



LEONARDO DA VINCI UNDER X-RAYS

GIULIA CAPELLI, CHIARA
CORAZZA, GIULIA PIERI,
LORENZO VERONESI

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Analyze and discover art

A MISTERY INSIDE A MISTERY: THE PERFECTION OF LEONARDO DA VINCI'S PICTORIAL TECHNIQUE

Training:

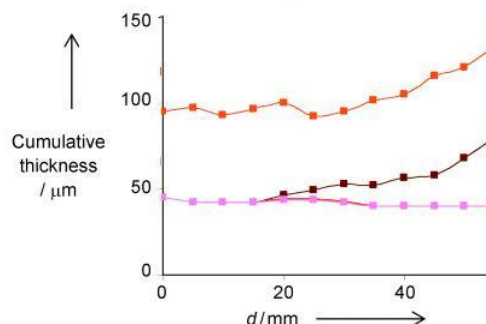
- Leonardo was born in Anchiano near Vinci in 1452 and died in France in the castle of Clos-Lucé in Amboise in 1519.
- He was a multifaceted artist, who devoted himself to art, architecture and science in its many aspects.
- He studied at Verrocchio's workshop who succeeded in instilling in the young artist that spirit of investigation and analysis of expression which were peculiar characteristics of the subsequent development of Leonardo da Vinci.

Leonardo's technique in painting:

- The CHIAROSCURO: the base of the painting was represented by a diligent drafting of the chiaroscuro, in this way it was easier to apply the colors on the subsequent layers
- TRANSPARENT COLOR AND VEIL: they play a very important role in the creation of colors
- The SHADED (lo "sfumato"): it is a technique that tends to blur the contours of the figures and make them less clear and pronounced, it allows to give a visual effect of "fading"

Leonardo's nuance revealed through X-ray fluorescent spectrography

- The studies were conducted by researchers from the "Center de recherche et de restauration des musées de France" (C2RMF) combining ancient texts with modern technologies.
- X-ray fluorescence spectra were used to determine the composition and thickness of each layer of matter. Through this technique it is possible to study the composition of the pigments in a painting and obtain information on the layers that compose it.
- The researchers applied their method to seven paintings in the Louvre.
- What did it turn out? Leonardo would have used multiple blends of materials and pigments to obtain the shadows on the faces.
- It has been hypothesized that the famous ombre, which characterizes four paintings in the Louvre, including La Gioconda, was obtained by applying a glaci (slight and soft thickness of the oil paint) composed of translucent layers with weak pigmentation.
- The thickness of the pigments is approximately 1-2 micrometers.



This is a representation of the superimposition of the layers in the face of the Mona Lisa, relative to a light area near the nose and a darker one, near the hair (the red line on the painting is relative to the area of interest of the analyzes and the area represented in the spectrum). After processing the data, the thickness and concentration of the pigments in the different layers were represented in the graph. It is part of the study conducted by the C2RMF researchers.

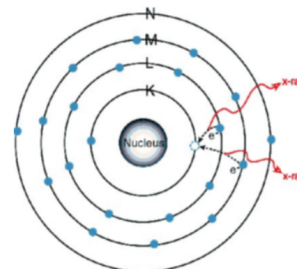
WHAT DOES IT MEAN TO PERFORM X-RAY FLUORESCENT SPECTROGRAPHY IN THE CONTEXT OF CULTURAL HERITAGE?

How do x-rays work?

X-rays are rays that, passing through matter, produce ions, therefore they are called ionizing radiations, they are rather energetic radiations, with high frequencies and low wavelengths.

What happens when an X-ray hits an atom?

1. The primary X-ray hits the atom
2. An electron from the innermost orbitals is ejected
3. An electron from the outermost orbitals fills the void in the inner orbital
4. The difference in energy causes a secondary X-ray to be generated



The energy difference between the various electronic levels is specific to each atom. Of the secondary X radiation, one can understand exactly which atom it came from.

For this to be possible the atoms must not be too small: atomic number greater than 15.

It is possible to identify the presence of an atom but it is not possible to understand which elements it is linked to, in fact it is an atomic and not a molecular technique.

Benefits and disadvantages of X-ray spectrography

In the field of cultural heritage it is a particular method of chemical analysis that does not need to take samples.

Fluorescent spectrometry consists in bombarding the area to be examined with X-rays, and studying which fluorescences are emitted.

This technique allows, in this application, to perform a mapping of the elements present and an investigation on the layers of the work.

BENEFITS:

- It is a non-destructive technique, it can be performed directly on site
- Highly specific technique for identifying elements
- Point-to-point mapping of elements by simply directing the X-ray beam
- With a primary (non-specific) X-ray, you can have a specific secondary X-ray for each atom
- Sometimes it is possible to perform a stratigraphy, but it is very difficult to understand which pigment belongs to which layer

DISADVANTAGES:

- It allows to identify which element is present, but for example not which pigment (atomic, non-molecular technique), it can identify, for example, the presence of copper, but it is not known what pigment this corresponds to: Malachite, copper resin, verdigris ...
- It is not possible to identify light elements.
- The passage is impeded by heavy elements

It is important to specify that all the analysis techniques are important if, in a given context, they allow to reveal significant information about the painting, the maximum results are obtained, however, when the same painting is analyzed with different techniques, which allow to reveal details and secrets. several of the same masterpiece.

THE BEAUTIFUL PRINCESS

Attributions that make people discuss, lost masterpieces, subjects with an enigmatic identity: when it comes to Leonardo, the mystery is always around the corner. While we are still anxiously awaiting the conclusion of the mystery story *Salvator Mundi*, we are enchanted by the enigmatic smile of the *Mona Lisa* and we admire the great technical error of the *Last Supper*, we take stock of a work that has driven scholars crazy over the last 20 years. Very elegant in her latest fifteenth-century Lombard fashion look, the *Beautiful Princess* looks in front of her with an absorbed air, regardless of the cloud of controversy that follows her on sight. Who is the lady? For some a girl of noble lineage, for others a 20th century cashier, "authoritarian and full of herself". The name, in fact, was given to him by Martin Kemp, professor at Oxford University and one of the leading experts of the Tuscan genius, who in 2011 validated with scientific analyzes the hypothesis already shared by distinguished art historians such as Nicholas Turner, Carlo Pedretti and Mina Gregori. Case closed? No way.



What does it represent? The profile of a young woman modestly dressed. The profile portrait was the preferred model of the ruling families in the Italian courts and especially in the North, especially in the Sforza family. According to the customs of the time, we know that the profile portrait was a must for the princesses, but for the lovers you could choose any other setting (just see the "*Lady with an Ermine*" and the "*Belle Ferroniere*", both lovers by Ludovico il Moro). The hairstyle worn by the woman is interesting: a very long tail braid which, according to the fashion of the time, was defined as a "coazzone".

During the examinations, five women were taken as a hypothetical model of the woman portrayed: Beatrice, wife of Ludovico, Isabella d'Aragona, wife of her nephew Gian Galeazzo, the nieces Bianca Maria and Anna and the illegitimate daughter Bianca. Among the five, the first three were discarded, since we have portraits of them, and the similarity does not subsist.



Instead, on the subject of Anna and Bianca, we do not have an evaluation on which to base ourselves. The most plausible hypothesis, however, is that it may be Bianca, daughter of Ludovico's lover: Bernardina de' Corradis. Bianca bethrothed of Galeazzo Sanseverino, captain of Ludovico's army. The two married in 1496 when Bianca was between thirteen and fourteen. From the sources we also know that Bianca became best friends with Ludovico's wife: Beatrice d'Este. Only eight months after the wedding, however, the poor girl died, perhaps of an ectopic pregnancy. Given the young age of the woman portrayed, the

identification with Bianca is very plausible. But the hypothesis of seeing Anna, Ludovico's granddaughter, as a model of the portrait should not be ruled out. She also died very young, only twenty-one years old. The work was object of many studies by the restorer Cotte and Kemp, one of the most famous Leonardo scholars.

The first step was the analysis of carbon 14 on paper. It has been deduced that 95% of the parchment can be inscribed in the period between 1440 and 1650. Archival documents reveal the relationships that existed between Leonardo and Galeazzo Sanseverino. Furthermore, through the X-rays, a fingerprint on the parchment came to light, which was compared with an imprint of another work by Leonardo: the "San Gerolamo penitente", not completed among other things, preserved in Vatican Picture Gallery. In the case of the "Beautiful Princess" the imprint is light, but at first glance they seem to coincide. Leonardo used to use his fingers and even the palm of his hand to paint his works, so it seemed another element that could ascertain the authorship of the work to Leonardo. (Giovanni Bellini and Dürer also used their fingers to complete their paintings, but Leonardo made more and much more visible use of them).

Obviously, at least according to the studies conducted since now, we cannot say with certainty whether the portrait on parchment was made by the master from Vinci. There are still too many questions and unresolved questions. At the beginning, the work was attributed to an anonymous German painter of the nineteenth century, part of the group of "Nazarenes". Its value was also not very high. At the famous "Christie's" auction in 1998, it was bought by a Canadian collector named Peter Silverman for \$ 21,850. Only later did the hypothesis of an attribution to Leonardo come forward. The doubts that still haunt scholars, however, are mainly two. Leonardo never painted on parchment, at least nothing has been preserved. It is therefore difficult to make comparisons with other works. Secondly, the profile portrait was not a model he used very much, indeed almost not at all. We have a drawing called "Portrait of a young woman in profile" preserved at the Windsor Library, but it is not enough to make a comparison, also because the technique used is different and the woman is not really in profile, but positioned at three quarters.

So, if there is no new archive discovery, it will be impossible to give certain answers. Until that time we could do nothing but wait.

Visible to the naked eye is the presence of three needle holes along the left margin. It was assumed that it was removed from a manuscript or book printed on parchment. It was concluded that the parchment had been torn from a copy of the "Sforziade", written by Giovanni Simonetta and kept in the National Library in Warsaw. The other copies are found in Paris, London and the Uffizi and all three have been used to commemorate important births in the Sforza family. The copy of our interest, that of Warsaw, was probably written to celebrate the marriage between Bianca Sforza and Galeazzo Sanseverino. In fact, there are many allusions. From the superimpositions that have been made, it seems that the sheet coincides both in length and in width with the other sheets of the manuscript. However, we do not know when and why it was detached.

Greenhalgh, a British forger, was part of the story of "The Beautiful Princess". In fact, the man spent four years and eight months in prison for having falsified and sold a copy of the painting, this is also told in his autobiography, a text in which he declares himself the author of "The beautiful princess".

THE BATTLE OF ANGIARI

LEONARDO'S WORK THAT BECAME FAMOUS NOT SO MUCH FOR
WHAT YOU CAN SEE BUT FOR WHAT YOU CAN'T SEE

The history of the painting:

- 1503: Leonardo receives the commission from the Gonfaloniere Piero Soderini to represent the Battle of Anghiari in the then Sala del Maggior Consiglio in Palazzo Vecchio in Florence, to celebrate the victory of Florence over Milan in the conflict of 1440
- Leonardo's painting is not visible in the room... it was probably covered or hidden by a fresco by Vasari.

"Search finds", the historical meaning of Vasari's flag:

Vasari's fresco represents the Battle of Marciano

A detail of the fresco reads "seek find" on a green flag, probably a sarcastic motto against a group of Florentine rebels who, fighting alongside their enemies, in search of freedom had instead found a very harsh punishment

Vasari's fresco is the one that many scholars believe to hide Leonardo's famous Battle of Anghiari, in this case could it also be a clue that Vasari wanted to leave us for the search for Leonardo's masterpiece?



The technique used:

LEONARDO USES THE ENCAUSTIC TECHNIQUE TO REALIZE THE WORK (heat the paint just applied with braziers). This technique, however, suitable for small surfaces, on large spaces would have caused the ruin of the painting.

"On the 6th of June 1505 on Friday at 13 o'clock I began to paint in the palace at which point of placing the brush the time spoiled and I rang at the counter requesting the little men to ragone. The cardboard was torn apart, the water was poured and the jar of water that was brought with it rupesi and immediately the weather spoiled and it rained until evening great water and the weather was like night "

Have the cardboards ever been shown on the wall?

It is not known what Leonardo made on the wall. In the middle of the sixteenth century Giorgio Vasari enlarged and completely remodeled the Salone, in doing so it is not known what fate he destined for Leonardo's painting.

To date we have only a few studies by Leonardo, the most famous of which are a study of a knight's head and that of Niccolò Piccinino's head.

Unfortunately, there are no studies on the final composition left.

Researches:



Research on the Battle of Anghiari conducted by Seracini with his research team

First clue: the words "search, find" painted in Vasari's fresco. From that moment on, Seracini carried out laser, radar and thermal scans in the Hall in order to be able to determine the location of Leonardo's painting (it should be in the area of the word "search and find"). Endoscopic analysis through Vasari's wall, in collaboration with the officials of the Opificio delle Pietre Dure, six access (image) points were created, in areas that did not have Vasari's original painting.



Seracini and his team cite four pieces of evidence to support the hypothesis that Leonardo's painting is behind Vasari's mural fresco, obtained thanks to endoscopic investigations with probes and micro-cameras and the sampling of some fragments:

1. The existence of a gap, about 3 cm, between the wall on which Vasari painted his fresco and the wall behind it through radar surveys carried out in the Hall. This discontinuity is borne solely by the right side of the east wall.
2. Fragments of red material were found on the original wall. Analyzed with IR spectroscopy and UV fluorescence, it was hypothesized that they were organic fragments that could be associated with red lacquer.
3. The beige layer on the original wall may have been applied only with a brush, highlighted by the images obtained with a high definition endoscopic probe. The fragments were covered with a fluid milky material. The beige flakes were formed by calcite, quartz, silicates and an organic component, discovered thanks to an IR spectrography
 - The material that covers them is milky white and, through an SEM-EDX analysis (technique that uses the emission of an X-ray beam), it was discovered to be calcium carbonate, this covers like a veil everything that is found below. The deposition of this material is probably due to carbonation processes.
4. A sample containing black colored material was found and analyzed. The analysis with SEM-EDX technology (Scanning electron microscope with microprobe) allows to identify the chemical components present in the sample. The relationship between these manganese and iron in the black pigment is reversed. This chemical composition is similar to that of the black pigments found in the brown sails of the Mona Lisa and St. John the Baptist.



All the evidence was found in the area of the famous inscription "search finds" (in Vasari's fresco).

The truth about Leonardo's painting

Chemists such as Mauro Matteini (chemistry expert in the field of cultural heritage) and Tomaso Montanari, either denied Seracini's tests or never had the opportunity to verify them. Cecilia Frosinini (director of the restoration section of the Opificio delle Pietre Dure) argues that there are a number of historical clues that support the hypothesis that the painting was never made.

WHETHER OR NOT THE BATTLE OF ANGIARI IS HIDING BEHIND THE VASARI FRESKO STILL
REMAINS A MYSTERY, WHICH PERHAPS WHO KNOWS ... ONE DAY IT WILL FINALLY BE REVEALED,
WHOEVER SEEKS WILL FIND ... OR MAYBE NOT.

THE VIRGIN OF THE ROCKS

Sometimes a painter can, for economic reasons, recycle an already used canvas by painting on original subject or even simply change your mind in the course of work by eliminating figures or landscapes he himself created (today in computer terms we would say overwrite). This technique was used even by great artists such as Leonardo da Vinci.

Non-invasive techniques

The painting object of the study is The Virgin of the Rocks, oil on panel where already in the past thanks to an infrared analysis at the National Gallery in London, where similar discoveries have been made, such as Maria herself in a different pose and position with reather those we can admire today. By analyzing the image using a technique developed in the last few years called macro-scan on X-ray fluorescence (MA-XRF) it is possible to determine the chemical composition of the subject under examination, without causing him any damage. In this way, a precise map of the painting is obtained, made up of an enormous amount of pixels, similar to a television image or the one we get with a home scanner or a photo via the smartphone but extremely accurate and much richer in information.



Science reveals hidden art

By combining this technique with a specially developed new algorithm, Professor Pier Luigi Dragotti of Imperial College London and Dr Catherine Higgitt of National Gallery found that Leonardo's original drawing contains traces of zinc, making it possible to highlight hidden figures like never before.

The automated process is much faster and more reliable than the manual one currently in use: the amount of data to be studied is enormous and must be analyzed with the utmost care every single layer of every single pixel with all the chemical information detected, e we are talking about several million elements.

The result, however, definitely repays the effort: the first infrared measurements at the time revolutionary, they appear crude today with respect to precision and even beauty (of course there is Leonardo's hand) of the images obtained with the new technique.

Technique that naturally due to its non-invasive nature will be able to find innumerable similar applications, while Professor Dragotti hopes to refine it further thanks to the contribution of artificial intelligence that will help uncover further secrets of works of art, well present yet hidden from the human eye.



THE ADORATION OF THE MAGI

The Adoration of the Magi, realised between 1481 and 1482, is a painting made by Leonardo da Vinci that portrays a very common iconographic scene for that time. The peculiarity of this painting is that it arrived to us as a big monochrome sketch. This has allowed scientists to better comprehend the pictorial technis of the painer throughtout specicif studies. To not ruin the painting, it had been given priority to non invasive diagnostic survays, in other words survays that were accomplished with special equipment that allowed researchers to observe and study the painting without the need of taking pieces off of it.

In particular, the equipement used is:

- **IR Reflectography** in the form of a Multi-NIR scanner that distinguish 14 different layers and gives back an image without optic deformation. This technique is established as the most effective survey technique in revealing the presence of preparatory drawings made by the artist above the preparation layer and covered by the paint.

To allow the survey, the painting is illuminated by common incandescent lamps connected to a voltage variator and suitably oriented. The infrared radiations reflected from the painting are detected by a camera system sensitive to 2000 nanometer wavelengths and with a filter that limits the exposure of the radiation to the infrared band only. The final image is finally projected on a high-resolution TV screen, which allows scholars to better examine the work.

- **Optical Coherence Tomography** which investigates the first layers of the surface, where the paints are present, the most important materials in the current visual degradation of the work. This technique basically consists of a rapid high-resolution 3D scan, using the principle of low-coherence interferometry (a method of measurement that uses interference between multiple waves that are coherent with each other). Compared to confocal microscopy, OCT can provide double the depth of penetration in highly dispersed samples such as paint layers because it exploits the coherence properties of light and only records coherent signals, making it optimal for the study of works of art.
- **UV false color** which discriminates, at the mapping level, the application of paints of different materials. This technique is one of the most popular, but it is not exhaustive. In fact, the process, which returns a trichromatic image using two components of the visible and one of the near infrareds, recognizes only some pigments, while for others the color differences are not immediately visible.
- **3D Optical Scanning** survey made it possible to measure with micrometric accuracy the dimensional variations produced on the support in these 11 years and therefore to evaluate the type of damage and its acceleration. This type of technique is very convenient for the non-invasive study of works of art. In fact, it provides a detailed image of the painting without the need to take samples, and thus ruin the work.



From the data that emerged, compared with other information resulting from diagnostic investigations carried out on different works by the same artist, such as the "Virgin of the Rocks" in London, the "Saint Anne, the Virgin and Child with the little lamb" in the Louvre and the unfinished "San Girolamo" of the Vatican Museums, it has been noted that Leonardo's painting technique, despite the passing of the years, remained practically unchanged.


The studies have led to understand that in an unspecified, but still ancient period, the surface had been covered by a coat of pigmented paint, probably used in order to lower the most dissonant differences in tone and brightness. The desired effect was to bring the reading and therefore the appreciation back to that of a known artistic category, that of monochrome, that is, a chiaroscuro painting, which uses tonal differences to suggest shapes and reliefs, and this explains the reason. for which it has come to us in such conditions.

Furthermore, it was noted that, unlike other works, for this work Leonardo does not use a cardboard to bring the drawing back to the table but creates a freehand drawing even if the scene is very complex.

And again, on the preparation layer Leonardo carried out the preliminary dry point graphic drawing freehand. He pulled the guided architectural construction lines with the help of a nail that marked the vanishing point (whose hole was found at the trunk of the central tree).

The pigments making up the painting, some interesting data emerged: the drawing, at first traced with a dry point, was made with a black watercolor given with a brush (which already makes the first changes compared to the original project). The OPD (the institute that took care of the restoration and study of the work), in fact, observed that the painter decidedly changed his mind between the first and second graphic phase, and then changed the idea further when, above the primer, goes on to give the first coats of color. Instead, the bluish traces are performed by means of a dye of vegetable origin, probably an indigo; finally, the preparatory drawing was "sealed" by a very thin transparent layer consisting of a binder and lead white. Only after creating this first preliminary layer did Leonardo begin to apply the different coats of color. The characteristic glazes were created with a mixture of brown-toned pigments in constant percentages in the different parts of the work: this means that the painter used a single and homogeneous batch of pigments, which he probably had available in his workshop.

“AND IF YOU WANT TO SUMMARIZE IN ONE JUST SINGLE WORD,
WELL, THERE IS WHAT WE’RE TRYING TO DO.WE’RE TRYING TO
GIVE A FUTURE TO OUR PAST IN ORDER TO HAVE A FUTURE.
AS LONG AS WE LIVE A LIFE OF CURIOSITY AND PASSION, THERE
IS A BIT OF LEONARDO IN ALL OF US.”



"Scientific analyzes of art masterpieces, paintings in particular, can provide us with extremely useful information: both to understand the details of the work, such as the composition of the pigments, and to reveal the fakes, or to bring to light paintings hidden by others. paintings.

At the basis of the method lies the characteristic signature that each atom has: the X-ray spectrum which is specific to each atomic element.

Art - magic word that opens hearts and minds. Which makes you dream, have fun but also cry. Looking at a beautiful painting fills the heart and lets us enter the extra dimensions of the soul: the artist's soul but also ours. An endless journey with speeds that are no longer limited by the speed of light, nor by space or time.

Leonardo's paintings, today as 500 years ago, arouse vivid emotions.
Never off, never outdated. "

