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
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Greenbelt, Maryland 20771

By

COMPUTER SCIENCES CORPORATION

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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
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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 HHHMMNNNN, 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)

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

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<td>Geocentric inertial unit vector components, equinox and epoch ICRS2000</td>
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<td>Internal</td>
</tr>
<tr>
<td>2.17</td>
<td>221</td>
<td>226</td>
<td>F6.2</td>
<td>Galactic longitude</td>
<td>deg</td>
<td>Internal</td>
</tr>
<tr>
<td>2.18</td>
<td>227</td>
<td>232</td>
<td>F6.2</td>
<td>Galactic latitude</td>
<td>deg</td>
<td>Internal</td>
</tr>
</tbody>
</table>

Magnitudes

<table>
<thead>
<tr>
<th>Word No.</th>
<th>Start</th>
<th>End</th>
<th>Type</th>
<th>Meaning</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>233</td>
<td>238</td>
<td>F6.3</td>
<td>Observed V magnitude</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.2</td>
<td>239</td>
<td>243</td>
<td>F5.2</td>
<td>Derived visual magnitude ($V'$)</td>
<td>magnitudes</td>
<td>Internal</td>
</tr>
<tr>
<td>3.3</td>
<td>244</td>
<td>248</td>
<td>F5.3</td>
<td>$V$ or $V'$' uncertainty</td>
<td>magnitudes</td>
<td>External/assigned/ internal</td>
</tr>
<tr>
<td>3.4</td>
<td>249</td>
<td></td>
<td>A1</td>
<td>Blended visual magnitude flag</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.5</td>
<td>250</td>
<td>251</td>
<td>I2</td>
<td>Source of visual magnitude</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.6</td>
<td>252</td>
<td></td>
<td>I1</td>
<td>$V'$ magnitude derivation flag</td>
<td>—</td>
<td>Internal</td>
</tr>
<tr>
<td>3.7</td>
<td>253</td>
<td>258</td>
<td>F6.3</td>
<td>B magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.8</td>
<td>259</td>
<td>264</td>
<td>F6.3</td>
<td>B-V color (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.9</td>
<td>265</td>
<td>269</td>
<td>F5.3</td>
<td>B or (B-V) magnitude uncertainty</td>
<td>magnitudes</td>
<td>External/assigned</td>
</tr>
<tr>
<td>3.10</td>
<td>270</td>
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<td>A1</td>
<td>Blended B magnitude flag</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.11</td>
<td>271</td>
<td>272</td>
<td>I2</td>
<td>Source of B magnitude</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.12</td>
<td>273</td>
<td>278</td>
<td>F6.3</td>
<td>U magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.13</td>
<td>279</td>
<td>284</td>
<td>F6.3</td>
<td>U-B color (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.14</td>
<td>285</td>
<td>289</td>
<td>F5.3</td>
<td>U or (U-B) magnitude uncertainty</td>
<td>magnitudes</td>
<td>External/assigned</td>
</tr>
<tr>
<td>3.15</td>
<td>290</td>
<td></td>
<td>A1</td>
<td>Blended U magnitude flag</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.16</td>
<td>291</td>
<td>292</td>
<td>I2</td>
<td>Source of U magnitude</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.17</td>
<td>293</td>
<td>296</td>
<td>F4.1</td>
<td>$ptv$ magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.18</td>
<td>297</td>
<td>298</td>
<td>I2</td>
<td>Source of $ptv$ magnitude</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>3.19</td>
<td>299</td>
<td>302</td>
<td>F4.1</td>
<td>$ptg$ magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>3.20</td>
<td>303</td>
<td>304</td>
<td>I2</td>
<td>Source of $ptg$ magnitude</td>
<td>—</td>
<td>Assigned</td>
</tr>
</tbody>
</table>

Table 3-1. SKYMAP SKY2000 Version 2 Master Catalog Record Format (3 of 4)
<table>
<thead>
<tr>
<th>Word No.</th>
<th>Start</th>
<th>End</th>
<th>Type</th>
<th>Meaning</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral Types</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>305</td>
<td>334</td>
<td>A30</td>
<td>Morgan-Keenan (MK) spectral type</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>4.2</td>
<td>335</td>
<td>336</td>
<td>I2</td>
<td>Source of MK spectral type data</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>4.3</td>
<td>337</td>
<td>339</td>
<td>A3</td>
<td>One-dimensional spectral class (i.e., HD, AGK3, or SAO)</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>4.4</td>
<td>340</td>
<td>341</td>
<td>I2</td>
<td>Source of one-dimensional spectral class data</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td><strong>Multiple Star Data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>342</td>
<td>348</td>
<td>F7.3</td>
<td>Separation of brightest and second brightest components</td>
<td>arcsec</td>
<td>External</td>
</tr>
<tr>
<td>5.2</td>
<td>349</td>
<td>353</td>
<td>F5.2</td>
<td>Magnitude difference of brightest and second-brightest components</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>5.3</td>
<td>354</td>
<td>360</td>
<td>F7.2</td>
<td>Orbital period**</td>
<td>yr</td>
<td>External</td>
</tr>
<tr>
<td>5.4</td>
<td>361</td>
<td>363</td>
<td>I3</td>
<td>Position angle</td>
<td>deg</td>
<td>External</td>
</tr>
<tr>
<td>5.5</td>
<td>364</td>
<td>370</td>
<td>F7.2</td>
<td>Year of observation</td>
<td>yr</td>
<td>External</td>
</tr>
<tr>
<td>5.6</td>
<td>371</td>
<td>372</td>
<td>I2</td>
<td>Source of multiplicity data</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>5.7</td>
<td>373</td>
<td>—</td>
<td>A1</td>
<td>Passband of multiple-star magnitude difference</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>5.8</td>
<td>374</td>
<td>380</td>
<td>F7.4</td>
<td>Distance to nearest neighboring star in Master Catalog</td>
<td>deg</td>
<td>Internal</td>
</tr>
<tr>
<td>5.9</td>
<td>381</td>
<td>387</td>
<td>F7.4</td>
<td>Distance to nearest neighboring Master Catalog star no more than two magnitudes fainter than this star</td>
<td>deg</td>
<td>Internal</td>
</tr>
<tr>
<td>5.10</td>
<td>388</td>
<td>395</td>
<td>I8</td>
<td>SKYMAP number of primary component</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>5.11</td>
<td>396</td>
<td>403</td>
<td>I8</td>
<td>SKYMAP number of secondary component</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>5.12</td>
<td>404</td>
<td>411</td>
<td>I8</td>
<td>SKYMAP number of tertiary component</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td><strong>Variable Star Data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>412</td>
<td>416</td>
<td>F5.2</td>
<td>Maximum variable magnitude**</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>6.2</td>
<td>417</td>
<td>421</td>
<td>F5.2</td>
<td>Minimum variable magnitude**</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>6.3</td>
<td>422</td>
<td>426</td>
<td>F5.2</td>
<td>Variability amplitude</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>6.4</td>
<td>427</td>
<td>—</td>
<td>A1</td>
<td>Passband of variability amplitude</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>6.5</td>
<td>428</td>
<td>435</td>
<td>F8.2</td>
<td>Period of variability</td>
<td>days</td>
<td>External</td>
</tr>
<tr>
<td>6.6</td>
<td>436</td>
<td>443</td>
<td>F8.2</td>
<td>Epoch of variability</td>
<td>Julian days –2,400,000</td>
<td>External</td>
</tr>
<tr>
<td>6.7</td>
<td>444</td>
<td>446</td>
<td>I3</td>
<td>Type of variable star</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>6.8</td>
<td>447</td>
<td>448</td>
<td>I2</td>
<td>Source of variability data</td>
<td>—</td>
<td>Assigned</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Field</th>
<th>Magnitude Type</th>
<th>Magnitudes</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Passband 1 magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.2</td>
<td>(V – passband 1) color</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.3</td>
<td>Passband 1 uncertainty in magnitude or color</td>
<td>magnitudes</td>
<td>External/assigned</td>
</tr>
<tr>
<td>7.4</td>
<td>A1 Passband 1, photometric system</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>7.5</td>
<td>Passband 1</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>7.6</td>
<td>I2 Source of passband 1: magnitude or color</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>7.7</td>
<td>Passband 2-magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.8</td>
<td>(V – passband 2) color</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.9</td>
<td>Passband 2 uncertainty in magnitude or color</td>
<td>magnitudes</td>
<td>External/assigned</td>
</tr>
<tr>
<td>7.10</td>
<td>A1 Passband 2, photometric system</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>7.11</td>
<td>Passband 2</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>7.12</td>
<td>I2 Source of passband 2: magnitude or color</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>7.13</td>
<td>(passband 1 – passband 2) color</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.14</td>
<td>A1 Blended passband 1 magnitude or color flag</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>7.15</td>
<td>A1 Blended passband 2 magnitude or color flag</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>7.16*</td>
<td>Passband 3 magnitude (observed)</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.17*</td>
<td>(V – passband 3) color</td>
<td>magnitudes</td>
<td>External</td>
</tr>
<tr>
<td>7.18*</td>
<td>Passband 3 uncertainty in magnitude or color</td>
<td>magnitudes</td>
<td>External/assigned</td>
</tr>
<tr>
<td>7.19*</td>
<td>A1 Passband 3, photometric system</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>7.20*</td>
<td>Passband 3</td>
<td>—</td>
<td>External</td>
</tr>
<tr>
<td>7.21*</td>
<td>I2 Source of passband 3: magnitude or color</td>
<td>—</td>
<td>Assigned</td>
</tr>
<tr>
<td>7.22*</td>
<td>A1 Blended passband 3 magnitude or color flag</td>
<td>—</td>
<td>Assigned</td>
</tr>
</tbody>
</table>

* 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, \( \varepsilon_\alpha \), approximately equals the propagated uncertainty in declination, \( \varepsilon_\delta \), and is given by
\[ \epsilon_\alpha \equiv \epsilon_\delta \equiv \frac{\epsilon_{\text{TOT}}}{\sqrt{2}} \]  

(3-1)

where \( \epsilon_{\text{TOT}} \) = 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)

<table>
<thead>
<tr>
<th>Value</th>
<th>Source Catalog</th>
<th>Common Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>none</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>1(98)</td>
<td>SAO Catalog</td>
<td>Smithsonian Astrophysical Observatory (SAO) Staff, SAO Star Catalog, Parts I-IV, Washington D.C.; Smithsonian Institution, 1966</td>
<td></td>
</tr>
<tr>
<td>5*</td>
<td>IDS</td>
<td>IDS (USNO, 1974)</td>
<td></td>
</tr>
<tr>
<td>6(98)</td>
<td>General Catalog of Trigonometric Stellar Parallaxes</td>
<td>Jenkins, L. F., Yale Catalogue of Trigonometric Stellar Parallaxes, New Haven: Yale University Observatory, 1952</td>
<td></td>
</tr>
</tbody>
</table>

**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)

<table>
<thead>
<tr>
<th>Value</th>
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<tbody>
<tr>
<td>7(98)</td>
<td>AGK-3</td>
</tr>
<tr>
<td>8(98)*</td>
<td>GCVS, 3rd Edition</td>
</tr>
<tr>
<td>9(98)</td>
<td>Catalog of Selected Spectral Types in the MK System</td>
</tr>
<tr>
<td>[10,23]</td>
<td>Michigan Catalog of 2-Dimensional Spectral Types, Volumes I-IV</td>
</tr>
</tbody>
</table>

### Common Name


### Reference

- IDS and SAO
- IDS and HD/HDE
- IDS and AGK3

### 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)
<table>
<thead>
<tr>
<th>Common Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>22*</td>
<td>Russian WBVR Catalog</td>
</tr>
<tr>
<td>27</td>
<td>Catalog of Red Magnitudes (CRM)</td>
</tr>
<tr>
<td>29</td>
<td>SAOJ2000</td>
</tr>
</tbody>
</table>

**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)**

<table>
<thead>
<tr>
<th>Value</th>
<th>Source Catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common Name</td>
</tr>
</tbody>
</table>

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3-10
<table>
<thead>
<tr>
<th>Value</th>
<th>Source Catalog</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;36&gt;</td>
<td>Namelists</td>
<td>Namelists of Variable Stars, Nos. 67-72</td>
</tr>
<tr>
<td>&lt;39&gt;</td>
<td>MK-Extension</td>
<td>Morris-Kennedy, P., 1983, MK Classification Extension (Mount Stromlo Observatory)</td>
</tr>
<tr>
<td>&lt;44&gt;</td>
<td>Abt, H.A. “A stars paper”. (different from Reference in Value 38)</td>
<td></td>
</tr>
<tr>
<td>&lt;46&gt;*</td>
<td>Skiff, B. Various unpublished lists and observations sent by private communication.</td>
<td></td>
</tr>
<tr>
<td>&lt;47&gt;</td>
<td>Griffin, R., and Griffin, R. 1986, Observatory, 106, 108</td>
<td></td>
</tr>
<tr>
<td>49*</td>
<td>GSC</td>
<td>The HST Guide Star Catalog</td>
</tr>
<tr>
<td>&lt;51&gt;</td>
<td>Harvard photometry</td>
<td>“H” coded (Harvard photometry) magnitudes from the BSC5</td>
</tr>
<tr>
<td>&lt;52&gt;</td>
<td>PPMN-HP subset</td>
<td>“H” coded positions (PPM High-Precision Subset, reference 16) from the BSC5</td>
</tr>
</tbody>
</table>

**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)**

<table>
<thead>
<tr>
<th>Value</th>
<th>Source Catalog</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Source Code Definitions (6 of 6)</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>TRC: The Tycho Reference Catalogue</td>
<td></td>
</tr>
<tr>
<td>81*</td>
<td>Catalog of O Stars (Garmany)</td>
<td></td>
</tr>
<tr>
<td>90*</td>
<td>SKY2000 (Determined from existing data)</td>
<td></td>
</tr>
<tr>
<td>94(98)</td>
<td>WDS Catalog or Blanco Catalog Reference from Value 19 or Reference from Value 3</td>
<td></td>
</tr>
</tbody>
</table>

**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 \times 10^{16}
\) m) can be computed from Equation (3-2).

\[
d = \frac{1}{p}
\]

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 (\( \alpha \)) and declination (\( \delta \)) 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°55.’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°, B1950. \( l \) and \( b \) also can be
calculated with Equation (3-4a,b) where the constants represent the transformation from \( X_{1950},
Y_{1950}, Z_{1950} \).

\[
\begin{align*}
l &= \tan^{-1}(Y_{gal}/X_{gal}) \\
b &= \sin^{-1}Z_{gal}
\end{align*}
\]

or

\[
\begin{align*}
l &= \tan^{-1}((0.492723 X_{1950} - 0.450421 Y_{1950} + 0.744543 Z_{1950})/ \\
&(-0.067154 X_{1950} - 0.872744 Y_{1950} + 0.483537 Z_{1950}))
\end{align*}
\]
\[ b = \sin^{-1}(-0.867601X_{1950} - 0.188375Y_{1950} - 0.4601998Z_{1950}) \]  

(3-4b)

### 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:

\[
\begin{align*}
\text{blank} &= \text{not blended} \\
\text{b} &= \text{blended}
\end{align*}
\]

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:

\[
\begin{align*}
\text{blank} &= \text{not blended} \\
\text{b} &= \text{blended}
\end{align*}
\]

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 \( p_t v \) 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 \( p_t v \) 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 \( p_t v \) magnitude contained in Word 3.17 (see Table 3-2).

3.3.19 Word 3.19
This word contains the observed \( p_t g \) magnitude. This magnitude corresponds approximately to \( B \).

3.3.20 Word 3.20
This is a two-digit word indicating the source of the \( p_t g \) 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

<table>
<thead>
<tr>
<th>First Two Digits of SKYMAP Version 3.7 Code*</th>
<th>MK Spectral Class</th>
<th>Approximate Temperature (K)</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>O</td>
<td>40,000</td>
<td>Hottest stars; showing He(^+) absorption lines</td>
</tr>
<tr>
<td>01</td>
<td>B</td>
<td>20,000</td>
<td>Shows He and H absorption lines</td>
</tr>
<tr>
<td>02</td>
<td>A</td>
<td>9,000</td>
<td>Very strong H absorption</td>
</tr>
<tr>
<td>03</td>
<td>F</td>
<td>7,000</td>
<td>Ca(^+) and H absorption with some metallic lines</td>
</tr>
<tr>
<td>04</td>
<td>G</td>
<td>5,500</td>
<td>Ca(^+), Fe, and metallic absorption lines strong</td>
</tr>
<tr>
<td>05</td>
<td>K</td>
<td>4,300</td>
<td>Strong metallic lines, with molecular bands</td>
</tr>
<tr>
<td>06</td>
<td>M</td>
<td>3,200</td>
<td>Cool red stars; prominent molecular bands, especially TiO</td>
</tr>
<tr>
<td>07</td>
<td>R</td>
<td>4,500</td>
<td>Hotter carbon stars, with C(_2) and CN bands</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>MK Luminosity Class</th>
<th>SKYMAP Version 3.7 Code*</th>
<th>Class Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5</td>
<td>Most Extreme Super Giants</td>
</tr>
<tr>
<td>Ia+</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>10</td>
<td>Luminous Super Giants</td>
</tr>
<tr>
<td>Ia - 0</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Ia</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Ia - lab</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>lab</td>
<td>14</td>
<td>Moderate Super Giants</td>
</tr>
<tr>
<td>I - II</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Ia - lb</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>lab - lb</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>lb</td>
<td>18</td>
<td>Less Luminous Super Giants</td>
</tr>
<tr>
<td>Bright Giants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lb - II</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>lb - Ila</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Ila</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Ila - Ilab</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Ilab</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>II - III</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Ila - IIb</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Ilab - IIb</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>IIb</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>IIb - III</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3-4. MK Luminosity Classes (2 of 2)

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

*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:

<table>
<thead>
<tr>
<th>Passband</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>V</td>
<td>3</td>
</tr>
<tr>
<td>R</td>
<td>4</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
</tr>
<tr>
<td>J</td>
<td>6</td>
</tr>
<tr>
<td>H</td>
<td>7</td>
</tr>
<tr>
<td>K</td>
<td>8</td>
</tr>
<tr>
<td>L</td>
<td>9</td>
</tr>
<tr>
<td>M</td>
<td>10</td>
</tr>
<tr>
<td>N</td>
<td>11</td>
</tr>
<tr>
<td>X</td>
<td>12</td>
</tr>
<tr>
<td>p (ptg)</td>
<td>2</td>
</tr>
<tr>
<td>p (ptv)</td>
<td>3</td>
</tr>
</tbody>
</table>

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)
<table>
<thead>
<tr>
<th>NUMERIC VARIABILITY CODE (V4.0 WORD 6.5; SKY2000 WORD 6.7)</th>
<th>CODE FROM GCVS, 4TH EDITION</th>
<th>CODE FROM CRM, 1994</th>
<th>CODE FROM NSV</th>
<th>NUMBER PRESENT IN VERSION 4.0 OF MASTER CATALOG</th>
<th>NUMBER PRESENT IN SKY2000 VERSION 2 MASTER CATALOG</th>
<th>TYPE OF VARIABLE</th>
<th>EXAMPLE</th>
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<td></td>
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<td>dCe</td>
<td>DCEP</td>
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<td>107</td>
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<td>β Dor</td>
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<td>112</td>
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<td>CEP</td>
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<td>27</td>
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<td>6</td>
<td>6</td>
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<td>132</td>
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<td>ACYG</td>
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<td>SXPH</td>
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**Table 3-5. Variable Star Codes (2 of 3)**

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<td>410 FKCom</td>
<td>FK, FK</td>
<td>FKCOM</td>
<td>3</td>
<td>3</td>
<td>FK COMAE BERENICES, G-K TYPES</td>
<td>V645 Mon</td>
<td></td>
</tr>
<tr>
<td>420 SXAri</td>
<td>SXA</td>
<td>SXAri</td>
<td>15</td>
<td>15</td>
<td>SX ARIETIS, B0p - B9p DWARFS (ROTATING VARIABLES)</td>
<td>V354 Ori</td>
<td></td>
</tr>
<tr>
<td>430 Ell</td>
<td>Ell</td>
<td>32</td>
<td>ROTATING ELLIPSOIDAL VARIABLES</td>
<td>α Vir</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>440 BY</td>
<td>BY</td>
<td>BY</td>
<td>19</td>
<td>19</td>
<td>BY DRACONIS EMISSION-LINE DWARFS</td>
<td>BY Dra</td>
<td></td>
</tr>
<tr>
<td>999 Cst</td>
<td>Cst</td>
<td>CST</td>
<td>80</td>
<td>80</td>
<td>CONSTANT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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:

<table>
<thead>
<tr>
<th>Standard Photometric System</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johnson</td>
<td>J</td>
</tr>
<tr>
<td>Russian</td>
<td>R</td>
</tr>
<tr>
<td>Cousins</td>
<td>C</td>
</tr>
<tr>
<td>Photo-</td>
<td>p</td>
</tr>
<tr>
<td>Kron (R1 and I)</td>
<td>K</td>
</tr>
<tr>
<td>Kron (R2 only)</td>
<td>k</td>
</tr>
<tr>
<td>Eggen</td>
<td>E</td>
</tr>
<tr>
<td>RXTE CCDST</td>
<td>X</td>
</tr>
</tbody>
</table>

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

**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 \( V – \text{passband 3} \) 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:

\[ X = \cos \alpha \cos \delta \]
\[ Y = \sin \alpha \cos \delta \]
\[ Z = \sin \delta \]  \hspace{1cm} \text{(4-1)}

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

\[ Z = X \times Y \]  \hspace{1cm} \text{(4-2)}

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:

\[ \alpha_j = \alpha_j + \mu_\alpha \Delta t + \left[ \frac{1}{2} \Delta \mu_\alpha \Delta t^2 \right] \]
\[ \delta_j = \delta_j + \mu_\delta \Delta t + \left[ \frac{1}{2} \Delta \mu_\delta \Delta t^2 \right] \]  \hspace{1cm} \text{(4-3)}
where the terms in square brackets represent error terms because of neglecting the secular acceleration \((\Delta \mu_\alpha, \Delta \mu_\delta)\) in proper motion and where

\[
(\alpha_r, \delta_r) = \text{right ascension and declination with proper motions corrected to epoch I}
\]

\[
(\alpha_J, \delta_J) = \text{right ascension and declination at standard catalog epoch J}
\]

\[
(\mu_\alpha, \mu_\delta) = \text{proper motion per year in right ascension and declination at standard epoch J; } \mu_\alpha \text{ in the SKY2000 Version 2 Master Catalog is in seconds of time per Julian year}
\]

\[
\Delta t = \text{difference in years and fraction of a year between epoch I and standard epoch J}
\]

\[
\Delta \mu = \left( \Delta \mu_\alpha^2 + \Delta \mu_\delta^2 \right)^{\frac{1}{2}} = \text{total secular acceleration in proper motion}
\]

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

\[
\Delta \mu = -2.05 \times 10^{-6} v_R \pi \mu / \text{year}
\]

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

\[
|v_R| = 250 \text{ km/sec}, \pi = 0.754 \text{ arcsec (\alpha Centauri)}, \mu = 10.13 \text{ arcsec (Barnard's star)}
\]

Some sample maximum uncertainties follow.

<table>
<thead>
<tr>
<th>(\Delta t) (years)</th>
<th>(1/2 \Delta \mu \Delta t^2) (arcseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.002</td>
</tr>
<tr>
<td>3</td>
<td>0.018</td>
</tr>
<tr>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>0.8</td>
</tr>
<tr>
<td>30</td>
<td>1.8</td>
</tr>
</tbody>
</table>

These results are upper limits because no one star has all the maximum values of \(v_R\), \(\pi\), and \(\mu\).

### 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 \((\alpha_0, \delta_0)\), in degrees, proper motions \((\mu_{\alpha 0}, \mu_{\delta 0})\), in seconds of arc per tropical century, parallax \((\pi_0)\), in seconds of arc, and radial velocity \((v_0)\), in km/sec, for B1950. If \(\pi_0\) or \(v_0\) is unspecified, set them both equal to zero.

**Step b:**

Calculate the rectangular components of the position vector \(\mathbf{r}_0\) and velocity vector \(\dot{\mathbf{r}}_0\) from

\[
\begin{bmatrix}
x_0 \\
y_0 \\
z_0
\end{bmatrix}
= \mathbf{r}_0 =
\begin{bmatrix}
\cos \alpha_0 \cos \delta_0 \\
\sin \alpha_0 \cos \delta_0 \\
\sin \delta_0
\end{bmatrix}
\]

\[(4-4)\]

\[
\begin{bmatrix}
x_0 \\
y_0 \\
z_0
\end{bmatrix}
= \mathbf{r}_0 =
\begin{bmatrix}
-\mu_{\alpha 0} \sin \alpha_0 \cos \delta_0 - \mu_{\delta 0} \cos \alpha_0 \sin \delta_0 \\
+\mu_{\alpha 0} \cos \alpha_0 \cos \delta_0 - \mu_{\delta 0} \sin \alpha_0 \sin \delta_0 \\
\mu_{\delta 0} \cos \delta_0
\end{bmatrix}
+ 21.095v_0\pi_0 r_0
\]

**Step c:**

Remove the effects of the E-terms of aberration to form \(\mathbf{r}_1\) and \(\dot{\mathbf{r}}_1\) from

\[
\mathbf{r}_1 = \mathbf{r}_0 - \mathbf{A} + (\mathbf{r}_0 \cdot \mathbf{A}) \mathbf{r}_0
\]

\[
\dot{\mathbf{r}}_1 = \dot{\mathbf{r}}_0 - \dot{\mathbf{A}} + (\dot{\mathbf{r}}_0 \cdot \dot{\mathbf{A}}) \mathbf{r}_0
\]

where

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

\[(4-5)\]

\[
\dot{\mathbf{A}} = \begin{bmatrix}
+1.245 \\
-1.580 \\
-0.659
\end{bmatrix} \times 10^{-3} \text{ per tropical century}
\]

and \((\mathbf{r}_0 \cdot \mathbf{A})\) is the scalar product.
Step d:

Form the vector

\[
R_i = \begin{bmatrix}
    r_i \\
    \cdot \\
    \cdot \\
    r_1
\end{bmatrix} = \begin{bmatrix}
    x_i \\
    y_i \\
    z_i \\
    \cdot \\
    \cdot \\
    \cdot \\
    r_1
\end{bmatrix}
\]

and calculate the vector

\[
R = \begin{bmatrix}
    r \\
    \cdot \\
    \cdot \\
    r
\end{bmatrix} = \begin{bmatrix}
    x \\
    y \\
    z \\
    \cdot \\
    \cdot \\
    \cdot \\
    z
\end{bmatrix}
\]

from

\[
R = M R_i
\]

where \( M \) is a constant \( 6 \times 6 \) matrix:

\[
M = \begin{bmatrix}
    +0.9999256782 & -0.0111820611 & -0.0048579477 & +0.000000242395018 & -0.00000002710663 & -0.00000001177656 \\
    +0.0111820610 & +0.9999374784 & -0.0000271765 & +0.00000002710663 & +0.00000024239787 & -0.00000000065878 \\
    +0.0048579479 & -0.0000271474 & +0.9999819997 & +0.00000001177656 & -0.00000000006582 & +0.000000242410173 \\
    -0.000051 & -0.238565 & +0.435739 & +0.99994704 & -0.01118251 & -0.00485767 \\
    +0.238514 & -0.002667 & -0.008541 & +0.01118251 & +0.99995883 & -0.00002718 \\
    -0.435623 & +0.012254 & +0.002117 & +0.00485767 & -0.00002714 & +1.00000956
\end{bmatrix}
\]

and set \((x, y, z, \cdot, \cdot, \cdot) = R'\).
Step e:

Calculate the FK5 mean position \((\alpha_1, \delta_1)\) proper motions \((\mu_{\alpha 1}, \mu_{\delta 1})\) in seconds of arc per Julian century, parallax \((\pi_1)\) in seconds of arc, and radial velocity \((v_1)\) in km/sec for J2000 from

\[
\begin{align*}
\alpha_1 &= \tan^{-1}(y/x) \\
\delta_1 &= \sin^{-1}(z/r) \\
\mu_{\alpha 1} &= \frac{x \dot{y} - y \dot{x}}{x^2 + y^2}, \mu_{\delta 1} = \frac{z(x^2 + y^2) - z(x \dot{x} + y \dot{y})}{r^2 \sqrt{x^2 + y^2}}
\end{align*}
\]

(4-8)

\[v_1 = (x \ddot{x} + y \ddot{y} + z \ddot{z})/(21.095\pi_0 r)\]

\[\pi_1 = \pi_0 / r\]

where

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

and \(\alpha_1\) and \(\delta_1\) are evaluated with respect to trigonometric quadrant.

If \(\pi_0\) is zero, then \(v_1 = v_0\).

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 \((\alpha_0, \delta_0)\), in degrees, proper motions \((\mu_{\alpha 0}, \mu_{\delta 0})\) in seconds of arc per Julian century, parallax \((\pi_0)\) in seconds of arc, and radial velocity \(v_0\) in km/sec for J2000. If \(\pi_0\) or \(v_0\) is unspecified, set them both equal to zero.

Step 2:

Calculate the rectangular components of the position vector \(r_0\) and velocity vector \(r_0\) from Equation (4-4).

Step 3:

Form the vector \(R_0 = [r_0, r_0]\) and calculate the vector \(R_1 = [r_1, r_1]\) from

\[R_1 = M^{-1}R_0\]  

(4-9)
where $M^1$ is a constant $6 \times 6$ matrix:

$$
\begin{bmatrix}
+0.9999256795 & +0.0111814828 & +0.0048590039 & -0.00000242389840 & -0.00000002710544 & -0.00000001177742 \\
-0.0111814828 & +0.9999374849 & -0.0000271771 & +0.00000002710544 & -0.00000024392702 & +0.00000000006585 \\
-0.0048590040 & -0.0000271557 & +0.9999881946 & +0.00000001177742 & +0.00000000006585 & -0.0000002424049595 \\
-0.0000551 & +0.238509 & -0.0435614 & +0.99994328 & +0.01118145 & +0.00000002710544 \\
-0.238560 & -0.002667 & +0.012254 & +0.99991342 & +0.00000001177742 & +0.00000000006585 \\
+0.435730 & -0.008541 & +0.002117 & +0.99996684 & +0.00000002710544 & +0.00000001177742 \\
\end{bmatrix}
$$

(4-10)

**Step 4:**

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

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

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

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

$$
\dot{r} = \dot{s} + A - (s \cdot A)s
$$

(4-11)

where $A$ is given in Step c of Section 4.1.3.1.

**Step 5:**

Calculate the FK4 mean $(\alpha_1, \delta_1)$ proper motions $(\mu_{\alpha_1}, \mu_{\delta_1})$ in seconds of arc per tropical century, parallax $(\pi_1)$ in seconds of arc, and radial velocity $(v_1)$ in km/sec for B1950, as given in Section 4.1.3.1, Step e, by setting $(x, y, z) = r$, $(\dot{x}, \dot{y}, \dot{z}) = \dot{r}$, and

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

In Step 4, set $(x_1, y_1, z_1) = \dot{r}$, $(\dot{x_1}, \dot{y_1}, \dot{z_1}) = \dot{r}$, and

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

Then

$$
v_1 = (x_1 x + y_1 y + z_1 z)/(21.095 \pi_0 r_1), \quad \pi_1 = \pi_0 / r_1
$$

(4-12)

If $\pi_0$ is zero, then $v_1 = v_0$.

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,

\[ V' = ptv + c_1 + a_1 \]  

(4-13)

For stars with only ptg observed,

\[ B' = ptg + c_2 + a_2 \]

\[ V' = B' - (B - V)^* \]

(4-14)

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

\[ c_1 = 0.24 - 0.03ptv \]

\[ c_2 = 0.161 - 0.024ptg \]

(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).

\[ c_1 = \begin{cases} -0.2016 + 0.0262ptv & (ptv \leq 7.5) \\ 17.1510 - 4.2873ptv + 0.2668ptv^2 & (ptv > 7.5) \end{cases} \]

(4-16)

\[ c_2 = 0.4589 - 0.0278ptg \]

(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 \( ptg \):

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

\[
V' = ptg - \langle (B-V)\rangle, \text{ when only } ptg \text{ is available}
\]

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:

\[
V' = B - (B-V)_{\text{standard}}
\]  

(4-19)

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:

\[
V' = B - (B-V)^*_{\text{standard}}
\]

(4-20)

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:

\[
V' = B - \langle (B-V)^*\rangle
\]

(4-21)

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

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

**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

<table>
<thead>
<tr>
<th>Method Flag</th>
<th>Derived V Uncertainty</th>
<th>Magnitude Origin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>N/A</td>
<td>None</td>
<td>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)<em>), [spectral class is observed between O and WC, and (B-V)</em> is available]</td>
</tr>
<tr>
<td>1</td>
<td>0.4, 0.5, 0.7</td>
<td>Converted HD/AGK-3 or SAO ptv and ptg, ptv [spectral class]</td>
<td>ptv and ptg are observed (ptg is not observed), ptg is observed (ptv is not observed, V is calculated from B and (B-V)<em>), [spectral class is observed between O and WC, and (B-V)</em> is available]</td>
</tr>
<tr>
<td>2</td>
<td>0.8, 0.8</td>
<td>Unconverted HD or SAO ptv and ptg, ptv</td>
<td>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]</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>Observed B and MK spectral type [(B-V) standard color]</td>
<td>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)]</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>Observed B and HD/AGK-3 or SAO spectral class [(B-V)* color]</td>
<td>B is observed [HD/AGK-3 or SAO spectral class with adopted average (B-V)* color]</td>
</tr>
<tr>
<td>5</td>
<td>1.0, 1.2</td>
<td>Adopted average color &lt;(B-V)*&gt;=+1.00 and observed B, observed HD/AGK-3 or SAO ptg</td>
<td>B is observed [observed HD/AGK-3 or SAO ptg with adopted average color &lt;(B-V)*&gt;=+1.00]</td>
</tr>
</tbody>
</table>

**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

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

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)

<table>
<thead>
<tr>
<th>MK Spectral Class</th>
<th>MK Luminosity Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>O9</td>
<td>-0.22</td>
</tr>
<tr>
<td>B0</td>
<td>-0.20</td>
</tr>
<tr>
<td>B1</td>
<td>-0.19</td>
</tr>
<tr>
<td>B2</td>
<td>-0.17</td>
</tr>
<tr>
<td>B3</td>
<td>-0.16</td>
</tr>
<tr>
<td>B4</td>
<td>-0.14</td>
</tr>
<tr>
<td>B5</td>
<td>-0.12</td>
</tr>
<tr>
<td>B6</td>
<td>-0.10</td>
</tr>
<tr>
<td>B7</td>
<td>-0.08</td>
</tr>
<tr>
<td>B8</td>
<td>-0.05</td>
</tr>
<tr>
<td>B9</td>
<td>-0.03</td>
</tr>
<tr>
<td>A0</td>
<td>-0.01</td>
</tr>
<tr>
<td>A1</td>
<td>0.01</td>
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<td>A3</td>
<td>0.06*</td>
</tr>
<tr>
<td>A4</td>
<td>0.08*</td>
</tr>
<tr>
<td>A5</td>
<td>0.10*</td>
</tr>
<tr>
<td>A6</td>
<td>0.13*</td>
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<td>A7</td>
<td>0.16*</td>
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<td>A8</td>
<td>0.19*</td>
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<td>A9</td>
<td>0.24*</td>
</tr>
<tr>
<td>F0</td>
<td>0.31*</td>
</tr>
<tr>
<td>F1</td>
<td>0.35</td>
</tr>
<tr>
<td>F2</td>
<td>0.40*</td>
</tr>
<tr>
<td>F3</td>
<td>0.45*</td>
</tr>
<tr>
<td>F4</td>
<td>0.50*</td>
</tr>
<tr>
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<td>0.56</td>
</tr>
<tr>
<td>F6</td>
<td>0.62</td>
</tr>
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<td>F7</td>
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<tr>
<td>F9</td>
<td>0.77</td>
</tr>
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</tr>
<tr>
<td>G1</td>
<td>0.88</td>
</tr>
<tr>
<td>G2</td>
<td>0.93</td>
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<tr>
<td>G3</td>
<td>0.98</td>
</tr>
<tr>
<td>G4</td>
<td>1.03</td>
</tr>
</tbody>
</table>
Table 4-4. Smoothed Values of (B–V) Standard (2 of 2)

<table>
<thead>
<tr>
<th>MK Spectral Class</th>
<th>MK Luminosity Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>G5</td>
<td>1.08</td>
</tr>
<tr>
<td>G6</td>
<td>1.13*</td>
</tr>
<tr>
<td>G7</td>
<td>1.18</td>
</tr>
<tr>
<td>G8</td>
<td>1.23*</td>
</tr>
<tr>
<td>G9</td>
<td>1.28*</td>
</tr>
<tr>
<td>K0</td>
<td>1.33*</td>
</tr>
<tr>
<td>K1</td>
<td>1.38*</td>
</tr>
<tr>
<td>K2</td>
<td>1.43*</td>
</tr>
<tr>
<td>K3</td>
<td>1.48</td>
</tr>
<tr>
<td>K4</td>
<td>1.53</td>
</tr>
<tr>
<td>K5</td>
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<td>1.61</td>
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<td>M2</td>
<td>1.62</td>
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<tr>
<td>M3</td>
<td>1.63*</td>
</tr>
<tr>
<td>M4</td>
<td>1.64*</td>
</tr>
</tbody>
</table>

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/IVCNlb/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:

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

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<th>Abbreviation</th>
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<tr>
<td>ACRS</td>
<td>Astrographic Catalog Reference Stars</td>
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<tr>
<td>AGK-3</td>
<td>Dritter Katalog der Astronomischen Gesellschaft</td>
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<tr>
<td>Arcmin</td>
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<td>arcsec</td>
<td>arcsseconds</td>
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<tr>
<td>B</td>
<td>blue</td>
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<tr>
<td>BD</td>
<td>Bonner Durchmusterung</td>
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<td>BSC</td>
<td>Bright Star Catalog</td>
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<tr>
<td>B-V</td>
<td>blue-minus-visual color</td>
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<td>CCD</td>
<td>charge-coupled device</td>
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<td>CCDST</td>
<td>CCD star tracker</td>
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<td>CD</td>
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<td>CN</td>
<td>cyanogen</td>
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<td>CP</td>
<td>Cape Photographic Durchmusterung</td>
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<td>CRM</td>
<td>Catalog of Red Magnitudes</td>
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<td>CSC</td>
<td>Computer Sciences Corporation</td>
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<td>CTD</td>
<td>charge transfer device</td>
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<td>CTDST</td>
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<td>DM</td>
<td>Durchmusterung</td>
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<td>FHST</td>
<td>fixed-head star tracker</td>
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<td>FK5</td>
<td>Fifth Fundamental Catalog</td>
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<td>GCI</td>
<td>geocentric inertial</td>
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<td>GCVS</td>
<td>General Catalogue of Variable Stars</td>
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<td>GSFC</td>
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<td>HD</td>
<td>Henry Draper Catalogue</td>
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<td>HDE</td>
<td>Henry Draper Extension</td>
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<td>HR</td>
<td>Harvard Revised</td>
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<td>IAU</td>
<td>International Astronomical Union</td>
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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
<table>
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<th>WDS</th>
<th>Washington Catalog of Visual Double Stars</th>
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<tr>
<td>RXTE</td>
<td>Rossi X-Ray Timing Explorer</td>
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<td>X</td>
<td>CCDST magnitude from RXTE</td>
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