Availability of Digital Sky Surveys for Gemini

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March 1995

Overview

The purpose for this document is to identify what digitized sky surveys should be available over the next ~5 years to Gemini. There are two basic types of digital catalogs under consideration here, namely object catalogs (containing positions, brightnesses, etc., for identified sources), and those containing compressed pixel images of raw plate material. Though either of these catalogs may be of use to Gemini, object catalogs will certainly be more manageable in terms of size. Such all-sky deep catalogs will probably have to be managed through some sort of relational database, capable of identifying stars within a given distance of any point on the sky within defined magnitude limits. Given the number of targets included in such catalogs (~10^9 objects), and the practical limits on computer hard disk space, it is likely that these catalogs will be stored on >100 CDROMs that will have to be located in a jukebox. It is assumed that catalogs such as the SAO and Bright Star Catalogs will be incorporated into the Gemini observatory control system, as they are at most observatories today.

Background

For at least the past decade, the need to identify guide stars at most telescopes has been driven by relatively simple requirements set by conventional autoguiders. For example, most telescopes equipped with autoguiders, upon pointing toward a science target, execute either a spiral or raster scan with the autoguider probe to locate a star in the field that is bright enough to establish an autoguider lock. From there, rapid low amplitude adjustments are made to tracking rates to maintain precise telescope pointing. This approach to guide star locating, though not terribly efficient, has been fine for most telescopes but will be grossly inadequate for operating the Gemini telescopes. In Gemini's case, some of the reasons for having a deep digitized sky survey available include:

- Astronomers interested in using the AO will need to identify *before* submitting observing proposals guide stars in the vicinity of science targets in order to estimate achievable strehls. Even with a future laser guide star implementation of the Gemini AO unit, pre-identification of natural guide stars for tip/tilt correction may likely be required.

- At the telescope, a utility may have to be available to the Gemini telescope operators to efficiently pre-position PWFS's during a telescope slew so reference stars are immediately available when the telescope is pointed at a science target.

- Ideally this functionality should be extended to on-instrument wavefront sensor (O-IWFS) guide star selection, though the faintness of the O-IWFS stars may make providing this in real time difficult.

- Staff astronomers, as part of the proposal technical review process, will need to check for guide star availability near science targets.

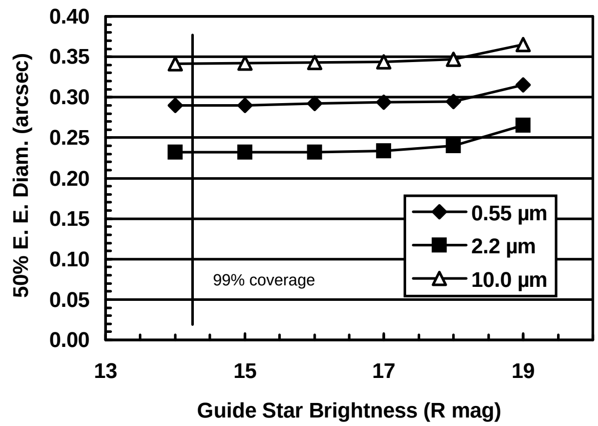

Figure 1 - Performance data for the Gemini peripheral WFS's created by Charles Jenkins is shown for 3 wavelengths, assuming nominal conditions (see A&G PDR documentation). In all cases 50% EE's drop to minima for stars brighter than the faint limit of the GSC (~16 mag). The vertical line at 14.2 mag shows the 99% sky coverage level.

The various WFS's in use at Gemini North and South will demand reference stars spanning many magnitudes in brightness. The high resolution WFS, used probably at the beginning of each night to calibrate the primary mirror figure, can use bright stars (limit is TBD) that almost certainly will be contained in existing catalogs, like the Bright Star or SAO catalogs. The next most restrictive field of view constraint on the WFS's will be occur with the PWFS's, which will have a maximum (slightly vignetted) field of view of 14 arcmin diameter. Figure 1 is a plot of the PWFS performance at 0.55, 2.2, and 10 µm and shows that for all such modes the PWFS's will give maximum theoretical correction with 99% sky coverage. Finally, the O-IWFS's, which have a highly restricted field of view of 3 arcmin diameter, will have to work down to ~18 mag to achieve 90% sky coverage. Current estimates of the AO system indicate significant near infrared correction can be achieved at such faint magnitudes as well. This goes *well* beyond the limiting magnitudes of catalogs used regularly in the control rooms of existing observatories, hence Gemini needs to identify next-generation digital catalogs that will support critical roles in future Gemini commissioning and operations.

HST Guide Star Catalog (GSC)

The GSC was created to support the Hubble Space Telescope and has been distributed freely to observatories around the world for several years. This catalog was designed to provide uniform sky coverage with field stars down to V ~ 16 mag. As such, it is not strictly a magnitude limited catalog. It contains ~15 million stars over the entire sky (including the ± 20° Galactic latitude region avoided by deeper catalogs) and is contained on 2 CDROMs in FITS formatted tables. The GSC is described in detail in a number of papers (Lasker et al. 1990, *A.J.*, **99**, 2019). The typical absolute positioning accuracy of tabulated stars is in the ~0.3" - 0.8" range, depending on the hemisphere and magnitude of stars. There are currently at least two programs freely available in the public domain to generate star charts from the GSC. These include a module under IRAF and 'Skymap', which is a standalone program that runs on Sparc platforms and is available via anonymous ftp from Harvard. Figure 2 shows a GSC plot created with

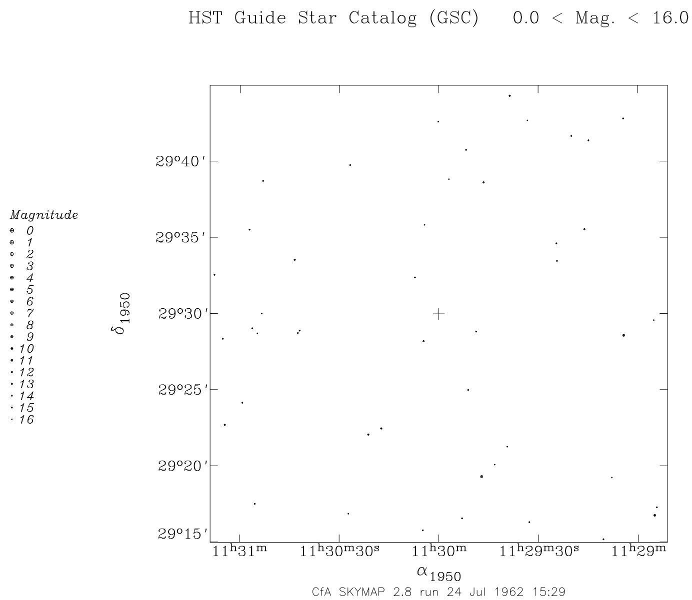

Figure 2 - A sample plot of the sky generated with Skymap and the HST Guide Star Catalog is shown. This plot pushes the depth of the GSC to its limits.

Skymap. The time required to generate this on a Sparc 20 directly from CDROM was only ~5 seconds.

The GSC is increasingly coming in use at existing observatories. In 1993 CFHT implemented it at the summit of Mauna Kea, where it has been enthusiastically embraced by the operations staff (telescope operators in particular) and visiting astronomers. At the observatory, the GSC is used to generate a plot of star positions, color coded according to brightness, with a graphic overlay of the autoguider acquisition field. Guide stars are therefore readily identified without using time consuming guide probe raster scans. This addition to the capabilities of the telescope control environment at CFHT has *significantly* increased overall efficiency and it is certainly conceivable that Gemini may need a similar utility for positioning WFS's.

Current models of the Gemini PWFS's nominal performance (assuming 10 e^- read noise) indicate that they will easily reach 99% sky coverage if a catalog like the GSC is used. This will be particularly helpful during commissioning so PWFS functions can be checked out anywhere on the sky with little pre-planning in the sense of generating star charts before attempting engineering runs.

Space Telescope Compressed Digitized Sky Survey & Second Generation Survey

In 1994 the Space Telescope Science Institute, in collaboration with the Astronomical Society of the Pacific, released a set of 101 CDROMs containing compressed images covering the entire sky with ~1.7" resolution (a factor of ~10 in compression was used). The first phase of the release was in the form of 61 CDROMs from the southern SERC J survey, and the remaining CDROMs from the POSS-I E-band northern survey will be distributed in 1995. The limiting magnitudes are ~21.5 mag in the southern plates and ~20.5 mag in the northern plates. These scans are bundled with display software that can be run on UNIX or VMS platforms. Astrometric calibration data are available and a photometric calibration database may be released in 1995. The accuracy of the astrometric calibration is under review (by DS) in order to determine if this survey can provide Gemini North with accurate pointing information.

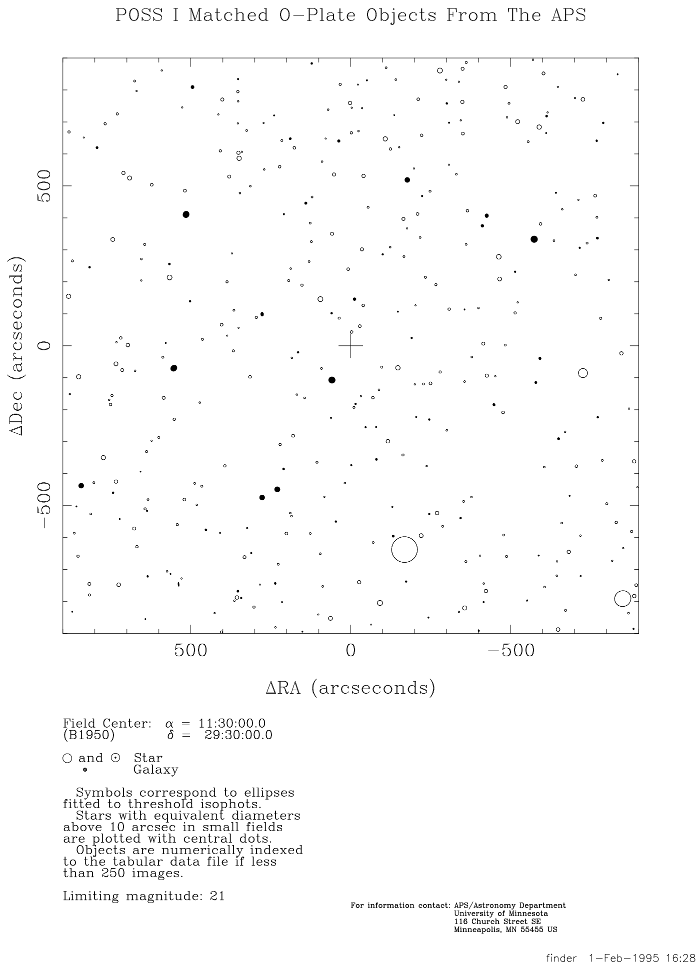

Figure 3 - The same region of the sky shown in Figure 2 is generated with the APS on-line utility, which is based upon POSS-I plates and has a limiting magnitude of ~21.

In addition, STScI is in the process of digitizing the most recent Schmidt surveys, with the intent of covering the sky with ~3500 plates at 1" scanned resolution. The surveys included in this effort include the POSS-II series at several wavelengths, the Second Epoch Southern Survey, which is under way at the AAO, and the UK Equatorial Red Survey.

University of Minnesota Automated Plate Scanner Catalog (APS)

The University of Minnesota recently completed scanning the POSS-I blue and red plates for |b| > 20°. Detected objects are catalogued as either stellar or non-stellar, with magnitudes, positions, colors, and shapes stored. A total of ~10^9 stars and a few million galaxies are recorded. This survey is discussed in detail in Pennington et al. 1993 (*P.A.S.P.*, **105**, 512). Stellar photometry is accurate to an rms error of ~0.20 mag from ~14-22 mag. Photometry degrades significantly for stars brighter than ~12 mag due to diffraction spikes on the original POSS-I plates. In terms of positional accuracy, several techniques are used to bootstrap the APS with other surveys, yielding a final rms positional error of ~0.25".

The distribution of this catalog is somewhat unusual in that it is only available on-line via Internet (http://isis.spa.umn.edu/homepage.aps.html) The database currently contains scans of 124 plates and is being expanded on a continuous basis. Access is simple through a Mosaic session, from which it is possible to spawn a telnet connection to the APS server. The user is prompted for the position of the field desired, its size, and magnitude limits. In ~2 minutes a Postscript plot file is generated, along with an ASCII table of objects' positions and brightnesses that is stored in a separate file. From there it is trivial to transfer star charts and tables via ftp (within the Mosaic session) to a local computer for print out. Figure 3 shows the same field plotted in Figure 2 except the APS server was used. In the future FITS formatted star charts will also be available. In its finished state, this database would be a useful tool for proposing astronomers (for

Gemini North) to assess the availability of faint stars for O-IWFS and AO WFS support, and potentially for Gemini during commissioning if no CDROM collection of stellar positional data is delivered in time. For long-term operations, having a local database is highly desirable (so we are not at the mercy of the APS server load or Internet connectivity) since there will almost certainly be situations on the summit demanding a star chart accurate down to ~21 mag.

APM, COSMOS, & SuperCOSMOS (ROE)

(much of the information in this section was kindly provided by Andy Lawrence)

Three major digital sky surveys have been completed or are underway in the UK. The APM project scanned the POSS-I plates for |b| > 20° in both O and E photographic bands. The scans were cross correlated to yield color information on ~10^8 objects. To date no mass distribution of the APM catalog has occurred nor is any planned to occur, though limited subsets of the catalog are available for personal research. The COSMOS project (coordinates, sizes, magnitudes, orientations, and shapes) has been operating at the Royal Observatory in Edinburgh for several years and was used to scan plates of the entire southern sky with IIIa-J and "short red" plates. This has led to the detection and classification of several hundred million targets. No CDROM distribution of the COSMOS database is planned either. Currently a fraction of the data are available on-line through a Web interface (http://xweb.nrl.navy.mil/www_rsearch/RS_form.html). Figure 2 is an example of the output from this service which is functionally similar to the APS server. Like the APS, if no southern sky catalog is released on CDROM in time for Cerro Pachon commissioning, it should be possible to use this on-line version of the COSMOS catalog to assist with commissioning tests of the O-IWFS's. Finally, SuperCOSMOS arguably represents the most ambitious digitized sky survey attempted to date anywhere. The new machine used for this project is scheduled to scan plates covering the entire sky for |b| > 10° using POSS-I and POSS-II plates (both colors for each) in the north as well as SERC J & R and ESO B & R plates in the south. The scanner consists of an air-bearing X-Y stage, a linear CCD detector with 2048 pixels, and DEC Alpha chips to handle processing. The scanner is housed in a high stability class 100 clean room that is isolated from external shock. SuperCOSMOS therefore has considerably greater positional

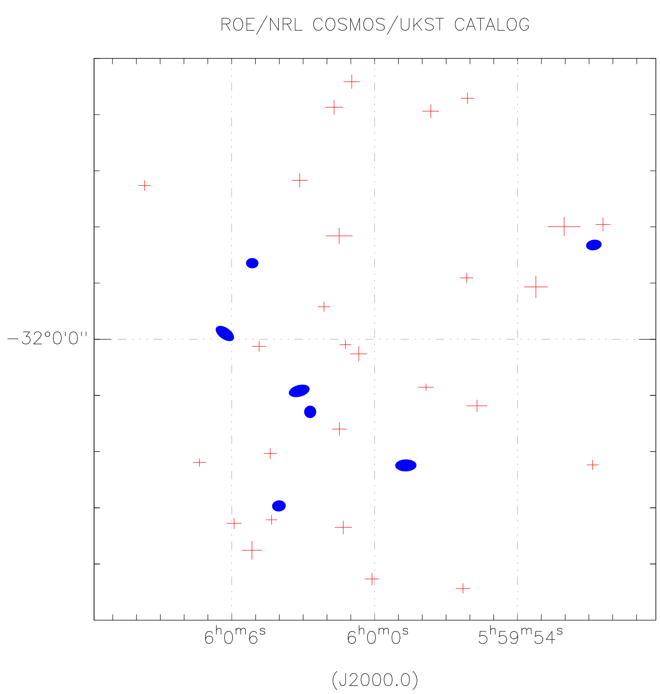

Figure 4 - A sample output of a region of the southern sky scanned by COSMOS is shown, as generated with the Web server at the NRL.

accuracy, scanning speed (a Schmidt plate can be scanned in ~2 hours), linear dynamic range, and scanning resolution than competing machines. On scales of tens of arcminutes the positions of targets have a certainty of ~0.2-0.3", which is ultimately limited by the PSF stability in the plate material. The main reason why there is no plan to release COSMOS data on CDROM is that it will be totally superseded with much higher quality data from SuperCOSMOS. Currently the plan is to scan the SERC J and POSS-I plates first. The time required to complete these initial scans and release the results on CDROM is estimated to be ~2 years (i.e., released in 1997). The data may also be released in an on-line basis and/or as compressed images, though the latter implies a huge number of CDROMs. Given the expected quality of the data produced by SuperCOSMOS, and the fact that it will be released on time scales that are roughly compatible with Gemini's commissioning (and certainly operational) schedules, it seems reasonable to plan on using this database within the Gemini operations centers as a long term solution to the need for deep digital sky surveys.

DENIS and 2MASS

In the near future a pair of ambitious near infrared surveys will begin, *greatly* expanding upon the last such survey completed in 1969 (TMSS). First, DENIS (deep near infrared survey of the southern sky) will map out the southern sky from a dedicated telescope at La Silla at I, J, and K. The project is being managed from the Observatoire de Paris. Cameras employing NICMOS3 arrays will be used for the J and K observations, while a Tektronix 1024^2 CCD will be used for the complementary I-band observations. Expected 3σ limiting magnitudes are 18 at I, 16 at J, and 14 at K, with spatial resolutions of 3" at J and K and 1.5" at I. The survey is expected to be completed sometime in 1996, with results released soon thereafter. Roughly 10^7 sources (stars and galaxies) will likely be found. Beyond dedicated data processing centers for future analysis of the expected ~3 Tb of data recorded with DENIS, specialized electronic catalogs including galaxy and stellar databases should be eventually released.

The 2MASS (2 micron all sky survey) survey will map >95% of the sky (100% is the goal) at J, H, and K_{short}. It is being managed principally from the University of Massachusetts, Amherst. A pair of 1.3 m telescopes, one located on Mount Hopkins near Tucson, and the other at Cerro Tololo, will be used in conjunction with 3 channel infrared cameras to simultaneously acquire data at J, H, and K_{short}. Based upon data collected with a prototype camera of ~200 deg^2 thus far, photometric sensitivity in the final survey will be ~14σ for K ~ 14 mag stars. A positional accuracy of 1" is expected. A scan rate of ~100 deg^2 in each band per night will be used to complete the entire survey no later than 2001. IPAC will be the principal data analysis site for the huge database collected, with various digital catalogs eventually being released.

These two surveys are mentioned primarily because it is likely over the lifetime of Gemini that near infrared wavefront sensors will be installed, demanding in turn the kinds of deep digital near infrared catalogs that are just now becoming available at optical wavelengths. Also, since these surveys will cover the Galactic plane they should include infrared guide stars *within* dark clouds, something that is totally lacking in photographic surveys.

Conclusions

There are a number of optical and infrared digital sky surveys planned that could be used to support commissioning and operational activities at both Gemini sites. The catalogs briefly described in this report are summarized in the Tables 1 and 2. In the near term, Gemini North will first require a catalog capable of supporting PWFS commissioning tests and the existing HST Guide Star Catalog will be deep enough to support such tests, as well as future PWFS operations. Currently the STScI Compressed Digitized Catalog of POSS-I plates is the only deep catalog available on CDROM. Since it is in compressed pixel form (not an object catalog), it is not ideal for future operations. Other deep survey catalogs exist (in object form), including the Minnesota APS and COSMOS catalogs. Both are currently available in limited distribution on-line via internet and will likely be fully posted on the internet over the next couple of years for general astronomical use. The APS and COSMOS projects represent possible sources for deep survey catalogs if a comprehensive CDROM distributed catalog is not released in time for Gemini commissioning or operations. Probably the best long term solution for an all sky digitized deep catalog lies in the SuperCOSMOS project. Using existing plates, scans should be completed over the next few years and released in CDROM format of adequate depth to support O-IWFS and adaptive optics demands. SuperCOSMOS should result in a multi-color database of the entire sky except with 10° of the Galactic plane (which to V ~ 16 mag is covered by the GSC). Finally, a pair of near infrared surveys are about to be launched that should yield stellar catalogs in the ~1.0 - 2.5 µm range that can be used to support future infrared WFS demands. It is too early to determine what type of distribution medium will be used when these surveys are completed.

	COSMOS	APM	STScI	SuperCOSMOS	2MASS	DENIS
SERC J	✓	✓	✓	(✓)	-	-
ESO B	-	-	-	(✓)	-	-
ESO R	-	-	-	(✓)	-	-
(2nd Southern R Survey)	-	-	(✓)	-	-	-
(SERC R)	-	-	(✓)	(✓)	-	-
Galactic Plane (short red)	✓	-	-	(✓)	-	-
(I, J, K)	-	-	-	-	-	(✓)
(J, H, K_{short})	-	-	-	-	(✓)	-

Table 1 - A list of digitized southern sky surveys is shown, from various sources. A ✓ indicates that a digitized survey has been completed, a () indicates a survey that is planned or underway, and a - indicates that no plans exist. Shaded boxes represent compressed image (pixel) survey formats, un-shaded boxes represent object catalogs. SuperCOSMOS results may also be released in pixel format.

	APM	STScI	USNO	APS	SuperCOSMOS	2MASS
POSS-I "O"	✓	✓	(✓)	✓	(✓)	-
POSS-I "E"	✓	-	-	✓	(✓)	-
Palomar "Quick V"	-	✓	-	-	-	-
(POSS-II J)	-	(✓)	(✓)	-	(✓)	-
(POSS-II R)	-	(✓)	-	-	(✓)	-
(POSS-II I)	-	(✓)	-	-	-	-
(J, H, K_{short})	-	-	-	-	-	(✓)

Table 2 - Same as Table 1 except northern digitized sky surveys are shown.