Sloan Magnitudes for the Brightest Stars

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Abstract Sloan magnitudes are reported for 3,969 stars brighter than r' ~ 7. The data are based upon Johnson-Cousins photometry which has been transformed to the Sloan system. Cousins $V–R_C$ and $R_C–I_C$ color indices are also provided as a by-product.

1. Introduction

The Sloan magnitude system is enjoying widespread acceptance in the astronomical community. Besides the Digital Sky Survey which bears its name, the Hubble Space Telescope, Pan-STARRS, and the Large Synoptic Survey Telescope programs are using it. The Sloan survey photometric system has five primary bands, u, g, r, i, and z, which span wavelengths from about 300 nm to one micron. When magnitudes are designated with primes, u', g', r', i', and z', they refer to other telescopes using the Smith *et al.* (2002) u'g'r'i'z' standard-star system, whose pass-bands differ slightly from those of the Sloan survey.

One reason for the popularity of the Sloan system is that these bands are more cleanly separated from one another than in older systems such as UBVRI. Another is that the magnitudes are directly related to absolute fluxes. APASS, the all-sky survey conducted by The American Association of Variable Star Observers (AAVSO 2013), has catalogued the magnitudes of 50 million stars in the range ~7.5 < V < ~17 based on photometry with the Johnson *et al.* (1966) B and V filters and the Sloan g', r', and i' filters. These bands extend from about 400 to 850 nm. An important aspect of the APASS system is that it relates and provides photometry from two heavily used photometric systems. The accuracy is a few hundredths of a magnitude near V = 10 and degrades to ~ 0.1 magnitude at V = 16.5. The magnitudes of stars brighter than V = 10 are systematically too faint because of detector saturation.

The present study provides Sloan magnitudes for the brightest stars. These results are similar in quality to APASS data and they cover a broader range of wavelengths. The magnitudes are derived from Johnson's UBVRI photometry in a two-step process. First, the Johnson magnitudes and color indices were transformed to the Cousins (1976a, 1976b) system. Then, Cousins values were transformed to Sloan magnitudes.

2. Transformation methods

The U, B, and V magnitudes of Johnson *et al.* (1966) and of Cousins (1976a, 1976b) are equivalent, but the R and I bands differ. Taylor (1986) lists four separate equations for transforming the Johnson V–R color index to Cousins $V–R_C$ and four other equations for R–I to $R_C–I_C$. Each equation pertains to specific stellar luminosity classes and a range of color indices. Every coefficient is accompanied by an uncertainty value so that the probable error of the color index can be computed. When more than one equation was applicable to a given star, the color index with the least probable error was adopted. More details of the Johnson-to-Cousins transformation are given in Appendix A.

Two independently derived sets of equations were used to transform between Cousins and Sloan u', g', r', i', and z' magnitudes. Fukugita *et al.* (1996) developed theoretical transformations to the Sloan magnitudes of the 20-inch photometric telescope collocated with the 2.5-m Sloan survey telescope. Smith *et al.* (2002) established a system of 158 standard stars with the 1.0-m telescope at the USNO Flagstaff Station and derived transformations based on actual photometry. More details of the Cousins to Sloan transformations can be found in Appendix B.

3. Sloan magnitude results

The Sloan magnitudes listed in Table 1 are averages based on the transformation equations of Smith *et al.* (2002) and of Fukugita *et al.* (1996). Each value is accompanied by its estimated uncertainty in units of 0.01 magnitude. These estimates are equal to the square roots of the sums of the squares of three components of uncertainties: that of the photometry of Johnson *et al.* (1966), Taylor's (1986) estimates of his transformation errors, and the standard deviation of the mean of each Smith/Fukugita average.

The mean uncertainty for the g', r', i', and z' bands is 0.03 magnitude while that for u' is 0.08 Thus the entries in this catalogue may be used as reference stars for bright objects where moderate accuracy is sufficient. In applications where higher accuracy is required (for example, color transformation) the primary standard stars should be used instead. In these respects, the data are similar to APASS.

The first 1,029 stars are accompanied by magnitudes for all five Sloan bands as well as Cousins $V–R_C$ and $R_C–I_c$ color indices. The remaining 2,940 stars list fewer than five Sloan magnitudes and no Cousins color indices because the Johnson data were incomplete. The absent magnitudes are indicated with the entry "99.99." A portion of Table 1 is included in the paper. The full table is available through the AAVSO ftp site at ftp:ftp.aavso.org/public/datasets/amalaj422.txt; is also available from the author and it will be made available through Vizier.

Table 1. Johnson, Cousins, and Sloan magnitudes for the brightest non-variable stars. This is an abbreviated version of the full table which contains data records for 3,969 stars. The full table is available through the AAVSO ftp site at ftp:ftp.aavso.org/public/datasets/amalaj422.txt.

	Johnson					Cousins		Sloan									
HD	*V*	*U–B*	*B–V*	*V–R*	*R–I*	$V–R_C$	$R_C–I_C$	*u′*		*g′*		*r′*		*i′*		*z′*	
496	3.88	0.84	1.03	0.75	0.52	0.52	0.47	6.62	5	4.35	4	3.55	4	3.30	3	3.18	3
571	5.04	0.26	0.40	0.42	0.29	0.27	0.28	6.65	9	5.17	3	4.96	2	4.91	2	4.90	3
1013	4.80	1.93	1.57	1.34	1.13	0.90	1.05	9.31	14	5.57	5	4.19	5	3.37	3	2.88	3
1280	4.61	0.05	0.06	0.08	0.01	0.03	0.03	5.75	13	4.55	3	4.71	2	4.90	2	5.05	3
1404	4.52	0.07	0.05	0.08	0.00	0.03	0.01	5.68	14	4.45	3	4.62	2	4.83	2	4.99	3
1522	3.55	1.17	1.22	0.85	0.59	0.59	0.52	6.84	7	4.13	4	3.15	5	2.85	3	2.69	3
1581	4.23	0.02	0.58	0.49	0.34	0.32	0.33	5.61	4	4.45	3	4.09	2	3.97	2	3.93	2
2151	2.80	0.11	0.62	0.50	0.34	0.33	0.34	4.33	3	3.05	3	2.64	2	2.53	2	2.49	2
2261	2.40	0.88	1.09	0.81	0.59	0.56	0.52	5.23	4	2.90	4	2.04	4	1.74	3	1.58	3
2262	3.94	0.10	0.17	0.14	0.08	0.07	0.09	5.20	11	3.94	3	3.99	2	4.12	2	4.24	3
2772	4.73	–0.36	–0.10	0.00	–0.12	–0.02	–0.07	5.22	8	4.58	2	4.88	3	5.18	3	5.39	3
3360	3.66	–0.89	–0.19	–0.08	–0.21	–0.08	–0.13	3.38	4	3.46	2	3.86	3	4.21	3	4.46	4
3369	4.36	–0.55	–0.16	–0.04	–0.12	–0.05	–0.07	4.56	6	4.18	2	4.54	3	4.83	3	5.04	4
3546	4.38	0.47	0.87	0.68	0.51	0.47	0.46	6.53	3	4.76	4	4.11	3	3.87	2	3.75	2
3627	3.28	1.48	1.28	0.92	0.66	0.64	0.60	7.02	12	3.89	4	2.84	5	2.47	3	2.26	3
3651	5.86	0.58	0.85	0.65	0.39	0.44	0.37	8.15	4	6.23	4	5.60	3	5.46	2	5.39	2
3817	5.33	0.60	0.89	0.71	0.46	0.49	0.42	7.67	4	5.72	4	5.04	3	4.84	2	4.75	2
3901	4.81	–0.66	–0.10	–0.01	–0.12	–0.03	–0.06	4.90	3	4.66	2	4.97	3	5.25	3	5.46	3
3919	4.59	0.72	0.97	0.75	0.52	0.52	0.47	7.13	4	5.03	4	4.27	3	4.03	2	3.90	2
4128	2.02	0.88	1.01	0.72	0.51	0.50	0.46	4.80	6	2.48	4	1.70	4	1.47	3	1.34	3

4. Summary

A catalogue of Sloan magnitudes for 3,969 stars brighter than r ~7 is presented. The data are based upon Johnson-Cousins UBVRI photometry which has been transformed to the Sloan system. Equations developed by Taylor (1986) were used to transform from the Johnson V–R and R–I color indices to Cousins $V–R_C$ and $R_C–I_C$ and these are reported for 1,029 of the stars. Two independently derived sets of equations (Fukugita *et al.* 1996, and Smith *et al.* 2002) were used to transform from Cousins magnitudes to Sloan u', g', r', i', and z'. The Sloan magnitude results are accurate to a several hundredths of a magnitude and they complement those of the APASS catalogue. Sloan data in the magnitude range 7 to 10 are still needed to fill the gap between the faint limit of this catalogue and the bright limit of APASS.

5. Acknowledgements

Brian Skiff (Lowell Observatory) suggested the transformation method used in this study and provided other helpful information. Comments from two anonymous referees led to improvements in the paper. Thanks are also due to Bruce Krobusek (CVAS) for participating in this project and to Ronald Baker (CVAS) for reviewing an early draft of the manuscript.

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Appendix A: Johnson to Cousins transformation equations

Taylor (1986) derived four separate equations for transforming the Johnson *et al.* (1996) R–I color index to Cousins (1976a, 1976b) $R_C–I_C$, and another four equations for V–R to $V–R_C$. Each equation pertains to specific stellar luminosity classes and a range of color indices as indicated below. The constants C_1 and C_2 apply a zero point offset that depends on right ascension. The transformations for R–I also depend on the factor δ_{BJ}(U–B) which is related to the Balmer-jump and was defined by Taylor. For some combinations of luminosity class with spectral type this term could not be determined accurately and such stars are not included in this study. Graphs showing the relationship between the Johnson and Cousins color indices follow the equations.

A.1. R–I to R–I_C equations

If 5400 < HR < 7200, C_1 = –0.009; otherwise C_1 = zero.

(1) All luminosity classes:
$R_C–I_C = 0.902\ ((R–I) – C_1) – 0.087\ \delta_{BJ}(U–B) + 0.073$

(2) All luminosity classes in a limited range of color indices:
$R_C–I_C = 0.762\ ((R–I) – C_1) – 0.073\ \delta_{BJ}(U–B) + 0.074$

(3) Giant stars in a limited range of colors:
$R_C–I_C = 0.953\ ((R–I) – C_1) – 0.030$

(4) Dwarf stars in a limited range of color indices:
$R_C–I_C = 0.978\ (R–I) – 0.012$

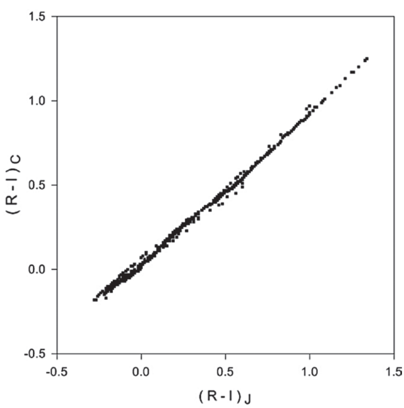

Figure A.1. The transformation from Johnson R–I to Cousins $R_C–I_C$. The function is multi-valued because there are four separate equations which apply to different luminosity classes in addition to the dependence on $\delta_{BJ}(U–B)$.

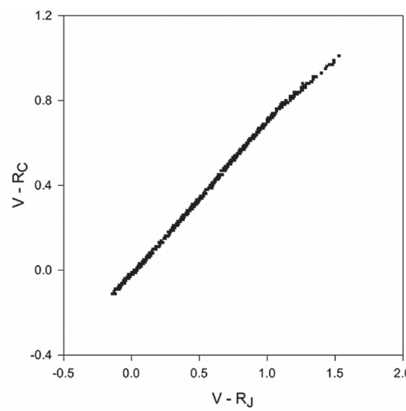

Figure A.2. The transformation from Johnson V–R to Cousins V–R_C. Unlike the R–I color index this one is almost single-valued since there is less dependence on luminosity class and no dependence on $\delta_{BJ}(U–B)$.

A.2. V–R to V–R_C equations

If HR > 4700, C_2 = –0.009; otherwise C_2 = zero.

(1) All luminosity classes except red dwarfs; a limited range of color indices:

$V–R_C = 0.717\ ((V–R) – C_2) – 0.021$

(2) All luminosity classes in a limited range of color indices:
$V–R_C = 0.717 ((V–R) – C_2) – 0.030$

(3) Giants in a limited range of color indices:
$V–R_C = 0.55 ((V–R) – C_2) + 0.16$

(4) Red dwarfs:
$V–R_C = 0.63 ((V–R) – C_2) + 0.07$

Appendix B: Cousins to Sloan transformation equations

The equations listed below were used for transformations from Cousins (1976a, 1976b) to Sloan. When two equations are available for the same magnitude the results were averaged. In some cases only one of the two equations could be used because fewer than five Cousins magnitudes or colors were available. Color–color graphs follow the equations.

B.1. Fukugita *et al.* (1996) equations

$g' = V + 0.56 (B–V) – 0.12$

$r' = V – 0.49 (B–V) + 0.11$

$r' = V – 0.84 (V–R_C) + 0.13$

$u'–g' = 1.38 (U–B) + 1.14$

$g'–r' = 1.05 (B–V) – 0.23$

$r'–i' \text{ (for } R_C–I_C < + 1.15) = 0.98 (R_C–I_C) – 0.23$

$r'–i' \text{ (for } R_C–I_C \geq + 1.15) = 1.40 (R_C–I_C) – 0.72$

$r'–z' \text{ (for } R_C–I_C < + 1.65) = 1.59 (R_C–I_C) – 0.40$

$r'–z' \text{ (for } R_C–I_C \geq + 1.65) = 2.64 (R_C–I_C) – 2.16$

B.2. Smith *et al.* (2002) equations

$g' = V + 0.54 (B–V) – 0.07$

$r' = V – 0.44 (B–V) + 0.12$

$r' \text{ (for } V–R_C < 1.00) = V – 0.81 (V–R_C) + 0.13$

$r' \text{ (for } V–R_C >=1.00) = \ldots$ no stars in this range

$u'–g' = 1.33 (U–B) + 1.12$

$r'–i' \text{ (for } R_C–I_C < 1.15) = 1.00 (R_C–I_C) – 0.21$

$r'–i'$ (for $R_C–I_C \geq 1.15$) = $1.42 (R_C–I_C) – 0.69$

$r'–z'$ (for $R_C–I_C < 1.65$) = $1.65 (R_C–I_C) – 0.38$

$r'–z'$ (for $R_C–I_C \geq 1.65$) … no stars in this range

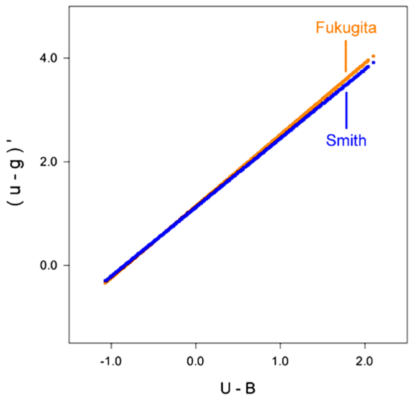

Figure B.1. The (u–g)' color index as a function of U–B.

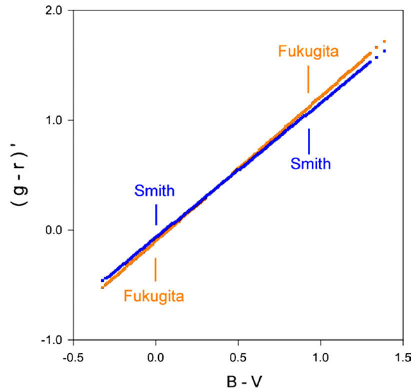

Figure B.2. The (g–r)' color index as a function of B–V.

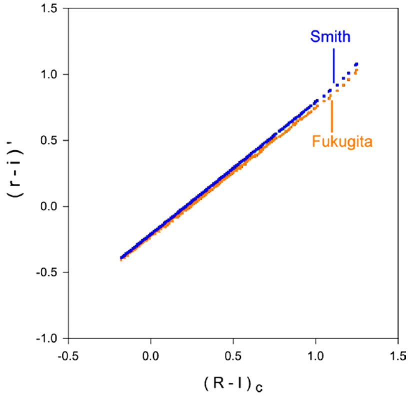

Figure B.3. The (r– i)' color indices as a function of $(R–I)_C$.

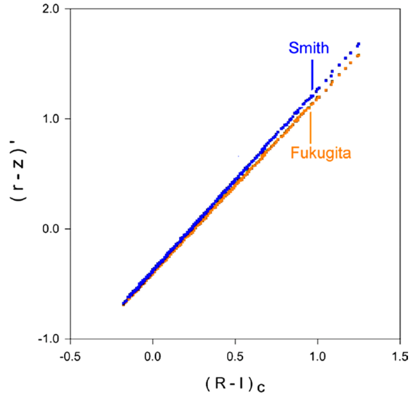

Figure B.4. The (r–z)' color indices as a function of $(R–I)_C$.

Appendix C: Data sources

The following data base files were used as input.

1) Johnson five-color photometry:
http://obswww.unige.ch/gcpd/cgi-bin/getStars.cgi?Ref=15&Photo=08

2) Johnson three-color photometry:
http://cdsarc.u-strasbg.fr/viz-bin/ftp-index?II/5A

3) Skiff luminosity classes and spectral types
http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=skiff%20mk%20type

4) *General Catalogue of Variable Stars*
http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=B/gcvs