Reflectivity characterization of various black and white materials

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ABSTRACT

We report on an expanded catalog[1–4] of various common (and uncommon) black and white materials used in the construction and/or baffling of optical systems and as screen material for calibration systems. Total reflectance is measured over a broad wavelength range ($250\ nm < \lambda < 2500\ nm$) that is applicable to ultraviolet, visible, and near-infrared instrumentation. Reflectivity data for the complete sample inventory will be available via Filtergraph, an online data visualization tool.

Keywords: optical instrumentation, infrared instrumentation, scattered light, stray light, black materials, white materials, calibration screens, reflectivity

1. INTRODUCTION

In order to control stray and scattered light within UV, Optical, and Near-IR instrumentation, careful consideration must be given to the optical design, baffling, and material choices or surface coatings surrounding the optical path within the instrument. This paper reports on total reflectivity measurements of several different materials and surface treatments that may be useful when developing an instrument with a well controlled stray and scattered light environment.

These samples add to a growing catalog of measurements primarily performed by undergraduate and graduate students in the Munnerlyn Astronomical Instrumentation Lab over the last eight years.[1–4] At least 14 students have contributed to this effort in some way, either through organizing samples, writing data reduction code, collecting measurements, or working on instrumentation to take additional measurements.[5]

2. MEASUREMENTS

As previously described,[4] Texas A&M University maintains a Materials Characterization Facility (MCF) that includes a wide range of instrumentation for investigating material properties. We used the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer and obtained reflectance profiles for the samples. With this system we measured precise reflectance values at each wavelength (in 1 or 2 nm steps) for the wavelength range $250\ nm < \lambda < 2500\ nm$. Figure 1 shows the instrumental setup of the spectrophotometer. The reference and test sample are placed in the 6 o'clock and 3 o'clock positions of the integrating sphere, respectively.

The data acquisition procedure involves obtaining a baseline measurement at each wavelength of the reference $BaSO_4$ wafers ($\sim 100\%$ reflectance) in both the reference and sample slots of the dual beam spectrophotometer. We then measure a second reference sample having 5% reflectivity (Labsphere SRS-05) and measure the reflectivity of the test sample. We compare the 5% reflectance reference sample to the values provided by the manufacturer and use this ratio to construct the absolute reflectivity of the test sample as a function of wavelength. During each day of testing the SRS-05 standard is measured to ensure measurements from different test days are tied to a common reference. The U-4100 changes detectors at 850 nm, which is likely the cause of the features visible in most material scans near this wavelength.

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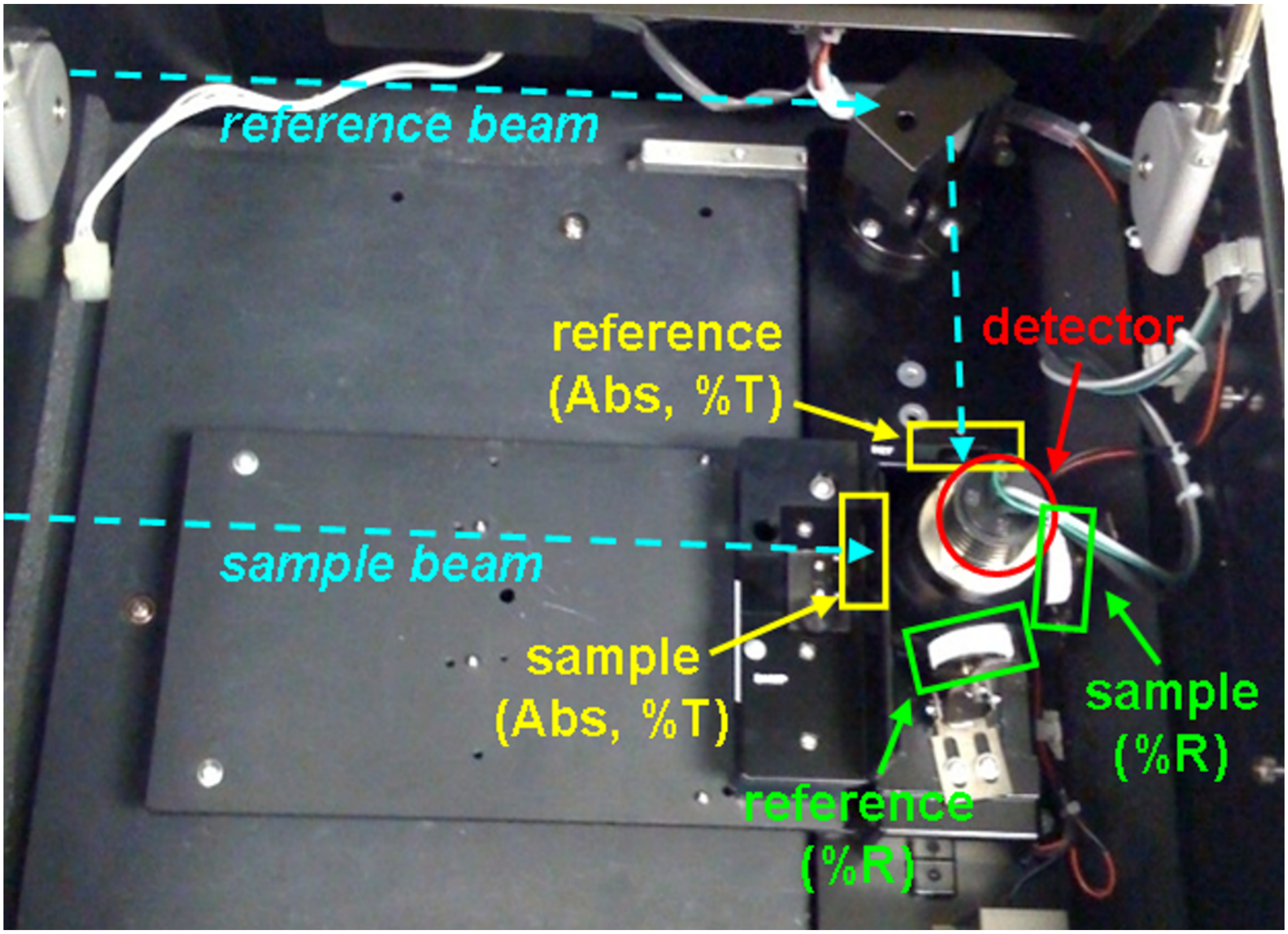

Figure 1. Interior of the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer.

The material scans result in a comma-separated value (csv) file with header information about the U-4100 configuration settings and columns for measurement wavelength and reflectance. A student written Python script reads in the SRS-05 reflectance standard measurement files as well as the files for each material tested and outputs calibrated reflectance data files as well as quick look figures of each sample. These data files are used to generate the figures seen in this paper, as well as added to the Filtergraph (Section 4) data visualization portal.

3. MATERIALS TESTED

Several variations of the Nyxlon wood treatment process, developed by Philip Evans (University of British Colombia), were tested, shown in Figure 3. The total reflectivity of the back side (untreated) of one of the samples was tested to provide a baseline comparison. Significant reduction in reflectivity is seen across the full tested spectrum. Reflectivity in UV and Optical bands is well below 5% for the treated samples. The spectral features seen in the NIR are likely due to water. The samples are stored in a plastic bag with desiccant packs to minimize water absorption by the samples.

Three solid materials were tested, black G10 Garolite, a composite material and black PLA (Polylactic Acid, Polyterra Charcoal Black Brand) filament for 3D printing, using both the default printing settings and a “Fuzzy Skin” print setting, available in the Ultimaker Cura control software. Samples were printed on an Ultimaker S5 3D printer. The fuzzy setting adds small random offsets (of order 0.2-0.3 mm) to the path of the print head during the printing process to generate a textured surface. The different print modes had a minimal impact on the overal reflectivity, though the fuzzy skin setting did slightly reduce the reflectivity between 250-1250 nm, and slightly increase reflectiving between 1250-2500nm. The primary concern when choosing between the two is aesthetics as the reflectivity difference is of order 0.5%.

Two paints/surface treatments were tested, Black 3.0, an acrylic paint and Birchwood Casey Aluminum Black. Black 3.0 is the latest version of matte black paint from Culture Hustle. It has admirable performance through the UV and Optical bands (<2% reflectivity), but rapidly increases to more than 6% reflectivity in the NIR. Surface preparation is important, on non-porous surfaces it can be difficult to get even coverage and no cracking or chipping when dried. Several light coats seem to work better. The Birchwood Casey Aluminum Black is a room temperature chemical conversion process that acts on bare aluminum to produce a dark grey or black surface, depending on the particular alloy. In practice it was found that the surface must be very clean and recently machined or abraded with fine grit sandpaper or Scotch-brite type pad. Consistent coverage and color was difficult to achieve. In some cases the result was very patchy with some portions of the sample appearing untreated. This is probably best left for touch ups (the stated use from the manufacturer), despite the author's hopes that it would be an inexpensive, durable surface treatment. Once a good sample was made, the performance was good, with 3-4% reflectivity across all measured wavelengths.

The final two samples are perhaps the most exciting materials. They are the Fineshut SP and Fineshut KIWAMI adhesive backed urethane foams. They are both available in sheets or strips (maximum 400×500 mm for SP and 480×280 mm for KIWAMI) at reasonable cost (\$0.03 USD/cm^2 - SP, \$0.12 USD/cm^2 - KIWAMI). The sheets can be applied easily to any flat surface, or by soaking in a dish of water with a few drops of dishwashing soap can be placed on a part and easily repositioned, then left to dry. Oversized pieces can be applied to a part and then trimmed using razor blades or x-acto style knife. The manufacturer will also laser cut pieces for complex parts. The material seems to be resistant to handling and can be lightly stretched to conform to curved surfaces. The exceptional performance is due to the structured surface which acts like many miniature light traps. Figures 5 and 6 show macro photos of each sample. The SP variety has a "grain" that improves performance slightly depending on the orientation. The KIWAMI variety has smaller structures with no preferred direction.

Table 1. Materials Tested

Code	**Sample**
B0077	Nyxlon (wood surface treatment)
B0077	Nyxlon (wood surface treatment) - Back Side
B0095	Flame-Retardant Garolite G-10/FR4 Sheet
B0096	Black 3.0 Paint
B0097	Fineshut SP – adhesive backed urethane foam
B0098	Fineshut KIWAMI – adhesive backed urethane foam
B0099	Nyxlon J
B0100	Nyxlon L
B0101	Nyxlon 3
B0102	Birchwood Casey Aluminum Black
B0106	PLA Default Print Settings
B0107	PLA "Fuzzy" Print Settings

4. FILTERGRAPH

Filtergraph[6] is an interactive web based portal for visualization of datasets. To facilitate comparison and filtering of the growing number of samples tested, all past and current reflectivity data is being added to a Filtergraph portal, accessible at https://instrumentation.tamu.edu/reflectivity-filtergraph. The current project website consists of static plots and it is difficult to compare materials or filter for particular characteristics (for

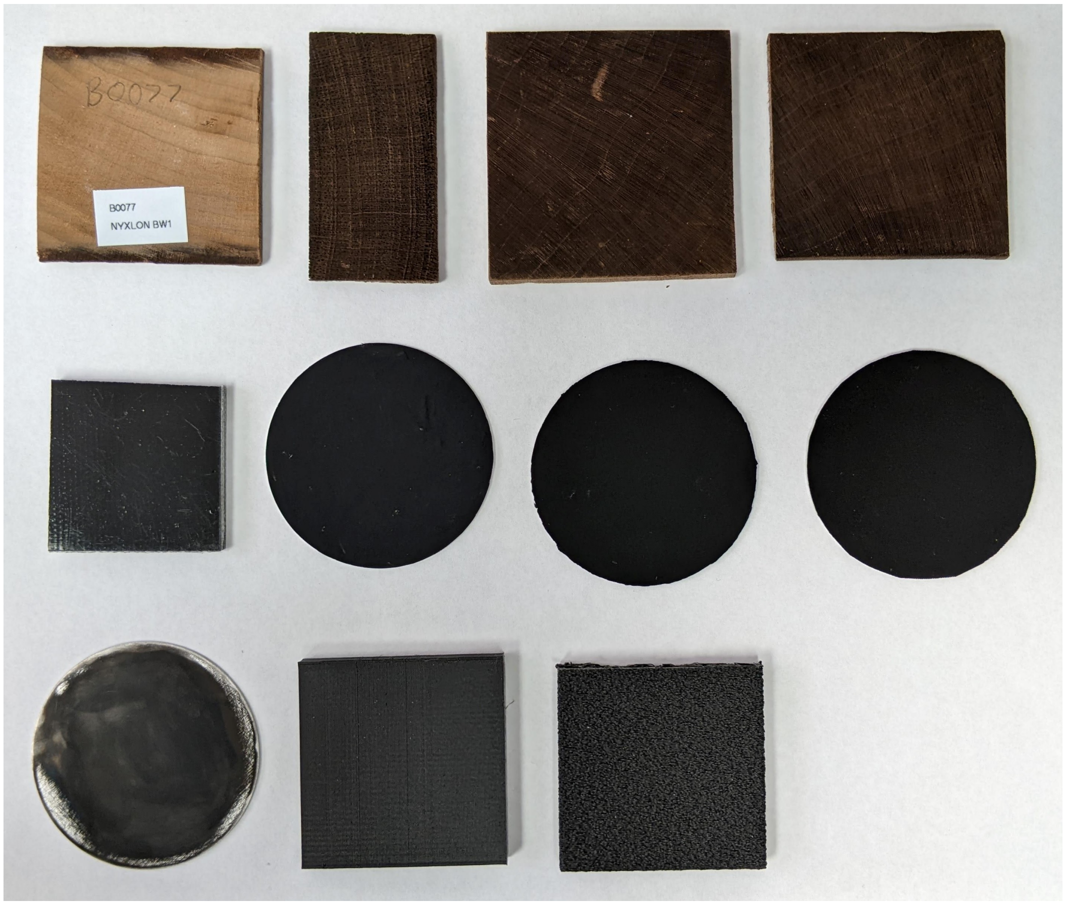

Figure 2. (Row 1, L to R) B0077 Nyxlon back side (to show original color), B0099 Nyxlon J, B0100 Nyxlon L, B0101 Nyxlon 3. (Row 2, L to R) B0095 Garolite G-10/FR4, B0096 Black 3.0, B0097 Fineshut SP, B0098 Fineshut KIWAMI (Row 3, L to R) B0102 Birchwood Casey Aluminum Black, B0106 Black PLA Default print, B0107 Black PLA "Fuzzy" print.

example, selecting all paints). The new Filtergraph portal collects all of the measurements into a single database and allows for easy filtering and display of the reflectivity data. Additional measurements of the samples for specular reflectivity and how well the white materials match a Lambertian surface[2,3,5] have been started and will be added to the Filtergraph portal as the rest of the sample library is tested.

5. CONCLUSIONS

We have presented additional total reflectance measurements of various materials that have been —or may be—used to minimize stray and scattered light within UV, optical, and near-infrared astronomical instruments. Control of stray light within an instrument is an important concern and the material choice and surface treatment within the instrument requires careful consideration. Information about the samples including reflectivity plots and text files of the calibrated data will be made available on the Munnerlyn Astronomical Instrumentation site at `https://instrumentation.tamu.edu/instruments/reflectance/` as well as the new Filtergraph portal. The same page includes information on how to suggest or submit a sample for testing. Due to resource availability no guarantee is made on sample testing turn around time and results will be made public on our website. We are also unable to return any samples that are submitted for testing.

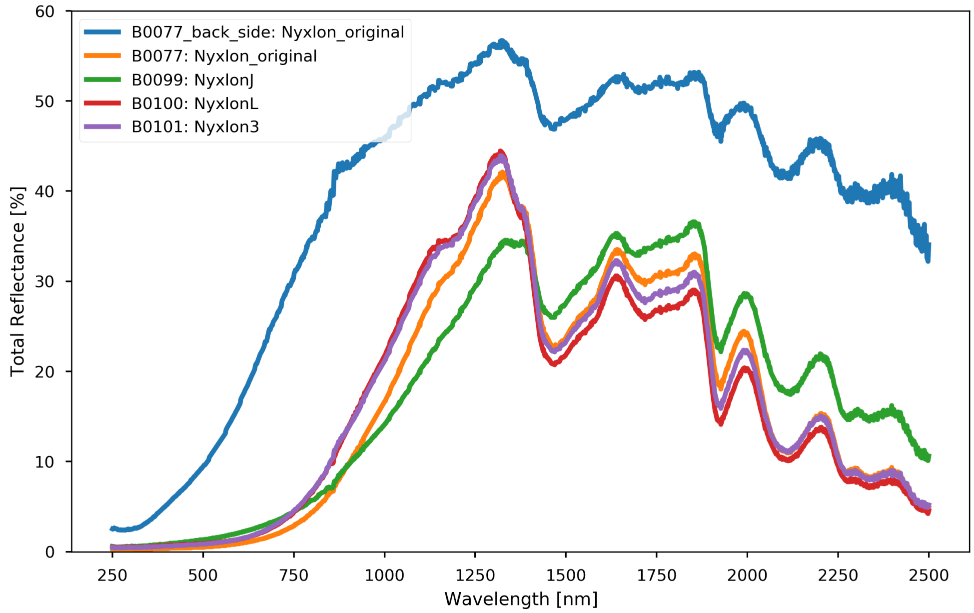

Figure 3. Additional measurements of variations of a wood blackening treatment4. The untreated sample is shown in blue, with reflectivity shown for several variations on the treatment process.

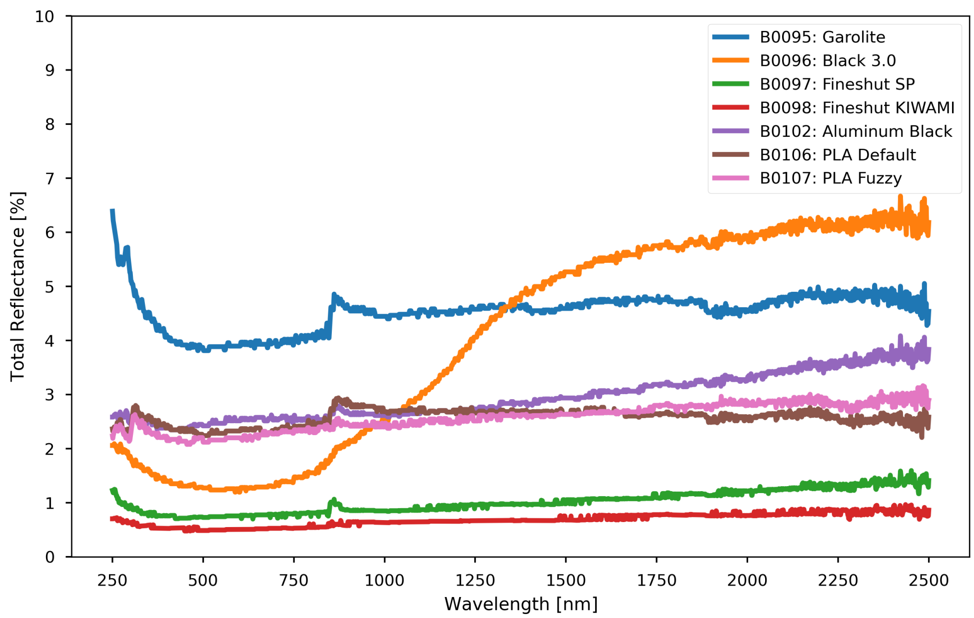

Figure 4. Several new materials were tested. Of particular note, the two Fineshut materials show excellent performance from the UV to NIR and are adhesive backed and very easy to apply either directly, or via submersion in soapy water to allow repositioning. The Fineshut materials can be laser cut to allow for coverage of complex parts. The Aluminum Black treatment for bare aluminum is effective, but difficult to get an even finish. The Aluminum must be freshly machined or cleaned with a Scotch Brite type pad immediately prior to application. PLA 'Fuzzy' print settings add small random motions to the 3D printer print head to generate a textured surface.

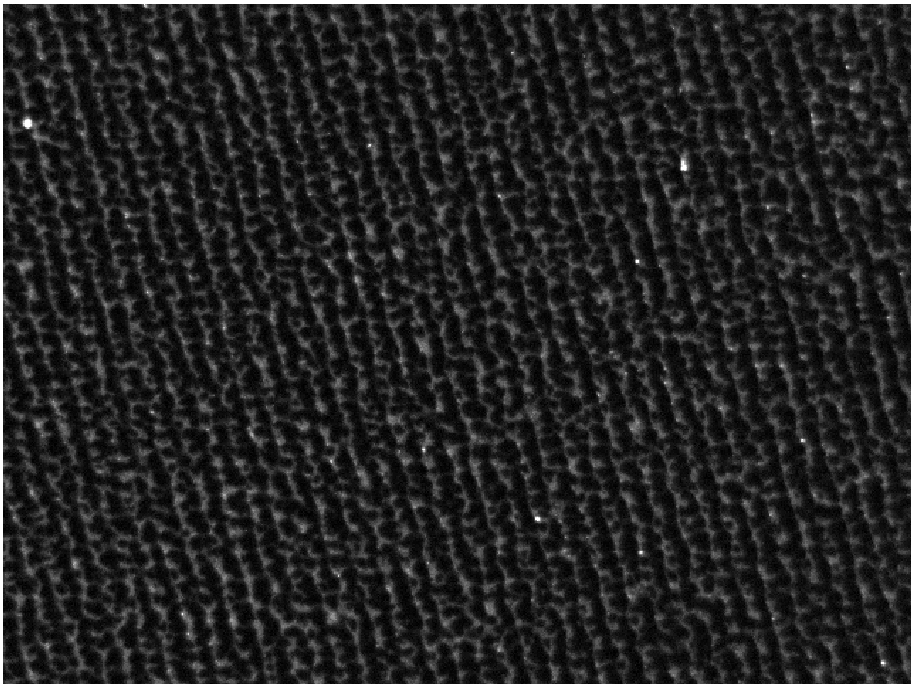

Figure 5. Fineshut SP, macro photo showing an 8 × 6 mm portion of the sample, the almost vertical line structures are roughly 200 microns apart.

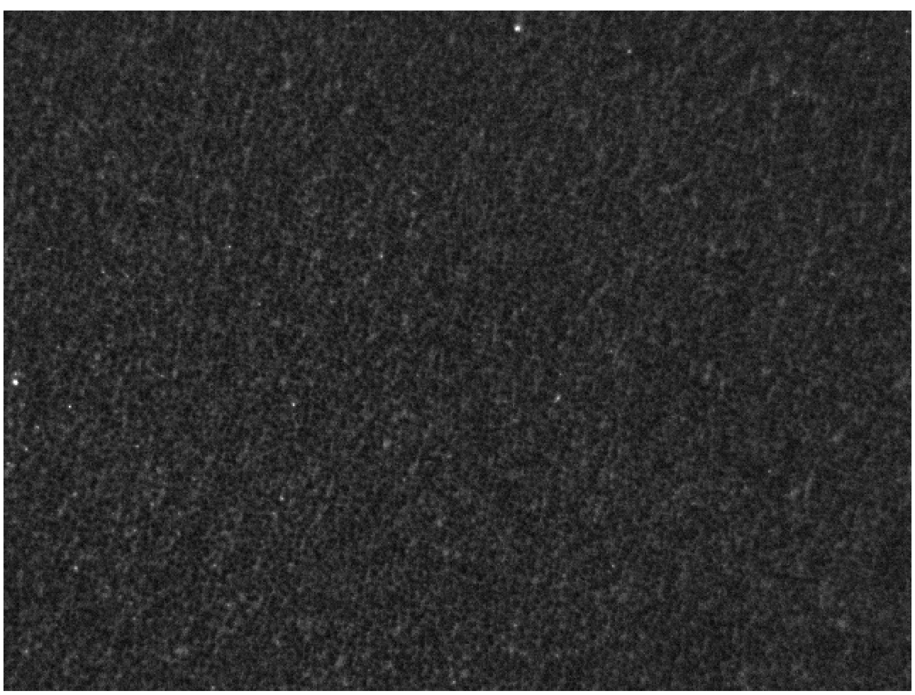

Figure 6. Fineshut KIWAMI, macro photo showing an 8 × 6 mm portion of the sample, the small holes are roughly 50 microns across.

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