Delivery: Version 2 of the SKYMAP SOHO Star Catalog

Attachment: Delivery Documentation for the Updated SKYMAP SOHO Star Catalog

This memorandum documents the analysis and quality assurance completed on the recently regenerated SOHO mission star catalog. This catalog was generated utilizing the SKYMAP SKY2000 Version 2 Master Catalog (MC) as input, and was quality assured in part using SOHO mission data. In addition, this memorandum provides specific information such as catalog format and recommendations for catalog use.

Introduction

Recently the Master Catalog used to generate mission-specific Run Catalogs was revised and improved to produce Version 2 of the SKY2000 MC. This version of the MC includes significantly improved astrometry, primarily from the recent ESA Hipparcos space astrometry mission. It also includes much more nearly complete photoelectric *V* and *B* passband photometry from the Tycho experiment onboard the Hipparcos satellite. The availability of improved star catalog source data together with changes in the attitude determination and control profile of the SOHO satellite have led to the regeneration of the SOHO mission star catalog.

Mission Requirements

The charge-coupled device star tracker (CCDST) used onboard SOHO utilizes a near-*V* filter to change the sensitivity curve of the CCDST to a curve closer to the Johnson *V* passband. Figure A-1 shows the sensitivity curve of the SOHO CCDST together with the standard astronomical Johnson *V* and Russian *R* passbands. Most of the predicted sensor magnitudes in the updated SOHO mission star catalog are based on photoelectric Johnson *V* magnitudes.

The pixels of the SOHO CCDST measure 40 arcseconds on a side, and star images are defocused over several pixels prior to flux integration and centroid determination. The pixel size is utilized in the mission star catalog generation software to adjust star position uncertainties to reflect the presence of near-neighboring stars. For pairs or groups of stars closer together than 40 arcseconds, a single blended catalog entry is produced (position of the brightest star, predicted magnitude a blend of two or more component predicted magnitudes).

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The limiting magnitude of the updated SOHO mission star catalog is 8.2 in the CCDST passband. This differs from the original catalog, which had a limiting sensor passband magnitude of 8.0. Changes to the SOHO attitude determination and control profile require the tracking of fainter stars on a regular basis, and the magnitude limit of the updated star catalog has been adjusted to accommodate this.

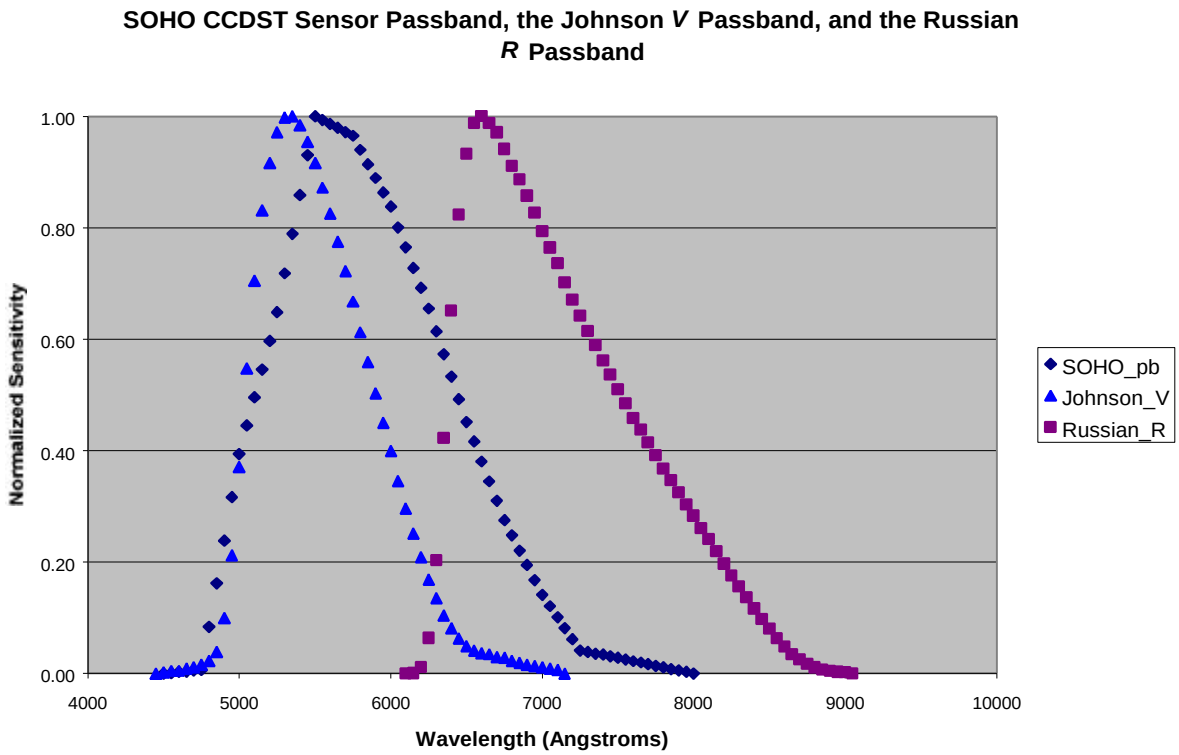

Figure A-1. SOHO CCDST Sensor Passband and the Standard Astronomical Johnson *V* and Russian *R* Passbands

Catalogs Produced

The catalogs prepared for delivery include an ASCII SKYMAP Run Catalog and the same Run Catalog in binary format. The ASCII catalog contains one entry per star, while the binary catalog may contain more than one entry for a given star since the SKYMAP binary Run Catalogs are organized into zones on the sky. Overlap between zones can cause a given star to be found in more than one zonal section of the catalog. Table A-1 describes the format of the ASCII Run Catalog records and the binary Run Catalog data records. Neither data format has changed since the pre-launch delivery of the original SKYMAP SOHO mission star catalog, although the header record in the binary Run Catalog now utilizes a four-digit year.

Table A-1. SKYMAP Run Catalog Record Format

<table>
<tr><th>Name</th><th>Type</th><th>Description</th></tr>
<tr><td>ISTDAT</td><td>I*4</td><td>SKYMAP number</td></tr>
<tr><td>FSTDAT(1)</td><td>R*4</td><td>X-component of GCI unit vector</td></tr>
<tr><td>FSTDAT(2)</td><td>R*4</td><td>Y-component of GCI unit vector</td></tr>
<tr><td>FSTDAT(3)</td><td>R*4</td><td>Z-component of GCI unit vector</td></tr>
<tr><td>FSTDAT(4)</td><td>R*4</td><td>Visual (V) or instrumental magnitude</td></tr>
<tr><td>FSTDAT(5)</td><td>R*4</td><td>Composite word (proper motion word):

Integer part—Direction of star’s total proper motion vector divided by 360.0, multiplied by 1000, and rounded to the nearest integer

Fractional part—Magnitude of star’s proper motion vector in arcseconds per year divided by 100</td></tr>
<tr><td>FSTDAT(6)</td><td>R*4</td><td>Composite word (quality flag word): Contains eight 4-bit flags used to quantify the quality of a star as a potential guide star; each flag measures the quality of a different physical aspects and includes the following:
<table>
<tr><th>Bits</th><th>Description</th></tr>
<tr><td>1-4</td><td>Variability</td></tr>
<tr><td>5-8</td><td>Color</td></tr>
<tr><td>9-12</td><td>Multiplicity</td></tr>
<tr><td>13-16</td><td>Near-neighbors</td></tr>
<tr><td>17-20</td><td>Position knowledge error</td></tr>
<tr><td>21-24</td><td>Magnitude knowledge error</td></tr>
<tr><td>25-28</td><td>Trackability near-neighbor (spare)</td></tr>
<tr><td>29-32</td><td>Identifiability near-neighbor (spare)</td></tr>
</table></td></tr>
<tr><td>FSTDAT(7)</td><td>R*4</td><td>Composite word (color word):

Integer part—(B-V) color multiplied by 100 and rounded to the nearest integer; = 999 if no (B-V) color is available

Fractional part—SKYMAP-coded spectral type divided by 100000</td></tr>
</table>

The predicted sensor magnitudes in the updated SOHO mission star catalog are based in large part on photoelectric Johnson *V* passband magnitudes. Test runs were completed of the mission star catalog generation software to verify that the selection of Johnson *V* passband magnitudes as input was the most desirable course. Mission data allowed the analysis of magnitude residuals before and after the test runs of the catalog generation software. Figure A-2 shows the residuals of Johnson *V* passband magnitudes versus mission data, while Figure A-3 shows residuals for the same stars after the application of the sensor magnitude prediction subsystem of the catalog generation software.

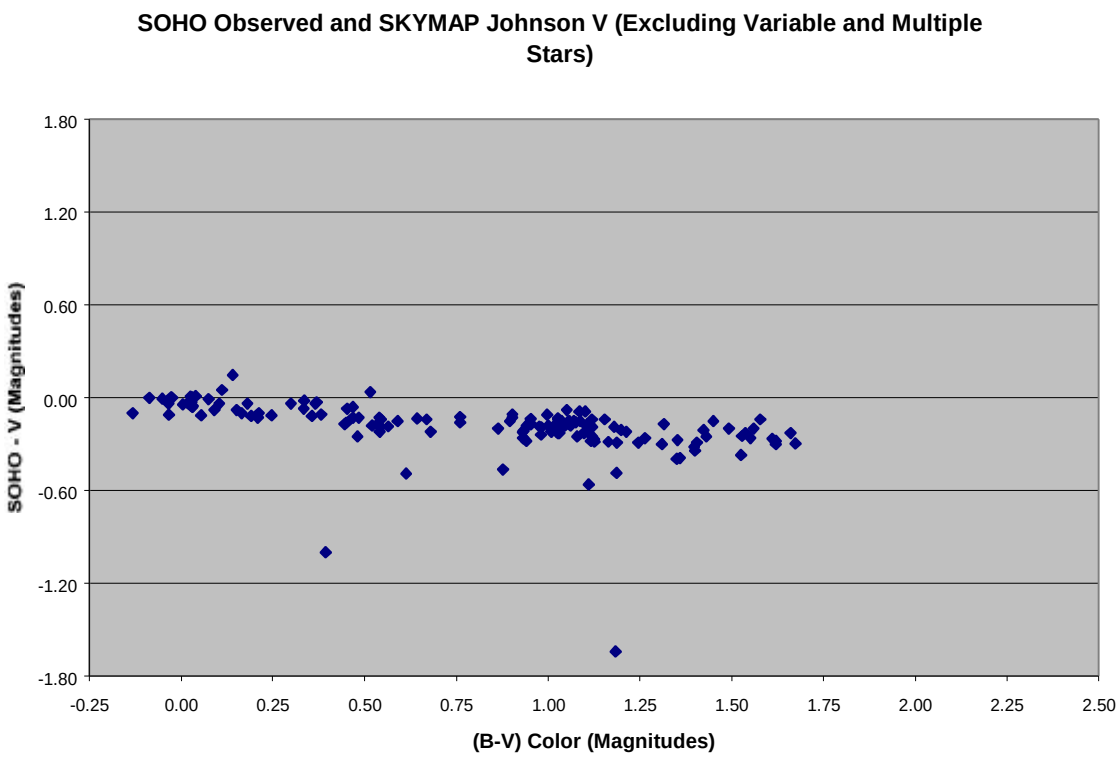

Figure A-2. SOHO Observations and SKYMAP Master Catalog Johnson *V* Magnitudes

Variable stars were excluded from Figures A-2 and A-3 since it is unknown at what point in a star's cycle of variability the SOHO observations were made. Similarly, magnitude data in the SKYMAP SKY2000 Version 2 MC do not include epoch information. Multiple stars were excluded since it is unclear precisely how the SOHO CCDST and image processing software behave in cases of one (or more) interfering near-neighbor stars near a tracked star. For this reason and others, the modeling of these situations in

the catalog generation software is not adequate to accurately predict what a given CCDST will detect, although these stars have not been excluded from the updated SOHO star catalogs. Use of the quality flags in the Run Catalogs will allow the identification of stars with interfering near-neighbors or with large-amplitude variability so that they may be avoided for use as guide stars if desired (see section "Recommendations for Catalog Use").

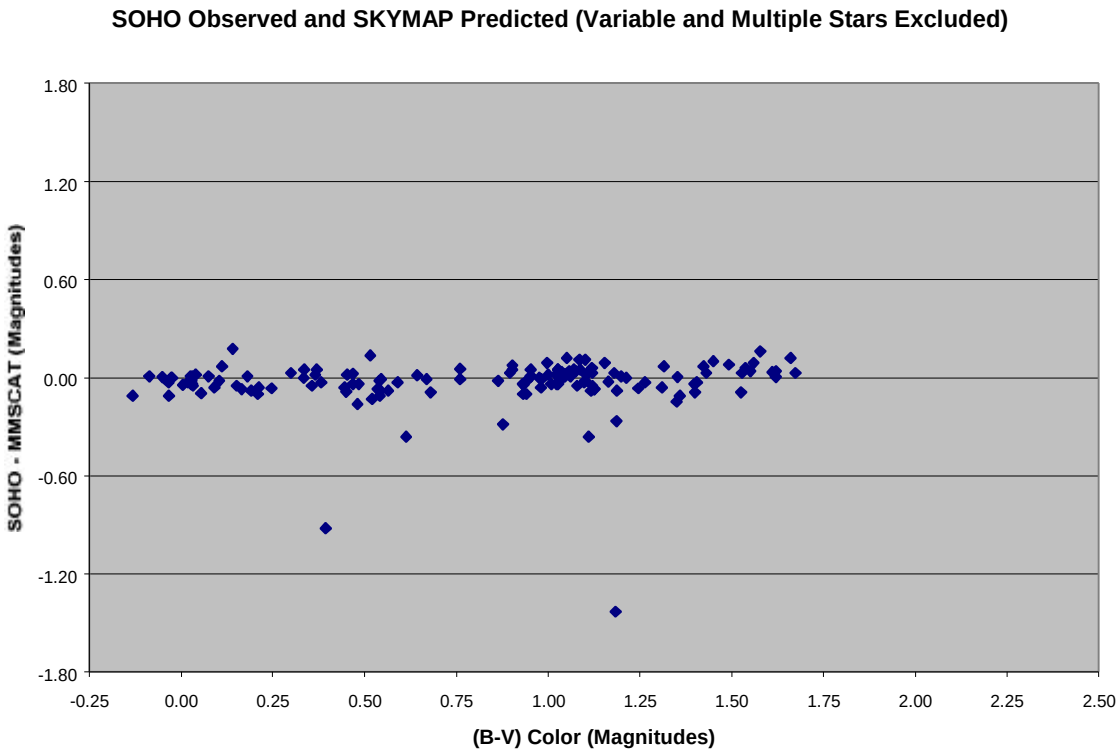

Figure A-3. SOHO Observations and SKYMAP Predicted SOHO CCDST Magnitudes

The outliers in Figures A-2 and A-3 are, at least in the cases of the most pronounced, all brighter when observed by the SOHO CCDST than predicted. This may indicate either additional detected radiation during the flux integration or in at least two cases may indicate a mis-identified star. Predicted catalog magnitudes can also be too faint relative to observations when a bright near-neighbor star has not been accounted for. None of the outlying stars in Figures A-2 and A-3 have bright near-neighbor stars, however, or any other known intrinsic qualities that would account for the differences between prediction and observation.

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Quality Assurance Analysis

The following quality assurance items were completed on the ASCII Run Catalog:

- Positions—GCI unit vector components were converted back to sexagesimal and compared to ICRS2000 positions in the SKY2000 Version 2 MC.

- Proper Motions—Values were checked against input values to ensure proper conversion into the Run Catalog proper motion format.

- Quality Flags—Quality flag values for selected stars were verified against namelist input values and against appropriate quantities in the SKY2000 Version 2 MC.

The binary Run Catalog was quality assured by translating it into ASCII utilizing the SKYMAP binary catalog conversion utility, then by automated byte-wise comparison to the ASCII Run Catalog produced by the mission star catalog generation software.

Recommendations for Catalog Use

The hexadecimal quality flags comprising data field seven in the Run Catalogs are useful in the identification of stars which, for one reason or another, would be undesirable for use as guide stars. These flags map position uncertainties, predicted magnitude uncertainties, and certain observed stellar quantities such as variability. The meanings of various quantities in these flags for the updated SOHO mission star catalog are as follows:

1. Quality flag one is the variability amplitude flag. It maps the amplitude of variability of a variable star (where known). The variability amplitude here refers to variability in a standard astronomical passband, usually *V* (visual) or *B* (blue). For SOHO, the sensor sensitivity curve is relatively close to *V*, making this flag more useful than for typical, red-sensitive CCDSTs. Nine Run Catalog stars have values of A for this flag, six have values of B, 43 have values of C, 13 have values of D, one (19500140, chi Cygni) has a value of E, and 513 have values of F.

- A flag value of 2 or less indicates an amplitude of variability of less than 0.3 magnitudes.
- A value of 4 or less indicates a variability amplitude of less than 0.5 magnitudes.
- A value of 6 or less indicates a variability amplitude of less than 1.0 magnitudes.
- A value of A or less indicates a variability amplitude of less than 5.0 magnitudes.
- A value of D or less indicates a variability amplitude of less than 10.0 magnitudes.

- A value of E indicates variability amplitude of at least 10.0 magnitudes.
- A value of F indicates a known variable star with unknown variability amplitude. Most variable stars with unknown variability amplitudes are relatively small-amplitude variables.

2. Quality flag two is a color flag. It maps the difference in magnitudes between a star's *V* magnitude and its predicted sensor magnitude. (Note that Figure A-2 shows this difference taken in the opposite sense [sensor minus *V*] as related to a star's *B-V* color.) Three Run Catalog stars have values of D or E in this flag: 4590082, 8260147, and 18320075. These are all very red stars, and two are also variable.

3. Quality flag three is a multiplicity flag. It maps the separations and magnitude differences of stars with bright near-neighbors. A value of 0 in this flag indicates that the star is not considered a multiple star. A value of 1 in this flag indicates that any near-neighbor is at least six magnitudes fainter than the catalog star, or is within the 40 arcsecond sensor resolution. Flag values of 2 through 7 map magnitude differences for near-neighbors with separations greater than the 40 arcsecond sensor resolution. A flag value of 7 indicates a magnitude difference of less than 1.0. This mapping changes in one-magnitude steps to a flag value of 2, which indicates a magnitude difference at least 5 magnitudes but less than 6 magnitudes. Five Run Catalog stars have values of 7 for this quality flag: 5380132, 6290178, 13170064, 16030088, and 18410060, indicating the presence of a relatively bright near-neighbor star outside the 40 arcsecond sensor resolution.

4. Quality flag four maps net position uncertainties in arcseconds (epoch 2000.0 position uncertainty of the catalog star plus an estimated contribution due an interfering near-neighbor). Two Run Catalog stars have values of D for this quality flag: 8090141 and 12260065. Both are relatively close to other, very bright stars.

- A flag value of 0 or 1 indicates a net position uncertainty of 1.0 arcsecond or less.
- A flag value of 5 or lower indicates a net position uncertainty of 5.0 arcseconds or less.
- A flag value of 9 or lower indicates a net position uncertainty of 30.0 arcseconds or less.
- A flag value of B or lower indicates a net position uncertainty of 100.0 arcseconds or less.
- A flag value of C or lower indicates a net position uncertainty of 200.0 arcseconds or less.
- A flag value larger than C indicates a net position uncertainty of more than 200.0 arcseconds.

5. Quality flag five maps the epoch 2000.0 position uncertainty of a star in the input SKY2000 Version 2 MC in arcseconds. A flag value of zero indicates an uncertainty less than 1.0 arcsecond. A flag value of 1 indicates an uncertainty less than 3.0 arcseconds but more than or equal to 1.0 arcsecond. These two bins will contain all stars in the SKY2000 Version 2 MC. Bin values for this flag were not changed, so

that the same mappings as in the pre-launch SOHO star catalog were used. Five Run Catalog stars have position uncertainties in the 1-3 arcsecond range: 3460138, 5560001, 8350154, 10430174, and 16060036.

6. Quality flag six maps the uncertainty of the predicted CCDST magnitude in magnitudes. This is based on the uncertainty of the MC magnitude input to the instrumental magnitude prediction subsystem and on the prediction method utilized for a given star by the software. Higher values in for this quality flag typically indicate incomplete or lower quality data used as input to the instrumental magnitude prediction system.

- A flag value of 2 or lower indicates a predicted magnitude uncertainty of less than 0.125 magnitudes.
- A flag value of 5 or lower indicates a predicted magnitude uncertainty of less than 0.750 magnitudes.
- A flag value of 7 or lower indicates a predicted magnitude uncertainty of less than 1.500 magnitudes.
- A flag value of B or lower indicates a magnitude uncertainty of less than 2.500 magnitudes.
- A flag value of D or lower indicates a magnitude uncertainty of less than 3.000 magnitudes.
- A flag value of F indicates a magnitude uncertainty of 3.250 magnitudes or more.

Quality flags seven and eight are not used by the SOHO mission and contain no information of a useful nature.

Approximately ninety pairs or groups of stars were identified in the Run Catalog and manually blended into single entries having the position of the brightest component and a blended instrumental magnitude. These are pairs or groups with separations of 40 arcseconds or less not blended automatically by the software due to insufficient information. Note that SKYMAP 5350069 in the Run Catalogs is a collective entry for the four brightest stars in theta1 Orionis (the Trapezium).

Version 2 of the SKYMAP SOHO Run Catalog contains 67191 entries, as compared to 54510 in the prelaunch catalog. This difference can be attributed mainly to the differing limiting magnitudes (8.2 for Version 2, 8.0 for Version 1). The differences between the content of the SKYMAP Version 4.0 Master Catalog (used for Version 1 of the SOHO Run Catalog) and that of the SKY2000 Version 2 Master Catalog (used to create Version 2 of the SOHO Run Catalog) also contribute to the difference in Run Catalog sizes.