Tyler and Stork have pointed out that the direction of the braids in the right border of the carpet pattern changes more than is consistent with the optical projection claim.[21] More recently, Falco describes "...a small change in optical perspective makes the same repeating structure fit at the rear, again to within better than 2 mm." [13, and Fig. 8, therein] In fact, however, the change is not "small" but corresponds to a change in orientation of lines by more than 18°—far larger than the equivalent evidence they fit elsewhere and too large to be compatible with the "small change in perspective." Some of the pattern lines are rotated a few degrees (roughly 2°), and others much larger. The change in position of a purported projector is severe indeed, and apparently larger than that consistent with the small change in location that leads to such a change in angle. Other lines change roughly $2-3°$. As such, the visual evidence in the white braided pattern at the right argues against the use of any projector.

5. CONCLUSIONS

The passage in *Husband and wife* claimed to have been traced under optical projection—the carpet region—was executed atop a uniform, featureless red layer of paint. This is clear from visual inspection, infra-red reflectography and x-radiography. Regardless, there are no pentimenti and underdrawings in the carpet passage. As such, this evidence supports the visual inspection *in situ*: there is no evidence of tracing such as pencil marks, incision marks and the white lines of the octagon, rosette and braid patters were clearly painted atop a red ground. Moreover the geometric analyses, such as given by Tyler, Robinson and Stork retain their force.[23,42]

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