RECENT ENHANCEMENTS TO AND FUTURE PLANS FOR THE *SKY2000 STAR CATALOG*

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Abstract

Our continuing efforts to improve the NASA *SKY2000* satellite attitude determination star catalog, previously known as *SKYMAP*, to make it into a modern, high-quality comprehensive source of stellar data, have allowed us to complete Version 3 of the *SKY2000* catalog (2000 June). The present version of the catalog contains 299,160 entries and is reasonably complete to visual magnitude 9. As with previous versions of the *SKY2000* and *SKYMAP* catalogs, the most important data in the catalog are astrometry and photometry, because this information is essential for spacecraft attitude determination and control. Accurate information on multiplicity, spectral type and luminosity class, and variability are also required to predict what the star trackers will detect. The *SKY2000 Version 3* catalog marks the global replacement of the Henry Draper (HD) spectral type data, as well as the global replacement of the photovisual (ptv) and photographic (ptg) magnitude data. During this process, 4,684 entries had HD or HD Extension (HDE) identifiers added, for a total of 210,062 entries with HD/HDE identifiers. A planned global replacement of variable star names/identifiers and variability data was not carried out because of resource constraints, but 311 variable star names/identifiers were added during analysis, bringing the total number of entries with variable star names or identifiers to 2,575.

The next planned update to the *SKY2000* catalog will include a global replacement of variable star names/identifiers and variability data. Catalogs to be utilized will include, but are not limited to, the *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1995) and the *New Catalogue of Suspected Variable Stars* (NSV) (Kukarkin *et al.* 1982). Completion of this updated version of the *SKY2000* catalog is anticipated in Spring, 2001. We intend eventually to utilize the AAVSO database to incorporate the highest quality data periods and amplitudes, particularly for long period variables, but this may not be possible for the next enhancement.

This paper describes the current status after recent enhancements of the *SKY2000* catalog and outlines plans for future improvements. This edition (*SKY2000*, version 3) and future editions of the catalog will be made available at Goddard's Flight Dynamics Web site: http://cheli.gsfc.nasa.gov/dist/attitude/skymap.html.

1. Introduction

The original *SKYMAP Master Star Catalog* (MC) (Gottlieb 1978) was developed to support fixed-head star trackers (FHST) in spacecraft attitude determination software developed at the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC). The first edition was designed as a compilation of stellar objects that would be essentially complete to blue and visual magnitudes of 9.0. Successive versions of the *SKYMAP* catalog were issued between 1978 and 1995 (McLaughlin 1983; Slater *et al.* 1995) to correct individual errors discovered in each interim, but the basic catalog content and format remained the same.

The development of more capable star trackers in the late 1980s and, especially, of charge-coupled device (CCD)-based detector systems, resulted in a decision to prepare an updated catalog that would include magnitude and color data in the near-infrared (IR). However, several other factors, including the availability of vastly superior and more abundant primary data, the presence of many "derived" data in the old *SKYMAP*, inadequate and sometimes erroneous cross identifications, and lingering errors for individual stars (especially multiple systems), led us to design and build a new catalog. Those efforts eventually resulted in 1996 in the *SKYMAP Version 4.0a Master Catalog*.

The availability of astrometric and photometric (Johnson BV) data from the Hipparcos mission allowed the creation of the *SKY2000 Version 2 Master Catalog*, which was reported on at the 87th Annual Meeting of the AAVSO in 1998 (Warren *et al.* 1999). This catalog also included for the first time CCD star tracker (CCDST) photometry from the Ball CT-601 star trackers onboard the Rossi X-ray Timing Explorer (RXTE) spacecraft. While significant improvements were made in the areas of astrometry, Johnson BV photometry, and in the inclusion of CCDST photometry, due to time and resource constraints other important areas such as spectral type information and catalog cross-reference identifiers were not updated significantly in the creation of the *SKY2000 Version 2 MC*.

2. Data content

The present MC, now known as *SKY2000 Version 3*, marks the global replacement of the Henry Draper (HD) spectral types and the photovisual (*ptv*) and photographic (*ptg*) magnitudes, each from primary sources. We have also incorporated additional CCD star-tracker data acquired from the Submillimeter Wave Astronomy Satellite (SWAS). A number of catalog cross-reference identifiers, including variable star designations, have been added as well.

Version 3 includes 299,160 star entries, an increase of 61 entries over *SKY2000 Version 2*. As in past versions of the MC, the latest version includes numerous catalog cross-reference identifiers, spectral-type and luminosity class information, and specialized data for double/multiple and variable stars. Also included are radial velocities, parallaxes, photometric data in the *UBVRI* passbands, and positional data in easy-to-use graphical inertial (GI) unit vector form. A review of the changes in data content to the MC is presented here.

2.1. HD spectral types

Spectral types are an important piece of data in the red-magnitude prediction subsystem that is used to estimate the brightnesses of stars in the CCDST passband. The MC contains fields for both Morgan-Keenan (MK) and HD spectral types, but 63% of the entries in the present MC are lacking MK types, making the HD spectral types very important in the generation of mission-specific subset catalogs for spacecraft attitude determination. The *SKY2000* Version 2 MC contained 286,812 entries with HD spectral types, but of these 58% were assigned a source code indicating that they were drawn either from the *Henry Draper* catalogs (HD, HDE, including the first but not the second extension) (Cannon and Pickering 1918–1924; Cannon 1925–1936) or the *Smithsonian Astrophysical Observatory* (SAO) (SAO 1966) catalogs. In addition to this ambiguity, some entries with HD spectral types and this source code (96) were discovered to be neither HD/HDE nor SAO stars. Accordingly, HD spectral-type data were globally replaced from the SAO, the *Positions and Proper Motions* catalogs (PPM) (Röser and Bastian 1991; Bastian and Röser 1993), and the HD catalogs (including both the first and second [Cannon and Walton Mayall 1949] extensions). The replacement process resulted in 294,132 entries with HD spectral types in the present MC, of which less than 0.1% are sourced ambiguously.

2.2. *ptv* and *ptg* magnitudes

While the presence of Johnson *BV* or CCDST photometry for almost all of the brighter stars in the present MC reduces the need for *ptv* and *ptg* magnitudes, they are sometimes the only magnitude data available for some of the fainter stars included in the MC. They also provide useful consistency checks for the Johnson *BV* magnitudes. *SKY2000* Version 2 included *ptv* and *ptg* data for only approximately two-thirds of all entries. Furthermore, only a very small proportion of these data was from the *SAO Catalog*, a valuable source of both types of magnitudes. The global replacement of these data from the SAO, the PPM, and the HD/HDE catalogs resulted in 273,202 entries with *ptv* magnitudes (an increase of approximately 30% from Version 2) and 255,362 entries with *ptg* magnitudes (an increase of approximately 40% from Version 2). Data from the SAO comprise approximately 22% of the *ptv* magnitudes, and approximately 4% of the *ptg* magnitudes in the present MC.

2.3. Cross-identifications

Although there are numerous cross-identifiers in the MC now, there is room for some improvement. Cross identifications are critical to any compiled catalog because they allow retrieval of new data from other sources and for data validation when questions arise. Even though we now have high accuracy positions for most of our stars, we must still retrieve data from sources that contain less accurate positions and only certain classical identifiers, some of which are known to be incomplete in the MC.

The second Henry Draper Extension (HD 272151–359083) was published only in chart form. Thus, only sparse cross identifications with other source catalogs have been made for specific stars over the years. Using the recent work of Nesterov *et al.* (1995), who measured accurate positions for HDE chart stars on paper copies of the original charts, then transformed them to J2000, we can cross-identify MC stars with HDE identifiers to complete the identification of HD stars in our catalog. This is important because HD numbers are widely used in other source catalogs and in the literature to identify stars for which we may need data in the future. During the processing of the HD/HDE catalogs, 4,684 MC entries had HD identifiers added.

There is a special *SKY2000* data field for variable star designations. These include GCVS names for known variables and NSV identifiers for suspected variables. A rather significant number of variable star names were omitted from the name field in past versions of the MC. The reason for this is unknown, but the situation represents a serious shortcoming and should be corrected, since variable star identification is an important aspect for a spacecraft guide star catalog. Although the effort to produce the present MC could not include a global replacement of these identifiers, it was possible to add 311 variable star names or NSV identifiers to entries found to be lacking them. The present MC now includes 2,575 entries with either a variable star name or an NSV identifier.

2.4. CCDST magnitudes

The *SKY2000* Version 2 MC contained 4,572 entries with CCDST magnitudes and uncertainties from the CT-601 star trackers onboard the RXTE spacecraft. From these 4,572 stars, it was possible to generalize and to improve the instrumental magnitude prediction results in the mission-specific subset catalogs used in spacecraft attitude determination. As part of the ongoing effort to improve the quality of the subset catalogs, we also acquired CCDST data from the CT-601 star tracker onboard SWAS. The data included more than six hundred stars for which RXTE CCDST magnitudes were not available. After transformation of the SWAS measurements to the photometric system defined by the RXTE star trackers, and after some few RXTE observations were replaced with SWAS observations, a total of 5,205 entries in the present MC have CCDST magnitude data.

3. Future enhancements

Both the MC and its associated subset catalog generation software (collectively called the *SKYMAP* System) are known to have certain deficiencies and areas that can be improved. For the MC, these improvements would result in an increase in the utility and reliability of the MC when utilized for mission star catalog generation and when used by amateur or professional astronomers. The explosion created by modern astronomical techniques in the field of star catalog work allows for a great deal of improvement to be made to the MC and requires frequent updates in order to keep data in the MC current.

We briefly review below our plans for the next improvements to the data content of the catalog. These plans are dependent on continuing financial support, but we are optimistic that implementation will be possible in a timely fashion due to the ongoing need for high quality mission-specific star catalogs for spacecraft attitude determination.

3.1. Cross-identifications and variability data

The incompleteness of the variable star name/NSV identifier field will be addressed globally by reprocessing the latest GCVS, NSV, and NSV *Supplement* (Kazarovets *et al.* 1998). At the same time, the variability data fields will be updated where appropriate (maximum/minimum magnitudes, amplitude of variability, passband of variability, etc.). In a limited number of cases where present data are inferior, it is also possible that Johnson *BV* magnitudes, *ptv* or *ptg* magnitudes, or MK or HD spectral-type data may be drawn from the variable star catalogs to be processed.

3.2. Photometric data

Photometric data, or brightnesses and colors, are, along with astrometric data, the fundamental information of the SKY2000 catalog, since they are very important for spacecraft attitude determination using star trackers. It is important to have not only the most accurate photometric data available, but also to include their mean errors whenever possible, since these contain information on variability and deviations in brightness that might be seen by spacecraft sensors. Although the Tycho experiment of the Hipparcos mission has provided us with observed photoelectric data (the most accurate kind) for almost all *SKY2000* stars, the short baselines of the Tycho photometric observations tend to produce small errors that hide variability. Thus, if high-quality ground-based data that were measured over a significantly longer time period are available with mean errors, it is better to use those. Our preferred hierarchy for photometric data is then: use high-quality ground-based data if they are available, observed Tycho data if they are not, or in some cases derived data based on photovisual and/or photographic magnitudes and spectral types if no photometric observations are available. In all cases, we wish to have some kind of brightness estimate available and to identify its source and data type, which gives an estimate of accuracy.

There are several different broad-band photometric systems that have been developed since the advent of the original Johnson system. The newer systems differ significantly only in the near-IR bands (*R* and *I*), where the Johnson system has difficulties. The astronomical community has essentially abandoned the Johnson system over the last several years and migrated to the Cousins (1981) system, which has *R* and *I* filters blueward of Johnson's and avoids many of the detector and atmospheric problems of the latter. We would like to replace all Johnson *RI* data in *SKY2000* with Cousins system data. Since there are more stars observed in the Johnson system at this point, we will transform stars having no Cousins data from Johnson *RI* to Cousins *RI* if they are in the color range where such transformation is valid (see Bessell 1983).

A final decision has not yet been reached as to what sources will be used in the upcoming update of *SKY2000*. The *General Catalogue of Photometric Data* (GCPD, see http://obswww.unige.ch/gcpd/gcpd.html) could be drawn upon as a pointer source for ground-based Johnson and/or Cousins photometry, while the *Tycho-2 Catalogue* (see http://www.astro.ku.dk/~erik/Tycho-2) would provide *BV* photometry on the system of the Tycho instrument. As the Tycho *BV* photometry presently contained in *SKY2000* had been converted to the Johnson system during the creation of the original Tycho, replacement of these data from the newer *Tycho-2* would require a conversion of the *BV* photometry in the latter catalog to the Johnson system. It is not clear at this time that such a conversion would result in a body of data quantitatively superior to the originally transformed Tycho photometry on the Johnson system. In any case, resources are not expected to be available to process data into *SKY2000* from both the GCPD and *Tycho-2* at the present time, so a decision will have to be made regarding the path we follow.

4. Summary

A new version of the *SKY2000* MC has been prepared to support spacecraft attitude determination and control requirements. The major enhancements in the new version include improved cross indexing among star designations, global replacement of HD spectral type and *ptv*/*ptg* magnitude data, the addition of CCDST photometry for more than five hundred entries, and the correction of many individual errors present, usually for double and multiple stars. Future plans call for significant improvements in data content, particularly for variable stars, and also for selected photometric data. We hope to produce a very high quality compilation of stellar data that will be useful in many areas of astronomy as well as in the original application of spacecraft attitude determination.

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