

# Did Caravaggio employ optical projections? An image analysis of the parity in the artist’s paintings

David G. Stork

Ricoh Innovations, 2882 Sand Hill Road Suite 115, Menlo Park CA 94 025 USA

## ABSTRACT

We examine one class of evidence put forth in support of the recent claim that the Italian Baroque master Caravaggio secretly employed optical projectors as a direct drawing aid. Specifically, we test the claims that there is an “abnormal number” of left-handed figures in his works and, more specifically, that “During the Del Monte period he had too many left-handed models.” We also test whether there was a reversal in the handedness of specific models in different paintings. Such evidence would be consistent with the claim that Caravaggio switched between using a convex-lens projector to using a concave-mirror projector and would support, but not prove, the claim that Caravaggio used optical projections. We estimate the parity (+ or –) of each of Caravaggio’s 76 appropriate oil paintings based on the handedness of figures, the orientation of asymmetric objects, placement of scabbards, depicted text, and so on, and search for statistically significant changes in handedness in figures. We also track the direction of the illumination over time in the artist’s oeuvre. We discuss some historical evidence as it relates to the question of his possible use of optics. We find the proportion of left-handed figures *lower* than that in the general population (not higher), and no significant change in estimated handedness even of individual models. Optical proponents have argued that *Bacchus* (1597) portrays a left-handed figure, but we give visual and cultural evidence showing that this figure is instead right-handed, thereby rebutting this claim that the painting was executed using optical projections. Moreover, scholars recently re-discovered the image of the artist with easel and canvas reflected in the carafe of wine at the front left in the tableau in *Bacchus*, showing that this painting was almost surely executed using traditional (non-optical) easel methods. We conclude that there is 1) no statistically significant abnormally high number of left-handed figures in Caravaggio’s oeuvre, including during any limited working period, 2) no statistically significant change in handedness among all figures or even individual figures that might be consistent with a change in optical projector, and 3) the visual and cultural evidence in *Bacchus* shows the figure was right-handed and that the artist executed this work by traditional (non-optical) easel methods. We conclude that the general parity and handedness evidence does not support the claim that Caravaggio employed optical projections.

**Keywords:** Caravaggio, Hockney projection theory, Baroque art, optical aids, concave mirror, convex lens, parity in art

## 1. INTRODUCTION

Michelangelo Merisi da Caravaggio (1571–1610), widely known as Caravaggio, was considered by many of his early 17th-century contemporaries to be the most important painter in Rome. His dramatic lighting, chiaroscuro, careful staging, and strong naturalism broke with the prevailing Mannerist style of Parmigianino, El Greco, Pontormo, Tintoretto, and others. His contemporaries criticized his work as being too natural—*too real*—for the religious subjects of his numerous public and church commissions. They criticized, moreover, his use of prostitutes and rough street people as models for sacred and religious figures such as Christ, Mary and Saints. Reflecting upon Caravaggio’s influence, Nicholas Poussin proclaimed, “He came to destroy painting,” and André Berne-Joffroy wrote “what begins in the work of Caravaggio is, quite simply, modern painting.”

Neither preparatory drawings nor unambiguous documentary records from fellow painters, patrons, portrait subjects or critics who observed him at work survive, and this lack has led to much speculation about Caravaggio’s studio praxis. Only the short record from Baglione’s 1603 libel suit mentions such direct observation; these include nothing about projection optics, our concern in this study. Well after Caravaggio’s death, Mancini,

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Send correspondence to [artanalyst@gmail.com](mailto:artanalyst@gmail.com).

Bellori and others discussed his possible techniques, though it is unclear how they could have known much of what they discussed. Christiansen and Puglisi described Caravaggio’s plausible working methods consistent with the stylistic and physical evidence, such as incision lines in the grounds in several paintings.<sup>1,2</sup> A revisionist theory has been proposed as well—one that claims Caravaggio secretly built optical projectors, illuminated his subjects by sunlight and projected their real images onto the canvas, traced these images and then filled in paint.<sup>3,4</sup> This theory has been extended to claim that Caravaggio created a light-sensitive chemical, applied it to his ground so that it would fluoresce for a while—glow—in response to illumination by the projected image. In this way the glowing chemicals would temporarily record or “fix” such a projected image, which Caravaggio could see and trace in his darkened studio.<sup>4-6</sup> If this claim could be confirmed, it would mean that artist Caravaggio employed a primitive automatic method for fixing a real image more than two centuries before the invention of photography.

One class of evidence put forth in support of the optical projection claim centers on the left-right parity of the images in his paintings, that is, whether a right-handed figure in the studio appears right-handed or instead left-handed in the final painting. A simple concave-mirror projector preserves this parity (i.e., a right-handed figure appears right-handed), while a simple convex lens projector inverts the parity (cf., Sect. 4).<sup>7</sup> Roberta Lapucci claims: “There is lots of proof [sic], notably the fact that Caravaggio never made preliminary sketches,” and that there is an “abnormal number” of Caravaggio’s subjects are left-handed. “That could be explained by the fact that the image projected on the canvas was backwards.” [8, quoted in] She is explicit about the time of such a purported abnormal excess in left-handed figures: “During the Del Monte period [1600–1610] he had too many left-handed models.” [5, p. 41] It was, in fact, the parity-preserving property of concave mirrors, among other reasons, that led Hockney and Falco to propose some artists as early as 1430, such as Jan van Eyck and the Master of the Flémalle, employed concave mirrors (rather than the more familiar convex lens) directly as a drawing aid.<sup>9</sup> Lapucci claims, further, to have identified a change in the parity of some individual figures Caravaggio’s œuvre (which she calls “symmetry”) and ascribes this purported change to the artist switching from a lens-based to a mirror-based projector.<sup>4</sup> These are the claims we test here.

In Sect. 2 we state the general hypothesis that Caravaggio employed optical projections directly while executing some of his paintings, and in Sect. 3 review some of the image and contextual evidence presented in earlier research on this question. We then state more carefully the specific parity claim we test here. In Sect. 4 we review the basic optics of lens, mirror, and catadioptric (lens plus mirror) projectors with special consideration of the parity of the real images they produce. We mention in passing some of the history of optics of the late 16th and early 17th century around Rome, including what Caravaggio might plausibly have known about optics. In Sect. 5 we describe the criteria and collection of the raw data, which is listed in Table 1 in the Appendix. We also search for a change in parity in Caravaggio’s works and individual figures. In Sect. 6 we summarize our conclusions.

## 2. THE TRACING THEORY AND CARAVAGGIO

Some scholars have been intrigued by the possibility that several artists may have traced optically projected images during the execution of their works. Such a procedure has been securely established for several artists, starting with Canaletto (1697–1768), extending through Thomas Eakins (1844–1916), and of course to numerous modern photorealists. One of the most thoroughly debated cases is that for the Dutch Golden Age master Johannes Vermeer.<sup>10</sup> While many scientists<sup>11</sup> and art historians<sup>12</sup> may grant that this artist might have *seen* images projected by a camera obscura, most experts remain unconvinced that this artist *directly traced* images during the execution of any of his works. David Hockney has proposed that artists as early as Jan van Eyck (1385?–1441) and the Master of the Flémalle, widely identified as Robert Campin (1380?–1444), traced projected images in the early Renaissance, nearly two centuries earlier than scholars have secure evidence any artist employed such a method. Hockney and his colleague Charles Falco argue that this procedure was perhaps the most important impetus for the rise in realism or “opticality” of the *ars nova* or “new art” of that time.<sup>3,9</sup> Over two dozen independent scientists, historians of optics, historians of art and prize-winning realist painters—including those in a four-day workshop devoted to testing Hockney’s theory—have examined the evidence, discovered new physical evidence, and have concluded by rebutting or rejecting Hockney’s tracing claim (or at best finding the claims unproven), at least for the early Renaissance. [13–19, and references therein]

The claim that Caravaggio used optics cannot be as easily dismissed. First, Caravaggio lived well after the Renaissance, in the Italian Baroque—an era providing early documentary evidence of appropriate images projected by mirrors or lenses. His first patron, Cardinal Francesco Maria del Monte, was interested in science; Giambattista della Porta experimented with optical projections, used them in his magic shows, and wrote about them over a decade before Caravaggio’s birth (cf., Sect. 4). It is highly likely, therefore, that Caravaggio had at the very least seen such projected images. There are incision lines in several of Caravaggio’s paintings, including *The Madonna dei Palafrenieri* and *Judith beheading Holofernes*, revealed through raking illumination, x-ray imaging and infra-red reflectography—incisions that some have argued are consistent with Caravaggio tracing of the outlines of a projected image.<sup>4</sup> Caravaggio would have faced a number of technical challenges in building and using a projector, but modern demonstrations or “re-enactments” show that it is *conceivable* this artist used optical projections.<sup>4</sup> It is reasonable, therefore, to test the claim that the artist might have experimented in incorporating projections into his praxis. It has even been suggested that Caravaggio applied to his ground special chemicals (crushed fireflies, lead white paint and mercury) that would fluoresce in response to the putative illuminating image and that the artist would then block all ambient light and make incision marks along the glowing contours.<sup>8</sup> Lapucci claims, in short, that the artist invented a method for temporarily but automatically recording and “fixing” a real image projected onto his canvas, all more than two centuries before the invention of silver-nitrate fixing for photography.

There is a significant and crucial gap between admitting the possibility Caravaggio *may have* used optics directly in his praxis and in demonstrating that he did *in fact* use optics, however.

### 3. PREVIOUS SCHOLARSHIP AND TESTS OF THE PROJECTION CLAIM

There are five general classes of technical evidence brought to bear on the projection claim for Caravaggio: geometric, lighting, physical, historical/documentary and parity.

#### 3.1 Geometric

The geometric image evidence used in support the optical projection claim is based on “anomalous” scale variations among objects in paintings. Hockney points to the disciple’s right hand, thrust back into the space in *Supper at Emmaus*, and argues that its size—abnormally large compared to the Saint’s left hand—is due to Caravaggio refocussing a concave mirror projector to overcome its limitations in depth of field.<sup>3</sup> Stork and Furuichi showed rigorously and quantitatively that the measured difference in sizes of the rendered hands demands that Caravaggio would have made extremely awkward, severe, conspicuous and implausible alterations to his studio to achieve such a refocussing.<sup>20,21</sup> This fact and subsidiary evidence lead to a rejection of Hockney’s optical claim for this painting.

#### 3.2 Lighting and illumination

The second class of evidence concerns the source of illumination. The ratio between the luminance of a projected image to that of its source object is given by

$$\frac{I_i}{I_o} = \frac{\rho A}{f^2} \cos^4 \alpha, \quad (1)$$

where  $\rho$  is the reflectivity of the mirror or the transmissivity of the lens,  $A$  is the facial area of the mirror or lens,  $f$  its focal length, and  $\alpha$  the angle with respect to the optical axis.<sup>22</sup> The image produced by optical projectors of the sort proposed for early artists, including Caravaggio, are much dimmer than the source scene. For example, the mirror Hockney and Falco infer that Lorenzo Lotto would have used for *Husband and wife* yields images of roughly three orders of magnitude lower in the luminance than the source scene itself.<sup>23</sup> (We note that Robinson and Stork used sophisticated computer ray tracing software and other considerations to rebut Hockney and Falco’s claim about this painting.<sup>24,25</sup>) Caravaggio’s works are generally larger than Lotto’s and this would imply Caravaggio use an even longer focal length mirror or lens (e.g.,  $f \sim 1\text{ m}$ ). Even with a plausible increase in the size of optical element, these facts imply that the reduction of luminance for the projected image in Caravaggio’s studio would be roughly four orders of magnitude. Thus the sun and a very large collection of

oil lamps are the only plausible illuminants in the Renaissance and Baroque that could yield a visible projected image.<sup>22</sup> Incidentally, there is no direct evidence that Caravaggio arranged his models outdoors in the direct sun (for a tracing), then re-staged his tableau in his dark basement while he applied paint, where he is known to have worked.

Stork and Nagy used computer graphics, including sophisticated modeling of the reflectance properties of the rear wall in Caravaggio's *The calling of St. Matthew*, to test whether the lighting as rendered was consistent with direct solar illumination or local artificial illumination. They could indeed make a simple computer graphics model with Lambertian (diffusely reflecting) rear wall with small local illumination consistent with the shading and shadow evidence in the painting. Such a dim-illumination model would be hard to reconcile with the optical projection claim.<sup>26</sup> Stork and Nagy could also create a model of the tableau consistent with solar illumination, but this model demanded a mildly complex (Cook-Torrance) reflectance model for the rear wall and specific placement of the overhanging room outside Caravaggio's studio. The diurnal motion of the sun, and numerous other constraints show that it would have been quite difficult, but not impossible, for Caravaggio to have traced optical projections to render the image we find in the painting.

Here and elsewhere, one might claim that Caravaggio employed optics selectively, tracing and recording some portions of an optical image, and deliberately ignoring or altering others, all to fit his artistic vision. The methodological drawbacks of such a scholarly stance are severe indeed. Arguments on authentication, praxis, and so on must rely on *interlocking* sets of evidence. The more *ad hoc* and underconstrained the evidence, the less persuasive the argument will be. In the absence of principled *a priori* criteria to assign "optical" and "non-optical" features, proponents would be underconstrained and thus feel free to select evidence to confirm their pre-determined "conclusion" and to exclude evidence that disconfirms this "conclusion." Such a stance would be methodologically vacuous, of course.

We mention in passing Hockney's closely related claim, viz., that Georges de la Tour, a follower of Caravaggio, traced optical projections in *Christ in the carpenter's studio*.<sup>3</sup> Hockney claimed that the light source was likely "outside the picture" or "in place of the other figure" (i.e., in place of Christ when St. Joseph was rendered, and in place of St. Joseph when Christ was rendered). Hockney explicitly rejected that the indoor source was in place of the candle depicted in the painting. A very wide range of evidence—cast shadows, occluding contours, computer graphics reconstruction of the tableau, inverting the forward appearance model of the floor—all give a consistent conclusion that the candle was indeed the source of illumination, thereby rejecting Hockney's claim for this painting.<sup>27–29</sup>

Self portraits cannot be executed by tracing the projection of a real image on the canvas. The artist/subject would have to be brightly illuminated (preferably by sunlight) yet visually sensitive to the dim projected image on the canvas, all in a setup of extreme implausibility. Moreover, when the artist/subject turns to trace his projected image, the image itself would move. For this and several subsidiary reasons, it is quite unlikely that Caravaggio executed any of his self portraits using optical projections, as Hockney himself admits.<sup>3</sup> Caravaggio's self portraits in oil may include *Boy with a basket of fruit* and a figure in *Martyrdom of St. Ursula* (cf., Sect. 5).

### 3.3 Physical

There are three subclasses of physical evidence put forth in support of the claim that Caravaggio used optics: the direction of brush strokes in some passages, the presence of incisions in the grounds of some works and chemical analysis of possibly fluorescent material in the grounds of some paintings. Candidate optical images in simple projectors would likely have been upside-down, regardless of parity (but see Sect. 4), and if Caravaggio painted under optical projections, then some of the brush strokes should be upside-down as well. To our knowledge, the only such evidence shows somewhat chaotic brush strokes rather than a statistical bias in strokes. Moreover such evidence is not yet amenable to independent scholarly scrutiny. The proper way to judge the direction of brush strokes is with independent observers judging the strokes without reference to the full painting or the shape of the depicted objects themselves. It is unlikely that such judgements can be made reliably from digital images unless such images are extremely high resolution or captured in raking illumination. Likewise, it would be rather difficult to estimate brush stroke direction in an unbiased way in museum settings, where paintings are hung right-side up. Of course, any study must show that upside-down strokes appear with statistical significance

because even paintings executed right-side up may include some apparently “upside-down” or haphazard strokes. We look forward to a careful study based on such evidence.

The second subclass of physical evidence concerns incisions in the grounds outlining some of the major contours in several paintings revealed through raking-light illumination, x-ray imaging and infrared reflectography. Optical proponents argue that these incisions show that Caravaggio traced the contours of a projected image.<sup>3,4</sup> Indeed, such contours may be consistent with the use of an optical projection, but as Christiansen, Puglisi and others showed, they are consistent with non-optical explanations as well.<sup>1,2</sup> Such incisions are found in the work of other “non-optical” artists such as Barocci, Caravaggio’s early master Cesari, among others.

The third subclass of physical evidence is chemical. Lapucci claims that Caravaggio used a concoction of crushed fireflies, lead white paint, and mercury in his ground and that this would glow and temporarily record a projected image which the artist would trace in his darkened studio.<sup>8</sup> There are a number of unanswered questions associated with that claim. For example, the incisions in *Crowning with thorns* do not mark some of the highest-contrast contours in the entire tableau (e.g., on St. John’s shoulder and neck), but instead mark some of the lowest-contrast contours, such as on the right of Roman soldier’s head—the precise opposite of what would have been natural in a projected image. Likewise, the incisions in *Sacrifice of Isaac* do not conform to what we would expect from an “optical” explanation either, but likely show the development of his design. [2, pp. 382–385] Most importantly, we do not yet have clear chemical analysis to show that Caravaggio’s canvas preparations had sufficient levels of chemicals that would lead to images he could plausibly trace (incise), that the incisions correspond to the bright “optical” contours, that plausible studio conditions would not lead to the fluorescent image being washed out by ambient light, and so forth.

The questions of incisions and possible fluorescence are the subject of ongoing research.

### 3.4 Historical and documentary

If Caravaggio traced optical projections, one might expect to find documentary evidence to this effect, but there is no such evidence. Shortly after Caravaggio’s death, there was a detailed and thorough inventory of the artist’s studio, including all his art materials, tools, and personal effects. It included optical elements such as the *speculo a scudo* or “shield mirror,” almost surely the large convex mirror in *Martha and Mary Magdalene*, which is completely useless as a projection mirror. The inventory mentioned pieces of glass (but did not refer to them as lenses) but no explicit description of relevant optical devices. It is hard to reconcile this fact with the claim that the artist had built an optical projector, even if he had tried to preserve some “trade secret.”

Caravaggio executed a number of formal portraits of educated, literate, cultural leaders: *Portrait of Cardinal Cesare Baronino* (an ecclesiastical historian), *Portrait of Maffeo Barberini* (Pope Urban VIII), *Portrait of Paul V Borghese* (Pope Paul V), *Portrait of Alof de Wignacourt and a page* (a Grand Master of the Knights Hospitaller of St. John) and *Portrait of Fra Antonio Martelli, a Knight of Malta*. If Caravaggio had required these figures to sit in chairs in direct sunlight so he could project their “wonderous” images onto a canvas, it seems certain that these subjects or their attendants would have mentioned something to this effect in their copious writings. Yet no such documentary evidence exists. It seems that either these portrait subjects and their attendants were remarkably oblivious to their unique environment throughout the period of equipment adjustment and putative tracing, or more plausibly that these portraits were executed by traditional (non-optical) easel methods.

Clearly, a full analysis of this historical and documentary evidence is beyond the scope of the current technical study, and we look forward to developments from historians of art, of the Catholic church, and of science in this matter.

### 3.5 Parity claim

We now turn to the central matter of our current research, the claim that evidence of parity in Caravaggio’s works implies this artist used optics directly when executing some of his works. First, we must clarify the concept of *parity* and distinguish it from its closely related term *symmetry*. Parity is a concept broadly applicable throughout science, and can refer to spatial relations between right-handed and left-handed DNA, inversion of space coordinates in particle physics, and much more. For our case, parity refers to whether or not the left-right relations in an object or scene is the same or is inverted in another object or scene. Note that left-right

“symmetry” refers to whether or not a *single* image or object appears unchanged when flipped left-to-right. Thus **O**, **I**, **W** and **U** are left-right symmetric. In contrast, parity describes the relation between two *different* objects or images. The symbols  $\sqsubseteq$  and  $\sqsupseteq$  are not symmetric and have different *parity*. The symbols **F** and **F** are each asymmetric yet have the same parity. We denote the (uninverted) relation between **R** and **R** as parity +, and the (inverted) relation between figures **b** and **d** as parity –.

As we shall see in Sect. 4, below, different types of projectors yield different parity relations between the source objects and the projected scene. Lapucci argues that there is a switch in parity in Caravaggio’s oeuvre, a switch she attributes to the artist changing from using one type of projector to another, for instance from using a concave mirror (parity +) to using a convex lens (parity –). Lapucci claims there is a parity switch in individual *models* who appears in two or more paintings, as we shall consider below.

#### 4. OPTICAL PROJECTORS AND IMAGE PARITY

First, we note that if an artist executes a painting by traditional easel methods (without optics) the parity will be +, that is, a right-handed subject as seen by the artist in the studio will appear right-handed in the final painting as seen by the viewer. As such, a significant deviation from parity + in paintings in itself would be evidence for the use of a projector that inverted the parity (specifically a convex lens projector). In fact, as we shall see in Sect. 5, the data reveals no such significant deviation from + parity.

Each type of optical projector yields a produces images with a characteristic parity with respect to the scene that it images. As shown in Fig. 1, a concave mirror (*catoptric*) projector preserves the parity of the scene—a tracing of its inverted, real image, when turned right-side up, has the same parity as the scene projected. That is, the parity associated with a simple concave mirror projector is +.<sup>7</sup>

Giambattista della Porta worked in Naples and his *Natural magic* of 1558, included studies of astrology, alchemy and natural philosophy, as well as a description of such a projector:

Opposite, place a mirror, not the kind that disperses the light by dissipating [a convex mirror], but the kind that unites by collecting together [a concave mirror]. Move it closer and further away from the hole until you see it reach the perfect and true quantity, approaching the necessary distance from the center. If you look attentively, you will see the face, gestures, movements and clothes of men, the blue sky with dispersed clouds, the very distant mountains, and, in a small circle on a piece of paper, which you will attach above the hole, you will see almost an epitome of the world. These things, when you see them all inverted, will make you marvel to no small degree. [30, translation by M. J. Gorman]

The second major class of projector is based on a convex lens (*dioptric*) projector. Figure 2 shows that a convex lens projector inverts the parity, i.e., the parity associated with a simple convex lens projector is –.

The parity of any projector can be inverted by the introduction of a simple plane mirror into its beam. Such an “injection mirror” would invert the image, and hence invert the parity, with no other significant visible effect. Such mirrors were used later, for instance, in the lens-based camera obscuras documented from the late 17th century.<sup>31</sup> As such, even if a projector might have been used, the relation of the fundamental projector and the parity may be disrupted by such a mirror. This fact adds a conceptual layer of uncertainty to any study, specifically any study making the argument for Caravaggio’s use of projectors.

#### 5. JUDGING PARITY

We now turn to the issue of judging parity in Caravaggio’s works. There are no universally accepted criteria for estimating the parity of an image without its source scene. We rely on the left-right orientation of objects of known asymmetry, the asymmetric placement of objects and the handedness of models, whom we (and Lapucci) assume are right-handed in the studio (but see below). Lappuci claims that an “abnormal number of [Caravaggio’s] subjects were left-handed...[t]hat could be explained by the fact that the image projected on the canvas was backwards...” She claims, further, that there is a switch in parity, that “[t]his [parity] anomaly disappears in the

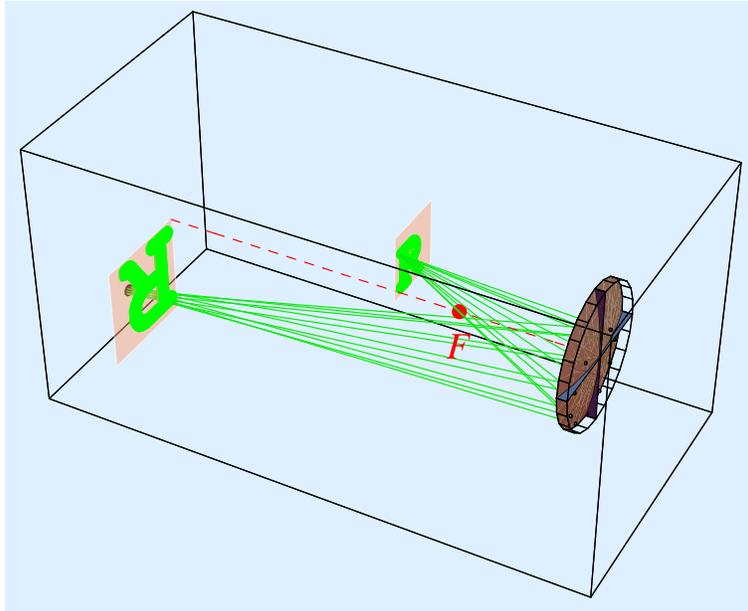


Figure 1. A concave mirror (catoptric) projector projects the image of an  $\mathbf{R}$  onto a screen (canvas). If this projected image is traced and the canvas turned right-side up, the parity of the recorded image matches that of the scene, as viewed from the position of the mirror or artist. That is, the parity associated with a concave mirror projector is  $+$ .

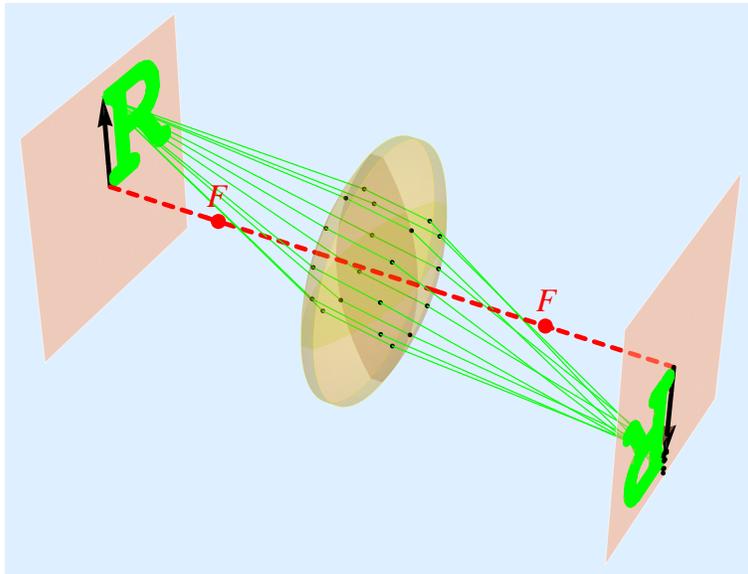


Figure 2. A convex lens (dioptric) projector projects the image of an  $\mathbf{R}$ , at the left, onto a screen (canvas), at the right. By convention, the optical axis is in the  $z$  direction and the focal points are labelled  $\mathbf{F}$  and  $\mathbf{F}'$ . If this image is traced, and the canvas then turned right-side up, the left-right orientation of the image is reversed compared to the scene. All simple camera obscuras and nearly all modern multi-lens cameras similarly produce projected real images of parity  $-$ . In standard film cameras, this parity reversal is corrected during film development, and in digital cameras this reversal is corrected in software.



Figure 3. Left: *Doubting Thomas* (1603) prods Christ’s crucifixion wound (on Christ’s right side) with his right index finger, so we estimate the parity as +. Right: Hockney argues that the figure in *Bacchus* (1597) is left handed, because he holds a glass of wine with his left hand. We reject Hockney’s reading of this work. A right-handed person pouring a liquid holds the container (the carafe) in his right hand, and glass in his left. Note too that the carafe is near the figure’s right hand, and placed closer to us, the viewer. Finally, the artist at his easel holding a paint brush appears in reflection in the carafe at the lower left as revealed through infrared reflectography (see Fig. 5), showing that the artist executed this work at least in its final stages by traditional (non-optical) easel methods.

artist’s later works, a sign that the instruments he used were improving.” [8, quoted in] She claims, moreover, that “[d]uring the Del Monte period he had too many left-handed models.” [5, p. 41]

Figure 3 shows two paintings to illustrate the problems of inferring parity. In *Doubting Thomas*, Thomas uses his right, pointing figure, to prod Christ’s wound. While of course we do not imagine that the model for Christ had an actual wound, surely Caravaggio and especially his church patrons who approved the work knew the church dogma (dating from Pope Innocent III 1160–1216) that Christ’s wound was on his right side. Although it is conceivable that a projected image was parity – and then “corrected” by Caravaggio, this would be mere speculation. In short, either we cannot tell the parity, or it is more likely parity + than –.

There are of course paintings in which the parity determination may be unclear because the evidence itself may be ambiguous or contradictory. Throughout this study, whenever there was an uncertain case we embraced a bias against uncertain parity (·) and thus toward finding evidence of parity (+ or –), a stance applied equally to each painting. This stance thus exposed any “abnormal” handedness and enhanced any putative change in the parity of the sort claimed by Lapucci. In short, our approach is biased in favor of finding evidence to support Lapucci’s claims.

What would be an “abnormal number” of left-handed subjects? About 8–15% of the general population is left handed.<sup>32</sup> Moreover, hand dominance becomes more pronounced in response to reading and writing; thus Caravaggio’s uneducated prostitutes and rough street models were even less biased toward right-handedness. Left-handedness is even more prevalent among males than females, and thus given the predominance of males in Caravaggio’s works, all other things being equal one would expect roughly 15% of the figure presentations to be of left-handed models. An “abnormal number” would have to be statistically significantly larger still.

First, we specify the paintings we do and do not consider. We shall study only works in oil on canvas, not ceiling paintings such as *Jupiter*, *Neptune and Pluto*, surely not executed by means of optics. Nor, of course, do we consider frescos, copies of works, nor any of the missing Caravaggio paintings, even though there may

be descriptions of them that could be analyzed for parity information. [33, cf. p. 253] There are, therefore, 76 works we study, as listed chronologically in the Appendix.

The types of visual evidence that may indicate parity include:

**Handedness of figures** We assume that (right-handed) figures in the studio write, wield a sword, pull teeth, and so forth with their right hand. Others have assumed that such a figure would hold a glass of wine in his right hand (but see Sect. 5.1, below).

**Orientation of written text** We assume that the orientation of letters and notation on sheet music is in traditional orientation.

**Orientation of asymmetric objects** We assume the strings on lutes, keyboard instruments, and so forth are traditional orientation in the studio. Likewise, scabbards are worn on the left side of a right-handed swordsman.

Here are some of the paintings and the evidence that their associated parity is +.

- In both *David and Goliath* and *David with the head of Goliath*, David holds his weapon with his right hand.
- In *Lute player* and *Musicians*, the models strum instruments with the traditional right hand, the thicknesses of the strings on instruments such as lutes and violins are in the traditional order (thick on top), the keyboard instruments have the longer (lower) strings at the left, and so forth.
- In *Boy peeling fruit*, the model holds fruit with his left hand and knife with his right hand.
- In *Doubting Thomas*, Thomas uses his right hand to prod the wound on Christ’s right side, the side of Christ that Caravaggio’s theologian patrons would have insisted bore the wound. (Of course we do not assume that the model had a true wound, just that the parity evidence, as weak as it may be, favors the + parity rather than – parity.)
- In *Tooth puller*, the dentist holds his pliers and pulls the tooth with his right hand.
- In *Mary and Martha*, there is a ring on Mary’s left hand (as is traditional for a right-handed woman) and she holds a flower in her right hand.
- In *Fortune teller*, the customer wears his scabbard on the traditional left side, and each figure put forth a right hand, the hand traditionally “read” by fortune tellers.
- In both versions of *St. Matthew and the angel* and in *St. Jerome writing*, the main figure holds a stylus in his right hand.

We mention in passing that the figure in *St. Catherine* holds her sword in both hands, and there is no persuasive evidence that she is left handed. The parity of other paintings listed in the Appendix are based on just such considerations.

## 5.1 *Bacchus*

The one Caravaggio painting promoted by Hockney as evidence for reversed parity (–), as would arise in a concave lens projector, is *Bacchus* (1597), shown Fig. 3. The evidence Hockney cites is simply that the figure holds his wine in left hand, whereas “[m]ost people lift a glass in their right hand.” Further, Hockney prints a left-right reversed version of the painting and claims it looks “more natural” than the work Caravaggio gives us. [3, p. 118]

Our reading *Bacchus* differs from Hockney’s. A right-handed person may indeed hold a glass in his right hand when making a toast, but when such a person pours wine from a carafe, he holds the *carafe* in his right hand, the glass in his *left*. This is the scene depicted here, and indeed the partially emptied carafe is placed on the table near the figure’s right hand, as if just returned to the table. Moreover, the figure is performing the

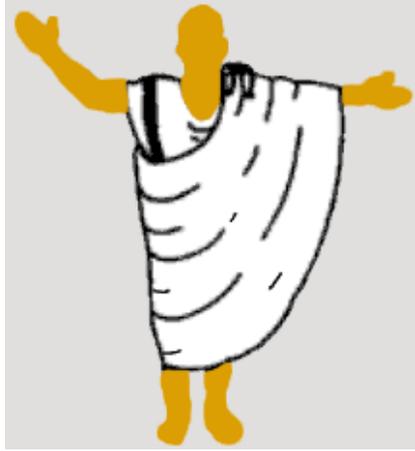


Figure 4. Right-handed figures wear togas with the *right* hand exposed. Thus the costume evidence in *Bacchus* suggests the figure is right-handed—not left-handed as claimed by Hockney and Lapucci. (Figure redrawn from Goldman.<sup>34</sup>)

tricky one-handed task of untying the tie on his robe (foreshadowing pleasures beyond mere alcohol) with his dextrous or *right* hand. His right arm is bare, without garment, thus giving the figure more freedom of motion (to pour wine), just as one would expect for a right-handed figure. Historians of Roman costumes confirm that leaving the preferred, dextrous, hand undraped because this will “allow for more right-arm freedom, or the right arm could have been taken out of the garment, leaving the shoulder bare,” as illustrated in Fig. 4. [34, p. 223] Moreover, the illumination direction is from the left in the painting Caravaggio gives us. This light direction is of course reading direction, and by far preferred in western art generally<sup>35</sup> and by far preferred in Caravaggio’s works, as shown in Table 1. We find the this direction of illumination, the above considerations, and many other informal aspects, lead to a more natural reading of the painting as Caravaggio gives us than with the reversed version.<sup>36</sup>

There is a more general problem with Hockney’s reading of this work, and the optical proponents generally. Are we to believe that Caravaggio arranged his tableau then rendered his scene in reverse, getting an orientation that he did not want or expect? Furthermore given that the reflection in the carafe shows Caravaggio painted the final portion at his easel, are we to assume that Caravaggio restaged his model left-right reversed (to match the projected image) or that he painting the figure reversed from what he saw before him? Both these implications of the optical projection theory seem unlikely.

In short, we reject Hockney’s claim that because the model in *Bacchus* is holding his wine glass in his left hand that he is rendered left-handed. The historical evidence for toga display, and visual evidence in lighting, and a close reading of the scenario displayed in the painting shows that the figure is in fact right handed. The rediscovery of the reflection of Caravaggio at his easel casts doubt on the Hockney claim that this painting was executed using optical methods.

How persuasive is the simple fact of a subject holding a glass in a particular hand in determining the handedness of the figure (and hence parity) of the purported projection from holding a glass? Consider the drinking figures in the works of Jan van Bijlert (1597–1671). The figure in *Portrait of a man holding a wine glass* holds his glass in his left hand but the figure in *Young man drinking a glass of wine* holds his glass in his right hand. Both of those paintings present parity evidence of the sort put forth by Hockney and Lapucci. The clear change in handedness in van Bijlert’s drinkers suggests that handedness can change due to reasons other than switching between purported lens-based and a concave mirror-based optical projectors. Artists change in response to compositional matters, direction of lighting, and so on. The 15% prevalence of left handers in the general public, and numerous compositional goals of artists make any such inferences tenuous indeed. In short, even if there *were* statistically significant proportion of left handers in Caravaggio’s works, it would mean little concerning the optical projection claim.

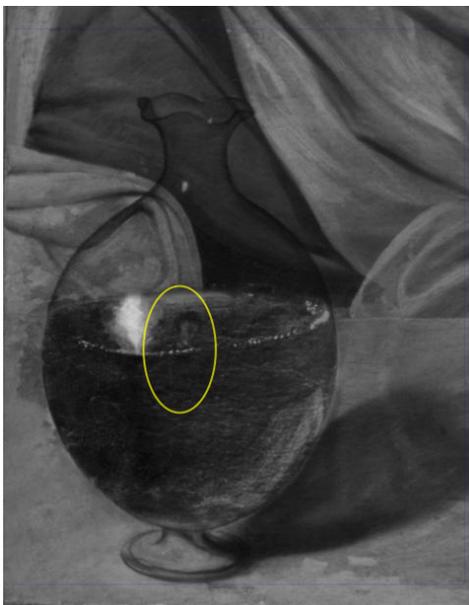


Figure 5. A detail of *Bacchus* shows the reflection of the artist and his easel in the carafe—a mini-self-portrait. This portrait was discovered during restoration treatment by Matteo Marangoni in 1922 and (after a recent cleaning) re-discovered through infra-red reflectography. The existence of this mini-self-portrait shows almost surely that at least this passage was executed by traditional easel methods—not optical methods.

## 6. CONCLUSIONS

The data in Table 1 show clearly that there is no “abnormal number” of left-handed figures in the oil paintings of Caravaggio. Nor are there “too many left-handed figures in the Del Monte period” 1600–1606. Of the figures in the 37 paintings that evidence any handedness, we might expect more than 15% of the figures to be left handed during any period Lapucci feels Caravaggio used a concave mirror projector. As mentioned above, we reject the claim that *Bacchus* depicts a left-handed figure. Scholars may dispute some of the individual estimates, but as mentioned above, the above judgements were under a lenient set of conditions to deliberately bias the results in favor or the Hockney/Lapucci claim. In sum, we reject Lapucci’s claim that an “abnormal number of [Caravaggio’s] subjects were left-handed...[t]hat could be explained by the fact that the image projected on the canvas was backwards...” and likewise reject her claim that there a switch in parity, i.e., “[t]his anomaly disappears in the artist’s later works, a sign that the instruments he used were improving.”

Although the results of our parity analysis do not *prove* that Caravaggio did not trace an optical projection, they comport with an independent scholarly consensus rejecting the Hockney/Falco claims (or at best finding the claims unproven) that artists as early as 1430 secretly traced projected images.<sup>13,37</sup>

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## Appendix

Table 1: This table shows a chronological list of the 76 paintings we studied. The number of figures in each painting that can be considered to be rendered left-handed, right-handed, or of uncertain or indeterminate handedness are shown in the columns **L**, **R** and **U**, respectively. The parity of every asymmetric object in any painting was found to be +, and this table shows how many such objects appear in each painting. The general lighting direction is shown as well. While there may be slight discrepancies in lighting direction within a given painting, in every painting the lighting is either generally from the left or generally from the right—never a mix of right and left. The final column contains the estimated parity of the painting as a whole, + or – (or · for uncertain parity), based on the predominance of the handedness of figures and objects. The execution dates are based on the study by Spike.<sup>33</sup>

Title	Date	L	R	U	+ Objects	Light	Parity
<i>Boy peeling a fruit</i>	1592	0	1	0	0	↘	+
<i>Self-portrait as Bacchus</i>	1593	0	1	0	0	↘	+
<i>Boy with a basket of fruit</i>	1593	0	0	1	0	↘	·
<i>Cardsharps</i>	1594	0	1	2	1	↘	+
<i>Musicians</i>	1595	0	1	3	4	↘	+
<i>St. Francis in ecstasy</i>	1595	0	0	2	0	↘	·
<i>St. Francis in meditation</i>	1595	0	0	1	1	↘	+
<i>Boy bitten by a lizard</i>	1595	0	0	1	0	↘	·
<i>Lute player</i>	1596	0	1	0	3	↘	+
<i>Still life with a basket of fruit</i>	1596	0	0	0	0	↘	·
<i>Medusa</i>	1597	0	0	1	0	↘	·
<i>Fortune teller</i>	1597	0	2	0	1	↘	+
<i>Portrait of a courtesan</i>	1597	0	1	0	0	↘	+
<i>Bacchus</i>	1597	1	0	0	0	↘	·
<i>Martha and Mary Magdalene</i>	1598	0	1	1	0	↘	+
<i>Penitent Magdalene</i>	1598	0	0	1	0	↘	·
<i>Rest on the flight into Egypt</i>	1598	0	1	3	1	↘	+
<i>Judith beheading Holofernes</i>	1598	0	1	2	0	↘	+
<i>Basket of fruit</i>	1598	0	0	0	0	↘	·
<i>Portrait of Fillide</i>	1598	0	0	1	0	↘	+
<i>St. Catherine of Alexandria</i>	1599	0	0	1	0	↘	·
<i>Narcissus</i>	1599	0	0	1	0	↘	·
<i>Conversion of Mary Magdalen</i>	1599	0	1	11	1	↘	+
<i>Martyrdom of St. Matthew</i>	1599	0	2	11	0	↘	+
<i>The calling of St. Matthew</i>	1600	0	5	2	1	↘	+
<i>Conversion of St. Paul</i>	1600	0	1	1	0	↘	+
<i>John the Baptist (Youth with ram)</i>	1600	0	0	1	0	↘	·
<i>Crucifixion of St. Peter</i>	1600	0	0	4	0	↘	·
<i>Victorious Cupid</i>	1601	0	1	0	3	↘	+
<i>St. Matthew and the Angel</i>	1602	0	1	1	0	↘	+
<i>Taking of Christ</i>	1602	0	0	7	0	↘	·
<i>Portrait of Cardinal Cesare Baronino</i>	1602	0	0	1	0	↘	·
<i>Entombment</i>	1602	0	1	5	0	↘	+
<i>Doubting Thomas</i>	1603	0	2	2	0	↘	+

Continued on next page...

Table 1 – Continued

Title	Date	L	R	U	+ Objects	Light	Parity
<i>Still life with fruit on a stone ledge</i>	1603	0	0	0	0	↙	.
<i>Madonna of Loreto</i>	1603	0	0	4	0	↙	.
<i>Portrait of Maffeo Barberini</i>	1603	0	1	0	0	↙	+
<i>St. Francis in meditation</i>	1603	0	0	1	0	↙	.
<i>Sacrifice of Isaac</i>	1603	0	1	2	0	↙	+
<i>St. John the Baptist</i>	1604	0	0	1	0	↙	+
<i>Agony in the garden</i>	1604	0	0	4	0	↙	.
<i>Crowning with thorns</i>	1605	0	0	4	0	↙	.
<i>Ecce homo</i>	1605	0	0	3	0	↙	.
<i>David and Goliath</i>	1605	0	0	2	0	↘	.
<i>Holy family</i>	1605	0	0	4	0	↙	.
<i>Death of the Virgin</i>	1605	0	0	11	0	↙	.
<i>St. John the Baptist</i>	1605	0	0	1	0	↙	.
<i>Portrait of Paul V Borghese</i>	1605	0	0	1	0	↙	.
<i>Madonna dei Palafrenieri</i>	1606	0	0	3	0	↙	.
<i>Supper at Emmaus</i>	1606	0	1	3	0	↙	+
<i>Seven acts of mercy</i>	1606	0	1	14	0	↙	+
<i>Madonna of the Rosary</i>	1606	0	0	12	0	↙	.
<i>David with the head of Goliath</i>	1607	0	1	1	0	↙	+
<i>Flagellation of Christ</i>	1607	0	0	3	0	↙	.
<i>St. Jerome writing</i>	1607	0	1	0	0	↙	+
<i>Crucifixion of St. Andrew</i>	1607	0	1	5	0	↙	+
<i>Portrait of Alof de Wignacourt and a page</i>	1607	0	1	0	0	↙	+
<i>Denial of St. Peter</i>	1607	0	0	3	0	↙	.
<i>Salomé with the head of St. John the Baptist</i>	1608	0	1	2	0	↙	+
<i>St. Francis in prayer</i>	1608	0	1	0	0	↙	+
<i>Portrait of Fra Antonio Martelli, a Knight of Malta</i>	1608	0	1	0	1	↙	+
<i>Beheading of St. John the Baptist</i>	1608	0	1	6	0	↙	+
<i>Sleeping Cupid</i>	1608	0	0	1	0	↙	.
<i>St. John the Baptist at the source</i>	1608	0	0	1	0	↙	.
<i>Burial of St. Lucy</i>	1608	0	0	11	0	↘	.
<i>Raising of Lazarus</i>	1608	0	1	12	0	↙	+
<i>Salomé with the head of St. John the Baptist</i>	1608	0	0	3	0	↙	.
<i>Narcissus</i>	1608	0	0	6	0	↙	.
<i>Annunciation</i>	1608	0	1	1	0	↙	+
<i>Nativity with Sts. Lawrence and Francis</i>	1609	0	0	7	0	↙	.
<i>St. John the Baptist</i>	1609	0	0	1	0	↙	.
<i>Adoration of the shepherds</i>	1609	0	0	6	0	↙	.
<i>Martyrdom of St. Ursula</i>	1610	0	1	3	1	↙	+
<i>Magdalen in ecstasy</i>	1610	0	0	1	0	↙	.
<i>St. John the Baptist reclining</i>	1610	0	0	1	0	↙	.
<i>David with the head of Goliath</i>	1610	0	1	1	0	↙	+