

# Sclerotic scatter and focusing in eye painting: light through darkness

## Dispersion et concentration sclérales dans les yeux peints : la lumière dans et par l'obscurité

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**ABSTRACT.** We aimed at searching in color art paintings through all art periods from Ancient Egyptian Art to Contemporary Art for sclerotic scatter (SS) and peripheral light focusing (PLF), using large-scale internet databases. These phenomena originate from the illuminated side of the eyeshell: limbal sclera for SS or cornea for PLF. They end at the darkness of the opposite limbal scleral side, where they are either scattered (SS) or concentrated (PLF) forming a clear arc or spot of light, respectively ("light through darkness").

We found SS and PLF in 83 and 2 paintings respectively out of 113,962 paintings analyzed. These forms of objective chiaroscuro help to reconstruct a basic sense of eyeball modelling by bringing the limbus out of the shadows. Among the paintings with SS, most were painted during the following periods: Renaissance (44), Baroque (15), Rococo (11). Sixty-one of the paintings with SS have a dark background compatible with the fact that SS is more easily observed under low ambient light illuminance ("light through darkness").

Acknowledgment of SS and PLF as subtle, rare characteristics of paintings should help see them in a new light, contribute to their proper treatment and restoration and is likely to enhance their economic value.

**KEYWORDS.** Sclerotic scatter, peripheral light focusing, art painting, chiaroscuro, Renaissance.

## Introduction

Sclerotic scatter (SS)<sup>1,2</sup> and peripheral light focusing (PLF)<sup>2</sup> are easily observed in daily life by an aware observer. The limbus is the junction between the cornea and sclera<sup>3</sup>. Sclerotic scatter<sup>1,2,4,5</sup> (Fig. 1, panel a) entails an initial scattering of light on the illuminated side of the eyeball, in the sclera at the limbus. Some of the scattered light travels through total internal reflection in the cornea and other complex pathways through the anterior chamber. It reaches the opposite, shaded side, where a second scattering of light in the sclera at the limbus occurs, forming a clear arc of light. Peripheral light focusing<sup>6-9</sup> (Fig. 1, panel e) – or "Coroneo effect" – entails the trans-cameral concentration (roughly 20 times) of postero-lateral light by the cornea (usually at the temporal side) to the opposite sclera near the limbus (usually on the nasal side) where the concentrated light appears as a bright spot of light .

In 2007 we came across the painting *Portrait of Michael Wolgemut* (1516) by Albrecht Dürer (Fig. 1, panel c). In this painting, we spotted a beautiful, although puzzling clear arc of light at the limbus on the shaded nasal side of the right eye. This arc of light was unmistakably SS. In 2015, after quite an extensive, albeit unmethodical search for SS and PLF in artistic painting, we had not found any further painting featuring either of these phenomena. Could it be that Dürer's master, Michael Wolgemut, was the only individual to have been painted with SS and that no painting

featuring PLF had ever been painted? We drew up the following study to answer this question. The aim of the study was to methodically search as exhaustively as possible for SS and PLF<sup>6-9</sup> in color paintings and pastels through all periods from ancient Egyptian art to contemporary art using large-scale internet databases. Data were collected between June 2015 and May 2021. All color paintings and pastels of all artists during all periods and all movements were analyzed (table S1) and high-definition photographs were systematically used to ascertain the presence of SS or PLF (see Methods).

## Methods

### *Aim of the study and collection of data*

The aim of this work was to search as exhaustively as possible for sclerotic scatter (SS)<sup>1,2,4</sup> and peripheral light focusing (PLF)<sup>6-9</sup> (Fig. 1) in color paintings and pastels through all periods from ancient Egyptian to contemporary art.

Sclerotic scatter (Fig. 1, panel a) is a complex, not completely understood phenomenon<sup>1,2,4,5</sup>. The limbus is the junction between the cornea and the sclera<sup>3</sup>. Sclerotic scatter entails an initial scattering of light on the illuminated side of the eyeball, in the sclera at the limbus. Some of the scattered light travels through total internal reflection in the cornea and other complex pathways through the anterior chamber. It reaches the opposite shaded side, where a second scattering of light in the sclera at the limbus occurs, forming a clear arc of light. The relative proportion of the intra-corneal and of the several trans-cameral pathways of light is still to be investigated and is beyond the scope of the present report.

Peripheral light focusing<sup>6-9</sup> (Fig. 1, panel e) – or "Coroneo effect" – entails the trans-cameral concentration (roughly 20 times) of postero-lateral light by the cornea (usually on the temporal side) to the opposite sclera near the limbus (usually on the nasal side) where the concentrated light appears as a bright spot of light.

In an effort to gather an exhaustive collection of SS and PLF in color art painting (and pastel), large internet databases were consulted. The Wikiart (<https://www.wikiart.org/>) database served as a reference. It was exhaustively consulted between June 2015 and May 2021. All color paintings and pastels of all artists of all art periods and art movements were analyzed (table S1). In each painting, SS and PLF were searched for. For each artist referenced in the Wikiart database, the Web Gallery of Art (<https://www.wga.hu/>) and Google Arts and Culture (<https://artsandculture.google.com/>) database were systematically consulted to look for additional relevant paintings. Other web resources (especially museum websites), textbooks and scientific publications were used to make our search as complete as possible. All in all, 113962 paintings of 2311 artists were examined (Table S1).

### *Selecting paintings with eyeball illumination compatible with SS and PLF occurrence*

Among the 113,962 paintings, we strove to identify a subset of paintings with light exposure of the eye compatible with SS or PLF.

For SS, such exposure entailed at least one eye in the painting meeting four criteria. The first criterium was that both limbi were visible. The second was that one limbus was in light. The third was that the opposite limbus was in the shade. The fourth was that additional sclera was visible beyond the limbus in the shade. The color paintings and pastels with eye exposure compatible with SS are listed in Table S2 and displayed as thumbnails in Fig. S1.

For PLF, such exposure entailed at least one eye in the painting meeting two criteria. The first was that, relative to the sagittal plane crossing the corneal apex in the primary position of gaze,

postero-lateral light should strike the lateral cornea on one side. The second was that the limbus on the opposite, shaded side, was visible. The color paintings with eye exposure compatible with PLF are listed in Table S4 and displayed as thumbnails in Fig. S1.

### **Selecting paintings with possible featuring of the two effects**

Among the subset of paintings with light exposure of the eye compatible with SS or PLF, we strove to identify the subset of paintings with possible featuring of SS or PLF. For each painting with suspected SS or PLF representation, the first step was to retrieve one (or several) high-definition digital photographs from photography agencies, museum databases, the Wikimedia Commons website or any other web resource available. The high-definition photographs were examined on a screen using the same scale as that of the real painting, when relevant data were available. For SS, possible featuring (Table S3) entailed the presence in the shaded sclera near the limbus of an arc of light that had to be thin, continuous (uninterrupted) and even (without much thickness variation). For PLF, possible featuring (Table S4) entailed the presence in the shaded sclera near the limbus of a bright spot of light.

### **Selecting paintings with probable featuring of the two effects**

For each painting with possible featuring of SS or PLF, two mandatory steps and one optional step were taken to upgrade the featuring from "possible" to "probable". The first, mandatory, step entailed modifying the high-definition photograph previously used using Adobe Photoshop Elements 15 so that the limbal arc of light (SS) or bright spot of light (PLF) was removed by assigning it the same color and tone as that of the neighboring sclera (Fig. S2). The original image and the modified one were repeatedly compared on a screen using the same scale as the real painting (when the relevant data were available) to make sure that the presence of the limbal arc of light (SS) or bright spot of light (PLF) was plausible. In some instances, photographs from textbooks were consulted to further ascertain the probable representation of SS. The second, mandatory, step was to prove that the clear limbal arc (SS) or bright spot of light (PLF) could be experimentally induced on healthy volunteers. To do so, a LED panel (Andoer W228 LED video lighting (China)) or LED light illuminating the face and the eye in the same fashion as that of the painting was used to induce the limbal arc of light (SS) or bright spot of light (PLF). A photograph unambiguously showing the limbal arc of light (SS) or bright spot of light (PLF) was then shot (Fig. S2).

The third, optional, step was to find published photographs<sup>1,2</sup>, when available, or personal photographs (E. Denion collection) displaying a limbal arc of light (SS) or bright spot of light (PLF) similar to that of the painting under scrutiny (Fig. S2).

If, for the painting under scrutiny, (step 1) iterative comparison of the original and the modified photograph unambiguously highlighted the presence of the limbal arc of light (SS) or bright spot of light (PLF) and (step 2) induction with a LED panel of the same limbal arc of light (SS) or bright spot of light (PLF) was possible, featuring of the limbal arc of light (SS) or bright spot of light (PLF) was then deemed "probable" (Table S3, Table S4, Fig. S2). For some paintings, the finding (step 3) of published photographs displaying the same limbal arc of light (SS) or bright spot of light (PLF) was a further argument rendering the featuring of these effects "probable".

The limbal arc of light of SS is seen – often rather faintly<sup>4</sup> – only when the contrast (i.e. difference of illuminance) between a powerful lateral light triggering the effect and the ambient light is extreme<sup>1,2</sup> (Fig. S3). This extreme contrast has lower values under mesopic conditions<sup>1</sup> i.e. in conditions with a dark ambient light, of which the illuminance ranges from 0.05 to 50 lux<sup>10</sup>. For this reason, regarding each of the paintings (see Fig. S2) with probable SS representation, we examined the background ambient light and classified it as dark (compatible with mesopic conditions) or not (Table S3).

## Results

All in all, 113,962 paintings from 2311 painters were analyzed in this study (Table S1).

We identified 909 paintings by 311 painters with eye exposure compatible with SS, (Table S2 and Fig. S1) among which we identified 83 paintings by 42 painters with probable SS (Fig. 1; Fig. 2; Table S3, Fig. S2). In one painting (Bronzino: Eleonora of Toledo and Her Son, 1545-1550) two characters displayed probable SS.

We identified 5 paintings from 5 painters with eye exposure compatible with PLF (Table S4 and Fig. S1), among which we identified 2 paintings with probable PLF, at the right nasal limbus (Fig. 1, panel f; Table S4; Fig. S2).



**Figure 1.** Sclerotic scatter (SS) and peripheral light focusing (PLF) in artistic painting.

Caption: Panel a. Bottom: schematic horizontal anterior eyeball cross-section. In SS, the lateral light (a) scattered in all directions at the nasal sclera (b) travels by total internal reflection through the cornea (c) and by intra-cameral pathways (d). It reaches the limbal sclera on the other (shaded) side where it is scattered again to form a clear arc of light (e). Top: detail of Portrait of a man by Antonello da Messina, 1474. Panel b. Top: detail of Portrait of man (known as "Le Condottière") by Antonello Da Messina, 1475 displaying SS at the temporal limbus. Bottom: similar SS elicited using a LED panel. Panel c. Top: detail of Portrait of Michael Wolgemut by Albrecht Dürer, 1516 displaying a SS at the nasal limbus. Bottom: similar arc of light elicited, using a LED panel. Panel d. Top left: detail of A Woman, by Robert Campin, c. 1435 displaying SS at the temporal limbus. Bottom left: detail of Saint Paul by Nicolas Tournier, c. 1630 displaying a clear arc of light (SS) at the temporal limbus. Top right and bottom right: removal of the arc of light (SS) hampers the rendering of the eyeball relief. Panel e. Bottom: schematic horizontal anterior eyeball cross-section. In peripheral light focusing (PLF) the postero-lateral light (a) is concentrated approximately 20 times by the cornea (b) through the anterior chamber (c) to the nasal sclera near the limbus (d). Top: detail of Portrait of A.V. Tropinin by Vasily Tropinin (c.1818). Panel f. Top left: detail of A Saltimbanco by Antonio Mancini (1879) with a nasal PLF. Top right: photograph displaying similar PLF. Bottom left: detail of Portrait of A.V. Tropinin by Vasily Tropinin (c.1818) with nasal PLF. Bottom right: photograph displaying similar PLF.

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Among the 83 paintings with probable SS, most were painted during the following periods: Renaissance (44 paintings), Baroque (15 paintings), Rococo (11 paintings) (Fig. 2; Fig. S2; Table S3). The bulk of the paintings (79 / 83) were painted before the modern and contemporary periods. No representation of SS was found in ancient Egyptian or Greek Art, medieval art, Chinese art, Korean art, Japanese art, Islamic art or Native art.

The first painters to have represented SS are Robert Campin (c. 1435) and Jan Van Eyck (1436).



Figure 2. Paintings with a probable featuring of sclerotic scatter over 6 centuries.

Caption: Each painting is represented by a slice of column labelled with the name of the painter with chronological arrangement from bottom to top. The Renaissance, Baroque and Rococo periods are represented in green, yellow and blue respectively.

Only five paintings featuring SS were painted after 1936, the year when Basil Graves clearly described SS using a schematic drawing<sup>4</sup>.

Jesus-Christ was the only character represented with SS more than once (9 times, by 6 different painters) (Fig. S2; Table S3).

Twenty artists painted SS more than once (2 to 6 times). The painters totaling the most SS representations were Antonello Da Messina (6 instances), Albrecht Dürer, Bronzino, Jean-Marc Nattier and Jean-Auguste-Dominique Ingres (5 instances each).

Among the 84 characters (in 83 paintings), presumed SS was located at the temporal side of the left eye in 70 cases, at a combined left temporal / right nasal location in 5 cases, at a right temporal location in 4 cases, at a right nasal location in 4 cases and at a combined right temporal / left nasal location in 1 case.

Vassily Tropinin was the only painter to have painted both SS and PLF.

Sixty-one of the 83 paintings with presumed SS were classified as having a dark background (Table S3).

## Discussion

### *Forms of chiaroscuro*

The propulsion of light into darkness characteristic of SS and PLF is an exquisite form of chiaroscuro. The use of chiaroscuro in art is accepted as a means of conveying a sense of relief, of modelling<sup>11-14</sup>. However, if one part of the eyeball is lighted, in the part left in the shade, clues to relief such as a clear cornea and iris separation from the sclera, the vascular network of the conjunctiva, the corneal reflex, the tear meniscus at the inferior eyelid-eyeball junction, the plica semilunaris, may fade away. In that case, chiaroscuro may harm the rendering of the eyeball relief and be counterproductive. Sclerotic scatter and PLF occur at the limbus, a key anatomical border zone. The eyeshell shape is roughly approximated as two fused truncated spheres<sup>3,15</sup>. The anterior sphere, the cornea, is  $1/6^{\text{th}}$  <sup>15</sup> of a 7.8 mm radius sphere<sup>3</sup> while the posterior sphere, the sclera, is the  $5/6^{\text{th}}$  <sup>15</sup> of an 11.8 mm radius sphere<sup>3</sup>. The curvilinear zone where the cornea and sclera fuse is the limbus<sup>3</sup>. Aside from being a zone of rupture of the curvature of the eyeshell, the limbus separates the very different tonalities of the glittering cornea<sup>15</sup> and of the colored iris seen through the cornea from the white, opaque sclera<sup>15-17</sup>. When SS and PLF occur on the shaded side of the eyeball, they bring the limbus out of the shadows, thereby reconstructing a rough, basic sense of eyeball modelling (Fig. 1, panel d). This sense is similar to Galileo's representation of moon craters seen with his telescope in the waxing light, where the basic sense of the crater relief is conveyed by a chiaroscuro effect with a round patch of dark for the hollow and a bright crescent for the brim<sup>18,19</sup>.

Sclerotic scatter and PLF are seen only when the illuminance of the lateral light striking the limbus or cornea on one side is far greater (roughly 34 times in mesopic conditions<sup>1</sup> for SS) than the illuminance of the ambient light bathing the dark opposite sclera<sup>12</sup> (Fig. S3). The ratio between the illuminance of the powerful lateral light eliciting SS and that of the ambient light is less considerable in mesopic conditions<sup>1</sup> (i.e. a low ambient light with illuminance between 0.05 and 50 lux<sup>10</sup>) than in photopic conditions (i.e. a high ambient light with illuminance > 50 lux). It may therefore be assumed that painters painting under mesopic conditions may have frequently observed and represented SS. The fact that among the 83 paintings with SS, 61 have a dark background, i.e., a low ambient light illuminance compatible with mesopic conditions (Fig. S2; Table S3) is consistent with this hypothesis. Bearing this in mind, it is unsurprising that Caravaggio – worthy to be called "The Master of Darkness"<sup>20</sup> – and some of his followers (Nicolas Tournier and Jusepe Ribera),

known for their "use of a deep chiaroscuro to model three-dimensional forms"<sup>14</sup>, are among the painters of the Baroque period having represented SS (Fig. S2; Table S3).



**Figure 3.** *Unveiling the arc of light of sclerotic scatter.*

Caption: a) the arc of light characteristic of sclerotic scatter at the limbal sclera on the nasal side of the left eye is not seen because the shade in this area is not deep enough given the illuminance of the lateral light striking the temporal part of the eyeball; b) the right hand is used to block most of the light that strikes the nose thereby deepening the shade at the nasal part of the eyeball enough to unveil the arc of light at the limbal sclera.

### ***A matter of "light through darkness"***

In humans, the very wide palpebral fissure<sup>16,17</sup>, the rearward-set temporal orbital margin<sup>21,22</sup> and the distinctly forward position of the eyeball in the orbit<sup>23</sup> leave the eyeshell (cornea and sclera) widely exposed to light, even when the eyeball is moved inwards or outwards. Direct or scattered daylight (albedo)<sup>6,8</sup>, results in almost infinite directions of light rays. Some of these rays strike the eyeshell, where they may induce SS and PLF (Fig. 1). These phenomena originate from the illuminated side of the eyeshell: limbal sclera (SS) or cornea (PLF). They end at the darkness of the opposite limbal scleral side, where they are either scattered (SS) or concentrated (PLF). Stars are not visible in daylight because their illuminance is inferior to that of the surrounding sky<sup>24</sup>. Similarly, SS and PLF, albeit present, are not seen when the illuminance in the sclera at the limbus on the dark

side is inferior or equal to that of the neighboring sclera<sup>1,2</sup> (Fig. S3). Only when the illuminance of the neighboring sclera is low enough do they become visible (Fig. 1). Hence, SS and PLF are quintessentially a matter of "light through darkness", the preposition "through" being bisemic and meaning both "from one side to the other" and "by means of".

### ***Very rare, hence precious effects to be preserved***

Although frequently observed in daily life by a trained eye, SS<sup>1,2</sup> and PLF<sup>2</sup> in painting are very rare: 83 and 2 paintings respectively, out of 113,962 paintings analyzed. The very specific lighting conditions required to elicit SS or PLF may explain why they have been so rarely painted in art. Regarding PLF, an additional explanation could be that the postero-lateral light necessary to induce the effect illuminates only roughly one third of the face (Fig. S1; Fig. S2), potentially leaving the painter without enough light to make out the features of the remaining two thirds.

Whether or not the limbal arc of light (SS) or spot of light (PLF) were purposely represented, they should be preserved. From this standpoint, the results of the present work are likely to be of interest for art restorers, conservators, art historians and art amateurs. Indeed, the original appearance ("normal condition") of a painting – of which SS and PLF may be part – is a necessary condition for proper treatment and restoration<sup>25</sup>. Furthermore, analysis of SS and PLF in art provides an opportunity to revisit well-known masterpieces and to discover new ones. As subtle, very rare intrinsic characteristics of paintings, in addition to extrinsic factors such as judgments of experts or access to the art networks, SS and PLF are likely to enhance the economic value of paintings<sup>26</sup>.

### ***Enigmatic clarities ("chiaroscuro") reflecting advanced realism***

The bulk of paintings with SS (79 of 83) and both paintings with PLF were painted years before the precise description of SS and PLF by Basil Graves for in 1936<sup>4</sup> and Minas Coroneo in 1990 respectively<sup>6</sup>. From painters' standpoint, SS and PLF must have appeared as enigmatic, incomprehensible, seemingly ectopic presences of light in the shaded side of the eyeshell. Taken literally "chiaroscuro", conveys this sense of enigmatic (oscuro) clarity (chiar). Contrary to John Constable's view that "We see nothing truly till we understand it"<sup>27</sup>, some painters with a keen eye were able to spot and properly paint SS or PLF despite presumably not comprehending these phenomena. This illustrates the fact that a painter "may paint an eye exceedingly well" without extensive physiological, anatomical or optical knowledge, one example being corneal reflection<sup>28</sup>. Ingres' famous motto, "Gentlemen, put white into your shades"<sup>29</sup> serves to show that chiaroscuro in painting has often been considered as appertaining to a voluntaristic, proactive<sup>11-13</sup>, not to say artificial<sup>30</sup> approach designed to create effects or render modelling. In contrast, SS in paintings derives from a keen sense of observation, realism, objectivity and ability to render reality. It is, so to speak, a form of objective chiaroscuro, reminiscent of Constable's view that "CHIAR'OSCURO does really exist in NATURE"<sup>31</sup>.

Interestingly, the first representation of SS was painted by Campin in c. 1435 and Van Eyck in 1436. Both painters achieved a "quantum leap" in modelling forms with shading and began to produce, for the first time ever, "photographic-looking" pictures<sup>14</sup>. It was the onset of a period of advanced realism, of which the advent was largely made possible thanks to oil painting<sup>14,32</sup>. Van Eyck is generally acknowledged to have invented oil painting and Da Messina is generally credited with having introduced the technique in Italy<sup>14,32</sup>. After Campin and Van Eyck, the Renaissance was characterized by many great realistic painters (Fig. 2; Table 1). Hence, in the present report, most of the paintings (44 of 83) featuring SS were painted during the Renaissance especially at the beginning of the 16<sup>th</sup> century (22 out of 83) (Fig. 2), one of the all-time artistic summits of art<sup>32</sup>.

Notably, several of the masters who represented SS were obsessed with objectivity and realism (Fig. 2, Fig. S1; Fig. S2). Albrecht Dürer, a master of naturalistic rendering<sup>33</sup> spoke of some of his paintings as "konterfei"<sup>34</sup> i.e., an "exactly like" representation. He abided by the rule that, "The more

accurately your work represents life, the better it will appear"<sup>34</sup>. Hans Holbein the younger, fully aware of his ability to erase the frontier between illusion and reality<sup>35</sup> wrote in Latin under the portrait of Derich Born, "If you added a voice, this would be Derich his very self". Driven by his search for truth through resemblance, Maurice-Quentin de La Tour masterfully used pastel to produce some of the most lively and true to life portraits ever<sup>36</sup>. Eager to teach his pupils how to paint as objectively as possible, Jean-Auguste Dominique Ingres enjoined them to "simply copy nature"<sup>29</sup>. Contemporary Korean artist Hyung Koo Kang, has painted hyper-realistic portraits that closely resemble photographs with, however, elements of fiction, especially an emphasized gaze (see: <https://artsandculture.google.com/story/the-hyperrealistic-portraits-of-hyung-koo-kang/vQICouR4VXMIKg>). Some modern or contemporary artists (Istvan Ilosvai Varga, Tony Sherman) likely represented SS, although in a less realistic way.

From the 15<sup>th</sup> century onwards, painters probably used optical projections with concave lenses<sup>14</sup>. These projections require a lot of light<sup>14</sup>, which could achieve the extreme contrast necessary to induce SS<sup>1,2</sup>.

We may wonder whether, among the 20 painters who represented SS more than one time, some purposely used specific lighting conditions of the eyeball to repeatedly induce it. This seems plausible for Antonello da Messina, who painted five portraits with presumed SS presenting an almost photographic realism<sup>37,38</sup> using the same head position (rotated on the right) with the subject gazing at the painter, a powerful light coming from a top and right location relative to the subject head to induce SS at the temporal limbus of the abducted left eye. Among these paintings, "Le Condottière" (1475) (Fig. 1, panel b) has one of the most naturalistic renderings<sup>38</sup>.

Despite being a matter of realism and objectivity, the painting of SS entails the painting of faces, which are especially difficult to paint<sup>14</sup> and, as being the result of man's hand, are bound to be tinted with subjectivity. Amaury-Duval, one of the pupils of Ingres, stated that despite Ingres's credo that one should "slavishly copy nature", even Ingres paintings were no exception to this rule<sup>29</sup>. This may have resulted in rather unconventional representations of the arc of light of SS from the standpoint of a trained observer: "too thick" (e.g., "Portrait of a man", 1474, by Antonello da Messina or "Venus in front of the mirror", 1614-15, by Peter Paul Rubens), "too bright" (e.g., "The Holy Family", 1620-25 by Jacob Jordaens) or not extended over the whole limbus (e.g., "Portrait of a man", c. 1435 by Robert Campin; "Portrait of a young man in red", c. 1505 by Circle of Raphael). (Fig. S2).

### ***Christ: the only subject represented more than once with SS***

Depicted in 9 paintings featuring SS, Christ was the only character to be painted more than once. Eight of the 9 paintings date from the Renaissance period (Table S3; Fig. S1; Fig. S2). In 8 of the 9 paintings, Christ was portrayed with the head straight ahead and the eyes in the primary position of gaze. In 5 of the 8 paintings featuring this head position, the light came from a mainly top-bottom and slightly right to left direction. Antonello da Messina was the first artist to use this light direction in 1465 (or 1475?<sup>38</sup>). He was followed by Hans Memling in 1478 (two paintings), Quentin Metsys c.1500 (one painting) in 1495 and Lucas Cranach the Elder in 1516-20 (one painting). Albrecht Dürer used the same head and eye position and light exposure for his 1500 self-portrait, where SS appears at the left temporal limbus (Fig. S1; Fig. S2). These findings are in accordance with Hockney's view that painters imitate one another, which may result in similar scales, compositions and effects<sup>14</sup>.

### ***Signs of beauty***

In SS and PLF, the contrast between the lighted limbus and the neighboring shaded sclera may give, as is often the case for black and white contrasts, "force and brilliancy"<sup>39</sup> to the gaze, potentially highlighted by the frequent placement of one eye at the center of portrait paintings<sup>40</sup>. The

persons depicted by "Le Condottière" (A. da Messina, 1475) and Michael Wolgemut (A. Dürer, 1516) present a formidably strong glare, which is largely ascribable to SS (Fig. 1 panel b and C; Fig. S2). Sclerotic scatter and PLF, certainly fall into the category of "happy distribution of light and shade" and, as such are "a source of pleasing effect"<sup>12</sup> and "beauty"<sup>12,13</sup>. Albrecht Dürer's desperate and fruitless quest for an ideal of beauty in his art during his whole life is epitomized by a sentence written in his chronicle, "I don't know what beauty is"<sup>41</sup>. Notwithstanding his alleged ignorance of the very nature of beauty, Dürer painted it. In his 1500 self-portrait (Fig. S2) and in the painting of his master Michael Wolgemut (1516) (Fig. 1 panel c; Fig. S2), his striving for perfection and objectivity resulted in a vivid, startling representation of SS. Objectivity had somehow generated beauty, objective beauty, i.e., a beauty that was more in the eye of the beheld than in that of the beholder.

### ***An attempt to include all paintings of all art periods***

To carry out as exhaustive an analysis as possible, all color paintings of all artists of all art movements from ancient Egyptian art to contemporary art were taken into account in the present report. Large-scale internet databases (Wikiart, Web Gallery of Art<sup>42</sup>, Google Arts and Culture, museums databases, etc...) were used to search for PLF and SS.

Sclerotic scatter and PLF were always assessed through a high-definition photograph of the painting under investigation. These photographs were examined on a screen using the same scale as the real painting (when the relevant data were available). Indeed, zooming in too much in a digital photograph may blur the limit of the SS arc of light, in a way similar to digital photographs of the terminator of the moon<sup>43</sup>. The use of high-definition photographs gave proper access to details and avoided pitfalls such as cracks in the paintings (see lines 7, 239 and 551 of Table S2).

We used multiple criteria to ascertain that the presence of PLF or SS was credible in each photograph of the painting under investigation: 1) digital removing of the limbal arc of light (SS) or bright spot of light (PLF) and comparison of the modified and original photographs ; 2) search for published real-life photographs with PLF or SS with light exposure similar to that of the painting ; 3) experimental induction of PLF or SS using a LED panel or light illuminating the face and the eye of healthy volunteers in the same fashion as that of the painting.

Among the present work limitations are: 1) a photograph is not the strict equivalent of a painting, a factor we minimized by never definitely assessing PLF and SS unless access to a high-definition photograph was possible; 2) that for copyright reasons paintings from some painters were not available in the Wikiart database (e.g.: Francis Bacon), leaving potentially relevant paintings unscreened; 3) that despite a multi-step approach, there remains a part of subjectivity in the appraisal of the presence of SS or PLF; 4) that for some paintings, retrieving a high-definition digital photograph was not possible.

### ***Accounting for SS and PLF non-representation***

Among the 909 paintings with light exposure compatible with SS and the 5 paintings with light exposure compatible with PLF, SS and PLF were represented in only 83 and 2 cases respectively (Fig. S1), leaving 826 and 3 cases of non-representation respectively. Regarding the 826 cases of SS non-representation, it may be that in such instances, the ratio of the illuminance of the lateral light illuminating the eyeball for the effect to be elicited to the illuminance in the non-illuminated part of the eyeball was not high enough. This ratio varies greatly from one eye to another<sup>1</sup>. Regarding the 3 cases of PLF non-representation, it may be that in such instances, either owing to a low corneal curvature in the painted subject<sup>6</sup> or to insufficient shade in the nasal part of the eyeball, PLF was not elicited. It may also be that the painter saw SS or PLF but did not paint it because it appeared to be enigmatic, and incomprehensible. It may be, lastly, that the painter was too far from the subject he painted to see SS or PLF.

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## Supplemental materials

The following supporting information can be downloaded at:

[https://figshare.com/articles/dataset/Supplemental-material\\_pdf/21153145](https://figshare.com/articles/dataset/Supplemental-material_pdf/21153145)

Figure S1: Complete set of paintings with a light orientation compatible with peripheral light focusing or sclerotic scatter; Figure S2: Complete set of paintings probably featuring peripheral light focusing or sclerotic scatter; Table S1: Detail about the 113,962 color paintings and pastels of 2311 painters analyzed in the present report. Painters having represented sclerotic scatter are displayed in bold characters.; Table S2: Details about the 909 paintings of 311 painters with light exposure of the eye compatible with the occurrence of sclerotic scatter. Painters having represented sclerotic scatter and paintings featuring sclerotic scatter are displayed in bold characters; Table S3: Details of the 83 paintings of 42 painters with probable sclerotic scatter representation; Tables S4: Details about the 5 paintings with a light exposure of the eye compatible with the occurrence of peripheral light focusing (PLF), among which 2 probably feature PLF. Painters having represented PLF are displayed in bold characters.

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