# A Short Tutorial on Strömgren Four-Color Photometry

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It is quite likely that the Strömgren four-color photometric system has become the most widely used system. I would like to describe the system briefly in this paper, and compare it to the *UBV* system. I will not describe the uses, as many papers using it exist in the literature. A few references will be given at the end, for further reading. A future paper will discuss how one might use the system on small telescopes, as a tutorial for those who are not yet using the system or for those not familiar with it.

Perhaps two things distinguish the system from the *UBV* system, in the main. One, the system is an intermediate-band system rather that a wide-band system. By this I mean that the filters are about 200 to 300 Å wide rather than 800 to 1000 Å wide as are the three in the *UBV* system. There are a number of advantages because of this, some of which I will mention below. One disadvantage is that the number of photons passing through the filters is lower than with the wider filters. If the difference is a factor of four (ratio of the bandwidths), then one would have a 1.5 mag brighter limiting magnitude for the same precision. However, the added "scientific resolution" (see below) more than makes up for this for most research programs.

Second, the bandpasses that define the system are filter defined, rather than defined by a combination of the filter, the atmospheric transmission, and the photomultiplier response. Hence, the filters can be used at any site and with almost any photomultiplier (1P21 or GaAs for example) and still produce the same photometric system to high accuracy.

The filters are approximately as follows:

| Filter: | Material: | Wavelength: | Bandpass: |
|---|---|---|---|
| *u* | Glass | 3500 Å | 300 Å |
| *v* | Interference | 4100 | 200 |
| *b* | Interference | 4700 | 200 |
| *y* | Interference | 5500 | 200 |

(See the Standard Star paper listed below for details.)

As such, the system is most commonly called the "uvby system." The letters stand for "ultraviolet, violet, blue, and yellow."

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The band passes can be defined by filters, by slots in a spectrograph, or by a combination of both.

Why did Strömgren choose these specific bandpasses and widths? If one considers the spectral distribution of typical main sequence stars, the dominant features are:

1. Color (due mainly to temperature differences). One can and does define different color indices, depending on the wavelength of interest. Examples are *B−V* and *b−y*, or *U−B* and *u−b*.

2. The Balmer discontinuity.

3. Blanketing absorption due to heavy elements.

4. Strong individual absorption lines.

Strömgren designed the uvby system to measure the first three of these, and in a way in which the parameters are well separated. Note that the Hβ photometric system is designed to measure the strength of the Hβ absorption line. Other systems have been designed to measure Hα, the CN band, and other features.

The *u*-band is located entirely below the Balmer discontinuity, and above the region of the atmospheric cutoff. It is wide enough to fill most of the region between these two wavelengths.

The *v*-band is located above the Balmer discontinuity, in the region where blanketing is strong. It does have the Hδ line near the center of the band.

The *b* and *y* bands are located above the point (about 4500 Å) where blanketing becomes important (for stars hotter than the Sun, anyway). As such, the *b−y* color index is rather free of blanketing effects, considerably more so than is *B−V* of the *UBV* system.

We can use *u−b* as a color index too, rather like *U−B*. The latter index is not a clean measure of the Balmer discontinuity, as both *U* and *B* slop over the region of the discontinuity. Note that *U−B* is also adversely affected by blanketing. For some stars, it is used as a discontinuity measure, ignoring blanketing effects, while for other stars it is used as a blanketing measure, ignoring discontinuity effects.

Strömgren defined a new index, actually a "color difference," called $c_1 = (u-v) - (v-b)$ as a measure of the discontinuity (the continuous hydrogen absorption). In essence, $(v-b)$ defines a color gradient, and $c_1$ measures how much *u* differs from that gradient. As the blanketing in *u* is about twice what it is in *v*, the $c_1$ index is free of both color and of blanketing effects, and therefore is a rather clean measure of the Balmer discontinuity.

In a similar way, Strömgren defined another color difference to measure the blanketing, $m_1 = (v-b) - (b-y)$. Here, $(b-y)$ defines the color gradient, and $m_1$ measures how much *v* differs from that gradient.

The *y* band is located at 5500 A, the same central wavelength as the *V* of the *UBV* system. As there are generally no strong features in the *V* bandpass, the intermediate-bandpass *y*-filter magnitude can be accurately compared to the wide-bandpass *V*-magnitude. So a magnitude measure with *u* can be accurately transformed to the *V*-magnitude system of the *UBV* system. Hence, no new *V*-magnitude system was defined for the uvby system. One just transforms directly to the *V* system.

The parameters of the system therefore are:

1. A *V* magnitude, measured with the *y* filter.

2. A *(b−y)* color index, measuring color, and hence used to determine temperature, interstellar reddening, etc., rather like *(B−V)* is used in the *UBV* system. The *(b−y)* index is freer of blanketing effects than *(B−V)* is, however. The wavelength separation of the *b* and *y* filters is about 70 percent less than that of the *B* and *V* filters, so the scale of the *(b−y)* index is about 70 percent of the scale of the *(B−V)* system. No problem.

3. The $m_1$ index, measuring blanketing, used particularly for determining abundance differences from star to star. There are calibrations between the measured parameter and [Fe/H], for example. In practice, one uses an index $\delta m_1$, which is the difference between a $m_1$ relation for the Hyades cluster stars and the measured $m_1$ index, to measure blanketing differences. It is this $\delta m_1$ that is calibrated to [Fe/H].

4. The $c_1$ index, measuring the Balmer discontinuity. This index is used to measure temperature (hence intrinsic color) for stars hotter than those where the discontinuity is at a maximum (about spectral type A2), and to measure absolute magnitude (surface gravity) for those stars cooler than the maximum. [The Hβ parameter measures temperature (intrinsic color) for the cooler stars and absolute magnitude (surface gravity) for the hotter ones.]

So a combination of these four parameters plus the Hβ one offers us the major things we want to know about the star, for an initial look - see, whether for astrophysics or for use in galactic structure studies. We get a measure of apparent brightness and of absolute brightness, hence of distance. We get a temperature measure, well calibrated with spectral type. We get a measure of the star's [Fe/H] abundance. From a combination of these, we also get a measure of the star's age, through stellar evolution model calibrations.

We also can estimate the interstellar reddening and absorption of the starlight, as we have a good measure of intrinsic color and we measure the *(b−y)* color. So the uvby, Hβ systems are excellent for studies of the interstellar absorbing matter as well as for studies of the stars themselves.

Note that transformation to the standard system (the system being defined as it is in the *UBV* system by reference to standard stars) is easier and more accurate than with the *UBV* system, due to the narrower bandwidths of the filters. No second order color terms are needed for extinction, so extinction transformations are easier also.

A typical transformation equation is:

$$c_1 = C + D \cdot c_1(obs) + F \cdot (b-y)$$

where:

C is the zero point correction,
D is the scale term,
$c_1$(obs) is the observed index, corrected for extinction,
$c_1$ is the value on the standard system, and
F is a color term, which allows for Hδ effects on *v*.

One could use the Hβ index in place of (b−y) in the last term and this has been occasionally done when the index was available before the uvby transformations where done.

When done with care, accuracies of 0.003 mag. have been achieved in routine work.

One should go to the astronomical literature to see applications; there are many. The system is excellent for all sky photometry and for work on variable stars as well. I will note here only a few more items to assist in understanding the literature:

1. As is done with $m_1$, a standard $c_1$ relation is defined. Rather than use the Hyades relation, a relation that defines the Zero Age Main Sequence is used. It is essentially the lower envelop of a $C_1$ *vs.* $(b-y)$ or Hβ diagram. So a parameter called $\Delta c_1$, which is the difference between the measured value and the standard value, for the same $(b-y)$ or Hβ, is used. This has been calibrated in terms of absolute magnitude for A- and F-type stars.

2. $E(b-y)$ is the color excess due to interstellar absorption. It is the difference between the measured color and the intrinsic color as estimated by either $c_1$ or Hβ. We call the intrinsic $c_1$ and $m_1$ parameter $c_0$ and $m_0$. The apparent magnitude corrected for interstellar absorption is called $V_0$.

3. The two plots mostly used are $c_0$ *vs.* $(b-y)_0$ and $m_0$ *vs.* $(b-y)_0$. Occasionally, Hβ is used instead of $(b-y)$ in these diagrams. (Remember that Hβ is a measure of absolute magnitude for B-type stars and of temperature for A- and F-type stars, while $c_0$ is a measure of temperature for B-type stars and of absolute magnitude for A- and F-type stars.) The axes in these plots are chosen so that cooler temperatures are always to the right and the brightest stars are to the top of the diagrams.

REFERENCES

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# SECTION 7.0*

## STRÖMGREN FILTERS

The Strömgren uvby is the most widely used intermediate-band photometric system. The letters u, v, b, y refer to the colors ultraviolet, violet, blue and yellow respectively. Because these filters have a narrow passband, the system is totally filter defined, and variations in detector spectral response, telescope transmission, and the second order terms used for the extinction corrections and the transformation equations can be safely ignored. In addition, the use of these filters provide more useful astrophysical information than the Johnson UBV system.

*Manufacturer*

These filters are manufactured by Spectro-Films, Inc., Woburn, Massachusetts to our specifications. Spectro-Films has been making the Strömgren filters for professional observatories worldwide for the last 10 years and is considered a major source for these filters. As a result, these filters used with the SSP-5 should match the results from most photometry programs throughout the world. Tables 7-1 list the filter specifications.

*vby Design*

*vby Filter Care*

The vby filters are multiple cavity interference type using dielectric quarter wave stacks with spacers of metal film. They have excellent transmission characteristic and long life when properly stored. However, all interference filters can be damaged when exposed to high humidity for long periods of time. When not used, these filters should be stored in a glass jar with a small amount of desiccant added to keep the air dry. In such an environment, these filters will last virtually forever.

*u Design*

*u Filter Care*

The u filter is made from 2 pieces of Schott colored glass. The first glass of UG11 defines the red side of the pass band and the WG345 defines the blue side. The red leak of the UG11 glass beyond 700 nm should not be a source of error since the response of the R4040 PMT is extremely small at that wavelength and redder. The surface of the UG11 glass has poor resistance to weathering (humidity) and must be protected in a manner similar to the vby filters. Unlike the interference filters which cannot be restored, the weathered surface of this filter can be repolished. If a small amount of weathering is observed, a white haze on the surface, a Q-tip with jewelers rouge and water can normally repolish the surface. Use light pressure and blow dry the filter immediately afterwards.

* *Excerpt from the Model SSP-5 Technical Manual for Theory of Operation and Operating Procedures*

| OPTICAL SPECIFICATIONS | | | |
|---|---|---|---|
| Filter | Center Wavelength | Bandpass | Type |
| u | 342 nm | 25 nm | 6mm UG11 + 1mm WG345 |
| v | 410±2 | 16±1.6 | interference |
| b | 470±2 | 19±1.9 | interference |
| y | 550±2 | 24±2.4 | interference |

| PHYSICAL SPECIFICATIONS | |
|---|---|
| DIAMETER | 12.7±0.15 mm |
| THICKNESS | 7.0±0.3 mm |
| SURFACE QUALITY | 80-50 |
| WEDGE | NOT TO EXCEED 5 ARC MIN |

Table 7-1. Optical and physical specifications of Strömgren filters