The Attitude Star Catalog

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Abstract

We describe the recreation of the Attitude Star Catalog (ASC). This step has proven necessary due to a number of mis-matches found in the subset of the delivered Initial Gaia Source List that constituted the ASC and because a significant percentage of ASC entries were found too close to bright neighboring objects than allowed by the on ground attitude reconstruction (OGA1) matching procedure.

Document History

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Contents

1 Introduction

The Attitude Star Catalog (ASC) will be used by the first iteration of the on ground attitude reconstruction. The current version was supplied as a subset of the Initial Gaia Source List in September but usage has revealed a number of grave problems that have made it necessary to recreate the ASC to provide a cleaner reference subset.

1.1 Objectives

This document describes the procedures, inputs and selection criteria to produce the Attitude Star Catalog.

1.2 References

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[DMP-001], Padeletti, D., Bastian, U., 2009, *OGA1 Process Description*, GAIA-C3-TN-ZARM-DMP-001, URL http://www.rssd.esa.int/cs/livelink/open/2861528

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Roeser, S., Demleitner, M., Schilbach, E., 2010, AJ, 139, 2440, ADS Link

[RLS-004], Smart, R., 2013, *The Initial Gaia Source List and the Attitude Star Catalog*, GAIA-C3-TN-OATO-RLS-004, URL http://www.rssd.esa.int/cs/livelink/open/3223578

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1.3 Acronyms

The following table has been generated from the on-line Gaia acronym list:

Acronym	Description
ASC	Attitude Star Catalogue
CCD	Charge-Coupled Device
ESAC	European Space Astronomy Centre (VilSpa)
ID	Identifier (Identification)
IGSL	Initial Gaia Source List
MDB	Main Database
OGA1	First On-Ground Attitude determination (in IDT)
RVS	Radial Velocity Spectrometer
SDSS	Sloan Digital Sky Survey
UCAC	USNO CCD Astrograph Catalogue
USNO	United States Naval Observatory

2 Historical Context

The original Attitude Star Catalog (ASC) was provided as a subset of the Initial Gaia Source List (IGSL, Smart (RLS-004)). The selection of the ASC entries relied on a simplistic cut in magnitude to reduce the number of entries per degree. Unfortunately it was revealed that this subset suffered from two problems:

1) The creation of the IGSL started with the dense deep catalogs (GSC23, SDSS, PPMXL) and this lead to the introduction of a number of false or double entries from the various contributing candidates that were in turn matched to the bright entries from the smaller more precise catalogs (TYCHO, HIPPARCOS, UCAC). The introduction of the incorrect entries is inevitable but the mis-matching to the brighter catalogs could have been avoided had we started with the less dense catalogs. Since the number of ASC entries is relatively small it was important that the reliability is as high as possible and the only way to achieve this was to regenerate from scratch the ASC starting with the smaller more precise contributing catalogs.

2) The selection criteria for the ASC simply reduced the number of objects per square degree to a few 100 by cutting in magnitude. There was no check made on nearest neighbor distances as it was felt the base criteria of no neighbor within 40”, which allowed for a few 1000 per square degree, would always be met with only a few 100 objects per square degree. However, partially

due to the mismatching described above, partially due to the existence of un-cataloged binary objects and also random location effects, it was found that this simplistic magnitude based cut led to around 20% of the ASC failing the nearest neighbor test.

To resolve these two problems the new creation of the ASC is generated starting from the sparse bright catalogs and a nearest neighbor test is applied to all entries. The source catalogs and procedures adopted are further described in the following sections.

3 Source Catalogs for the ASC

The source catalogs used to produce the ASC are:

- GSC2.3: The Second Guide Star Catalog version 2.3 (Lasker et al., 2008), 9.4x10^8 objects all sky, magnitude limit R_F 21.5. This catalog forms the bulk of the photometry and defines the red and blue magnitudes as this is the sky survey with the largest number of objects on a homogenous system. All catalogs are missing some bright stars (V $<$ 8.0) and to complete GSC23 in this respect it was supplemented with the sky2000 catalog. This sometimes lead to double entries which we have attempted to clean. The IGSL should be complete in this region and most double entries have been removed except for some multiple entries of high proper motion objects that remain across the whole of the magnitude range.
- PPMXL: Positions and Proper Motions "Extra Large" Catalog, (Roeser et al., 2010), 9.1x10^8 entries. Produced as a combination of the USNO-B and the Two Micron Sky Survey point source catalog. The positions and proper motions should be the most precise available for the objects fainter than the UCAC4 limit.
- UCAC4: USNO CCD Astrograph Catalog version 4 (Zacharias et al., 2004), 1.1x10^8 entries of mostly stars, magnitude limit $R_F < 17$. This is the most precise astrometric catalog in the range V=11-16 currently available that is all sky. There are no original magnitudes in this catalog.
- Tycho-2: (Høg et al., 2000), 2.4x10^6 stars, magnitude limit $R_F < 12$. This catalog forms the backbone of all the major ground based catalogs currently available. The astrometric information is mostly superseded by UCAC4 however this catalog provides the photometric information for most objects in this magnitude range.

In addition all objects in the HIPPARCOS (Perryman et al., 1997) and Sky2000 (Myers et al., 2001) catalogs are included with no cut on magnitude.

4 Production of the ASC

This production of the ASC started with the HIPPARCOS catalog and then progressively matched the other catalogs in the following order: TYCHO2, sky2000 and UCAC. This provides the candidate list for the selection of the ASC. These objects were matched to the GSC23/PPMXL to provide two magnitudes for the objects that did not have magnitudes in either the TYCHO2 or sky2000. Two magnitudes are needed to estimate the Gaia G magnitude using the relations in appendix B.

All the source catalogs have been included in a mysql database and each catalog matched to the master list using a nearest-neighbor approach with a limit of 5″. The large matching radius was adopted to minimize the number of duplicate entries and because the resolution of the original starting catalog, the GSC23, is around this value. If, from a new catalog two entries are matched to the same object a new entry is generated and only the closest of the two entries is listed as a match. Initially all entries are included.

Positions and proper motions are assigned following the priority order UCAC4, Tycho-2, HIPPARCOS, sky2000. If the object is not in one of these catalogs it was not included in the ASC candidate list. The classification is always set to star.

The magnitudes are assigned following the equations in appendix B. The red, blue and Gaia magnitudes used follow this priority order: Tycho, sky2000, GSC23.

Once a G magnitude has been calculated all objects with G $<$ 13.4 are considered candidate ASC objects. All entries are provided with the sourceID from the IGSL with 30000000 added to the runningnumber part to avoid any possible ambiguity with other entries.

5 Entry selection criteria

The requirements on the Attitude Star Catalog (ASC) for on ground attitude reconstruction come from Padeletti & Bastian (DMP-001)

1) G magnitude brighter than 13.4.
2) A positional accuracy be better than 200 mas.
3) 75 isolated bright stars per square degree. Since we have indexed in healpix6 there 41253/49152 = 0.84 degrees / pixel, so at this pixel level we have a requirement of 63 stars per pixel.
4) An isolation criteria that there is no other bright (G¡13.7) object within 40”.

To keep the size of the catalog as small as possible we also apply a constraint that the number

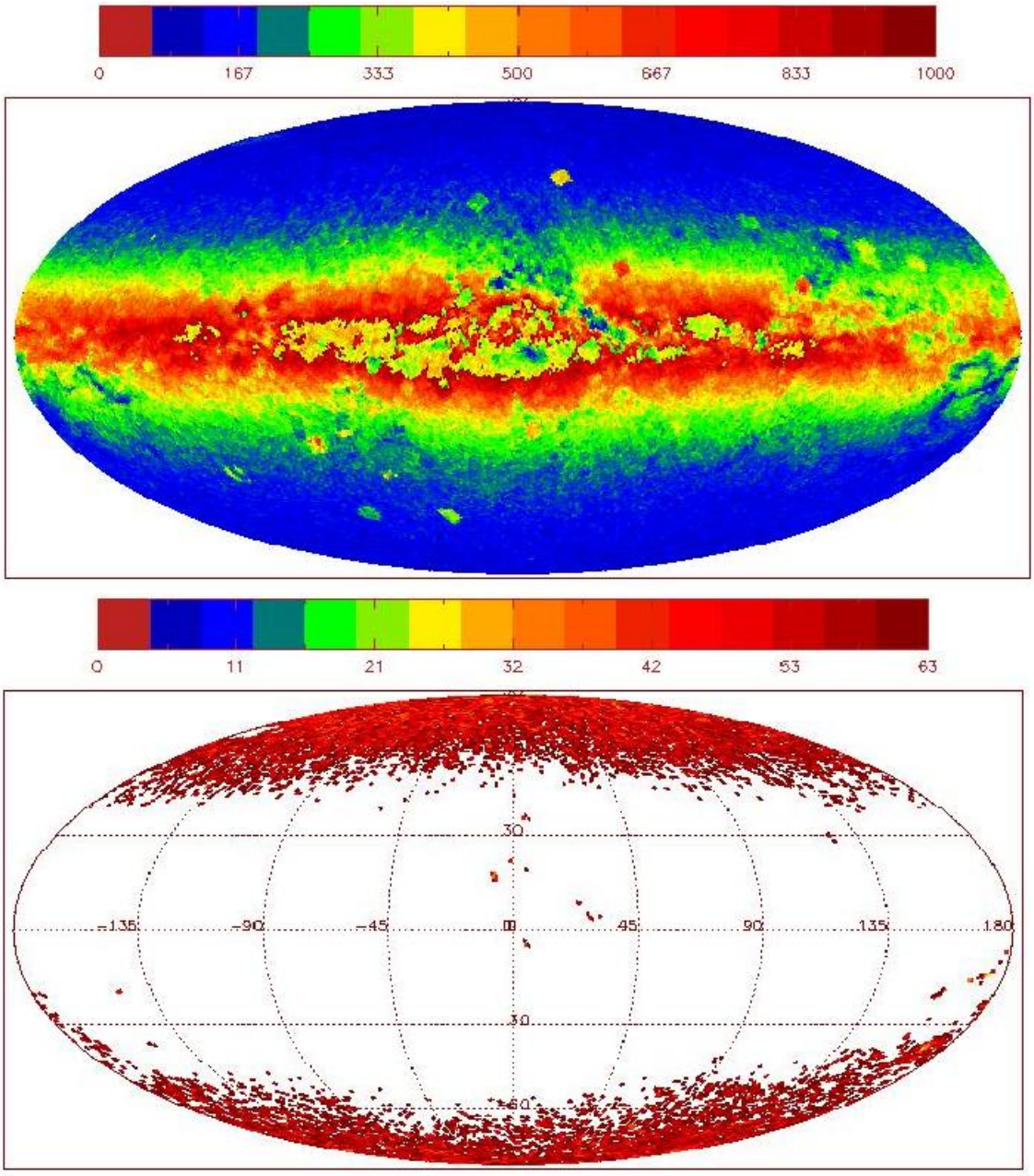

FIGURE 1: The Attitude Star Catalog. Top panel: Distribution of densities for all healpix level 6 regions. Bottom panel: Regions with less than 63 entries per healpix level 6 region.

of objects within any region should not be more than 1000, if this occurs we reduce the number of objects by lowering the magnitude cut from 13.4 to 12.4, 11.4 and finally 10.4 if required.

In Figure 1 top panel we show the ASC density per region as a function of galactic coordinates after applying the 4 selection criteria and the cut on magnitude in the very dense regions. The number of ASC stars per region ranges from 23 to 583. Of the 49152 healpix 6 level regions 6904 have less than 63 ASC stars per region and 42248 have at least 63. In Figure 1 bottom panel we show the ASC density for the regions with less than 63 objects.

6 The Catalog

The ASC is currently available in the Gaia MDB under CU3/Auxdata/IGSL.AscSource. The data has exactly the same format as the IGSL catalog and the various columns are listed in appendix A and the photometric transforms adopted in appendix B.

Appendix A: Overview of the tables in MDB/CU3/AuxData/IGSL/
The following table describes the parameters associated with the table IgslSource which are identical to the ASC structure.

Name	Description	Type	Units
solutionId	Solution Identifier	long	
sourceId	source identifier	long	
alpha	Right Ascension at catalogue epoch	double	rad
delta	Declination at catalogue epoch	double	rad
alphaError	Error in Right Ascension	float	rad
deltaError	Error in Declination	float	rad
alphaEpoch	Mean Epoch of Right Ascension	float	GaiaTime
deltaEpoch	Mean Epoch of Declination	float	GaiaTime
sourcePosition	Source of the position estimate	byte	
muAlpha	Proper motion in RA * at catalogue epoch	float	mas/year
muDelta	Proper motion in DEC at catalogue epoch	float	mas/year
muAlphaError	Error in Proper motion in RA	float	mas/year
muDeltaError	Error in proper motion in DEC	float	mas/year
sourceMu	Source of the proper motions	byte	
galacticLon	Galactic Longditude	float	deg
galacticLat	Galactic Latitude	float	deg
eclipticLon	Ecliptic Longditude	float	deg
eclipticLat	Ecliptic Latitude	float	deg
magBJ	B mag measure, GSC23 system	float	mag
magBJError	Error in B mag measure	float	mag
sourceMagBJ	source B mag	byte	
magRF	R mag measure, GSC23 system	float	mag
magRFError	Error in R mag measure	float	mag
sourceMagRF	source of R mag	byte	
magG	G mag estimate	float	mag
magGError	Error in G mag estimate	float	mag
sourceMagG	Source G mag	byte	
magGrvs	Grvs mag estimate	float	mag
magGrvsError	Error in Grvs mag estimate	float	mag
sourceMagGrvs	Source Grvs mag	byte	

Name	Description	Type	Units
classification	Classification	boolean	
sourceClassification	source of Classification	byte	
toggleASC	Toggle for Atittude Star Catalog	boolean	
auxGSC23	Present in the GSC2.3 catalog	boolean	
auxSDSS	Present in the SDSS catalog	boolean	
auxUCAC	Present in the UCAC3 catalog	boolean	
auxLQRF	Present in the LQRF QSO aux catalog	boolean	
auxTYCHO	Present in the TYCHO2 catalog	boolean	
auxHIP	Present in the Hipparcos catalog	boolean	
auxPPMXL	Present in the PPMXL catalog	boolean	
auxOGLE	Present in the OGLE catalog	boolean	
auxTMASS	Present in the Two MASS PSC catalog	boolean	
auxEPC	Present in the Ecliptic Poles Catalog	boolean	

Parameters Detailed description

- Solution Identifier (**solutionId**): See Hernandez (JH-008).
- source identifier (**sourceId**): Source identifier as defined in GAIA-CD-TN-ARI-BAS-020-01
- Right Ascension at catalogue epoch (**alpha**): The right ascension at epoch and equinox J2000
  Range: [0, 2 * pi]
- Declination at catalogue epoch (**delta**): The declination at epoch and equinox J2000
  Range: [- pi/2, pi/2]
- Error in Right Ascension (**alphaError**): The mean error in the right ascension at mean epoch
- Error in Declination (**deltaError**): The mean error in the declination at mean epoch
- Mean Epoch of Right Ascension (**alphaEpoch**): The mean epoch of the right ascension Julian Year in TCB. Note if there are proper motions the actual position will be at J2000 to have a consistent catalog and this is provided if the user wishes to add new information or find the best position.
- Mean Epoch of Declination (**deltaEpoch**): The mean epoch of the declination Julian Year in TCB. Note if there are proper motions the actual position will be at J2000 to have a consistent catalog and this is provided if the user wishes to add new information or find the best position.

- Source of the position estimate (**sourcePosition**):

  The code that appears in the IgslReferences that describes where the positional information comes from.

- Proper motion in RA * cos(dec) at catalogue epoch (**muAlpha**): Proper motion in right ascension multiplied by cos(declination).

- Proper motion in DEC at catalogue epoch (**muDelta**): Proper motion in declination

- Error in Proper motion in RA (**muAlphaError**): Mean error of proper motion in RA * cos(declination)

- Error in proper motion in DEC (**muDeltaError**): Mean error of proper motion in declination

- Source of the proper motions (**sourceMu**):

  The code that appears in the IgslReferences that describes where this data point comes from.

- Galactic Longditude (**galacticLon**): Galactic Longditude calculated in float to use for indexing
  Range: [0, 360]

- Galactic Latitude (**galacticLat**): Galactic Latitude calculated in float to use for indexing
  Range: [- 90, 90]

- Ecliptic Longditude (**eclipticLon**): Ecliptic Longditude calculated in float to use for indexing
  Range: [0, 360]

- Ecliptic Latitude (**eclipticLat**): Ecliptic Latitude calculated in float to use for indexing
  Range: [- 90, 90]

- B mag measure, GSC23 system (**magBJ**): The B_J magnitude from the GSC23 when present or estimated from transformations when not present in the GSC23 or too bright to be reliable from GSC23. Very similar to B Johnson.

- Error in B mag measure (**magBJError**): Error in the B_J magnitude

- source B mag (**sourceMagBJ**): Code in IgslReferences that describes where this magnitude comes from.

- R mag measure, GSC23 system (**magRF**): The R_F magnitude from the GSC23 when present or estimated from transformations when not present in the GSC23 or too bright to be reliable from GSC23. Very similar to R cousins.

- Error in R mag measure (**magRFError**): Error in R_F
- source of R mag (**sourceMagRF**): Code in IgslReferences that describes where this magnitude comes from.
- G mag estimate (**magG**): Estimated G magnitude based on transformations in livelink document RLS 001
- Error in G mag estimate (**magGError**): Estimated of error on G magnitude
- Source G mag (**sourceMagG**): Code in IgslReferences that describes which transformation used.
- Grvs mag estimate (**magGrvs**): Estimated G_rvs magnitude based on transformations in livelink document RLS 004
- Error in Grvs mag estimate (**magGrvsError**): Estimated of error on G_rvs magnitude
- Source Grvs mag (**sourceMagGrvs**): Code in SourceCatalogIDs that describes where base magnitudes came from
- Classification (**classification**): Classification, simply a 0=star and 1=nonstar taken from different sources as given in the souceClass field
- source of Classification (**sourceClassification**): Code in IgslReferences that describes where this datapoint comes from.
- Toggle for Atittude Star Catalog (**toggleASC**): A boolean that indicates if the objects is to be used for the Atittude Star Catalog.
- Present in the GSC2.3 catalog (**auxGSC23**): A boolean that indicates if the objects is present in the GSC2.3 cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the GSC2.3 id is in the SourceCatalogIDs as idGSC23.
- Present in the SDSS catalog (**auxSDSS**): A boolean that indicates if the objects is present in the SDSS cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the SourceCatalogIDs as idSDSS
- Present in the UCAC3 catalog (**auxUCAC**): A boolean that indicates if the objects is present in the UCAC cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the iSourceCatalogIDs as idUCAC.
- Present in the LQRF QSO aux catalog (**auxLQRF**): A boolean that indicates if the objects is present in the CU3 QSO Aux cat GIQC, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the SourceCatalogIDs as idLQRF.

- Present in the TYCHO2 catalog (**auxTYCHO**): A boolean that indicates if the objects is present in theTYCHO2 cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the SourceCatalogIDs as idTYCHO
- Present in the Hipparcos catalog (**auxHIP**): A boolean that indicates if the objects is present in the Hipparcos catalog, 0=no, 1=yes=true.
- Present in the PPMXL catalog (**auxPPMXL**): A boolean that indicates if the objects is present in the PPMXL cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the SourceCatalogIDs as idPPMXL
- Present in the OGLE catalog (**auxOGLE**): A boolean that indicates if the objects is present in the OGLE cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the SourceCatalogIDs as idOGLE
- Present in the Two MASS PSC catalog (**auxTMASS**): A boolean that indicates if the objects is present in the Two-MASS cat, 0=no, 1=yes. Version and catalog details in the SourceCatalogReferences table. If yes the ID is in the the SourceCatalogIDs as idTMASS.
- Present in the Ecliptic Poles Catalog (**auxEPC**): A boolean that indicates if the objects is present in the EPC, false=no, true=yes. Version and catalog details in the SourceCatalogReference table. If yes, the number in the SourceCatalogIDs table is the number in EPC.

Appendix B: Magnitude Transformations: Explanations for source codes for GSC2 blue/red magnitudes (B_J/R_f) and Gaia main / RVS magnitudes (G/G_{RVS}).

01 $R_F/B_J =$ value GSC23, $\sigma = 0.3$
10 R_F $= V - 0.0478 - 0.5739(B-V) - 0.0938(B-V)^2 - 0.4606(B-V)^3 + 0.8419(B-V)^4 - 0.3472(B-V)^5$, $\sigma = \sigma_B$, Note valid only for $(B-V) < 2.5$.
13 B_J $= V + 0.0036 + 0.8768(B-V) - 0.0594(B-V)^2$, $\sigma = \sigma_B$, Note valid only for (B − V) < 2.5.
16 R_F $= V_T - 0.0478 - 0.578(B_T-V_T) - 0.0677(B_T-V_T)^2 - 0.2828(B_T-V_T)^3 + 0.4395(B_T-V_T)^4 + 0.1541(B_T-V_T)^5$, $\sigma = \sigma_{V_T}$, Note valid only for $(B_T-V_T) < 2.5$.
17 B_J $= V_T - 0.0036 + 0.655(B_T-V_T) - 0.0429(B_T-V_T)^2$, $\sigma = \sigma_{B_T}$, Note valid only for $(B_T-V_T) < 2.5$.
28 G $= V_T - 0.0246 - 0.3354(B_T-V_T) - 0.02558(B_T-V_T)^2 - 0.05153(B_T-V_T)^3$, $\sigma = (0.2916 + \sigma^2_{V_T} + \sigma^2_{B_T})^{1/2}$
29 G_{RVS} $= V_T - 0.1313 - 1.3422(B_T-V_T) - 0.09316(B_T-V_T)^2 - 0.0663(B_T-V_T)^3$, $\sigma = (0.2916 + \sigma^2_{V_T} + \sigma^2_{B_T})^{1/2}$
50 G $= R_F - 0.0158 + 0..2915(B_J-R_F) - 0.0347(B_J-R_F)^2 - 0.0301(B_J-R_F)^3$, $\sigma = 0.4$
51 G_{RVS} $= R_F - 0.0974 - 0.4830(B_J-R_F) - 0.0184(B_J-R_F)^2 - 0.0178(B_J-R_F)^3$, $\sigma = 0.5$
52 G $= V - 0.0247 - 0.2888(B-V) - 0.0353(B-V)^2 - 0.0839(B-V)^3$, $\sigma = 0.6$
54 G $= V - 0.0208 - 0.1004(V-I) - 0.1593(V-I)^2 + 0.0083(V-I)^3$, $\sigma = (\sigma^2_V + \sigma^2_I)^{1/2}$
55 G_{RVS} $= V - 0.1333 - 1.4654(B-V) - 0.1075(B-V)^2 - 0.0768(B-V)^3$, $\sigma = 0.6$
57 G_{RVS} $= V - 0.0501 - 1.1667(V-I) - 0.0052(V-I)^2 + 0.0011(V-I)^3$, $\sigma = (\sigma^2_V + \sigma^2_I)^{1/2}$

The B, V represent published Johnson-Cousins magnitudes from sky2000, V_T, B_T Tycho magnitudes. The σ represents the nominal error of the derived transformation, these are added in quadrature to the published errors. Equations 10-21 were determined from a combination of Johnson - GSC2 transformations derived internally and Tycho - Johnson transformations published in the "Guide to the Tycho-2 Catalog" (Hog et al., `http://www.astro.ku.dk/~erik/Tycho-2/`).