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A John White Alexander painting: A comparison of imaging technologies for resolving a painting under another painting

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ABSTRACT
Reflectance imaging spectroscopy (RIS) in the visible and near infrared is revolutionizing the way cultural heritage investigators may analyze paintings nondestructively. In an ongoing, highly collaborative project, the authors are investigating a painting by American artist John White Alexander (1856–1915). The painting, titled *A Study in Pink*, is in the collection of the Virginia Museum of Fine Arts (VMFA). An x-radiograph taken in 2014 revealed that there was a painting of another female figure, rotated 180 degrees, underneath the current composition. With this discovery, *A Study in Pink* became an ideal case study for evaluating the advantages and limitations of nondestructive instrumentation for the purpose of providing useful art historical information on cultural heritage objects. The study examined the information obtained using low cost (US$15,000) as well as high cost (US$300,000) imaging instrumentation. Additionally, the authors are seeking ways of making these technologies robust for in-field non-experts, as well as practical research instruments for undergraduate and graduate education. The preliminary research results revealed that the face of the female figure underneath *A Study in Pink* could be partially retrieved using RIS multi-spectral imaging equipment operating from 900-1700 nm and more completely revealed using RIS equipment operating from 400-2350 nm.

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KEYWORDS
John White Alexander; reflectance imaging spectroscopy; multi-spectral imaging; *A Study in Pink*; underpainting

RÉSUMÉ
La spectroscopie d'imagerie par réflectance (RIS) dans le visible et le proche infrarouge révolutionne la façon dont les chercheurs du patrimoine culturel peuvent analyser les peintures de manière non destructive. Dans un projet collaboratif en cours, les auteurs étudient une peinture de l'artiste américain John White Alexander (1856–1915), A Study in Pink, qui est dans la collection du Virginia Museum of Fine Arts (VMFA). Une radiographie, prise en 2014, a révélé qu'il y avait une autre figure féminine, tournée à 180 degrés, peinte sous la composition actuelle. Grâce à cette découverte, A Study in Pink est devenue une étude de cas idéale pour évaluer les avantages et les limites de techniques d'analyse non destructive employées dans le but de fournir des informations utiles à l'histoire de l'art des biens du patrimoine culturel. L'étude a examiné les informations obtenues à l'aide d'instruments d'imagerie à faible coût (15 000 $ US) et à coût élevé (300 000 $ US). En outre, les auteurs cherchent des moyens de rendre ces technologies robustes pour le travail de terrain réalisé par des non-spécialistes, ainsi que pratiques comme instruments de recherche pour les études de premier cycle et de deuxième cycle. Les résultats préliminaires de cette étude indiquent que le visage de la figure féminine peinte sous la surface de A Study in Pink peut être partiellement révélé en utilisant l'équipement d'imagerie multispectrale RIS fonctionnant de 900 à 1700 nm, et plus entièrement révélé avec l'équipement RIS fonctionnant entre 400 et 2350 nm. Traduit par Elisabeth Forest.

RESUMO
A espectroscopia de imagem refletetida (RIS) no visível e no infravermelho próximo está revolucionando a maneira pela qual os pesquisadores do patrimônio cultural podem analisar as pinturas de forma não destrutiva. Em um projeto contínuo e altamente colaborativo, os autores estão investigando uma pintura do notável artista americano John White Alexander (1856–1915). A pintura, intitulada Um Estudo em Rosa, pertence à coleção do Museu de Belas Artes da Virgínia (VMFA). Uma radiografia tirada da pintura em 2014 revelou que havia uma pintura de outra figura feminina, girada 180 graus, sob a camada de tinta visível e a composição atual. Com essa descoberta, Um Estudo em Rosa tornou-se um estudo de caso ideal para avaliar as vantagens e limitações da instrumentação de analise não destrutiva com o objetivo de fornecer informações úteis sobre conservação, curadoria e história da arte à respeito de bens culturais. O

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estudo examinou as informações obtidas usando instrumentos de imagem de baixo custo (US $ 15.000) e de alto custo (US $ 300.000). Além disso, os autores estão buscando formas de tornar essas tecnologias robustas para não especialistas da area, bem como práticas para o ensino de graduação e pós-graduação, tanto como ferramentas de demonstração em sala de aula quanto em instrumentos de pesquisa. Os principais resultados preliminares deste estudo são que a face conhecida da figura feminina retratada sob a superfície de Um Estudo em Rosa pode ser parcialmente recuperada usando o equipamento de imagem multi-espectral RIS de baixo custo operando de 900-1700 nm e mais completamente visualizado com equipamentos RIS de custo mais alto operando de 400 a 2350 nm. Traduzido por Marcia Rizzo e Beatriz Haspo.

RESUMEN

La espectroscopía de imágenes de reflectancia (RIS) de luz visible y cercana al infrarrojo está revolucionando la forma en que los investigadores del patrimonio pueden analizar pinturas en forma no destructiva. En un proyecto en curso, altamente colaborativo, los autores están investigando una pintura del renombrado artista estadounidense John White Alexander (1856–1915). La pintura, titulada *Un estudio en rosa*, pertenece a la colección del Museo de Bellas Artes de Virginia (VMFA). Una imagen de Rayos X de la pintura tomada en 2014, reveló que había una pintura de otra figura femenina, rotada 1800, bajo la capa pictórica visible y composición actual. *Un estudio en rosa* se convirtió en un caso de estudio para evaluar las ventajas y limitaciones de la instrumentación no destructiva para proporcionar información útil para conservación, curaduría e historia del arte de objetos del patrimonio cultural. El estudio examinó la información obtenida usando instrumentación de imagen de bajo costo (US $15,000) así como de alto costo (US $300,000). Adicionalmente, los autores están buscando maneras de robustecer estas tecnologías para ser utilizadas por no expertos en el campo, así como hacerla útil para educación a nivel licenciatura y posgrado, tanto como herramienta para demostrar en el salón de clase, así como instrumento de investigación. Los resultados preliminares más importantes de este estudio indican que la cara conocida de la figura femenina plasmada bajo la superficie de *Un estudio en rosa* podría ser parcialmente recuperada utilizando el equipo de imagen multiespectral RIS de bajo costo, operando de 900 a 1700 nm, y más completamente revelada con el equipo RIS de alto costo operando de 400 a 2350 nm. Traducido por Vera de la Cruz Baltazar y revisado por Amparo Rueda.

1. Introduction

Cultural heritage science continues to be driven by the imperative to develop non-invasive analytical methods. In the last decade and a half, spectral reflectance imaging methods in the visible and near infrared (Delaney et al. 2005, 2016; Ricciardi et al. 2009; Liang 2012; Cesaratto et al. 2013; Vitorino et al. 2015; Cucci, Delaney, and Picollo 2016), along with MA-XRF mapping methods (Woll et al. 2005, 2008; Alfeld et al. 2011, 2013; Janssens et al. 2013; Trentelman et al. 2015; Alfeld and de Viguerie 2017; Romano et al. 2017) have revolutionized researchers' ability to uncover images of subsurface features, and to spatially resolve the material components of paintings, works on paper, and parchment (Delaney et al. 2014). Used in combination, these techniques provide even more impressive results (Janssens et al. 2016), especially when combined with truly three-dimensional imaging techniques such as neutron activation autoradiography (Alfeld et al. 2015; Trentelman et al. 2015). Spatial registration of images produced from different imaging modalities has constituted a powerful recent breakthrough (Conover, Delaney, and Loew 2015; Hoogstede et al. 2016), and computational methods and signal processing techniques continue to drive the field (Huang et al. 2016). Several of the authors of this paper have been extensively involved in driving these methodologies to produce valuable research results for museums and to impact undergraduate and graduate research and education in art and science fields (Uffelman 2007a, 2007b, 2011; Uffelman et al. 2014; Mass et al. 2015; O'Connell et al. 2016; Uffelman, Brown, et al. 2017; Uffelman, Stephenson, et al. 2017). In this context, the authors are interested in obtaining high-quality research results while also evaluating and developing robust methodologies for relatively inexperienced researchers in the field. The authors are also evaluating the equipment that museums and academic institutions might want to obtain and/or share from the standpoint of data quality and cost.

2. John White Alexander

A leading figure in American portraiture and figurative art, John White Alexander (1856–1915) painted and exhibited extensively in America and Europe. VMFA's painting *A Study in Pink* (Figure 1(a)) is characteristic of Alexander's many depictions of elegant female figures in paintings located in numerous museum collections. Alexander was an illustrator, decorative painter, and well-known portrait and figurative artist. He was born in Allegheny, Pennsylvania, in 1856, and orphaned

Figure 1. (a) John White Alexander, *A Study in Pink*, 1896, oil on canvas, 190.50 × 90.17 cm. Virginia Museum of Fine Arts, Richmond. J. Harwood and Louise B. Cochrane Fund for American Art and partial gift of Juliana Terian Gilbert. Courtesy of Travis Fullerton © Virginia Museum of Fine Arts, 2010.111. (b) X-radiograph of *A Study in Pink*. Virginia Museum of Fine Arts.

around the age of five. Alexander's early years were challenging, but he found enjoyment through sketching and drawing. He moved to New York City at age 18 to pursue illustration work and found an entry-level support staff position at *Harper's Weekly* where he eventually became an illustrator. Later he turned to painting and traveled to Europe in 1877 to study at the Royal Academy in Munich. Alexander joined a fellow American artist, Frank Duveneck, in Germany, and began focusing on portraiture while painting in Polling, Bavaria, a small town outside of Munich. The two traveled around Germany and Italy where Alexander met James Abbott McNeil Whistler. Alexander and Whistler became good friends, and Whistler would eventually have a strong influence on Alexander's painting style. In 1882 Alexander returned to New York City, resuming illustration work for a period while accepting portrait commissions from prominent Americans. He married Elizabeth Alexander (no relation) in 1887 in New York City and moved to Paris three and a half years later. The couple remained in Paris for nine years, returning periodically to the states so that Alexander could address important portrait and mural commissions as well as other responsibilities. In 1900 they returned to New York City where they remained until Alexander's death in 1915.

3. *A Study in Pink*

Painted in Paris in 1896, *A Study in Pink* depicts a young female seen from behind with her face in profile as she turns to her right. Balancing herself with her left arm, she leans down to adjust her dress with her right hand. The painting, signed and dated, is in almost untouched condition. It is unvarnished (except for a part of the signature), has never been removed from its original stretcher, and contains only very minor retouching.

Alexander applied broad vigorous brushstrokes over a thin ground using a very coarse open weave canvas. The coarse texture of the canvas was left visible in the paint surface for textural effect. Alexander achieved other textural effects by scratching horizontal lines in the dress using the end of a paintbrush and a fine tool while the paint layer was still wet. The artist preferred a coarse canvas (Goley 2018a, 8) and thin ground because the combination facilitated a matte and textured effect (Goley 1989, 8; Mayer and Myers 2013, 20–21, 33). This type of canvas[1] "so typified Alexander's Parisian oeuvre that critics eventually referred to it as *toile* Alexander" (Goley 1989, 8). Other evidence pointing to Alexander's preference for a matte surface appeared in an article in the *Neue Free Press* in 1898. A visitor seeing *A Study in Pink* and four other Alexander paintings at the *First Vienna Secession* exhibition "wondered" if the "canvases were finished or whether they still needed to be varnished" (Goley 2018a, 95, 237n75).

The woman in VMFA's painting has been identified as the French model Juliette Very (Goley, pers. comm. 2015). Juliette was a model the artist found well suited for his relaxed and stylized figural compositions. Years after working for Alexander, Juliette modeled for August Rodin, and may have been introduced to Rodin by Alexander (Goley, pers. comm. 2015).

VMFA's painting was at one time mistitled *Portrait Study in Pink (The Pink Gown)* (Leff 1980, 29–30; Goley, pers. comm. 2015). However, *Portrait Study in Pink* is a lost portrait of the artist's wife, Elizabeth (Goley, pers. comm. 2015), painted in 1895 and listed in the couple's handwritten notebooks. VMFA's painting is listed in the notebooks with three different titles.[2] In her recent biography of Alexander (Goley 2018a) Goley has retitled VMFA's painting *A Study in Pink*. This new title is based on an early listing, *A Studie in Pink*, used in an exhibition catalogue to reference the painting when it was on exhibit in Vienna in 1898 (*Kunstausstellung der Vereinigung bildender Künstler Österreichs, Secession* 1898; Goley, pers. comm. 2017). VMFA has followed suit, adopting this new title for clarity.

4. Changes by the artist

The VMFA canvas was reworked by the artist. A photograph of VMFA's painting, published in 1898 by Keyser (249), depicts a slightly different composition from the current painting (Figure 2). In the earlier composition the dress had a narrower skirt, and was more simply rendered, with soft folds and rounded outlines. This design was adjusted sometime after the photograph was taken. Alexander added fabric along the right side to create a more voluminous skirt and painted tighter, more angular folds along the bottom.

When the painting was examined by VMFA conservators prior to purchase in 2010, brushstrokes in the paint film were discovered that did not correspond to the image on the surface. The brushstrokes also did not appear to be related to the first figural representation published by Keyser. This inconsistent brushwork was extensive, initially suggesting that the canvas had been substantially reworked.

An x-radiograph was taken of the painting in 2014. It revealed a completely different composition underneath (Figure 1(b)). Both the final painting and the underlying painting are visible in the x-radiograph. The final figure (visible figure) is less defined than the underpainted figure in the x-radiograph, but a few areas are discernible. These include the visible figure's back, waist and left elbow; the dark red trim of the neckline in the dress; the upper section of the skirt; a fold in the dress; a vertical highlight above her head; and folds of the dress near the floor (Figure 3(a,b)).

Unlike the stylized and informal figural representation in the final painting, the underpainting, visible in the x-radiograph, contains a full-length portrait of a female. This earlier figure is executed in the opposite orientation, rotated 180 degrees with respect to the final figure. While the female in *A Study in Pink* is seen from behind, the female in the underpainting is posed differently. She faces the viewer with her body slightly turned. Her full-length dress has ruffled sleeves and a narrow waist (Figure 4(a)). The x-radiographic image in the underpainting is much easier to read than the x-radiographic image of the final figure due to the artist's extensive use of lead white and/or other radio-opaque pigments. The figure's head, neck, shoulders, chest, waist, arms, upper section of the dress, and upper section of the skirt are visible (Figure 4(a,b)). Unfortunately, the background and lower section of the skirt are not discernible.

Ground and paint layers have oozed through the open canvas weave and are visible on the reverse. The paint colors—deep purple, light purple, reddish purple, dark green, dark gray, and medium gray—represent a very different palette from that used in the final composition, indicating that these colors are related to the underpainting.

The overlapping paint layers in the x-radiograph make it difficult to discern details in the face and dress of the figure in the underpainting. Given the technical limitations of the x-radiographic examination, and the museum's keen interest in retrieving as much information related to the underpainting as possible, *A Study in Pink* became an ideal candidate for evaluation using RIS equipment in three spectral regions with three different instruments (from 400 to 1000 nm; from 900 to 1700 nm; from 400 to 2350 nm).

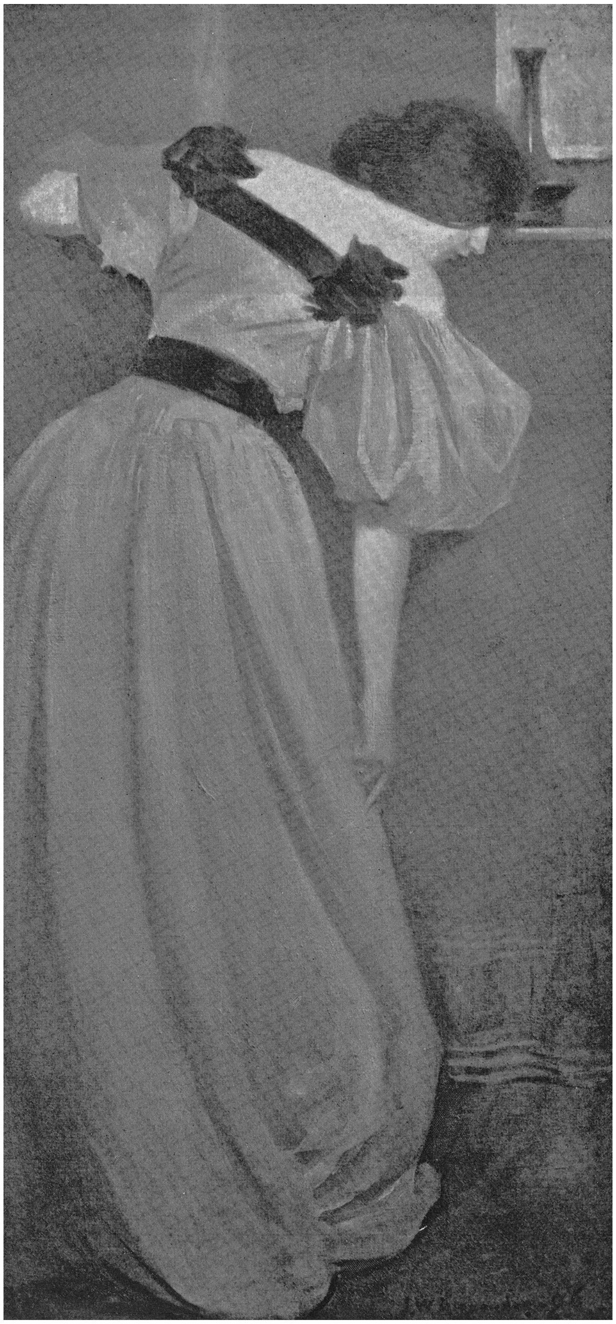

Figure 2. John White Alexander, *A Study in Pink*, 1896, oil on canvas, 190.50 × 90.17 cm. Photograph of the earlier composition published by Keyser. Alexander later made adjustments to this dress along the bottom and along the right as seen in VMFA's painting, Figure 1(a). Photograph lost. Reproduction from *The International Studio,* 1898. Courtesy of the Studio International Foundation.

5. Equipment and methods

RIS in the visible and near infrared (VNIR) from 400 to 1000 nm captures the visible region of the electromagnetic spectrum (from 400 to 700 nm) and the near IR (700-1000 nm). Even crude measurements in this region (one reflectance measurement every 50 nm) can provide information that assists in pigment identification, especially if those data are combined with data obtained from other methodologies (e.g., XRF). In addition, the RIS data from 700-1000 nm in the IR can begin to reveal underdrawings and underpaintings that can be more fully imaged at longer wavelengths.

A relatively low cost VNIR RIS multi-spectral system used to image the painting from 400 to 1000 nm was developed at the National Gallery of Art, Washington, DC (Ricciardi et al. 2009; Delaney et al. 2014). The specifications were generously shared with Washington and Lee University (W&L) so that the system might be duplicated there. The system uses a four-megapixel Retiga

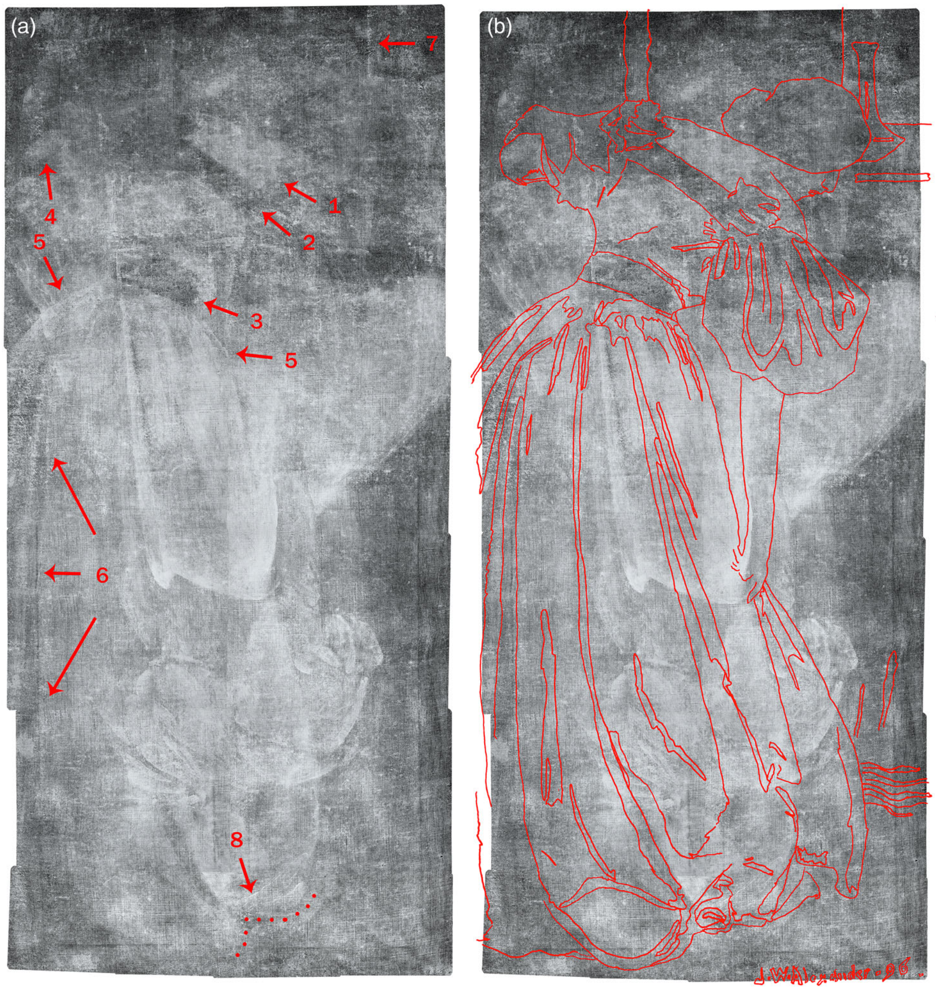

Figure 3. (a) X-radiograph of *A Study in Pink*. Arrows indicate areas that correspond to the final figure in *A Study in Pink* as well as the earlier composition published by Keyser. Areas include the female's back (1) waist (3) and elbow (4); the dark red trim along the low neckline of the dress (2); the top of the skirt around the hips (5); a shadow of a fold in the dress (6); and the white vertical highlight above the head and to the left of the vase (7). One area in the x-radiograph corresponds to a fold and outline in the dress related to the image published by Keyser (8). (b) Tracing of the final figure in *A Study in Pink* superimposed on the x-radiograph. The tracing of the figure's hair corresponds to the radio-transparent (dark) area in the x-radiograph.

4000R 1394 monochrome S-CCD, 12-bit, cooled camera obtained from Q-Imaging; a Schneider 23 mm f/1.4 xenoplan C-mount lens; 13-band pass filters (40 nm FWHM/25 mm diameter from Andover Corporation) that span 400–1000 nm in 50 nm increments; and a laptop-controlled 20-position filter wheel from Finger Lakes Instrumentation (CFW-3–20). The entire system fits in a suitcase and is highly portable. Two to four Solux 5100 K 50-watt lamps (~1000 lux at the painting; a safe illumination level, considering the time required to collect the images) are used to diffusely illuminate the object under study. The resulting images are spatially registered using software developed by Conover, Delaney, and Loew (2015). Spatial registration simply means ensuring that every corresponding pixel in each image at the different wavelengths is perfectly aligned; this is important for creating a cube of image data that can be computationally processed. The data in the cubes are converted to apparent reflectance with the ENVI software package from Harris Geospatial Solutions. This conversion permits the reflectance information to be compared to reference databases for different pigments. The typical time to acquire the "white reference cube," "painting cube," and "dark cube" (the three registered cubes needed for flat-fielding the registered images) is approximately 60 total minutes for the 13 filters. Flat fielding is a process by which the illumination on a white standard and the random signal acquired from taking an image with the lens fully covered are used to correct for uneven illumination of the painting; this ensures that differences in reflectance only come from material differences within the object. At VMFA two tungsten halogen lamps (Lowel Omni 3400 K 650-watt lights operated with a rheostat at ~50%) were used to

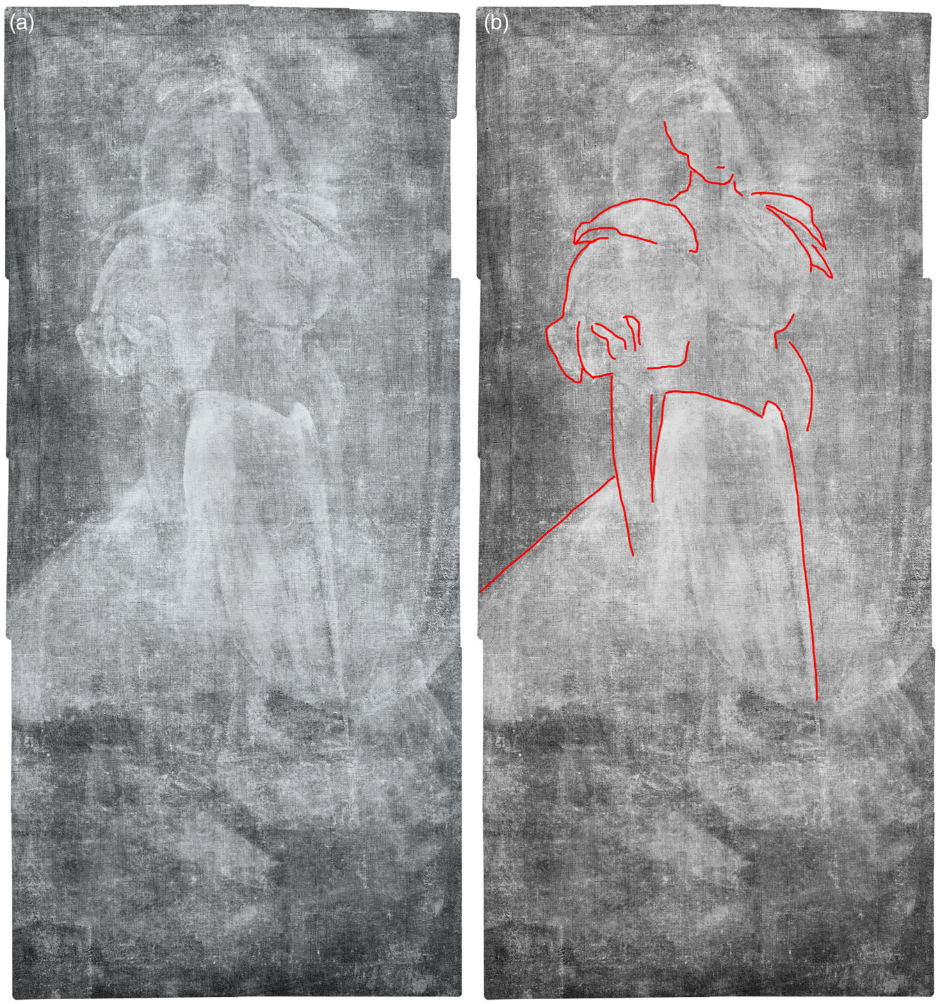

Figure 4. (a) X-radiograph of *A Study in Pink* rotated 180 degrees revealing the female figure in the underpainting. (b) Tracing of this figure superimposed on the x-radiograph to aid in visualization. The radio-opaque (light) and radio-transparent (dark) paint passages associated with the lower composition reveal the female figure and dress. The lighter radio-opaque vertical area to the left of the figure's right arm may be another positioning of her right arm. The lighter radio-opaque area just beyond the drawn red line along the left side of her skirt may be additional fabric.

diffusely illuminate the painting (≤225 lux). An infrared (IR) thermometer was used to periodically monitor the temperature of the painting.

RIS multi-spectral imaging from 900 to 1700 nm captures a portion of the near infrared (VNIR: 400–1000 nm) and part of the shortwave infrared (SWIR: 1000–2500 nm). At the spectral resolution obtained from the five filters in this region, pigment information cannot be obtained, but images of underdrawings and underpaintings, that would be otherwise unattainable, can be extracted using computational analyses (e.g., principle component analysis).

The 900–1700 nm RIS multi-spectral system used to image the painting from 900–1700 nm employs a Goodrich Sensors Unlimited InGaAs 640SDV IR camera with an Edmund Optics 50 mm f/2.15 SWIR lens, five 25 mm diameter Spectrogon filters (975 nm, 56 nm bandwidth [FWHM], >70% transmission; 1116 nm, 70 nm bandwidth, >50% transmission; 1400 nm, 100 nm bandwidth, >60% transmission; 1520 nm, 90 nm bandwidth, >60% transmission; 1675 nm, 90 nm bandwidth, >70% transmission), and a laptop-controlled 20-position filter wheel from Finger Lakes Instrumentation (CFW-3–20). The entire 900 to 1700 nm RIS multi-spectral system fits in a suitcase and is highly portable. The resulting images are processed using the same software used for the 400–1000 nm RIS multi-spectral system. The typical time to acquire the "white reference cube," "painting cube," and "dark cube" (the three registered cubes needed for flat-fielding the registered images) is approximately 30 total minutes for the 5 filters. At VMFA two tungsten halogen lamps (Lowel Omni 3400 K 650-watt lights operated with a rheostat at ~50%) were used to diffusely illuminate the painting (≤225 lux). An IR thermometer was used to periodically monitor the temperature of the painting.

RIS from 400 to 2350 nm captures the VNIR (400–1000 nm) and most of the SWIR (1000–2500 nm) regions of the electromagnetic spectrum. These data provide pixel-by-pixel reflectance spectra (with a spectral resolution of 2–4 nm) that can be referenced for not only pigment identification but for the identification of binding media. In addition, the full image cube can reveal features drawn or painted beneath the painting's surface.

The VNIR-SWIR RIS system used to image the painting was a Surface Optics Corporation SOC-760 VNIR-SWIR instrument. It gathers images from 400 to 2350 nm, providing 320 VNIR images (1.9 nm spectral resolution) and 400 SWIR images (3.4 nm spectral resolution) and registers all of the images into a single data cube. The spatial resolution is 640 vertical pixels by up to 2048 horizontal pixels. The slit width is 20 micrometers; the field of view is 12.5° vertical; the instantaneous field of view is 340 µrad. The SWIR camera is an SBF178 InSb with SOC Custom Readout, 640 spatial pixels, 400 spectral pixels, a 20 micrometer pixel, and A/D resolution of 16 bits. Two tungsten halogen lamps (Lowel Omni 3400 K 650-watt lights) were used at VMFA to diffusely illuminate the painting (≤400 lux). The cube scan rate, under the illumination used to safely examine the painting, was typically 2–5 minutes. The system was calibrated with an in-scene white standard and absolute wavelength. An IR thermometer was used to periodically monitor the temperature of the painting.

Principal Component Analysis (PCA) was used to gain deeper insight into the reflectance data that were collected. PCA is a transformation of the data where they can be represented or plotted along new axes. For example, if the image data are acquired in a series of wavelengths or filters, wavelength or filter number would be a natural choice for an axis, but it is not the only choice. In PCA, the first axis (first principal component) is chosen so that it spans the greatest variability in the data. The second axis is chosen to be orthogonal to the first and represent the next-greatest variability remaining in the data set, and so on. Typically, the first few principal components are plotted to explore the most significant features in the data. Minimum noise fraction (MNF) transforms the data in a similar fashion, such that the components ("bands") are ranked from highest to lowest signal-to-noise ratio (Harris Geospatial Solutions 2017). The images plotted in the first bands have the highest signal to noise; the last bands contain mostly noise.

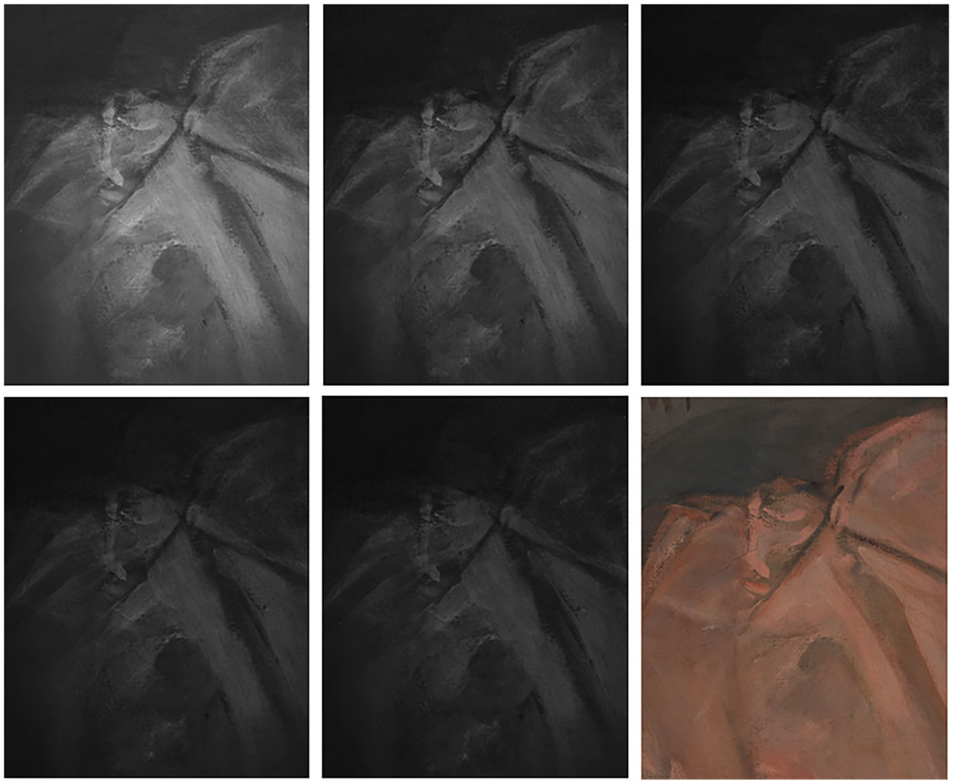

Figure 5. Top left to right: Near infrared reflectance images centered at 975, 1116, and 1400 nm. Bottom left to right: Images centered at 1520 and 1675 nm, and the visible light image of the area of the painting, detail of Figure 1(a), being imaged in the five IR bands. The IR images were flat-fielded and corrected to apparent reflectance. Note that these images are rotated 180 degrees with respect to the orientation of the female figure in the final painting.

Figure 6. Left: Image of minimum noise fraction band 3 (MNF band 3), calculated using the Spectral Hourglass Wizard in ENVI, clearly revealing the face in the underpainting. Right: Detail of Figure 1(a), visible light image of the area corresponding to PCA band 3. Note that both of these images are rotated 180 degrees with respect to the orientation of the female figure in the final painting.

6. Results and discussion

RIS using a multi-spectral system from 400 to 1000 nm did not yield any noteworthy results, either in the 13 individual reflectance images or in any of the PCA results generated by using the ENVI Spectral Hourglass Wizard. RIS using a multi-spectral system from 900 to 1700 nm revealed little detail of the figure in the underpainting when the five individual spectral bands were examined (Figure 5). However, the PCA results were revelatory (Figure 6). The PCA images were obtained using the minimum noise fraction (MNF) algorithm in ENVI, and band number 3 (the five spectral bands generate five MNF bands of increasing noise) clearly revealed the face.

Given the RIS results from 900 to 1700 nm, the authors were eager to employ the Surface Optics HSI system; it yielded impressive results. With 720 spectral bands generating 720 MNF bands in the PCA treatment,

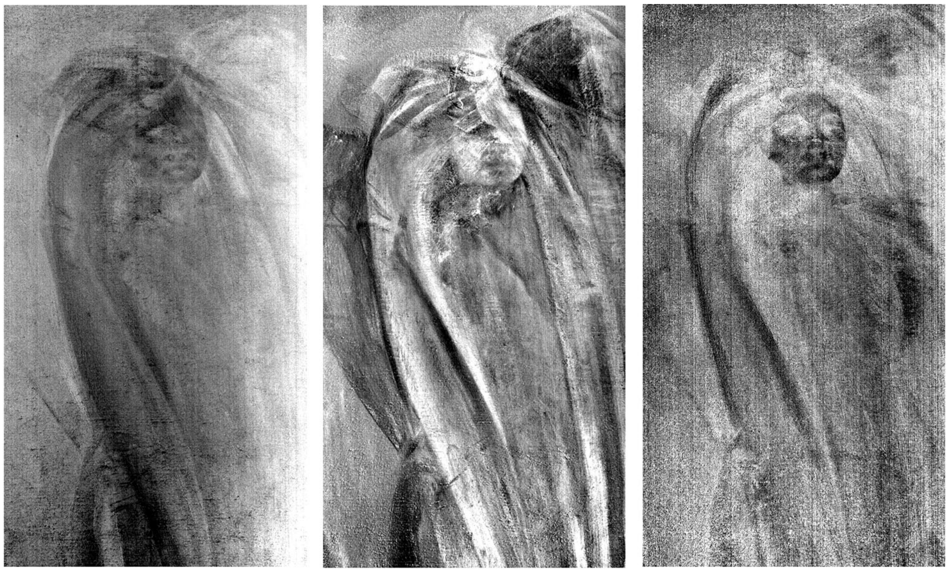

Figure 7. Left to right: Images of MNF bands 4, 5, and 14, calculated using Spectral Hourglass Wizard in ENVI, using the reflectance data cube collected with the SOC RIS camera system. Note that these images are rotated 180 degrees with respect to the orientation of the female figure in the final painting.

all MNF bands higher than roughly band 22 were mainly noise. Among the 22 MNF bands that showed spatial features, several had components of the face of the female figure in the underpainting; the most interesting were MNF bands 4, 5, and 14 (Figure 7). Utilizing a slightly different spatial subset, taking different combinations of MNF images, and then using false color RGB display of three of the band math outcomes generated the best and most complete image of the face of the female figure in the underpainting (Figure 8).

7. Identifying the figure in the underpainting

During the mid-1890s Alexander's models were primarily his wife and Juliette Very. Juliette is often shown from behind, in partial or full profile. Elizabeth, on the other hand, is "almost always" depicted "from the front with an intellectually alert expression" (Goley 2018a, 182). The frontal position of the figure in the underpainting is consistent with a characteristic pose that the artist often used to depict Elizabeth.

The VNIR-SWIR RIS image of the female face in the underpainting (a composite of MNF images from the PCA of the HSI cube) (Figure 9(a)), provided important facial detail, enough detail to compare it with various representations of the artist's wife, including one photograph and several painted portraits. The photograph of Elizabeth (Figure 9(b)) was flipped to assist with the comparison (Figure 9(c)), and with this adjustment striking similarities became evident. Most noticeable are the

Figure 8. Combinations of spectral band math performed on MNF bands 4, 5, and 14, fed into the false color red, green, and blue channels, generated this image of the woman underneath the final painting. Note that this image is rotated 180 degrees with respect to the orientation of the female figure in the final painting.

Figure 9. (a) Image of Figure 8 in black and white for comparison purposes. Note that this image is rotated 180 degrees with respect to the orientation of the female figure in the final painting. (b) Photograph of Elizabeth Alexander, date unknown. (c) Same photograph of Elizabeth Alexander flipped to aid in comparison with Figure 9(a). (Figure 9(b) is an online photograph. URL related to this photograph, accessed November 29, 2017, is no longer accessible. Present location of photograph unknown).

similarities in the figures' faces, jaws, cheeks and eyebrows.

Of the portraits of Elizabeth, *Portrait Study in Pink* (Figure 10(b)) (Mourey 1900, 72) is remarkably similar to both the VNIR-SWIR RIS image and the x-radiographic image. The face in the portrait, specifically the chin, jaw, cheeks, left eyebrow, and forehead, closely resembles the face in the VNIR-SWIR RIS image (Figure 10(c)). The slightly turned frontal pose, puffy sleeves, flared skirt, and waistline are similar to the corresponding areas in the x-radiograph (Figure 10(a)). Given the strong similarity between these two technical images and *Portrait Study in Pink*, it is reasonable to suggest that the underpainting is a portrait of Elizabeth.

In fact, it is possible that the underpainting represents a preliminary version of *Portrait Study in Pink* that the artist deemed unsuccessful and abandoned. There are a few differences in the two portrayals, and perhaps these differences represent adjustments made by the artist in an effort to improve perceived weaknesses in the first composition. In *Portrait Study in Pink* Elizabeth's sleeves, bodice, and neckline differ in style, and she is positioned left of center with her head tilted slightly backwards.

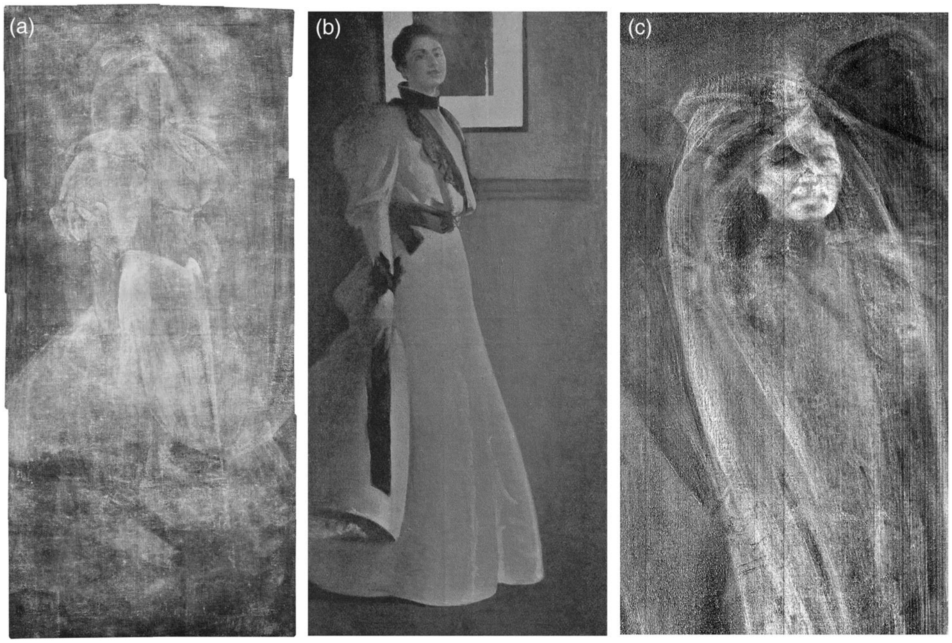

Figure 10. (a) X-radiograph of *A Study in Pink* rotated 180 degrees revealing the female figure in the underpainting. (b) Lost painting, John White Alexander, *Portrait Study in Pink*, also known as *E. A. A. Pink in Tone*, 1895, oil on canvas, ca. 190 × 90 cm, dimensions from the Alexander notebooks. Photograph lost. Reproduction from *The International Studio,* 1900. Courtesy of the Studio International Foundation. (c) Image of Figure 8 in black and white for comparison purposes.

The underpainting was also compared to commissioned portraits, where the sitter is neither Elizabeth nor Juliette. One commissioned work painted before *Portrait Study in Pink* provides the possibility that the underpainting is not Elizabeth. A portrait of Mrs. J. Randolph Coolidge, Jr., painted in 1894 (Figure 11), appears to contain the same purple and green colors that are present on the back of the VMFA canvas. As mentioned before these colors are related to the underpainting and not the final image. Both paintings contain deep reddish purple, dark and light purple, and dark green paint, color combinations not seen in any other paintings studied by the two VMFA conservator authors, including paintings executed after 1896. The colors in the Coolidge portrait seem unique, and Goley believes that the beautiful purple and green iridescent silk dress in Mrs. Coolidge's portrait was provided by the sitter (Goley, pers. comm. 2018b). If the pigments on the VMFA canvas are the same pigments used in the Coolidge portrait then the underpainting may be an earlier representation of Mrs. Coolidge and not Elizabeth. Future analysis with MA-XRF could clarify the relationship between the Coolidge portrait and the underpainting.[3]

A comprehensive but not exhaustive review of the Alexander archives (Alexander Papers) did not uncover any description or reference to an overpainted work or reused canvas. In addition, no listing has been found in the artist's notebooks that matches, describes, or refers to the VMFA underpainting. Since the underpainting appears to be a finished portrait, it is conceivable that the painting may have been exhibited prior to being overpainted. If that were the case, one would expect to find the portrait listed prior to 1896 and no longer listed after 1896, the year when the second composition was painted.

Two paintings are listed in the Alexander archives prior to 1896 but not listed after 1896. Both are lost. One painting, *Etude Yellow and Green,* also known as *Portrait Jaune* (Goley 2018a, 61), is most likely not related to VMFA's underpainting. The portrait has a related sketch (Goley 2018a, 64, fig. 33) with a female figure in a completely different pose from the pose in the VMFA underpainting. In addition, the palette is predominantly yellow (Goley 2018a, 61, 235n48), a palette that does not match the palette in VMFA's underpainting. Further research regarding the other lost painting, titled *Harmony*, is required before any determination can be made about its relation to VMFA's underpainting. This research may be facilitated by Goley's upcoming publication of Alexander's catalogue raisonné.

8. Conclusion

Clearly, there are many nondestructive analytical techniques and imaging technologies that are powerful by themselves and even more powerful taken in combination (including many methods the authors have not yet applied to *A Study in Pink*). Relatively inexpensive

Figure 11. John White Alexander, *Mrs. J. Randolph Coolidge, Jr. (Mary Hamilton Hill)*, 1894, oil on canvas, 182.88 × 107.31 cm. Courtesy © 2019 Museum of Fine Arts, Boston. Gift of J. Gardner Coolidge, 1980.659.

and easy to operate RIS systems can produce useful results, but cannot produce anything approaching the VNIR-SWIR RIS spectrometer-grade spectral resolution results over the entire surface of a painting. Such data can be critical for binder identification as well as unambiguous identification of many pigments (Delaney et al. 2016, 2017). The VNIR-SWIR RIS systems also dramatically enhance the imaging options by adding much higher dimensionality to the data set. The literature is rapidly expanding with MA-XRF results generated from several different scanning systems, and the authors are planning future MA-XRF campaigns on *A Study in Pink*, scanning both from the front and back of the painting. The MNF data here, in conjunction with the earlier x-radiograph, however, reveal an important identification of canvas re-use by John White Alexander. The findings from the MNF data, x-radiograph, art historical research, and future MA-XRF mapping could provide enough information to definitively identify the figure in the underpainting.

Notes

1. The canvas was made for Alexander by a French colorman, C. Collardeau, beginning in 1892 (Goley communication with Mayer and Myers. See Mayer and Myers 2013, 98n41). Alexander was introduced to a coarse weave canvas by the Nabis in Le Pouldu (Goley 2018a, 193).
2. Various titles and descriptive names were used for the same painting by the Alexanders in their handwritten notebooks. For example, VMFA's composition, exhibited in Paris at Galerie George Petit (1896), in Vienna (1898), and in Copenhagen (date unlisted) is called *Book case-Pink, Pink Portrait (book case),* and *Pink with bookcase*, respectively. *Portrait Study in Pink* is also called *E. A. A. Pink in Tone* in the notebooks, where the initials E. A. A. refer to Elizabeth Alexander Alexander.

3. The different pigments on the back of the painting, corresponding to the underpainting, indicate that a careful campaign of MA-XRF scanning is warranted. This analysis might reveal the color of the dress and other design or compositional features related to the image that could further aide in identifying the figure in the underpainting.

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No potential conflict of interest was reported by the authors.

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