A Reflection on Optical Coatings

Measuring the Impact of Dielectric Reflective Coatings on Image Brightness

By Jim Thompson

EDITORS NOTE:

In the following article, Jim Thompson compares relative image brightness of the traditional Schmidt-Cassegrain design to that of a specific Ritchey-Chrétien of same aperture across various targets, filters and sensors. Jim uses SCTs as reference points because of the tremendous popularity and, therefore, near-universal familiarity of that historic design. When we asked SCT enthusiasts to preview the article, several were quick to point out the relative advantages of their SCTs, including lack of diffraction spikes, fully enclosed tube, accommodation of the popular HyperStar system, ease of collimation, overall versatility, etc. Others noted, for example, that the primary mirror of current Meade 8-inch ACFs are actually 8.25 inches in diameter and that we were, therefore, not actually comparing like apertures. Our answer to those objections is that the following is not a direct comparison of the overall performance of competing designs, but an analysis of just a single aspect – image brightness – based upon specific coating-reflectivity data.

This past spring I did some telescope testing for my friend Rock Mallin, with the objective of comparing, back-to-back, a typical commercially available Schmidt-Cassegrain telescope (SCT) to an equivalent aperture Ritchey-Chrétien (RC). To perform the test, I used my own 8-inch Meade LX-10, comparing it to an 8-inch MallinCam VRC loaned to me by Rock. As expected, the VRC was found to provide superior image brightness, but many people who reviewed my test report questioned how much of the difference was due to the fact that I have an older model of SCT. How would the VRC compare to a more modern SCT?

The differences in image brightness between the two scopes I tested, once focal ratio was been accounted for, is due to the differences in the transmissive efficiency of each scope's optics. The SCT has four reflective surfaces (two sides of corrector plate, primary and secondary mirrors) at which some of the incoming light can be lost. The RC has no corrector plate and

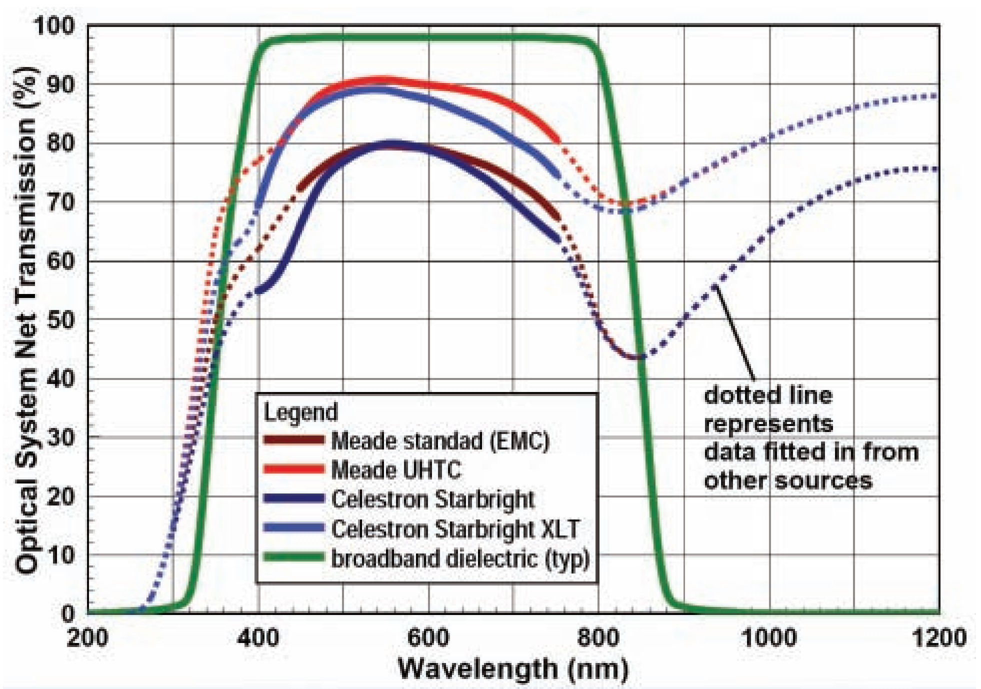

Figure 1: Optical System Spectral Transmission By Coating System: Total system response data is available from Meade and Celestron for the visual band. Data for outside the visual band, and for a typical dielectric mirror has been estimated by combining data from several third-party sources.

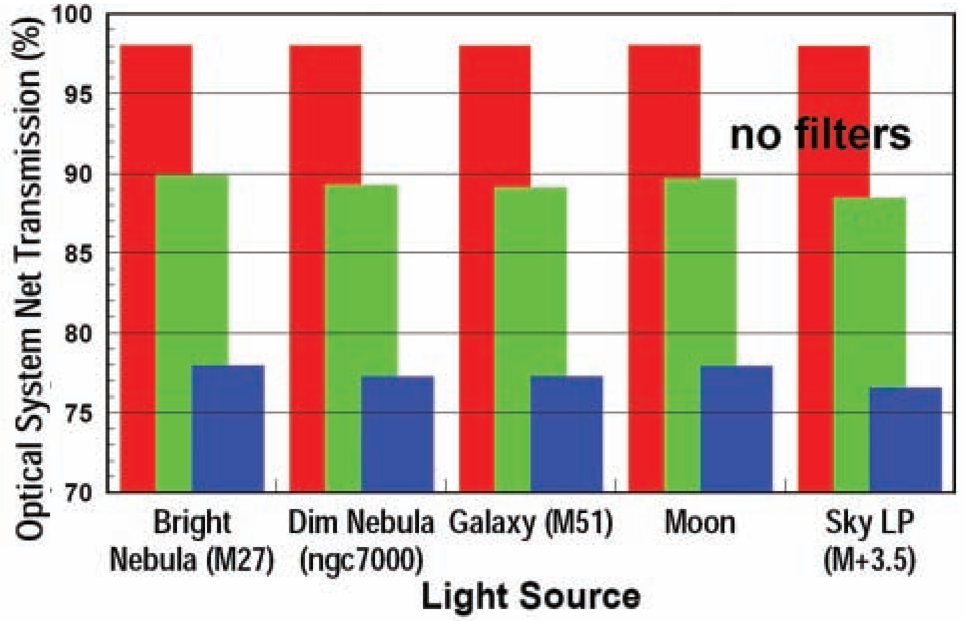

Figure 2: Predicted Optical System Net Transmission – Visual Use: The improvement in image brightness between standard coatings, UHTC coatings, and dielectric coatings is consistent regardless of the target when the scopes are being used visually.

therefore only has two reflective surfaces to worry about.

The two scopes also have different coating technologies applied, the SCT using traditional metallic aluminum coatings with a dielectric protective topcoat, and the VRC has purely dielectric reflective coatings. Finally the LX-10 used in my testing is about 10 to 15 years old, so on top of the fact that it has older technology coatings there has possibly been some degradation of the coatings as well. To fully understand the differences in performance between these two types of scope, it is necessary to examine the coating technologies in more detail.

I was able to easily find manufacturer published data from Meade and Celestron on their coating systems. Meade identifies two coating systems: standard, and Ultra High Transmission Coatings (UHTC). Today's "standard" Meade coating is equivalent to the EMC coating system on my LX-10. Celestron also has two coating systems: Starbright, and Starbright XLT.

On all SCT mirrors, the coating providing the bulk of the reflectivity is an initial layer of pure metallic aluminum. To protect the aluminum from corrosion and to improve its reflective properties, a thin dielectric coating is applied on top. Mirror top coat materials include various combinations of SiO, MgF2, SiO2, and TiO2. Corrector plates also have coatings applied in order to reduce reflectivity. Corrector plate anti-reflection coating materials include various combinations of Al2O3, TiO2, and MgF2.

Figure 1 shows the transmission data provided by each manufacturer for their coating systems. The plot shows the net percentage of light passed by the entire optical system. I have combined the manufacturer data with other information available on the web in order to extrapolate the performance graphs beyond just the visual band.

The mirrors of the RC I tested do not use a metallic coating to give them their reflectivity. They use a completely dielectric coating. A dielectric coating works much the same way as a band-pass filter made for light pollution. Many thin alternating layers of non-conductive (dielectric) material are applied to the glass substrate, which in this case is the mirror blank. A small percentage of the incoming light is reflected at each interface between layers due to the change in refractive index. The thickness of each layer is selected very carefully so that each layer's reflection is in phase with the neighboring layer's reflection, resulting in constructive wave interference. The result is very high (99.9-percent) reflectivity for the design wavelength.

Dielectric coatings are very hard and durable, making them easy to care for. They have been in use for several years on mirror diagonals, and now that the costs to apply are coming down, dielectric coatings are becoming popular on telescope optics as well.

Figure 1 shows a typical transmission curve for an RC with dielectric coated mirrors. I was unable to find data specific to the VRC's actual mirrors, so the plot shown is an amalgamation of data from several different coating suppliers in North America. Note that outside the design wavelength band, dielectric mirrors have basically zero reflectivity. This was a surprise to me when I initially discovered it.

To determine the impact of coating systems on telescope performance, I combined the data in Figure 1 with the spectral data I had already on hand for the detector (human eye, MallinCam), light source (bright nebula, dim nebula, galaxy, Moon, light polluted sky), and filter (no filter, Astronomic UHC, Baader UV/IR, 680-nm Pass). By stacking these four things together numerically, detector + filter + telescope + light source, I was able to predict the relative brightness of each coating system. I used the Meade system to perform my calculations.

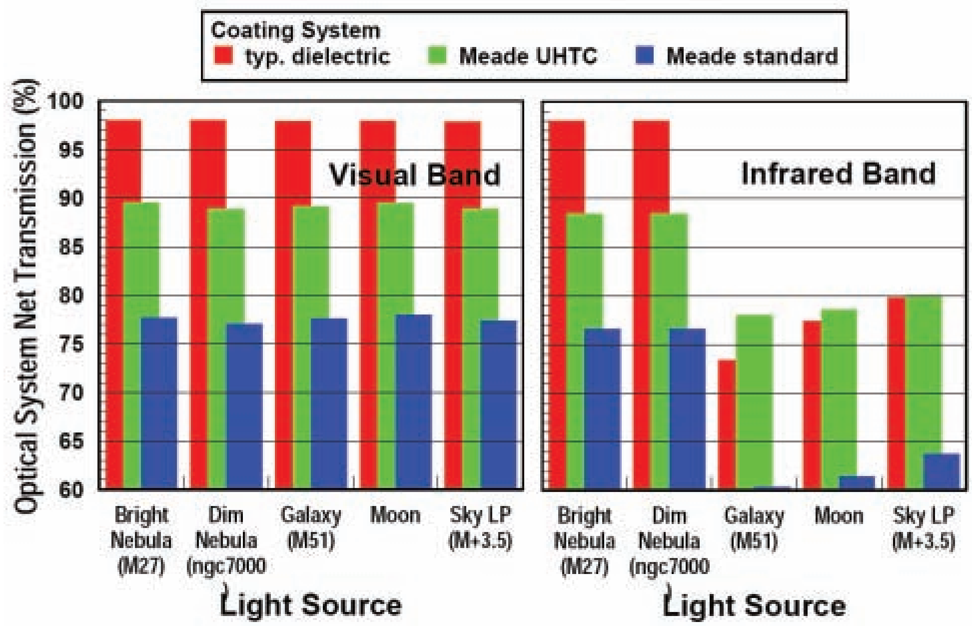

Figure 3: Predicted Optical System Net Transmission – CCD Use: In the visual band, the difference in image brightness between different coatings is very similar with a CCD as it is for visual observation. The performance is quite different in the near-infrared band however, having implications when viewing IR-rich objects like galaxies, globular clusters, the Moon or even planetary work.

Figure 2 shows the relative brightness of each coating system when the scopes are used visually. Regardless of light source, the more modern Meade UHTC coating is about 16-percent brighter than the standard coating. The dielectric coated RC performs even better, at about 27-percent brighter than the standard-coated SCT.

Figure 3 shows the relative brightness of each coating system when the scopes are used with a typical CCD camera, in this case a MallinCam Xtreme (sensor = Sony ICX418AKL). Relative scope performance on bright and dim nebulae is similar to what was found during visual use, but performance on infrared-rich light sources like galaxies and the Moon varies significantly.

To confirm my predictions of relative brightness, I went back to some of the images I collected during my telescope comparison testing. **Figure 4** shows screen captures of M42 from my testing taken with my SCT and the RC, with no filters. Accounting for the focal ratio difference (f/10 versus f/8), the RC image still took less exposure time to get the same relative image brightness.

Using the exposure times as a measure of the relative brightness between the two scopes, the RC was about 26-percent brighter than the SCT. The predictions in Figure 3 suggest that the RC should be around 26- to 27-percent brighter, meaning that the optics in my LX-10 don't seem to have degraded at all; a reasonable and entirely believable outcome. My LX-10 may be 10 to 15 years old, but it has coatings that include a protective dielectric top coat which prevents degradation. I have also cleaned my mirrors and corrector plate within the last 12 months, so scope performance should be pretty close to on-spec.

Figure 5 shows screen captures from my testing with a 680-nm high-pass filter. Based on the exposure time and the difference in focal ratio, the RC was approximately 20-percent brighter than the SCT. My predictions suggest the RC should be about 21-percent brighter than the SCT. Again my direct observations are consistent with the predicted brightness of these different telescopes. Having two separate observations corroborate my predictions gives me a high level of confidence that the predictions are accurate.

Continuing with that assumption, the fol-

Figure 4: SCT/RC Visual Comparison – M42 with no filters: These video frames of M42 from the author's MallinCam were captured at different exposure times in order to match image brightness. The different exposure times can then be used to calculate the relative brightness of the two telescope systems.

lowing conclusions can be made about the performance of these different scopes when used with a MallinCam or other CCD based device: (1) When viewing emission nebulae or solar system objects using the entire band of the CCD (i.e., no filters), the RC is 26- to 28-percent brighter than SCTs with standard coatings, and 9- to 10-percent brighter than SCTs with enhanced coatings like UHTC or Starbright XLT.

(2) When viewing galaxies or clusters using the entire band of the CCD, the RC is 24- to 25-percent brighter than SCTs with standard coatings, and 4- to 5-percent brighter than SCTs with enhanced coatings.

(3) When limited to just the visual band

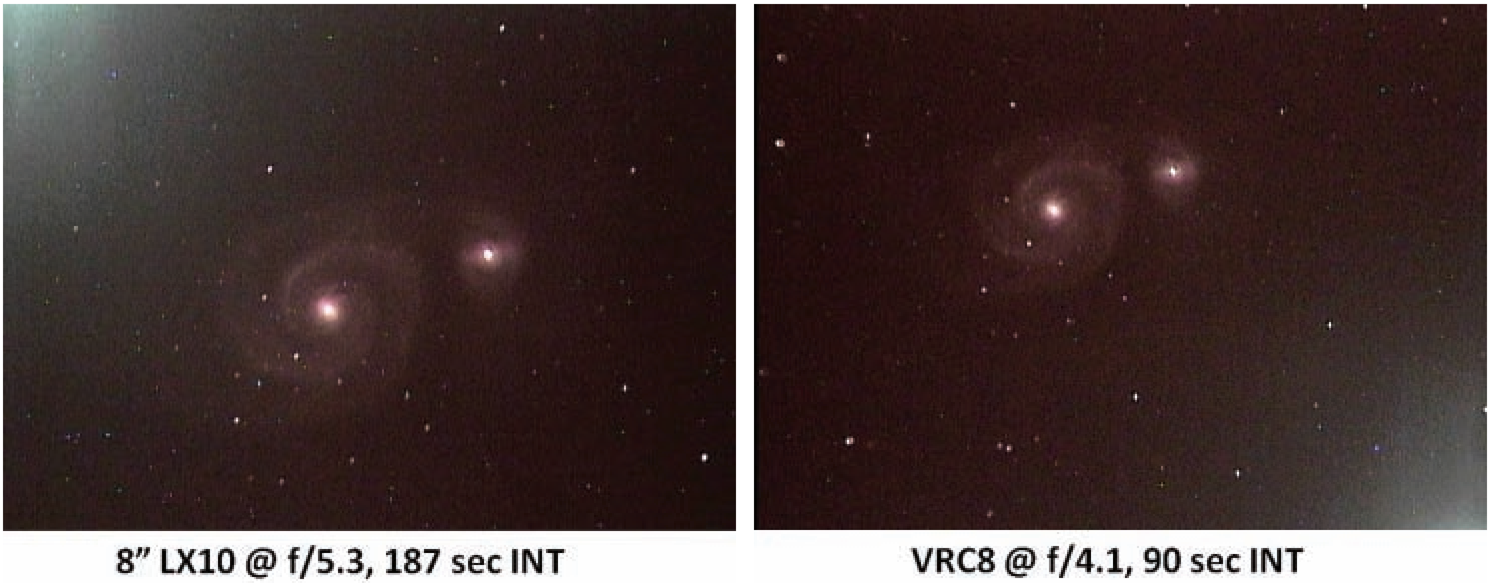

Figure 5: SCT/RC Visual Comparison – M51 with 680-nm high-pass filter: These video frames of M51 from the author's MallinCam were captured at different exposure times but with an IR high pass filter installed.

(400-700 nm) using a UV/IR Cut filter, the RC is 25- to 27-percent brighter than SCTs with standard coatings, and 9- to 10-percent brighter than SCTs with enhanced coatings, regardless of the target.

(4) When limited to just the infrared band (>700 nm) using an IR high-pass filter, the RC is approximately 20- to 25-percent brighter than SCTs with standard coatings, and 1- to 6-percent dimmer than SCTs with enhanced coatings, assuming the target is IR-rich such as the Moon, planets, galaxies, or clusters. Optics with dielectric reflective coatings designed for visual use are probably not as suitable for use with IR high-pass filters that have cut-off wavelengths above 800 nm.

Thus, the bottom line is that by test and by calculation, the optical system of the RC with its dielectric coatings generally results in greater image brightness compared to modern SCTs, regardless of coating technology. One question I can't answer for certain is how a hypothetical but entirely possible SCT with dielectric mirror coatings may compare to the RC. Based on the fact that an SCT has a corrector plate at which some percentage of the incoming light is lost, but an RC does not, I would have to guess that the RC will always be a little brighter than the SCT. As for the question on whether or not it is worthwhile to upgrade my old LX-10 for a modern RC or SCT with UHTC optics, getting a 15- to 25-percent increase in image brightness is pretty significant.

For questions please contact me through email at: karmalimbo@yahoo.ca. ATT