LACMA

ULTRAVIOLET-INDUCED VISIBLE FLUORESCENCE AND ULTRAVIOLET REFLECTANCE IMAGING WORKFLOW

Version 1.1 April 2024

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Conservation Center

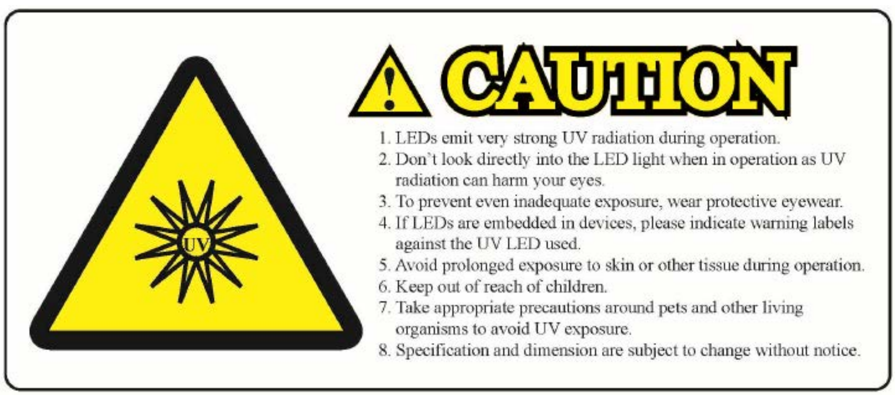
ABOUT THIS DOCUMENTATION

This document will present the workflow and equipment used by LACMA's Conservation Center photo studio to produce consistent ultraviolet-induced visible fluorescence [UV-F] and ultraviolet reflected [UV-R] images.

SAFETY, PRECAUTIONS AND PERSONAL PROTECTIVE EQUIPMENT

All regions of ultraviolet radiation (UVA, UVB and UVC) are dangerous to people and objects. Ultraviolet damage is cumulative so exposure should be minimized.

Radiation lamps, either LED or metal-halide bulbs, should always be shielded and never be viewable to the naked eye even though it may appear that little or no light is emanating from the device, radiation is being produced. Exposure to these wavelengths may cause skin cancer or damaged of different degrees, and temporary or permanent vision loss or impairment. All UV devices should have warning labels as shown below.



Personal Protective Equipment recommendations:

- Wear ultraviolet protective glasses, goggles, or face shields.
- Wear protective clothing leaving skin exposed as little as possible.
- Avoid unnecessary ultraviolet radiation exposure to artworks and people by limiting the time the fixture is being used. Have task lights handy to use during setups because the working environment should be as dark as possible.
- Be aware of the heat generated by the radiation source, traditional bulb fixtures require a warm-up period, and they get hot after several minutes of use.

REQUIRED SOFTWARE AND HARDWARE

This workflow is based on the use of Adobe Camera Raw (ACR) and DNG images. Processing is done using Adobe's Bridge and Photoshop, alternatively Adobe's Lightroom can be used as well.

BASIC IMAGING REQUIREMENTS

Equipment:

Cameras:
- Sony Alpha 7R IV – normal
- Sony Alpha 7R IV – Full Spectrum UV-Vis-IR
- Fujifilm GFX100 - Normal

Lenses:
- Voigtlander 65mm F2 Macro APO-Lanthar with Hoya HD3 UV filter
- Sony FE 90mm F2.8 Macro G OSS with Hoya HD3 UV filter
- Fujifilm GF 110mm F5.6 T/S Macro Hoya Evo UV(0) filter
- Fujifilm GF 120mm F4 Macro with Hoya Evo UV(0) filter
- Fujifilm GF 63mm F2.8 with Hoya Evo UV(0) filter

Filters:

For UV-F:
- Peca #916 Visible Band Pass
- Peca #918 Visible Band Pass
- X-Nite CC1 / Schott BG40
- Kodak Wratten No. 2E / Tiffen Haze 2E / MidOpt LP470

For UV-R:
- X-Nite 330C / MidOpt BP365 / Peca #900 (Kodak Wratten 18A)

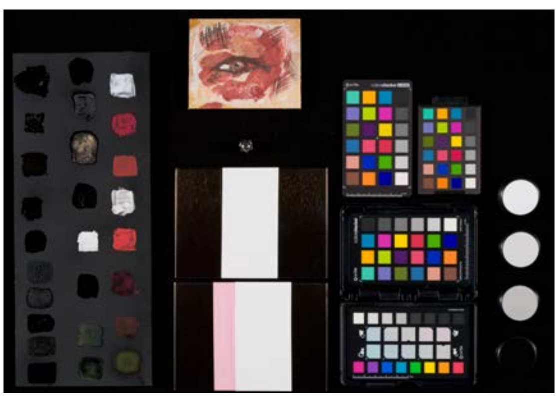
Radiation Sources:
- Waveform Lighting realUV[tm] 365nm 20W UV LED Flood Light, with Midwest Optics Bandpass Filter center on 365nm (MidOpt BP365), rectangular sheet 150x115mm, 2mm thick
- Wildfire Long-Throw[tm] 250 Series 3, 250-Watt Metal Halide Ultraviolet Lighting Fixture, Model LT-250WS 50° Wide Spot. Outfitted with Kopp 1041 filter.

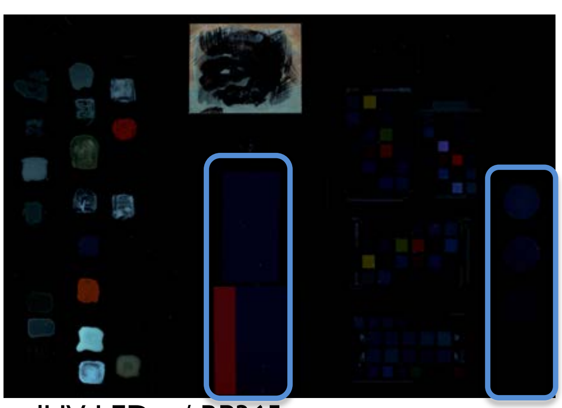
PREPARING THE RADIATION SOURCES

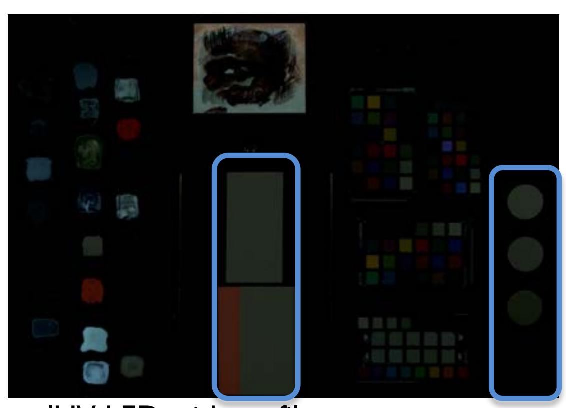
The Wildfire metal halide lamps mentioned in this guide have been discontinued (see appendix) and have been replaced by LED units, by the same manufacturer, at a very steep price increase. The metal halide units are still very functional and true workhorses. I have been using them for over 10 years, and as long as I have viable metal halide bulbs, I will continue to use them. Drawbacks with these units are that they require a five-minute warm-up period before generating a stable radiation output. Once turned off they require a cool down delay before they can be turn on again (automatically controlled by a thermostat in the fixture). The metal halide bulb has a power distribution curve that is segmented in narrow bands that includes the desired 365nm peak and other peaks in the visible, which are blocked by the Kopp 1041 filter (provided by the manufacturer). However, it also transmits a small amount in the near infrared (NIR) which is not blocked by the Kopp 1041 and must be blocked by a different filter at another stage (see camera filtration) This NIR "leak" is not a problem and can be blocked efficiently in the final image. It is important to be aware of this.

While the Wildfire doesn't require any special preparation, the realUV^{tm} LED radiation source does need some additions and modifications. The initial price point of this radiation source makes it very attractive $165.00 vs. $3000.00+ for the Wildfire. The fixture is advertised as only emitting a narrow band peaking at around 365nm radiation (which I have corroborated with my own spectroradiometric measurements), but testing clearly shows that another interaction, or some kind of transmission is taking place that I have yet to determine. Due to this stray radiation, the image is less reliable with the potential of misinterpretation making the fluorescent images not useful (see figures below, notice how the Spectralons®and Simple UV-F targets both reflect white).
To correct this issue, extra filtration must be applied to the radiation source. I am using the Midwest Optics Bandpass Filter peak 365nm (MidOpt BP365), rectangular sheet 150 x 115mm, 2mm thick. The price of each filter is $1200.00, which now increases the price to $1365.00, still better than the cost of the Wildfire.

The fixture comes with a U-bracket (yoke) without a method to attach it to a light stand, so the hole in the U-bracket must be made wider (with a drill bit). A yoke-to-stand adapter can then be attached (Avenger E390 TVMP or Impact TVMP CA-116P). Lastly, since the fixture has an electrical plug that lacks an on/off switch, I use a small power strip that has an on/off switch to provide electricity to the unit as needed.


Visible Image


realUV LED w/ BP365


realUV LED with no filter

PREPARING THE SIMPLE UV-F TARGET

This target is an affordable option to the more expensive and scientific grade Spectralon® reference target, refer to the full article in the appendix.

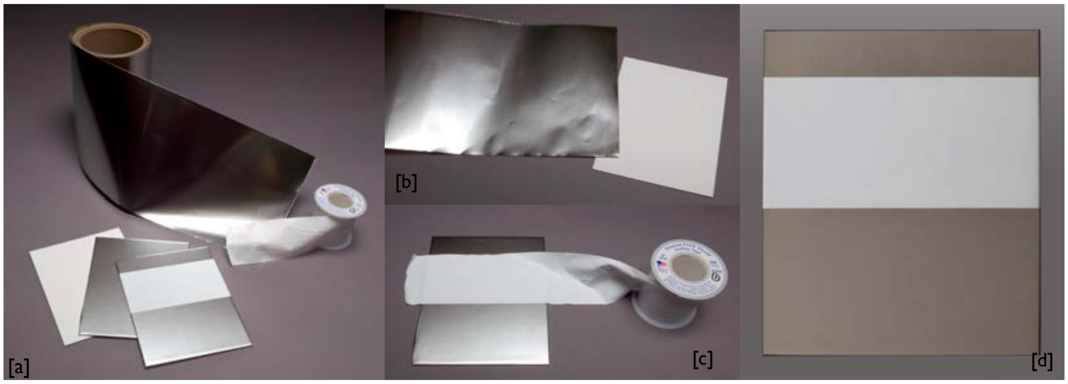


Figure 1. Assembling the UV-F target:
(a) Polished stainless-steel mirror-like foil with adhesive backing,
PTFE high-density pipe thread white tape 2" wide,
4x5 acid free mat board (shown in three stages).
(b) Wrapping the stainless-steel foil around the mat board.
(c) Wrapping the PTFE white tape around the foiled card.
(d) Finished UV-F target.

Materials (Figure 1a):

1) Polished Multipurpose 304 Stainless Steel Mirror-Like Foil with adhesive backing 0.0020" Thick. 6" Wide (McMaster-Carr #8452K95) ($179.00)
2) High-Density Thread Sealant Tape PTFE, 0.0035" Thick, 2" Wide, 14 Yard Long, White (McMaster-Carr #6802K87) ($40.00)
3) Two-ply acid free mat board 4x5" ($10.00)
4) Non-fluorescing black paper tape ($10.00)

Assembling the simple UV-F target (Figure 1):

1. Adhere the foil to a 4x5 inch acid-free mat board (Figure 1b).
2. Place a strip of the PTFE tape over the foil at one end, wrapping the PTFE tape around the board (Figure 1c).
3. Secure the PTFE at the back with non-fluorescing tape.

Note: Keep the working countertop clear and clean, providing the PTFE tape with a suitable grime-free surface while attaching it to the foiled 4x5" board.

Avoid touching the surface of the PTFE tape during the assembly process, as well as while in use. As with the Spectralon®, the PTFE tape can get soiled with oils and grime which will appear as fluorescence. When this happens replacing the strip of PTFE tape with a new one is simple (Step 2 and Figure 1c), and the cost is very low. This ensures that a fully functional target is always at hand and reliable (Figure 1d).

CAMERAS SETTINGS AND FILTRATION

All cameras are preset to record in RAW, using the white balance “shadow/shade” setting, this provides a pleasant previsualization of the capture until the image is processed (See Image Processing). I manually set the ISO at base-line level (e.g., 50 or 100), mid-range f/ stop (e.g., f/8 or f/11) and a slow shutter speed between 5 and 15 seconds.

The filtration of the camera lens depends on the camera that I am using.

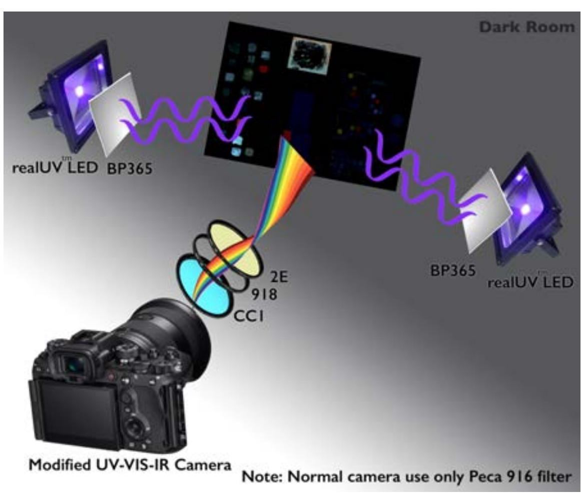
- For UV-induced visible fluorescence (UV-F):
  - Normal camera gets filtered with the Peca 916 filter.
  - Modified camera is filtered using: Xnite CC1 + Peca 918 + Tiffen 2E.

- For UV reflectance (UV-R):
  - Modified camera filtered with the Xnite 330C.

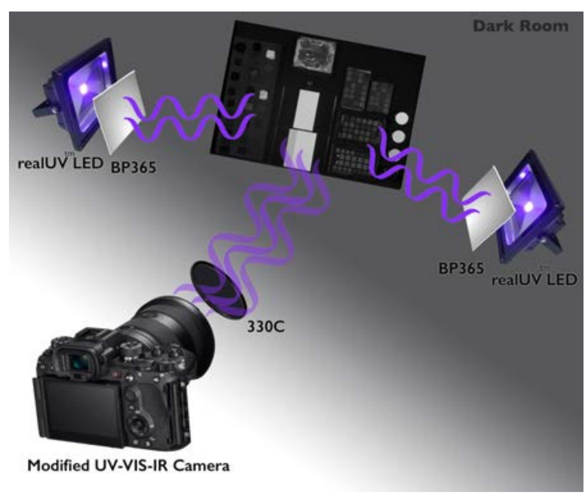
Note: Filters can be substituted using any of the ones listed on page 3.

INITIAL WORKFLOW SET UP

When photographing works of art on an easel I follow the traditional copy setup. The radiation sources are placed between 25 and 35 degrees on either side of the plane of focus, at the object level (see diagrams). I cross “irradiate” the artwork trying to get even as possible coverage/glow of the surface. The radiation sources are placed four to five feet away from the artwork and the camera is placed in front, perpendicular to the plane of focus, framing the artwork as tightly as possible including the reference targets. Regarding reference targets, I regularly include the simple UV-F target alongside a ColorChecker – classic (mini or passport size).



Ultraviolet-induced visible fluorescence setup



Ultraviolet reflected setup

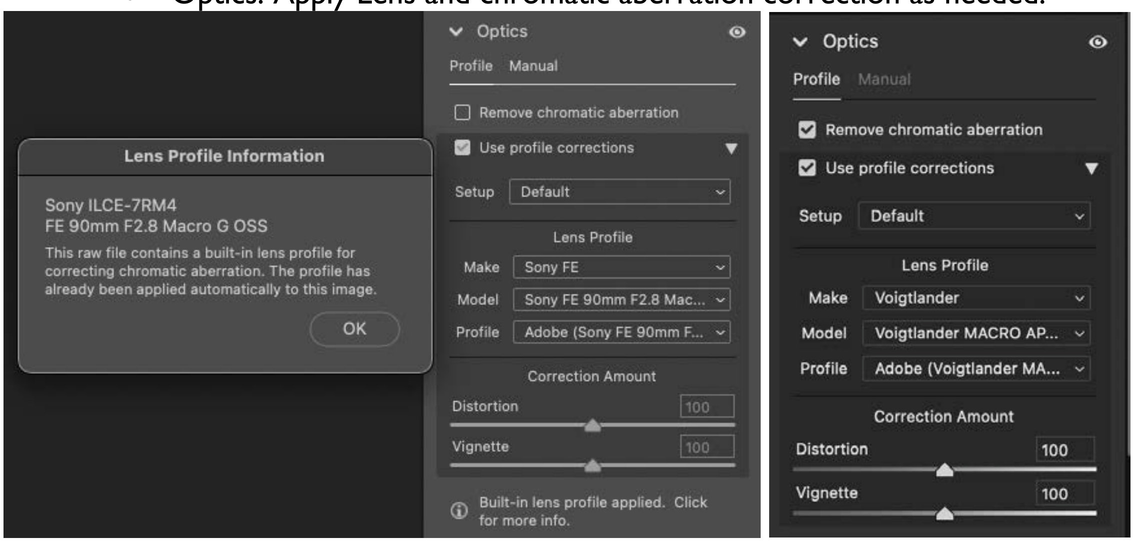
IMAGE PROCESSING

Image processing is all done in Adobe Camera Raw (ACR) which can be accessed either via Bridge or Photoshop. I prefer doing all my work inside of Bridge, currently using ACR version 16.2 and Bridge 2024 (14.0.1.137) I only use Photoshop at the end of the process to generate derivatives and printing if needed.

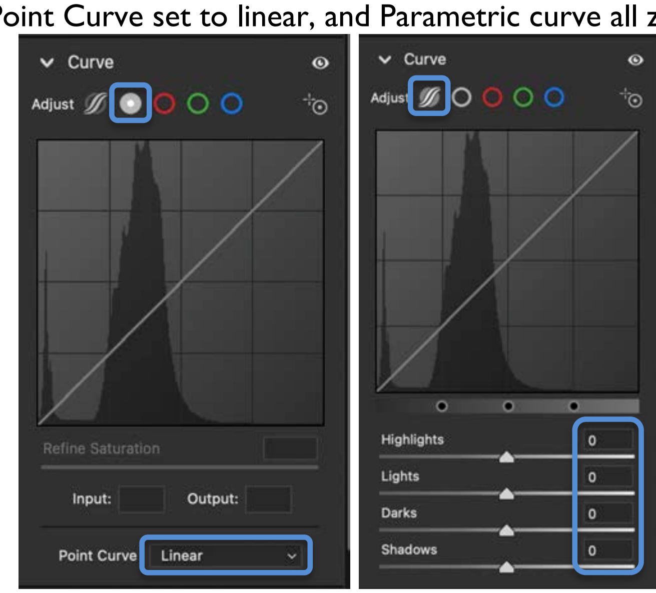
In ACR these are the settings I currently use, going from the bottom to the top:

- Calibration: Process Version 2

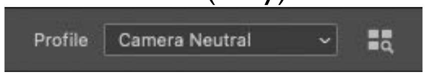
- Optics: Apply Lens and chromatic aberration correction as needed.



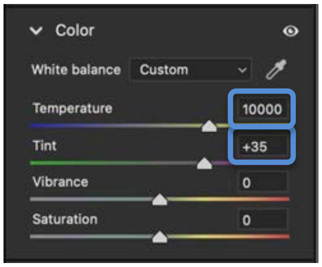
- Curve: Point Curve set to linear, and Parametric curve all zeroed out

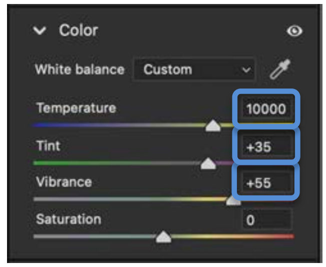


- Profile: Camera Neutral (Sony) or Adobe Standard (Fujifilm)



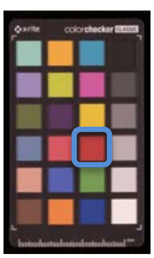
- Color: White balance is custom set to:
    - Temperature: 10000
    - Tint: +35
    - Vibrance: +55 (Only Fuji)

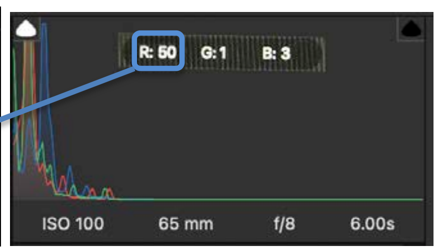




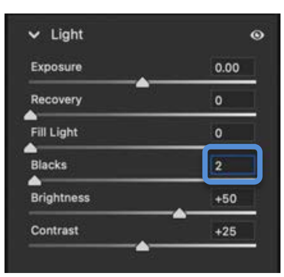
Sony Fuji

- Light:
    - Exposure adjustment:
      Exposure is done based on a known fluorescence level that is included in at least one of the reference targets. I use the red patch (Number: 15 or C3) on the ColorChecker to set my exposure value. Referring only to the red channel RGB measurements I set the red response to around 50.





    - Black: 2 (Only Fuji)

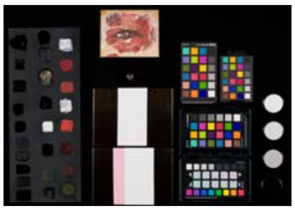


Fuji

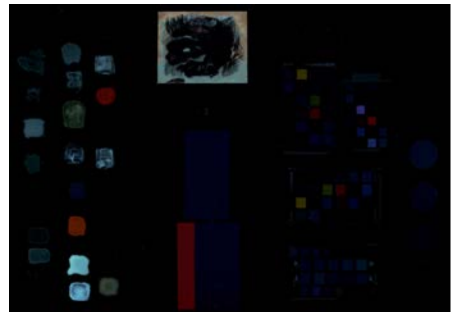
Note: Every other setting is left at the ACR default.

SAMPLE IMAGES

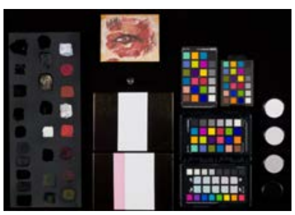
Sony A7RIV Camera:

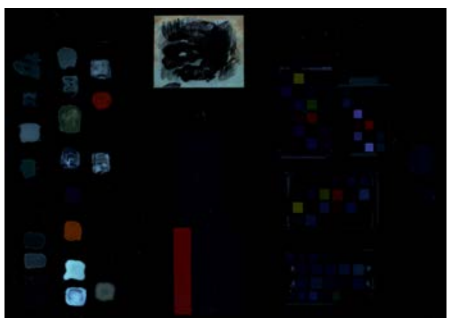

Visible Image

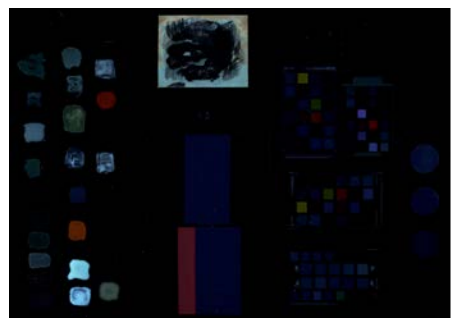

WildFire w/ Kopp1041


realUV LED w/ BP365

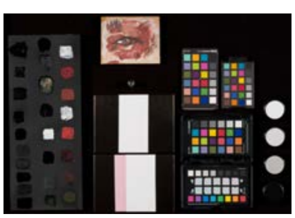
Sony A7RIV Full Spectrum Camera:


Visible Image

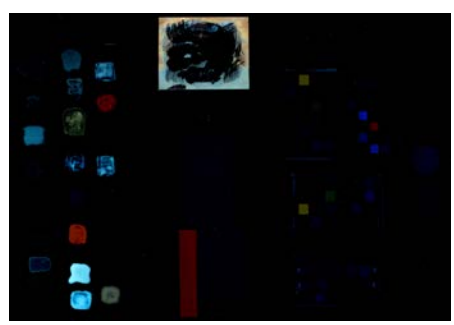

WildFire w/ Kopp1041


realUV LED w/ BP365

Fuji GFX100 Camera:


Visible Image


WildFire w/ Kopp1041


realUV LED w/ BP365

APPENDIX

Product specifications provided by the manufacturers:

Wildfire

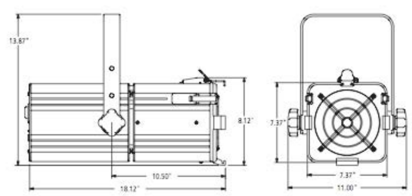
Long-Throw™ 250 Series 3

250 Watt Metal Halide Ultraviolet Lighting Fixtures

The LT-250 Series 3 from Wildfire is the perfect balance of power and portability for a wide variaty of applications requiring high output true 365nm black light. Standard features include, versatile interchangeable reflectors, smart universal voltage electronic ballasting, advanced air cooling and intelligent DMX control for maximum flexibility and ease of integration with other lighting systems.

Features:

- Versatile Interchangeable Reflectors
- Smart Universal Voltage Electronic Ballasting
- Intelligent Dmx Control / Status Monitoring
- Hinged Lens Door for Easy Lamp Access
- Safety Cutoff Switch for Safe Re-lamping
- Heavy Duty Extruded Aluminum Construction
- Stainless Steel Hardware
- Made in the USA

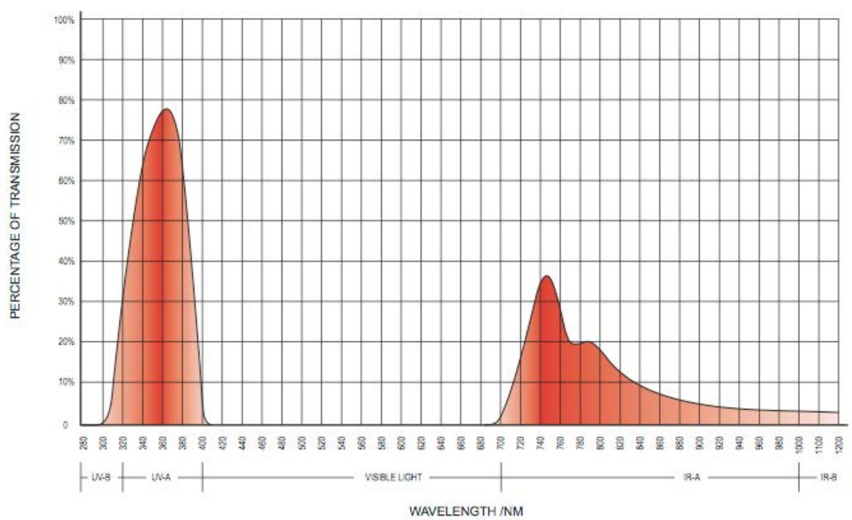


Standard Equipment:

139-002	250W IronArc Lamp
147-020	Quick Trigger Clamp
147-002	Safety Cable

Optional Accessories:

146-001	7.5" Barn Doors
145-001	7.5" DMX Iris
147-007	Floor Stand
125-005-02	20° Spot Reflector
125-006-02	50° Wide Spot Reflector
125-007-02	90° Flood Reflector



Photometrics Chart:

Model LT-250S 20° Spot

Distance in **Feet**/Meters

	5/1.52	10/3.05	20/6.10	30/9.14	40/12.19	50/15.24	60/18.29	70/21.33	80/24.38	90/27.43	100/30.48	110/33.53	120/36.57
Beam Diameter Feet	1.80	3.50	7.10	10.60	14.10	17.60	21.20	24.70	28.20	31.70	35.30	38.80	42.30
Beam Diameter Meters	.55	1.07	2.16	3.23	4.30	5.36	6.46	7.53	8.59	9.66	10.76	11.83	12.89
Peak UV-A Intensity µW/cm²	644.0	161.5	40.2	17.8	10.0	6.4	4.4	3.2	2.5	1.9	1.6	1.3	1.1

Model LT-250WS 50° Wide Spot

Distance in **Feet**/Meters

	5/1.52	10/3.05	20/6.10	30/9.14	40/12.19	50/15.24	60/18.29	70/21.33	80/24.38	90/27.43	100/30.48
Beam Diameter Feet	4.70	9.30	18.70	28.00	37.30	46.60	56.00	65.30	74.60	83.90	93.30
Beam Diameter Meters	1.43	2.83	5.70	8.53	11.37	14.20	17.07	19.90	22.74	25.57	28.44
Peak UV-A Intensity µW/cm²	545.0	136.2	34.0	15.1	8.5	5.4	3.7	2.7	2.1	1.6	1.3

Model LT-250F 90° Flood

Distance in **Feet**/Meters

	5/1.52	10/3.05	20/6.10	30/9.14	40/12.19	50/15.24	60/18.29	70/21.33	80/24.38
Beam Diameter Feet	10.00	20.00	40.00	60.00	80.00	100.00	120.00	140.00	160.00
Beam Diameter Meters	3.05	6.10	12.19	18.29	24.38	30.48	36.57	42.67	48.77
Peak UV-A Intensity µW/cm²	266.0	66.5	16.3	15.1	7.3	4.1	2.6	1.8	1.3

realUV™ LED Flood Lights

PN: 7022

Waveform Lighting's realUV™ LED flood lights provide high power ultraviolet light at 365 nanometers or 395 nanometers. These wavelengths are considered true UV-A wavelengths, and are the optimal wavelengths for activating and observing fluorescence and other UV-A phenomenon.

The flood light emits strong UV light at a 120 degree angle, providing wide but directed UV light optimal for UV curing applications as well as observing fluorescence effects.

With an IP65 rating, the flood light can be used in wet locations.

The flood light includes a standard US-style 3-prong plug for easy connectivity, and can be installed using the included mounting bracket.

PRODUCT AND FEATURES

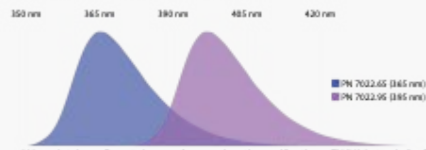
- Available in either 365 nm or 395 nm
- The light emitted from the 365 nm version is largely invisible, but a miniscule amount of visible light is also emitted and appears as a very dim, bluish-white light.
- The 395 nm version emits a portion of its output energy in the visible wavelength range and appears as a dim, violet light.
- Dimensions of 7.1 x 5.5 x 3.6 inches
- AC 120-240V input via 3-prong US-style plug
- IP65 waterproof rating, not dimmable

PHOTOMETRIC SPECIFICATIONS

UV output (365 nm):	8.0 W
UV output (395 nm):	6.0 W
Radiometric Efficiency (365 nm):	40%
Radiometric Efficiency (395 nm):	30%
Spectrum FWHM:	10 nm
Emission angle:	120 deg

Download full photometric reports at https://www.waveformlighting.com/photometrics

TYPICAL EMISSION SPECTRUM



We maintain a ±5 nm tolerance for wavelength specifications. FWHM stands for Full-Width Half-Max, the size of the wavelength range across which irradiance is measured to be at least 50% of the peak wavelength irradiance value.

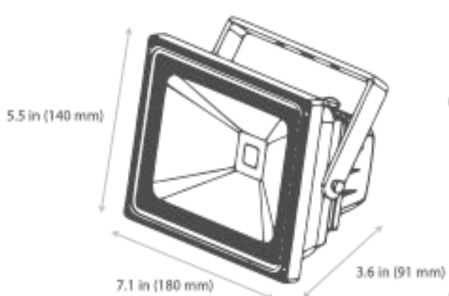
ELECTRICAL SPECIFICATIONS

Input type:	US-style 3-prong Plug
Input voltage:	AC 120-240V / 50-60 Hz
Input current (@120V AC):	165 mA
Input current (@240V AC):	85 mA
Safety Approvals:	CE, RoHS

MECHANICAL SPECIFICATIONS

Length:	7.1 in (180.3 mm)
Width:	5.5 in (139.7 mm)
Height:	3.6 in (91.4 mm)
Lamp material:	Aluminum
IP Rating:	IP65

PRODUCT DIMENSIONS

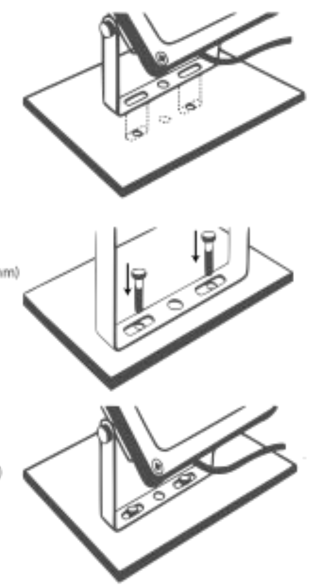


MOUNTING BRACKET DIMENSIONAL DETAIL

PART NUMBERS AND ORDERING

365 nm:	7022.65
395 nm:	7022.95

MOUNTING INSTRUCTIONS



STEP 1
With the lamp unplugged, locate a stable and secure mounting surface and prepare two holes approximately 3.5 inches (90 mm) apart so that mounting screws or bolts (sold separately) can be attached. Mounting screws or bolts should have threads less than 0.3 inches (8.0 mm / M8) in diameter.

STEP 2
Align the lamp mounting bracket so that the rectangular openings align with the mounting holes. Then, insert the screws or bolts through the holes and tighten.

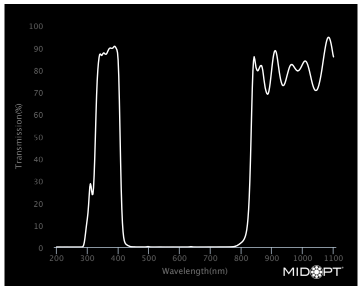
STEP 3
Ensure that the lamp is securely fastened and then plug the lamp into an electrical outlet. The lamp is now ready for use!

waveform lighting

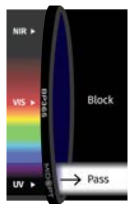
WAVEFORM LIGHTING, LLC 4400 NE 77th Ave Ste 275 | Vancouver, WA 98662, USA
https://www.waveformlighting.com | support@waveformlighting.com

home › filters › bandpass › bp365

BP365 Near-UV Bandpass Filter



BP365 UV Bandpass dichroic filters can be used with all UV LED, UV fluorescent and other UV-producing lamp-based lighting. BP365 filter material is designed to block the visible and pass UV light, including 395nm and all other popular UV LED wavelengths. It is also useful for near-UV fluorescence imaging, blocking visible light and light from UVC LED excitation sources, allowing early removal of biofilms (for instance, in disinfection applications or biofouling of ship hulls) through tryptophan fluorescence detection. The substrate material is low-expansion Borofloat, making this filter particularly heat resistant.



› Learn more about UV Imaging
› Learn more about Fluorescence Imaging
› View all Bandpass Filters

StablEDGE

Useful Range : 335-400nm
FWHM : 80nm
Tolerance : +/- 10nm
Peak Transmission : ≥85%
Surface Quality : 40/20
Compatible LED : 365nm

Download Transmission Data

BP365 Transmission Data (Typical)

wavelength (nm)	transmission (%)	wavelength (nm)	transmission (%)
1100	85.82	650	0.01
1090	92.96	640	0.16
1080	94.02	630	0.07
1070	87.30	620	0.01
1060	78.20	610	0.02
1050	72.03	600	0.01
1040	70.77	590	0.01
1030	74.44	580	0.02
1020	80.40	570	0.01
1010	83.81	560	0.01
1000	82.67	550	0.01
990	80.09	540	0.03
980	79.72	530	0.02
970	81.66	520	0.00
960	82.01	510	0.01
950	77.90	500	0.19
940	73.31	490	0.07
930	74.48	480	0.04
920	82.66	470	0.04
910	88.60	460	0.04
900	81.24	450	0.11
890	70.33	440	0.25
880	70.68	430	0.84
870	79.77	420	2.90
860	81.16	410	26.41
850	80.23	400	84.32
840	83.99	390	90.47
830	38.87	380	89.65
820	9.92	370	89.34
810	3.71	360	86.95
800	1.98	350	87.14
790	0.96	340	86.90
780	0.35	330	68.49
770	0.15	320	26.75
760	0.08	310	28.57
750	0.06	300	12.97
740	0.06	290	2.11
730	0.06	280	0.00
720	0.03	270	0.00
710	0.03	260	0.00
700	0.04	250	0.00
690	0.03	240	0.00
680	0.01	230	0.00
670	0.01	220	0.00
660	0.00	210	0.01
		200	0.01

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Lens O.D. (mm)

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The performance of a filter is based on what happens to light passing through the filter. The apparent color of light reflected off the surface is not a reliable way to judge the filter's capabilities. Batch-to-batch difference in the apparent color of the coatings or filter substrates can often be easily seen when looking at two examples of the same filter type. The color of the coating does not indicate a disparity in performance. Filters 62mm and greater have a surface quality tolerance of 60/40.

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A Simple Ultraviolet-Induced Visible Fluorescence Target or a low-cost alternative to a Spectralon®

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Abstract

A prevailing question among conservators and imaging professionals producing cultural heritage documentation and research is how to obtain an ultraviolet-induced visible fluorescence (luminescence) image that allow us to assess the quality of the filtration used and the environment in which the image is being captured. The literature on this topic generally recommends use of delicate and expensive control targets. This article describes a simple low-cost method to create and use a target that can aid in capturing images that are consistent and thus raising the confidence level of the images created.

Introduction

This paper reports on the assembly and use of a simple, low-cost target to aid in the systematic production of ultraviolet-induced visible fluorescence (luminescence) images. The goal was to make a simple target - one that can be used as a calibration tool, monitors light leaks in the environment, and aids with the position of radiation fixtures. For the purpose of this paper the term ultraviolet-induced visible fluorescence [UV-F] will refer to the luminescence generated in the visible spectrum when the surface of an art object is irradiated with an ultraviolet source. The term "light leak" is used to denote the photographic evaluation of the environmental conditions under which an object is being imaged. An essential condition for this process is that there are no other light or radiation sources that would interfere with the generation of the UV-F image.

Many scholarly publications have been devoted to the methods used to obtain the best UV-F images possible. [1,2,3,4] They also have described the development of a purpose-built UV-F target by the company UV Innovations™. [5]

At the core of these techniques is the fundamental dependence on the use of at least one costly target. What they all have in common is that controlling and verifying the imaging environment is based on the use of Labsphere's Spectralon® standard ($400 and up) or similar commercial targets. In addition, the UV Innovations target ($875) is intended to generate more repeatable and comparable images by determining the intensity of fluorescence produced by different proprietary materials in the target itself. This target was not designed to evaluate the imaging environment, or the proper filtration used during the UV-F imaging session. Therefore, it is necessary to use a Spectralon® or similar targets in addition to the UV Innovations one.

The Spectralon® target most widely used, and the focus of this article is the 99% reflectance target, which appears flat and solid white to the naked eye. It is worth noting that Spectralon® standards are important to calibrate other imaging and analytical spectroscopic techniques. The Spectralon® standards are directly traceable to NIST, hence commanding a premium price.

Even though the UV Innovations™ website has information about its creation and testing, there are no published data describing the manufacture and composition of the UV Innovations™ target. The literature on the Spectralon® characterizes it as follows:

Spectralon® *is a fluoropolymer, which has the highest diffuse reflectance of any known material or coating over the ultraviolet, visible, and near-infrared regions of the spectrum. It exhibits highly Lambertian behavior and can be machined into a wide variety of shapes for the construction of optical components such as calibration targets, integrating spheres, and optical pump cavities for lasers.* [6]

A ***fluoropolymer*** *is a fluorocarbon-based polymer with multiple carbon–fluorine bonds. It is characterized by a high resistance to solvents, acids, and bases. The best-known fluoropolymer is polytetrafluoroethylene [PTFE]. The trademark Teflon was coined by the DuPont Company in 1946.* [7]

An issue with routine use of the Spectralon® is that this target has a very delicate surface, which is unexpected because Teflon is known to be an impermeable and inert material. But the fact is that the Spectralon® becomes dirty quickly if not handle with caution, accumulating oils and soil that fluoresce under UV radiation. Once dirty it loses its much-desired quality of remaining photographically neutral, i.e., appearing dark in an image taken under ideal environmental conditions. As can be seen in Figure 1b the two older, soiled Spectralon® standards fluoresce (in the circle) while the newer ones (in the rectangle) remain dark.

In an effort to refurbish the Spectralon® standards and remove the top soiled layer, an attempt was made to "clean" them. Initially they were treated with reagent grade acetone which prove ineffective. Next, they were sanded with several fine-grit micromesh sandpapers (used for cross-section preparation). Sanding was only partially successful as can be seen in the Figure 1d (red circle). Alternatively, a microtome might possibly be used to remove a thin layer from the surface of the Spectralon® to provide a "new" clean surface. [8] This method was not used due to inaccessibility to this tool.

Given the sensitivity of the Spectralon® surface, the need to regenerate it frequently (if possible), and specially its high cost, finding an alternative would be very advantageous. It should be noted that even though the Spectralon® may look clean under visible light, damages due to dirt on the surface will make it inappropriate for use under UV radiation. For these reasons the search for another target material that is cost effective, accessible, easy to replace and worry-free, led to the development of the simple UV-F target described in this paper.

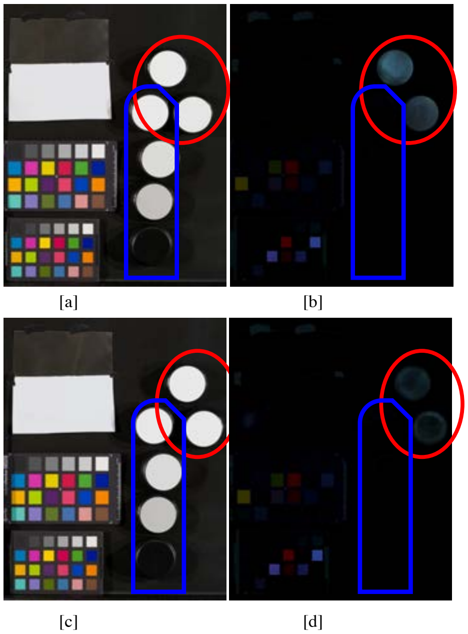


Figure 1. *UV-F testing targets set-up: (a) and (c) are visible images; (b) and (d) are the UV-F images, (b) shows the two older/soiled Spectralon® standards {circled in red}, (d) shows the same Spectralon® standards {circled} after sanding.*

Searching for a suitable, more affordable, substitute for the Spectralon® that is widely available to cultural heritage professionals was sought. The Passport ColorChecker® by Calibrite [formerly X-rite] ($100) was a possible candidate. This target is designed to profile a camera's response to color under visible light conditions. It does contain, however, a few patches that fluoresce under UV radiation (Figure 1b-d), thus providing a basic measurement of the UV exposure levels that is different from the UV-Innovation™ target. In contrast, the Spectralon® provides more information on the environmental lighting conditions.

A very simple and interesting way of testing for stray UV radiation and total light exposure was suggested by Peter Hansel in the book Photography for the Scientist. Hansel writes in chapter 8:

"A piece of polished metal, such as a penknife blade, should always be included…. As polished metal does not itself fluoresce, no image of it should be recorded. However, any visible reflections… will indicate the degree and character of visible light "leakage" within the system." [9]

Combining Hansel's comments with the fact that the Spectralon® is composed of Teflon, a search was undertaken to find comparable materials with which to construct a simple target for monitoring environmental light leaks. A target was developed to achieve this, and to serve as a calibration tool under UV radiation (Figure 2). Two materials were selected from the McMaster-Carr catalog - a polished stainless-steel mirror-like foil with adhesive backing, and high-density polytetrafluoroethylene (PTFE) white pipe thread sealant tape.

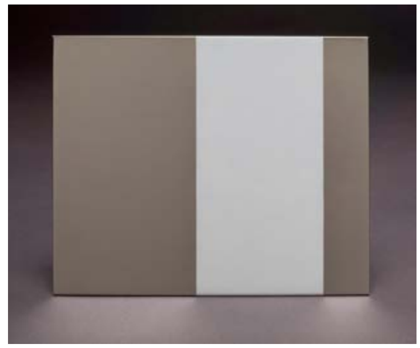


Figure 2. *The simple ultraviolet-induced visible fluorescence target.*

Materials (Figure 3a)

1) Polished Multipurpose 304 Stainless Steel Mirror-Like Foil with adhesive backing 0.0020" Thick. 6" Wide (McMaster-Carr #8452K95) ($179.00)
2) High-Density Thread Sealant Tape PTFE, 0.0035" Thick, 2" Wide, 14 Yard Long, White (McMaster-Carr #6802K87) ($40.00)
3) Two-ply acid free mat board 4x5" ($10.00)
4) Non-fluorescing black paper tape ($10.00)

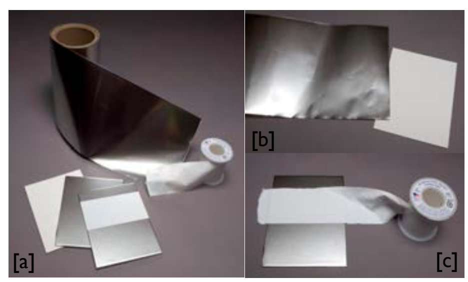


Figure 3. *Assembling the UV-F target: (a) Polished stainless-steel mirror-like foil with adhesive backing, PTFE high-density pipe thread white tape 2" wide, 4x5 acid free mat board (shown in three stages). (b) Wrapping the stainless-steel foil around the mat board. (c) Wrapping the PTFE white tape around the foiled card. Finished UV-F target (See figure 2).*

Assembling the simple UV-F Target

Making the target is straight forward (Figure 3):

1) Adhere the foil to a 4x5 inch acid-free mat board (Figure 3b).
2) Place a strip of the PTFE tape over the foil at one end, wrapping the PTFE tape around the board (Figure 3c).
3) Secure the PTFE at the back with non-fluorescing tape.

Note: Keep the working countertop clear and clean, providing the PTFE tape with a suitable protective contact surface while attaching to the foiled 4x5" board.

Avoid touching the surface of the PTFE tape during the assembly process, as well as while in use. As with the Spectralon®, the PTFE tape can get soiled with oils and grime which will appear as fluorescence. When this happens replacing the strip of PTFE tape with a new one is simple (Step 2 and figure 3c), and the cost is very low. This ensures that a fully functional target is always at hand and reliable (Figure 3d). If desired, different sized targets and configurations can be made to suit different imaging needs.

Measuring and Comparing the Simple UV-F Target vs the Spectralon® 99% reflectance standard

In order to validate the use of the PTFE tape as a low-cost replacement for the Spectralon® standard for this method of imaging, an unbiased scientific spectroscopic approach was implemented to measure and compare them. It is important to point out that this paper is not suggesting that the PTFE is a replacement when a scientific grade standard is needed for the calibration of analytical equipment and control of scientific data.

Spectroscopic measurements were performed to obtain reflectance data across the visible spectrum using commonly available instruments and a scientific grade one.

Instrumentation and Software

Measurements and processing of the spectra was done with:

- Cary 60 UV-Vis Spectrophotometer (250-850 nm) by Agilent with Barrelino remote diffuse reflectance accessory by Harrick Scientific
- Gregtagmacbeth i1Pro (1) Spectrophotometer (380-730 nm)
- X-Rite i1Pro (3) Spectrophotometer (380-730 nm)
- SpectraShop™ 6 by Robin Myers
- Microsoft Excel

Measurement results

Using the i1Pro (3) Spectrophotometer and processing the data using SpectraShop™ 6 (CIELAB 1976) spectral curves were obtained for four different 99% reflectance Spectralon® standards, three one-inch round and one 2x2 inch (left side of figure 4). From the graphs we can clearly see that the reflectance behavior is as expected, a linear response (for clean and soiled targets) at or close to 99% reflectance in the visible spectrum range of 380 to 730 nm. L*a*b* values are shown as reference as well.

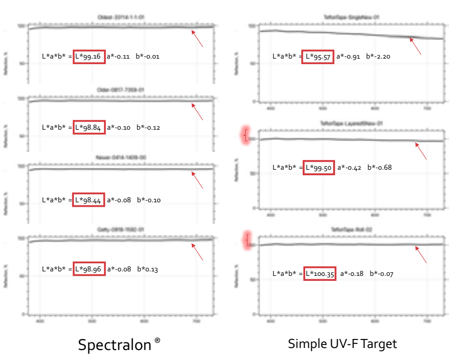


Figure 4. *Reflectance measurements*

When comparing against measurements made for the PTFE tape on the simple UV-F target,

we can see that the curves obtained vary depending on the amount of PTFE layers used. When a single layer of PTFE is used, we can see reflectance interference coming from the shiny foil underneath, causing the curve to slope down at higher visible nanometer values (Figure 4, top right graph). In contrast when we measured the 5-layer PTFE tape, the shiny foil effect is eliminated, and we obtain a straight-line across the spectrum very much like the Spectralon's® one (Figure 4, middle right graph).

Please note the slight shift up on the Y axis of these two last graphs marked with the red bracket.

The last graph was made out of curiosity to see what result would be obtained when measuring the PTFE tape directly in its spool (Figure 4, bottom right graph).

To corroborate the i1Pro (3) measurements, the scientific grade Cary60 with the Barrelino attachment was used to measure reflectance spectra response from 250 to 850 nm, data processing was done with Agilent's software and Microsoft Excel®.

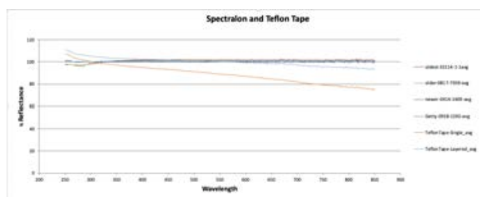


Figure 5. *Reflectance measurements*

The measurement results from the Carry60 plus Barrelino yield spectral curves that are very much in line with the previous findings (Figure 5), corroborating the i1Pro (3) measurements. The 5-layered PTFE tape behaves very similarly to the other four Spectralon® targets. Although the Carry 60 provides measurements in a wider range of spectra, the values graphed are cropped to resemble and match the ones produced by the i1Pro (3).

Using the simple UV-F target

As with any other target the UV-F target must be positioned within the scene to be imaged, close to the artwork and under the same lighting/radiation conditions as the subject being photographed. When it is placed near the center of the scene, the target helps to determine if the radiation sources are positioned appropriately at the right distance and angle. Under proper lighting conditions the polished stainless-steel foil remains completely dark, without reflecting any blue/violet light. The foil will also reveal any other light source that is leaking into the scene by reflecting the invasive light.

The next step, after determining that the environment is appropriate to successfully acquire UV-F images, is to evaluate the quality of the UV radiation sources and the efficacy of the camera filtration. This is accomplished by confirming that the strip of PTFE is completely dark in the captured images (do not rely on the *insitu* visual appearance). If the PTFE tape shows any color (e.g., violet or magenta), this indicates that the radiation sources are not properly filtered and/or that the camera filtration pack is not the appropriate one to use. Results achieved with this procedure should be comparable to those obtained when using the Spectralon® target.

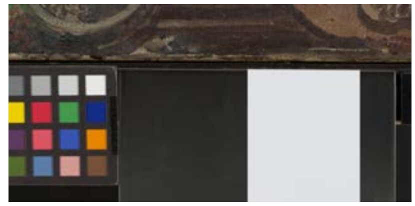
Figure 6 shows examples of the UV-F target in use. Figure 6a is a visible image containing a new Spectralon® on the right and the UV-F target in the center. Figure 6b is the same image under UV radiation. Note how the UV-F target and Spectralon® responded similarly, remaining completely dark. Figures 6c and 6d represent a different setup showing the effect that the UV radiation has on an older, used Spectralon®. Note here how the UV-F target remains dark, but the Spectralon® fluoresces. Lastly Figures 6e and 6f show the behavior of the UV-F targets under controlled conditions described above; in contrast to Figure 6g indicating a light leak (this image has been enhanced to show this fine distinction for this publication).

[a]

[b]

[c]

[d]



[e]

[f]

[g]

Figure 6. *Using the simple UV-F target. (a) Visible image of targets. Left: older ColorChecker® Mini; center: UV-F target; right 4 Spectralon® 99, 75, 50 and 2 % diffuse reflectance. (b) UV fluorescence comparing the UV-F target to the Spectralon®. (c) Visible image of targets. Left: Spectralon 99% reflectance; bottom center: new ColorChecker® Passport; upper center: Egyptian blue target; right: UV-F target. (d) UV fluorescence comparing the soiled Spectralon to the UV-F target. (e) Visible image. Left: partial ColorChecker® Mini; right: UV-F target. (f) UV fluorescence with the UV-F target, without light leak. (g) with light leak.*

Conclusion

Imaging targets are an essential tool in the acquisition of thorough cultural heritage documentation. They enable the photographer to evaluate an array of conditions that impact the quality of the images generated. Commercial UV-F target selection is limited, they are costly and improper handling can render them useless. This paper introduces a cost-effective and simple solution to achieving the similar results for UV-F imaging as obtained with the commercial Spectralon®. Constructed from the same material as the Spectralon® (PTFE), the simple UV-F target uses PTFE tape in combination with a highly reflective metal sheet. This simple combination will provide confirmation of a light leak free environment and indicate that the proper camera filtration and radiation emission is achieved to obtain accurate results. The simple UV-F target is accessible to everyone, easy to assemble, affordable, and ensures that a reliable system will always be available when capturing UV-F images.

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Author Biography

Yosi Pozeilov joined the Los Angeles County Museum of Art (LACMA), Conservation Center as the Senior Conservation Photographer in 2003. In addition to being responsible for all the technical and scientific imaging for the Conservation Center, Yosi has been implementing computational imaging techniques like Reflectance Transformation Imaging (RTI), photogrammetry and spectral imaging. He also established protocols to streamline condition reporting with the use of mobile technology and imaging-based systems on handheld devices.