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CONNOISSEURSHIP AND TECHNICAL ANALYSIS
RE-EVALUATING THE *LAUGHING CAVALIER* FORGERY 100 YEARS AFTER THE COURT CASE

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N. Vyncke: automated craquelure analysis
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ABSTRACT

A century after the 1925 trial, the *Laughing Cavalier* painting is once again the subject of extensive examination. Its recent resurfacing provides a rare opportunity to re-evaluate the painting itself and the methods used to analyse it during the court case. This allows us to study the evolution of connoisseurship in the field of forgery detection. It also enables us to consider how art-historical research and technical analysis and methods can be effectively combined in this area.

This essay marks the beginning of the ERC-funded Consolidator Grant project ARTDETECT, that will systematically analyse a variety of painted forgeries and reference works over the next few years. The project will also critically assess methods that can help to recognise and identify forged paintings and explore innovative ways to make the authentication process more effective and efficient.

INTRODUCTION

The court case in 1925 concerning the relatively small, round painting in the style of Frans Hals, the *Laughing Cavalier* (fig. 1), was a pivotal moment in the history of connoisseurship. For the first time, chemical and technical evidence was used in a Dutch court to expose a forged painting. However, the evidence did not lead to a conviction as the lawsuit was halted before reaching a conclusion. Nevertheless, thanks to the archives and publications of Cornelis Hofstede de Groot (1863-1930), the expert involved in the attribution, we can study the case in great detail: both his own views and those of his opponents, as well as the evidence presented in court are documented [1]. The original court documents can be examined at the RKD Netherlands Institute for Art History, and had not been fully explored until now [2]. For over half a century, the location of the painting in question was unknown. Seymour Slive mentioned that the painting was held in a private collection in Rotterdam in his oeuvre catalogue of the works of Hals [3, vol. III, p. 135-136]. It resurfaced unexpectantly in 2024, which provided a unique opportunity to assess the painting anew, to study the earlier evaluations of the picture in relation to the work itself as well as reference works, and to reflect on the evolution of connoisseurship in the field of forgery detection.

Cornelis Hofstede de Groot first saw the painting in April 1923, when the art dealer Theo van Wijngaarden (1874-1952) presented the work to him together with another work in the manner of Frans Hals, namely *Boy Smoking* (fig. 2). At that time, Hofstede de Groot was one of the leading experts on Dutch seventeenth-century paintings. After an honourable career as deputy director of the Royal Picture Gallery the Mauritshuis in The Hague (1891-1896), director of the Print Room at the Rijksmuseum (1896-1898) and dozens of prestigious publications, he lived as an independent art historian providing certificates of authenticity on a regular basis (Ekkart 1979). He had played a key role in exposing the deceit of Leo Nardus (1868-1955) in 1908, a dubious painter and art dealer who had sold ninety three pictures ‘under gross false pretences’, as Hofstede de Groot concluded, to the American collector Joseph Widener.

When Hofstede de Groot travelled to the United States of America to assess the paintings and brought three other experts with him: Roger Fry, Wilhelm Valentiner and Bernard Berenson. Most of these works turned out to be wrongly attributed, heavily overpainted or even downright fakes [4; 5; 6].

Strikingly, neither the *Laughing Cavalier* nor the *Boy Smoking* raised any suspicion with him. Hofstede de Groot deemed both paintings to be 'authentic and characteristic' works by Frans Hals' [7; 1]. He provided a certificate of authenticity for the *Laughing Cavalier* and decided to purchase the *Boy Smoking* for his own collection. The fee for his assessment, fl.1000,-, was later deducted from the purchase price of fl.30.000,- [5, note 45, p. 264; 8].

The *Laughing Cavalier* was subsequently offered for sale by a certain H. De Haas at the Frederik Muller & Co auction house in Amsterdam. Accompanied by the certificate, it was sold on the 8th of June 1923 for fl. 50.000,-. [9] This was roughly the equivalent of fourteen years' salary for the average man). [5, p. 46]

A few months afterwards, however, the buyer demanded to be reimbursed claiming that the painting was in fact a forgery. The auction house looked into the matter and asked the paintings conservator Derix de Wild for advice, who suspected that the painting was of a much more recent date than the seventeenth century, because the paint had not completely hardened yet in several locations. [1, p. 44-45] The auction house then asked Hofstede de Groot to cover a third of the damages suffered (circa fl.16.666,-). Hofstede de Groot refused to do so. He indicated that in his view he could not be held accountable for the prices fetched by paintings he had authenticated, and he offered to research the painting anew. After a second inspection, however, he concluded once again that the painting was by Frans Hals. [1, p. 7-8]

The auction house then subpoenaed the seller, De Haas on December 9th 1923. Muller and Co. demanded annulment of the purchase contract and reimbursement of the purchase amount, including interest as well as their litigation expenses. The court subsequently appointed three expert witnesses on November 27th 1924 to determine if the painting was 'by the hand of Frans Hals or one of his contemporaries, or if was a modern painting created by an imitator', namely Sir Charles Holmes, director of the National Gallery in London, Prof. dr. Wilhelm Martin, director of the Royal Cabinet of Paintings the Mauritshuis in the Hague and Prof. dr. F. Scheller, chair of Inorganic Chemistry at the Technical College of Delft (nowadays known as Delft University of Technology). [1, p. 8; 8] The specialists studied the painting together in March 1925 and wrote a joint report, which they submitted on the April 30th 1925. Their individual analysis were included as enclosures. [2; 1]

The materials science part of the investigation was particularly disconcerting. Only the first test yielded a positive result: the paint layer did not dissolve when treated with the standard ninety six percent alcohol solution, as one would expect of a seventeenth-century painting. However, when lightly touched with a cotton swab soaked in water, the paint became soft. With a soft brush and water the paint layer could even be entirely removed. Moreover, the researchers found artificial ultramarine in several locations throughout the painting, a pigment that was not available until 1826. The researchers also discovered cobalt blue in several locations in the background, a pigment that was not commercially manufactured until the early nineteenth century. A chemical analysis of the white used in the painting identified it as zinc white, a pigment that has only been available since 1781. Radiography of the picture also revealed two nails below the paint layer that had been hammered into the picture from the front. These were machine-made and could therefore not have been produced before the nineteenth century. The conclusion was clear: the painting could not be by Frans Hals or one of his contemporaries. It was made by a modern forger or imitator.

The lawsuit received much press coverage and constituted a serious blow to the reputation of Cornelis Hofstede de Groot. When the legal proceedings had dragged on for one

and a half years, he suddenly brought it to a halt, presumably to avoid further damage to his reputation. Before the judge could reach a verdict, Hofstede de Groot purchased the contested painting for the full amount of fl. 50.000,- which made the lawsuit redundant. He then defended his point of view in his publication *Real or Fake? The Eye or Chemistry?*. In a nutshell, he argued that his expert eye should outweigh the chemical evidence presented in court. It is a position one can hardly imagine taking nowadays, and therefore an interesting benchmark in our study of the development of connoisseurship in the field of forgery detection. What criteria did Cornelis Hofstede de Groot use to substantiate his attribution? And what led him to dismiss 'chemistry' so radically? How did his opponents and later experts assess this painting? And can a new art-historical and technical analysis of the painting provide more insights into its attribution and into the evolving field of forgery detection?

METHODS

The following methods were used to study the earlier evaluations of the *Laughing Cavalier,* to examine the painting anew, to test new analytical techniques, to support a new hypothesis, to relate it to reference works, to the evolution of connoisseurship in the field of forgery detection.

1. Archival research/primary documents: We studied various archival documents, including private notes and correspondence about the painting, the court reports and the photographs that were submitted as evidence (figs. 4 & 5). [2] See also the transcripts of interviews with H.A. de Haas by Marijke van den Brandhof, and interviews with the Wijngaarden family by Jonathan Lopez. [10; 5] The Hofstede de Groot archive at the RKD also contains correspondence between Holmes and Martin pertaining to the lawsuit. [2]

2. Literature research: We analysed Cornelis Hofstede de Groot's publications about the attribution, as well as other, later expert assessments. [7; 1; 11, p. 18, 49; 3, vol. III, p. 135-36; 12, no. 343; 4; 13, cat. No. F01; 6; 14, no. X4; 15, cat. no. 71]

3. Visual examination, photography and non-invasive microscopy: We studied the *Laughing Cavalier* in regular visible light and raking light, with a digital microscope (Dino-Lite AM7515MZT), and a Hirox-microscope. It was photographed by Prof. Maximiliaan Martens in high resolution using a Nikon® D850 digital reflex camera (full frame 45.7MP BSI CMOS sensor) with a VR 24-120 mm, f/4G lens at a resolution of 5504 x 8256 pixels at 300 ppi (VIS, UVF with and without orange filter). Infrared reflectography was by Prof. Martens with a commercial Osiris infrared camera, manufactured by Opus Instruments (Cambridge, United Kingdom). The OSIRIS is equipped with an InGaAs array sensor operating at wavelengths from 900 to 1700 nm, and object resolution down to 0.05 mm. The panel was recorded with a camera-object distance of 90 cm, a focal length of 43 mm, an f/11 diaphragm and indirectly illuminated at 850 Lux by continuous reflected light with 2 x 300 W Tungsten Halogen Elinchrome Scanlite 300. The entire picture surface was imaged in 1 recording of 4096 x 4096 pixels each. Afterwards, in Adobe Photoshop CS5®, the recorded image's legibility was enhanced by histogram correction and the application of the filter 'Unsharp Mask'. 1 vertical line per horizontal stich due to a dead pixel in the sensor has been corrected with the retouching tool.

4. Non-invasive technical analysis: We made a new radiograph (with a Kramex PX-30N portable X-ray unit, 15 MA/80 KVP, 4.0 sec., distance to film 115 cm), did point XRF (X-Ray Fluorescence spectroscopy) measurements, using a Bruker ARTAX µ-XRF-spectrometer, 50kV, 600µA, 120 sec. Mo-anode and a 0.060 µm capillary lens, usually without He-flush; and MA-XRF

(macroscopic XRF imaging) with two different instruments: a Bruker Crono XRF scanner at the Netherlands Cultural Heritage Agency (RCE), making use of a Rh X-ray tube operated at 40 kV and 80 µA with a 1 mm collimator and no filters [16] and the MA-XRF scanner developed at Antwerp University, making use of a Rh X-ray tube operated at 40 kV and 200 µA with a 1 mm collimator and no filters. At the RCE, the painting was scanned with a pixel size of 1.0x0.836 mm^2 and a dwell time of 70 ms per pixel; at Antwerp University, it was scanned with a pixel size of 0.6x0.6 mm^2 and a dwell time of 150 ms per pixel. HIS (Hyperspectral Imaging, also known as RIS Reflectance Imaging Spectroscopy) was acquired with a Specim IQ camera (Specim, Spectral Imaging Ltd., Oulu, Finland) sensitive to the spectral range from 400-1000 nm. [17]

5. Paint samples: We also took a numbers of micro paint samples in inconspicuous locations, mostly under the frame, and analysed these with the following techniques: Microscopy, SEM-EDX, binding medium analysis (FTIR and THM-GC/MS) by KIK-IRPA, Raman analysis by Eva Vermeersch and Peter Vandenabeele, UGent and lead isotope analysis by Paolo d'Imporzano at VU University, see the specifications below.

Microscopy and SEM-EDX: Microscopy of paint cross-sections was done with a Leica DMLM microscope, at a magnification of 100x, 200x, 500x, and 1000x). Images were recorded in plain polarized light, bright field illumination (BF), and in ultraviolet illumination (UV), with λ ex. = 365nm, 385nm, and 470nm. Additionally, we used a Thermo Scientific, Helios G4 PFIB UXe scanning electron microscope, equipped with a Thermo Fisher Ultralight detector of carbon-coated samples.

FTIR and THM-GC/MS: The Fourier-transform infrared spectroscopy (FTIR) was done with a Bruker Hyperion 3000. By averaging 128 spectra (4000 to 650 cm-1) with a resolution of 4 cm-1 for both sample and background measurements, the detector (MCT) provides an adequate signal-to-noise ratio. The spectra were obtained and processed using OPUS 7.2 FTIR software. The samples were subsequently analysed using thermally assisted hydrolysis and methylation - gas chromatography/mass spectrometry (THM-GC/MS). Pyrolysis was performed in the absence of oxygen, in a helium atmosphere at 480°C, in a Frontier Lab pyrolysis unit model 3030. The sample, supplemented with 4 µL TMAH (5% in methanol), is placed in a steel cup and then falls into a hot oven. The chromatographic column was connected directly to the pyrolysis unit, without using the classic injector. A Supelco SLB-5ms column (length 20 m, internal diameter 0.18 mm, film thickness 0.18 µm) was used for the chromatographic separation (Thermo Focus – ISQ MS instrument). This device operates at a constant flow of 0.9. The following temperature program was used: 1.5 minutes at 35°C, followed by rapid heating at 60°C/min to 100°C, then at 14°C/min to 250°C. Finally, further heating was carried out at 6°C/min to 315°C. This final temperature was maintained for 2 minutes. The components to be separated are ultimately detected using a mass spectrometer, which allows the various separated components to be identified with high sensitivity (quadrupole MS, Thermo PolarisQ, scanned between 29 and 650 amu, MS at 220°C, transfer line at 290°C).

Micro-Raman Spectroscopy: Measurements were performed using a Bruker Optics *Senterra* dispersive Raman spectrometer that is equipped with an Olympus microscope. An XYZ motorized stage is used for focusing the laser on the sample. The spectrometer has a Nd:YAG (532 nm) laser and neutral density filters are used to control the laser power ranging between 0.04 (1%) and 15.08mW (100%) for the 532 nm laser. The detection is achieved by using a thermoelectrically cooled charge-coupled-device (CCD) detector, operating at a temperature of -65°C. A microscope turret is equipped with objectives of which the magnifications range from

5x (numerical aperture (NA): 0.1), 20x (NA: 0.4), 50x (NA:0.75) to 100x (NA: 0.9). Respectively, the following spot sizes are obtained: 50µm, 10 µm, 4 µm and 2 µm (visual inspection, 785 nm laser). The system is controlled by OPUS software (Bruker).

Lead isotope analysis: The lead isotope ratio (LIR) analysis was conducted by dissolving the samples in 1 millilitre of 3 M HNO_3. The samples were treated and then diluted to 2 mL to achieve a Pb concentration of 25 ppb. The solutions were doped with a Tl solution (5 ppb) to correct for mass-dependent fractionation and analysed using a Thermo Scientific™ Neoma™ MC-ICP-MS equipped with an Apex Ω desolvating nebuliser. A blank was also analysed to monitor environmental contamination. An in-house standard solution (CPI) was analysed to monitor the precision and accuracy of the method. The blank value (36 pg) was considered negligible relative to the final LIR of the samples. Data from the in-house standard CPI confirm that the method's accuracy and precision were optimal. For comparison we studied *Boy Smoking* (fig. 2) as much as possible with the same techniques.

6. Digital Craquelure analysis: For craquelure detection, we employed a robust and efficient crack detection method based on deep convolutional neural networks (CNNs) that is capable of exploiting and integrating multiple imaging modalities [18]. The approach performs pixel-wise classification, assigning each pixel to either the crack or non-crack (background) class. As a preprocessing step, morphological filtering is applied to suppress the majority of background pixels, both accelerating inference (the classification process) and improving the localization of crack boundaries where CNNs often struggle with. For each painting, we trained the CNN from scratch on single-modality data (RGB or IR), using manual annotations of cracks and background. The model is then iteratively refined through an active learning strategy. Additional annotations are selectively provided in regions where the network's predictions are unsatisfactory, followed by retraining. This on-line learning process enables the model to progressively improve the classification performance as more annotated examples become available.

7. Contextual research: We related the earlier views and evidence found in the literature and archives to our new observations and technical analysis, and did some additional literature and archival research to provide context for our new hypothesis, and did some additional literature and archival research to provide context for our new hypothesis.

RESULTS

Hofstede de Groot's analysis [19]

Although Hofstede de Groot hardly defines criteria for assessing paintings, the way in which he attacks his opponents is revealing. Hofstede de Groot mainly directs his arrows at Professor Wilhelm Martin. The latter allegedly appealed too often to his 'sense of style' (*stijlgevoel*): "*In an earlier polemic against Rembrandt scholars, Prof. Martin declared with great self-confidence, that by possessing a sense of style he noticed things, which must have escaped his opponents because they did not have this sense of style, or at least to a lesser degree than he did. I then very clearly pointed out to him that what he considered to be a sense of style had nothing to do with it, and I must also state here that the fact that the highly learned gentleman does not*

recognize the hand of Frans Hals in every brushstroke in this painting proves very clearly that he does not possess the very least feeling for the style of Frans Hals either". [1, p. 28-29]

What is striking in this reasoning is that Hofstede de Groot does not reject 'sense of style' as a criterion. To him it was apparently perfectly natural for connoisseurs to have a 'feeling' for a painter's characteristic style, allowing them to see more and judge better than a layman. That 'feeling' (*gevoel*) seems to have been for Hofstede de Groot a mainly intuitive insight, which in principle needed little explanation. Circumstances did, of course, compel him to refute the arguments of his opponents. He therefore framed his booklet as a '*negatio*', as a denial of the contrary, of the expert opinions that had been used against him in court.

In doing so, he did not shy away from technical evidence. In particular, the discovery of modern nails in the picture and the solubility of the paint layer seem to have worried him. Therefore, he consulted the painter and restorer who had asked him to assess the painting in 1923, Theo van Wijngaarden (1874-1952), nowadays better known as the mentor and business associate of master forger Han van Meegeren (1889-1947). Van Wijngaarden immediately admitted that he had hammered modern nails into the painting. These would not be situated underneath the paint layer, however. He claimed that he had covered the nail heads with tiny retouches himself. He also provided an explanation for the solubility of the paint layer: he was in the possession of a product –invented by himself but kept a secret– that could render any old master painting in oil soluble in water, which he demonstrated on the spot on another seemingly old painting. Ignorant of the massive swindling for which Van Wijngaarden would later become known, Hofstede de Groot did not raise further questions. He mentioned Van Wijngaarden in good faith in his publication and indicated that the restorer was willing to demonstrate his product on any old master painting. [1, p. 13]

Having thus 'refuted' the chemical evidence, Hofstede de Groot proceeded to counter Martin's style analysis. In the expert report, Martin had indicated that he recognized a certain similarity to Hals's oeuvre (notably elements that seemed to have been copied from Hals's famous *Merry Drinker* at the Rijksmuseum, fig. 3), but that he did not encounter the distinctive characteristics of Hals' own hand, which he had described in rather broad terms as a 'playfulness of spirit' (*dartelheid van geest*), a 'secure hand' (*zekerheid van voordracht*), a 'virtuoso manner of painting' (*gave schilderwijze*) and 'a light-hearted mobility in head and body' (*luchtige bewegelijkheid in hoofd en lichaam*). [1, p. 82-83] Several elements in particular deviated from what Martin would have expected of Hals: the stockiness of the shoulder area in relation to the head, the rough indication of the left cheek and neck which did not show the underlying structure, the coarse definition of the hair, the way in which the mouth and teeth were depicted and the light reflection on the lower lip.

According to Hofstede de Groot, however, a 'secure hand' was a rather 'subjective feeling'. Although this remark seems to imply that he believed that Martin's criteria were perhaps not objective or clear enough, he merely objects to Martin's application of the criterion. Hofstede de Groot argues that the disputed picture does, in fact, show 'a secure hand'. He also believes that 'playfulness of spirit' is a valid criterion, but he claims that it does not apply to all Hals's works. The regent group portraits of Frans Hals, for example, are far from playful in his view, thereby touching indirectly on the ambivalence of the term. Did it allude to a certain playfulness in the subject depicted or rather in the handling of the brush? Moreover, in Hofstede de Groot's view, the coarse brushwork was not unusual for Hals, and neither was the stockiness of the shoulder area. He provided no fewer than twenty comparative examples to substantiate his claims. [1, p. 20-21] Ironically, one of the reference works he used has the same provenance

as the contested *Laughing Cavalier*. It was the picture of *Boy Smoking* that Theo van Wijngaarden had asked him to assess in 1923 and that Hofstede de Groot had liked so much that he had purchased it for himself (fig. 2).

Many of Hofstede de Groot's reference works have been de-attributed since then. He thus did not just lack clear criteria to distinguish between an authentic Hals and an imitation, but also a clear frame of reference, which makes his mistaken attribution somewhat understandable. In Wilhelm Valentiner's 1923 Hals oeuvre catalogue, for example, a selection of 322 paintings are attributed to the master without much explanation. [20] This is about forty percent more than today's most positive estimate, 229 paintings, to be found in the 2014 edition of Slive's oeuvre catalogue. [21] Claus Grimm's most recent catalogue classifies 199 works as entirely or partly by the master's hand. [14] It brings to mind how broadly Hals's oeuvre was defined at the beginning of the 20th century and how much the paintings ascribed to Hals's hand varied in quality. The fact that Hofstede de Groot stuck to his attribution even when confronted with ample counter arguments is also less surprising than it might seem at first glance. It is reminiscent of the 'sunk cost fallacy', the phenomenon described by Daniel Kahneman and Amos Tversky that investors who lose money several times on the same project tend to repeat their mistake and –against their better judgment– invest in the same project again. [22; 23] After all, Hofstede de Groot had invested in his attribution both literally (with his purchase) and figuratively (with his reputation).

While the unclear frame of reference gave Hofstede de Groot some leeway for new attributions, the chemical analyses left no room for doubt. If the painting had indeed been made with modern materials, it could not possibly be by Hals. Perhaps against his better judgment, Hofstede de Groot opted for a frontal attack. He stated that the samples taken would be taken exclusively from later retouches, not the original paint layer. The Professor in Chemistry had not understood what exactly he had been researching. In the introduction, he explained that his defence was directed mostly at Professor Martin, rather than Prof. F. Scheffer: "*as one cannot argue with a chemist about art. In painting the eye must hold the highest authority, just as the ear does in matters of music. Here, not the tuning fork; there, not the test tube*."[1, p. 5]

The fact that Hofstede de Groot did not bother to have the paint layer that he believed to be original tested by a second chemist, gives the impression that he must have at least suspected something was wrong. In a personal letter to Prof. Scheffer, dated 30 May 1925, published in his *Real or Fake* booklet, Hofstede de Groot speculated that Hals might have invented zinc white long before the commercial version came in use, and that he could have perhaps used very pure natural ultramarine, lacking the characteristic uncoloured or weakly coloured parts, which could have made it look like artificial ultramarine. Only the cobalt blue he could not explain away, but he trusted, nevertheless, that there would be a plausible explanation. [1, p. 35-39] Instead of opting for further chemical analysis, Hofstede de Groot emphatically objects to the taking of micro-samples in his booklet. Scheffer had stated in his court report that he had only taken a few samples in discrete locations, such as under the frame, because he: "*wanted to demonstrate with this report that the often-feared chemical analysis is possible without causing noticeable damage to a painting*". Hofstede de Groot, however, argued that although the damage caused by taking small paint samples for chemical analysis is minor, it is not imperceptible, and added rather defensively: "*I shudder at the thought that it could become the norm in the future to examine masterpieces of old painting in this way*". [1, p. 34]

The use of new scientific research techniques in 1925

Although the technical analysis done for the court case was very innovative at the time, the two art experts appointed by the court, Holmes and Martin, did not share Hofstede de Groot's deep distrust of chemistry in the context of art attributions. Quite the contrary, the two museum directors were impressed with the new possibilities. As their personal correspondence to each other and to Hofstede de Groot has been preserved in Hofstede de Groot's archive at the RKD Netherlands Institute for Art History, we can reconstruct their response in great detail. [2]

According to a letter by Charles Holmes to Dr. Martin dated 6 January 1925, the director of the National Gallery had accepted his appointment as an expert-witness in the court case before he had received image material: "*I will do all I can to co-operate with you and your colleague [...] Is any good photograph of the disputed picture available?*". After he had studied the painting together with Dr. Martin and Prof. Scheffer in The Hague in early March 1925, he was particularly enthusiastic about the scientific research tools and techniques. In a letter to Dr. Martin dated 14 March 1925, he wrote: "*I am particularly anxious to know the result of Prof. Scheffer's chemical analysis of the blue pigment. Also, I found his use of the microscope so instructive that I want to install a similar instrument here*".[2] The Dutch court case thus inspired him to acquire the very first microscope for the National Gallery in London. It was a significant step, nine years before a scientific department was established at the museum with the appointment of a Scientific Adviser, F.I.G. Rawlings, by Holmes's successor director Augustus Daniel. [24]

Professor Scheffer's report for the court gives an overview of the experts' observations through the microscope as well as further chemical tests that were executed to identify the modern materials. [1, p. 85-89] The joint report describes that the men started with a general examination by using a looking glass with a 6x magnification, when they noticed a 'suspicious, modern looking ultramarine' (*verdacht, modern uitziend ultramarijn*) mixed with several colours as well as 'a curious, slippery sheen of the paint '(*een eigenaardigen, glibberigen glans der verf*) and a un-seventeenth-century like paint application (*een niet zeventiende eeuwsch aandoende manier van verf opleggen*). [1, p. 76] Scheffer also took various photographs and then proceeded with a number of chemical tests, including the tests with alcohol and water, which confirmed that the paint medium was not oil, but a gelatinous material, presumably size. Subsequently, Prof. Scheffer took a number of surface samples from inconspicuous locations in the presence of the other expert-witnesses, which were examined through the microscope, and subsequently analysed with additional chemical tests by Prof. Scheffer. He used a hydrochloric acid solution to discolour the suspicious blue, which resulted in the formation of a hydrogen gas, confirming that the blue was ultramarine. Through the microscope it could be identified as artificial ultramarine since it lacked the characteristic uncoloured or little coloured particles which are always present in the natural pigment. In a sample taken from the background, Dr. Holmes believed he recognized cobalt blue and further tests by Scheffer indeed confirmed his suspicion. With a hydrochloric acid solution, he separated the blue (which did not lose its colour!) from the binding medium and iron containing parts (presumably a yellow brown ochre). Through the microscope it could indeed be identified as cobalt blue. In his report, Scheffer explains that the only cobalt compound that was used for paintings in the seventeenth century was smalt, which is recognizable through its sharp forms, transparency and colour. The blue in the sample looked nothing like that and it also showed a different refractive index, confirming

that it was cobalt blue. Furthermore, chemical analysis identified the white as zinc white. [1, p. 87-88]

Just like Holmes, Wilhelm Martin, the director of the Royal Cabinet of Paintings the Mauritshuis in The Hague, was convinced by the scientific tools and techniques, which –as he explained– provided irrefutable proof that the painting could not date from the seventeenth-century. He had been on amicable terms with Hofstede de Groot (the two men addressed one another as *'amice'* in their correspondence) and, out of respect, he informed him of the findings in the expert report as soon as he had formally submitted it to the court on April 30th 1925: "*It is our unanimous opinion that this is the work of a modern imitator, and I do not believe that any valid objections can be raised to our report, given that the ultramarine used in the painting is artificial ultramarine (the manufacturing dates from 1826: it was not made before that date) and the blue used to paint the entire background turned out to be cobalt (this paint was not manufactured until 1820-30), while the white is zinc white, a pigment that was not known before 1781. The varnish can be removed with alcohol, and when one then continues to rub with water, the entire paint disappears. There are also numerous stylistic objections, but I would like to refer you to the report itself. However, I felt I should inform you of this as soon as possible*". [2] It was to no avail, however. Hofstede de Groot could not be convinced of the validity of the scientific analysis. [1, p. 40]

Apart from the microscopic analysis and chemical tests to identify materials, the use of radiographs was also relatively new. In fact, it was the first time that this technique was used to expose a forgery. Marijnissen mentions that radiographs were used for the first time as scientific evidence in the 1932 Wacker/Van Gogh forgery case in Berlin, thereby overlooking the earlier *Laughing Cavalier* court case. [25, p. 2] Interestingly, two positive radiographs (rather than negatives, as is current today) were used in the lawsuit and referred to as 'photographs' (*röntgenfoto's*, *foto's*) in point nine of Scheffer's report (figs 4 & 5). [1, p. 88] The originals have probably come down to us through Hofstede de Groot's archive, which still includes the visible light photographs. The radiographs must have later been moved to the RKD's image files, where they were recently rediscovered by Michiel Franken. [26; 27; 28] The reason for the use of positives is presumably that these show the modern nails that the expert-witnesses discovered below the paint layer most clearly. Because the frontal image shows the nails largely from above, a second image was made at an angle (*met schuin invallend licht)*, which clearly reveals the post-nineteenth-century nails, as mentioned in point nine of Scheffer's report. [1, p. 88] Regular photography did not reveal retouches at the location of the nails, though these might have been hard to recognize since all the paint was in fact of modern origin. To exclude the possibility that the nails were hammered from the front *through* the paint layer after the picture had been finished, Scheffer checked the paint covering the nails, and confirmed that both the binding medium and pigments were consistent with the surrounding paint. [1, p. 88-89] Apparently, the use of UV light to identify recent retouches was not yet common practice.

Scheffer also looked into the wood used for *The Laughing Cavalier*. He noticed that the round panel consisted of three planks that varied in date. Although the panel was cradled on the back, he could see enough to conclude that the middle plank was old while the two flanking planks seemed to be less than a hundred years old, without specifying exactly how he has reached this conclusion. [1, p. 88] In their joint report the expert-witnesses explained that: 'Several points have not been elaborated upon, firstly in order not to damage the painting by removing paint in conspicuous places, and secondly in order not to turn this report into a 'manual for forgers'. [1, p. 76]

Attribution to Han van Meegeren

At the time of the court case, it was not known how De Haas had come into possession of *The Laughing Cavalier*. He had apparently told the auction house that it came from an old English family. The court ruling of November 27th 1924 specifies: "*that the defendant did not disclose, which the claimant could not have known at the time, but which the claimant now knows, namely that this certificate was not issued by Dr Hofstede de Groot to some old family, but was issued in return for payment of f. 1000 to a certain Frans [sic] van Wijngaarden, restorer and dealer (scavenger) of old paintings, who owned the painting in April 1923 and from whose hands, directly or indirectly, it came into the defendant's possession*." [8] Although Theo van Wijngaarden is mistakenly called 'Frans' in the document, it is noteworthy that he already had a bad reputation as 'scavenger' (*scharrelaar*) at the auction house.

Later, in an interview with Marijke van den Brandhof in the 1970s, De Haas admitted that he had, in fact, been asked by the well-known master forger Han van Meegeren (1889-1947) to present the painting at the auction house. [10; 5, note 45, p. 264] As Jonathan Lopez described, De Haas and Van Meegeren had been friends since college when they were both members of the Delft catholic student association Virgilius. De Haas was an engineer with a wife and six children to support. This might have made him susceptible to dubious financial proposals. [5, p. 44-45] In any case, the provenance of the painting strengthened Lopez's suspicion that the work may be an early forgery by van Meegeren, and in his book he ascribes both the *Laughing Cavalier* and *Boy Smoking* to Van Meegeren which he both dated to circa 1922.[5, p. 40-51] In his view, *Boy Smoking* showed that Van Meegeren improvised freely in the style of Hals: "*it is forgery at its most complex and inventive- and after only two years on the job, this was quite an impressive accomplishment*". [5, p. 42]

The idea that Van Meegeren had created the painting was not new. Already in 1925 rumours spread that the *Laughing Cavalier* was made by either Van Meegeren or Nardus. This claim was firmly and publicly denied by Hofstede de Groot. In an interview with the newspaper *Het Vaderland* of June 10th 1926, he exclaimed: "*they should wish they could paint like that!*". [29; 5, p. 48, 64-65] Since then the paintings have been attributed alternately to Han van Meegeren [11; 5, p. 40; 13, cat. No. F01; 14, cat. no. X3-X4] and to (the workshop) of Theo van Wijngaarden [30; 31] while it was tacitly assumed that both paintings were created by the same hand. Only one author, Michiel Franken, attributed the *Laughing cavalier* to an anonymous forger. [15] (Apart from the fact that the paintings were presented at the same time and by the same person to Hofstede de Groot, the pictures were also both painted with a protein-based medium, as a report by the chemist Froentjes and conservator De Wild for the director of the Groninger Museum revealed in 1950. [32] According to Van Meegeren expert Jonathan Lopez, Theo van Wijngaarden had invented precisely such a binding medium, working by trial and error, using a painter's manual that was still in possession of the family when he interviewed his descendants, namely H. Bartel's *Handboek voor schilders* from 1918. [5, p. 40, p. 263, note 40] After experimenting with a 'milk-based casein paint' (which did not look good), Van Wijngaarden allegedly obtained more success using a 'gelatin glue'. 5, p. 40, p. 263, note 40] Moreover, according to his family, Van Wijngaarden himself was not a very gifted painter of human faces, making Van Meegeren the more likely candidate in Lopez's view. [5, p. 40-41]

New stylistic and technical analysis

When researching the *Laughing Cavalier* anew, on the one hand a number of the same methods were used as in 1925 (style analysis, XR, PLM microscopy) and on the other hand also a number of newer techniques were applied (UVF, digital microscopy (x50 and x300), SEM-EDX microscopy, MA-XRF, RIS, micro-Raman spectroscopy) to study the materials, techniques and genesis of the *Laughing Cavalier*. Furthermore, we compared the *Laughing Cavalier* not only to reference works by Frans Hals, but also to *Boy Smoking*, since Theo van Wijngaarden presented both paintings at the same time to Hofstede de Groot and it is commonly assumed that they were created by the same hand.

Our first observations with the naked eye and with the aid of digital microscopes revealed a number of subtle anomalies in the *Laughing Cavalier* that had not been noticed before. In comparison with Hals's well-known *Merry Drinker*, the *Laughing Cavalier* lacks the subtle transitions in colours and tones that lend the original a strong sense of three-dimensionality and the illusion of a greasy, blushing skin (compare figs. 6 and 7). The brushwork in the *Laughing Cavalier* is indeed quite crude, as noted by many previous observers, and the many dispersed contrasts in the face make it appear flatter and less coherent. Furthermore, while Hals's characteristic 'ribbon touch' (thick loose accents with raised edges on both sides) are imitated throughout the painting, his rhythmical darker accents (a kind of hatching with the brush, which are amply used in the *Merry Drinker*) are missing.

Interestingly, while the brushwork in *Boy Smoking* appears similarly crude as the *Laughing Cavalier* at first sight, this imitation does contain both ribbon touches and the kind of hatching of the brush that is reminiscent of Hals's genre paintings (fig. 8). From up close, the paint application is actually quite different from the *Laughing Cavalier*. The paint layer is much more thinly applied in *Boy Smoking*, exposing the layer below in far more places than in the *Laughing Cavalier* and in Hals's *Merry Drinker*, where we see a ground layer only occasionally exposed near contour lines (see also below the discussion of the infrared reflectographs and several cross-sections). Moreover, the background has been indicated with broad loose accents in virtually all directions, while it is more evenly applied in the *Laughing Cavalier* and Hals's original. On the other hand, the suggestion of three-dimensionality in the face and the tonal transitions are more successful in *Boy Smoking* than in the *Laughing Cavalier*. When compared to the lively *Merry Drinker* though, the dark shadows and angular shapes in the boy's face make it look somewhat caricaturesque (compare figs. 2 and 3). Furthermore, the suggestion of proportion and underlying structure in the body and hand of the boy are rather weak, compared to Hals's original. In short, while both the *Laughing Cavalier* and *Boy Smoking* are clearly Hals imitations, their execution and the exact characteristics that are imitated, differ considerably.

The infrared reflectograms (IRR) of the two Hals imitations reveal further differences in the build-up of the paintings (figs. 9 & 10). The images confirm the previous observation regarding the thickness of the paint layer. Indeed, the IRR of *Boy Smoking* clearly shows the wood grain. This is a feature that does not occur in original works by Frans Hals or the *Laughing Cavalier*. *Boy Smoking* also contains thin, dark sketch lines applied with a fluid material that bleeds into the wood grain. These are visible at the height of his lower lip and below the pipe. Again, this is a feature that cannot be found in Hals's works or the *Laughing Cavalier*.

A newly made radiograph of the *Laughing Cavalier* (fig. 11), studied in the negative as is standard nowadays, revealed additional anomalies. The radiograph shows that the two industrial nails that played a key role in the 1925 expert report have been removed. However, the

keen observer will note that this did not completely erase the evidence. The thickness of the paint accrued around the former nail heads still shows that the paint layer was applied on top of a nail (detail of fig. 11). Other noteworthy features include curious cracks and small, round lacunae that are not present in Hals's original works (see the same detail of fig. 11). These are indicative of an unusual drying process and choice of materials, as we will see in the sections on microscopy, microsamples and craquelure analysis below.

Non-invasive microscopic analysis of the *Laughing Cavalier* (with Dino-lite and Hirox) provided further insight into the lacunae and cracks. The round lacunae visible on the radiograph are caused by tiny air bubbles, which were present in large quantities in the wet paint, indicating that the binding medium cannot have been oil (figs. 12a +b). A close-up of a regular photograph of *Boy Smoking* suggests that the white paint in this work shows the same little burst air bubbles (fig. 12c). Furthermore, a Hirox microscope revealed that a crack in the *Laughing Cavalier* was caused by the varnish rather than the paint layer, suggesting artificial ageing and a forger's practice. The other craquelure patterns also differ considerably from the cracks in Hals's original paintings, as will be discussed in more detail in the section on craquelure analysis.

Non-invasive macro techniques : MA-XRF and RIS

The MA-XRF investigation of the *Laughing Cavalier* revealed several issues with the use of pigments, which confirm and expand upon the conclusions of the 1925 report. In addition, a comparison with the MA-XRF scan of *Boy Smoking* unveiled several notable differences. The zinc (Zn) distribution image of the *Laughing Cavalier* suggests that the main white pigment is zinc white, which was not used before the nineteenth century, clearly indicating that the painting is a forgery. As the 1925 court report indicates, zinc white was not invented until 1780, although earlier forms of zinc white exist. However, its commercial availability was considerably later. Zinc white appeared in Germany under the name 'Zinkblume' on the market in 1834, after Roux had recommended it as a painters pigment in 1824. [33] Zinc white pigment was readily available to painters only from c. 1850, after which E. Leclaire had begun to manufacture zinc white in an industrial manner. [34] The ability of MA-XRF to provide representative images of the entire painting also allows us to conclude that this zinc-based material is used throughout the work and not just in isolated repairs. By contrast, the MA-XRF scan of *Boy Smoking* revealed the element Zn mostly in repaired spots, which will be explored in more detail in the section 'microsamples.' (fig. 13).

It is worth noting that the *Laughing Cavalier* also contains lead (Pb), most likely in the form of lead white, which was not noticed in 1925 (fig. 14). It is visible to a lesser degree in the bright tones of the painting, suggesting that a mixture of zinc white and lead white was used. Furthermore, it is also present in the ground layer, which follows the structure of the wooden support. In *Boy Smoking* lead (Pb) is the main white pigment. The strong contrasts in the Pb distribution image indicate the absence of a Pb-containing ground layer (see also 'Microsamples' below).

It is also striking that cobalt (Co) is present in the surface layers of the *Laughing Cavalier*, which would have been highly unusual in an original work by Hals, where it is commonly found only in only in outdoor backgrounds depicting blue skies and in the depiction of blue or blueish items such as fabrics. By contrast, cobalt (Co) is absent from *Boy Smoking*

(see fig. 15). XRF alone does not always give conclusive results concerning the exact identification of pigments. However, the most common cobalt-containing pigment used in the seventeenth century was smalt, a ground potassium-rich glass, coloured blue by the addition of cobalt. Smalt commonly contains contaminants from the cobalt ore used (potassium (K), nickel (Ni), arsenic (As) and bismuth (Bi)) that are absent in this painting.[35] This suggests that this cobalt was refined in an modern industrial process that removed these contaminants.

While the *Boy Smoking* appears to be in line with expectations so far, two minor elements indicate otherwise. Firstly, there is chromium (Cr) present in the boy's dark hair and various dark shadows (fig. 16). In the *Laughing Cavalier,* the presence of chromium (Cr) could not be confirmed, because its abundance was below the detection limits of the Bruker CRONO under the chosen experimental conditions. Cr-based pigments have only been in use since the nineteenth century, which is a clear indication that this work was created later. Furthermore, barium (Ba) is present in both paintings, but not in correlation with zinc (Zn), which suggests the use of barium sulfate as an extender or substrate for an organic dye (fig. 17). In the *Boy Smoking*, the Ba-map partially overlaps with the Cr-map which may indicate the use of chromium yellow, which will explored in the section 'Microsamples IV: barium-containing pigments'.

The other elemental distribution images do not show anything out of the ordinary. They indicate the use of pigments that were widely available in the seventeenth century. The distribution maps for Fe and Mn, for instance, are consistent with the expected iron, and manganese containing earth pigments, ochre and umber (figs. 18 & 19). This is also in line with the rather weak Ti signals, as the earth pigments always tend to be contaminated with associated minerals like the titanium oxides; Ti white would give a much clearer signal. The Ca map indicates bone black pigments, which were commonly used by Hals, as well as chalk and gypsum fillers (fig. 20). Another fairly common pigment, vermilion (Hg), was found in the hand of *Boy Smoking* and in a spot in the background, albeit at a very low level of abundance (fig. 21). In the *Laughing Cavalier,* the presence of vermilion (Hg) could not be confirmed, because its abundance was below the detection limits of the Bruker CRONO under the chosen experimental conditions.

To evaluate the RIS data, the data was normalized to a white reference, the data cubes of paintings were fused and the RIS data evaluated by Manivault 1.3. [36] Most clusters are rather non-descriptive browns that indicate a broad mixture of pigments. Notably, with the exception of low reflectance clusters, for which RIS is not the best method, the clusters describe features in only one of the paintings, which confirms that the two painting are notably different in their use of pigments (fig. 22). However, the background of the *Laughing Cavalier* shows a characteristic reflection pattern of cobalt blue with reflection minima at 575, 630 nm (fig. 23). Due to the mixture with a red pigment the reflectance in the blue range below 500 nm was completely absorbed, yielding the dark brown we observe in visual impressions.

Microsamples I: zinc white, artificial ultramarine, cobalt blue

In the 1925 court case, the finding of several anachronistic pigments played a major role. For the legal procedure, the identification of zinc white on the *Laughing Cavalier*, would probably have been accomplished with conventional transmitted light microscopy. In his report for the court case, Scheffer briefly states that he identified the white in the collar as zinc white by using chemical analysis. [1, p. 88] Under the microscope, zinc white would show up as very

fine colourless particles with very high refractive indices (ω = 2.01, ε = 2.03). The extremely small particles (< 2 μm) are too fine to discern any crystal faces, or extinction, under the light microscope. Around 1925, professor Scheffer, being from Delft, most probably would have also confirmed the presence of zinc in his samples by means of an additional microchemical test, developed by his colleague Behrens, the thiocyanate test. [37, 38]

We found evidence for this zinc white pigment also in a paint cross section taken from the depicted shoulder at the lower left edge of the painting (HdG 1/1, fig. 24). This section showed on top a relatively thin, light-coloured layer. The layer just below it, is almost equally light coloured, but shows the admixture of some fine-grained blue pigments. This layer also shows the presence of brownish yellow particles that seem to be of organic nature. Examination of the section in ultraviolet light under the microscope showed the typical bright sparkling fluorescence of the zinc oxides in this second layer (fig. 24, b and c). The signal at 380nm, especially, can be attributed to ZnO band gap emission. [39]

The lowest, much darker layer, of the sample also contains some seemingly organic, reddish particles in addition to a much larger amount of dark blue pigment. The luminescent sparkles of the second layer seem to occur in the lighter blue paint that is rich in 'flat', horizontally stretched flakes visible in the BSE. [This is visible on an image, made with the Thermo Scientific, Helios G4 PFIB UXe scanning electron microscope, equipped with a Thermo Fisher Ultralight detector of carbon-coated samples.] These horizontally oriented particles are confined to that particular layer and appear to be of a higher atomic number than the particles around it (fig. 24, a). A mineral phase overlay and mapping for the individual pigments gave further insight in the distribution of the pigments. (fig. 25) The elemental distribution image indicates that the upper paint layer for the pale purplish-brown jacket of the *Laughing Cavalier*, was created using a calcium-rich pigment (brownish also in the phase overlay, fig. 25b) (fig. 26). Surprisingly, we found no correlation in that top layer with a mapping at the emission lines (Fe-L_{α} at 0.705 keV) for iron. This should have been expected if the brownish colour had been accomplished with the use of brown or yellow ochres. The second layer with the luminescent particles showed a prominent mapping that would suggest the presence of zinc, as the emission energies taken for Zn are: Lα = 1,011.7; Lβ = 1,034.7. The elemental distribution image also indicates the presence of some aluminum (Al) and iron (Fe) in that same layer (fig. 26, a, d, and f). The analyses of the fine-grained particles of dark blue in the lowest layer, showed signals for elements such as sodium, aluminum, silicon and sulfur. These are elements that are consistent with ultramarine, a sulfide-containing sodium-aluminum silicate ($Na_{8-10}Al_6Si_6O_{24}S_{2-4}$), and we could confirm its presence with Raman spectroscopy.

The finding of this blue also played a significant role in the 1925 legal case. Natural ultramarine, even the most carefully prepared, is always accompanied by associated minerals such as diopside, calcite, sodalite, and pyrite. The absence of these smaller components suggests that the blue could be of synthetic nature. This was also the main argument for the rejection of the blue in Scheffer's report. However, a quick observation under the microscope of the blue pigment itself would have been sufficient. Although chemically of the same nature, under the microscope they look entirely different. The pigment particles of the natural variant appear as isotropic, glassy particles with an irregular size, angular shape and conchoidal fracture. The synthetic variant of ultramarine is equally isotropic and has the same refractive index (c. N_D = 1.50), but the particles are significantly smaller and of regular particle size. The rounded grains of the artificial variant are so small that any fracture cannot be observed under the light microscope. The microchemical identification of ultramarine, natural or not, would in

1925 have focused on the presence of sodium, and sulfidic sulfur, as these elements do not occur in any other blue pigment.

Scheffer also reported on the presence of cobalt blue. This type of blue was also proof of a chronological inconsistency, as it was invented by Louis Jacques Thenard only in 1802. In our examination of the paint cross-sections, it seemed initially somewhat difficult to find conclusive evidence for its presence in the paint of the *Laughing Cavalier*. Cobalt blue has a glass-like composition based on the fusion of cobalt salts with aluminum salts: $CoO.Al_2O_3$. Therefore, we examined the lowest layer of blue in the paint cross-section more closely, specifically for the presence of Al and Co. The elemental distribution image for aluminum showed fair amounts of Al in the two lower layers, containing blue pigments. The lowest, darkest, blue layer showed the presence of rather coarse Al-containing particles mixed with more fine-grained Al-containing material. Those very fine components may in fact correlate with the ultramarine to the Na-, S-, and Si-maps. The second, lighter, blueish layer with the fluorescent parts only seems to have the coarse Al-particles. The correspondence with the cobalt distribution image was more difficult. Some correlation between the two distribution maps could be suggested but the Co-signal was so weak that it appeared hardly above noise level. (fig. 28, a, and c). The presence of the cobalt blue pigment in the paint sample, however, had already been positively identified previously by means of polarized light microscopy (PLM) and with RIS during an earlier stage of this research (fig. 23).

Microsamples II: binding medium

In the 1925 report by Scheffer, the performance of the *Laughing Cavalier* under the alcohol test was an important issue. [1, p. 85-89] This test has to do with the way paints 'dry'. Watercolor paints literally dry by evaporation of the water. The drying process of such paintings is fully completed as soon as all water has evaporated. The 'drying' process of oil paints is entirely different, and depends on oxidation rather than evaporation. When an oil painting is put to dry, the fatty acid chains of the oils begin to take up oxygen from the air, forming cross links between the fatty acid molecules. This crosslinking gradually transforms the paint into a more or less elastic gel that feels dry to the touch. The paint would then feel dry, but can still be readily dissolved. It is only in the next step of the process, that these oxidized chains begin to break up in smaller fragments and begin to cross-link. These fragments then also make chemical bonds with metal ions from various pigments, forming metal soaps molecules. Only then does it become a very hard paint layer. And only then, is the fully dried paint no longer susceptible to solvents such as concentrated alcohol. Whenever there was any doubt about the age of a painting, a good resistance against a cotton swab with alcohol would have given a convincing answer.

The full drying and hardening of oil paints is influenced by factors such as the thickness of the layers and the choice of pigments, but it always takes a considerable amount of time. The maker of the *Laughing Cavalier* did, of course, not have the decennia of time to wait for his paints to become convincingly hard and insoluble. He therefore chose to use a binding medium that would look convincing and stand the test: gelatin glue! Gelatine is a mixture of various amino acids. This proteinaceous medium is prepared by cooking up sinews, bones and other waste products of animals. The preparation process of these materials invariably results in the breaking up of the bonds (predominantly H-bonds) in the triple–helix structure of the collagen. They separate into disordered 'random' coils of single protein chains: polymers with long

molecular chains 'floating' in water. When the water evaporates from a paint mixture in such a medium, the single 'random' protein coils undergo partial rearrangement back into collagen-like triple helices. The misalignment of the single strands means that the renaturation causes nodes, involving only parts of certain strands. [40] The paint thickens and becomes more gel-like. When the water continues to evaporate this process creates further nodes of the remaining strands, so that a continuous three-dimensional network structure emerges. The chains get so close together that they become intertwined, lose their mobility and the glue-bound pigments become solid paints. [41] Paints that do not dissolve in alcohol.

Scheffer performed the same alcohol test and noted down that the paints on the *Laughing Cavalier* did not react, as we discussed above. However, he did not stop there, but also tested the solubility of the paint with a cotton swap dipped in plain water. We found the spot where this test was performed at the lower left under the frame. In water these protein chains clearly had lost their bonds and started floating again. Rubbing with water instead of alcohol, had dissolved the paint and caused stains, smears and ugly tidelines. This effect became all the more apparent when we examined a cross section made from a dark hardened fragment taken from the water stain (fig. 27).

It showed an off-white ground layer that appeared reasonably well preserved. But on top of that ground was a 'glassy' layer that appeared very dark because it hardly reflected any of the incident light. It did show a blueish fluorescence at a wavelength of 365 nm. And dispersed all over this layer we observed a multitude of blue, white yellowish and reddish pigment particles. These particles became dislodged from the original stratigraphy and had followed the flow of the liquidized medium. Some of the particles ended floating on top of the liquid, others in swirls and curls in the viscous liquid. The evaporation of the water after the test, had made the protein strands rearrange again, thereby freezing the loosened particles in their new positions.

Observations with the scanning electron microscope, demonstrate the effect of the 'water-test' to the organization of the paint structure (fig. 28). The layer from the previous sample, that was so rich in 'flat' horizontally stretched flakes (fig. 24 a), accompanying the typical bright sparkling luminescence is gone. The flakes now have lost their orientation and original coherence. Some of them (yellowish in the phase map) ended up clustered together in all directions on top of the solidified glue layer. Others appear taken-up in random orientation, in a stringy trail with blue and other pigment particles from other layers. And a few individual particles just sit in the glue. The elemental distribution maps indicate that all pigments have been loosely dispersed and mixed by the water test. (fig.29) The maps for the Zn-containing pigments and those for ultramarine (Si, Al), cobalt blue (Co, Al), ochres and other iron-based pigments (Fe) show that they have lost all intentional arrangement. They all ended up in solidified stringy tufts.

During our analysis we were surprised by the strong signals (fig.29 f) we found for the presence of phosphorus (P). This element is not a frequent occurrence in historical pigments. It can point to the presence of of bone or ivory black. However, in the analysis of the sample from the *Laughing Cavalier*, the phosphorus was not related to any black pigment, but appeared somehow associated with the pigments in the cross-section. This element may give yet another indication for the binding medium. Gelatin often contains fair amounts of phosphorus. The exact amount of P may vary, by product and preparation, but gelatin made from high-phosphorus animal bones can be a significant source.[42] The amounts of phosphorus in the cross sections and the manner in which it appears distributed in the *Laughing Chevalier*, have never been encountered on any genuine seventeenth-century oil painting. To our knowledge

Scheffer has, apart from simple solubility tests, not performed any specific chemical analysis in 1925, to make a positive identification of gelatin proteins. In contrast to plant-based glues, adhesives of animal origin contain proteins and therefore nitrogen. The proteinaceous medium could therefore have been identified with the Griess test. A small paint sample is heated with a little bit of MnO_2 in a micro-test tube. The mouth of the test tube is covered with a piece filter paper moistened with a freshly prepared reagent of 1% sulphanilic acid and 0.1% 1-naphtylamine solutions in 30% acetic acid. This very sensitive reagent (limits c. 0.02 - 2 µM) would have shown a red or pink colouration. This test must have been known at the Delft laboratory; it had already been described in the nineteenth century and was widely used. [43] In *Boy Smoking* gelatine glue was eventually identified in 1950 by Froentjes and De Wild, as we have seen. [32] A new analysis with Fourier-transform infrared spectroscopy (FTIR) and thermally assisted hydrolysis and methylation - gas chromatography/mass spectrometry (THM-GC/MS), performed by Louise Decq at the Royal Institute for Cultural Heritage (KIK-IRPA) in Brussels, confirmed the presence of a protein-containing binding medium in the *Laughing Cavalier*, while the binding medium in the Boy Smoking could not be identified (presumably because of the small sample size).

Microscamples III: barium-containing pigments

The elemental distribution images, obtained by macro x-ray fluorescence scanning (MA-XRF), showed in the face of the *Laughing Cavalier*, a quite peculiar application of a barium-rich (Ba) material (fig. 17). The finding of Ba in the scan cannot be related to the use of barium chromate yellow ($K_2Ba(CrO_4)_2$), a pale yellowish pigment. Because, if that were the case, our scans would of course also have shown the presence of chromium in the same areas. In a similar way, the barium signal could not be interpreted as the presence of lithopone pigment. Lithopone is a synthetic inorganic white pigment consisting of a mixture of zinc sulfide and barium sulfate in a 3:7 ratio. However, in that case Zn should have shown up in the scans for the same areas. Instead, the Ba-containing areas seem to coincide with reddish skin tones. This is a strong indication that the signal refers to the use of barium salts as a substrate for a modern synthetic organic pigment.

Many early synthetic organic colourants were developed, primarily as textile dyestuff, at the end of nineteenth century. These early synthetic dyes could not be directly mixed with binding media. As those dyes would dissolve into the medium, rather than get dispersed, the colours would bleed. To overcome such unfavorable reaction, the size of the coloured particles of synthetic organic colourants was increased by wet-collating with inorganic substrates. Extenders like chalk or barium sulfate were predominantly used to create stronger adsorption bonds and to ensure more resistance to cracking and bleeding. As barium sulfates have a low tendency to flocculate and form aggregates, they improve the flowing properties of organic pigments and the effective dispersion of them in paints respectively. Therefore, in artist quality paints barium sulfates were used in large quantities with synthetic organic pigments. For instance during the production by the Talens paint factory of Harrisonrood Fijn in 1925, 2500 grams of Helioechtrood RL were mixed with barium sulphate in an equal ratio. [44] Contemporary to the production date of the *Laughing Chevalier*, there are two possibilities for the organic colourant that could have been used in combination with the barium sulfate. The first is the β-naphtol pigment: PR3. [45] This colourant was for the first time described in 1872 as aniline red, but was produced as an artist pigment only as late as 1904.[46] In the Netherlands, it came on the market under various trivial names, like Permanentrood, Helioechtrood,

Hansarood. The other frequently used pigment was PR83, generally known as alizarin crimson. This synthetic anthraquinone was invented by Lieberman and Graebe in 1869 as replacement for natural madder dye. [47] It was found as a colourant in paintings from the early twentieth century. Alizarin crimson is a deep red with high tinting strength, and makes uniquely deep muted mixtures with other pigments.

Both pigments profit from the use of barium sulfate extenders. The very fine orthorhombic (monoclinic) crystals of barium sulfate have low refractive indices (α = 1.634, β = 1.636, γ = 1.646) that give them limited opacity in oils. They are transparent enough to allow light passing through from lower layers. But at the same time a certain amount of incident light is also scattered. In aqueous media, such as gum, tempera, or proteinaceous glue type binders, the refractive indices of c. 1.64, would make it a more opaque paint with increased diffuse light scattering. This would make barium-extended organic colourants ideal for painting rosy flesh tones. Indeed, the skin tones as found on the *Laughing Cavalier*.

Therefore, we proceeded with Raman spectroscopy to identify the exact type of red used. A non-invasive surface point analysis proved unsuccessful, as the varnish layer did not allow for the signal to penetrate sufficiently to get a clear reading. A portable EZRaman-I dual Raman analyser (TSI, Irvine, USA) was used. This fibre optic-based spectrometer is equipped with a diode laser (785 nm) and a thermoelectrically cooled (-50˚C) CCD detector. The standard lens with a ~7 mm working distance was selected. Spectra were acquired in the range of 125-2200 cm-1, with a spectral resolution of ~6 cm-1. The laser power was being adjusted (maximum output power 400 mW) during each measurement to avoid sample damage or alterations. The time of the measurement and the number of accumulations were adjusted to ensure good signal-to-noise (S/N) ratios. Wavelength calibration was performed using sulphur, epsilon-caprolactone (Acros Organics), cyclohexane (Kaiser), polystyrene pellets (Aldrich), and acetonitrile (Panreac)/toluene (UCB; mixed in 50/50 volume%). Fortunately, we were able to take a microsample near an existing crack at the side of the cheek which was subsequently analyzed with Micro-Raman spectroscopy. It gave a very clear match for Pigment Red 83 (fig. 30), a pigment that had not been identified during the research for the 1925 lawsuit.

Just as with the *Laughing Cavalier*, our MA-XRF analysis of the reddish paints of *Boy Smoking*, showed considerable amounts of barium (fig. 17). Pending the outcome of further (Raman) analyses of the organic red component, we assume that here too, barium sulfate must have served as a substrate. Again, the most likely candidates would be the aniline red PR3, or alizarin crimson PR83 for the actual colouring component. We were also struck by the prominent presence of chromium (Cr) in most of the reddish and dark brown areas in *Boy Smoking* (fig. 16). Although we have not made a positive identification of it by polarized light microscopy (PLM), we strongly suspect that the red paint may have been spiked with some chrome yellow. This, then, would constitute another pigment inconsistency as chrome yellow was first synthesized in the early 1800s and its earliest known use on a work of art was in 1810. [48]

Microscamples IV: the ground layer, carbon blacks and lead whites

It was customary for seventeenth-century painters to work on primed panels. This was done by integrally covering the panel with a white priming of chalk in animal-skin glue. Panels originating from Northern Europe were prepared with calcium carbonate grounds. The ground layer needed

to be thick enough to hide the irregularities of the wood grain, while functioning as a smooth enough to accept the paints. In their time, all panel painters worked on even, smooth and light coloured substrate to apply paint layers on. However, over the years, the thickness of such chalk grounds has decreased due to the drying and hardening of the paint and ground layers, which tend to settle in. After tens or hundreds of years, the layers often become so thin that the texture of the substrate, whether canvas weave or wood grain, becomes visible. These relief features are just as much as craquelures, characteristic aspects of old paintings.

In an attempt to reconstruct these thin layers, the painter of *Boy Smoking*, apparently chose to abandon the flattened chalk-glue ground layer all together and applied his paints immediately on the bare panel, as was observed in the MA-XRF Pb map and IRR above (figs. 10 and 14). Paint cross-sections confirm that the paints on this panel were applied extremely thin, and without any intermediate ground layer (fig. 31) The paints are so thin that not only the colour of the wood, but also the irregularities in the wood grain texture become apparent, similar to an aged seventeenth-century paint structure. However, this is a shortcut that, of course, no seventeenth-century craftsman would have made.

Not only the manner of application, but also the components of the paints are rather peculiar compared to original works by Frans Hals. The painter of *Boy Smoking* did effectively imitate the dynamic and loose brushstrokes of Frans Hals. However, being more a draughtsman than a good colourist, he accomplished his contrasts by varying admixtures of carbon black to almost all of his paints. It testifies of a modern approach to colour mixing, which differs considerably from the working methods of Hals, who used carbon-containing black sparingly and certainly not for all darker or shadowy parts. [6; 19]

Examination of a paint sample taken from one of the strongest highlights in the boy's starched white collar illustrates the particular use of pigment and medium (fig. 32) In both images of the sample in reflected light and in UV-fluorescence the white paint appears to be mixed with particles of carbon black. This pigment is not only present in the lower layers in the grey of the collar, but also in the upper brighter area for the highlight.

The image of the same area taken with the scanning electron microscope (fig. 32 c) shows other technical aspects of the painting. At the lower area of the section we see, again, the features of the wood cells without any intermediate ground layer, in direct contact with the greyish paint. And in the upper region of the section the paint appears to have a 'mottled' appearance. These spots are caused by accumulations of a carbon-rich organic matter, which is very much lighter than the surrounding lead white pigments. We have taken this as a typical feature of the gelatinous medium that was used for this painting. Medium rich bubbles are often formed in gelatinous paints by rapid stirring, too energetic handling of the brush, or just improper thinning with water.

The effect is evidently caused by the attempt to mimic, with glue paints, the swift and rapid brush strokes that Frans Hals accomplished in oils. Excessive brushing and applying the paint too briskly tends to drive excessive air into gelatine glue paint films. Good oil paints naturally flow out without any bubbles. In the gelatin glue, air bubbles tend to get trapped. Eventually, the medium accumulated in those voids.

In the elemental distribution image (fig. 33 b) it can be seen that there is indeed a fair amount of carbon-rich (C) organic material evenly distributed in the paint, but also accumulated in those spots. The presence of carbon rich material in the lower area, however, is

probably due to the admixture of carbon black with the lead white. Of course a fair amount of carbon was also observed in the adhering wood cells at the lower part of the paint structure. We did again find the presence in that area of phosphorus-containing (P) material (33 c, and purple in 33 a). It appears in angular, seemingly crystalline particles, as well as adhering to the wood material at the lower right of the section. It may again be related to the use of a gelatin-glue binder. [49]

Although the white paint in *Boy Smoking* is indeed lead white as would have been expected on a seventeenth-century Dutch painting, it is not quite similar. The traditional 'stack process' of the lead white that Frans Hals would have used, is completely different from any modern uniformly synthesized, 'flat' lead white. Ancient lead white is never harsh or cool in appearance, but rather creamy, sometimes even a bit warm-yellowish, or pearlescent. It was not produced as a slick, dull pigment with even particle size, but rather more often coagulated and grainy, or smooth as creamy butter. (49) Some lead whites had a rather cool tone; but most others were – because of the presence of mono- and/or tetra- oxides – slightly more creamy-yellowish.

In the nineteenth and twentieth century, the modern pigment industry began to produce much more pure and refined lead white without any acetates or oxides. And many paint factories also added a certain amount of zinc white to their lead white paints. This adulteration extended the drying time and influences the paints working properties. Such additions were hardly ever indicated on the paint tube. This would explain the not very big, but persistent peaks for zinc (Zn) in our spectra of lead white paints on *Boy Smoking* in our XRF point measurement (fig. 34). This also is a recurrent feature in many of the forgeries that Han van Meegeren was to make in the 1930s and 1940s. It seems that in almost all of his paintings the lead white paints are adulterated with notable amounts of a zinc-based compound. [6, p. 94] The weak Zn signals can also be seen (rather vaguely) in the MA-XRF distribution map for Zn, notably in the boy's hand (see fig. 13).

Another way in which lead white in early twentieth-century paints differs from their seventeenth-century counterparts, it is in its isotopic composition. Because its manufacture begins with metallic lead sourced from mined ores, the pigment carries with it a chemical fingerprint. The lead isotope ratios are inherited from the original galena deposits. These ratios vary according to the geological age and conditions under which the ore formed (e.g. hydrothermal processes), making lead-isotope analysis a powerful tool for tracing pigment provenance and, in some cases, supporting or challenging the attributions of artworks.

Lead isotope studies rely on the four stable isotopes of lead, namely 204Pb, 206Pb, 207Pb, and 208Pb. Because 206Pb, 207Pb, and 208Pb are radiogenic, meaning that they are continually produced through the decay of uranium and thorium over time. Ore bodies formed in different ages and under different conditions acquire distinct isotopic signatures. Once galena forms, however, its low uranium- and thorium-content means that its isotopic composition remains essentially unchanged, preserving its isotopic composition unless mixed with lead from other sources. The traditional production of lead white is based on exposing metallic lead to for example vinegar vapours and carbon dioxide–rich environments, such as manure, over several weeks. This process converts the metal into lead carbonates, without altering its isotopic composition. Thus, the pigment's signature directly reflects the ore from which the metal was originally smelted. [51; 52; 53]

By the seventeenth century, the Netherlands emerged as the leading producer and exporter, thanks to the implementation of the Dutch stack process. Dutch lead white circulated and was widely used across Europe, but other production centres using different sources of lead, such as lead white from Venice, were still available. Data of isotopes of lead white made the identification possible of four characteristic isotopic types in Europe. This information is useful for differentiating between paintings. Dutch lead white (characteristic of the seventeenth century and containing lead of English provenance), fourteenth- to seventeenth-century Venetian lead white (Alpine), thirteenth- to fifteenth-century Germany lead white (only a few examples of this type have been found in drawings) and, finally, 'modern' lead white (poorly characterized and found in later retouching or paintings made after at least 1750) could be identified as separate categories. In this context, it must be noted that all analysed seventeenth-century Dutch paintings made in the Netherlands only contain Dutch lead white. In the same period, however, Dutch lead white can also be found in Germany, Denmark, England France and Italy. Italian lead white can also be found in Denmark and France but, to date, it has not been identified in seventeenth-century Dutch paintings. Hence, currently, we can conclude that seventeenth-century Dutch paintings have extremely well-characterised lead isotope compositions. Three samples from the *Boy Smoking* and one sample from the Laughing Cavalier were analysed for their lead-isotope ratios (LIR). The results were compared with published LIR datasets, with particular focus on seventeenth-century Dutch paintings and authenticated works by Frans Hals. [52; 53; 54; 55; 56; 57; 58] For context, LIR data for lead white produced after the 18th century ('modern' lead white in the figure) were also considered. [52; 55]

The LIR results for the *Laughing Cavalier* (figures a and b) show that this painting contains lead white consistent with the modern material. Its isotopic signature is clearly incompatible with that of seventeenth-century Dutch paintings and, in particular, with known LIR signatures of artworks of Frans Hals (fig.35a). Notably, the three samples from *Boy Smoking* exhibit LIR values compatible with lead white produced in Venice, as indicated by sixteenth-century Venetian reference samples (fig. 35 b). [52] This Venetian-type lead white differs from anything reported for seventeenth-century Dutch paintings, including those by Hals. Lead white with Venetian-like LIR signatures has also been documented in mid-nineteenth-century Danish drawings (DE in the figure), roughly seventy years before *Boy Smoking* was painted, making it plausible that this material could still have been available in the early twentieth century. Overall, neither painting contains the lead white characteristics of the materials used in the Netherlands during the period when Frans Hals was active. This supports the conclusion that both works are forgeries and that the painter-imitators did not use historically accurate lead white. Furthermore, the lead whites used in the *Laughing Cavalier* and *Boy Smoking* differ considerably form one another, which is compatible with the conclusion that the two forgeries show significant differences in their style, technique and use of materials.

Craquelure analysis

Although the 1925 court report mentions that the paint of the *Laughing Cavalier* looks remarkably fresh, as we have seen, no further analysis of the cracks, or lack thereof, is performed, nor is a comparison made with original works by Hals. By now, the painting has actually aged at least a full century. Nevertheless, the craquelure patterns in the painting differ noticeably from those in Hals's original works. Craquelure morphology and patterns are often overlooked by art experts, but tend to provide subtle yet crucial indications that a painting is a

forgery. Since different types of pigments, binding media, and aging processes can impact craquelure morphology and patterns, it is one of the most difficult aspects of old paintings to successfully mimic. Within the ARTDETECT project, therefore, craquelure patterns and morphology play a key role. Our initial research and experiments demonstrate the promising capabilities for both successful in-depth analysis of cracks and their automated detection. For this case study, we compared The *Laughing cavalier* and *Boy smoking* to original paintings by Hals and experimented with a robust crack detection method based on deep convolutional neural networks, developed at Ghent University by Aleksandra Pizurica and her team (see above 'Methods') (figs. 36 -38).

The *Laughing Cavalier* displays various craquelure patterns. The vertical, long cracks along the wood grain, which are caused by the expansion and shrinkage of the wooden panel, as well as the so-called 'youth craquelures' in parts of the white collar, which are more fluid in appearance and formed during the initial drying process of the paint, are clearly distinguishable. A very fine pattern of craquelures is visible in the background. The dark paints around the face of *The Laughing Cavalier* have a more prominent pattern in raking light, with visible surface relief.

It is important to note that two-dimensional digital mapping and the actual three-dimensional surface of the painting must be repeatedly compared to draw valid conclusions. In the early stages of research, automated craquelure analysis detected and visualized all types of cracks, craquelures, and other surface layer anomalies. In the case of the *Laughing Cavalier*, for example, the cracks between the wooden planks of the panel and the high impasto of certain paint streaks were detected. These patterns are mostly irrelevant to the scope of the research and cannot be defined as "craquelure." For us, the purpose of mapping craquelure patterns digitally is to compare the patterns of different paintings (or sections of paintings) to distinguish between artificial and authentic craquelure. Craquelure patterns can vary greatly, and the distinctive shape or length of these cracks can be caused by various factors. Certain pigments or paint mixtures are more prone to cracking due to hardness, aging properties, or a combination of materials. Initial results of craquelure analysis demonstrate this phenomenon, and the main elements and colour passages in a painting's composition are often reflected in the crack patterns. For example, the dark hat of the *Laughing Cavalier* shows little craquelure, while the darker parts of the face are clearly discernible, showing the contours of the composition.

Frans Hals predominantly painted life-size portraits and figures on canvas. For this comparison, we selected a smaller size portrait on panel with a undisputed attribution: *Portrait of a Man* at the Royal Cabinet of Paintings the Mauritshuis in The Hague (fig. 39). Cross-checking this false and authentic portrait respectively in the field of craquelure patterns could be a real eye opener for forgery detection. The digitized craquelure-map of *Portrait of a Man* shows a remarkable absence of cracks in the background. The face is also lacking craquelure, whilst the dark areas of the clothing are full of small cracks of different directions and forms. The area behind the neck of the depicted man shows the distinct pattern of fine horizontal lines, as often to be encountered on seventeenth-century panel paintings when observed form close by. The white collar has craquelures that have horizontal and vertical directions, almost perpendicular to each other. An initial comparison between the *Laughing Cavalier* and this *Portrait of a Man* from 1660 thus demonstrates an almost complete opposite between the two portraits respectively with regard to less and heavily cracked surface layers for particular areas. The *Boy Smoking* also differs greatly from the authentic painting, and shows a lack of cracks in the

darker areas like the *Laughing Cavalier*, though it generally contains a somewhat finer craquelure pattern than the Laughing Cavalier.

DISCUSSION: New insights into forgeries

Over the past century, technical research has become much more integrated into (advanced) authenticity research than it was a century ago, in 1925. Nevertheless, many attributions still rely almost exclusively on visual assessment in practice. Admittedly, even in the most advanced authenticity research, the expert's eye is often still key. Hofstede de Groot was not wrong to stress its importance. Positive attributions necessarily involve making an informed judgement about how consistent a certain artist's style, technique, use of materials and workshop practice (including the use of studio assistants) can be expected to be, as well as having a thorough understanding of the work's condition (so as not to mistake retouched areas for original passages). For example, old master painters varied their styles and techniques consciously in relation to the topic to be depicted, the work's exact location, its price and art theoretical notions; they also collaborated with studio assistants in various ways. These factors all need to be taken into account when attributing old master paintings. [59, p.79-162] In short, positive attributions cannot be based on scientific evidence alone. In the case of forgeries, however, technical evidence can provide a definitive answer when anachronistic materials are found in the original support or paint layers. However, caution is needed as forgeries do not necessarily contain anachronistic materials, and such materials can be misleading without a thorough understanding of the artwork's condition.

One hundred years after the court case, our re-evaluation of the *Laughing Cavalier* confirms that the technical analysis conducted in 1925 was accurate. All the anomalies identified a century ago could be replicated and corroborated. This painting does indeed contain several anachronistic pigments and materials that are an integral part of it, including zinc white, artificial ultramarine, cobalt blue, and an unusual water-soluble binding medium. The researchers recognised the medium that could successfully withstand the alcohol swab test as a well-known 'forger's trick' (*vervalschers truc*). [1, p. 77] Although it would have been possible at the time to identify the binding medium more precisely, to our knowledge this was not done. Perhaps the researchers did not test it further because they wanted to avoid their report being used as a 'manual for forgers' (*handleiding voor vervalschers*). [1, p. 76]

Furthermore, by employing a variety of additional research methods and techniques, we gained a deeper understanding of the forger's working method and identified further anomalies in terms of style, technique and materials used. Non-invasive macroscopic techniques, especially MA-XRF, allowed us to identify and visualise the anachronistic materials consistently throughout the painting, not just in isolated spots. MA-XRF also revealed pigments that had previously gone unnoticed and these were analysed further in individual samples, where needed. Although the white paint used in the *Laughing Cavalier* was indeed a zinc white, it also contained lead white, as did the ground layer. Lead isotope analysis showed that the lead had a very different (more modern) origin than seventeenth-century Dutch lead white. Additionally, the presence of barium in the face of the *Laughing Cavalier* led us to discover, using Raman spectroscopy, the presence of the modern Pigment Red 83 throughout the cavalier's cheeks.

While the *Laughing Cavalier* and the *Boy Smoking* were consistently attributed to the same hand in previous literature, our combined stylistic and technical analysis suggests

otherwise. As we have seen, most authors attributed the paintings based on their style and provenance to either the well-known twentieth-century forger Han van Meegeren, his business associate Theo van Wijngaarden, or someone in the latter's workshop. However, closer examination of the style, technique and materials used in these paintings makes it highly improbable that they are by the same hand. Notably, the painter of the *Boy Smoking* skipped the ground layer, used a unique 'bleeding' underdrawing (visible in the IRR below the mouth and pipe), and applied the background colour in a less uniform manner. The accents on top are also significantly different, as is the suggestion of three-dimensionality. While both the *Laughing Cavalier* and the *Boy Smoking* mimic Frans Hals's characteristic 'ribbon touches' (loose accents with raised edges on both sides), only the *Boy smoking* also mimics his characteristic 'rhythmic' parallel strokes, and focuses more on the suggestion of three-dimensionality. In terms of materials, it is interesting to note that the different pigment mixtures used in both paintings, barely overlap (see fig. 22). The most striking difference is in the white paints: the main white pigment used in the *Laughing Cavalier* is the anachronistic zinc white, while the *Boy Smoking* is painted with the more historically accurate pigment lead white. However, upon close analysis, the lead white paint used in the *Boy Smoking* was found to be contaminated with small amounts of zinc, which was presumably unknown to the forger as these contaminants were not usually indicated on the paint tubes. Similarly, the zinc white in the *Laughing cavalier*, also contained small amounts of lead white. Additionally, lead isotope analysis revealed that the lead white pigments used both works had a different origin. Lastly, only the *Boy Smoking* revealed the presence of a barium-containing yellow pigment, presumably barium chromate yellow.

As with other art historical attributions, forgeries are often attributed to painters with well-known names. However, our in-depth study of the *Laughing Cavalier*, compared with original works by Frans Hals on the one hand, and the related forgery *Boy Smoking* on the other, requires a more nuanced understanding of early twentieth-century forgery practices. Although the two forgeries were presented to Hofstede de Groot at the same time by the same dubious associate of Han van Meegeren, Theo van Wijgaarden, who already had a poor reputation at the time and was being referred to in the court documents as a 'scavenger' [8], the differences in style, technique and use of materials suggests that they were actually made by different hands. Since both works were offered to Hofstede de Groot by Van Wijngaarden and both contain the kind of binding medium Van Wijngaarden had experimented with, it is likely that the forgeries were created in his circle. Art historians often unconsciously assume that there is a Robin Hood-like master forger who single-handedly deceives experts — a popular misconception that forgers regularly exploit. For example, the well-known twentieth-century forger Wolfgang Beltracchi compared himself to Robin Hood, battling the untrustworthy art market. [60] It is therefore understandable that the secondary literature presumed that forgers like Han van Meegeren and Theo van Wijngaarden worked largely alone. However, the technical evidence points in a different direction, which we were able to corroborate through contextual research. As early as the beginning of the twentieth century, there were several forgery rings active, including in The Hague, Paris and Antwerp. In Antwerp, for example, the dealer Jean Defort was sentenced to fourteen months in jail in 1902 for ordering acquaintances to forge paintings in the styles of Rubens or Hals for him, which he then sold as 'originals'. [61, p. 99] A late nineteenth-century book on forgeries by Paul Eudel mentions that hundreds of forgeries in the styles of seventeenth-century masters were created in Belgium in the preceding forty years, often on top of re-used old paintings: Hobbema, Teniers, Van Mieris, Metsu, Ruysdael and especially Van Goyen (as the latter had become particularly fashionable). [62]

The same book also mentions that forgers commonly used glue to avoid detection by the alcohol test, though it states that the glue was usually added as an intermediate layer. [62, p. 96] Furthermore, a 1927 article on a forged Rembrandt painting, copied after Rembrandt's portrait of Jacob Trip at the National Gallery in London, shows that the alcohol test could still occasionally reveal forgeries around 1925. [63] We also came across an early example of not only the use of radiography, but also UV fluorescence and polarised light to expose a forgery. In 1930, Professor Cellevier used these methods at the Louvre Museum in Paris to analyse forged Jean-François Millet paintings, created at the request of the artist's grandson. [64; 65]

In short, this first ARTDETECT case study shows that our thinking about forgeries and their detection needs to be refined. Of course, high-quality forgeries have become considerably more sophisticated over the past century. Improvement in both forgeries and their detection are not unlike an arms race, with the exposure of forgeries proving instructive not only for experts, but also for forgers. The ARTDETECT project aims to develop tools that can aid experts in the detection of forgeries by conducting more systematic and in-depth research in the coming years than has been done so far.

Apart from the in-depth technical insights provided by high-tech analytical instruments, we have also identified warning signs that can be more readily observed. For example, the radiograph in this case provided evidence that the paint layer had been applied on top of a nail with a small, perfectly round head, that had later been removed, while the infrared reflectogram of the *Boy Smoking* revealed that the entire ground layer had been skipped in this painting. Furthermore, curious air bubbles and suspicious crack patterns are visible throughout both forgeries. These kinds of warning signs will play a key role in the project as we aim to develop innovative ways to predict which paintings are suspect effectively and efficiently. In a world of art that continues to be plagued by forgeries, our goal is to help experts quickly and effectively focus their attention on the highest risks by creating shortlists of combined risk factors and developing automated tools that can effectively visualise significant anomalies.

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IMAGE CAPTIONS

Fig. 1. *Laughing Cavalier*, Hals forgery created before 1923, diameter: 36 cm, Private Collection

Fig. 2. Boy Smoking, forgery created before 1923, 57.5 x 49 cm, Groninger Museum, Groningen (Inv. Nr. 1931.0108)

Fig. 3. Frans Hals, Merry Drinker, ca. 1628 - ca. 1630, signed with ligated monogram, centre right: 'FH', 81 cm x 66.5 cm, oil on canvas, Rijksmuseum Amsterdam (Inv. Nr. SK-A-135)

Figs. 4 & 5. Radiographs of fig. 1 taken in 1925

Fig. 6. Detail of fig. 3

Fig. 7. Detail of fig. 1

Fig. 8. Detail of fig. 2

Fig. 9. Infrared reflectogram of fig. 1

Fig. 10 (& detail). Infrared reflectogram of fig. 2

Fig. 11 (& detail). Radiograph of fig. 1

Fig. 12a + b. Dino-lite and Hirox image of round lacunae in *Laughing Cavalier*

Fig. 12 c. A close-up of a regular photograph of the *Boy Smoking* showing similar round lacunae

Fig. 13. MA-XRF Zn distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 14. MA-XRF Pb-L distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 15. MA-XRF Co distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 16. MA-XRF Cr distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 17. MA-XRF Ba-L distribution images of figs. 1 and 2 (RCE settings, see 'Methods')

Fig. 18. MA-XRF Fe distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 19. MA-XRF Mn distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 20. MA-XRF Ca distribution images of figs. 1 and 2 (left: UA settings, right: RCE settings, see 'Methods')

Fig. 21. MA-XRF Hg distribution images of figs. 1 and 2 (RCE settings, see 'Methods')

Fig. 22. RIS analysis of figs. 1 and 2

Fig. 23. RIS analysis of figs. 1 and 2

Fig. 24. Microscopy of paint cross section from *Laughing Cavalier*. a, back scattered electron image, mag. 300x, scale bar = 200 µm; b, light microscopy, mag. 100x, BF illumination; c, UV-fluorescence, λ ex. = 365nm

Fig. 25a-c. part of cross section (fig. 26) from *Laughing Cavalier*. a, back scattered electron image, mag. 2400x, 15 kV; b, mineral phase overlay on BSE image

Fig. 26. elemental distribution maps from part of cross section (fig. 26) from *Laughing Cavalier*. Elements in reading order: Al-Ca-Co-Fe-Si-Zn

Fig. 27 Microscopy of paint cross section from *Laughing Cavalier*. a, light microscopy, mag. 500x,BF illumination; b, UV-fluorescence, λ ex. = 365nm

Fig. 28a + b Microscopy of paint cross section from Laughing Cavalier. a, back scattered electron image, mag. 800x, 15 kV; b, mineral phase overlay on BSE image

Fig. 29 a-f. elemental distribution maps from cross section(fig. 30) from Laughing Cavalier. Elements in reading order: Zn-Co-Al-Si-Fe-P

Fig. 30. Identification of Pigment Red 83 with micro-Raman spectroscopy in sample from *Laughing Cavalier*

Fig. 31. Microscopy of paint cross section (HdG2-2) from *Boy Smoking*. a, light microscopy, mag. 1000x,BF illumination; b, UV-fluorescence, λ ex. = 365nm

Fig. 32. Microscopy of paint cross section from the *Boy Smoking*. a, light microscopy, mag. 100x,BF illumination; b, UV-fluorescence, λ ex. = 365nm; c, back scattered electron image, mag. 500x, 15 kV

Fig. 33 a-c. Microscopy of paint cross section from the *Boy Smoking*. a, mineral phase overlay on BSE image (fig. 11 c); b, elemental distribution map for C; c, elemental distribution map for P

Fig. 34 a + b. Elemental analysis of whitish paint on the *Boy Smoking*. a, area of white paint with air bubbles on the surface, bright mark is measurement spot; b, x-ray fluorescence spectrum shows distinctive peak for Zn (Kα = 8,64) in lead white.

Figs. 35 a + b. Lead isotope ratios of samples taken from *Laughing Cavalier* and *Boy Smoking* compared to reference data

Fig. 36. Automated craquelure analysis of fig. 1

Fig. 37. Automated craquelure analysis of fig. 2

Fig. 38. Automated craquelure analysis of fig. 39

Fig. 39 (& detail). Frans Hals, *Portrait of Man*, ca. 1660, 31.1 cm x 25.5 cm, oil on panel, Royal Cabinet of Paintings the Mauritshuis, The Hague (Inv. Nr. 928)

CONNOISSEURSHIP AND TECHNICAL ANALYSIS
Re-evaluating the *Laughing Cavalier* forgery 100 years after the court case

Illustrations



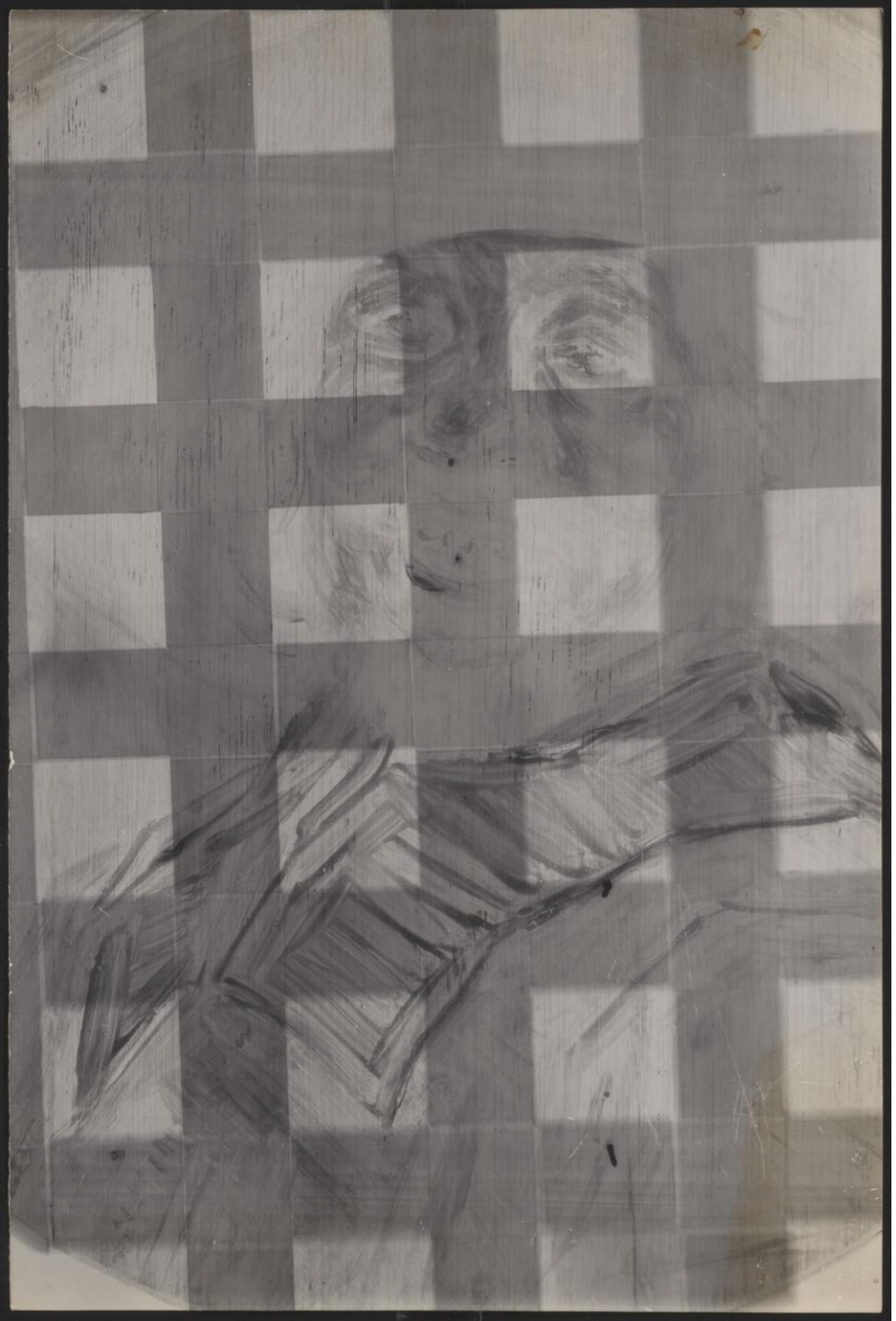
Fig. 1. *Laughing Cavalier*, Hals forgery created before 1923, diameter: 36 cm, Private Collection.



Fig. 2. *Boy Smoking*, forgery created before 1923, 57.5 x 49 cm, Groninger Museum, Groningen (Inv. Nr. 1931.0108)



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Figs. 4 & 5
Radiographs of fig. 1 taken in 1925



Fig. 6 (detail of fig. 3)



Fig. 7 (detail of fig. 3)



Fig. 8 (detail of fig. 2)

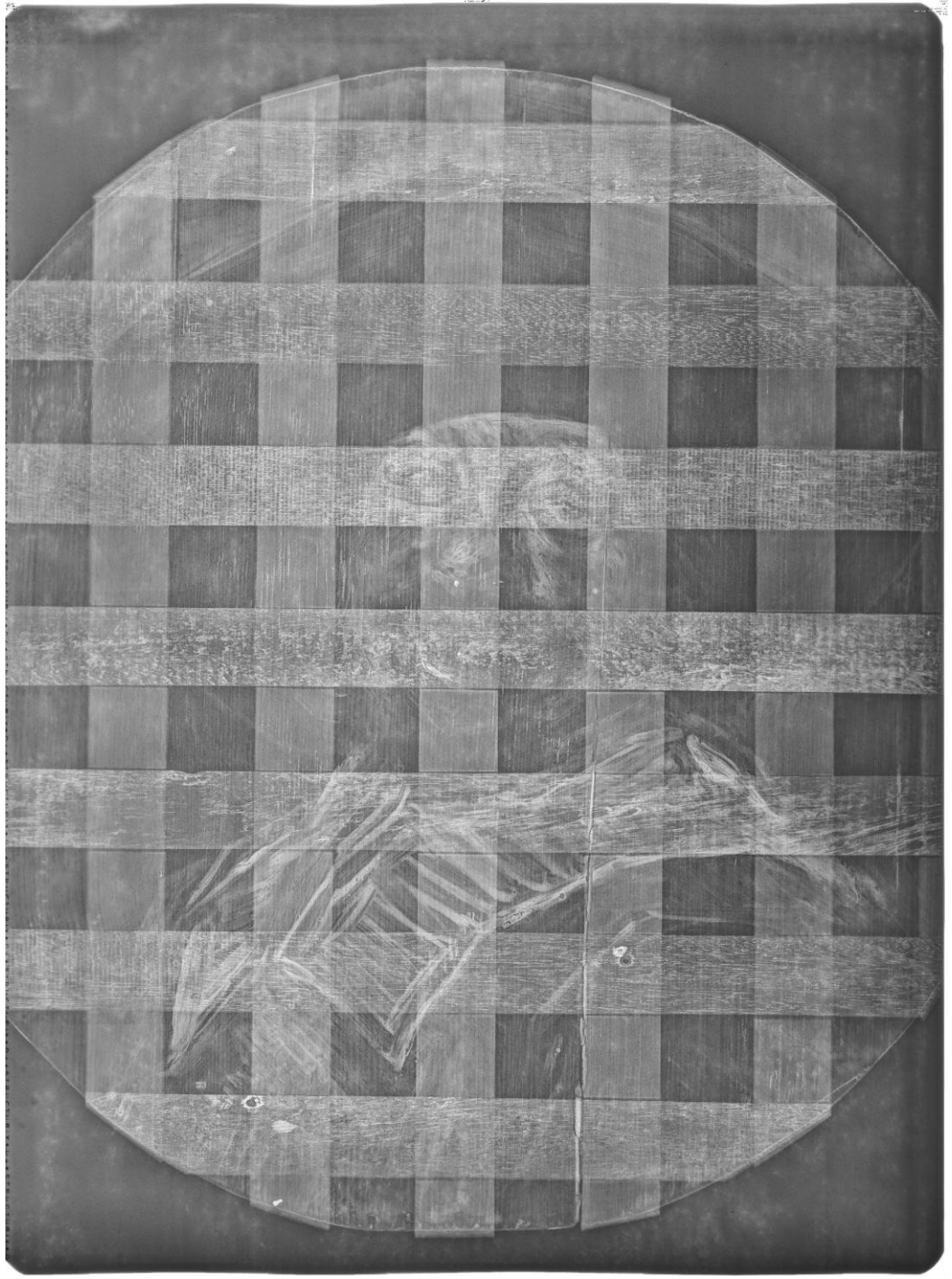


Fig. 9. Infrared reflectogram of fig. 1





Fig. 10 & detail
Infrared reflectogram of fig. 2



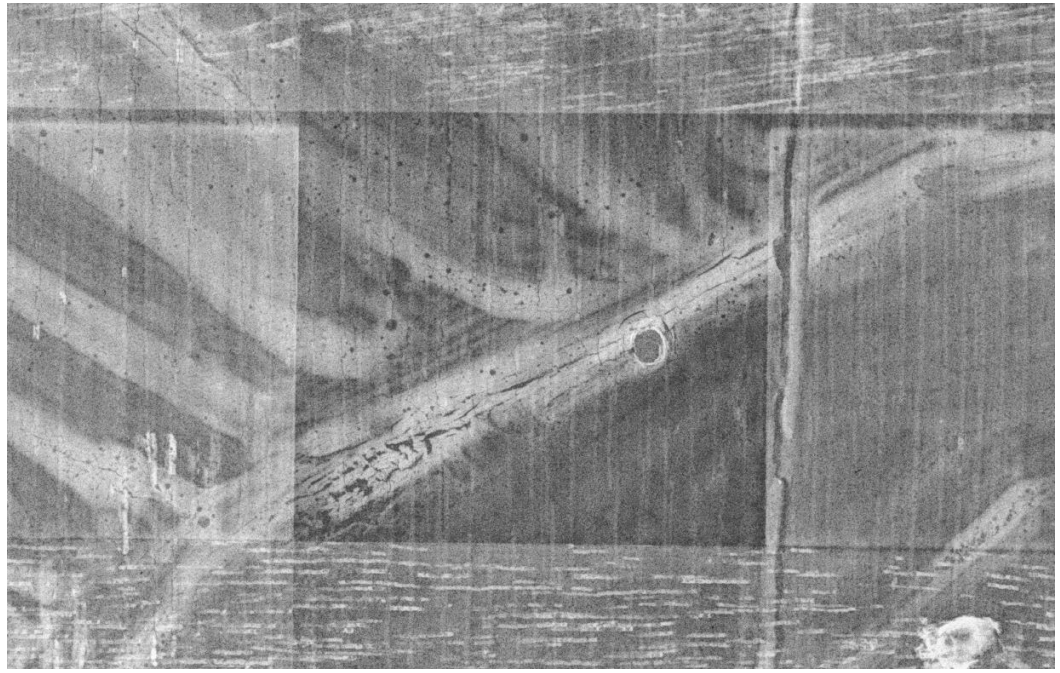


Fig. 11 & detail
Radiograph of fig. 1.



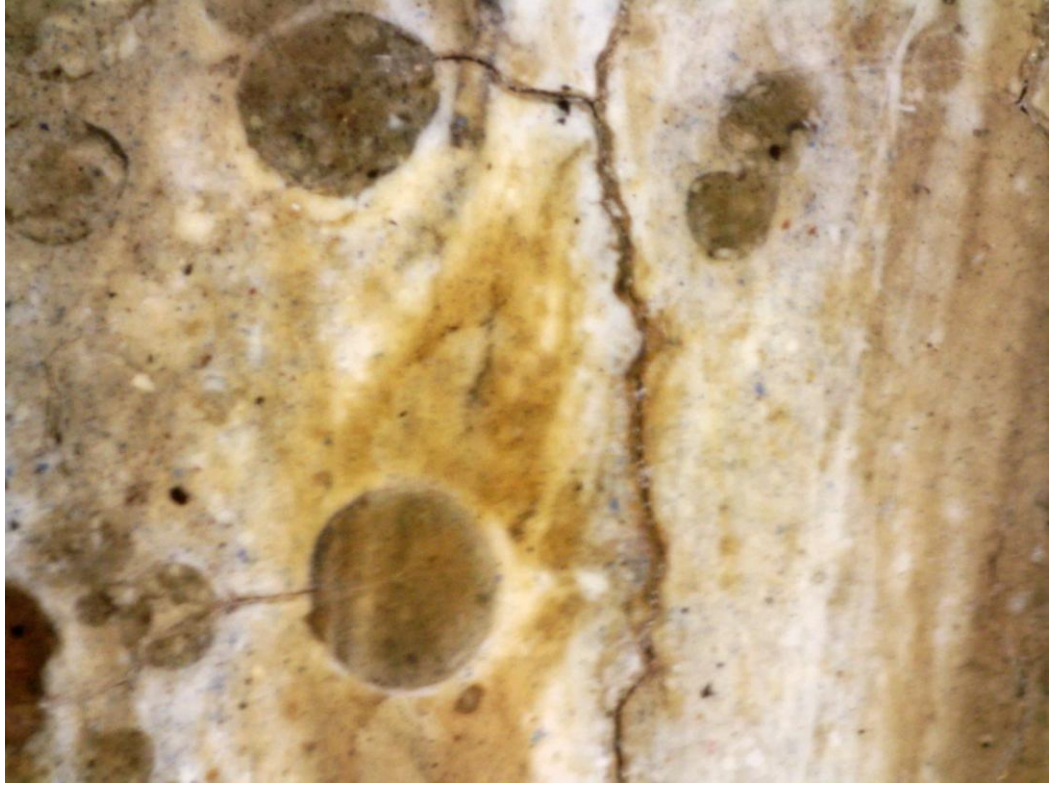


Fig. 12a + b Dino-lite and Hirox image of round lacunae in *Laughing Cavalier*



Fig. 12 c. A close-up of a regular photograph of the *Boy Smoking* showing similar round lacunae

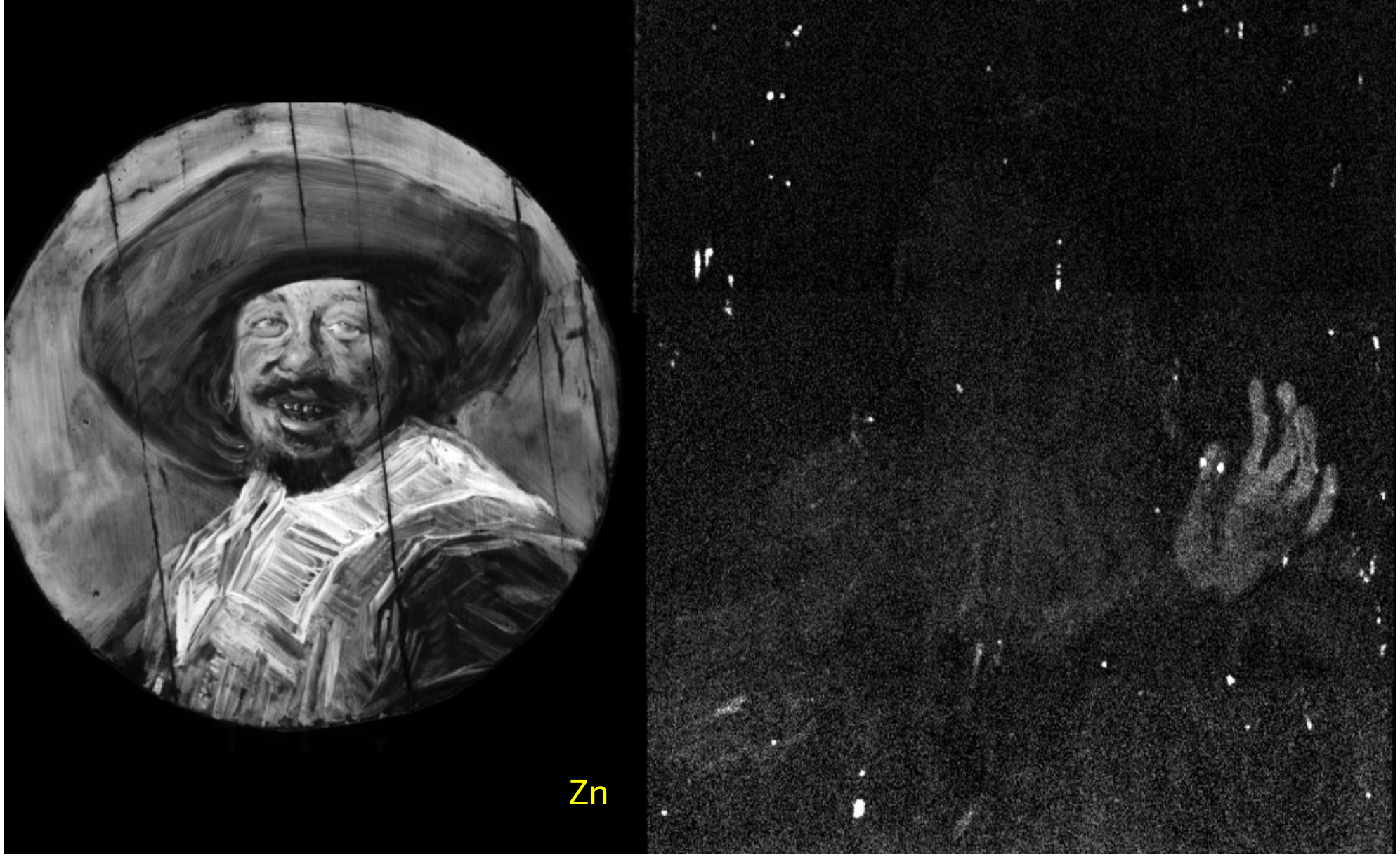


Fig. 13. MA-XRF Zn distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)



Fig. 14. MA-XRF Pb distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)

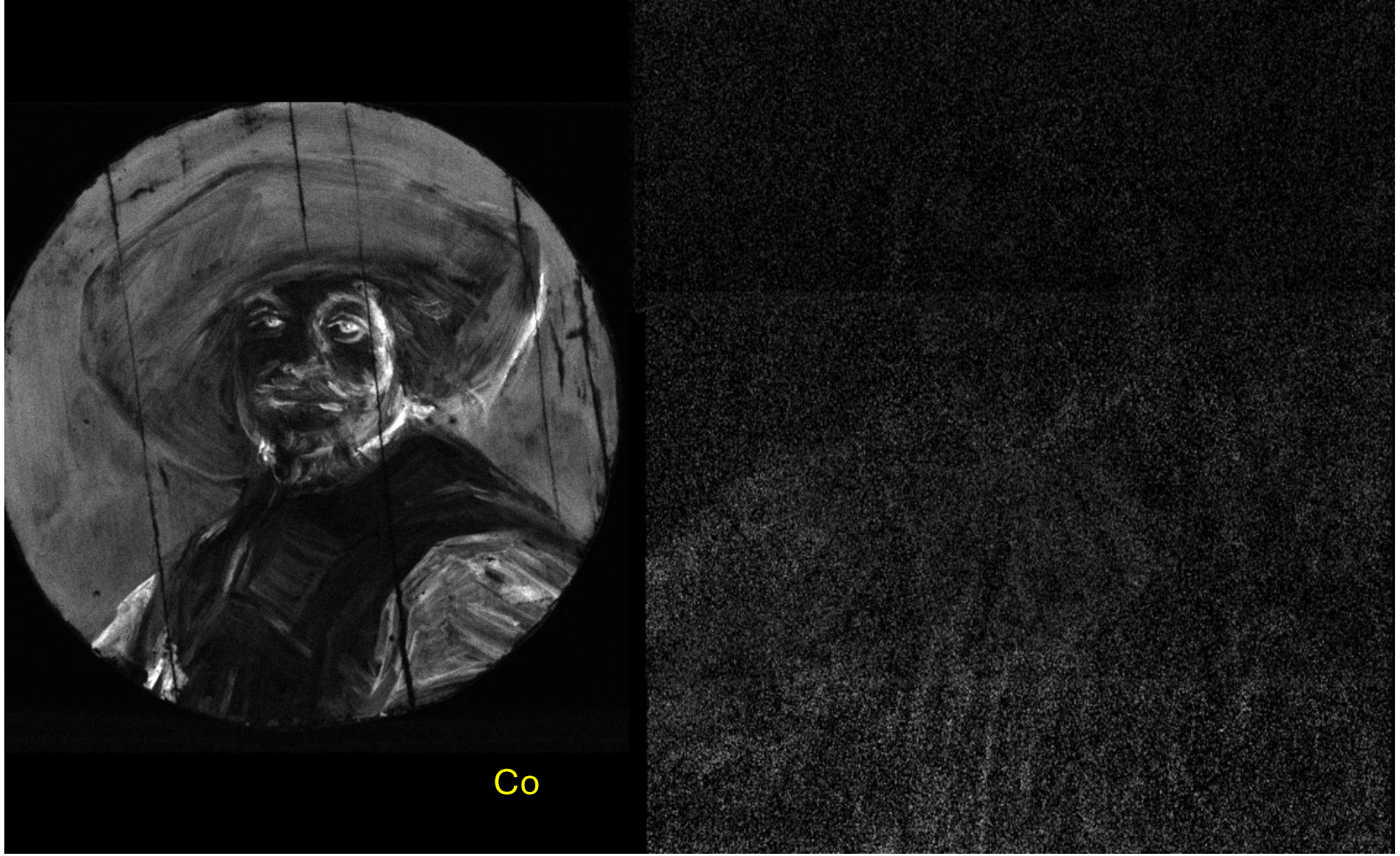


Fig. 15. MA-XRF Co distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)

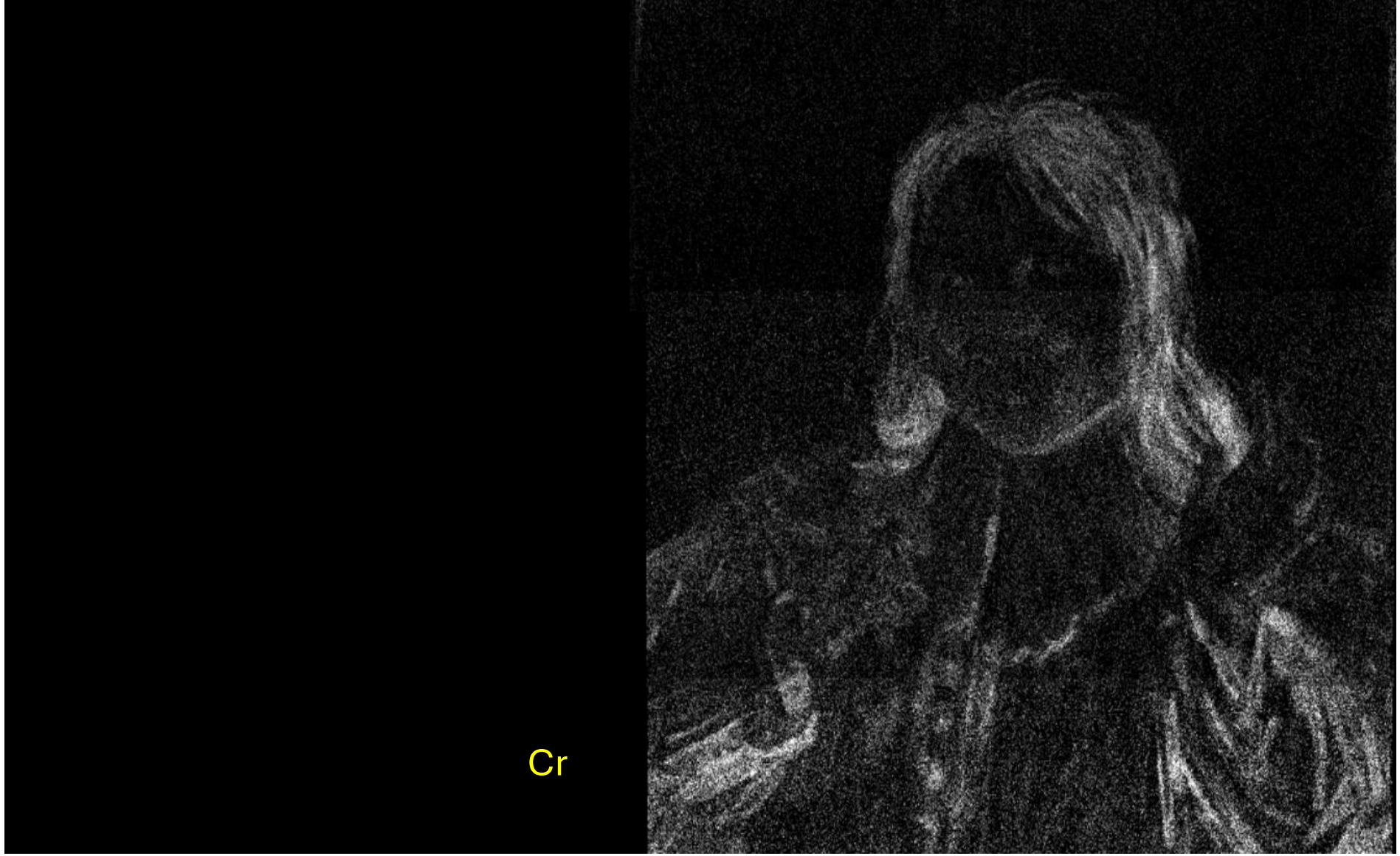


Fig. 16. MA-XRF Cr distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)

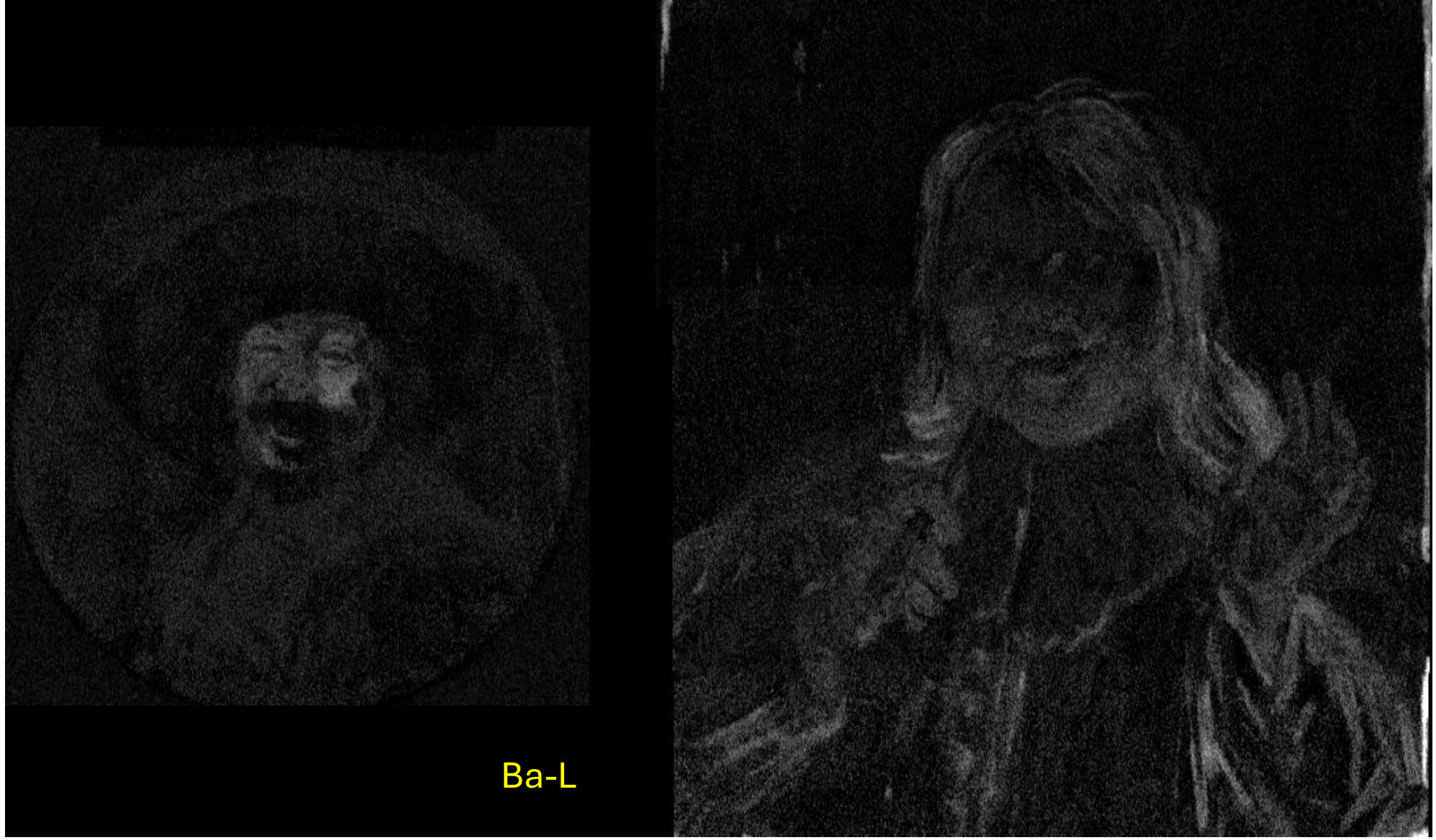


Fig. 17. MA-XRF Ba-L distribution images of figs. 1 and 2
(RCE settings, see ‘Methods’)

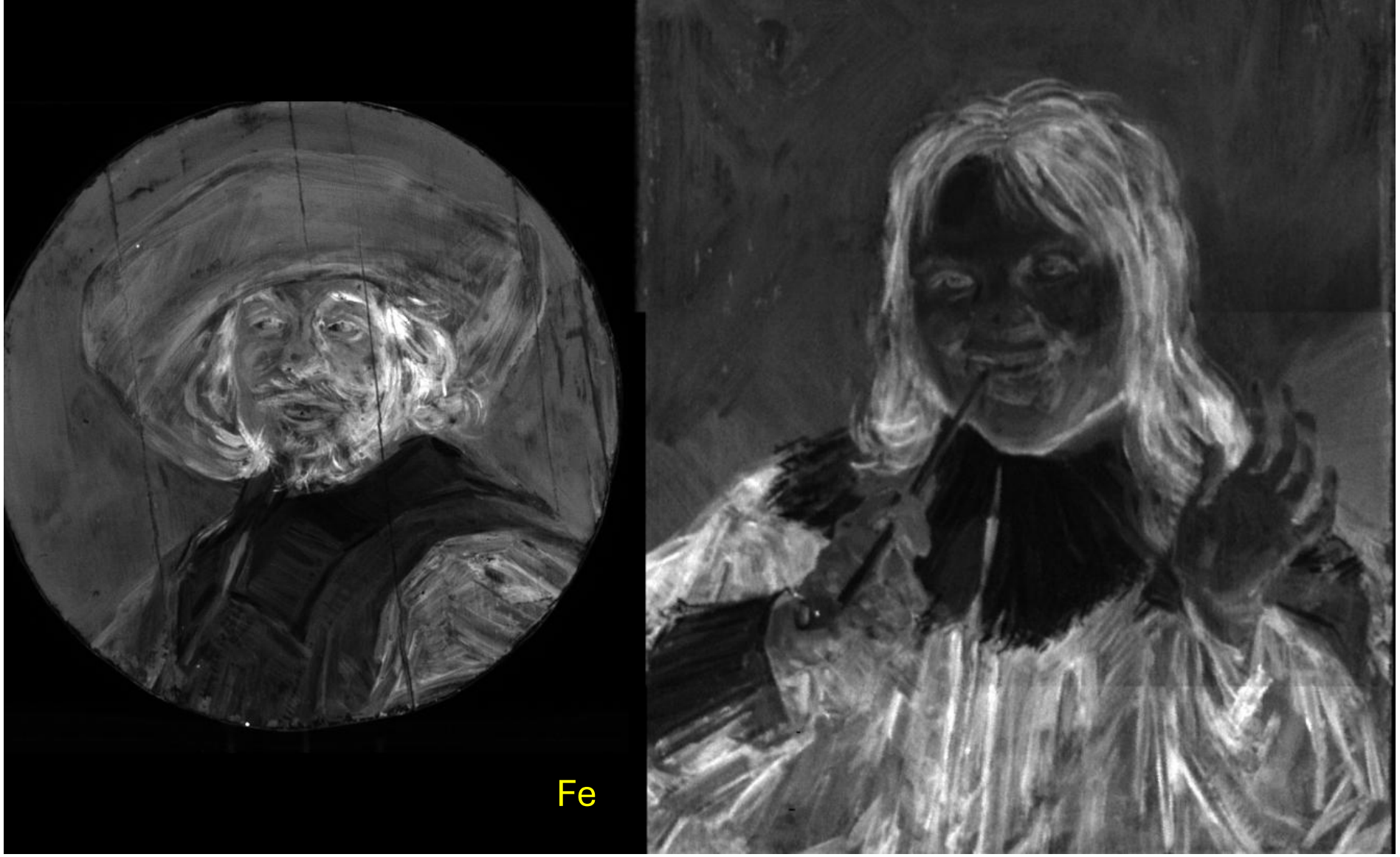


Fig. 18 MA-XRF Fe distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)

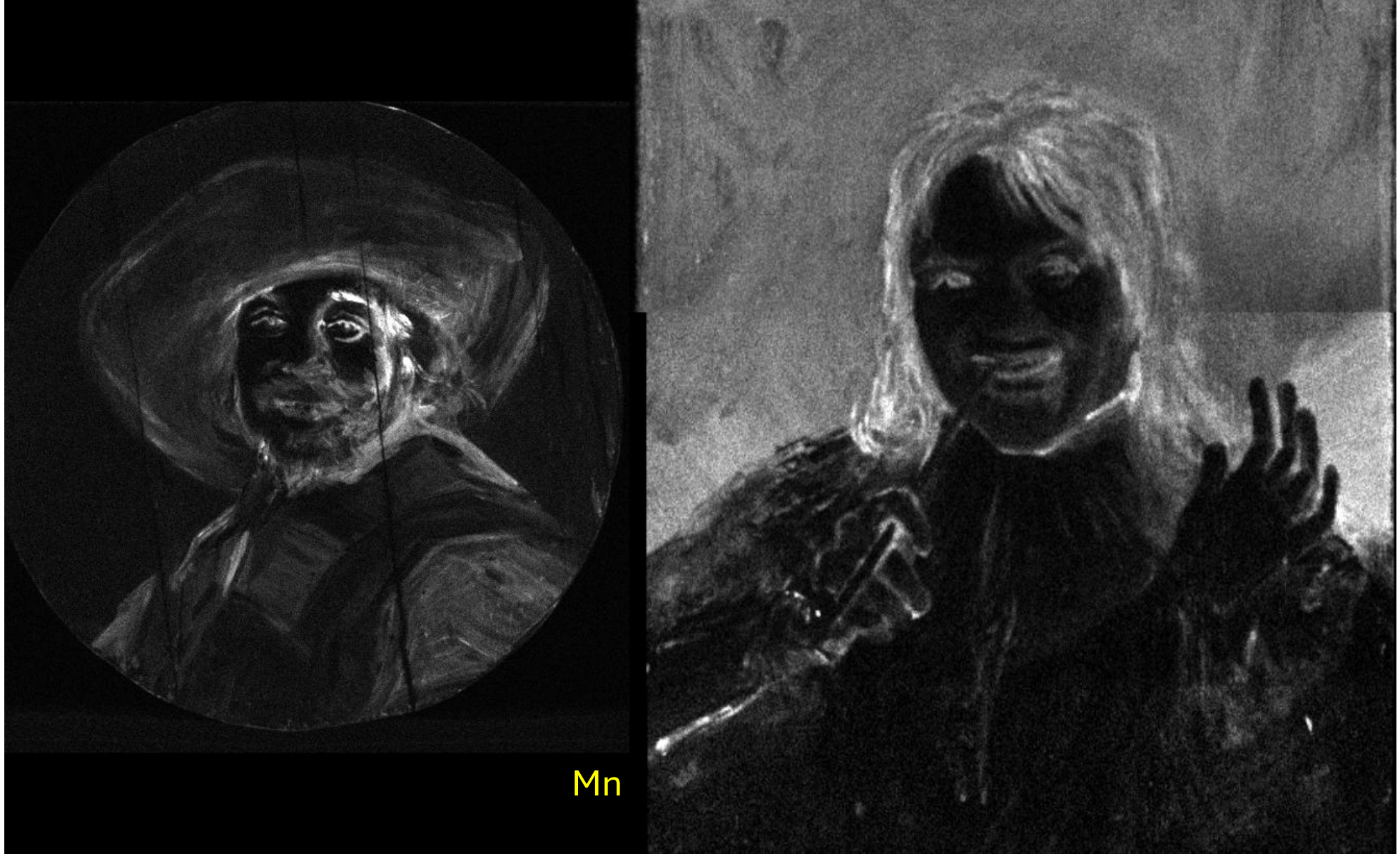


Fig. MA-XRF xx distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)

Fig. 19

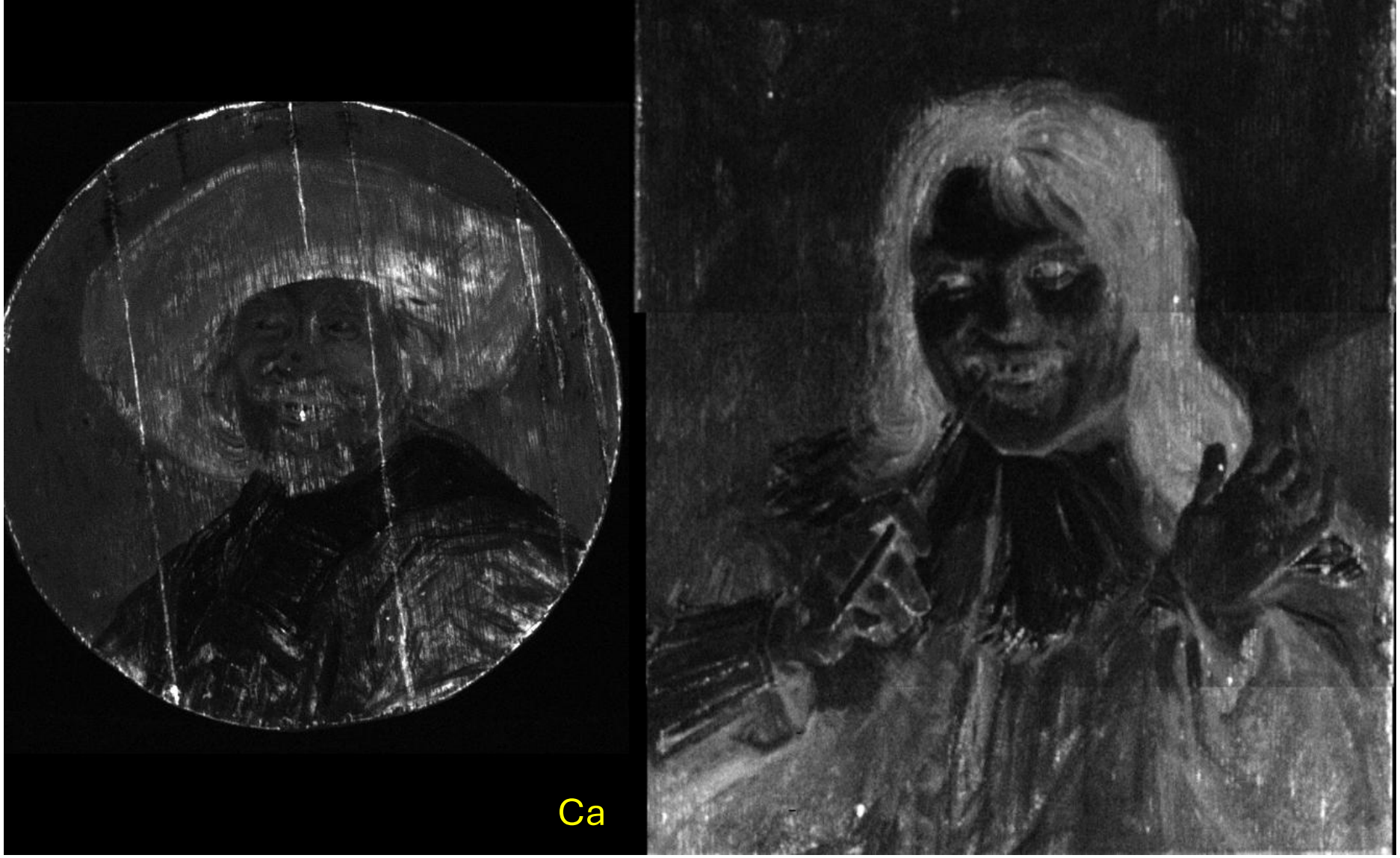


Fig. 21. MA-XRF Ca distribution images of figs. 1 and 2
(left: UA settings, right: RCE settings, see ‘Methods’)

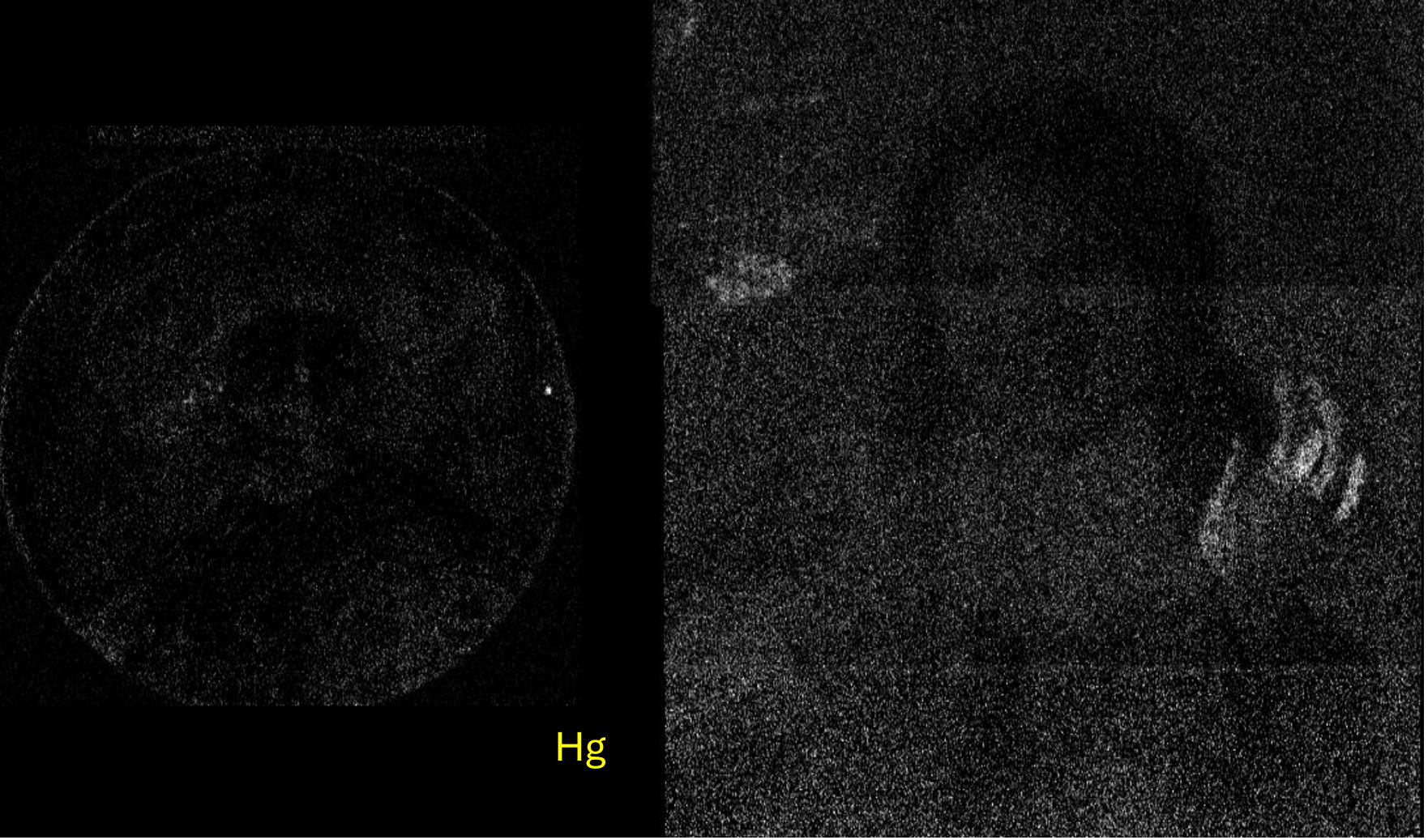


Fig. 20. MA-XRF Hg distribution images of figs. 1 and 2 (RCE settings, see ‘Methods’)

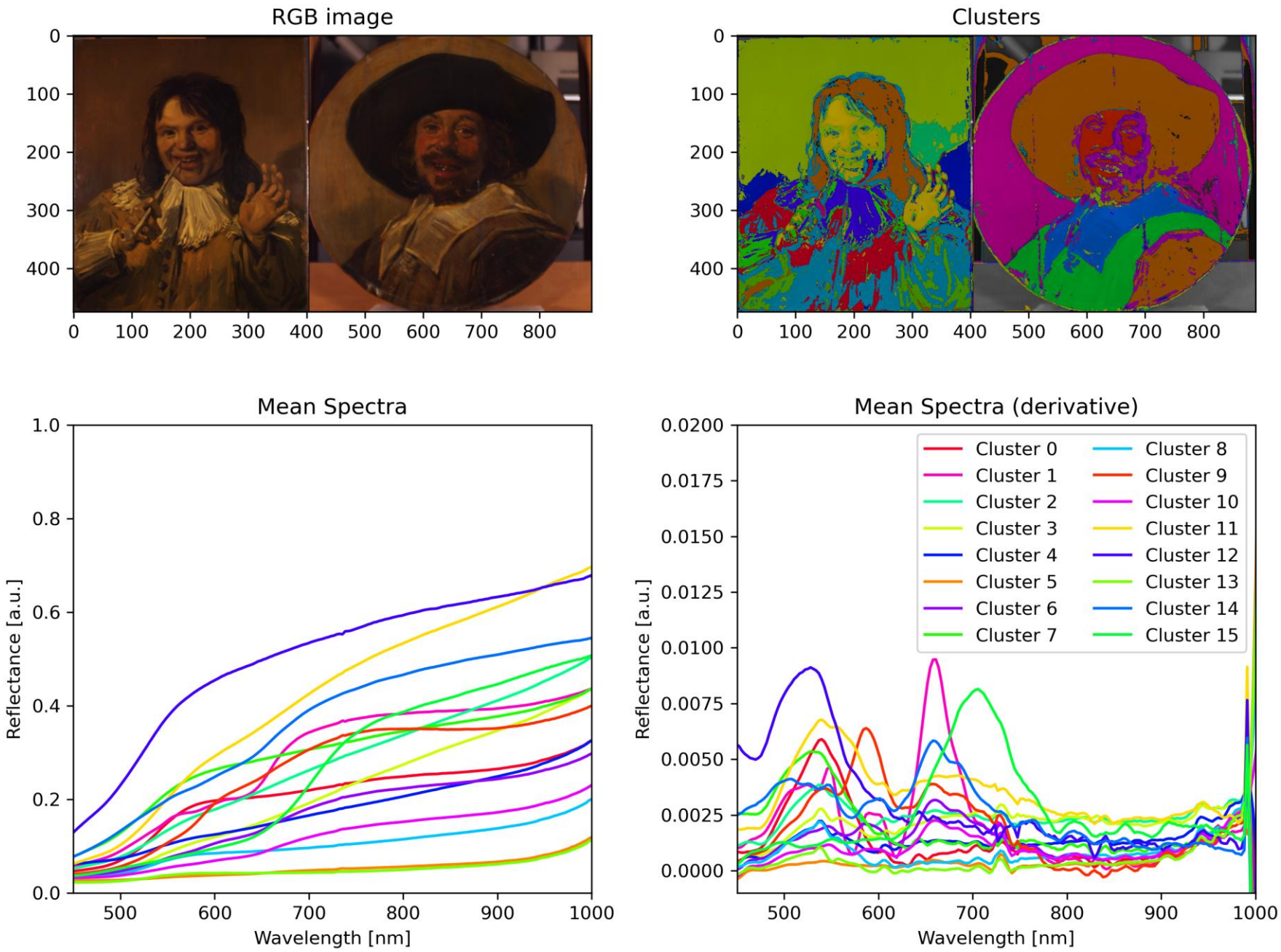


Fig. 22. RIS analysis of figs. 1 and 2

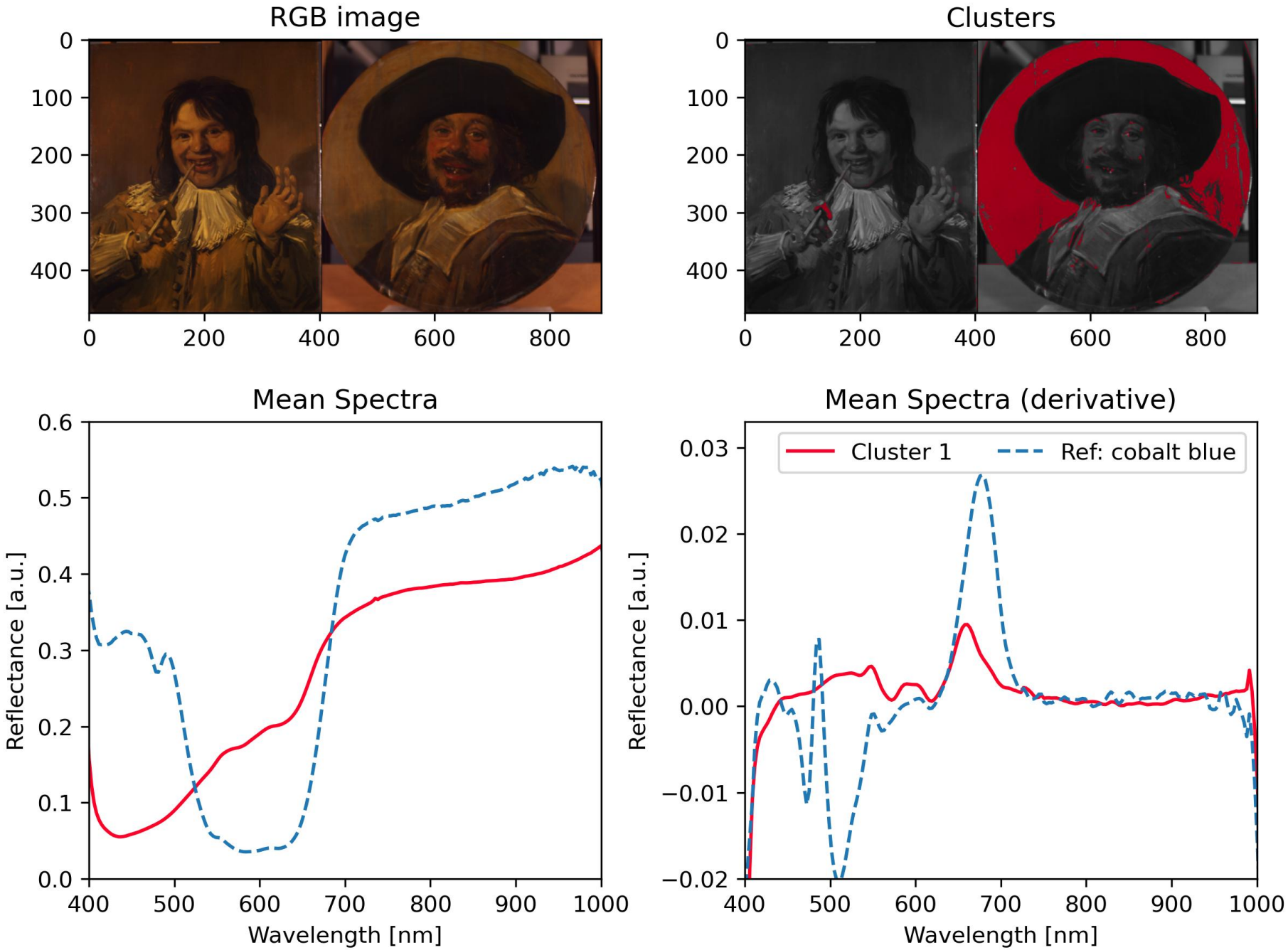


Fig. 23. RIS analysis of figs. 1 and 2

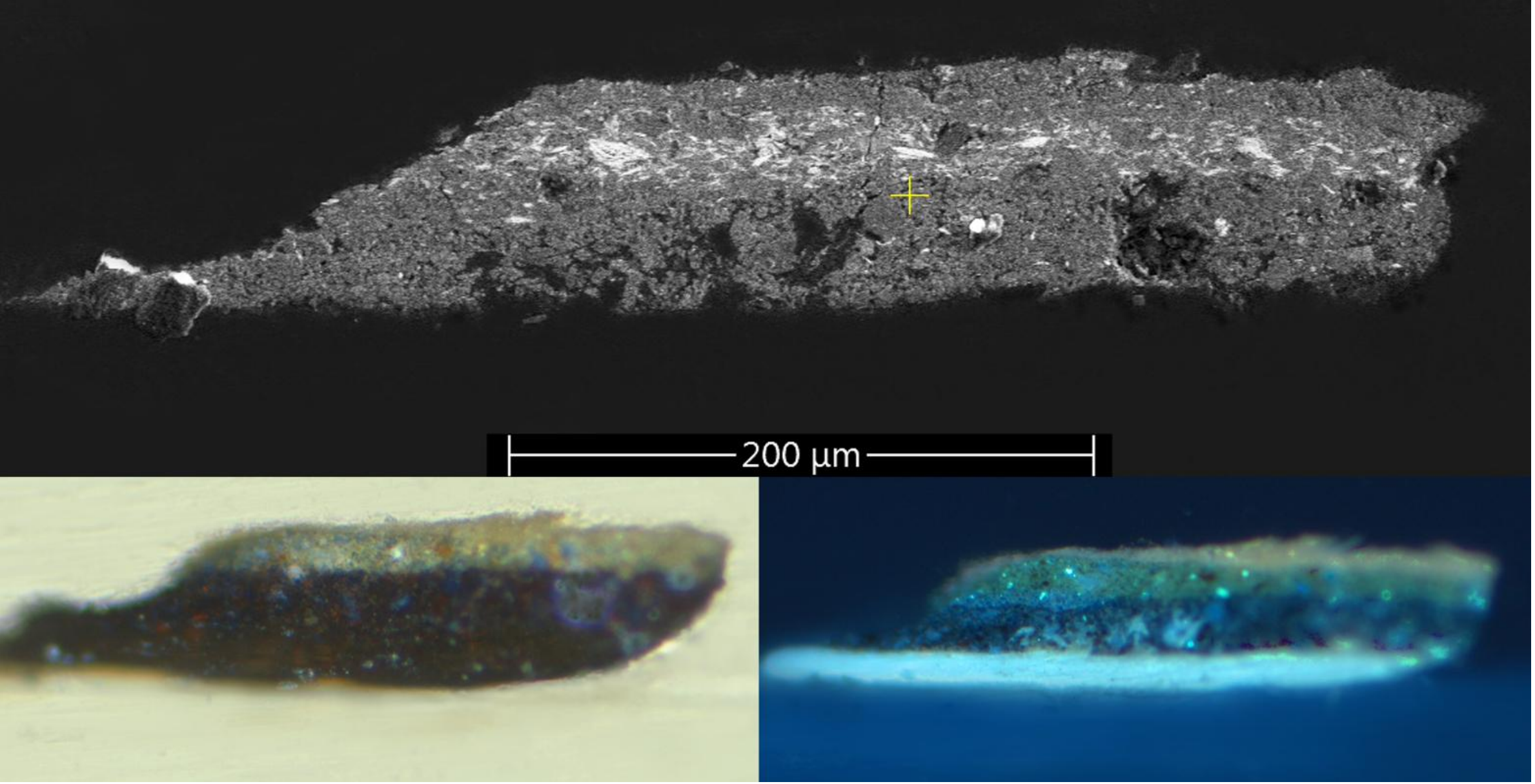


Fig. 24 Microscopy of paint cross section from *Laughing Cavalier*.
a, back scattered electron image, mag. 300x, scale bar = 200 µm; b, light microscopy, mag. 100x, BF illumination; c, UV-fluorescence, λ ex. = 365nm

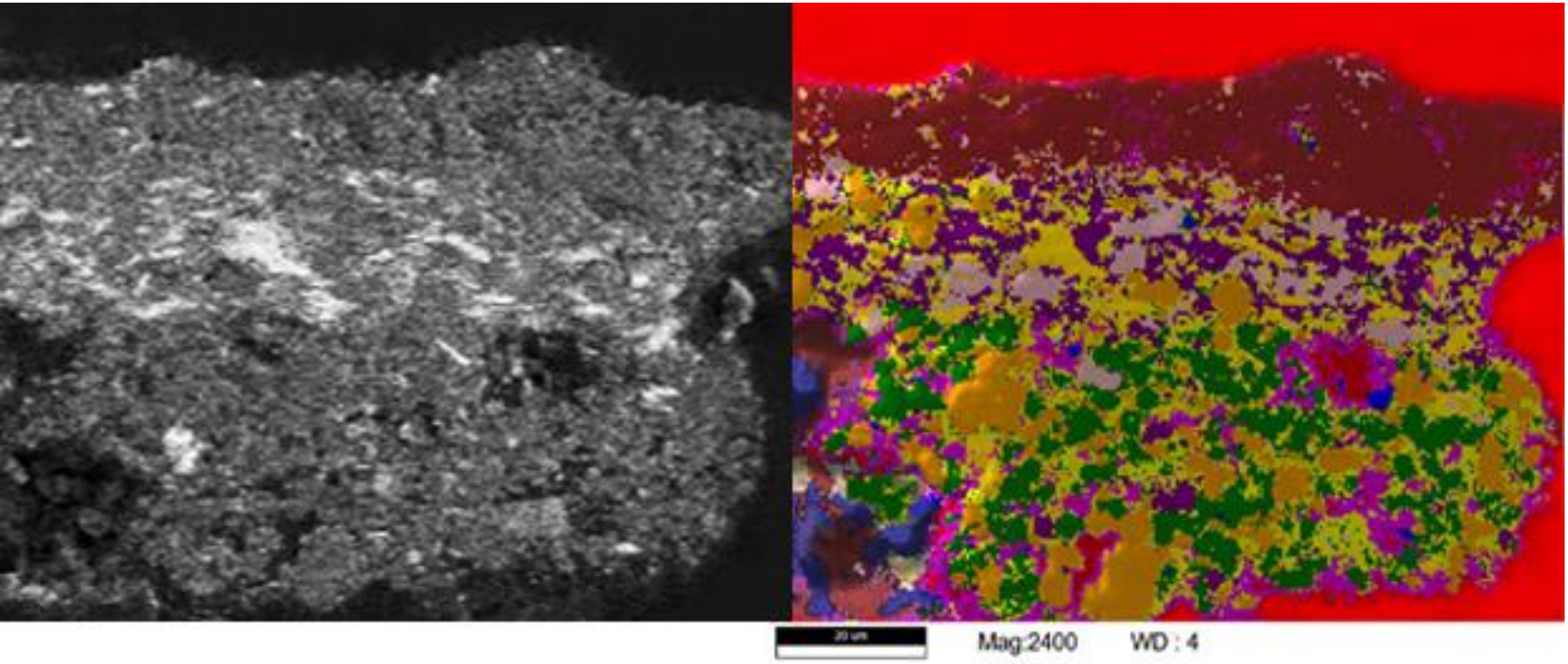


Fig. 25. part of cross section (fig. 26) from *Laughing Cavalier*.
a, back scattered electron image, mag. 2400x, 15 kV; b, mineral phase overly on BSE image

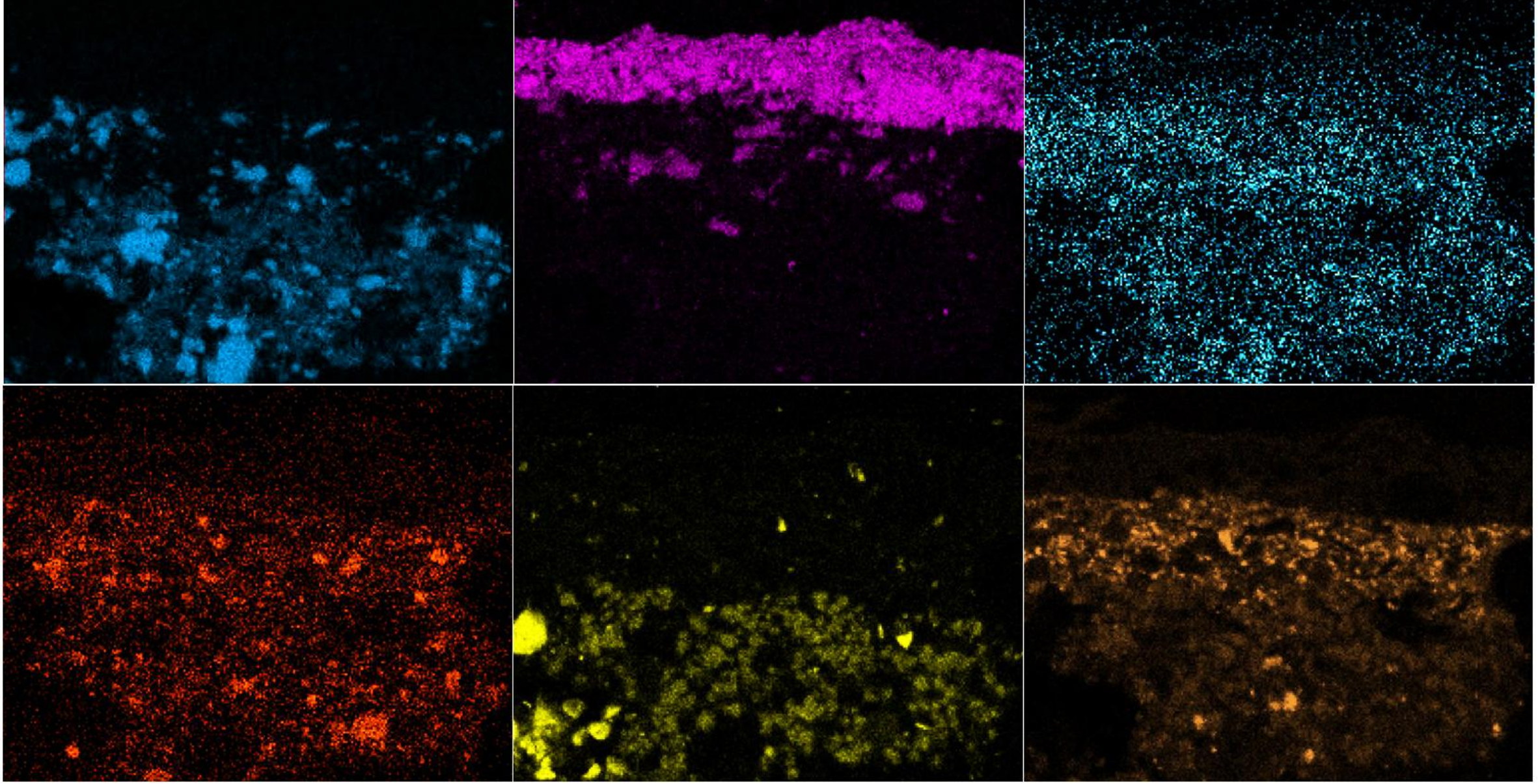


Fig. 26. elemental distribution maps from part of cross section (fig. 26) from *Laughing Cavalier*. Elements in reading order: Al-Ca-Co-Fe-Si-Zn.

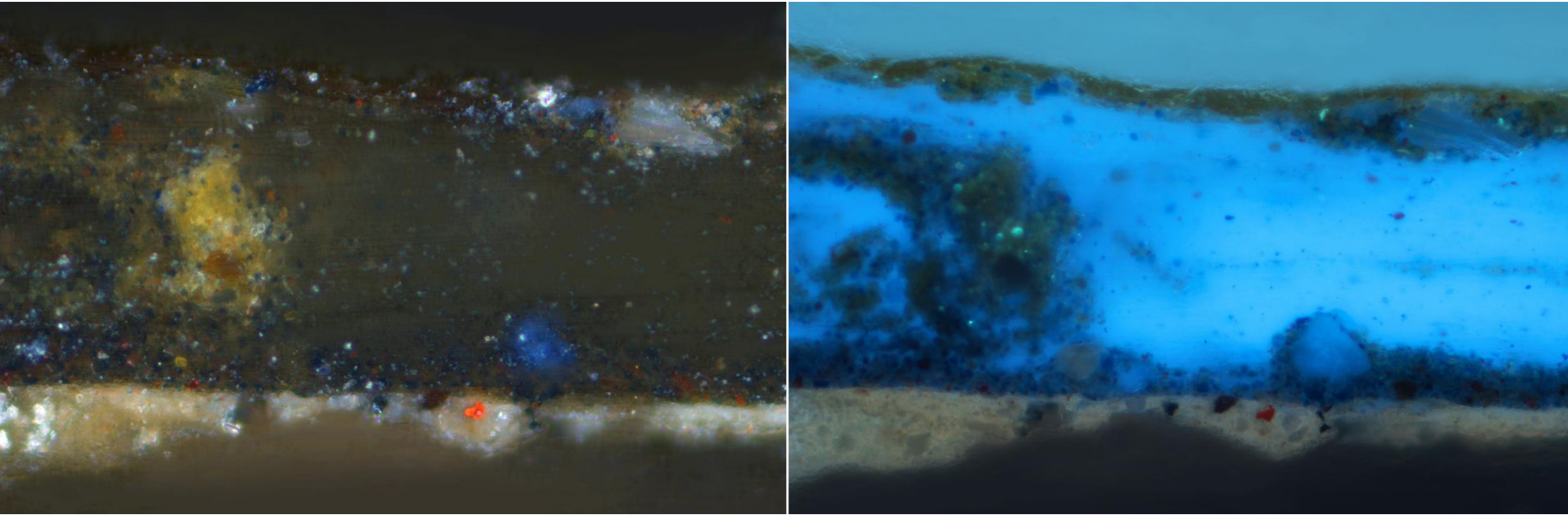


Fig. 27 Microscopy of paint cross section from *Laughing Cavalier*.
a, light microscopy, mag. 500x,BF illumination; b, UV-fluorescence, λ ex. = 365nm

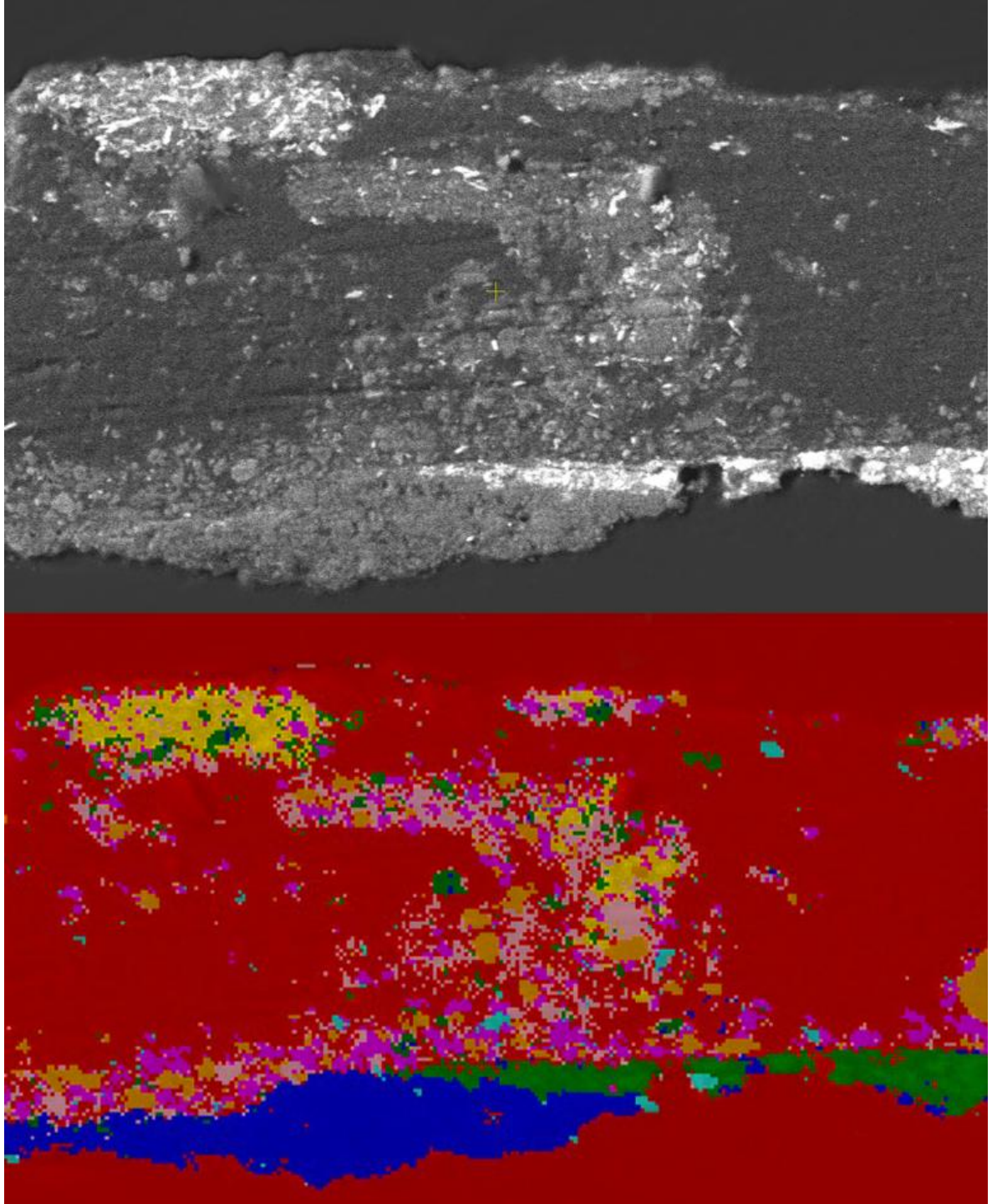


Fig. 28
Microscopy of paint cross section from *Laughing Cavalier*.
a, back scattered electron image, mag. 800x, 15 kV;
b, mineral phase overly on BSE image

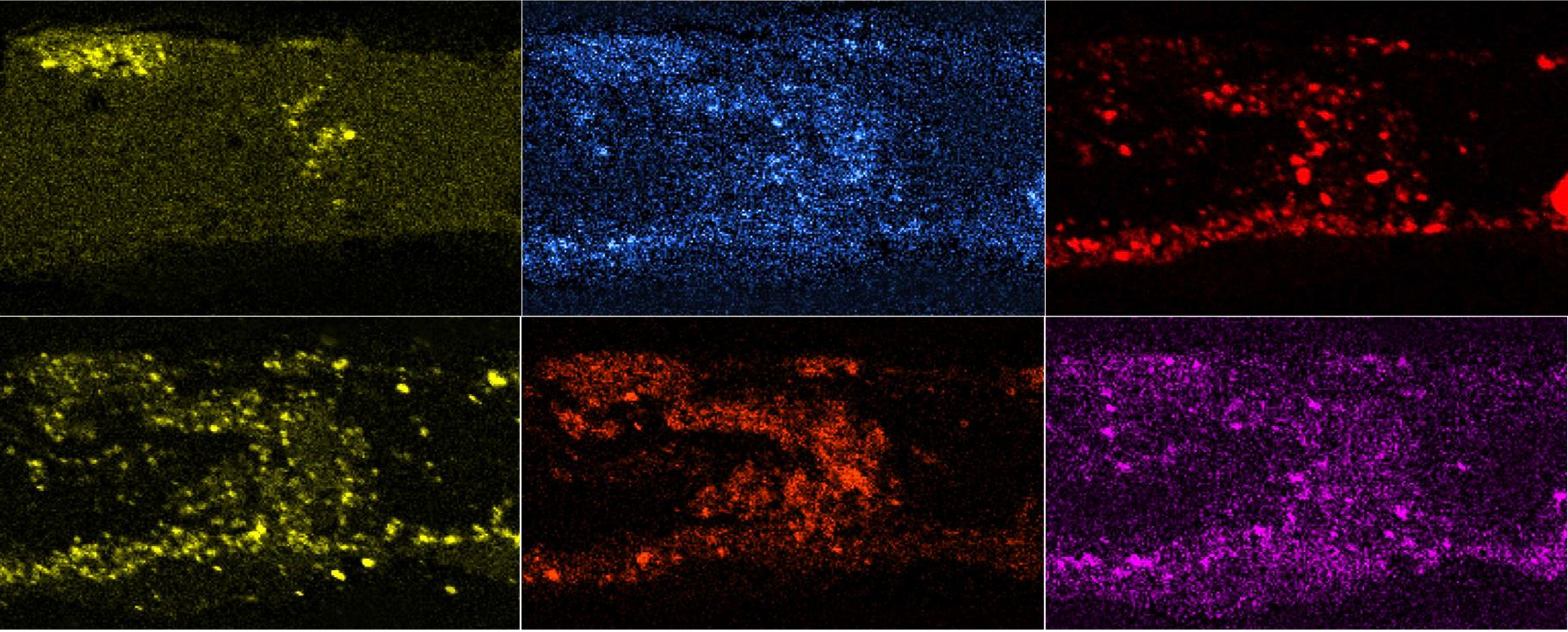


Fig. 29 a-f.
elemental distribution maps from cross section(fig. 30) from Laughing Cavalier.
Elements in reading order: Zn-Co-Al-Si-Fe-P.

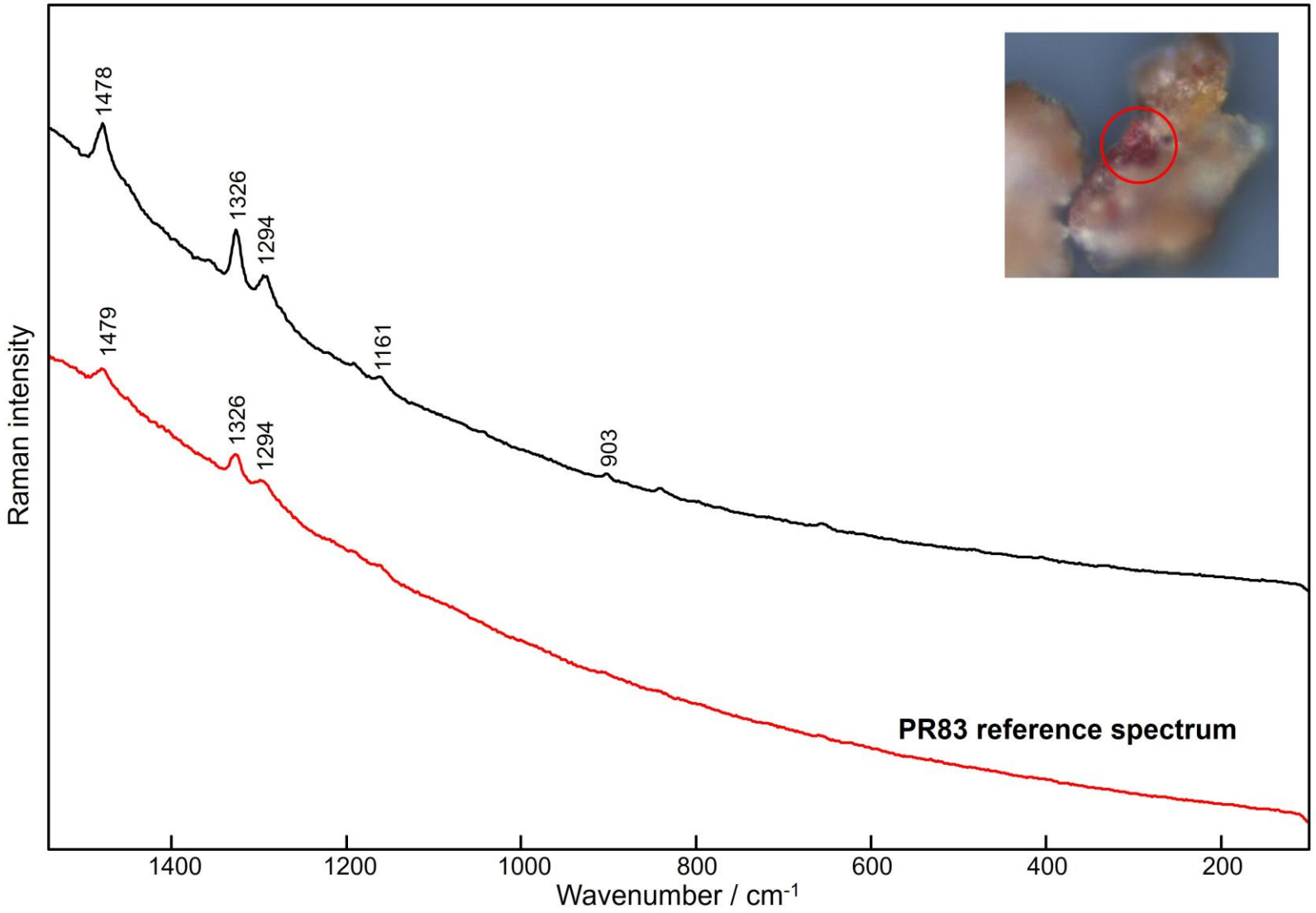


Fig. 30 Identification of Pigment Red 83 with micro-Raman spectroscopy in sample from *Laughing Cavalier*

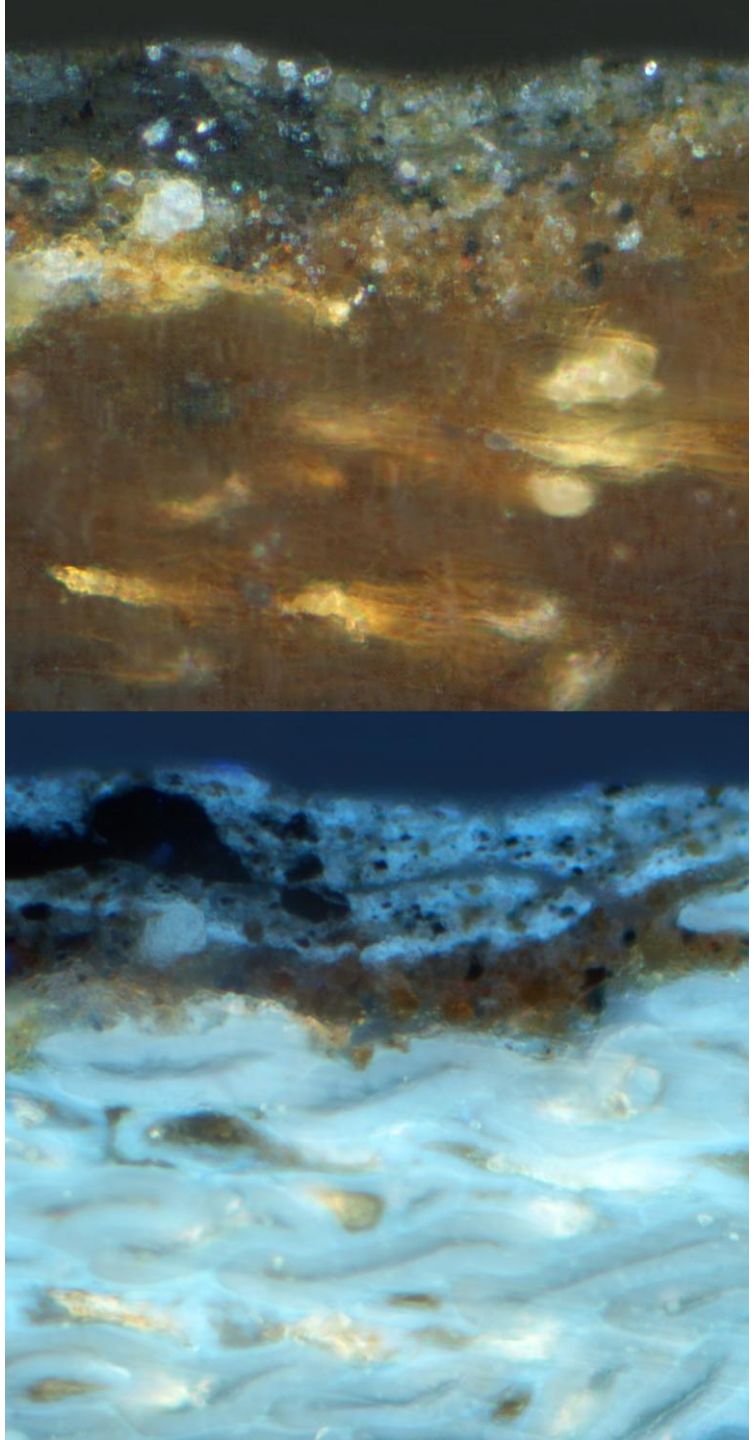


Fig. 31
Microscopy of paint cross section (HdG2-2) from *Boy Smoking*.
a, light microscopy, mag. 1000x,BF illumination; b, UV-fluorescence, λ ex. = 365nm

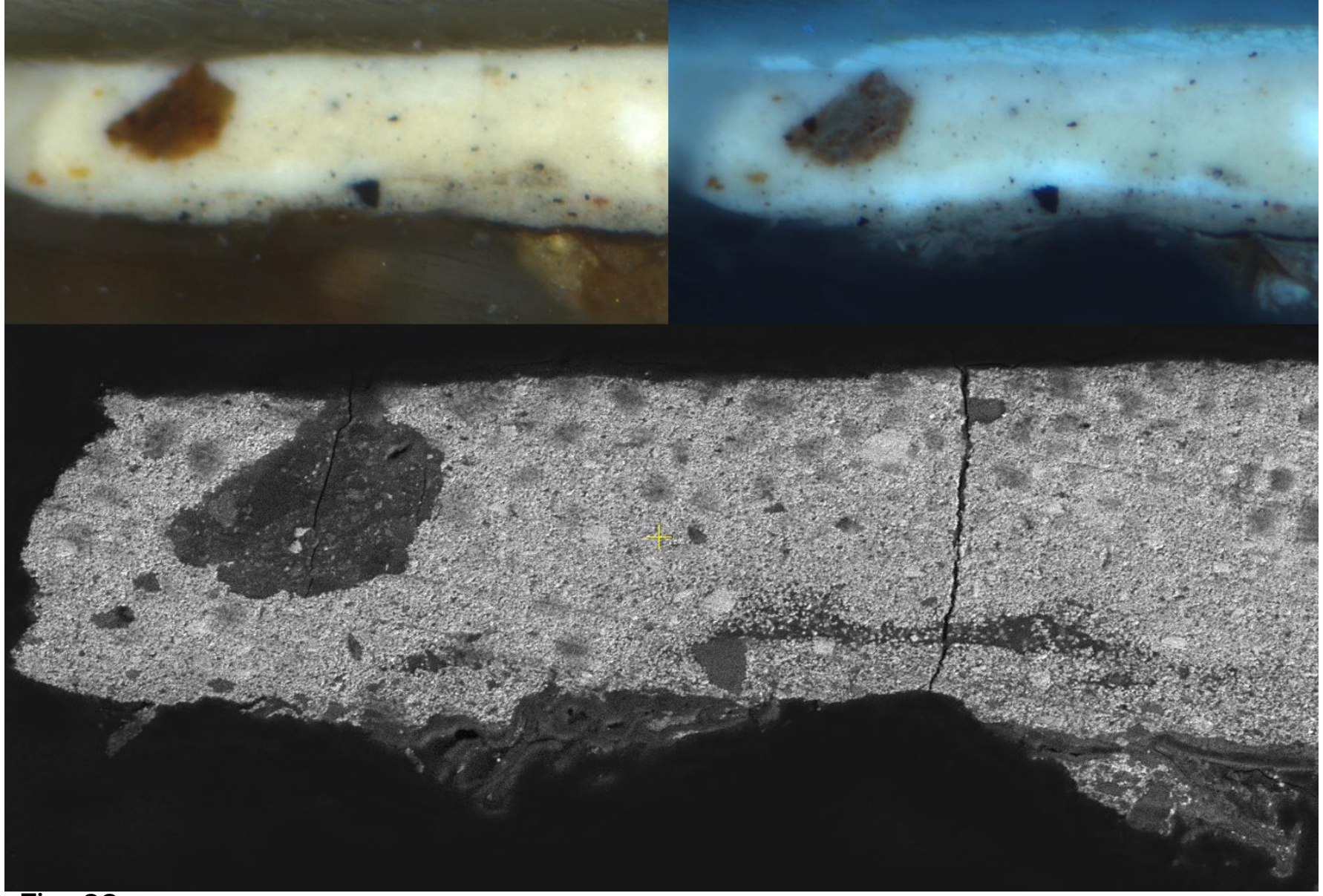


Fig. 32
Microscopy of paint cross section from the *Boy Smoking*.
a, light microscopy, mag. 100x,BF illumination; b, UV-fluorescence, λ ex. = 365nm;
c, back scattered electron image, mag. 500x, 15 kV

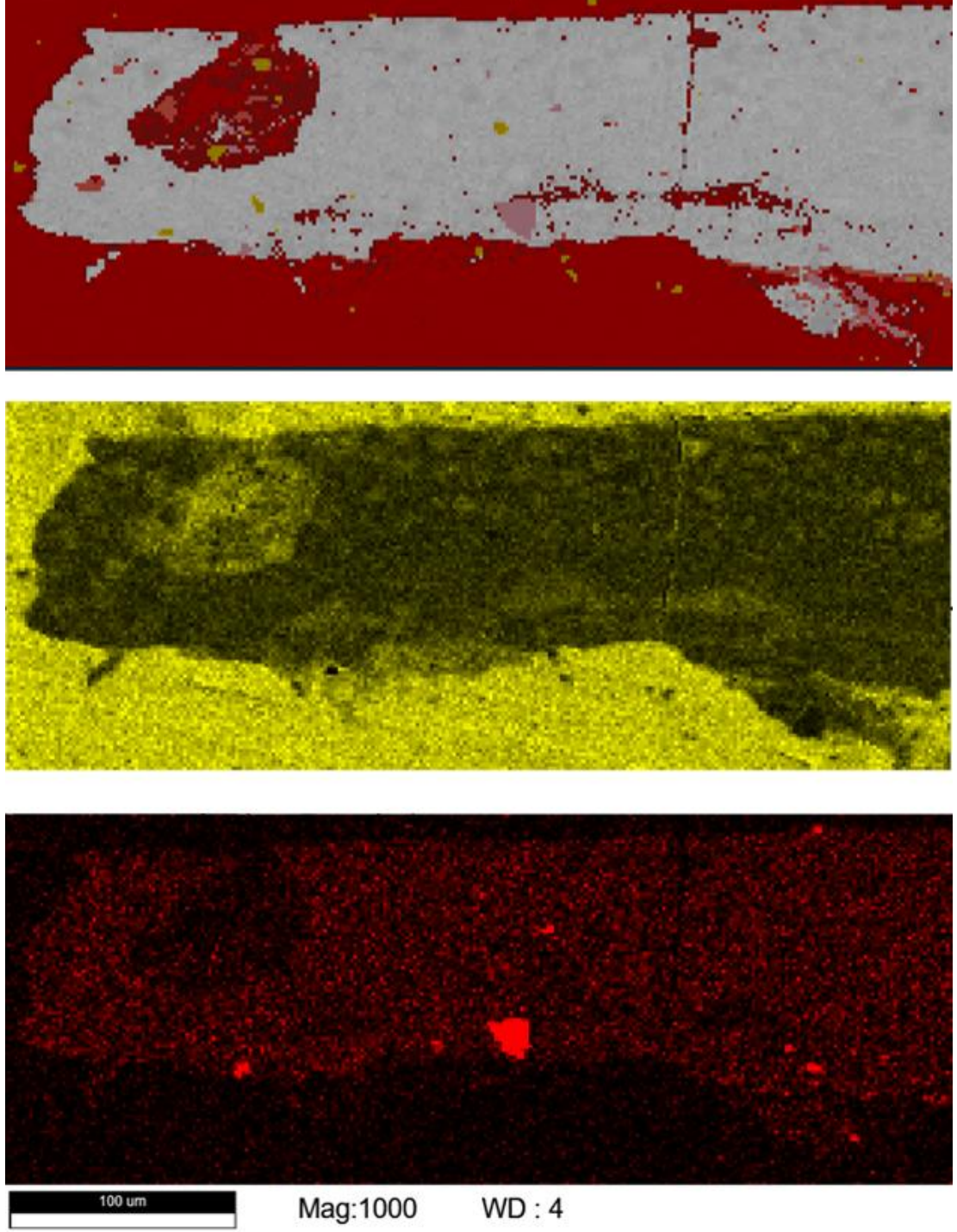


Fig. 33
Microscopy of paint cross section from the *Boy Smoking*.
a, mineral phase overlay on BSE image (fig. 11 c); b, elemental distribution map for C; c, elemental distribution map for P.

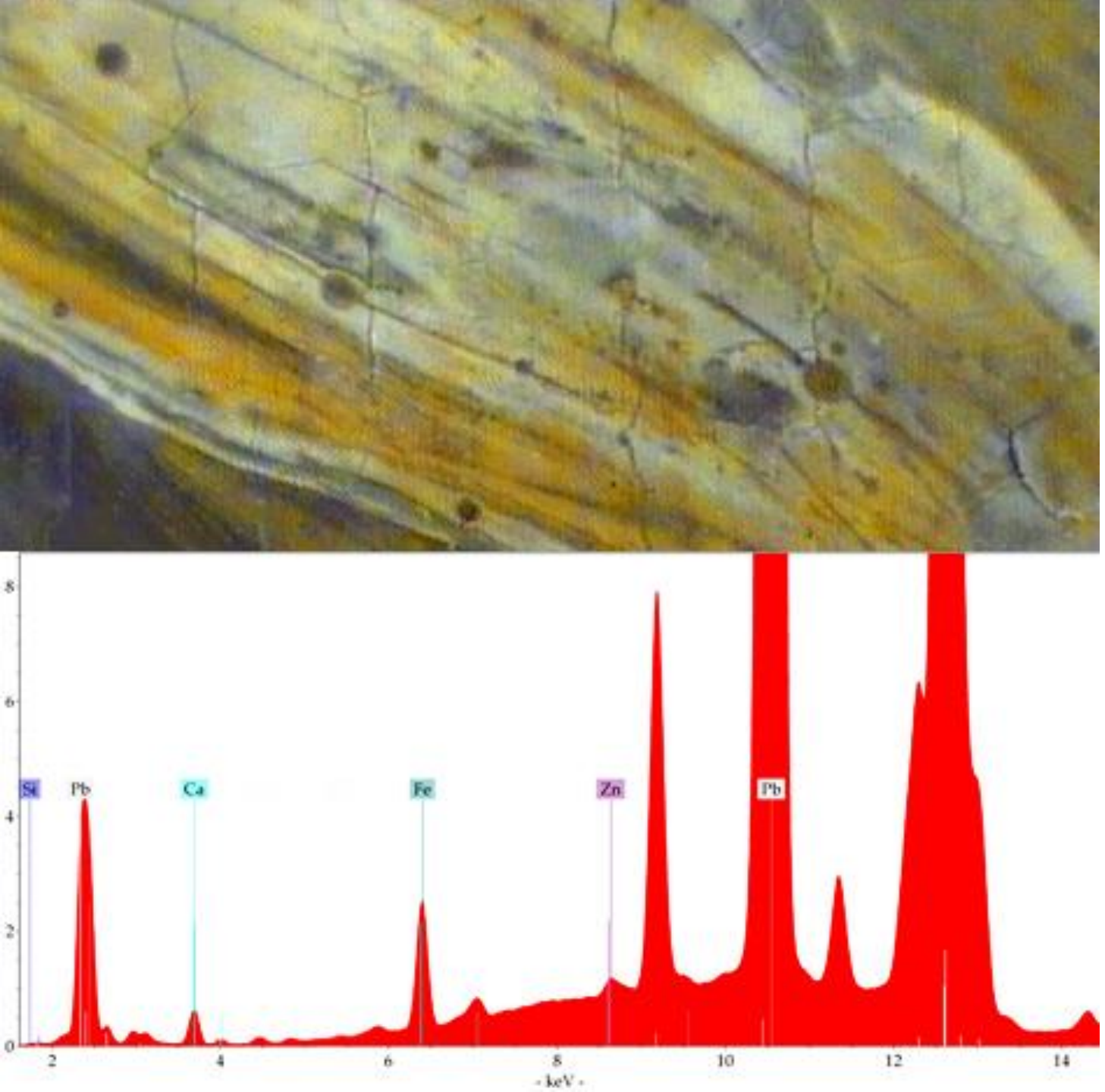
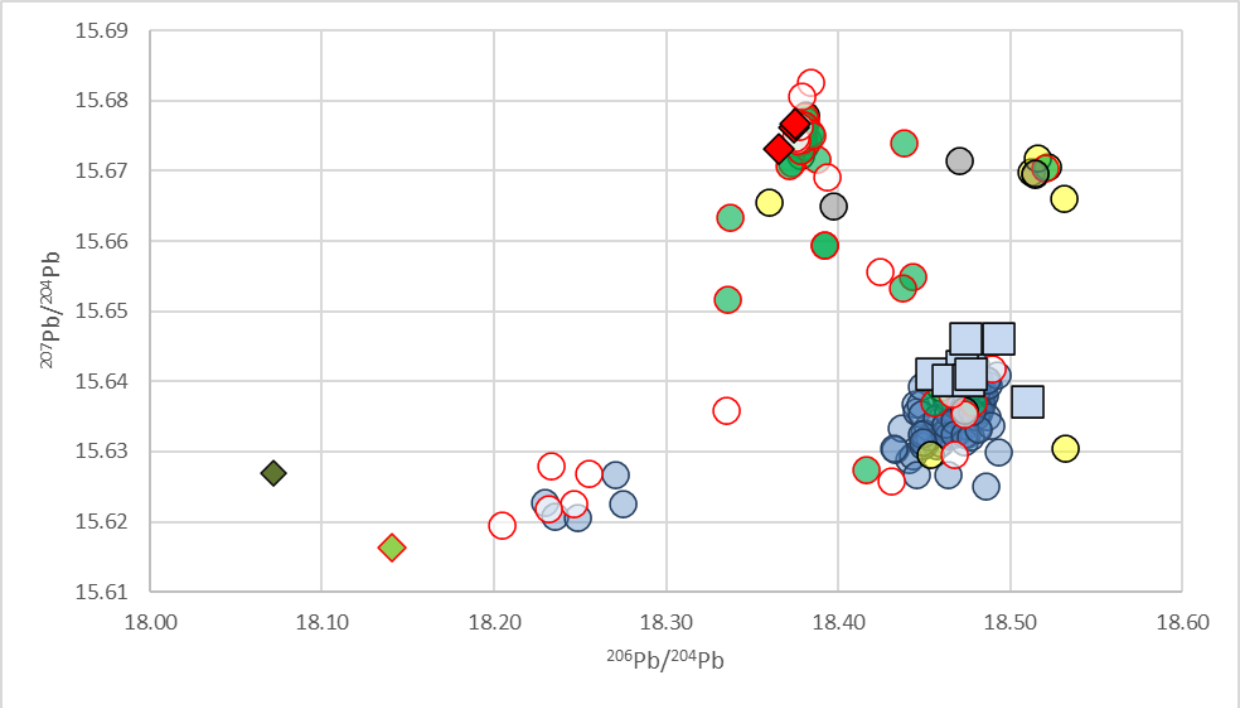
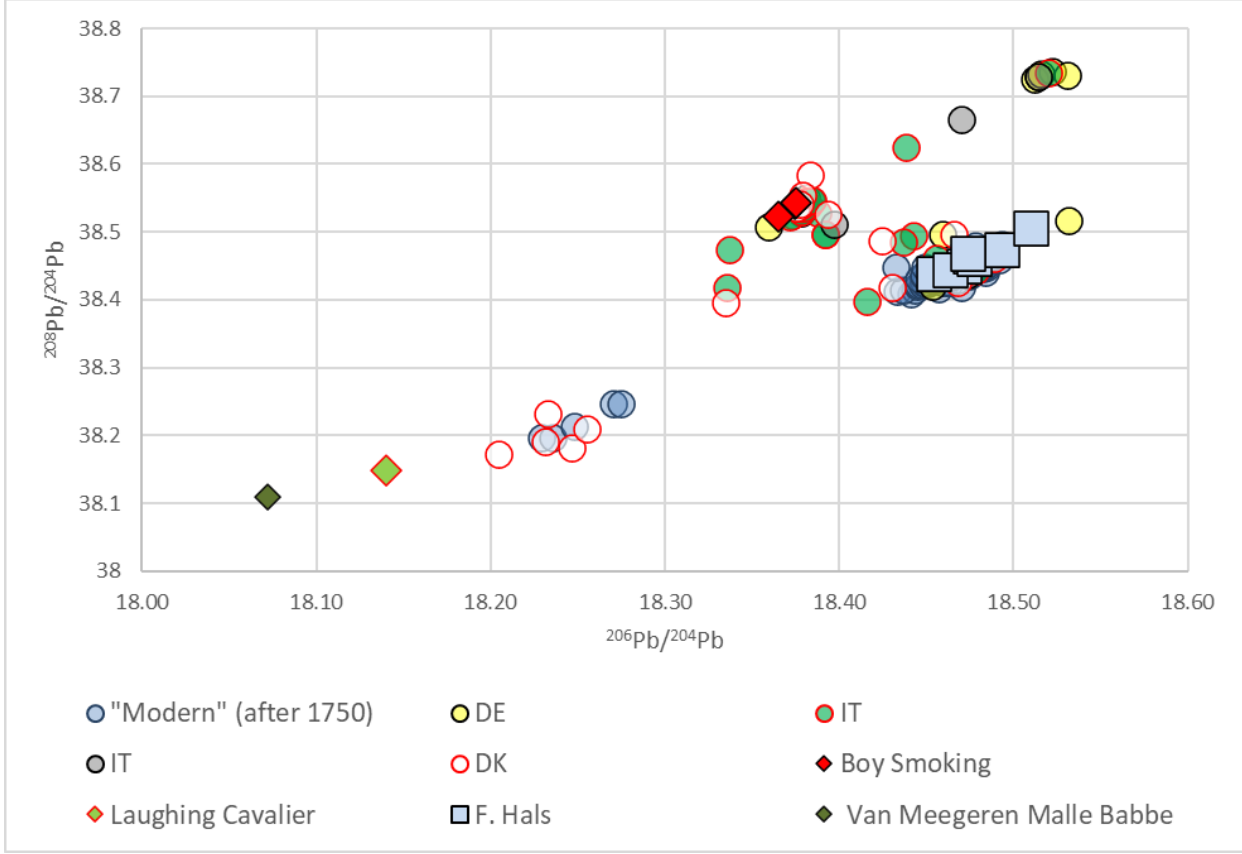


Fig. 34
Elemental analysis of whitish paint on the *Boy Smoking*.
a, area of white paint with air bubbles on the surface, bright mark is measurement spot; b, x-ray fluorescence spectrum shows distinctive peak for Zn (Kα = 8,64) in lead white.





Figs. 35a + b. Lead isotope ratios of samples taken from *Laughing Cavalier* and *Boy Smoking* compared to reference data

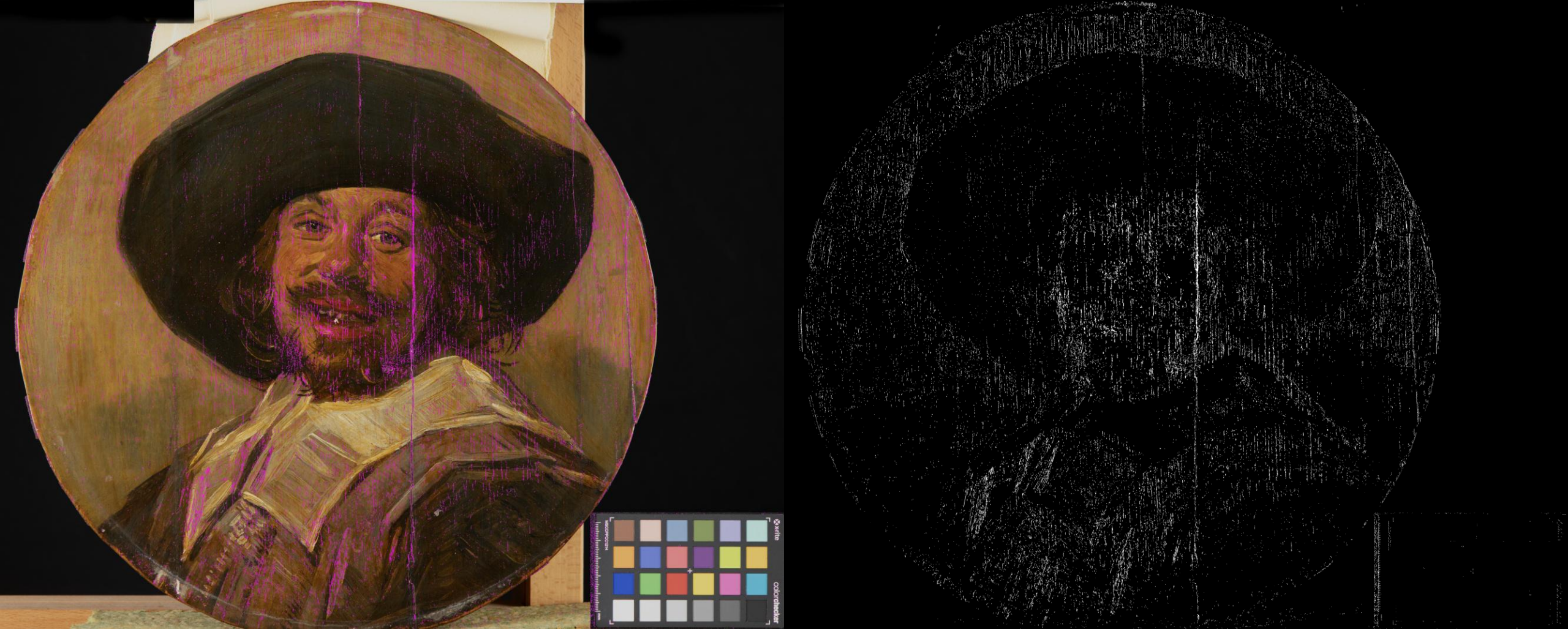


Fig. 36. Automated craquelure analysis of fig. 1



Fig. 37. Automated craquelure analysis of fig. 2



Fig. 38. Automated craquelure analysis of fig. 39

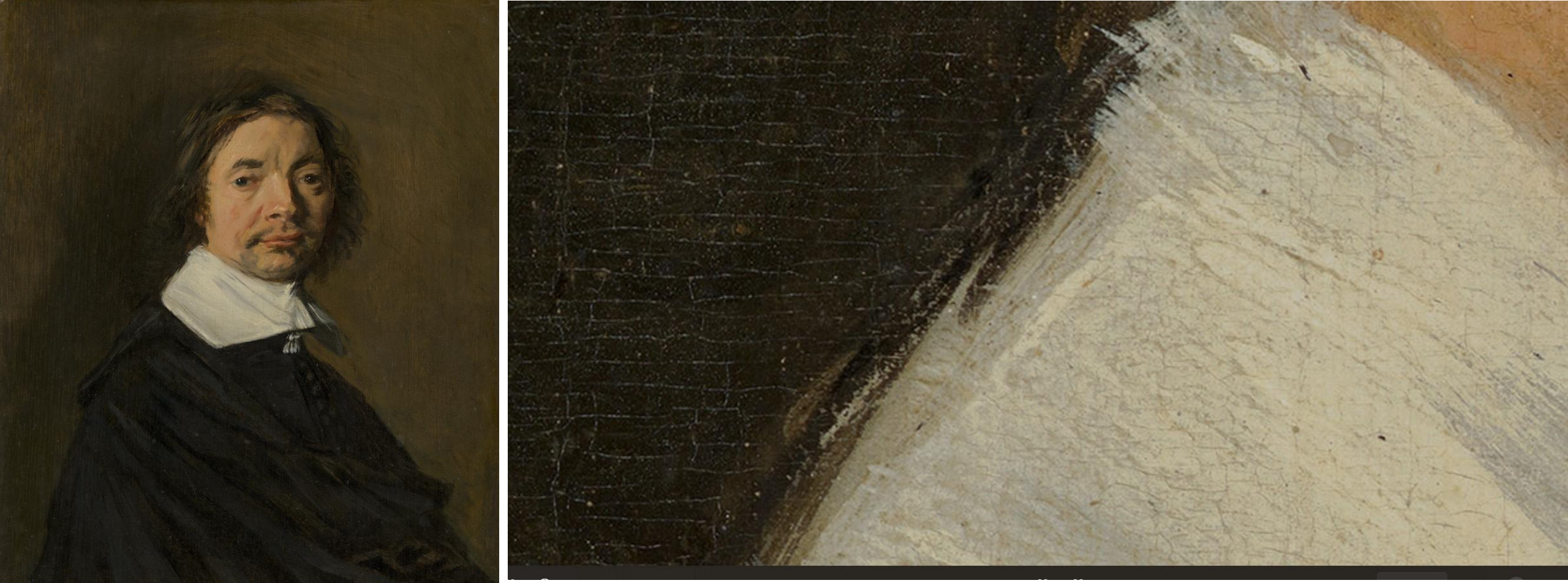


Fig. 39. & detail
Frans Hals, *Portrait of Man*, ca. 1660, 31.1 cm x 25.5 cm, oil on panel, Royal Cabinet of Paintings the Mauritshuis, The Hague (Inv. Nr. 928)