A New Look at Johnson/Cousins Photometric Filters

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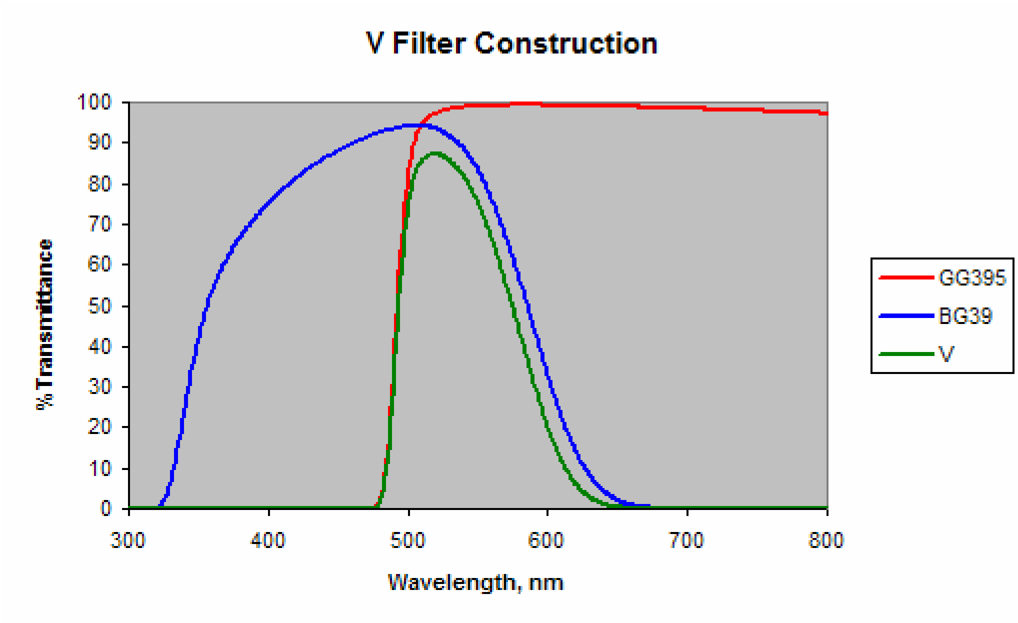
Abstract

Some of the Schott glasses originally prescribed by Bessell in creating Johnson/Cousins UBVRcIc photometric filters for use in CCD cameras are no longer available. We have selected new glasses, and added interference coatings, to create a new set of filters that accurately match the original Johnson/Cousins bandpasses. This paper will describe the new prescriptions and give preliminary results from on-telescope tests.

Introduction

Photometric filters were first used to better match photomultiplier tube output to photographic magnitudes. The first UVB (U= ultraviolet; V=visible=green; B= blue) filters were used in this way. The advent of CCD (charge-coupled device) cameras led to further filter development, because CCDs were sensitive in the red and near-infrared, and picked up light "leaks" from the filters that the early photomultiplier detectors could not detect. These "leaks" arose from the glass filters also transmitting light in the near-infrared. For example, deep-blue Schott B25 glass used in the B filter also transmits near-infrared light above 700 nm. Cyan Schott glass BG39 is used in the B filter to eliminate the near-infrared "leakage" from BG25. These photometric filters were developed with colored glasses produced by Schott Glass Industries of Duryea, Pennsylvania.

For example, the photometric V filter is made from two Schott glasses; 2 mm of cyan BG39 and 2 mm of yellow GG495, as shown below. BG39 defines the trailing edge, or high wavelength side of the V band pass. It cuts out all near-infrared light. GG495 defines the leading or low-wavelength edge as a cut-on filter, eliminating UV and blue light. These glasses are bonded together with UV-cured, UV-transmitting epoxy. The resulting V spectral curve is shown in green.



Bessell (Bessell, Michael, S. "UVBRI Filters for CCD Photometry", *CCD Astronomy*, Fall 1995, pp. 20-23) defined several CCD filter "recipes" made from Schott glasses for the entire set of UVBRI filters. Unfortunately, Schott Glass discontinued some of the glasses that Bessell specified in his work by the time that Chet Schüler introduced Schüler Astro-Imaging UVBRI filters in 1997. Schüler had to redefine the filters to match Bessell's work as closely as possible with the existing Schott glasses at that time. Some of those glasses are no longer made today, and Astrodon-Schuler photometric filters must be made with other Schott glasses.

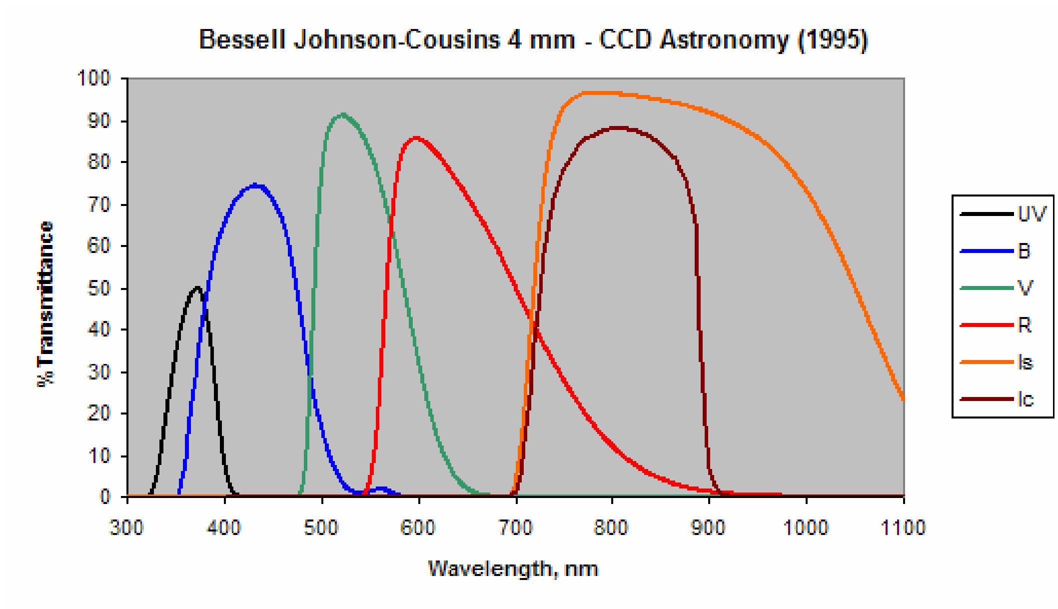
Thus, the glass recipes and resulting curves have changed over time. The purpose of this short article is to (1) trace the history of the UVBRI spectral curves, (2) propose slight modifications that best match Bessell's goals for photometric filters with existing Schott glasses, and (3) summarize test results on the new formulations taken at the U.S. Naval Observatory at Flagstaff, Arizona.

Bessell's Spectral Curves

Bessell (1995) defined the following Schott Glass recipes for 4 mm filters (glasses highlighted in yellow are no longer available):

Filter	Glass 1	Glass 2	Glass 3
U	1 mm UG1	2 mm S8612*	1 mm WG295**
B	1 mm GG385	1 mm BG4	2 mm BG39
V	2 mm GG495	2 mm BG39	
R	2 mm OG570	2 mm KG3	
I	2 mm RG9	2 mm WG295	

*Substitute BG39 for S8612 **WG395 is a filler glass to achieve 4 mm thickness



These filter scans appear different than those presented in Bessell's article because he normalized their maximum throughput signals to 100%.

The I filter curve presented in Bessell's plot is now designated as Ic. This filter has a steep cutoff near 900 nm and no transmission at longer wavelengths. It cannot be made from Schott glasses like the other photometric filters. It additionally requires a dielectric coating to block longer near-infrared wavelengths with a proposed 50% cut-off at 870 nm. Bessell stated this in the text of the article.

However, the "CCD Filter Recipe" that Bessell proposed, using 2 mm of Schott RG9 glass and 2 mm of Schott WG295 filler glass actually corresponds to what is now referred to as Is, as shown above. So, there is some confusion because two types of "I" filters described.

The Ic filter in part is used in part to avoid the non-linear response of the Silicon CCD detector near its long wavelength limit above 1000 nm. This is only important in studies involving the reddest stars.

Also notice that the UV filter only achieves about 50% peak transmission in a region where CCD detectors are already inefficient. UV sensitivity in current CCDs has improved considerably, but UV measurements are still problematic.

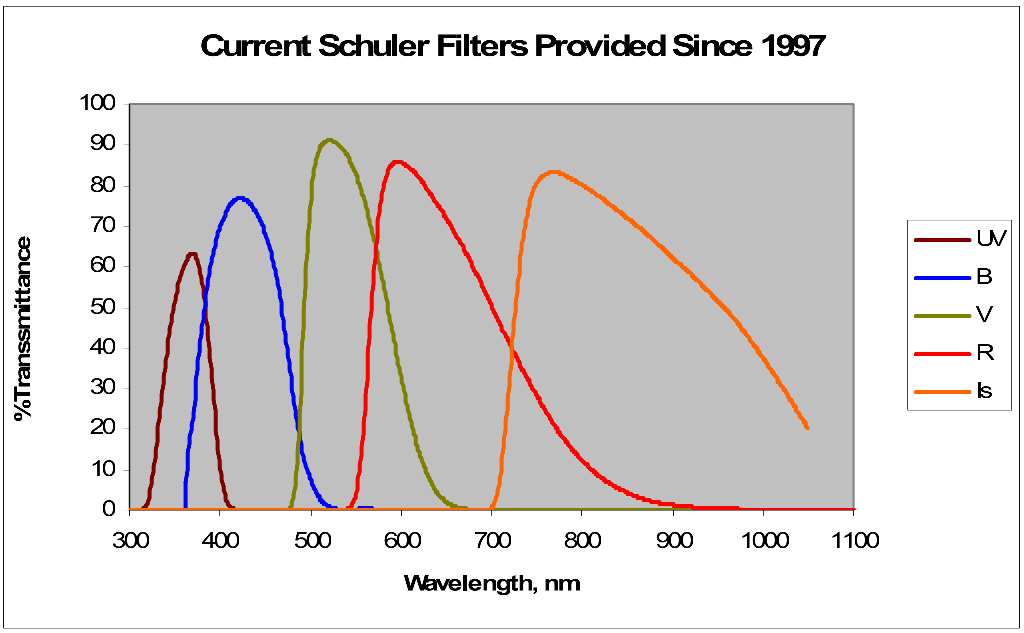
Schüler Filters

Schüler maintained the same glass formulations for the widely used B and V filters, but had to change those for the other filters, Again, glasses highlighted in yellow are no longer available from Schott Glass.

Filter	Glass 1	Glass 2	Glass 3
U	1 mm UG1	1 mm BG39	2 mm WG295**
B	1.5 mm BG25	1 mm BG39	1.5 mm GG385
V	2 mm GG495	2 mm BG39	
R	2 mm OG570	2 mm KG3	
I	3 mm RG9	1 mm KG4	

**WG395 is a filler glass to achieve 4 mm thickness

Most Schuler filters made in the past 8 years have been made with these formulations. The spectra of Schuler filters are shown below and may be compared with those from the original Bessell design above. The discontinued glasses are still available. Some vendors ordered large quantities and still have them in inventory.



Proposed Changes for Testing

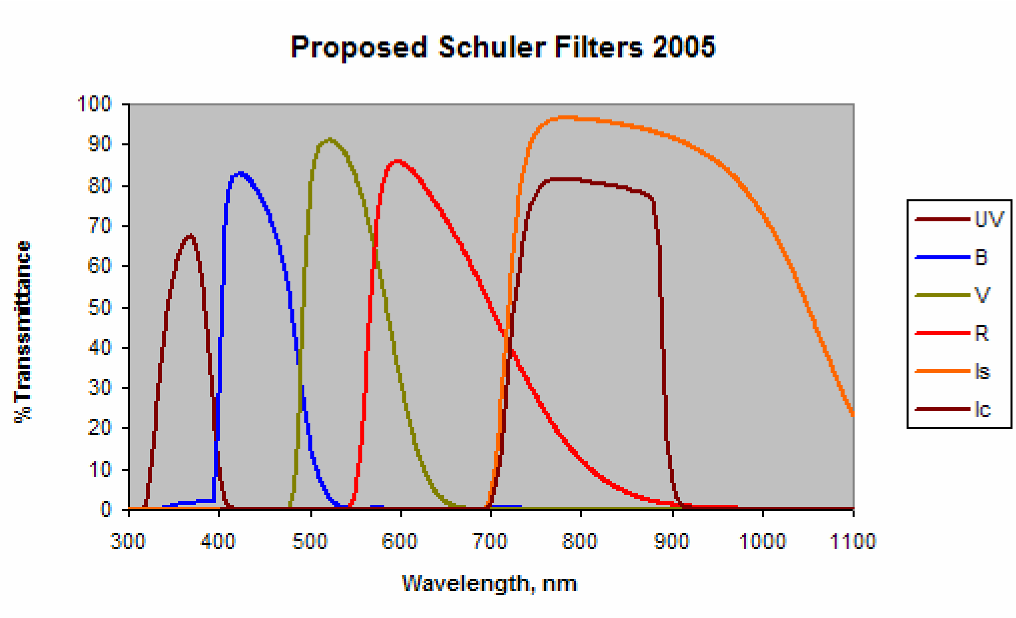
Based upon currently available Schott glasses, the following formulations are proposed:

Filter	Glass 1	Glass 2	Glass 3
U	1 mm UG1	3 mm BG40	
B	1.5 mm BG25	1.5 mm BG40	1 mm GG395
V	2 mm GG495	2 mm BG39	
R	2 mm OG570	2 mm KG3	

Is	2 mm RG9	2 mm WG295	
Ic	1 mm RG9	3 mm *	

* borofloat glass with dielectric coating

The spectral curves corresponding to these formulations are shown below:



These spectral curves represent photometric filters with anti-reflective (A/R) coatings on both surfaces. Less expensive filters without A/R coatings have approximately 92% of the throughput shown above.

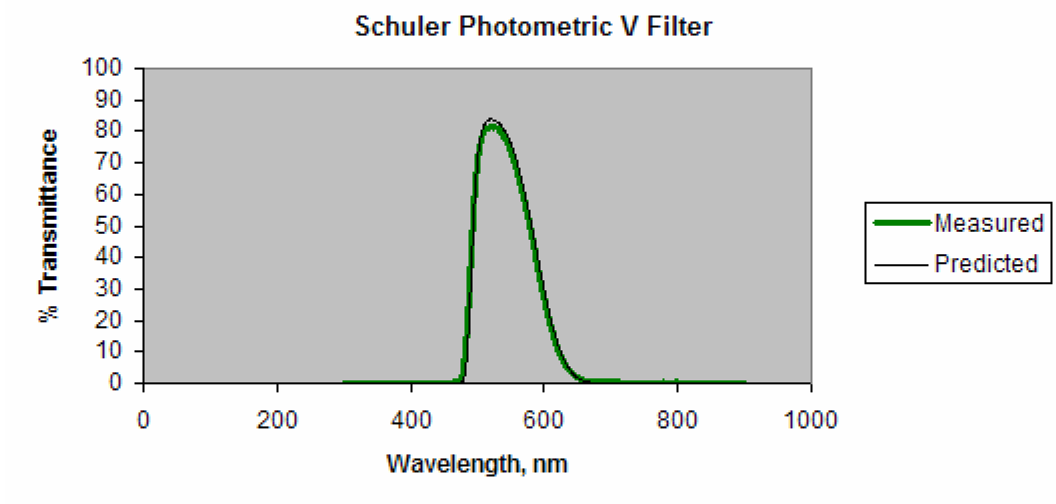
A 5% improvement in peak transmission of the UV and B filters were gained by these formulations. The V and R filters have not changed over time.

The Ic filter utilizes a clear glass with a dielectric coating to achieve the recommended cut-off near 900 nm. The addition of the dielectric coating increases the price of the Ic filter over the Is filter made solely from Schott glasses.

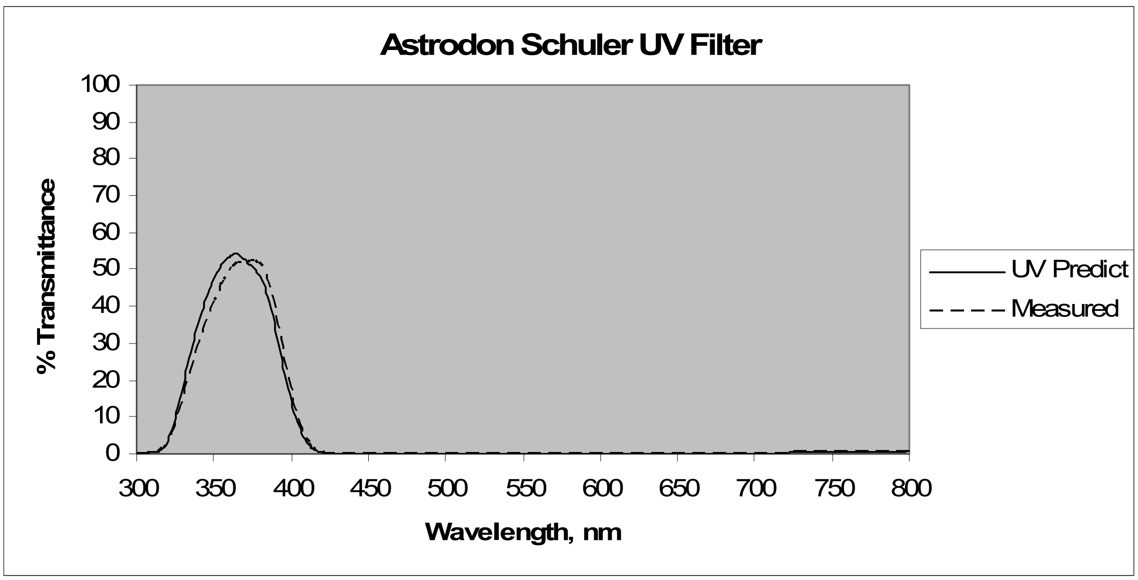
Test Results

Spectral Results

Spectral scans were taken of the V filter and compared with the predicted spectrum based upon Schott below. The predicted spectrum now includes the Fresnel surfaces losses. There is close agreement between the two.



The UV performance, including surface reflective losses, are compared below:



The U filter only achieves about 52% peak throughput, and is thus not very efficient. A/R coating would increase the throughput to 55-56%.

Photometric Test Results

3" square filters, 4 mm thick were prepared from these formulations and delivered to Dr. Arne Henden for testing at the 1 m telescope at the U.S. Naval Observatory at Flagstaff, Arizona.

Coef	**Night 1**	**Night 2**	**Average**	**Expected**
V	-0.014	-0.003	-0.008	0.0
B-V	0.986	0.948	0.967	1.0
V-Rc	0.986	1.003	0.994	1.0
Rc-Ic	1.029	1.029	1.000	1.0

Date	filt	V	B-V	V-R	R-I
050817	USNO	-4.539	-0.297	0.129	0.309
050818	USNO	-4.503	-0.284	0.131	0.335
Ave	USNO	-4.52	-0.290	0.130	0.322

050819	Astrodon Schuler	-4.657	-0.085	-0.149	
050821	Astrodon Schuler	-4.640	-0.063	-0.165	0.677
Ave	Astrodon Schuler	-4.648	-0.074	-0.157	0.677

Filter	B	V	R	I
USNO	-4.811	-4.521	-4.651	-4.973
Astrodon Schuler	-4.722	-4.648	-4.491	-5.168

From these results:

- Schuler B is more efficient than USNO B
- Schuler V is less efficient than USNO V
- Schuler R is more efficient than USNO R
- Schuler I is less efficient than USNO I (both dielectric)

Fogging of V Filters

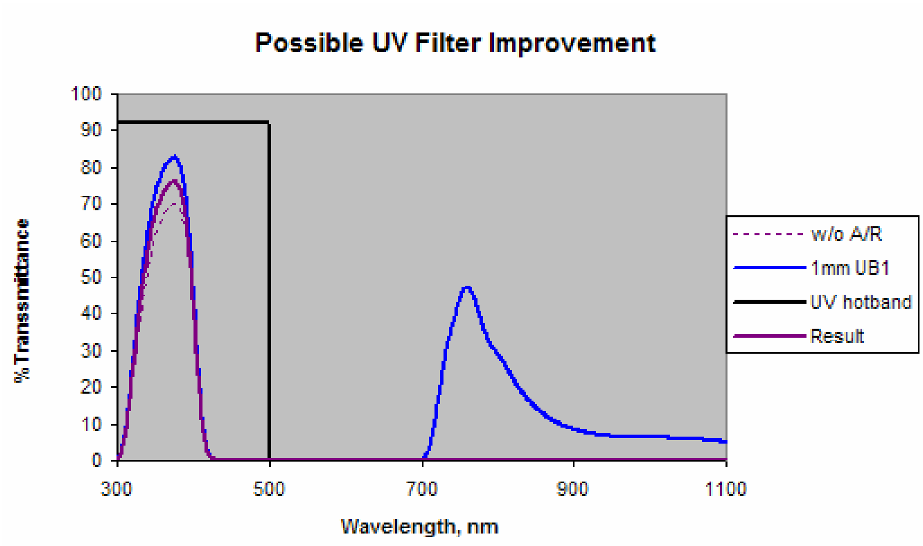
As an aside, a number of members have noticed that some filters become frosted over time, losing transparency and degrading performance. This primarily comes from the BG39 glass used in the V and B filters. In the B filter, the BG39 glass can be protected in between the two other glasses. However, it is exposed in 4 mm thick V glasses. This frosting arises from moisture attack of the surface leading to surface crystallization. G. Walker (priv. comm..) has shown that hydrogen peroxide appears to remove this crystallization easily. The only other method of removing the crystallization is to repolish the filter.

One classical approach to preventing the frosting would be to eliminate the surface hydroxyl groups and form a hydrophobic surface. Such reactants include chlorotrimethylsilane and hexamethyldisiloxane. Once reacted, water does not wet the glass. It beads up and rolls off. The first of these compounds was purchased and applied to BG39 glass. No difference in wetting was detected. This is because BG39 is not a silicate glass where the above surface chemistry can be applied. It is a phosphate glass. A telephone call to Schott glass confirmed this, and we were informed that even their scientists have not found a means to stabilize the surface and prevent the frosting. Another solution is to add a protective glass to the V filter, making it thicker than the other, and hence not parfocal. A final possibility is to use two thin pieces of GG495 rather than the single 2mm glass, and sandwich the BG39. The problem with this solution is the difficulty in UV-curing the glue used in making the filter.

Summary and Path Forward

Overall for the low price of the Astrodon-Schuler filters, they performed reasonably well, i.e. within 15% overall of the USNO BVRI filters. The UV filter did not perform as well.

Some improvements can be made. For example, borofloat glass was used for the dielectric coating used with RG9 in the Ic filter. Another glass with a higher transmission can be used in the future. The U filter had only moderate peak transmission of about 52%. The problem with the U filter is that most Schott glasses used to block the near-infrared transmission of the UG1 glass (see below) also decrease its UV transmission. One option is to use another dielectric coating. Such coatings are called UV hot mirror. The following figure shows a possible U filter made with 1 mm UG1 and 3 mm of a filler glass (e.g. WG295) coated with a UV hot mirror coating.



The idealized UV hot mirror spectrum is based upon data supplied by one manufacturer. If successful, this could lead to an increase in peak UV throughput to the 70-75% range, compared to the current 52%. This would increase the cost of the U filter, as does the addition of the dielectric coating on the Ic filter. As with A/R coatings, there are always compromises between cost and performance.