UV-induced visible luminescence for conservation documentation

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1. INTRODUCTION

A variety of materials luminesce when exposed to UV radiation. This property can be used as a tool for the examination and documentation of cultural heritage materials -- to characterize and differentiate materials, to establish the condition of an object, and to reveal past treatments. Materials have been examined with UV radiation since UV lamps became commercially available around 1925 (de la Rie, 1982) with early published examples of "fluorescence analysis" (Radley & Grant, 1933, 1935, 1939, 1959) and cultural heritage applications (Lyon, 1934; Rorimer, 1931, 1934). Since these early applications, UV lamps, radiation, and luminescence have been used routinely in conservation. UV lamps are "rapid, affordable, and accessible" examination tools (Tragni, Chen, & Kushel, 2005) that are commonly available in conservation laboratories. Longwave, UVA radiation (320-400 nm), lamps are most commonly used in conservation documentation, although there is some use of shortwave, UVC radiation (185-280 nm), lamps (Capua, 2014; Daffner, Kushel, & Messinger, 1996; Reilly & Mortimer, 1998). UV radiation is considered non-destructive and allows the study of a large surface without sampling (Rorimer, 1931). UV-induced visible luminescence is observed through direct visual examination or recorded through photography. Photographic documentation provides permanence and greater sensitivity than does observation by the human eye (Rorimer, 1931). Digital photography provides additional benefits to film documentation including the immediacy of the results, the difference in sensitivity, and the control and maintenance of color accuracy (Tragni et al., 2005). This chapter will look at the application of UV-induced visible luminescence (UVL) in conservation examination and documentation and discuss the development and limitation of UVL, including the need for standardization and targets.

Terminology

A range of terms have been used when discussing techniques related to UV radiation and the overarching category of imaging that are not always applied consistently. Early references referred to "fluorescence" and the use of "ultra-violet rays" (Lyon, 1934; Rorimer, 1931, 1934). Radley and Grant (1959) used the phrase "fluorescence analysis" and de la Rie (1982) "fluorescence" and "ultraviolet light". More recently the *AIC Guide to Digital Photography and Conservation Documentation* in a section addressing "Ultraviolet Terminology" clarified that "light" should be used for the visible part of the electromagnetic spectrum (400-700 nm) and “radiation” should be used for ultraviolet and infrared (IR) (Warda, Frey, Heller, Vitale, & Weaver, 2011: 152). Furthermore, they prescribed using “ultraviolet irradiation” instead of “ultraviolet illumination” and “ultraviolet-induced visible fluorescence” instead of “ultraviolet fluorescence.” Articles in the *Journal of the American Institute of Conservation* (JAIC) closely follow the *AIC Guide* recommendations and use “UV-induced visible fluorescence” or “UV-Vis” (Alarcón, Hern, & Pearlstein, 2013; Arslanoglu, Centeno, Digney-Peer, & Duvernois, 2013; Garland, Bernstein, & Rogers, 2015; Pearlstein et al., 2015; Ravines, Baum, Cox, Welch, & Helguera, 2014); as do other recent references (McGlinchey Sexton, Messier, & Chen, 2014; Rogge & Lough, 2013; Tragni et al., 2005).

There seems to be some confusion with the definitions of photoluminescence, luminescence, and fluorescence, with luminescence and fluorescence often used interchangeably as far back as Radley and Grant (Radley & Grant, 1959). Some recent publications have used “luminescence” instead of “fluorescence” (Dyer & Sotiropoulou, 2017; Dyer, Verri, & Cupitt, 2013; Russell, Rayner, & Bescoby, 2017; Tanimoto & Verri, 2009; G Verri, 2009a). In one case, a source introduced the method under “photoluminescence photography”, but instead used “UV-induced visible fluorescence” in order to follow “well-established terminology” (Kakoulli, Radpour, Lin, Svoboda, & Fischer, 2017). Photoluminescence, or photo-induced luminescence, is the absorption of wavelengths by a material and then the reemission of longer wavelengths that correspond with lower energy (Tragni et al., 2005). Photoluminescence includes fluorescence and phosphorescence. Fluorescence lasts only during the period of excitation, while phosphorescence persists after the excitation has ended (Radley & Grant, 1959). Since the distinction between phosphorescence and fluorescence is not always clear, Verri et al. (2008) proposed the use of “luminescence” as a general term when the photoluminescence lifetime of a compound is unknown.

Even the overarching category of imaging, encompassing UV techniques, does not have consistent terminology. A variety of terms have been used including “multiband” (Grifoni et al., 2015), “broadband spectral imaging” (Kakoulli & Fischer, 2015), “multimodal” (Ravines et al., 2014), “multispectral imaging” (Dyer & Sotiropoulou, 2017; Dyer et al., 2013), “technical photography” (Cosentino, 2015), and “forensic photography” (Baldia & Jakes, 2007; Kakoulli et al., 2017). Documentation techniques include different modalities of imaging, both reflectance and luminescence, complicating terms. Geffert et al. (2018) described upcoming efforts for the ISO 19264 and the ISO JWG26 working group to standardize the terminology.

For the sake of consistency, this chapter will use UV-induced visible luminescence (UVL) to reference the imaging technique.

2. APPLICATIONS

UVL is widely used in conservation for characterizing and differentiating some materials, establishing the condition, and revealing past treatments for a range of materials and objects. This section will look at these applications, presenting past studies to illustrate the range of materials documented and analyzed using UVL.

UVL has been used for the documentation and analysis of a range of materials. An example of this range of materials and applications includes the chapter titles from Radley and Grant (1959): Agriculture; Bacteriology; Botany; Construction Materials and Glass, Metals, etc; Drugs; Foods and Food Products; Medical and Biological Sciences; Minerals and Gems; etc.; in addition to Museum Work. It is also worth noting this breadth of topics since many heritage objects include a combination of materials from these different sources. Overlapping with some of the topics covered listed by Radley and Grant, Rorimore (1931) presented chapters specific to works of art: Stone; Ivory and Bone; Ceramics; Textiles; Prints, Drawings, and Palimpsests; Metal; Glass and Enamel; Woodwork, Furniture and Wood Sculpture; and Painting.

2.1 Characterization and differentiation of materials

UVL cannot be used independently to conclusively identify materials and requires complementary analytical techniques, but it is widely used for the characterization and differentiation of materials. A variety of materials have distinctive luminescence when exposed to UV radiation that can provide information that aids in characterization. Materials that look similar in visible light may respond differently when irradiated by UV radiation providing the means of differentiating materials.

UV radiation, when used to examine and document paintings, can be used to characterize and differentiate varnishes and pigments. Varnishes have characteristic luminescence, natural resins have a green fluorescent color (with the exception of an orange luminescence of shellac), and synthetic resins have a milky luminescence (Lomax & Fisher, 1990). Some pigments have specific luminescence that can provide information for material characterization. For example, zinc white fluoresces light chrome-yellow, lead white fluoresces white, titanium white fluoresces violet, orpiment fluoresces bright yellow and cadmium and chromes have either a greenish or a brownish black appearance (Radley & Grant, 1959). Mairinger (2000: 66) provided a table of pure pigment powders and characteristic luminescence. Studies investigating material identification for paintings include a study of luminescence of paint and varnish focusing on oil paintings (de la Rie, 1982); a study on the identification of materials in paintings by Picasso (Arslanoglu et al., 2013); and a study on the materials used by a futurist artist, Giacomo Balla (Rava, Radelet, Giovagnoli, Poli, & Piccirillo, 2013).

For paper and parchment objects, UV radiation can be used to differentiate inks (Radley & Grant, 1959; Rorimer, 1931) and to enhance faded or obscured details (Knox & Easton, 2003; Russell et al., 2017). Iron gall ink is transparent in IR radiation but absorbs UV radiation allowing for the differentiation between inks and also enhancing faded details written with iron gall ink (Mairinger, 2000; Warda et al., 2011). Easton and Knox (2003) presented the enhanced detection of original text of the Archimedes palimpsests as an improvement from previous multispectral imaging that deciphered two inks. UV radiation can enhance faded details when the parchment luminesces and the ink absorbs the radiation, increasing the contrast between the parchment and writing (Knox & Easton, 2003).

UV radiation can aid in the differentiation of glass formulations. Reilly and Mortimer (1998) presented shortwave and longwave UV radiation to locate non-original pieces of glass and support the conservation and care of chandeliers. The luminescence can act as an indicator for the continental origin as lead glass and soda lime glass have different luminescence. Lead glass luminesces green with UVA radiation and luminesces blue with UVC radiation (Warda et al., 2011); uranium glass luminesces bright yellow/green with UVA radiation (Grant, 2000).

Other examples include UV radiation being used to document feathers to identify biopigments and differentiation of pigmentary color and a non-iridescent structural color (Riedler, Pesme, Druzik, Gleeson, & Pearlstein, 2014). It has also been used to characterize surface tarnish on daguerreotypes (Daffner et al., 1996); to investigate and characterize madder on ceramics (Scolf & Schilling, 1991); and to characterize materials and to differentiate old and new materials used for sculpture (Radley & Grant, 1959).

2.2 Establishing the condition

UVL is used to document the condition of objects by providing information about the materials and conservation state. The use of UV radiation may reveal or differentiate materials, features, or conditions that may not be observed in visible light. The technique has been paired with other imaging techniques to investigate and document overall condition of objects: paintings (Lyon, 1934; Muir & Khandekar, 2006; Rava et al., 2013), photographic materials (Tragni et al., 2005), and a woodcut print (Jue, Eng, & Takahatake, 2016).

Ravines et al. (2014) used UVL as one of a few techniques to record the baseline condition of a daguerreotype collection. Another study on daguerreotypes indicated that UVA was used to “accentuate surface anomalies” including scratches and applied color despite no luminescence of the materials, and luminescence from UVC radiation was used to observe surface tarnish (Daffner et al., 1996).

On paper objects, UVL can reveal mold and tidelines not observed in visible light (Grant, 2000). A literature review of foxing on paper included a discussion about the similarities between UVL of foxing and iron gall ink corrosion with the possibility of examination using UV radiation for early detection (Choi, 2007). Choi discussed the use of UVL to classify foxing stains and identify the stage in the foxing formation.

Other examples include a study of silk-screened linen wall panels by Matisse where UVL provided an indication of the condition of the original printing ink and was used to map the extent of the damage on the oversized objects (Orlofsky & Kaldany, 2014). In the case of some stones like marble, limestone, and alabaster, UV radiation can be used to distinguish old stone from newly cut stone or artificially aged stone (Grant, 2000; Radley & Grant, 1959; Rorimer, 1931). UVL can be used to determine the relative degree of aging for ivory (Rorimer, 1931) and to determine older woods (often luminesce) from freshly cut woods (little luminescence) (Grant, 2000). It is also used for the identification and pigmentation of feathers (Pearlstein et al., 2015; Riedler et al., 2014) and can be used as an indicator light-induced degradation of feathers (Pearlstein et al., 2015).

2.3 Revealing past treatments

The identification of past treatments is closely linked to the characterization and differentiation of materials. Past conservation treatments include non-original materials that may respond differently to UV radiation, allowing these past treatments to be revealed when documented with UVL.

UV radiation is widely used for revealing past conversation treatments of paintings. Conservation treatments of paintings can be separated from the paint surface with a varnish layer. When examined under UV radiation the varnish will luminesce and the overlying treatment will likely absorb the radiation making it visible under these conditions (de la Rie, 1982; Lyon, 1934; Rorimer, 1931).

Many adhesives tend to luminesce and repairs of ceramics implementing adhesives become apparent with UV radiation. In the case of fills, the material of the fill will likely have a different luminescence than the original material. Grant (2000) included examples of characteristic luminescence of adhesives: “epoxies (bright yellowish white); poly(vinyl acetate), e.g., Elmer’s Glue® (bluish milky fluorescence); shellac (bright orange); cellulose acetate, e.g., UHU® (milky white fluorescence); and cellulose nitrate, e.g., DUCO® (greenish yellow).” Neiro (2003) presented a treatment for adhesive replacement on archaeological ceramics initially treated with cellulose nitrate. Cellulose nitrate has a bright yellow luminescence, which provided visibility of the adhesive and allowed for a method of tracking the removal and replacement of the cellulose nitrate.

Other examples of objects and the use of UV radiation for revealing past treatments include daguerreotypes and baskets. In a study looking at the analysis and characterization of tarnish on daguerreotypes, Daffner et al. (1996) presented the use of UVC to observe tarnish which may be an indication of past treatments. Alarcón et al. (2013) included UV radiation to distinguish structural repairs of basketry from original material.

Hickey-Friedman (2002) described UVL as a “diagnostic tool for identifying surface inconsistencies on the object”, which is relevant both for observing past treatments and also forgeries. The revealing of past treatments and the detection of forgeries is similar in that it is relying on the introduction of non-original materials that respond differently to the original materials when irradiated with UV radiation. Rorimer (1931), in presenting the various materials and applications, linked many examples back to detecting forgeries. Radley and Grant (1959) covered a variety of different materials in the discussion of “fluorescence analysis” applications for detecting forgeries in museum work including differing luminescence responses for imitations and repairs of fossils and remains; old and freshly cut marble and alabaster; surface alterations on ceramic objects; and inks, paper and pigments including repairs and forgeries. In addition to the section on museum works, Radley and Grant included a section on legal and criminological applications which discussed the use of UVL for the detection of forgeries, erasures, and alterations.

3. REPRODUCIBILITY AND COMPARABILITY

Many studies have included UV radiation or UVL as one of a few examination methods including other imaging techniques and analytical methods. In some cases, there is little to no information about the setup, acquisition, or processing related to the method. In most cases, the technique is not the focus of the paper. While this shows that the technique has been widely used and is established as a tool for conservation documentation, this lack of focus and information about the method can also be an indication of the need for standardization and means of increasing the reproducibility and comparability of the method.

While UVL has been considered rapid, affordable, and accessible and UV lamps are found in most conservation laboratories, there are factors that limit the analytical capabilities of the technique including reproducibility and comparability. These factors include the material being examined, the UV radiation source, and the capturing device and image processing, and they influence the resulting color and intensity of the luminescence examined and documented.

3.1 Materials

UVL is used for the characterization and differentiation of materials as some materials exhibit characteristic luminescent colors and intensities when excited by UV radiation (de la Rie, 1982). The luminescence of a material is influenced by the type and amount of the material present, the mixture of the material with other materials, impurities, and the condition of the material (aging and degradation) (Tragni et al., 2005). Impurities impact the color and intensity of luminescence, which Radley and Grant (1959) consider a weakness of the technique. In addition, an object may contain multiple materials that luminesce and may have an imbalance of intensities making it difficult to observe or document (Tragni et al., 2005).

3.2 UV radiation sources

A wide range of UV radiation sources are available, which vary in the wavelength output (peak and distribution), the filtration of the source, and the intensity impacting the resulting color and intensity of the luminescence (Tragni et al., 2005). The output of the UV source can include a broad or narrow range of wavelengths and sometimes stray radiation outside the UV region. Different wavelengths can influence the resulting luminescence and stray radiation can obstruct the observation of some luminescence.

There are two main types of sources: continuous and flash. Continuous UV sources are more widely used for heritage applications than flash. Electronic flashes have UV output, but many units now have built-in filtration to eliminate this output (Warda et al., 2011). Continuous UV sources include high-pressure and low-pressure mercury lamps and LEDs. High-pressure mercury discharge lamps or high intensity discharge (HID) lamps have a dominant peak at 365 nm (UVA) with a broadband between about 325 and 400 nm although there is emission in the visible and IR regions (Dyer et al., 2013; Warda et al., 2011). A Wood's filter is often used in order to absorb the visible light and transmit the UV radiation; however, these sources still have visible and IR output which can influence the observed luminescence (Dyer et al., 2013; Warda et al., 2011). Low-pressure (fluorescent) lamps are also used for UVA radiation sources and include black light blue (BLB) bulbs. These have lower intensities than the high-pressure lamps and may have significant visible light leakage, but they do not require a transformer, long warm up times, and they can be turned on and off more easily (Warda et al., 2011). Low-pressure mercury bulbs have a dominant peak at 254 nm and are used as UVC sources, without phosphor coatings and with filtration to remove the visible wavelengths (Warda et al., 2011).

Light-emitting diodes (LEDs) with emissions in the UVA region are available and used as UV sources. These have been more widely used in the form of UV flashlights (McGlinchey Sexton et al., 2014; Pearlstein et al., 2015; Warda et al., 2011). Flashlights are small and portable, but they are not the best option for photography (Baldia & Jakes, 2007). Photo-induced luminescence setups (although not UVL) are incorporating visible LEDs to induce luminescence (Daveri et al., 2016; Dyer & Sotiropoulou, 2017; G Verri, 2009b); and there are some multispectral setups based on LEDS including UV LEDs (Christens-Barry et al., 2009). As LEDs continue to develop, they are becoming more popular as UV sources (McGlinchey Sexton & Messier, 2015) and will become more widely used for UVL documentation.

3.3 Capture device and image processing

The capture device and image processing influence the final imagery and interpretation of the results. Silicon sensors in consumer digital cameras are inherently sensitive to UV and IR radiation, but generally have an IR block filter over the sensor to optimize visible, color photography. The sensitivity of consumer digital cameras differs between models and manufacturers, which will impact the resulting UVL images. Visible bandpass filters (i.e., IDAS-UIBAR or Peca 918 filters) are recommended to block UV and IR radiation in addition to a UV block filter (i.e., Kodak Wratten 2E filter) (Dyer et al., 2013; 'UV Innovations:

Ultraviolet Photography Standards', 2017). Not using these filters or using different filters can cause a color shift and influence the intensity of the luminescence.

Camera settings, image processing, and calibration will also influence the results. One challenge of UVL is establishing the best exposure for the documentation. Changing the camera settings will impact the exposure and resulting color and intensity of the resulting luminescence. White balance and other image processing steps, as with reflected techniques, greatly influences the results. Image processing related to different reference targets, workflows, and calibration steps will also impact the results. Geffert et al. (2018) presented the use of two targets and reported that they were unable to get the expected values (provided by the accompanying documentation for each target) with the same settings.

The interpretation of UVL results can present its own challenges. Rorimer (1931) stressed the need for laboratory experience in order to obtain valid conclusions. Tragni et al. stated that "...examination under UV radiation is subject to confusion in observations and to the subjectivity of the viewer. A good understanding of photographic materials and fluorescence phenomena is necessary, and conclusions should always be drawn by considering additional evidence about the object" (2005: 8). The interpretation of UVL results requires experience and expertise with the method and materials, and generally the technique does not provide conclusive evidence independently but requires the use of complementary techniques, especially for material identification.

4. STANDARDIZATION AND TARGETS

Reproducibility and comparability of results can be improved through the standardization of the method and the use of reference targets. Hickey-Friedman (2002) noted that early scientific publications stressed reproducibility and the use of standards; however, in 2002 these were no longer routine. As an example of an early scientific publication, Radley and Grant discussed the standardization and limitation of "fluorescence analysis":

> In the early days the results were so encouraging that it was hailed as a rapid, accurate and reproducible method, and for many purposes, indispensable to the analyst. Maturer consideration showed that the accuracy is limited, and the reproducibility is dependent on strict standardisation of working conditions…The conclusion to be drawn from such a survey is, that if applied with discretion and under standard conditions, fluorescence analysis is a most valuable aid to the scientific worker, especially in routine work or sorting tests, and may usually supplement, though seldom completely replace, ordinary testing or analytical methods (Radley & Grant, 1959).

Radley and Grant further noted that results can vary between users, which they attribute to "lack of precision in defining the technique" (Radley & Grant, 1959).

Shifting from the emphasized reproducibility and use of standards found in early scientific publications, many articles did not provide specific information about the UV radiation source and the wavelengths used to irradiate the object, an indication that standardized working conditions may fallen from being routine. More recently there has been work towards standardization and the use of reference targets to improve reproducibility and comparability.

Inclusion of targets in the image field of view provides a reference that can act as technical metadata and also a visual reference for the viewer (McGlinchey Sexton et al., 2014; Warda et al., 2011). With a color reference and reflected, visible imaging, the colors provide known RGB values in the image and the colors in the object can be visually referenced to the color scale. While colors in visible light can be compared to a standard color scale, this is not as straight forward with luminescence imaging and a reference scale (Tragni et al., 2005). Tragni et al. indicated that without metering devices or color scales for luminescence imaging, the documentation of luminescent materials can provide inaccurate results in color and intensity.

Custom made targets have been created to increase reproducibility and comparability. These include using mat board coated in shellac as a gauge for setting exposure (Tragni et al., 2005) and references made from materials with known fluorescent colors like zinc white, true madder lake, and shellac combined with a forensic fluorescent ruler (Warda et al., 2011). These home-made targets attempt to provide a reference between images to increase comparability of the method, but the luminescence of the materials may not be consistent, the materials may change over time, and the range of intensities of the target may not align with the object and materials being documented.

In recent years, there have been a couple of initiatives working to address the challenges of the reproducibility and comparability of UVL documentation, with one initiative focusing on standardization (Dyer et al., 2013) and the other initiative focusing on the development of a UV target (McGlinchey Sexton et al., 2014; ‘UV Innovations’, 2017).

4.1 *Multispectral Imaging in Reflectance and Photo-induced Luminescence Modes: A User Manual*

In an effort to address the challenges of reproducibility and comparability of spectral data, Dyer et al. (2013) developed a user manual aimed to establish a set of “widely-accessible methods and protocols" for multispectral imaging that includes UVL. The manual resulted from the Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to conservation and restoration (CHARISMA) project funded by the European Union 7th Frame Work Program for Research Infrastructures. The CHARISMA project included twenty-two European institutions and aimed to "develop and promote best scientific practice for the interdisciplinary study of cultural heritage and to disseminate this knowledge" (Dyer et al., 2013: Foreword). The user guide was developed to optimize methodologies of image acquisition and processing for the documentation of art objects focusing on readily available equipment and user-friendly resources. The guide includes both theory about acquisition and post-processing and practical details for setup, equipment, and acquisition ('CHARISMA: Technical Imaging', 2017). "These tools enable the consistent application of the post-processing methods that have been developed and facilitate the comparison and interpretation of the resulting images, thus maximising the value of the information that can be obtained from such imaging methods" (Dyer et al., 2013: Foreword).

In order to increase reproducibility and comparability, the presented methodology produces device-independent images focusing on three aspects: (a) understanding experimental factors which informs (b) optimizing experimental procedures, and (c) developing freely available image calibration and correction protocols (Dyer et al., 2013: 9). Similar to the previous discussion of the factors that influence the color and intensity of luminescence, Dyer et al. identified four main effects impacting reproducibility and device dependence for luminescence imaging: spatial inhomogeneities of the radiation source; ambient stray radiation; camera response (luminescence calibration); and pigment binder effect (2013: 23-34). Addressing these factors, image calibration and correction protocols are presented based on images of a uniform reflective board, Spectralon diffuse reflectance targets, and an X-rite ColorChecker.

After presenting the acquisition and post-processing theory, Dyer et al. provided descriptions for experimental setup (equipment selection, setting up equipment, image capture) and image post-processing. The project included the development of freely available image calibration and correction protocols using VIPS and nip2 software and post-processing workspace for multispectral images, both reflected and photo-induced luminescence images. VIPS is an open source image processing software and nip2 is a graphical user-interface. The project developed a step-by-step workflow to accompany the *post-processing workspace* specifically created for reflected and photo-induced luminescence images that can be downloaded from the British Museum's CHARISMA project site ('CHARISMA: Technical Imaging', 2017).

Dyer et al. (2017) provided a great resource for the community that worked to address the issues of reproducibility and comparability of reflected and luminescence imaging for cultural heritage documentation. The manual included a strong emphasis on readily available equipment and open access software taking into consideration the required components of accessibility for non-technical users, a strong advantage to the document. While open access software can be advantageous for heritage users providing a low cost option when paired with the readily available equipment, open access software can also be unsustainable especially when long-term funding is not included for the maintenance after the project is completed (Geffert et al., 2018). Even beyond the software, the support of an initiative like this, that are initially funded under larger projects, include the risk of losing support when the funding is over. The front cover of the manual included "version 1.0", which indicates that the authors had the intention of additional versions to include updates and developments. Even with good intentions, time and funding become an issue in maintaining and updating software and documents. For the document and software to continue to be a resource for the community, there is a need for additional funding and support in order to update and maintain both.

4.2 *UV Innovations: Ultraviolet Photography Standards*

Another recent effort to address the challenges of reproducibility and comparability of UVL documentation of cultural heritage materials was the development of the UV Innovations Target-UV (McGlinchey Sexton et al., 2014; 'UV Innovations', 2017). The motivations of developing the target include "repeatable and consistent" results acknowledging the importance of targets as technical metadata and a visual reference in an image in addition to the lack of available standards for UVL available for conservation documentation (McGlinchey Sexton et al., 2014). The standardization of the technique and use of a target would allow for "the meaningful comparison of images made by different users, in different places, over the course of time" ('UV Innovations', 2017).

The Target-UV is described as "a calibration reference to control color and intensity of UVA induced visible fluorescence" ('UV Innovations', 2017). Accompanying the Target-UV, is the UV-Gray, a gray card used to set the camera white balance for UVL imaging. The Target-UV includes two sides with a total of four intensity levels (low, medium, high, and ultra), and for each intensity level there are three grey patches and a red, green, and blue patch. The target is intended to be included in the field of view with the object being documented, and the patches are used to control color and intensity for imaging with UVA radiation, specifically sources with the major emission peaks around 360-370 nm.

McGlinchey Sexton et al. (2014) presented the development of the Target-UV including the major goals of the research and development. The goals included finding a stable UVL pigment for the target, managing intensity of the luminescence (inclusion of three intensity levels on the target), identifying and controlling variables (camera sensitivity and filtration, radiation sources, image processing, user perception), defining a “neutral grey”, executing round robin testing, and producing the targets. Permanence testing indicated that the materials used for the Target-UV are stable (McGlinchey Sexton & Messier, 2015). The round robin test indicated that there was a high degree of variability in UVL documentation protocols and workflows, the Target-UV target and workflow significantly reduced variability, and software was a significant variable. Workflows for the setup and capture that cover RAW settings, white balance, image evaluation and file management using Adobe Lightroom and Photoshop are available on the UV Innovations website (‘UV Innovations’, 2017). These workflows with the Target-UV attempt to control some of the variables to produce more consistent and comparable results.

The UV Innovations workflow for the Target-UV aligns with targets and workflows used for reflected, visible light photography that are currently being used routinely in conservation documentation. This provides a familiar workflow that can be more easily adapted and implements tools that are already being used. The workflows include step-by-step guides for setup and acquisition with screenshots to provide clear indications of tools and settings. In addition to the provided workflows, the website includes resources and references for equipment including a shortlist of suppliers and an FAQ page.

While the target and workflows are addressing the needs for improving reproducibility and comparability of UVL results, there are still some challenges. The Target-UV is priced at $875[1], which is out of the reach of some conservation labs and institutions. The target does not work as well for low intensity images, which was also feedback received during the round robin test (McGlinchey Sexton et al., 2014).

Another challenge is that the Target-UV results may not match with visual perception or previous UVL results. Previously discussed in this section were the factors that impact reproducibility and comparability. Even with the use of this target and workflow, there may be a difference due to radiation sources, differences in human vision, and variation in camera position (‘UV Innovations’, 2017). The target has been calibrated with a UVA

[1] Price in June 2018.

radiation source with a single peak at approximately 368 nm and will appear neutral with this radiation source; however, there is a range of UV sources with variation in peak emission and also the emission of blue light in the visible range. Since there is such a variation in UV sources, the target may not appear neutral with all UV sources. In addition to the source, there is also variation in the camera sensitivity, human perception, and processing software.

5. DISCUSSION

UVL is one of many techniques used in museum imaging as a conservation documentation technique. Imaging has a long history of object documentation for access, education, research, and conservation within museums and heritage institutions. Since early in its existence, a range of photographic techniques has been used as non-destructive and portable tools to document cultural heritage objects. Museum imaging can be categorized into three main areas: collections photography, conservation documentation, and scientific imaging. These are defined by different techniques, workflows, and applications, yet they are interrelated and overlap. Collections photography includes 2D visible photography to provide records for exhibition and collection purposes. Conservation documentation includes 2D and broadband spectral imaging techniques to record the condition of an object, inform the treatment, and increase the understanding of an object. Scientific imaging includes optical measurement techniques for spectral and spatial measurement and material identification.

Defining these categories and presenting the structure acknowledges the contributions from many fields for the continued development of the techniques and technologies and builds a ground for understanding how these fields and categories connect and overlap to encourage development. UVL imaging is used as a conservation documentation technique, but understanding the relationship between conservation documentation and scientific imaging and investigating the best practices and standards of each category can inform how the technique is used and developed.

The examination and documentation of luminescence induced by UV radiation has become standard for conservation because it is rapid, affordable, and accessible. At its basics, the technique requires a UV source and a camera for photographic recording. Some of the components that make the technique more flexible and accessible also impact the accuracy and reliability. There is a balance between the accessibility of a technique and its accuracy. As mentioned by McGlinchey Sexton et al. (2014), the UVL protocols and workflows are highly variable and produce a range of results. Steps to increase the reproducibility and comparability of the technique, a shift towards more scientific imaging, can increase the costs and complexity making the technique less affordable and accessible. The CHARISMA user manual can still be challenging to adapt as some of the steps to increase reproducibility and comparability make the technique more complex and a little less accessible. While the UV Innovations workflow builds on acquisition and processing tools similar to the AIC guidelines for conservation documentation (Warda et al., 2011), the cost of the Target-UV can be considered high and may be out of the reach of some conservation labs and institutions.

There is a need to understand the limitations of the technique and to acknowledge that it is one of the few tools that is available in many museums and conservation laboratories (Hickey-Friedman, 2002). Hickey-Friedman discussed weighing this balance of the limitations of the technique, its accessibility, and the need of standardization. In discussing how to move forward with the technique, the question was posed, “Can conservators improve UV examination with reproducible and qualitative results through standard examination techniques?” Hickey-Friedman discussed the technique as a valuable diagnostic tool providing immediate results and one of the “few available, affordable techniques”, but emphasized the importance to record reproducible results.

In response to Hickey-Friedman (2002), there has been a continued discussion about the standardization of the technique as seen by Tragni et al. (2005) and followed by the creation of the CHARISMA guidelines and the Target-UV. Within cultural heritage documentation, there is a movement towards imaging standards and best practices. Collections photographers are using the US-based Federal Agencies Digitization Guidelines Initiative (FADGI) (Rieger, 2016) and the European-based Metamorfoze (van Dormolen, 2012), which come together with ISO 19264-1:2017 (BSI Standards Publication, 2017).

6. CONCLUSIONS

> These rays cannot of course be used as a sort of magic to answer all kinds of questions, but they bring into view definite factors which are not to be observed in any other way and which, properly interpreted, can be used as evidence in arriving at conclusions (Rorimer, 1931: 15–16).

UV-induced visible luminescence is a valuable examination and documentation technique for a variety of materials and objects to characterize and differentiate some materials, establish the condition of an object, and reveal past treatments. It is widely used for conservation documentation because it is rapid, affordable, and accessible. Some of the components that make the technique more flexible and accessible also impact the accuracy and reliability, and it is important to understand the limitations of the technique specifically looking at reproducibility and comparability. Recent efforts have worked to improve reproducibility and comparability focusing on standardization and the creation of a target. These recent efforts have moved UVL and conservation documentation towards more reproducible and comparable imaging, but there are still limitations. There is a balance of accessibility of the technique and the accuracy and reliability. Looking at the museum imaging categories and the relationship between conservation and scientific imaging we can better understand this dynamic. We do not have a perfect solution, but we are headed in the right direction by investigating and developing standardization and targets.

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