CSC-96-932-24

Computer Sciences Corporation

SKYMAP Requirements, Functional, and Mathematical Specifications

CSC

Volume 3

Revision 3

(SKYMAP SKY2000 Version 2 Master Catalog Format Specifications)

August 1999

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland 20771

CONTRACT GS-35F-4381G
Task Order No. S-24280-G

August 1999

CSC-96-932-24

SKYMAP Requirements, Functional, and Mathematical Specifications

Volume 3
Revision 3

(SKYMAP SKY2000 Version 2 Master Catalog Format Specifications)

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland 20771

By

COMPUTER SCIENCES CORPORATION

Under

CONTRACT GS-35F-4381G
Task Order No. S-24280-G

August 1999

The primary contributor to this document is

C. Sande — CSC

Other contributors include

N. Ottenstein — CSC

Developed Under the Direction of — D. Tracewell, GSFC/Code 570

Through — D. Oza, CSC/Applied Research Department

Preface

This document revises Revision 2 of the third volume of requirements, functional, and mathematical specifications for the SKYMAP System (553-FDD-94/016R2UD0). As of the date of publication, only Volume 2, containing Instrumental Red Magnitude Prediction Subsystem Specifications (CSC-96-932-06) has also been updated to reflect the SKY2000 Version 2 Master Catalog. Volume 1 contains specifications for standard SKYMAP System software and is expected to be updated in the near future. Subsequent volumes are expected to contain specifications for additional subsystems, as required.

Abstract

This document presents format requirements, functional, and mathematical specifications for the SKYMAP SKY2000 Version 2 Master Catalog. The format is designed to facilitate the incorporation of data critical to the support of future National Aeronautics and Space Administration (NASA) missions using charge-coupled device (CCD) star trackers (CCDSTs) for attitude determination.

Keywords: *CCD, CCDST, SKYMAP, star catalog*

Change Information Page

List of Effective Pages	
Page Number	**Issue**
Title	Revision 3
i-ii, I, and I-iv	Revision 3
1-1	Revision 3
2-1	Revision 3
3-1 through 3-31	Revision 3
4-1 through 4-14	Revision 3
5-1	Revision 3
A-1 through A-7	Revision 3
AA-1 and AA-2	Revision 3
B-1 through B-4	Revision 3

Document History			
Document Number	**Status/Issue**	**Publication Date**	**CCR Number**
553-FDD-94/016R0UD0	Original	July 1994	550-1151
553-FDD-94/016R1UD0	Revision 1	September 1995	550-1238
553-FDD-94/016R2UD0	Revision 2	September 1996	550-1409, 550-1420
CSC-96-932-24	Revision 3	August 1999	MMFD-1011

Contents

Figures

Tables

Section 1. Introduction

This document presents format requirements, functional, and mathematical specifications for the SKYMAP SKY2000 Version 2 Master Catalog. The modifications are designed to facilitate the incorporation of magnitude data in several passbands critical for the support of future National Aeronautics and Space Administration (NASA) missions using charge-coupled device (CCD) star trackers (CCDSTs) for attitude determination. The modifications also allowed the accommodation of newer higher-accuracy astrometric data.

1.1 Need for SKYMAP Master Catalog Record Format Modifications

Flight dynamics analysts use the SKYMAP Master Catalog to prepare mission star catalogs for attitude determination support of specific missions with star sensors. The SKY2000 Version 1 Master Catalog has the following deficiencies in the data format and content:

- No observed *V* magnitudes or (*B*-*V*) colors for more than half the catalog entries
- Insufficient storage precision for improved catalog positions
- No allowance in the catalog format for the addition of magnitudes measured by CCDST's
- Missing or inaccurate catalog cross-reference information
- Missing or inaccurate double- and multiple-star information

1.2 Goals of the Record Format Modifications

In general, the primary goal of this SKYMAP format specification is to aid the analyst in providing improved attitude support for missions using CCDSTs.

To accomplish this goal, the record format modifications to SKY2000 Version 1 are as follows:

- Provide word lengths long enough to accommodate new higher-accuracy astrometric data
- Add data words to accommodate measured CCDST magnitudes, including uncertainties, photometric systems and passbands, and sources
- Add a data word for a standard International Astronomical Union (IAU) catalog identifier

Section 2. Requirements

This section is a description of the specific requirements for the SKYMAP SKY2000 Version 2 Master Catalog that will satisfy the specific goals in Section 1.

SKYMAP Master Catalog data are used by star identification routines and fine attitude determination routines. As such, the catalog must be complete to the star tracker's limiting magnitude, provide data for accurate prediction of instrumental magnitudes, and contain accurate star positions. Other information, such as data on multiple stars or stars of variable brightness, is also included so that additional constraints may be placed on mission star catalog data.

To support the older fixed-head star trackers (FHSTs) (Torgow, 1986) and the current CCDSTs, the following attributes are required for the SKYMAP Master Catalog:

2.1 It must contain data for all stars with either measured Johnson blue (*B*) or visual (*V*) magnitudes 9.0 or brighter.

2.2 It must contain observed *V* or derived V' magnitudes for at least 90% of included stars.

2.3 It must contain magnitude information in other passbands and on other magnitude systems (e.g., *B* magnitudes on the Johnson system, or red [*R*] magnitudes on the Russian system).

2.4 It must contain epoch 2000.0 star position, proper motion, radial velocity, and parallax data.

2.5 It must indicate uncertainties at the position epoch associated with star positional data.

2.6 It must contain cross-identification information to assist in referencing data from other published star catalogs.

2.7 It must include spectral type information.

2.8 It must contain data concerning multiple star systems and stars of variable brightness.

2.9 The only default value must be a blank field.

2.10 All source codes must consistently indicate a specified source catalog.

2.11 The SKYMAP SKY2000 Version 2 Master Catalog must be a sequential alphanumeric file as opposed to a binary file. This will enable browsing and editing of star data without the need for SKYMAP-specific software.

Section 3. SKYMAP Master Catalog Functional Specifications

This section contains a description of the SKYMAP SKY2000 Version 2 Master Catalog format, including a definition of each variable. The 7 overall SKY2000 Version 2 data words differ for 7 individual data subwords from Version 1 and eight new data subwords have been added. Table 3-1 lists the SKY2000 Version 2 Master Catalog data words for each star. The source column indicates whether the data are observed, assigned, or derived. A description of each of the data words listed in Table 3-1 follows.

3.1 Star Identifiers

Star identifiers are provided in the SKY2000 Version 2 Master Catalog to facilitate cross-referencing to other published star catalogs. The word number refers to the information contained in Table 3-1.

3.1.1 Word 1.0

The SKYMAP Master Catalog identification system is defined so that stars may be added to the catalog without stars already present having to be renumbered. Each SKYMAP star is assigned an International Astronomical Union (IAU) identifier of the form SKY2000 JHHMMSS.SS±DDMMSS.S, where HHMMSS.SS denotes hours, minutes, and seconds of time, and DDMMSS.S denotes degrees, minutes, and seconds of arc, where both coordinates are in the International Celestial Reference System (ICRS) at epoch 2000.0. This identifier is formed by truncating the right ascension (Word 2.1) and the declination (Word 2.2) to the required lengths.

3.1.2 Word 1.1

Each SKYMAP star is assigned a number of the form HHMMNNNN, where *HH* denotes the hours of right ascension, epoch 2000.0; *MM* denotes the minutes of right ascension, epoch 2000.0; and *NNNN* denotes a running index, starting at 0001. Originally, numbers were assigned in order of increasing right ascension, but this order was not maintained as position data were altered, new stars were added, and duplicate stars were deleted. All SKYMAP stars must have a SKYMAP number and an IAU identifier, whereas only a large proportion of the SKYMAP stars will include any of the other standard reference identifiers.

3.1.3 Word 1.2

Henry Draper (HD) Catalog numbers, defined by Cannon and Pickering (1918–24) in the HD Catalog, Cannon (1925–36) in the first HD Extension (HDE), and Cannon and Walton Mayall (1949) in the second HDE, are in order of increasing right ascension at epoch 1900.0. Values range from 1 to 225,300 for original HD stars, from 225,301 to 272,150 for the first extension, and from 272,151 to 359,083 for the second extension. A code 9 following the HD number indicates that there is more than one entry in the HD corresponding to this star, indicating a resolved or unresolved double or multiple star system. The SKY2000 Version 2 Master Catalog may have a single entry or multiple entries, depending on the separations involved. A colon following the code 9 field indicates that the HD number is uncertain.

3.1.4 Word 1.3

The Smithsonian Astrophysical Observatory (SAO) number is a six-digit integer used principally in the SAO Catalog (Smithsonian Astrophysical Observatory Staff, 1966). These numbers are assigned sequentially within declination zones 10 degrees wide, beginning at the North Celestial Pole. Therefore, increasing SAO numbers correspond approximately to decreasing declination at epoch 1950.0. A colon following the SAO number indicates that the SAO number is uncertain.

3.1.5 Word 1.4

The Durchmusterung (DM) identifier is obtained from the extensive DM catalogs: the Bonner Durchmusterung (BD) (Argelander, 1859-62), the Southern Durchmusterung (SD) (Schönfeld, 1886), the Córdoba Durchmusterung (CD) (Thome, 1892–1914; Perrine, 1932), and the Cape Photographic Durchmusterung (CP) (Gill and Kapteyn, 1896–1900). The DM identifier is a coded composite of the DM zone and sequential index. It is a two-character identifier of the particular DM catalog, and a two- and five-digit integer. The first two digits represent the 1-degree-high declination zone (equinox 1855.0 for BD and SD, 1875.0 for others) into which the star falls, and the last five digits form a sequential index within that zone assigned in order of increasing right ascension (equinox 1855.0). A lowercase letter (excluding *p*, *s*, and *x*) following the sequential index indicates that the star is a DM supplement star. A lowercase *p*, *s*, or *x* following the supplement star field indicates a component identified using the notation contained in the Positions and Proper Motions (PPM) North and PPM South catalogs. An uppercase A, B, or C, etc., may also be used to identify the component. A colon following the component field indicates that the DM identifier is uncertain.

Collectively, these catalogs cover the whole sky, with the BD extending from the North Pole to -2 degrees (zones +89 to -1), the SD from -02 to -23 (zones -02 to -22), the CD from -22 to the South Pole (zones -22 to -89), and the CP from -18 to the South Pole (zones -18 to -89). SKYMAP uses the convention of the HD, slightly modified in the -22 zone, i.e., BD from +89 to -01, SD from -02 to -21, CD from -22 to -51, and CP from -52 to -89.

3.1.6 Word 1.5

Harvard Revised (HR) numbers, from the updated revised edition of the Yale Bright Star Catalog (Warren, 1994), are frequently cross-referenced in scientific literature. They are defined in order of increasing right ascension, equinox 1900.0, beginning with 1 and ending with 9110. Only 9110 objects stars have HR numbers, of which 9096 are stellar objects consistently bright enough for inclusion in SKYMAP.

3.1.7 Word 1.6

This word contains the Washington Catalog of Double Stars (WDS) identifier, in which components are identified. The source of this number is Worley and Douglass (1994). This number is assigned as a function of the star's right ascension and declination at J2000. A colon following the five-digit component field indicates that the WDS identifier is uncertain.

Table 3-1. SKYMAP SKY2000 Version 2 Master Catalog Record Format (1 of 4)

Word No.	Start	End	Type	Meaning	Units	Source
Star Numbers and Names						
1.0*	1	27	A27	IAU identifier	—	Assigned
1.1	28	35	I8	*SKYMAP* number	—	Assigned
1.2	36	43	I6, A1, A1	HD number	—	External
1.3	44	50	I6, A1	SAO number	—	External
1.4	51	63	A10, A1, A1, A1	DM number	—	External
1.5	64	67	I4	HR [= BS] number	—	External
1.6	68	83	A10, A5, A1	WDS number	—	External
1.7	84	90	I6, A1	PPM number	—	External
1.8	91	98	I8	*SKYMAP* number of last *SKYMAP* entry merged with this star	—	Assigned
1.9	99	108	A10	Star name (or AG designation)	—	External
1.10	109	118	A10	Variable name (or questionable variability flag)	—	External
Positions and Proper Motions						
2.1	119	129	I2, I2, F7.4	Right ascension, equinox, epoch, and equator of ICRS2000	hr, min, sec	External
2.2	130	140	A1, I2, I2, F6.3	Declination, equinox, epoch, and equator of ICRS2000	±deg, arcmin, arcsec	External
2.3	141	146	F6.4	Position uncertainty at ICRS2000	arcsec	External/ assigned
2.4	147	—	A1	Blended position flag	—	Assigned
2.5	148	149	I2	Source of position data	—	Assigned
2.6	150	157	F8.5	Proper motion in right ascension (ICRS2000)	sec/yr	External
2.7	158	165	F8.4	Proper motion in declination (ICRS2000)	arcsec/yr	External
2.8	166	167	I2	Source of proper motion data	—	Assigned

Table 3-1. SKYMAP SKY2000 Version 2 Master Catalog Record Format (2 of 4)

Word No.	Start	End	Type	Meaning	Units	Source
2.9	168	173	F6.1	Radial velocity	km/sec	External
2.10	174	175	I2	Source of radial velocity data	—	Assigned
2.11	176	183	F8.5	Trigonometric parallax	arcsec	External
2.12	184	191	F8.6	Trigonometric parallax uncertainty	arcsec	External/ assigned
2.13	192	193	I2	Source of trigonometric parallax data	—	Assigned
2.14–2.16	194	220	3(F9.6)	Geocentric inertial unit vector components, equinox and epoch ICRS2000	—	Internal
2.17	221	226	F6.2	Galactic longitude	deg	Internal
2.18	227	232	F6.2	Galactic latitude	deg	Internal
Magnitudes						
3.1	233	238	F6.3	Observed V magnitude	magnitudes	External
3.2	239	243	F5.2	Derived visual magnitude (V´)	magnitudes	Internal
3.3	244	248	F5.3	V or V´ uncertainty	magnitudes	External/ assigned/ internal
3.4	249	—	A1	Blended visual magnitude flag	—	Assigned
3.5	250	251	I2	Source of visual magnitude	—	Assigned
3.6	252	—	I1	V’ magnitude derivation flag	—	Internal
3.7	253	258	F6.3	B magnitude (observed)	magnitudes	External
3.8	259	264	F6.3	B-V color (observed)	magnitudes	External
3.9	265	269	F5.3	B or (B-V) magnitude uncertainty	magnitudes	External/ assigned
3.10	270	—	A1	Blended B magnitude flag	—	Assigned
3.11	271	272	I2	Source of B magnitude	—	Assigned
3.12	273	278	F6.3	U magnitude (observed)	magnitudes	External
3.13	279	284	F6.3	U-B color (observed)	magnitudes	External
3.14	285	289	F5.3	U or (U-B) magnitude uncertainty	magnitudes	External/ assigned
3.15	290	—	A1	Blended U magnitude flag	—	Assigned
3.16	291	292	I2	Source of U magnitude	—	Assigned
3.17	293	296	F4.1	ptv magnitude (observed)	magnitudes	External
3.18	297	298	I2	Source of ptv magnitude	—	Assigned
3.19	299	302	F4.1	ptg magnitude (observed)	magnitudes	External
3.20	303	304	I2	Source of ptg magnitude	—	Assigned

Table 3-1. SKYMAP SKY2000 Version 2 Master Catalog Record Format (3 of 4)

Word No.	Start	End	Type	Meaning	Units	Source
Spectral Types						
4.1	305	334	A30	Morgan-Keenan (MK) spectral type	—	External
4.2	335	336	I2	Source of MK spectral type data	—	Assigned
4.3	337	339	A3	One-dimensional spectral class (i.e., HD, AGK3, or SAO)	—	External
4.4	340	341	I2	Source of one-dimensional spectral class data	—	Assigned
Multiple Star Data						
5.1	342	348	F7.3	Separation of brightest and second brightest components	arcsec	External
5.2	349	353	F5.2	Magnitude difference of brightest and second-brightest components	magnitudes	External
5.3	354	360	F7.2	Orbital period**	yr	External
5.4	361	363	I3	Position angle	deg	External
5.5	364	370	F7.2	Year of observation	yr	External
5.6	371	372	I2	Source of multiplicity data	—	Assigned
5.7	373	—	A1	Passband of multiple-star magnitude difference	—	External
5.8	374	380	F7.4	Distance to nearest neighboring star in Master Catalog	deg	Internal
5.9	381	387	F7.4	Distance to nearest neighboring Master Catalog star no more than two magnitudes fainter than this star	deg	Internal
5.10	388	395	I8	*SKYMAP* number of primary component	—	Assigned
5.11	396	403	I8	*SKYMAP* number of secondary component	—	Assigned
5.12	404	411	I8	*SKYMAP* number of tertiary component	—	Assigned
Variable Star Data						
6.1	412	416	F5.2	Maximum variable magnitude**	magnitudes	External
6.2	417	421	F5.2	Minimum variable magnitude**	magnitudes	External
6.3	422	426	F5.2	Variability amplitude	magnitudes	External
6.4	427	—	A1	Passband of variability amplitude	—	External
6.5	428	435	F8.2	Period of variability	days	External
6.6	436	443	F8.2	Epoch of variability	Julian days –2,400,000	External
6.7	444	446	I3	Type of variable star	—	External
6.8	447	448	I2	Source of variability data	—	Assigned

Table 3-1. SKYMAP SKY2000 Version 2 Master Catalog Record Format (4 of 4)

Word No.	Start	End	Type	Meaning	Units	Source

Red Magnitude Data						
7.1	449	454	F6.3	Passband 1 magnitude (observed)	magnitudes	External
7.2	455	460	F6.3	{V – passband 1} color	magnitudes	External
7.3	461	465	F5.3	Passband 1: uncertainty in magnitude or color	magnitudes	External/ assigned
7.4	466	—	A1	Passband 1, photometric system	—	External
7.5	467	—	A1	Passband 1	—	External
7.6	468	469	I2	Source of passband 1: magnitude or color	—	Assigned
7.7	470	475	F6.3	Passband 2-magnitude (observed)	magnitudes	External
7.8	476	481	F6.3	{V – passband 2} color	magnitudes	External
7.9	482	486	F5.3	Passband 2: uncertainty in magnitude or color	magnitudes	External/ assigned
7.10	487	—	A1	Passband 2, photometric system	—	External
7.11	488	—	A1	Passband 2	—	External
7.12	489	490	I2	Source of passband 2: magnitude or color	—	Assigned
7.13	491	496	F6.3	{passband 1 – passband 2} color	magnitudes	External
7.14	497	—	A1	Blended passband 1 magnitude or color flag	—	Assigned
7.15	498	—	A1	Blended passband 2 magnitude or color flag	—	Assigned
7.16*	499	504	F6.3	Passband 3 magnitude (observed)	magnitudes	External
7.17*	505	510	F6.3	{V – passband 3} color	magnitudes	External
7.18*	511	515	F5.3	Passband 3: uncertainty in magnitude or color	magnitudes	External/ assigned
7.19*	516	—	A1	Passband 3, photometric system	—	External
7.20*	517	—	A1	Passband 3	—	External
7.21*	518	519	I2	Source of passband 3: magnitude or color	—	Assigned
7.22*	520	—	A1	Blended passband 3 magnitude or color flag	—	Assigned

* Indicates fields added to *SKY2000 Version 1* for *SKY2000 Version 2*

** Indicates that data for these fields have not been added to the *SKY2000 Master Star Catalog*

3.1.8 Word 1.7

This word contains the PPM (North) Catalogue (Röser and Bastian, 1988), PPM (South) Catalogue (Bastian et al., 1993), PPM Supplement (1994), and PPM Bright Star Supplement (1993) number. This is a six-digit integer. A colon following this six-digit field indicates that the PPM number is uncertain.

3.1.9 Word 1.8

Some stars have essentially duplicate entries in SKYMAP because of inadequate cross-referencing among processed source catalogs. This can also result in the case of sub-arcsecond binary pairs, or pairs for which the secondary component is found to be too faint for inclusion in SKYMAP. When duplicate entries are discovered and merged, the SKYMAP number of the entry that was last merged into this entry is saved in Word 1.8. The SKYMAP number of a merged entry will not be used for any other star. These SKYMAP numbers are currently being consolidated and documented.

3.1.10 Word 1.9

The star name (Bayer and/or Flamsteed designation) consists of a Greek letter and/or Arabic number followed by the name of the constellation containing the star. It is encoded in SKYMAP as a formatted field with Greek letters represented by two- or three-character transliterations and constellations as standard three-character abbreviations. The star name is frequently used in the literature for stars brighter than 6.0 magnitude. In the event that the star does not have a name, this word may contain an AG designation from the German series of Astronomische Gesellschaft catalogs.

3.1.11 Word 1.10

The variable name consists of one or two letters and an abbreviation of the name of the constellation containing the star. Variable stars are frequently referred to by this name. A number in this field is an identifier from the New Catalog of Suspected Variable Stars (NSV, Kukarkin et al., 1982) and indicates that the star is suspected of variability.

3.2 Position and Proper Motion Data

The parameters presented in this section allow computation of the position of each star at any epoch and equinox. This is accomplished by adding corrections for proper motion and precession to the position given at the standard epoch.

3.2.1 Words 2.1 and 2.2

The basic position in the Master Catalog is right ascension, which is measured in hours, minutes, and seconds, and declination, which is measured in degrees, arcminutes, and arcseconds, at epoch 2000.0 in the ICRS.

3.2.2 Word 2.3

The position uncertainty in arcseconds is either taken from the source catalog from which the position data are taken and propagated to 2000.0 or assigned based on source catalog uncertainty statistics. For example, for Hipparcos stars, the uncertainties are propagated from epoch 1991.25 uncertainties in the Hipparcos catalog (ESA SP-1200, 1997). The propagated uncertainty in right ascension, ε_α, approximately equals the propagated uncertainty in declination, ε_δ, and is given by

$$e_a \cong e_d \cong \frac{e_{TOT}}{\sqrt{2}} \tag{3-1}$$

where ε_{TOT} = total propagated uncertainty. The propagated uncertainties are calculated using the source catalog position uncertainties at the position epoch and the uncertainties in the proper motions.

3.2.3 Word 2.4

This one-digit character word contains the blended position flag, as follows:

blank = not blended
b = blended

3.2.4 Word 2.5

This two-digit integer word contains the source of the star positions. All source codes within the Master Catalog share identical definitions, as indicated in Table 3-2.

Table 3-2. Source Code Definitions (1 of 6)

Value	Source Catalog	
	Common Name	Reference
0	none	—
1(98)	SAO Catalog	Smithsonian Astrophysical Observatory (SAO) Staff, *SAO Star Catalog, Parts I-IV*, Washington D.C.: Smithsonian Institution, 1966
2(98)	HD and HDE Catalogs	Cannon, A. J., and E. C. Pickering, *Harvard Annals*, vols. 91-99, 1918-24, Cambridge, Massachusetts: Harvard University; Cannon, A. J., *Harvard Annals,* vol 100, 1925-36, Cambridge, Massachusetts: Harvard University; and Cannon, A. J., and M. Walton Mayall, *Harvard Annals*, vol. 112, 1949, Cambridge, Massachusetts: Harvard University
3(98)	Blanco UBV Catalog	Blanco, V. M., et al., *Publ. U. S. Naval Obs.*, 2nd series, vol. 21, 1968
4(98)	Catalog of Stellar Spectra in the MK System	Jaschek, C., H. Conde, and A. C. de Sierra, *Publ La Plata Obs. Ser Astron.* 28, No. 2, 1964
5*	IDS	IDS (USNO, 1974)
6(98)	General Catalog of Trigonometric Stellar Parallaxes	Jenkins, L. F., *Yale Catalogue of Trigonometric Stellar Parallaxes*, New Haven: Yale University Observatory, 1952

NOTE

(98) = indicates data included via SKYMAP MC Version 3.7

*** = no data present in SKY2000 Version 2**

[ ] = added for SKYMAP Version 4.0; < > = added for SKYMAP Version 4.0a; {} = added for SKYMAP SKY2000 Version 1

All other sources added for SKY2000 Version 2

Table 3-2. Source Code Definitions (2 of 6)

Value	Source Catalog	
	Common Name	Reference
7(98)	AGK-3	Dieckvoss, W., and O. Heckmann, *Dritter Katalog der Astronomischen Gesellschaft*, Astronomisches Rechen-Institut, Heidelberg, Germany, 1975
8(98)*	GCVS, 3rd Edition	Kukarkin, B. V., et al., *General Catalog of Variable Stars*, 3rd edition, Moscow: Publishing House of the Academy of Sciences of the U.S.S.R., 1971
9(98)	Catalog of Selected Spectral Types in the MK System	Jaschek, M., "Catalogue of Selected Spectral Types in the MK System", *Centre de Données Stellaires Information Bulletin*, vol. 15, p 121, 1978
[10,23]	Michigan Catalog of 2-Dimensional Spectral Types, Volumes I-IV	Houk, N., and A. P. Cowley, *Michigan Catalogue of 2-Dimensional Spectral Types for the HD Stars, vol. 1., (Zones -89 to -53 Degrees)*, Ann Arbor: The University of Michigan, 1975, and Houk, N., *Michigan Catalogue of 2-Dimensional Spectral Types for the HD Stars, vol. 2., (Zones -52 to -40 Degrees),* Ann Arbor: The University of Michigan, 1978, and Houk, N., *Michigan Catalogue of 2-Dimensional Spectral Types for the HD Stars, vol. 3., (Zones -40 to -26 Degrees),* Ann Arbor: The University of Michigan, 1982, and Houk and Smith-Moore, *Michigan Catalogue of 2-Dimensional Spectral Types for the HD Stars, vol. 4, (Zones -25 to -12 Degrees)*, Ann Arbor: The University of Michigan, 1988
11(98)	General Catalogue of Stellar Radial Velocities	Wilson, R. E., *General Catalogue of Stellar Radial Velocities*, Washington, D.C.: Carnegie Institution of Washington, 1953
12*	IDS and SAO	
13*	IDS and HD/HDE	
14*	IDS and AGK3	
[15]	FK5 and FK5 Extension	Fricke, W., H. Schwan, and T. Lederle, "Fifth Fundamental Catalogue (FK5), Part I. The Basic Fundamental Stars", *Veroeff. Astronomisches Rechen Institut*, No. 32, Heidelberg, Germany, 1988, and Fricke, W., H. Schwan, and T.E. Corbin, "Fifth Fundamental Catalogue (FK5), Part II. The FK5 Extension", *Veroeff. Astronomisches Rechen Institut*, No. 33, Heidelberg, Germany, 1991
[16]	PPM North and PPM South Catalogs and PPM Supplement	Röser, S., and U. Bastian, "Catalogue of Positions and Proper Motions", *A&AS*, vol. 74, p. 449, 1988, and Bastian, U., et al., "Catalogue of Positions and Proper Motions - South", 1993, and Röser, S., U. Bastian, and A. Kuzmin, "Catalogue of Positions and Proper Motions – 90,000 Stars Supplement," A&AS, vol. 105, p. 301, 1994

NOTE

(98) = indicates data included via SKYMAP MC Version 3.7

*** = no data present in SKY2000 Version 2**

[ ] = added for SKYMAP Version 4.0; < > = added for SKYMAP Version 4.0a; {} = added for SKYMAP SKY2000 Version 1

All other sources added for SKY2000 Version 2

Table 3-2. Source Code Definitions (3 of 6)

Value	Source Catalog

	Common Name	Reference
[17]	ACRS	Corbin, T.E., and S.E. Urban, *Astrographic Catalog Reference Stars,* United States Naval Observatory*,* 1991
[18]	Hipparcos Input Catalog Version 2 Annex	Turon, C., et al., “The Hipparcos Input Catalog, Version 2”, *Centre de Données Stellaires Information Bulletin*, vol. 43, p. 5, 1993
[19]	WDS Catalog	Worley, C. E., and G. G. Douglass, *Washington Catalog of Visual Double Stars 1994.0*, United States Naval Observatory, 1994
[20]	Catalogue of Homogeneous Means in the UBV System	Mermilliod, J. C., *Catalogue of Homogeneous Means in the UBV System*, Institut d’Astronomie, Universite de Lausanne, 1994
[21]	Photoelectric Photometric Catalog in the UBVRI System	Lanz.T.,”Photoelectric Photometric Catalogue in the Johnson UBVRI System”, A&AS. vol. 65, p. 165, 1986
[22]*	Russian WBVR Catalog	Kornilov et al., “WBVR Catalog of Various Bright Stars in the Northern Sky”, *Proceedings of the State Astronomical Institute at Sternberg*, vol. 63, Moscow: Moscow University, 1991
[24]	Catalogue of Photoelectric Magnitudes and Colours of Visual Double and Multiple Systems	Wallenquist, Aa., *A Catalogue of Photoelectric Magnitudes and Colours of Visual Double and Multiple Systems*, Uppsala Astronomical Observatory Report No. 22, 1981
[25]	Bright Star Catalog 5th Edition	Warren, W., *The Bright Star Catalogue, 5th Revised Edition, Version 2*, 1994
[26]	Bright Star Supplement	Warren, W., *A Supplement to the Bright Star Catalogue*, 1994
[27]	Catalog of Red Magnitudes (CRM)	Warren, W., *Northern Hemisphere Catalog of Red Magnitudes*, 1994 (From 22 and other sources)
[28]	New Catalog Of Suspected Variable Stars (NSV)	Kukarkin, B. V., et al., *New Catalog of Suspected Variable Stars*, Moscow: Nauka Publishing House, 1982
[29]	SAOJ2000	SAO on FK5 at J2000, 1989
[30]	GCVS, 4th edition	Kholopov, P. N., et al., *General Catalogue of Variable Stars*, fourth edition, Moscow: Nauka Publishing House, 1985-88
[31]	CRM (non-GCVS variable data)	Warren, W., *Northern Hemisphere Catalog of Red Magnitudes*, 1994
<32>	Four -Color (uvby)	Olsen, E. H., 1983 A&AS, 54, 55. “Four-colour uvby and H-beta photometry of A5 to G0 stars brighter than 8.3 mag.”
<33>	Hipparcos Main Input Catalogue Version 2	Turon, C., et al., The Hipparcos Input Catalogue, Version 2, CDS Bull. No. 43, p.5 , 1993

NOTE

(98) = indicates data included via SKYMAP MC Version 3.7

*** = no data present in SKY2000 Version 2**

[ ] = added for SKYMAP Version 4.0; < > = added for SKYMAP Version 4.0a; {} = added for SKYMAP SKY2000 Version 1

All other sources added for SKY2000 Version 2

Table 3-2. Source Code Definitions (4 of 6)

Value	Source Catalog	
	Common Name	Reference

<34>*	IRS Catalog	Corbin, T.E., 1991, U.S. Naval Observatory, International Reference Stars Catalog
<35>	HD Extension Charts	Nesterev, V.V., Kuzmin, A.V., Ashimbaeva, N.T., Volchkov, A.A., Röser, S., Bastian, U., 1995 A&AS, 110, 367, “The Henry Draper Extension Charts: A catalogue of accurate positions, proper motions, magnitudes and spectral types of 86933 stars.”
<36>	Namelists	Namelists of Variable Stars, Nos. 67-72
<37>*	DS-programme star positions	Cvetkovic, Z., 1992, A&AS, 96, 191, “A preliminary compilation of DS-programme star positions”
<38>		Abt, H.A. 1984, ApJ, 285, 247
<39>	MK-Extension	Morris-Kennedy, P., 1983, MK Classification Extension (Mount Stromlo Observatory)
<40>*	Astrometric Studies	Gatewood, G., de Jonge, J.K., and Heintz, W.D., 1995, AJ, 109, 434, “Astrometric Studies in the Region of Algol”
<41>*	Precision Studies	Gatewood, G., 1994, PASP, 106, 138. “One milliarcsecond precision studies in the regions of delta Equulei and chi1 Orionis”
<42>*	FK5 Supplement	Schwan, H., Bastian, U., Bien, R., Jaehrling, R., Jahreiss, H., Röser, S. 1993, *Veroeffent. Astron. Rechen Institut Heidelb.* No. 34. “Improved Mean Positions and Proper Motions for the 995 FK4 Sup Stars Not Included in the FK5 Extension"
<43>		Buscombe, W. 1995, unpublished. General Catalogue of MK Classifications, Dearborn Observatory, Northwestern University
<44>		Abt, H.A. “A stars paper”. (different from Reference in Value 38)
<45>*		Abuladze 1982, Abastumani Bull., 55, 1. “UBV 366 Stars Missed by JCM. V range 6-10, of real interest. Accuracy acceptable.”
<46>*		Skiff, B. Various unpublished lists and observations sent by private communication.
<47>		Griffin, R., and Griffin, R. 1986, Observatory, 106, 108
<48>		Hauck, B., and Mermilliod, M. 1990, A&AS, 86, 107. “Uvby, beta Photoelectric Photometric Catalogue”.
49*	GSC	The HST Guide Star Catalog
<51>	Harvard photometry	“H” coded (Harvard photometry) magnitudes from the BSC5
<52>	PPMN-HP subset	“H” coded positions (PPM High-Precision Subset, reference 16) from the BSC5
NOTE **(98) = indicates data included via SKYMAP MC Version 3.7** *** = no data present in SKY2000 Version 2** **[ ] = added for SKYMAP Version 4.0; < > = added for SKYMAP Version 4.0a; {} = added for SKYMAP SKY2000 Version 1** **All other sources added for SKY2000 Version 2**		

Table 3-2. Source Code Definitions (5 of 6)

Value	Source Catalog	
	Common Name	**Reference**
<53>*	Geneva photometric Catalog	Rufener, F. 1988, *Catalogue of Stars Measured in the Geneva Observatory Photometric System,* 4th ed., Geneva Observatory

<54>	MK Catalogs	Jaschek, C., Conde, H., and de Sierra, A.C. 1964, *Catalogue of Stellar Spectra Classified in the Morgan-Keenan System,* Publ. La Plata Obs., Ser. Astron. 28, No. 2 and/or Kennedy (1983), et al.
<55>	Catalog of Carbon Stars	Stephenson, C.B. 1989, *A General Catalog of Cool Galactic Carbon Stars,* 2nd ed., Publ. Warner & Swasey Obs., 3, No. 2, (Catalog A3156)
<56>	Cordoba DM (CD)	Thome, J.M. 1892-1932, Córdoba Durchmusterung, Resultados del Observatorio Nacional Argentino 16, 17, 18, and 21
{57}*	Cape DM (CPD)	Cape Photographic Durchmusterung
{58}	Bonner DM (BD)	Argelander, F. 1859-1862; Küstner, F. 1903; Becker, F. 1951; Schmidt, H. 1968, Bonner Sternverzeichnis and Bonner Durchmusterung
{59}*	Southern DM (SD)	Schönfeld, E. 1886; Becker, F. 1949; Schmidt, H. 1967, Bonner Sternverzeichnis and Bonner Durchmusterung
<60>*	HD Extension 2	Henry Draper Extension 2 (Cannon and M. Walton Mayall 1949)
[61]*	ACRS Part II	
<62>		Fekel et al. 1995, AJ, 109, 2821
<63>		Stephenson, C.B. 1984, *General Catalog of S Stars*,2nd edition, Publ. Warner & Swasey Obs., 3, No. 1
64	TAC	Zacharias, N., et al., 1996, "The Twin Astrograph Catalog (TAC*),* Version 1.0", AJ, 112, 2336, November, 1996)
65	ACT	Urban, S.E., Corbin, T.E., and Wycoff, G.L., 1998, *The ACT Reference Catalog*
66	The Hipparcos Output Catalogue (HIP)	ESA SP-1200, 1997, Hipparcos Main Catalog
67	The Hipparcos Output Catalogue (HIPc)	ESA SP-1200, 1997, Hipparcos Components Catalog
68	The Tycho Output Catalogue (TYC)	Høg, E., and G. Bässgen, and U. Bastian, et al., *The Tycho Catalogue*, A&A 323, L57-L60 (1997)
69*	SIMBAD	SIMBAD Database
70	RXTE	Data gathered from the RXTE CCD star trackers

NOTE

(98) = indicates data included via SKYMAP MC Version 3.7

*** = no data present in SKY2000 Version 2**

[ ] = added for SKYMAP Version 4.0; < > = added for SKYMAP Version 4.0a; {} = added for SKYMAP SKY2000 Version 1

All other sources added for SKY2000 Version 2

Table 3-2. Source Code Definitions (6 of 6)

Value	Source Catalog	
	Common Name	**Reference**
80	TRC	The Tycho Reference Catalogue
81*		Catalog of O Stars (Garmany)
90*		SKY2000 (Determined from existing data)
94(98)	WDS Catalog or Blanco Catalog	Reference from Value 19 or Reference from Value 3

95(98)	Michigan, Volumes I-IV or Catalog of Selected Spectral Types	Reference from Value 10 or Reference from Value 9
96(98)	SAO or HD/HDE Catalog	Reference from Value 1 or Reference from Value 2
97(98)*	SKYMAP Master Catalog Version 3.7 (Miscellaneous)	Slater, M., *SKYMAP Star Catalog Data Base Generation and Utilization System Description Revision 3 - Update 1*, Computer Sciences Corporation, 554-FDD-89/001R3UD1, CSC/SD-89/6036R3UD1, August 1992 [original source not identified in SKY2000 3.7]
98(MK)	SKYMAP 3.7	Reference from Value 97 [original data sources are identified in SKYMAP 3.7]
99	Miscellaneous	Source is neither SKYMAP 3.7 nor identified

NOTE

(98) = indicates data included via SKYMAP MC Version 3.7

*** = no data present in SKY2000 Version 2**

[ ] = added for SKYMAP Version 4.0; < > = added for SKYMAP Version 4.0a; {} = added for SKYMAP SKY2000 Version 1

All other sources added for SKY2000 Version 2

3.2.5 Words 2.6 and 2.7

Words 2.6 and 2.7 contain the proper motion in right ascension and declination. Proper motion is measured in seconds of time per year in word 2.6 and in arcseconds per year in word 2.7.

The term *proper motion* refers to the motion of the star across the sky because of the tangential velocity of the star relative to the Sun. Equation (4-3) may be used to apply proper motion corrections from one epoch to another. The magnitude of the effect is usually less than 20 arcseconds per 100 years, although occasionally it is as large as 50 arcseconds per 100 years.

3.2.6 Word 2.8

This two-digit integer word indicates the source of the proper motion data (see Table 3-2).

3.2.7 Word 2.9

The radial velocity of a star is defined as its motion relative to the Sun in the direction directly toward (negative values) or away from (positive values) the Sun.

3.2.8 Word 2.10

This two-digit integer word contains the source of the radial velocity of a star (see Table 3-2).

3.2.9 Word 2.11

When word 2.11 is blank, no trigonometric parallax (p) was available in the source catalogs. Negative p is not physically significant, but it is recorded here because it is statistically significant. The only direct measurement of distance available to astronomers for objects outside the Solar System is p. When a relatively close star is observed against a background of distant objects at opposite ends of the Earth's orbit (6 months apart), a small trigonometric parallax can sometimes be seen. The size of this effect is always less than 1 arcsecond. If the trigonometric parallax angle in seconds of arc is known, the distance in parsecs (pc), d, to the star (1 parsec = 3.085678×10^{16} m) can be computed from Equation (3-2).

$$d = \frac{1}{p} \tag{3-2}$$

Almost all Master Catalog stars have measured trigonometric parallaxes, although many are negative, primarily from the Tycho catalog. These parallaxes, together with their associated uncertainties, are meaningful only out to a distance of approximately 100 pc.

3.2.10 Word 2.12

This word contains the uncertainty in the trigonometric parallax value contained in Word 2.11.

3.2.11 Word 2.13

This two-digit integer word indicates the source of the trigonometric parallax data (see Table 3-2).

3.2.12 Words 2.14, 2.15, and 2.16

Right ascension (α) and declination (δ) at the standard epoch and equinox (ICRS2000) are converted to a corresponding GCI unit vector. The GCI unit vector (X, Y, Z) is given by Equation (4-1).

3.2.13 Words 2.17 and 2.18

Galactic longitude (l) and latitude (b) are defined at epoch and equinox of B1950 and are computed from the Galactic unit vector (X_{gal}, Y_{gal}, Z_{gal}) of the star as indicated in Equation (3-3). l is referenced to the galactic center, which is at right ascension = $17^h42.^m4$, declination = $-28^o55.'0$, epoch and equinox of B1950 (Abell, 1982). b is referenced to the North Galactic Pole, which is at right ascension = 12^h49^m and declination = $+27.4^o$, B1950. l and b also can be calculated with Equation (3-4a,b) where the constants represent the transformation from X_{1950}, Y_{1950}, Z_{1950}.

$$\begin{aligned} l &= \tan^{-1}(Y_{gal} / X_{gal}) \\ b &= \sin^{-1} Z_{gal} \end{aligned} \tag{3-3}$$

or

$$l = \tan^{-1}((0.492723\, X_{1950} - 0.450421\, Y_{1950} + 0.744543\, Z_{1950})/ (-0.067154\, X_{1950} - 0.872744\, Y_{1950} + 0.483537\, Z_{1950})) \tag{3-4a}$$

$$b = \sin^{-1}(-\ 0.867601\ X_{1950} - 0.188375\ Y_{1950} - 0.4601998\ Z_{1950}) \qquad (3\text{-}4b)$$

3.3 Magnitude Data

The parameters presented in this section are needed for star field matching and are necessary when performing limiting magnitude analysis involving CCDSTs, charge transfer device (CTD) star trackers (CTDSTs), and FHSTs.

3.3.1 Word 3.1

In SKY2000 Version 2, the visual magnitude is generally observed in the photoelectric *V* passband of Johnson and Morgan (1953). *V* magnitudes are taken mainly from sources 20, 27, and 68, all of which contain photoelectric photometry.

3.3.2 Word 3.2

When no observed *V* magnitude (effective wavelength 5,500 Å) (Word 3.1) is available, a derived visual (*V′*) magnitude is calculated according to the procedures given in Section 4.2.

3.3.3 Word 3.3

This word contains the derived *V′* or observed *V* magnitude uncertainty.

3.3.4 Word 3.4

This one-digit character word contains the blended visual magnitude flag for Word 3.1, as follows:

blank = not blended

b = blended

3.3.5 Word 3.5

This is a two-digit integer word indicating the source of the observed visual magnitude in Word 3.1 (see Table 3-2).

3.3.6 Word 3.6

Derived *V′* magnitudes given in Word 3.2 are calculated using various methods, as specified in Section 4.2. Typical initial magnitudes are photovisual (*ptv*) or photographic (*ptg*), and the method used is dependent on the source of the input magnitude. Anticipated uncertainties associated with each method are indicated by values 1 through 5 and are described in Table 4-2.

3.3.7 Word 3.7

This word contains the observed Johnson *B* magnitude, measured in magnitudes.

3.3.8 Word 3.8

The (*B–V*) color refers to the observed difference between Johnson *B* and *V* magnitudes.

3.3.9 Word 3.9

This word contains the (*B–V*) color or *B* magnitude uncertainty, measured in magnitudes (Word 3.7 or 3.8).

3.3.10 Word 3.10

This one-digit character word contains the blended (*B–V*) color or *B* magnitude flag, as follows:

blank = not blended

b = blended

3.3.11 Word 3.11

This is a two-digit integer word indicating the source of the (*B–V*) color or *B* magnitude in Word 3.7 or 3.8 (see Table 3-2).

3.3.12 Word 3.12

This word contains the observed Johnson ultraviolet (*U*) magnitude, measured in magnitudes.

3.3.13 Word 3.13

The word contains the observed (*U–B)* color in magnitudes.

3.3.14 Word 3.14

This word contains the (*U–B)* color or ultraviolet magnitude uncertainty, measured in magnitudes (Word 3.12 or 3.13).

3.3.15 Word 3.15

This one-digit character word contains the blended (*U–B*) color or ultraviolet magnitude flag, as follows:

blank = not blended

b = blended

3.3.16 Word 3.16

This two-digit word indicates the source of the (*U–B)* color or ultraviolet magnitude in Word 3.12 or 3.13 (see Table 3-2).

3.3.17 Word 3.17

This word generally contains the observed *ptv* magnitude. This magnitude corresponds approximately to *V*. However, when Word 3.18 indicates the source to be the WDS or General Catalog of Variable Stars (GCVS) (third or fourth edition), this word contains a *ptv* or *v* (visual eye estimate of Johnson *V*). The two are not distinguished.

3.3.18 Word 3.18

This is a two-digit word indicating the source of the *ptv* magnitude contained in Word 3.17 (see Table 3-2).

3.3.19 Word 3.19

This word contains the observed *ptg* magnitude. This magnitude corresponds approximately to *B*.

3.3.20 Word 3.20

This is a two-digit word indicating the source of the *ptg* magnitude contained in Word 3.19 (see Table 3-2).

3.4 Spectral Types

The parameters presented in this section are needed to predict the expected apparent brightness of a star at passbands other than those at which the star has been observed.

3.4.1 Word 4.1

Word 4.1 is a 30-character word that contains spectral type data comprising spectral class, luminosity class, and peculiarity code in standard astronomical notation. Routines that use the instrumental magnitude prediction software and mission catalog generation routines will include the SKYMAP conversion lookup tables (Tables 3-3 and 3-4) to convert the standard astronomical notation to the SKYMAP-coded form.

The Morgan-Keenan (MK) spectral type is normally used when predicting instrumental magnitudes. Many star systems are listed with multiple MK spectral types in various source catalogs. For single stars, multiple types can indicate a range of types. Often, the star is variable and is listed with two types (a maximum blue value and a maximum red value). When two entries are given, a (–) or (+) flag divides the spectral type field into two parts. A (–) value indicates that the second entry refers to a range, and a (+) value indicates that the second entry refers to the second component. The spectral class may be followed by a lowercase alphanumeric character (such as *m, w,* or *p*), which indicates (1) strong metallic lines, (2) weak metallic lines, or (3) peculiar metallic lines (or some other peculiarity), respectively. The luminosity class may be followed by an alphanumeric character of either case in parentheses “( )”, indicating some peculiarity in line strength.

At least two major cases have been identified for the type field. That is, either the full MK spectral type is available (case 1), or the MK luminosity class is unavailable (case 2) and the Mount Wilson

(MW) luminosity class is available. For case 2, the MW luminosity class comes first in the field, followed by the spectral class. No other data are given, and no blanks appear until after the spectral class.

The order of the data in the type field will be as listed below. The brackets and commas are used for clarity. They will not appear in the data field.

CASE 1: One Entry: {MK spectral class, MK luminosity class, MK peculiarity code, blanks}. Other possible MK forms are included in Appendix A.

Two Entries: {MK spectral class, MK luminosity class, MK peculiarity code, [– or +], MK spectral class, MK luminosity class, MK peculiarity code, blanks}

CASE 2: One Entry: {MW luminosity class, spectral class, blanks}

Two Entries: {MW luminosity class, spectral class, [– or +], MW luminosity class, spectral class, blanks}

The spectral class (Table 3-3) of a star is the most important piece of information from the trio of data comprising the spectral type stored in SKYMAP, because it indicates the color for a star. The spectral class and color are related to the stellar surface temperature.

The luminosity class comprises the second part of the two-dimensional MK classification system. It expresses the intrinsic brightness of a star. If two stars equally distant from the Earth have the same spectral class (i.e., identical surface temperature) but different luminosities, the emitting surface areas and radii of the stars must be significantly different. One of the principal means of determining luminosity class is from the spectral line profiles, which are heavily affected by the gravitational force near the surface of a star.

Table 3-3. MK Spectral-Class Sequence

First Two Digits of SKYMAP Version 3.7 Code*	MK Spectral Class	Approximate Temperature (K)	Brief Description
00	O	40,000	Hottest stars; showing He^+ absorption lines
01	B	20,000	Shows He and H absorption lines
02	A	9,000	Very strong H absorption
03	F	7,000	Ca^+ and H absorption with some metallic lines
04	G	5,500	Ca^+, Fe, and metallic absorption lines strong
05	K	4,300	Strong metallic lines, with molecular bands
06	M	3,200	Cool red stars; prominent molecular bands, especially TiO
07	R	4,500	Hotter carbon stars, with C_2 and CN bands

08	N	3,200	Cooler carbon stars, with C_2, CN, CH bands; no TiO
09	C	3,100–4,600	Carbon overabundant; rare giant stars
10	S	3,200	Heavy metal oxide stars; giants with strong ZrO, LaO, YO bands
11	WR	30,000	Similar to O type, with strong, wide, emission lines
12	WC	23,000	Wolf-Rayet stars with C overabundance
13	WN	38,000	Wolf-Rayet stars with N overabundance
NOTE *Given for reference only, the Master Catalog does not give the MK spectral type in the SKYMAP coded forms.			

At the basic level, the luminosity class is assigned a Roman numeral from I to V to show radii ranging from 500 to 0.3 times the radius of the Sun. (Note that for a given luminosity class, the radius is not constant with varying temperature; however, it is a relatively slowly varying function.) As a result, the luminosity class tends to be a rough measurement, and the ability to discern the luminosity class is strongly dependent on the dispersion being used. High-dispersion catalogs contain information at various intermediate levels.

The MK luminosity class and the general name associated with the major classes are shown in Table 3-4. The observed MK luminosity class is also stored in Word 4.1. The SKY2000 coded form of MK spectral class and MK luminosity class is not given in the Master Catalog record format.

Table 3-4. MK Luminosity Classes (1 of 2)

MK Luminosity Class	SKYMAP Version 3.7 Code*	Class Name
0	5	Most Extreme Super Giants
Ia+	9	
I	10	
Ia - 0	11	
Ia	12	Luminous Super Giants
Ia - Iab	13	
Iab	14	Moderate Super Giants
I - II	15	
Ia - Ib	16	
Iab - Ib	17	
Ib	18	Less Luminous Super Giants

Ib - II	19	
II	20	Bright Giants
Ib - IIa	21	
IIa	22	
IIa - IIab	23	
IIab	24	
II - III	25	
IIa - IIb	26	
IIab - IIb	27	
IIb	28	
IIb - III	29	

Table 3-4. MK Luminosity Classes (2 of 2)

MK Luminosity Class	SKYMAP Version 3.7 Code*	Class Name
III	30	Normal Giants
IIb - IIIa	31	
IIIa	32	
III-IIIa	33	
IIIab	34	
III-IV	35	
III-IIIb	36	
IIIb	38	
III-V	39	
IV	40	Subgiants
IVa	42	
IVab	44	
IV - V	45	
IVb	48	
V	50	Main Sequence Dwarfs
Va	52	
Vab	54	
V - VI	55	
Vb	58	
VI	60	Subdwarfs
c	-10	Mt. Wilson Classes
sd	-20	
d	-30	
sg	-40	
g	-50	

NOTE

*Given for reference only, the Master Catalog does not give MK luminosity classes in SKYMAP coded forms.

Stellar peculiarities indicate deviations from the norm for a star with a given spectral class and luminosity class. In the SKYMAP Master Catalog, the observed MK peculiarities are also stored in Word 4.1. Stellar peculiarities include general stellar peculiarities, chemical abundance peculiarities, and peculiarities in the characteristics of line strengths.

3.4.2 Word 4.2

This two-digit integer word is the source flag for the spectral type data contained in Word 4.1 (see Table 3-2).

3.4.3 Word 4.3

This three-character word contains the one-dimensional spectral type in the SAO, HD, AGK-3, or any other non-SAO system, consisting of spectral class only. A composite spectral class from the

SAO catalog (source codes 1 and 29, the first on B1950 and the second on J2000) is indicated by "+++".

3.4.4 Word 4.4

This two-digit integer word contains the source of the one-dimensional spectral type data contained in Word 4.3 (see Table 3-2).

3.5 Multiple Star Data

Whenever two stars brighter than the sensor-limiting magnitude are situated close together in the sky, data reduction programs may have difficulty determining which one was observed by the sensor. Therefore, these programs may wish to avoid stars having nearby companions. Attitude control programs will also want to avoid selecting these stars as control or guide stars. A star may have a close companion if it is a physical multiple star or if it is part of an optical double (i.e., two stars that are not physically associated but that appear near one another).

Double stars may be recognized as having valid entries in Words 5.1 through 5.7 of the Master Catalog. Stars near one another to a separation of 0.6 degree are included, along with closer stars, in the nearest neighbor computations (Word 5.8).

3.5.1 Word 5.1

The component separation of the double star system is contained in this word. The observation referred to in Word 5.1 was made in the year noted in Word 5.5 and in the passband noted in Word 5.7. If the observation of a star occurred more than a few years from the epoch of interest, the stars of the multiple star system may have moved significantly relative to one another. Thus, the separation may no longer be valid. As a general rule, if a separation is greater than approximately 30 arcseconds, the separation and position angle (Word 5.4) will change very slowly. This is because, at the distances of virtually all stars, a 30-arcsecond separation implies that the stars are orbiting each other at such large distances that the period of the orbit is thousands of years or longer. Stars with smaller separations are either (1) located very near to one another, in which case the separation will vary rapidly but will always be small, or (2) located at a great distance from one another but, by chance, are now aligned nearby along the line of sight from the Earth. In the latter case, the stars are moving very slowly relative to one another; therefore, the separation between them will remain small for a long time. Therefore, stars with separations over 30 arcseconds can always be assumed to have separations equal to the value given, and stars with smaller separations can always be assumed to have separations smaller than 30 arcseconds.

3.5.2 Word 5.2

This word contains the magnitude difference between components. This difference may be positive or negative according to the designation of the primary component in the source catalog referenced in Word 5.6.

3.5.3 Word 5.3

This word contains the orbital period in years.

3.5.4 Word 5.4

This word contains the position angle (PA), measured in degrees. The position angle is defined as measured from north (0°) through east (90°) to 360°.

3.5.5 Word 5.5

This word contains the year in which the separation and PA observation (Words 5.1 and 5.4, respectively) were measured. This has bearing on the validity of the assumption that the separation is still valid (see Section 3.5.1).

3.5.6 Word 5.6

This two-digit integer word contains the source of multiplicity data (see Table 3-2).

3.5.7 Word 5.7

This one-character word contains the passband of the multiple star magnitude difference, as follows:

Passband	Code
U	1
B	2
V	3
R	4
I	5
J	6
H	7
K	8
L	9
M	10
N	11
X	12
p (ptg)	2
p (ptv)	3

Codes are not given in the Master Catalog and are described here for reference purposes only. The codes are used internally by the SKYMAP System software and are used to define the passbands contained in the Master Catalog.

3.5.8 Word 5.8

The separation in degrees to the nearest Master Catalog star is contained in Word 5.8. If the nearest neighbor is a member of a double or multiple star system with this star, Word 5.8 is made negative; hence, –0.01 means that the nearest star to this star is 0.01 degree away and is part of a multiple star system. If the angle is greater than 0.6 degree, this field is left blank.

3.5.9 Word 5.9

Word 5.9 is identical to Word 5.8, with the additional restriction that the neighbor must be no more than two visual magnitudes fainter than the star in question. If the angle is greater than 0.6 degree, this field is left blank.

3.5.10 Word 5.10

This eight-digit integer word contains the SKYMAP number of the brightest component.

3.5.11 Word 5.11

This eight-digit integer word contains the SKYMAP number of the second brightest component.

3.5.12 Word 5.12

This eight-digit integer word contains the SKYMAP number of the third brightest component.

3.6 Variable Star Data

Stars with varying brightness (variable stars) may pose a problem for mission planners and data analysts. If, for example, the limiting magnitude of a sensor is 7.0, and a star varies in brightness between magnitudes 6.0 and 8.0, a data analysis program must include the star in its star catalog because it is sometimes sufficiently bright to be observed. However, mission planners cannot be sure it will be detectable and thus cannot plan to use it for control purposes unless they are able to predict its brightness as a function of time. The information contained in this section of the Master Catalog will allow the user to identify variable stars and to determine their brightest and faintest magnitudes, but not necessarily predict brightness as a function of time, which is not possible for some types of variables.

3.6.1 Word 6.1

This word contains the brightest magnitude possible for the star (maximum light).

3.6.2 Word 6.2

This word contains the faintest magnitude possible for the star (minimum light).

3.6.3 Word 6.3

This word contains the variability amplitude for a regular variable or well-observed irregular variable star. This amplitude is the difference between the brightest and faintest magnitudes possible for the star.

3.6.4 Word 6.4

This one-character word contains the passband of variability for a variable star (e.g., the *V* passband).

3.6.5 Word 6.5

This word contains the period of variability for a regular variable star in days. This period is the duration of one cycle of the star's variation in brightness. Irregular and most semiregular variables do not have meaningful periods because their variations are not readily predictable.

3.6.6 Word 6.6

The epoch of variability of a variable star is the time of a reference point in its brightness variation, usually the time when the star is at its faintest. It is expressed in Julian days minus 2,400,000. More detailed information on the meaning of epoch for each type of variable can be obtained from Kukarkin and Parenago (1963). All irregular and most semiregular variables have meaningless epochs because their variations are not readily predictable.

3.6.7 Word 6.7

The variability type code is a numerical code for the type of variability. Table 3-5 cross-references this code to the normal alphabetic codes used in Kholopov et al. (1985-8) and those listed in the *Catalog of Red Magnitudes* (Warren 1994), which includes a brief definition of the type of variation. The first digit of the three-digit variability code contains the type of variable. A value of 1 indicates that the star is a pulsating variable. Most pulsating variables are predictable. A value of 2 indicates that the star is an eruptive variable, usually having unpredictable variations. A value of 3 indicates that the star is an eclipsing variable, most of which have predictable variations. A value of 4 indicates that the star is a rotating variable.

The second digit of the code denotes the class of variable; for example, stars with a 1 as the first digit and 2 as the second digit are all RR Lyrae-type variables.

The third digit is the subclass of variable. A 0 denotes that no subdivision exists for that type of variable or that the subdivision is unknown for that star. When fewer than three digits are present (blank, zero, 1, 9, or 10), the definition is given in Table 3-5.

3.6.8 Word 6.8

This two-digit integer word contains the source of variability data (see Table 3-2).

3.7 Red Magnitude Data

Observed red (passband 1), infrared (passband 2), or CCDST (passband 3) magnitude data from various sources are currently expected to be available for less than 10 percent of all SKYMAP stars down to *V* magnitude 9.0.

3.7.1 Word 7.1

This word contains the observed red passband 1 magnitude, measured in magnitudes.

Table 3-5. Variable Star Codes (1 of 3)

NUMERIC VARIABLILITY CODE (V4.0 WORD 6.5; SKY2000 WORD 6.7)	CODE FROM GCVS, 4TH EDITION	CODE FROM CRM, 1994	CODE FROM NSV	NUMBER PRESENT IN VERSION 4.0 OF MASTER CATALOG	NUMBER PRESENT IN SKY2000 VERSION 2 MASTER CATALOG	TYPE OF VARIABLE	EXAMPLE
0 or BLANK				294617	294152	NOT KNOWN TO BE VARIABLE	-
1						UNCLASSIFIED VARIABLE	-
9	-	-		1910	1901	SUSPECTED VARIABLE	
10	* OR OTHER NOTATION	*		668	662	SEE GCVS 4TH EDITION FOR CLASSIFICATION	
111	dCep	dCe	DCEP	107	107	GALACTIC PLANE CLASSICAL CEPHEID, DELTA CEPHEI-TYPE	β Dor
112	CW, CWa, CWb	CW	CW	7	7	HALO CEPHEID (POPULATION II), W VIRGINIS	RU Cam
113	Cep	Cep	CEP	14	14	RADIALLY PULSATING, HIGH LUMINOSITY CEPHEIDS	kap Pav
114	Cep(B)			8	8	CEPHEIDS DISPLAYING TWO OR MORE SIMULTANEOUSLY OPERATING PULSATION MODES	
115	dCepS			27	27	DELTA CEPHEID VARIABLES WITH LIGHT AMPLITUDES < 0.5 MAG IN v AND ALMOST SYMMETRIC LIGHT CURVES	
120	RR	RR,RRc	RR	9	9	RR LYRAE TYPE, A-F GIANTS	FW Lup
121	RRab			20	20	RR LYRAE TYPE WITH ASYMMETRIC LIGHT CURVE	UV Oct
122	RRc		RRC	7	7	RR LYRAE TYPE WITH SINE CURVE LIGHT CURVE	V1719 Cyg
123	RR(B)					RR LYRAE TYPE SHOWING 2 SIMULTANEOUSLY OPERATING PULSATION MODES	
130	RV	RV	RV	4	4	RV TAURI TYPE (YELLOW SUPERGIANTS OF TYPES F-G)	RVa; V820 Cen
131	RVa			6	6	SUPERGIANT WITH DOUBLE WAVE VARIATION, ALTERNATING PRIMARY AND SECONDARY MAXIMA, AND A CONSTANT MEAN MAGNITUDE	R SCT
132	RVb			4	4	SAME AS 131 WITH A VARIABLE MEAN MAGNITUDE	U Mon
133	aCyg	aCy	ACYG	28	28	ALPHA CYGNI (DENEB)-TYPE SUPERGIANTS DENEB	ε Ori

Table 3-5. Variable Star Codes (2 of 3)

NUMERIC VARIABLILITY CODE (V4.0 WORD 6.5; SKY2000 WORD 6.7)	CODE FROM GCVS, 4TH EDITION	CODE FROM CRM, 1994	CODE FROM NSV	NUMBER PRESENT IN VERSION 4.0 OF MASTER CATALOG	NUMBER PRESENT IN SKY2000 VERSION 2 MASTER CATALOG	TYPE OF VARIABLE	EXAMPLE
134	SXPhe	SXP	SXPHE	3	3	SX PHOENICIS, PULSATING SUBDWARFS OF STELLAR POPULATION II	VW Ari
140	bCep	bCe	BCEP	77	77	BETA CEPHEI (BETA CANUS MAJORIS) TYPE WITH LOW AMPLITUDE VARIATIONS	β Cru

141	bCepS			3	3	BETA CEPHEI-TYPE VARIABLES WITH SHORT PERIODS	
150	dSct	dSc	DSCT	48	49	DELTA SCUTI TYPE WITH LOW AMPLITUDE, BLUE PULSATING	δ Sct C; α Lyr
160	aCV	aCV	ACV	184	183	MAGNETIC VARIABLE, B8p-A7p, α2 CAN VEN	ε UMa
161	aCVo			5	5	RAPIDLY OSCILLATING α2 CAN VEN	
170	L	L	L	41	41	SLOW IRREGULAR VARIABLES	V341 Car
171	Lb	Lb	LB	399	397	SLOW, IRREGULAR VARIABLE OF LATE SPECTRAL TYPE	β Peg
172	Lc	Lc	LC	44	44	IRREGULAR SUPERGIANT OF LATE TYPES	α Sco
180	M	M	M	175	172	RED MIRA-TYPE VARIABLE OF LONG PERIOD AND LARGE AMPLITUDE	ο CET; χ Cyg
181	PVTel		PVTel	2	2	PULSATING HELIUM SUPERGIANTS	PV Tel
190	SR	SR	SR	80	80	SEMIREGULAR VARIABLE	VZ Cam
191	SRa	SRa	SRA	51	51	SEMIREGULAR GIANT OF LATE SPECTRAL TYPE	T Cen
192	SRc	SRc	SRC	39	39	SEMIREGULAR SUPERGIANT NEAR THE GALACTIC PLANE	α ORI
193	SRd	SRd	SRD	40	40	SEMIREGULAR GIANT OR SUPERGIANT OF SPECTRAL TYPE F, G, OR K	V441 Her
194	SRb	SRb	SRB	331	332	SEMIREGULAR GIANT OF LATE SPECTRAL TYPE AND ALMOST REGULAR VARIATION	ρ Per
200	Ia		IA	1	1	IRREGULAR VARIABLE OF EARLY SPECTRAL TYPE, SUBJECT TO ERUPTIONS (WHITE IRREGULAR)	MU Cen
201	WR	WR	WR	8	8	ERUPTIVE WOLF-RAYET (HOT) STARS	γ Vel
210	INT		INT	4	4	T TAURI ORION VARIABLES	γ Cas+XP, RW Aur
220	UV	UV	UV	22	21	UV CETI K-M STARS (SLOW)	UV Cet
221	UVN		UVN	1	1	UV CETI IN A NEBULA	
230	RCB	RCB	RCB	3	3	IRREGULAR, R CORONA BOREALIS TYPE	R CrB
240	UG		UG	1	1	U GEMINORUM (DWARF NOVAE)	WW Cet
241	UGSS		UGSS			SS CYGNI-TYPE U GEM VARIABLES	U Gem
242	UGSU		UGSU			SS URSAE MAJORIS-TYPE U GEM VARIABLES	VW Hyi

Table 3-5. Variable Star Codes (3 of 3)

NUMERIC VARIABLILITY CODE (V4.0 WORD 6.5; SKY2000 WORD 6.7)	CODE FROM GCVS, 4TH EDITION	CODE FROM CRM, 1994	CODE FROM NSV	NUMBER PRESENT IN VERSION 4.0 OF MASTER CATALOG	NUMBER PRESENT IN SKY2000 VERSION 2 MASTER CATALOG	TYPE OF VARIABLE	EXAMPLE
243	UGZ		ZCAM			Z CAMELOPARDALIS-TYPE U GEM VARIABLES	Z Cam
244	ZAnd	ZAn	ZAND	8	8	Z ANDROMEDAE SYMBIOTIC VARIABLES	SS Lep
245			ZZC	2	1	ZZ CETI VARIABLES	
260	N		N	1	1	NOVAE (CLOSE BINARY SYSTEMS)	V Per
261	Na					RAPIDLY DEVELOPING NOVA	V720 Sco, GK Per
262	Nb					SLOWLY DEVELOPING NOVA	X Cir, RR Pic
263	Nr	NR	NR	1	1	RECURRENT NOVA	T CrB
264	gCas	gCa	GCAS	108	106	P CYGNI, NOVA-LIKE VARIABLE, B EMISSION STARS	γ Cas
265	SN,SNI,SNI I		SN			SUPER NOVA, SUPER NOVAE TYPES I AND II	
266	Nc			1	1	SLOWLY DEVELOPING NOVA, MAX LIGHT > DECADE, SLOWLY FADING	
267	Nl			1	1	NOVALIKE VARIABLES	
270	I	I	I	24	22	RAPID, IRREGULAR VARIABLES	VW Dra
271	IN,In	IN	IN	35	35	ORION-TYPE IRREGULARS (IRREGULAR IN NEBULA)	AB Aur
272	XI	XI	XI	1	1	X-RAY IRREGULAR VARIABLES	AR Psc
273	RS	RS	RS	42	40	RS CANUM VENATICORUM VARIABLES	δ Eri
274	Is, Isa,Isb		IS	13	13	RAPID IRREGULAR VARIABLES	CV Dra
275	S		S	23	23	UNSTUDIED VARIABLES WITH RAPID LIGHT CHANGES	
300	E	E	E	63	62	ECLIPSING BINARY	ψ Ori
310	EA	EA	EA	66	67	ALGOL-TYPE ECLIPSING BINARY	Ell+βCep β Per
320	EB	EB	EB	21	21	BETA LYRAE-TYPE ECLIPSING BINARY	ζ And
330	EW	EW	EW	13	13	CONTACT-TYPE ECLIPSING BINARY (W URSAE MAJ)	AW UMa
340			ELL	3	3	ELLIPSOIDAL-TYPE ECLIPSING BINARY	AO Cas
350	SDor	SDO	SDOR	7	7	S DORADUS ERUPTIVE, HIGH LUMINOSITY IRREGULARS	P Cyg
410	FKCom	FK, FKC	FKCO M	3	3	FK COMAE BERENICES, G-K TYPES	V645 Mon
420	SXAri	SXA	SXARI	15	15	SX ARIETIS, B0p - B9p DWARFS (ROTATING VARIABLES)	V354 Ori
430	Ell	Ell		32	32	ROTATING ELLIPSOIDAL VARIABLES	α Vir
440	BY	BY	BY	19	19	BY DRACONIS EMISSION-LINE DWARFS	BY Dra
999	Cst	Cst	CST	80	80	CONSTANT	

3.7.2 Word 7.2

This word contains the observed {*V*–passband 1} color, measured in magnitudes.

3.7.3 Word 7.3

This word contains the passband 1 magnitude or color uncertainty, measured in magnitudes.

3.7.4 Words 7.4, 7.10, and 7.19

These one-character words contain the photometric systems to which red passbands 1-3 belong. The standard photometric systems are described in Table 3-6. Valid codes for these words are as follows:

Standard Photometric System	Code
Johnson	J
Russian	R
Cousins	C
Photo-	p
Kron (R1 and I)	K
Kron (R2 only)	k
Eggen	E
RXTE CCDST	X

3.7.5 Words 7.5, 7.11, and 7.20

These one-character words contain the passbands of the photometric systems to which red magnitudes 1-3 belong (e.g., the *R* or *I* passbands). (See the table given for Word 5.7 in Section 3.5.7.)

3.7.6 Word 7.6

This two-digit integer word contains the source of passband 1 magnitude or color (see Table 3-2).

3.7.7 Word 7.7

This word contains the observed red passband 2 magnitude.

3.7.8 Word 7.8

This word contains the observed {*V*–passband 2} color.

3.7.9 Word 7.9

This word contains the passband 2 magnitude or color uncertainty, measured in magnitudes.

Table 3-6. Standard Photometric Systems

Standard System*	Standard Passband	Effective** Wavelength (A)	Absolute Flux*** (Jansky)	Effective** Bandwidth (A) (D l_{eff})	Percent Bandwidth (D l_{eff}/ l_{eff})	Effective Halfpower Width (A) (D $l_{½}$)
Johnson	*U*	3,500	1,720.0	680	19	700
	B	4,430	4,490.0	990	22	1,000
	V	5,540	3,660.0	900	16	900
	R	6,940	2,780.0	2,070	30	2,200
	I	8,780	2,240.0	2,320	26	2,400
	J	12,500	16,35.0	3,800	30	3,800
	H	16,500	1,070.0			
	K	22,000	665.0	4,800	22	4,800
	L	36,000	277.0	7,000	19	7,000
	M	48,000	164.0	12,000	25	12,000
	N	102,000	42.6	57,000	48	57,000
Cousins	*R*	6,380	3,060.0	1,380		
	I	7,970	2,420.0	1,490		
Kron	*R*	7,200	TBS			1,800
	I	10,300				1,800
Russian	*W*	3,540	TBS	460	13	
	B	4,380	4,490	870	20	
	V	5,510	3,660	890	16	
	R	7,120	2,780	1,220	17	
CCDST	typical	7,800	-		[55]	4200
Other	*ptg*	4,270	~4,490			
	ptv	5,440	~3,660			

NOTES

*Because photometric systems tend to evolve over time, the effective wavelengths, bandwidths, and absolute flux values presented may vary with the observer, and therefore with the source catalog. Values representative of the particular source catalog must be used when they are available. These effective wavelengths, bandwidths, and absolute flux values are taken from Table 4.1.1-1 of Miller and Slater (1993).

**Assumes a flat input spectrum.

***Unless indicated otherwise for a specific system, all absolute zero-point fluxes are based on a standard A0 V star with magnitudes V_0, B_0, U_0, R_0, I_0, J_0 set to 0, and colors U-B = B–V = V–R = V–I = V–J set to zero {1 Jansky = 10^{-30} W/cm^2 Hz}.

3.7.10 Word 7.12

This two-digit integer word contains the source of passband 2 magnitude or color (see Table 3-2).

3.7.11 Word 7.13

This word contains the observed (passband 1 – passband 2) color, measured in magnitudes.

3.7.12 Words 7.14 and 7.15

These words contain the blended passband 1, 2 magnitude or color flags.

3.7.13 Word 7.16

This word contains the observed red passband 3 magnitude.

3.7.14 Word 7.17

This word contains the observed {V – passband 3} color.

3.7.15 Word 7.18

This word contains the passband 3 magnitude or color uncertainty, measured in magnitudes.

3.7.16 Word 7.21

This two-digit integer word contains the source of passband 3 magnitude or color (see Table 3-2).

3.7.17 Word 7.22

This word contains the blended passband 3 magnitude or color flag.

Section 4. SKY2000 Master Catalog Mathematical Specifications

This section contains the derivations for the derived data in the Master Catalog.

4.1 Position Data

Catalog star positions are presented at the standard equinox, equator, and epoch, ICRS2000. To determine a star's position at an epoch and equinox different from the catalog standard, corrections must be made for precession of the Earth's axis and proper motion of the star across the sky. The Master Catalog provides position and proper motion information.

4.1.1 Position at a Standard Epoch

All positions have been propagated from the source catalog epochs to ICRS2000 by the application of systematic corrections at the source catalog epoch where necessary and after applying proper motion corrections.

SKY2000 stores the positions both in terms of right ascension (α) and declination (δ), and as a unit vector in a rectilinear coordinate system defined as follows:

$$X = \cos\alpha \cos\delta$$

$$Y = \sin\alpha \cos\delta \qquad (4\text{-}1)$$

$$Z = \sin\delta$$

The (X, Y, Z) coordinate system definition corresponds to the projection of the Earth's North Pole onto the celestial sphere as the Z-axis, and the vernal equinox as the X-axis, at epoch ICRS2000. The Y-axis completes a right-handed orthonormal coordinate system such that

$$Z = X \times Y \qquad (4\text{-}2)$$

Neglecting the effect of heliocentric parallax (always less than 1 arcsecond), this coordinate system is identical to the GCI frame used repeatedly for attitude determination functions.

4.1.2 Proper Motion

For lengths of time of up to several hundreds of years, proper motion corrections can be applied linearly, as follows:

$$\alpha_I = \alpha_J + \mu_\alpha \Delta t + \left[\tfrac{1}{2}\Delta m_a \Delta t^2\right]$$

$$\delta_I = \delta_J + \mu_\delta \Delta t + \left[\tfrac{1}{2}\Delta m_d \Delta t^2\right] \qquad (4\text{-}3)$$

where the terms in square brackets represent error terms because of neglecting the secular acceleration ($\Delta m_a, \Delta m_d$) in proper motion and where

(α_I, δ_I)	= right ascension and declination with proper motions corrected to epoch I
(α_J, δ_J)	= right ascension and declination at standard catalog epoch J
(μ_α, μ_δ)	= proper motion per year in right ascension and declination at standard epoch J; m_a in the SKY2000 Version 2 Master Catalog is in seconds of time per Julian year
Δt	= difference in years and fraction of a year between epoch I and standard epoch J
$\Delta\mu$	$= \left(\Delta m_a^2 + \Delta m_d^2\right)^{\frac{1}{2}}$ = total secular acceleration in proper motion

The maximum error term can be estimated from Equation 9.15 on page 129 of *Principles of Astrometry* (van de Kamp, 1967)

$$\Delta m = -2.05'' \times 10^{-6} \, v_R pm/\text{year}$$

by using the following maximum values of radial velocity, parallax, and proper motion:

$$|v_R| = 250 \text{ km/sec}, \; p = 0.754 \text{ arcsec} \,(a \text{ Centauri}), \; m = 10.13 \text{ arcsec} \,(\text{Barnard's star})$$

Some sample maximum uncertainties follow.

Δt (years)	[1/2 $\Delta\mu$ Δt^2] (arcseconds)
1	0.002
3	0.018
10	0.2
20	0.8
30	1.8

These results are upper limits because no one star has all the maximum values of v_R, π, and μ.

4.1.3 Precession

Because the Earth's spin axis precesses with a period of 26,000 years, star positions in the J2000 system change slowly. This effect is known as precession.

The following methods, taken from the *Explanatory Supplement to the Astronomical Almanac* (Seidelmann, 1992), allow conversion of B1950 positions and proper motions to J2000 and conversion of J2000 measurements to B1950, with the effects of precession between the 1950 and 2000 epochs reflected in the result.

4.1.3.1 Conversion of Stellar Positions and Proper Motions From the FK4 System at B1950 to FK5 System at J2000

A matrix method for calculating the mean place of a star at J2000 on the FK5 system from the mean place at B1950 on the FK4 system, ignoring the systematic corrections FK5–FK4 and individual star corrections to the FK5, is as follows:

Step a:

From a star catalog, obtain the FK4 position (α_0, δ_0), in degrees, proper motions ($\mu_{\alpha 0}$, $\mu_{\delta 0}$), in seconds of arc per tropical century, parallax (π_0), in seconds of arc, and radial velocity (ν_0), in km/sec, for B1950. If π_0 or ν_0 is unspecified, set them both equal to zero.

Step b:

Calculate the rectangular components of the position vector $\boldsymbol{r}_0$ and velocity vector $\dot{\boldsymbol{r}}_0$ from

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = r_0 = \begin{bmatrix} \cos\alpha_0 \cos\delta_0 \\ \sin\alpha_0 \cos\delta_0 \\ \sin\delta_0 \end{bmatrix}$$

(4-4)

$$\begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{z}_0 \end{bmatrix} = \dot{r}_0 = \begin{bmatrix} -\mu_{\alpha 0}\sin\alpha_0\cos\delta_0 - \mu_{\delta 0}\cos\alpha_0\sin\delta_0 \\ +\mu_{\alpha 0}\cos\alpha_0\cos\delta_0 - \mu_{\delta 0}\sin\alpha_0\sin\delta_0 \\ \mu_{\delta 0}\cos\delta_0 \end{bmatrix} + 21.095\,\nu_0\pi_0 r_0$$

Step c:

Remove the effects of the E-terms of aberration to form $\boldsymbol{r}_1$ and $\dot{\boldsymbol{r}}_1$ from

$$\boldsymbol{r}_1 = \boldsymbol{r}_0 - A + (\boldsymbol{r}_0 \cdot A)\boldsymbol{r}_0$$

$$\dot{\boldsymbol{r}}_1 = \dot{\boldsymbol{r}}_0 - \dot{A} + (\boldsymbol{r}_0 \cdot \dot{A})\boldsymbol{r}_0$$

where

$$A = \begin{bmatrix} -1.62557 \\ -0.31919 \\ -0.13843 \end{bmatrix} \times 10^{-6} \text{ radians}$$

(4-5)

$$\dot{A} = \begin{bmatrix} +1.''245 \\ -1.''580 \\ -0.''659 \end{bmatrix} \times 10^{-3} \text{per tropical century}$$

and $(\boldsymbol{r}_0 \cdot A)$ is the scalar product.

Step d:

Form the vector

$$R_1 = \begin{bmatrix} r_1 \\ \dot{r}_1 \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \\ \dot{x}_1 \\ \dot{y}_1 \\ \dot{z}_1 \end{bmatrix}$$

and calculate the vector

$$R = \begin{bmatrix} r \\ \dot{r} \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix}$$

from

$$R = MR_1 \tag{4-6}$$

where M is a constant 6×6 matrix:

$$\begin{bmatrix} +0.9999256782 & -0.0111820611 & -0.0048579477 & +0.00000242395018 & -0.00000002710663 & -0.00000001177656 \\ +0.0111820610 & +0.9999374784 & -0.0000271765 & +0.00000002710663 & +0.00000242397878 & -0.00000000006587 \\ +0.0048579479 & -0.0000271474 & +0.9999881997 & +0.00000001177656 & -0.00000000006582 & +0.00000242410173 \\ -0.000551 & -0.238565 & +0.435739 & +0.99994704 & -0.01118251 & -0.00485767 \\ +0.238514 & -0.002667 & -0.008541 & +0.01118251 & +0.99995883 & -0.00002718 \\ -0.435623 & +0.012254 & +0.002117 & +0.00485767 & -0.00002714 & +1.00000956 \end{bmatrix} \tag{4-7}$$

and set $(x, y, z, \dot{x}, \dot{y}, \dot{z}) = \boldsymbol{R'}$.

Step e:

Calculate the FK5 mean position (α_1, δ_1) proper motions ($\mu_{\alpha 1}$, $\mu_{\delta 1}$) in seconds of arc per Julian century, parallax (π_1) in seconds of arc, and radial velocity (ν_1) in km/sec for J2000 from

$$\alpha_1 = \tan^{-1}(y/x)$$

$$\delta_1 = \sin^{-1}(z/r)$$

$$\mu_{\alpha_1} = \frac{x\dot{y} - y\dot{x}}{x^2 + y^2}, \mu_{\delta_1} = \frac{\dot{z}(x^2 + y^2) - z(x\dot{x} + y\dot{y})}{r^2\sqrt{x^2 + y^2}} \tag{4-8}$$

$$\nu_1 = (x\dot{x} + y\dot{y} + z\dot{z})/(21.095\pi_0 r)$$

$$\pi_1 = \pi_0/r$$

where

$$r = \sqrt{x^2 + y^2 + z^2}$$

and α_1 and δ_1 are evaluated with respect to trigonometric quadrant.

If π_0 is zero, then $\nu_1 = \nu_0$.

4.1.3.2 Conversion of Stellar Positions and Proper Motions From the FK5 System at J2000 to FK4 System at B1950

A matrix method for calculating the mean location of a star at B1950 on the FK4 system from the mean location at J2000 on the FK5 system, ignoring the systematic corrections FK4-FK5 and individual star corrections to the FK4, is as follows.

Step 1:

From a star catalog, obtain the FK5 position (α_0, δ_0), in degrees, proper motions ($\mu_{\alpha 0}$, $\mu_{\delta 0}$) in seconds of arc per Julian century, parallax (π_0) in seconds of arc, and radial velocity ν_0 in km/sec for J2000. If π_0 or ν_0 is unspecified, set them both equal to zero.

Step 2:

Calculate the rectangular components of the position vector $\boldsymbol{r}_0$ and velocity vector $\dot{\boldsymbol{r}}_0$ from Equation (4-4).

Step 3:

Form the vector $\boldsymbol{R}_0 = [\boldsymbol{r}_0\ \dot{\boldsymbol{r}}_0]$ and calculate the vector $\boldsymbol{R}_1 = [\boldsymbol{r}_1\ \dot{\boldsymbol{r}}_1]$ from

$$\boldsymbol{R}_1 = M^{-1}\boldsymbol{R}_0 \tag{4-9}$$

where M^{-1} is a constant 6×6 matrix:

$$\begin{bmatrix} +0.9999256795 & +0.0111814828 & +0.0048590039 & -0.00000242389840 & -0.00000002710544 & -0.00000001177742 \\ -0.0111814828 & +0.9999374849 & -0.0000271771 & +0.00000002710544 & -0.00000242392702 & +0.00000000006585 \\ -0.0048590040 & -0.0000271557 & +0.9999881946 & +0.00000001177742 & +0.00000000006585 & -0.00000242404995 \\ -0.000551 & +0.238509 & -0.435614 & +0.99990432 & +0.01118145 & +0.00485852 \\ -0.238560 & -0.002667 & +0.012254 & -0.01118145 & +0.99991613 & -0.00002717 \\ +0.435730 & -0.008541 & +0.002117 & -0.00485852 & -0.00002716 & +0.99996684 \end{bmatrix} \quad (4\text{-}10)$$

Step 4:

Include the effects of the E-terms of aberration as follows. Form $\boldsymbol{s}_1 = \boldsymbol{r}_1/r_1$ and $\dot{\boldsymbol{s}}_1 = \dot{\boldsymbol{r}}_1/r_1$, where

$$r_1 = \sqrt{x_1^2 + y_1^2 + z_1^2}$$

Set $\boldsymbol{s} = \boldsymbol{s}_1$, and calculate $\boldsymbol{r}$ from $\boldsymbol{r} = \boldsymbol{s}_1 + A - (\boldsymbol{s} \cdot A)\boldsymbol{s}$, where A is given in Step c of Section 4.1.3.1.

Set $\boldsymbol{s} = \boldsymbol{r}/r$ and iterate the expression for $\boldsymbol{r}$ once or twice until a consistent value of $\boldsymbol{r}$ is obtained. Then calculate

$$\dot{\boldsymbol{r}} = \dot{\boldsymbol{s}}_1 + A - (\boldsymbol{s} \cdot \dot{A})\boldsymbol{s} \quad (4\text{-}11)$$

where $\dot{A}$ is given in Step c of Section 4.1.3.1.

Step 5:

Calculate the FK4 mean (α_1, δ_1) proper motions $(\mu_{\alpha 1}, \mu_{\delta 1})$ in seconds of arc per tropical century, parallax (π_1) in seconds of arc, and radial velocity (ν_1) in km/sec for B1950, as given in Section 4.1.3.1, Step e, by setting $(x, y, z) = \boldsymbol{r}'$, $(\dot{x}, \dot{y}, \dot{z}) = \dot{\boldsymbol{r}}'$, and

$$r = \sqrt{x^2 + y^2 + z^2}$$

In Step 4, set $(x_1, y_1, z_1) = \boldsymbol{r}_1'$, $(\dot{x}_1, \dot{y}_1, \dot{z}_1) = \dot{\boldsymbol{r}}_1'$, and

$$\boldsymbol{r}_1 = \sqrt{x_1^2 + y_1^2 + z_1^2}$$

Then

$$\nu_1 = (x_1\dot{x}_1 + y_1\dot{y}_1 + z_1\dot{z}_1)/(21.095\pi_0 r_1), \quad \pi_1 = \pi_0/r_1 \quad (4\text{-}12)$$

If π_0 is zero, then $\nu_1 = \nu_0$.

Angular values are obtained as in Section 4.1.3.1.

4.2 Derived V Magnitude (V′)

When an observed visual magnitude is not available, a visual magnitude must be derived (V'). When a B magnitude is not available, V' is derived from the *ptv* and *ptg* magnitudes obtained from the HD, PPM, AGK-3, or other source catalog such as the SAO or the WDS. The conversion equations adopted below are taken from the Version 3.7 *SKYMAP System Description, Revision 3, Update 2* (Lennon, 1994), and are augmented by additional equations when spectral class is not available.

4.2.1 Converted HD/PPM ptv/ptg or Any Other Non-SAO Magnitudes

The *ptv* and *ptg* magnitudes from the PPM and HD or any other non-SAO catalog are treated the same. For stars with *ptv* or both *ptv* and *ptg* observed,

$$V' = ptv + c_1 + a_1 \tag{4-13}$$

For stars with only *ptg* observed,

$$B' = ptg + c_2 + a_2$$

$$V' = B' - (B - V)^* \tag{4-14}$$

where c_1 and c_2 are magnitude-dependent correction factors given by

$$c_1 = 0.24 - 0.03ptv$$

$$c_2 = 0.161 - 0.024ptg \tag{4-15}$$

where a_1 and a_2 are spectral class-dependent factors listed in Table 4-1 and where $(B–V)^*$ is the mean difference of B and V magnitudes for the spectral class range in Tables 4-1 and 4-3. $(B–V)^*$ values do not correspond to intrinsic $(B–V)$ values that have no interstellar reddening but instead reflect the mean interstellar reddening of subsets of analyzed stars. Except where indicated, Table 4-1 can be used when the HD, PPM, or any other non-SAO spectral class is available. Error allowances are presented in Table 4-2 for each configuration of methods for obtaining V'.

4.2.2 Converted SAO ptv/ptg Magnitudes

Equations (4-13) and (4-14), containing different values for the correction factors (c_1, c_2, a_1, a_2), can be used for *ptv* and *ptg* magnitudes given in the SAO Catalog (Smithsonian Astrophysical Observatory Staff, 1966). Equations (4-16) and (4-17) replace Equation (4-15) for c_1 and c_2. Values from Table 4-3 replace those from Table 4-1 for a_1 and a_2. Except where indicated in Table 4-3, the same values of $(B–V)^*$ can be used when the SAO spectral class is available. This analysis is further documented in Nigam et al. (1982).

$$c_1 = \begin{cases} -0.2016 + 0.0262\,ptv \; (ptv \le 7.5) \\ 17.1510 - 4.2873\,ptv + 0.2668\,ptv^2 \, (ptv > 7.5) \end{cases} \tag{4-16}$$

$$c_2 = 0.4589 – 0.0278ptg \tag{4-17}$$

4.2.3 Unconverted ptv/ptg Magnitudes From Any Source

When no spectral class (or color) data are available, the derived magnitude, V', is given by the following adopted equations, which are based on the assumption that V and B are approximately equal to *ptv* and *ptg*:

$$V' = ptv, \text{ when } ptv \text{ is available}$$

(4-18)

$$V' = ptg - \langle (B-V)^* \rangle, \text{ when only } ptg \text{ is available}$$

where $\langle (B-V)^* \rangle = +1.000$ is the adopted color from Table 4-1 for late G or early K class stars. The value selected is judged to be more representative of typical reddened stars than the intrinsic color $(B-V)_0$. Past distributions of SKYMAP stars by magnitude indicate that the value of +0.45, often adopted as the average intrinsic color, is not as likely as +1.00 for a typical faint, reddened star.

4.2.4 Observed B Magnitude

When the observed B magnitude and MK spectral class and luminosity class are given, the derived magnitude, V', is computed by the following equation:

$$V' = B - (B-V)_{\text{standard}} \quad (4\text{-}19)$$

where the value of the standard color is taken from Table 4-4.

When the MK spectral class and luminosity class are not available, V' is computed from the following equation:

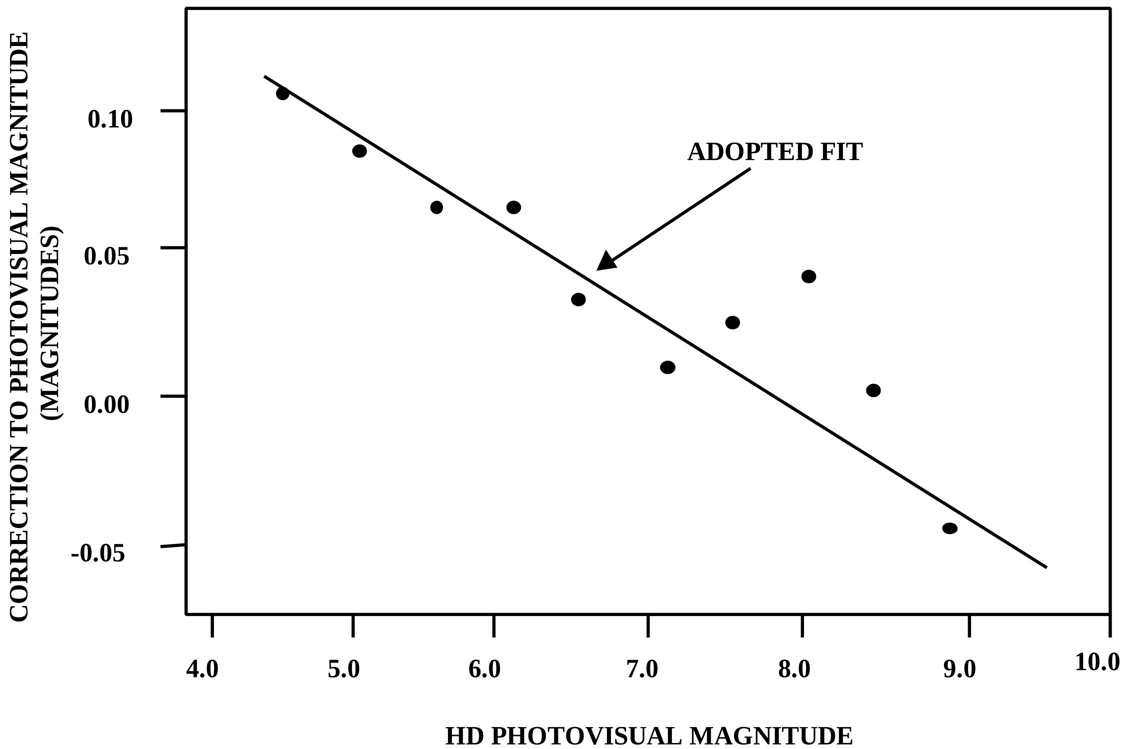
$$V' = B - (B-V)^* \quad (4\text{-}20)$$

where $(B-V)^*$ is taken from Table 4-1 for HD/PPM or SAO spectral class.

When no spectral data (or color) is available, V' is computed from the following equation:

$$V' = B - \langle (B-V)^* \rangle \quad (4\text{-}21)$$

where $\langle (B-V)^* \rangle = +1.00$ is adopted as above in Equation (4-18).



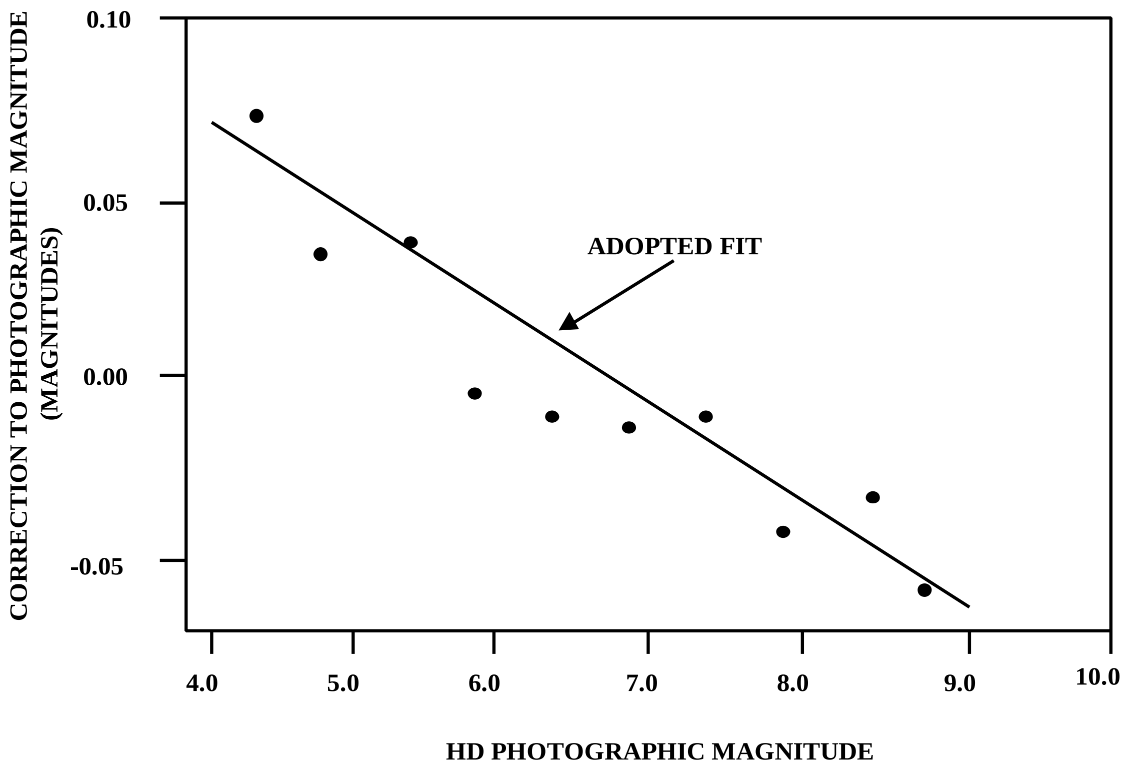


Figure 4-1. Corrections to HD, PPM, or Any Other Non-SAO ptv and ptg Magnitudes

Table 4-1. Spectral Class-Dependent Correction Factors in Magnitudes for HD, PPM, or Any Other Non-SAO ptv and ptg Magnitude Conversion

Range No.	Range of MK/HD Spectral Class	a_1	a_2	(B- V)*
1	O3-O9.5[1]	-0.20	+0.11	+0.25
2	B0-B3	+0.01	+0.08	+0.12
3	B3.5-B7	+0.03	+0.03	-0.03
4	B7.5-B9.5	+0.02	+0.02	-0.01
5	A0-A3	+0.06	+0.05	+0.11
6	A3.5-A7	+0.05	+0.07	+0.26
7	A7.5-A9.5	+0.05	+0.07	+0.29
8	F0-F3	+0.06	+0.03	+0.38
9	F3.5-F7	+0.06	+0.01	+0.47
10	F7.5-F9.5	+0.08	-0.02	+0.53
11	G0-G3	+0.05	+0.01	+0.64
12	G3.5-G7	+0.03	-0.03	+0.85
13	G7.5-G9.5	-0.01	-0.05	+0.93
14	K0-K3	-0.02	-0.02	+1.14
15	K3.5-K7	-0.04	+0.09	+1.40
16	K7.5-K9.5	+0.04	-0.07	[+1.49]
17	M0-M3[2]	-0.06	+0.02	+1.57
18	M3.5-M9.5[3]	-0.06	0.00	+1.62
19	R	-0.12	+0.11	+1.25
20	N	-0.03	+0.11	[+1.00]
21	C	-0.01	-0.01	–
22	S	-0.08	+0.06	[+0.22]
23	WR,WC,WN	+0.02	+0.05	+0.22

NOTES

[ ] Interpolated or estimated

– Unknown

1. Corresponds to HD Oa, Ob, Oc
2. Corresponds to HD Ma
3. Corresponds to HD Mb, Mc, Md

Table 4-2. Error Allowances in Magnitudes for Various Derived V Magnitude Computational Methods

Method Flag	Derived V ¢ Uncer-tainty	Magnitude Origin	Description
Blank	N/A	None	
1	0.4, 0.5, 0.7	Converted HD/AGK-3 or SAO *ptv* and *ptg*, *ptv*, *ptg* [spectral class]	*ptg* and *ptv* are observed, *ptv* is observed (*ptg* is not observed), *ptg* is observed (*ptv* is not observed, *V′* is calculated from *B′* and (*B*-*V*)*) [spectral class is observed between O and WC, and (*B*-*V*)* is available]
2	0.8, 0.8	Unconverted HD or SAO *ptv* and *ptg*, *ptv*	*ptv* and *ptg*, *ptv* are observed (*ptg* is not observed) [spectral class is outside range of O to WC, *ptv* is used for *V′* in both cases]
3	0.8	Observed *B* and MK spectral type [(*B*-*V*) standard color]	*B* is observed [spectral class is observed between O and WC and (*B*-*V*) is available, *ptv* is not observed and the star is not listed in the HD or SAO catalog, *V′* is calculated from *B* and (*B*-*V*))
4	0.8	Observed *B* and HD/AGK-3 or SAO spectral class [(*B*-*V*)* color]	*B* is observed [HD/AGK-3 or SAO spectral class with adopted average (*B*-*V*)* color]
5	1.0, 1.2	Adopted average color <(*B*-*V*)*>= +1.00 and observed *B*, observed HD/AGK-3 or SAO *ptg*	*B* is observed [observed HD/AGK-3 or SAO *ptg* with adopted average color <(*B*-*V*)* >=+1.00]

NOTES

See Table 4-1 for (*B*-*V*)*

<(*B*-*V*)*> = adopted average (*B*-*V*)*

MK type = spectral class and luminosity class in this context

Table 4-3. Spectral Class-Dependent Correction Factors in Magnitudes for SAO ptv and ptg Magnitude Conversion

Range No.	Range of MK/SAO Spectral Class	a_1	a_2	(B- V)*
1	O3-O9.5[4]	-0.05	0.01	+0.25
2	B0-B3	-0.04	0.01	+0.12
3	B3.5-B7	-0.05	-0.04	-0.03
4	B7.5-B9.5	-0.05	-0.05	-0.01
5	A0-A3	0.01	-0.06	+0.11
6	A3.5-A7	0.00	-0.07	+0.26
7	A7.5-A9.5	-0.05	-0.01	+0.29
8	F0-F3	-0.00	-0.03	+0.38
9	F3.5-F7	-0.01	0.00	+0.47
10	F7.5-F9.5	0.02	0.06	+0.53
11	G0-G3	0.01	0.04	+0.64
12	G3.5-G7	0.00	0.03	+0.85
13	G7.5-G9.5	0.00	0.01	+0.93
14	K0-K3	0.00	0.02	+1.14
15	K3.5-K7	-0.05	0.08	+1.40
16	K7.5-K9.5	0.04	-0.06*	[+1.49]
17	M0-M3[5]	-0.07	0.13	+1.57
18	M3.5-M9.5[6]	-0.09	0.04	+1.62
19	R	0.06	0.22*	+1.25
20	N	0.03*	-0.25*	[+1.00]
21	C	0.03	0.94*	—
22	S	0.26*	—*	[+0.22]
23	WR, WC, WN	-0.00*	-0.07*	+0.22

NOTES

— Unknown

[ ] Interpolated or estimated

* In the catalog software, the correction factors (a_1, a_2) were assigned a value of 0 because the error in the calculated correction was larger than the correction.

4. Corresponds to SAO Oa, Ob, Oc

5. Corresponds to SAO M0, M1

6. Corresponds to SAO M2, M3, M4

Table 4-4. Smoothed Values of (B- V) Standard (1 of 2)

MK Spectral Class	MK Luminosity Class				
	I	II	III	IV	V
O9	-0.22	[-0.24]	-0.25	[-0.27]	-0.25
B0	-0.20	-0.22	-0.23	-0.25	-0.23
B1	-0.19	-0.19	-0.21	-0.23	-0.20
B2	-0.17	-0.17	-0.19	-0.20	-0.17
B3	-0.16	-0.14	-0.17	-0.17	-0.15
B4	-0.14	-0.12	-0.15	-0.14	-0.14
B5	-0.12	-0.09	-0.14	-0.12	-0.12
B6	-0.10	-0.06	-0.13	-0.10	-0.11
B7	-0.08	-0.03*	-0.11	-0.10	-0.09
B8	-0.05	-0.01*	-0.10	-0.09	-0.07
B9	-0.03	0.02*	-0.07	-0.05	-0.04
A0	-0.01	0.04*	-0.03	-0.02	-0.02
A1	0.01	0.06*	0.01	0.02	0.02
A2	0.04*	0.08*	0.05	0.05	0.05
A3	0.06*	0.10*	0.09	0.09	0.09
A4	0.08*	0.13*	0.12	0.12	0.13
A5	0.10*	0.16*	0.16	0.15	0.16
A6	0.13*	0.19	0.20	0.18	0.18
A7	0.16*	0.22	0.24	0.22	0.20
A8	0.19*	0.25	0.27	0.25	0.23
A9	0.24*	0.28	0.29	0.28	0.27
F0	0.31*	0.31	0.31	0.30	0.30
F1	0.35	0.34	0.33	0.32	0.33
F2	0.40*	0.37	0.36	0.35	0.35
F3	0.45*	0.40	0.39	0.37	0.38
F4	0.50*	0.43	0.42	0.39	0.41
F5	0.56	0.46	0.46	0.41	0.44
F6	0.62	0.49	0.50*	0.45	0.47
F7	0.67	0.55	0.54*	0.48	0.49
F8	0.72	0.62	0.58*	0.52	0.52
F9	0.77	0.69	0.62*	0.55	0.55
G0	0.83	0.77	0.66	0.59	0.57
G1	0.88	0.84	0.71	0.62	0.59
G2	0.93	0.88	0.75	0.65	0.61
G3	0.98	0.93	0.79	0.68	0.63
G4	1.03	0.95	0.83	0.73	0.66

Table 4-4. Smoothed Values of (B- V) Standard (2 of 2)

MK Spectral Class	MK Luminosity Class				
	I	II	III	IV	V
G5	1.08	0.97	0.88	0.77	0.68
G6	1.13*	1.00	0.92	0.82	0.70
G7	1.18	1.03	0.94	0.85	0.73
G8	1.23*	1.07	0.95	0.88	0.76
G9	1.28*	1.12	0.97	0.93	0.80
K0	1.33*	1.17	1.00	0.96	0.85
K1	1.38*	1.23	1.10	1.00	0.88
K2	1.43*	1.35	1.17	—	0.93
K3	1.48	1.43	1.28	—	0.97
K4	1.53	1.52	1.42	—	1.05
K5	1.56	1.55	1.50	—	1.11
K6	1.57	1.58*	1.51*	—	1.16
K7	1.58	1.60*	1.52*	—	1.22
K8	1.59	1.62*	1.53*	—	1.28
K9	1.60	1.64*	1.54*	—	1.34
M0	1.60	1.65	1.55	—	1.39
M1	1.61	1.66	1.57	—	1.44
M2	1.62	1.67	1.59	—	1.48
M3	1.63*	1.68	1.61	—	1.53
M4	1.64*	1.69	1.64	—	1.57

NOTES

* Uncertain results due to lack of data.

— Unknown

[ ] Interpolated or estimated

Appendix A. Sample MK Spectral Types

The MK spectral types are stored in the SKY2000 Master Catalog Version 4.1 (Word 4.1) exactly as they appear in the individual source catalogs. This produces many variations on the standard forms given in Section 3.4.1. Typical examples are given in the following lists. Note that some of these examples are not true MK types, but rather are test examples used to verify the behavior of the software.

The first list concentrates on slashes for uncertainty, blank spaces for reading convenience, various indicators of peculiarity such as "( )" or following alphanumeric character(s), and on "[ ]" as indicator of another type from a different source. Examples with similar characteristics are grouped together.

- {B1s; B2nn; A3m; B3ne; 06fpe; +0a}. {M5.4e; B9.5 Vn}. {A1pSi; Kp Ba; Ap CrEuSc; G5 var 0 [G0 Ia]}.
- {M0 M5e;G5wF0; G0wA5 V; F1mA9 [F0 V]}.
- {K1 IIIp; B3 Iae; K2 IIICN1.5; G8 III CN1 [G8II]}. {B2 (III); B3 (III) ne}.
- {O8 III((f)); K0 III (CNII); G8/K0 III (CNIV); K2 IIICNII}.
- {B9.5/A0.V; B2/3 II/III; G5 Ia/II; K2 III/IVCNIb/II}.
- {F3 IV/V [F3 V]; K4.5 Ib-11 [K5 Ib]; M1-M2 Ia-Iab [M1 Ia]}.
- {AlmA5-F0; F0-2IV; K0 II-III; A2-3 IV-V; F7; Ib-IIv}.
- {G5/8 III + A8/F; G5 III + F2 V}.

The second list is the output test results used by the software developers to validate the algorithm that converts MK spectral types to SKYMAP numeric code. The focus is on compressed forms (no blank spaces), hyphens indicating uncertainty in general, and various indicators of peculiarity. About half of the input types are also actual entries from various source catalogs and the other half are fictitious values designed to test the flexibility of the algorithm. A "1" in the last column indicates a double star, while "2" indicates two possible types for a single star, and "0" indicates a single star with one MK spectral type.

Such entries as given in these two lists also may appear in the SKY2000 Master Catalog followed by a MK peculiarity code.

The third list gives the conversion for eight types that the software could not convert. These eight types are entered through a NAMELIST.

A.1 SCR Number: 1016 (CONVERSION OF SPECTRAL TYPE DATA)

The SKYSPEC routine converts a spectral type from packed astronomical notation to the numerical SKYMAP notation. The software assumes no more than two spectral types in a single packed astronomical entry. Calling sequence argument descriptions follow:

Name	Type	I/O	Description
C$SP	C*30	I	Spectral type in packed astronomical notation
SPEC1	I*4	O	First spectral class (SKYMAP notation)
LUM1	I*4	O	First luminosity class (SKYMAP notation)
SPEC2	I*4	O	Second spectral class (SKYMAP notation)
LUM2	I*4	O	Second luminosity class (SKYMAP notation)
C$PEC	C*30	O	Peculiarity code (astronomical notation): not converted
ISEC	I*4	O	Second spectral type flag (ITYPE below): = 0, second spectral type not defined = 1, two spectral types = 2, two spectral types referring to a range

Note: Test 1: Performed by J. Lennon (SCR Tester), date: 8/20/94; Verified by D. Mucci (Task leader), date: 10/15/94

Item	C$SPEC (Input Spectral Type)	Output SKYMAP Spectral Types				
		SPEC1	LUM1	SPEC2	LUM2	ITYPE
1	{O}9II	{900}	{20}	0	0	0
2	B8.0II-III	1800	25	0	0	0
3	A4.1III	2410	30	0	0	0
4	FI	3007	10	0	0	0
5	G0V	4000	50	0	0	0
6	K	5007	0	0	0	0
7	MI-II	6007	15	0	0	0
8	R3.3III-IV	7330	35	0	0	0
9	N0.9	8090	0	0	0	0
10	C9.0	9900	0	0	0	0
11	S4.4IV	10440	40	0	0	0
12	WR8.5V	11850	50	0	0	0
13	WC	12007	0	0	0	0
14	WNV	13007	50	0	0	0
15	F3.4+F3.5	3340	0	3350	0	1
16	F3.4+	3349	0	0	0	0
17	F3.4+II	3349	20	0	0	0
18	F3.4+Ia+	3349	9	0	0	0
19	F3.4+Ia++F3.5	3349	9	3350	0	1
20	F3.4-F3.5	3340	0	3350	0	2
21	F3.4-	3348	0	0	0	0
22	F3.4-II	3348	20	0	0	0
23	F3.4-Ia+	3348	9	0	0	0
24	F3.4-Ia+-F3.5	3348	9	3350	0	2
25	cF3.4	3340	-10	0	0	0
26	cF3.4+cF3.5	3340	-10	3350	-10	1
27	cF3.4-cF3.5	3340	-10	3350	-10	2
28	sdF3.4	3340	-20	0	0	0
29	dF	3007	-30	0	0	0
30	FIa-{0}+FI{a}-{0}	3007	11	3007	{11}	1
31	FIa-{0}	3007	11	0	0	0
32	FI{a}-OIa-{0}	3007	{9}	{7}	{11}	{1}
33	F+Ia-{0}	3009	11	0	0	0
34	F-Ia-OIa-{0}	3008	{9}	7	11	2
35	F-Ia-O-Ia-{0}	3008	{9}	{7}	{11}	{2}
36	O	7	0	0	0	0
37	cOc	46	-10	0	0	0
38	O+OO	7	0	7	5	1
39	O++OO	9	0	7	5	1
40	O--OO	8	0	7	5	2
41	gF3.4+	3349	-50	0	0	0
42	Fa	3016	0	0	0	0
43	Fa+	3019	0	0	0	0
44	Fa-	3018	0	0	0	0
45	Fa-F3a	3016	0	3300	0	2
46	Fb	3036	0	0	0	0
47	Fc	3046	0	0	0	0

Note: Brackets { } denote entry modified from original value.

Item	C$SPEC (Input Spectral Type)	Output SKYMAP Spectral Types				
		SPEC1	LUM1	SPEC2	LUM2	ITYPE
48	Fd	3066	0	0	0	0
49	Fe	3076	0	0	0	0
50	Ff	3096	0	0	0	0
51	A4.5Ia-O	2450	11	0	0	0
52	A4.5+Ia-O	2459	11	0	0	0
53	A4.5-Ia-O	2458	11	0	0	0
54	O{0}	7	5	0	0	0
55	O+{0}	9	5	0	0	0
56	O+O5	7	0	500	0	1
57	WR	11007	0	0	0	0
58	dMd	6066	-30	0	0	0
59	F6.5-IIa-IIab+	3658	23	0	0	0
60	F6.5-Ia-O	3658	11	0	0	0
61	AVn	{2000}	{50}	0	0	0
62	F6.5-	3658	0	0	0	0
63	F6.5III+	3650	30	0	0	0
64	KCN	5007	0	0	0	0
65	M9.9Ia-Iab(M5/M2/M9)	6990	13	0	0	0
66	9.5	0	0	0	0	0
67	WC-WN	12007	0	13007	0	2
68	S5I+(S5/S2/S9)	10500	10	0	0	0
69	o5	{500}	0	0	0	0
70	O-Ia-{0}-O-Ia-Iab	8	11	8	13	2
71	O+Ia++O+Ib	9	9	9	18	1
72	OIa+-OIab-Ib	7	9	7	17	2
73	K5Vn-M0V	5500	50	{6000}	{50}	{2}
74	PECULIAR	99999	0	0	0	0
75	NOVA	99998	0	0	0	0
76	O+O{0}	7	0	7	5	1
77	blank	0	0	0	0	
78	AIa+	2007	9	0	0	0
79	AIa+-AII	2007	9	2007	20	2
80	gG-gG5	4007	-50	4500	-50	2
81	sgG-sgG5	4007	-40	4500	-40	2
82	cCc	9046	-10	0	0	0
83	sgGe-+sdFe	4078	-40	3076	-20	1
84	sdBb+cA	1036	-20	2007	-10	1
85	OIa-{0}	7	11	0	0	0
86	OIa-O1	7	12	100	0	2
87	OIa-OIa+	7	12	7	9	2
88	A0Ia+	2000	9	0	0	0
89	A0Ia+A1Ia	2000	12	2100	12	1
90	A0Ia++A2.2II	2000	9	2220	20	1
91	G4-{0}	4408	5	0	0	0
92	G4.4-OII	4440	0	7	20	2
93	G4.4-II	4448	20	0	0	0
94	G4.4+II	4449	20	0	0	0
95	NOVA	99998	0	0	0	0

Note: Brackets { } denote entry modified from original value.

Item	C$SPEC (Input Spectral Type)	Output SKYMAP Spectral Types SPEC1	LUM1	SPEC2	LUM2	ITYPE
96	PECULIAR	99999	0	0	0	0
97	A0Ia-OIa-{0}	2000	12	7	11	2
98	A0Ia-{0}-A0Ia+	2000	11	2000	9	2
99	G9+	4909	0	0	0	0
100	O+{0}	9	5	0	0	0
101	A0Ia++G0Ia+	2000	9	4000	9	1
102	A0Ia+G0Ia	2000	12	4000	12	1
103	A0Ia-OIa-O	2000	12	7	11	2
104	G9Ia-{0)-G9Ia-{0}	4900	11	4900	11	2
105	G9Ia-O5	4900	12	500	0	2
106	G9+II	4909	20	0	0	0
107	G9.7+	4979	0	0	0	0
108	G9.7+G9.8	4970	0	4980	0	1
109	G9-II	4908	20	0	0	0
110	G9.7-	4978	0	0	0	0
111	G9.7-G9.8	4970	0	4980	0	2
112	G+G1	4007	0	4100	0	1
113	G-G1	4007	0	4100	0	2
114	G++G1	4009	0	4100	0	1
115	G-+G1	4008	0	4100	0	1
116	G+CN	4007	0	9007	0	1
117	G+O5	4007	0	500	0	1
118	G++O	4009	0	7	0	1
119	G+OII	4007	0	7	20	1
120	G+{0}+OIII	4009	5	7	30	1
121	G+Oa	4007	0	16	0	1
122	G9+{0}	4909	5	0	0	0
123	OfIV-OeV	96	40	76	50	2
124	PECULIAR	99999	0	0	0	0
125	NOVA	99998	0	0	0	0
126	G9Ia-{0}	4900	11	0	0	0
127	K7.9I-II-G9.9IIa	5790	15	4990	22	2
128	MII-III+R3.1I-II	6007	25	7310	15	1
129	RIa+	7007	9	0	0	0
130	Q+Q	0	0	0	0	0
131	C	{9007}	0	0	0	0
132	S { } +S	10007	0	{10007}	0	{1}
133	+S	0	0	0	0	0
134	A0V+A0IV	2000	50	2000	40	1
135	Aa+	2019	0	0	0	0
136	AIa-O	2007	11	0	0	0
137	sdWR9.0+	11909	-20	0	0	0
138	dCN2.4	9007	-30	0	0	0
139	sgM3.4+sdWR9.0	6340	-40	11900	-20	1
140	sgM+sdWR9.0	6007	-40	11900	-20	1
141	C	9007	0	0	0	0
142	S	10007	0	0	0	0

Note: Brackets { } denote entry modified from original value.

Item	C$SPEC (Input Spectral Type)	Output SKYMAP Spectral Types				
		SPEC1	LUM1	SPEC2	LUM2	ITYPE
143	WR	11007	0	0	0	0
144	WC	12007	0	0	0	0
145	WNa	13016	0	0	0	0
146	cA	2007	-10	0	0	0
147	sdWR9.0	11900	-20	0	0	0
148	dCN2	9007	-30	0	0	0
149	sgM3.4-sdWR9.0	6340	-40	11900	-20	2
150	gK0.9+sgM3.4	5090	-50	6340	-40	1
151	sdMa	6016	-20	0	0	0
152	sgOb	36	-40	0	0	0
153	gMcII	6046	-50	0	0	0
154	G9++G8	4909	0	4800	0	1
155	G9+-G8	4909	0	4800	0	2
156	G9--G8	4908	0	4800	0	2
157	G9-+G8	4908	0	4800	0	1
158	G9+{0}	4909	5	0	0	0
159	G9+Oa	4900	0	16	0	1
160	G9+OII	4900	0	7	20	1
161	G9+O2	4900	0	200	0	1
162	G9+OO	4900	0	7	5	1
163	A0.5IV+A0.7IV	2050	40	2070	40	1
164	sgGe-+sdfe	4078	-40	0	-20	1
165	cCc--cCc-	9048	-10	9048	-10	2

Note: Brackets { } denote entry modified from original value.

Unconverted Spectral Types

```
&NLPDSP
C$PDSP(1)      =  'G8-K0III+F-G'
IPDSPC(1,1)    =  4800
IPDLUM(1,1)    =  30
IPDSPC(1,2)    =  5000
IPDLUM(1,2)    =  30
IPDSPC(1,3)    =  3007
IPDLUM(1,3)    =  0
IPDSPC(1,4)    =  4007
IPDLUM(1,4)    =  0
IPDSEC(1)      =  1
C$PDSP(2)      =  'C(R)e'
IPDSPC(2,1)    =  9007
IPDLUM(2,1)    =  0
IPDSEC(2)      =  0
C$PDSP(3)      =  's3,9'
IPDSPC(3,1)    =  10300
IPDLUM(3,1)    =  0
IPDSPC(3,2)    =  10900
IPDLUM(3,2)    =  0
IPDSEC(3)      =  0
C$PDSP(4)      =  'sdOB'
IPDSPC(4,1)    =  7
IPDLUM(4,1)    =  -20
IPDSPC(4,2)    =  1007
IPDLUM(4,2)    =  -20
IPDSEC(4)      =  0
C$PDSP(5)      =  'B9V+F8V-G0IV'
IPDSPC(5,1)    =  1900
IPDLUM(5,1)    =  50
IPDSPC(5,3)    =  3800
IPDLUM(5,3)    =  50
IPDSPC(5,4)    =  4000
IPDLUM(5,4)    =  40
IPDSEC(5)      =  1
C$PDSP(6)      =  'C5,5J'
IPDSPC(6,1)    =  9500
IPDLUM(6,1)    =  0
IPDSPC(6,2)    =  9500
IPDLUM(6,2)    =  0
IPDSEC(6)      =  0
C$PDSP(7)      =  'C3,5J'
IPDSPC(7,1)    =  9300
IPDLUM(7,1)    =  0
IPDSPC(7,2)    =  9500
IPDLUM(7,2)    =  0
IPDSEC(7)      =  0
C$PDSP(8)      =  'K1III CN1 -'
IPDSPC(8,1)    =  5100
IPDLUM(8,1)    =  30
IPDSEC(8)      =  0
&END
```

Abbreviations and Acronyms

ACRS	Astrographic Catalog Reference Stars
AGK-3	Dritter Katalog der Astronomischen Gesellschaft
Arcmin	arcminutes
arcsec	arcsceconds
B	blue
BD	Bonner Durchmusterung
BSC	Bright Star Catalog
B-V	blue-minus-visual color
CCD	charge-coupled device
CCDST	CCD star tracker
CD	Cordoba Durchmusterung
CN	cyanogen
CP	Cape Photographic Durchmusterung
CRM	Catalog of Red Magnitudes
CSC	Computer Sciences Corporation
CTD	charge transfer device
CTDST	CTD star tracker
DM	Durchmusterung
FHST	fixed-head star tracker
FK5	Fifth Fundamental Catalog
GCI	geocentric inertial
GCVS	General Catalogue of Variable Stars
GSFC	Goddard Space Flight Center
HD	Henry Draper Catalogue
HDE	Henry Draper Extension
HR	Harvard Revised
IAU	International Astronomical Union

ID	identifier; cross-identifier
I	infrared
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
km	kilometer
MC	Master Catalog
MK	Morgan-Keenan
MW	Mount Wilson
NASA	National Aeronautics and Space Administration
NSV	New Catalogue of Suspected Variable Stars
PA	position angle
pc	parsec
PPM	Positions and Proper Motions (Catalogue)
ptg	photographic
ptv	photovisual
R	red
R-I	red-minus-infrared color
SAO	Smithsonian Astrophysical Observatory [Star Catalog]
SD	Southern Durchmusterung
SOHO	Solar and Heliospheric Observatory
SWAS	Submillimeter Wave Astronomy Satellite
U	ultraviolet
U-B	ultraviolet-minus-blue color
UBV	Ultraviolet-Blue-Visual
USNO	United States Naval Observatory
v	visual eye estimate of Johnson V
V	photoelectric photometric visual magnitude
V′	derived visual magnitude
V-R	visual-minus-red color
WBVR	Russian four-band photometry

WDS	Washington Catalog of Visual Double Stars
RXTE	Rossi X-Ray Timing Explorer
X	CCDST magnitude from RXTE

Bibliography

Abell, 1982

Aitken, R. G., *New General Catalog of Double Stars Within 120º of the North Pole*, Vols. 1 and 2, Washington, D.C.: Carnegie Institute of Washington, 1932

Allen, C. W., *Astrophysical Quantities,* London, 1973

Argelander, F. W. A., "Bonner Sternverzeichniss," Sections 1-3, *Astron., Beob., Sternwarte Königl*, *Rhein*, Vols. 3-5, Bonn: Friedrich-Wilhelms University, 1859-1862

Ball Aerospace, *User's Manual For the SWAS CT-601 Star Tracker,* Ball Aerospace Systems Division, February 1994

Barker, J., and A. Miller, *SKYMAP Requirements, Functional, and Mathematical Specifications, Volume 3, Revision 1 (SKYMAP Master Catalog Version 4.0 Format Specifications),* Goddard Space Flight Center, Flight Dynamics Division, 553-FDD-94/016R1UD0, prepared by Computer Sciences Corporation, September 1995

Bastian, U., et al., *"Catalogue of Positions and Proper Motions - South,"* 1993

Blaauw, A., "The Calibration of Luminosity Criteria," *Basic Astronomical Data*, ed. K. Å. Strand. Chicago: University of Chicago Press, 1963

Blanco, V. M., et al., *Publ. U.S. Naval Obs.,* 2nd Series, Vol. 21, 1968

Cannon, A. J., *Harvard Annals,* Vol. 100. Cambridge, Massachusetts; Harvard University, 1925–36.

Cannon, A. J., and M. Walton Mayall, *Harvard Annals*, Vol. 112. Cambridge, Massachusetts: Harvard University, 1949

Cannon, A. J., and E. C. Pickering, *Harvard Annals*, Vols. 91-99. Cambridge, Massachusetts: Harvard University, 1918-24

Cleavinger, R. L., *Configuration Item Specification—Stellar Aspect Sensor,* Ball Aerospace Systems Division, 40781, 1973

Corbin, T. E., and S. E. Urban, *Astrographic Catalog Reference Stars,* United States Naval Observatory, 1991

Dieckvoss, W., "Photographic Proper Motions," *Basic Astronomical Data*, ed. K. Å. Strand. Chicago: University of Chicago Press, 1963

Dieckvoss, W., and O. Heckmann, *Dritter Katalog der Astronomischen Gesellschaft,* Astronomisches Rechen-Institut, Heidelberg, Germany, 1975

Fitzgerald, M. P., 1973 A&AS, Vol. 9, p. 297

Fricke, W., H. Schwan, and T. E. Corbin, "Fifth Fundamental Catalogue (FK5), Part II, The FK5 Extension," *Veröff. Astronomisches Rechen Institut, No. 33,* Heidelberg, Germany, 1991

Fricke, W., H. Schwan, and T. Lederle, "Fifth Fundamental Catalogue (FK5), Part I, The Basic Fundamental Stars," *Veröff. Astronomisches Rechen Institut, No. 32,* Heidelberg, Germany, 1988

Gill, D., and J. C. Kapteyn, "Cape Photographic Durchmusterung," Parts I-III, *Ann. Cape Obs.*, Vols. 3-5, 1896-1900

Gottlieb, D. M., and W. L. Upson, III., "Local Interstellar Reddening," *Astrophysical Journal*, 1969, Vol. 157, p. 611

Hoffleit, D., *Catalogue of Bright Stars*. New Haven, Connecticut: Yale University Observatory, 1964

Høg, E., et al., "The Tycho Catalogue", A&A 323, p. L57-L60, 1997

Houk, N., and A. Cowley, "Spectral Classification and Multicolor Photometry," Ch. Fehrenbach and B.E. Westerlund, International Astronomical Union Symposium No. 50, 1973

Houk, N., *The Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. II, Zones - 52° to - 40°*. Ann Arbor: The University of Michigan, 1978

Houk, N., *The Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Volume III, Declinations - 40 to - 26 Degrees.* Ann Arbor: The University of Michigan, 1982

Houk, N., A. Cowley, *Michigan Catalogue of 2-Dimensional Spectral Types for the HD Stars, Vol. 1 (Zones -89 to -53 Degrees.* Ann Arbor: The University of Michigan, 1975

Houk, N., and Smith-Moore, *Michigan Catalogue of 2-Dimensional Spectral Types for the HD Stars, Vol. 4, (Zones -25 to -12 Degrees).* Ann Arbor: The University of Michigan, 1988

Jaschek, M., "Catalogue of Selected Spectral types in the MK System," *Centre de Données Stellaires Information Bulletin*, 1978, Vol. 15, p. 121

Jaschek, C., H. Conde, and A. C. de Sierra, *Publ. La Plata Obs. Ser. Astron.*, Vol. 28, 1964

Jenkins, L. F., *General Catalog of Trigonometric Stellar Parallaxes*. New Haven, Connecticut: Yale University Observatory, 1952

Johnson, H. L., and W. W. Morgan, *Astrophysical Journal*, 1953, Vol. 117, p. 313

Keenan, P. C., *Classification of Stellar Spectra in Basic Astronomical Data*, ed. K.Å. Strand. Chicago: University of Chicago Press, 1963

Kornilov, V. G., et al., "WBVR Catalog of Various Bright Stars in the Northern Sky," *Proceedings of the State Astronomical Institute at Sternberg*, Vol. 63, Moscow: Moscow University, 1991

Kukarkin, B. V., et al., *General Catalog of Variable Stars*, 3rd ed. Moscow: Publishing House of the Academy of Sciences of the U.S.S.R., 1971

Kukarkin, B. V., and P. P. Parenago, "Surveys and Observations of Physical and Eclipsing Variable Stars," *Basic Astronomical Data*, ed. K. Å. Strand. Chicago: University of Chicago Press, 1963

Lanz, T., *"Photoelectric Photometric Catalogue in the Johnson UBVRI System," A&AS,* Vol. 65, p. 195, 1985

Lennon, J., *SKYMAP Star Catalog Data Base Generation and Utilization: System Description; Revision 3, Update 2,* Goddard Space Flight Center, Flight Dynamics Division, 554-FDD-89/001R3UD2, prepared by Computer Sciences Corporation, February 1994

Mermilliod, J. C., *Catalogue of Homogeneous Means in the UBV System,* Institut d'Astronomie, Universite de Lausanne, 1994 (in preparation)

Mihalas, D., *Galactic Astronomy*, San Francisco: W.H. Freeman and Company, 1968

Miller, A., and Myers, J., et al., *SKYMAP Requirements, Functional, and Mathematical Specifications, Volume 3, Revision 2 (SKYMAP Master Catalog Version 4.1 Format Specifications),* Goddard Space Flight Center, Flight Dynamics Division, 553-FDD-94/016R2UD0, prepared by Computer Sciences Corporation, September 1996

Miller, A., et al., *SKYMAP Requirements, Functional, and Mathematical Specifications*, *Volume 2, Revision 1, Instrumental Red Magnitude Prediction Subsystem*, Goddard Space Flight Center, Flight Dynamics Division, 553-FDD-93/077R1UD0, prepared by Computer Sciences Corporation, June 1997

Morgan, W., and P. Keenan, "Spectral Classification," *Annual Review of Astronomy and Astrophysics*, 1973, Vol. II, p. 29

Morgan, W. W., P.C. Keenan, and E. Kellman, *An Atlas of Stellar Spectra.* Chicago: University of Chicago Press, 1953

Nicolet, B., "Catalog of Homogeneous Data in the UBV System," *Astronomy and Astrophysics Supplement*, 1978, Vol. 34, p. 1

Nigam, R. C., S.P. Singhal, and R. R. Johnson, "SKYMAP Error Report," item B61-I-42604-11, Computer Sciences Corporation Internal Memorandum to D. Griffith, Goddard Space Flight Center, May 20, 1982

Perrine, C. D., "Córdoba Durchmusterung," Part V, *Resultados Obs. Nacional Argentino*, Vol. 21, 1932

Perryman, M. A. C., et al, “The Hipparcos Catalogue”, A&A 323, p. L49-L52, 1997

Regardie, M., S. Devlin, and J. Roitz, *J2000.0 Coordinate Conversion Software Mathematical Background and System Description, Revision 1*, Computer Sciences Corporation (CSC), CSC/SD-89/6148, September 1989

Röser, S., and U. Bastian, "Catalogue of Positions and Proper Motions,*" A&AS*, Vol. 74, p. 449, 1988

Sande, C., and Home, A., *Star Catalog Analysis Report, SKYMAP SKY2000 Version 2 Master Catalog Data Analysis*, Goddard Space Flight Center, Flight Dynamics Division, CSC-96-932-06, prepared by Computer Sciences Corporation, January 1999

Schönfeld, E., "Bonner Sternverzeichness, "Section 4, *Astron. Beob. Sternwarte Konigl, Rhein*, Vol. 8. Bonn: Friedrich-Wilhelms University, 1886

Seidelmann, P. K., *Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac*, Mill Valley, California: University Science Books, 1992

Sharpless, S., "Interstellar Reddening," *Basic Astronomical Data*, ed. K.Å. Strand. Chicago: University of Chicago Press, 1963

Smithsonian Astrophysical Observatory Staff, *Smithsonian Astrophysical Observatory Star Catalog*, Parts I-IV. Washington, D.C.: Smithsonian Institution, 1966

Stecher, T. P., "Interstellar Extinction in the Ultraviolet II," *Astrophysical Journal Letters*, 1969, Vol. 157, p. L125

Strand, K. Å., "Trigonometric Stellar Parallaxes," *Basic Astronomical Data*, ed. K.Å. Strand. Chicago: University of Chicago Press, 1963

Thome, J. M., "Cordoba Durchmusterung," Parts I–IV, *Resultados Obs. Nacional Argentino*, Vols. 16-19, 1892-1914

Torgow, J. S., *User's Guide to the Standard Star Tracker,* Ball Aerospace Systems Division, April 1986

Turon, C., et al., "The Hipparcos Input Catalogue, Version 2," *Centre de Données Stellaires Information Bulletin*, Vol. 43, p. 5, 1993

United States Naval Observatory Staff, "Index Catalog of Visual Double Stars," United States Naval Observatory, 1974-75 (magnetic tape)

van de Kamp, *Principles of Astrometry*, W. H. Freeman and Company, 1967

Wallenquist, Å., *A Catalogue of Photoelectric Magnitudes and Colours of Visual Double and Multiple Systems*, Uppsala Astronomical Observatory Report No. 22, 1981

Warren, W., *The Bright Star Catalogue, 5th Revised Edition, Version 2*, 1994 (machine version)

Warren, W., *A Supplement to the Bright Star Catalogue*, 1994

Warren, W., *Northern Hemisphere Catalog of Red Magnitudes*, 1994

Whitford, A. E., "The Law of Interstellar Reddening," *Astronomical Journal*, 1958, Vol. 63, p. 201

Wilson, R. E., *General Catalog of Stellar Radial Velocities*, Washington, D.C.: Carnegie Institution of Washington, 1953

Worley, C. E., and G. G. Douglass, *Washington Catalog of Visual Double Stars 1994.0*, United States Naval Observatory, 1994

Distribution List

Organization	Name of Recipient	Copies
National Aeronautics and Space Administration		
GSFC/570	Tracewell, D.	5
Raytheon		
Information Technology and Scientific Services Division	Warren, W.	1
Computer Sciences Corporation (CSC)		
CSC/BR0	Oza, D.	1
CSC/BR0	Beri, A.	1
CSC/BR0	Home, A.	1
CSC/BR0	Miller, A.	1
CSC/CK1	Sande, C.	5
		9