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THE GUIDE STAR CATALOG

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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.

- 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 $0\farcs33$ 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 ($0\farcs33$, guide star relative to target; $0\fm4$ 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."6 (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."05 – 0."1), large field (at least 6°.6 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.

ACKNOWLEDGEMENTS

We thank the large number of ST ScI staff members who made this program possible; many of their contributions are identifiable in the bibliography at the end of Paper III.

The GSC is based on photographic data taken at the Palomar Schmidt, operated by the California Institute of Technology, and at the UK Schmidt, operated by the UK Science and Engineering Research Council.

THE GUIDE STAR CATALOG. II.
ASTROMETRIC AND PHOTOMETRIC ALGORITHMS AND PRECISION.

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Abstract: The algorithms used in photometric and astrometric calibration of the Guide Star Catalog, as well as the analyses of the related errors are discussed. The precision requirements of $0\overset{\prime\prime}{.}33$ for relative positions and of $0\overset{\text{m}}{.}4$ for photometry are generally fulfilled.

I. INTRODUCTION

The photometric and astrometric data in the Hubble Space Telescope (HST) Guide Star Catalog (GSC) are based on the image processing described in the first paper of this series, specifically on a photometric parameter which estimates the integrated photographic intensity above a threshold as produced by the COSMOS algorithm (Lutz 1979)[5] or a related construct for blended images, and on astrometric x, y measurements produced by a seven parameter, modified Gaussian centroider.

II. PHOTOMETRIC DATA REDUCTION

The reference data for the photometric data reduction are a sequence of six stars, roughly in the range from $9\overset{\text{m}}{.}0$ to $14\overset{\text{m}}{.}5$, which were generally chosen to be near the center of each plate, near at least 2 SAOC stars, and within a one-half degree square. Each star in the sequence has photoelectric B and V magnitudes with a precision of $0\overset{\text{m}}{.}05$. At the time of this Symposium, the Guide Star Photometric Catalog (GSPC, Lasker *et al.* 1987), including detailed finding charts, is in the final stages of preparation for publication.

The least-squares solution fits the logarithms of the photometric parameters to the reference magnitudes, generally with a second-order fit, but for a small percentage of the plates a curve of first or third order was used. The photometric sequence generally had a formal error of $0\overset{\text{m}}{.}05$. As an independent check, the GSC magnitudes were compared to those from the $\delta = +28°$ band of sky observed by McGraw et al. (1987) using the CCD Transit Instrument of the University of Arizona. Tentatively, the results show differences of the order of $0\overset{\text{m}}{.}25$ *rms* between the two surveys. A worst case estimate of the precision of the magnitudes comes from the comparison of calculated magnitudes of stars which appear on

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more than one plate. The plate to plate differences may be as high as $1^{m}_{\cdot}0$ but are generally about $0^{m}_{\cdot}5$.

III. ASTROMETRIC DATA REDUCTION

The reference catalogs for the astrometric data reduction are the AGK3 in the north and the SAOC in the south. This coincides with the dividing line between the two plate surveys so that the Palomar plates are reduced with the AGK3 and most of the SRC plates are reduced using the SAOC for reference. The exception to the latter is for plates centered at $\delta = -65°$ to $-90°$, where we used the CPC. This is because at the time of the construction of the SAOC, the CPC, on which most of the southern SAOC was based, was only completed to $\delta = -64°$ (Eichhorn, 1974). No catalog corrections were introduced, since each GSC plate solution used only data from one catalog and the plate solutions are catalogued independently.

The x, y measurements were determined from the scan data according to the algorithm described in the first paper of this series. Because of the problems with centroiding images of the very bright stars, we did not use any reference stars brighter than $7^{m}_{\cdot}5$ in the astrometric solutions. This had the added benefit of eliminating most of the Boss General Catalogue (GC) stars from the SAOC. According to Eichhorn (1974), the GC stars have a systematic error within the catalog.

The plate model was based on extensive testing, not only for the most accurate astrometric solution, but also for the most successful pointing of the Space Telescope (Russell and Williams, 1986). Because of the pointing algorithm used by the HST, the relative positions, *i.e.* separations, of two guide stars and the observing target are the only astrometric information critical to the spacecraft's operation. The separations are required to have a precision of $0''_{\cdot}33$, or a single position to have a precision of $0''_{\cdot}25$. This meets the specification that targets can be placed in a $2''$ square aperture with 99% reliability. The astrometric testing included not only investigations into the astrometric precision, but simulated pointings in test fields to verify that the specifications were met.

The plate model includes ten constants in each of the ξ and η coordinates; it appears as a general third order polynomial, and only includes geometric terms, *i.e.*, no terms using magnitude or color are used. Some magnitude-related effects were noted, especially at the plate edges, but attempts to remove them resulted in less effective pointing of the telescope. The plate model is of the most general form used for Schmidt telescopes. Further testing showed that pre-corrections or other attempts to use less than the most general form of the plate model adversely affect the internal precision of the solutions. Details will be included as part of the forthcoming Guide Star Catalog publications.

The standard errors of unit weight of the plate solutions vary with the precision of the reference catalog from about $0''_{\cdot}4$ in the north to $1''_{\cdot}5$ in some areas of the south. The GSC includes a single entry for the precision of the positions; it is the square-root of the sum of the squares of the ξ and η errors, calculated rigorously from the full covariance matrix of the solution. This calculated error estimate may be several seconds of arc for stars in the extreme plate corners from the least accurate areas of the SAOC. Admittedly this is not realistic, but was allowed because it discouraged choosing guide stars from plate corners for HST operations.

Another way of checking the astrometric precision is to look at the plate-to-plate differences for positions of stars which appeared on more than one plate. As for the photometry above, this provides a worst case estimate. For the check-plates examined to date, the largest plate-to-plate differences are about $3''$; none are as large as $4''$; however, the typical values for the positional differences computed for common stars from adjacent plates are generally about 0$''$.5. These are approximately the values expected from the plate solutions and the internal precision of the measurements. However, even in the plate corners the relative positions have an precision of 0$''$.25 and so will successfully point the telescope; and when guide stars and targets require data from different plates, a local astrometric overlap solution is performed to remove the systematic differences.

Advanced astrometric algorithms, which are based on the plate to plate differences and are currently being investigated, may lead to removal of the largest errors from the plate edges within the GSC.

IV. MAINTENANCE AND ENHANCEMENTS

Two items have the highest priority for improvements to the GSC astrometry and photometry:

- New image processing with enhanced algorithms will improve both the photometry and the astrometry.
- Melding the 1500 individual plate solutions into one catalog will provide the best catalog for the user.

The first step to maintaining and improving the GSC, as suggested in the first paper of this series, is to adopt a new catalog structure for later versions of the GSC, which separately stores the observed data, *i.e.* x, y, and image parameters, as well as the algorithmic constructs, *i.e.* plate solutions and photometric calibrations, and applies the latter to the former only in staging the catalog for the consumer. Then, changes in either the image processing or the data reductions can be adopted easily, only by changing the pointers in the catalog staging software.

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THE GUIDE STAR CATALOG. III.
STRUCTURE AND PUBLICATION, STATUS AND PLANS.

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Abstract: The current structure and content of the Guide Star Catalog (GSC), as well as future enhancements in this area are described. An overview of the forthcoming publications is given, both with regard to scientific papers and electronic media.

I. INTRODUCTION

The astronomical resources, plate scanning, image processing, and photometric as well as astrometric calibration, leading to the object-specific information contained in the Guide Star Catalog (GSC), are described in the first and second parts of this series of presentations. This part describes the GSC entries derived from the catalog construction process as well as the properties of the GSC as a whole.

II. STRUCTURE AND CONTENT

Access to the GSC has to be accommodated by identification as well as by celestial area. Together with the expected volume of data, this led to the formulation of a structure which would allow fast access, but would not require inordinate amounts of storage space nor specific software components.

The GSC is organized into 10,000 regions; each region therefore holds a few thousand individual object entries. In order to account for the varying population of the catalog as a function of galactic latitude, the region size is not fixed, but varies, so that the number of objects per region is nearly constant.

Each object in the GSC carries a 10-digit number as identification. The first five digits encode the region number; the last five specify the number of the star within the particular region. Since only a few thousand objects are contained in each region (leaving some room for future expansion), this identification scheme is noncontiguous, *i.e.*, there are many 10-digit numbers which do not correspond to an entry in the catalog.

Although this nomenclature as such does not encode coordinates, the region structure of the GSC would provide a hidden coordinate-encoding if the region boundaries were fixed;

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assuming coordinate updates, this would lead to the well-known problems of coordinate-related nomenclature techniques. Therefore, an additional feature has been adopted for the GSC regions: they are not (primarily) defined by their celestial coordinates, but by their *content*. In other words, once an object has become a member of a region, it remains part of it regardless of position updates. Therefore, the maximum and minimum coordinates of regions may overlap slightly, once updating activity has occurred.

Each region is thus characterized by its center (reference) position and extent, as well as by the number of objects it contains. (Back-pointers to the individual plates from which objects appear in the region as well as several organizational items are available in addition.) For each entry the following information is contained in the GSC:

- Identification (GSC Number).
- Position, in the form of offsets (ξ, η) to the region reference position.
- Position standard deviation (*one* per position).
- Magnitude band descriptor.
- Magnitude and magnitude standard deviation.
- Object classification (star versus non-star) and quality.
- Source plate (or catalog) identification.
- Various flags.

Note also that object data derived from different plates (*i.e.*, for objects appearing on more than one plate) are stored separately, but with the *same* identification.

III. PUBLICATION

The publication of the Guide Star Catalog is scheduled for 1988; it will consist of a descriptive part in a number of papers in the astronomical literature, and the bulk of the data will be published in electronically readable format. The papers will contain detailed descriptions of all aspects related to the GSC, specifically:

- Background information about the GSC and the Guide Star Selection System in the context of the Space Telescope mission.
- Astronomical data (plates, catalogs).
- Software system used for catalog construction.
- Hardware system used for plate scanning.
- Image processing algorithms.
- Calibration (photometry, astrometry).
- Catalog structure.
- Description of data formats and access software.

In addition, these publications will contain detailed error analyses and extensive statistical information on all aspects of the GSC, the processing, and the various reference materials used in the derivation of the data.

The catalog data themselves, as well as the statistical information mentioned above, plus basic access software and user information in the form of text, will be made available in computer-readable form. The following table may serve as a brief sample of the information provided in the main part of the GSC:

GSC ID	α	δ	σ_{pos}	m	σ_m	B	C	*Plate*	N	*Flags*
8016 0798	23 32 16.07	-42 05 57.5	0.3	14.30	0.44	0	01	00CW	2	FFFFFFTF
8016 1092	23 30 05.86	-42 07 01.3	0.4	13.35	0.44	0	02	01LP	2	FFFFFFTF
8016 1092	23 30 05.83	-42 07 00.9	0.3	13.60	0.44	0	02	00CW	2	FFFFFFTF
8016 0771	23 31 34.64	-42 07 10.1	0.5	11.94	0.44	0	02	01LP	2	FFFFFFTF
8016 0771	23 31 34.62	-42 07 09.4	0.4	12.06	0.44	0	01	00CW	2	FFFFFFTF
8016 1229	23 30 27.29	-42 08 01.1	0.4	15.33	0.47	0	01	01LP	1	FFFFFFFF
8016 1073	23 31 31.65	-42 08 51.2	0.4	11.07	0.44	0	30	01LP	2	FFFFFFTF
8016 1073	23 31 31.65	-42 08 50.6	0.4	11.17	0.44	0	30	00CW	2	FFFFFFTF
8016 1209	23 32 13.84	-42 08 47.0	0.4	15.52	0.48	0	01	01LP	1	FFFFFFFF
8016 1014	23 30 39.25	-42 09 19.1	0.4	12.86	0.44	0	01	01LP	2	FFFFFFTF

In this example, B is the encoded plate passband, C the encoded object classification, N the number of entries (from different plates) for the given object; several flags serve as indicators for cross-identification and house-keeping functions.

The volume for the entire set of data is expected to be in the range of one to two Gigabytes. Therefore, distribution on magnetic tape would require up to 20 rolls of tape (even at high density and large blocking); the associated effort with regard to tape duplication is prohibitive for mass distribution, and may only happen in exceptional cases. Currently, compact optical disks (CDs) seem to be the medium of choice; the data would require two or three platters; both the manufacturing and distribution process are comparatively simple, and readers for compact optical disks are available at low cost. However, details of volume and file structure need to be addressed before publication.

At ST ScI, the Guide Star Astrometric Support Program (GASP, McLean *et al.* 1988) has been modified to use a sample compact optical disk containing portions of the GSC as well as image information, and has thus demonstrated the feasibility of this approach.

IV. ENHANCEMENTS AND PLANS

At the time of this symposium, the Guide Star Catalog is complete to more than 90%. The number of objects in the complete catalog will be somewhat larger than 20 million.

Plans for enhancements in the image processing and calibration areas, as well as with regard to the incorporation of new surveys, have been described in the previous parts of this series. From the organizational (data base) point of view, we anticipate an enhanced catalog structure for the future, which will, however, retain the basic GSC nomenclature and region scheme. This new structure is based on the need to:

- preserve raw data (image features) obtained directly from the underlying plates;
- perform re-calibration of selected plates without affecting the rest of the catalog;

- provide corrections in an orderly and trackable way; and
- provide cross-references to other catalogs.

To achieve this goal, it is expected that the main part of the catalog will contain object names, image features, and other information, directly derived from the plates, but without any additional calibration. A second part will contain these constructs, *e.g.*, plate solutions and photometric transformations. Addenda and error corrections will be carried in a third part. Cross-references to other catalogs (as well as the catalog data themselves) will also be added to the new structure. The various pieces of information related to one object would be combined by a software module — the catalog server — upon demand, *i.e.*, upon a request by a user for data from the catalog. This enhancement would allow the efficient incorporation of new survey data, and also of other catalog data as they become available in the community.

ACKNOWLEDGEMENTS

Due to the very nature and size of the Guide Star Selection System project, which contained — as an integral part — all the efforts leading to the generation of the Guide Star Catalog, a large team of scientists, software professionals, engineers, operators, and (last but not least) managers, was required to cover all the different areas of expertise needed. Therefore, this series of papers reflects the efforts of all the past and present staff members of the Space Telescope Science Institute who have been and still are involved in this endeavor, as well as the contributions from a number of distinguished colleagues in the international astronomical community; we would like to extend our gratitude for their help to all of them.

REFERENCES and PROJECT BIBLIOGRAPHY for PAPERS I, II, & III

BENEDICT, G. F.: 1979, "Space Telescope Astrometry Team, Guide Star Selection System, Specifications and Design", Univ. of Texas, Austin.

DUDA, R. O., HART, P. E.: 1973, *Pattern Classification and Scene Analysis,* Wiley, New York.

EICHHORN, H.: 1974, *Astronomy of Star Positions,* F. Ungar Publ. Co., New York, pp. 189-219.

GILLESPIE, B. A., HARVEL, C. A., JENKNER, H., LASKER, B. M., RUSSELL, J. L.: 1984, "The Space Telescope Guide Star Selection System", *Bull. AAS,* **16**, 498.

JENKNER, H.: 1983, "Astronomical and Statistical Algorithms Used in the Space Telescope Guide Star Selection System", in: *Proc. Statistical Methods in Astronomy,* ESA SP-201, 65.

JENKNER, H.: 1984, "Principles of Astronomical Catalog and Data Base Construction and their Application towards the Space Telescope Guide Star Selection System", in: *Proc. International Course on Data Handling in Astronomy and Astrophysics,* ed. B. Hauck and G. Sedmak, Memorie Societa Astronomica Italiana.

JENKNER, H., DAMASHEK, M., GARNAVICH, P. M., LASKER, B. M., RUSSELL, J. L.: 1984, "Guide Star Catalog Construction", *Bull. AAS,* **16**, 498.

JENKNER, H., GILLESPIE, B. A., HARRISON, J. J., LASKER, B. M., MCLEAN, B. J., POLLIZZI, J. A., ROSENTHAL, D. A., RUSSELL, J. L., STURCH, C. R., WILSON, D. S.: 1985, "The Guide Star Catalog – Structure and Publication", *Bull. AAS,* **17**, 549.

KINSEY, J. H., DENMAN, R. J., EVZEROV, A.: 1984, "Laser Interferometer Enhanced Positional Precision of a Scanning Microdensitometer for Astronomical Plate Scanning", *Rev. Sci. Instr.,* **55**, 1960.

LASKER, B. M.: 1984a, "Schmidt Astronomy and the Space Telescope", in: *Astronomy with Schmidt-Type Telescopes (Proc. IAU Colloquium No. 78),* ed. M. Capaccioli.

LASKER, B. M.: 1984b, "The Guide Star Selection System for the Space Telescope: Long-Term Activities", in: *Science from Measuring Machines (Proc. Royal Greenwich Obs. Workshop),* ed. I. N. Reid and P. C. Hewett.

LASKER, B. M., DAMASHEK, M., GARNAVICH, P. M.: 1986, "A Shaped Aperture for Two-Dimensional Microdensitometry", *Publ. A.S.P.,* **98**, 125.

LASKER, B. M., KINSEY, J. H.: 1984, "PDS Sampling", *Bull. AAS,* **16**, 498.

LASKER, B. M., *et al.*: 1987, "The Guide Star Photometric Catalog", *in preparation.*

LUTZ, R. K.: 1979, "An Algorithm for the Real Time Analysis of Digitized Images", *Computer Journal,* **23**, 262.

MCGRAW, J. T., *et al.*: 1987, *private communication.*

MCLEAN, B. M., *et al.*: 1988, "The Guide Star Astrometric Support Package," *in preparation.*

RUSSELL, J. L.: 1986, "The Guide Star Selection System and the Guide Star Catalog for Space Telescope", in: *Astrometric Techniques (Proc. IAU Colloquium No. 109),* ed. H. Eichhorn and R. J. Leacock, p. 721.

RUSSELL, J. L., EGRET, D.: 1986, "Hipparcos – The Tycho Input Catalog", in: *Highlights of Astronomy,* ed. J.-P. Swings, p. 713.

RUSSELL, J. L., WILLIAMS, C. A.: 1986, "Testing Schmidt Plates for Astrometric Purposes," in: *Astrometric Techniques (Proc. IAU Colloquium No. 109),* ed. H. Eichhorn and R. J. Leacock, p. 721.

SANDERS, W. L., SCHRÖDER, R.: 1980, "Membership in the Open Cluster NGC 6494", *Astron. Astrophys.,* **88**, 102.

STOBIE, R. S., OKAMURA, S., DAVENHALL, A. C., MACGILLIVRAY, H. T.: 1984, "Power Spectrum Analysis of Astronomical Photographs Digitized with Small Apertures", in: *Astronomical Photography 1984 (Occasional Reports Roy. Obs. Edinburgh),* ed. M. E. Sim and K. Ishida.

STURCH, C., LASKER, B. M., MALLAMA, A., MCLAUGHLIN, S., RUSSELL, J. L., SIEGEL, M., WISNIEWSKI, W., LOPEZ, C., HENRY, G.: 1984, "The GSSS Photometry Catalog," *Bull. A.A.S.,* **16**, 499.