*Under One Sky: The IAU Centenary Symposium*
*Proceedings IAU Symposium No. 349, 2019*
*C. Sterken, J. Hearnshaw & D. Valls-Gabaud, eds.*

doi:10.1017/S1743921319000486

# IAU Commission 25, and the development of early photometric systems

**Christiaan Sterken**

University of Brussels (VUB), Pleinlaan 2, 1050 Brussels, Belgium
email: csterken@vub.ac.be

**Abstract.** The *International Astronomical Union* was conceived in 1918, and was formed one year later in Brussels. One of the 32 initial Commissions was the *Committee on Stellar Photometry* that later on became IAU Commission 25 *Astronomical Photometry and Polarimetry*, and since 2015 Commission B6 with the same name. The initial functions to be exercised by the Committee were

($a$) to advise in the matter of notation, nomenclature, definitions, conventions, etc., and

($b$) to plan and execute investigations requiring the cooperation of several observers or institutions.

The basic philosophy was that IAU Commission 25 was to be an advisory body, rather than a decision-making committee that imposes its regulations. This position was reconfirmed at the 10th IAU General Assembly in 1958.

From the early days on, the Commission members engaged in the teaching of the principles of photometric measurement – either via the Commission meetings and the ensuing reports, or via external means, such as lectures and publications. The topics of instruction dealt with absorption of light in the atmosphere, the modification imposed by the character of the receiving apparatus, the unequal response of different receivers to a same stimulus, and variations in the data-recorder response from one experiment to another.

From the 1930s on it was suggested that IAU Commission 25 takes responsibility in matters of standard stars, standard filters and standard calibration methods.

During the first half-century since its foundation, Commission 25 was an active forum for discussions on the basic principles of astronomical photometry, including the associated problems of transformability of magnitudes and colour indices from one instrumental configuration to another. During the second half-century of its existence, the Commission has served as a sort of news agency reporting on the developments in detector engineering, filter technology and data reduction. All along the Commission members were committed to *accuracy* and *precision*, a struggle that was primarily driven by the jumps forward in performance and sensitivity of every new detector that was introduced.

The development over one century shows that the Commission was continuously touching on the philosophy of precise measurement, where accurate measuring – for a select group of pioneers – was an end in itself.

This presentation looks back on the opinions of key players in the photometric standardisation debate, and briefly presents two case studies that illustrate the illusionary accuracy reached over a century in determining, as Commission member Ralph Allan Sampson put it, *“a detail like magnitude”*.

**Keywords.** techniques: photometric, instrumentation: detectors, history and philosophy of astronomy, standards, IAU Commission 25, IAU Commission B6

---

## 1. Introduction

The *International Astronomical Union* (IAU) was conceived in 1918, and was formed one year later in Brussels. One of the prominent founding members was renowned

**Figure 1.** Washburn Observatory staff, Madison 1936. Left to right: *rear*, Edward Bernet, Gerald Kron and Albert Whitford, *front*: Charles Morse Huffer, Elsie DeNoyer (observatory secretary and stenographer for a few years in the mid 1930s) and Joel Stebbins. Credit University of Wisconsin-Madison Dept. of Astronomy.

photometrist Joel Stebbins (1878–1966), who catapulted the field of astronomical photometry into the modern age of highly-sensitive linear photodetectors that eventually resulted in the – since long taken for granted – pipe-line digital recording and processing of stellar-light data.

Stebbins came to Madison in 1922 to take over the directorship of Washburn Observatory, which he primarily used as testing ground for new instrumentation (Susalla and Lattis 2010, p. 25–29). Stebbins was an innovator in the application of the sensitive electric detector – that he called an "electric eye" – to measure the brightness of celestial objects, in particular the changes in magnitude of variable stars that he observed with photocells provided by Jakob Kunz (1874–1938). Photoelectric photometry was in its infancy till the mid-1940s, i.e., till photomultiplier tubes became available. Albert Whitford (1905–2002) and Gerald Kron (1913–2012) both joined the Washburn Observatory in 1931. We refer to Hearnshaw (1996, Chap. 5) for a well-documented review of the origins of photoelectric photometry over more than half a century (1892–1945), and also to the review of Weaver (1946).

Campbell and Stebbins (1920) presented a 48-page report to the American Section of the (proposed) IAU. The American Section held its first meeting in the office of the *National Research Council* in Washington, D.C., on March 8, 1919 (20 of the 33 members were present). Astronomer William Wallace Campbell (*National Academy of Sciences*) was appointed permanent Chairman of the Section, and Joel Stebbins (*American Astronomical Society*), Secretary. A second meeting was held on June 23–24, after which the delegation departed on June 30 for London and for a constitutive assembly of the IAU in Brussels in July.

The report describes that special subcommittees were constituted, among which the *Committee on Stellar Photometry* that was made up by Frederick Hanley Seares (Chairman), Solon Irving Bailey, Frank C. Jordan, John Adelbert Parkhurst, and Joel Stebbins himself. That Committee later became IAU Commission 25 *Astronomical Photometry and Polarimetry*, and since 2015 Commission B6 with the same name. The Committee comprised Frederick H. Seares (Chairman), Benjamin Baillaud, Arthur Stanley Eddington, Jakob Karl Ernst Halm, Henrietta Swan Leavitt, Philibert Jacques Melotte, John Adelbert Parkhurst, Ralph Allan Sampson and Herbert Hall Turner. Surprisingly, Stebbins, 'the' pioneer of the development of photoelectric photometry, did not join Commission 25 as a member. Figure 1 shows a picture of Washburn Observatory staff, see also Lattis and Lattis (2019) for some earlier pictures of Campbell and Stebbins – taken by the latter – during their visit to Belgium in 1919.

Seares *et al.* (1920) stipulated an immediate specification of the functions to be exercised by the *Committee on Stellar Photometry*, viz.,:

(a) *To advise in the matter of notation, nomenclature, definitions, conventions, etc., whose universal adoption will simplify and unify the publication and use of photometric results.*

(b) *To plan and execute investigations requiring the cooperation of several observers or institutions.*

That report recalls the definition of the scale of magnitudes, i.e., the Pogson (1857) logarithmic† scale

$$m - m_0 = -0.4\,(\log I - \log I_0), \tag{1.1}$$

(where $I$ refers to the perceived or measured brightness of a celestial object), as well as the definition of colour index being the difference of photographic magnitude *minus* visual or photovisual magnitude. Seares *et al.* (1920) stress the requirement of numerical standards that bear in mind *"the ever-increasing precision which characterizes the metrical results of science"*. Thus, in matter of standard stars,

> *"The thing to be emphasized is evidence, not authority, and the evidence should be frequently reviewed. . . "*

and further

> *". . . it seems undesirable that any particular set of standard magnitudes be designated by the adjective 'international'. Such an action on the part of an International Committee would necessarily convey the impression of an authoritativeness and finality of decision which it would be difficult to justify in view of the present outstanding differences in the results of different observers."* (Seares *et al.* 1920, p. 83)

The above statement clearly underlines the basic philosophy that IAU Commission 25 was to be an advisory body, rather than a decision-making committee that imposes its regulations. This position was reconfirmed at the 10th IAU General Assembly in 1958 (Sadler 1960, p. 369):

> *"When it comes to the operation of observing programmes a commission of the I.A.U. is a consultative and not a legislative body. It can recommend procedure, but individual astronomers can adopt any course they please. Generally speaking, I.A.U. commissions have been careful not to make recommendations on observational procedure unless it has become apparent that workers in the relevant field are prepared to accept them."*

The principle of staying clear of anyone's particular set of standards has a great historical antecedent: the presentation to the French National Assembly by Nicolas de Condorcet on March 26, 1791, in which was proclaimed that the Academy had attempted to exclude anything that might suggest the influence of France's national interests in the choice of metric units and standards: the French *Académie* initially tried to exclude any arbitrary qualification that might suggest the influence of a particular French interest in such a way that posterity would never be able to tell which nation had carried out the metric reform, as expressed by Condorcet (Bigourdan 1901).‡

† Herschel (1847, Chap. III), though, advocates a power law: shifting the zero-point of the traditional magnitude scale by $0\overset{\mathrm{m}}{.}41$ will render the magnitudes equal to the square root of the reciprocal of the brightness of the star, see also Young (1990, p. 311).

‡ *"L'Académie a cherché à exclure toute condition arbitraire, tout ce qui pourrait faire soupçonner l'influence d'un intérêt particulier à la France, ou d'une prévention nationale . . . "*, see http://smdsi.quartier-rural.org/histoire/30mars91.htm and Sterken (1992b).

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

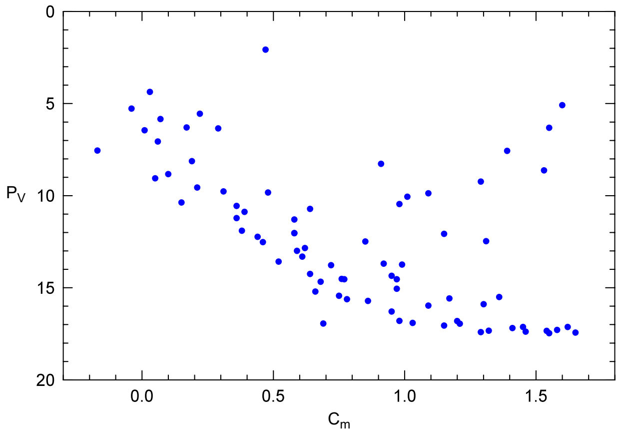



**Figure 2.** $P_{\rm V}$ versus $C_{\rm m}$ diagram of *North Polar Sequence* stars, based on tabular data presented in the report of Commission 25 at the first IAU GA in 1922.

The noble principle of not imposing authority in deciding which standards to use was quickly transgressed: at the very first IAU General Assembly (Rome 1922), the Commission, under the presidency of F.H. Seares, published a Table with photographic and photovisual magnitudes of 96 stars of the *North Polar Sequence*, a standard sequence near the celestial North Pole outlined by Leavitt (1917). The photovisual magnitude $P_{\rm V}$ and associated colour index $C_{\rm m}$ are rendered in Fig. 2, which illustrates that standard stars were picked over a fair region of the magnitude-colour diagram. Nevertheless, for about two thirds of these stars an approximate spectral type – and, obviously, luminosity class – was not known. Moreover, the sequence did not contain enough different types of stars to permit accurate transformations between photometric data sets.

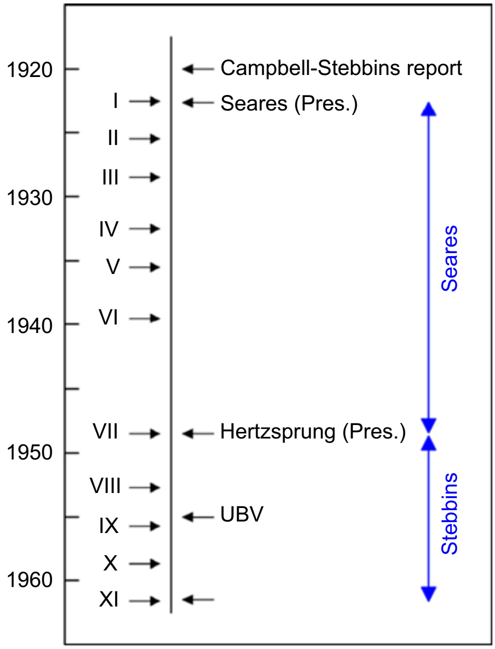
As mentioned previously, Stebbins was not a member of Commission 25, at least as long as Seares was its President: Stebbins joined in 1948 at age 60, and remained till 1962. All along, Seares was a regular member of Commission 25 too. Kron joined in 1948 and served up to 1973, and Whitford became a Commission 25 member in 1955. From correspondece between Stebbins and Seares (1935–1936), Lattis (2018) did not notice any kind of animosity or negative talk between them. Obviously, 1948 seemed like the closing of an era, and the opening up of a new era with Stebbins' move to Lick Observatory. Figure 3 illustrates the timeline of the first four decades of Commission 25 presidencies, as well as the moment of breakthrough of the first worldwide photoelectric photometric system.

## 2. "Visual" magnitudes

The term *visual magnitude* is a conception that is not only detector-dependent, but also time-dependent. The visual scale was the first of all photometric scales, based on the sensitivity of the human eye – that is, a detector with an effective wavelength of about 550 nm. The early magnitude classes as we know them from Ptolemy's *Almagest* (Toomer 1984) were later replaced by a logarithmic scale as specified in Eq. 1. The greatest asset of visual data is that they have been collected over a very long time base – decades to many centuries.

With the introduction of the photographic emulsion as detector, various different "visual" magnitude scales were defined and labeled as $m_{\rm pg}$ (photographic magnitude) or $m_{\rm pv}$ (photovisual magnitude, as obtained by combining an orthochromatic emulsion and a proper yellow filter). One of these variants was the so-called "international" $I_{\rm pv}$ scale. One should realise that the spectral ranges for photographic photometry were chosen without regard to any astrophysical requirements.

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press




| | |
|---|---|
| 1922–1925 | F.H. Seares |
| 1925–1928 | F.H. Seares |
| 1928–1932 | F.H. Seares |
| 1932–1935 | F.H. Seares |
| 1935–1938 | F.H. Seares |
| 1938–1948 | E. Hertzsprung |
| 1948–1952 | W.M.H. Greaves |
| 1952–1955 | W.M.H. Greaves |
| 1955–1958 | R.H. Stoy |
| 1958–1961 | R.H. Stoy |
| 1961–1964 | V.B. Nikonov |
| 1964–1967 | V.B. Nikonov |
| 1967–1970 | A.W.J. Cousins |
| 1970–1973 | D.L. Crawford |
| 1973–1976 | M. Golay |
| 1976–1979 | M.F. McCarthy |
| 1979–1982 | J.A. Graham |
| 1982–1985 | J. Tinbergen |
| 1985–1988 | F.G. Rufener |
| 1988–1991 | I.S. McLean |
| 1991–1994 | A.T. Young |
| 1994–1997 | J.D. Landstreet |
| 1997–2000 | C. Sterken |
| 2000–2003 | C. Sterken |
| 2003–2006 | A.U. Landolt |
| 2006–2009 | P. Martinez |
| 2009–2012 | E.F. Milone |
| 2012–2015 | S.J. Adelman |
| 2015–2018 | A.M. Magalhaes |

**Figure 3.** Timeline of IAU General Assemblies 1922–1962. Commission 25 Presidency of Seares is indicated, as well as Stebbins' membership from 1948 on. $UBV$ indicates the introduction of the Johnson $UBV$ system. Past Presidents of Commission 25 (now B6) are listed on the right.

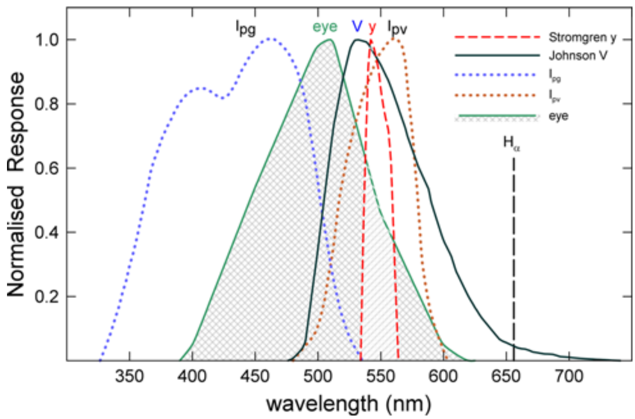



**Figure 4.** Normalised photometric response curves of various "visual" magnitude scales: the human eye in scotopic vision, the $I_{\rm pg}$ and $I_{\rm pv}$ photographic bands, the Johnson $V$ and the Strömgren $y$ photomultiplier-based bands. The red tail of the Johnson $V$ band is defined by the response of the detector, and not by the $V$-filter cutoff. The vertical dashed line at wavelength 656 nm indicates the position of $H_\alpha$.

In the early 1950s appeared the photomultiplier-based $V$ magnitude scale of the Johnson $UBV$ system (Johnson and Morgan 1953), and the fast spread of Johnson's system made the $I_{\rm pg}$ and $I_{\rm pv}$ magnitudes entirely obsolete. Figure 4 shows the divergence in passband between these three so-called "visual" magnitudes, in addition to the associated $I_{\rm pg}$ photographic magnitude. As the Johnson system is defined for use with a reflecting telescope with aluminised mirror at 700 feet elevation, and by means of one particular detector – the RCA-1P21 photomultiplier tube – some "Johnson $V$" magnitudes

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

obtained with a different photomultiplier may very well include much longer wavelengths, and very likely admit the $H_\alpha$ Balmer line, whether in emission or not. The zero points of the photographic and photo-visual magnitudes were defined through the *International Polar Sequence* (Oort 1950, p. 215). The visual magnitude, $V$, in use today, has a zero point adjusted to agree with the magnitudes of the North Polar Sequence stars given by Stebbins *et al.* (1950).

## 3. On teaching of the principles of photometric measurement

The 1920s concluded the emergence of astrophysical discoveries on topics like the Harvard Sequence of stellar spectra, black-body radiation, the period-luminosity relation for Cepheids, the Hertzsprung-Russell diagram, etc. (see Longair 2019, Table 1). Detectors, especially photoelectric cells, were in the hands of small groups of experts in the US (Wisconsin, Illinois, Lick) and Europe (Berlin, Tübingen).

The view that the teaching of photometric techniques is a prerequisite was expressed, implicitly or explicitly, in more than one of the Commission reports. For example, in *IAU Transactions* 21B, C. Sterken explicitly calls for returning to the teaching of the fundamentals of photometry to all observers (Bergeron 1992, p. 242).

Ralph Allan Sampson (1866–1939), another first-day member of Commission 25, was the first to take on the path of teaching. In a lecture at the *The Royal Institution of Great Britain*, he mentions the "hill of difficulties" that must be climbed to obtain *"true luminosity"* (Sampson 1921), viz.,

> *"We can easily justify this view by mentioning the first* [difficulties] *that occur – absorption of light in the atmosphere and possibly beyond it, the difficulty of defining and establishing a measure of intensity for each radiation, the modification imposed on the original emission by the character of the receiving apparatus, the unequal response of different receivers to the same stimulus, variations in the index*† *of the receivers from one experiment to another."*

Or, expressed in the language of mathematics, Sampson explains that the photometrist measures in a wavelength interval $(\lambda 1, \lambda 2)$

$$I = \int_{\lambda 1}^{\lambda 2} E(\lambda)\, s_i(\lambda)\, s_e(\lambda)\, s_t(\lambda)\, s_r(\lambda)\, s_d(\lambda)\, d\lambda \tag{3.1}$$

where $E(\lambda)$ is the stellar irradiance and $s_i, s_e, s_t, s_r, s_d$ represent, respectively, the spectral transmissions of the interstellar medium, the terrestrial atmosphere, the telescope, the photometric system and the spectral sensitivity of the detector.‡

He cautiously refers to absorption *possibly* beyond the Earth's atmosphere, an indirect reference to Shapley's explicit assumption that *"Absorption in space like that produced by the terrestrial atmosphere is therefore excluded ..."* (Shapley and Ames 1929, p. 2). It was the very precise photoelectric work of Stebbins, Huffer and Whitford (see Fig. 1) that properly quantified interstellar absorption and led to a view of the Galaxy being much larger than Kapteyn's but at least a factor of two smaller than Shapley's, or, in Stebbin's own words: *"We shrunk the universe!"* (Lattis 2014, and references therein).

Sampson ponders

> *"Can we afford all that attention to a detail like magnitude? If we did, how far would we be the wiser?"*

† The *index* of a vintage measuring apparatus typically was a needle that points to a number on a scale, or a pen on a chart recorder.

‡ $s_e(\lambda)$ is not strictly correct: extinction also depends on the elevation of the site: $s_e(\lambda, h)$, hence the specification of altitude in the definition of the $UBV$ system.

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

He explains further that, if we accept that the Sun and the stars are black bodies,

> *"The position of maximum intensity gives the temperature, and the integral of radiation will then indicate the surface or extent of the radiating body. ... A single measure has no meaning except for stars at equal temperatures ...".*

This was followed by a firm statement

> *"... existing magnitude work, now of very great extent, and representing an enormous amount of work, has been undertaken upon lines which, without other aid, lead nowhere in particular."*†

This is exactly how John Herschel titles his third Chapter *"Of Astrometry, or the Numerical Expression of the Apparent Magnitudes of the Stars"* (Herschel 1847) – a magnitude alone is a measured quantity that tells us nothing about the physics of the star: ***photometry becomes a tool of astrophysics only when magnitude is complemented with at least one colour index***. This insight leads to the concept of a "photometric system". Beware, though, that the colour (index) of a star is important not only for its astrophysical significance, but because colour index is essential (Fowler 1925, p. 86) for determining the colour equations of various magnitude systems – even for the accurate transformation of black-body photometry (Young 1974, p. 181).

## 4. Photometric Systems

A working definition of a photometric system is given by Sterken *et al.* (2011, p. 10):

> "*a calibrated subspace of magnitudes (or fluxes) and colour indices (or flux gradients) where the zero points and scales of (each) magnitude and colour have been carefully defined and calibrated by adequate (stellar) standards*".

A crucial element of a photometric system is its bandwidth: wide-band systems (e.g., the $UBV$ system) cover at least 30 nm in each band, intermediate bands (e.g., $uvby$ system) are about 10–30 nm wide, and narrow-band systems cover no more than a few nm, and transmit only a very small part of the spectral energy distribution of a star.

Stebbins and Whitford (1945) photoelectrically determined the mean colours – i.e., the logarithm of the ratio of two stellar energy distributions – of unreddened main-sequence stars grouped by spectral type, and computed black-body colours for six wavelengths from Planck's formula. Figure 5 shows their measured colour index for B0, A0, G0 and M1 main-sequence stars, and demonstrates that:

(*a*) the colour index is almost linear in $1/\lambda$;
(*b*) some stars show deviations, notably in the band that contains the Balmer Jump;
(*c*) the colour indices have a common zero point at $1/\lambda = 1.75$ (570 nm).

Thus, *if* stars radiate as black bodies, *then* the flux distribution log $I$ (as a function of $\lambda^{-1}$) is characterised by one single gradient, and *hence* the stellar spectrum is described by one single colour index. In other words:

> *if the stellar energy distribution is commensurable with black-body radiation, only two passbands are necessary to adequately describe the stellar continuum.*

† Sampson's assertion implicitly refers to all-sky magnitudes, but is not relevant to the use of magnitude time-series for investigating eruptions, flares, eclipses, and so on. Beware, however, of relying on a seemingly sinusoidal light curve – obtained in just one single passband – as sole argument for attributing cyclic variability to stellar pulsation, since light curves of some rotating variables may very well mimic the typical periodic behaviour of pulsating stars (such as the ellipsoidal variables, see Hall 2005, Fig. 4.8).

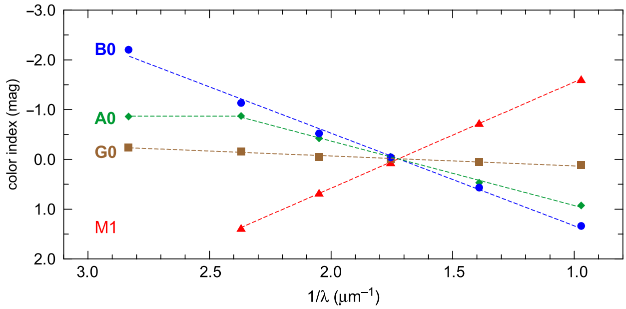



**Figure 5.** Observed colour index for main-sequence stars grouped by spectral type as a function of $1/\lambda$. The dashed lines are linear fits (for spectral type A0 the fit is constrained to $1/\lambda < 2.4$), and visualise black-body spectral energy distributions. Source: Sterken (2010, p. 222).

Consequently, the greater the deviations from black-body radiation, the greater the number of passbands that are needed and the higher the required order‡ of a photometric system; with $n$ bands come $n-1$ colour indices. The choice of passbands should be guided by astrophysical reasons and take into account interstellar-reddening effects and spectral emission and absorption lines that also work as deviations from a black-body energy distribution.

Note, however, that in order to be linearly *transformable* from one set of magnitudes and colour indices to another, the function $E(\lambda)$ in Eq 3.1 should have continuous derivatives, so that the Taylor expansion of that function is valid over the entire spectral wavelength interval. The problem, every photometrist knows, sits in the fact that the transformation equations involve the first and – occasionally – the second derivative of the spectral irradiance $E(\lambda)$ of the observed object, modified by the passage through the atmosphere and through interstellar space. In practice, the reduction procedures assume that these first derivatives can be approximated by using the colour indices of the object in question. This approximation does work for most stars that are unreddened and that have spectral energy distributions that do not violate the conditions for Taylor series expansion. Still, Young (1992) demonstrates that the classical series expansion in King's theory (King 1952) needs to be carried out to at least fourth order if millimagnitude accuracy is to be achieved.

Numerous photomultiplier-based photometric systems were designed since Johnson's $UBV$ system. All these systems use the magnitude scale (Eq. 1), except for Walraven's $VBLUW$ system (Pel and Lub 2007) that bypasses magnitude altogether by expressing all quantities in terms of $\log I$. The *Asiago Database on Photometric Systems* (ADPS) project outlines a detailed overview of more than 200 photometric systems, including basic information and reference data, and an extensive bibliography. Munari *et al.* (2002) give detailed information and historical references, passband data, response curves and a link to the *General Catalogue of Photometric Data*.

## 5. A century of problems

The very wide passband of the eye introduces substantial colour effects, and this is one of the reasons for the difficulties encountered in comparing measurements obtained by different visual observers. But by the 1920s, the accuracy (not precision, see Sect. 7) of a single magnitude measurement was already remarkably high: the very first report of Commission 25 mentions $\pm 0\overset{\mathrm{m}}{.}024$ for the magnitude range 2.6–16.0 (Fowler 1922, p. 69).

‡ The order of a photometric system is the dimension of the vector space of significant and non-redundant magnitude and colour-index parameters.

It was Greaves, in 1948 at the IAU VIIth General Assembly, who concluded (Oort 1950, p. 271)

> *"It is especially important that it should be realized that every instrument, working under prescribed conditions, will, if high accuracy is the aim, define its own magnitude system and that this system will differ from other systems by a colour term and, possibly, by an additional term involving average line intensity... The best service that the Commission can perform at present is to stimulate discussion and research on the one hand, and, on the other, to emphasize that the study of some very important problems can be advanced by systematic work on established lines... In the meanwhile discussion can do nothing but good, and it seems very desirable that most of the time available to the Commission at the General Assembly should be devoted to some kind of symposium dealing with the matters raised..."*

Stoy, in 1952, was one of the first to really sound the alarm bell:

> *"Perhaps the first problem of general photometry is to consider all the multitudinous series of magnitudes that have been used, and are likely to continue to be used in practice, to see if it is possible to produce a generally acceptable definition of the magnitude of a celestial body which is such that whenever or however it is measured with reasonably suitable apparatus, the same result will be obtained within the limit of observational error. Until different observers agree on just exactly what they are trying to measure, they are unlikely to arrive at concordant results"* (Oosterhoff 1954, p. 355).

Weaver, endorsed by Shapley at IAU VIII in Rome (1952), stated that

> *"the diversity of colour systems and zero points of magnitude scales now found in the literature of photo-electric photometry is a source of great inconvenience to any investigator interested in comparing and making use of the results of several observers"* (Oosterhoff 1954, p. 363).

Shapley, in turn, remarks that

> *"... a photo-electric magnitude system depends on the type of telescope, whether silvered or aluminized (when a mirror), the age (or stage of decay) of the silver or aluminium coating, the precise nature of the filters used, and, of course, upon the characteristics of the photo-electric equipment"* (Oosterhoff 1954, p. 367),

thus, again, stresses the impact of $s_t, s_r, s_d$ – just like Sampson did a quarter of a century earlier.

Six years later the situation was that, although the $I_{\mathrm{pg}}, I_{\mathrm{pv}}$ system was extensively used, there was still no unanimity about its definition: some observers attempted to retain the original 1922 definition, some the extended polar observations of Seares *et al.* (1941), some the interim definition of Redman (1952, p. 364) and some modified versions of the *"rather limited Californian definition"* (Stebbins *et al.* 1950). The confusion lies mainly in defining the zero-point and colour characteristics of the photographic magnitudes (Sadler 1960).

Figure 6 illustrates the family tree of a number of traditional photometric systems positioned on three detector branches. The metaphor, however, depicts the view as seen by the designer of each system, and shrouds the problem that Shapley refers to: except for some "pure" systems such as the Geneva 7-colour system, several favourite systems are accompanied by "clone" versions of the original, and are incompatible with each other

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

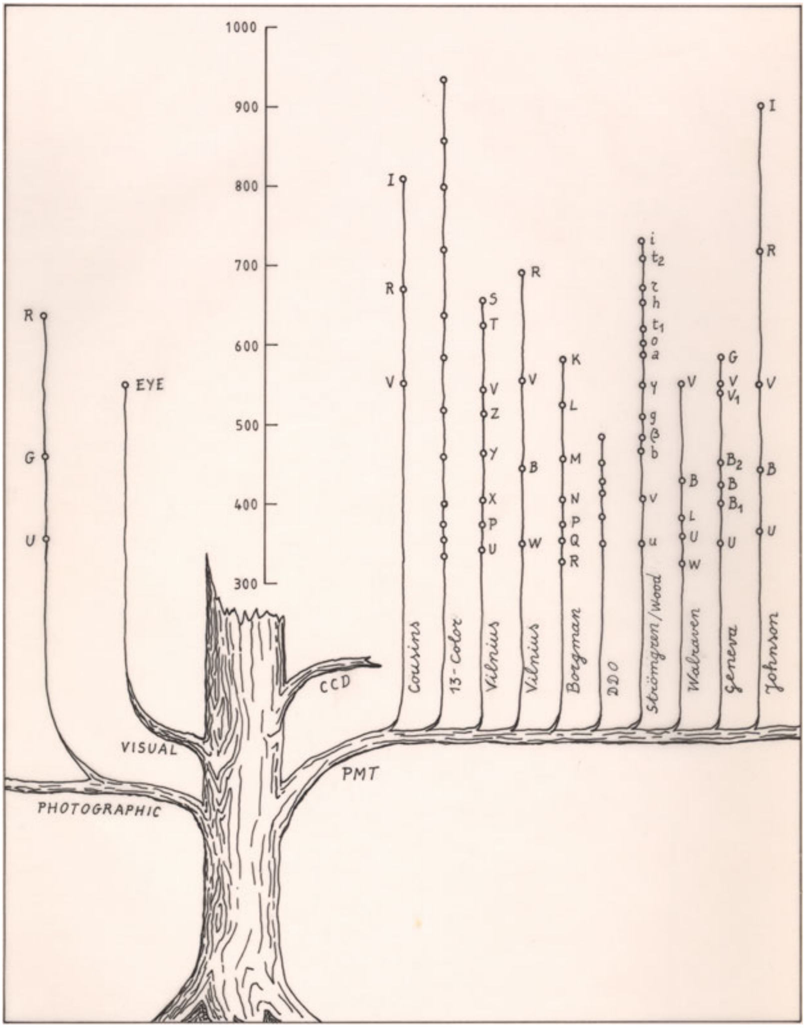



**Figure 6.** Genealogy for some well-known photometric systems. Open circles indicate the position of the central wavelength of the indicated systems (in nm, increasing along the vertical direction). Source: Sterken (1992a).

and also with the original system they came from. These clones differ in characteristics such as detectors, bandwidths, shape of the response curves, and so on. As such, it is virtually impossible to merge magnitudes and colour indices from one clone system to another, let be from entirely dissimilar systems. This figure clearly illustrates Hoag's statement (IAU GA 12, Pecker 1964, p. 265)

> *"... the whole history of the systems so far has depended greatly on the receivers and not on astrophysical choices."*

## 6. Just two examples

Differences between photometric systems cause tie-in problems when combining magnitudes and colours of stars with peculiar spectra, and may result in severe discrepancies that render light curves with a long time-baseline critically dependent on the instrumental

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

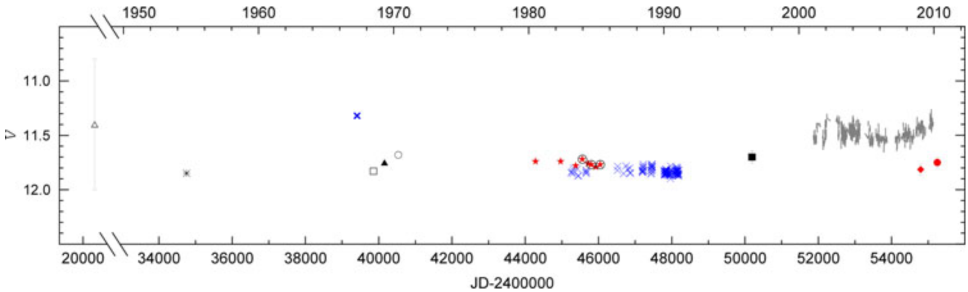



**Figure 7.** $V$ light curve of S 22, adapted from Sterken (2019). The leftmost point is taken from the Henry Draper Catalogue: the observing date probably is around 1917, and this photographic magnitude is not directly comparable with $V$. The ■ data point was obtained with the IUE Fine Error Sensor that measured unfiltered light in a passband with a bandwidth that was a factor 3 to 10 larger than the passbands used for the other magnitudes in this graph.

**Figure 8.** Set of vintage Kunz photocells conserved at the Department of Astronomy, University of Wisconsin-Madison. Photo C. Sterken.

setup. Two examples suffice to illustrate the long-term problems for a quantity as simple as a “visual magnitude”.

### 6.1. *Hen-S 22*

Hen-S 22 (HD 34664) is a luminous star of the Large Magellanic Cloud that was for the first time studied by Henize (1956), who listed it as an $11^{\text{m}}_{.}4$ star. The object exhibits the B[e] phenomenon: its spectrum is dominated by a curtain of narrow emission lines. Shore (1992) announced that the star underwent massive shell ejection, and concluded that S 22 likely was in the luminous blue variable shell-ejection phase, with dramatic changes to come: the optical brightness of S 22 apparently had increased by more than one magnitude since 1983. Figure 7 shows the $V$-type magnitudes derived from various sources. Although the light curve, at first glance, displays strong variability during half a century before 1970, the data collected during the last four decades show – besides evidence for systematic effects – only signs of mild variability. This is not surprising, for this data set involves half a dozen different $V$ filters, and almost every set of symbols was obtained with a dissimilar detector. Any supplementary magnitude that may possibly turn up from archived notebooks of the pre-1950s era will most likely have been obtained by a vintage photocell as depicted in Fig. 8, and will *de facto* not be commensurable with previous photographic magnitudes, nor with photomultiplier or CCD results obtained since the 1950s. The bonus of observing from space is obvious: space-borne instruments reduce the factor $s_e(\lambda)$ in Eq. 3.1 to a scalar, but this advantage is entirely lost when considering the single data point obtained with the IUE Fine Error Sensor that measured unfiltered light in a passband with a bandwidth that was a factor 3 to 10 larger than the passbands used for the other magnitudes in Fig. 7.

We cannot forgo comparing this very poor result with the status of accuracy of the visual magnitudes in the 1920s: there is no improvement at all in this particular case,

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

and the picture lends credence to Andrew Young's shocking statement at the XXIth IAU General Assembly (Buenos Aires 1991):

> *"... even a schoolchild with a plastic ruler can make more accurate absolute measurements than can astronomers when they compare the brightness of stars visible with the naked eye ... "* (Sterken 1992a, p. 149).

### 6.2. *Data mining in digitised photographic archives*

Because of the nonlinearity of the photographic process, it was much more difficult to establish an accurate Pogson scale photographically than to visually compare stars of similar brightness. The nonlinear response of the photographic emulsion is dealt with via the *characteristic curve*, i.e., the nonlinear relation between measured density and intensity. The derivation of the parameters of the characteristic curve is a tedious job, and requires the availability of calibration spots for every batch of plates, or of calibration sequences of standards stars on each plate. The parameters of any solution are strongly dependent on the plate emulsion, but also on other factors, such as "baking" of the emulsion, and even the choice of the developer has an impact on granularity (Difley 1968) – not to speak of the conditions of overland and overseas transport of "un-"deep-frozen plates.

Laycock *et al.* (2010), for example, bypass the characteristic curve altogether and calibrate instrumental magnitudes extracted from the plates directly via a non-linear fitted function against a catalogue of known magnitudes. This magnitude extraction is a critical step, as it involves subtraction of widely different object and background densities that relate to, respectively, linear and non-linear response regimes of the characteristic curve. The same problem also applies to defocussed images that are easily handled by a linear detector, but cause problems for the non-linear photographic emulsion.

Photographic accuracy and precision depend on image structure, the stellar spectral energy distribution, and (for eye estimates) on the experience of the estimator. The various data reduction approaches have led to conflicting results in the analysis of different sets of plates of the same object: an interesting case is outlined in a comparison of vintage-plate photometry of KIC 8462852, see Schaefer (2016) and the discussion in Hippke *et al.* (2017).

The issue here is that – in a way analogous to what is described in Section 6.1 – one analysis concludes that the light curves show systematic dimmings over a century-long timebase, whereas the other data-reduction approach implies that there are just no such secular trends in the magnitude data.

## 7. Conclusions

During the first half-century since its foundation in 1922, Commission 25 was an active forum for discussions on the basic principles of astronomical photometry, including the associated problems of transformability of magnitudes and colour indices from one instrumental configuration to another. This activity was supplemented by indirect and direct teaching of photometry basics by members of the Commission. The *IAU Transactions* thus became a treasure trove of advice to the community of photometrists, and to the IAU members at large.

Though Symposia were not organised, several Colloquia and Workshops took place with or without IAU support by Commission 25 members, for example *Stellar Photometry – Current Techniques and Future Developments* (Butler and Elliott 1993), *Stellar Photometry: Past, Present, and Future* (Sūdžius *et al.* 2004), *The 2007 ESO Instrument Calibration Workshop* (Kaufer and Kerber 2008), *The Future of Photometric, Spectrophotometric and Polarimetric Standardization* (Sterken 2007), *Calibration and Standardization of Large Surveys and Missions in Astronomy and*

*Astrophysics* (Fermilab 2012), and most recently, *Calibration and Standardization Issues in UV-VIS-IR Astronomy* (IAUXXX-FM12, 2018), a Focus Meeting organised at the XXXth General Assembly in Vienna. The volume *Astronomical Photometry: Past, Present, and Future* (Milone and Sterken 2011) summarises the march towards increased precision and accuracy, and in so doing also illustrates the role that Commission 25 has played in that development.

During the second half-century of its existence, the Commission has served as a sort of news agency reporting on the developments in detector engineering, filter technology and data reduction. And the news anchors had their hands full explaining the strive of *accuracy* and *precision*, a struggle that was mainly driven by the jumps forward in performance and sensitivity of every new detector that was introduced.

In this context it is important to recall the divergence between these concepts: *precision* stands for how finely a result reproduces, *accuracy* is how close a result is to the true value. Young (1994) puts it like this:

> *"By 'precision' is meant the repeatability of a measurement, usually under fixed conditions. On the other hand, 'accuracy' means the absence of error, as measured against some external standard, such as a set of standard stars."*

King, at the 10th IAU General Assembly (Sadler 1960, p. 370) already stressed

> *"The practice in the past has been to make the observations first and then to consider their meaning. The shortcomings of various magnitude systems have been discovered by bitter experience rather than foreseen, and the productivity of photometric observations has suffered".*

Fabry (1933) already said almost the same on photometry in general:

> *"On a commencé par faire des mesures, sans avoir une compréhension très nette de ce qu'on mesurait"* – we have started to measure without having a clear apprehension of what we were measuring.

Fabry, King and others simply say that we should *think first, then establish procedures, and finally carry them out*. And, *teach the community of measurers how to standardise* and, consequently, *how to calibrate*.

It is clear that the problems that we still encounter, are far from new. It should again be emphasised that most recommendations were formulated already as early as the first days of the Commission, and with a renewed intensity in the mid-1950s. The warnings were subsequently ignored to make place for the "golden sixties" with the proliferation of the many different photometric systems – several of them in disharmony with their own progenitors and clones – and the erection of dozens of photometric telescopes. From then on, IAU reports, indeed, mainly dealt with long lists of places where newer and bigger photometric telescopes were commissioned, and with applications of photometry to research topics.

A question an uninitiated may ask is *why is it that a field of experimental science lingers over in darkness during such a long time, whereas present-day detectors have become optimal in terms of quantum efficiency, linearity and speed, and are matched with performant data-reduction algorithms and powerful statistical tools?* The answer is multifaceted, viz.,

• The nature of the problem: the difficulties of choosing standard stars increase with the level of precision attainable – also in spectroscopy (Batten 1985).

• The fact that, whereas radial velocity standards have their fundamental quantity (velocity) determined in terms of the kilometre and the second, this is not the case with photometric standards, which merely are a group of stars that oft have more or less

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

irreconcilable fundamental quantities, and that are accessible – that is, observable with high precision – only during a very short part of the year.

• The role of the Commission, as explained before, was basically advisory and supportive. This is why Becker's concrete proposal (Oosterhoff 1954, IAU VIII, 1952 p. 363) that the IAU should undertake the task of making standard filters generally available (construction, distribution and sponsoring) was withdrawn.

• Another reason for the unfortunate situation was that an observer is more or less bound to use a photometer-telescope combination and its associated photometric system that is available at the (visitor-operated) observatory, even if that system was never designed for the task that it will ultimately help carry out. This situation thus calls for the *'Maslow Effect'* (Maslow 1966):

> *"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail".*

This is in stark contrast with the emergence of the early photoelectric systems, whose development was driven by people who understood both the physics and the technology.

• Problems caused by individualist approaches, lack of understanding of the basics of measurement, the inherent difficulty of calibrated measurement, and a high time pressure in our "publish or perish" environment.

• Lack of expert training and teaching in calibrated photometry.

• Whereas Eq. 1 worked fine with the photocell and photomultiplier detector (that are, in essence, 1-pixel cameras), the expression falls short for two-dimensional detectors like the photographic plate and the CCD detector: $s_d(\lambda)$ should be written $s_d(\lambda, x_1, x_2, T)$, where $x_1, x_2$ are the coordinates of the image centroid, and $T$ the detector temperature. And, another embedded factor that I would call "operator term" $s_o(\mathrm{sky}, \mathrm{PSF}, \mathrm{FF}, \ldots)$ deals with the sky-background removal (or plate fog), whether aperture or point-spread-function magnitude extraction is applied, dome or sky flatfielding is implied, the degree of smearing of stellar profiles, as well as the impact of undocumented or unknown pipeline reductions or on-board processing of data collected from space that also contributes to lowering the level of precision.

High-precision photometry requires a modelling approach to quantify the effects of image position, flatfielding, etc., but this is not done at all. Instead, an operator $\mathcal{D}$ is applied on the extracted magnitudes $m$, to decorrelate for the geometrical position, detector temperature etc. by minimising a least-squares sum. The resulting parameters then provide minute corrections to the magnitudes. However, one must verify that

($a$) there is an empirical ground for including a particular observable,

($b$) one is sure that the data statistics are not dominated by outliers,

($c$) constant stars are still constant after decorrelation, and

($d$) the resulting parameters behave coherently over time – that is, that the assumption of correlation is valid for all data in the time series to which the procedure is applied.

Not to forget a manipulation $\mathcal{C}$ that consists in auto-clipping outlier data (also called wildshot observations) that is usually applied before $\mathcal{D}$.

The main problem with this post-reduction handling is not only that there hardly is a coherent technical understanding of the corrections that are made, but that $\mathcal{D}$ as well as $\mathcal{C}$ are applied on the *science data*, and not on the *control data* – a change in the $\mathcal{D}$ parameters will modify the light curve: in variable star work, outliers should be removed on the basis of statistics on the (constant) comparison stars. In short, Sampson's *"a detail like magnitude"* may thus look like

$$m = -2.5 \log \left\{ \mathcal{D}\,\mathcal{C} \left( \int_{\lambda 1}^{\lambda 2} E(\lambda)\, s_e(\lambda)\, s_i(\lambda)\, s_t(\lambda)\, s_r(\lambda)\, s_o\, s_d(\lambda, x_1, x_2, T)\, d\lambda \right) \right\} \quad (7.1)$$

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

• The false belief that differential photometry eliminates all systematic errors is fatal: not only the colour equation, but also the $\mathcal{D}$ and $\mathcal{C}$ operators affect both magnitudes in different ways.

The development over one century shows that Commission 25 was continuously touching on the philosophy of precise measurement, in which accurate measuring – for a select group of pioneers – was an end in itself. Not only Stebbins and his team, with the first-time detection of the secondary minimum of Algol with a selenium cell in 1910 (Stebbins 1910, p. 99), but also with the fine work on interstellar extinction, as mentioned on page 389, are textbook examples of this spirit.

## Acknowledgements

I thank James M. Lattis for his help and support during my visit at the University of Wisconsin-Madison Archives, and I am indebted to the University of Wisconsin-Madison Archives for providing the photograph shown in Fig. 1.

## References

Batten, A. H. 1985, *The choice of standard stars*, In *Calibration of Fundamental Stellar Quantities*, 3–16. eds. D.S. Hayes, L.E. Pasinetti, and A.G. Davis Philip, (Dordrecht: Reidel)

Bergeron, J. 1992, *Trans IAU* 21B, 242

Bigourdan, G. 1901, *Le système métrique des poids et des mesures*, (Paris: Gauthier-Villars)

Butler, C. J. and Elliott, I. (eds.) 1993, *Stellar Photometry – Current Techniques and Future Developments*, (Cambridge, UK: Cambridge University Press)

Campbell, W. W. and Stebbins, J. 1920, *Report on the Organisation of the International Astronomical Union*, in *Proceedings of the National Academy of Sciences of the United States of America*, Volume 6, Issue 6, 349

Difley, J. A. 1968, *Two Photographic Developers for Astronomical Use*, *AJ*, 73, 762

Fabry, Ch. (1933) *La photométrie astronomique et celle des physiciens*, in *Annuaire du Bureau des Longitudes*, p. B2, (Paris: Gauthier-Villars et Cie)

Fermilab 2012, *Calibration and Standardization of Large Surveys and Missions in Astronomy and Astrophysics*, 16–19 April 2012, https://indico.fnal.gov/event/4958/

Fowler, A. 1922, *Trans IAU*, 1, 69

Fowler, A. 1925, *Trans IAU*, 2, 86

Hall, D. S. 2005, in *Light Curves of Variable Stars*, ed. C. Sterken and C. Jaschek, pp. 117–121. (Cambridge: Cambridge University Press)

Hearnshaw, J. B. 1996, *The Measurement of Starlight: Two Centuries of Astronomical Photometry*, (Cambridge: Cambridge University Press)

Henize, K. G. 1956, *Catalogues of Halpha-emission Stars and Nebulae in the Magellanic Clouds*, *ApJS*, 2, 315

Herschel, J. F. W. 1847, *Results of astronomical observations made during the years 1834, 5, 6, 7, 8, at the Cape of Good Hope; being the completion of a telescopic survey of the whole surface of the visible heavens, commenced in 1825*, (London: Smith, Elder and co)

Hippke, M., Kroll, P., Matthai, F. *et al.*2017, *Sonneberg Plate Photometry for Boyajian's Star in Two Passbands*, *ApJ*, 837, 85

IAU FM12 2018, *Calibration and Standardization Issues in UV-VIS-IR Astronomy*, Focus Meeting 12 organized at the XXXth General Assembly in Vienna

Johnson, H. L. and Morgan, W. W. 1953, *Fundamental stellar photometry for standards of spectral type on the revised system of the Yerkes spectral atlas*, *ApJ*, 117, 313

Kaufer, A. and Kerber, F. (eds.) 2008, *The 2007 ESO Instrument Calibration Workshop*, ESO Astrophysics Symposia, Springer

King, I. 1952, *Effective extinction values in wide-band photometry*, *AJ* 57, 253

Lattis, J. M. 2014, *The Stebbins Galaxy: the origins of interstellar medium studies in the shrinking super-galaxy*, *JAHH*, 17, 240

Lattis, J. M. 2018, Personal communication (email August 22)
Lattis, J. M. and Lattis, A. J. 2019, *American Astronomers in Belgium, 1919: Snapshots from the Founding of the IAU*, these Proceedings
Laycock, S. *et al.*2010, *Digital Access to a Sky Century at Harvard: Initial Photometry and Astrometry*, *AJ*, 140, 1062
Leavitt, H. S. 1917, *The North Polar Sequence*, *Annals of the Astronomical Observatory of Harvard College* 71, no. 3, Cambridge, Mass.
Longair M. 2019, *100 Years of Astronomy, Astrophysics and Cosmology. A celebration of the centenary of the IAU*, these Proceedings
Maslow, A. H. 1966, *The Psychology of Science*, p. 15. (London: Harper & Row)
Milone, E. F. and Sterken, C. 2011, *Astronomical Photometry: Past, Present, and Future*, Springer Astrophysics and Space Science Library series
Munari, U., Fiorucci, M. and Moro, D. 2002, *Asiago Database on Photometric Systems*, http://ulisse.pd.astro.it/Astro/ADPS/, last accessed September 1, 2018
Oort, J. H. 1950, *Trans IAU* 7, 271
Oosterhoff, P. Th. 1954, *Trans IAU* 8, 363 and 367
Pecker, J.-C. 1964, *Trans IAU* 12, 265
Pel, J. W. and Lub, J. 2007, *The Walraven VBLUW Photometric System: 32 Years of 5-Channel Photometry*, in *The Future of Photometric, Spectrophotometric and Polarimetric Standardization*, ed. C. Sterken, San Francisco: Astronomical Society of the Pacific Conference Series, Vol. 364, p. 63
Pogson, N. 1857, *Magnitudes of Thirty-six of the Minor Planets for the first day of each month of the year 1857*, *MNRAS* 17, 12
Redman, R. O. 1952, in Oosterhoff (1954, ed.), *Trans IAU* 8, 364
Sadler, D. H. 1960, *Trans IAU* 10, 370
Sampson, R. A. 1921, *The Measurement of Starlight*, *The Observatory*, 44, 298
Schaefer, B. E. 2016 *KIC 8462852 Faded at an Average Rate of 0.164±0.013 Magnitudes per Century from 1890 to 1989*, *ApJL*, 822, 34
Seares F. H., Bailey, S. I., Jordan, F. C., Parkhurst, J. A. and Stebbins, J. 1920, *Report of the Committee on Stellar Photometry*, in Campbell and Stebbins (1920), p. 381
Seares F. H., Ross, F. E., Joyner and M. C. 1941, *Magnitudes and colours of stars north of +80 deg*, *Mount Wilson Papers*, 6
Shapley, H. and Ames, A. 1929, *The Coma-Virgo Galaxies, I On the Transparency of Intergalactie Space*, *Harvard College Observatory Bulletin* No. 864
Shore, S. N. 1992, *The Luminous Blue Variables in the Ultraviolet*, in *Nonisotropic and Variable Outflows from Stars*, ASP Conf. Series, eds. L. Drissen, C. Leitherer and A. Nota, Vol. 22, p. 342
Stebbins, J. 1910, *The measurement of the light of stars with a selenium photometer, with an application to the variations of Algol*, *Apj*, 32, 185
Stebbins J. and Whitford A. J. 1945, *Six-colour photometry of stars. III. The colours of 238 stars of different spectral types*, *ApJ*, 102, 318
Stebbins, J., Whitford, A. E. and Johnson, H. L. 1950, *Photoelectric Magnitudes and Colours of Stars in Selected Areas 57, 61, and 68*, *ApJ*, 112, 469
Sterken, C. 1992a, *On the future of existing photometric systems*, *Vistas in Astronomy*, 35, 139
Sterken, C. 1992b, *On the impact of an ultimate metrological reform in astronomical photometry*, *Vistas in Astronomy*, 35, 263
Sterken, C. (ed.) 2007, *The Future of Photometric, Spectrophotometric and Polarimetric Standardization*, San Francisco: *Astronomical Society of the Pacific Conference Series*, Vol. 364
Sterken, C. 2010, *Writing a Scientific Paper II. Communication by Graphics*, in *Scientific Writing for Young Astronomers*, (Paris: EDP Sciences)
Sterken, C. 2019, in *Southern Horizons in Time-Domain Astronomy*, Proceedings IAU Symposium No. 339, E. Griffin (ed.), Cambridge: Cambridge University Press p. 25
Sterken, C. and Manfroid, J. 1992, *Astronomical Photometry, A Guide*, Astrophysics and Space Science Library, Vol. 175, (Dordrecht: Kluwer)

https://doi.org/10.1017/S1743921319000486 Published online by Cambridge University Press

Sterken, C., Milone, E. F., Young, A. T. 2011, *Photometric Precision and Accuracy*, in *Astronomical Photometry: Past, Present, and Future*, E. F. Milone and C. Sterken (eds.). Astrophysics and Space Science Library, Vol. 373, Berlin: Springer

Sūdžius, J., Straižys, V. and Davis Philip, A. G. 2004, *Stellar Photometry: Past, Present, and Future*, (Vilnius: Vilnius University)

Susalla, P. and Lattis, J. 2010, *Wisconsin at the Frontiers of Astronomy: A History of Innovation and Exploration*, State of Wisconsin Blue Book 2009–2010, 100–187, (Madison: University of Wisconsin-Madison)

Toomer, G. J. 1984, *Ptolemy's Almagest*, (New York: Springer-Verlag)

Weaver, H. F. 1946, *The development of astronomical photometry*, *Popular Astronomy*, 54, 211/287/339/389/451/504

Young, A. T. 1974, in *Methods of Experimental Physics*, Vol 12, *Astrophysics. Part A: Optical and Infrared*, Carleton, N. (ed.), (New York: Academic Press)

Young, A. T. 1990, *Astronomical computing: how we perceive star brightnesses*, *Sky and Telescope*, 79, 311

Young, A. T. 1992, *Improvements in photometry. V – High-order moments in transformation theory*, *A&A*, 257, 366

Young, A. T. 1994, in *The Impact of Long-term Monitoring on Variable Star Research: Astrophysics, Instrumentation, Data Handling, Archiving*, eds. C. Sterken and M. de Groot, NATO Advanced Science Institutes Series C: Mathematical and Physical Sciences, (Dordrecht: Kluwer)