THE GUIDE STAR CATALOG. I.
OVERVIEW, HISTORY, AND PROSPECTIVE.

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Abstract: An astronomical overview of the Guide Star Catalog, together with its history, the properties of its current implementation, and the prospects for enhancement are presented.

I. OVERVIEW

The Hubble Space Telescope (HST) will use off-axis guide stars to achieve its pointing performance. The selection of these guide stars uses a catalog specifically constructed for this task, the Space Telescope Guide Star Catalog (GSC), which, when completed, will consist of $\sim 2 \times 10^7$ stars and other objects in the 9^m to 16^m range.

The catalog is based on microdensitometer scans of the UK SERC J survey in the south and a 1982 epoch "Quick V" survey made with the 48-inch Schmidt on Palomar Mountain. The image processing algorithms used to produce an inventory of classified objects from the scans are:

- the background follower, which spline-fits a surface to a grid of sky estimates covering the plate;
- the object identifier, which is based on the COSMOS algorithm (Lutz 1979)[5];
- the blend resolver, which searches multiply-peaked objects by correlation against a library of star images;
- the astrometric centroider, which contains the Sanders-Schröder (1980) algorithm, generalized with an additional parameter, a variable exponent ("hardness") in place of the usual 2 in the Gaussian expression;
- a corresponding photometric estimator, which approximates the logarithm of the image intensity; and

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[5]References for all three papers of this series can be found at the end of Paper III.

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- the classifier, which uses a multi-variate Bayesian approach (Duda and Hart 1973), operating on selected image features (COSMOS parameters, hardness, correlation with model diffraction spikes, *etc.*), to discriminate stars from other objects (*e.g.*, galaxies, unresolved blends).

The production is carried out as a series of pipeline processes organized on a plate basis and controlled by a software executive. The plate measurements (x, y, photometric parameter, and object classification), which are the results of this sequence, are the inputs to the calibration and archive procedures described in the following two papers.

Many details of these algorithms have been described in recent publications and conference proceedings (astronomical and computational methods in Jenkner 1983, Lasker 1984a and 1984b, and Russell 1986; astrometric topics in Russell and Williams 1986; and scanning techniques in Kinsey *et al.* 1984, Lasker and Kinsey 1984, and Lasker *et al.* 1986); a definitive series of publications presenting the GSC algorithms, the statistical properties of the GSC processing, and the data itself is currently being prepared for 1988 publication. The remainder of this paper complements those publications by presenting an informal history of the evolution of the GSC concept, an account of the limiting properties of its present implementation, our own aspirations for its maintenance and enhancement, and a number of potential avenues for collaboration.

II. THE EVOLUTION OF THE GSC CONCEPT

The concept of a Guide Stars Selection System (GSSS) originally envisioned for the HST by the Astrometry Science Team (Benedict 1979) featured a production scanning and astrometry system in which specific target fields would be scanned and analyzed in response to their being incorporated into observing plans. While such a "schedule-driven" concept would have worked, the difficulty of doing such delicate work and of maintaining a suitably skilled staff for a program demanding two-shift operations over fifteen years motivated us to seek a more automated approach.

This, in addition to the realization that many HST observations did not require the full $0''.33$ astrometric precision (*e.g.*, just placing an object within one of the camera apertures has no particular precision requirement), led us to the concept of using relatively coarse (50μ) scans to construct an all-sky catalog of "rough coordinates" that could be used for scheduling those observations with minimal precision requirements and also for planning further work on fields requiring greater precision. The idea then was that improved coordinates would be obtained later by re-scanning the target area (and perhaps a few guide stars) at higher resolution to support the astrometrically most demanding observations.

The throughput requirement for building such a catalog in time for the then scheduled HST launch (early 1985 at the time of the GSSS design review) was to scan and process one plate in twelve hours. These constraints led us to 50μ scans made at 200 mm/sec. Further testing showed that this configuration with a suitably apodized aperture (*e.g.*, Lasker *et al.* 1986) supports the full GSSS specification ($0''.33$, guide star relative to target; $0^m.4$ in the V passband) in uncluttered fields but deteriorates significantly as field complexity grows. The desirability of a scan raster somewhat finer than 50μ is supported by the calculations of power spectra for typical plates (Stobie *et al.* 1984; Lasker and Kinsey 1984); these show that, while sample sizes in the range of $15 - 18\mu$ are needed to record *all* of the plate information, ***nearly all*** of it is recorded with 25 micron samples.

Towards the end of 1984, this realization, combined with schedule relief due to the extension of the HST's launch date to then mid-1986, motivated the successful search for a faster

PDS operating configuration, *i.e.*, less than 12 hours for a 25μ full-plate scan; this was achieved by a combination of replacing the logarithmic amplifier and of tuning the PDS's driving software, internal microcode, acceleration ramps, and mechanical dampers, thus making the construction of a catalog based on these finer scans feasible even against the constraint of the then scheduled HST launch date. For many purposes these 25μ scans effectively replace the plate; and the requirements for securely archiving the data and for making it conveniently accessible led to its transcription from magnetic tape (three 6250 bpi rolls per plate) to optical disks (four plates per disk), a program that is still in progress with completion estimated for 1988. These disks are currently accessible to prospective users through the Guide Star Astrometric Support Program (GASP, McLean *et al.* 1988); eventually they will also be incorporated into the HST data archive.

III. THE GSC: CURRENT PROPERTIES AND PROSPECTIVE

The GSC in its present implementation adequately supports HST operations and has other obvious applications too numerous to list here. However, as one may reasonably expect for a first catalog of this size, the GSC does have certain restrictions as to limiting magnitude, completeness, and reliability, as follows:

- *First,* while the nominal magnitude range is ninth to fifteenth, constraints due to computing time and to clutter at low galactic latitudes sometimes required setting the faint cutoff as bright as thirteenth; this was done on a plate-by-plate basis.

- *Second,* the completeness of the catalog is limited not only by the variable magnitude limit just described, but by systematic effects due to variable background, clutter, and vignetting. An evaluation of these effects will be included in the GSC publication; for now, we offer the estimate that the catalog is reasonably complete to fifteenth at high galactic latitudes and to thirteenth at lower ones.

- *Third,* known defects in the image processing lead to mis-classified (in the sense of star versus non-star) objects, missed objects (*e.g.*, unresolved blends, very large images), and false images (*e.g.*, plate defects, erroneous detections around bright stars); these defects occur at the level of about 1% in uncluttered fields, and of 3% in cluttered ones.

We are proceding with an ongoing effort to address these limitations in the GSC, as well as to incorporate new materials (especially of recent epoch) as they become available; this will result in a re-issue of the GSC (and its supporting software) from time to time as significant improvements are put in place.

Future maintenance will also address an additional set of scientific goals needed to increase the generality and scientific usefulness of the GSC. The present GSC does not contain the raw (image feature) data; recalibration of the transformations requires recomputing of the entire catalog; and the entry and tracking of hand-generated errata is *ad hoc,* intrusive, and subjective. The generalization which we expect to introduce as a major future revision to the catalog (*i.e.*, GSC-II) is to create a new structure, containing as separate entities the raw data, the transformations, and the errata; then the catalog server will process all three elements in order to furnish information to the user. This generalization greatly simplifies catalog maintenance; it also supports material from a multitude of epochs, colors, and data-sources, thus facilitating the generation of proper motions, colors, and inter-catalog checks.

IV. RECOMMENDATIONS

Improving our knowledge of the properties of the sky at these fainter magnitudes is certainly a tedious and slowly convergent process, and the need for improvements to the image processing and to the calibrations are obvious:

- Taking our catalog size and an estimated 99% reliability, one concludes that the GSC contains 2×10^5 errors that we wish to eliminate!
- The current version of the GSC consists of the data incorporated directly from ~1500 plate solutions, and the obvious potential for improvements achieved by considering these solutions as a set of partially overlapping data remains to be realized.

Other presentations at this meeting describe programs of comparable scope (*e.g.,* by Monet and by Pennington), and the burden is upon us to organize our efforts in a complementary way. We feel that the following approaches should be specifically considered by the participants of this symposium and by the astronomical community as a whole:

- True confidence in the quality of the image processing and the calibrations is best achieved by the comparison of efforts by independent groups. Open interchange of catalog data between groups, a provision within each catalog structure to contain the results of other catalogers in an identifiable way, and agreements and procedures to avoid inadvertent release of (shared pre-publication) data are needed to facilitate this important mode of checking.
- The calibrations of the photographic photometry are based on a relatively small number of reference stars (*e.g.,* $\sim 10^4$ from Lasker *et al.* [1987] were used in the GSC), such that the calibrations, as well as the possible checks in them for internal consistency, are relatively weak. Improvements in the set of the all-sky photometric calibrators, to increase their numbers and to go to fainter magnitudes, are thus of great value.
- The astrometric reductions are generally based on reference catalogs with precisions of the order of $0\farcs6$ (s. e.) at the GSC plate epoch (*i.e.,* AGK3, SAOC, CPC). The models on which such calibrations are based can be improved and further validated by testing against high-precision (of the order of $0\farcs05 - 0\farcs1$), large field (at least $6\fdg6$ square) reference catalogs covering the magnitude range from the brightest reference stars used (say, 7^{th}) to the catalog limit (16^{th}). We support and urge continuing work toward the astrometric standard regions chosen by the working group on parallax standards of IAU Commission 24. We also endorse the creation of new whole-sky astrometric catalogs — more dense, fainter magnitudes, and/or more accurate — which would greatly improve future versions of the GSC and other survey catalogs.
- Refinements are needed to the art of transforming a large (conceivably all-sky) set of plate solutions for magnitudes and positions into a parallel set that in some sense, perhaps local adjustments or a general self-consistent overlap, is smooth at plate boundaries and makes effective statistical use of information in the plate-overlap regions.
- An obvious product of every catalog construction program is a list of galaxies. The photometric calibration of these is best done against a set of reference galaxies; the available stellar calibrators have very different spatial frequencies and saturation properties. Efforts to assemble an all-sky set of (relatively featureless) galaxies that will serve as photometric references are essential to this program.

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