Characterization of the Reflectivity of Various Black and White Materials

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ABSTRACT

We report on an expanded catalog of total reflectance measurements of various common (and uncommon) materials used in the construction and/or baffling of optical 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.

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

1. INTRODUCTION

Maximizing the sensitivity of any optical or infrared astronomical instrument requires careful consideration of stray and scattered light within. Minimization of these unwanted reflections and scattering can be accomplished via baffles, material surface finishes, and coatings. In the first several papers of this series,[1–3] a broad range of black materials and coatings were tested. We now report on an expanded set of samples. The total reflectivity measurements are relevant to ultraviolet, optical, and near-infrared instrumentation (250 nm $< \lambda <$ 2500 nm). Updates to the project website (https://instrumentation.tamu.edu/instruments/reflectance/) including downloadable data files and interactive plots are in progress.

2. TOTAL REFLECTANCE MEASUREMENTS

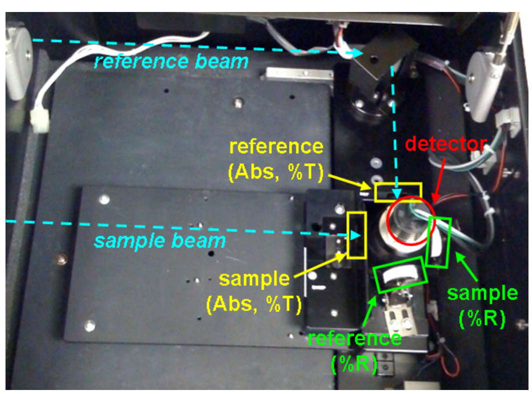

Figure 1. Internal view of the U-4100 UV-Visible-NIR Spectrophotometer. Test samples are placed at the 3 o'clock position (sample %R).

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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.

The U-4100 dual beam spectrophotometer uses two different lamps to cover a wide range of wavelengths. A deuterium lamp covers the far UV (< 345 nm), and a tungsten lamp is used for UV, visible, and near-IR measurements. The U-4100 is capable of measuring both reflectance and transmittance of solid and liquid 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 Hitachi High-Tech U-4100 UV-Visible-NIR 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 small features visible in most material scans near this wavelength.

Several new materials listed in Tables 1 and 2 have been tested since our 2014 and 2018 publications on this subject.[1–3] Total reflectance measurements are shown in Figures 2, 4, 5 and 6.

Table 1. Black materials tested.

Code	Sample
B0075	Conclarity 2" Black Felt Tape
B0076	Krylon Ultra-Flat
B0077	Nyxlon (wood surface treatment)
B0078	Avery Marks-A-Lot Permanent Marker
B0079	Sharpie Permanent Marker
B0080	Speedball Super Black #3338 Ink
B0081	Koh-I-Noor Trans.Mix 9065F.BLA Ink
B0082	Rapidograph Ultradraw 3085F.BLA Ink
B0083	Dixon Redimark Permanent Marker
B0084	Metron Solvent Resist Ink
B0085	Metron Permanent Ink
B0086	Ground glass slide with black anodized Aluminum backing
B0087	Krylon Industrial Acryli-Quik, Ultra Flat Black
B0088	Krylon Interior Exterior, Ultra Flat Black
B0089	Rustoleum Flat Protective Enamel, Flat Black
B0090	Krylon Supermax, Flat Black
B0091	CRC All Purpose Enamel 18008, Flat Black
B0092	Black Anodized Aluminum - Backer for B0086
B0093	Alion Science and Technology MH-2200
B0094	Sharpie water based paint/flat black wide tip paint pen

Table 2. White materials tested.

Code	Sample
W0039	Tyvek Solid Fabric type 10, McMaster Carr part 1650T21
W0040	Tyvek #1070 1443R STYLE Type 14, www.questoutfitters.com
W0041	Tyvek #1071 1460C STYLE, www.questoutfitters.com
W0042	Tyvek #1075 1443R STYLE Type 14-S (metallized), www.questoutfitters.com
W0043	Polytetrafluoroethylene (PTFE) sheet

3. MATERIALS TESTED

Samples were prepared out of both metal and non-metal materials. Sample sizes were limited to two inch square or round, and no more than 0.75 inch thick in order to accommodate the space constraints of the spectrophotometer. A list of newly tested samples is provided in Tables 1 and 2. Previous sample labeling schemes based on alphanumerical codes to indicate material type, if it was a paint, fabric, or other material etc. became confusing due to the broad range of materials tested to date. All samples have been re-named into two categories, black material labels start with 'B' followed by a four digit number, white materials start with 'W', again followed by a four digit number. The number indicates the order in which the samples were created, similar sample types are not guaranteed to be consecutive.

Several different classes of materials were tested. The first was a collection of commercially available black spray paints, samples B0076 and B0087-B0091. Samples were prepared on 6061 aluminum blanks, sanded with 120 grit sandpaper and painted with several light coats. Samples B0087 and B0088 were coated with SEM 39683 primer prior to painting. Two additional paints were tested, MH-2200 from Alion Science and Technology and a Sharpie water based flat black paint pen. MH-2200 was applied using a single action airbrush with 20-30 psi micron filtered nitrogen as propellant. Stock viscosity was used and a minimum of two passes, one horizontal and one vertical, eight passes is typical depending on brush distance. Unpainted surfaces should be masked with 3M Blue Painters Tape. Prep Aluminum surfaces to vacuum clean prior to painting, no primer.[4]

The second collection of materials were selected as candidates for painting the edges of lenses and prisms to reduce scattering. These samples were painted onto microscope slides with two different preparations. The first was a clean microscope slide to check adhesion on a smooth polished surface. In the second preparation, a microscope slide was converted to a "fine grind" surface, similar to what is a common edge finish for lenses, using a "fine" diamond sharpening plate (600 grit) to grind the surface, using water for lubrication. Samples include some that have been used by commercial lens manufacturers,[5] including several different permanent markers and India inks. Additional variants of these materials were tested as well as two industrial marking paints. Sample B0086 consisted of a blank microscope slide with the back side fine ground and a black anodized aluminum backer plate in an attempt to recreate a lens mounted in an anodized Aluminum cell. The backer plate was also scanned separately (B0092).

The cyclical variability seen in B0092 as well as all of the permanent marker samples starting around 1500 nm is an artifact of the particular piece of anodized Aluminum (see Figure 4, B0092) which was slightly visible through the permanent marker. The various permanent markers were difficult to apply to the slides, coverage was streaky and incomplete. The ground glass surface was better, but still somewhat patchy. This resulted in reflection of both the permanent marker as well as the anodized Aluminum backer. In the future, these samples will be tested without a backer material or a different backer material. The Speedball Super Black (B0080) was the easiest India Ink to apply, drying quickly and evenly with a matte finish. Koh-I-Noor and Rapidograph (B0081, B0082) tended to pool and dried with a glossy surface. These two required multiple coats to get complete coverage and took much longer to dry. Two industrial marking inks from Metron performed well (B0084, B0085) and have the advantage of being available in both small amounts packaged with a precision applicator tip (Figure 3), as well as larger quantities suitable for painting larger areas. The Metron inks are fairly thick, however both list the ability to be thinned with water. This application method has not yet been tested.

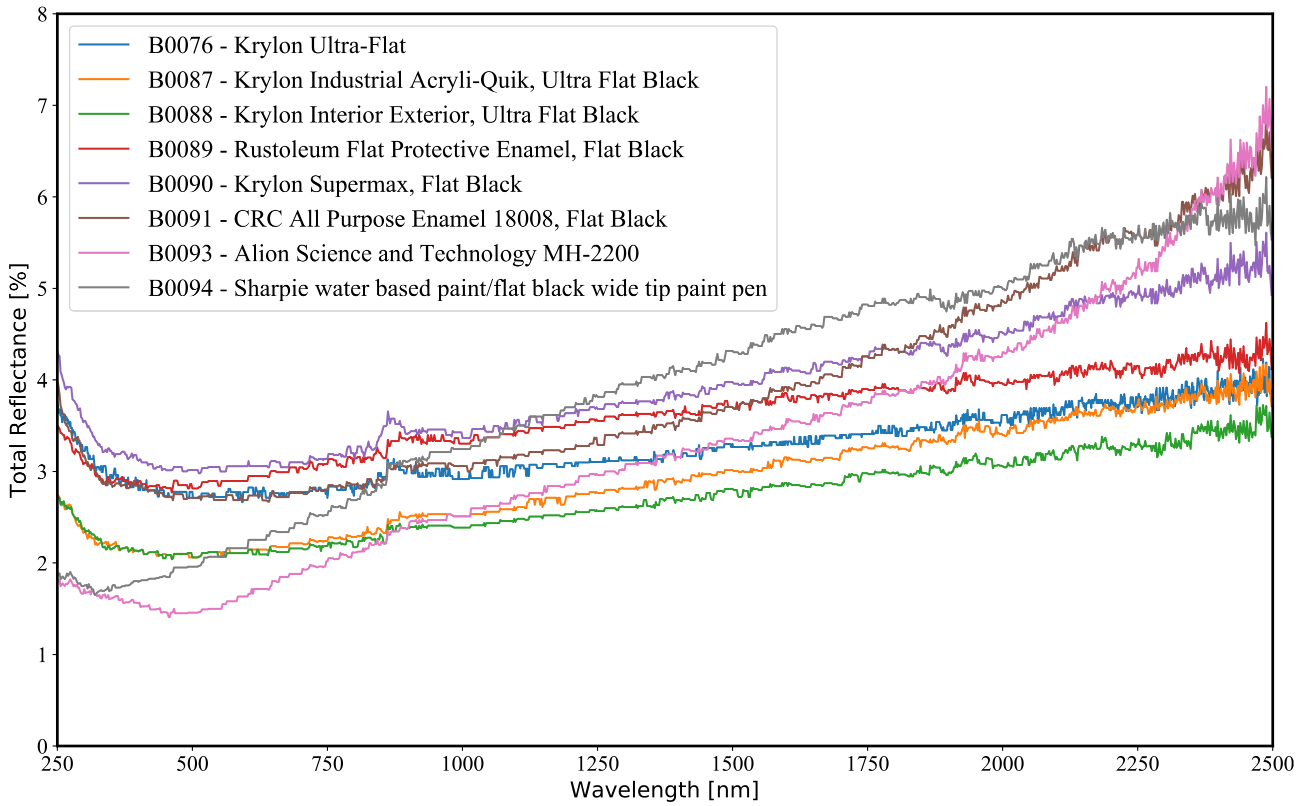

Figure 2. A range of black spray paints were tested (B0076, B0087-91). B0093 was also sprayed, via a single action airbrush

Figure 3. Metron industrial ink packaged with a precision applicator tip. The tip is self cleaning when the cap is put on.

Several other materials were tested, Philip Evans from the University of British Columbia has developed a wood treatment that produces a black surface called Nxylon (from Greek for the Goddess of night, Nyx, and xylon, from wood). The absorption features between 1250-2500 nm are likely due to water. An inexpensive black felt tape was also tested that may be useful in stray light control in a laboratory optical setup. It has very good performance from 250-700nm and then total reflectance begins to rise quickly. These materials are shown in Figure 5.

Several white materials were tested, a sample of Tyvek fabrics as well as a piece of PTFE sheet. Most of the Tyvek fabrics have very flat reflectance across the full visual spectrum with only minor variation across most of the short wave infrared spectrum. They are lightweight, durable, and water resistant and sheets can be sewn or bonded together and would make a good flat field calibration screen.

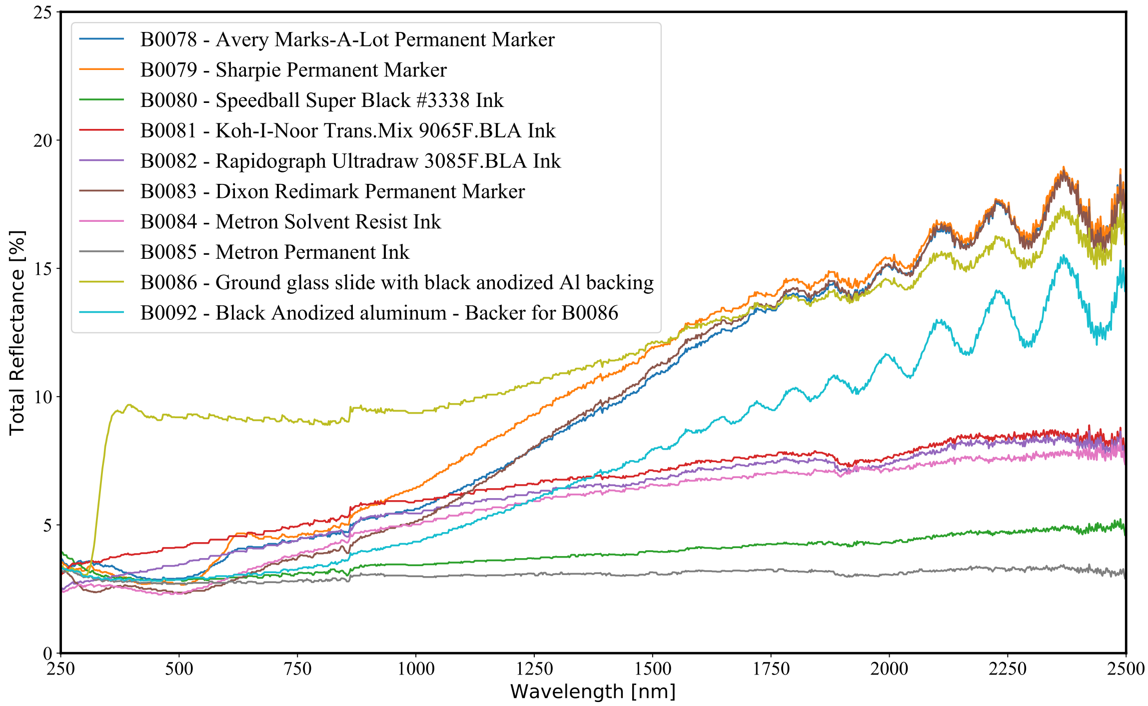

Figure 4. Lens and prism edge blackening candidates, a mixture of permanent markers, India inks and industrial marking inks.

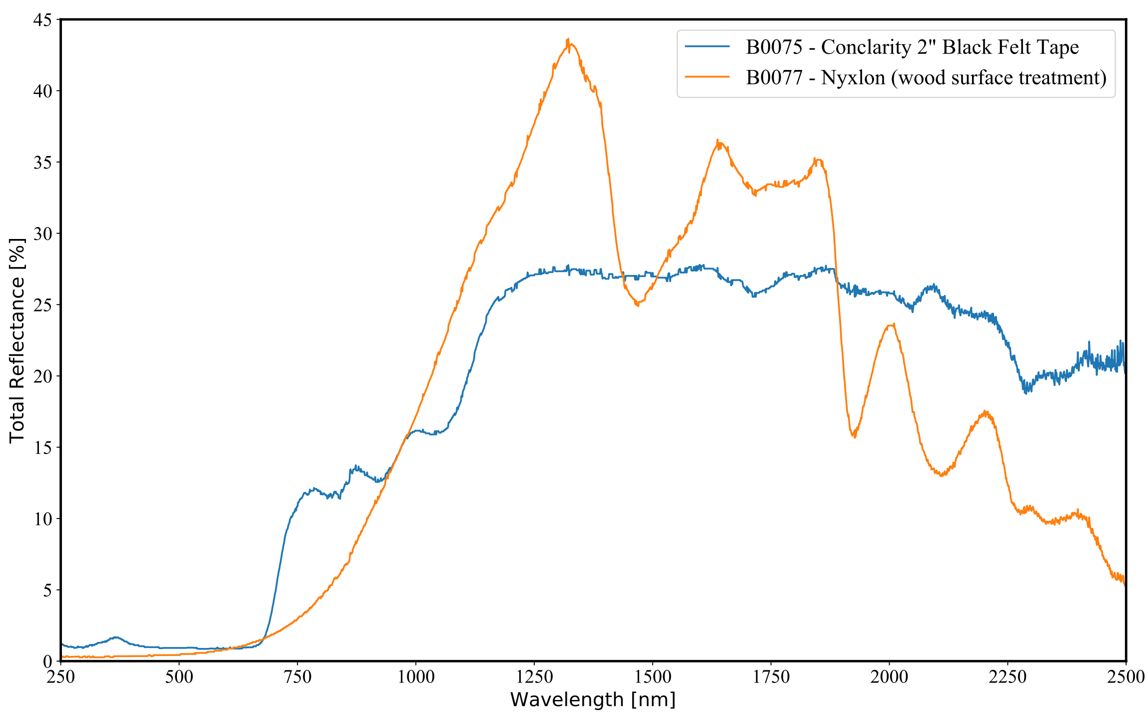

Figure 5. Other black materials, including black felt tape and a wood substrate with black surface treatment.

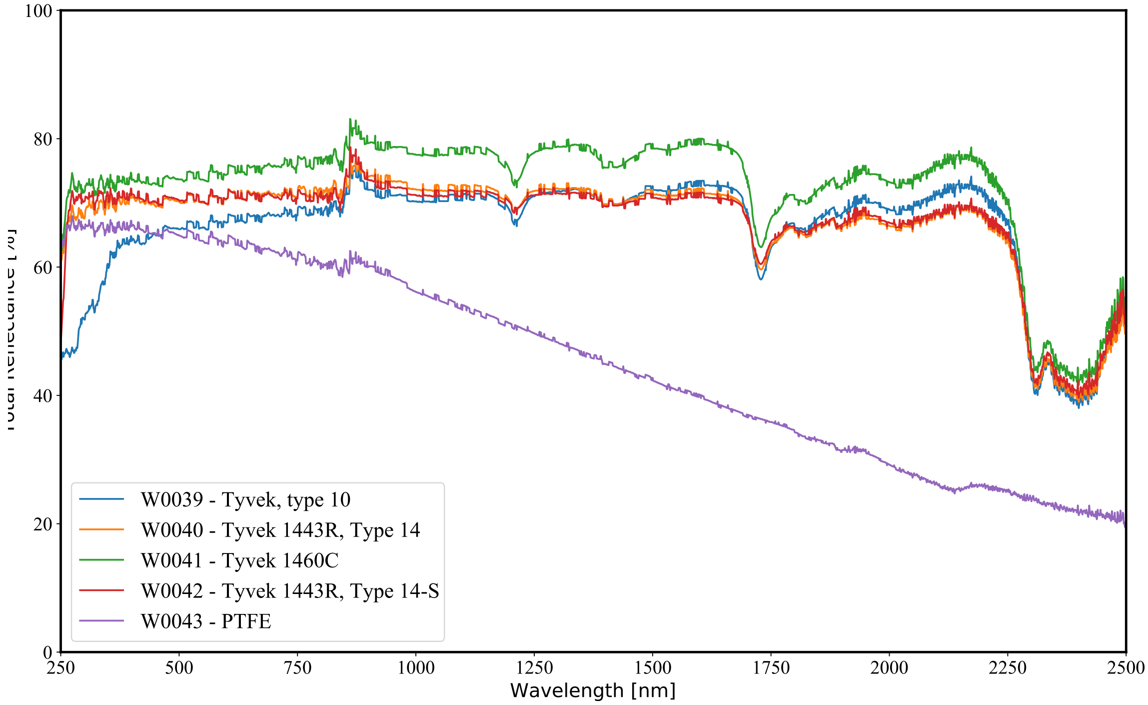

Figure 6. White materials that may be used as calibration screens. PTFE is best suited for optical applications, where the total reflectance is still relatively high (> 60%).

4. 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 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 at https://instrumentation.tamu.edu/instruments/reflectance/. 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.

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