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# Two Rembrandt portraits in focus: assessing a potential relationship

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This study presents a comparative technical analysis of *Portrait of a 39-Year-Old Woman* (The Nivaagaard Collection, Denmark) and *Portrait of a Man* (The Metropolitan Museum of Art, USA), two oval-format paintings by Rembrandt that were previously proposed as pendants. The paintings were examined and analyzed non-invasively focusing on materials, technique and condition. While both paintings have similar supports and pigments consistent with 17th-century practice, differences were identified in the application of vermilion and the use of smalt, and in the signatures and inscriptions. The woman's portrait has undergone alterations and additions, while the man's portrait has remained in an unaltered condition. This research contributes new comparative data on Rembrandt paintings from the early 1630s and highlights the value of technical examination in assessing early 17th-century Dutch portraits.

*Portrait of a 39-Year-Old Woman* (The Nivaagaard Collection, Nivå, Denmark) and *Portrait of a Man* (The Metropolitan Museum of Art, New York, USA; The Met), two oval-format works attributed to Rembrandt van Rijn, have been dated to shortly after the artist moved from Leiden to Amsterdam in 1632 to work in the large, very active studio of Hendrick van Uylenburgh (ref. 1, p. 365). The first painting depicts a woman holding a small prayer book and dressed in a dark, unembellished gown that conveys modesty and restraint. She has a prominent forehead, tightly combed hair covered by a simple cap, and a crisp white piped collar around her neck. The sitter is portrayed over a plain background, with a soft light from the upper left that highlights her physiognomy. The overall impression is one of seriousness and integrity; the small prayer book adds meaning of spiritual devotion to the current composition. The second one portrays a middle-aged man seated in a three-quarter pose, dressed in dark, formal attire typical of the early 17th century. He is wearing a broad, white ruff that frames his face, and a black coat with simple lines. The sitter's expression is calm and reserved, and his gaze meets the viewer directly; the background is plain, allowing the figure to dominate the composition. Rembrandt's handling of light and shadow emphasizes the contours of the face and hands, lending depth and realism. Subtle variations in tone bring out the texture of the skin and fabric, while the restrained palette reinforces the sober character of the portrait.

The authors of *A Corpus of Rembrandt Paintings, Volume II: 1631-1634* were the first to mention, in 1986, that these two works may have been pendants (ref. 2, pp. 261-262). Pendants are paintings that work together to convey a specific meaning to the viewer and are therefore intended to be displayed together. Pendant portraits typically reflect a balanced visual

relationship and a familiar bond between the sitters, most commonly husband and wife, engaged couples, or siblings. They are usually compositionally and thematically related, have similar dimensions, format and facture, but may also differ in detail or perspective. Pendants may be created as an intentional pair from the first commission, but that is not always the case. Buyers of a one-off picture would sometimes later request that the artist paint a pendant (see <https://www.tate.org.uk/art/art-terms/p/pendant>, and <https://www.nationalgallery.org.uk/paintings/glossary/pendant>; both accessed 14 January 2026). Compositional and technical correspondence are supporting criteria for understanding if two paintings should be considered as pendants, although the strongest evidence is usually provided by documentary accounts, such as workshop records, letters and a solid provenance trajectory (refs. 3,4. Comprehending whether paintings are pendants has implications for understanding artists' practices, provenance and historical context, with implications for museum exhibitions and conservation decisions (see, for example ref. 3, p. 330). The hypothesis that *Portrait of a 39-Year-Old Woman* and *Portrait of a Man* were pendants was based on the comparable dimensions and oval formats of the two works, similar style and position of the inscriptions with the sitters' ages, and their inclusion as a pair at an auction in Paris in 1801 (ref. 2, pp. 256-262). The same authors who proposed that the paintings were conceived as companion pieces, along with other scholars in the intervening years, also presented counterarguments, including differences in the scale of the figures and in their respective placement in the picture plane, as well as the common 18th-century practice of pairing unrelated paintings (ref. 2, pp. 261-262, ref. 5, pp. 550-554, ref. 6, p. 517). In 2024, in the catalog *Dutch and Flemish Paintings at the Nivaagaard Collection*, Angela Jager and Jørgen Wadum

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presented a thorough discussion of the art historical and technical information available at the time of writing concerning *Portrait of a 39-Year-Old Woman* and *Portrait of a Man* (ref. 7, pp. 186–203). This catalog entry addresses questions surrounding the identity of the sitters, which led the authors to a few candidates but none were confirmed, and the provenance of the two paintings as a pair before the Paris auction in 1801, which does not continue beyond Claude Tolozan's (1728–96) ownership. The chronology of alterations and conservation treatments of *Portrait of a 39-Year-Old Woman* and a brief comparative analysis of the technical findings on both portraits as they stood at the time of writing are also included. Wadum and Jager state that the question of whether the two portraits are pendants remains unanswered, as additional technical and archival research is needed to further contextualize Rembrandt's workshop practices in pendant portraiture in the 1630s.

In this article, we present and discuss the results of an imaging and analytical campaign carried out to investigate and compare the materials, structure and facture of the two paintings. By outlining their similarities and differences, this study provides relevant evidence to further the discussion surrounding their possible relationship as pendants. This campaign was prompted by the expert meeting and in-focus exhibition that took place at The Nivaagaard Collection in September 2024, *Rembrandt Reunited*, which displayed the two portraits together for the first time since the Paris auction in 1801.

The non-invasive methods used in *Portrait of a 39-Year-Old Woman* included X-ray fluorescence (XRF) mapping, multiband imaging in the visible range (VIS), UV-induced luminescence (UVL), UV reflectance (UVR) and infrared reflectance in two wavebands (IRR at 850 nm and 1070 nm). The methods were complemented by an X-radiograph recorded in 1966 at the National Gallery of Denmark (SMK). In *Portrait of a Man*, the techniques included optical microscopy, X-radiography, infrared reflectography (IRR) and XRF mapping.

Typically, Rembrandt's methodical approach to portraiture began by applying, over the ground preparation, a monochrome, brushed-in sketch to broadly establish the composition and the tonal values. Then, he worked from back to front, laying-in a neutral background and leaving a reserve for the main figure, which was then defined in its outlines and details during the build-up stage (ref. 2, p. 42, ref. 8). IRR, autoradiography, X-radiography and XRF mapping in previous studies have revealed that Rembrandt frequently made both major and minor changes (e.g., shifting limbs or adjusting facial contours) as he built up successive paint layers (refs. 8,9, pp. 9–100, ref. 10, pp. 52–62). Scientific studies of Rembrandt's paintings have revealed a palette that includes lead white, chalk, lead-tin yellow, bone or ivory black, charcoal, lamp black, red, yellow and brown earths, pararealgar, orpiment, vermilion, smalt, azurite, vivianite, and red and yellow lakes (ref. 10, pp. 52–62, ref. 11, pp. 101–104, refs. 12,13, pp. 35–47, refs. 14–18).

## Methods

### *Portrait of a 39-Year-Old Woman* – Multiband imaging

Five spectral datasets were acquired: visible (VIS), UV-induced luminescence (UVL), infrared reflectance at wavebands 850 nm (IRR 850) and 1070 nm (IRR 1070), and UV reflectance (UVR). The entire workflow, from capture to processing and output delivery, aimed to follow the guidelines for multiband acquisition described by Dyer, J., Verri, G., Cupitt, J. in

*Multispectral imaging in reflectance and photo-induced luminescence modes: a user manual*. CHARISMA, 2013.

An unmodified and a modified Nikon D800, bearing full-frame 36.2 MP sensors, were used for all the spectral recordings, with the modified DSLR camera operating approximately within the 350–1100 nm spectral range. The camera body was coupled with a Nikkor 135 mm f/3.5 AI prime lens. This setup was used at a fixed aperture of f/8 to minimize inherent chromatic artefacts and geometric distortions, as well as to maximize the depth of field during capture. The shutter speed varied between 1/160 to 30 seconds depending on the desired exposure for each spectral acquisition. The camera, operated in fully manual mode, had picture style set to 'Neutral' and an ISO speed of 100. The white balance was set to 5400 K, except for UV-induced visible luminescence image acquisition, when it was set to 6500 K.

As radiation sources, two Elinchrom ELC500 coupled with Rotalux Go Recta Softbox were used for the VIS and IRR 850 captures, while two arrays of two Philips Infrared Heat Lamps were employed for the IRR 1070, and two Madatec UV LED, inherently filtered lamps with peak emission at 365 nm for the UVL and UVR datasets. All the radiation sources were positioned outside the family of angles, in a 45/45-degree setup relative to the painting surface.

Optical filters, or combinations thereof, mounted on the lens ensured the passage of the desired waveband interval for each spectral acquisition. For both the VIS and UVL datasets, the UV-IR cut filter MidOpt BP550 was used. The IRR 850 dataset was acquired with a MidOpt BP850 bandpass that has an 820–910 nm useful range and peak transmission at 850 nm. The IRR 1070 capture entailed a combination of a Madatec Bi1070, an interference filter with useful range at 1060–1080 nm and peak transmission at 1070 nm, and a longpass filter BlackDove LP950 to cut out any undesired transmissions below 900 nm. For the UVR setup, a combination of a Near-UV bandpass MidOpt BP365 and a Near-IR-block MidOpt BP485 filter ensured a clean recording of the UV-reflected signal. The modified camera body features an Astronomik MC-Klargas clip filter built in, designed solely to protect the sensor. The combination of sensors, radiation sources and optical filters is summarized in Table 1.

Each spectral dataset was captured in a mosaic of 21 images (three columns by seven rows) at a resolution of 680 ppi (ca. 27 pixel/mm) by installing the sensor on a motorized and programmable rig Edelkroner SliderPLUS with a vertical module to retain the focus by maintaining the focal plane parallel to the entire painting surface, ensure an adequate overlap between each capture, and automate the shooting session for all the spectral datasets.

The camera characterization was performed using as target references an X-Rite ColorChecker Classic and an array of four Zenith Polymer® Diffuse Reflectance Standards grayscale tiles with 99%, 60%, 25% and 2.5% reflectances. BaslCColor Input 6 was used to profile all the reference images. Measured L\*, a\* and b\* values of the color and grayscale patches ensured the creation of tailored color and tone profiles for each spectral band (ref. 19). Both targets were shot at the start of each spectral capture session to ensure adequate exposure. The RAW files, processed using CaptureOne Pro 21, were treated linearly and cleared of any undesired color correction before assigning the respective color profiles. Flat fielding ensured the correction of any light fall-off or eventual aberrations of the optical system. Individual

**Table 1 | Combinations of sensor, radiation source and optical filters used for each spectral dataset in the multiband imaging acquisition for *Portrait of a 39-Year-Old Woman***

Spectral dataset	Sensor	Radiation source	Filter(s)
VIS	Nikon D800	Elinchrom ELC500	MidOpt BP550
UVL	Nikon D800	Madatec UV LED	MidOpt BP550
IRR 850	Full-spectrum Nikon D800	Elinchrom ELC500	MidOpt BP850
IRR 1070	Full-spectrum Nikon D800	Philips Infrared Heat Lamps	Madatec Bi1070 + BlackDove LP950
UVR	Full-spectrum Nikon D800	Madatec UV LED	MidOpt BP365 + MidOpt BP485

output images were uncompressed TIFF files with 16-bit depth encoded in eciRGB v2 color space.

The individual spectral datasets were demosaiced in PTGui, and the resulting images registered in Adobe Photoshop® with the automatic alignment option of the image stacking tool. Subsequently, false-color composites were obtained: two false-color infrared (FCIR 850 and FCIR 1070), a false-color UV (FCUV), and a chromatic image (CHR). The latter was produced following the process described in ref. 20.

Further image processing operations were conducted to visually enhance the inscriptions on the painting. Individual images in the regions of interest of the *aetatis suae* inscription and the signature were cropped from a false-color composite obtained by shifting the R and G channels from CHR to G and B, respectively, and combining IRR 850 in the remaining R channel. The color model was converted from RGB to Lab. When additional contrast enhancement was required, the L\* component images were further processed using a parabolic function (Eq. 1):

$$x_i = 4(x - 90)^2 \quad (1)$$

### Portrait of a 39-Year-Old Woman – X-ray fluorescence (XRF) mapping

Elemental mapping was performed in the public exhibition gallery of the Nivaagaard Collection using a Bruker CRONO® system developed by XGLab S.R.L. The instrument consists of a measuring head with an air-cooled micro-focus Rh-target X-ray tube and a 30 mm<sup>2</sup> XFlash® silicon drift detector (SDD) with a beryllium window. The focal distance, which can be adjusted by varying the distance between the paint surface and the measuring head, was set to approximately 5 mm. The instrument was operated at 50 kV and 0.06 mA, using unfiltered radiation in an air atmosphere. The elemental 2D mapping of the painting's surface was achieved through an automatic XY-motorized stage with a 30 ms/pixel acquisition time and a 1 mm spot/step size, and was performed in four adjacent tiles (with approximately 3 cm overlap) to cover the entire area. The acquired data cubes were processed and stitched using open-source PyMCA (version 5.6.7) and Datamuncher (Gamma version 1.1, ref. 21) software. When necessary, additional contrast adjustments were applied to the acquired maps to enhance the visibility of details.

### Portrait of a 39-Year-Old Woman – X-radiography

The X-radiograph used in this study is a digital demosaicing of the four analog plates captured by Steen Bjarnof during the 1966–69 restoration campaign at SMK. Details of the original experimental setup are unknown.

### Portrait of a Man – Optical microscopy and UV photography

Optical microscopy and photomicrography were carried out with an Olympus SZX9 dual objective stereozoom microscope equipped with a Lumenera Infinity 3 camera, a dual gooseneck fiber optic illuminator, plan and plan apo objectives allowing 4.7× to 85.5× magnifications. UV photography was conducted with a Canon 5DS camera with Kodak 2E and Kodak CC40R filters. Illumination was provided by two 4-foot 40 W GE F40BLB lamps (UV-A glass mercury vapor lights with a peak at 365 nm).

### Portrait of a Man – X-radiography

For capturing the digital X-radiograph of *Portrait of a Man*, a Baltospot LLX110-DA-0 source with a 0.4 mm focal spot (IEC336), a focal spot to film distance (FFD) of 84.8 cm (33 3/8 in), and a Baltospot DC1 controller were used. This computed radiography system was used in conjunction with an HPX-1 Plus scanner, Industrex software, and Flex XL Blue 5537 plates.

### Portrait of a Man – Infrared reflectography (IRR)

The infrared reflectogram (IRR) was acquired in a single capture using an Apollo NIR camera, sensitive in the 900–1700 nm range, and equipped with a 128×128 pixel InGaAs sensor. Two Lowel Tota lamps (R7, 120 V, 500 W bulb) on a variable transformer, no filters, and a normal lens (Tele Vue

Optics, 150 mm focal length, 2 element, F/8–F/11) were used. Post-processing was done using Photoshop®. A level adjustment set the white point at the brightest part of the image; the black point was not adjusted. The midtones were brightened using the level adjustment so that detail in some of the darker areas could be read more easily. A sharpening adjustment was made using the “unsharp mask” tool with settings of 150%, radius of 1 pixel, threshold of 1. No tonal reference markers were used for adjustments.

### Portrait of a Man – X-ray fluorescence (XRF) mapping

Elemental mapping was carried out using a Bruker M6 Jetstream® instrument equipped with a 30 mm<sup>2</sup> XFlash® SDD and an air-cooled micro-focus Rh-target X-ray tube operated at 50 kV and 0.5 mA. The painting was mapped with an approximately 580 μm spot size, a 650 μm step size, and an acquisition time of 80 ms/pixel. The focal distance was set to approximately 15 mm. The scan was performed in an air atmosphere, using unfiltered radiation. Instrument calibration is checked periodically using a set of NIST standards. The spectra were processed using the Bruker M6 Jetstream® software and PyMCA software (version 5.9.2). The spatial distributions of the elements of interest were obtained using both the M6 Jetstream® software and fundamental parameters modeling in PyMCA. For the latter, the raw Bruker data were transferred into PyMCA-readable format using the open-source Datamuncher code.

### Effect of instrumental differences on data interpretation

The IR images were primarily used to support the interpretation of the XRF maps and X-radiographs for each painting. Because the two IR datasets were produced with different experimental setups and spectral ranges, their comparison was limited to features on the paintings that can be observed with both narrowband IR reflectance at 1070 nm and broadband IR reflectography.

To ensure comparability between the XRF mapping results, the 8-bit grayscale maps acquired with each scanner were normalized by rescaling pixel intensities to the full 8-bit range. Quantitative analysis and assessment of trace elements were outside the scope of this work; therefore, as this study was limited to a comparison of relative elemental distributions, differences in analytical conditions did not significantly affect interpretation.

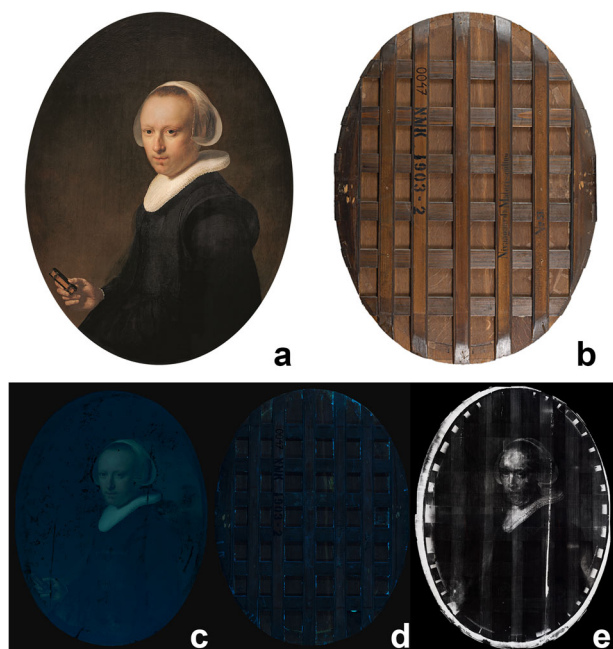
## Results

### Portrait of a 39-Year-Old Woman – Condition

A comprehensive reconstruction of *Portrait of a 39-Year-Old Woman's* conservation history can be found in (ref. 7, p. 199). The painting underwent a major restoration treatment in 1966 at SMK; no report describing the intervention exists. Today, the painting is in good, stable condition, although the X-radiograph and UVL highlight areas of the paint that were previously treated. Damage to the paint film was caused by two vertical cracks running along the joints: one crossing the hand holding the book up to middle height, and the second crossing the right side of the coat, the back of the collar, and the shoulder; both were filled before retouching. The X-radiograph revealed woodworm channels partially filled with a radio-paque material where the second and third boards from the left join, an operation that might have occurred during manufacture of the wooden support. Pinpoint losses in the paint film are mostly recorded on the background and on the gown, as suggested by the retouches. More localized interventions are also visible, especially in the background areas around the head. Small areas of retouching are also present on the sitter's face and on the righthand side of the coif, where the paint is thinner in the darker tones. Residues of an old natural resin are visible on the right, as well as cleaning tests performed just left of the woman's head. A glossy, evenly distributed varnish imparts a subtle sheen to the surface.

### Portrait of a 39-Year-Old Woman – Support and ground preparation

The support consists of an oak panel composed of three vertical boards, joined and shaped into an upright oval with a beveled edge around its perimeter, indicating that the panel retains its original shape. The boards, as reported in *A Corpus of Rembrandt Paintings, Volume II*, measure 18 cm,



**Fig. 1** | Rembrandt van Rijn. *Portrait of a 39-Year-Old Woman*. Oil on oak panel, 76.5 cm × 58.5 cm (originally 74.5 cm × 55 cm). The Nivaagaard Collection, 0047 NMK. Photographs of the recto (a) and the verso (b) taken under visible light, UVL of the recto (c) and the verso (d), and X-radiograph acquired in 1966 (e).

19.5 cm and 17.5 cm in width from left to right, respectively (ref. 2, p. 258). A dendrochronological study, aided by computed tomography (CT) scanning, has shown that the boards were sourced from the Baltic area and have a felling date after 1616–1625 (Daly, A., dendro.dk report n. 2024:49). Bomford et al. (ref. 8, p. 23) suggest that Rembrandt procured multiple supports in batches from panel maker shops, an observation based on dendrochronological studies of his works. The panel was extended by adding an oak rim of varying width around its entire perimeter, an alteration that Wadum places outside of Rembrandt's workshop at a date roughly between 1650 and 1720 (ref. 7, p. 186). Viewing the panel from the reverse, the original beveling appears to remain intact beneath a structure of wedges that were installed to compensate for the difference in thickness of the panel in preparation for the installation of the extension rim. The wedges are interspaced with a filling material that appears radiopaque in the X-radiograph (Fig. 1e). The extension restricts access to the edges of the original support, preventing further examination of the ground preparation. The back of the panel was thinned and cradled, possibly at the turn of the 19th century (ref. 7, p. 199), and preexisting inscriptions or markings may have been removed in the process. Panel makers' punch marks are sometimes visible on the reverse of 17th century Dutch paintings, attesting to the quality of the panel production according to the regulations imposed by the local Guild of St. Luke. The Guild represented and controlled the market of a variety of crafts; alongside painters, it encompassed sculptors, engravers, bookbinders and glass painters (refs. 22,23). The UVL imaging of the reverse did not reveal any production-related inscriptions in the small areas between the battens, and only highlighted residual traces of adhesives from the cradling remain visible (Fig. 1d).

The panel was prepared with an off-white, yellowish ground (ref. 7, p. 197) which, as suggested by the lead distribution map (Pb La line, reflecting both surface and subsurface lead-containing materials due to its relatively high penetration depth) presented in Fig. 2b, contains a lead-based pigment, most likely lead white (basic lead carbonate,  $2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$ ). Rembrandt's panel paintings commonly feature a ground preparation with two layers: one made of chalk ( $\text{CaCO}_3$ ) bound in glue at the bottom, and a lead white-containing layer on top (ref. 24, pp. 318–334). While the presence of a chalk layer underneath the lead-containing one cannot be ruled out, it

could not be confirmed; as mentioned above, access to the edges of the original panel is blocked by the extension rim, and in the XRF mapping the signal corresponding to the calcium (Ca) distribution is masked by the lead white in the layer on top. The presence of underdrawing could not be determined with certainty from the IRR 850 and IRR 1070 nm images (Figs. S1 of the Supplementary Information file and 3a, respectively).

### Portrait of a 39-Year-Old Woman – Paint layers

The painting's brushwork is described in detail in the catalog entry compiled by Jager and Wadum (ref. 7, pp. 197–199). Pigments were identified from the combined results of multiband imaging and XRF mapping; no samples were taken from *Portrait of a 39-Year-Old Woman*.

The painting presents alterations to its original composition. Scholars of the Rembrandt Research Project (RRP, an initiative of the Netherlands Organization for Scientific Research, focused on organizing and categorizing research on Rembrandt) agreed that the right hand holding the prayer book is a later addition painted by a different artist, who likely also changed the position and contours of the woman's right arm and elbow (ref. 2, pp. 260–261). Initially, the elbows were positioned slightly higher and wider, implying that the forearms may have rested on the armrests of a chair with the hands resting on the lap, although no evidence confirms the presence of painted hands in the lower area of the painting. These observations have been further elaborated in (ref. 7, pp. 186–203), where the authors propose that the hand holding the book was added at around the same time as the extension rim. Visually, the hand's skin appears darker than the sitter's face because of a tonal effect imparted by the background paint underneath, and horizontal, hairline cracks reported on the black sleeve and in the shadow on the hand do not develop on the rest of the woman's gown (ref. 2, pp. 260–261). The IRFC 1070 (Fig. 3b) and the Pb La, copper (Cu) and iron (Fe) XRF maps (Fig. 2b, f, g) support these observations. The hand holding the book does not show evidence of exposed ground in the midtones and shadows, and the paint mixture identified on the hand's skin contains lead white and a red iron-containing earth pigment. A Cu-based pigment, whose composition could not be established, was detected only on the sleeve of the arm holding the book. Similarly, the IRR 850 and IRR 1070 images as well as the XRF maps highlight the extent of the overpaint over the background close to the edge of both arms. This attempt to conceal the preexisting outline significantly altered the figure's posture.

Aside from the use of lead white in the ground preparation, the Pb M distribution map (Fig. 2c), which registers lead-containing compounds on or close to the surface due to the lower-energy of the Pb M line compared to the Pb L, indicates that this pigment is also present in the paint layers, particularly in the face and hand skin tones, as well as in the sitter's head-dress and collar. Furthermore, the two Pb distribution maps show adjustments to the contours of the woman's lower back and left arm, revealing alterations to the original composition.

Bone or ivory black, made by calcinating bones and characterized by the presence of Ca and phosphorous (P) in addition to carbon (ref. 25), was used to paint the woman's garment, her eyes and hair, the shadows cast on her face and hand, and the cover of the prayer book, as shown by their respective distribution maps (Fig. 2d, e). The background in the upper part of the painting also appears to contain this pigment, as observed in the IRR 1070 (Fig. 3a).

A Cu-based pigment was used in the now darkened cover of the prayer book held by the woman, as indicated by the corresponding distribution map (Fig. 2f). It is not possible to establish whether this pigment is inorganic (i.e., azurite,  $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$ ) or a metal-organic complex such as a pigment from the verdigris family, e.g.,  $\text{Cu}(\text{CH}_3\text{COO})_2 \cdot \text{CuO}(\text{OH})_2$ . A Cu-based pigment was also probably used in the background as well as in an attempt to rework the right arm of the figure, as revealed through enhanced contrast, which was necessary to make the Cu distribution visible in areas with weaker signals.

One or more Fe-based earth pigments were used to produce the reddish-brown tones in the background and in the woman's hair and skin (Fig. 2g). The presence of relatively small amounts of manganese (Mn)



**Fig. 2 | Portrait of a 39-Year-Old Woman.** Elemental distribution maps obtained by XRF mapping: Pb La (b), Pb M (c), Ca K (d), P K (e), Cu K (f), Fe K (g), Mn K (h), K K (i), Hg L (j), Zn K (k), and Ti K (l). In b, the arrows indicate adjustments that

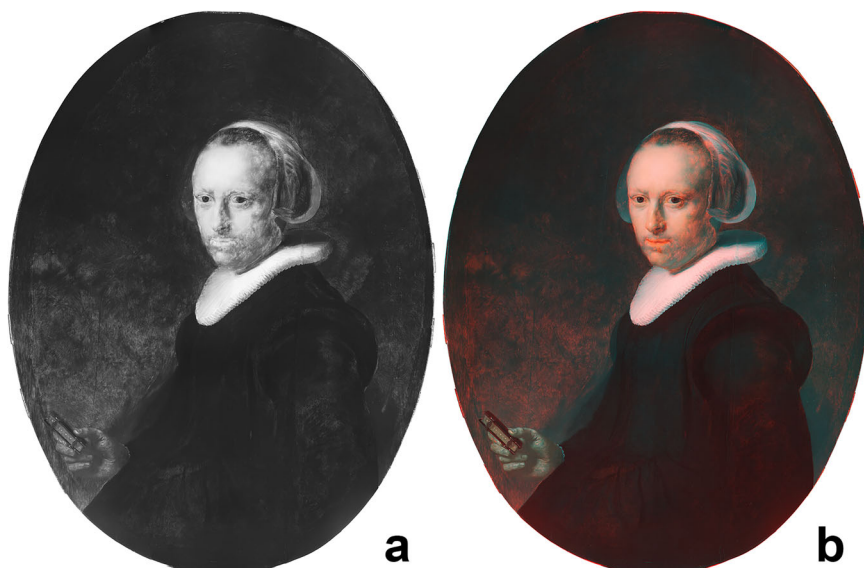
resulted in the repositioning of the sitter’s right arm, the reduction of the collar size, and the reworking of the left arm. Note that the contrast of the Cu K distribution map (f) has been adjusted to enhance the visibility of details.

indicates the use of a brown earth such as umber or sienna in the background, while the signal located in the darker tones of the flesh modeling may be associated with the tinted ground that was partially left exposed during the build-up stage (Fig. 2h). The yellowish color of the prayer book’s fore edge appears to contain relatively high amounts of Fe, which could be associated with a yellow earth. Together with the IRR images, Pb La and enhanced Cu distribution maps, the Fe and Mn maps further emphasize a reserve left in the area of the woman’s collar (Supplementary Information file, Fig. S1); this was initially planned to be larger, and was reduced in size during the build-up phase. Other smaller adjustments are visible in the sitter’s lower back and around the contour of the head, which was slightly reduced in size.

The weak signal associated with potassium (K) in the corresponding map indicates that pigments containing this element were used to a very limited extent, with comparatively higher quantities in the shaded area below the woman’s nose and in her lips (Fig. 2i). These results can be associated with the localized use of a red lake pigment, also revealed in the UVL image by a red luminescence (Fig. 1c), for which K is commonly a component of the inorganic substrate (ref. 26). However, the presence of K in deeper layers may be masked by the overlying paint.

Vermilion (mercury sulfide, HgS) was used throughout in the flesh tones, primarily in the face, with relatively smaller amounts applied to the hand, mainly in the fingertips as shown by the Hg distribution map (Fig. 2j). The pigment is broadly distributed across the sitter’s face, extending to the

**Fig. 3 | Portrait of a 39-Year-Old Woman.** Infrared reflectance image captured at 1070 nm (a) and corresponding infrared false-color image (b).



neck, forehead and the portion of the ear not covered by the headdress. This application imparts a warm tone to the woman's overall complexion. Reddish tones are found on the cheeks, over the left brow ridge, around the eyes, on the nose (both along the bridge and the contour of the nostril), and on the chin. A strong Hg signal is also recorded on the lips. The flesh modeling on the woman's face is built up with thin paint applications resulting in smooth transitions of tones and hues. In shaping the midtones and shadows, Rembrandt intentionally let the tinted ground partly show through to modulate the tones in the composition. The partially exposed preparation can be observed, under normal light, in several areas including the side of the nose, the right eyebrow and the eye sockets, the lower cheek and the neck. The IRR 1070 and IRFC 1070 images confirm these observations by revealing an uneven pattern, which can also be observed in the infrared imagery of other Rembrandt portraits of the same period (e.g., *Self-portrait bare headed*, 1633—Center de recherche et de restauration des musées de France (C2RMF), 2011, Infrared reflectography / Self-portrait bare headed, RKD Research, available at: <https://rkd.nl/technical/5003553>, accessed 14 January 2026; and *Portrait of Maertgen van Bilderbeecq*, 1633—Städel Museum, 2002, Infrared reflectography / Portrait of Maertgen van Bilderbeecq, RKD Research, available at: <https://rkd.nl/technical/5011421>, accessed 14 January 2026). Wherever the IR-absorbent, lead white-containing paint becomes thinner, the signal from the tinted ground emerges and assumes a bright red tint in the IRFC 1070 composite. In the highlights, the brushwork follows the shape of the depicted feature, with linear strokes on the nose and more curved passages under the eyes, on the right cheekbone and on the chin, while the brushwork on the forehead seemingly follows the direction of the light illuminating the scene from upper left. The impression of the brush marks is also visible in the X-radiograph.

The relatively strong Ca signal corresponding to the cracks in the wooden panel suggests that a calcium carbonate ( $\text{CaCO}_3$ )-based paste was used as a filling material (ref. 7, p. 199). In those same areas, the paint was retouched with pigments containing Fe and Mn. The Ca signals within the cracks could also derive from an exposed chalk ground. As mentioned in the section on support and ground preparation, while this possibility cannot be excluded, given that Rembrandt's panel paintings often have two layers in their ground preparations, the presence of a chalk layer cannot be confirmed from the Ca map alone, as its signal would be masked by the lead white-containing layer on top. A zinc-rich pigment, probably zinc white (zinc oxide,  $\text{ZnO}$ ), rather than lithopone ( $\text{ZnS}\cdot\text{BaSO}_4$ ) due to the very low signal observed for barium (Ba), and titanium white (titanium dioxide,  $\text{TiO}_2$ ) are present in retouched areas (Fig. 2k, l), indicating conservation interventions

that took place no earlier than the mid-19th century and the second quarter of the 20th century, respectively (ref. 25).

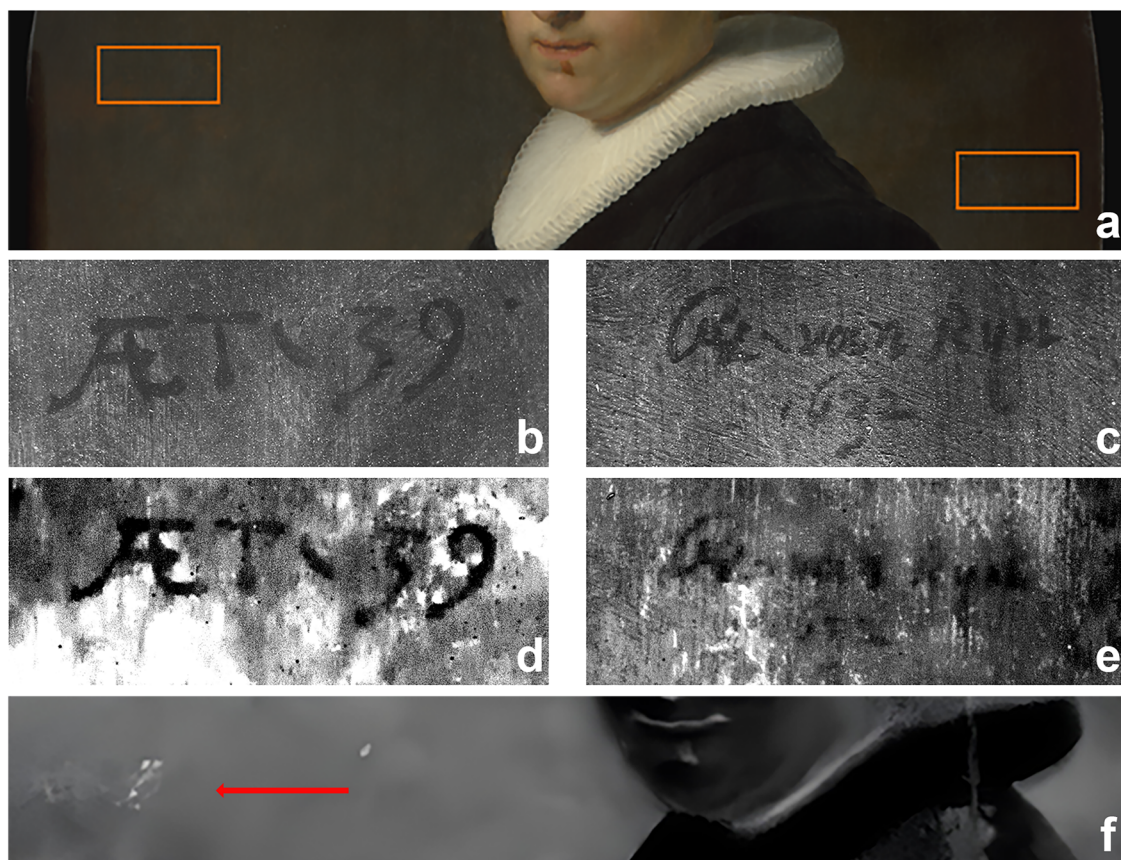
#### **Portrait of a 39-Year-Old Woman – Inscriptions**

*Portrait of a 39-Year-Old Woman* was treated at SMK between 1966 and 1969, and a visual examination was undertaken in March 1969. During this examination, black and white, high-contrast photographs documenting the treatment clearly showed a signature and an *aetatis* inscription (Fig. 4) (ref. 7, footnotes 1,13,16,17). The signature is in the background at right, near the figure's left shoulder, and consists of a monogram "RHL", followed by a backward-sloping stroke, and then "van Ryn / 1632" (Fig. 4c, e) (ref. 2, p. 260, ref. 7, p. 186). The *aetatis* inscription, written in larger characters than the signature, is located on the left side of the background, level with the figure's chin (approximately 2 cm higher than the signature), and consists of "ÆT", followed by a backward-sloping stroke, and then "39" (Fig. 4b, d). In *A Corpus of Rembrandt Paintings, Volume II*, the authors state that both the signature and inscription in *Portrait of a 39-Year-Old Woman* "make an impression of authenticity" (ref. 2, p. 260), and researchers who examined the signature under magnification in 2004 deemed it "reliable" (ref. 7, pp. 189–190). However, during the present investigation, the *aetatis* inscription was barely noticeable and the signature could not be readily observed under normal light.

In the attempt to enhance the visibility of the inscriptions in the painting, the authors applied image processing to the multispectral dataset. Partial results were obtained by combining IRR 850 nm with the chromatic image (CHR) to further enhance the contrast between the background and the inscription. The color space of the resulting image was converted from RGB to Lab. While the  $L^*$  component provided a satisfactory result for the *aetatis* inscription, the readability of the signature remained insufficient, even after additional processing with a parabolic function (Fig. 4d, e). XRF mapping revealed that the paint in the *aetatis* inscription is composed primarily of an Fe-containing pigment (Fig. 4f), while no elemental composition information could be obtained for the signature, suggesting that it might have been painted with a pigment containing an element not detectable by XRF, such as carbon-based black, or in amounts below the detection limit of the technique.

#### **Portrait of a Man – Condition**

The condition of the painting is excellent. In 1993, Hubert von Sonnenburg, former Chairman of the Paintings Conservation Department at The Met, removed a thick, discolored natural resin varnish as described in the



**Fig. 4 | Portrait of a 39-Year-Old Woman.** Locations of the *aetatis* inscription and the alleged signature, indicated by the rectangles on the left and right of the sitter, as seen from the viewer’s standpoint, respectively (a). Images of the *aetatis* inscription “ÆT · 39” (b and d), and of the signature and date (c and e); (b and c) correspond to the images revealed using high-contrast photography in 1966, and (d and e) to the

ones resulting from the image processing carried out in 2024. In e, the signature remains poorly visible. In (f), the arrow points to the *aetatis* inscription as seen in a super-resolved detail of the Fe K distribution map generated using the *Enhance* feature in Adobe Camera Raw.

**Fig. 5 | Rembrandt van Rijn. Portrait of a Man.** Oil on oak panel, 74.7 cm × 55.5 cm. Signed, dated, and inscribed (center right) “RHL van Rijn” [initials in monogram] / 1632 (center left) “ÆT · 40”. Gift of Mrs. Lincoln Ellsworth, in memory of Lincoln Ellsworth, 1964. The Metropolitan Museum of Art, 64.126. Recto, photograph taken under normal illumination (left) and photograph taken under UV illumination (right). In the image on the right, the green arrows indicate areas of retouching along the perimeter and the red arrows point to areas with fluorescent varnish residues.



conservation report *Rembrandt, Portrait of a Man* (Department of Paintings Conservation Files, The Metropolitan Museum of Art, New York, 1993). The photograph taken under UV illumination shown in Fig. 5 (right) attests to its fine condition. In this image, small areas of retouching are visible along

the perimeter where contact with the frame caused abrasion and areas where there appears to be very thin, fluorescent varnish residues. These residues are not discolored and have no detrimental impact on the appearance when the painting is viewed with visible illumination.

**Fig. 6 | Portrait of a Man.** X-radiographs, full area (left) and detail of the sitter's head (right). In the image to the left, the arrows indicate adjustments to the position of the collar and to the contour of the sitter's receding shoulder. Department of Paintings Conservation, The Met.



### **Portrait of a Man – Support and ground preparation**

The support of *Portrait of a Man* is an oak panel made of three vertical boards joined together, which retains its original shape, dimensions and bevels. The overall dimensions of the panel are 74.7 cm × 55.5 cm. Viewed from the reverse of the painting, starting from the left-hand side, the maximum widths of the boards are: 18 cm, 19.5 cm and 18 cm, respectively. The bevels on the reverse are irregular, measuring 1 to 3 cm in width. Most likely, Rembrandt ordered the panel from a panel maker, though there are no panel-maker marks. There is no physical evidence indicating that the support was originally square; the direction of the brushstrokes and intact paint texture along the perimeter suggest that the format has not been altered. In a 1995 dendrochronology study, Peter Klein established that the oak boards were sourced from the Baltic/Polish region and had a 1621 earliest felling date, more plausible between 1625 and 1631 (Klein, P., “Portrait of a Man,” Dendrochronology Report, October 5, 1995). In a dendrochronological reevaluation, Aoife Daly concluded that the boards have a felling date after 1616–1625, matching the dating established for the Nivaagaard painting (Daly, A., dendro.dk report n. 2024:49). In her dendrochronology report, A. Daly reported that a board from *Portrait of a Man* showed similarities with a board from *Portrait of a 39-Year-Old Woman* and that both boards may be from the same forest though not from the same tree. On the verso of the painting, a thinly applied brown paint partially removed is visible around the accession number; in addition, remnants of paper framing tape around the perimeter, and several inventory labels attached by the Met’s Registrar Office serve as reminders of frequent trips back and forth over the years from The Met to the owner’s residence (Supplementary Information, Fig. S2).

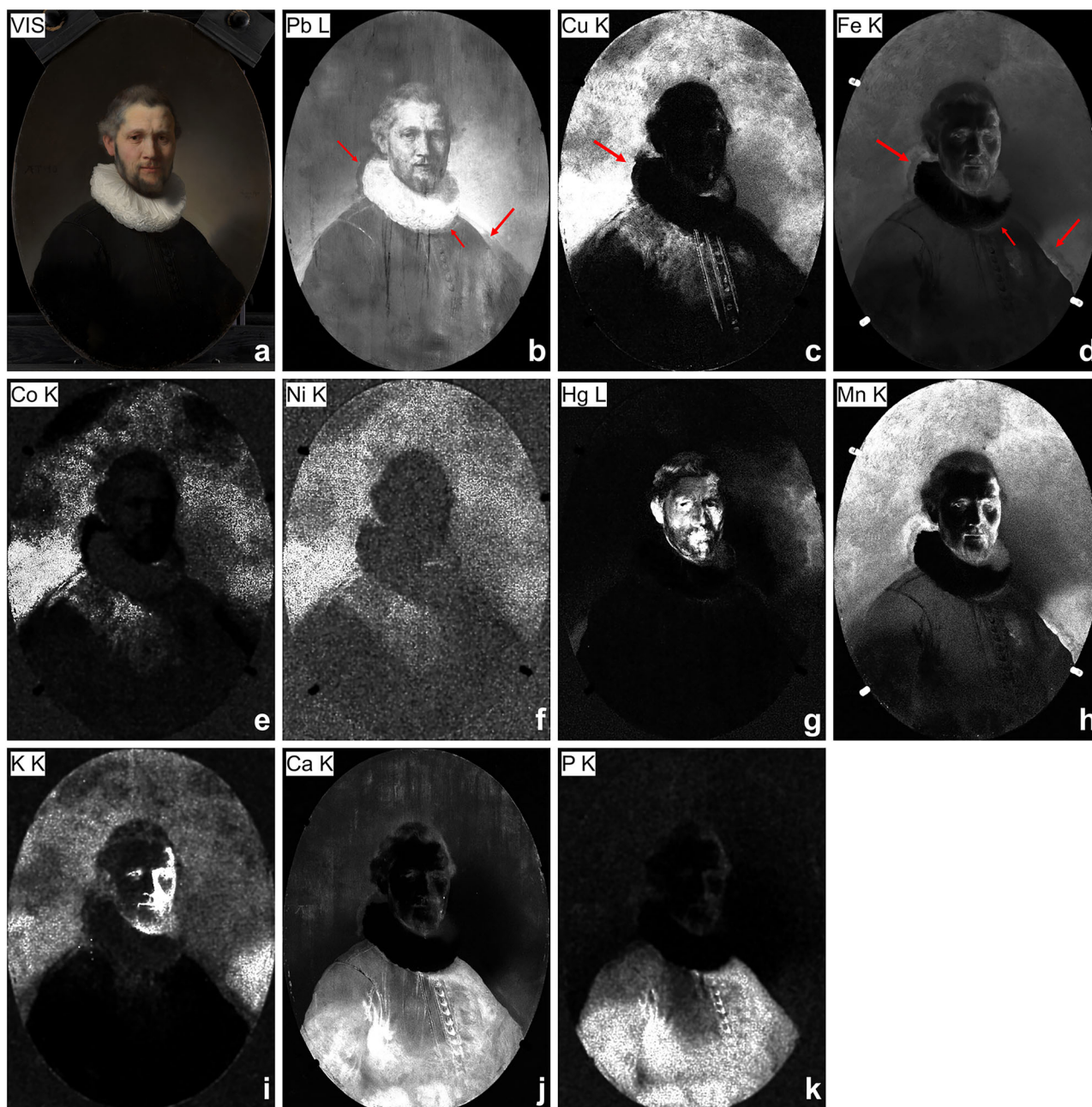
A film X-radiograph of the full painting, consisting of four plates spliced together, and a separate single plate of the head were captured in 1994 (X-radiography Files, Department of Paintings Conservation, The Metropolitan Museum of Art, New York). A digital radiograph acquired in 2025 is shown in Fig. 6. These X-radiographs revealed that the ground preparation is thinly applied; observation of the painting under magnification indicated that this ground preparation is light in color. No samples were taken to investigate the ground preparation but judging from the appearance in the X-radiograph and the examination of the painting under a microscope, it contains lead white. In Fig. 6, an area of reserve and the slight adjustment to the final position of the collar and various adjustments to the contour of the sitter’s receding shoulder can be distinguished. These adjustments are also visible in the IRR presented in Fig. 7.

The Ca distribution (Fig. 8j) map shows, in the background of the painting, a material, which may correspond to chalk in the bottom



**Fig. 7 | Portrait of a Man.** Infrared reflectogram. The arrows indicate adjustments to the position of the collar and to the contour of the sitter’s receding shoulder. Department of Paintings Conservation, The Met.

layer of the ground preparation. This result, together with the microscopy observation and the appearance in the X-radiograph, suggests that the ground preparation is consistent with those reported by Karin Groen for Rembrandt panel paintings dating from the 1630s: a chalk layer at the bottom and a lead white white-containing layer on top (ref. 24, pp. 318–334). As mentioned above, a sample cross section would be necessary to confirm the structure and composition of the ground.



**Fig. 8 | Portrait of a Man.** Elemental distribution maps obtained by XRF mapping: Pb La (b), Cu K (c), Fe K (d), Co K (e), Ni K (f), Hg L (g), Mn K (h), K K (i), Ca K (j), and P K (k). In b, the arrows indicate adjustments to the final position of the collar at left, in the contour where the collar meets the jacket, and in the sitter's receding

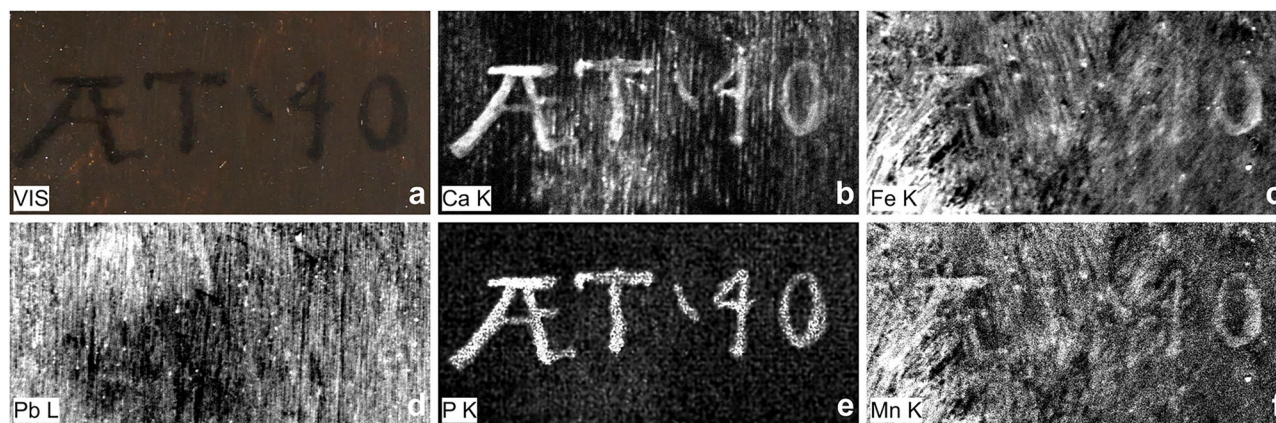
shoulder; in c, the arrow points to the background at left, where it was initially laid-in, leaving a reserve for the collar; and in d, the arrows show similar features as those indicated in (b).

### Portrait of a Man – Paint layers

In general, the execution of the portrait can be described as confident and direct from start to finish, with no significant changes and only minor adjustments as described in more detail below. The brushwork in this portrait has been previously described by H. von Sonnenburg (ref. 27, p. 90). No samples were taken from *Portrait of a Man* to investigate the paints, so the pigment compositions were inferred from the elemental distribution maps obtained by XRF mapping. The Pb La distribution map presented in Fig. 8b reflects the use of the pigment lead white. In this map, the slight adjustments to the final position of the collar are visible in the reserve at left and in the contour where the collar meets the jacket. The fabric of the man's collar is translucent and realistic in comparison to the woman's, which is

Painted in a buttery white paint with added light gray shadow areas. Various adjustments to the contour of the sitter's receding shoulder are also visible in the Pb distribution map, and in the X-radiograph and IRR (Figs. 6 and 7).

The Cu distribution observed in this painting could be due to the use of a Cu-based pigment such as azurite or to a member of the verdigris family (Fig. 8c), and the Fe distribution map reflects the use of an Fe-containing earth pigment (Fig. 8d). Both maps indicate that these pigments, along with lead white as mentioned above, were used for the adjustments. The Cu distribution map revealed how the background at left was initially laid-in, leaving a reserve for the collar, as seen in the Pb La distribution map; and the Fe distribution shows how the Fe-based pigment was used to make the final adjustment to the contour of the collar.



**Fig. 9** | **Portrait of a Man.** Elemental distribution maps acquired in the inscription (a): Ca K (b), Fe K (c), Pb La (d), P K (e), and Mn K (f).

Cobalt (Co), which corresponds to the blue pigment smalt, is present in the background and in the sitter's jacket at right (Fig. 8e). Smalt is made by grinding potash glass, and is generally characterized by the presence of Co, silicon (Si) and K, along with variable amounts of other elements, most commonly nickel (Ni), arsenic (As), bismuth (Bi), Fe, magnesium (Mg) and aluminum (Al) (refs. 25,28); the Ni distribution observed in *Portrait of a Man* (Fig. 8f) co-locates with the Co distribution, as expected for smalt. Smalt may range from a deep blue hue to a pale, almost translucent blue depending on the Co content (refs. 28,29, pp. 71–122, ref. 30,31, pp. 114–122). The use of smalt with a low Co content for translucency has been observed in paintings by Rembrandt (ref. 10, pp. 52–62, ref. 15). Blue smalt particles in *Portrait of a Man* are not distinguishable under magnification in the areas that show Co by XRF mapping; we did not analyze paint samples to determine the Co content in the particles and to assess if the paints have degraded. In addition to possible loss of color due to degradation, very pale blue smalt may have been added as a bulking agent, for translucency, and/or as a drier to speed up the curing of the oil in the first stages of painting (ref. 15). It was Rembrandt's practice to work from back to front, and the smalt distribution seems to correspond with the blocking-in of the background, with the figure left in reserve (ref. 6).

In the flesh tones, the Pb La and Hg L distribution maps show the presence of Pb white and the strategic use of vermilion in features on the highlighted side of the face (i.e., the cheek, eye and ear) as well as in the cheek in the shadow side, the side of the nose, the nostril, the lips, chin, and along the contour where the jawline and neck meet the collar (Fig. 8g). The use of vermilion is also revealed in the underlayer, specifically in the shadow side of the forehead and in the undermodeling of the hair at top left. Some vermilion is also visible in the background at right, used apparently to provide a slightly warmer tone to an area above the cast shadow, where the painting is signed and dated. When the painting is examined under magnification, the warm underpaint corresponding to the Hg distribution is visible. The Mn distribution map (Fig. 8h) shows the use of an umber pigment for the shadows of the face; the shadow areas in the flesh also contain relatively smaller amounts of a Cu-based pigment and K (Fig. 8c, i). The Cu distribution in the sitter's face seems to correspond to Rembrandt imparting a cool color to the half-tones. The presence of K in paintings may have multiple origins. In this case, the K distribution co-locates mainly with that of Mn from umber in the sitter's face (Fig. 8h). K is a common constituent of umber and other Fe-containing earth pigments, with variable amounts depending on the sources of the materials (refs. 32–34). K from smalt is likely contributing to the K distribution observed in the background and it cannot be ruled out that a relatively smaller amount of the element is present as a component of a red lake substrate (ref. 26). Therefore, it is not possible to fully assign the K distribution without the analysis of samples.

The co-location of Ca and P in the flesh indicates that Rembrandt used a bone or ivory black pigment (Fig. 8j, k). While in the areas where P has been identified, it is possible to assign the presence of Ca to a black pigment,

Ca in other areas may be in part reflecting the use of pigments such as Fe-containing earth (ref. 33) and calcium carbonate ( $\text{CaCO}_3$ ). A technique for molecular analysis in a sample, such as Raman spectroscopy, would be necessary to identify the source/s of the Ca.

### Portrait of a Man – Inscriptions

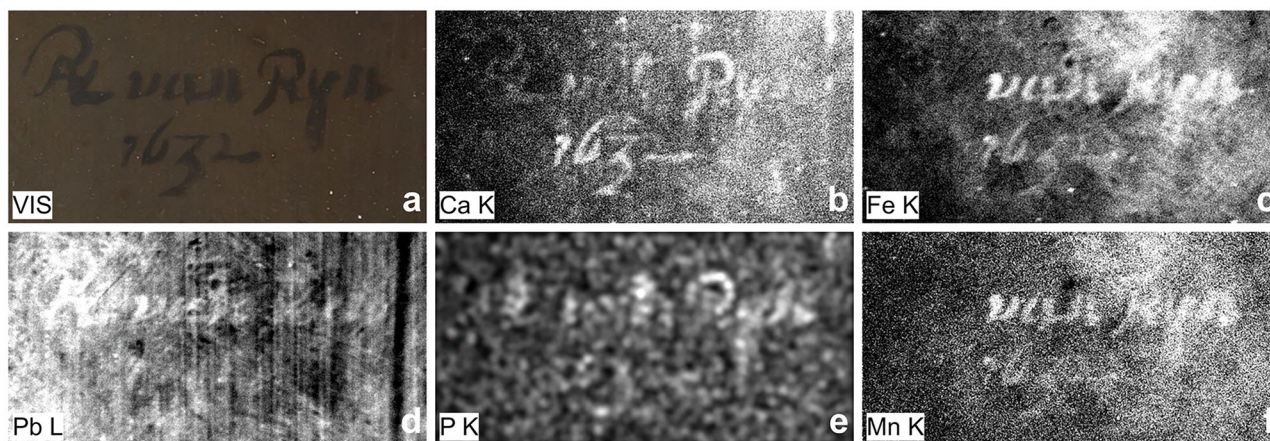
The portrait is signed in the background, at center right “RHL van Rijn [initial in monogram] / 1632” and the inscription “ÆT · 40” is at left and positioned slightly higher than center (Supplementary Information file, Fig. S3). The signature is described by the authors of *A Corpus of Rembrandt Paintings, Volume II* as “[it] makes a reliable impression” and the ÆT · 40 as “large unsteady letters” (ref. 2, p. 240). In *Dutch Paintings in The Metropolitan Museum of Art, Volume II*, Walter Liedtke describes the signature and date as “certainly authentic” while the *aetatis* inscription is described as “large and rather crude... [it] must be by another hand, and could date from a later period” (ref. 5, p. 550).

Figures 9a and 10a show photographs taken under visible illumination in the inscription and the signature, and Fig. 10 presents partial photomicrographs of these taken with the same magnification. The microscopic examination indicated that both the inscription and the signature are painted directly on top of the background paint; it is clear in the photomicrographs shown in Fig. 11 that their scales are different. Also, the paints have different characteristics, the handling is different, and we agree with the previous assessment that the signature and inscription appear to have been done by different hands (ref. 5, p. 550). In the signature, the paint is thin, fluid and rapidly applied with confidence. By contrast, the handling in the inscription is labored and the paint is more thickly applied.

Under magnification, the pigment mixtures of the signature and *aetatis* appear different. XRF mapping showed that the inscription contains mainly Ca and P, possibly in the form of a bone or ivory black pigment, along with some Fe and Mn indicating the use of an umber (Fig. 9b–f). The paint in the signature and date contains a Pb-based pigment, Fe and Mn, from an umber, and Ca and P from a bone or ivory black pigment (Fig. 10b–f). These results indicate that the paints in the signature and inscription have different compositions; we cannot rule out that components other than those observed might be below the detection limit of XRF mapping.

### Discussion

This study aimed to explore similarities and differences of the materials, structure and facture of two paintings attributed to Rembrandt, *Portrait of a 39-Year-Old Woman* and *Portrait of a Man*. The two paintings retain the original oval format, size and beveling, and, although *Portrait of a 39-Year-Old Woman* was enlarged at a later date, their original sizes are comparable. These common characteristics constitute an element of argumentation for a possible close relationship, as mentioned for the first time in *A Corpus of Rembrandt Paintings, Volume II* (ref. 2, p. 162). A dendrochronological study (Daly, A., dendro.dk report n. 2024:49) not only



**Fig. 10 | Portrait of a Man.** Elemental distribution maps acquired in the signature (a): Ca K (b), Fe K (c), Pb La (d), P K (e), and Mn K (f).



**Fig. 11 | Portrait of a Man.** Photomicrographs showing the 'E' in the inscription (left) and a detail in the signature (right). Visible illumination, original magnification for both images: 22.5 $\times$ .

reports matching earliest felling dates for both wooden supports, but also reveals that a board from *Portrait of a Man* showed similarities with a board from *Portrait of a 39-Year-Old Woman* and that both boards may be from the same oak forest. Although these results may suggest that the two supports were produced around the same time, the hypothesis that the boards were stored in the workshop and worked at different times cannot be excluded. As mentioned above, the market of wooden painting supports in 17th-century Amsterdam was regulated by the Guild of St. Luke, and it is commonly agreed that Rembrandt purchased readily prepared panels in batches (ref. 8, p. 23). The hypothesis that the two panels were procured from the same supplier is enticing, but neither of the two paintings bear maker's marks on the reverse to corroborate it. The search for a panel maker's branding on the reverse of *Portrait of a 39-Year-Old Woman* was unsuccessful because it was thinned in preparation for the installation of the cradle and only small areas not covered by the cradle members could be observed. If any traces remain, they would probably be covered by the batons of the cradle. The support of *Portrait of a Man* has not undergone alterations and no panel maker's mark is visible.

In accordance with Groen's description of grounds in Rembrandt's early panel paintings, consisting of a chalk layer at the bottom and a lead white-containing layer on top (ref. 24, pp. 318–334), the Pb La distribution maps confirm the presence of a lead white layer in both *Portrait of a Man* and *Portrait of a 39-Year-Old Woman*. In the case of the Man, the Ca distribution in the background may be reflecting the presence of a chalk layer in the ground preparation. However, sample cross sections from both paintings are necessary to gain a comprehensive understanding of the structure and composition of the grounds.

Generally, Rembrandt worked out his compositions directly on the support, starting with a quickly brushed lay-in, usually done with a brownish translucent paint. This monochrome compositional sketch served to both broadly position the figures in the composition, so that the background could be worked up around a reserve, and to establish a reference for the tonal modeling (ref. 35). Adjustments to the figure's outlines, which are not infrequent in Rembrandt's portraits, were made during the build-up stages. Analyses of *Portrait of a 39-Year-Old Woman* and *Portrait of a Man* show similar changes from the original lay-in. In the woman's portrait, the collar was considerably reduced in size, while in the man's portrait, there are changes to the contour of the collar at left and to the position of the shoulder at right.

The two paintings, on the other hand, diverge in the modeling of the flesh. Both portraits show a controlled exposure of the tinted ground to modulate the middle and dark tones. However, the use of vermilion differs in the modeling of body color; it is more subtle and strategic in *Portrait of a Man* than in *Portrait of a 39-Year-Old Woman*. The mercury distribution map of *Portrait of Maertgen van Bilderbeecq* (1633) (ref. 36) bears similarities with the one recorded for the Nivaagaard painting; vermilion was more generally applied to impart a warmer and pinker complexion to the sitter, and then used in more localized areas to reinforce the blush tones in the highlights. Even though variations may not be uncommon in pendants accepted to be by Rembrandt (ref. 6, p. 517), our findings suggest that the materialities of *Portrait of a Man* and *Portrait of a 39-Year-Old Woman* ultimately diverge.

The pigments in *Portrait of a Man* and *Portrait of a 39-Year-Old Woman* constitute a limited palette and are consistent with those in use by 17th-century Dutch artists: lead white, bone or ivory black, Fe-containing earth pigments, umber, and vermilion were identified. Copper was also detected in both paintings, although the molecular composition/s of the material/s was/were not determined.

As an element of distinction between the two paintings, the analysis revealed the presence of smalt in *Portrait of a Man*, which was not detected in *Portrait of a 39-Year-Old Woman*. Rembrandt employed smalt in different ways: as a blue pigment alone and mixed with other pigments as well as for translucency, texture and as a drier (ref. 10, pp. 52–62, refs. 11,13,15). Rembrandt used smalt pervasively in his late paintings (refs. 11,15), but this pigment has also been reported in works dating to the 1630s, such as *Anna and the Blind Tobit* (ca. 1630), *Saskia van Uylenburgh as Flora* (1635), in which smalt was detected in the underlayers that are part of an earlier composition (ref. 8, pp. 62–69 and 89–99), and in *The Standard Bearer* (1935) (ref. 16).

The potassium distribution observed by XRF mapping could be associated with the use of lakes in *Portrait of a 39-Year-Old Woman*; in the case of *Portrait of a Man*, potassium from smalt is contributing to the distribution observed in the background but it cannot be ruled out that a

relatively smaller amount of the element is present as a component of a red lake substrate. Fe- and Cu-containing pigments identified in the prayer book added by a different artist in *Portrait of a 39-Year-Old Woman* are consistent with pigments typically used in 17th-century paintings and do not indicate the presence of modern materials. The pigments identified in the later addition align with documentary evidence, including the description of the prayer book in an 1801 sale catalog (Getty Provenance Index, Sale Catalog F-1, Lot 0097), and the rarity of the silver clasps and corner fittings (as depicted in the portrait) on pocket-sized church books in the first half of the 17th century (ref. 37, pp. 296–297, ref. 38, pp. 12–19). Together, these details suggest that the addition was made between 1650 and 1720 (ref. 7, p. 186).

In both paintings the signature consists of the monogram “RHL” followed by a backward-sloping stroke and then “van Ryn / 1632”. Rembrandt used this signature for a short period in 1632, as he abandoned the “L” (Leyden, “from Leiden”) during the course of that year (ref. 39). However, although the 1966 photographs and past examinations (ref. 2, p. 260, ref. 7, note 1) affirmed the presence and authenticity of both the signature and the *aetatis* inscription in *Portrait of a 39-Year-Old Woman*, these are now nearly invisible with the naked eye. We could only partially recover the inscriptions through image processing, and, unlike the results of the analyses of the *Portrait of a Man*, XRF mapping of the Nivaagaard portrait did not reveal the elemental composition of the paint in the signature. These particular circumstances make it challenging to compare the materials in the two signatures. Complementary analyses and a paleographic comparison of the inscriptions, on these and other portraits of the same period, would be necessary to investigate possible relationships.

While the results of this study alone cannot answer the long-debated question on the relationship between *Portrait of a Man* and *Portrait of a 39-Year-Old Woman* as pendants, they underscore the critical role that a multi-technique analytical approach has in evaluating pendant relationships and in contributing to the ongoing debate over pendant portrait Dutch production in the 17th century. Future studies of the ground preparations and paint stratigraphies, along with comparative analyses of signatures and of the use and distribution of pigments such as smalt and vermilion in other paintings produced by Rembrandt in the early 1630s, would be necessary to fully contextualize the similarities and differences observed between these portraits, as well as to help settle perennial questions regarding pendant portraits by Rembrandt in general.

## Data Availability

The datasets from the Nivaagaard and Met paintings are available upon reasonable request.

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## Author contributions

All authors contributed to the conceptualization and to deriving the overarching conclusions. SAC performed the analysis and interpretation of the data from the Met's painting. GP conducted the XRF mapping analysis and interpreted the data from the Nivaagaard painting, while CP carried out the multiband imaging and its data interpretation. DM contributed to the interpretation of the results in the context of 17th century Dutch painting practice and of Rembrandt's materials and technique in particular, and provided a conservation perspective. SAC and GP wrote the initial draft with inputs from CP and DM. All authors read and approved the final manuscript.

## Competing interests

All authors declare no financial competing interests and GP, CP, and DM declare no non-financial competing interests. Silvia A. Centeno is an Associate Editor at *npj Heritage Science*.

## Additional information

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