The AXAF (Chandra) Guide and Acquisition Star Catalog V1.5 (AGASC 1.5)

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Abstract. Chandra's Aspect Camera Assembly (ACA) measures positions of selected stars to acquire and hold target pointings, and for post facto aspect determination. The selection and matching of the guide stars is governed by data in the AXAF (Chandra) Guide and Acquisition Star Catalog (AGASC). Based originally on version 1.1 of the Guide Star Catalog for the Hubble Space Telescope, the AGASC has been extended and refined in several stages, with data from additional catalogs and with recalibrations using on-orbit ACA observations.

In 2002 the Chandra X-ray Center (CXC) completed a major upgrade of AGASC. We merged data from three catalogs—Tycho-2, GSC-ACT, and 2MASS. The Tycho-2 data substantially improve the photometric and astrometric measurements of stars as faint as V=12, while the GSC-ACT merge decreases by about half the systematic astrometric errors down to the catalog limit of about V=14.5. The 2MASS data identify galaxies down to J=12.5. These new catalog data enhance the value of AGASC for scientific as well as operational purposes.

Specifically for Chandra's operational use of AGASC, we recalibrated the estimated ACA magnitudes based on Chandra on-orbit measurements, and implemented a more sophisticated calculation of the effect of nearby stars on the best-fit centroid of a guide star.

This paper presents the rationale for and the process of updating the AGASC. We then discuss the improvements in performance that we expect to result, and introduce the online AGASC 1.5 query tool `http://cxc.harvard.edu/agasc`.

1. Introduction

The AXAF (Chandra) Guide and Acquisition Star Catalog (AGASC) governs the selection and recognition of stars used by Chandra's Aspect Camera Assembly (ACA) to acquire and hold Chandra target pointings. The selected stars' positional data also enable post facto aspect determination and reconstruction of sharp images from dithered observations.

AGASC originated with version 1.1 of the Guide Star Catalog for the Hubble Space Telescope[1], and has been extended and refined in several stages. The Chandra X-ray Center (CXC) completed a major upgrade in 2002. The upgrade corrected errors introduced in earlier versions; incorporated data from additional catalogs; recalibrated ACA magnitudes based on accumulated on-orbit star observations with Chandra; and improved estimates of stellar centroid spoiling by nearby objects.

2. Merges from Three Catalogs

AGASC previously incorporated data from the GSC 1.1, PPM, Tycho-1, and ACT catalogs. The recent upgrade merged data from three additional catalogs—Tycho-2, GSC-ACT, and 2MASS—into AGASC.

2.1. Tycho-2

The Tycho-2 Catalog (Hog et al. 2000) is an astrometric reference catalog containing positions and proper motions as well as two-color photometric data for the 2.5 million brightest stars in the sky. Components of double stars with separations down to 0.8 arcsec are included. Tycho-2 supersedes Tycho-1, and the ACT and TRC catalogs based on Tycho-1.

Proper motions precise to about 2.5 mas/yr are given as derived from a comparison with the Astrographic Catalog (AC) and 143 other ground-based astrometric catalogs, all reduced to the Hipparcos celestial coordinate system. For only about 4% of stars, no proper motion could be derived.

2.2. GSC-ACT

The original GSC 1.1 positions have random position errors of about 0.4 arcsec, but also systematic position errors of about 0.3 arcsec, due to errors in the reference catalogs (AGK3, SAO, CPC) and also to their low stellar density. STScI performed a recalibration of the GSC 1.1, using the PPM catalog for a denser reference star network, resulting in the GSC 1.2.

In the GSC-ACT project[2], Bill Gray also recalibrated the GSC 1.1, but using the ACT (Astrographic Catalog/Tycho) data from the U.S. Naval Observatory. In the GSC-ACT, GSC 1.1 systematic errors were reduced via recalibration of 42 plate coefficients plate-by-plate, using the proper-motion-corrected ACT stars for reference.

In creating AGASC 1.5, we matched (2 arcsec search radius) both the GSC-ACT and GSC 1.2 against the radio source positions that define the International Celestial Reference System (ICRS) (Gambis 1999). From 43 independent sources matched, the GSC 1.2 showed a mean positional difference of 0.40 arcsec, RMS 0.35. From 44 sources, the GSC-ACT showed mean 0.28 arcsec, RMS 0.25. The

[1]The Guide Star Catalog (GSC) was prepared by the Space Telescope Science Institute (STScI), 3700 San Martin Drive, Baltimore, MD 21218, USA. STScI is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under contract with the National Aeronautics and Space Administration (NASA).

[2]`http://www.projectpluto.com/gsc_act.htm`

denser reference star network of the GSC-ACT results in a superior calibration; this is the catalog we chose to improve AGASC positions for stars that had only GSC 1.1 (no Tycho or PPM) data.

2.3. 2MASS

Using a pre-release (June 2001) tabulation of extended objects in the 2MASS catalog (Jarrett et al. 2002), kindly provided by Tom Jarrett (IPAC) and John Huchra (CfA), we improved AGASC's identification of galaxies and objects near galaxies. For reliability of AGASC, any AGASC object with an extended 2MASS object within 5 arcsec was judged to be a galaxy. Just 70% of 2MASS galaxies have matches within that distance in AGASC.

Examination of 2MASS galaxies on the Digital Sky Survey optical images indicated that optical galaxy brightness extends visibly to about twice r_{20} on average, and in about 25% of cases to $3r_{20}$. Any AGASC object within $3r_{20}$ of a 2MASS galaxy was marked as close to an extended object.

3. Recalibration

3.1. Recalibrating Aspect Camera Magnitude

A poorly estimated AGASC magnitude has sometimes resulted in Chandra's failing to acquire a star. More importantly, large star magnitude errors caused too many stars to be rejected from consideration, with the result that targets either were rejected or had a number of guide stars that was less than optimal.

Inclusion of Tycho-2 data to a completeness limit of V=11.5 (rather than the previous V=10 limit of Tycho) significantly lowers the magnitude and position errors on an additional 1.5 million stars in AGASC. The most significant improvement in Aspect Camera magnitude estimates results from the accurate tabulated colors available.

Experience in operating Chandra for a year also gave the opportunity to do a new polynomial fit, by comparison with colors from Tycho-1, to observed Aspect Camera magnitudes for 1939 stars. In AGASC 1.5, MAG_ACA—the estimated magnitude for the Aspect Camera Assembly—is derived from V and $B - V$ via the polynomial color equation

$$MAG\_ACA = V + C_0 + C_1(B - V) + C_2(B - V)^2 + C_3(B - V)^3$$

For published magnitudes from Tycho catalogs, we use $C_0 = 0.428638$, $C_1 = -0.774029$, $C_2 = 0.283002$, $C_3 = -0.267284$.

3.2. Recalibrating Spoiler Codes

AGASC 1.5 incorporates the results of a study by David Morris of the offset induced in the computed centroid of a guide star by a nearby star. The study considered the effects of distance between star and spoiler, rotation angle between the two, magnitude difference between them, and their position on the ACA focal plane. High Resolution PSFs were produced both by raytrace simulations and by centroid aligning and stacking many thousand actual ACA star images. The study showed good agreement among combinations of the two PSF models and two algorithms. In AGASC 1.5, the aspect quality ("spoiler") code assigned to a star is the maximum centroid offset (in units of 50 milliarcsec) expected to be induced by any star within 80 arcsec, as a function of their magnitude difference and separation. For Chandra operations, stars whose centroid offsets would reach 50 milliarcsec are rejected as guide stars.

4. Stellar Surface Density

AGASC 1.5 is in everyday use for guiding Chandra and for reconstruction of dithered X-ray images to Chandra's unprecedented spatial imaging resolution.

The new catalog has an average stellar surface density of 9.5 per square degree, for unspoiled stars that have color information and are brighter than $MAG\_ACA = 10.2$. Near the galactic poles ($b > 80°$), where the stellar surface density is lowest, there are 4.1 such stars per square degree. The desired Chandra figure of merit (FOM) of 5.1 per square degree over 95% of the sky is not quite achievable with these original selection criteria. With accurate ACA magnitudes included, however, Chandra now routinely uses stars to mag 10.8, for which the FOM is easily met.

5. Conclusions

AGASC 1.5 currently represents the only available catalog that *combines* high quality astrometry on the ICRS system down to 14.5 mag with detailed color and proper motion information down to about 12th. In addition, the "spoiler codes" that indicate the degree to which any stellar centroid might be disturbed by nearby objects is a unique feature.

These properties make AGASC 1.5 a potentially important catalog for guide star selection for other space- and ground-based telescopes (e.g., for telescope guiding or Adaptive Optics). AGASC 1.5 should also prove useful for a variety of scientific purposes.

AGASC 1.5 may be queried online at `http://cxc.harvard.edu/agasc`.

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