POTENTIAL APPLICATIONS OF GSC–II FOR GAIA OPERATIONS

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ABSTRACT

The GSC–II is a project to create a complete catalogue of stars and galaxies to about 18th magnitude, containing colors, magnitudes, positions, and proper motions. As such, it would provide an object list for the construction of an input catalogue for possible future astrometric satellites such as GAIA. With a schedule that is compatible with the projected timeframe of GAIA, the GSC–II could be available in time to support preparatory astrophysical observations for an input catalogue. In addition, the availability of the digitized images to prepare finding charts would improve the efficiency of this task.

Key words : Catalogues, Astrometry, Galactic Structure

1. INTRODUCTION

In contemplating the planning and implementation of all-sky survey missions – specifically GAIA – it is useful to recall that an important part of observational astronomy has historically been the creation of catalogs containing the reference and program objects required to support such observing programs. As the technological complexity, and cost, of building and operating telescopes has increased enormously over the last 20 years, so has the demand to provide the best scientific return for these investments by optimizing observing efficiency, which in turn depends on the use of proper pointing and input catalogs.

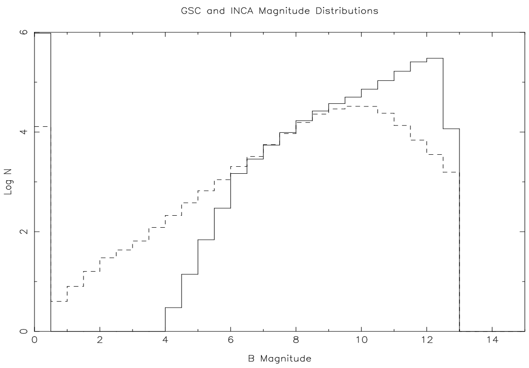
1.1 The Guide Star Catalogue

This need for a deeper, all-sky catalogue was highlighted in the last decade by the creation of the Guide Star Catalog (GSC) to satisfy the pointing requirements of the Hubble Space Telescope (HST). A description of the catalogue may be found in a set of three papers (Paper-I: Lasker *et al.* 1990, Paper-II: Russell *et al.* 1990, Paper-III: Jenkner *et al.* 1990).

The GSC is used for HST observation planning as well as target aquisition and tracking and has proven to be very reliable for its intended purpose. In addition, since its publication on CD-ROM, this catalogue has become widely used by many ground-based telescopes to provide finding charts and improve telescope efficiency by speeding the process of finding guide stars.

Another use of the GSC was to complement the extensive work done by the HIPPARCOS and TYCHO input catalogue consortia to enhance and optimize data processing procedures employed by these massive projects. To assist with the preparatory ground-based observations, the GSC was used to provide identification charts for many HIPPARCOS objects. The INCA database contained the bright stars that could not be measured from the Schmidt plates during the GSC construction and the merging of the two datasets was performed to create a complete magnitude limited input catalogue for TYCHO (Egret *et al.* 1992), as illustrated in Figure 1.

Figure 1. B Magnitude distributions (GSC - Solid line; INCA - Dotted line)



1.2 Digitized Sky Survey

The archive of digitized plate material used to create the GSC has proven to be equally valuable for observation planning. These data allow the rapid semi-automatic creation of finding charts (see figure 2), limited only by the depth of the Schmidt plates that were digitized; and they provide the ability to measure object coordinates accurately. They are also used for investigation of HST failed acquisition and other aspects of spacecraft operation.

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The image archive has also been used extensively for scientific programs. These include finder charts for many ground-based projects such as the CfA redshift survey and for multi-object fibre spectrograph runs, as well as identification of sources detected in UV (Shara *et al.* 1993) and X-ray surveys (Maccacaro *et al.* 1994, M^{c}Lean *et al.* 1994).

Recognizing the usefulness of these data to the astronomical community, the Space Telescope Science Institute (ST ScI) has published the *Digitized Sky Survey* CD-ROM set. This contains a subset of the scan data (the POSS-I E and SERC-J surveys) that have been compressed using the H-transform technique (White *et al.* 1992) by a factor of approximately 10, reducing the data volume from 600 GByte to a more manageable 60 GByte. This set of 102 CD-ROMs is distributed to the community by the Astronomical Society of the Pacific.

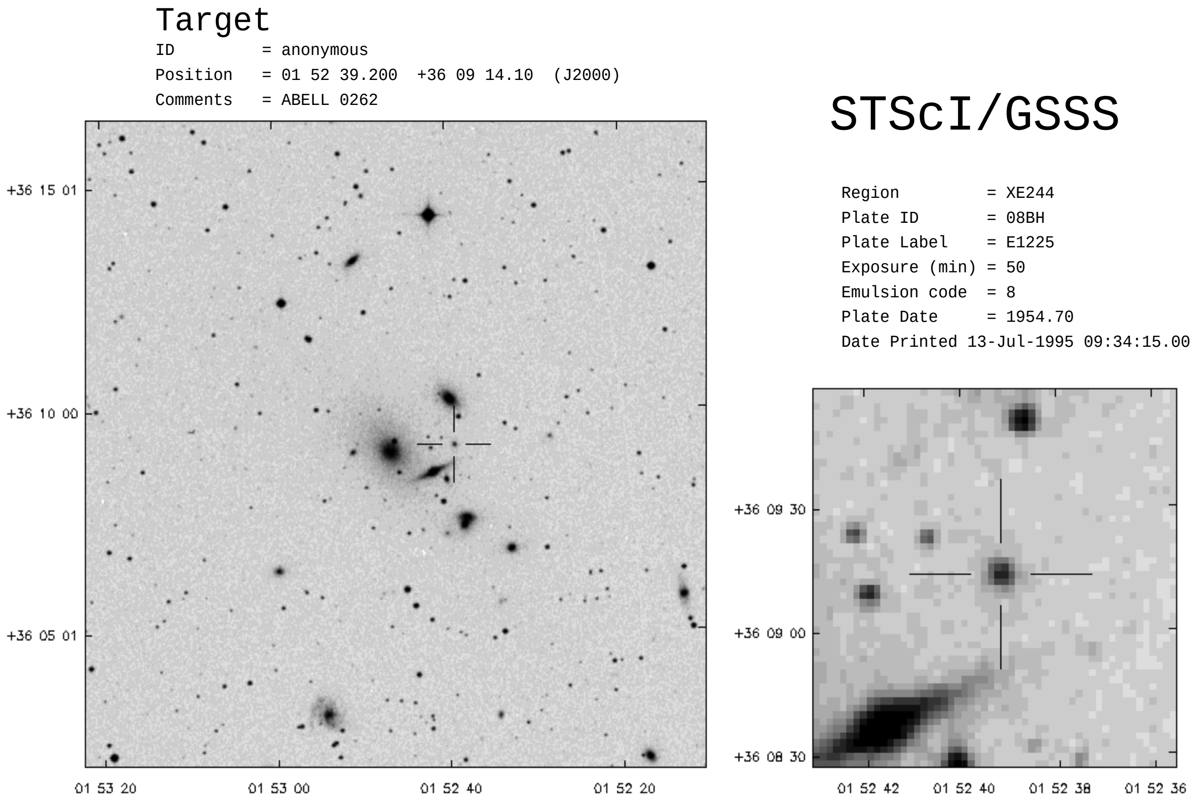
All of the other digitized scans created at the ST ScI are being compressed in the same manner and written to CD-Recordable discs. These are being placed in a CD-ROM jukebox which is accessible to the astronomical community as part of the HST Data Archive and Distribution Service (DADS) via StarView and the WWW. Additionally, the compressed data for the newer surveys is being copied for use at the European Southern Observatory (ESO).

2. GSC–I PROPERTIES

This pointing catalogue for HST was originally (GSC 1.0) published as a two-volume CD-ROM set in 1989, and was updated (GSC 1.1) in 1992 by the addition of the brighter stars from the HIPPARCOS-INCA database and the correction of various kinds of errata. The catalogue contains positions, magnitudes, and classifications of approximately $2x10^7$ objects and is complete to 16th magnitude at high galactic latitudes while remaining density limited in the galactic plane. The positions have a relative accuracy of 0.3-0.5$''$ and an absolute accuracy of 0.5-1.5$''$. The GSC is distributed by the ST ScI, which also provides WWW network access to it.

An analysis of the GSC position errors has demonstrated the presence of plate-based systematic errors which are largest at the plate edges (see Paper-II and Taff *et al.* 1990a) and of a magnitude term as a function of radial distance (Morrison *et al.* 1995). The magnitude errors are typically 0.2–0.4 mag, but larger at the plate edges due to vignetting and other field effects such as emulsion sensitivity variations. There is also an offset in the published magnitudes of the galaxies because the photometric parameter used was only appropriate for stellar images (see Paper II). This was later quantified by Alonso *et al.* (1993). For reasons of HST operations, the GSC–I objects were only classified into star/non-star groups, and the classification algorithm was biased towards the rejection of objects from the stellar class.

Figure 2. Example of an HST Finder Chart generated from the GSC Scan Archive



Although the GSC–I has been used with great success operationally and scientifically, it became clear (even during its construction) that it was possible to improve the scientific usefulness by addressing the calibration problems addressed above; and indeed, beginning with the initial development of the GSC-concept, it was clear that an increase in scope to include multi-color, multi-epoch data would eventually lead to the requirement of a second catalog, the GSC–II.

3. GSC–II PROJECT

It was generally acknowledged that the proper motions of the guide stars during the proposed lifetime of HST would pose a potential problem for the accurate pointing of the telescope during the latter half of its operation. In order to be prepared for this, NASA and ST ScI negotiated access to the original plates of the POSS-II survey, and in partnership with the Anglo-Australian Observatory (AAO), undertook the the Second Epoch Southern (SES) survey with the UK Schmidt (Lasker and Cannon 1990). These new surveys, when combined with the material used in the GSC–I, will provide the material to generate a GSC–II based on at least two epochs and two passbands.

Scanning of the new materials is being done with the ST ScI Guide Star Automatic Measuring MAchines (GAMMA). The GAMMAs, *c.f.* Lasker *et al.* (1994), are laser illuminated systems built on a PDS substrate (Paper I). They have sub-micron metrology, low-scattered light, and a combined throughput of 6 plates per day. The sampling interval is 15 microns, which corresponds to a pixel size of $1''$; and the full-plate images, which are 23040×23040 pixels in size (1.1 Gbyte), are archived to Optical WORM discs.

Once the GSC–II concept was established, it became evident that, even beyond the original motivations in HST operations, it would address a number of other astronomical needs, of which a few are listed here: a) As the next generation of large-aperture, *new-technology* telescopes become available, there are increasing demands for fainter catalogues to support remote or queue scheduling capabilities. b) Many of these telescopes have active optics, and efficient operations requires convenient access to stars within a small field near the target for tip/tilt corrections and for dynamic maintenance of collimation. c) The all sky nature of the GSC–II makes it a natural data source for research in galactic structure, for example in the pursuit of rare objects distributed over wide fields. d) A natural expectation is that the GSC-II will be the *next generation* catalogue for future space missions – indeed, it is in this regard that the GSC–II is being presented to the present *GAIA Workshop.*

Once the broad applications of the GSC–II were recognized and its resource requirements were considered with care, it was clear that the project needed to be expanded beyond its original ST ScI context. This led to the formation of a GSC–II consortium, with the formal goal of producing the GSC–II as an all-sky catalogue of positions, proper motions, magnitudes and colours, complete to 18th magnitude. The GSC–II will be based primarily on the material listed in Table 1. Additional Schmidt material will be sought as required; the possibility of obtaining additional data from the NPM and SPM plate collections (Klemola *et al.* 1987, Lopez *et al.* 1986) has been the subject of recent discussions.

A major contribution to the infrastructure of the project is a contract to the ESO, which provides partial support for the plate scanning. The pipeline software, calibrations, databases, and production of the GSC–II itself are based on ST ScI collaborations with the Italian Council for Research in Astronomy (CRA) and the Astrophysics Division of the European Space Agency (ESA SA).

Table 1. Summary of Digitized Survey Plates Available for the GSC–II

Survey	**Epoch**	**Band**	**Mean Depth**	**Dec. Zones**	**Number Plates**	**Scan Size pixels**	**Pixel Size μ**	**Status as of 1995 July**
Pal QV	1983-85	V	19.5	+90:+06	613	14000^2	25	Completed
SERC J	1975-87	J	23.0	−20:−90	606	14000^2	25	Completed
SERC EJ	1979-88	J	23.0	−00:−15	288	14000^2	25	Completed
POSS-I	1950-58	E	20.0	+90:−30	935	14000^2	25	824 plates to −18
POSS-I	1950-58	O	21.0	+90:−30	935	14000^2	25	Selected plates only
POSS-II	1987-96	J	22.5	+90:+00	894	23040^2	15	250
POSS-II	1987-96	R	20.8	+90:+00	894	23040^2	15	307
POSS-II	1987-97	N	19.5	+90:+00	894	23040^2	15	100
SES	1990-96	R	22.0	−20:−90	606	23040^2	15	188
SERC ER	1990-95	R	22.0	−00:−15	288	23040^2	15	78

3.1 GSC–II Algorithms and Calibrations

The algorithmic requirements for overcoming many of the deficiencies in the GSC–I have been investigated and are now well understood. Advanced astrometric techniques for Schmidt plates such as subplates and masks (Taff *et al.* 1990b; Bucciarelli, *et al.* 1994; Bucciarelli, *et al.* 1995; Bastian, *et al.* 1995), Collocation methods (Lattanzi and Bucciarelli 1991), and moving filters (Röser *et al.* 1995) are now available. An example of the improvement is shown in Figure 3, where the mean error in a plate overlap area is seen to fall from $0.8''$to $0.3''$. In addition, recent work on the magnitude equation (Morrison *et al.* 1995) now enables that effect to be corrected. Better classification algorithms, which will allow an unbiased classification to be produced, may be based on neural nets (Odewan 1994) or decision trees (Weir *et al.* 1995), both of which have been widely used in recent years. With a more reliable classifier, better photometric algorithms which rely on the object type can be employed, *e.g.,* using a PSF fitting technique for stars while performing a density-to-intensity calibration and integration for galaxies.

GSC–II will also be based on better plate material and reference catalogues. The POSS-II (J and F plates), ER, and SES surveys have finer grain emulsions, hence better resolution, and a deeper limiting magnitude than the original POSS surveys. The Guide Star Photometric Catalog (GSPC–I; Lasker *et al.* 1988) is being supplemented by CCD observations to provide a set of standard stars to at least 18th magnitude over the entire sky for each Schmidt plate (GSPC–II; Ferrari *et al.* 1994). The future availability of the HIPPARCOS and TYCHO catalogues will provide a dense grid of very accurate astrometric standards to tie the plates to the inertial reference frame and may allow the mapping of field variations in the sensitivity of the plate emulsions.

The feasibility of obtaining good proper motions from the Schmidt plates is best seen in a recent Ph.D. thesis by Spagna (1995). This investigation is part of a larger project to study galactic structure and dynamics along a meridional section of the Galaxy. Immediate goals are photometric parallaxes and galactic (U, V) velocities to be used as er a probe of galactic dynamics (Lattanzi *et al.* 1993, Spagna *et al.* 1995). The survey, which is magnitude limited survey at $V = 18.5$, achieves accuracies of about 0.1 mag and 3 mas yr^{-1} (see Figure 4).

The expected improvement in the projected precision of GSC–II compared to the original GSC, conservatively based on the studies cited above, in shown in Table 2.

3.2 GSC–II Status and Outlook

At the support levels provided by the collaboration cited above, the GSC–II, defined as a two-epoch, two-passband catalog with properties given in Table 2, and with a minimal database facility, is an undertaking that can be completed within the established 4 year schedule.

Presently, about 25% of the 3600 new plates required for the GSC–II have been scanned; and the present scanning rate is slightly in excess of 1000 plates/year. This will lead to our approaching the completion of plate scanning at the end of 1997. Software for nearly all of the image-processing and object identification tasks is already in place. The remaining code, mostly pertaining to calibrations and reductions, has already been prototyped; and a production pipeline system will be completed in 1996.

Additional partners are being actively sought in order to increase the GSC–II scope to include additional passbands and epochs where available and to enhance the scientific potential of the catalog by exceeding the goals given in Table 2. Also, considering the size of the catalog (approximately 2 TByte), one easily identifies the rewards of added database effort; the problems of access to the GSC–II in a rapid and user-friendly manner still need to be addressed.

Figure 3. Astrometric errors, as demonstrated with quarter-plate corner-to-center overlaps. Scale bar is 5 ″in length.

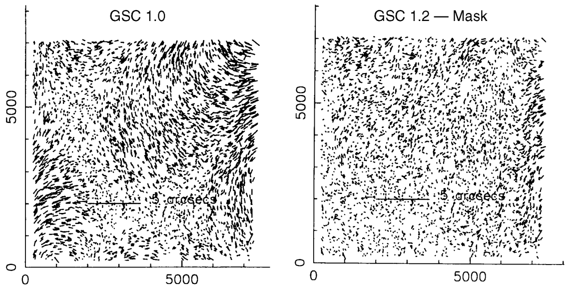
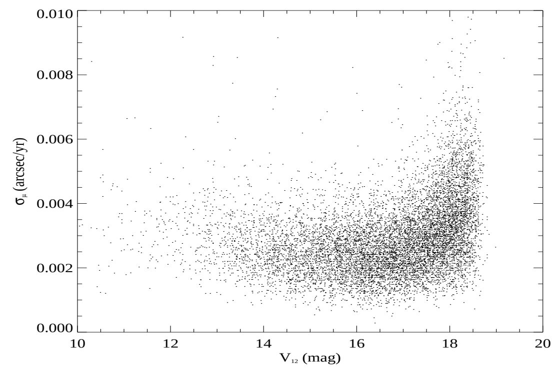


Table 2. Properties of GSC–I and GSC–II

Property	GSC 1.2	GSC 2.0
Epochs	1	2
Passbands	1	>2
Lim. Mag.	15	>18
Rel. Pos.	0.4	0.15
Abs. Pos.	1.0	0.5
Proper motions	–	<4.0 mas yr^{-1}
Mag. Err.	0.4	0.1-0.2
Classification accuracy	99% stellar Limit 15th mag	>95% unbiased Limit 18th mag

Figure 4. Total Internal Proper Motion Errors



3.4. Application to Astrometric Missions

The resounding success of the HIPPARCOS and TYCHO projects demonstrated the feasibility and desirability of using an input catalogue to define the targets to be observed. Not only does this simplify the data aquisition and reduction process, but it allows other preparatory observations to be made which enhance the scientific value of the mission.

The GSC–II is the only project currently planned to produce an all-sky catalogue of stars with colours and proper motions and with special attention to the range $9 < V < 18$, which is understood to be of particular relevance to GAIA. (Other large area mapping projects, including those using CCD detectors, which are the ultimate future of ground-based sky surveys, are currently planned to do only portions of the sky and are mainly focused on faint galaxy catalogues.)

The planned GSC–II, an undertaking already in progress, is ideally suited as an object list for the construction of an input catalogue for GAIA. This proposed mission could use this information for the identification of stars down to its stated goal of 16th magnitude, but would also have field-information of potential "spoiler" objects (which may affect the data reduction) down to 18th magnitude. The availability of the digitized images would also prove useful for preparatory observations and for mission operations.

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